

Hunting for the Higgs Boson and more at the LHC



**Committee for the
Collaboration of the
Czech Republic with
CERN
and the
Czech Physical Society**

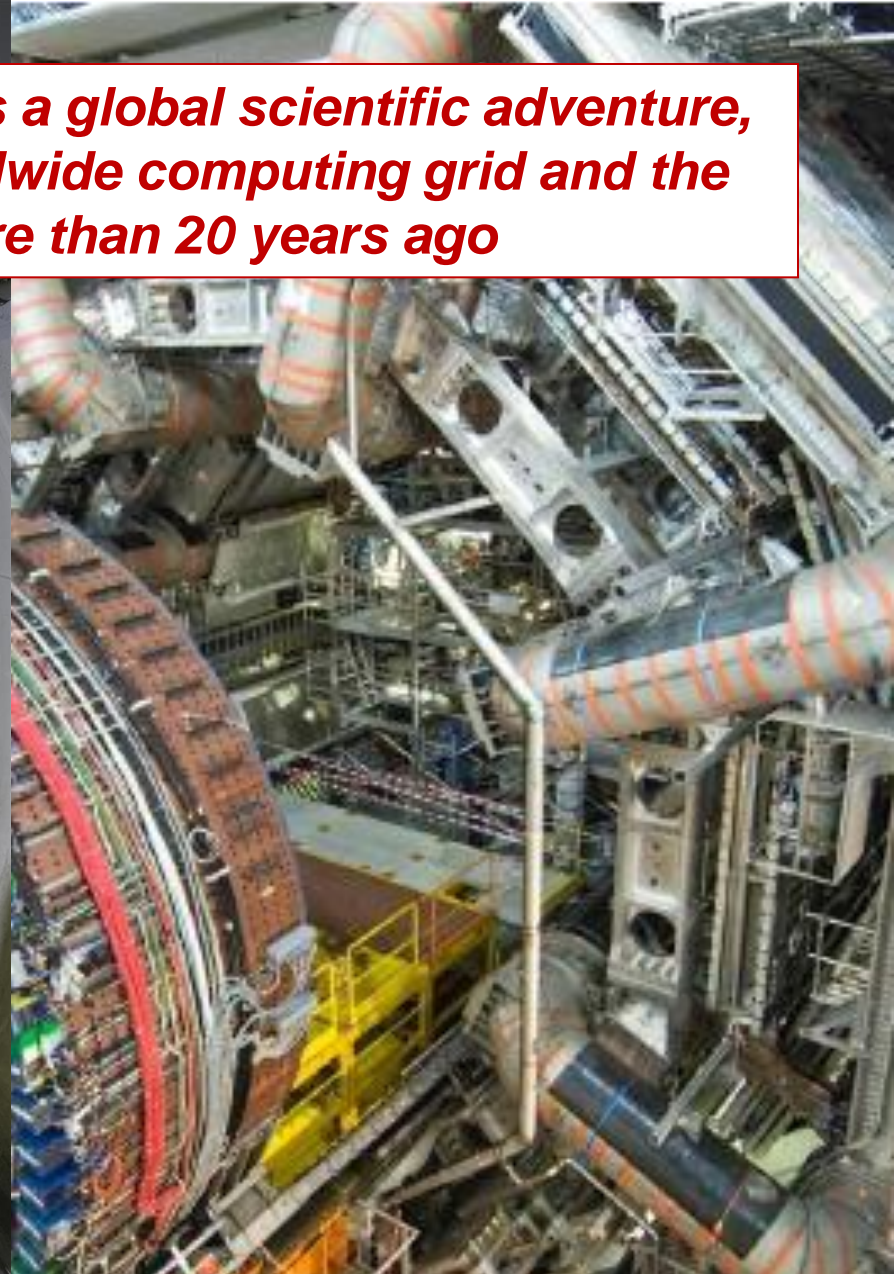
**With recent results from
ATLAS and CMS**

**Drawing by
Sergio Cittolin**

**Peter Jenni (CERN)
25th October 2012**



The Large Hadron Collider project is a global scientific adventure, including the accelerator, the worldwide computing grid and the experiments, initiated more than 20 years ago



Prague, 25-10-2012
P Jenni (CERN)

LHC Roadmap

It is a great privilege and pleasure to present now first physics results

History of the Universe

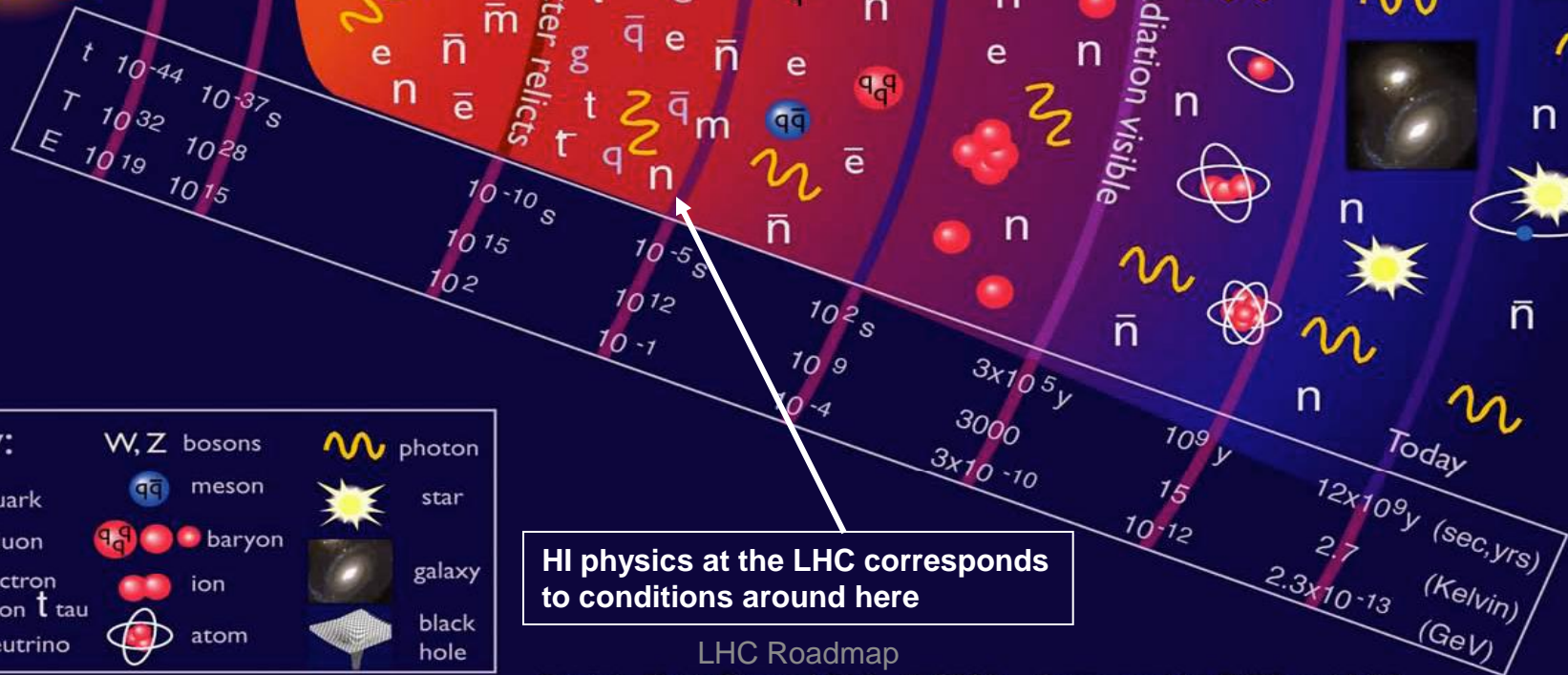
pp physics at the LHC corresponds to conditions around here

BIG BANG

Inflation

possible dark matter relicts

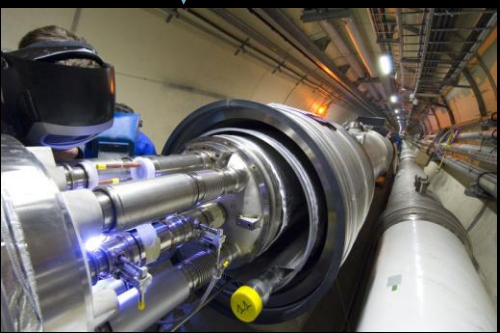
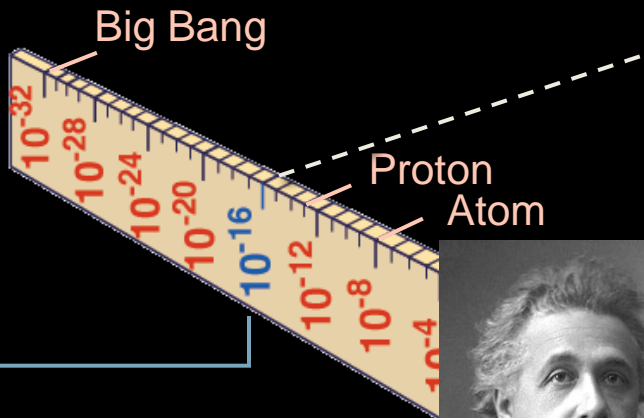
cosmic microwave radiation visible



Key:

W, Z bosons	meson	photon
quark	baryon	star
gluon	ion	galaxy
electron	atom	black hole
muon		
tau		
neutrino		

HI physics at the LHC corresponds to conditions around here

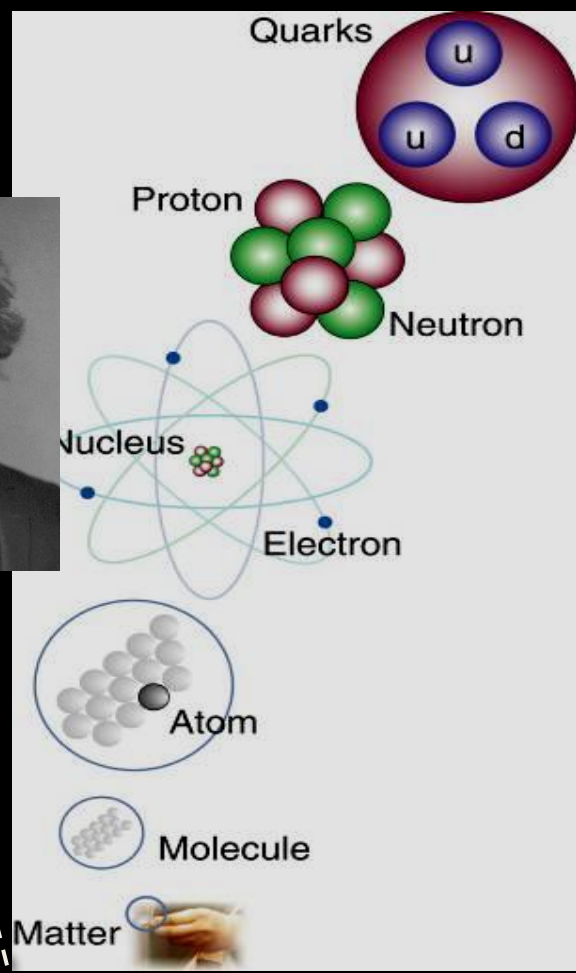
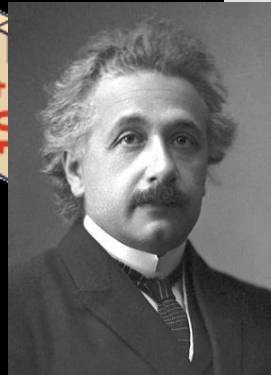


LHC

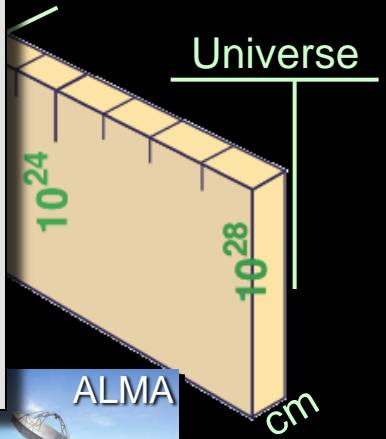
Super-Microscope



Study physics laws of first moments after Big Bang
 increasing Symbiosis between Particle Physics,
 Astrophysics and Cosmology



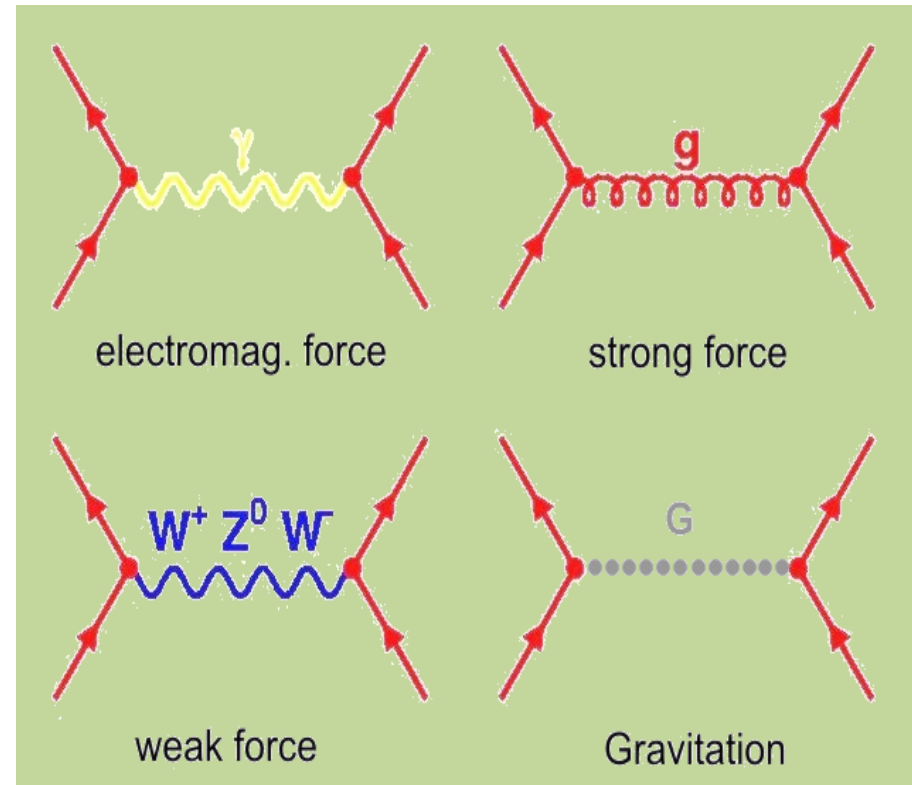
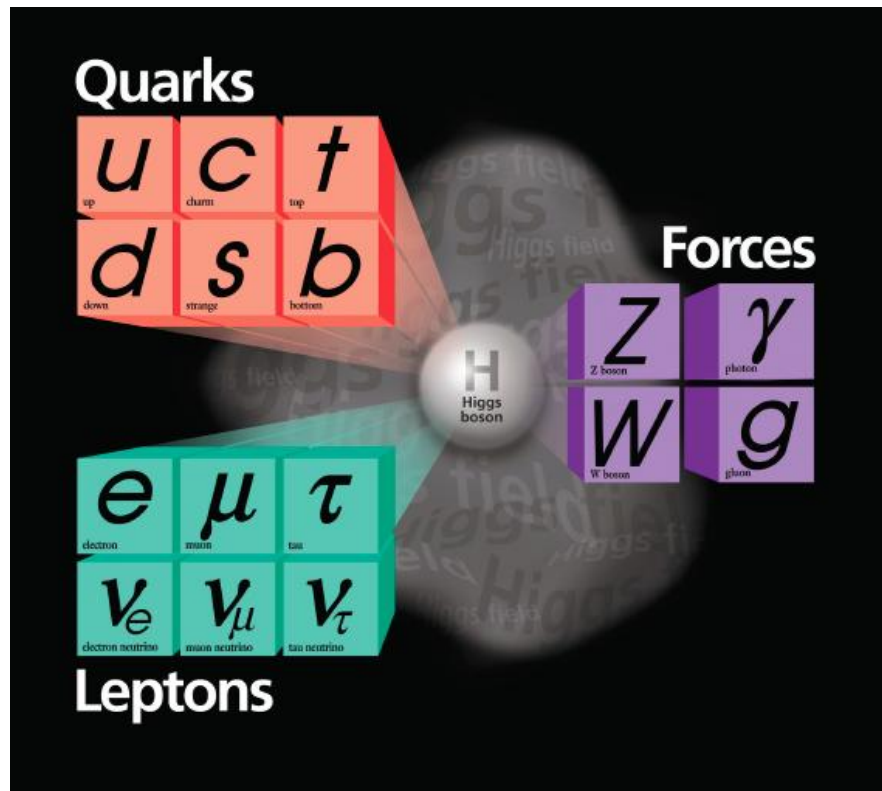
Radius of Galaxies



Universe



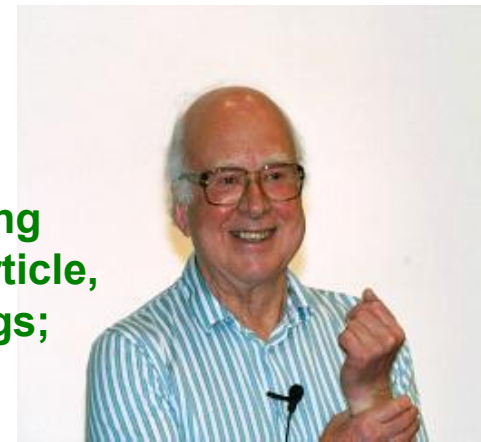
The Standard Model of Particle Physics



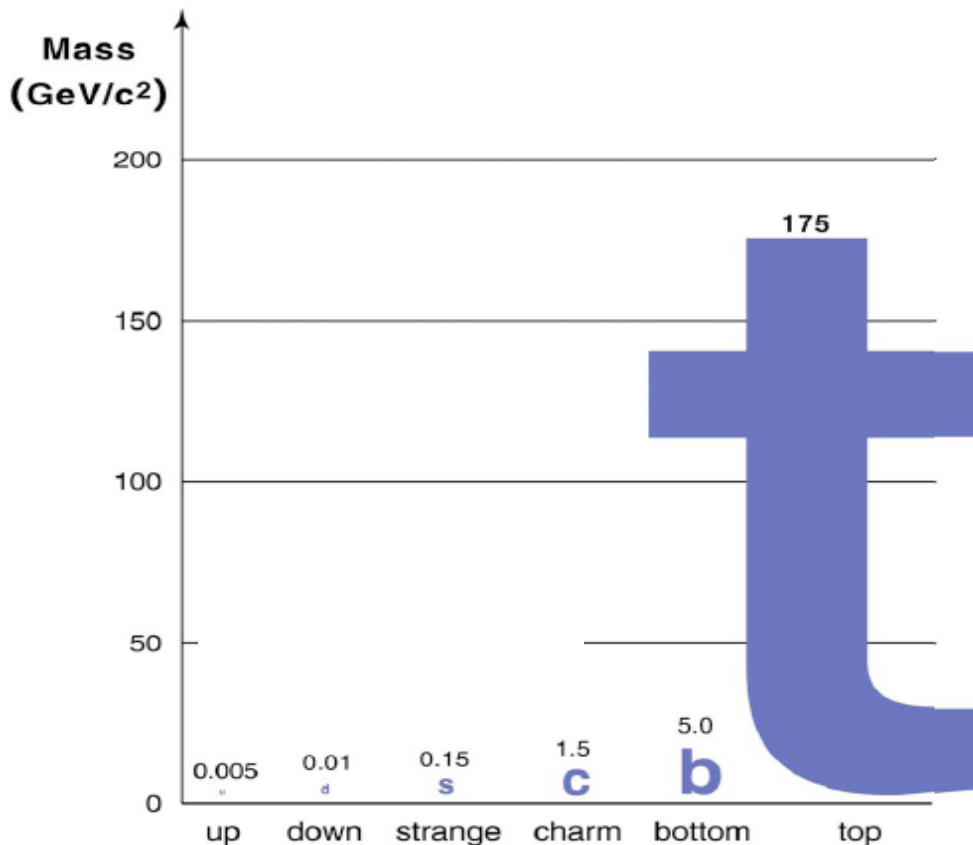
- (i) Constituents of matter: quarks and leptons
- (ii) Four fundamental forces
(described by quantum field theories, except gravitation)
- (iii) The Higgs field (problem of mass)

A most basic question is why particles (and matter) have masses (and so different masses)

The mass mystery could be solved with the 'EW symmetry breaking mechanism' which predicts the existence of a new elementary particle, the 'Higgs' particle (theory 1964: R. Brout and F. Englert; P.W. Higgs; G.S. Guralnik, C.R. Hagen and T.W.B. Kibble)



Peter Higgs



Quarks

The Higgs (H) particle has been searched for since decades at accelerators, but not yet found...

The LHC has sufficient energy to produce it for sure, if it exists



Francois Englert

Supersymmetry (SUSY)

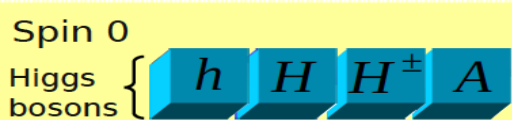
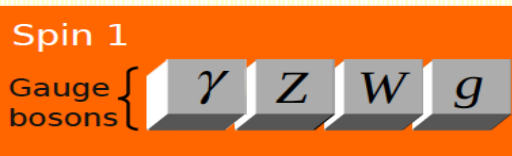
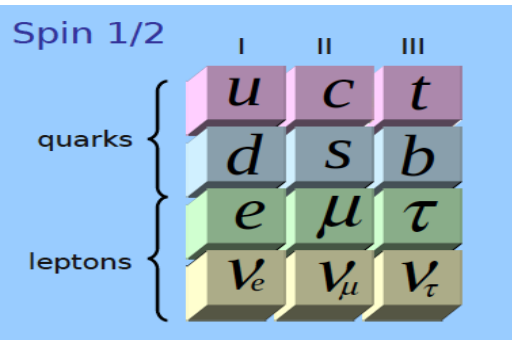
(Julius Wess and Bruno Zumino, 1974)

Establishes a symmetry between fermions (matter) and bosons (forces):

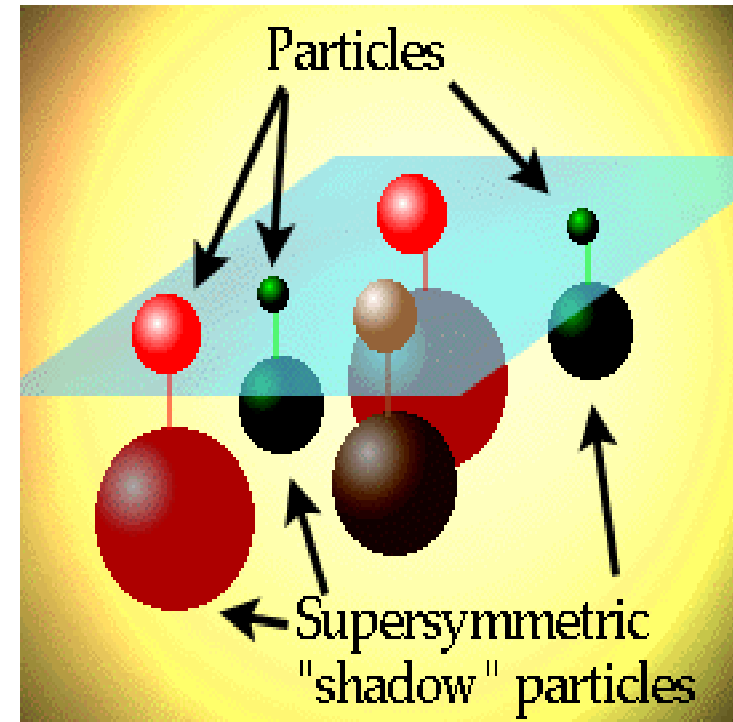
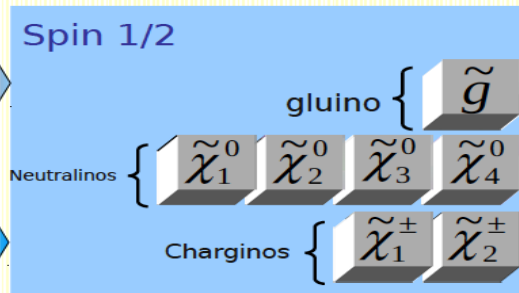
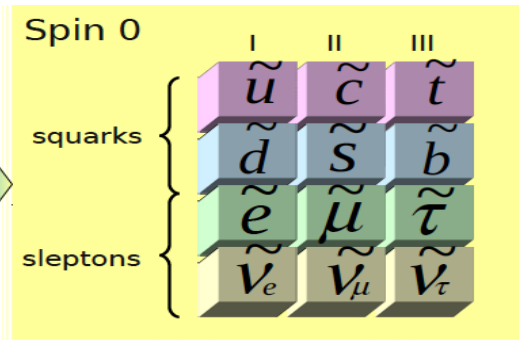
- Each particle p with spin s has a SUSY partner \tilde{p} with spin $s - 1/2$

- Examples q ($s=1/2$) \rightarrow \tilde{q} ($s=0$) squark
 g ($s=1$) \rightarrow \tilde{g} ($s=1/2$) gluino

Our known world...



Maybe a new world?



Motivation:

- Unification (fermions-bosons, matter-forces)
- Solves some deep problems of the Standard Model

Dark Matter in the Universe

Astronomers found that most of the matter in the Universe must be invisible Dark Matter

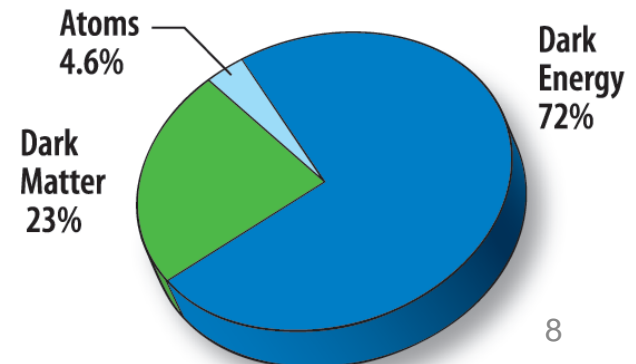


Vera Rubin ~ 1970

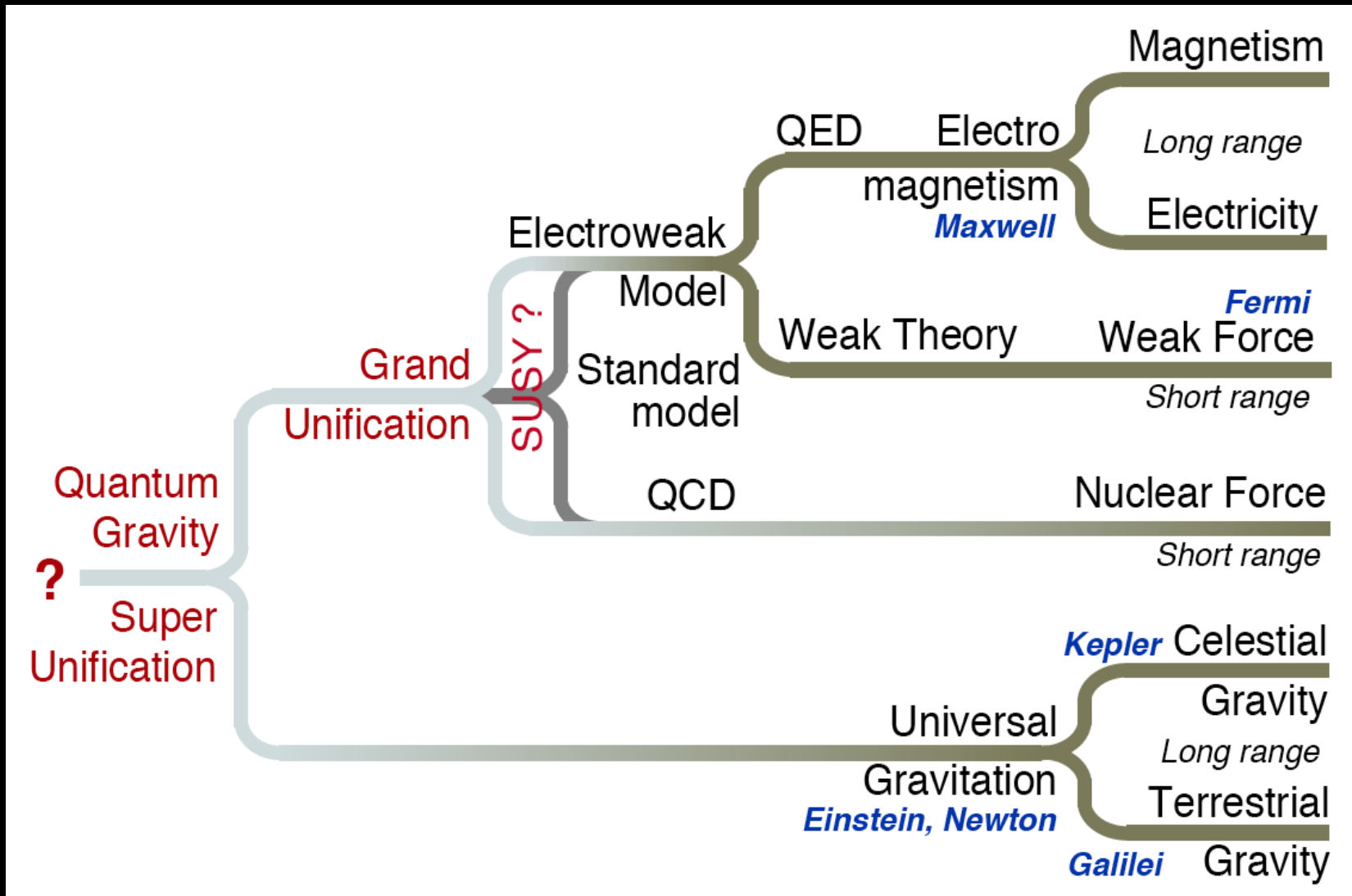
‘Supersymmetric’ particles ?



F. Zwicky 1898-1974



Unification of Forces



How the LHC came to be ...

(see a nice article by Chris Llewellyn Smith in Nature 448, p281)

Some early key dates

1977 The community talked about the LEP project, and it was already mentioned that a new tunnel could also house a hadron collider in the far future

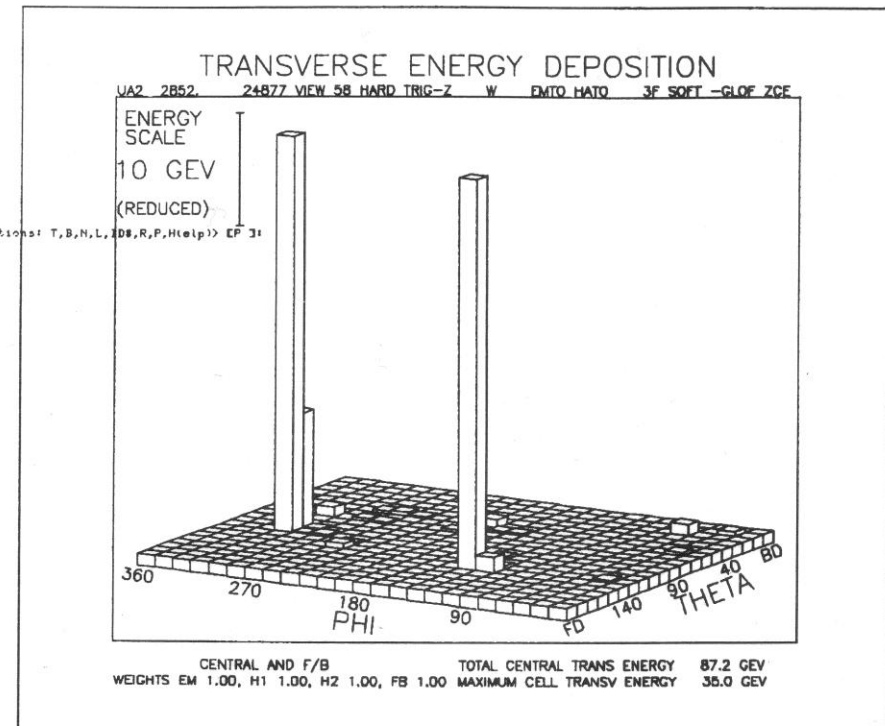
1981 LEP was approved with a large and long (27 km) tunnel

1983 The early 1980s were crucial:

The real belief that a 'dirty' hadron collider can actually do great discovery physics came from UA1 and UA2 with their W and Z boson discoveries at CERN

This also triggered a famous quote from a 1983 New York Times editorial:

'Europe: 3 - US Not Even Z-Zero'



A very early Z \rightarrow ee online display from one of the detectors (UA2)



21-27 March 1984

***ATLAS was borne with the Letter of Intent (Lol),
submitted on 1st October 1992, 20 years ago***

**1991 December CERN Council:
‘LHC is the right machine for
advance of the subject and the
future of CERN’
(thanks to the great push by
DG C Rubbia)**

**1993 December proposal of LHC
with commissioning in 2002**

1994 June Council:

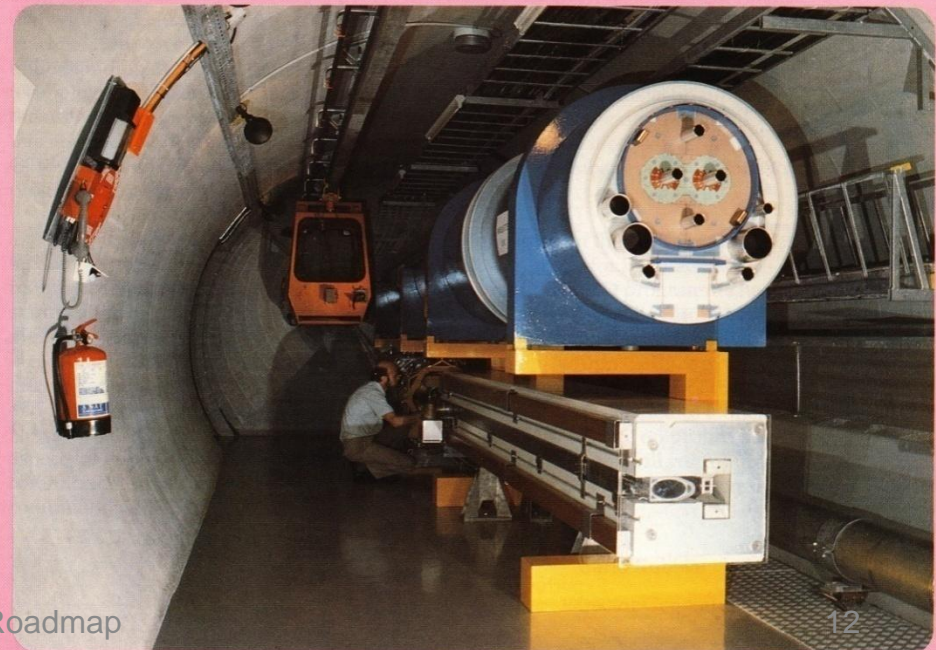
**Staged construction was proposed,
but some countries could not yet
agree, so the Council session vote
was suspended until**

16 December 1994 Council:

***(Two-stage) construction of LHC
was approved***

Prague, 25-10-2012
P Jenni (CERN)

N° 1
July 1991
(supplement
to CERN Courier
July/August 1991)



The two-stage approval of LHC was understood to be modified in case sufficient CERN non-member state contributions would become available

A lot of LHC campaigns and negotiations took place in the years 1995 - 1997, including also the experiments

Japan, Russia, India, Canada and the USA were agreeing in that phase to contribute to the LHC

(Israel contributed all along to the full CERN programme and LHC)

1997

December Council approved finally the single-stage 14 TeV LHC for completion in 2005



Signature of the US-CERN agreement in December 1997:
R Eisenstein (NSF), C Llewellyn Smith (CERN DG), M Krebs (DOE)

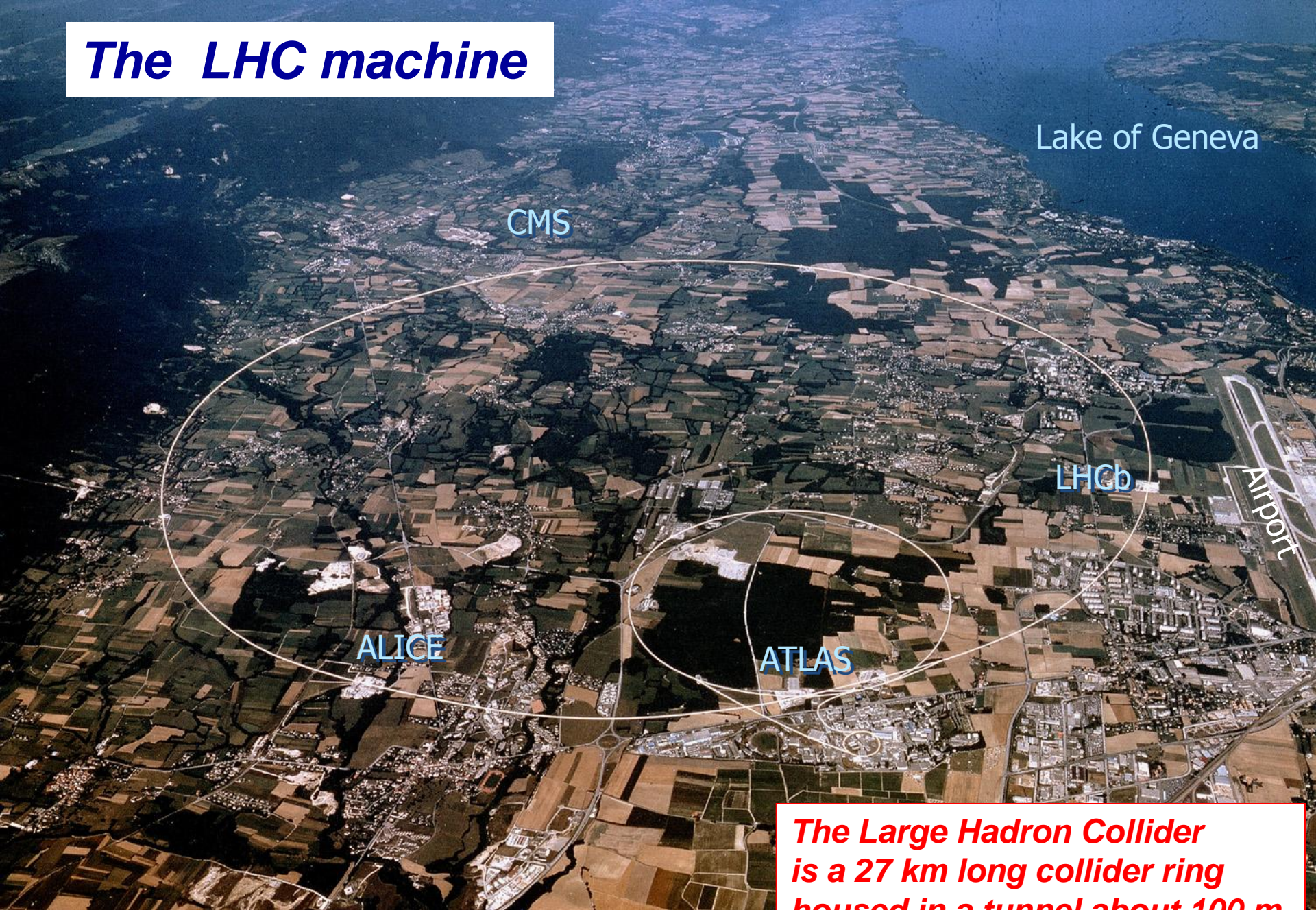
Les Horribles Cernettes



The first picture on the Web in 1992 !



The LHC machine



Lake of Geneva

CMS

LHCb

ALICE

ATLAS

Airport

The Large Hadron Collider is a 27 km long collider ring housed in a tunnel about 100 m underground near Geneva

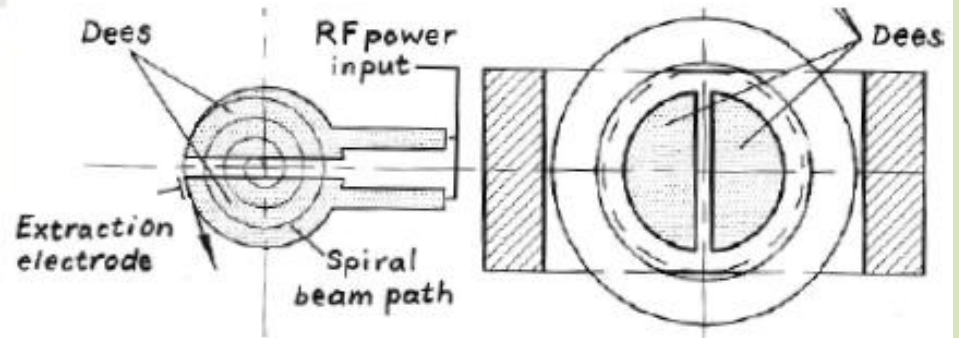
The first cyclotron and the Berkeley one



Ernest Lawrence
(1901 - 1958)



**The first circular accelerator
(Berkeley 1930)**



The most challenging components are the 1232 high-tech superconducting dipole magnets

Magnetic field: 8.4 T

Operation temperature: 1.9 K

Dipole current: 11700 A

Stored energy: 7 MJ

Dipole weight: 34 tons

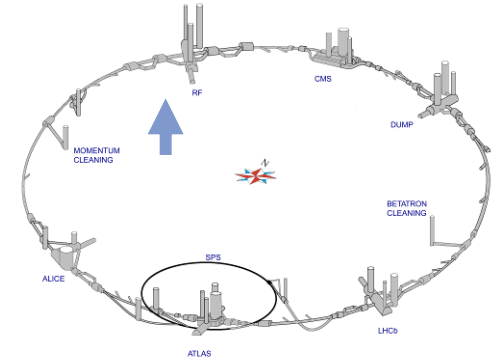
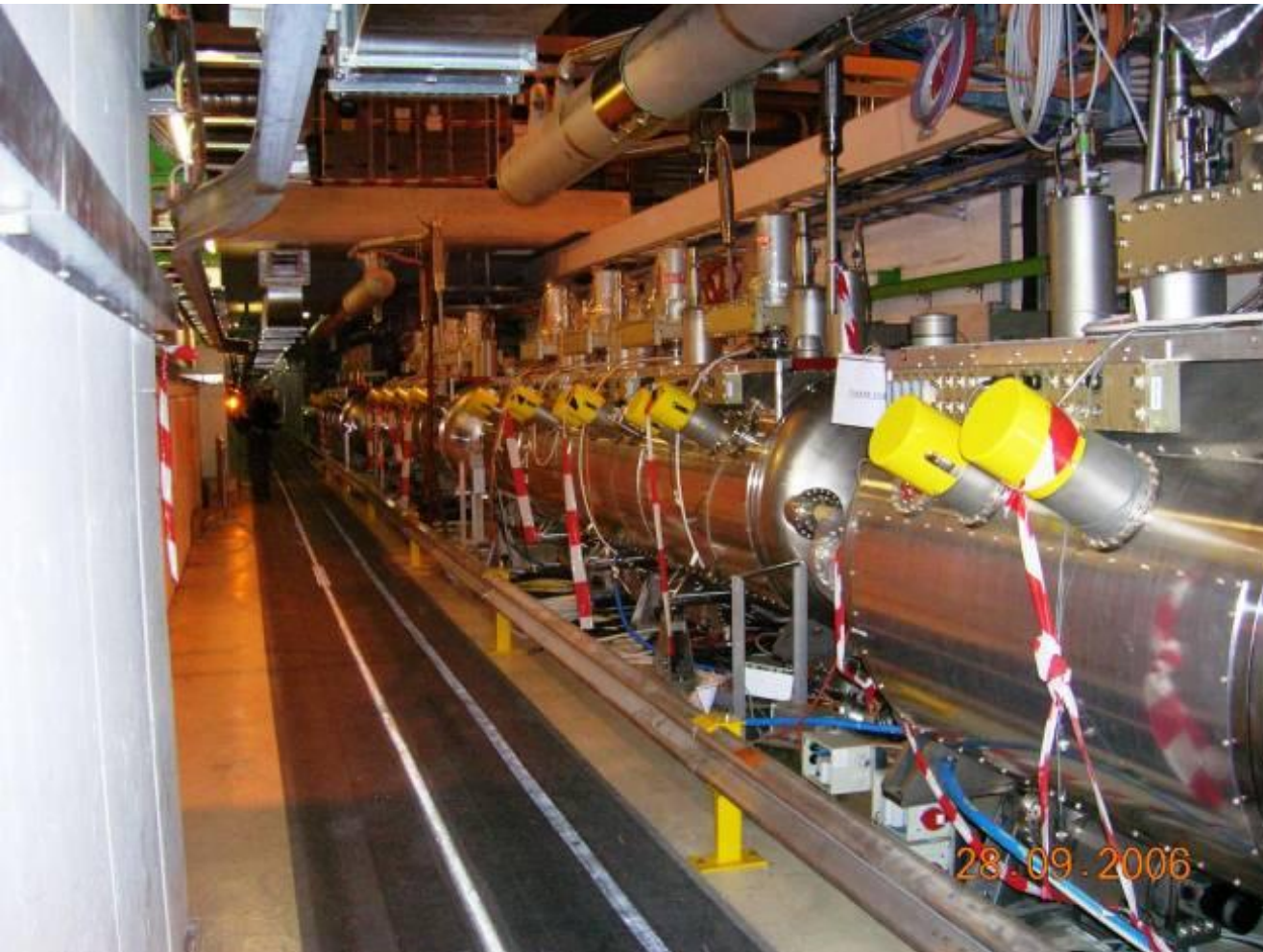
7600 km of Nb-Ti superconducting cable



Prague, 25-10-2012
P Jenni (CERN)

LHC Construction Project Leader Lyndon Evans

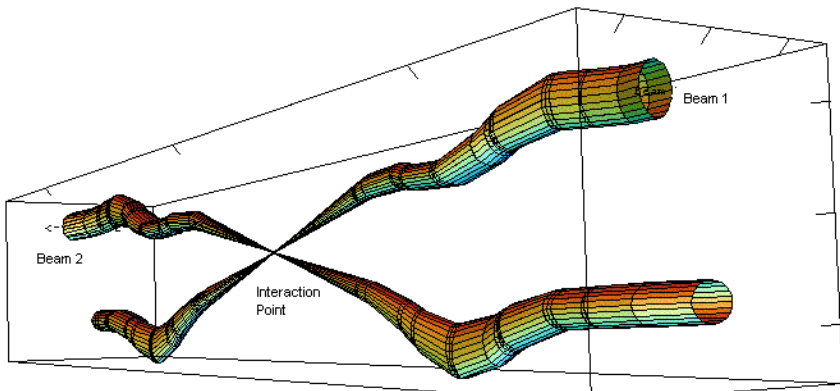
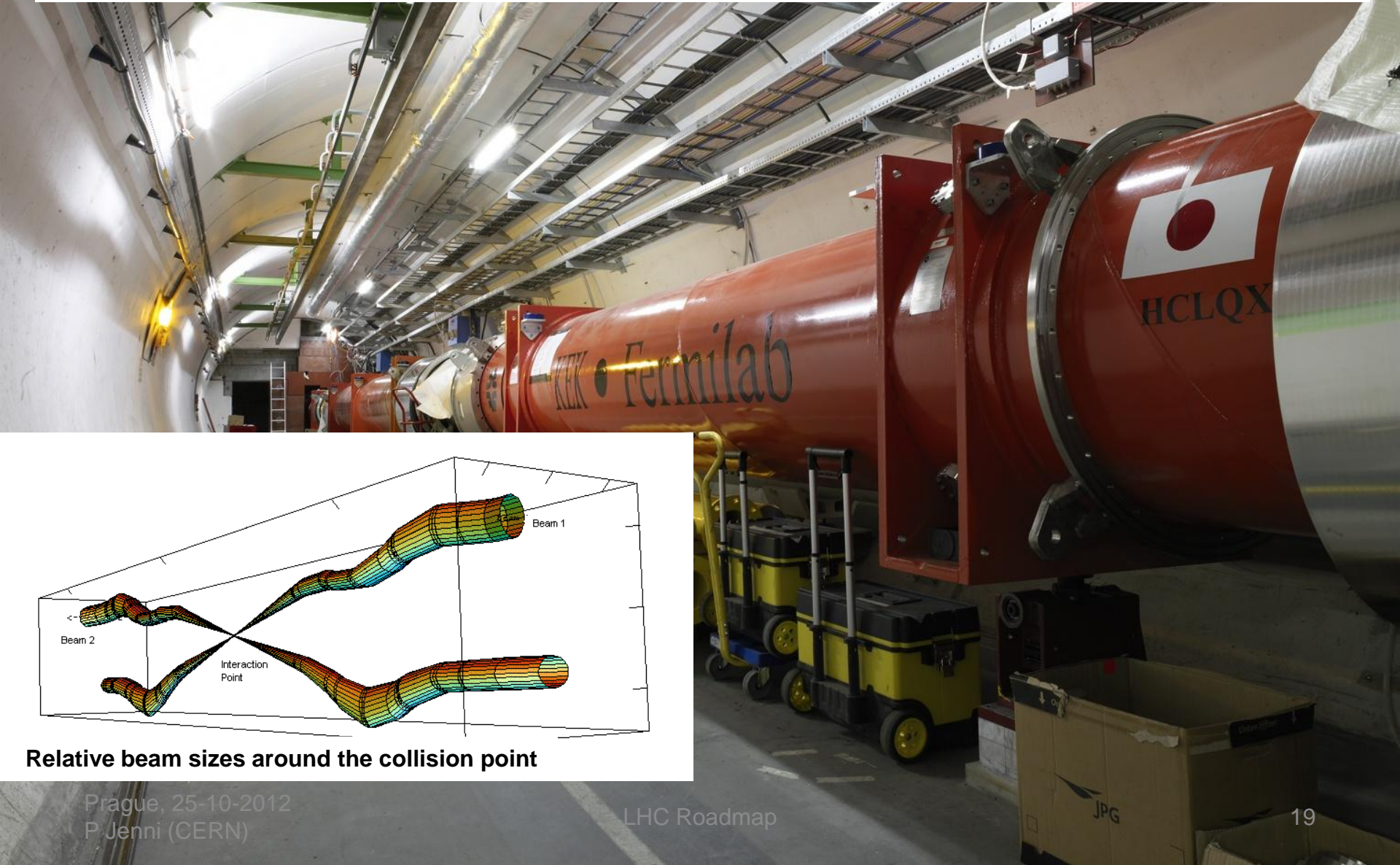
The particle beams are accelerated by superconducting Radio-Frequency (RF) cavities



Note: The acceleration is not such a big issue in pp colliders (unlike in e^+e^- colliders), because of the $\sim 1/m^4$ behaviour of the synchrotron radiation energy losses [$\sim E_{\text{beam}}^4/Rm^4$]

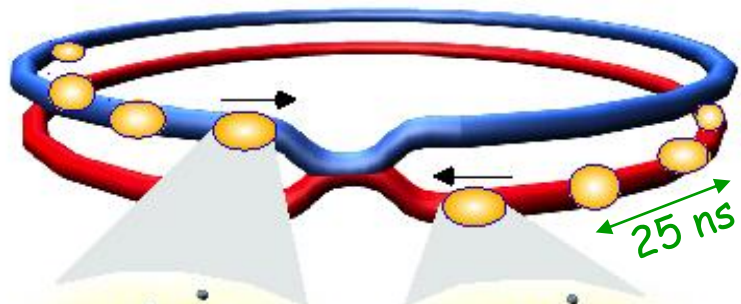
	LHC at 7 TeV	LEP at 100 GeV
Synchrotron radiation loss	6.7 keV/turn	3 GeV/turn
Peak accelerating voltage	16 MV/beam	3600 MV/beam

Special quadrupole magnets ("Inner Triplets") are focussing the particle beams to reach highest densities ("luminosity") at their interaction point in the centre of the experiments



Relative beam sizes around the collision point

Collisions at LHC

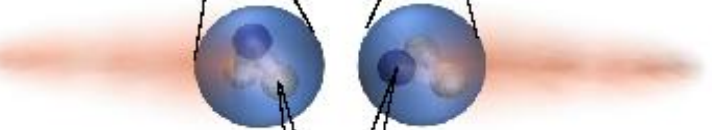


Proton-Proton	
Protons/bunch	10^{11}
Beam energy	7 TeV (7×10^{12} eV)
Luminosity	10^{34} cm ⁻² s ⁻¹

Bunch



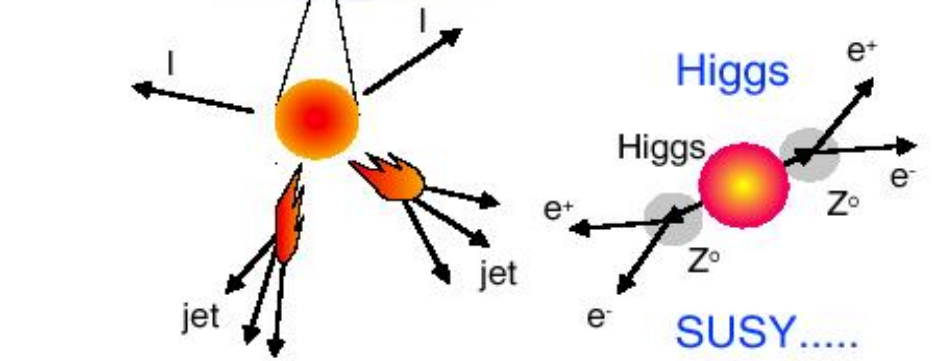
Proton



**Parton
(quark, gluon)**



Particle



Event rate:

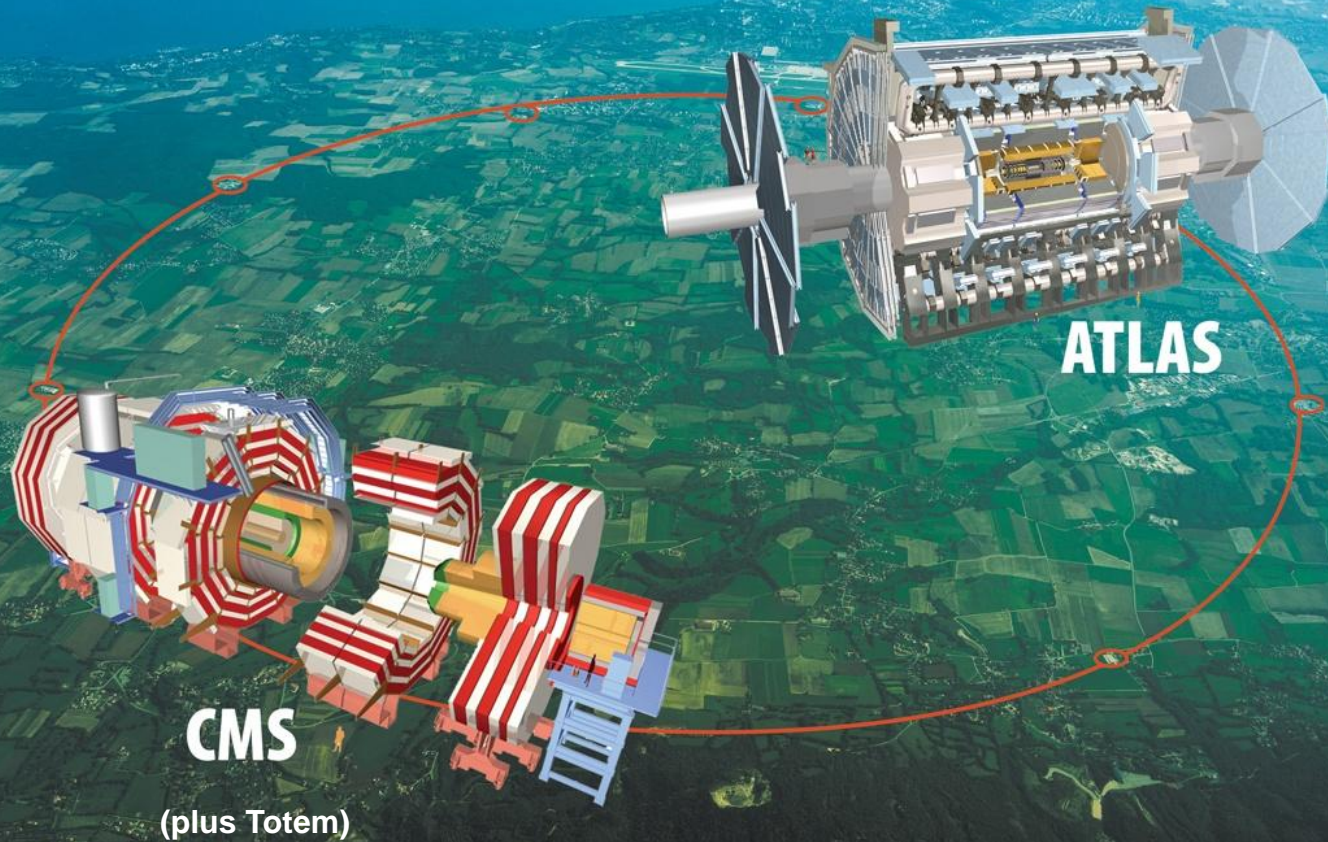
$N = L \times \sigma (pp) \approx 10^9$ interactions/s

