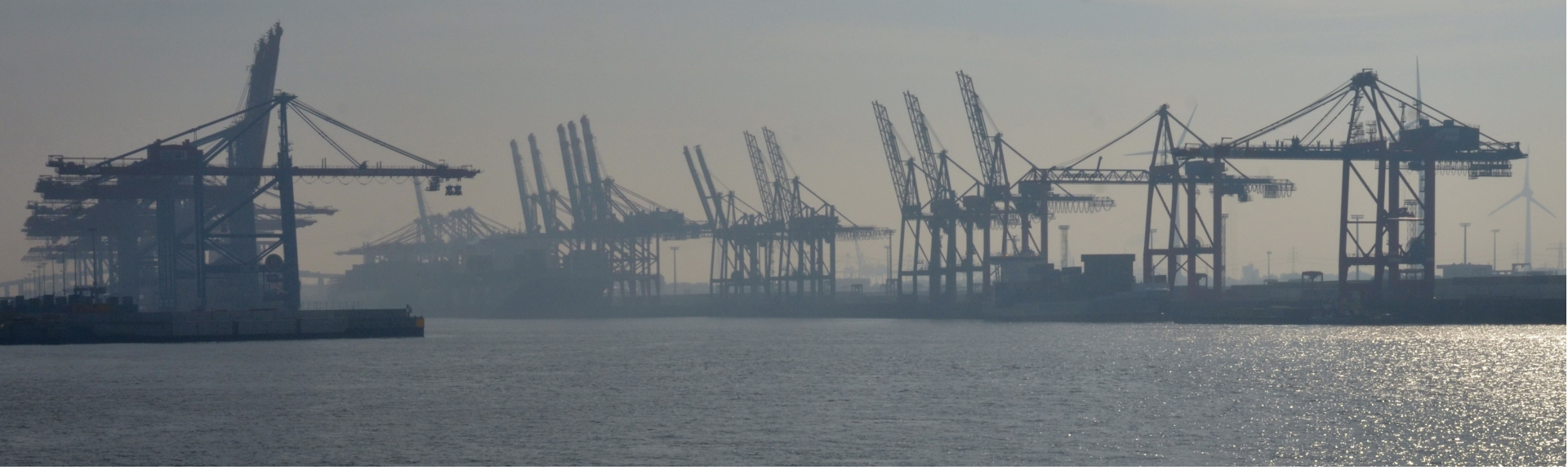


QCD at colliders

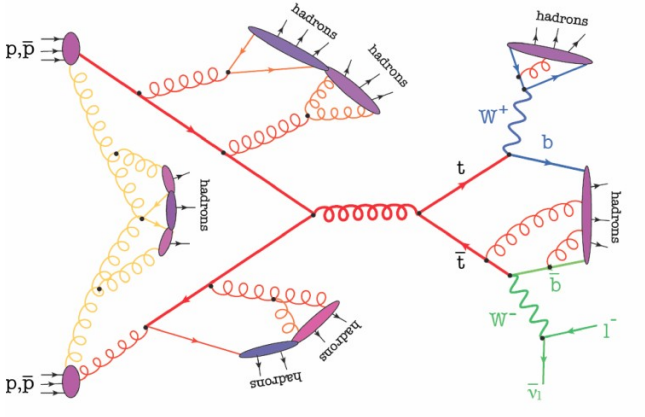
Katharina Müller
on behalf of the LHCb collaboration
Physik Institut
University of Zurich

University of Zurich[UZH]

Outline

talk presents recent results on production of

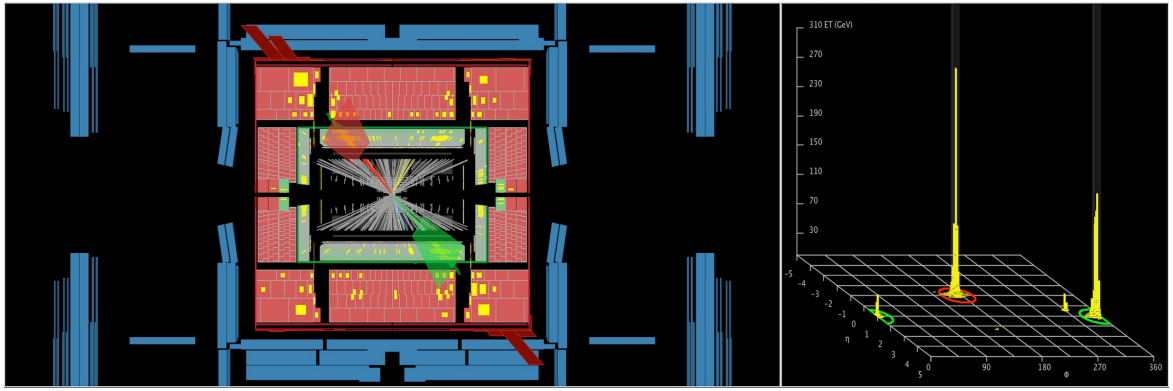
- jets
- isolated photons
- inclusive single vector bosons
- vector bosons plus jets
- heavy quark (not top)



Drawing: K. Hamilton

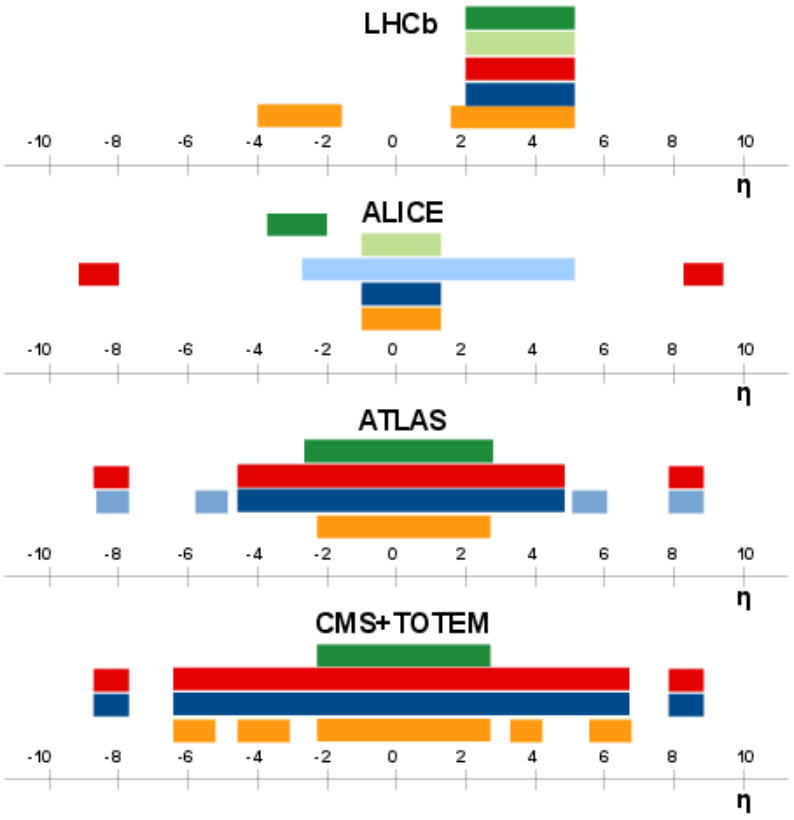
does not cover

- multibosons→ talk by Sandra Kortner this afternoon
- heavy ion
- diffraction
- double parton scattering
- soft QCD
- ...



highest mass central dijet event collected by ATLAS - M=4.23 TeV
https://twiki.cern.ch/twiki/bin/view/AtlasPublic/EventDisplayStandAlone

Coverage of LHC detectors



- ATLAS and CMS:
  precision tracking and muon identification in central region
- ATLAS and CMS:
  forward calorimetry - measurements of electrons and jets for $|\eta| < 5$
- ALICE focus on heavy ion physics
  very high multiplicity events
- LHCb:
  coverage for $\eta > 2$ – excellent tracking and particle identification
  low p_T, low mass triggers
  → complementary measurements

Jets

Inclusive jets @ 8 TeV

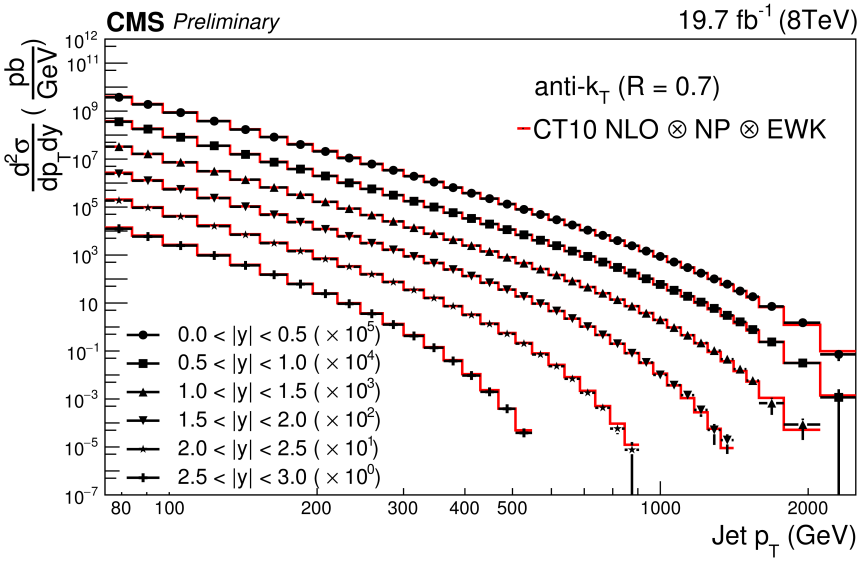
p_T(jet)>74 GeV

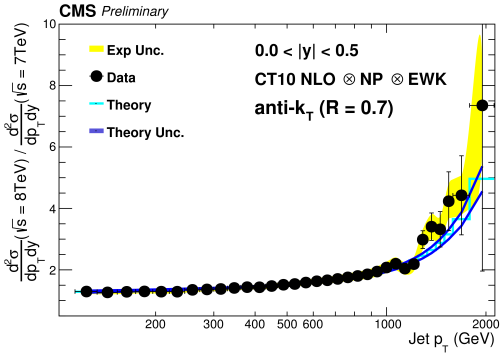
sensitive to α_s and PDF

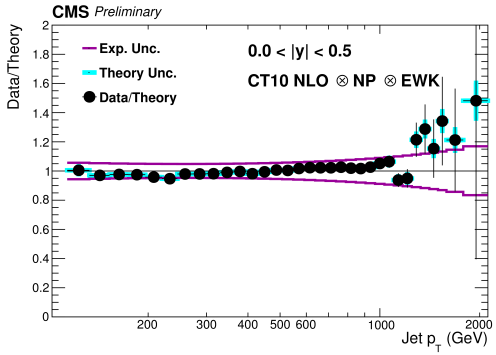
uncertainties highly correlated

overall good description by NLO measurement at 2.76 TeV arXiv:15120612

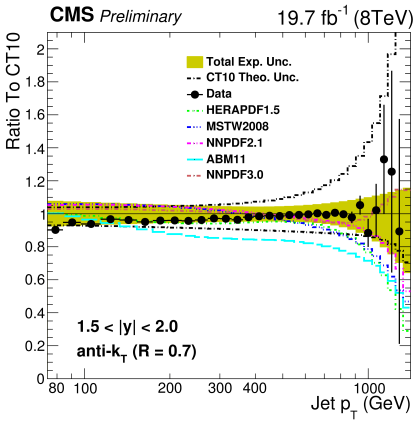
ratio between 7 and 8 TeV described within uncertainties

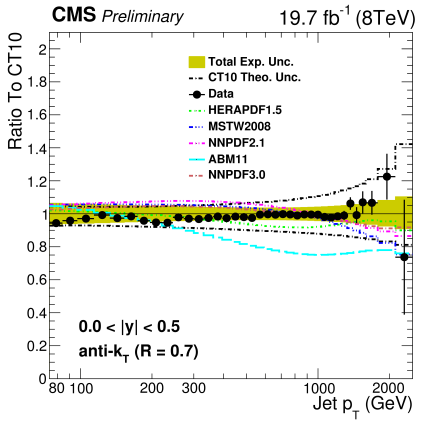






ratio to theory for different PDF sets → valuable input for PDFs





Inclusive jets at 13 TeV

CMS-PAS-SMP-15-007
ATLAS-CONF-2015-034

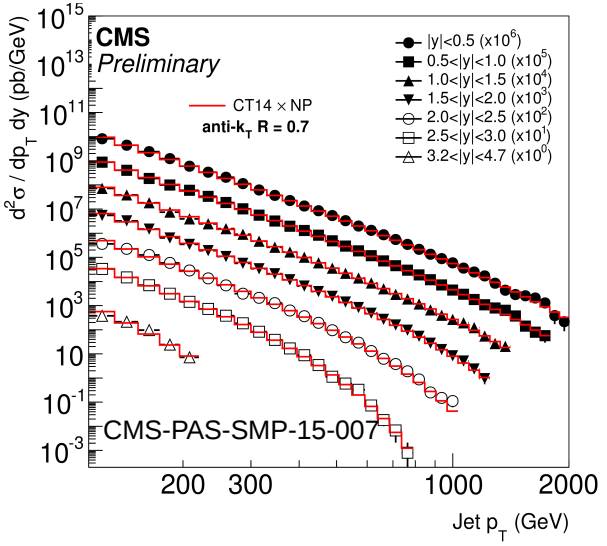
CMS: double differential x-sections with R=0.7 and 0.4
ATLAS: differential x-section with R=0.4

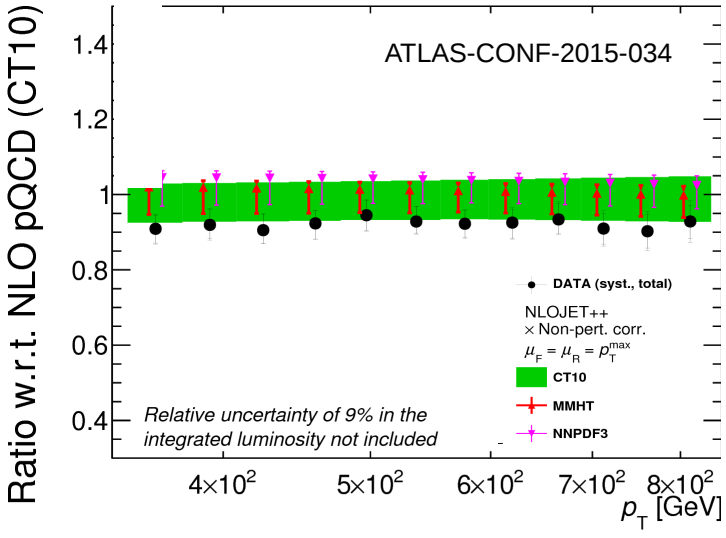
jet p_T: consistent with predictions
over large range of p_T

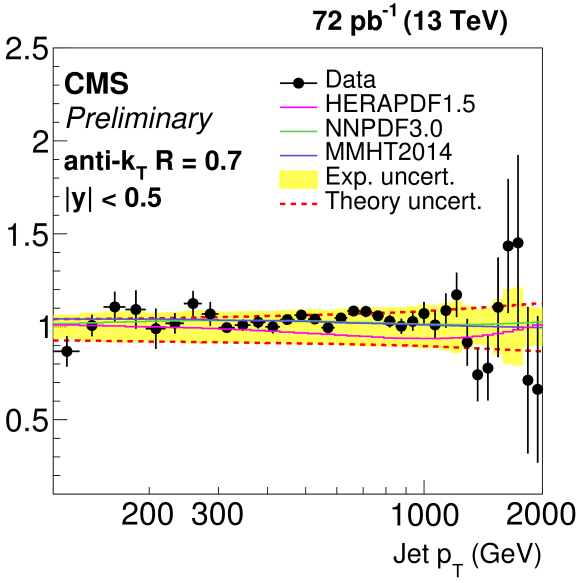
ratios over NLOJet++
- R=0.7 good overall agreement
- R=0.4 5-10% overestimation
→ indication of soft effects?

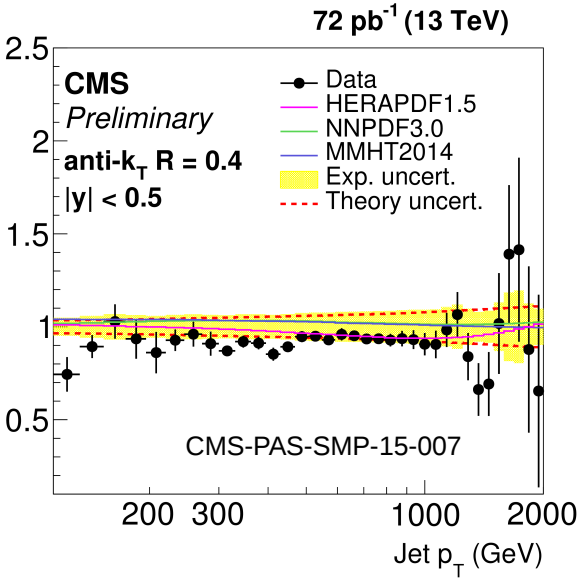
this was already observed at lower cm energies

NLOJet++ predictions









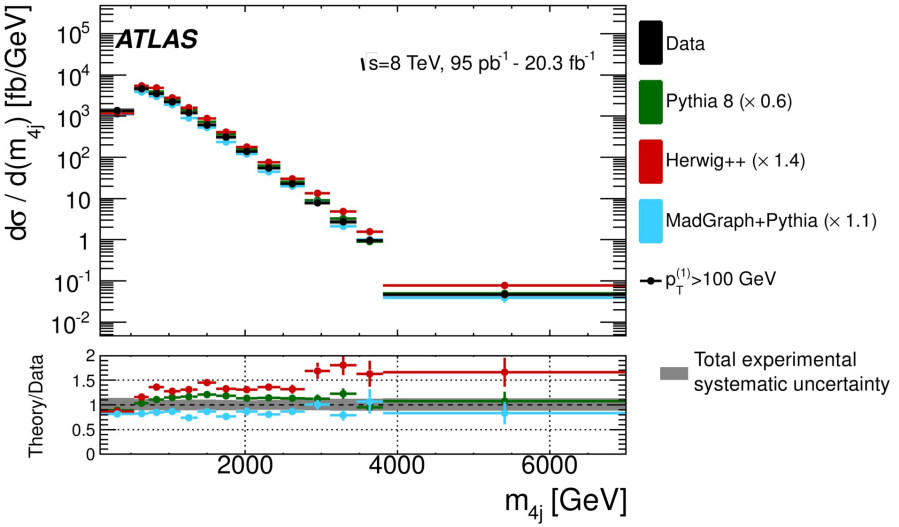
Multijets: 4-jets @ 8 TeV

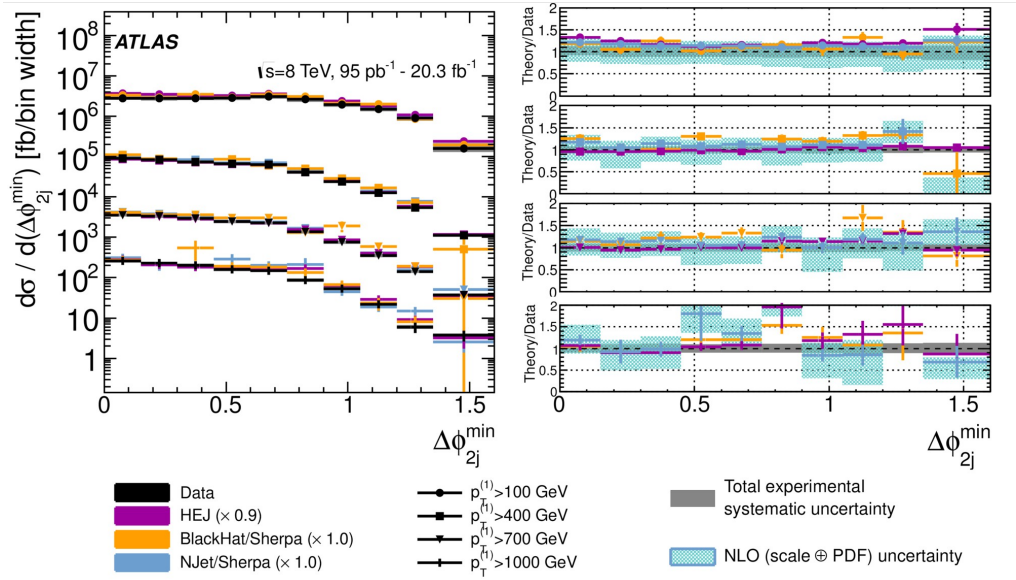
JHEP 12 (2015) 105

four jet events: background for many searches

topological variables sensitive to
QCD colour factors, spin of gluons
hadronisation models

invariant 4-jet mass
HERWIG++ overshoots for high inv. masses





min. angular separation for different p_T

test description of small and
wide angle radiation

- NLO predictions (Blackhat or Njet/Sherpa)
  compatible within large uncertainties
- HEJ (all-order resumm.): good description
- HERWIG ++ very good

but no prediction describes all distributions

(CMS 7 TeV result:
Eur. Phys. J. C 75 (2015) 302)

