The first year of the LHC: the HEP tools scorecard

HEPTools final meeting
Granada, Nov 25-26 2010

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CERN PH-TH

Introduction

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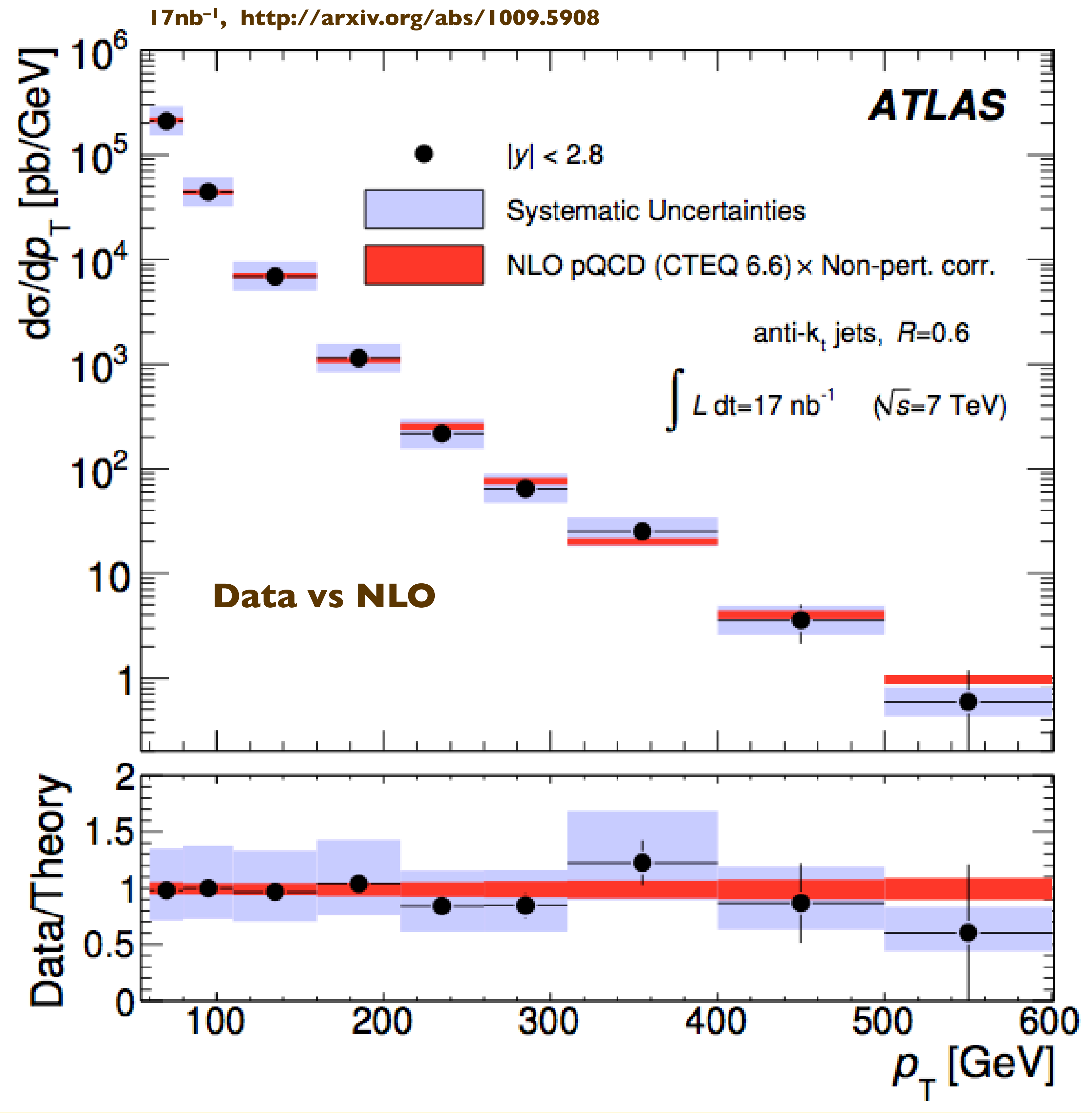
  - Things that we had no clue, didn't bother to study and make predictions for, and turned out to be exciting

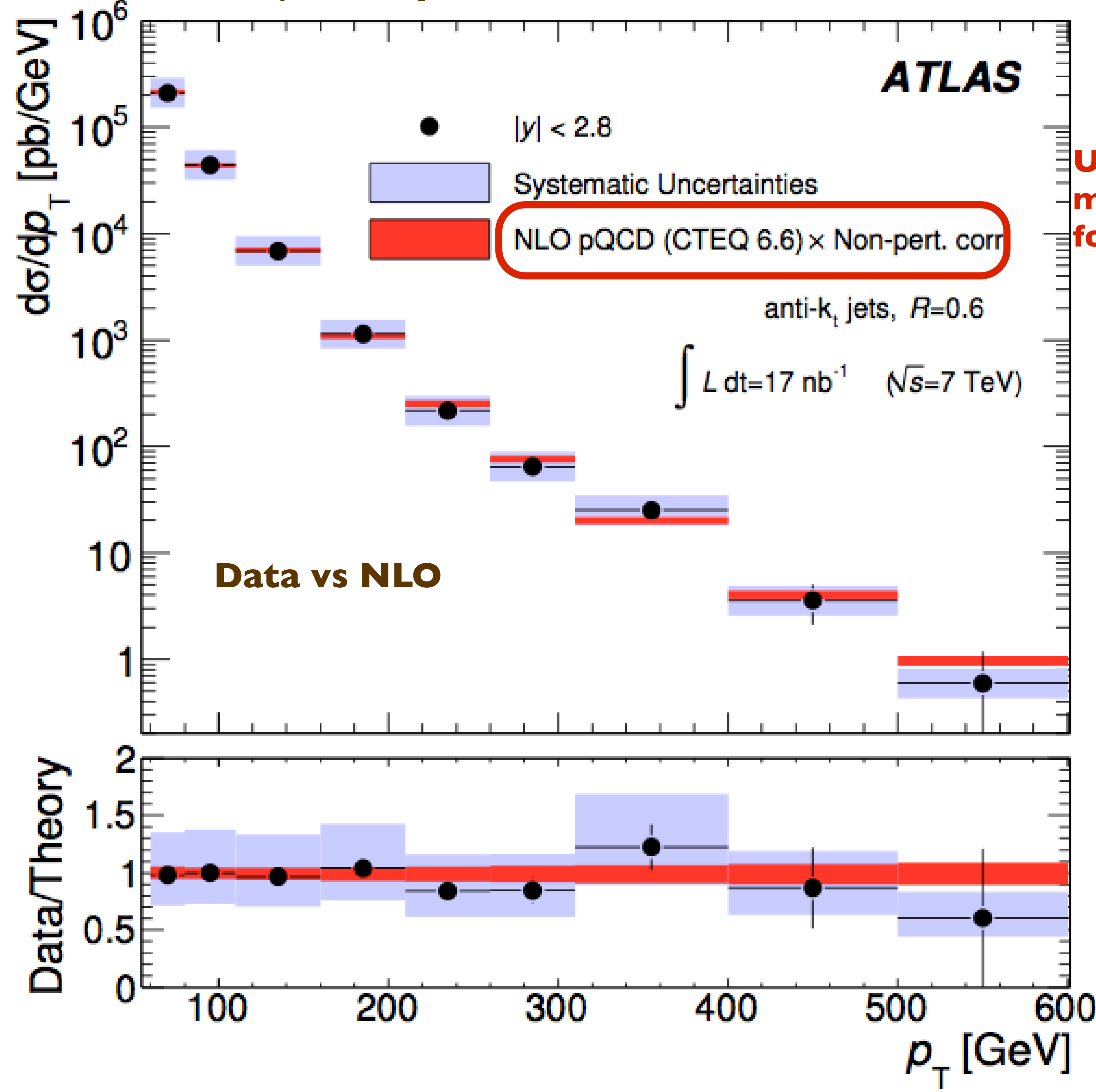
Jets

Inclusive jet E_T spectrum



Inclusive jet E_T spectrum

17nb⁻¹, http://arxiv.org/abs/1009.5908



Unfolded cross-section measurement, suitable for comparison with NLO

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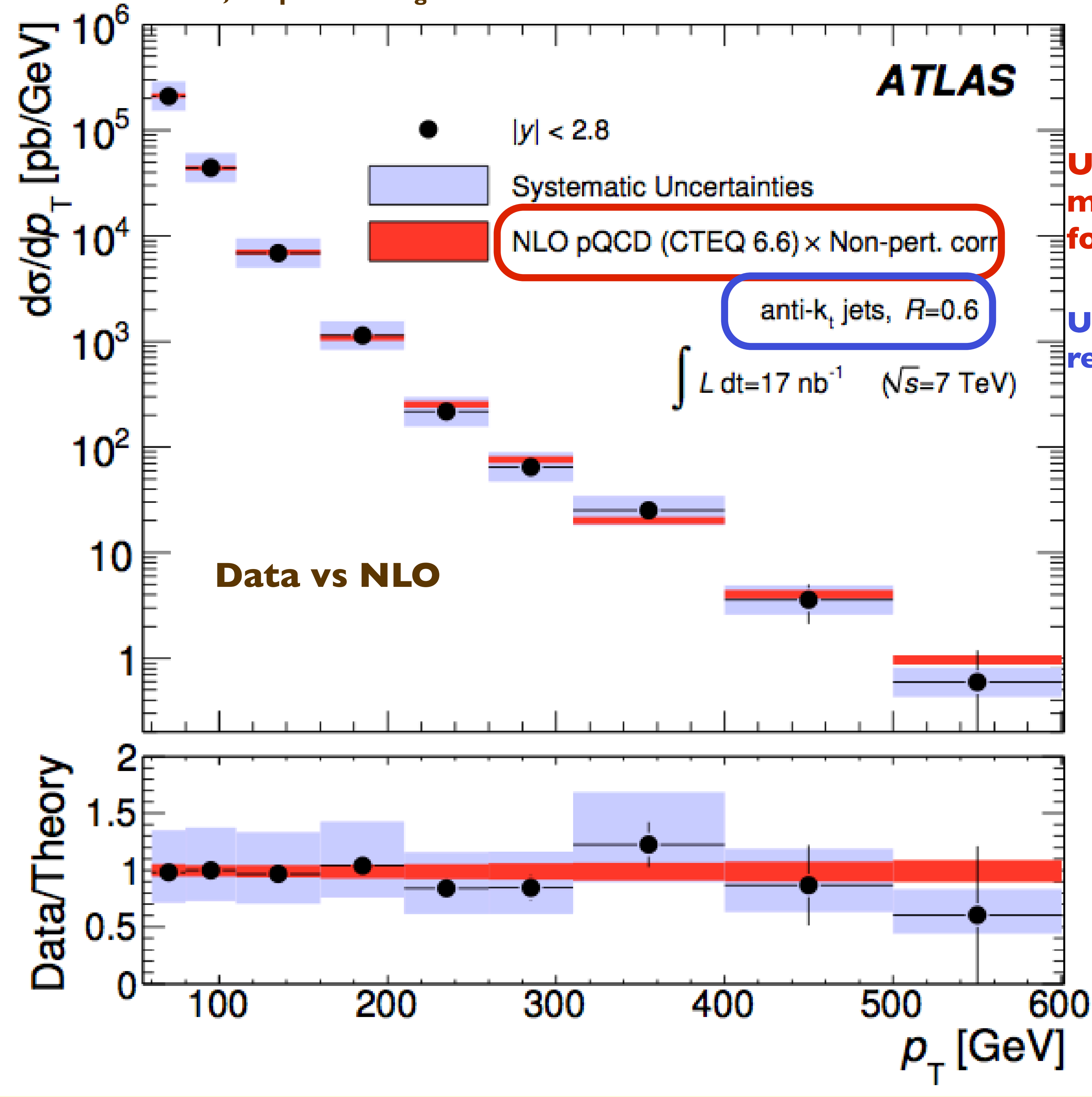
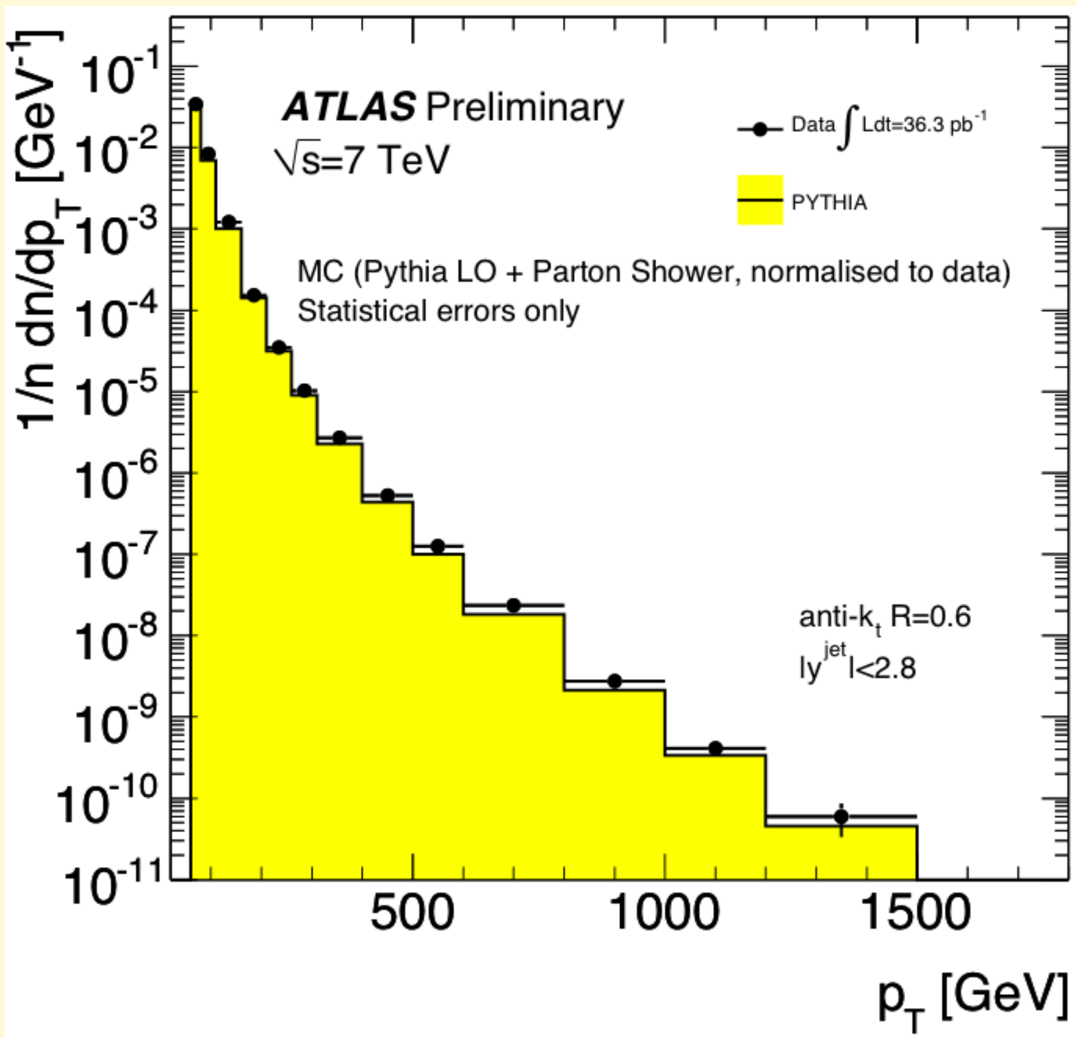
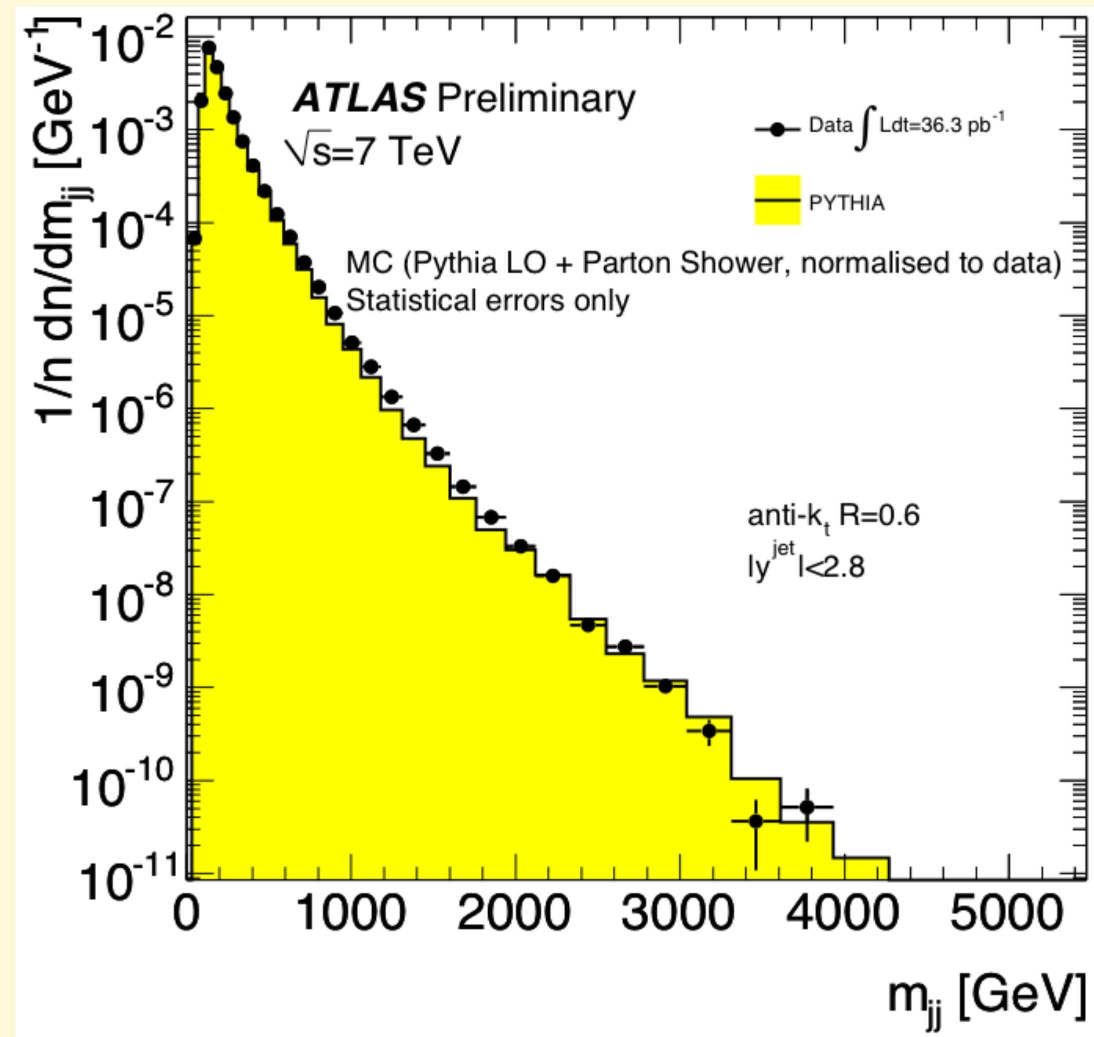


Unfolded cross-section measurement, suitable for comparison with NLO

Use of modern jet reconstruction tools

Full 2010 luminosity update:





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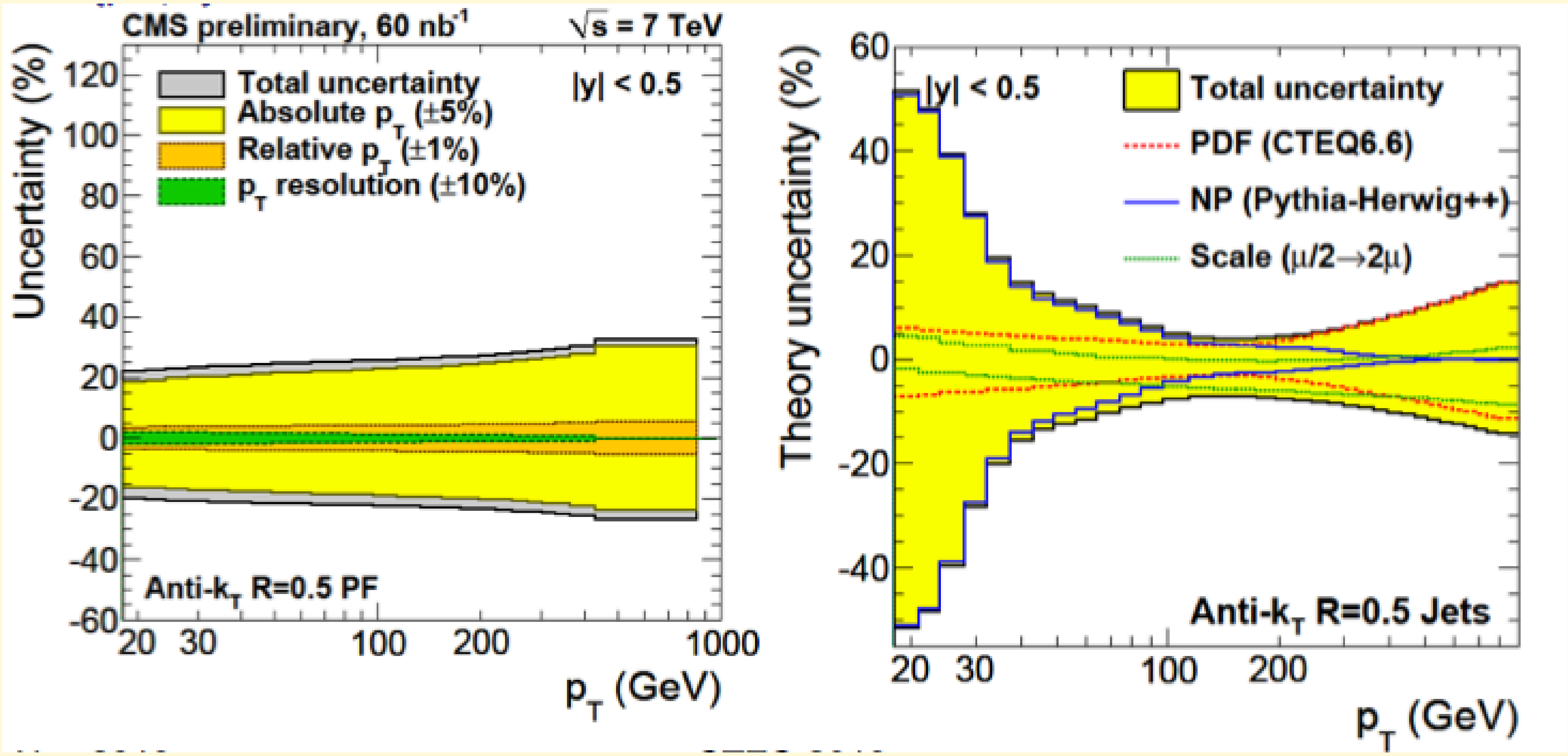
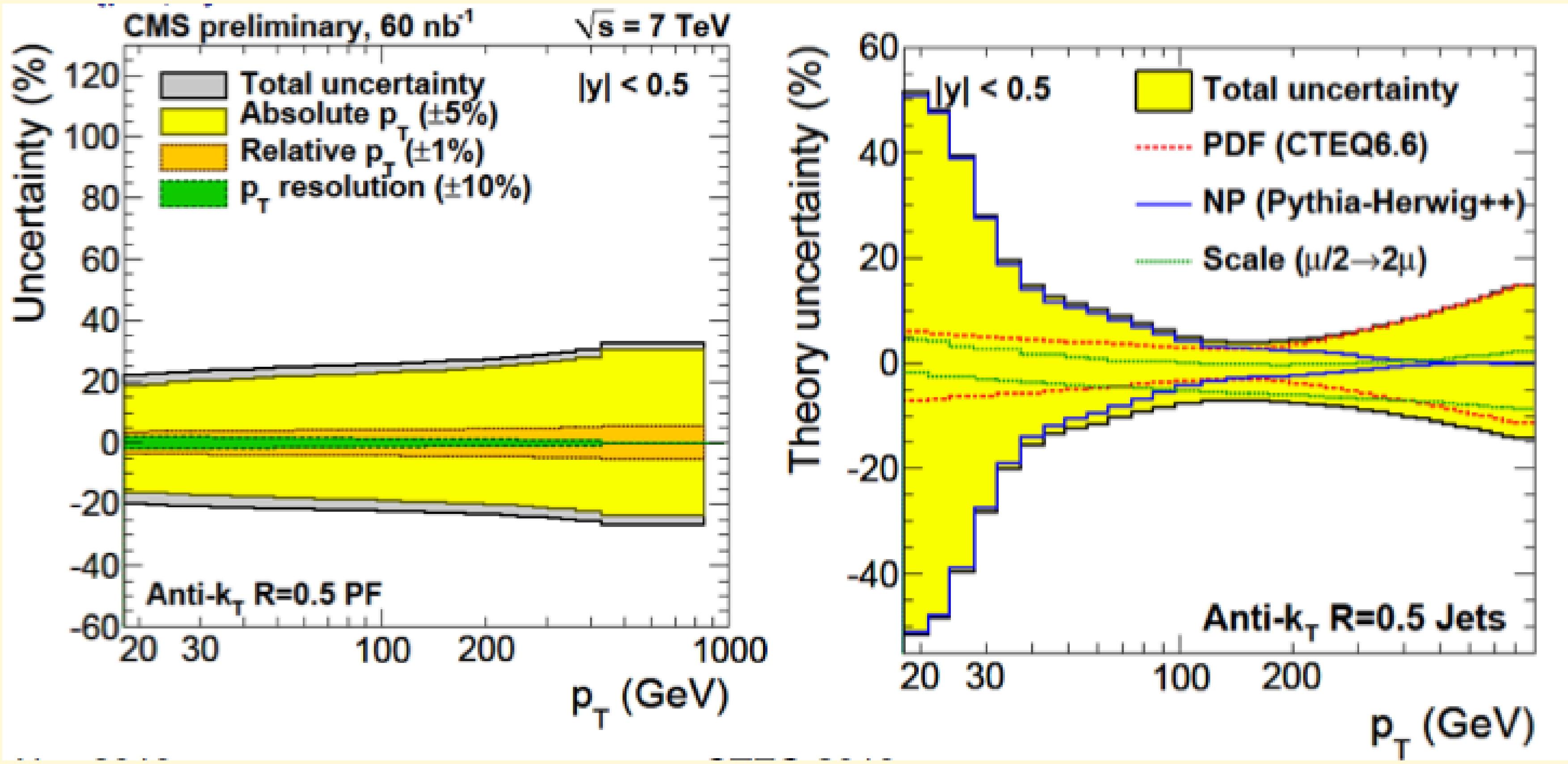


PDF will be dominant source of theoretical systematics at large E_T



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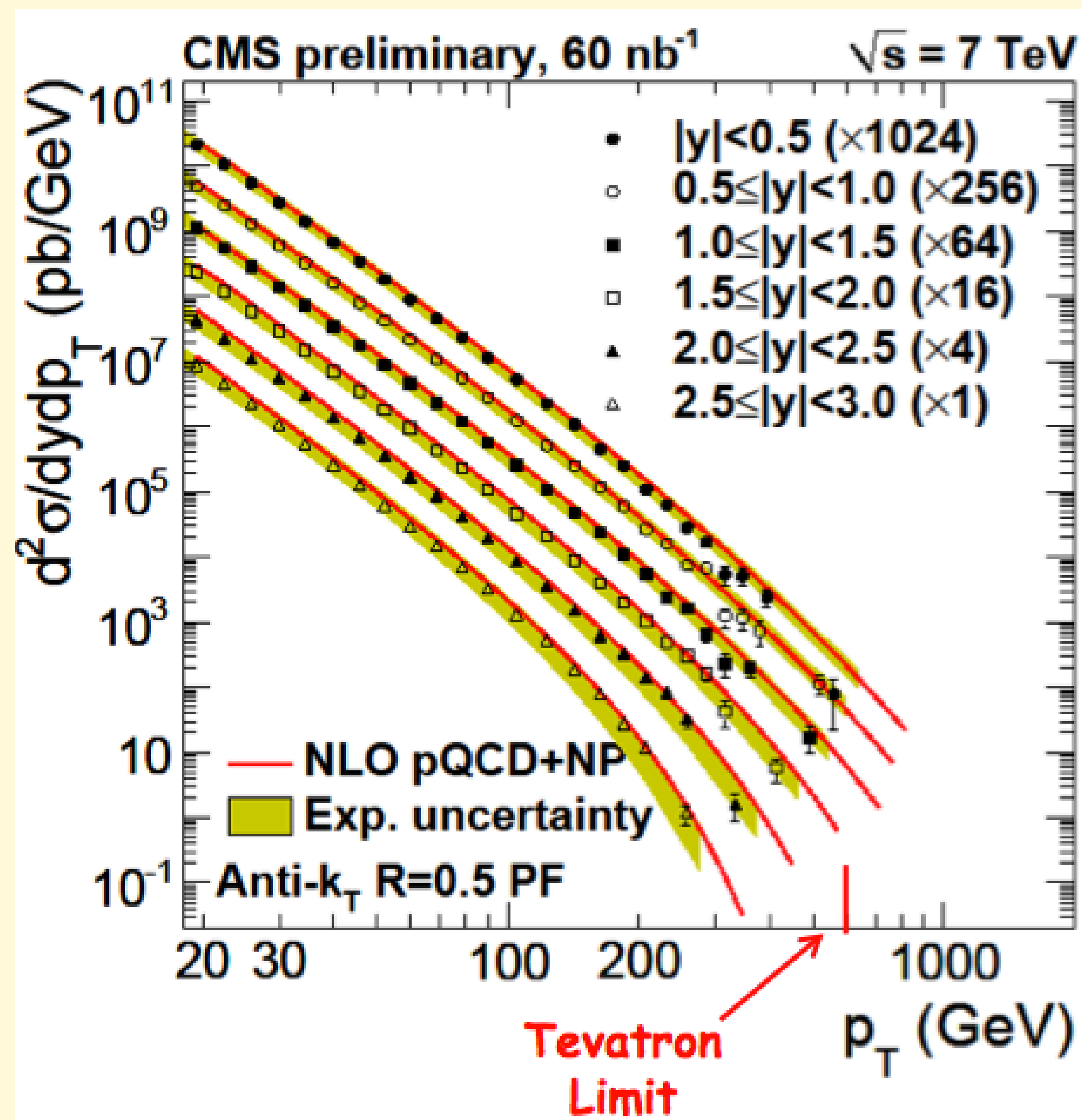
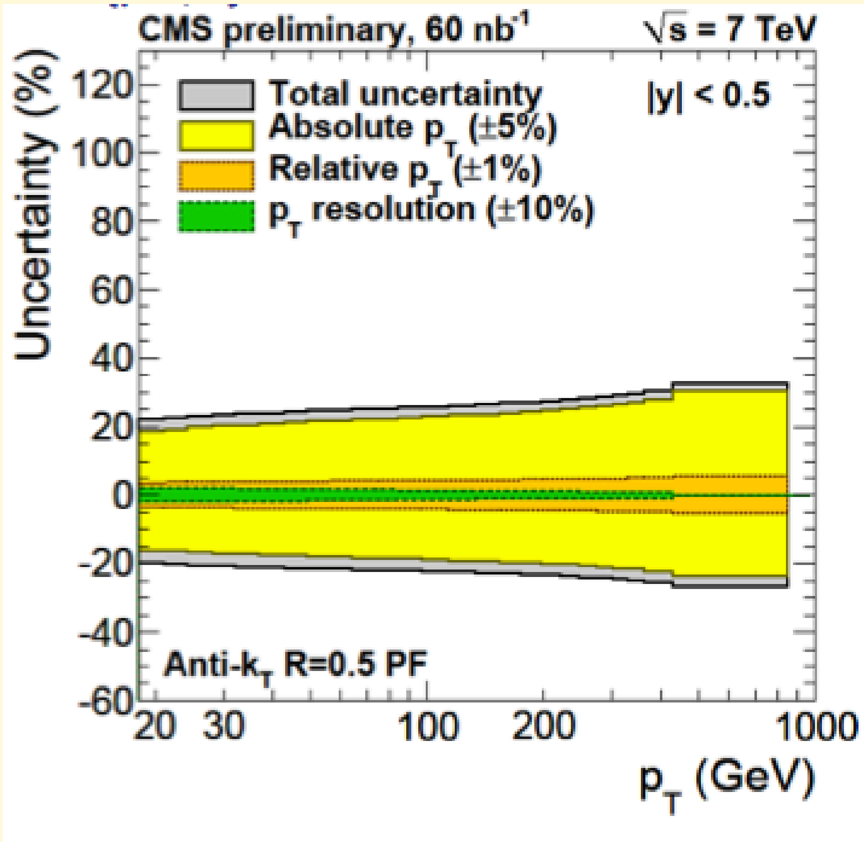
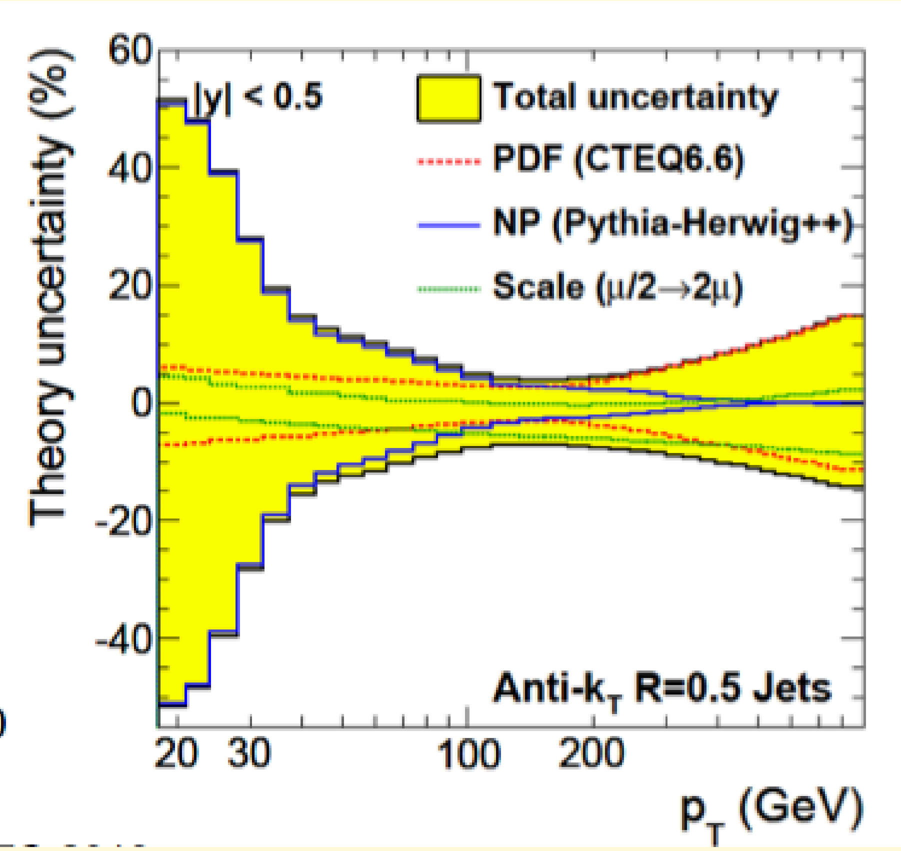
How powerful will be the jet data at large η in reducing this systematics?







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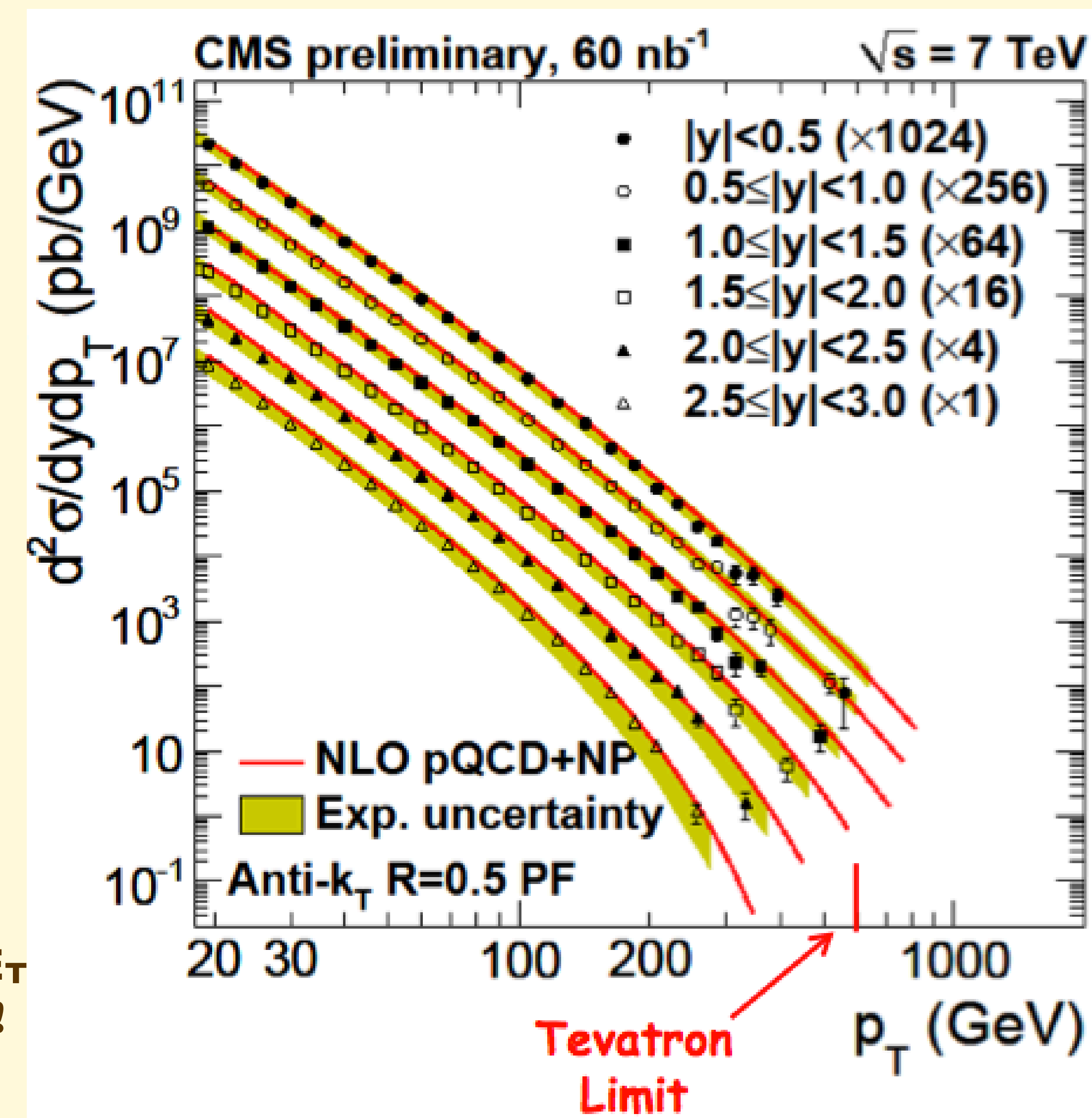
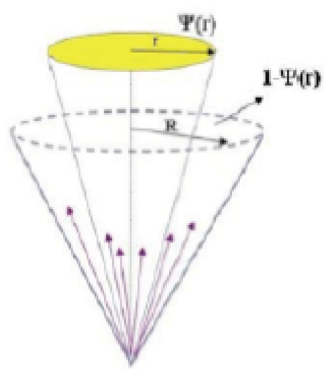


Notice reach in E_T down to 20 GeV!!

