Measurements of *W* Boson Yields in Pb+Pb at 2.76 TeV/nucleon via single muons with the ATLAS detector

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We report on the first measurements of *W* boson production in lead-lead collisions measured by the ATLAS detector at the nucleon-nucleon centre of mass energy $\sqrt{s_{NN}}$ = 2.76 TeV. These measurements are done via the muon decay of *W* bosons. We present a measurement of *W* bosons yields produced in heavy ion collisions as function of centrality, ratios of W+/W− and *W*/*Z*. For a subset of the $W \rightarrow \mu\nu$ decays, we report on muon rapidity and charge asymmetry measurements. These measurements are the first ATLAS results on *W* measurements in lead-lead collisions at the LHC.

Theory

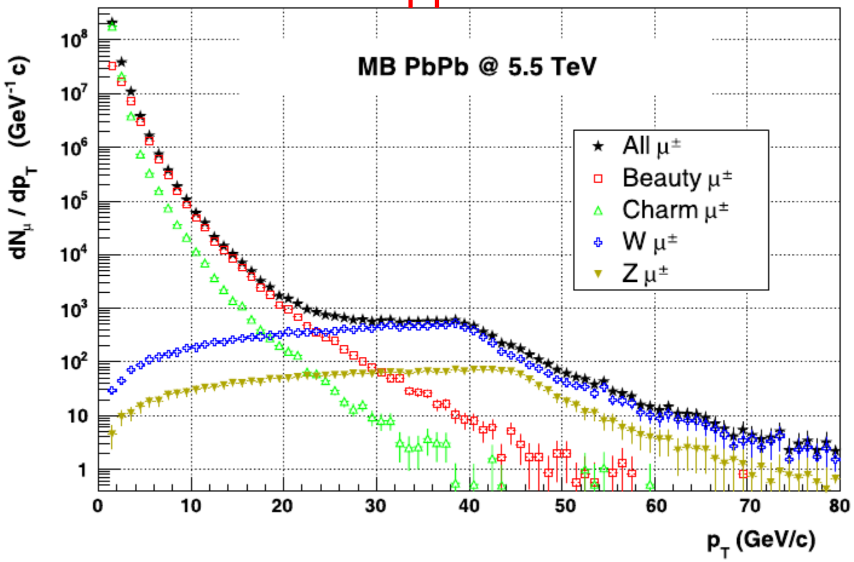
- Standard Model theory predicts an order magnitude more *W* than *Z* produced at 2.76 TeV.
  - Thus W bosons allow for a more precise measurement of electroweak suppression in deconfined matter than Z bosons.
- Neither muons, nor electroweak bosons, interact with deconfined matter created in heavy ion collisions.
  - Observation of $W \rightarrow \mu$ could therefore be used as a direct measurement of the number of primary nucleon-nucleon collisions.
- Since a lead atom has more neutrons than protons we expect the excess of *d*-valence quark to produce slightly more W^- than W^+.
  - However, in a nucleus-nucleus collision, all nucleons are part of the nuclear system leading to a system where the nucleon parton distribution function (PDF) can be modified by processes such as shadowing.
  - We will study this by the rapidity dependent charge asymmetry of muons from *W* decays.

$W^{\pm}$ analysis - introduction

- Problems:
  - $W \rightarrow \mu\nu$ needs missing energy term to be reconstructed, which is impossible in a *Pb+Pb* environment.
    - QCD is a large background.
  - Due to larger track multiplicities isolation requirements on the lepton introduce centrality dependent systematic uncertainty.
  - Larger risk of matching the MS muon with the wrong ID track in *Pb+Pb* collisions and in *p+p*.
- We can only rely on p_T distribution of muons.
  - We apply some additional quality checks on the muons to reduce backgrounds from decays in flight, poorly reconstructed tracks etc.