CMS: azimuthal decorrelations @ 8 TeV

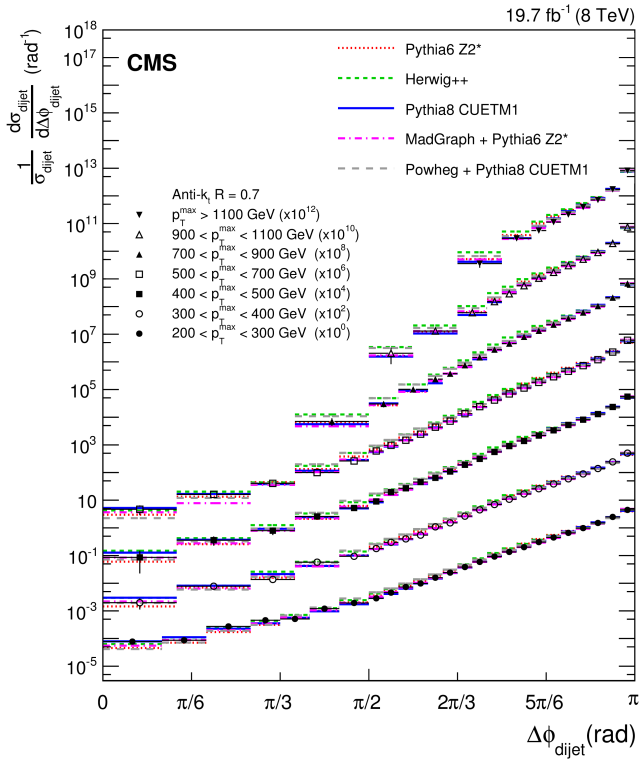
arXiv:1602.04384

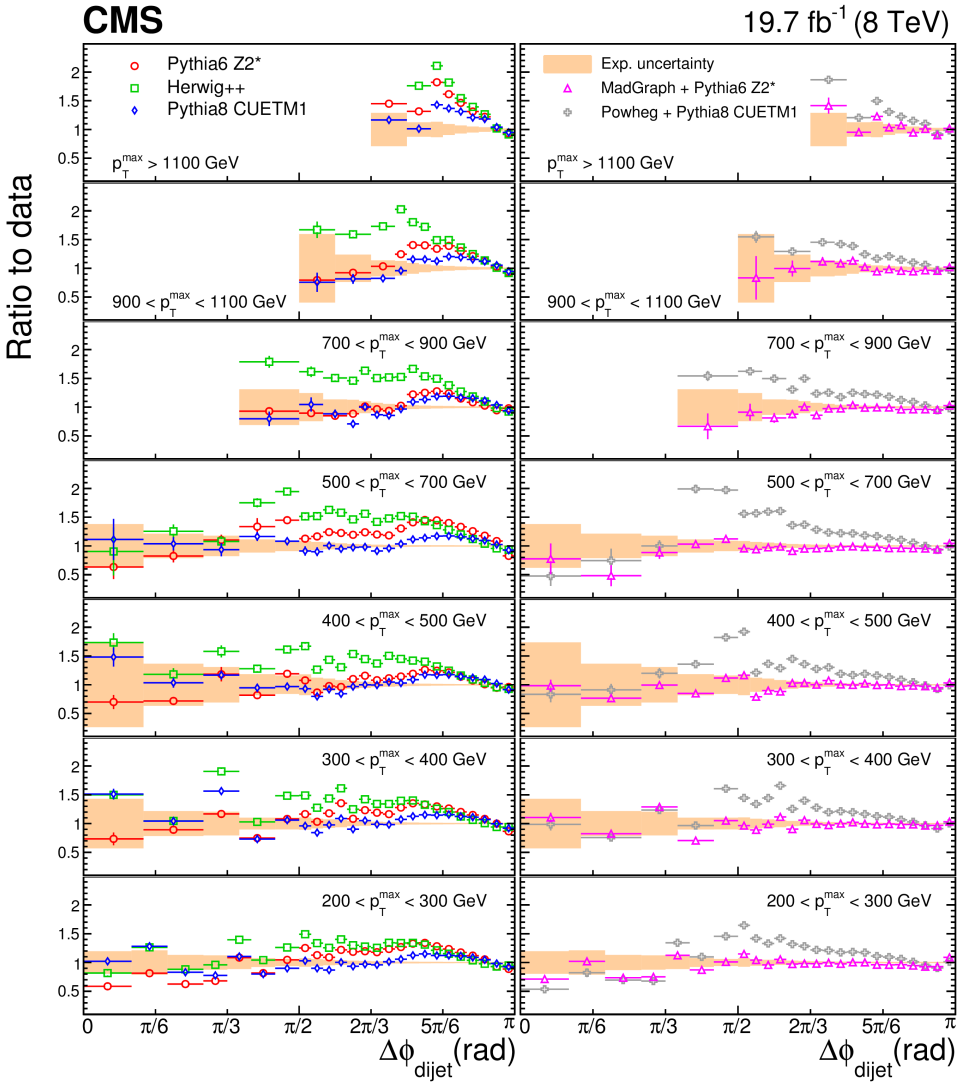
two leading jets with p_T>100 GeV, |y|<5

comparison to generator plus PS:

- LO or NLO:
  PYTHIA6, PYTHIA8, HERWIG++,
  POWHEG do not describe data
- MADGRAPH: good description

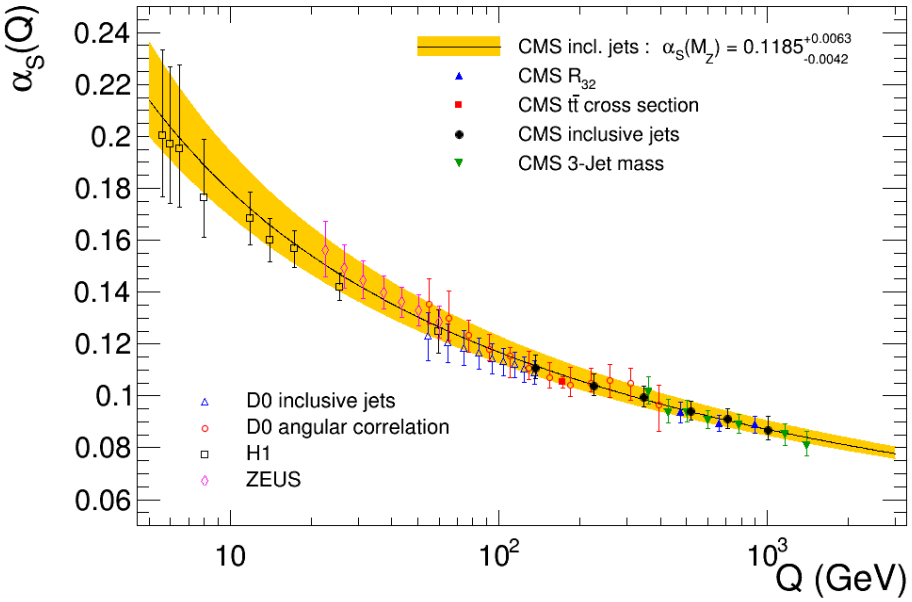
→ need to improve MC predictions for multijet production





Strong coupling constant

hep-ex/1410.6765, hep-ex/1412.1633

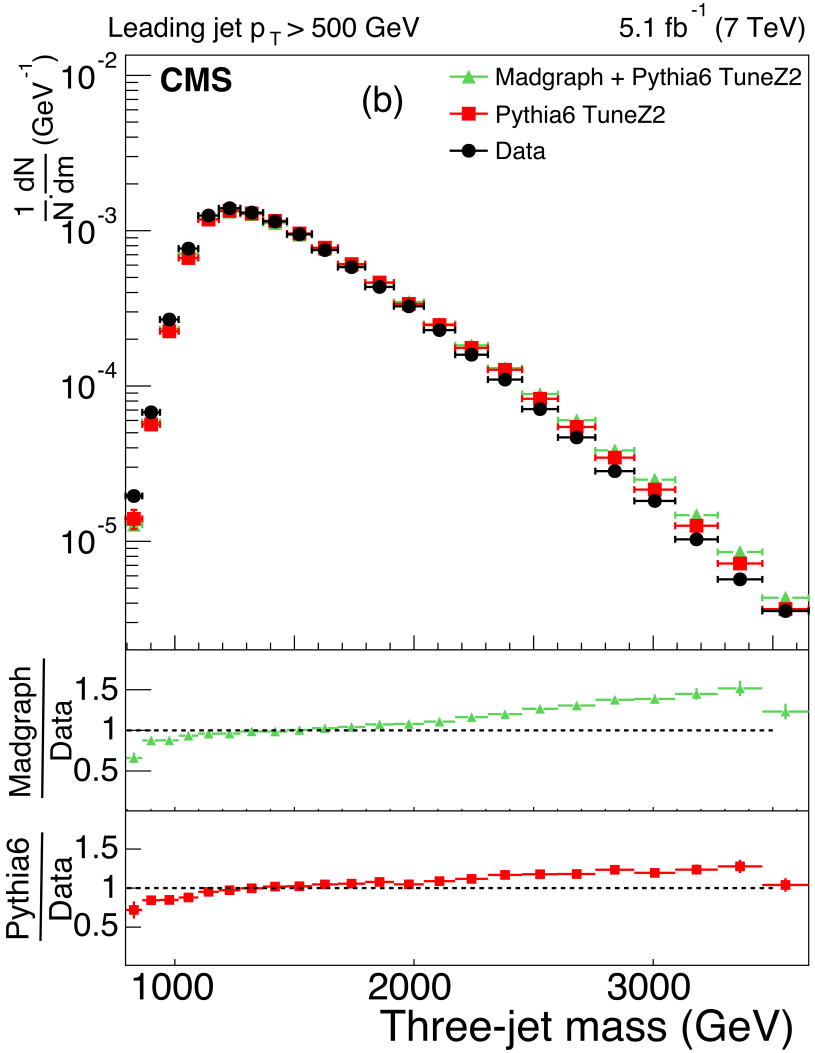


$\alpha_S(Q)$ evolution as determined from

- inclusive jet analysis (solid curve with yellow uncertainty band)
- ttbar x-section
- 3-jet mass

→ range in Q up to ~ 1.4 TeV

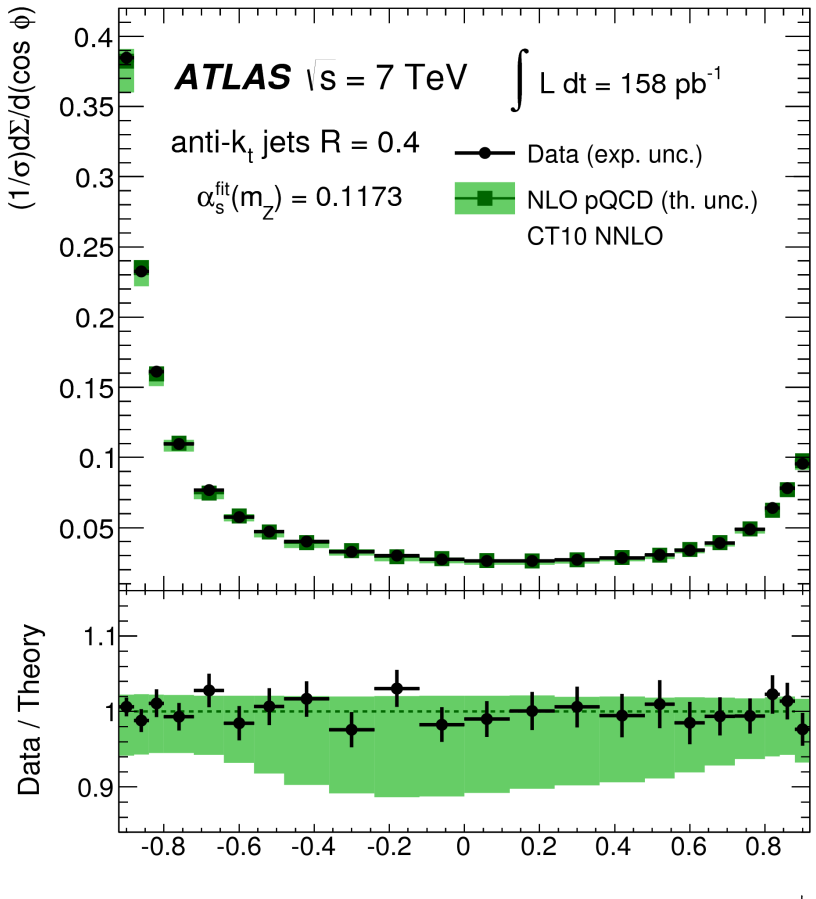
Eur. Phys. J. C 75 (2015) 302

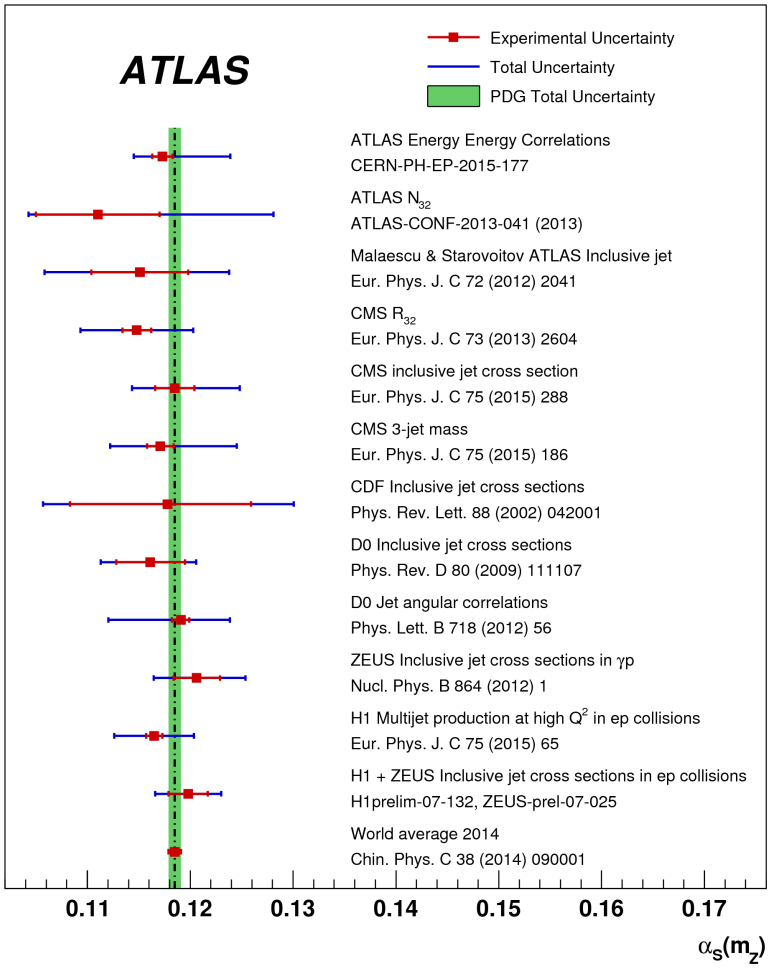


Strong coupling constant

Physics Letters B 750 (2015) 427-447

transverse energy-energy correlations





$$\alpha_s(m_Z) = 0.1173 \pm 0.0010\,(\text{exp.})\ {}^{+0.0063}_{-0.0020}\,(\text{scale})\ \pm 0.0017\,(\text{PDF})\ \pm 0.0002\,(\text{NPC})$$

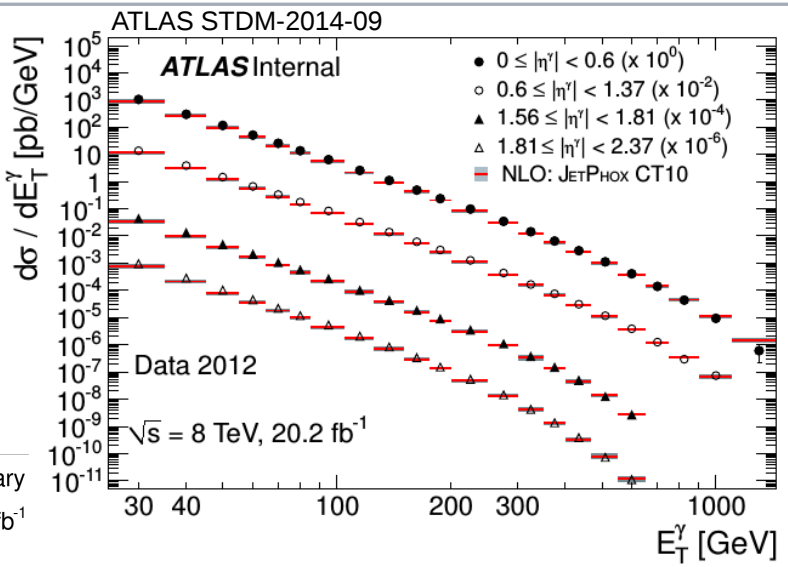
→ theoretical uncertainties dominating

Isolated photons

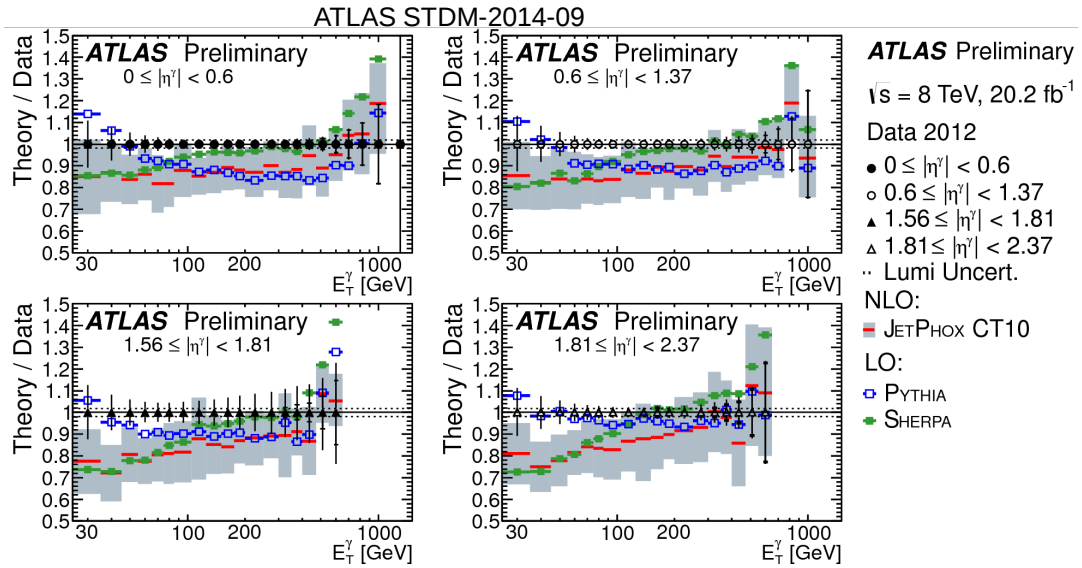
Inclusive photons @ 8 and 1.96 TeV

comparison:
NLO: JetPhox and PeTer with CT10
LO MC+PS: SHERPA, PYTHIA8

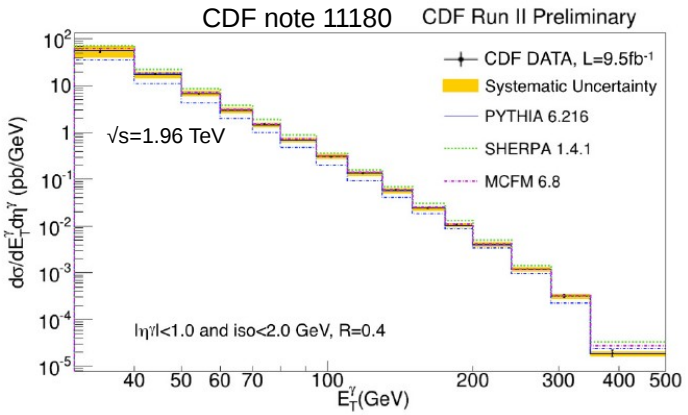
dominant systematic uncertainties:
energy scale, unknown admixture of fragmentation
background correlations



ATLAS: 25< E_T <1500 GeV
measurement over 10 orders of magnitude!



