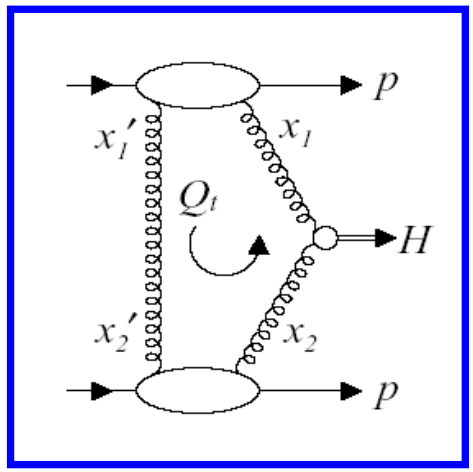
Diffraction and Forward Physics at the LHC

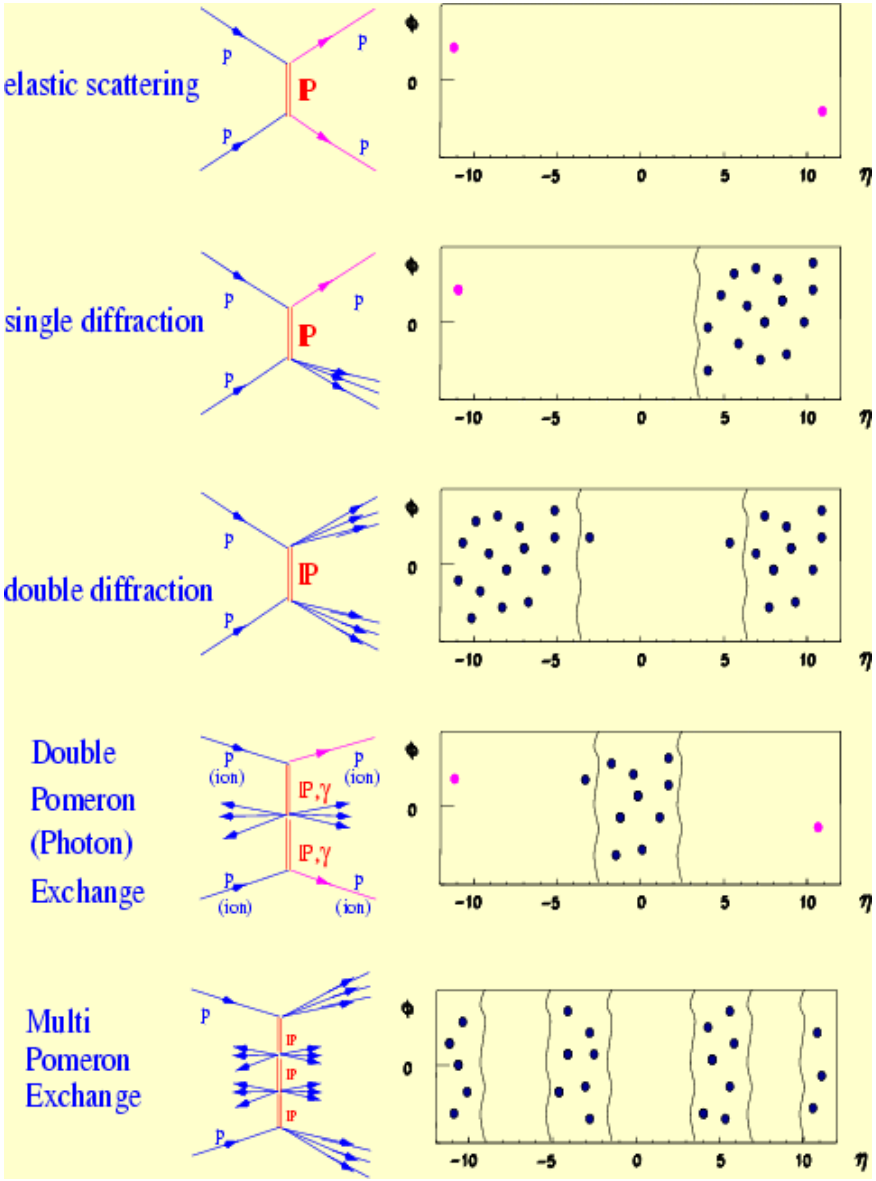


Albert De Roeck (CERN)

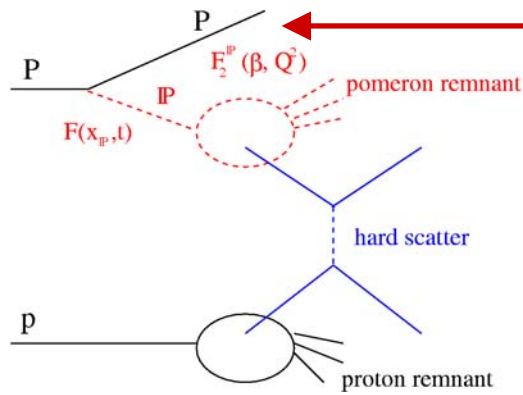
From Colliders to Cosmic Rays

Prague, Czech Republic,
7-13 September

Diffraction at LHC:



- PP scattering at highest energy
- Soft & Hard Diffraction



ξ = proton momentum loss
Reconstruct ξ with roman pots

$\xi < 0.1 \Rightarrow$ O(1) TeV "Pomeron beams"
E.g. Structure of the Pomeron $F(\beta, Q^2)$
β down to ~ 10^{-3} & Q^2 ~10^4 GeV^2
Diffraction dynamics?
Exclusive final states ?

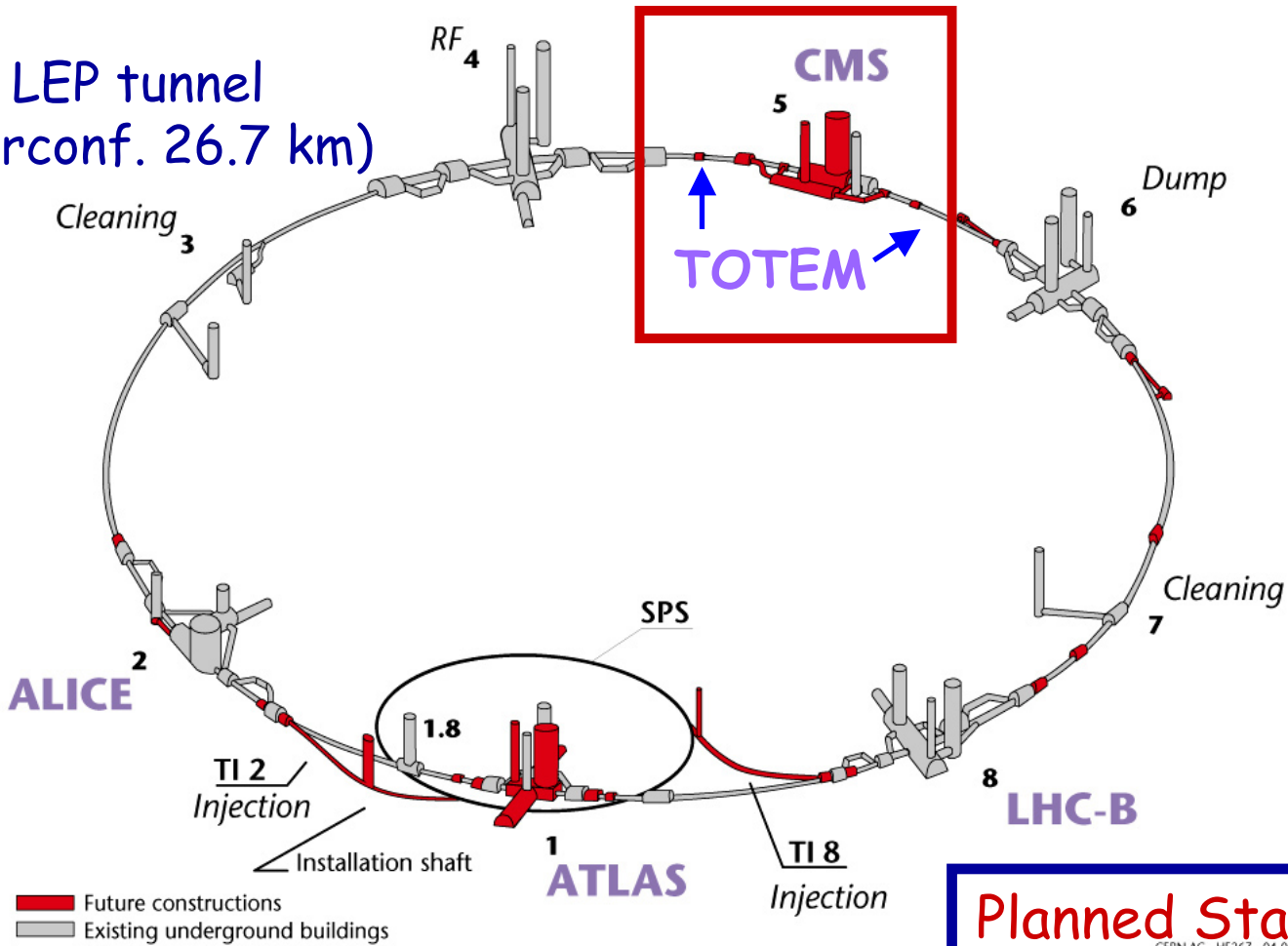
- Gap dynamics in pp presently not fully understood!

The Large Hadron Collider (LHC)

PP collisions at
$\sqrt{s}$ = 14 TeV

Layout of the LEP tunnel including future LHC infrastructures.

In LEP tunnel
(circonf. 26.7 km)



5 experiments

25 ns bunch spacing
$\Rightarrow$ 2835 bunches
10^{11} p/bunch

Design Luminosity:
$10^{33}cm^{-2}s^{-1}$ -$10^{34}cm^{-2}s^{-1}$
$\Rightarrow$100 fb^{-1}/year

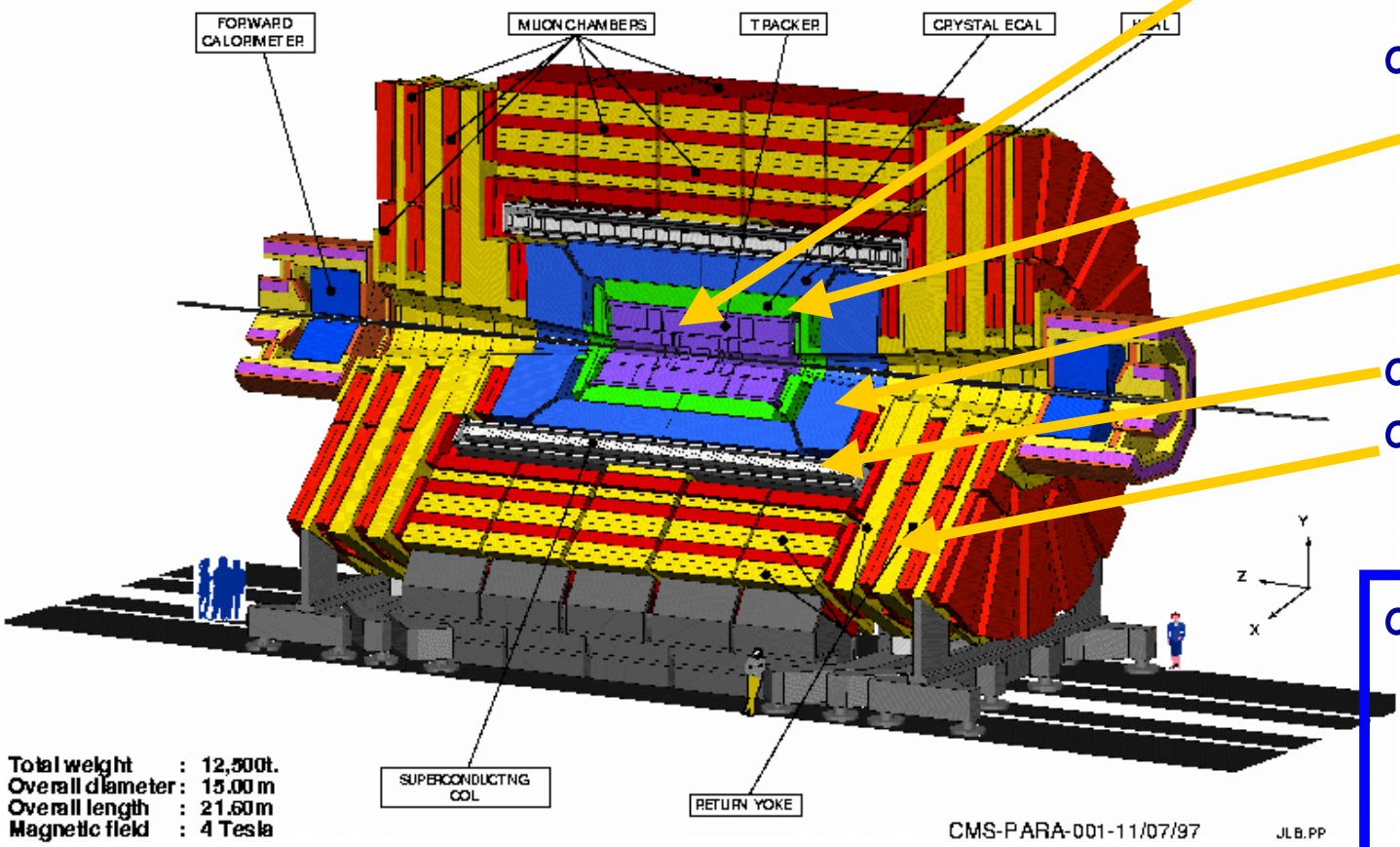
23 inelastic events
per bunch crossing

Planned Startup: Summer 2007

CERN AC - HF267 - 04-07-1997

The CMS experiment

A Huge enterprise !