Principle behind *W* identification

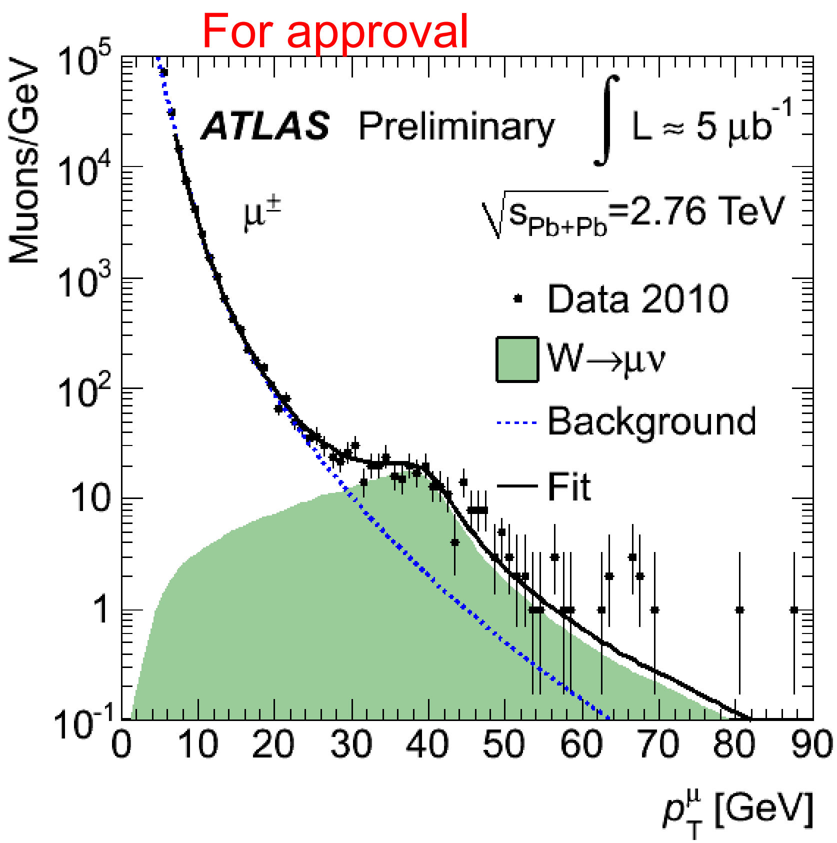
Not for approval



Electroweak boson detection in the ALICE muon spectrometer
Z. Conesa del Vallea for the ALICE Collaboration
Eur. Phys J. C 49, 149-154 (2007)

- Muons from *W* are in average more energetic than muons from QCD processes.
- At high transverse momenta, the two dominating sources of single muons are *b*-quark decays and *W* decays.
- The muons from *W* creates a "shoulder" in the p_T spectrum.
- By comparing the how much the *W* component must be scaled compared to the background we can determine the number of *W* in data.

