Weak-boson production in p–Pb collisions at 8.16 TeV with ALICE

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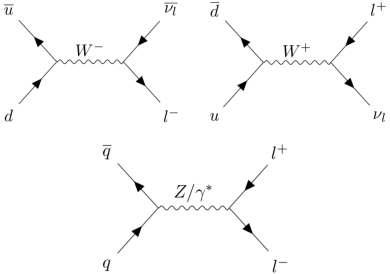
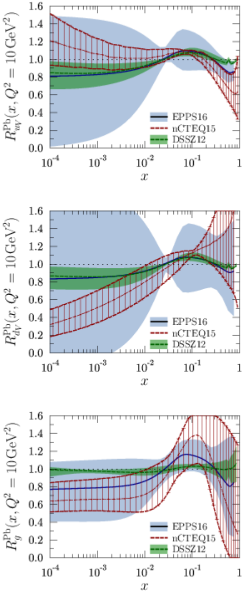
Physics motivation

Z and W are sensitive probes of the nuclear Parton Distribution Function (PDF):

- produced in the hard processes at inital stages of the collisions,
- sensitive to the nuclear modification of the PDF,
- in their leptonic decay: insensitive to the strongly interacting medium.

Z and W production at leading order:





Physics motivation

Production cross-section: to be compared to the expression obtained using QCD factorization theorem:

$$\sigma_{AB} \propto \sum_q \frac{4\pi e_q^2 \alpha^2}{9\hat{s}} f_q(x_1, Q^2) f_{\bar{q}}(x_2, Q^2).$$

W charge asymmetry: sensitive to the d/u ratio, partial cancellation of theoretical and experimental uncertainties:

$$A \equiv \frac{N_{\mu^+ \leftarrow W^+} - N_{\mu^- \leftarrow W^-}}{N_{\mu^+ \leftarrow W^+} + N_{\mu^- \leftarrow W^-}}.$$

Nuclear modification factor: evaluates the supression or enhancement of the production due to nuclear effects:

$$R_{AA(pA)} \equiv \frac{1}{\langle T_{AA(pA)} \rangle} \frac{\mathrm{d}N_{AA(pA)}/\mathrm{d}y}{\mathrm{d}\sigma_{pp}/\mathrm{d}y},$$

with T_{AA}: nuclear overlap function from Glauber model.

nPDF models

nPDF set	EPS09	nCTEQ15	EPPS16
Order	NLO	NLO	NLO
Flavour separation		valence quarks	valence + sea quarks
Proton baseline	CTEQ6.1	CTEQ6M-like	CT14NLO
Free parameters	15	35	52
Data points	929	708	1811
Included experimental data			
DIS in l^-+A	✓	✓	✓
Drell-Yan in p+A	✓	✓	✓
RHIC pions d+Au	✓	✓	✓
ν-nucleus DIS			✓
Drell-Yan in π+A			✓
LHC p–Pb dijets			✓
LHC p–Pb W and Z			✓

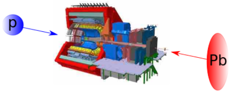
PoS (HardProbes2018) 014

Z and W in p–Pb with ALICE

Coverage of the muon spectrometer: $2.5 < y_{\mathrm{lab}} < 4$.

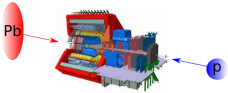
Asymmetrical collisions → rapidity shifted between CMS and lab frames: $\Delta y = \pm 0.4654$.

p–Pb (p-going):



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

Pb–p (Pb-going):



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

Bjorken-x coverages (in the $2 \to 1$ approximation: $x = \frac{M}{\sqrt{s_{\mathrm{NN}}}} e^{\pm y}$):

Collision	Rapidity	Boson	Bjorken-x
p–Pb	$2.03 < y_{\mathrm{cms}} < 3.53$	Z	$3.27 \times 10^{-4} < x < 1.47 \times 10^{-3}$
		W	$2.89 \times 10^{-4} < x < 1.29 \times 10^{-3}$
Pb–p	$-4.46 < y_{\mathrm{cms}} < -2.96$	Z	$2.16 \times 10^{-1} < x < 9.66 \times 10^{-1}$
		W	$1.90 \times 10^{-1} < x < 8.52 \times 10^{-1}$

p–Pb at 8.16 TeV

Data sample: from proton–lead collisions at $\sqrt{s_{\mathrm{NN}}} = 8.16$ TeV in November and December 2016.