Mostly soft (low p_T) events

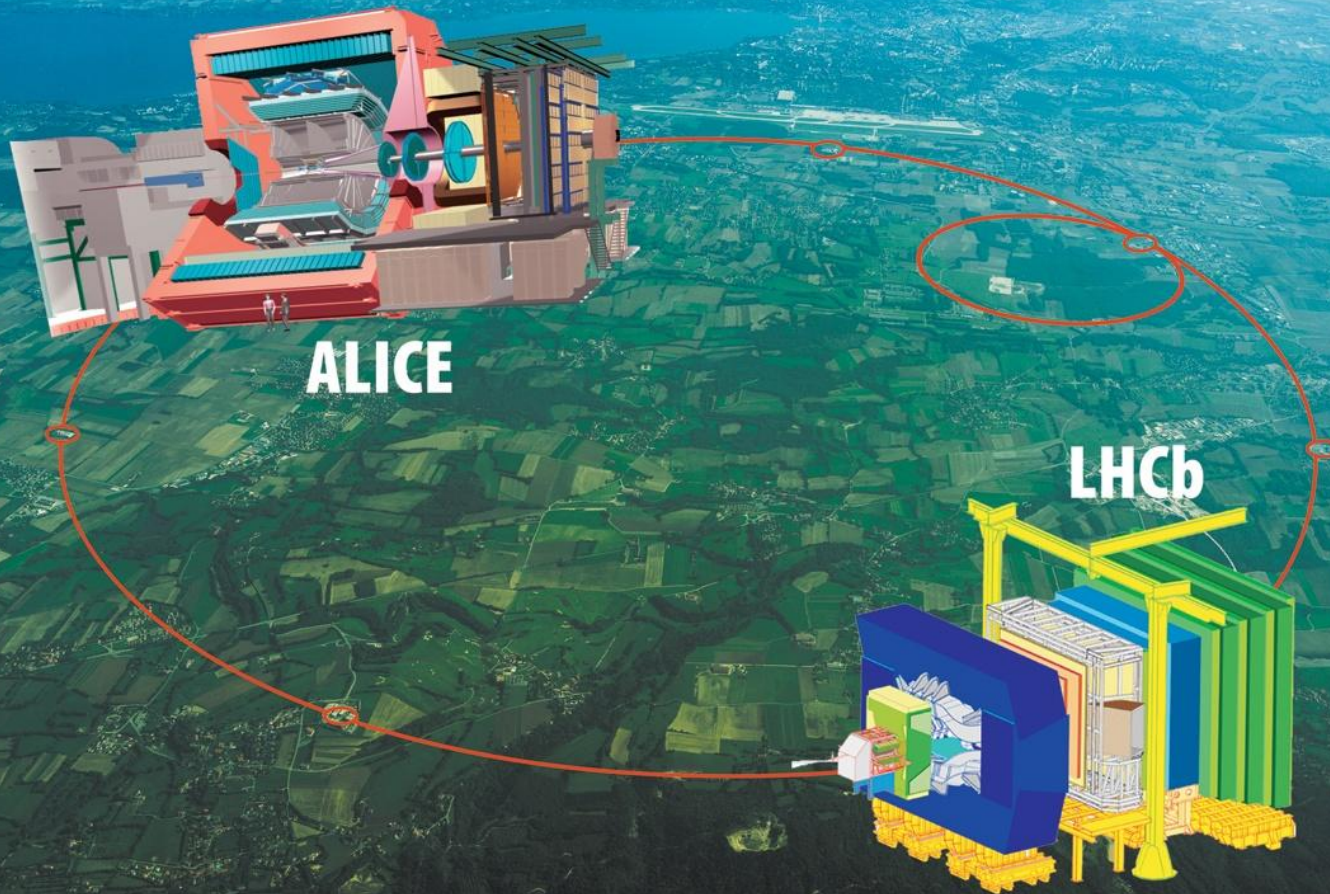
Interesting hard (high- p_T) events are rare

**Selection of 1 in
10,000,000,000,000**

General purpose detectors



Specialized detectors



The LHC World of CERN

Plus smaller
local earldoms
LHCf (point-1)
TOTEM (point-5)
Moedal (point-8)

CMS

3000 Physicists
184 Institutions
38 countries
550 MCHF

ALICE

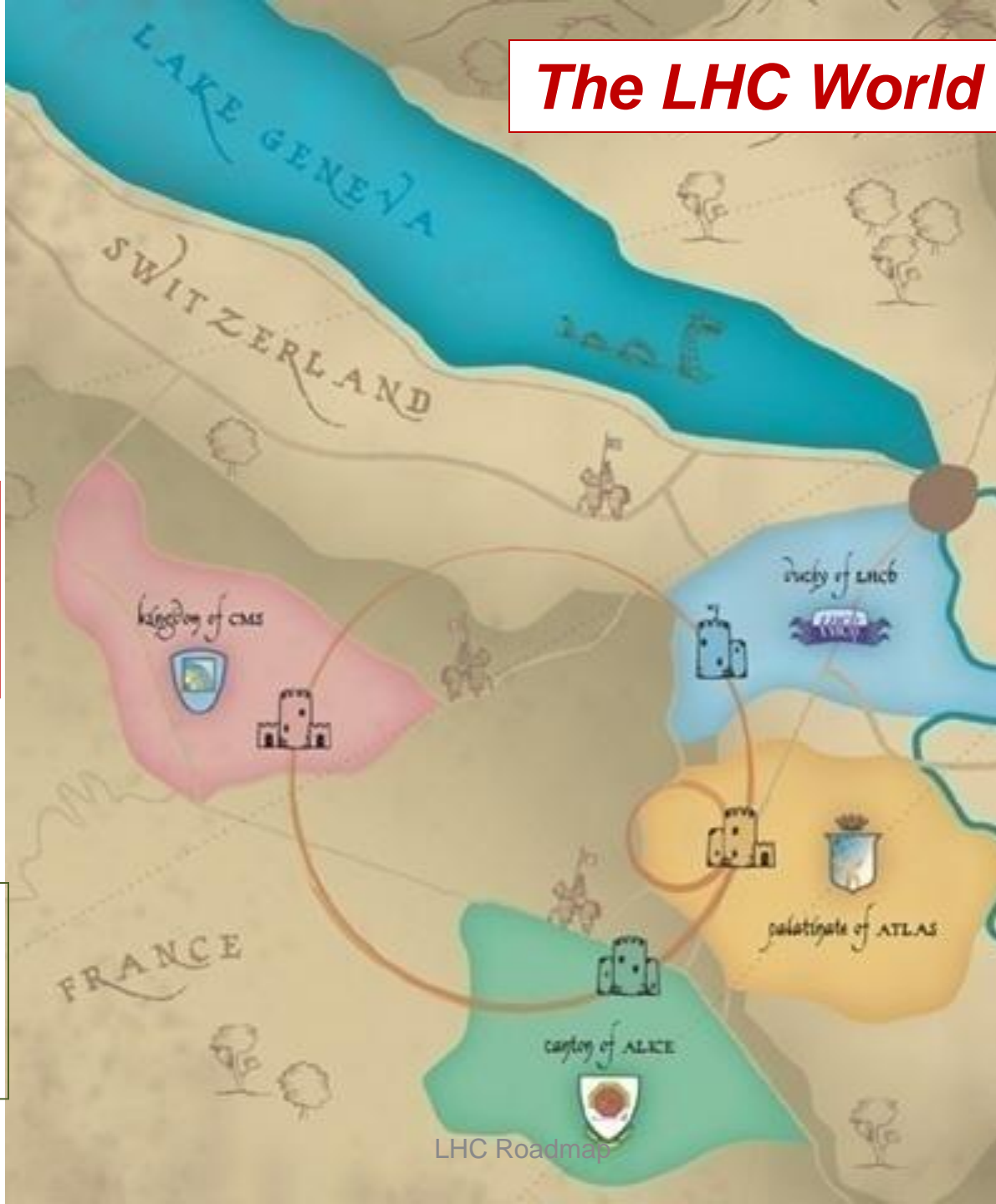
1000 Physicists
105 Institutions
30 countries
150 MCHF

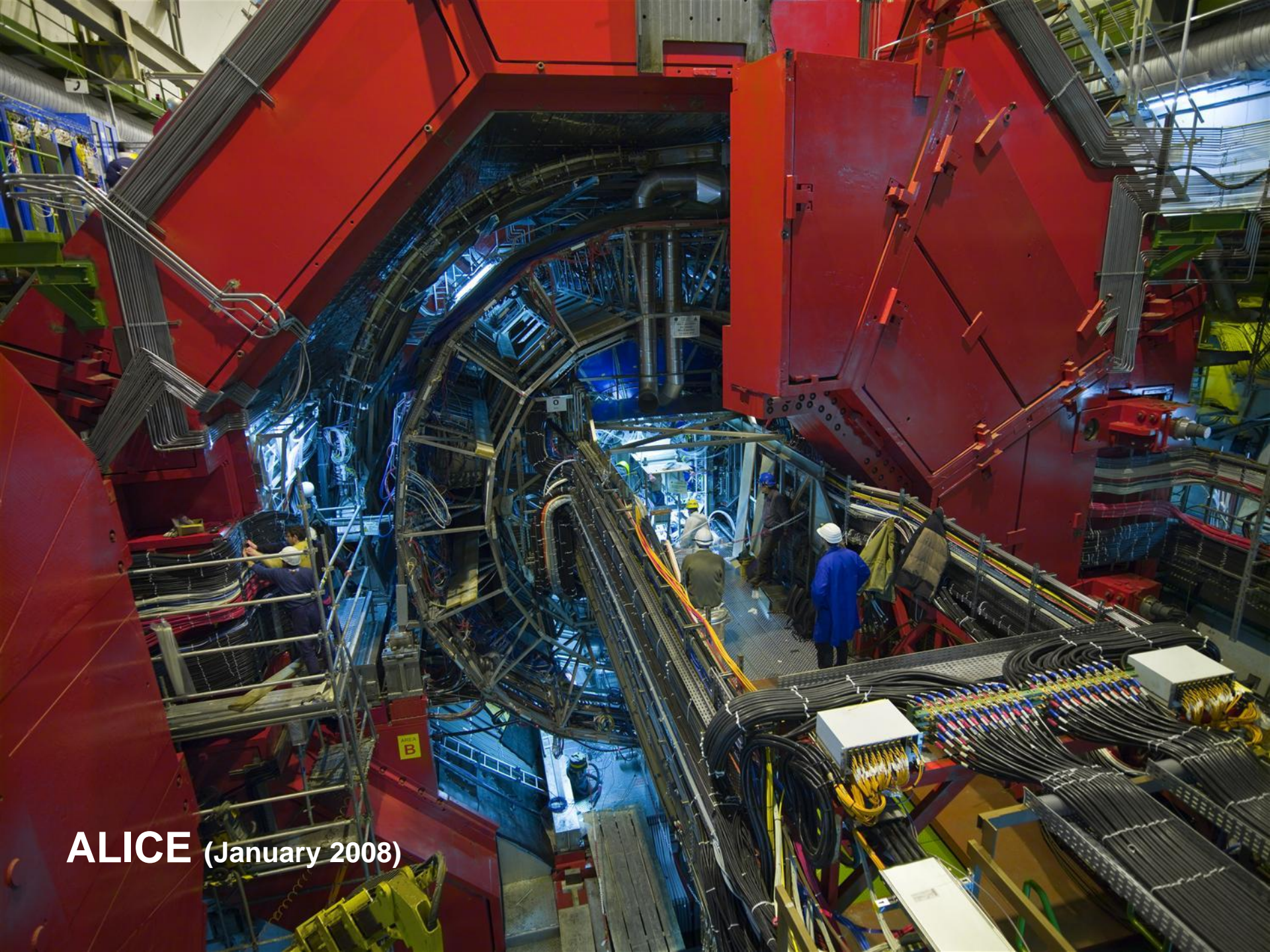
LHCb

730 Physicists
54 Institutions
15 countries
75 MCHF

ATLAS

3000 Physicists
176 Institutions
38 countries
550 MCHF





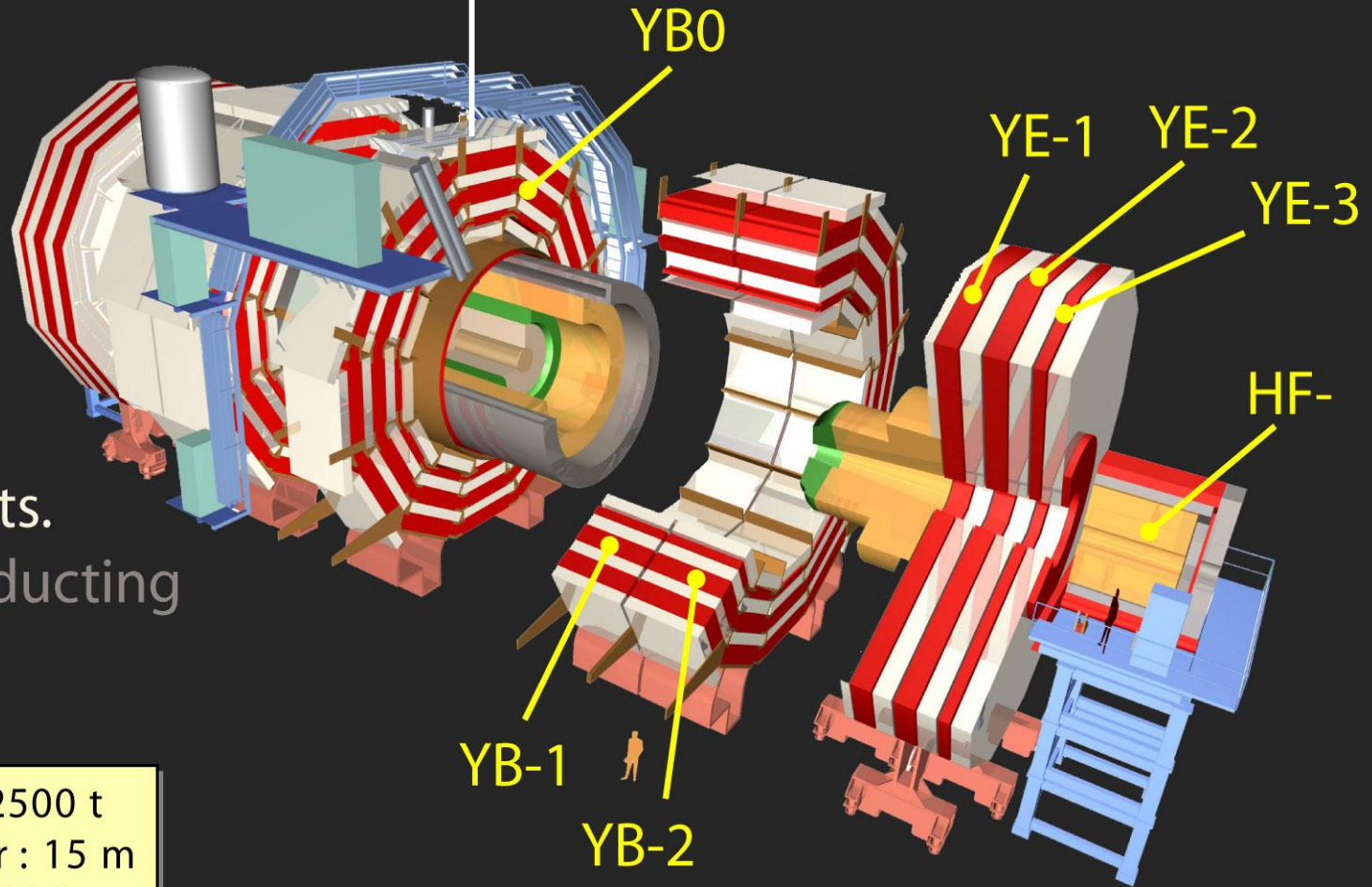
ALICE (January 2008)

Exploded View of CMS

Plus Side

Minus Side

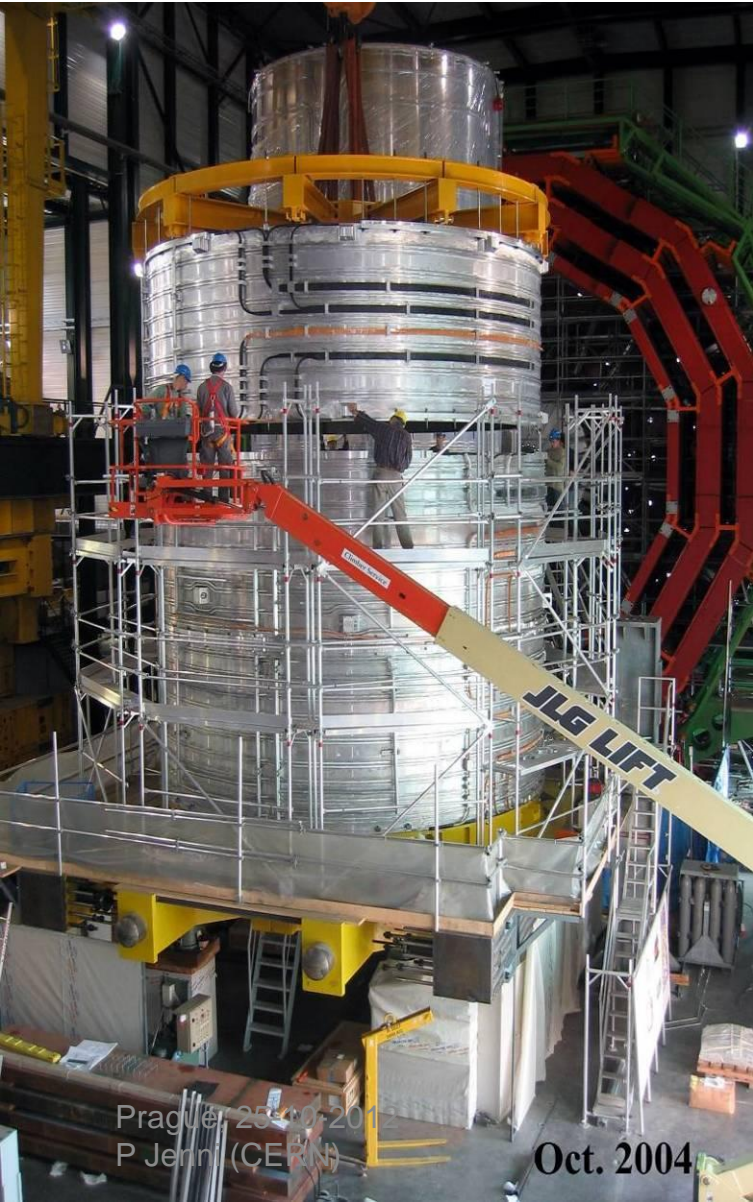
- Pixels
- Tracker
- ECAL
- HCAL
- MUON Dets.
- Superconducting Solenoid



Total weight : 12500 t
Overall diameter : 15 m
Overall length : 21.6 m
Magnetic field : 4 Tesla

<http://cms.cern.ch>

An Example of an Engineering Challenge: CMS Solenoid



CMS solenoid:

Magnetic length 12.5 m

Diameter 6 m

Magnetic field 4 T

Nominal current 20 kA

Stored energy 2.7 GJ

Tested at full current in Summer 2006



CMS before closure 2008



ATLAS Collaboration

(Status June 2012)

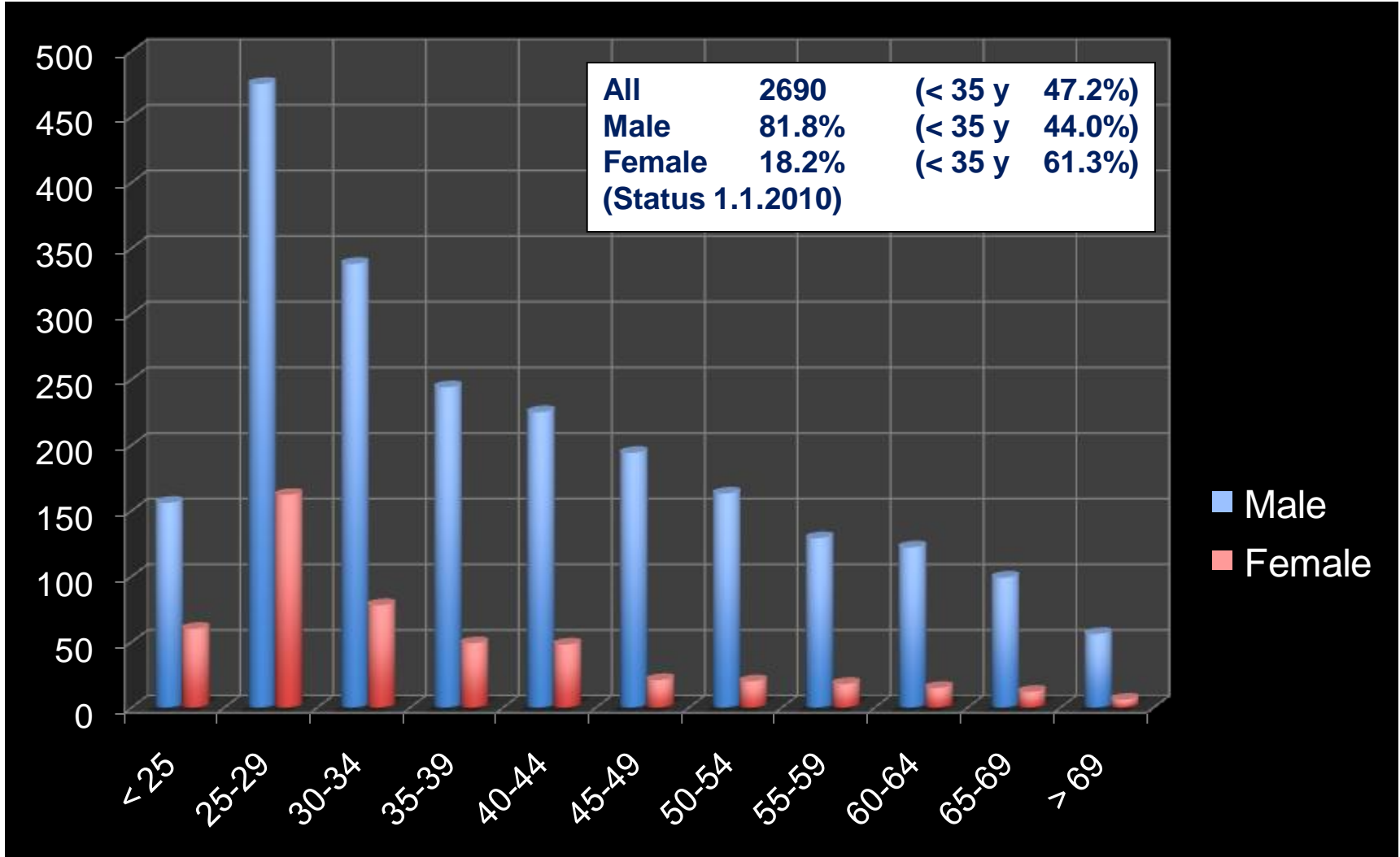
38 Countries
176 Institutions
3000 Scientific participants total
(1000 Students)

ATLAS enjoys a longstanding and very fruitful partnership with the Czech groups since the very first days



Adelaide, Albany, Alberta, NIKHEF Amsterdam, Ankara, LAPP Ancey, Argonne NL, Arizona, UT Arlington, Athens, NTU Athens, Baku, IFAE Barcelona, Belgrade, Bergen, Berkeley LBL and UC, HU Berlin, Bern, Birmingham, UAN Bogota, Bologna, Bonn, Boston, Brandeis, Brasil Cluster, Bratislava/SAS Kosice, Brookhaven NL, Buenos Aires, Bucharest, Cambridge, Carleton, CERN, Chinese Cluster, Chicago, Chile, Clermont-Ferrand, Columbia, NBI Copenhagen, Cosenza, AGH UST Cracow, IFJ PAN Cracow, SMU Dallas, UT Dallas, DESY, Dortmund, TU Dresden, JINR Dubna, Duke, Edinburgh, Frascati, Freiburg, Geneva, Genoa, Giessen, Glasgow, Göttingen, LPSC Grenoble, Technion Haifa, Hampton, Harvard, Heidelberg, Hiroshima IT, Indiana, Innsbruck, Iowa SU, Iowa, UC Irvine, Istanbul Bogazici, KEK, Kobe, Kyoto, Kyoto UE, Kyushu, Lancaster, UN La Plata, Lecce, Lisbon LIP, Liverpool, Ljubljana, QMW London, RHBNC London, UC London, Lund, UA Madrid, Mainz, Manchester, CPPM Marseille, Massachusetts, MIT, Melbourne, Michigan, Michigan SU, Milano, Minsk NAS, Minsk NCPHEP, Montreal, McGill Montreal, RUPHE Morocco, FIAN Moscow, ITEP Moscow, MEPHI Moscow, MSU Moscow, LMU Munich, MPI Munich, Nagasaki IAS, Nagoya, Naples, New Mexico, New York, Nijmegen, Northern Illinois, BINP Novosibirsk, Ohio SU, Okayama, Oklahoma, Oklahoma SU, **Olomouc**, Oregon, LAL Orsay, Osaka, Oslo, Oxford, Paris VI and VII, Pavia, Pennsylvania, NPI Petersburg, Pisa, Pittsburgh, **CAS Prague**, **CU Prague**, **TU Prague**, IHEP Protvino, Rome I, Rome II, Rome III, Rutherford Appleton Laboratory, DAPNIA Saclay, Santa Cruz UC, Sheffield, Shinshu, Siegen, Simon Fraser Burnaby, SLAC, South Africa, Stockholm, KTH Stockholm, Stony Brook, Sydney, Sussex, AS Taipei, Tbilisi, Tel Aviv, Thessaloniki, Tokyo ICEPP, Tokyo MU, Tokyo Tech, Toronto, TRIUMF, Tsukuba, Tufts, Udine/ICTP, Uppsala, UI Urbana, Valencia, UBC Vancouver, Victoria, Warwick, Waseda, Washington, Weizmann Rehovot, FH Wiener Neustadt, Wisconsin, Wuppertal, Würzburg, Yale, Yerevan

Age distribution of the ATLAS population





ATLAS Overview Week

A meeting of the world-wide ATLAS Collaboration building a detector for the near future of particle physics at the Large Hadron Collider at CERN. 13 –19 September 2003, Prague, Czech Republic

ATLAS has a long-standing, excellent, cooperation with the Czech teams, since the official start of the project in 1992

An important milestone was the ATLAS Collaboration meeting in Prague 2003, just before we started installing the detector





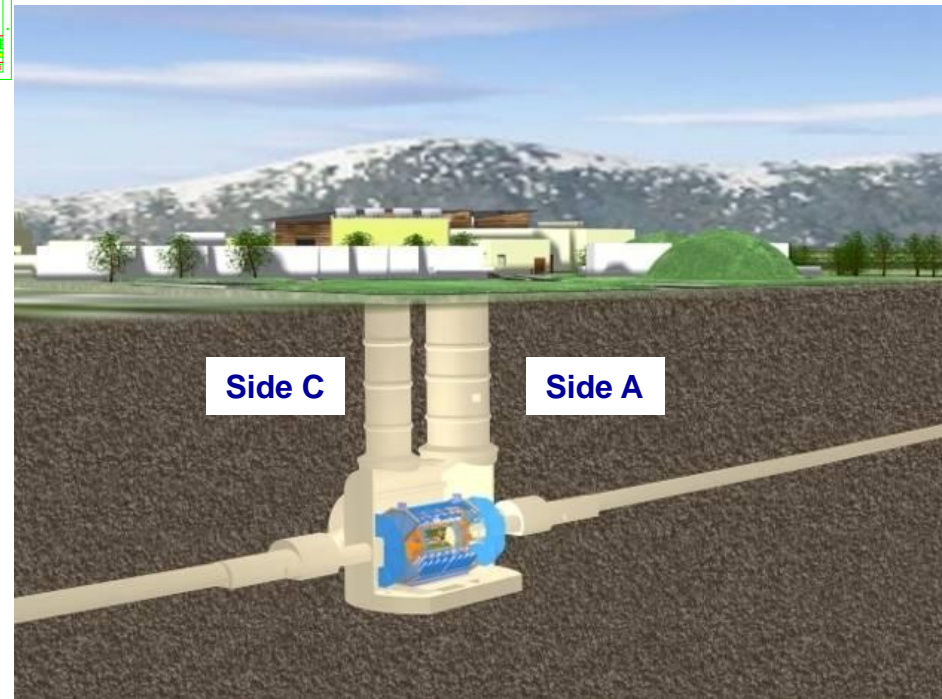
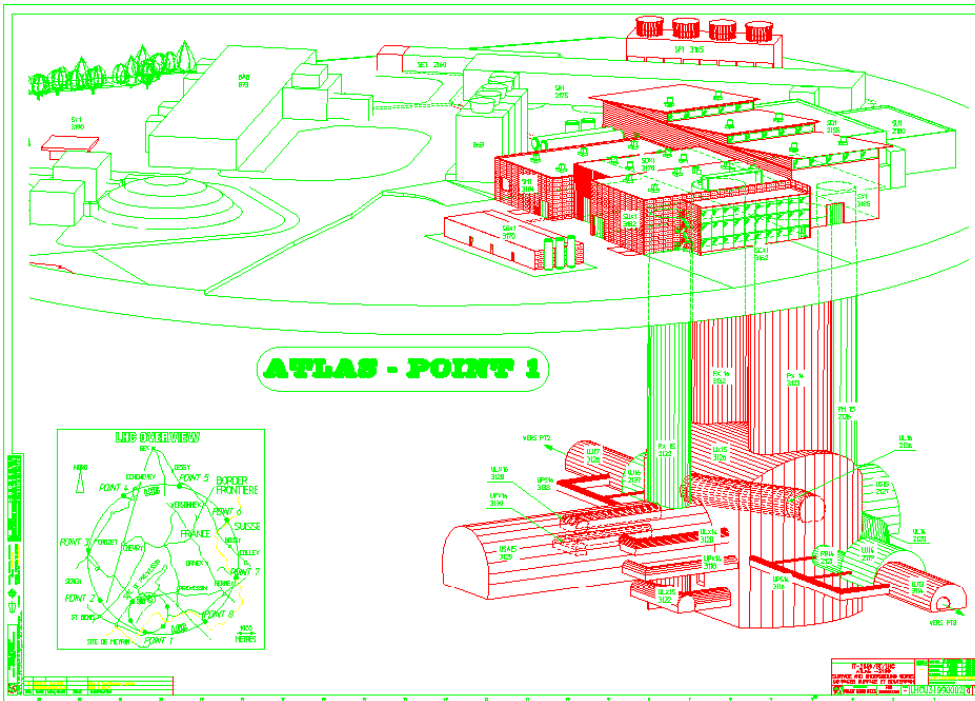
ATLAS OVERVIEW WEEK
13 - 19 September, 2003
Praha, Czech Republic

Petr KRÁNEK
Jiří NIEDERLE
Petr MAREŠ
Karel JUNGWIRTH
Ivan WILHELM
Petr ŠENK
Petr POŽÁR

Professor J Niederle (1939-2010) opening the ATLAS Overview Week in Prague

The Underground Cavern at Point-1 for the ATLAS Detector

Length = 55 m
 Width = 32 m
 Height = 35 m



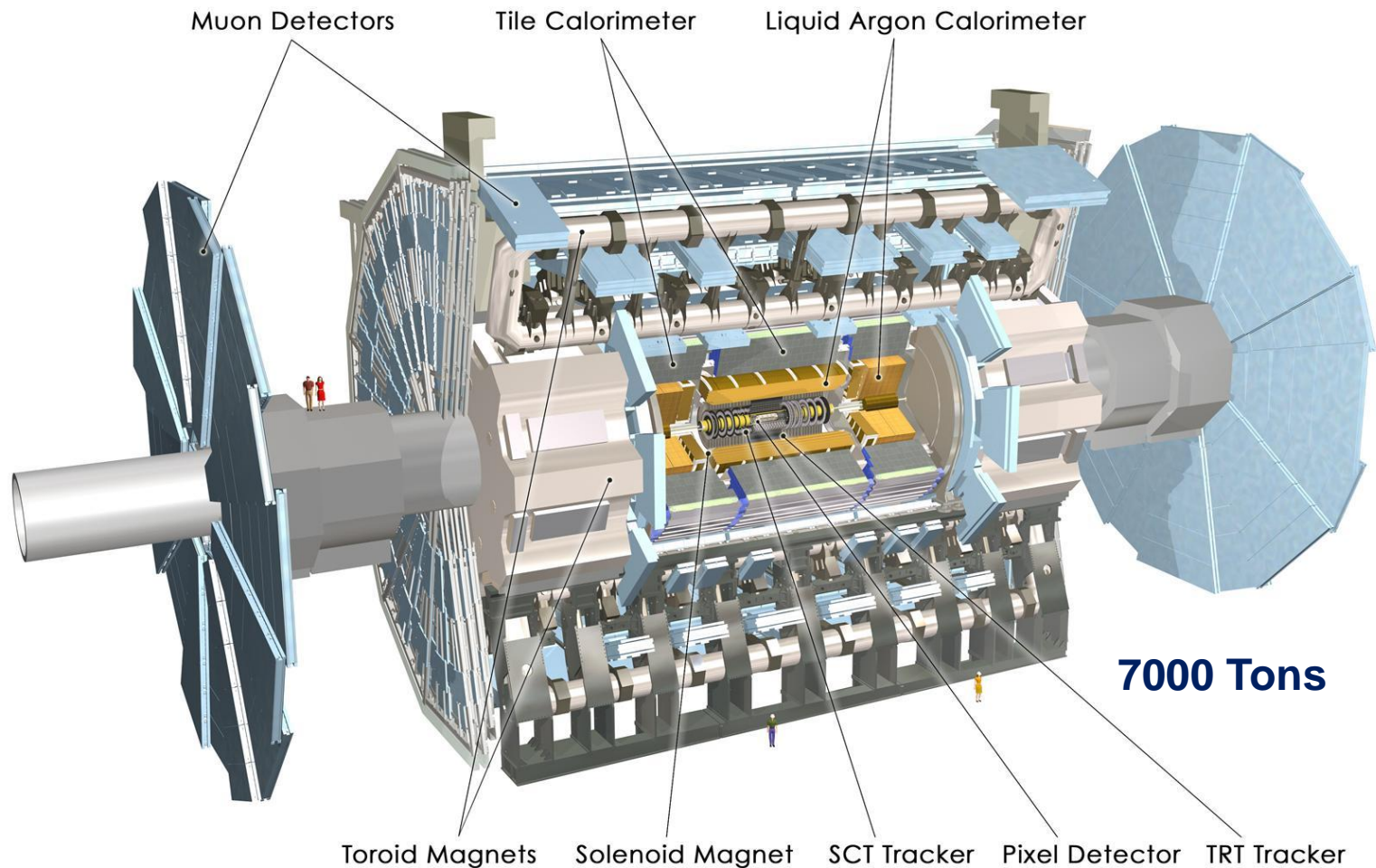
ATLAS Detector

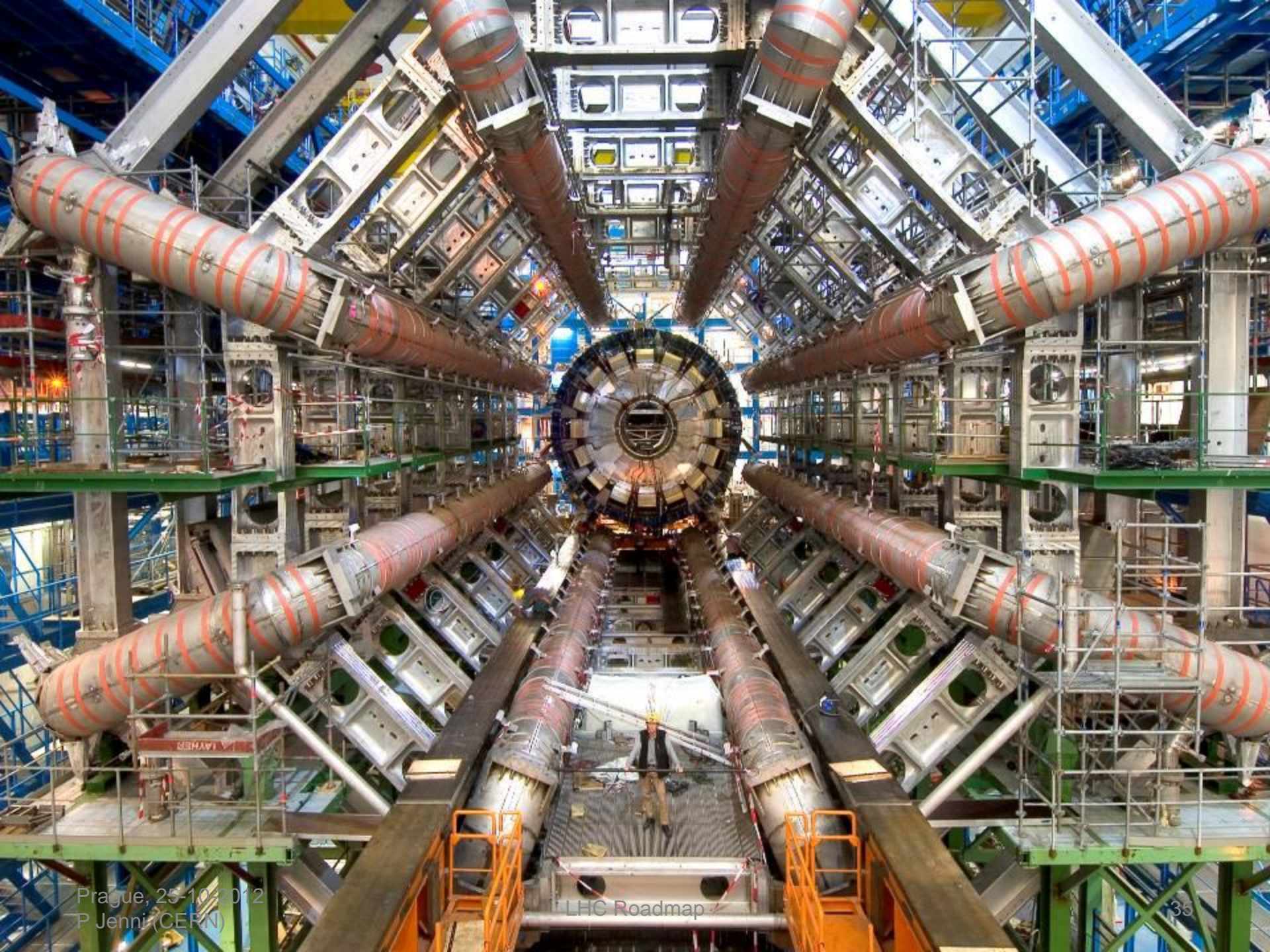


ATLAS superimposed to
the 5 floors of building 40

45 m

24 m



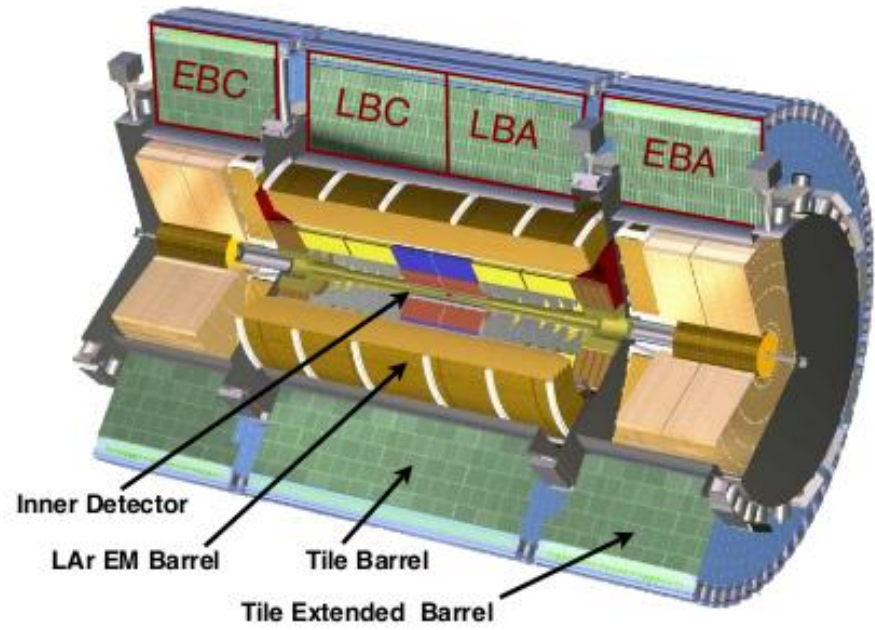
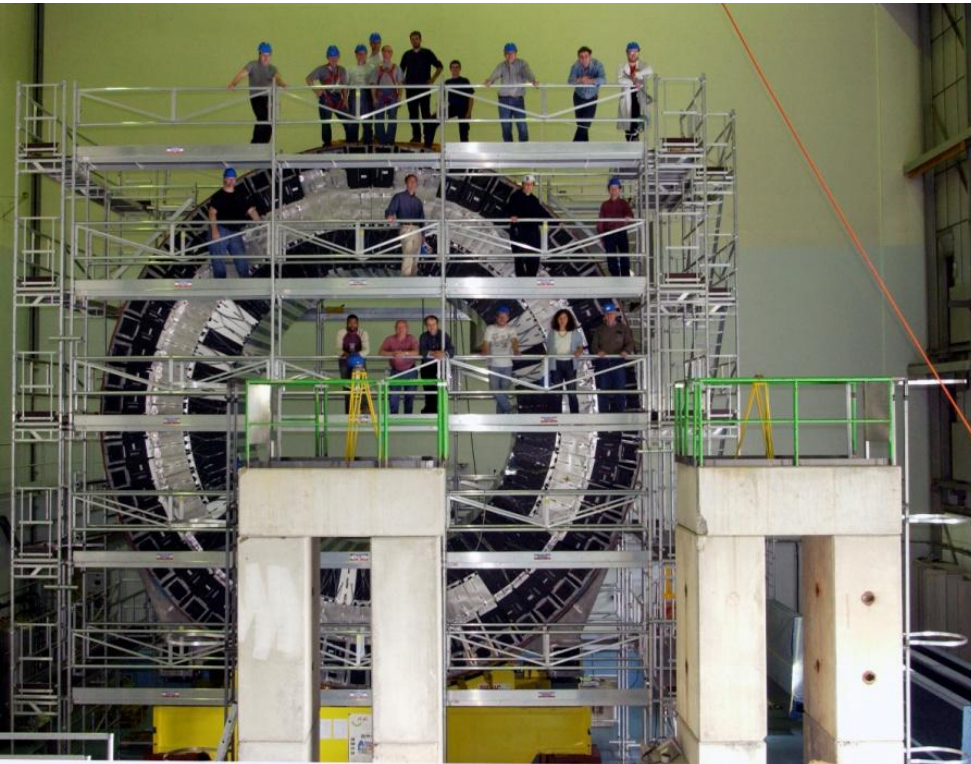




**Hector Berlioz, “Les Troyens”, opera in five acts
Valencia, Palau de les Arts Reina Sofia, 31 October -12 November 2009**

Tile Calorimeter

EBC pre-assembly on the surface, April 2003



Rupert Leitner Project Leader 2001-2004



Tile Calorimeter sub-module construction in Prague 1999



Czech Deputy Prime Minister Petr Mares visiting the Tile Calorimeter pre-assembly (Dec 2003)



Prague, 2
P Jenni (C

Transport of part of the Barrel Tile Calorimeter to the experimental area Point-1 (Sep 2004)

EBA assembly 24 May 2006



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64
79

ANL39

ANL30

ANL64

ANL40

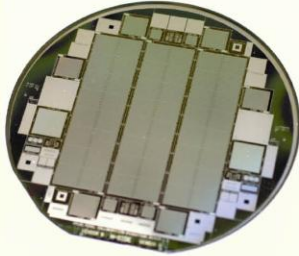
Position 17

ATLAS Supplier Award

In recognition of excellent supplier performance

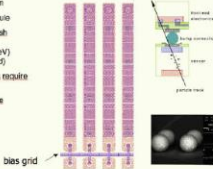
ATLAS Supplier Award for ON Semiconductor

Supplier of Silicon Sensors for the ATLAS Pixel Detector



Design of the sensor

- pixel size $50 \mu\text{m} \times 400 \mu\text{m}$
- 40960 channels per module
- 10 years operation in harsh radiation environment:
 - up to $10^{13} \text{ n}_{\text{eq}}/\text{cm}^2$ (10 Mrad)
 - and 500 kGy (= 50 krad)
- difficult access conditions require high reliability
- testability of sensor before module assembly
 - bias grid



The ON Semiconductor Czech Republic foundry of Roznov, Czech Republic has supplied a total of 515 production sensor wafers containing a total of 1177 production sensor tiles within the technical specifications for the ATLAS Pixel Detector. These sensors were delivered on schedule and within budget.

The requirements of the ATLAS Pixel Detector were very demanding. It is the first large-scale silicon detector to combine such a complex sensor layout (46080 individual pixel implants arranged as a two-dimensional array within a 10 cm^2 active area) with extreme radiation requirements (reliable operation to a total dose of 10^{13} cm^{-2} neutron-equivalent, roughly ten times higher than for typical strip sensors). Achieving these requirements led to the first commercial implementation of several new sensor technologies. The high-dose sensor requirement led to the use of a low-dose boron implantation (so-called "p-spray" isolation) which allowed breakdown-free operation of the sensors at bias voltages above 600V after the full radiation dose. The silicon bulk material was specially processed using the DOFZ technique (diffusion oxygenation at very high temperature to embed significant Oxygen in the Silicon lattice and improve the depletion behavior of the material after high radiation doses). In addition, the need to achieve high quality and yield in volume production required a new testing capability, implemented as a "bias grid" which allows a complete IV characterization of the sensor tile with a single set of measurements.

ON Semiconductor, in its Roznov foundry, has produced wafers satisfying all of these requirements with excellent yield. As there are three sensor tiles per wafer, and the full wafer must be bump-bonded, high yield is essential to control the overall cost. The success yield achieved is 99.99%. The performance of the sensors is excellent. The ATLAS Pixel Detector is now ready for the start of the ATLAS data taking.

The Prague groups (and Czech industry) are also important collaborators on the semiconductor tracking system (SCT and Pixels)

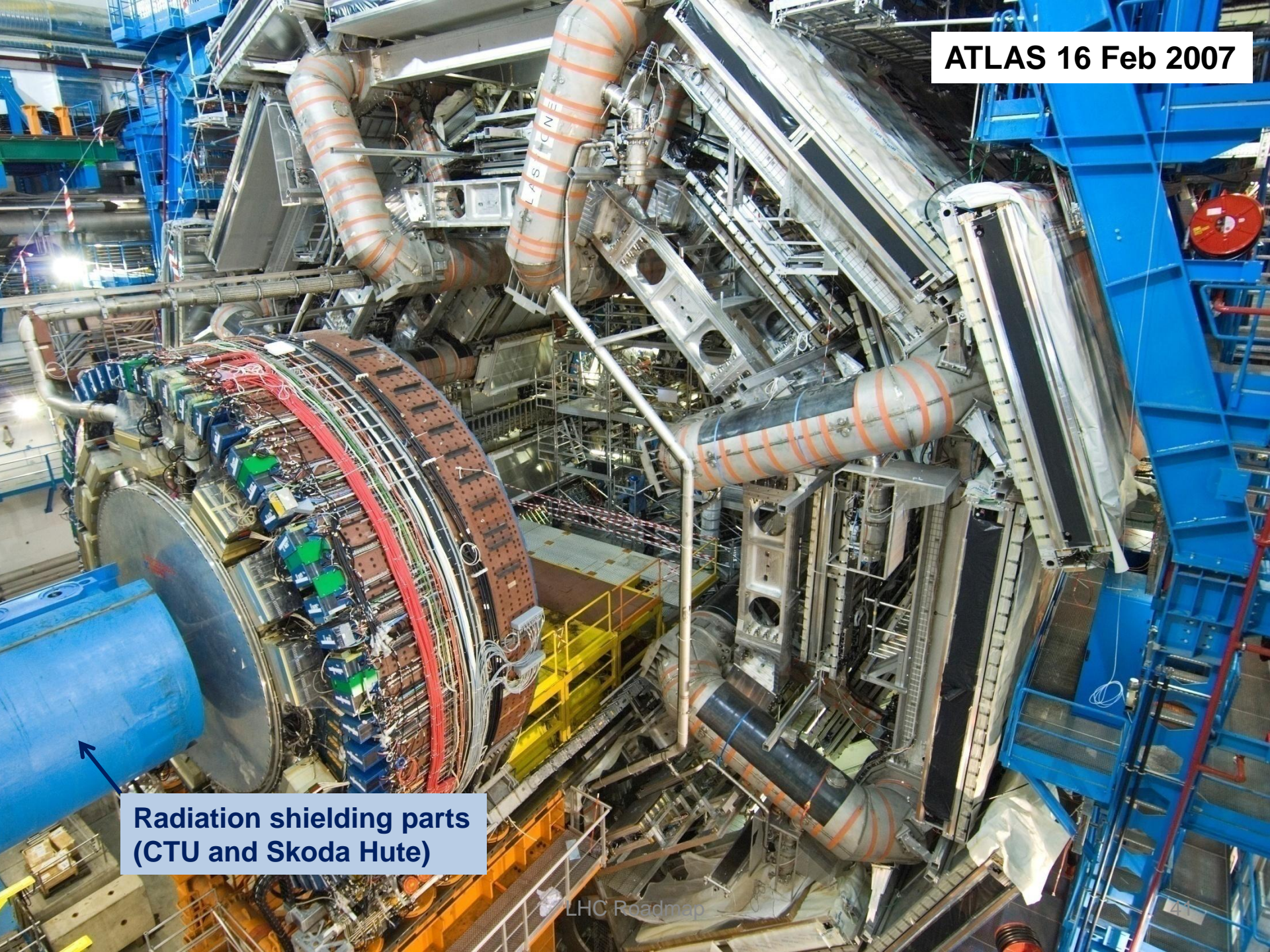
ATLAS Supplier Award ceremony for 'On Semiconductor' (ex 'Tesla') in 2007

(Also 'Skoda Hute' received the same award in 2004 for their shielding work)

Prague, 25-10-2012
P Jenni (CERN)



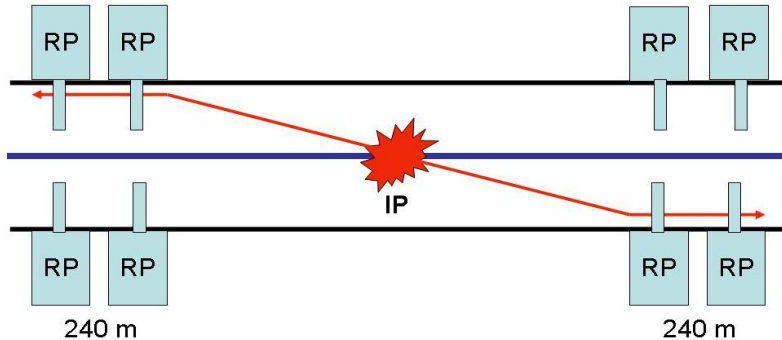
ATLAS 16 Feb 2007



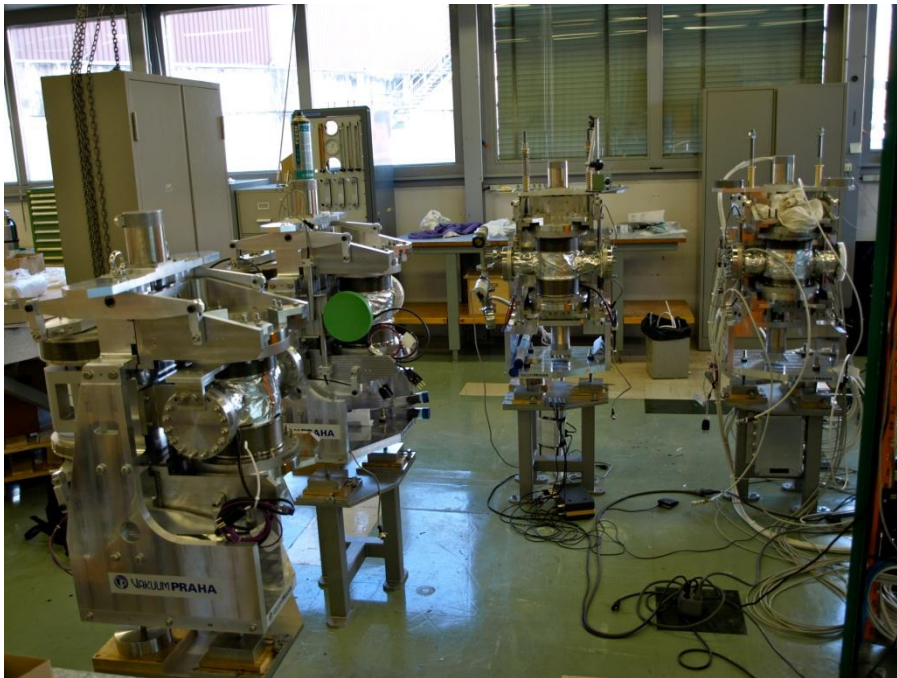
**Radiation shielding parts
(CTU and Skoda Hute)**

ATLAS Roman Pots (ALFA)

There is also a strong involvement of Czech colleagues and industry in ALFA since the Palacky University in Olomouc joined ATLAS in 2008



**Absolute
Luminosity
For
ATLAS**



Prague, 25-10-2012
P Jenni (CERN)

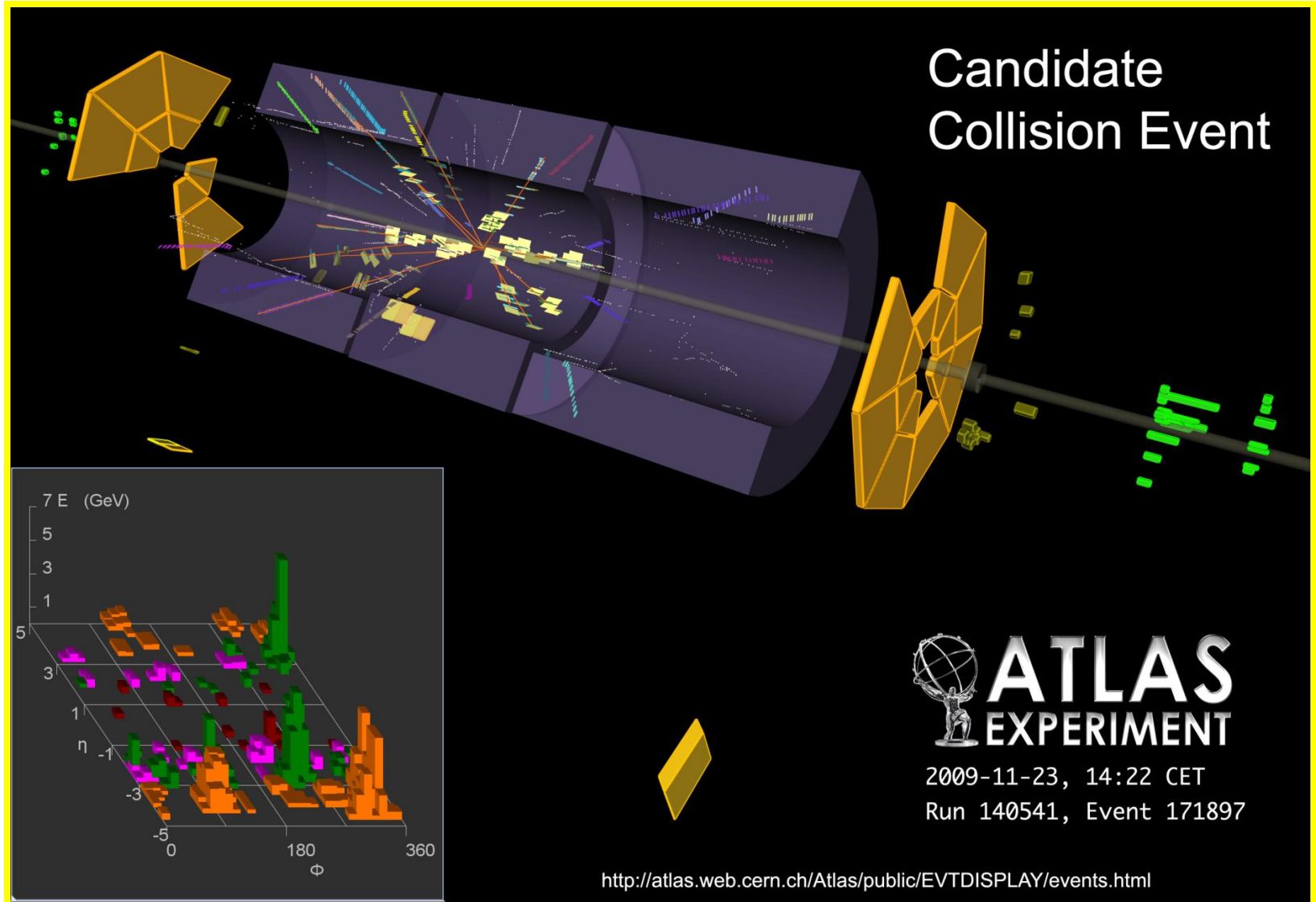


**Roman Pots mechanics,
based on Czech work in
the Totem experiment**

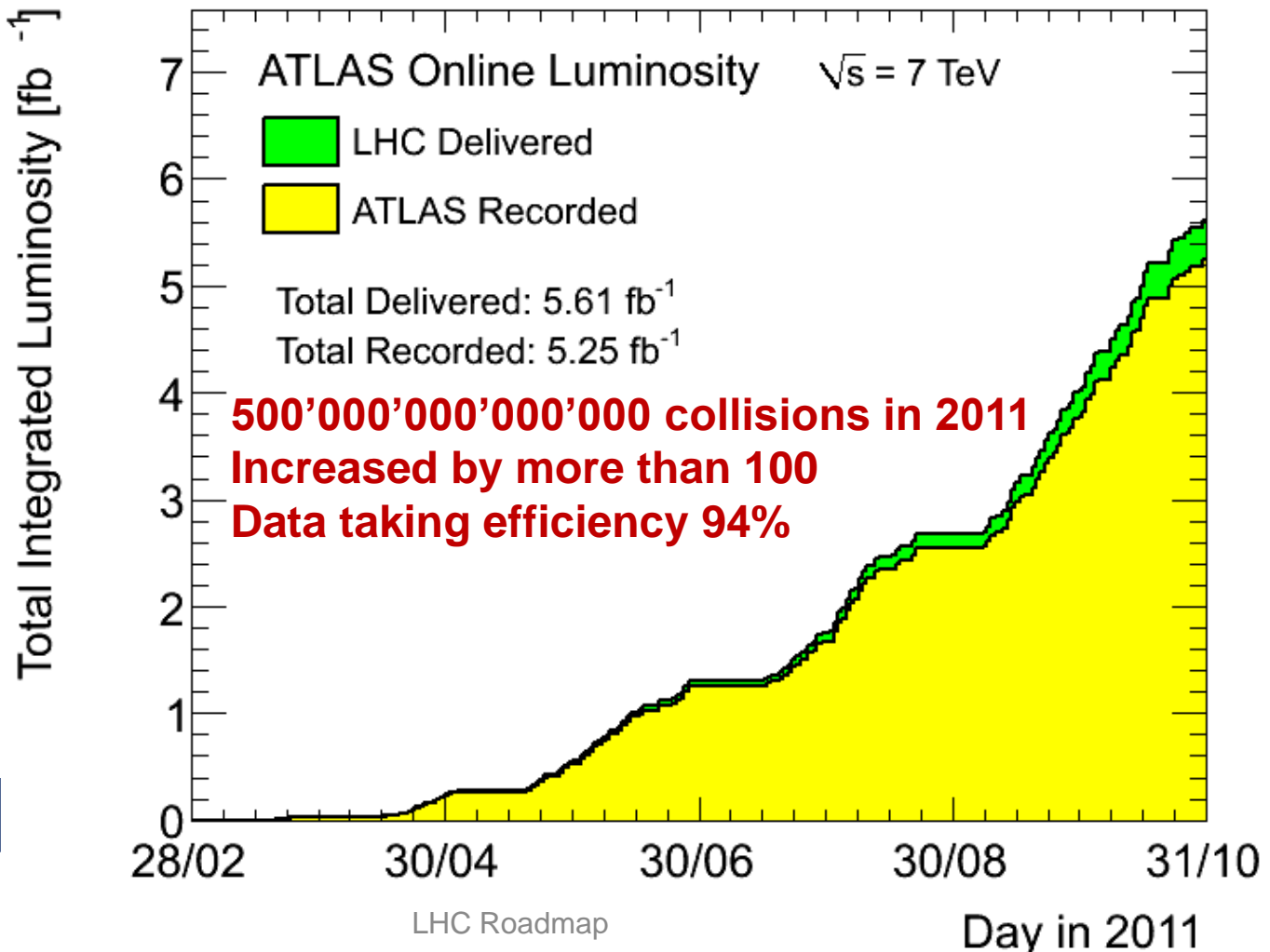
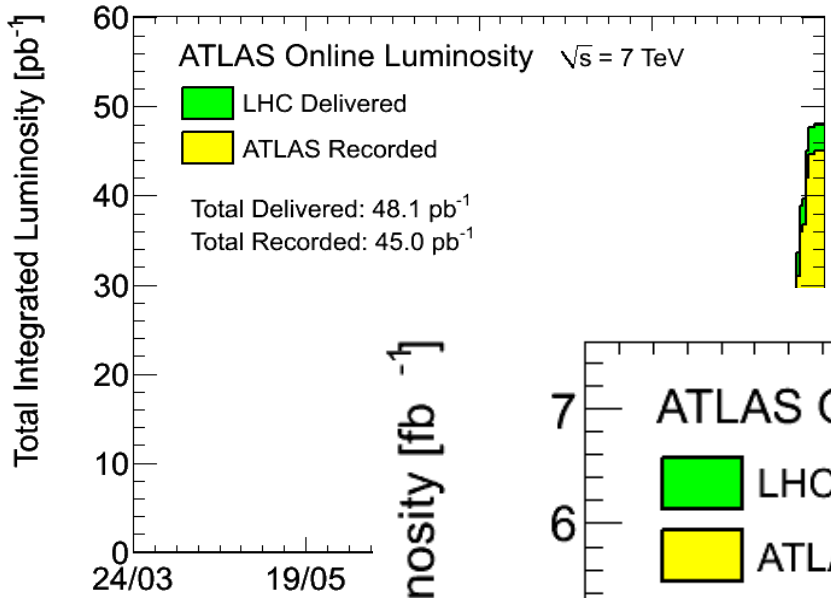
The joy in the ATLAS Control Room when the first LHC beam collided on November 23rd, 2009....