Extracting $W \rightarrow \mu\nu$ from data

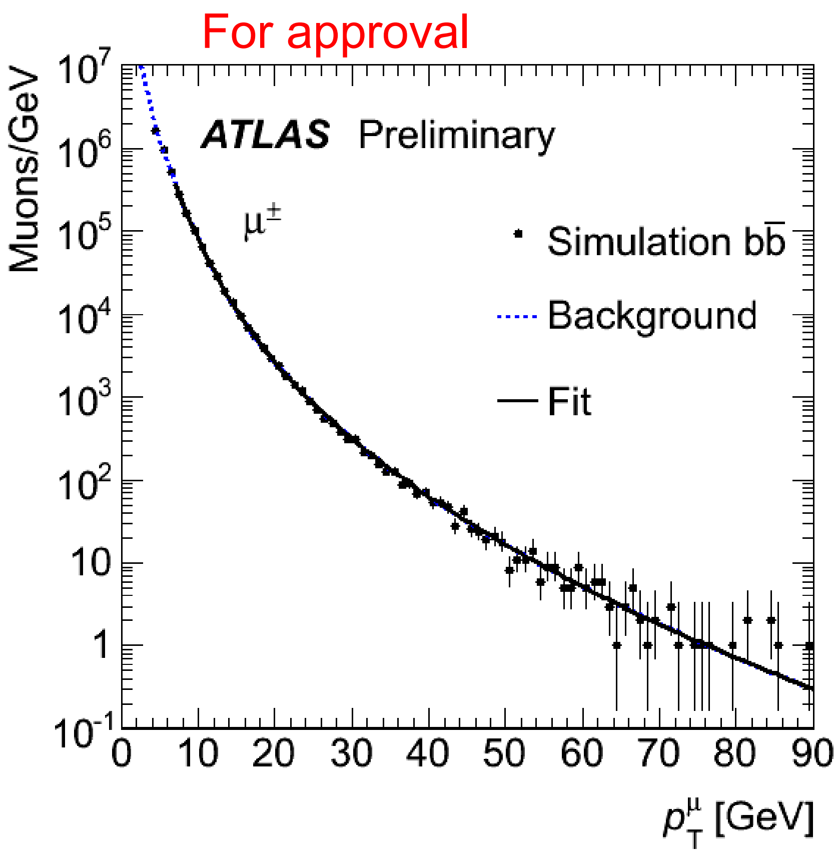


1) Veto dimuons with $m_{\mu\mu}$>66 GeV (Z/DY candidates)
2) Veto obvious decays in flight.
   - Efficiency loss on *W* MC <0.3%.
3) Build a template from $W \rightarrow \mu\nu$ MC @2.76 TeV *pp*.
4) Use a function to describe background.

$$b(x) = \alpha_1 \cdot e^{-\alpha_2 x} + \alpha_3 \cdot \frac{e^{\alpha_4 \sqrt{x}}}{x^{2.5}}$$

5) Find the best estimate on number of *W* by fitting signal+background to data.
   - Unbinned log-likelihood fit with MINOS errors.

Cross check of fitting technique



- We tested the fit on 5 million simulated $b\bar{b}$ events.
  - p+p @ √s=2.76 TeV
  - Estimated number of *W* = 0 (+11.4 -0)
  - χ^2/dof = 89.7/75
- Hence, we see no *W* signal where there is none to be seen.

W & *Z* event selection

- December *Z* analysis:
  - two combined muon with opposite charge
  - $p_T > 20$ GeV (per muon)
  - $|\eta| < 2.5$
  - $|\eta_1 + \eta_2| > 0.01$ (cosmic rejection)
  - mass window [66, 116] GeV
- (This) *Z* selection for *W*/*Z* ratio:
  - *W* muon selection per muon
  - *Z* selection from above
  - The muons must have a common vertex.

- *W* analysis:
  - combined muon
  - $|\eta| < 2.5$
  - Track quality:
    - B-layer hits > 0
    - Pixel hits > 0
    - SCT hits > 5
    - Pixel holes +SCT holes < 2
  - Charge measured in toroid must be consistent with charge measured in solenoid.
  - Momentum in MS must be within 50% of momentum in ID.
  - Maximum scattering angle along track < $4\ \sigma_{MSC.}$

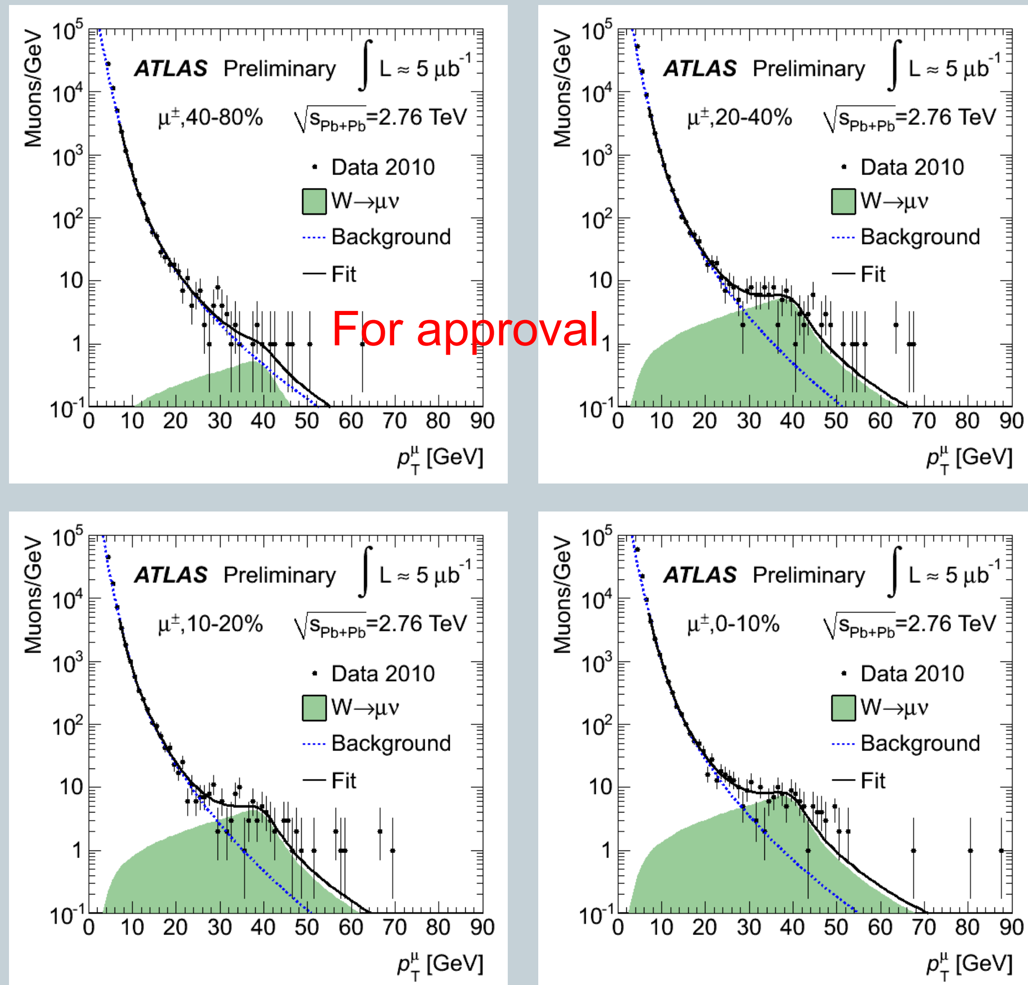
Item 1:

Are electroweak bosons suppressed in the quark-gluon plasma?

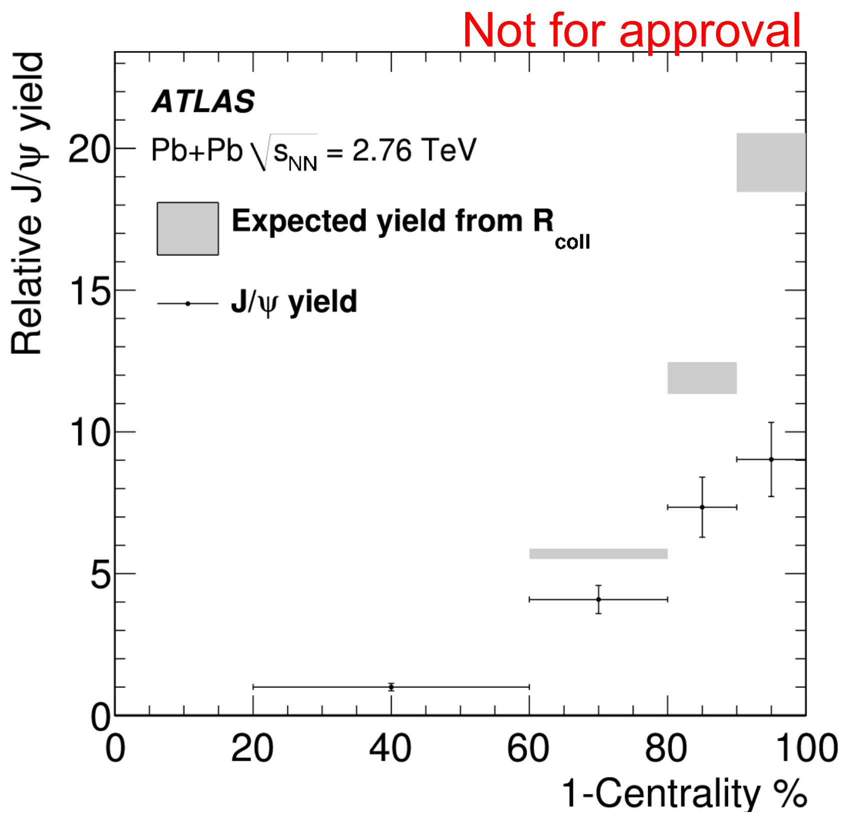
Number of W per centrality bin

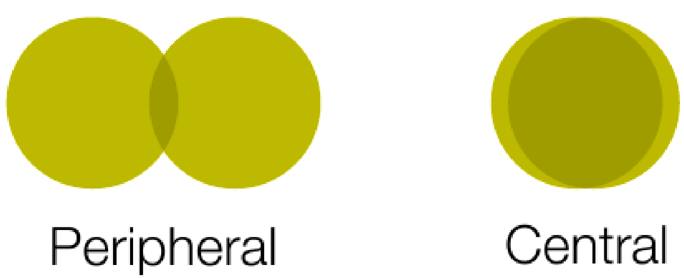
- Divide Pb+Pb dataset in subsets of centrality, and fit each subset independently.
  - The peripheral subset suffers from low statistics, but the other three allow more precise EW measurement than Z bosons.

