LHC physics: lessons and prospects

Symposium for the 20th anniversary of the accession of the Czech Republic to CERN

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Moreover

- Point 1 gives us something concrete to plan the future around
    - *..... despite the fact that nothing else, among the many anticipated new BSM manifestations, as been found*
- Points 2 and 3 justify a new, higher, degree of ambition in this planning

Outline

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3. Pushing the precision goals of LHC physics

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4. Conclusions

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“Higgs boson”:

- The physical excitation of a scalar field, whose vacuum expectation value breaks SU(2)⊗U(1) gauge invariance

“SM” Higgs boson:

- As above, but in addition:
  - the field is elementary (i.e. not composite)
  - it sits in a **single** $SU(2)_W$ **doublet**, it is the sole responsible of the masses of all fermions and EW gauge bosons

Examples

The following coupling breaks gauge symmetry, it is a Higgs coupling:

$$L = \frac{g^2}{4}\ (v + H(x))^2\ W^+_\mu W^{-\mu} = m_W^2\ W^+_\mu W^{-\mu}\ +\ \frac{2m_W^2}{v}\ HW^+_\mu W^{-\mu}$$

This coupling does not break gauge invariance:

$$L = A\frac{\alpha}{4\pi}\frac{1}{M}\ H\ F_{\mu\nu}F^{\mu\nu} + B\frac{\alpha}{4\pi}\frac{1}{M}\ H\ F_{\mu\nu}\tilde{F}^{\mu\nu}$$

This is what happens, e.g., in Hgg and Hγγ, where A~1, B=0, M~(m_{top},m_W) and α~(α_S,α_{em}), resp.

Notice: it H did not break gauge invariance, its coupling to W and Z would be O(α) (like for its coupling to photons), not of O(1)!!

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- why is $BR(H \to ZZ^*) >> BR(H \to \gamma\gamma)$
- why $BR(H \to ZZ^*)/BR(H \to \gamma\gamma)$ is so close to the SM value (in non-Higgs interpretations, this is typically a pure accident, even if the previous point holds)
- if *Whatever(126)* does not break EW symmetry:
  - what does it, in these models?
  - given the strong limits on the Higgs, how do these models reconcile with the EW precision tests?

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I think it is fair to say that no Higgs-impostor model proposed so far answers in a satisfactory way to all these questions

The clarification of the exact details of the EWSB mechanism, and of whether this is just SM or whether it involves more structure: extra Higgs fields, SUSY or other new symmetries, new strong interactions, all-of-the-above, and-more ....
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- Search for independent evidence of BSM phenomena, possibly directly linked to EWSB

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(2) $m_H^2 = m_Z\, m_{top} \times (1.00 \pm 0.01_{(mH,\, mtop)})$!!

(1) has been known for a while, and we still don't know what it is telling us.
(2) is new, and looks even weirder and more misterious!

Why is it challenging?

Production rates are large ....

N events / fb^{-1}	8 TeV	14 TeV
$N(H\to\gamma\gamma)$	50	130
$N(H\to ZZ^*)$	3	7
$N(H\to WW^*)$	240	620
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..... **BUT**

- large backgrounds force to impose tight selection cuts, reducing the signal efficiency and the statistical power of these large event samples
- large theoretical uncertainties limit the precision of the extraction of Higgs couplings

Why is it challenging?

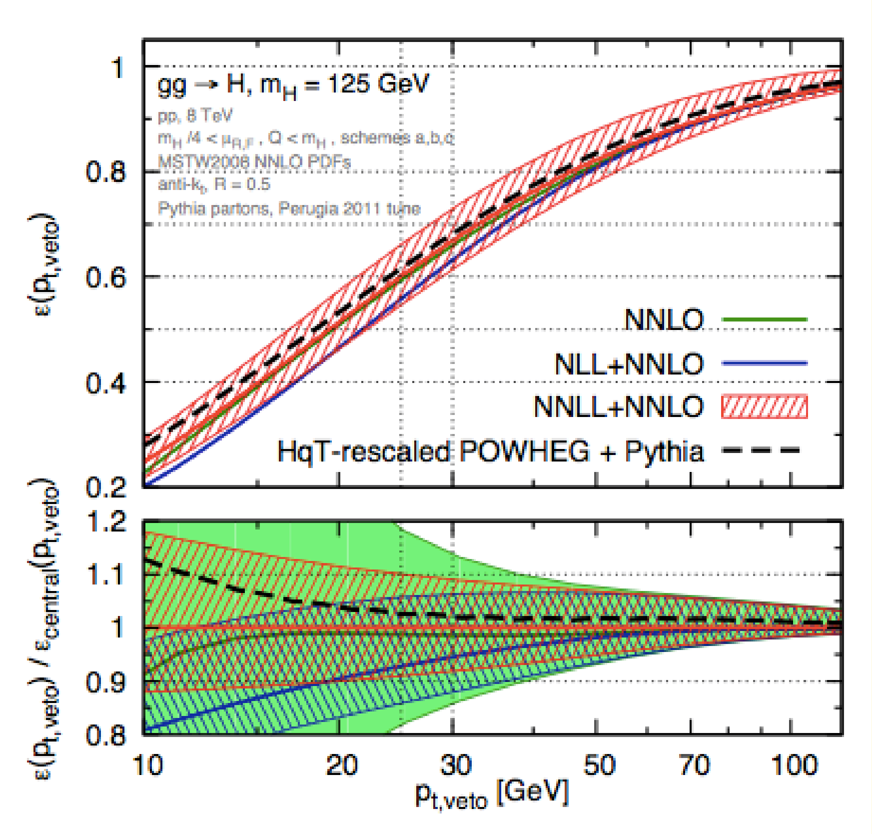
H coupling ~ N(events) / [Lum x σ_{TH}(coupling=1) x efficiency (selection cuts)]

Theoretical uncertainties on production rates

14 TeV	δ(pert. theory)	δ(PDF, α_S)
gg→H	± 10 %	± 7%
VBF (WW→H)	± 1 %	± 2%
qq→WH	± 0.5 %	± 4%
(qq,gg)→ZH	± 2 %	± 4%
(qq,gg)→ttH	± 8 %	± 9%

Theoretical uncertainties on modeling of selection cuts.

Ex. jet veto efficiency, required to reduce bg's to H→WW*



Banfi, Monni, Salam, Zanderighi, arXiv:1206.4998

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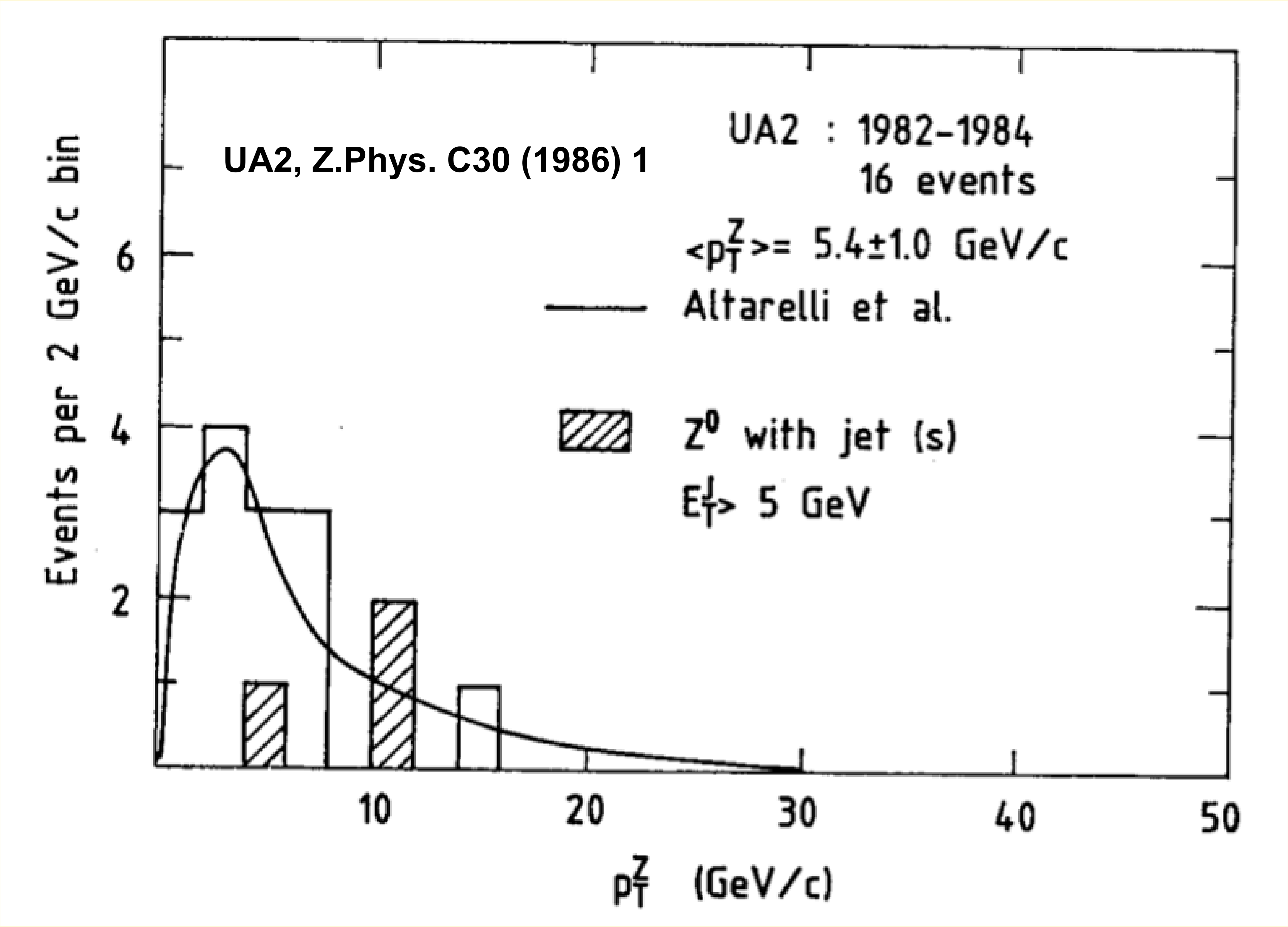
To put it in perspective, W/Z physics started like this ....., from a score of events:



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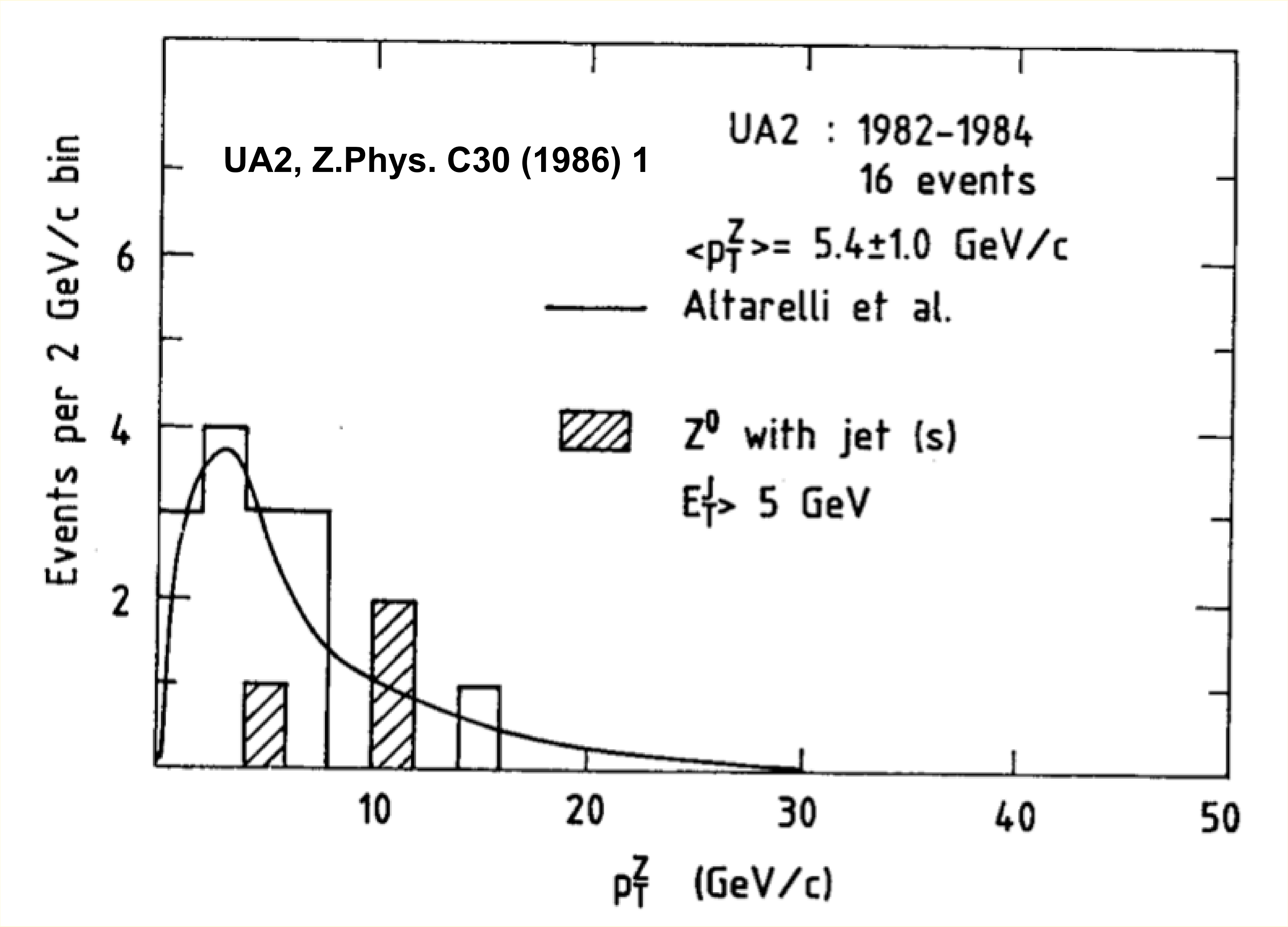
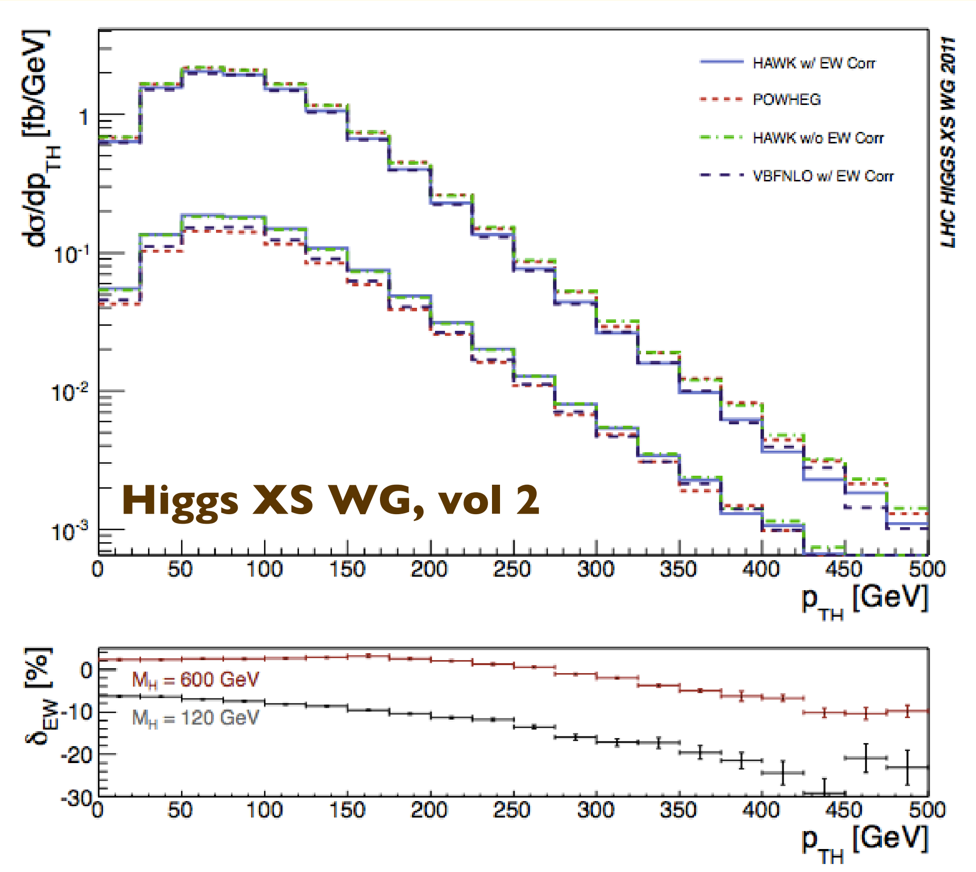


Looking forward to the first measurement of $p_T(gg \to H \to ZZ^*)$ with the 15-20 events that you will have by the end of 2012!

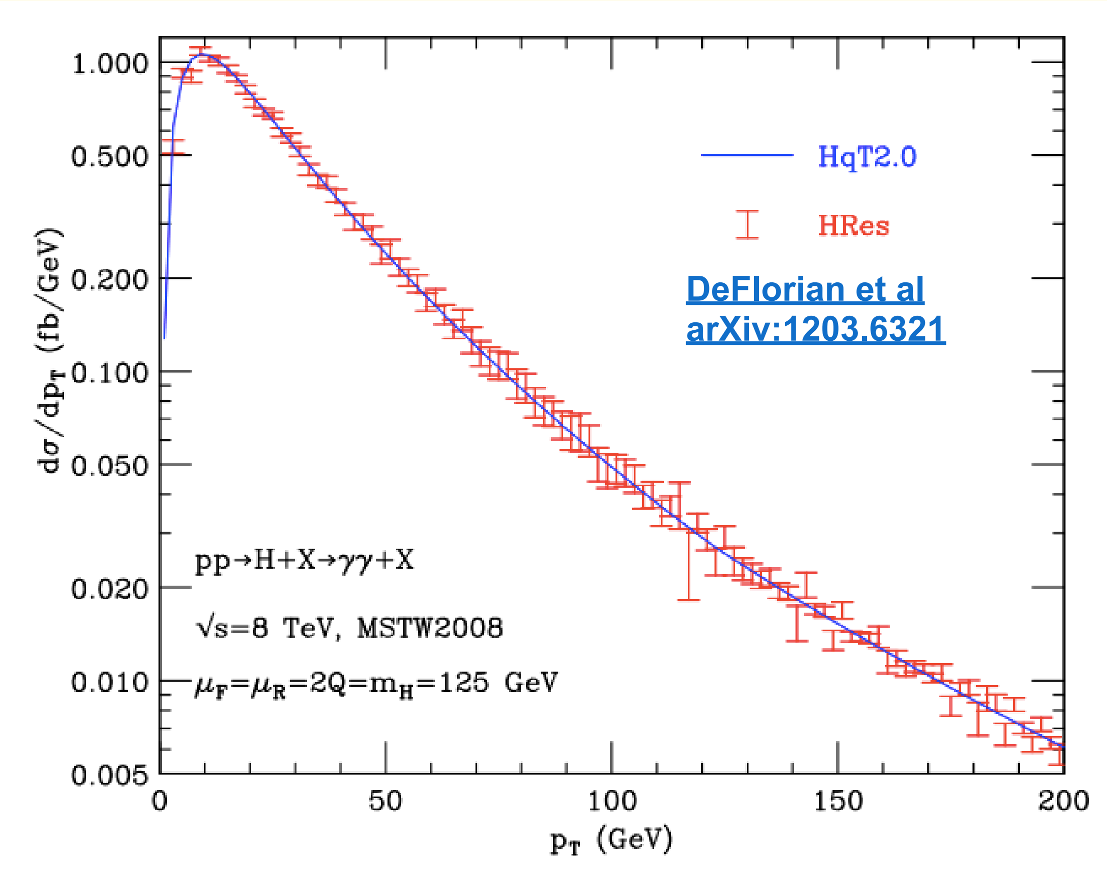
Much will be learned to improve our QCD modeling of Higgs production, form the thousands of ($gg \to H \to ZZ^*$) events that will become available in the future

