LHC, year 2: where we stand

DESY,

November 22, 2011

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LHC, year 2: where we stand

or:

there is life at the LHC even w/out H&SUSY

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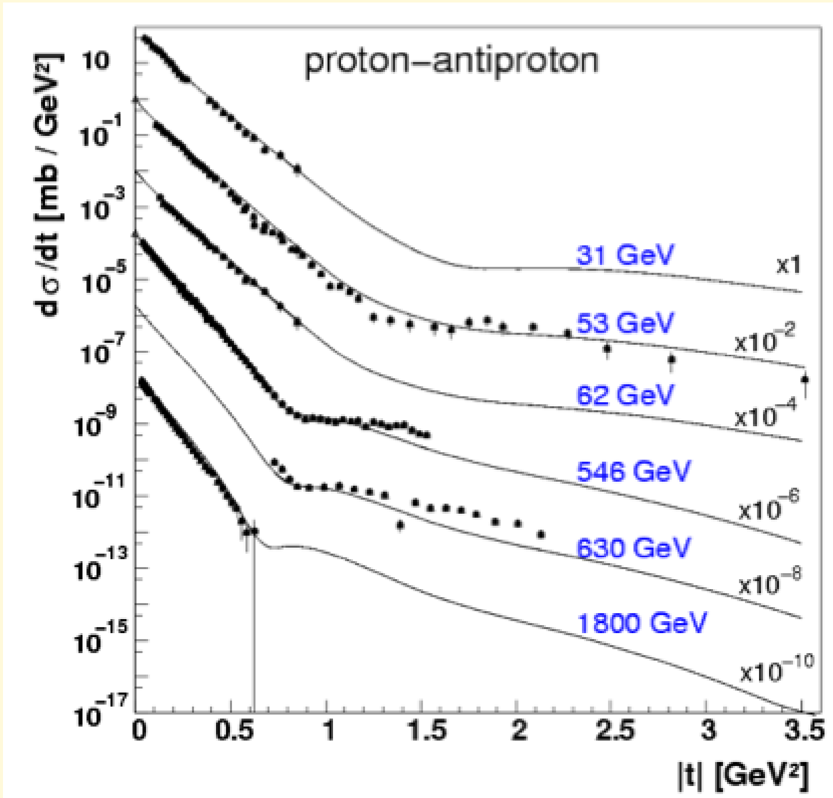
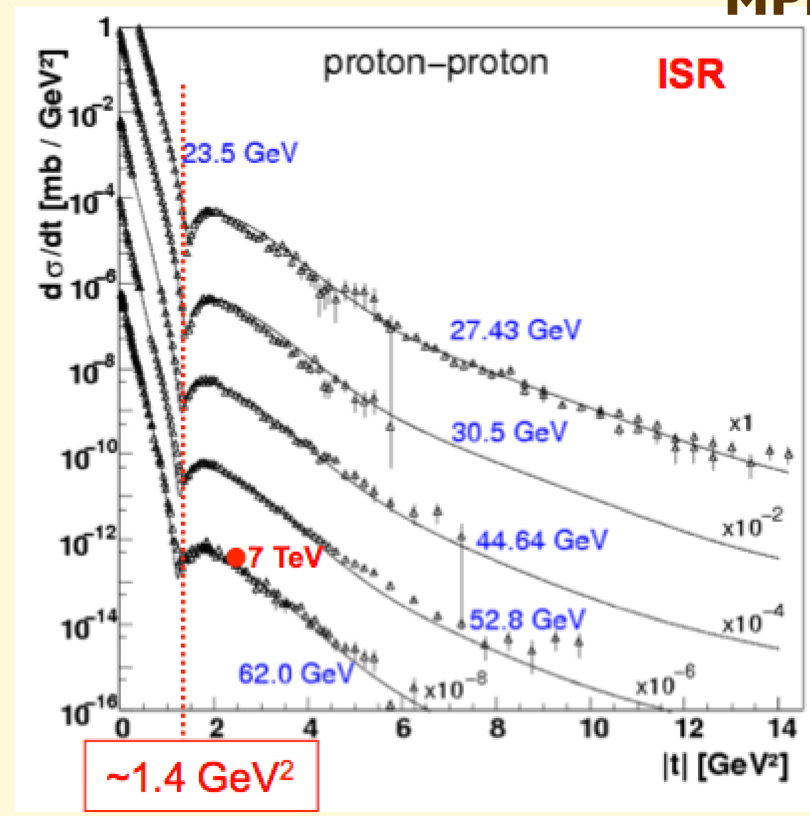
Outline

- Focus on what has been seen, not on what hasn't
  - Lessons learned, surprises, open issues
- Global properties of protons and their interactions
  - Interesting, yet to be understood dynamics, at low Q^2
  - PDF issues
- EW measurements
- Challenging probes of high-Q^2 dynamics
- Surprises from the flavour sector

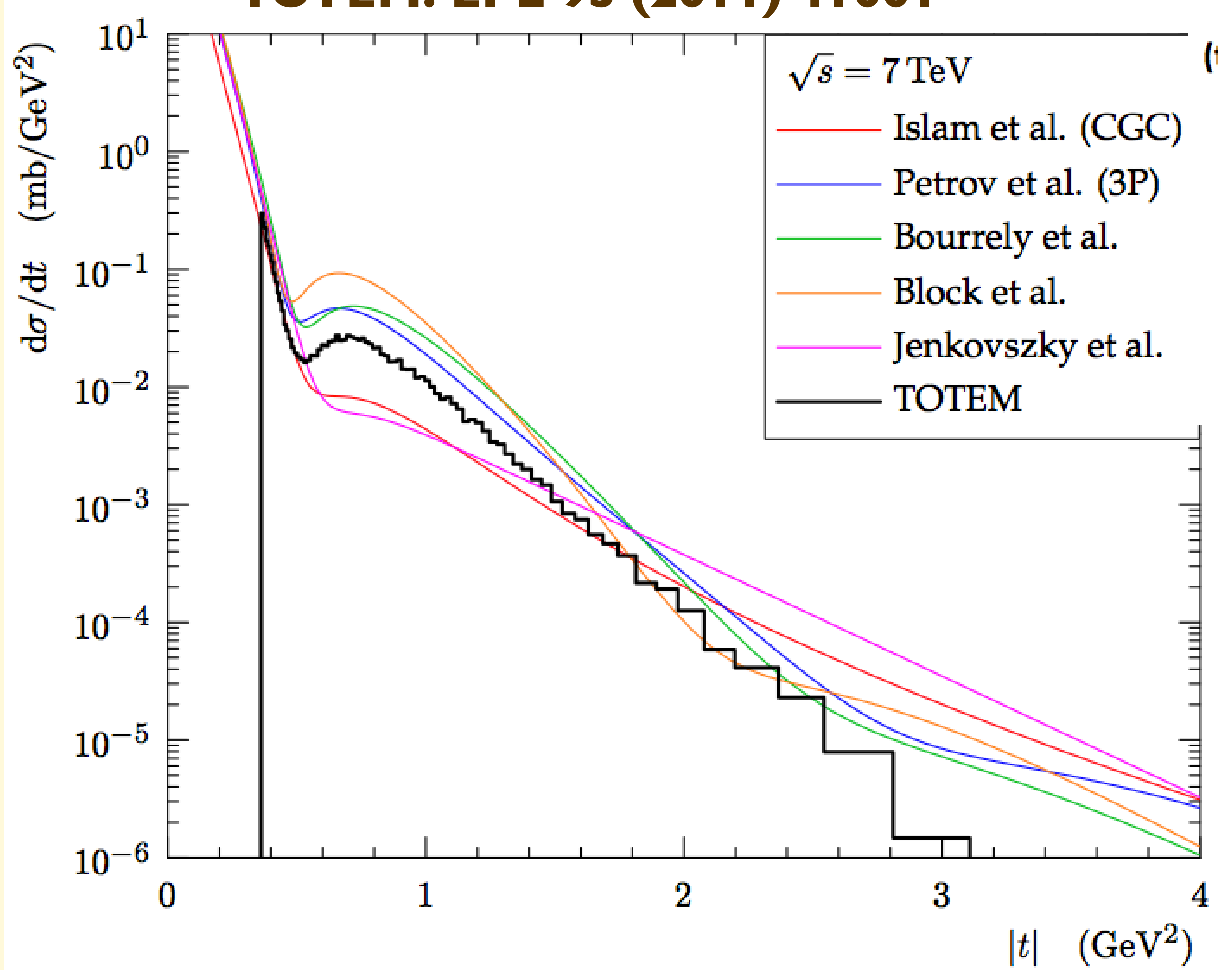
TOTEM: elastic cross section

See also K.Osterberg, MPI 2011





TOTEM: EPL 95 (2011) 41001



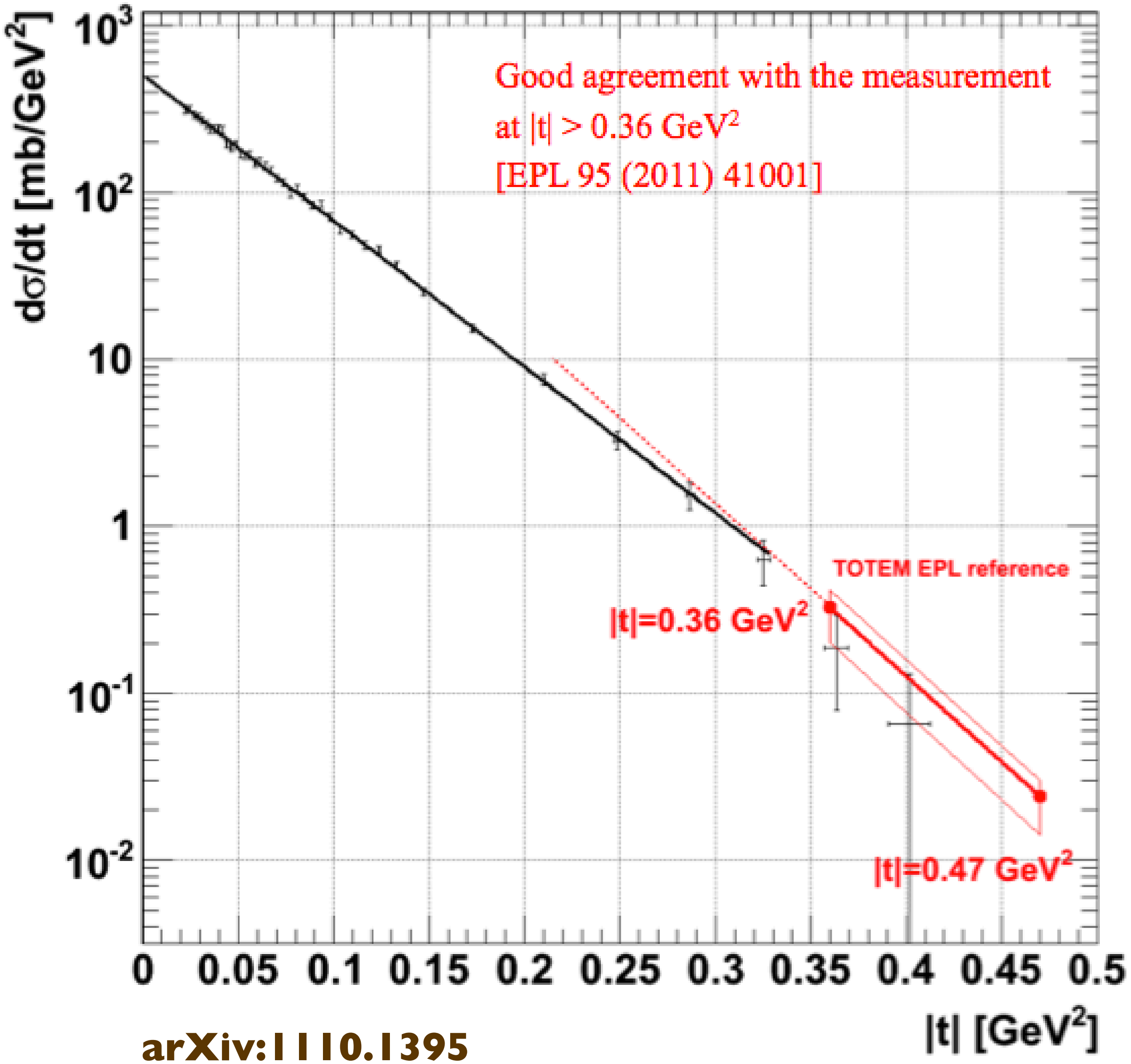
B (t=-0.4 GeV²)	t_{DIP}	t^{-n} [1.5–2.5 GeV²]
20.2	0.60	5.0
23.3	**0.51**	**7.0**
22.0	**0.54**	**8.4**
25.3	0.48	10.4
20.1	0.72	4.2
23.6 ± 0.5	0.53 ± 0.01	7.8 ± 0.3

More, available, data will allow to extend the measurement up to O(4-5 GeV^2)

TOTEM elastic and total cross sections

K.Eggert, HCP 2011

Final Differential Cross-Section for t > 2 x 10 $^{-2}$ GeV^2
(Data taking: June 2011 for 20 min.)



arXiv:1110.1395

Extrapolation to t = 0:

$$\left.\frac{d\sigma}{dt}\right|_{t=0} = 5.037\times10^2\,\mathrm{mb/GeV^2}$$

Exponential slope

$$B|_{t=0} = 20.1\,\mathrm{GeV^{-2}}$$

Total elastic cross-section:

$$\sigma_{EL} = 8.3\,\mathrm{mb}^{(\mathrm{extrapol.})} + 16.5\,\mathrm{mb}^{(\mathrm{measured})} = 24.8\,\mathrm{mb}$$

Extract total cross-section

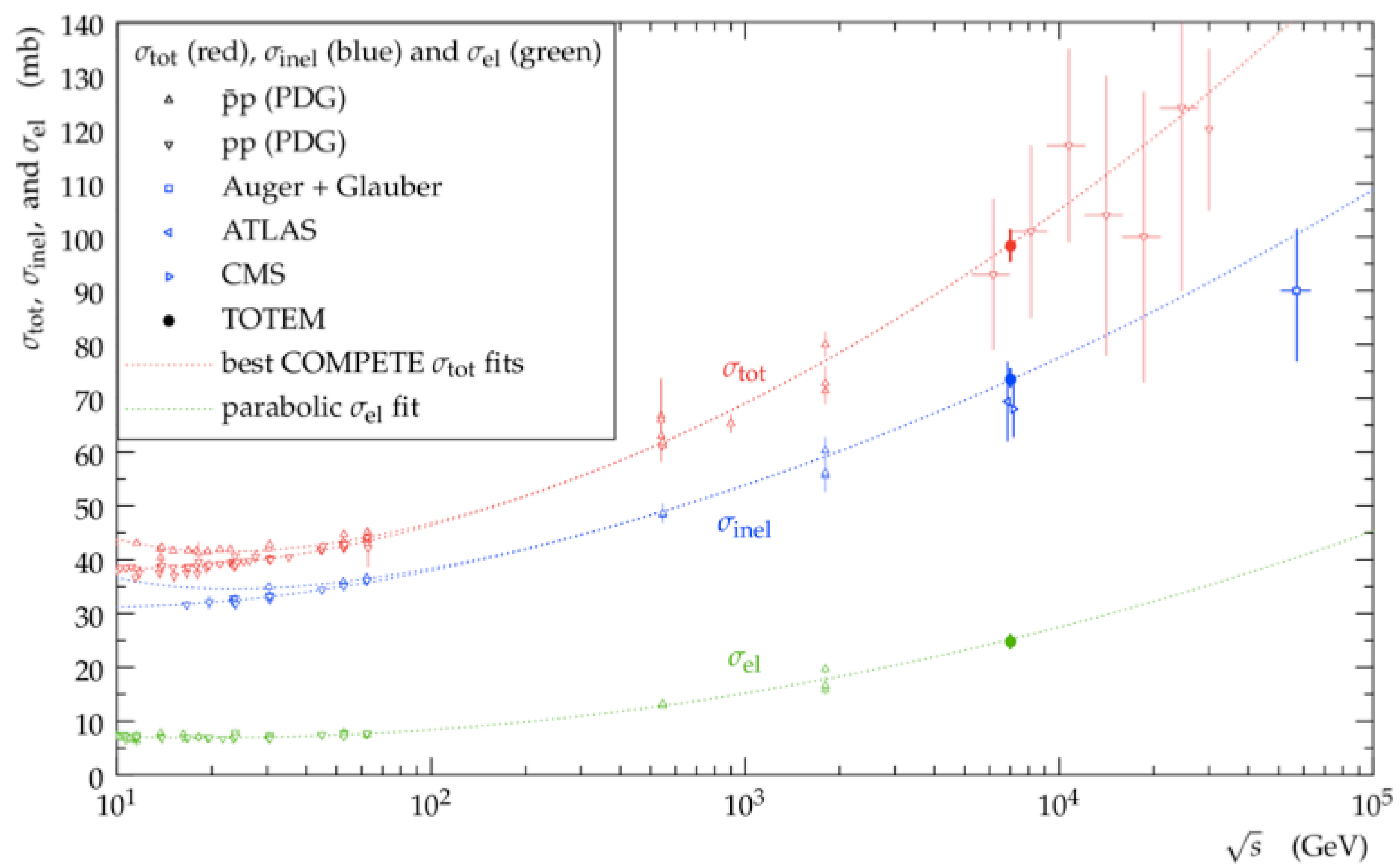
Optical Theorem: $$\sigma_{TOT}^2 = \frac{16\pi(\hbar c)^2}{1+\rho^2}\cdot\left.\frac{d\sigma_{EL}}{dt}\right|_{t=0}$$

$$\rho = 0.14^{+0.01}_{-0.08}$$ from Compete Coll.

$$\frac{d\sigma_{EL}}{dt} = \frac{1}{L}\cdot\frac{dN_{EL}}{dt}$$

Normalisation with luminosity from CMS
Uncertainty ± 4% **Crucial!!**

Inelastic rates, comparison with lower-E fits and with other LHC experiments



$$\sigma_T = \left(98.3 \pm 0.2^{(stat)} \pm 2.7^{(syst)} \begin{bmatrix} +0.8 \\ -0.2 \end{bmatrix}^{(syst\ from\ \rho)}\right)\ \text{mb}$$

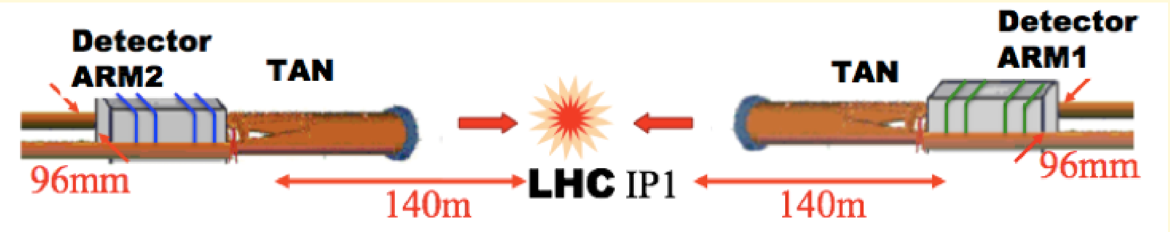
$$\sigma_{inel} = \sigma_{tot} - \sigma_{el} = \left(73.5 \pm 0.6^{(stat)} \begin{bmatrix} +1.8 \\ -1.3 \end{bmatrix}^{(syst)}\right)\text{mb}$$

σ_{inel} (TOTEM)	**$(73.5 \pm 0.6^{stat}\ {}^{+1.8}_{-1.3}\ {}^{syst})$ mb**
σ_{inel} (CMS)	$(68.0 \pm 2.0^{syst} \pm 2.4^{lumi} \pm 4^{extrap})$ mb
σ_{inel} (ATLAS)	$(69.4 \pm 2.4^{exp} \pm 6.9^{extrap})$ mb
σ_{inel} (ALICE)	$(72.7 \pm 1.1^{model} \pm 5.1^{lumi})$ mb

Valuable input for modeling of low-mass diffractive events

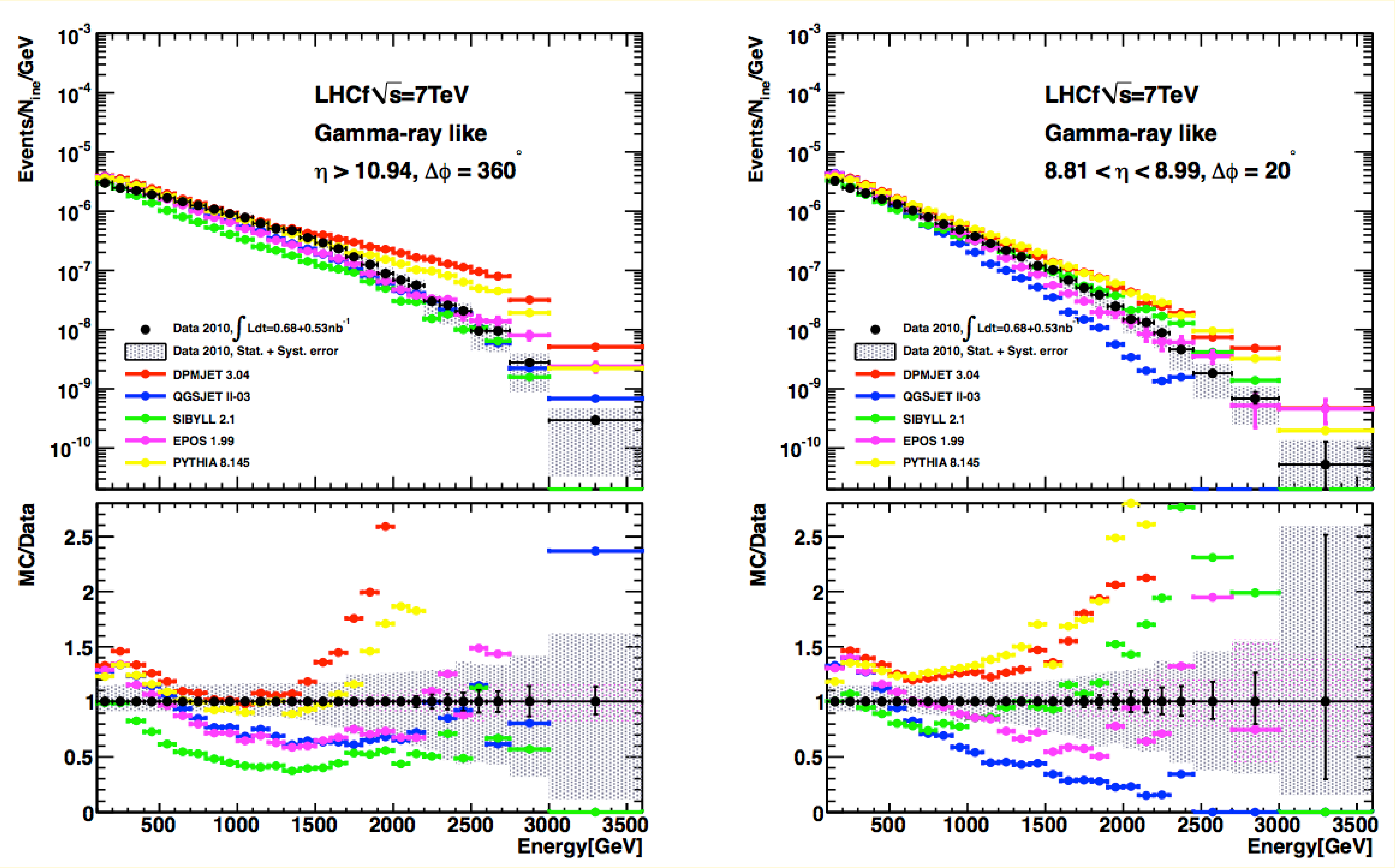
LHCf: Very forward energy flow

See also K.Noda, MPI 2011



"Measurement of zero degree single photon energy spectra for √s = 7 TeV proton-proton collisions at LHC"

PLB 703 (2011) 128

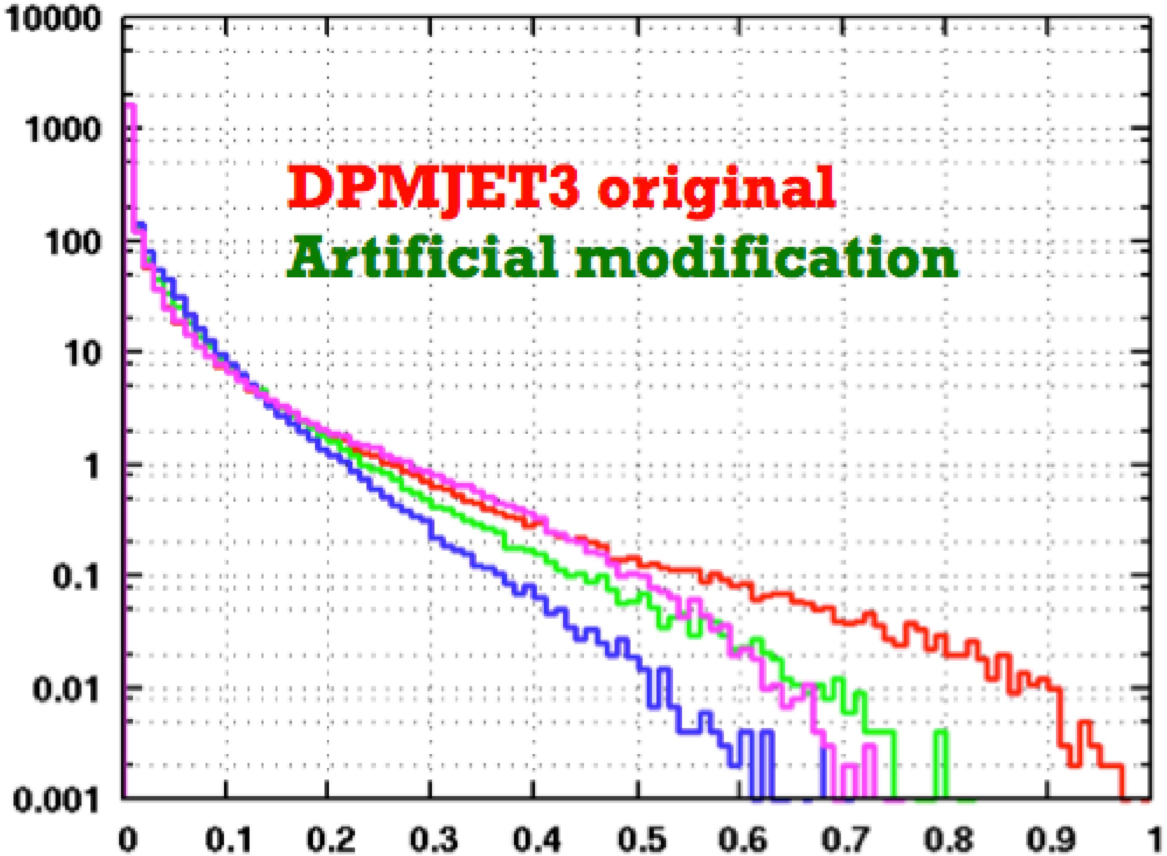


Impact on modeling of HECR showers: first assessment

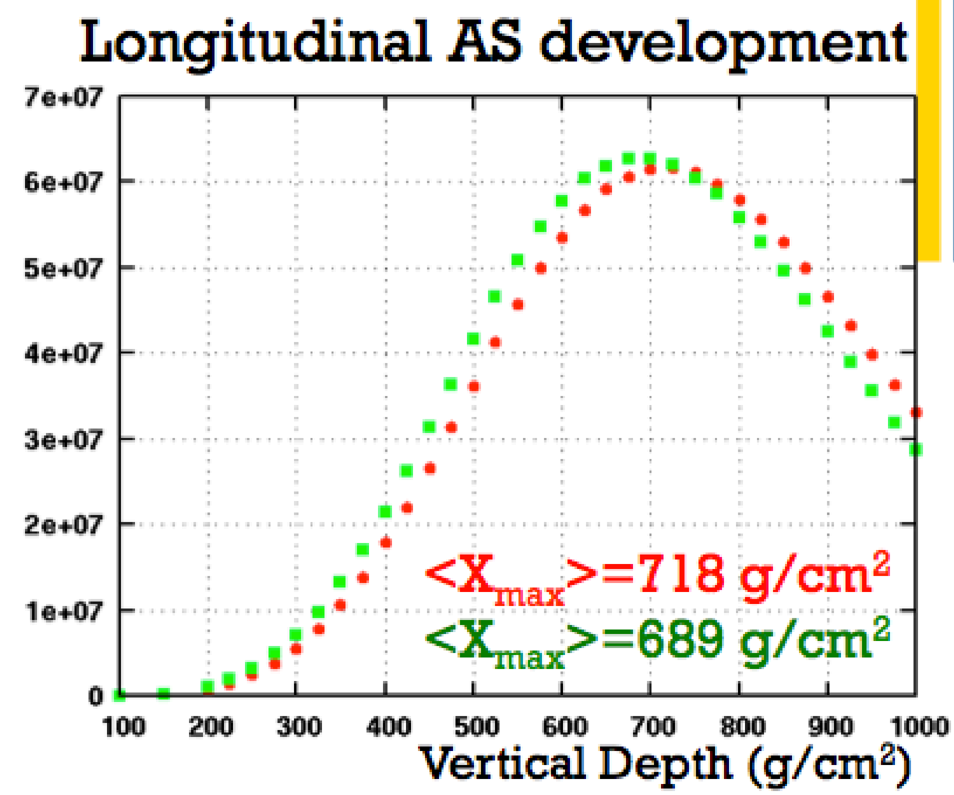
A.Tricomi, HCP 2011

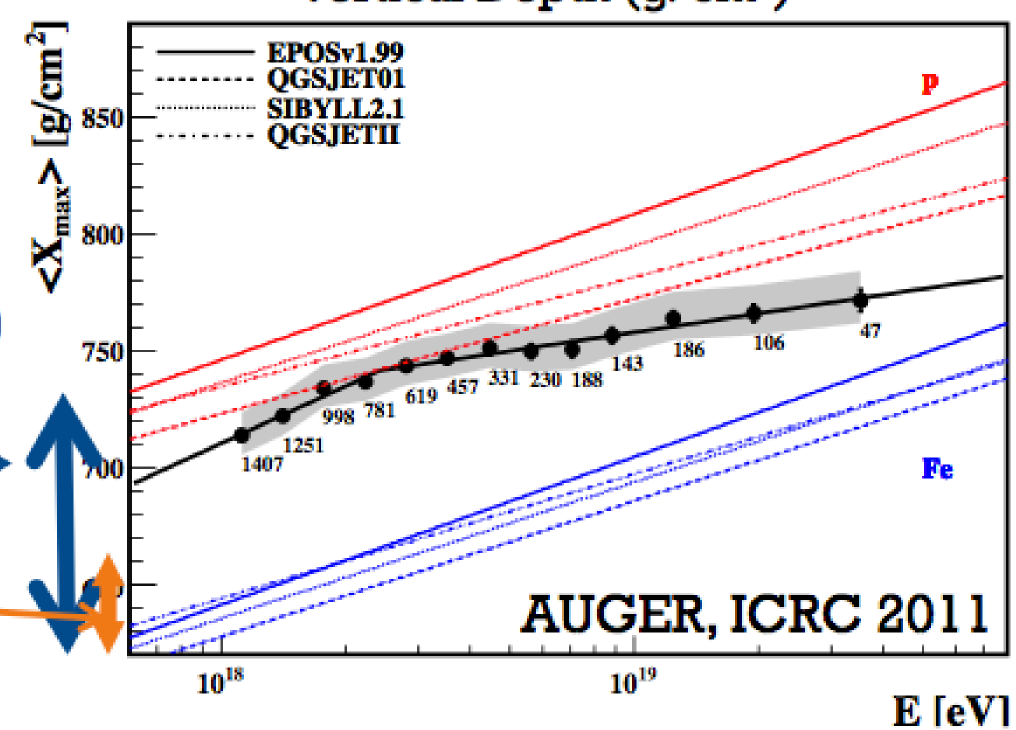
+ π^0 spectrum and air shower

14



π^0 spectrum at $E_{lab} = 10^{17}$eV





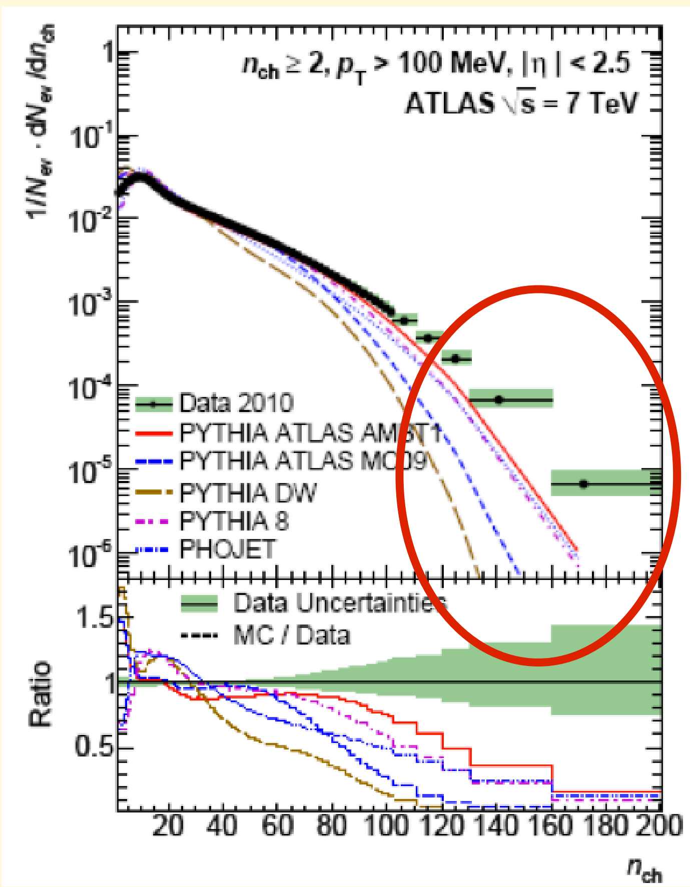
- ✓ Artificial modification of meson spectra (in agreement with differences between models)
- ✓ $\Delta\langle X_{max}(\text{p-Fe})\rangle \sim 100$ g/cm^2
- ✓ Effect to air shower ~ 30 g/cm^2

