Measurement of the Z^0 boson production in p–Pb collisions at 5.02 TeV with ALICE

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JRJC 2015
La Saulaie, Chedigny

Outline

- Introduction and physics motivation

- Experimental apparatus
  - ALICE detector
  - Analysed data and beams configuration

- The analysis
  - Events selection and signal extraction
  - MC simulation and efficiency correction
  - Background contribution

- Results
  - Compared with theory
  - Compared to other experimental results

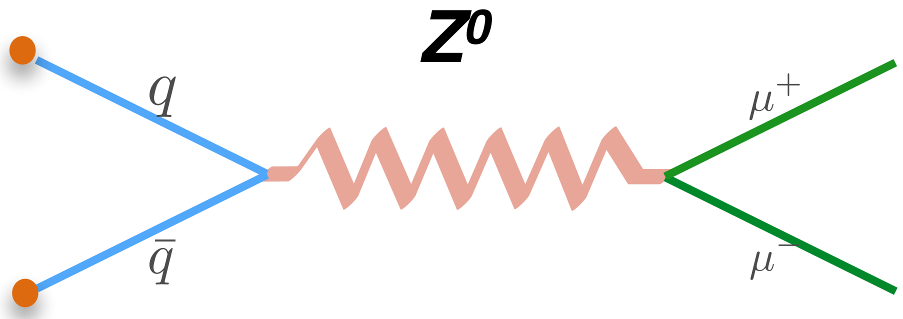
- Conclusion and perspectives

Introduction = Answer for these questions

- What is the Z boson ?
  - How is produced ?
  - How does decay ?
- What are PDFs ?
  - What is different in heavy-ions collisions ?
  - What is a nuclear PDF set ?
  - How can we constrain it ?
- How can we use the Z boson in constraining those sets ?
  - Why the Z boson is a good probe for nuclear effects ?

Introduction and Motivation I

- The Z^0 is one of the three gauge bosons that carry the weak interaction
- The Z^0 boson production is dominated by the quark-antiquark annihilation process
- Z^0 boson decays to muon pair with 3% branching ratio.



- In p-p collisions, the Z^0 boson production is measured with high precision with different experiments.
- This production is sensitive to the PDF : $f(x,Q^2)$

$$\begin{cases} Q^2 \equiv M_Z^2 \\ x = (M_Z/\sqrt{s_{NN}})e^{\pm y} \text{ is the fraction of the nucleon momentum carried by the parton (q)} \end{cases}$$

Introduction and Motivation II

- In heavy-ions collisions, the PDFs are affected by the presence of a nuclear medium → Nuclear Shadowing
- One should define the nuclear PDF : $f_A(x,Q^2) = R(x,Q^2,A)\times f(x,Q^2)$

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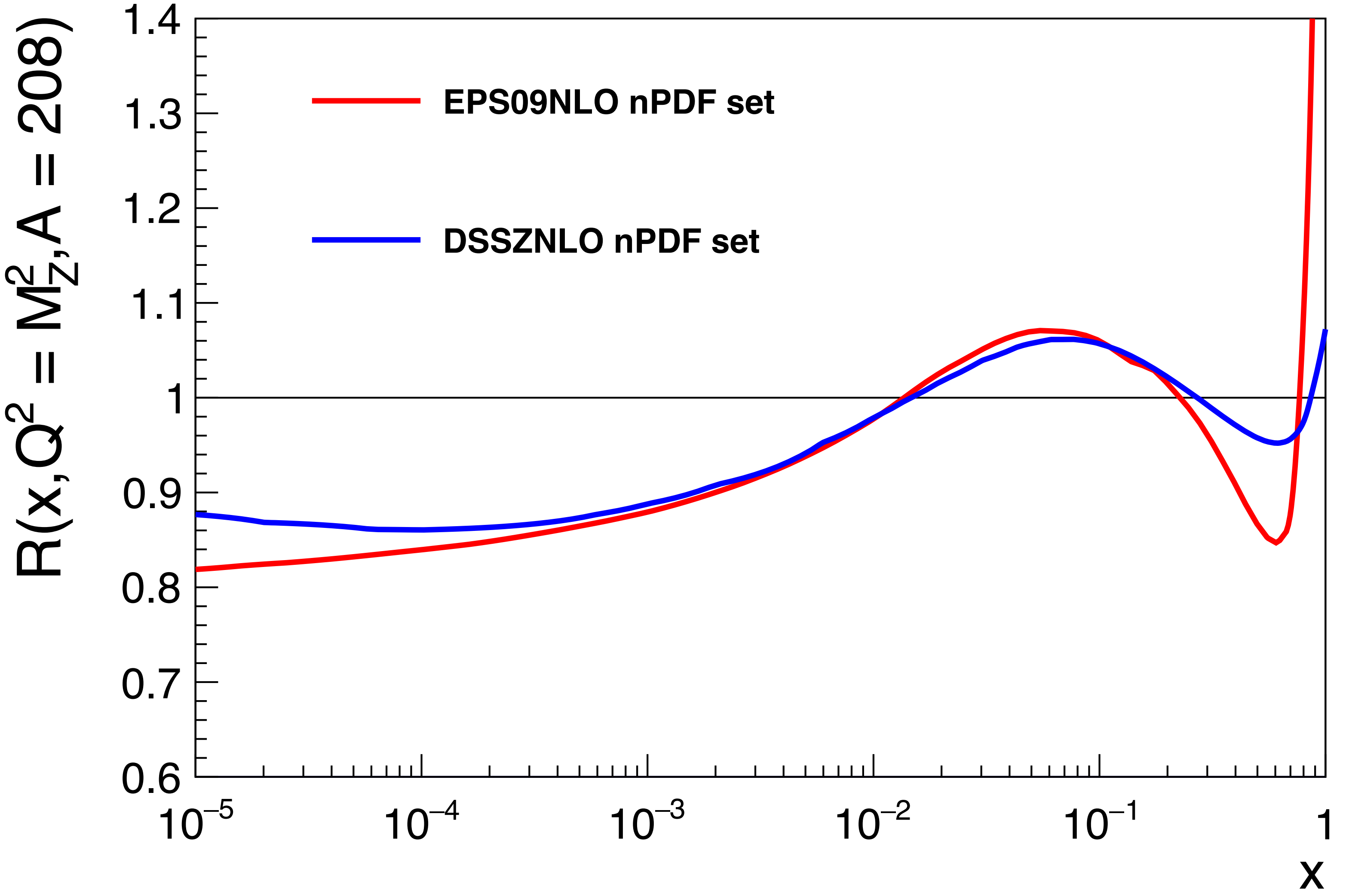

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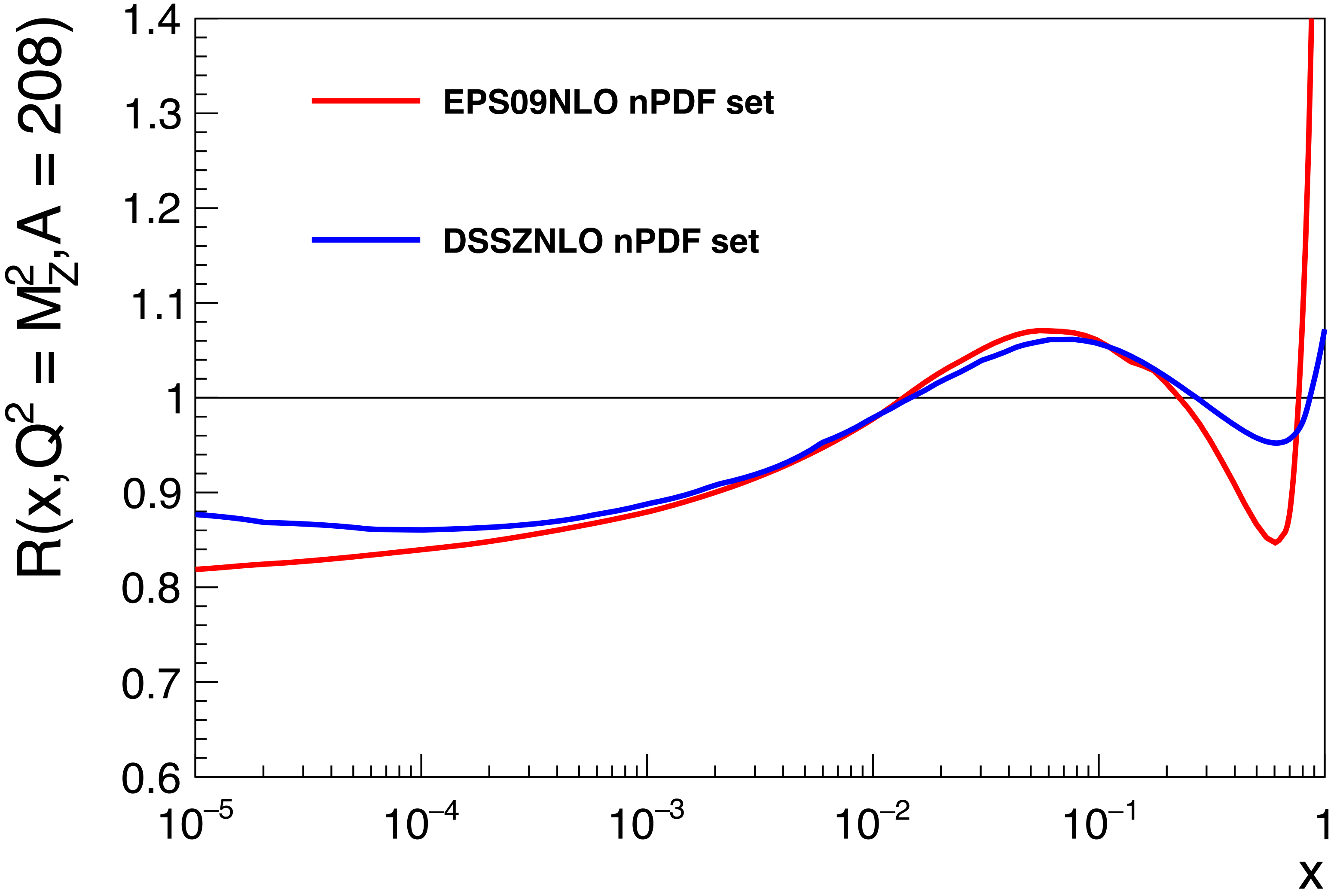
- One should define the nuclear PDF : $f_A(x,Q^2) = R(x,Q^2,A) \times f(x,Q^2)$
- Due to the lack of the experimental data, nPDF are less known than the PDF.



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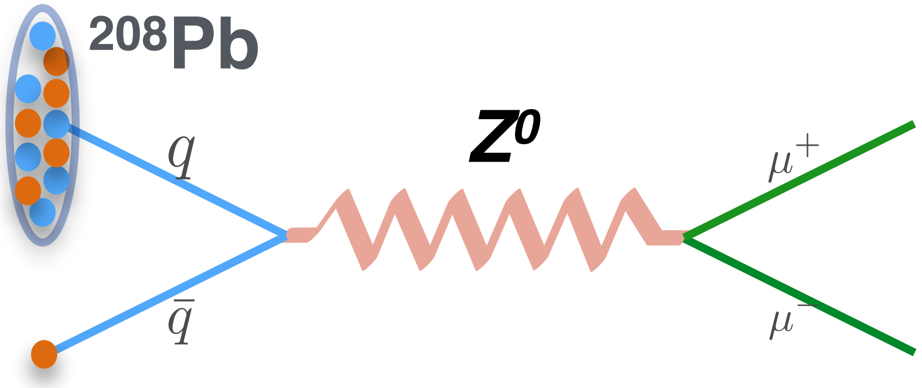

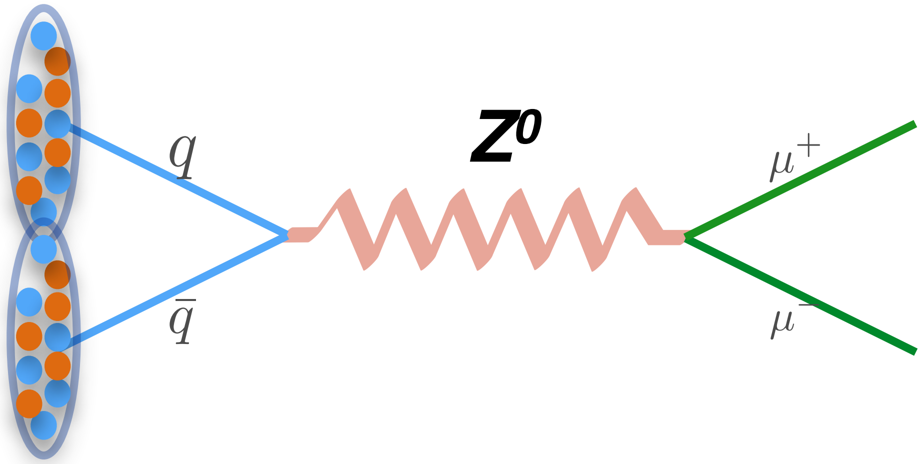

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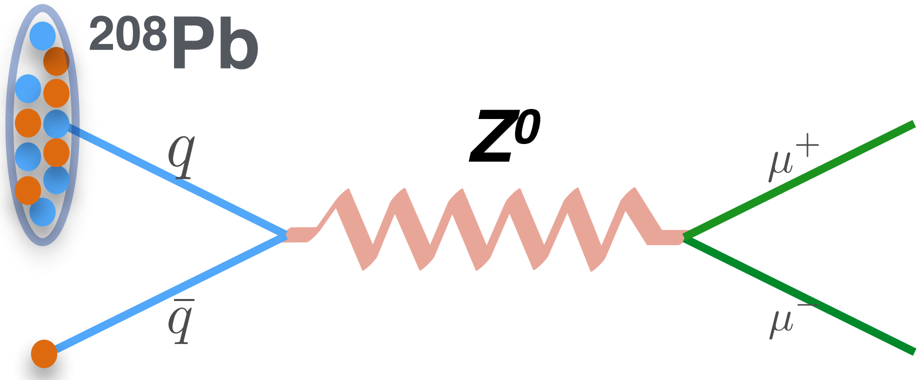

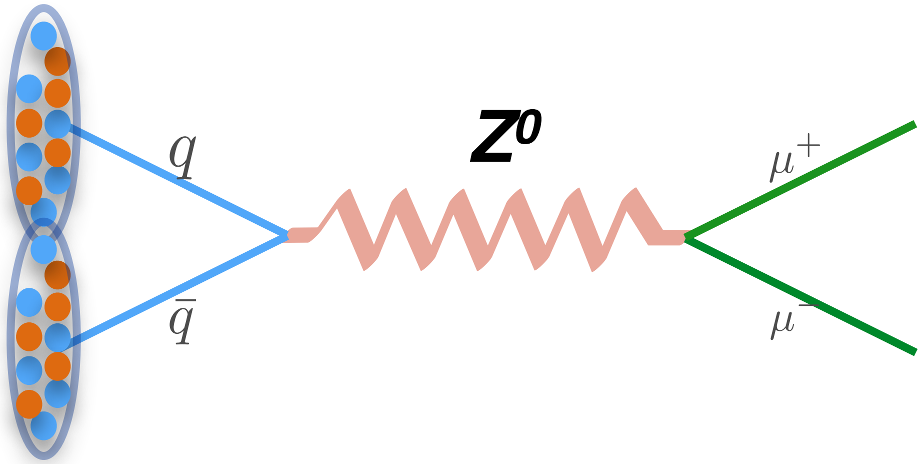

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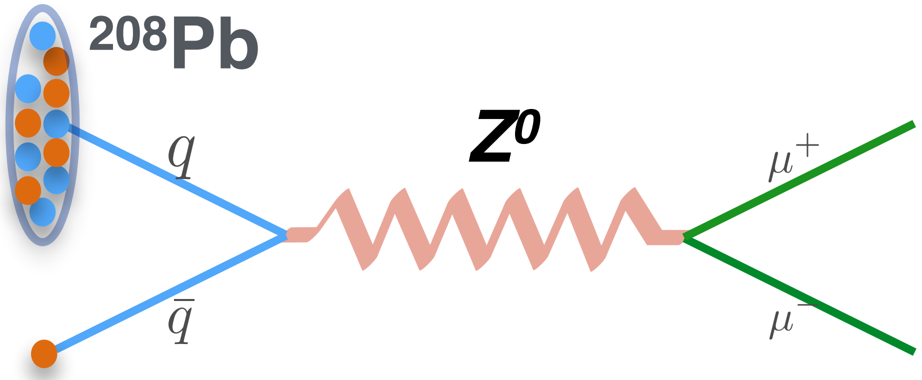

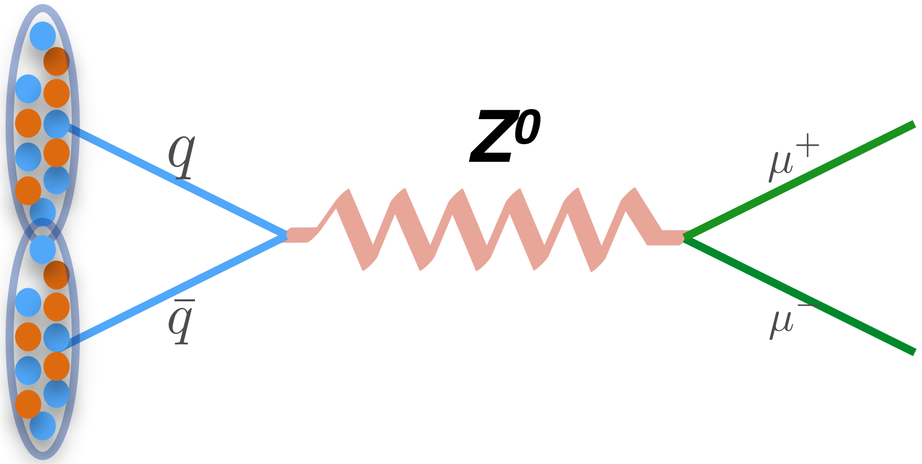

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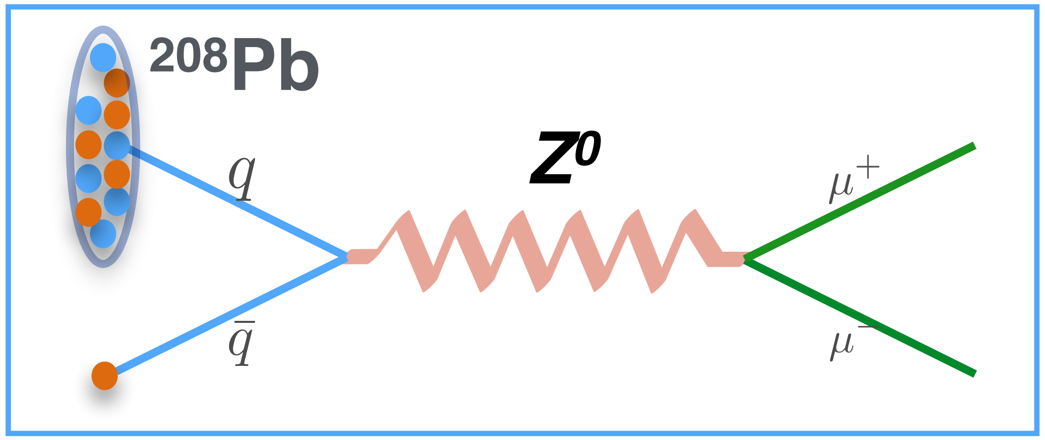

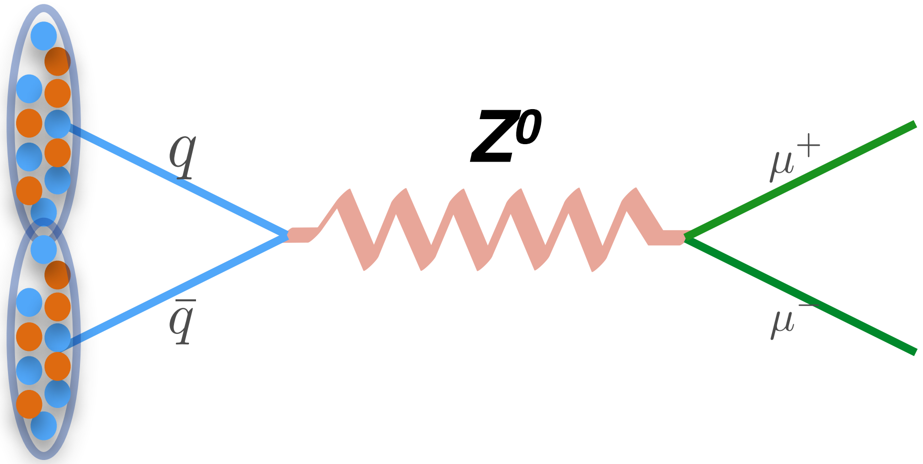

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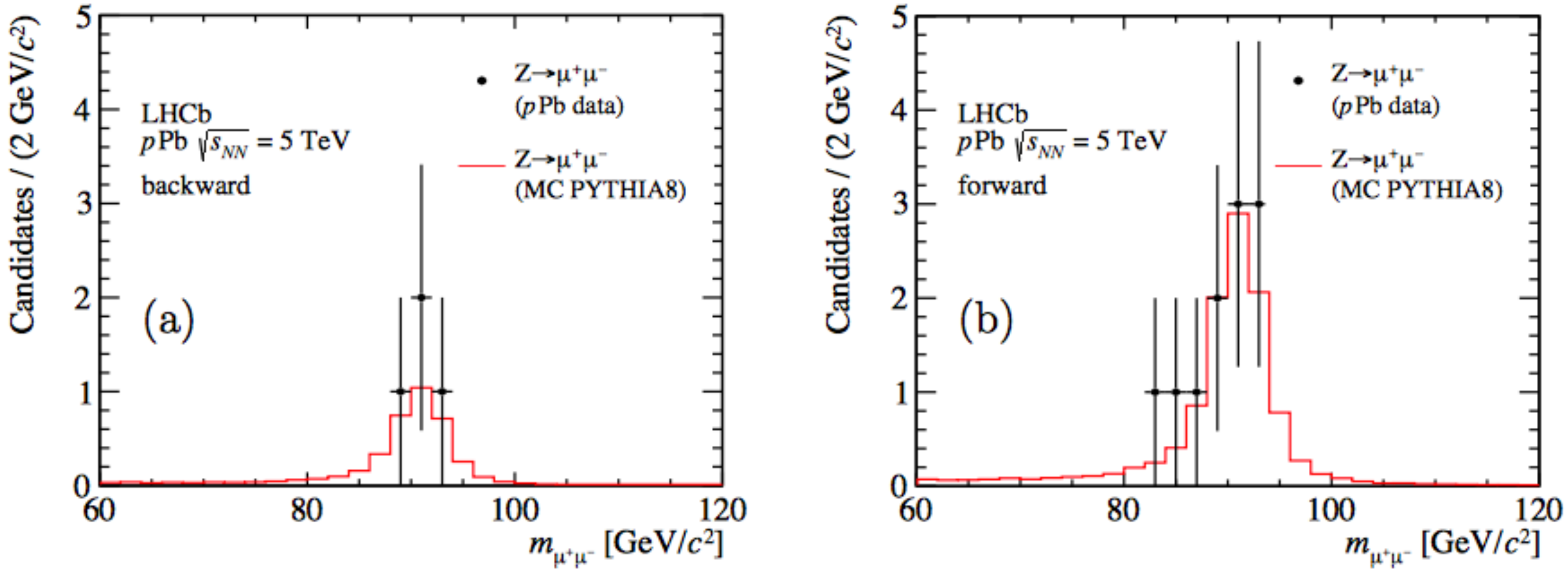
Introduction and Motivation IV