- Tracking
  - Silicon pixels
  - Silicon strips
- Calorimeters
  - PbW04 crystals for Electro-magn.
  - Scintillator/steel for hadronic part
- 4T solenoid
- Instrumented iron for muon detection

- Coverage
  - Tracking
    - $0 < |\eta| < 3$
  - Calorimetry
    - $0 < |\eta| < 5$

Main program: EWSB, Beyond SM physics…

Diffraction and Forward Physics at LHC

TOTEM:

- Approved July 2004 (TDR of TOTEM web page http://totem.web.cern.ch/Totem/)
- TOTEM stand alone
  - Elastic scattering, Total pp cross section and soft diffraction.

CMS:

- EOI submitted in January 2004: /afs/cern.ch/user/d/deroeck/public/eoi_cms_diff.pdf
  - Diffraction with TOTEM Roman Pots and/or rapidity gaps
- Technical Proposal in preparation for new forward detectors (CASTOR, ZDC,+...)
  - Diffractive and low-x physics part of CMS physics program (low + high β)

CMS+TOTEM:

- Prepare common LOI due in November 2005 (K. Eggert/ADR organizing)
  - Full diffractive program with central activity. TOTEM will be included as a subdetector in CMS (trigger/data stream)

ATLAS:

- LOI submitted (March 04) for RP detectors to measure elastic scattering/ total cross sections/luminosity. Diffraction will be looked at later

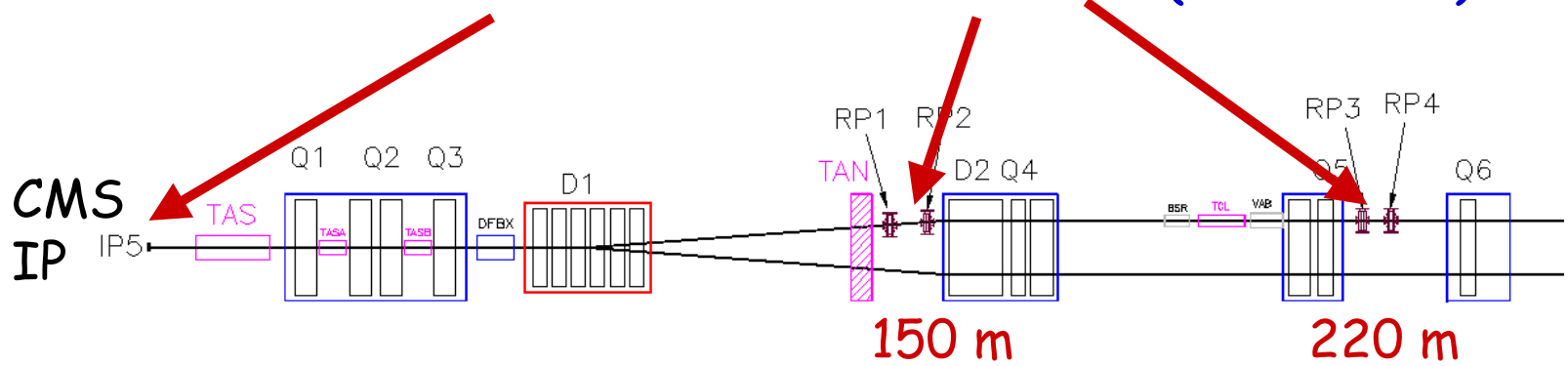
ALICE, LHCb: no direct forward projects plans but keeping eyes open.

FP420: Collaboration for R&D and feasibility study for detectors at 420 m

Roman Pot Detectors (TOTEM)

TOTEM physics program: total pp, elastic & diffractive cross sections

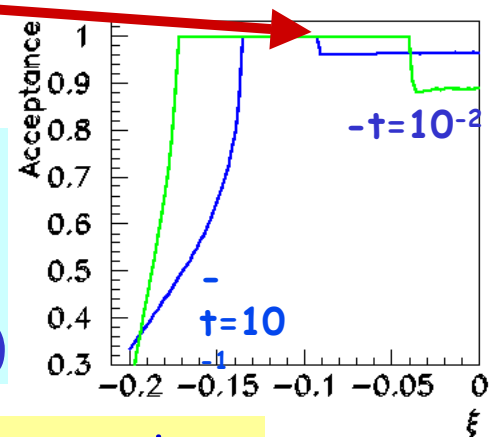
Apparatus: Inelastic Detectors & Roman Pots (2 stations)



High β^* (1540m): Lumi 10^{28}-10^{31}cm^{-2}s^{-1} (few days or weeks)

>90% of all diffractive protons are seen in the Roman Pots.

Proton momentum measured with a resolution ~10^{-3}



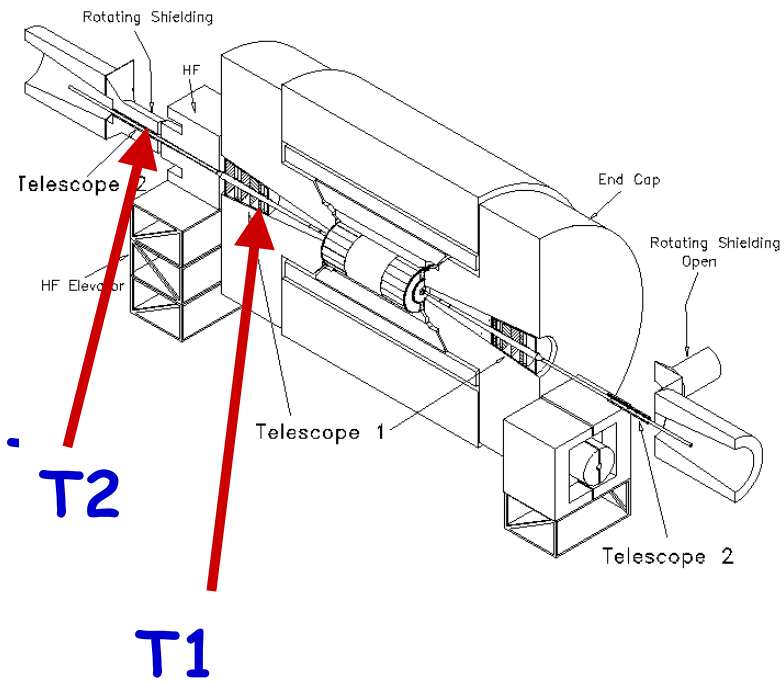
Low β^*: (0.5m): Lumi 10^{33}-10^{34}cm^{-2}s^{-1}

220m: $0.02 < \xi < 0.2$

300/400m: $0.002 < \xi < 0.02$ (RPs in the cold region/ under discussion in CMS/ATLAS)

ξ = proton momentum loss

TOTEM/CMS Forward Detectors

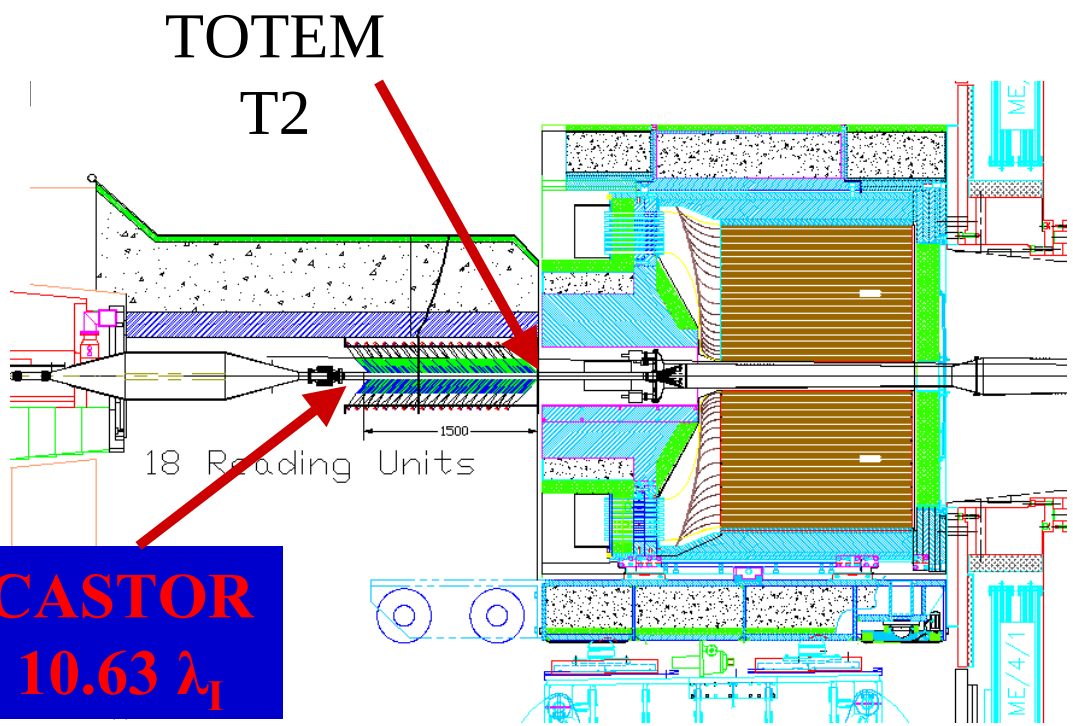


T1/T2 inelastic event taggers

- T1 CSC/RPC tracker ('99 LOI)
- T2 GEM or Silicon tracker (TOTEM/New)
- CASTOR Calorimeter (CMS/New)
- ZDC Calorimeter (CMS/New)

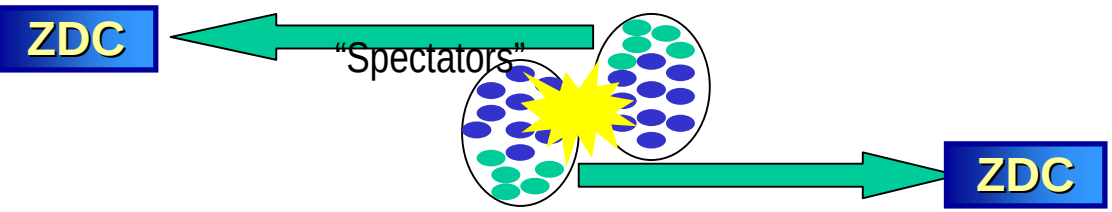
T1 $3.1 < \eta < 4.7$
T2 $5.3 < \eta < 6.7$
Castor $5.25 < \eta < 6.5$

Extend the reach in η from $|\eta| < 5$ to $|\eta| < 6.7$

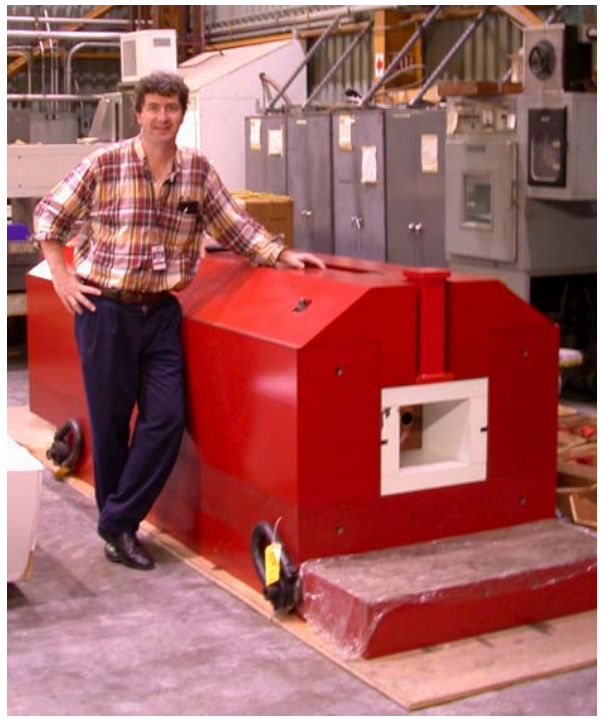


Opportunities to contribute to the LOI !!