Properties of final states in “0-bias” events

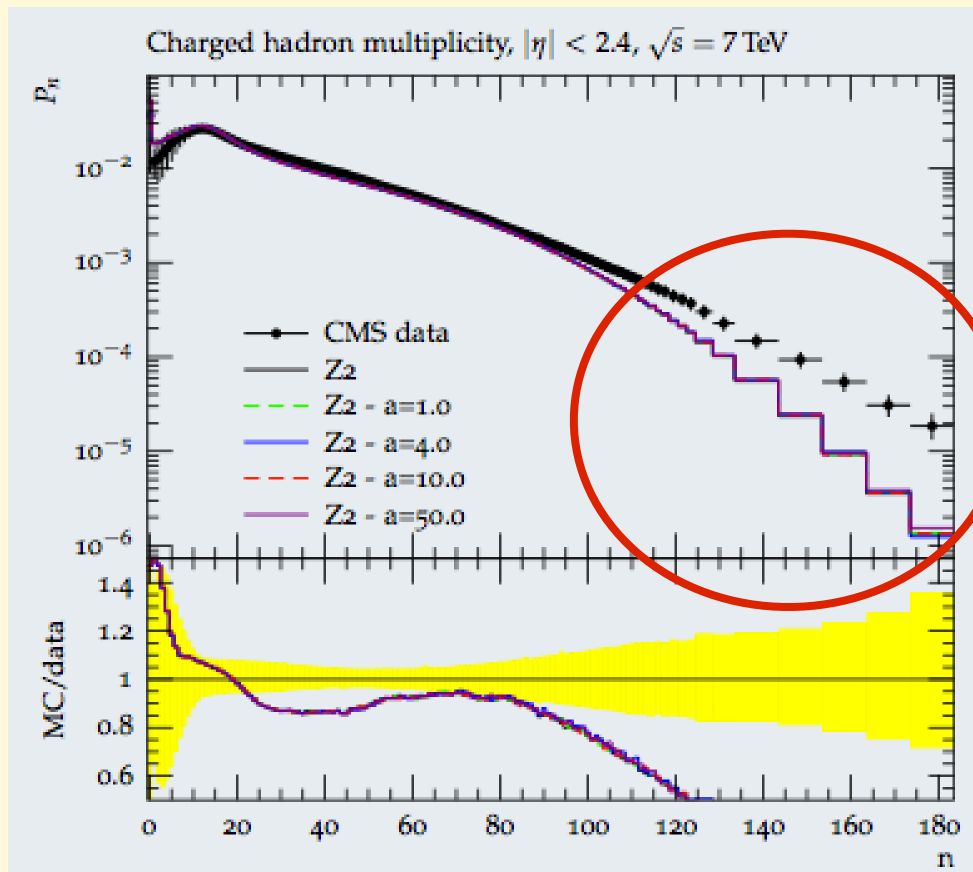
⇒ **The MPI Workshop this week at DESY covers this and more in full detail**

Just a few remarks on an issue that particularly intrigues me

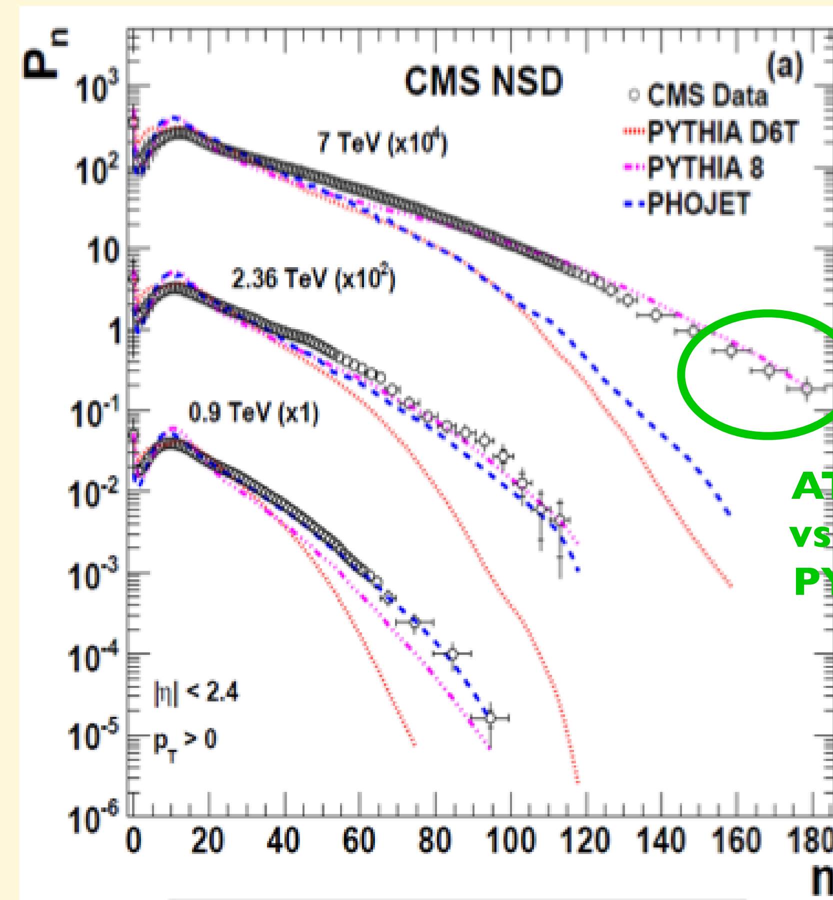
Large multiplicity final states



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



S.Alderweireldt, MPI-2011



??? ATLAS vs CMS PY8 ???

R.Rougny, HCP-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?
- .....

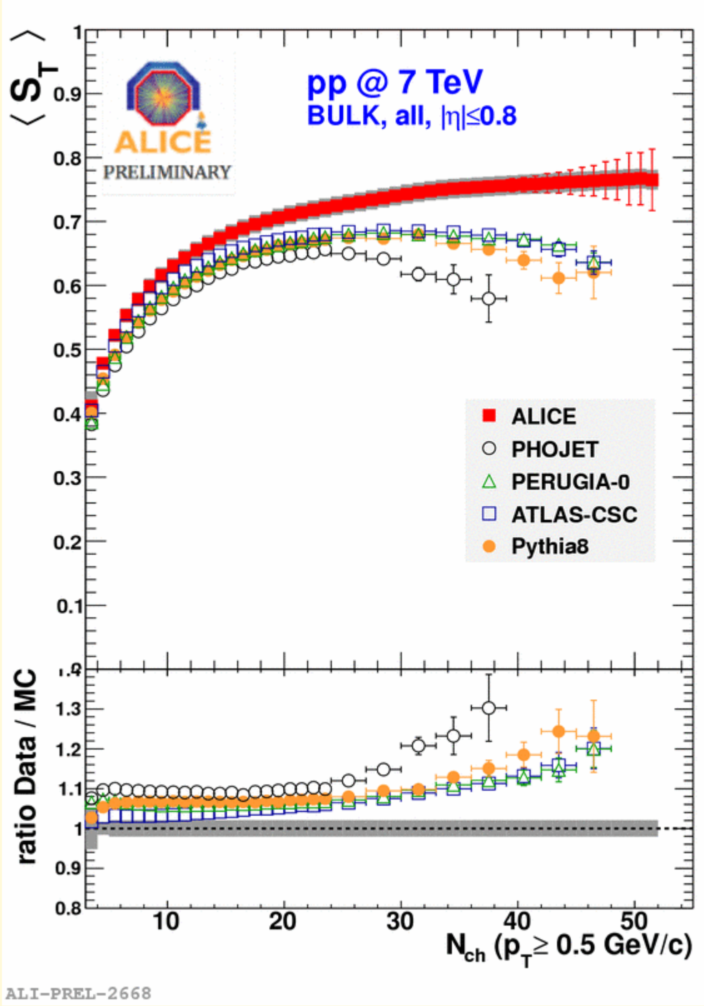
Are we staring at something *fundamental*, or is this just QCD chemistry and MC-tuning?

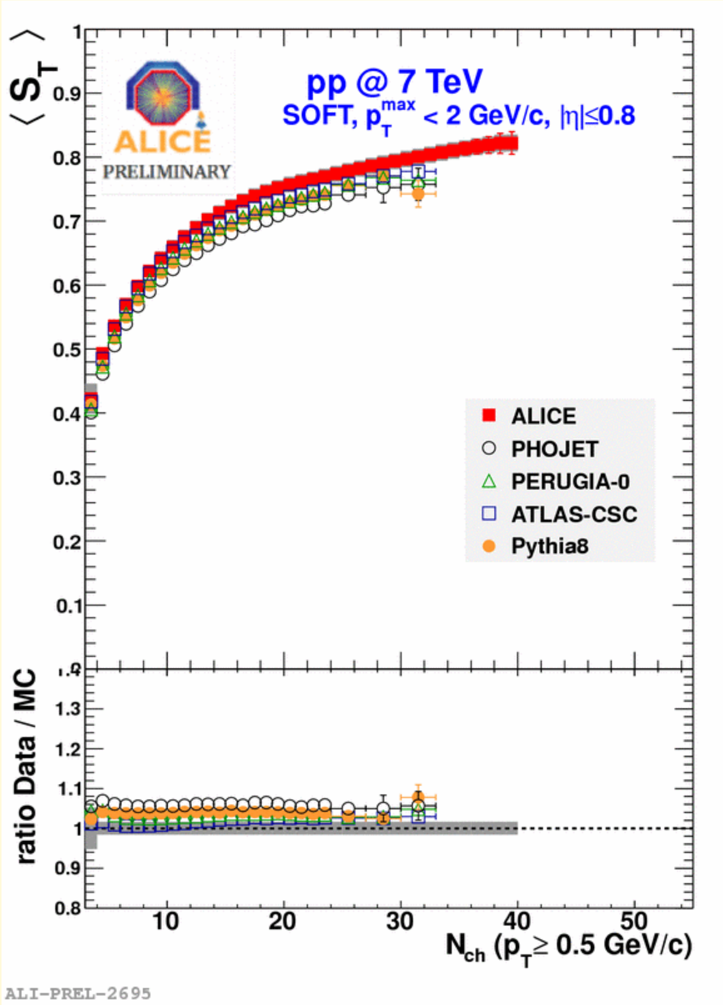
.... see also the CMS ridge effect

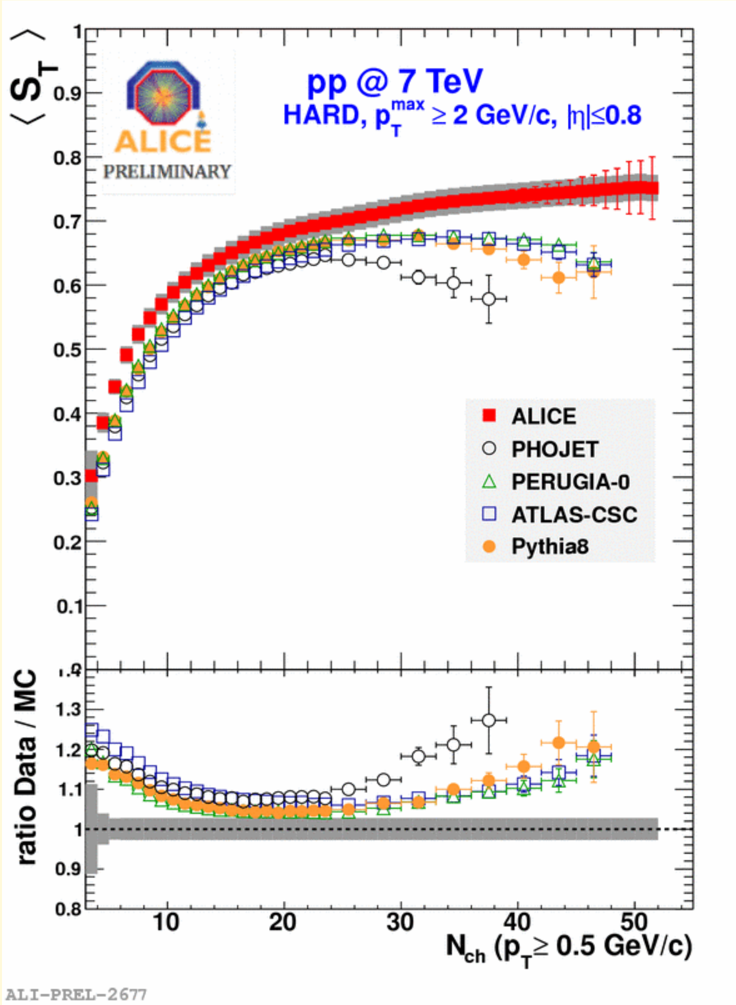
Further insight and puzzles on large-N_{ch} events

ALICE study of transverse sphericity vs N_{ch} **arXiv:1110.2278**

J.F. Grosse-Oetringhaus, MPI-2011







Events are generically more spherical, less jetty, than MC.

Most of the discrepancy comes however from hard events, not soft ones

However, this study does not explore the region of extreme N_{ch} (>100) where the major discrepancies observed by ATLAS/CMS appear

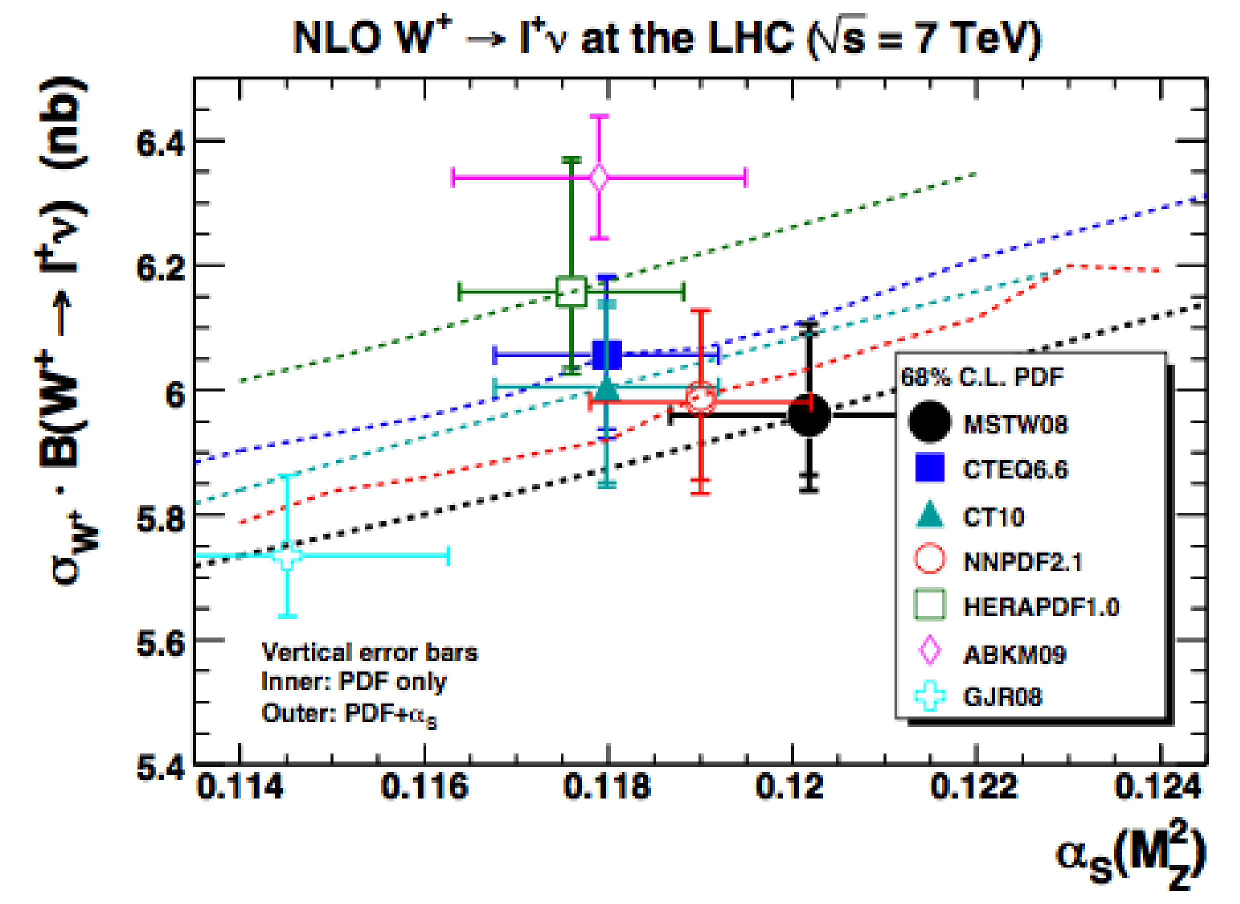
Open challenge:

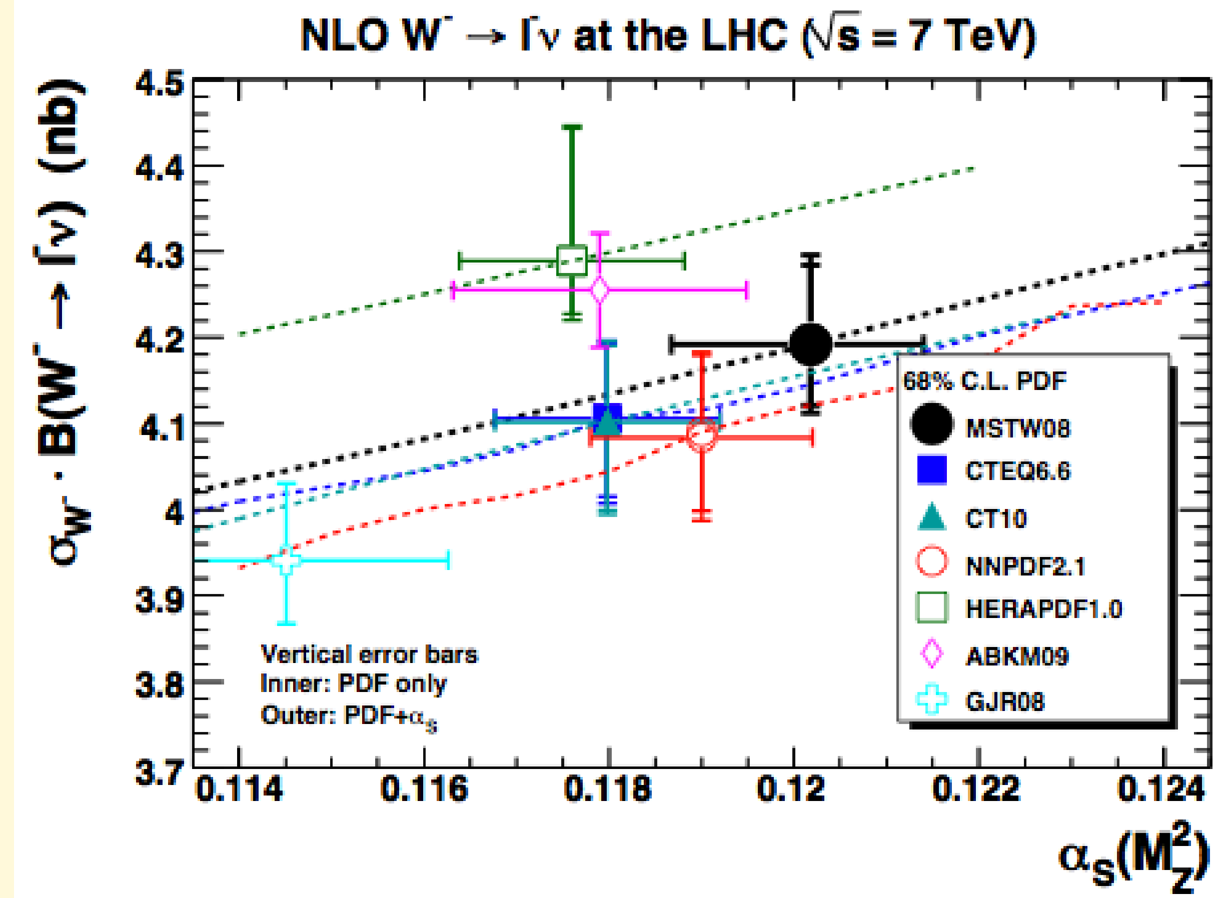
To prove that the underlying mechanisms of multiparticle production at high energy are *understood*, in addition to being simply *properly modeled*

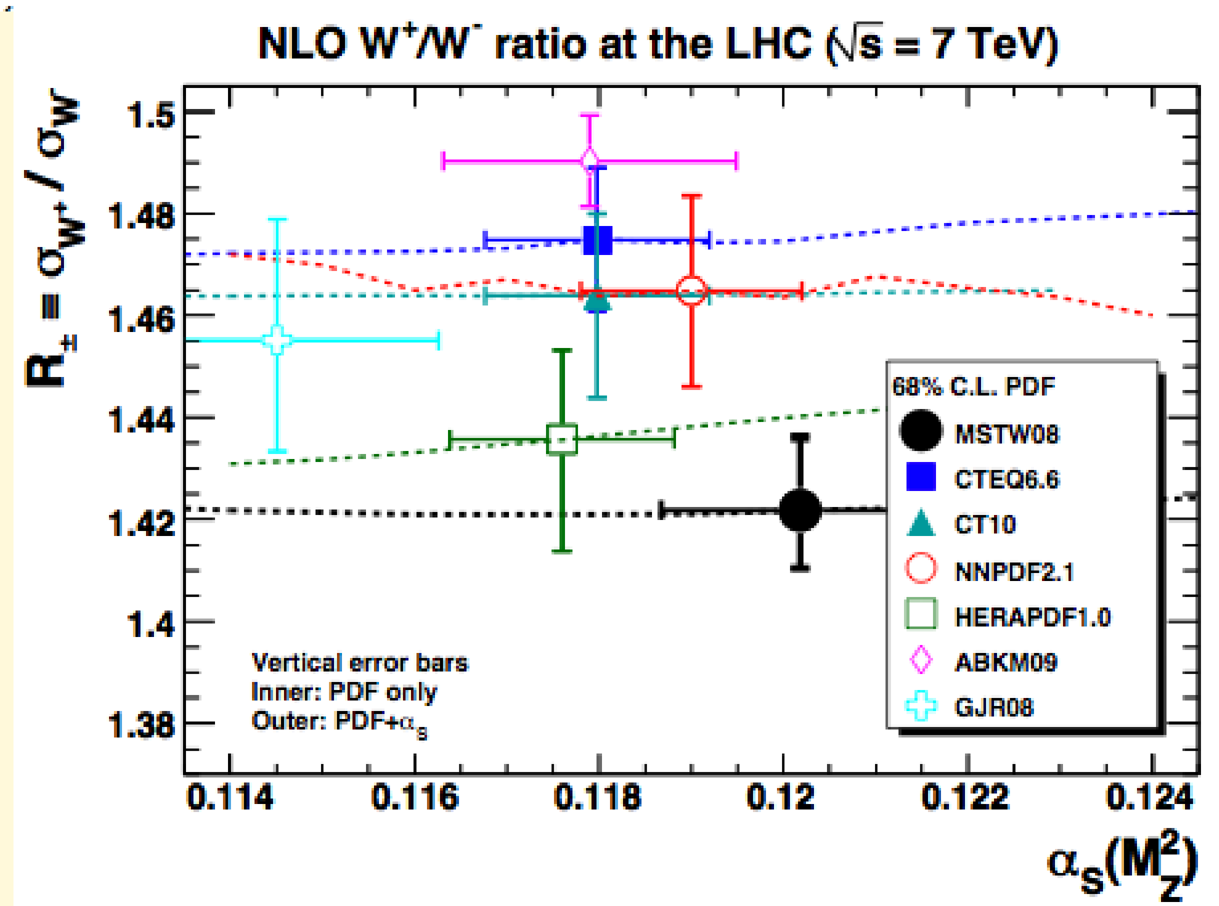
The proton structure at short-distance: PDFs

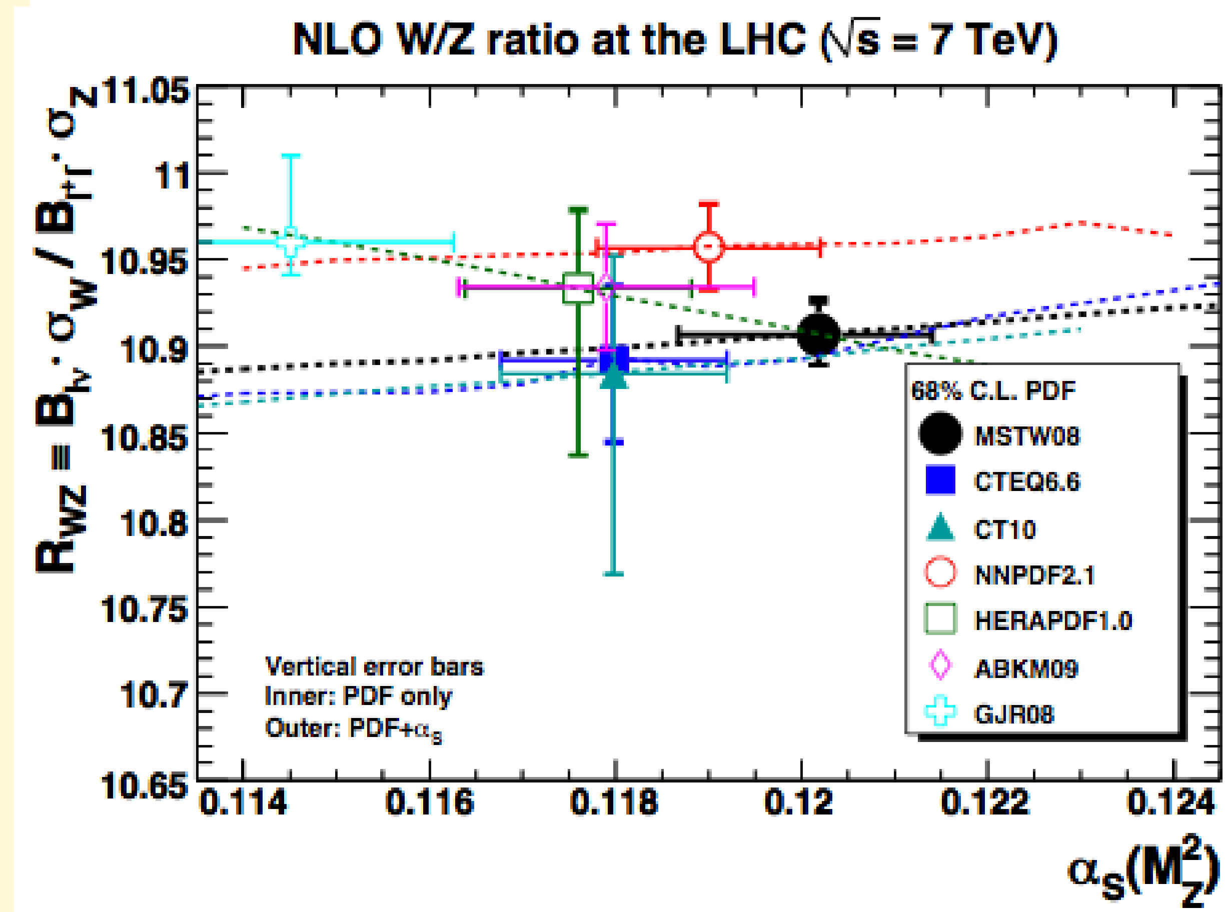
- For yrs we've argued that we can predict W and Z cross sections to % accuracy, and use them as luminometers
- Now data have reached a 3-4% precision, and theory predictions, driven by PDF fits, are off from each other by at least as much
- The consequences of the PDF uncertainties are important for the whole physics programme:
  - Higgs cross sections: exclusion limits if no signal, measurement of couplings if signal
  - m_W, $\sin\theta_W$, $\sigma(tt)$ vs mtop, ...
- Using LHC data to pin down PDF systematics is becoming an urgent need!

Benchmark W cross sections









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

Correlations among W/Z cross sections

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

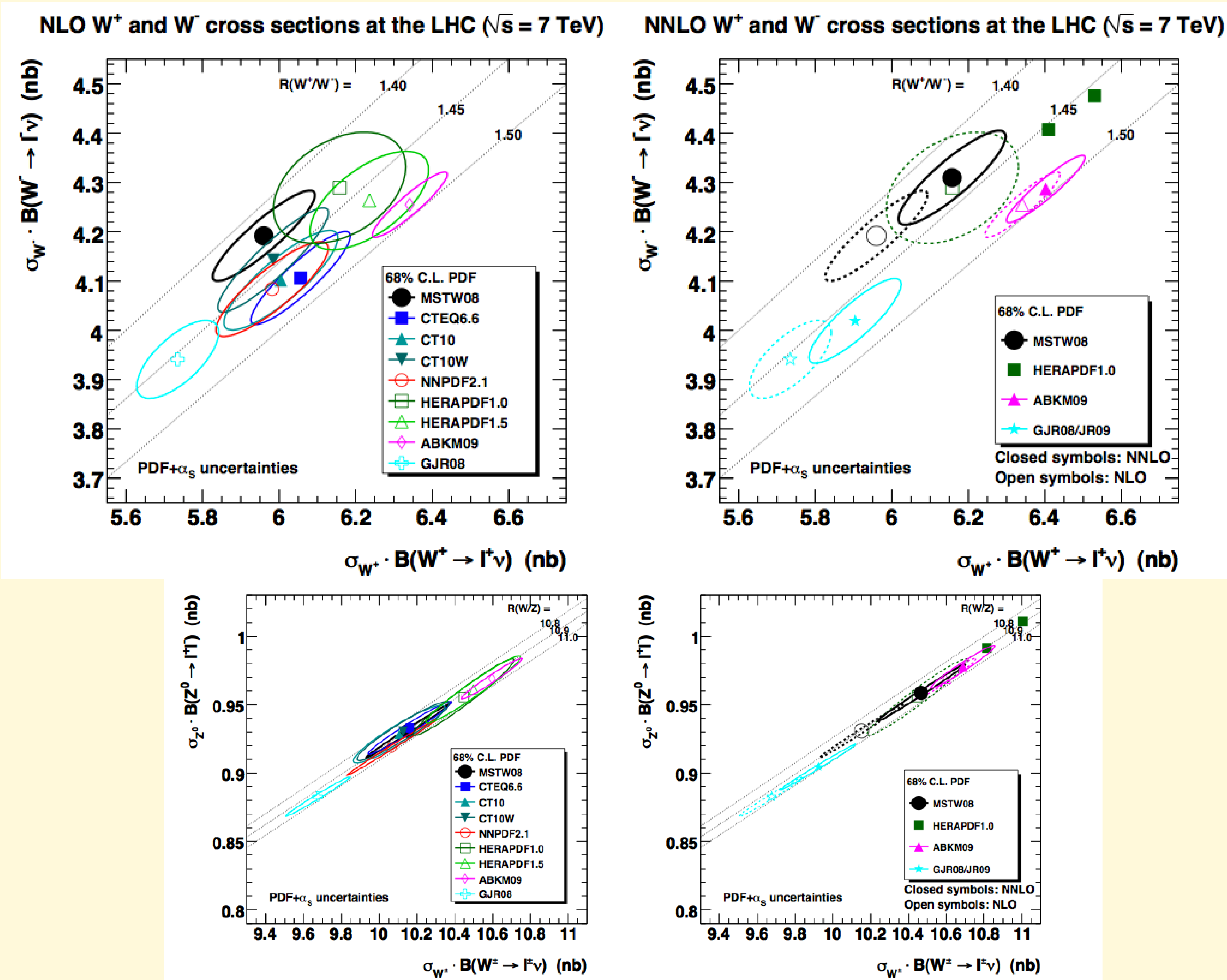
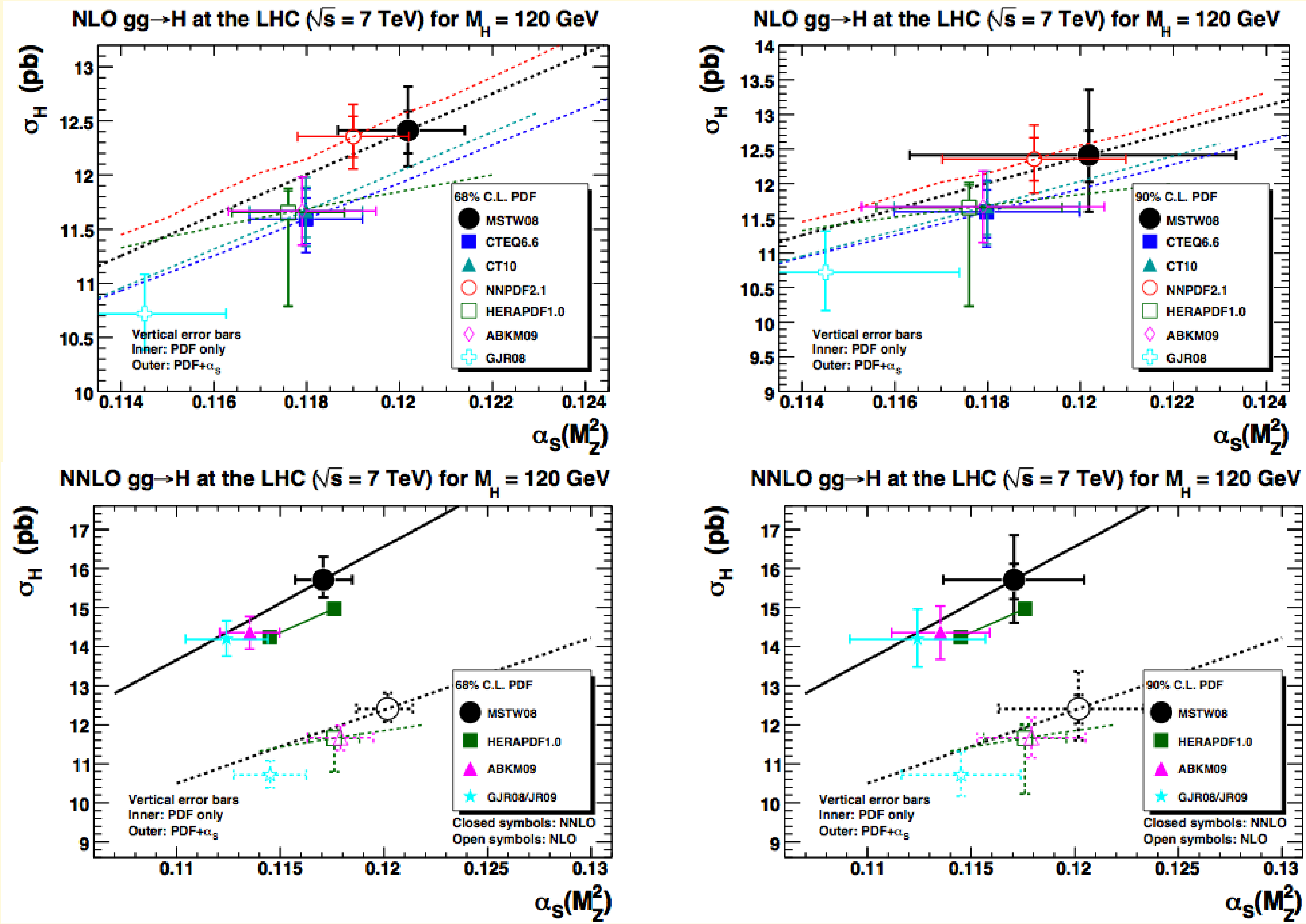


Figure 16. $W^{\pm}$ ($= W^{+} + W^{-}$) versus Z^{0} total cross sections at (a) NLO and (b) NNLO, then (c,d) the same plots with ellipses accounting for PDF correlations between the two cross sections.

