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

Mohamad Tarhini
PHENIICS Doctoral School Days
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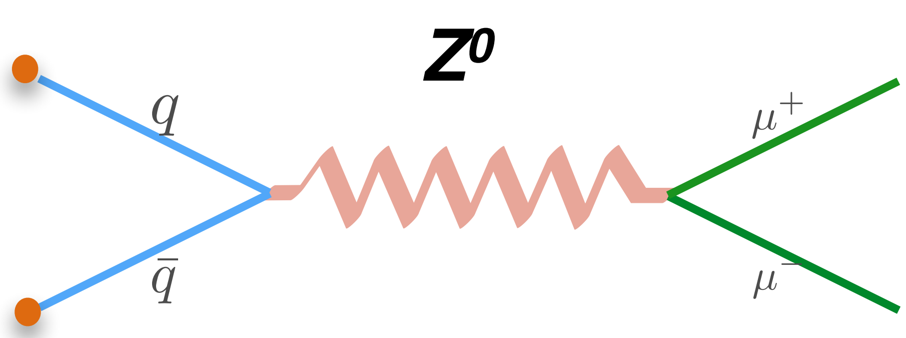
Outline

- 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
- Results
  - Compared with theory
  - Compared to other experimental results
- Conclusion and perspectives

- What is the Z boson ?
  - How is it produced ?
  - How does it 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 in different experiments.
- This production is sensitive to the PDF : $f(x,Q^2)$

$$\begin{cases} Q^2 \equiv M_Z^2 \\ x = (M_Z/\sqrt{s_{NN}})e^{\pm y} \end{cases}$$

$x = (M_Z/\sqrt{s_{NN}})e^{\pm y}$ is the fraction of the nucleon momentum carried by the parton (q)

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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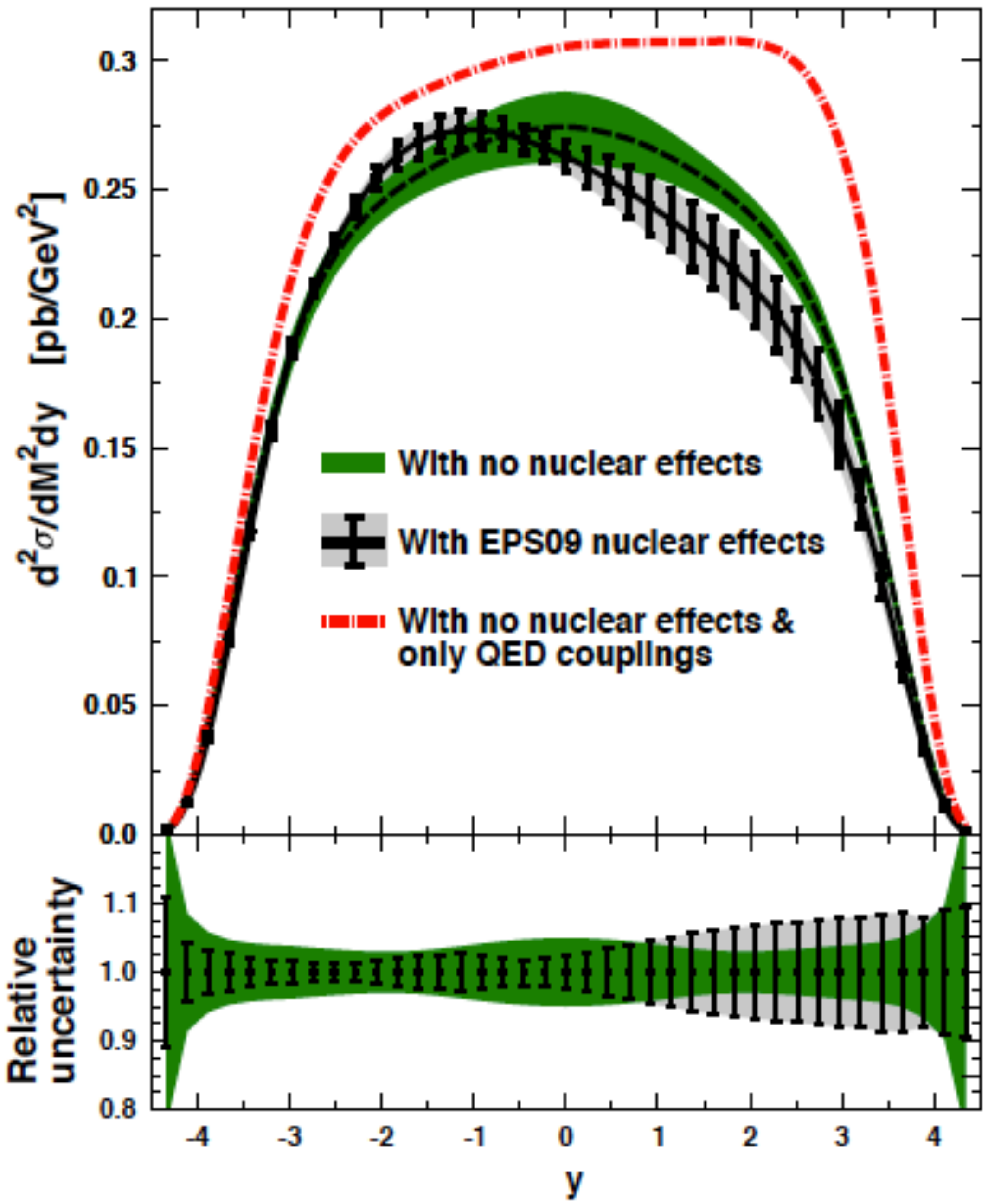

Theoretical calculation for the Z-boson production cross section in p-Pb collisions with and without nuclear effects [1]

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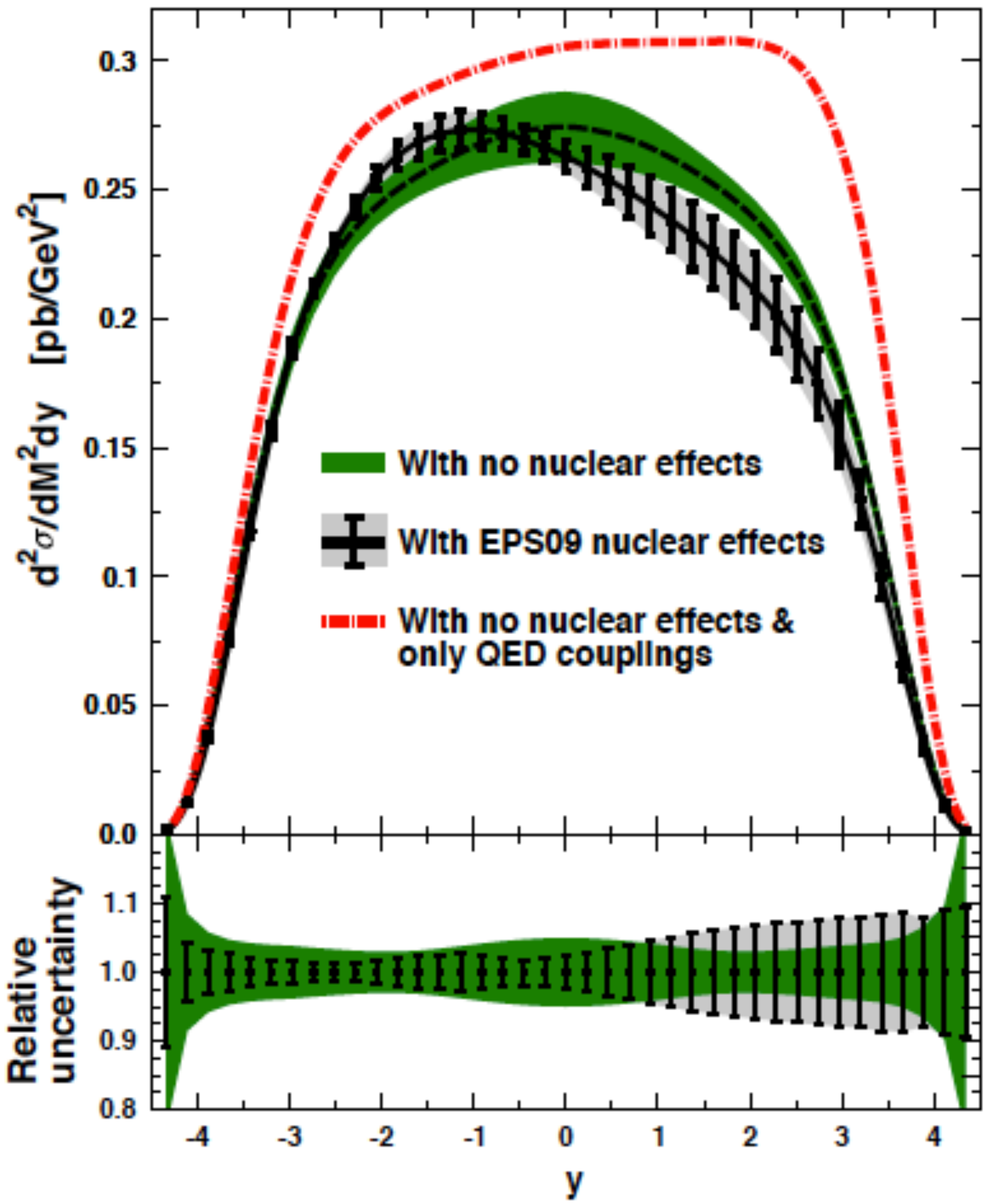
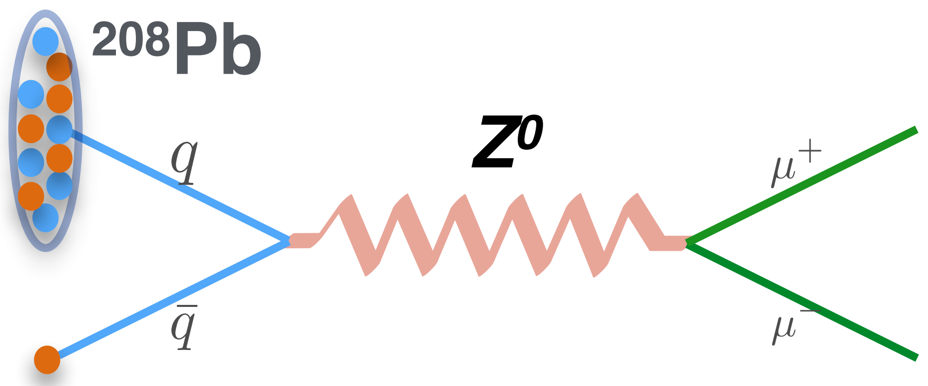
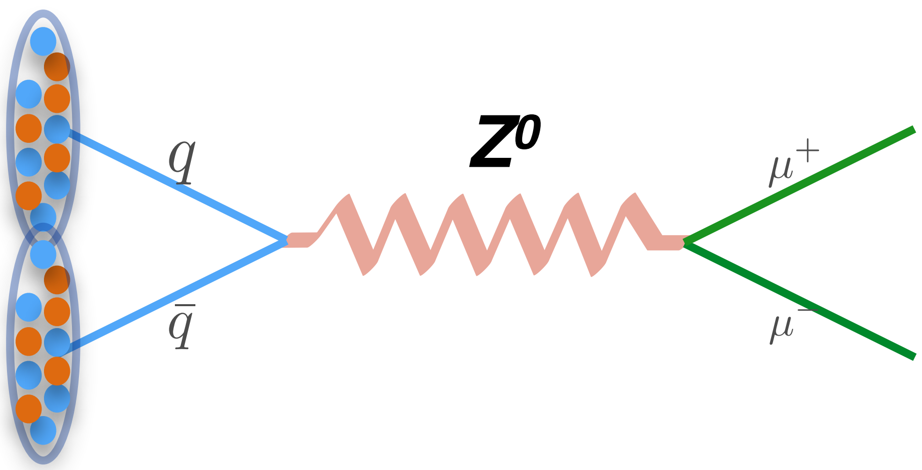


- Due to the lack of the experimental data, nPDF are less known than the PDF.

Theoretical calculation for the Z-boson production cross section in p-Pb collisions with and without nuclear effects [1]

- Before the LHC, the Z^0 boson production was not studied in nuclear collisions.





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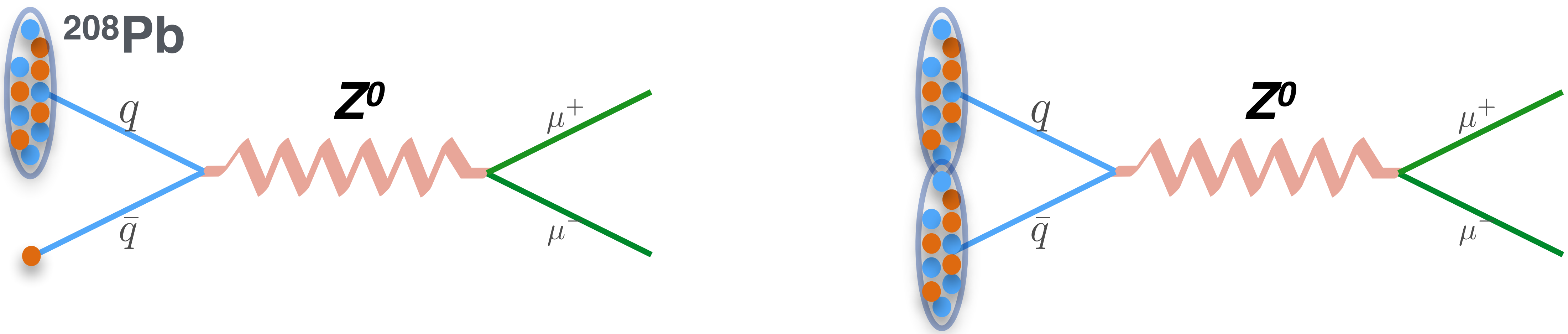

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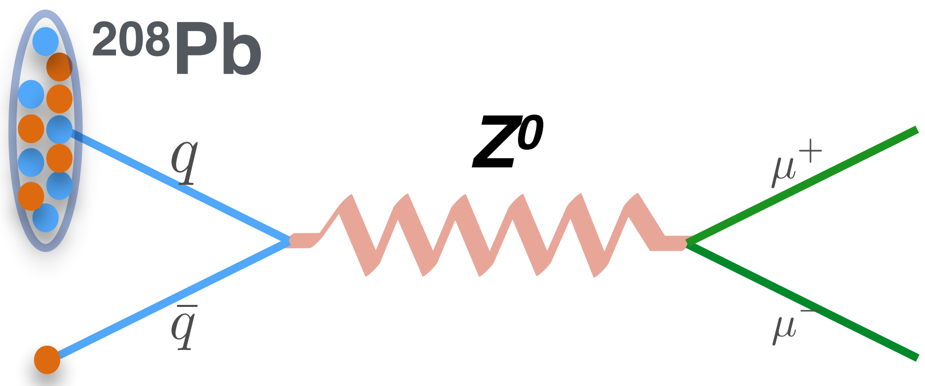