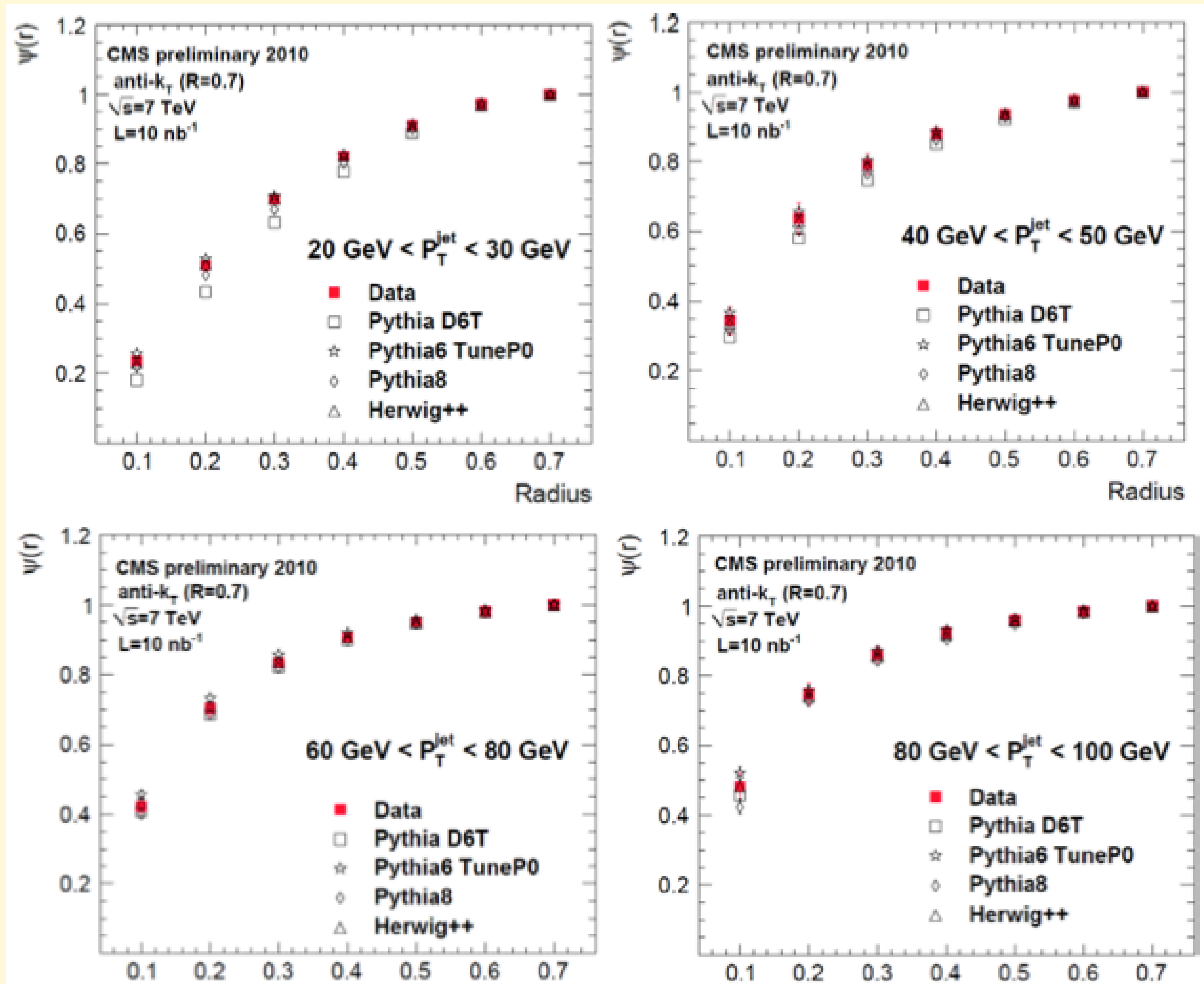
Integrated jet shape

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



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

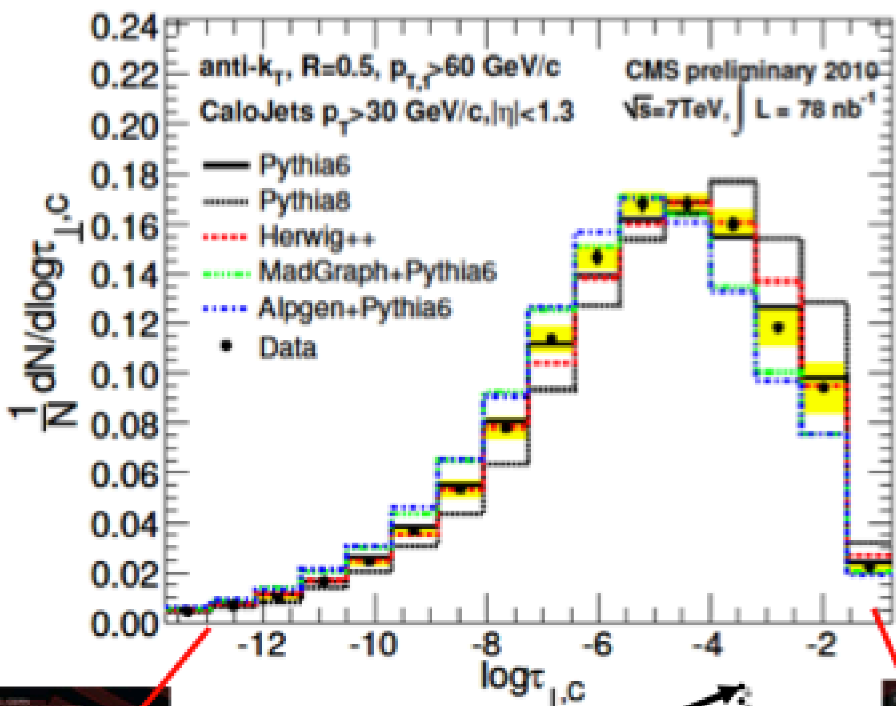


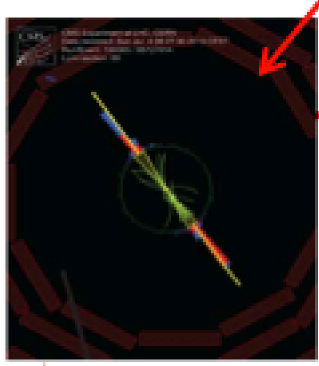
78 nb^{-1} CMS PAS QCD-10-014

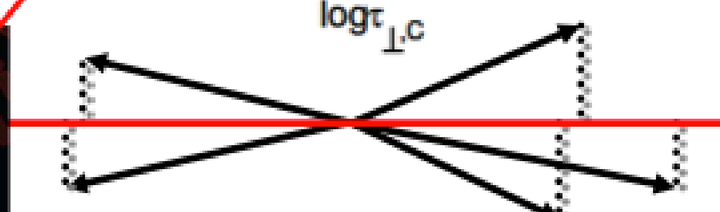
Event Shapes

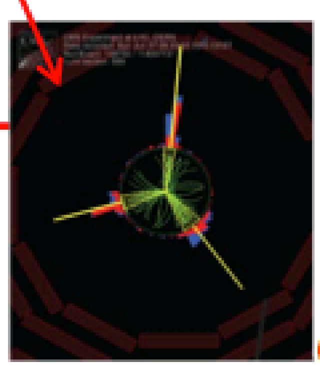
QCD High PT

- Event shapes provide geometric information about energy flow in hadronic events
- Useful for tuning of MC models for non-perturbative effects
- Robust against experimental uncertainties



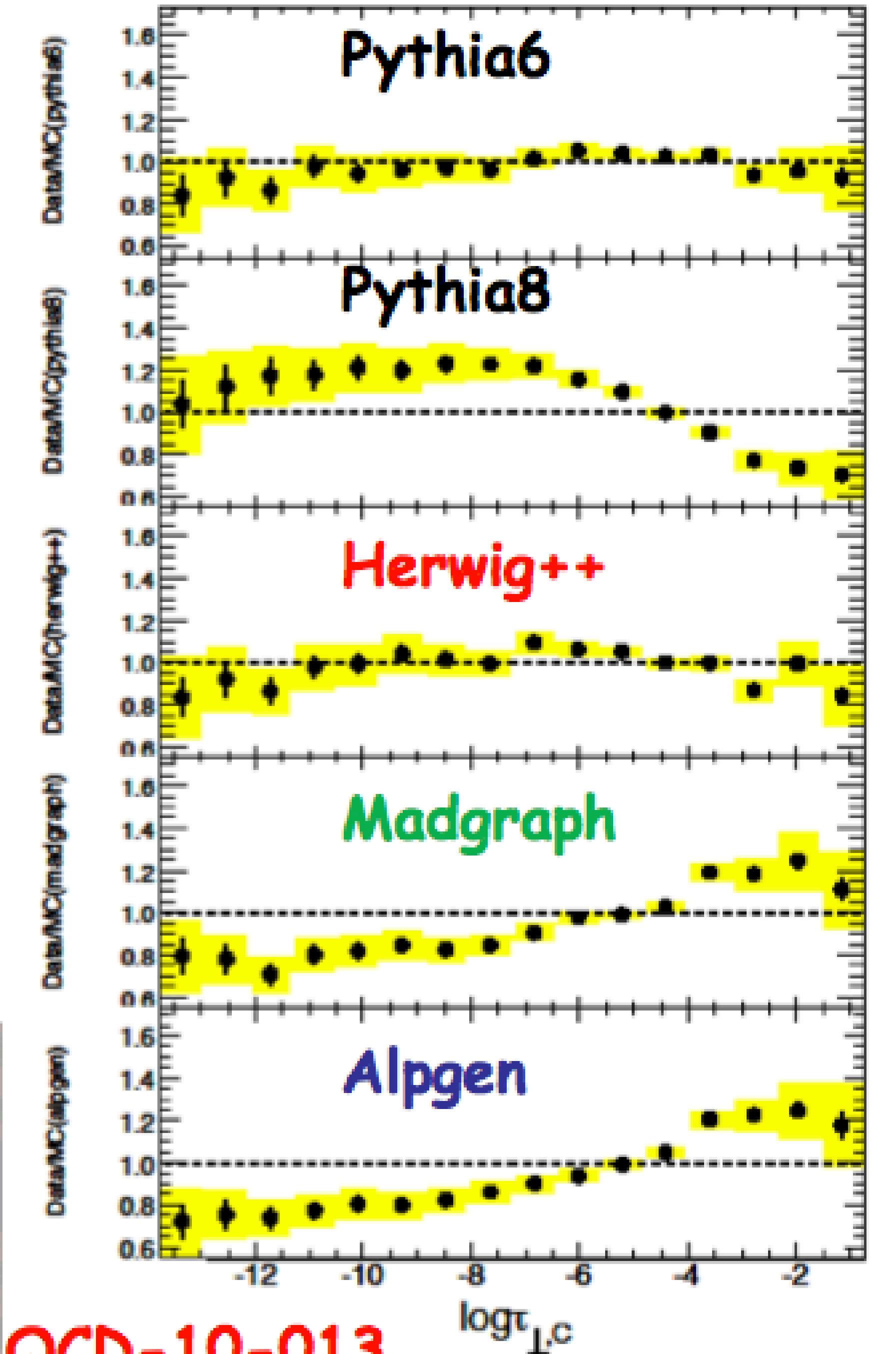






$$T_{\perp,C} \equiv \max_{\vec{n}_T} \frac{\sum_{i\in\mathcal{C}} |\vec{p}_{\perp,i} \cdot \vec{n}_T|}{\sum_{i\in\mathcal{C}} p_{\perp,i}}$$

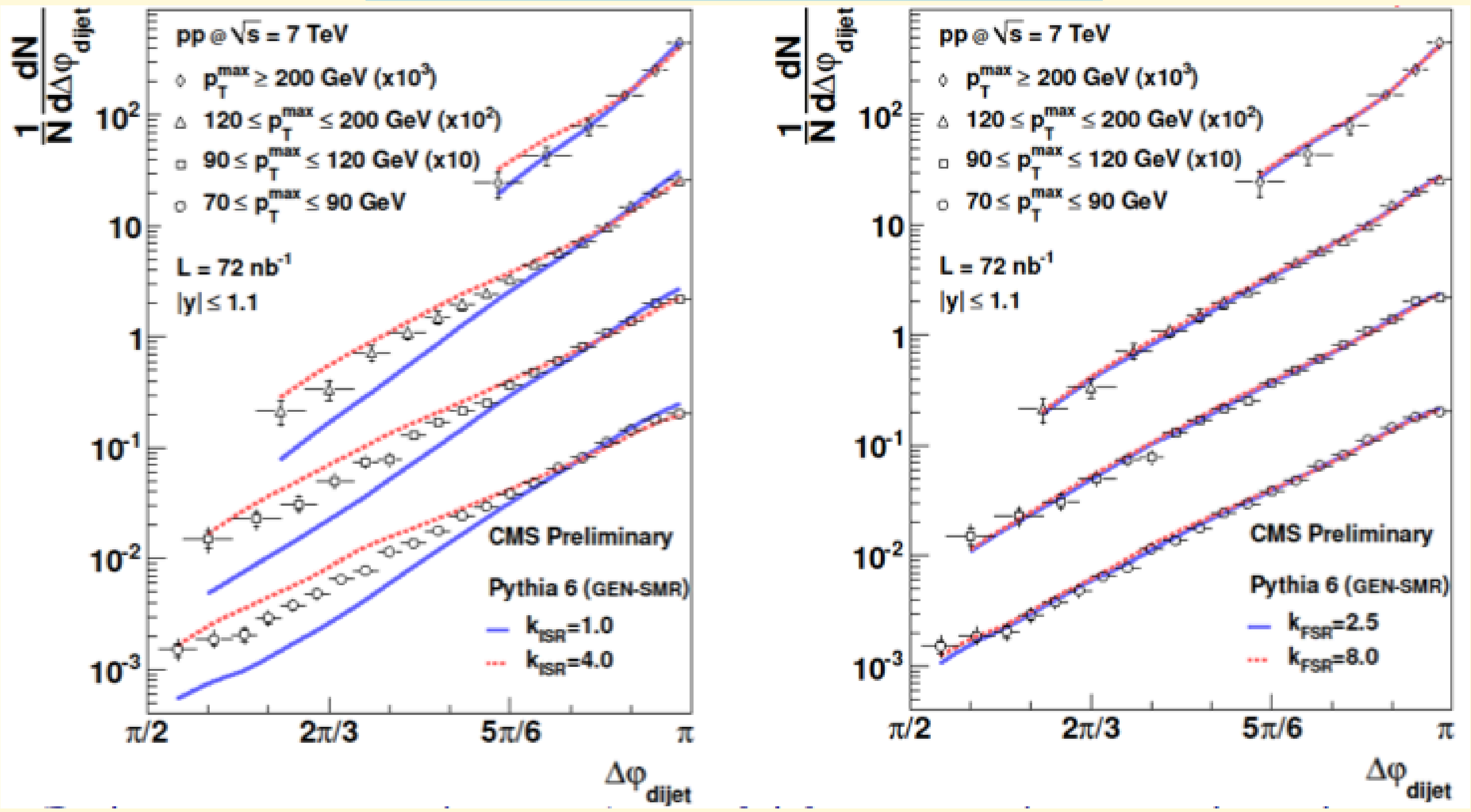
Central transverse thrust



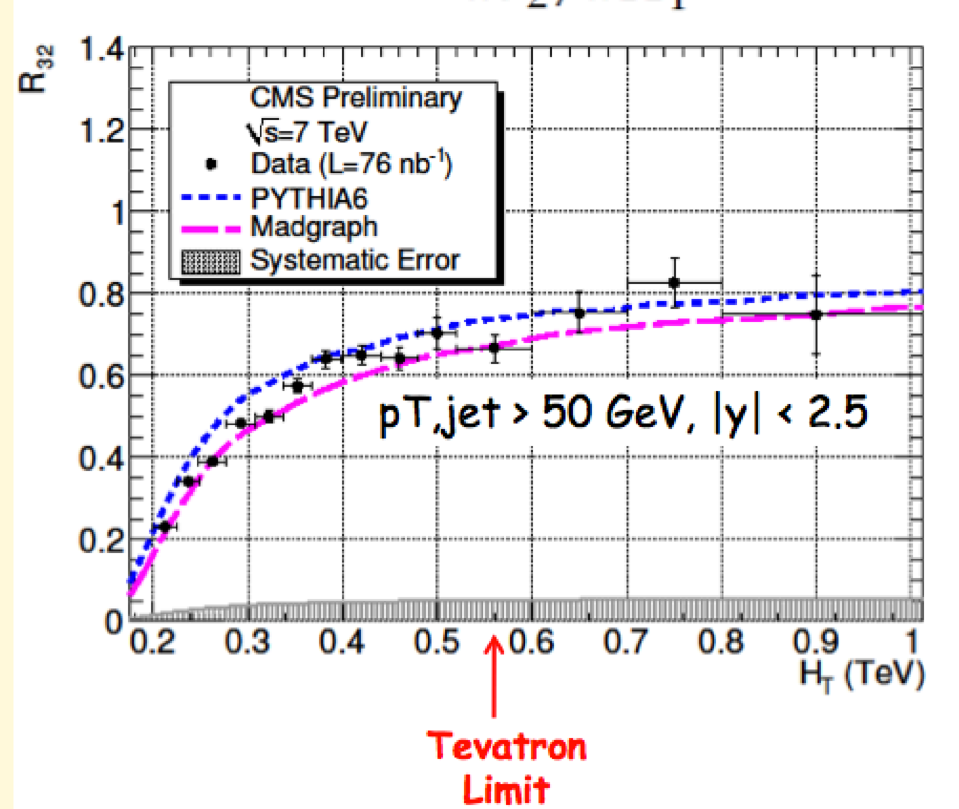
QCD-10-013

Other global properties of jet final states

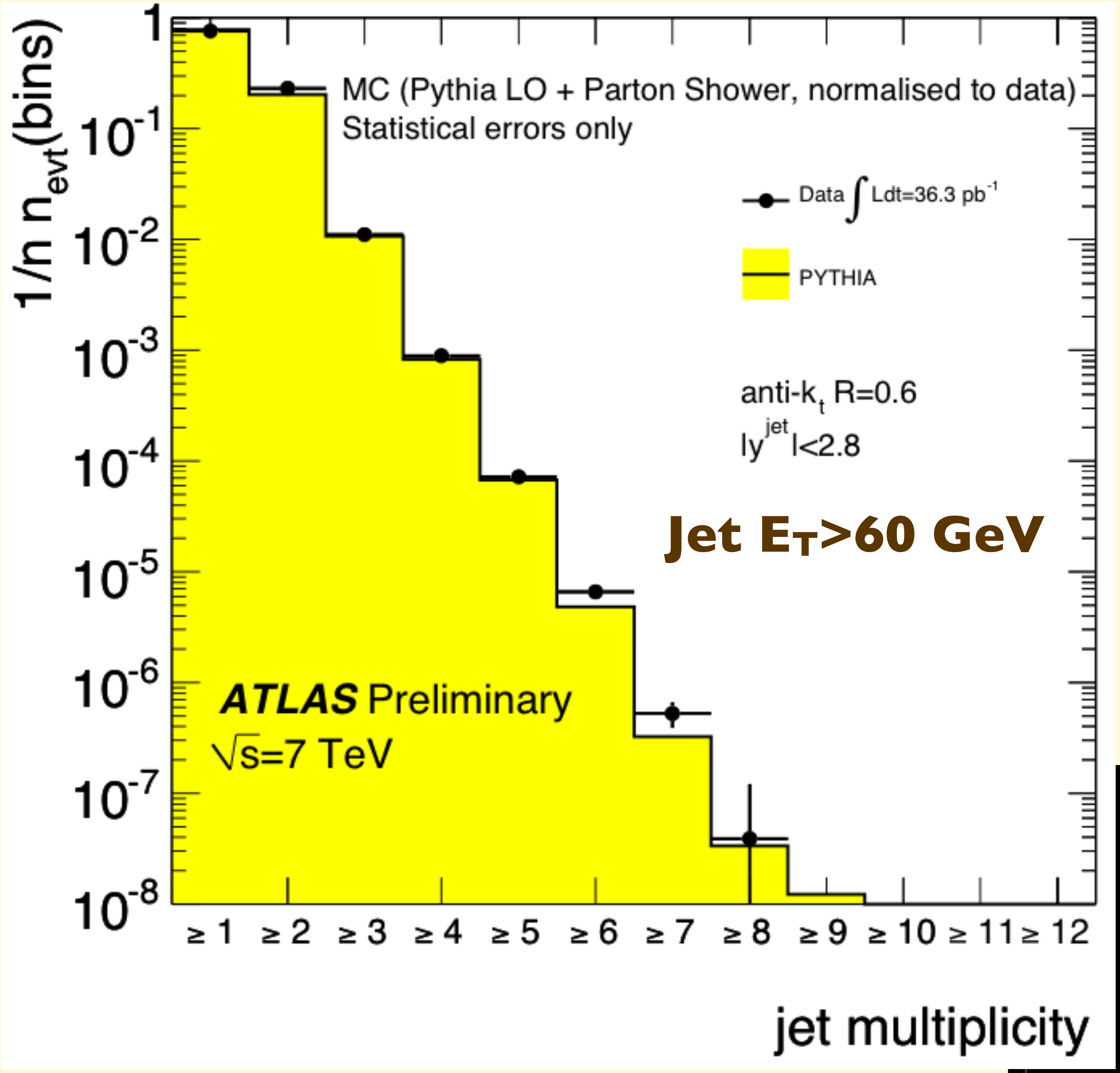
Dijet Angular Decorrelation

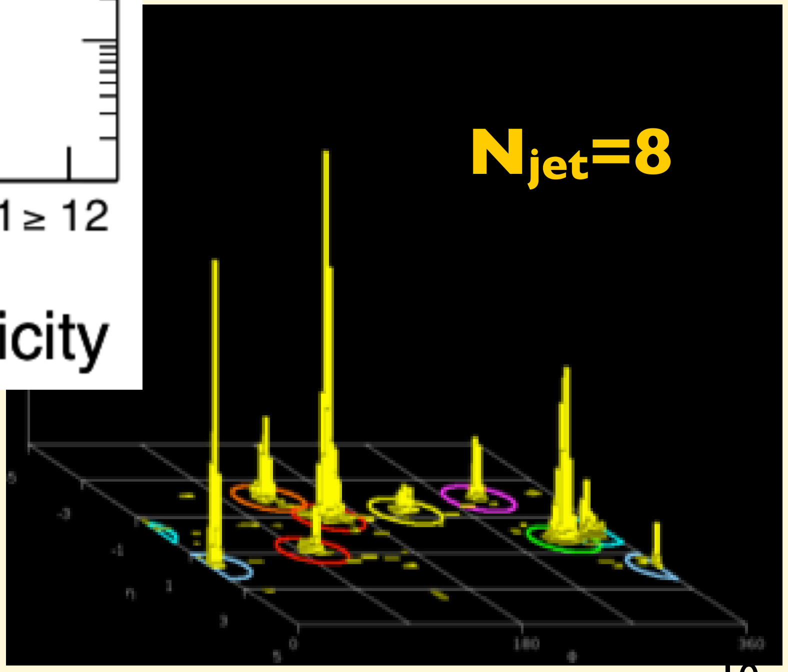


$$R_{32} = \frac{d\sigma_3/dH_T}{d\sigma_2/dH_T}$$



Multijets





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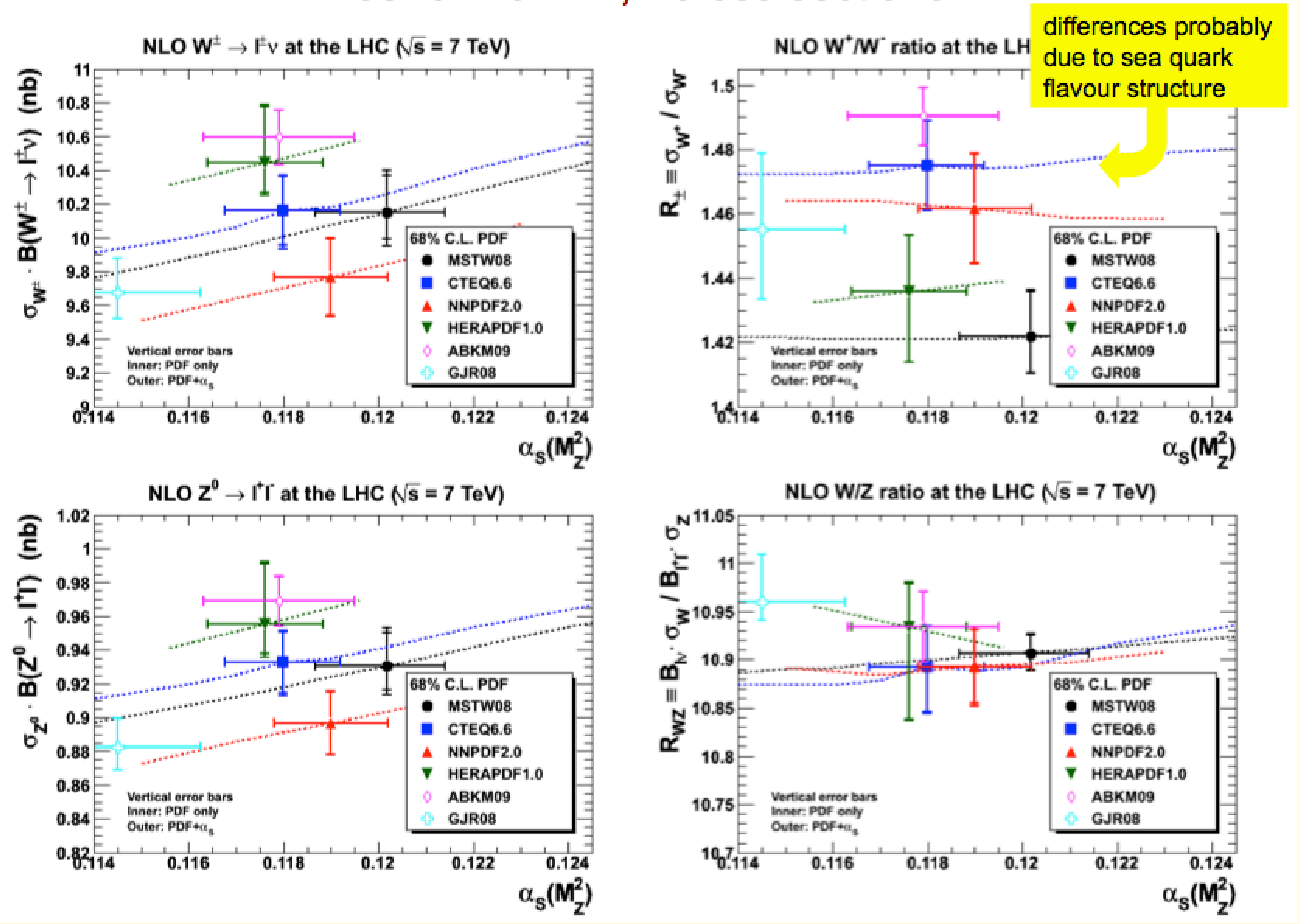
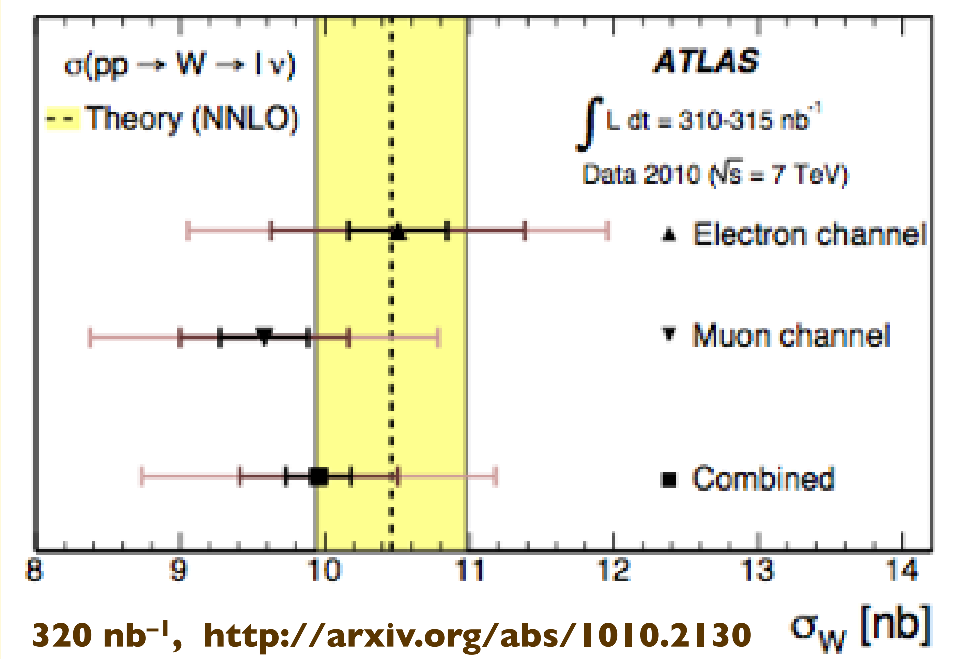
W/Z

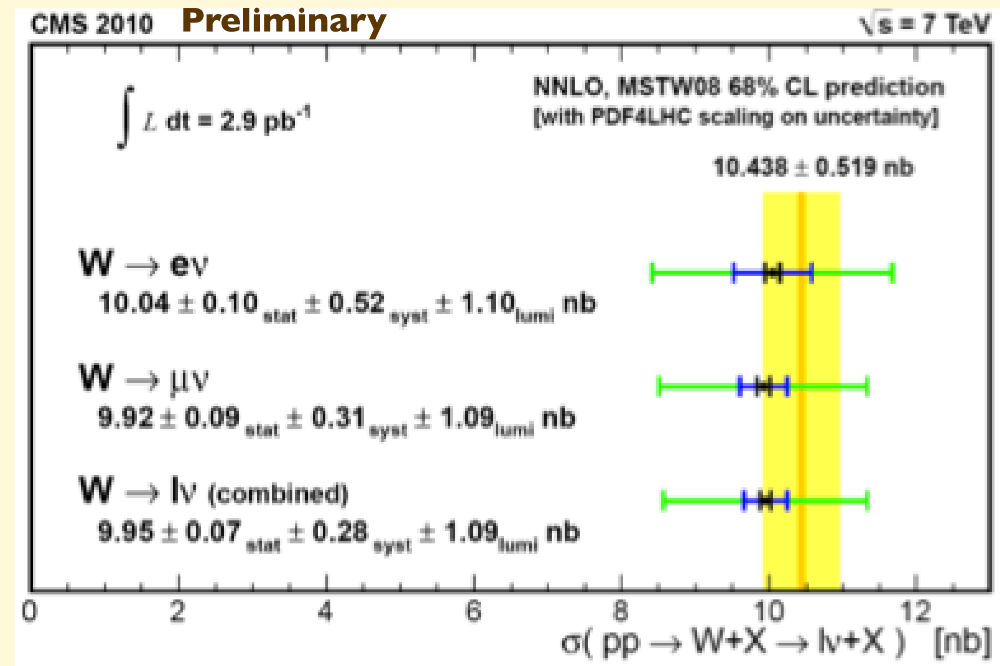
benchmark W,Z cross sections

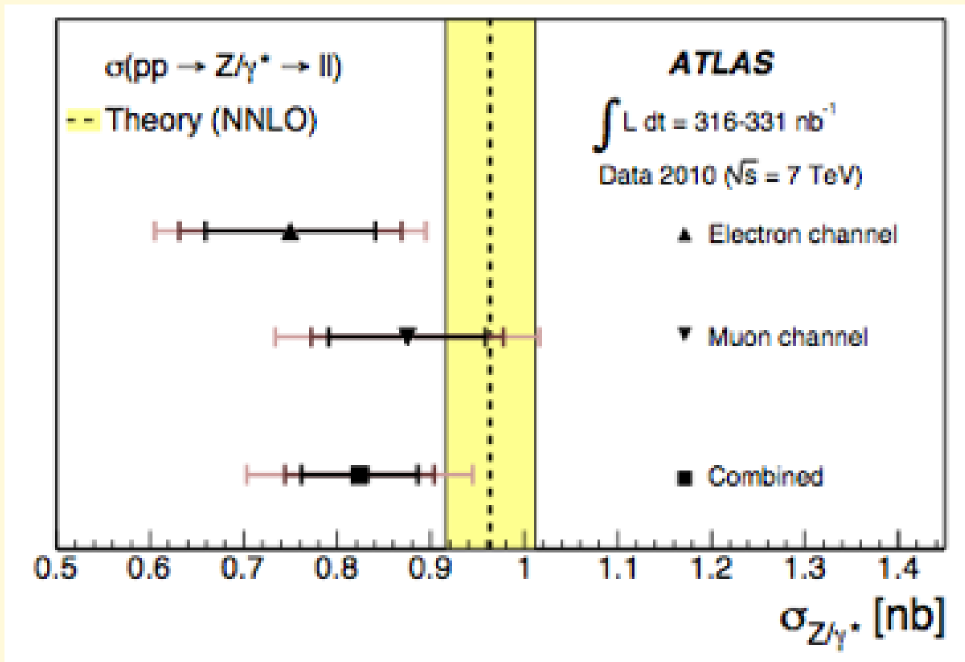


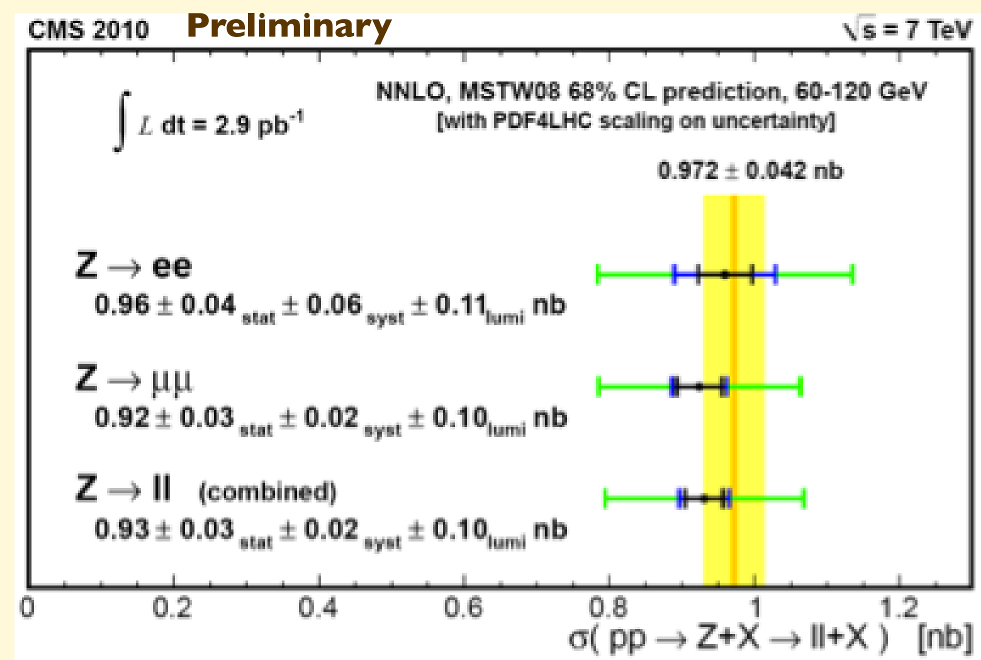
From W.J. Stirling talk at Trento Workshop “LHC at the LHC”

