W-boson production measurement with ALICE in p–Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV

Kgotlaesele Johnson Senosi

for the ALICE Collaboration July 28, 2015

II Heavy Ion Collisions in the LHC era and Beyond (July 26 - August 01)

science & technology
Department:
Science and Technology
REPUBLIC OF SOUTH AFRICA

NRF National Research Foundation
iThemba LABS Laboratory for Accelerator Based Sciences

ALICE

University of Cape Town · iYunivesithi yaseKapa · Universiteit van Kaapstad

Outline

✓Introduction

✓ALICE setup

✓Data samples

✓Analysis strategy

✓Results

✓Summary

Introduction

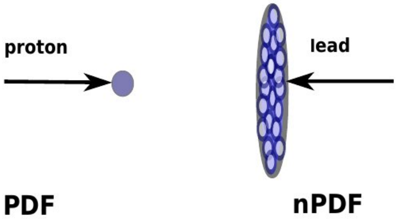
- W bosons are electroweak particles produced in initial hard interactions
- Quark-antiquark annihilation is the dominant production mechanism

$$u\bar{d} \rightarrow W^{+} \qquad d\bar{u} \rightarrow W^{-}$$

- In proton-proton collisions $\Rightarrow$ access to valence quark parton distribution functions (PDFs)

In heavy-ion collisions (p–Pb and PbPb):

- Sensitive to nuclear PDFs
(modification of PDFs inside the nucleus)
- Test the binary scaling of hard processes



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ALICE

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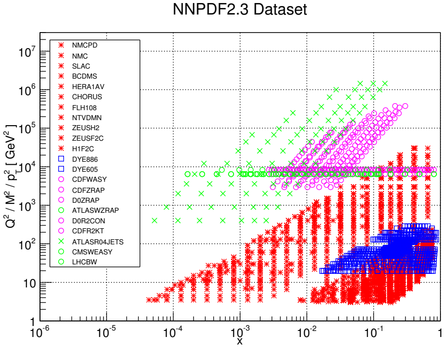

Nucl. Phys. B 867 (2013) 243

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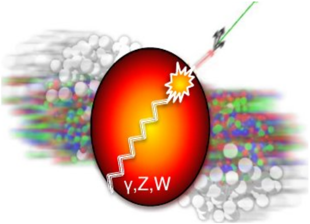
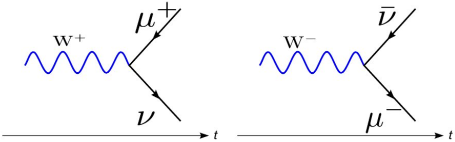
In heavy-ion collisions (p–Pb and PbPb):

- Sensitive to nuclear PDFs (modification of PDFs inside the nucleus)
- Test the binary scaling of hard processes
- Good probe to access shadowing and anti-shadowing
- Not sensitive to strong interaction ⇒ reference for medium-induced effects



Introduction

- Measured in semi-muonic decay ⇒ final state is not affected by the hot and dense QCD medium



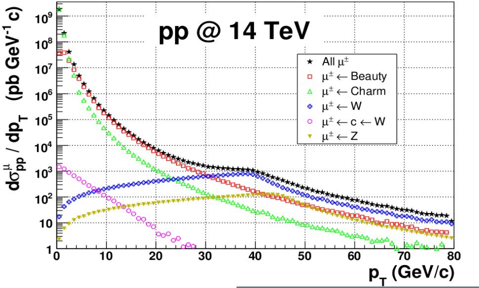
- Signal is a Jacobean peak in the single muon p_T-differential distribution with maximum at $p_T \sim M_W/2$
- Dominant contribution above $p_T \sim 30$ GeV/c with main background from Z/γ^* and muons from heavy-flavour hadron decays

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

W-boson signal is extracted by fitting the single muon p_T spectrum with suitable description of the signal and background