Example: gg->H cross section

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



Example: gg->H cross section

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

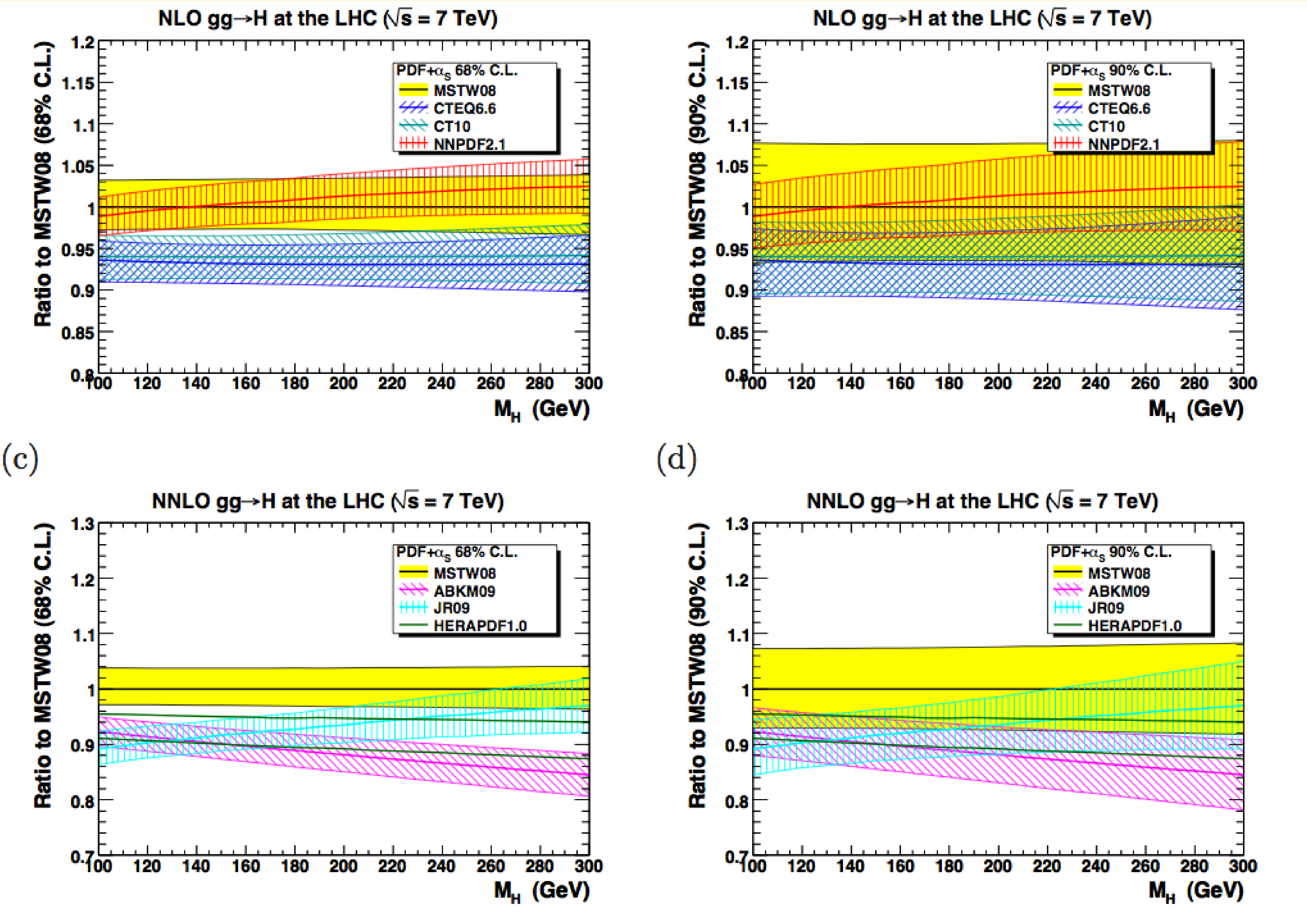
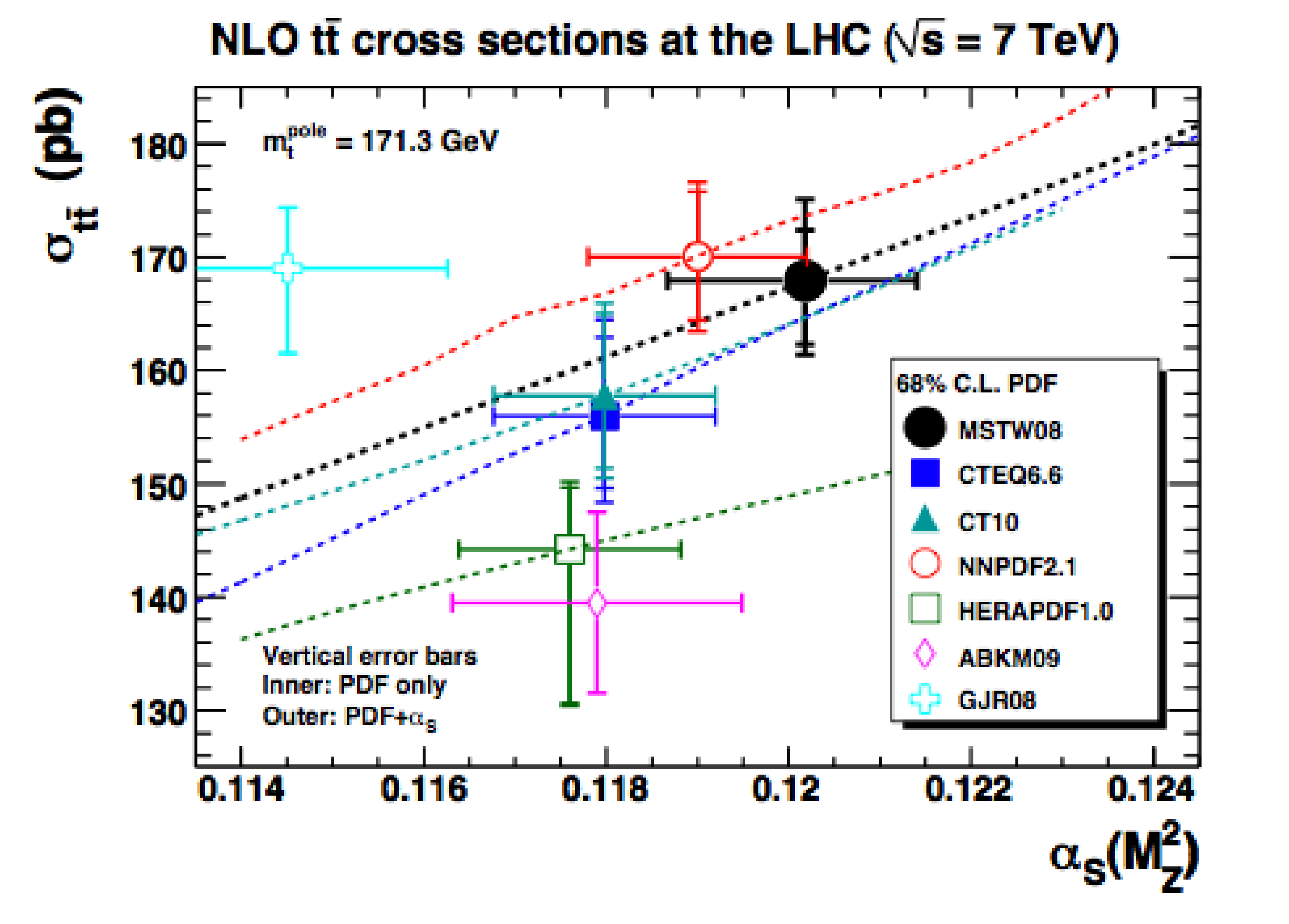
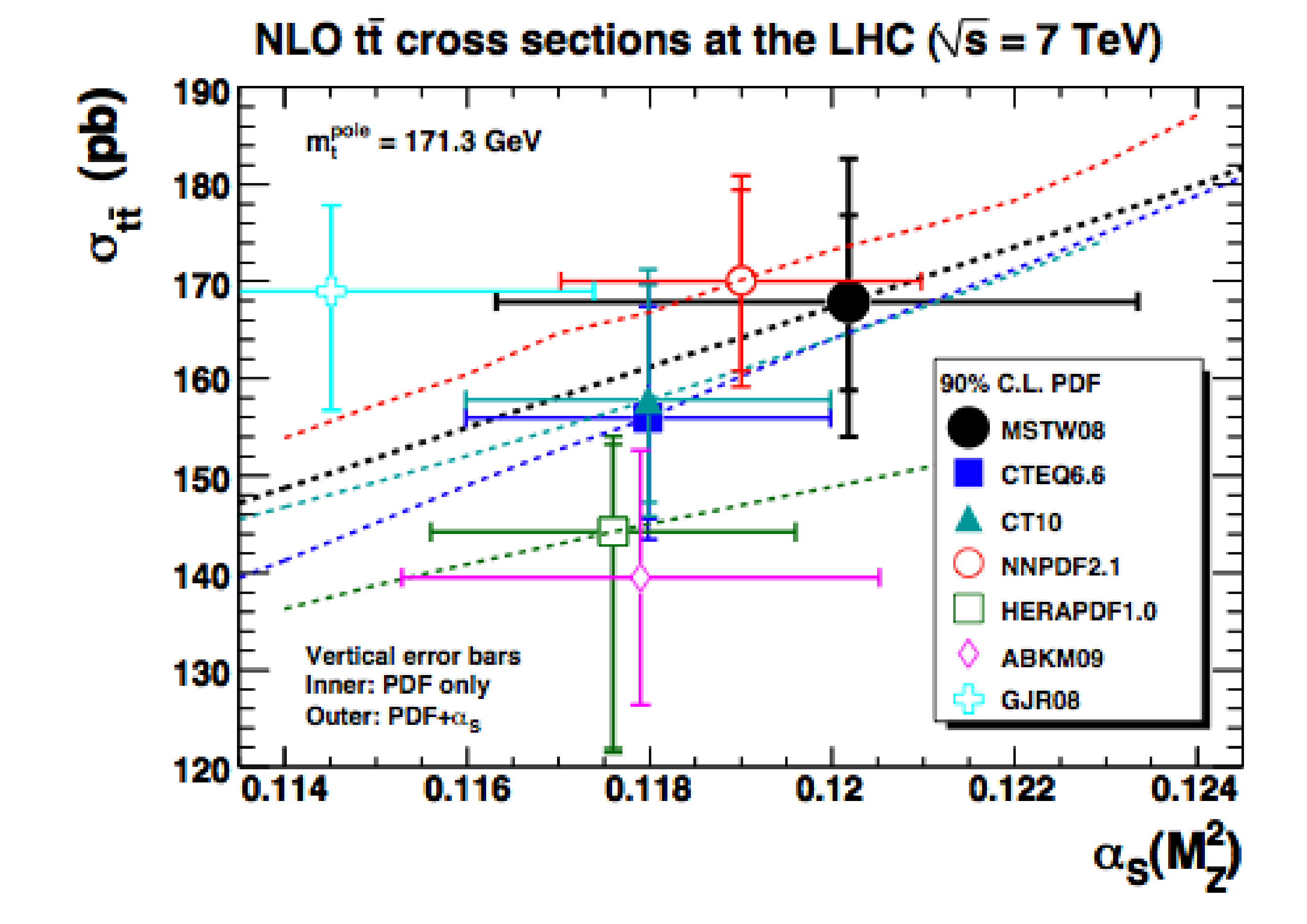


Figure 15. Ratio to the MSTW08 prediction for $gg \to H$ with PDF+α_S uncertainties for (a) NLO at 68% C.L., (b) NLO at 90% C.L., (c) NNLO at 68% C.L., (d) NNLO at 90% C.L.

Impact of PDF uncertainties on observables
Example: t-tbar cross section

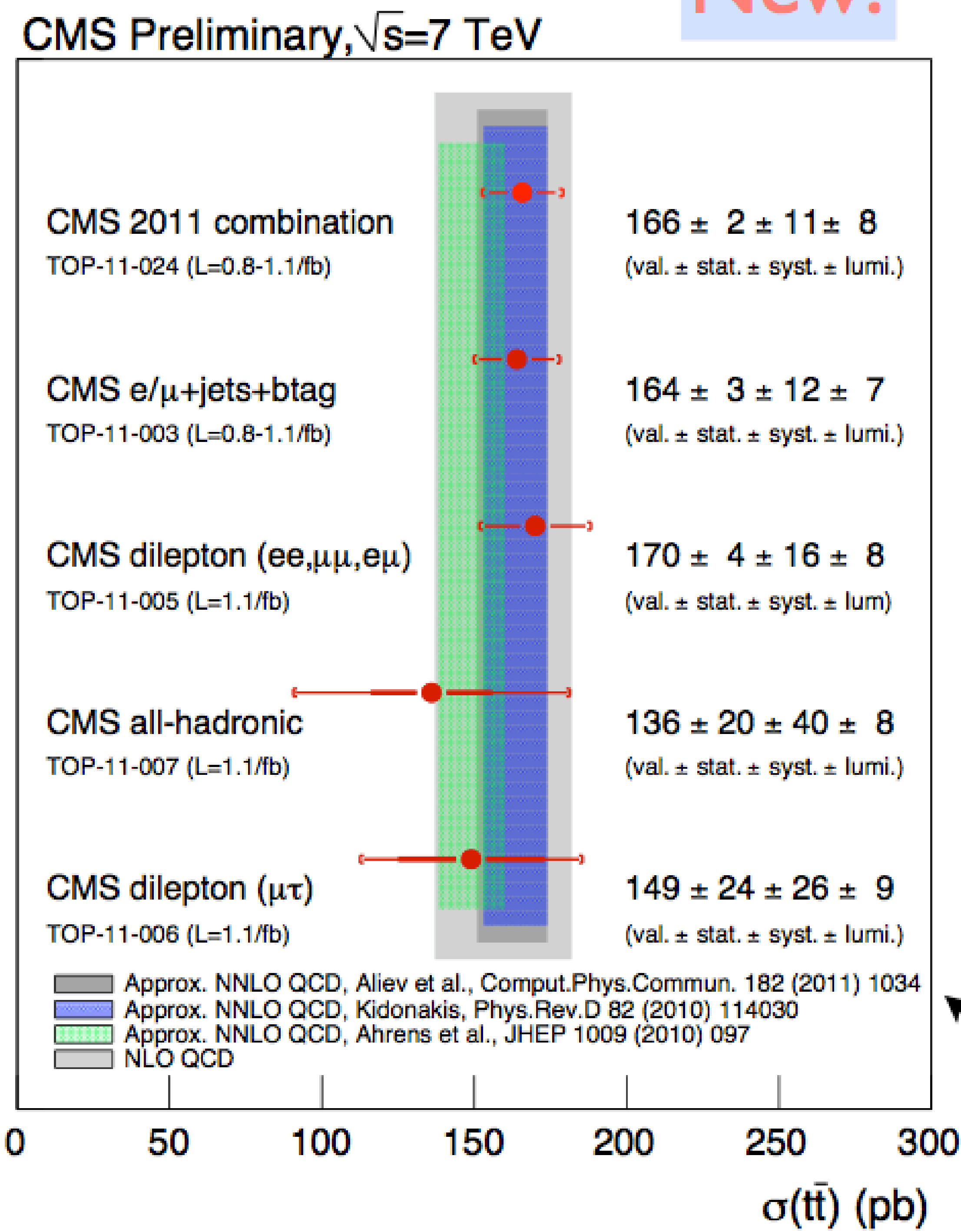




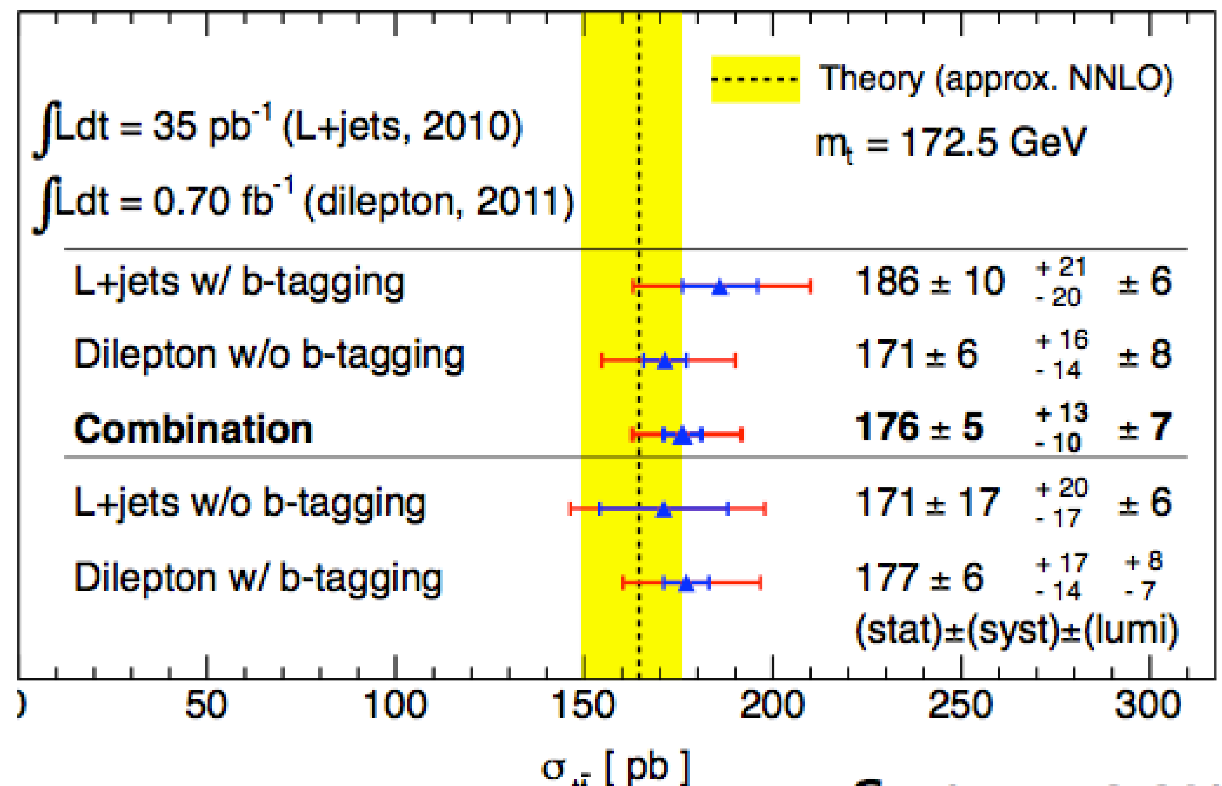
G. Watt, http://arXiv.org/pdf/1106.5788

Combined cross section

(CMS-TOP-11-024) New!



(ATLAS-CONF-2011-108)



$\delta\sigma/\sigma$ = 8.8%

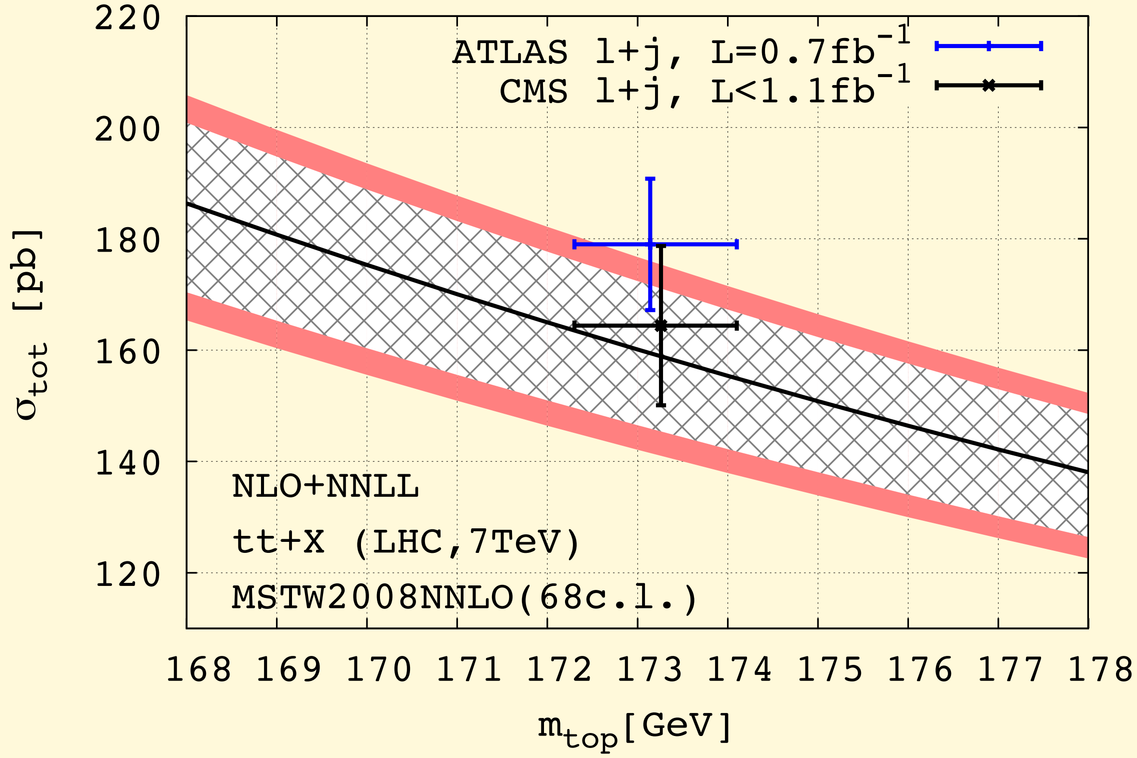
$$176 \pm 5(\text{stat.}) \pm ^{13}_{10}(\text{syst.}) \pm 7(\text{lumi})$$

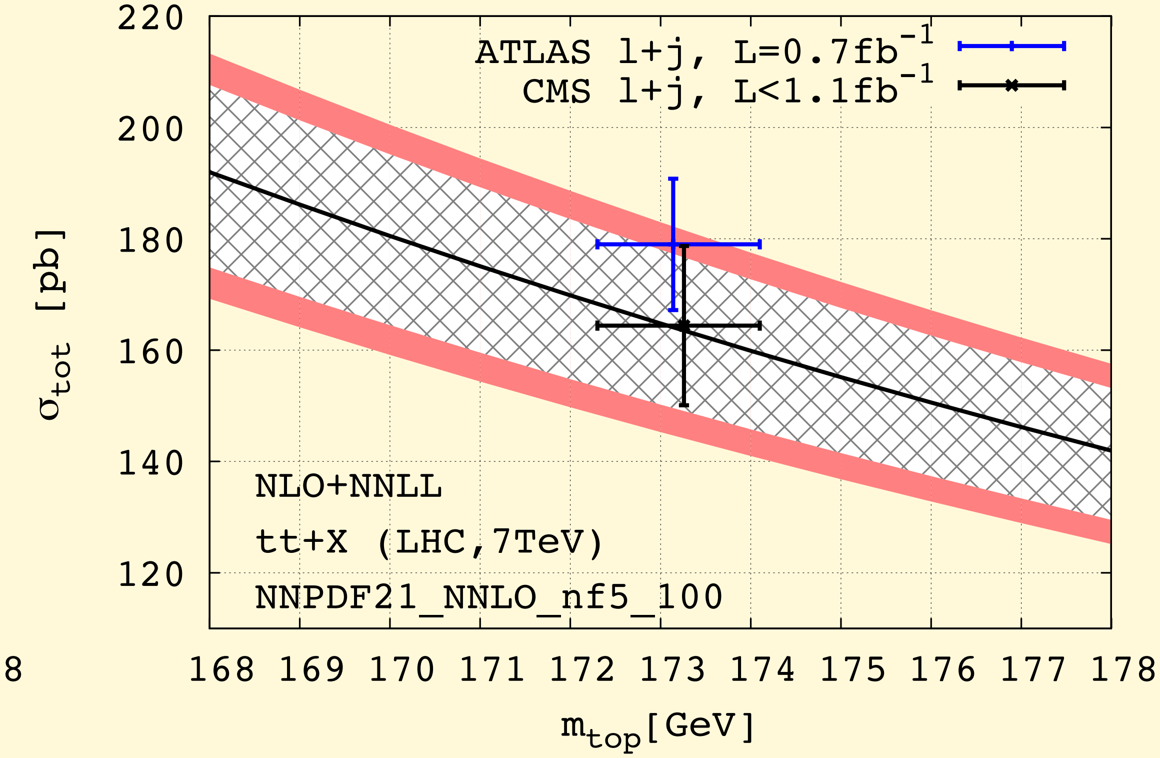
$\delta\sigma/\sigma$ = 8%

$$\sigma_{t\bar{t}} = 165.8 \pm 2.2(\text{stat.}) \pm 10.6(\text{syst}) \pm 7.8(\text{lumi.})\ \text{pb}$$

Top cross sections

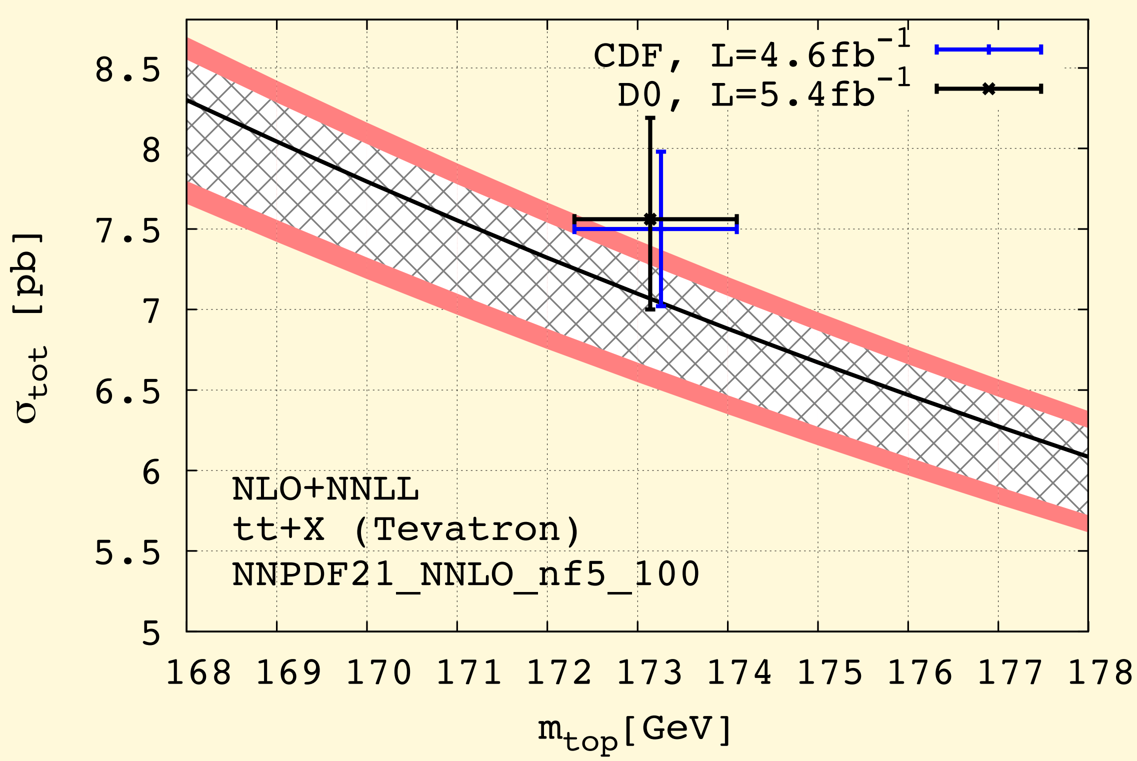
M.Cacciari, M.Czakon, M.Mangano, A.Mitov, P.Nason, to appear

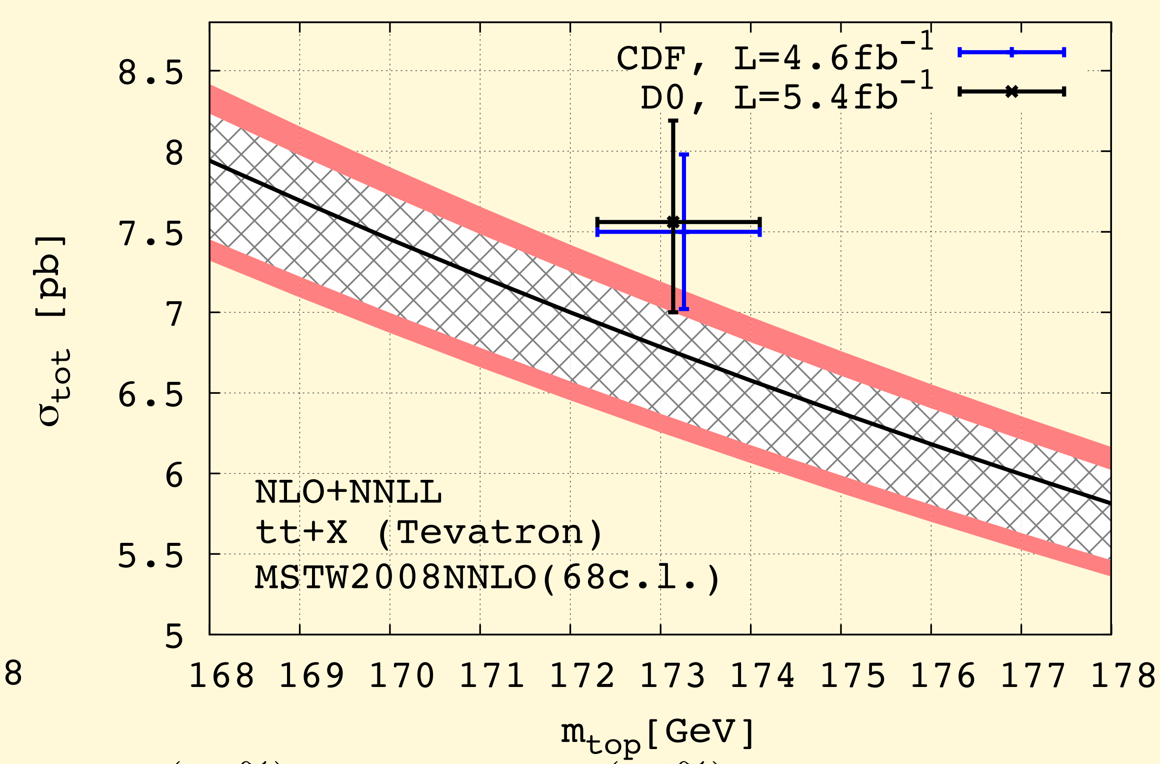




$$\sigma_{\rm tot}^{\rm NLO+NNLL}({\rm LHC_{7TeV}};\ m_t = 173.3\ {\rm GeV}) = 159\ {}^{+12\,(7.5\%)}_{-14\,(8.8\%)}\ [{\rm scales}]\ {}^{+4\,(2.5\%)}_{-4\,(2.5\%)}\ [{\rm PDF}]\ {\rm pb}$$ **MSTW2008 NNLO**