First collisions at the LHC end of November 2009 with beams at the injection energy of 450 GeV

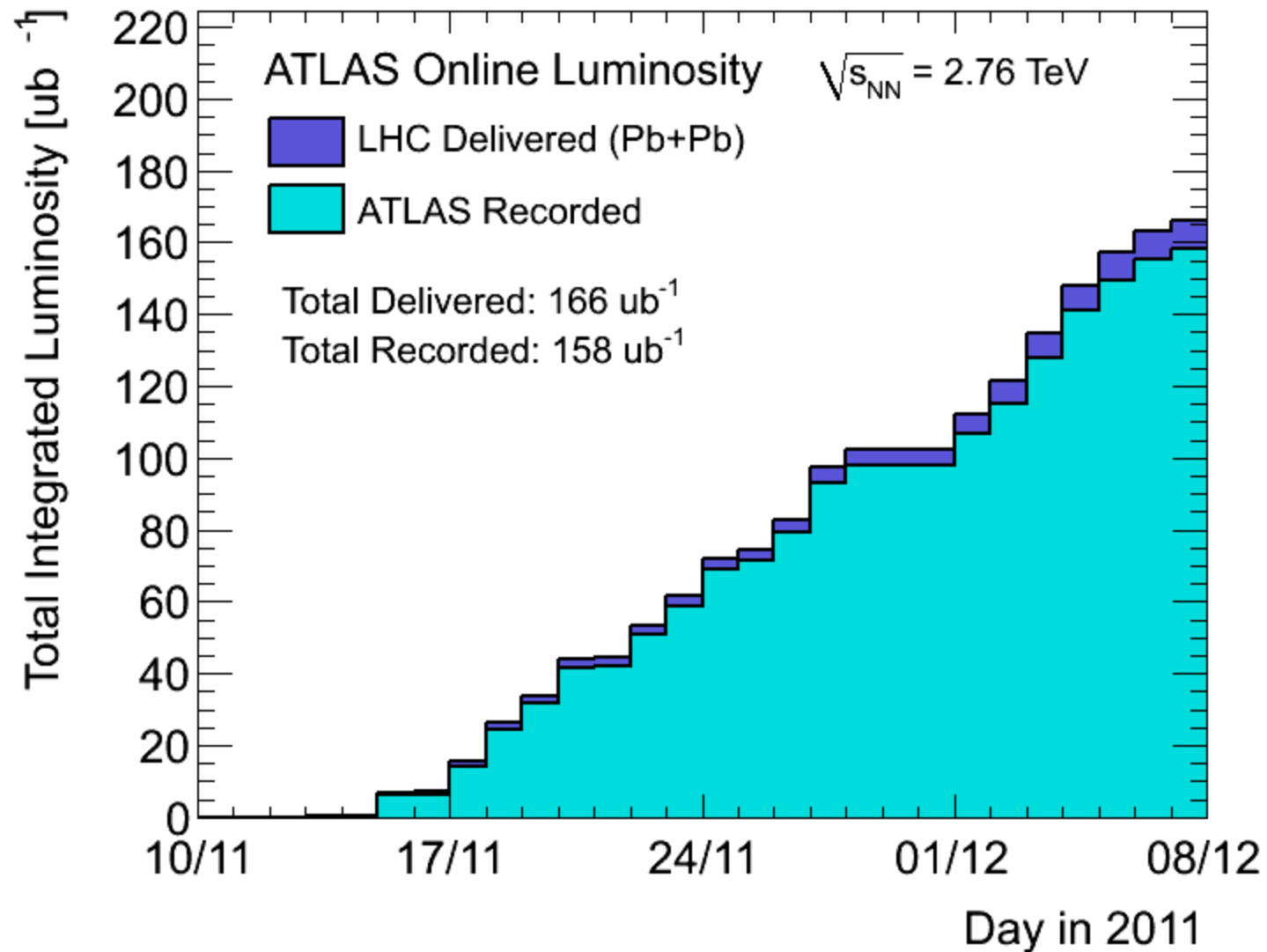


A lot of exciting physics results were already possible thanks to the superb LHC performance in 2011



$$N_{\text{events}} = \sigma \int L dt$$

Heavy Ion Running in 2011





**During the short Winter shut-down on 8 March 2012:
Visit of the Deputy Minister Ivan Wilhelm in ATLAS**

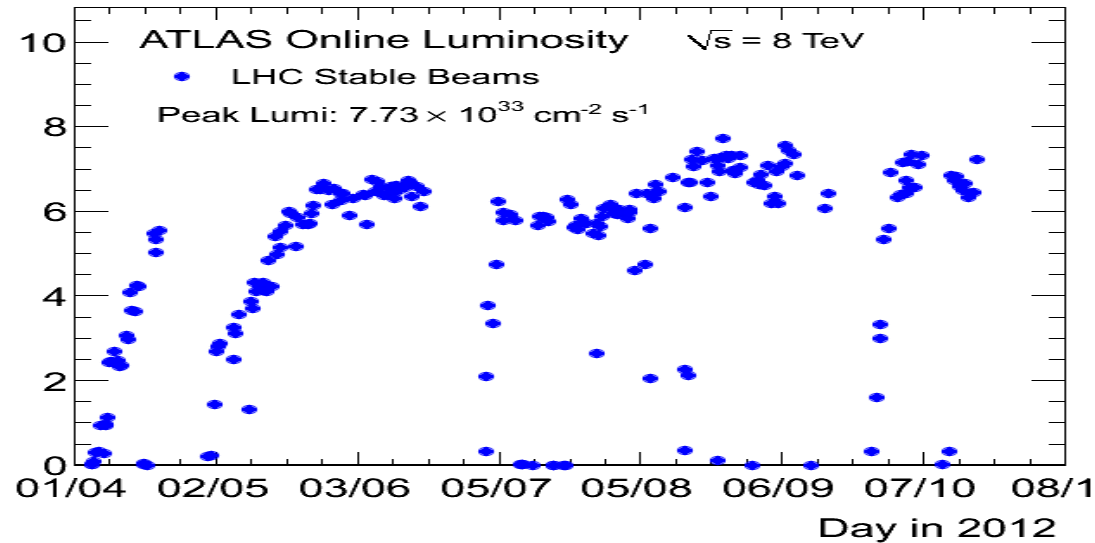
Current LHC Operation:

1380 bunches per beam

50 ns bunch spacing

1.5×10^{11} protons / bunch

Peak Luminosity per Fill [$10^{33} \text{ cm}^{-2} \text{ s}^{-1}$]

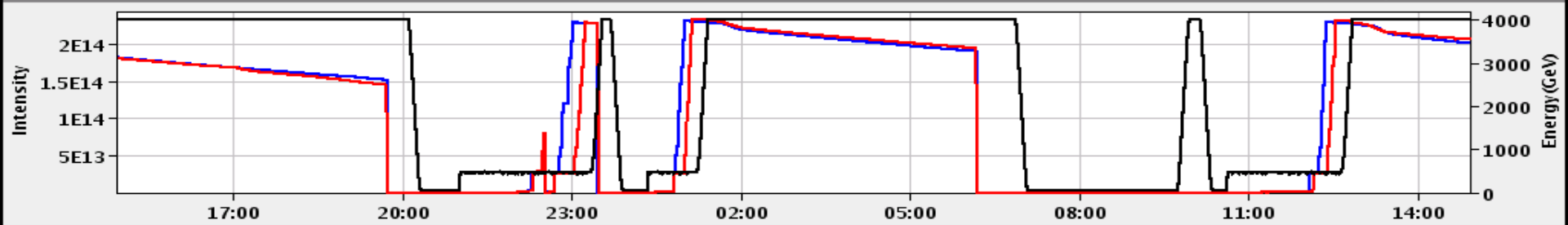


22-Oct-2012 14:54:48 Fill #: 3208 Energy: 4000 GeV I(B1): 2.02e+14 I(B2): 2.07e+14

Experiment Status	ATLAS	ALICE	CMS	LHCb
Instantaneous Lumi [(ub.s) ⁻¹]	5394.2	5.976	5253.7	398.0
BRAN Luminosity [(ub.s) ⁻¹]	5351.2	3.943	4618.0	240.2
Fill Luminosity (nb) ⁻¹	28330.6	30.5	24854.2	1727.9
BKGD 1	0.724	0.834	2.375	0.911
BKGD 2	104.642	0.000	3.854	27.452
BKGD 3	1.855	9.490	18.651	1.334

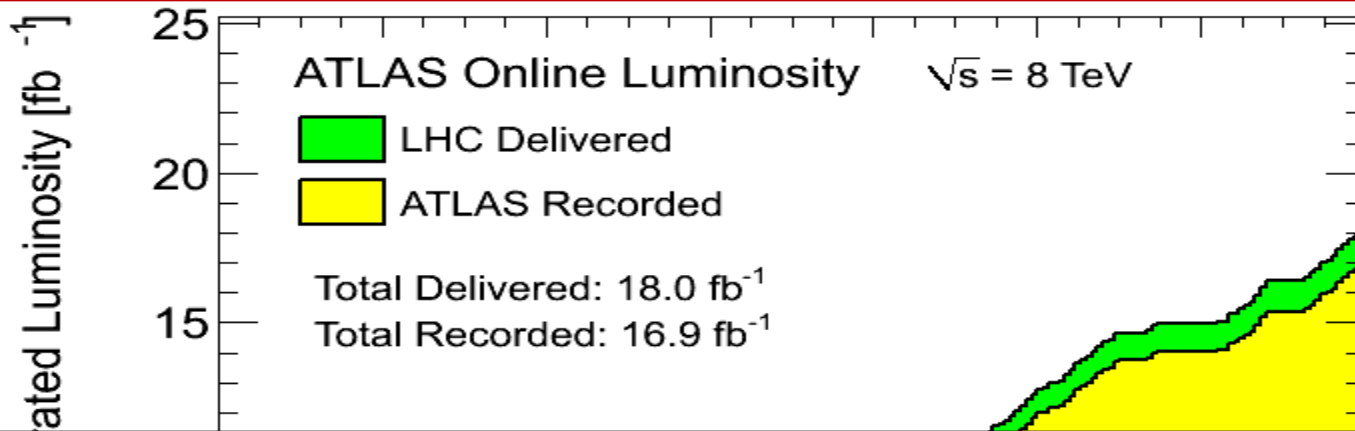
LHCb VELO Position **IN** Gap: -0.0 mm **STABLE BEAMS** TOTEM: **STANDBY**

Performance over the last 24 Hrs Updated: 14:54:47



— I(B1) — I(B2) — Energy

But the LHC (at 8 TeV) and ATLAS performances are even more fantastic this year



ϵ (Physics) = ϵ (Data-Taking) x ϵ (Data-Quality)
Today: ϵ (Physics) ~ 88%

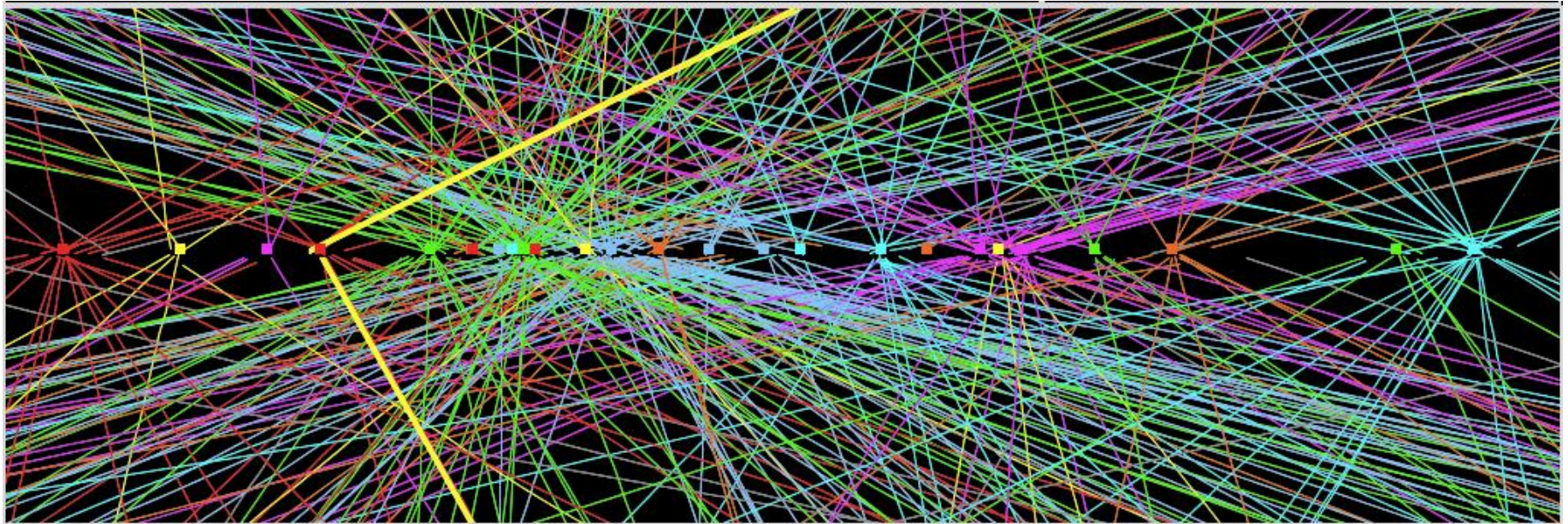
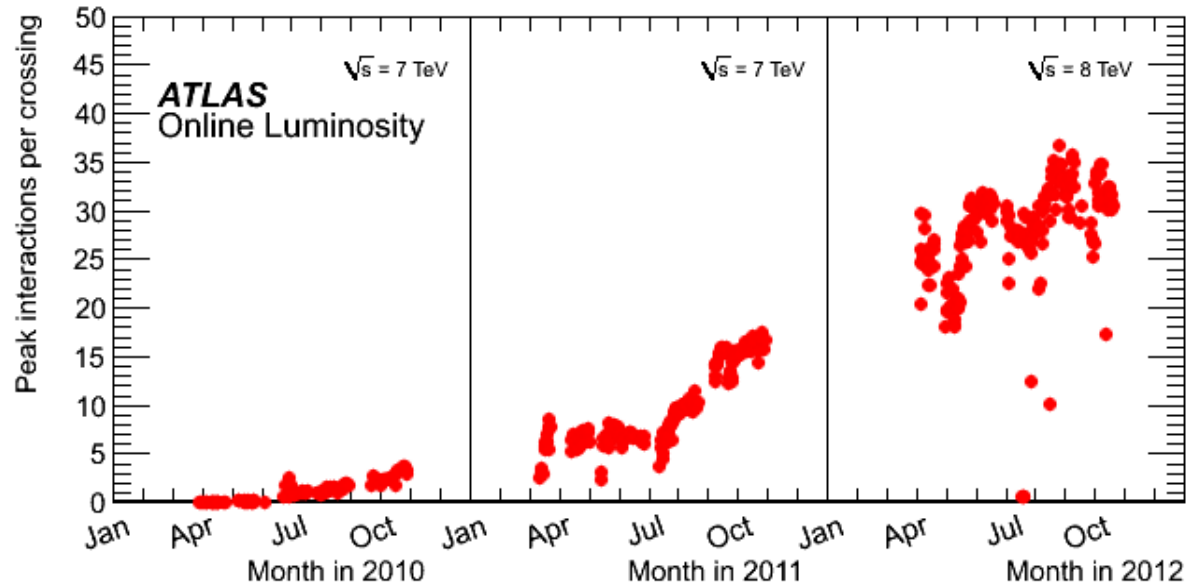


Data Quality			ATLAS p-p run: April-Sept. 2012							
Inner Tracker			Calorimeters		Muon Spectrometer				Magnets	
Pixel	SCT	TRT	LAr	Tile	MDT	RPC	CSC	TGC	Solenoid	Toroid
100	99.3	99.5	97.0	99.6	99.9	99.8	99.9	99.9	99.7	99.2
All good for physics: 93.7%										

Prag P Je Luminosity weighted relative detector uptime and good quality data delivery during 2012 stable beams in pp collisions at $\sqrt{s}=8 \text{ TeV}$ between April 4th and September 17th (in %) – corresponding to 14.0 fb^{-1} of recorded data. The inefficiencies in the LAr calorimeter will partially be recovered in the future.

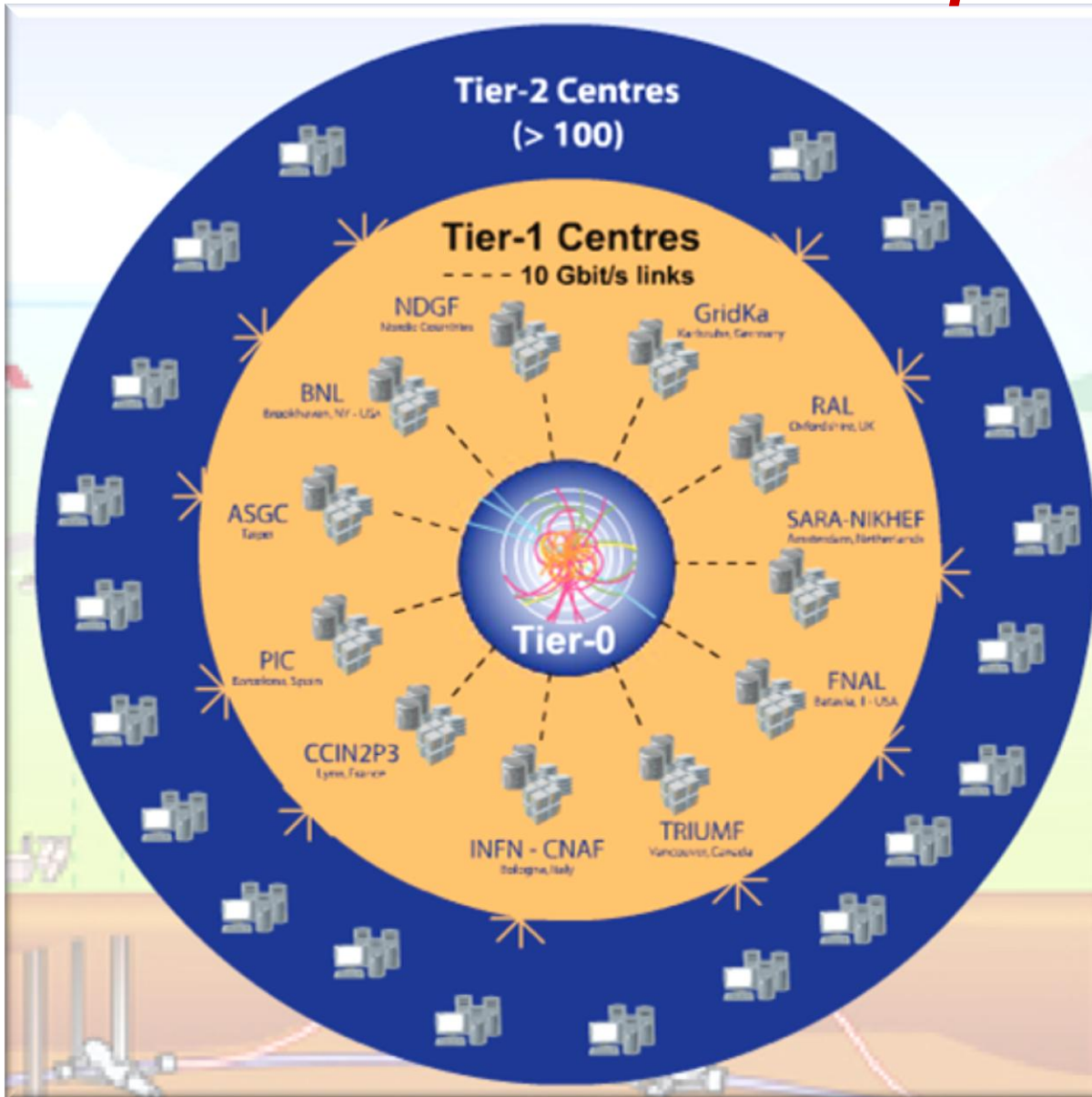
Excellent LHC performance is a (nice) challenge for the experiment:

- Trigger
- Pile-up
- Maintain accuracy of the measurements in this environment



Inner Detector for a $Z \rightarrow \mu\mu$ event with 25 primary vertices

The Worldwide LHC Computing Grid (wLCG)



Tier-0 (CERN):

- Data recording
- Initial data reconstruction
- Data distribution

Tier-1 (11 centres):

- Permanent storage
- Re-processing
- Analysis
- Simulation

Tier-2 (federations of ~130 centres):

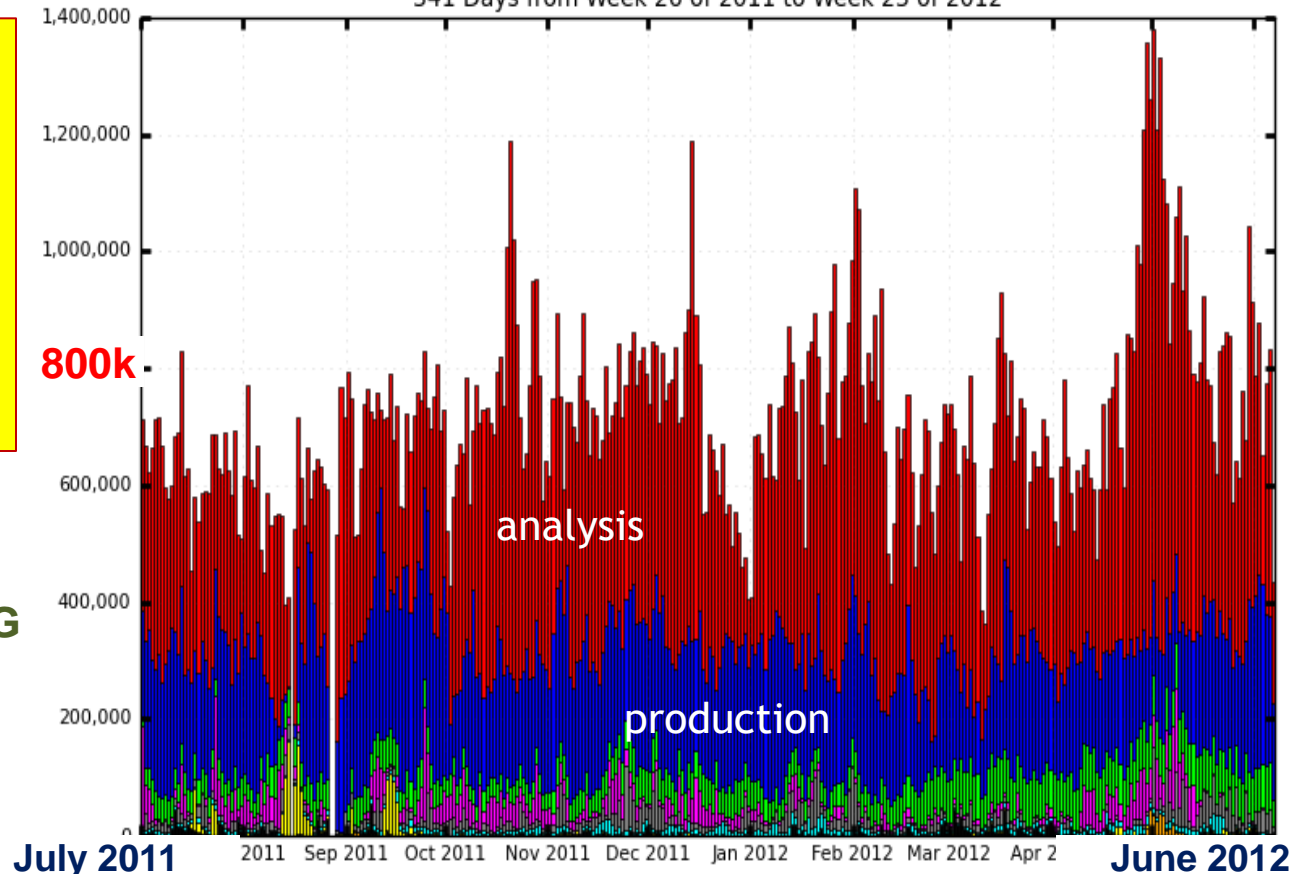
- Simulation
- End-user analysis

Computing Grid Delivers Physics

ATLAS jobs per day across all Tier-1 & Tier-2s

Completed jobs

341 Days from Week 26 of 2011 to Week 23 of 2012



Maximum: 1,379,139 , Minimum: 0.00 , Average: 708,214 , Current: 435,602

Data preparation:

- First-pass reconstruction at Tier-0 within ~2 days
- Calibration good for physics analysis on Grid within ~1 week

The high quality of the WLCG computing system allows LHC experiments to show results from data taken just few weeks before

First Physics Highlights

ATLAS and CMS have already published together close to 400 papers in scientific journals (and many more as public conference notes...)

It is obviously not possible to cover all these results...

No attempt is made to show in a democratic way always CMS and ATLAS results, but often ATLAS examples are given that represent typically results from both!

Note that all public results from CMS and ATLAS are available at:
<https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResults>
<https://twiki.cern.ch/twiki/bin/view/AtlasPublic>

The European Physical Journal
EPJ C
Recognized by European Physical Society
Particles and Fields
volume 72 · number 3 · march · 2012

Measurements of the nuclear modification factor R_{pA} in central heavy-ion collisions at three different center-of-mass energies, as a function of p_T for neutral pions, charged hadrons, and charged particles, compared to several theoretical predictions. From the CMS Collaboration: Study of high p_T charged particle suppression in PbPb compared to pp collisions at $\sqrt{s_{NN}} = 2.76$ TeV.

Societ  Italiana di Fisica
Springer

PHYSICAL REVIEW LETTERS
Articles published week ending 16 MARCH 2012

Published by American Physical Society, APS physics
Volume 108, Number 11

Physics Highlights:

General event properties

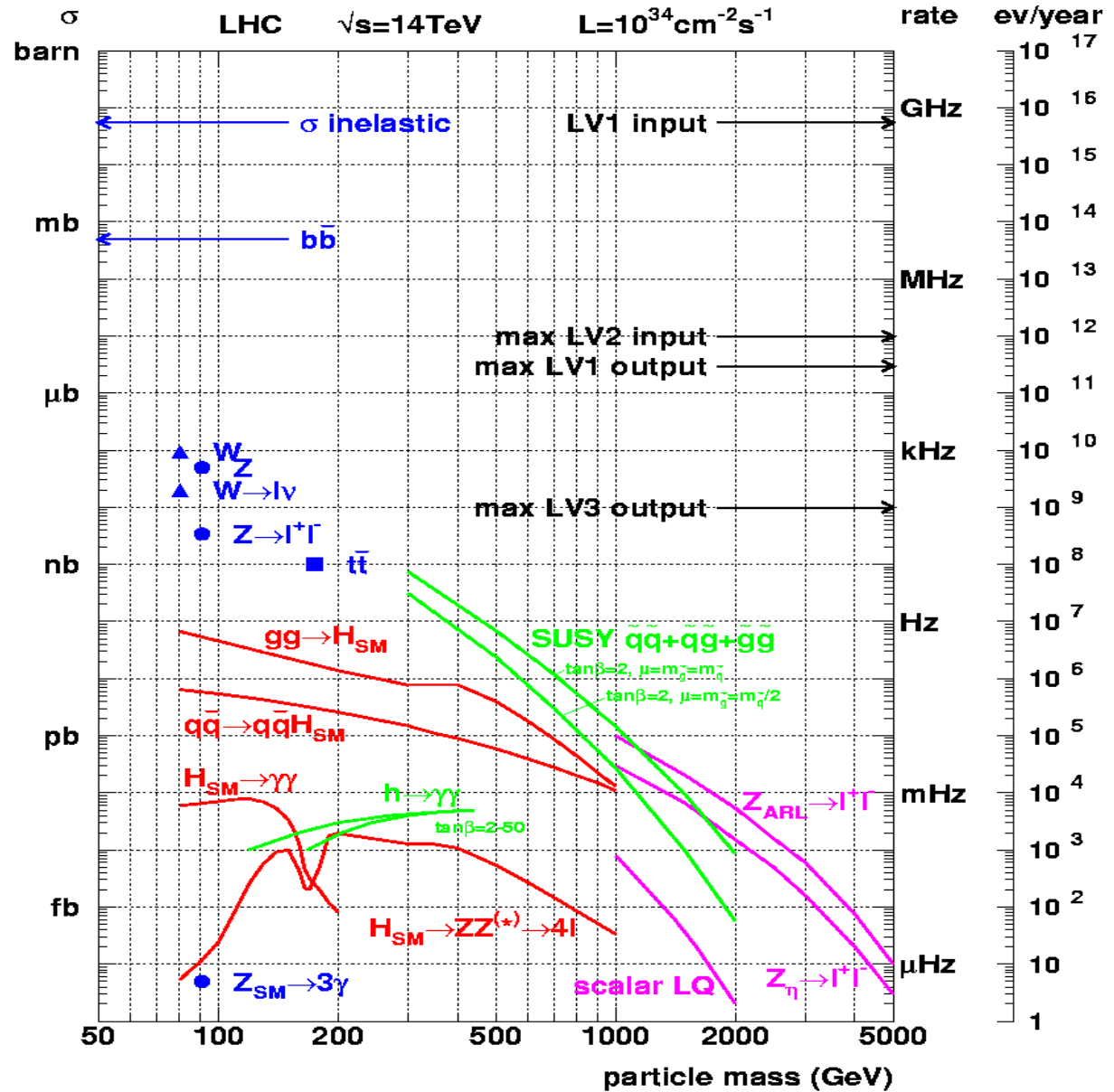
Heavy flavour physics

Standard Model physics including QCD jets

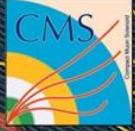
Higgs searches

Searches for SUSY

Examples of searches for 'exotic' new physics



General Event Properties and Resonances



CMS Experiment at the LHC, CERN

Data recorded: 2010-Jul-09 02:25:58.839811 GMT(04:25:58 CEST)

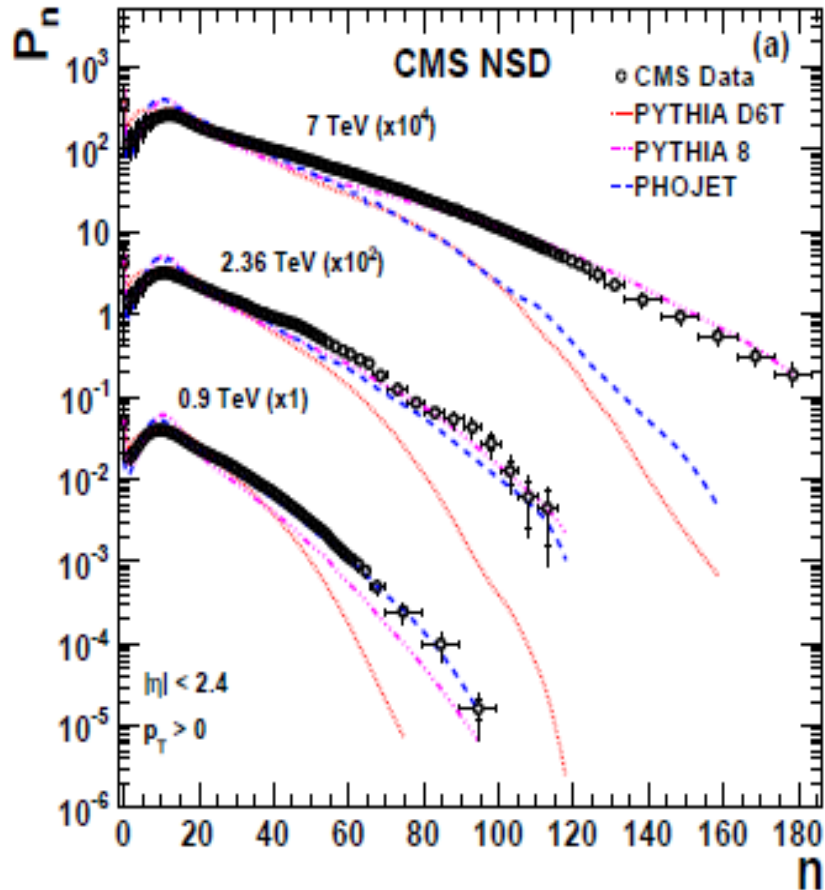
Run / Event: 139779 / 4994190



(c) Copyright CERN, 2010. For the benefit of the CMS Collaboration.

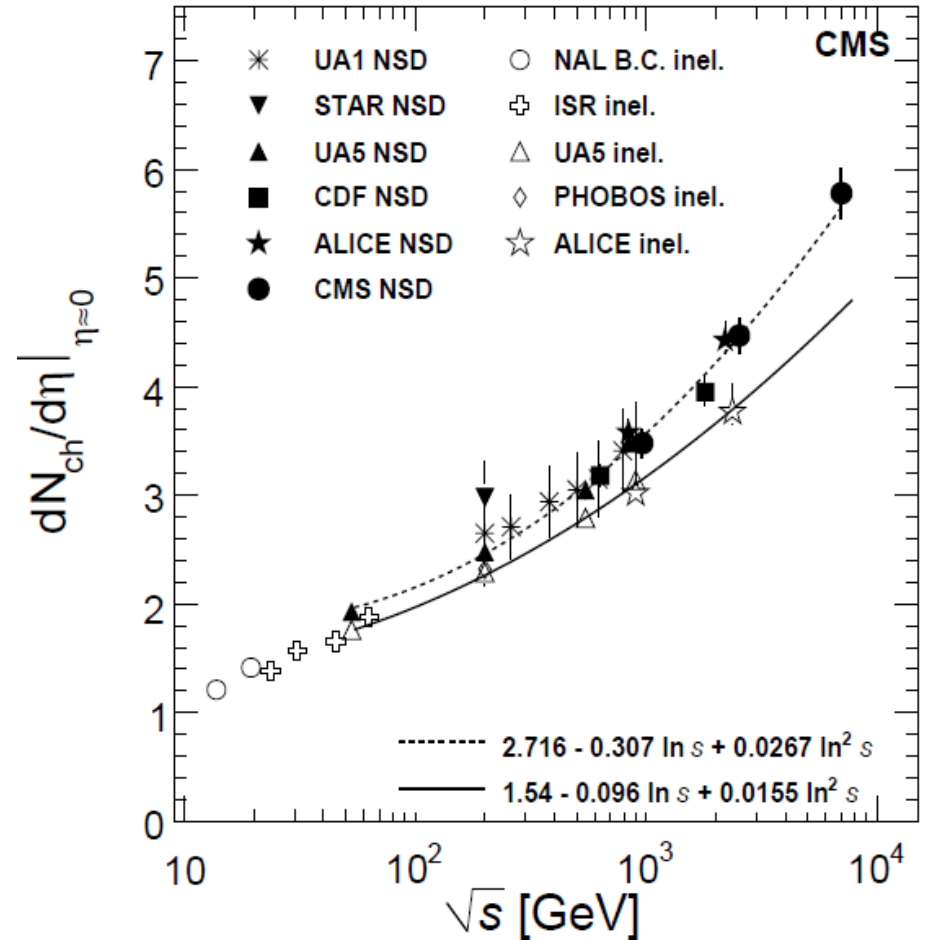
<http://cms.cern.ch/>

Charged hadron multiplicities at the three different \sqrt{s}



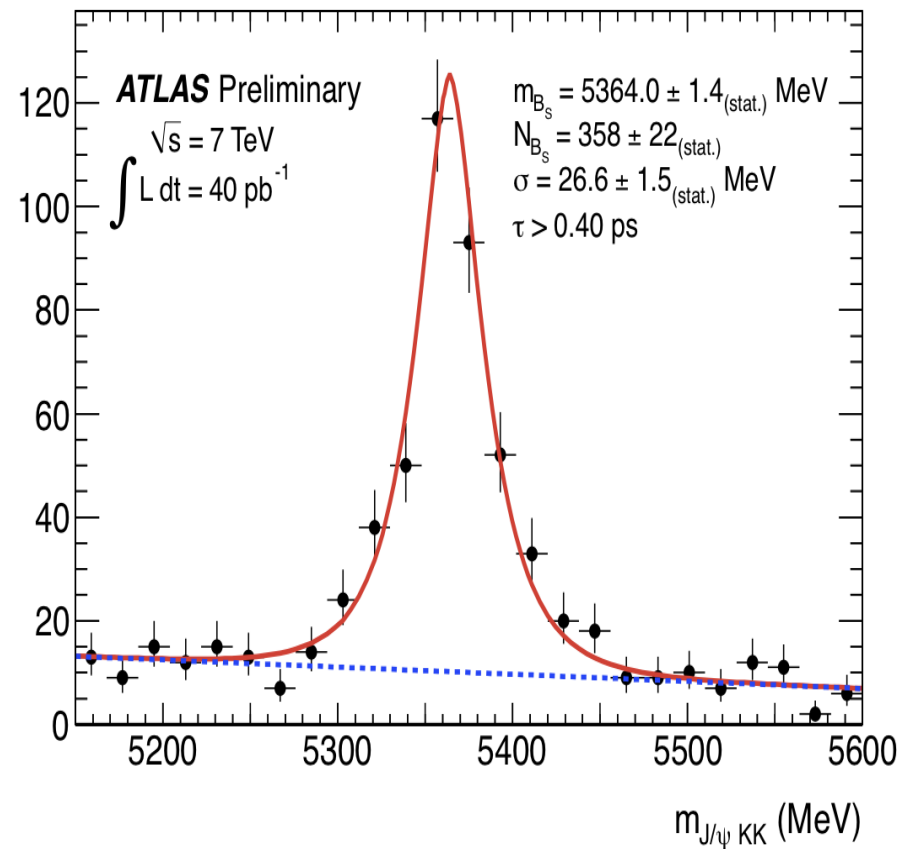
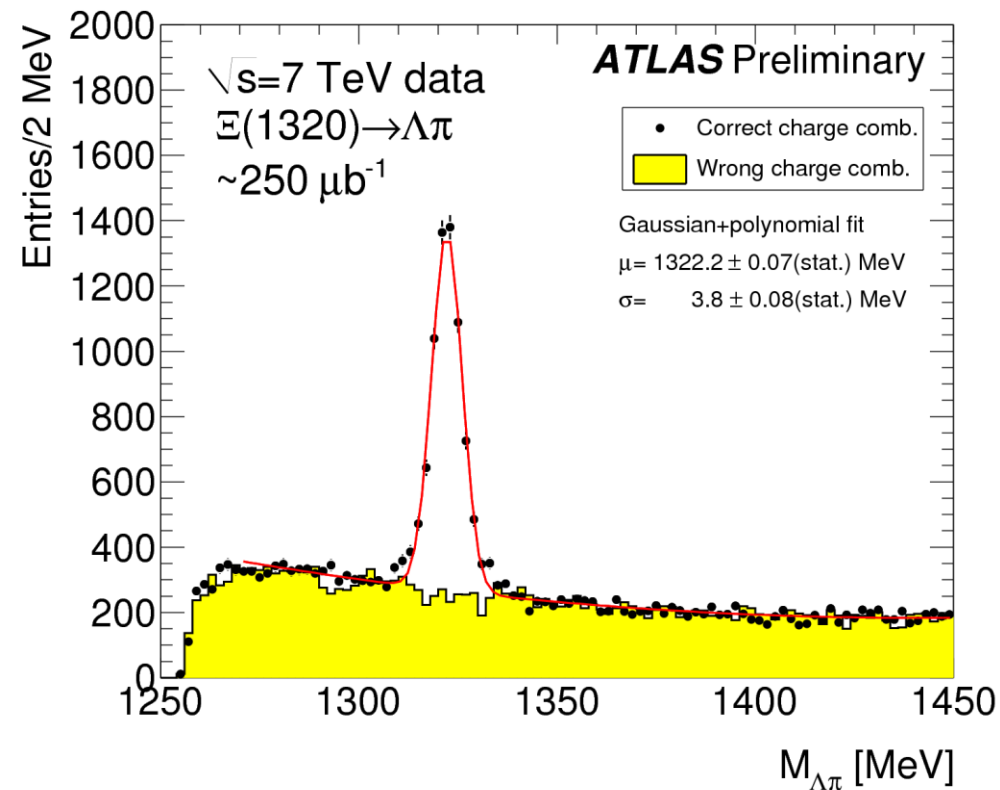
JHEP 01 (2011) 079

Average charged particle density for the central η region (pp and $\bar{p}p$)



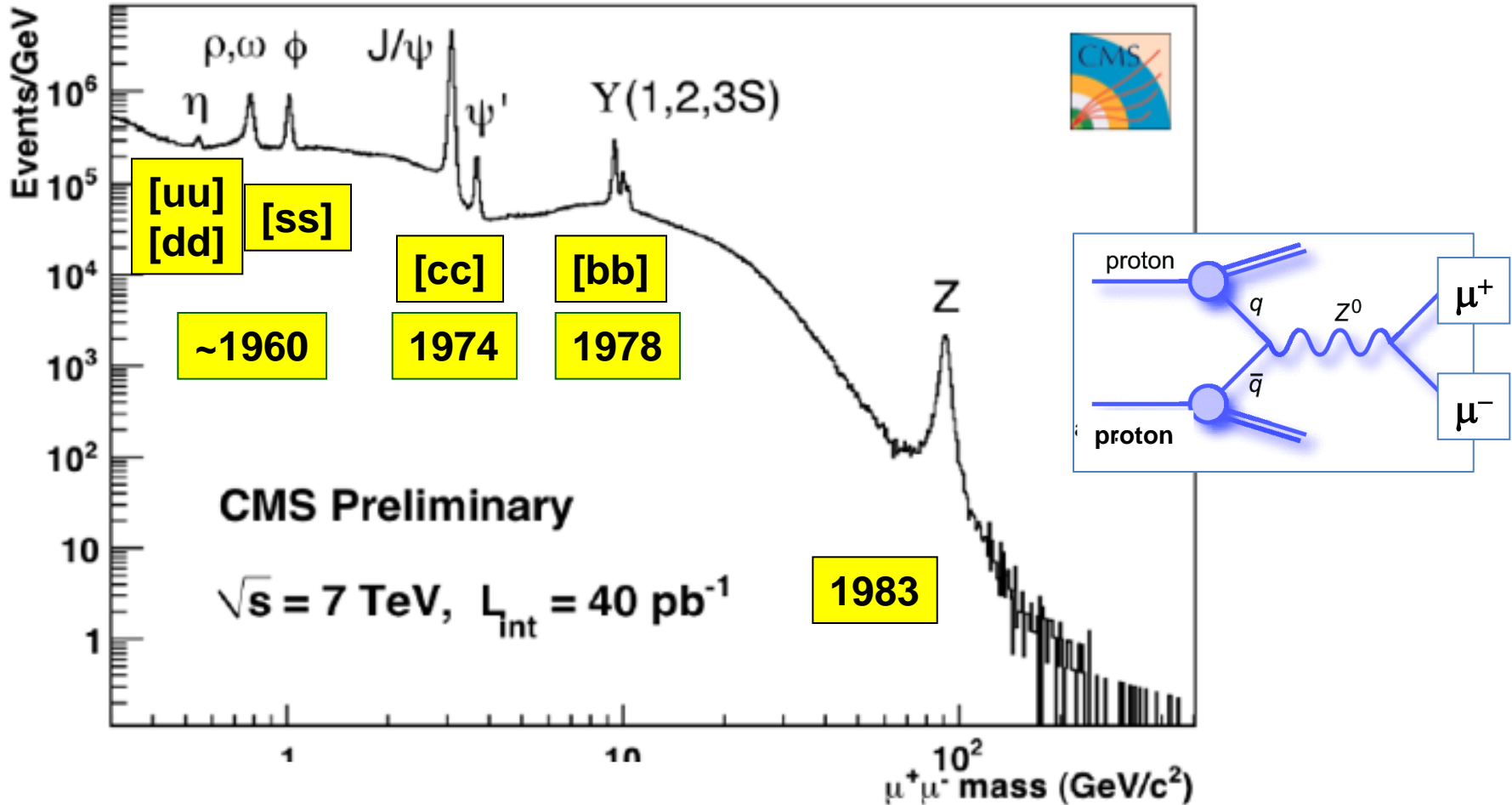
Phys. Rev. Lett. 105 (2010) 022002

Examples of reconstructed final states



2010

Data corresponding to $\sim 40 \text{ pb}^{-1}$ collected
→ re-discovery of the Standard Model



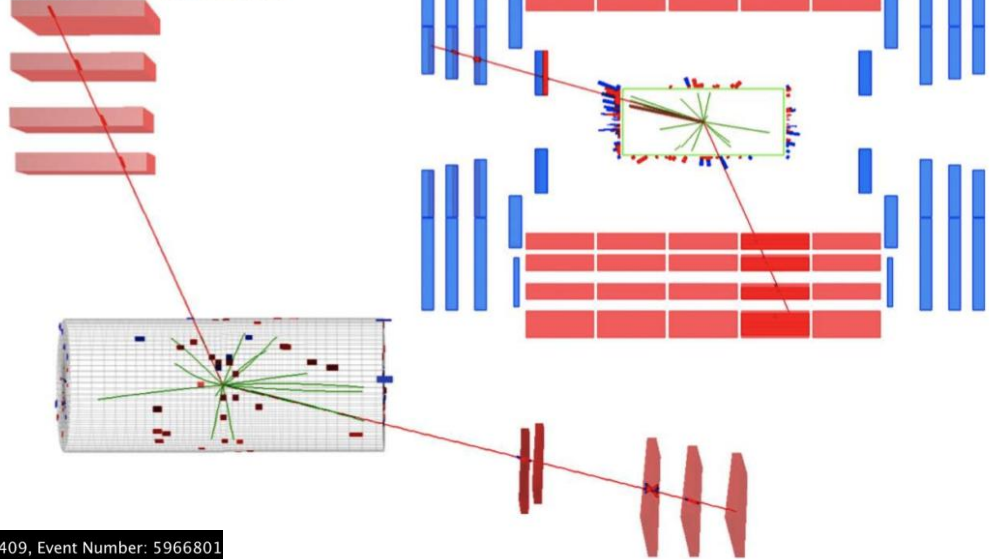
The di-muon spectrum recalls a long period of particle physics:
Well known quark-antiquark resonances (bound states) appear “online”

Standard Model Physics



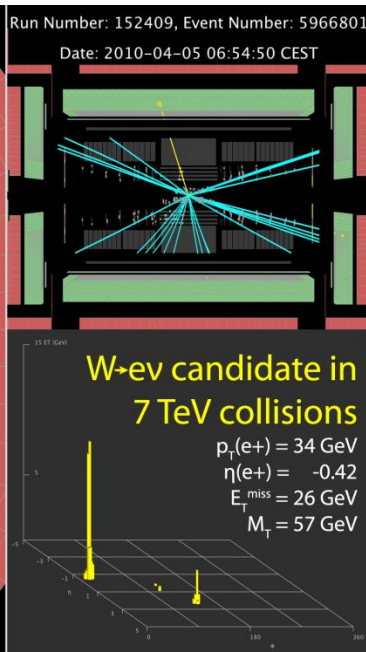
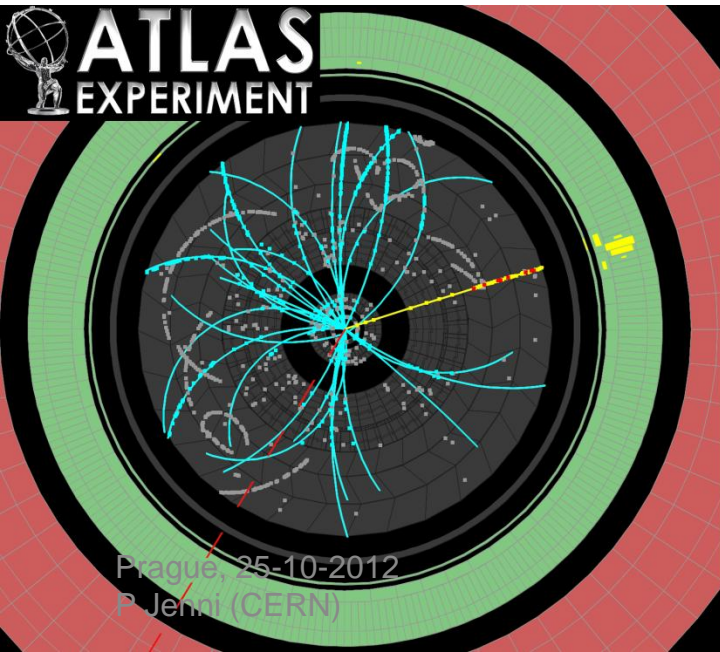
CMS Experiment at LHC, CERN
 Run 136087 Event 39967482
 Lumi section: 314
 Mon May 24 2010, 15:31:58 CEST

Muon $p_T = 27.3, 20.5$ GeV/c
 Inv. mass = 85.5 GeV/c²



Candidate $Z \rightarrow \mu^+\mu^-$

$W \rightarrow e\nu$ candidate



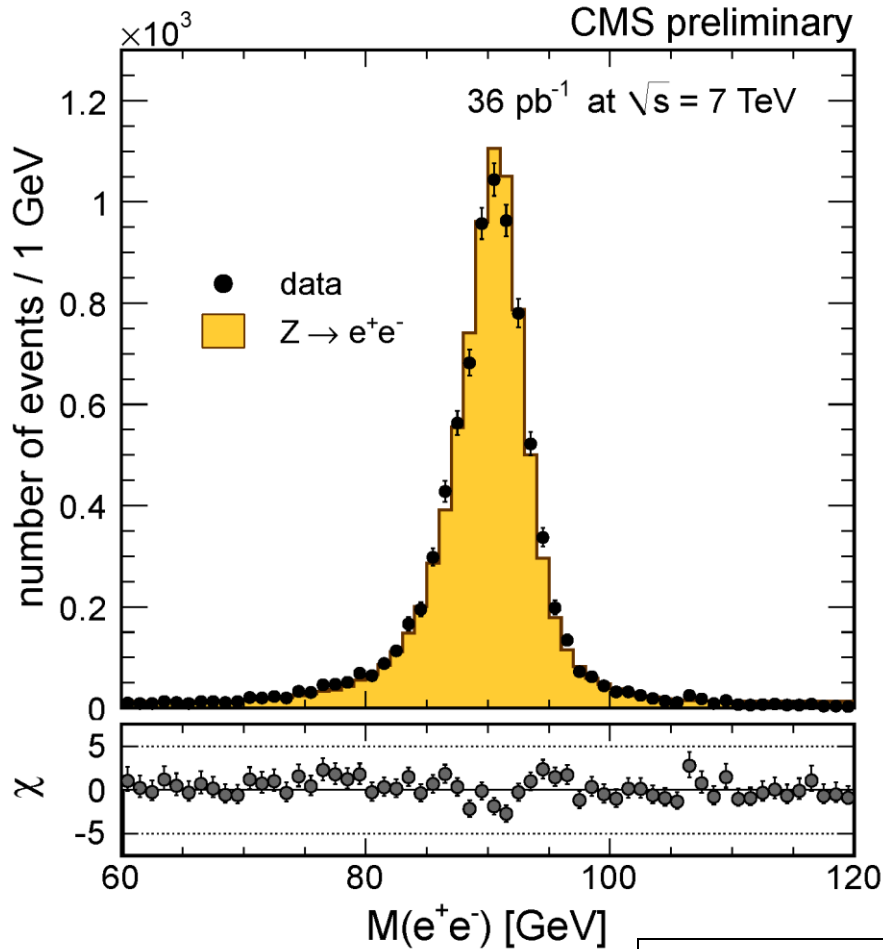
In its 2011 dataset (~ 5 fb⁻¹)
 ATLAS has:

- ~ 30 M $W \rightarrow \mu\nu, e\nu$ events
- ~ 3 M $Z \rightarrow \mu\mu, ee$ events

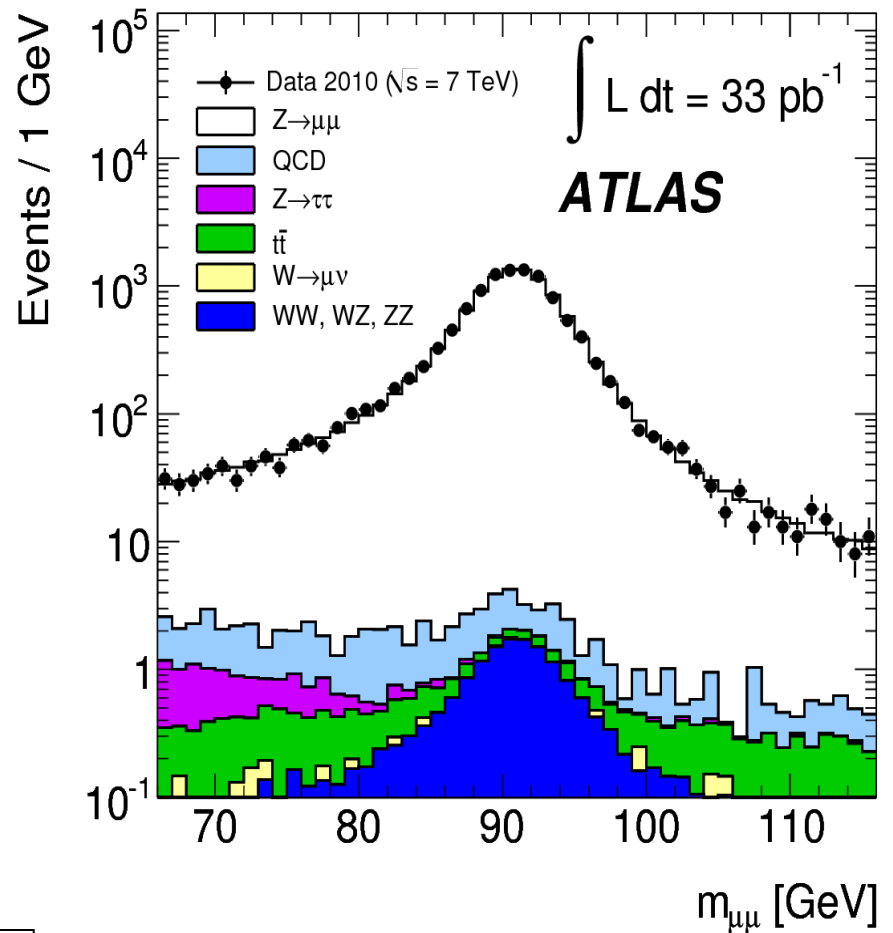
after all selection cuts

Z and W production

Phys Rev D85 (2012) 072004



JHEP 10 (2011) 132

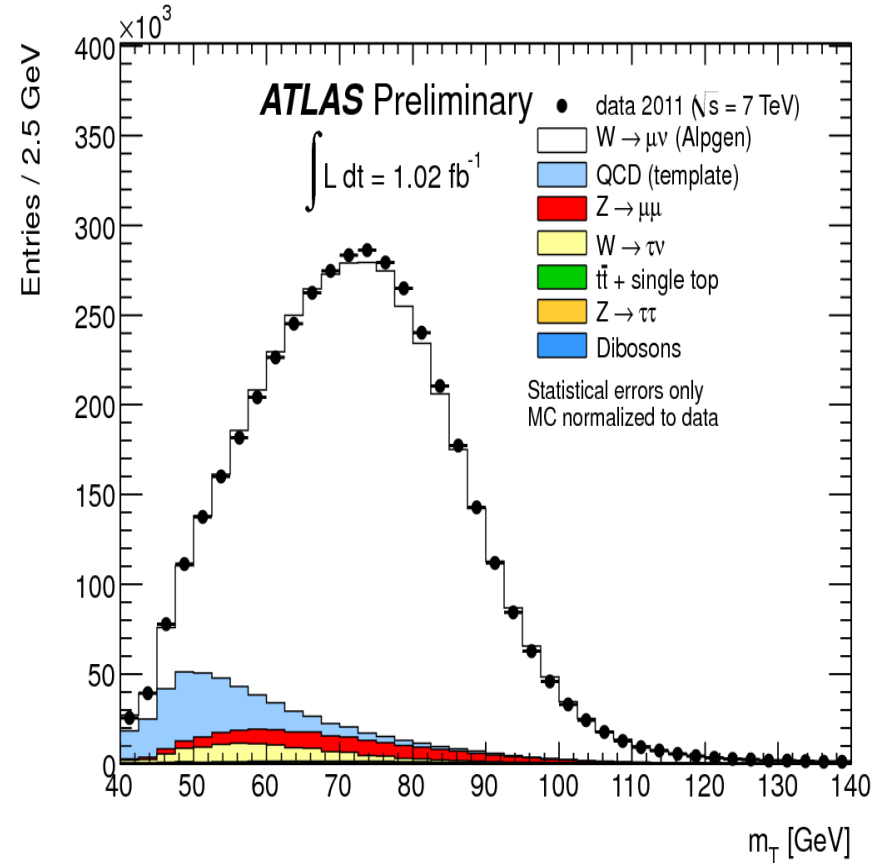
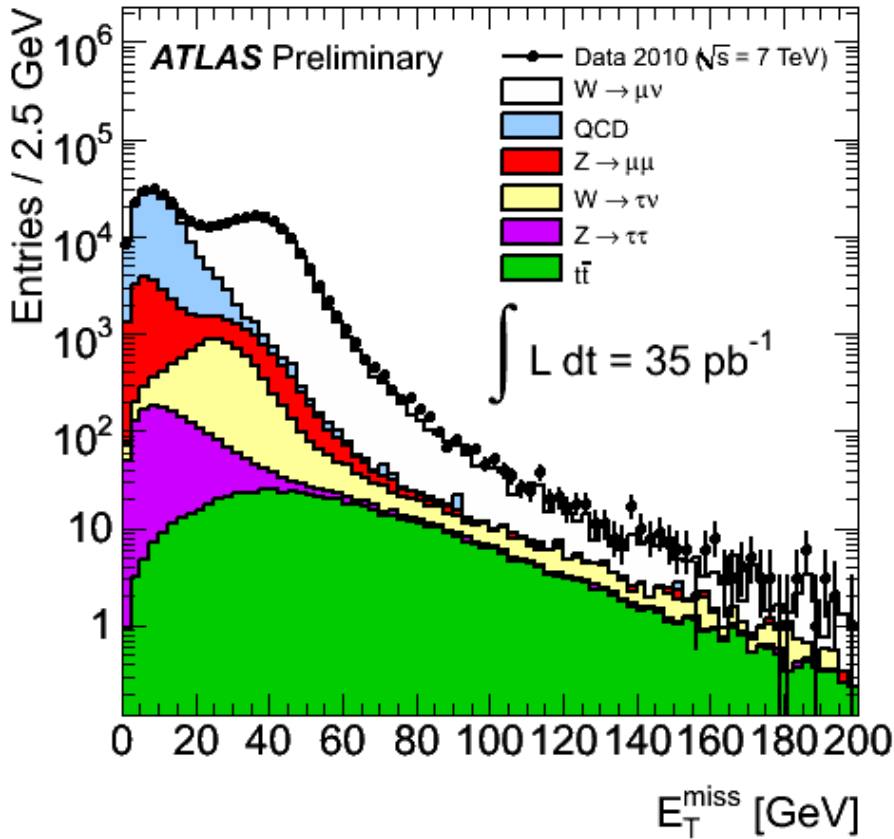


Z peak (di-lepton pair mass distributions, can be extracted essentially background-free)

$$m = \sqrt{(E_1 + E_2)^2 - (\vec{p}_1 + \vec{p}_2)^2}$$

W transverse mass

μ with $p_T > 20$ GeV, $E_T^{\text{miss}} > 25$ GeV



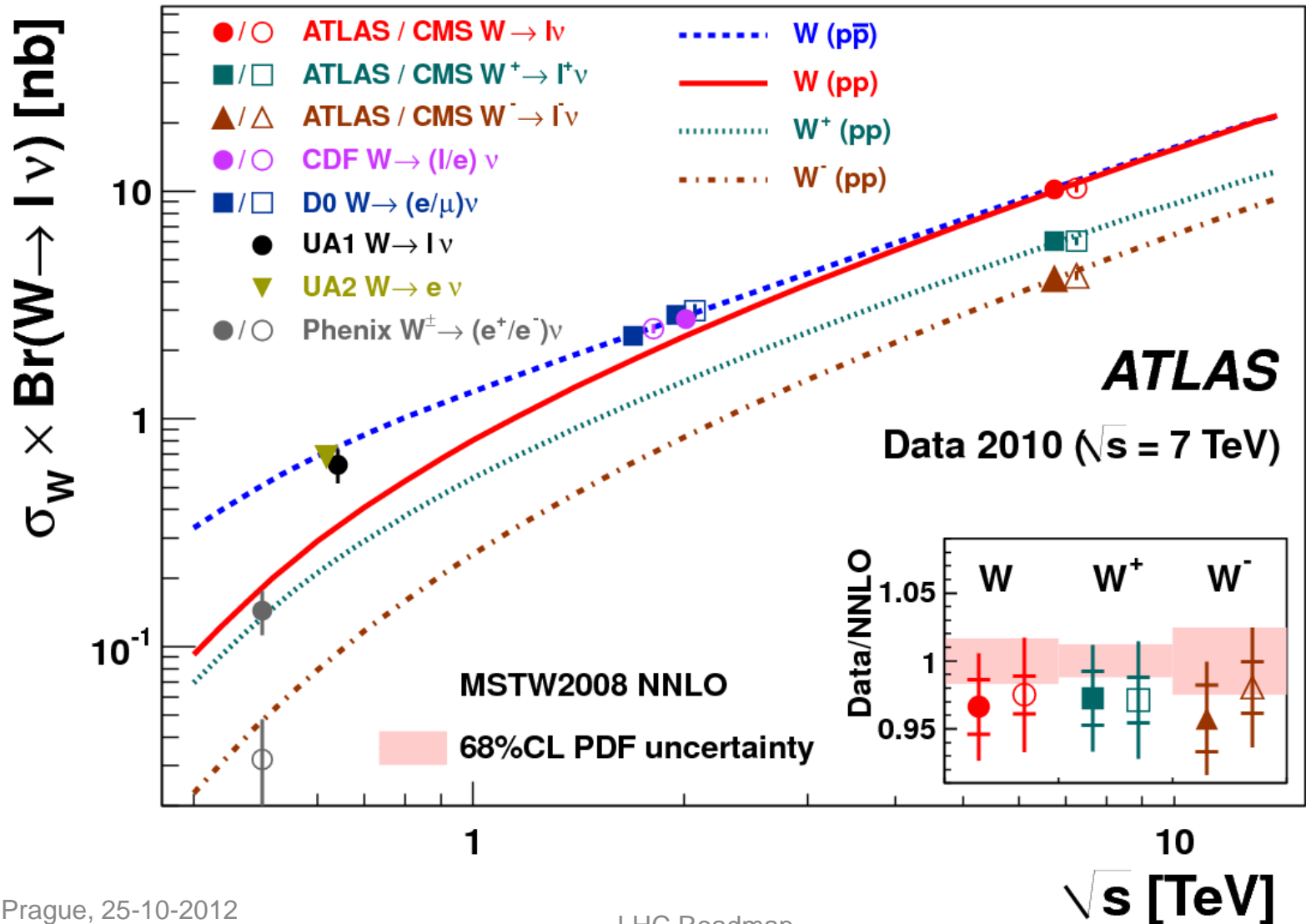
Missing transverse energy
from the $W \rightarrow \mu + \nu$ decays

ATLAS-CONF-2011-041

$$m_T = \sqrt{2p_T^\ell p_T^\nu (1 - \cos(\phi^\ell - \phi^\nu))}$$

W cross section measurement with e and μ

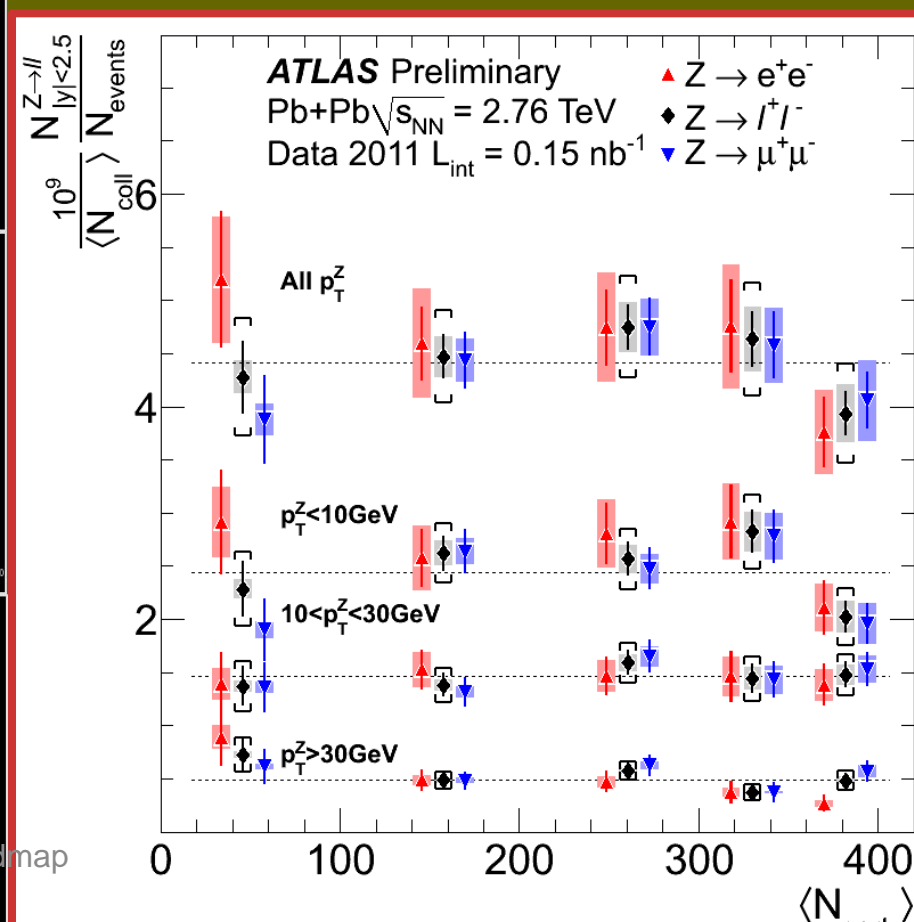
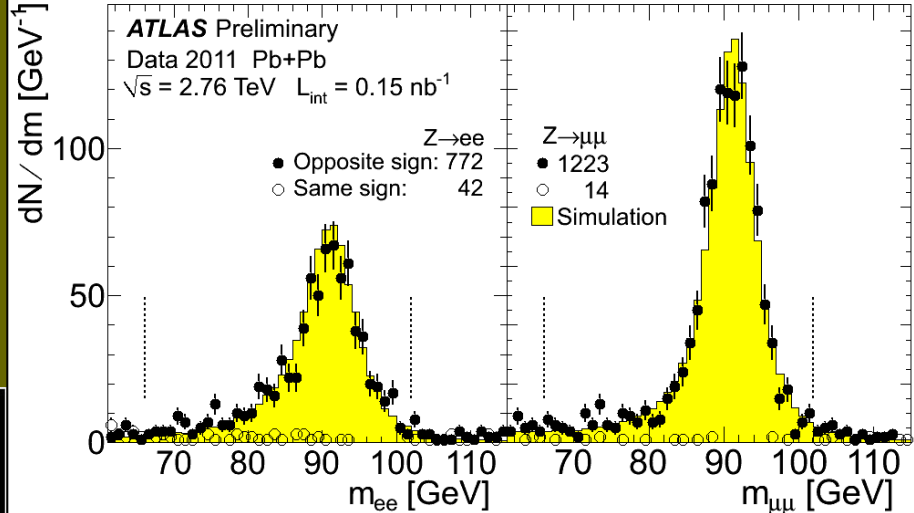
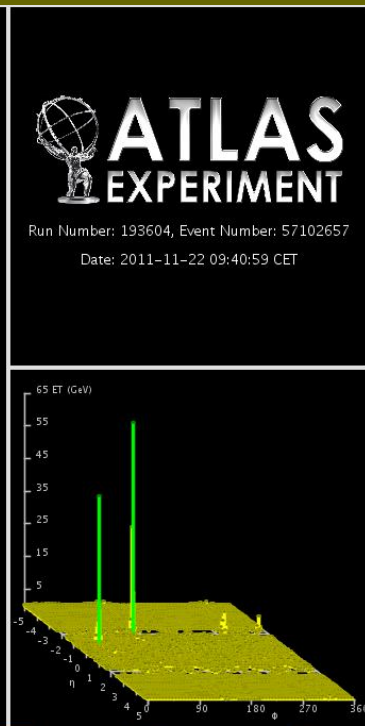
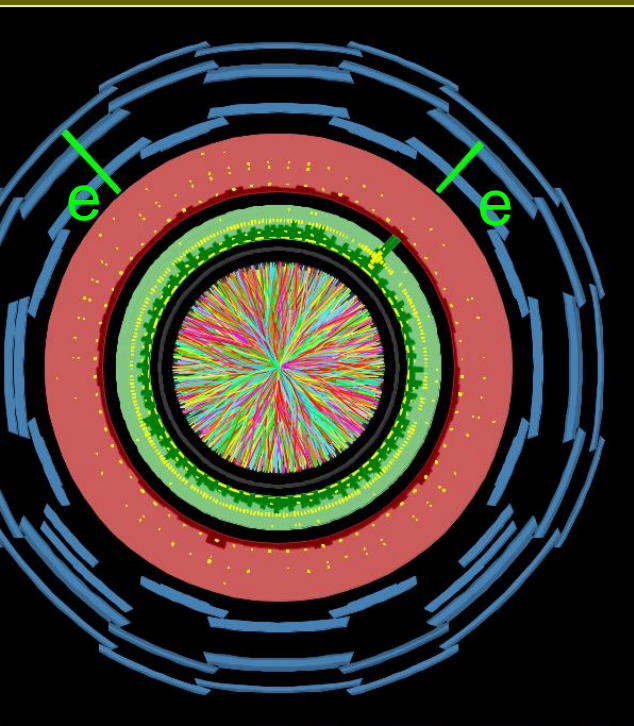
Phys Rev D85 (2012) 072004



Z → ee, μμ in Heavy Ions

- Studied with full 2011 dataset (~ 150 μb⁻¹)
- As expected: no suppression observed of the weakly interacting bosons

ATLAS-CONF-2012-119



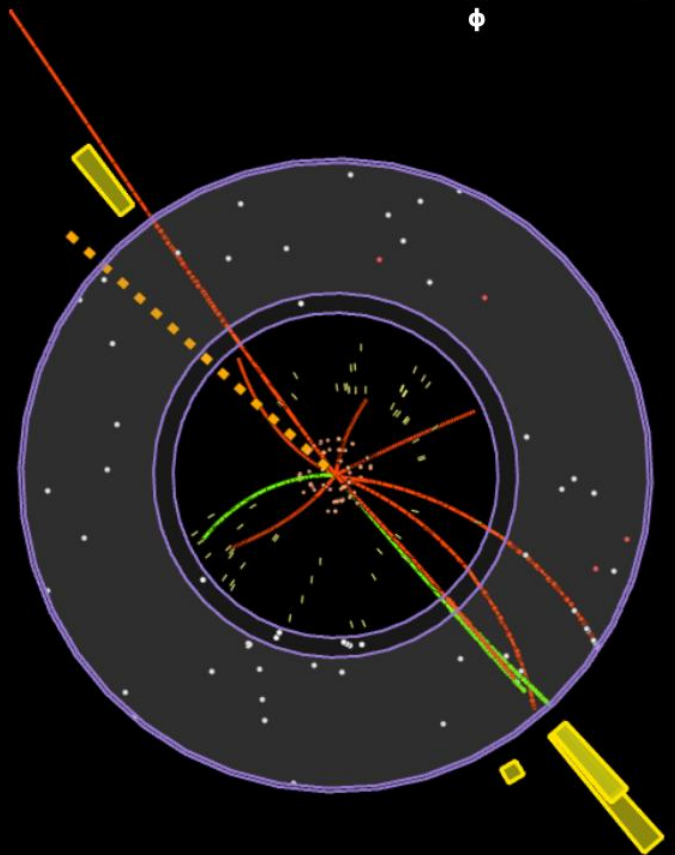
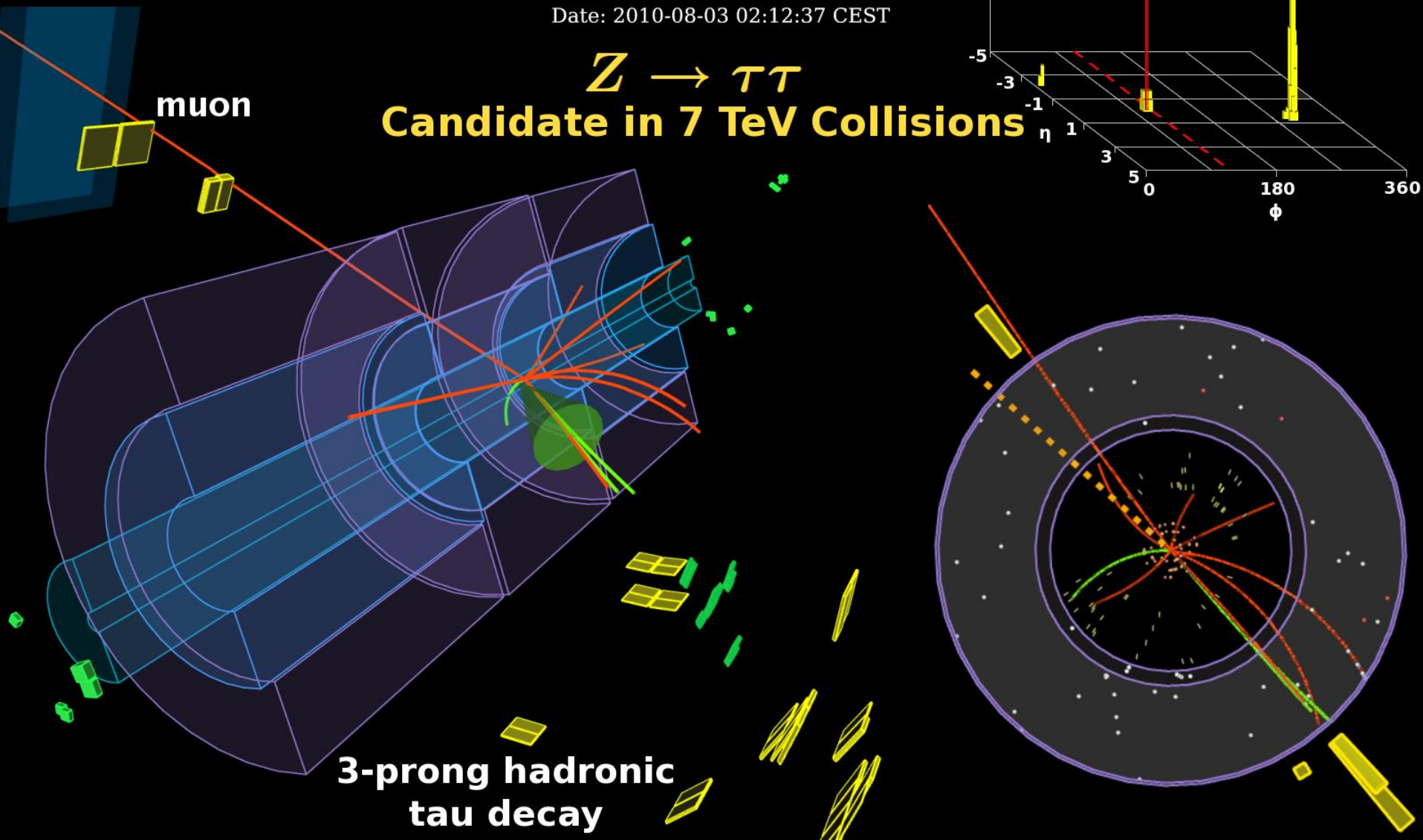
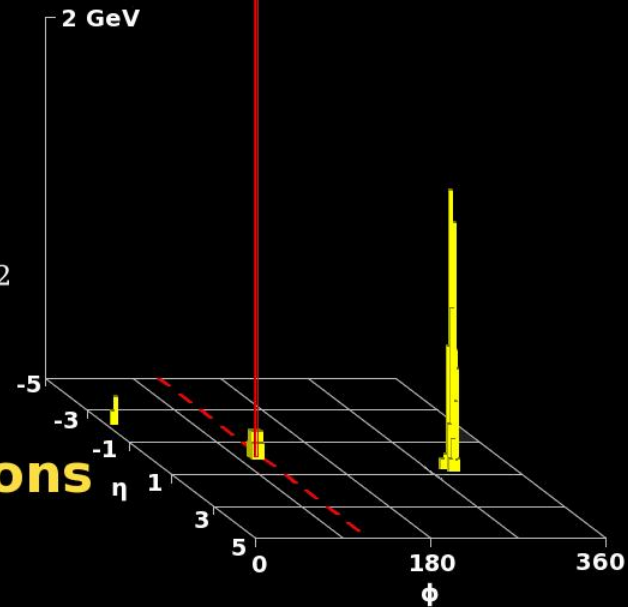
$p_T(\mu) = 18 \text{ GeV}$
 $p_T^{\text{vis}}(\tau_h) = 26 \text{ GeV}$
 $m_{\text{vis}}(\mu, \tau_h) = 47 \text{ GeV}$
 $m_T(\mu, E_T^{\text{miss}}) = 8 \text{ GeV}$
 $E_T^{\text{miss}} = 7 \text{ GeV}$

ATLAS EXPERIMENT

Run Number: 160613, Event Number: 9209492

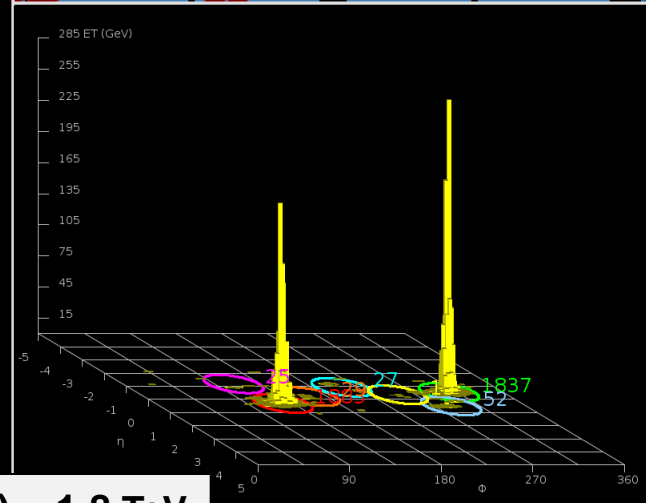
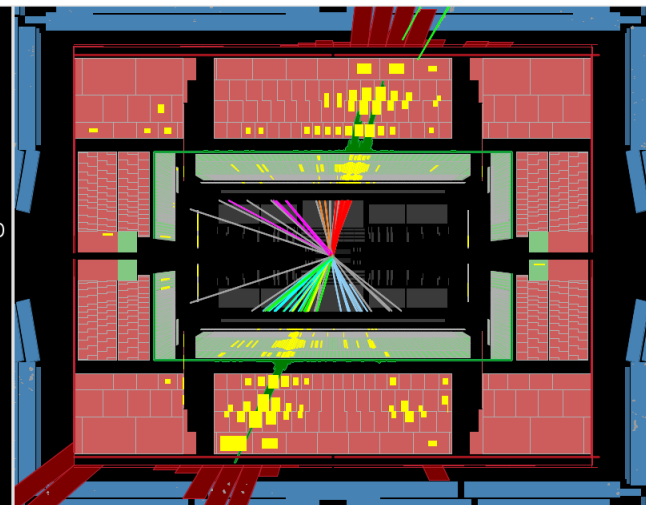
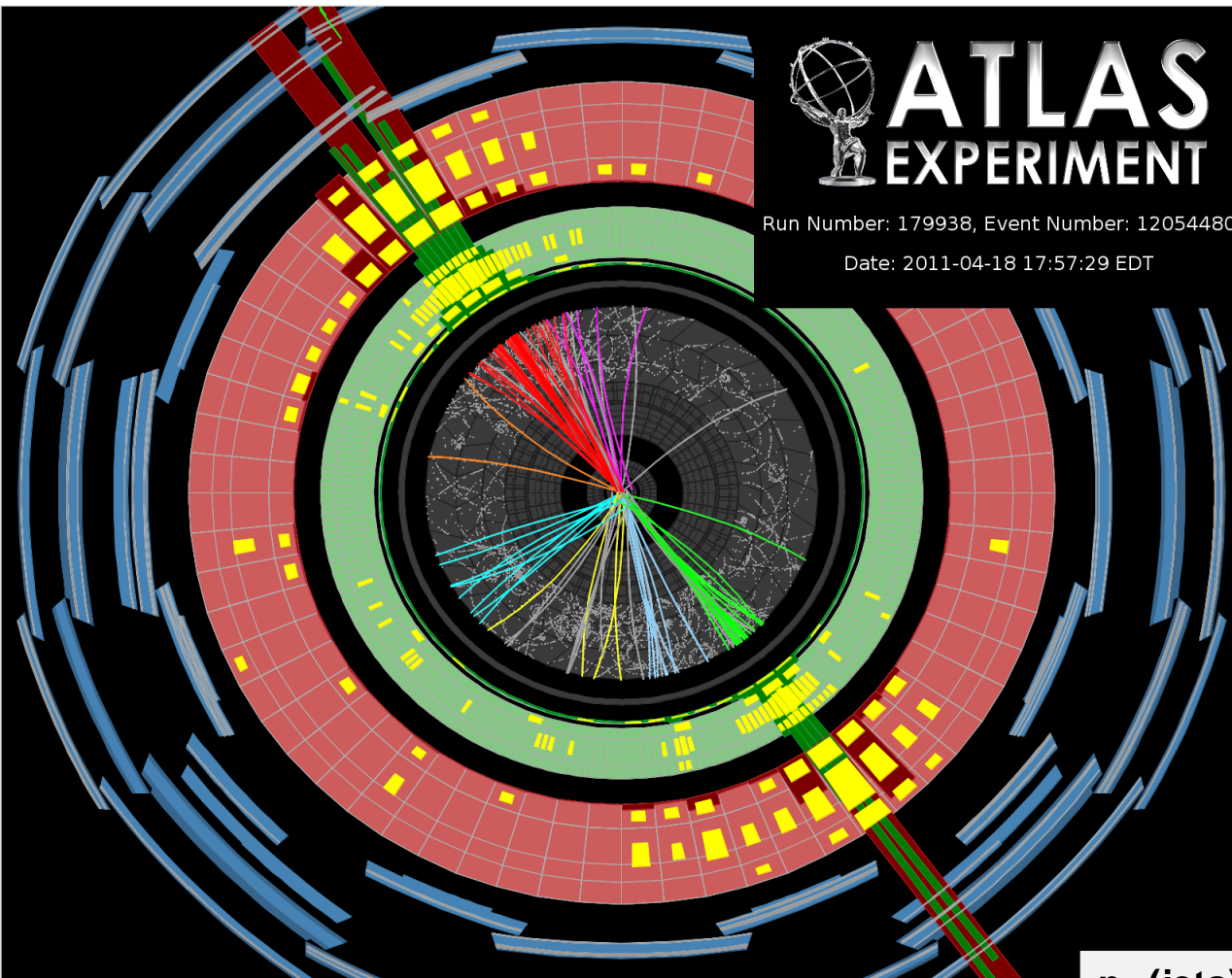
Date: 2010-08-03 02:12:37 CEST

$Z \rightarrow \tau\tau$ Candidate in 7 TeV Collisions

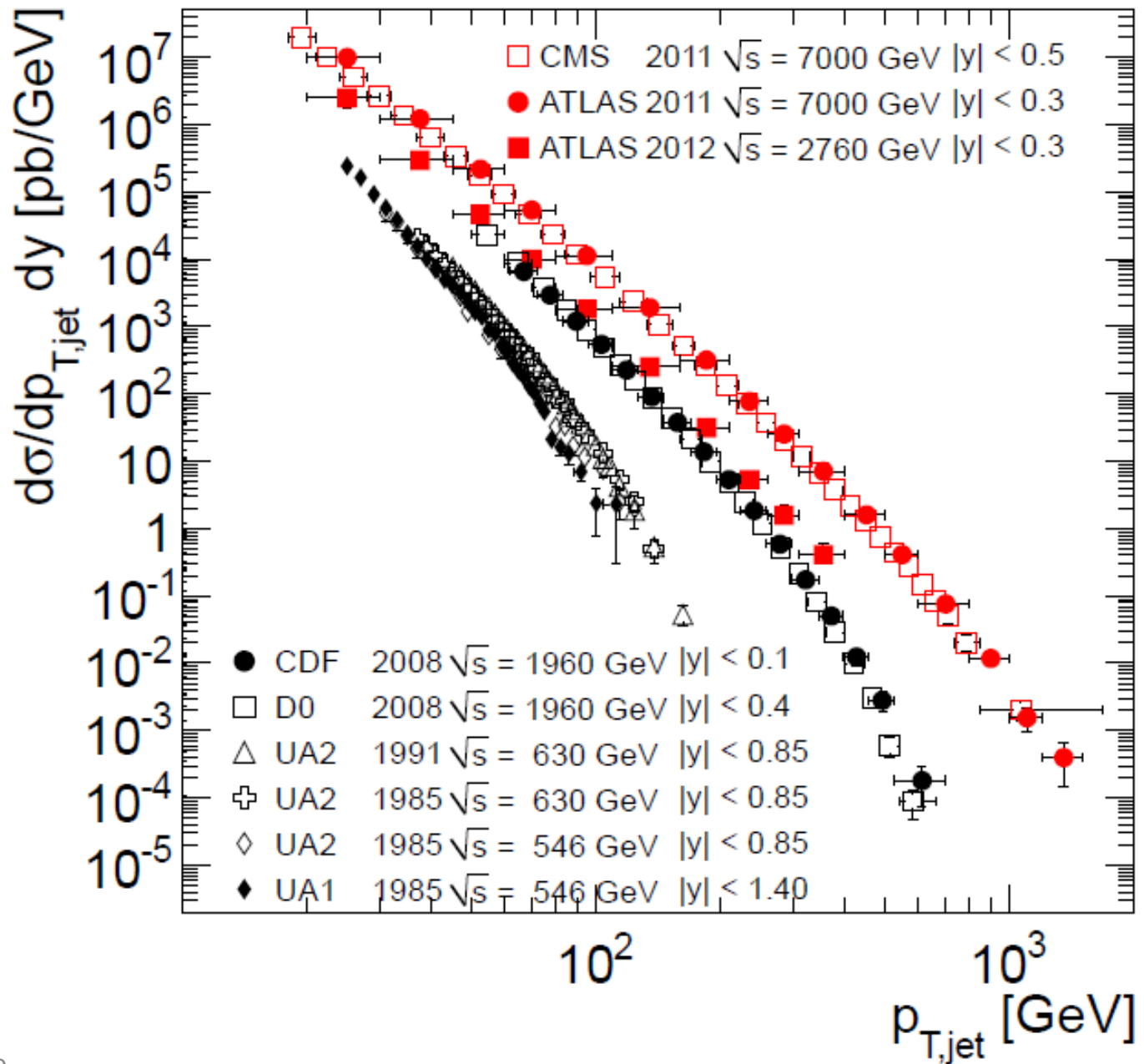


Jet physics

One of the most spectacular dijet events: $M_{jj} \sim 4 \text{ TeV}$



p_T (jets) $\sim 1.8 \text{ TeV}$



Very detailed jet measurements are now available from LHC that can be compared with QCD calculations ...

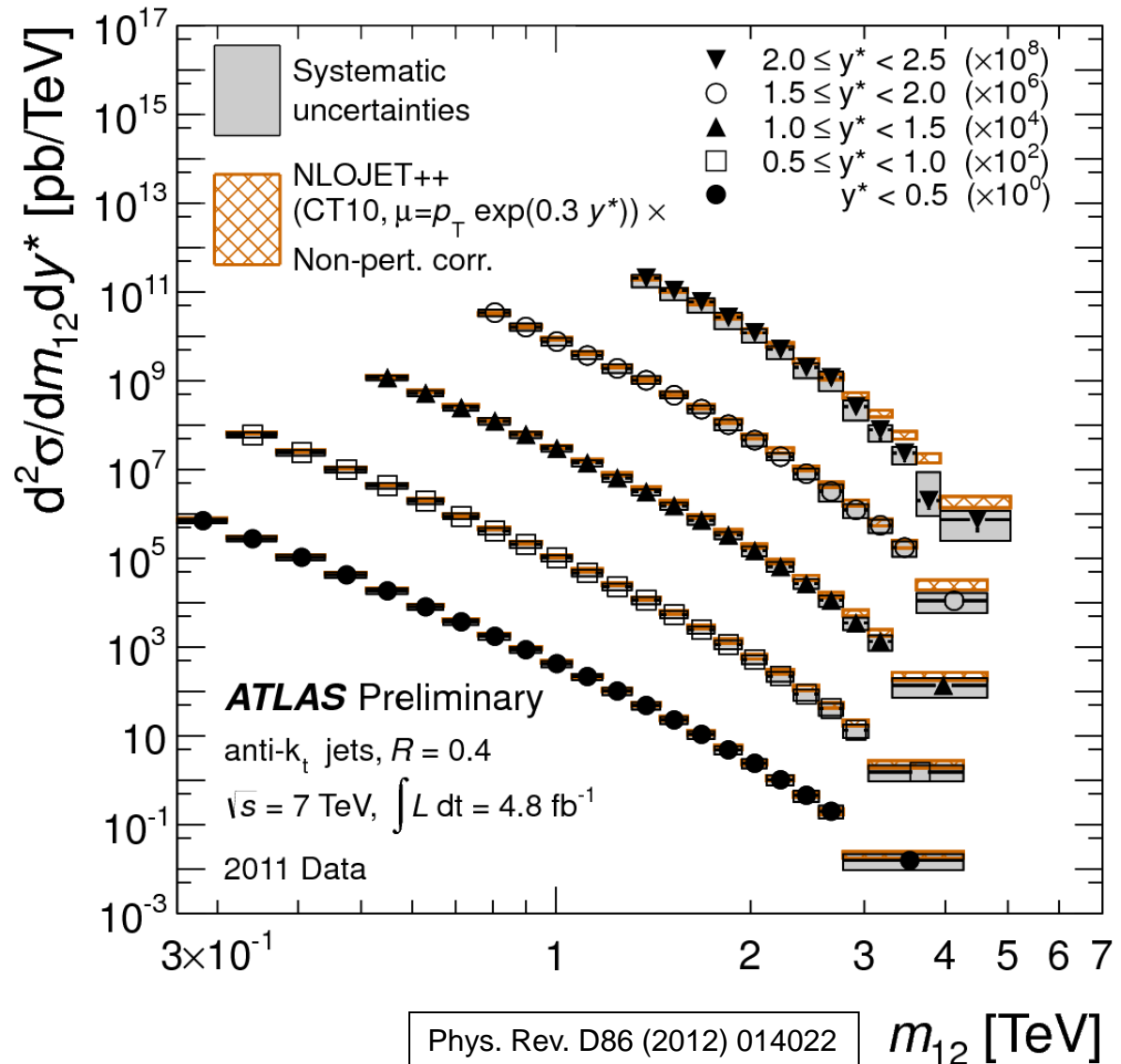
Example:

The inclusive di-jet cross sections as a function of the di-jet mass for various rapidity separations

The data are spanning jets over a large phase space:

- $20 \text{ GeV} < p_T < 2 \text{ TeV}$
- $|\eta| < 4.4$

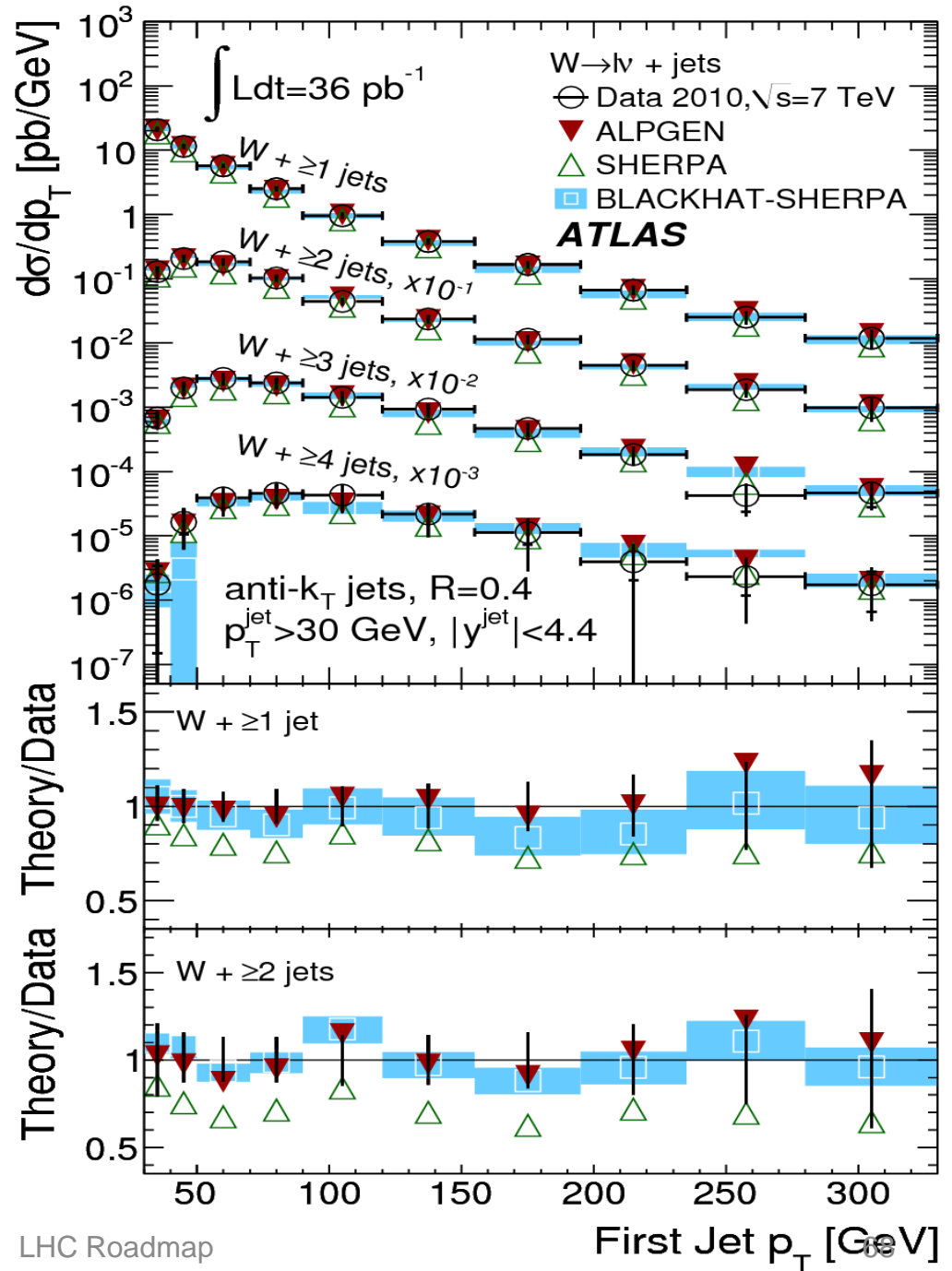
$$(y^* = 0.5 |\eta_1 - \eta_2|)$$



$W + \text{jet}(s)$ production

Both an interesting QCD measurement as well as a dominant background to many searches

Phys. Rev. D85 (2012) 092002



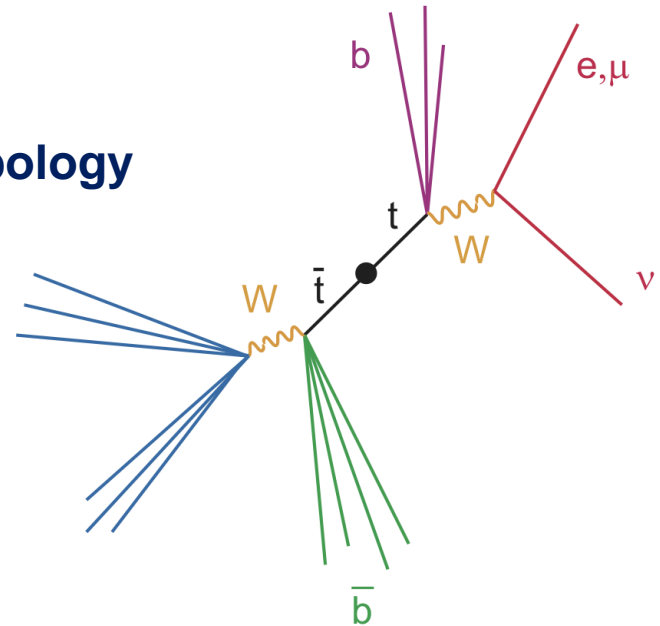
Top measurements

- Complete set of ingredients to investigate production of $t\bar{t}$, which is the next step in verifying the SM at the LHC:

- **$e, \mu, E_T^{\text{miss}}, \text{jets}, \text{b-tag}$**

- Assume all tops decay to Wb : event topology then depends on the W decays:

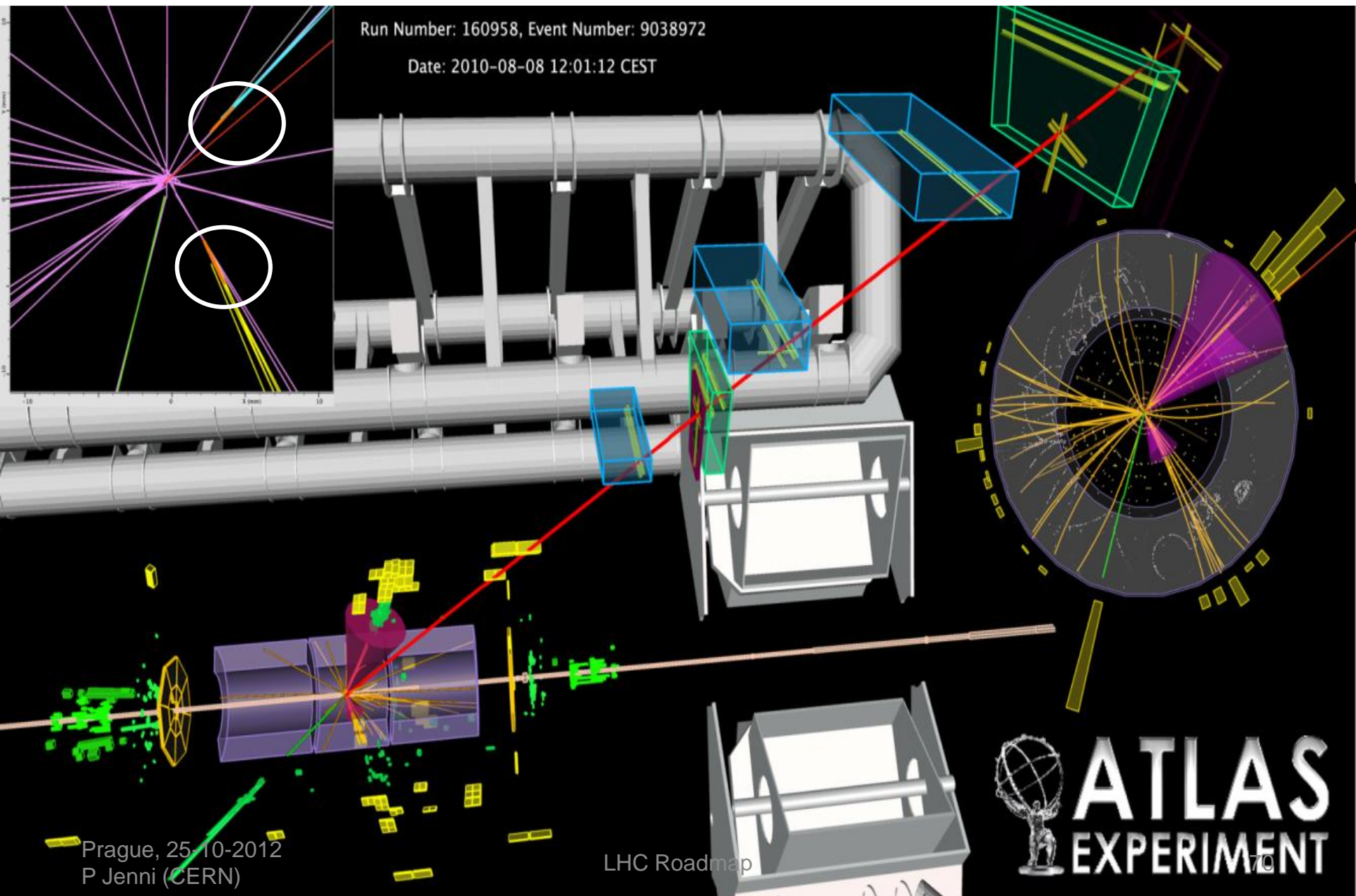
- one lepton (e or μ),
 $E_T^{\text{miss}}, jjbb$ (37.9%)
- di-lepton ($ee, \mu\mu$ or $e\mu$),
 E_T^{miss}, bb (6.46%)

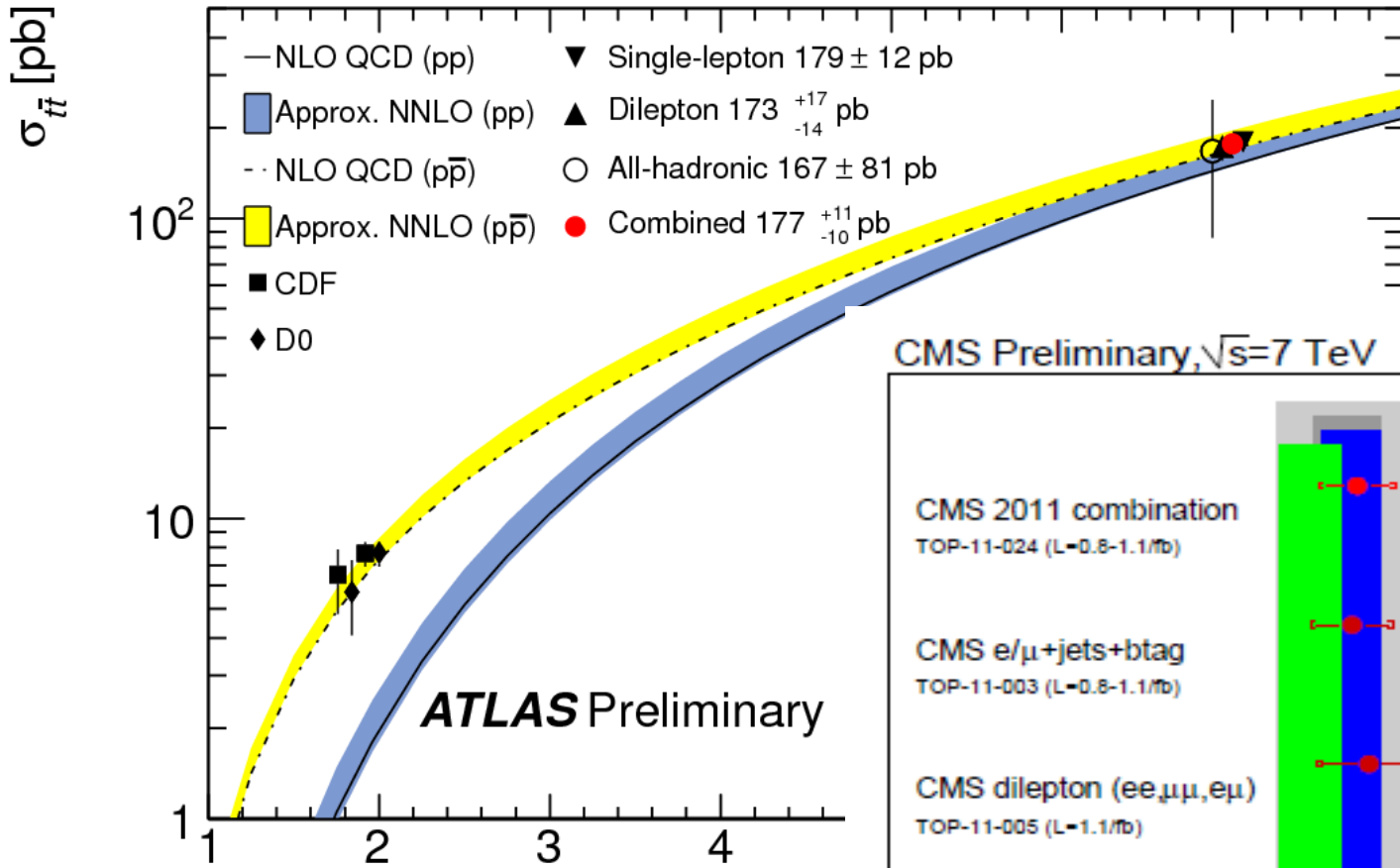


- **Data-driven methods to control QCD and W +jets backgrounds**

$t\bar{t}$ candidate event

$e + \mu + 2 \text{ jets (b-tagged)} + E_T^{\text{miss}}$

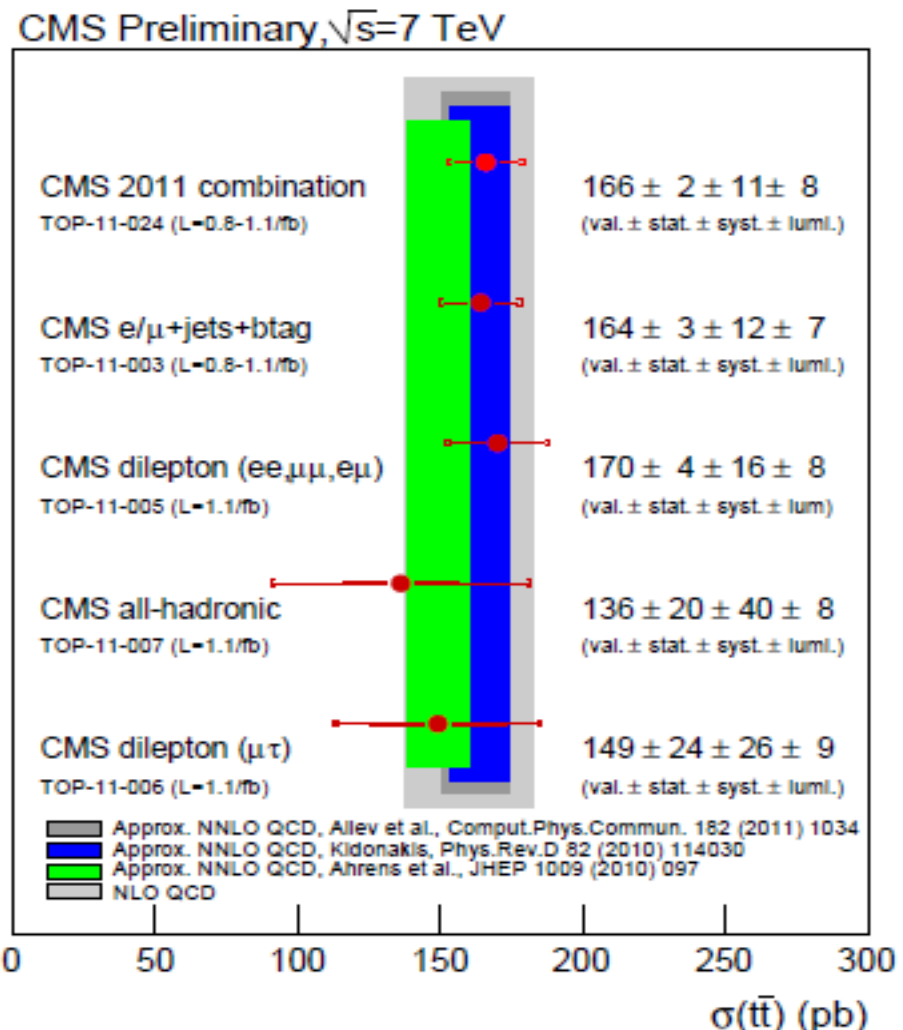




ATLAS-CONF-2012-024

CMS-TOP-11-024

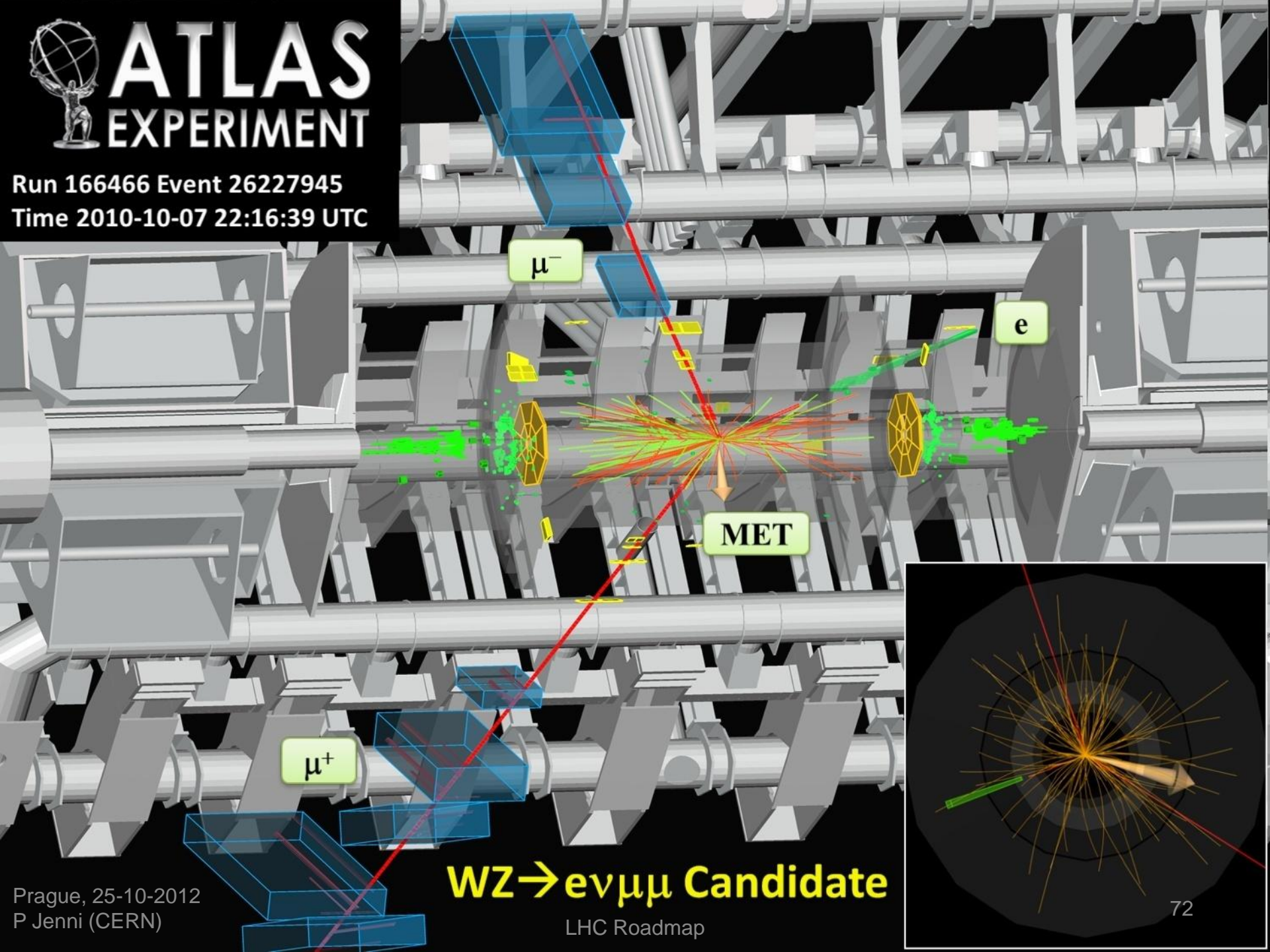
$t\bar{t}$ pair production cross-sections