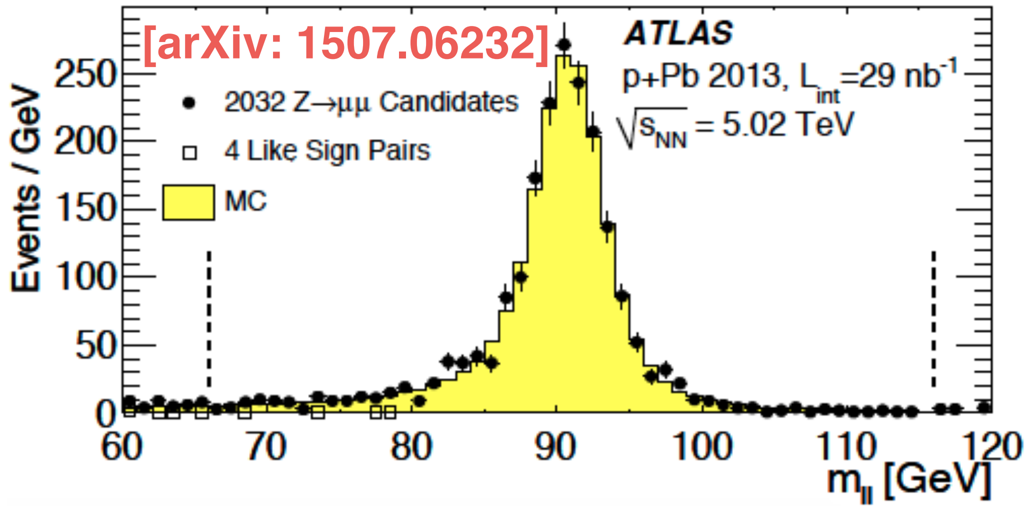
The Z^0 boson production in p-Pb collisions is measured by other experiments:

1- LHCb

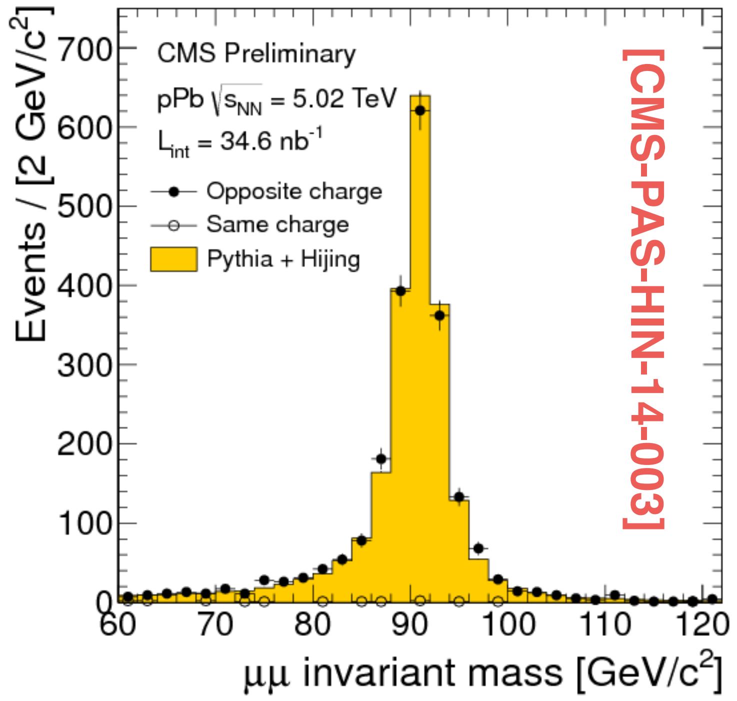
[JHEP 09 (2014) 030]



2- ATLAS and CMS

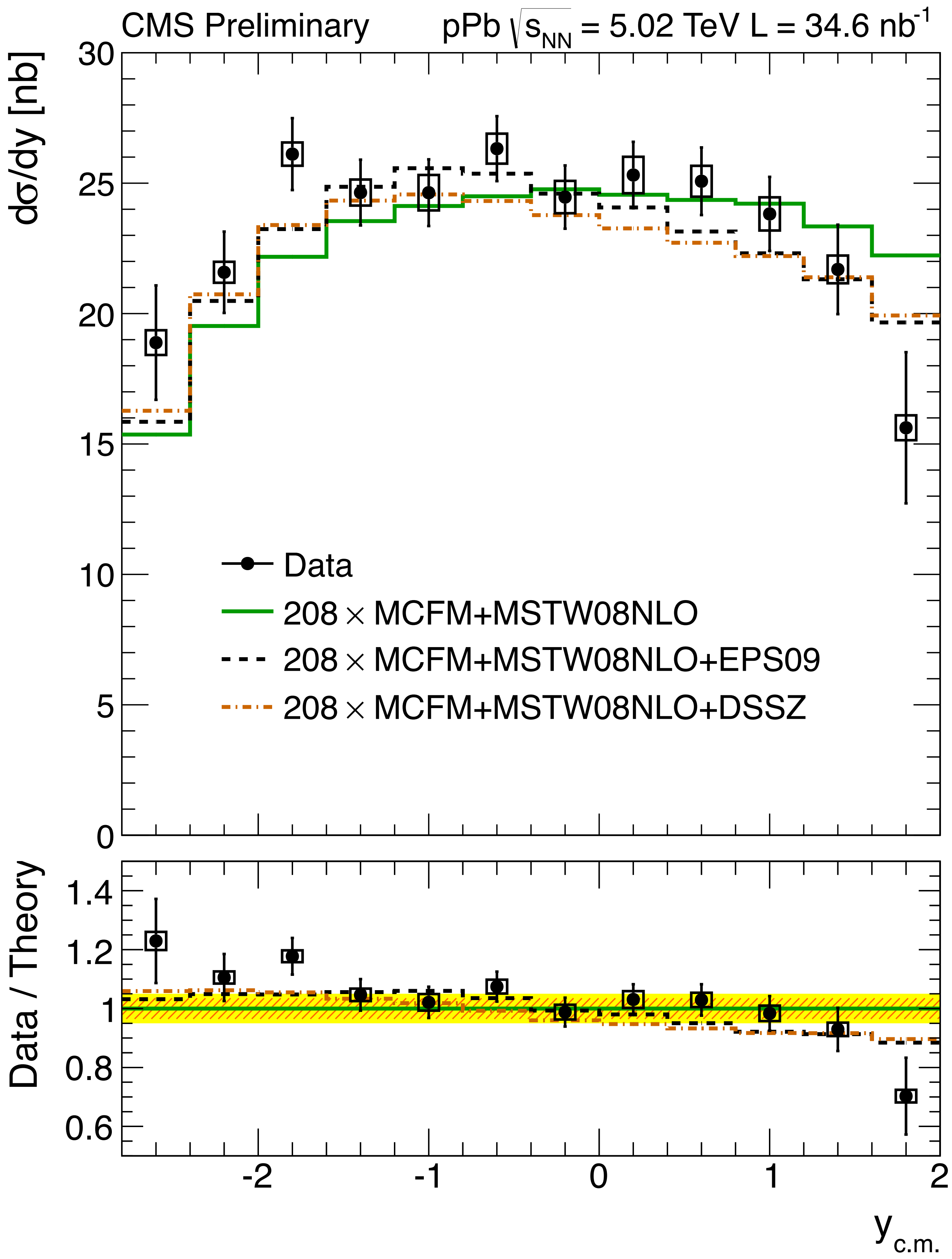


[arXiv: 1507.06232]



[CMS-PAS-HIN-14-003]

Introduction and Motivation V



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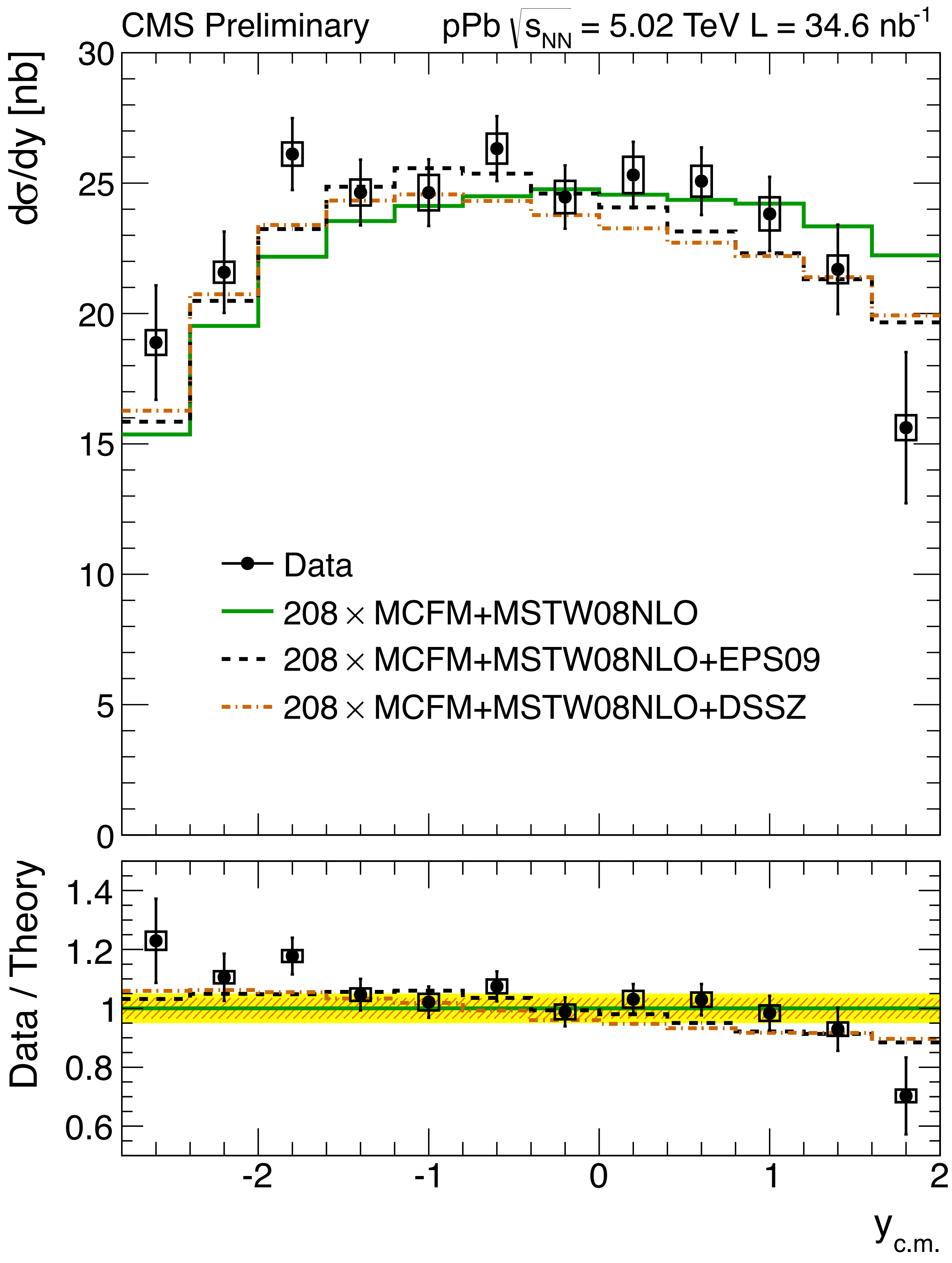
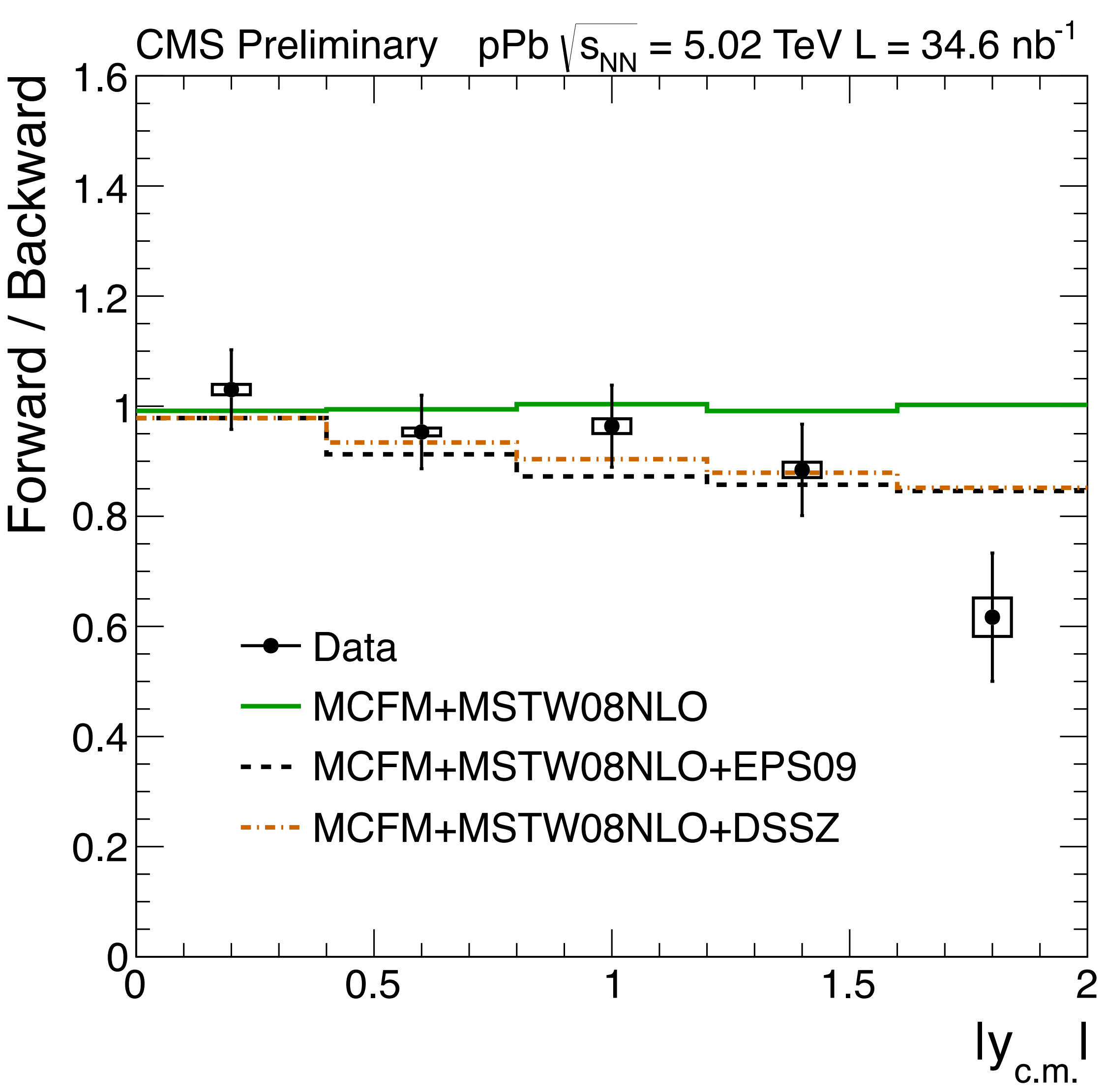
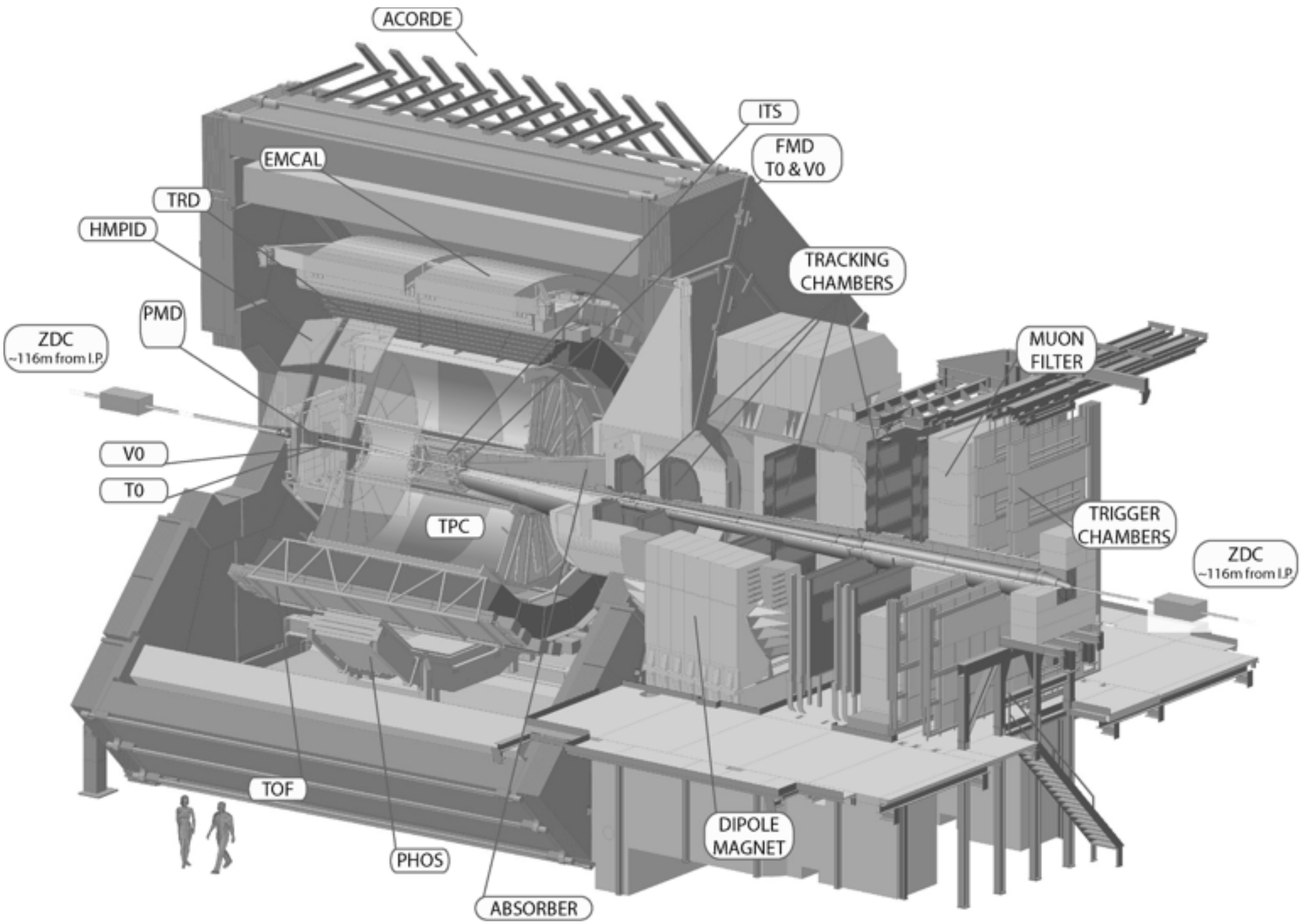




$$R_{FB}(|y|) = \frac{\sigma_{+|y|}}{\sigma_{-|y|}}$$

- Better quantity to test the nPDF sets.
- Uncertainty on the PDF is cancelled for the theory predictions.

ALICE Detector



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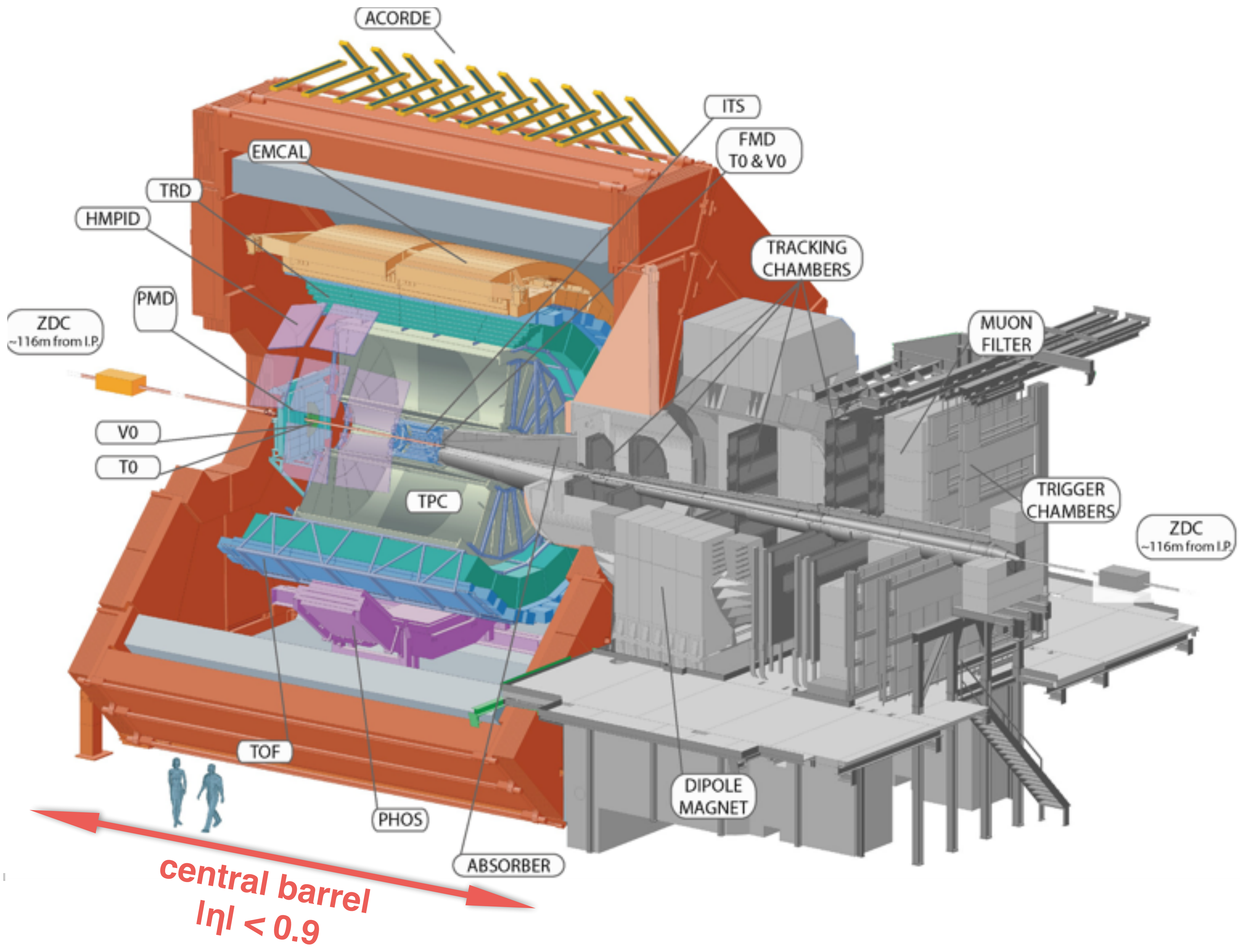