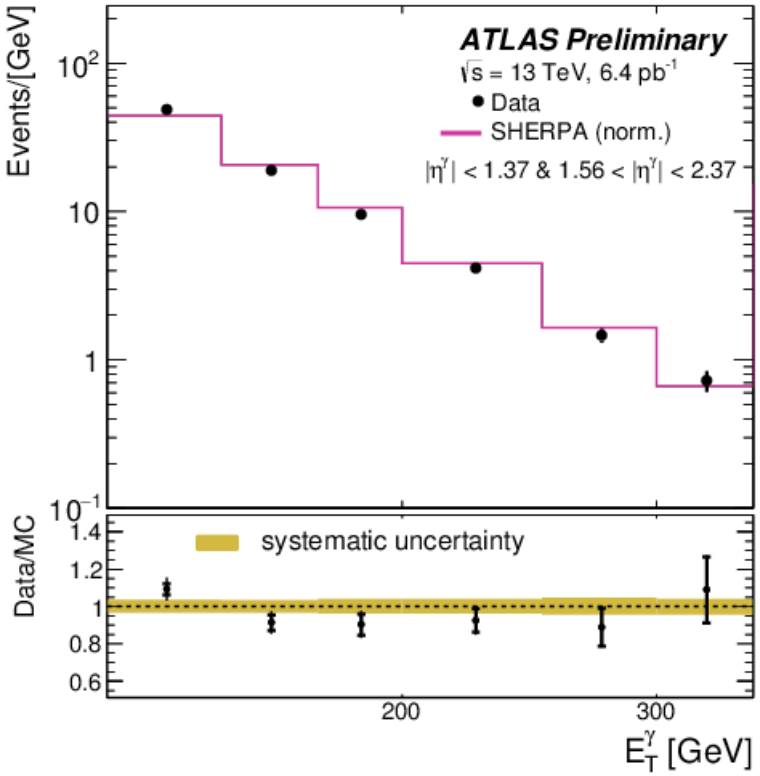
JetPhox: describes shape, but too low
LO parton shower MC different trends
largest differences at low E_T

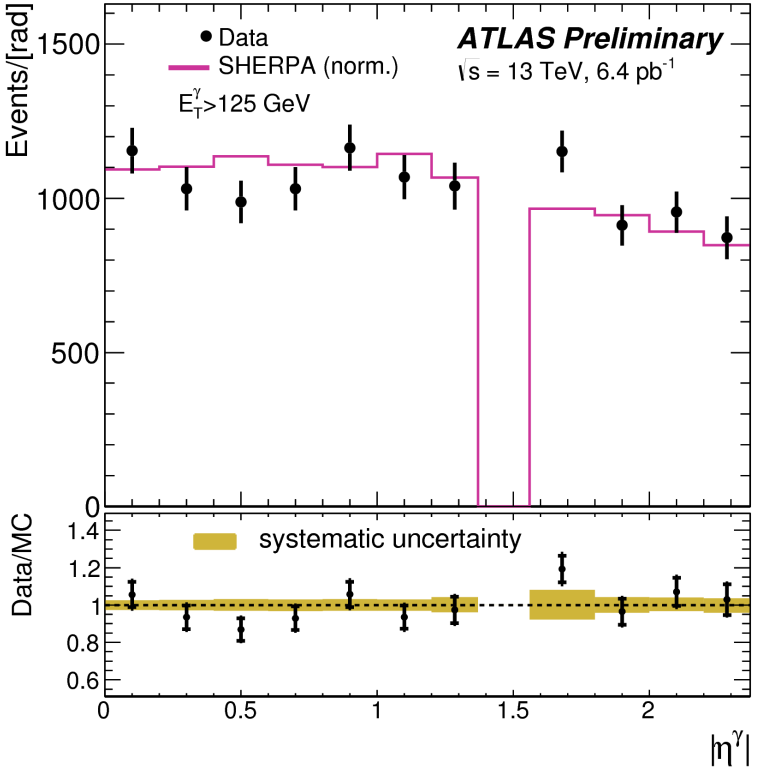


Inclusive photons @ 13 TEV

luminosity: 6.4± 0.6 pb^{-1} ,<μ>=20
E^{γ}_{T} = 125 GeV, $|\eta^{\gamma}| < 2.37$

no unfolding - detector level quantities





good description by Sherpa 2.1+ CT10 full simulation

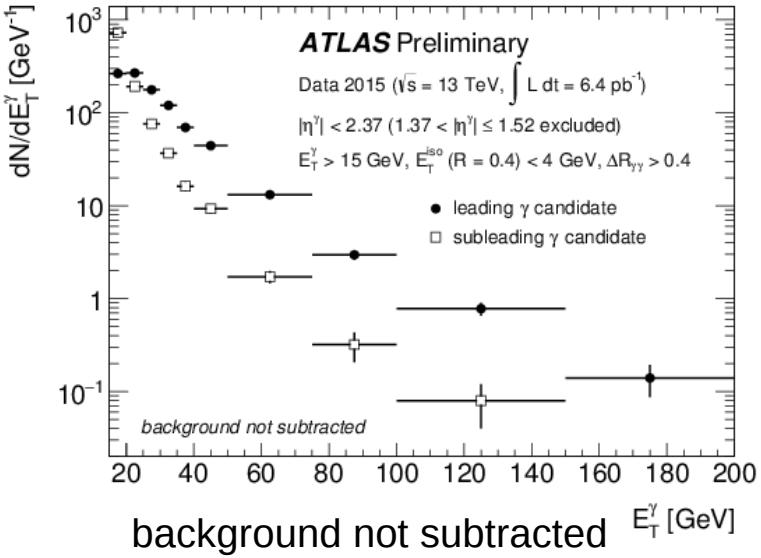
Inclusive di-photons @ 7 and 13 TEV

ATL-PHYS-PUB-2015-020
EUR. PhysJ. C74 (2014) 3129

- irreducible background to H→ γγ
- sensitive to q,g →γ fragmentation
- predictions challenging: emission of soft gluons and fragmentation
- $M_{\gamma\gamma}$<700 GeV

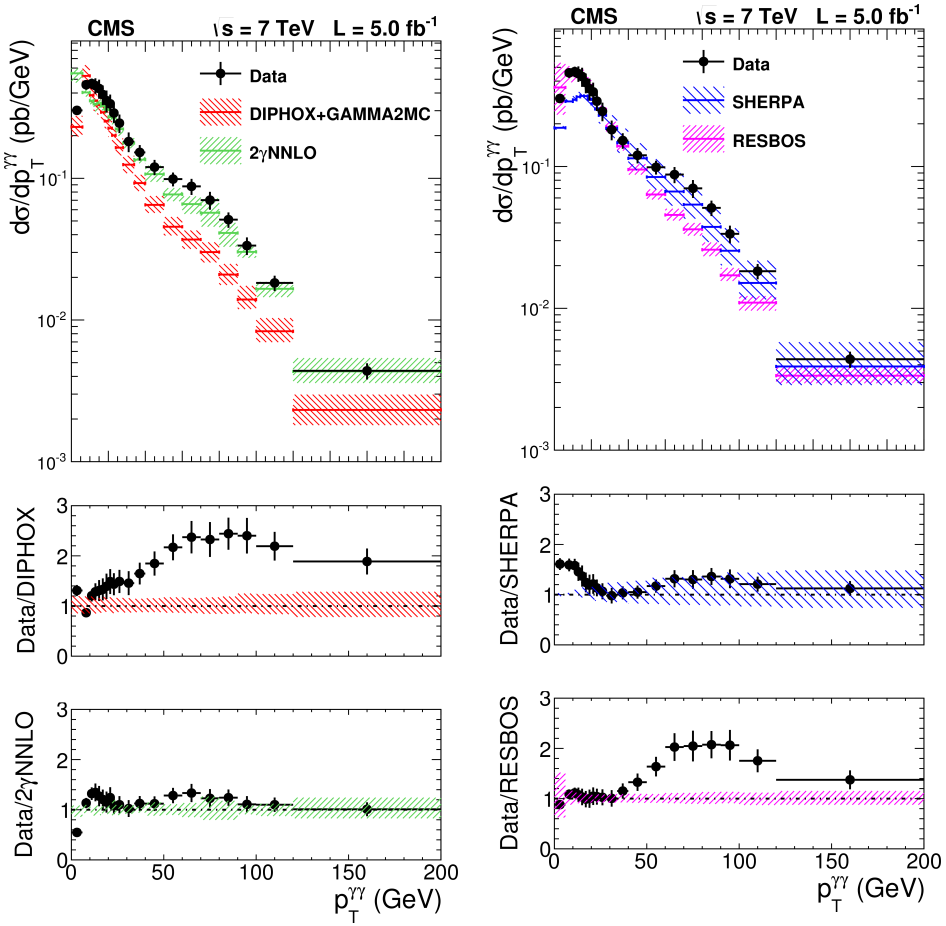
→ NNLO needed for description of high p_T

ATL-PHYS-PUB-2015-020



background not subtracted
(40% leading, 50% sub-leading)

EUR. PhysJ. C74 (2014) 3129



Pairs of photons with jets @ 7 TeV

jets: anti-kt R=0.5
p_T>25 GeV, |η|<4.7
photons: E^{γ}_T > 40, 25 GeV, $|\eta^{\gamma}|$ < 2.5

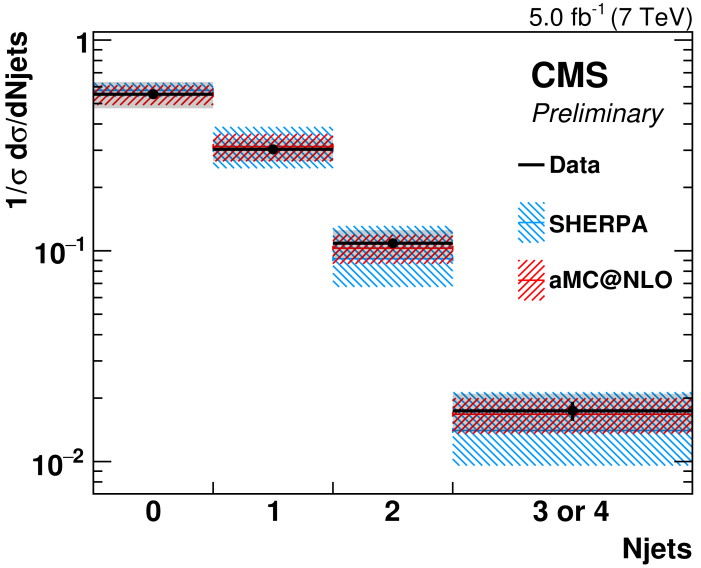
major background for Higgs produced in VBF

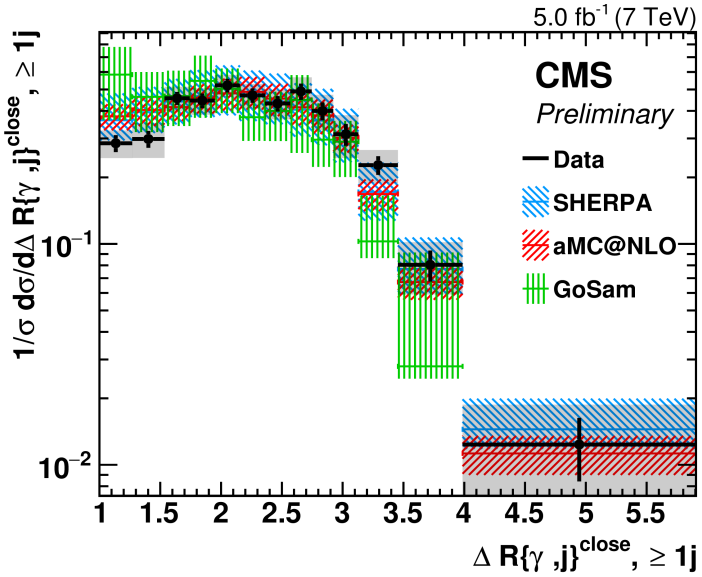
diff. xsection: jet multiplicity, p_T, angular correlations

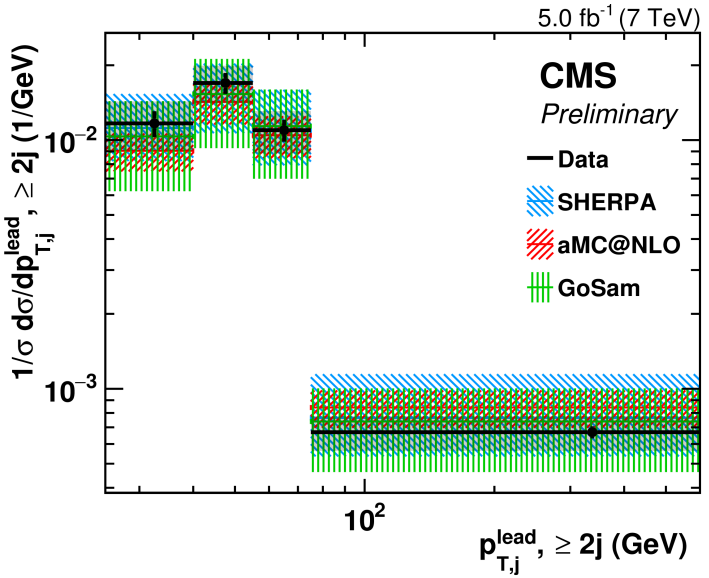
measurement at particle level

→ aMC@NLO and Sherpa: good description

→ NLO(GoSam) corrected for PS and UE: discrepancies for angular correlations





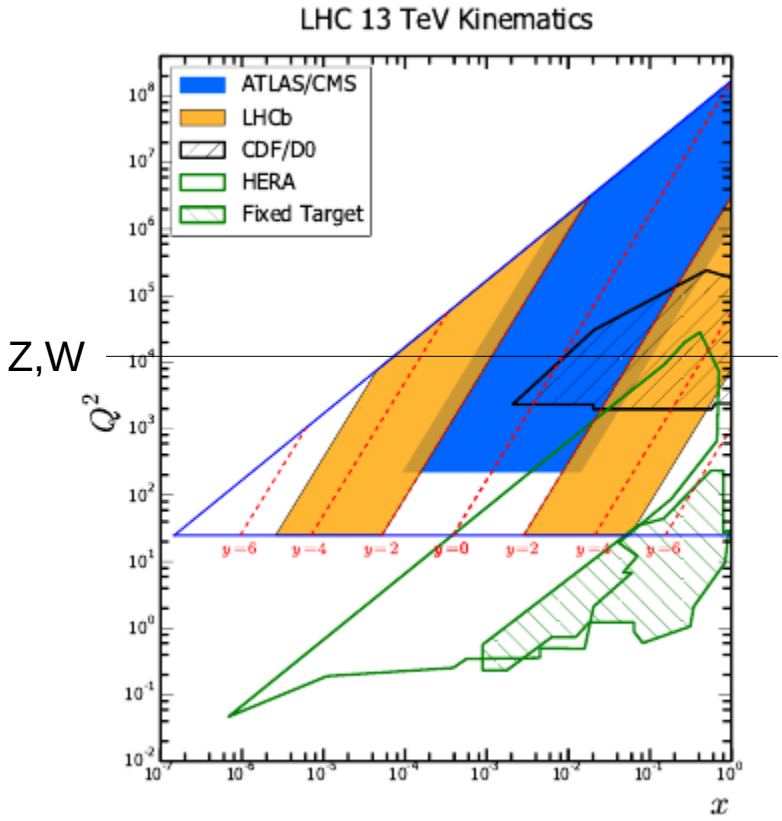


Inclusive W and Z bosons

Vector boson production

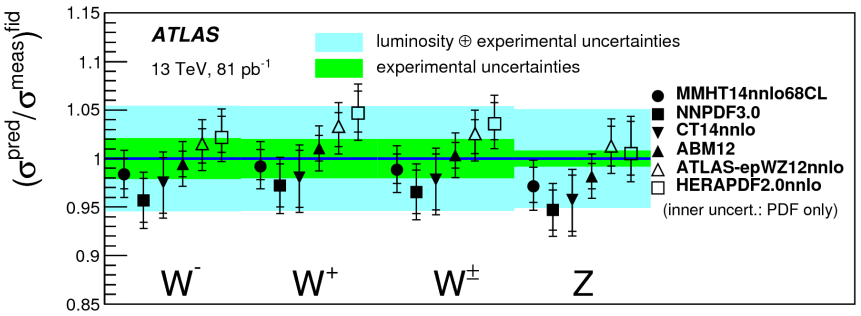
$$\underbrace{\sigma(x, Q^2)}_{hadronic\ x-sec.} = \sum_{a,b} \int_0^1 dx_1\, dx_2 \underbrace{f_a(x_1 Q^2) f_b(x_2 Q^2)}_{PDFs\ 2-8\,\%} \times \underbrace{\hat{\sigma}(x_1, x_2, Q^2)}_{partonic\ x-sec.:\ NNLO\ 1\,\%}$$

- x-section measurements and ratios sensitive to parton density functions (PDFs)
- measurements used to constrain PDFs → important for e.g. searches
- LHC, HERA, Tevatron and fixed target data: wide range in x-Q^2 plane



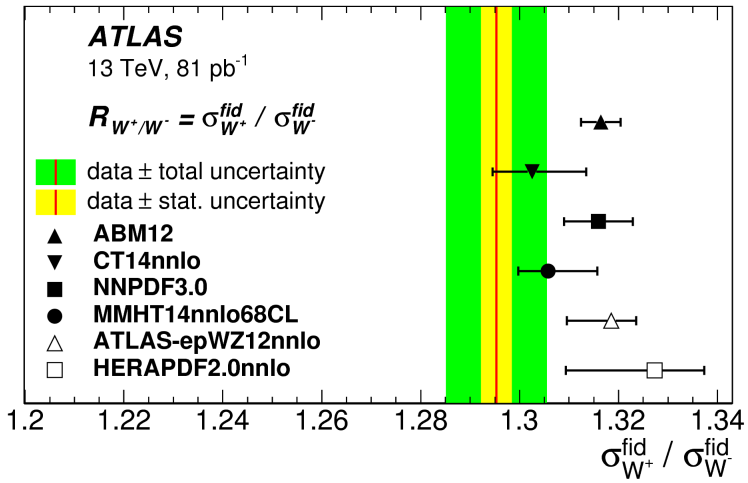
W,Z @ 13 TeV

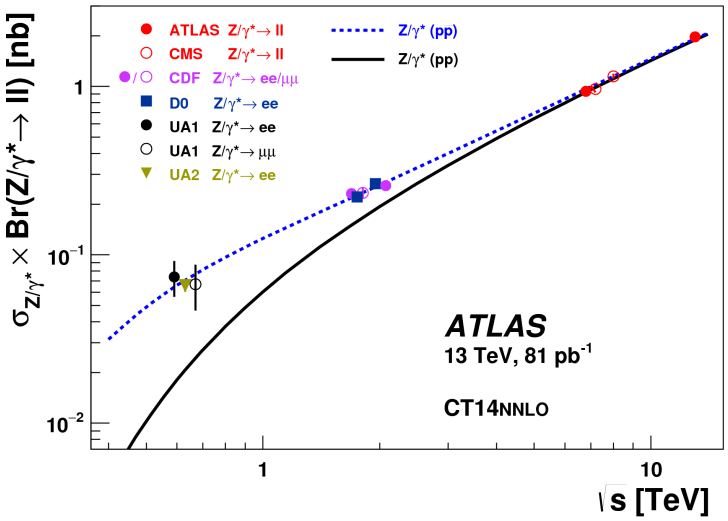
arXiv:1603.09222



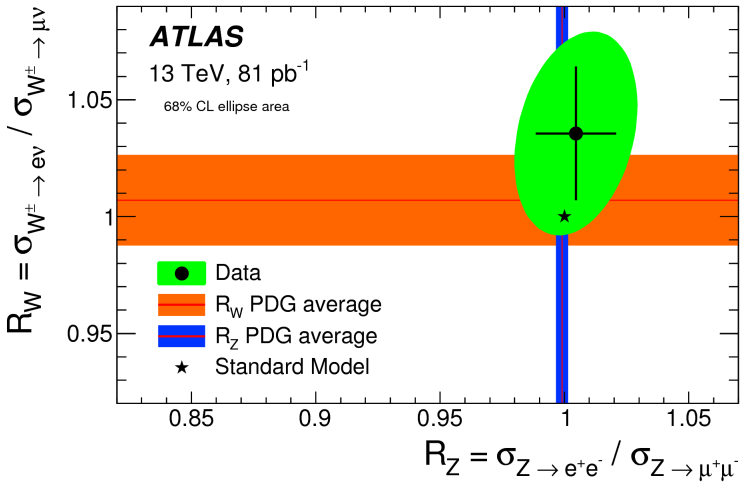
good agreement with predictions
lumi uncertainty 5%
systematic uncertainties 2%(W), 1%(Z)

W⁺/W⁻ ratio: uncertainty 0.8%





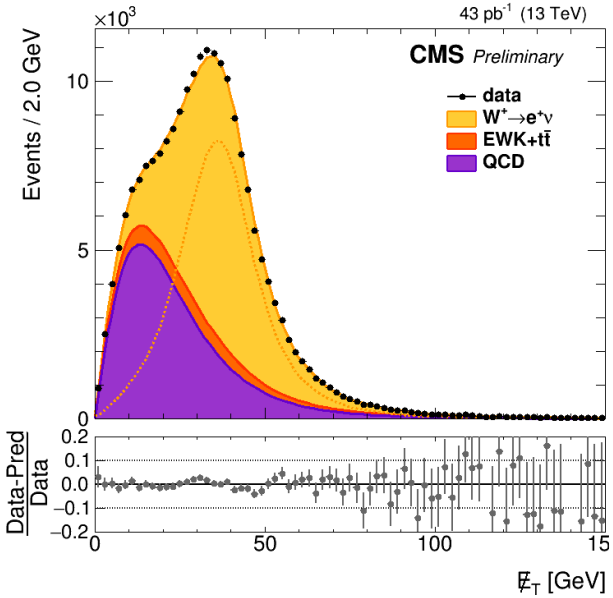
test of lepton universality



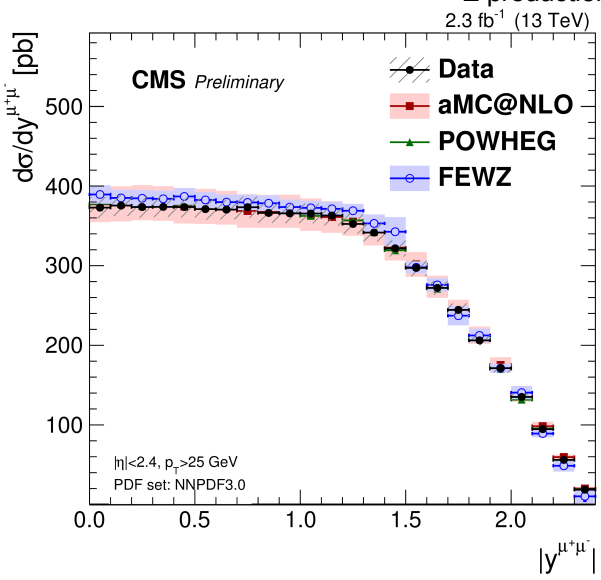
Z,W @13 TeV

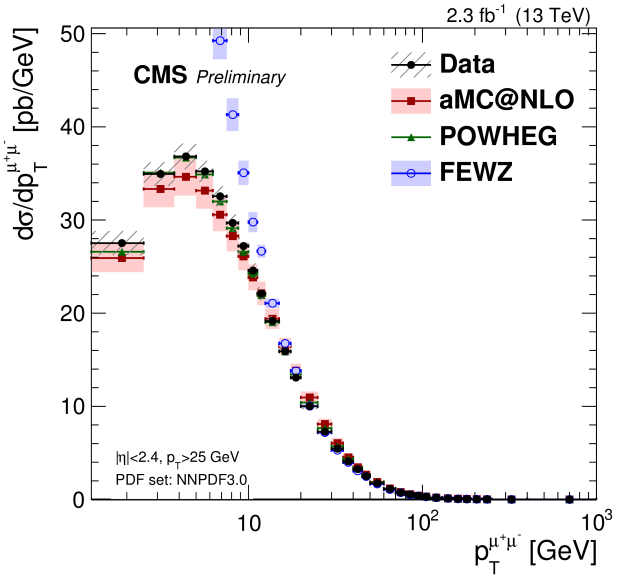
CMS-PAS-SMP-15-004
CMS PAS SMP-15-011

CMS-PAS-SMP-15-004

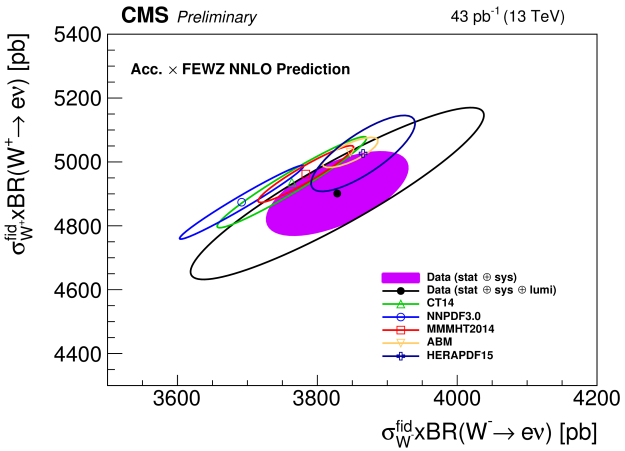


Z production: CMS-PAS-SMP-15-011





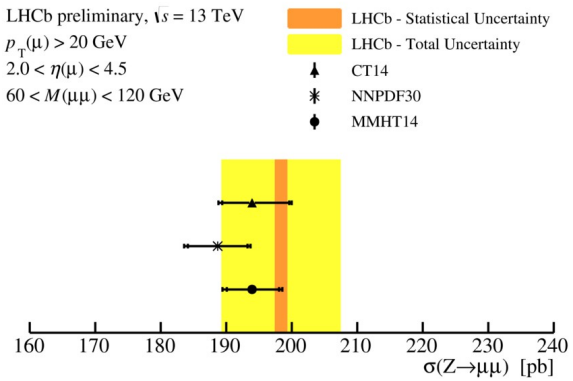
CMS-PAS-SMP-15-004



luminosity uncertainty 4.8 (W), 2.7% (Z)
Z: inclusive and differential results
detector description well understood
x-sections well described by predictions

