Electroweak probes in LHCb - results and prospects

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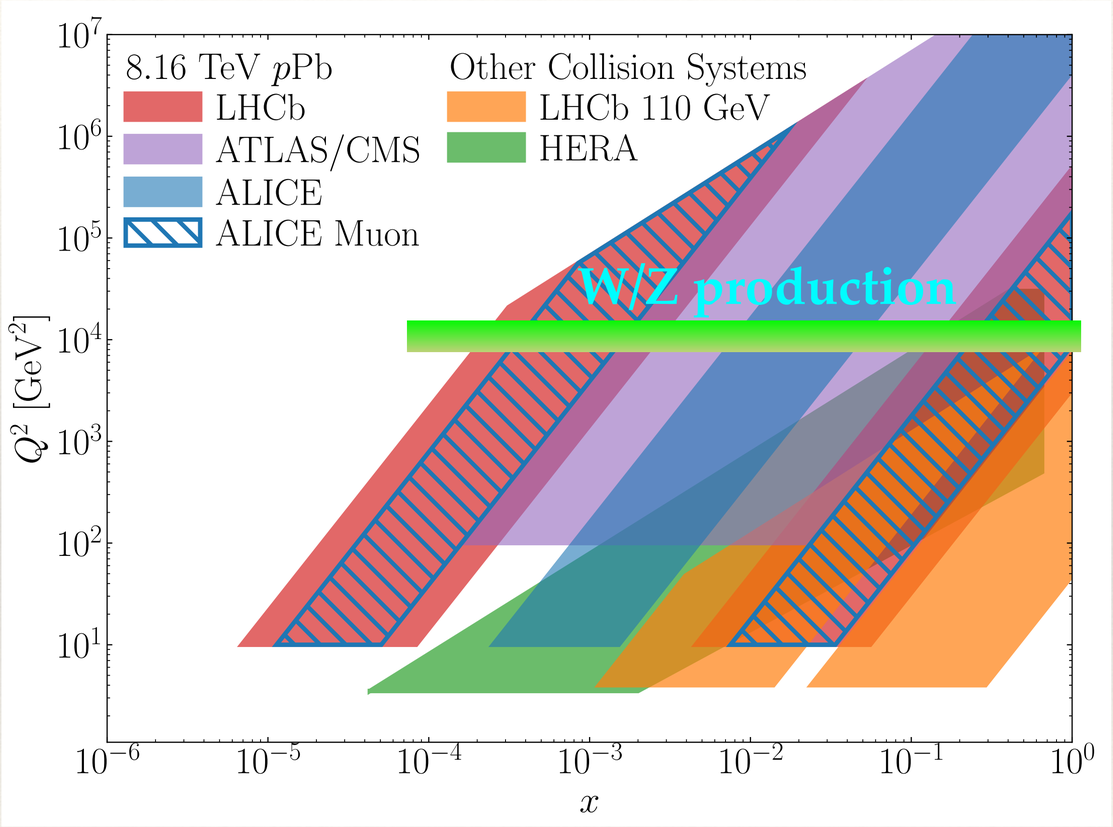
on behalf of the LHCb collaboration

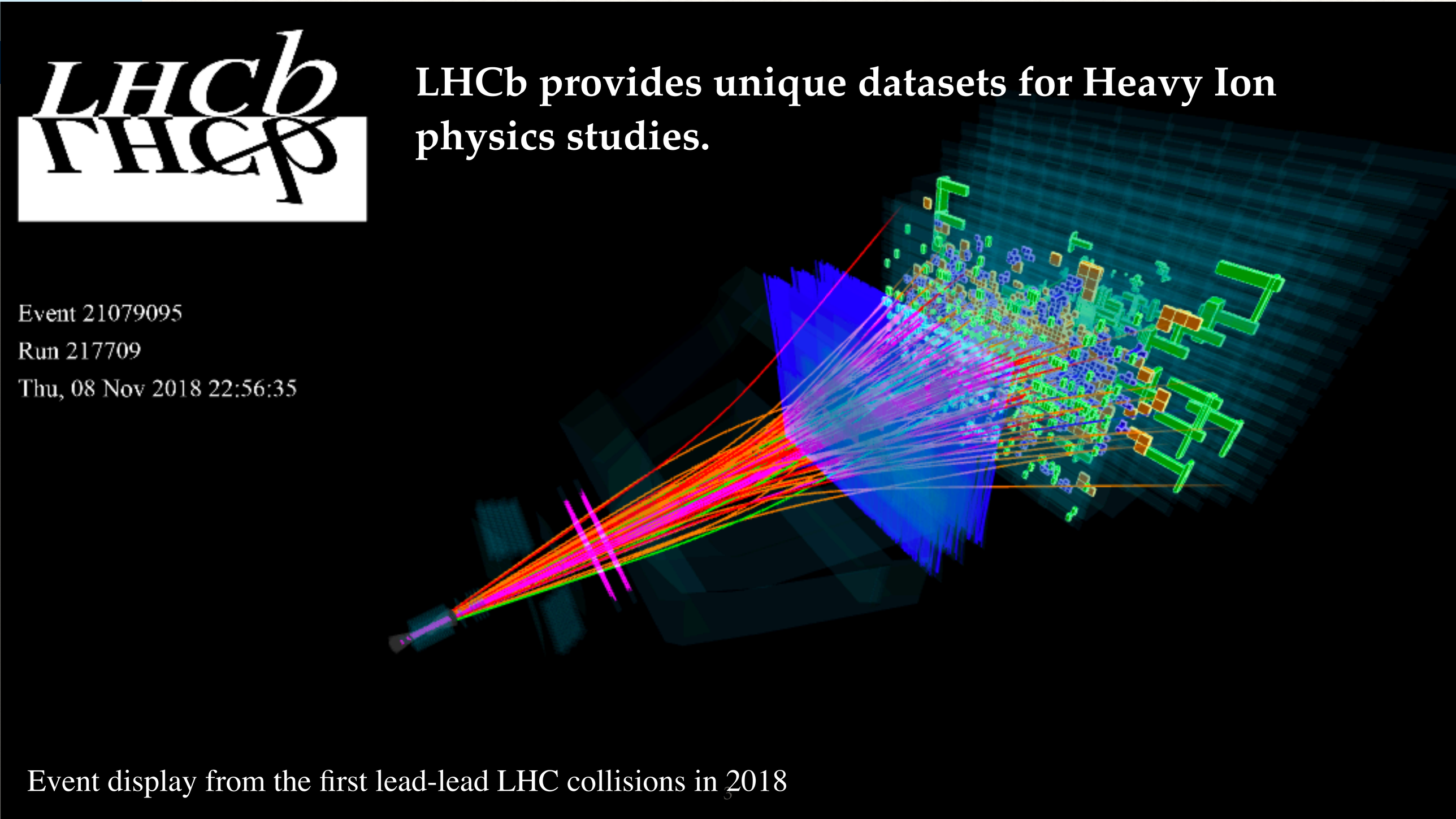
Physics Motivation for the EW probes

- **Electroweak bosons are unmodified by the hot and dense medium created in nucleus–nucleus collisions,**
- **Their leptonic decays pass through the medium without being affected by the strong interaction.**
- **Therefore, electroweak boson productions well "conserved" the initial conditions of the collisions, can be:**
  - **used to probe (cold) nuclear effects and constraint nPDFs for Bjorken-x from ~10^{-4} to 1 at $Q^2 \sim 10^4$ GeV^2**
  - **and can be used as a calibration of the nuclear modification factor of other processes:**

$$Z_{AA} = \frac{R_{AA}(X)}{R_{AA}(EW)} = \frac{N^X_{Pb+Pb}}{\sigma^X_{Pb+Pb}} \times \frac{\sigma^{EW}_{Pb+Pb}}{N^{EW}_{Pb+Pb}}$$



LHCb provides unique datasets for Heavy Ion physics studies.