Centrality	N_W^{fit}	p-value
40-80%	12^{+13}_{-12}	0.81
20-40%	118^{+17}_{-24}	0.68
10-20%	97^{+16}_{-18}	0.42
0-10%	165^{+23}_{-25}	0.42
W (all)	399^{+36}_{-38}	0.52



Normalizing yields





- We compare the number of observed signal events with the mean number of binary collisions calculated with the Glauber model (N_{col}).
  - We normalize N_{col} to the peripheral centrality bin, and call this ratio R_{col}.
    - Accounts for difference in bin sizes.
- Finally: The yield is normalized to the R_{col} in each centrality bin and divided by the central yield.

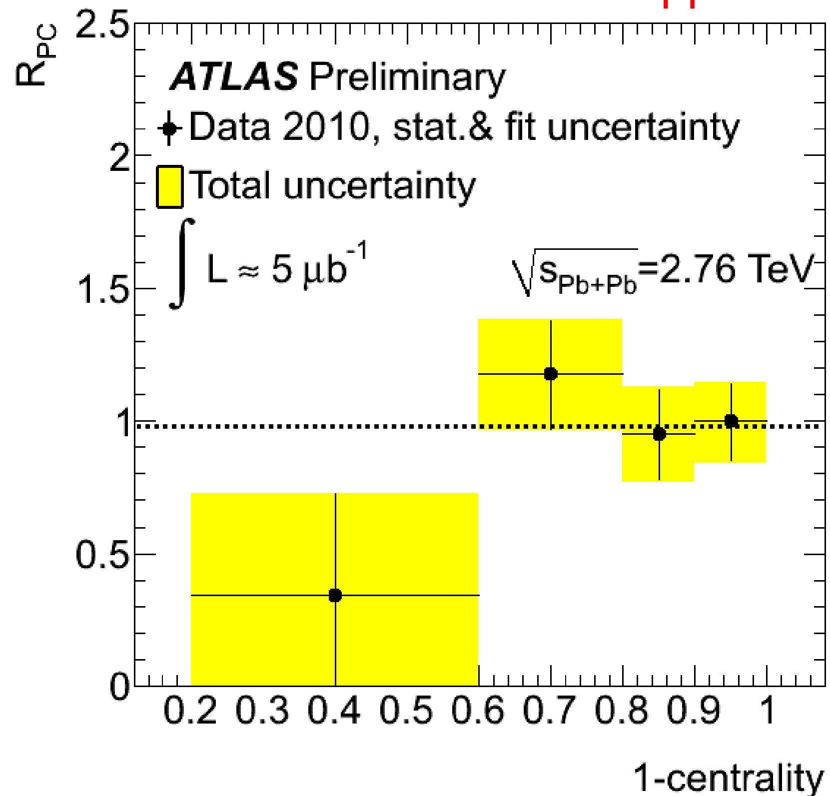
Centrality[%]	R_{col}	$\sigma(R_{col})$ [%]
40-80	1	-
20-40	5.7	4.7
10-20	11.9	6.3
0-10	19.3	7.5

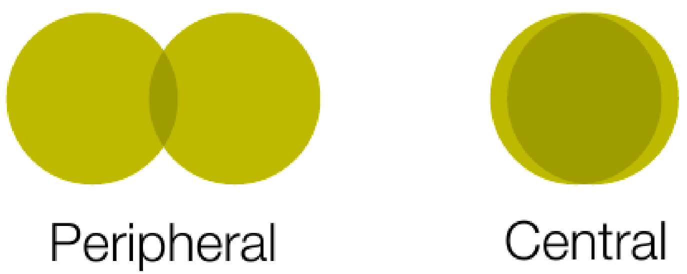
R_{PC}: $W \rightarrow \mu\nu$

- Vertical error bars indicate the MINOS 1σ interval, while yellow region includes the uncertainty from R_{col} as a systematic effect.

- The no suppression hypothesis (flat line) is fitted to the data with χ^2/dof = 3.7/3.
  - **Result is consistent with no suppression of W bosons.**

For approval





Item 2:

Is the *W*/*Z* ratio predicted by Standard Model correct in heavy ion collisions?