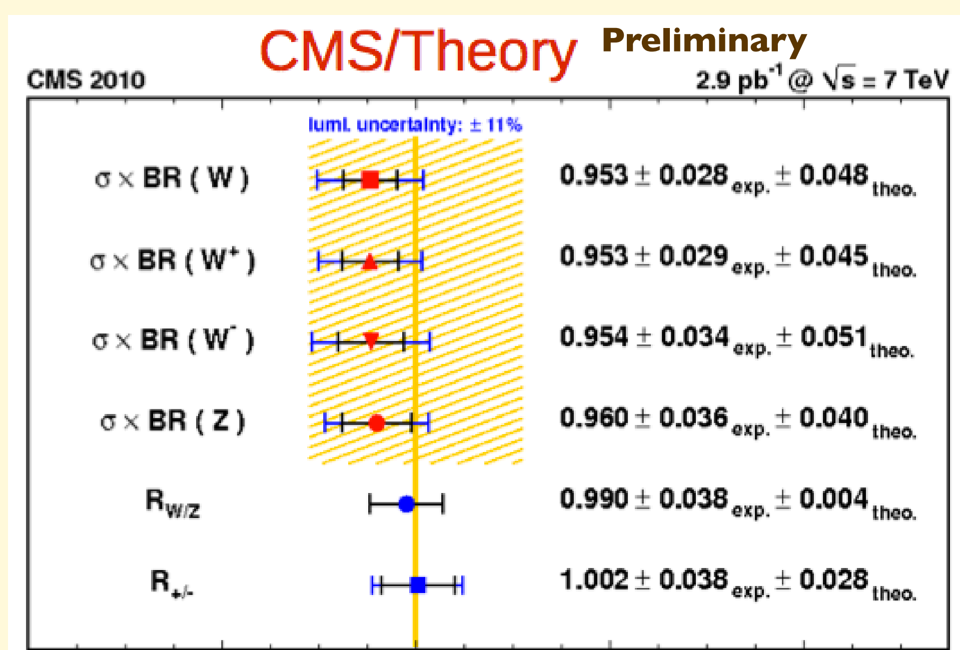


320 nb⁻¹, http://arxiv.org/abs/1010.2130

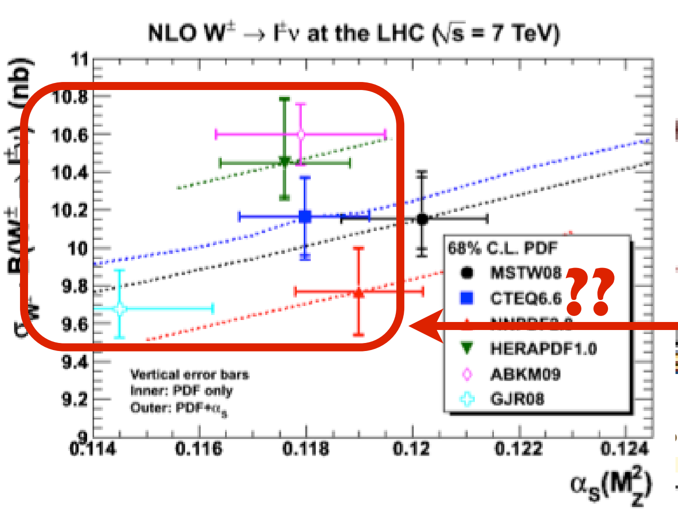


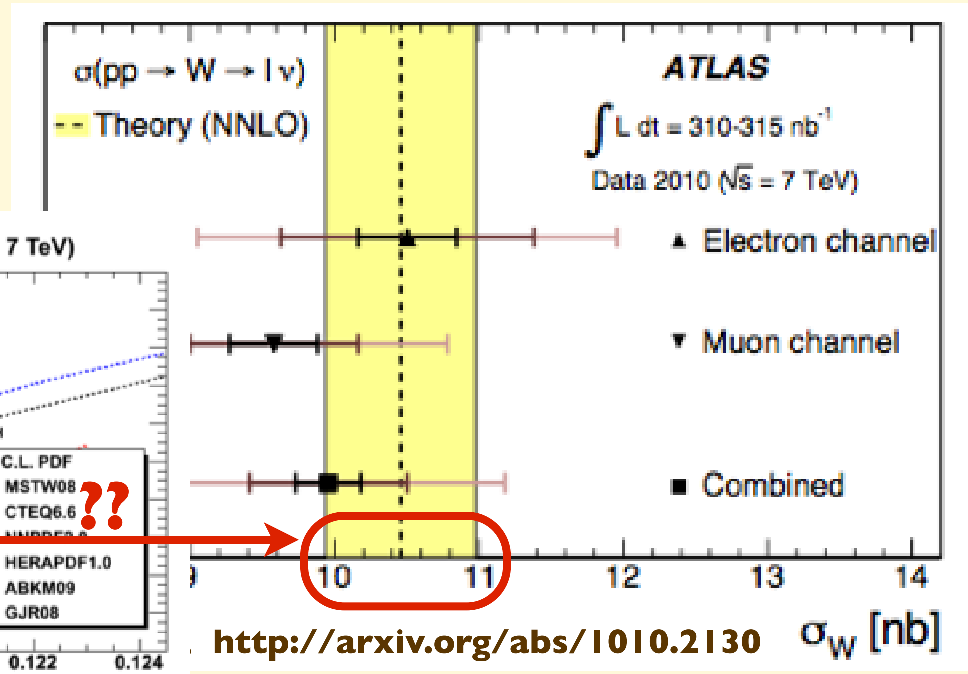






See S.Stoynev for the CMS collab., CTEQ Workshop Nov 19-20 2010





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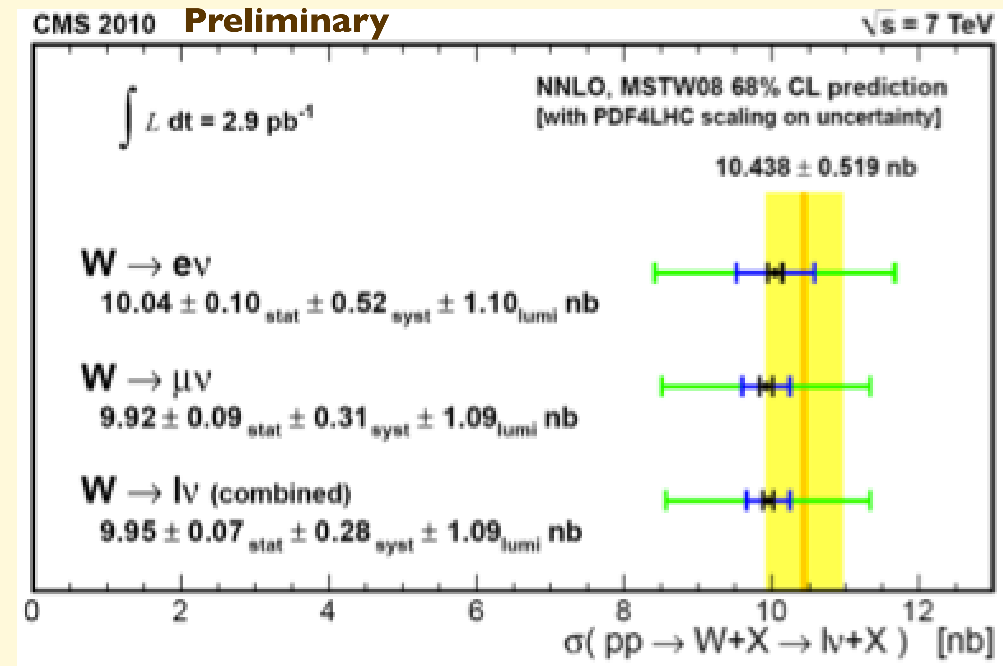

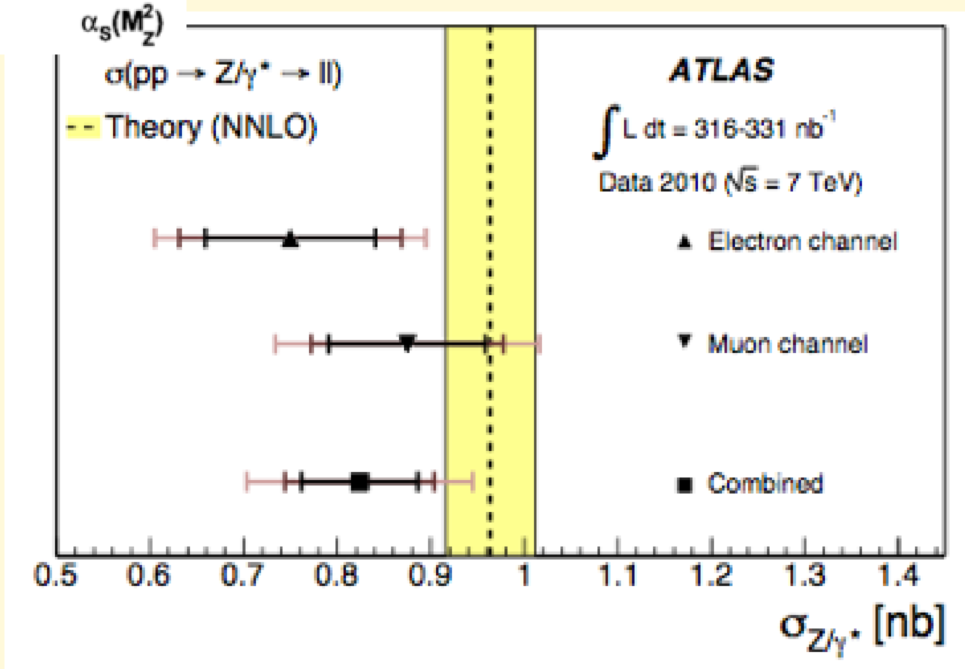

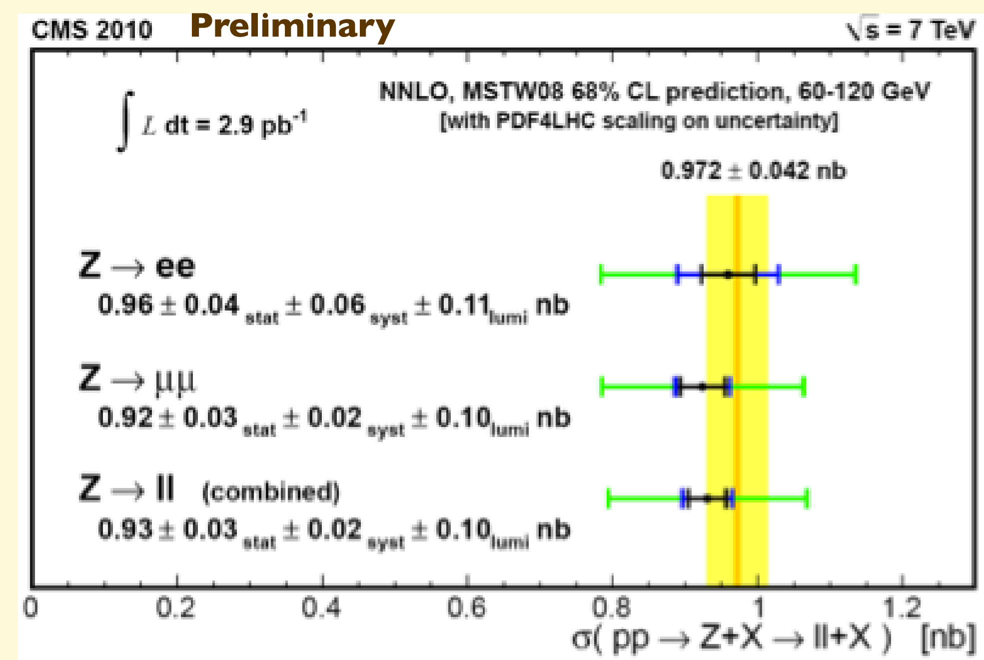

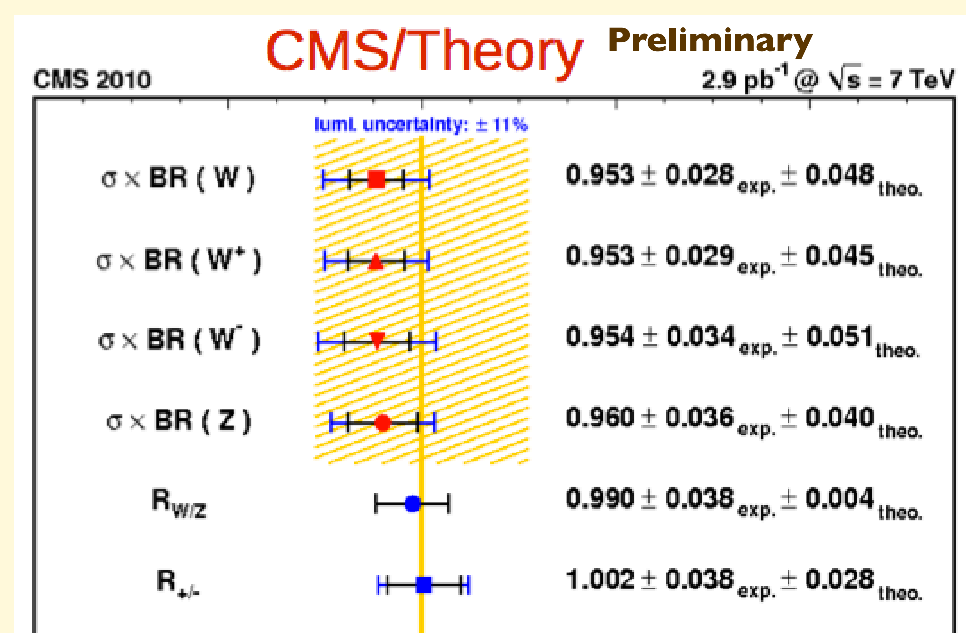

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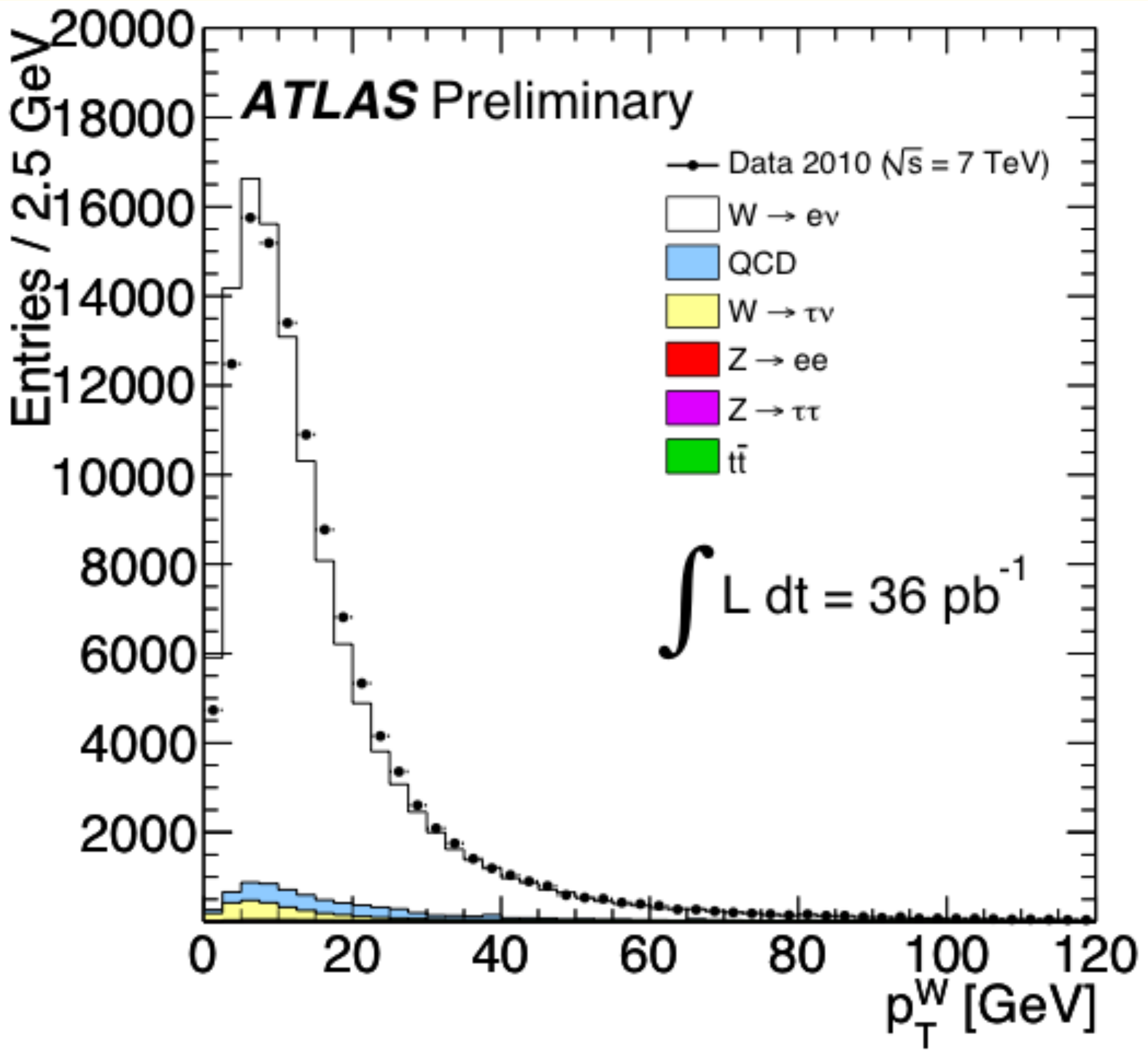
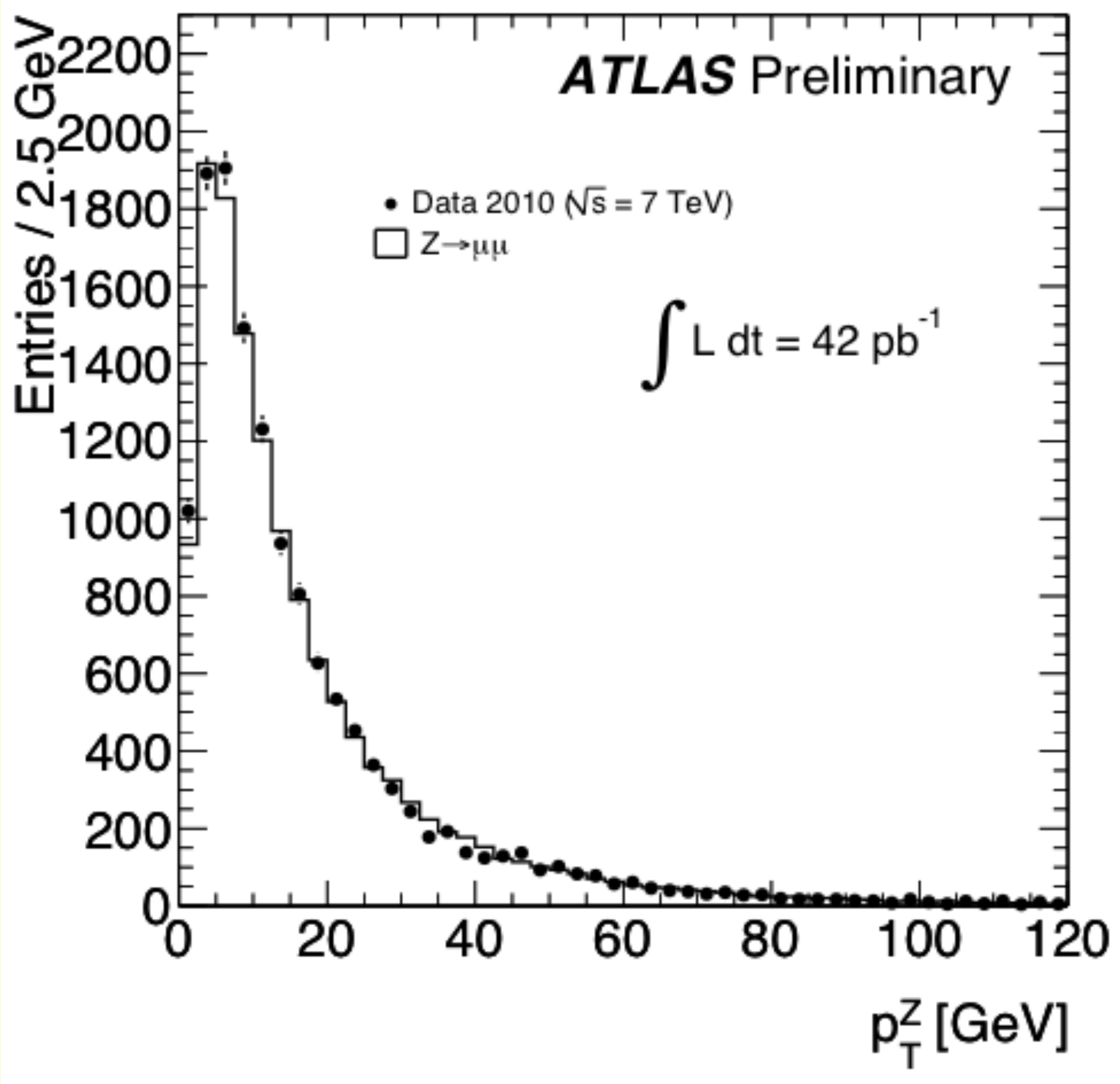
W/Z pt spectra





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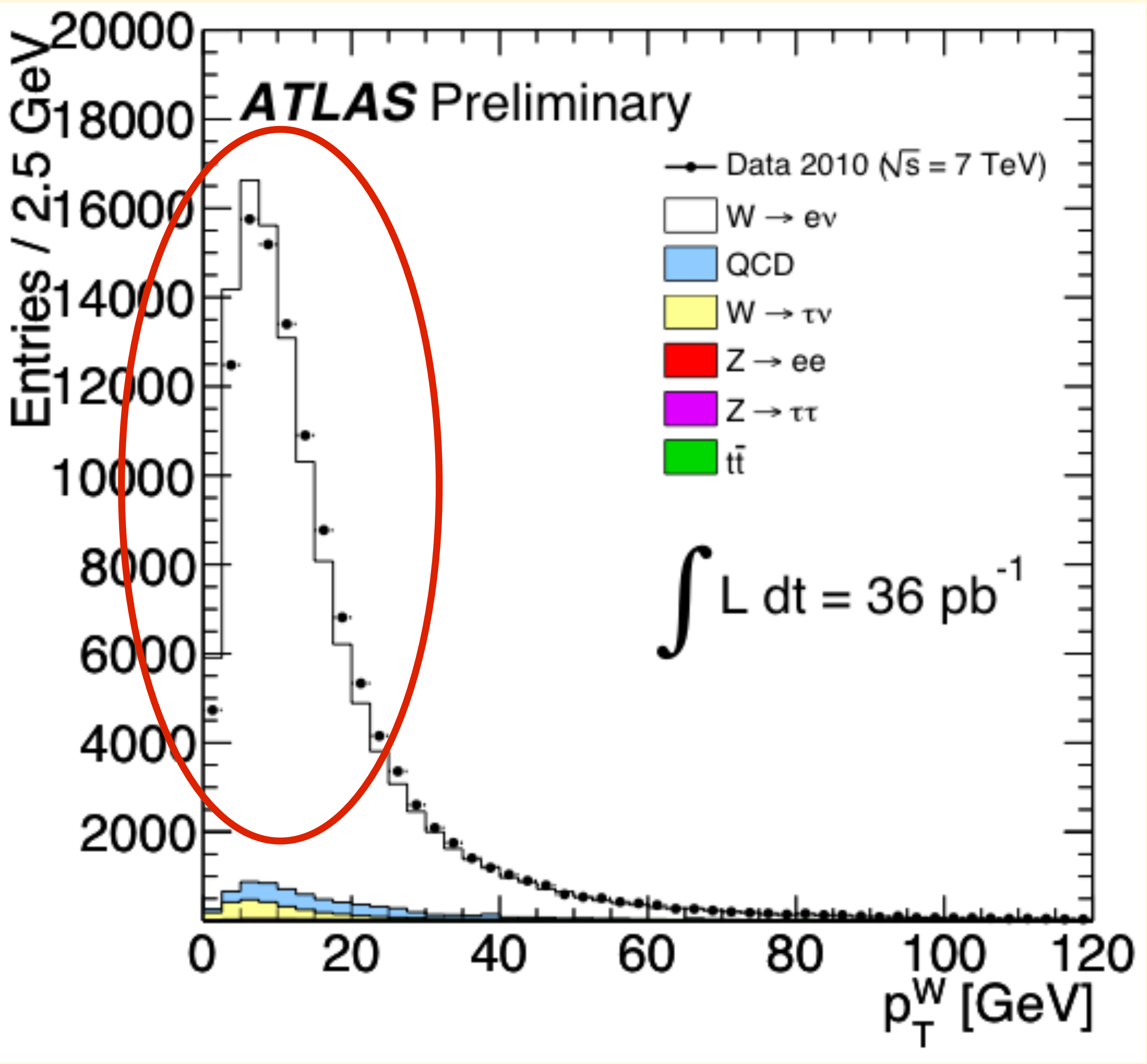
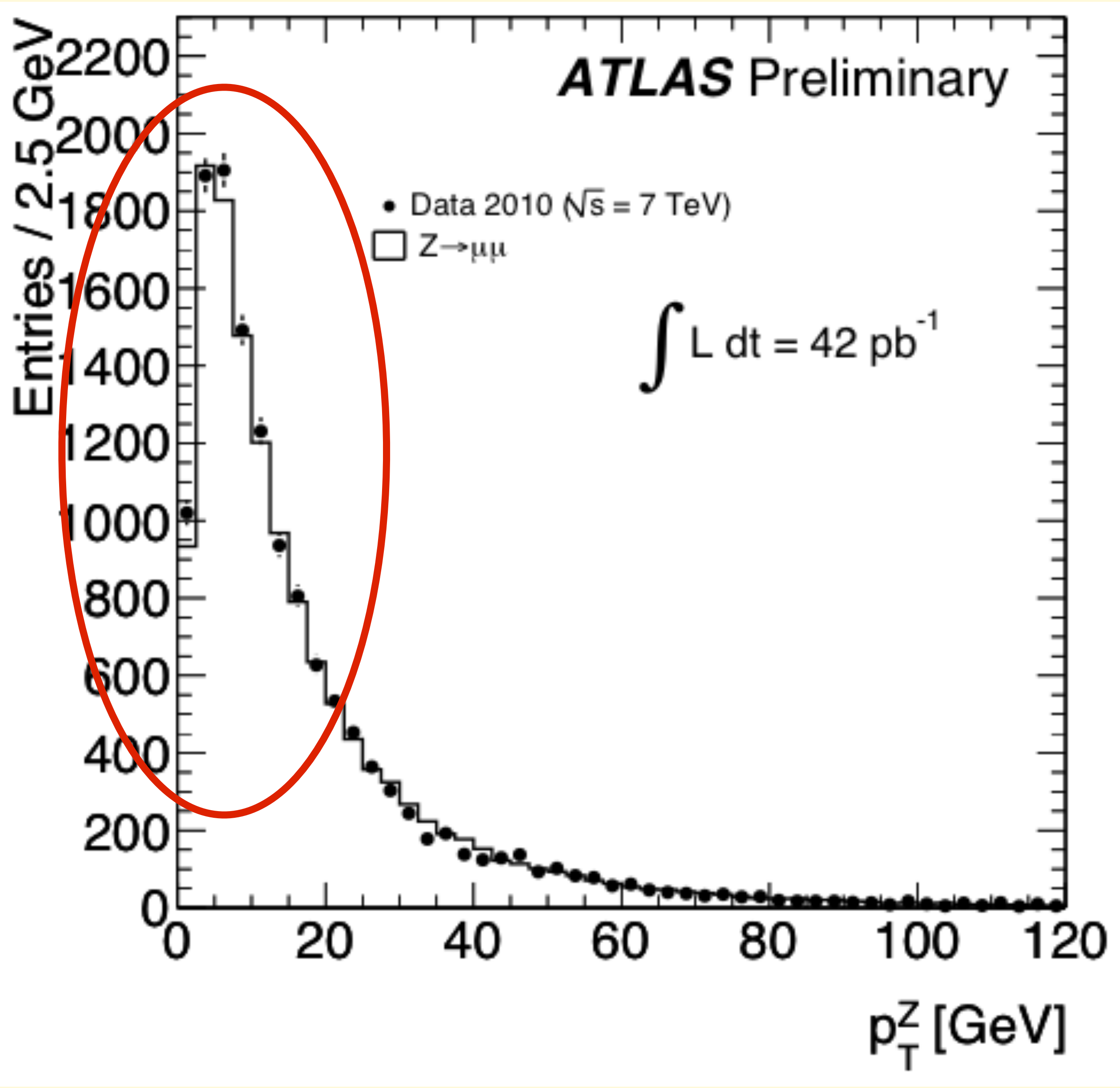
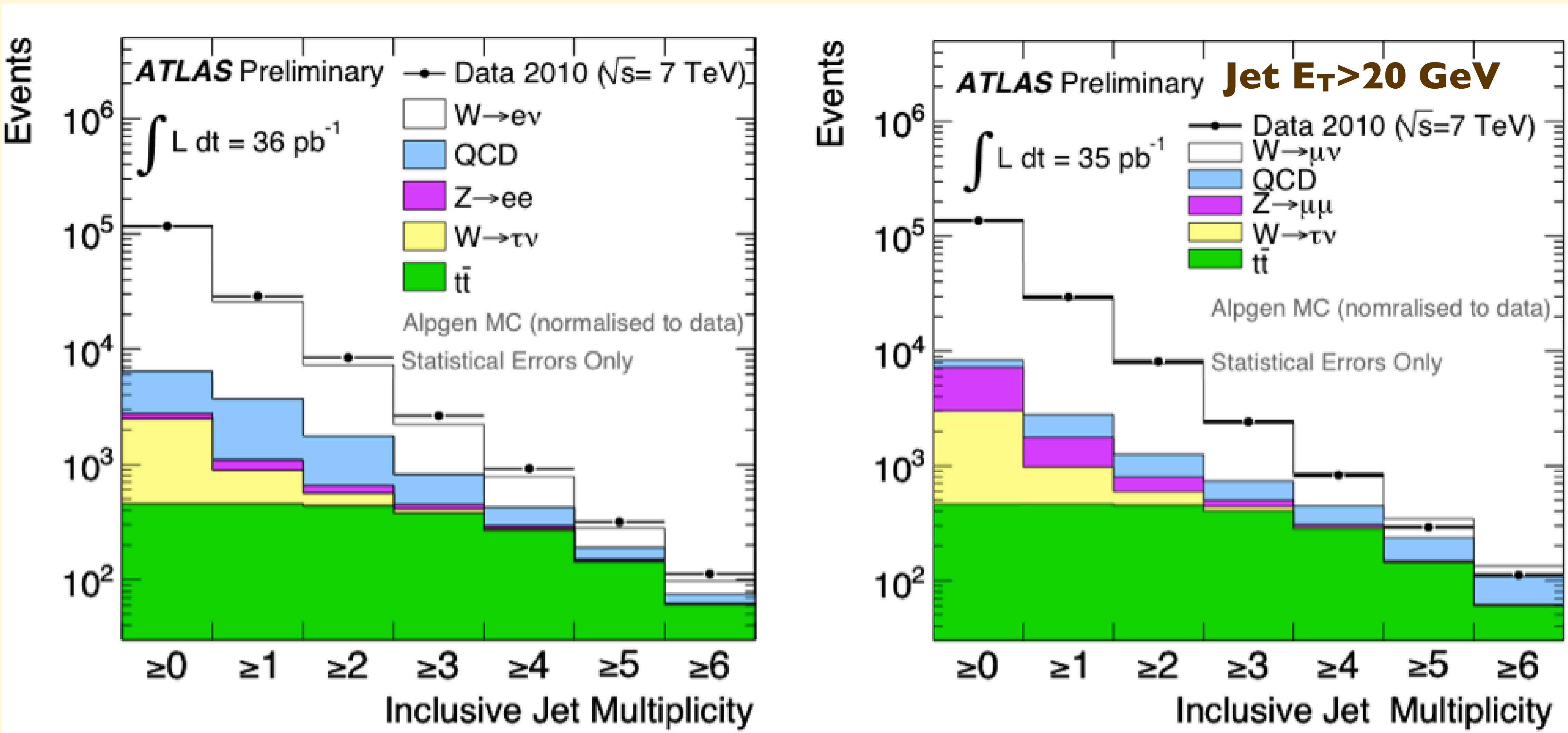




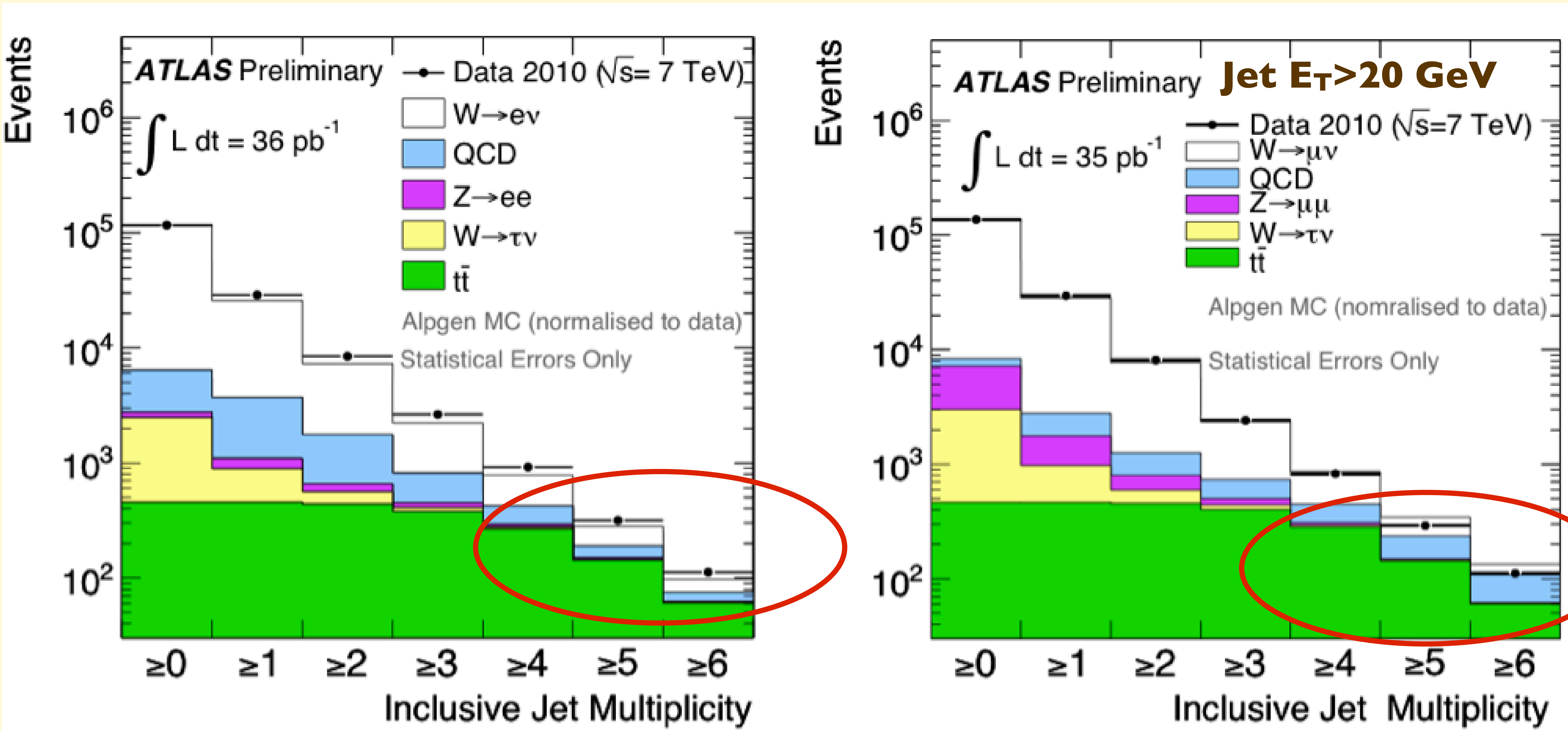
From the perspective of QCD, the modeling of W and Z pt is the same. So the different levels of agreement between data and theory in these two plots suggest that some more tuning of the detector description is required before moving on to quantitative tuning of QCD MCs.