Trigger classes:

- `CINT7`: Minimum Bias, logical `AND` between V0A and V0C,
- `CMSH7`: single muon with $p_{\mathrm{T}} > 4.2$ GeV/c, and MB,
- `CMUL7`: unlike-sign muon pair, each with $p_{\mathrm{T}} > 0.5$ GeV/c, and MB.

Collision	LHC period	N_{runs}	N_{CMSH}	N_{CMUL}
p–Pb	LHC16r	57	XXX	XXX
Pb–p	LHC16s	80	XXX	XXX

p–Pb at 8.16 TeV

Luminosity of the periods:

$$\mathscr{L} = \frac{N_{MB}}{\sigma_{MB}} = \frac{F_{norm} \times N_{CMUL}}{\sigma_{MB}}.$$

- F_{norm}: normalization factor to obtain N_{MB} from N_{CMUL},
- σ_{MB}: MB cross section estimated with Van-der-Meer scans.

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LHC16r:

$$\mathscr{L} = 8.47 \pm 0.01 \pm 0.17\,\mathrm{nb}^{-1}.$$

LHC16s:

$$\mathscr{L} = 12.75 \pm 0.01 \pm 0.25\,\mathrm{nb}^{-1}.$$

Z: analysis strategy

Z cross section:

$$\sigma_{Z\to\mu\mu} = \frac{N_Z}{\mathscr{L} \times \epsilon}.$$

Z candidates: opposite-sign muon pairs in the fiducial region:

$$\begin{cases} -4 < \eta_\mu < -2.5, \\ p_{\mathrm{T}}(\mu) > 20 \text{ GeV}/c, \\ 60 < m_{\mu^+\mu^-} < 120 \text{ GeV}/c^2. \end{cases}$$

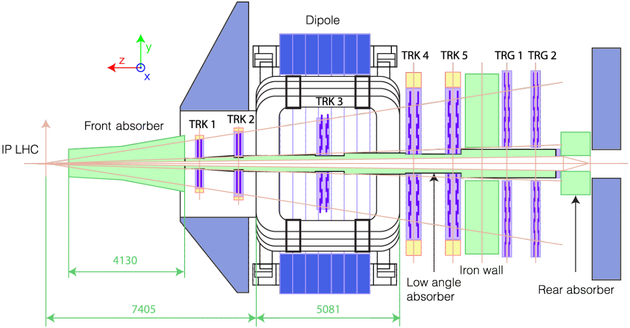
Three steps:

- measure N_Z the number of dimuons from Z decay in the data,
- estimate the efficiency ϵ of the detector over the period,
- evaluate the cross section from N_Z, accounting for the luminosity and efficiency.

Z: selection of the Z candidates

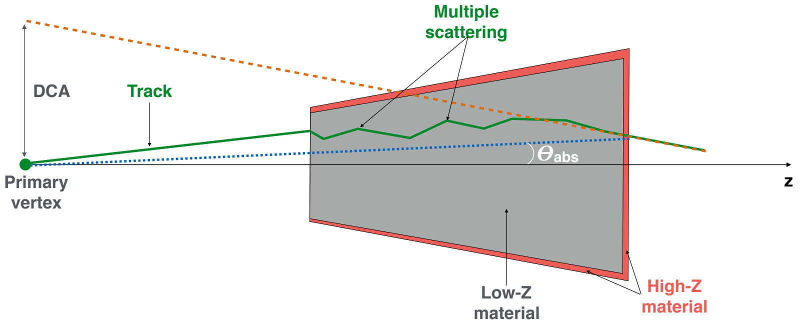
Selection: unlike-sign muon pairs reconstructed within the geometrical acceptance of the muon spectrometer ($-4 < \eta < -2.5$). Offline cuts applied to remove some background:

- **transverse momentum**: $p_{\mathrm{T}} > 20$ Gev/c to reject muons from the decays of low mass quarkonia, and reduce combinatorial background,
- **trigger-tracker matching**: to ensure that each track reconstructed by the muon tracking system matches a track segment in the trigger chamber,



Z: selection of the Z candidates

- **radial transverse position**: $17.6 < R_{abs} < 89.5$ cm to remove tracks going through multiple scattering,
- **product of the track momentum to its distance of closest approach**: $p \times DCA < 6\sigma$ as to reject tracks that are not coming from the interaction vertex.



Z: selection of the Z candidates

Z candidates: counting the opposite-sign muon pairs that pass the selection, in the fiducial region:

$$\begin{cases} -4 < \eta_\mu < -2.5, \\ p_\mathrm{T}(\mu) > 20 \text{ GeV}/c, \\ 60 < m_{\mu^+\mu^-} < 120 \text{ GeV}/c^2. \end{cases}$$

Proton–lead:

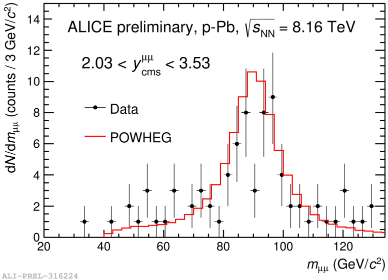
$$N_Z^{pPb} = 64 \pm 8\,(\mathrm{stat}),$$

3 times higher than at 5.02 TeV.

Lead–proton:

$$N_Z^{Pbp} = 34 \pm 6\,(\mathrm{stat}),$$

15 times higher than at 5.02 TeV.



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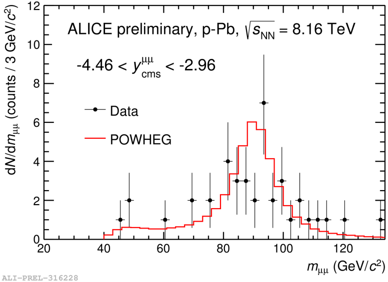

ALI-PREL-316228

Z: background evaluation

Sources of background:

- $Z \to \tau\tau \to \mu\mu$, pairs from charm, bottom and top (FONLL, POWHEG), $\sim 1\%$ of the yield,
- combinatorial background (same-sign dimuon invariant mass distribution), negligible or substracted from Z candidates.

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Overall, background small if not negligible, taken as systematic uncertainty on the signal extraction.

Z: efficiency

Goal: account for the loss of signal because of the detector.

Method:

- simulate $Z \to \mu\mu$ in p–Pb collisions with POWHEG + Pythia,
- simulate the particle transport through the detector with GEANT,
- compare the MC Truth and Rec distributions to evaluate the fraction of Z candidates that are not reconstructed.

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Results:

$$\epsilon_{p-Pb} = XXX, \qquad \epsilon_{Pb-p} = XXX.$$

Z: systematics

- **Signal extraction**: background taken as systematics,
- **luminosity**: systematics from the evaluation of F_{norm} and σ_{MB},
- **MC inputs**: efficiency computation dependent on the choice of PDF and nPDF sets, alignment files, transport code,
- **detector simulation**: various corrections to account for some disagreements between the detector simulation with GEANT and what is observed in data.

All sources combined quadratically. Amount for 6.6% of the final cross section in p–Pb, 5.2% in Pb–p.

W:analysis strategy

Analysis similar in essence to the Z one:

$$\sigma_{W^\pm \to \mu^\pm \nu} = \frac{N_{W^\pm}}{\mathscr{L} \times \epsilon}.$$

Two differences:

- looking at single muon distribution with $p_{\mathrm{T}} > 10$ GeV/c,
- trigger class is `CMSH` instead of `CMUL`.