Z @ 13 TeV - forward

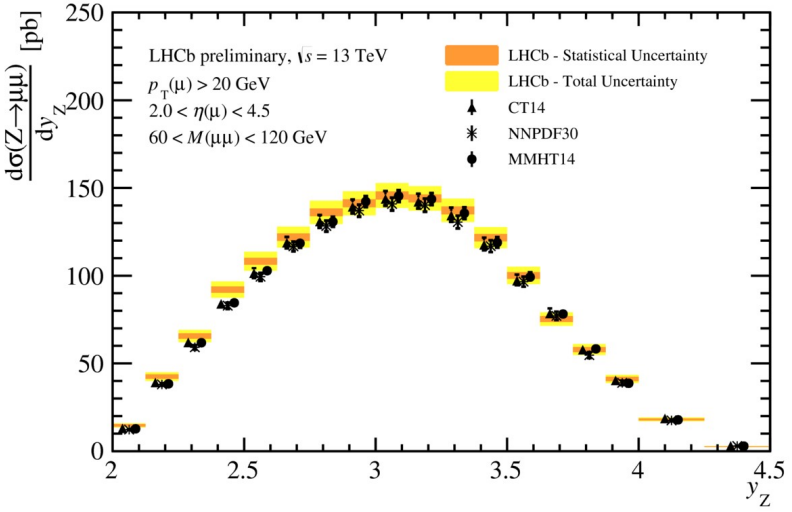
fiducial volume:
$2.0<\eta<4.5$, $p_T>20$ GeV
$60 < M(\mu\mu) < 120$ GeV

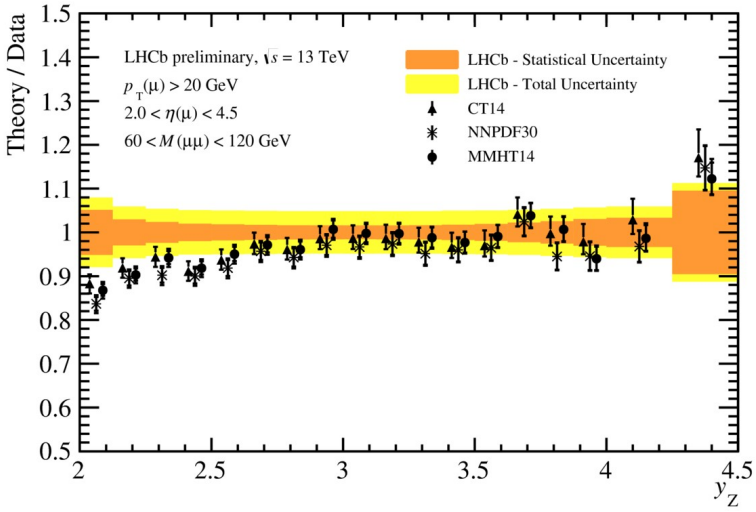


luminosity uncertainty: 3.9%

sensitivity to PDFs with more statistics
note: high rapidities are sensitive
to low and high x (close to one)

p_T and φ^* distributions also available





Z/γ*: φ* @ 1.96 TeV for 30 <$M_{\mu\mu}$ < 500 GeV

Phys. Rev. D 91, 072002

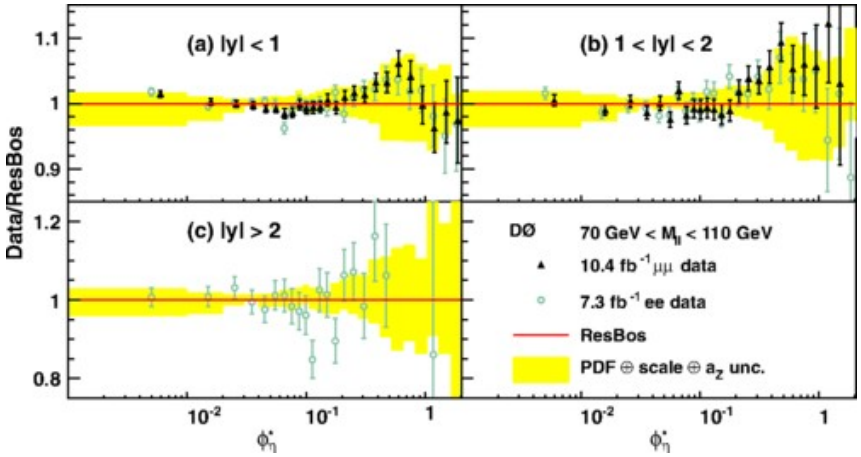
$\varphi^* = \tan((\pi-\Delta\varphi)/2)\sin\theta$

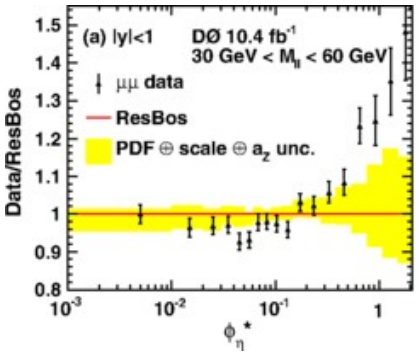
→ probes same physics as p_T^{ll}

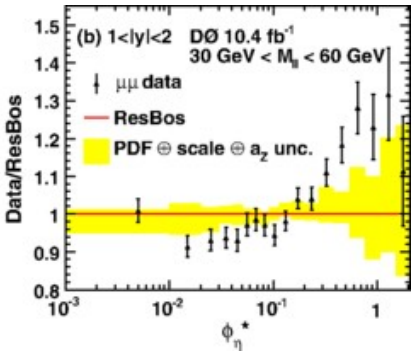
but: less sensitive to detector resolution and efficiency

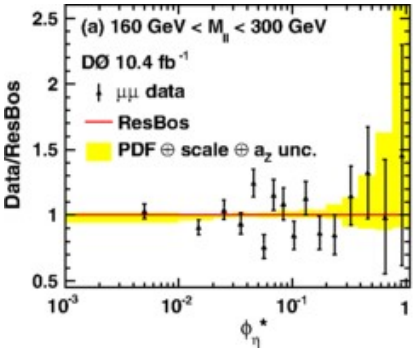
- Z peak: good description by RESBOS
- large theoretical uncertainties for large φ*

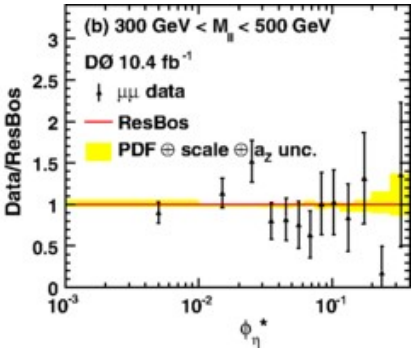
M away from Z mass: description within large uncertainties











Z/γ* φ* @ 8 TeV

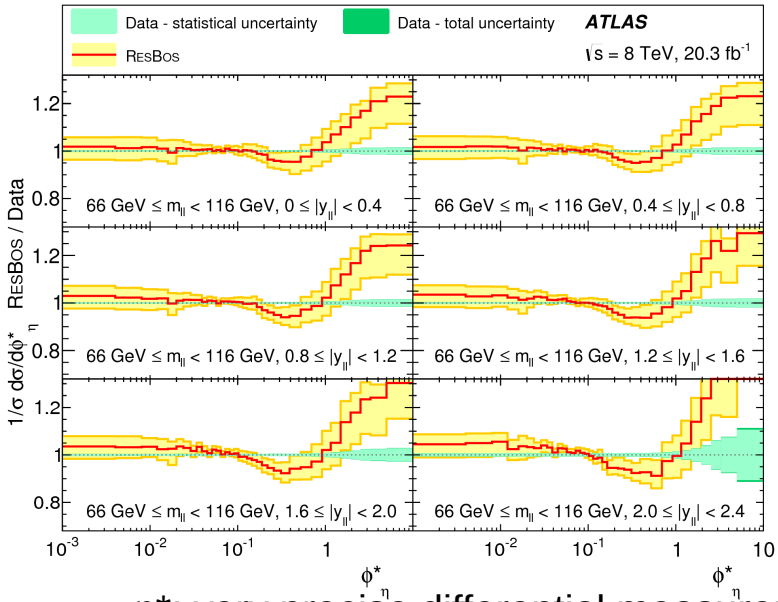
arXiv:1512.02192

low p_T: soft-gluon re-summation, non perturbative effects of intrinsic p_T of partons

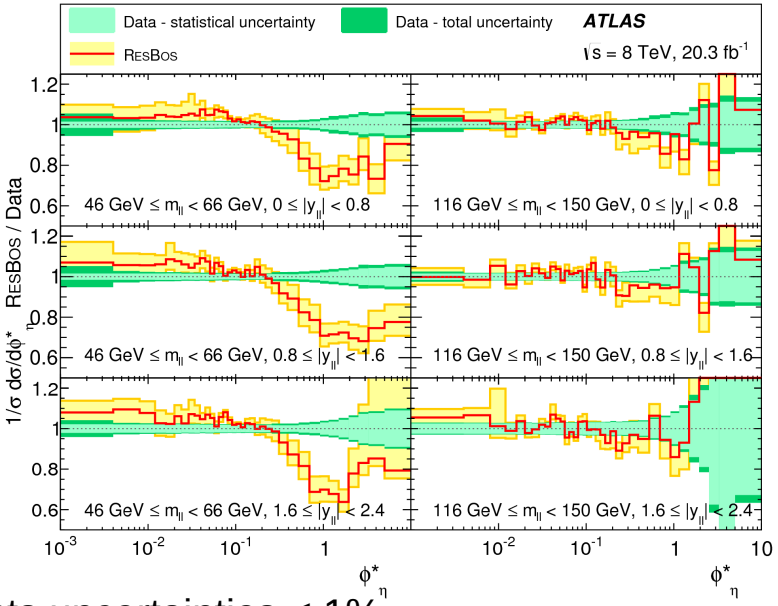
high p_T: fixed order QCD

→ test of several aspects of QCD

66<M<116 GeV



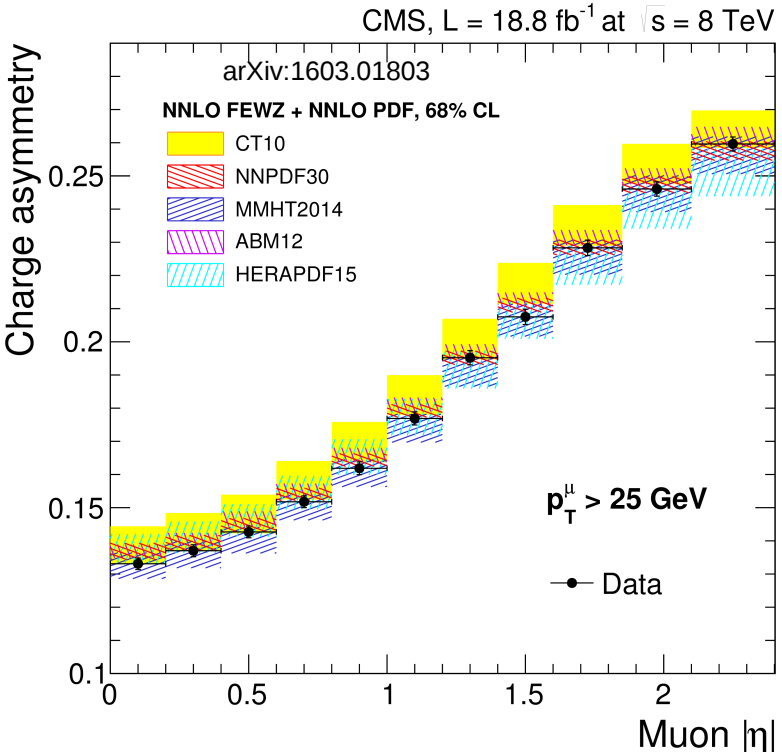
46<M< 66 GeV 66<M<150 GeV

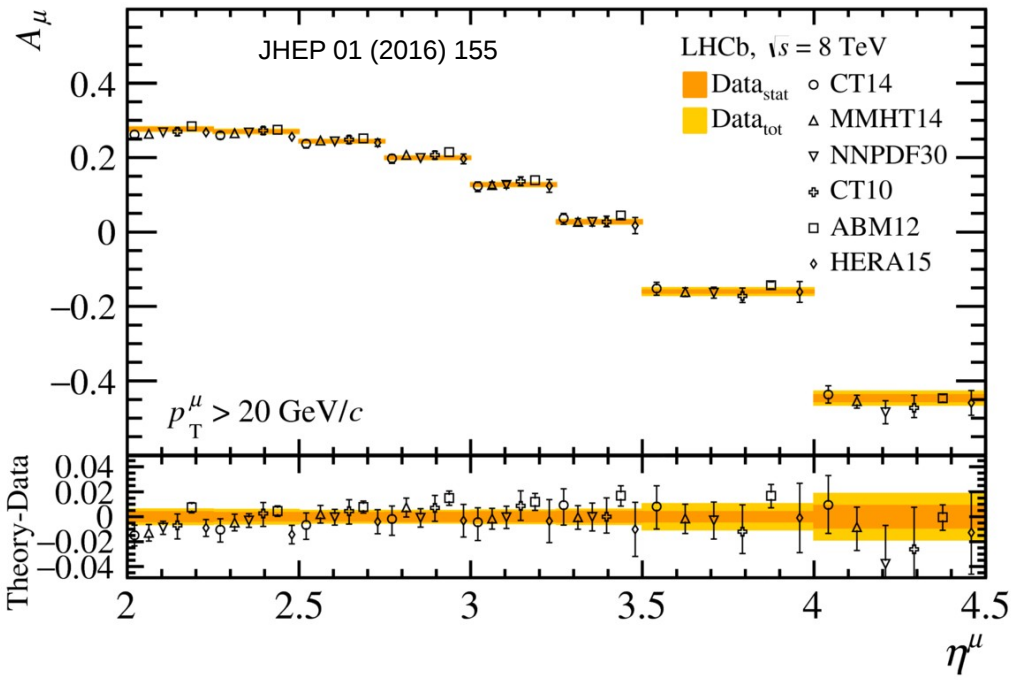


- φ*: very precise differential measurements uncertainties < 1%
- RESBOS predictions agree except for high φ*:
  NNLO+NNLL crucial to reproduce low φ*
- φ*<0.5 RESBOS describes evolution with mass
- MC generators+PS also describe low p_T: 5<p_T<100 GeV with M> 46 GeV

W @ 8 TeV: lepton charge asymmetry

JHEP 01 (2016) 155
arXiv:1603.01803





lepton charge asymmetry $A_\mu(\eta_i) = \dfrac{\sigma_{W^+\to\mu^+\nu}(\eta_i) - \sigma_{W^-\to\mu^-\overline{\nu}}(\eta_i)}{\sigma_{W^+\to\mu^+\nu}(\eta_i) + \sigma_{W^-\to\mu^-\overline{\nu}}(\eta_i)}$

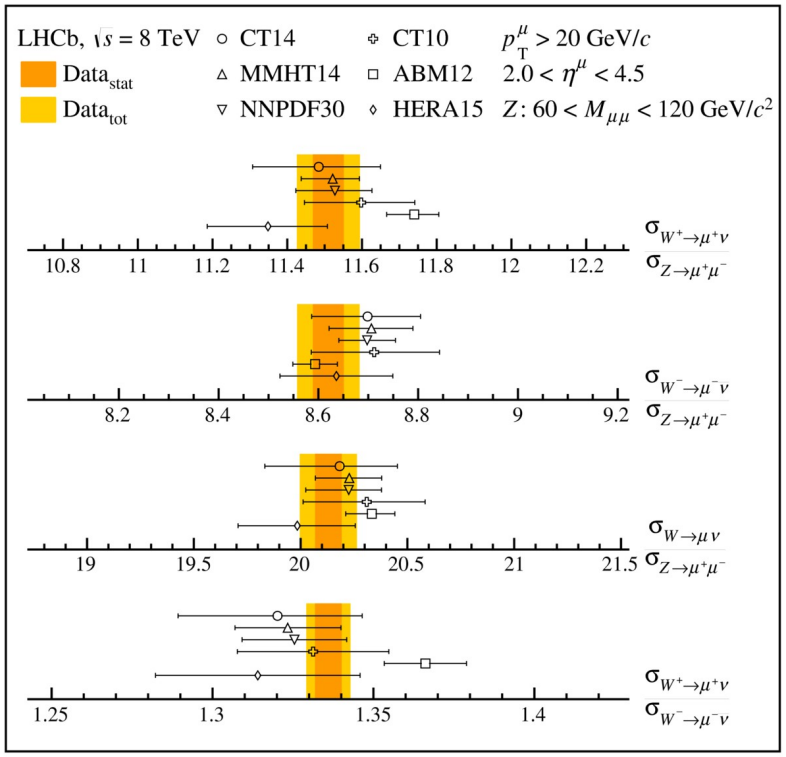
high experimental precision – uncertainties at % level
agreement with different PDF sets within 1-2%
asymmetry constrains u/d PDF ratio

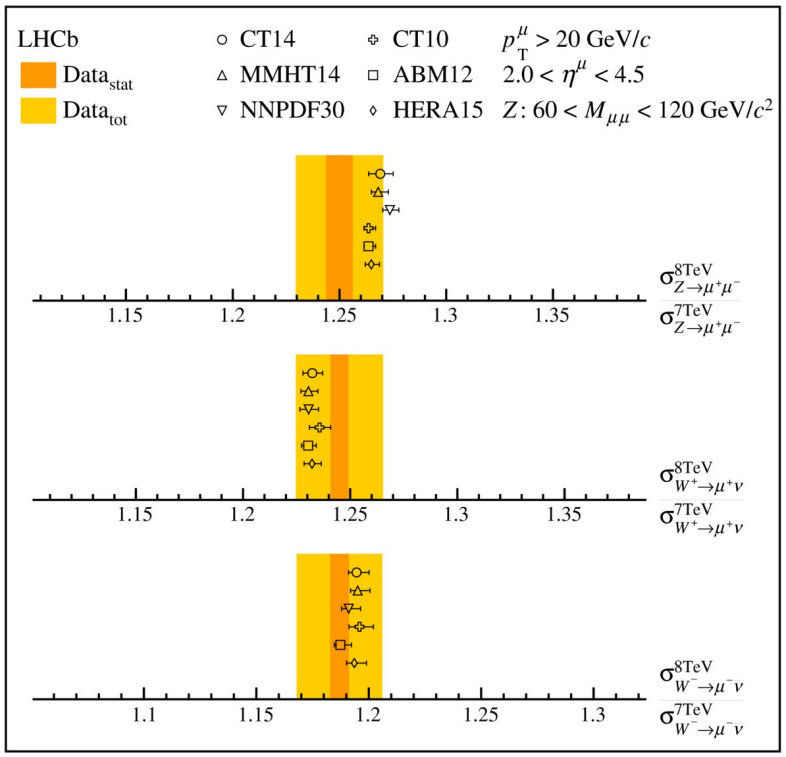
differential W^+ and W^- x-sections also available

W, Z – dependency on center of mass energy

JHEP 01 (2016) 155

- ratio W/Z or W^+/W^- : sensitive test of predictions
- ratio at different cm energies: PDF uncertainties very much reduced