p_T(H) in qq → qq H



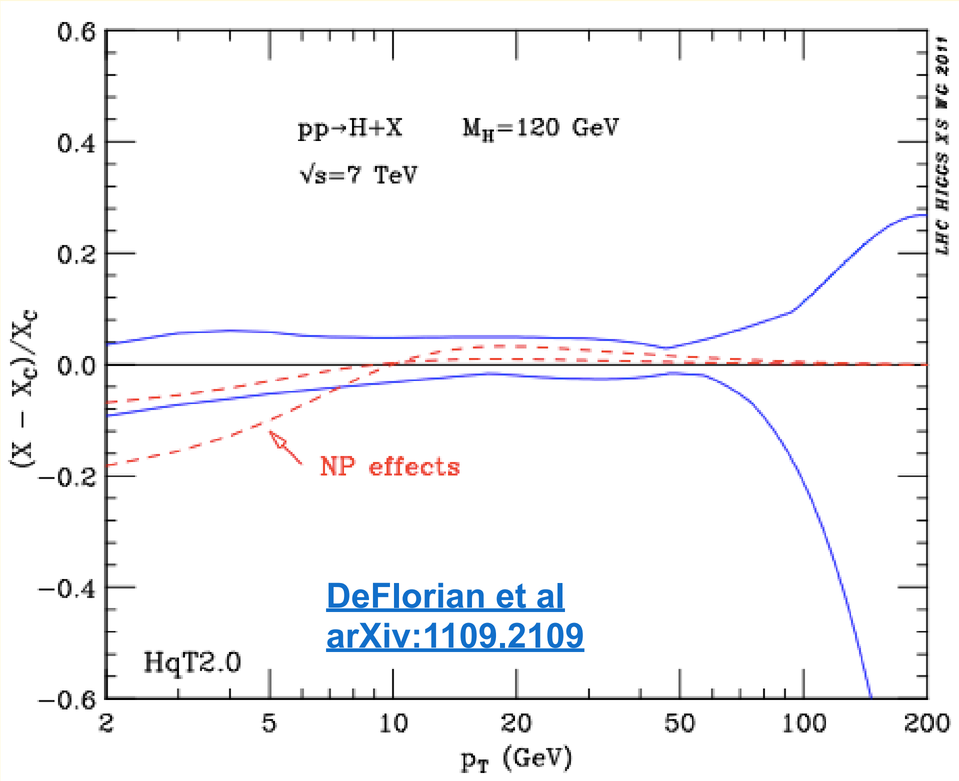
p_T(peak)~60 GeV

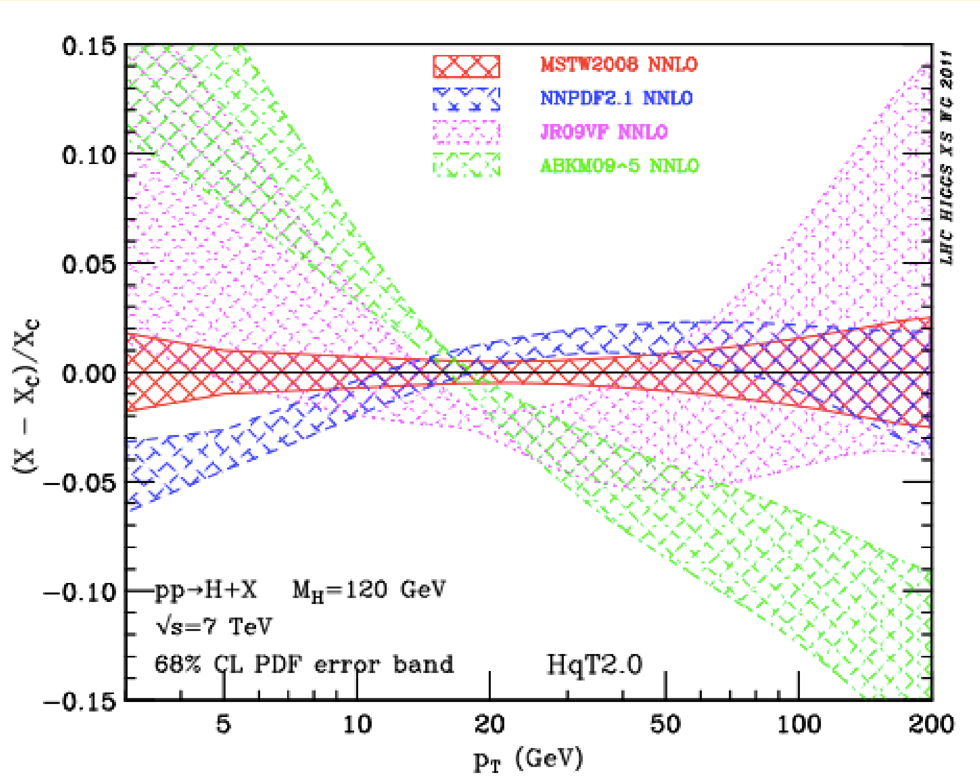
p_T(H) in gg → H



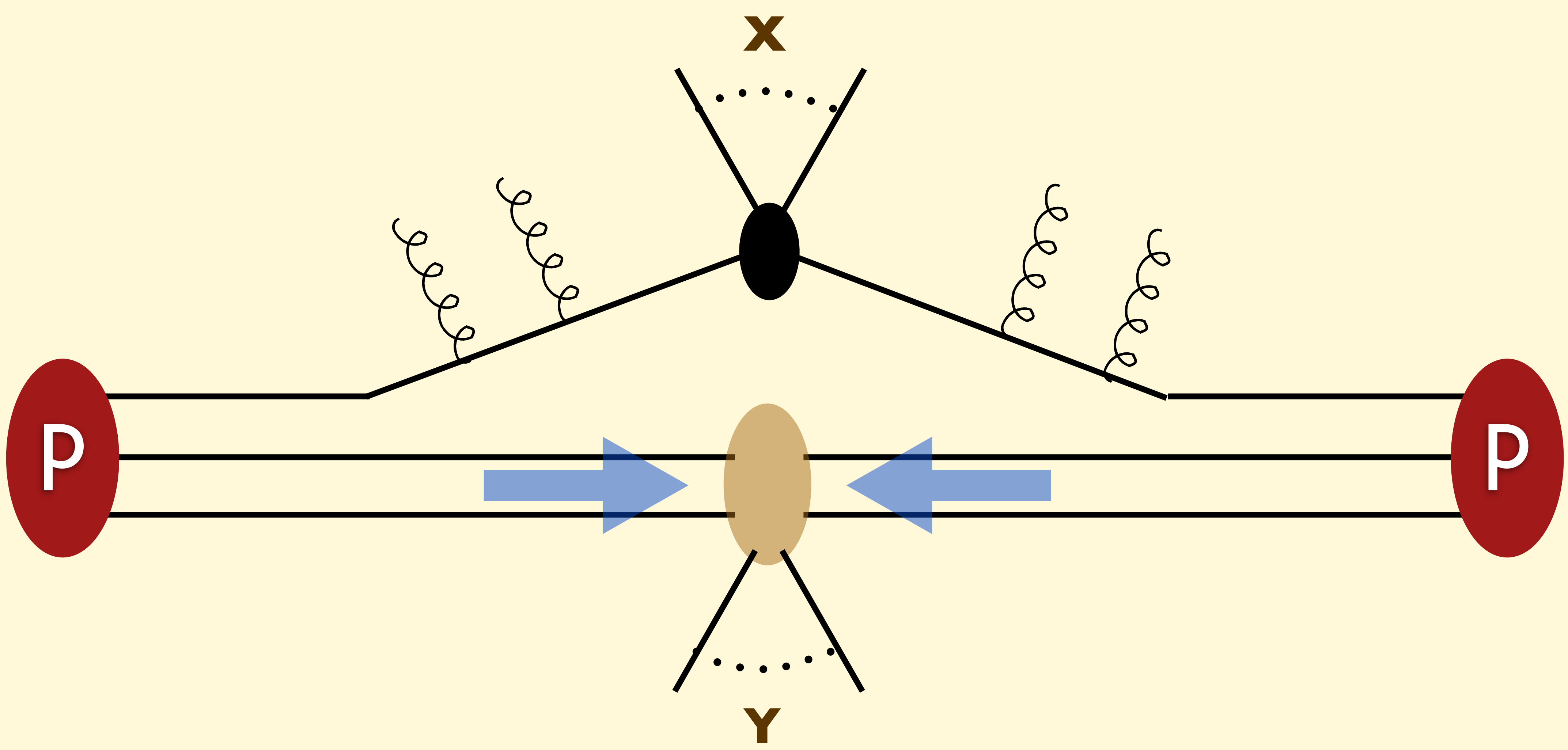
p_T(peak)~10 GeV

TH systematics for p_T(H) in gg → H





Snapshot of a hard pp collision



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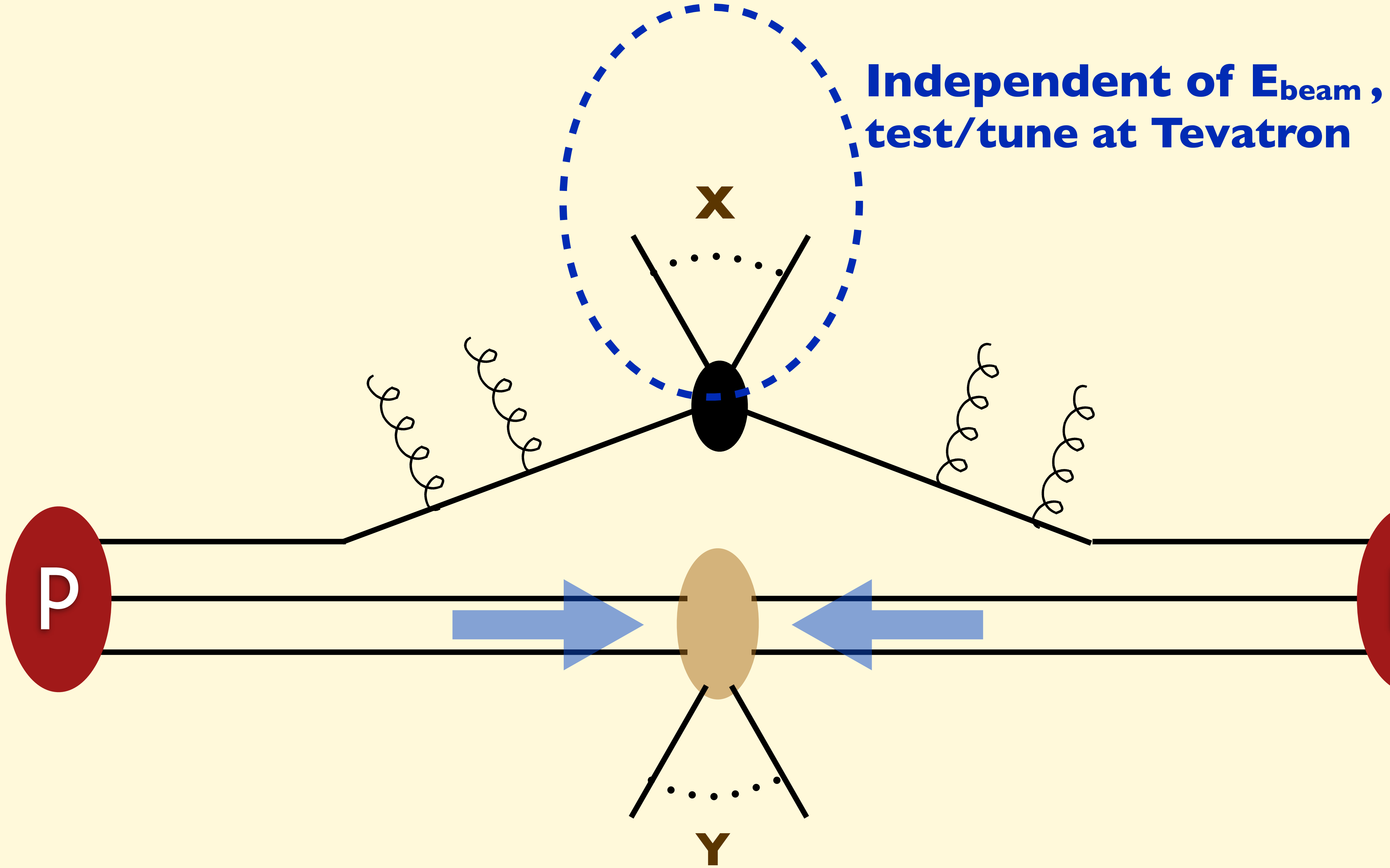
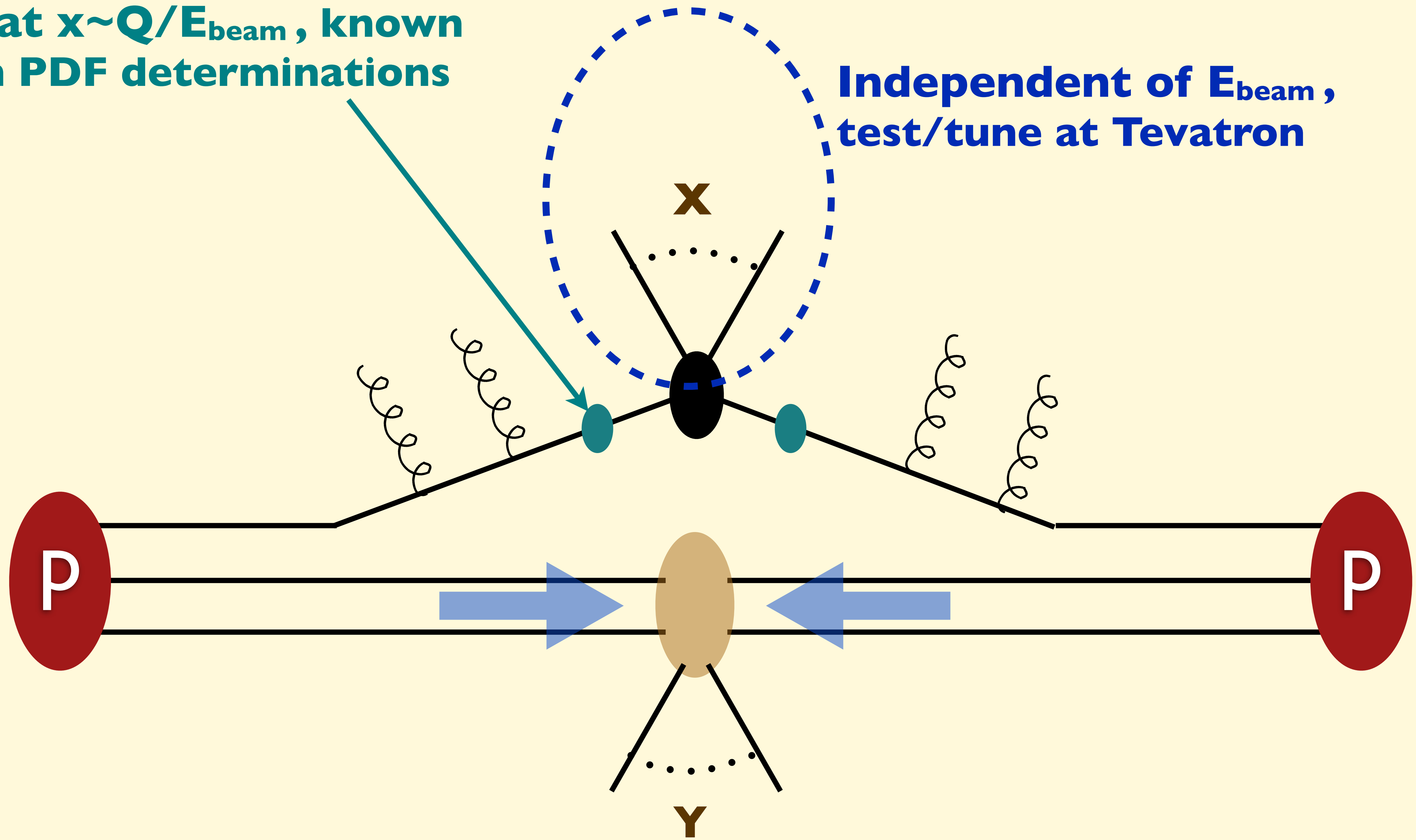


Snapshot of a hard pp collision

f(x) at x~Q/E$_{beam}$, known from PDF determinations

Independent of E$_{beam}$, test/tune at Tevatron



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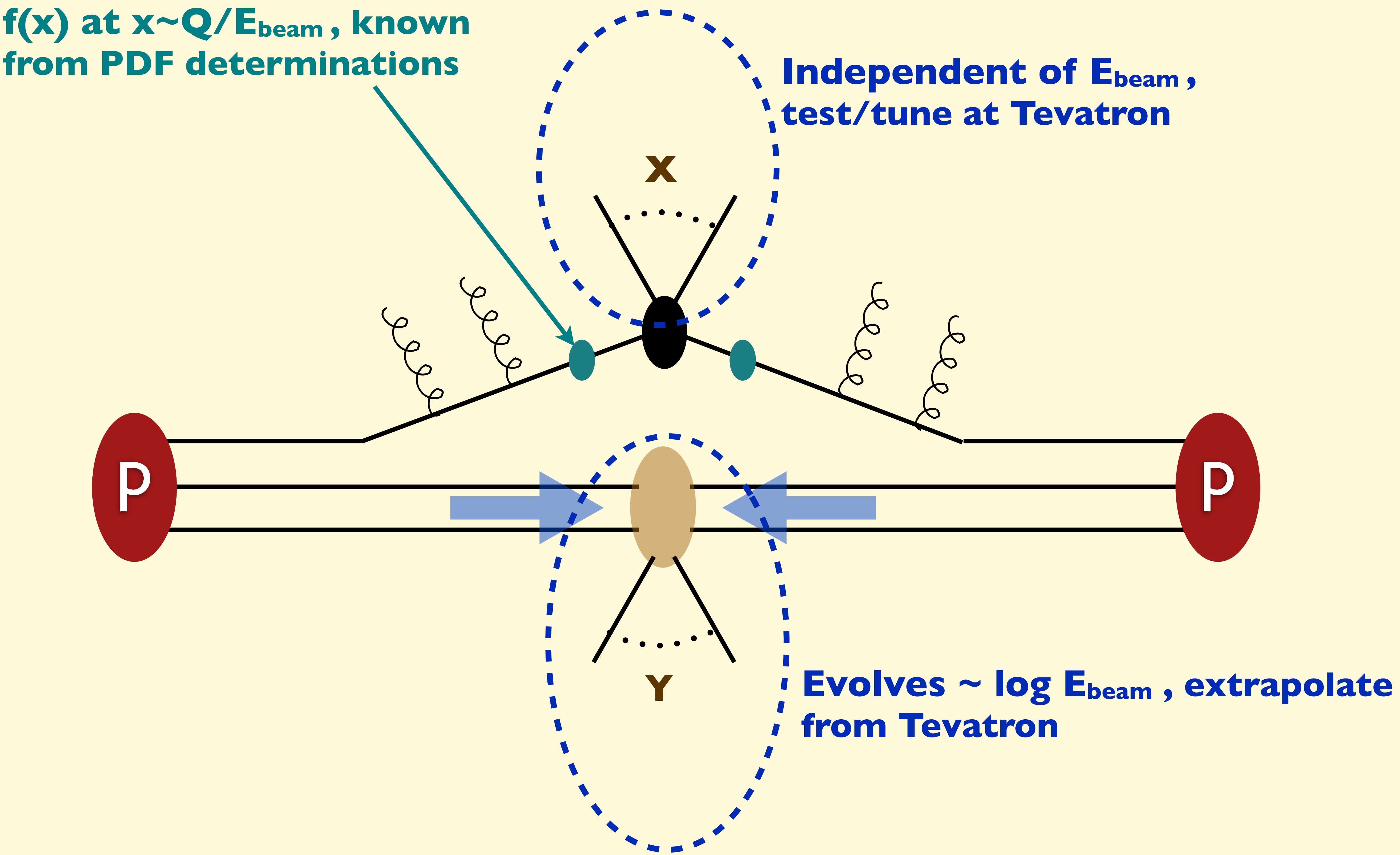

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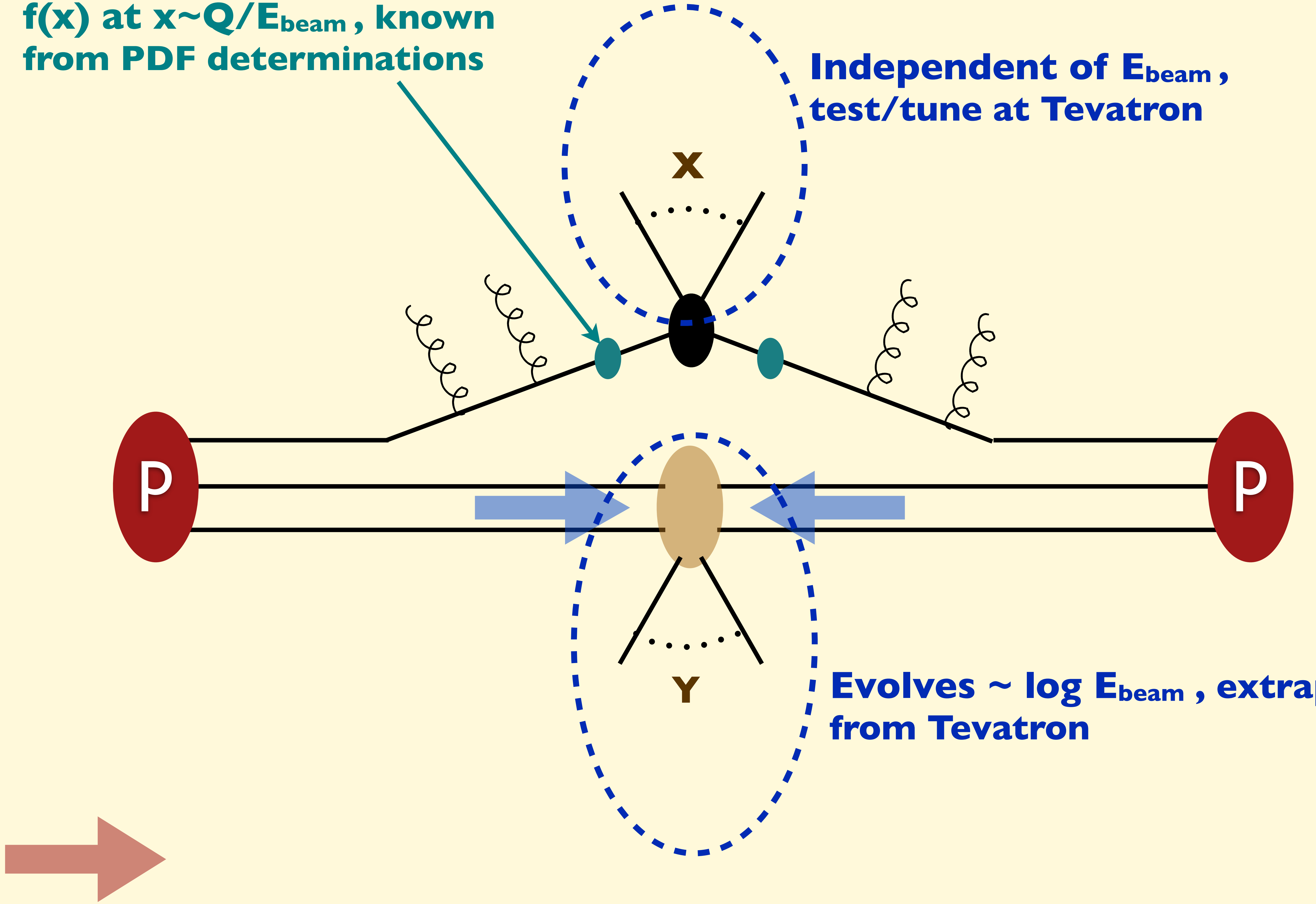

Evolves ~ log E_{beam}, extrapolate from Tevatron

all seems to be under control and easily predictable at the LHC

... on the other hand ...

