W-boson production measurements with ALICE in p-Pb collisions at 5.02 TeV

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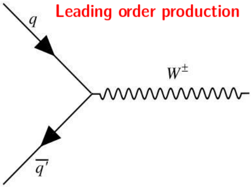
Outline

Whys and Hows

Whys:

- W is an electroweak probe produced in hard interactions



In proton–proton collisions:

- sensitive to parton distributions functions (PDFs)

In proton-lead collisions:

- sensitive to modification of parton distributions inside the nucleus
- test binary scaling of hard processes

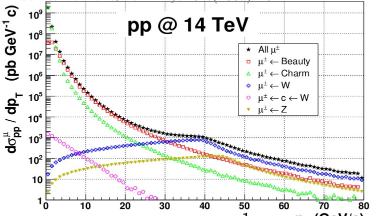
In lead-lead collisions:

- not sensitive to strong interaction ⇒ reference probe for medium-induced effects.
- test binary scaling of hard processes

Hows:

- Cross section of muons from W-boson decays at forward rapidity is measured by fitting the p_{T} distribution of single muons
- W boson is the main contributor to the single muon p_{T} spectrum at $p_{\mathrm{T}} > 30$ GeV/c
- W decay is a Jacobean peak over Z/γ^* and QCD background
- Maximum production at $p_{\mathrm{T}} \sim M_{\mathrm{W}}/2$

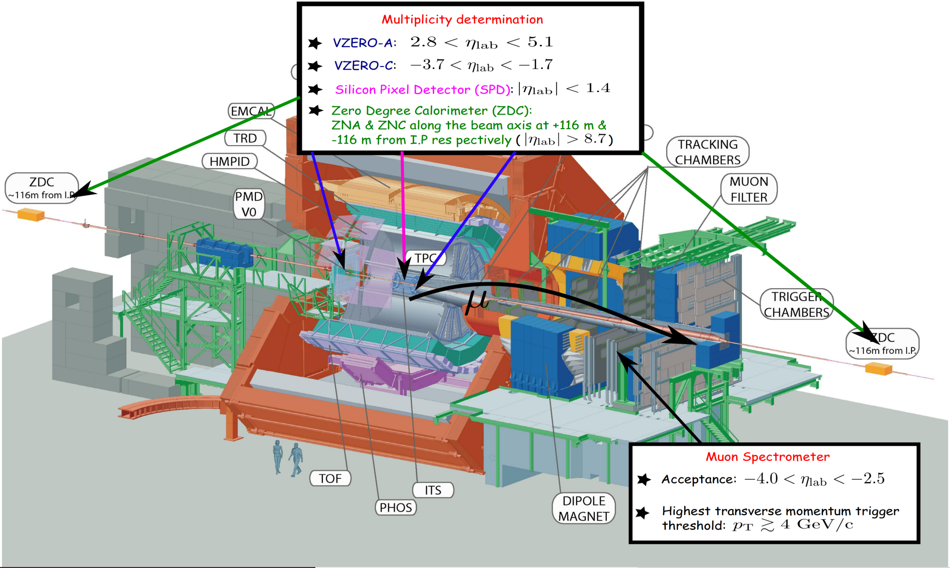
Z. Conesa del Valle, Eur. Phys. J.C(2007)149



Based on $\mathrm{L_{int}} = 30\ \mathrm{pb}^{-1}$

ALICE setup

- ALICE layout outlining detectors used for multiplicity (event activity) determination and muon reconstruction



Multiplicity determination

- VZERO-A: $2.8 < \eta_{\rm lab} < 5.1$
- VZERO-C: $-3.7 < \eta_{\rm lab} < -1.7$
- Silicon Pixel Detector (SPD): $|\eta_{\rm lab}| < 1.4$
- Zero Degree Calorimeter (ZDC): ZNA & ZNC along the beam axis at +116 m & -116 m from I.P res pectively ($|\eta_{\rm lab}| > 8.7$)

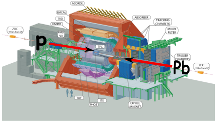
Muon Spectrometer

- Acceptance: $-4.0 < \eta_{\rm lab} < -2.5$
- Highest transverse momentum trigger threshold: $p_{\rm T} \gtrsim 4$ GeV/c