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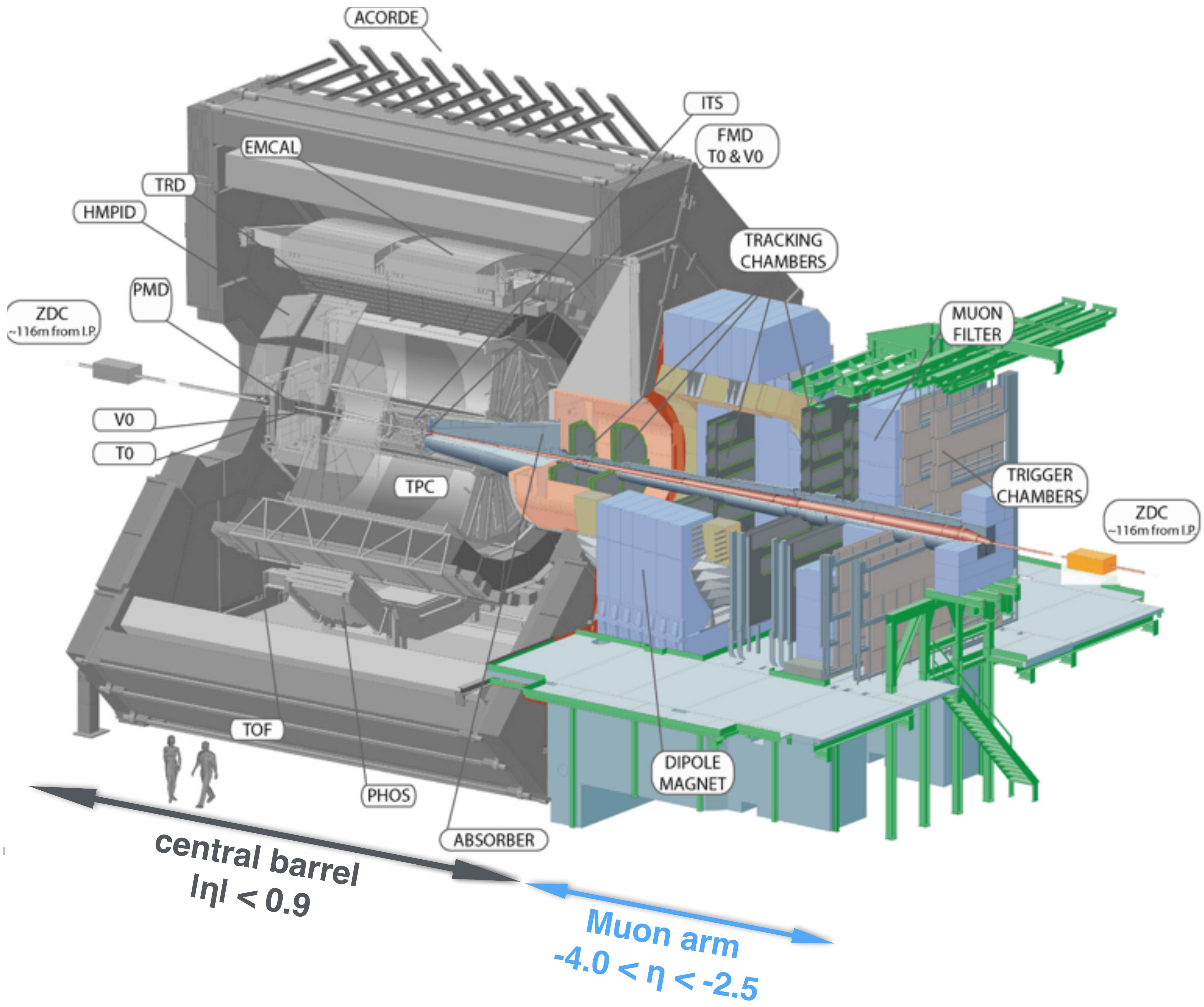

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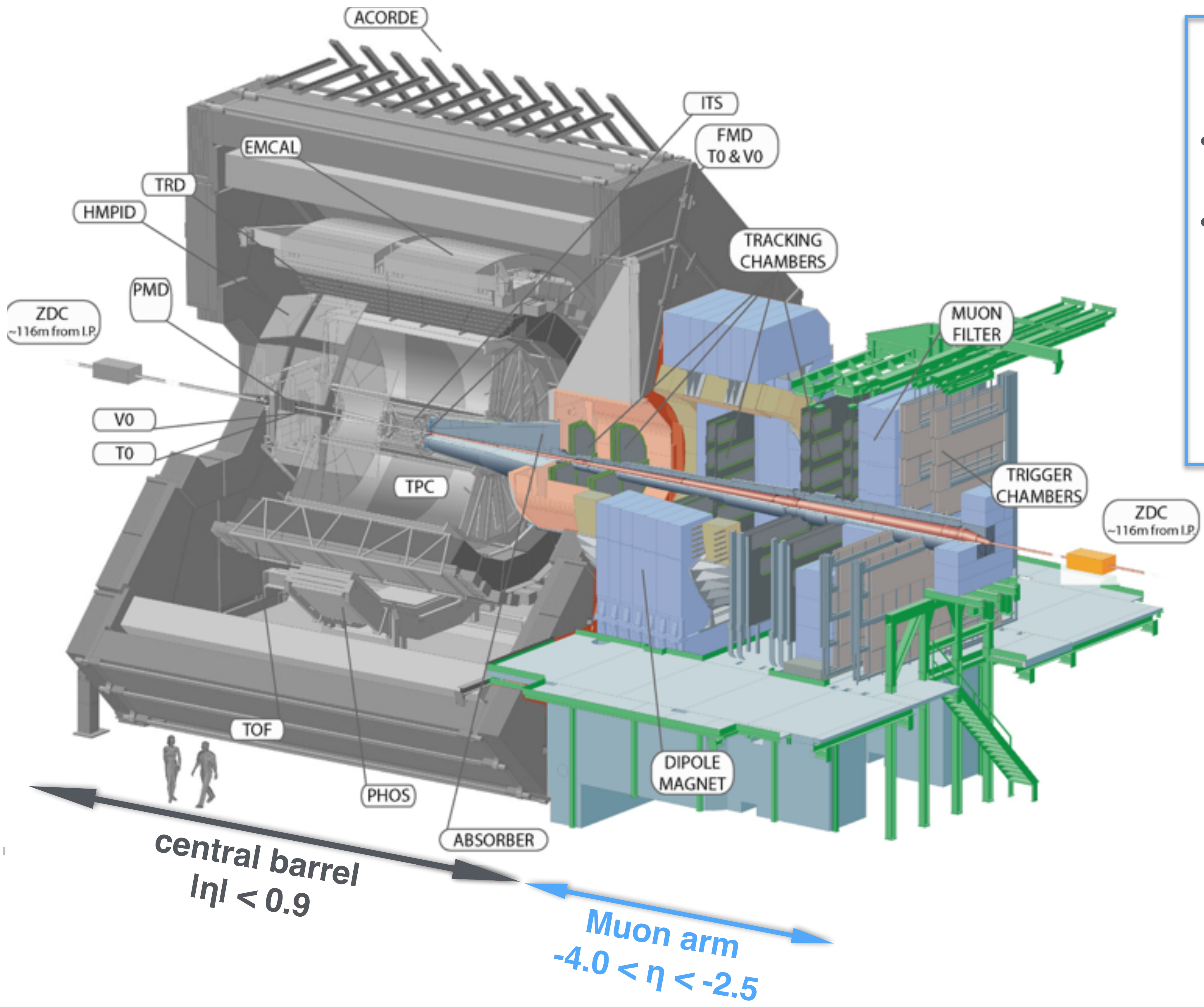
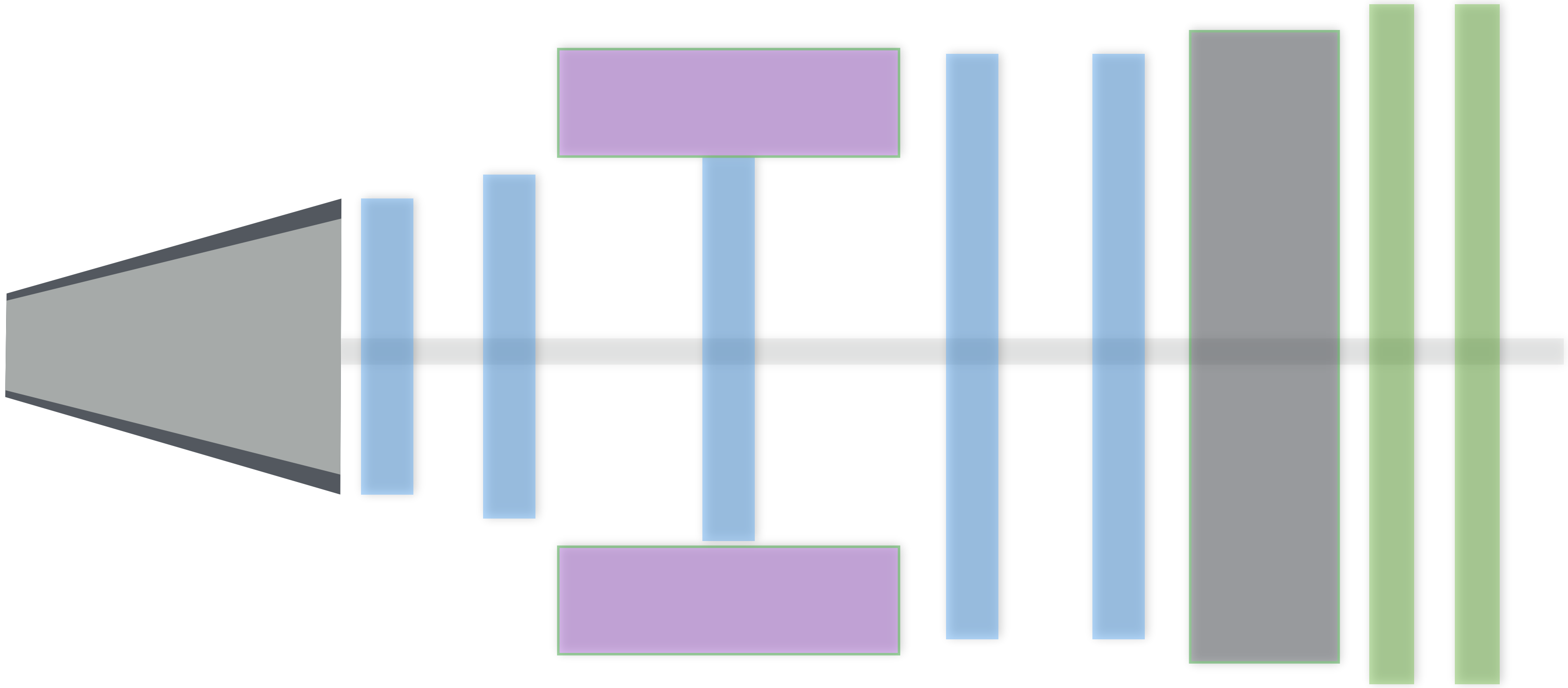


$Z \rightarrow \mu^+ \mu^-$

- Detected in the muon arm
- Region covered by **LHCb and** Complementary to **ATLAS** and **CMS** one

Muon Spectrometer



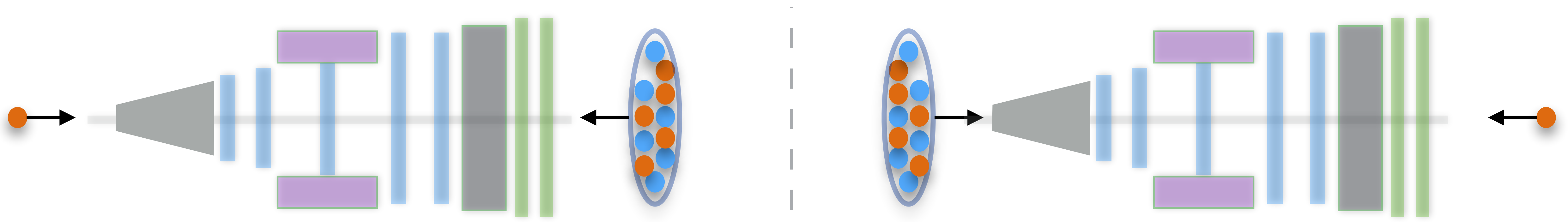
Acceptance	
polar / azimuthal angular coverage	[171°,178°] / 360°
minimum muon momentum/ transverse momentum	4 GeV/c / 0.5 GeV/c
pseudo-rapidity	$-4 < \eta < -2.5$

Front absorber	
Thickness	4.3 m (60 χ_0)
Dipole magnet	
Nominal field / field integral	0.67 T / 3 Tm
5 tracking stations	
Nb of chambers per station	2
Spatial resolution (bending plane)	~70 µm
2 trigger stations	
Nb of chambers per station	2

Analysed Data

- Data used in this analysis taken in 2013.
- The single magnet design of the LHC resulted in beams energy asymmetry.

CM rapidity is shifted w.r.t Lab one and two rapidity regions corresponding to two beams configuration



$$2.03 < y_{cm} < 3.53$$

$$10^{-3} < x < 10^{-2}$$

$$L_{int} = 5.01 \pm 0.20\ \text{nb}^{-1}\ \text{(dimuon)}$$

$$-4.46 < y_{cm} < -2.96$$

$$0.2 < x < 1$$

$$L_{int} = 5.81 \pm 0.20\ \text{nb}^{-1}\ \text{(dimuon)}$$

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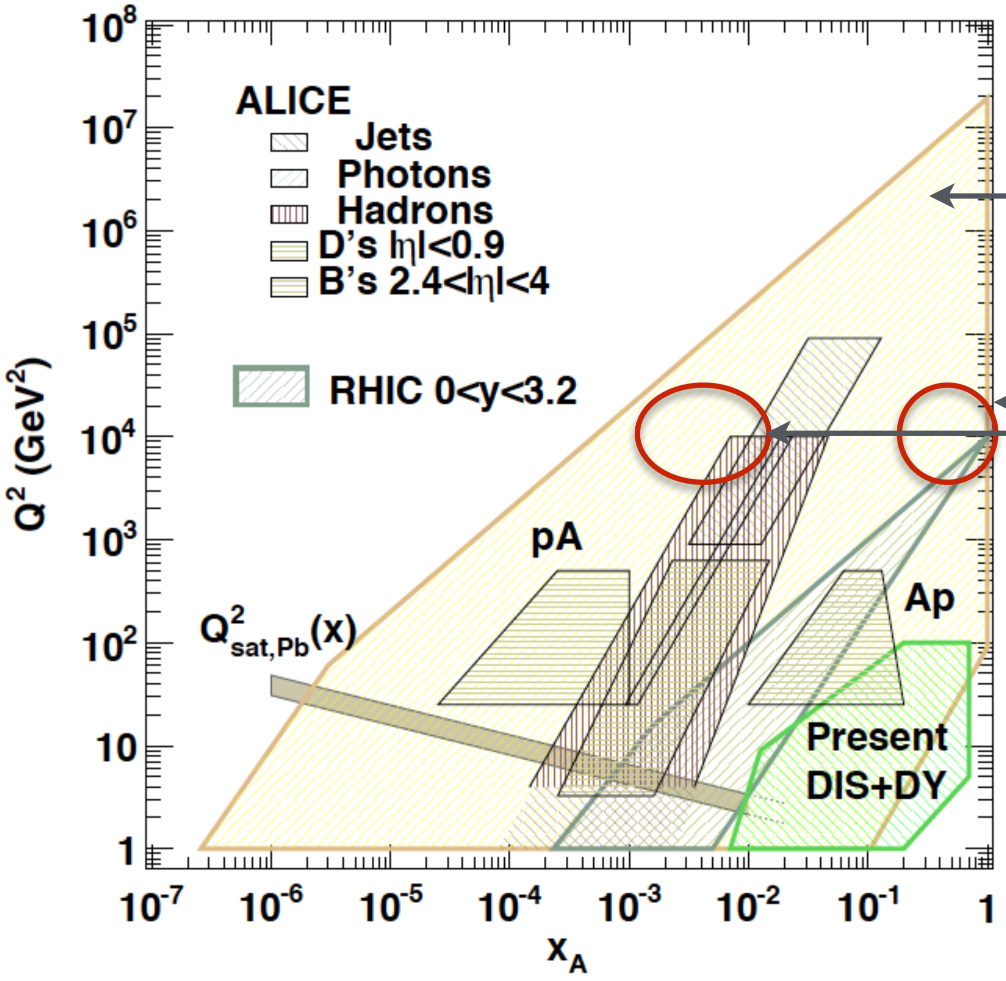

Maximum kinematic reach of LHC in probing the nPDF

phase space probed with this analysis in the two rapidity regions

[J.Phys. G39 (2012) 015010]

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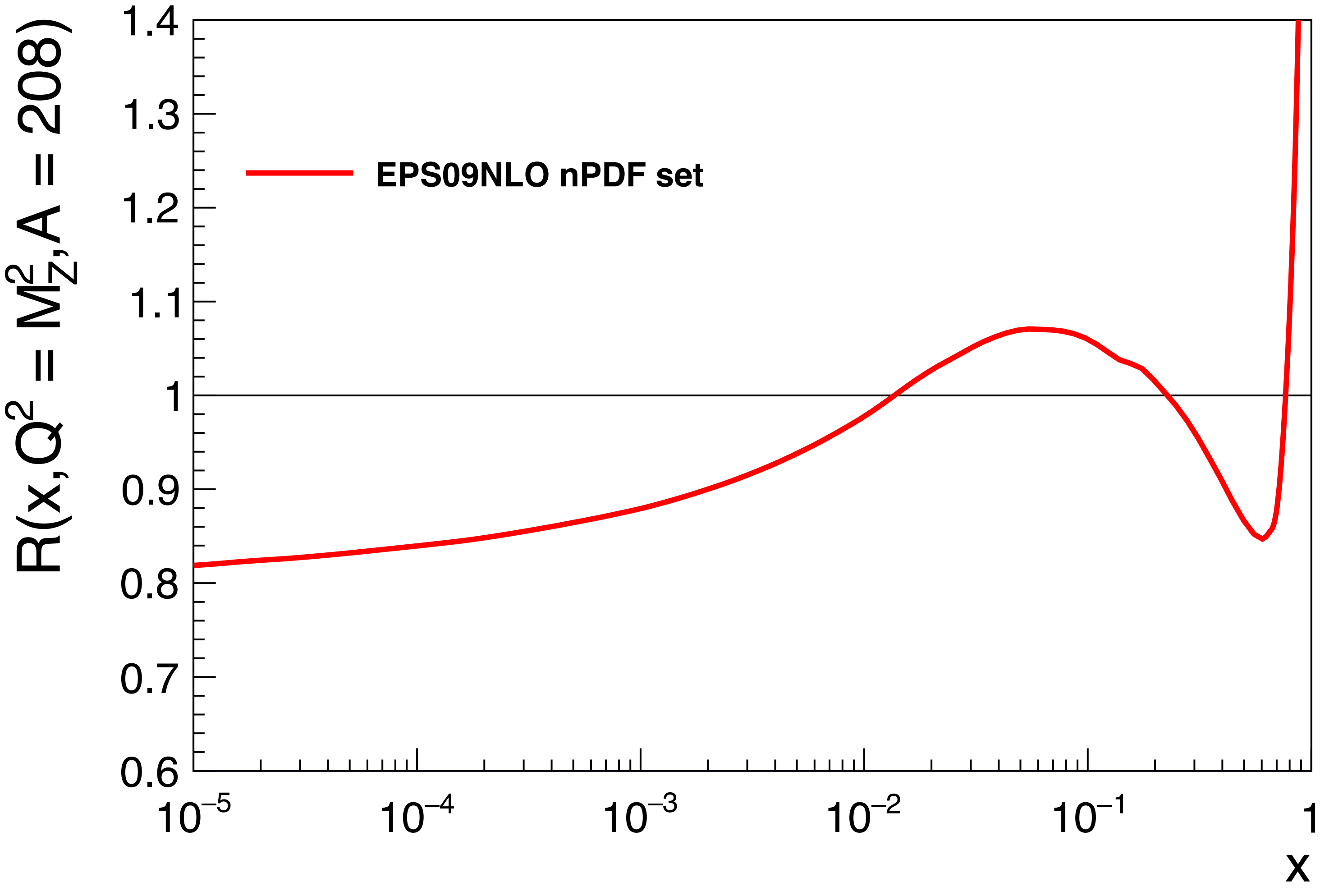

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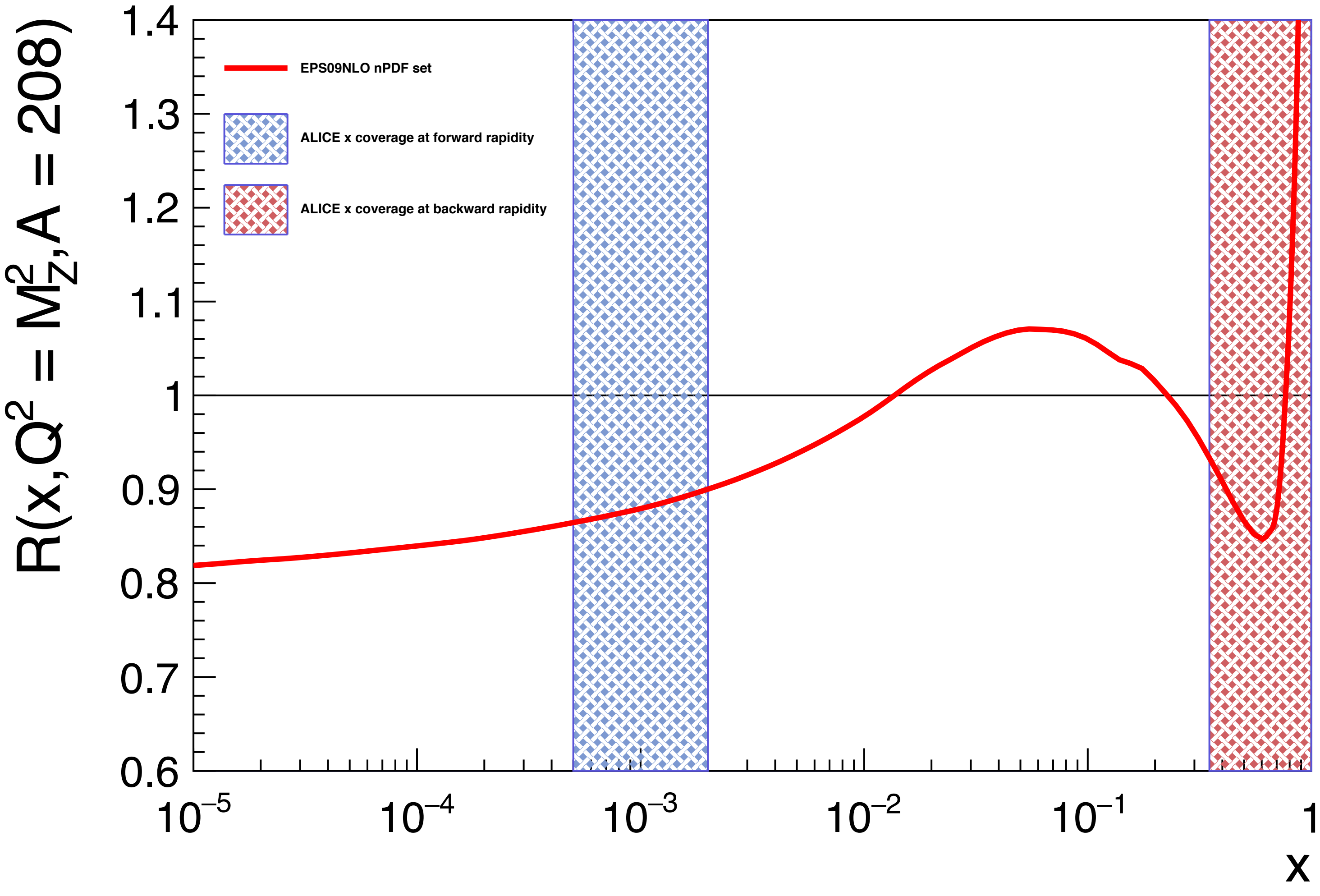

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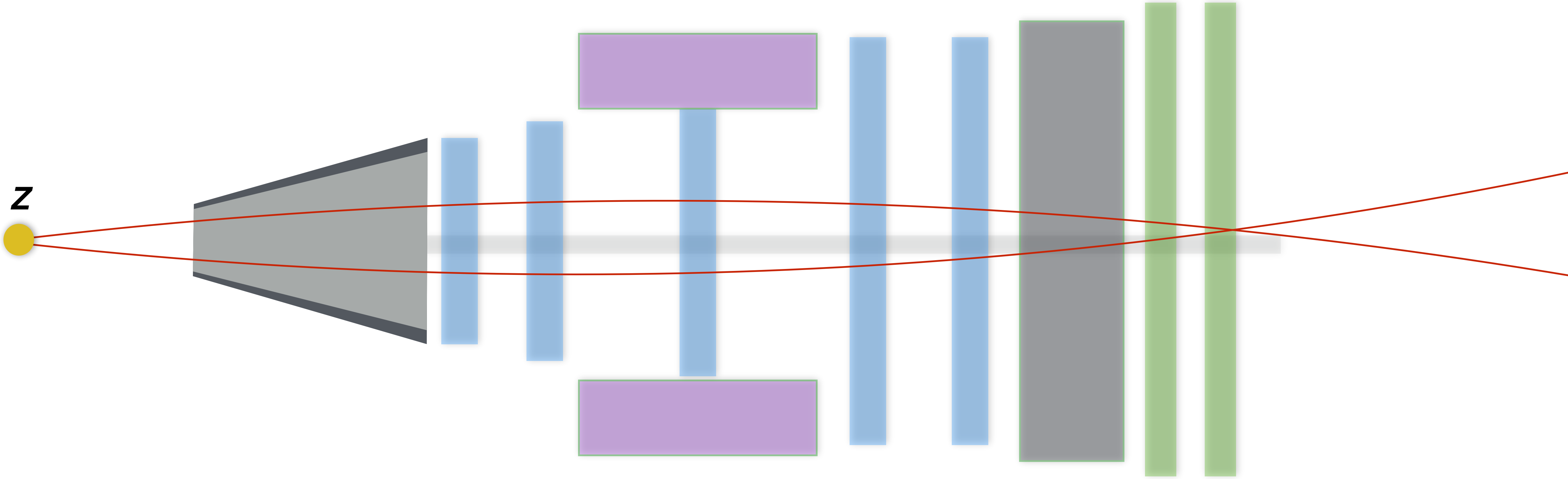

