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

Mohamad Tarhini

Rencontres QGP France 2015

13-10-2016

Outlook

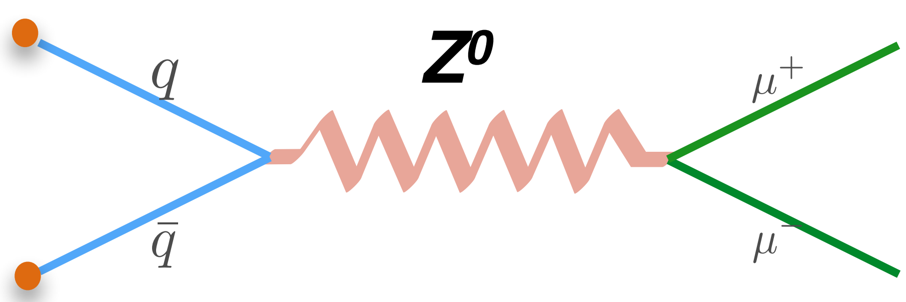
- Introduction and physics motivation
- Experimental apparatus
  - ALICE detector
  - Analysed data and beams configuration
- The analysis
  - Events selection and signal extraction
  - MC simulation and efficiency correction
  - Background contribution
- Results
  - Compared with theory
  - Compared to other experimental results
- Conclusion and perspectives

Introduction and Motivation I

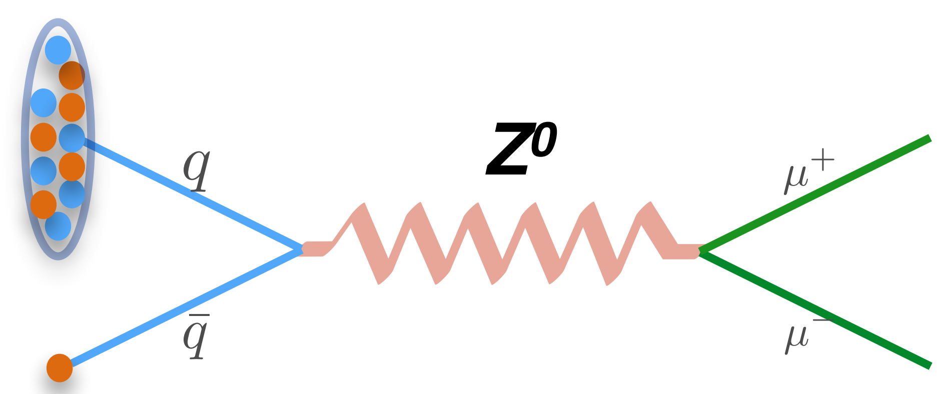
- Z^0 boson production is dominated by the quark-antiquark annihilation process
- Z^0 boson decays to muon pair with 3% branching ratio.

Introduction and Motivation I

- 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-A collisions Z^0 boson production is important to constrain nuclear PDF sets.



PDF : $f(x,Q^2)$



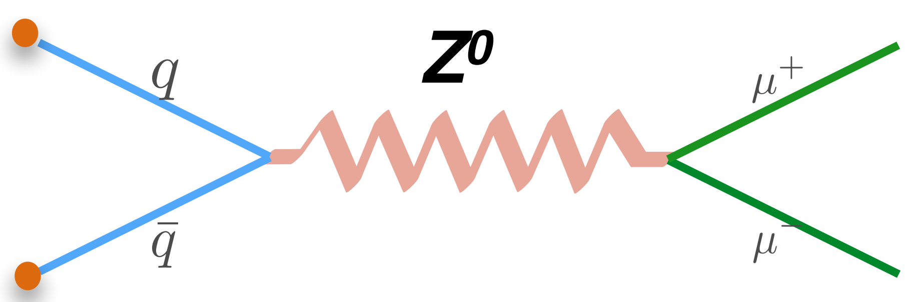
nuclear PDF: $f_A(x,Q^2) = R(x,Q^2,A) \times f(x,Q^2)$

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

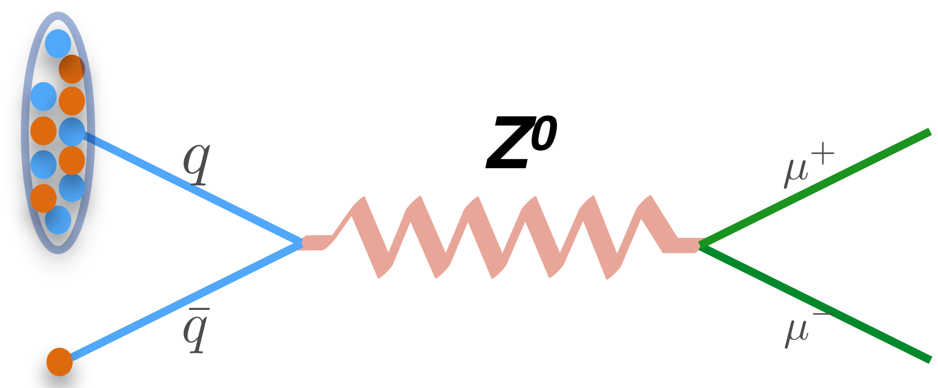
$x = (M_Z/\sqrt{s_{NN}})e^{\pm y}$ is the fraction of the nucleon momentum carried by the parton (q)

- 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-A collisions Z^0 boson production is important to constrain nuclear PDF sets.

Crucial for QGP study



PDF : $f(x,Q^2)$



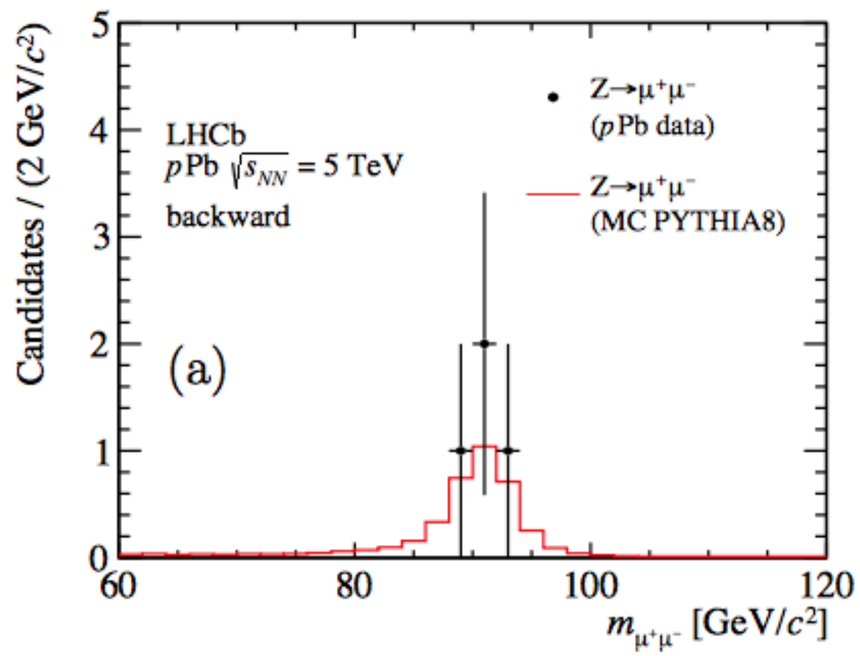
nuclear PDF: $f_A(x,Q^2) = R(x,Q^2,A) \times f(x,Q^2)$

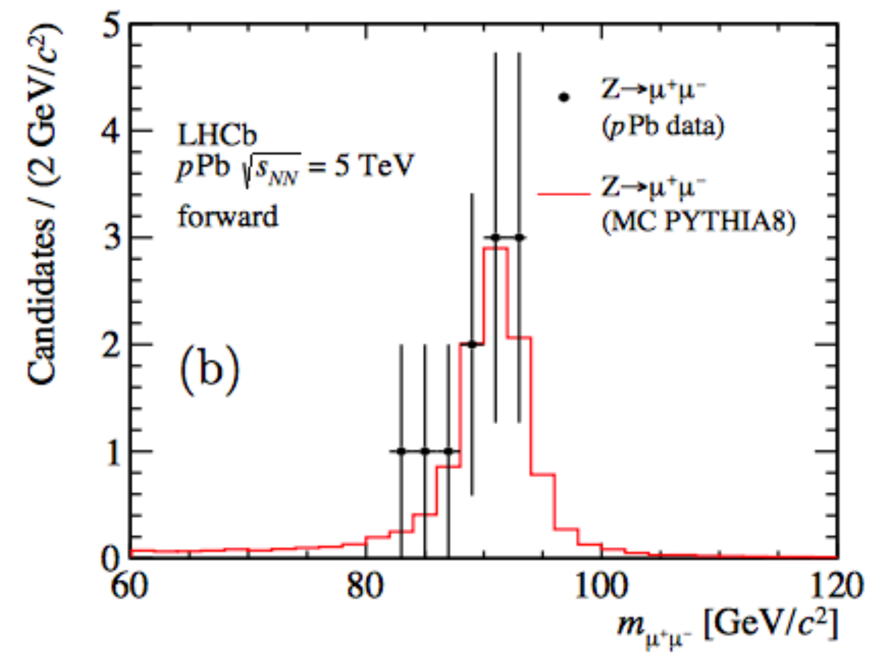
$Q^2 \equiv M_Z^2$

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

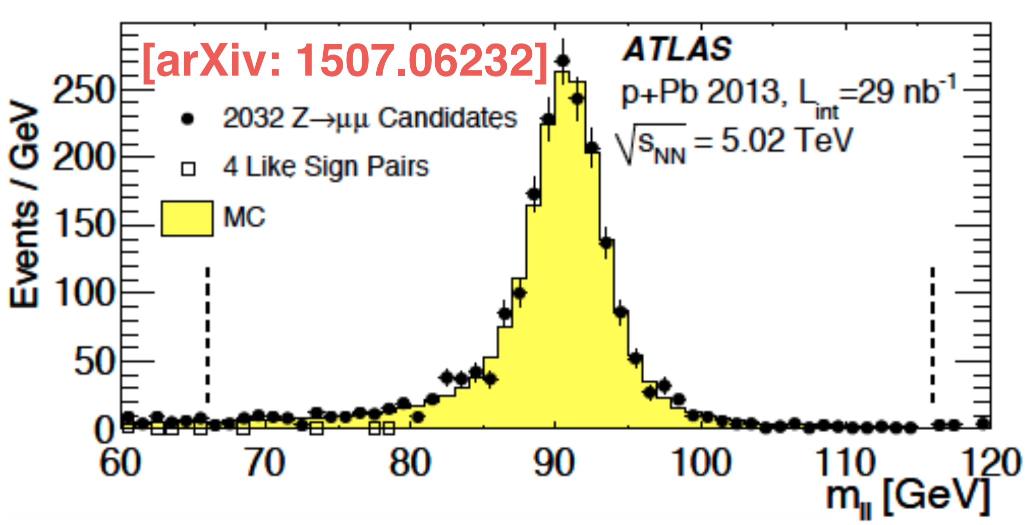
Z^0 boson production in p-A collisions is measured by other experiments:

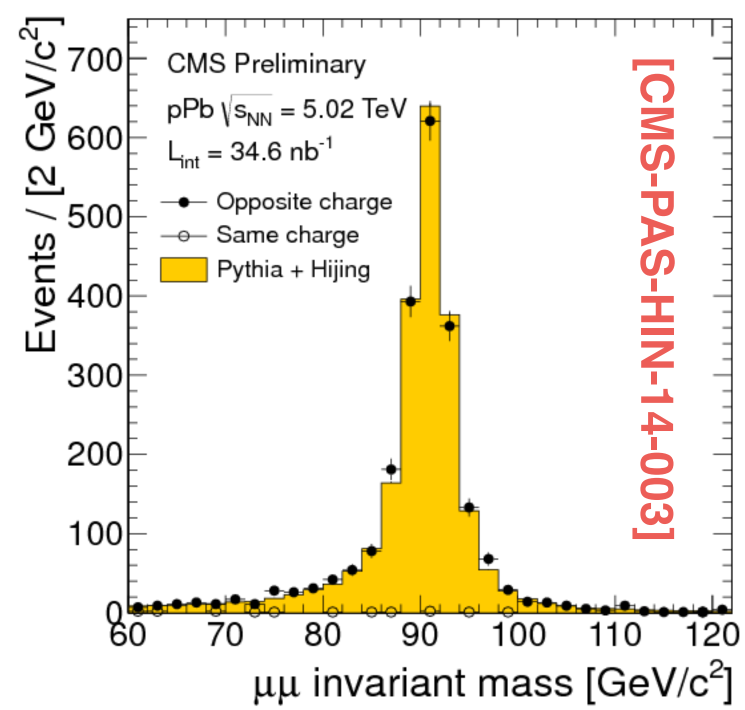
1- LHCb [JHEP 09 (2014) 030]