Data Samples

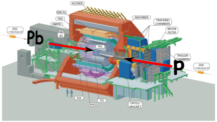
- p-Pb collisions at $\sqrt{s_{\mathrm{NN}}} = 5.02$ TeV ($\mathrm{E_p} = 4$ TeV and $\mathrm{E_{Pb}} = 1.58$ TeV)
- Two beam configurations with a rapidity shift ($\triangle y = 0.465$) in the proton direction

Forward (p–Pb)



$2.03 < y_{\mathrm{cms}} < 3.53$

Backward (Pb–p)



$-4.46 < y_{\mathrm{cms}} < -2.96$

$\Rightarrow y_{\mathrm{cms}}$ covered by the muon spectrometer

- Statistics
  - high p_{T} muon triggered events (V0A & V0C & muon with $p_{\mathrm{T}} \gtrsim 4$ GeV/c)

	Integrated Luminosity (nb^{-1})
Forward	**4.9**
Backward	**5.8**

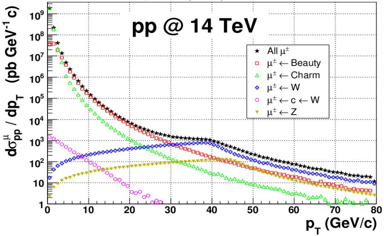
- Muon track selection:
  - geometrical acceptance cuts
  - matching of the tracking and trigger tracks to reduce background from punch-through hadrons
  - correlation of momentum (p) and **D**istance of **C**losest **A**pproach (DCA) to the interaction point to reduce fake and beam gas tracks

Analysis strategy

Background sources:

- $8 < p_{\mathrm{T}} < 40$ GeV/c heavy-flavour decay muon background is dominant
- $p_{\mathrm{T}} > 50$ GeV/c Z/γ^{*} is the main source of background

Zaida del Valle, Eur. Phys. J.C(2007)149



- $\mathrm{W}^{\pm}$ signal is extracted by fitting the single muon p_{T} spectrum with:

$$\mathtt{f}(p_{\mathrm{T}}) = \mathtt{N}_{\mu\leftarrow\mathrm{QCD}} \cdot \mathtt{f}_{\mu\leftarrow\mathrm{QCD}} + \mathtt{N}_{\mu\leftarrow\mathrm{W}} \cdot \mathtt{f}_{\mu\leftarrow\mathrm{W}} + \mathtt{N}_{\mu\leftarrow\mathrm{Z}/\gamma^{*}} \mathtt{f}_{\mu\leftarrow\mathrm{Z}/\gamma^{*}}$$

where:

$\mathtt{f}_{\mu\leftarrow\mathrm{QCD}}$ = phenomenological function or FONLL based template [JHEP **1210** (2012) 137]

$\mathtt{f}_{\mu\leftarrow\mathrm{W}}, \mathtt{f}_{\mu\leftarrow\mathrm{Z}/\gamma^{*}}$ = POWHEG based Monte Carlo (MC) templates [JHEP 0807(2008)060]

$\mathtt{N}_{\mu\leftarrow\mathrm{QCD}}, \mathtt{N}_{\mu\leftarrow\mathrm{W}}$ = free normalization parameters

$\mathtt{N}_{\mu\leftarrow\mathrm{Z}/\gamma^{*}}$ = fixed to $\mathtt{N}_{\mu\leftarrow\mathrm{W}}$, using ratios of cross-sections from MC $\frac{\sigma_{\mu\leftarrow\mathrm{Z}/\gamma^{*}}}{\sigma_{\mu\leftarrow\mathrm{W}}}$

- Extracted signal is corrected for Acceptance×Efficiency $(\mathrm{A} \times \varepsilon)$ to obtain the yield

Signal (W) and Z/γ^* templates

Simulation configuration:

- W and Z/γ^* events generated using POWHEG (default) with CTEQ6m PDFs in pp and pn collisions
- Forced to decay to $\mu^{\pm}$

Generators and their roles:

◇ **POWHEG:**

- generate hard events, no showering and no shadowing

◇ **PYTHIA6.4:**

- used to include shadowing parameterized by EPS09 (p and n considered inside the Pb)
- used only for systematic determination

Combine pp and pn with

$$\frac{1}{N_{\rm pPb}} \cdot \frac{dN_{\rm pPb}}{dp_{\rm T}} = \frac{Z}{A} \cdot \frac{dN_{\rm pp}}{dp_{\rm T}} + \frac{A-Z}{A} \cdot \frac{dN_{\rm pn}}{dp_{\rm T}}$$

to obtain the templates, where

$A = 208$ (mass number of the Pb nucleus)
$Z = 82$ (atomic number of the Pb nucleus)