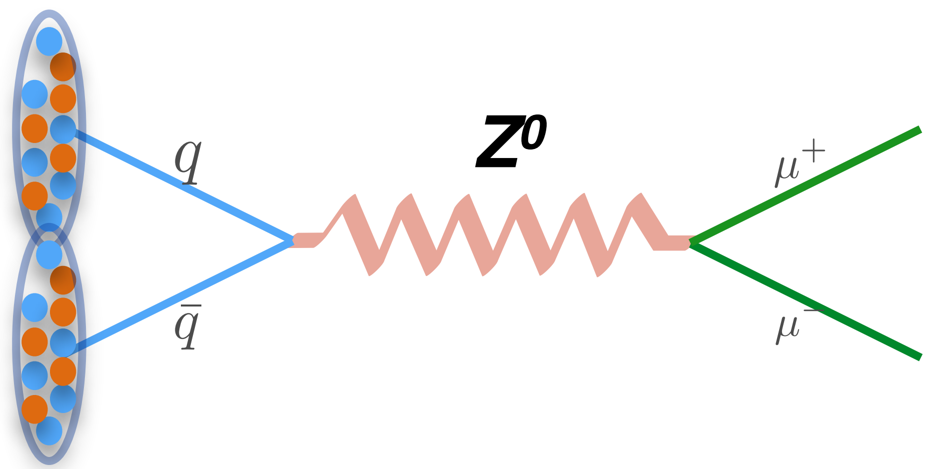

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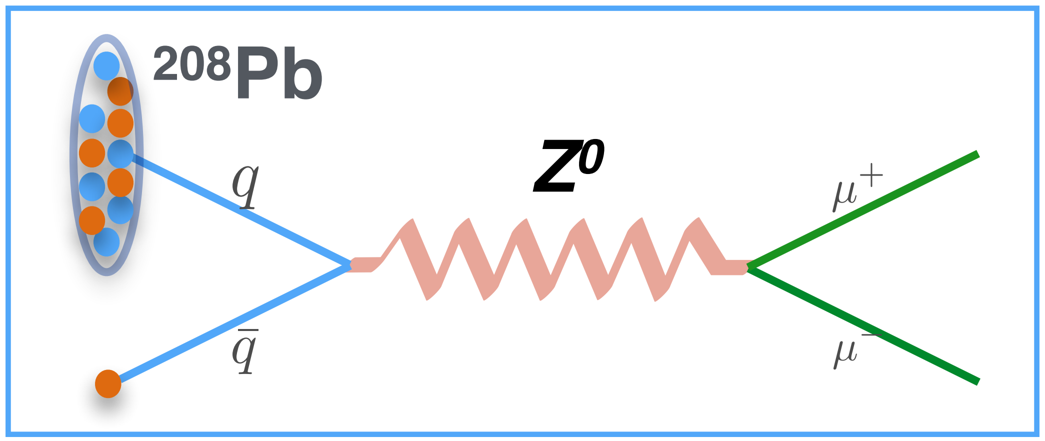

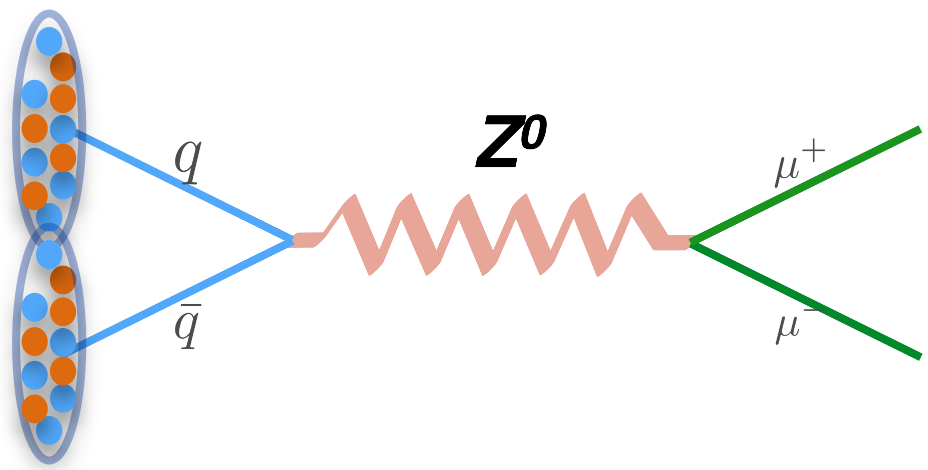

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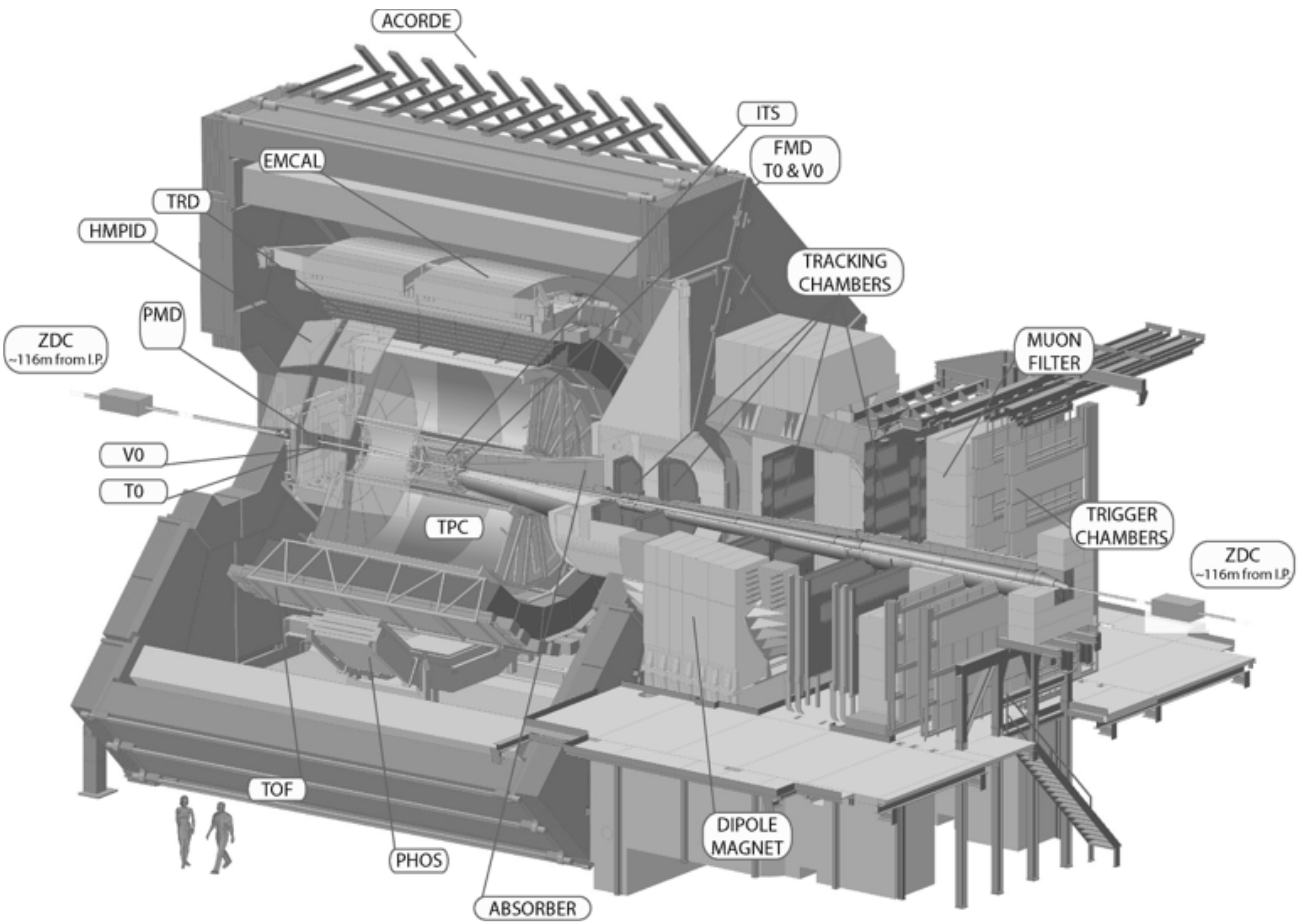
ALICE Detector



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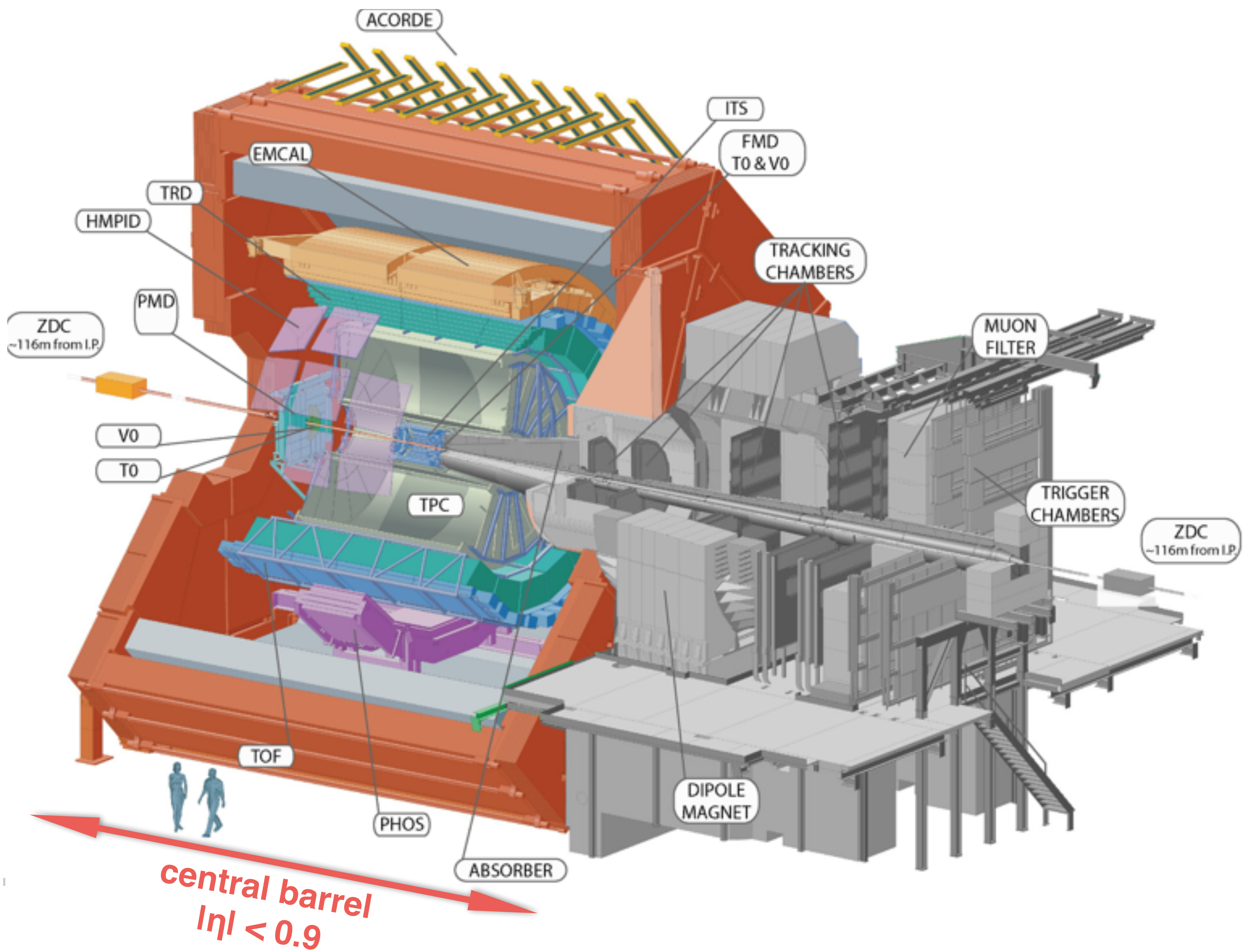

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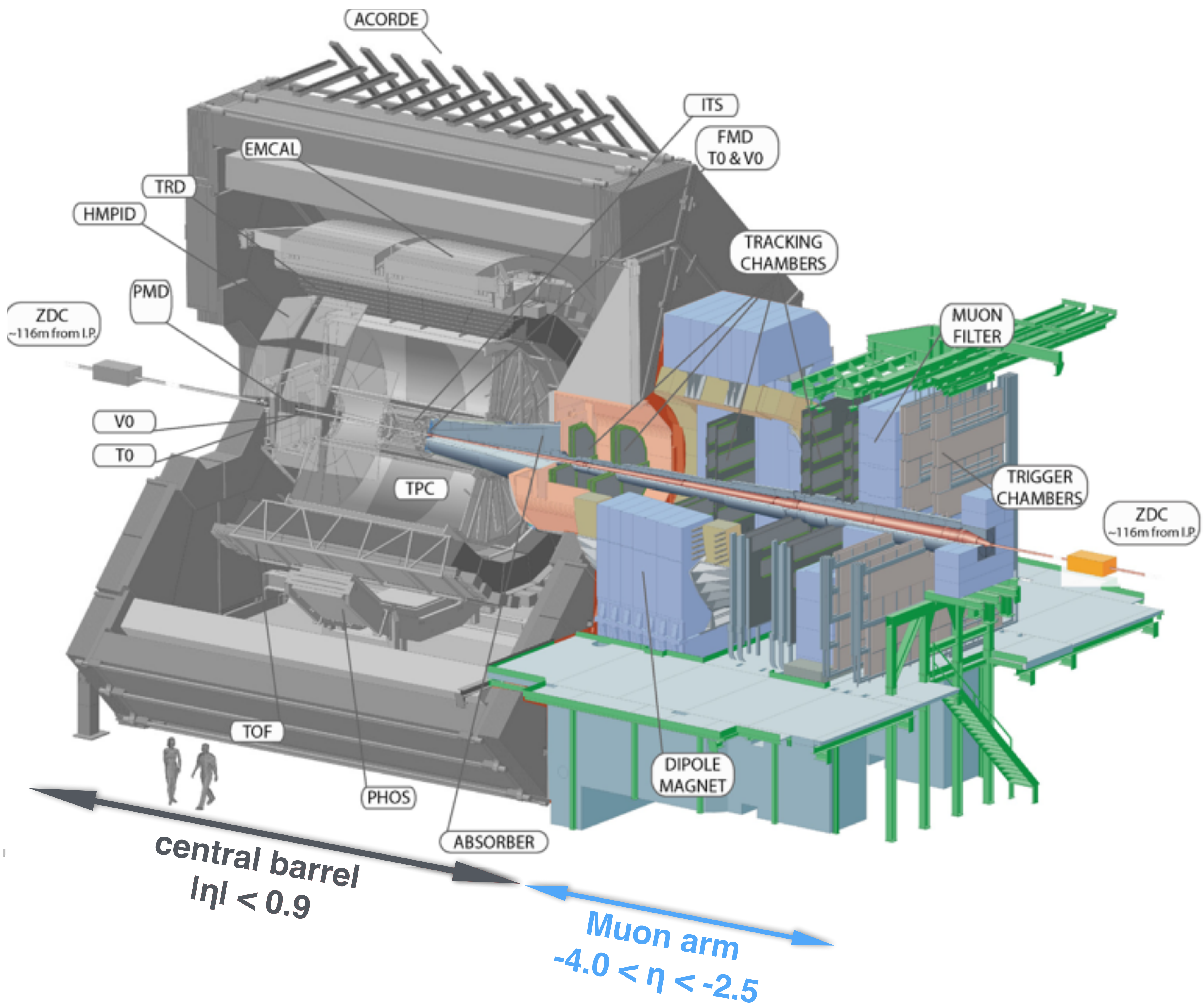