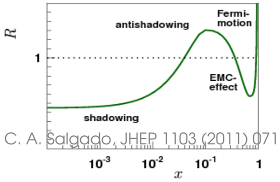
Simulations

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



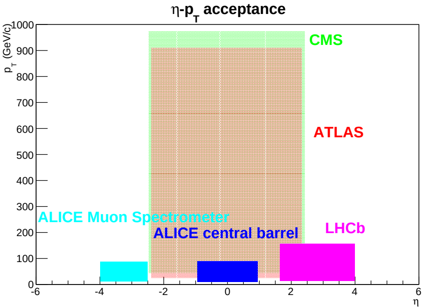
Introduction

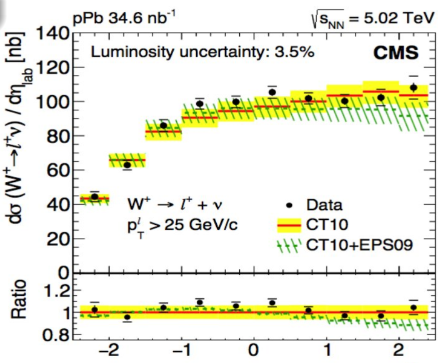
- W-boson production has been measured in p–Pb collisions at 5.02 TeV by the CMS collaboration in $|\eta| < 2.4$
- The ALICE Muon Spectrometer covers the kinematic region $-4 < \eta < -2.5$ complementary to CMS $\Rightarrow$ (anti-)shadowing is more pronounced



H. Paukkunen & C. A. Salgado, JHEP 1103 (2011) 071

p_T and η coverage of the LHC experiments





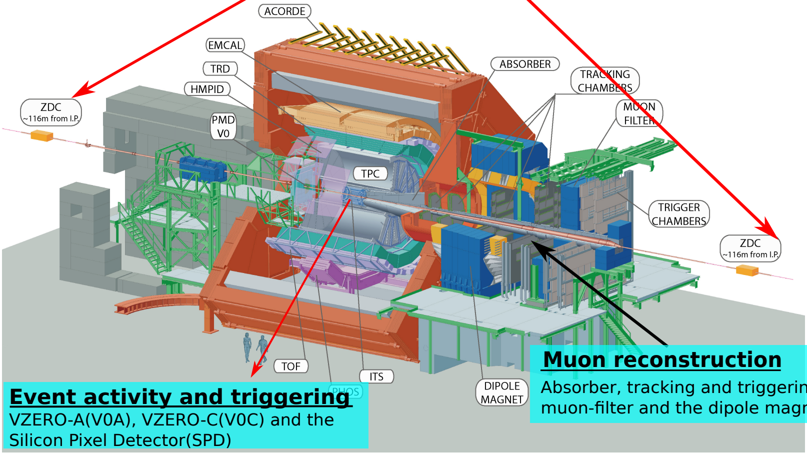
CMS collaboration:arXiv:1503.05825

ALICE Setup

Detectors used for the measurement

Event activity

Zero Degree Calorimeter (ZDC) ZNA and ZNC



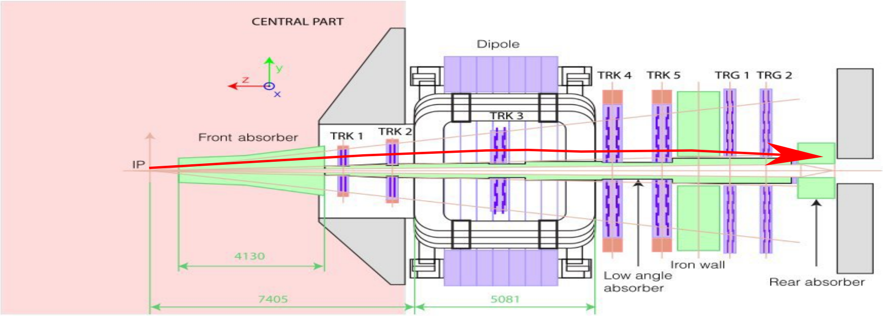
Event activity and triggering

VZERO-A(V0A), VZERO-C(V0C) and the Silicon Pixel Detector(SPD)

Muon reconstruction

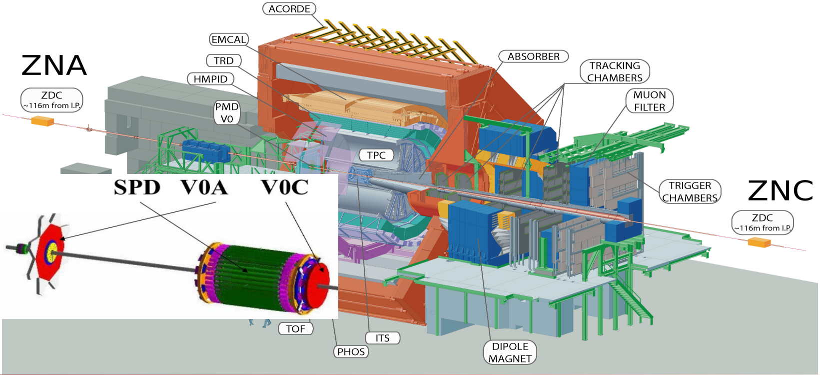
Absorber, tracking and triggering chambers, muon-filter and the dipole magnet