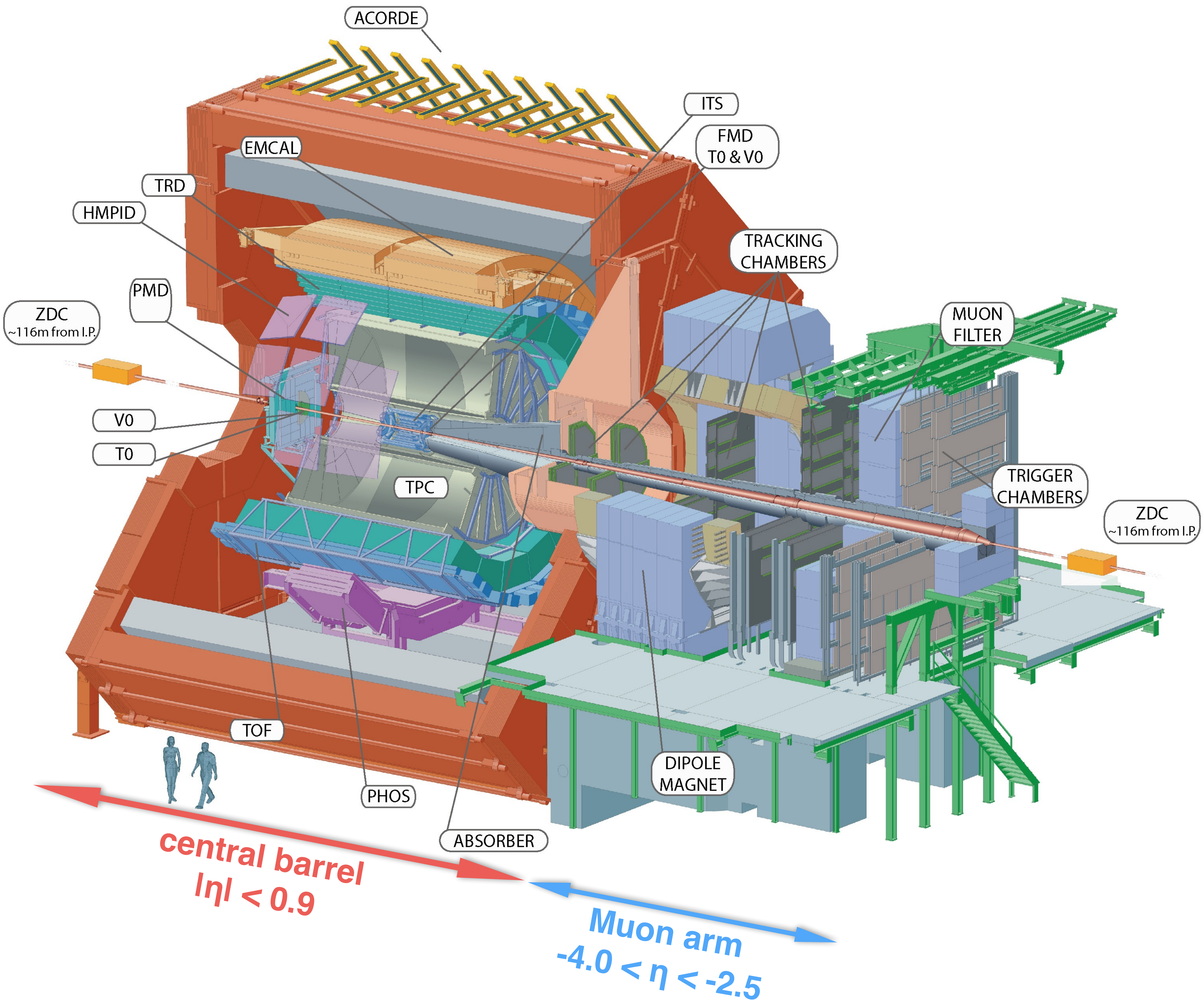


2- ATLAS and CMS

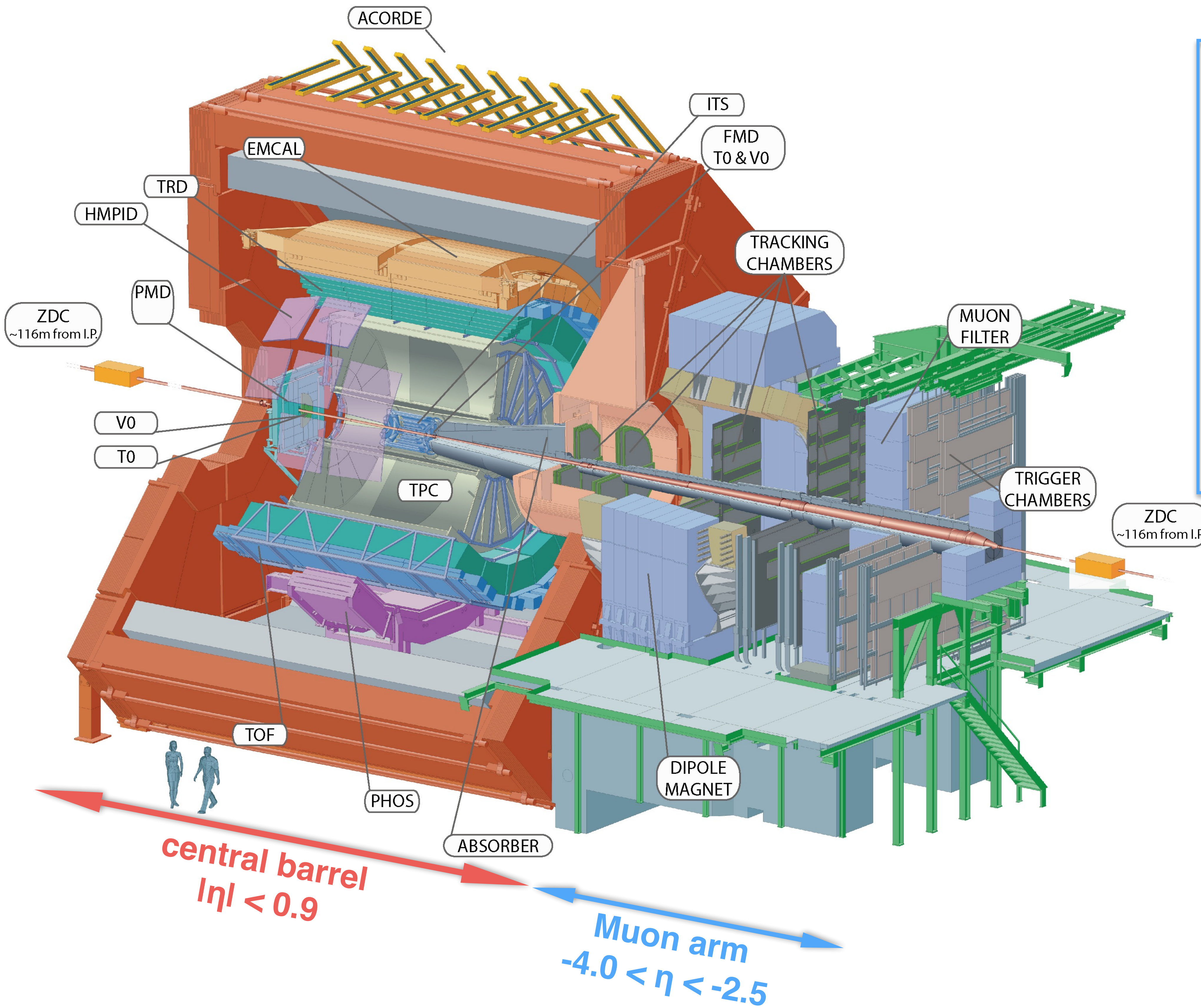




ALICE Detector



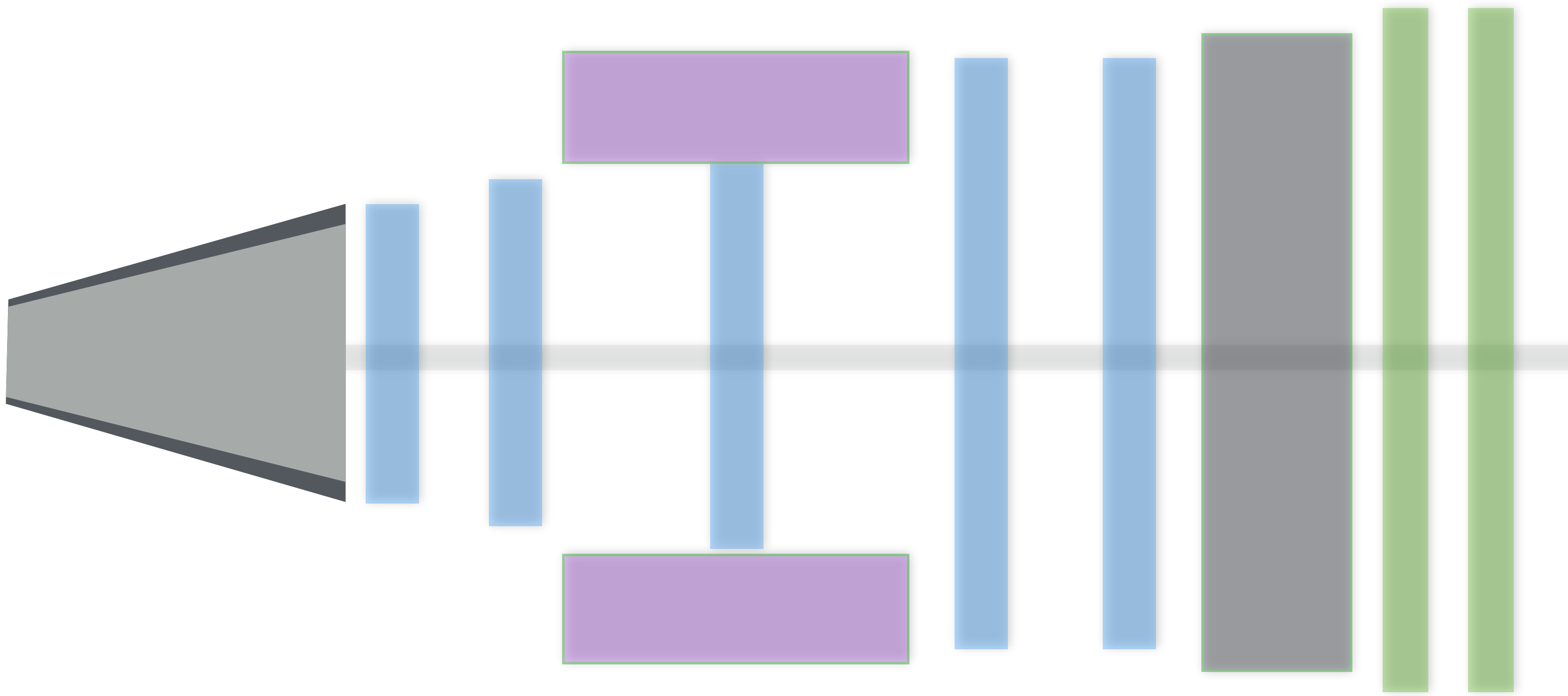
ALICE Detector



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

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

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.

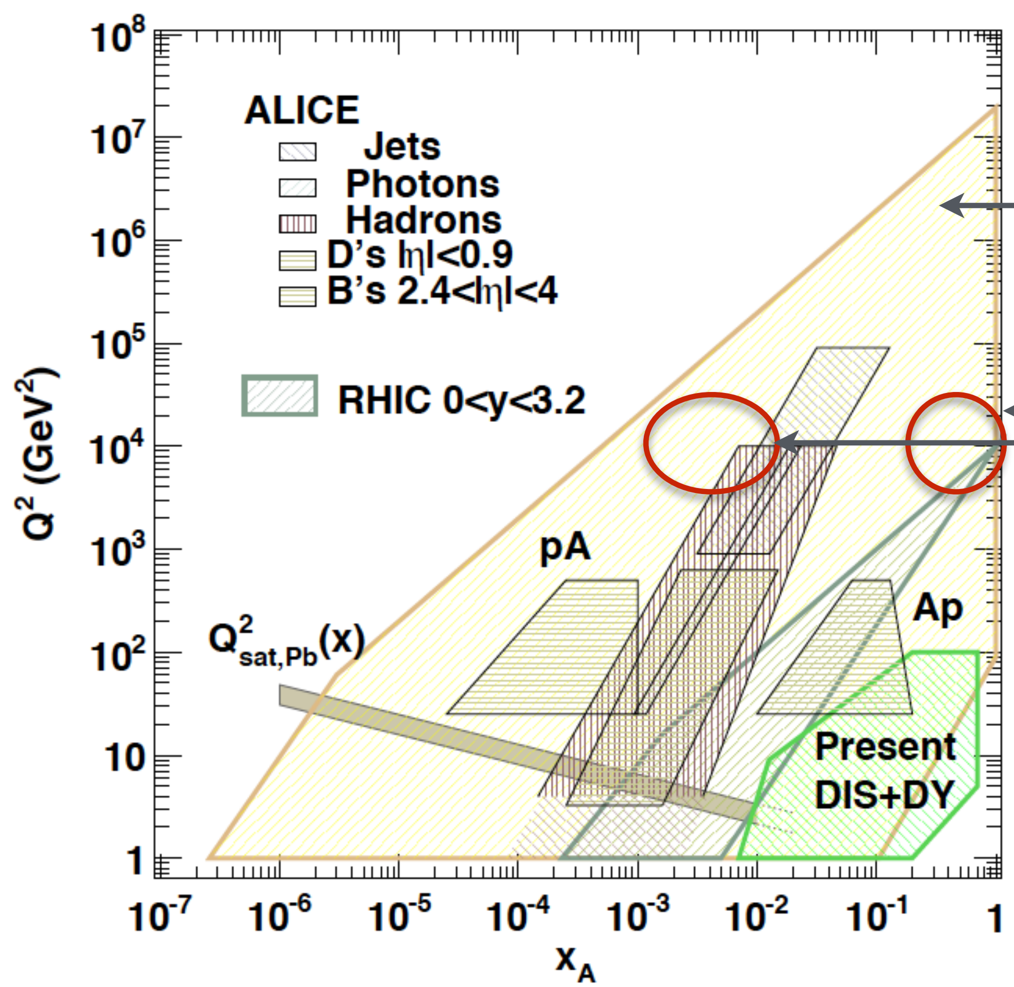
CM rapidity is shifted w.r.t Lab one and two rapidity regions corresponding to two beams configuration

$2.03 < y_{cm} < 3.53$	$-4.46 < y_{cm} < -2.96$
$10^{-3} < x < 10^{-2}$	$0.2 < x < 1$
$L_{int} = 5.01 \pm 0.20\ nb^{-1}$ (dimuon)	$L_{int} = 5.81 \pm 0.20\ nb^{-1}$ (dimuon)

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



Maximum kinematic reach of LHC in probing the nPDF

phase space probed with this analysis in the two rapidity regions

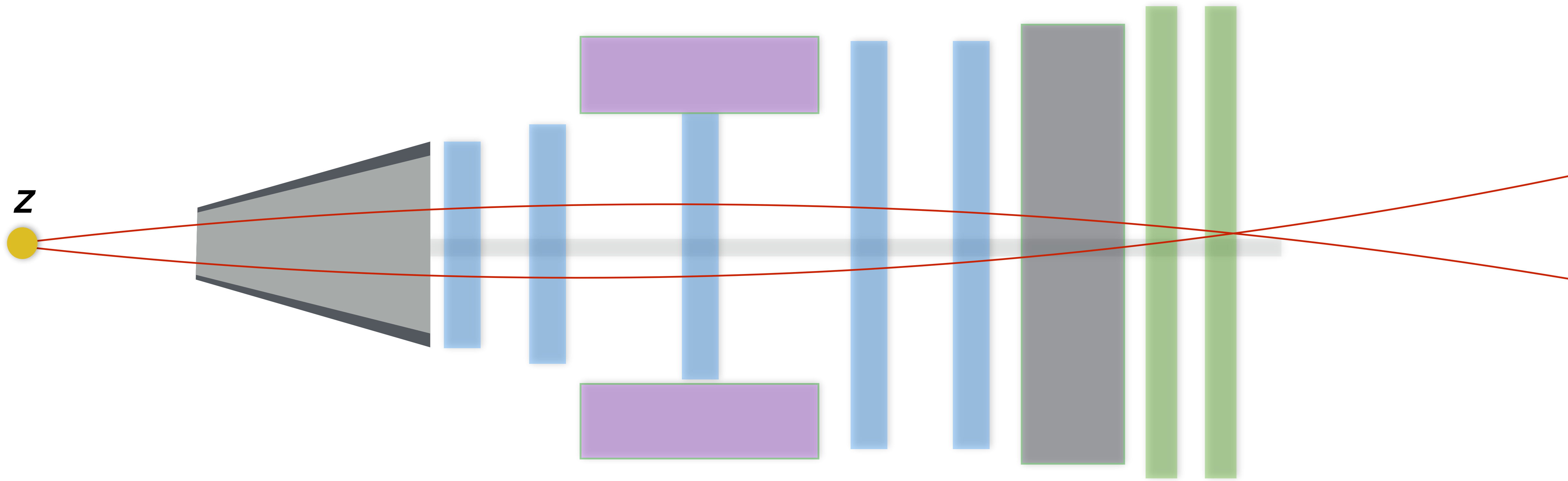
[J.Phys. G39 (2012) 015010]