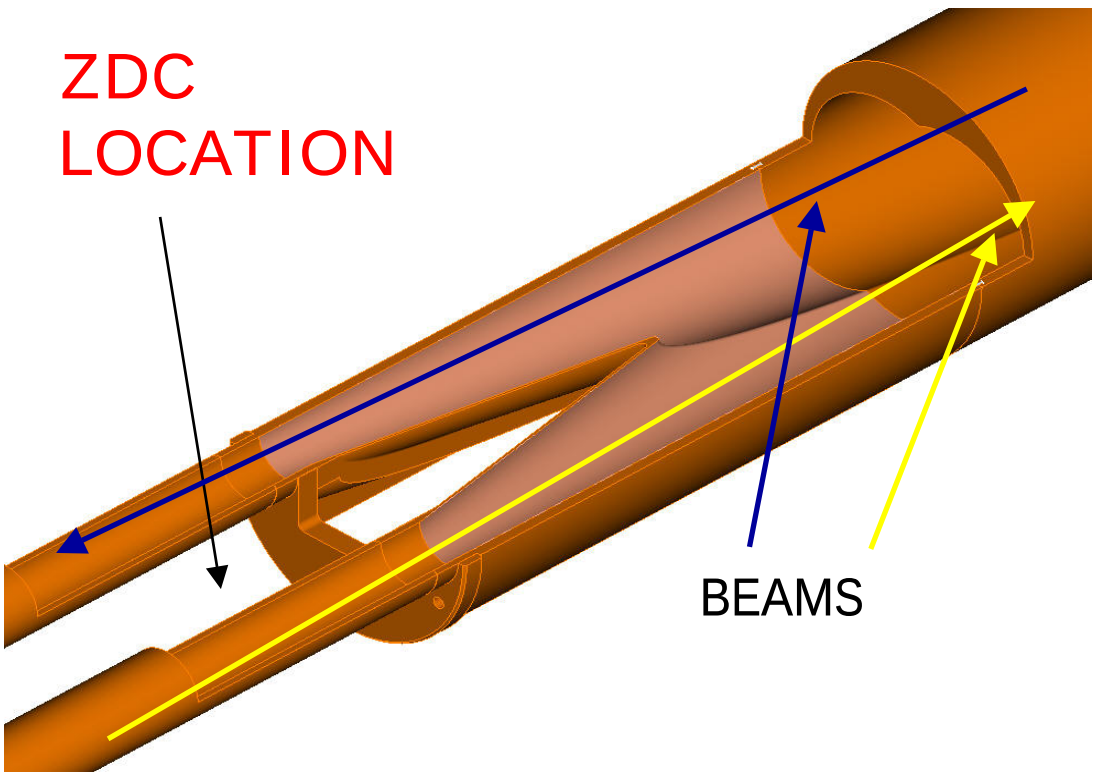
ZDC: zero degree calorimeter (CMS)



Beam pipe splits 140m from IR



ZDC LOCATION



Tungsten/ quartz fiber or PPAC calorimeter
EM and HAD section

Funding pending in DOE

Measurement of σ_{tot} at Tevatron and LHC

1. Luminosity-independent measurement using the Optical Theorem

$$\left.\begin{aligned} L\,\sigma_{tot}^2 &= \frac{16\,\pi}{1+\rho^2}\times\left.\frac{dN_{el}}{dt}\right|_{t=0} \\ L\,\sigma_{tot} &= N_{el}+N_{inel} \end{aligned}\right\} \Rightarrow \boxed{\sigma_{tot} = \frac{16\,\pi}{1+\rho^2}\times\frac{(dN_{el}/dt)\big|_{t=0}}{N_{el}+N_{inel}}}$$

M. Deile HCP05

Used by E710, E811, CDF.

TOTEM:

- Measure the total rate $N_{el} + N_{inel}$ with an expected precision of 0.8 %
  (running for 1 day at $L = 1.6 \times 10^{28}\ cm^{-2}\ s^{-1}$).
- Extrapolate the elastic cross-section to t = 0: systematics dominated: 0.5 %
  (statistical error after 1 day: 0.07 %)
- ρ unknown, from COMPETE prediction: $\rho = 0.1361 \pm 0.0015\ ^{+0.0058}_{-0.0025}$ 0.2 %

1 %

2. Elastic Scattering in Coulomb/Nuclear Interference Region

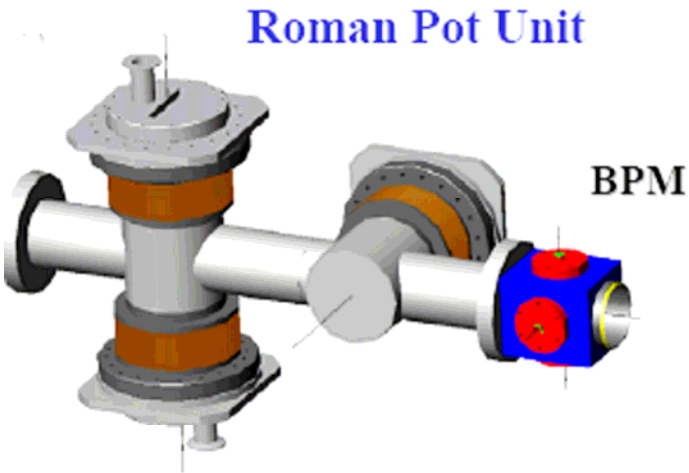
Fit $\frac{dN}{dt} = L\pi\left|f_C\,e^{-i\alpha\phi(t)} + f_N\right|^2 \approx L\pi\left|-\frac{2\alpha G^2(t)}{|t|}e^{-i\alpha\phi(t)} + \frac{\sigma_{tot}}{4\pi}(i+\rho)e^{-b|t|/2}\right|^2$ (required reach in t: $|t|_{min} \le 6\times10^{-4}\ GeV^2$)

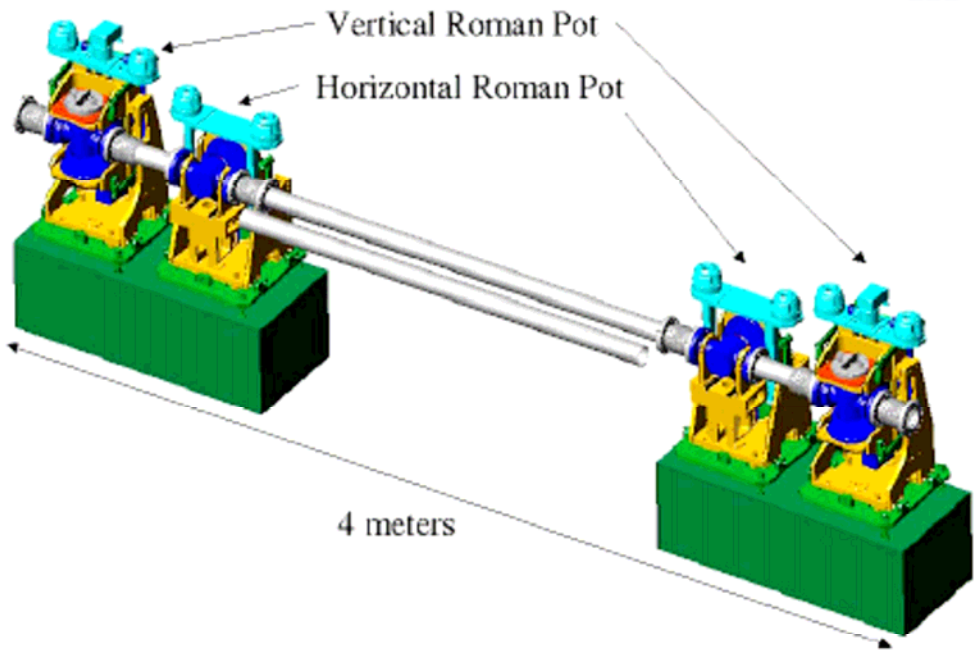
free parameters: L, σ_{tot}, ρ, b

planned by ATLAS

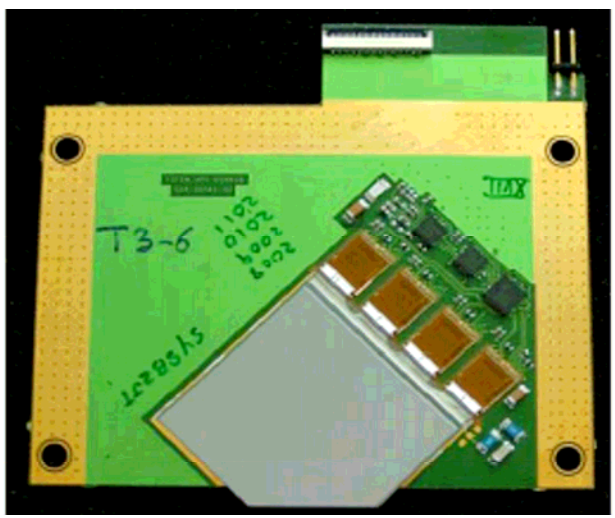
difficulty: uncertain phase $\phi(t)$

TOTEM Roman Pot Station





"edgeless" Si strip detectors
(10 planes per pot)



Measurement of very small p scattering angles (few μrad):

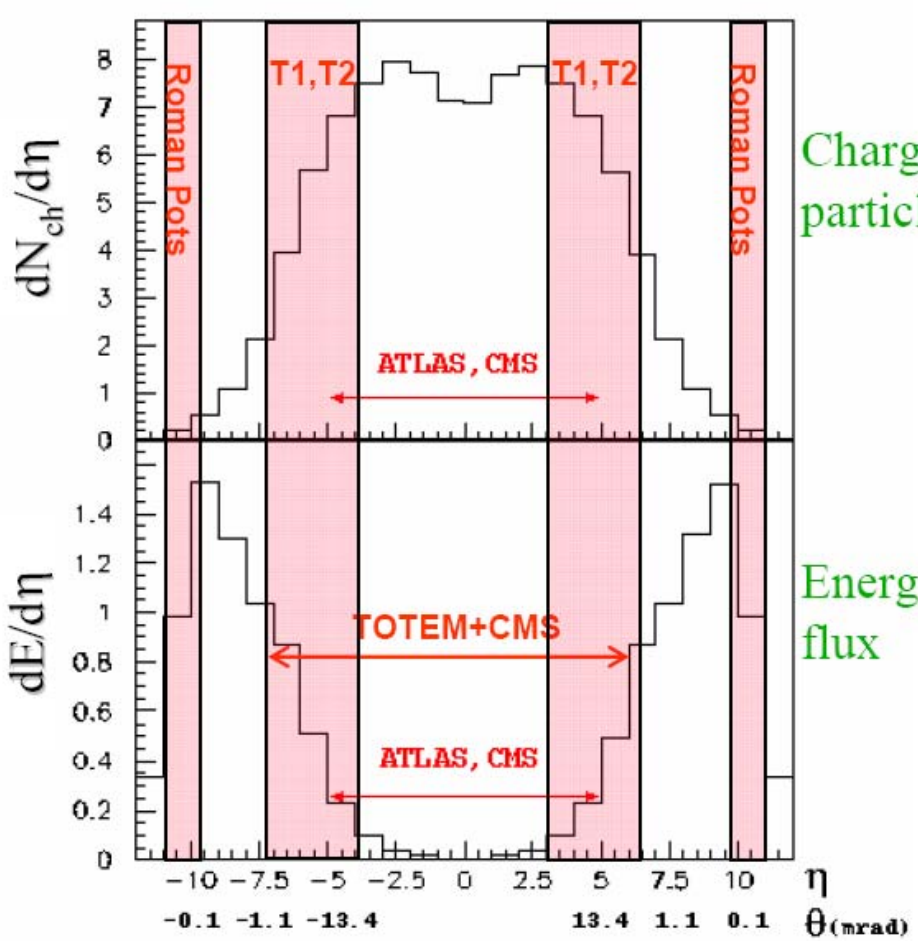
TOTEM @RP: $\sigma_{beam} \approx 80$ μm (E710: $\sigma_{beam} \approx 1$ mm)

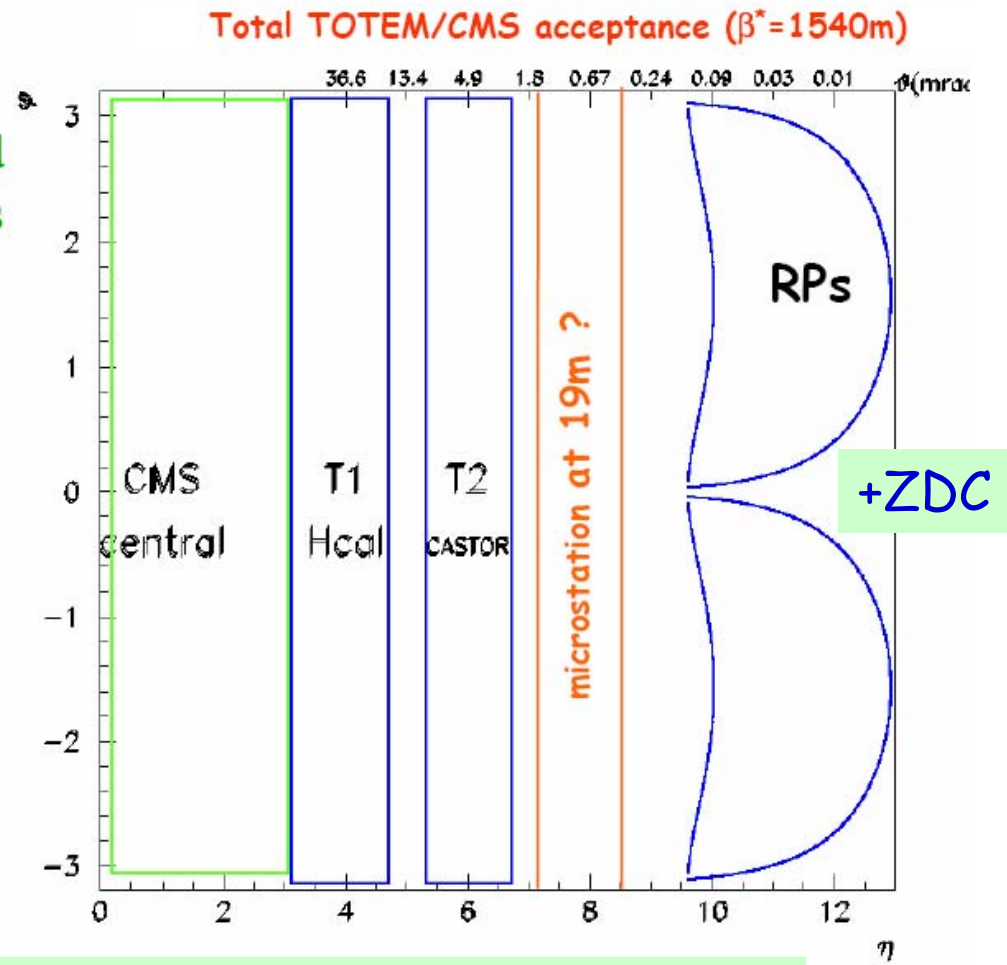
Leading proton detection at distances down 10 σ_{beam} + d

Need "edgeless" detectors (efficient up to physical edge) to minimise d.