Muon reconstruction



- Reconstructed within the pseudorapidity acceptance $-4.0 < \eta_{\text{lab}} < -2.5$
- Minimum p_{T} trigger is 0.5 GeV/c with a minimum momentum (p) threshold of 4 GeV/c
- Muon track selection in addition to geometrical acceptance cuts:
  - offline 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

Event activity determination



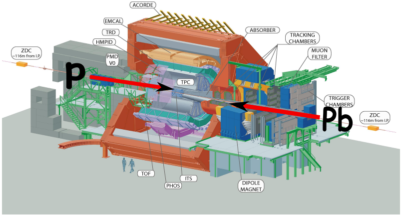
Estimators:

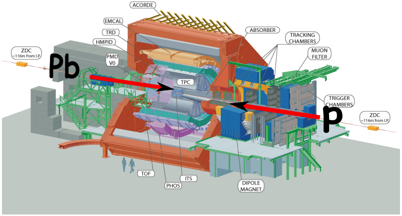
- VZEROs (V0A and V0C) cover the pseudorapidity acceptance $2.8 < \eta_{\mathrm{lab}} < 5.1$ and $-3.7 < \eta_{\mathrm{lab}} < -1.7$, respectively
- The 2nd layer of the SPD (CL1 estimator): $|\eta_{\mathrm{lab}}| < 1.4$ coverage
- ZNA and ZNC placed ± 112.5 m from the interaction point along the beam pipe

Data Samples

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

p-going (forward rapidity, y_{cms}) Pb-going (backward rapidity, $-y_{\mathrm{cms}}$)





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

- Trigger: high-p_{T} muon triggered events (Minimum-Bias (MB,coincidence of V0A and V0C) & muon with $p_{\mathrm{T}} \gtrsim 4$ GeV/c)

Integrated Luminosity

Forward: 4.9 nb^{-1}
Backward: 5.8 nb^{-1}

Signal extraction

Signal extraction based on a combined fit $f(p_T)$:

$$f(p_T) = N_{\mu\leftarrow HF} \cdot f_{\mu\leftarrow HF} + N_{\mu\leftarrow W} \cdot f_{\mu\leftarrow W} + N_{\mu\leftarrow Z/\gamma^*} f_{\mu\leftarrow Z/\gamma^*}$$

$f_{\mu\leftarrow HF}$ = FONLL based template and phenomenological functions

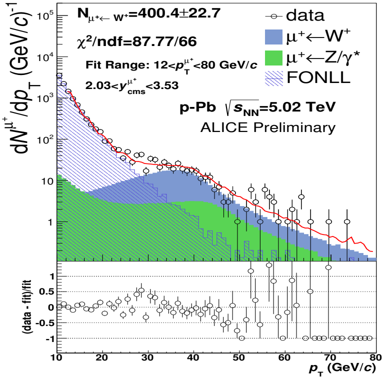
$f_{\mu\leftarrow W}, f_{\mu\leftarrow Z/\gamma^*}$ = POWHEG based Monte Carlo (MC) templates

$N_{\mu\leftarrow HF}, N_{\mu\leftarrow W}$ = free normalization parameters

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

- $N_{\mu\leftarrow W}$ is extracted between 10 and 80 GeV/c and corrected for acceptance×efficiency (obtained from simulation)

- Normalize the yield to MB cross section to obtain $\sigma_{\mu^\pm\rightarrow W^\pm}$



Analysis Strategy

W and Z/γ^* Monte Carlo (MC) templates

- Based on POWHEG (NLO) generator with CTEQ6m
- Interfaced with PYTHIA6.4:
  $\Rightarrow$ apply showers to POWHEG hard events
  $\Rightarrow$ parametrize nPDFs using EPS09