Track And Event Selection

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

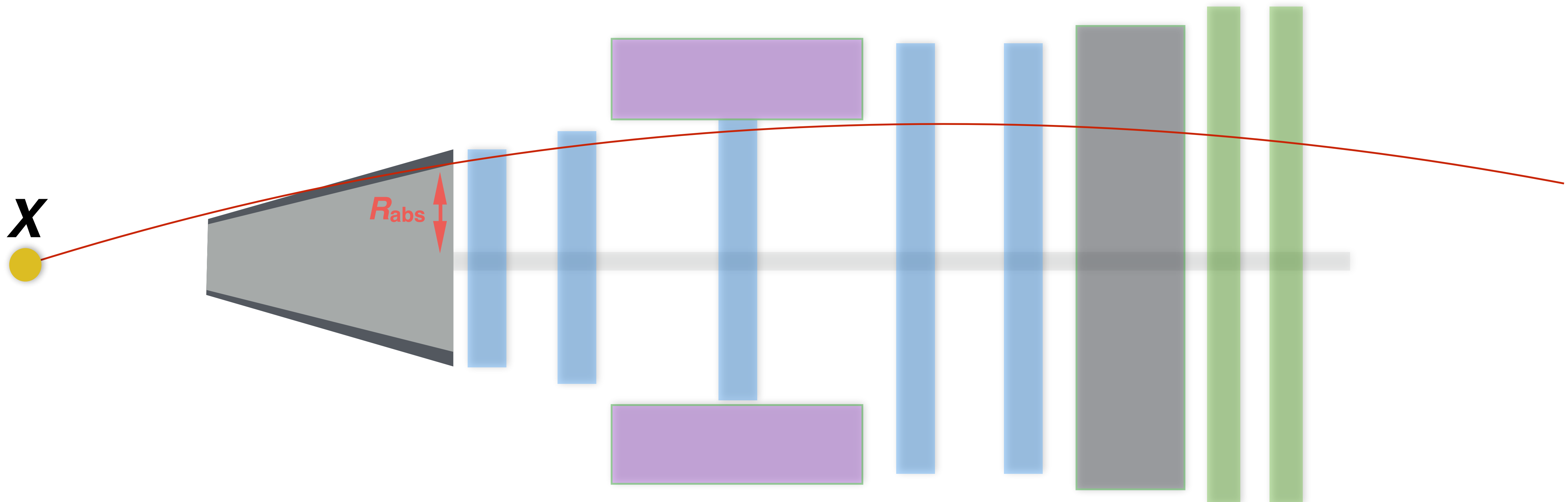
Track And Event Selection

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



Track And Event Selection

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

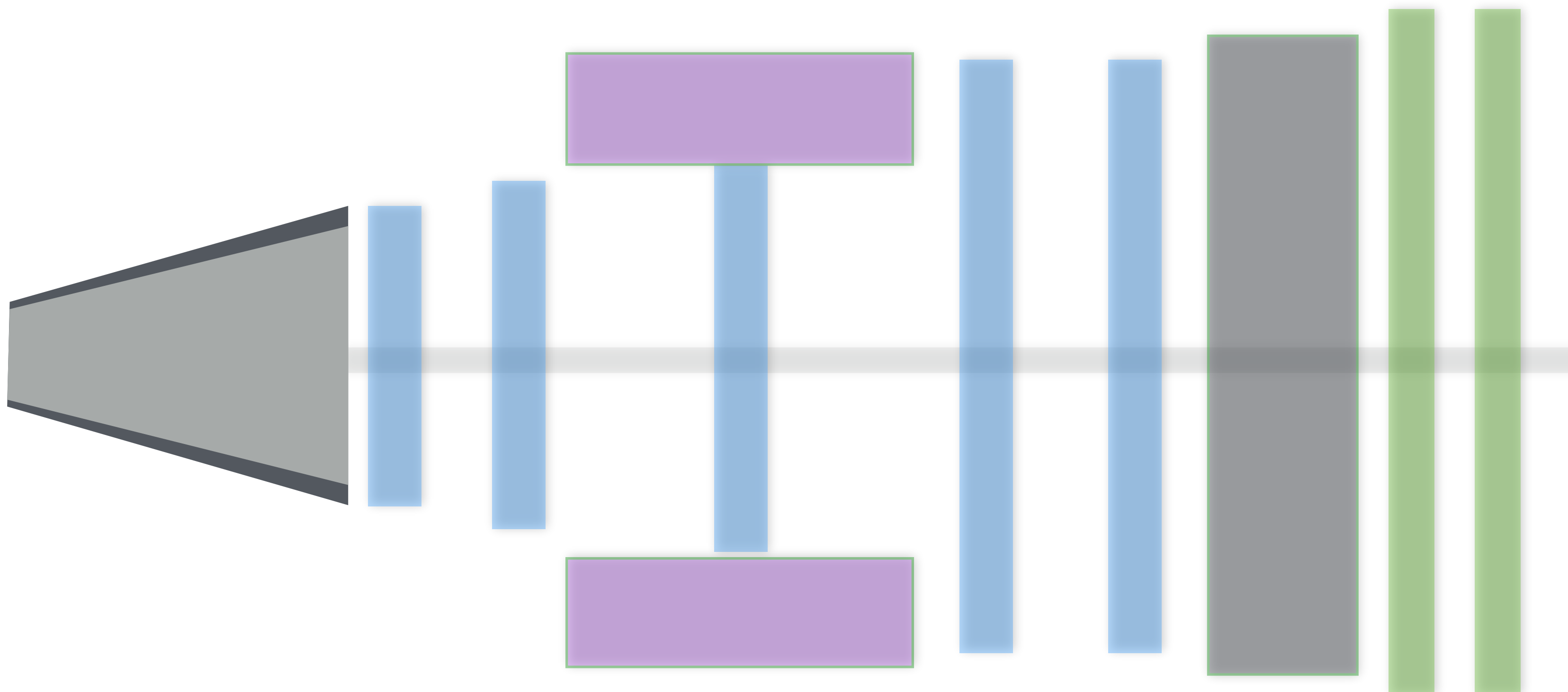


- **Single muon selection:**

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

Track And Event Selection

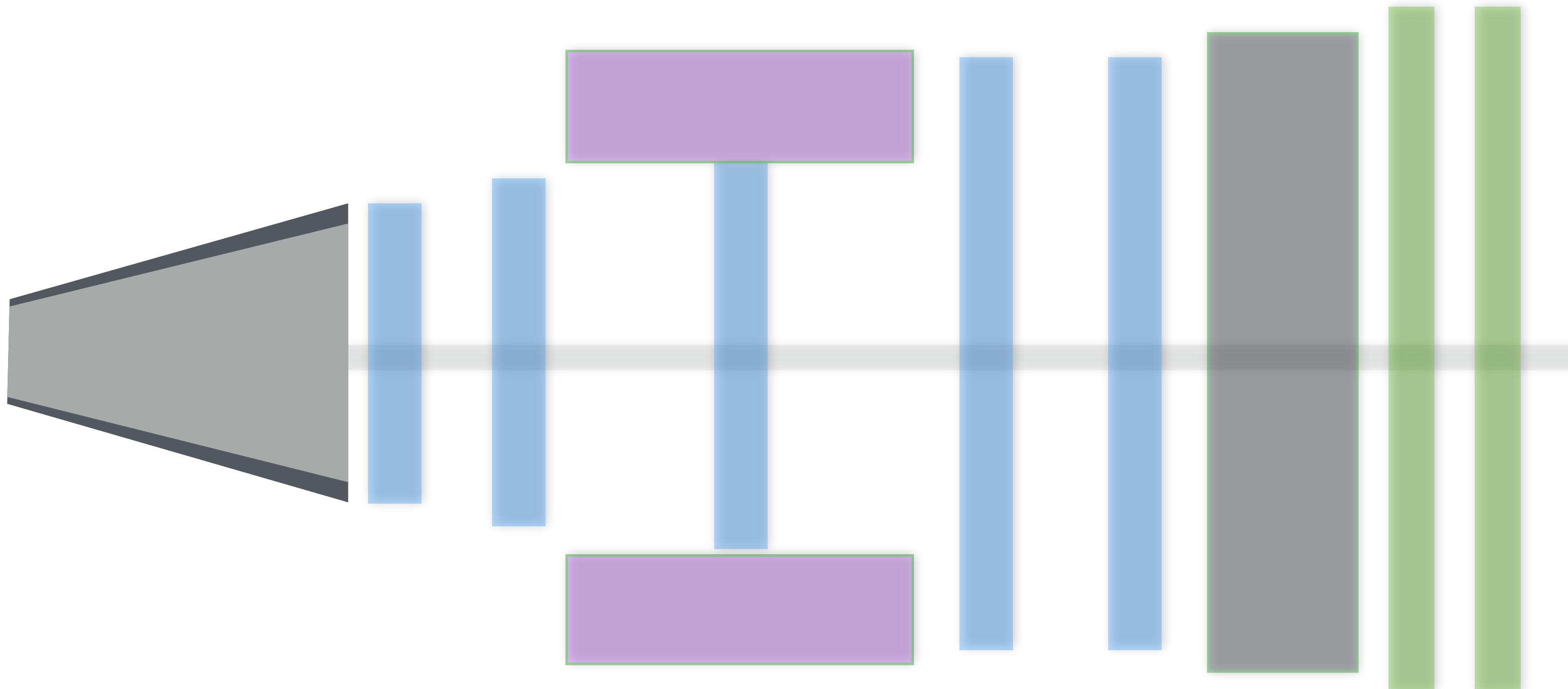
- Z candidates are obtained by combining opposite-charge muon tracks that fulfil the single muon selection:



- **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

Track And Event Selection

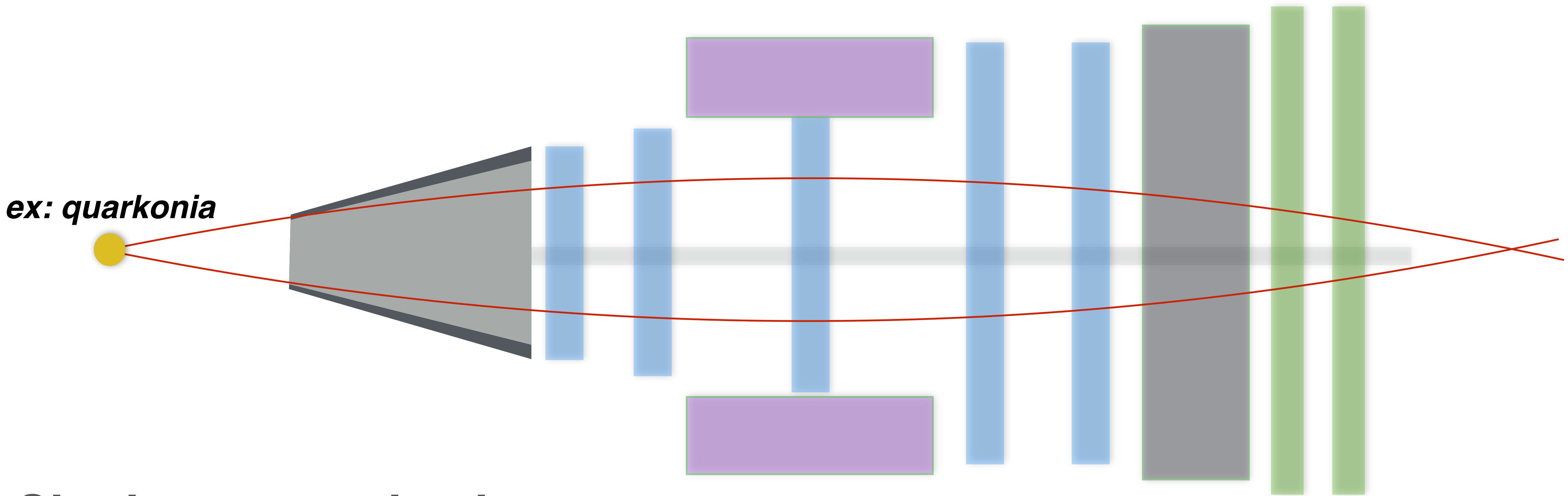
- Z candidates are obtained by combining opposite-charge muon tracks that fulfil the single muon selection:



- **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

Track And Event Selection

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

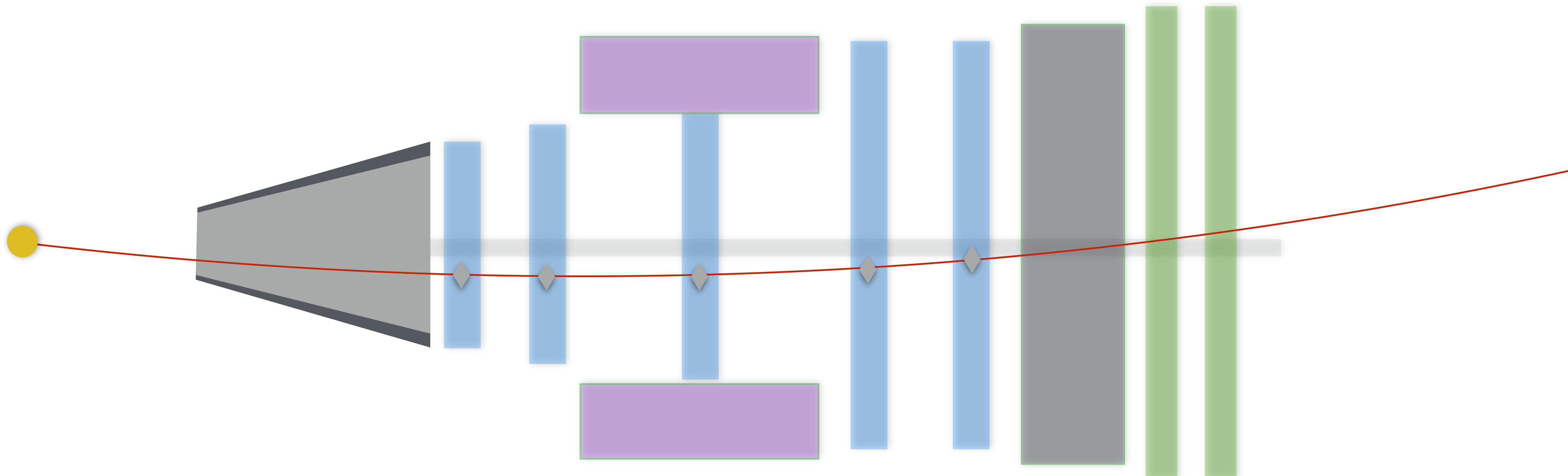


- **Single muon selection:**

  - $17.6 < R_{abs} < 89.5$ 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

Track And Event Selection

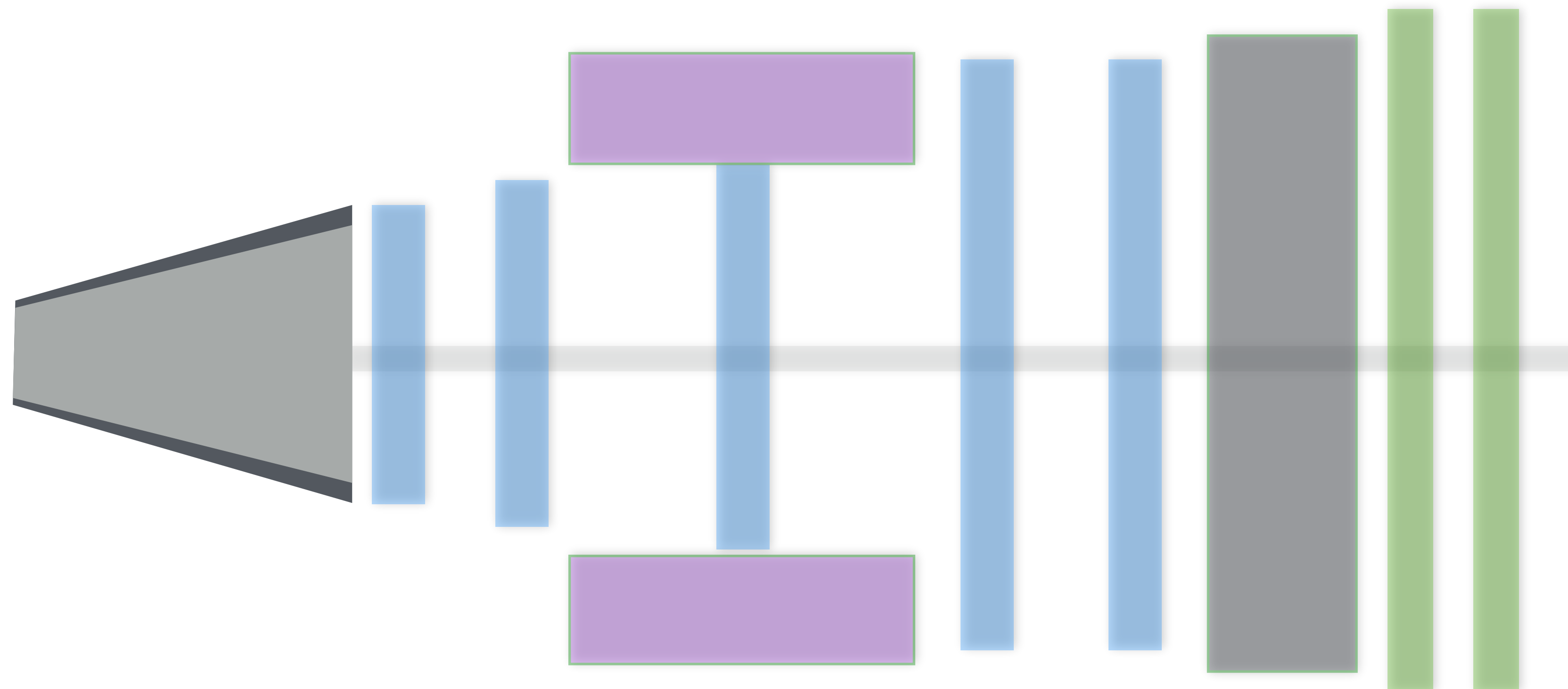
- Z candidates are obtained by combining opposite-charge muon tracks that fulfil the single muon selection:



- **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

Track And Event Selection

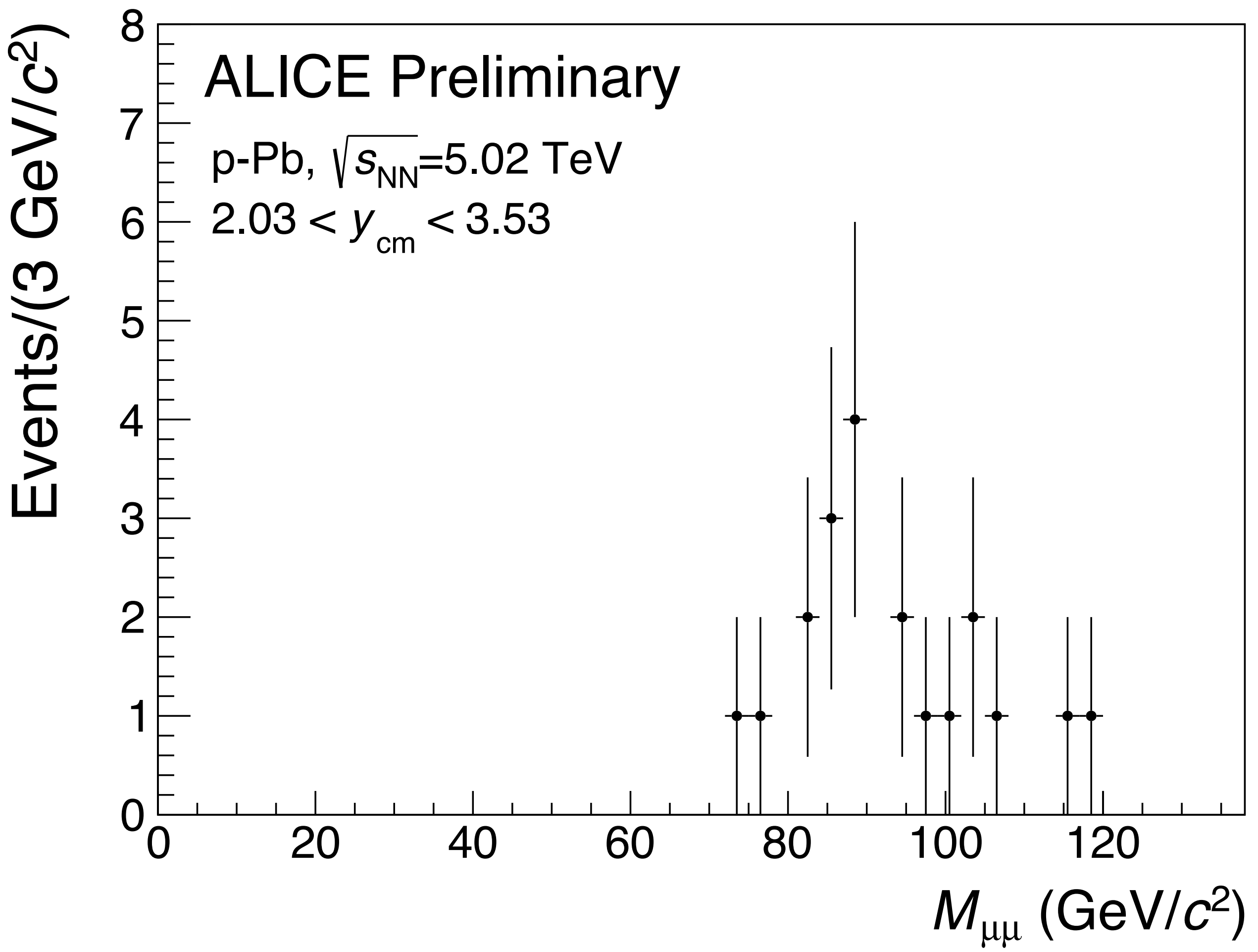
- Z candidates are obtained by combining opposite-charge muon tracks that fulfil the single muon selection:

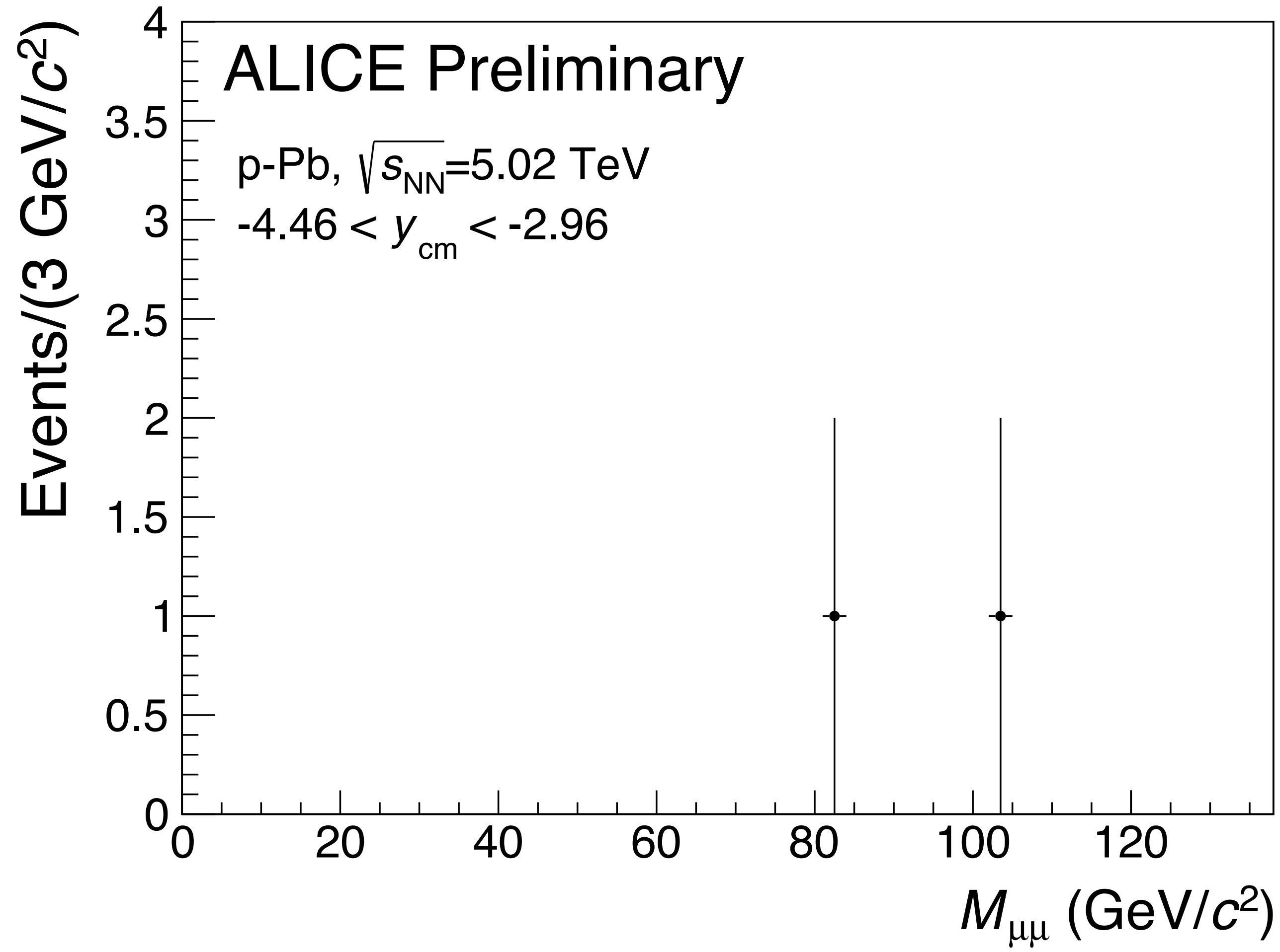


- **Single muon selection:**
  - $17.6 < R_{abs} < 89.5$ cm: rejects muons crossing the thick part of the front absorber
  - A cut on pDCA to reject fake muon that are not pointing to the vertex
  - Pseudo-rapidity cut, $-4 < \eta_{\mu} < -2.5$ to reject muon at the acceptance edge
  - $p_T(\mu) > 20$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





N_Z (2.03 < y_{cm} < 3.53) = 21 ± 5 (stat)

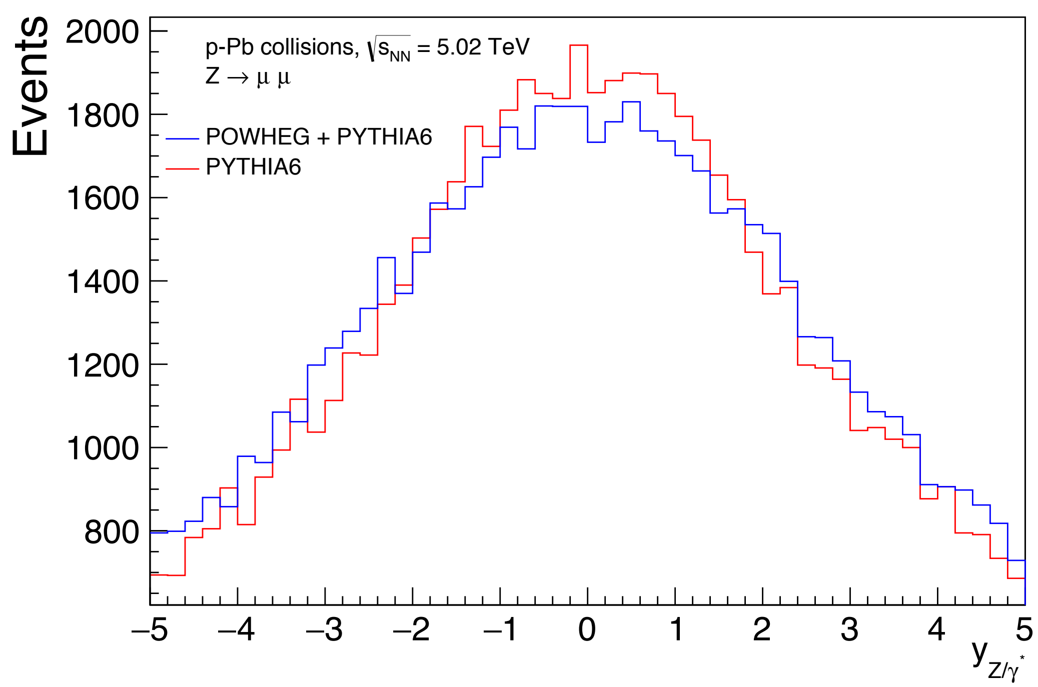
N_Z (-4.96 < y_{cm} < -2.46) = 2 ± 1 (stat)

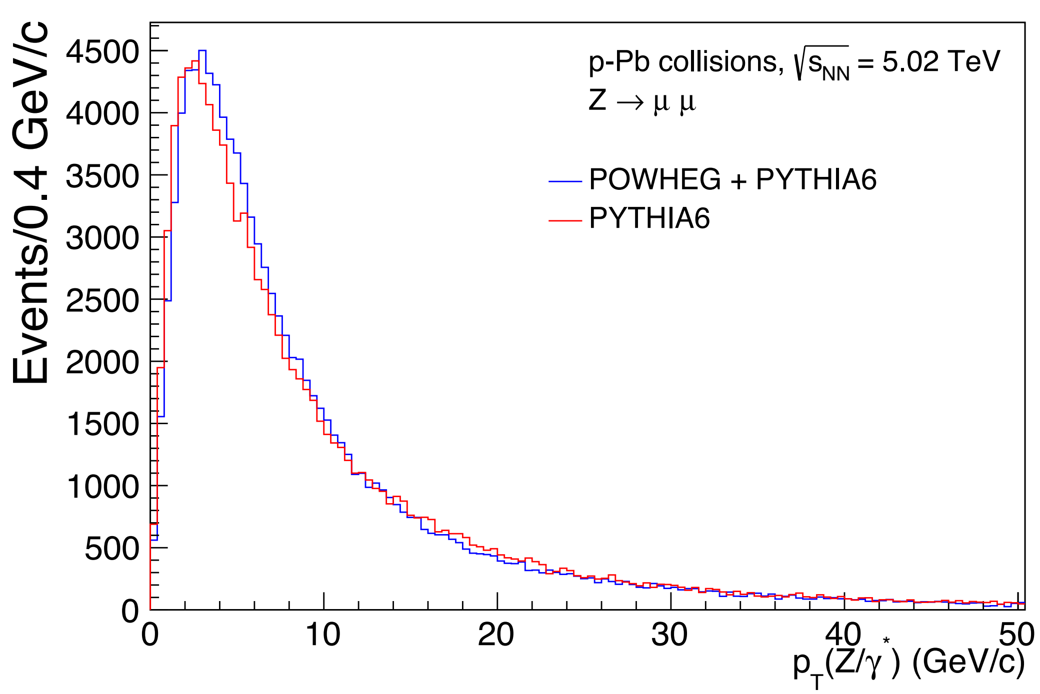
MC Simulation I

- Full simulation is done:
- POWHEG used as particle generator:
  - Take NLO contributions into account.
  - Need to be interfaced with MC shower program (PYTHIA-6).

MC Simulation I

- Full simulation is done:
- POWHEG used as particle generator:
  - Take NLO contributions into account.
  - Need to be interfaced with MC shower program (PYTHIA-6).