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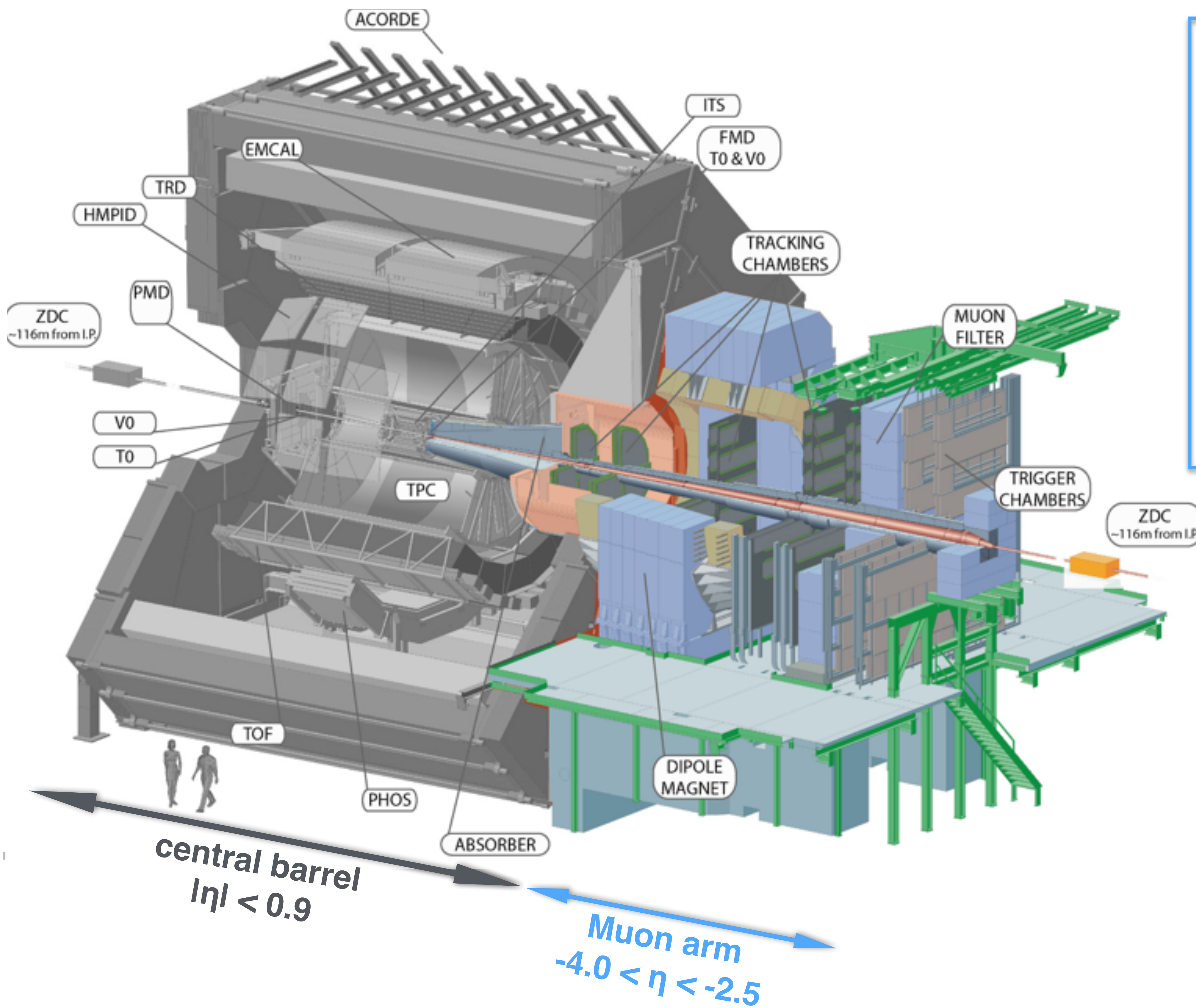

$Z \rightarrow \mu^+ \mu^-$

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

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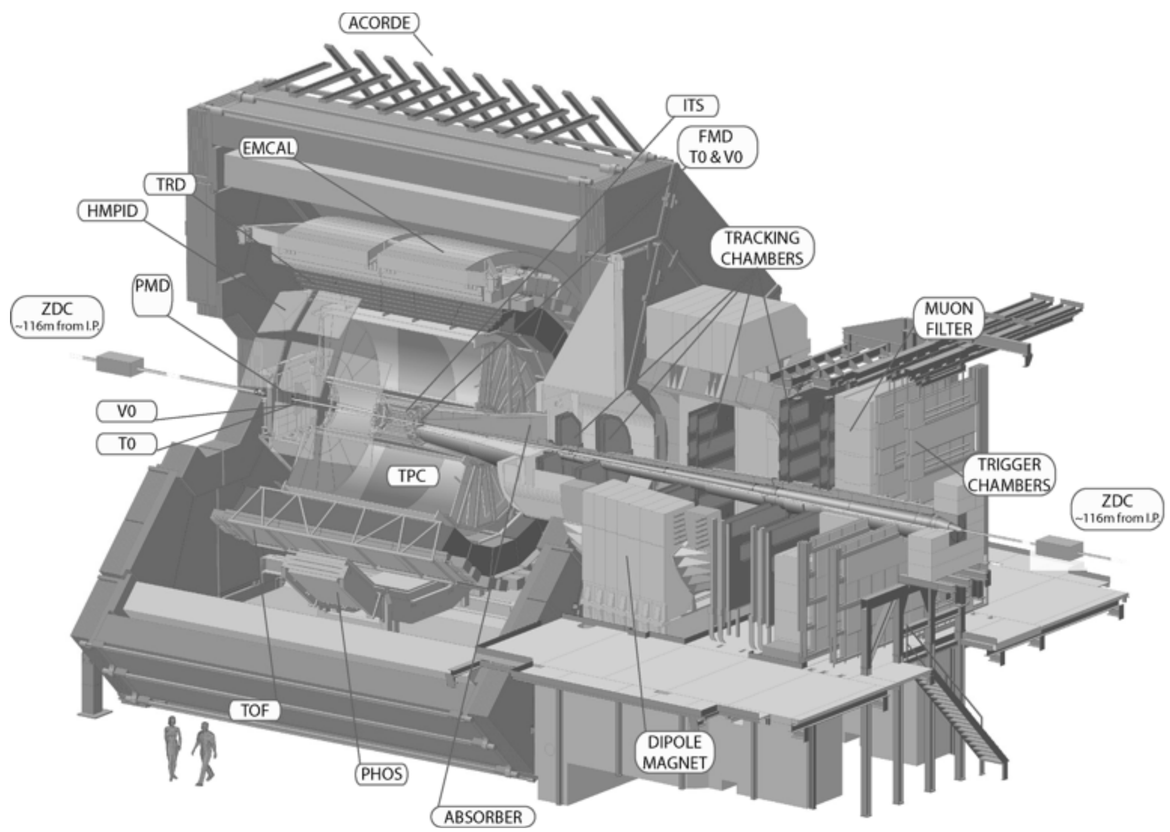

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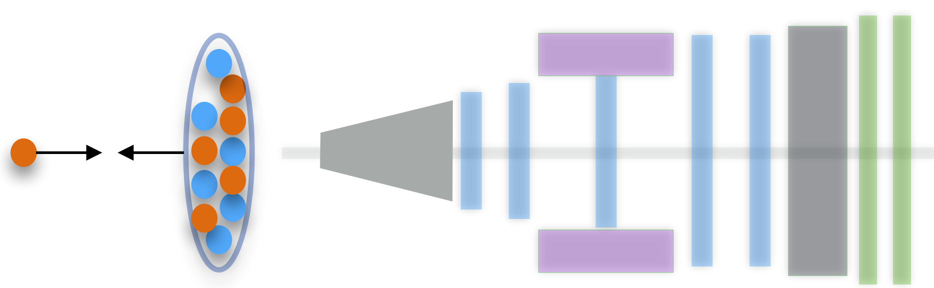
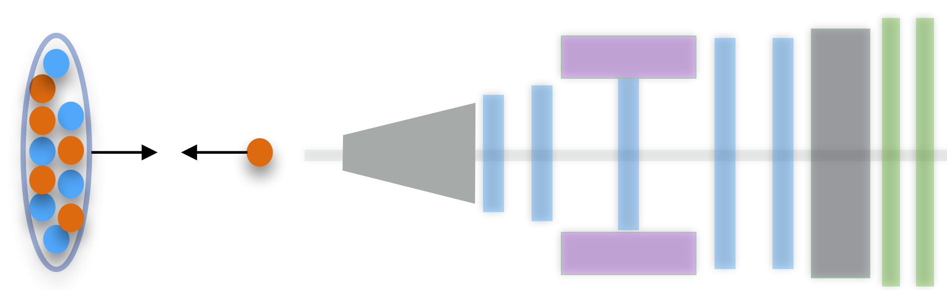
- Detected in the muon arm
- Region covered by **LHCb and** Complementary to **ATLAS** and **CMS** one

- In p-Pb collisions, due to the LHC design, the muon spectrometer covers two centre-of-mass rapidity regions:

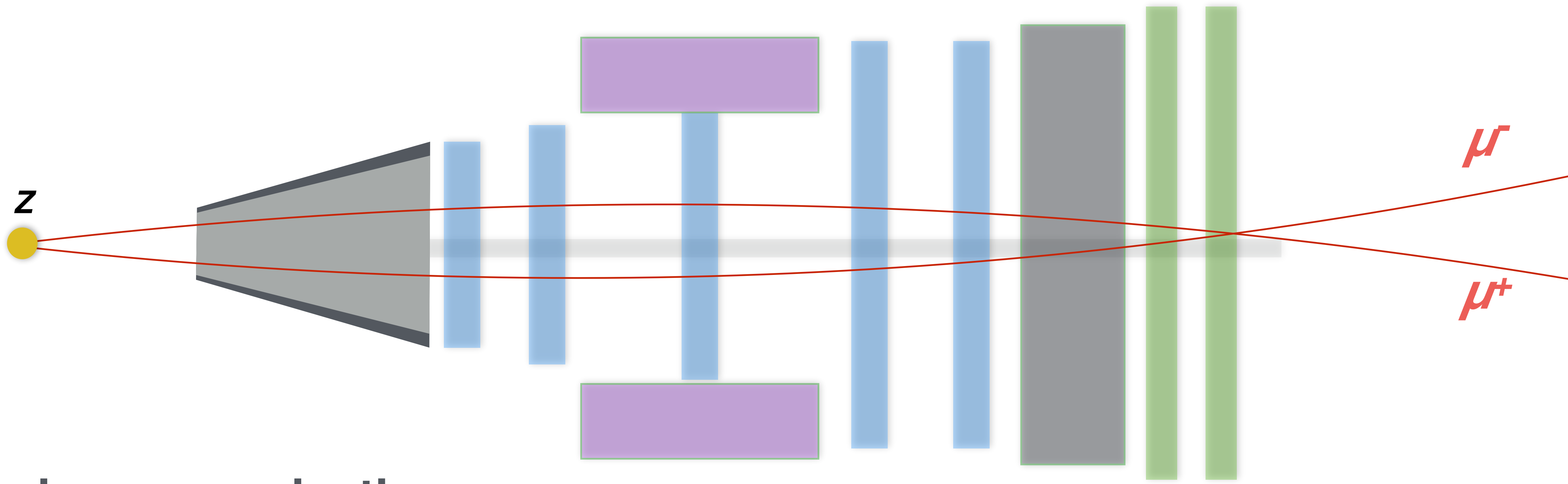
$2.03 < y_{cm} < 3.53$ and $-4.46 < y_{cm} < -2.96$





Track And Event Selection

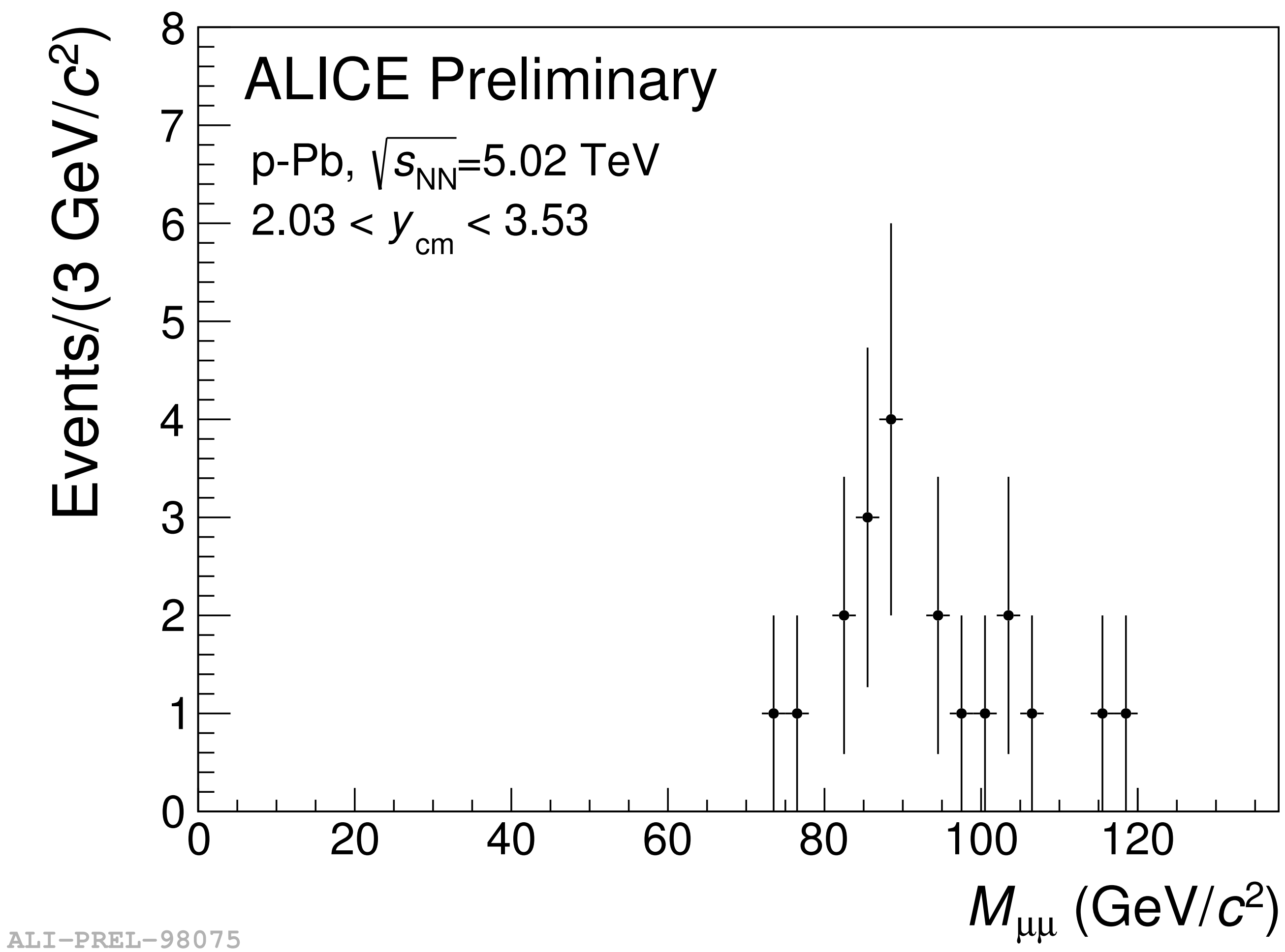
- Z candidates are obtained by combining opposite-charge muon tracks that fulfil the single muon selection:

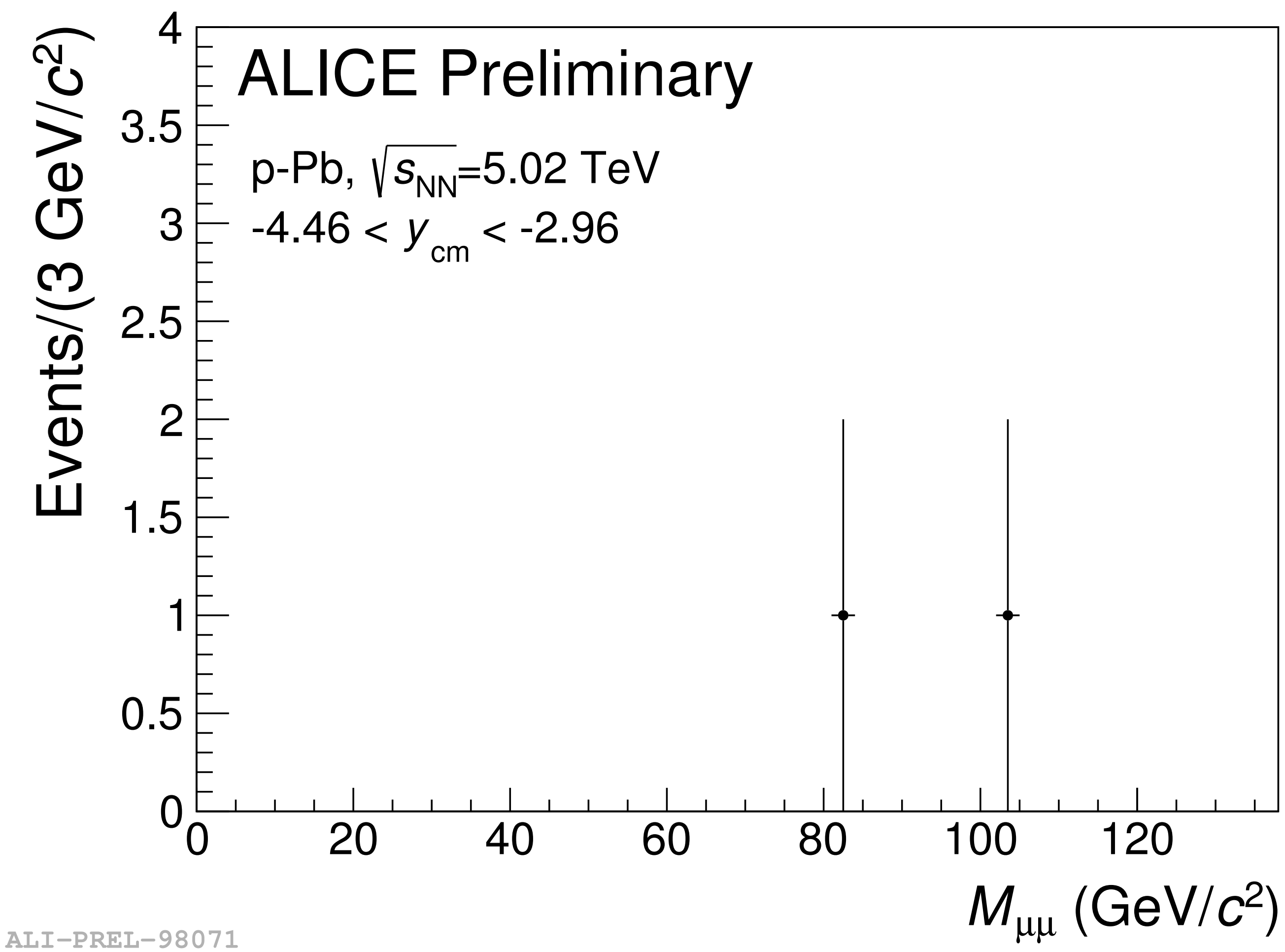


- **Single muon selection:**
  - $17.6 < R_{abs} < 89.5$ cm: rejects muons crossing the thick part of the front absorber
  - A cut on pDCA to reject fake muon that are not pointing to the vertex
  - Pseudo-rapidity cut, $-4 < \eta_{\mu} < -2.5$ to reject muon at the acceptance edge
  - $p_T(\mu) > 20$ Gev/c, to reject muon from background and other sources
  - Cuts on muons that do not match the trigger

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.