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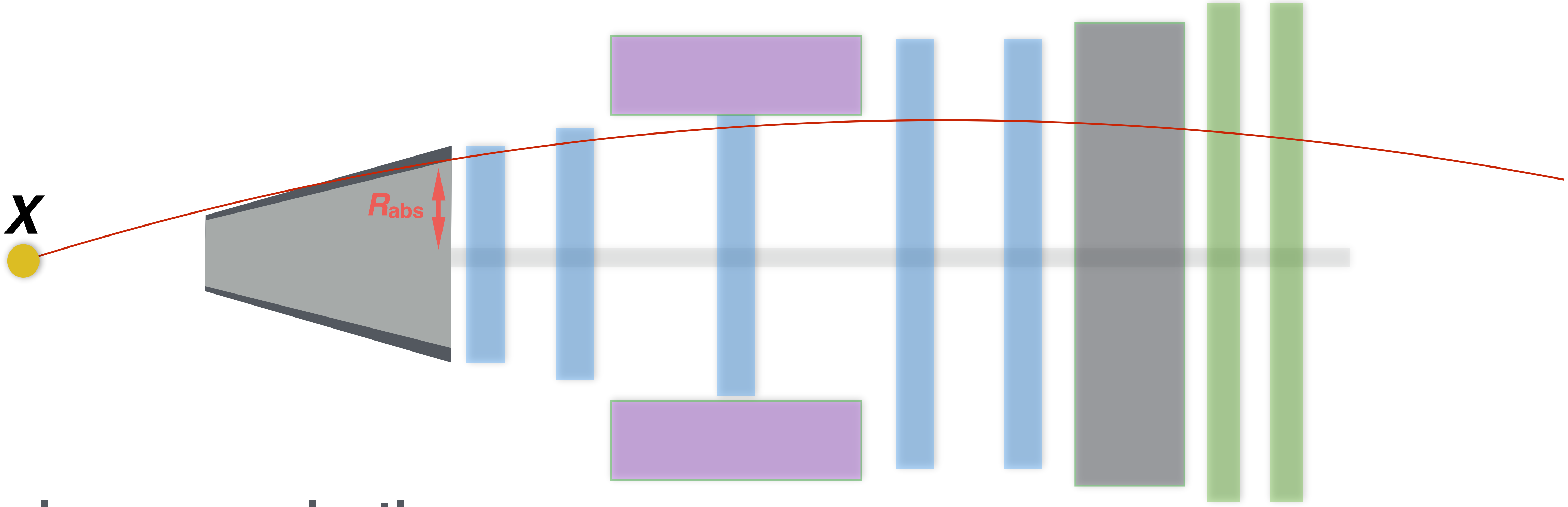

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  - $17.6 < R_{abs} < 89.5$ cm: rejects muons crossing the thick part of the front absorber

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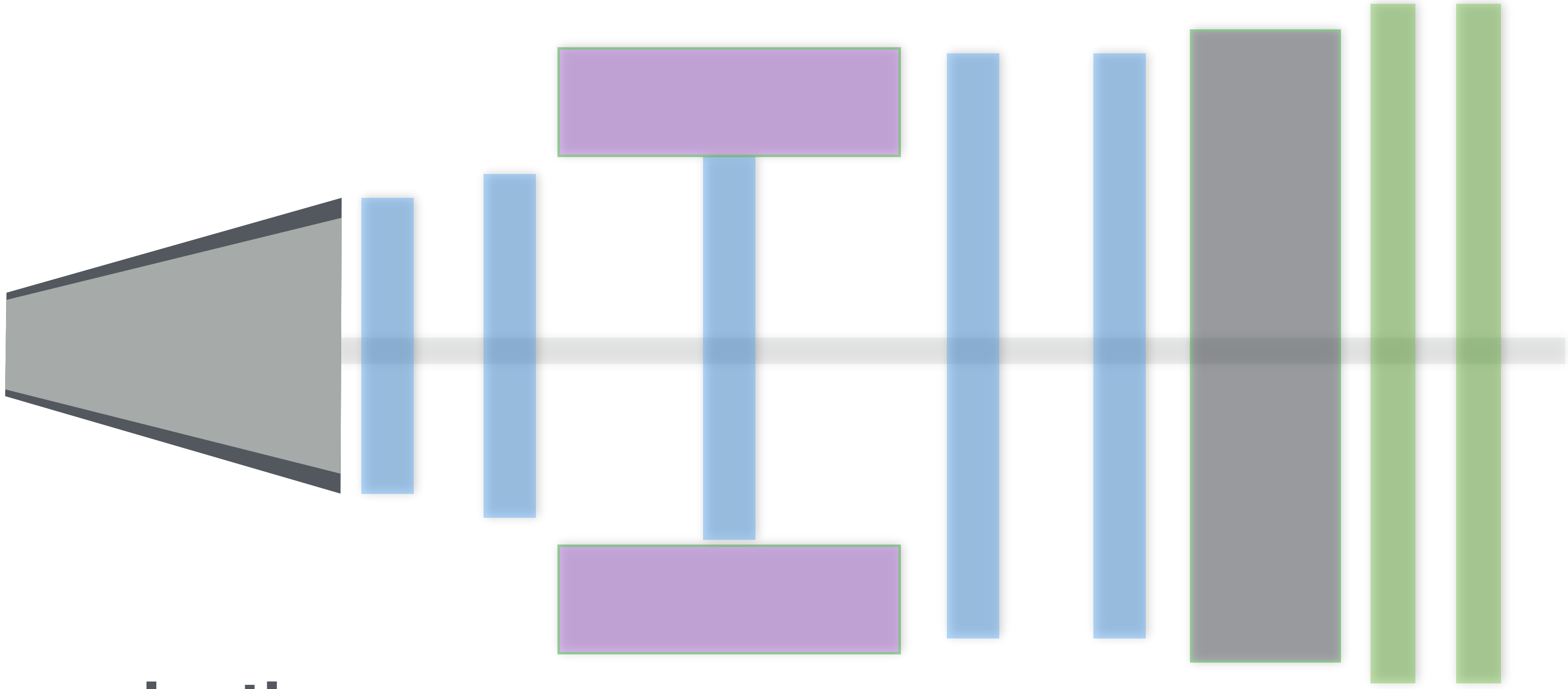

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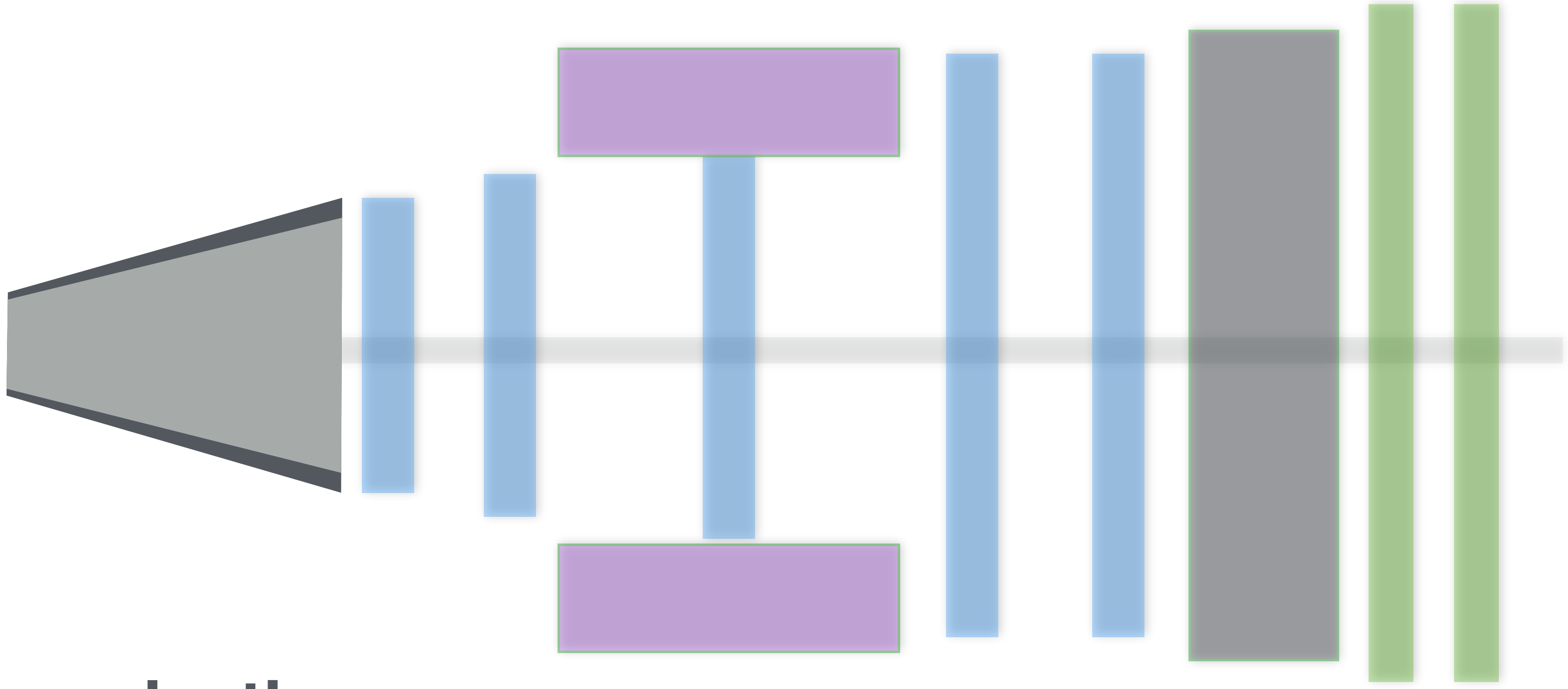

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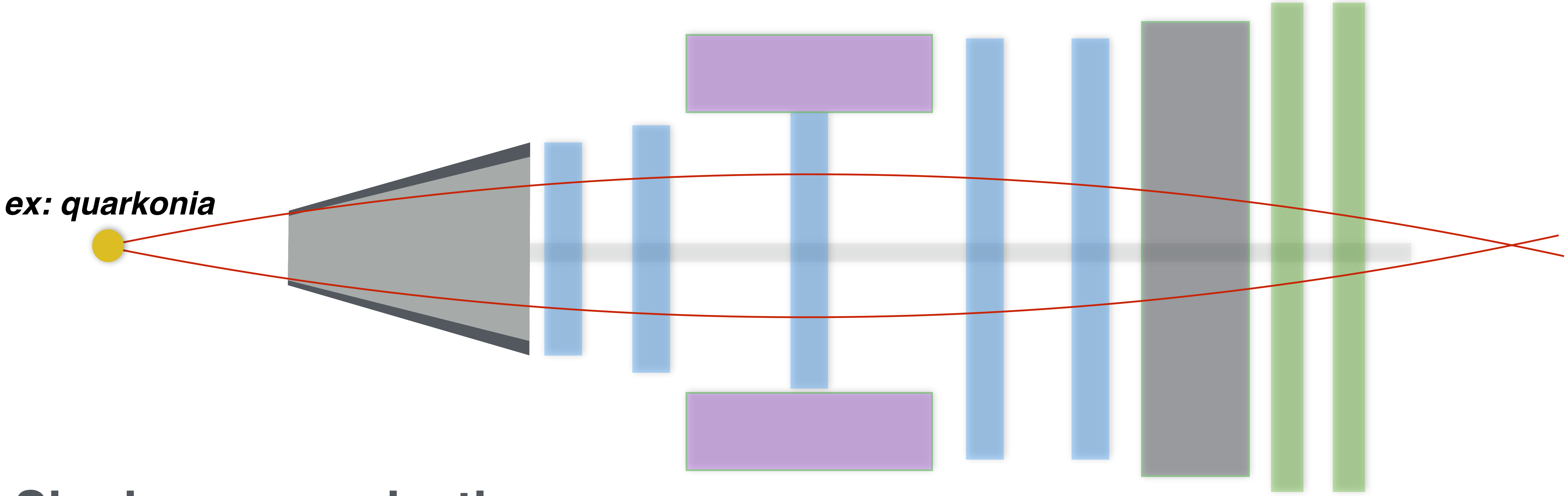

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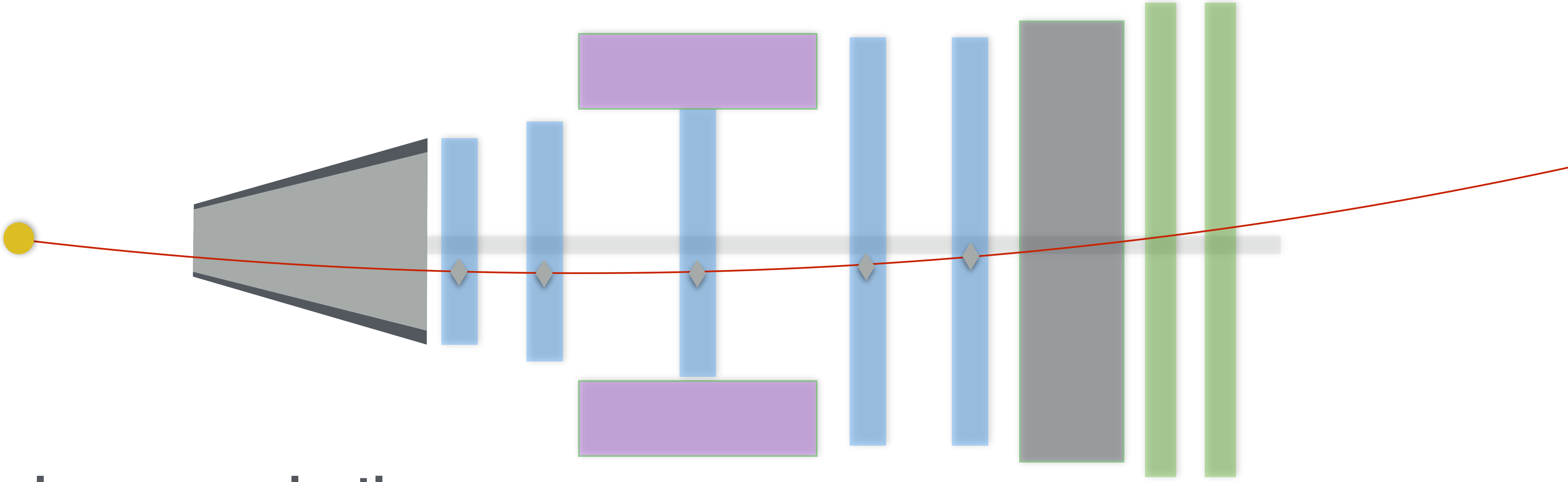

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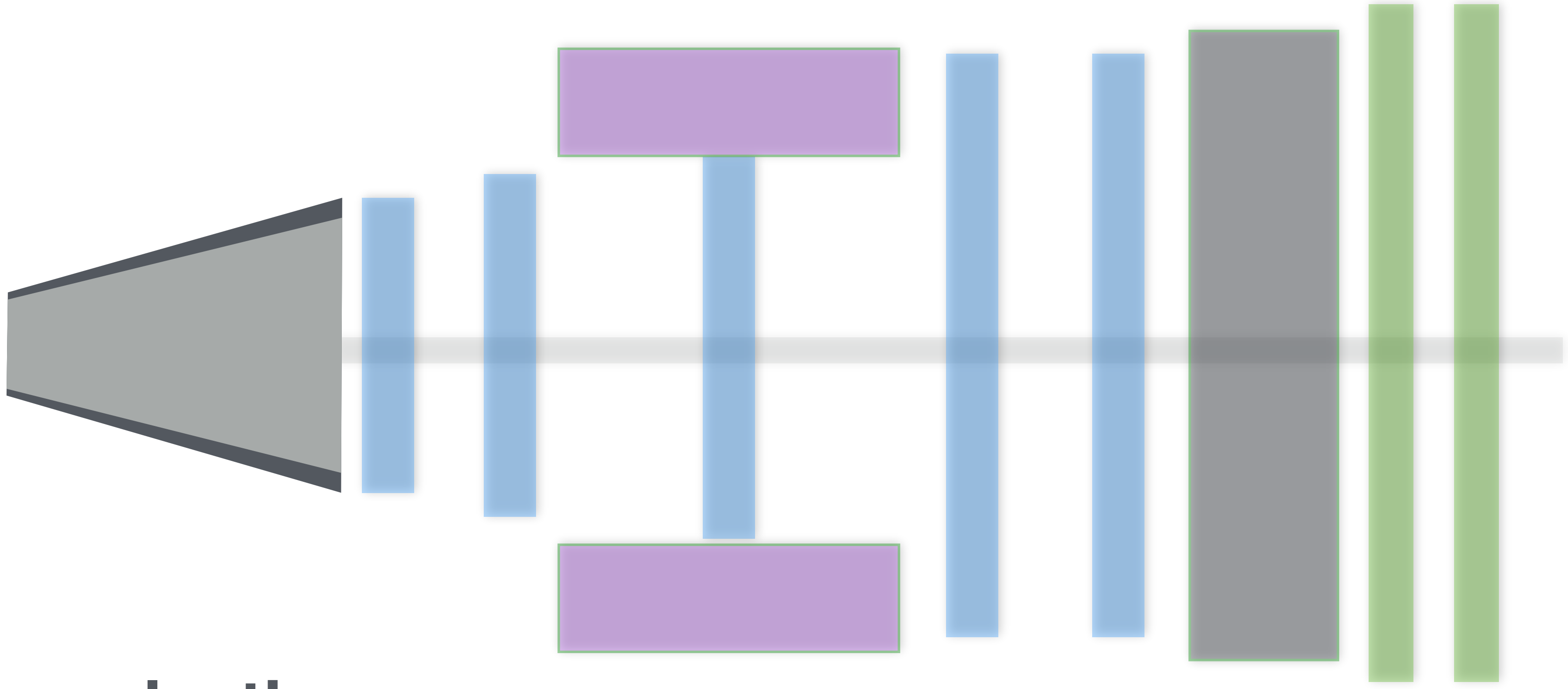

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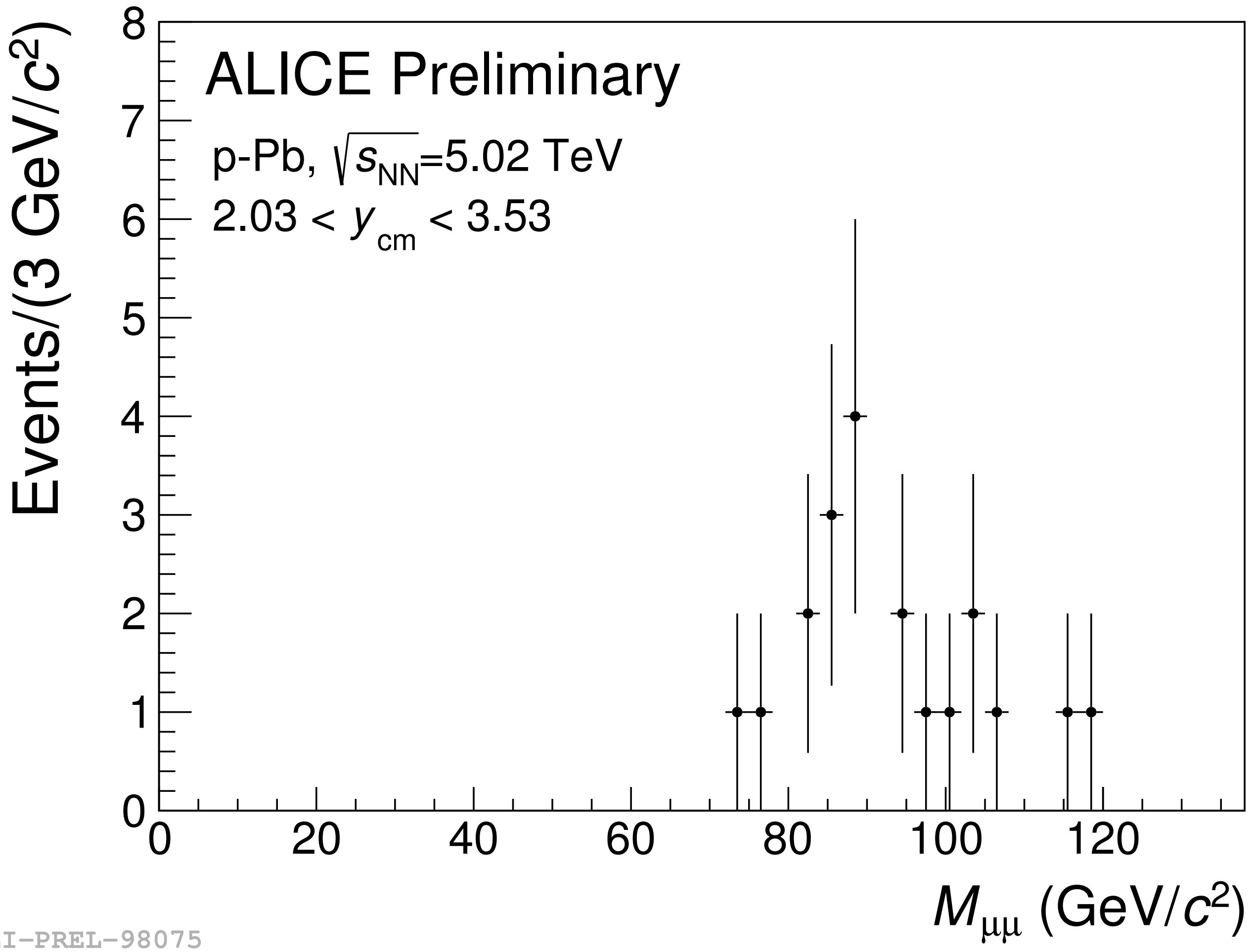
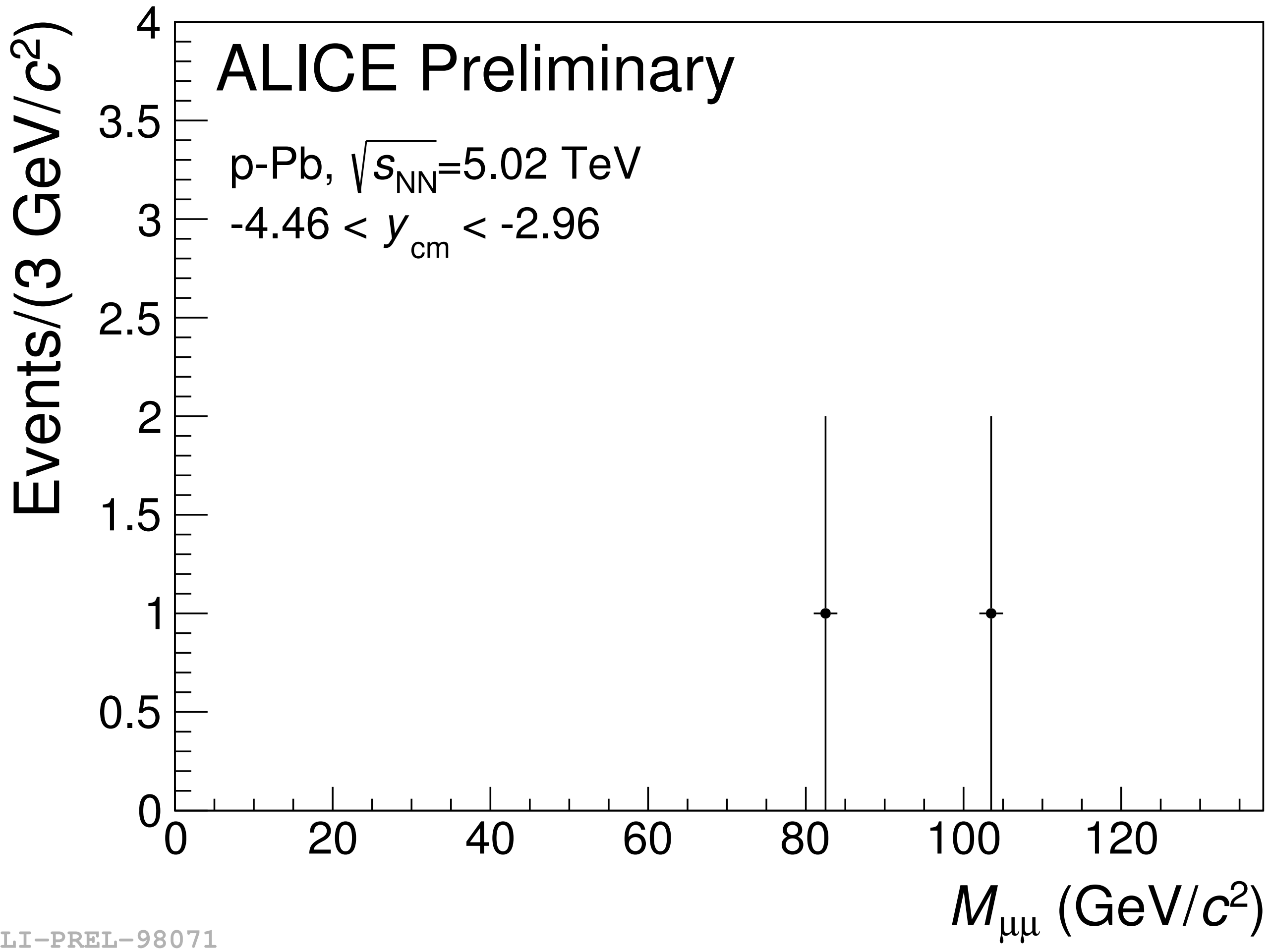
Signal Extraction

- This selection criteria resulted in the following invariant mass spectra in the two rapidity regions
- At backward rapidity, low statistics is due to lower detector efficiency and kinematical acceptance.