Event display from the first lead-lead LHC collisions in 2018

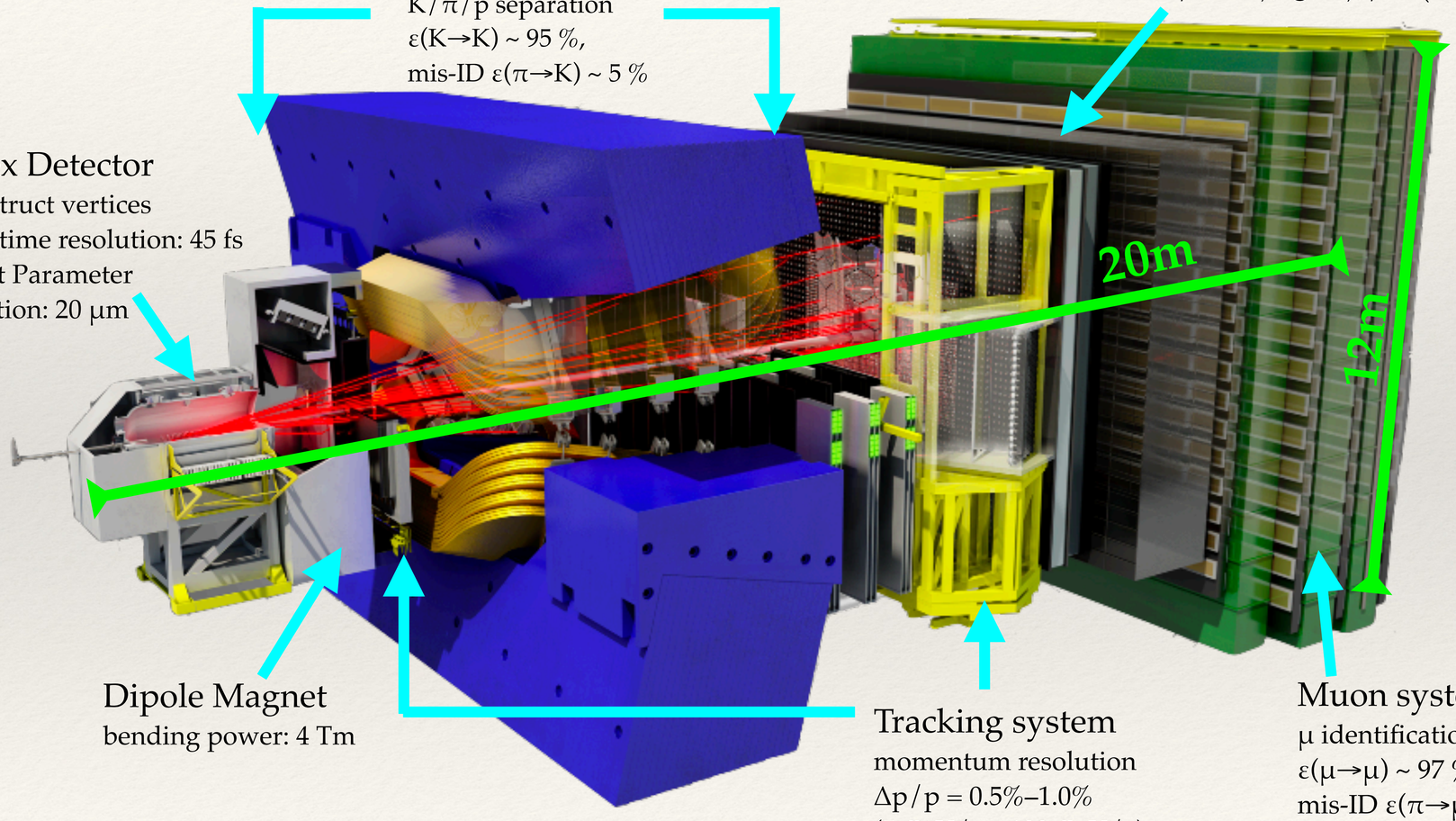
[JINST 3 (2008) S08005]
[IJMPA 30 (2015) 1530022]

The LHCb detector is special

- **LHCb is the only detector fully instrumented in forward region**
- **Unique kinematic coverage**

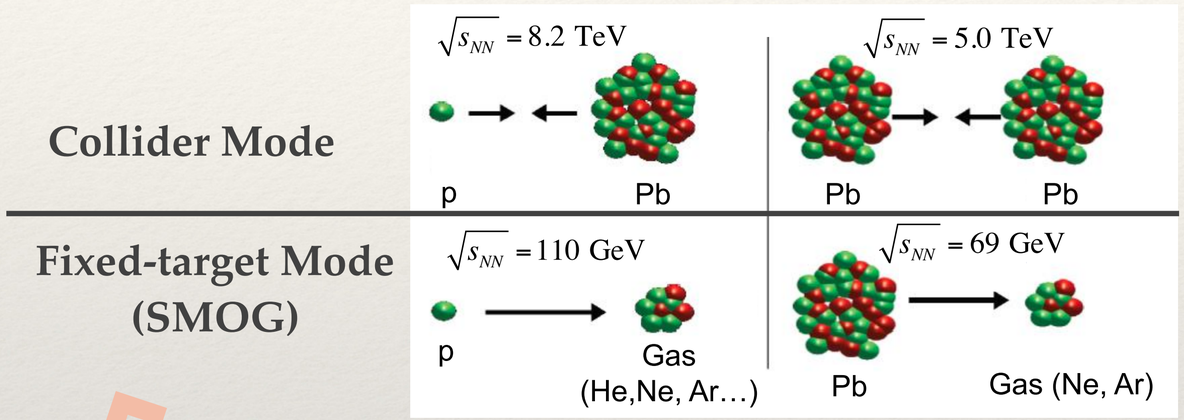
$$2 < \eta < 5$$

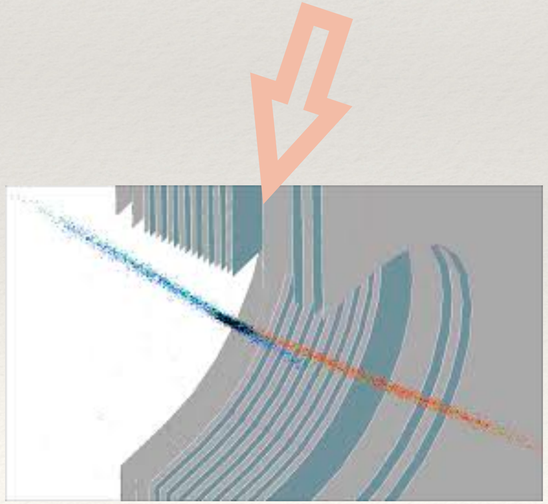
- **A high precision device, down to very low-p_T, excellent particle ID, precision vertex reconstruction and tracking.**



LHCb running modes and kinematic coverage

Both the collider mode and fixed-target mode running at the same time:





Collider mode:

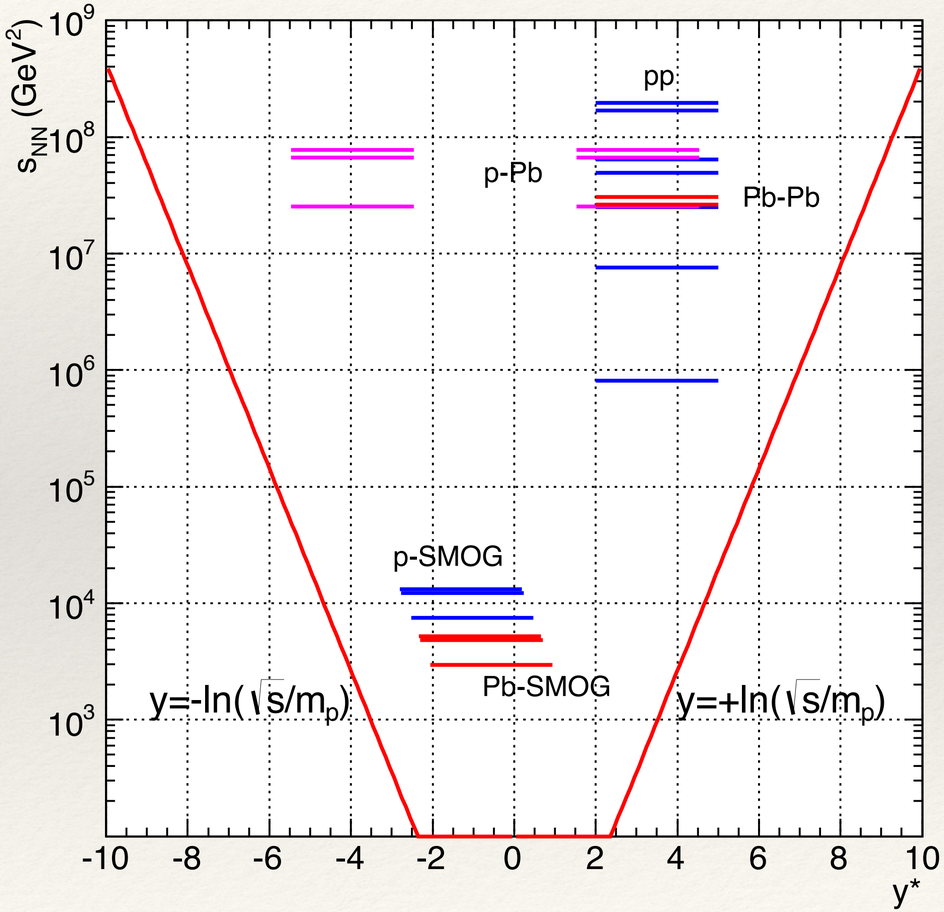
Forward and backward coverage

Fixed-target mode:

Central and backward coverage

$\sqrt{s_{NN}}$: 69 - 110 GeV, fills the gap between SPS (20 GeV) and RHIC (200 GeV) energy scales

Kinematic Acceptance



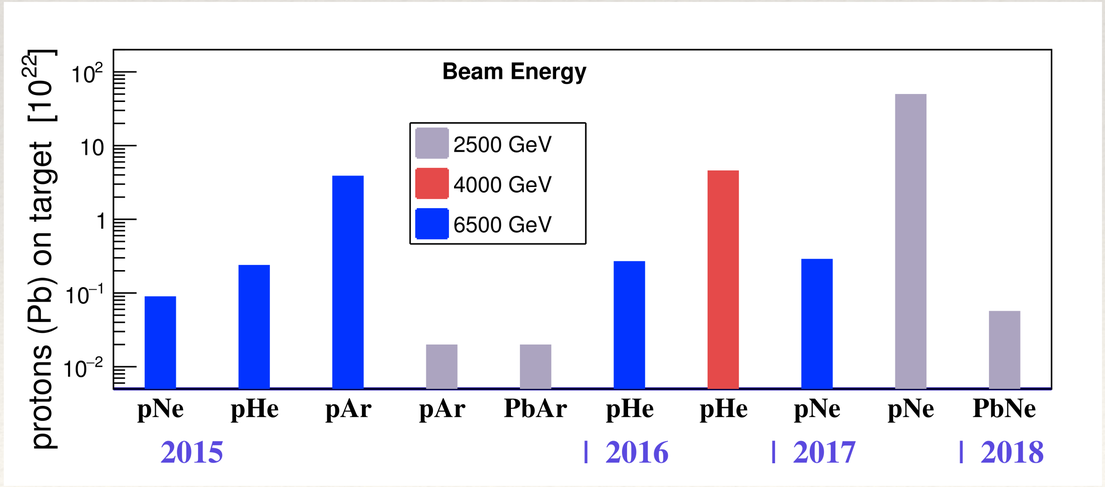
Data samples

- **Colliding beam mode (pPb and PbPb):**

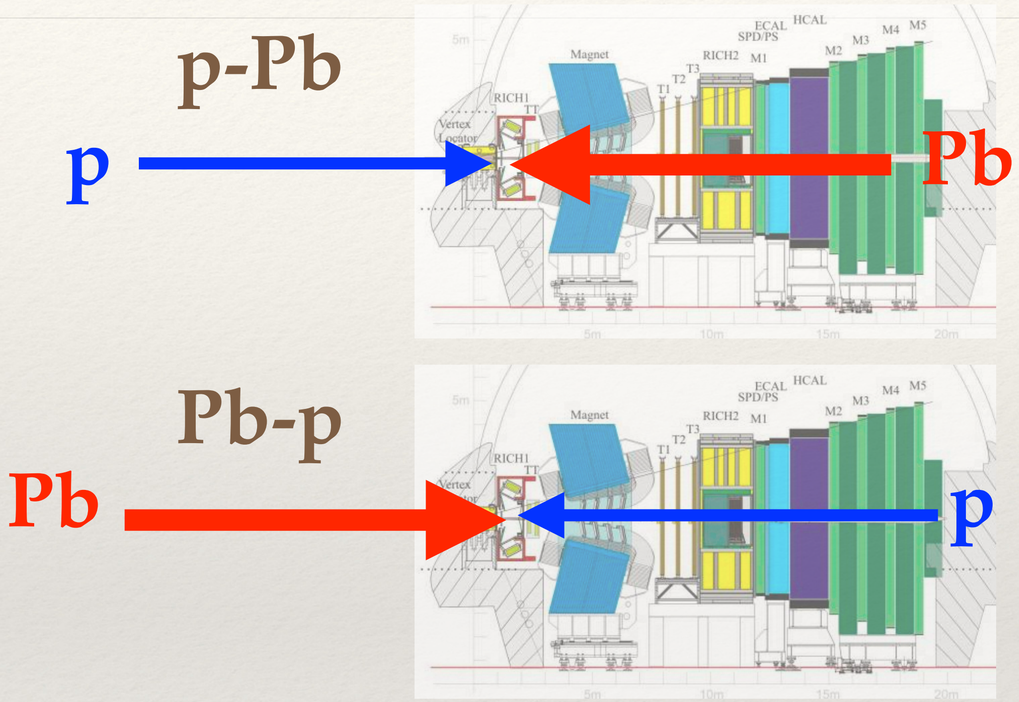
$\sqrt{s_{NN}}$	2013 5.02 TeV		2016 8.16 TeV		2015 5.02 TeV	2017 5.02 TeV	2018 5.02 TeV
	pPb	Pbp	pPb	Pbp	PbPb	XeXe	PbPb
$\mathcal{L}$	1.1 nb^{-1}	0.5 nb^{-1}	13.6 nb^{-1}	20.8 nb^{-1}	10 $\mu\mathrm{b}^{-1}$	0.4 $\mu\mathrm{b}^{-1}$	$\sim$ 210 $\mu\mathrm{b}^{-1}$

- **Fixed Target mode (SMOG):**
  - **$\sqrt{s_{NN}}$: 69-110 GeV**

$$\int \mathcal{L}dt \sim 5\mathrm{nb}^{-1} \times \frac{(protons\ on\ target)}{10^{22}} \times \frac{p_{gas}}{2 \times 10^{-7}\mathrm{mbar}} \times \mathrm{Exp\_efficiency}$$



Setups for proton-ion collisions



- **Forward production:**
  - Center of mass rapidity coverage: $1.5 < y^* < 4.0$
  - $L = 13.5\ nb^{-1}$
- **Backward production:**
  - Center of mass rapidity coverage: $-5.0 < y^* < -2.5$
  - $L = 20.8\ nb^{-1}$

- Rapidity coverage in center of mass frame considers a rapidity shift of about 0.47 w.r.t. the lab frame coverage $2.0 < y < 4.5$
- Common range for the measurements: $2.5 < |y^*| < 4.0$

