ATLAS results on Standard Model and Heavy Ions

Frédéric Derue, LPNHE Paris
(on behalf of the ATLAS collaboration)

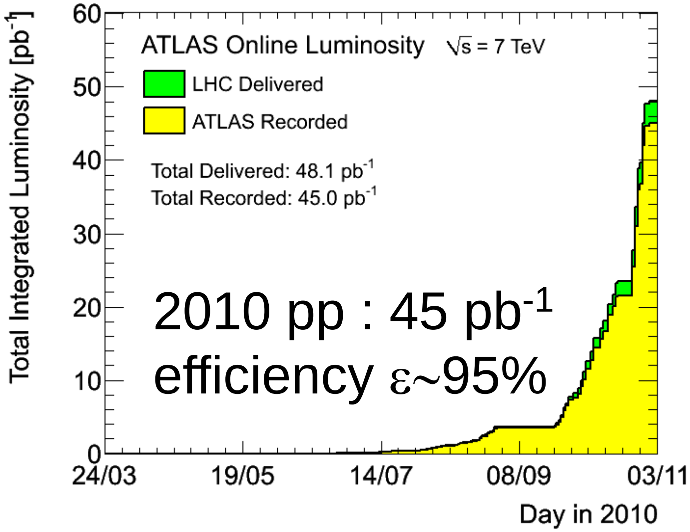
New trends in High Energy Physics
Alushta, Crimea, Ukraine, September 3-10, 2011

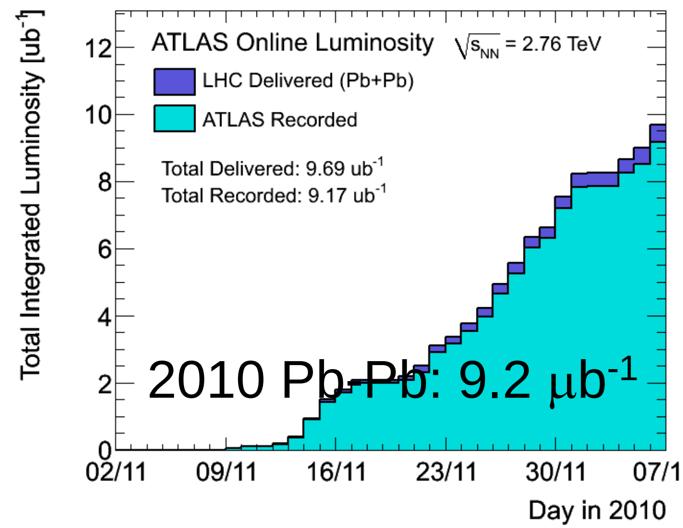
SM proton-proton results
e/μ/γ/jets results
W/Z results

Heavy Ions results
W/Z production
dijet asymmetry

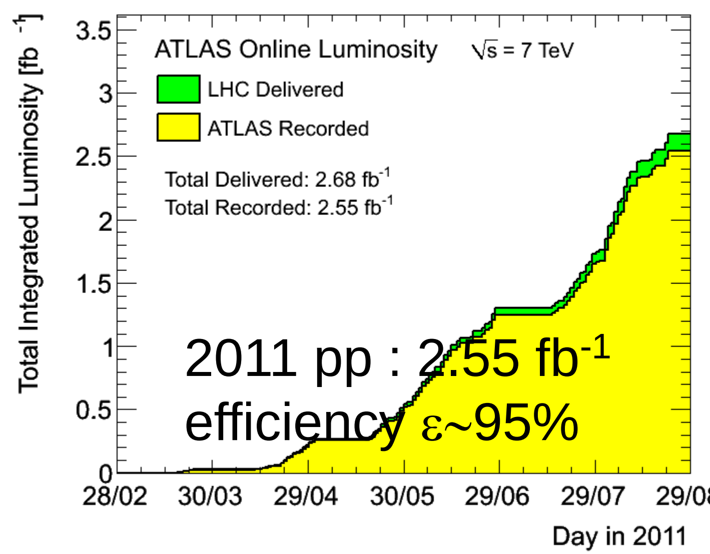
Data collection

2010 operation : gradual (~exponential) ramp up of instantaneous luminosity. One month of data taking for Heavy Ions by end of 2010





2011 : sustained delivery
of integrated luminosity
peak luminosity 2.37×10^{33} cm^{-2} s^{-1}
best in a day : >95 pb^{-1}

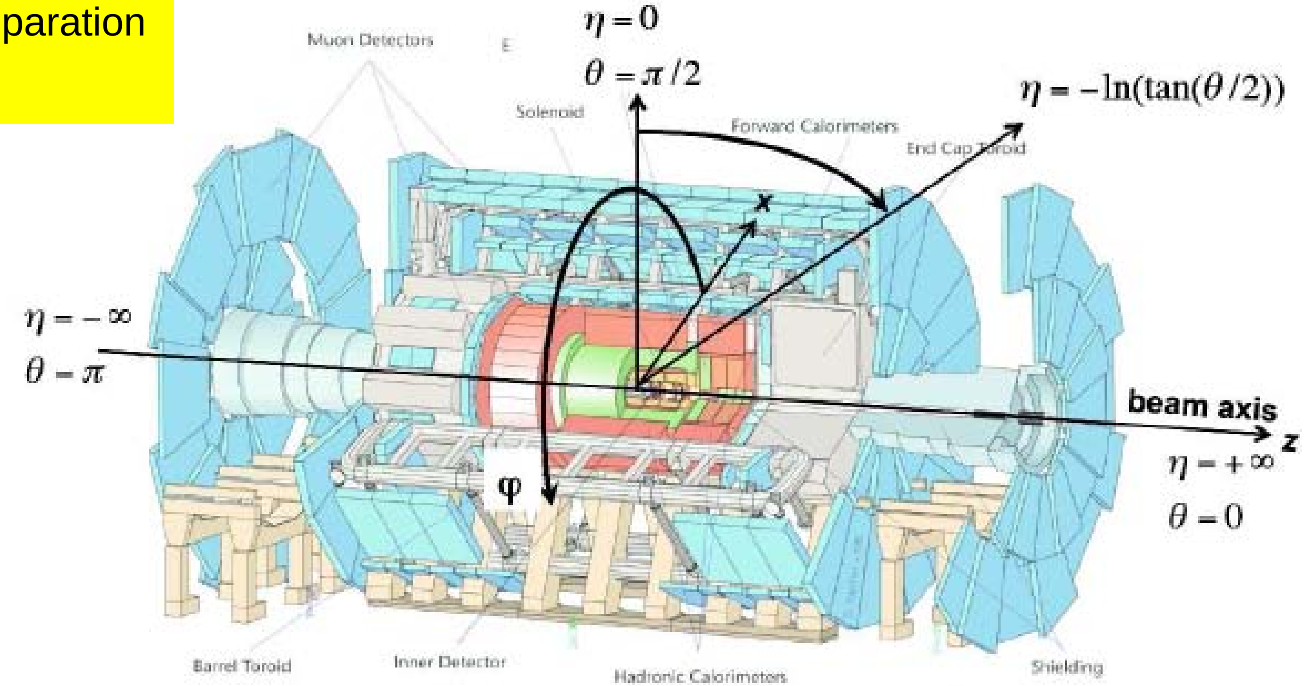


Many results from 2010 data
Some results with up to 1.2 fb^{-1}

The ATLAS detector

Muon spectrometer (|η|<2.7) : air-cores toroids with gas-based chambers. Trigger and measurement. Momentum resolution <10% up to Eμ~1 TeV

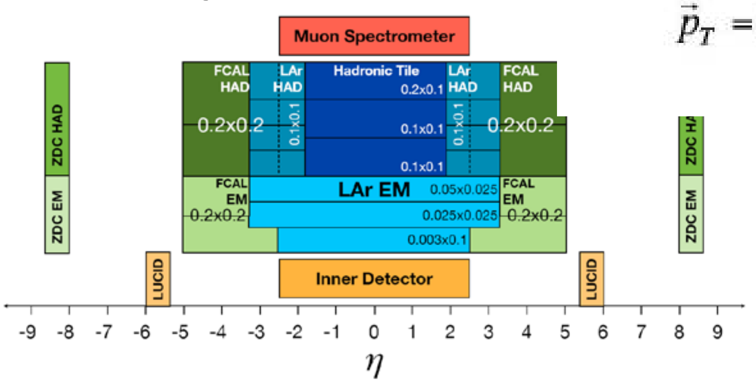
Inner Detector (|η|<2.5) :
Si pixel, SCT, TRT
Tracking and vertexing. e/π separation
$\sigma/p_T \sim 0.038\%\ p_T\ (\mathrm{GeV}) \oplus 1.5\%$



$$\vec{p}_T = (p_x, p_y) \qquad p_T = p \sin\theta, \quad E_T = E \sin\theta \qquad \vec{E}_T^{miss} = -\sum_{clusters\ i} E_i \hat{n}_i$$

EM calorimeter (|η|<3.2) :
Pb/LAr accordion
Trigger and e/γ reco and id
$\sigma/E \sim 10\%/\sqrt{E}\ (\mathrm{GeV}) \oplus 0.7\%$

ZDC (|η|>8.3) :
Zero Degree Calorimeter
for Heavy Ions studies

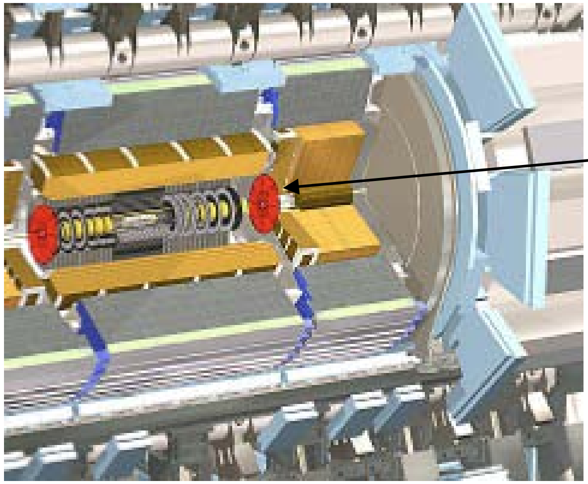


HAD calorimeter (|η|<5) :
Fe/scintillator tiles (central),
Cu/W Lar (fwd),
Trigger, jets and Etmiss.
$\sigma/E \sim 50\%/\sqrt{E}\ (\mathrm{GeV}) \oplus 3\%$

Trigger

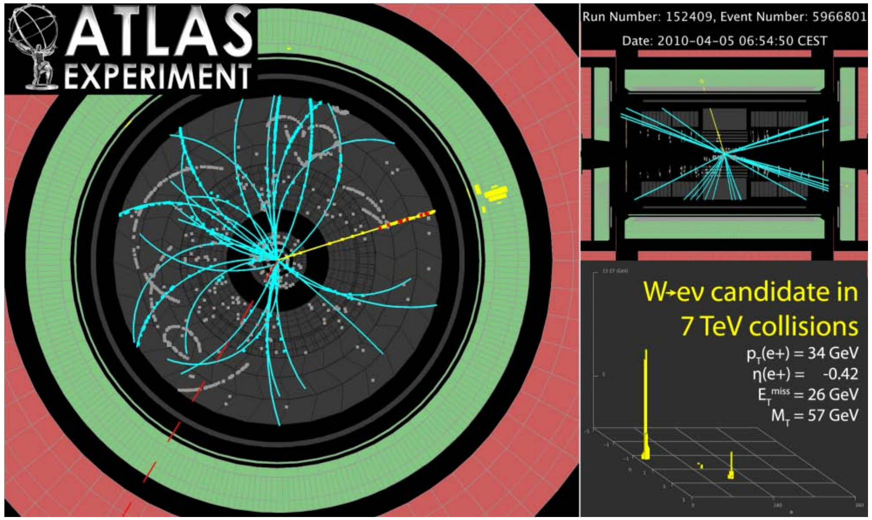
- **p-p collisions**
  - standard triggers for physics, e.g
    - inclusive e p_T>20 GeV, μ p_T>18 GeV
    - inclusive jet p_T>180 GeV
    - ETmiss > 60 GeV
    - di-photon p_T>20 GeV
    - …
  - such triggers are not prescaled
  - supplemented by supporting and monitoring triggers
  - sophisticated and flexible menus

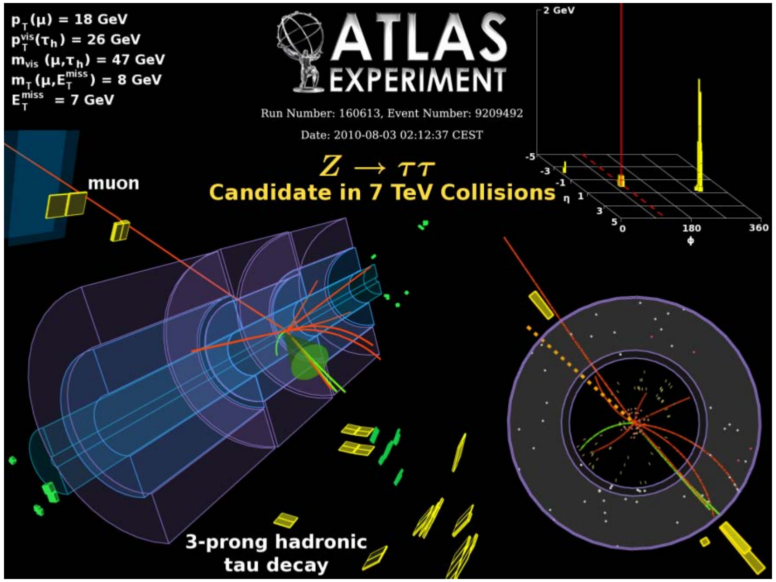
trigger	L1 item	L1 Rate (Hz)	EF Rate (Hz)
e20_medium	EM14	8500	50
2e12_medium	2EM7	5700	1
g80_loose	EM30	700	3
2g20_loose	2EM14	750	2
mu18	MU10	5300	40
2mu10	2MU10	100	1
xe60	XE40	300	4
j180	J75	200	6
tau29medium_xe35	TAU11_XE20	3800	6
tau16_e15	TAU6_EM10	7500	6
j75_xe45	J50_XE20	500	10

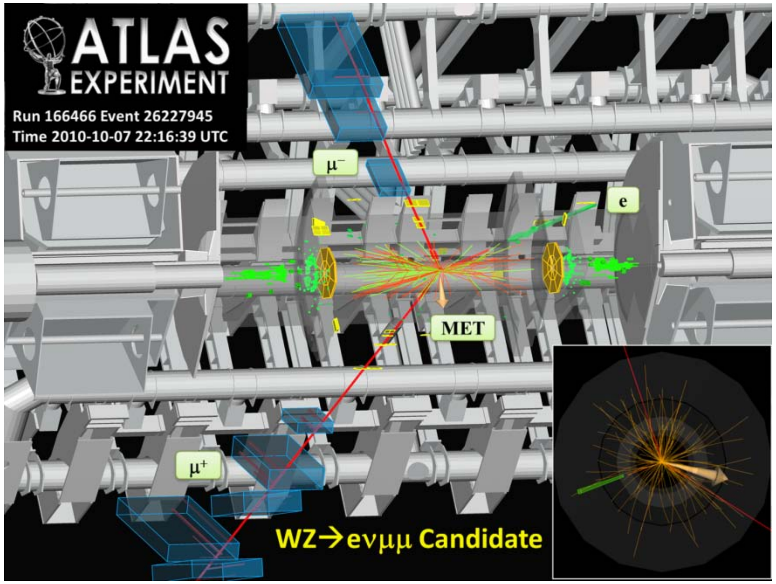


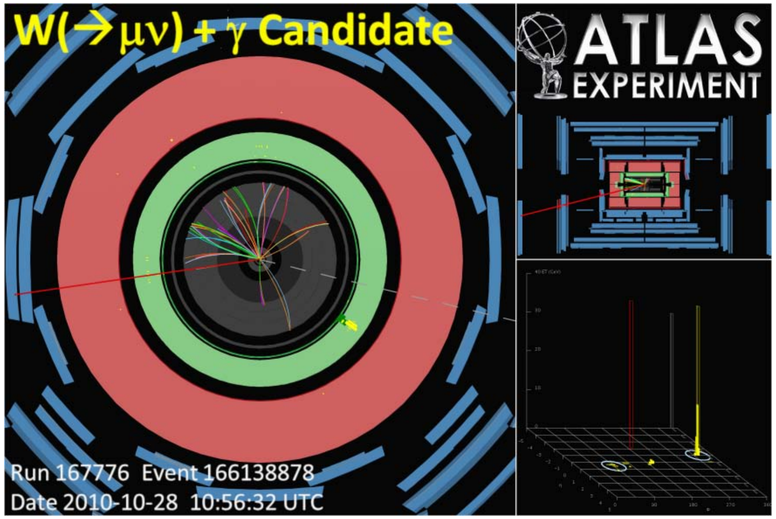
- **Pb-Pb collisions**
  - coincidence in (Level 1) Minimum Bias Trigger Scintillators (2.1<|η|<3.9)
  - coincidence in Zero Degree Calorimeter (|η|>8.3)