ALI-PREL-98075



ALI-PREL-98071

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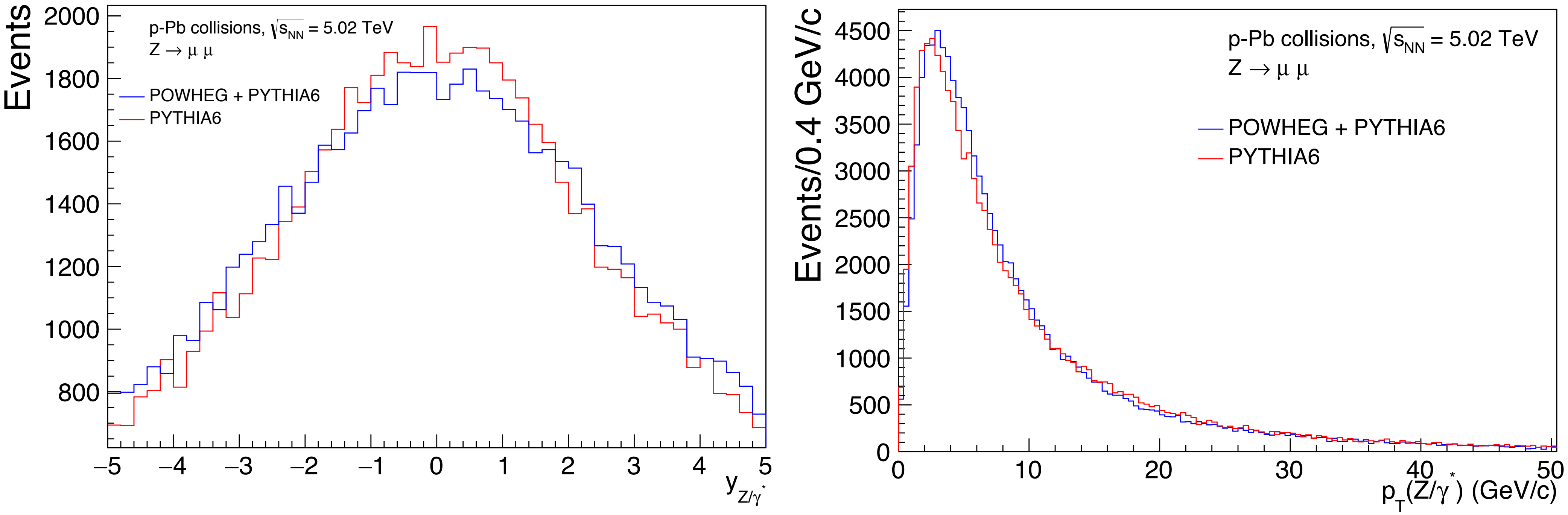

comparison between POWHEG and PYTHIA as particle generator via pT and rapidity distribution

MC Simulation I

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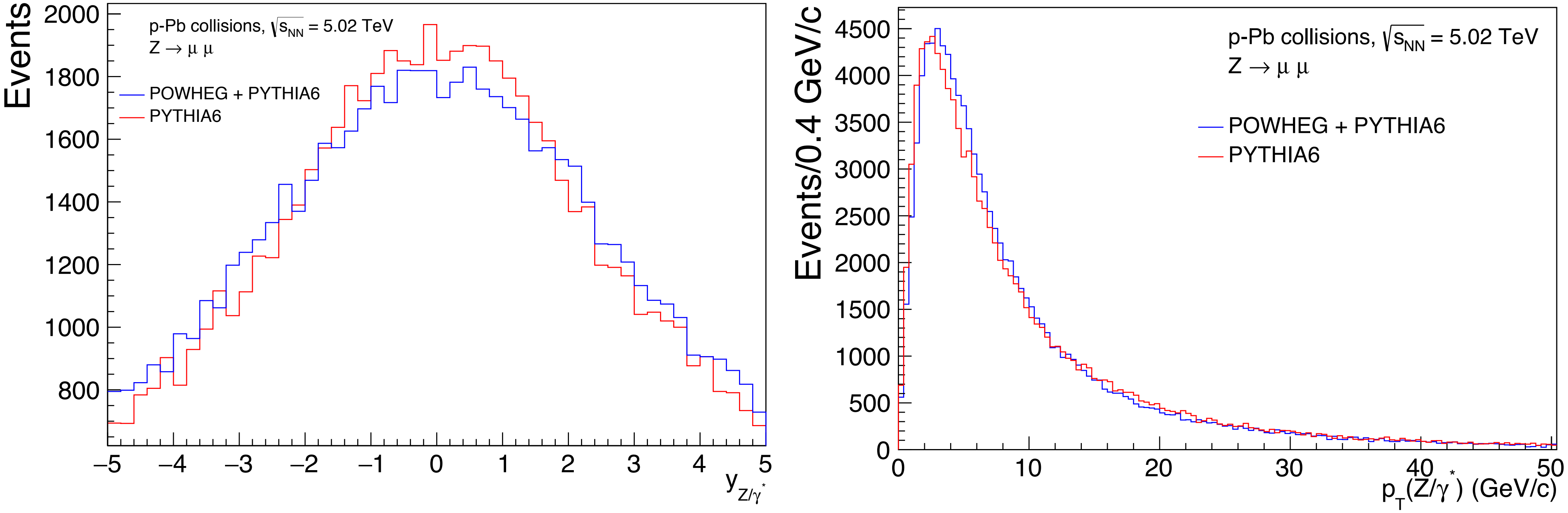
- EPS09NLO set is used to take nuclear shadowing into account.
- ALICE detector is simulated with GEANT-3.



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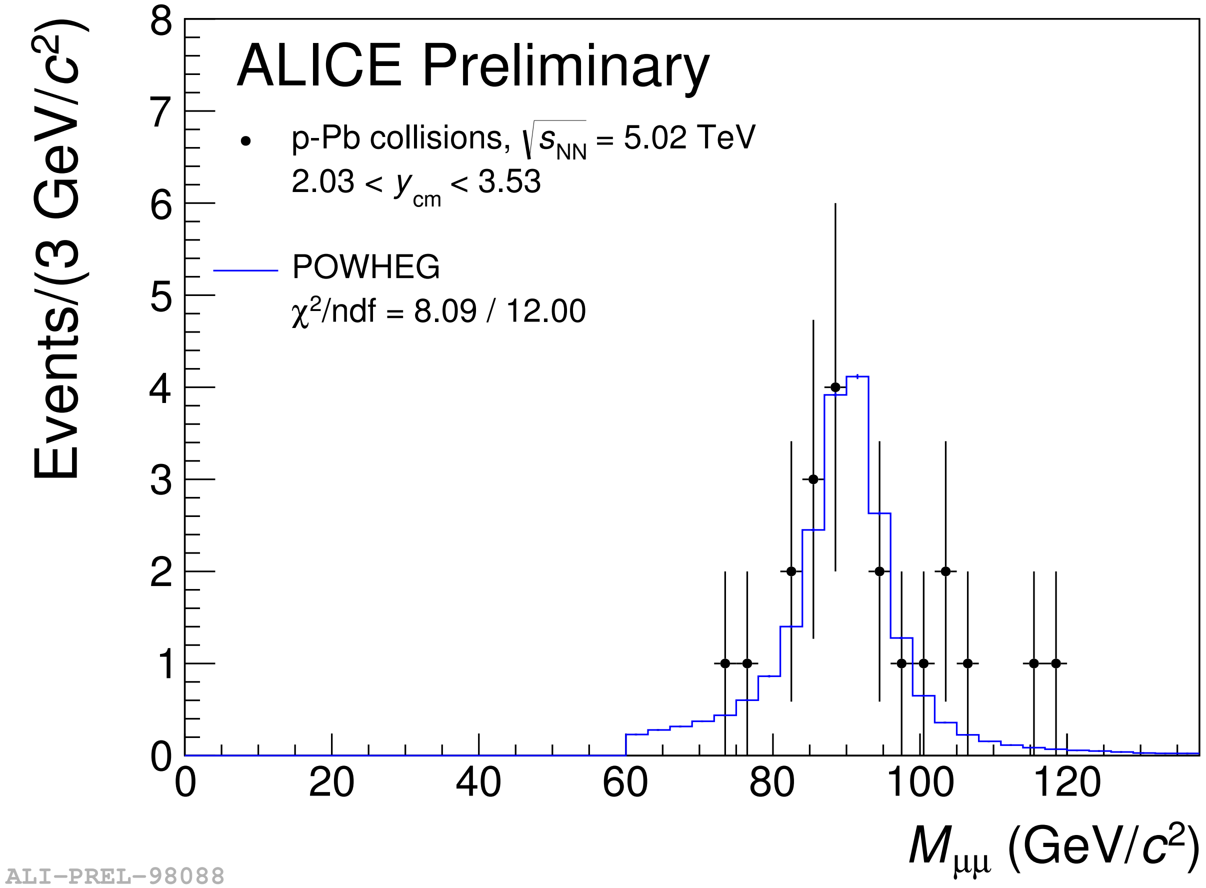
MC Simulation II

Does data distribution agree with MC ?



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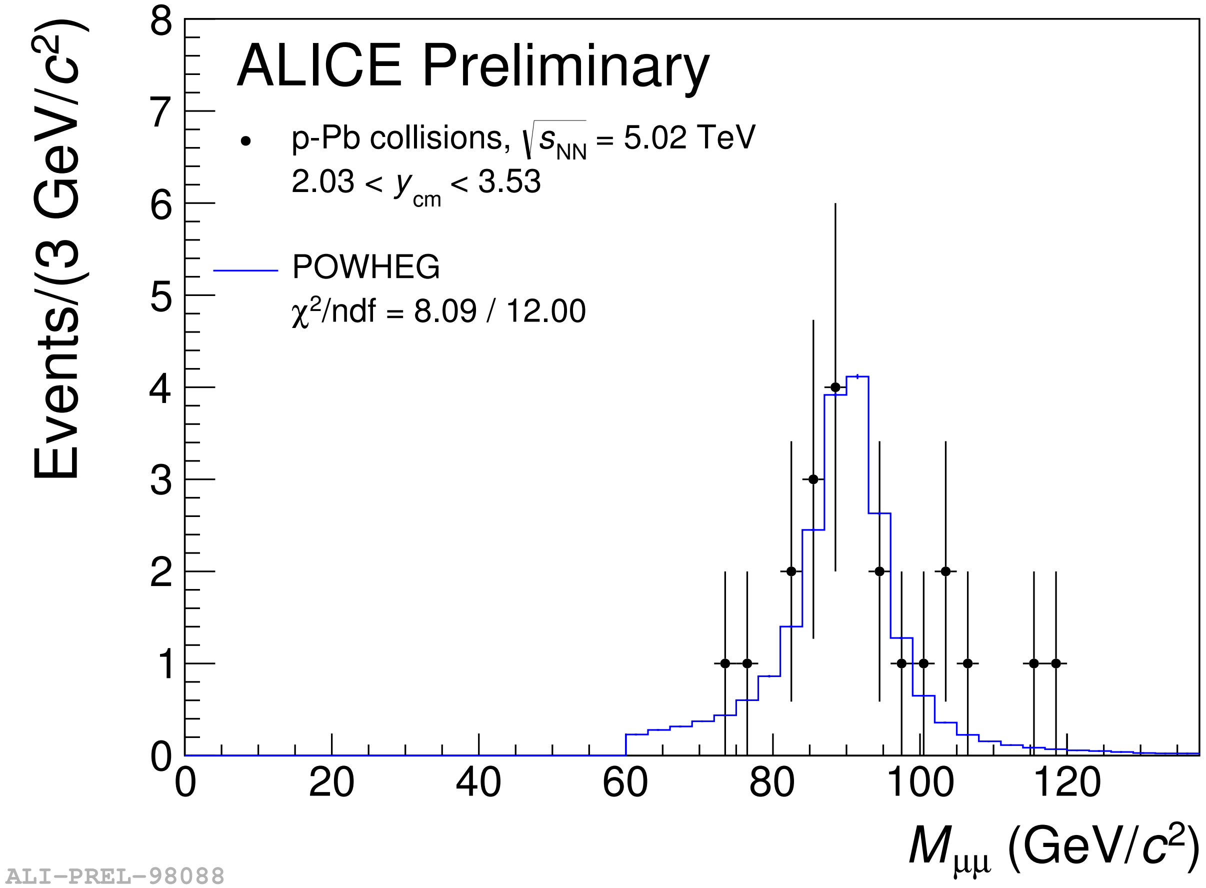

ALI-PREL-98088

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Detector Efficiency:

The detector efficiency is calculated in both rapidity regions as the ratio between the reconstructed and generated events:

$$\boldsymbol{\varepsilon(2.03 < y_{cm} < 3.53) = 83.54 \pm 0.72\ (stat) \pm 0.44\ (sys)\ \%}$$

$$\boldsymbol{\varepsilon(-4.46 < y_{cm} < -2.96) = 63.67 \pm 1.40\ (stat)\ 0.27\ (sys)\ \%}$$

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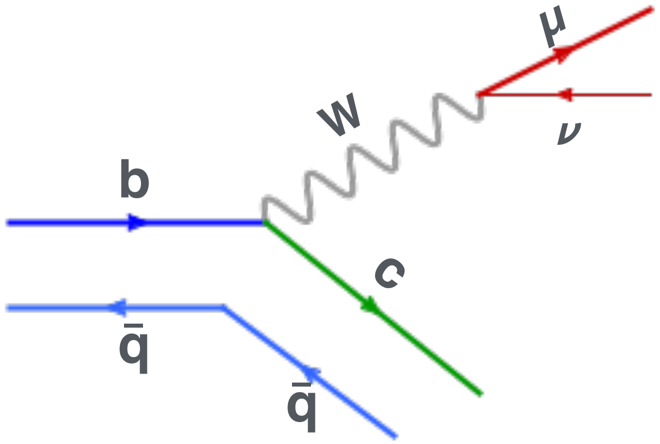

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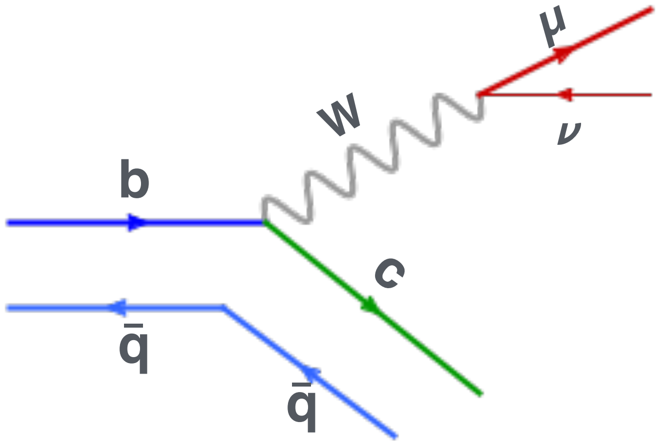
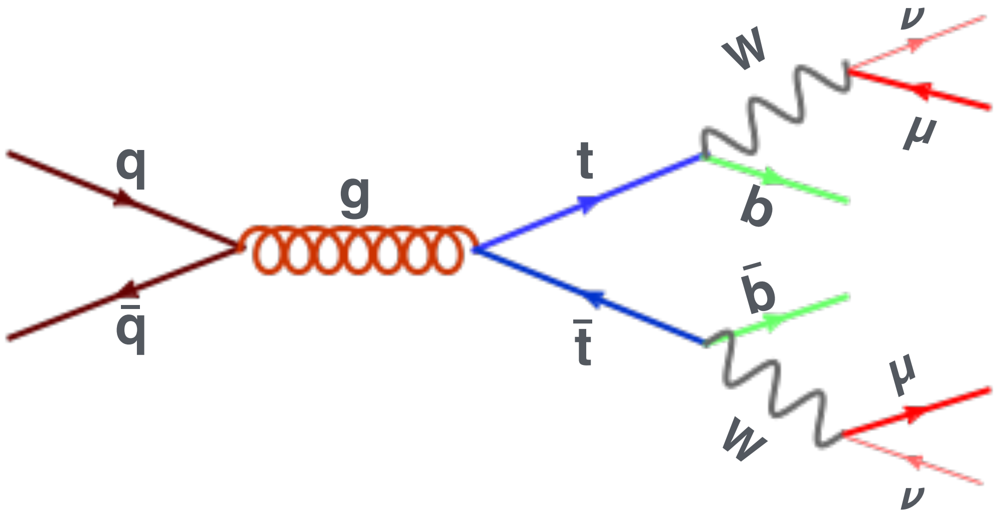


Using PYTHIA simulation (distribution normalised by FONLL cross sections), the contribution from this source in the high mass region is negligible

Background Contribution II

3- $t\bar{t} \rightarrow \mu\mu$



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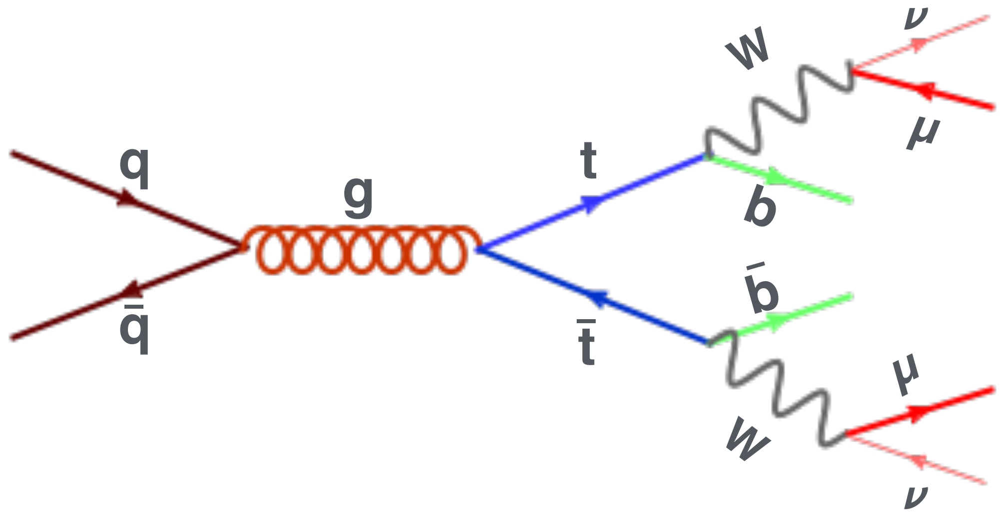

contribution from this source is higher at mid-rapidity.

Background Contribution II

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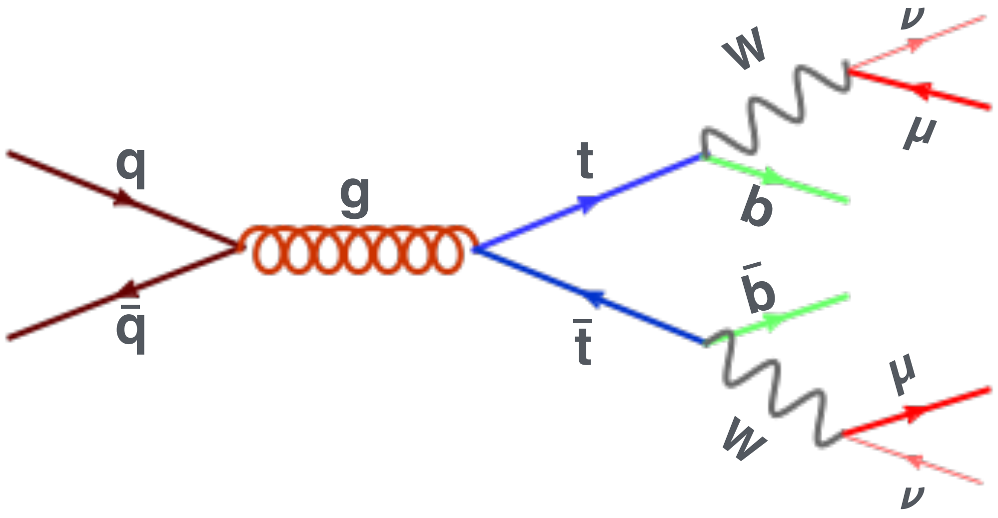
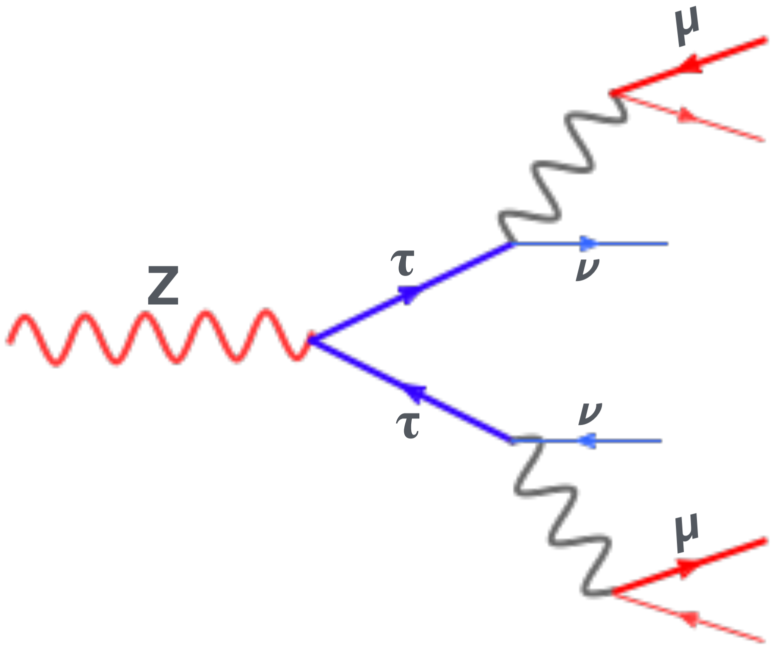


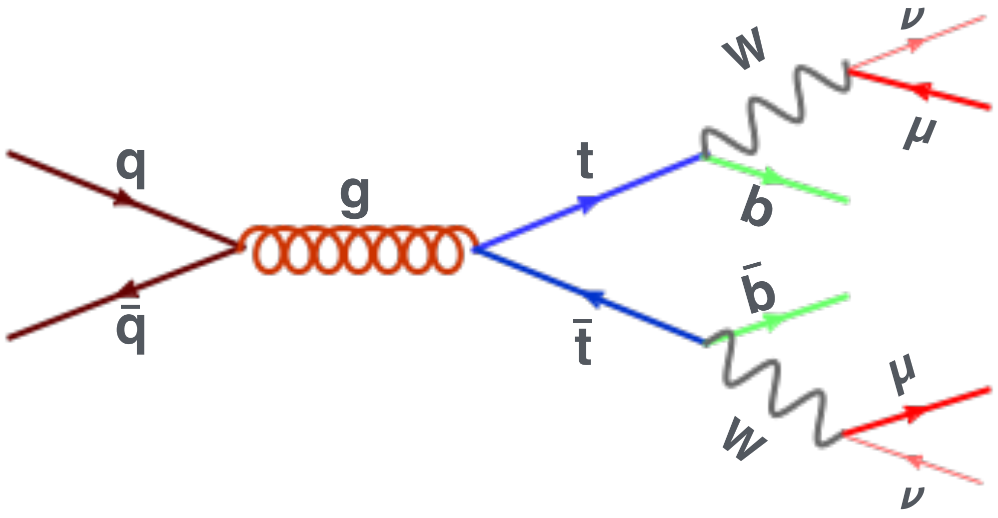
contribution from this source is higher at mid-rapidity.