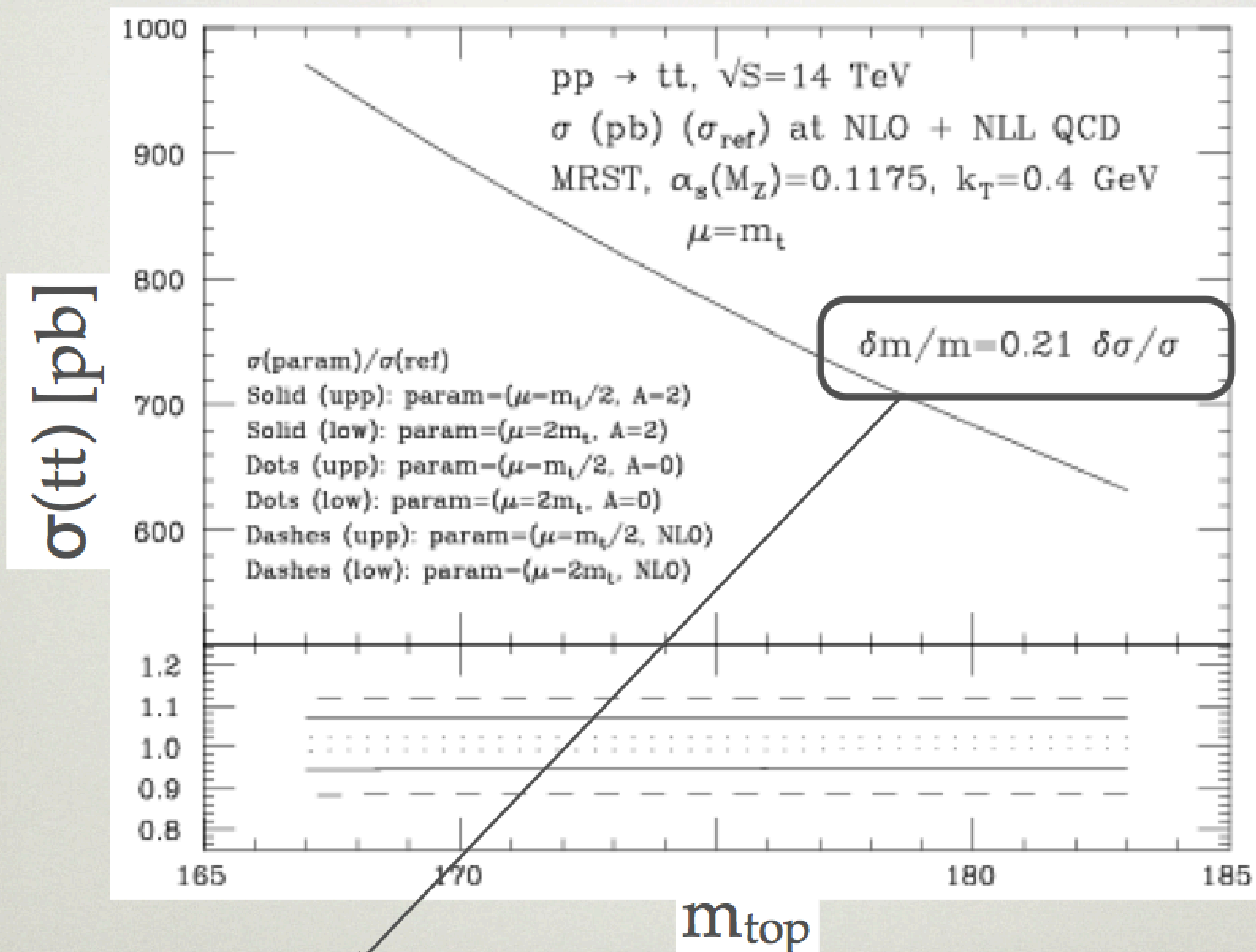
$$\sigma_{\rm tot}^{\rm NLO+NNLL}({\rm LHC_{7TeV}};\ m_t = 173.3\ {\rm GeV}) = 163\ {}^{+13\,(8.0\%)}_{-14\,(8.6\%)}\ [{\rm scales}]\ {}^{+5\,(3.1\%)}_{-5\,(3.1\%)}\ [{\rm PDF}]\ {\rm pb}$$ **NNPDF2.1 NNLO**





$$\sigma_{\rm tot}^{\rm NLO+NNLL}({\rm Tevatron};\ m_t = 173.3\ {\rm GeV}) = 6.72\ {}^{+0.21\,(3.1\%)}_{-0.40\,(6.0\%)}\ [{\rm scales}]\ {}^{+0.16\,(2.4\%)}_{-0.11\,(1.6\%)}\ [{\rm PDF}]\ {\rm pb}$$ **MSTW2008 NNLO**

$$\sigma_{\rm tot}^{\rm NLO+NNLL}({\rm Tevatron};\ m_t = 173.3\ {\rm GeV}) = 7.03\ {}^{+0.21\,(3.0\%)}_{-0.42\,(6.0\%)}\ [{\rm scales}]\ {}^{+0.13\,(1.8\%)}_{-0.12\,(1.7\%)}\ [{\rm PDF}]\ {\rm pb}$$ **NNPDF2.1 NNLO**



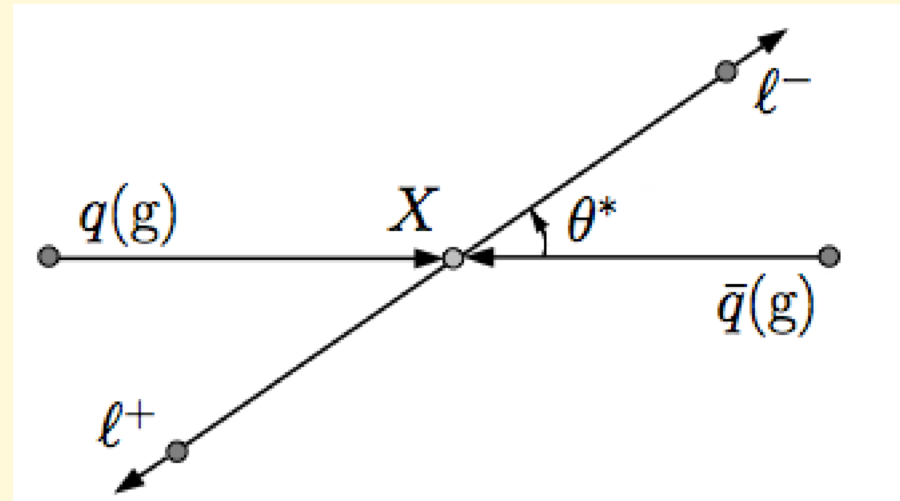
$\Delta\sigma/\sigma = \pm 5\% \Leftrightarrow \Delta m/m = \pm 1\% \lesssim 2$ GeV, comparable to Δm_{direct}

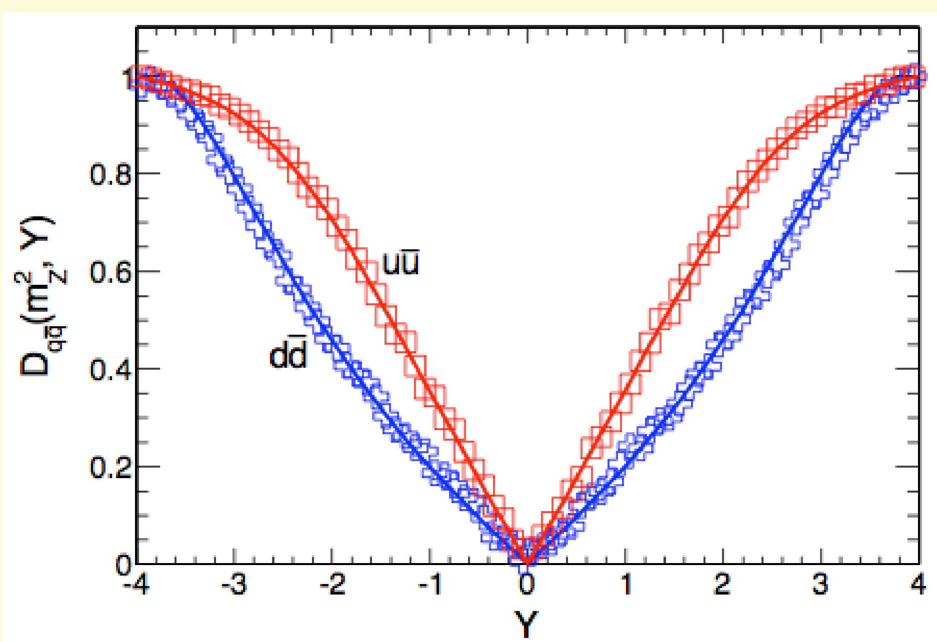
First experiences with measurement of $\sin^2\theta_W$

CMS, arxiv:1110.2682

Observable: lepton angular distribution in $pp \to Z/\gamma \to \ell^+\ell^-$

in a multivariate analysis including
dilepton mass and rapidity





Dilution factor: ~probability of guessing correctly which initial-state parton is the quark and which the antiquark

$$\sin^2\theta_{\text{eff}} = 0.2287 \pm 0.0020\,(\text{stat.}) \pm 0.0025\,(\text{syst.})$$

LEP/SLC accuracy: $\delta\sin^2\theta_W = 2\times10^{-4}$

source	correction	uncertainty
PDF	–	±0.0013
FSR	–	±0.0011
LO model (EWK)	–	±0.0002
LO model (QCD)	+0.0012	±0.0012
resolution and alignment	+0.0007	±0.0013
efficiency and acceptance	–	±0.0003
background	–	±0.0001
total	+0.0019	±0.0025

… all of the above, and more ….

➡

Use LHC data to better constrain PDFs

LHC4PDFs

... the data we would love to have

- Medium- and large-x **gluon**
  - Prompt photons
  - Inclusive Jets
  - t-quark distributions ($p_\perp$, y) ?
- **Light flavour separation** at medium- & small-x
  - Low-mass Drell-Yan
  - Z rapidity distribution
  - W(+jets) asymmetry
- **Strangeness & Heavy Flavours**
  - $W + c$ $\Rightarrow$ strange PDF
  - $Z + c$, $\gamma + c$ $\Rightarrow$ charm PDF
  - $Z + b$ $\Rightarrow$ bottom PDF

Most likely 1-few fb^{-1} are enough to reach the systematic limits of these measurements as inputs for PDF fits

These measurements may need O(10) or more fb^{-1}

Fiducial vs total cross sections

ATLAS, Arxiv:1109.5141

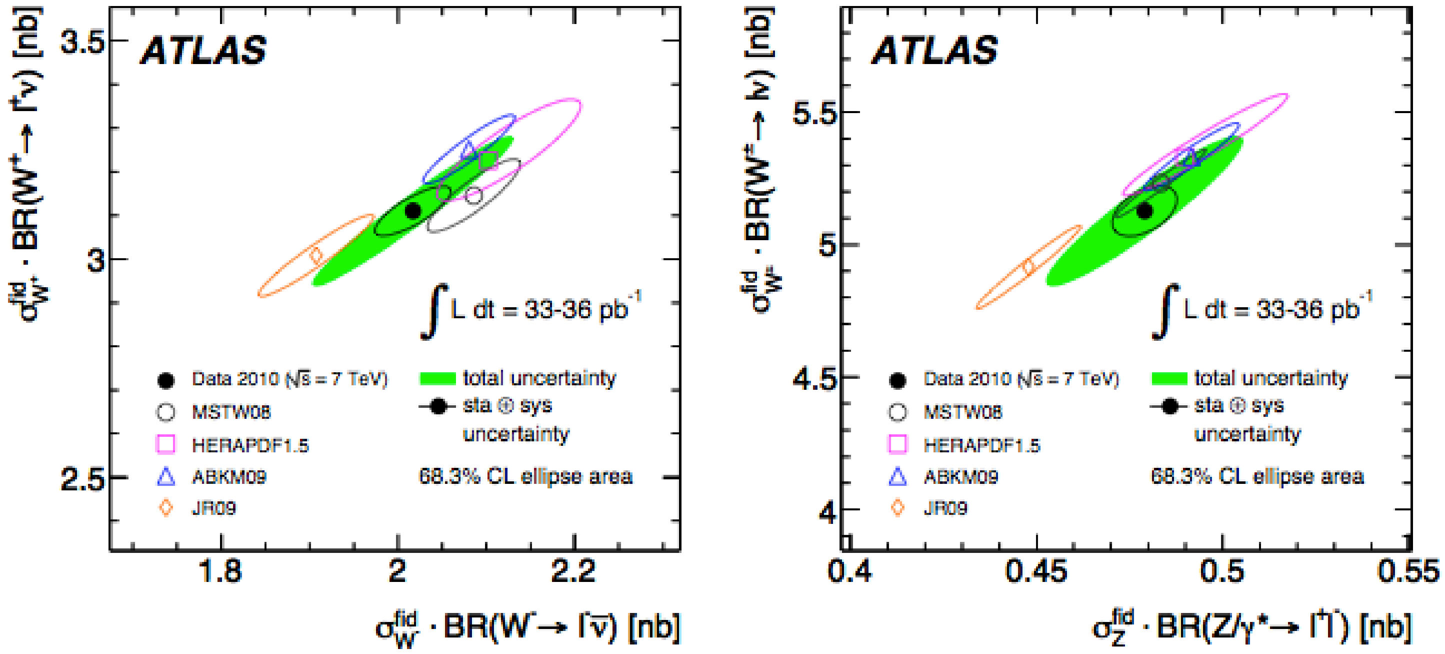


FIG. 15. *Measured and predicted fiducial cross sections times leptonic branching ratios, σ_{W^+} vs. σ_{W^-} (left) and ($\sigma_{W^+} + \sigma_{W^-}$) vs. σ_{Z/γ^*} (right). The ellipses illustrate the 68 % CL coverage for total uncertainties (full green) and excluding the luminosity uncertainty (open black). The uncertainties of the theoretical predictions correspond to the PDF uncertainties only.*

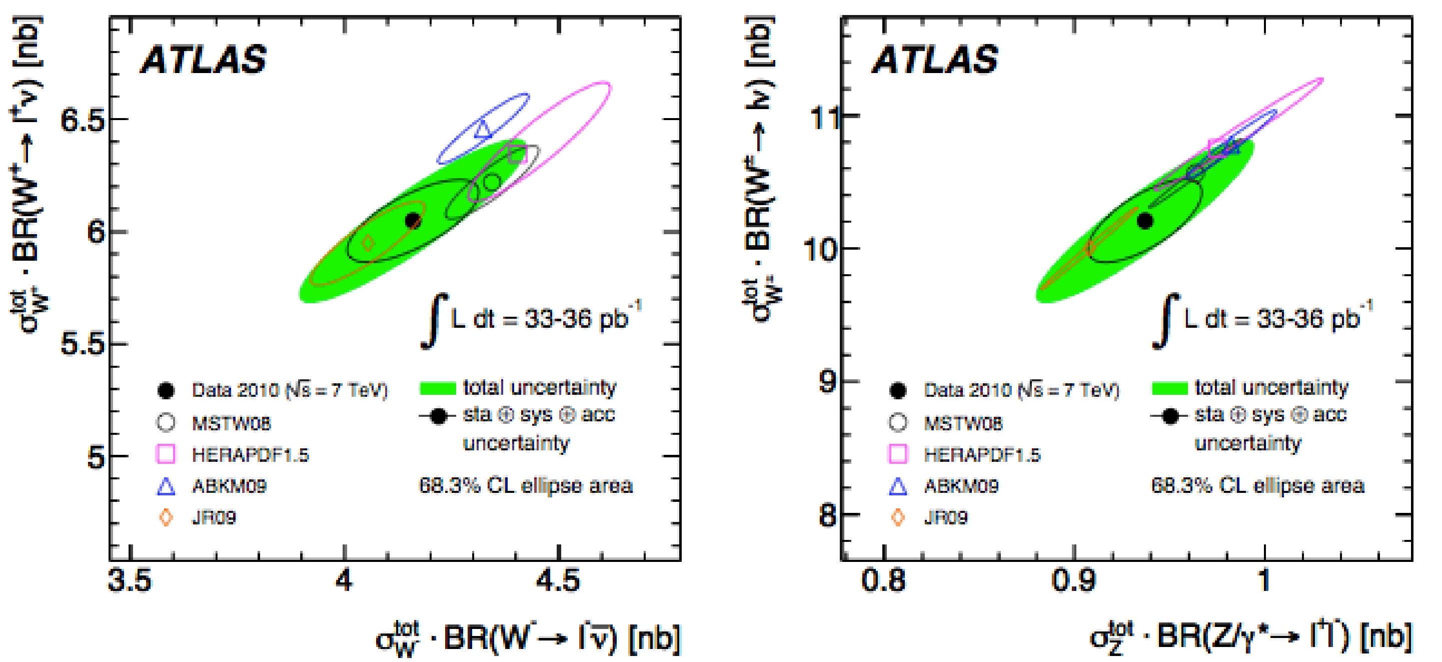


FIG. 16. *Measured and predicted total cross sections times leptonic branching ratios: σ_{W^+} vs. σ_{W^-} (left) and ($\sigma_{W^+} + \sigma_{W^-}$) vs. σ_{Z/γ^*} (right). The ellipses illustrate the 68 % CL coverage for total uncertainties (full green) and excluding the luminosity uncertainty (open black). The uncertainties of the theoretical predictions correspond to the PDF uncertainties only.*

$\sigma^{fid}_W \cdot \mathbf{BR}(W \to \ell\nu)$ [nb]
$|\eta_\ell| < 2.5,\ p_{T,\ell} > 20$ GeV, $p_{T,\nu} > 25$ GeV and $m_T > 40$ GeV

	sta	sys	lum	acc
W^+	3.110 ± 0.008	± 0.036	± 0.106	± 0.004
W^-	2.017 ± 0.007	± 0.028	± 0.069	± 0.002
$W^\pm$	5.127 ± 0.011	± 0.061	± 0.174	± 0.005

$\sigma^{fid}_{Z/\gamma^*} \cdot \mathbf{BR}(Z/\gamma^* \to \ell\ell)$ [nb]
$|\eta_\ell| < 2.5,\ p_{T,\ell} > 20$ GeV and $66 < m_{\ell\ell} < 116$ GeV

	sta	sys	lum	acc
Z/γ^*	0.479 ± 0.003	± 0.005	± 0.016	± 0.001
	<1%	**1%**	**3%**	**<1%**

$\sigma^{tot}_W \cdot \mathbf{BR}(W \to \ell\nu)$ [nb]

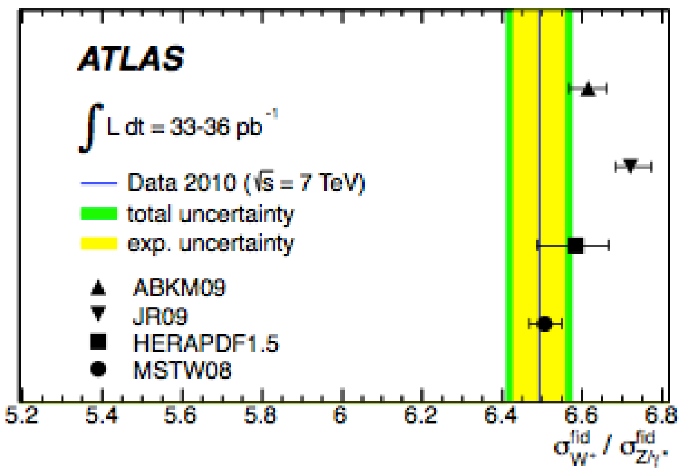
	sta	sys	lum	acc
W^+	6.048 ± 0.016	± 0.072	± 0.206	± 0.096
W^-	4.160 ± 0.014	± 0.057	± 0.141	± 0.083
$W^\pm$	10.207 ± 0.021	± 0.121	± 0.347	± 0.164

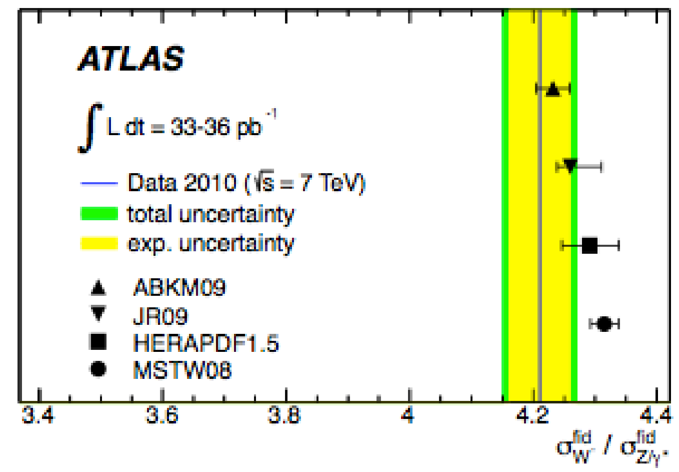
$\sigma^{tot}_{Z/\gamma^*} \cdot \mathbf{BR}(Z/\gamma^* \to \ell\ell)$ [nb]
$66 < m_{\ell\ell} < 116$ GeV

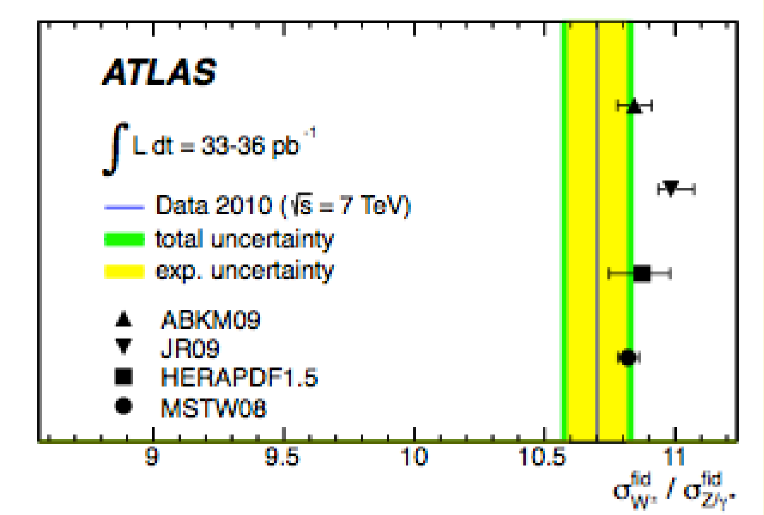
	sta	sys	lum	acc
Z/γ^*	0.937 ± 0.006	± 0.009	± 0.032	± 0.016
				1.5%

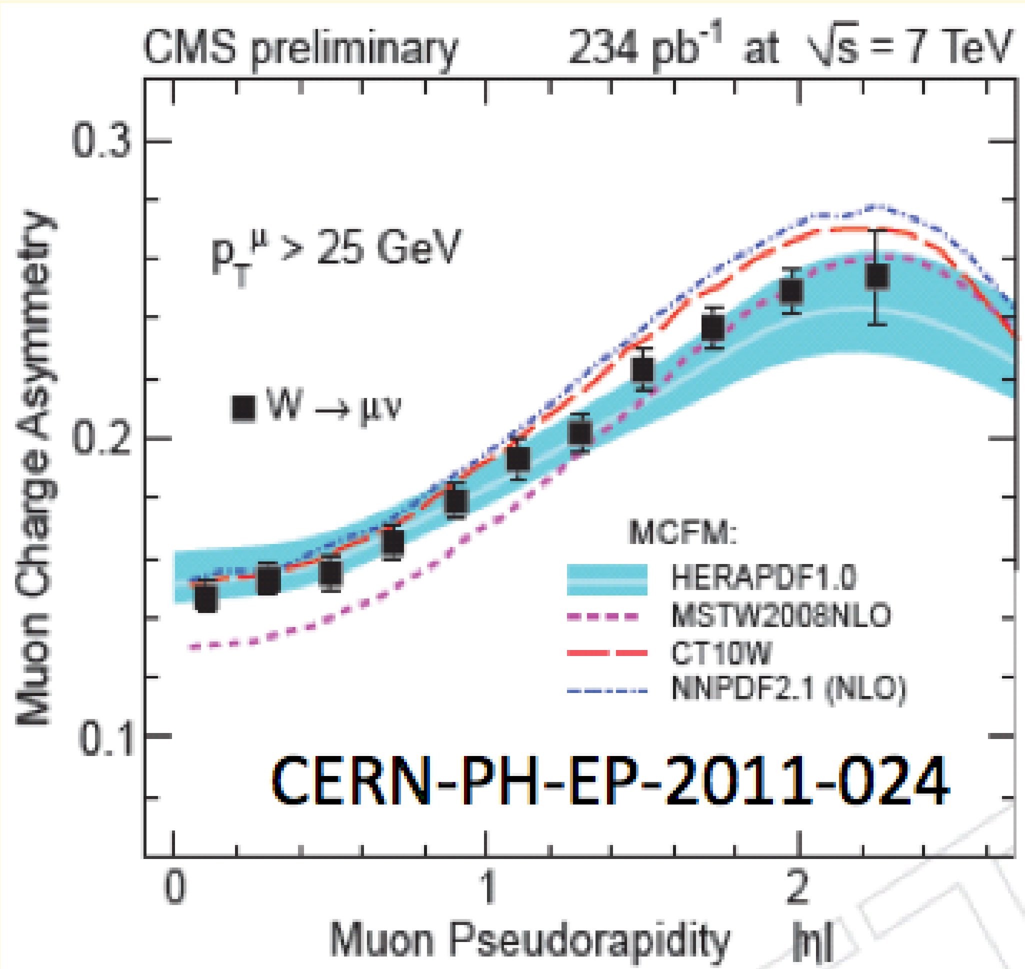
Fiducial cross sections provide greater resolution power in telling PDFs apart

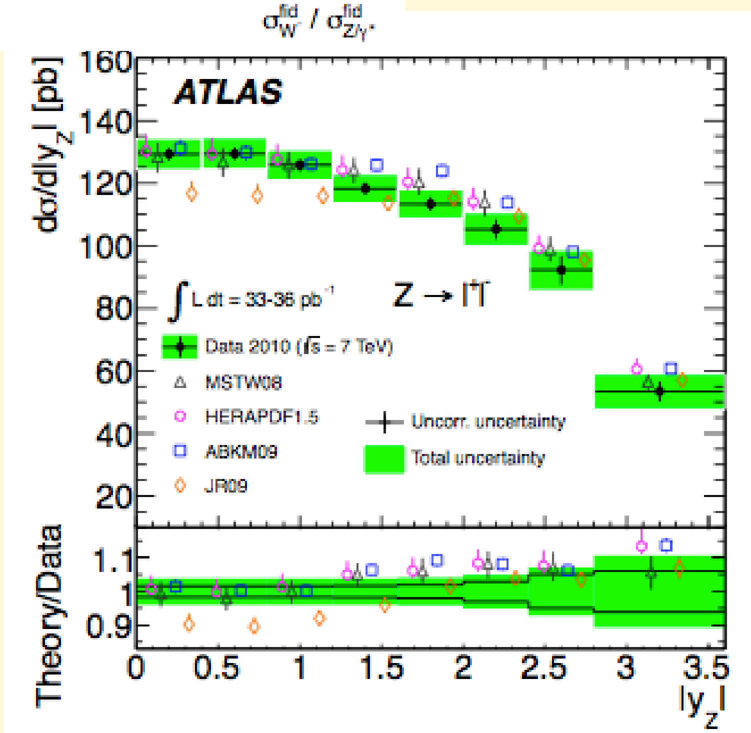
Different sets give best fits to different observables. E.g.:











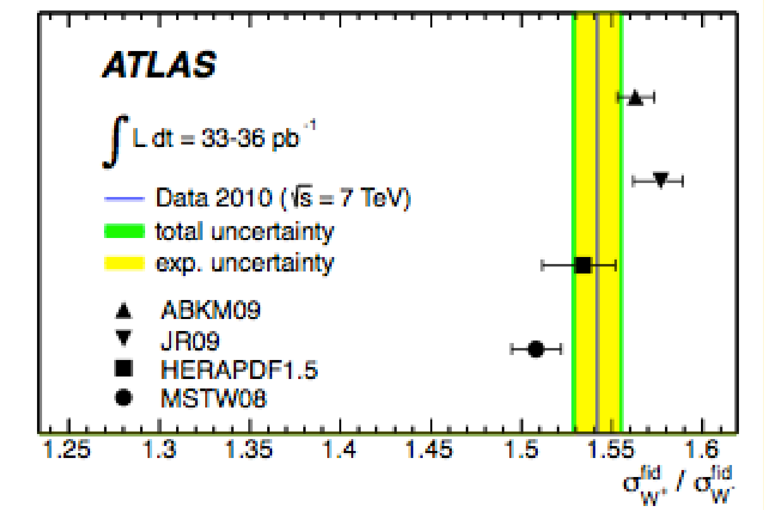
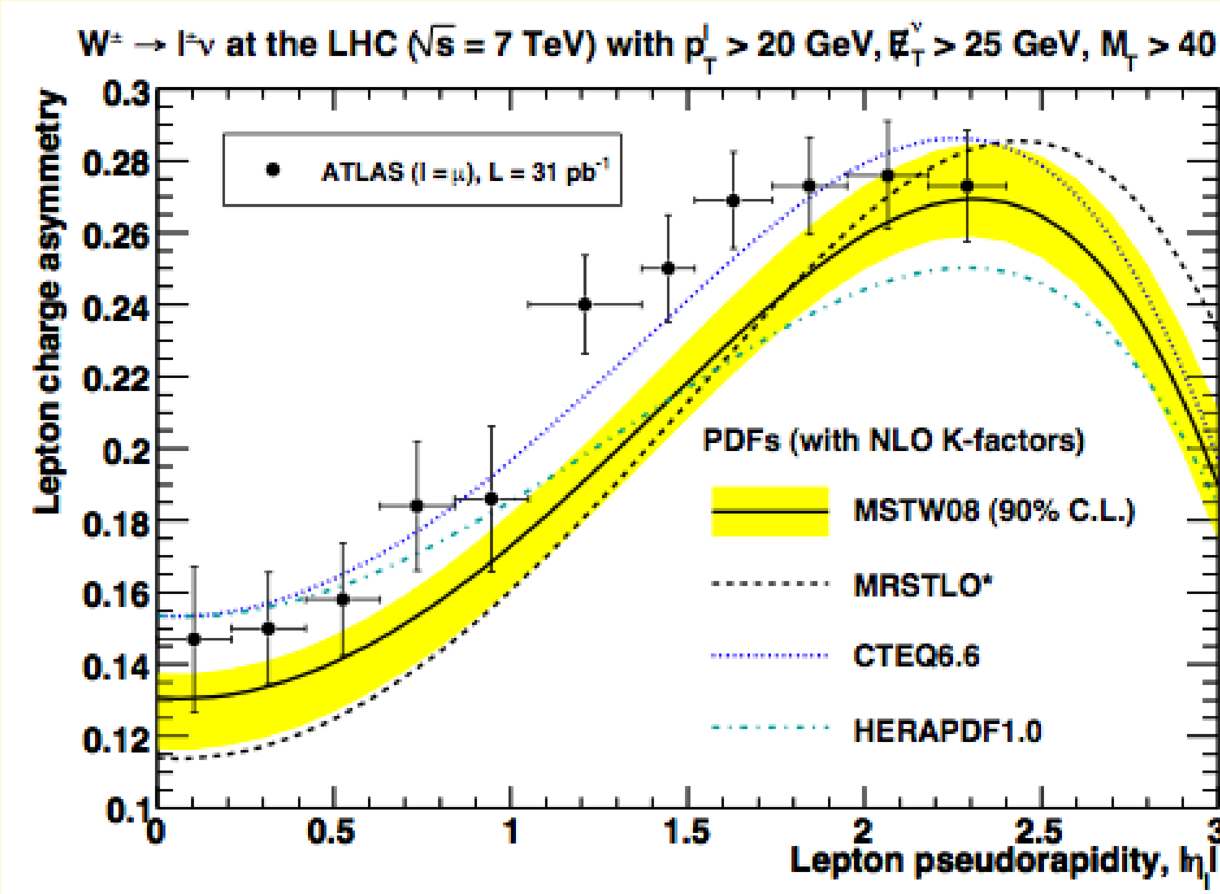


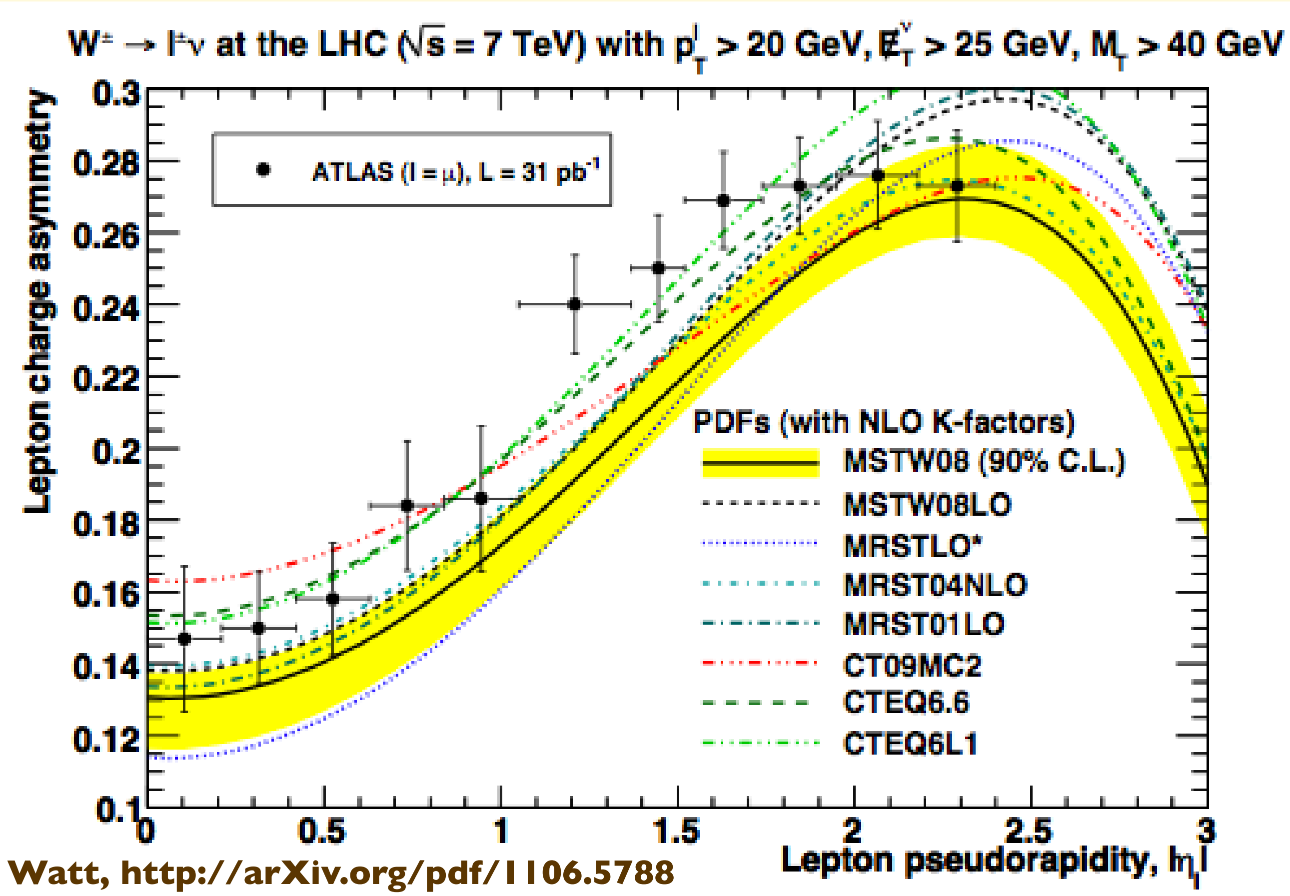
table entries NOT to be taken at face value!