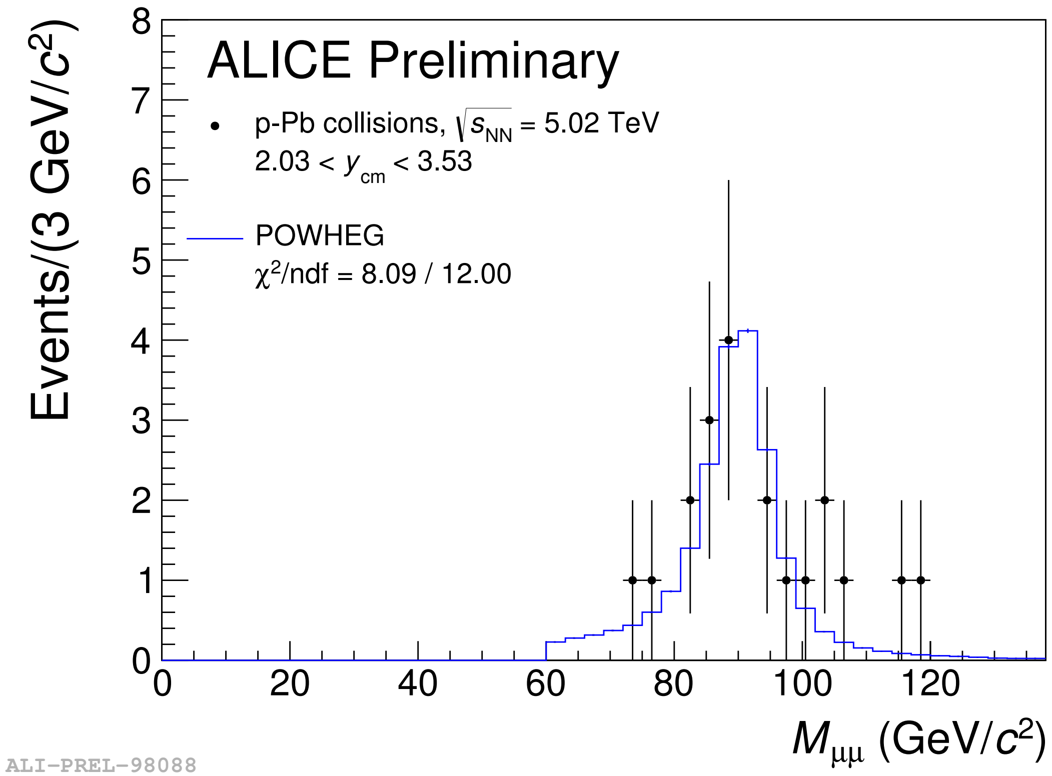




- The contribution from different background sources is evaluated with MC simulations and it is very small.

Detector Efficiency

- POWHEG used as particle generator:
  - Take NLO contributions into account.
  - Need to be interfaced with MC shower program (PYTHIA-6).
- ALICE detector is simulated with GEANT-3.



- The number of simulated events is normalised to data.
- MC distribution describes well the data in forward rapidity region.

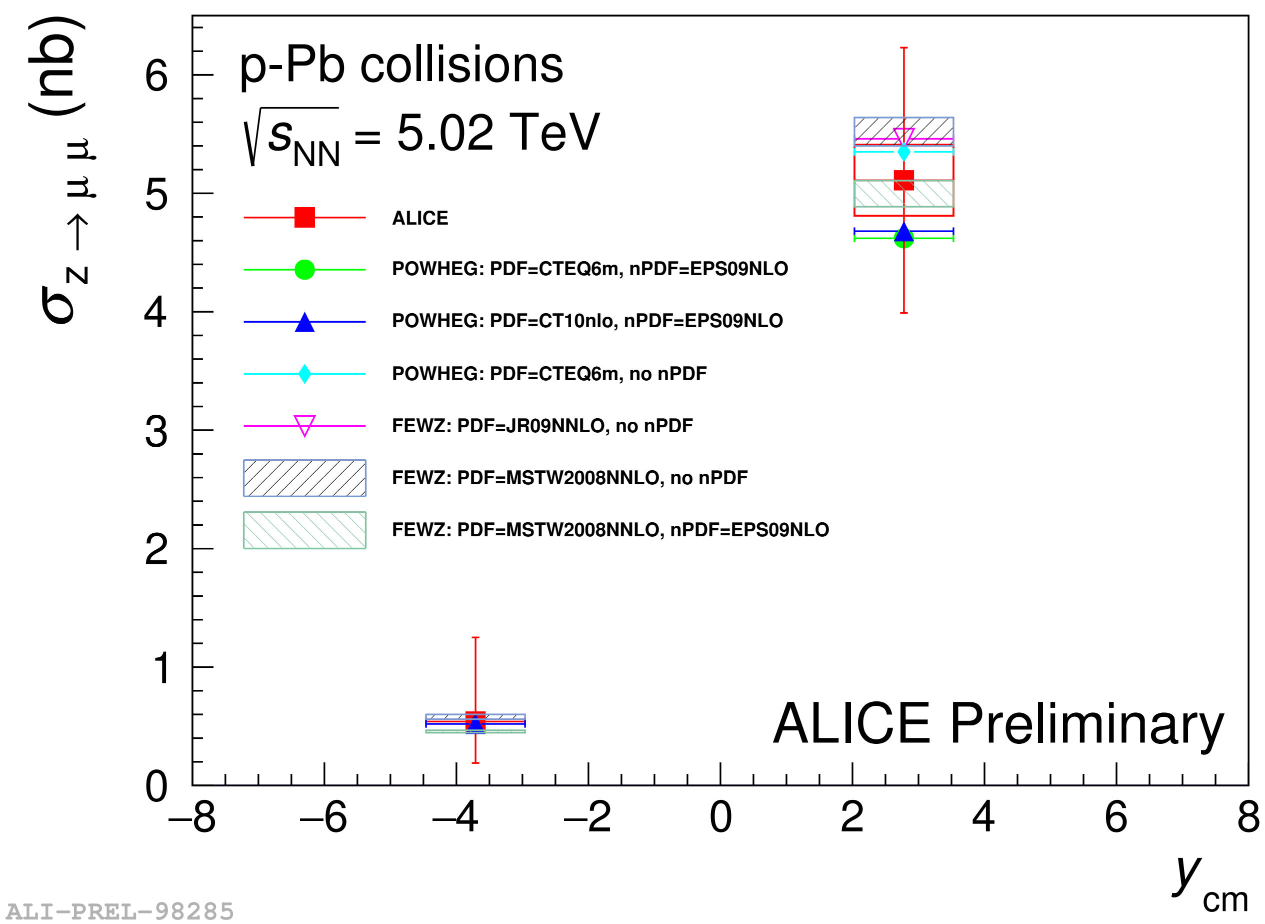
The detector efficiency is calculated in both rapidity regions as the ratio between the reconstructed and generated events:

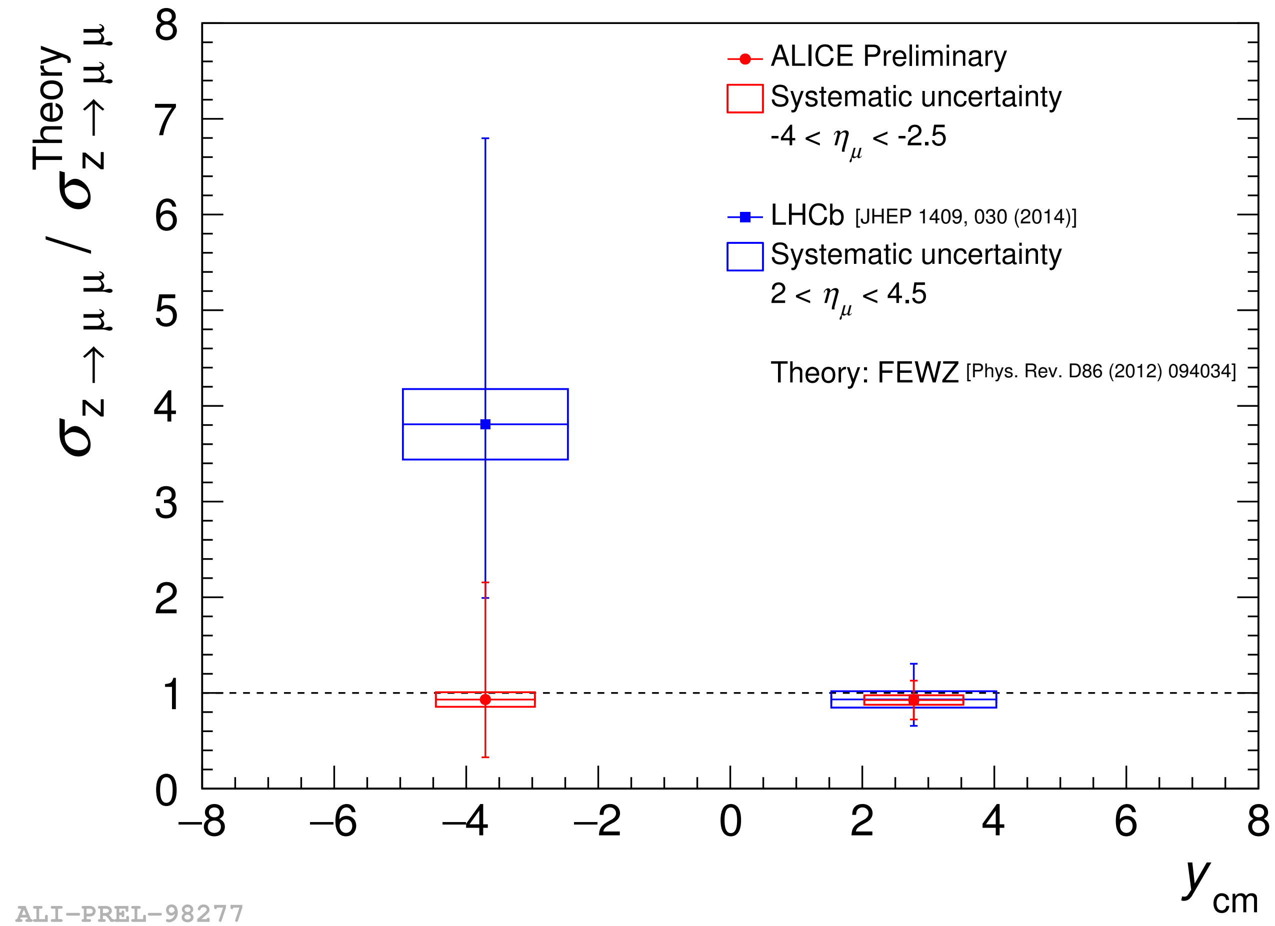
$$\varepsilon(2.03 < y_{cm} < 3.53) = 83.54 \pm 0.72\ \%$$

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

Results

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





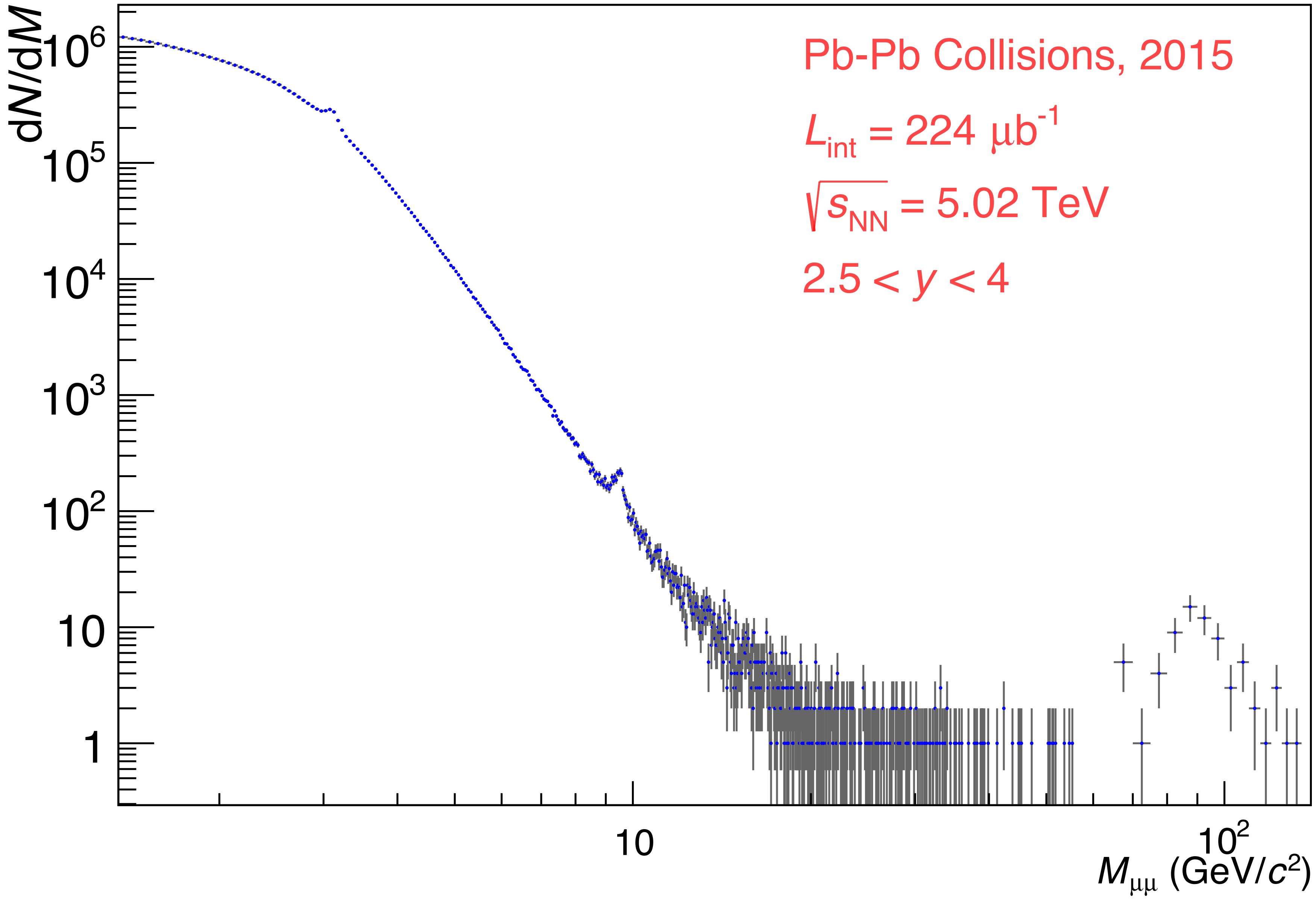
- Within large statistical uncertainty, results agree with theory predictions in both rapidity regions.
- The results from ALICE and LHCb are in agreement in the positive rapidity region

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.