CMS/TOTEM: a "complete" LHC detector

CMS/TOTEM will be the largest acceptance detector ever built at a hadron collider





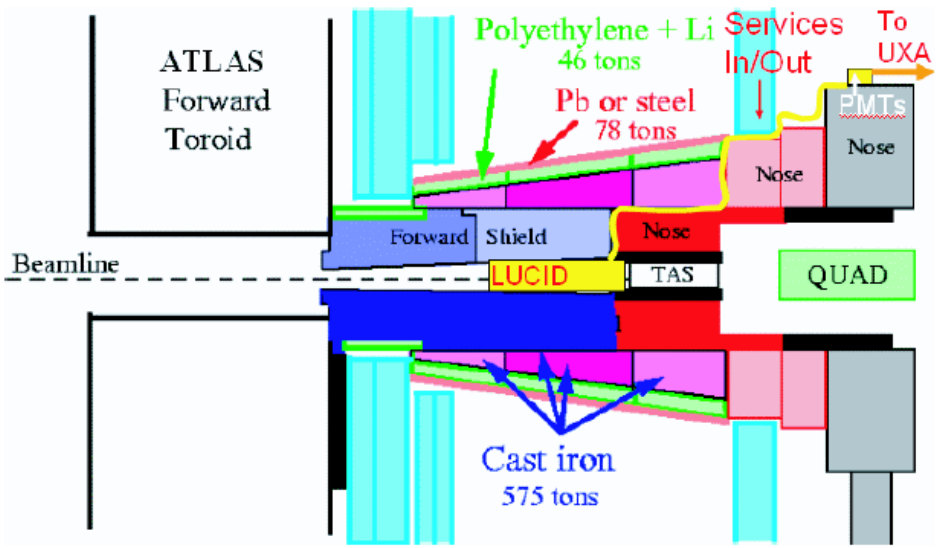
K. Eggert

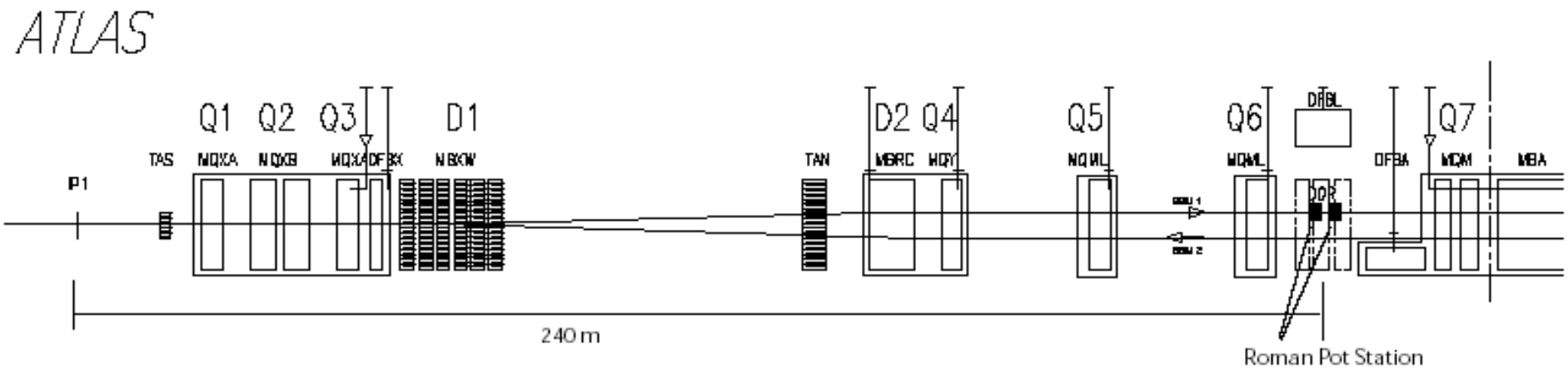
Still studying other regions (19m, 25m, 50m…)

ATLAS LOI for forward detectors

ATLAS submitted a LOI on forward detectors for luminosity measurement and monitoring (May '04)

Roman Pots at 240 m
Cerenkov Counter (LUCID) 5.4 <η< 6.1





Forward Physics Program (CMS/TOTEM LOI)

- Soft & Hard diffraction
  - Total cross section and elastic scattering (TOTEM, precision of O(1)%)
  - Gap survival dynamics, multi-gap events, proton light cone ($pp \rightarrow 3jets+p$), odderon
  - Diffractive structure: Production of jets, W, J/ψ, b, t, hard photons
  - Double Pomeron exchange events as a gluon factory (anomalous W,Z production?)
  - Diffractive Higgs production, (diffractive Radion production?), exclusive SPE??
  - SUSY & other (low mass) exotics & exclusive processes
- Low-x Dynamics
  - Parton saturation, BFKL/CCFM dynamics, proton structure, multi-parton scattering…
- New Forward Physics phenomena
  - New phenomena such as DCCs, incoherent pion emission, Centauro's
- Strong interest from cosmic rays community
  - Forward energy and particle flows/minimum bias event structure
- Two-photon interactions and peripheral collisions
- Forward physics in pA and AA collisions
- Use QED processes to determine the luminosity to 1% ($pp \rightarrow ppee$, $pp \rightarrow pp\mu\mu$)

Many of these topics are of direct interest for the CR community

Diffraction at LHC

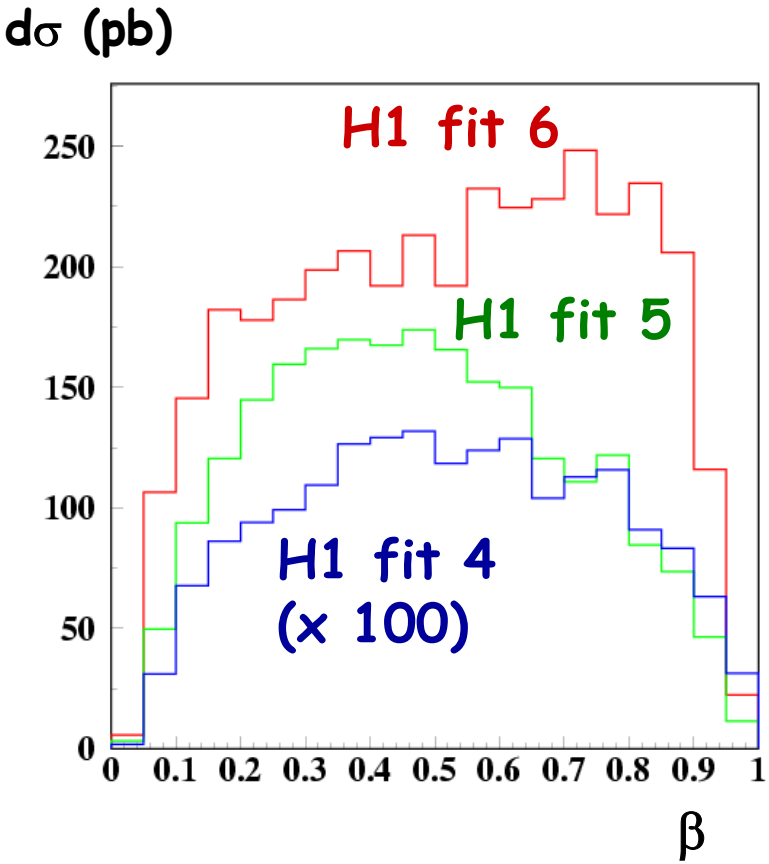
Plan to use both rapidity gap and proton tagging techniques

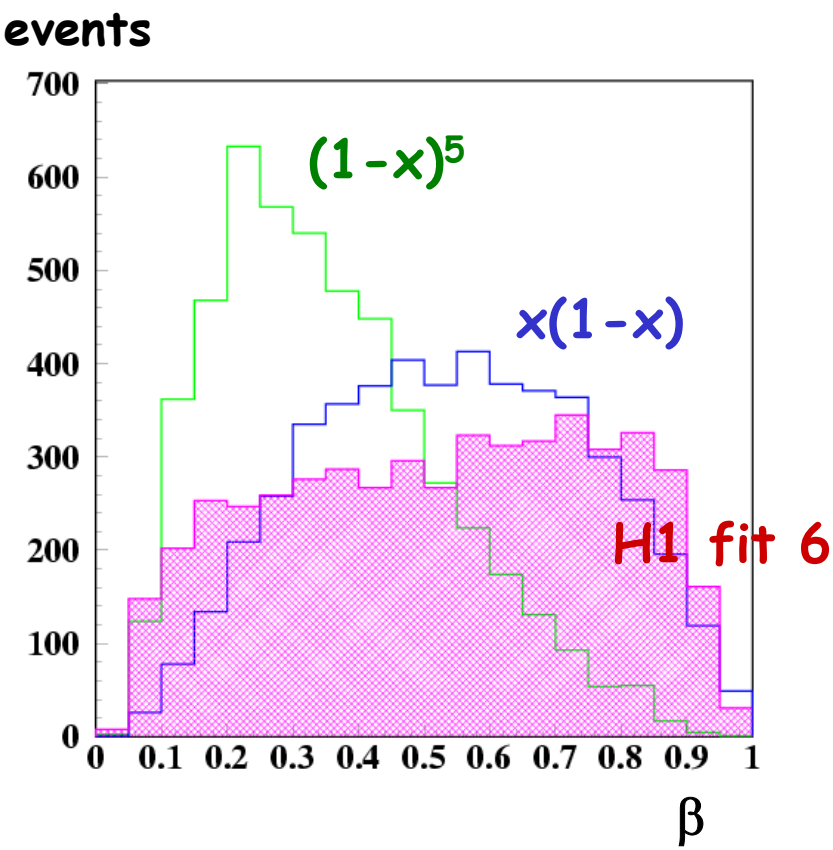
- Rapidity gaps based on the central detector
  - Used extensively at HERA and the Tevatron
  - Uses correlation between the η_{max} and ξ, the momentum loss of the proton
  - Once detector/readout stable, can be lead first results quickly.
    Many significant HERA papers, like F_2^D, are still with rapgaps
  - Only usable if pile up small and can be controled
  - Cannot distinguish between outgoing proton or low mass system
  - Need Monte Carlo based corrections
- Tagging protons based on detectors along the beamline
  - Clean measurement for non-dissociative final protons, kinematics!
  - Need to understand positioning, alignment, acceptance corrections…
    This can take some time (HERA & Tevatron experience)
  - May have reduced luminosity: can insert RPs only when beams/background low and stable

Experience from both HERA and Tevatron vital

DPE: β from Di-jet events

P_t>100 GeV/c for different structure functions





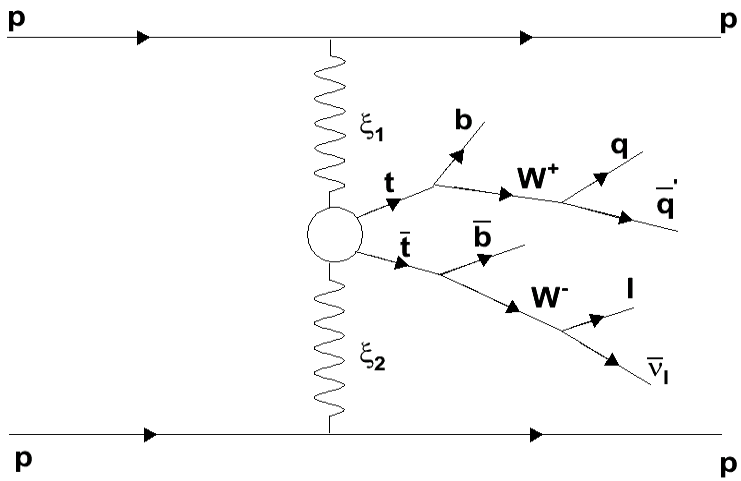
$\beta=\Sigma_{jets}\ E_T\ e^{-\eta}/(\sqrt{s}\ \xi)$: ξ from Roman Pots; E_T and η from CMS