Angular coefficients of lepton pairs in Z events

ATLAS STDM-2014-10
Phys. Lett. B750 (2015) 154

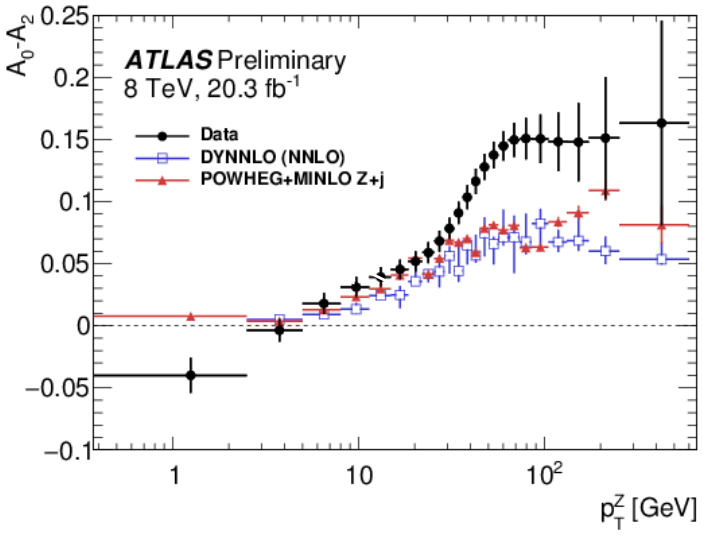
in Z rest frame:

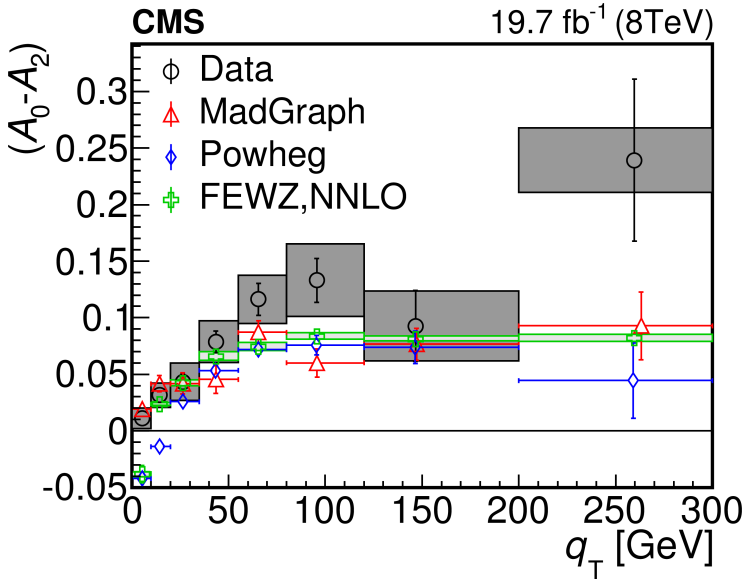
$$\frac{d^2\sigma}{d\cos\theta^* d\phi^*} \propto \left[(1+\cos^2\theta^*) + A_0\frac{1}{2}(1-3\cos^2\theta^*) + A_1\sin(2\theta^*)\cos\phi^* + A_2\frac{1}{2}\sin^2\theta^*\cos(2\phi^*) + A_3\sin\theta^*\cos\phi^* + A_4\cos\theta^* + A_5\sin^2\theta^*\sin(2\phi^*) + A_6\sin(2\theta^*)\sin\phi^* + A_7\sin\theta^*\sin\phi^*\right].$$

θ* and φ* : polar and azimuthal angles of negative lepton in the rest frame of Z

A_0 -A_7 eight angular coefficients, A_0 -A_2 related to polarization of Z
→ A_5 -A_7 measured for the first time by ATLAS

A_0-A_2:very sensitive to higher order effects: Lan-Tung Relation (NLO) predicts it to be 0

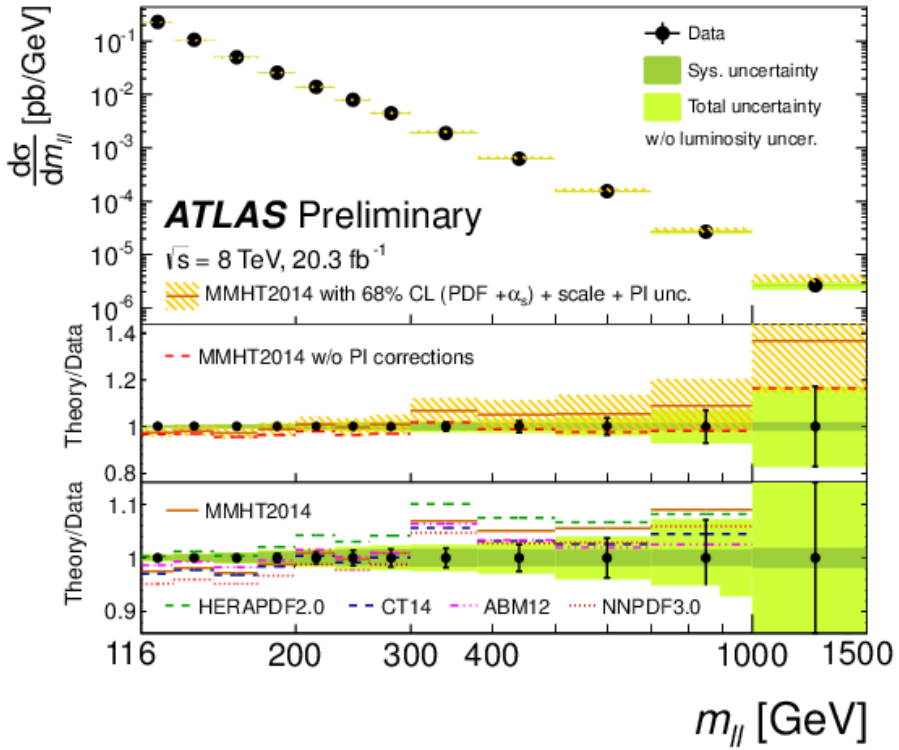




A_0-A_2significant difference to $O(\alpha^2_s)$
→ higher-order corrections needed

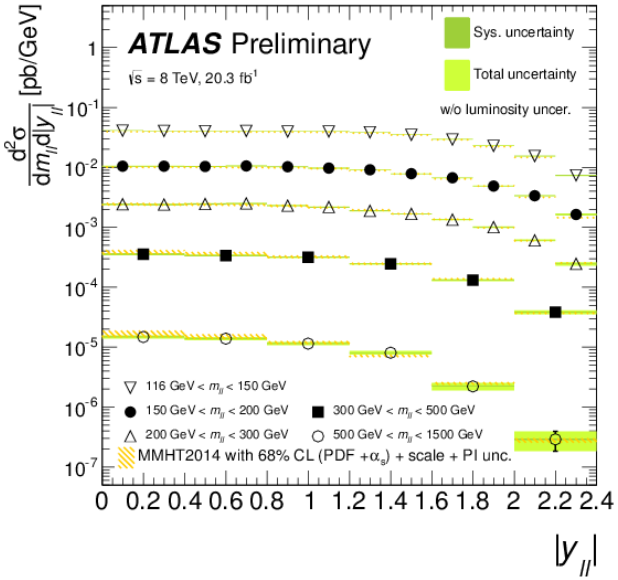
High mass Drell-Yan production @ 8 TeV

Drell-Yan lepton pair production: $Z/\gamma^* \rightarrow \ell\ell$
for $116 < M_{\ell\ell} < 1500$ GeV

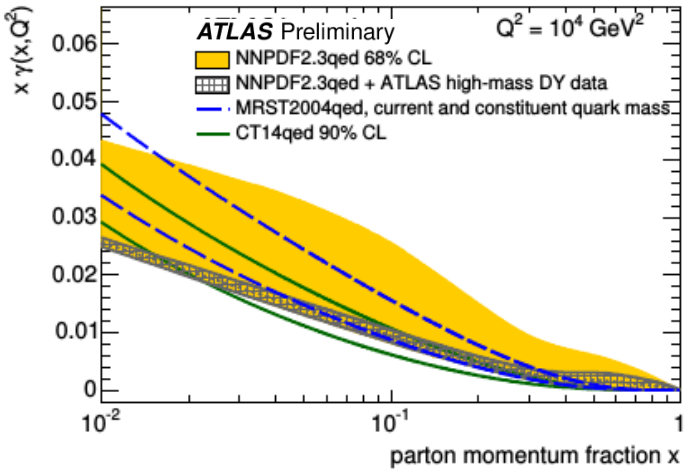


→ photon induced (PI) processes up to 15%
with large uncertainty of 60-90%
sensitivity to photon PDF via $\gamma\gamma \rightarrow \ell\ell$

→ predictions using various PDF sets generally agree
largest differences at low masses
→ sensitivity to PDFs



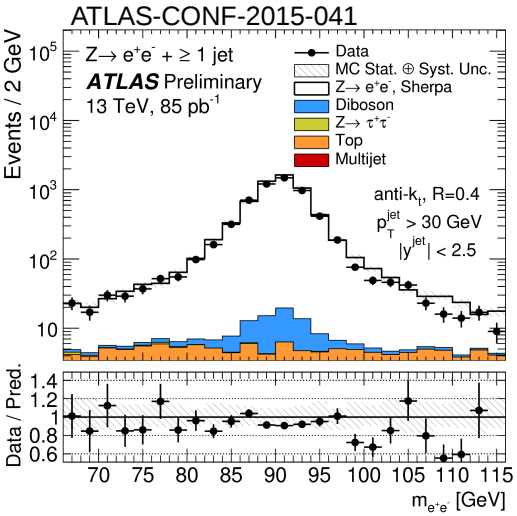
including ATLAS results significantly reduces PDF uncertainty



W and Z bosons with jets

Z plus jet @ 13 TeV

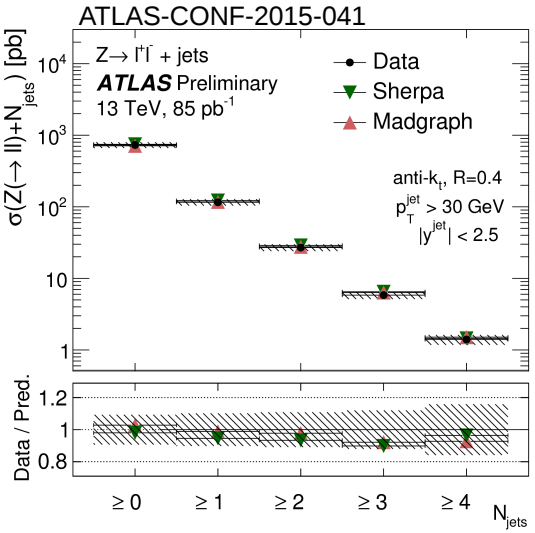
ATLAS-CONF-2015-041
CMS-PAS-SMP-15-010



ATLAS:

Z plus up to 4 jets
p_T > 30 GeV and |y| < 2.5

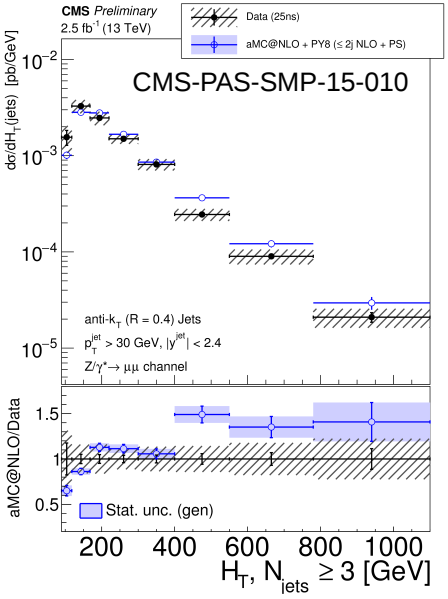
jet multiplicity:
well described by
Sherpa & Madgraph

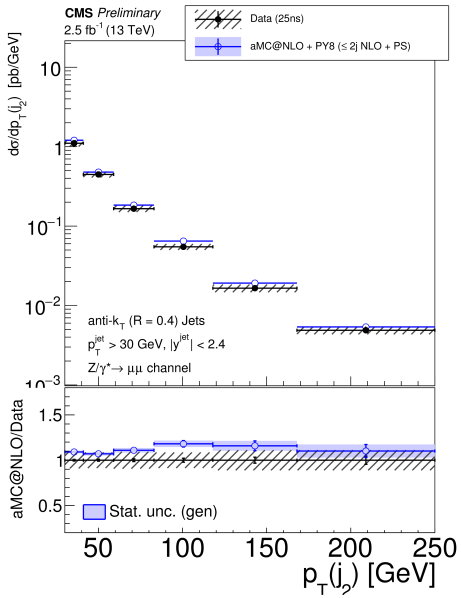


CMS

p_T > 30 GeV and |y| < 2.5
ΔR(muon-jet)>0.4

differential:jet multiplicity
p_T and y of the three leading jets,
H_T: scalar sum of jet p_T



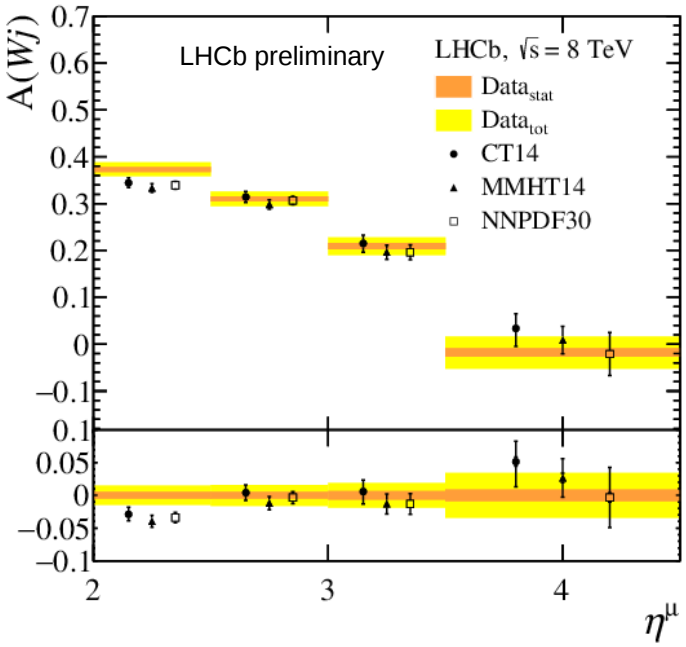


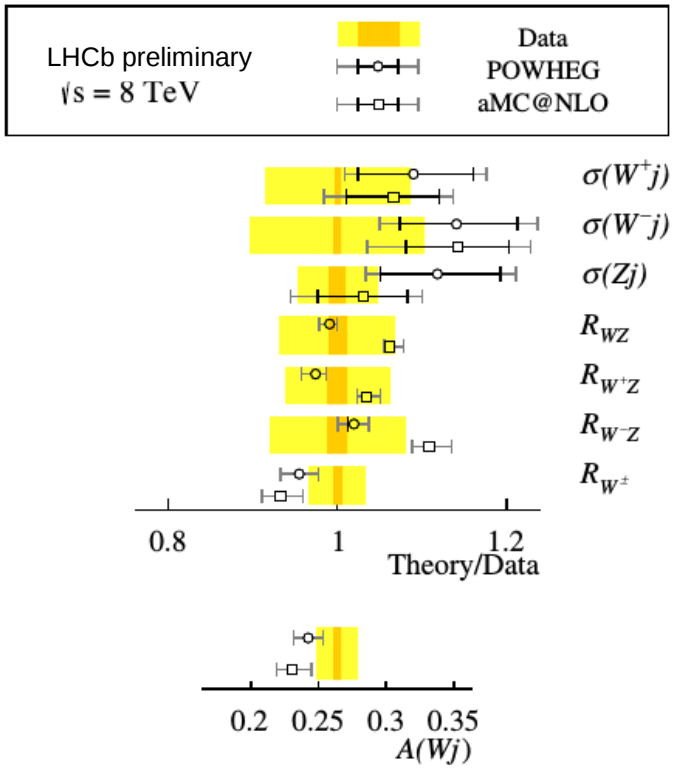
W, Z plus jet @8 TeV - forward

agreement with NLO (+PS)

many differential distributions available
general good description by predictions

W + jet: lepton charge asymmetry





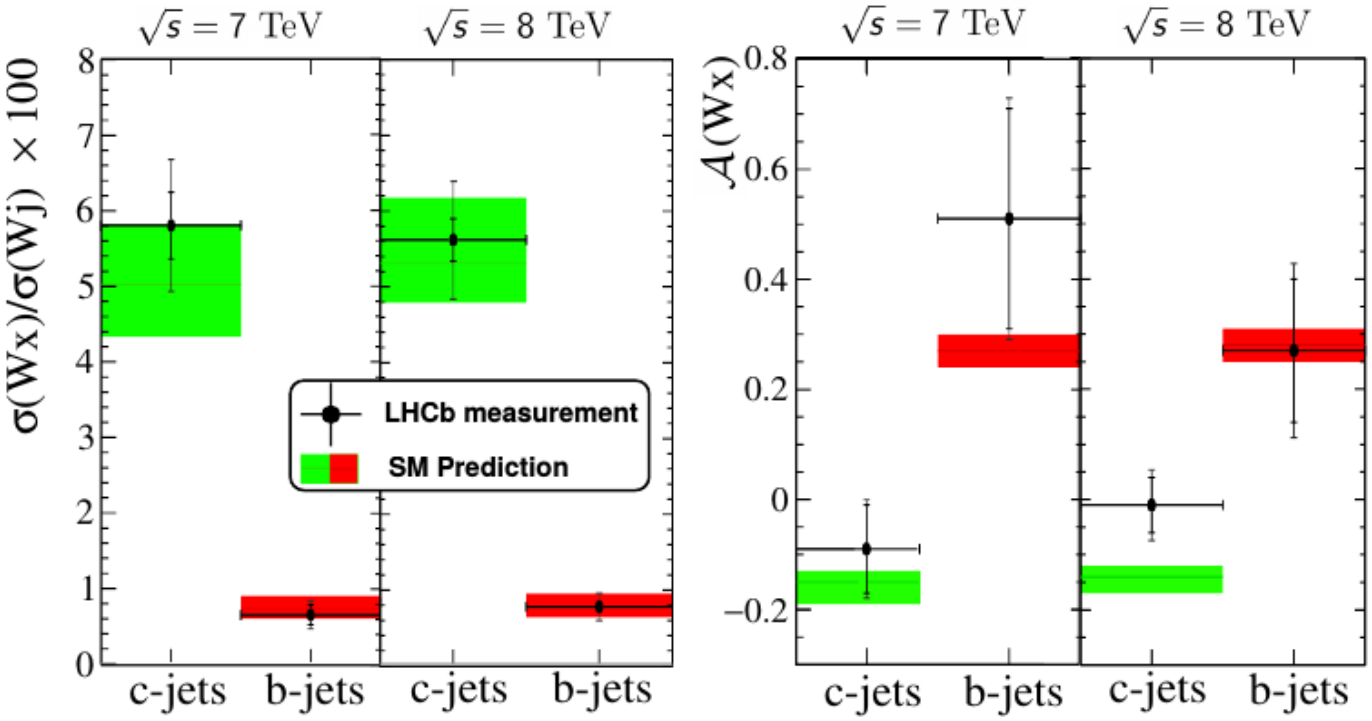
W + (b, c)-jet ratios and asymmetries

PRD 92 (2015) 052001

b&c-tagging: secondary vertex & jet properties
efficiencies: b-tag 65%, c-tag: 25%

W+c sensitive to s-quark, W+b to gluon PDF

predictions @NLO: MCFM – overall good agreement



W plus two b-jets

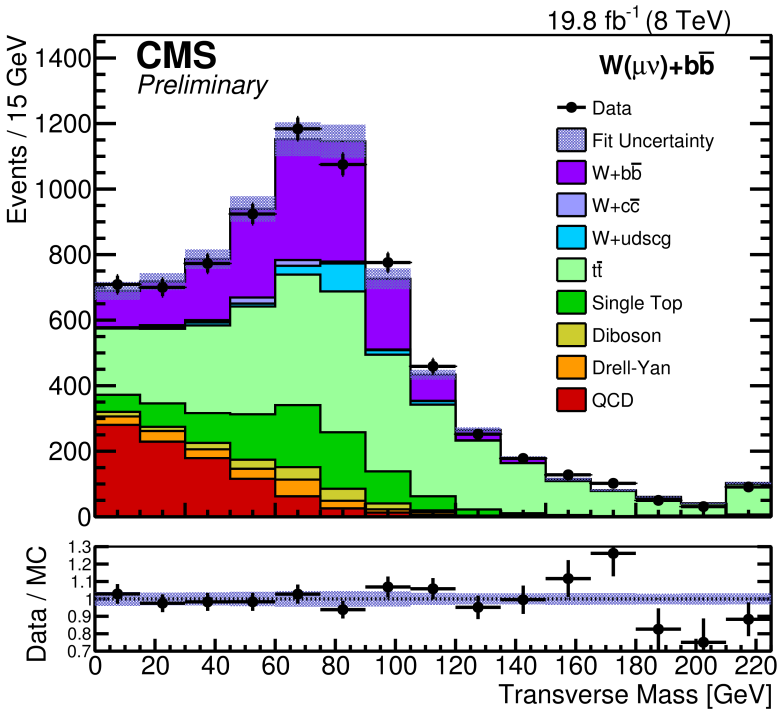
two b-tagged jets with p_T>35 GeV |η|<2.4