Perspectives

- In November/December 2015, ALICE collected data from Pb-Pb collisions at a centre-of-mass energy of 5.02 TeV



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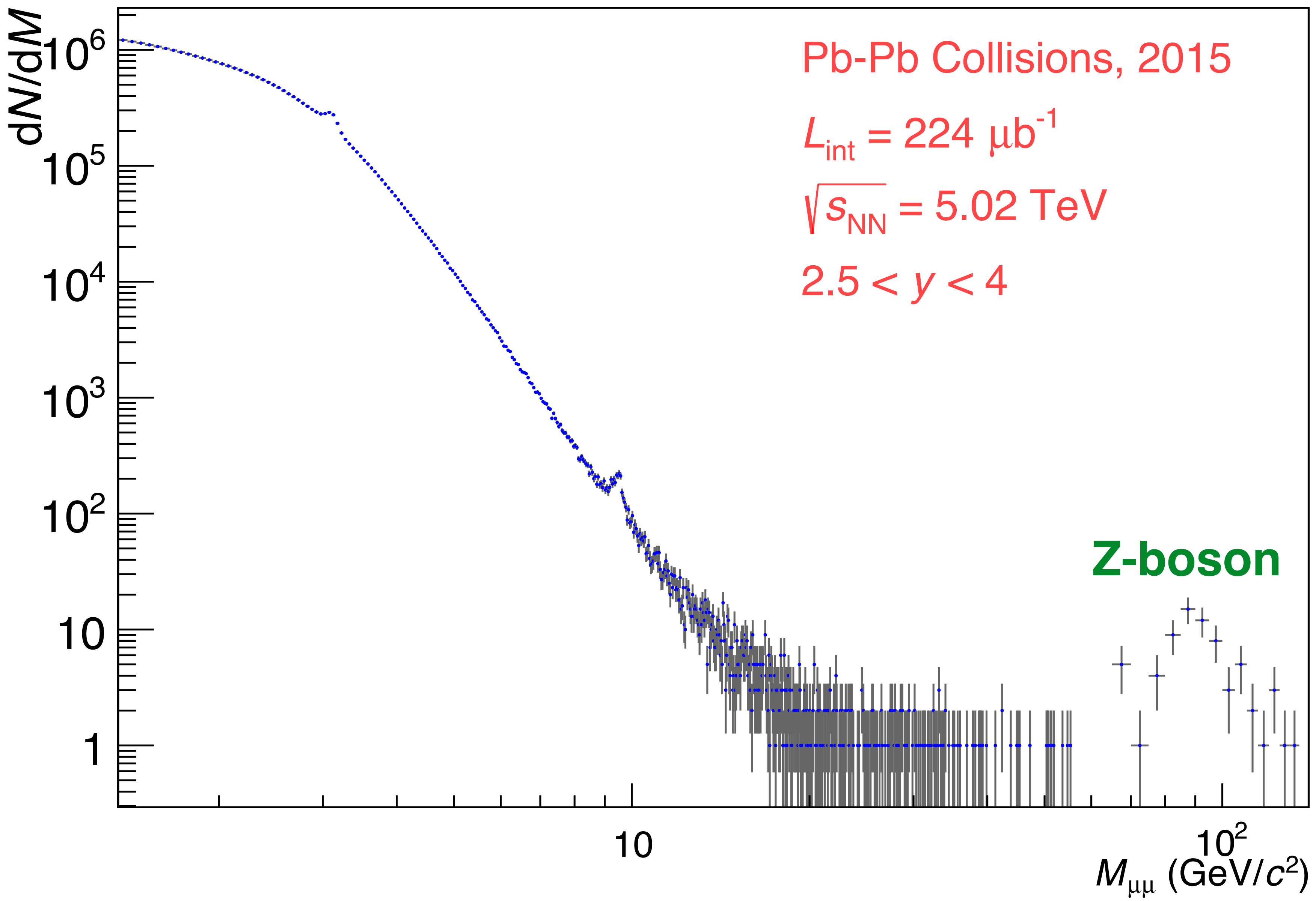

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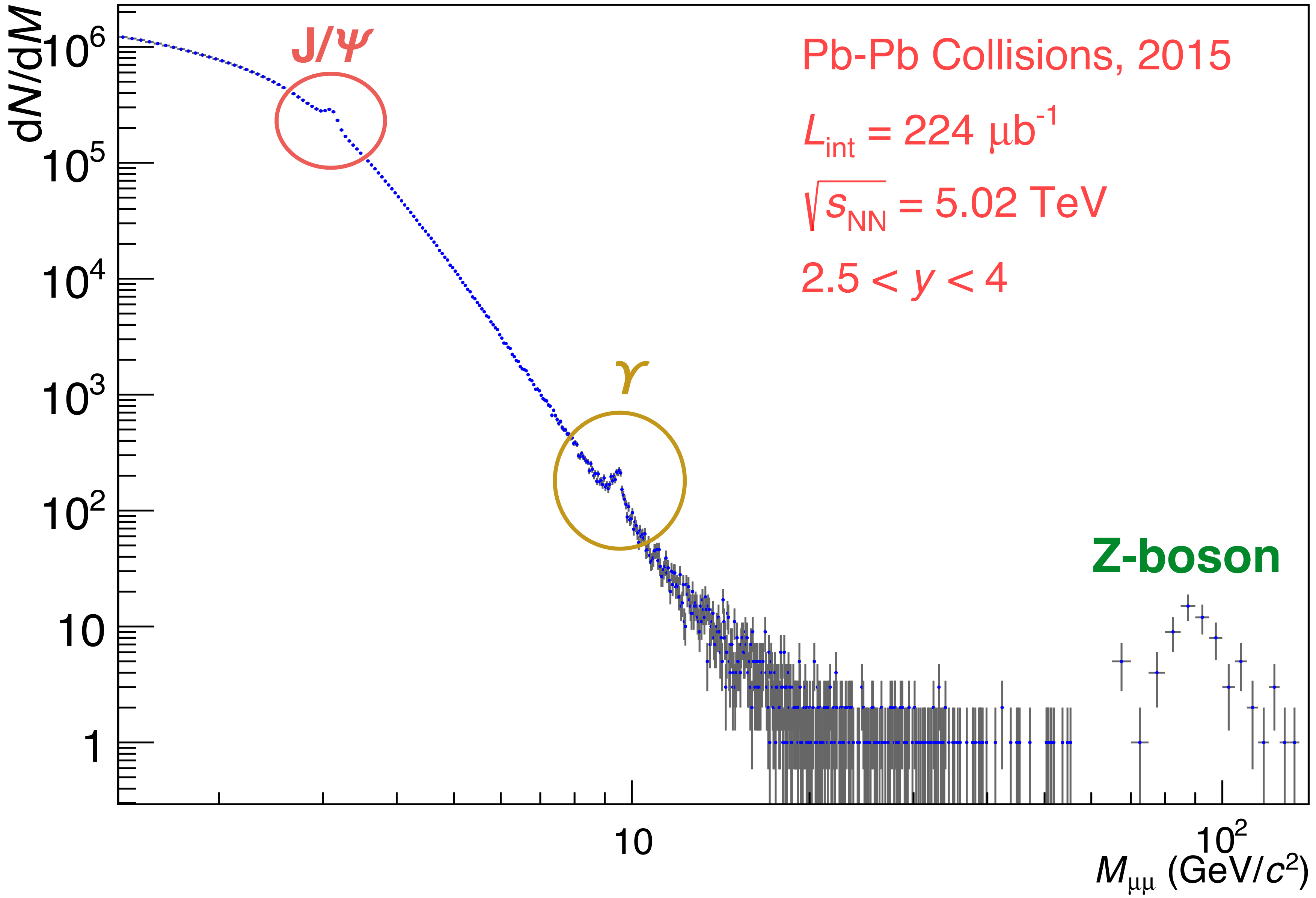


- Measurement of the Z-boson production: ~ same motivations as in p-Pb
- Measurement of the J/Ψ ($c\bar{c}$ resonance) and Υ ($b\bar{b}$ resonance): To study the properties of a new state of matter called quark-gluon plasma

BACKUP

Background Contribution I

With the cut on the muon pT, the expected contribution from background is very small

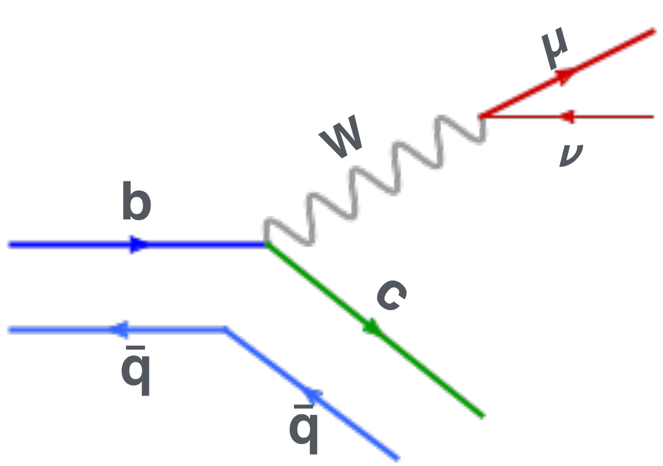
Possible sources:

1- One or two muons are mis-identified hadrons (pion, kaon,..) :

- No electric charge correlation for dimuon from this source

→ By looking at Like-Sign dimuon distribution, this contribution is negligible

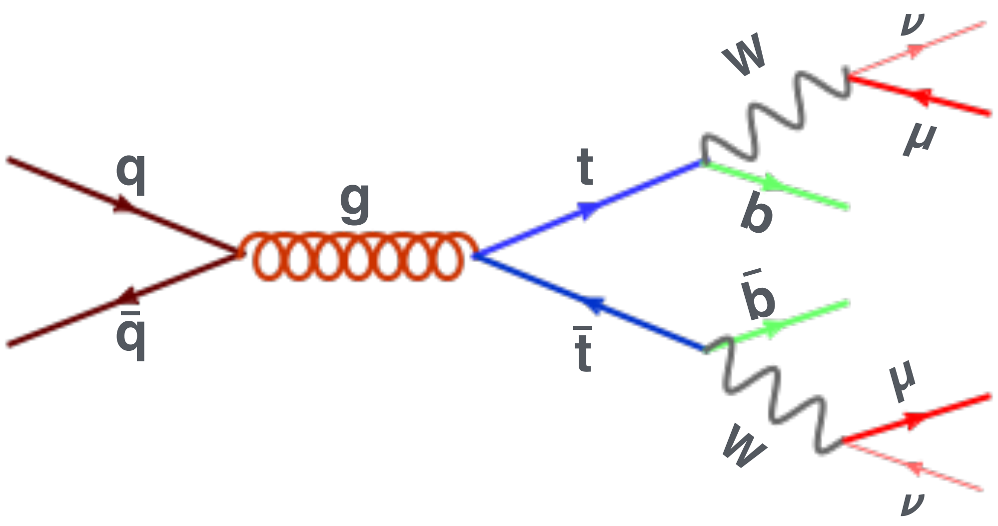
2- Semileptonic decay of $b\bar{b}$ or $c\bar{c}$ pairs :



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

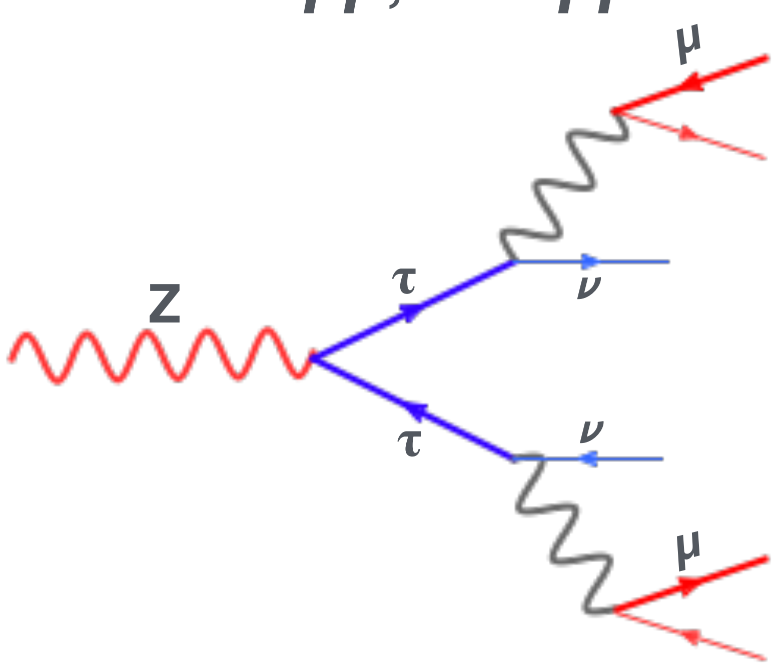
Background Contribution II

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



contribution from this source is higher at mid-rapidity.

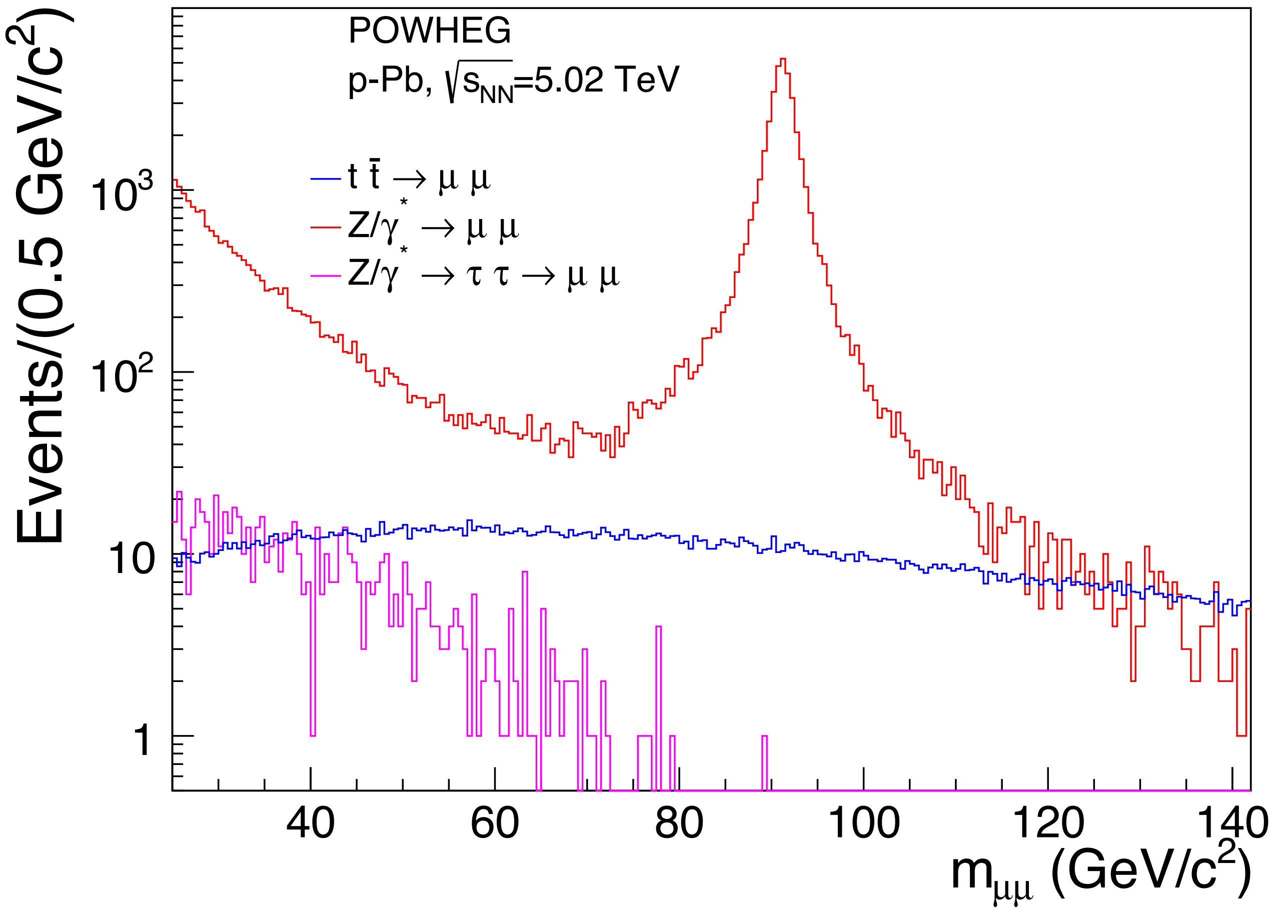
4- $Z \rightarrow \tau\tau \rightarrow \mu\mu$, $t\bar{t} \rightarrow \mu\mu$