4- $Z \rightarrow \tau\tau \rightarrow \mu\mu$



Background Contribution II

3- $t\bar{t} \to \mu\mu$



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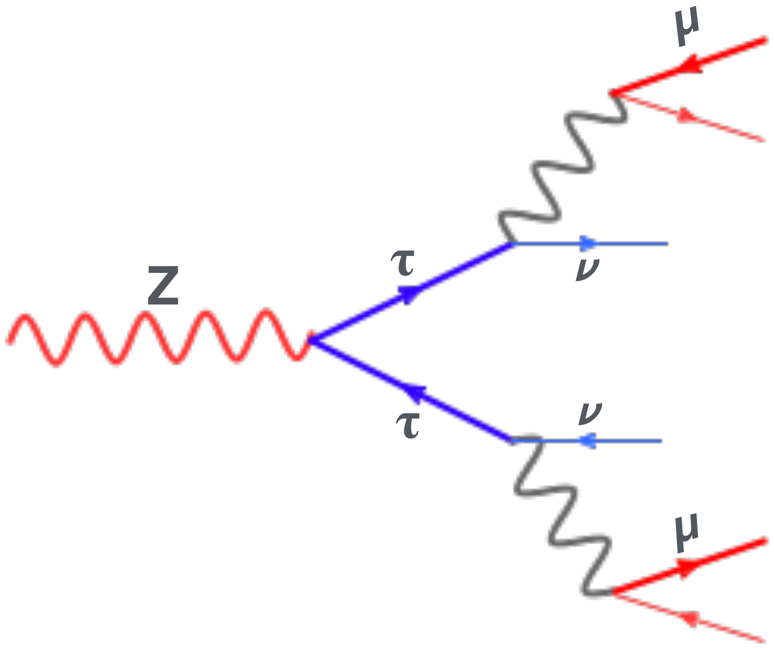

Due to missing energy from neutrinos, contribution from this source is higher at low-mass region.

Background Contribution II

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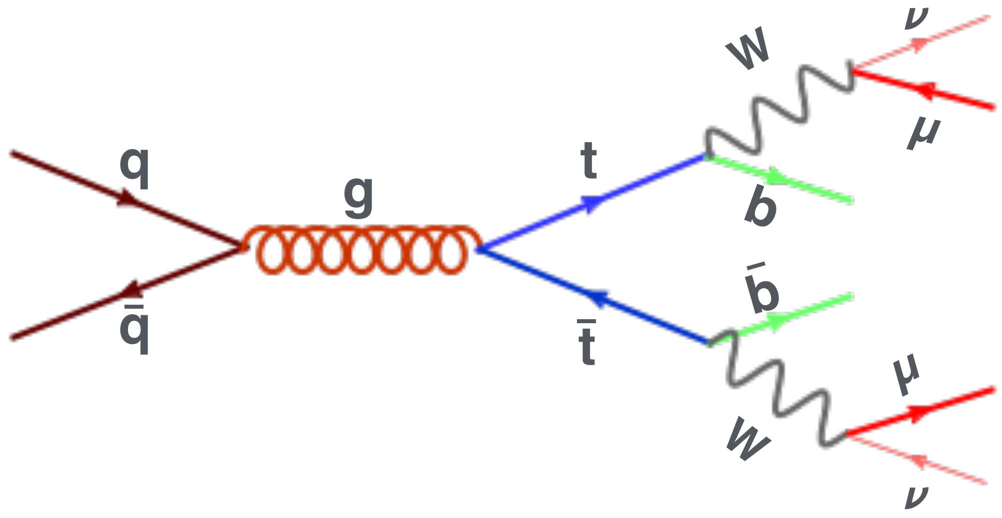

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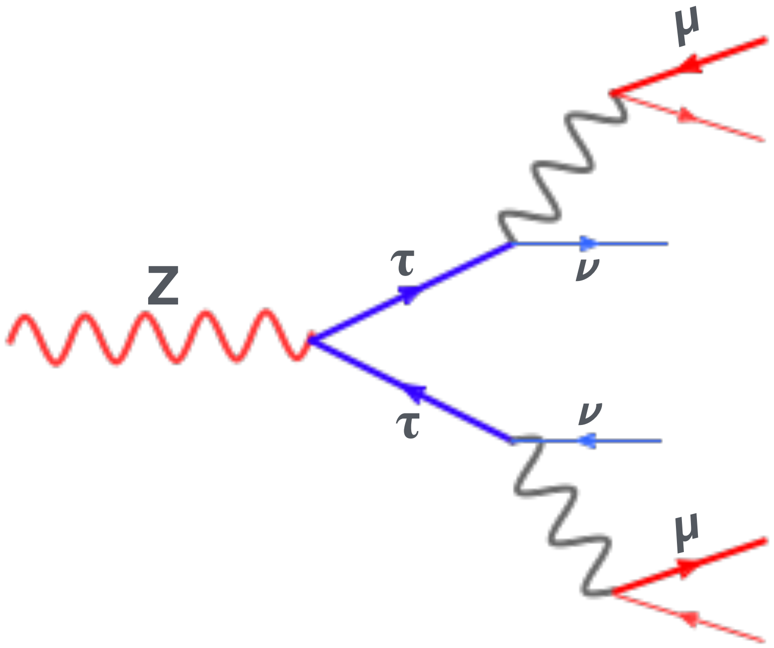


Due to missing energy from neutrinos, contribution from this source is higher at low-mass region.

contribution from these two sources is estimated using POWHEG simulation to be less than 0.4% (0.2%) in forward (backward) rapidity region.

Cross section Results

$$\sigma_{Z\rightarrow\mu^+\mu^-} = \frac{N_Z}{L \times eff}$$

The cross sections are defined in the fiducial region:

$$\begin{cases} 60 < m_{\mu\mu} < 120\ \mathrm{GeV}/c^2 \\ p_T(\mu) > 20\ \mathrm{GeV}/c \\ -4.0 < \eta_\mu < -2.5 \end{cases}$$

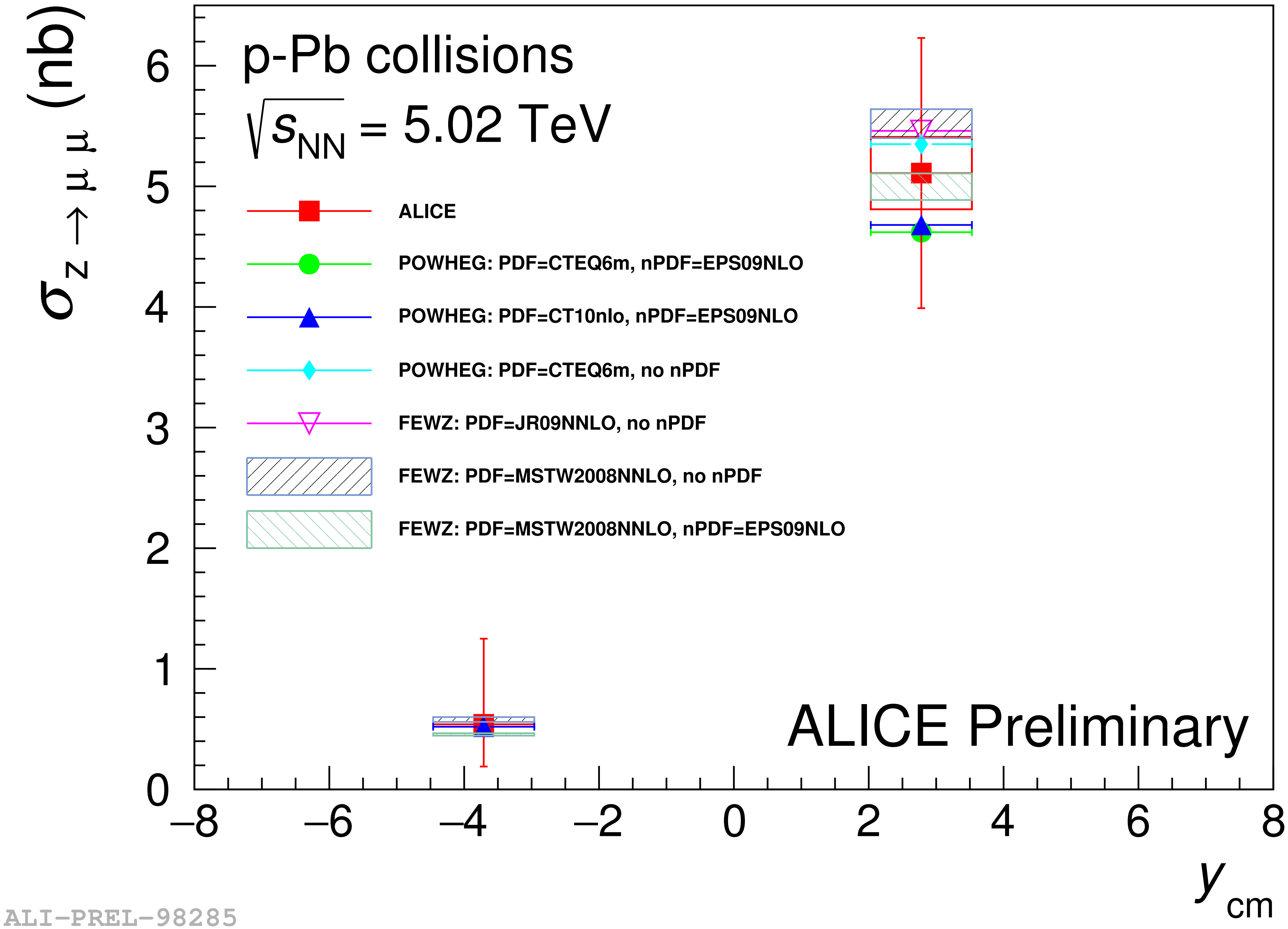
$$\sigma_{Z\rightarrow\mu^+\mu^-}(2.03 < y_{cm} < 3.53) = 5.11 \pm 1.12\ (\mathrm{stat})\ \pm 0.30\ (\mathrm{sys})\ \mathrm{nb}$$

$$\sigma_{Z\rightarrow\mu^+\mu^-}(-4.46 < y_{cm} < -2.96) = 0.54^{+0.71}_{-0.35}\ (\mathrm{stat})\ \pm 0.04\ (\mathrm{sys})\ \mathrm{nb}$$

- At backward, the statistical uncertainty is defined as the 68% confidence interval assuming a poisson distribution for the number of Z candidates.

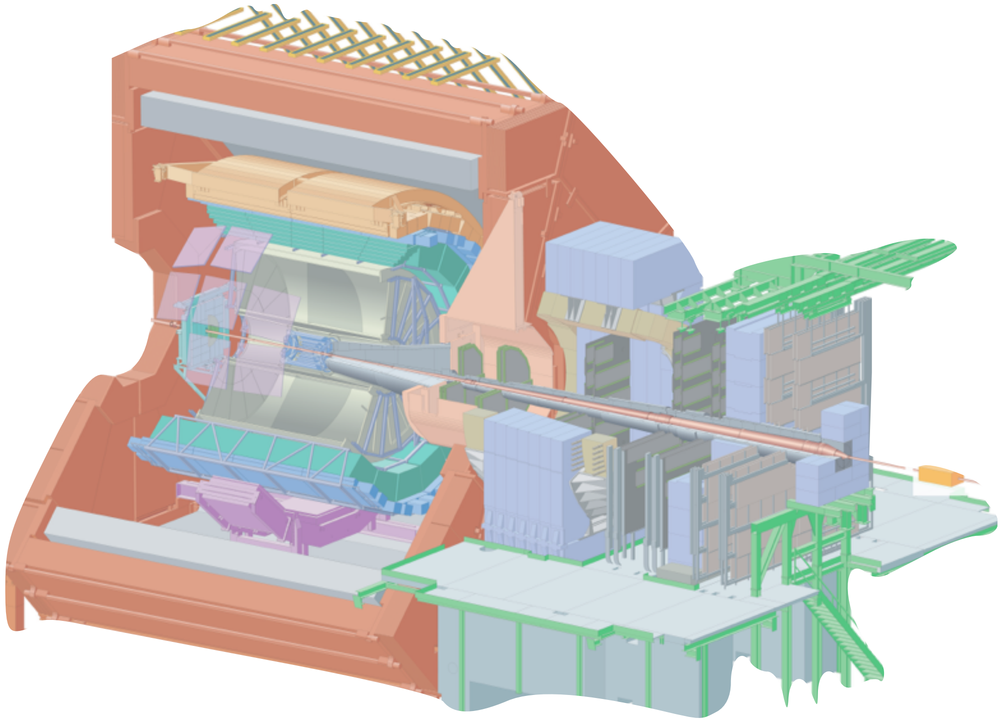
- Different sources of systematic uncertainty (efficiency, luminosity,...) are summed quadratically.

Results Vs Theory

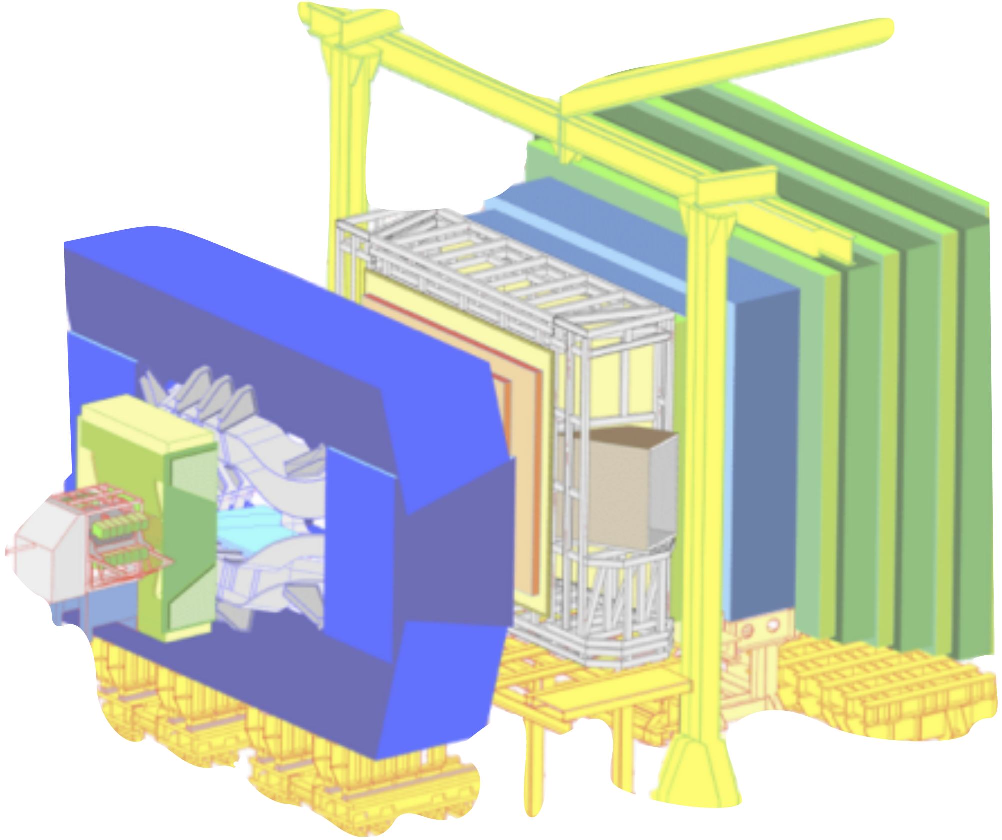


ALI-PREL-98285

- Within large statistical uncertainty, results agree with theory predictions in both rapidity regions.



Comparison to LHCb results



LHCb Analysis

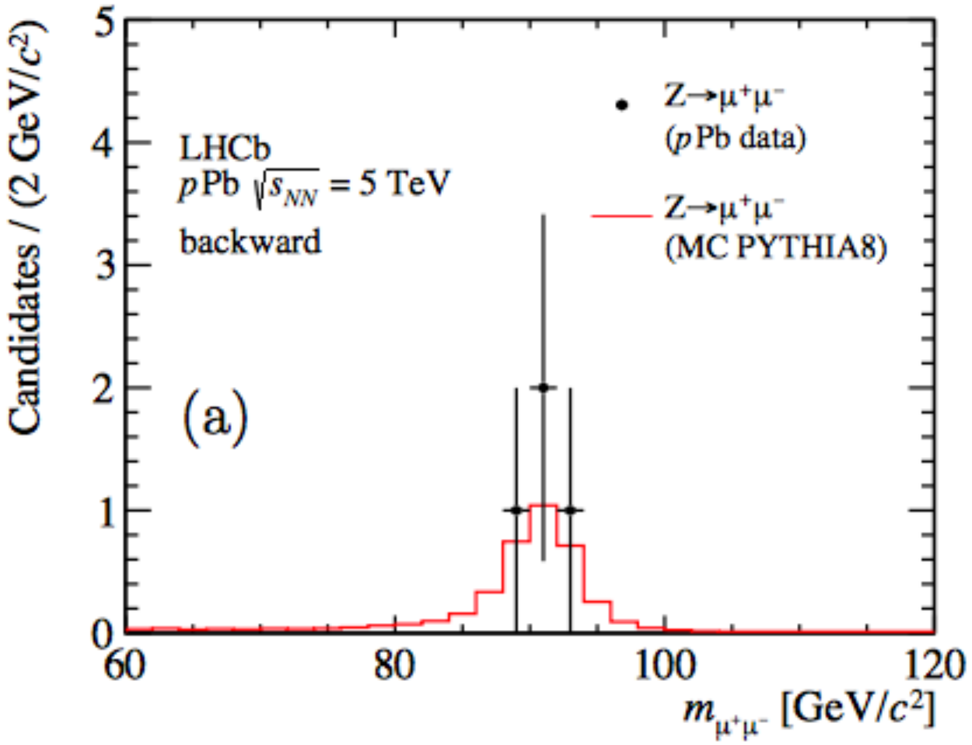
Fudicial region:

$60 < m_{\mu\mu} < 120$ GeV/c^2

$p_T(\mu) > 20$ GeV/c

$2.0 < \eta_\mu < 4.5$

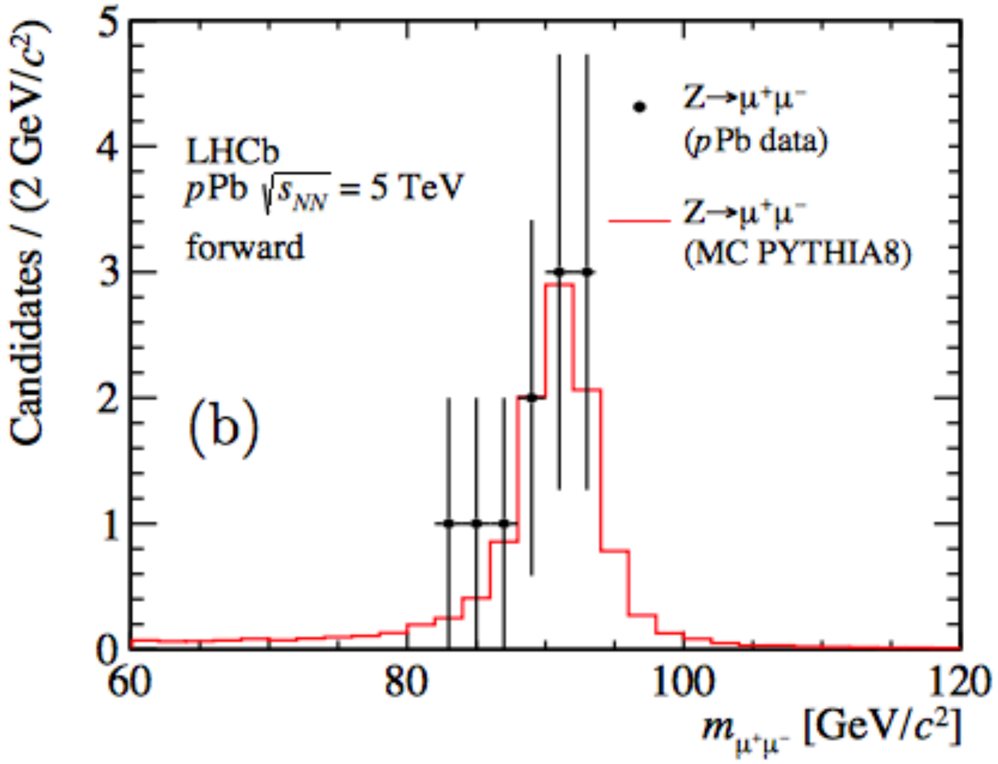
$-4. < \eta_\mu < -2.5$ for ALICE



$-4.47 < y_{cm} < -2.47$

$L_{int} = 0.521 \pm 0.011$ nb^{-1}

$$\sigma_{Z\to\mu^+\mu^-} = 13.5^{+5.4}_{-4}\ \text{(stat)}\ \pm 1.2\ \text{(sys) nb}$$

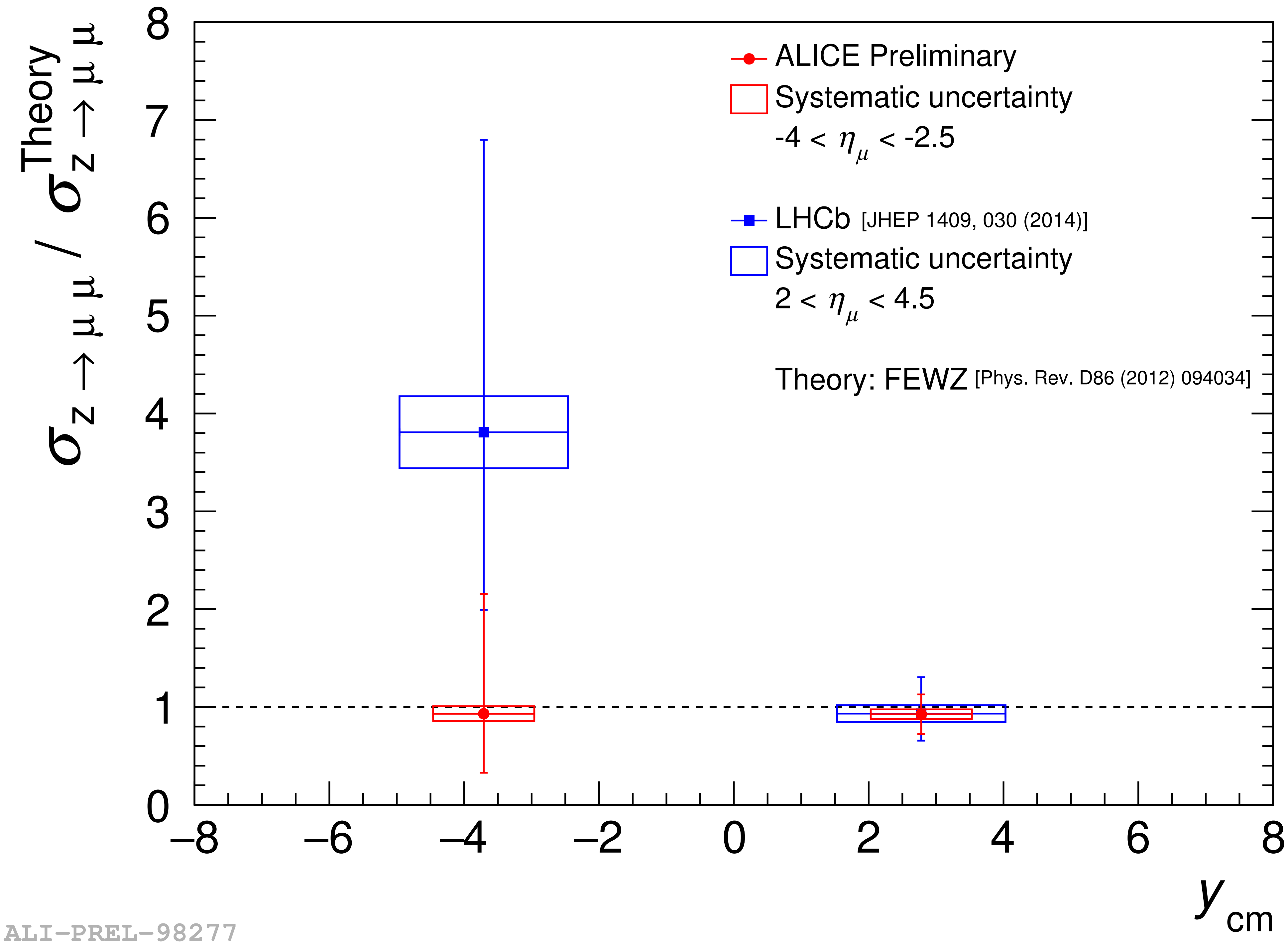


$1.53 < y_{cm} < 4.03$

$L_{int} = 1.099 \pm 0.021$ nb^{-1}

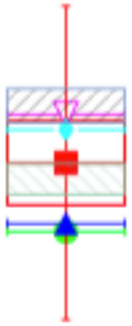
$$\sigma_{Z\to\mu^+\mu^-} = 10.7^{+8.4}_{-5.1}\ \text{(stat)}\ \pm 0.26\ \text{(sys) nb}$$

Comparison To LHCb



- At forward, the results from the two experiments agree with unity.
- At backward rapidity, no fair conclusion can be made with large statistic uncertainties for both experiments.

