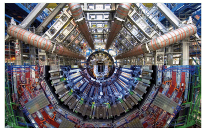
SM and Heavy Ions results from ATLAS and CMS

Elisabetta Gallo (DESY and University of Hamburg)
On behalf of the ATLAS and CMS Collaborations

DESY

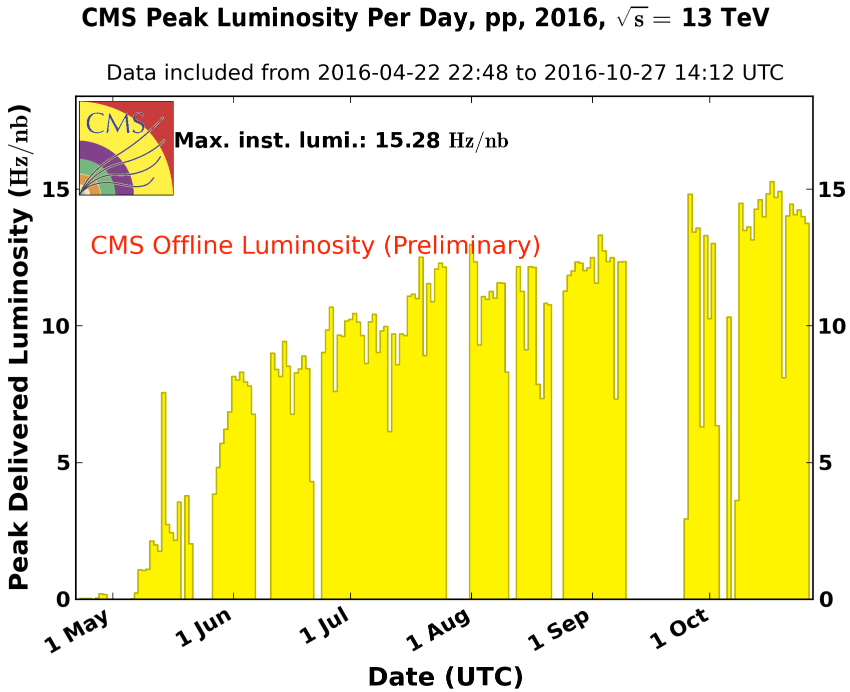
Universität Hamburg
DER FORSCHUNG | DER LEHRE | DER BILDUNG

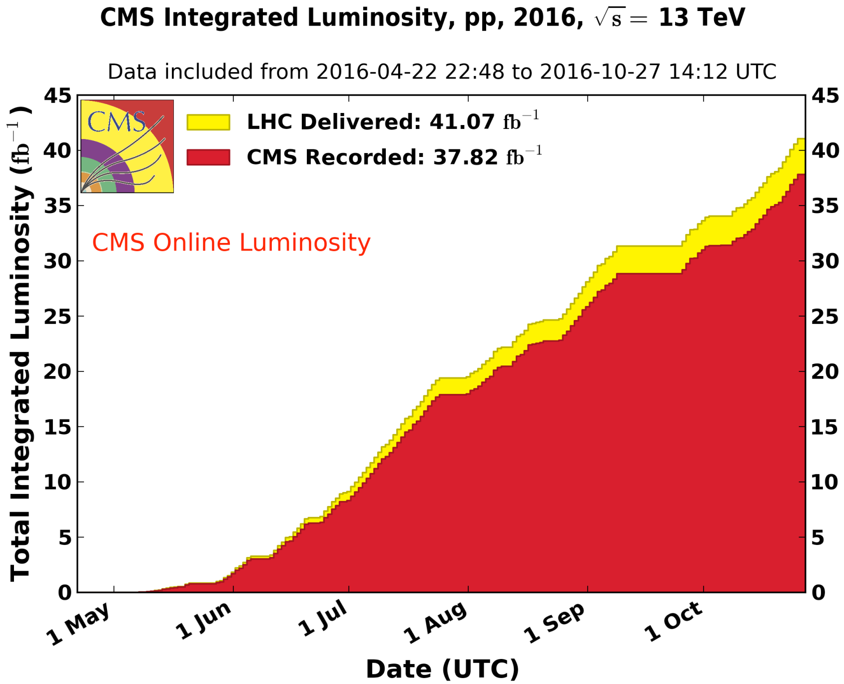


Highlights from:
W/Z, diboson production
Top
Jets (see also ATLAS A. Minaenko's talk)
Heavy Ions at CMS (ATLAS R. Slovak's talk)

mainly 13 TeV data shown here

A very successful 2016 Run

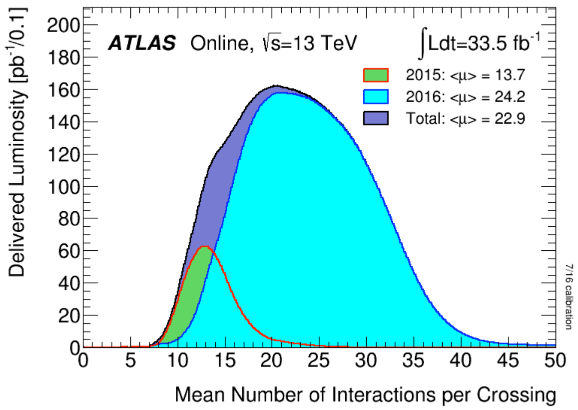


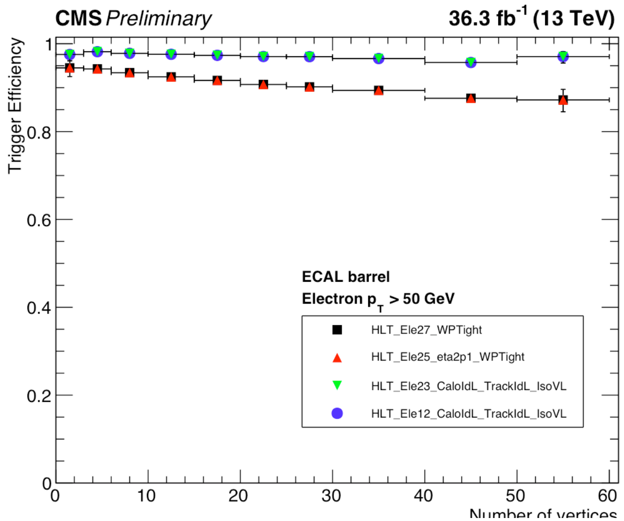


- LHC exceeded expectations for 2016, excellent performance
- LHC peak efficiency of 58% and more than 50% of the time in Stable Beam between TS2 and TS3
- Max inst luminosity achieved of 1.5 X 10^{34} cm^{-2} sec^{-1}

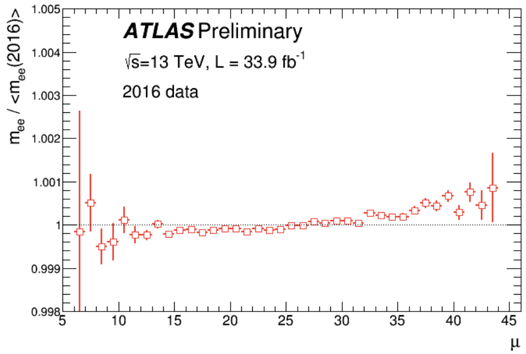
- Both ATLAS and CMS: 92% data-taking efficiency and ~ 36 fb^{-1} of data collected in 2016 for physics
- 1/3 of 2016 presented already last summer

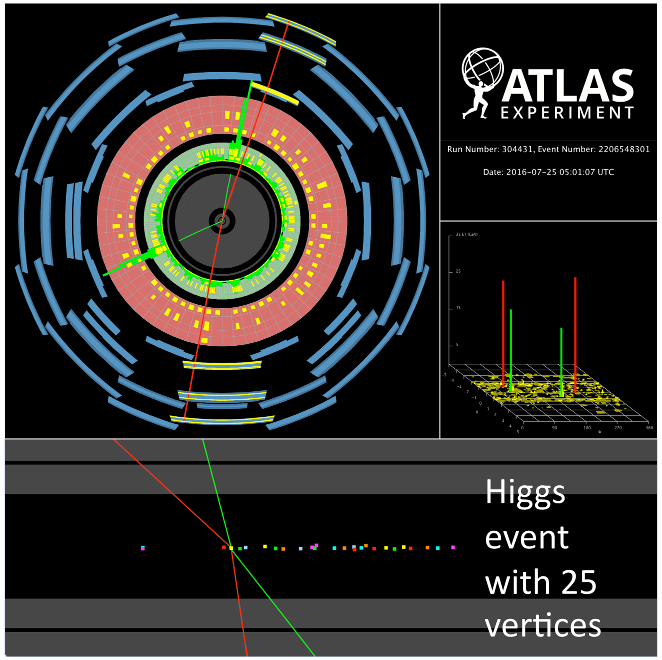
Performance in 2016



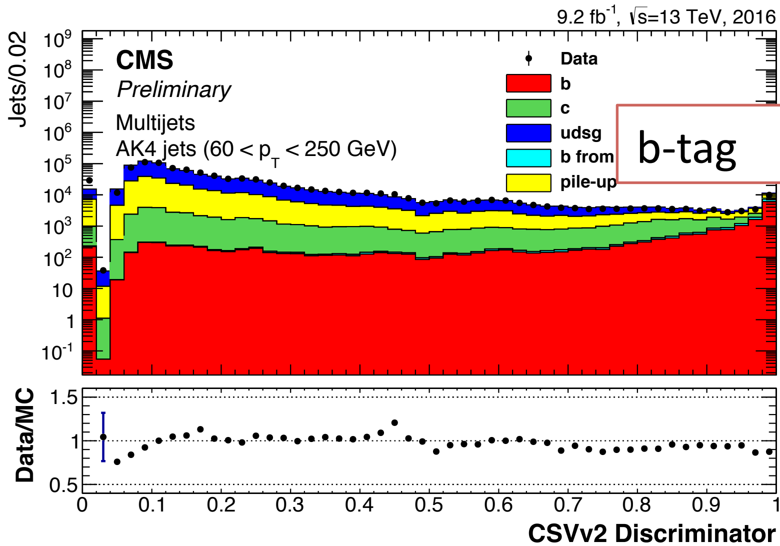


Electron triggers and reconstruction



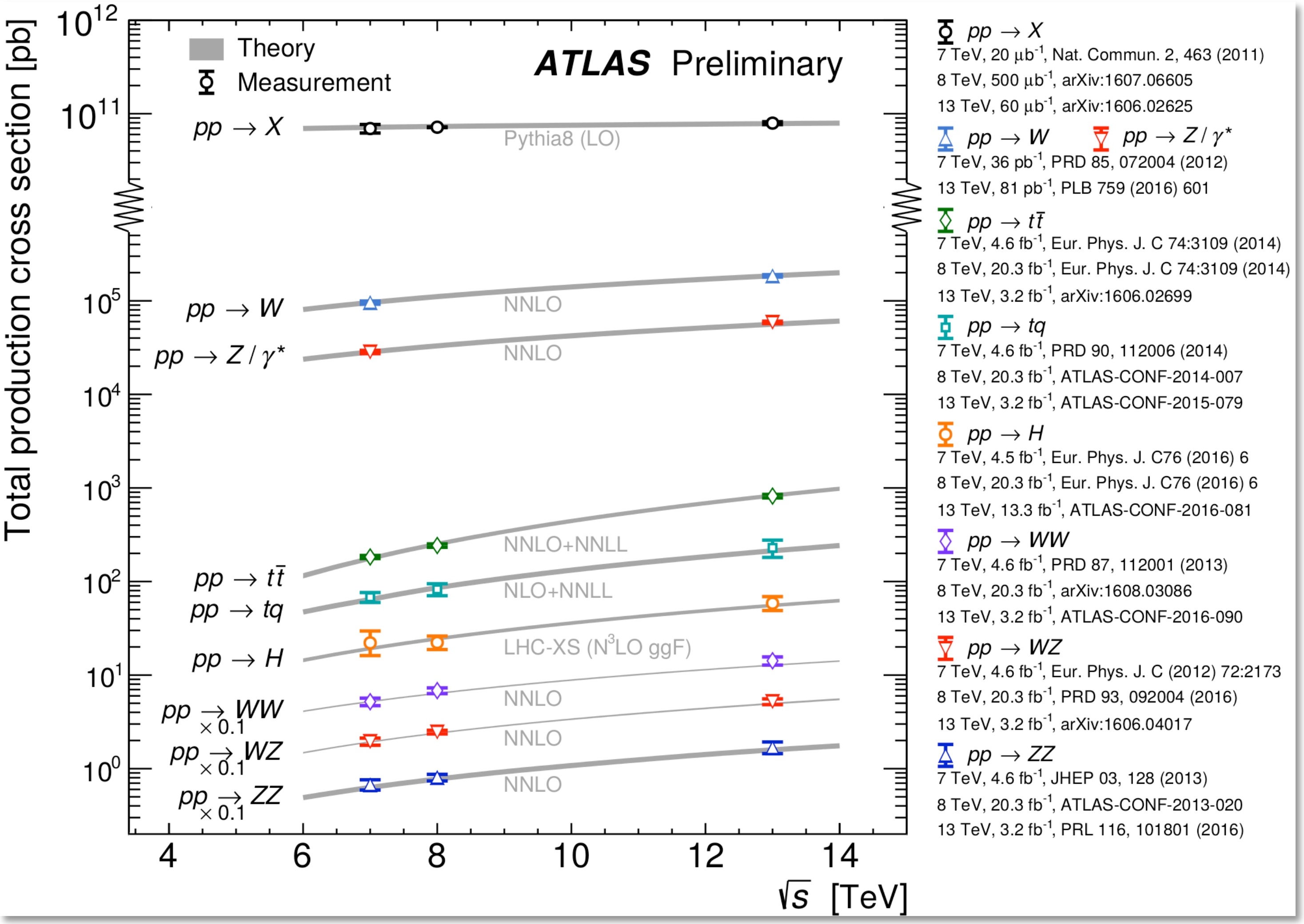


Excellent performance of both experiments in spite of the high pile-up

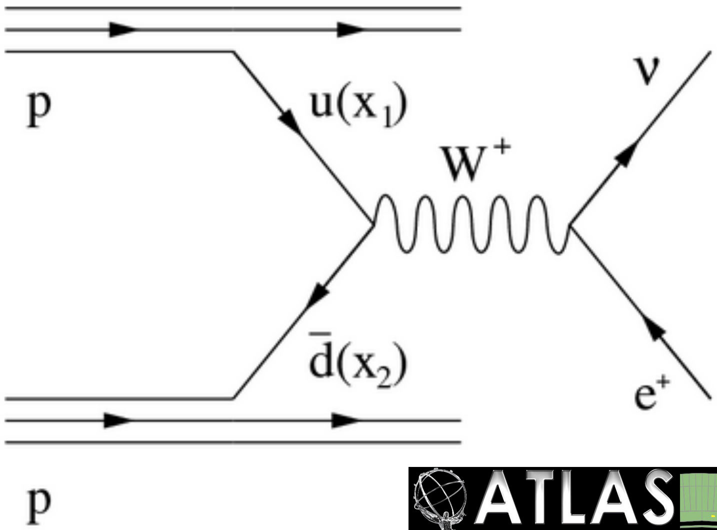


b-tag

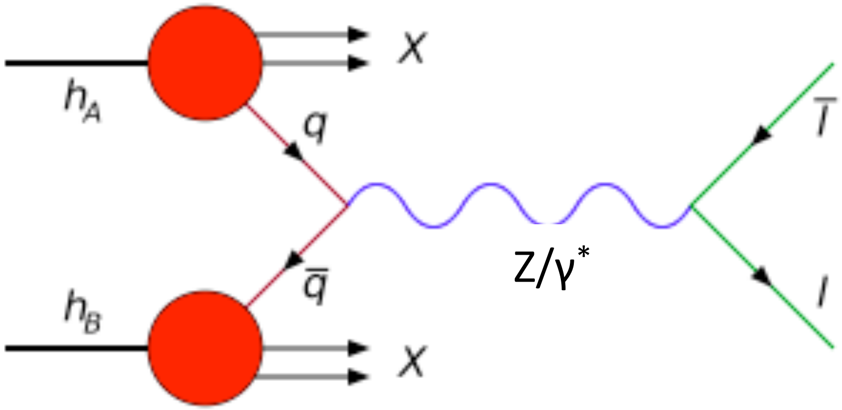
Standard Model Cross-Sections



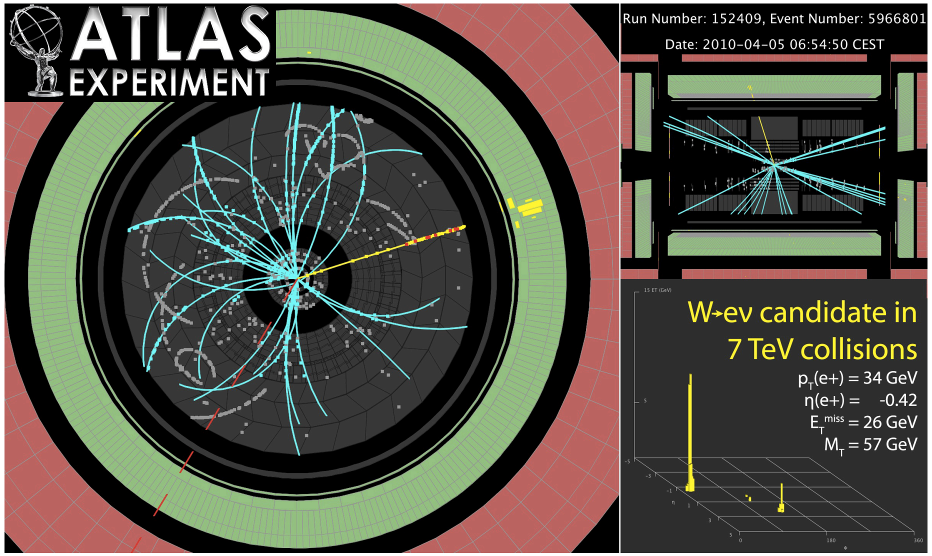
W/Z physics



p
u(x1)
W+
ν
d̄(x2)
e+
p



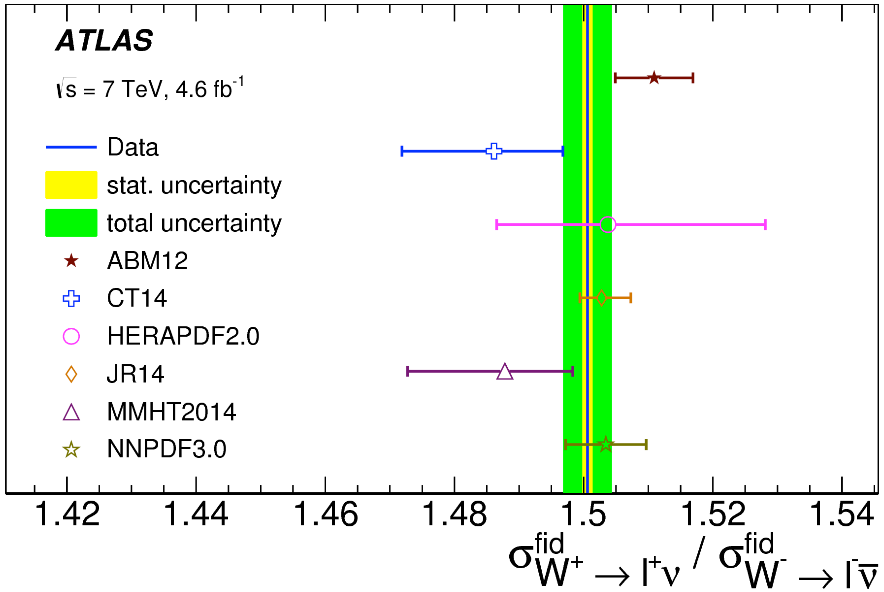
hA
X
q
Z/γ*
hB
X

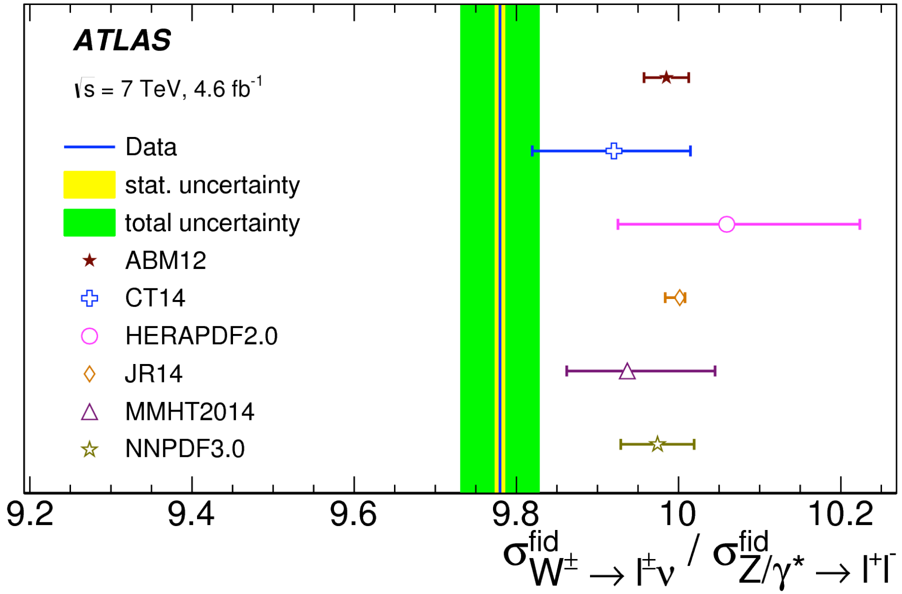


ATLAS EXPERIMENT
Run Number: 152409, Event Number: 5966801
Date: 2010-04-05 06:54:50 CEST
W→eν candidate in 7 TeV collisions
pT(e+) = 34 GeV
η(e+) = -0.42
ETmiss = 26 GeV
MT = 57 GeV