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W: signal extraction

Fit of the single muon p_{T} distribution:

$$f(p_{\mathrm{T}}) = N_{bkg} \cdot f_{bkg}(p_{\mathrm{T}}) + N_{\mu\leftarrow W} \cdot (f_{\mu\leftarrow W}(p_{\mathrm{T}}) + R \cdot f_{\mu\leftarrow Z}(p_{\mathrm{T}})) ,$$

- $f_X(p_{\mathrm{T}})$: MC templates (FONLL, POWHEG),
- N_X: free parameters,
- R: ratio of the Z to W cross-sections from POWHEG.

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W: signal extraction

All templates normalized to 1, then feeded to the fit function applied to the p_{T} distribution. N_W extracted by integrating the W template after fit above 10 GeV/c.

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Compared to 5.02 TeV: X times more counts in p–Pb, X times in Pb–p.

W: signal extraction

Fitting procedure: relies on the fit range, the templates... Can be accounted for by varying several parameters.

- **Fit range**: test the fit stability, vary the constrains on HF / bosons,
- **FONLL**: vary the cross section inputs (factorization and renormalization scales),
- **POWHEG**: vary the PDF and nPDF sets.

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Overall, several hundreds of fits. Final N_W and statistical uncertainty by averaging, systematics on signal extraction as the RMS.

Collision	N_{W^-}	N_{W^+}
p–Pb	XXX	XXX
Pb–p	XXX	XXX

W: efficiency and systematics

Efficiency: computed the same way as for Z by comparing MC Truth and Rec distributions.

Collision	**Boson**	**Efficiency**
p–Pb	W^-	XXX
	W^+	XXX
Pb–p	W^-	XXX
	W^+	XXX

Systematics: on signal extraction: comes from the fit procedure, background analysis embedded in the procedure. Same sources for efficiency, detector response and luminosity as for Z. As percentages of the final cross section:

p–Pb		**Pb–p**	
W^-	W^+	W^-	W^+
XXX	XXX	XXX	XXX

Results

W$^-$ **boson**:

W$^+$ **boson**:

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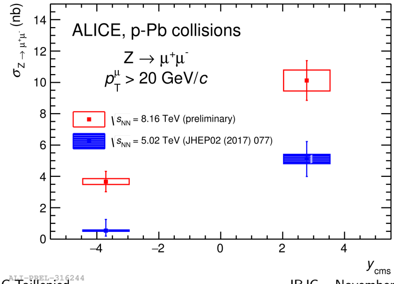
Z boson:



- Similar trend at 5.02 and 8.16 TeV,
- increase of statistics leads to a reduction of the relative uncertainty on the cross sections.

Results

W boson: charge asymmetry

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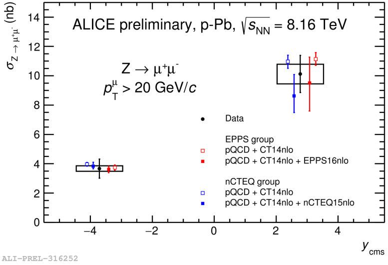
Z boson: comparison with theory



- Same trend at both energies,
- statistical uncertainty much lower (TBC),
- to be compared to theoretical predictions.

- Measurement well reproduced by theory, both from EPPS and nCTEQ models,
- statistical limitations prevent to draw any firm conclusion on nuclear modifications.

Conclusion

Status of the Z analysis:

- preliminary plots approved,
- presented at EPS-HEP 2019, published in PoS,
- paper on the way, with Z in Pb–Pb.

Status of the W analysis:

- lots of recent progresses,
- still some work to do, mostly on systematics,
- statistics should allow for differential studies, aiming for 3 bins in rapidity.

Service task: writing a task in O2 for the monitoring of the MID, preparation for run 3. To be installed for the commissioning in 2020.

Thank you!