W+jets



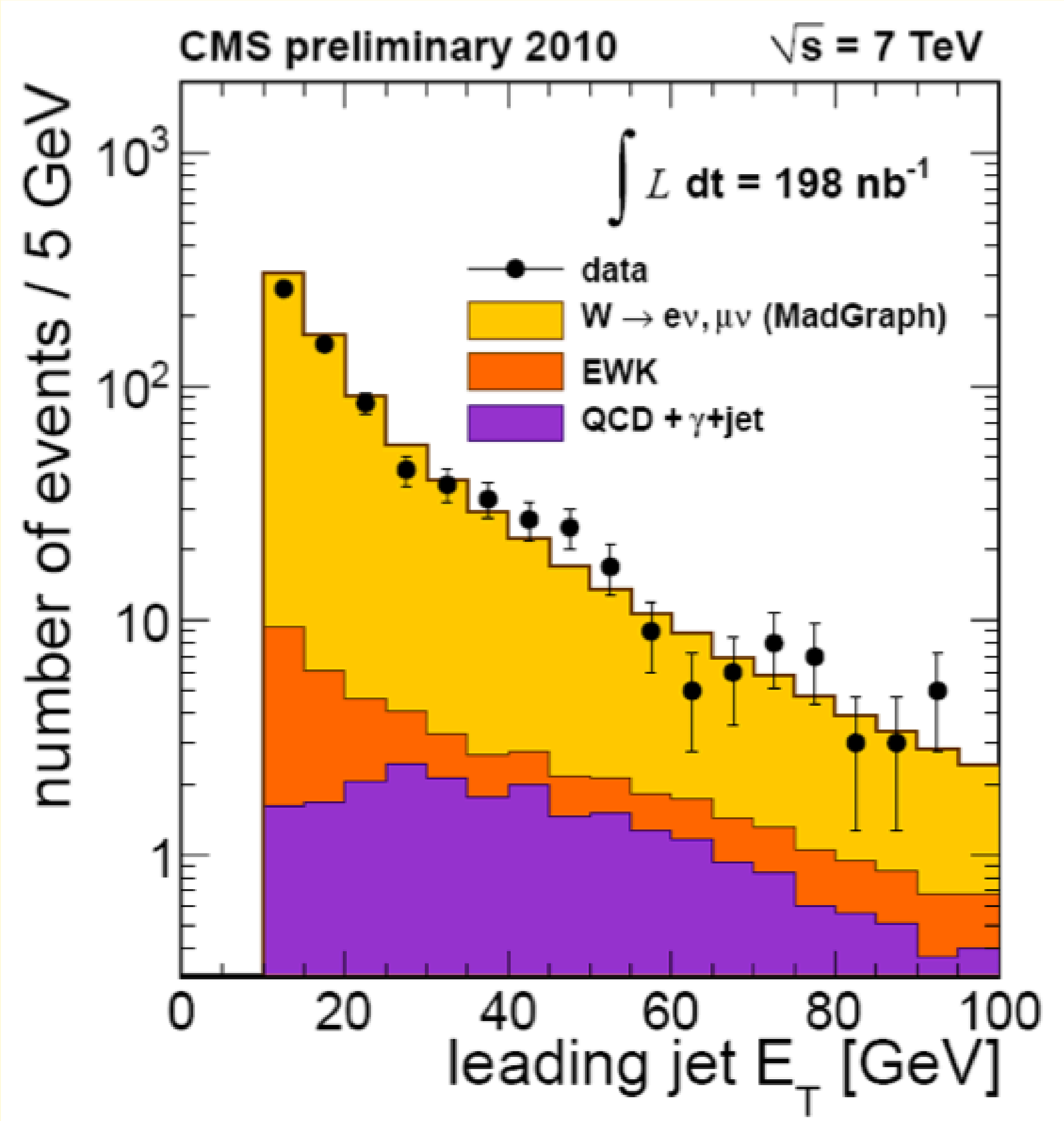
Events
ATLAS Preliminary
Data 2010 (√s= 7 TeV)
∫L dt = 36 pb-1
W→eν
QCD
Z→ee
W→τν
tt̄
Alpgen MC (normalised to data)
Statistical Errors Only
≥0 ≥1 ≥2 ≥3 ≥4 ≥5 ≥6
Inclusive Jet Multiplicity
Events
ATLAS Preliminary
Jet ET>20 GeV
Data 2010 (√s=7 TeV)
∫L dt = 35 pb-1
W→μν
QCD
Z→μμ
W→τν
tt̄
Alpgen MC (nomralised to data)
Statistical Errors Only
≥0 ≥1 ≥2 ≥3 ≥4 ≥5 ≥6
Inclusive Jet Multiplicity

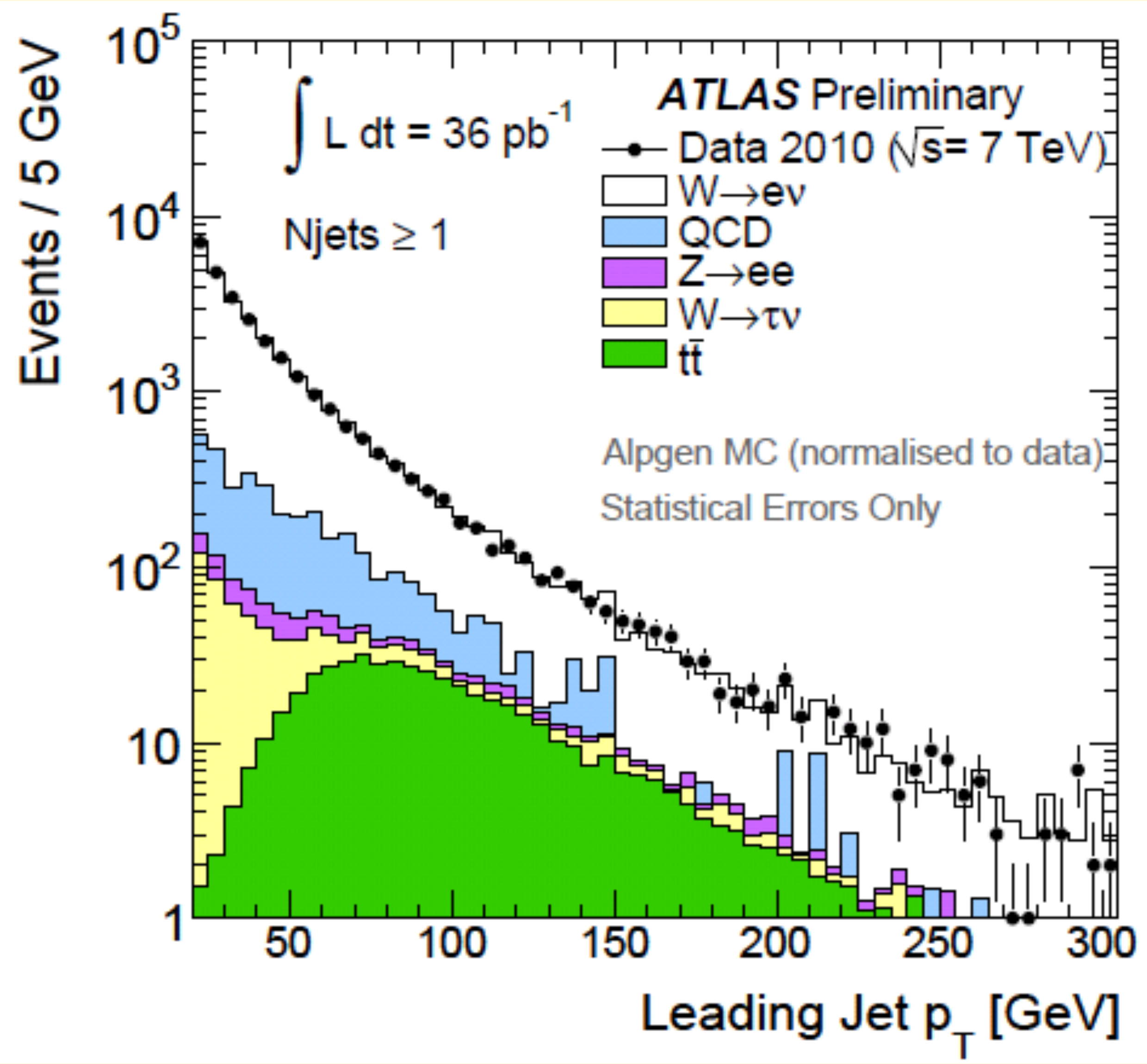
W+jets



Statistics even out in the e and mu channels at large N_{jet}, making the agreement even more remarkable

W+jets, E_T spectrum

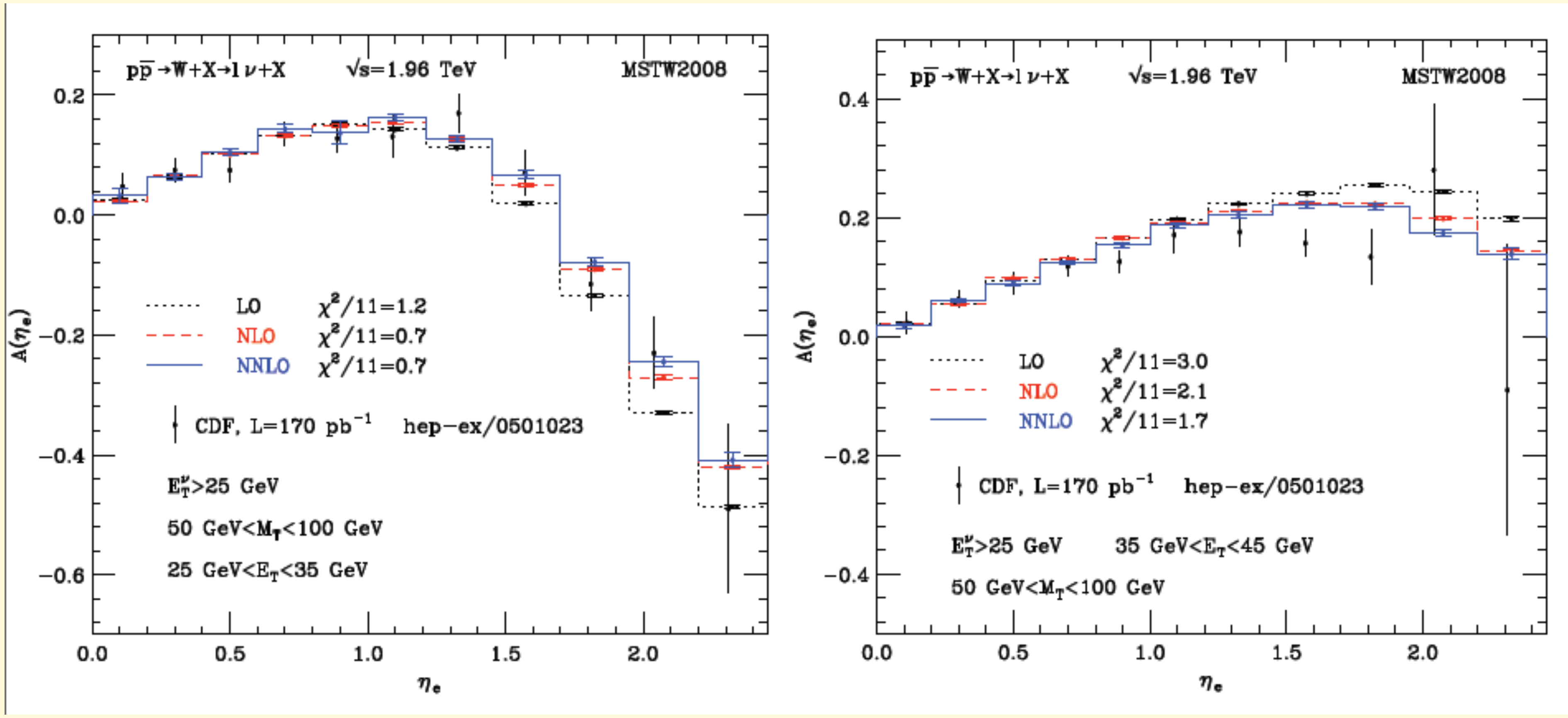


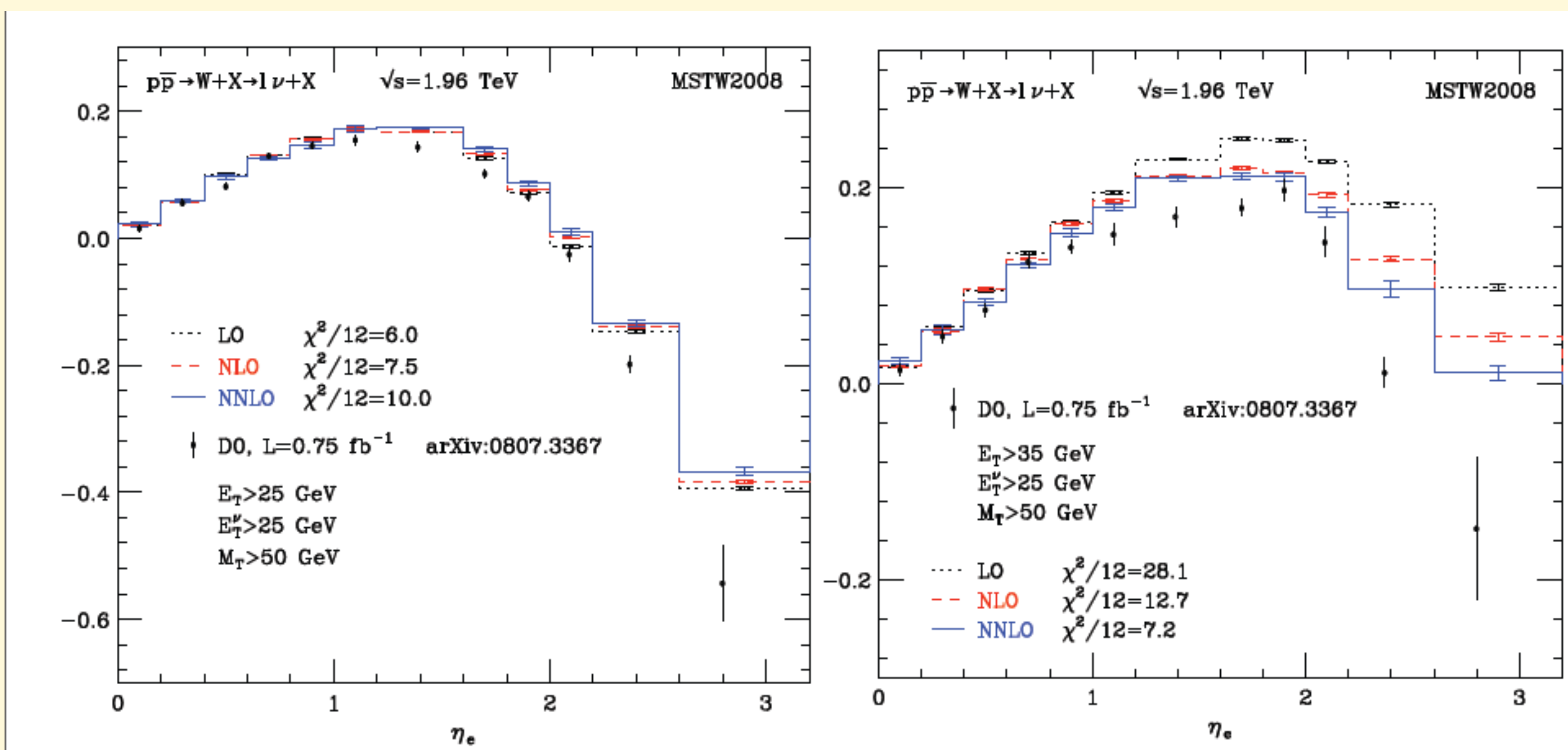


See S.Stoynev for the CMS collab., CTEQ Workshop Nov 19-20 2010

See P-H Beauchemin for the ATLAS collab., CTEQ Workshop Nov 19-20 2010

Lepton rapidity charge-asymmetry in W production at the Tevatron

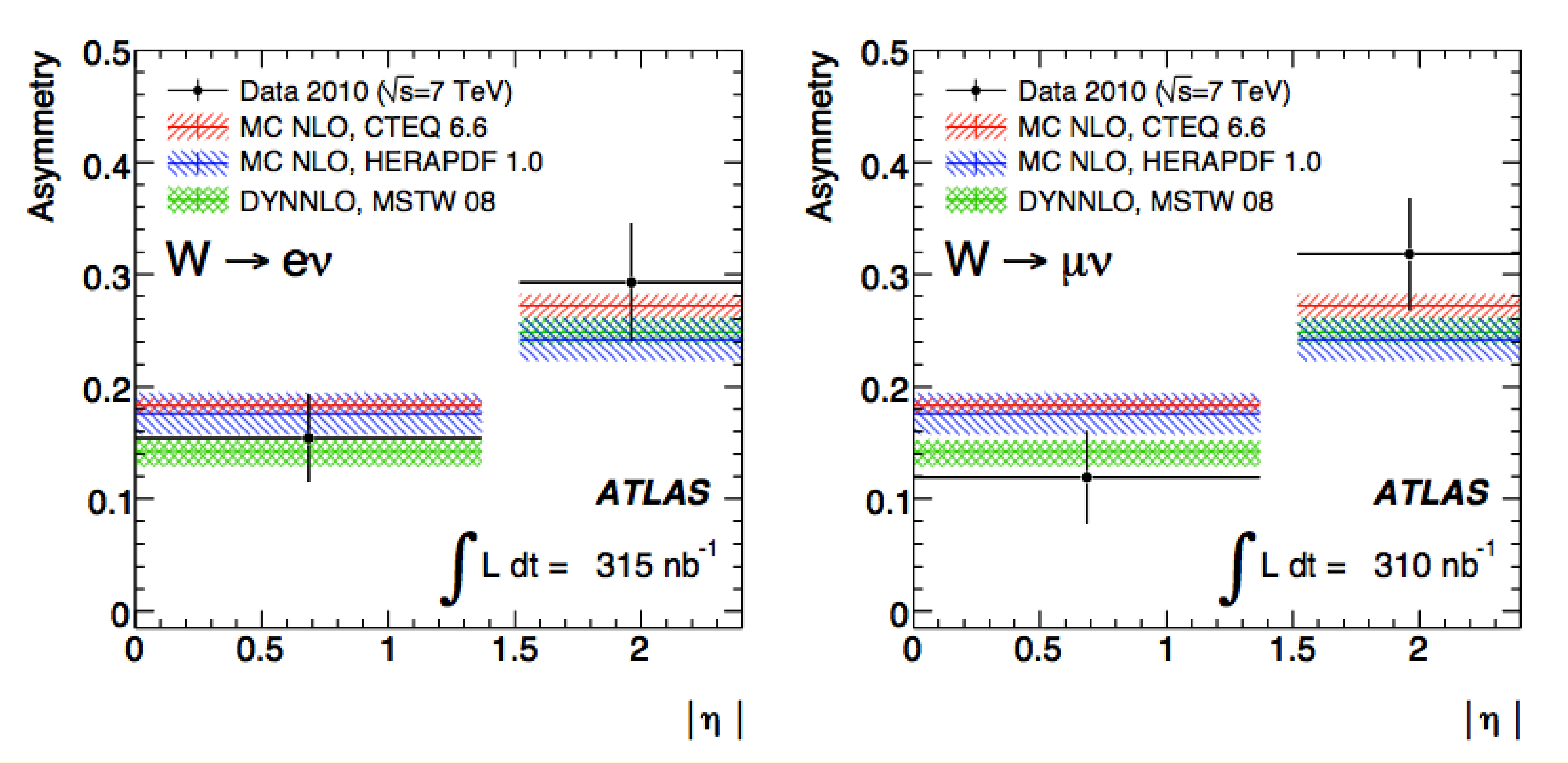




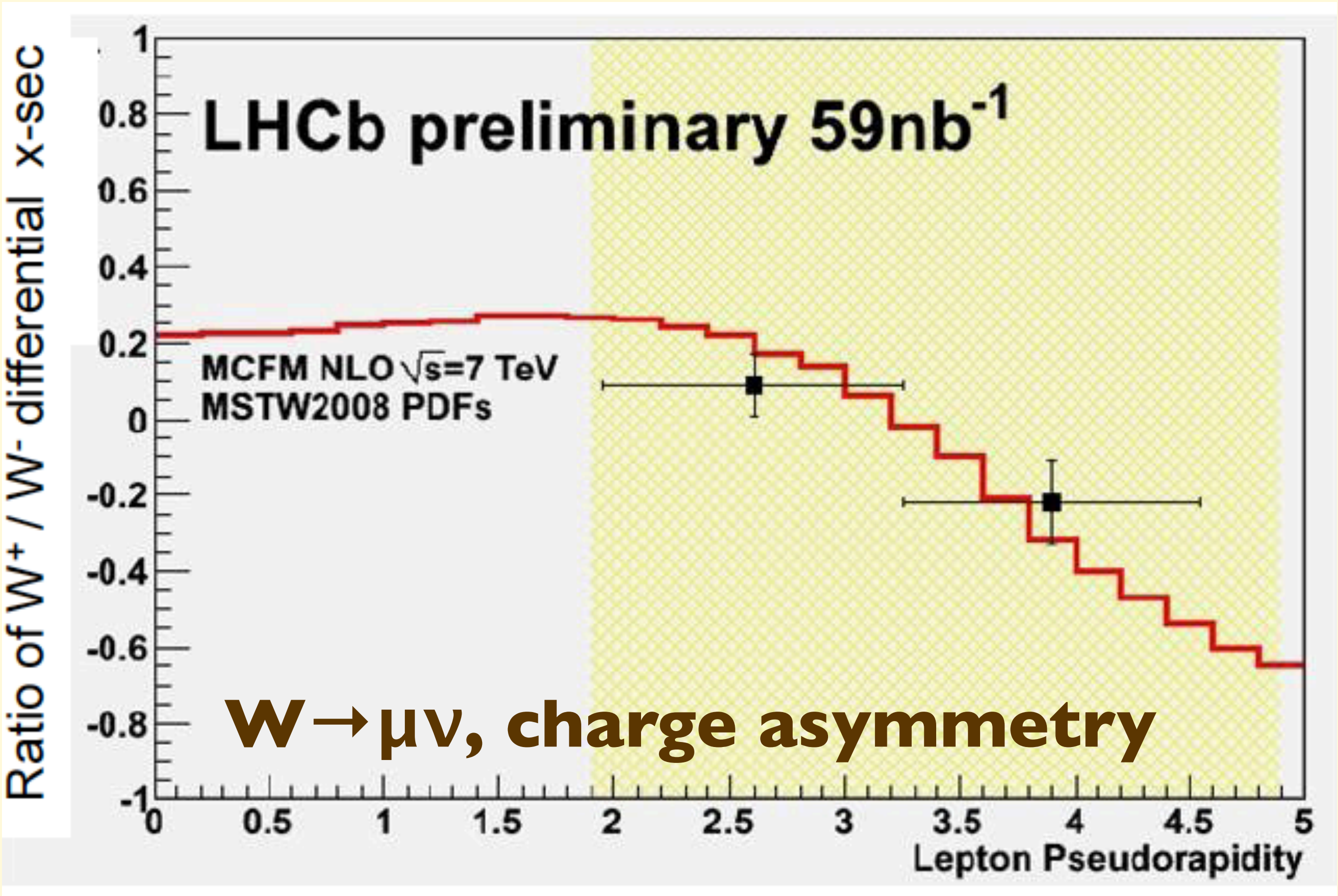
Lepton integrated charge asymmetry at the LHC

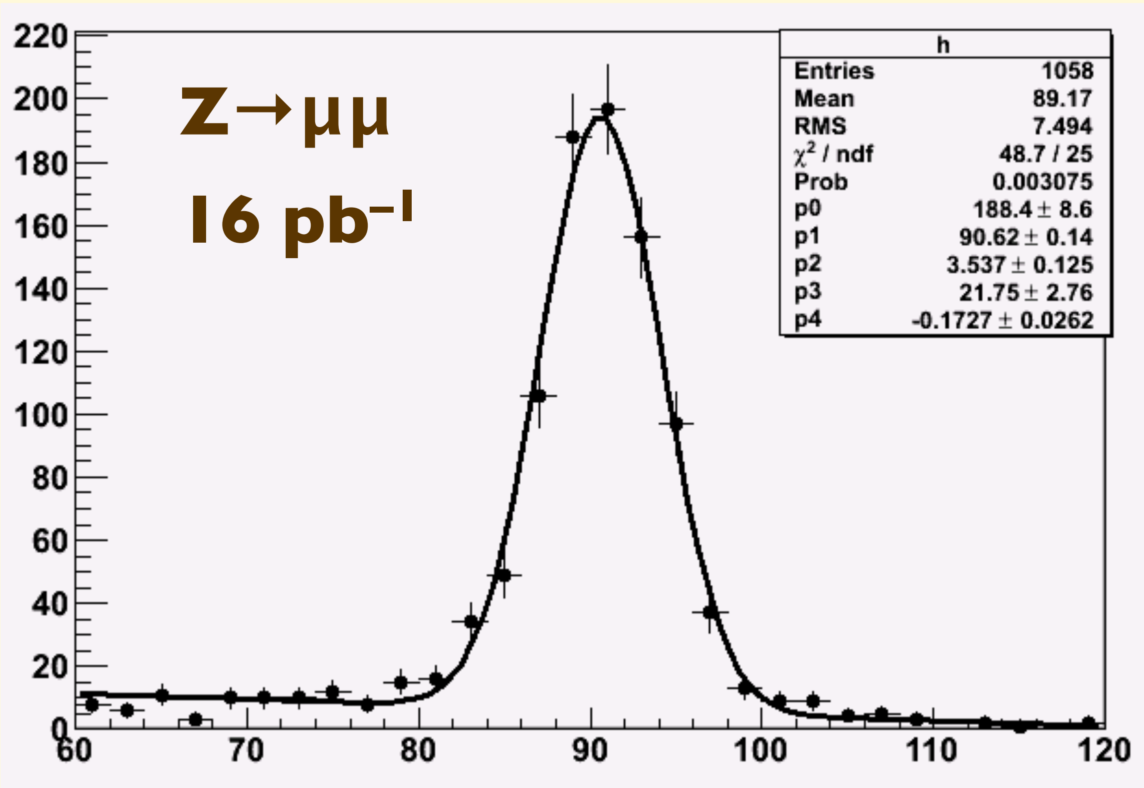
$$A_\ell = \frac{\sigma^{\mathrm{fid}}_{W^+} - \sigma^{\mathrm{fid}}_{W^-}}{\sigma^{\mathrm{fid}}_{W^+} + \sigma^{\mathrm{fid}}_{W^-}}$$

320 nb^{-1}, http://arxiv.org/abs/1010.2130



EW boson production in the forward region, LHCb

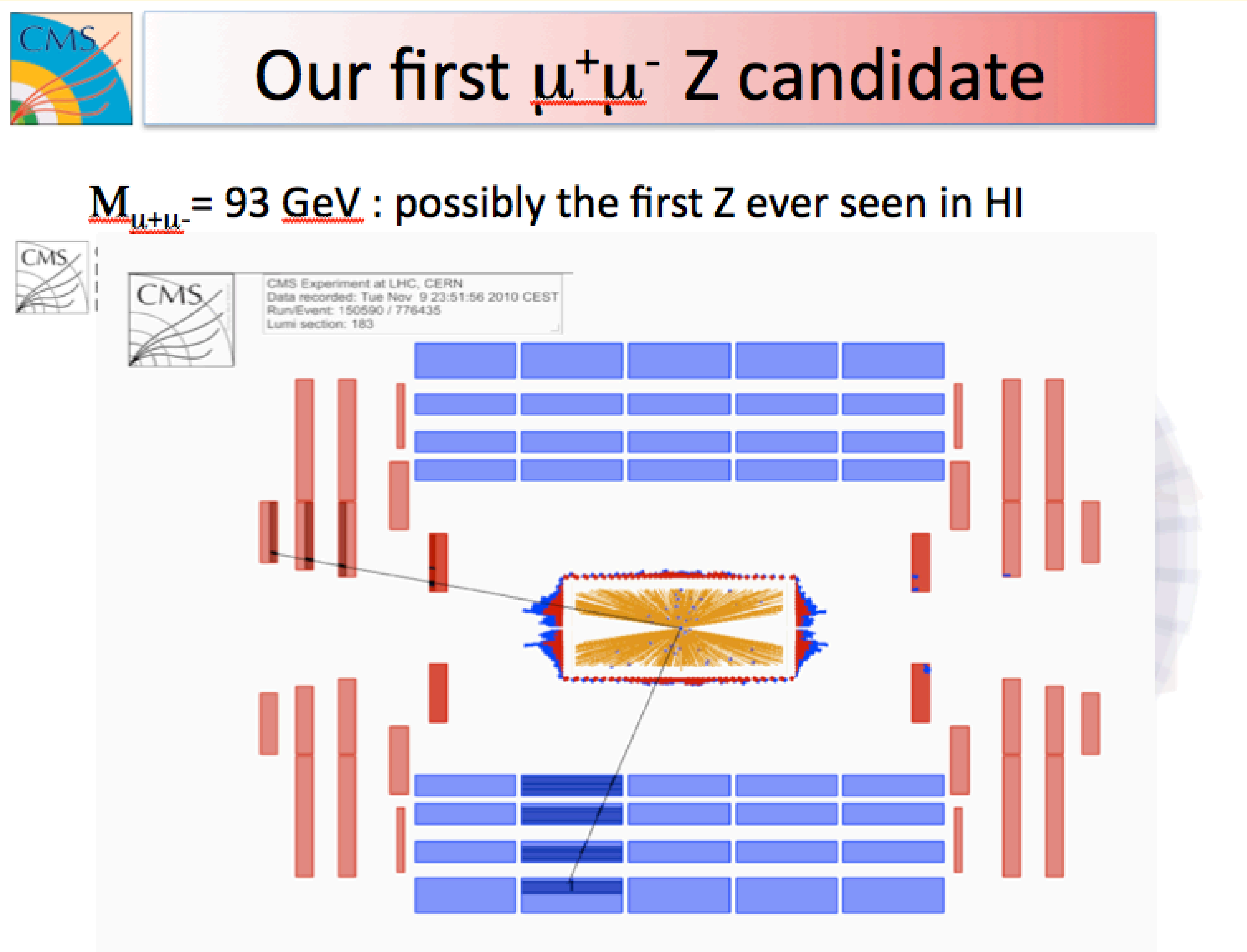




These observations open the way for many interesting new measurements, from PDF constraints, to a determination of A_{FB} and $\sin^2\theta_W$

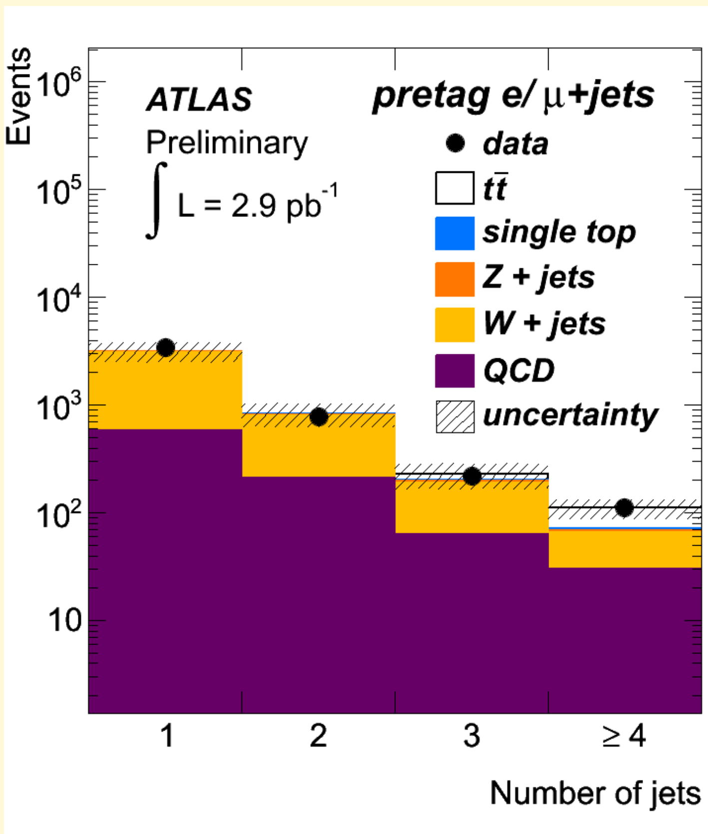
See S.Stone, for the LHCb collab., 104th LHCC session, http://indico.cern.ch/conferenceDisplay.py?confId=112439

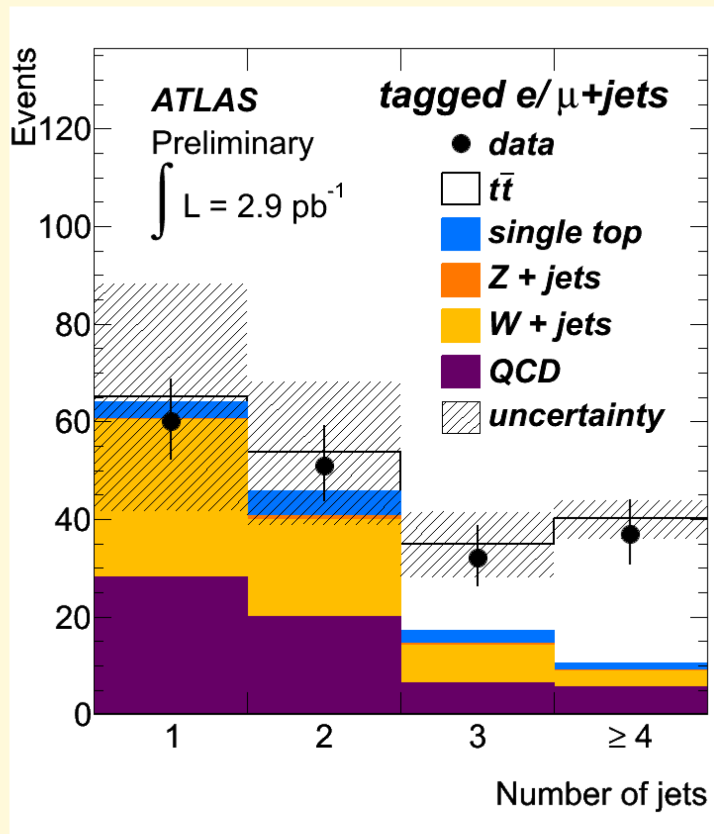
EW boson production in Pb Pb collisions, CMS

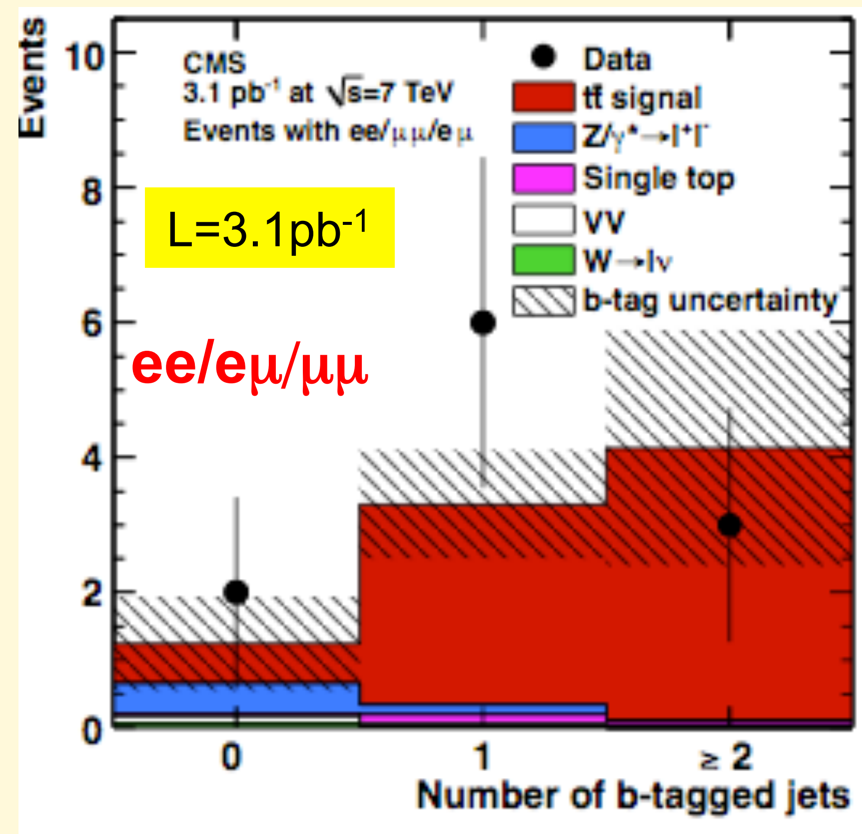


Heavy quarks

Top







1 e or μ with p_T>20 GeV, E_T^{miss}>20 GeV, $E_T^{miss}+m_T(W)$>60 GeV
N_{jets} with p_T>25 GeV, with no b-tag requirement or at least one b-tag
Signal defined to have 4 or more jets, and at least 1 b-tag