W/Z cross sections at 7 TeV

ATLAS
arXiv:1612.03016



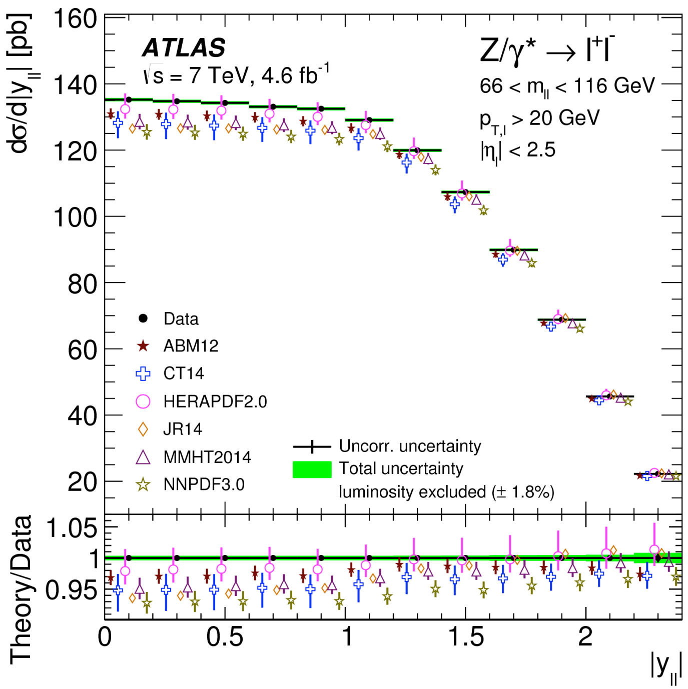


Based on ~15M W events, 1.6 M Z's with 2011 data.
New very precise measurement of the inclusive Z and W cross sections, with syst. unc. of ~0.6% (W) and <0.32% (Z) (+1.8% due to luminosity determination).
In good agreement with theory, NNLO QCD+NLO EW, sensitive to PDFs

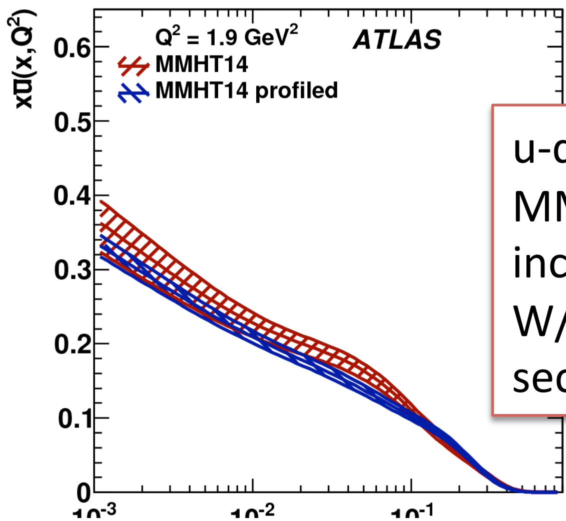
Take ratios to decrease uncertainties, i.e. luminosity unc. cancel.
Some tensions of the W/Z ratio compared to recent PDF parametrizations

W/Z cross sections at 7 TeV

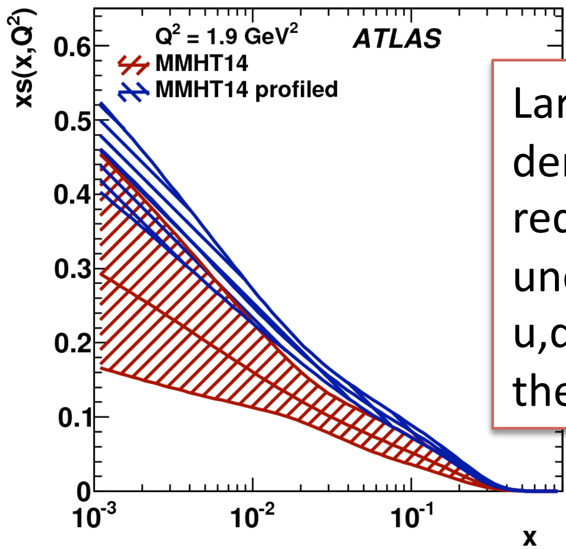
ATLAS
arXiv:1612.03016



New precise measurements of Z and W differential cross sections and of the $W^{+/-}$ asymmetry (0.5-1% syst.), all sensitive to PDFs



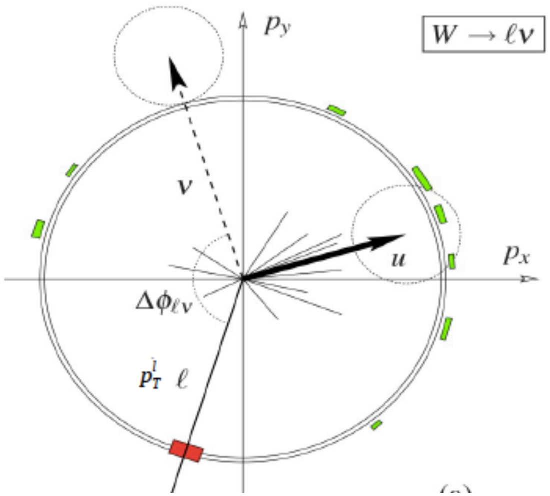
u-density in MMHT14 after including new W/Z diff. cross-sections data



Larger strange-density and reduced uncertainty for u,d,s by including these data

W mass

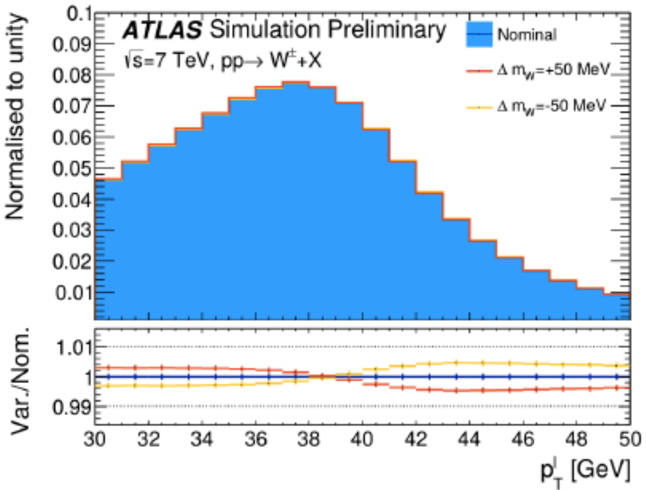
ATLAS-CONF-2016-113

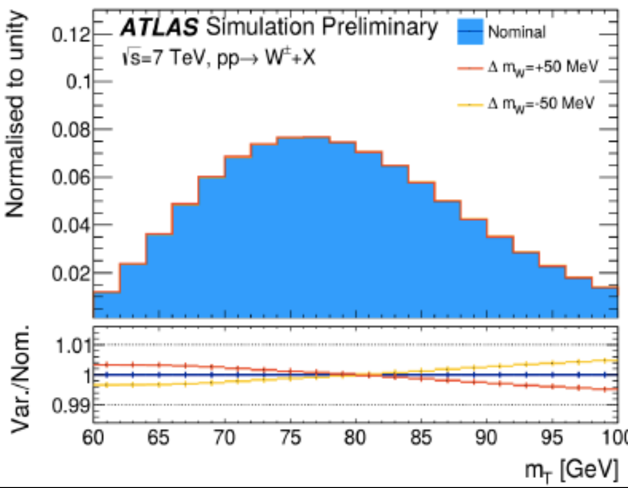


- Method: reconstruct mass sensitive variables from lepton and recoil kinematics, both in muon and electron channels
- fit expected templates with different masses to data for p_T^l and m_T
- excellent understanding of calibration of recoil and leptons
- excellent understanding of exp and theo uncertainties (see also previous differential measurements)
- cross-check with Z events

$$\vec{p}_T^{\,miss} = -\left(\vec{p}_T^{\,\ell} + \vec{u}_T\right), \quad m_T = \sqrt{2 p_T^{\ell} p_T^{miss} (1 - \cos\Delta\phi)}$$

2011 data, 7 TeV
4.6 fb^{-1} electron
4.1 fb^{-1} muon





W mass

ATLAS-CONF-2016-113

Combined categories	Value [MeV]	Stat. Unc.	Muon Unc.	Elec. Unc.	Recoil Unc.	Bckg. Unc.	QCD Unc.	EWK Unc.	PDF Unc.	Total Unc.	χ^2/dof of Comb.
m_T, W^+, e-μ	80370.0	12.3	8.3	6.7	14.5	9.7	9.4	3.4	16.9	30.9	2/6
m_T, W^-, e-μ	80381.1	13.9	8.8	6.6	11.8	10.2	9.7	3.4	16.2	30.5	7/6
m_T, $W^\pm$, e-μ	80375.7	9.6	7.8	5.5	13.0	8.3	9.6	3.4	10.2	25.1	11/13
p_T^ℓ, W^+, e-μ	80352.0	9.6	6.5	8.4	2.5	5.2	8.3	5.7	14.5	23.5	5/6
p_T^ℓ, W^-, e-μ	80383.4	10.8	7.0	8.1	2.5	6.1	8.1	5.7	13.5	23.6	10/6
p_T^ℓ, $W^\pm$, e-μ	80369.4	7.2	6.3	6.7	2.5	4.6	8.3	5.7	9.0	18.7	19/13
p_T^ℓ, $W^\pm$, e	80347.2	9.9	0	14.8	2.6	5.7	8.2	5.3	8.9	23.1	4/5
m_T, $W^\pm$, e	80364.6	13.5	0	14.4	13.2	12.8	9.5	3.4	10.2	30.8	8/5
m_T-p_T^ℓ, W^+, e	80345.4	11.7	0	16.0	3.8	7.4	8.3	5.0	13.7	27.4	1/5
m_T-p_T^ℓ, W^-, e	80359.4	12.9	0	15.1	3.9	8.5	8.4	4.9	13.4	27.6	8/5
m_T-p_T^ℓ, $W^\pm$, e	80349.8	9.0	0	14.7	3.3	6.1	8.3	5.1	9.0	22.9	12/11
p_T^ℓ, $W^\pm$, μ	80382.3	10.1	10.7	0	2.5	3.9	8.4	6.0	10.7	21.4	7/7
m_T, $W^\pm$, μ	80381.5	13.0	11.6	0	13.0	6.0	9.6	3.4	11.2	27.2	3/7
m_T-p_T^ℓ, W^+, μ	80364.1	11.4	12.4	0	4.0	4.7	8.8	5.4	17.6	27.2	5/7
m_T-p_T^ℓ, W^-, μ	80398.6	12.0	13.0	0	4.1	5.7	8.4	5.3	16.8	27.4	3/7
m_T-p_T^ℓ, $W^\pm$, μ	80382.0	8.6	10.7	0	3.7	4.3	8.6	5.4	10.9	21.0	10/15
m_T-p_T^ℓ, W^+, e-μ	80352.7	8.9	6.6	8.2	3.1	5.5	8.4	5.4	14.6	23.4	7/13
m_T-p_T^ℓ, W^-, e-μ	80383.6	9.7	7.2	7.8	3.3	6.6	8.3	5.3	13.6	23.4	15/13
m_T-p_T^ℓ, $W^\pm$, e-μ	80369.5	6.8	6.6	6.4	2.9	4.5	8.3	5.5	9.2	18.5	29/27

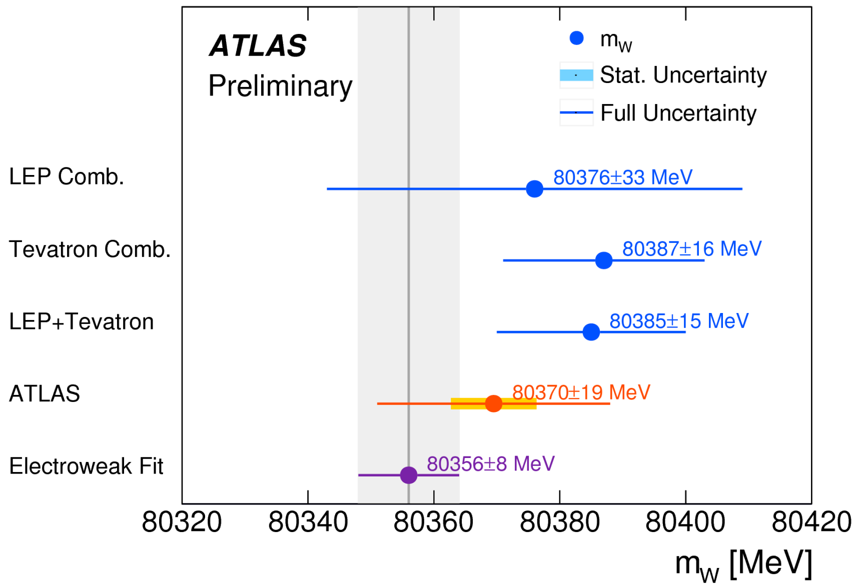
categories

Combined m_W= 80370 ±7(stat.) ±11 (exp.) ±14 (mod.syst.) = ± 19 total (MeV)

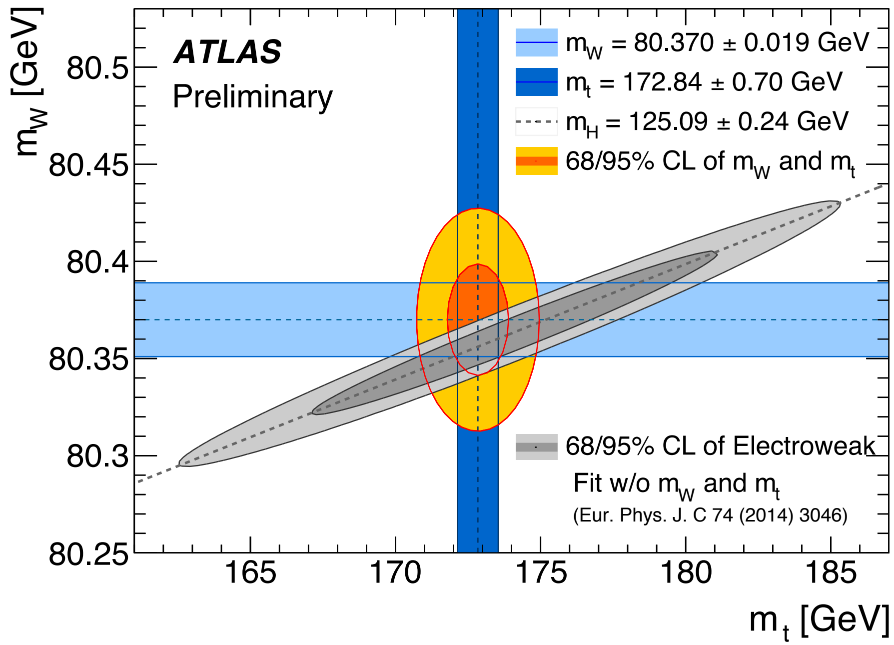
Fit of all categories together taking into account correlations

W mass

ATLAS-CONF-2016-113



m(top) latest ATLAS measurement, m_H from combination ATLAS+CMS



m_W = 80370±19 MeV
Similar precision to CDF or D0 alone
Theory NNLO precision 8 MeV

CDF: 80389±19 MeV
D0: 80375±23 MeV
PDG: 80385±15 MeV

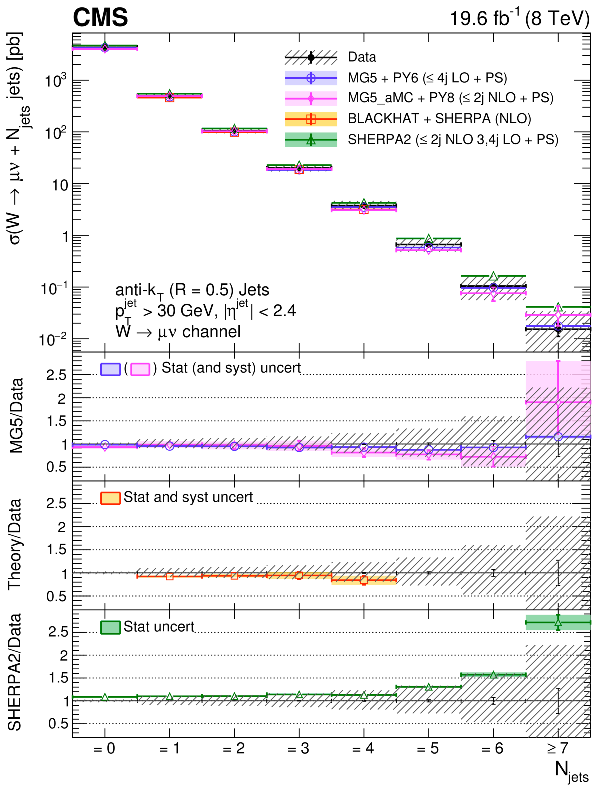
$$m_W^2\left(1-\frac{m_W^2}{m_Z^2}\right)=\frac{\pi\alpha}{\sqrt{2}G_F}(1+\Delta r)$$

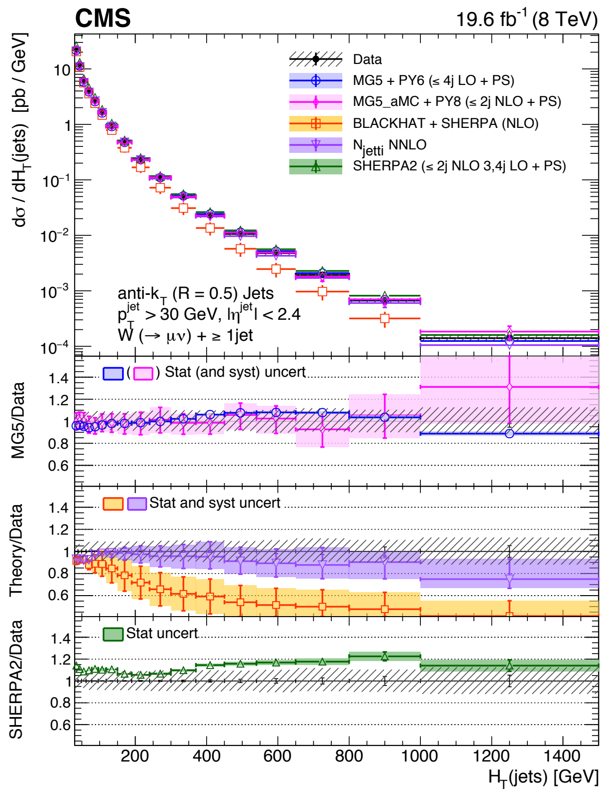
Also mass different measured:
$m(W^+)$**-**$m(W^-)$= -29 ± 28 MeV