- the energy reach at the LHC is such that in many instances we are exploring kinematical regions never probed before
- cross sections for many processes of interest at the LHC were too small at the Tevatron to give significant tests of our dynamical understanding
- this is particularly true of
  - final states with many jets, especially if produced in association with gauge bosons and/or heavy quarks (such as bottom and top)
  - vector-boson fusion configurations
  - etc.
- Last but not least:
  - **the experimental accuracy of LHC measurements sets new standards of precision for the theoretical calculations**

Describing the dynamics of LHC collisions: a renewed theoretical challenge

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- Validation: comparison of predictions against a huge body of LHC experimental data

Example of PDF uncertainties: impact on the gg->H cross section

G. Watt, http://arXiv.org/pdf/1106.5788

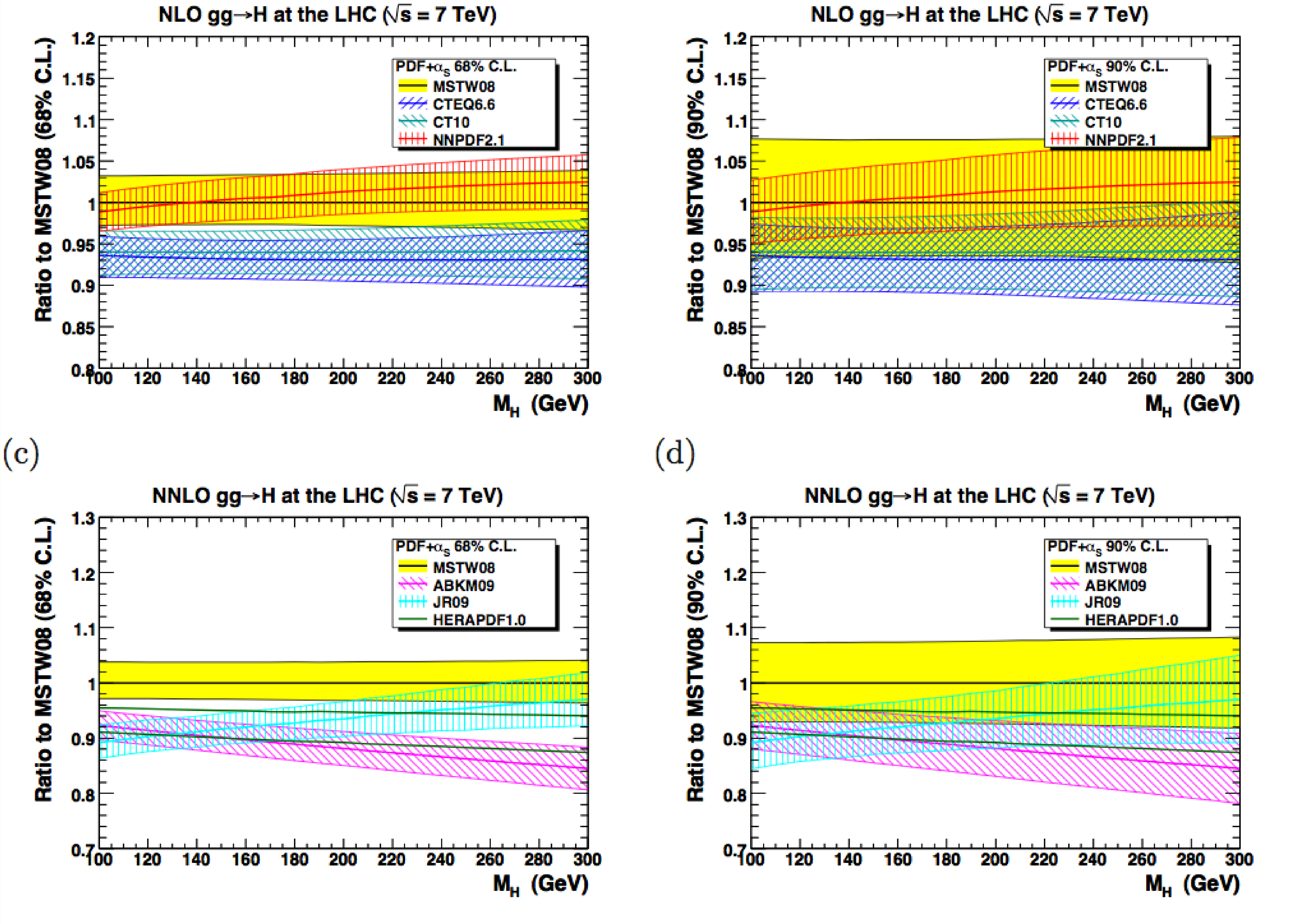
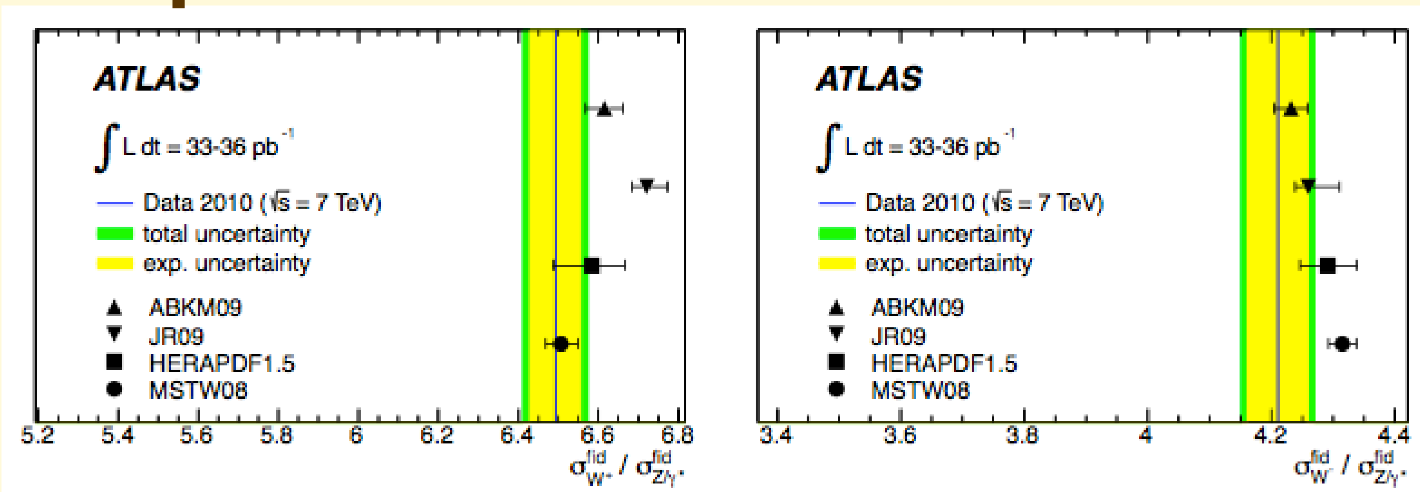
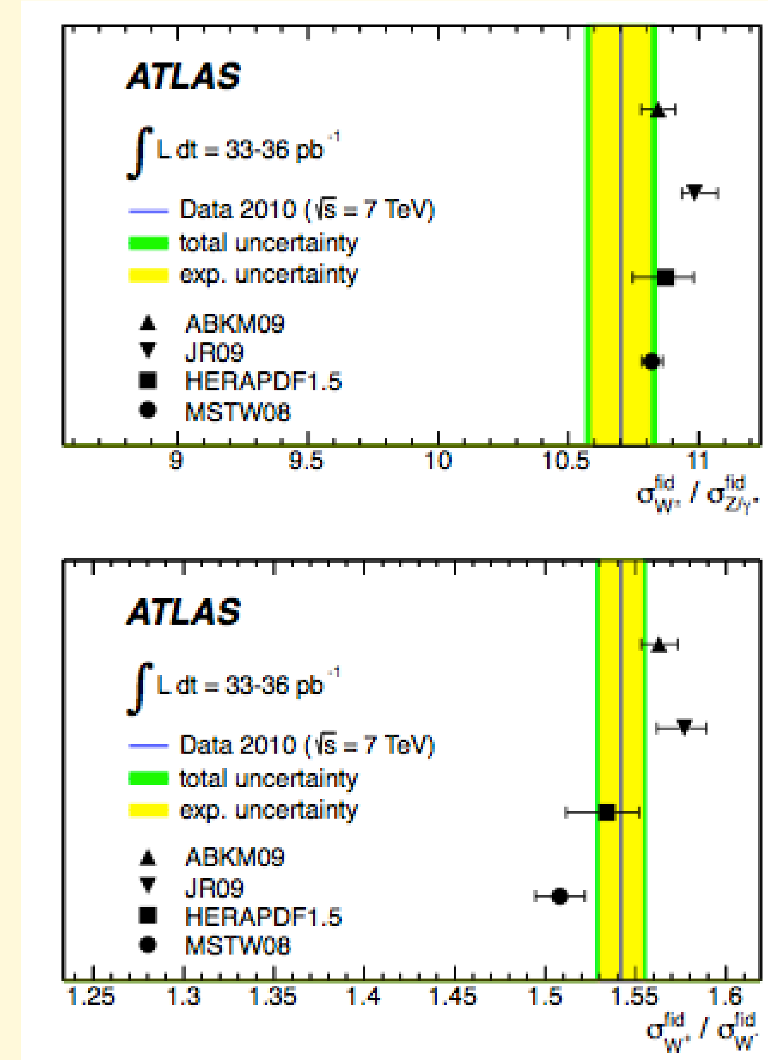
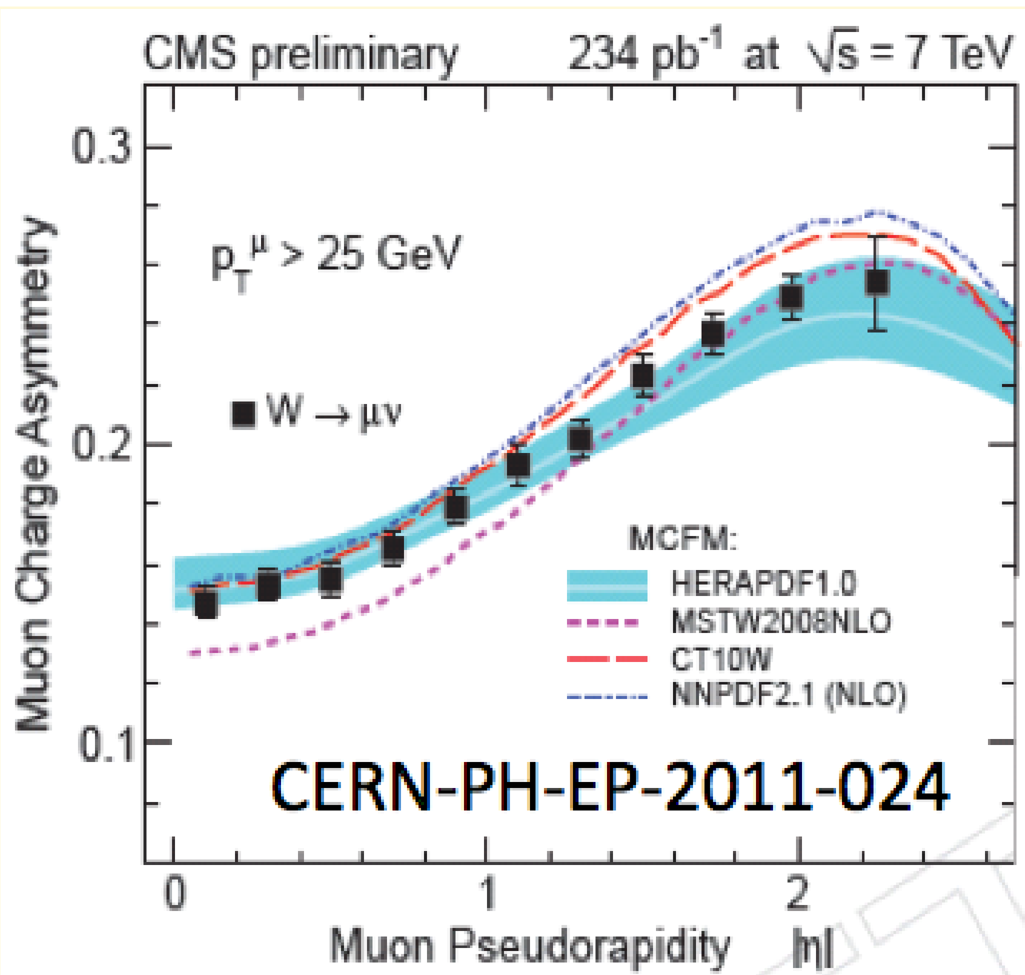


Figure 15. Ratio to the MSTW08 prediction for $gg \to H$ with PDF+α_S uncertainties for (a) NLO at 68% C.L., (b) NLO at 90% C.L., (c) NNLO at 68% C.L., (d) NNLO at 90% C.L.

Comparisons of various PDF sets to W/Z production data at the LHC







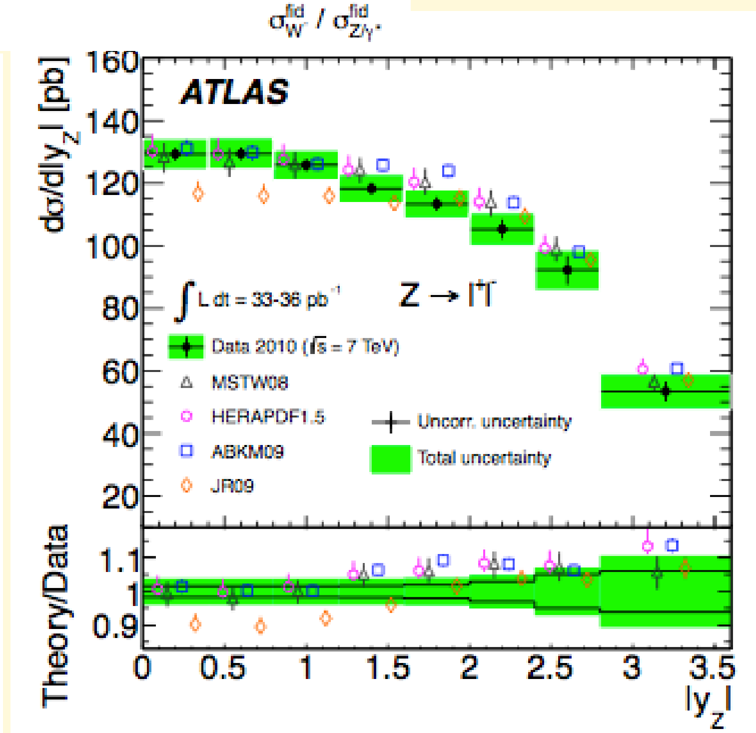


table entries NOT to be taken at face value!

	ABKM	JR	HERA	MSTW
W+/Z	☹	☹	☺	☺
W–/Z	☺	☺	☹	☹
W/Z	☺	☹	☹	☺
W+/W–	☹	☹	☺	☹
y(Z)	☹	☹	☹	☺
y(μ←W)			☺	☹

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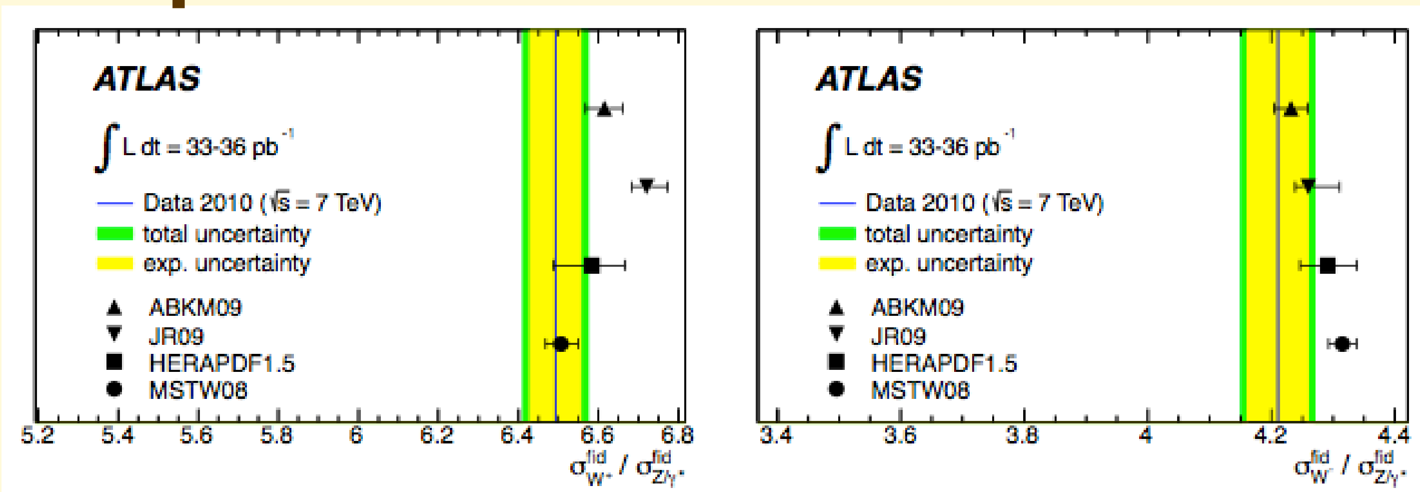

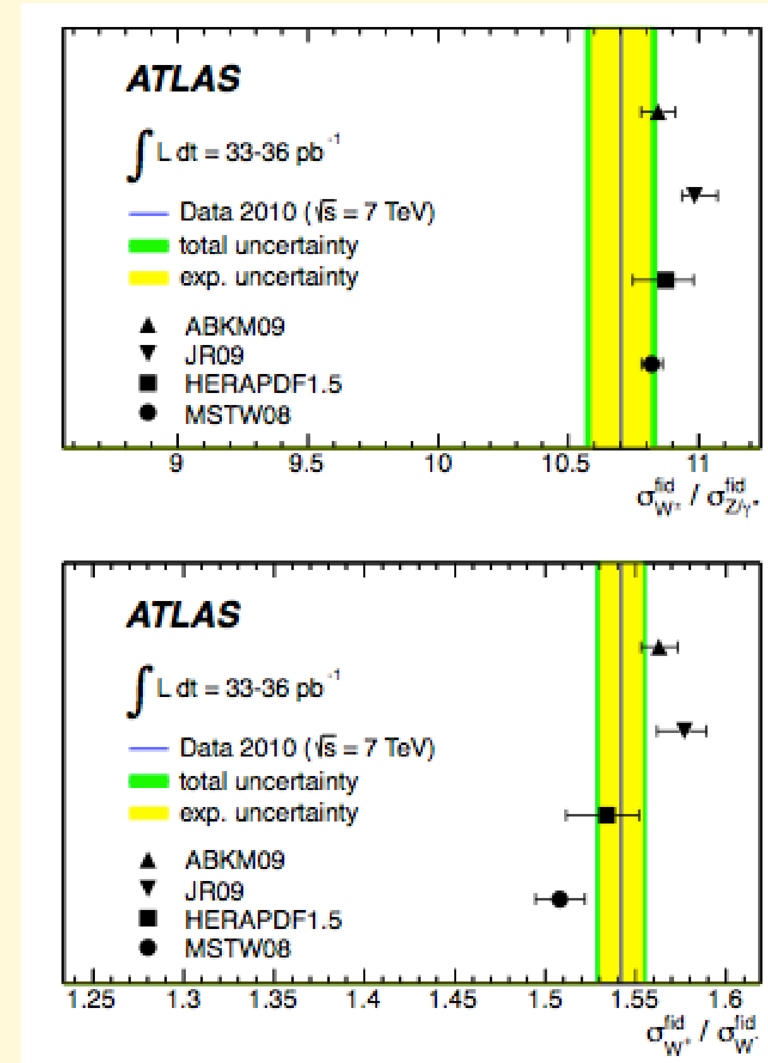

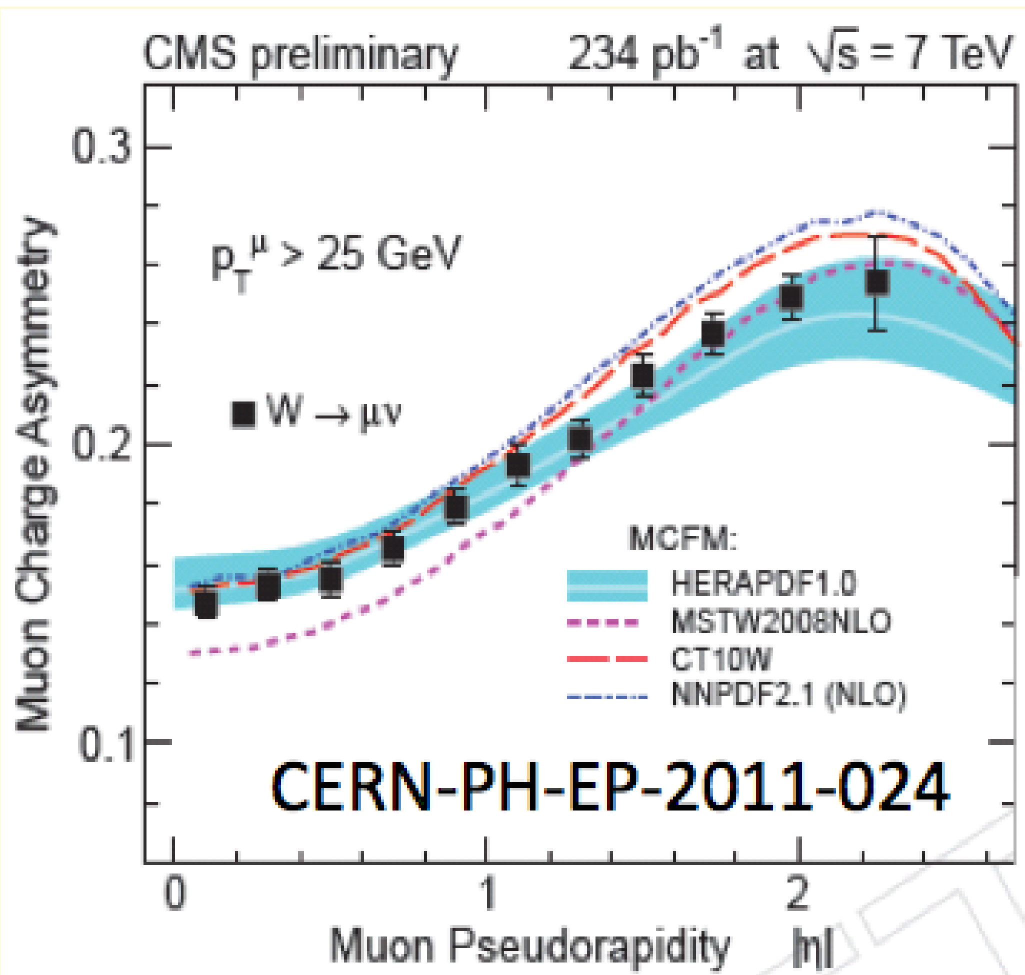

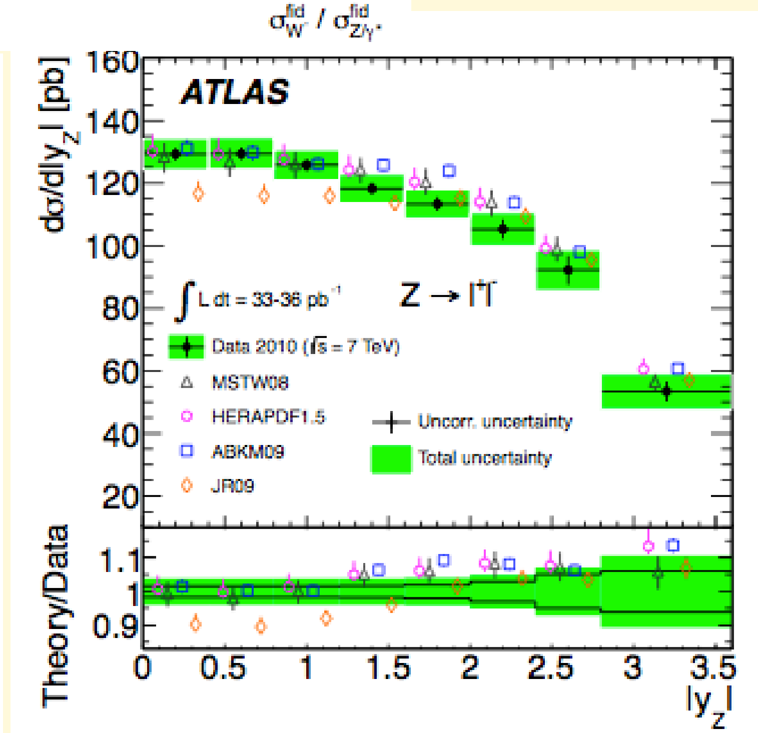

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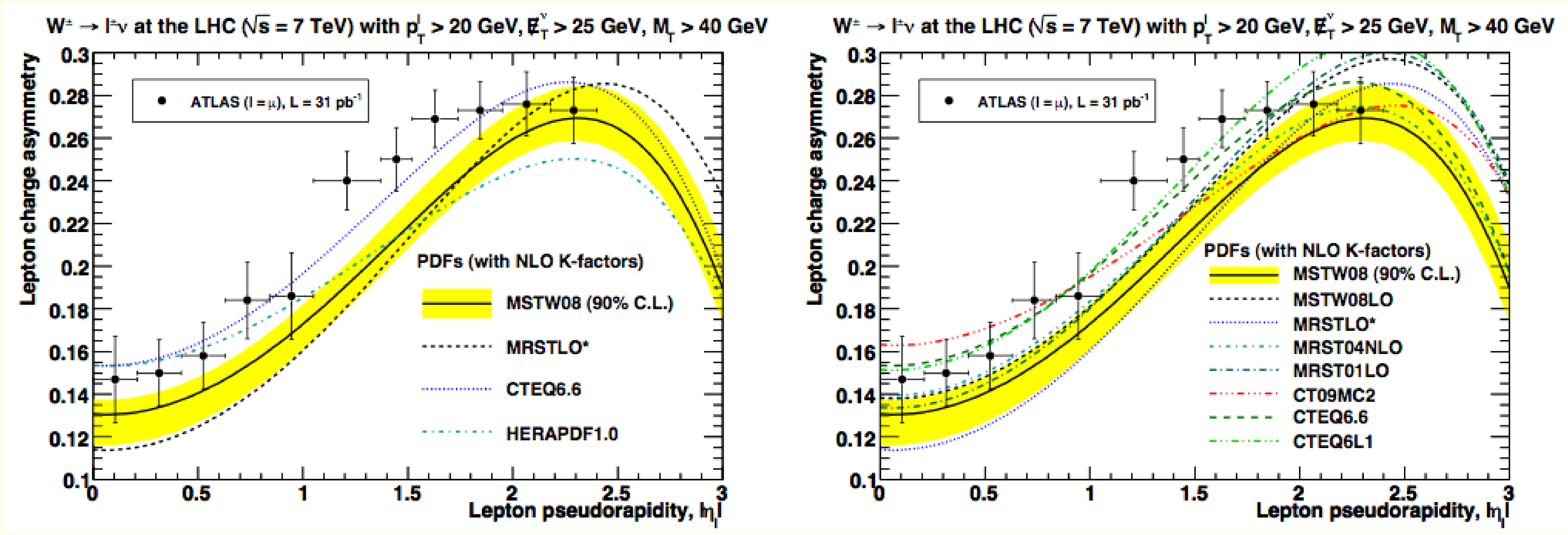
Need global fits of rates and distributions to judge which PDF set is best