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

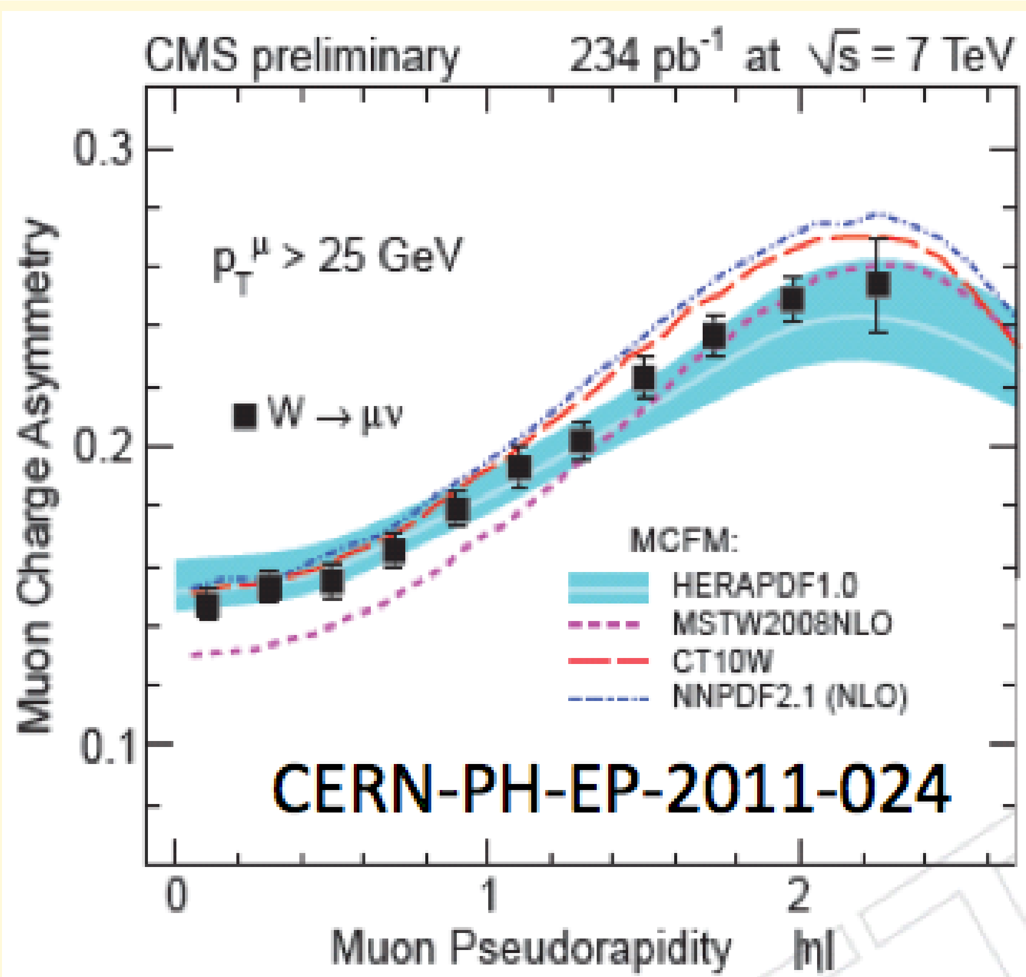
Need global fits of rates and distributions to judge which PDF set is best

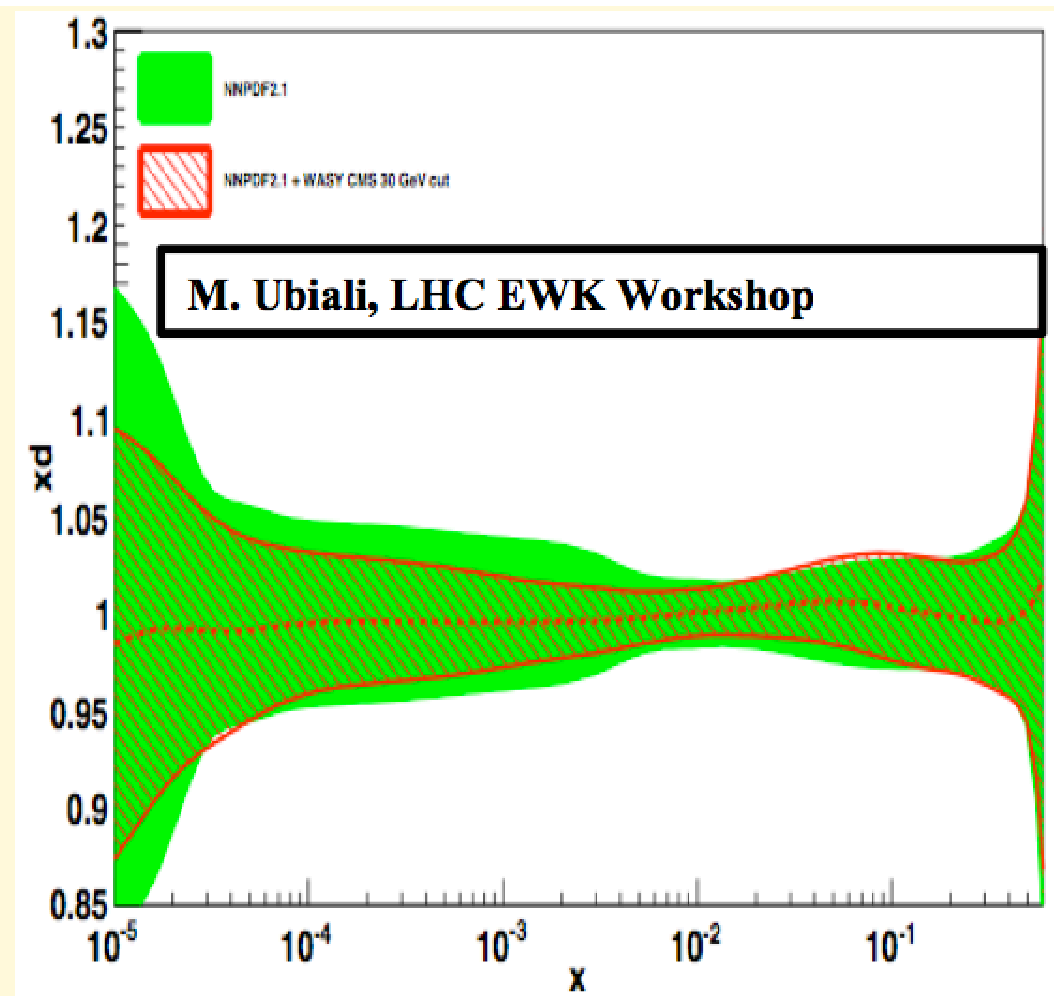
Lepton charge asymmetry in W production



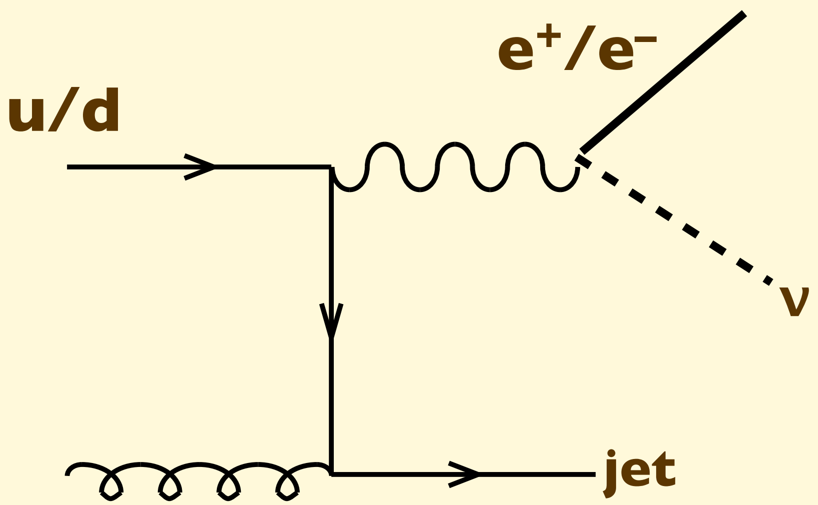


G. Watt, http://arXiv.org/pdf/1106.5788

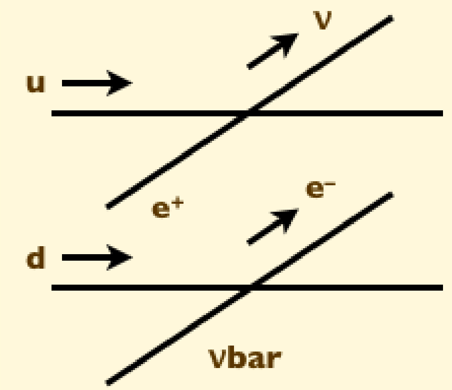


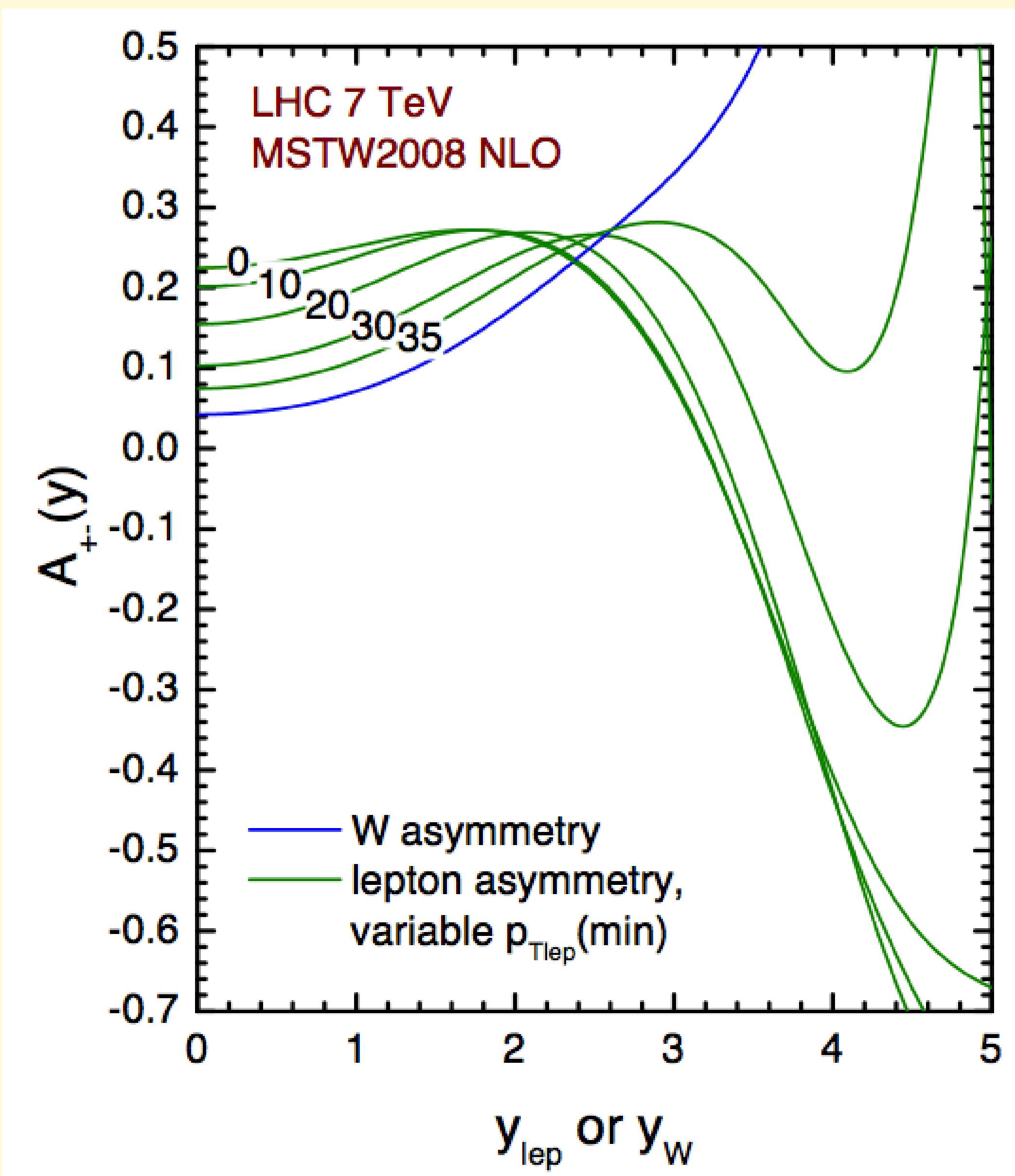


W charge asymmetry at large lepton pt

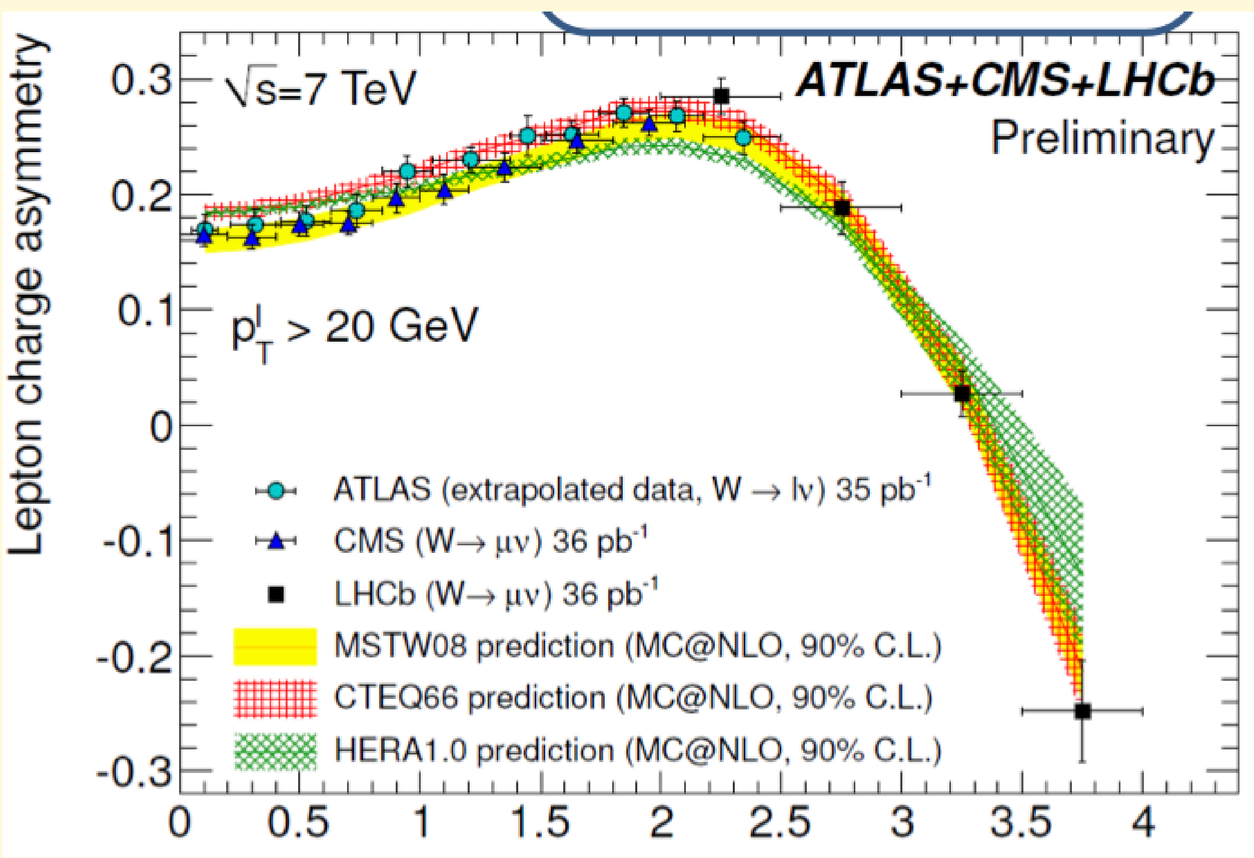


At large pt this diagram dominates.
V–A does not align the lepton with the IS quark, so u/d asymmetry dominates over V–A effects, which cause the bend over of the asymmetry at small ptW





⇒ push the measurement to large pt
⇒ also consider large-pt and large-MET, to probe large x values
⇒ fully exploit rapidity coverage



W+charm (CMS, 35pb^{-1})

$$\underline{For\ \ p_T^{jet}>20\ \ GeV\,,|\eta^{jet}|<2.1:}$$

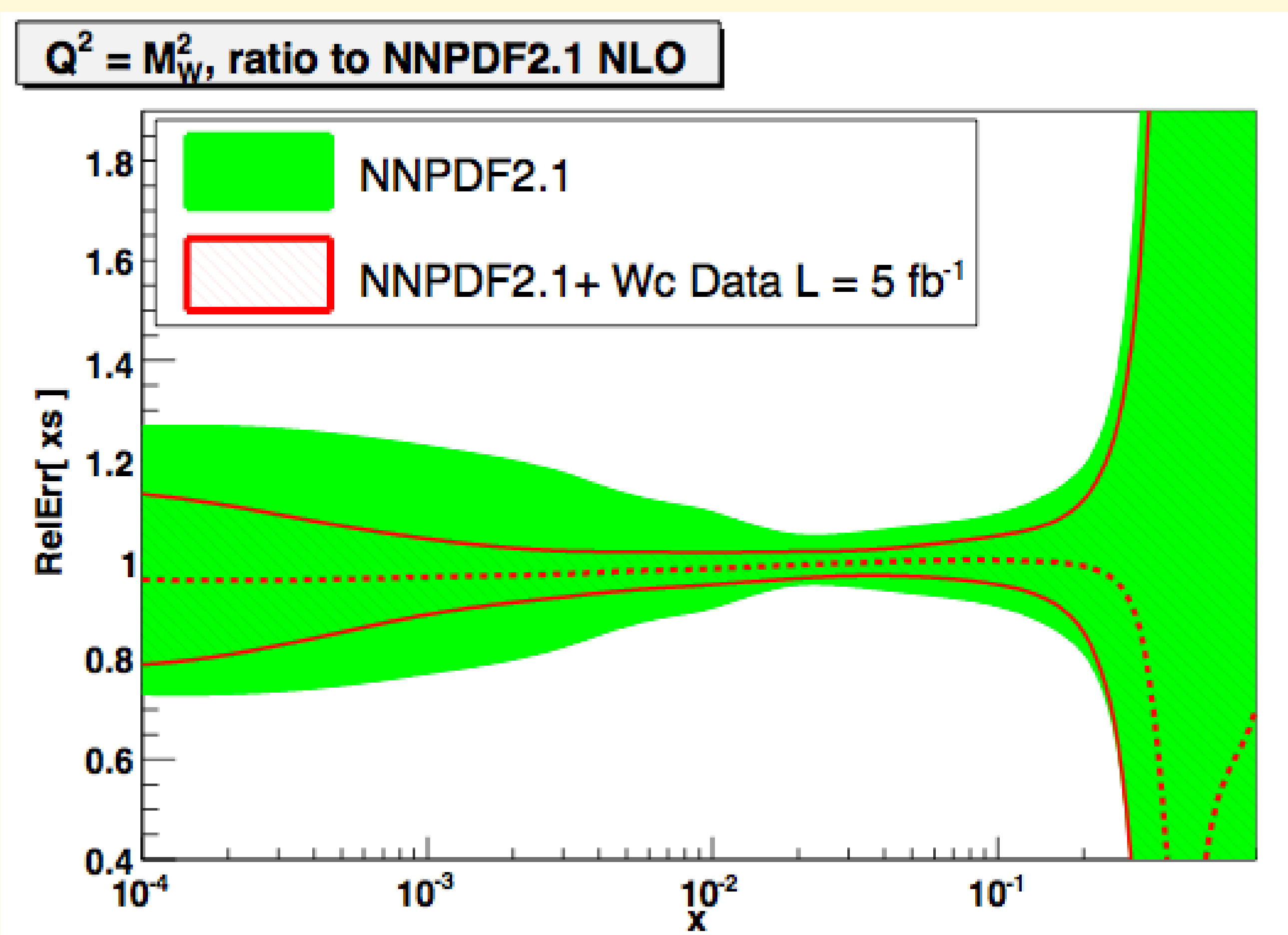
$$\frac{\sigma(W^+ + charm)}{\sigma(W^- + charm)} = 0.92 \pm 0.19(stat.) \pm 0.04(syst.);\quad \frac{\sigma(W + charm)}{\sigma(W + jets)} = 0.142 \pm 0.015(stat.) \pm 0.024(syst.)$$

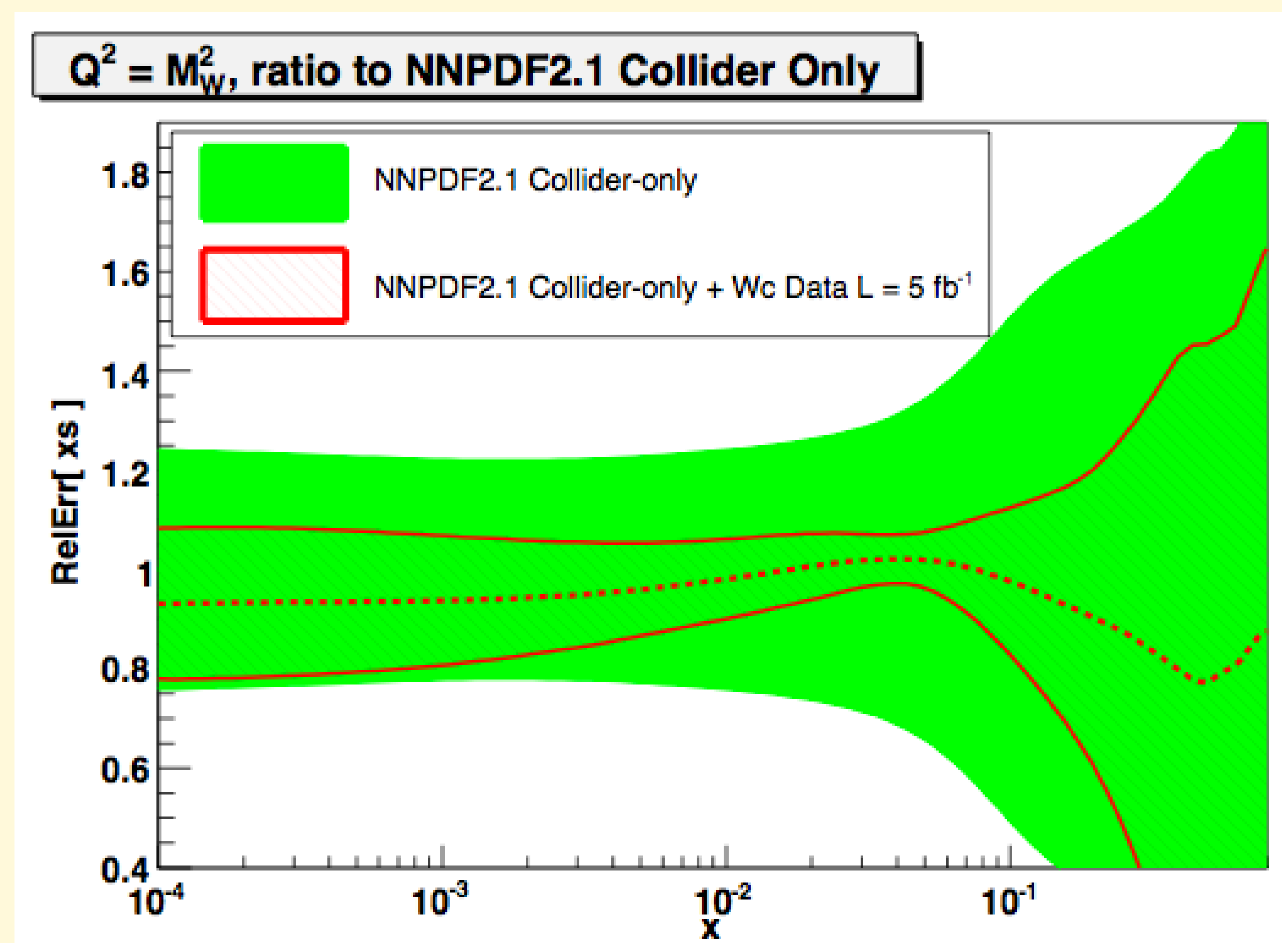
need at least 1fb^{-1} to match stat, likely 10 fb^{-1} to allow study of pt spectrum

ratio ≠ 1 ⇒ s ≠sbar

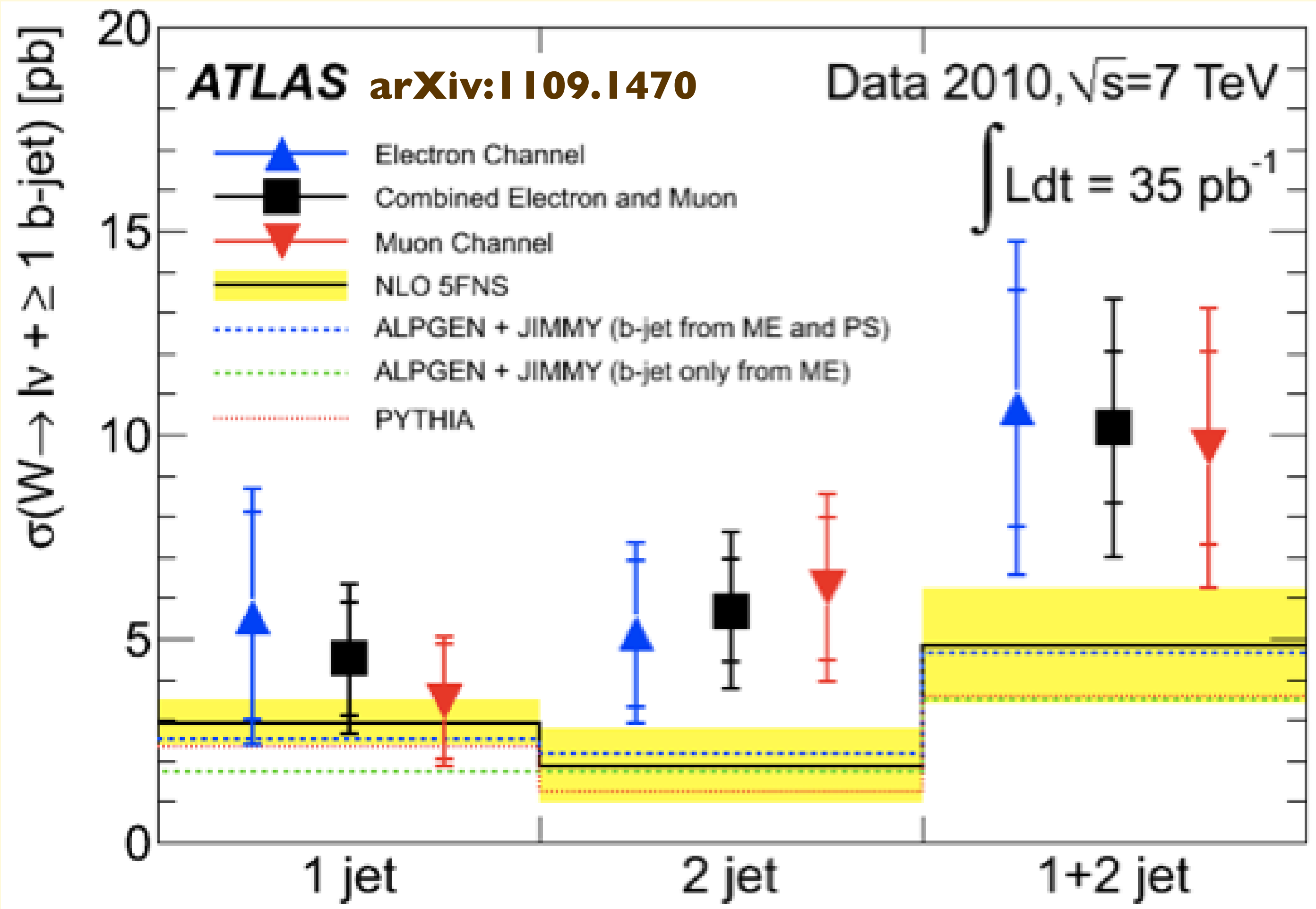
⇒ impact on sinθ_W extraction from Z decays, etc.etc.

Juan Rojo, preliminary





W+b (ATLAS, 35pb^{-1})



Z+b (ATLAS, 35pb^{-1})

arXiv:1109.1403

Experiment	$(7.6^{+1.8}_{-1.6}(\text{stat})^{+1.5}_{-1.2}(\text{syst})) \times 10^{-3}$
MCFM	$(8.8 \pm 1.1) \times 10^{-3}$
ALPGEN	$(6.2 \pm 0.1\ (\text{stat only})) \times 10^{-3}$
SHERPA	$(9.3 \pm 0.1\ (\text{stat only})) \times 10^{-3}$

Table 5: Experimental measurement and predictions of the average number of b-jets produced in association with a Z boson, with the same fiducial region as defined in the text for σ_b.