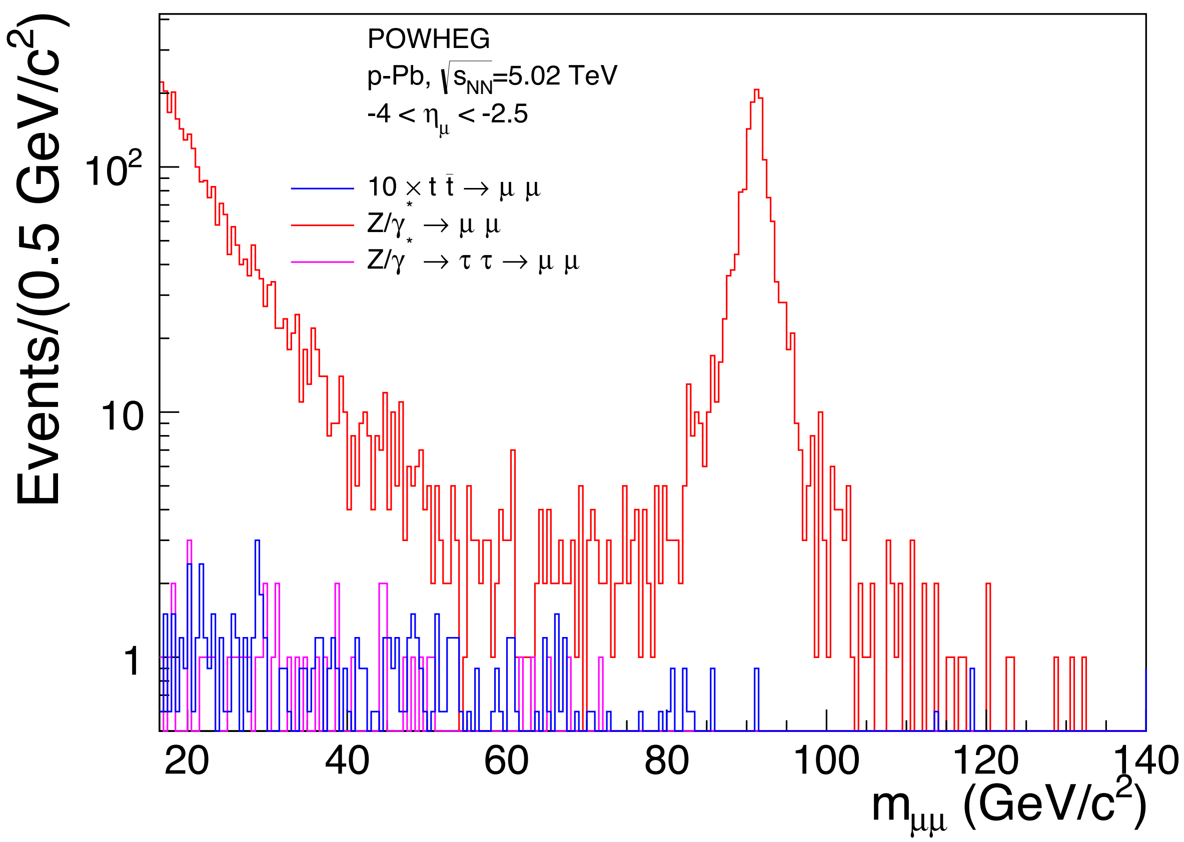


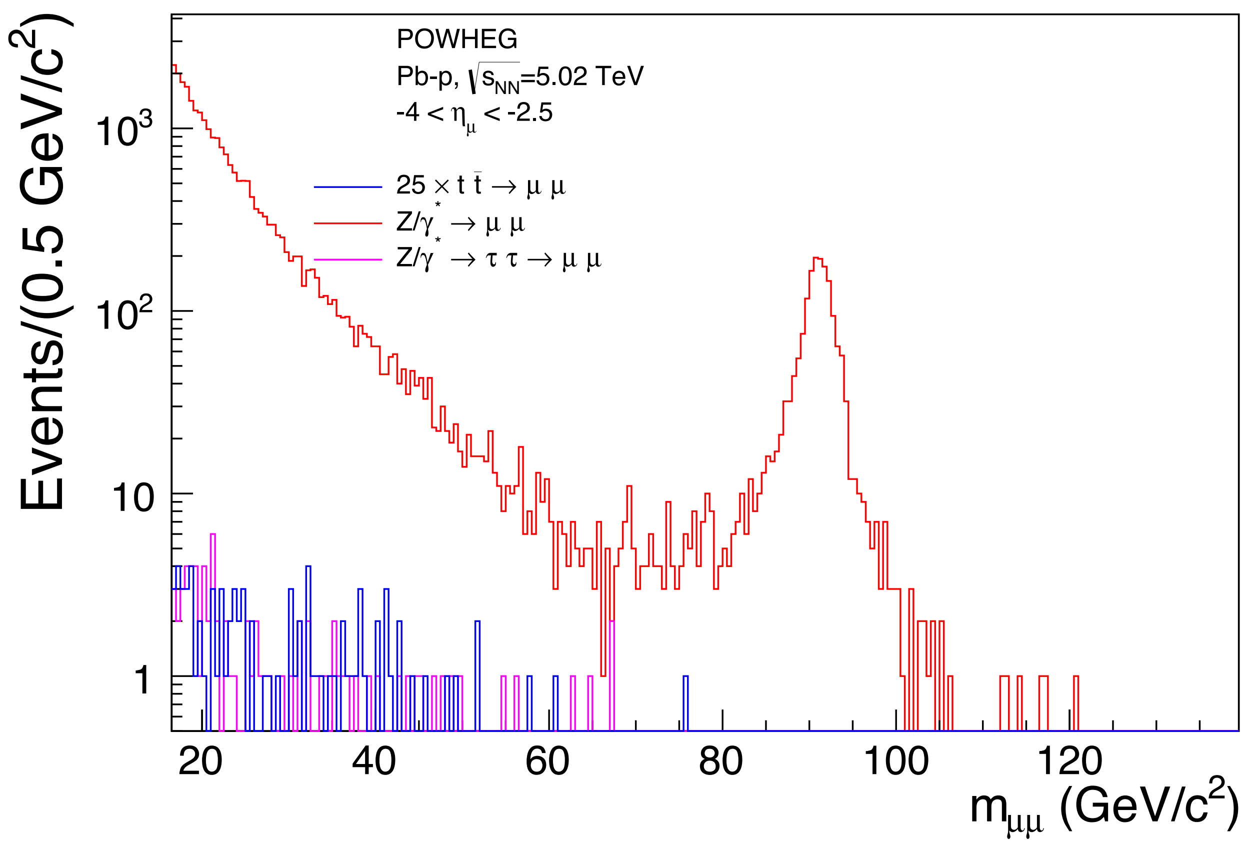
Due to missing energy from neutrinos, contribution from this source is higher at low-mass region.