Standard Model results









e/μ from Heavy Flavour cross section

Differential cross section

$$\frac{\Delta\sigma_i}{\Delta p_{T_i}} = \frac{N_{\mathrm{sig}_i}}{\Gamma_{\mathrm{bin}_i}\cdot\int\mathcal{L}dt}\cdot\frac{C_{\mathrm{migration}_i}}{\epsilon_{(\mathrm{reco+ID})_i}\cdot\epsilon_{\mathrm{trigger}_i}},$$

- N_{sig} : number of signal lepton with p_T in bin i of width Γ_i
- $\varepsilon_{trigger}$ and $\varepsilon_{reco+ID}$ are the efficiency of trigger and reconstruction level
- $C_{migration}$ is the bin migration correction factor, ratio of the number of charged leptons in bin i of true p_T and the number in the same bin of reconstructed p_T
- $\int\mathcal{L}dt$: integrated luminosity

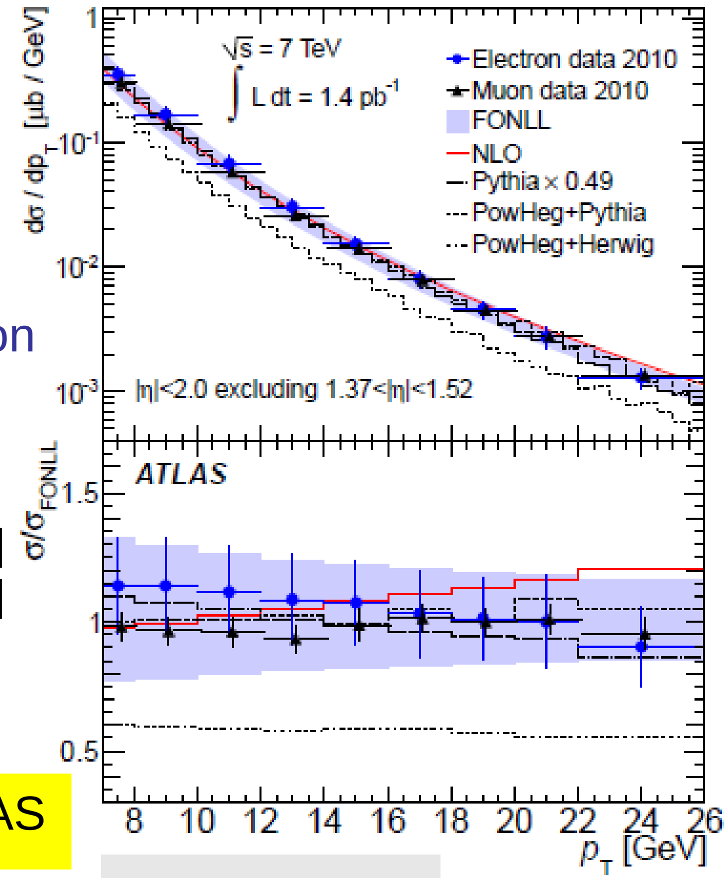
Analysis (1.4 pb^{-1})

- selection of non isolated electrons and muons restricted in E_T=7-26 GeV and $|\eta|<2.5$, excluding $1.37<|\eta|<1.52$
- $\varepsilon_{reco+ID}$ estimated from Tag&Probe and simulation
- $C_{migration}$ is estimated from Pythia

Results

σ^{e}_{HF} = 0.946 ± 0.020 (stat.) ± 0.146 (sys.) ± 0.032 (lumi.) [μb]

σ^{μ}_{HF} = 0.818 ± 0.003 (stat.) ± 0.036 (sys.) ± 0.028 (lumi.) [μb]



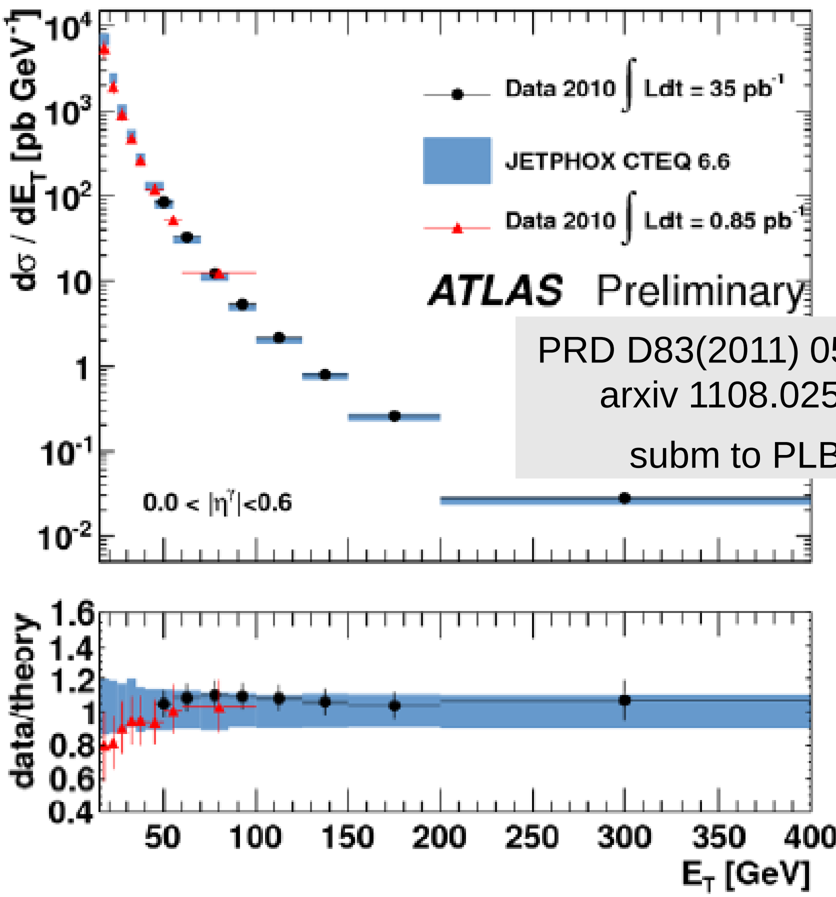
Good understanding of both inclusive e and μ by ATLAS

subm to PLB

γ inclusive and $\gamma\gamma$ production

γ inclusive production

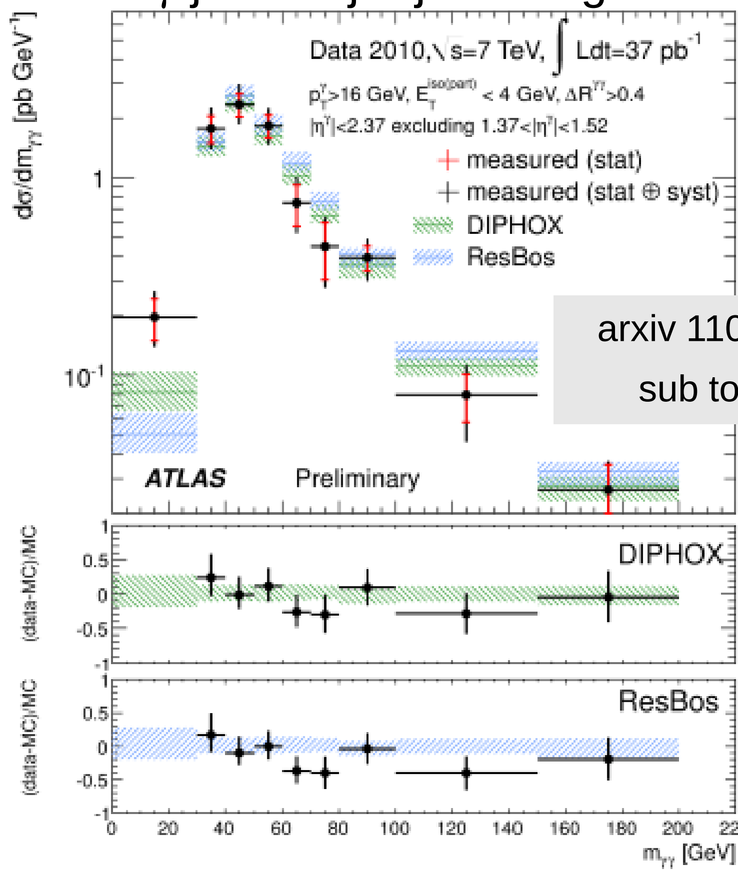
L=0.85 pb^{-1}: 15-100 GeV, |η|<1.37, 1.52<|η|<1.81
L=35 pb^{-1} : 45-400 GeV, |η| bins :
0-0.6, 0.6-1.37, 1.52-1.81, 1.81-2.37



PRD D83(2011) 052005
arxiv 1108.0253,
subm to PLB

$\gamma\gamma$ production

Two tight and isolated photons
Selection (see Fig.), subtraction
of γ-jet and jet-jet background



arxiv 1107.0581,
sub to PRD

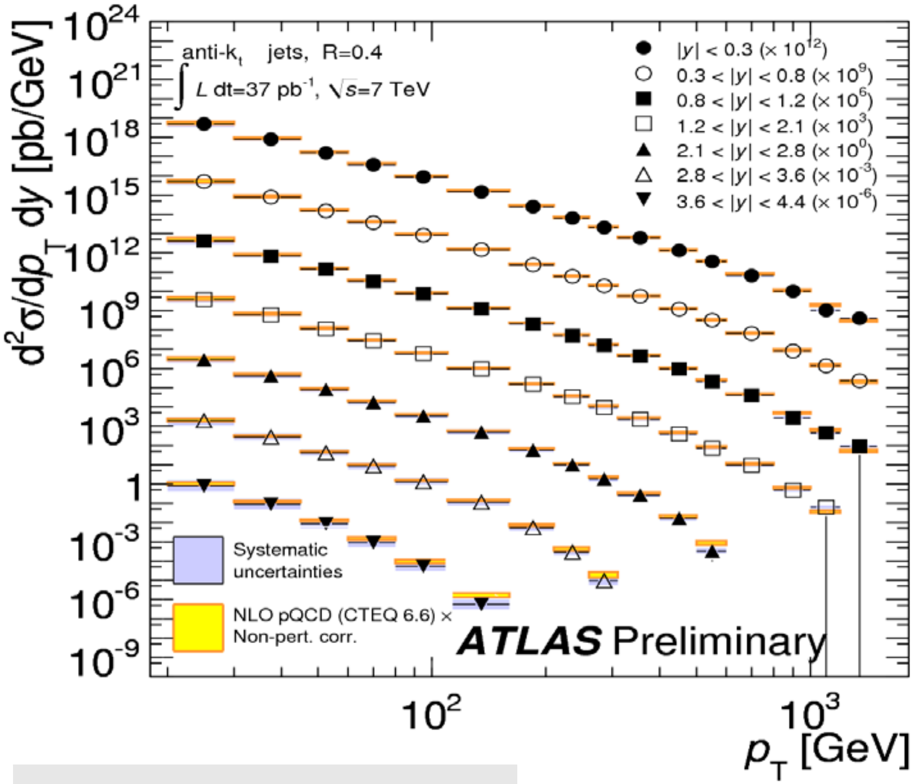
Good agreement between data and NLO predictions above 35 GeV

Good agreement in $m_{\gamma\gamma}$ except at low values, can be related in discrepancy observed in $\Delta\phi_{\gamma\gamma}$

jet inclusive cross section

anti-k_T jets with R=0.4 or 0.6

20 GeV<p_T<1.5 TeV



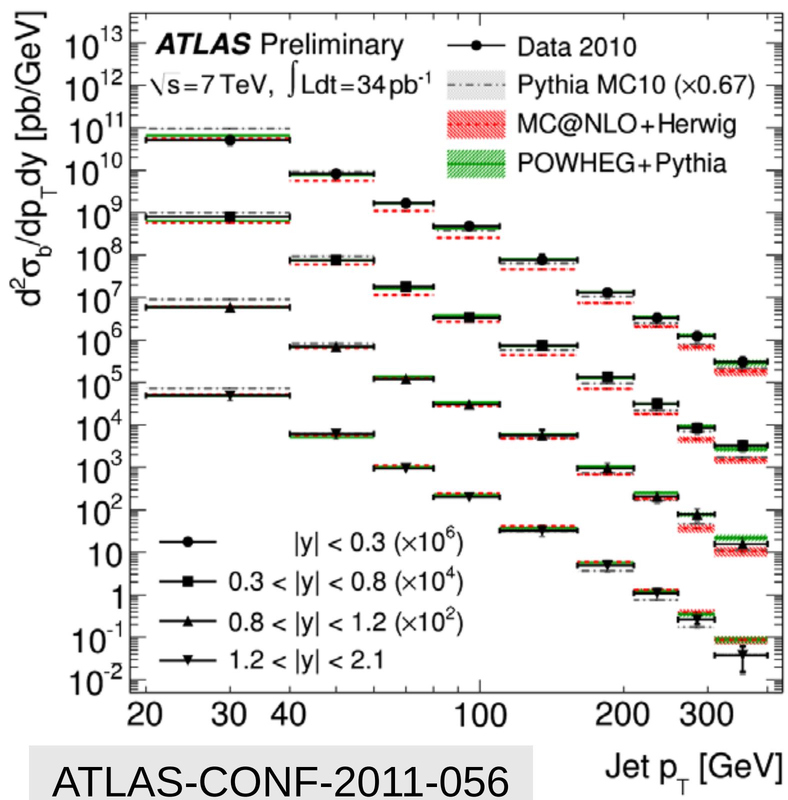
ATLAS-CONF-2011-047

good agreement between NLO predictions and data

b-jet production cross section

jets 20<p_T<400 GeV, |y|<2.1

b-tag : presence of secondary vertex or muon $p_T$rel (p_T relative to jet axis)



ATLAS-CONF-2011-056

ATLAS-CONF-2011-057

good agreement with NLO predictions

W/Z production (motivations)

- **W/Z boson**
  - W/Z bosons are used to study detector response
  - dominant signal and/or background in other analyses
  - more energy and cross section than at Tevatron
- **W/Z production cross section**
  - Drell-Yan production of W and Z bosons calculable to high orders in pQCD
  - higher order QCD corrections modify the cross section by 30-40% and have visible effect on kinematics
- **W/Z + jets**
  - σ(W/Z+≥Njets) - test of higher order calculations and pQCD
  - production of W/Z + b-jets is important for other studies
- **diboson production**
  - cross section measurement
  - determination of Triple Gauge Couplings to provide a model independent test for New Physics