Lepton charge asymmetry in W production

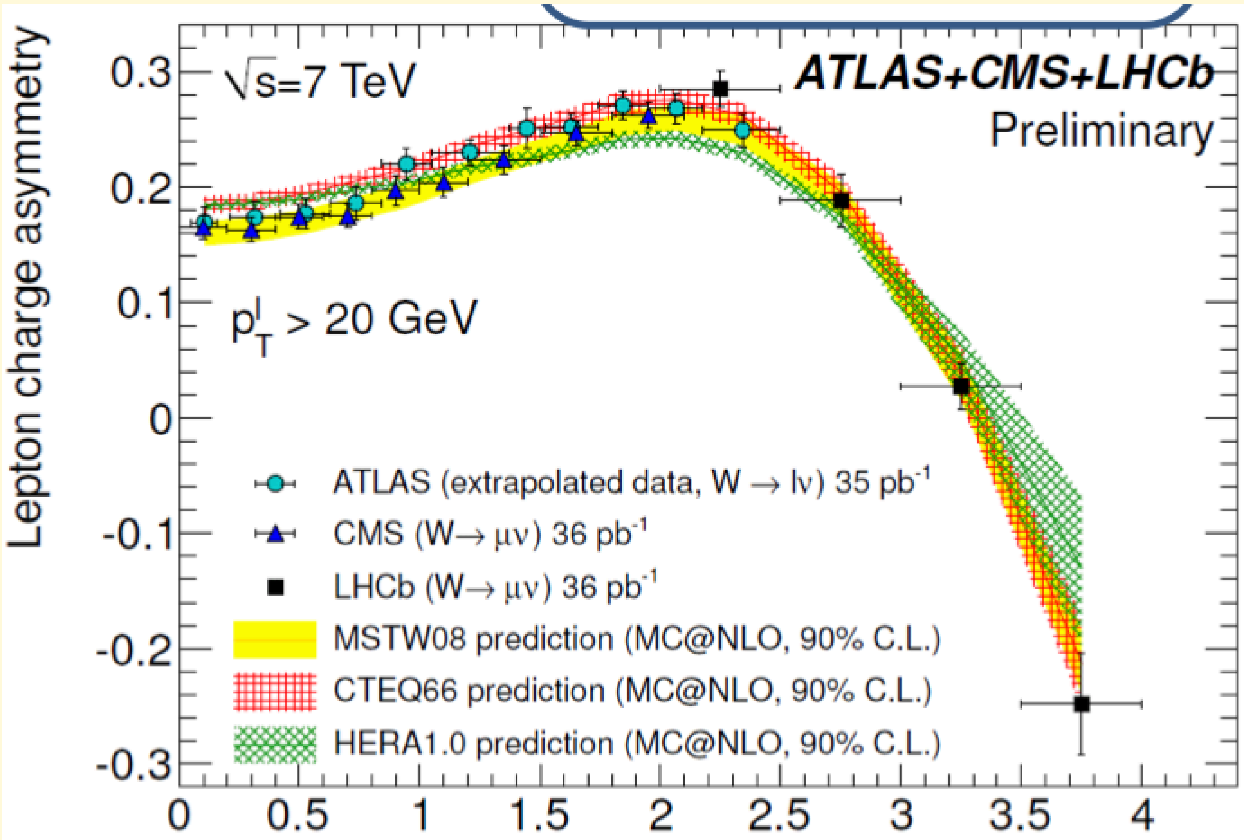


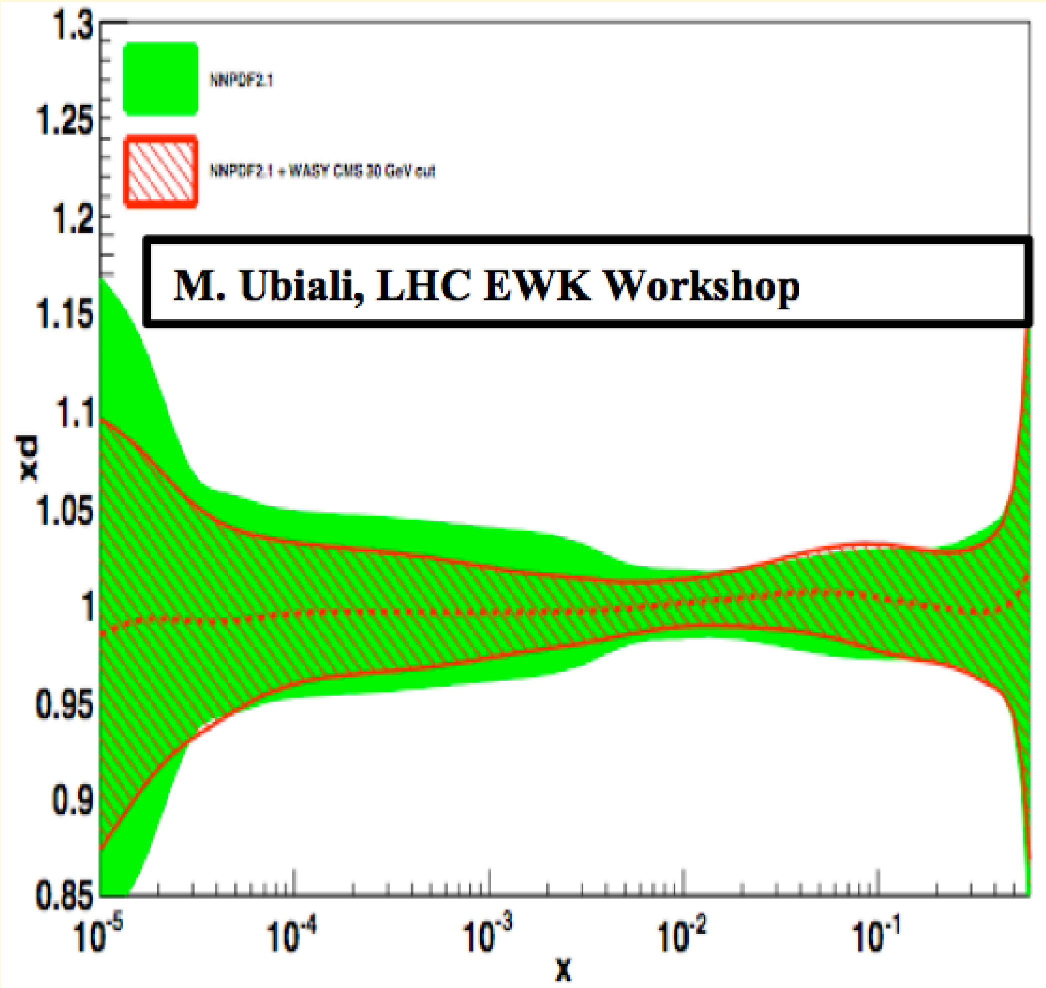
G. Watt, http://arXiv.org/pdf/1106.5788

⇒ **push the measurement to large pt**

⇒ **also consider large-pt and large-MET, to probe large x values**

⇒ **fully exploit rapidity coverage**





... all of the above, and more ....

➡

Use LHC data to better constrain PDFs

The “tools”: recent progress and state of the art

Parton-level, fixed order calculations

- DY: NNLO predictions available for both total rates and lepton differential distributions. Intrinsic TH precision ±1-2% (excl PDF)
- Jets: automatic tools for calculation of NLO rates and distributions for multijet final states (δ_{TH}~10-20%) :
  - pp → 2,3,4 jets
  - pp → W/Z + 1,2,3,4,(5) jets (up to 8 jets at LO)
  - associated production of heavy quarks and 1,2 jets
  - ....
- Top quark pairs: full NNLO for qqbar→ttbar completed, gg→ttbar forthcoming, resummation of NNLL (δ_{TH}~3-4%)
- Inclusion of EW corrections (typically effects of O(few %))
- Work in progress towards jet cross-sections at NNLO

The "tools": recent progress and state of the art

Full shower MCs, with hadronization and UE

- NLO parton level + shower
  - MC@NLO
  - POWHEG
  - aMC@NLO (automatic generation of NLO partonic cross sections, and merging with shower MC)

PDF extraction

- NNLO analyses, including quark mass effects
- Consistent frameworks for rigorous handling of experimental and theoretical systematics
- Several approaches, allowing for robust cross-checks
  - MSTW, CTEQ, NNPDF, HERApdf, JR, ABKM
  - Future use of full NLO+shower MCs for analysis of input data

Hadronization, jet structure, underlying event, etc

- New frameworks for shower evolution (Herwig++, Pythia8, Sherpa, Geneva, Vincia, KRKMC, ...)
- New phenomenological models for multiparticle interactions
- Global fits of event properties

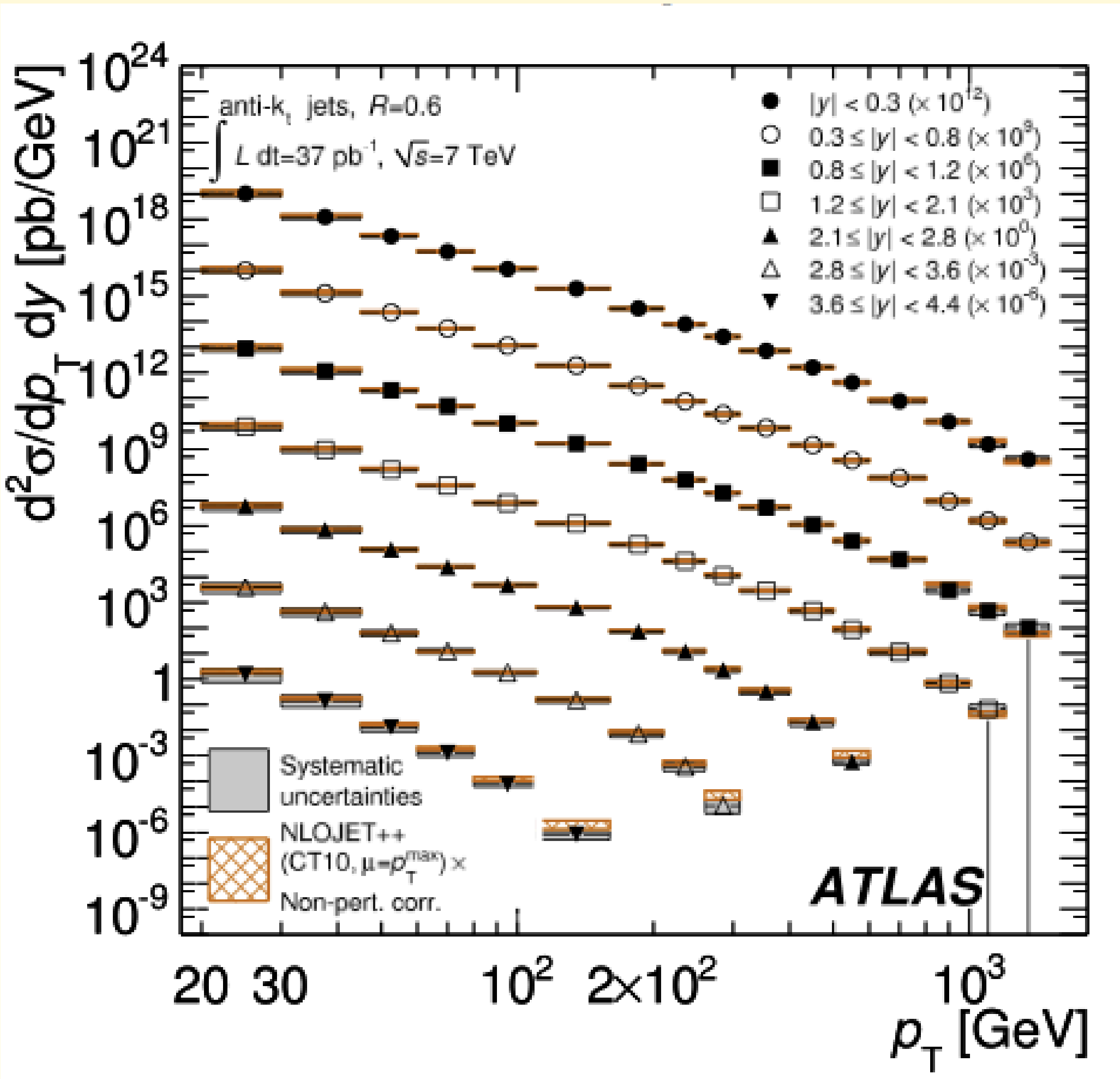
➡

Theory calculations for hard hadronic collisions are getting mature to be challenged at the few % level

Examples

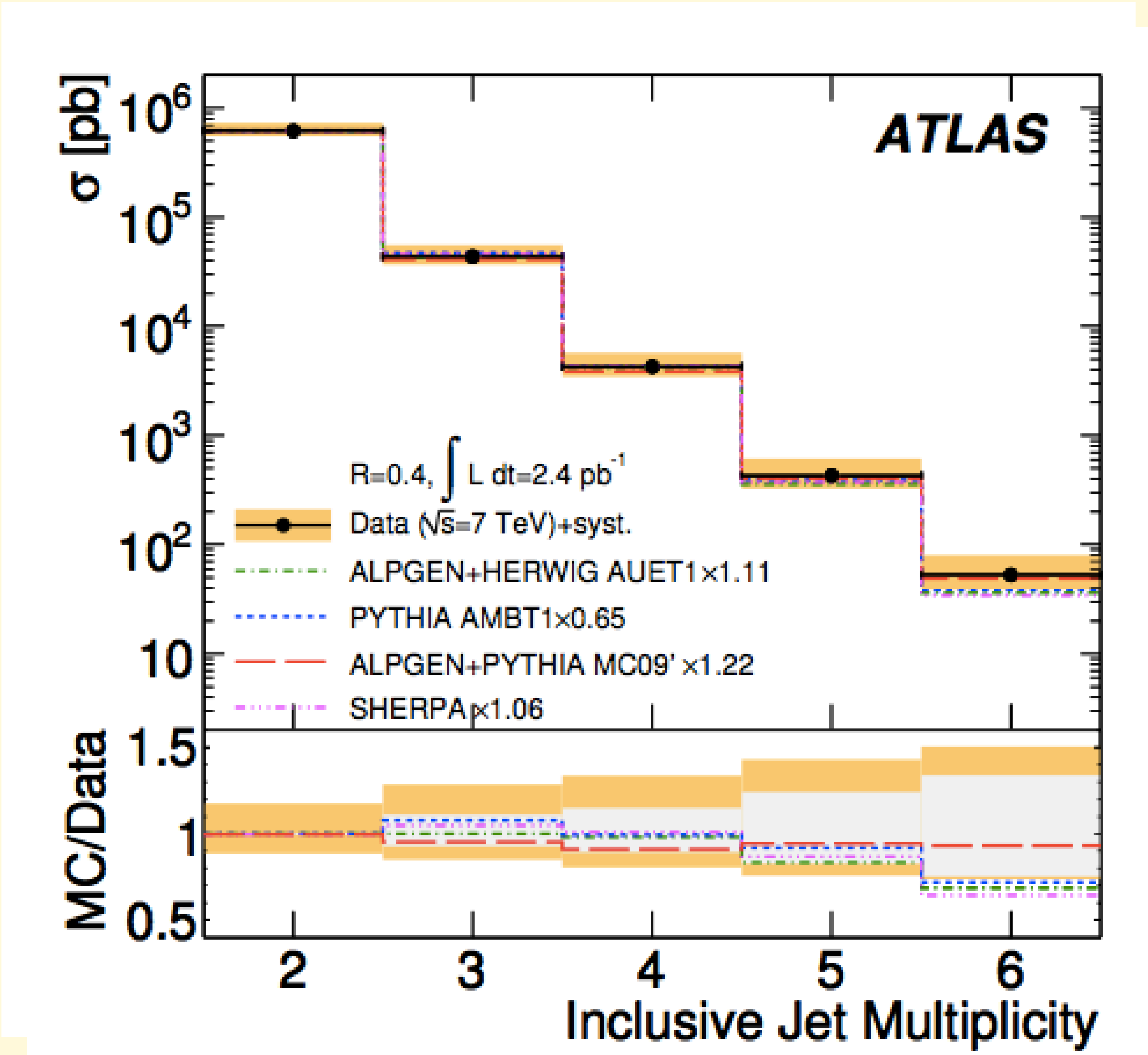
- Inclusive jet production
  - tests of quark substructure, PDF constraints, ...
- multijet final states
  - tests of higher-order calculations, search for new massive objects, ...
- associated production of W/Z+jets
  - bg to top studies, BSM searches

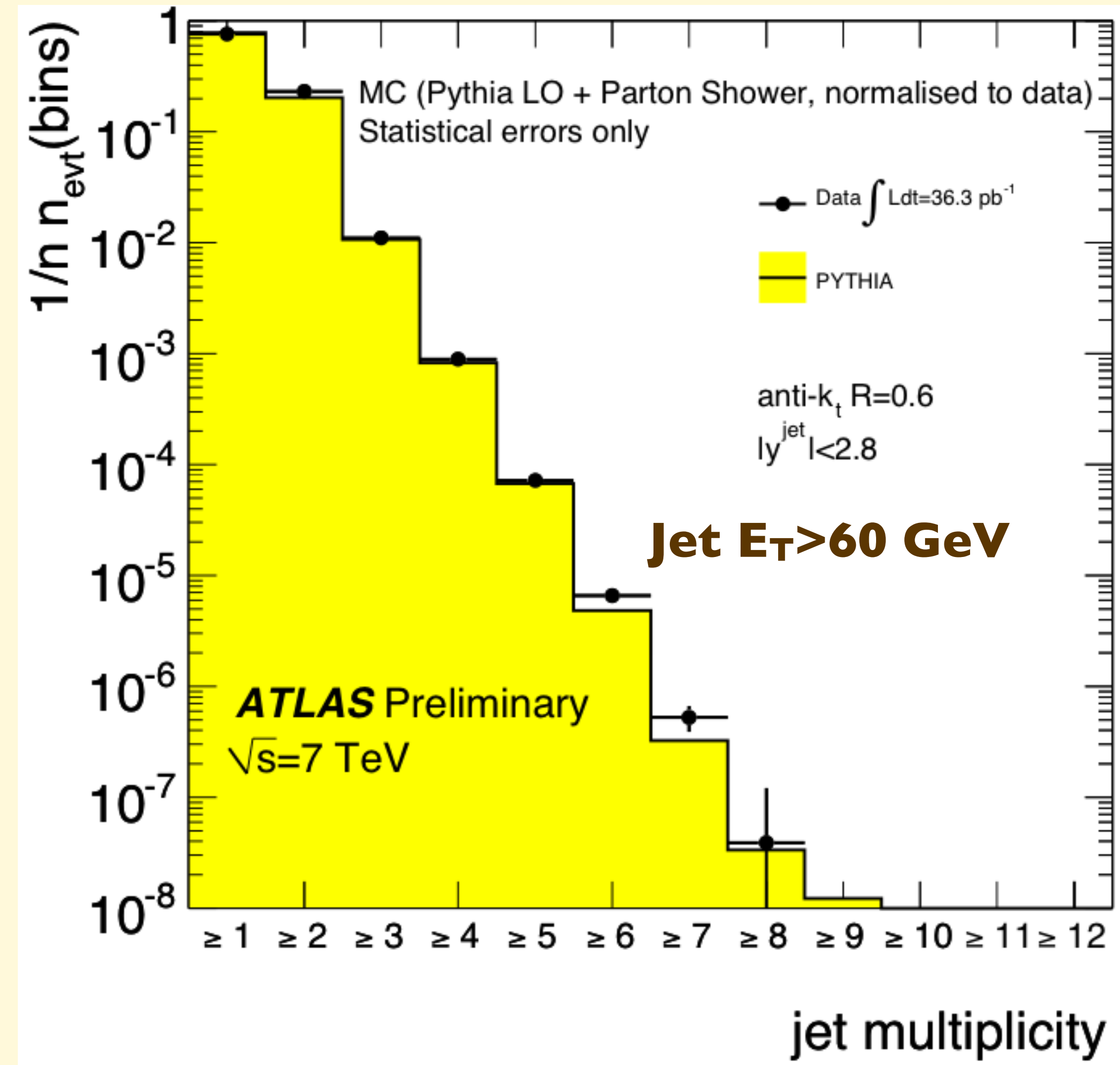
Jet cross section



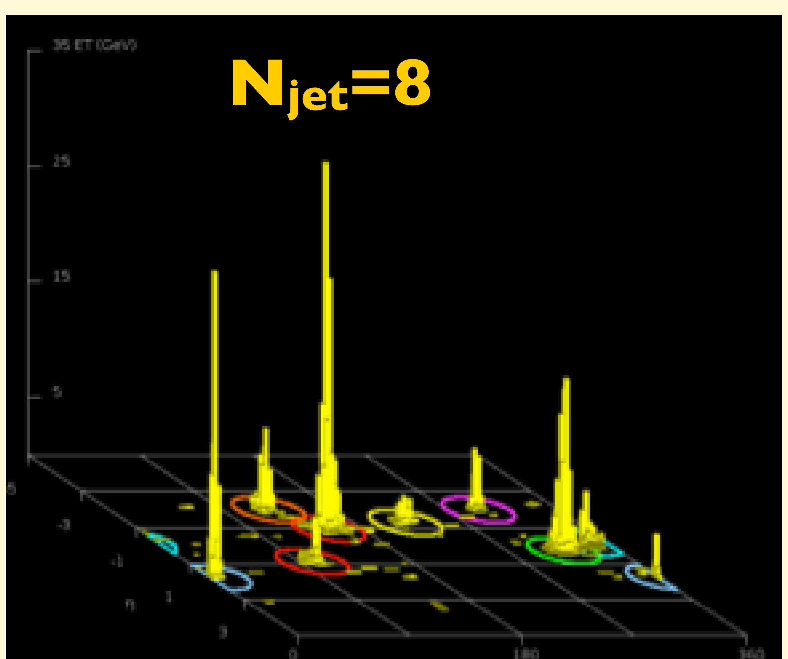
Rates span 10 orders of magnitude!

Multijets





Should probe N_{jet}~11-12 by end of 2012 !