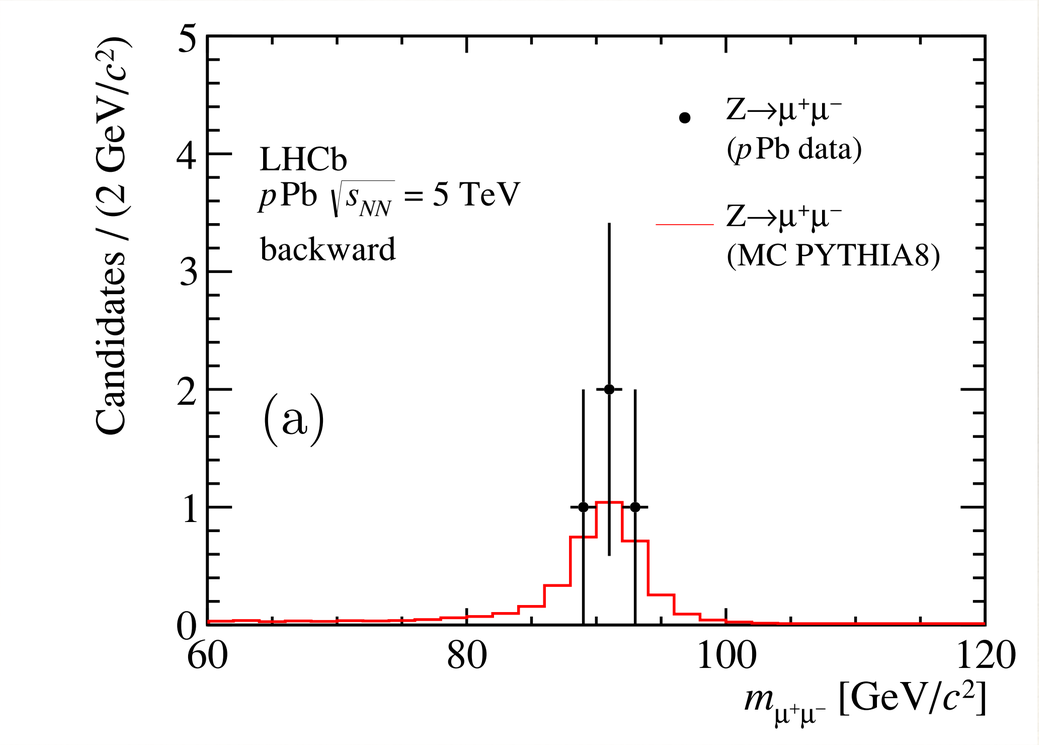
The LHCb EW probe results and projections

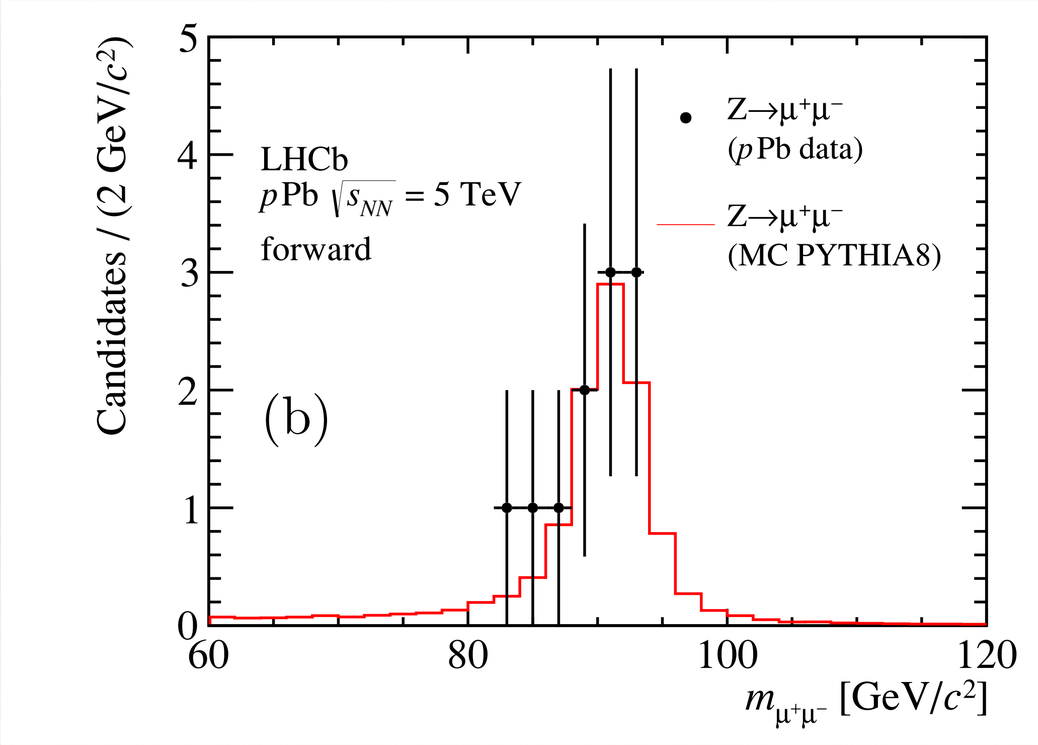
- 5 TeV pPb Z boson production
  【JHEP09(2014)030】
- 8 TeV pPb Z boson production
  【Work in progress, only projection is shown】
- Projections of pPb Drell-Yan production at Run 3 and 4:
  【LHCb-CONF-2018-005】

5 TeV pPb Z boson production

- 5 TeV pPb (2013 dataset) Z boson production
- Integrated luminosity: forward (1.099 ± 0.021 nb^{-1}) / backward(0.521 ± 0.011 nb^{-1})
- Yields: backward (4 events) / forward (11 events)

【JHEP09(2014)030】





5 TeV pPb Z boson production

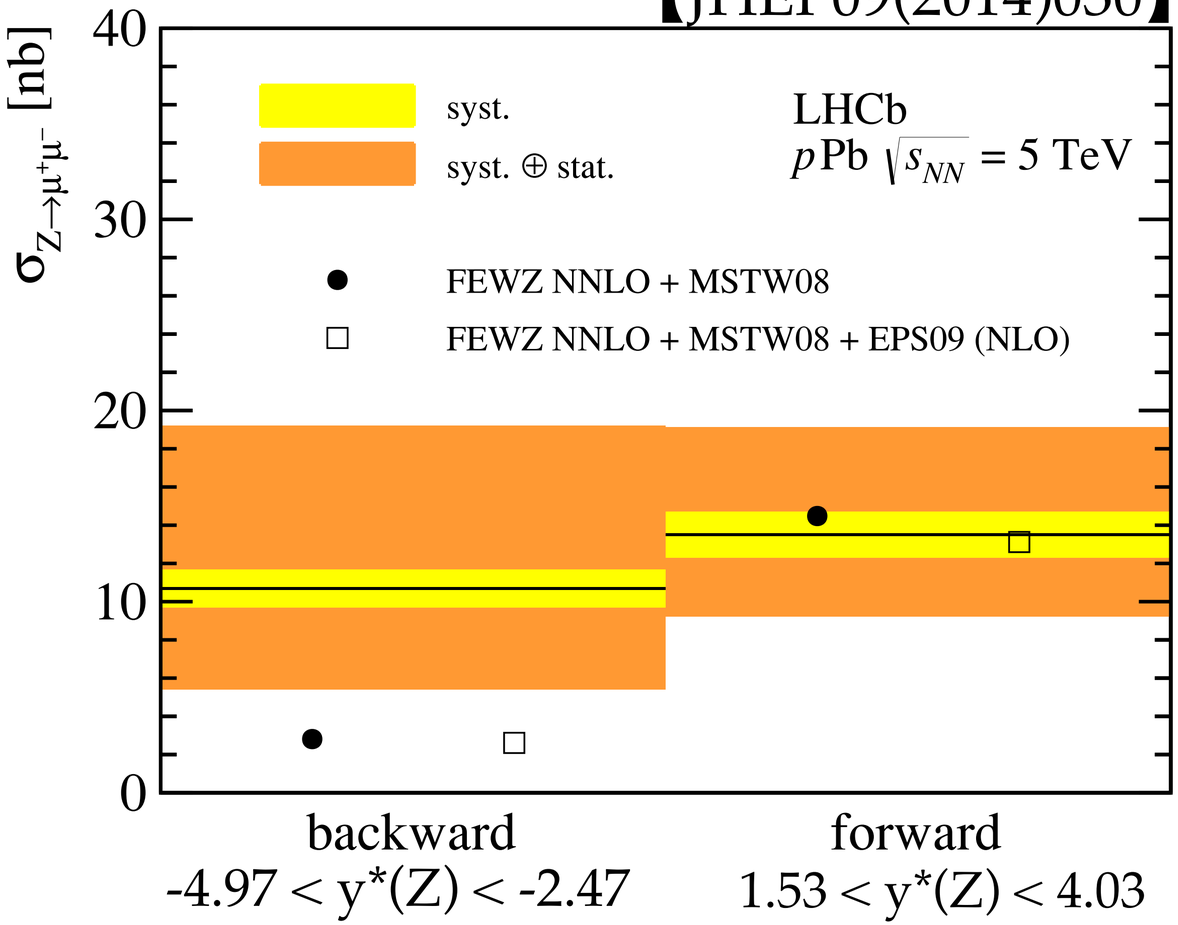
- cross-sections in acceptance:
  $60<m_{\mu^+\mu^-}<120$ GeV,
  $p_T(\mu^\pm)>20$GeV,
  $2.0<\eta(\mu^\pm)<4.5$
- Results:
  - Forward:

$$\sigma_{Z\to\mu^+\mu^-}(\text{fwd}) = 13.5^{+5.4}_{-4.0}(\text{stat.}) \pm 1.2(\text{syst.})\ \text{nb}$$