Use leptonic decay channels, mostly e and μ

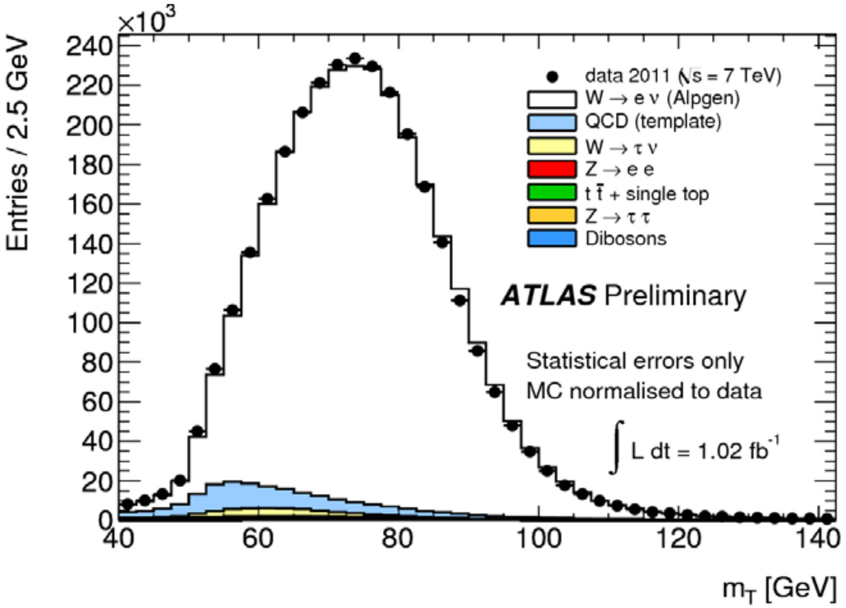
W and Z selection

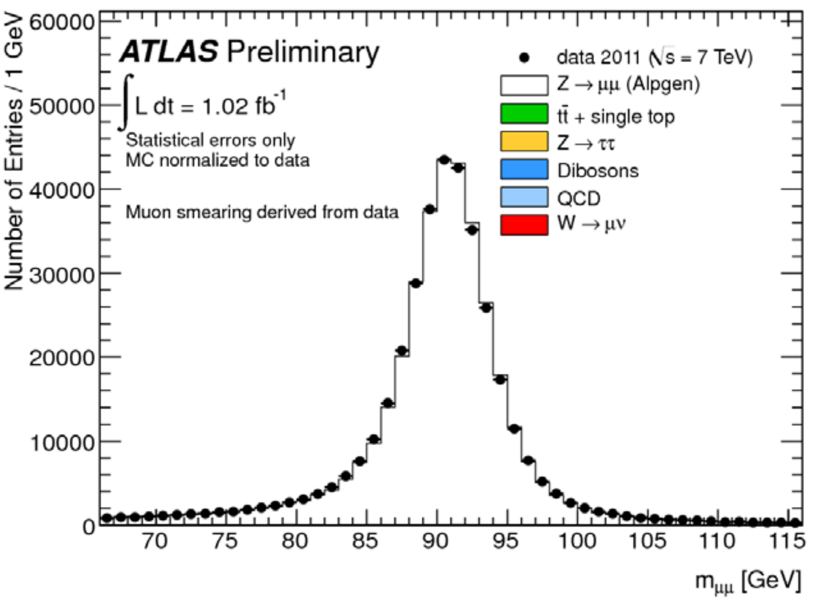
W→lν

- one e/μ with p_T>20 GeV
- E_T^{miss}>25 GeV, $m_T(l, E_T^{miss})$>40 GeV
- QCD from data fitting E_T^{miss}(e) and studying control regions in iso- E_T^{miss} plane (μ)
- ~131-140k candidates with 7-9% bkg in 2010, much more in 2011 (see plot)

Z→ll

- two e/μ with p_T>20 GeV
- m_{ll}=66-116 GeV
- QCD from data fitting m_{ll} line shape control regions in (iso, m_{ll}) plane
- ~10-12k candidates with 1-2% bkg in 2010, much more in 2011 (see plot)



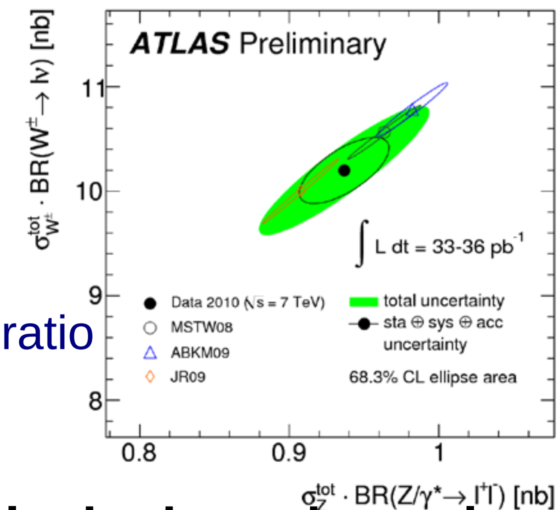


experimental uncertainties reduced by using data driven methods to control efficiencies, backgrounds and signal shapes
experimental and theoretical uncertainties of same size

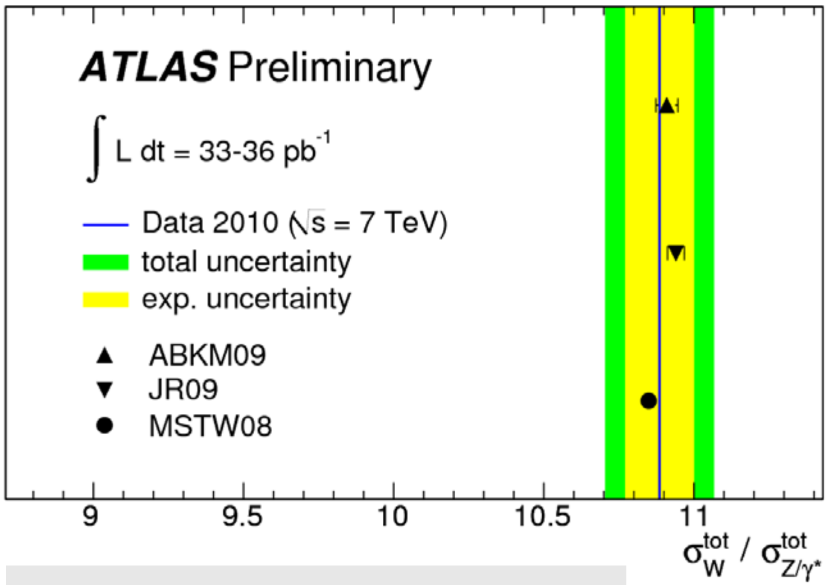
W and Z inclusive cross sections

W/Z production total cross section (e/μ)

		σ [nb]	stat.	sys.	lumi.	acc.
$\sigma_W \cdot \mathrm{BR}(W \to e\nu)$	=	10.255	0.031	0.190	0.349	0.084
$\sigma_W \cdot \mathrm{BR}(W \to \mu\nu)$	=	10.210	0.030	0.179	0.373	0.153
$\sigma_{Z/\gamma*} \cdot \mathrm{BR}(Z/\gamma* \to ee)$	=	0.952	0.010	0.026	0.032	0.019
$\sigma_{Z/\gamma*} \cdot \mathrm{BR}(Z/\gamma* \to \mu\mu)$	=	0.935	0.009	0.009	0.032	0.019



☆ detector related uncertainties partially cancel in the ratio

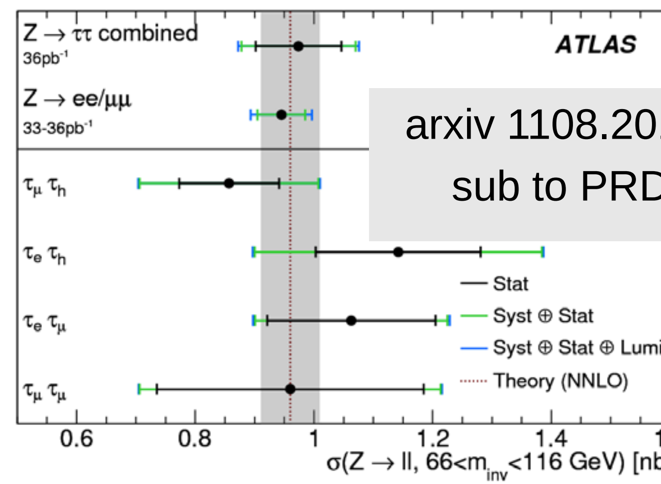


http://arxiv.org/abs/1010.2130
More details in EPS talk
by M. Bellomo

Results in the τ channel

$\sigma_W \cdot \mathrm{BR}(W\to\tau\nu) = 11.1 \pm 0.3$ (stat.) $\pm$ 1.7 (sys.) $\pm$ 0.4 (lumi.) [nb]

$\sigma_{Z/\gamma*} \cdot \mathrm{BR}(Z/\gamma^*\to\tau\tau) = 0.97 \pm 0.07$ (stat.) $\pm$ 0.06 (sys.) $\pm$ 0.03 (lumi.) [nb]



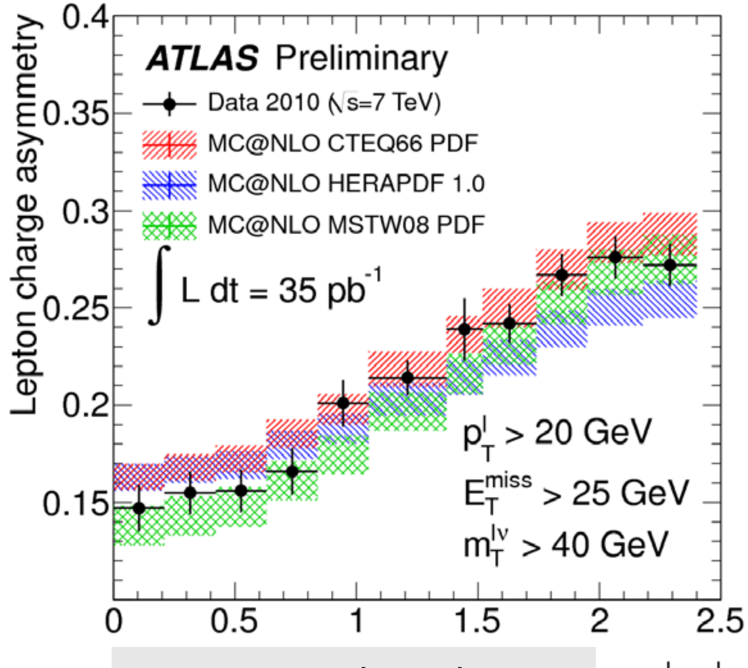
arxiv 1108.2016, sub to PRD

Good agreement with NLLO PDFs prediction
A few differences between different PDFs

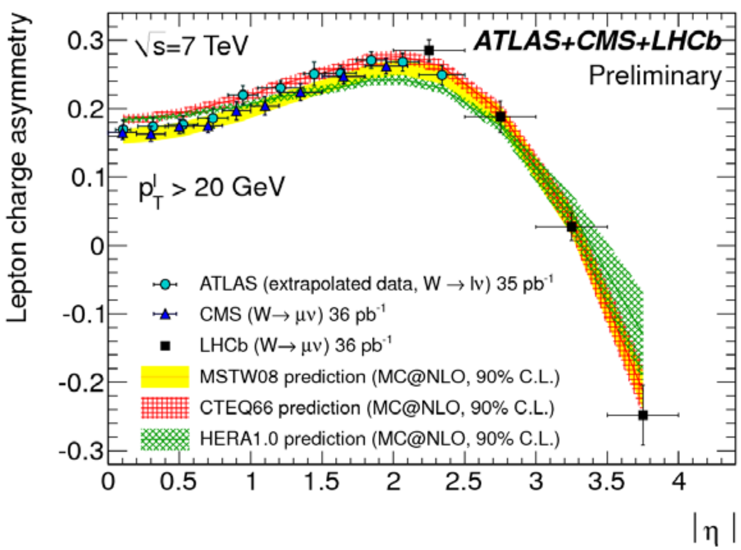
W differential charge asymmetry

- **W lepton charge asymmetry**
  - η(W±) measurements constrain PDF of u and d
  - ≠u,d momentum W± produced asymmetrically
    - charge asymmetry of l,ν from W decays
    - but V-A interaction reduces the observable asymmetry in the lepton rapidity distributions
  - experimentally, a clean way tbuo do this study is to measure the charge asymmetry as a function of the lepton pseudo-rapidity

$$A(\eta_l) = \frac{\sigma^{W^+}(\eta_l) - \sigma^{W^-}(\eta_l)}{\sigma^{W^+}(\eta_l) + \sigma^{W^-}(\eta_l)}$$



PLB 701 (2011) 31



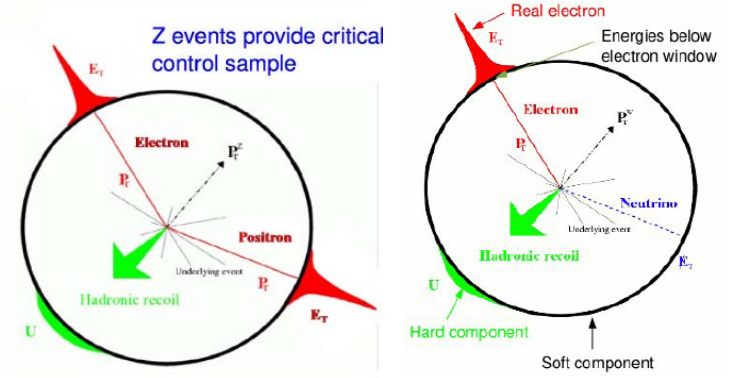
- this measurement is rather sensitive to PDFs because most systematic uncertainties cancel in the ratio

Reasonable agreement with different PDFs predictions

ATLAS-CONF-2011-129
LHCb-CONF-2011-039
CMS-EWK-10-006

Z and W p_T measurement

At LO $p_T^{W/Z}$ =0; non zero value is generated through the hadronic recoil of ISR p_T^R

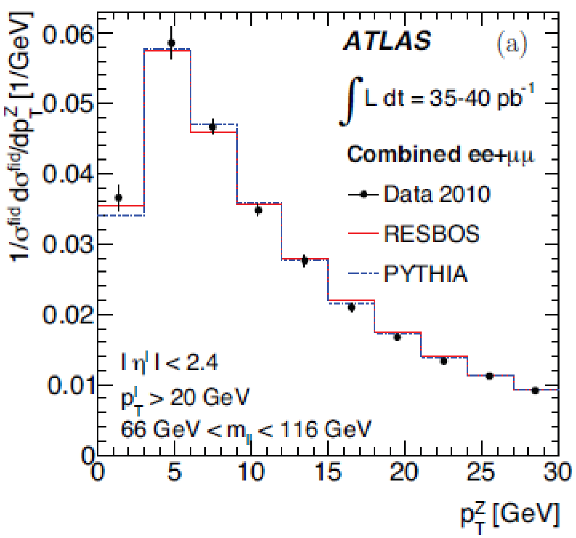


Z p_T

- Z provide critical control sample for W
- to model high-p_T lepton kinematics
- p_T^Z reconstructed from 2 leptons
- detector and FSR effects removed with a bin-per-bin unfolding