ATLAS EXPERIMENT

Run 166466 Event 26227945
Time 2010-10-07 22:16:39 UTC



μ^+

μ^-

e

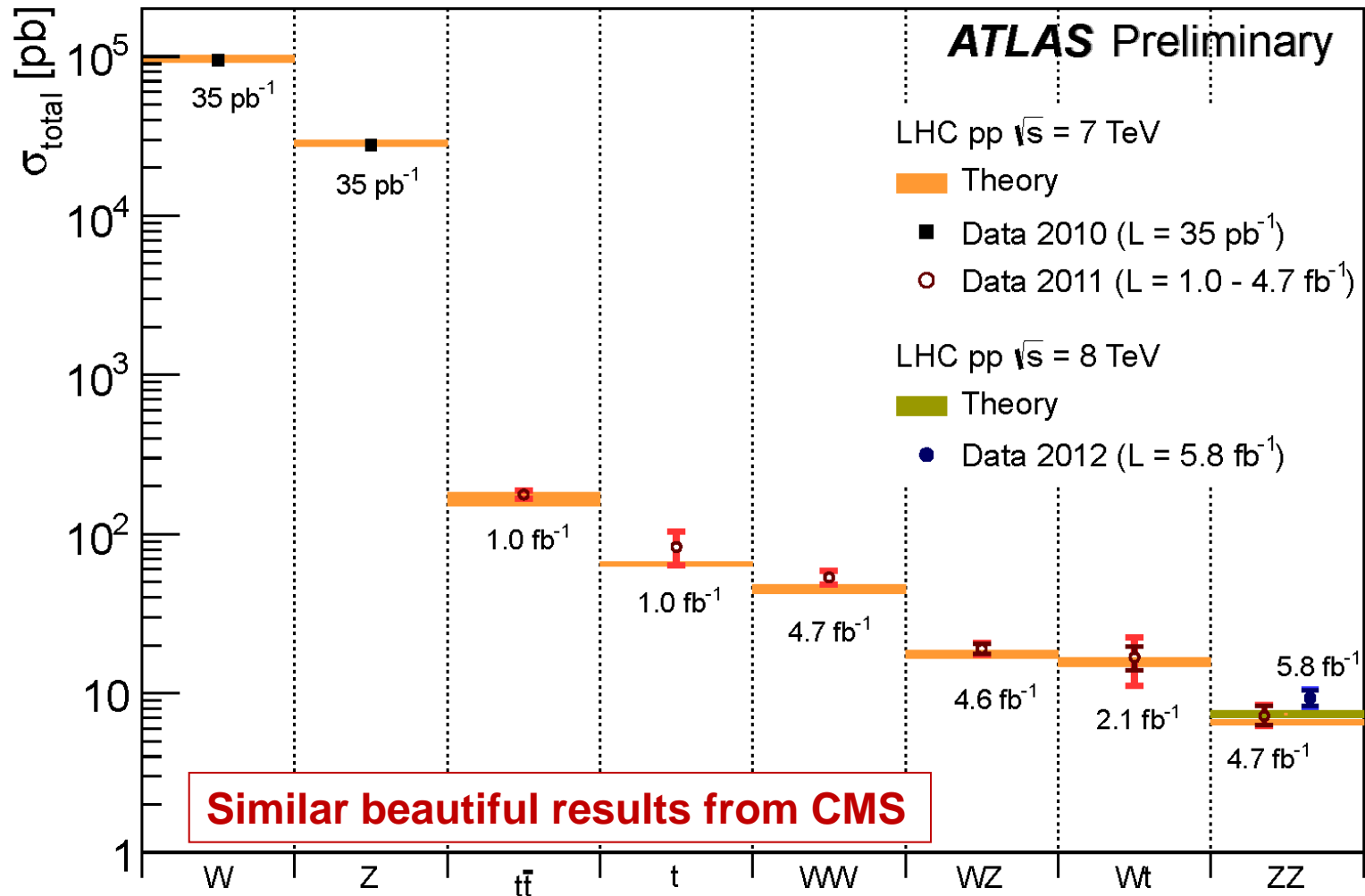
MET

$WZ \rightarrow e\nu\mu$ Candidate

LHC Roadmap

Prague, 25-10-2012
P Jenni (CERN)

A summary of Standard Model measurements

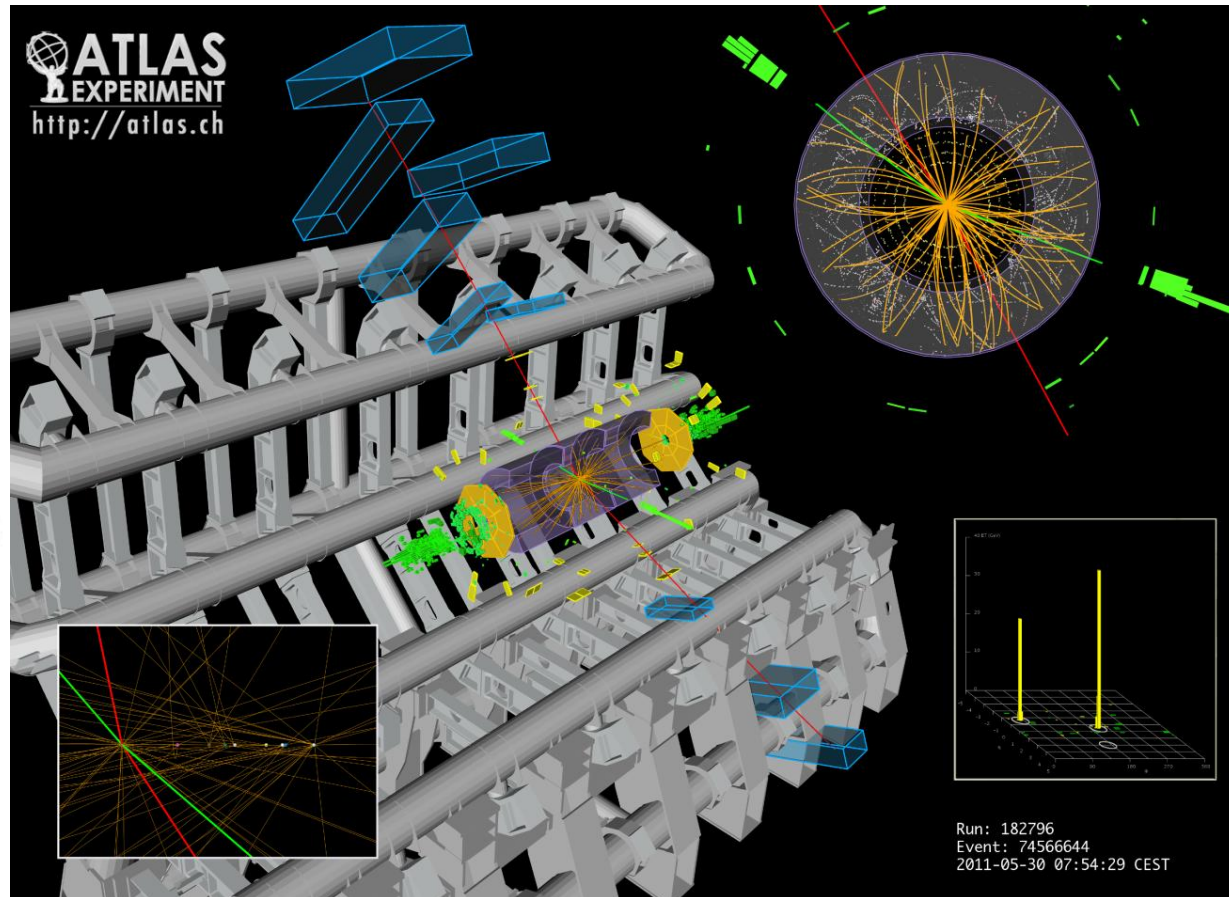


The excellent performance in measuring Standard Model physics gives confidence for the readiness of the two experiments to search for New Physics

We are in the year of the Dragon...



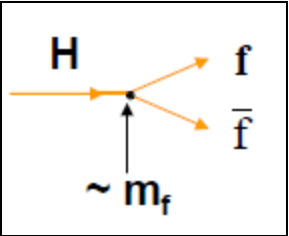
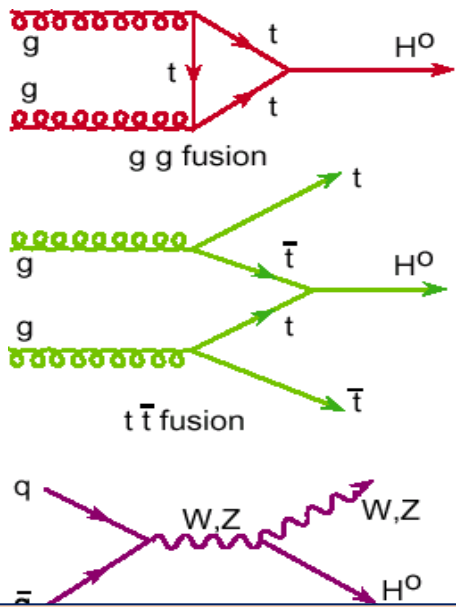
Candidate for a 124.5 GeV mass
 $H \rightarrow \mu\mu ee$ event in ATLAS



*... but it will also be remembered
as the one of the Higgs Boson !*

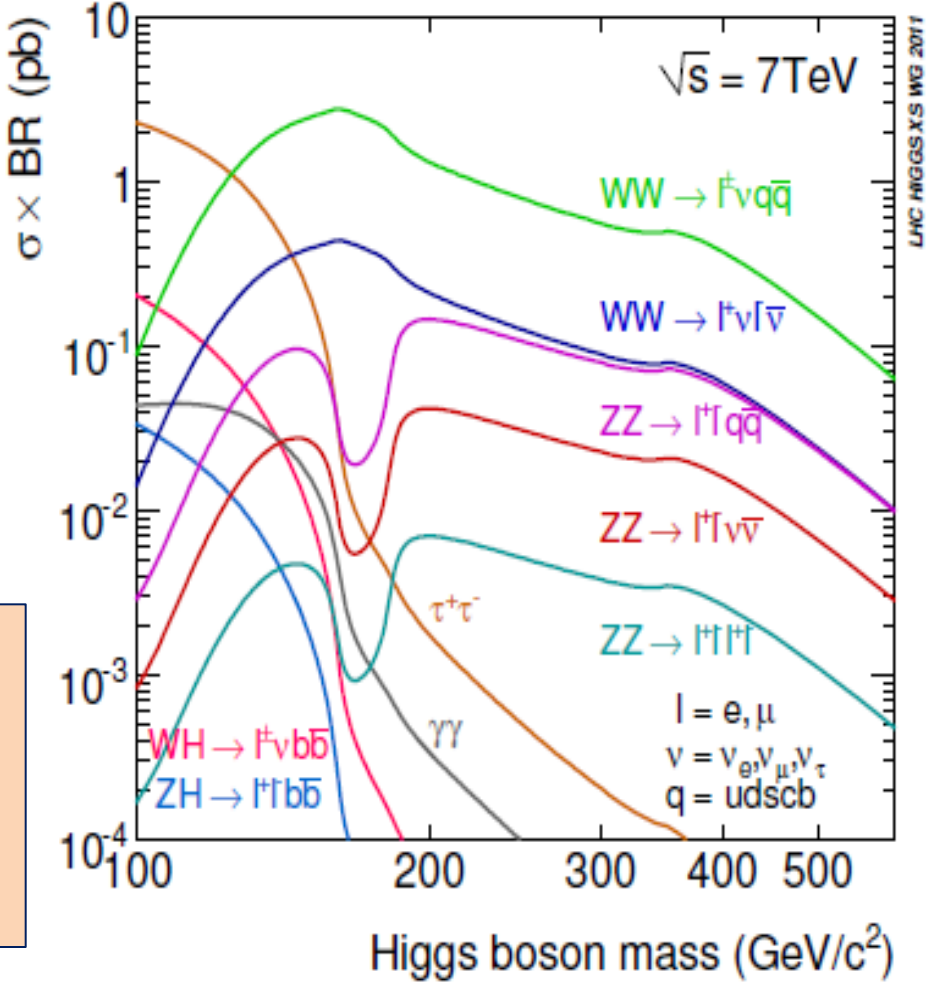
Search for the boson (H) of the EW symmetry breaking

SM H boson production cross sections times observable decay branching ratios at 7 TeV



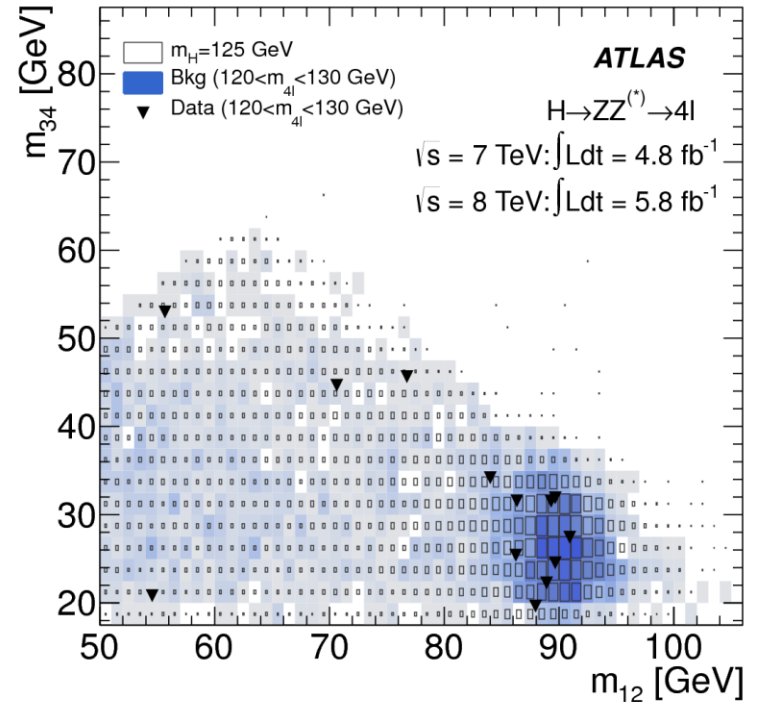
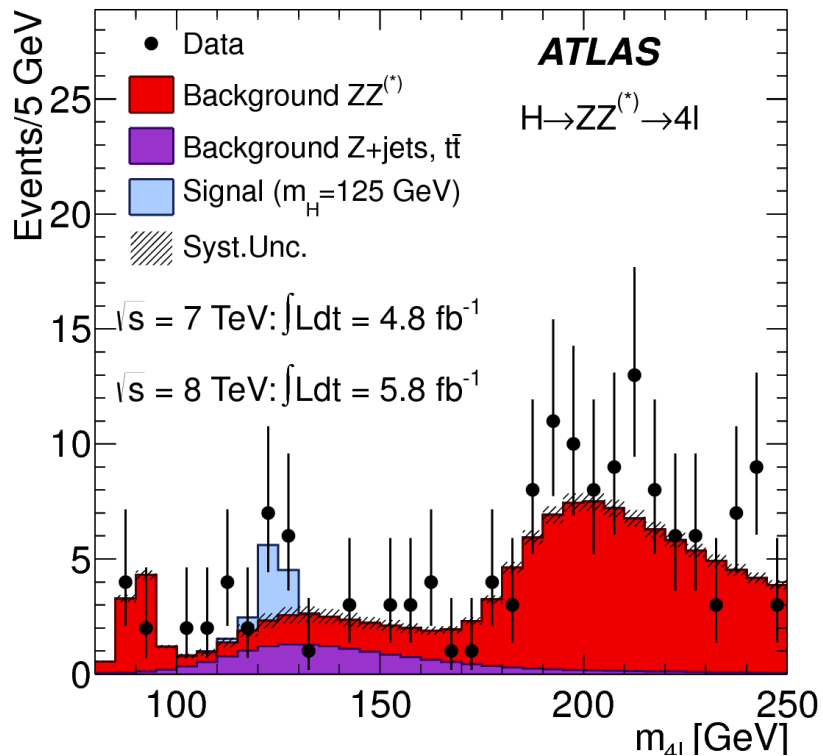
Best channels at the LHC:

< 130 GeV	$H \rightarrow \gamma\gamma$
125-180 GeV	$H \rightarrow WW^{(*)} \rightarrow l\nu l\nu$
125-300 GeV	$H \rightarrow ZZ^{(*)} \rightarrow ll ll$
300-600 GeV	$H \rightarrow ZZ \rightarrow ll\nu\nu$



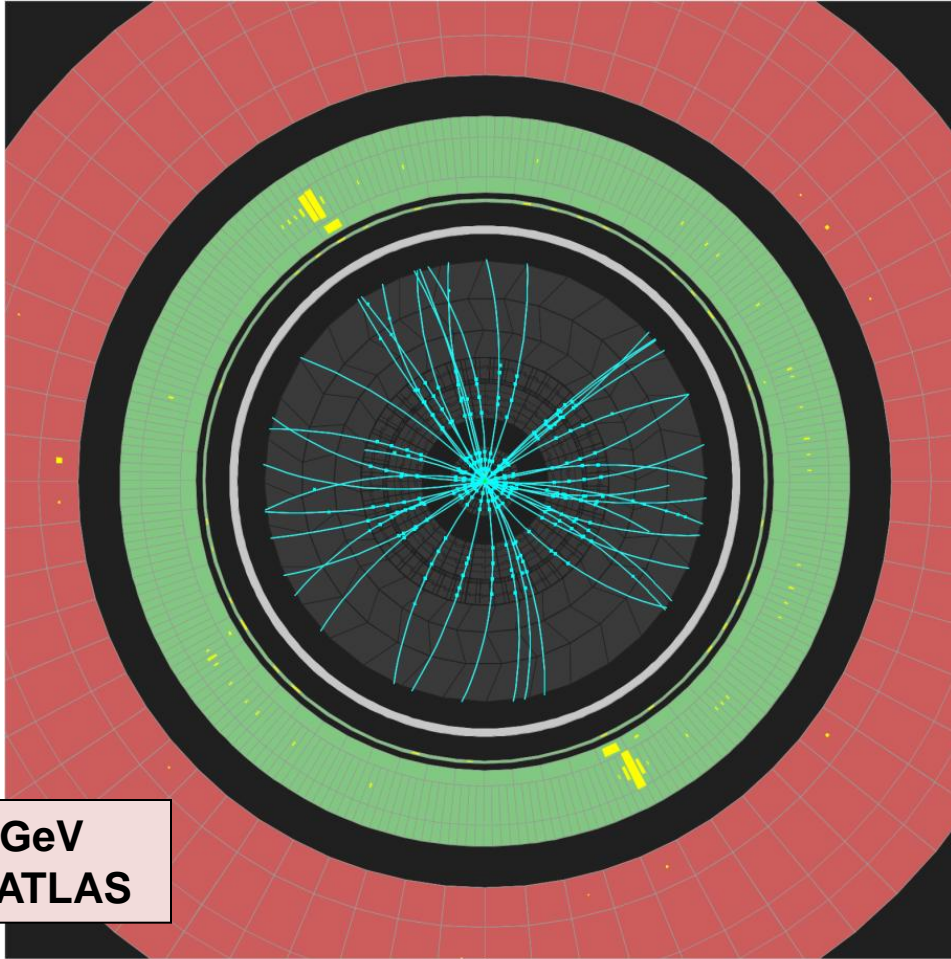
ATLAS $H \rightarrow ZZ^{(*)} \rightarrow 4l$ ($4e, 4\mu, 2e2\mu$)

- ❑ Rare process, small cross section: $\sigma \sim 2\text{-}5$ fb
 - ❑ However: pure: $S/B \sim 1$
 - ❑ 4 leptons: $p_T^{1,2,3,4} > 20, 20, 7, 7$ GeV; $m_{12} = m_Z \pm 15$ GeV
 - ❑ Main background: $ZZ^{(*)}$ (irreducible)
- In addition: $Zbb, Z\text{+jets}, tt$ with two leptons from b-quarks or jets

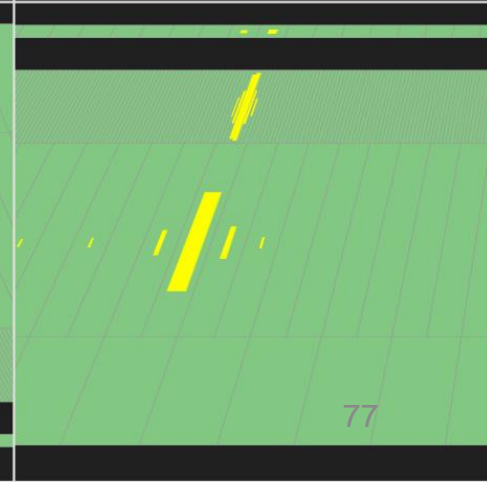
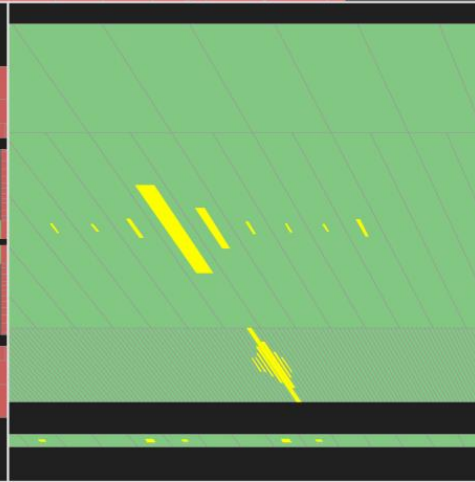
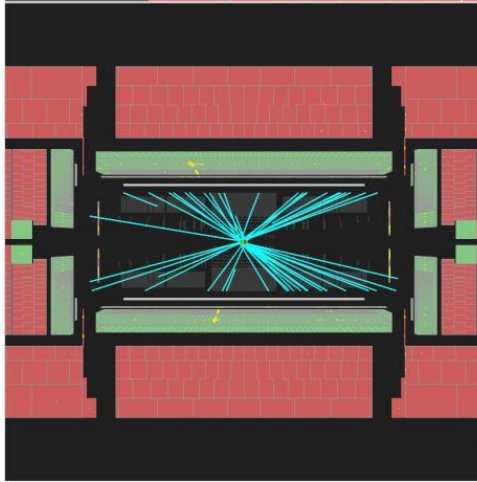
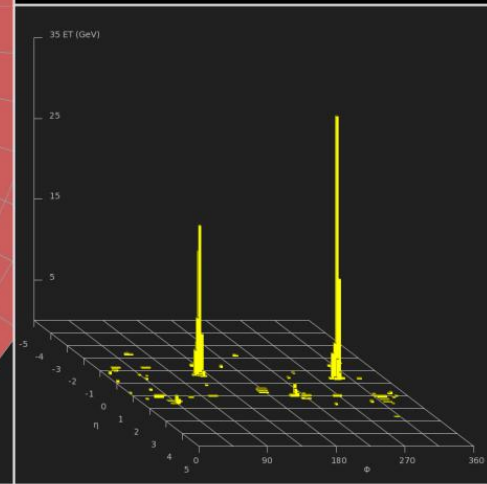


	Signal	$ZZ^{(*)}$	$Z + \text{jets}, tt$	Observed
4μ	2.09 ± 0.30	1.12 ± 0.05	0.13 ± 0.04	6
$2e2\mu/2\mu2e$	2.29 ± 0.33	0.80 ± 0.05	1.27 ± 0.19	5
$4e$	0.90 ± 0.14	0.44 ± 0.04	1.09 ± 0.20	2

Phys. Lett. B 716 (2012) 1



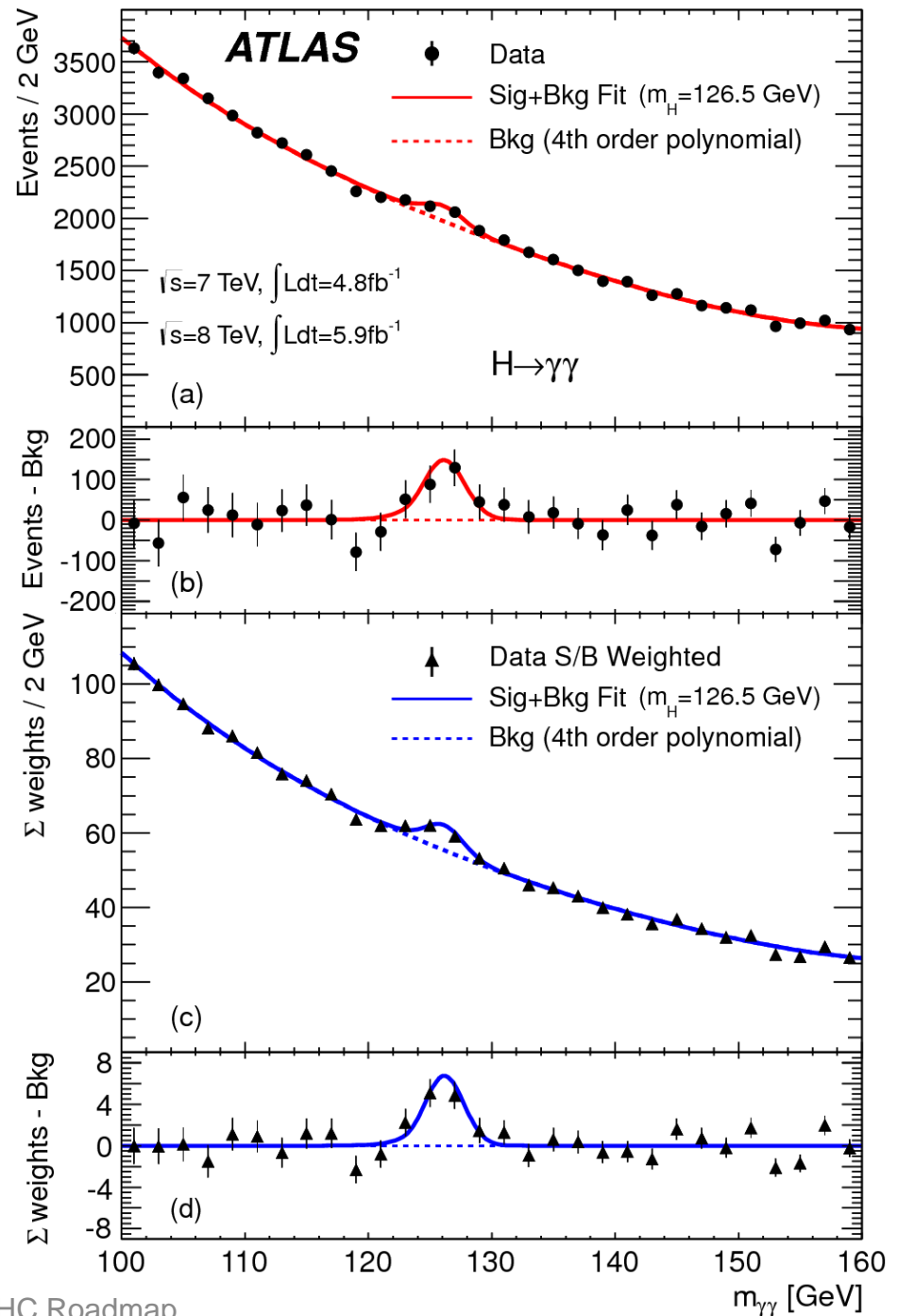
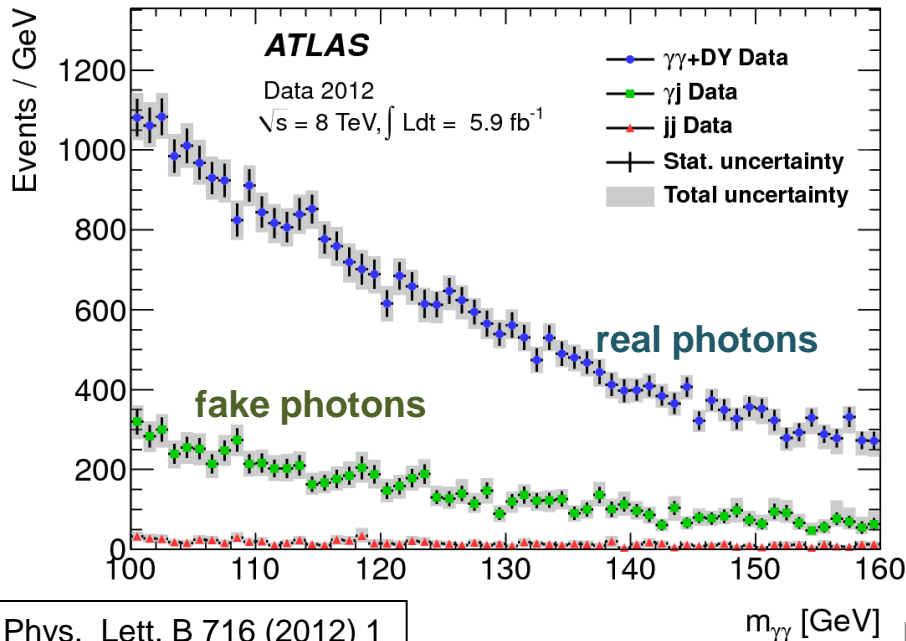
**Candidate for a 126.6 GeV
mass $H \rightarrow \gamma\gamma$ event in ATLAS**

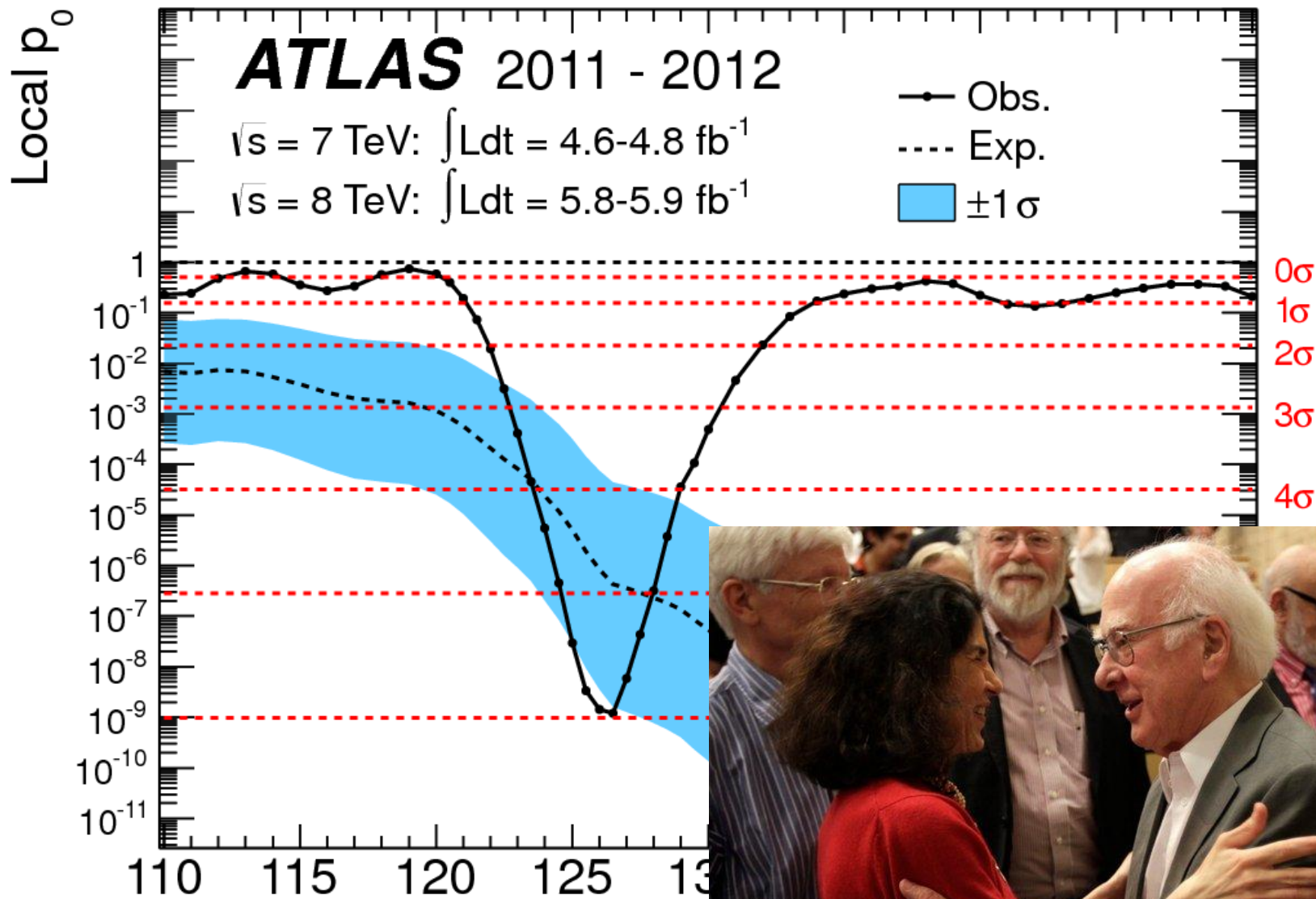


ATLAS $H \rightarrow \gamma\gamma$

- Small cross-section: $\sigma \sim 40$ fb
- Expected S/B ~ 0.02
- Simple final state: two high- p_T isolated photons: $E_T(\gamma_1, \gamma_2) > 40, 25$ GeV
- Main background: $\gamma\gamma$ continuum (irreducible) and fake γ from γj and jj events (reducible)

Analysis is done separately in 10 subcategories with different resolutions and backgrounds, then statistically combined with a likelihood method

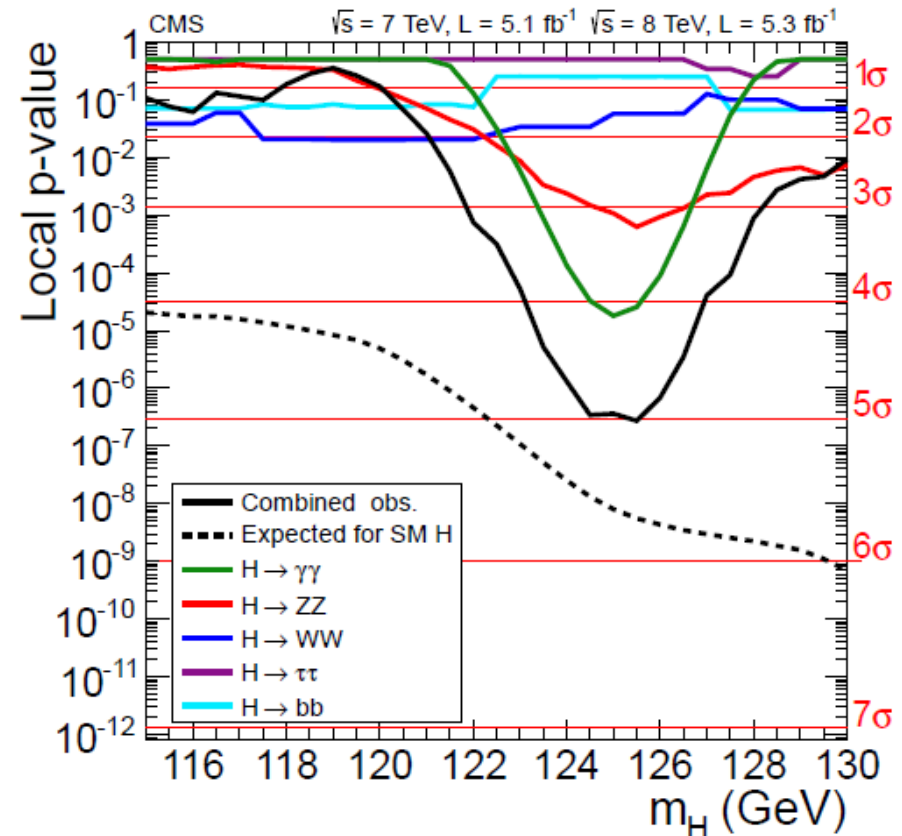
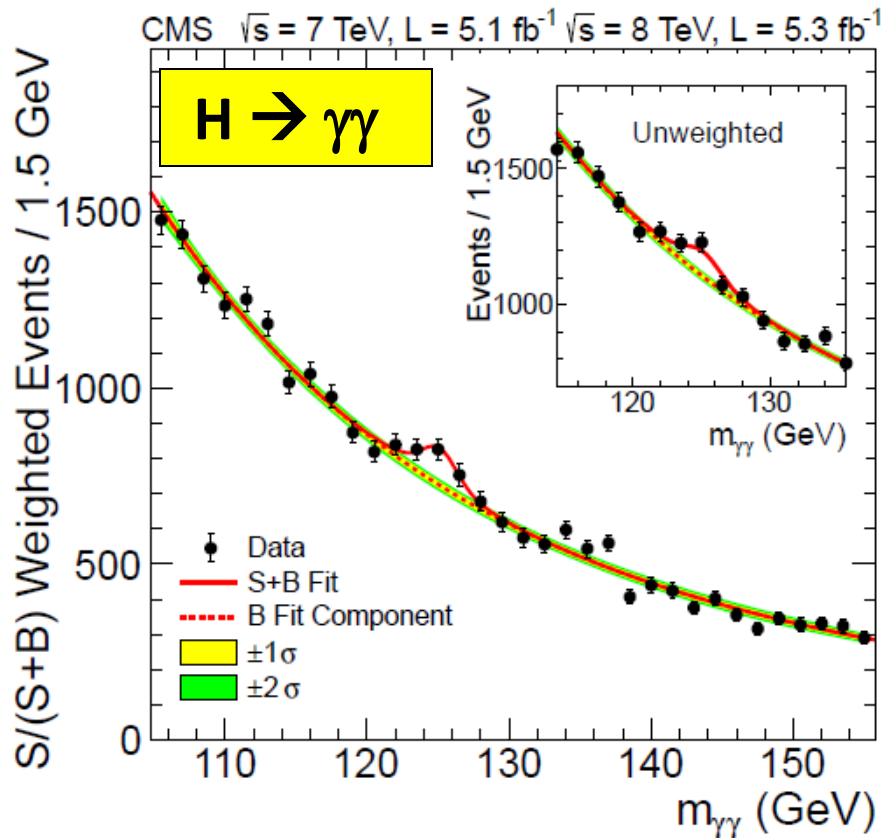




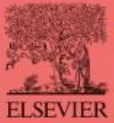
Phys. Lett. B 716 (2012) 1

Prague, 25-10-2012
 P Jenni (CERN)

CMS Higgs result example and summary



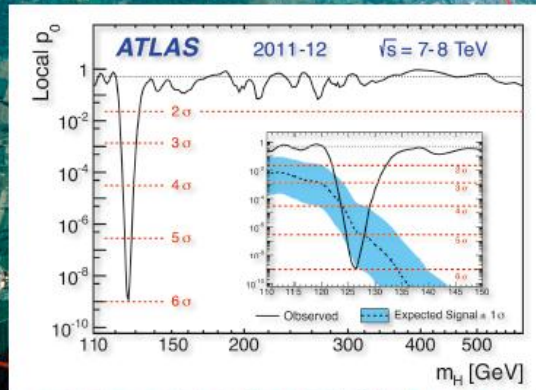
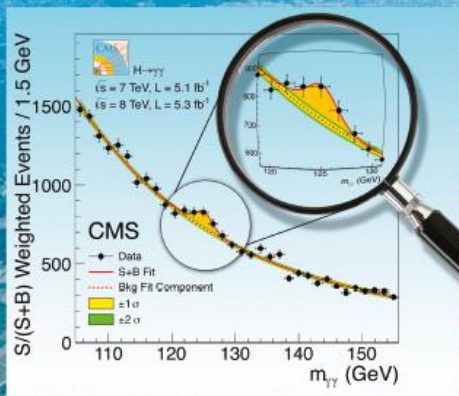
Phys. Lett. B 716 (2012) 30



PHYSICS LETTERS B

Available online at www.sciencedirect.com

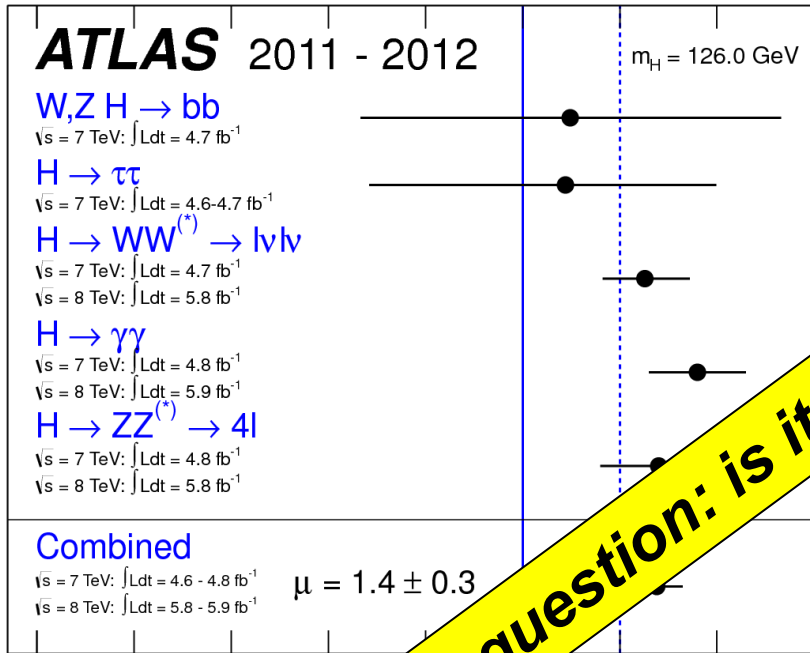
SciVerse ScienceDirect



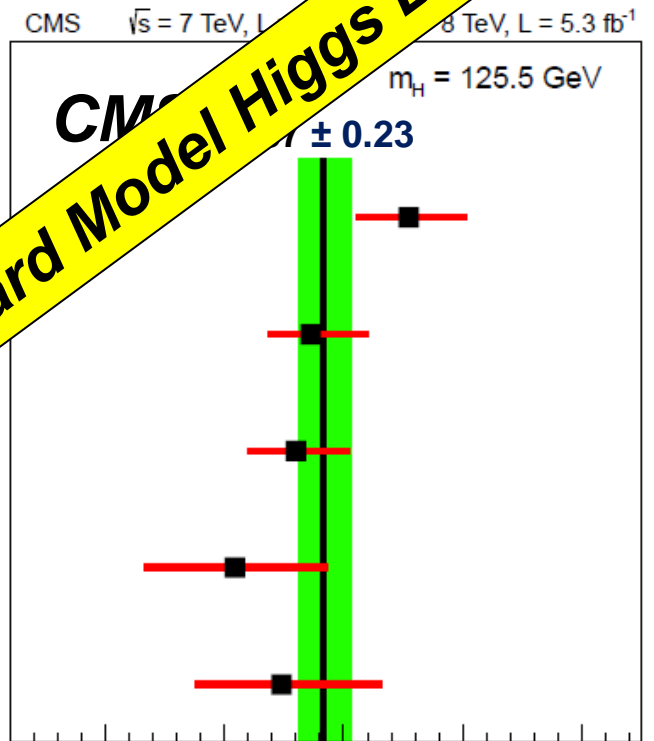
**F Englert and P Higgs
CERN, 4th July 2012**

Properties, as far as known with the limited statistics...

$\mu = 0$ background only hypothesis
 $\mu = 1$ SM Higgs hypothesis



Phys. Lett. B 716 (2012) 1-29 Signal strength (μ)



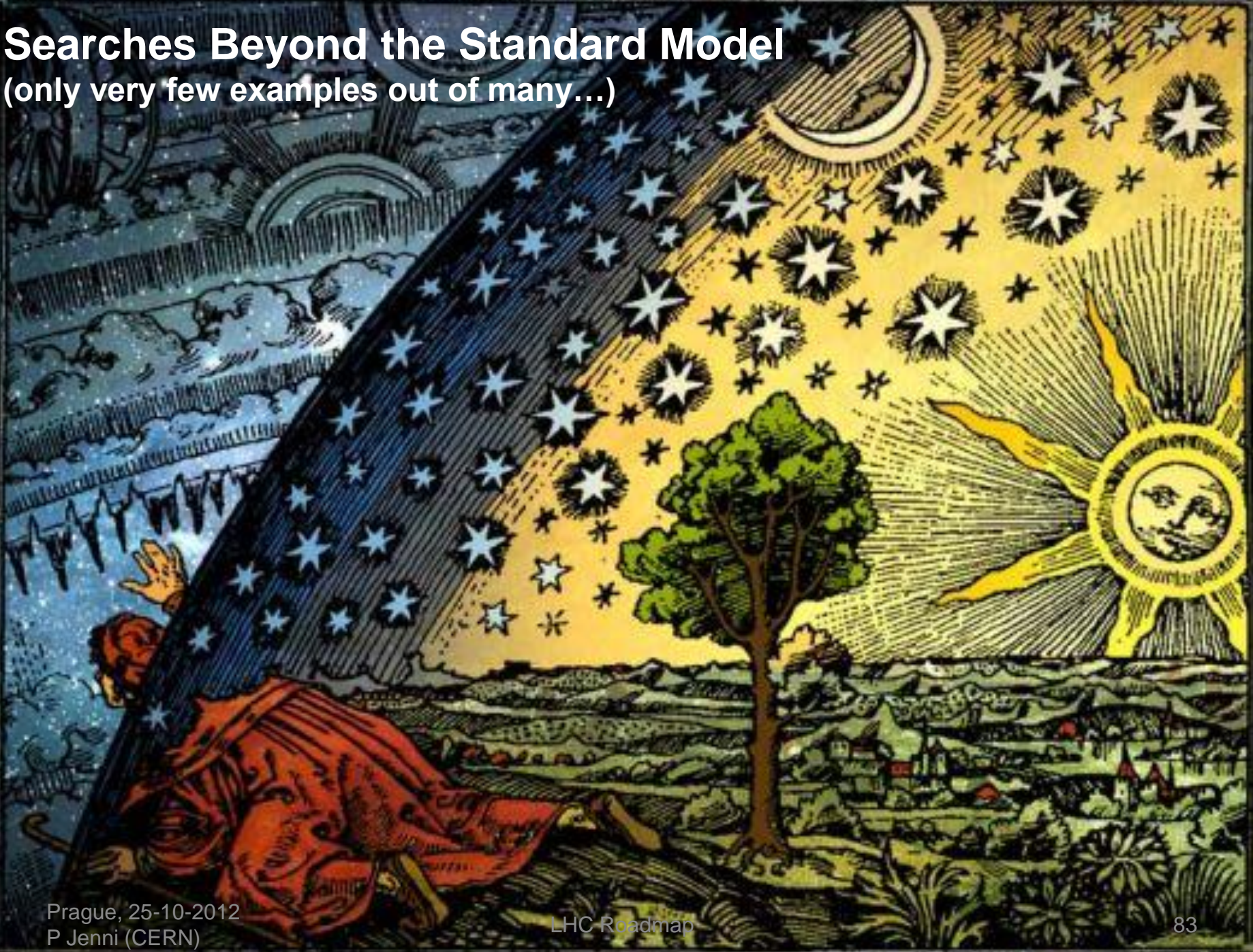
Phys. Lett. B 716 (2012) 30 Best fit $\sigma/\sigma_{\text{SM}}$

The burning question: is it the Standard Model Higgs Boson?

Mass = $126.0 \pm 0.4 \text{ (stat)} \pm 0.4 \text{ (syst)} \text{ GeV}$

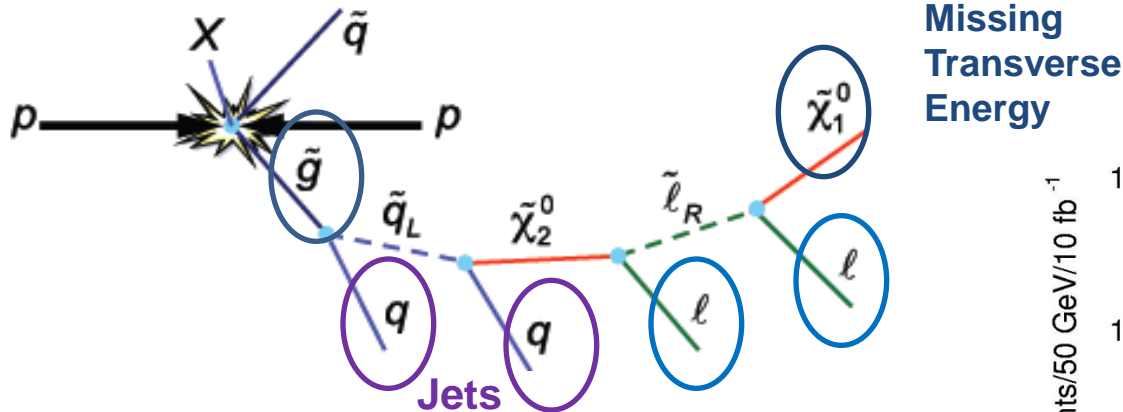
Mass = $125.3 \pm 0.4 \text{ (stat)} \pm 0.5 \text{ (syst)} \text{ GeV}$

Searches Beyond the Standard Model (only very few examples out of many...)