High β region probed/ clear differences between different SFs

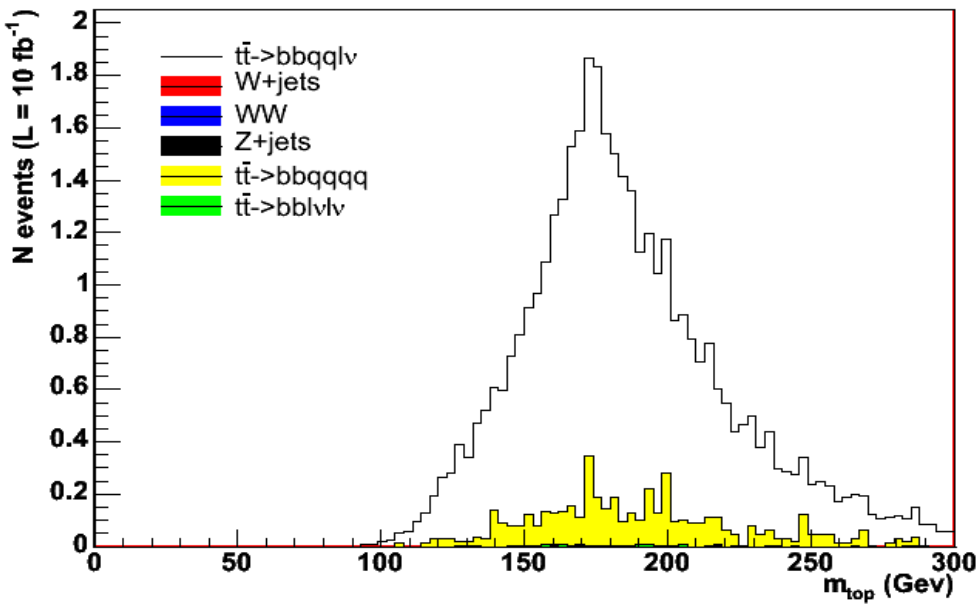
Novel channels: eg diffractive top

Decay Channel

A. Vilela



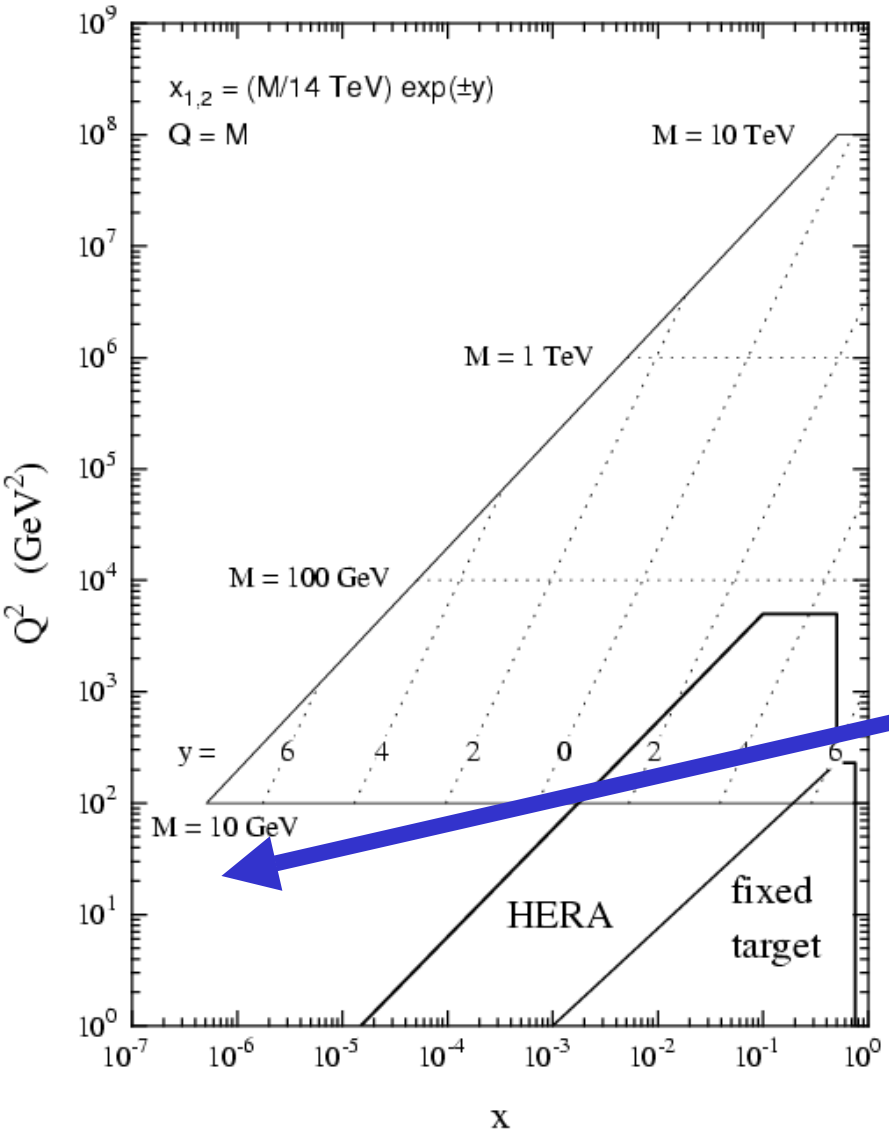
Top mass peak
Efficiency still to be increased



- $pp \rightarrow p + (t\bar{t}) + X + p$
- $t\bar{t} \rightarrow b\bar{b}\, l\, \bar{\nu}_l q \bar{q}' (l = e, \mu)$

With low Etjet cuts O(100) events/10 pb^{-1}

Low-x at the LHC



LHC: due to the high energy can reach small values of Bjorken-x in structure of the proton $F(x,Q^2)$

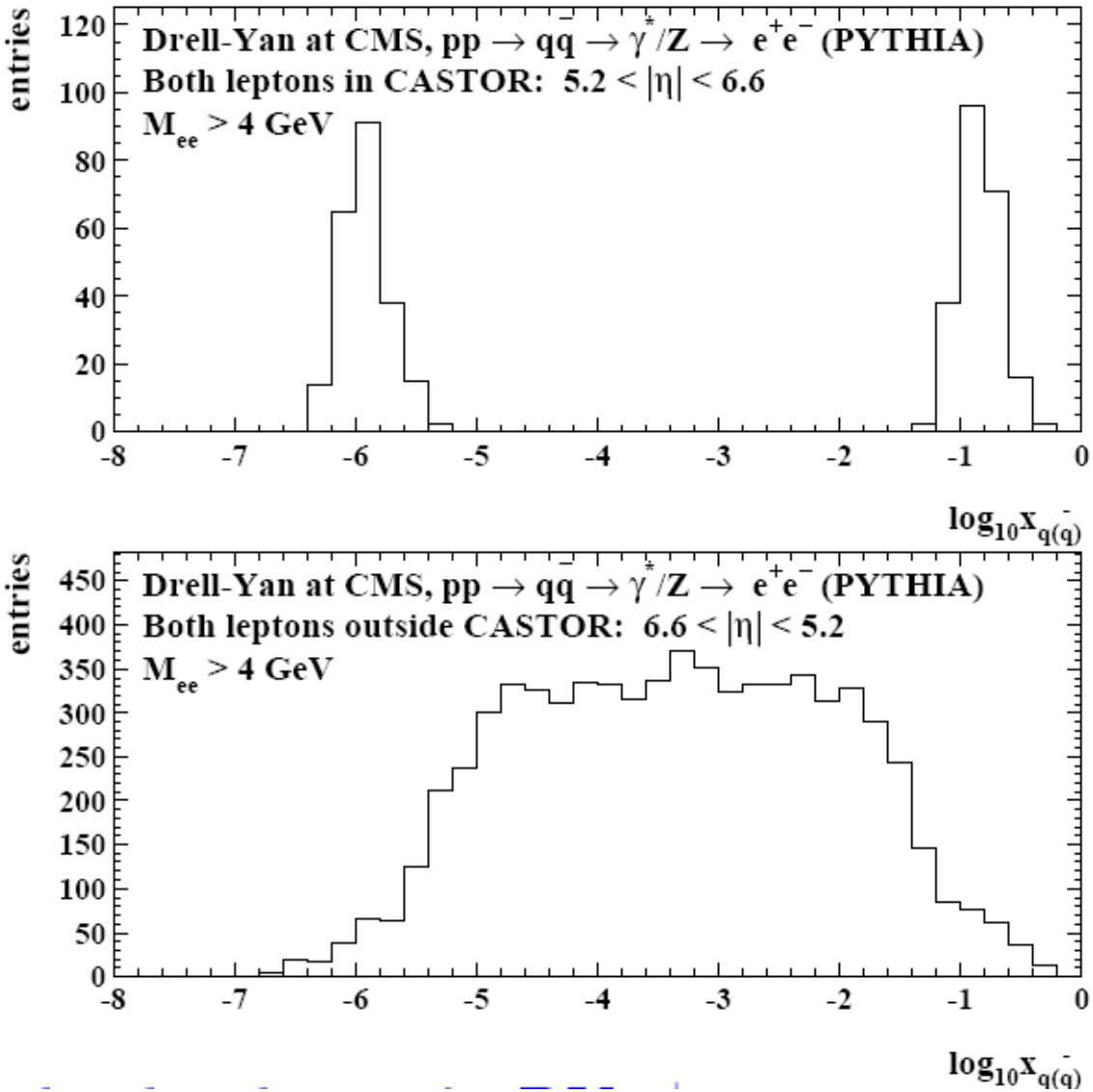
Processes:

- Drell-Yan
- Prompt photon production
- Jet production
- W production

If rapidities below 5 and masses below 10 GeV can be covered $\Rightarrow$ x down to 10^{-6}-10^{-7}
Possible with T2 upgrade in TOTEM (calorimeter, tracker) $5<\eta<6.7$!

Proton structure at low-x !!
Parton saturation effects?