Heavy flavour background

◇ FONLL:

- Muons from B and D mesons in pp collisions at $\sqrt{s} = 5.02$ TeV
  http://www.lpthe.jussieu.fr/~cacciari/fonll/fonllform.html
- CTEQ6.6 parton distribution functions is used
- small effects of nuclear modification of the PDFs at high p_{T}
  Nuclear Physics A 00 (2014) 1–4

◇ Phenomenological functions used by other LHC experiments:

- ATLAS ATLAS-COM-CONF-2011-088:

$$f_{bkg}(p_{\mathrm{T}}) = a \cdot \exp\left(-b \cdot p_{\mathrm{T}}\right) + c \cdot \frac{\exp(-d \cdot \sqrt{p_{\mathrm{T}}})}{p_{\mathrm{T}}^{2.5}}$$

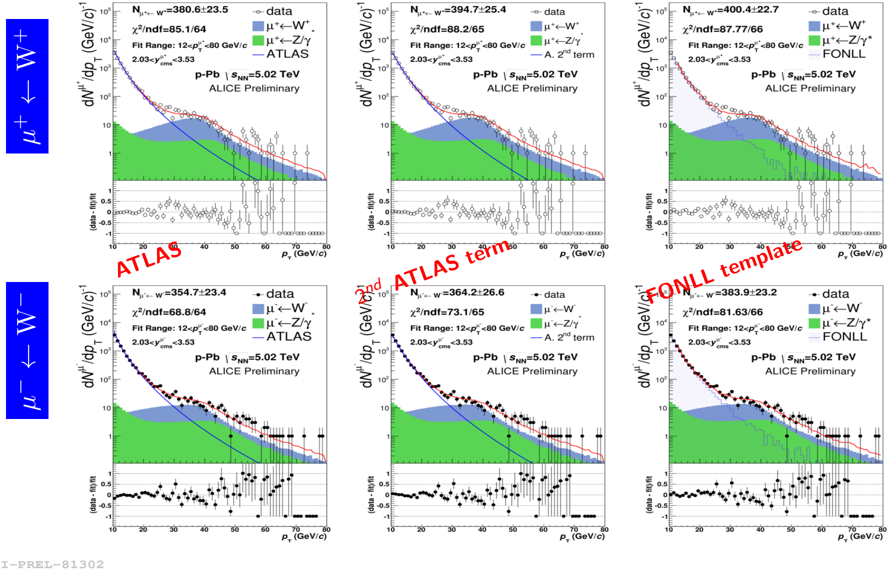
- 2^{nd} term of ATLAS:

$$f_{bkg}(p_{\mathrm{T}}) = c \cdot \frac{\exp(-d \cdot \sqrt{p_{\mathrm{T}}})}{p_{\mathrm{T}}^{2.5}}$$

Signal extraction: Global fits

- Fit range $12 < p_{T} < 80$ GeV/c, $N_{\mu\leftarrow W}$ extracted by integrating from $10 < p_{T} < 80$ GeV/c

Forward rapidity



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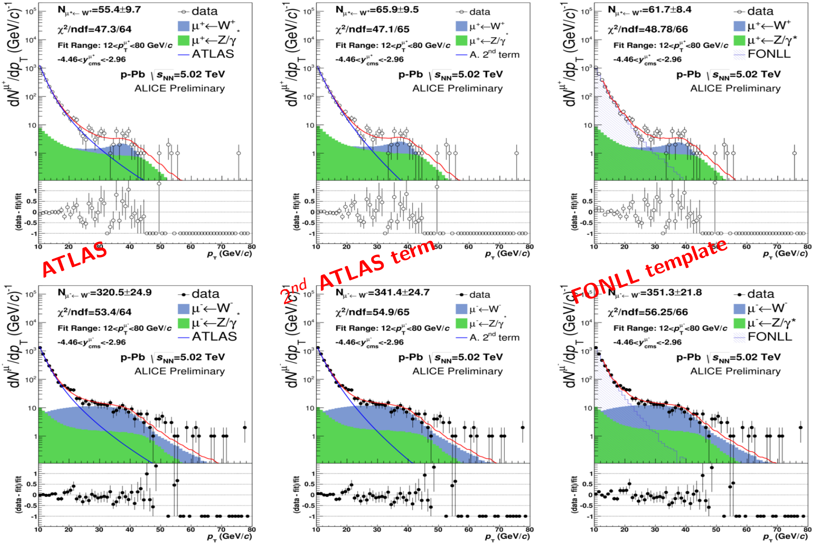
Backward rapidity