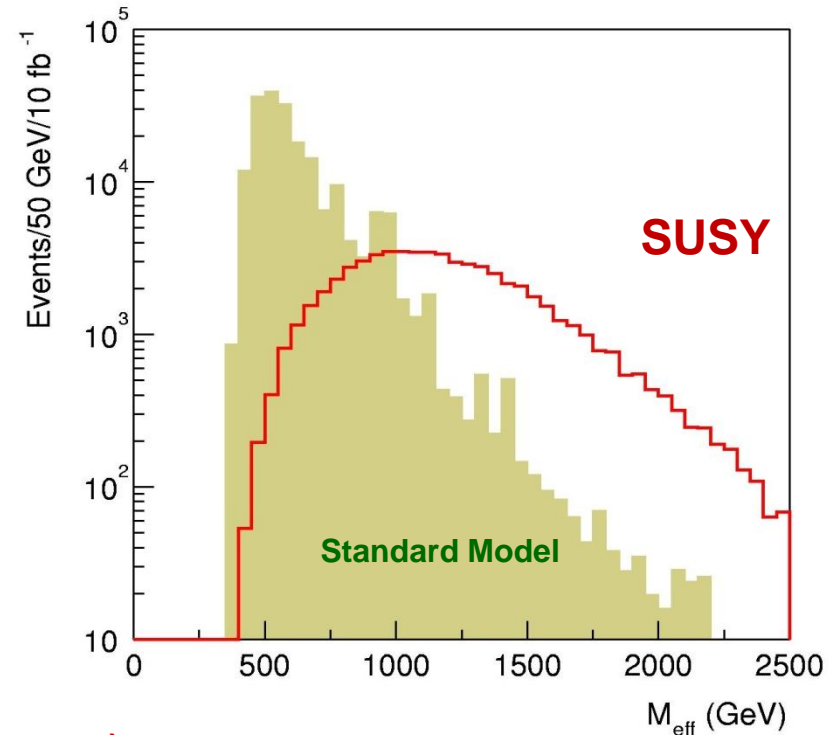
In practice SUSY searches at LHC are rather complicated

- Complex (and model-dependent) squark/gluino cascades



- Focus on signatures covering large classes of models while strongly rejecting SM background

- large missing E_T
- High transverse momentum jets
- Leptons
 - Perform separate analyses with and without lepton veto (0-lepton / 1-lepton / 2-leptons)
- B-jets: to enhance sensitivity to third-generation squarks
- Photons: typically for models with the gravitino as LSP

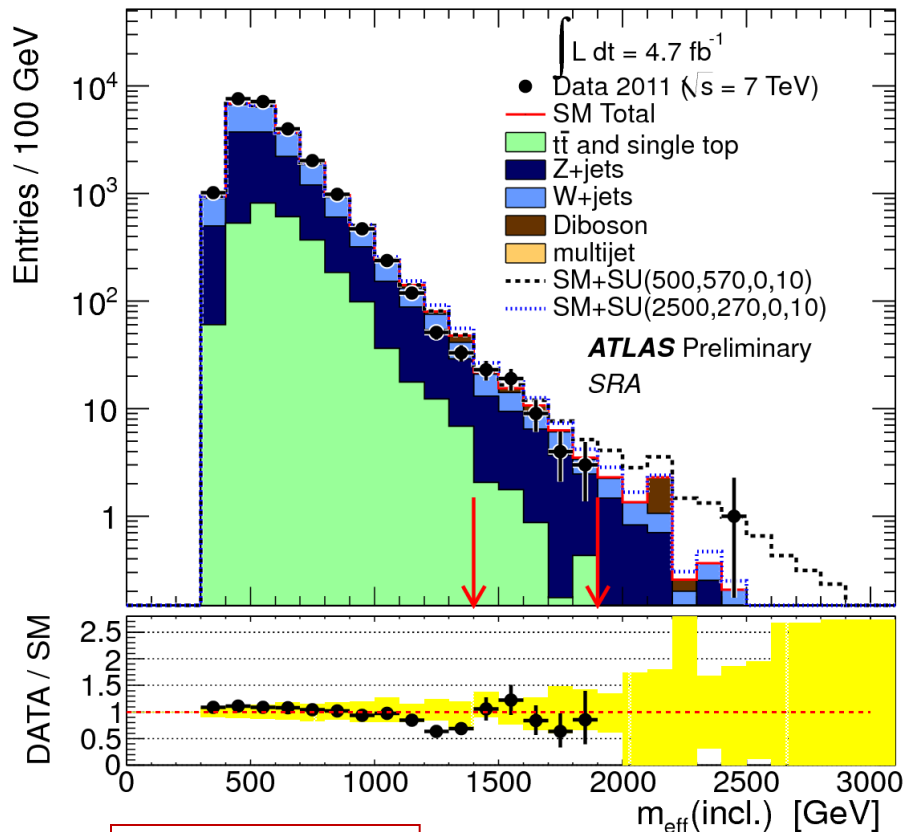


$$M_{\text{eff}} = E_{\text{miss}} + \sum p_T(\text{jets})$$

Analyses re-optimized and updated with full 2011 Luminosity

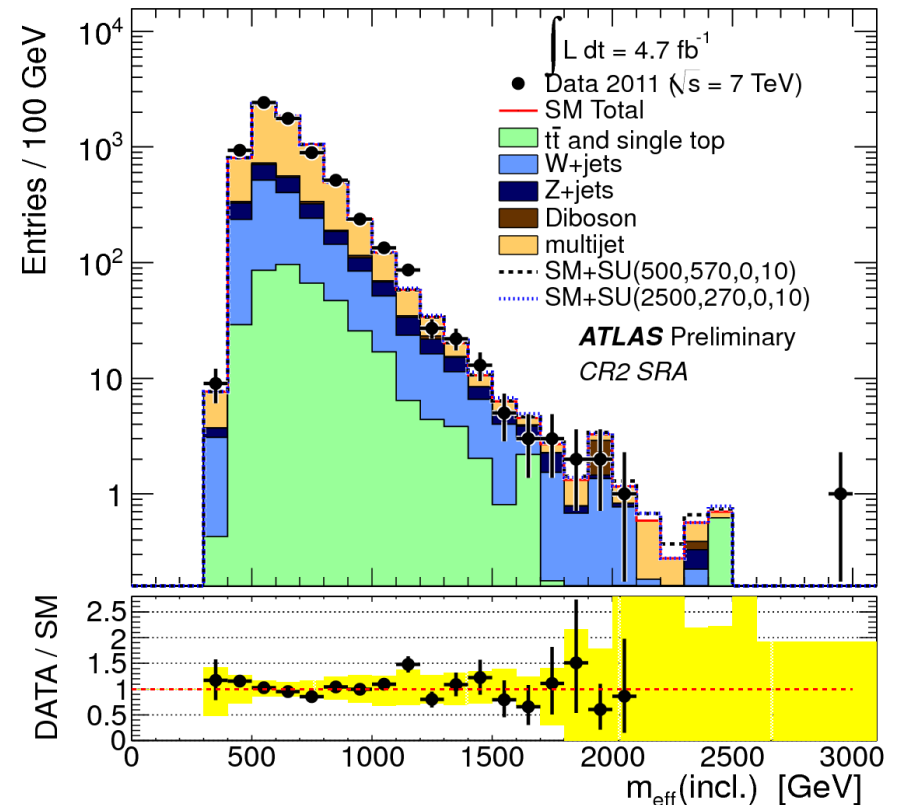
- 0-lepton + 2-6 jets + high MET (based on Et-miss+jet triggers)
- 0-lepton + 6-9 (multi-)jets + MET (based on multi-jet triggers)
- 1-lepton + 3,4 jets + high MET (based on lepton triggers)

Example: 0-leptons + 2-6 Jets analysis



A signal region

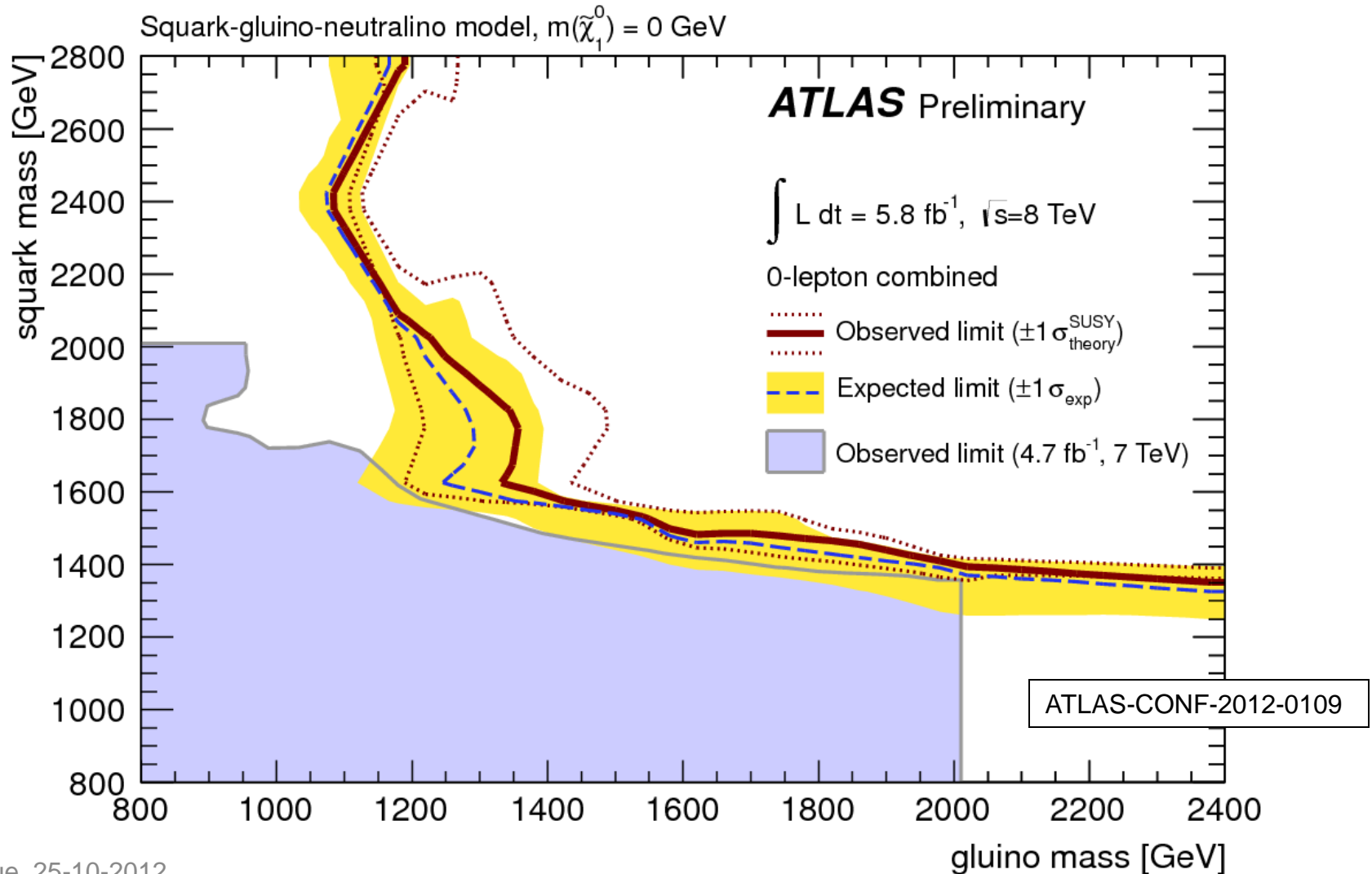
ATLAS-CONF-2012-033, 037, and 041



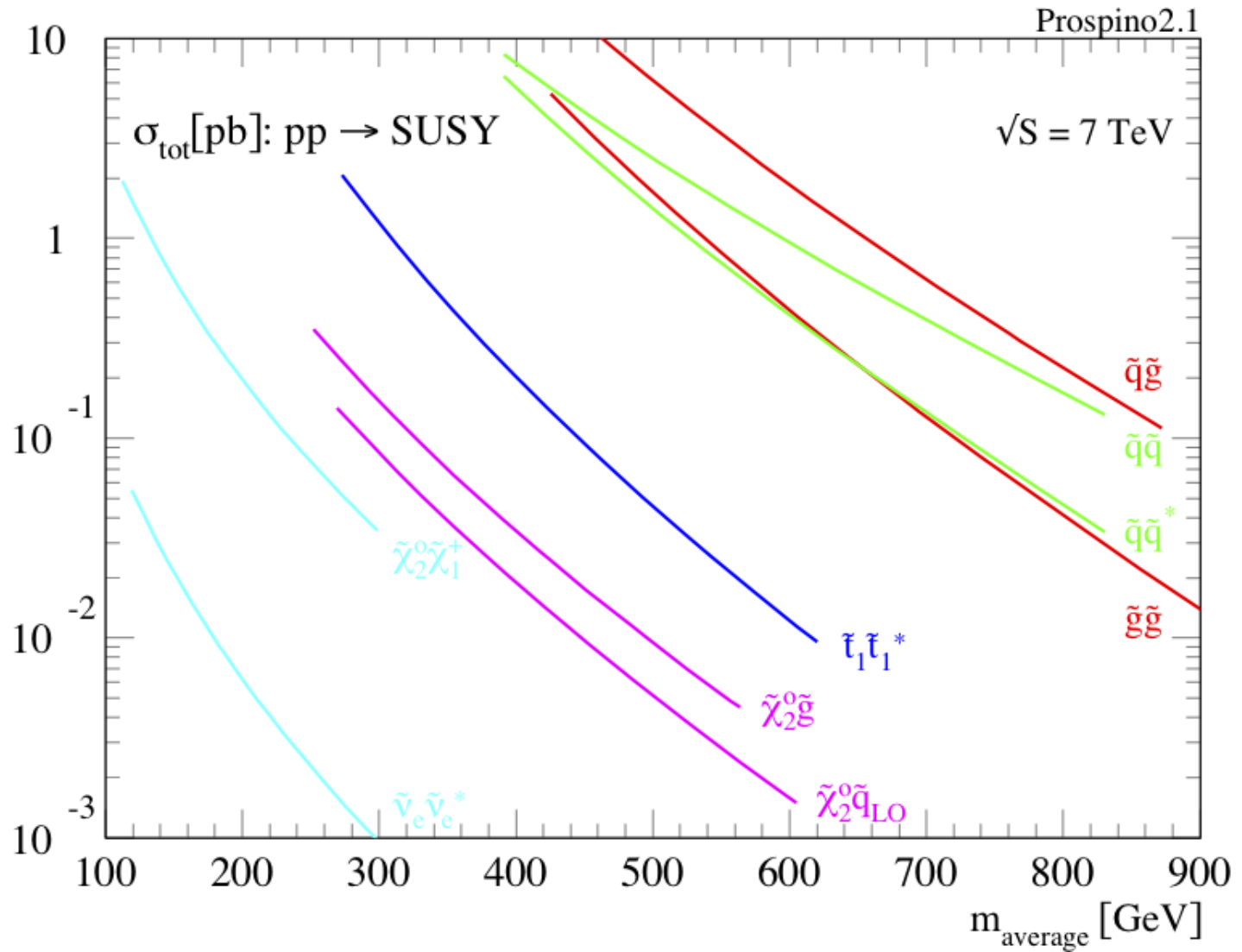
A control region where no signal is expected

Interpretation of the results

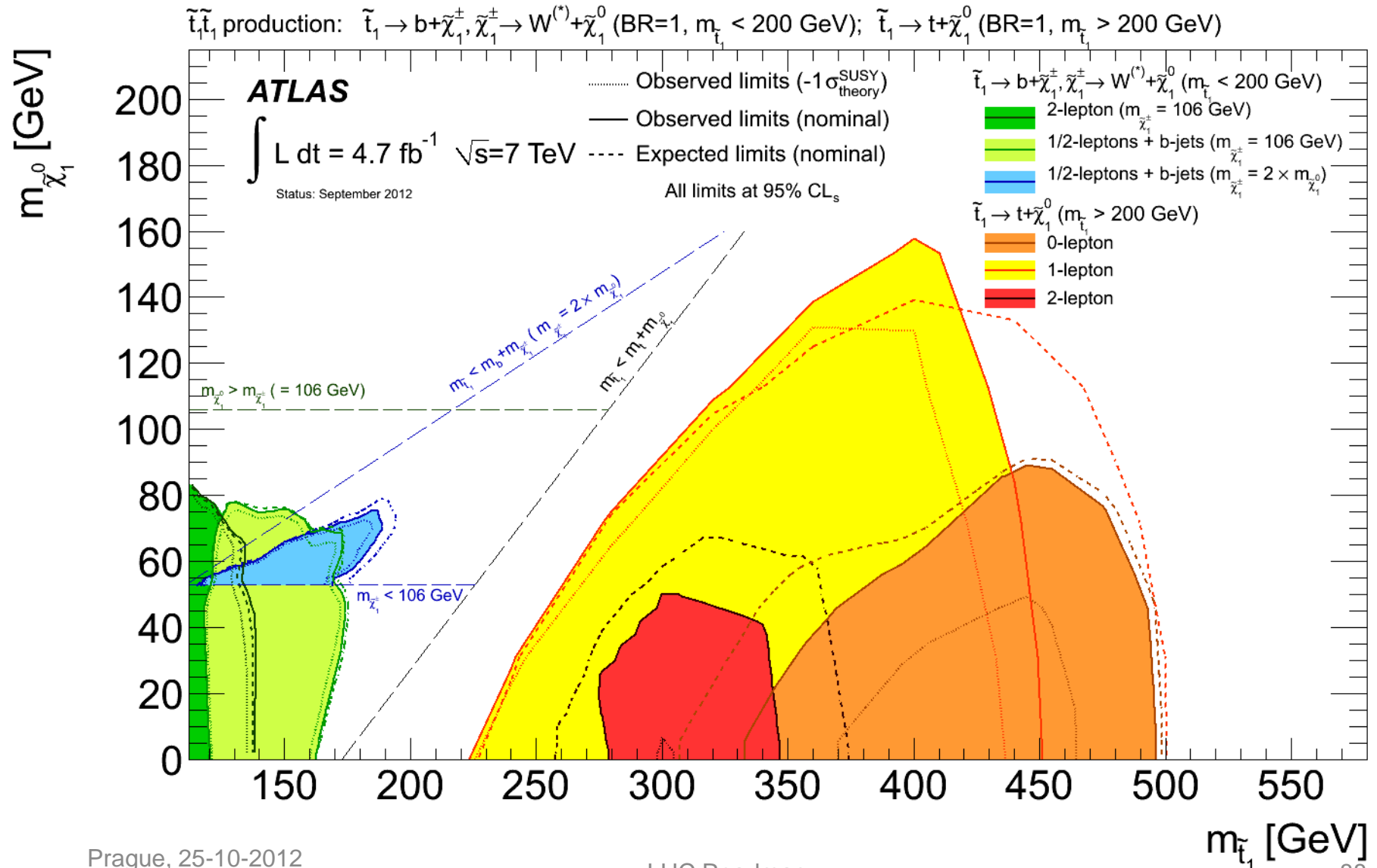
Consider phenomenological MSSM models containing only squarks of 1st and 2nd generation, gluino and light neutralinos



Expected production cross-sections at LHC



Summary of five dedicated searches for top squark pair production for theoretically preferred models with relatively light 3rd generation squarks



ATLAS SUSY limits

ATLAS SUSY Searches* - 95% CL Lower Limits (Status: SUSY 2012)

Inclusive searches

MSUGRA/CMSSM : 0 lep + j's + $E_{T,miss}$
 MSUGRA/CMSSM : 1 lep + j's + $E_{T,miss}$
 Pheno model : 0 lep + j's + $E_{T,miss}$
 Pheno model : 0 lep + j's + $E_{T,miss}$
 Gluino med. $\tilde{\chi}^{\pm}$ ($\tilde{g} \rightarrow q\bar{q}\tilde{\chi}^{\pm}$) : 1 lep + j's + $E_{T,miss}$
 GMSB : 2 lep (OS) + j's + $E_{T,miss}$
 GMSB : 1-2 τ + 0-1 lep + j's + $E_{T,miss}$
 GGM : $\gamma\gamma$ + $E_{T,miss}$

$L=5.8 \text{ fb}^{-1}, 8 \text{ TeV}$ [ATLAS-CONF-2012-109]	1.50 TeV	$\tilde{q} = \tilde{g}$ mass
$L=5.8 \text{ fb}^{-1}, 8 \text{ TeV}$ [ATLAS-CONF-2012-104]	1.24 TeV	$\tilde{q} = \tilde{g}$ mass
$L=5.8 \text{ fb}^{-1}, 8 \text{ TeV}$ [ATLAS-CONF-2012-109]	1.18 TeV	\tilde{g} mass ($m(\tilde{q}) < 2 \text{ TeV}$, light $\tilde{\chi}_1^0$)
$L=5.8 \text{ fb}^{-1}, 8 \text{ TeV}$ [ATLAS-CONF-2012-109]	1.38 TeV	\tilde{q} mass ($m(\tilde{g}) < 2 \text{ TeV}$, light $\tilde{\chi}_1^0$)
$L=4.7 \text{ fb}^{-1}, 7 \text{ TeV}$ [ATLAS-CONF-2012-041]	900 GeV	\tilde{g} mass ($m(\tilde{\chi}_1^0) < 200 \text{ GeV}$, $m(\tilde{\chi}_1^{\pm}) = \frac{1}{2}(m(\tilde{\chi}_1^0) + m(\tilde{g}))$)
$L=4.7 \text{ fb}^{-1}, 7 \text{ TeV}$ [Preliminary]	1.24 TeV	\tilde{g} mass ($\tan\beta < 15$)
$L=4.7 \text{ fb}^{-1}, 7 \text{ TeV}$ [ATLAS-CONF-2012-112]	1.20 TeV	\tilde{g} mass ($\tan\beta > 20$)
$L=4.8 \text{ fb}^{-1}, 7 \text{ TeV}$ [ATLAS-CONF-2012-072]	1.07 TeV	\tilde{g} mass ($m(\tilde{\chi}_1^0) > 50 \text{ GeV}$)

$\int L dt = (1.00 - 5.8) \text{ fb}^{-1}$
 $\sqrt{s} = 7, 8 \text{ TeV}$

ATLAS Preliminary

3rd gen. squarks
gluino mediated

$\tilde{g} \rightarrow b\bar{b}\tilde{\chi}_1^0$ (virtual b) : 0 lep + 1/2 b-j's + $E_{T,miss}$
 $\tilde{g} \rightarrow b\bar{b}\tilde{\chi}_1^0$ (virtual b) : 0 lep + 3 b-j's + $E_{T,miss}$
 $\tilde{g} \rightarrow b\bar{b}\tilde{\chi}_1^0$ (real b) : 0 lep + 3 b-j's + $E_{T,miss}$
 $\tilde{g} \rightarrow t\bar{t}\tilde{\chi}_1^0$ (virtual t) : 1 lep + 1/2 b-j's + $E_{T,miss}$
 $\tilde{g} \rightarrow t\bar{t}\tilde{\chi}_1^0$ (virtual t) : 2 lep (SS) + j's + $E_{T,miss}$
 $\tilde{g} \rightarrow t\bar{t}\tilde{\chi}_1^0$ (virtual t) : 3 lep + j's + $E_{T,miss}$
 $\tilde{g} \rightarrow t\bar{t}\tilde{\chi}_1^0$ (virtual t) : 0 lep + multi-j's + $E_{T,miss}$
 $\tilde{g} \rightarrow t\bar{t}\tilde{\chi}_1^0$ (virtual t) : 0 lep + 3 b-j's + $E_{T,miss}$
 $\tilde{g} \rightarrow t\bar{t}\tilde{\chi}_1^0$ (real t) : 0 lep + 3 b-j's + $E_{T,miss}$

$L=2.1 \text{ fb}^{-1}, 7 \text{ TeV}$ [1203.6193]	900 GeV	\tilde{g} mass ($m(\tilde{\chi}_1^0) < 300 \text{ GeV}$)
$L=4.7 \text{ fb}^{-1}, 7 \text{ TeV}$ [1207.4686]	1.02 TeV	\tilde{g} mass ($m(\tilde{\chi}_1^0) < 400 \text{ GeV}$)
$L=4.7 \text{ fb}^{-1}, 7 \text{ TeV}$ [1207.4686]	1.00 TeV	\tilde{g} mass ($m(\tilde{\chi}_1^0) = 60 \text{ GeV}$)
$L=2.1 \text{ fb}^{-1}, 7 \text{ TeV}$ [1203.6193]	710 GeV	\tilde{g} mass ($m(\tilde{\chi}_1^0) < 150 \text{ GeV}$)
$L=5.8 \text{ fb}^{-1}, 8 \text{ TeV}$ [ATLAS-CONF-2012-105]	850 GeV	\tilde{g} mass ($m(\tilde{\chi}_1^0) < 300 \text{ GeV}$)
$L=4.7 \text{ fb}^{-1}, 7 \text{ TeV}$ [ATLAS-CONF-2012-108]	760 GeV	\tilde{g} mass (any $m(\tilde{\chi}_1^0) < m(\tilde{g})$)
$L=5.8 \text{ fb}^{-1}, 8 \text{ TeV}$ [ATLAS-CONF-2012-103]	1.00 TeV	\tilde{g} mass ($m(\tilde{\chi}_1^0) < 300 \text{ GeV}$)
$L=4.7 \text{ fb}^{-1}, 7 \text{ TeV}$ [1207.4686]	940 GeV	\tilde{g} mass ($m(\tilde{\chi}_1^0) < 50 \text{ GeV}$)
$L=4.7 \text{ fb}^{-1}, 7 \text{ TeV}$ [1207.4686]	820 GeV	\tilde{g} mass ($m(\tilde{\chi}_1^0) = 60 \text{ GeV}$)

3rd gen. squarks
direct production

$bb, b_1 \rightarrow b\tilde{\chi}_1^{\pm}$: 0 lep + 2-b-jets + $E_{T,miss}$
 $bb, b_1 \rightarrow t\tilde{\chi}_1^{\pm}$: 3 lep + j's + $E_{T,miss}$
 \tilde{t} (very light), $\tilde{t} \rightarrow b\tilde{\chi}_1^{\pm}$: 2 lep + $E_{T,miss}$
 \tilde{t} (light), $\tilde{t} \rightarrow b\tilde{\chi}_1^{\pm}$: 1/2 lep + b-jet + $E_{T,miss}$
 \tilde{t} (heavy), $\tilde{t} \rightarrow t\tilde{\chi}_1^0$: 0 lep + b-jet + $E_{T,miss}$
 \tilde{t} (heavy), $\tilde{t} \rightarrow t\tilde{\chi}_1^0$: 1 lep + b-jet + $E_{T,miss}$
 \tilde{t} (heavy), $\tilde{t} \rightarrow t\tilde{\chi}_1^0$: 2 lep + b-jet + $E_{T,miss}$
 \tilde{t} (GMSB) : $Z(\rightarrow ll) + b$ -jet + $E_{T,miss}$

$L=4.7 \text{ fb}^{-1}, 7 \text{ TeV}$ [ATLAS-CONF-2012-106]	480 GeV	b mass ($m(\tilde{\chi}_1^0) < 150 \text{ GeV}$)
$L=4.7 \text{ fb}^{-1}, 7 \text{ TeV}$ [ATLAS-CONF-2012-108]	380 GeV	\tilde{g} mass ($m(\tilde{\chi}_1^{\pm}) = 2m(\tilde{\chi}_1^0)$)
$L=4.7 \text{ fb}^{-1}, 7 \text{ TeV}$ [CONF-2012-059]	135 GeV	\tilde{t} mass ($m(\tilde{\chi}_1^0) = 45 \text{ GeV}$)
$L=4.7 \text{ fb}^{-1}, 7 \text{ TeV}$ [CONF-2012-070]	120-173 GeV	\tilde{t} mass ($m(\tilde{\chi}_1^0) = 45 \text{ GeV}$)
$L=4.7 \text{ fb}^{-1}, 7 \text{ TeV}$ [1208.1447]	380-465 GeV	\tilde{t} mass ($m(\tilde{\chi}_1^0) = 0$)
$L=4.7 \text{ fb}^{-1}, 7 \text{ TeV}$ [CONF-2012-073]	230-440 GeV	\tilde{t} mass ($m(\tilde{\chi}_1^0) = 0$)
$L=4.7 \text{ fb}^{-1}, 7 \text{ TeV}$ [CONF-2012-071]	298-305 GeV	\tilde{t} mass ($m(\tilde{\chi}_1^0) = 0$)
$L=2.1 \text{ fb}^{-1}, 7 \text{ TeV}$ [1204.6736]	310 GeV	\tilde{t} mass ($115 < m(\tilde{\chi}_1^0) < 230 \text{ GeV}$)

Very similar limits come from CMS

EW direct

$l_1 l_2, l \rightarrow l\tilde{\chi}_1^0$: 2 lep + $E_{T,miss}$
 $\tilde{\chi}_1^+ \tilde{\chi}_1^- \rightarrow l\nu(l\bar{\nu}) \rightarrow l\nu\tilde{\chi}_1^0$: 2 lep + $E_{T,miss}$
 $\tilde{\chi}_1^+ \tilde{\chi}_1^- \rightarrow 3l(l\nu\nu) + \nu + 2\tilde{\chi}_1^0$: 3 lep + $E_{T,miss}$
 AMSB (direct $\tilde{\chi}_1^{\pm}$ pair prod.) : long-lived $\tilde{\chi}_1^{\pm}$
 AMSB : long-lived $\tilde{\chi}_1^{\pm}$

$L=4.7 \text{ fb}^{-1}, 7 \text{ TeV}$ [CONF-2012-076]	93-180 GeV	\tilde{l} mass ($m(\tilde{\chi}_1^0) = 0$)
$L=4.7 \text{ fb}^{-1}, 7 \text{ TeV}$ [CONF-2012-076]	120-330 GeV	$\tilde{\chi}_1^{\pm}$ mass ($m(\tilde{\chi}_1^0) = 0, m(\tilde{l}, \tilde{\nu}) = \frac{1}{2}(m(\tilde{\chi}_1^{\pm}) + m(\tilde{\chi}_1^0))$)
$L=4.7 \text{ fb}^{-1}, 7 \text{ TeV}$ [CONF-2012-077]	60-500 GeV	$\tilde{\chi}_1^{\pm}$ mass ($m(\tilde{\chi}_1^0) = m(\tilde{\chi}_2^0), m(\tilde{\chi}_1^0) = 0, m(\tilde{l}, \tilde{\nu})$ as above)
$L=4.7 \text{ fb}^{-1}, 7 \text{ TeV}$ [ATLAS-CONF-2012-111]	210 GeV	$\tilde{\chi}_1^{\pm}$ mass ($1 < \tau(\tilde{\chi}_1^{\pm}) < 10 \text{ ns}$)
$L=4.7 \text{ fb}^{-1}, 7 \text{ TeV}$ [CF-2012-034]	118 GeV	$\tilde{\chi}_1^{\pm}$ mass ($1 < \tau(\tilde{\chi}_1^{\pm}) < 2 \text{ ns}$, 90 GeV limit in [0.2, 90] ns)

Long-lived particles

Stable \tilde{g} R-hadrons : Full detector
 Stable \tilde{t} R-hadrons : Full detector
 Metastable \tilde{g} R-hadrons : Pixel det. only
 GMSB : stable $\tilde{\tau}$

$L=4.7 \text{ fb}^{-1}, 7 \text{ TeV}$ [ATLAS-CONF-2012-075]	985 GeV	\tilde{g} mass
$L=4.7 \text{ fb}^{-1}, 7 \text{ TeV}$ [ATLAS-CONF-2012-075]	683 GeV	\tilde{t} mass
$L=4.7 \text{ fb}^{-1}, 7 \text{ TeV}$ [ATLAS-CONF-2012-075]	910 GeV	\tilde{g} mass ($\tau(\tilde{g}) > 10 \text{ ns}$)
$L=4.7 \text{ fb}^{-1}, 7 \text{ TeV}$ [ATLAS-CONF-2012-075]	310 GeV	$\tilde{\tau}$ mass ($5 < \tan\beta < 20$)

RPV

RPV : high-mass $e\mu$
 Bilinear RPV : 1 lep + j's + $E_{T,miss}$
 BC1 RPV : 4 lep + $E_{T,miss}$

$L=1.1 \text{ fb}^{-1}, 7 \text{ TeV}$ [1109.3089]	1.32 TeV	$\tilde{\nu}_{\tau}$ mass ($\lambda_{311}=0.10, \lambda_{312}=0.05$)
$L=1.0 \text{ fb}^{-1}, 7 \text{ TeV}$ [1109.6606]	760 GeV	$\tilde{q} = \tilde{g}$ mass ($ct_{\tau, \text{LSP}} < 15 \text{ mm}$)
$L=2.1 \text{ fb}^{-1}, 7 \text{ TeV}$ [ATLAS-CONF-2012-035]	1.77 TeV	\tilde{g} mass
$L=4.4 \text{ fb}^{-1}, 7 \text{ TeV}$ [ATLAS-CONF-2012-113]	700 GeV	\tilde{q} mass ($3.0 \times 10^{-5} < \lambda_{211} < 1.5 \times 10^{-5}, 1 \text{ mm} < ct < 1 \text{ m}, \tilde{g}$ decoupled)

Other

RPV $\tilde{\chi}_1^0 \rightarrow qq\mu$: μ + heavy displaced vertex
 Hypercolour scalar gluons : 4 jets, $m_{\tilde{g}} = m_{\tilde{\chi}_1^0}$
 Spin dep. WIMP interaction : monojet + $E_{T,miss}$
 Spin indep. WIMP interaction : monojet + $E_{T,miss}$

$L=4.6 \text{ fb}^{-1}, 7 \text{ TeV}$ [ATLAS-CONF-2012-110]	100-287 GeV	sgluon mass (incl. limit from 1110.2693)
$L=4.7 \text{ fb}^{-1}, 7 \text{ TeV}$ [ATLAS-CONF-2012-084]	709 GeV	M^* scale ($m_{\chi} < 100 \text{ GeV}$, vector D5, Dirac χ)
$L=4.7 \text{ fb}^{-1}, 7 \text{ TeV}$ [ATLAS-CONF-2012-084]	548 GeV	M^* scale ($m_{\chi} < 100 \text{ GeV}$, tensor D9, Dirac χ)

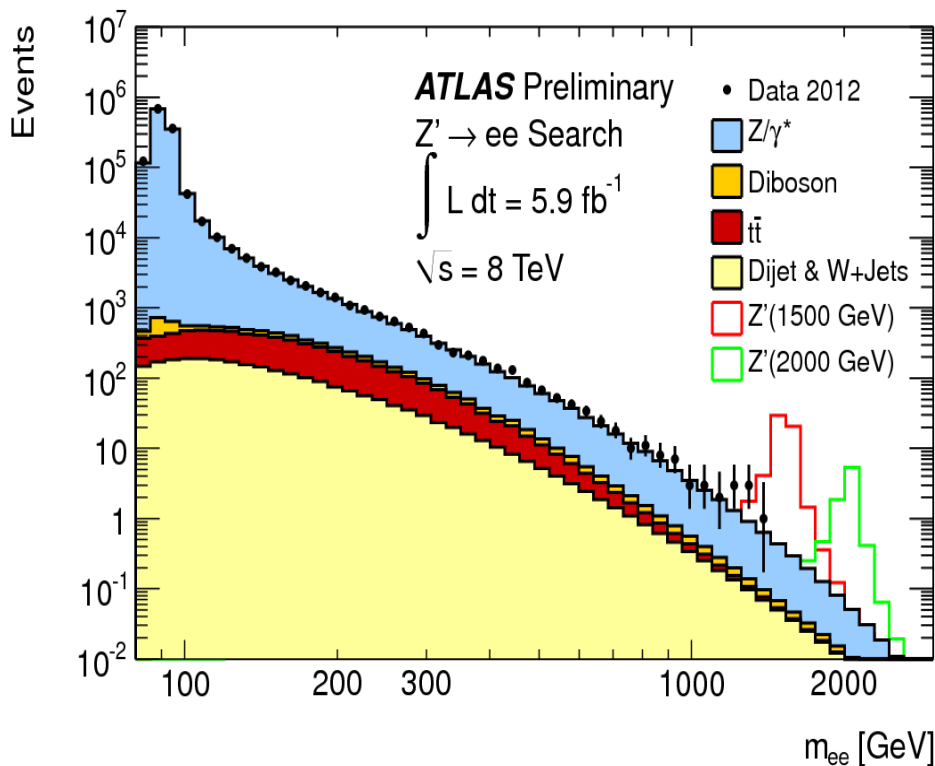


*Only a selection of the available mass limits on new states or phenomena shown.
 All limits quoted are observed minus 1σ theoretical signal cross section uncertainty.

Searches for heavy W and Z like particles

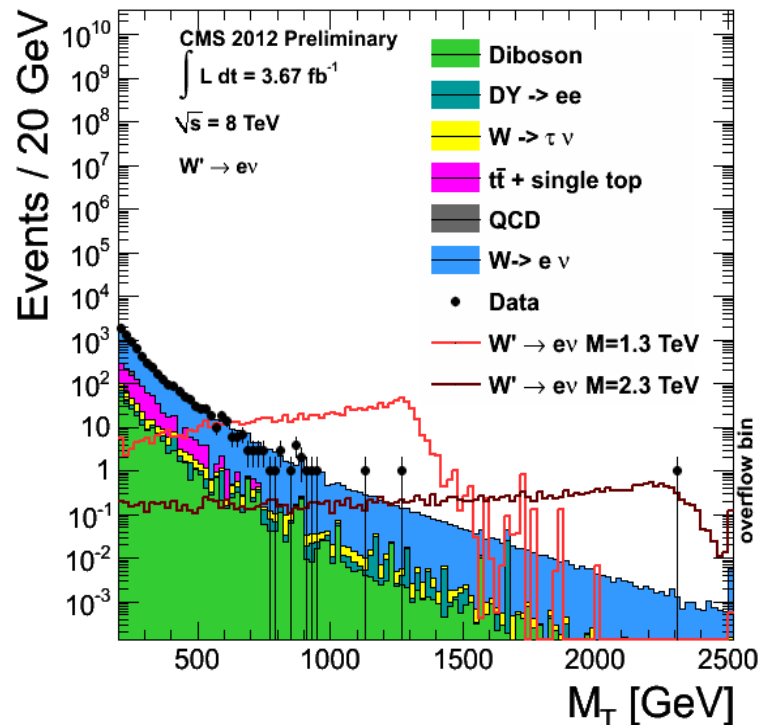
These searches are quite straight-forward, following basically the same analyses as for the familiar W and Z bosons

Z': Di-lepton pairs

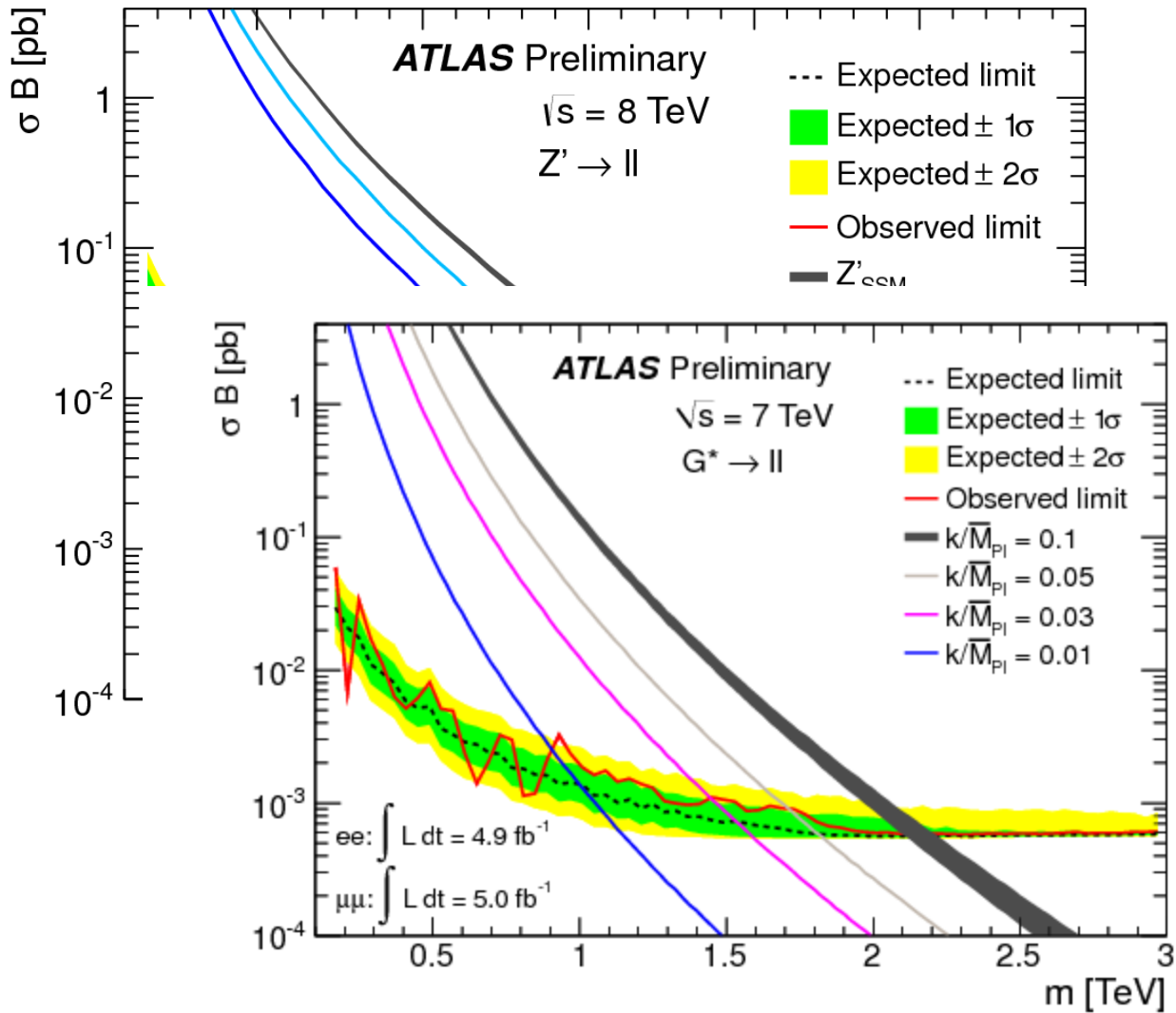


ATLAS-CONF-2012-129

W': Lepton + ETmiss



CMS-EXO-12-010



R Sundrum
L Randall
F Gianotti

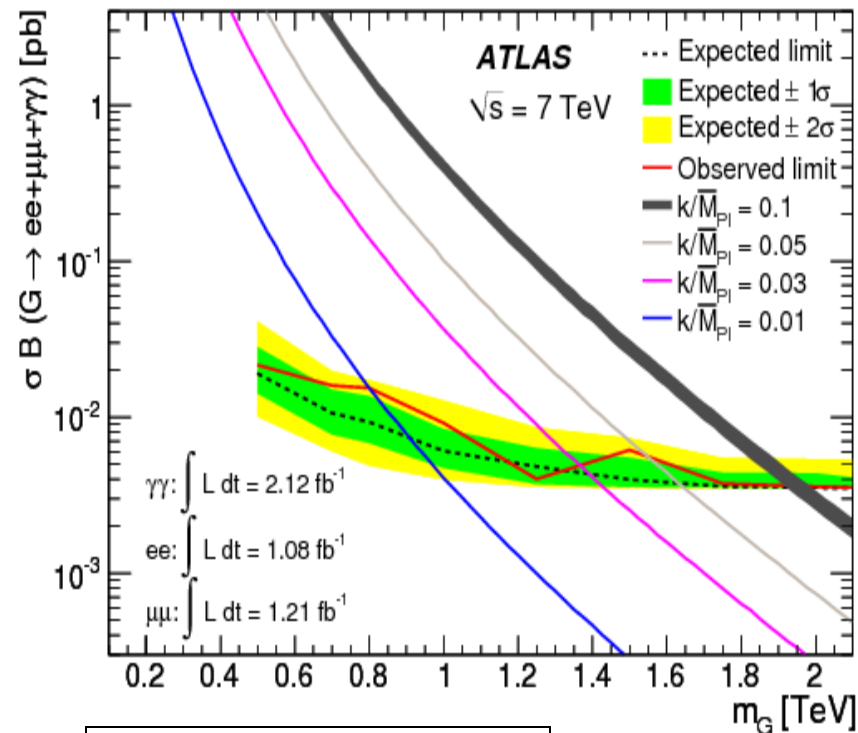
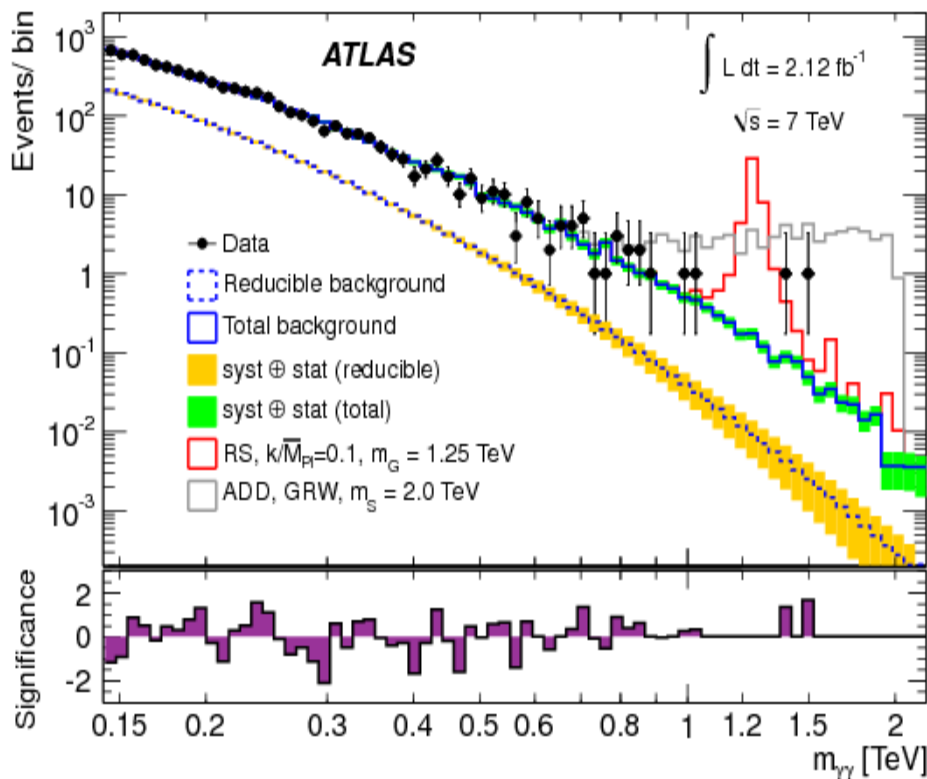
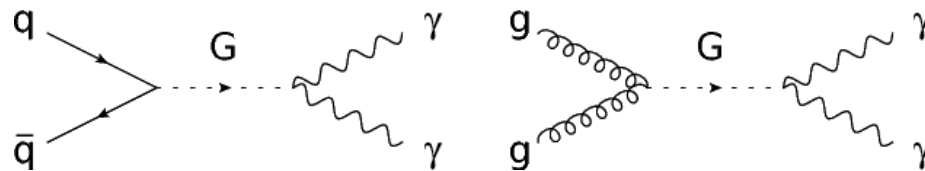
ATLAS-CONF-2012-129

ATLAS-CONF-2012-007

Randall-Sundrum Graviton

New particles decaying into two photons

Example for a search of extra dimension signals (Kaluza-Klein Graviton in the Randall-Sundrum and Arkani-Hamed, Dimopoulos and Dvali models)

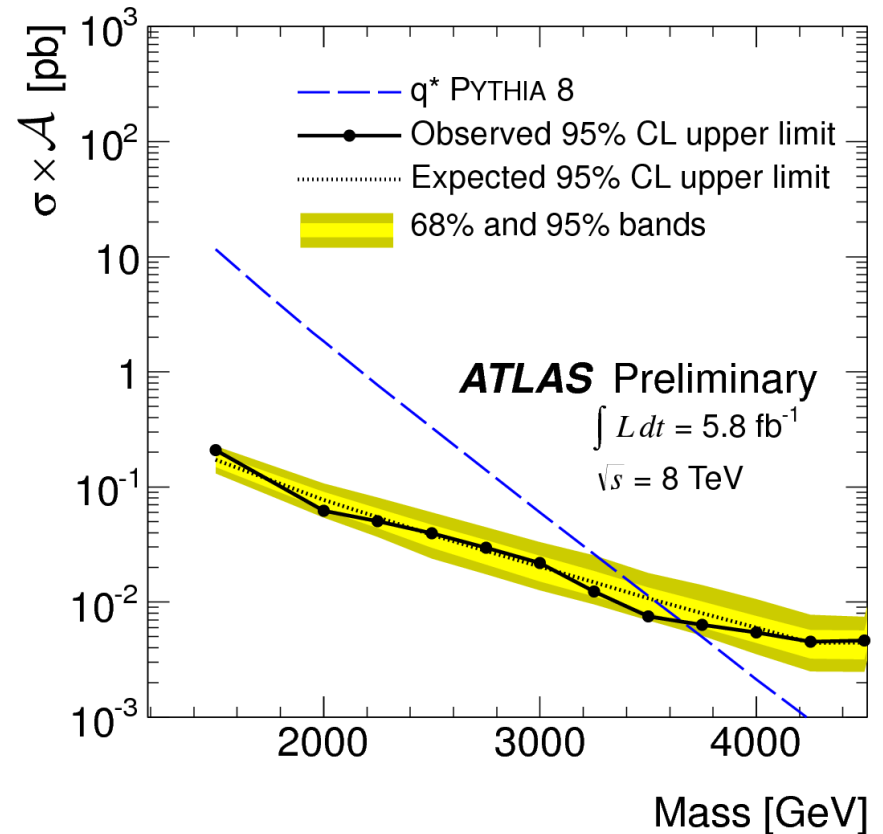
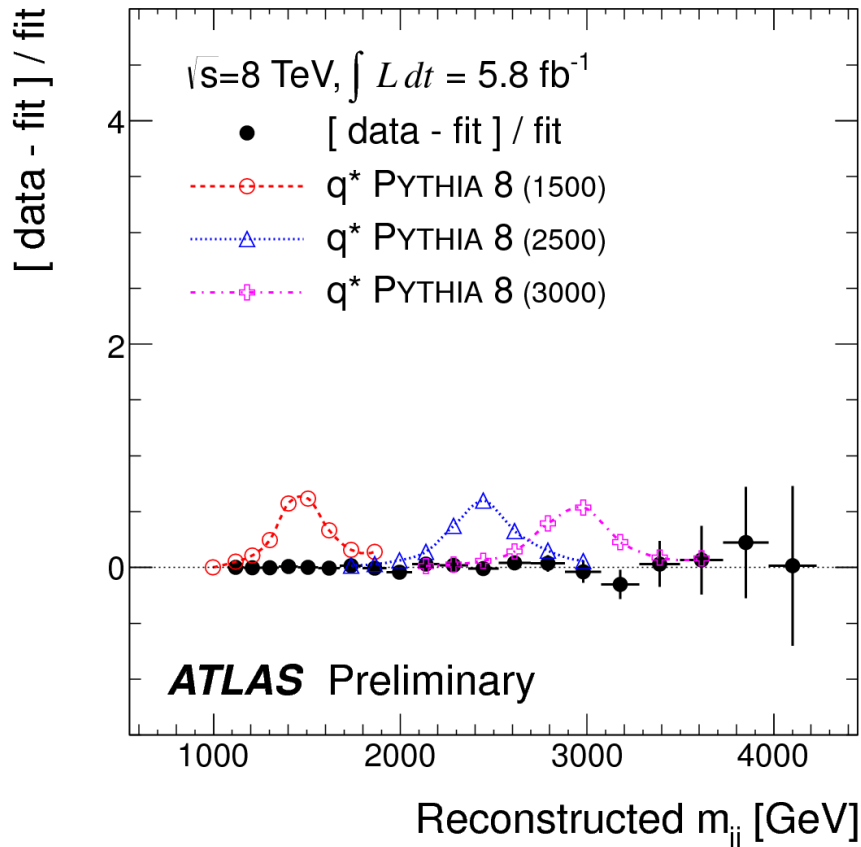


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Example of searches for New Physics as deviations from QCD behaviour of hadronic jet distributions

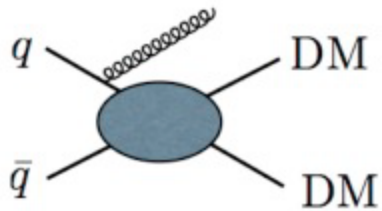
Search for resonances in the di-jet mass spectrum

ATLAS-CONF-2012-088

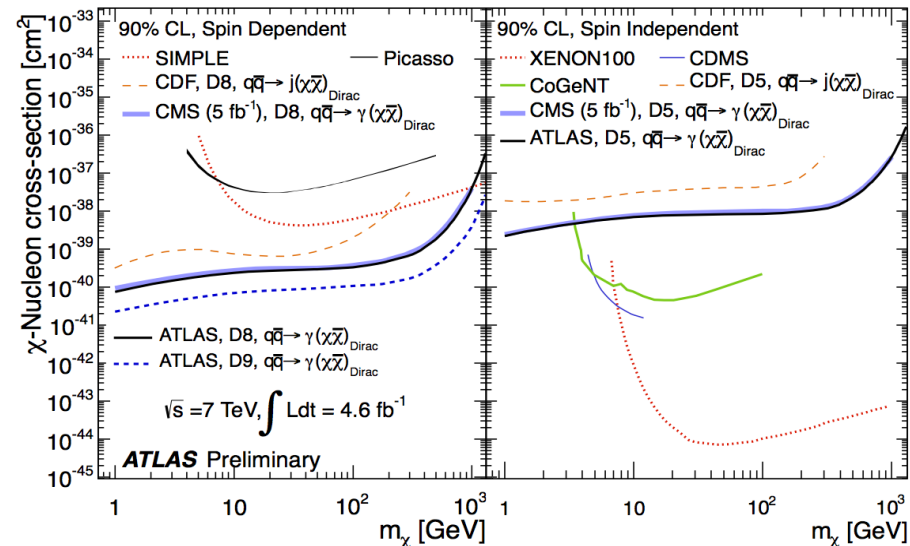
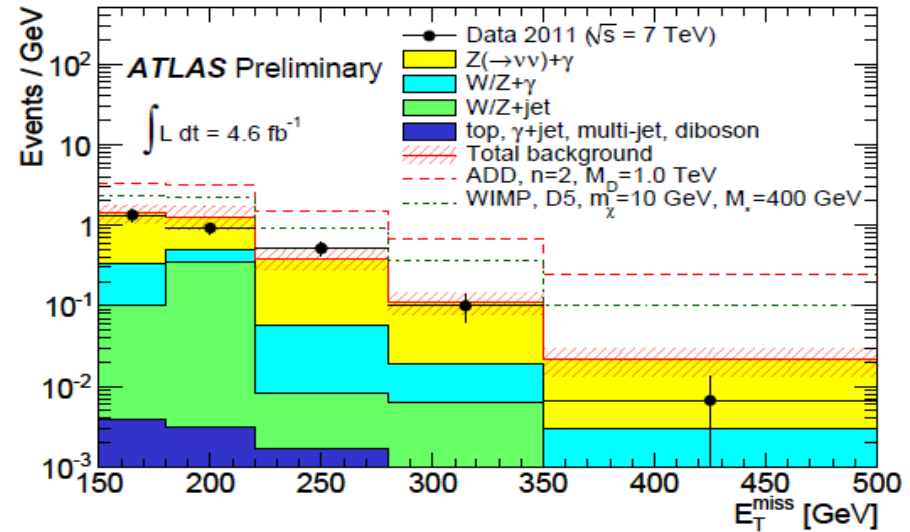
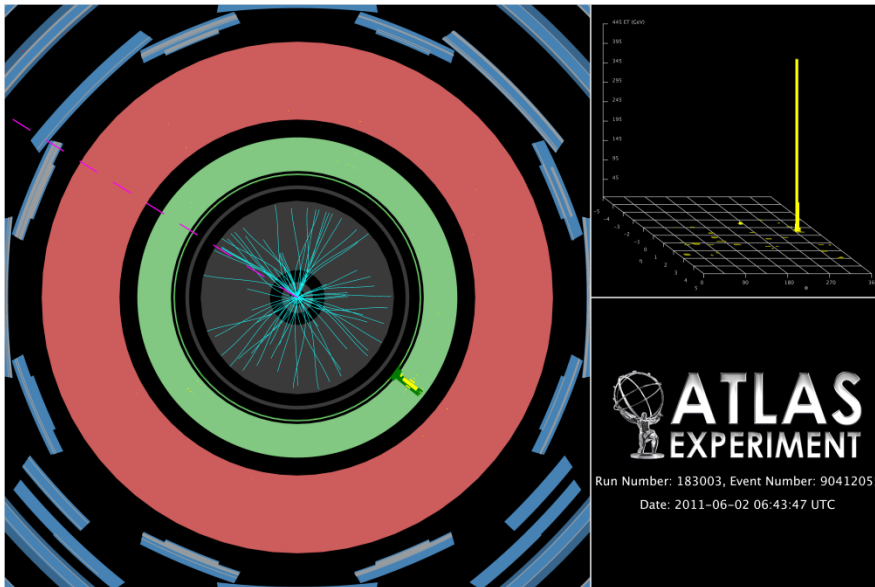


95% CL excluded mass: 3.66 TeV

Search for direct Dark Matter (DM) particles in pair-production



A single photon (150 GeV) or jet plus ETmiss



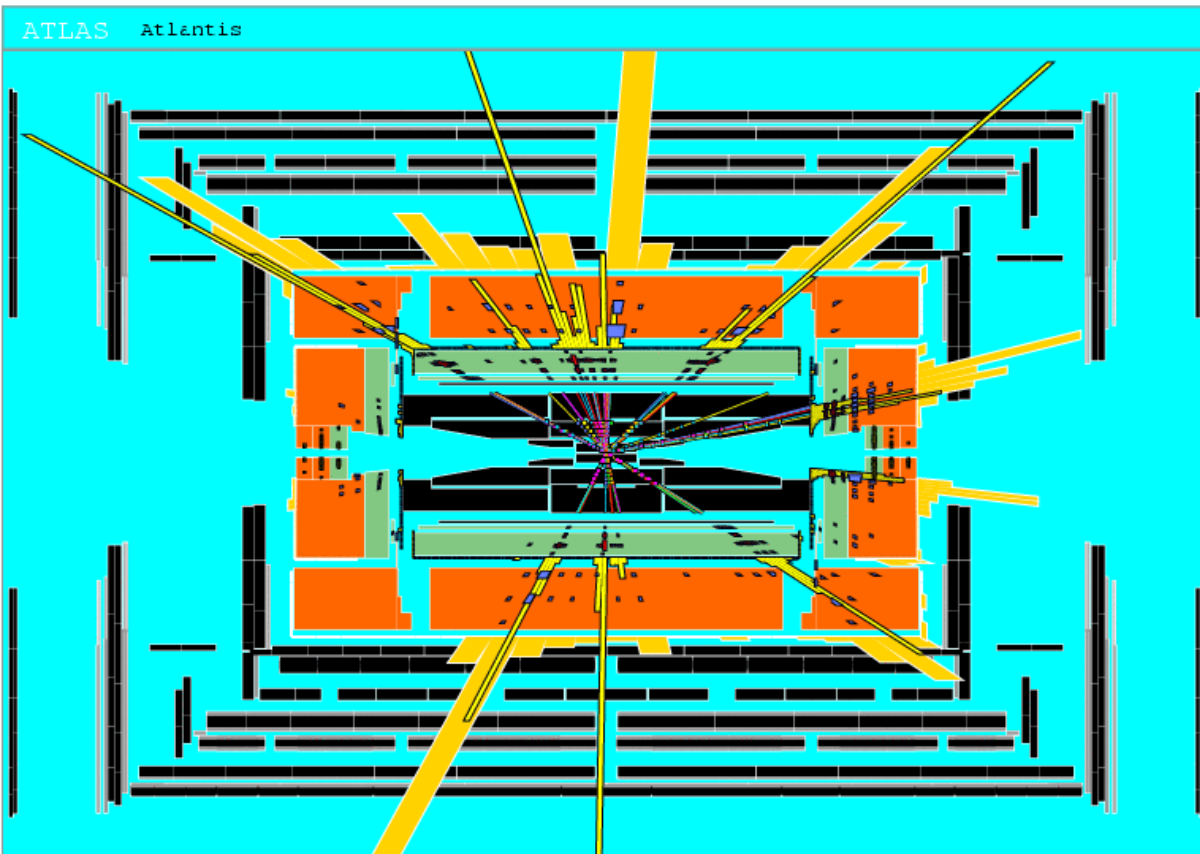
ATLAS-CONF-2012-085
arXiv:1210.4491v1[hep-ex]