W/Z ratio

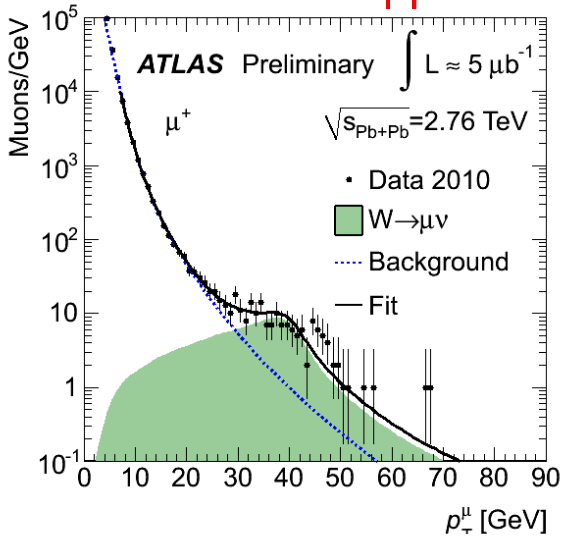
- The ratio of the cross sections of *W*- and *Z*-bosons is an important test of the Standard Model.
- To calculate it we need to correct for geometrical acceptance and muon reconstruction efficiency.
  - Here these parameters are taken from simulated samples.
    - Agreement between simulation and data is much better than the statistical uncertainty.
    - Systematics is 3-4%.
- Theory @ 2.76 TeV:
  - With or without nuclear modification to PDF:
    - Pb+Pb, $R_{W/Z} = 11.5 \pm 0.7$
  - NNLO QCD with MSTW2008 PDF:
    - pp: $R_{W/Z} = 11.3 \pm 0.6$
    - nn: $R_{W/Z} = 10.8 \pm 0.6$
- Result: $\boldsymbol{R_{W/Z} = 10.5 \pm 2.3}$

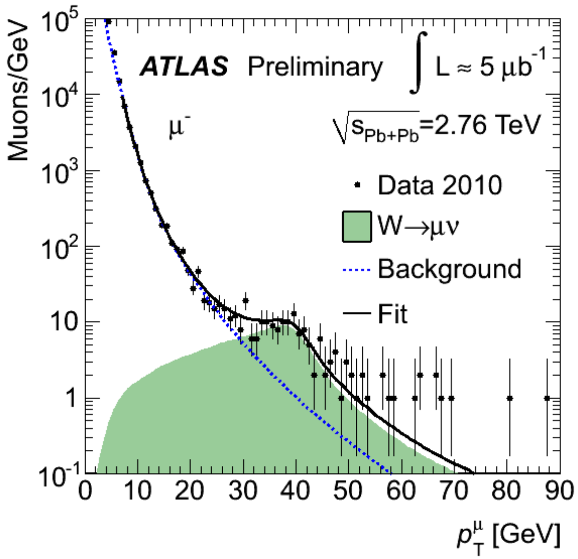
Item 3:

Is the W^+/W^- ratio predicted by Standard Model correct in heavy ion collisions?

W^+ versus W^-

For approval





- Due to the larger number of *d*-valence quarks than *u*-valence quark in a lead atom we expect to see slightly more W^- than W^+.
  - Theory (Paukkunen, Salgado): $R_{W+/W-} = 0.90 \pm 0.04$
  - Observed:

$$R_{W^+/W^-} = \frac{198^{+25}_{-26}}{204^{+27}_{-31}} = 0.97^{+0.18}_{-0.19}$$

Centrality	N_W^{fit}	p-value
40-80%	12^{+13}_{-12}	0.81
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10-20%	97^{+16}_{-18}	0.42
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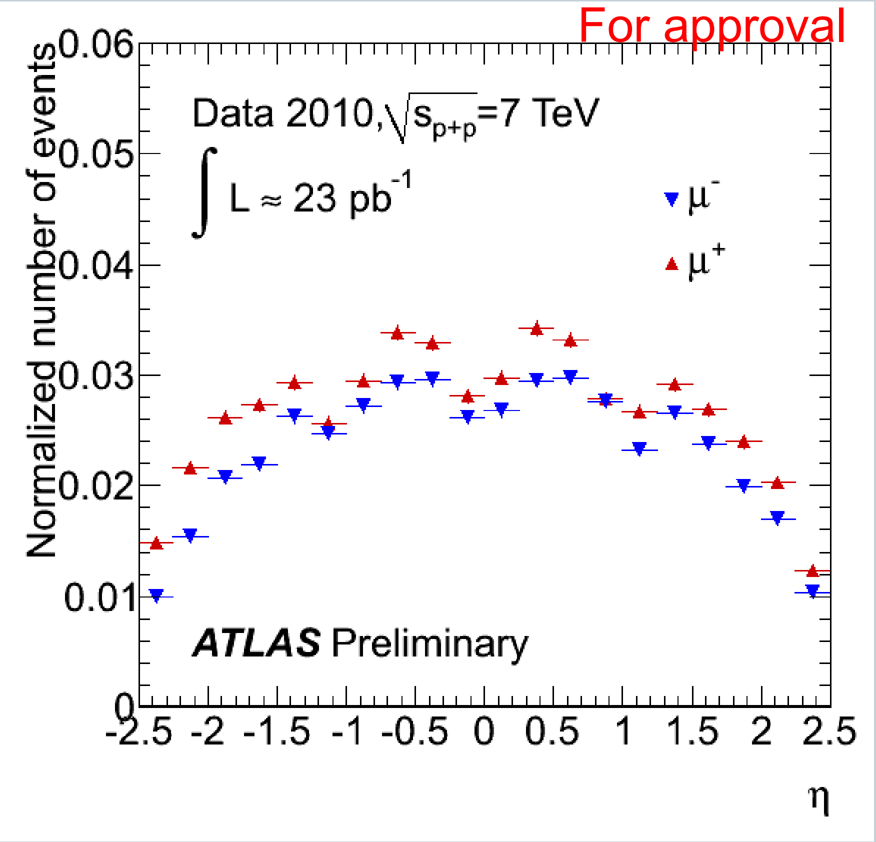
W^-	204^{+27}_{-31}	0.21
W^+	198^{+25}_{-26}	0.97
W (all)	399^{+36}_{-38}	0.52

Item 4:

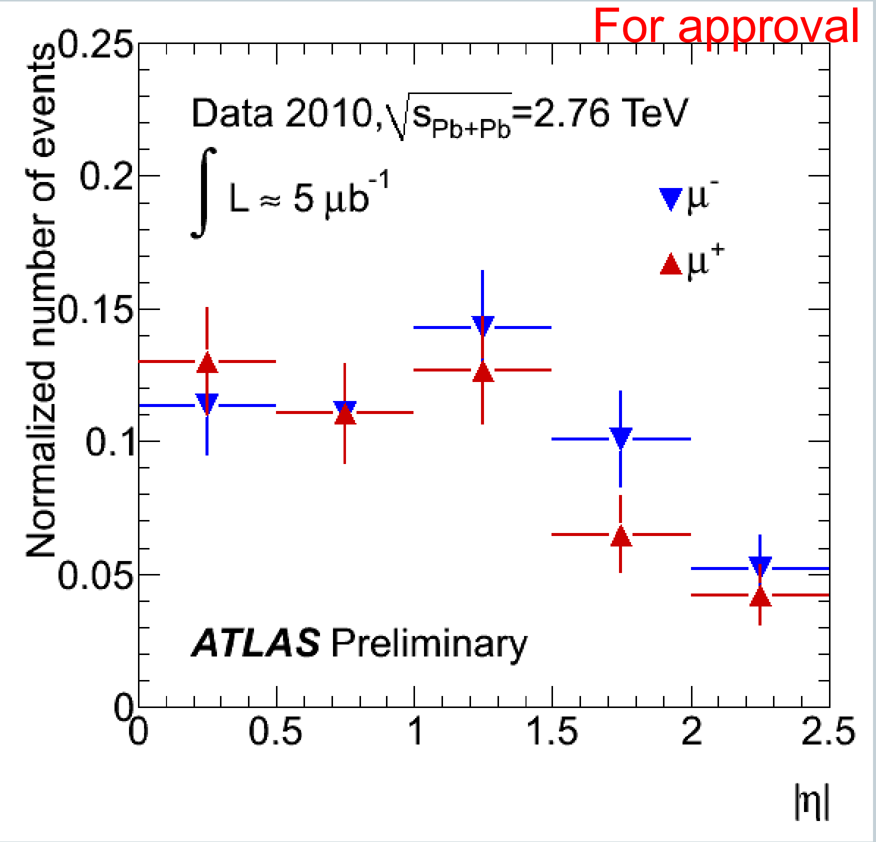
Can we observe any nuclear modifications to the W^+/W^- asymmetry as a function of rapidity in heavy ion collisions?