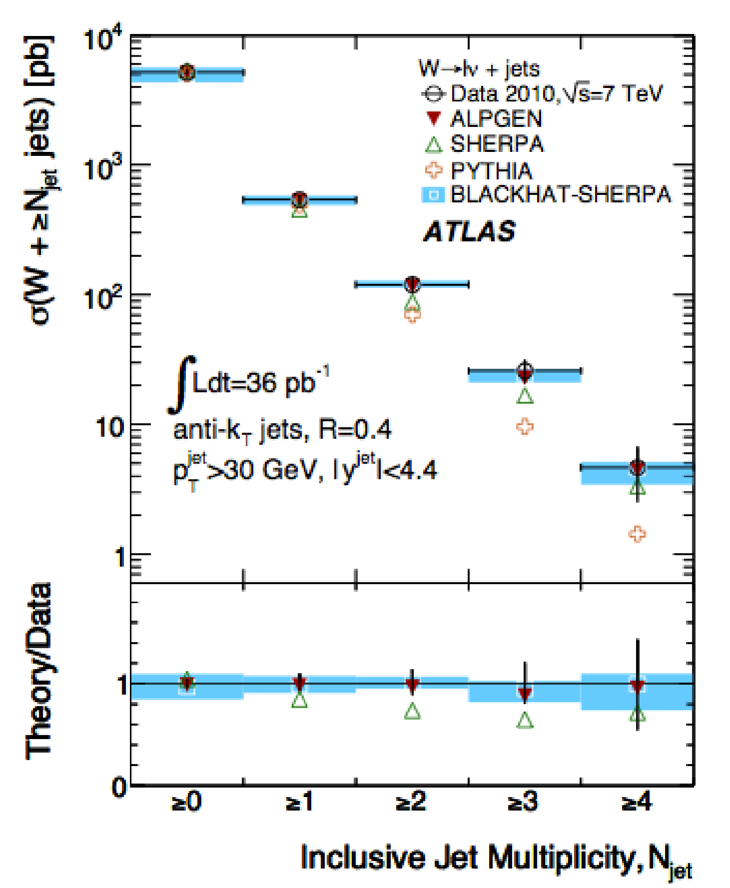
Number of Feynman diagrams, at Born level, in the quantum mechanical amplitude for:
$gg \rightarrow g_1\ g_2 \ldots g_{nj}$

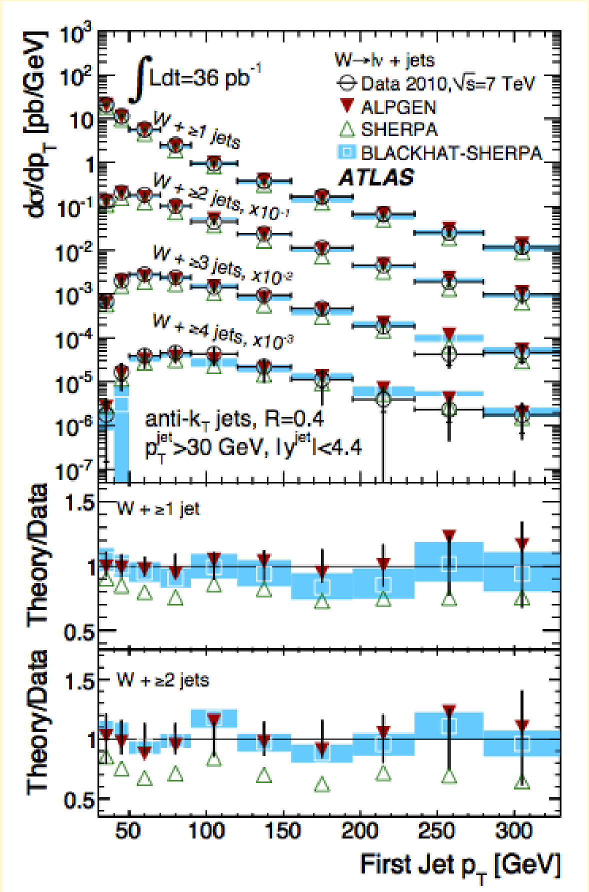
n_j	2	3	4	5	6	7	8
# diag's	4	25	220	2485	34300	5×10^5	10^7

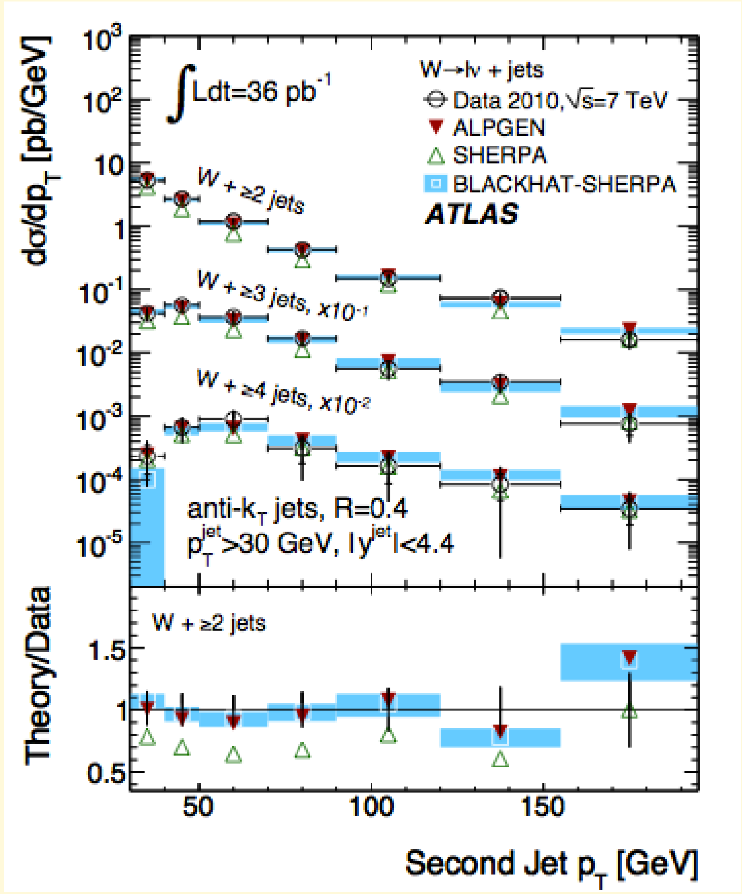
W+jets

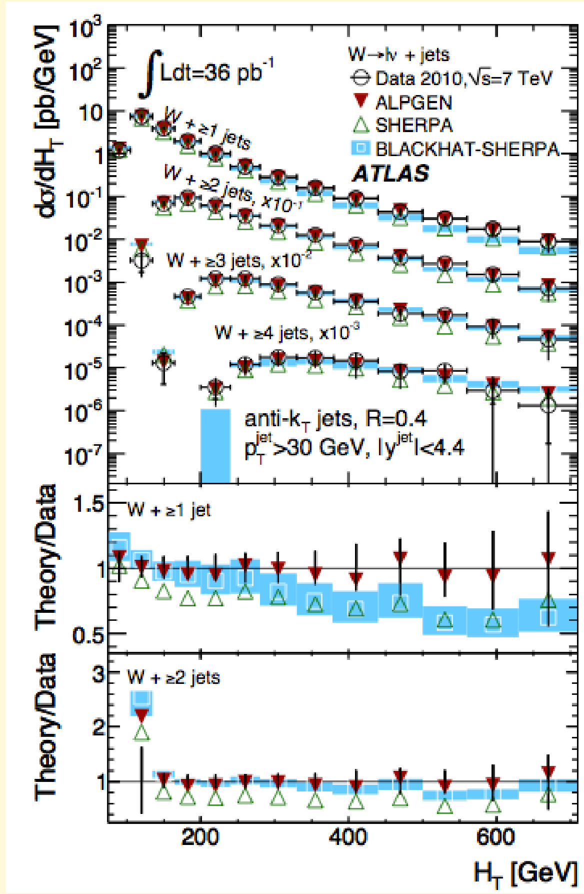
ATLAS, arXiv:1201.1276

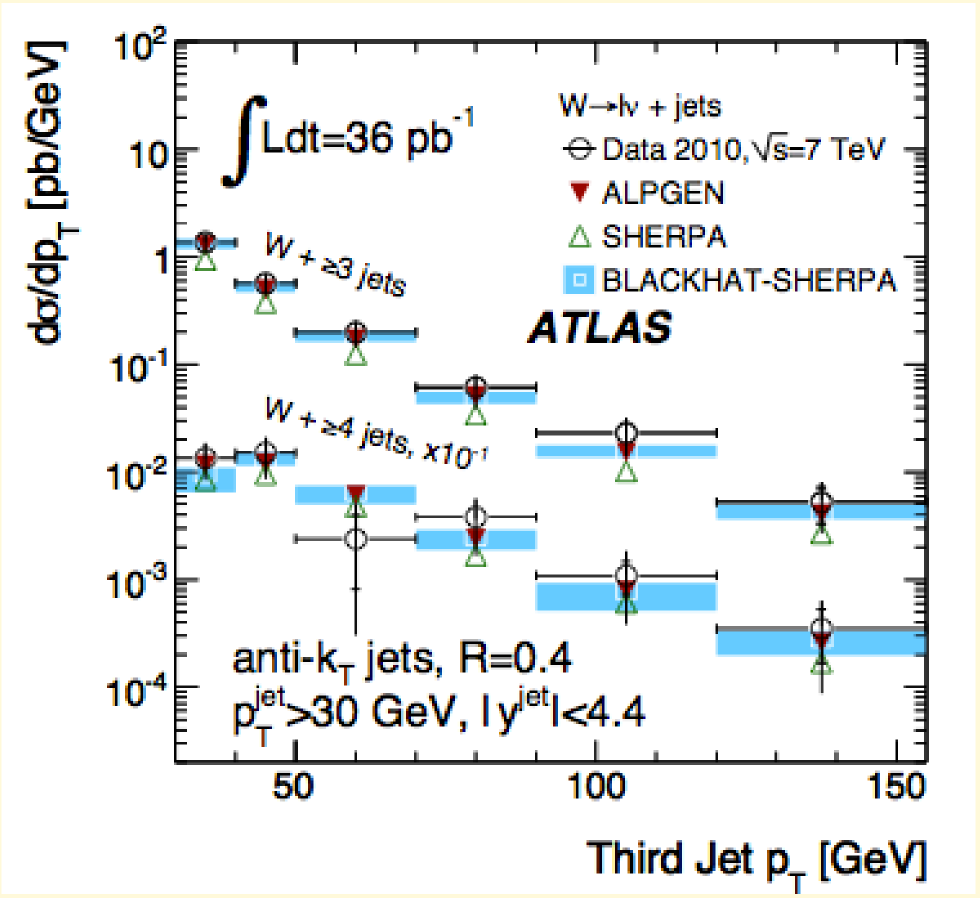
Alpgen Sherpa and Pythia σ_{tot} normalized to $\sigma_{NNLO}(W)$

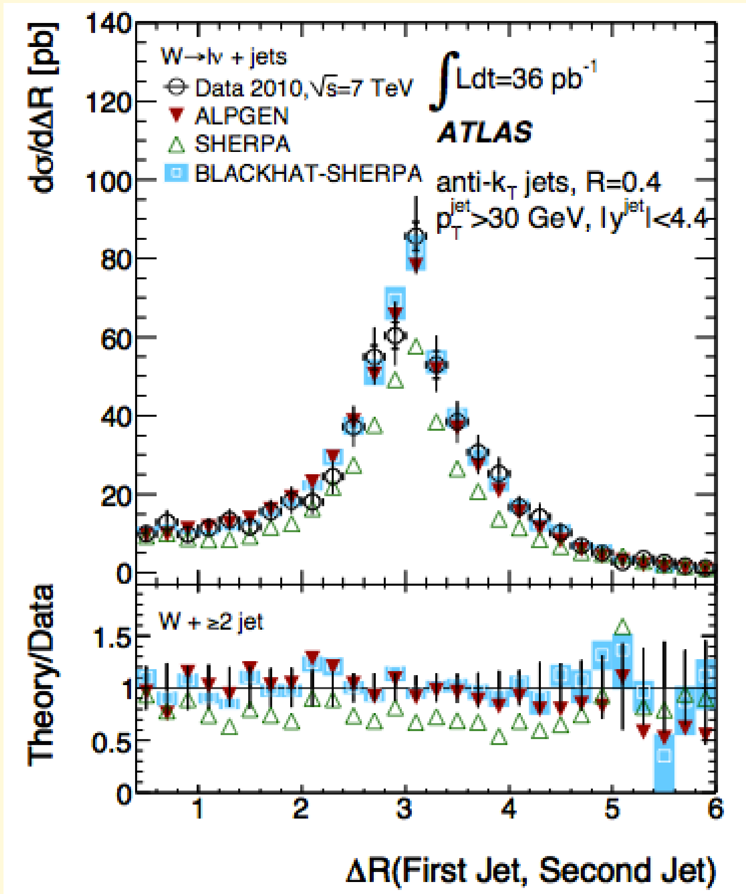


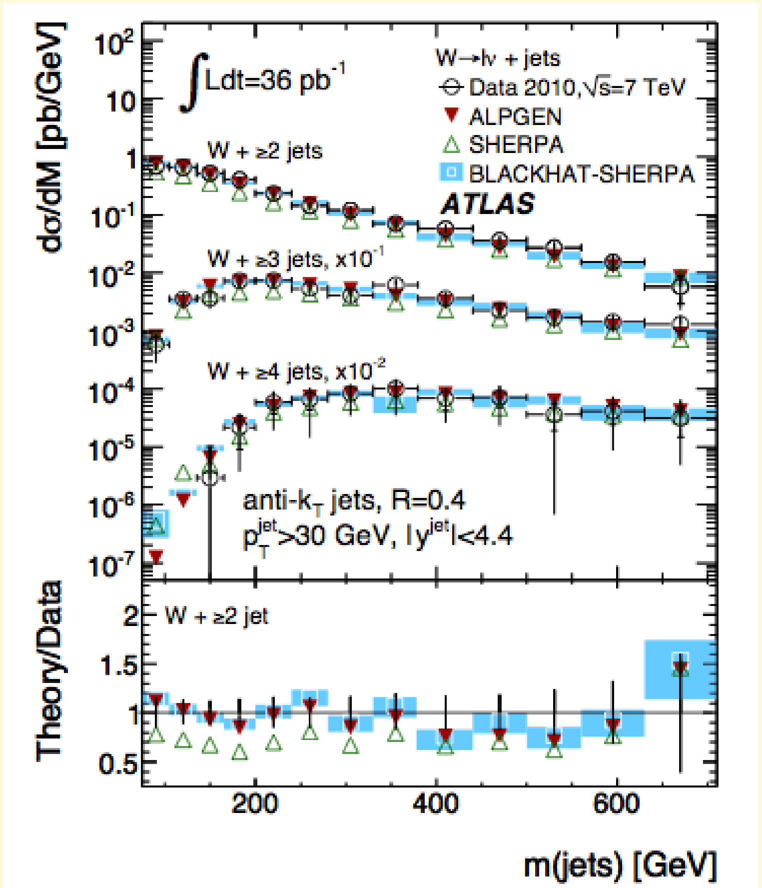










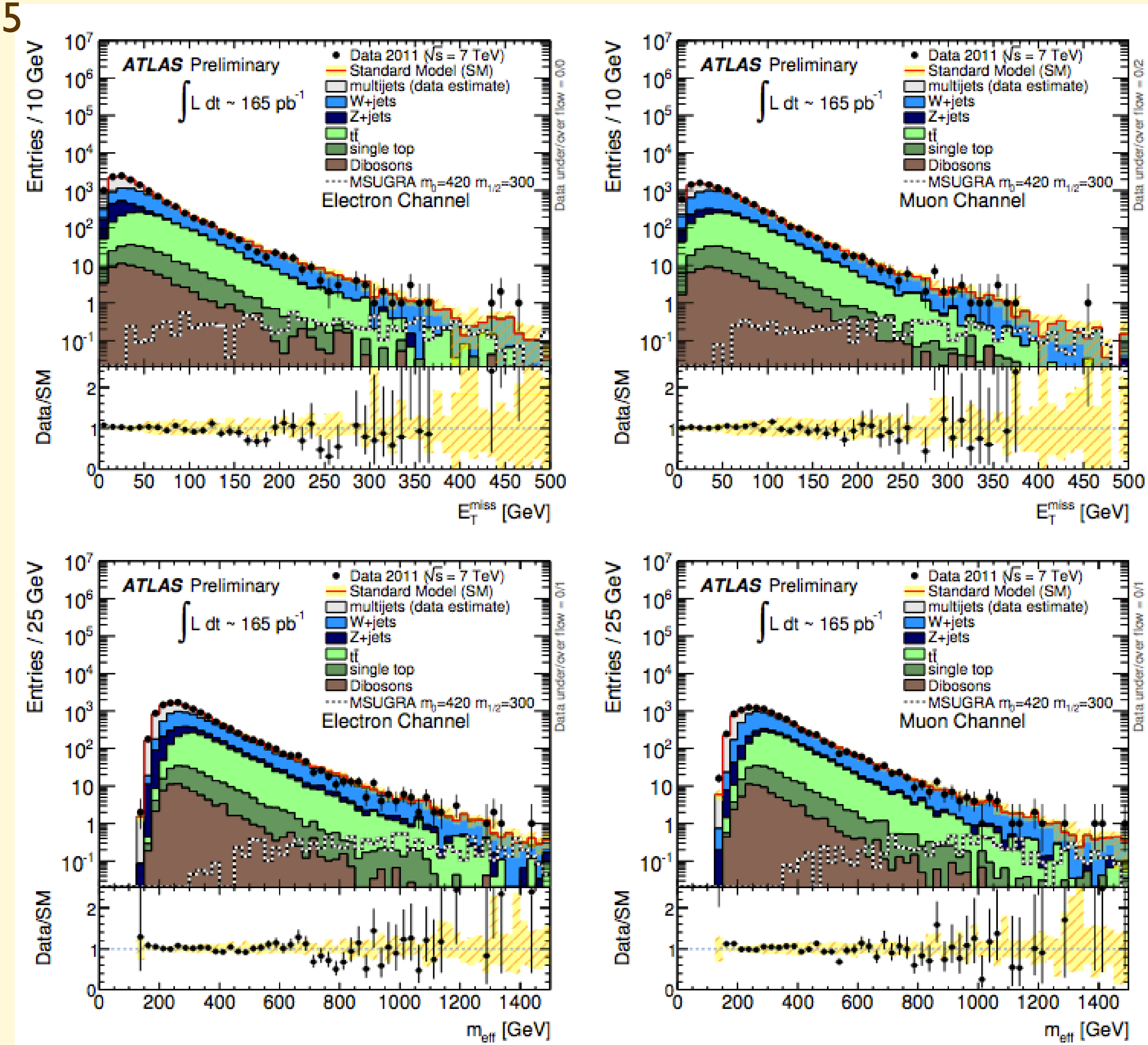


ATLAS 0.16fb^{-1}: SUSY search in ℓ+jets+MET

ATLAS-CONF-2011-090

Signal region:

- $\geq$3 jets w. E_T>25 GeV, $|\eta|$<2.8, E_{T1}>60 GeV
- M_{TW}>100 GeV ⇒ **typically this is a far off-shell W**
- MET>125 GeV, MET/M_{eff}>0.25



W+jets MC normalized to control region, defined by same jet and lepton cuts, but

- 30<MET<80 GeV
- 40<M_{TW}<80 GeV

Bg MC tools:

- W/Z+jets: Alpgen+Herwig/Jimmy(AUE1 tune)
- top (single and pair): MC@NLO +Herwig
- WW/WZ: Herwig, scaled to σ_{NLO}

Studies of jet activity in final states with dijets at large Δy

ATLAS, JHEP 1109 (2011) 053

indirect validation of jet-veto suppression efficiency for bgs

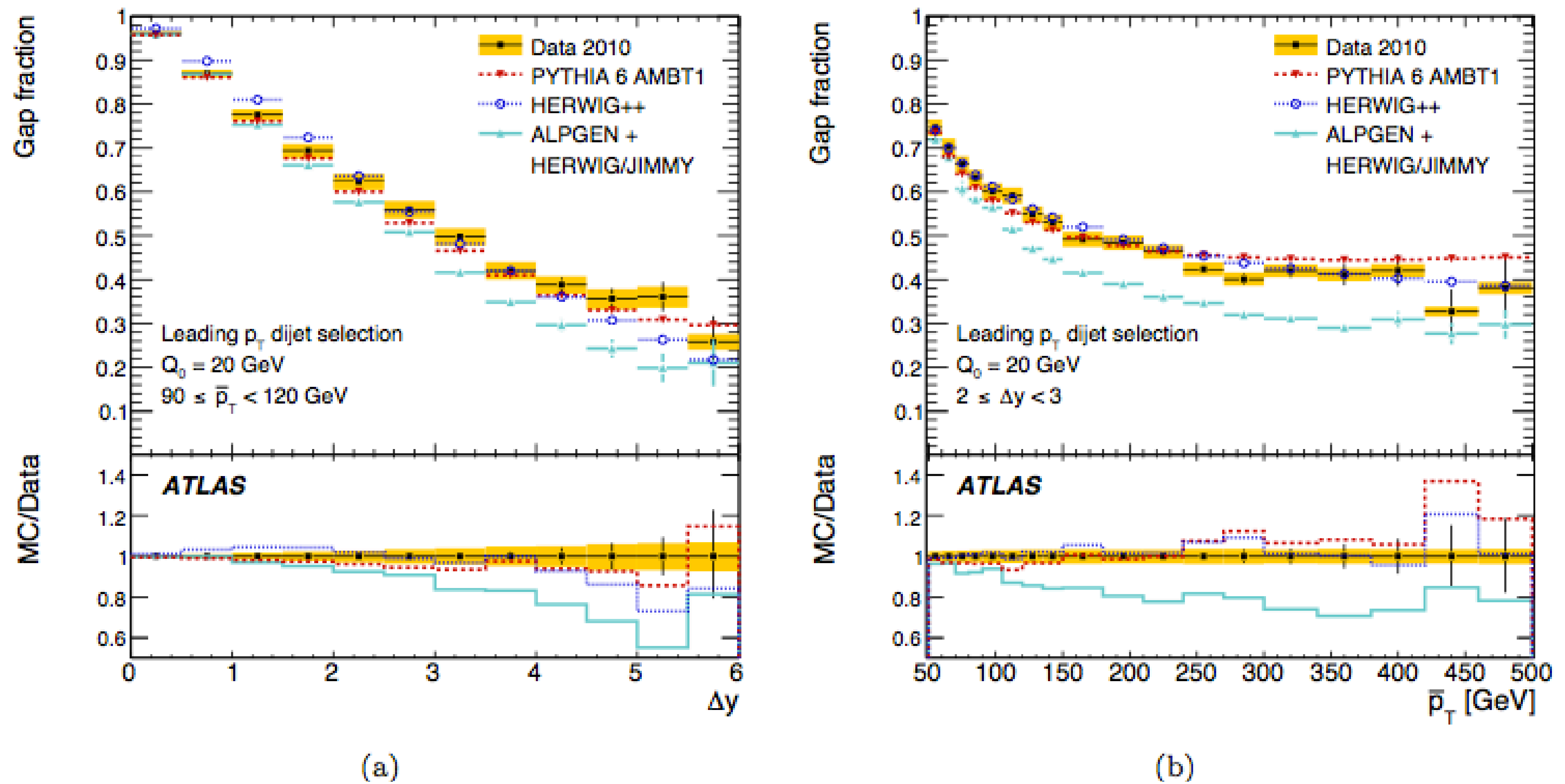


Figure 2. Gap fraction as a function of Δy, given that the dijet system is defined as the leading-p_T jets in the event and satisfies $90 \le \overline{p}_T < 120$ GeV (a). Gap fraction as a function of $\overline{p}_T$ given that the rapidity interval is $2 \le \Delta y < 3$ (b). The (corrected) data are the black points, with error bars representing the statistical uncertainty. The total systematic uncertainty on the measurement is represented by the solid (yellow) band. The dashed (red) points represents the PYTHIA prediction (tune AMBT1), the dot-dashed (blue) points represents the HERWIG++ prediction (tune LHC-UE7-1) and the solid (cyan) points represents the ALPGEN prediction (tune AUET1).