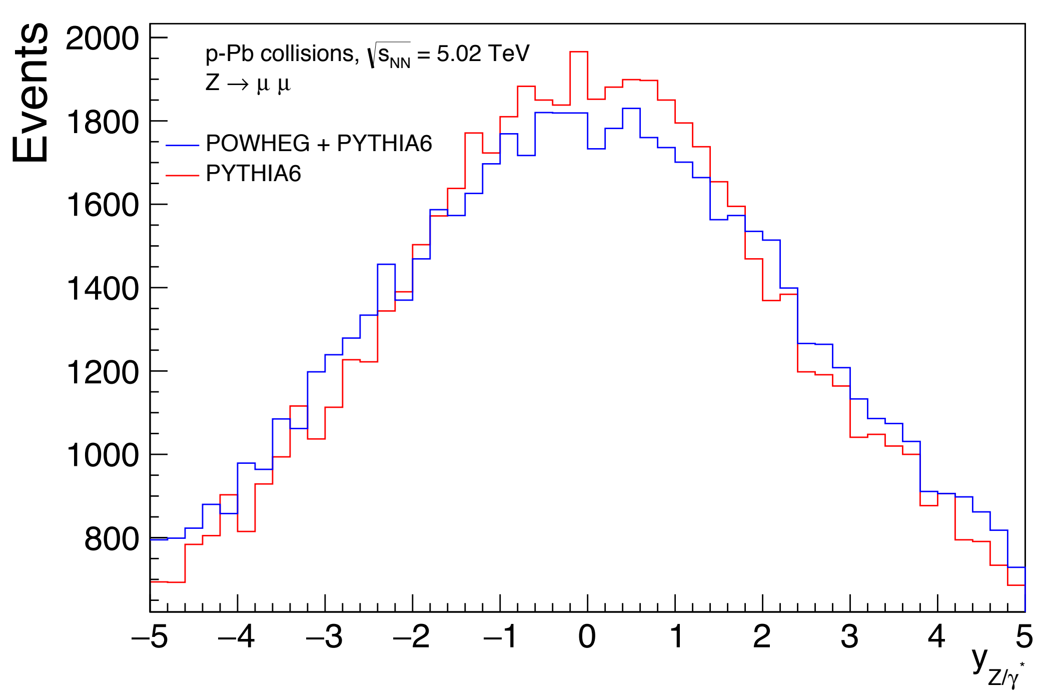


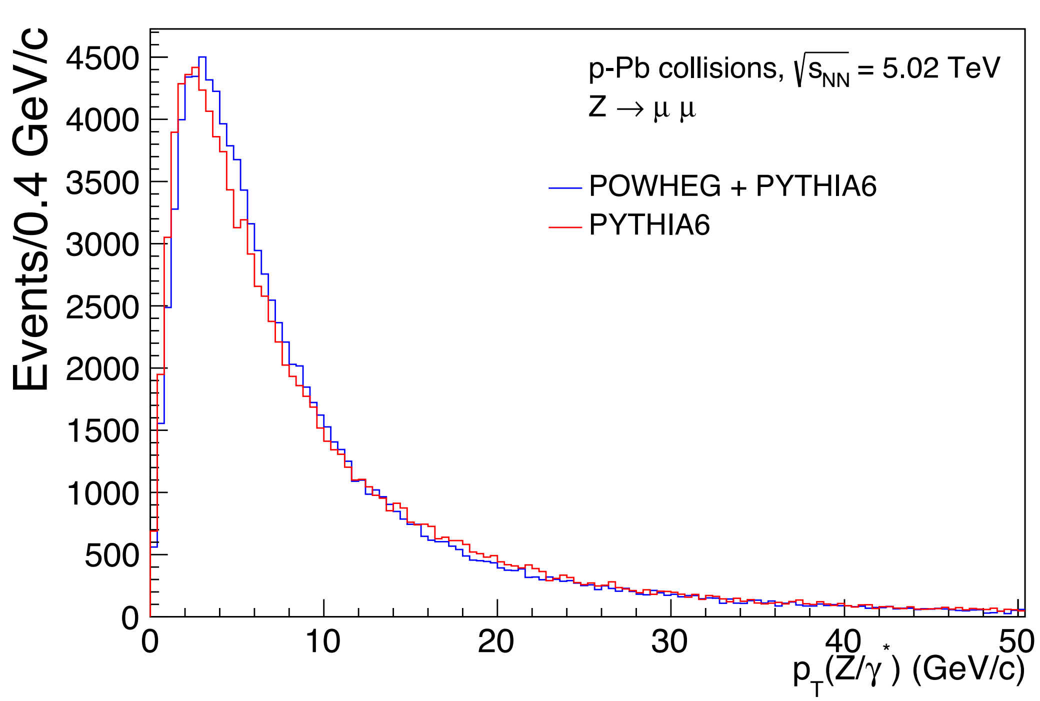


comparison between POWHEG and PYTHIA as particle generator via pT and rapidity distribution

MC Simulation I

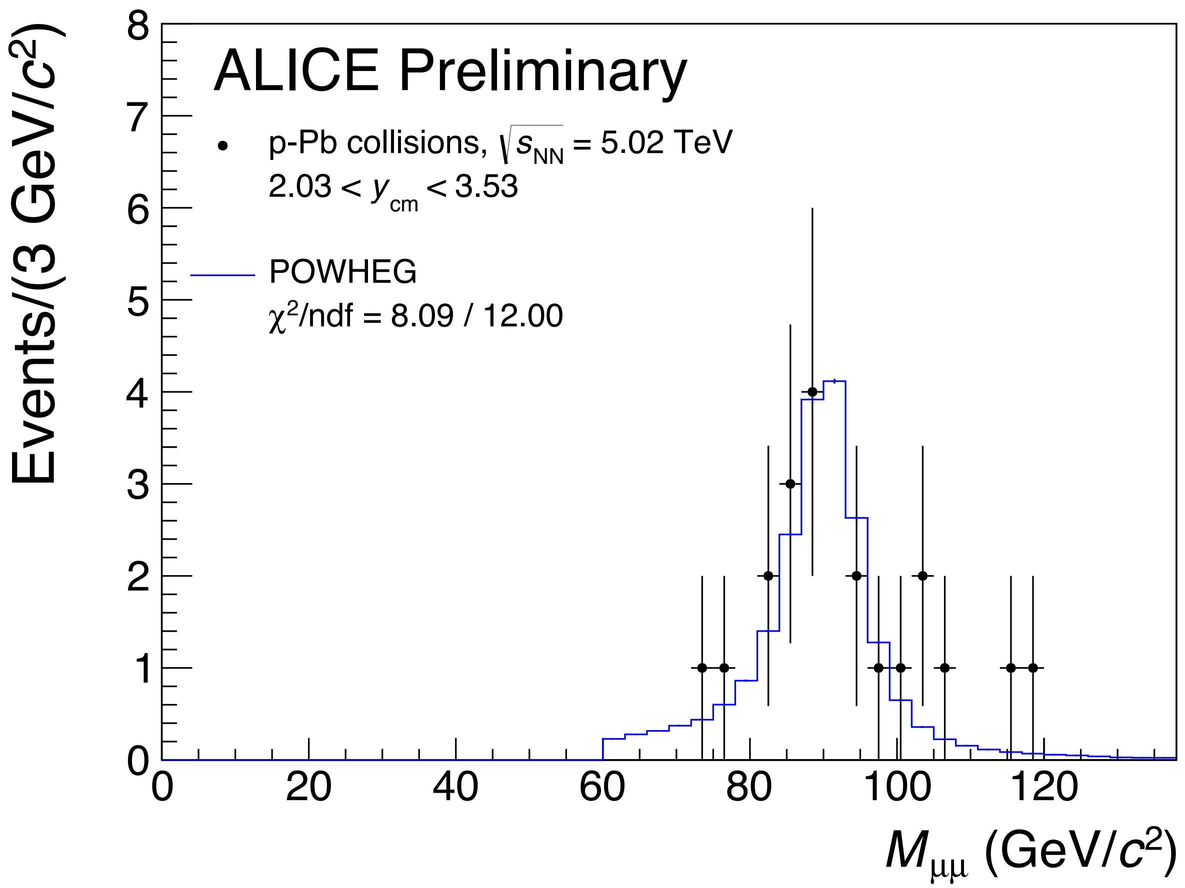
- Full simulation is done:
- POWHEG used as particle generator:
  - Take NLO contributions into account.
  - Need to be interfaced with MC shower program (PYTHIA-6).
- EPS09NLO set is used to take nuclear shadowing into account.
- ALICE detector is simulated with GEANT-3.





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

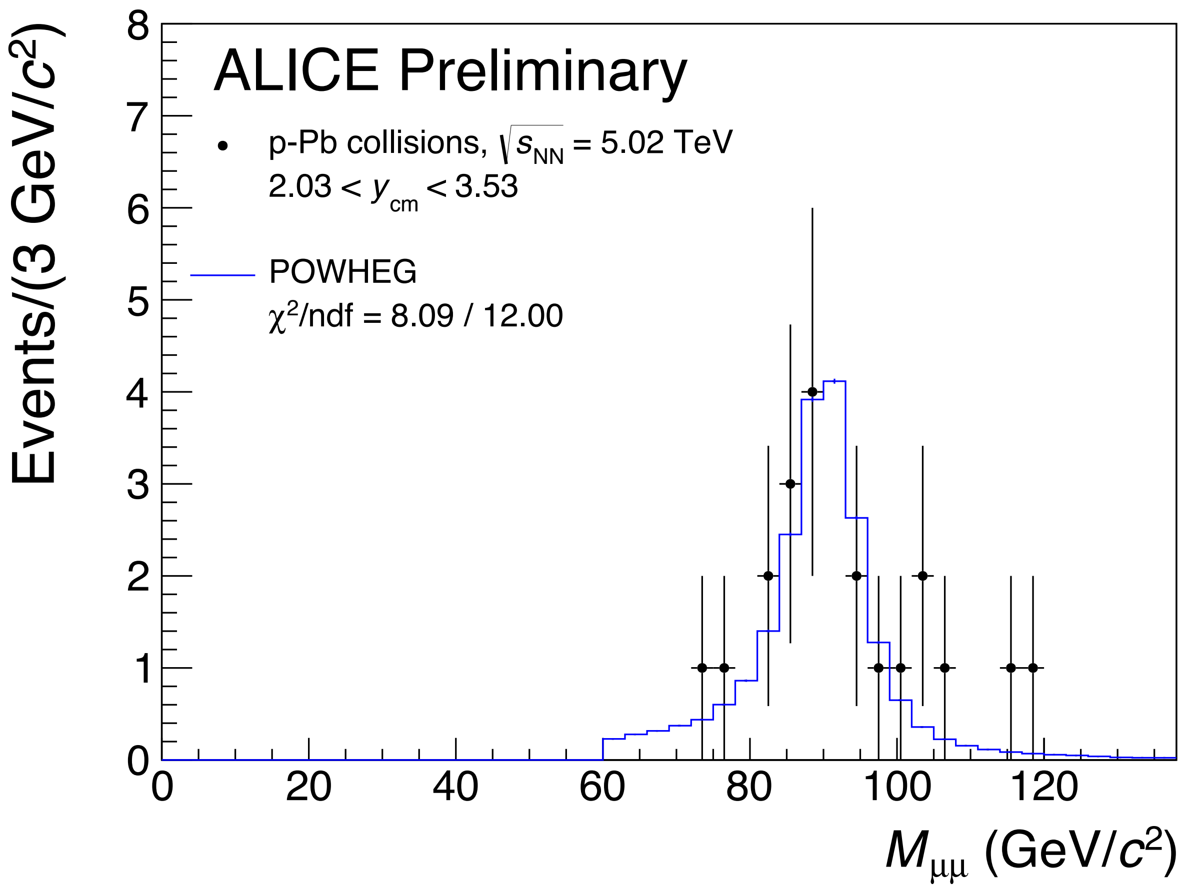
Does data distribution agree with MC ?



- The number of simulated events is normalised to data.
- Statistics are not enough to make the comparison in backward rapidity region.
- MC distribution describes well the data in forward rapidity region.

MC Simulation II

Does data distribution agree with MC ?



- The number of simulated events is normalised to data.
- Statistics are not enough to make the comparison in backward rapidity region.
- MC distribution describes well the data in forward rapidity region.

Detector Efficiency:

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

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

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

Background Contribution I

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

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,..) :

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

Background Contribution I

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

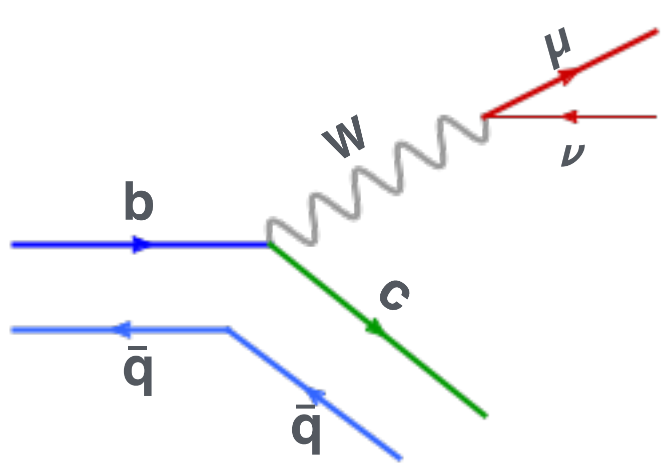
Possible sources:

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 :



Background Contribution I

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

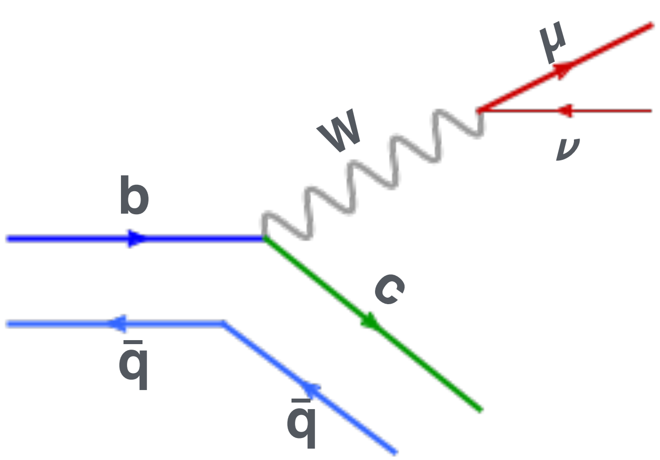
Possible sources:

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

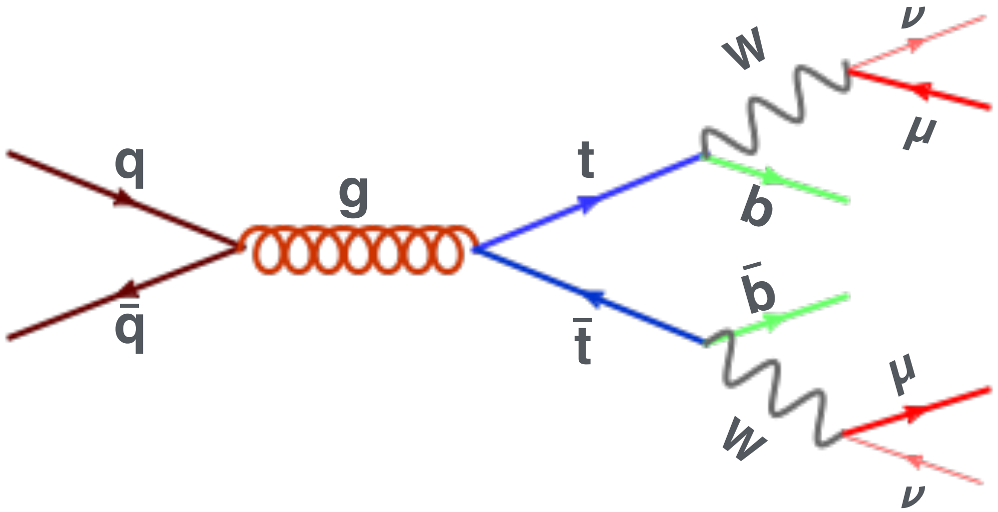
2- Semileptonic decay of $b\bar{b}$ or $c\bar{c}$ pairs :