  - Backward:

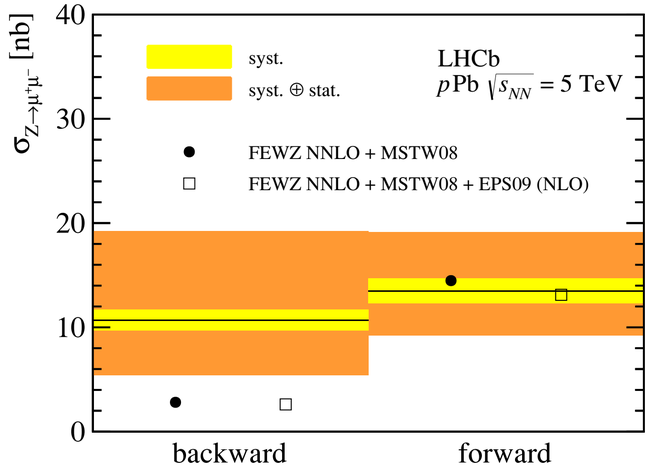
$$\sigma_{Z\to\mu^+\mu^-}(\text{bwd}) = 10.7^{+8.4}_{-5.1}(\text{stat.}) \pm 1.0(\text{syst.})\ \text{nb}$$

【JHEP09(2014)030】



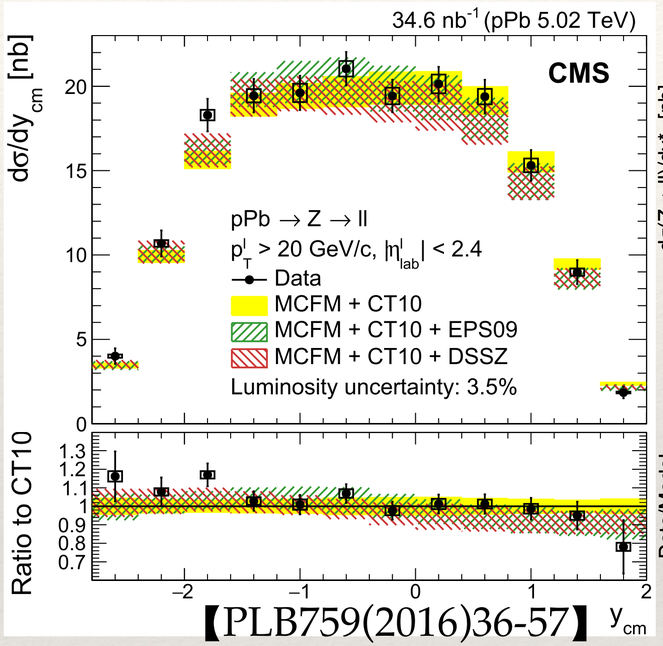
Compare with other experiments

LHCb



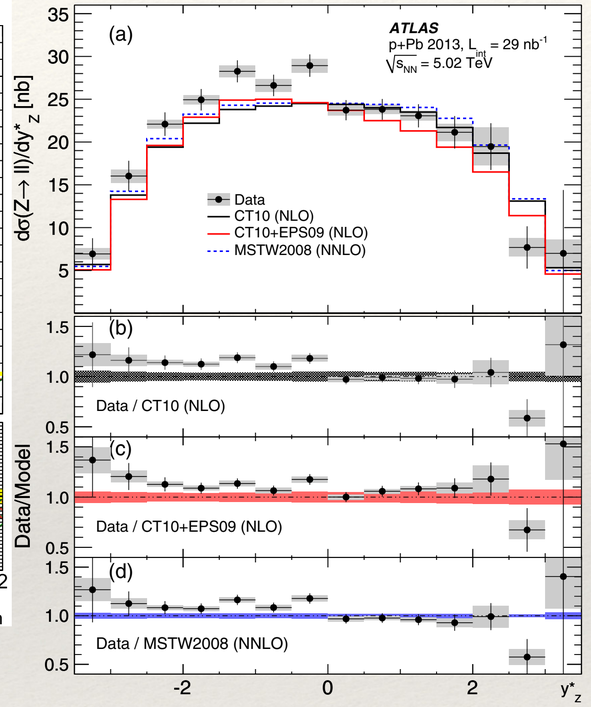
【JHEP09(2014)030】

CMS



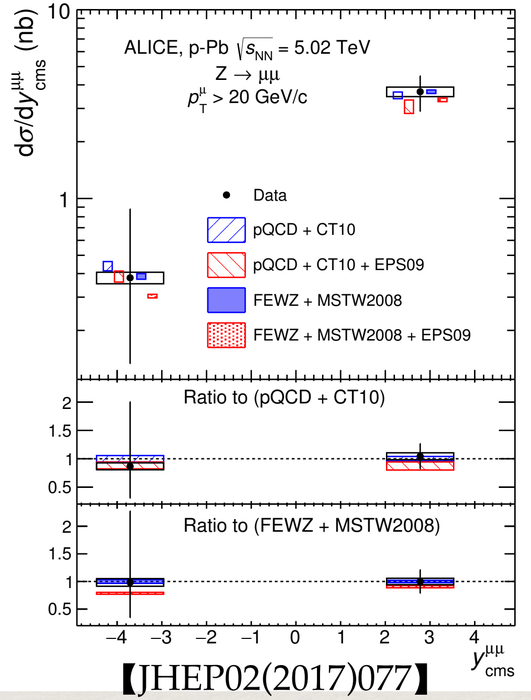
【PLB759(2016)36-57】

ATLAS



【PRC92,044915(2015)】

ALICE



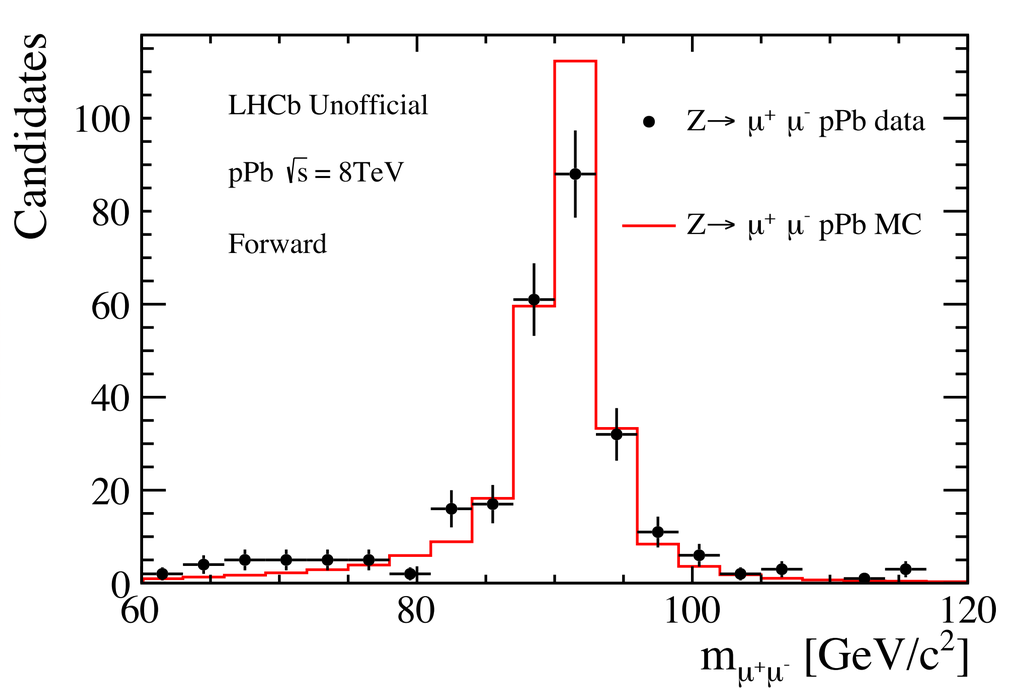
【JHEP02(2017)077】

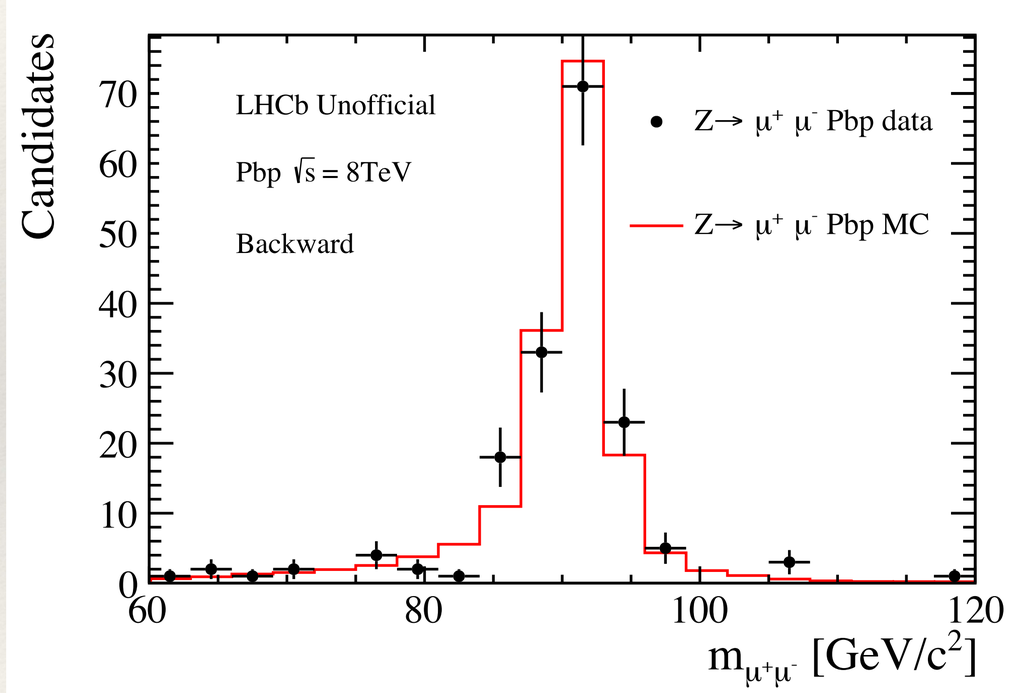
- Forward: all show good agreement
- Backward:
  - LHCb, CMS and ATLAS : theory prediction below data measurement
  - ALICE: good agreement, but data error bar is huge.