8TeV/7TeV and 14TeV/8TeV cross section ratios: the ultimate precision

MLM and J.Rojo, arXiv:1206.3557

$E_{1,2}$: different beam energies

X,Y: different hard processes

$$R_{E_2/E_1}(X) \equiv \frac{\sigma(X, E_2)}{\sigma(X, E_1)}$$

→

- TH: reduce "scale uncertainties"
- TH: reduce parameters' systematics: PDF, m_{top}, α_S, ... at E_1 and E_2 are fully correlated
- TH: reduce MC modeling uncertainties
- EXP: reduce syst's from acceptance, efficiency, JES, ...

$$R_{E_2/E_1}(X,Y) \equiv \frac{\sigma(X, E_2)/\sigma(Y, E_2)}{\sigma(X, E_1)/\sigma(Y, E_1)} \equiv \frac{R_{E_2/E_1}(X)}{R_{E_2/E_1}(Y)}$$

→

- TH: possible further reduction in scale and PDF syst's
- EXP: no luminosity uncertainty
- EXP: possible further reduction in acc, eff, JES syst's (e.g. $X,Y=W^+,W^-$)

Following results obtained using best available TH predictions: NLO, NNLO, NNLL resummation when available

8 TeV / 7 TeV: NNPDF results

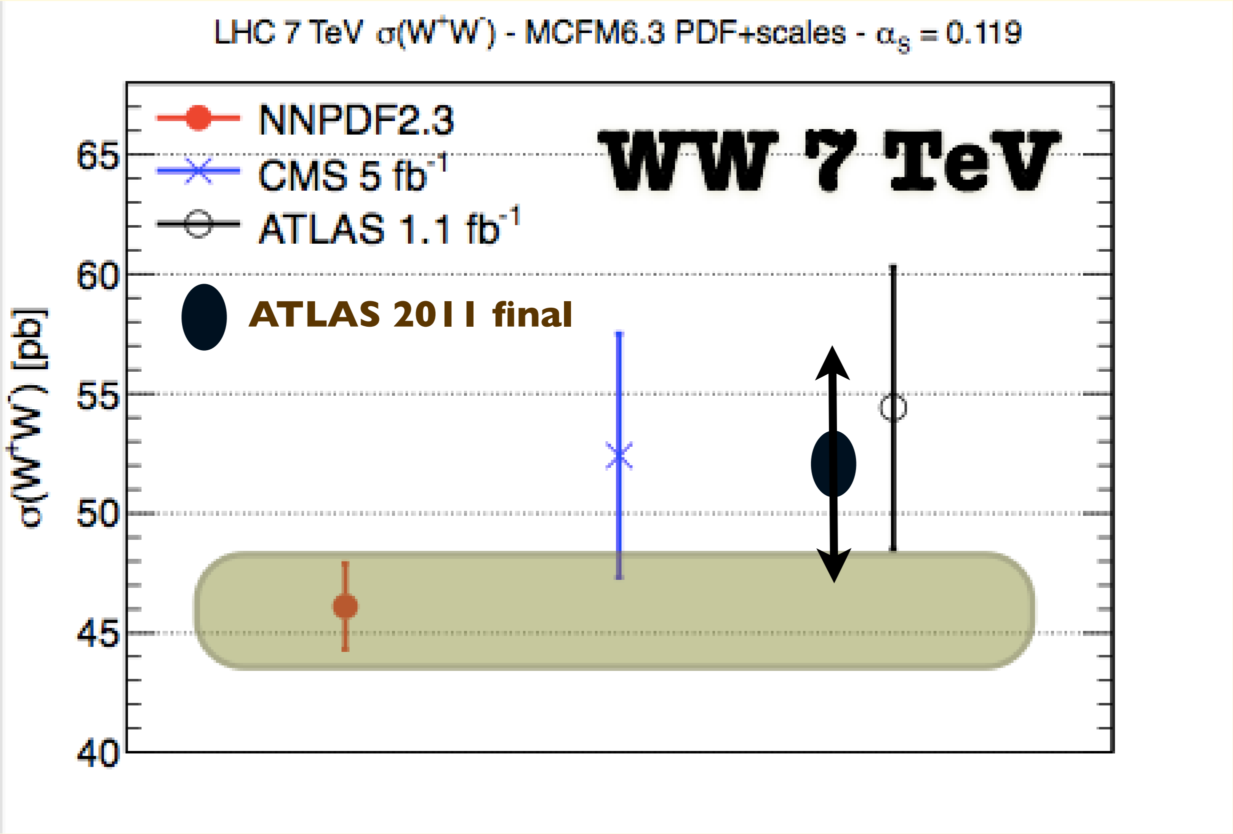
CrossSection	$r^{th,nnpdf}$	$\delta_{PDF}(\%)$	δ_{α_s} (%)	δ_{scales} (%)
$t\bar{t}/Z$	1.231	0.28	−0.23 − 0.24	0.17 − 0.33
$t\bar{t}$	1.432	0.25	−0.15 − 0.20	0.14 − 0.33
Z	1.163	0.08	−0.04 − 0.08	0.05 − 0.09
W^+	1.148	0.08	−0.01 − 0.06	0.06 − 0.08
W^-	1.167	0.09	−0.03 − 0.06	0.06 − 0.07
W^+/W^-	0.983	0.08	0.00 − 0.02	0.00 − 0.02
W/Z	0.994	0.03	−0.02 − 0.02	0.02 − 0.00
ggH	1.273	0.11	−0.04 − 0.06	0.24 − 0.16
$ggH/t\bar{t}$	0.889	0.22	−0.15 − 0.11	0.41 − 0.22
$t\bar{t}(M_{tt} \geq 1\text{TeV})$	1.807	0.73	0.00 − 0.00	0.61 − 0.54
$t\bar{t}(M_{tt} \geq 2\text{TeV})$	2.734	3.60	0.00 − 0.00	0.00 − 1.45
$\sigma\text{jet}(p_T \geq 1\text{TeV})$	2.283	1.02	0.00 − 0.00	5.89 − 0.91
$\sigma\text{jet}(p_T \geq 2\text{TeV})$	7.386	4.70	0.00 − 0.00	2.33 − 1.08

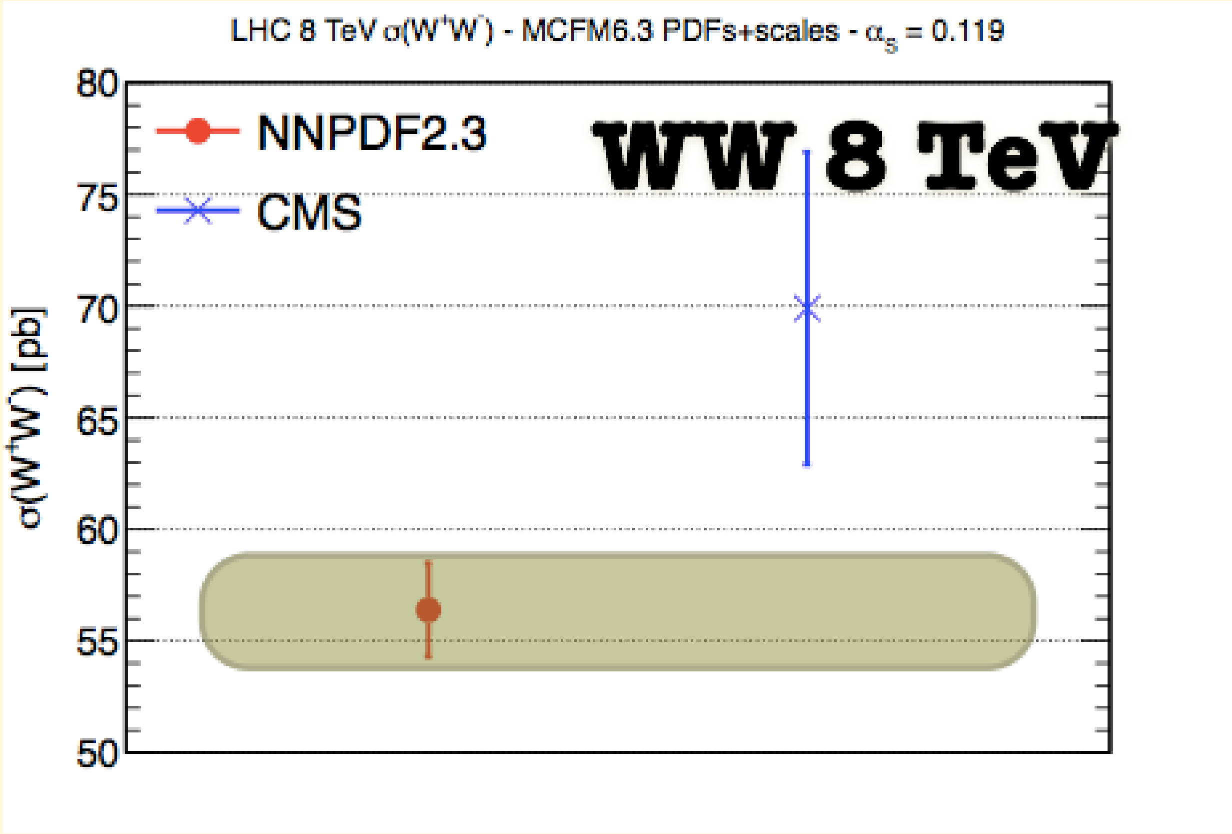
- $\delta<10^{-3}$ in $W^\pm$ ratios: absolute calibration of 7 vs 8 TeV lumi
- $\delta<10^{-2}$ in $\sigma(tt)$ ratios
- $\delta_{scale} < \delta_{PDF}$ at large p_T^{jet} and M_{tt}: constraints on PDFs

8 TeV / 7 TeV: NNPDF vs MSTW vs ABKM

Ratio	$r^{th,nnpdf}$	$\delta_{PDF}(\%)$	$r^{th,mstw}$	$\delta_{PDF}(\%)$	$\Delta^{mstw}(\%)$	$r^{th,abkm}$	$\delta_{ABKM}(\%)$	Δ^{abkm} (%)
$t\bar{t}/Z$	1.231	0.28	1.227	0.24	0.37	1.247	0.55	-1.20
$t\bar{t}$	1.432	0.25	1.428	0.24	0.34	1.452	0.55	-1.35
Z	1.163	0.08	1.163	0.09	-0.02	1.165	0.08	-0.15
W^+	1.148	0.08	1.149	0.10	-0.06	1.150	0.07	-0.18
W^-	1.167	0.09	1.167	0.09	0.02	1.170	0.08	-0.23
W^+/W^-	0.983	0.08	0.984	0.05	-0.08	0.983	0.04	0.05
W/Z	0.994	0.03	0.994	0.02	-0.02	0.994	0.03	-0.04
ggH	1.273	0.11	1.274	0.17	-0.05	1.240	0.16	2.65
$ggH/t\bar{t}$	0.889	0.22	0.000	0.00	0.00	0.000	0.00	0.00
$t\bar{t}(M_{tt} \geq 1\text{TeV})$	1.807	0.73	1.791	0.66	0.95	1.855	1.02	-2.61
$t\bar{t}(M_{tt} \geq 2\text{TeV})$	2.734	3.60	2.645	2.84	3.61	2.645	4.04	3.61
$\sigma\text{jet}(p_T \geq 1\text{TeV})$	2.283	1.02	2.290	1.99	0.13	2.268	2.03	1.08
$\sigma\text{jet}(p_T \geq 2\text{TeV})$	7.386	4.70	7.915	4.29	-7.59	7.695	4.92	-4.59

- Several examples of 2-2.5σ discrepancies between predictions of different PDF sets





Diboson cross section ratios

8 over 7 TeV	$R^{\mathrm{th,nnpdf}}$	$\delta_{\mathrm{PDF}}(\%)$	$\delta_{\mathrm{scales}}\ (\%)$	
WW	1.223	$\pm$ 0.1	$-0.4 - 0.2$	
$gg \to WW$	1.330	$\pm$ 0.2	$-0.0 - 0.0$	(scale errors missing)
WW/W	1.057	$\pm$ 0.1	$-0.3 - 0.2$	
WZ	1.209	$\pm$ 0.4	$-1.2 - 0.4$	
ZZ	1.165	$\pm$ 0.4	$-0.6 - 1.1$	
$gg \to ZZ$	1.218	$\pm$ 1.2	$-0.0 - 0.0$	(scale errors missing)
ZZ/Z	1.000	$\pm$ 0.4	$-0.5 - 1.1$	
WW/WZ	1.012	$\pm$ 0.4	$-0.2 - 1.0$	
WW/ZZ	1.050	$\pm$ 0.4	$-0.9 - 0.7$	
WZ/ZZ	1.038	$\pm$ 0.5	$-1.7 - 0.4$	

14 TeV / 8 TeV: NNPDF results

CrossSection	$r^{\text{th,nnpdf}}$	$\delta_{\text{PDF}}(\%)$	δ_{α_s} (%)	δ_{scales} (%)
$t\bar{t}/Z$	2.121	1.01	−0.84 − 0.75	0.42 − 1.10
$t\bar{t}$	3.901	0.84	−0.51 − 0.66	0.38 − 1.07
Z	1.839	0.37	−0.10 − 0.34	0.28 − 0.18
W^+	1.749	0.41	−0.03 − 0.27	0.31 − 0.18
W^-	1.859	0.39	−0.08 − 0.26	0.32 − 0.13
W^+/W^-	0.941	0.28	0.00 − 0.05	0.00 − 0.04
W/Z	0.976	0.09	−0.07 − 0.04	0.04 − 0.02
ggH	2.564	0.36	−0.10 − 0.09	0.89 − 0.98
$ggH/t\bar{t}$	0.657	0.75	−0.56 − 0.41	1.38 − 1.05
$t\bar{t}(M_{tt} \geq 1\text{TeV})$	8.215	2.09	0.00 − 0.00	1.61 − 2.06
$t\bar{t}(M_{tt} \geq 2\text{TeV})$	24.776	6.07	0.00 − 0.00	3.05 − 1.07
$\sigma\text{jet}(p_T \geq 1\text{TeV})$	15.235	1.72	0.00 − 0.00	2.31 − 2.19
$\sigma\text{jet}(p_T \geq 2\text{TeV})$	181.193	6.75	0.00 − 0.00	3.66 − 5.76

- $\delta < 10^{-2}$ in $W^\pm$ ratios: absolute calibration of 14 vs 8 TeV lumi
- $\delta \sim 10^{-2}$ in $\sigma(tt)$ ratios
- $\delta_{scale} < \delta_{PDF}$ at large p_T^{jet} and M_{tt}: constraints on PDFs

14 TeV / 8 TeV: NNPDF vs MSTW vs ABKM

Ratio	$r^{\text{th,nnpdf}}$	$\delta_{\text{PDF}}(\%)$	$r^{\text{th,mstw}}$	$\delta_{\text{PDF}}(\%)$	$\Delta^{mstw}(\%)$	$r^{\text{th,abkm}}$	$\delta_{\text{ABKM}}(\%)$	Δ^{abkm} (%)
$t\bar{t}/Z$	2.121	1.01	2.108	0.95	0.93	2.213	1.87	-3.99
$t\bar{t}$	3.901	0.84	3.874	0.91	0.97	4.103	1.87	-4.90
Z	1.839	0.37	1.838	0.41	0.04	1.855	0.34	-0.87
W^+	1.749	0.41	1.749	0.49	0.03	1.767	0.30	-0.98
W^-	1.859	0.39	1.854	0.42	0.21	1.879	0.32	-1.11
W^+/W^-	0.941	0.28	0.943	0.19	-0.19	0.940	0.13	0.13
W/Z	0.976	0.09	0.976	0.10	0.03	0.977	0.10	-0.14
ggH	2.564	0.36	2.572	0.57	-0.30	2.644	0.66	-3.12
$ggH/t\bar{t}$	0.657	0.75	0.000	0.00	0.00	0.000	0.00	0.00
$t\bar{t}(M_{tt} \geq 1\text{TeV})$	8.215	2.09	7.985	2.02	3.12	8.970	3.58	-8.83
$t\bar{t}(M_{tt} \geq 2\text{TeV})$	24.776	6.07	23.328	4.32	6.05	23.328	4.93	6.05
$\sigma\text{jet}(p_T \geq 1\text{TeV})$	15.235	1.72	15.193	1.62	-1.33	14.823	1.84	1.13
$\sigma\text{jet}(p_T \geq 2\text{TeV})$	181.193	6.75	191.208	3.34	-6.52	174.672	4.94	2.69

- Several examples of 3-4σ discrepancies between predictions of different PDF sets, even in the case of W and Z rates

Xsection ratios as probes of BSM contributions

Assume the final state **X** receives both SM and BSM contributions:

$$\sigma^{exp}(pp \to X) = \sigma^{SM}(pp \to X) + \sigma^{BSM}(pp \to X)$$

Define the ratio:

$$R^X_{7/8} = \frac{\sigma^{exp}(pp \to X; 7\ \mathrm{TeV})}{\sigma^{exp}(pp \to X; 8\ \mathrm{TeV})} = \frac{\sigma^{exp}_X(7)}{\sigma^{exp}_X(8)}$$

We easily get:

$$R^X_{7/8} \sim \frac{\sigma^{SM}_X(7)}{\sigma^{SM}_X(8)} \times \left\{ 1 + \frac{\sigma^{BSM}_X(7)}{\sigma^{SM}_X(7)}\ \Delta_{7/8}\left[\frac{\sigma^{BSM}_X}{\sigma^{SM}_X}\right] \right\}$$

where:

$$\Delta_{7/8}\left[\frac{\sigma^{BSM}_X}{\sigma^{SM}_X}\right] = 1 - \frac{\sigma^{BSM}_X(8)/\sigma^{SM}_X(8)}{\sigma^{BSM}_X(7)/\sigma^{SM}_X(7)} \sim 1 - \frac{\mathcal{L}^{BSM}_X(8)/\mathcal{L}^{BSM}_X(7)}{\mathcal{L}^{SM}_X(8)/\mathcal{L}^{SM}_X(7)} = \Delta_{7/8}\left[\frac{\mathcal{L}^{BSM}_X}{\mathcal{L}^{SM}_X}\right]$$

Therefore:

relative BSM contamination

$$\frac{\delta R^X_{7/8}}{R^X_{7/8}} = \frac{\delta R^{SM}_{7/8}}{R^{SM}_{7/8}} + \frac{\sigma^{BSM}_X(7)}{\sigma^{SM}_X(7)} \times \Delta_{7/8}\left[\frac{\mathcal{L}^{BSM}_X}{\mathcal{L}^{SM}_X}\right]$$

theory systematics in 7→8 TeV extrapolation

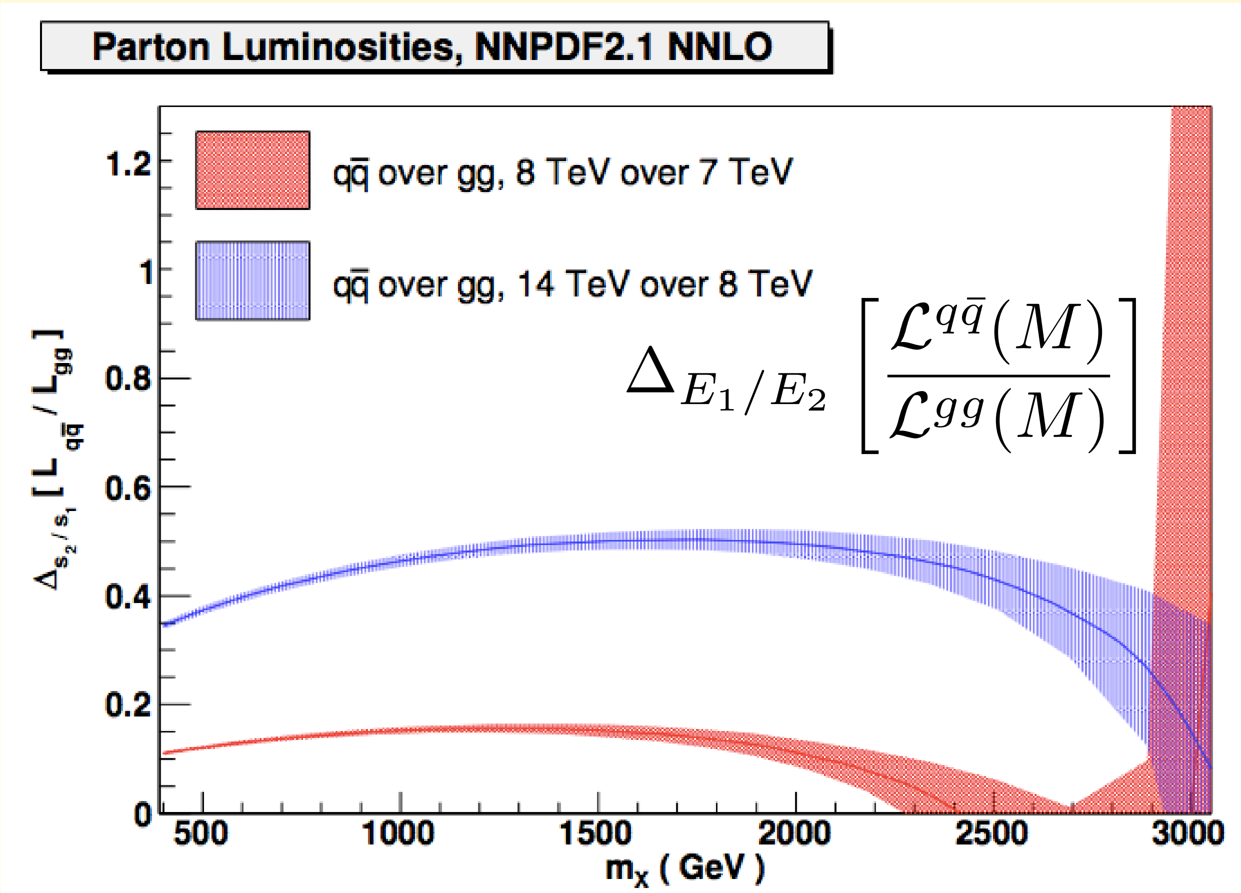
Energy dependence of the relative BSM contamination