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

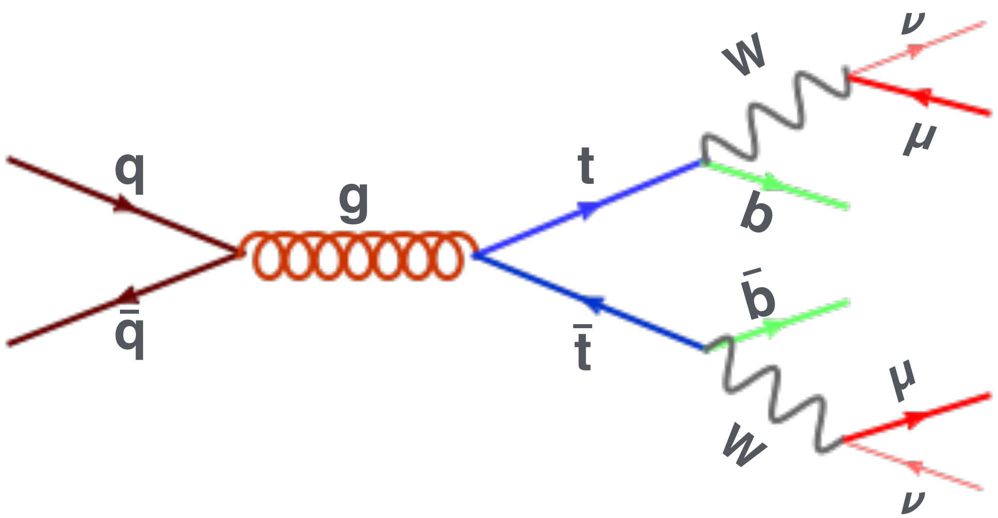
Background Contribution II

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



Background Contribution II

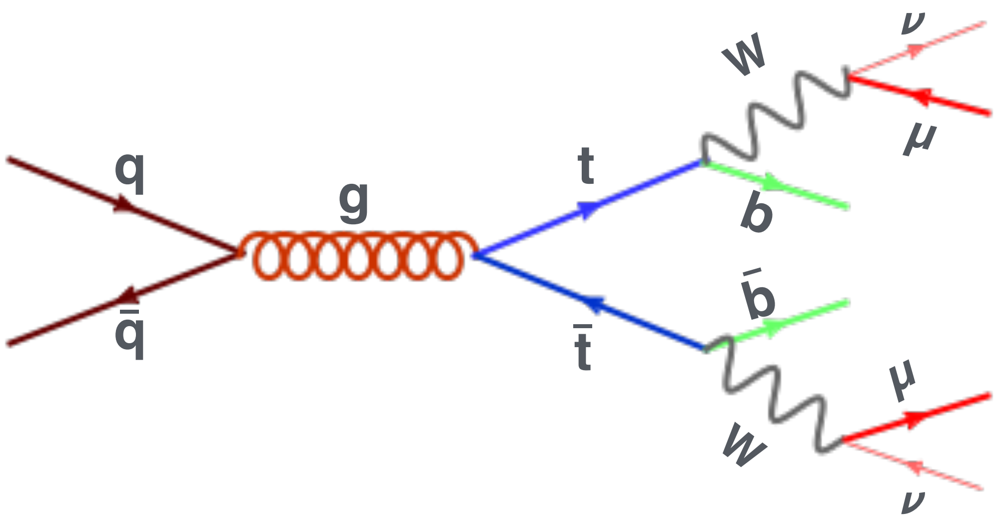
3- $t\bar{t} \rightarrow \mu\mu$



contribution from this source is higher at mid-rapidity.

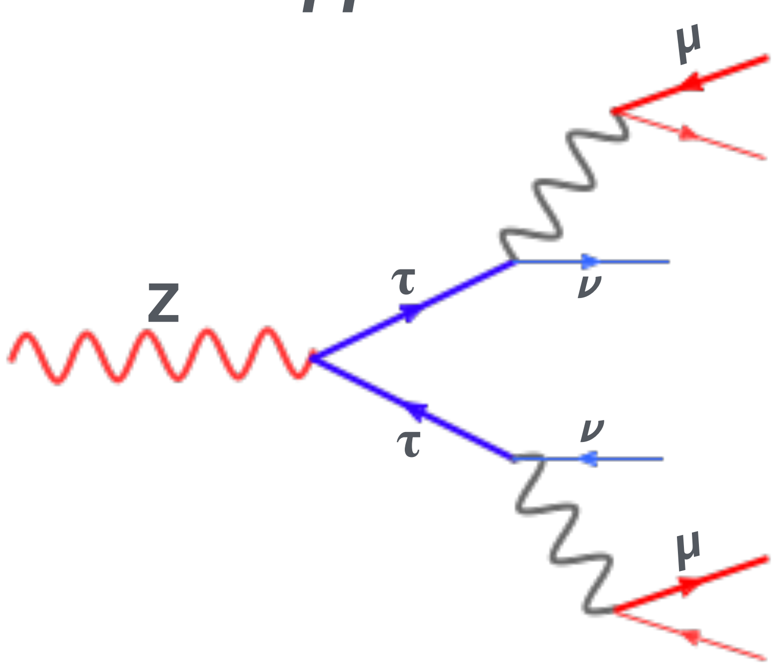
Background Contribution II

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

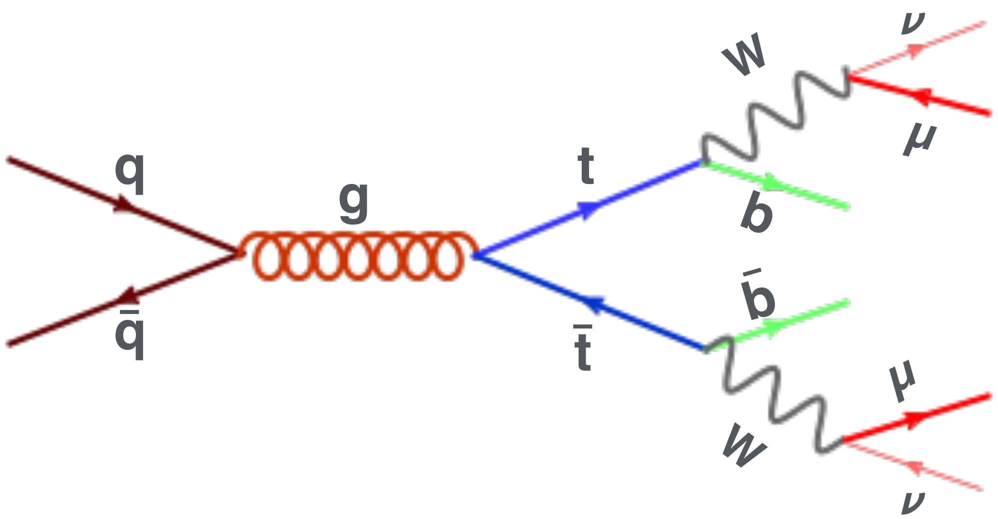


contribution from this source is higher at mid-rapidity.

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

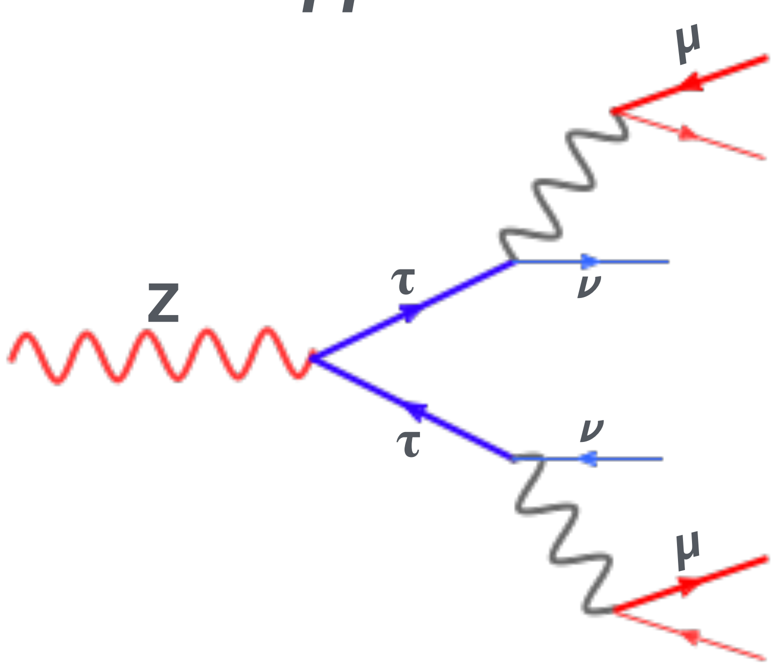


3- $t\bar{t} \rightarrow \mu\mu$



contribution from this source is higher at mid-rapidity.

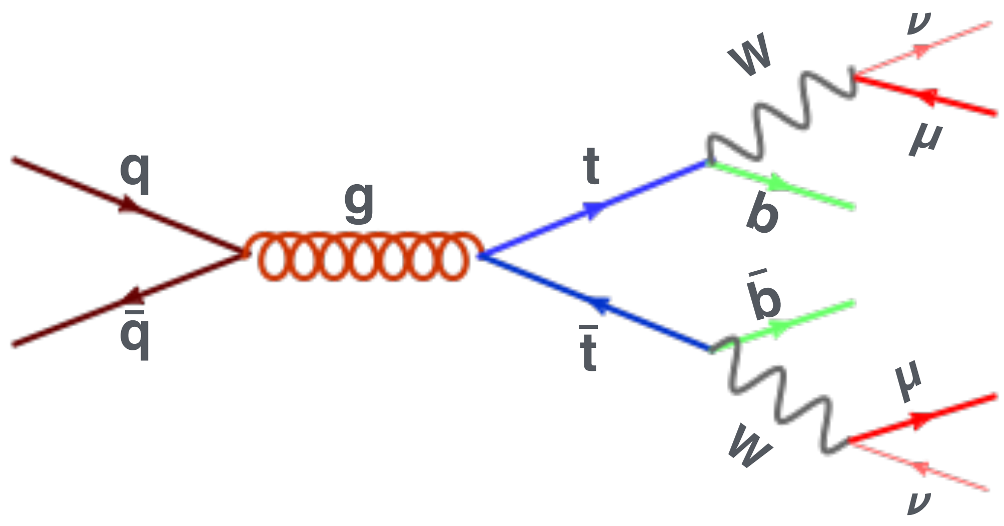
4- $Z \rightarrow \tau\tau \rightarrow \mu\mu$



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

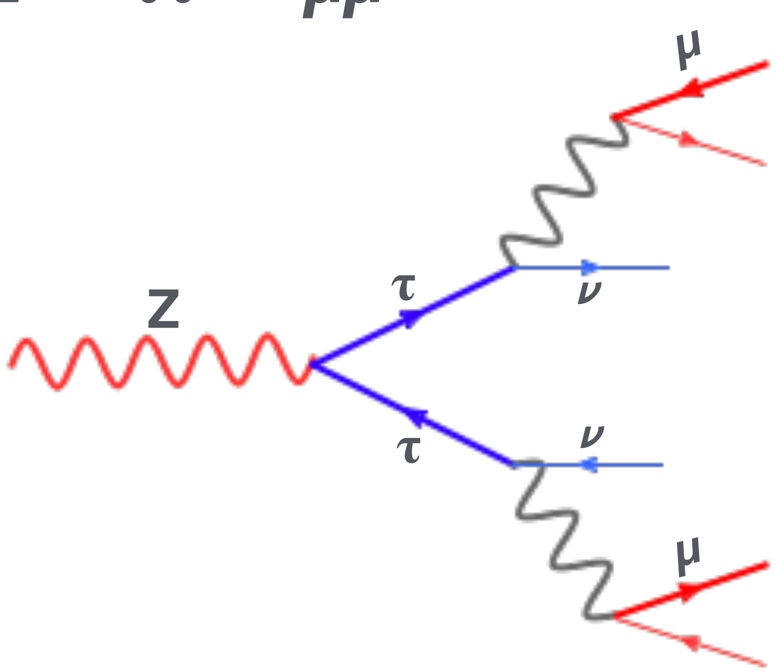
Background Contribution II

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



contribution from this source is higher at mid-rapidity.

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



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:

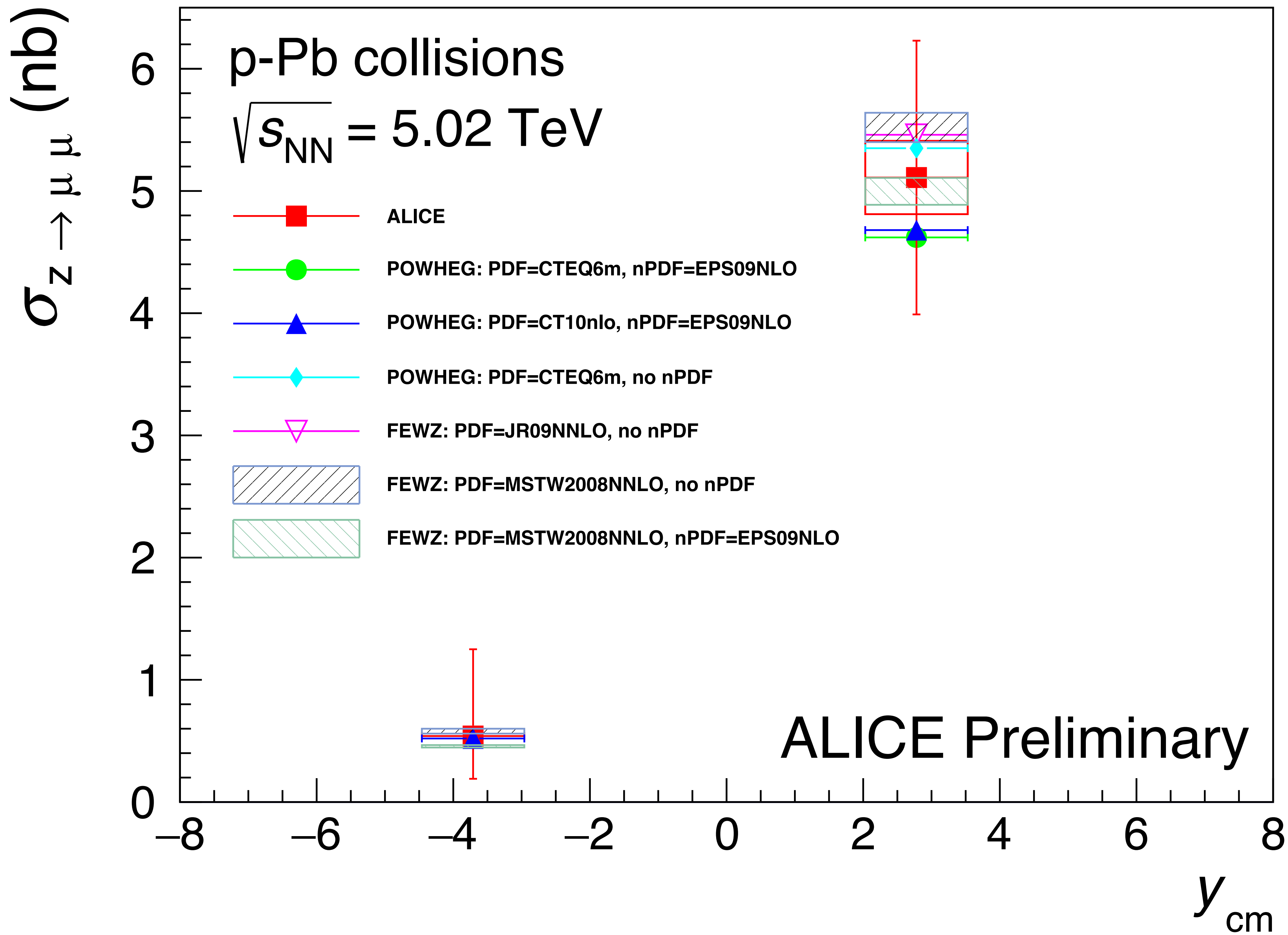
$$\begin{cases} 60 < m_{\mu\mu} < 120 \text{ GeV}/c^2 \\ p_T(\mu) > 20 \text{ GeV}/c \\ -4.0 < \eta_\mu < -2.5 \end{cases}$$