Drell-Yan production



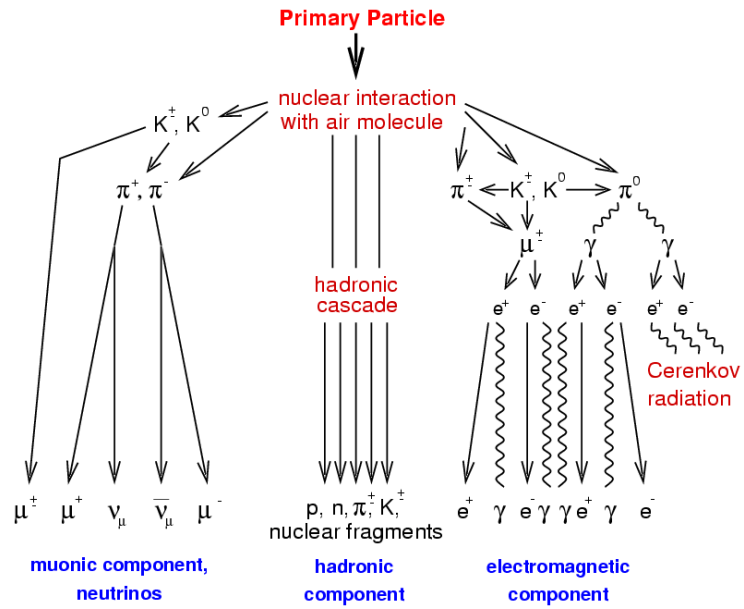
E. Sarkisyan

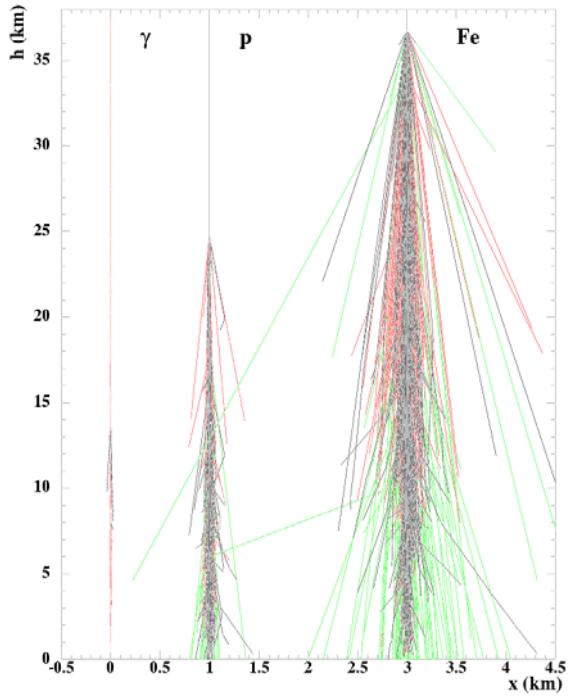
Drell-Yan into electrons

Includes (fast) CASTOR simulation

Large rapidity needed for low-x reach

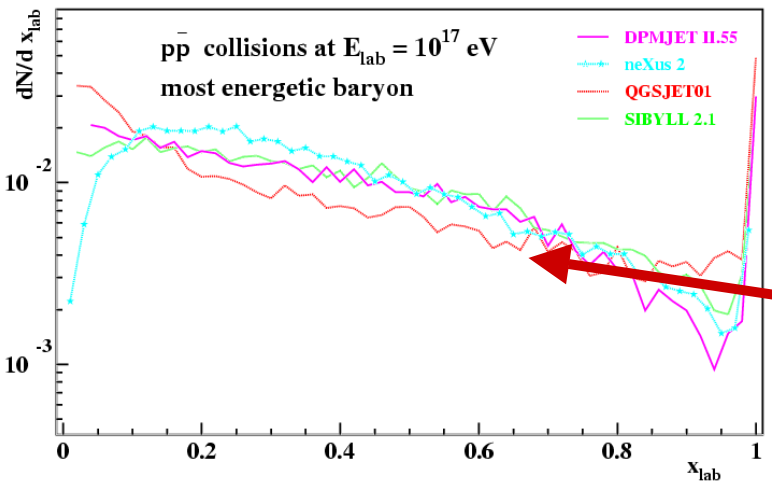
High Energy Cosmic Rays





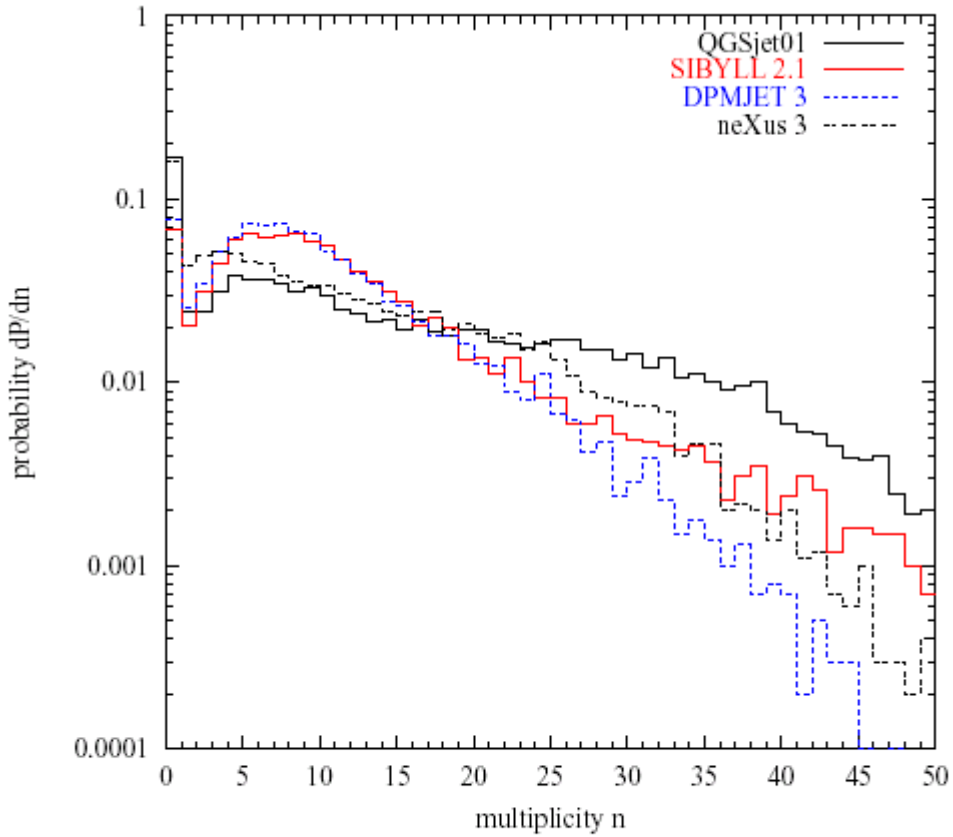
Cosmic ray showers: Dynamics of the high energy particle spectrum is crucial

Karlsruhe, La Plata



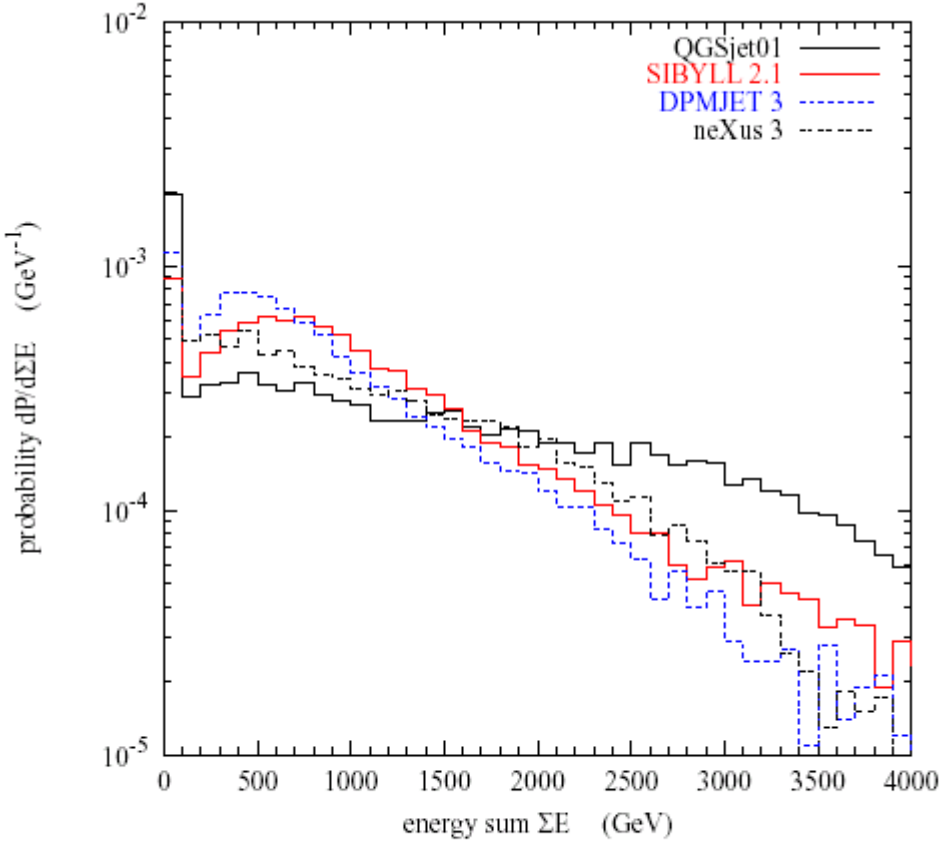
Interpreting cosmic ray data depends on hadronic simulation programs
Forward region poorly know/constrained
Models differ by factor 2 or more
Need forward particle/energy measurements
e.g. $dE/d\eta$...

Model Predictions: proton-proton at the LHC



total multiplicity in forward detector

$(5 \leq \eta \leq 7)$



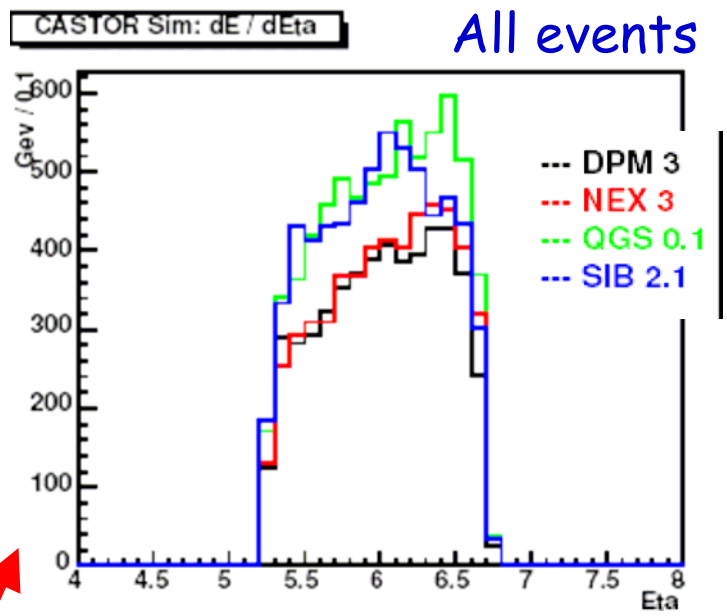
total energy in forward detector

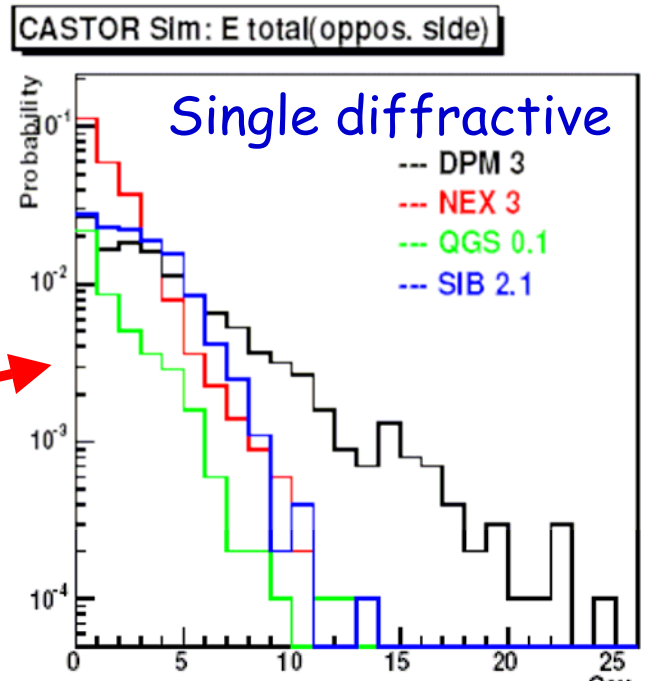
$(5 \leq \eta \leq 7)$

Predictions in the forward region within the CMS/TOTEM acceptance

Possible Forward Measurements

- Energy flow at high pseudorapidity (~ 6.7)
- Transverse energy (limited)
- Total/inelastic cross sections
- Fraction of diffractive dissociation
- Particle multiplicities
- Electrons, photons, hadrons
- Jets more limited (accpetance)
- (muons maybe in limited region with additional detectors, see H. Jung et al HERA/LHC workshop)





Full simulation

V. Popov, R. Engel, T. Dova

FP420

CERN-LHCC-2005-025
LHCC-I-015

FP420 : An R&D Proposal to Investigate the Feasibility of Installing Proton Tagging Detectors in the 420m Region at LHC

M. G. Albrow, T. Anthonis, M. Arneodo, R. Barlow, W. Beaumont, A. Brandt, P. Bussey, C. Buttar, M. Capua, J. E. Cole, B. E. Cox,*, C. DaVià, A. DeRoeck,*, E. A. De Wolf, J. R. Forshaw, J. Freeman, P. Grafstrom,+, J. Gronberg, M. Grothe , J. Hasi, G. P. Heath, V. Hedberg,+, B. W. Kennedy, C. Kenney, V. A. Khoze, H. Kowalski, J. Lamsa, D. Lange, V. Lemaitre, F. K. Loebinger, A. Mastroberardino, O. Militaru, D. M. Newbold, R. Orava1, V. O'Shea, K. Osterberg, S. Parker, P. Petroff, J. Pinfold, K. Piotrzkowski, M. Rijssenbeek, J. Rohlf, L. Rurua, M. Ruspa, M. G. Ryskin, D. H. Saxon, P. Schlein, G. Snow, A. Sobol, A. Solano, W. J. Stirling, M. Tasevsky, E. Tassi, P. Van Mechelen, S. J. Watts, T. Wengler, S. White, D. Wright

LOI submitted to the LHCC end of June

58 authors
29 institutes

FP420 plans

- Feasibility study for the development of detectors to measure protons at 420 m from the IP, during low β optics at the LHC
  - Main physics aim pp $\rightarrow$ p+ X + p
    - Higgs, New physics
    - QCD studies
    - Photon induced interactions
- First meeting at FNAL April 26 2005
  - Green light for the UK funds
  - Decide to submit a LOI to the LHCC
- Further meetings/collaboration web page

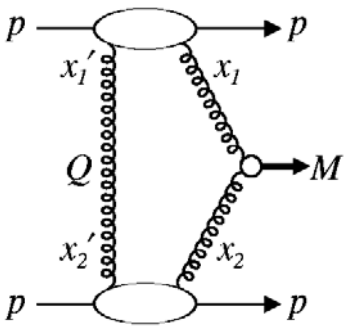
  http://www.fp420.com
- Next meeting 11 October at CERN