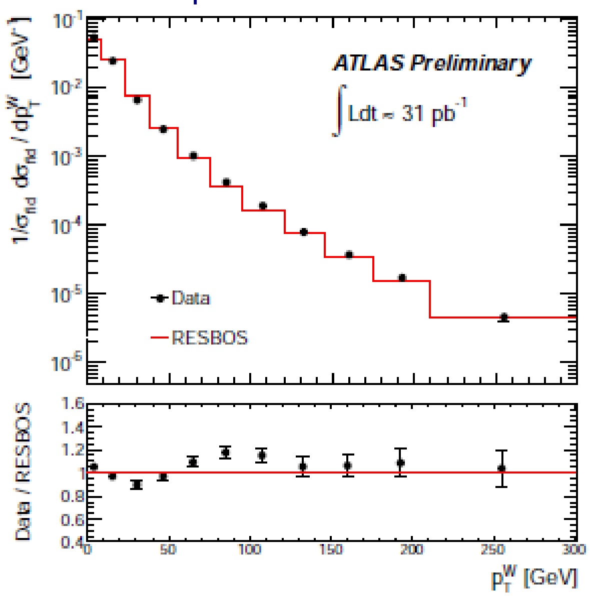
W p_T

- for precise m_W measurement
- cannot reconstruct p_T^W easely (ν in final state)
- p_T^W reconstructed from p_T^R



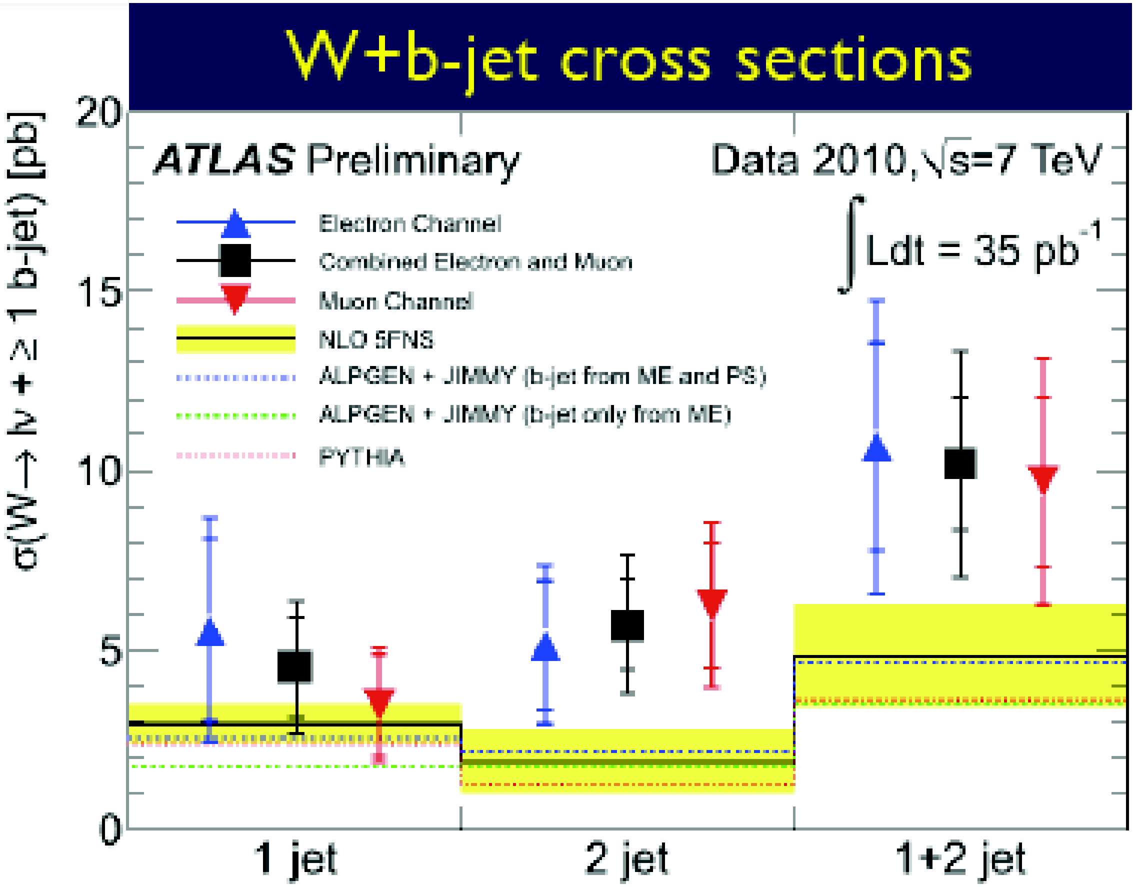
http://arxiv.org/abs/1107.2381
More details in EPS talk
by R. Reece

Reasonable agreement of measurements with theory predictions



W/Z+jets production at LHC

- **W+b-jet**
  - 1st measurement in exclusive jet bins
  - uncertainty : ~20% stat., ~25% syst.



NLO agrees within 1.5 σ with the measurements

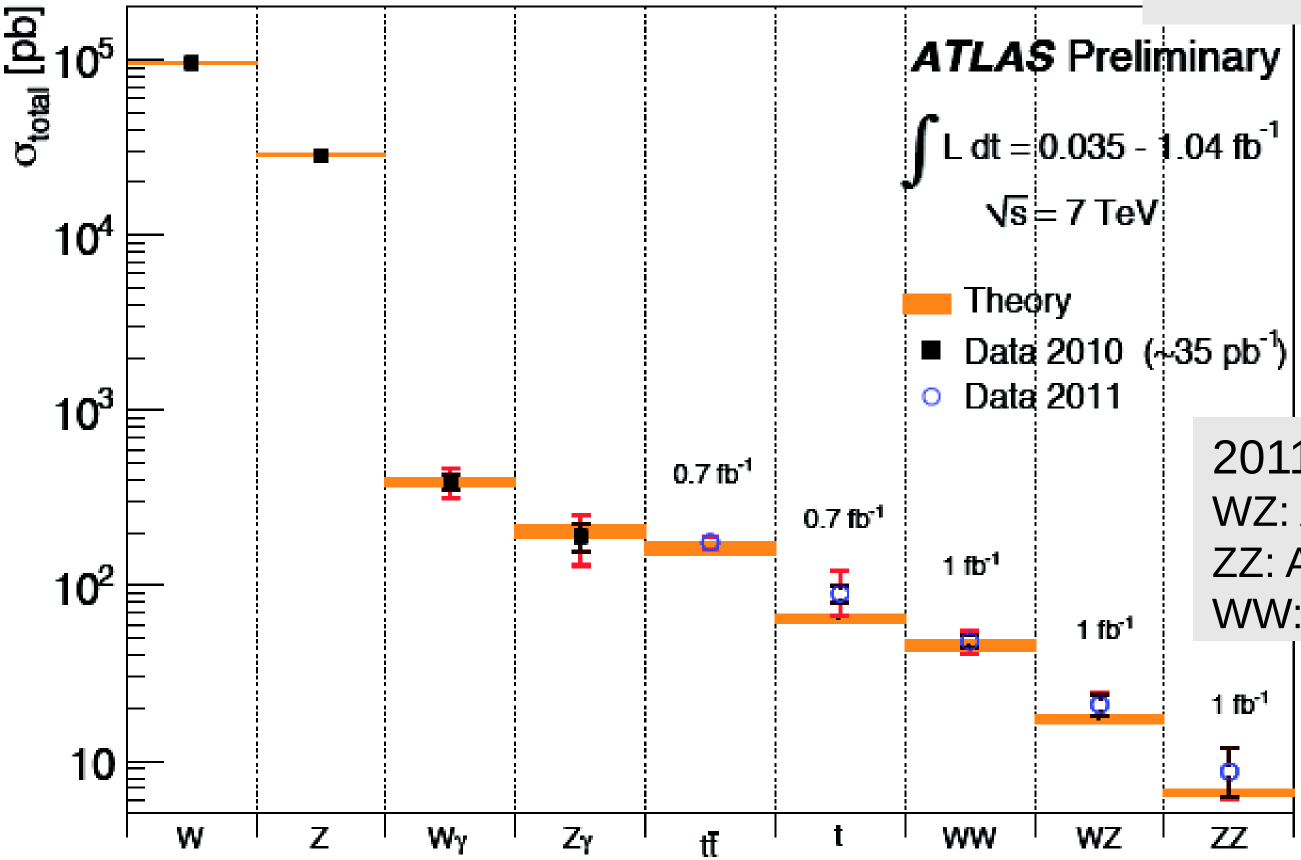
- dominant systematics
  - b-tagging & SV mass template ≈16%
  - top background ≈12%
  - QCD background ≈7%
  - W + b-jet modeling ≈10%
  - jet + b-jet energy scale ≈7%

Paper in preparation
More details in EPS talk by A. Messina

W,Z and di-bosons cross sections

WW: 414 events, ~40% bkg
WZ : 71 events, ~15% bkg
ZZ : 12 events, negligible bkg

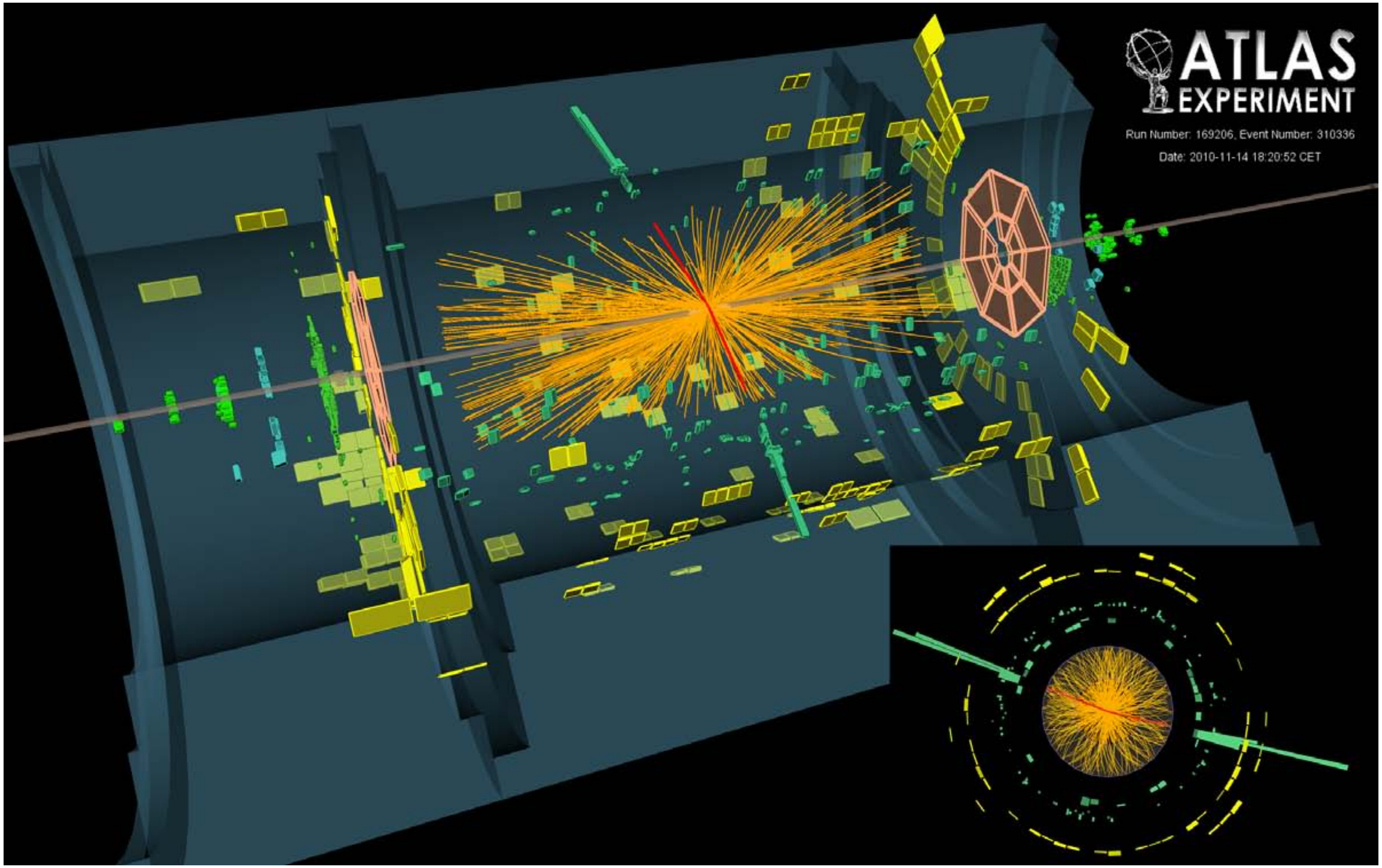
2010 results
Wγ and Zγ: arxiv 1106.1592, accept by JHEP
WW: PRL 107, 041802 (2011)



2011 results
WZ: ATLAS-CONF-2011-099
ZZ: ATLAS-CONF-2011-107
WW: ATLAS-CONF-2011-110

Overall good agreement between measurements and theory

Heavy Ions results



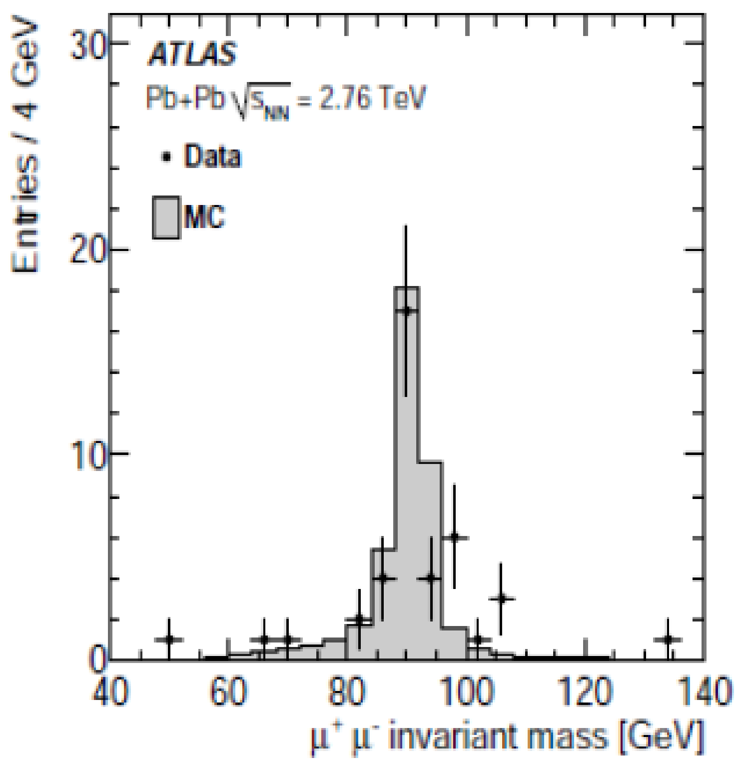
Heavy Ions collision with a candidate Z→ee events, m_{ee}~104 GeV

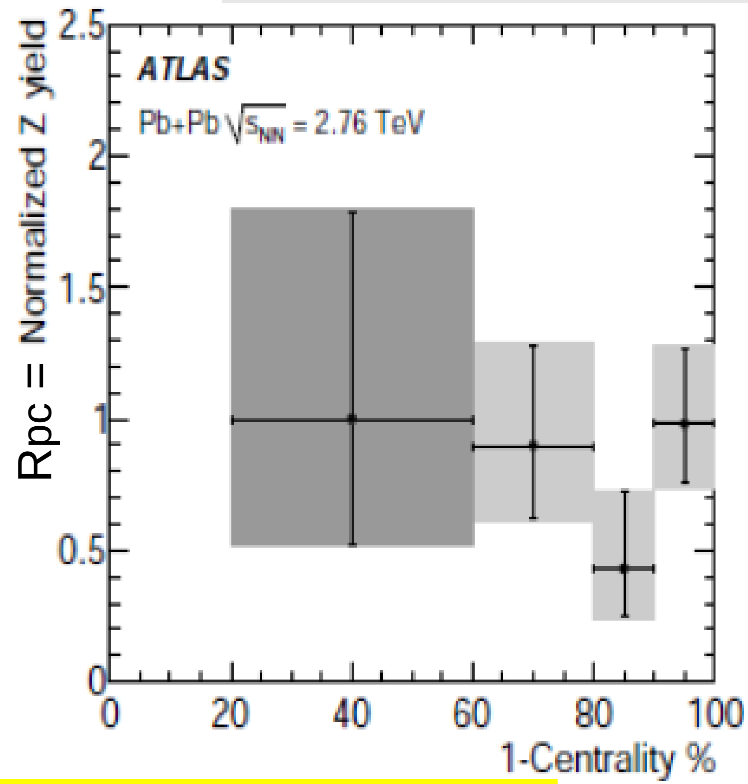
Z production in Pb-Pb collisions

- **Analysis**
  - $Z \rightarrow \mu\mu$ channel explored
  - integrated luminosity analyzed : 7 μb^{-1}
  - muons with p_T>20 GeV and $|\eta|$<2.5
  - 38 candidates in the mass window 66-116 GeV