POWHEG:JHEP 0807(2008)060, CTEQ: JHEP 0207(2002)012, PYTHIA6.4: JHEP 05(2006)026, EPS09: JHEP 0904(2009)065

Generation done for pp and pn separately and combined with:

$$\frac{1}{N_{\mathrm{pPb}}}\frac{\mathrm{d}N_{\mathrm{pPb}}}{\mathrm{d}p_{\mathrm{T}}} = \frac{Z}{A}\frac{1}{N_{\mathrm{pp}}}\frac{\mathrm{d}N_{\mathrm{pp}}}{\mathrm{d}p_{\mathrm{T}}} + \frac{A-Z}{A}\frac{1}{N_{\mathrm{pn}}}\frac{\mathrm{d}N_{\mathrm{pn}}}{\mathrm{d}p_{\mathrm{T}}}$$

A = 208 and Z = 82

Heavy-flavour Monte Carlo (MC) templates

- Based on Fixed Order Next-to-Leading-Log (FONLL) with CTEQ6.6
- Muons from B and D decays in pp at $\sqrt{s} = 5.02$ TeV (FONLL)
  $\Rightarrow$ used for heavy-flavour semi-muonic decays description
- Phenomenological function previously used by ATLAS

FONLL: JHEP 1210(2012)137, ATLAS: ATLAS-COM-CONF-2011-088

Computing the cross section

- Cross section is computed as follows:

$$\sigma_{\mu\leftarrow \mathrm{W}} = \frac{N_{\mu\leftarrow \mathrm{W}}}{A \times \epsilon} \times \frac{1}{L_{\mathrm{int}}}$$

where L_{int} is

$$L_{\mathrm{int}} = \frac{N_{\mathrm{MB}}}{\sigma_{\mathrm{MB}}} = \frac{N_{\mathrm{MSH}} \times F_{\mathrm{norm}}}{\sigma_{\mathrm{MB}}}$$

and $A \times \epsilon$ is the acceptance and efficiency factor:
$\Rightarrow$Forward rapidity: 0.88 and Backward rapidity: 0.77 $\Leftarrow$

- N_{MB} is the number of minimum-bias events
- N_{MSH} is the number of high p_{T} triggered muon events
- F_{norm} computed with two methods is the number of minimum-bias events per N_{MSH}
  - $\Rightarrow$ Online and offline information - takes into account pile-up
- The inelastic cross section were evaluated independently using van der Meer scans $\Rightarrow$ σ_{MB} is 2.09 ± 0.07 b and 2.12 ± 0.06 b for the p–Pb and Pb–p data samples respectively JINST 9 (2014) 11, P11003

Systematic Uncertainties

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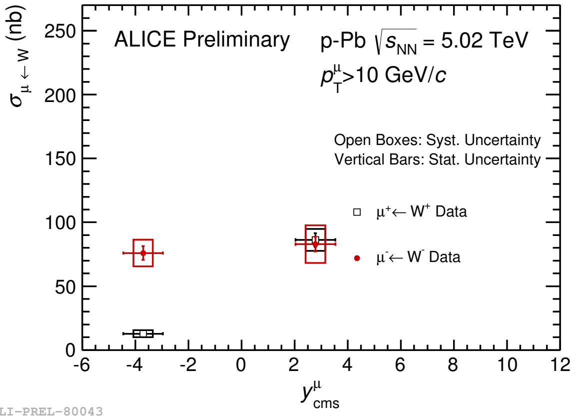
$N_{\mu \leftarrow W}$ is a weighted average of several trials varying:

- p_T fit range, description of heavy-flavour decay muons
- Fraction of muons from Z to W cross sections were obtained with PYTHIA and POWHEG
- Alignment $\rightarrow$ variation of positions of detector elements

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 %
Pile-up	0 – 7.5%
Normalisation to MB	
– F_{norm}	1%
– σ_{MB}	3.2% (forward) 3% (backward)

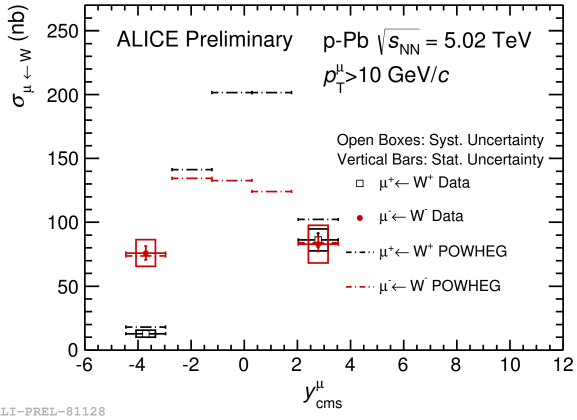
Cross section



- Cross section of muons from $W^{\pm}$ measured at forward and backward rapidity
- Isospin effects more visible at backward rapidity