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

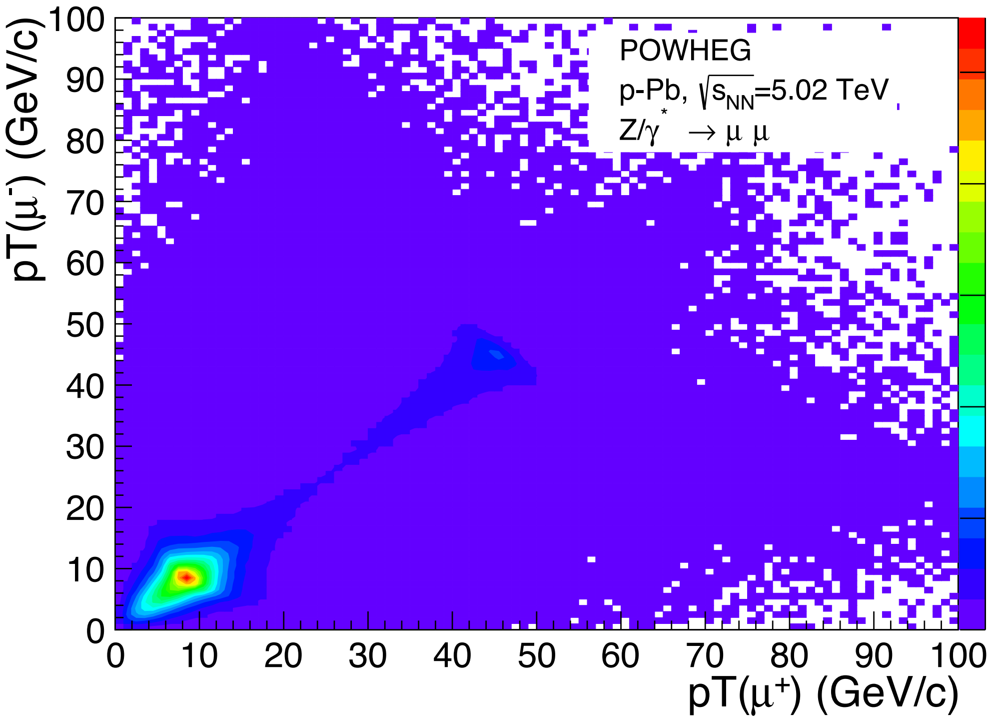
Background Contribution

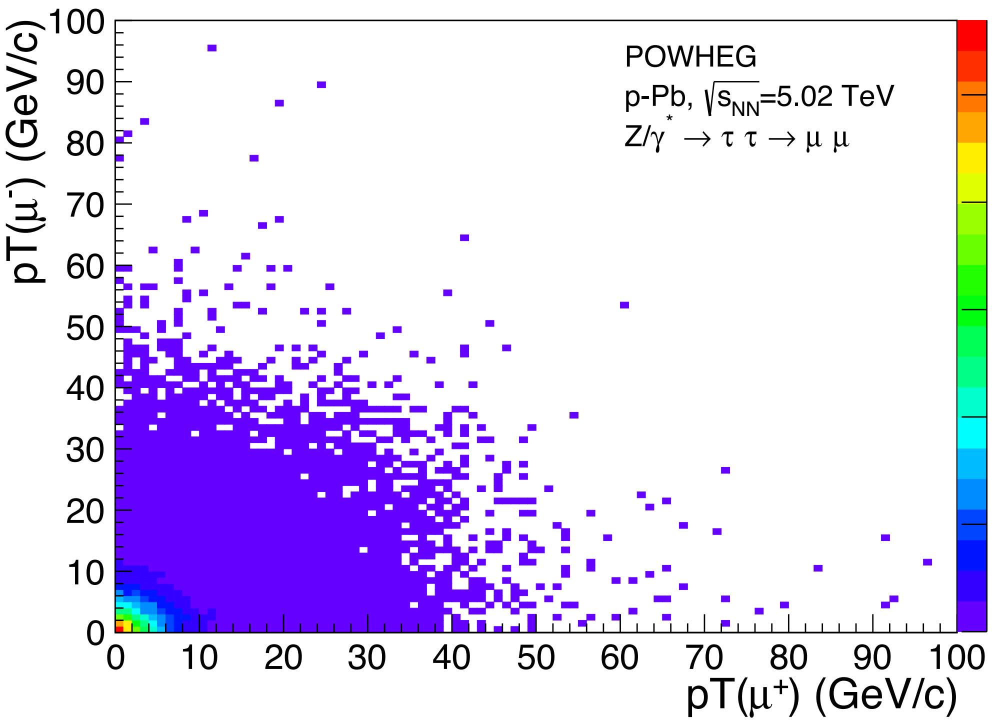


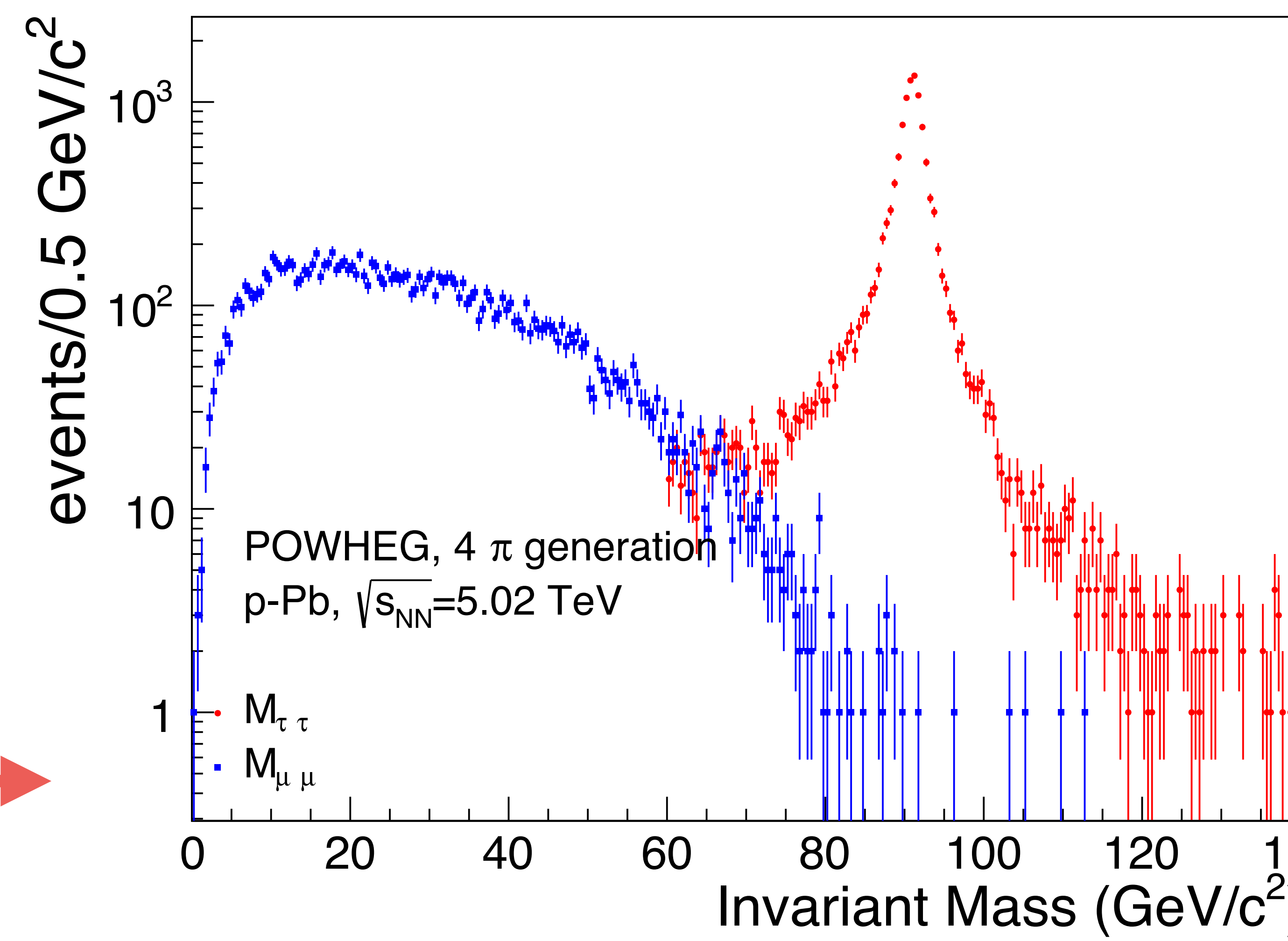




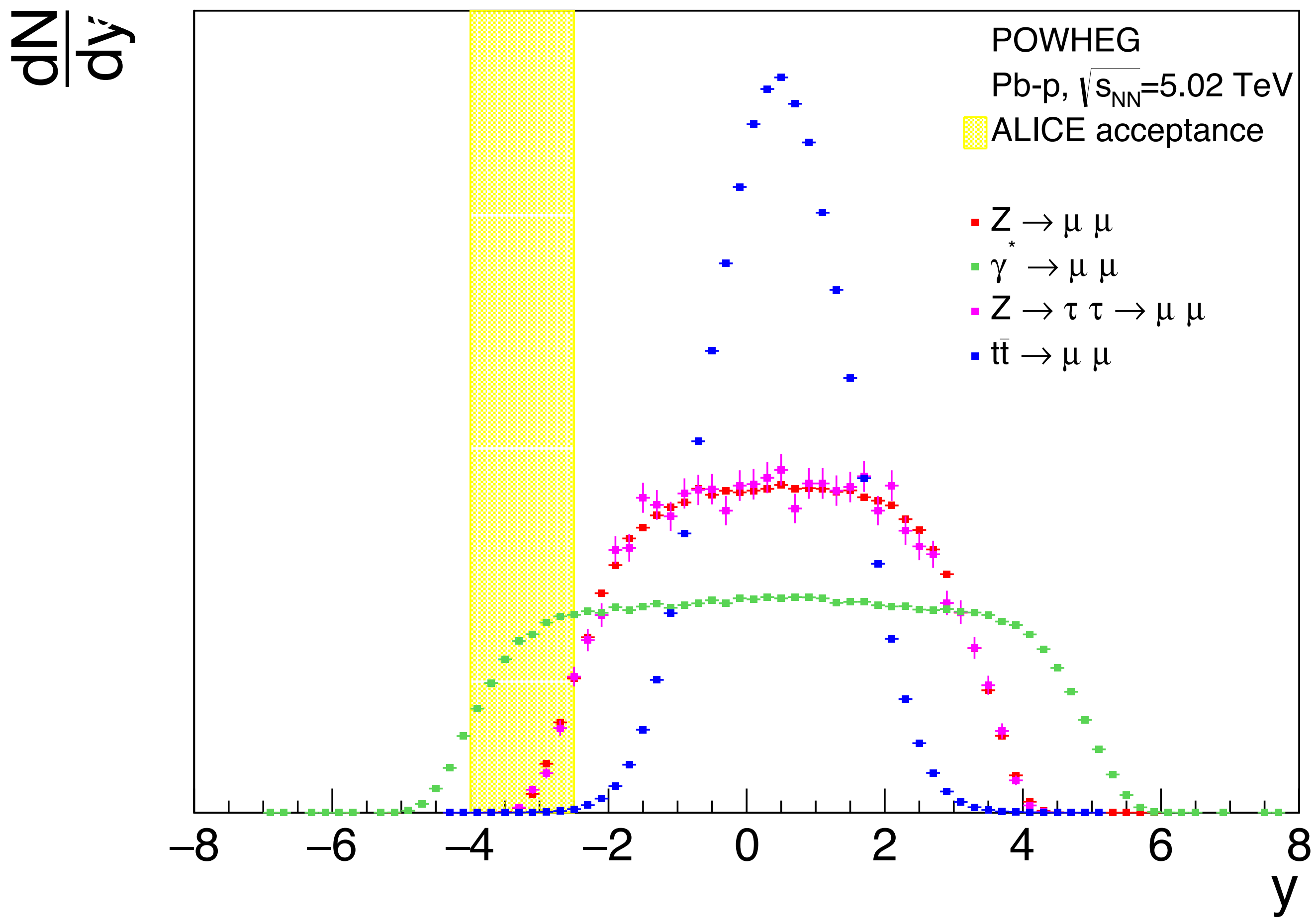
- The Muons pT shape in **$Z \rightarrow \tau\tau \rightarrow \mu\mu$** is different than the **$Z \rightarrow \mu\mu$** one because the muons are not produced back-to-back in the Z rest frame:



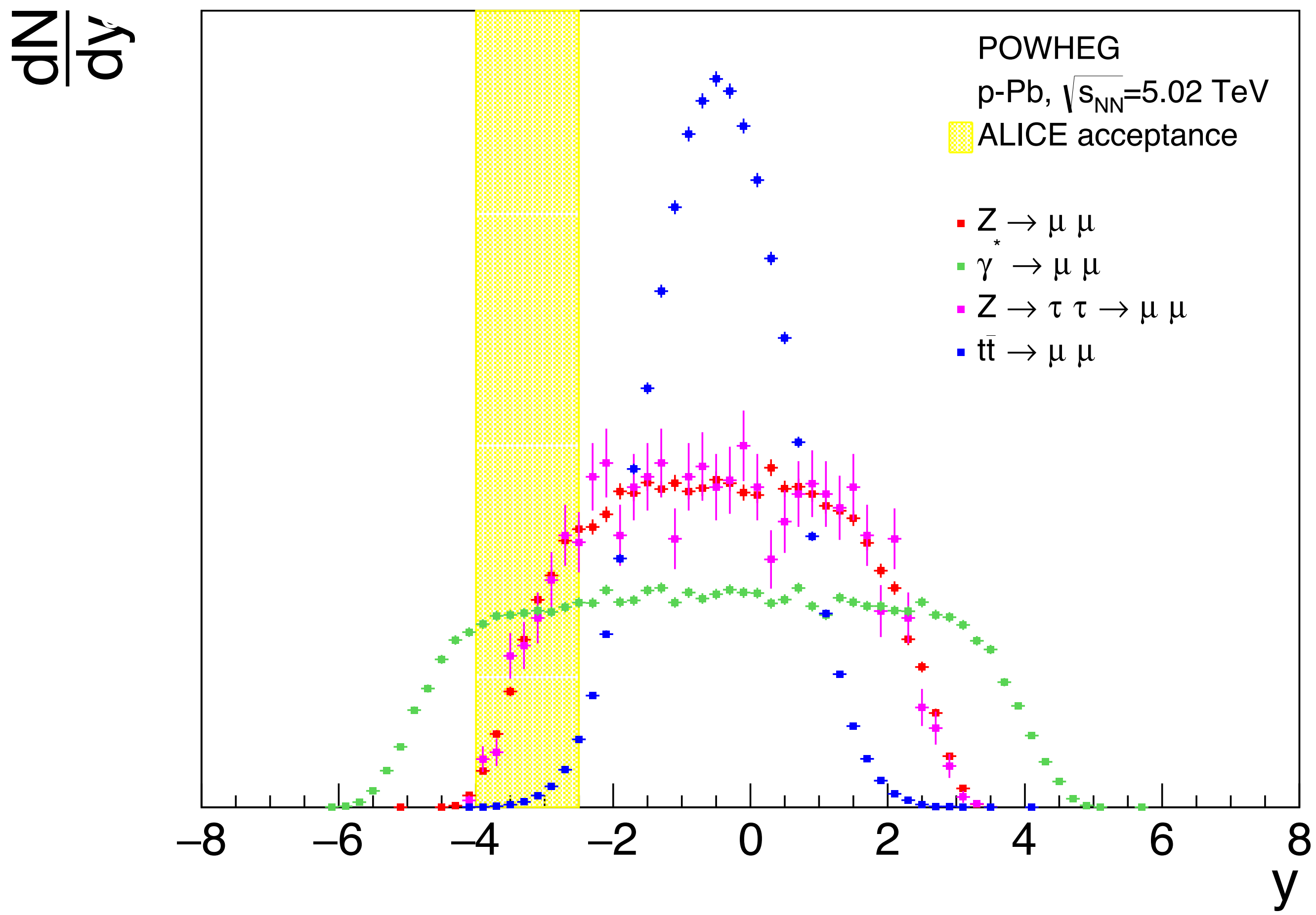




- The contribution from this source is more important at low mass.