$\mu^+ \leftarrow W^+$

$\mu^- \leftarrow W^-$



Systematics on the signal extraction

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◇ $\mathrm{N}_{\mu\leftarrow\mathrm{W}}$ is extracted from a large number of fit trials, varying:

- The p_{T} range where the fit is performed
- QCD or Heavy-flavour decay muons background description
- Fraction of Z/γ^* to W decay muons: ⇒ obtained using PYTHIA and POWHEG
- Alignment effects ⇒ vary the position of detector elements

◇ Weighted average over

- (3 background descriptions)×(different p_{T} ranges)×(2 $\mathrm{N}_{\mu\leftarrow\mathrm{Z}/\gamma^*}/\mathrm{N}_{\mu\leftarrow\mathrm{W}}$)×(2 alignment configurations)×(1 MC templates for the signal) trials:

$$<\mathrm{N}_{\mu\leftarrow\mathrm{W}}> = \frac{\sum_{i=1}^{n} w_i \mathrm{N}_{\mu\leftarrow\mathrm{W},i}}{\sum_{i=1}^{n} w_i} \qquad w_i = \frac{1}{\left(\frac{\sigma_{\mu\leftarrow\mathrm{W}}}{\sqrt{\mathrm{N}_{\mu\leftarrow\mathrm{W}}}}\right)^2}$$

where $\sigma_{\mu\leftarrow\mathrm{W}}$ is the statistical uncertainty per trial

- the statistical error is given by propagating the error on each trial

$$\delta^{\mathrm{stat}}_{<\mathrm{N}_{\mu\leftarrow\mathrm{W}}>} = \frac{\sqrt{\sum_{i=1}^{n}(w_i\sigma_{\mu\leftarrow\mathrm{W},i})^2}}{\sum_{i=1}^{n} w_i} \cdot \sqrt{n}$$

- systematic error is estimated assuming $\mathrm{N}_{\mu\leftarrow\mathrm{W}}$ is extracted from a uniform distribution

$$\delta^{\mathrm{syst}}_{<\mathrm{N}_{\mu\leftarrow\mathrm{W}}>} = \frac{\mathrm{N}_{\mu\leftarrow\mathrm{W}}(\mathrm{max.}) - \mathrm{N}_{\mu\leftarrow\mathrm{W}}(\mathrm{min.})}{\sqrt{12}}$$

Acceptance $\times$ Efficiency correction

- Yield is obtained by correcting $N_{\mu\leftarrow W}$ by $A \times \varepsilon$
- $A \times \varepsilon$ is computed from the templates
- For $\mu^{\pm} \leftarrow W^{\pm}$ it is:

	$A \times \varepsilon$	
	μ^{+}	μ^{-}
p–Pb	0.888	0.887
Pb–p	0.775	0.760

Systematics:

- **Signal extraction**
  $\Rightarrow$ vary between $\sim$ 6 % and $\sim$ 10 %
- **Alignment effects**
  $\Rightarrow$ systematics from detector configuration found to be $< 1\%$
- **Tracking/trigger efficiencies**
  $\Rightarrow$ tracking 2%, trigger 1% and track and trigger matching 0.5%
  $\Rightarrow$ propagate to $N_{\mu\leftarrow W}$ $\Rightarrow$ Conservative uncertainty of 2.5% considered

◇ **These systematics holds for all event activity (multiplicity) bins**

Computing the cross section

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- Cross-section is computed as:

$$\sigma_{\mu \leftarrow \mathrm{W}} = \frac{\mathrm{N}_{\mu \leftarrow \mathrm{W}}}{\mathrm{A} \times \varepsilon} \times \frac{1}{\mathrm{L}_{\mathrm{int}}}$$

where the integrated luminosity is:

$$\mathrm{L}_{\mathrm{int}} = \frac{\mathrm{N}_{\mathrm{MB}}}{\sigma_{\mathrm{MB}}} = \frac{\mathrm{N}_{\mathrm{MSH}} \times \mathrm{F}_{\mathrm{norm}}}{\sigma_{\mathrm{MB}}}$$