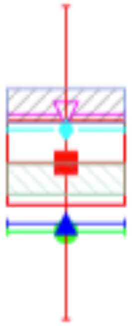
Some Perspectives



- It seems that we only need more statistics.

- This could be better in LHC-Run-2
  - Higher luminosity
  - Phase-space gain factor (if $\sqrt{s_{NN}}$ = 8 TeV)

Some Perspectives



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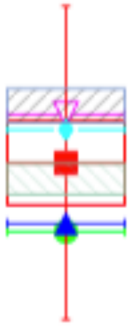
Forward to backward ratio:

$$R_{FB}(|y|) = \frac{\sigma_{+|y|}}{\sigma_{-|y|}}$$

- With ALICE, it can be measured in $2.96 < |y_{cm}| < 3.53$.

Some Perspectives



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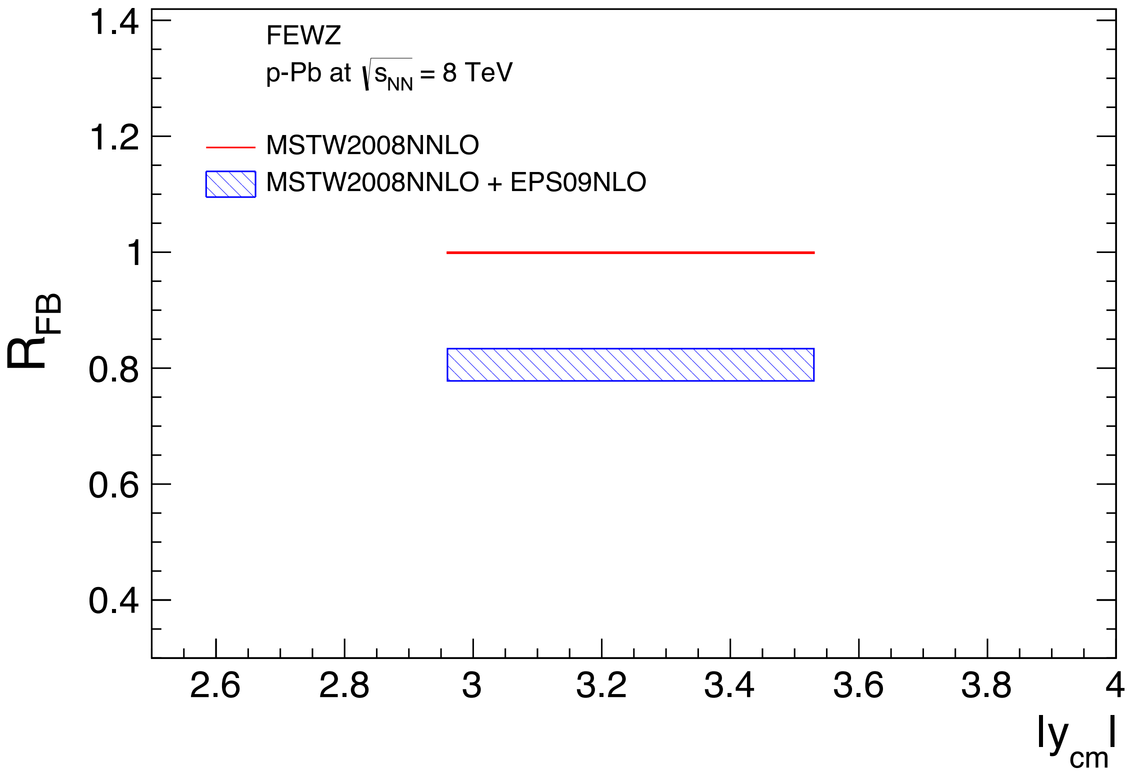
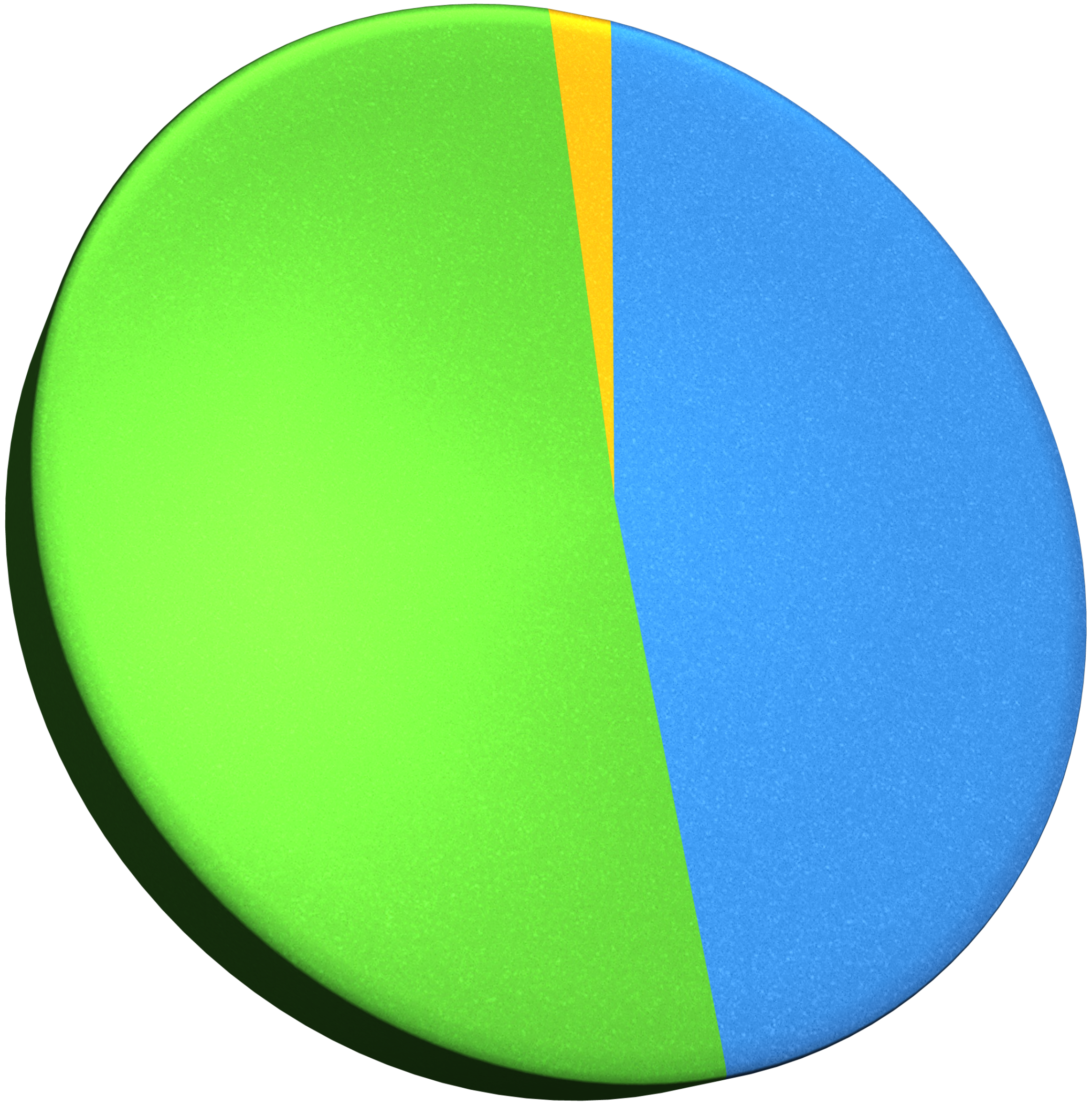


R_{FB} FEWZ prediction at $\sqrt{s_{NN}} = 8$ TeV

Conclusion

- Z boson production is important to constrain nuclear PDF sets.
- The cross section $\sigma_{Z \rightarrow \mu\mu}$ is determined in p-Pb collisions at 5.02 TeV in two rapidity regions.
- An agreement is found (within large uncertainty) between the obtained cross sections and theoretical predictions in both rapidity regions.
- At forward rapidity, an agreement is found between ALICE and LHCb results.
- In Run-2, statistics are expected to be higher ···

At this point, with 95% CL, you are:

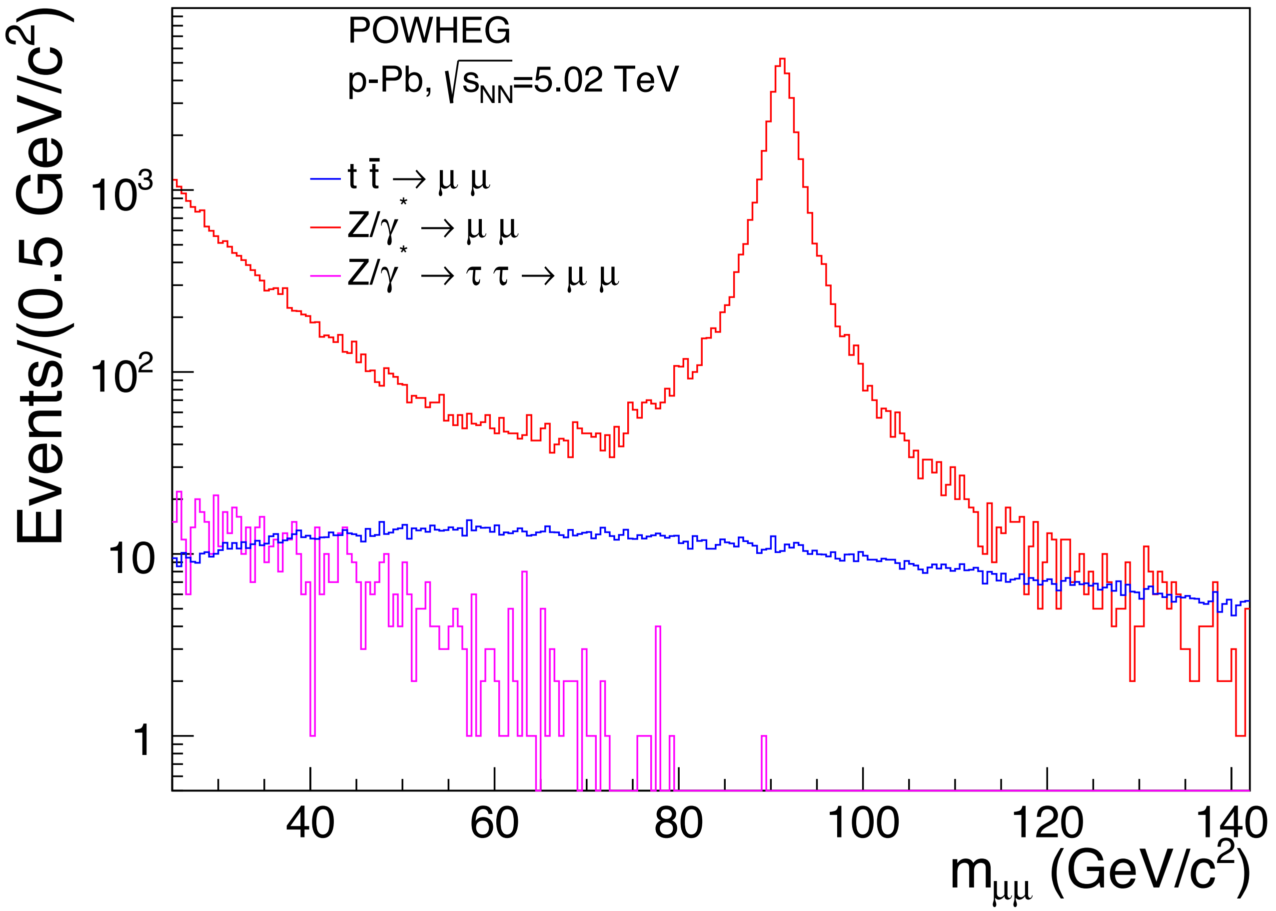


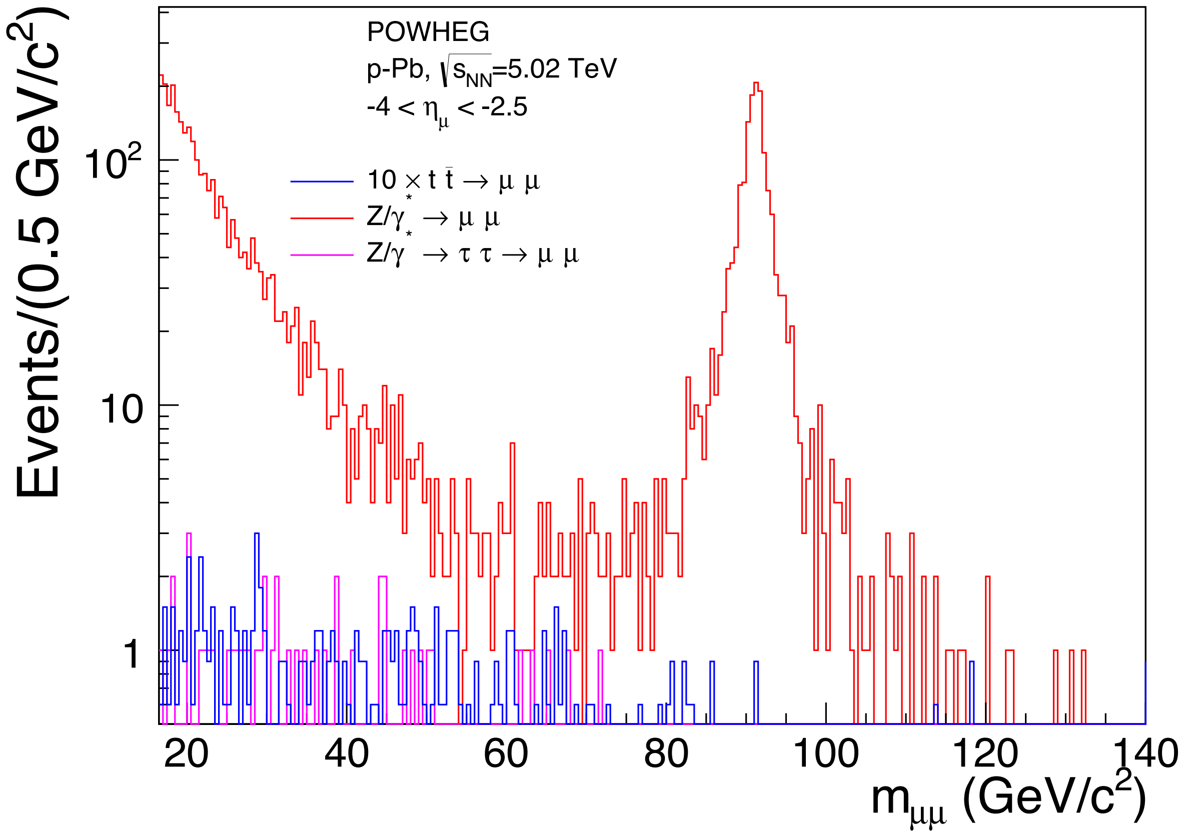
- 🔵 Checking Facebook
- 🟢 Feeling bored and do not have wifi to check Facebook
- 🟠 Something else