Z+b (CMS, 35pb^{-1})

$$\text{CMS}: R(Z \to ee) = \frac{\sigma(pp \to Z + b + X)}{\sigma(pp \to Z + j + X)} = 5.4 \pm 1.0(\text{stat}) \pm 1.2(\text{syst})\%$$

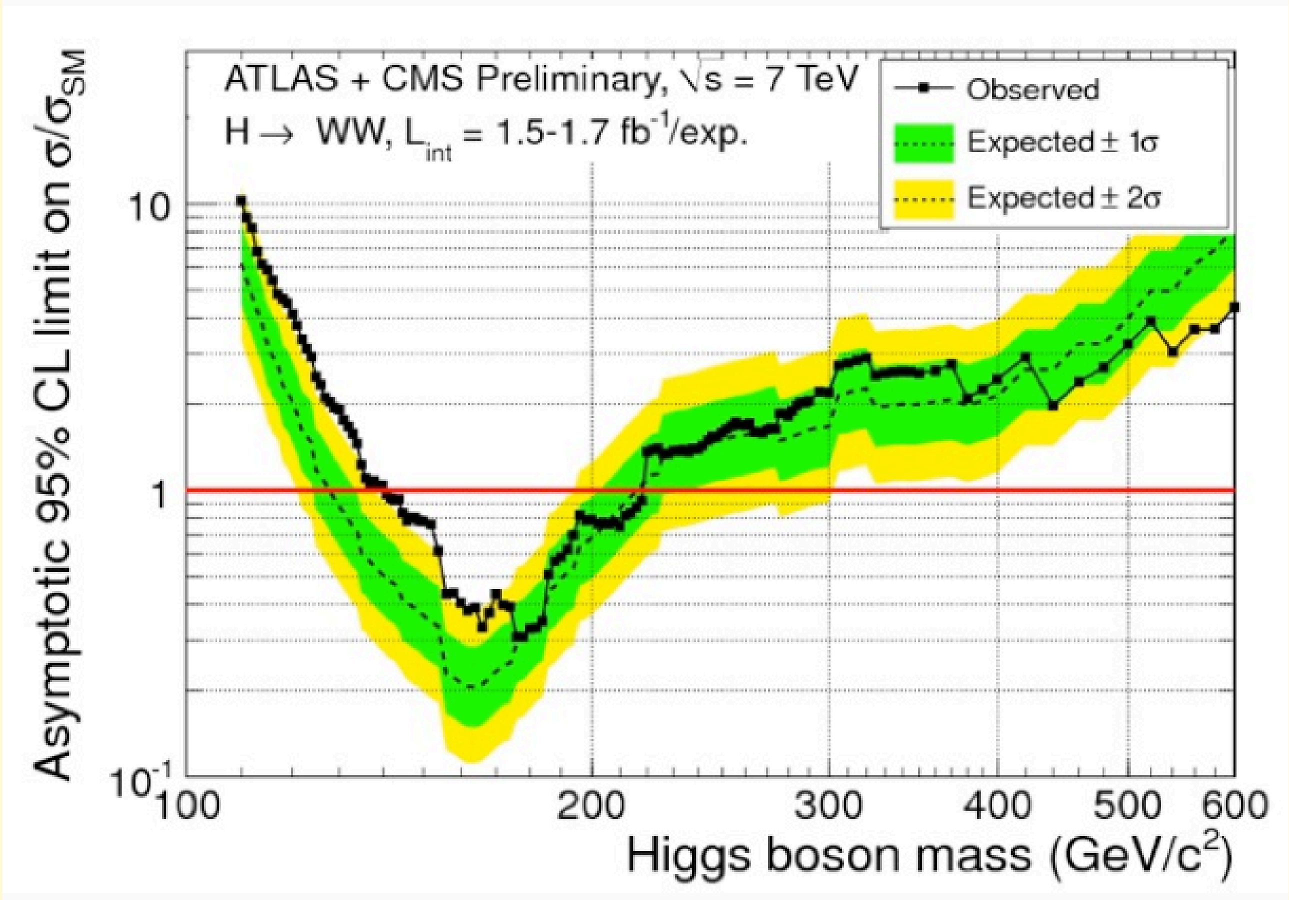
In agreement with :

- MCFM (NLO) : 4.3±0.5 (theory)
- MadGraph (LO – Fixed flavour scheme):
  5.1 ± 0.2(stat) ± 0.2(syst) ± 0.6(theory) (also in agreement with LO + variable flavour scheme).

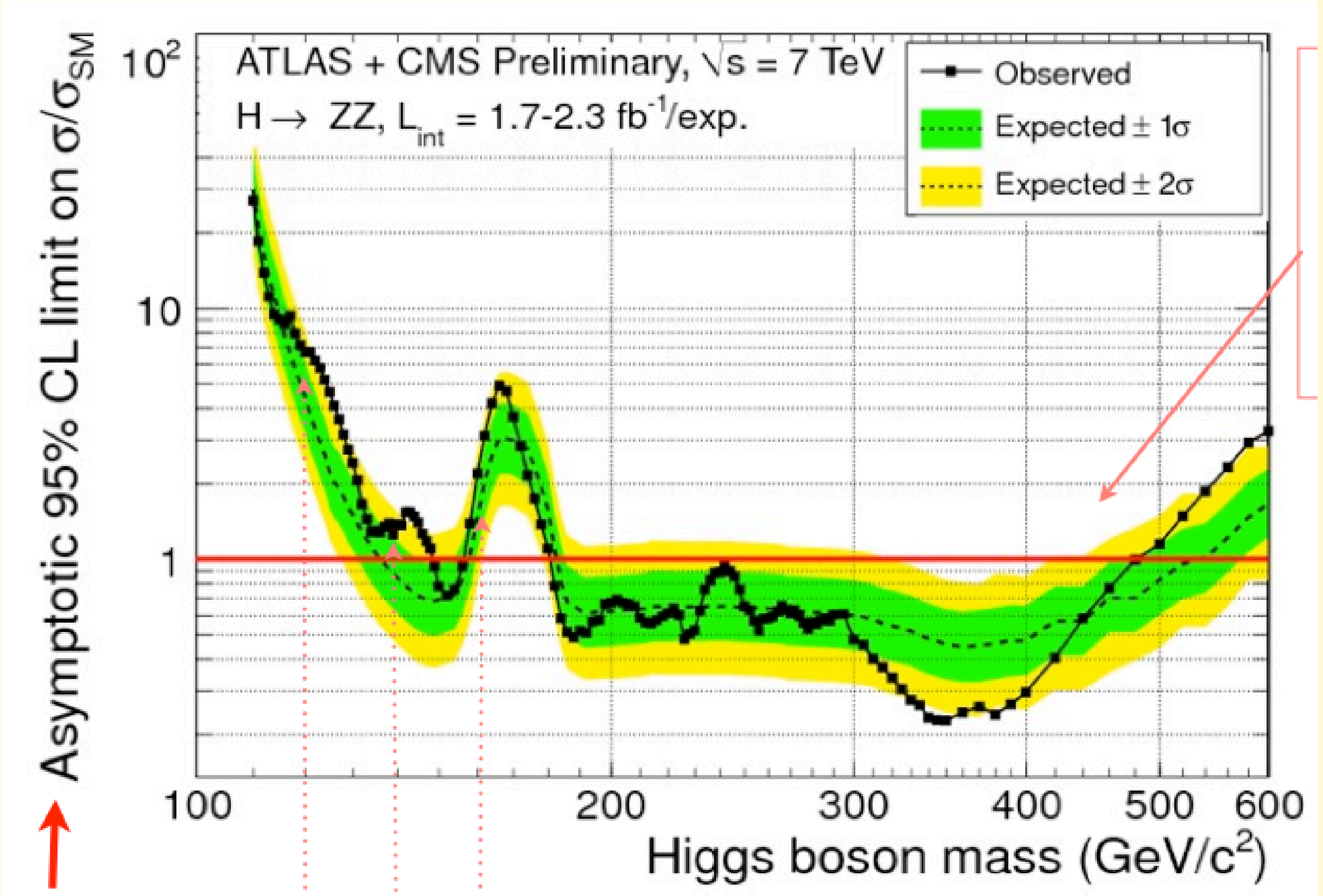
The greater statistics from 2011-12 will allow complete studies of pt distributions, 1 vs 2-jet ratios, PDF systematics, etc.

From W/Z/top as probes of the proton structure,

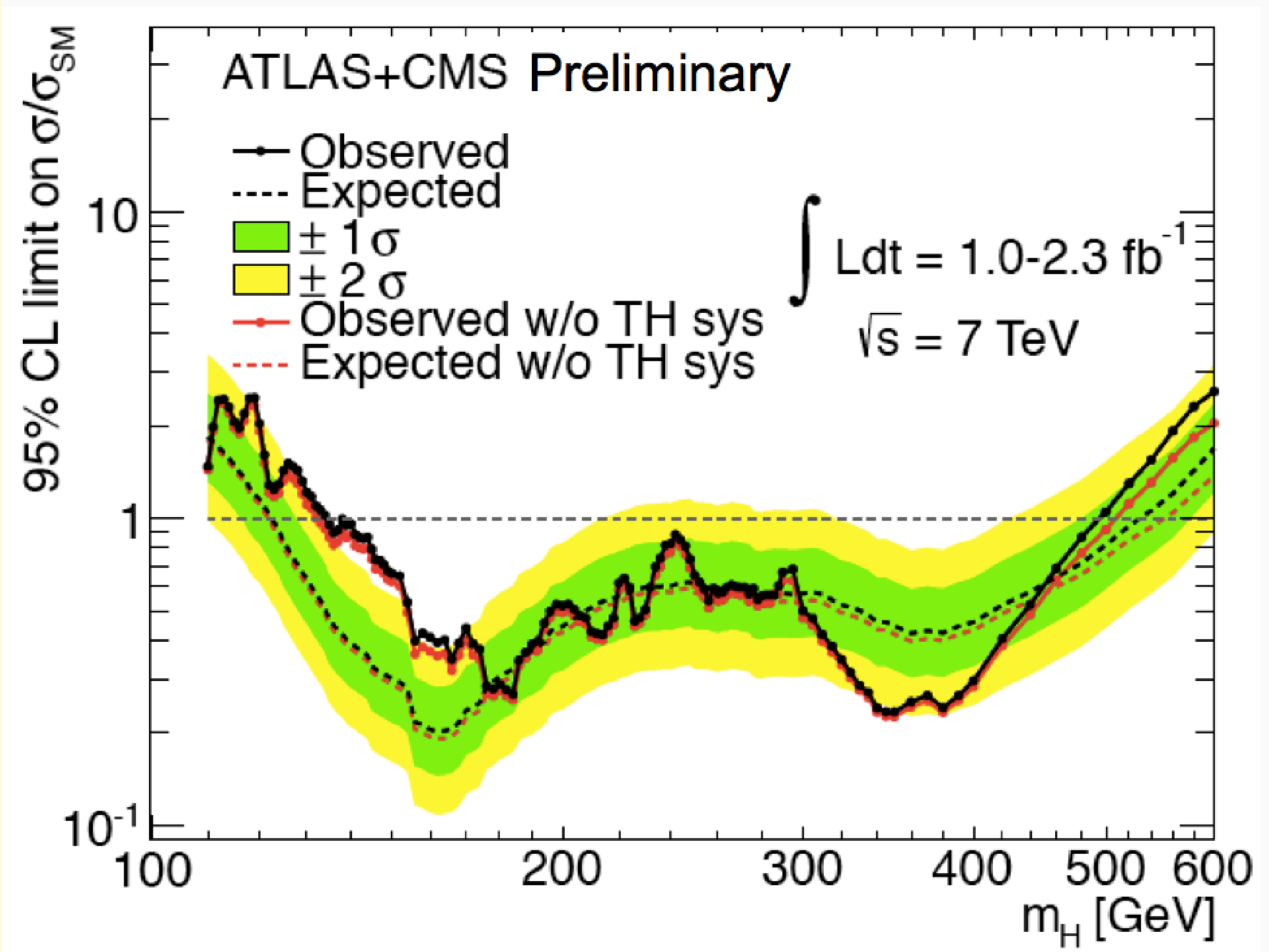
to W/Z/top as probes of EW physics



ATLAS + CMS Preliminary, √s = 7 TeV
H → WW, L_int = 1.5-1.7 fb^-1/exp.
Observed
Expected ± 1σ
Expected ± 2σ
Asymptotic 95% CL limit on σ/σ_SM
Higgs boson mass (GeV/c²)



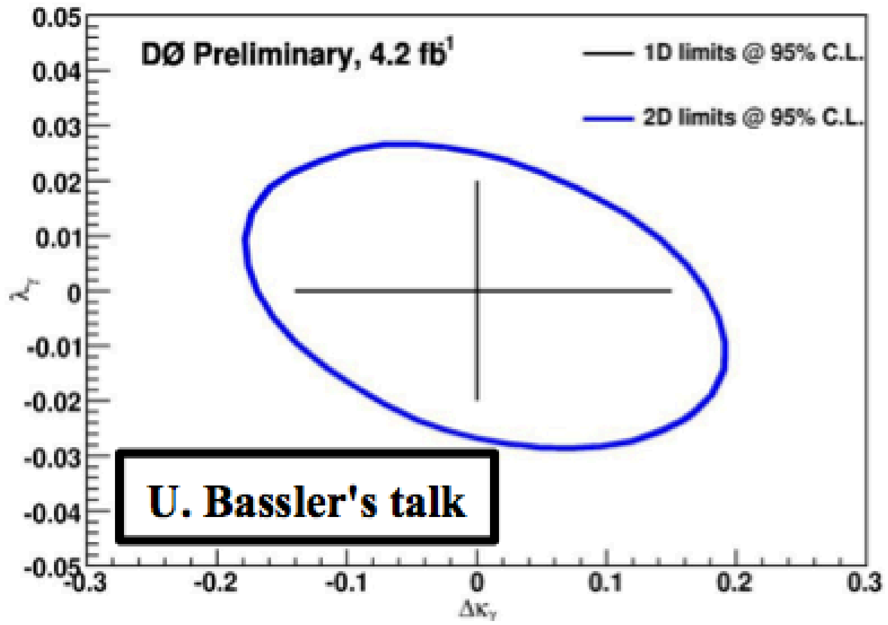
ATLAS + CMS Preliminary, √s = 7 TeV
H → ZZ, L_int = 1.7-2.3 fb^-1/exp.
Observed
Expected ± 1σ
Expected ± 2σ
Asymptotic 95% CL limit on σ/σ_SM
Higgs boson mass (GeV/c²)



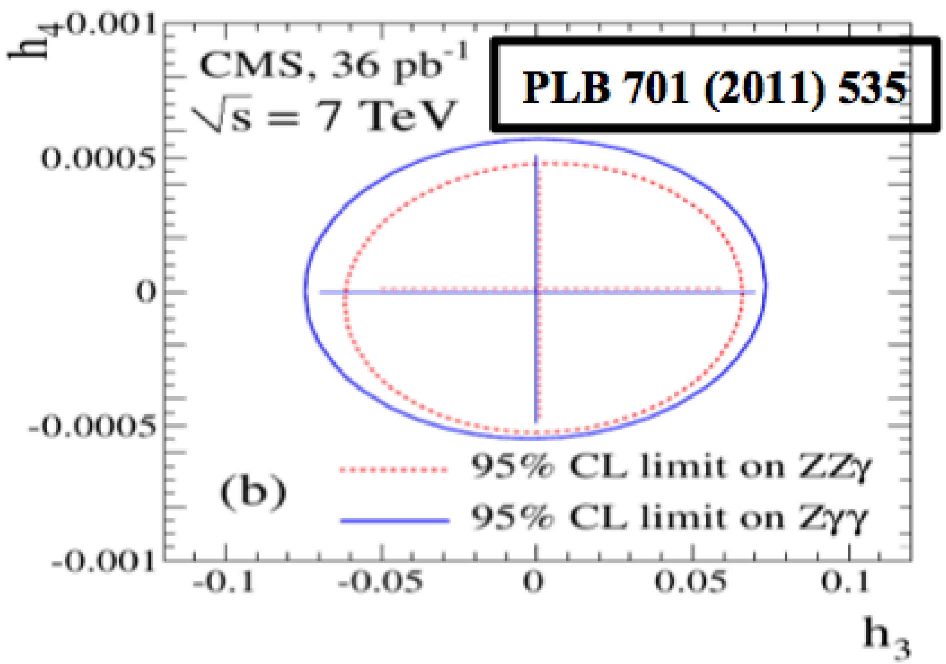
ATLAS+CMS Preliminary
Observed
Expected
± 1 σ
± 2 σ
Observed w/o TH sys
Expected w/o TH sys
∫ Ldt = 1.0-2.3 fb^-1
√s = 7 TeV
95% CL limit on σ/σ_SM
m_H [GeV]

Multi-gauge boson production: TGCs

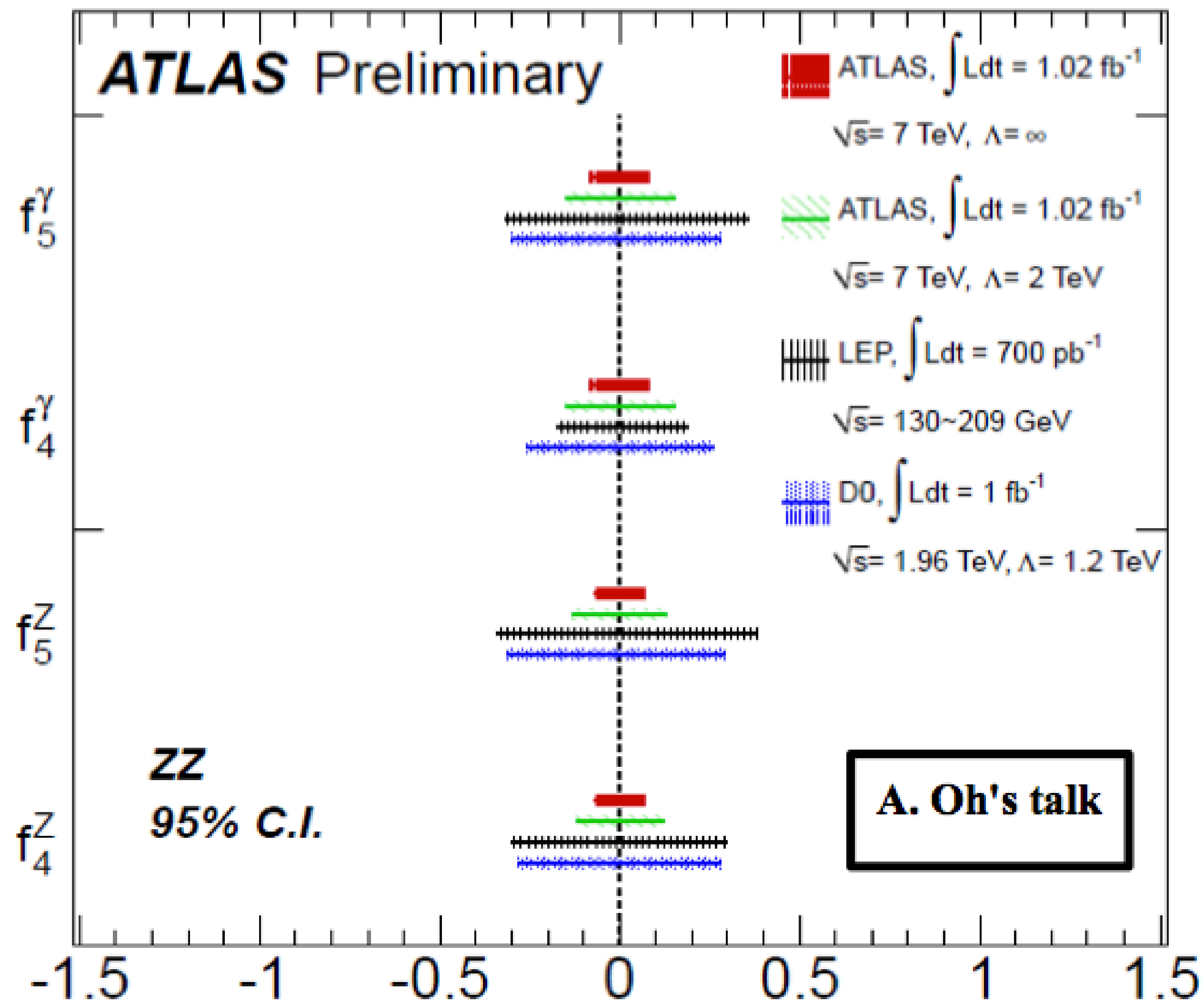
Wγ and Zγ results, anomalous TGC limits (LHC, D0)



Latest stringent TGC limits from Tevatron



Large center-of-mass at LHC pays off (stringent limits on h4 with low statistics)



LHC taking over Tevatron efforts with >1 fb^{-1}:

- Equivalent / larger SM yield
- More sensitivity to new physics scales (effects increasing with $\sqrt{s}$)

Ciemat — Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas

J. Alcaraz, W/Z Physics, EPS-HEPP 2011 Conference 26

This physics is statistics limited. NLO EW tests require O(10^3 fb^{-1})

Multi-gauge boson production:

WWW → 3lept's

$\sigma(W) = 100$ nb

$\sigma(WW) = 50$ pb $\sigma(WW) / \sigma(W) = 0.5 \times 10^{-3}$

$\sigma(WWW) = 60$ fb $\sigma(WWW) / \sigma(WW) = 10^{-3}$

$\sigma(WWW \to 3\,\ell) = 0.7$ fb $\Rightarrow$ **20 events/30 fb^{-1}** $\ell = e,\mu$

ZWW → 4lept's

$\sigma(Z) = 30$ nb

$\sigma(ZW) = 20$ pb $\sigma(ZW) / \sigma(Z) \sim 10^{-3}$

$\sigma(ZWW) = 50$ fb $\sigma(ZWW) / \sigma(ZW) \sim 2 \times 10^{-3}$

$\sigma(ZWW \to 4\,\ell) = 0.15$ fb $\Rightarrow$ **5 events/30 fb^{-1}** $\ell = e,\mu$

$\sigma(W) / \sigma(Z) \sim 3$

$\sigma(WW) / \sigma(ZW) \sim 2.5$

$\sigma(WWW) / \sigma(ZWW) \sim 1.2$

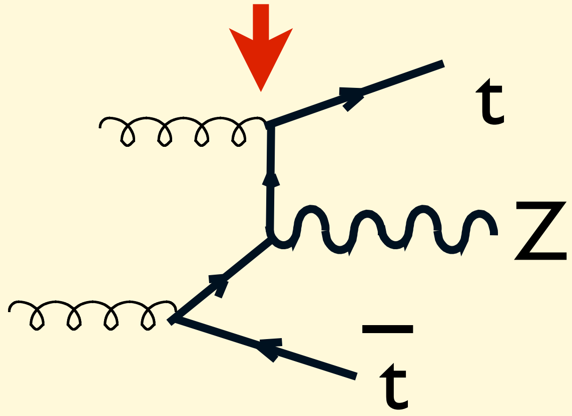
Ratio determined by couplings to quarks, u/d PDF

↓

Ratio determined by couplings among W/Z, SU(2) invariance

Multi-gauge boson production:
ttZ → WWZ → 4lept's

$\sigma(Ztt) = 100\ \mathrm{fb} = 40_{(uubar+ddbar)}\ \mathrm{fb} + 60_{(gg)}\ \mathrm{fb} = 100\ \mathrm{fb}$



The gg part is directly proportional to the ttZ coupling. **First** "direct" measurement (indirect: virtual corrections to Z self-energy)

$\sigma(Ztt) \times B(Z\to\ell\ell) \times B(tt\to\ell'\ell'') = 0.3\ \mathrm{fb} \Rightarrow$ 10 events/30 fb^{-1} $\ell = e,\mu$

ttW → 3 W → 3lept's

$\sigma(Wtt)=110\ \mathrm{fb}$

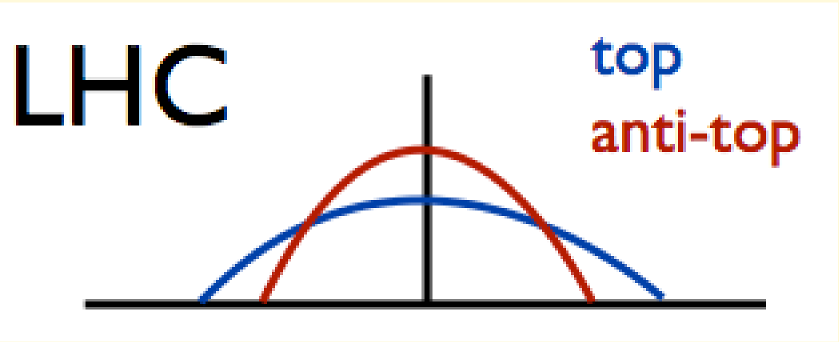
Notice $\sigma(Wtt) \sim \sigma(Ztt)$, while typically $\sigma(W) \sim 3\,\sigma(Z)$. The reason is that Wtt cannot have a gg production channel!!

$\sigma(Wtt) \times B(W\to\ell) \times B(tt\to\ell'\ell'') = 1.2\ \mathrm{fb} \Rightarrow$ 40 events/30 fb^{-1} $\ell = e,\mu$

$\sigma(Wtt) / \sigma(tt) = 0.7 \times 10^{-3}$

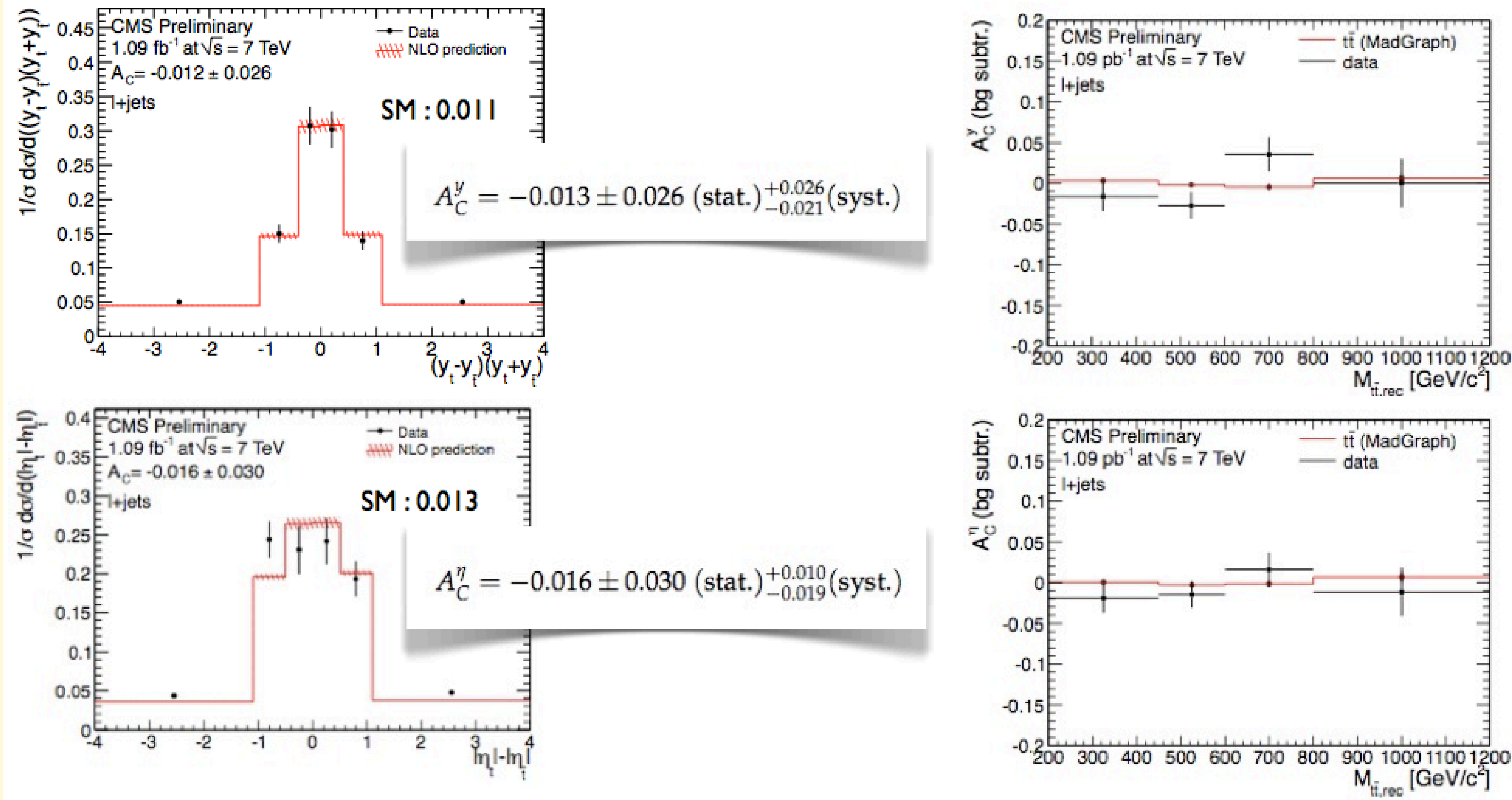
Top charge asymmetry

T.J. Kim, HCP 2011



Still no sensitivity to SM-size asymmetry, and likely also neither to a Tevatron-like anomaly

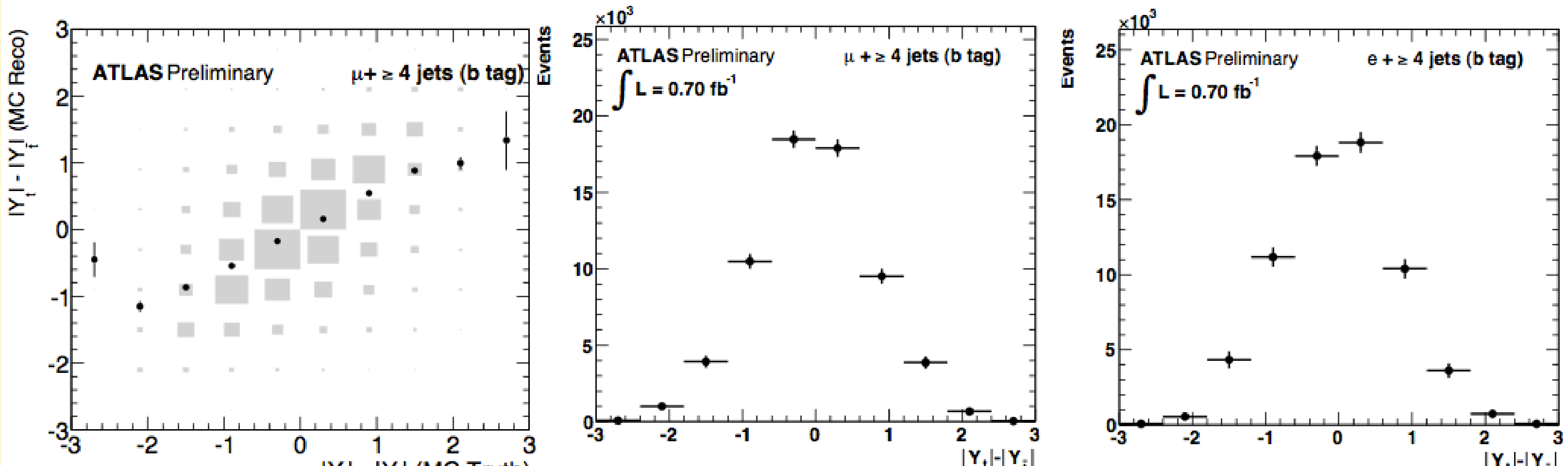
CMS (TOP-11-014 with 1.1 fb^{-1})



$$A_C^y = -0.013 \pm 0.026\ (\text{stat.})^{+0.026}_{-0.021}\ (\text{syst.})$$

$$A_C^\eta = -0.016 \pm 0.030\ (\text{stat.})^{+0.010}_{-0.019}\ (\text{syst.})$$

ATLAS (ATLAS-CONF-2010-119 with 0.7 fb^{-1})



Muon	Electron
$A_C = -0.028 \pm 0.019\,(\text{stat.}) \pm 0.022\,(\text{syst.})$	$A_C = -0.009 \pm 0.023\,(\text{stat.}) \pm 0.032\,(\text{syst.})$

- Matrix method for QCD estimation
- Bayesian Unfolding

Combined

A_c = 0.006 MC@NLO

$$A_C = -0.024 \pm 0.016\,(\text{stat.}) \pm 0.023\,(\text{syst.})$$

Challenging QCD calculations at high-Q^2

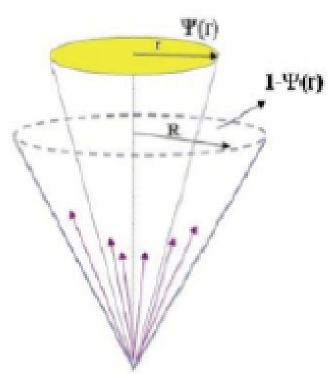
- Multijet final states (high order in α_S)
- Extreme kinematical configurations (eg. multi-scale, large Sudakovs, resummations)
- Validate predictions for backgrounds to new physics

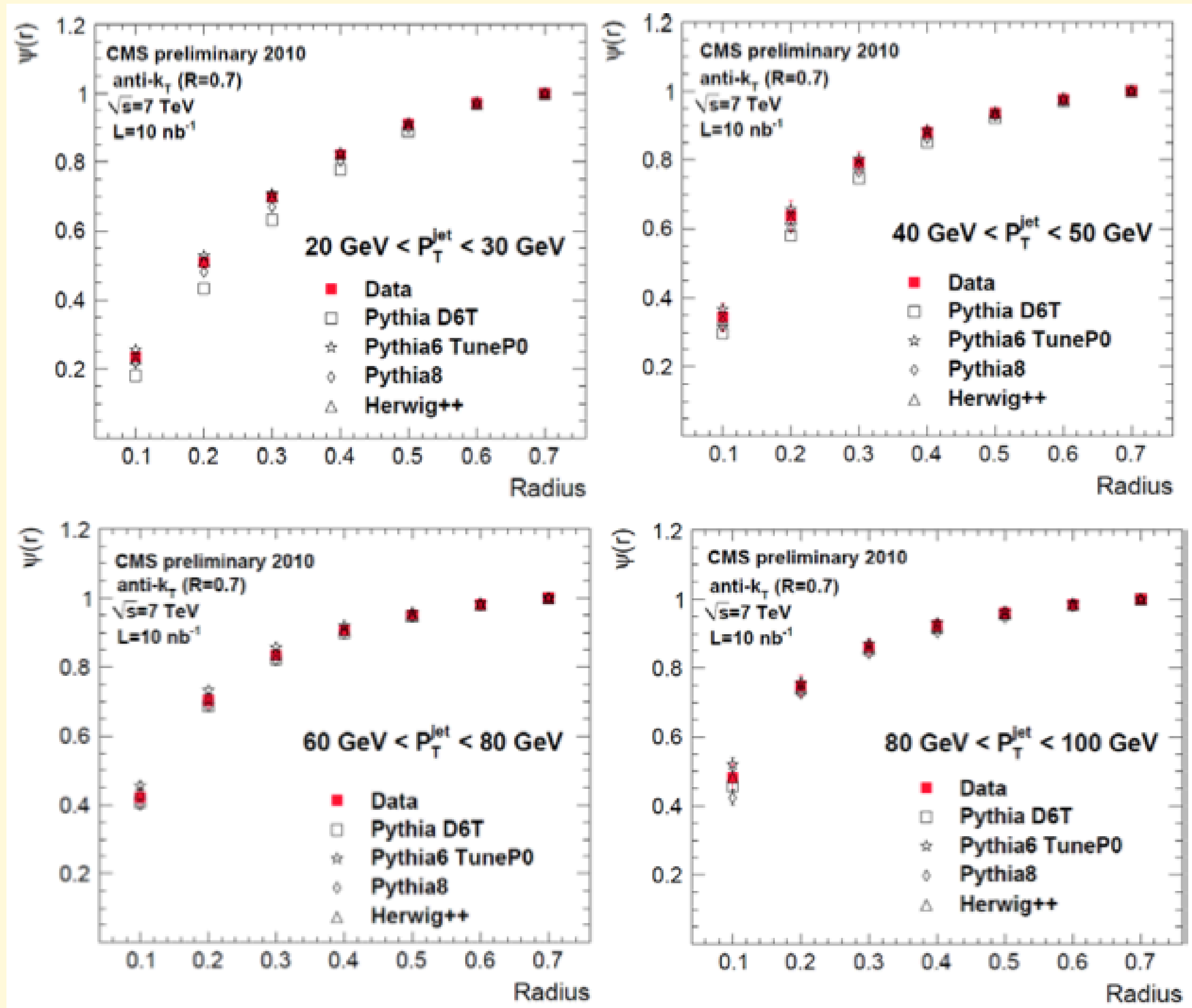
from 2010, O(nb^{-1}) studies ....