W+jets, Z+jets

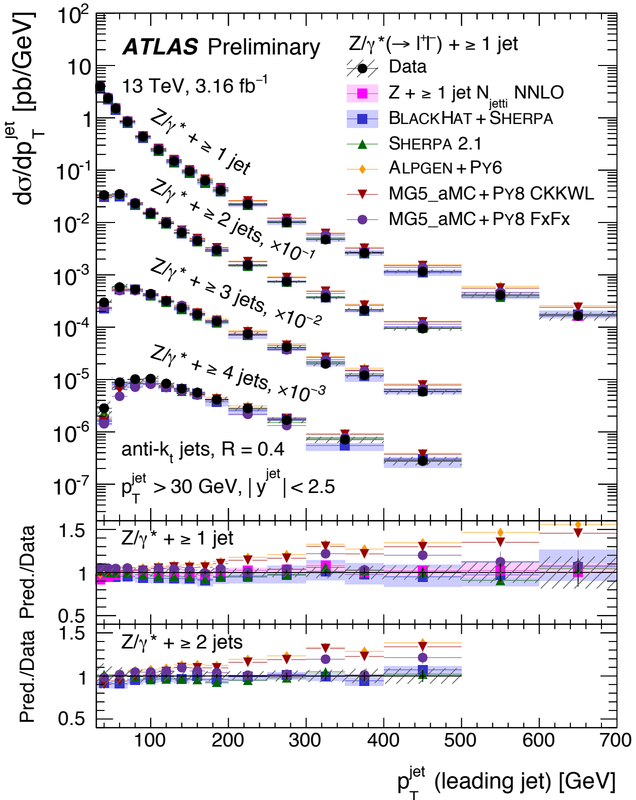
CMS arXiv:1610.04222

ATLAS-CONF-2016-046





W+jets 8 TeV, up to 7 jets

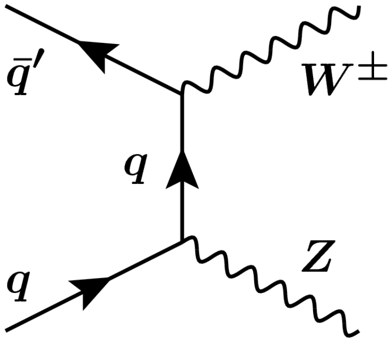


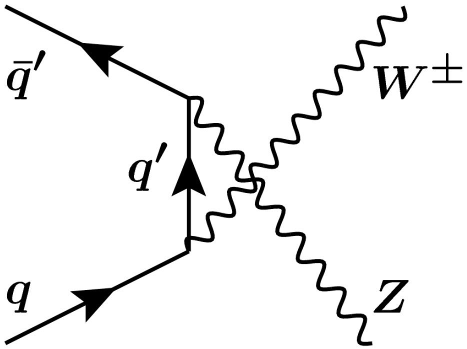
Z+jets 13 TeV

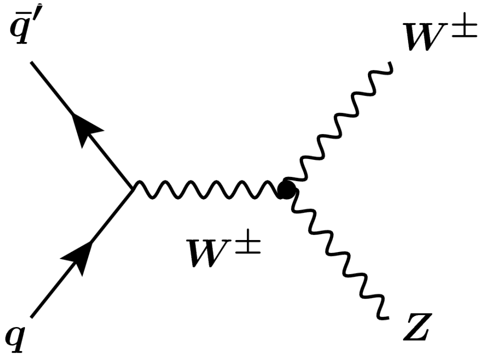
BlackHat+Sherpa: NLO up to 4 jets,
NNLO calculation recently available Z/W+≥1j (Boughezal et al.)

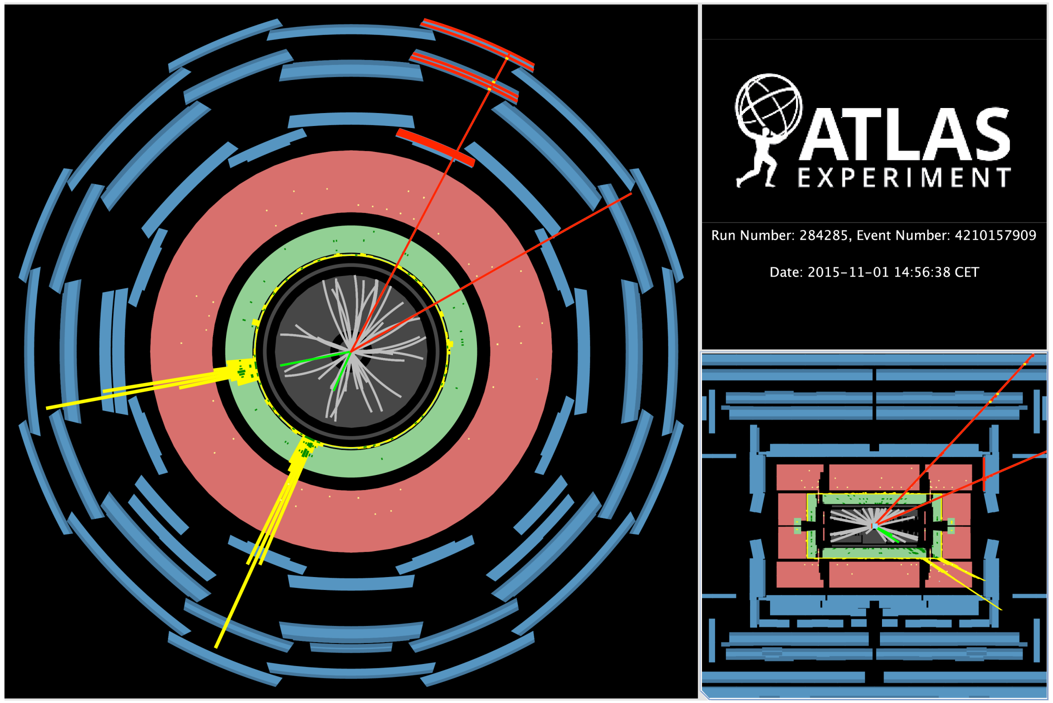
Good agreement with pQCD calculations

Diboson production







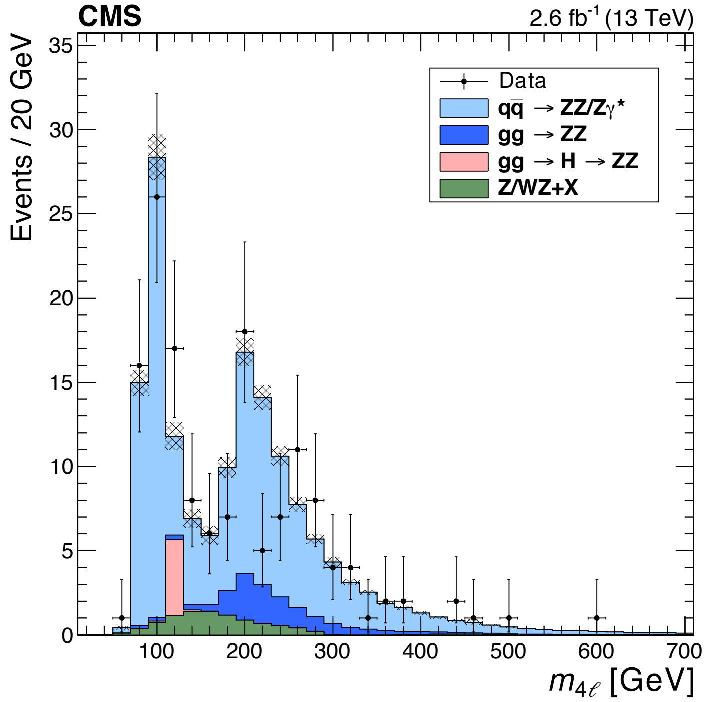


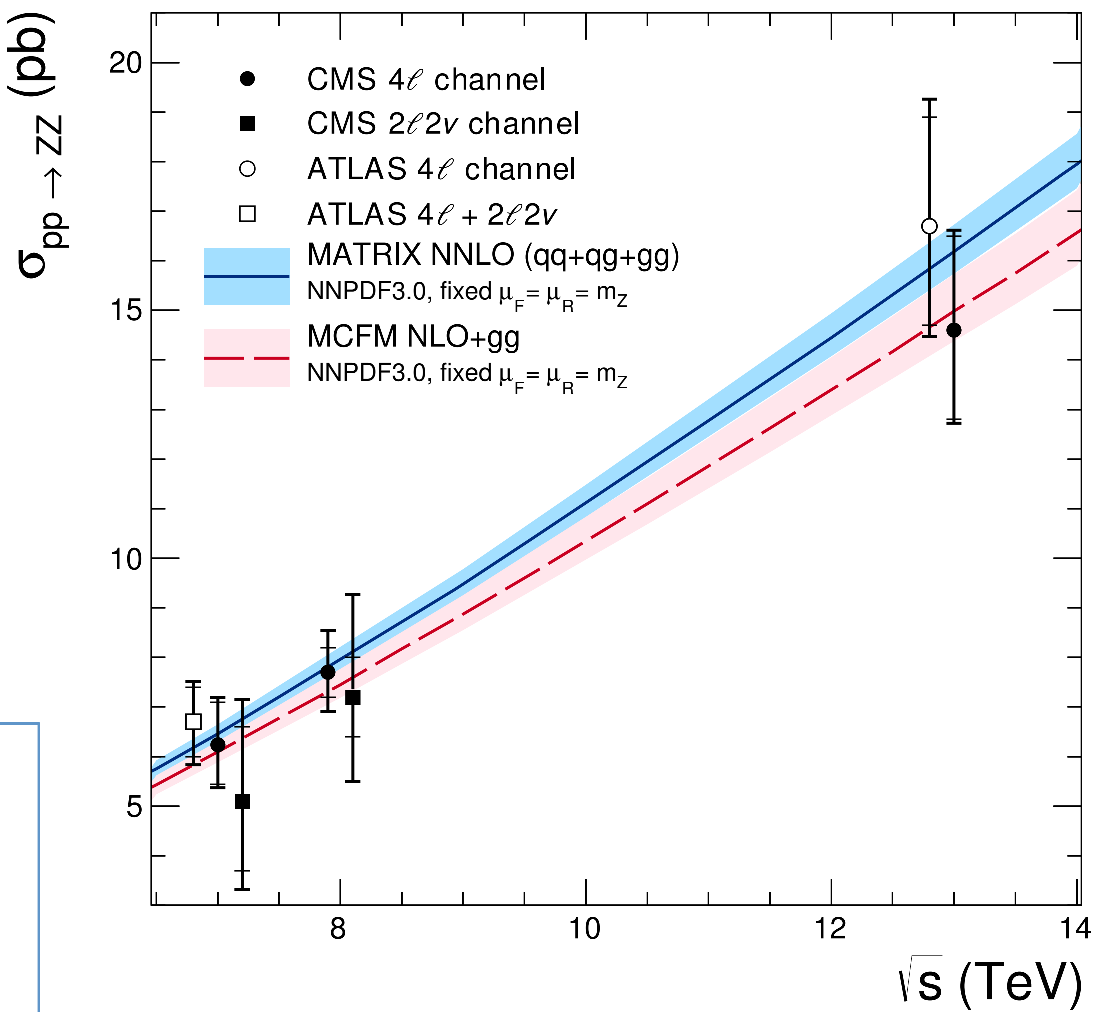
ZZ, WZ, WW
Test of QCD+EW and search for anomalous TCG couplings. Background process for Higgs boson production and new resonant states

ZZ production at 13 TeV

CMS PLB 763 (2016) 280

ATLAS PRL 116, 101801(2016)



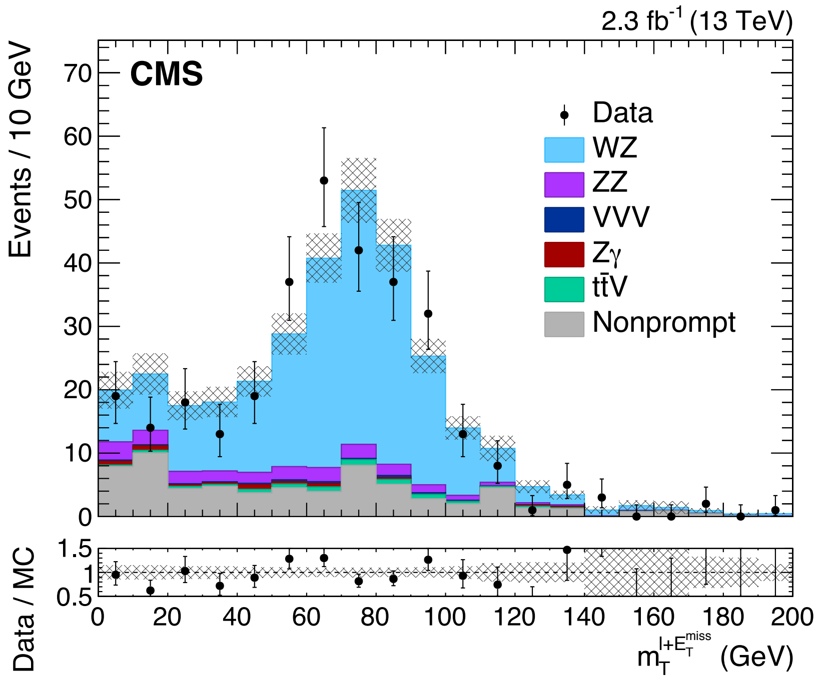


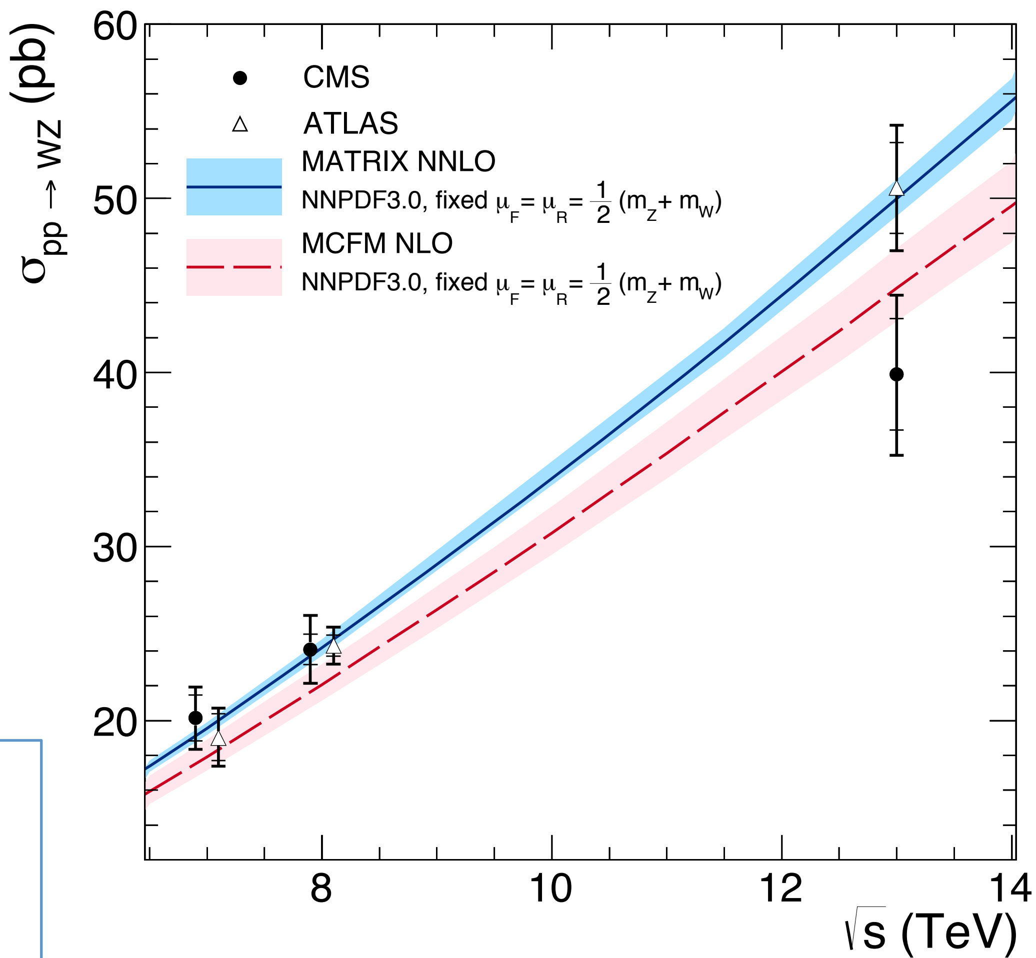
- Recent NNLO calculation MATRIX available (Grazzini et al.), with reduced theoretical uncertainties
- Data in good agreement with theory

WZ production at 13 TeV

CMS arXiv:1609.05721, 1607.06943

ATLAS Phys. Lett. B 762 (2016) 1

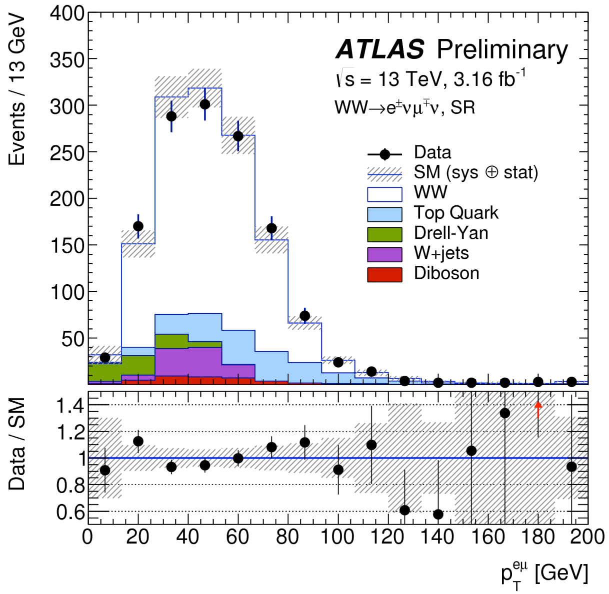


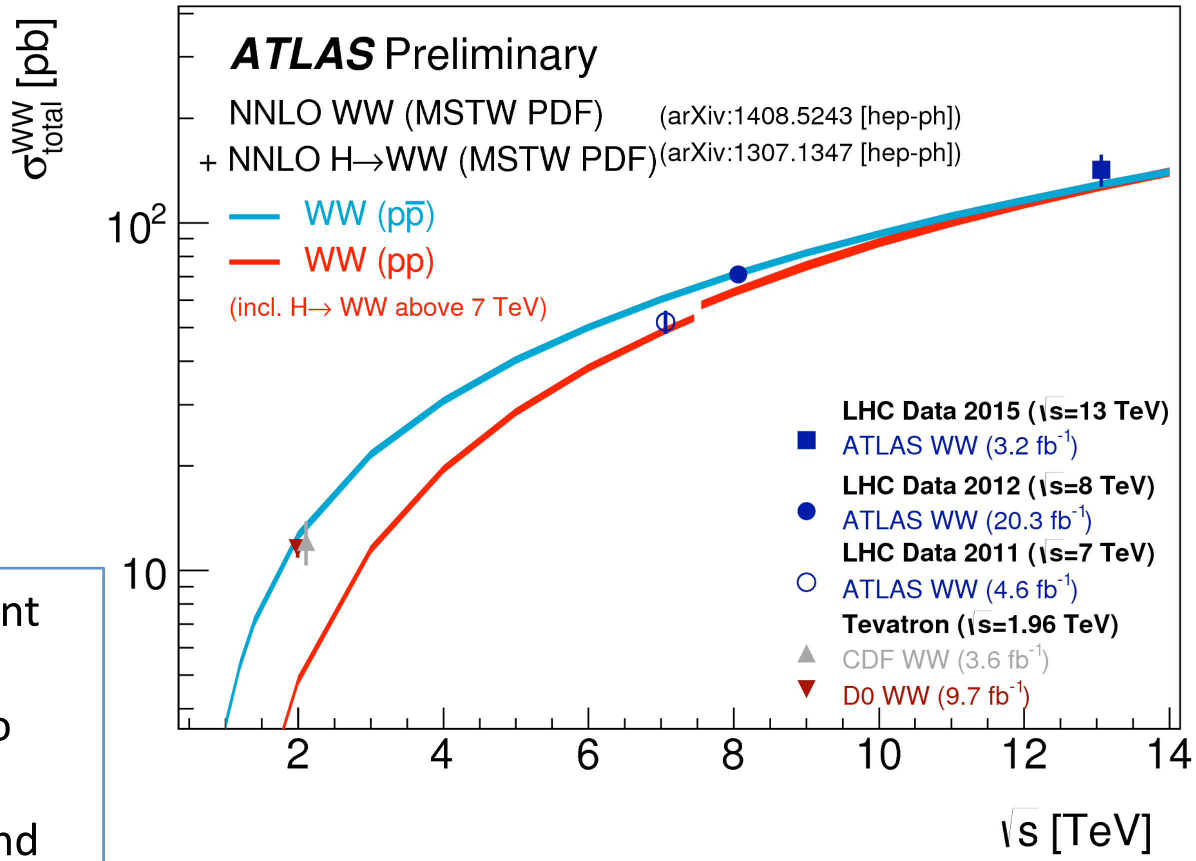


- About 300 WZ events observed
- CMS result here slightly lower than NNLO prediction, ATLAS in good agreement

WW cross section at 13 TeV

ATLAS-CONF-2016-090

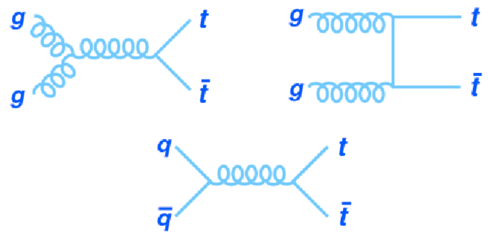


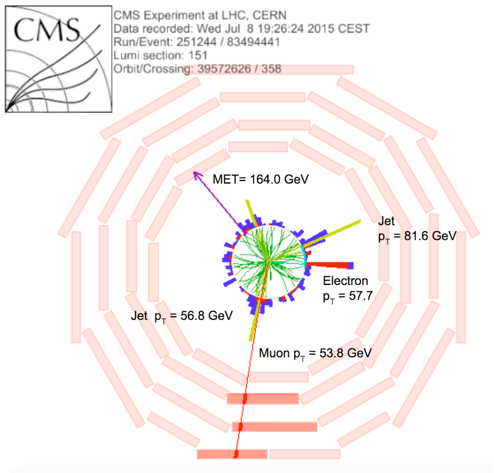


- About 1000 signal WW event in eμ channel
- require 0 jets and 0 b-jets to suppress top
- Background from tt+jets and Drell-Yan in control regions fit together with signal.