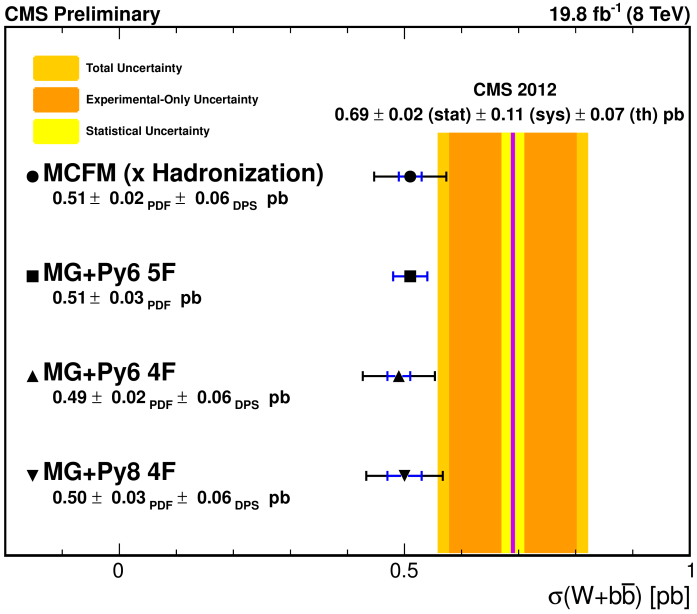
b-tagging: secondary vertex & jet properties
40% tagging efficiency

mis-tag: 1% charm, 0.1% light jets

lepton from W: p_T>30 GeV |η|<2.1

signal yield: likelihood fit to M_T





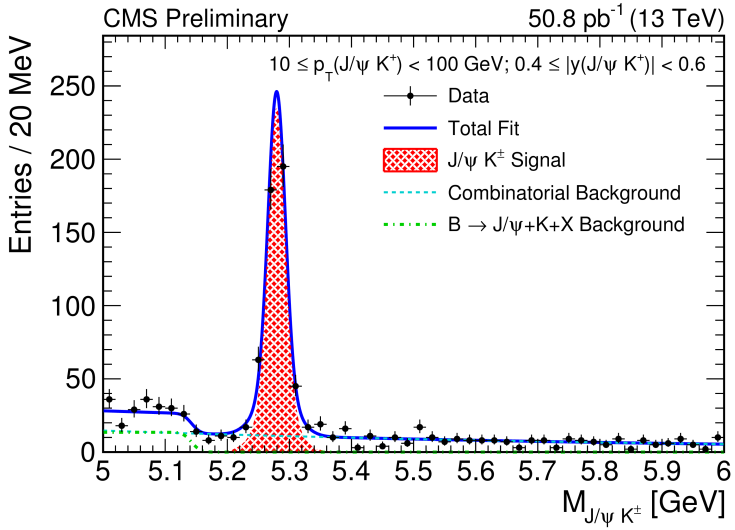
results in agreement with SM predictions

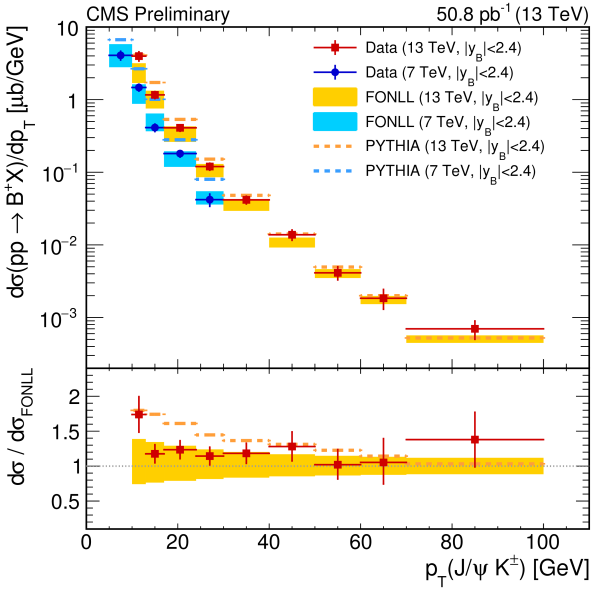
estimated DPS contribution: 10%

Heavy Quarks

B - production @13 TeV

CMS-PAS-BPH-15-004

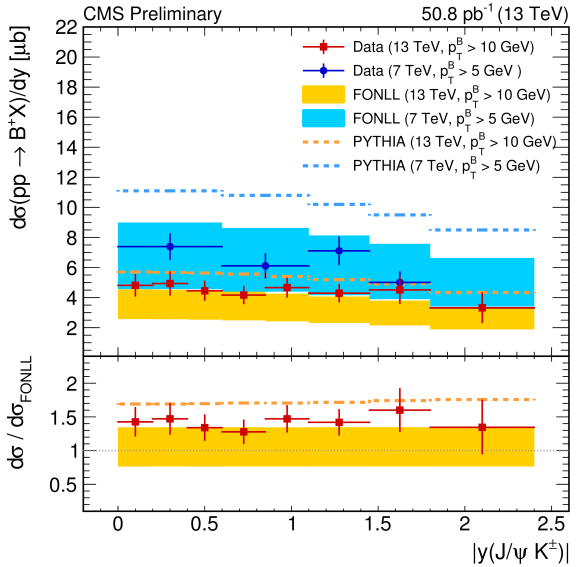




B$^+$ → J/ψK$^+$, J/ψ → μμ
10< p$_T$(B)< 100 GeV

7 TeV: p$_T$(B)> 5 GeV

good description by FONLL
PYTHIA significantly overestimates the x-section



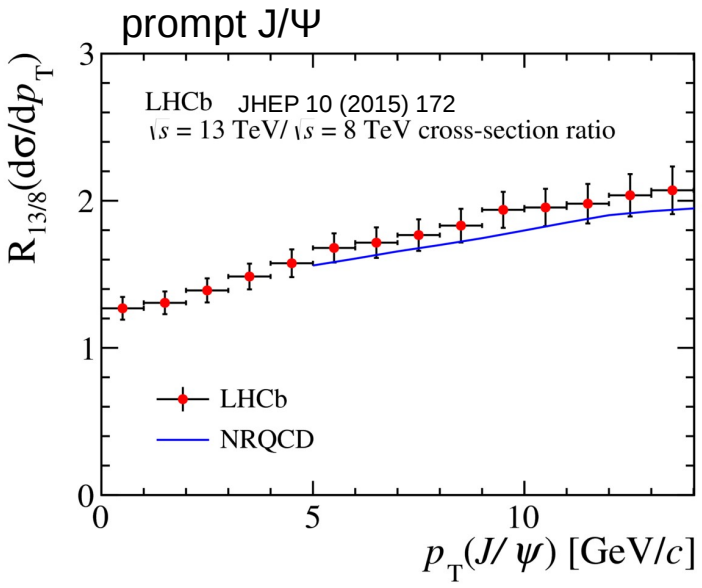
J/Ψ @13 TeV

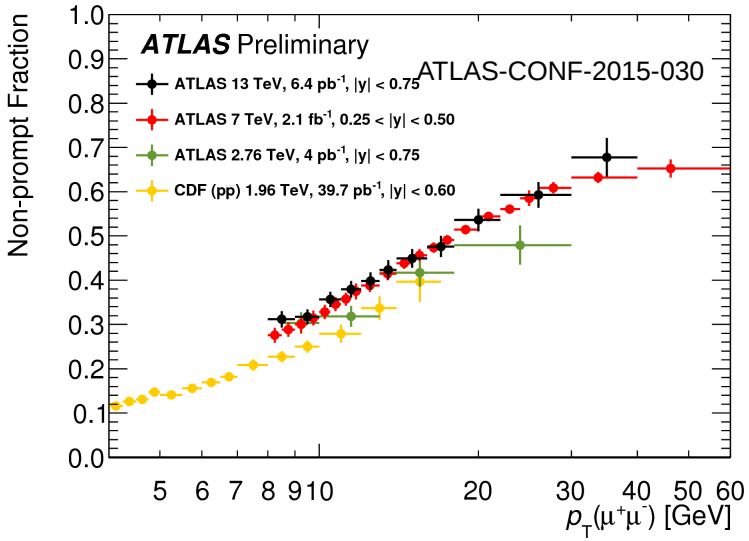
separate prompt J/Ψ and J/Ψ from b
pT<14 GeV, 2<y<4.5
extrapolated total bb-bar x-section

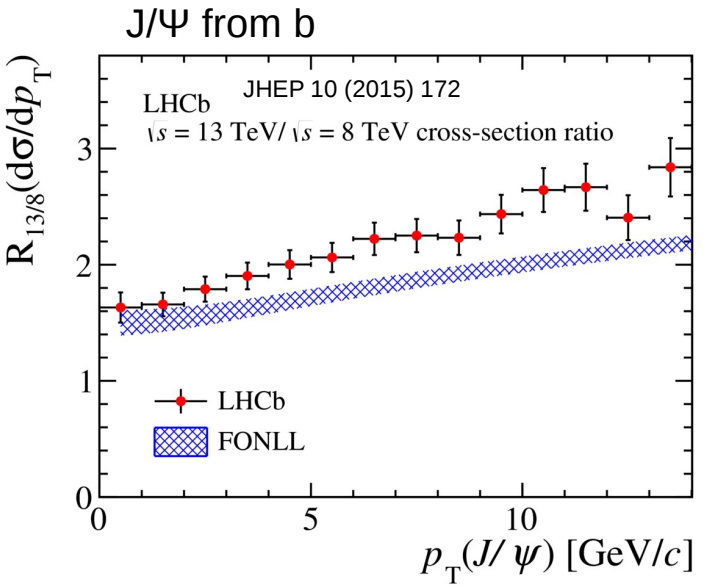
LHCb 515±2±53μb

forward: x-section @ 13TeV is harder
than @ 8 TeV
J/Ψ from b: predictions describe p_T and y distributions
but lie below the ratio of cm energy

central: non-prompt fraction independent of
cm energy







J/Ψ and Ψ(2S) @ 7 and 8 TeV

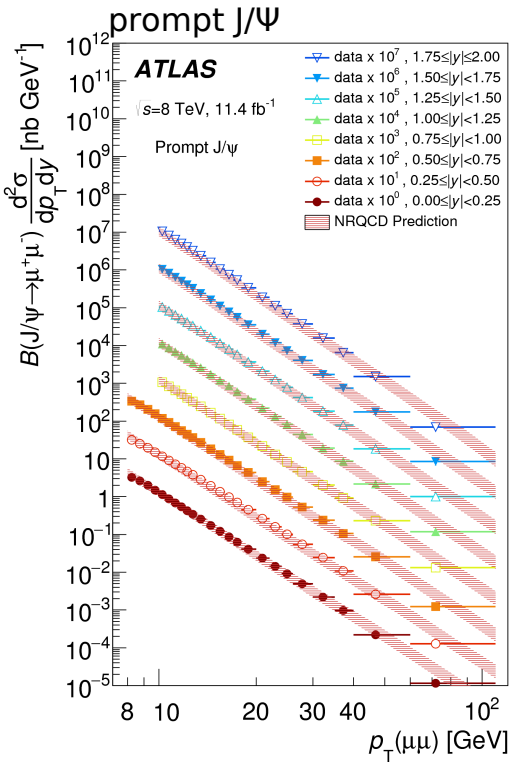
arXiv:1512.03657

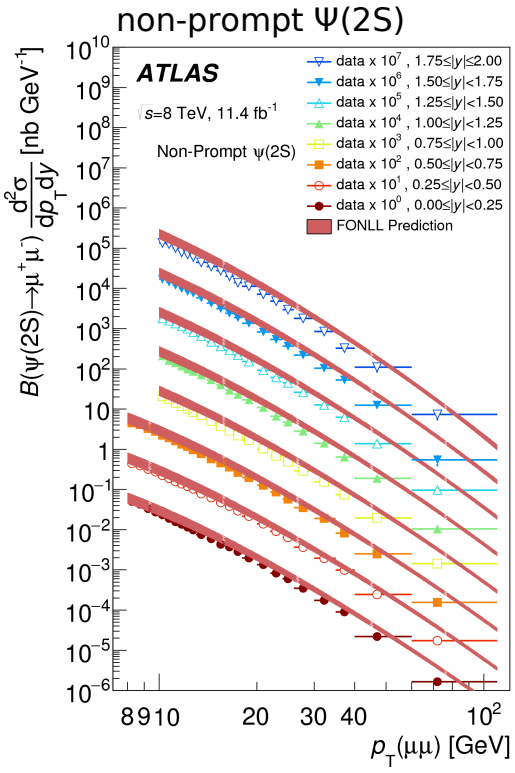
extend previous measurements to higher p_T and cm energies

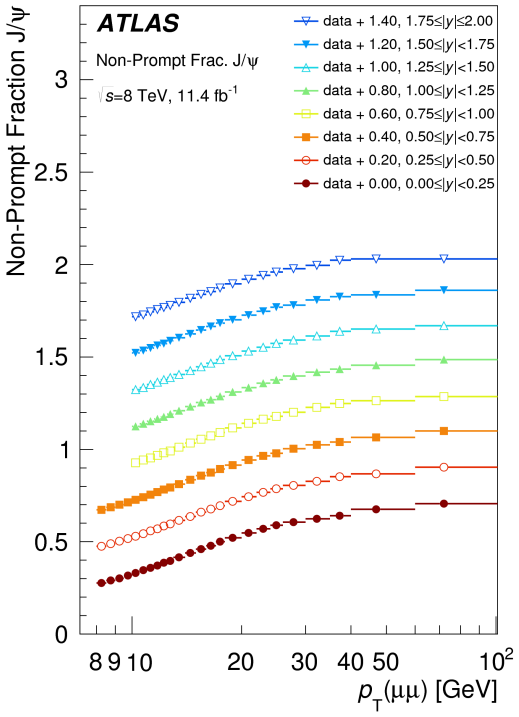
prompt: good agreement with NRQCD

non-prompt: fixed order NLL slightly overestimate at highest p_T

non-prompt fraction increases with p_T, constant p_T>40 GeV







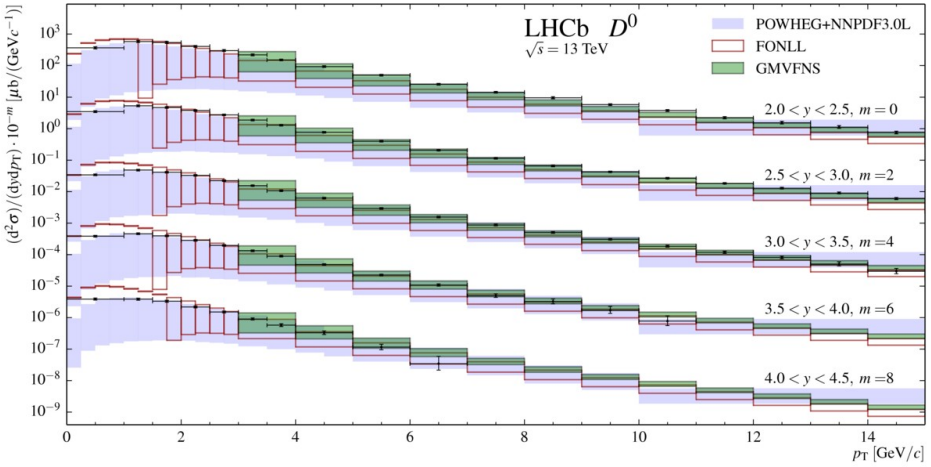
Charm @ 13 TeV

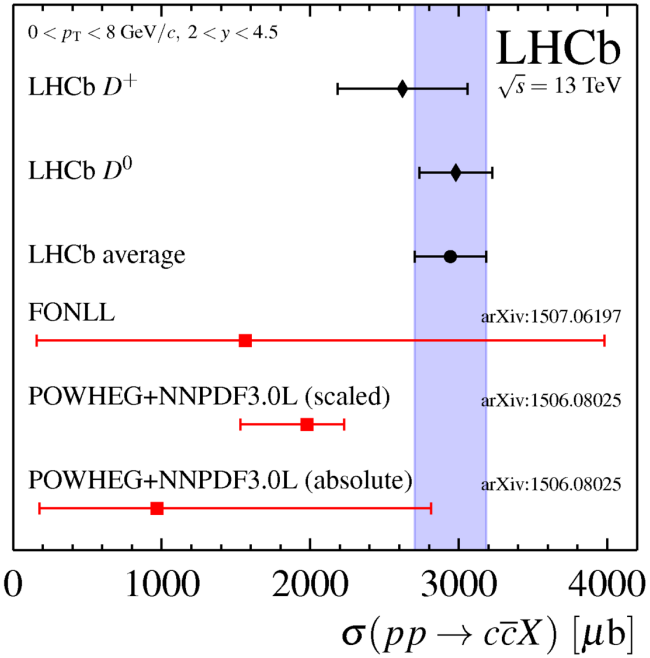
arXiv:1510.01707

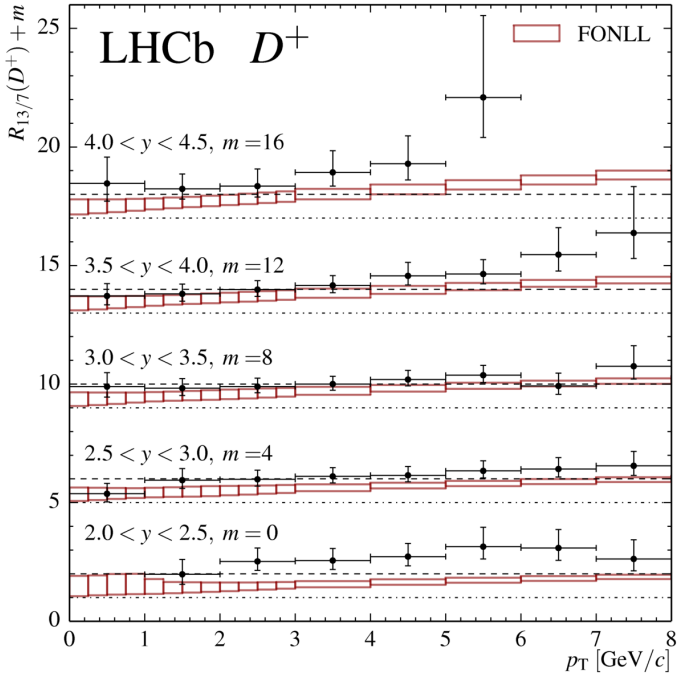
D^0, D^+, D^+_s, and D^{*+} production

$0 < p_T < 15$ GeV and $2.0 < y < 4.5$

- agreement with NLO predictions large uncertainties at low p_T
- ratios of x-sections for 13 and 7 TeV reduced uncertainties predictions show tendency to lie below the data





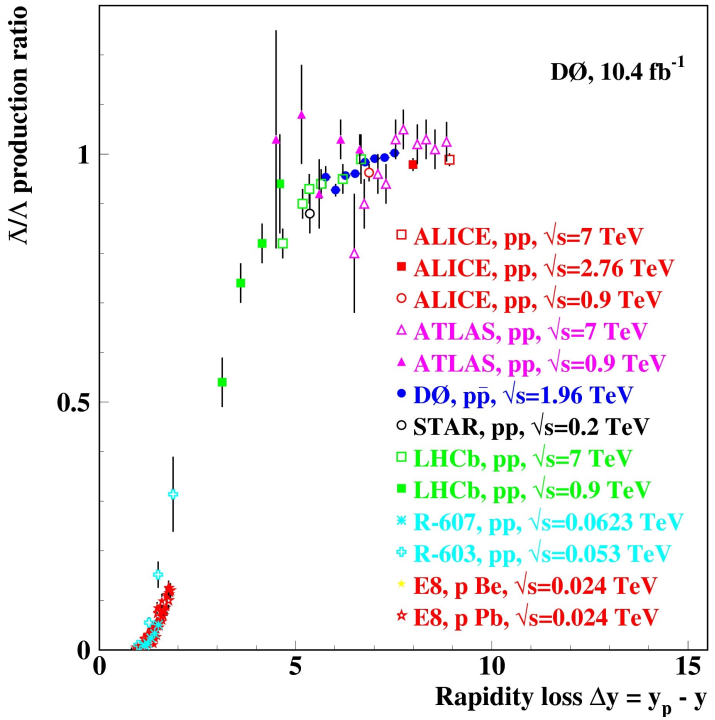


D0: Λ and $\bar{\Lambda}$

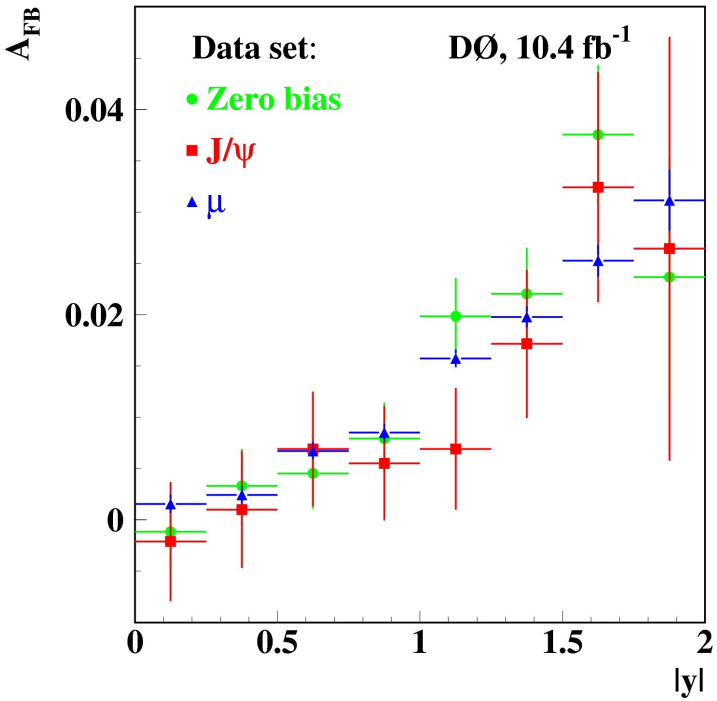
Phys. Rev. D 93, 032002 (2016)

- $p\bar{p}$ collisions with full data set
- forward: Λ ($\bar{\Lambda}$) in direction of the proton

$$A_{FB} = \frac{\sigma_F(\Lambda) - \sigma_B(\Lambda) + \sigma_F(\bar{\Lambda}) - \sigma_B(\bar{\Lambda})}{\sigma_F(\Lambda) + \sigma_B(\Lambda) + \sigma_F(\bar{\Lambda}) + \sigma_B(\bar{\Lambda})}$$



→ production ratio $\bar{\Lambda}/\Lambda$ app. universal with rapidity loss independent of cm energy or target Z