Need higher precision!

8 TeV pPb Z boson production

- 8 TeV pPb (2016 dataset) Z boson production (expected to be ready for QM 2019)
- Integrated luminosity: forward (12.18 $\pm$ 0.32 nb^{-1}) / backward(18.58 $\pm$ 0.46 nb^{-1})





Plots are confidential on this page! **not efficiency corrected.**

8 TeV pPb Z boson production

- Projection based on 2013 5 TeV results

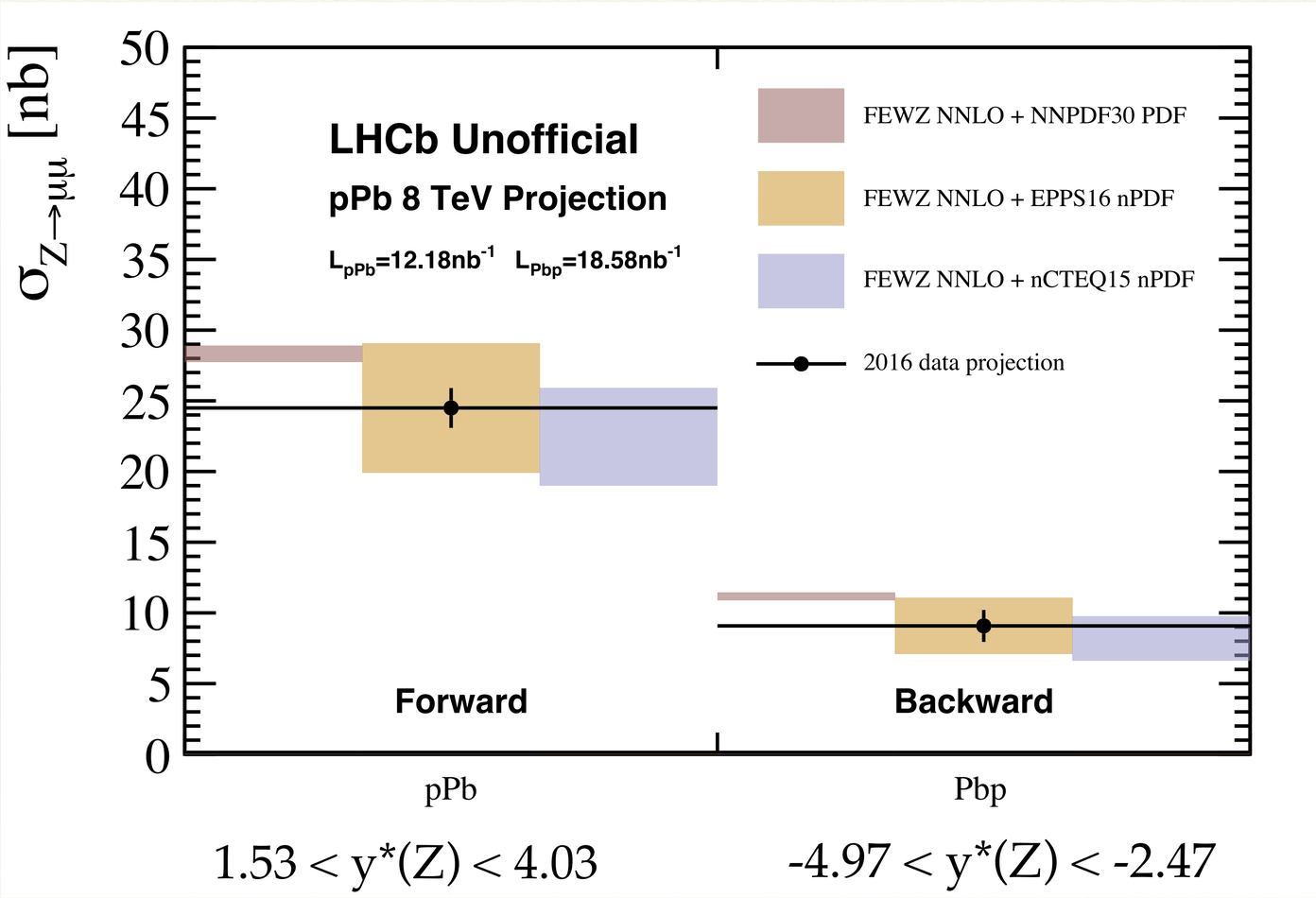
Central values:

FEWZ NNLO + EEPS16 nPDFs

Projected uncertainties:

- **forward: 4.7/sqrt(12.18/1.099) = 1.41 nb**
- **backward: 6.75/sqrt(18.58/0.521) = 1.13 nb**

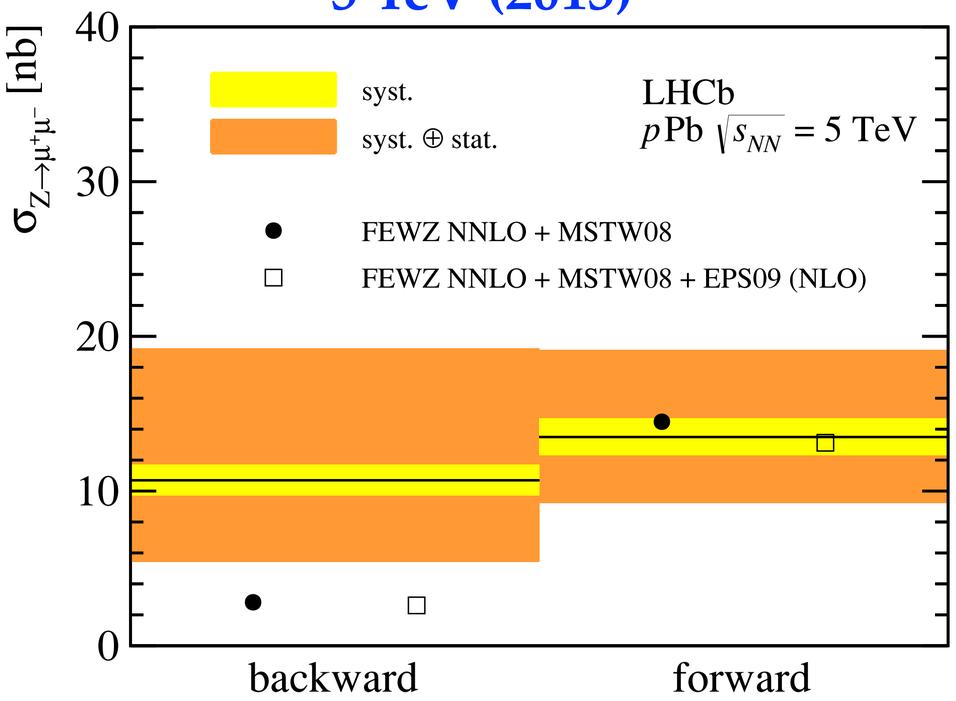
much higher statistics, higher precision!