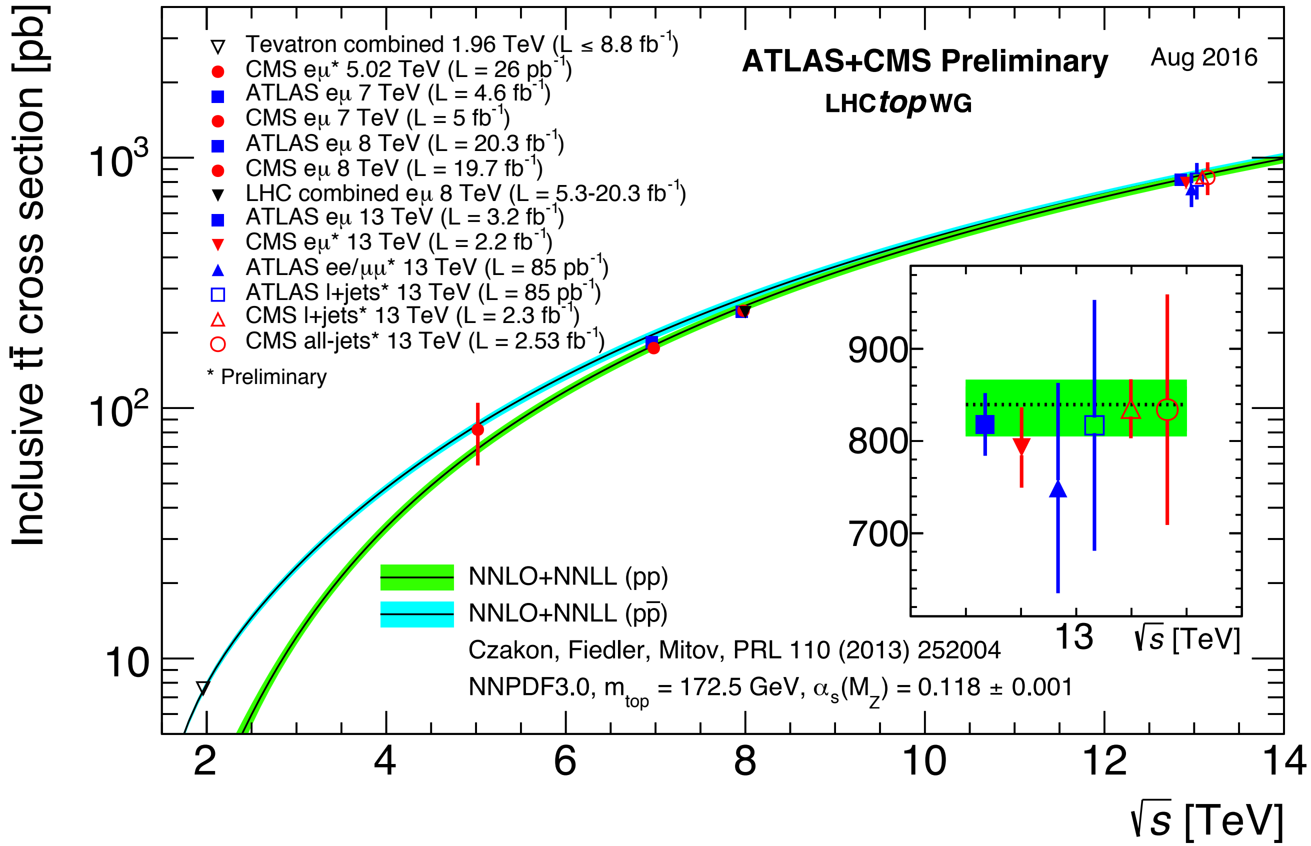
$$\sigma^{\mathrm{fid}}_{WW\rightarrow e\mu} = 529 \pm 20\ (\mathrm{stat.}) \pm 50\ (\mathrm{syst.}) \pm 11\ (\mathrm{lumi.})\ \mathrm{fb}$$

Top



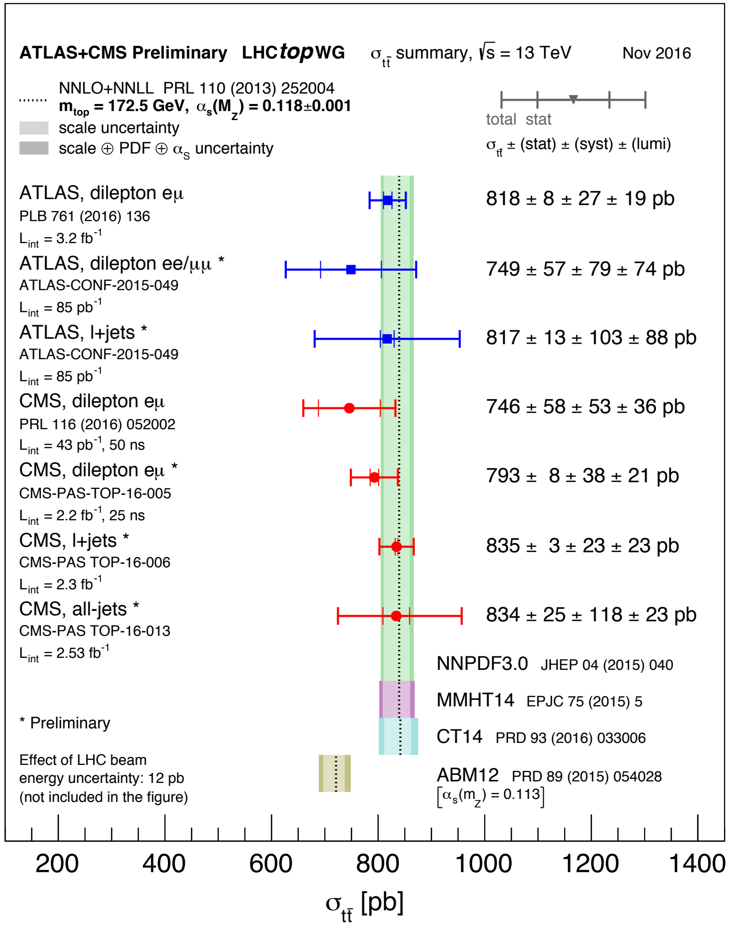


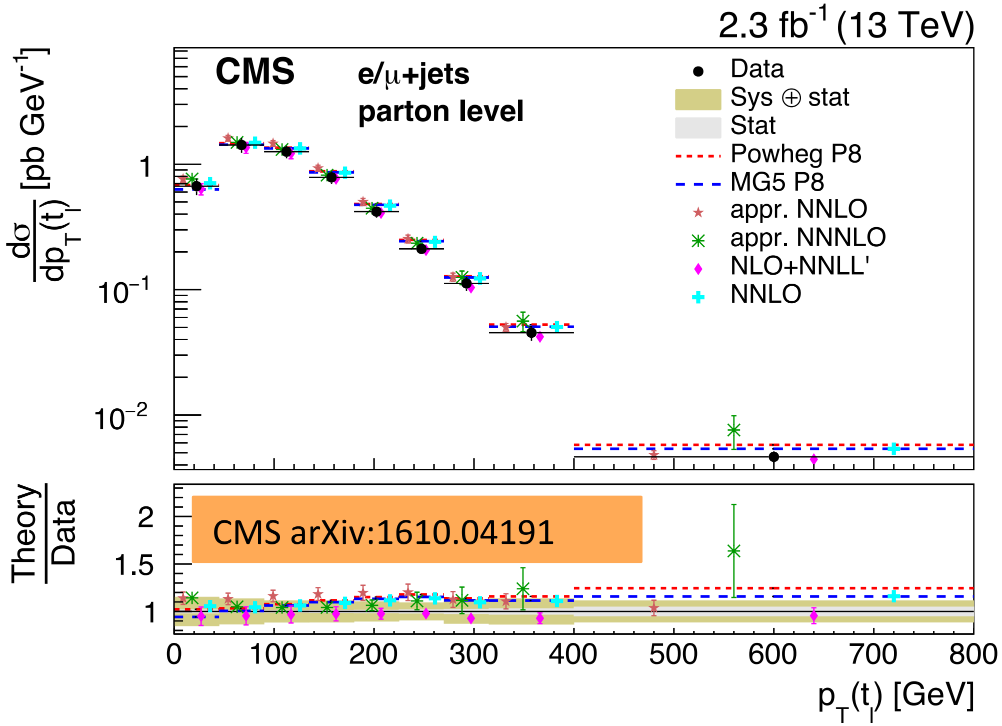
CMS Experiment at LHC, CERN
Data recorded: Wed Jul 8 19:26:24 2015 CEST
Run/Event: 251244 / 83494441
Lumi section: 151
Orbit/Crossing: 39572626 / 358
MET= 164.0 GeV
Jet p_T = 81.6 GeV
Electron p_T = 57.7
Jet p_T = 56.8 GeV
Muon p_T = 53.8 GeV



ATLAS+CMS Preliminary
LHCtopWG
Aug 2016
Tevatron combined 1.96 TeV (L ≤ 8.8 fb^{-1})
CMS eμ* 5.02 TeV (L = 26 pb^{-1})
ATLAS eμ 7 TeV (L = 4.6 fb^{-1})
CMS eμ 7 TeV (L = 5 fb^{-1})
ATLAS eμ 8 TeV (L = 20.3 fb^{-1})
CMS eμ 8 TeV (L = 19.7 fb^{-1})
LHC combined eμ 8 TeV (L = 5.3-20.3 fb^{-1})
ATLAS eμ 13 TeV (L = 3.2 fb^{-1})
CMS eμ* 13 TeV (L = 2.2 fb^{-1})
ATLAS ee/μμ* 13 TeV (L = 85 pb^{-1})
ATLAS l+jets* 13 TeV (L = 85 pb^{-1})
CMS l+jets* 13 TeV (L = 2.3 fb^{-1})
CMS all-jets* 13 TeV (L = 2.53 fb^{-1})
* Preliminary
Inclusive $t\bar{t}$ cross section [pb]
10^3
10^2
10
2
4
6
8
10
12
14
$\sqrt{s}$ [TeV]
900
800
700
13
$\sqrt{s}$ [TeV]
NNLO+NNLL (pp)
NNLO+NNLL ($p\bar{p}$)
Czakon, Fiedler, Mitov, PRL 110 (2013) 252004
NNPDF3.0, m_{top} = 172.5 GeV, $\alpha_s(M_Z)$ = 0.118 ± 0.001

Top cross section at 13 TeV



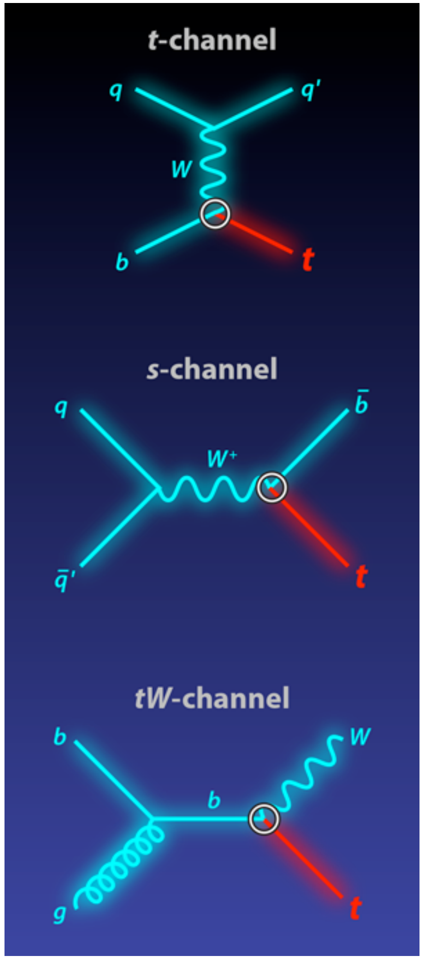


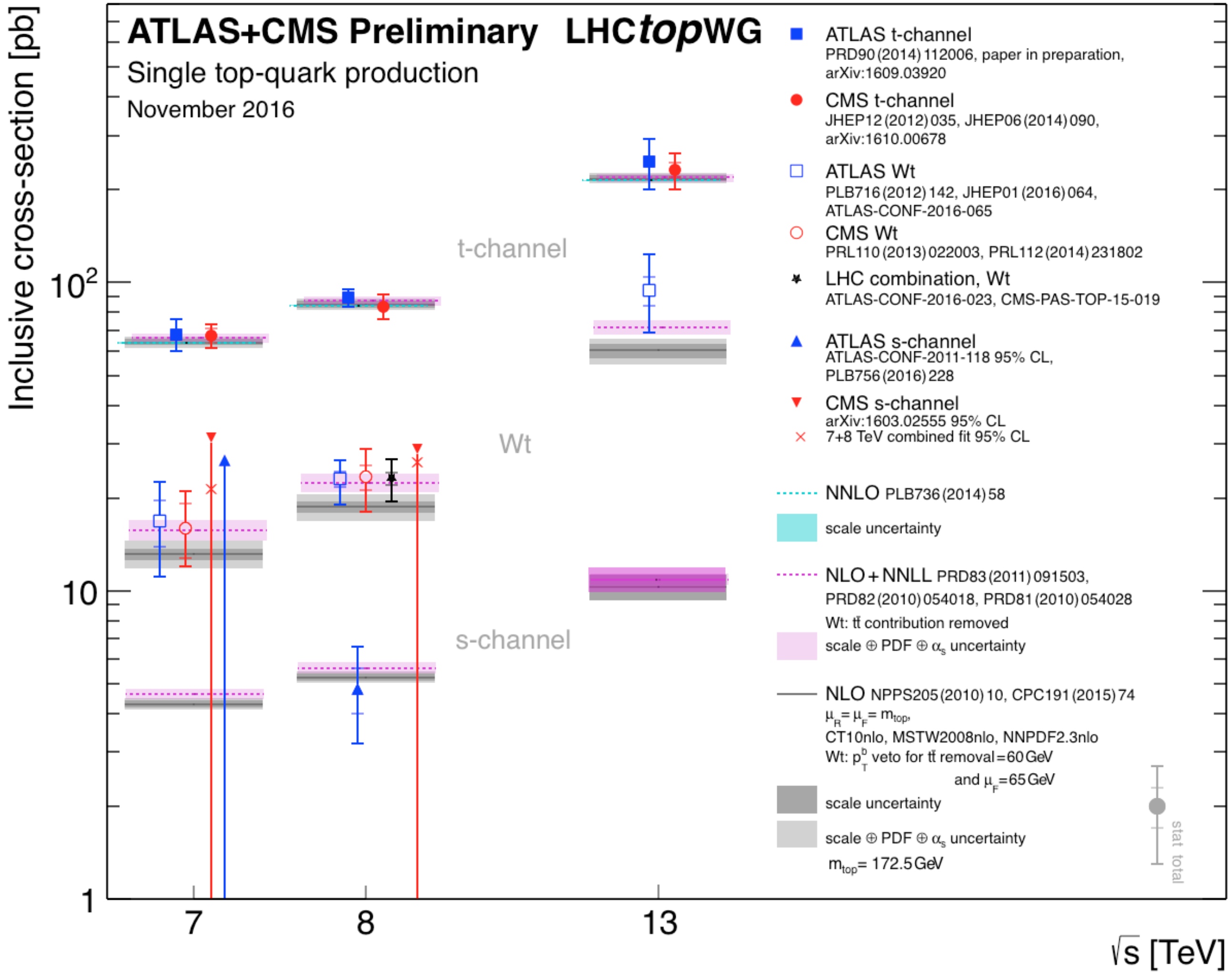
Precision around 4% in the l+jets channel

(TOP-16-006 ready for submission)

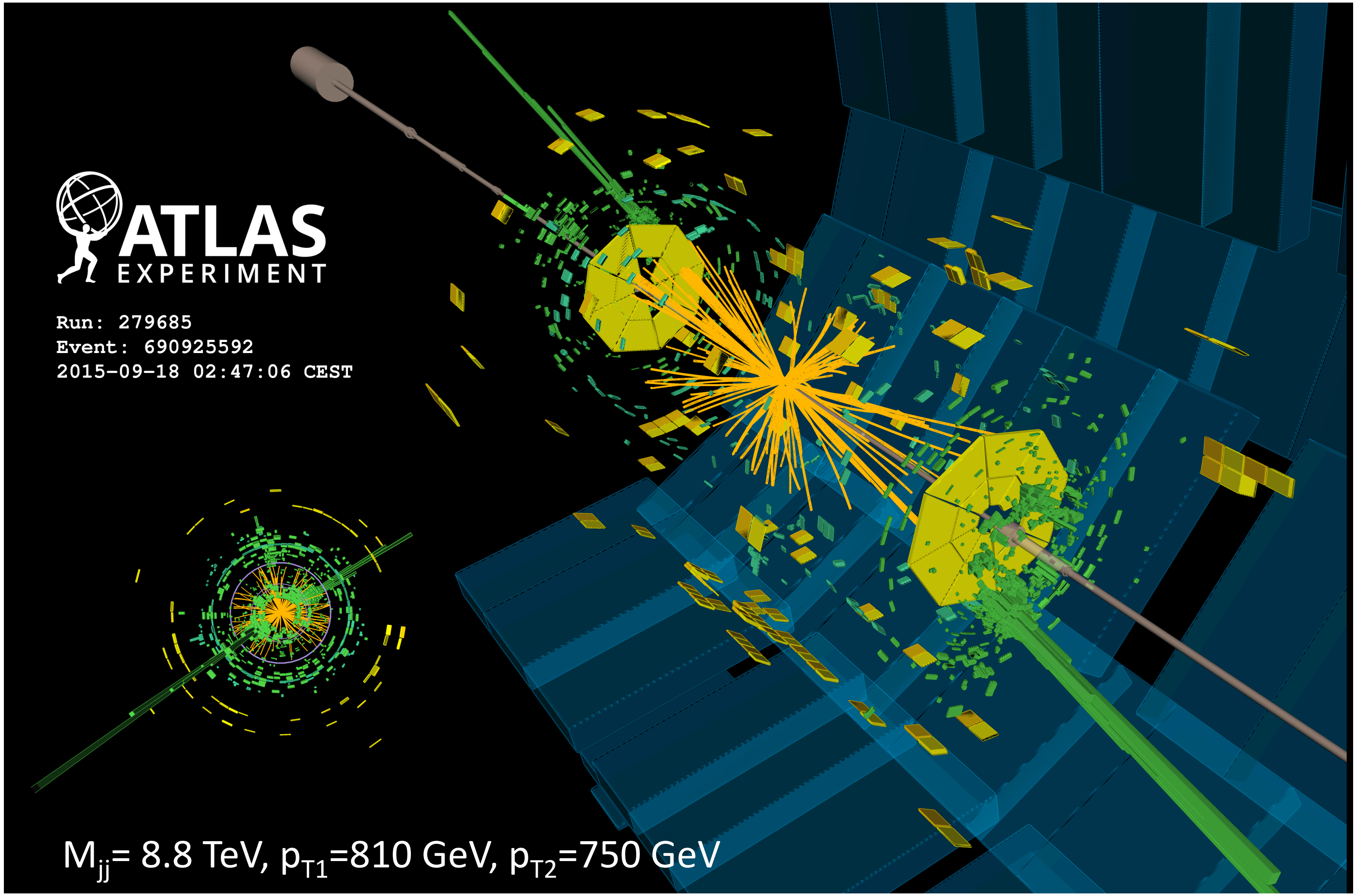
Differential cross sections in l+jets channel at 13 TeV. Top p_T slightly softer than MCs at p_t>200 GeV, also observed at 8 TeV.
Good agreement with full NNLO differential calculation available (Czakon et al. 1511.00549)