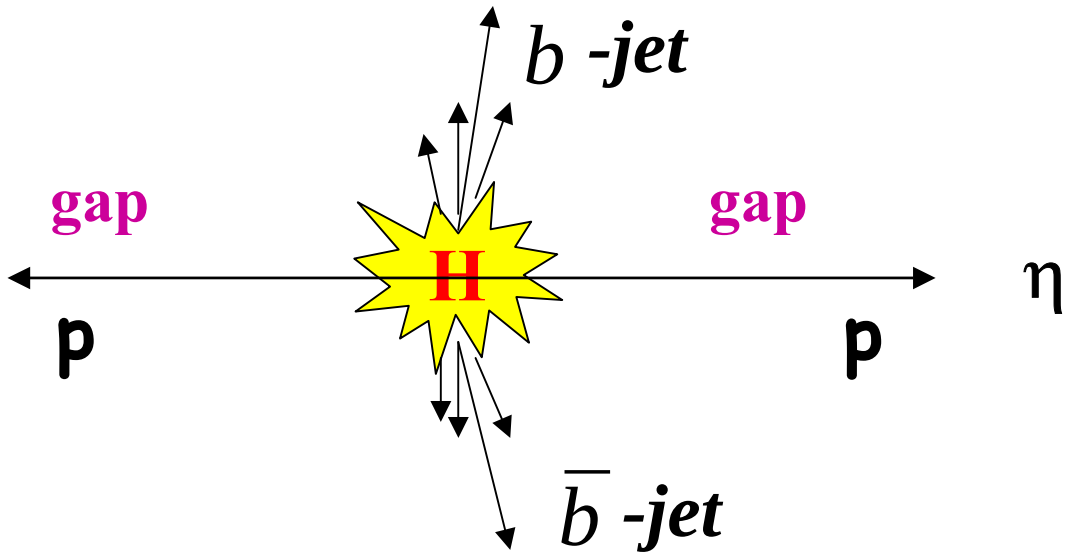
  Note: this is an open (proto-)collaboration

Contacts: B. Cox (Manchester), A. De Roeck (CERN)

Diffractive Higgs Production

Exclusive diffractive Higgs production pp→ p H p : 3-10 fb
Inclusive diffractive Higgs production pp → p+X+H+Y+p : 50-200 fb

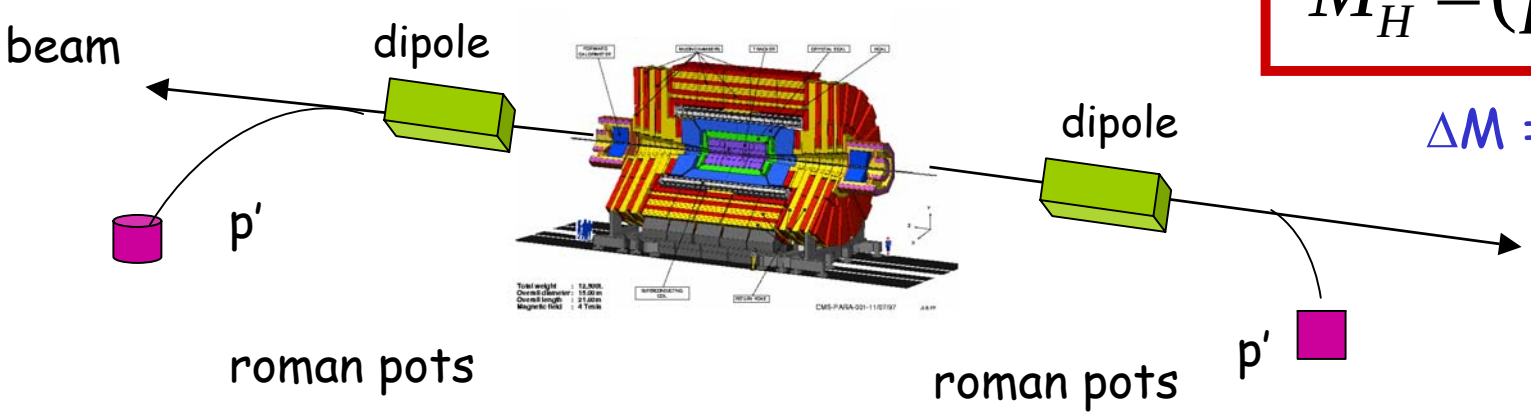




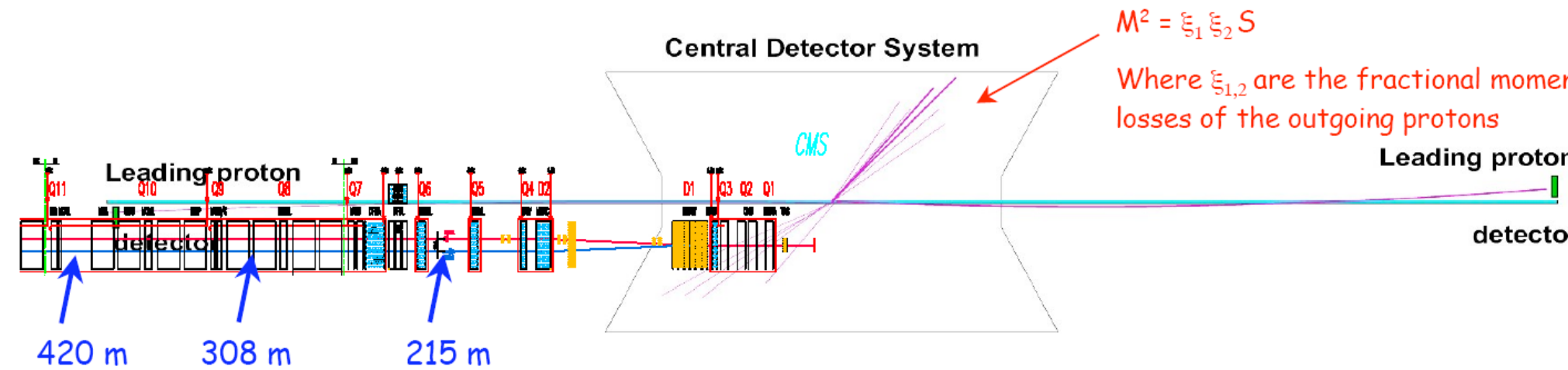
E.g. V. Khoze et al
M. Boonekamp et al
B. Cox et al.
V. Petrov et al…
Levin et al…

$$M_H^2 = (p + \bar{p} - p' - \bar{p}')^2$$

ΔM = O(1.0 - 2.0) GeV

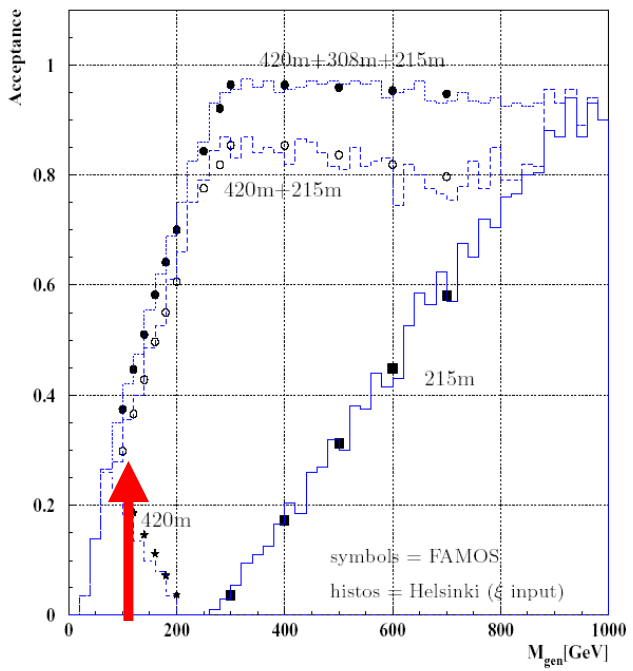


Roman pot acceptances



FD420

TOTEM (ATLAS)



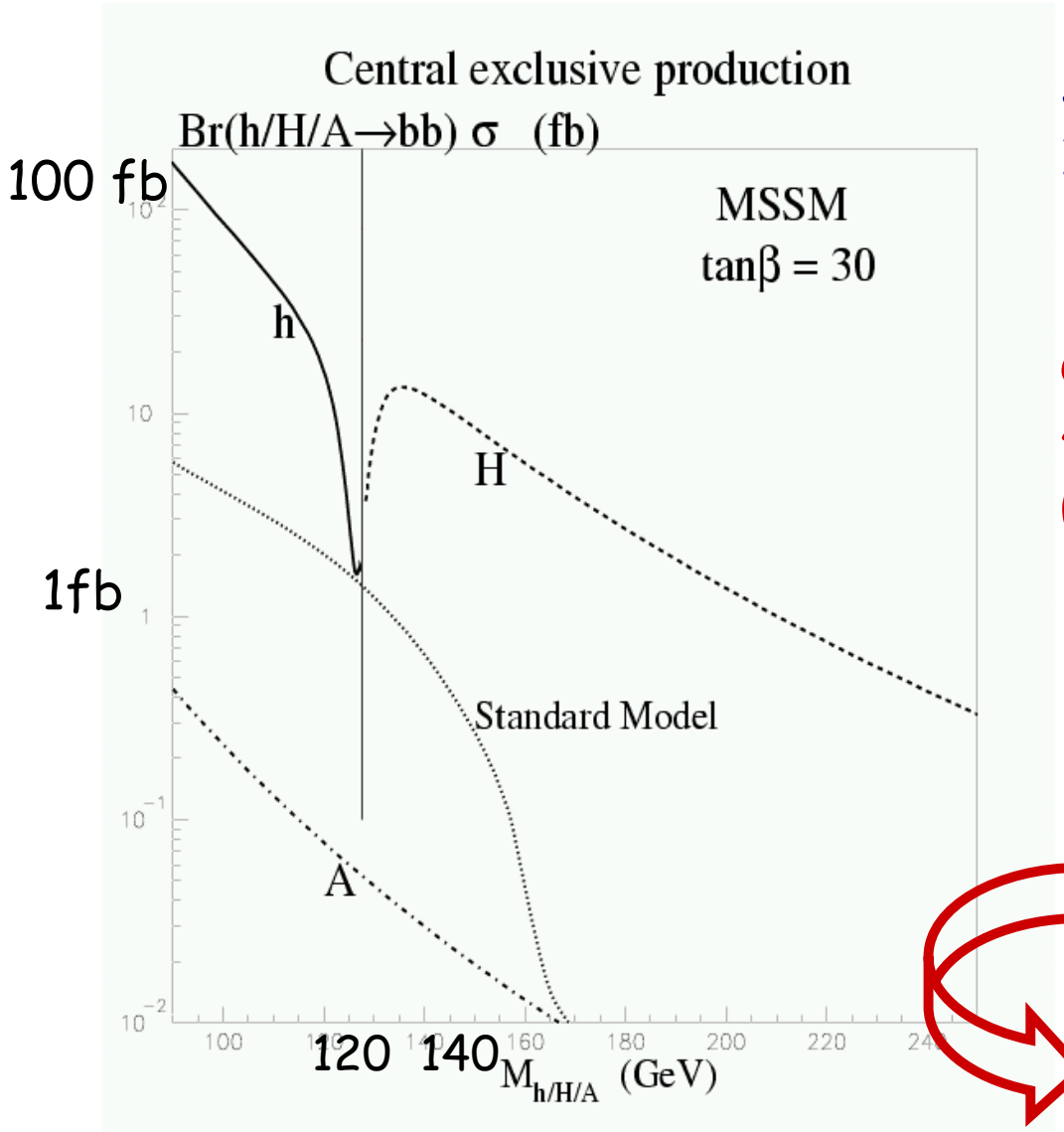
Low β^*: (0.5m): Lumi 10^{33}-10^{34}cm^{-2}s^{-1}

220m: $0.02 < \xi < 0.2$

300/400m: $0.002 < \xi < 0.02$

RPs in the cold region/FD420 are needed to access the low ξ values

Higgs Studies



SM Higgs: (30fb^{-1})
11 signal events (after cuts)
O(10) background events

Cross section factor
~ 10-20 larger in MSSM
(high tanβ)

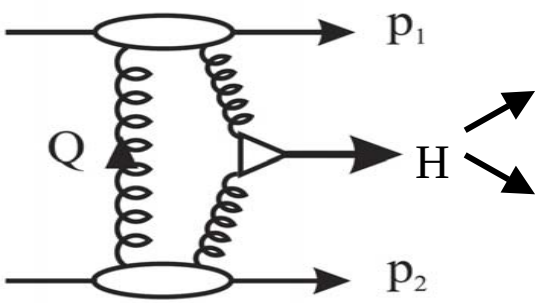
Kaidalov et al.,
hep-ph/0307064

⇒Study correlations between the outgoing protons to analyse the spin-parity structure of the produced boson

A way to get information on the spin of the Higgs
⇒ADDED VALUE TO LHC

Exclusive Higgs production

Standard Model Higgs



b jets : M_H = 120 GeV s = 2 fb (uncertainty factor ~ 2.5)

M_H = 140 GeV s = 0.7 fb

M_H = 120 GeV : 11 signal / O(10) background in 30 fb^{-1} with detector cuts

WW^* : M_H = 120 GeV s = 0.4 fb

M_H = 140 GeV s = 1 fb

M_H = 140 GeV : 8 signal / O(3) background in 30 fb^{-1} with detector cuts

- The b jet channel is possible, with a good understanding of detectors and clever level 1 trigger (need trigger from the central detector at Level-1)
- The WW^* (ZZ^*) channel is extremely promising : no trigger problems, better mass resolution at higher masses (even in leptonic / semi-leptonic channel)
- If we see SM Higgs + tags - the quantum numbers are 0^{++}