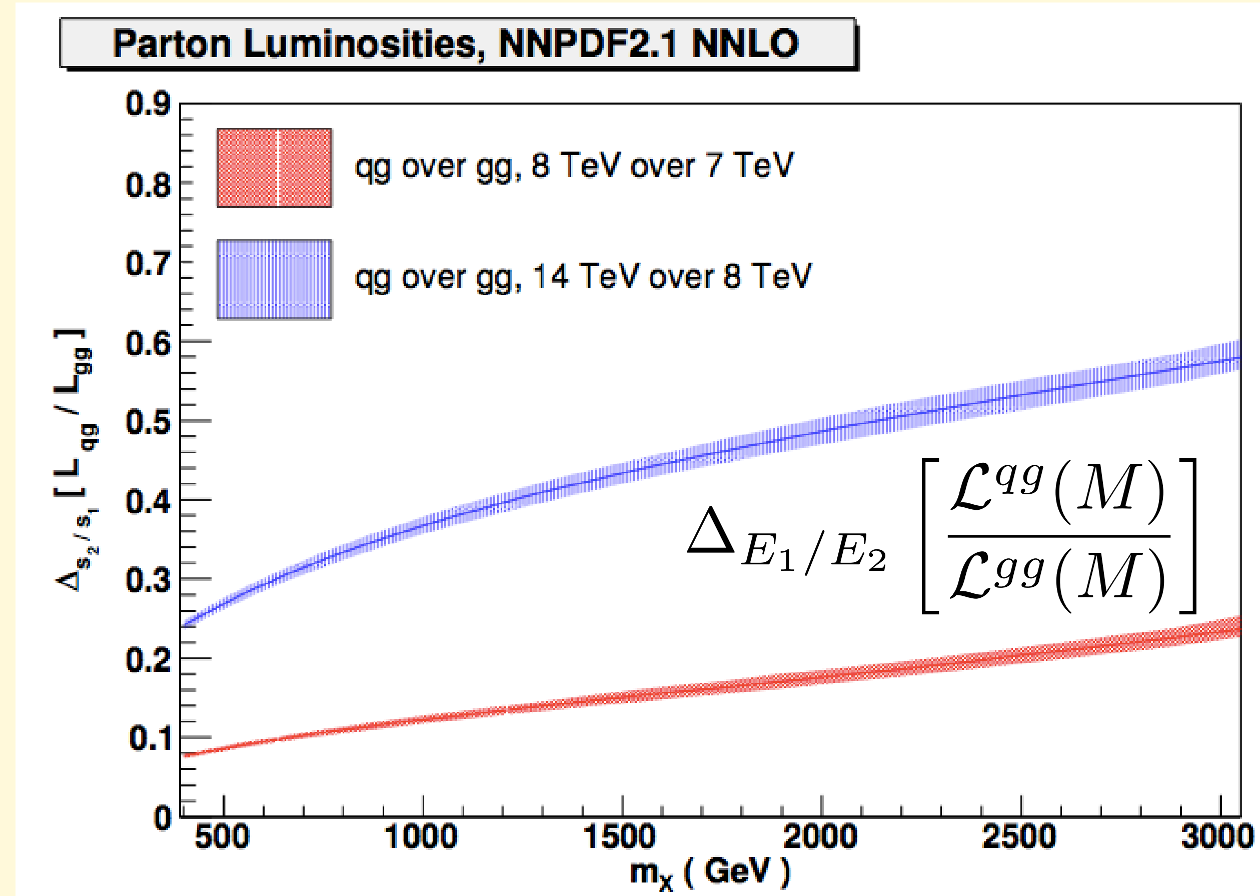
E.g., assuming σ_{SM}(pp→X)=σ(gg→X) and σ_{BSM}(pp→X)=σ(qq→X) (*)

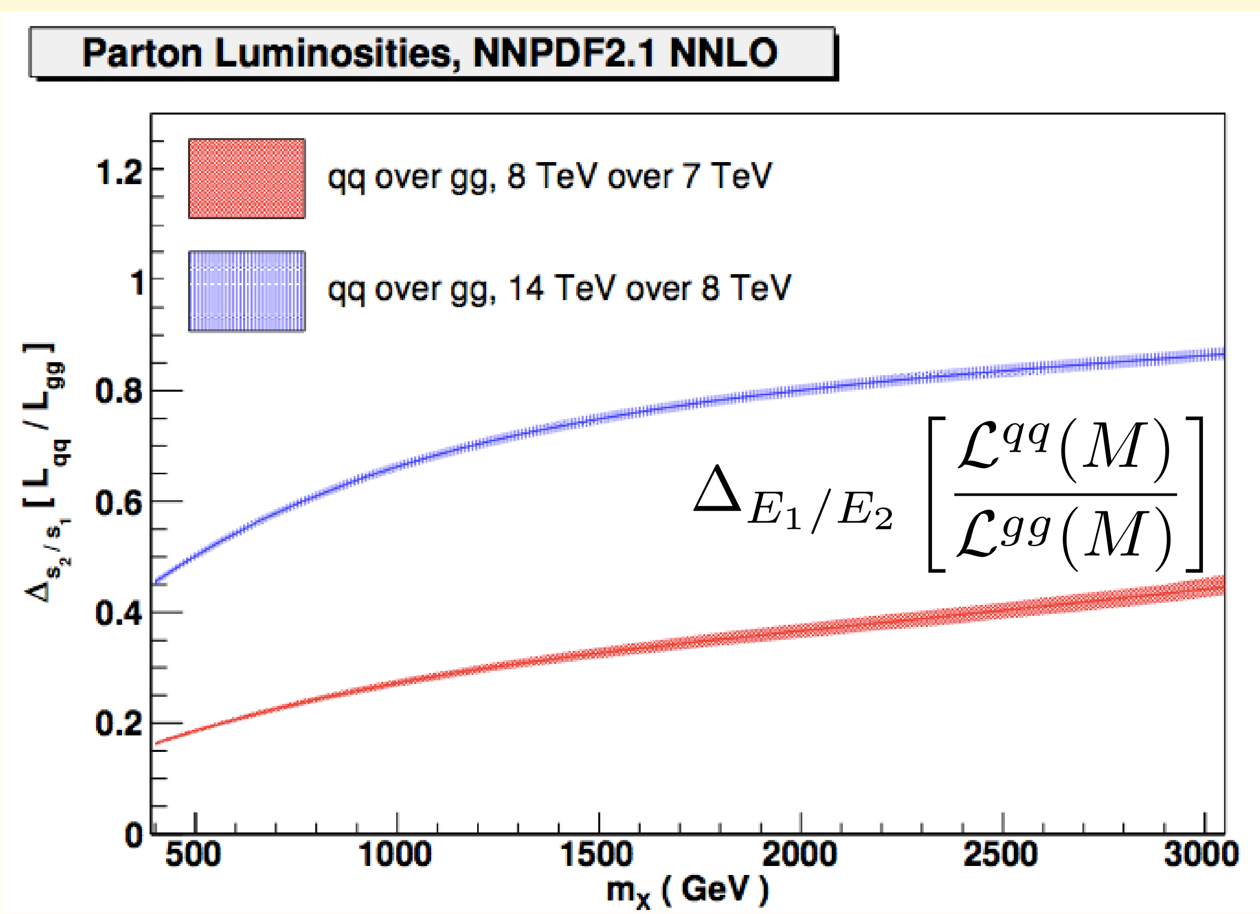
$$\Delta_{7/8}\left[\frac{\mathcal{L}^{BSM}_X}{\mathcal{L}^{SM}_X}\right] = \Delta_{7/8}\left[\frac{\mathcal{L}^{q\bar{q}}(M)}{\mathcal{L}^{gg}(M)}\right]$$

(*) e.g. SM: gg→tt and BSM: qqbar→Z'→tt

Examples of E-dependence of luminosity ratios







Given the sub-% precision of the SM ratio predictions, there is sensitivity to BSM rate contributions at the level of few% (to be improved with better PDF constraints, especially for 8/14 ratios)

Worth exploring in more detail the possible implications of precise measurements of energy (double-)ratios

E.g.

(1) $\sigma_{VBF}(H)$ grows with E differently than $\sigma_{gg}(gg \to H)$ or $\sigma_{qq}(VH)$: is there something to be learned from

$$R_H(8)/R_H(14)$$

for $R_H = \sigma(gg \to H)/\sigma_{qq}(VH)$ or $\sigma(gg \to H)/\sigma_{VBF}(H)$?

(2) Study ratios of asymmetries at different energies (lepton charge asym, t vs tbar asymm in single-top production, etc)

(3) Study ratios in different rapidity ranges, or with different kinematical cuts, to increase sensitivity to particular x-ranges of PDF, or to particular dynamical regimes

Finally, where PDF systematics are negligible, and if there is no new physics, Xsection (double)ratios provide excellent benchmarks for calibration, anaysis validation, etc.

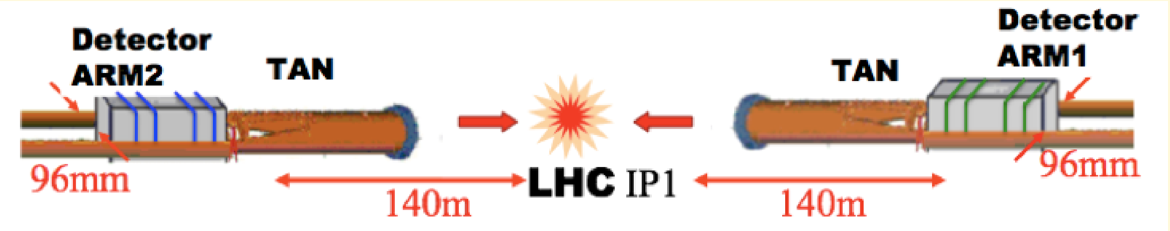
Powerful diagnostic tool when coming back after 2 yrs of shut-down!

Experimental challenge to match this precision. Requires great degree of correlation in the systematics of the analyses at different energies (eff's, bg subtraction, JES, ...)

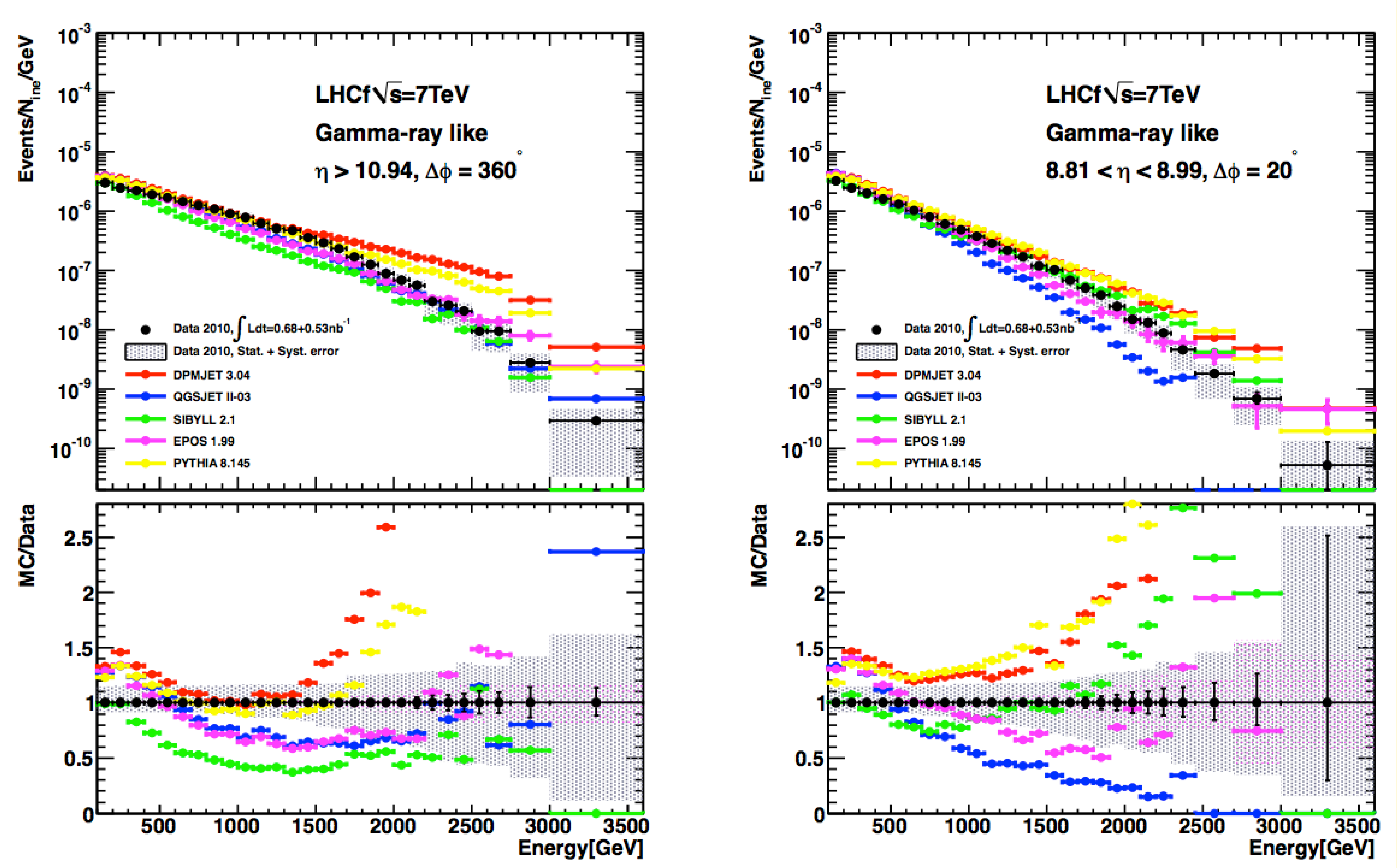
Coherent efforts to plan the analyses having in mind the needs of XS (double)ratios are worth consideration

There is more at the LHC than *just* high-Q^2 physics .....

LHCf: Very forward energy flow

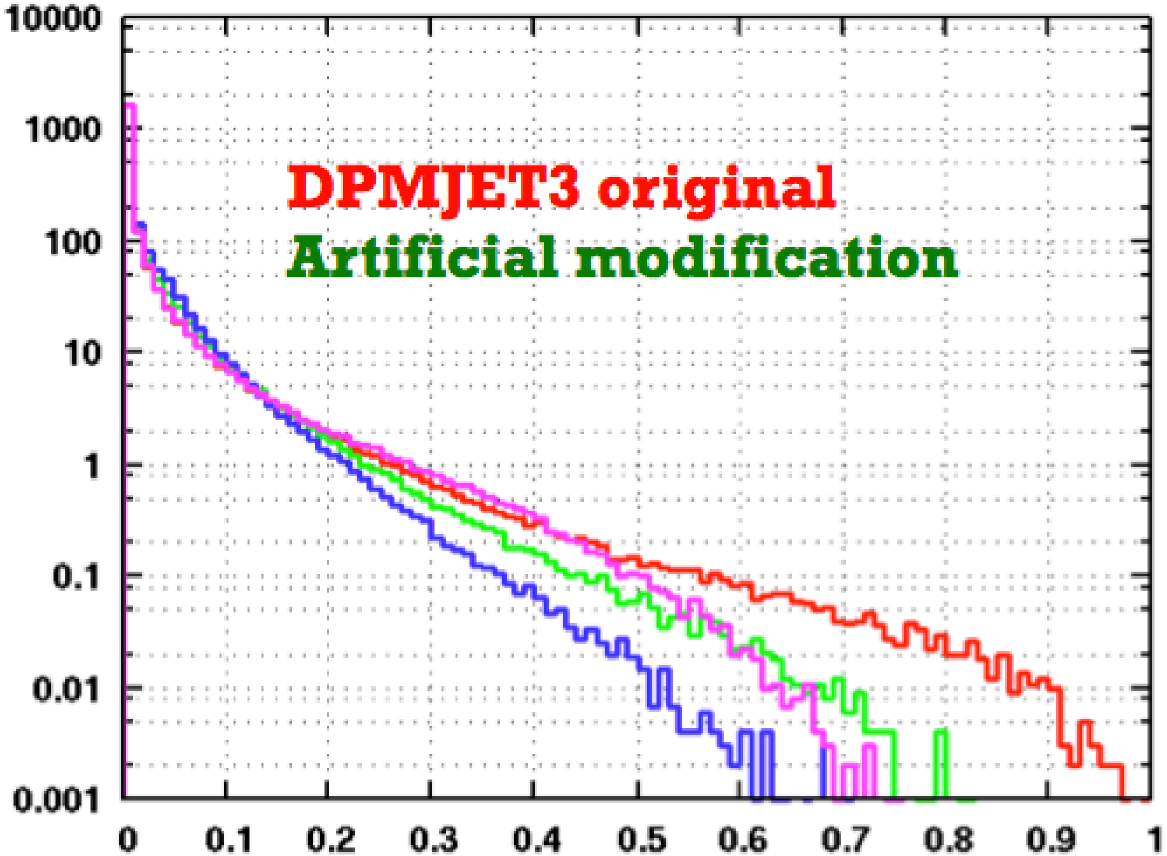


"Measurement of zero degree single photon energy spectra for $\sqrt{s}$ = 7 TeV proton-proton collisions at LHC"
PLB 703 (2011) 128