Single top


t-channel
s-channel
tW-channel


ATLAS+CMS Preliminary LHCtopWG
Single top-quark production
November 2016
Inclusive cross-section [pb]
√s [TeV]
t-channel
Wt
s-channel
ATLAS t-channel
PRD90(2014)112006, paper in preparation, arXiv:1609.03920
CMS t-channel
JHEP12(2012)035, JHEP06(2014)090, arXiv:1610.00678
ATLAS Wt
PLB716(2012)142, JHEP01(2016)064, ATLAS-CONF-2016-065
CMS Wt
PRL110(2013)022003, PRL112(2014)231802
LHC combination, Wt
ATLAS-CONF-2016-023, CMS-PAS-TOP-15-019
ATLAS s-channel
ATLAS-CONF-2011-118 95% CL, PLB756(2016)228
CMS s-channel
arXiv:1603.02555 95% CL
7+8 TeV combined fit 95% CL
NNLO PLB736(2014)58
scale uncertainty
NLO+NNLL PRD83(2011)091503, PRD82(2010)054018, PRD81(2010)054028
Wt: tt̄ contribution removed
scale ⊕ PDF ⊕ αs uncertainty
NLO NPPS205(2010)10, CPC191(2015)74
CT10nlo, MSTW2008nlo, NNPDF2.3nlo
scale uncertainty
scale ⊕ PDF ⊕ αs uncertainty
m_top = 172.5 GeV
stat
total

Jets

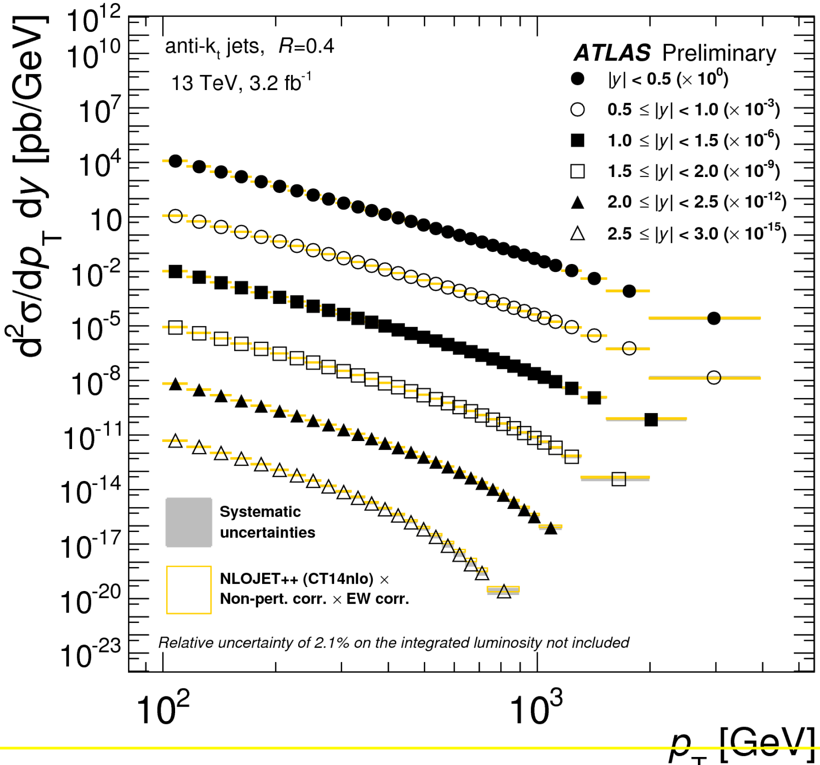

ATLAS
EXPERIMENT
Run: 279685
Event: 690925592
2015-09-18 02:47:06 CEST
M_{jj}= 8.8 TeV, p_{T1}=810 GeV, p_{T2}=750 GeV

Jet cross sections

CMS arXiv:1609.05331

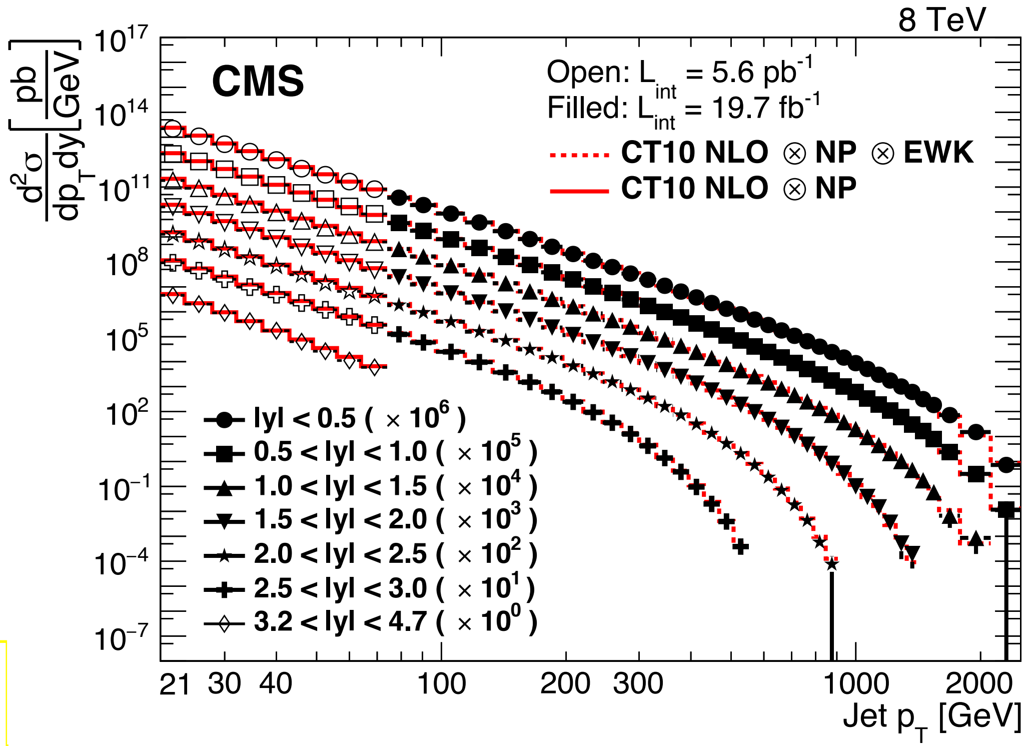
ATLAS-CONF-2016-092

13 TeV data



Range in p_T^{jet} from 100 GeV to 3.2 TeV with |y|<3 covered.

Recent new measurement from CMS from inclusive jets at 8 TeV, extraction of α_S from these data

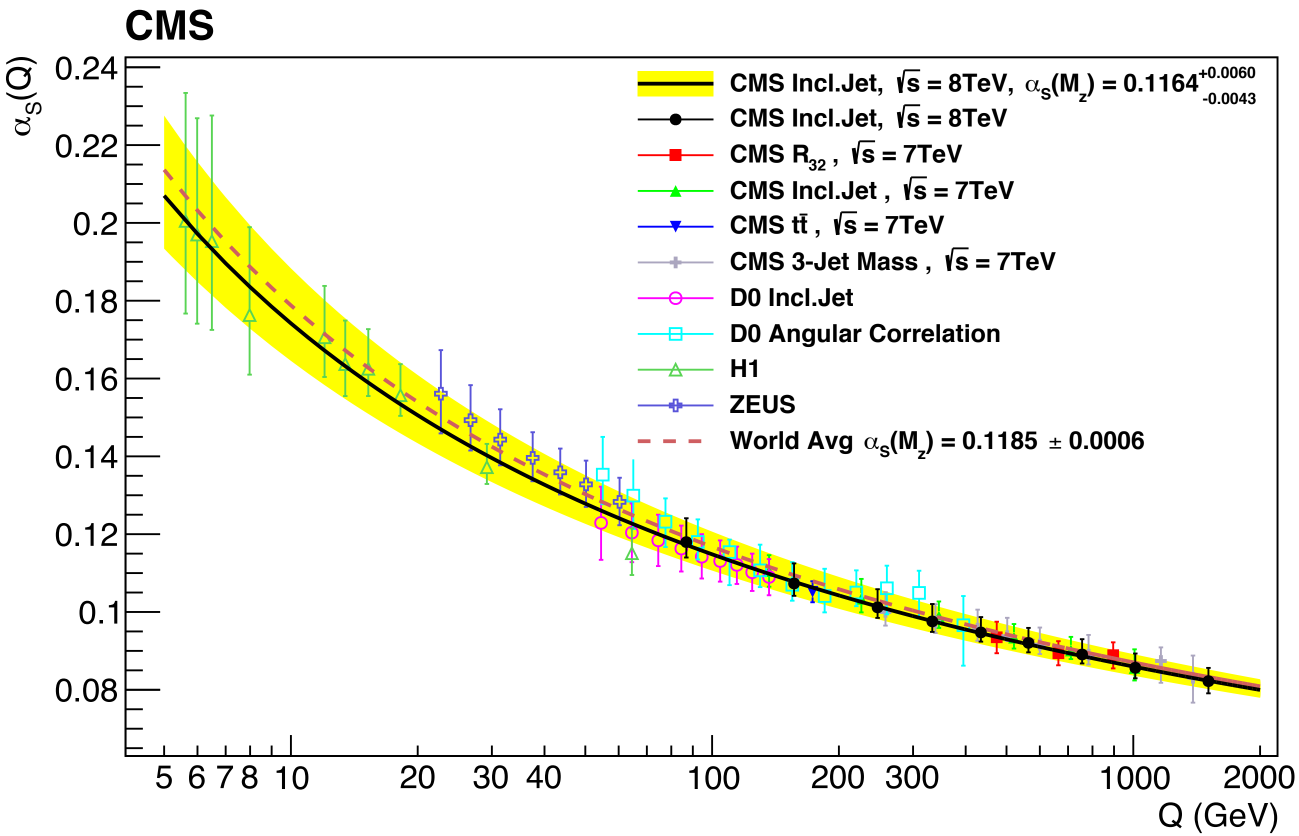


Good agreement with the NLO QCD prediction over several orders of magnitude

Measurement of α_s

CMS arXiv:1609.05331

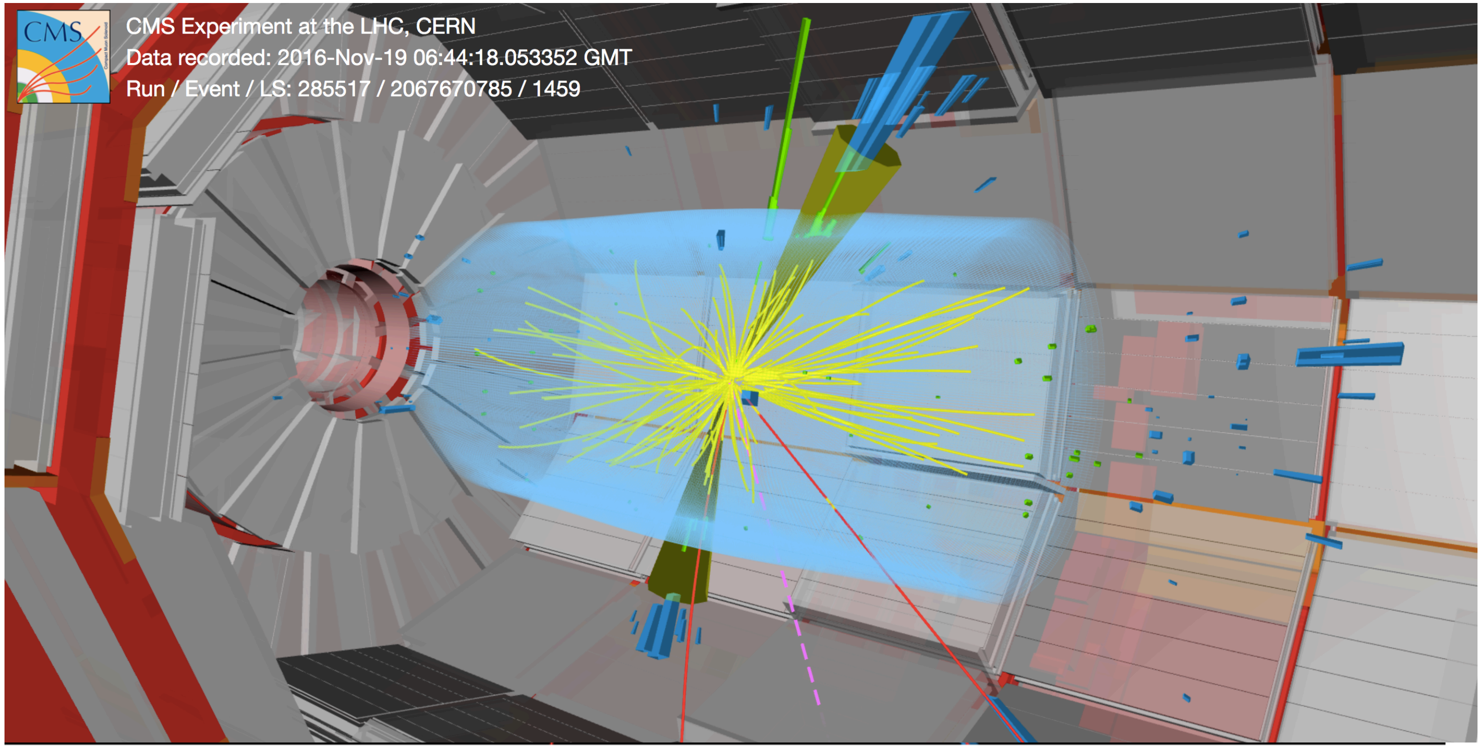
$$\alpha_S(M_Z)(\mathrm{NLO}) = 0.1164^{+0.0025}_{-0.0029}(\mathrm{PDF})^{+0.0053}_{-0.0028}(\mathrm{scale}) \pm 0.0001(\mathrm{NP})^{+0.0014}_{-0.0015}(\exp) = 0.1164^{+0.0060}_{-0.0043}$$



Extraction of α_s from theory prediction at NLO with CT10 NLO, also in 9 p_T ranges.
Largest uncertainty due to factorisation and renormalisation scales, i.e. higher orders.

CMS Heavy Ions Results

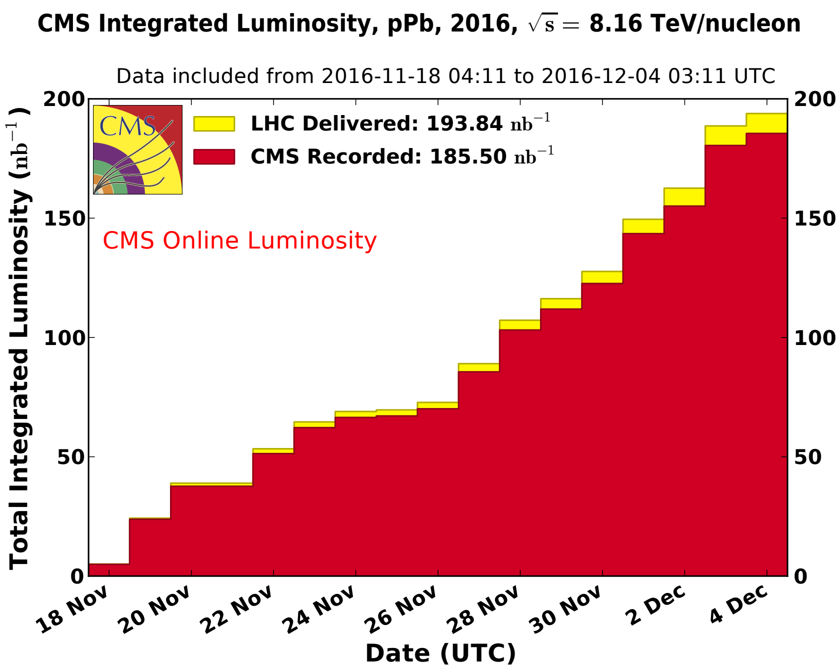
ttbar → (Wb)(Wb)→(lνb)(lνb) candidate event

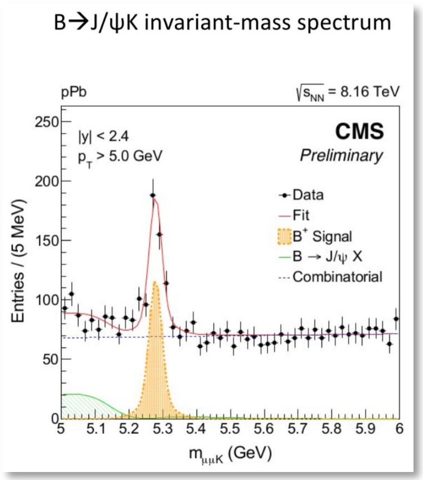


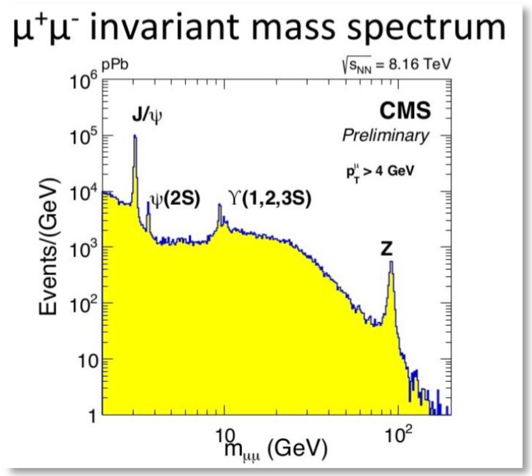
- ak4PFJetsCHS:
  - E_{T1} = 104 GeV, eta1 = 0.7, phi1 = 1.27, csvV2 = 0.995
  - E_{T2} = 87 GeV, eta2 =-0.2, phi2 =-2.05, csvV2 = 0.983
- Global muons:
  - (muon1) p_{T1} = 89 GeV, eta1 = 1.1, phi1 = -2.1
  - (part of jet) p_{T2} = 14 GeV, eta2 =-0.2, phi2 = -2.0
- Electron:
  - p_T = 91 GeV, eta = 0.1, phi = 1.
- MET:
  - p_T = 49 GeV, phi = -1.54