- A_{FB} is a function of |y|
- does not depend on data composition

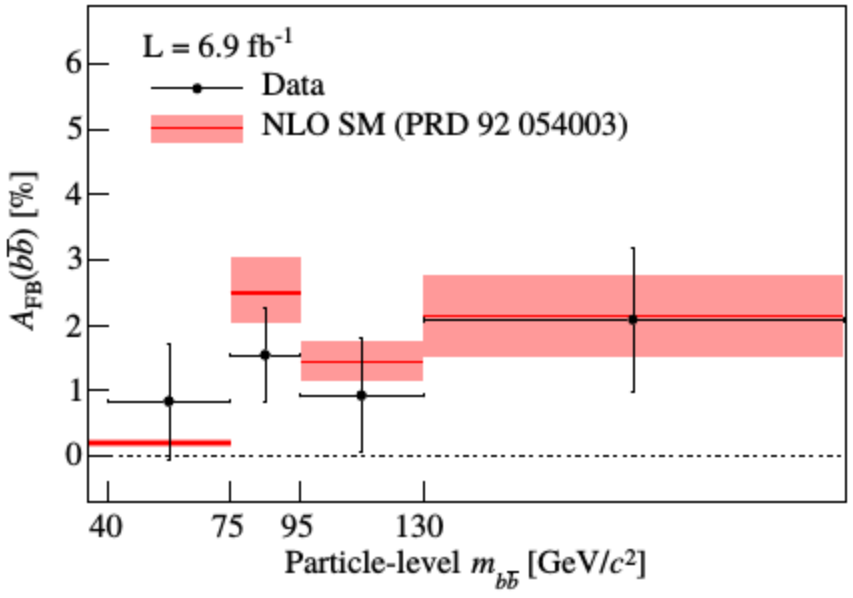
→ probability for Λ increases

CDF: A_{FB} in b-quark pairs

arXiv:1601.06526

- forward: b-quark in direction of the proton
- tag b or $\bar{b}$ by soft muon in jet
- jets identified as b-jets by secondary vertex

$$A_{FB} = \frac{N_Q(\cos\Theta > 0) - N_Q(\cos\Theta < 0)}{N_Q(\cos\Theta > 0) + N_Q(\cos\Theta < 0)}$$



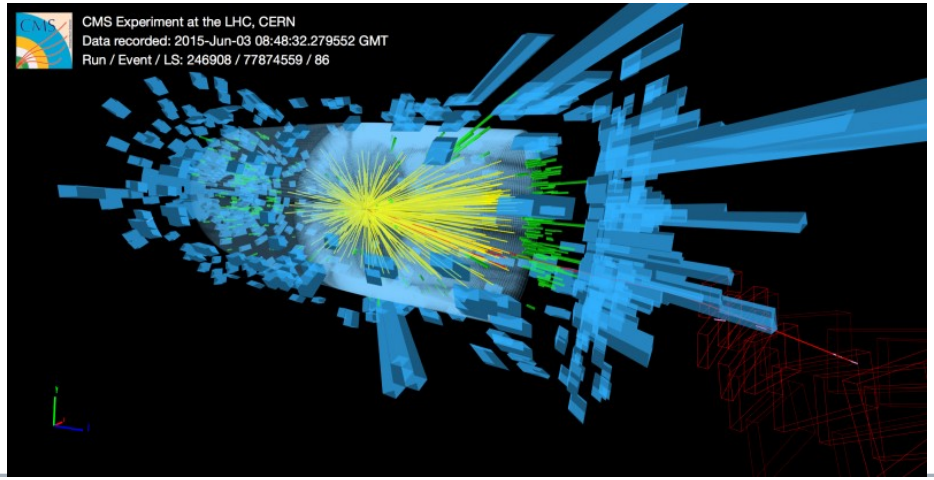
tendency of increase around Z mass

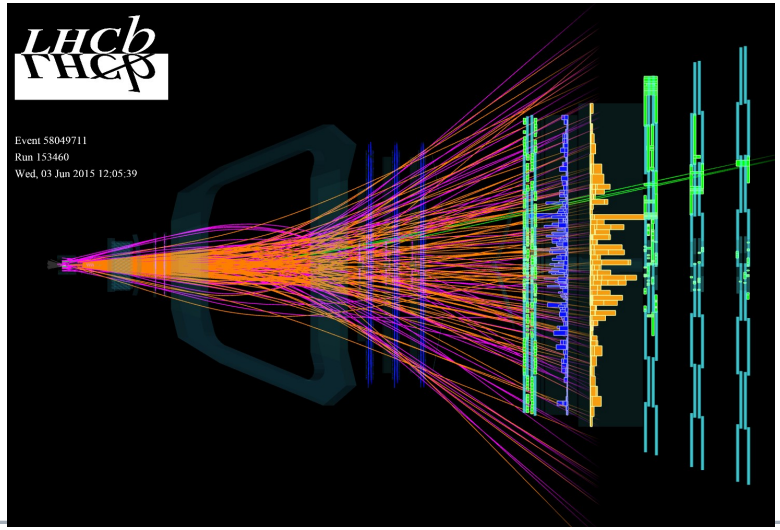
predicted: contribution of electroweak processes

similar measurement by LHCb: Phys. Rev. Lett. 113 (2014) 082003

Conclusions

- LHC high-precision QCD measurements at 7 and 8 TeV being complemented by the first results at 13 TeV
- combinations of measurements taken at different energies
  → cancellation of uncertainties
  → better constraint of theoretical inputs (e.g. PDF's) and more stringent tests
- measurements of multiple final states
  → explore regions of phase space where current theory still struggles to match data
- systematic exploration of final states with several beam energies
  → may improve our understanding of QCD





Talks in parallel sessions

ATLAS

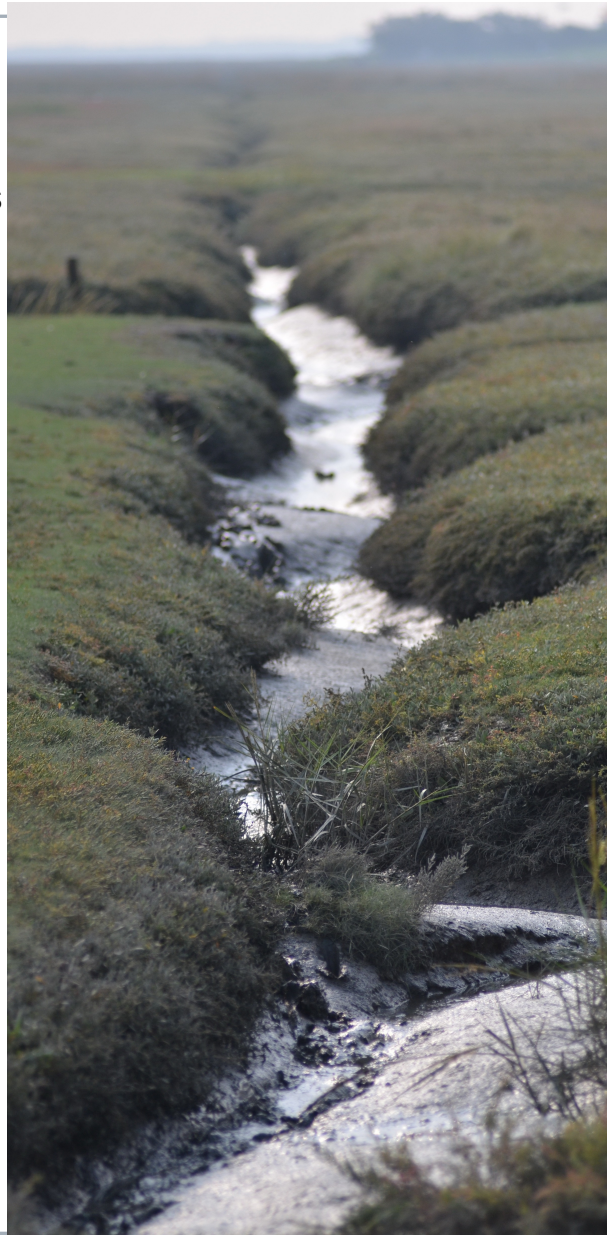
- Juan Terron: Tue 11:48 WG2 Photon production cross sections
- Artem Maevskiy Tue 15:10 WG4 Results on B-Physics and Quarkonia
- Alexey Ezhilov: Wed 9:00 WG2/3 DY p_T distributions and angular coefficients in Z boson decays
- Marisa Sandhoff: Wed 9:50 WG2/3 Jets in association with a W or Z boson
- Elena Yatsenko: Wed 14:30 WG1/3 DY cross sections
- Hayk Pirumov: Wed 14:45 WG1/3 W and Z 13 TeV
- Melissa Ridel: Wed 15:40 WG2 4-jet production x-sections and Et correlations
- Susan Cheatham Thu 10:00 WG4 J/Ψ and Υ

CMS

- Kai-Feng Chen: Tue 14:50 WG4 Heavy Flavour results
- Paolo Gunnellini: Tue 16:55 WG1/2 Jets at 2.76, 7 and 8 TeV
- Ji Yeon Han: Wed 9:25 WG2/3 Jets in association with a W or Z boson
- Feng. Zhang: Wed 10:10 WG2/3 V plus jets
- Gabor Veres: Wed 15:15 WG2 Multi-jet production and jet correlations
- Panos Kokkas: Wed 17:25 WG2 Dijet azimuthal decorrelation

LHCb

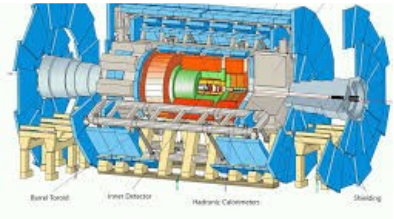
- Tomasz Szumiak Tue 14:30 WG4 13 TeV cross-section measurements
- Lorenzo Sestini: Wed 15:40 WG1/3 W, Z and top production measurements



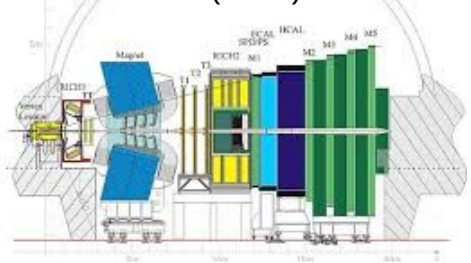
Backup

Detectors

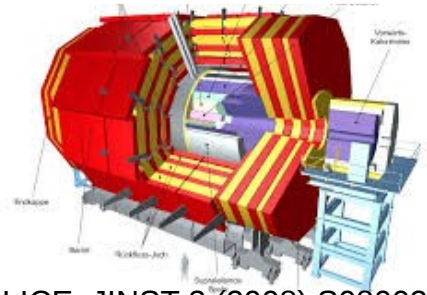
ATLAS JINST 3 (2008) S08003



LHCb JINST 3 (2008) S08005

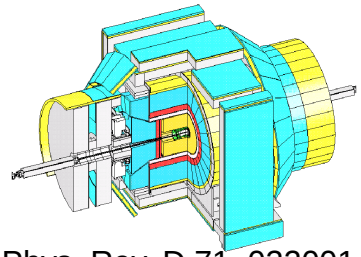


CMS JINST 3 (2008) S08004

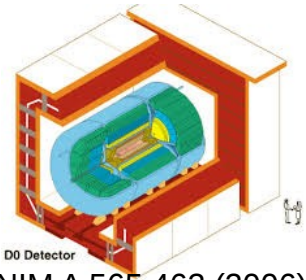


ALICE: JINST 3 (2008) S08002

Experiment	cm energy [TeV]	integrated luminosity [fb^{-1}]
ATLAS, CMS	7 8 13	6 22 4
ALICE	7 8 13	0.005 0.01 0.007
LHCb	7 8 13	1.0 2.0 0.3
CDF, D0	1.96	10



CDF: Phys. Rev. D 71, 032001 (2005)



D0: NIM A 565,463 (2006)

Isolated photons

→ test pQCD in a cleaner environment, less affected by hadronisation effects

main background from $\pi^0 \rightarrow \gamma\gamma$: 10^5 jets/photon

→ photon isolation needed

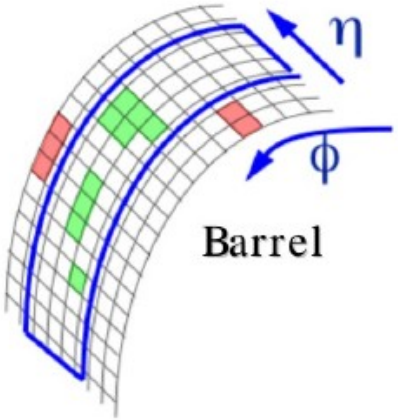
dominant production process: qg → qγ → probe gluon PDF

photon identification

CMS:

2-dimensional clusters
barrel: narrow in eta,
variable in phi

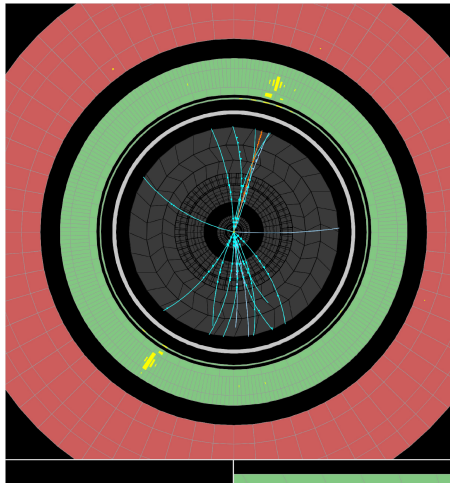
endcap: 5x5 clusters



ATLAS:
cut based analysis
efficiency: 90% E_T>50 GeV

converted photons: two tracks pointing to cluster

CDF:
neural net based on shower shape



2-photon candidate by ATLAS
https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PAPERS/STDM-2011-05

Jet reconstruction

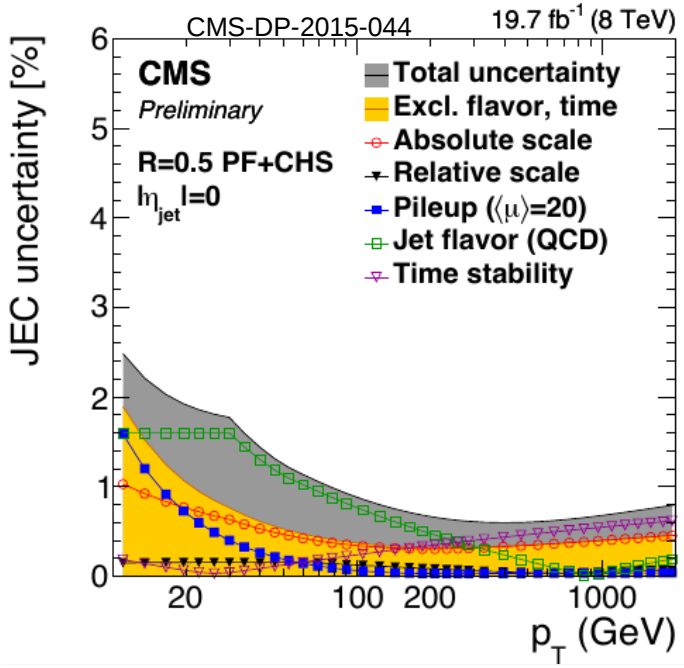
CMS & LHCb:
input: Particle Flow objects
particles identified from information in tracker and calorimeters

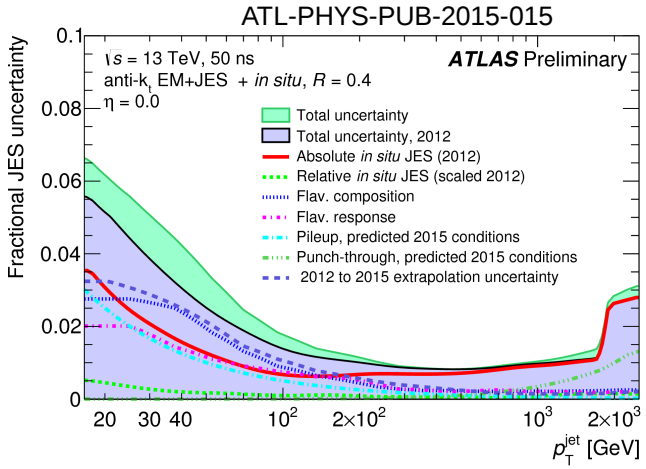
ATLAS:
merge calorimeter cells to topo-clusters
input: topo-clusters

JES O(1%) for intermediate p_T

dominant uncertainties:

- time stability at high p_T
- jet flavour composition
- pileup for low p_T
- absolute calibration





Inclusive jets @ 2.76 TeV

arXiv:15120612

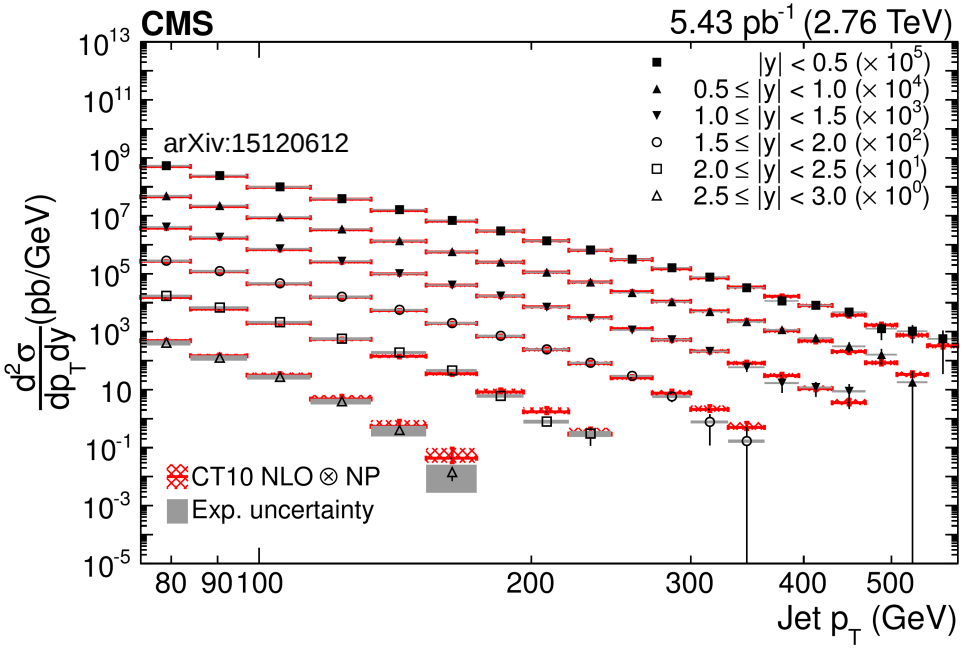
luminosity: 5.43 pb^{-1}, p_T(jet)>74 GeV

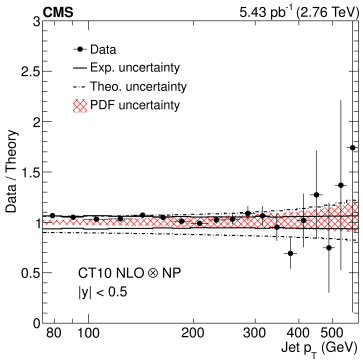
sensitive to α_s and PDF

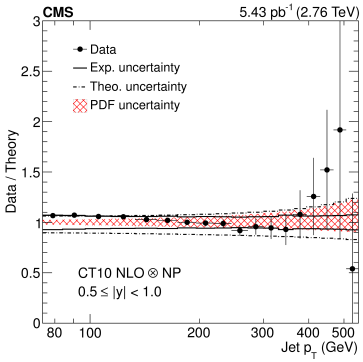
double differential cross-sections
high rapidities: agreement poorer

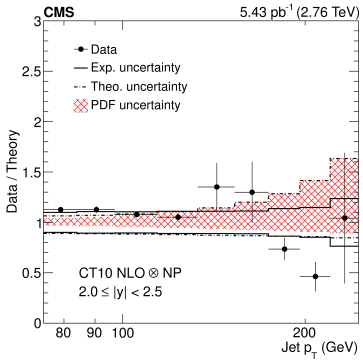
Be aware:
uncertainties highly correlated

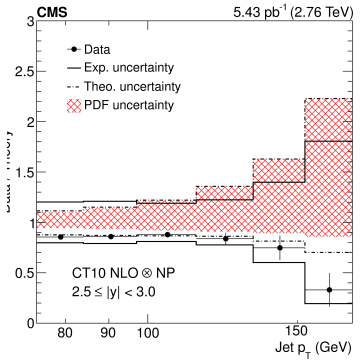
overall good description by NLO











Z/γ* φ* @ 8 TeV

arXiv:1512.02192

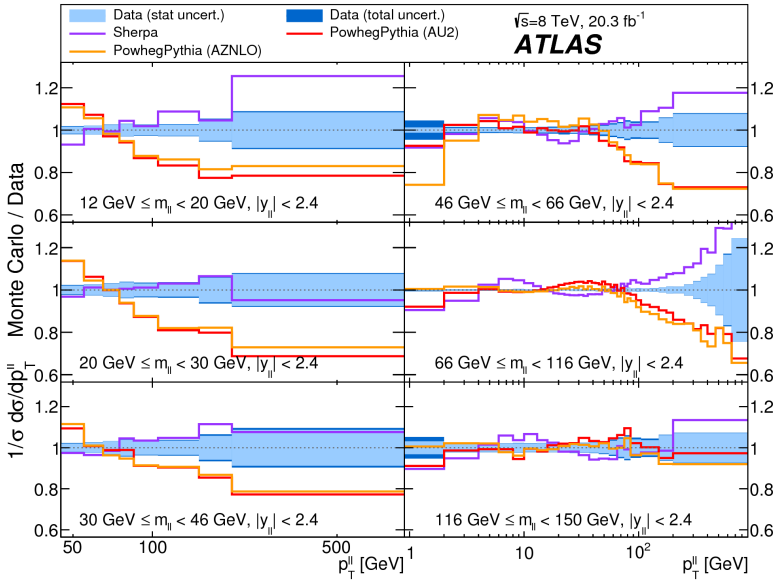
low p_T: soft-gluon re-summation, non perturbative effects of intrinsic p_T of partons

high p_T: fixed order QCD

→ test of several aspects of QCD

normalised x-section ratio, 66<M<116 GeV:
data over prediction vs φ* for different y bins

normalised x-section ratio |y|<2.4:
data over prediction vs p_T for different mass bins