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

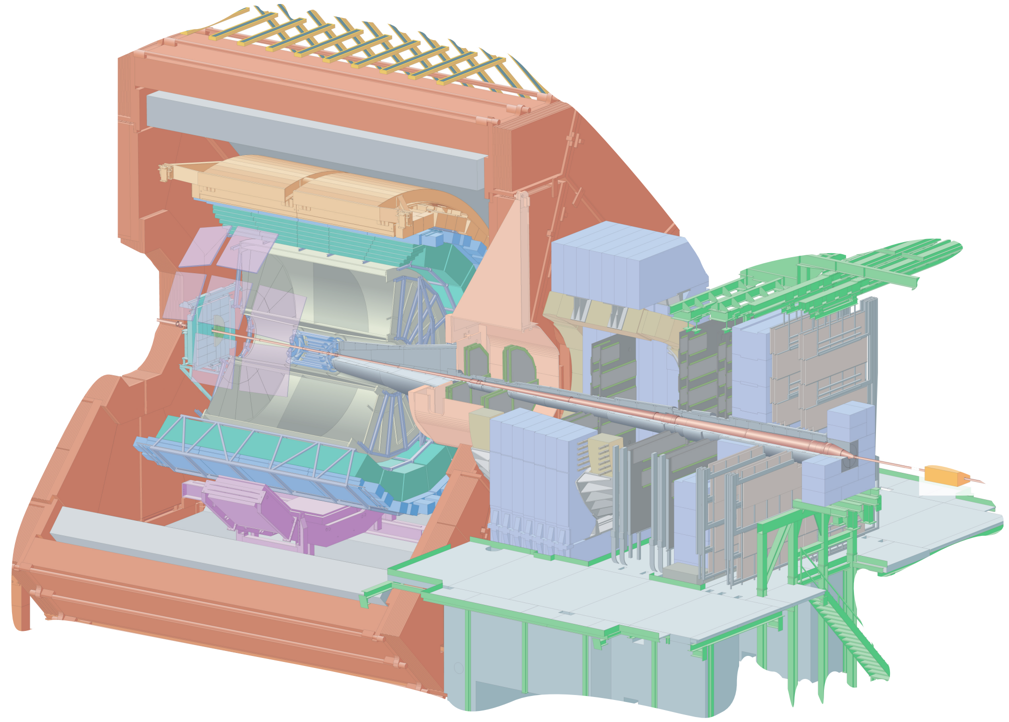
$$\sigma_{Z\rightarrow\mu^+\mu^-}(-4.46 < y_{cm} < -2.96) = 0.54^{+0.71}_{-0.35} \text{ (stat)} \ \pm 0.04 \text{ (sys) nb}$$

- 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.

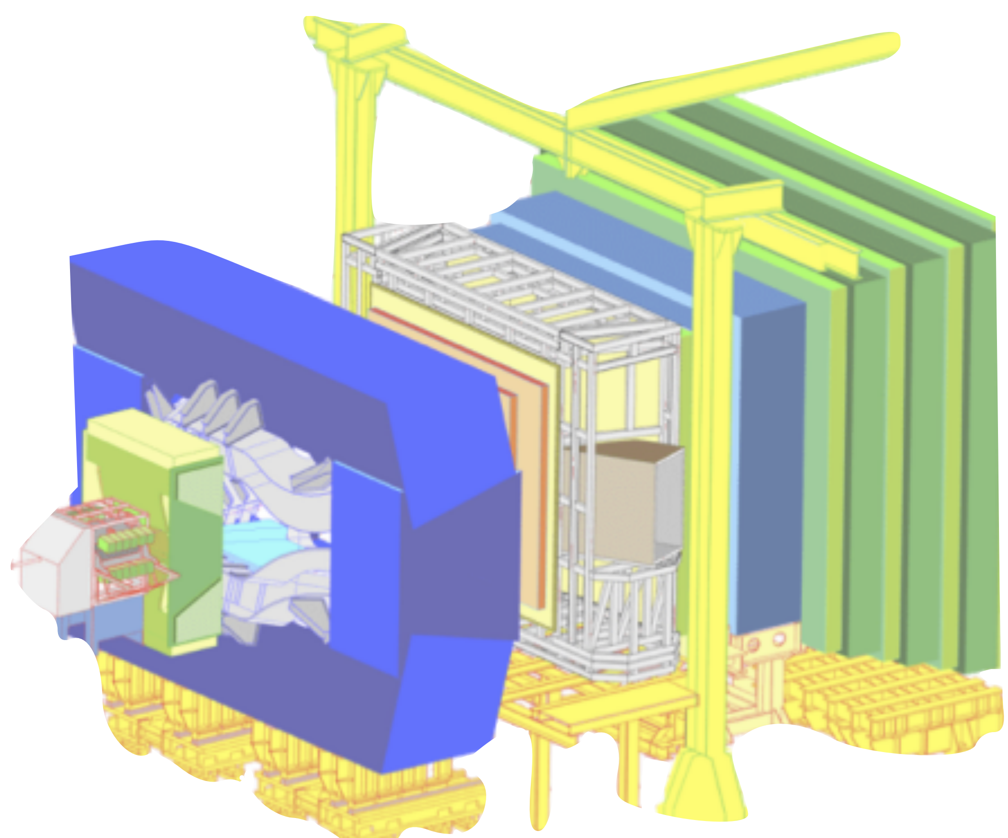
Results Vs Theory



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



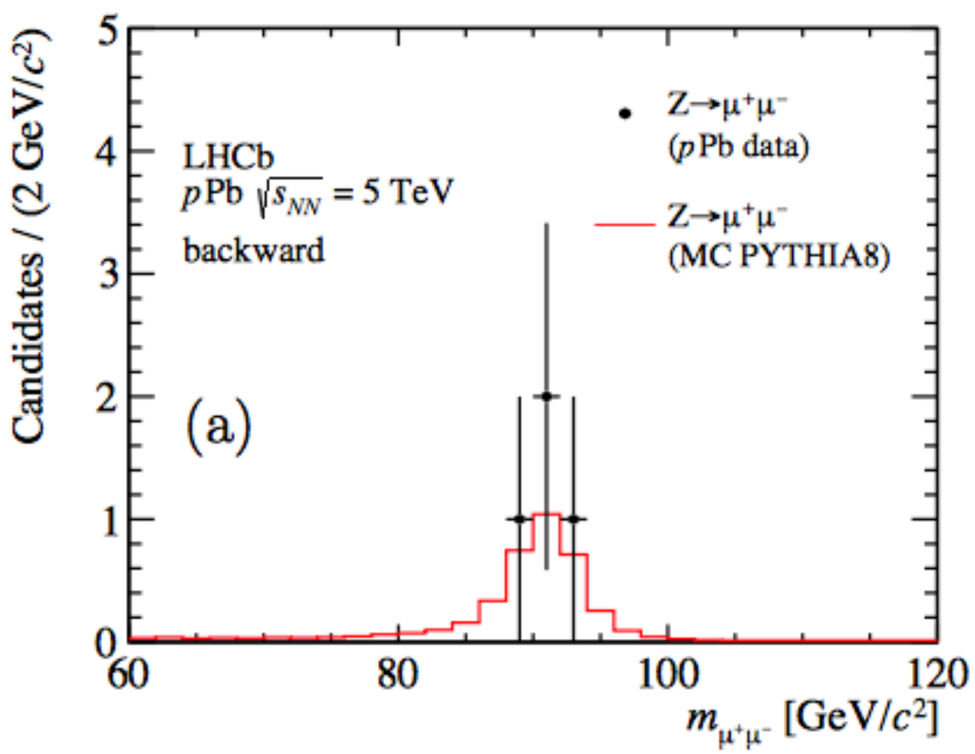
Comparison to LHCb results



Fudicial region:

- $60 < m_{\mu\mu} < 120$ GeV/c^2
- $p_T(\mu) > 20$ GeV/c
- $2.0 < \eta_\mu < 4.5$

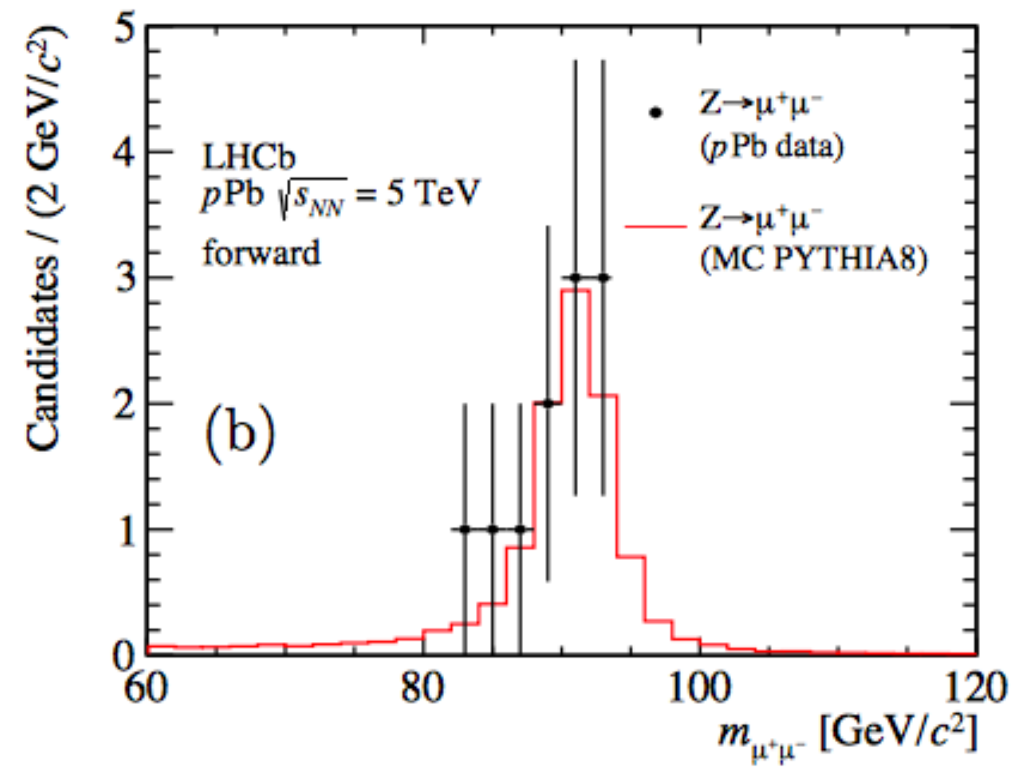
$-4. < \eta_\mu < -2.5$ for ALICE



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

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

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

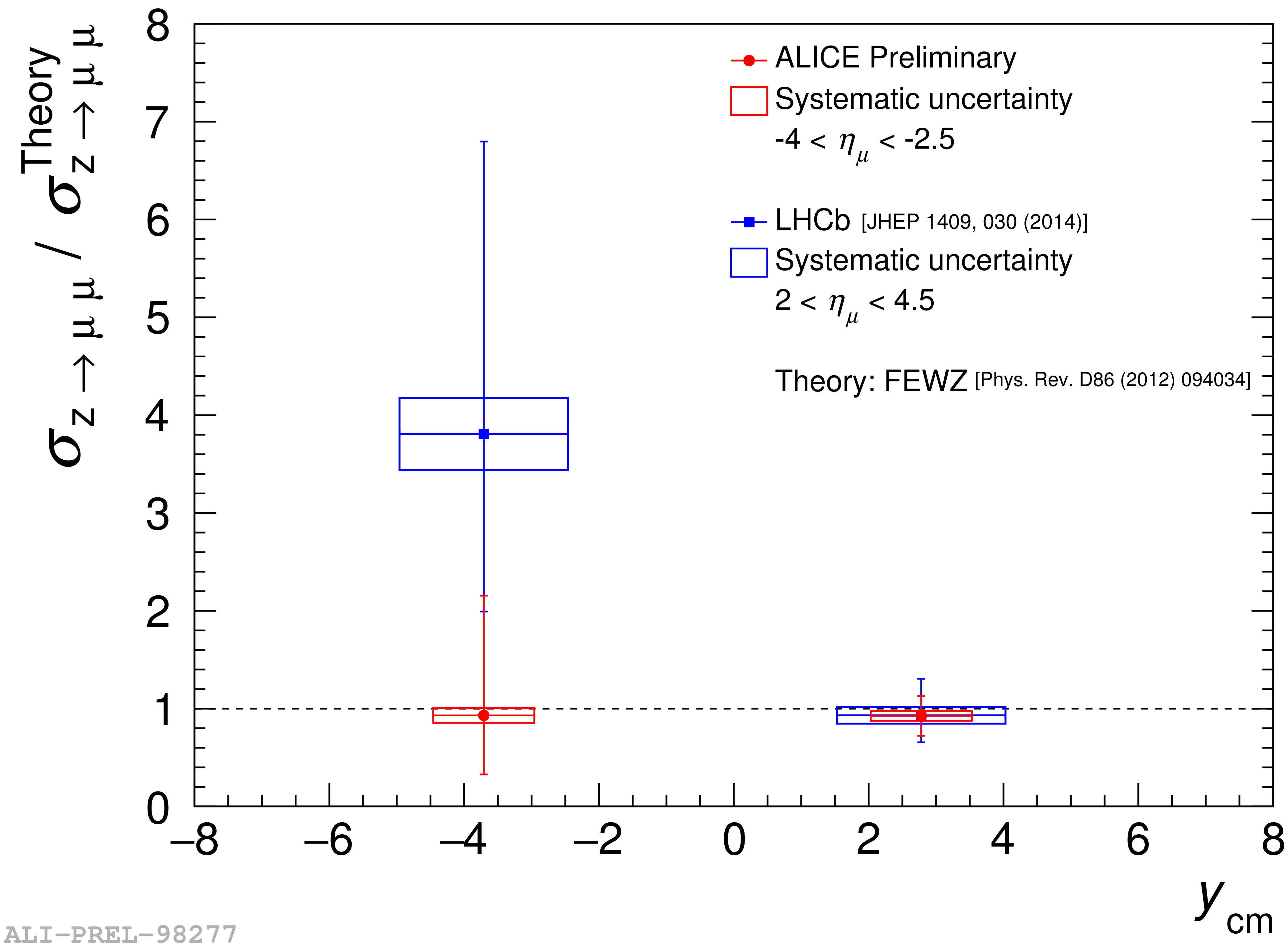


$1.53 < y_{cm} < 4.03$

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

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

Comparison To LHCb

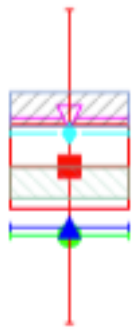


- At forward, the results from the two experiments agree with unity.
- At backward rapidity, no fair conclusion can be made with large statistic uncertainties for both experiments.