From the pPb 2016 run at √s=8.16 TeV

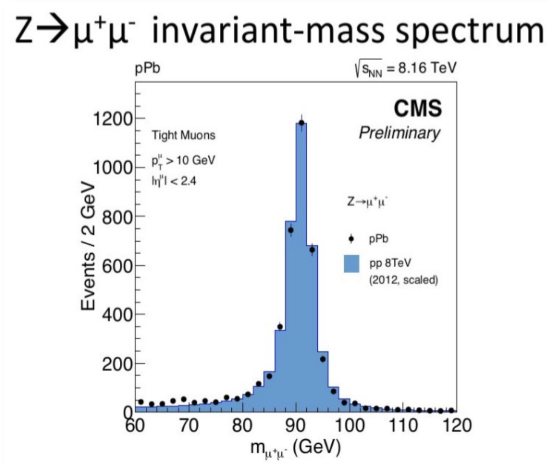
2016 Heavy Ions Run







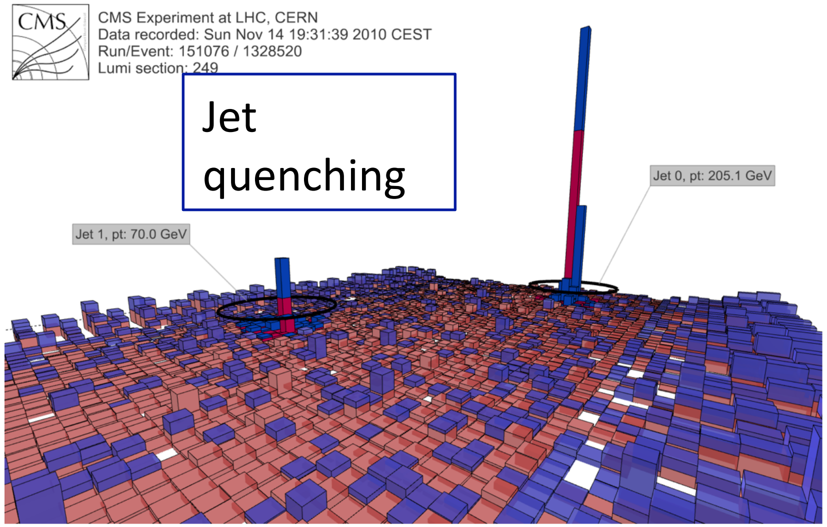
Run 2		
pp	5 TeV	~30pb^{-1}
Pb-Pb	5 TeV	~0.5 nb^{-1}
p-Pb (2016)	8 TeV	~190 nb^{-1}
Pb-Pb(2016)	5 TeV	~0.5 nb-1



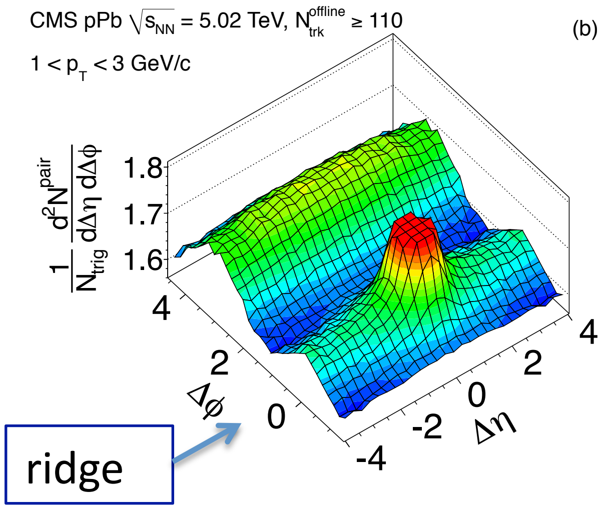
Probes

- Hard probes (J/Psi, Y, jets, Z,...) are modified in the QCD medium. Nuclear modification factor:

$$R_{AA} = \frac{dN_{AA}/dp_T}{N_{coll}dN_{pp}/dp_T}$$



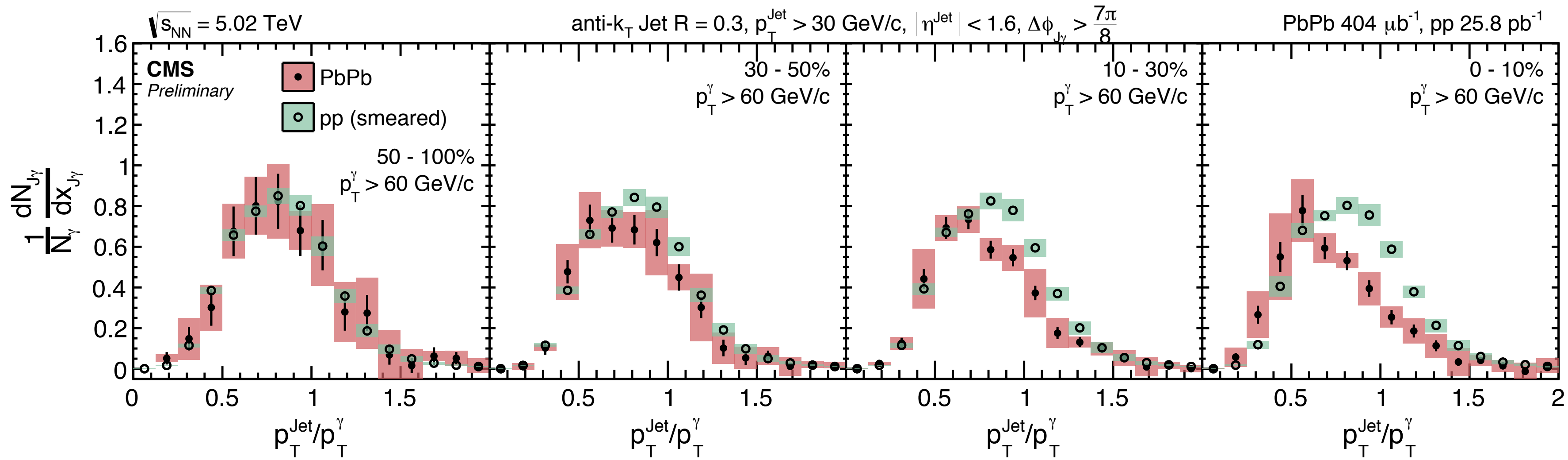
- Soft probes (collective phenomena): study two-particle correlations, ridge structure observed at Delta-phi~0 up to very large Delta-eta
- Two particles at very different eta are connected, collective phenomena



Isolated photons+jets

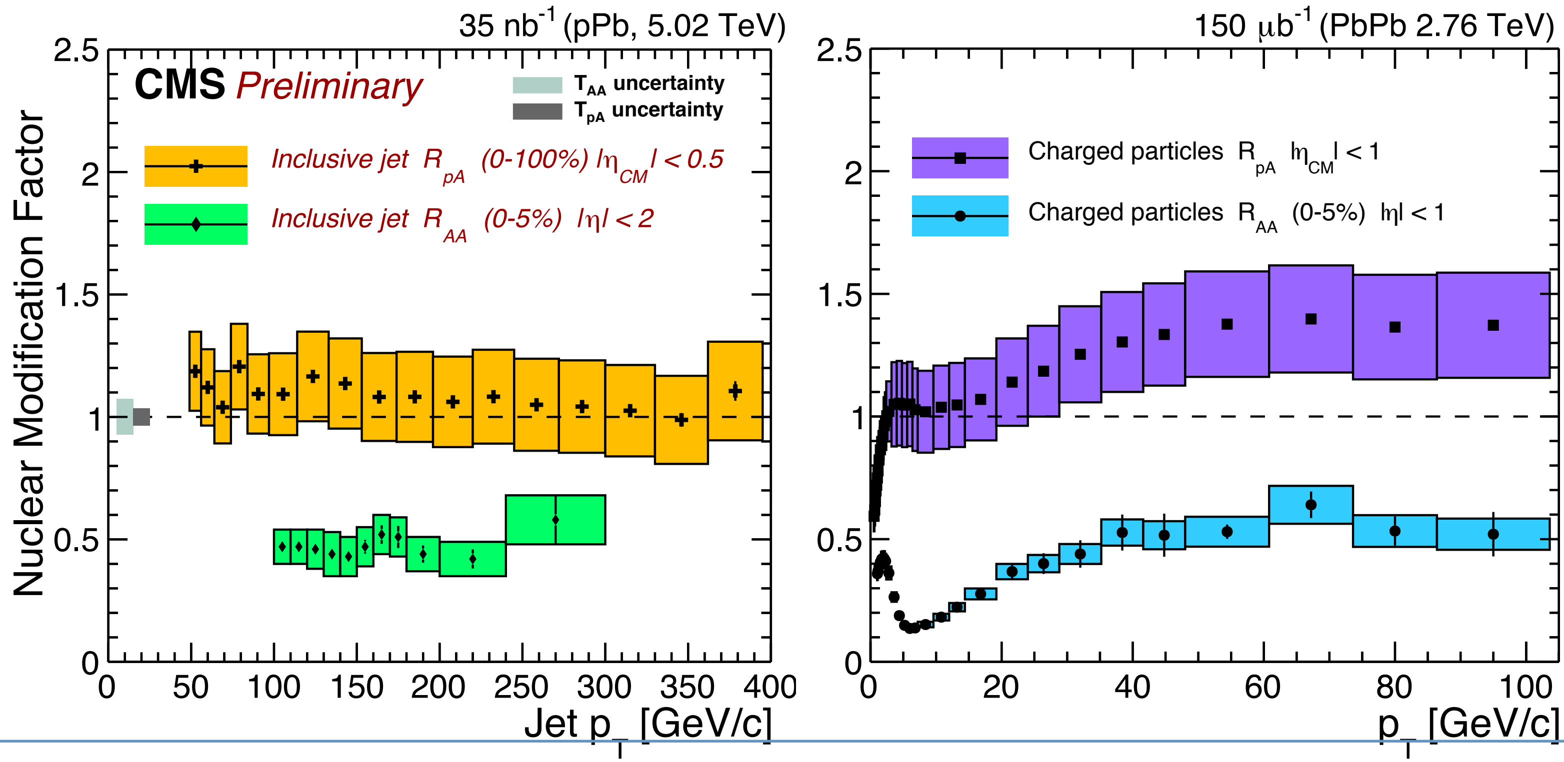
CMS-PAS-HIN-16-002

2015 data



- Study the jet-photon balance in events with one high p_T photon and a jet with p_T>30 GeV
- Photons should not be „modified“ when traversing the medium
- Significant imbalance of the ratio jet/gamma is observed, especially in central collisions, compared to pp (here smeared to take into account different jet resolution in pp and PbPb)
- Clear shift of the jet spectra to lower values

R_{AA} for particles and jets

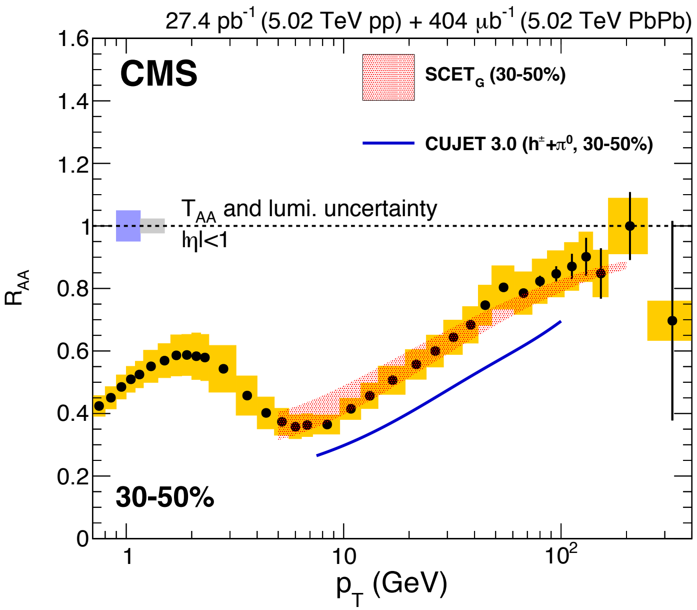


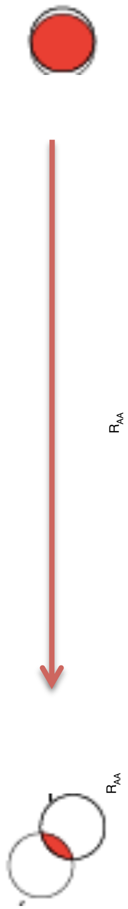
- Run1 results shown here
- Jets and charged particles are suppressed in AA collisions in central collisions
- pA used as reference, R_{pA} is ~1 for high p_T (>2 GeV for tracks) particles and jets
- It indicates energy loss of partons in the hot and dense medium

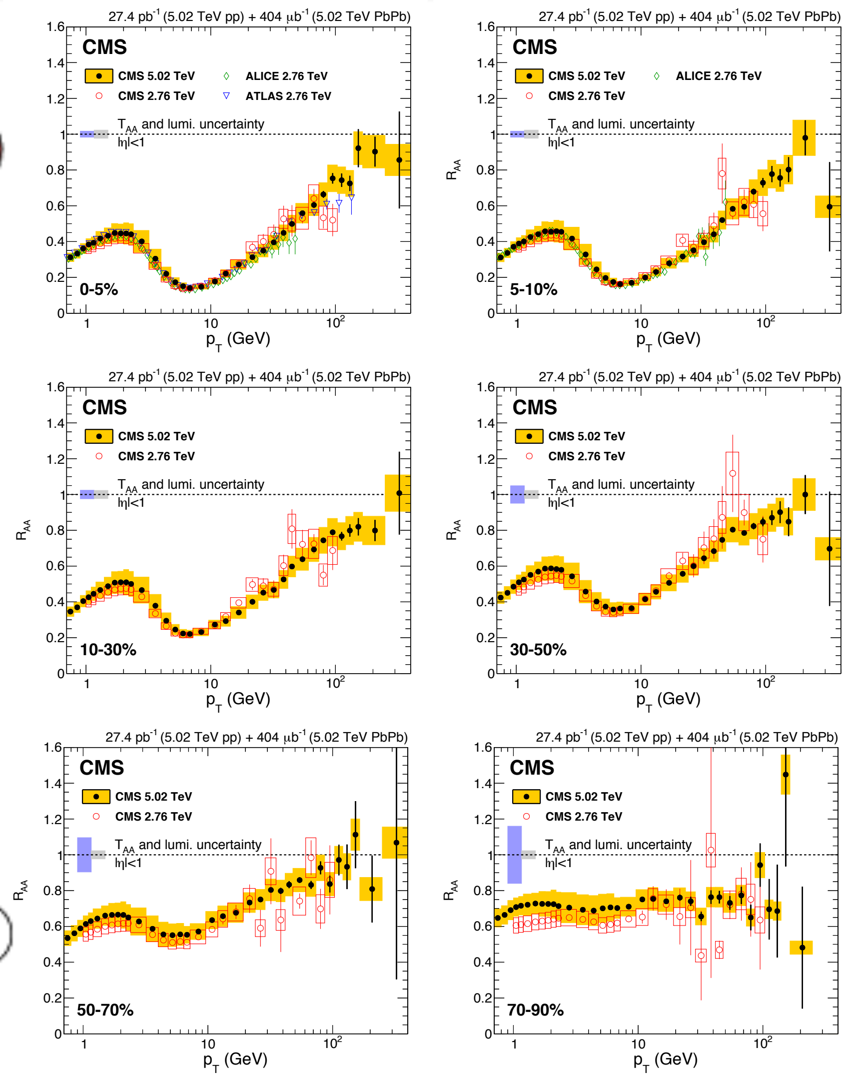
R_{AA} for charged particles

CMS arXiv: 1611.01664

- Run 2 2015 data at √s=5.02 TeV
- 0.7 < p_T< 400 GeV
- R_{AA} is 7-8 for the most central 5% collisions and p_T~6-9 GeV
- As the collisions become more peripheral, there is a weakening of the suppression and less p_T dependence
- Models reproduce the data