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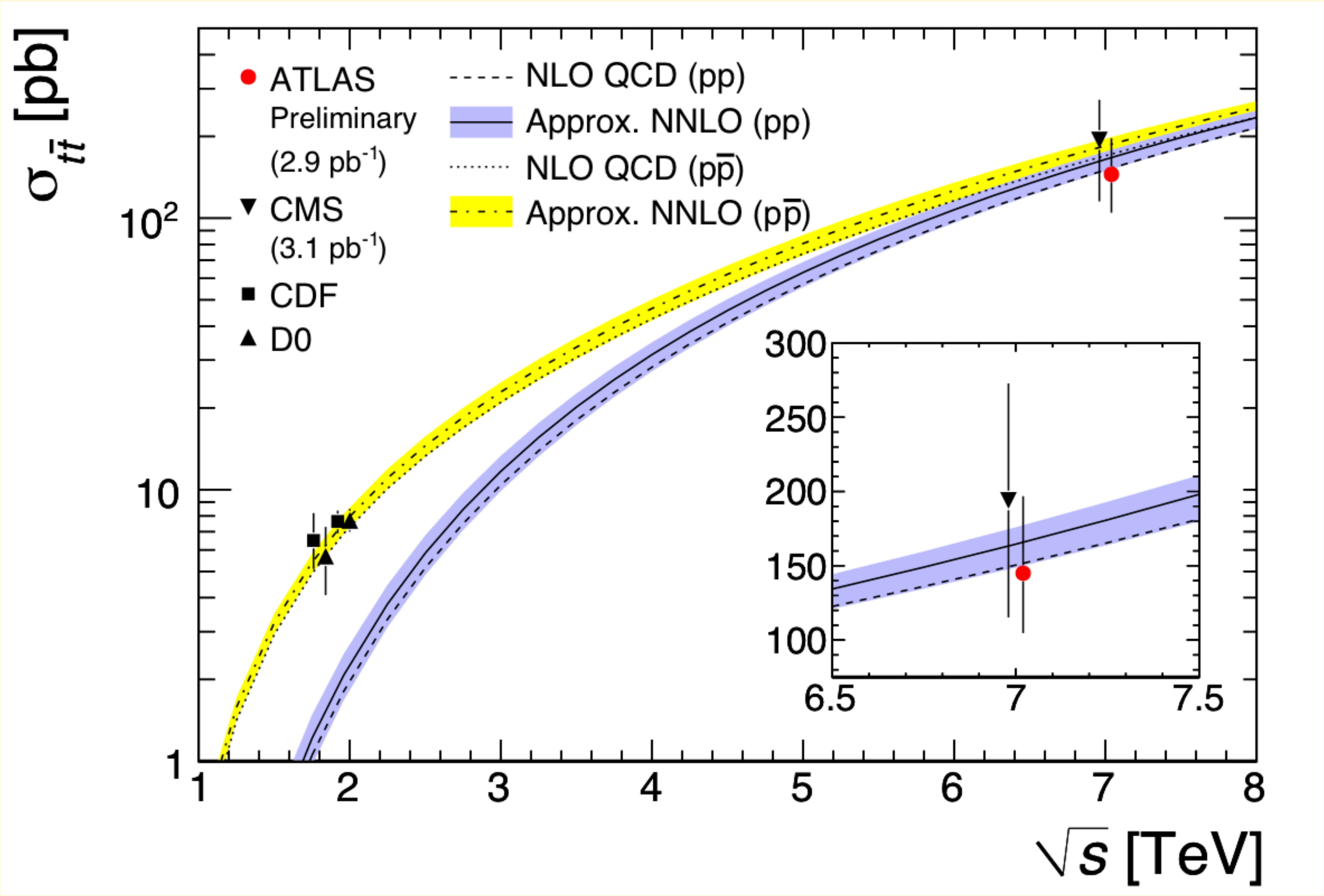


(1) ATLAS (lepton+b+≥3 jets and dileptons+≥2jets): $\sigma_{ATLAS} = 145 \pm 31 \begin{matrix} +42 \\ -27 \end{matrix}$ pb

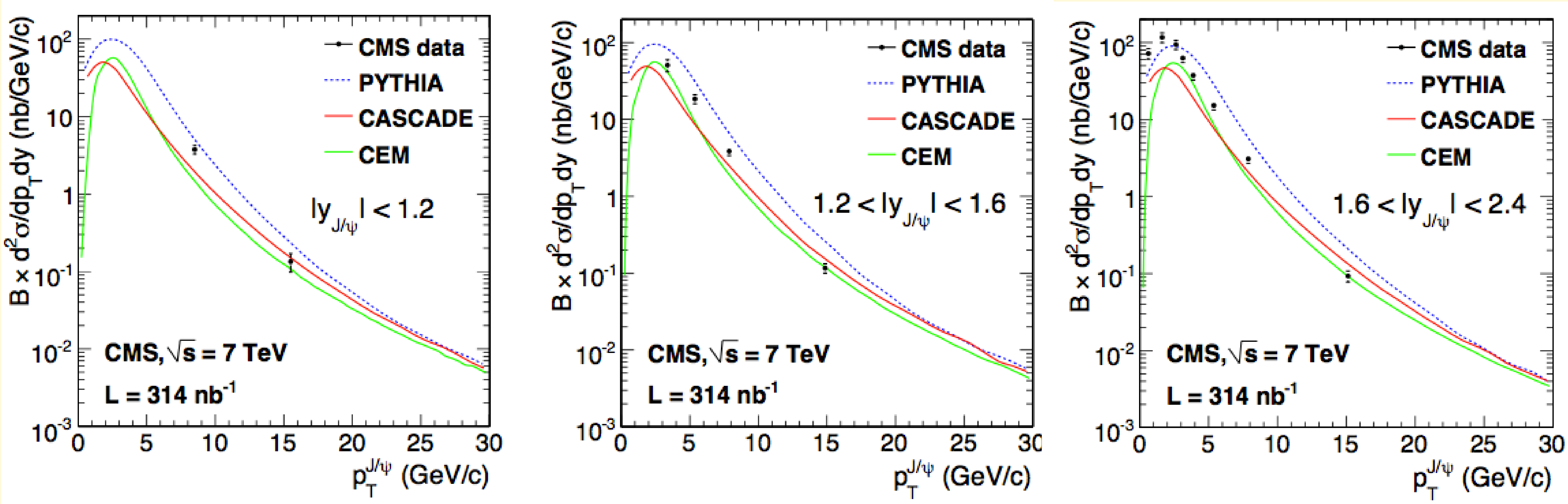
(2) CMS (dileptons+≥2jets): $\sigma_{CMS} = 194 \pm 72_{stat} \pm 24_{syst} \pm 21_{lum}$

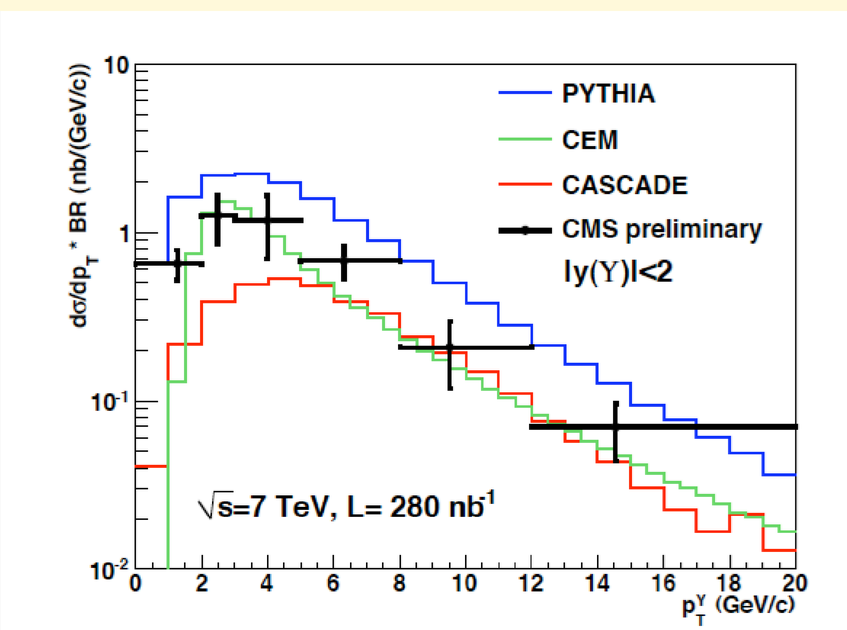
$$\sigma_{TH} = 167 \begin{matrix} +13 \\ -10 \end{matrix} \text{ pb}$$

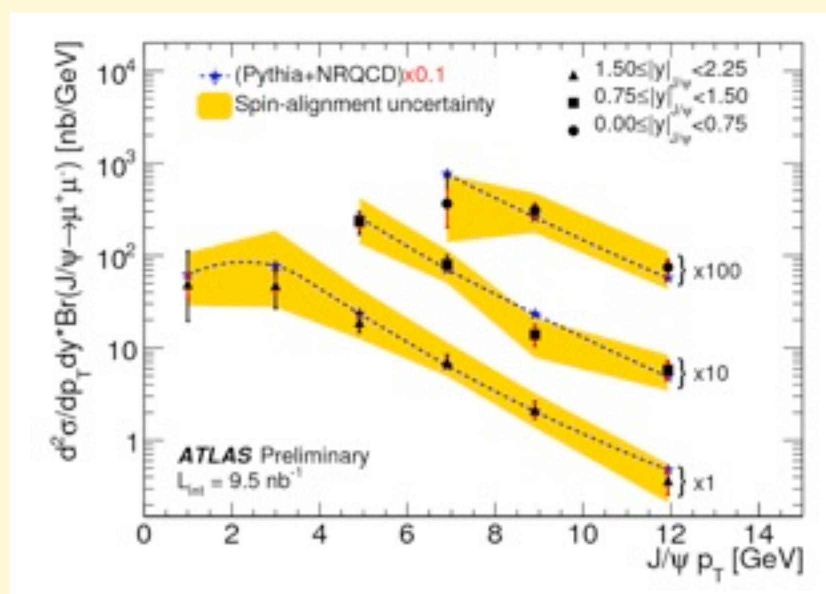
(1) **See P. Wells, for the ATLAS collab., 104th LHCC session, http://indico.cern.ch/conferenceDisplay.py?confId=112439**

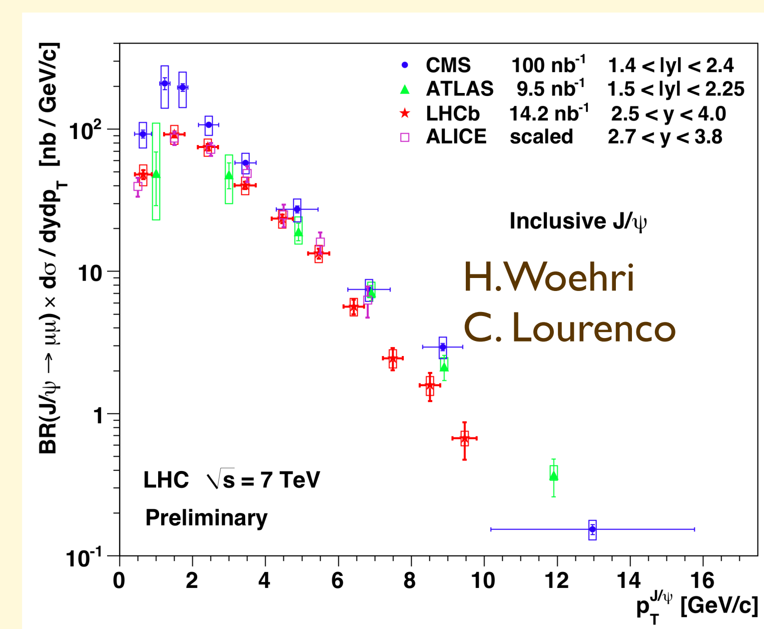
(2) **arXiv:1010.5994**

Few words about quarkonium









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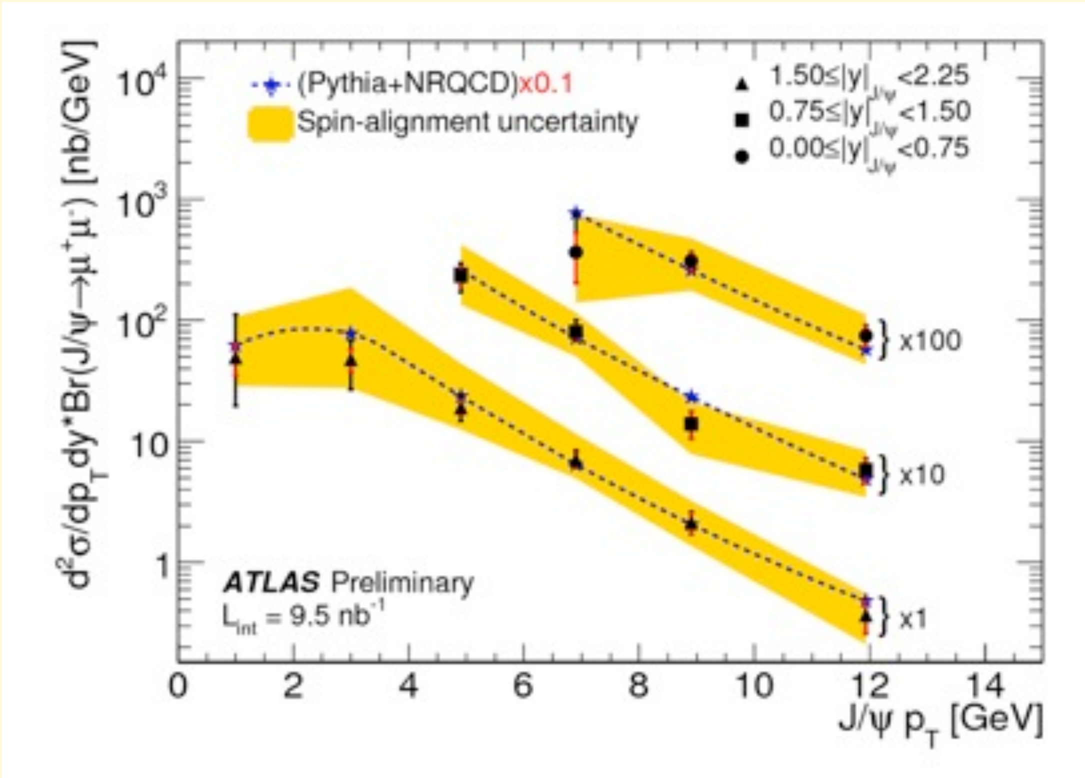
(Pythia+NRQCD)x0.1
Spin-alignment uncertainty
1.50≤|y|J/ψ<2.25
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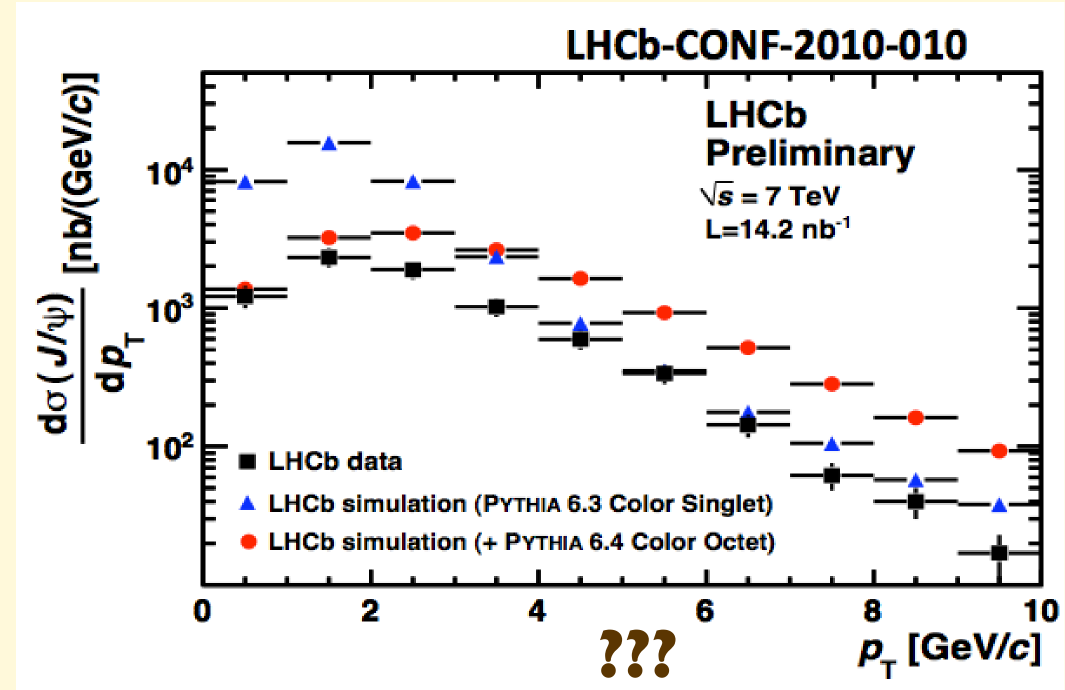
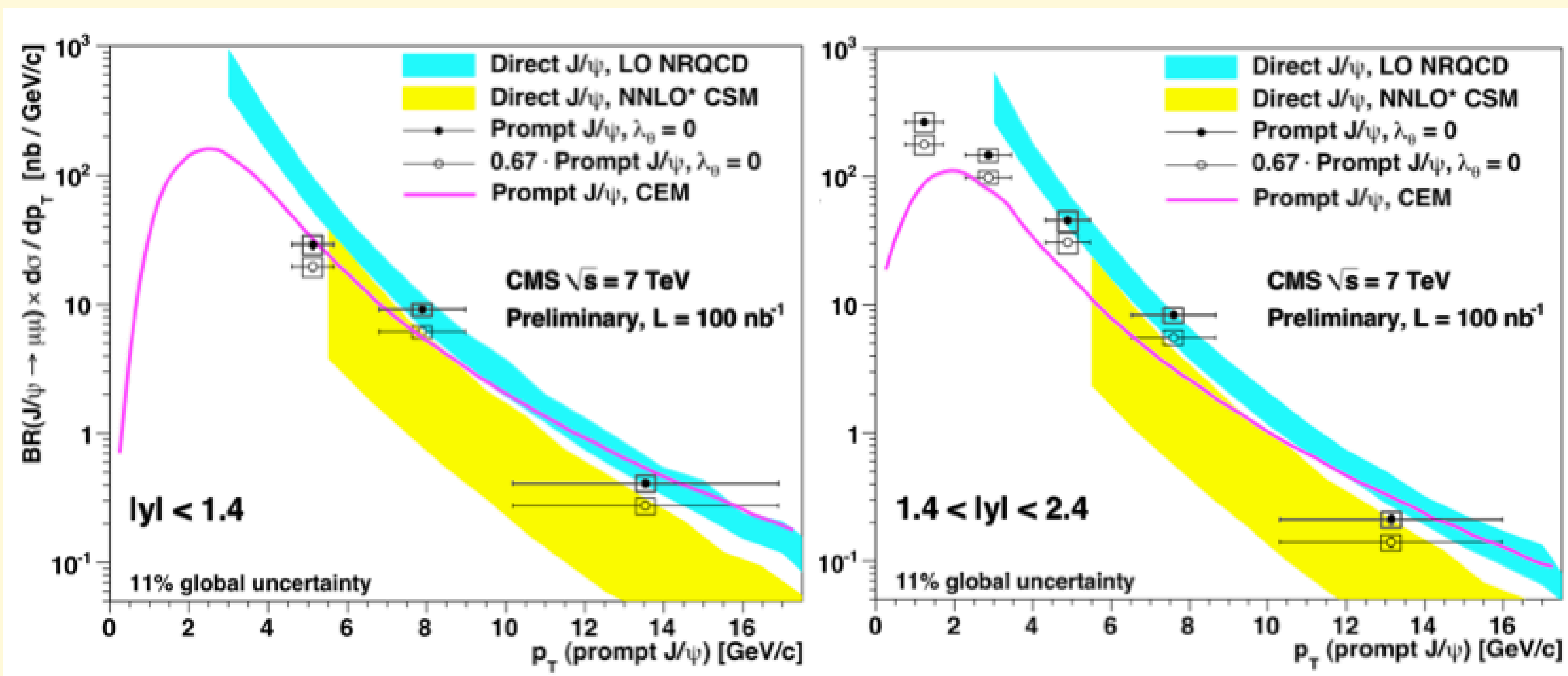
x100
x10
x1
ATLAS Preliminary
Lint = 9.5 nb-1
d2σ/dpTdy*Br(J/ψ→μ+μ-) [nb/GeV]
J/ψ pT [GeV]

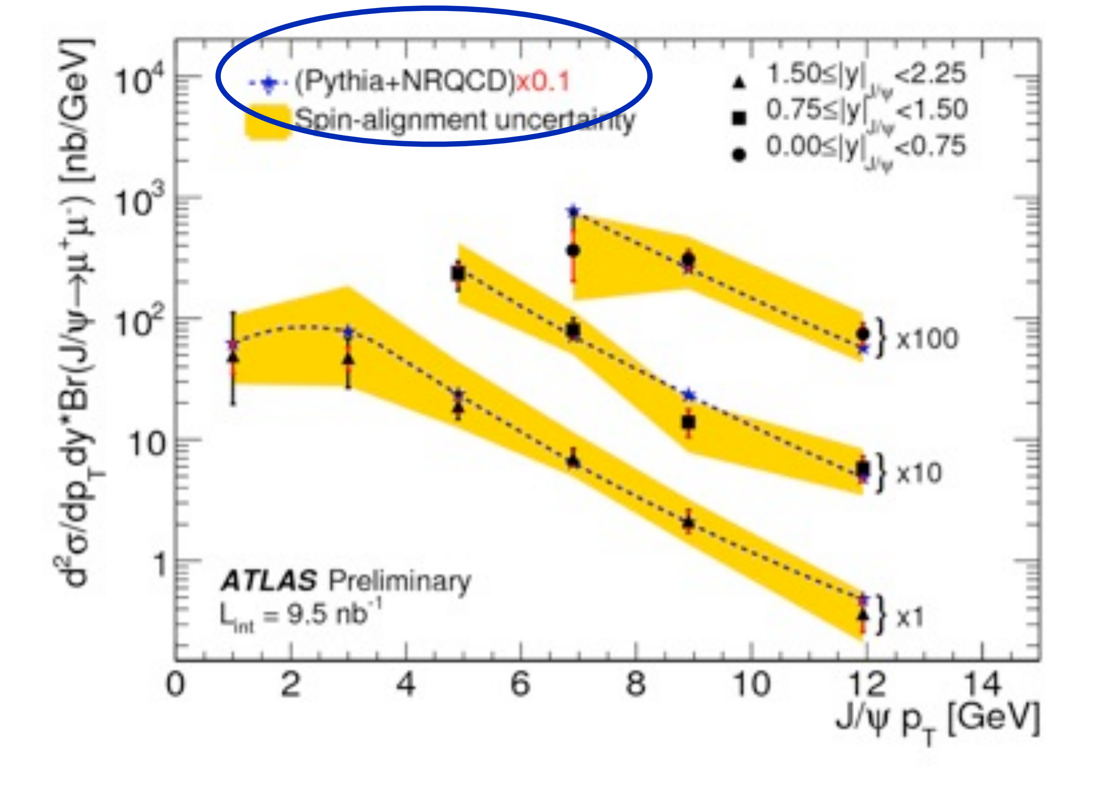

LHCb-CONF-2010-010
LHCb
Preliminary
√s = 7 TeV
L=14.2 nb-1
LHCb data
LHCb simulation (PYTHIA 6.3 Color Singlet)
LHCb simulation (+ PYTHIA 6.4 Color Octet)
dσ(J/ψ)/dpT [nb/(GeV/c)]
pT [GeV/c]

???

???


Direct J/ψ, LO NRQCD
Direct J/ψ, NNLO* CSM
Prompt J/ψ, λθ = 0
0.67 · Prompt J/ψ, λθ = 0
Prompt J/ψ, CEM
CMS √s = 7 TeV
Preliminary, L = 100 nb-1
|y| < 1.4
1.4 < |y| < 2.4
11% global uncertainty
BR(J/ψ → μμ) × dσ / dpT [nb / GeV/c]
pT (prompt J/ψ) [GeV/c]

???



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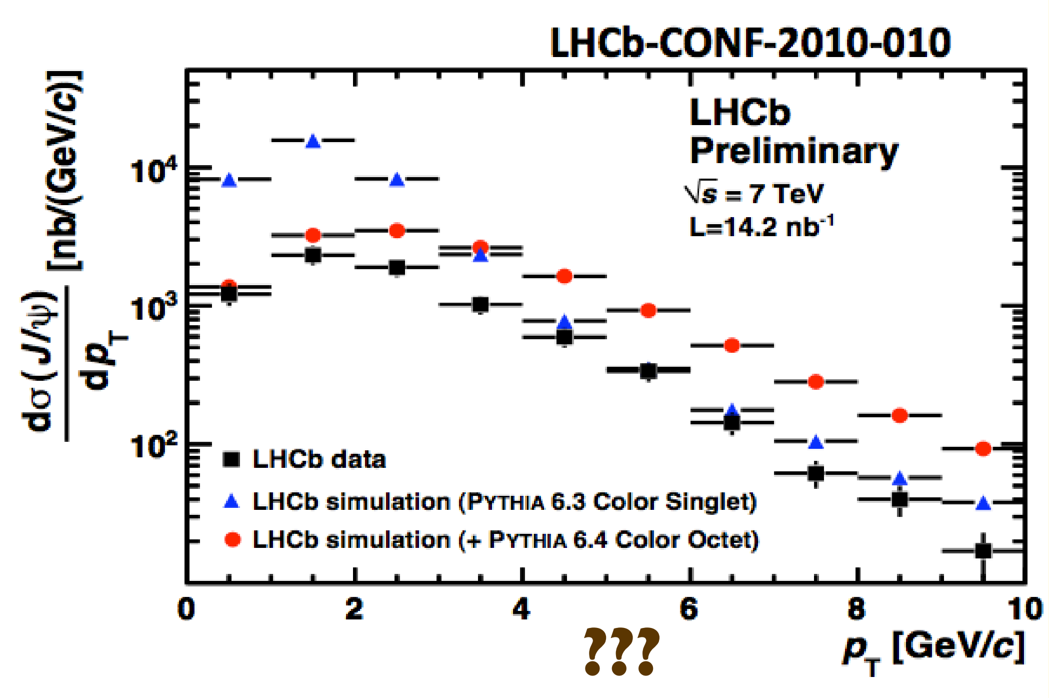

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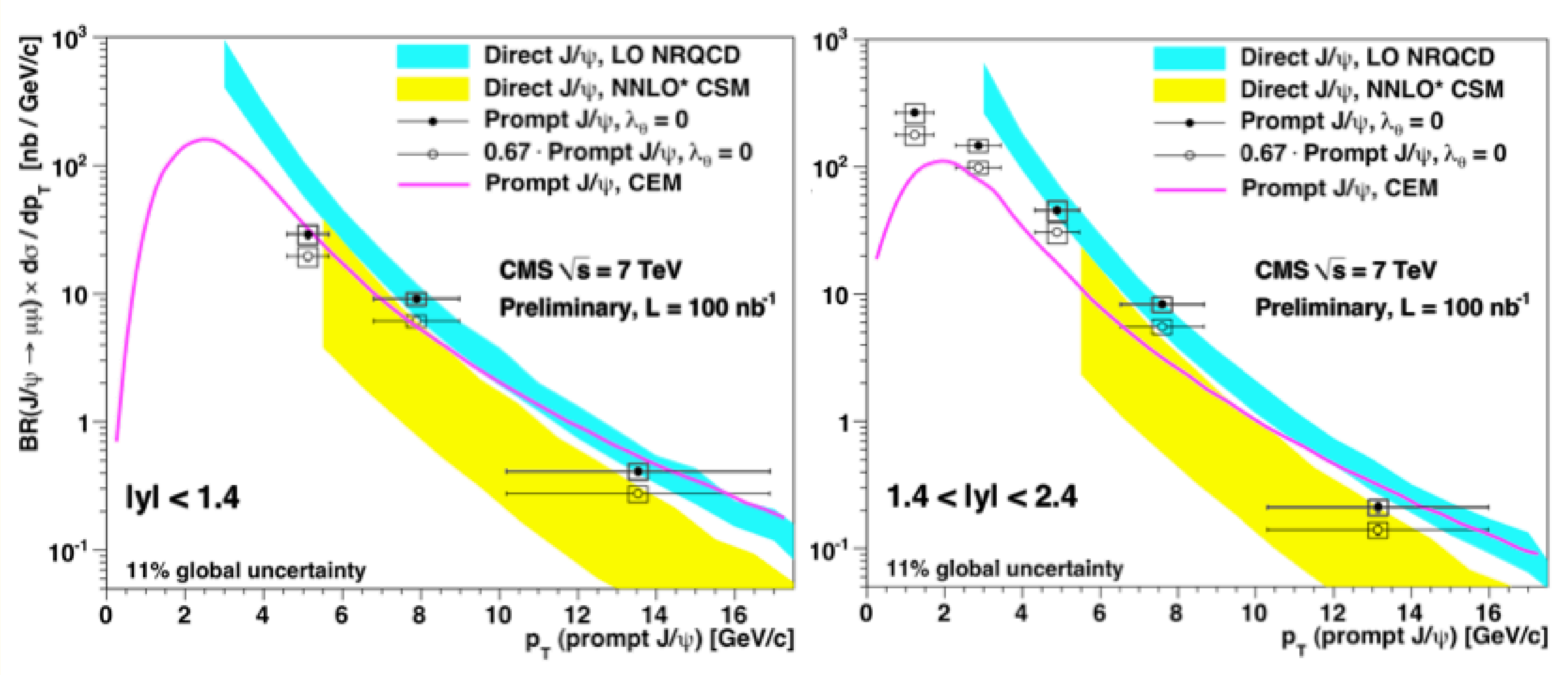

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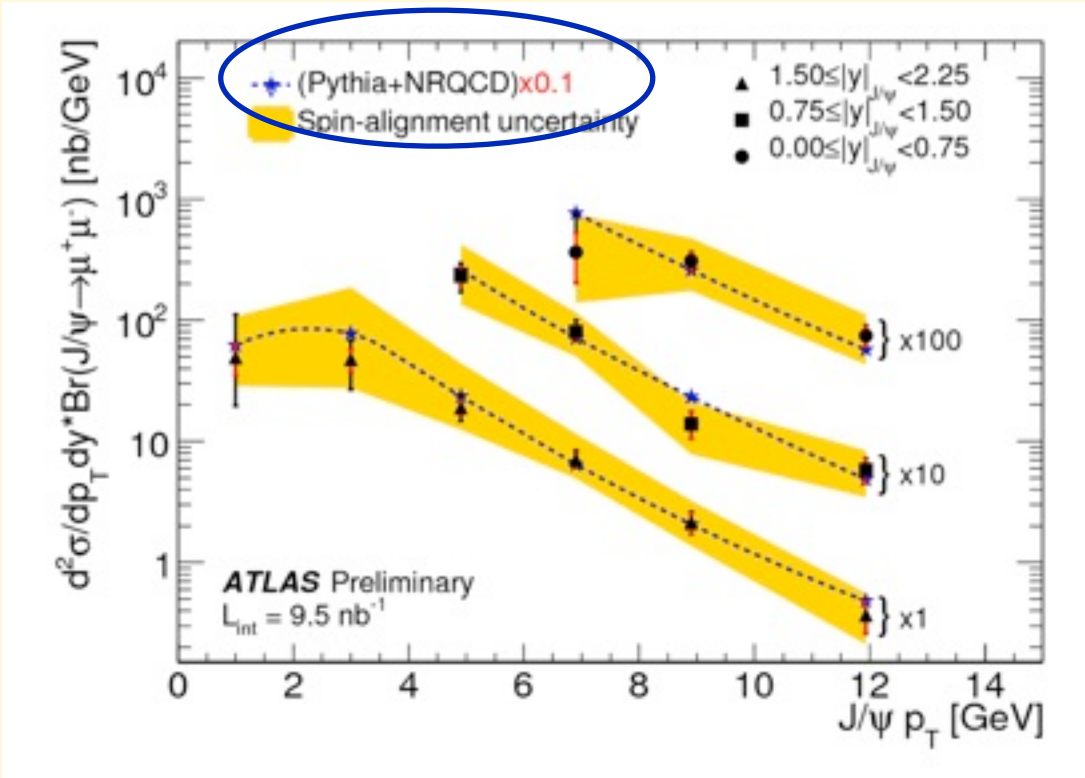
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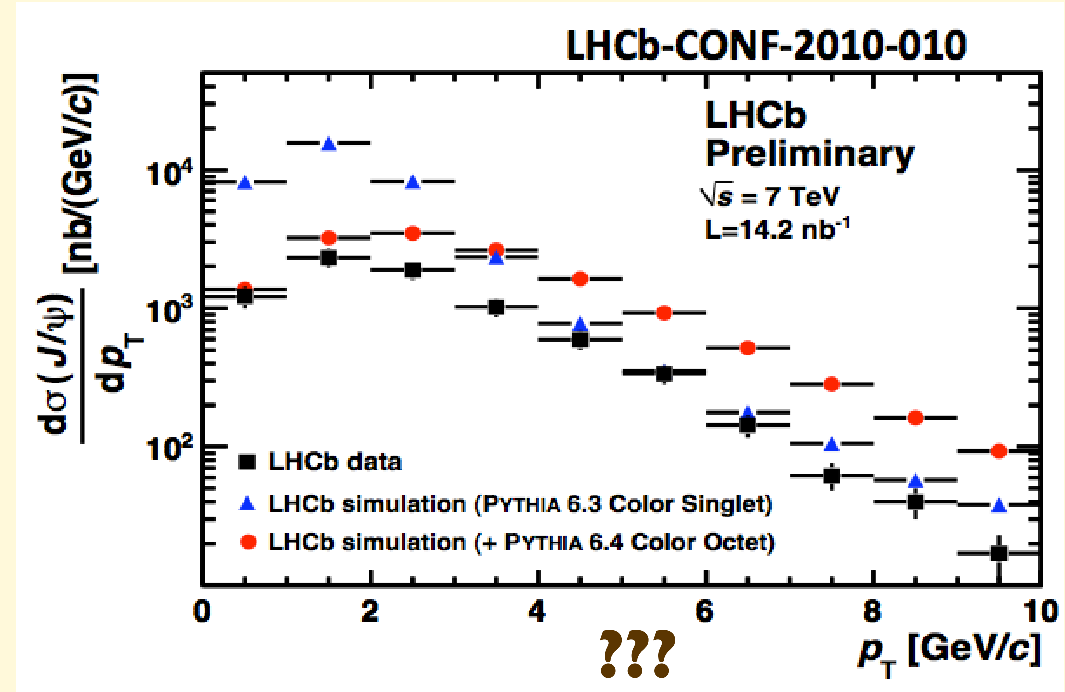
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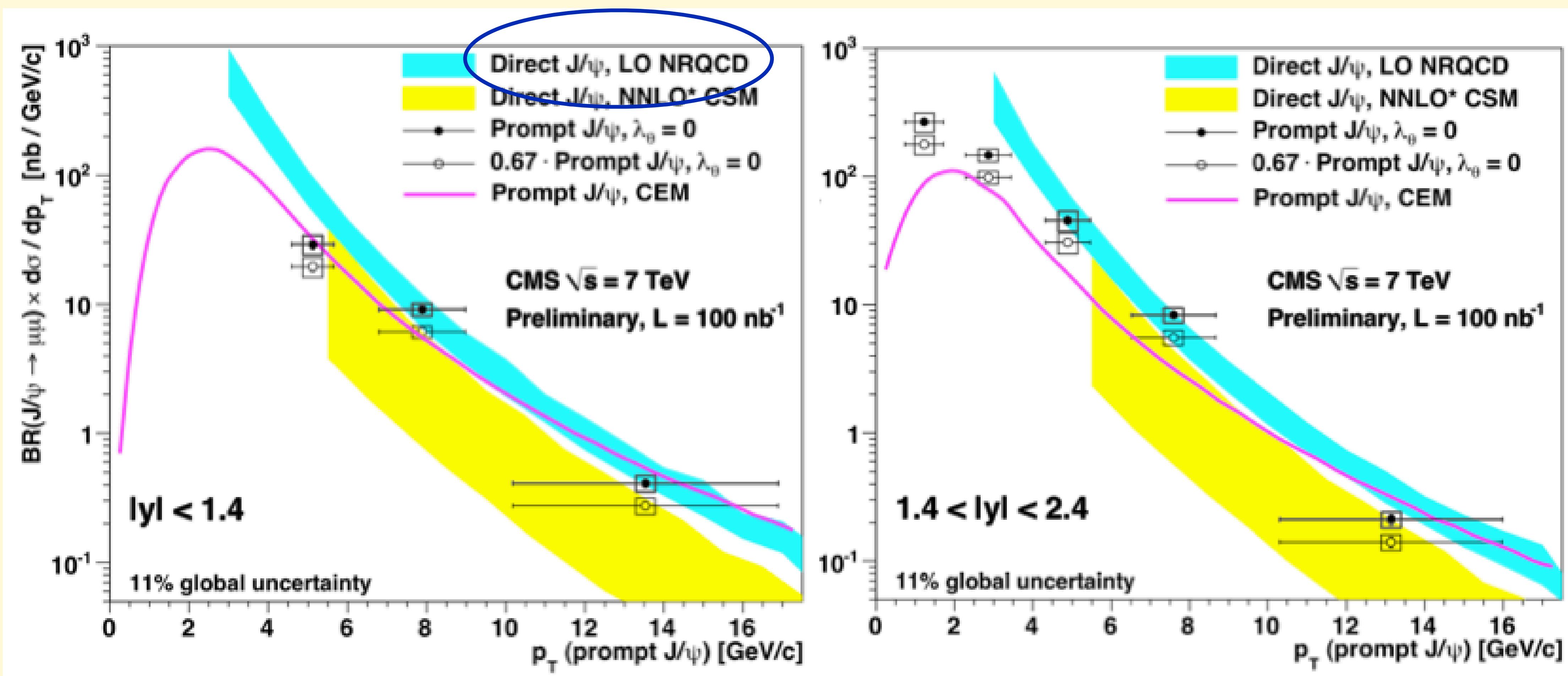
???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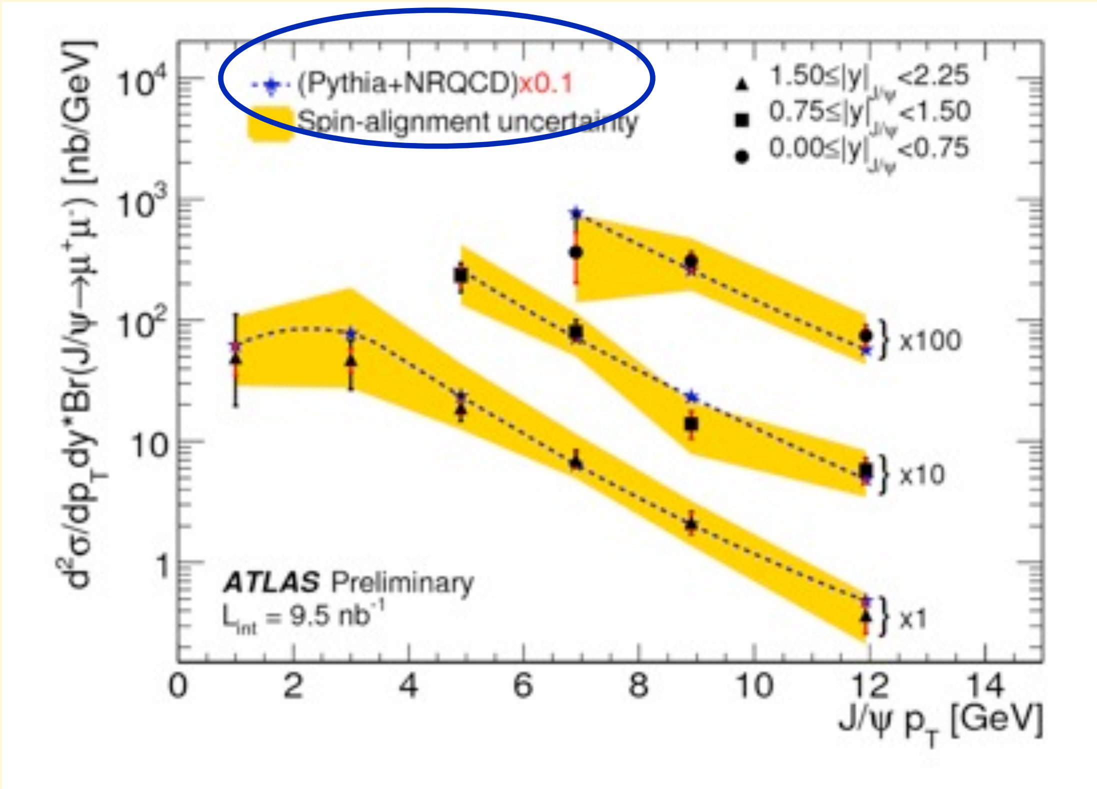