Integrated jet shape

Probes modeling of shower evolution, with implications for:
- precision QCD studies (e.g. jet E_T spectrum, data vs NLO)
- jet spectroscopy (e.g. top mass determination)
- multiparton matrix-elements/shower matching
- pt W

$$\Psi(r) = \frac{1}{N_{jets}} \sum_{jets} \frac{P_T(0,r)}{P_T^{jet}(0,R)}$$

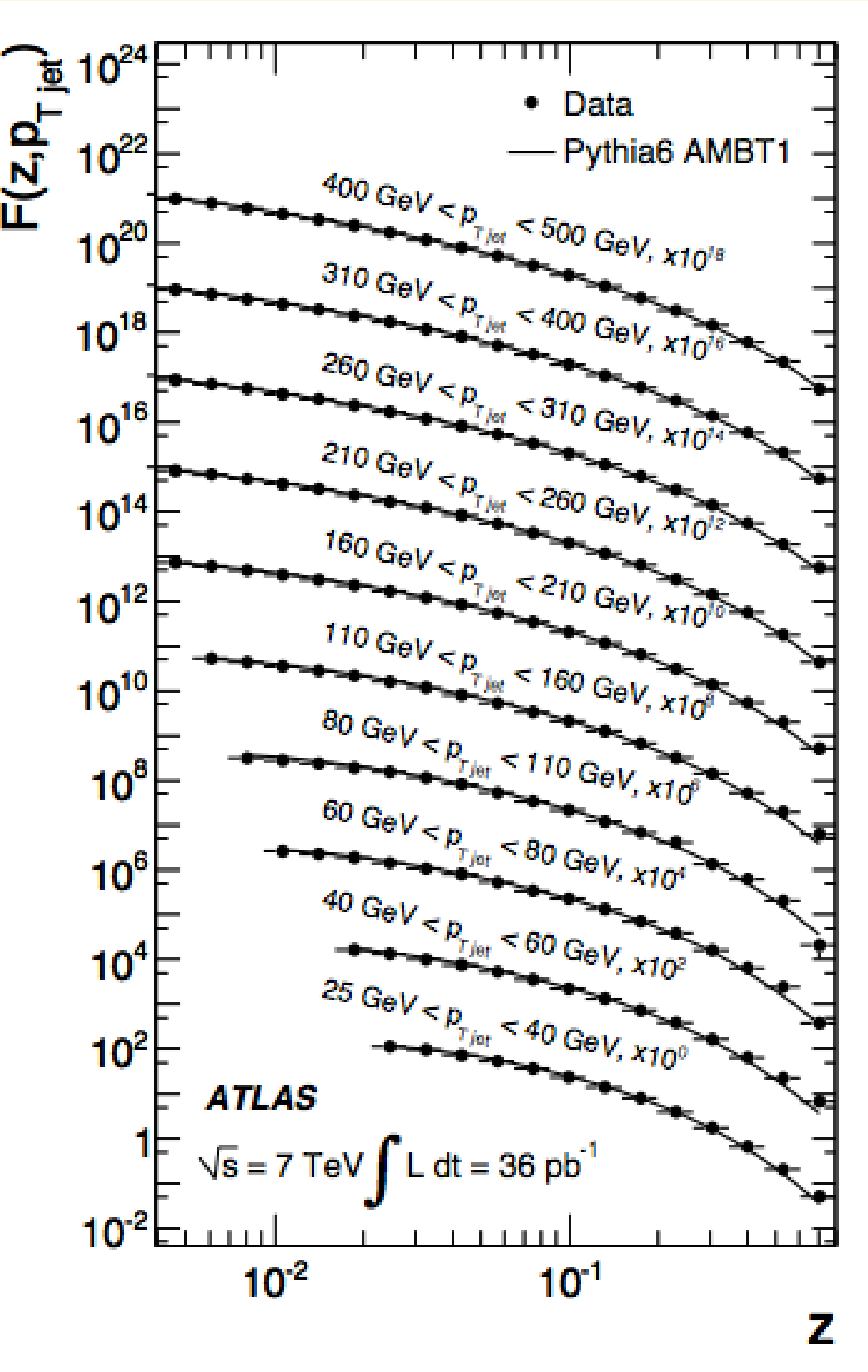


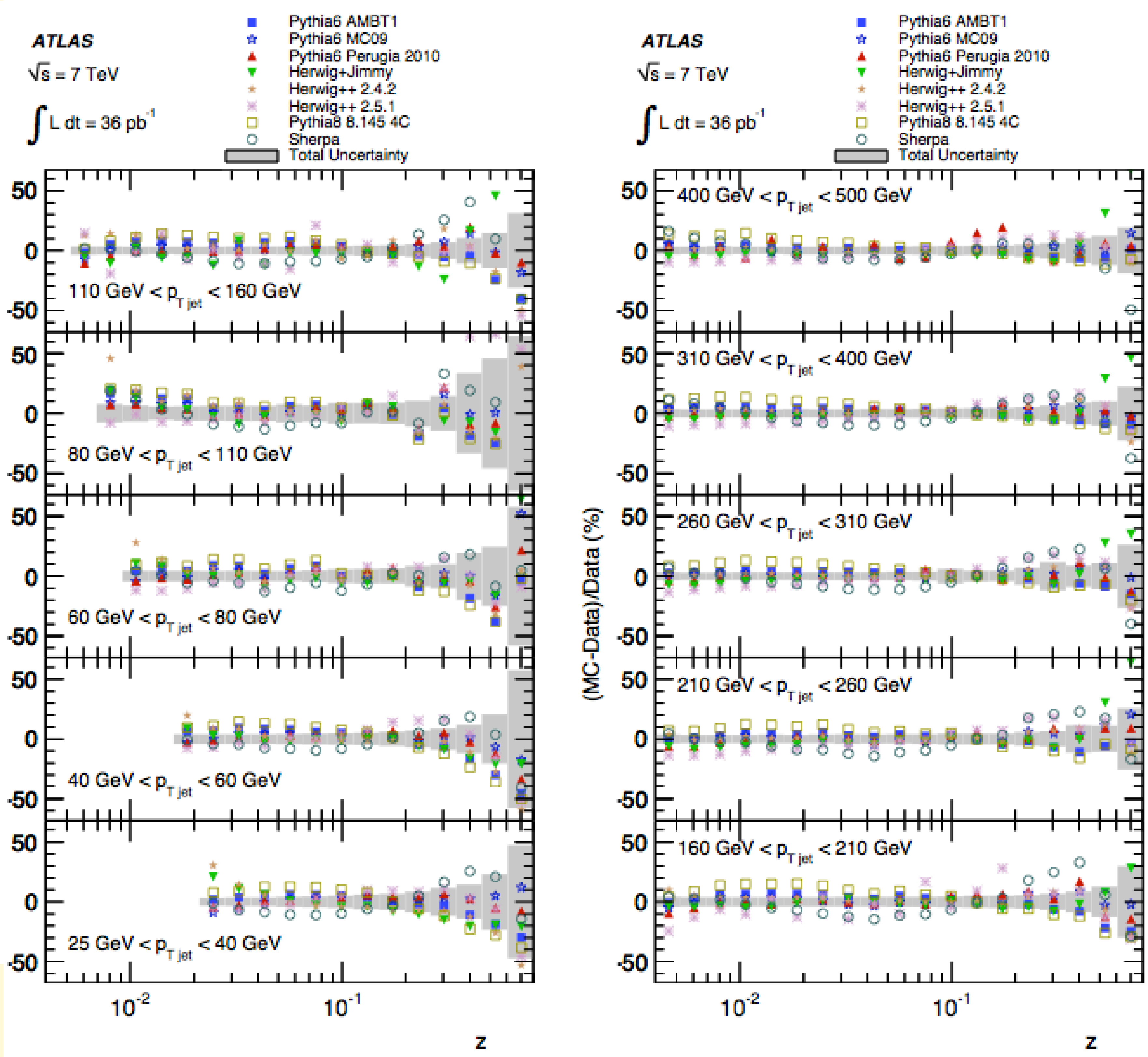


78 nb^{-1} CMS PAS QCD-10-014

Jet fragmentation function

ATLAS, arXiv:1109.5816

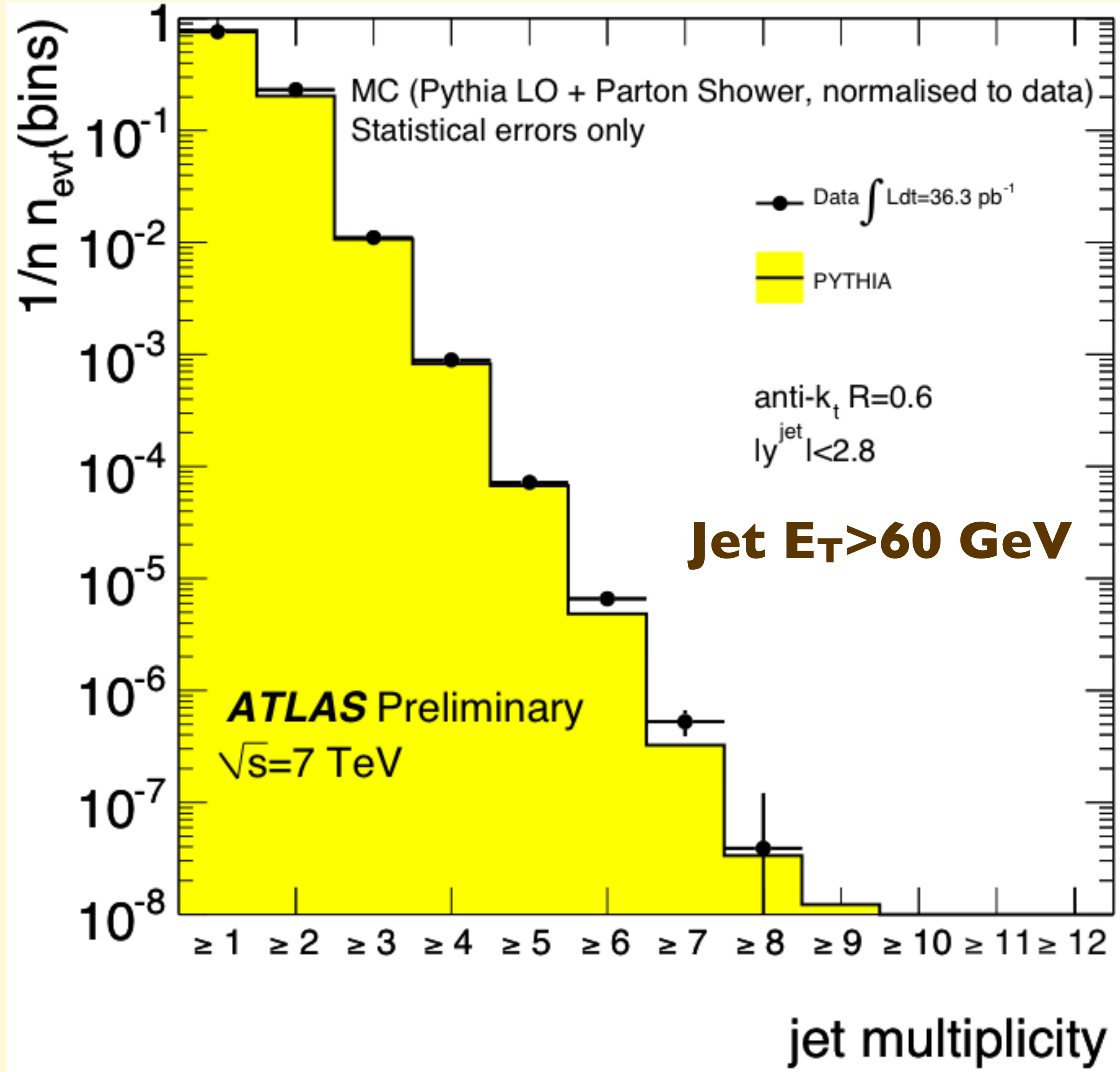


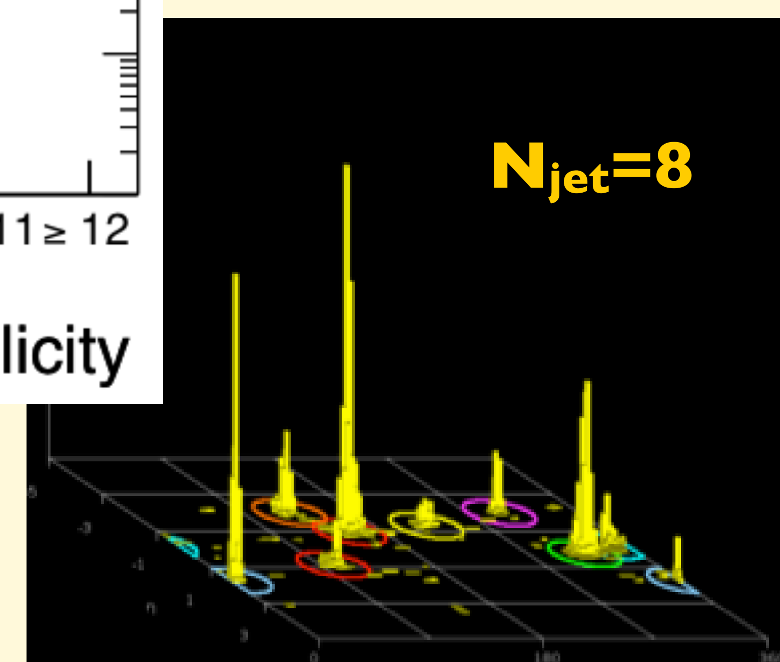


plus

- **jet shapes**
- **ptrel spectra**
- **<N_{ch}> and <z> distributions,**
- **....**

Multijets

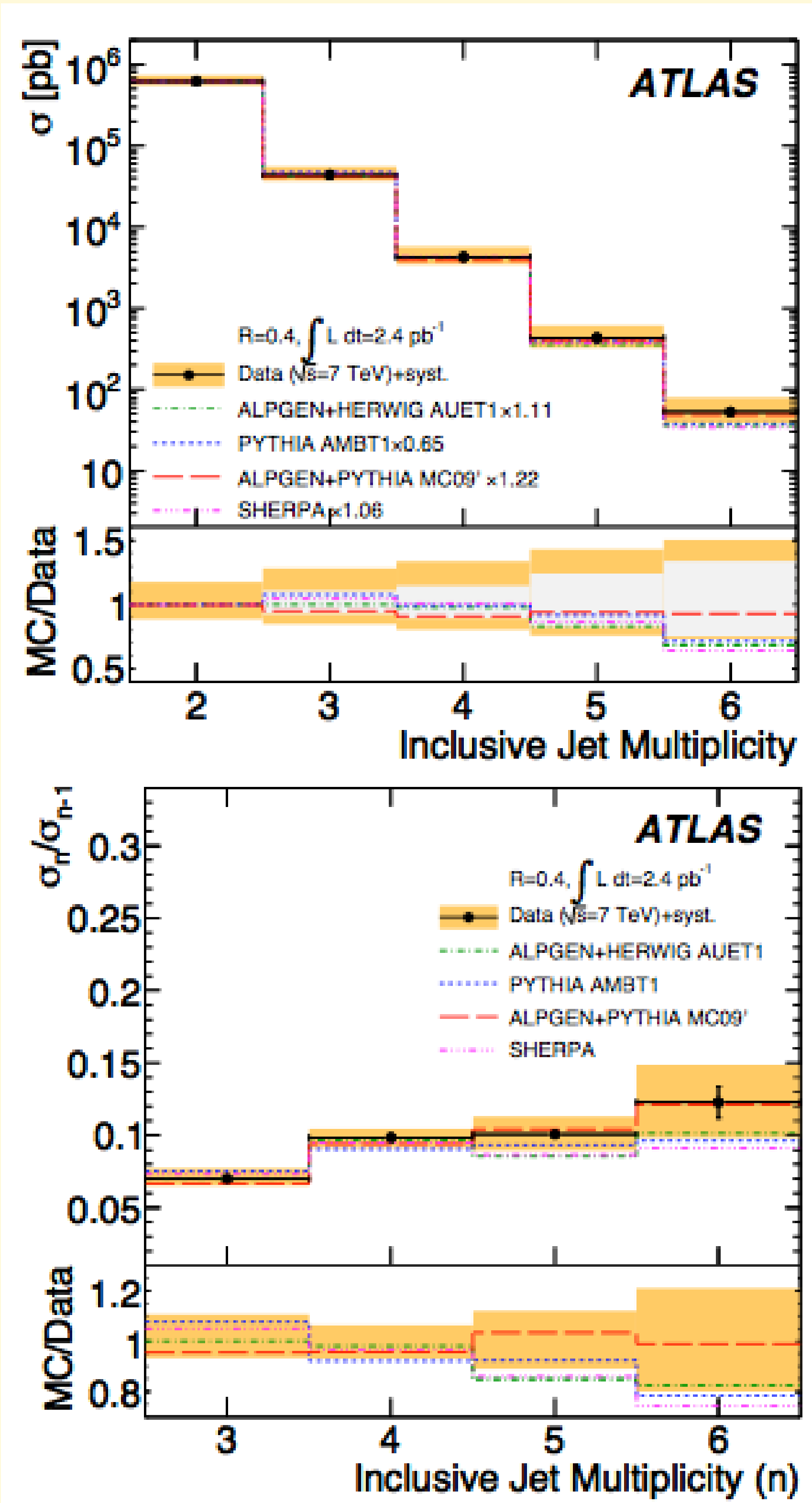


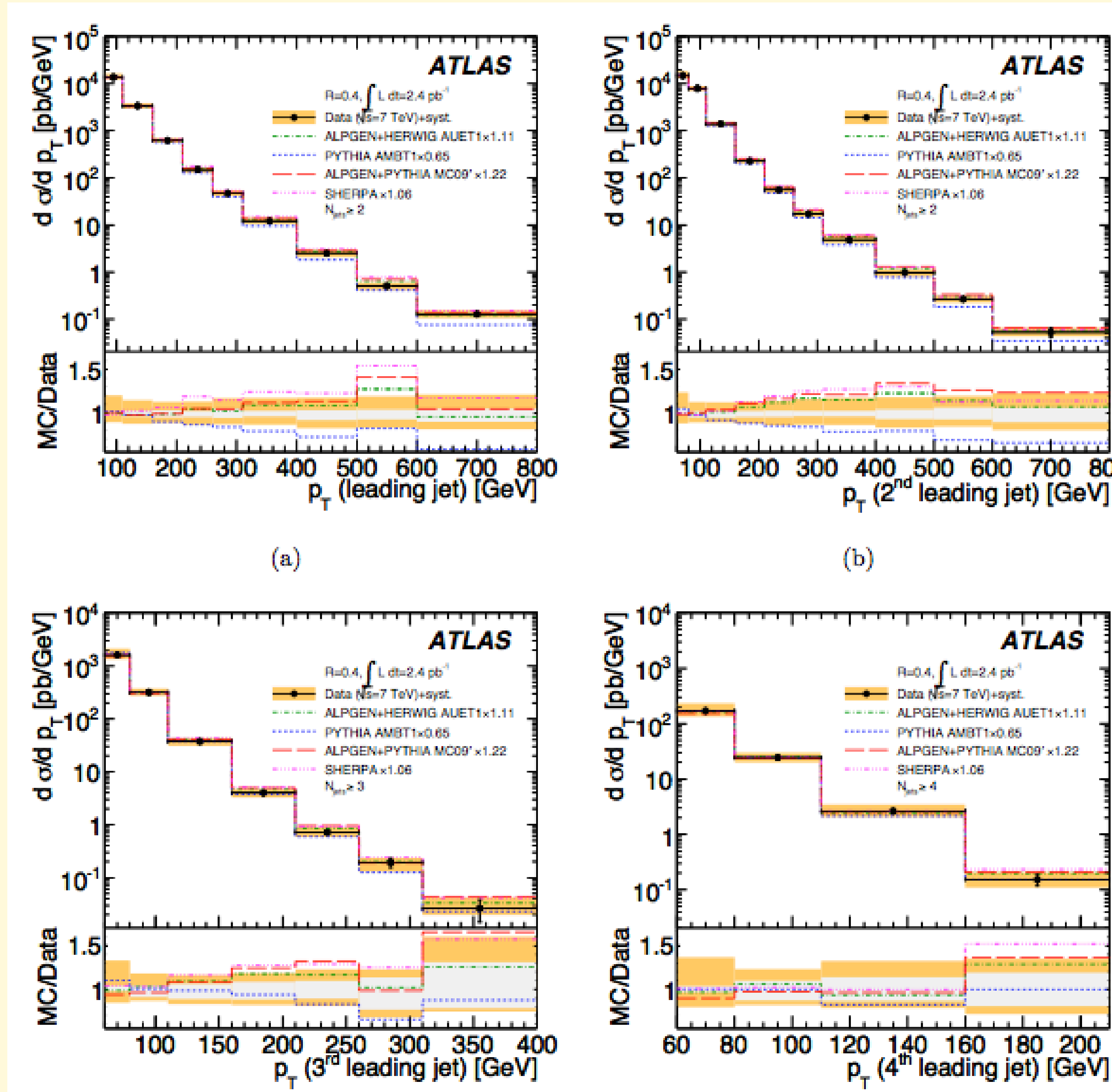


Should probe N_{jet}~11-12 by end of 2012 !

Multijets

ATLAS, arXiv:1107.2092





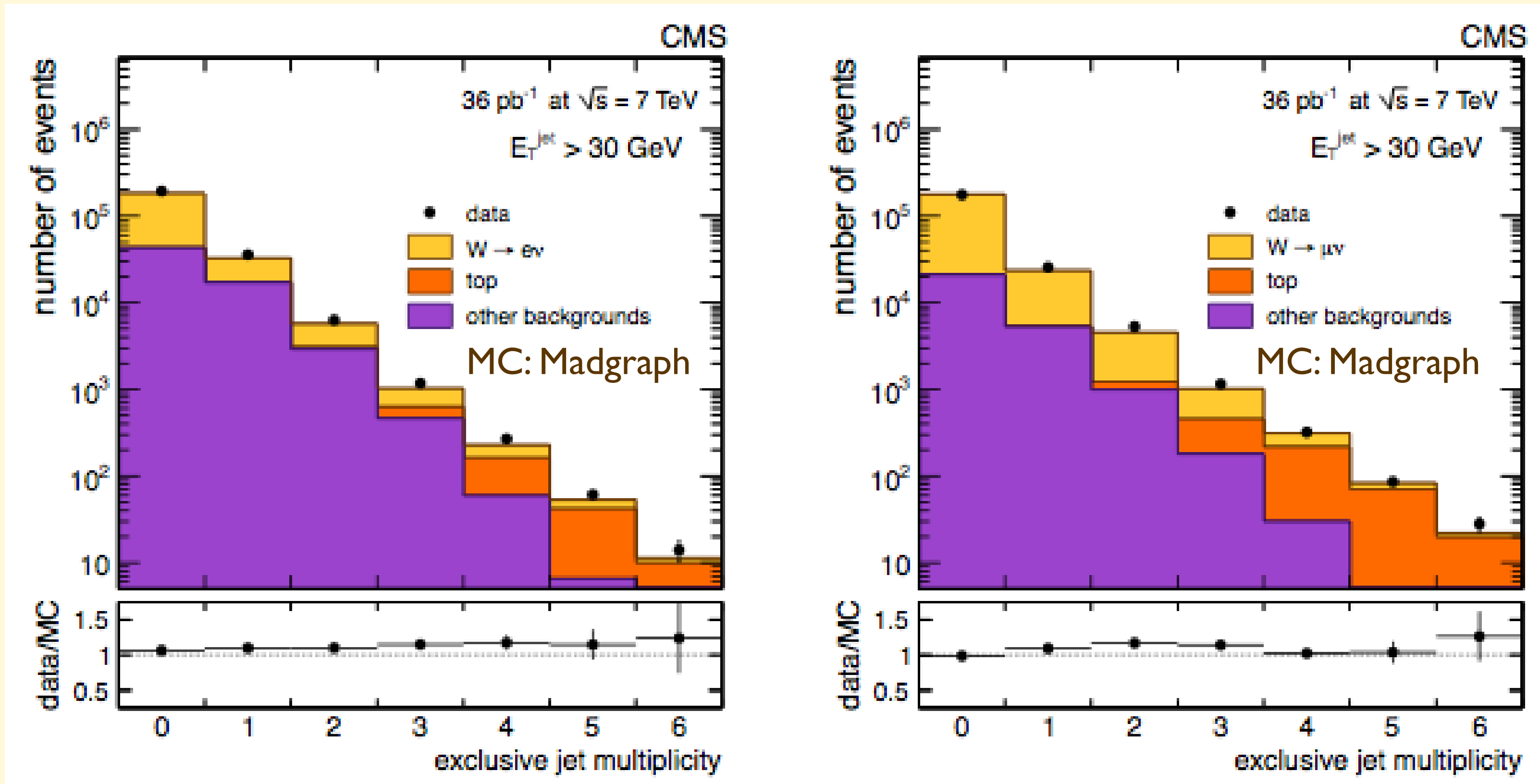
Excellent agreement, including for Pythia standalone --- cfr what happens in W+jets, see later