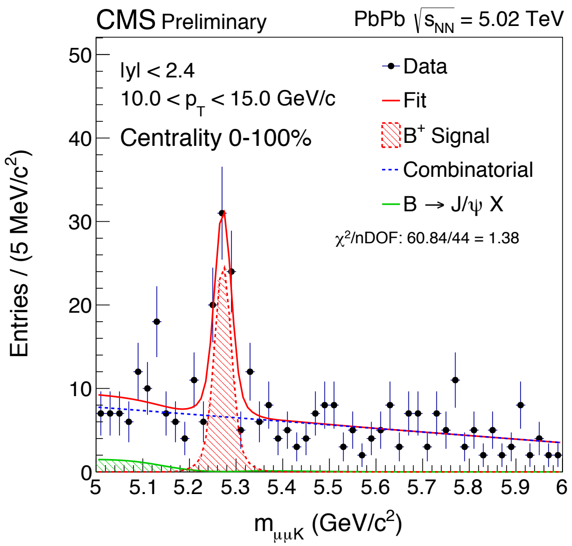


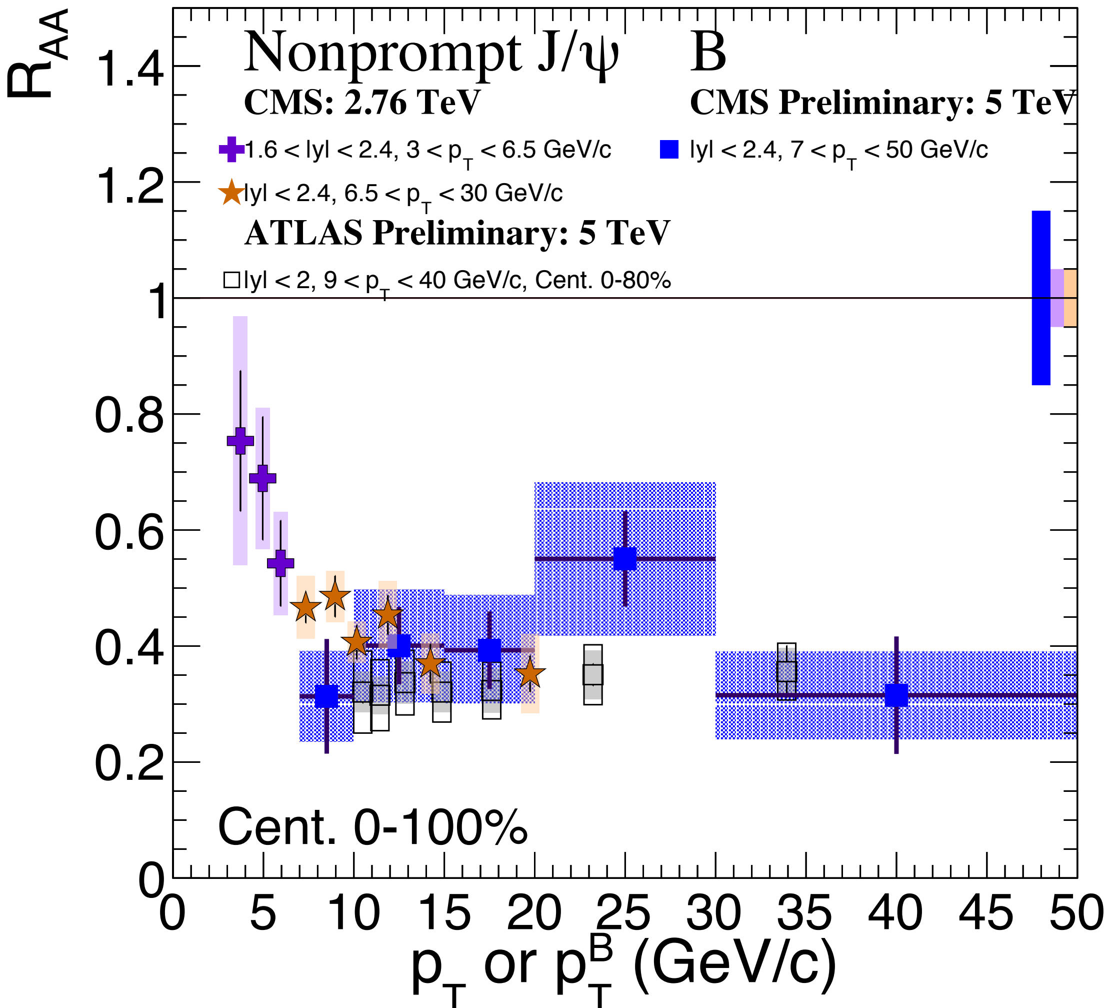




R_{AA} for J/Psi and B mesons

CMS-PAS-HIN-16-011

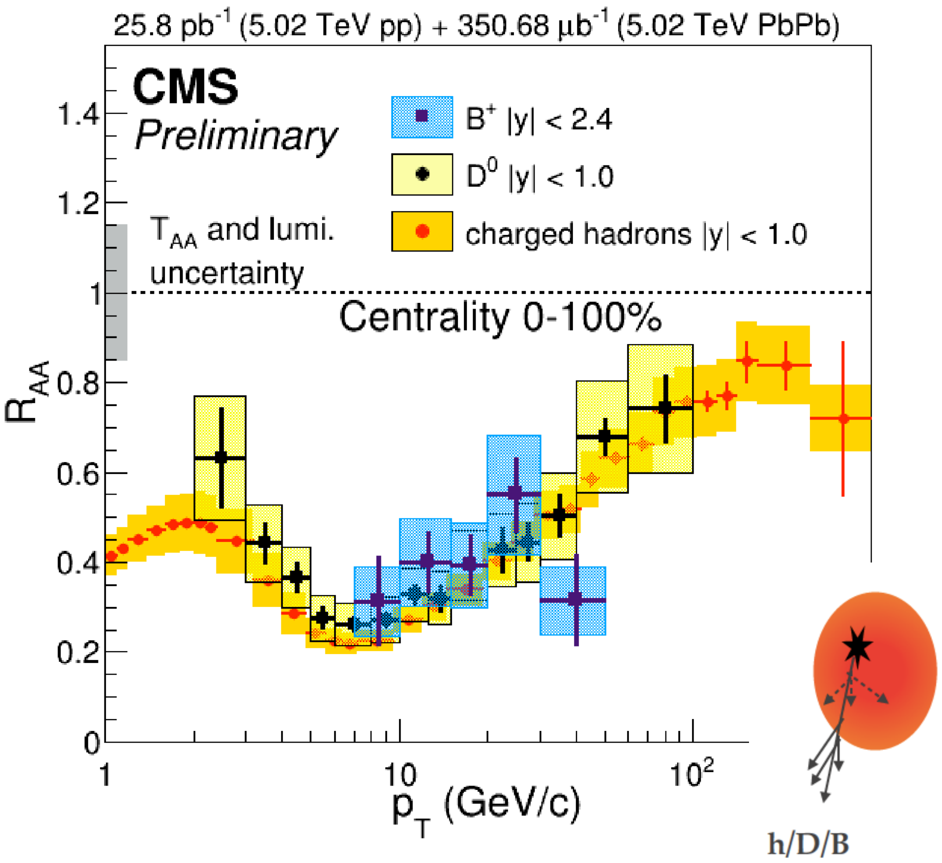


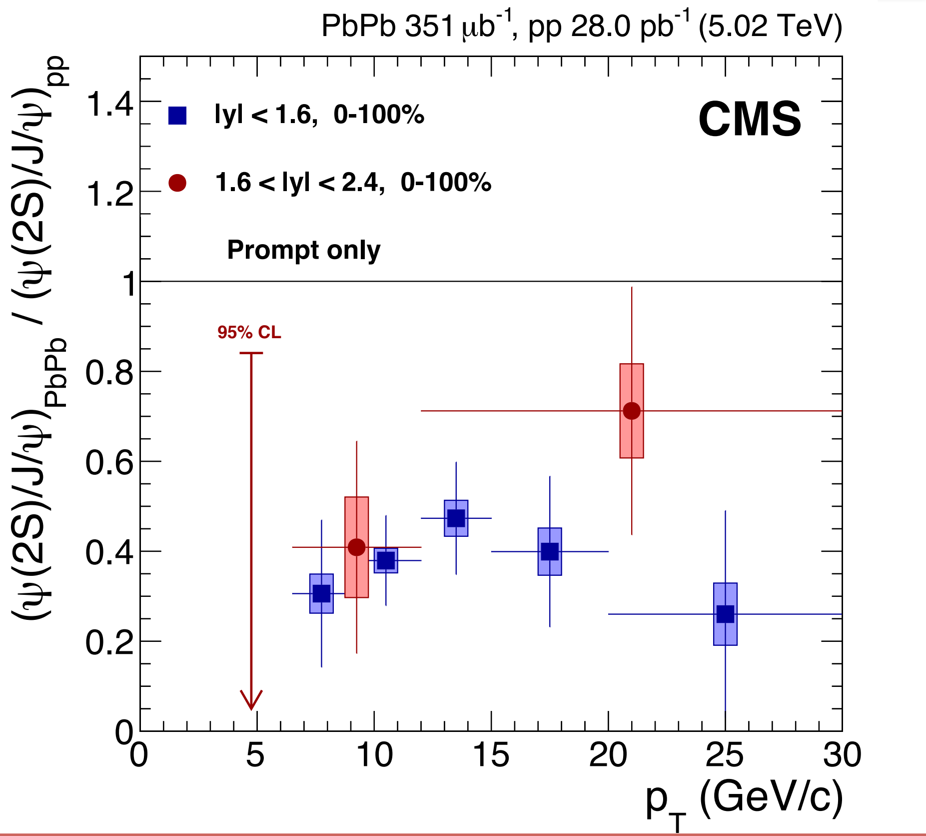


- First measurement of B mesons, 2015 data
- Strong suppression observed, comparable to non-prompt J/Psi at high p_T

Flavour dependence, ψ(2S)

CMS arXiv:1611.01438





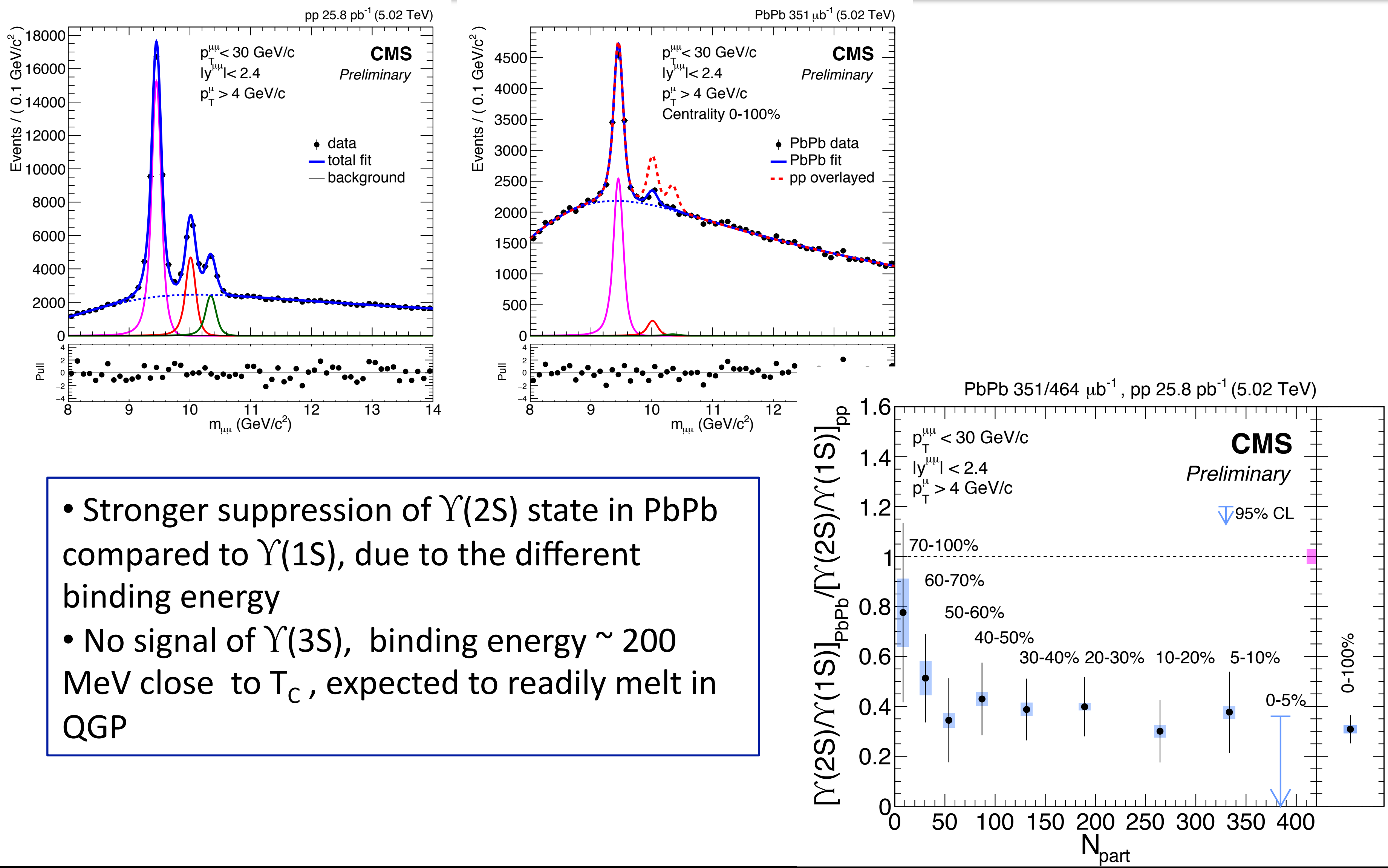
No evidence for a dependence on the particle flavour (b~ c~ light flavour)

However still limited statistics, fragmentation is different for uds,c,b, etc.

Dependence instead on the binding energy in mesons, a mesurement of the temperature T_C of the deconfined QGP. Strong suppression of ψ(2S)-to-J/Psi ratio in PbPb compared to pp

ϒ excited states

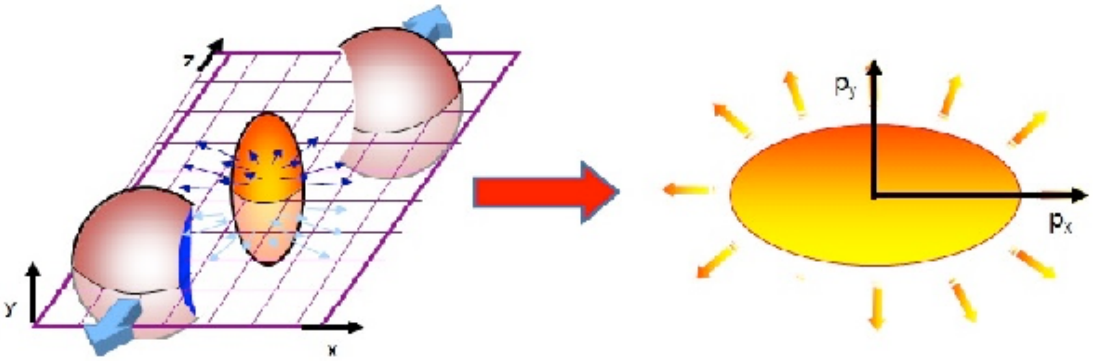
CMS-PAS-HIN-16-008

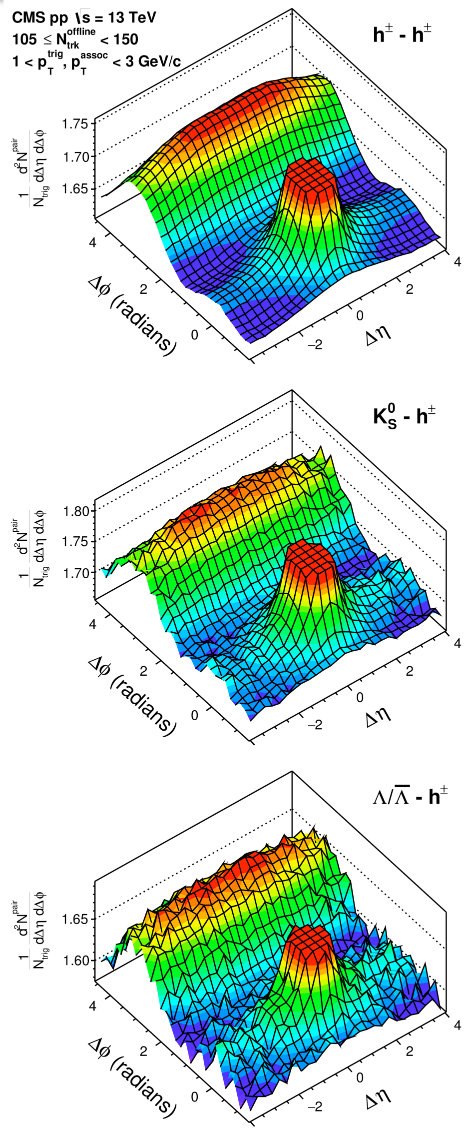


- Stronger suppression of ϒ(2S) state in PbPb compared to ϒ(1S), due to the different binding energy
- No signal of ϒ(3S), binding energy ~ 200 MeV close to T_C, expected to readily melt in QGP

Anisotropic flow

CMS arXiv:1606.06198



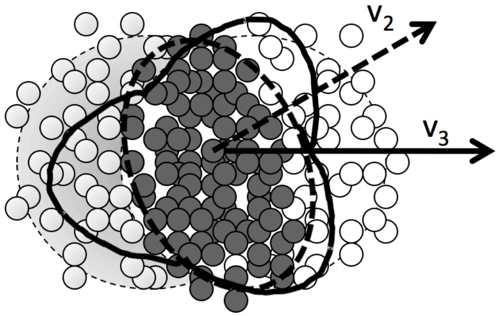


$$\frac{1}{N_{\text{trig}}}\frac{dN^{\text{pair}}}{d\Delta\phi} = \frac{N_{\text{assoc}}}{2\pi}\left[1 + \sum_n 2V_{n\Delta}\cos(n\Delta\phi)\right]$$

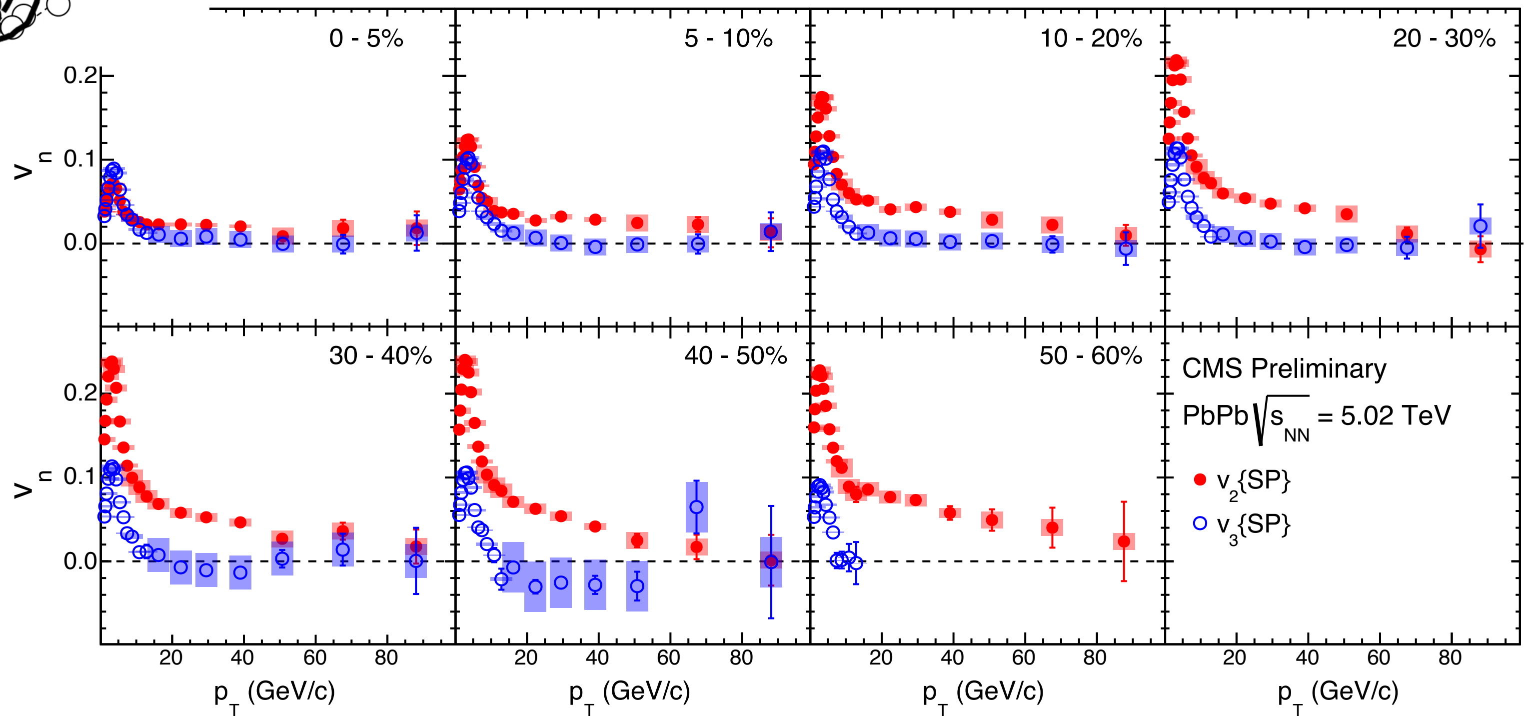
Azimuthal anisotropy characterized by n-order Fourier harmonic v_n in the phi angle relative to the reaction plane

Anisotropic flow

CMS-PAS-HIN-15-004



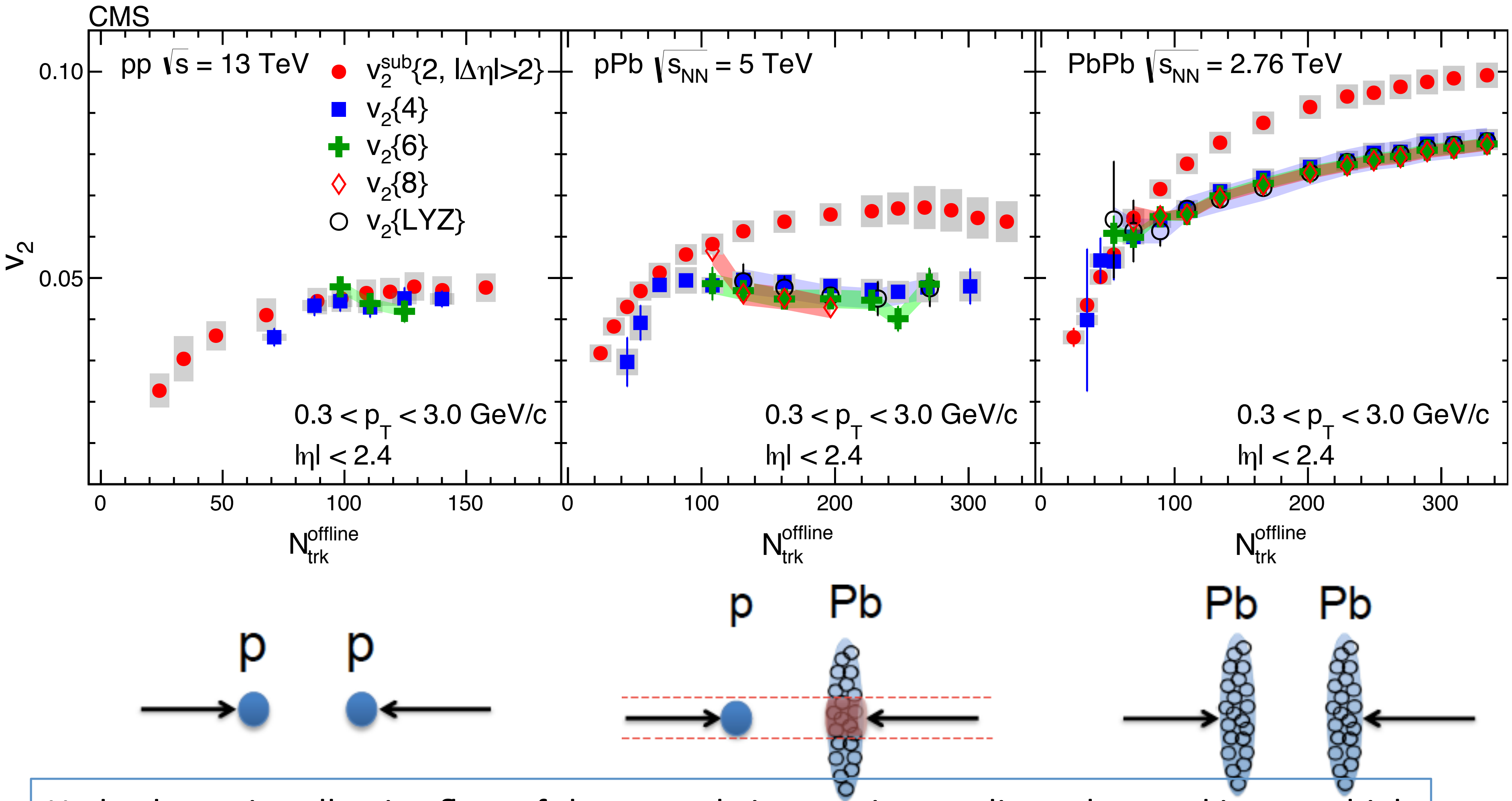
v_2 and v_3 reflect the medium response to its initial geometry and fluctations



Elliptic (v_2) and triangular (v_3) flow measured up to very high p_T ,~100 GeV

Anisotropic flow

CMS PLB 765 (2017) 193



Hydrodynamic collective flow of the strongly interacting medium observed in pp at high multiplicity, pPb and PbPb