CMS: Sub. to Phys. Rev. Lett.
arXiv:1204.0821v1[hep-ex]
arXiv:1206.5663[hep-ex]

Prague, 25-10-2012
P Jenni (CERN)

LHC Roadmap

If theories with Extra-dimensions are true, microscopic black holes could be abundantly produced and observed at the LHC

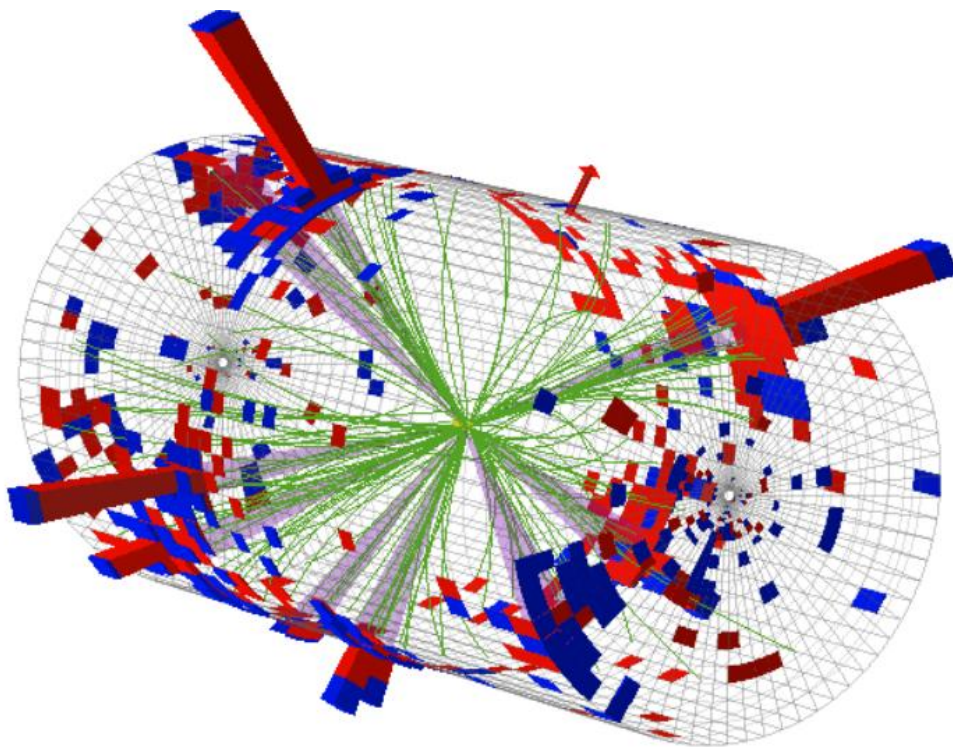


Simulation of a black hole event with $M_{\text{BH}} \sim 8 \text{ TeV}$ in ATLAS



They decay immediately through Stephen Hawking radiation

If theories with Extra-dimensions are true, microscopic black holes could be abundantly produced and observed at the LHC



CMS Experiment at LHC, CERN
Data recorded: Mon May 23 21:46:26 2011 EDT
Run/Event: 165567 / 347495624
Lumi section: 280
Orbit/Crossing: 73255853 / 3161

A real 'candidate' event of a 'black hole' in CMS with 9 jets and $ST = 2.6$ TeV



They decay immediately through Stephen Hawking radiation

Search for Microscopic Black Hole production in models with large extra dimensions

(Arkani-Hamed, Dimopoulos, Dvali)

Decay into many objects (jets, leptons, photons)

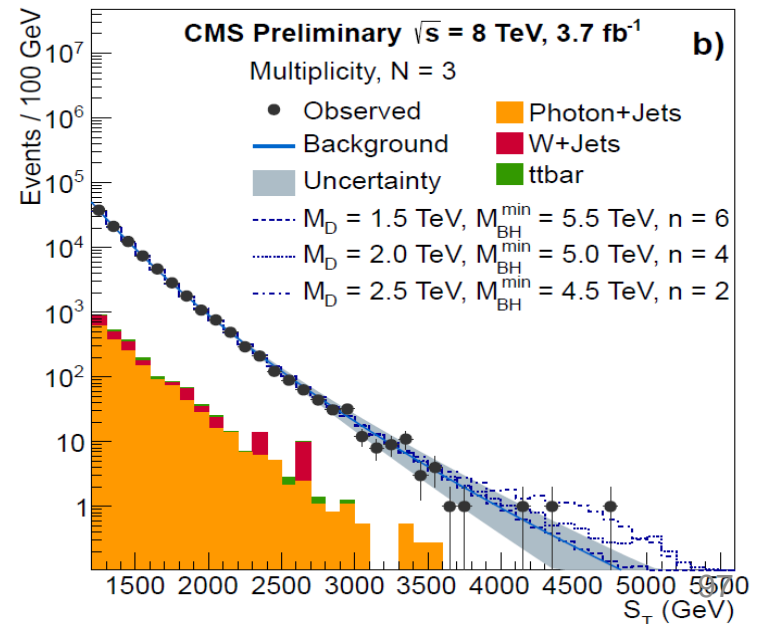
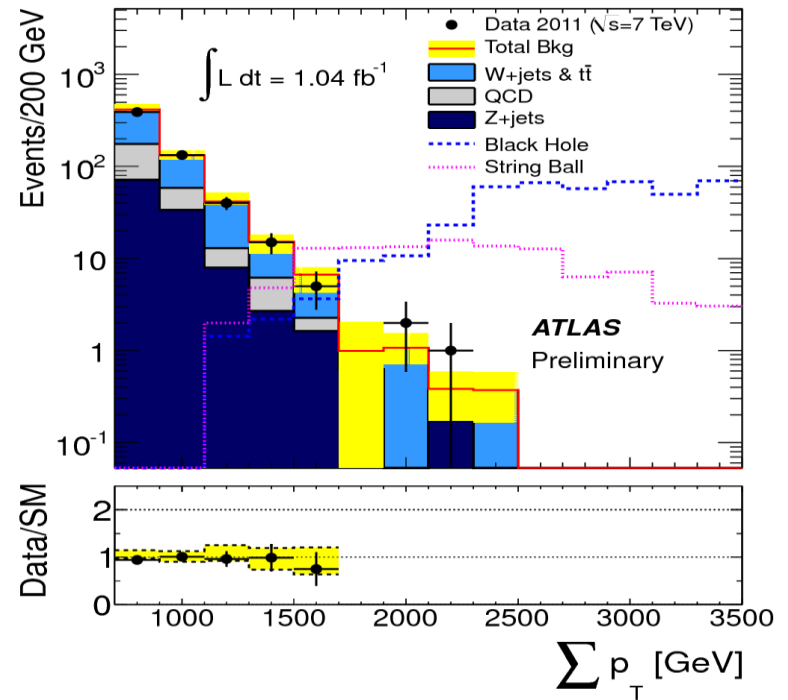
ATLAS-CONF-2011-147
arXiv:1204.4646v1[hep-ex]

Σp_T : scalar sum of the E_T of the N objects in the event

Examples: (ATLAS) at least one electron or muon and two or more jets, (CMS) any three objects

No deviation is seen for events with at least 3 objects with > 50 GeV p_T

CMS-EXO-12-009



ATLAS 95%CL limits

ATLAS Exotics Searches* - 95% CL Lower Limits (Status: LHCC, Sep 2012)

Extra dimensions

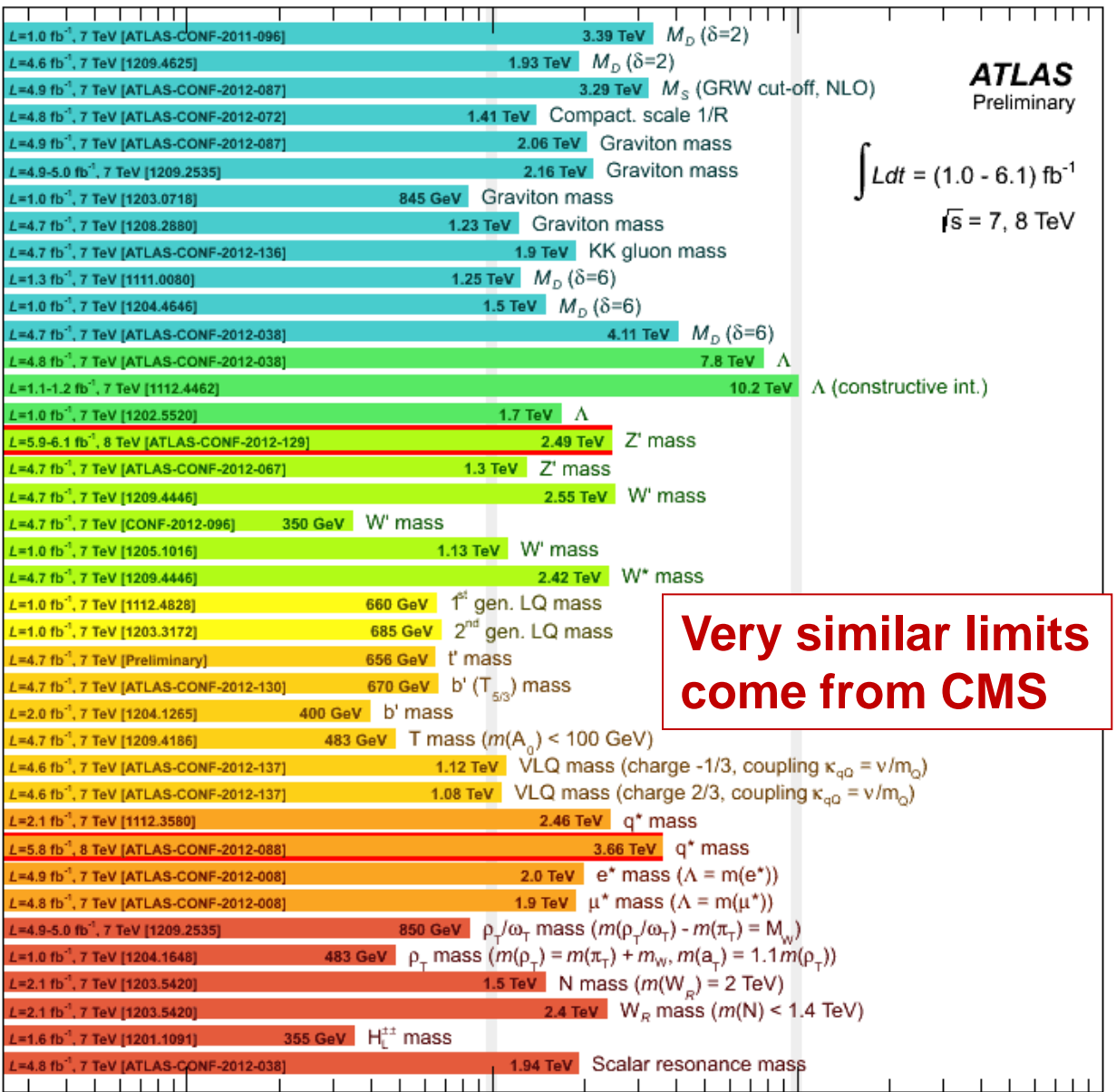
CI

V'

New quarks

Excited fermions

Other



Very similar limits come from CMS

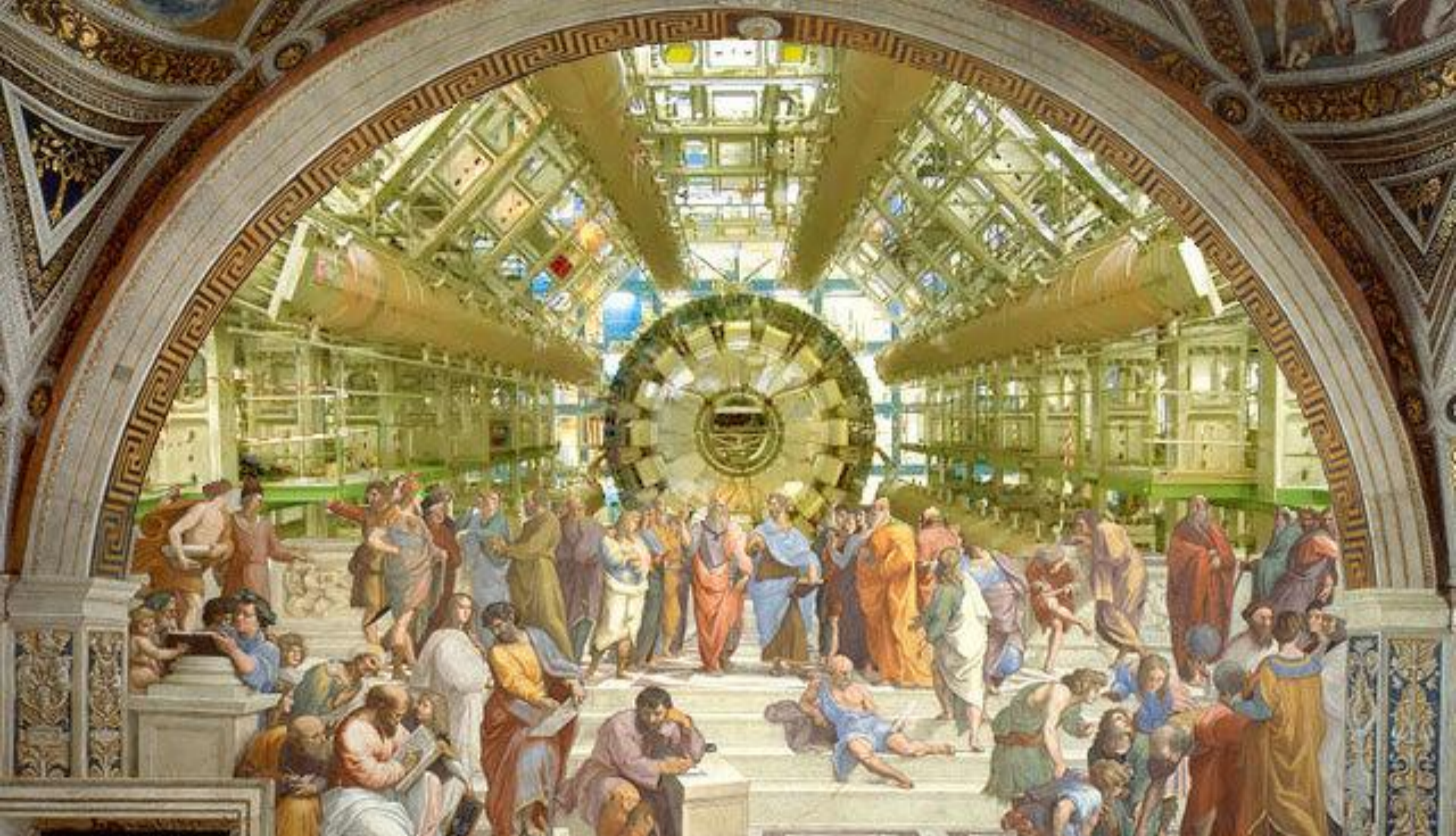
ATLAS Preliminary

$$\int L dt = (1.0 - 6.1) \text{ fb}^{-1}$$

$$\sqrt{s} = 7, 8 \text{ TeV}$$

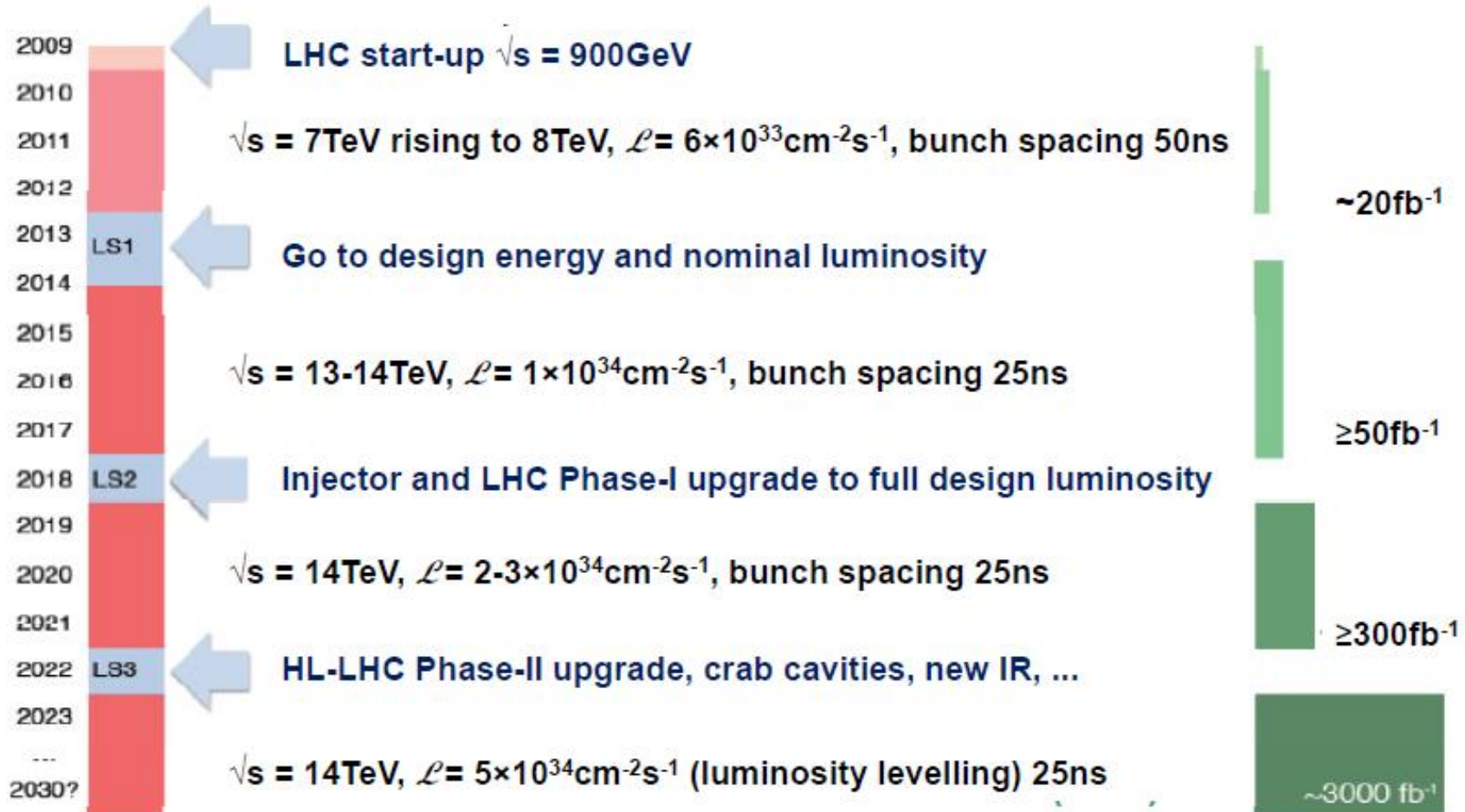
Mass scale [TeV]

*Only a selection of the available mass limits on new states or phenomena shown



***This was a very restricted selection, just examples,
of first physics highlights from ATLAS and CMS***

LHC Schedule Assumptions



20 years of working with the Czech colleagues and friends in ATLAS was a real pleasure, and we are looking forward to a bright common future with LHC and its upgrades of the machine and the experiment

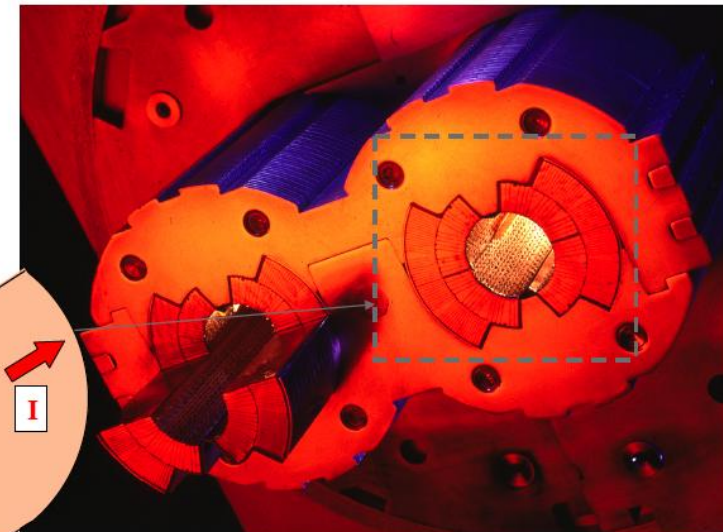
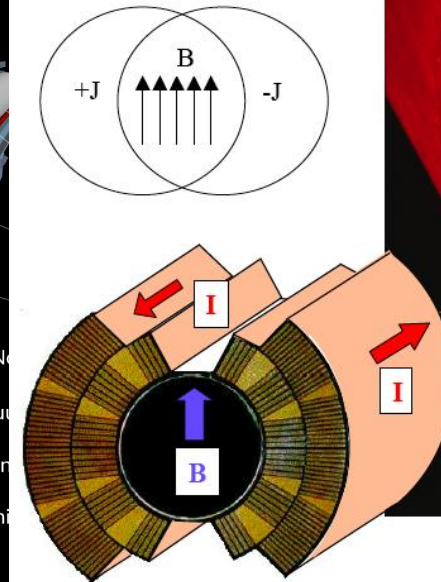
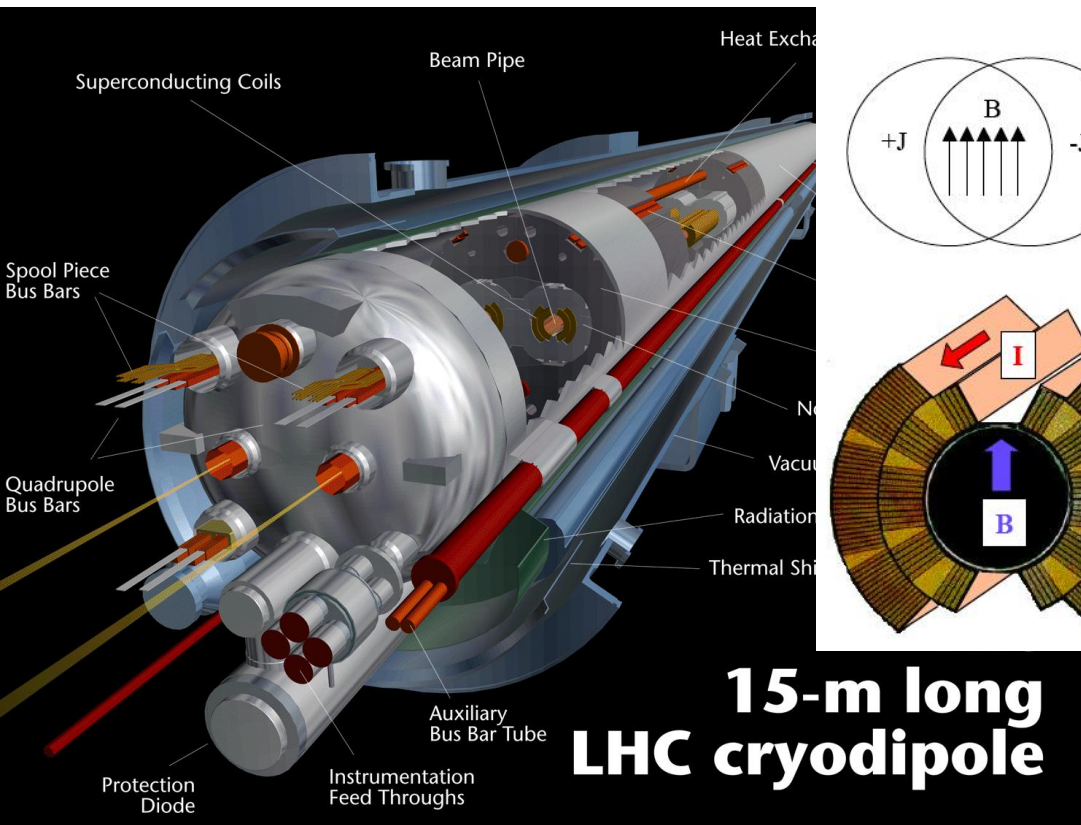


Exciting times for discoveries are ahead of us!

Thank You!

Spares

LHC Accelerator Challenge: Dipole Magnets



Magnetic Field for Dipoles
 $p \text{ (TeV)} = 0.3 \text{ B(T)} R(\text{km})$

For $p = 7 \text{ TeV}$ and $R = 4.3 \text{ km}$
 $\Rightarrow B = 8.4 \text{ T}$
 $\Rightarrow \text{Current } 12 \text{ kA}$

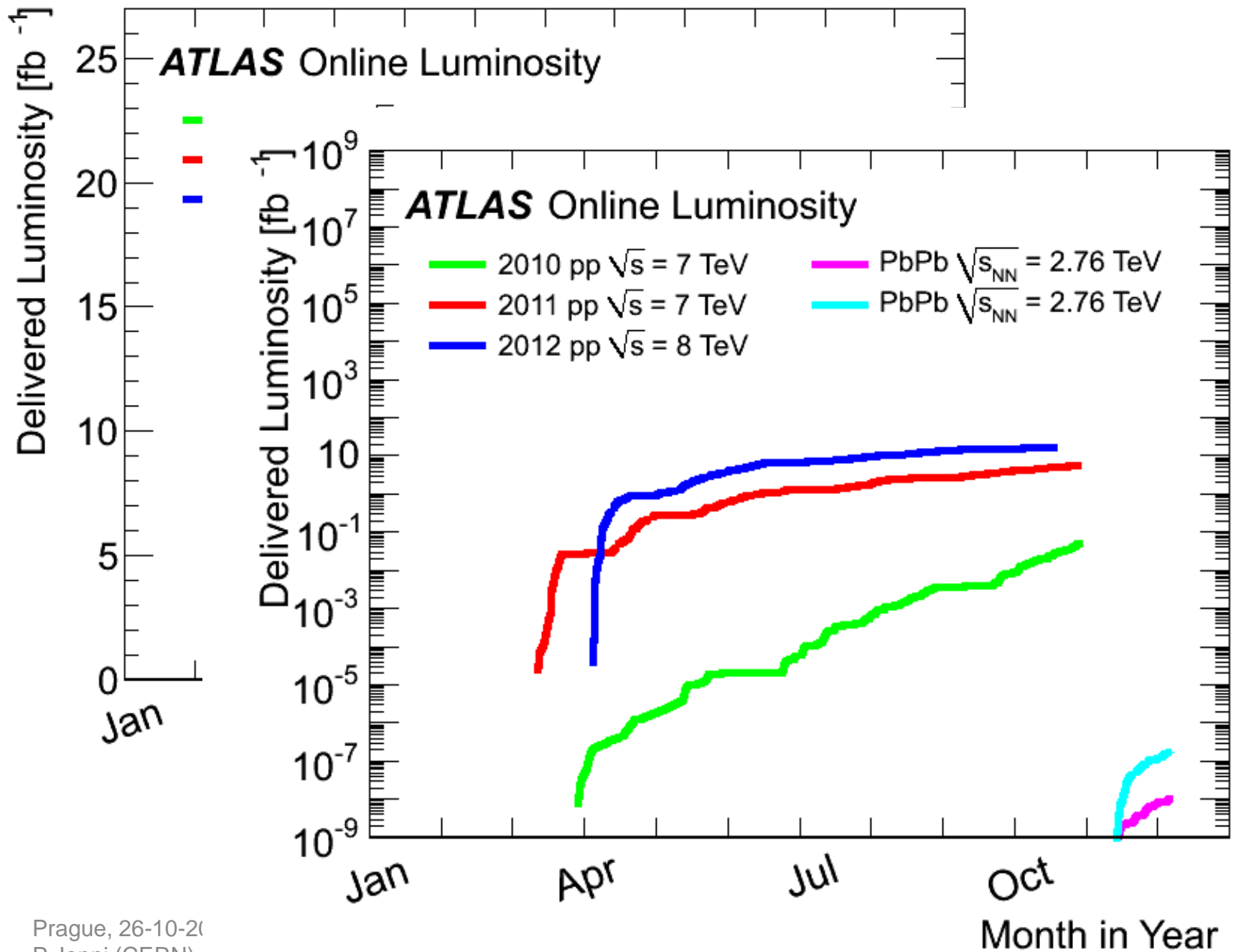
Coldest Ring in the Universe ?
 1.9 K (CMBR is about 2.7 K)

LHC magnets are cooled with pressurized superfluid helium

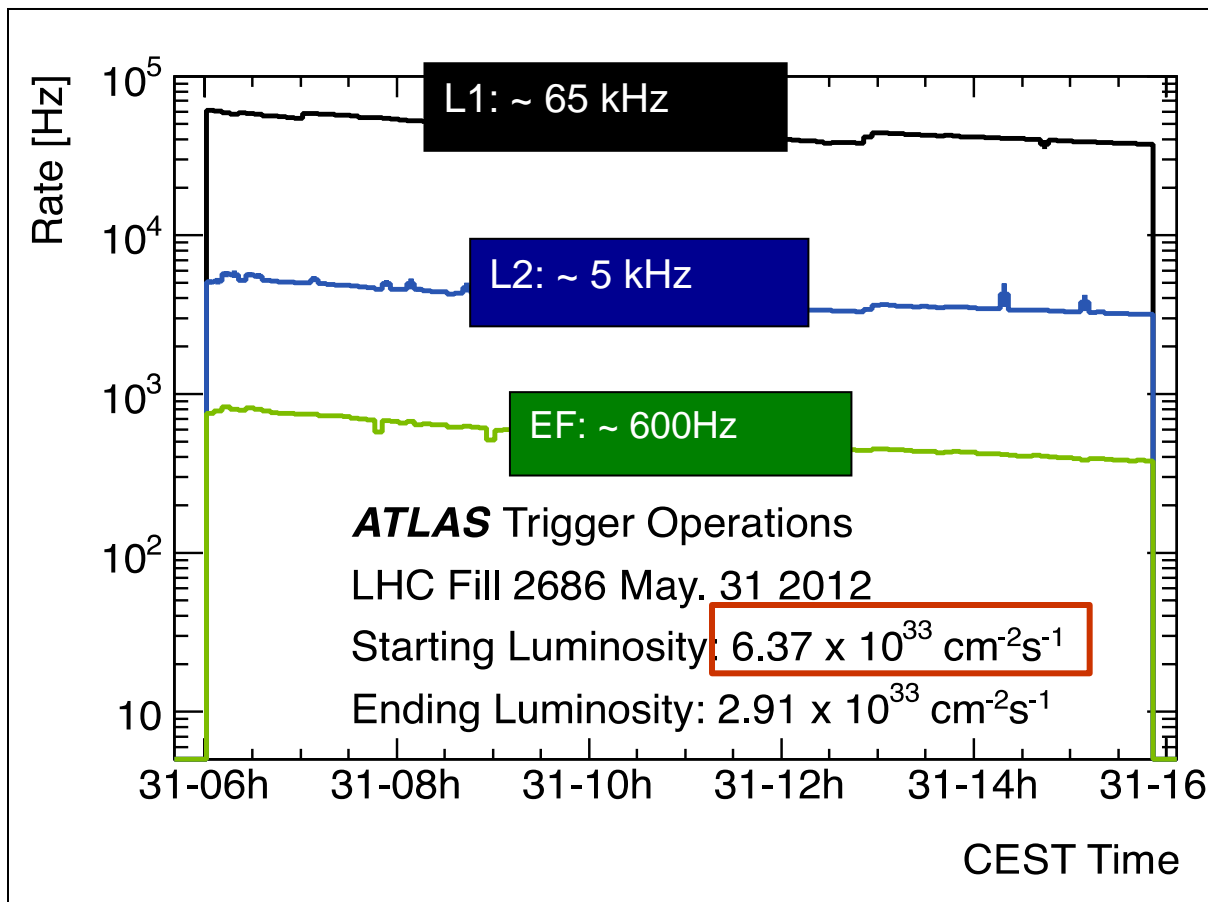


Interconnections of two magnets

One (superconductor) joint failed on 19th September 2008, and it caused a catastrophic He-release that made serious collateral damage to sector 3-4 of the LHC machine



Example for the typical trigger rates



Three levels of event selections:

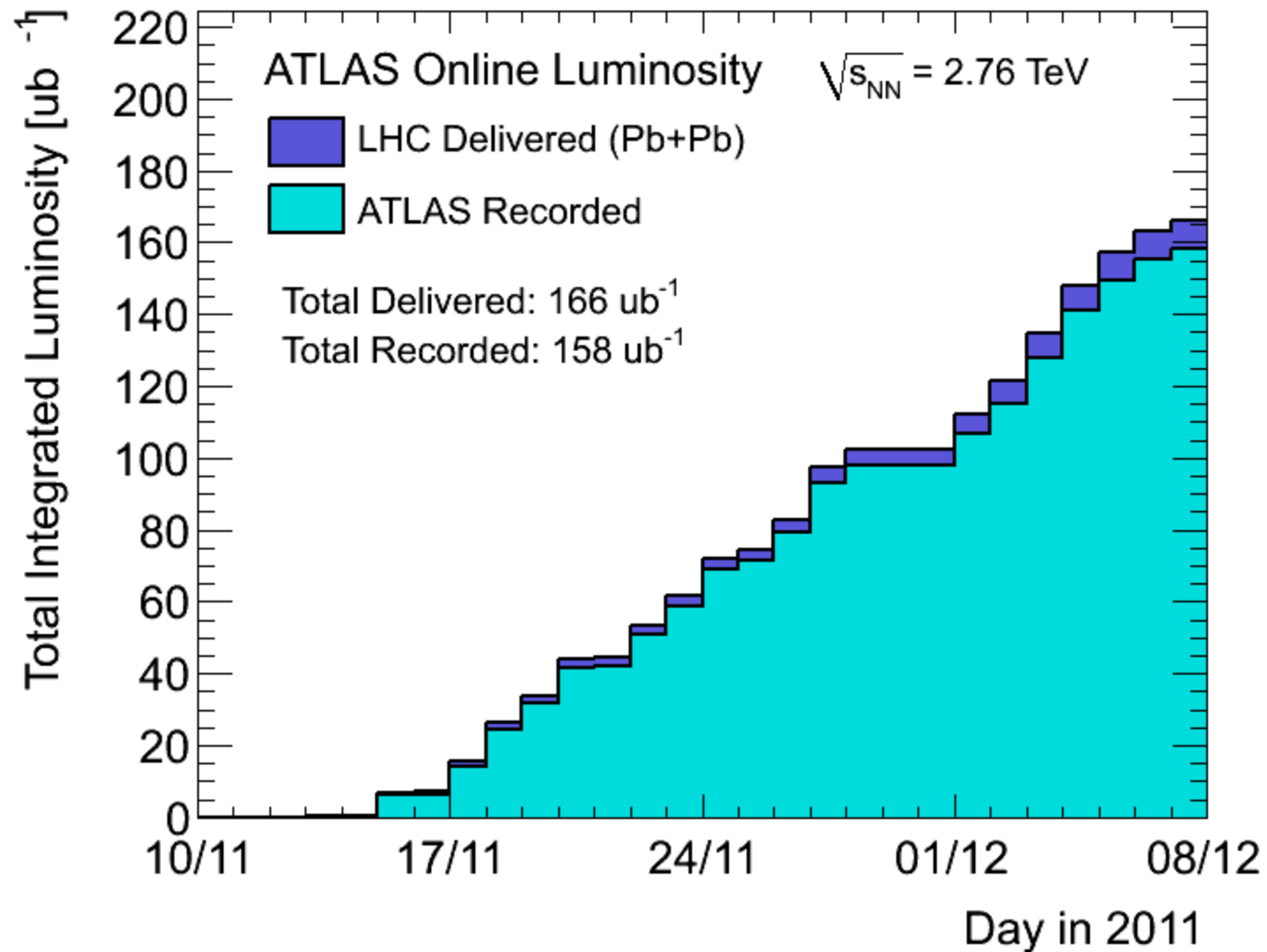
Level-1 underground with purpose-made electronics and processors

Level-2 and Event Filter in a large computer farm located at the surface of Point-1

(Noted in the plot are the output rates)

- ❑ Typical recorded rates for main streams e/γ , Jets/ τ/E_T^{miss} , Muons: ~ 100 Hz each
- ❑ Delayed stream (future Tier0 reconstruction): B-physics (~65 Hz) and Hadronic (~80 Hz)
- ❑ Note: currently 564 items in the trigger menu

Heavy Ion Running in 2011



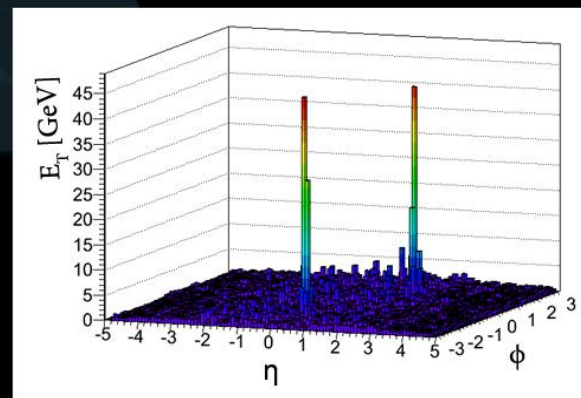
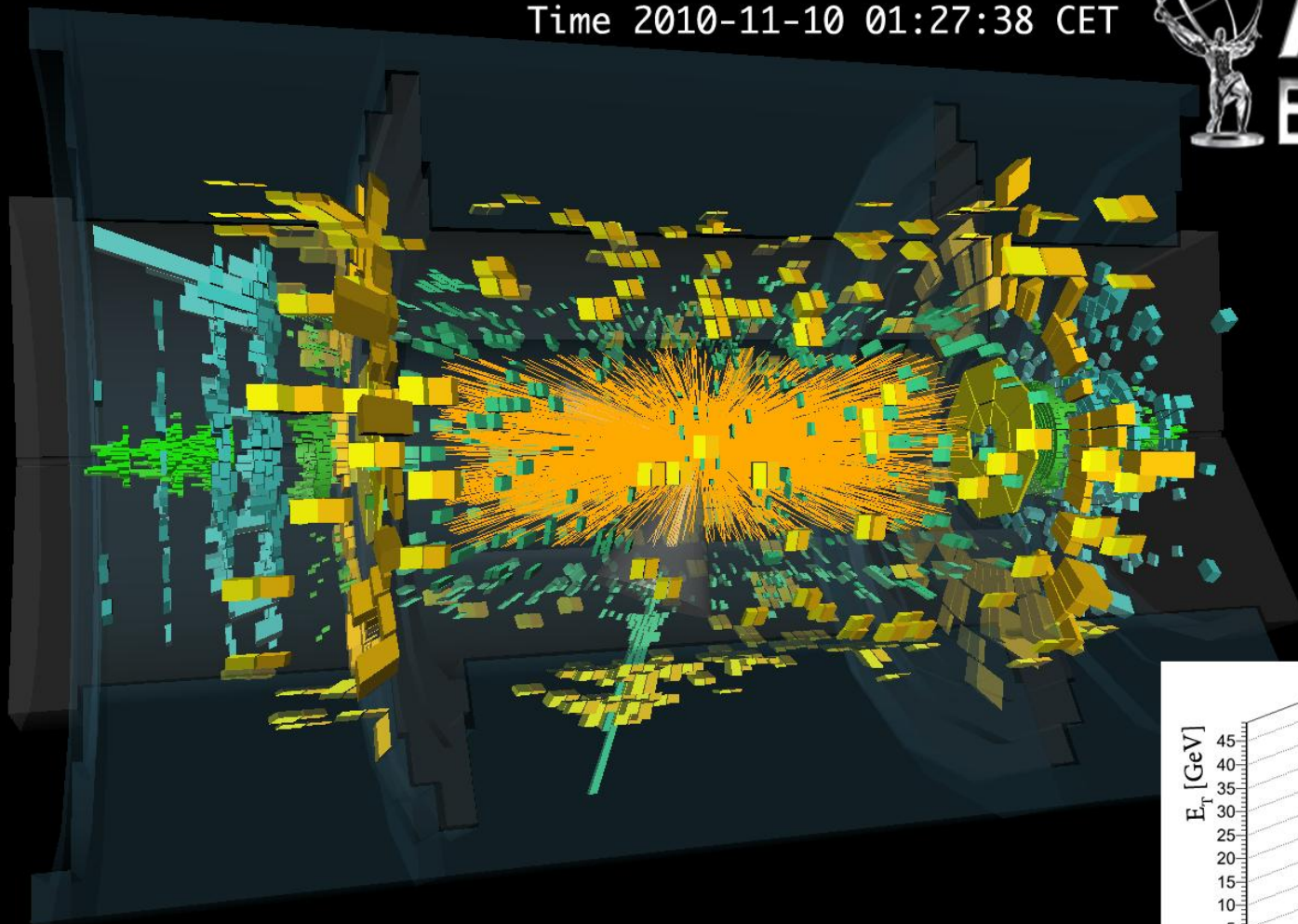
Pb-Pb event with jets

Uncorrected p_T of
each jet ~ 160 GeV

Run 168875, Event 1577540
Time 2010-11-10 01:27:38 CET



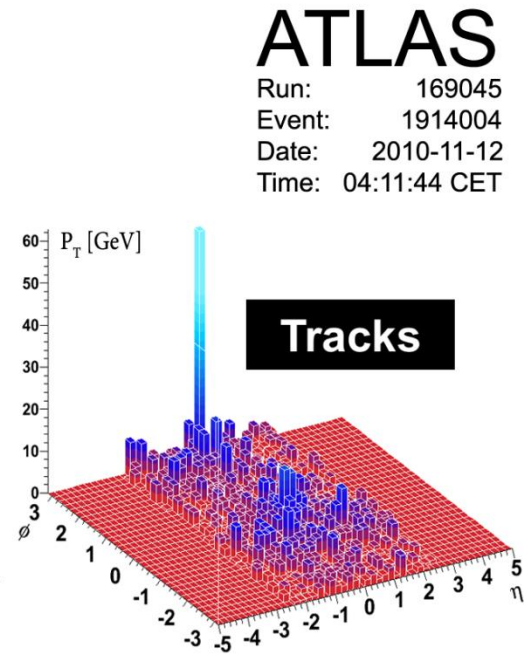
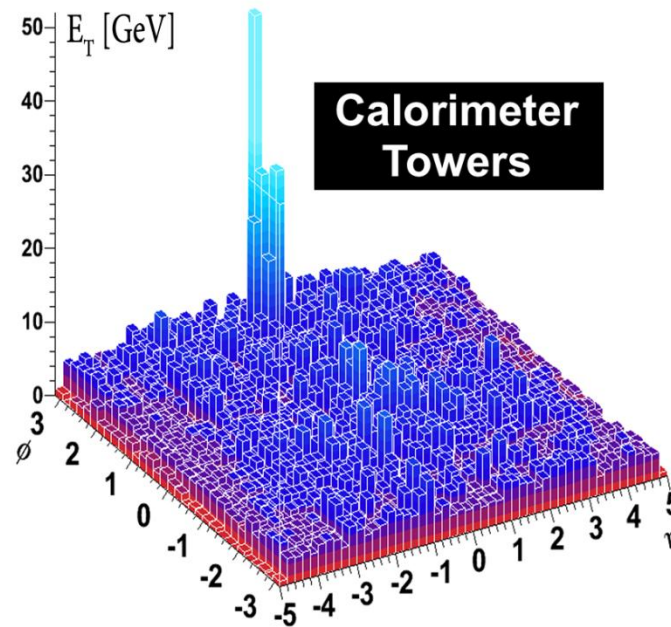
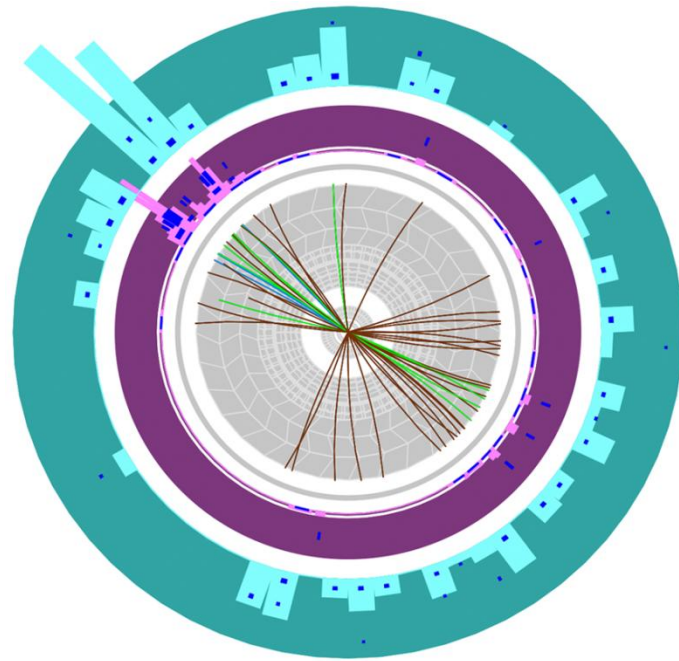
ATLAS EXPERIMENT



Heavy Ion Collision Event with 2 Jets

Observation of a Centrality-Dependent Dijet Asymmetry in Lead-Lead Collisions at $\sqrt{s_{NN}} = 2.76$ TeV with the ATLAS Detector at the LHC

G. Aad *et al.* (The ATLAS Collaboration)*



ATLAS

Run: 169045
Event: 1914004
Date: 2010-11-12
Time: 04:11:44 CET

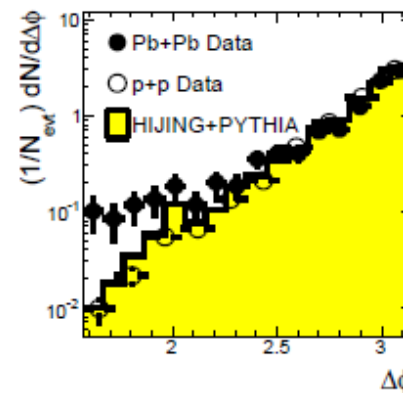
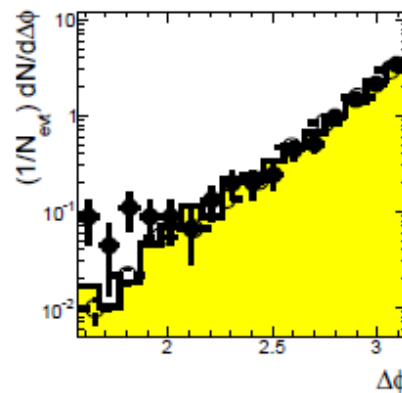
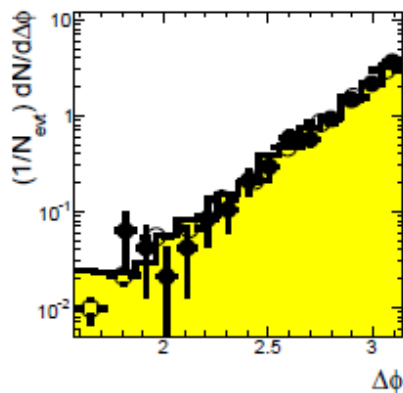
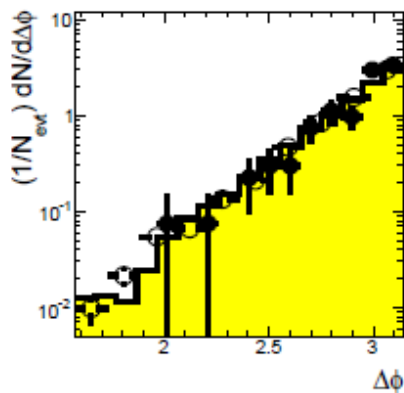
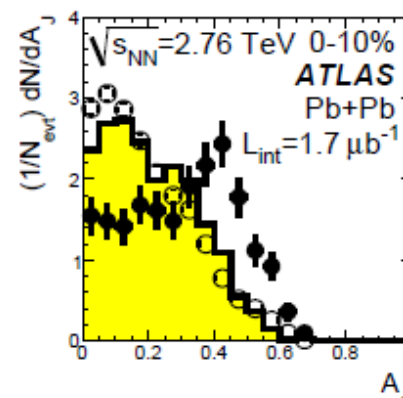
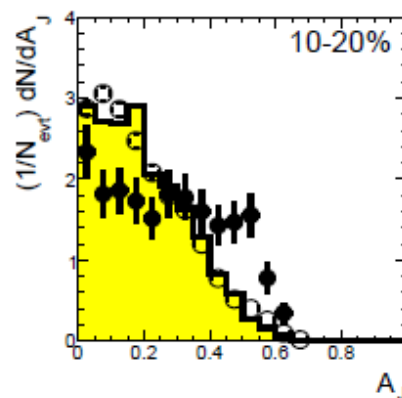
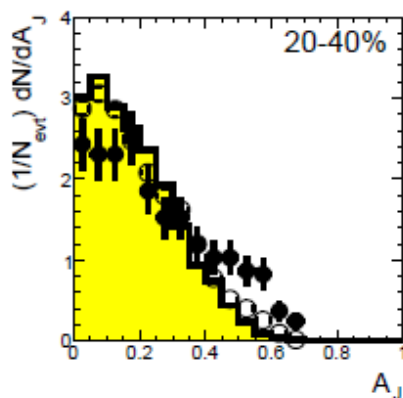
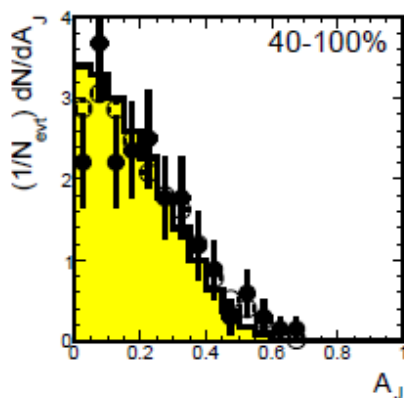
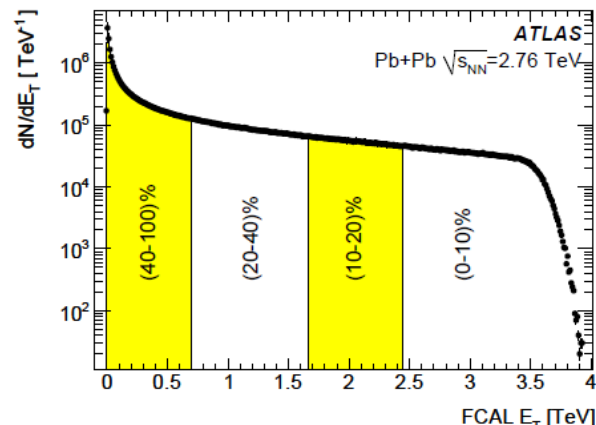
Phys. Rev. Lett. 105 (2010) 252303

Measured di-jet asymmetry A_J as a function of the centrality

($1.7 \mu\text{b}^{-1}$)

$$A_J = \frac{E_{T1} - E_{T2}}{E_{T1} + E_{T2}}, \Delta\phi > \frac{\pi}{2}$$

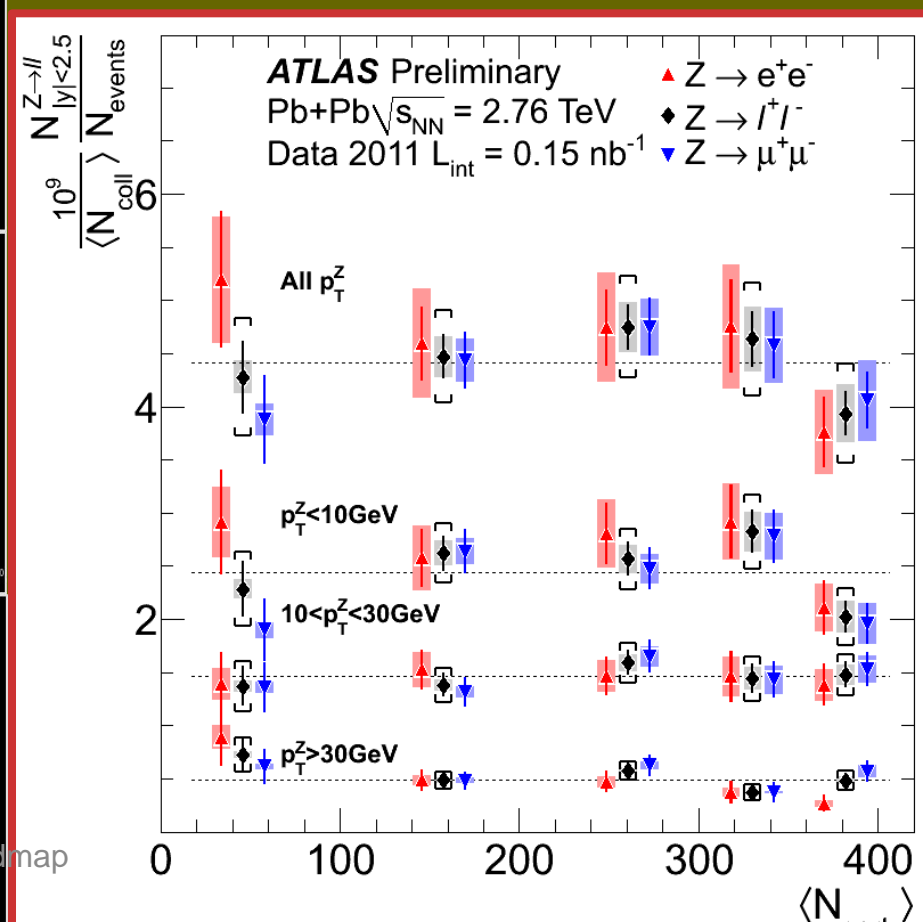
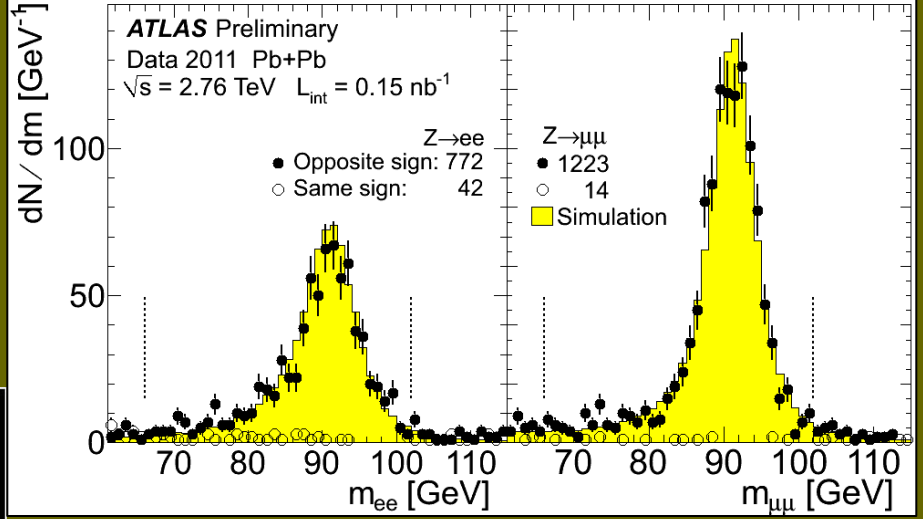
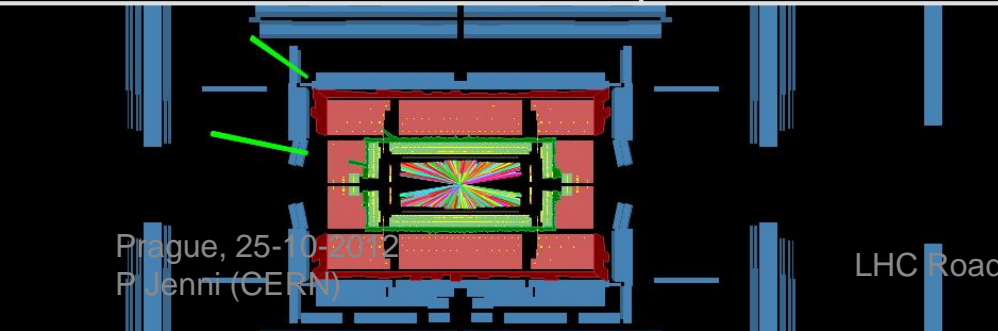
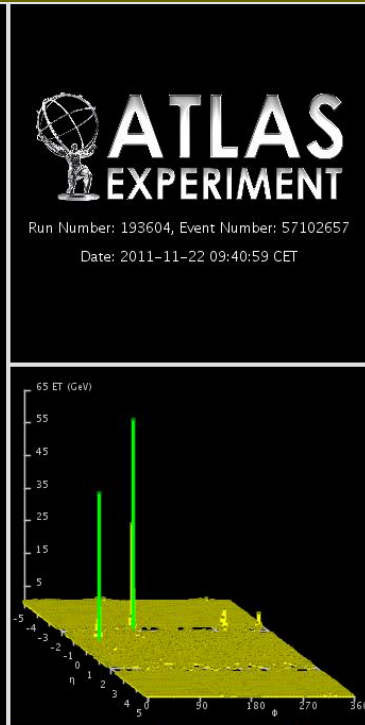
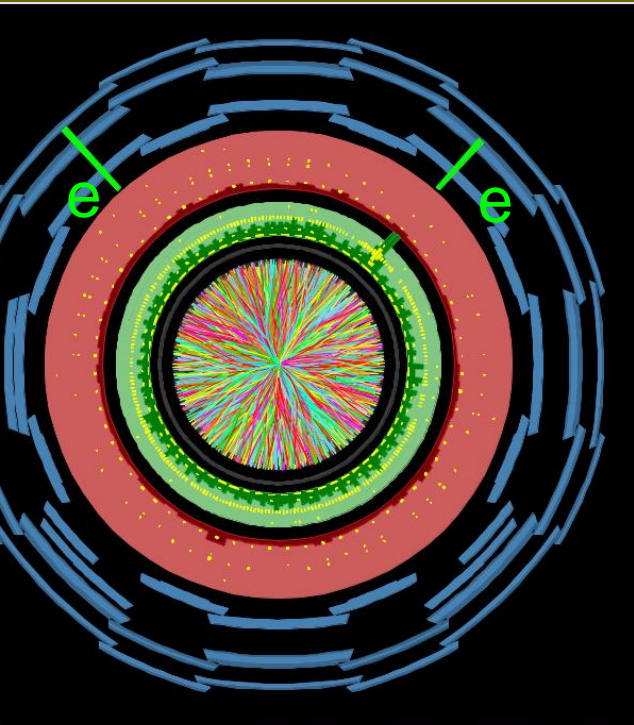
Centrality bins defined with the ET in FCAL