- High p_{T} muon triggered (MSH) data sample
- Number of MSH events ($\mathrm{N}_{\mathrm{MSH}}$) must be normalized to the number of minimum-bias (MB) events N_{MB} to obtain the integrated luminosity:

◇ The normalization factor $\mathrm{F}_{\mathrm{norm}}$ is:

- computed with two methods
- takes into account pile-up

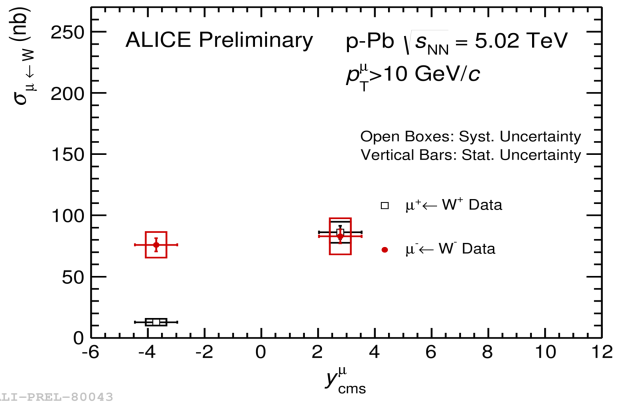
⇒ Systematic difference between these methods is $\sim$ 1%

◇ $\sigma_{\mathrm{MB}} = 2.09 \pm 0.07$ b and $\sigma_{\mathrm{MB}} = 2.12 \pm 0.06$ b for p–Pb and Pb–p respectively

JINST 9 (2014) 11, P11003

Cross section

- Cross sections of $\mu \leftarrow \mathrm{W}$ is measured in two rapidity intervals, $2.03 < y^{\mu}_{\mathrm{cms}} < 3.53$ and $-4.46 < y^{\mu}_{\mathrm{cms}} < -2.96$



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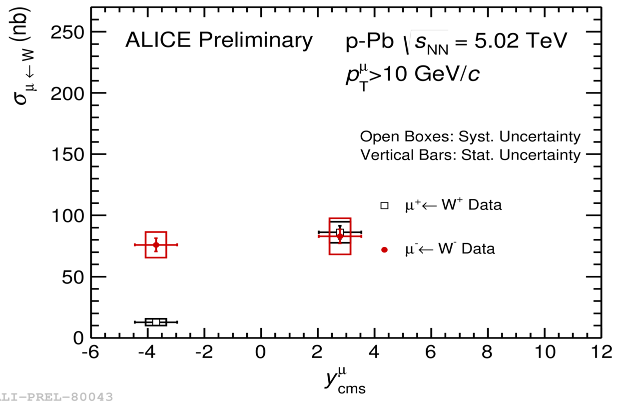
- As expected there is large difference between $\mu^+ \leftarrow \mathrm{W}^+$ and $\mu^- \leftarrow \mathrm{W}^-$ at backward rapidity $\Rightarrow$ isospin effects



Cross section vs pQCD at NLO calculations

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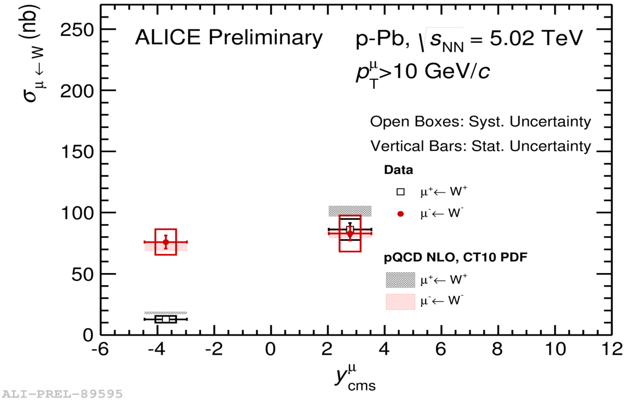