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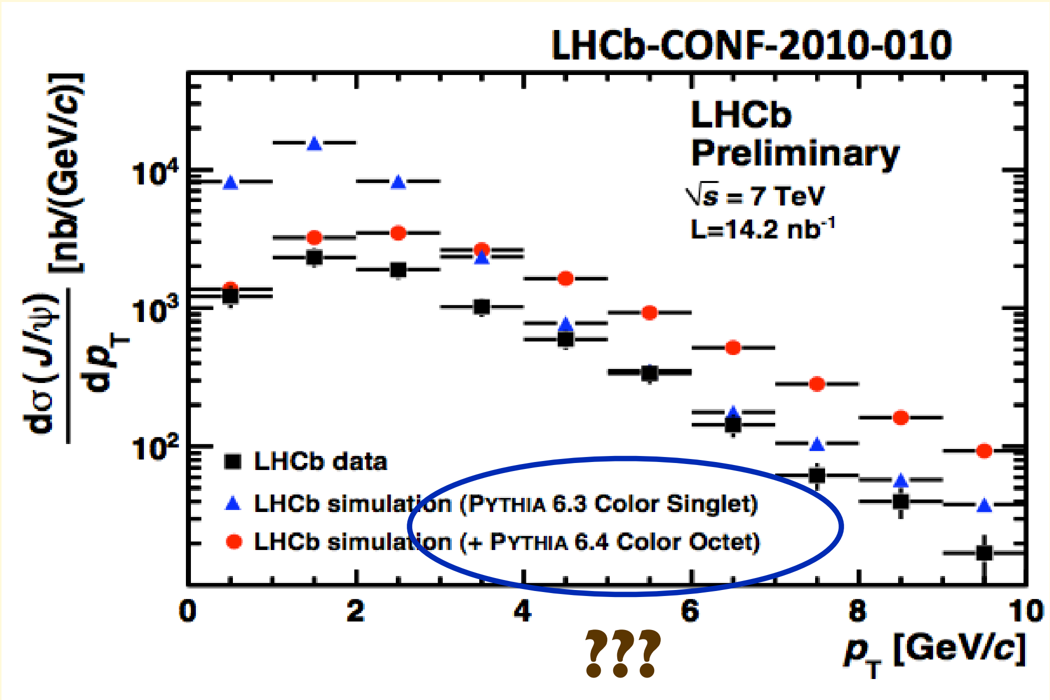

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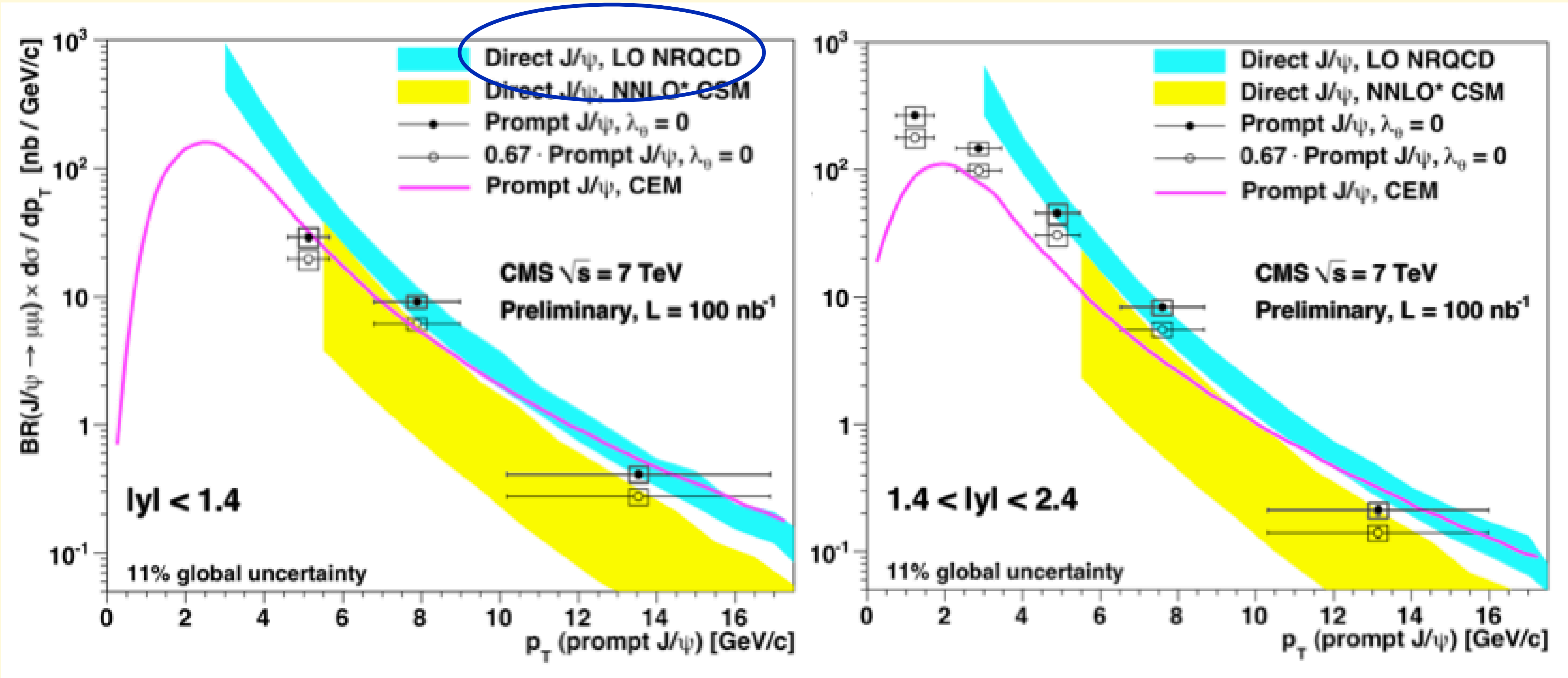

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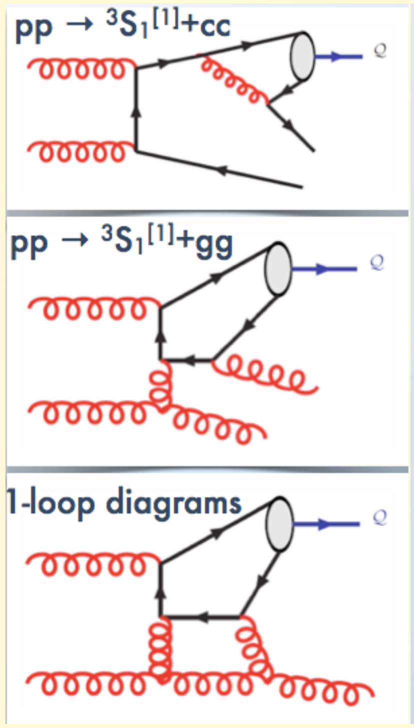
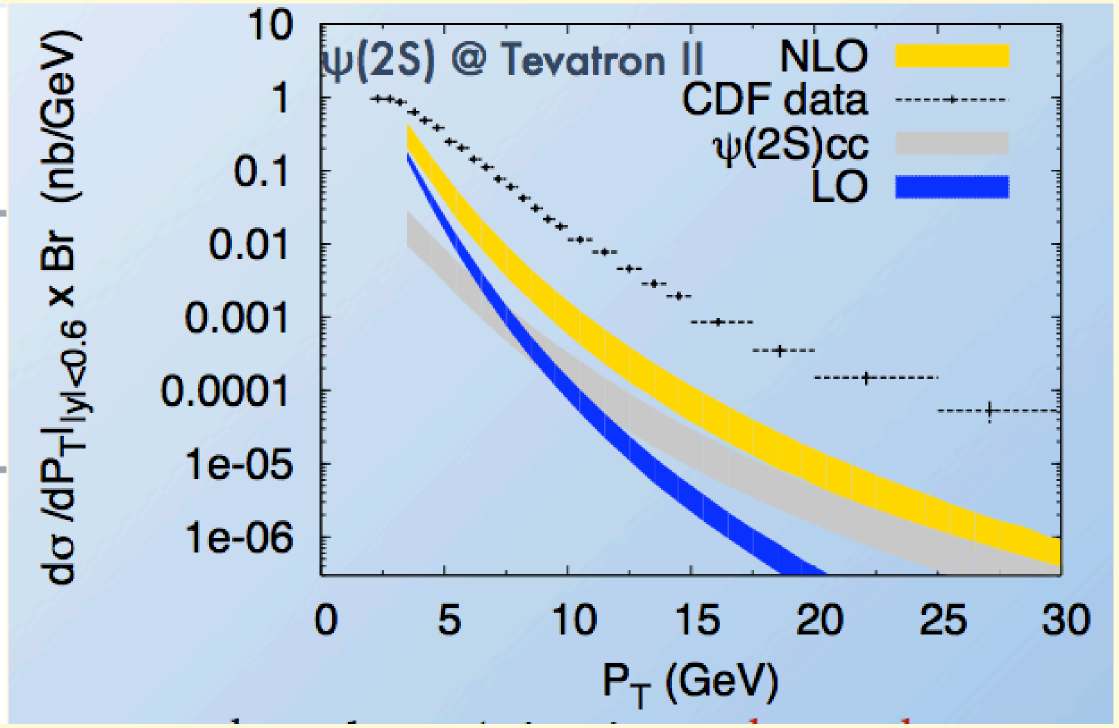
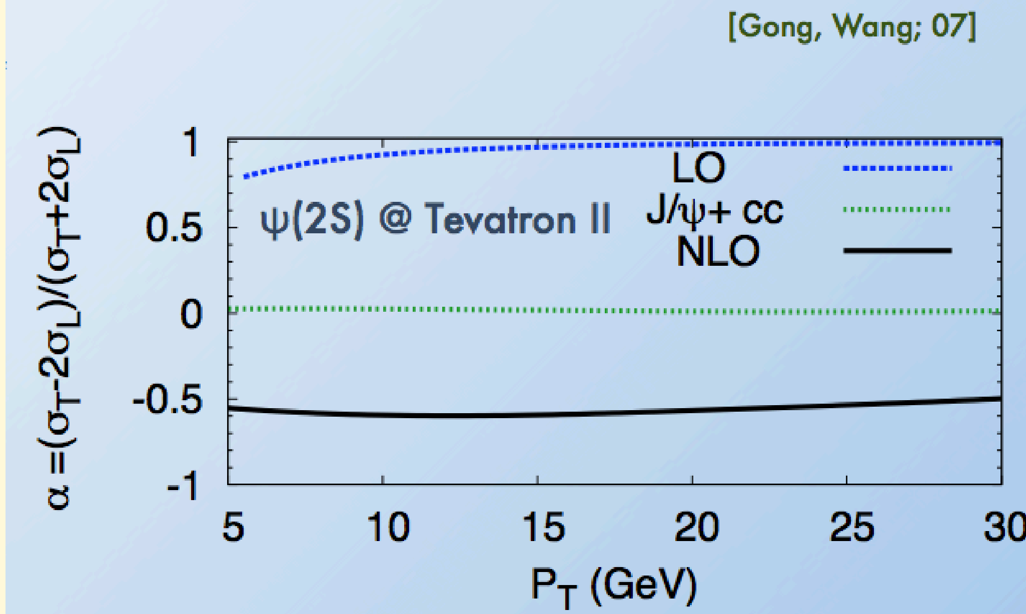
NLO Singlet contributions

Campbell, Maltoni, Tramontano



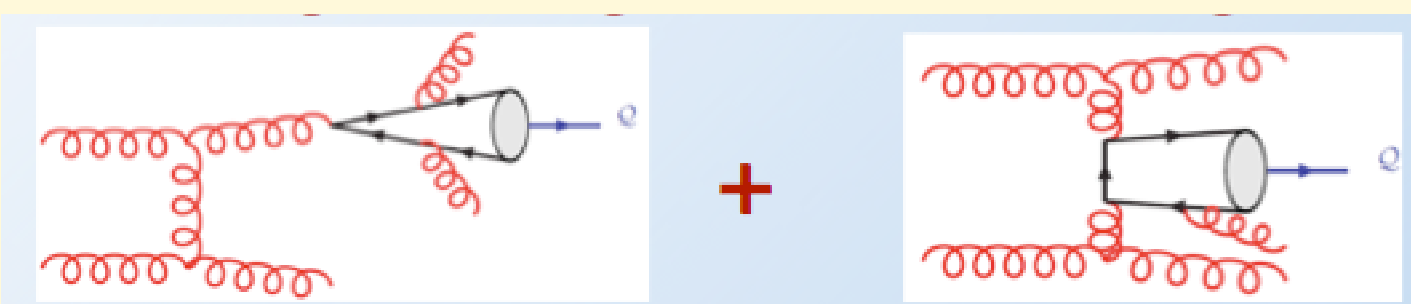




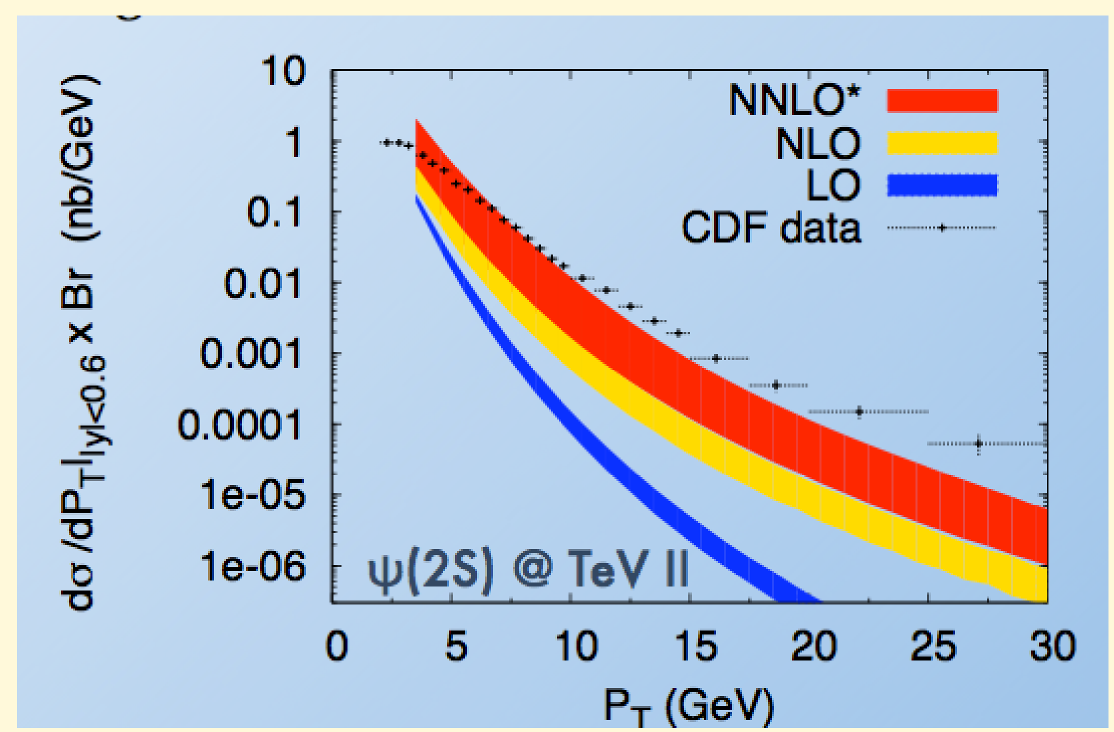
- New channels at α_s^4 strongly affect the polarization parameter α (polar asymmetry in the c.m. helicity frame)
- Polarization is longitudinal component at NLO
- Large correction may arise at order α_s^5 because new channels with a different p_T scaling open up at that order. One of them is the gluon fragmentation $g^* \to {}^3S_1^{[1]}$ ...

"NNLO" Singlet contributions

Artoisenet, Campbell, Lansberg, Maltoni, Tramontano



- IR cutoff logarithmic dependence expected to disappear at large p_T, but sizable at moderate p_T.
- This gives a large uncertainty on the normalization, the shape is rather stable though.

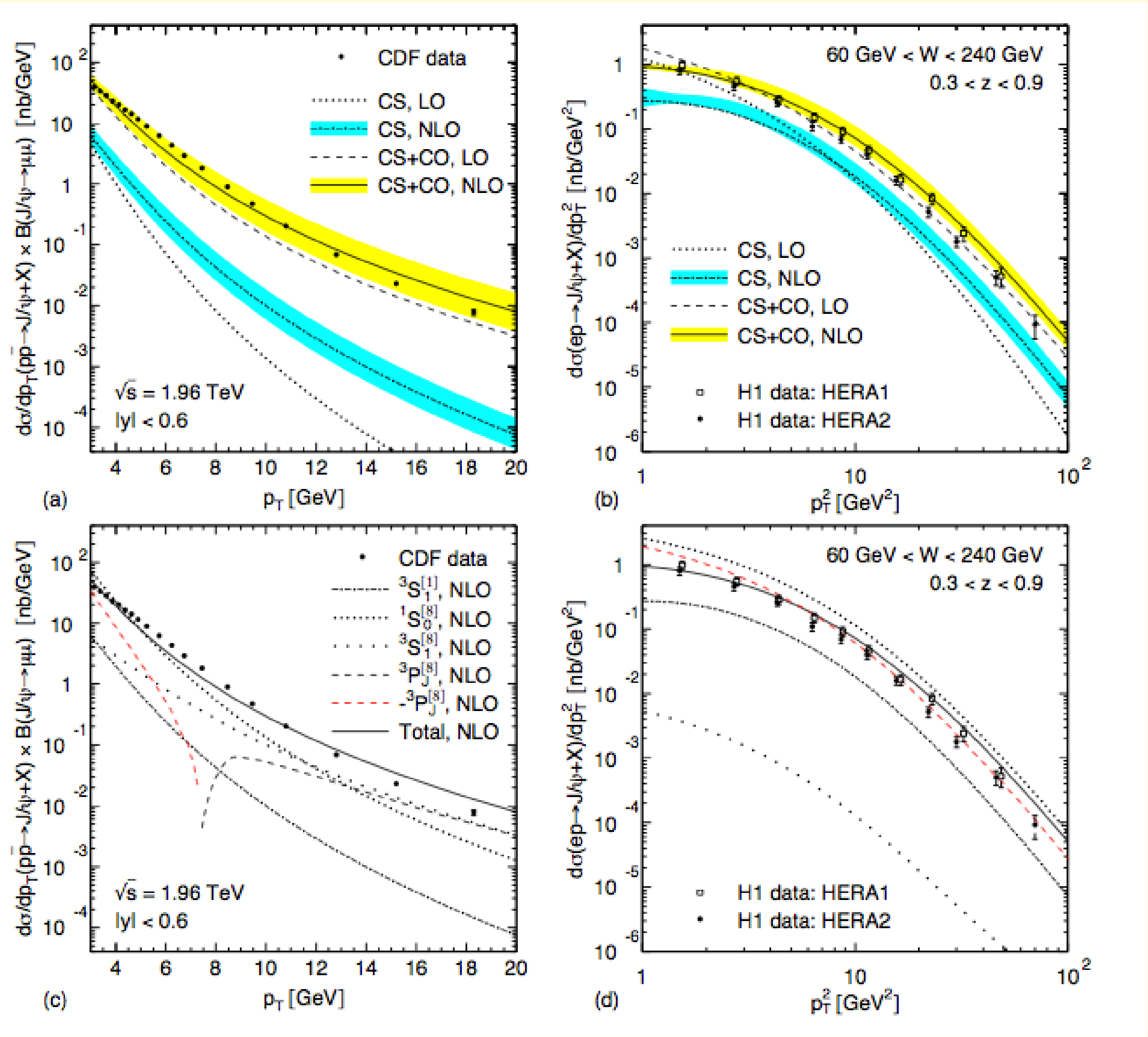


Material on this slide from Fabio Maltoni's talk at "Hard Probes 2010", Eilat

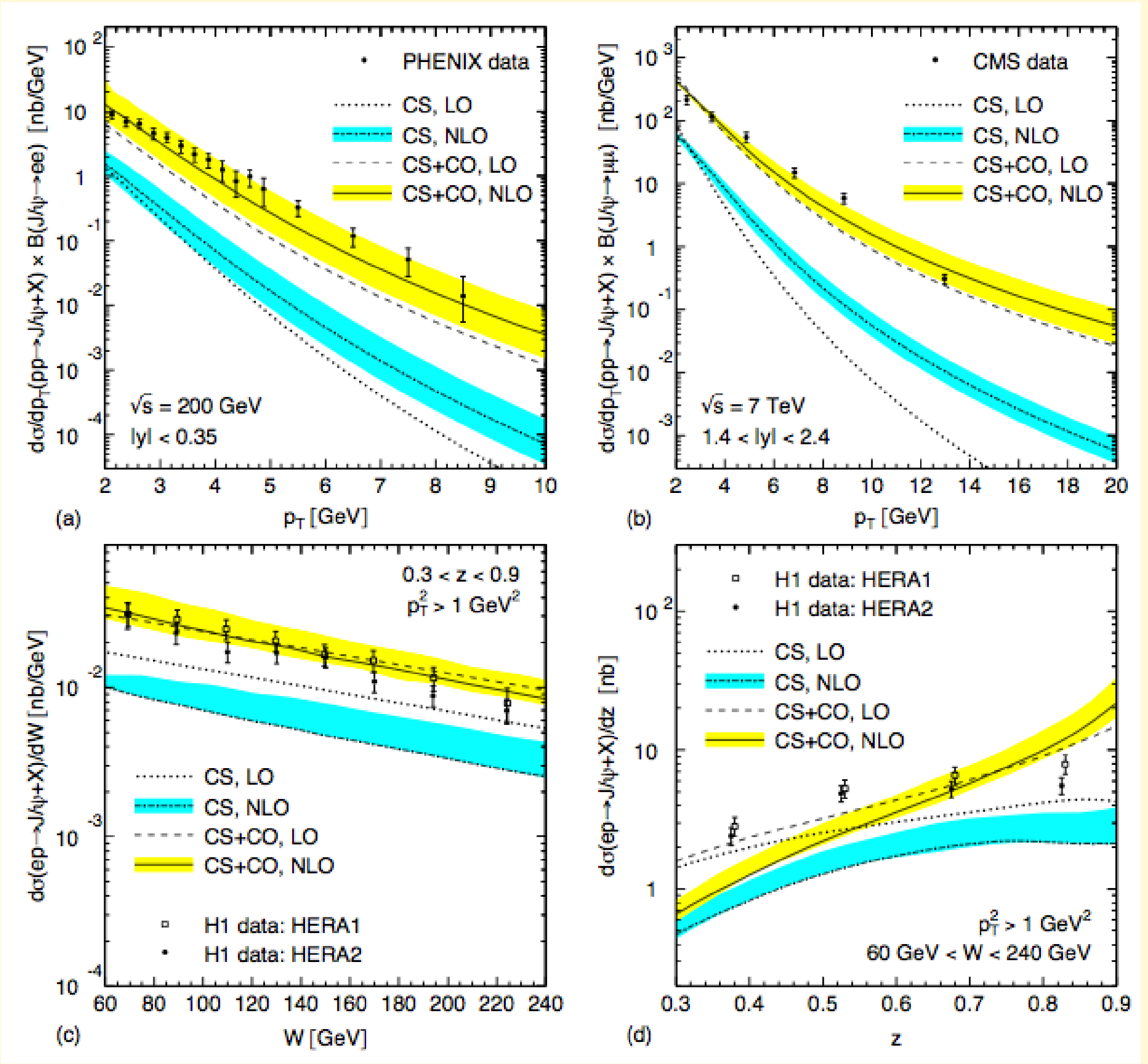
Reconciling J/ψ production at HERA, RHIC, Tevatron, and LHC with NRQCD factorization at next-to-leading order

Mathias Butenschön, Bernd A. Kniehl

arXiv:1009.5662v1

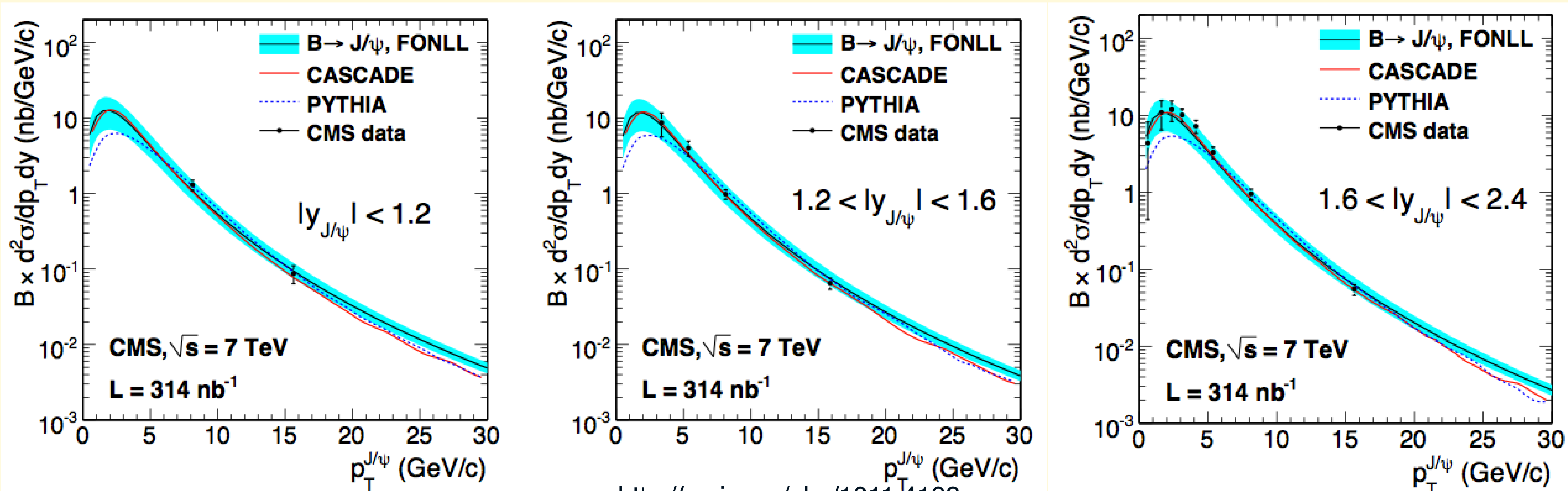


Fit inputs

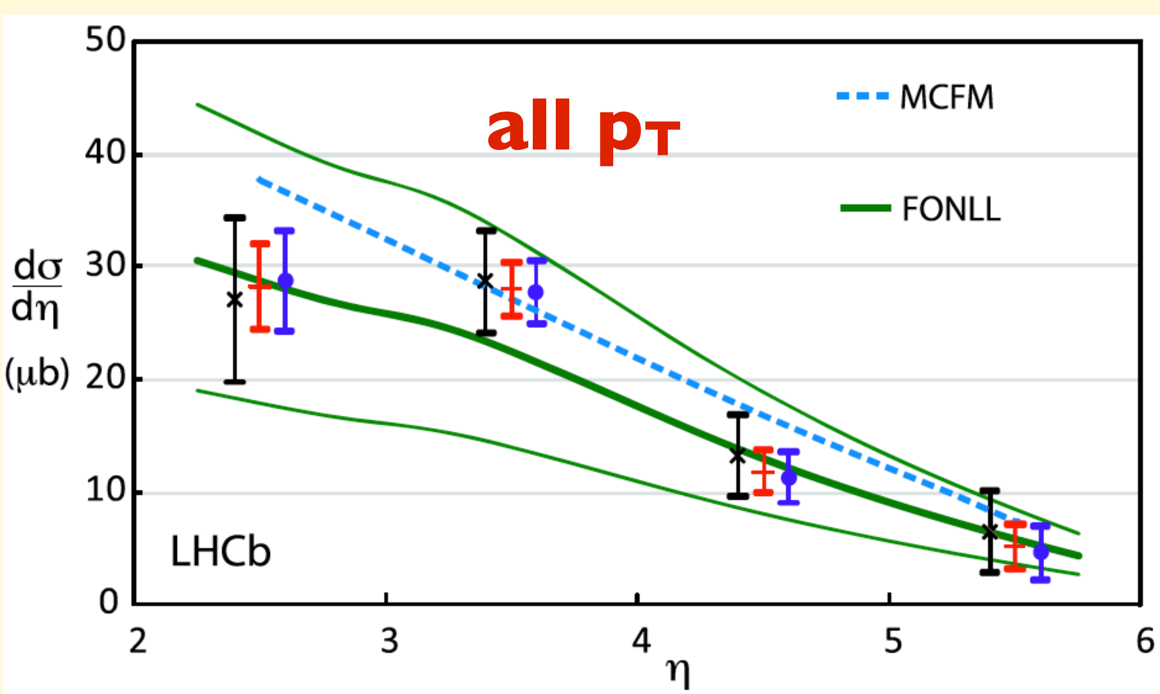


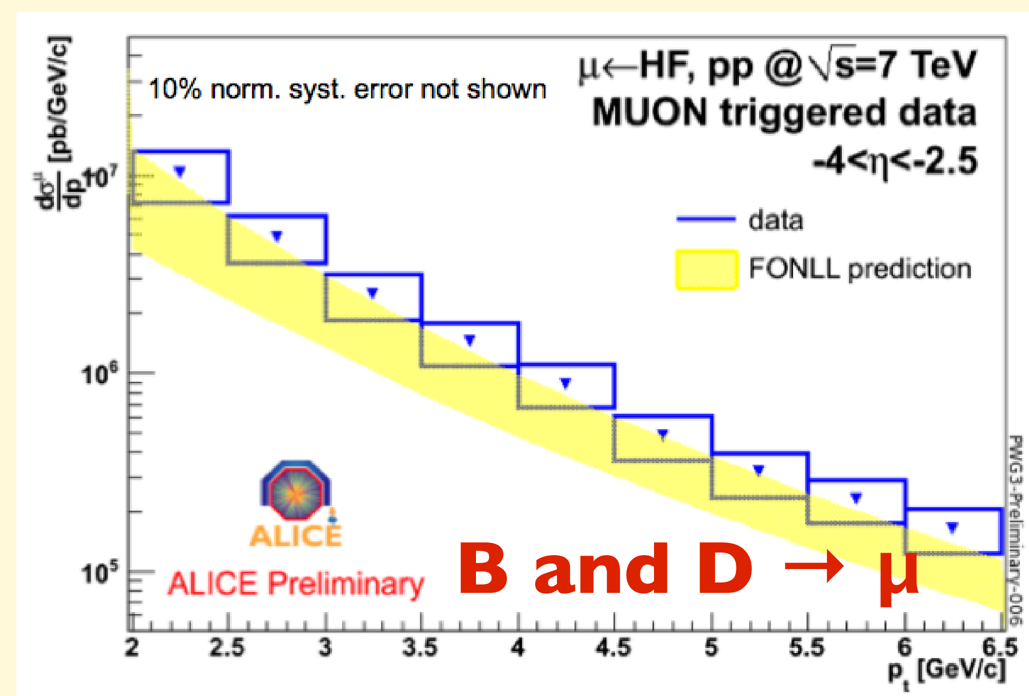
Predicctions

Open Q: by and large good agreement of data and NLO



http://arxiv.org/abs/1011.4193



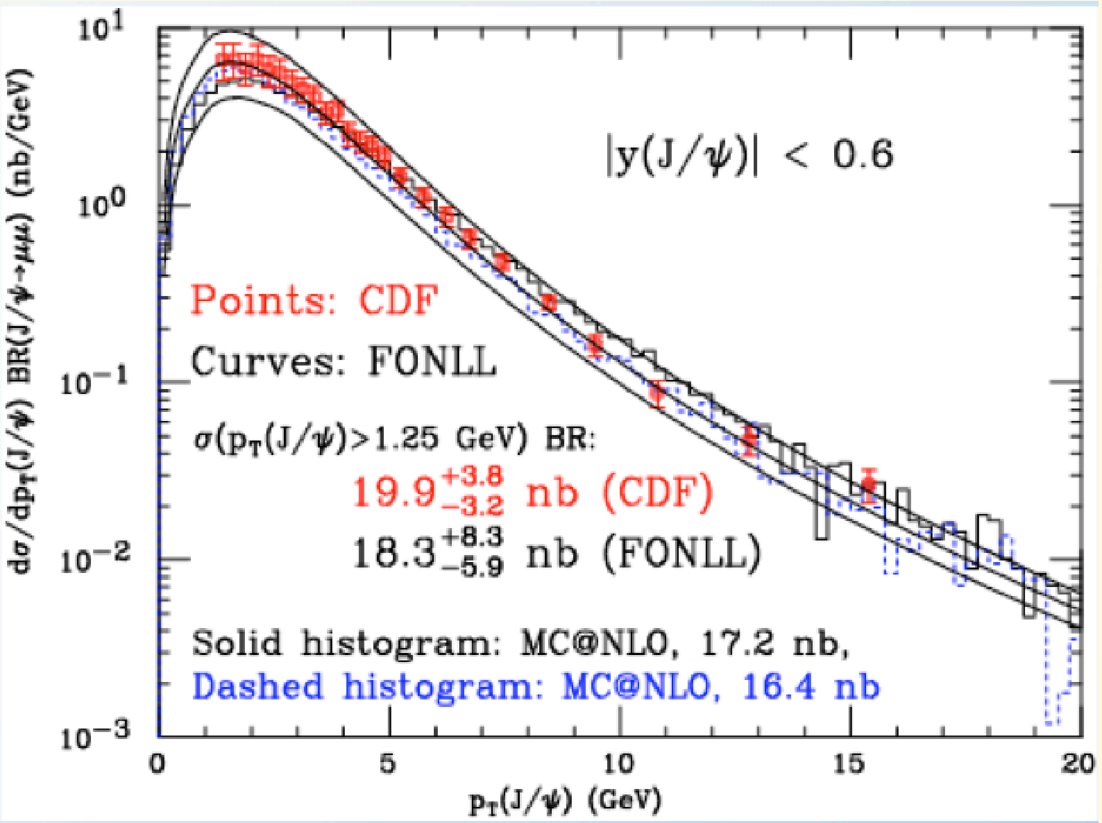


This agreement is one of the most significant results from LHC-2010

Why is it not trivial?