- φ*: very precise differential measurements uncertainties < 1%
- RESBOS predictions agree except for high φ* or masses <M(Z)
  NNLO+NNLL crucial to reproduce low φ*
- MC generators+PS also describe low p_T: 5<p_T<100 GeV with M> 46 GeV

Angular coefficients of lepton pairs in Z events

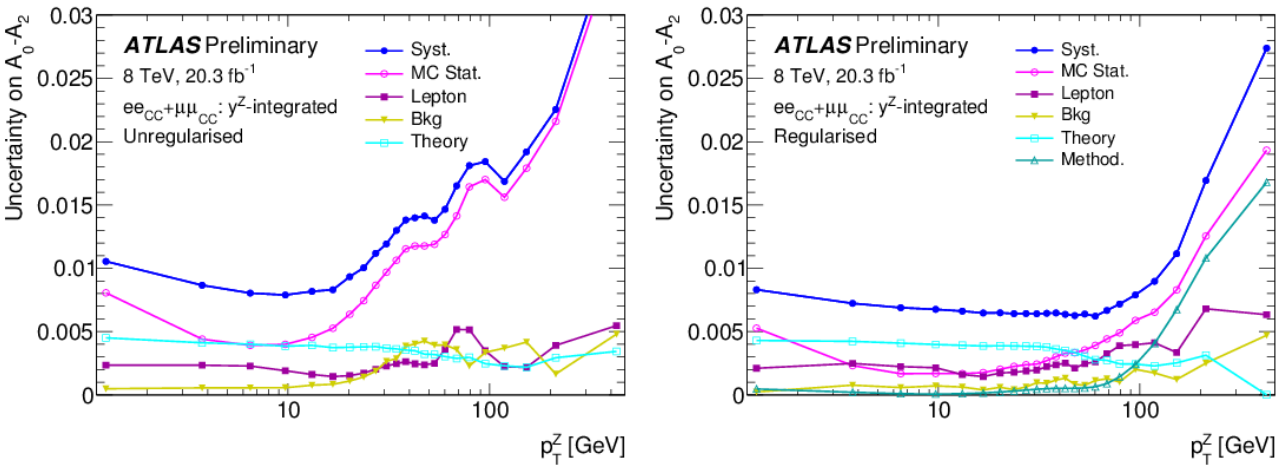
in Z rest frame:

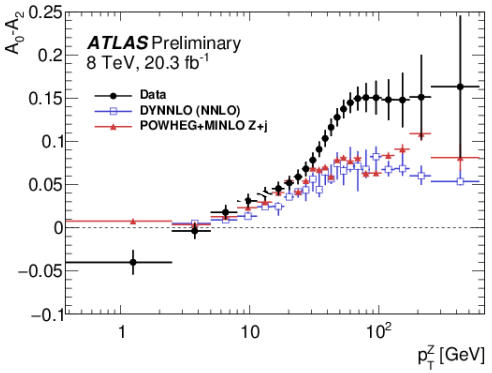
ATLAS analysis

$$\frac{d^2\sigma}{d\cos\theta^* d\phi^*} \propto \Big[(1+\cos^2\theta^*) + A_0\frac{1}{2}(1-3\cos^2\theta^*) + A_1\sin(2\theta^*)\cos\phi^* + A_2\frac{1}{2}\sin^2\theta^*\cos(2\phi^*) + A_3\sin\theta^*\cos\phi^* + A_4\cos\theta^* + A_5\sin^2\theta^*\sin(2\phi^*) + A_6\sin(2\theta^*)\sin\phi^* + A_7\sin\theta^*\sin\phi^*\Big].$$

- electron and muon channel → important x-checks (CMS: muon only)
- coefficients extracted by fitting templates of the P_i polynomial terms to angular distributions profile likelihood to optimise systematics
- regularisation based on higher order derivatives → smoothes result and introduces significant correlations of uncertainties of neighbouring bins.

effect of regularisation





ATLAS: inclusive jets at 13 TeV

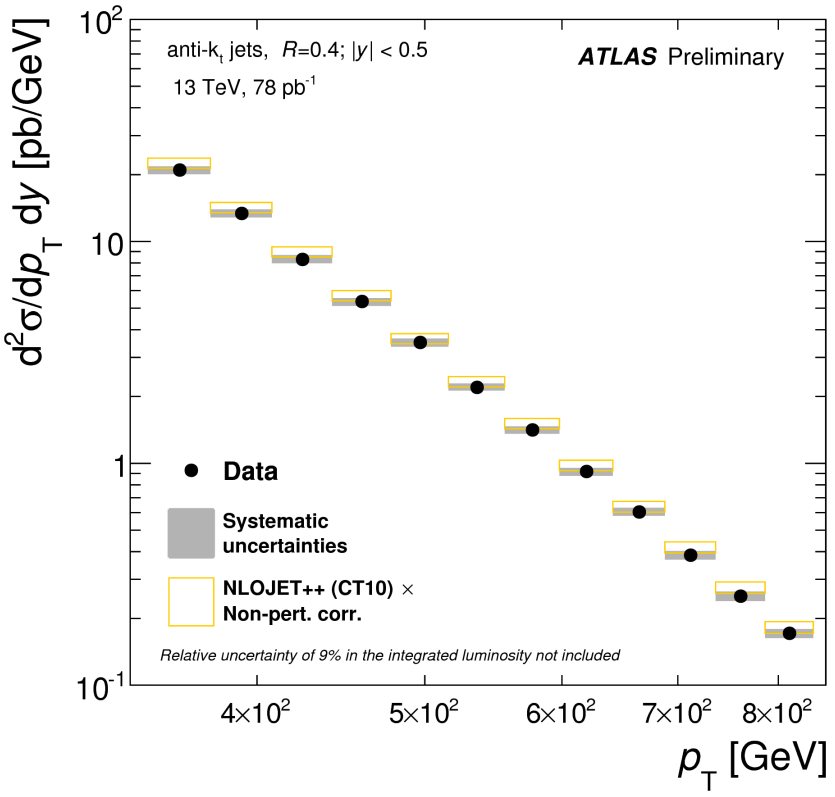
ATLAS-CONF-2015-034

Differential cross section with R=0.4

comparison: NLOJet++

jet transverse p_T: consistent with predictions using different PDFs over large range of p_T

uncertainties highly correlated



multijets: 4-jets @ 8 TeV

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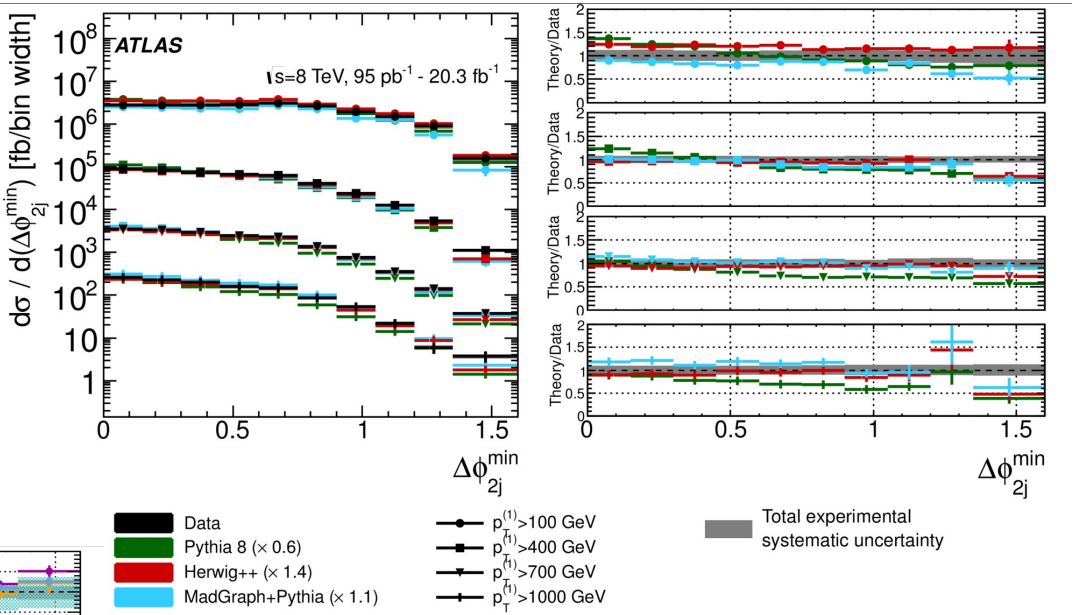
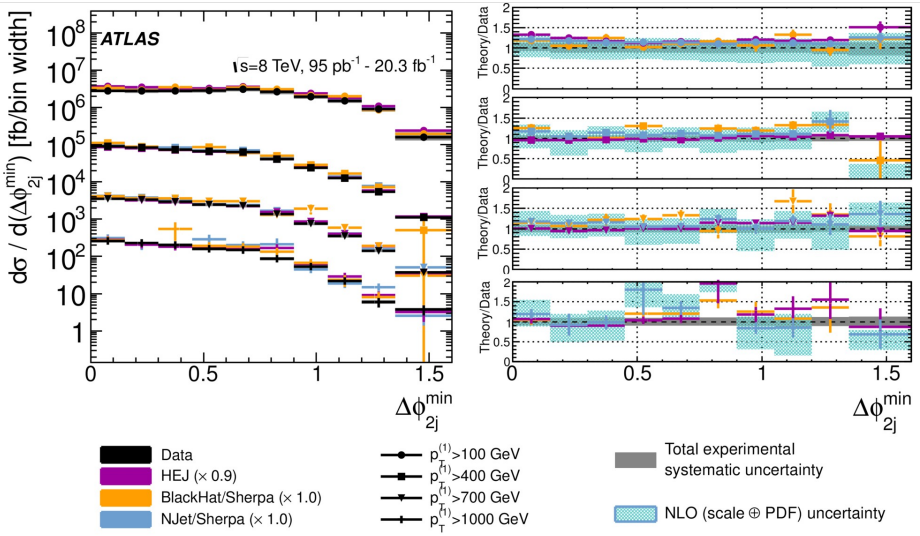
topological variables sensitive to QCD colour factors, spin of gluons hadronisation models

minimal angular separation for different p_T

→ test description of small and wide angle radiation

- HERWIG++: very good
- PYTHIA8: slope smaller





NLO predictions (BlackHat/Sherpa and Njet/Sherpa) compatible within large uncertainties
HEJ (all-order resummation: good description

Z/γ* transverse momentum and φ* @ 8 TeV

arXiv:1512.02192

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- φ*: very precise differential measurements uncertainties < 1%
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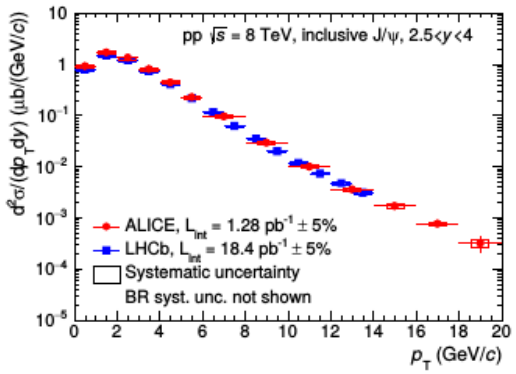
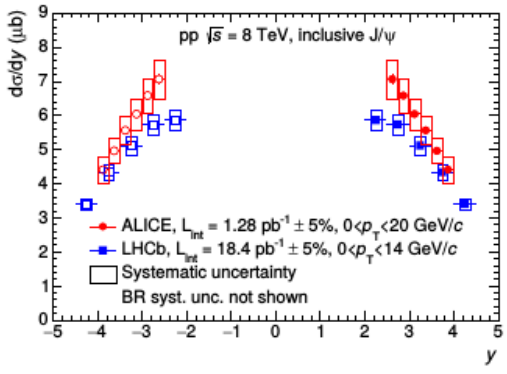
  NNLO+NNLL crucial to reproduce low φ*
- MC generators+PS also describe low p_T: 5<p_T<100 GeV with M> 46 GeV

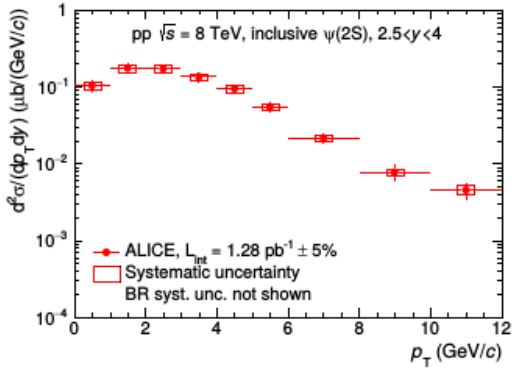
Charmonium @ 8 TeV – forward (ALICE)

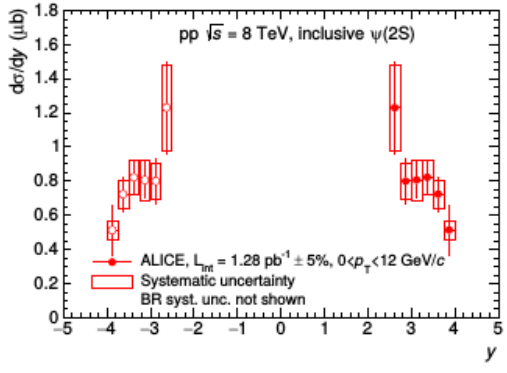
arXiv: 1509.082581

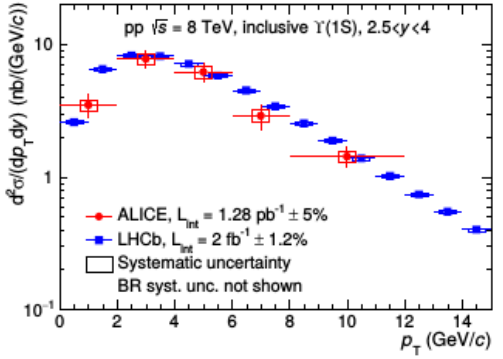
- J/Ψ: extend to pT<20 GeV
  good agreement with LHCb
- Ψ(2S) first measurement at 8 TeV
- Upsilon: agreement with LHCb
  within 1.5 σ
- x-section increases from 7 TeV by
  about 30%

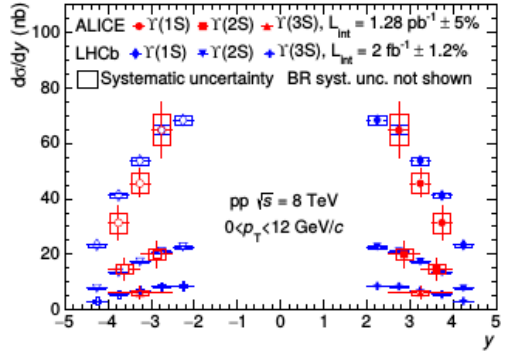












Multijets: 4-jets @ 8 TeV

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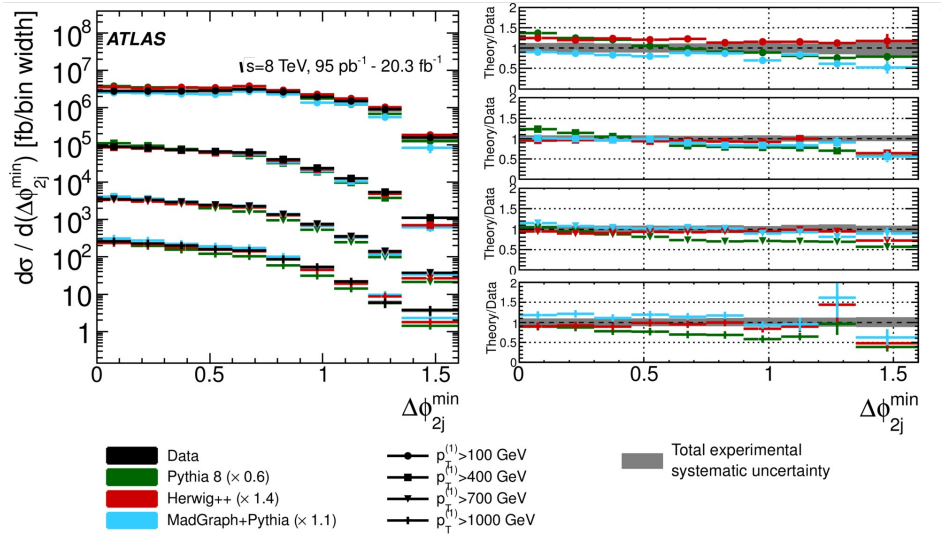

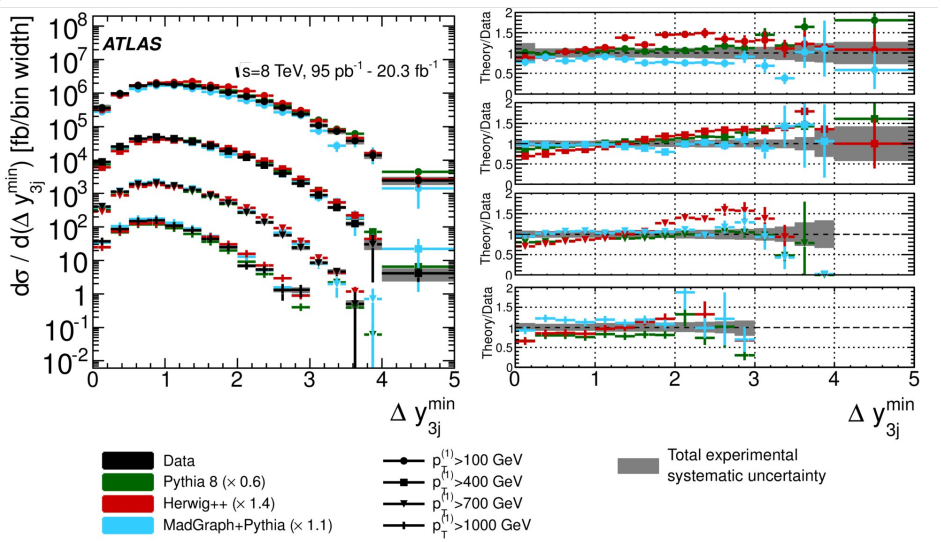

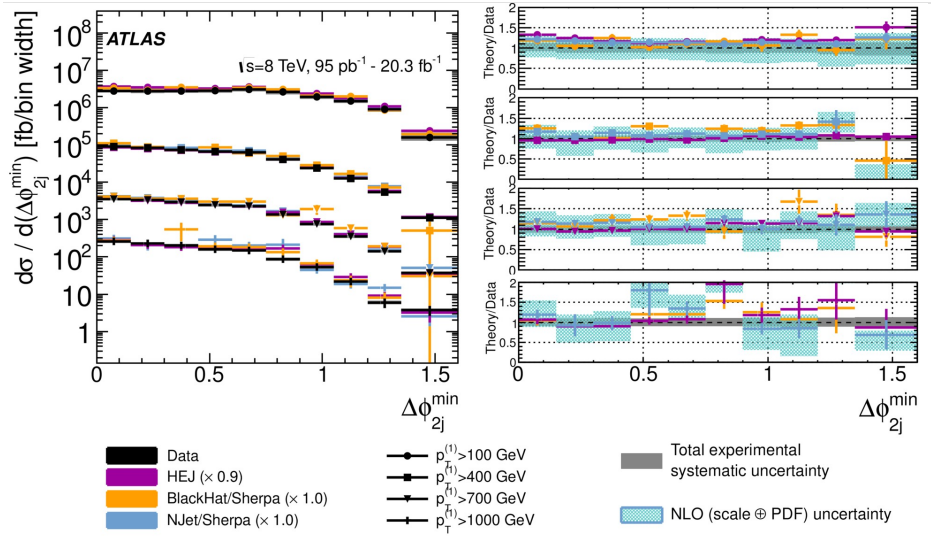

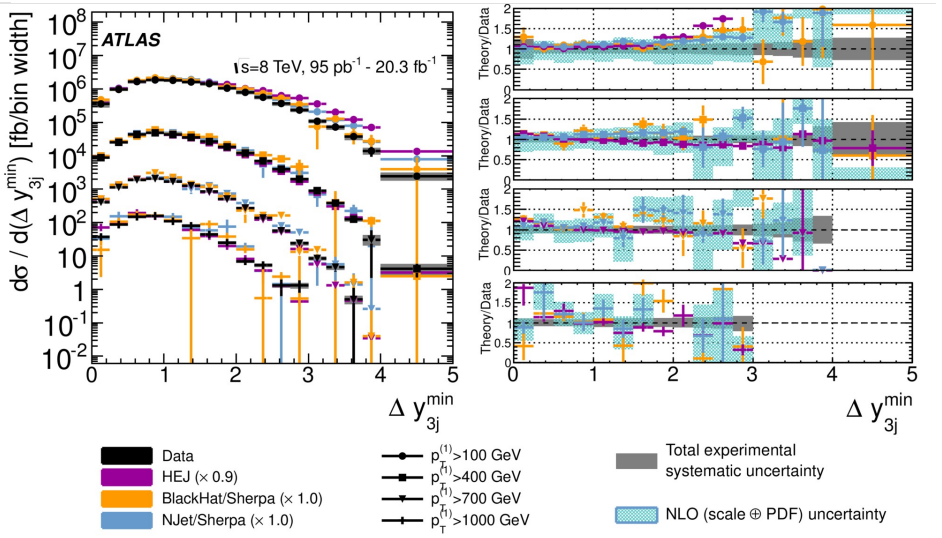

W plus jet @ 1.96 TeV

one central (|y| <1) lepton and at least one jet with E_T > 25 GeV, |y| <2

syst. uncertainties: 8% (>=1 jet) 28% 4 jets
predictions LO ALPGEN+PYTHIA plus k-factor
→ theoretical uncertainties very high - dominated by missing higher orders