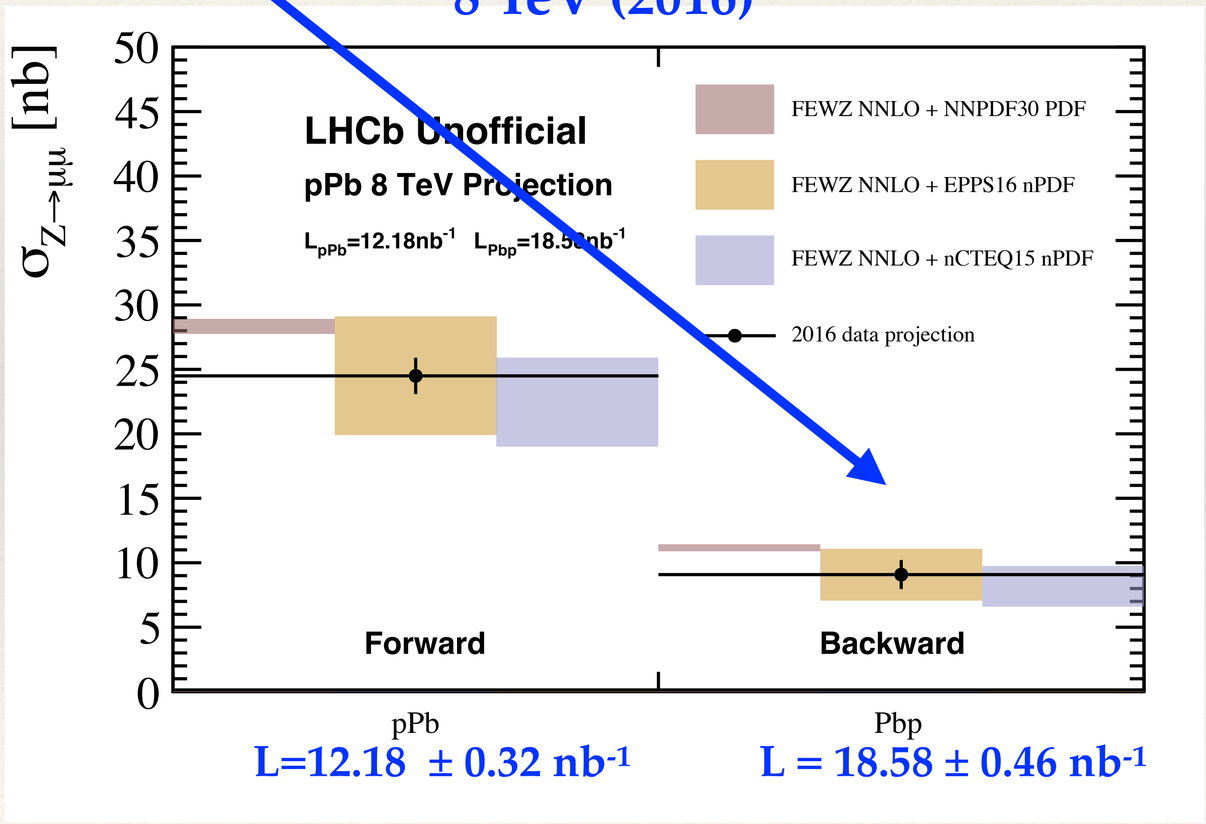
8 TeV pPb Z boson production

With the 2016 8 TeV dataset higher precision, it would be interesting to see if measured value is still higher than the theory prediction!

5 TeV (2013)



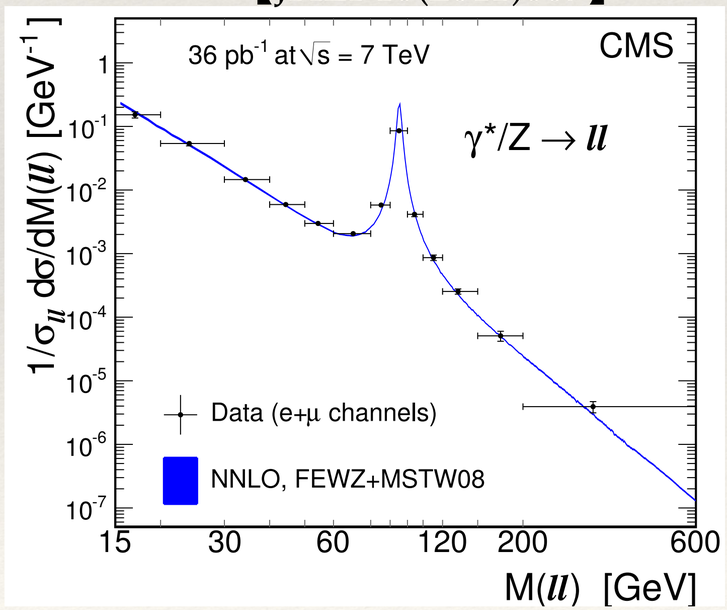
8 TeV (2016)

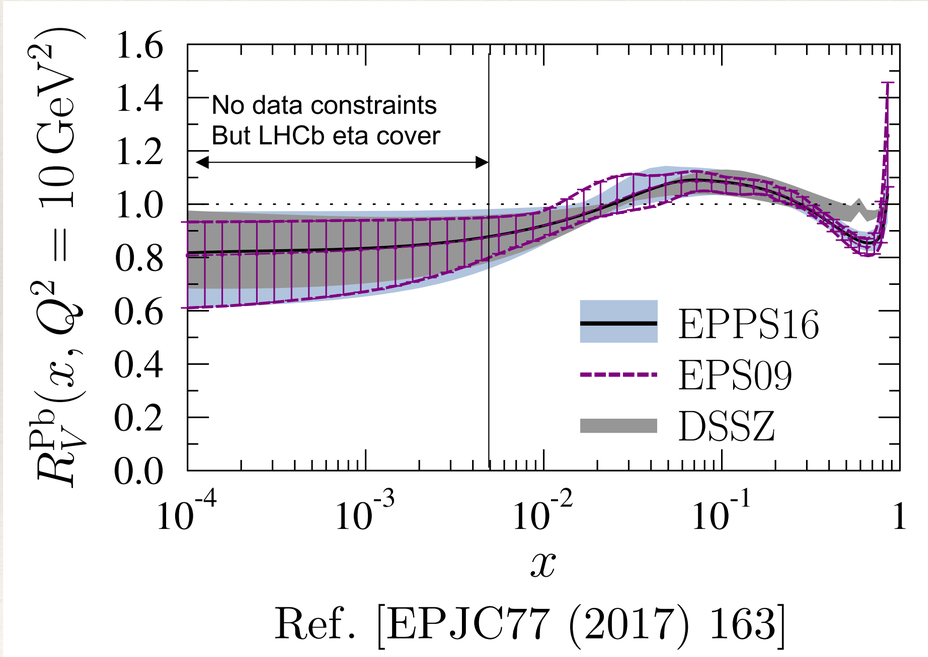


Projection of Drell-Yan R_{pPb} to Run 3 and 4

- With high statistics in Run 3 and 4, a full DY mass spectrum can be used to constraint the nPDFs,
- esp. gluon nPDFs at small Bjorken-x with Q^2 down to 10 GeV^2.
  - gluon saturation could be observed
  - a reference measurement wrt heavy flavor productions
    - heavy quark production can be used to constraint gluon nPDFs
    - but can be heavily modified by energy loss