W/Z+jets cross sections

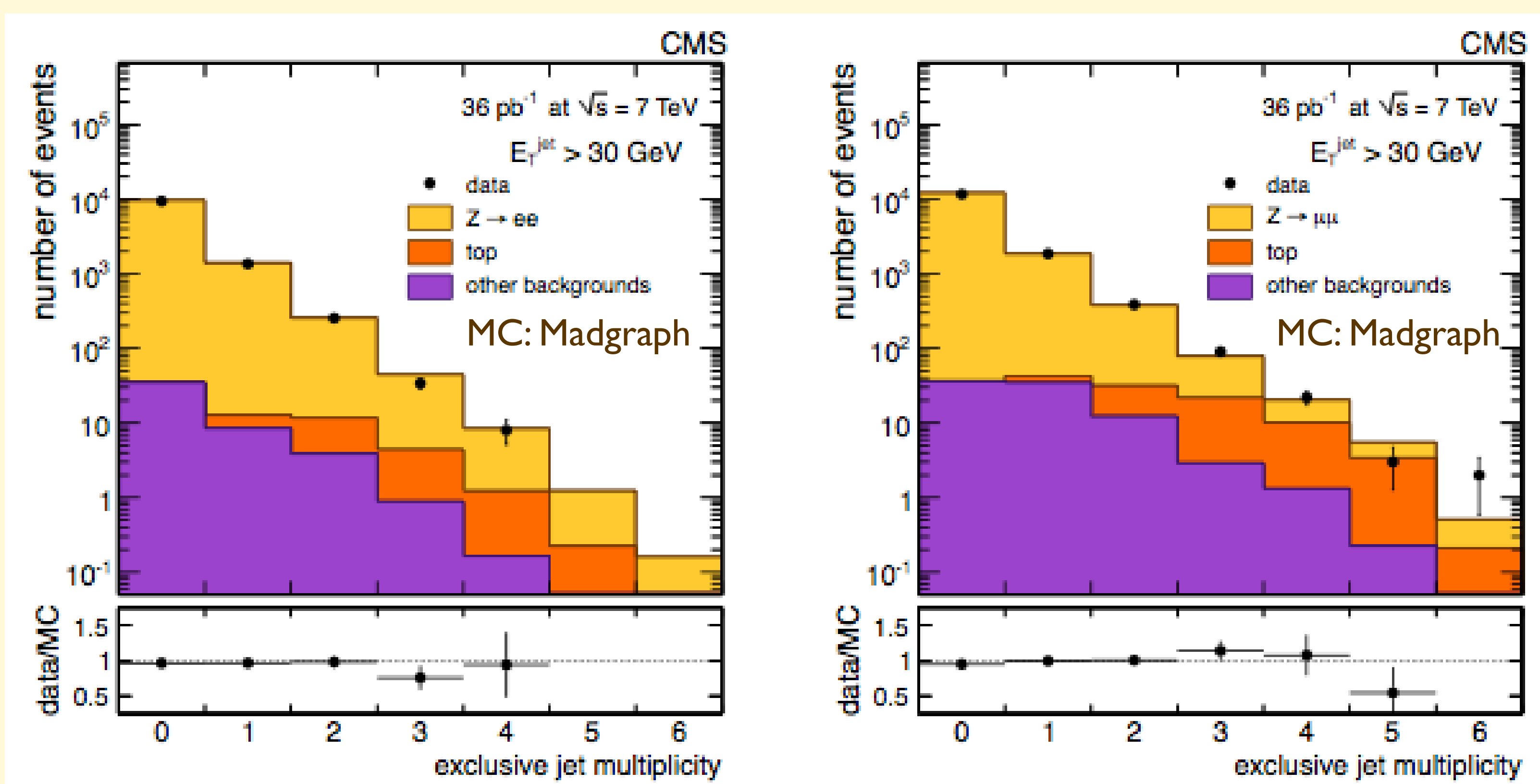
CMS, arXiv:1110.3226

Uncorrected, unsubtracted, rates

W+jets



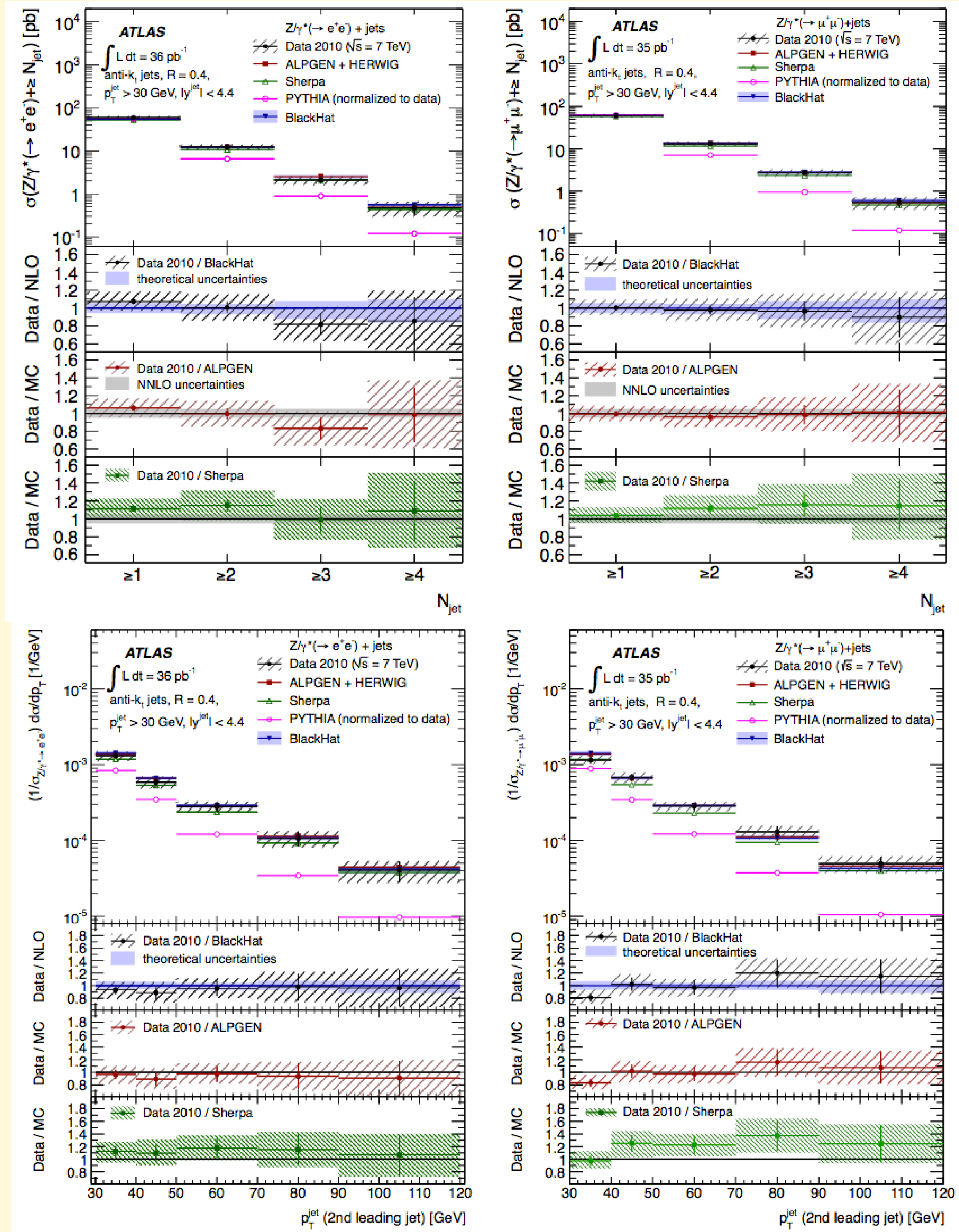
Z+jets



Z+jets cross sections

ATLAS, 36pb⁻¹, arXiv:1111.2690

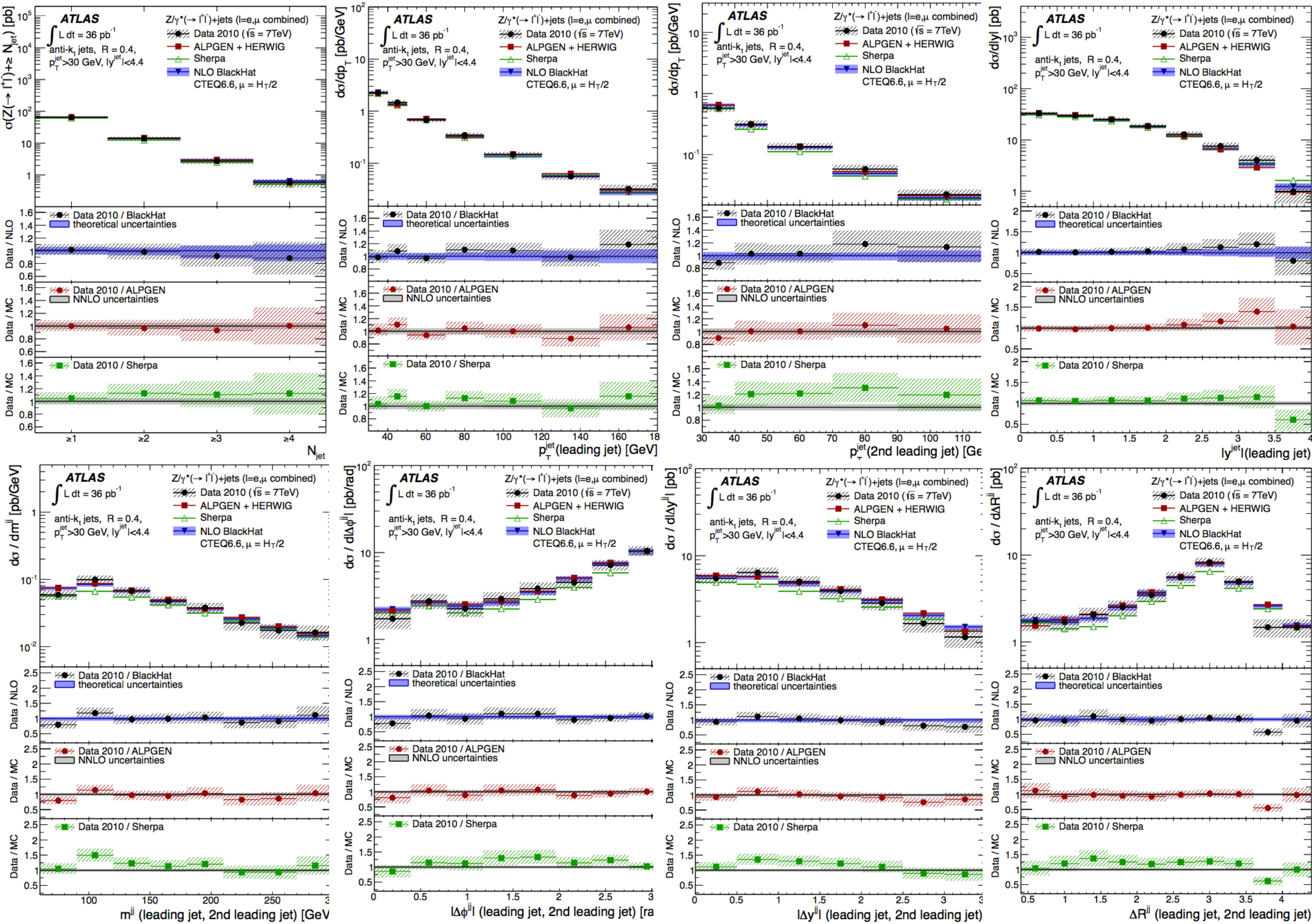
Alpgen and Sherpa normalized to $\sigma_{NNLO}(Z)$



Z+jets cross sections

ATLAS, 36pb^{-1}, arXiv:1111.2690

Alpgen and Sherpa normalized to $\sigma_{NNLO}(Z)$



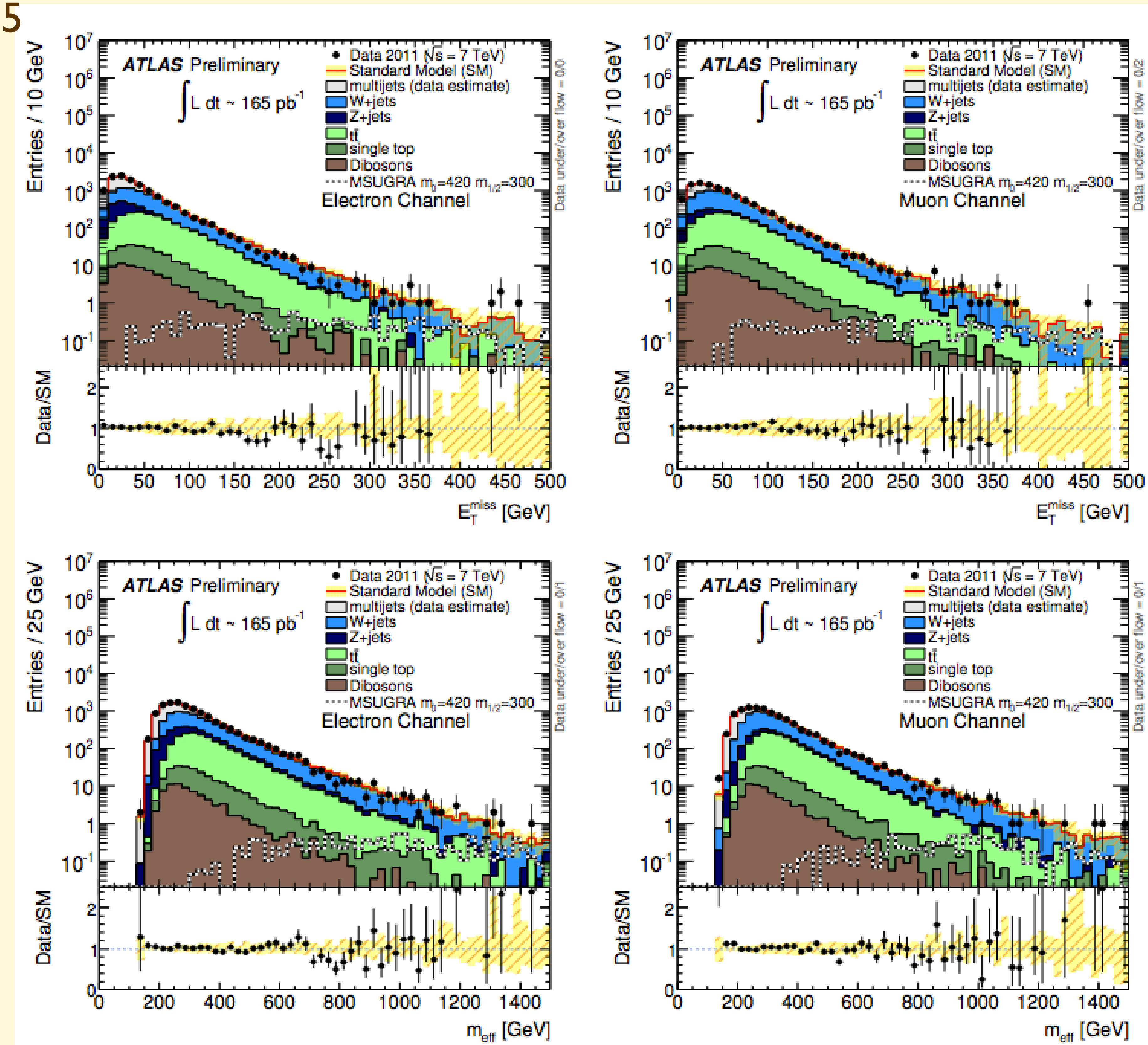
- **Plenty of W/Z+jets studies in the context of BSM searches**
- **Distributions not corrected to particle level, so only comparisons against showered/hadronized MC predictions are possible**
- **However they are of great interest, since they typically probe kinematical distributions of dynamical interest, complementary to the standard E_T spectra of QCD studies**

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}

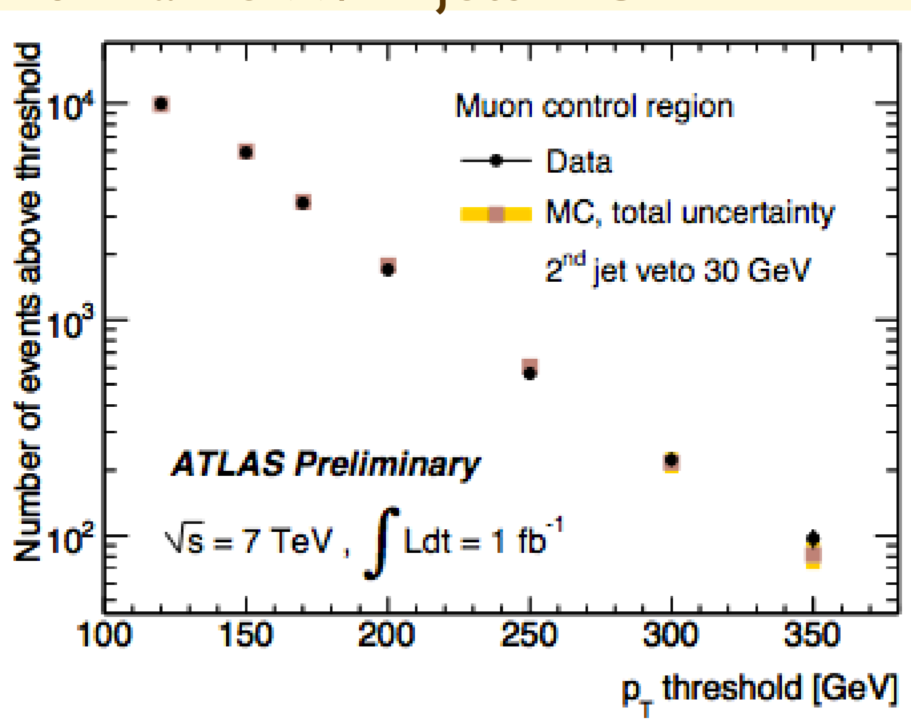
ATLAS 1fb^{-1} study of 1-jet+MET (ADD extra-dim search)

ATLAS-CONF-2011-096

Selection:
- LowPt: $\mathbf{E_{T1}}$>120 GeV, |η|<2; $\mathbf{E_{Tmiss}}$>120 GeV; $\mathbf{E_{T2}}$<30 GeV, |η|<4.5
- HighPt: $\mathbf{E_{T1}}$>250 GeV, |η|<2; $\mathbf{E_{Tmiss}}$>220 GeV; $\mathbf{E_{T2}}$<60 GeV, $\mathbf{E_{T3}}$<30 GeV, |η|<4.5; Δφ(jet$_2$,MET)>0.5
- VeryHighPt: $\mathbf{E_{T1}}$>350 GeV, |η|<2; $\mathbf{E_{Tmiss}}$>300 GeV; $\mathbf{E_{T2}}$<60 GeV, $\mathbf{E_{T3}}$<30 GeV, |η|<4.5; Δφ(jet$_2$,MET)>0.5

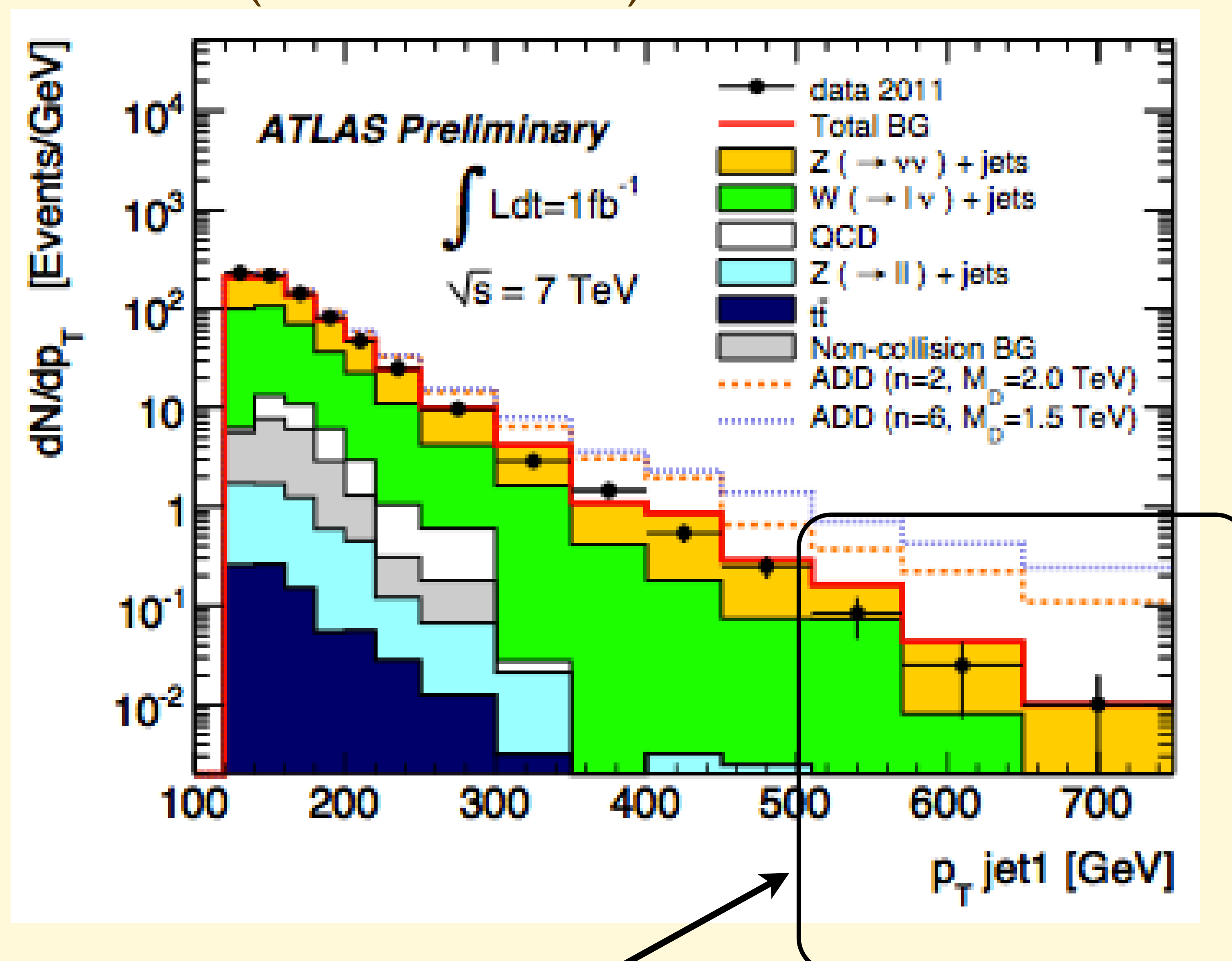
Exclusive final states, Sudakov-like regions

Control regions, defined by same cuts plus presence of leptons, to normalize W/Z+jets MC



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

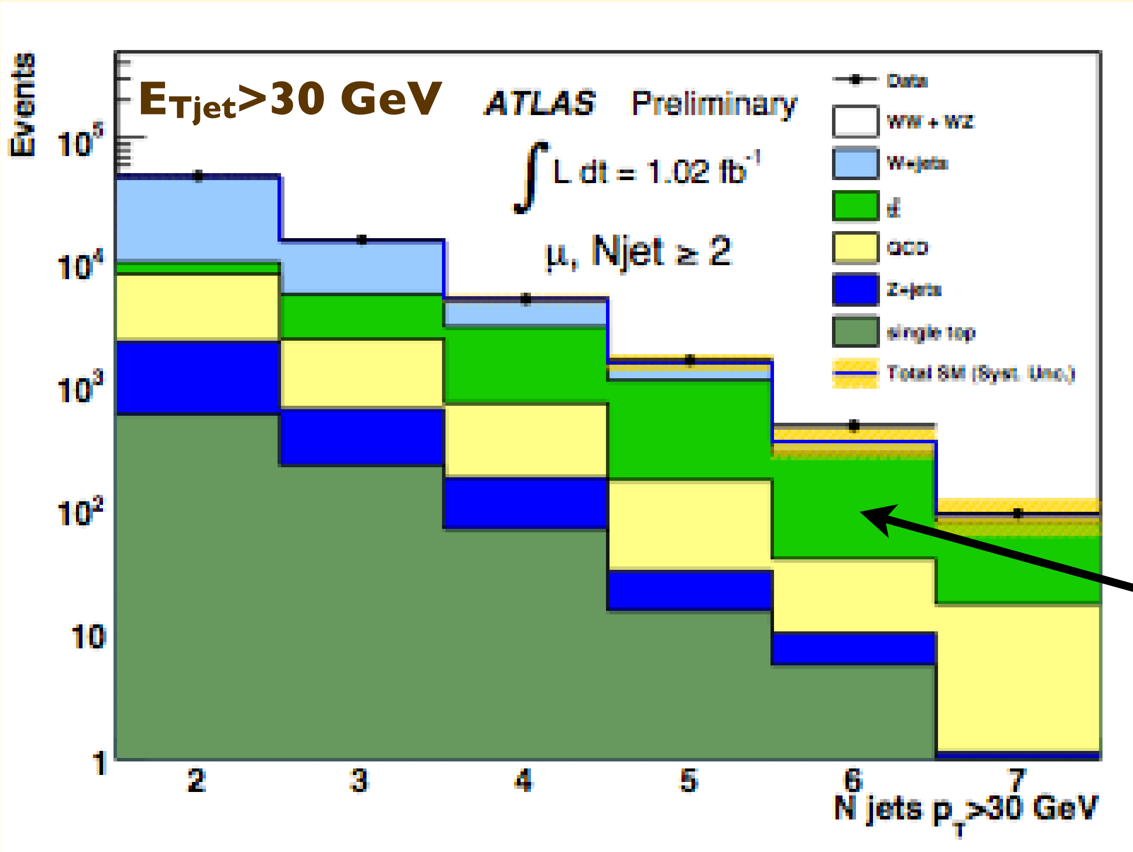
Results (LowPt selection)



H_T ~ 1-1.5 TeV and no 2nd jet > 30 GeV !!

ATLAS 1fb^{-1} study of mjj spectrum in Wjj events

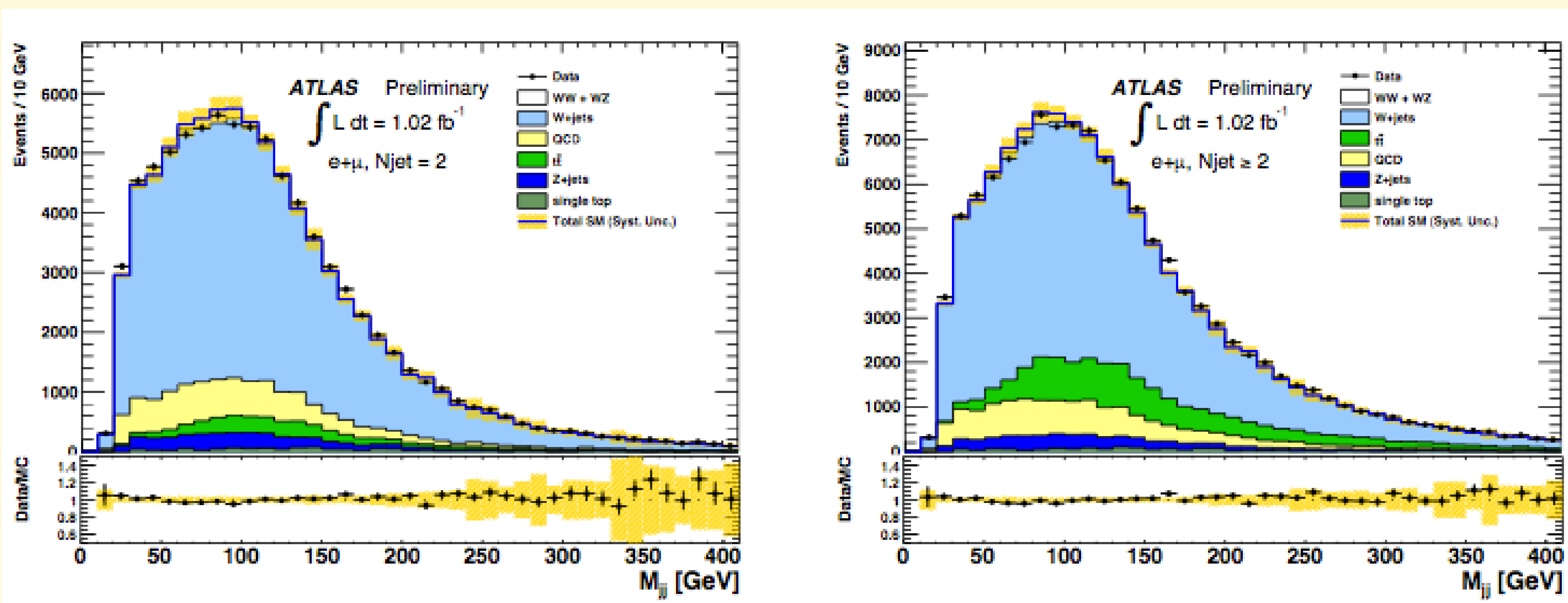
ATLAS-CONF-2011-097



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}

N_{jet}>4 dominated by t tbar: not a compelling test of W+multijets, but a good test of ttbar+multijets



While waiting for the Higgs, great

excitement comes from flavour physics ....

First observation ever of CP violation in up-type quark sector

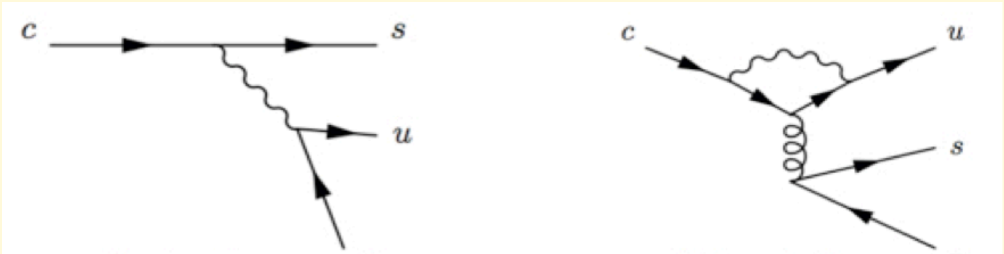
M.Charles, LHCb, 580 pb^{-1}, HCP 2011:

Time-integrated asymmetry in SCS decays: $D^0 \to K^+K^-$ vs $D^0 \to \pi^+\pi^-$

$$\Delta a_{CP} \equiv a_{K^+K^-} - a_{\pi^+\pi^-} = -(0.82 \pm 0.21 \pm 0.11)\%$$

Significance: 3.5 σ

$$a_f \equiv \frac{\Gamma(D^0 \to f) - \Gamma(\bar{D}^0 \to f)}{\Gamma(D^0 \to f) + \Gamma(\bar{D}^0 \to f)}$$



(a) Tree diagram. (b) Penguin diagram.

Theory assessment:
Isidori, Jernej, Kamenik, Ligeti, Perez, arXiv:1111:4987

“While a sufficient QCD enhancement of the penguin matrix element cannot be excluded at the present time, if similar CP violation is observed in other channels as well (e.g., pseudoscalar-vector final states, three-body decays, Ds or Λc decays), then it would suggest that the measurement is due to new short distance physics ...”

Theory assessment:
Brod, Kagan, Zupan, arXiv:1111:5000

“We have shown that it is plausible that the standard model accounts for the measured value of ΔA_{CP} . Nevertheless, new physics could be at play. [...] An example of new physics in QCD penguins that could yield direct CP asymmetries as large as 1%, without violating the D^0 mixing bounds, is provided by supersymmetric gluino-up squark loops”

Updated limits on $B \rightarrow \mu\mu$

LHCb, 2010 data, previous limit:

$BR(B_s \rightarrow \mu^+\mu^-) < 4.3\ (5.6) \times 10^{-8}$ @ 90 (95% CL)

$BR(B^0 \rightarrow \mu^+\mu^-) < 1.2\ (1.5) \times 10^{-8}$ @ 90 (95% CL)

D.Martinez Santos, LHCb, ~400 pb^{-1}, HCP 2011:

Results

(to be submitted to PLB)

$B_s \rightarrow \mu\mu$	at 90% CL	at 95% CL
Expected BR limit (bkg. + SM hypothesis)	1.1×10^{-8}	1.4×10^{-8}
Observed BR limit	1.3×10^{-8}	1.6×10^{-8}

$B^0 \rightarrow \mu\mu$	at 90% CL	at 95% CL
Expected BR limit (bkg. only hypothesis)	2.5×10^{-9}	3.2×10^{-9}
Observed BR limit	3.0×10^{-9}	3.6×10^{-9}

Combining 2010 (PLB 699 (2011) 330) +2011 analysis: ~400 pb^{-1} in total:

	at 90% CL	at 95% CL
Observed $BR(B^0 \rightarrow \mu\mu)$ limit	2.6×10^{-9}	3.2×10^{-9}
Observed $BR(B_s \rightarrow \mu\mu)$ limit	1.2×10^{-8}	1.4×10^{-8}

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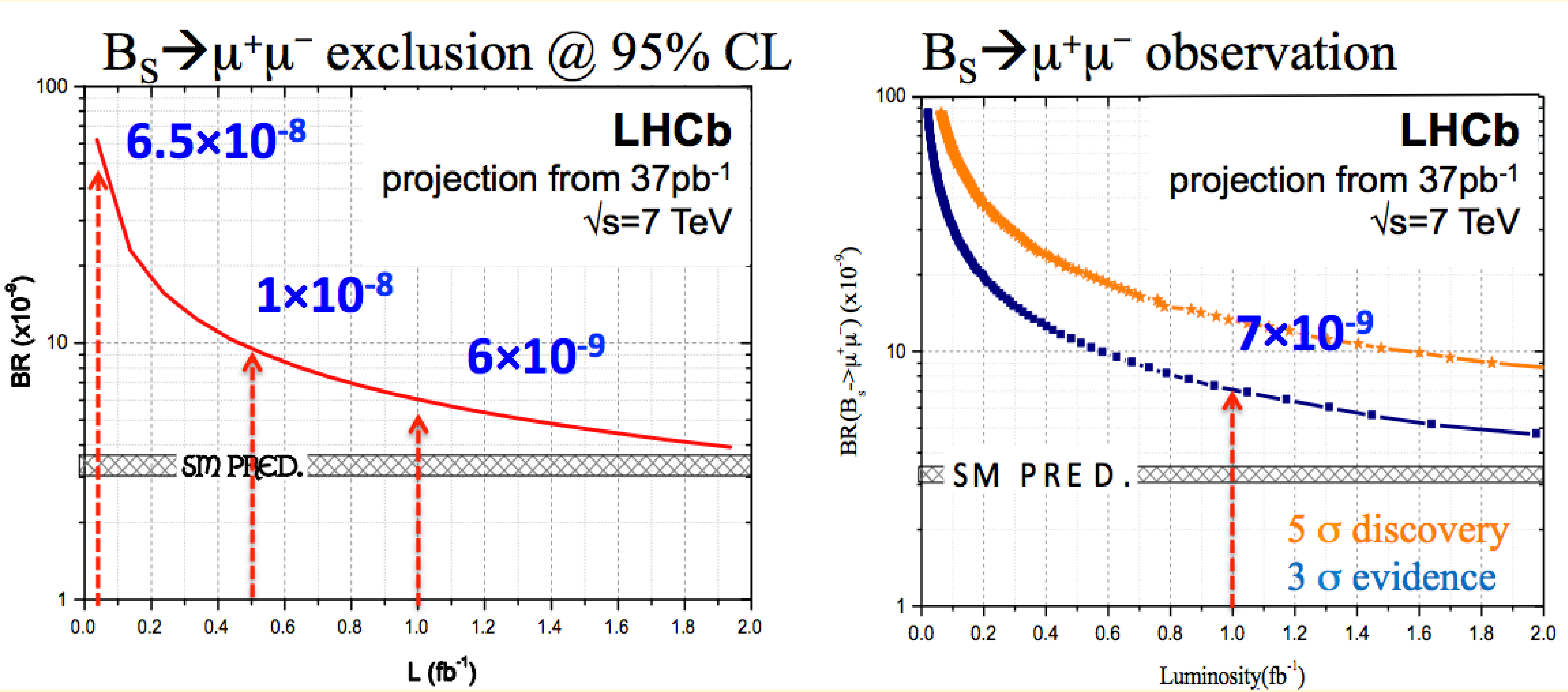
LHCb, projections:



Measurements I didn't talk about

- Minimum bias and UE studies (see MPI 2011 for a review)
- Diffraction, forward physics (see MPI 2011)
- Inclusive jet cross sections
- Quarkonium production, polarization
- Open charm and beauty production
- More on B decays and spectroscopy, and flavour in general
- Hard photon(s) production
- Searches, searches, searches, searches, searches, searches, ...
- Heavy ion programme
- ..... and much more!

Conclusions

- **New physics is *not* jumping at us**
  - wherever it is, it's hiding well, and we'll suffer to dig it out!
  - better be ready with finely honed theory tools!
- **LHC measurements moved to a new phase of quantitative and precision level**
  - proton structure (cross sections, PDFs)
  - final state dynamics
  - extreme kinematical configurations
  - EW and flavour sector parameters
- **It's a great reward for theorists to see the fruits of years of work developing tools**
  - theory/data agreement beyond expectations and hopes
  - thanks to the expt's for the thorough and incisive tests of theory
  - still, interesting open issues and problems to keep the challenge up

We enter year-3 of the LHC with even greater expectations and confidence that major discoveries are *just* behind the corner!