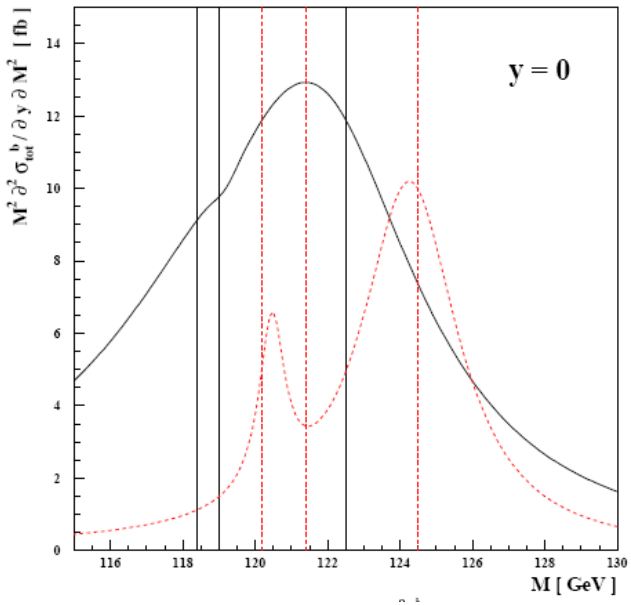
Phenomenology moving on fast

See e.g. J. Forshaw HERA/LHC workshop

"lineshape analysis"

J. Ellis et al.
hep-ph/0502251

Scenario with CP violation in the Higgs sector and tri-mixing

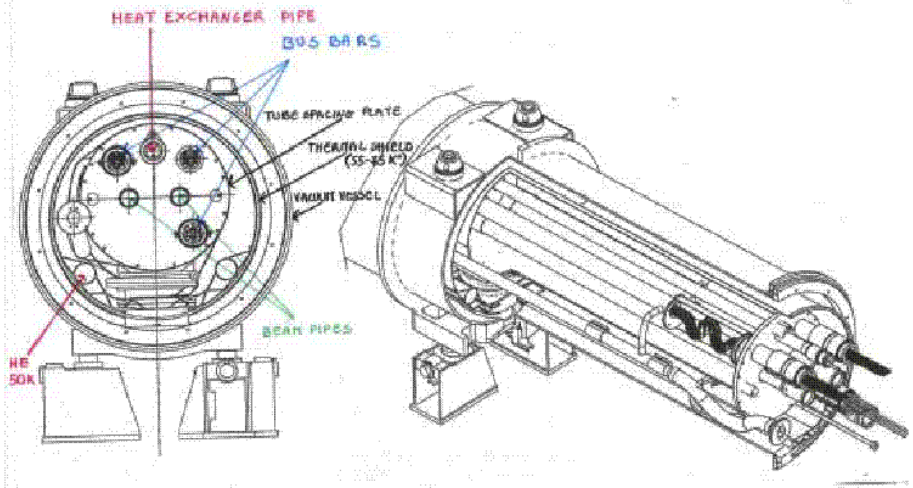


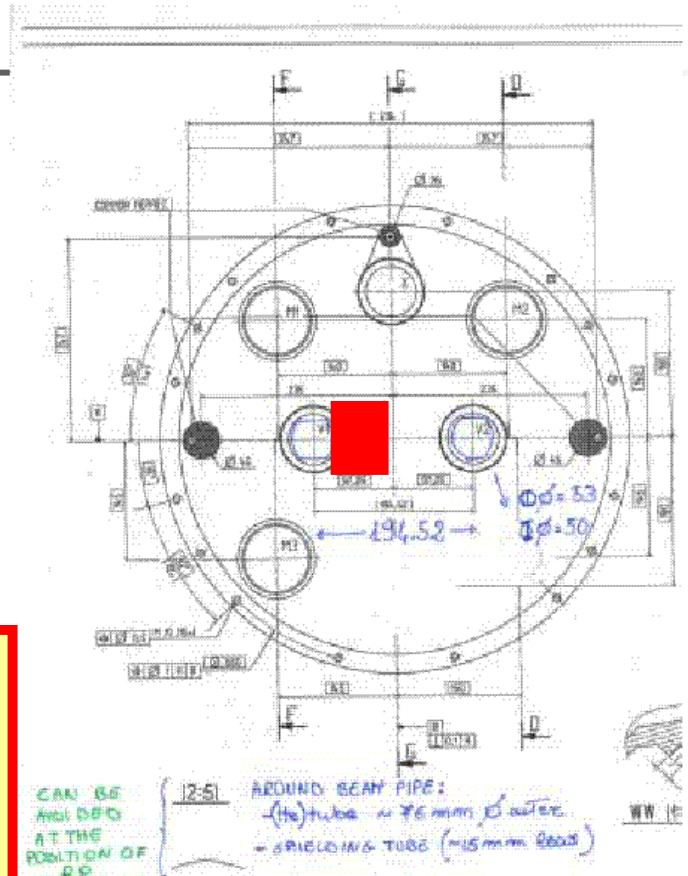
Experimental check: L. Rurua

This example shows that exclusive double diffraction may offer unique possibilities for exploring Higgs physics in ways that would be difficult or even impossible in inclusive Higgs production. In particular, we have shown that exclusive double diffraction constitutes an efficient CP and lineshape analyzer of the resonant Higgs-boson dynamics in multi-Higgs models. In the specific case of CP-violating MSSM Higgs physics discussed here, which is potentially of great importance for electroweak baryogenesis, diffractive production may be the most promising probe at the LHC.

Detectors at 300/400m

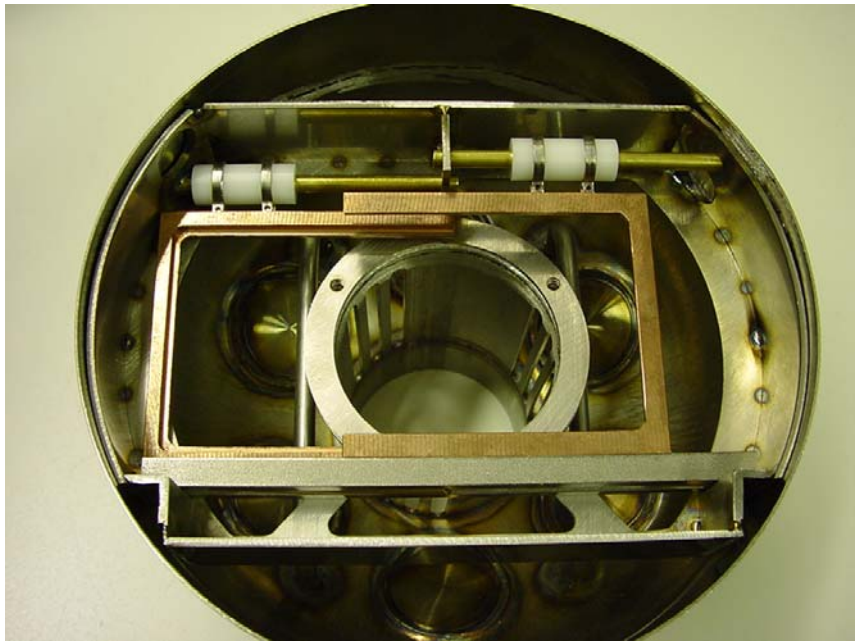
- Cold section: Detectors have to be integrated with cryostat
  Two options discussed with the machine
  Prefered option: 15m cold-warm transition with the detectors at 'room' temperature.



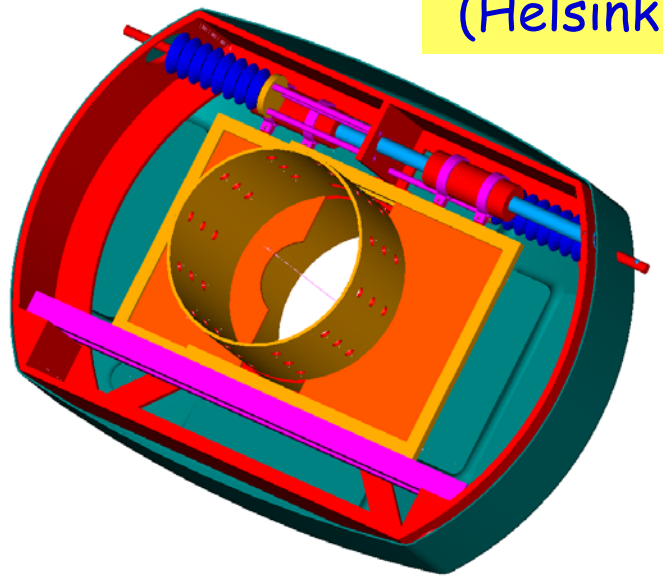


- Many machine components already ordered, some already delivered
- Machine wants "easy" start-up/no perturbation
  ⇒ Change means an "LHC upgrade" (phase II)
  ⇒ aim for 2009 run

Detectors: micro stations…

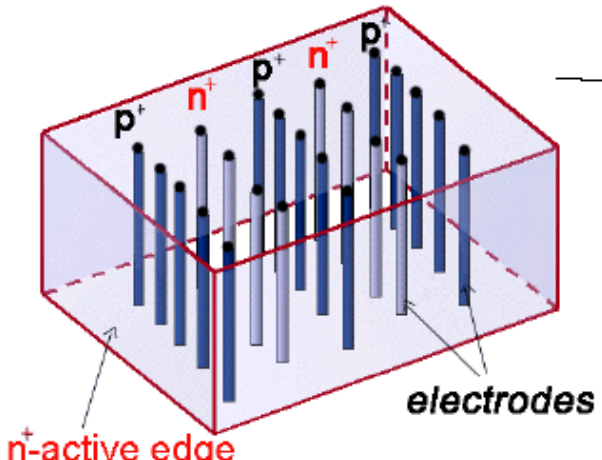


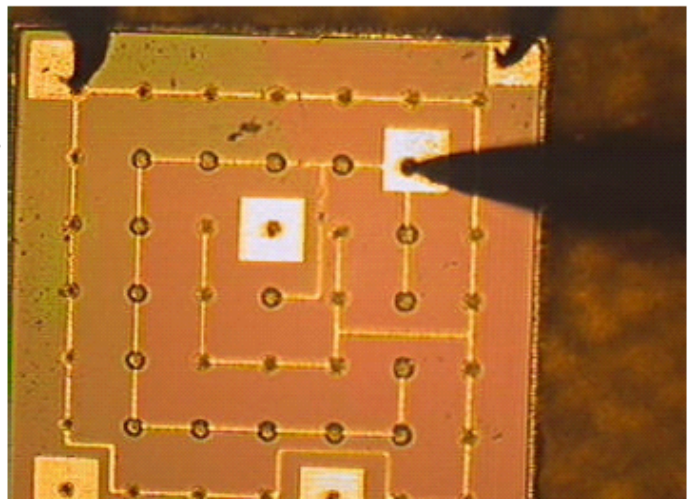
μ-station concept
(Helsinki propsal)



3D DETECTORS AND ACTIVE EDGES

Brunel, Hawaii, Stanford





Summary

- Diffractive and forward physics is on the physics program of LHC experiments. CMS+TOTEM developing, working towards a LOI.
  - ⇒ Diffractive and forward physics will be done from the start at the LHC
  - ⇒ Don't hesitate to come up with new ideas, new measurements, new test!
- Upgrades for the experiments are being proposed
  - In particular large momentum for 420m region is materializing.
  - CMS/ATLAS expand coverage in the forward coverage
- Large field of Physics Topics
  - Hard (& soft) diffraction, QCD and EWSB (Higgs), New Physics
  - Low-x dynamics and proton structure
  - Two-photon physics: QCD and New Physics
  - Special exotics (centauro's, DCC's in the forward region)
  - Cosmic Rays, Luminosity measurement, pA, AA…

- Opportunities for present/new collaborators to join forward physics
  - ⇒ No doubt will provide useful measurements for the CR community

Running Scenarios

Scenario Physics:	1 low |t| elastic, σ_{tot}, min. bias, soft diffraction	2 diffraction	3 large |t| elastic	4 hard diffraction large |t| elastic (under study)
β^* [m]	1540	1540	18	90
N of bunches	43	156	2808	936
N of part. per bunch	0.3×10^{11}	$(0.6 - 1.15) \times 10^{11}$	1.15×10^{11}	1.15×10^{11}
Half crossing angle [μrad]	0	0	160	100
Transv. norm. emitt. [μm rad]	1	1 - 3.75	3.75	3.75
RMS beam size at IP [μm]	454	454 - 880	95	200
RMS beam diverg. [μrad]	0.29	0.29 - 0.57	5.28	2.4
Peak luminosity $[cm^{-2} s^{-1}]$	1.6×10^{28}	2.4×10^{29}	3.6×10^{32}	2×10^{31}

CMS+TOTEM: Diffraction at $\beta^* = 0.5$ m