Cross section

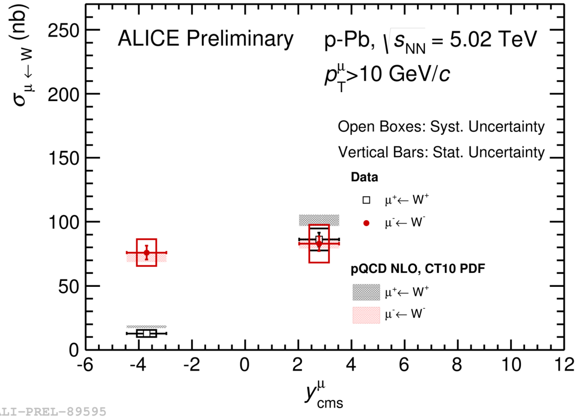
Theory: Theory: Alioli, Nason, Oleari and Re. JHEP 0807 (2008) 060



- Cross section of muons from $W^{\pm}$ measured at forward and backward rapidity compared with POWHEG Next-to-Leading order calculation
  - shadowing not taken into account in the theory

Cross section

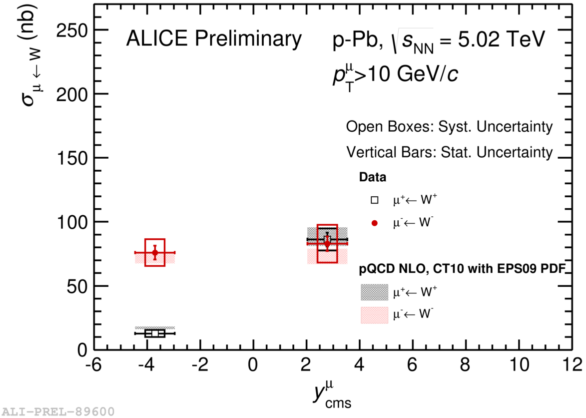
Theory: Hannu Paukkunen, pQCD NLO with CT10



- Cross section of muons from $W^{\pm}$ measured at forward and backward rapidity compared with pQCD calculation **without shadowing**

Cross section

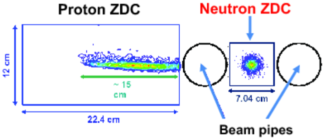
Theory: Hannu Paukkunen: pQCD with CT10 and EPS09



- Cross section of muons from $W^{\pm}$ measured at forward and backward rapidity compared with pQCD calculation **with shadowing**

Test of binary scaling

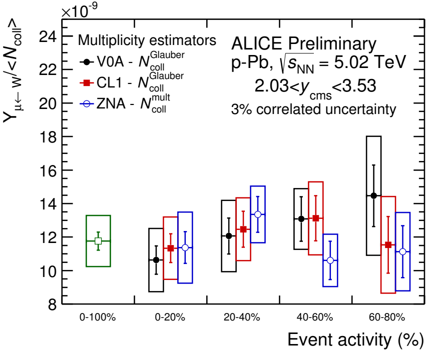
- Production of W bosons is a hard process thus is expected to scale with the number of collisions ($\langle N_{\rm coll} \rangle$)
- $\langle N_{\rm coll} \rangle$ is expected to be correlated with event activity (central, semi-central, peripheral)
- Different estimators with different approaches were used to classify event activity:
  - Glauber Model + Negative Binomial Distribution fit to the signal in the V0A or V0C and the clusters in the first layer of the SPD (CL1)
  - Hybrid method: scaling $N_{\rm coll}$ in minimum-bias collisions by the ratio between the average multiplicity density measured at mid-rapidity in a given ZDC energy event class and the one measured in minimum bias collisions (ZNA and ZNC)