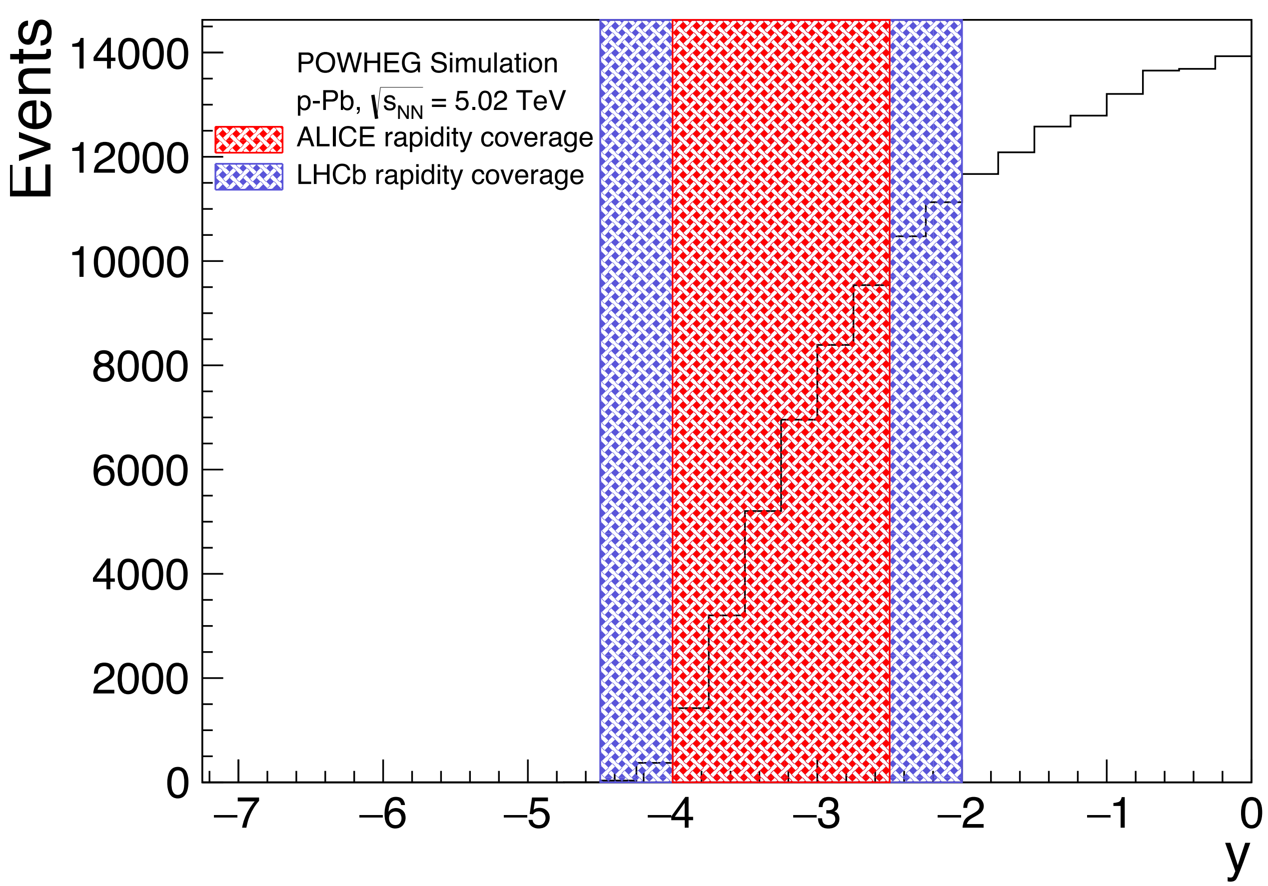
Pb-p

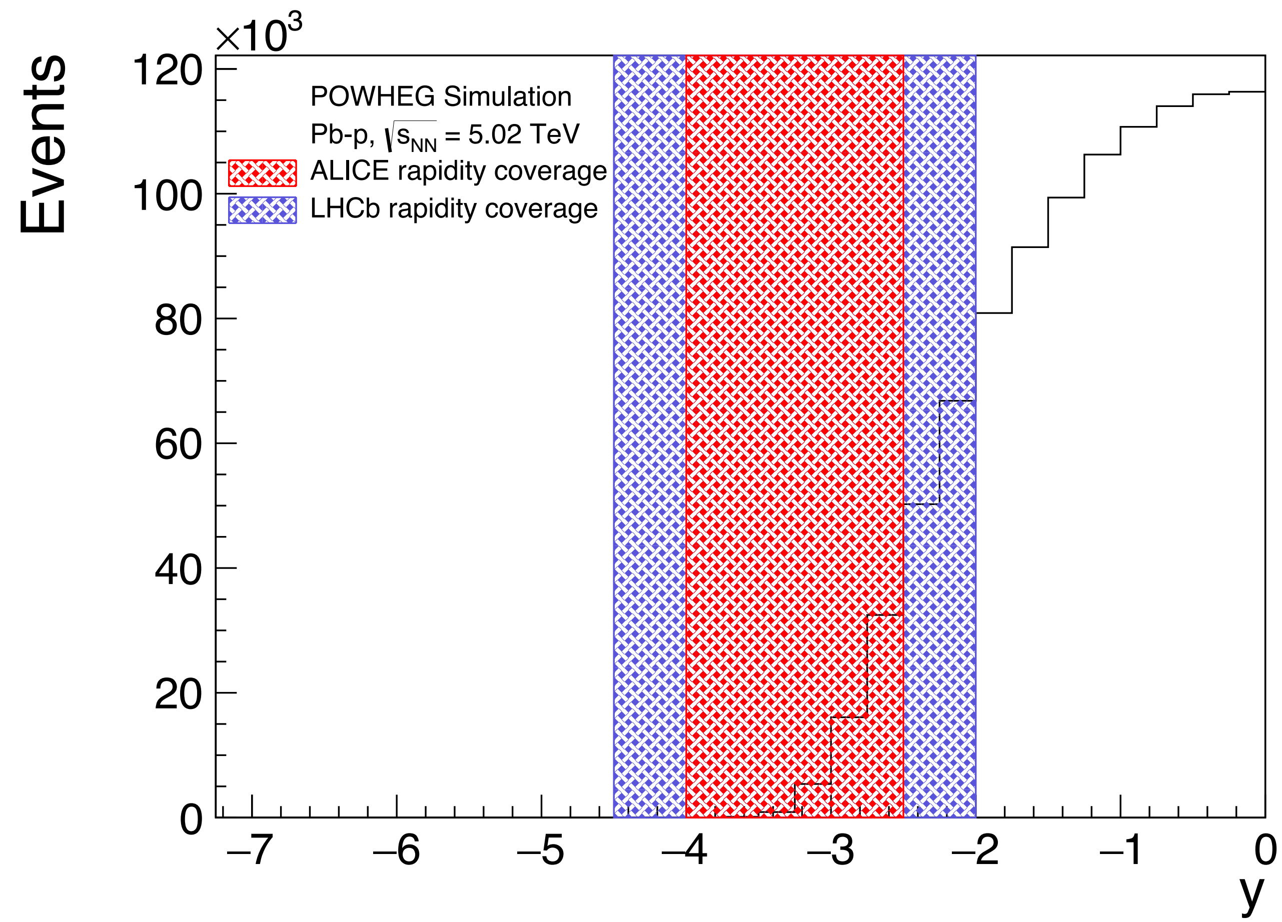


p-Pb

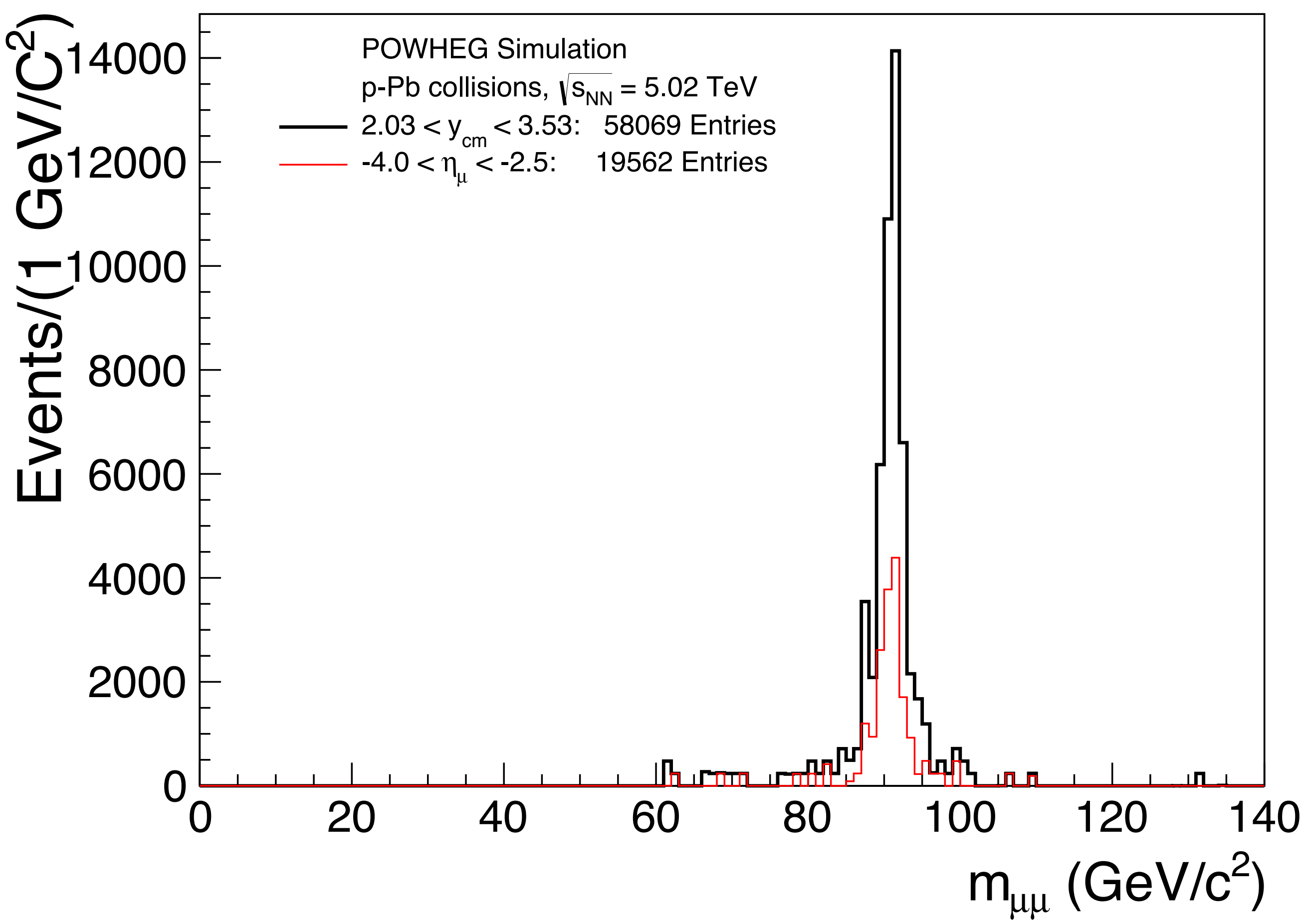
- The three rapidity distributions are normalised.
- **Z →*μμ*** and **ɣ* →*μμ*** distributions are separated according to the invariant mass (>60 GeV and < 60 GeV).

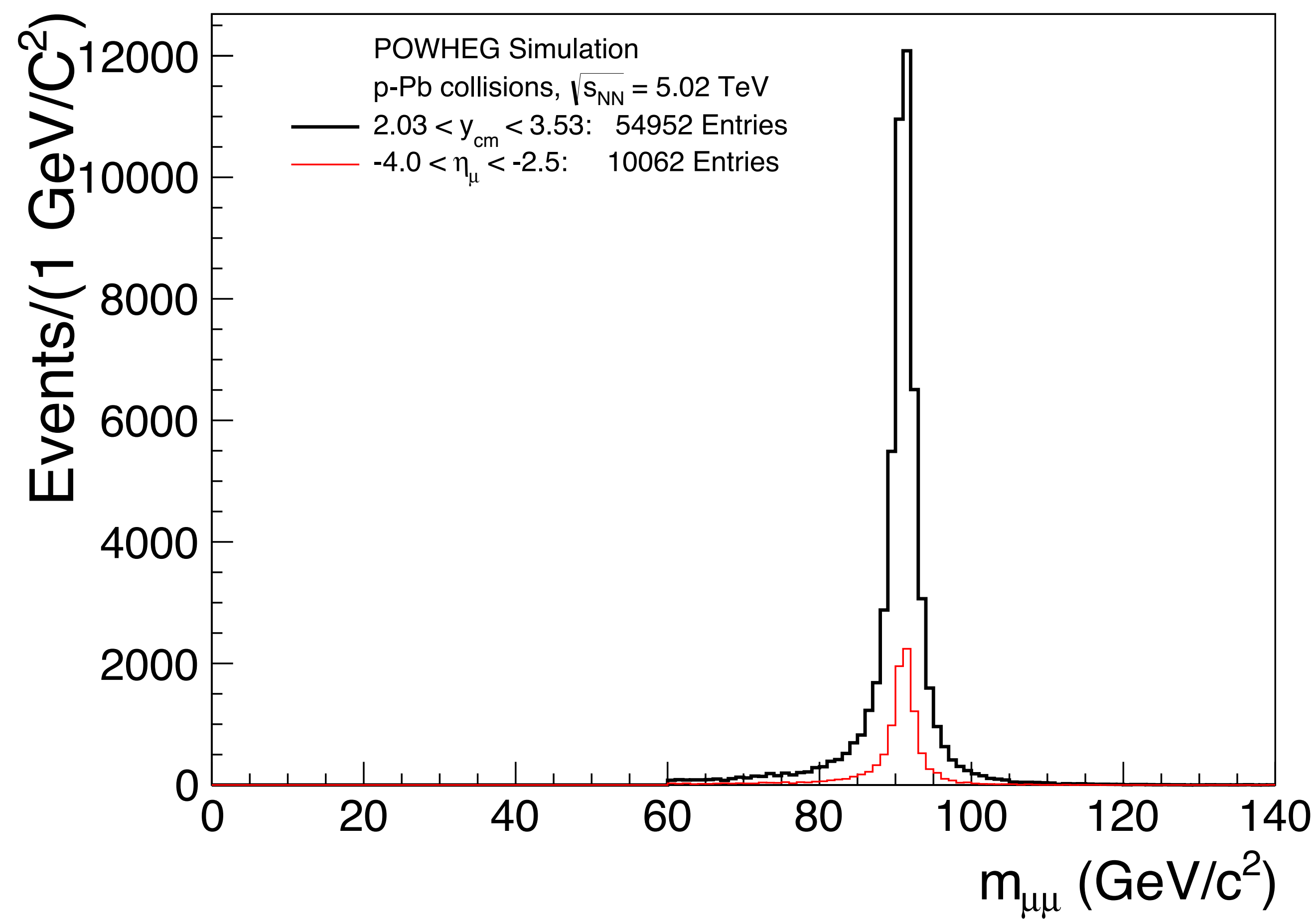
ALICE and LHCb rapidity





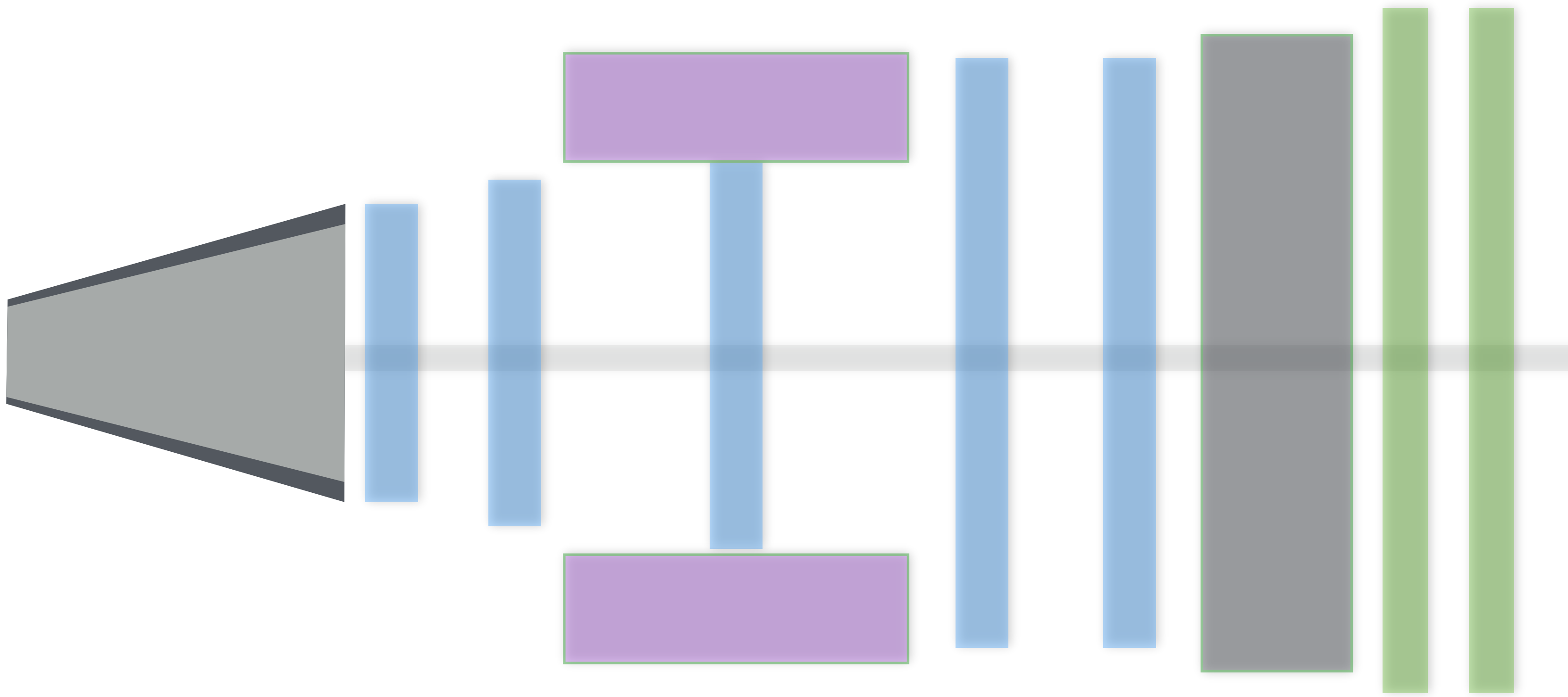
ALICE and LHCb acceptances





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

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

Cross section Results

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

The cross sections are defined in the fiducial region:

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

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

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

- 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.

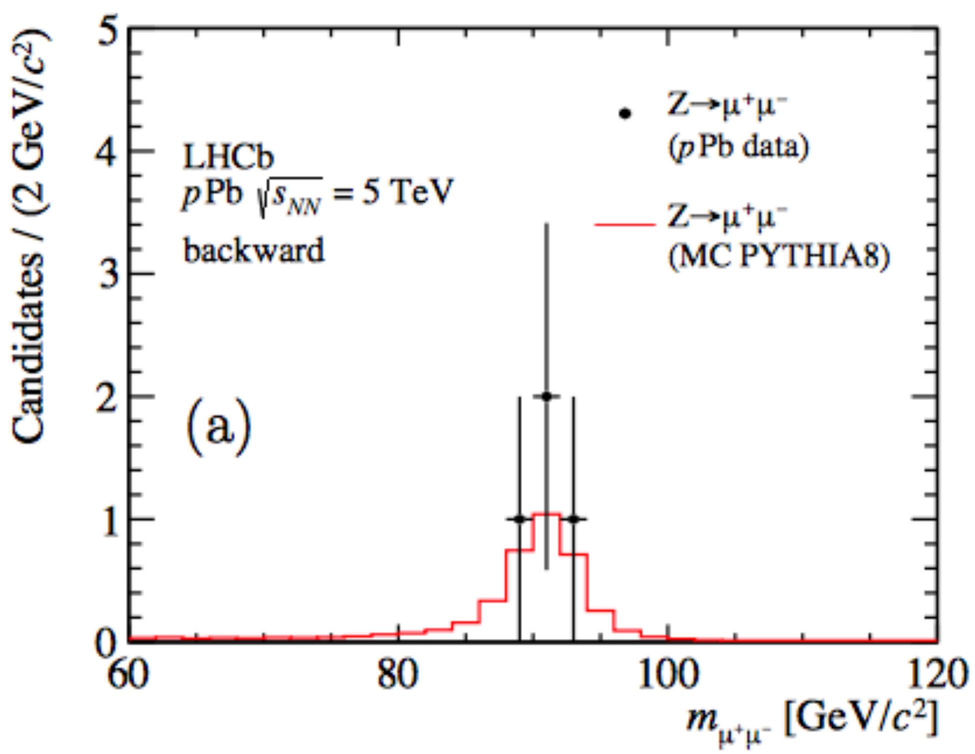
Summary of systematic uncertainties

	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%

LHCb Analysis

Fudicial region:

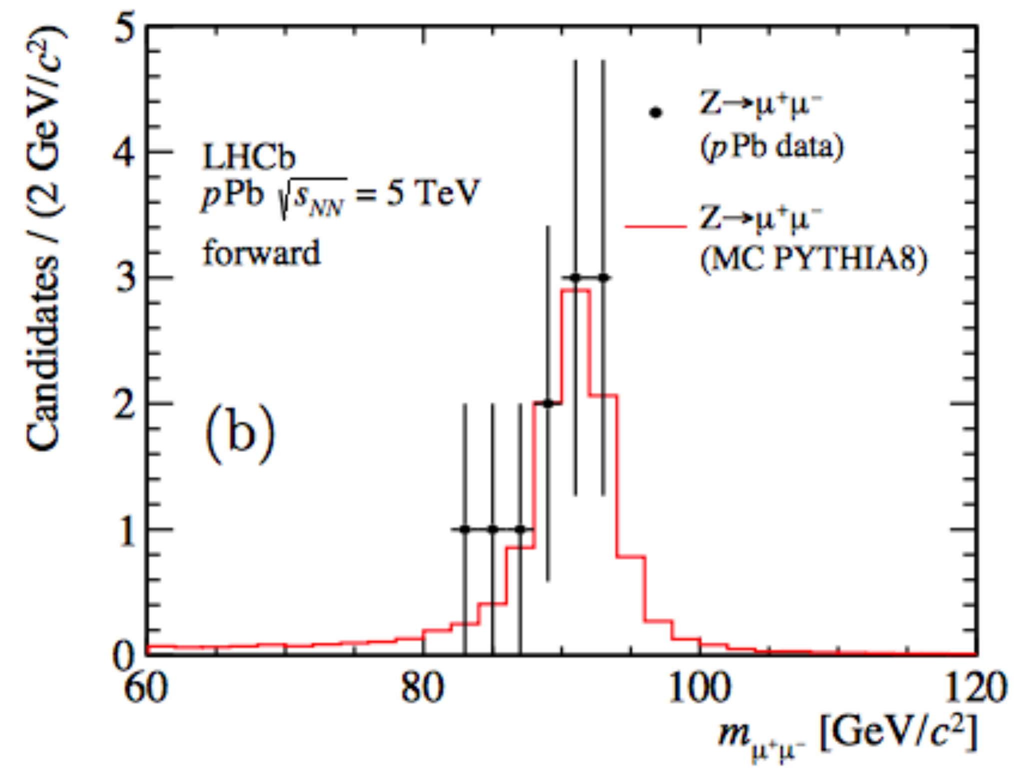
- $60 < m_{\mu\mu} < 120\ \mathrm{GeV}/c^2$
- $p_T(\mu) > 20\ \mathrm{GeV}/c$
- $2.0 < \eta_\mu < 4.5$ — $-4. < \eta_\mu < -2.5$ for ALICE



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

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

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



$1.53 < y_{cm} < 4.03$

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

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