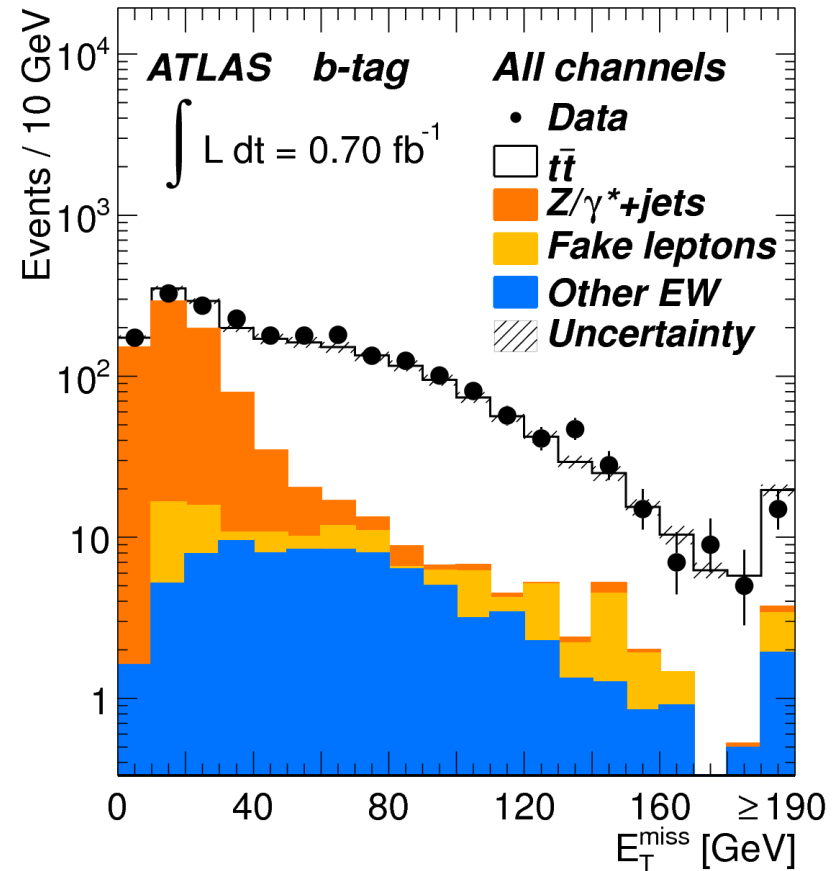
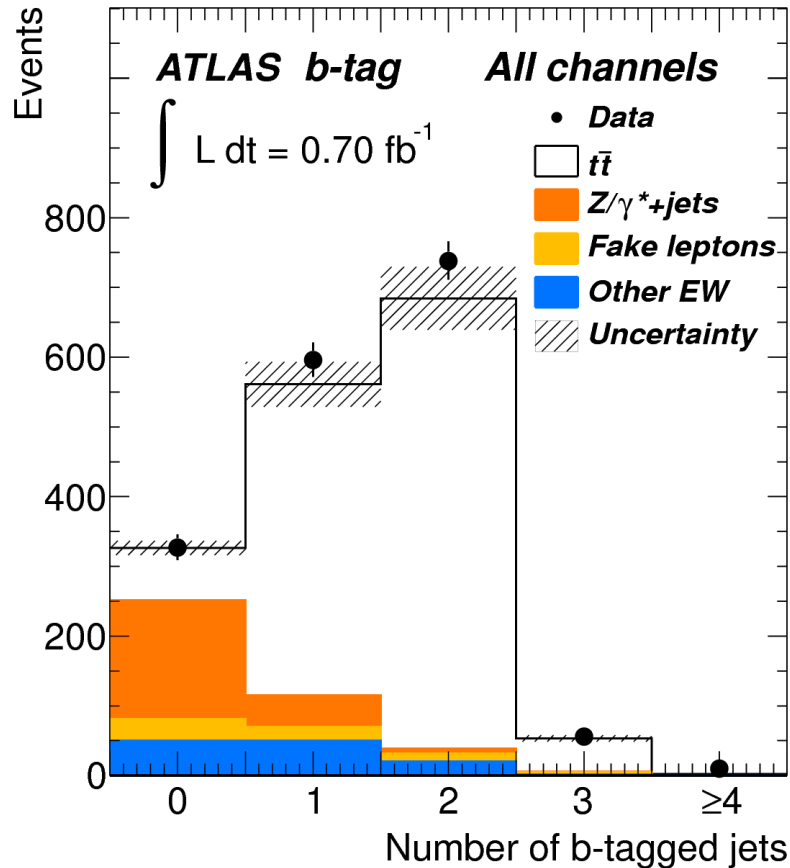
Such an effect could be the first direct indication of 'jet-quenching'

Z → ee, μμ in Heavy Ions

- Studied with full 2011 dataset (~ 150 μb⁻¹)
- As expected: no suppression observed of the weakly interacting bosons

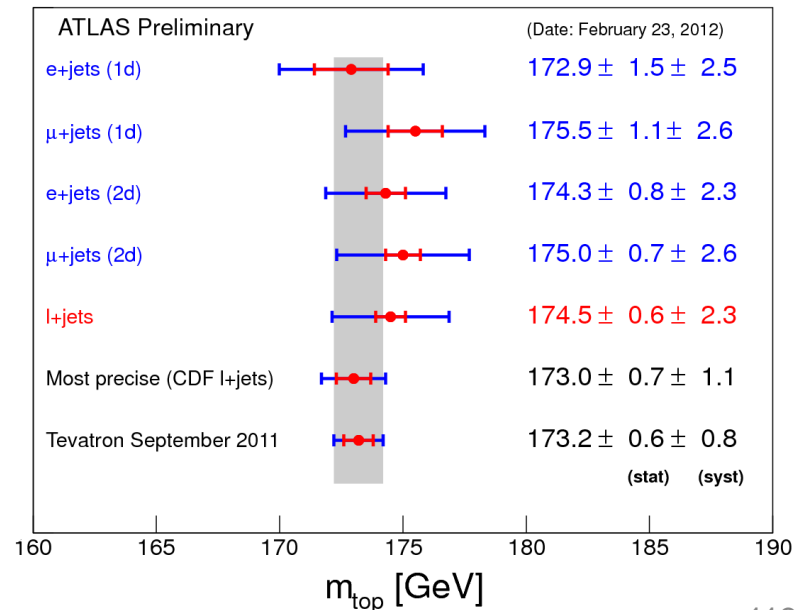
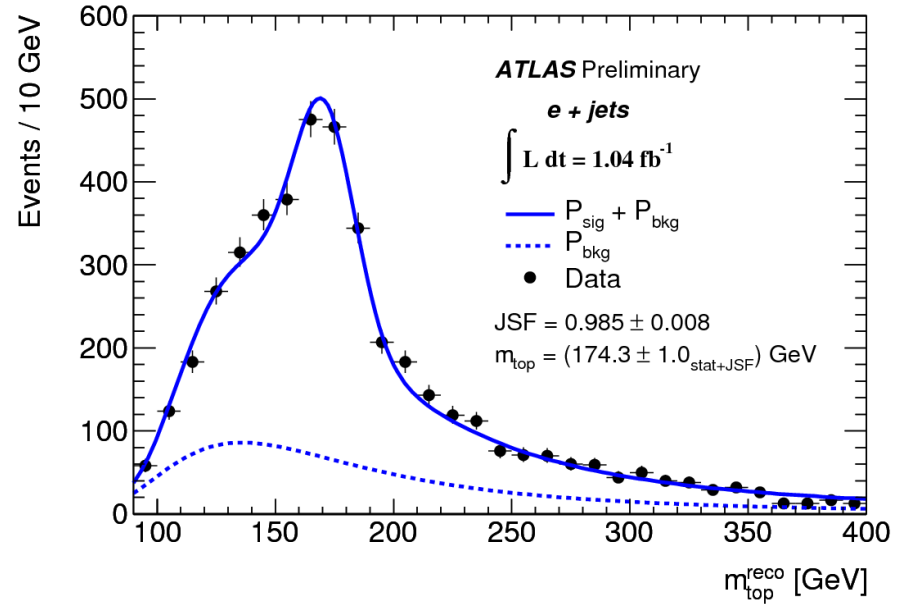
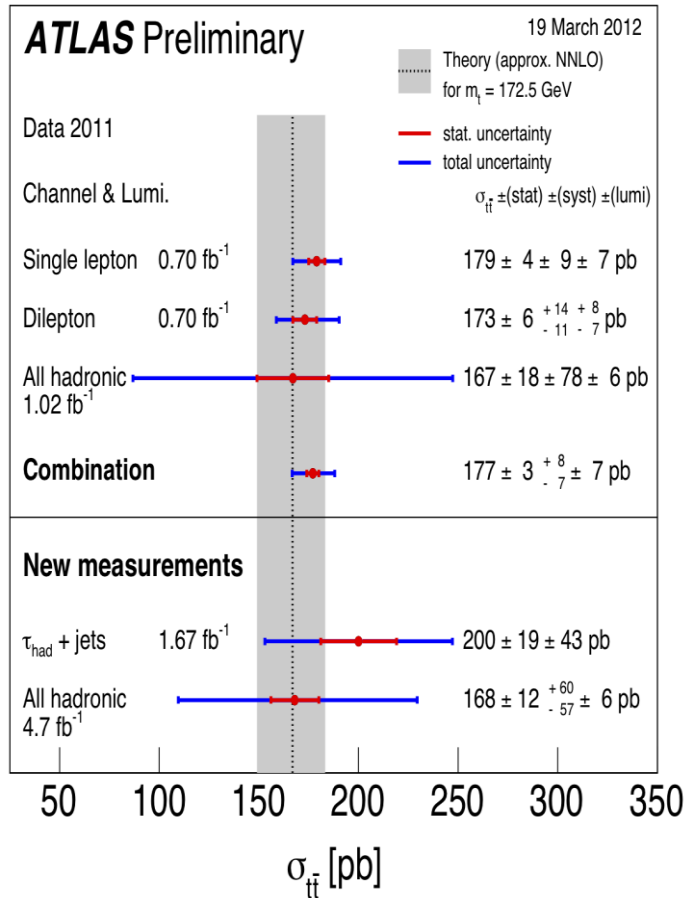


Example of top signals in the case of di-lepton channels



JHEP 1205 (2012) 059

More details on top measurements...



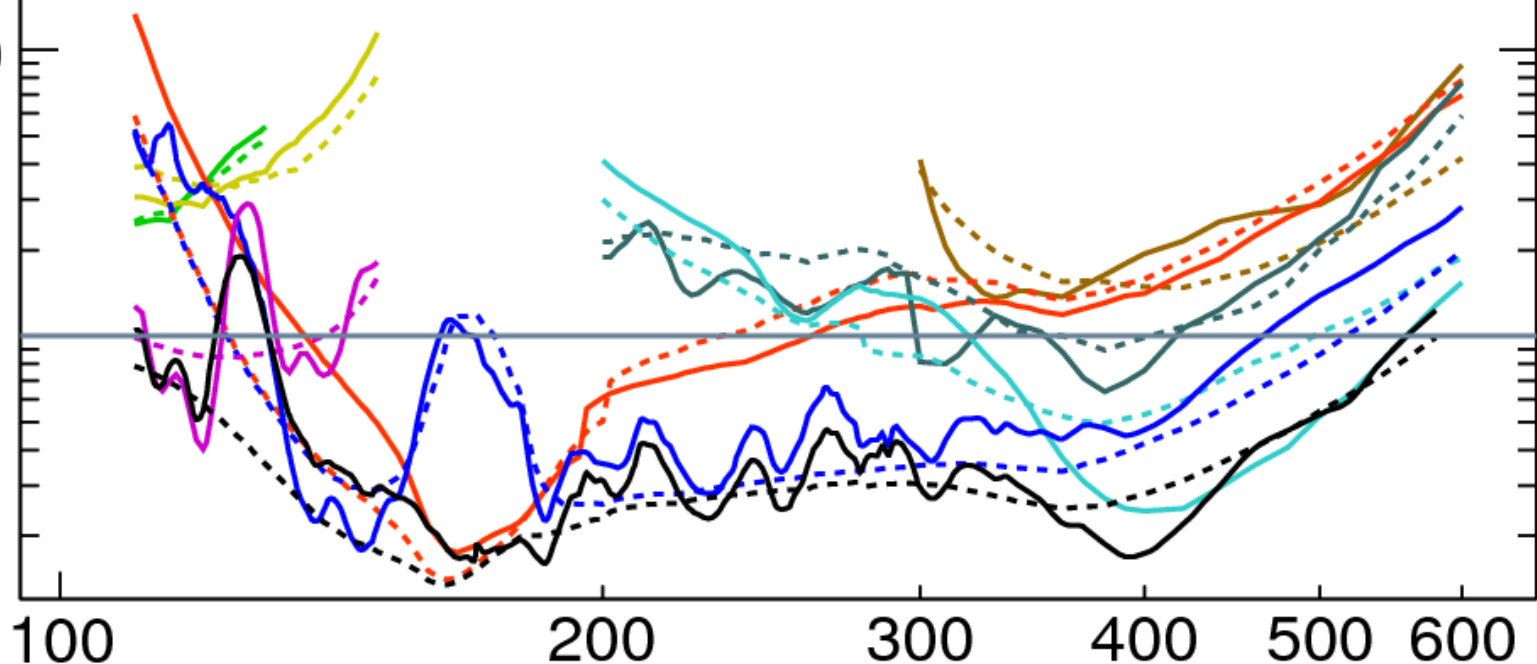
Higgs Boson Decay	Subsequent Decay	Sub-Channels	$\int L dt$ [fb ⁻¹]	Ref.
2011 $\sqrt{s} = 7$ TeV				
$H \rightarrow ZZ^{(*)}$	4ℓ	$\{4e, 2e2\mu, 2\mu2e, 4\mu\}$	4.8	[3]
$H \rightarrow \gamma\gamma$	–	10 categories $\{p_{Tt} \otimes \eta_\gamma \otimes \text{conversion}\} \oplus \{2\text{-jet}\}$	4.8	[4]
$H \rightarrow WW^{(*)}$	$\ell\nu\ell\nu$	$\{ee, e\mu/\mu e, \mu\mu\} \otimes \{0\text{-jet}, 1\text{-jet}, 2\text{-jet}\} \otimes \{\text{low, high pile-up}\}$	4.7	[5]
$H \rightarrow \tau\tau$	$\tau_{\text{lep}}\tau_{\text{lep}}$	$\{e\mu\} \otimes \{0\text{-jet}\} \oplus \{\ell\ell\} \otimes \{1\text{-jet}, 2\text{-jet}, VH\}$	4.7	[6]
	$\tau_{\text{lep}}\tau_{\text{had}}$	$\{e, \mu\} \otimes \{0\text{-jet}\} \otimes \{E_T^{\text{miss}} < 20 \text{ GeV}, E_T^{\text{miss}} \geq 20 \text{ GeV}\}$ $\oplus \{e, \mu\} \otimes \{1\text{-jet}\} \oplus \{\ell\} \otimes \{2\text{-jet}\}$	4.7	
	$\tau_{\text{had}}\tau_{\text{had}}$	$\{1\text{-jet}\}$	4.7	
$VH \rightarrow Vbb$	$Z \rightarrow \nu\nu$	$E_T^{\text{miss}} \in \{120 - 160, 160 - 200, \geq 200 \text{ GeV}\}$	4.6	[7]
	$W \rightarrow \ell\nu$	$p_T^W \in \{< 50, 50 - 100, 100 - 200, \geq 200 \text{ GeV}\}$	4.7	
	$Z \rightarrow \ell\ell$	$p_T^Z \in \{< 50, 50 - 100, 100 - 200, \geq 200 \text{ GeV}\}$	4.7	
2012 $\sqrt{s} = 8$ TeV				
$H \rightarrow ZZ^{(*)}$	4ℓ	$\{4e, 2e2\mu, 2\mu2e, 4\mu\}$	5.8	[3]
$H \rightarrow \gamma\gamma$	–	10 categories $\{p_{Tt} \otimes \eta_\gamma \otimes \text{conversion}\} \oplus \{2\text{-jet}\}$	5.9	[4]
$H \rightarrow WW^{(*)}$	$e\nu\mu\nu$	$\{e\mu, \mu e\} \otimes \{0\text{-jet}, 1\text{-jet}, 2\text{-jet}\}$	5.8	[8]

ATLAS 2011 + 2012 Data

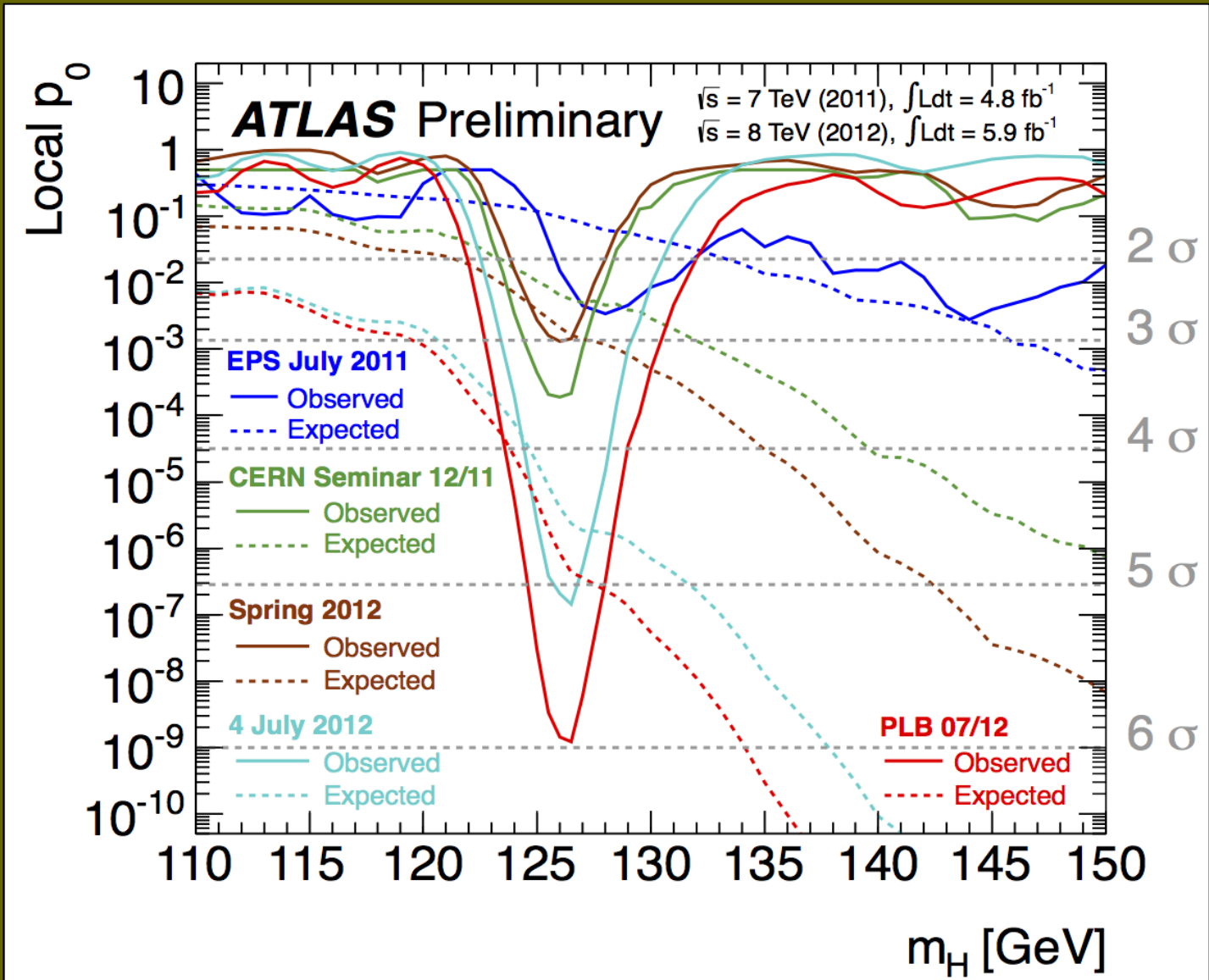
$\int L dt \sim 4.6-4.8 \text{ fb}^{-1}, \sqrt{s} = 7 \text{ TeV}$ $\int L dt \sim 5.8-5.9 \text{ fb}^{-1}, \sqrt{s} = 8 \text{ TeV}$

95% CL Limit on $\sigma/\sigma_{\text{SM}}$

- | | | |
|---|---|--|
| --- Expected Combined | --- Expected $H \rightarrow ZZ^* \rightarrow \ell\ell\ell\ell$ | --- Expected $H \rightarrow WW^* \rightarrow \ell\nu\ell\nu$ |
| — Observed Combined | — Observed $H \rightarrow ZZ^* \rightarrow \ell\ell\ell\ell$ | — Observed $H \rightarrow WW^* \rightarrow \ell\nu\ell\nu$ |
| --- Expected $H \rightarrow \gamma\gamma$ | --- Expected $H \rightarrow ZZ^* \rightarrow \ell\nu\nu$ | --- Expected $H \rightarrow WW^* \rightarrow \ell\nu q\bar{q}$ |
| — Observed $H \rightarrow \gamma\gamma$ | — Observed $H \rightarrow ZZ^* \rightarrow \ell\nu\nu$ | — Observed $H \rightarrow WW^* \rightarrow \ell\nu q\bar{q}$ |
| --- Expected $H \rightarrow b\bar{b}$ | --- Expected $H \rightarrow ZZ^* \rightarrow \ell\ell q\bar{q}$ | --- Expected $H \rightarrow \tau\tau$ |
| — Observed $H \rightarrow b\bar{b}$ | — Observed $H \rightarrow ZZ^* \rightarrow \ell\ell q\bar{q}$ | — Observed $H \rightarrow \tau\tau$ |

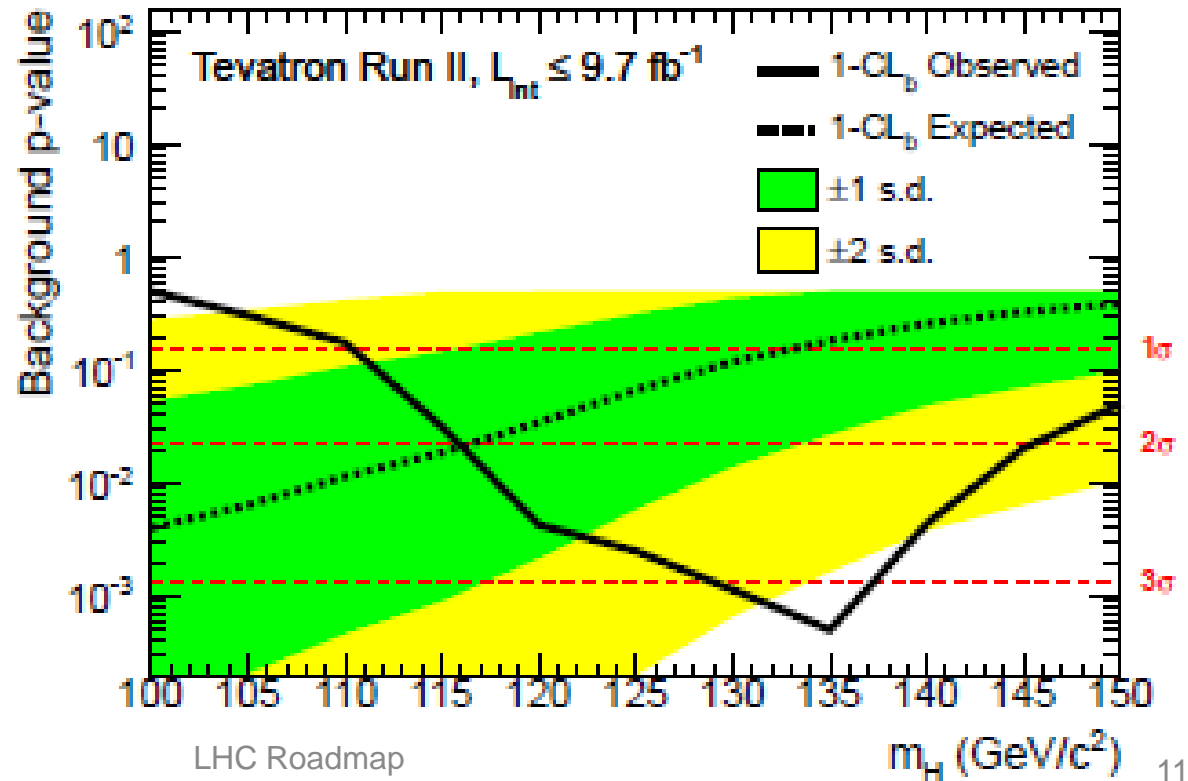
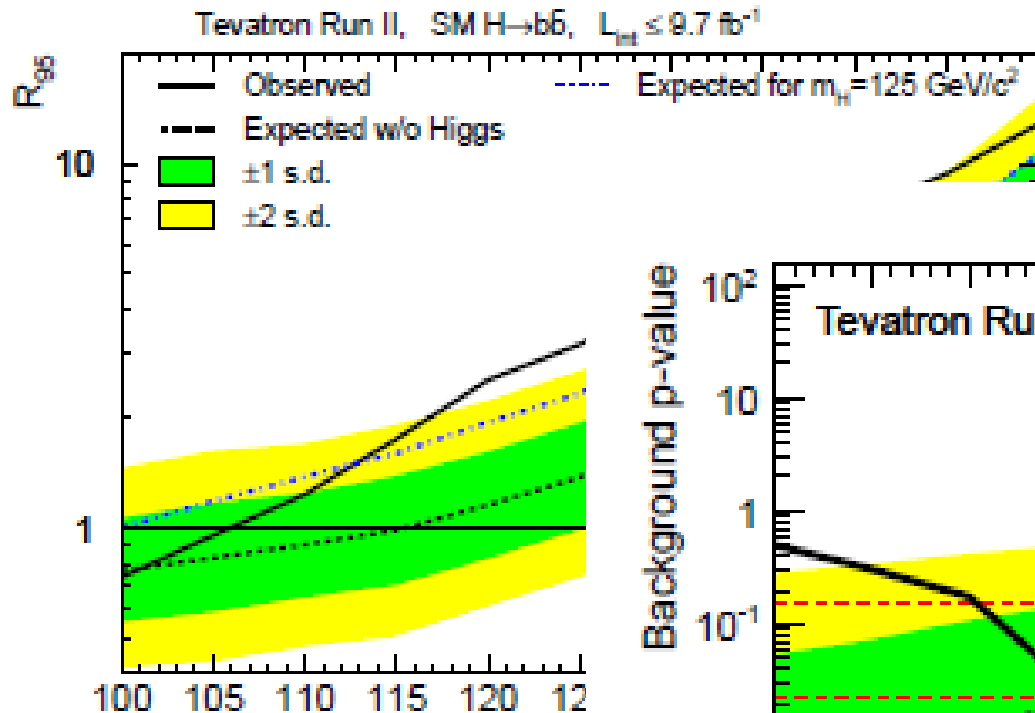


Evolution of the excess with time



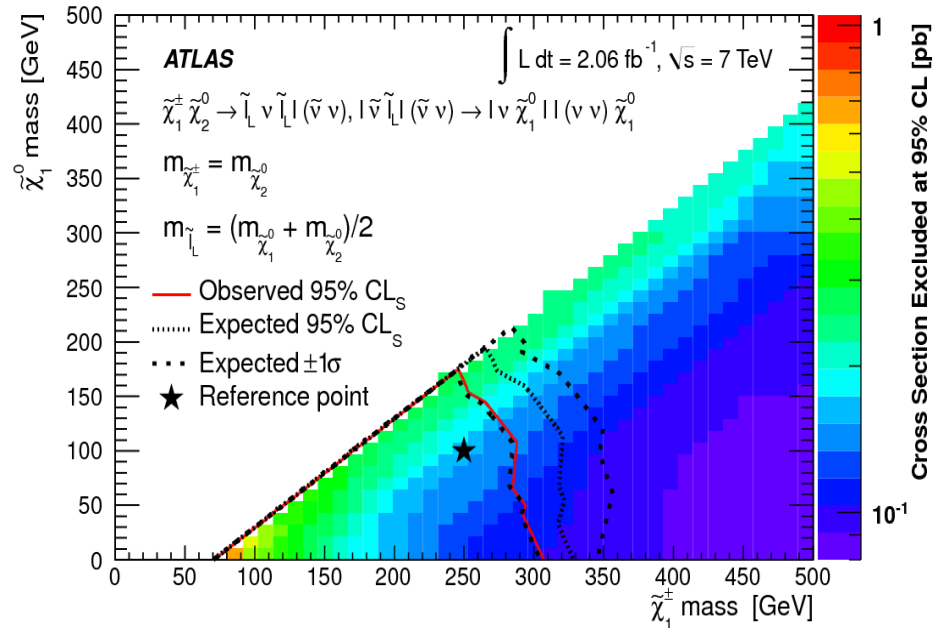
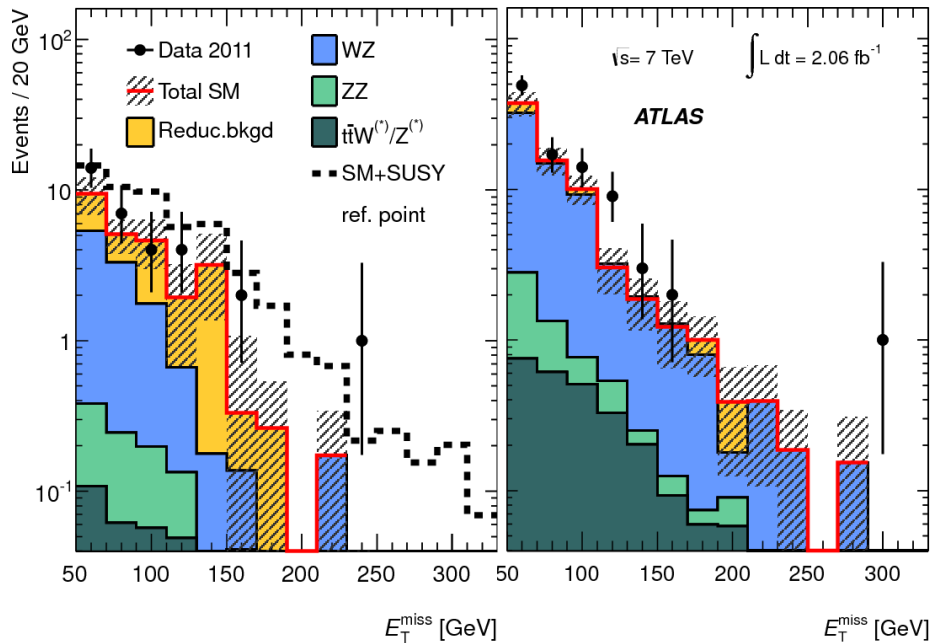
CDF and D0 Collaborations

Evidence for a particle produced in association with weak bosons and decaying to a bottom-antibottom quark pair in Higgs boson search at the Tevatron, submitted to Phys. Rev. Lett. (2012), arXiv:1207.6436.



Searches for charginos/neutralinos

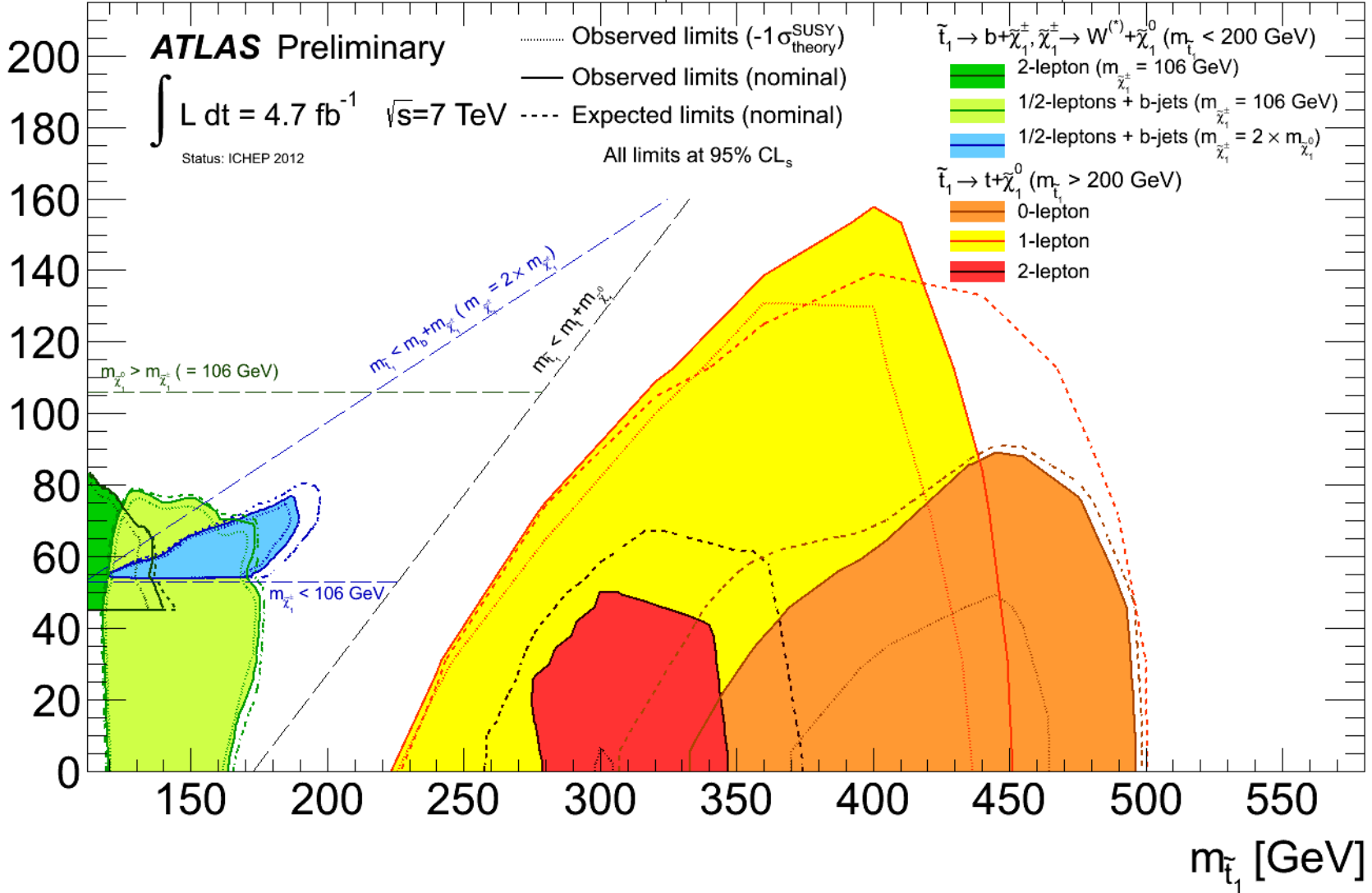
- Direct chargino/neutralino production cross section in the pb range
- ATLAS has searched for this in 3-lepton final state
- Limits in the $m(\chi_{\pm 1}^{\pm}/\chi_2^0) \sim 250$ GeV region have been set



(Z-depleted and Z-enriched signal regions)

$m_{\tilde{\chi}_1^0}$ [GeV]

\tilde{t}_1, \tilde{t}_1 production: $\tilde{t}_1 \rightarrow b + \tilde{\chi}_1^\pm, \tilde{\chi}_1^\pm \rightarrow W^{(*)} + \tilde{\chi}_1^0$ (BR=1, $m_{\tilde{t}_1} < 200$ GeV); $\tilde{t}_1 \rightarrow t + \tilde{\chi}_1^0$ (BR=1, $m_{\tilde{t}_1} > 200$ GeV)

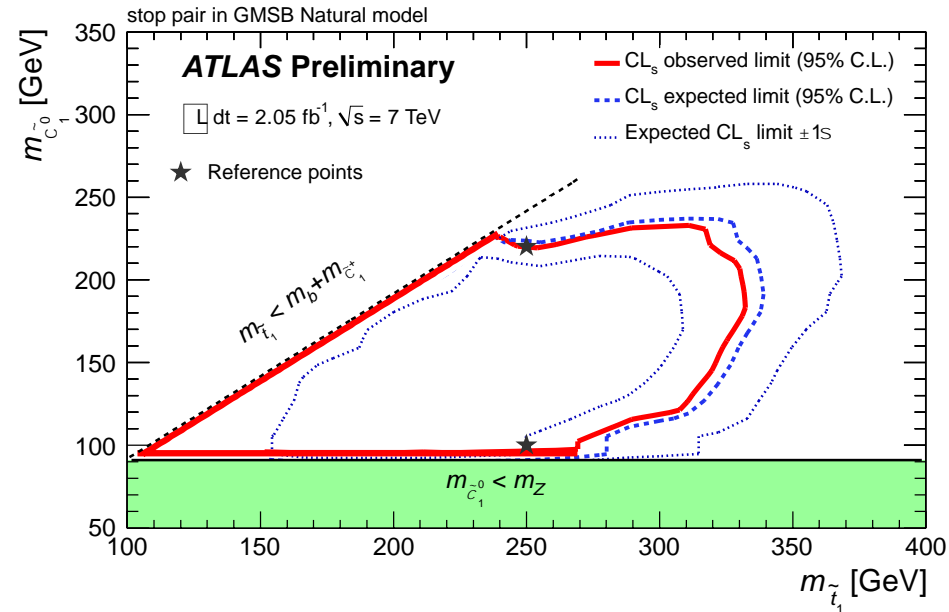
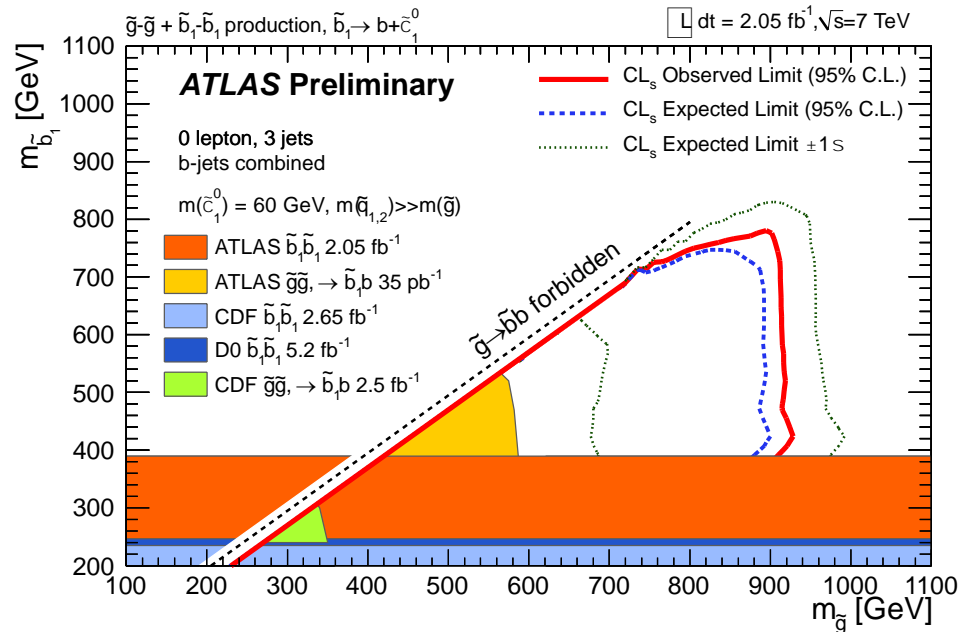


SUSY - 3rd generation squarks

- **Look for light stop and sbottom (“Naturalness”): from gluino decay + direct production**
 - **Gluino-mediated sbottom search in events w/ b-jets + 0,1-lepton + MET [ATLAS-CONF 2012-003]**
 - **Gluino-mediated stop search in events w/ SS dilepton + 4 jets + MET [ATLAS-CONF 2012-004]**
 - **Direct sbottom search in events w/ 2 b-jets + MET [arXiv:1112.3832]**
 - **Direct stop search in events w/ dilepton + b-jets (GMSB interpretation) [ATLAS-CONF 2012-036]**

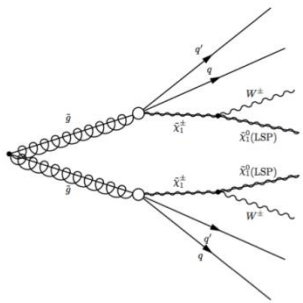
Strong limits from search for gluino-mediated sbottom production in events with b-jets

First limits on direct stop pair production, assuming (a.o.) the decay chain: $t_1 \rightarrow t + \chi^0 \rightarrow t + Z(l\bar{l}) + G$

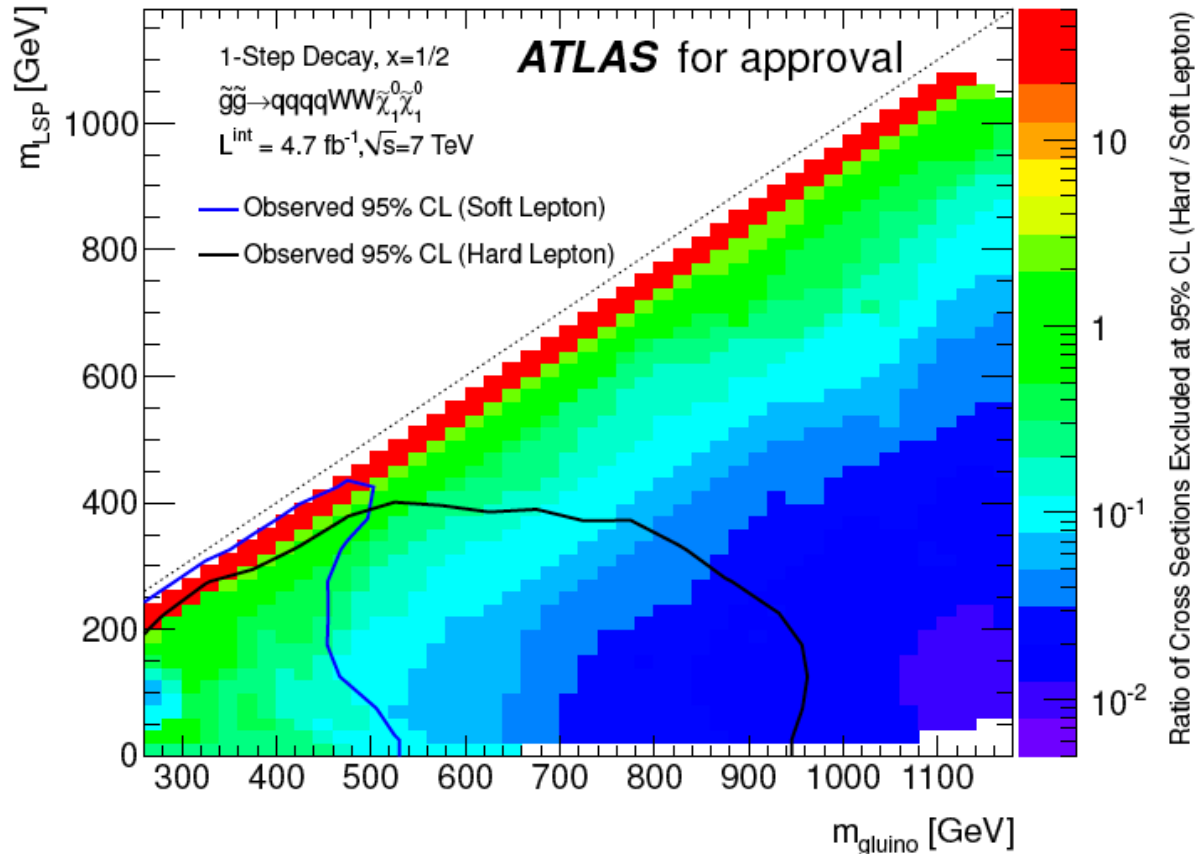
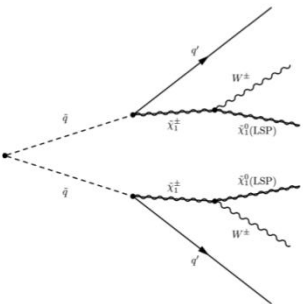


SUSY searches: “soft” leptons

- Dedicated search in “strong” production to deal with “compressed mass spectra (small DM)
- 1-soft lepton + 2 jets + high MET

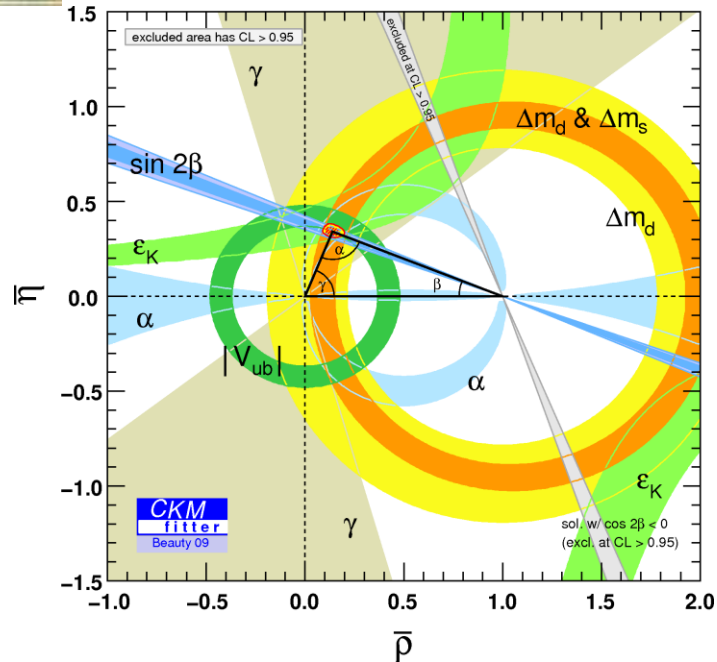
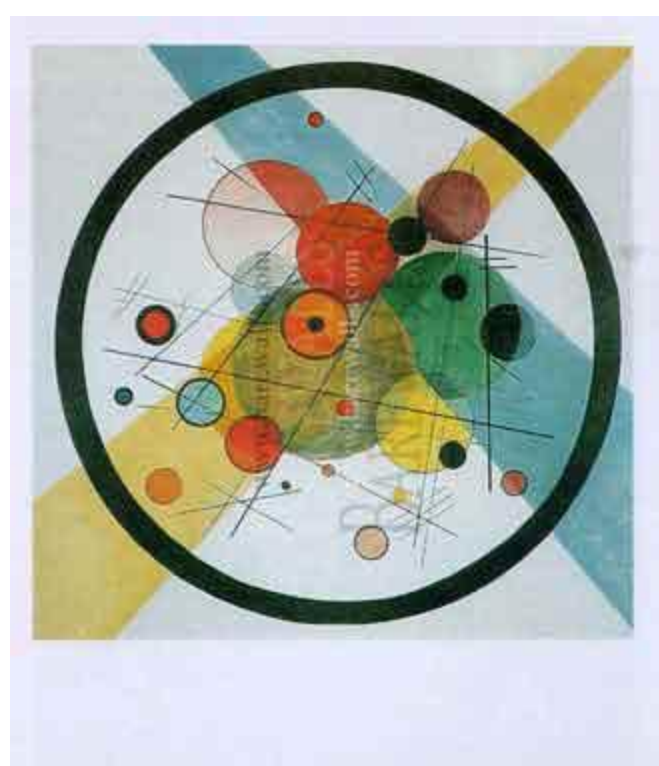


1-step simplified models leading to final states with leptons + jets + MET





Early hints of news from 'Beyond the Standard Model' may come from 'beautiful' flavour physics...



Rare decays: $B_s \rightarrow \mu^+ \mu^-$

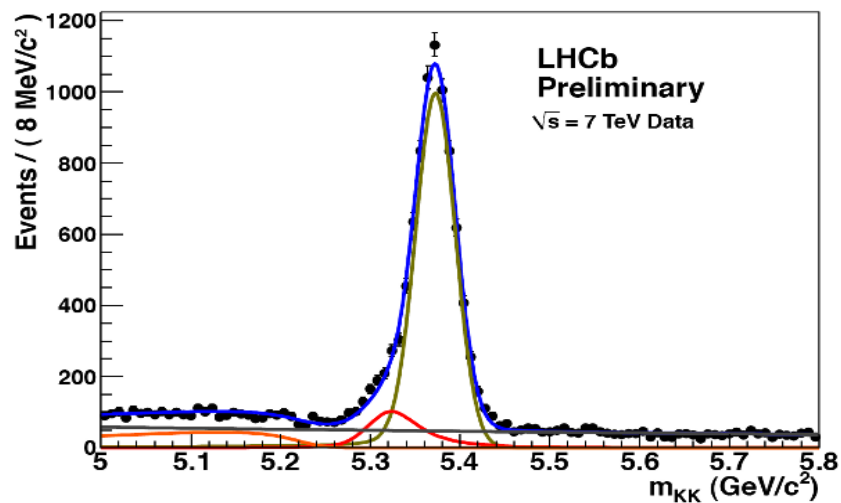
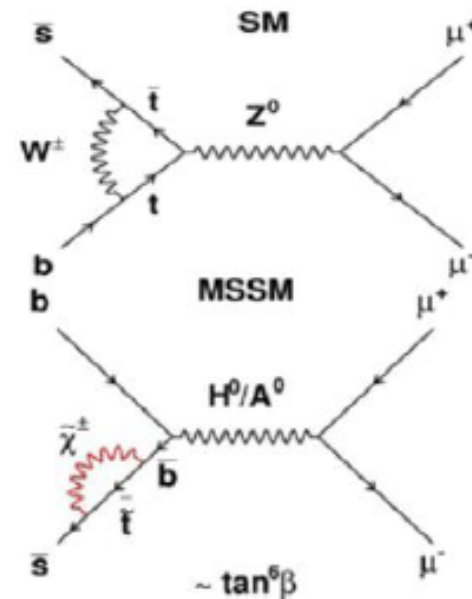
One of the most sensitive probes of New Physics

- Standard Model: FCNC, helicity suppressed:

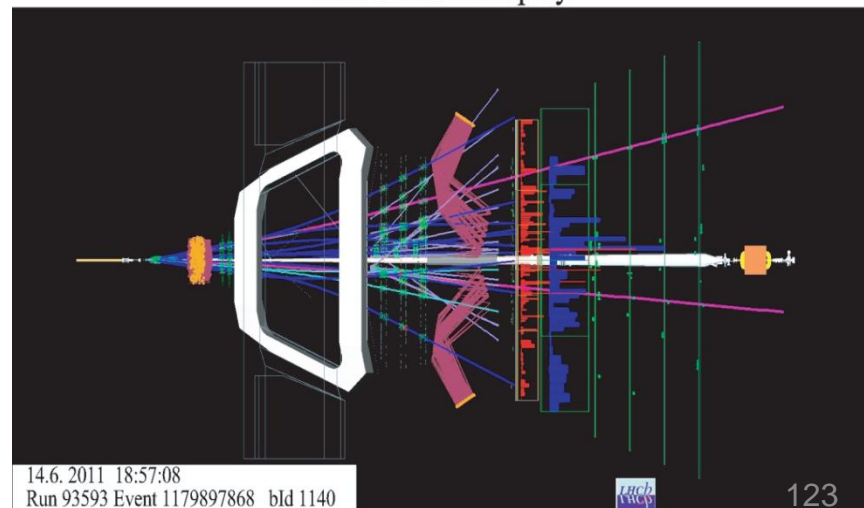
$$\text{Br}(\text{SM}) = (3.2 \pm 0.2) \times 10^{-9}$$

- Can be enhanced in NP models.

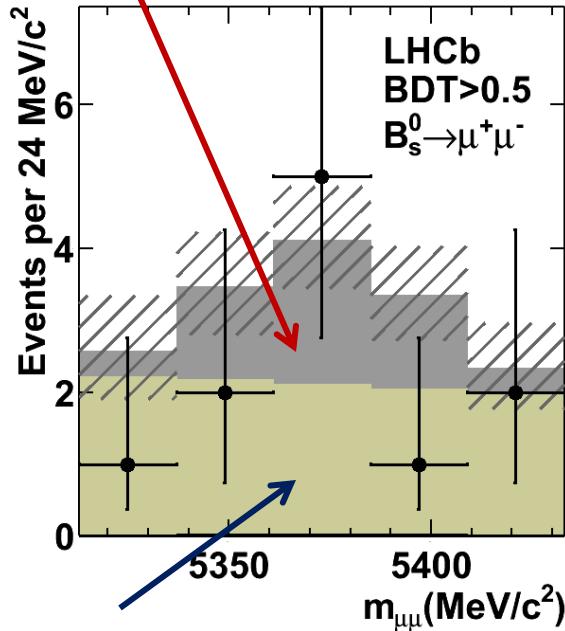
$$\text{MSSM: BR} \propto \left(C_{S,P}^{\text{MSSM}}\right)^2 \propto \frac{\tan^6 \beta}{M_A^4}$$



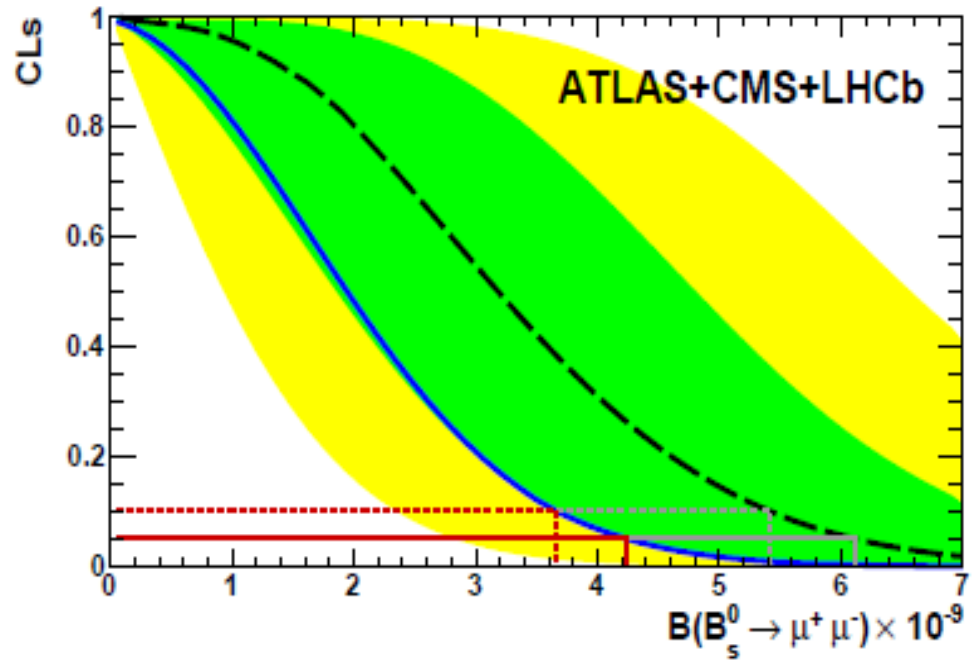
LHCb Event Display



Standard Model



Combinatorial Background



	CDF	CMS	Atlas	LHCb	SM
Luminosity (fb ⁻¹)	10	4.9	2.4	1.1	
Br(B _d → μ ⁺ μ ⁻) 95% CL (x10 ⁻⁹)	4.6	1.8		1.03	0.10 ± 0.01
Br(B _s → μ ⁺ μ ⁻) 95% CL (x10 ⁻⁹)	31	7.7	22	4.5	3.2 ± 0.2

→ **No deviation (yet) observed from Standard Model (combined limit from all the 3 exp'ts is 4.2 x 10⁻⁹)**

Phys. Rev. Lett. 108 (2012) 231801 and LHCb-PAPER-2012-017