Rpc : yield scaled by the ratio of the mean number of binary collisions in each centrality bin to that of the most peripherical one

Phys. Lett. B 697:294-312, 2011



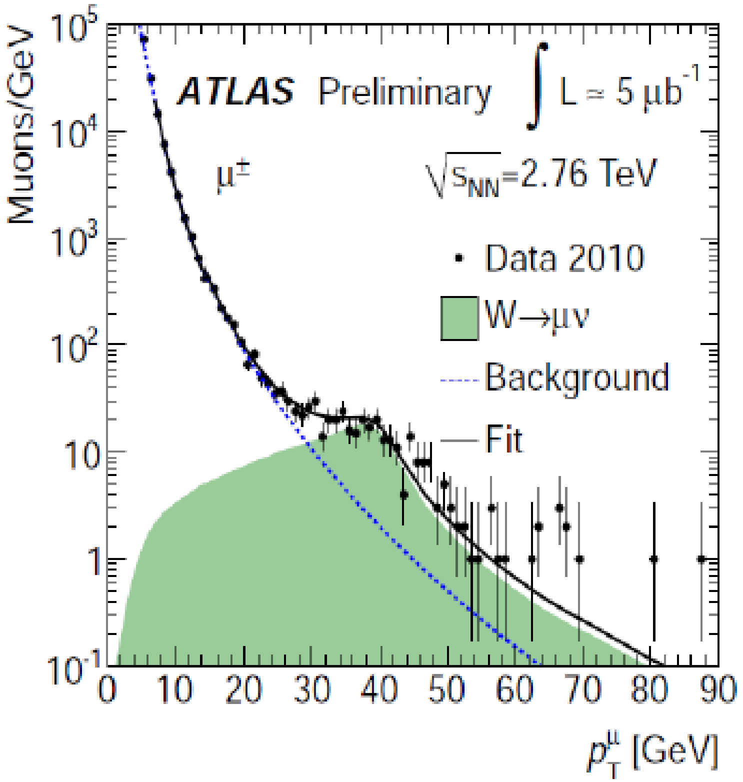


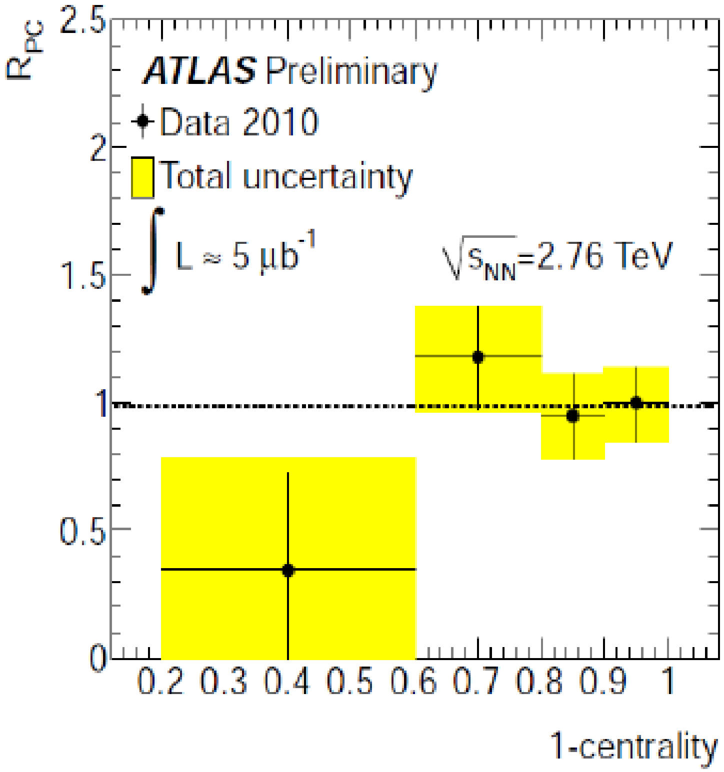
Not enough statistics to draw conclusion on normalized yield

W production in Pb-Pb collisions

- **Analysis ($W \to \mu\nu$)**
  - veto dimuons with $m_{\mu\mu}$>60 GeV (DY & Z candidates) and decays in flight
  - build a template from $W \to \mu\nu$ MC@2.76 TeV pp
  - use a function to describe background
  - find the best estimate of the number of W

ATLAS-CONF-2011-078





R_{pc} result is consistent with no W suppression, as expected

dijets in Pb-Pb collisions

Selection

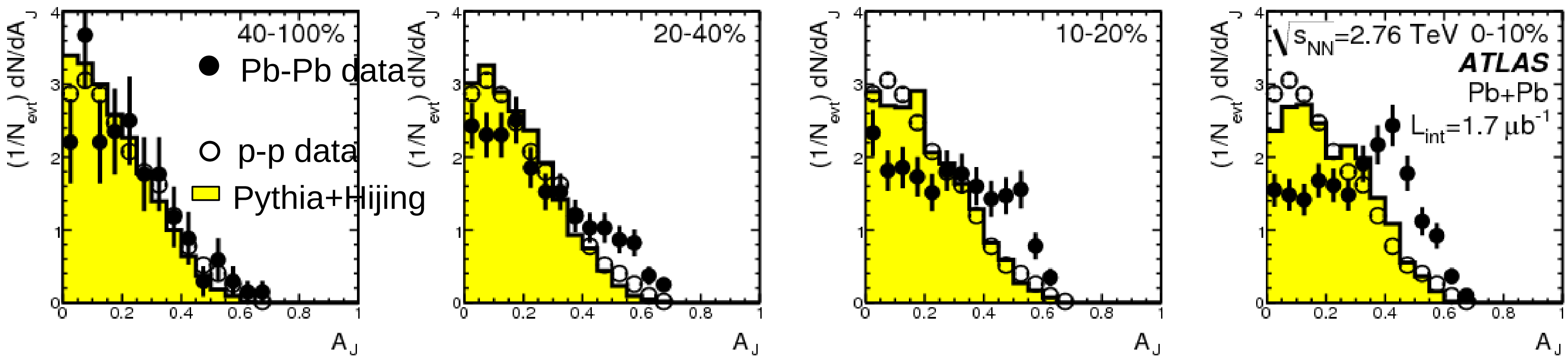
Phys. Rev. Lett. B 105:252303, 2010

- jets from anti-kT algorithm R=0.4, $\Delta\phi>\pi/2$, ~1700 events with ET>100 GeV, $|\eta|<2.8$

E_T balance

$$A_J = \frac{E_{T1}-E_{T2}}{E_{T1}+E_{T2}} \qquad E_{T1} > 100\,GeV \quad E_{T2} > 25\,GeV$$

dijets are expected to have A_J~0 with deviations expected from gluon radiation falling outside the jet cone, from instrumental effects. Energy loss in the medium could lead to much stronger deviations in the reconstructed energy balance



- Pythia+Hijing illustrate effect of Heavy Ions background on jet reconstruction, not any underlying physics process
- the dijet asymmetry in peripheral Pb-Pb events is similar to that in both p-p and simulated events; however, as the events become more central, the Pb-Pb data distributions develop different characteristics, indicating an increased rate of highly asymmetric dijet events
- R varied to 0.2, 0.6 : large asymmetry not reduced
- jets remain back-to-back

First indication of jet suppression

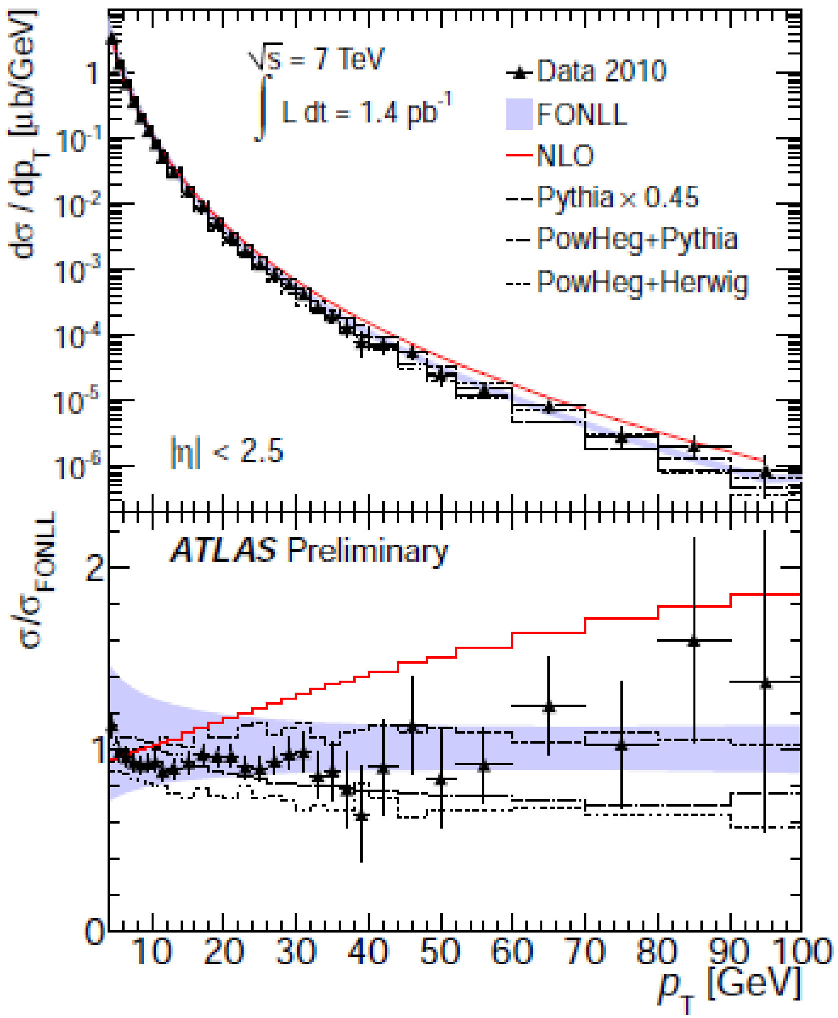
Conclusion

- **General comments**
  - ATLAS experiment at LHC has collected so far >2.5 fb^{-1} of pp collision data and 9.2 μb^{-1} of Pb-Pb data
  - detector is performing well and only part of data analyzed yet
- **Standard Model results**
  - brief overview of a few results, from cross sections of “simple objects” (e,μ,γ,jets) to W/Z events
  - much more results available
  - overall good agreement between data measurement and theory expectations
- **Heavy Ions results**
  - i have flashed only very few results obtained by ATLAS
  - leptonic probes : Z and W productions consistent with simple scaling with N_{coll}
  - high p_T observables : jet production suppressed by a factor 2 in central collisions
- **References**

https://twiki.cern.ch/twiki/bin/view/AtlasPublic
https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/CONFNOTES
https://twiki.cern.ch/twiki/bin/view/AtlasPublic/StandardModelPublicCollisionPlots

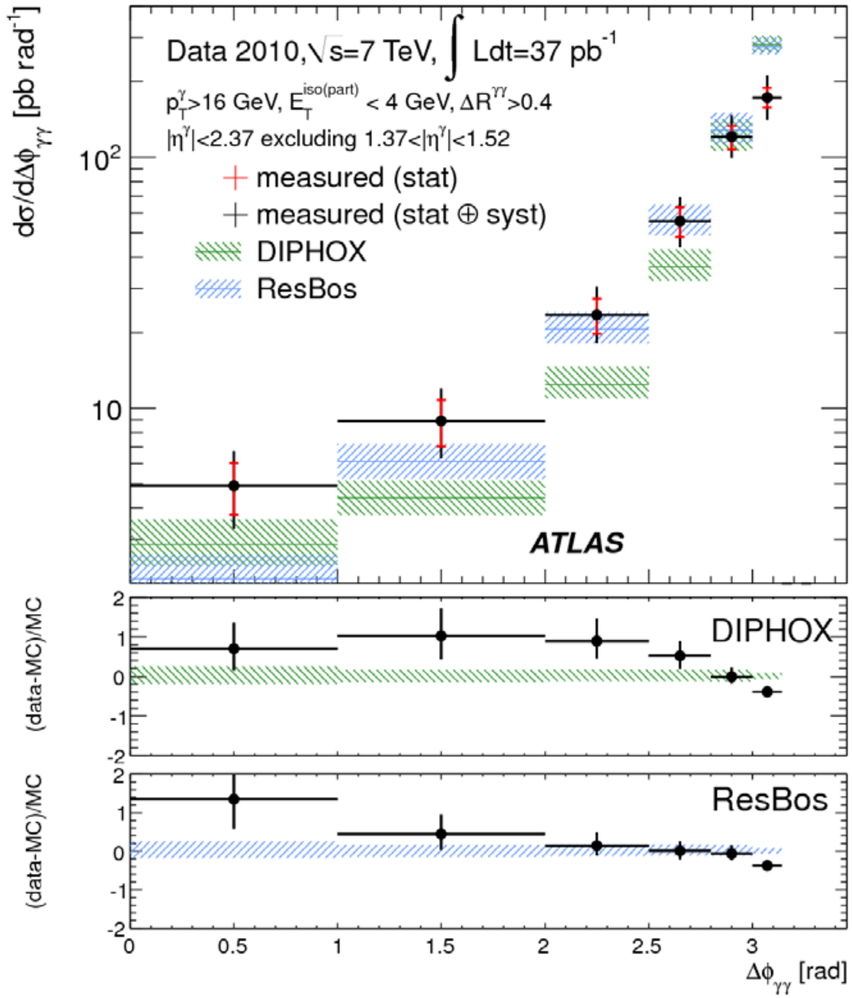
Back up slides

e/μ from Heavy Flavour cross section



For muons with p_T > 25 GeV a deviation from the NLO central prediction is seen, indicating the sensitivity of the data to the NLL high-p_T resummation, for the first time in heavy-flavour production at a hadron collider

γγ production



Cross section measurements

- **Ingredients**

$$\sigma_{fid} = \frac{N - B}{C_{W/Z} \cdot L_{int}}, \quad \sigma_{tot} = \frac{\sigma_{fid}}{A_{W/Z}}$$

  - N_{obs} : number of events observed in the signal region
  - N_{bkg} : estimated number of background events
  - A : kinematic acceptance factor, estimated with generator level Monte Carlo
  - C : summarizes reconstruction efficiency, estimated with reconstructed Monte Carlo, corrected with scale factors
  - L_{int} : integrated luminosity
- **Fiducial cross section**
  - corrected for efficiency factor C
  - adjusted to data/Monte Carlo differences
- **Total cross section**
  - corrected for acceptance factor A

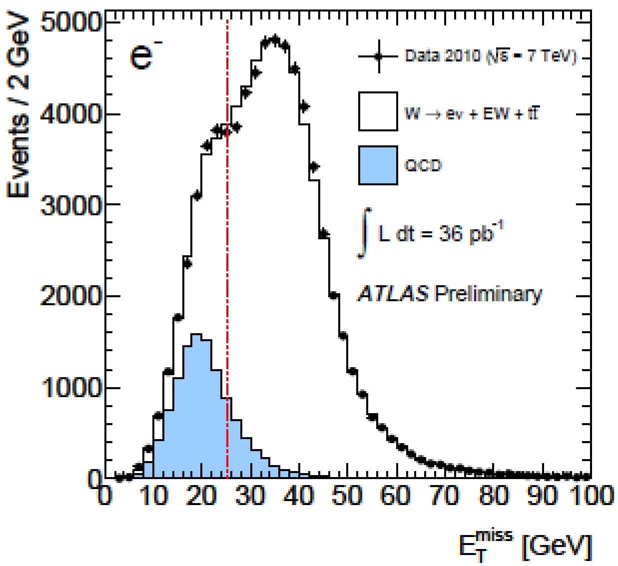
QCD estimation

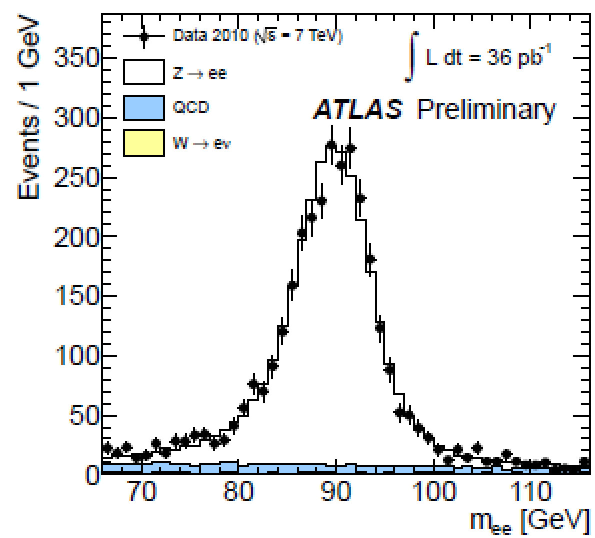
$W \to e\nu$: template fit to $E_{\mathrm{T}}^{\mathrm{miss}}$. Template derived from data with inverted electron ID and isolation.