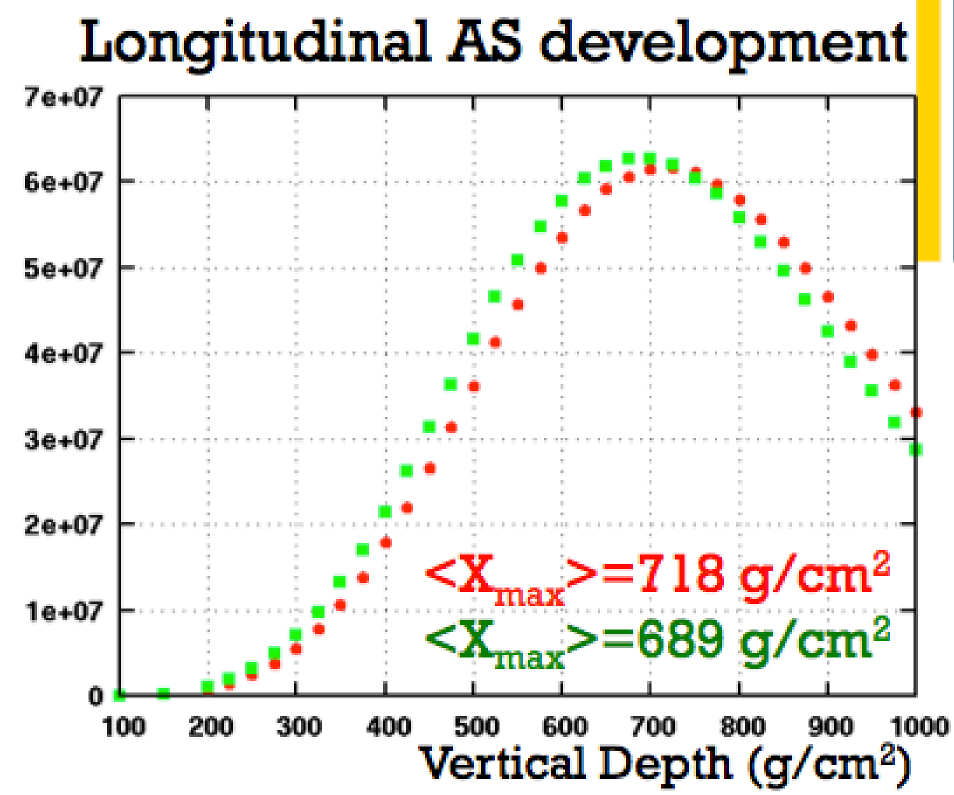


Impact on modeling of HECR showers: first assessment

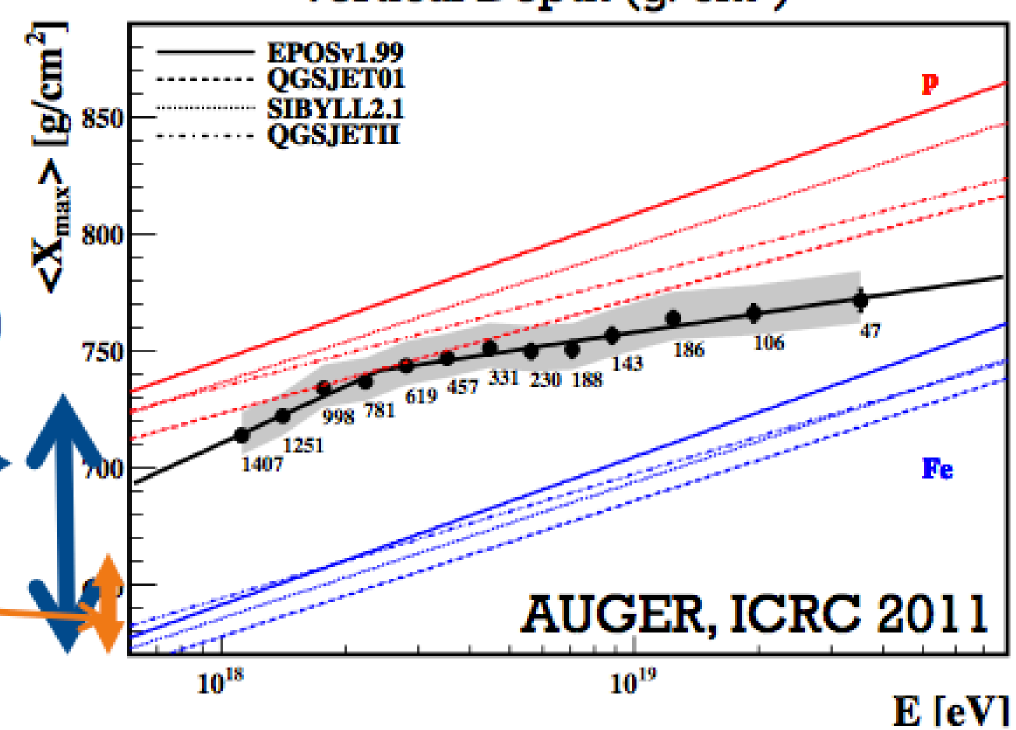
+ π^0 spectrum and air shower

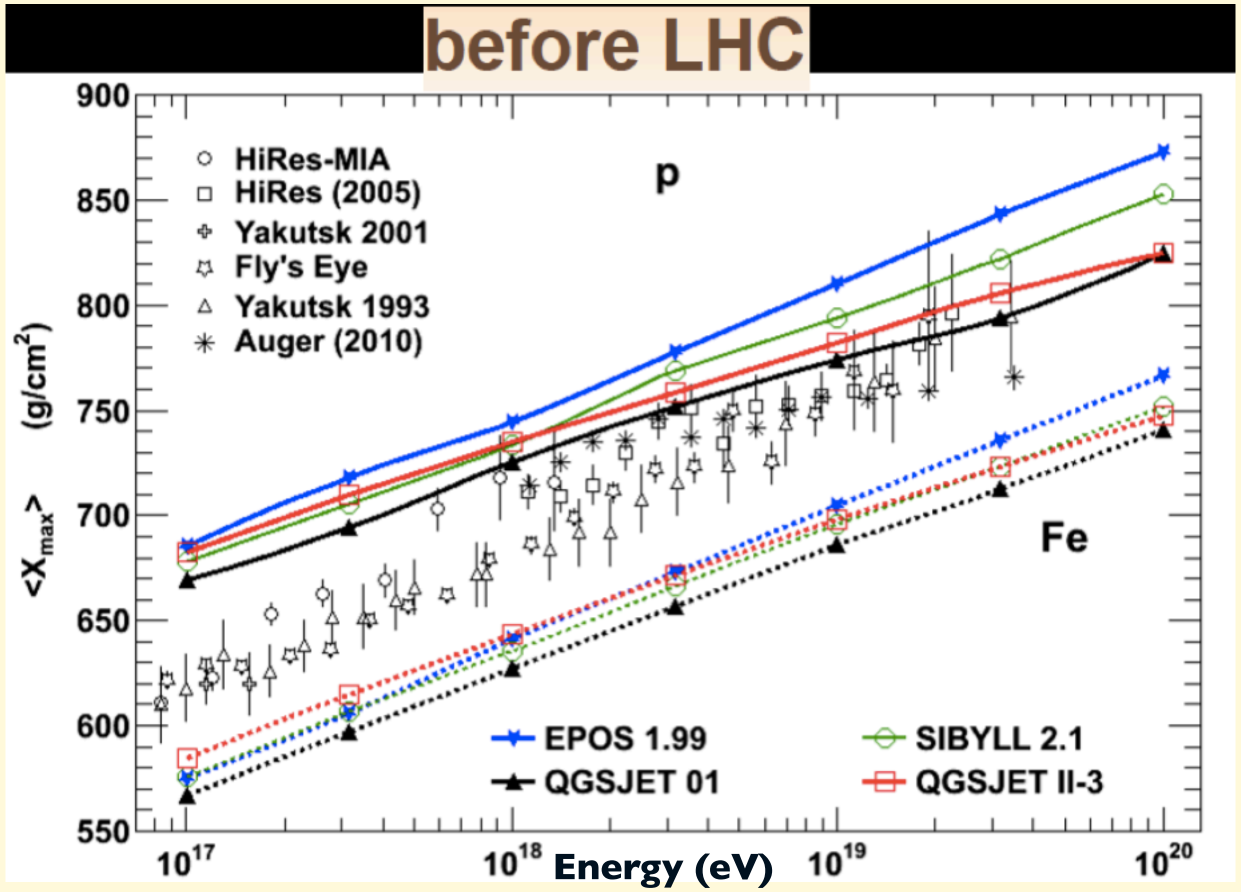


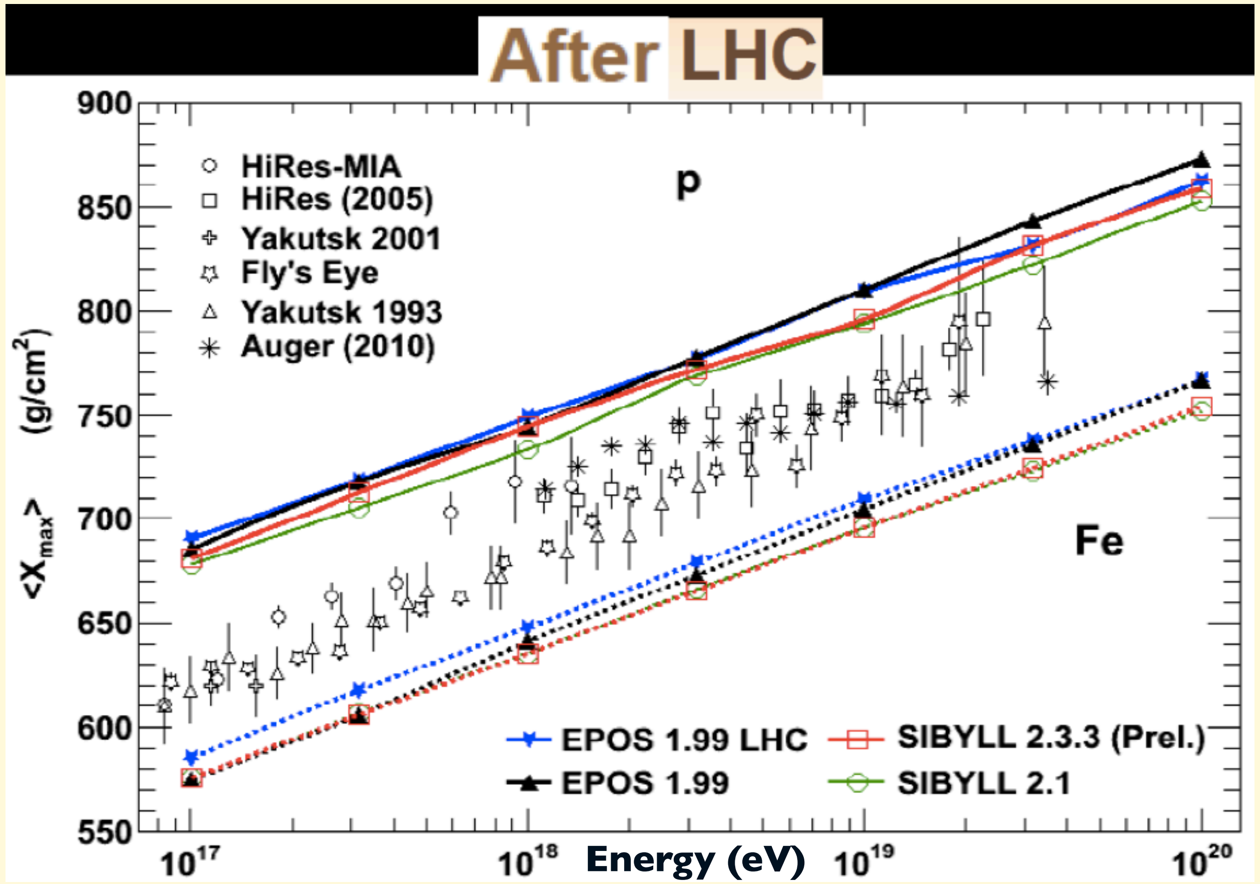
π^0 spectrum at $E_{lab} = 10^{17}$eV



- ✓ Artificial modification of meson spectra (in agreement with differences between models)
- ✓ Δ<X_{max}(p-Fe)> ~ 100 g/cm^2
- ✓ Effect to air shower ~ 30 g/cm^2





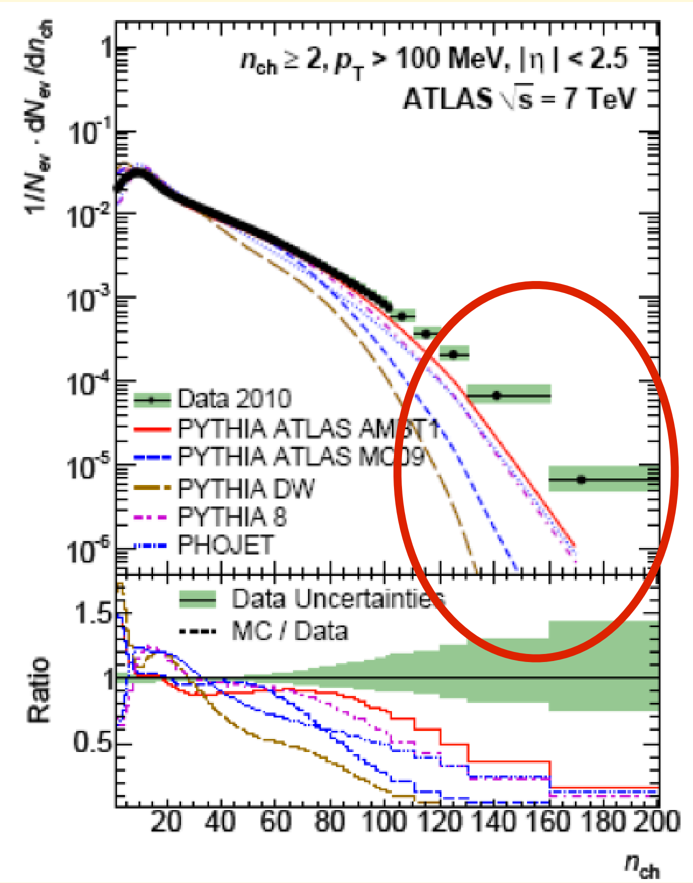


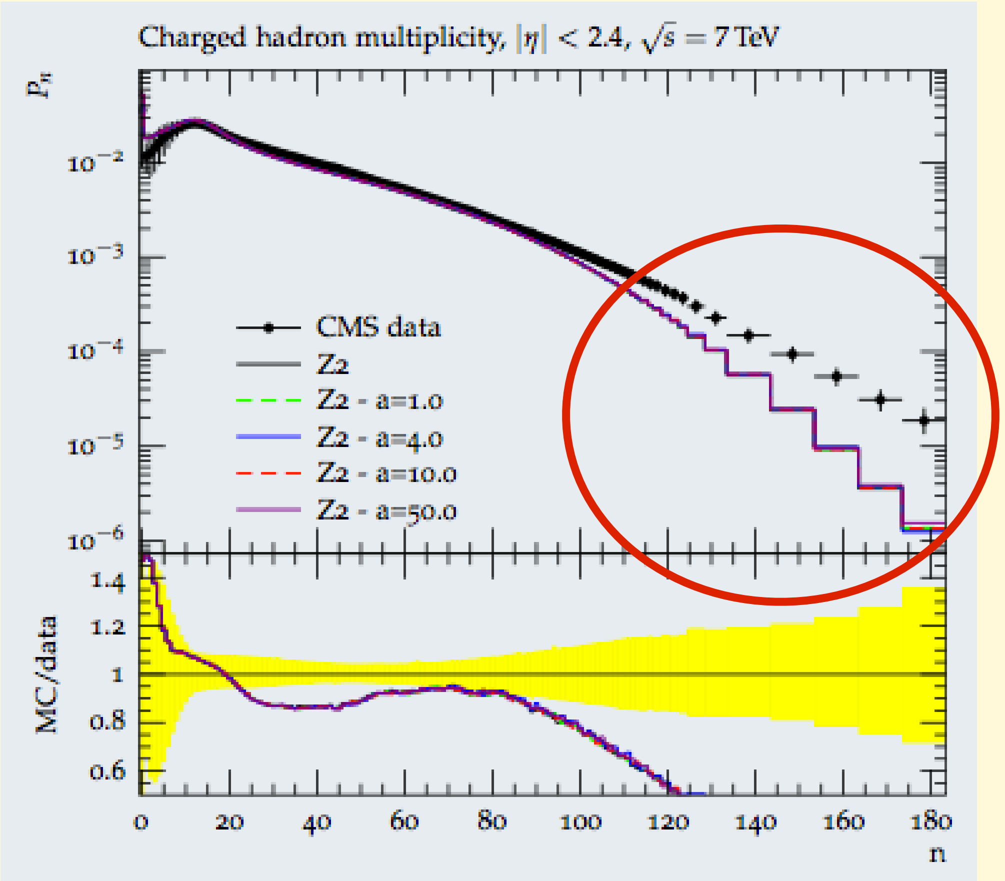
From A.Olinto at
International Symposium on Future Directions in UHECRs, Febr 13-16 2012, CERN

Notice: p was more uncertain than Fe (higher E; cross section and shower evolution dominated in Fe by nuclear break-up etc, phenomenologically better modeled.)
Key inputs for these improvements:
- total/inelastic pp cross sections
- forward spectra

Properties of final states in “0-bias” events

Large multiplicity final states





ATLAS, http://arxiv.org/pdf/1012.5104v2

S.Alderweireldt, MPI-2011

Need a detailed characterization of the structure of large-multiplicity final states:

- are they dominated by 2-jets back to back?
- are they dominated by many soft jets (e.g. multiple semi-hard collisions)
- do they look “fireball”-like (spherically symmetric)?
- does the track-pt spectrum of high-Nch events agree with MCs?
- y-distribution of very soft tracks in high-Nch events?
- .....

Are we staring at something *fundamental*, or is this just QCD chemistry and MC-tuning?

.... see also the CMS ridge effect

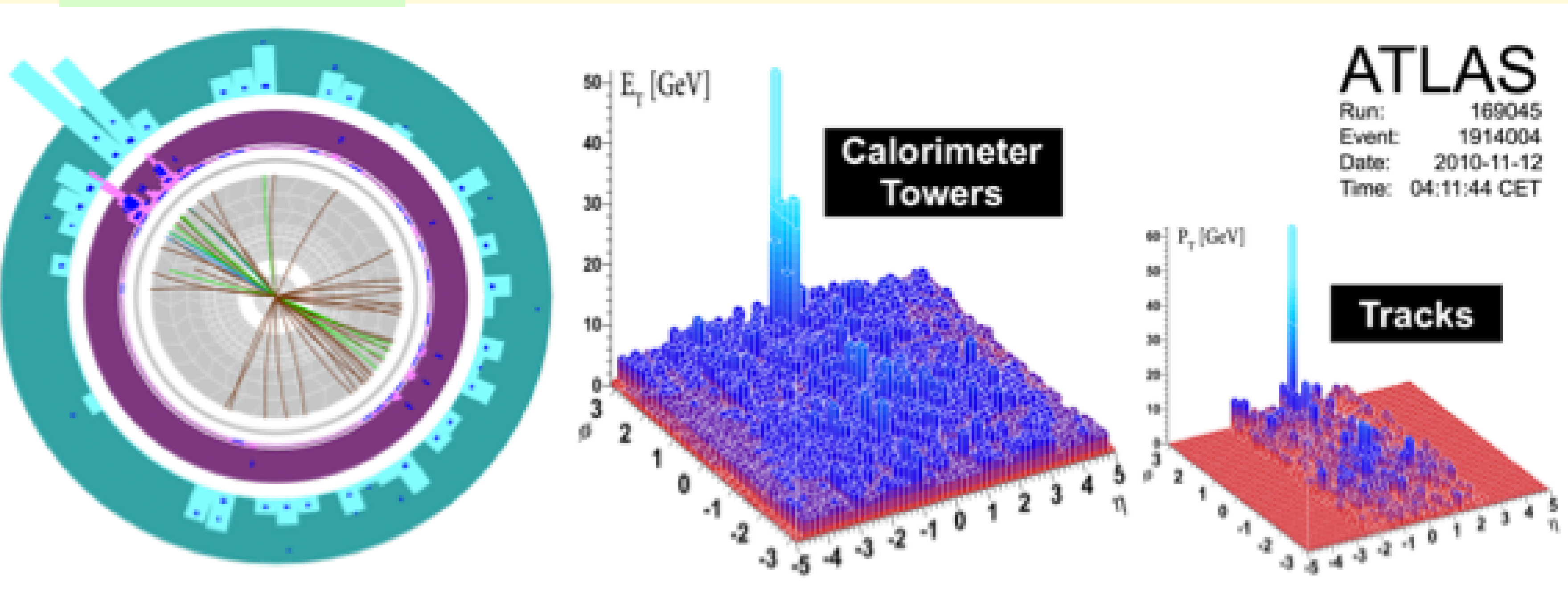
Open challenge:

To prove that the underlying mechanisms of multiparticle production at high energy are *understood*, in addition to being simply *properly modeled*

Hard probes in Pb-Pb collisions ....

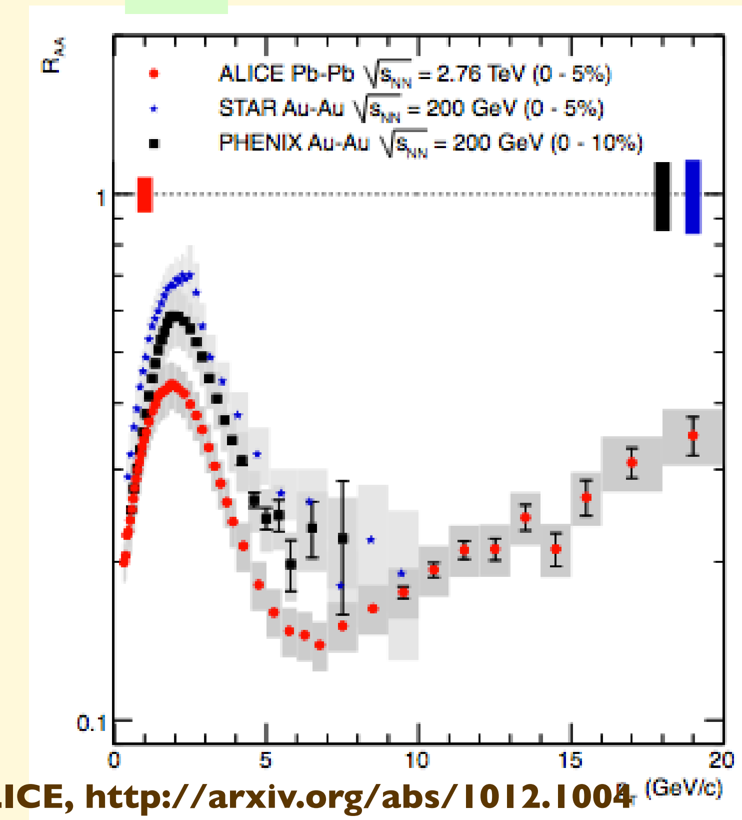
- $\sqrt{S_{NN}}$ = 2.76 TeV => 14 times larger than any previous heavy ion experiment (RHIC)

Jet quenching



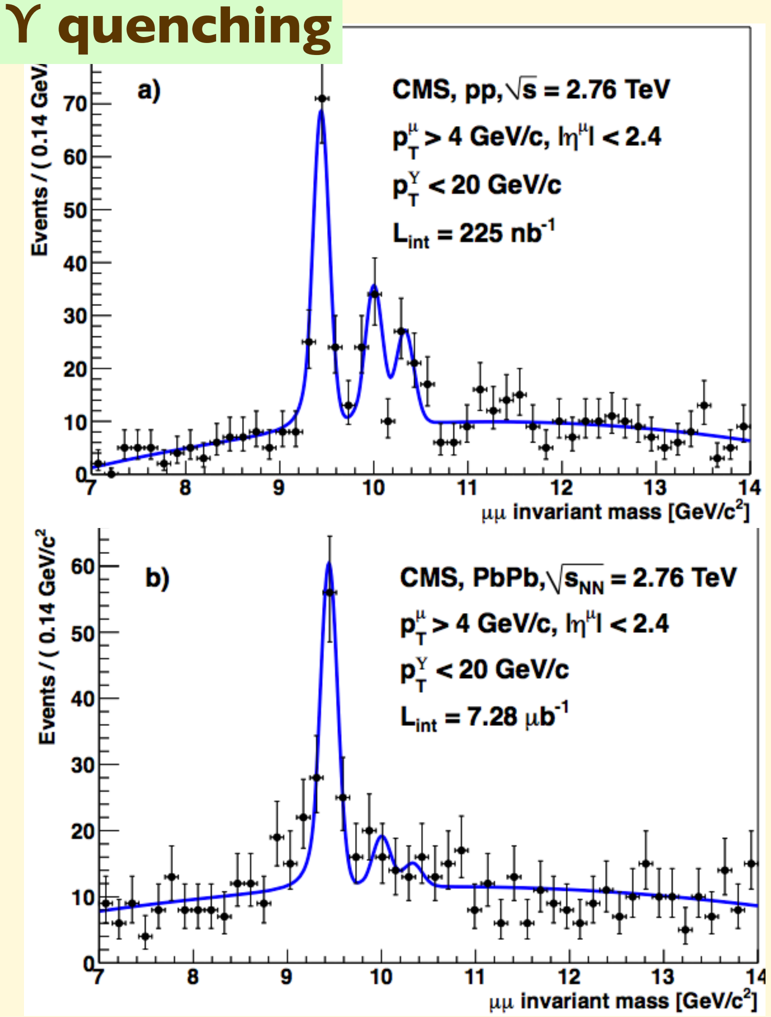
ATLAS, http://arxiv.org/abs/1011.6182

R_{AA}

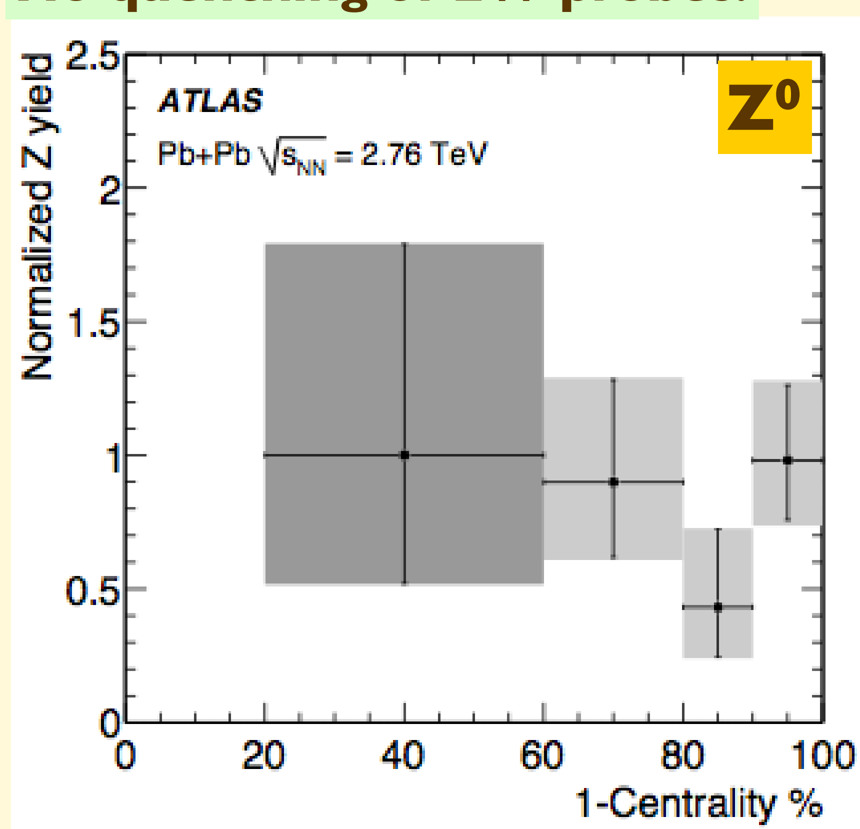


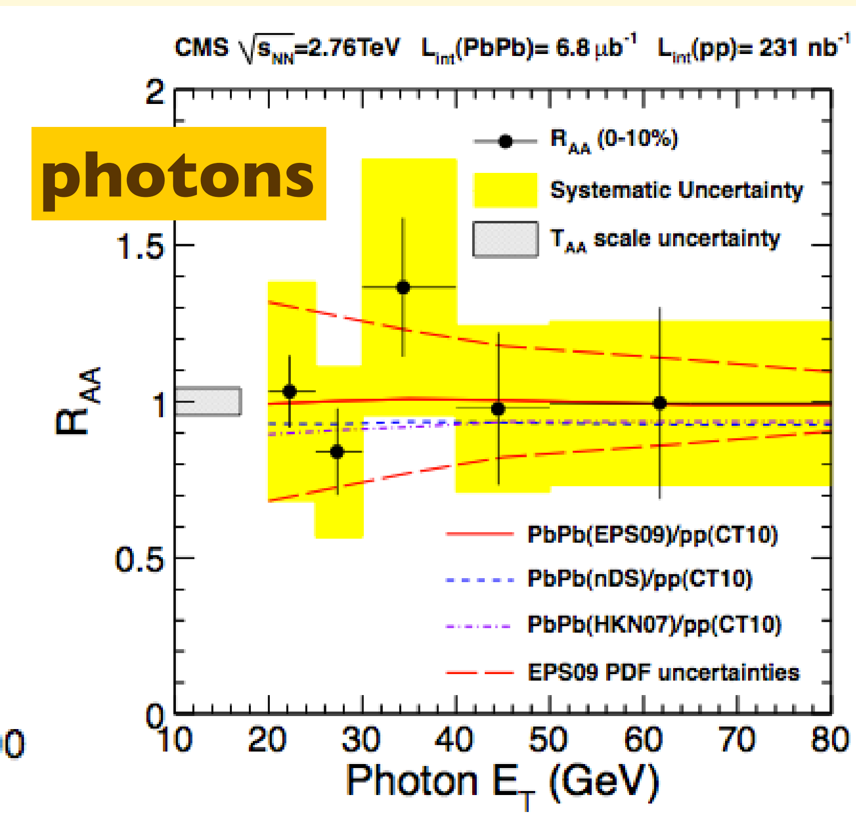
ALICE, http://arxiv.org/abs/1012.1004

Υ quenching



No quenching of EW probes:





ATLAS, http://arxiv.org/abs/1012.5419 **CMS, http://arxiv.org/abs/1201.3093**

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- **The LHC is more than Higgs and BSM. A continued programme of precise EW and QCD measurements will benefit the H studies and BSM searches, and will enrich our global understanding of natural phenomena**