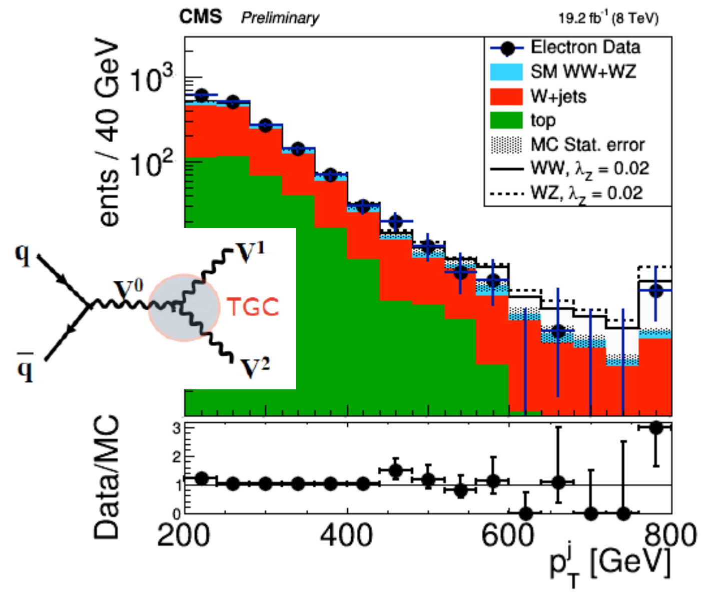
Summary

- Precision measurements in W/Z, jets and top physics from ATLAS and CMS
- Textbook measurements of the W mass at ATLAS, m_W=80370 ± 19 MeV
- Theory calculations at more orders, following experimental increasing precision
- Wide range of heavy ions results: nuclear modification factor measured with several hard probes, suppression of excited quarkonium states observed, collective flow measured
- 2016 last pPb run for a long period, no heavy ion run next year
- In pp we have taken O(2%) of the data until the end of HL-LHC, exciting times ahead

Backup slides

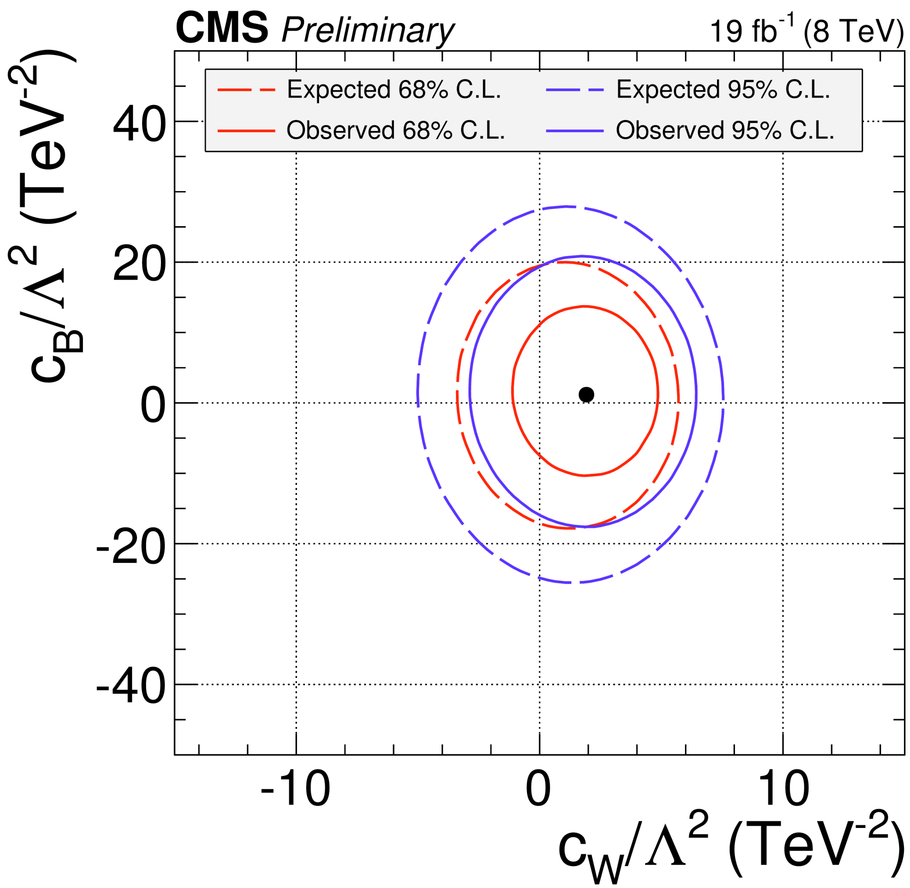
Anomalous couplings in WW, WZ

CMS-PAS-SMP-13-008
SMP-16-012



	8 TeV	13 TeV
c_{WWW}/Λ^2	[-2.7, 2.7]	[-9.5, 9.4]
c_W/Λ^2	[-2.0, 5.7]	[-12.6, 12.0]
c_B/Λ^2	[-14, 17]	[-56.1, 55.4]

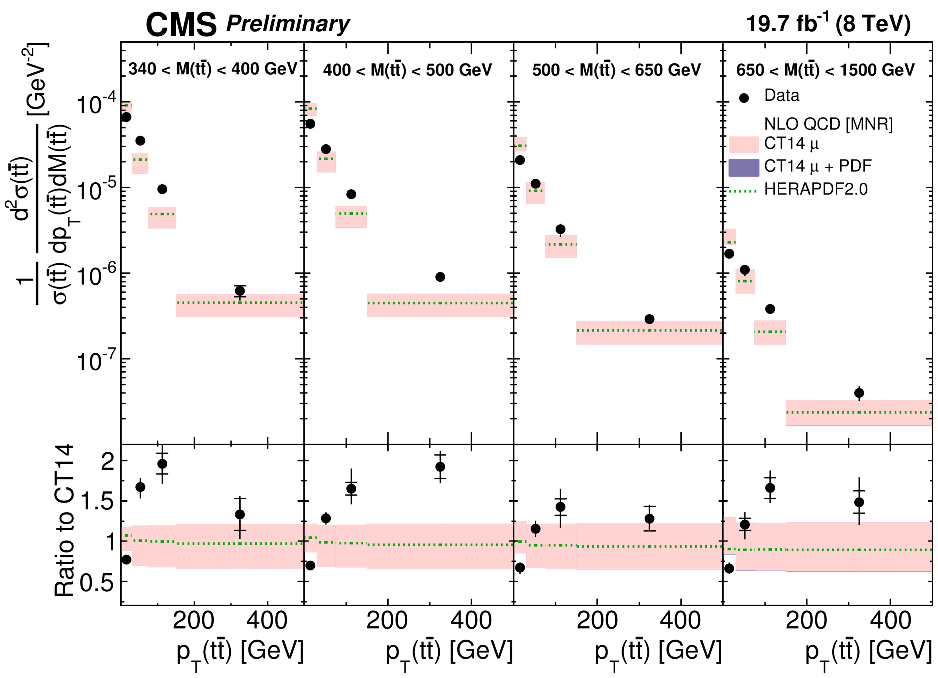
New limits on anomalous TGC in the context of Effective Field Theory.

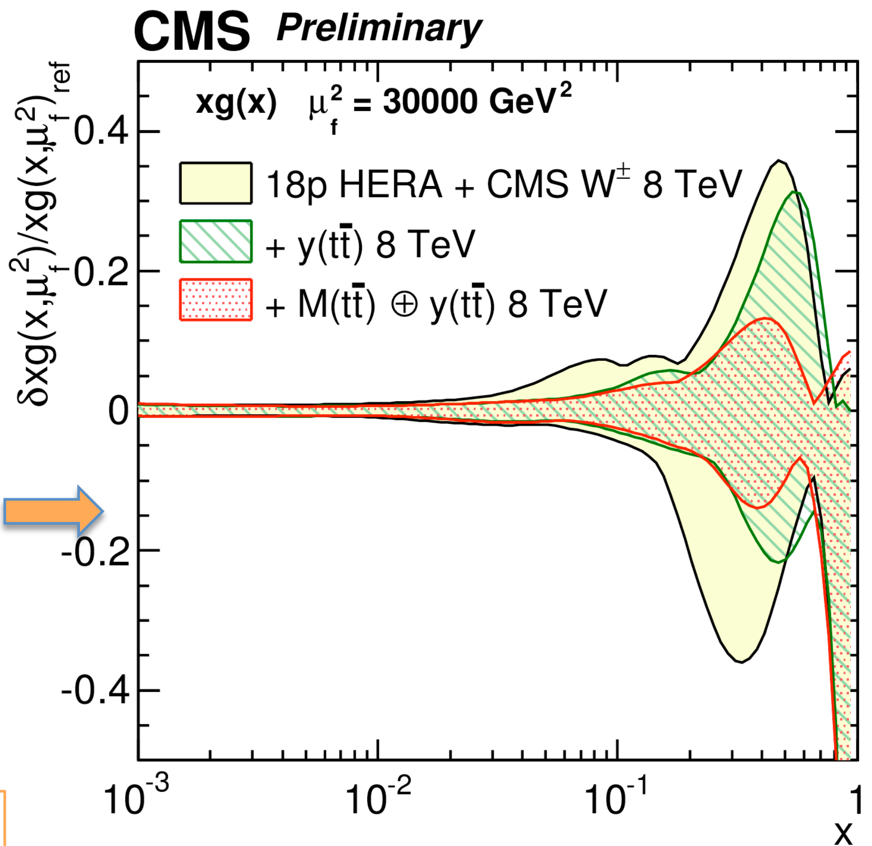


$$L^{NP} = L^{SM} + \frac{1}{\Lambda^2} L^6 + ...$$

Top double differential

CMS-PAS-TOP_14-013





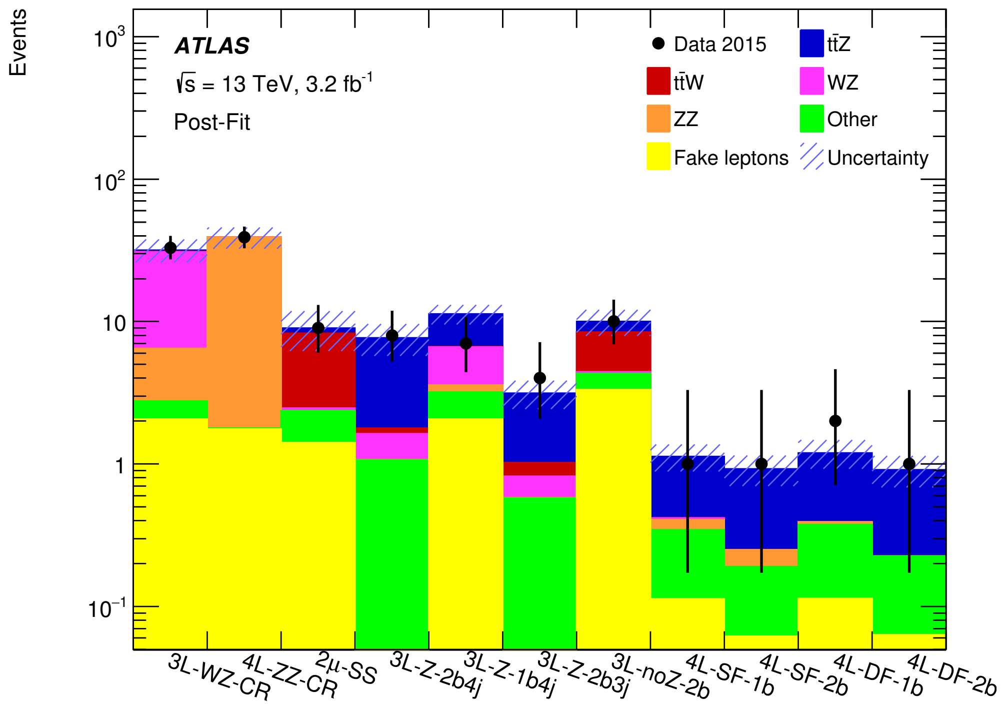
Double differential cross-sections are sensitive to the gluon distribution at high x . Fit to HERA data+CMS W asymmetry data at 8 TeV +these data

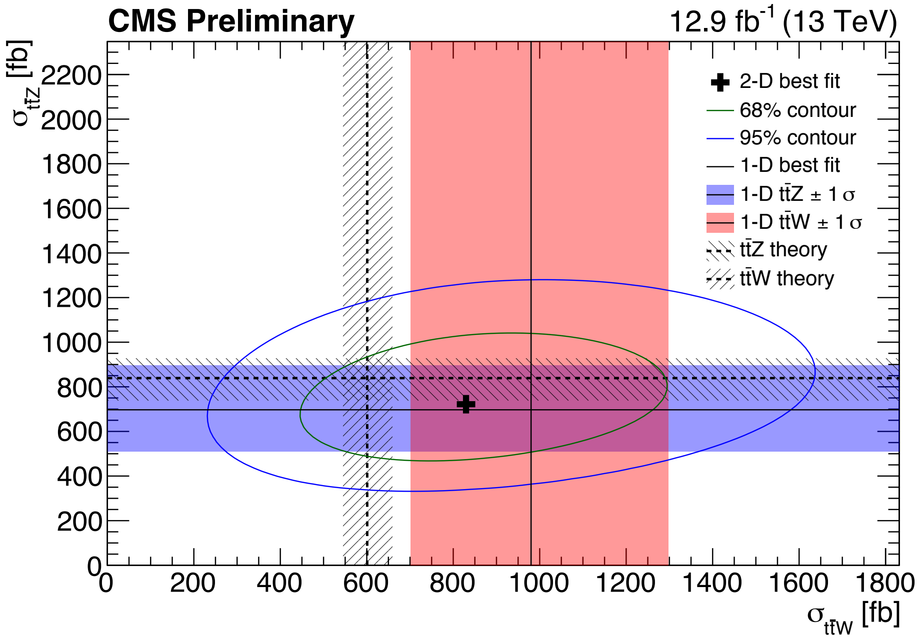
Compared to the HERA+CMS W only fit, the uncertainty in the gluon PDF reduced by a factor of 2 at x~0.3 especially due to the p_T(tt) amd M(tt)

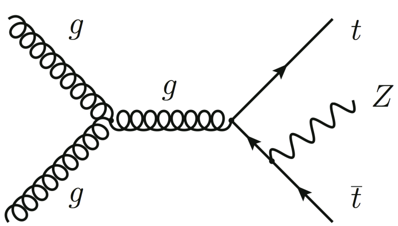
ttZ, ttW

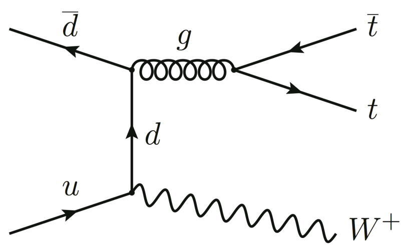
CMS-PAS-TOP-16-007

ATLAS arXiv:1609.01599









A test of the SM couplings

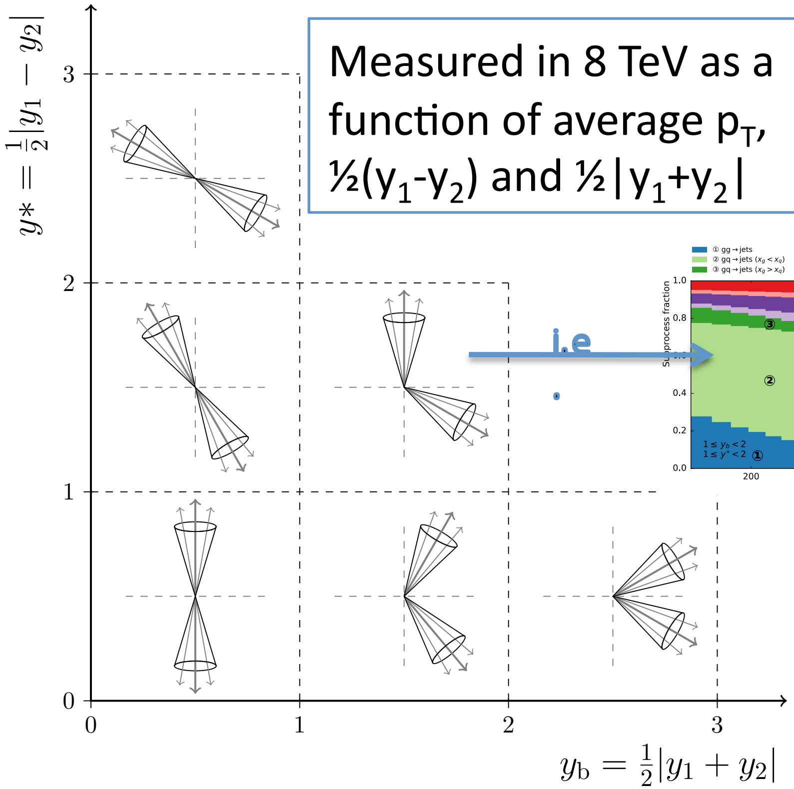
σ(ttZ) = 0.9 ± 0.3 pb (3.9σ)

σ(ttW) = 1.5 ± 0.8 pb (2.2σ)

CMS: ttZ 3.9σ, ttW 4.6σ observed

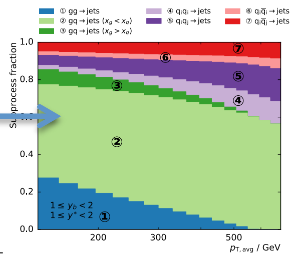
Triple differential dijet

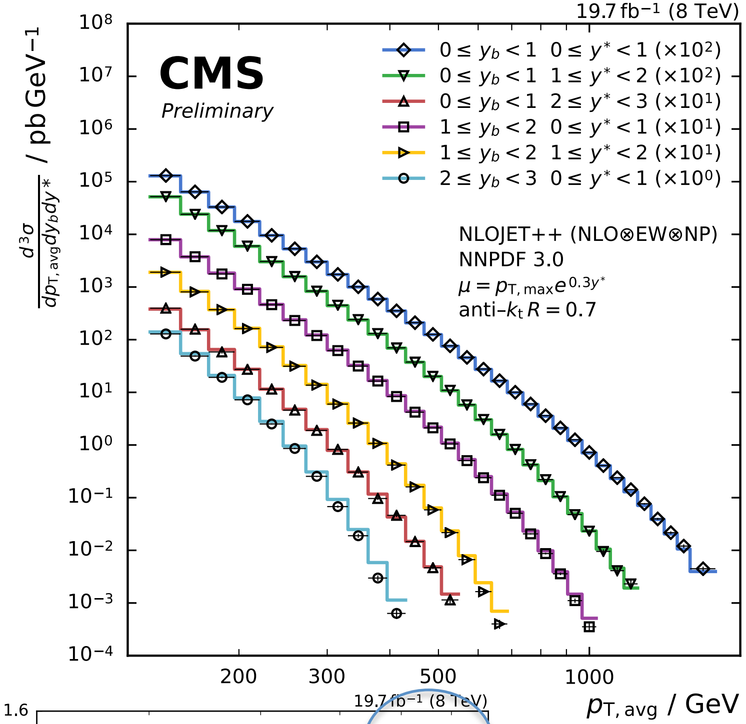
CMS-PAS-16-011

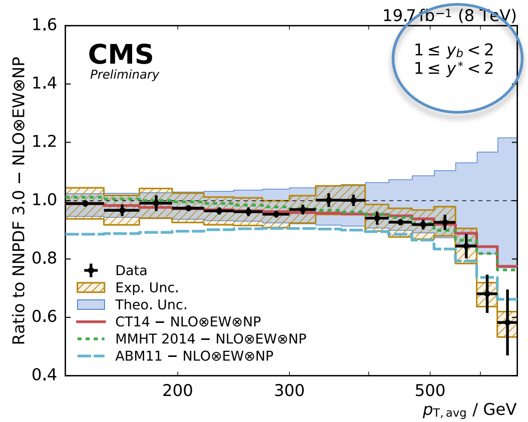


Measured in 8 TeV as a function of average p_T, ½(y_1-y_2) and ½|y_1+y_2|

i.e







Ratio to theory with different PDFs for one example bin

Triple differential cross sections are sensitive to PDFs, different x and parton compositions in the 6 regions

$$x_{1,2} = \frac{p_T}{\sqrt{s}}(e^{\pm y_1} + e^{\pm y_2})$$