$Z \to ee$: template fit to $m_{\ell\ell}$ to a sample with looser electron ID, extrapolated to the signal region.

$W \to \mu\nu$: matrix method using track isolation.

$Z \to \mu\mu$: ABCD method with track isolation in $m_{\mu\mu}$ side-band.





Ryan Reece | Penn | ryan.reece@cern.ch | ATLAS W and Z cross sections | EPS-HEP 2011 12 / 31

Systematic uncertainties for W/Z selection

- $\delta\sigma_{W\to e\nu}$ of $1.8 - 2.1\,\%$, dominated by electron reconstruction, identification and $E_{\mathrm{T}}^{\mathrm{miss}}$
- $\delta\sigma_{Z\to ee}$ of $2.7\,\%$, dominated by el. reconstruction and identification

Electron channels (%)	$W^{\pm}$	W^{+}	W^{-}	Z
Trigger	0.4	0.4	0.4	<0.1
Reconstruction	0.8	0.8	0.8	1.6
Identification	0.9	0.8	1.1	1.8
Isolation	0.3	0.3	0.3	—
Energy scale and resolution	0.5	0.5	0.5	0.2
Defective LAr channels	0.4	0.4	0.4	0.8
Charge misidentification	<0.1	0.1	0.1	0.6
$E_{\mathrm{T}}^{\mathrm{miss}}$	0.8	0.7	1.0	—
Pile-up	0.3	0.3	0.3	0.3
Vertex position	0.1	0.1	0.1	0.1
QCD Background	0.4	0.4	0.4	0.7
EWK+$t\bar{t}$ Background	0.2	0.2	0.2	<0.1
$C_{W/Z}$ Theor. uncertainty	0.6	0.6	0.6	0.3
Total Exp. uncertainty	**1.8**	**1.8**	**2.0**	**2.7**
$A_{W/Z}$ Theor. uncertainty	1.4	1.6	1.9	1.9
Total excluding Luminosity	2.3	2.4	2.8	3.3

- $\delta\sigma_{W\to\mu\nu}$ of $1.6 - 1.7\,\%$, dominated by muon efficiencies, QCD background and $E_{\mathrm{T}}^{\mathrm{miss}}$
- $\delta\sigma_{Z\to\mu\mu}$ of $0.9\,\%$, dominated by muon efficiencies

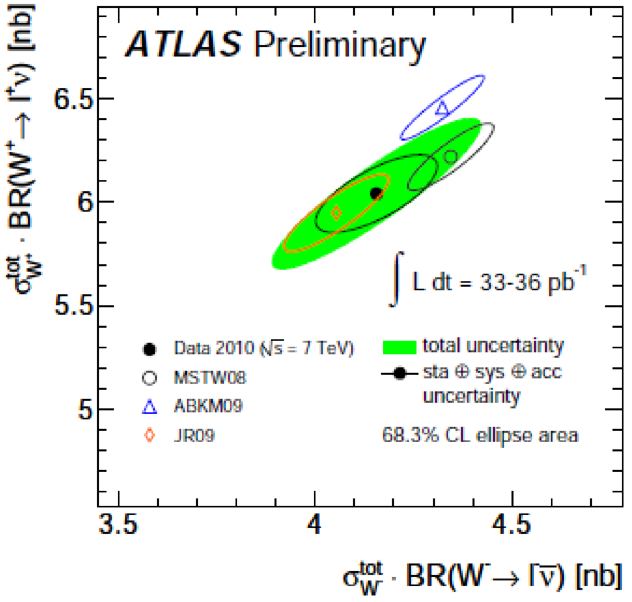
Muon channels (%)	$W^{\pm}$	W^{+}	W^{-}	Z
Trigger	0.5	0.5	0.5	0.1
Reconstruction	0.4	0.3	0.3	0.6
Isolation	0.2	0.1	0.2	0.3
p_{T} Resolution	0.04	0.03	0.05	0.02
p_{T} Scale	0.4	0.6	0.6	0.2
$E_{\mathrm{T}}^{\mathrm{miss}}$	0.5	0.4	0.6	-
Pile-up	0.3	0.3	0.3	0.3
Vertex position	0.1	0.1	0.1	0.1
QCD Background	0.6	0.5	0.8	0.3
EWK+$t\bar{t}$ Background	0.4	0.3	0.4	0.02
$C_{W/Z}$ Theor. uncertainty	0.8	0.8	0.7	0.3
Total Exp. uncertainty	**1.6**	**1.7**	**1.7**	**0.9**
$A_{W/Z}$ Theor. uncertainty	1.4	1.6	2.0	2.0
Total excluding Luminosity	2.1	2.3	2.6	2.2

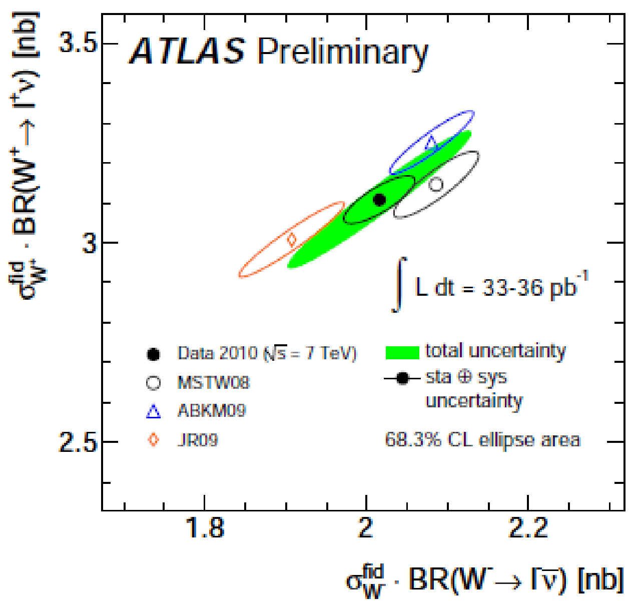
W production cross section vs theory

- **Total cross sections**
  - overall remarkable agreement with NLLO PDF predictions
  - a few differences between different PDFs (w/ only 68% CL PDF errors)
  - comparing total cross sections, the acceptance uncertainty accounts for effect of different PDFs

  on the unmeasured phase space ….

- **Fiducial cross section**
  - comparing in the fiducial region disentangles theory and experimental effects
  - this enables more interesting comparisons among different PDF sets
  - first dedicated calculation of NNLO predictions based on FEWZ and DYNNLO with experimental cuts

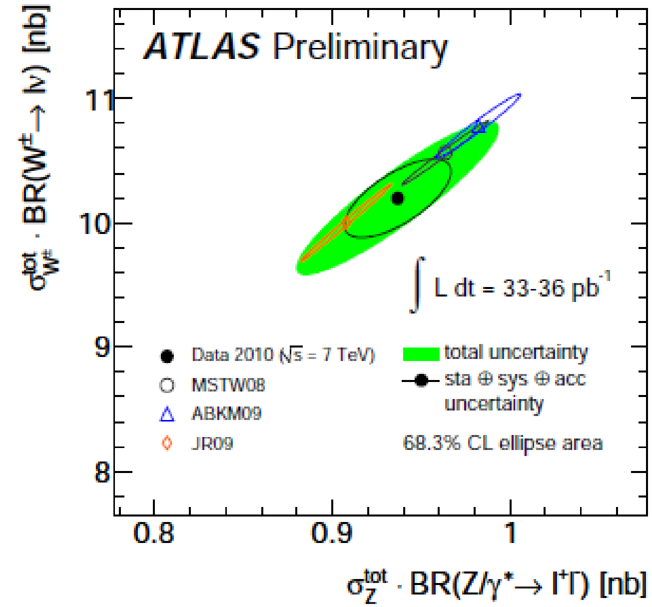




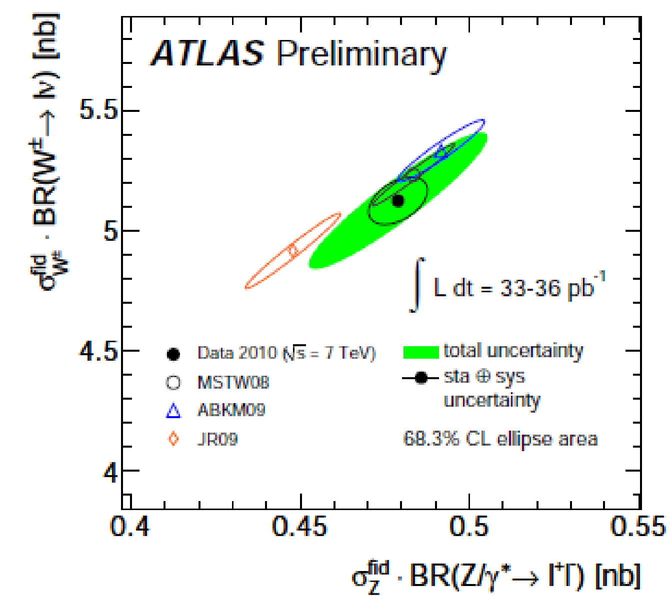
Z production cross section vs theory

- **Total cross sections**
  - overall remarkable agreement with NLLO PDF predictions
  - a few differences between different PDFs (w/ only 68% CL PDF errors)
  - comparing total cross sections, the acceptance uncertainty accounts for effect of different PDFs

  on the unmeasured phase space ….

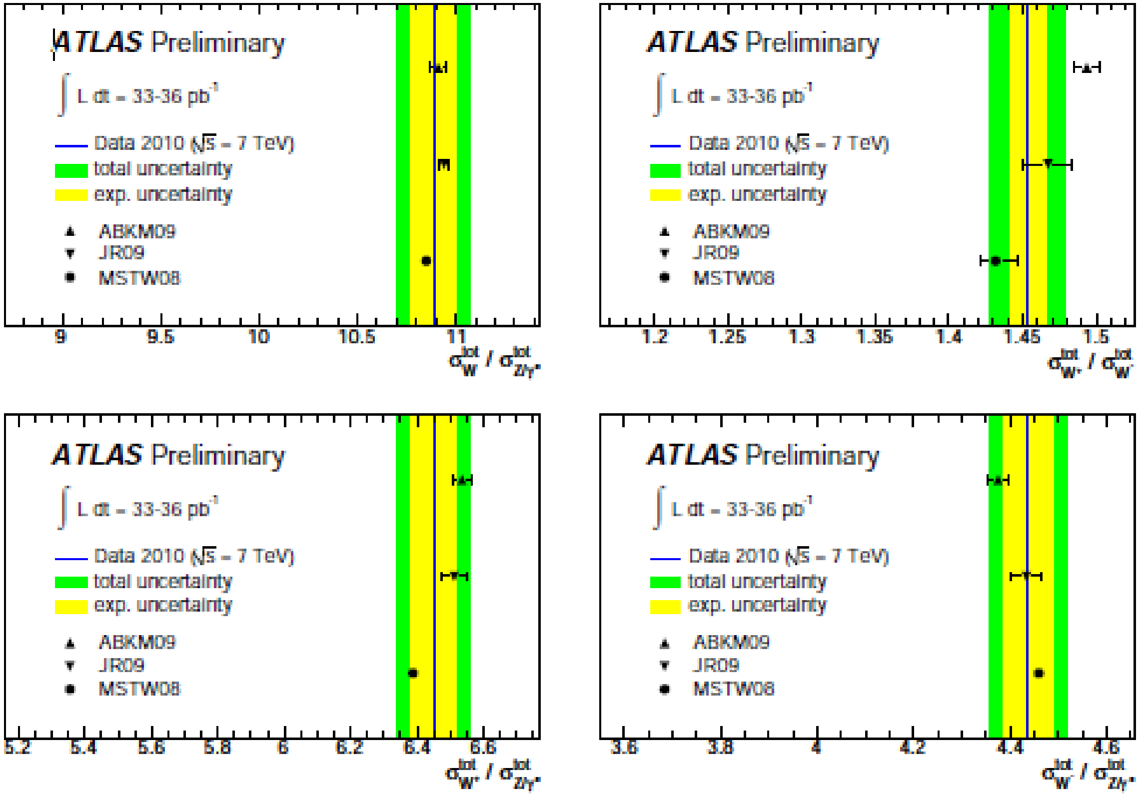


- **Fiducial cross section**
  - comparing in the fiducial region disentangles theory and experimental effects
  - this enables more interesting comparisons among different PDF sets
  - first dedicated calculation of NNLO predictions based on FEWZ and DYNNLO with experimental cuts



W/Z production cross sections vs theory

- $W^{\pm}/Z$, W^{+}/W^{-} ratios profit from exp. and theor. systematics cancellation
- $W^{\pm}/Z$ ratio measured with total uncert. of $1.5\,\%$, W^{+}/W^{-} with $1.2\,\%$



Comparison with theory : lepton universality

- New measurements of the ratios of the e and μ branching fractions

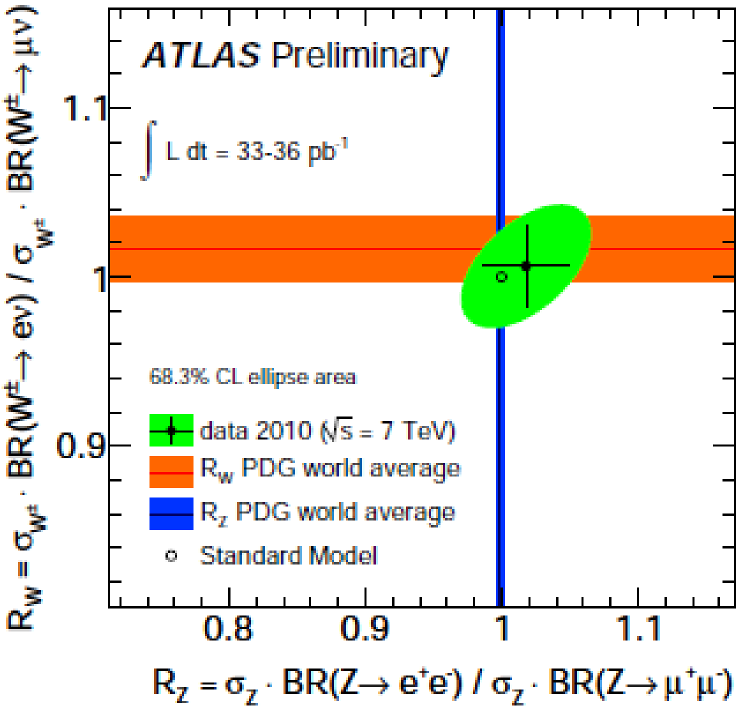
$$R_W = \frac{\sigma_W^e}{\sigma_W^\mu} = \frac{Br(W\to e\nu)}{Br(W\to\mu\nu)} = 1.006 \pm 0.004\,(\mathrm{sta}) \pm 0.006\,(\mathrm{unc}) \pm 0.023\,(\mathrm{cor}) = 1.006 \pm 0.024$$

$$R_Z = \frac{\sigma_Z^e}{\sigma_Z^\mu} = \frac{Br(Z\to ee)}{Br(Z\to\mu\mu)} = 1.018 \pm 0.014\,(\mathrm{sta}) \pm 0.016\,(\mathrm{unc}) \pm 0.028\,(\mathrm{cor}) = 1.018 \pm 0.031$$