It took a while to establish consistency between Tevatron data and pQCD

hep-ph/0411020

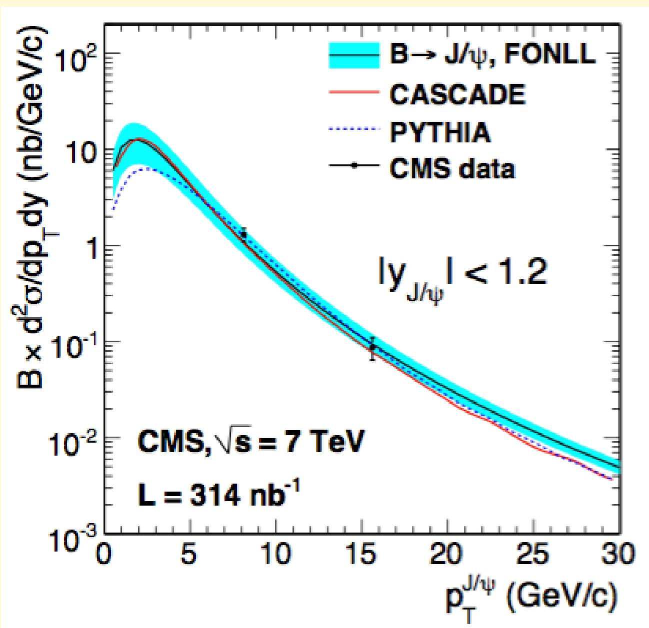


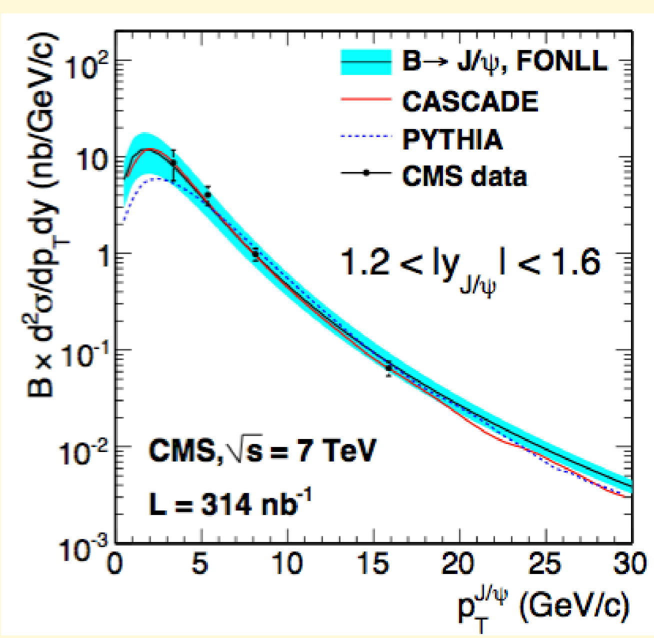
The dynamical regime of the LHC is theoretically more challenging

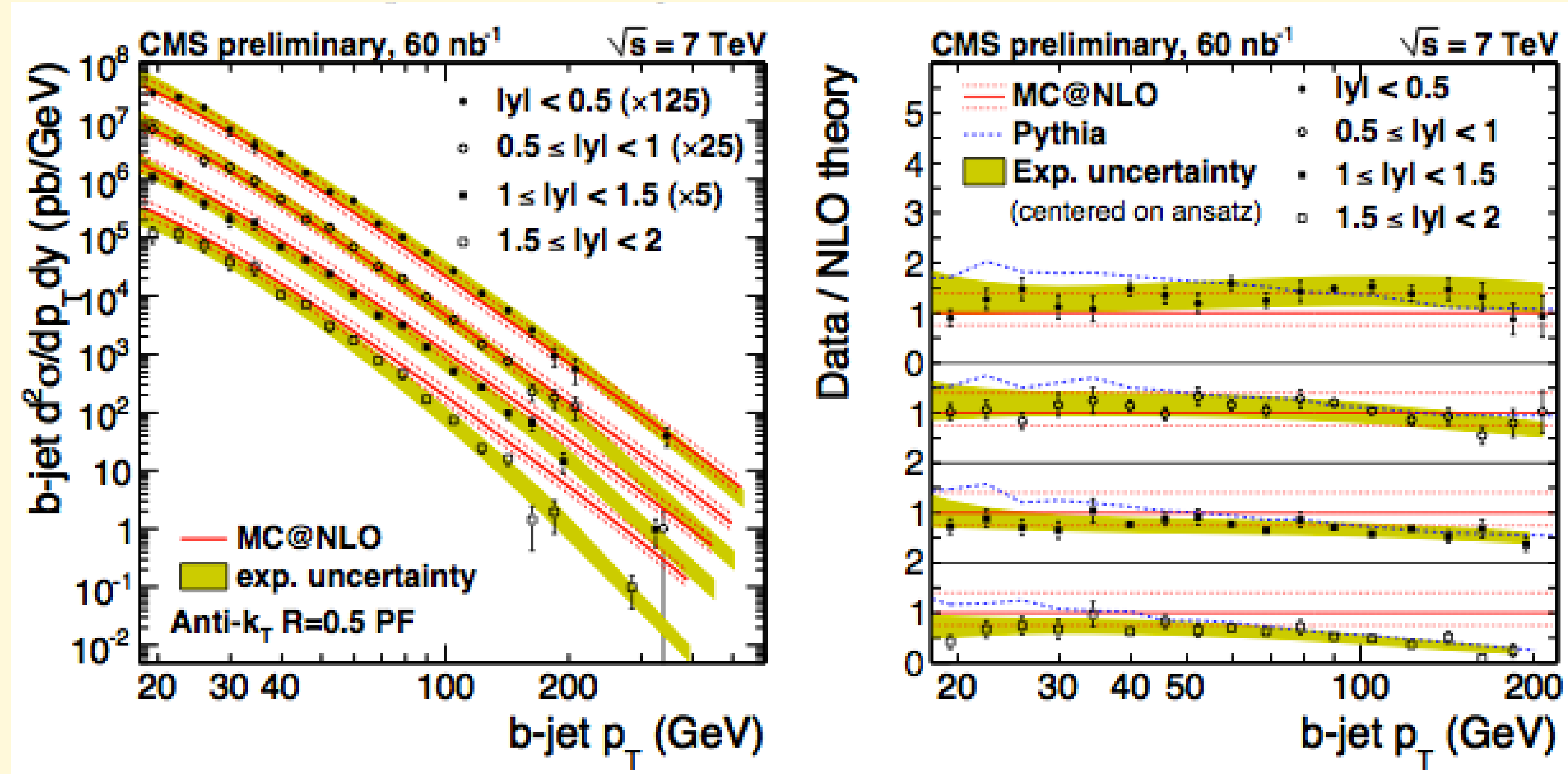
- large S => small x
- large rapidity (ALICE, LHCb)
  - o access to even smaller x
  - o small pt, sensitivity to higher-twist effects

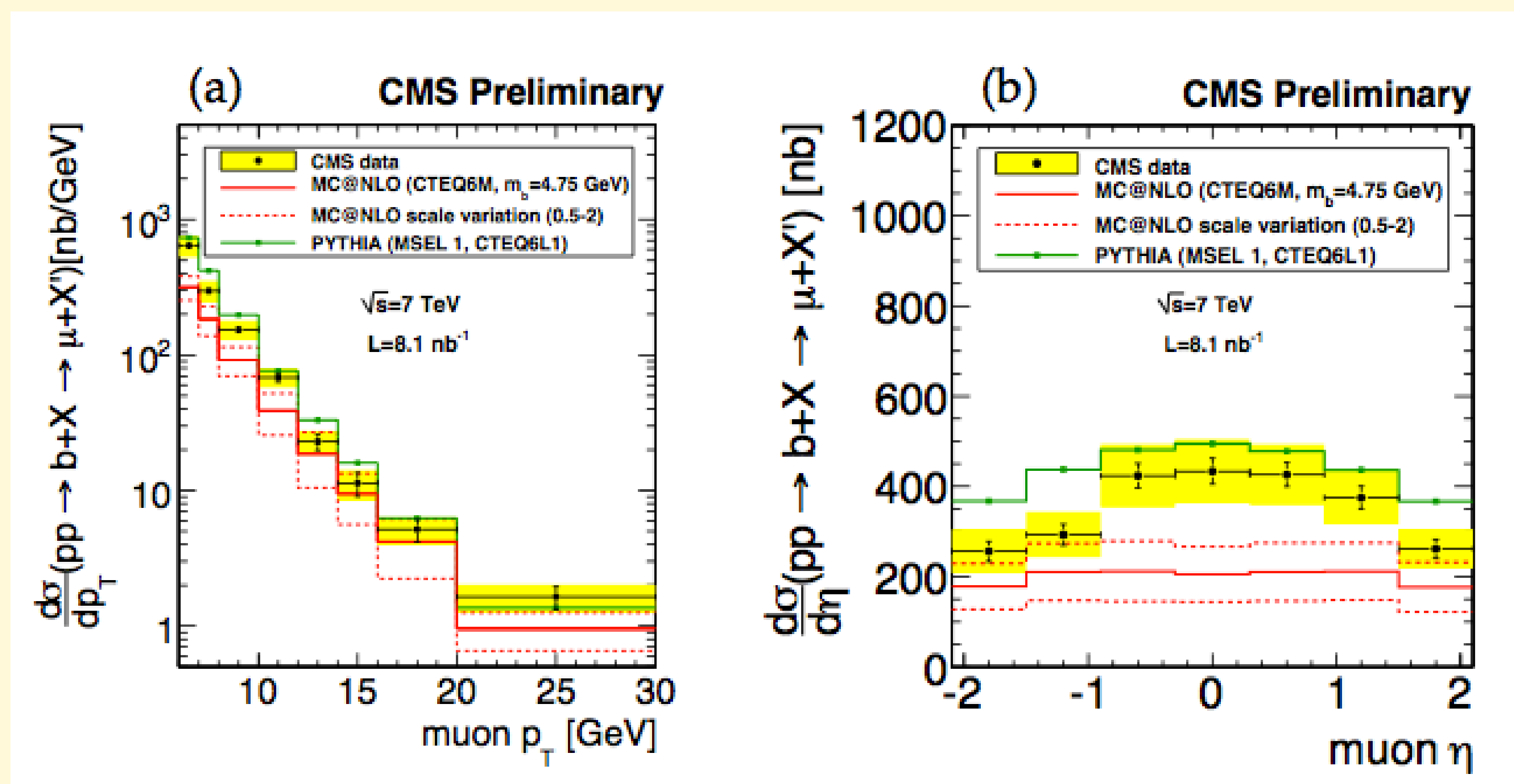
Nason, Dawson, Ellis
Collins, R.K.Ellis
Ball, Ellis
Catani Ciafaloni Hautmann
....

.... still, some inconsistency and disagreement needs to be sorted out









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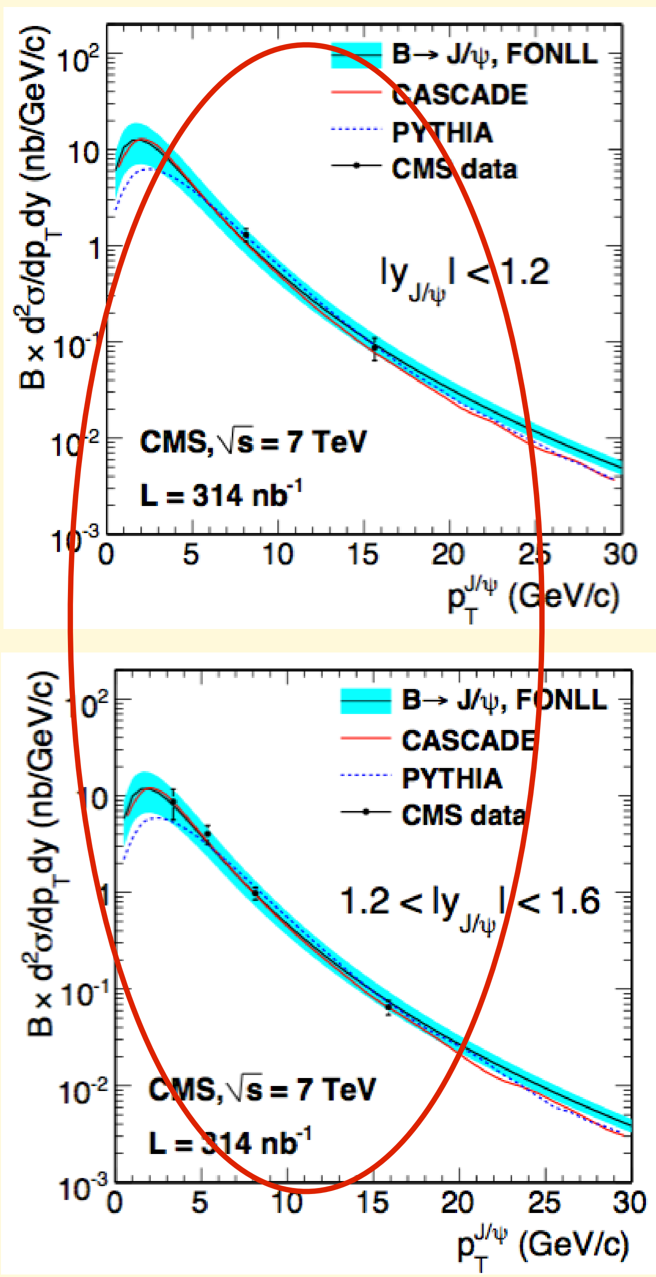

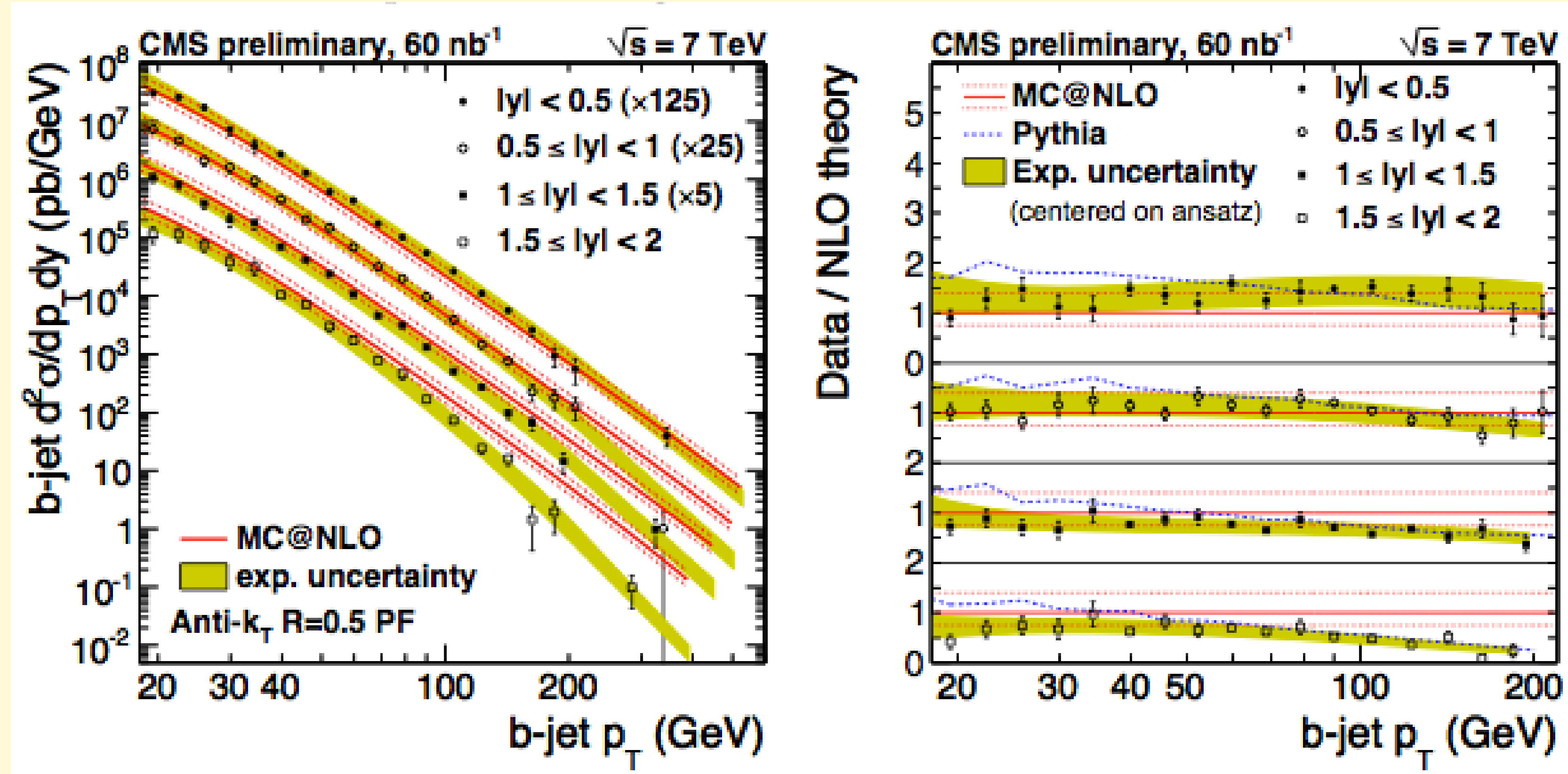

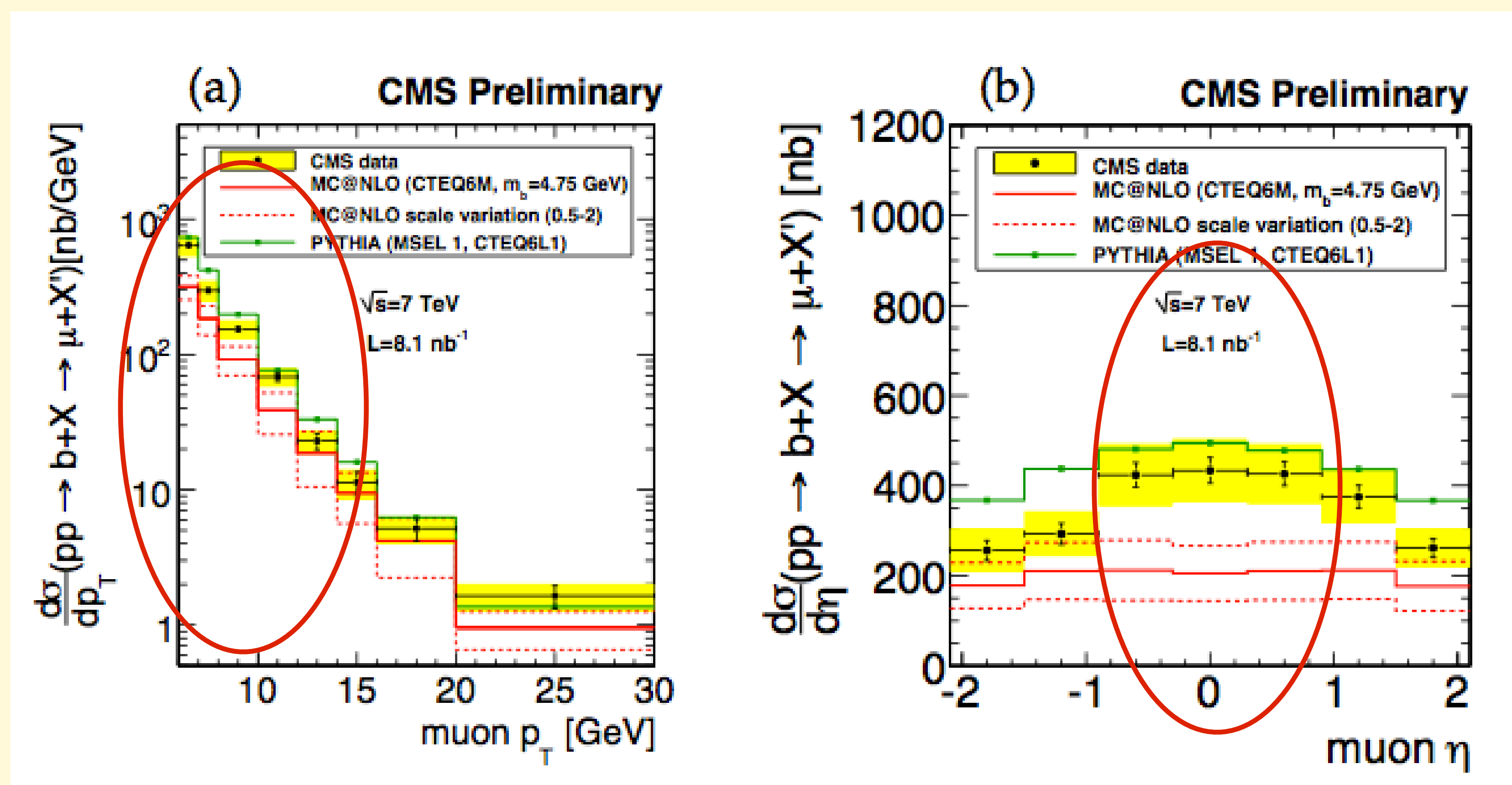

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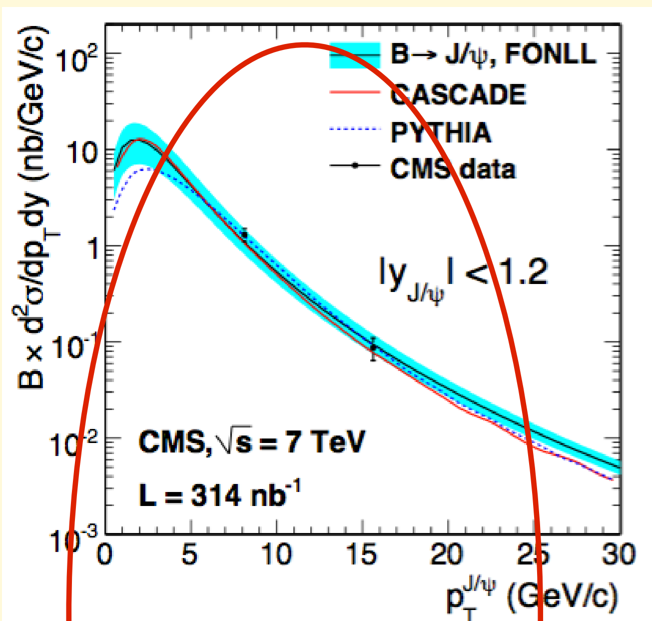
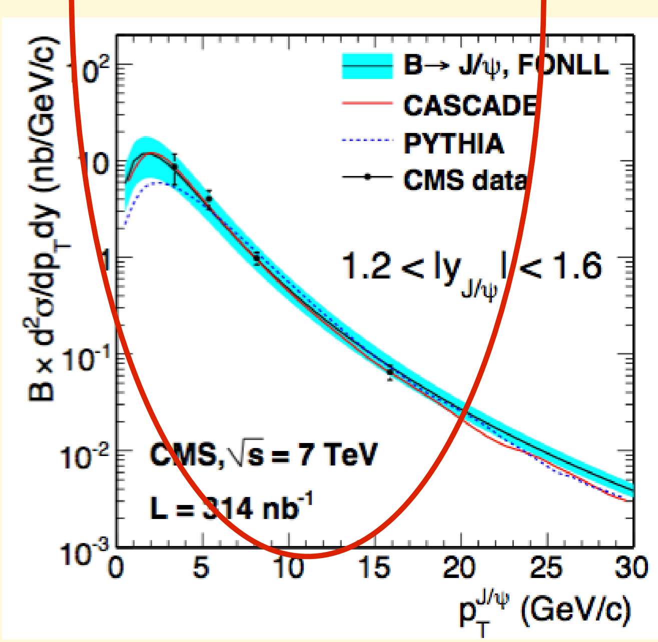
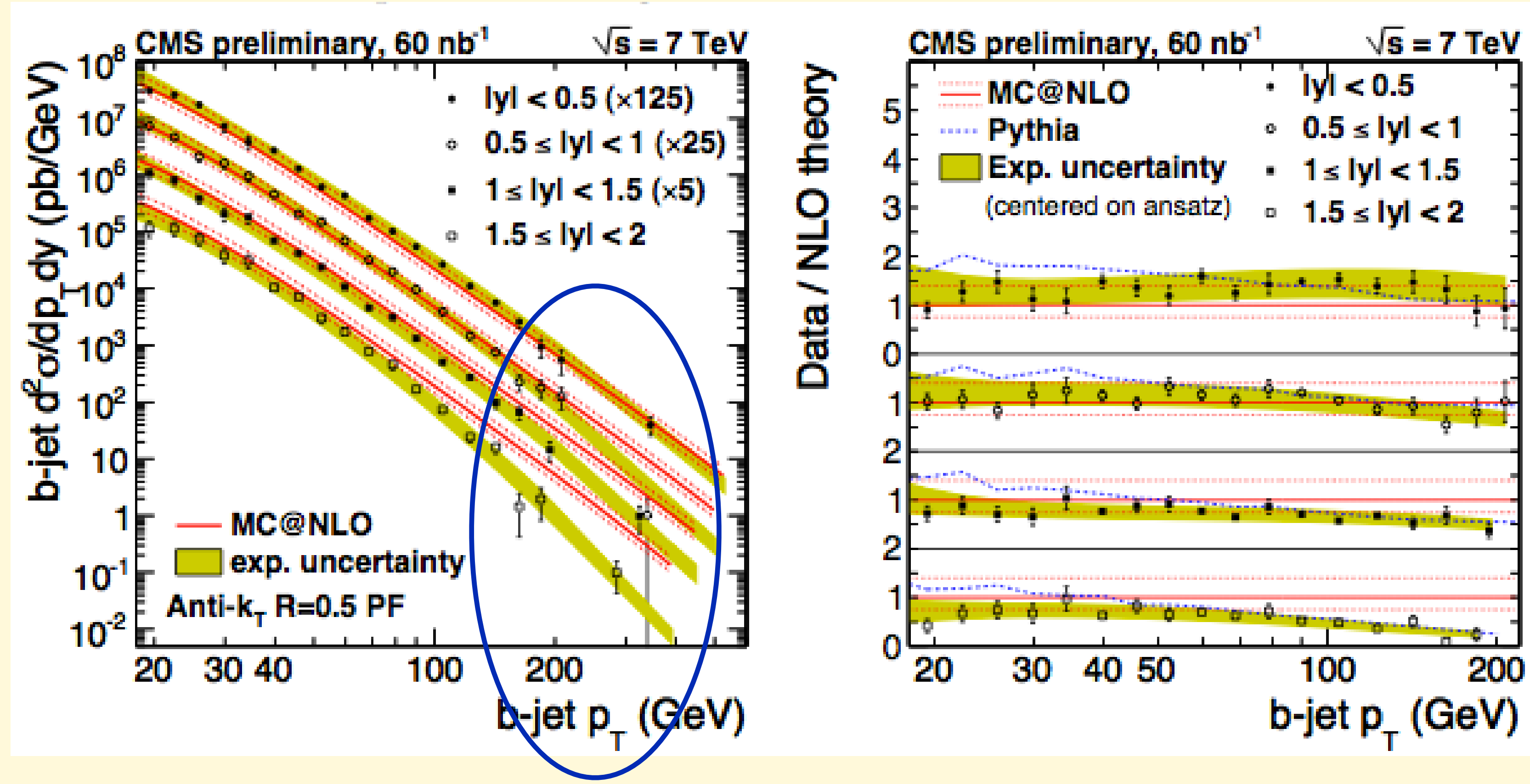
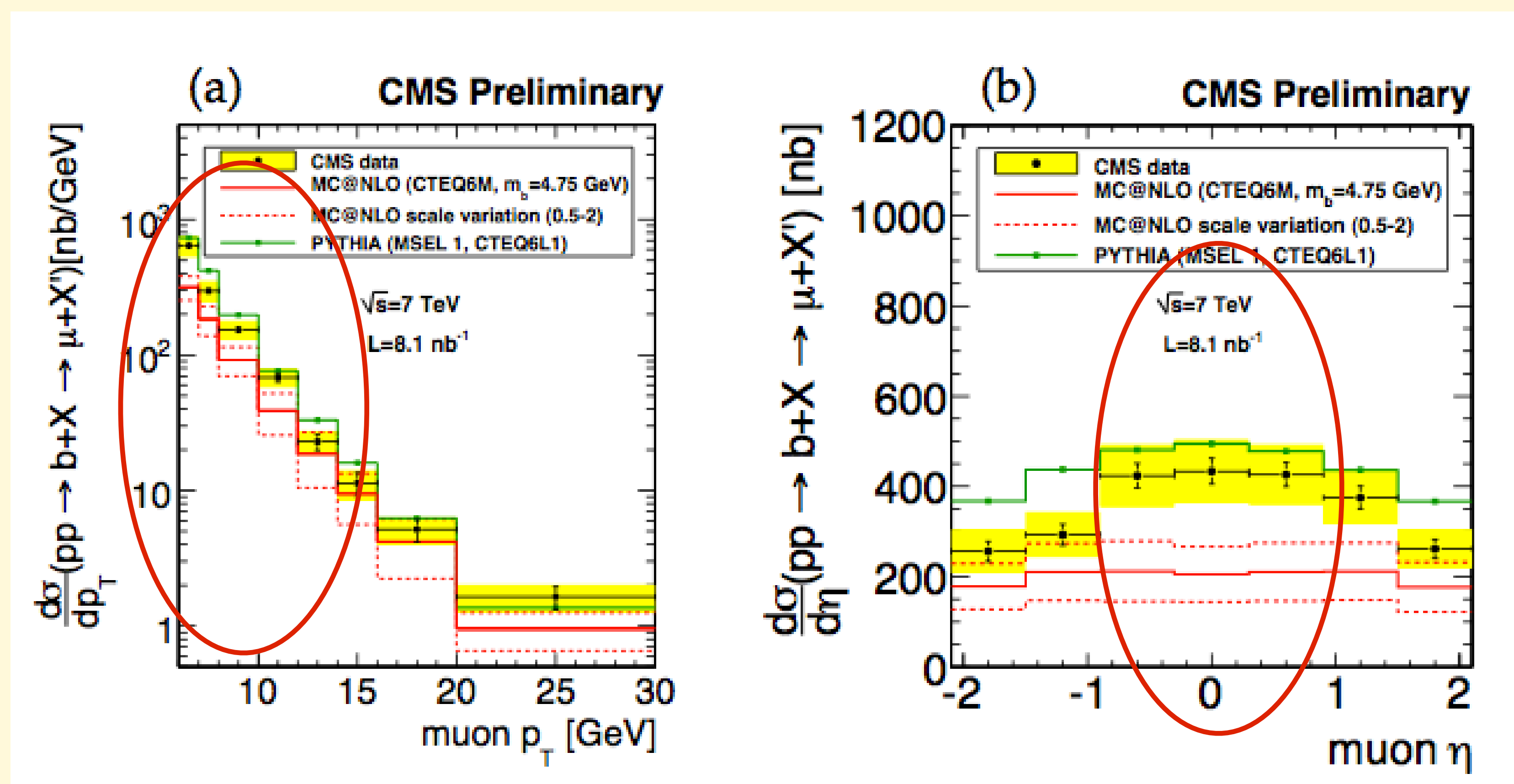
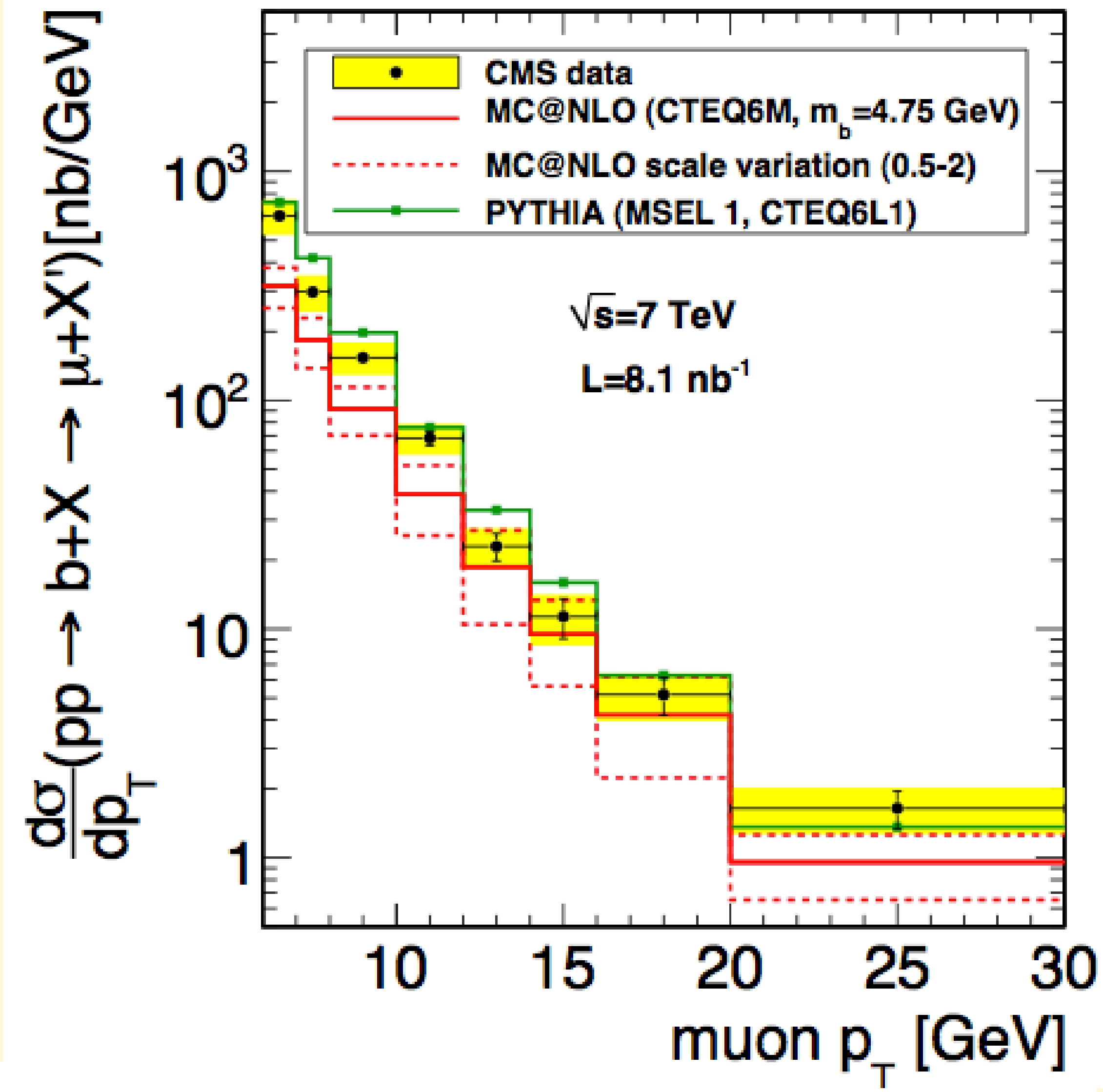
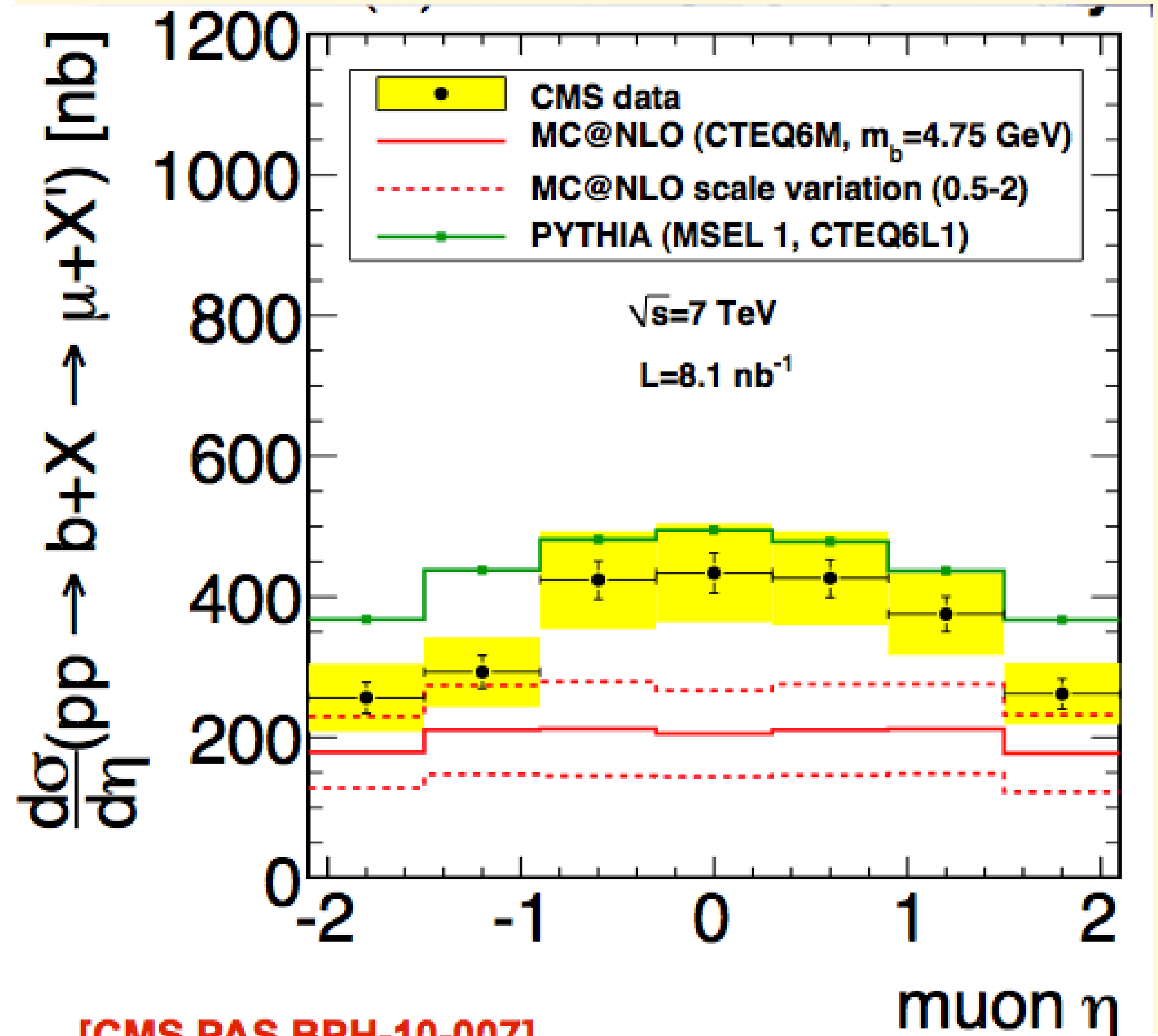