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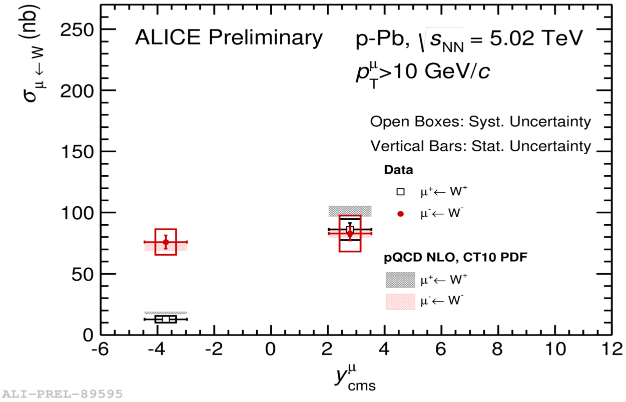
- pQCD at NLO with CT10 (PDFs) predictions by H. Paukkunen are in agreement with measurements (**Theoretical predictions:** Paukkunen, Salgado, JHEP 1103 (2011) 071)



Cross section vs pQCD at NLO calculations with nuclear PDF

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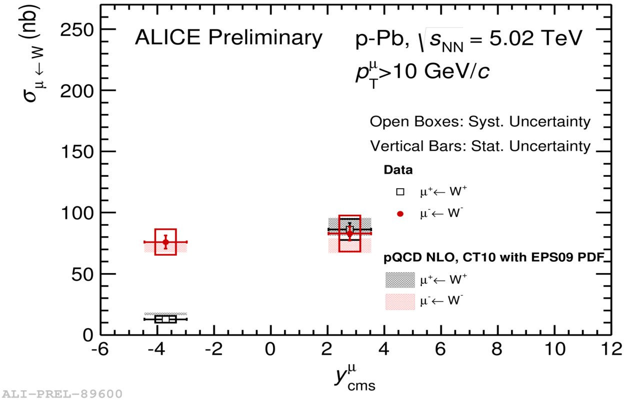

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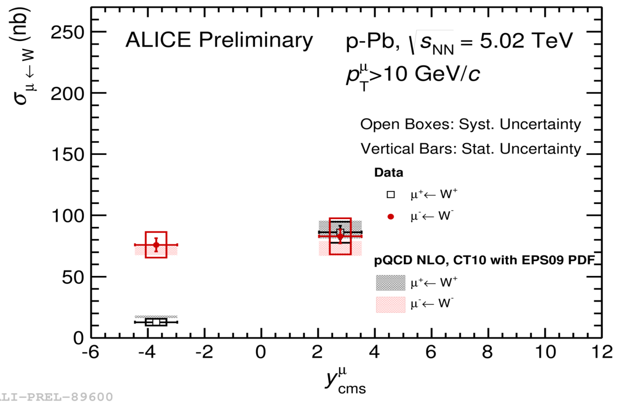

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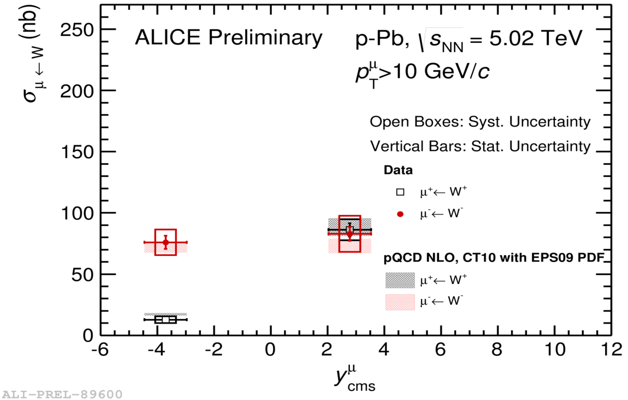
- pQCD at NLO with CT10 (PDFs) and EPS09 (nPDFs) predictions by H. Paukkunen are compared with measurements. (**Theoretical predictions:** Paukkunen, Salgado, JHEP 1103 (2011) 071)
- With shadowing the theory is in better agreement with the measured $\sigma_{\mu^+ \leftarrow \mathrm{W}^+}$ and $\sigma_{\mu^- \leftarrow \mathrm{W}^-}$ at forward rapidity within uncertainty



Determination $\langle N_{coll} \rangle$

- N_{coll} is the number of binary nucleon-nucleon collisions
- Since W production is a hard process it is expected to scale with N_{coll}
- The average number of binary collisions $\langle N_{coll} \rangle$ is expected to be correlated with event activity/multiplicity

◇ Different multiplicity estimators with different approaches were used to extract $\langle N_{coll} \rangle$:

- Glauber Model+Negative Binomial Distribution fits to amplitude of
  ⇒ V0A and V0C detectors
  ⇒ clusters from the first layer of the SPD (CL1)

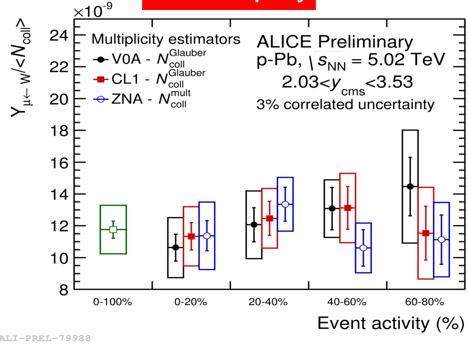
- Hybrid method:
  ⇒ ZNA and ZNC: scaling $\langle N_{part} \rangle$ in minimum-bias collisions by the ratio between the average multiplicity density measured at mid-rapidity in a given ZN energy event class and the one measured in minimum bias collisions

Systematic uncertainty on the normalisation to $\langle N_{coll} \rangle$ range from 8% to 21% depending on a multiplicity bin

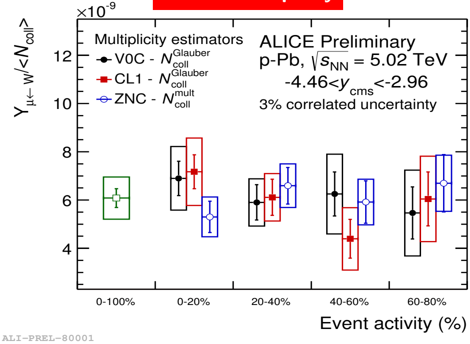
Yield/$\langle N_{coll} \rangle$

- In order to increase statistics $\mu^+ \leftarrow W^+$ and $\mu^- \leftarrow W^-$ were combined
- $\mu \leftarrow W$ yield per binary collision is independent of collision multiplicity within systematics

Forward rapidity



Backward rapidity



Conclusions

- Production of W^- and W^+ was measured in two rapidity ranges in p-Pb collisions at $\sqrt{s_{\mathrm{NN}}}$=5.02 TeV

Cross-section:

- theory is consistent with measurement

$\Rightarrow$ even more so for pQCD at NLO using CT10 with EPS09

Yield normalized to $\langle \mathrm{N_{coll}} \rangle$:

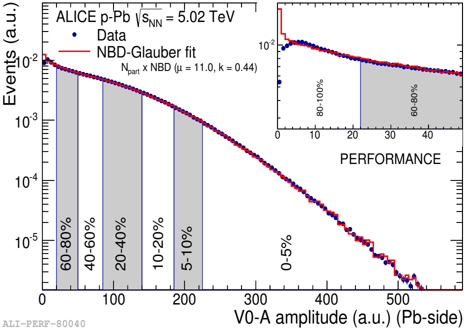
- estimated with 3 multiplicity estimators

- independent of the collision multiplicity within systematics

Backup

$\langle N_{coll} \rangle$

$$\langle N_{coll} \rangle = \langle N_{part} \rangle_{MB} \times \left(\frac{\langle dN/d\eta \rangle_i}{\langle dN/d\eta \rangle_{MB}} \right)_{-1<\eta<0} - 1$$



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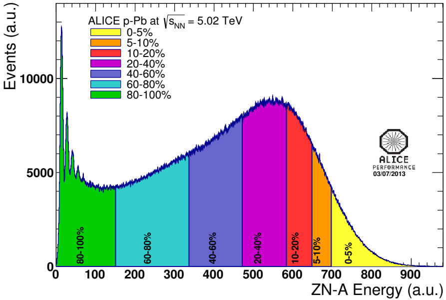

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Summary of the systematics

◇ Systematics on the generator based on POWHEG and PYTHIA

- PYTHIA also used to take into account shadowing effects

◇ Other systematics:

- variation of the input PDFs
- Z/γ^* to $W^{\pm}$ fraction

both negligible

◇ Summary of the systematics:

Signal extraction *(includes alignment, fit stability/shape, etc.)*	from $\sim$ 6% to $\sim$ 10%
Acc.$\times$Eff.	
– track./trig. efficiencies	2.5%
– alignment	$<$ 1 %
Normalisation to MB	
– F_{norm}	1%
– σ_{MB}	3.2% (forward) 3% (backward)