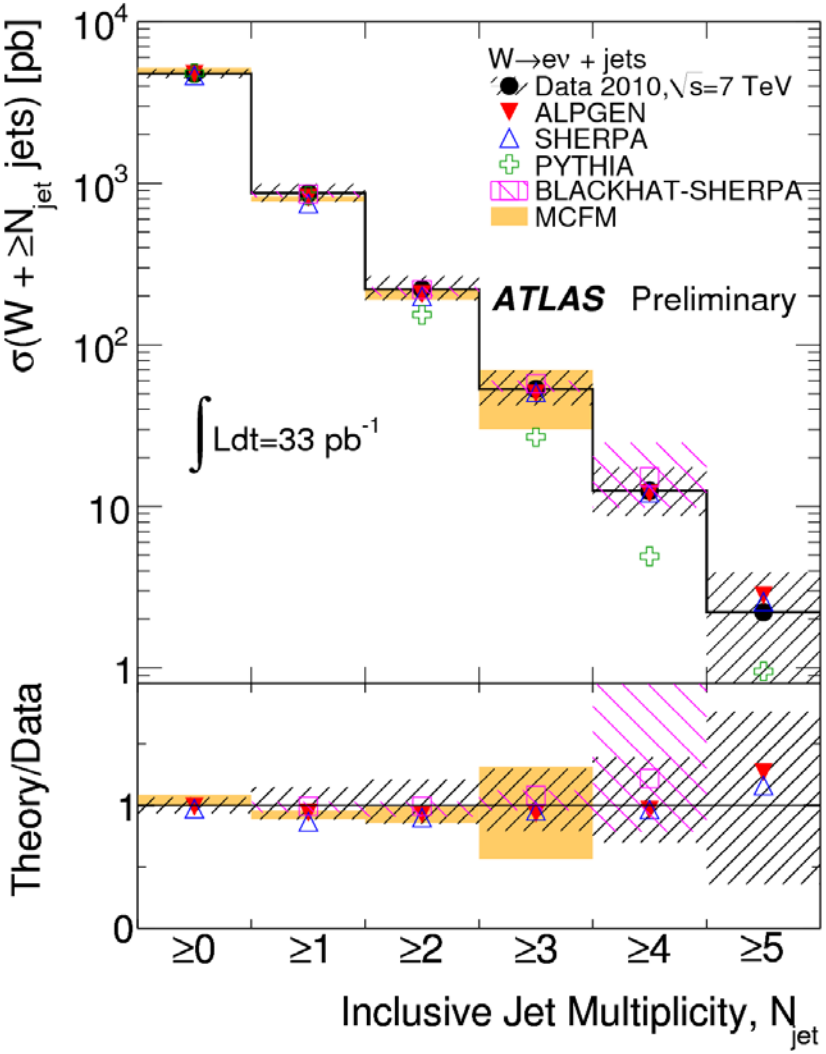
- Inserting R_Z PDG value into the present measurement for a combined cross section analysis

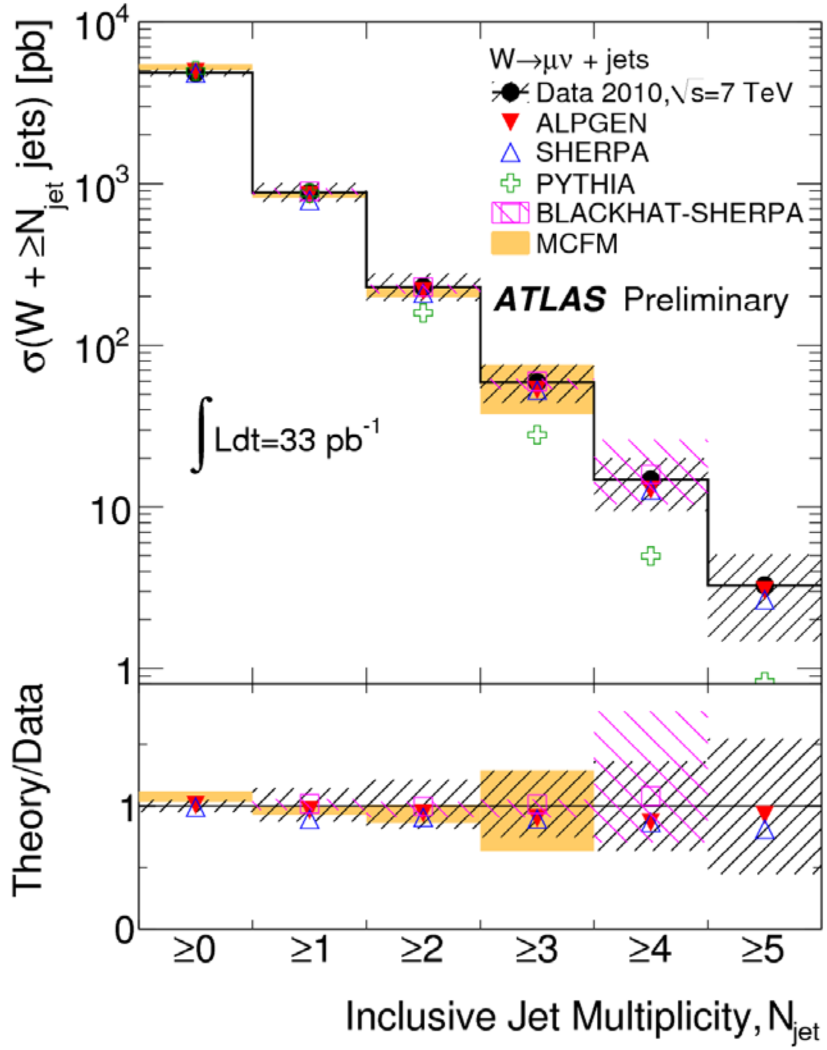
$\Rightarrow$ reduction of correlated R_W systematic uncertainty

$\Rightarrow$ improved result of $R_W = 0.999 \pm 0.021$.



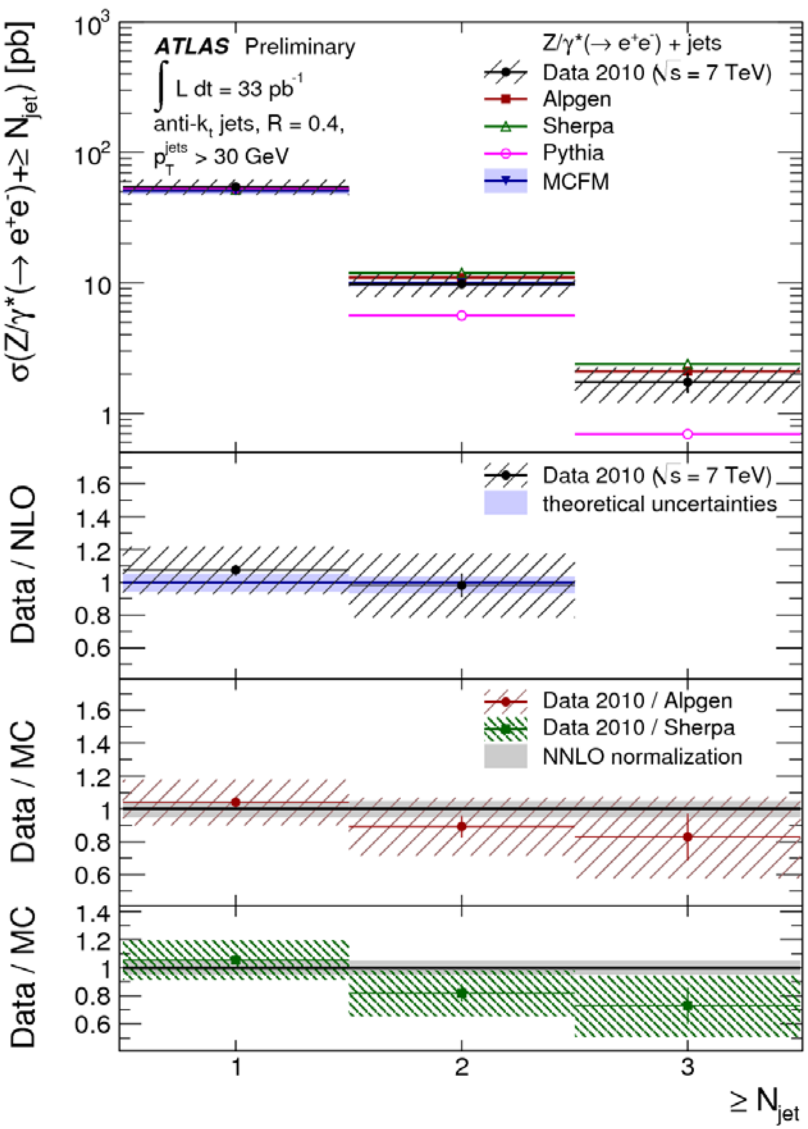
W+jets : e and μ channels

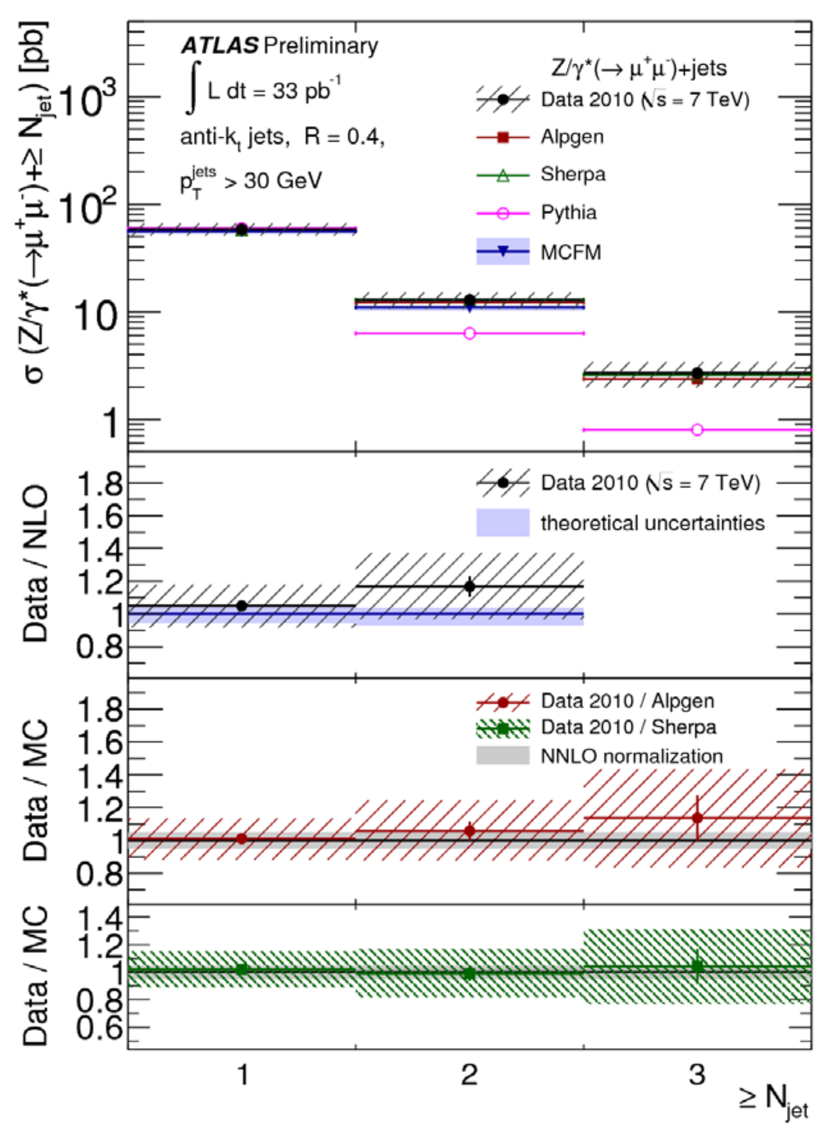




ATLAS-CONF-2011-060

Z+jets : e and μ channels





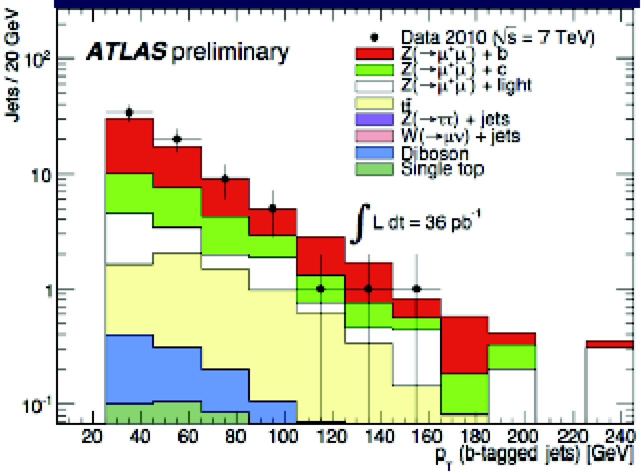
ATLAS-CONF-2011-042

Z+b measurements

$$\sigma = \frac{N_b}{C_e \times \mathcal{L}_e + C_\mu \times \mathcal{L}_\mu}$$

- Inclusive b-jet production cross section in association with a Z boson
- Jet fitted yield is corrected for all detector effects with MC LO matched prediction for Zjet (including heavy flavour) from ALPGEN and SHERPA
- uncertainty: ≈ 20% stat. and ≈23% syst.
- dominant systematics:
  - b-tagging & SV mass template ≈10%
  - Z+b-jet modeling ≈10%
  - Jet + bjet energy scale ≈4%
- MCFM in good agreement with data within uncertainty