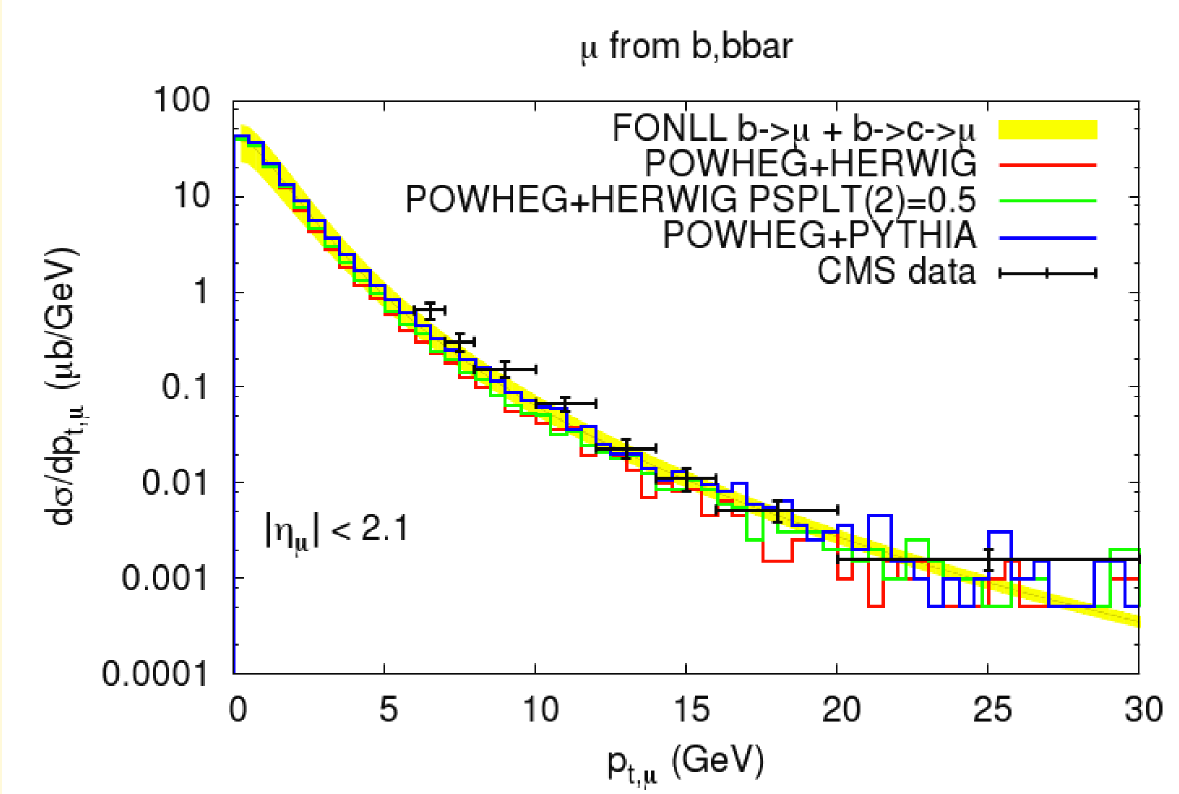


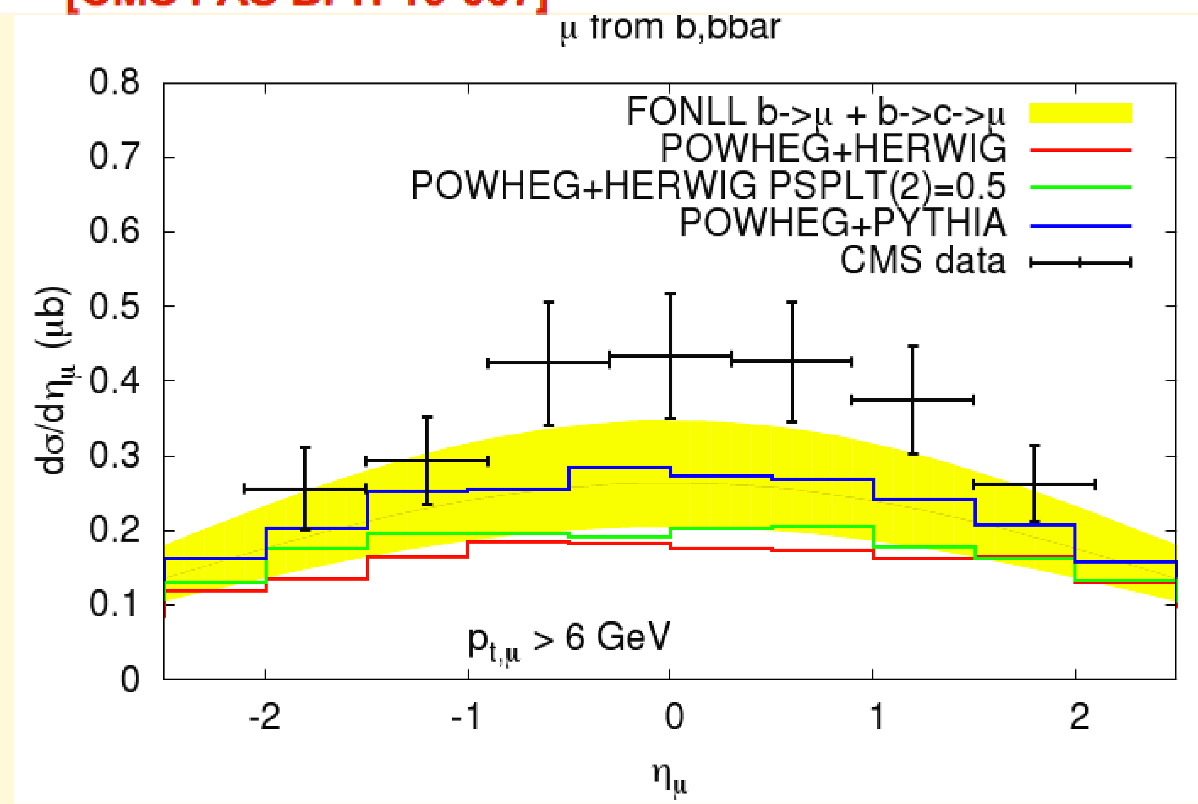




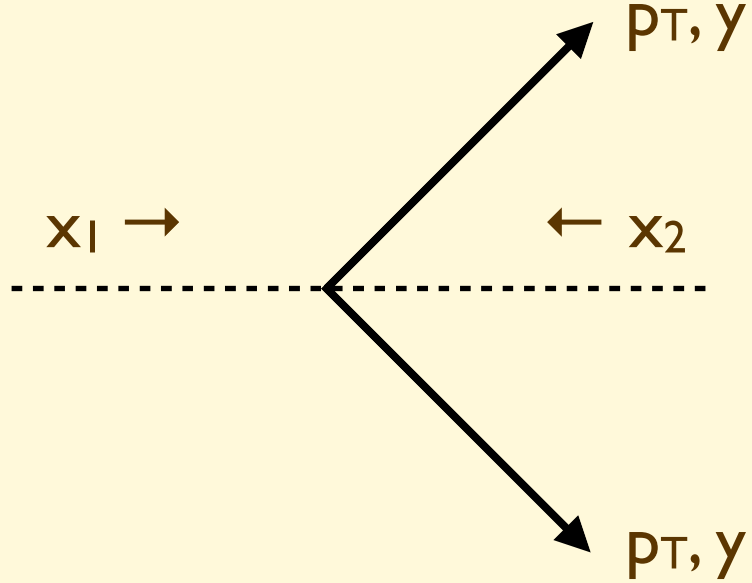


[CMS PAS BPH-10-007]

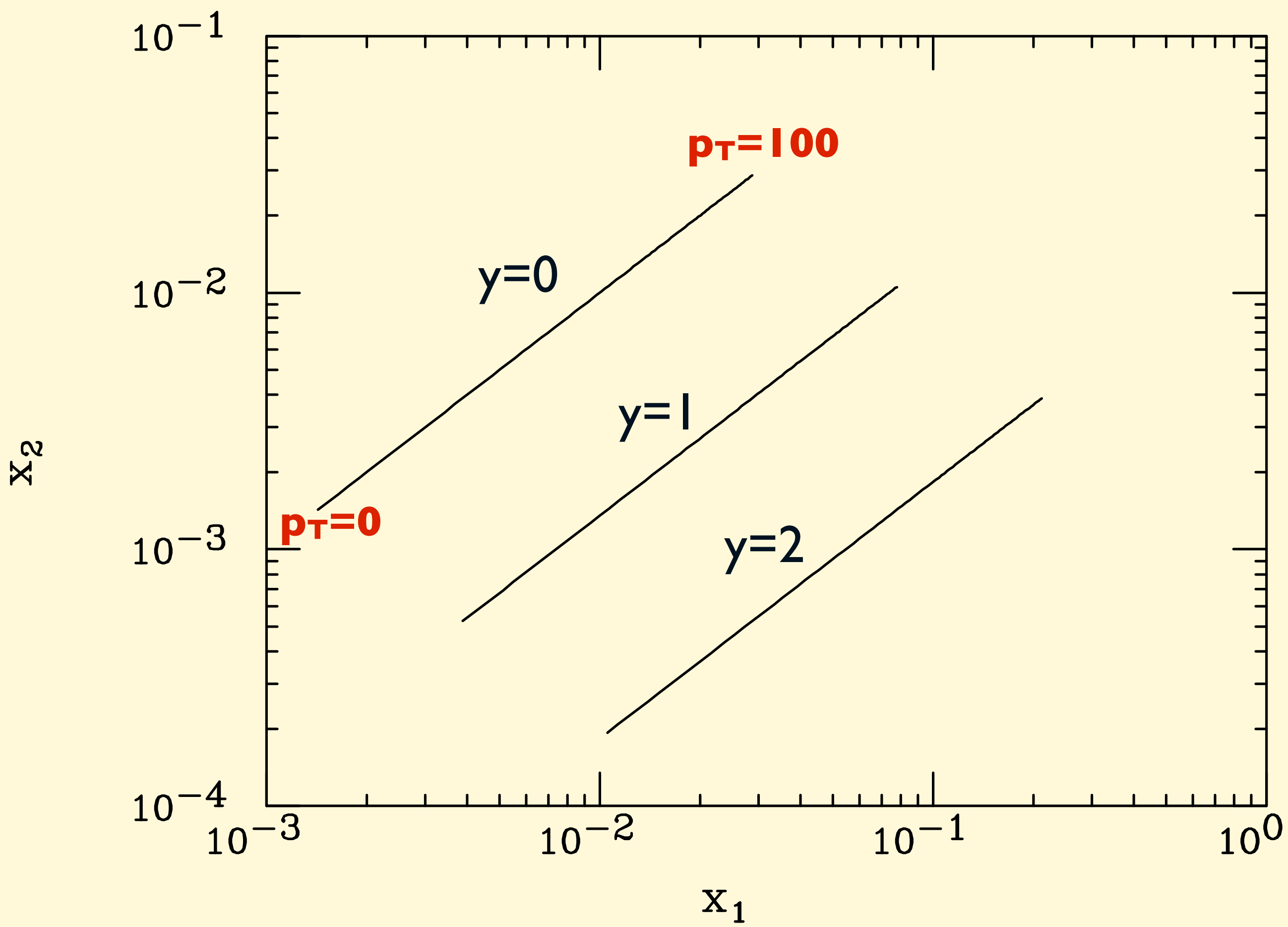


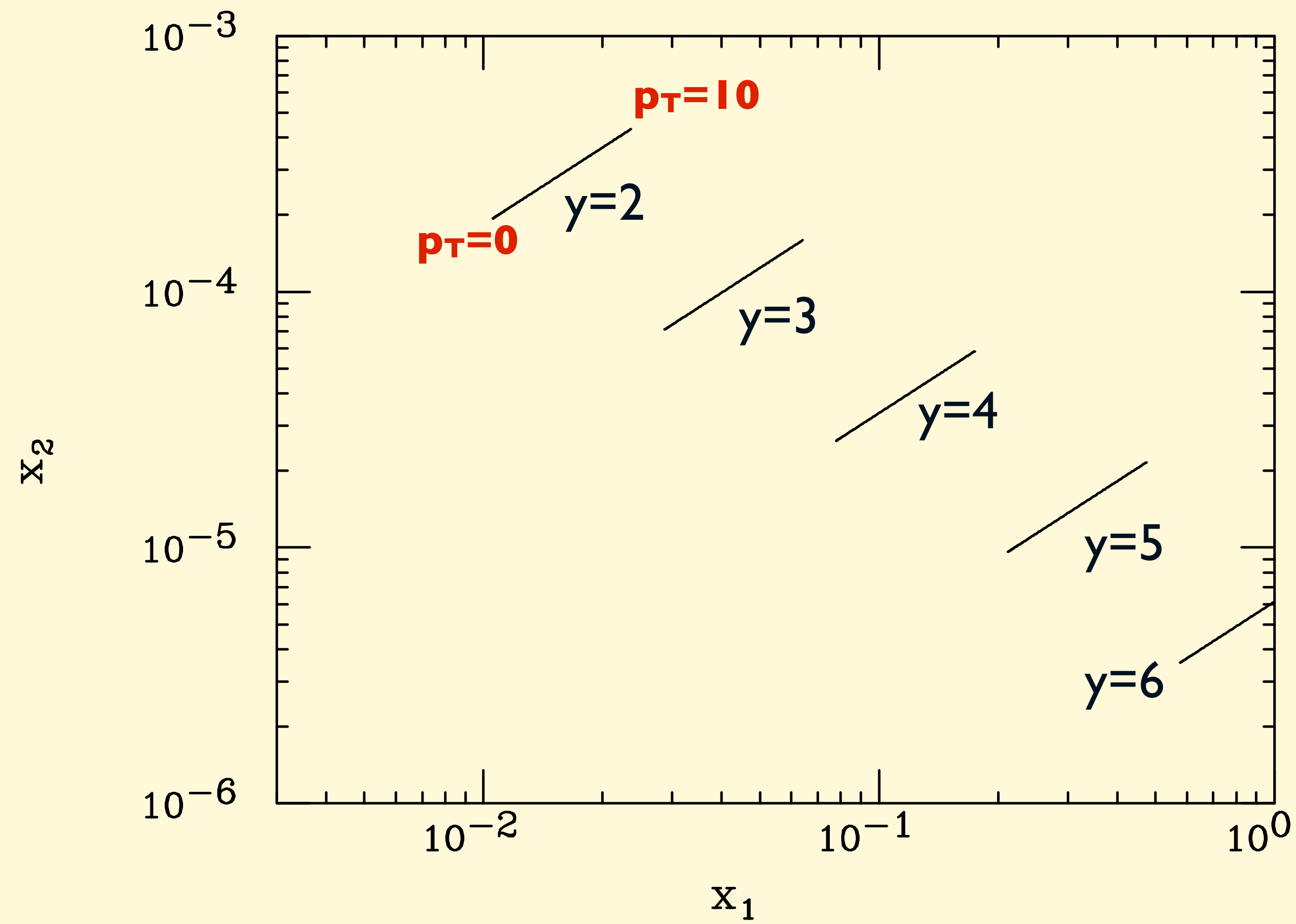


Kinematic reach

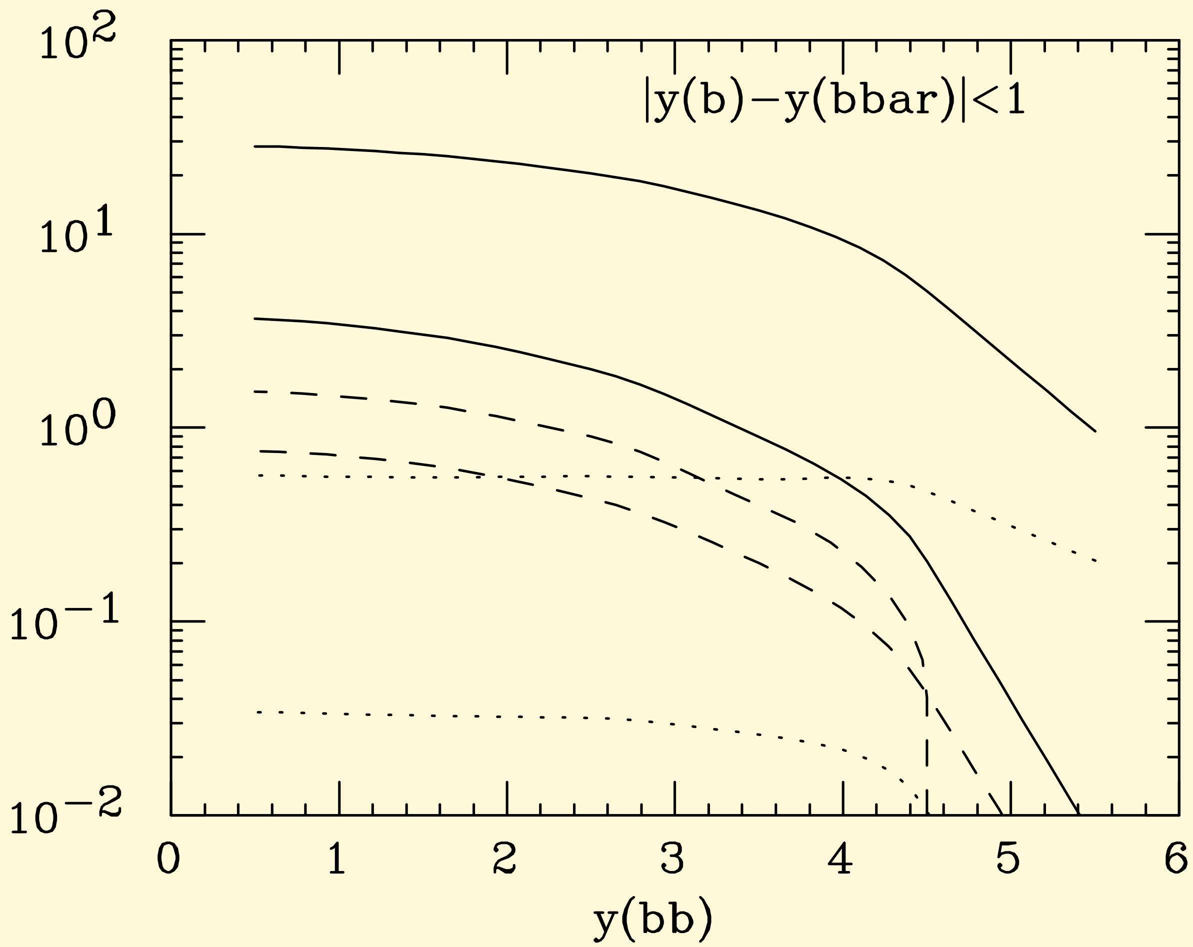


$$x_{1,2} = \frac{m_T}{E_b}\, e^{\pm y}$$





Initial state composition:



gg

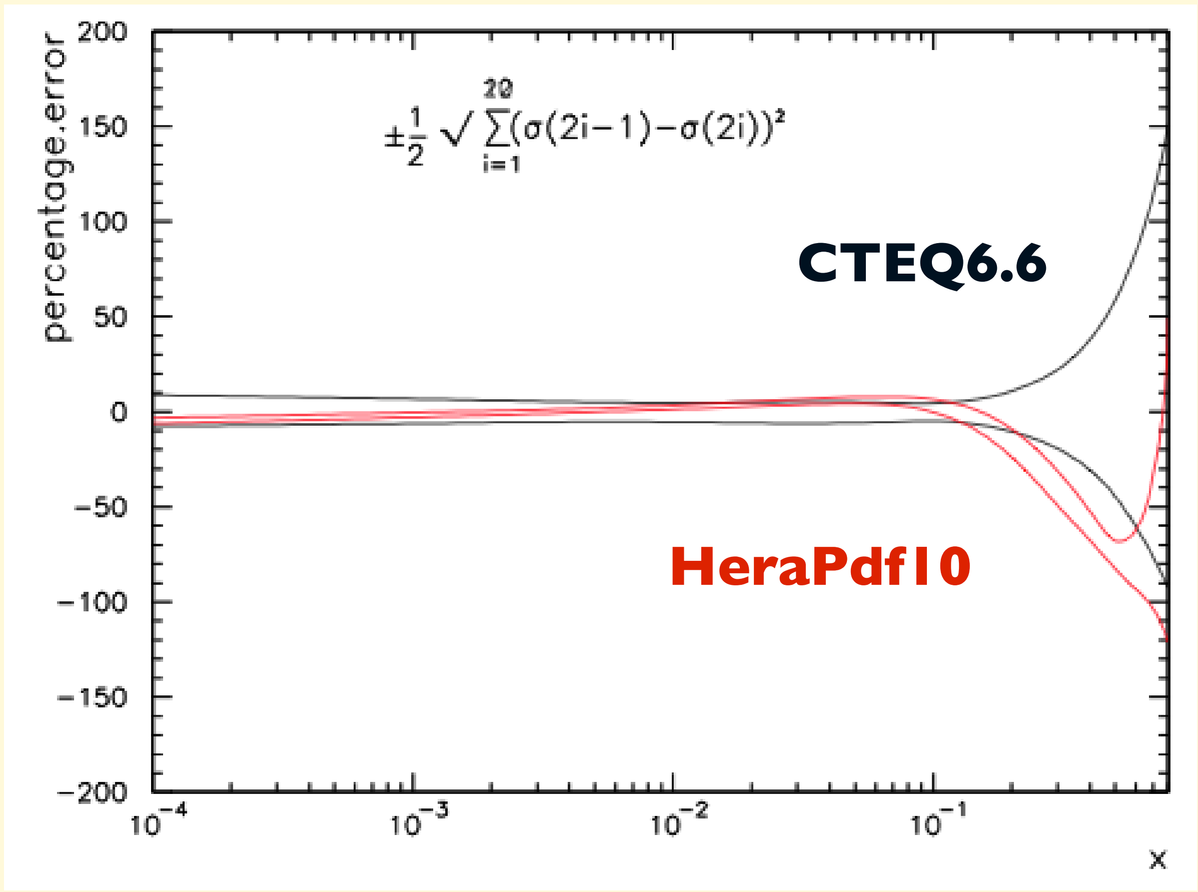
qg

qqbar

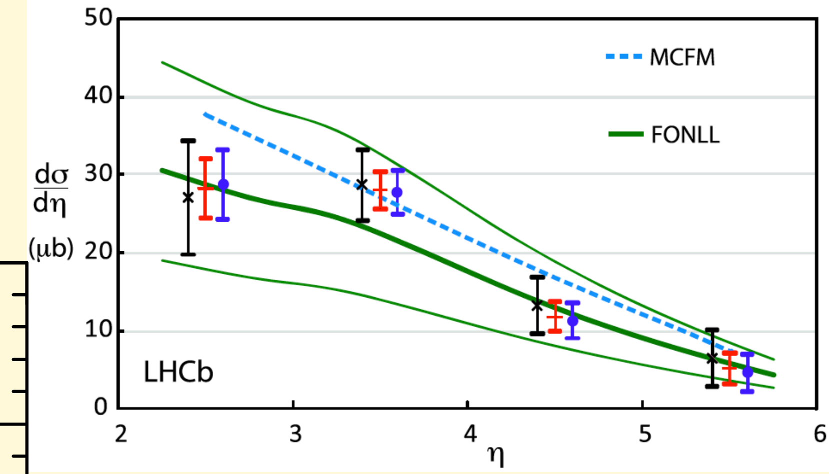
Upper curves: $p_T>0$

Lower curves: $p_T>12$ GeV

Dominated by gg initial state, possibly sensitive to gluon PDF



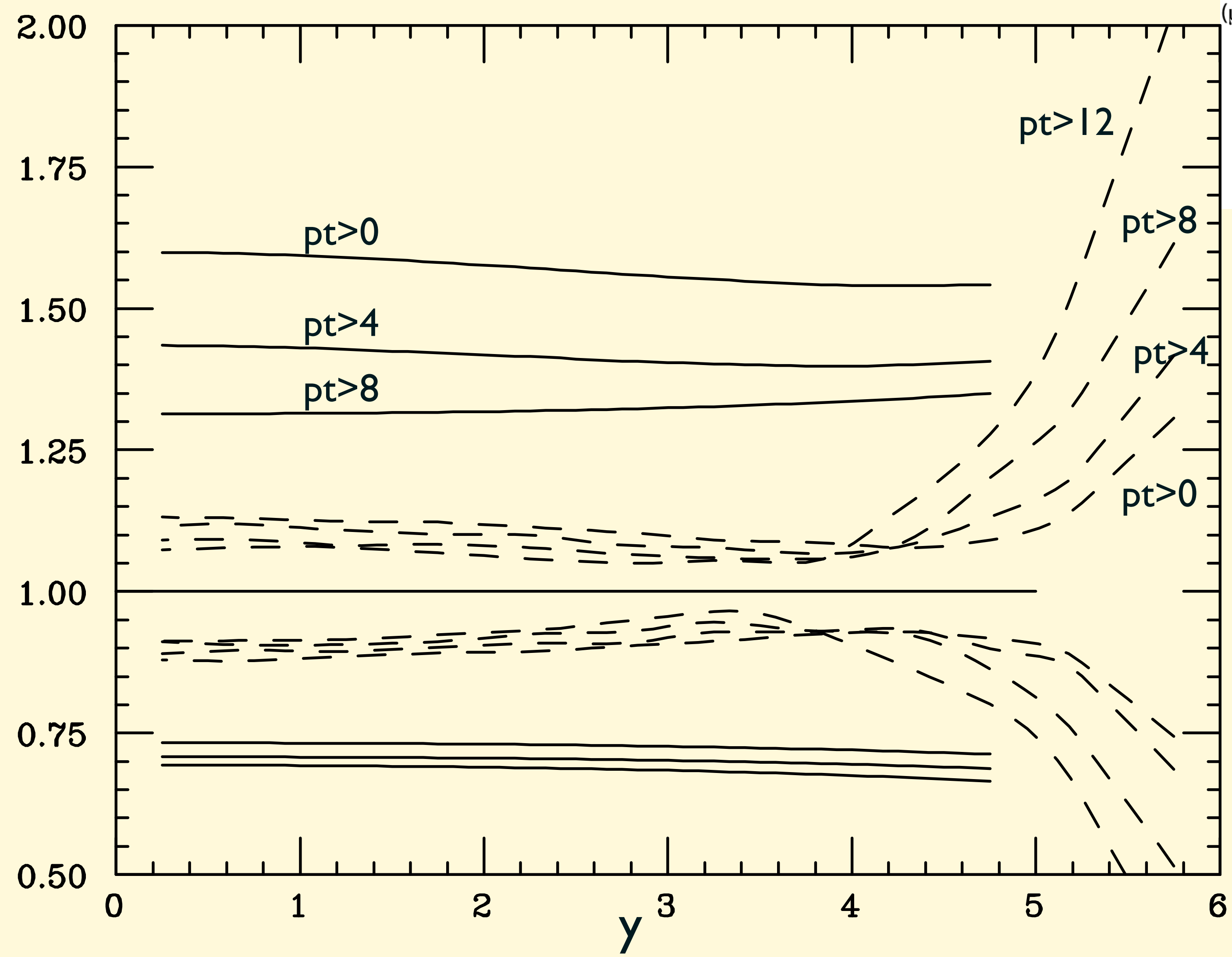
Scale vs PDF systematics



Solid lines: scale/mass systematics

$$\frac{\frac{d\sigma}{dy}(\mu_R^{max}, \mu_F^{max}, m_b^{max})}{\frac{d\sigma}{dy}(\mu_R^0, \mu_F^0, m_b^0)}$$

$$\frac{\frac{d\sigma}{dy}(\mu_R^{min}, \mu_F^{min}, m_b^{min})}{\frac{d\sigma}{dy}(\mu_R^0, \mu_F^0, m_b^0)}$$



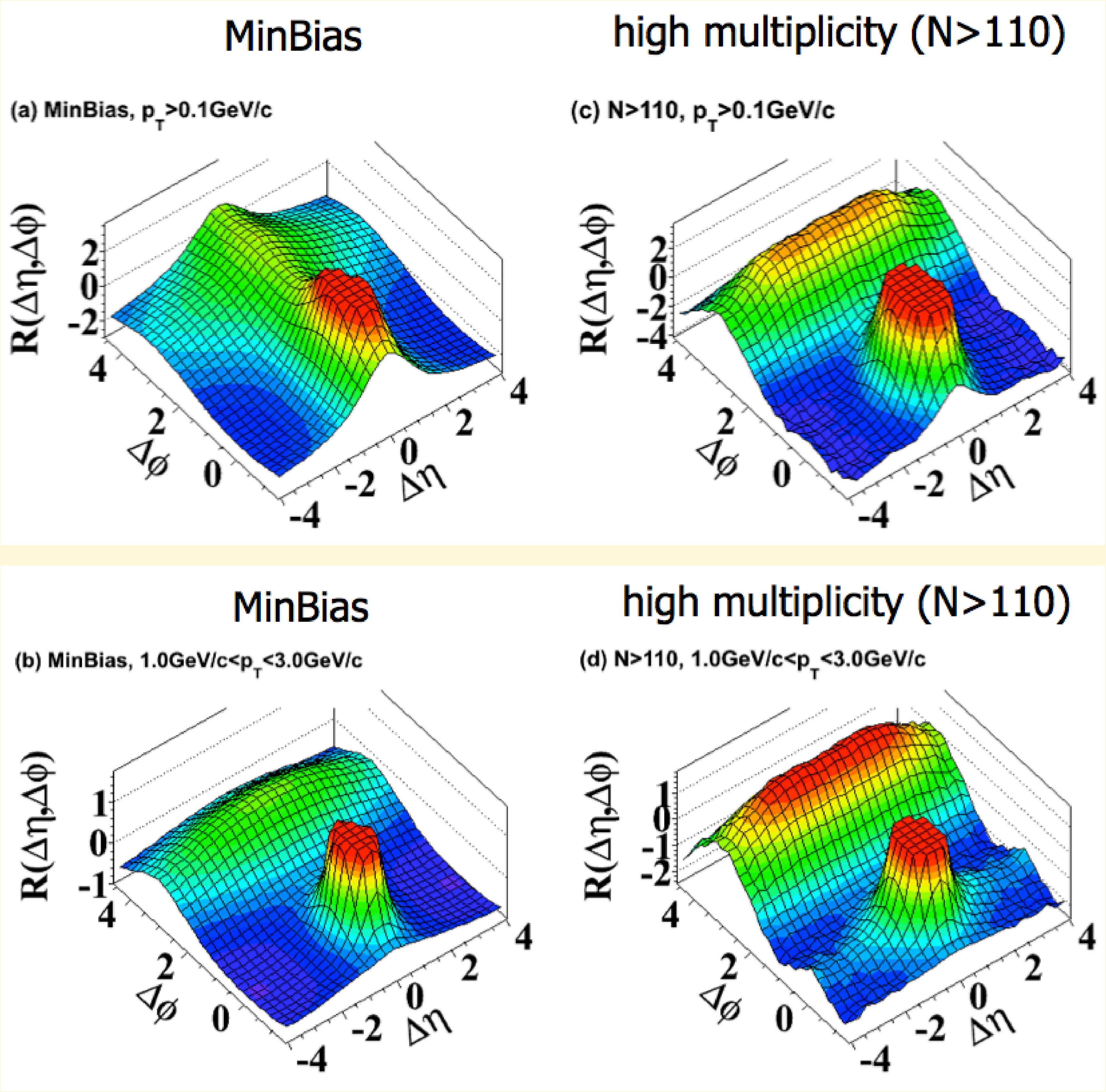
Dashed lines: PDF systematics (CTEQ6.6)

$\mu_{\mathbf{F,R}}^{\mathbf{max,min,0}}, \mathbf{m_b^{max,min,0}}$ parameter values at **maximum, minimum and central** values of the cross-section

- great stability of the y distribution vs scale/mass variations
- scale systematics fully correlated in y, so **y shape is robust**
- scale dependence at the ±30% level dominates over mass-dependence for $p_T \gtrsim m_b$
- PDF systematics affects the shape of the y distribution well beyond the effects of scale variations, once y>4 => **PDF sensitivity**

CMS's "ridge" in high-multiplicity events

2-particle correlation function $S_N(\Delta\eta,\Delta\varphi) = \frac{1}{N(N-1)} \frac{d^2 N^{signal}}{d\Delta\eta d\Delta\varphi}$



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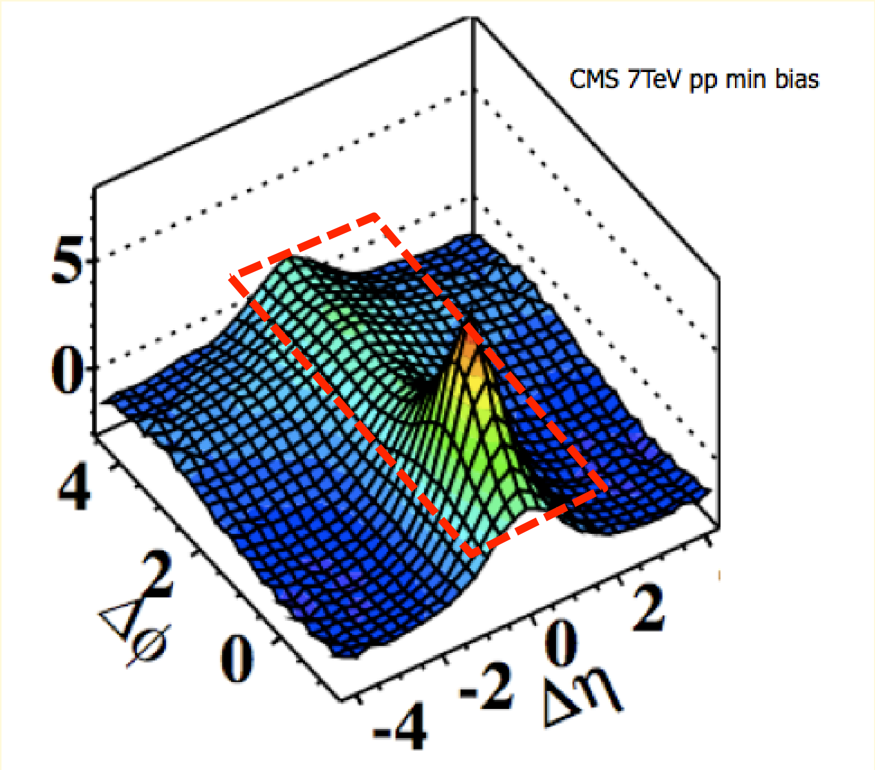
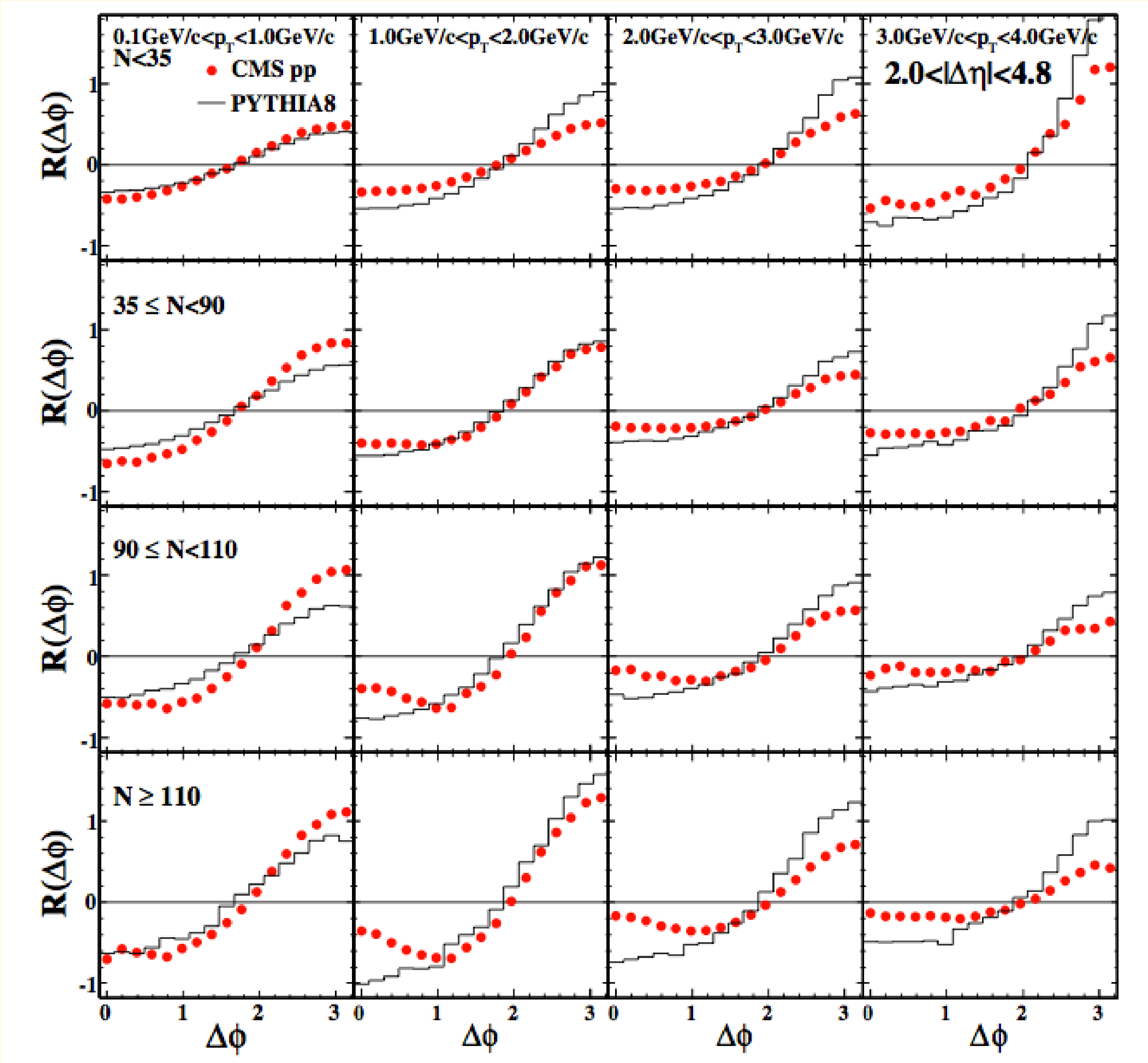


Integrating in eta, outside of the jet region:



Many of us tried, but failed to explain this observation using pQCD (we thought it was a colour coherence effect, which only full matrix-element calculations can describe accurately)