【JHEP10(2011)007】





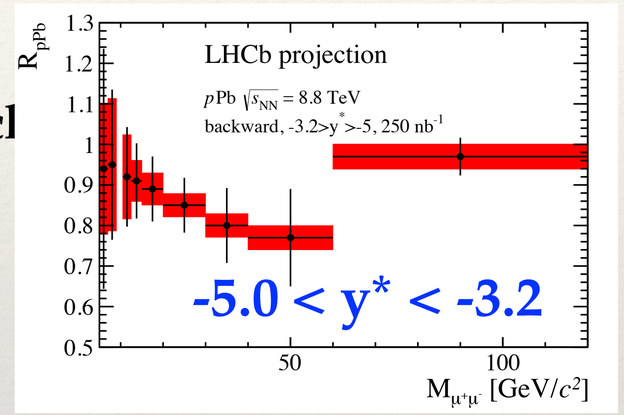
Ref. [EPJC77 (2017) 163]

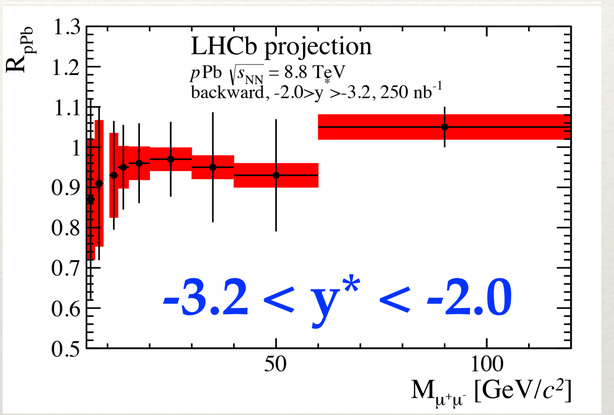
Projection of DY R_{pPb} to Run 3 and 4

LHCb-CONF-2018-005

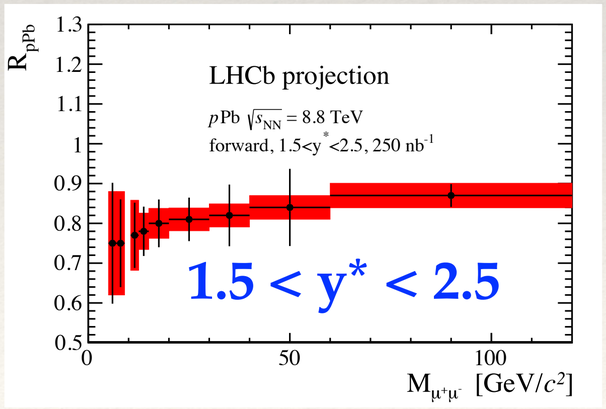
- **Projection assumes (HL-LHC yellow report WG5):**
  - **sqrt(sNN) = 8.8 TeV**
  - **pPb L = 500 nb^{-1} in total (250 nb^{-1} for pPb and Pbp eacl**
  - **pp reference L = 104 pb^{-1}**
- **Projection based on Run 1 pp measurement:**
  - **yields ~ 4.6k forward Z, and 2k backward Z.**
- **Projected Central values take :**
  - **EPPS 16 nPDF at NNLO**

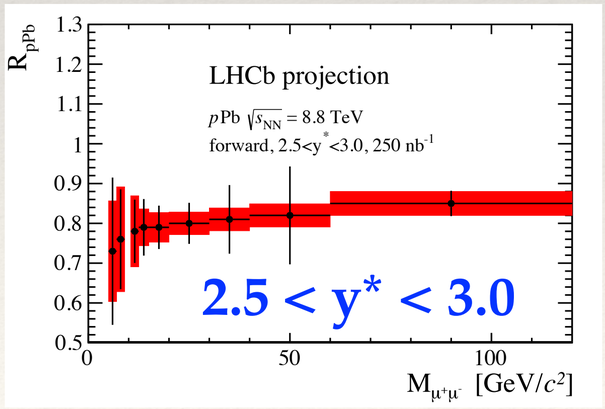
backward

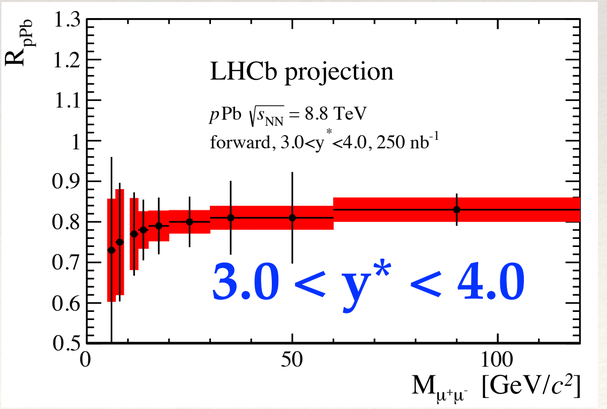




forward



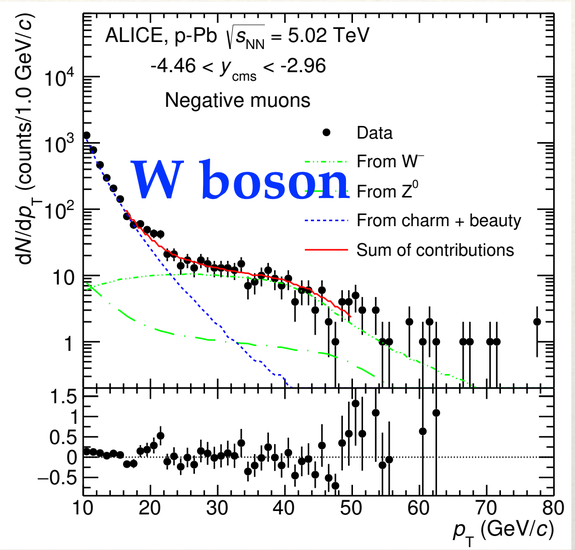


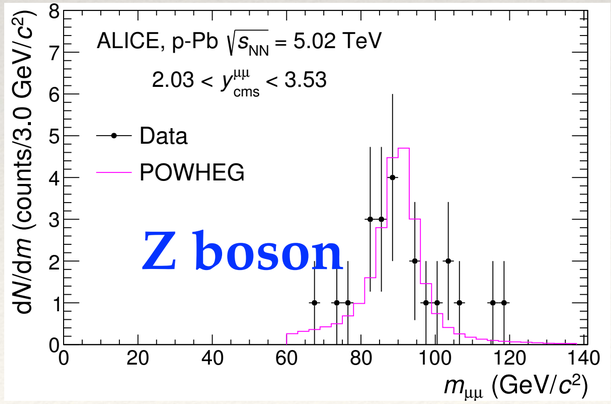


What else can we do at LHCb?

【JHEP02(2017)077】

- How about W at pPb?
  - Yes, we can do it. One just need to model the backgrounds + a fit using muon p_T spectrum
  - W cross-section is O(10) times larger than Z.
  - Projections:
    - 2013 5 TeV: >100 W bosons
    - 2015 7 TeV: > 3k W bosons





What else can we do at LHCb?

- **How about W/Z at PbPb?**
  - **Possible, limited by statistics so far:**

	2013		2016		2015	2017	2018
$\sqrt{s_{NN}}$	5.02 TeV		8.16 TeV		5.02 TeV	5.02 TeV	5.02 TeV
	pPb	Pbp	pPb	Pbp	PbPb	XeXe	PbPb
$\mathcal{L}$	1.1 nb^{-1}	0.5 nb^{-1}	13.6 nb^{-1}	20.8 nb^{-1}	10 μb^{-1}	0.4 μb^{-1}	$\sim$ 210 μb^{-1}

  - **Projections based on 2013 pPb Z production results:**
    - **2015 PbPb: several Z bosons, < tens W boson**
    - **2018 PbPb: tens Z bosons, hundreds W bosons**

Conclusion and outlook

- LHCb provides a unique opportunity to probe the cold nuclear matter effects using W/Z boson production
- pPb->Z boson production at 5 TeV is published
- pPb->Z boson production at 8 TeV is expected to be public for QM 2019
- pPb->W boson production measurement is under proposal
- Projection of pPb DY production to Run 3 and 4 shows a chance to probe low Bjorken-x at low Q^2 (not only Q^2 at WZ mass scale)
- Expecting to have more PbPb data to perform