Muon pseudorapidity

p+p at 7 TeV



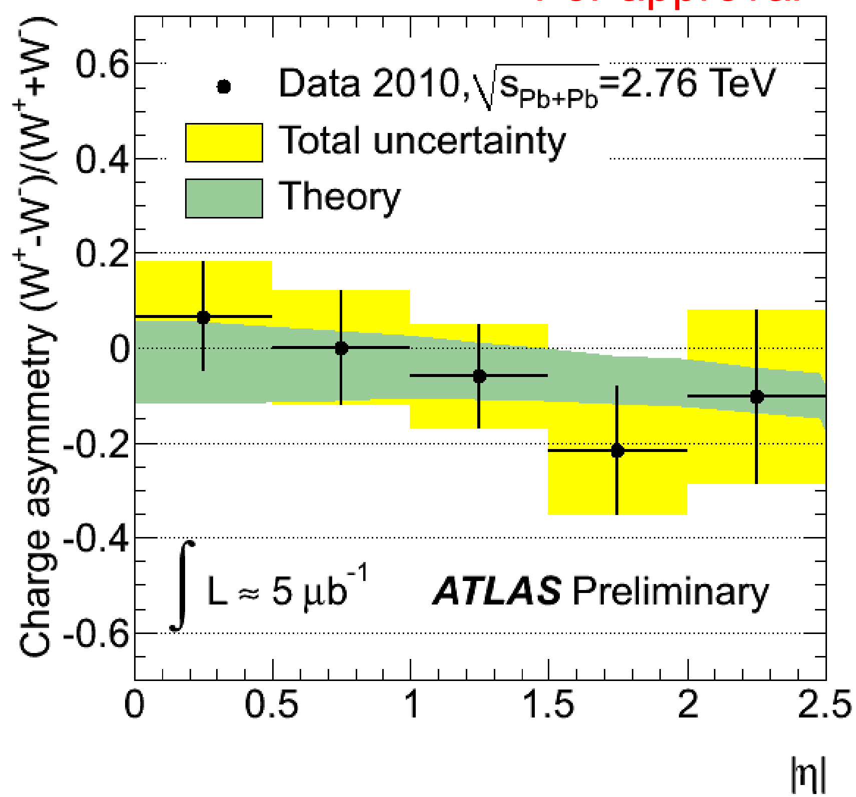
Pb+Pb at 2.76 TeV



Muon charge asymmetry from *W* decays

- Precision test of *W* charge asymmetry provides information on parton distribution functions.
  - Nuclear effects may give modifications to the PDFs.
- We measure the charge asymmetry for all muons at p_T>30 GeV as a function of pseudorapidity.
  - This includes 19% background contamination, dominated by bbbar. The effect of the background is included as a systematic.
  - No charge dependent acceptance effect was observed at high p_T, so we do not correct for efficiency or acceptance effects.
- **No asymmetry is observed.**
  - Statistical uncertainty is still limiting, but with higher accumulated statistics a detailed measurement of the charge asymmetry where only central collisions events are selected will be possible.

For approval



$$A_\mu = \frac{d\sigma_{\mu^+}/d\eta - d\sigma_{\mu^-}/d\eta}{d\sigma_{\mu^+}/d\eta + d\sigma_{\mu^-}/d\eta}$$

Conclusions & summary

- First measurements of *W* production in *Pb+Pb* collisions at ATLAS were presented.
- The observation of **no suppression** [1)] for *W*-bosons confirms that they are produced at the initial phase of the collisions and that neither the *W* nor the muon interact with the medium.
- The ratio of ***W/Z*** production in *Pb+Pb* collisions as well as the W^+/W^- ratio agree with Standard Model predictions [1)].
- A first *W* charge asymmetry versus pseudorapidity was presented.
  - Limited statistics, but we expect that higher integrated luminosity will allow us to explore the nuclear modifications to the PDF.

[1)] within our uncertainties

Extra material