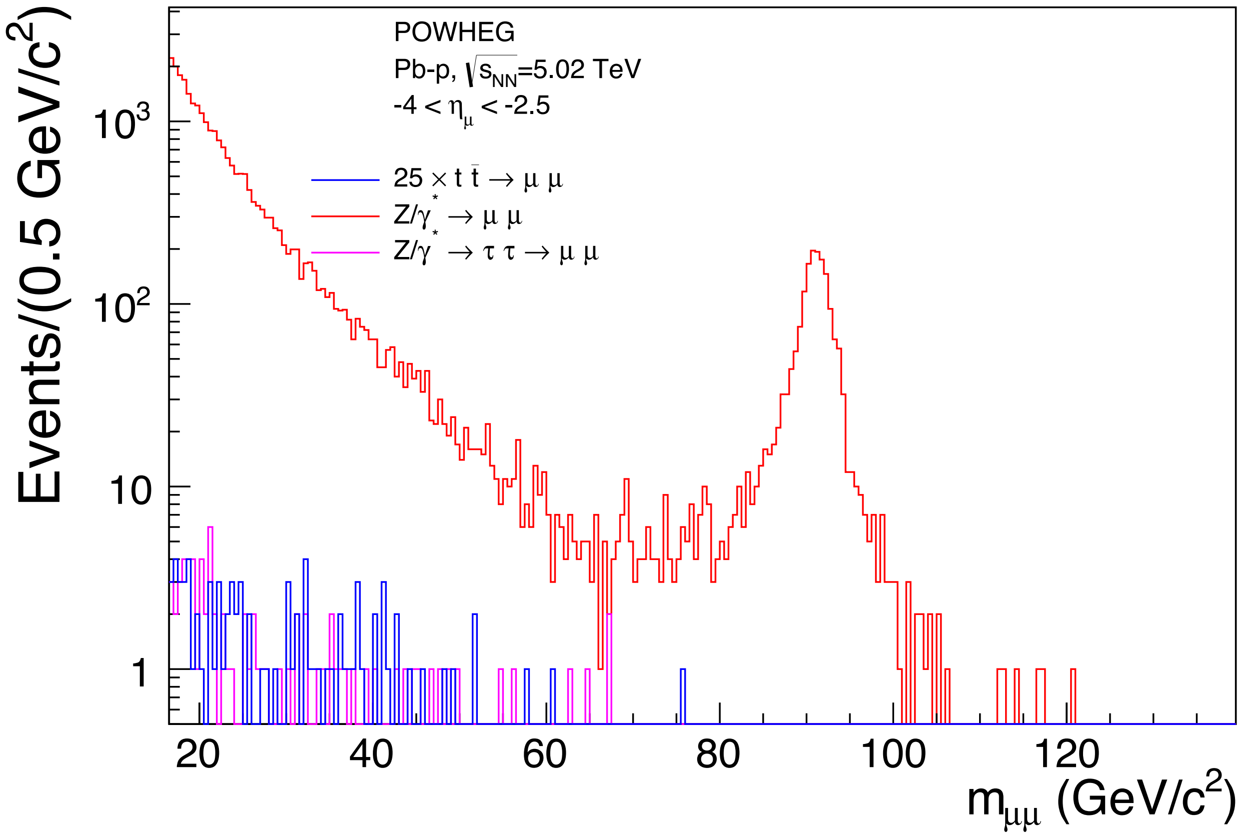
Thank you

BACKUP

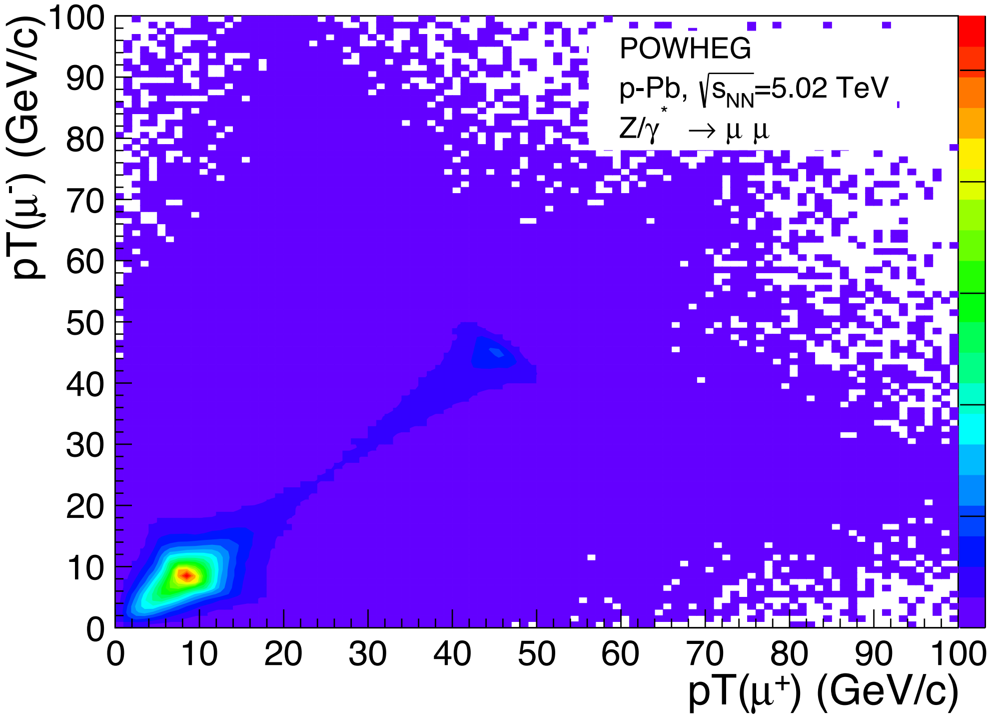
Background Contribution

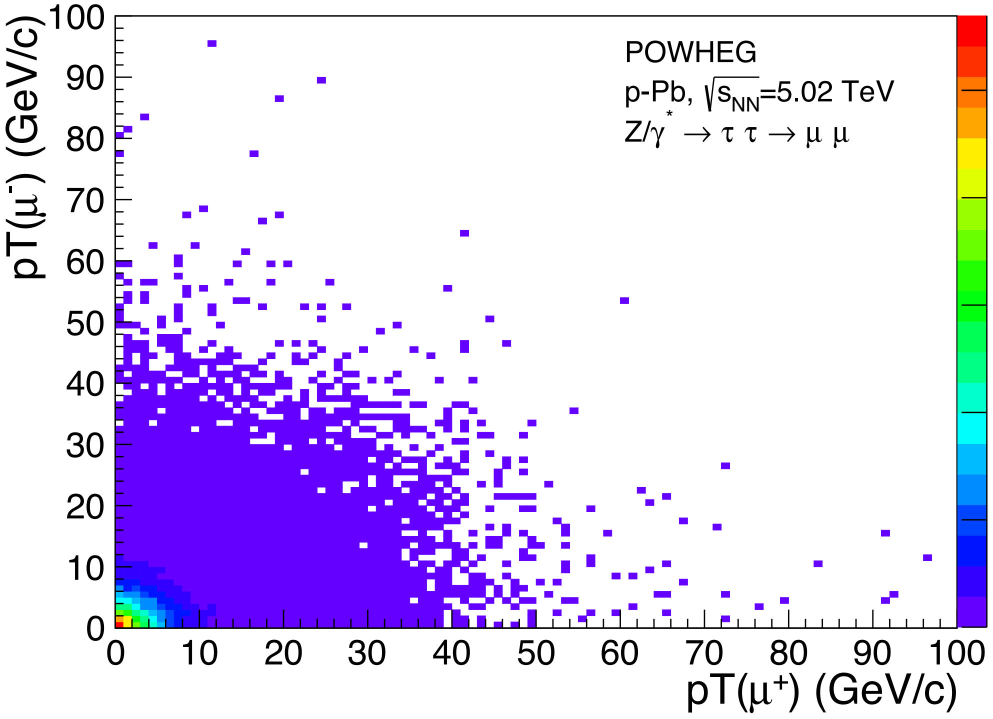


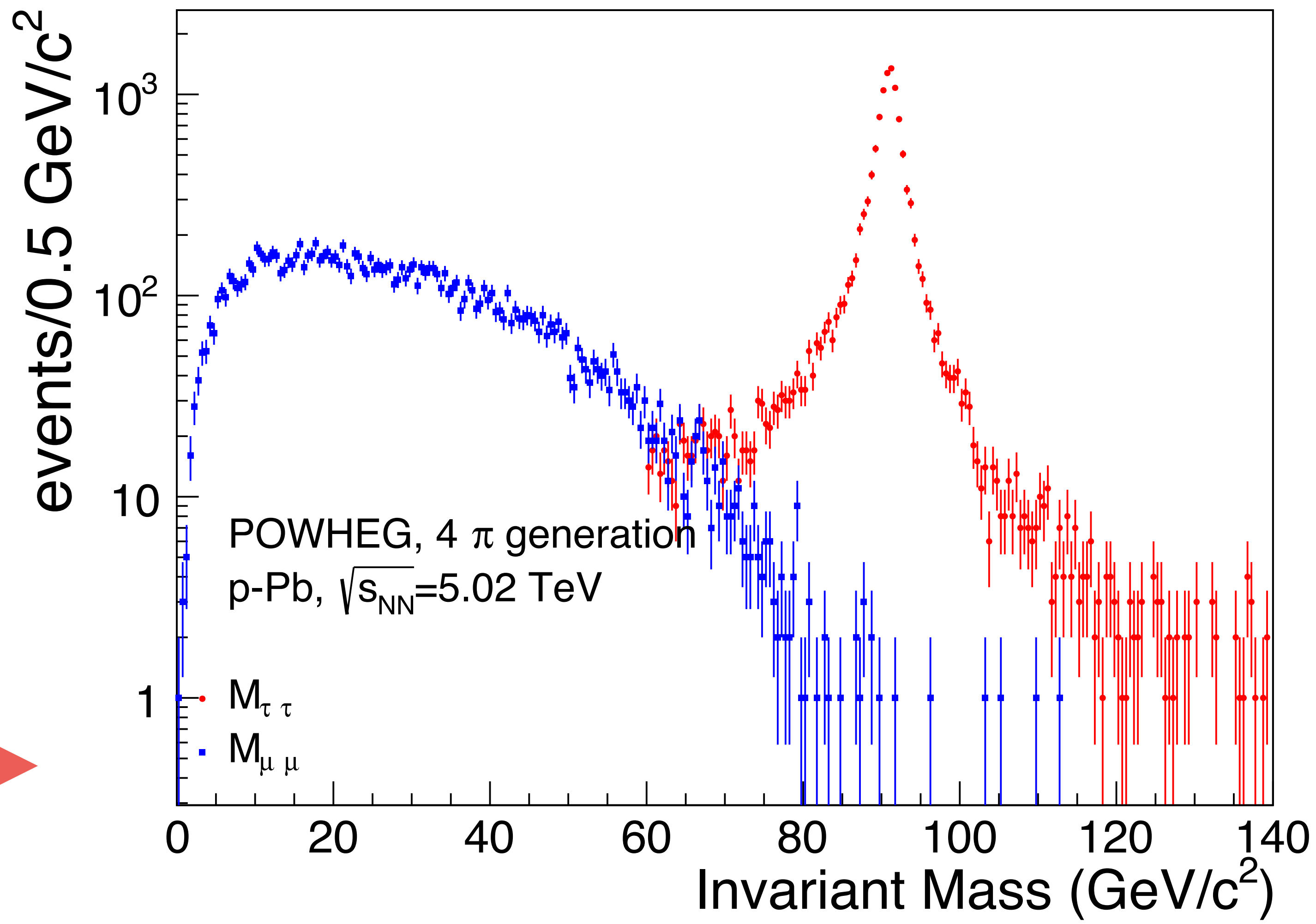




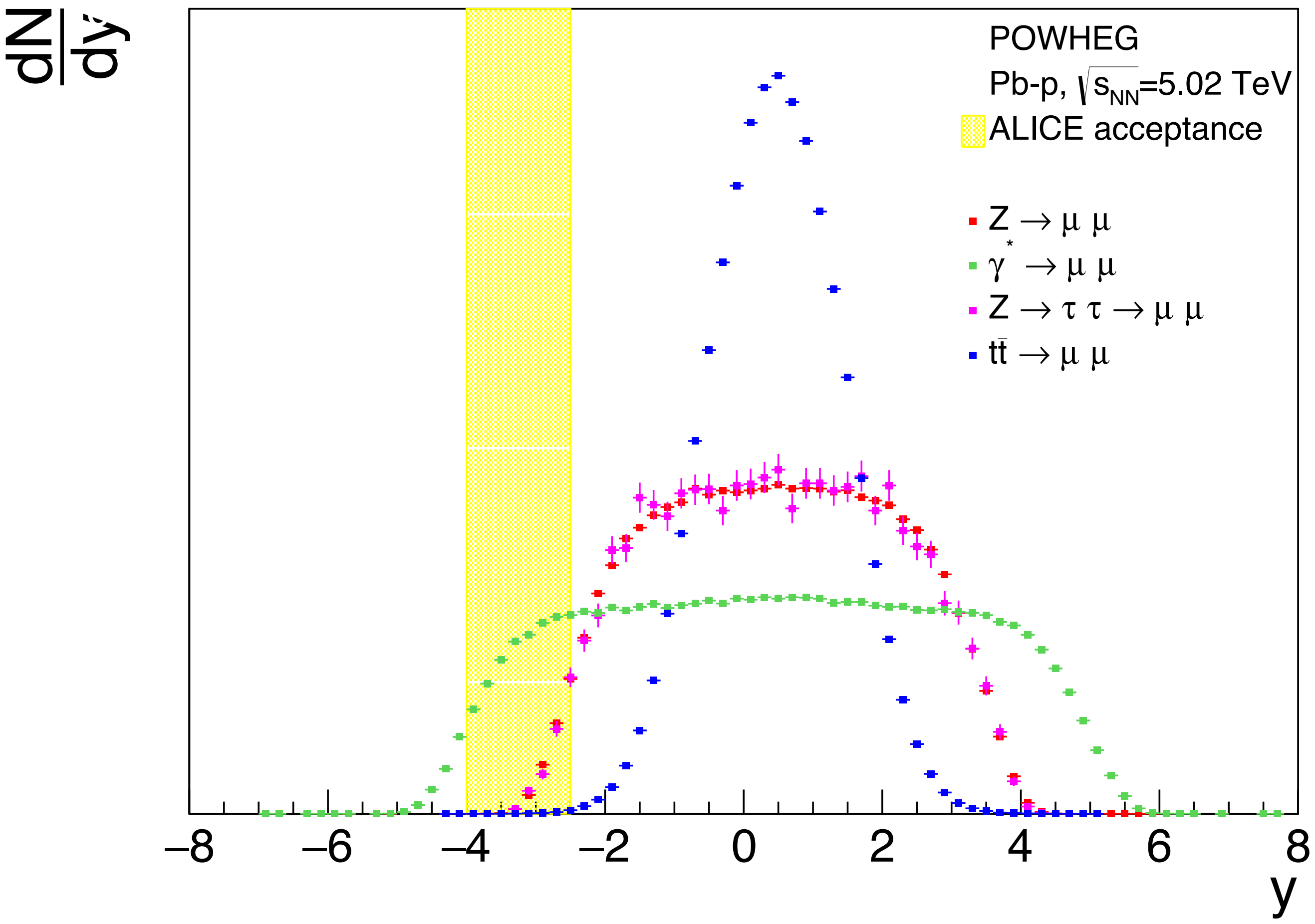
- The Muons pT shape in **$Z \rightarrow \tau\tau \rightarrow \mu\mu$** is different than the **$Z \rightarrow \mu\mu$** one because the muons are not produced back-to-back in the Z rest frame:



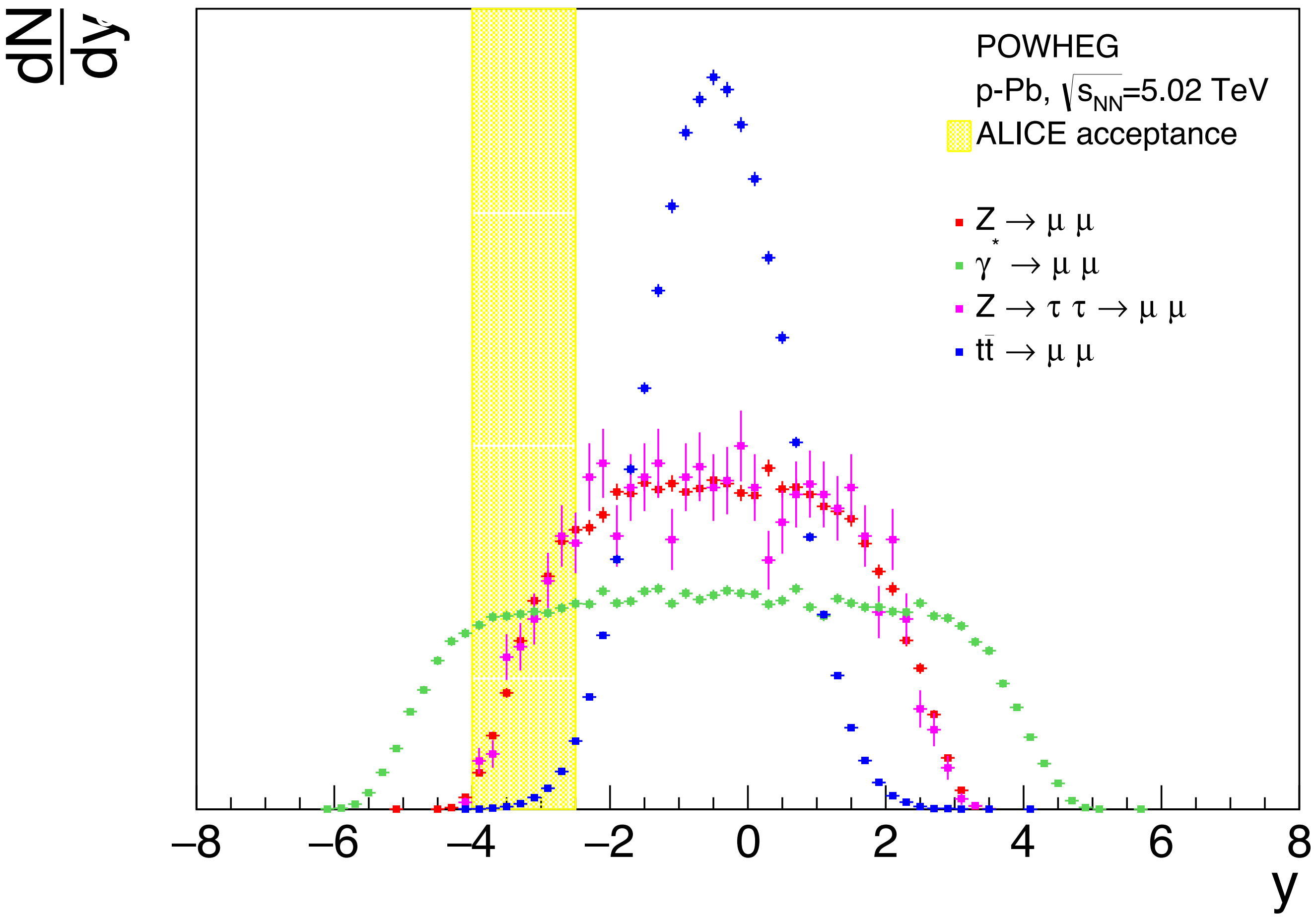




- The contribution from this source is more important at low mass.



Pb-p



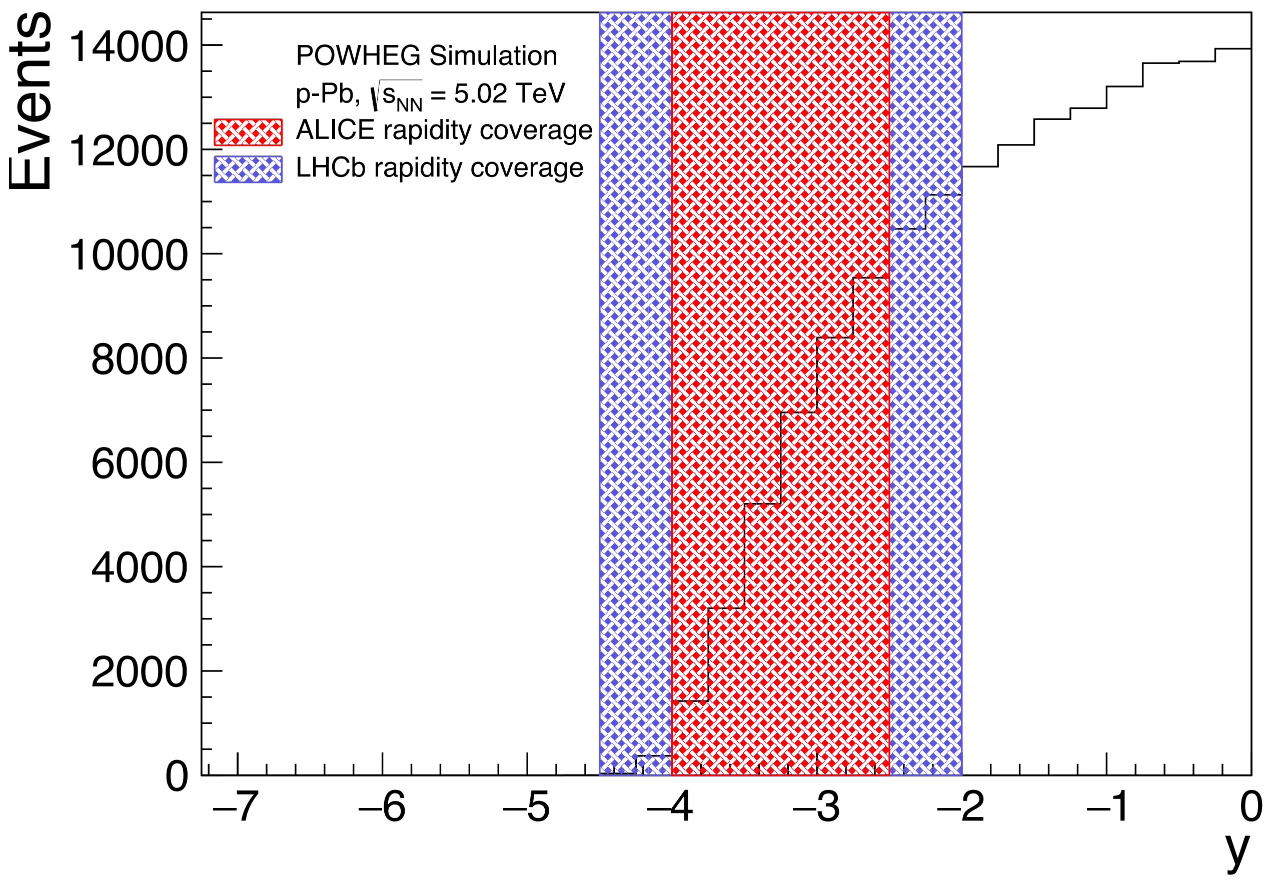
p-Pb

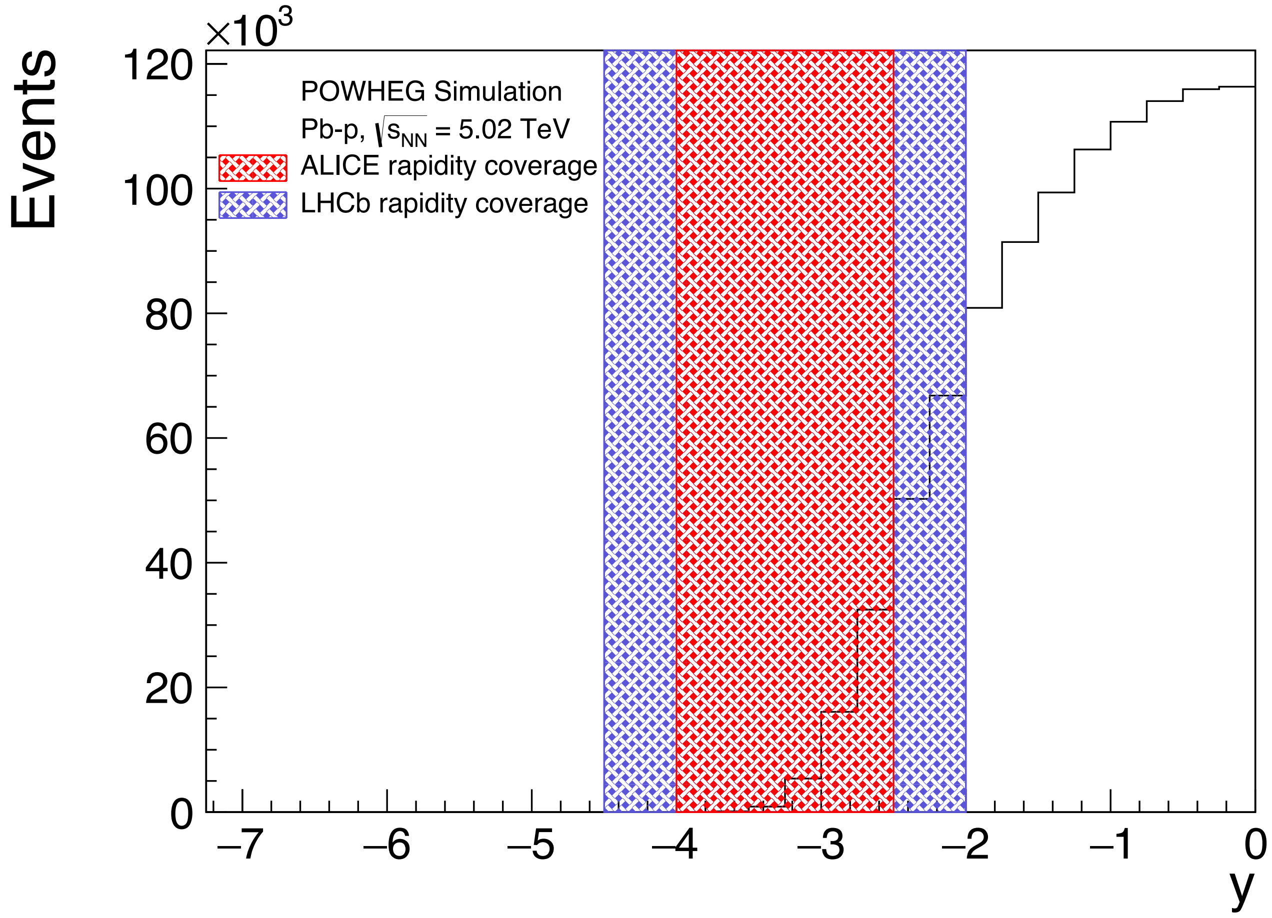
- The three rapidity distributions are normalised.
- **Z →*μμ*** and **ɣ* →*μμ*** distributions are separated according to the invariant mass (>60 GeV and < 60 GeV).

Summary of systematic uncertainties

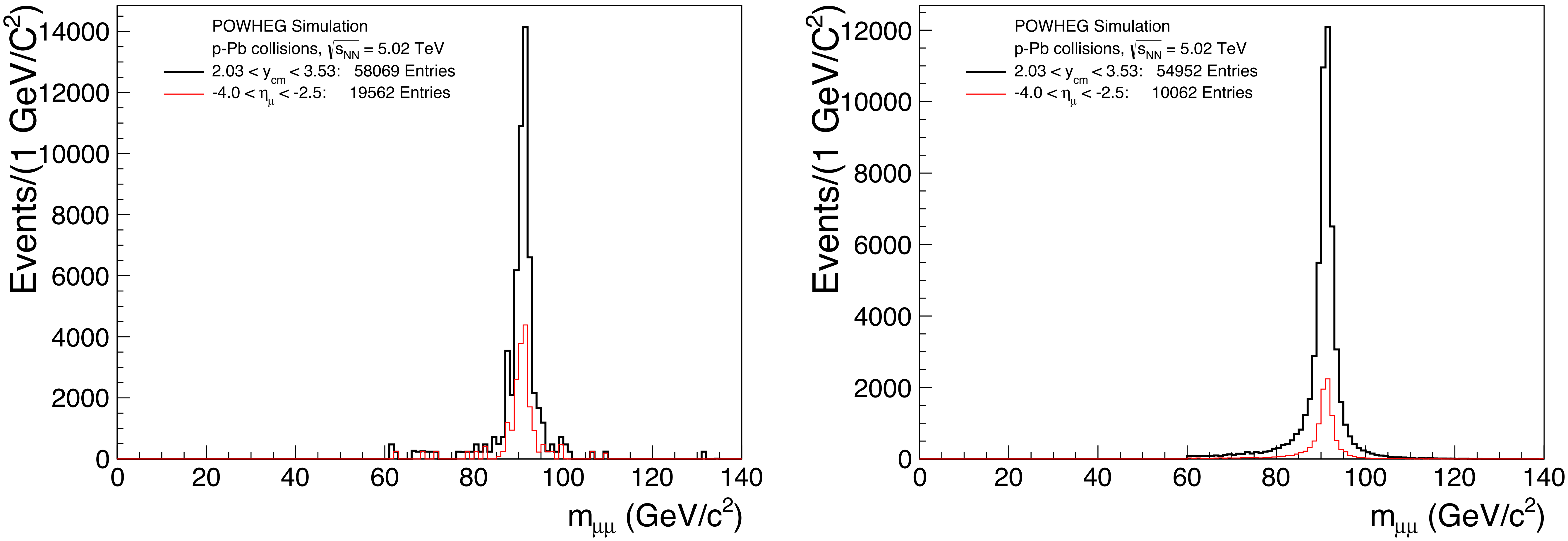
	Efficiency	Tracking efficiency	Trigger efficiency	Matching efficiency	Cluster resolution	σ_{MB}
Forward	1%	4%	2%	1%	1.3%	3.2%
backward	2%	6%	2%	1%	0.2%	3%

ALICE and LHCb rapidity





ALICE and LHCb acceptances



	Forward	**Backward**
ALICE	29.12 ± 0.29	18.31 ± 0.18
LHCb	45.43 ± 0.29	28.15 ± 0.37