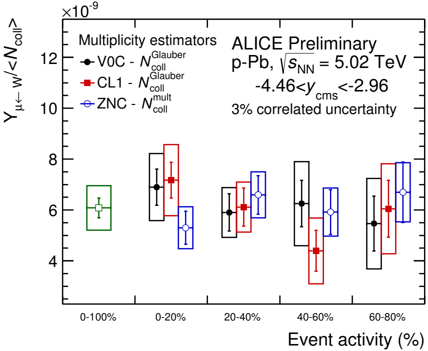
- $\langle N_{\rm coll} \rangle$ systematic uncertainty is multiplicity bin dependent, varies between 8 - 24%

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

- Signal extraction done separately for $\mu^{+} \leftarrow W^{+}$ and $\mu^{-} \leftarrow W^{-}$ and then combined
- Yield is normalized to $\langle N_{coll} \rangle$ to test binary scaling
- The yield per binary collisions is independent of event activity within uncertainties
- Yield normalized to $\langle N_{coll} \rangle$ compatible within uncertainties among estimators



ALI-PREL-79988



ALI-PREL-80001

Summary

- Production of W bosons has been measured at forward and backward rapidity

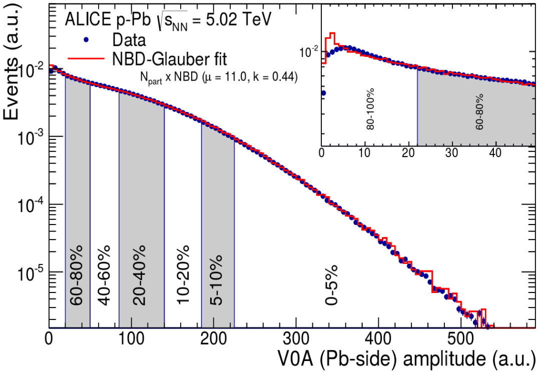
- Cross section
  - Isospin effects more prominent at backward rapidity ($\sigma_{\mu^- \leftarrow \mathrm{W}^-} > \sigma_{\mu^+ \leftarrow \mathrm{W}^+}$)
  - pQCD calculations with and without nuclear PDFs describe the measurements (same observation as CMS in a complementary rapidity region)
    $\Rightarrow$ Predictions with nPDFs seem closer to data

- Yield normalized to $\langle N_{\mathrm{coll}} \rangle$
  - Measurements performed with different estimators are consistent between one another
  - Production of W-boson scales with $\langle N_{\mathrm{coll}} \rangle$ with uncertainties

Backup

Glauber+NBD

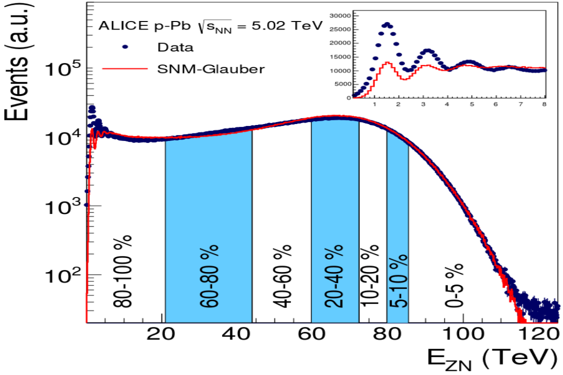
- Glauber MC to obtain P(N_{part}) assuming N_{part} = number of particle sources ancestors
- multiplicity distribution per ancestor from Negative Binomial Distribution (NBD)
- minimization procedure to find NBD parameter values
- centrality classes defined slicing measured multiplicity distributions in percentiles of cross section



ALICE, Phys. Rev. C88, 044909 (2013)

Hybrid

- Similar procedure but coupled with a model for slow nucleon emission (SNM) No model is currently available for LHC energies
- Features of emitted nucleons weakly dependent on projectile energy from 1 GeV to 1 TeV
- "Phenomenological" model based on experimental results at lower energies



F. Sikler, arXiv: 0304.065

Systematics on the signal extraction

ALICE

◇ $N_{\mu\leftarrow W}$ 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 $W^\pm$ muons: ⇒ obtained using PYTHIA and POWHEG
- Alignment effects ⇒ vary the position of detector elements

◇ Weighted average over

- (3 background description)×(different p_T ranges)×(2 $N_{\mu\leftarrow Z/\gamma^*}/N_{\mu\leftarrow W}$)×(2 alignment configurations)×(1 MC templates for the signal) trials:

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

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

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

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

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

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