Z+b uncorrected b-jet spectrum

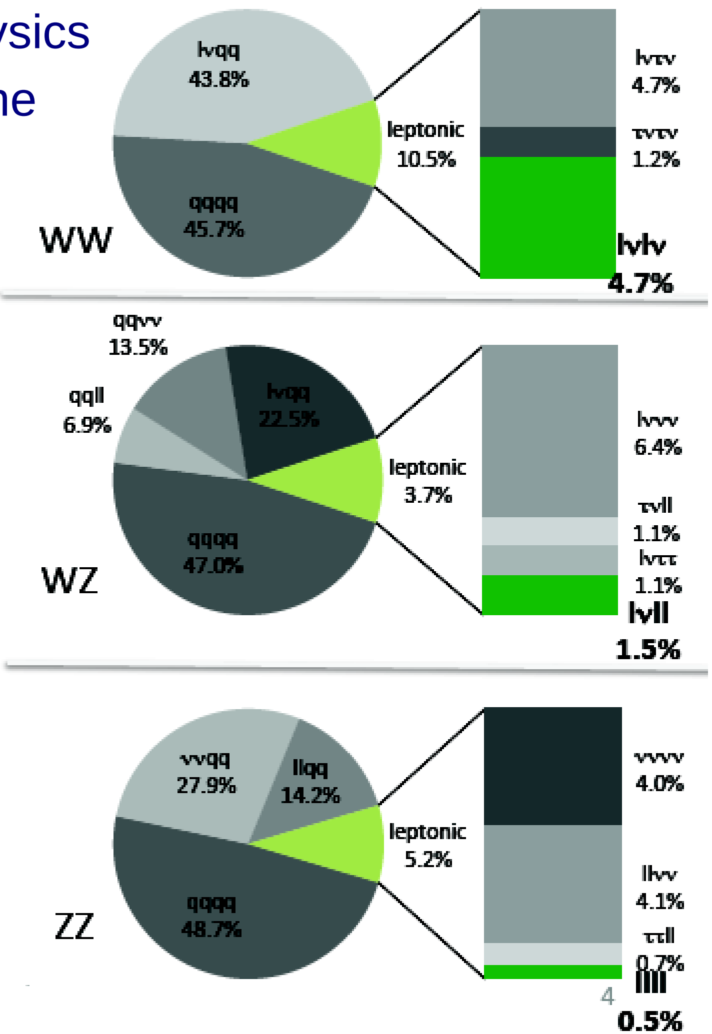


Experiment	$3.55^{+0.82}_{-0.74}(\text{stat})^{+0.73}_{-0.55}(\text{syst}) \pm 0.12(\text{lumi})$ pb
MCFM	3.40 ± 0.44 pb
ALPGEN	2.23 ± 0.01(stat only)pb
SHERPA	3.33 ± 0.04(stat only) pb

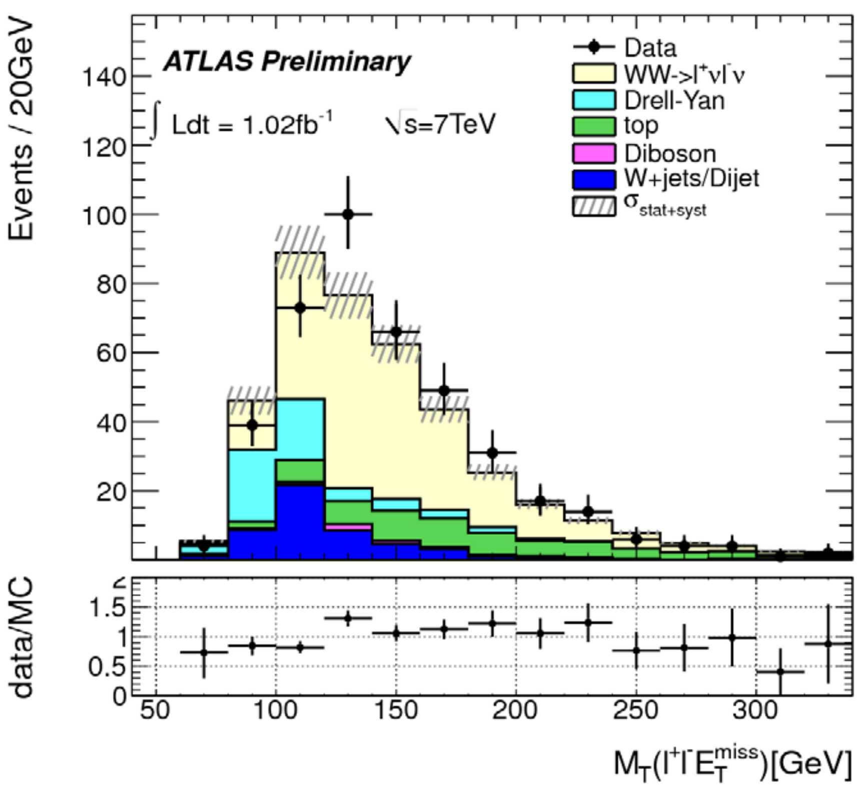
Heavy di-boson production at LHC

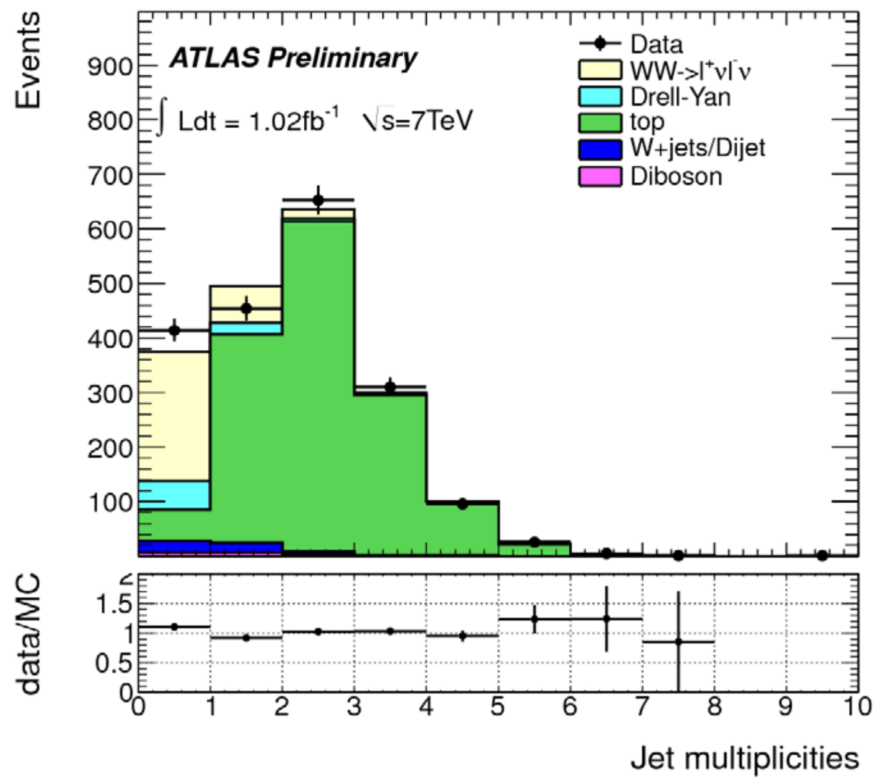
- **Probes the electroweak gauge symmetry of the SM**
  - determination of Triple Gauge Boson Couplings provide a model Independent test for “new” physics
  - measure “fiducial” cross sections to minimize the dependence on theoretical predictions
  - sensitivity increases with energy reach
- **Background to many searches**
- **Signal and background**
  - use leptonic decays
    - small branching ratios, low background
    - tau decays contribute to e/μ channels
  - clean but small signal

Bckgnd	WW	WZ	ZZ
top	35%	12%	incl. DD
W+jets	30%	0%	incl. DD
Z+jets	32%	52%	incl. DD
VV	4%	28%	incl. DD
Z+gamma	incl. in VV	8%	incl. DD
S/B	1.4	4	30
S/sqrt(B)	18	12	17
	2l+MET	3l+M_Z+MET	$2M_Z$



ATLAS-CONF-2011-107

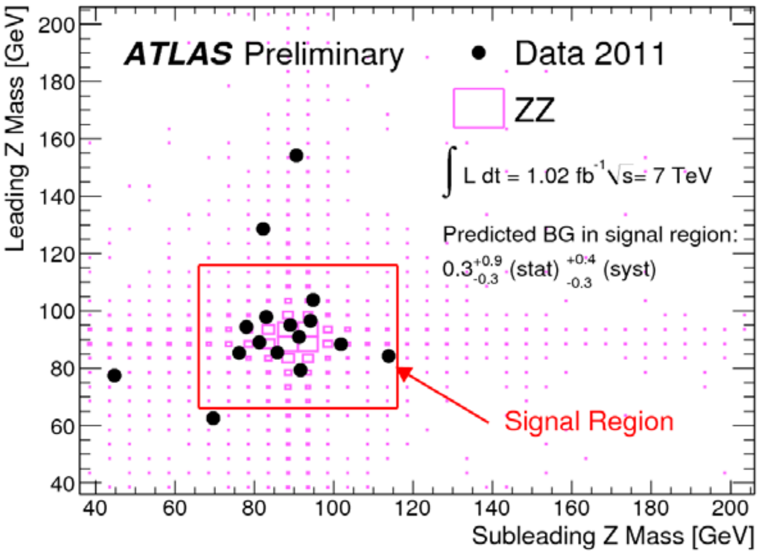




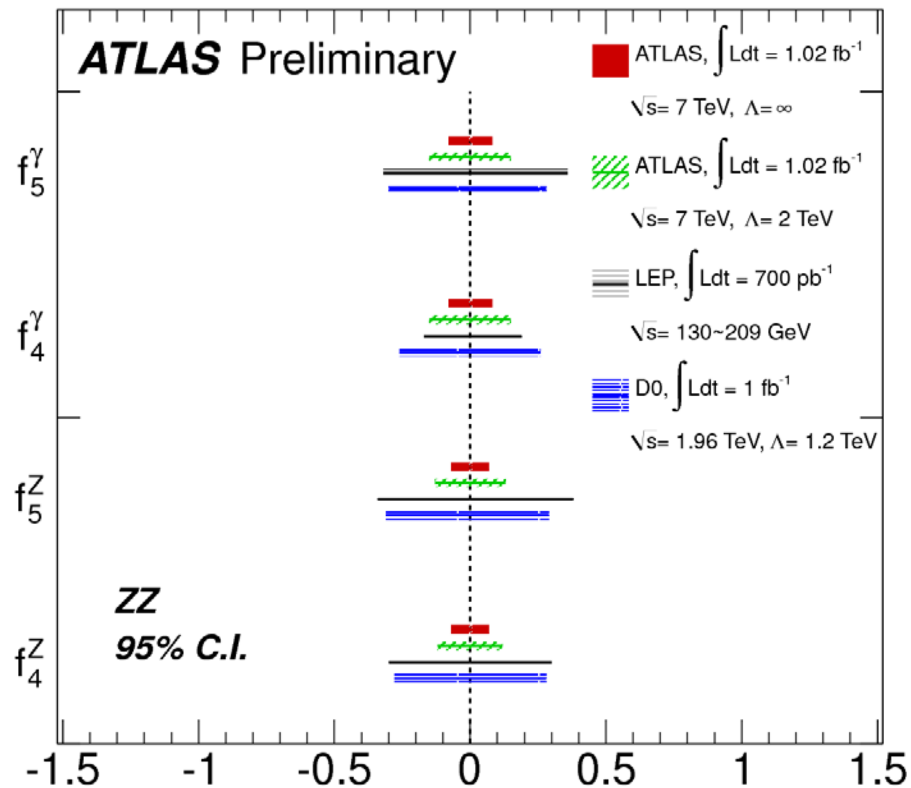
$$\sigma_{WW} = 48.2 \pm 4.0(\mathrm{stat}) \pm 6.4(\mathrm{syst}) \pm 1.8(\mathrm{lumi})\ \mathrm{pb.}$$

ZZ production

ATLAS-CONF-2011-107

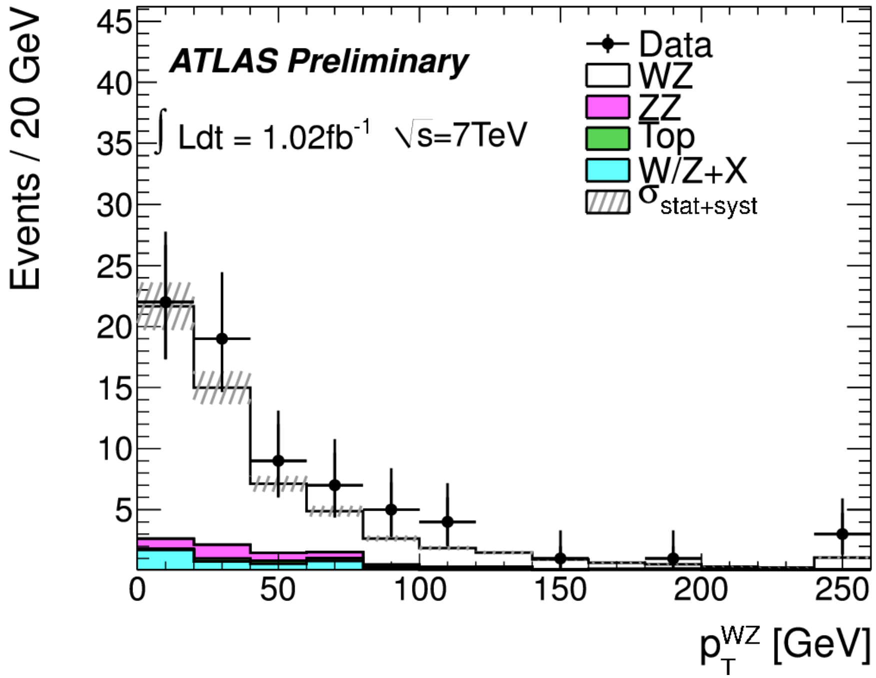


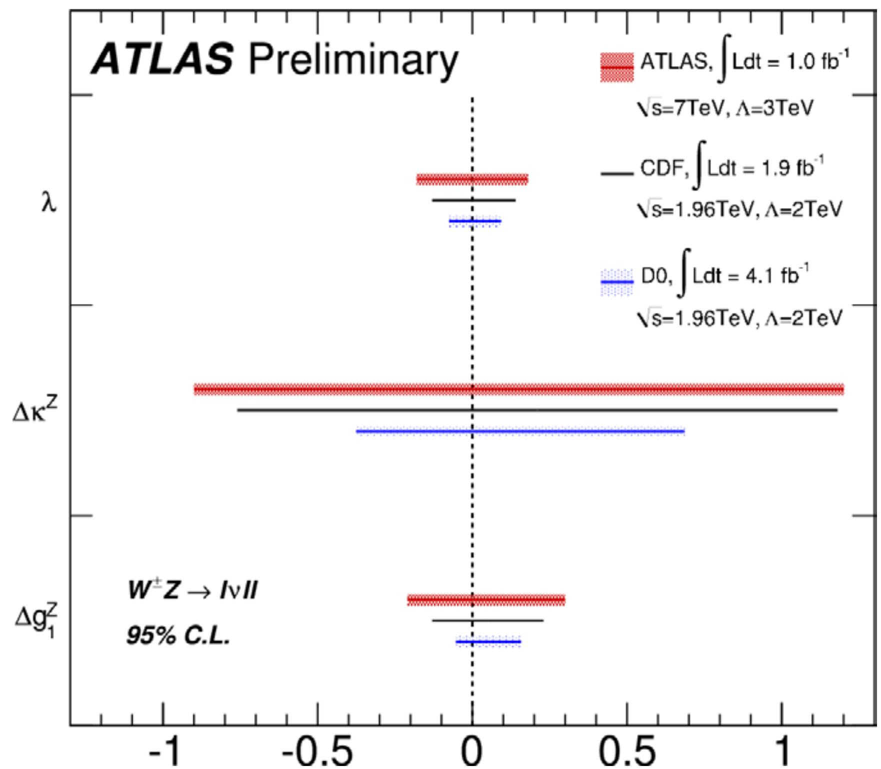
$$\sigma_{ZZ}^{tot} = 8.4^{+2.7}_{-2.3}\,(\text{stat})\,^{+0.4}_{-0.7}\,(\text{syst}) \pm 0.3\,(\text{lumi})\,\text{pb}.$$



WZ production

ATLAS-CONF-2011-099





$$\sigma^{fid}_{WZ\to\ell\nu\ell\ell} = 118^{+18}_{-16}(\text{stat})\ ^{+6}_{-6}(\text{syst})\ ^{+5}_{-5}(\text{lumi})\ \text{fb}$$

$$\sigma^{tot}_{WZ} = 21.1^{+3.1}_{-2.8}(\text{stat})\ ^{+1.2}_{-1.2}(\text{syst})\ ^{+0.9}_{-0.8}(\text{lumi})\ \text{pb.}$$

Centrality definition for Pb-Pb collisions