Conclusion

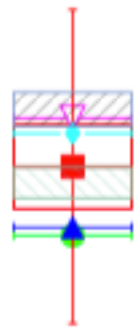
- Z boson production is important to constrain nuclear PDF sets.
- The cross section $\sigma_{Z\rightarrow\mu\mu}$ is determined in p-Pb collisions at 5.02 TeV in two rapidity regions.
- An agreement is found between the obtained cross sections and theoretical predictions in both rapidity regions.
- At forward rapidity, an agreement is found between ALICE and LHCb results.

Some Perspectives



- It seems that we only need more statistics.
- Could it be in LHC-run2 ?

Some Perspectives

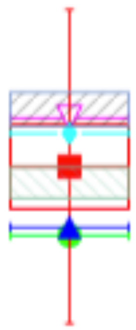


- It seems that we only need more statistics.
- Could it be in LHC-run2 ?

Forward to backward ratio: $$R_{FB}(|y|) = \frac{\sigma_{+|y|}}{\sigma_{-|y|}}$$

- Better quantity to test the nPDF sets.
- With ALICE, it can be measured in $2.96 < |y_{cm}| < 3.53$.
- Uncertainty on the PDF is cancelled for the theory predictions.

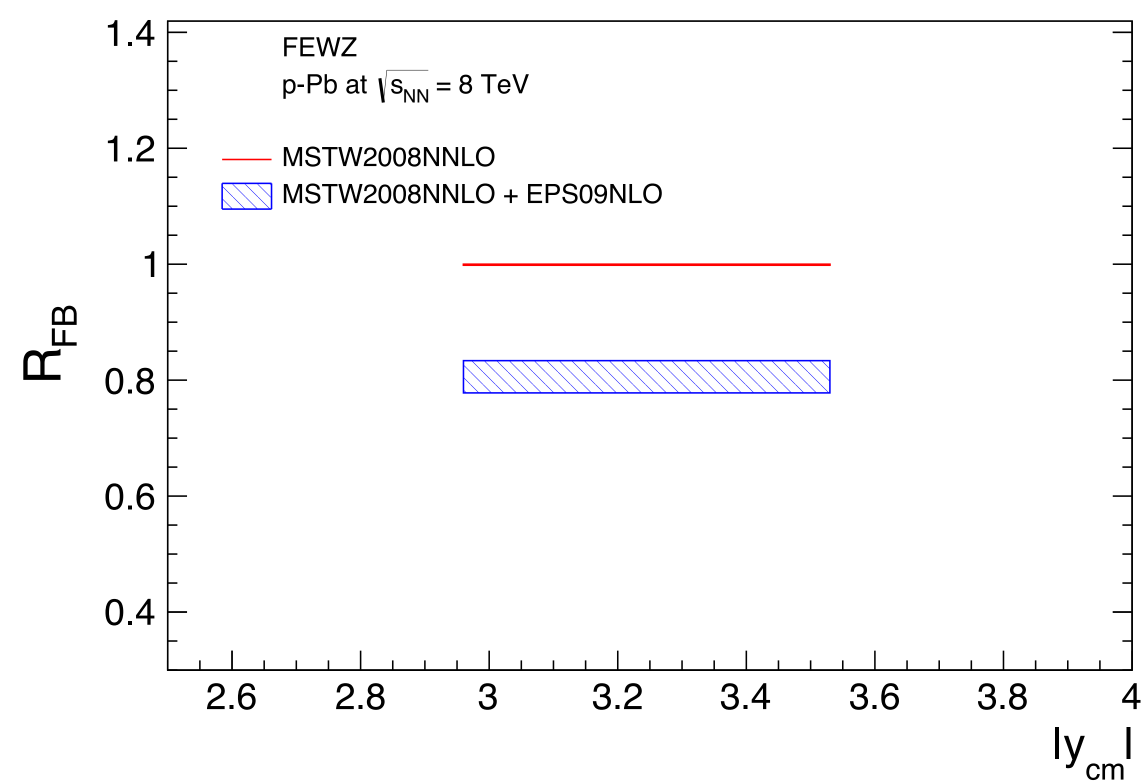
Some Perspectives



- It seems that we only need more statistics.
- Could it be in LHC-run2 ?

Forward to backward ratio: $$R_{FB}(|y|) = \frac{\sigma_{+|y|}}{\sigma_{-|y|}}$$

- Better quantity to test the nPDF sets.
- With ALICE, it can be measured in $2.96 < |y_{cm}| < 3.53$.
- Uncertainty on the PDF is cancelled for the theory predictions.



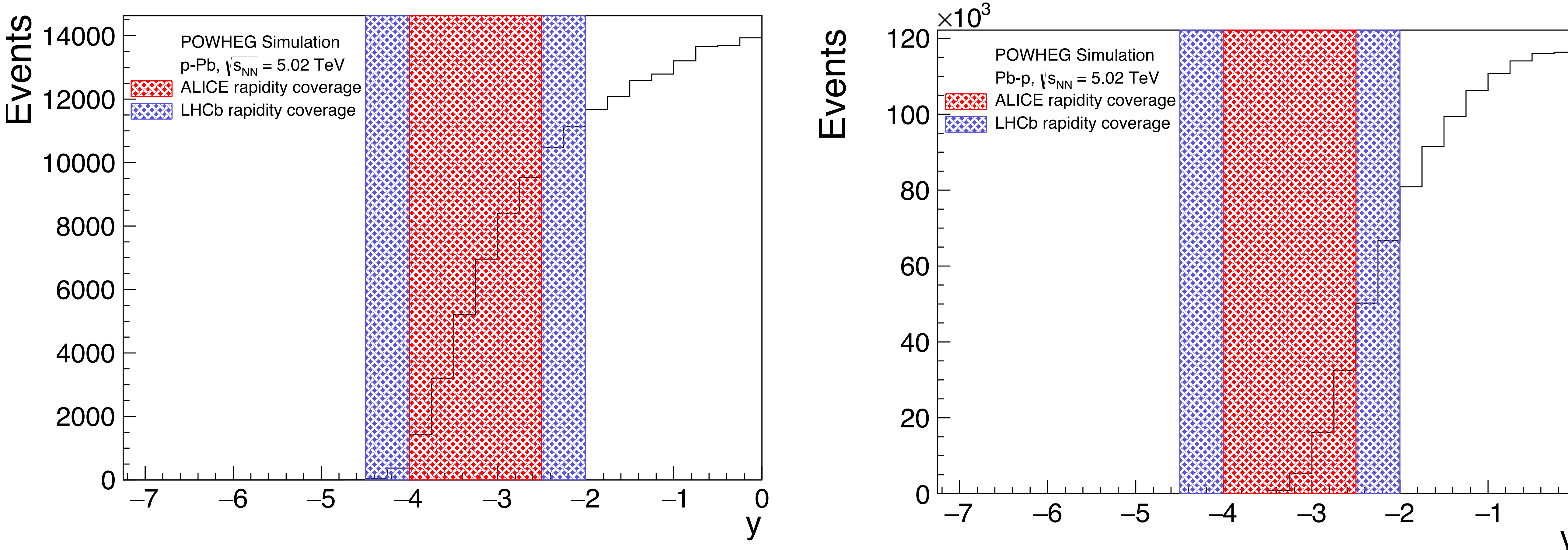
R_{FB} FEWZ prediction at $\sqrt{s_{NN}}$ = 8 TeV

BACKUP

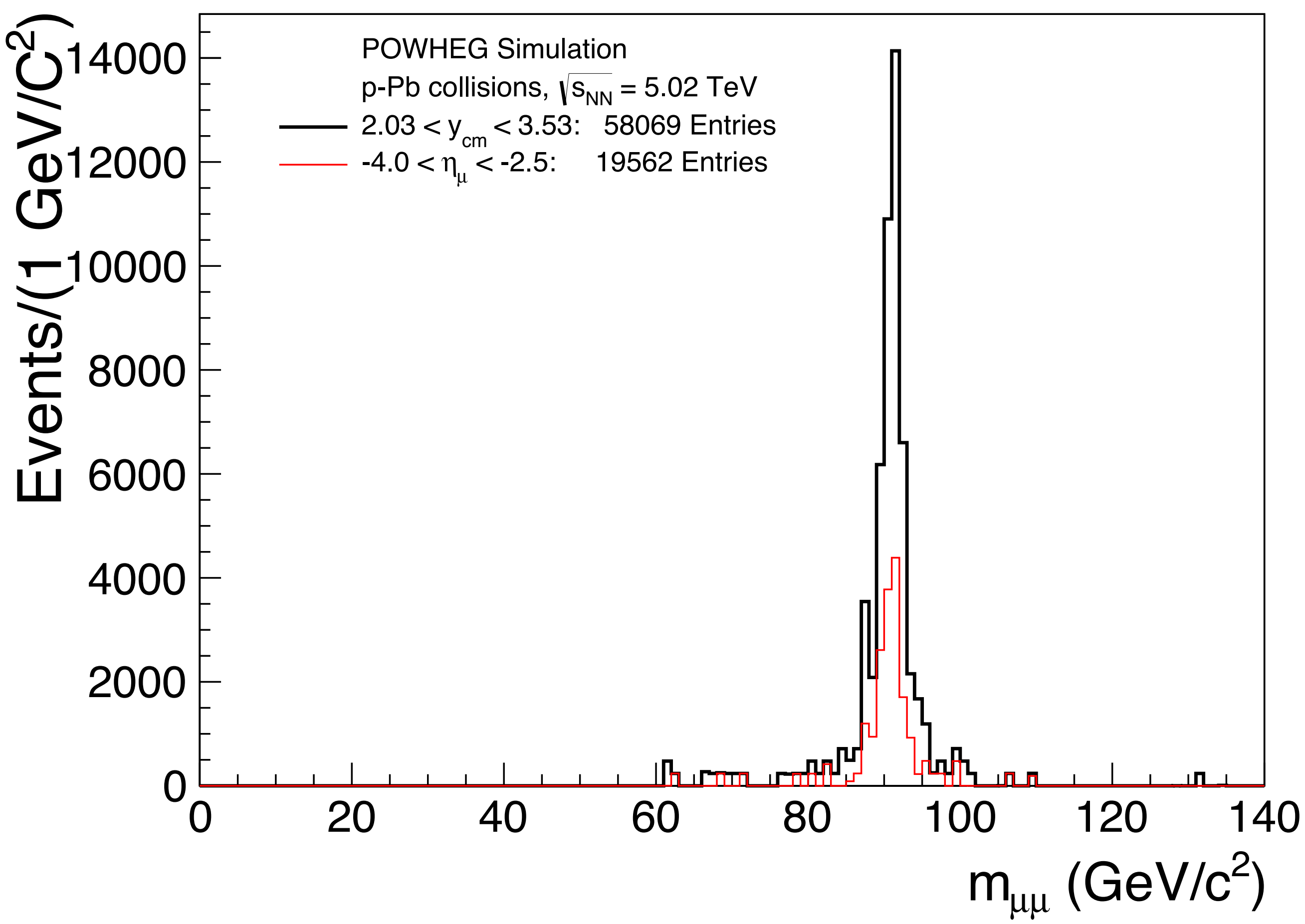
Summary of systematic uncertainties

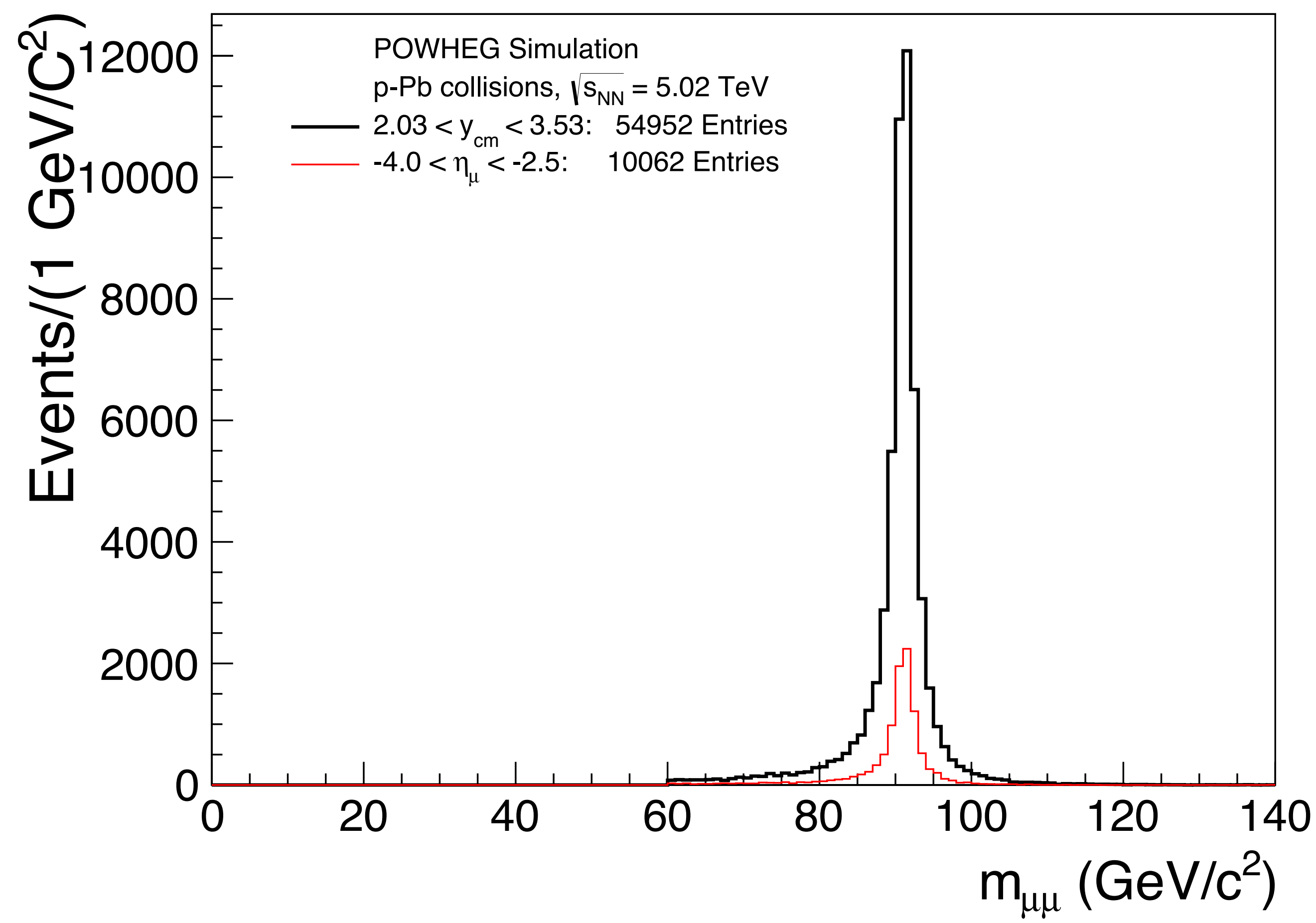
	Efficiency	Tracking efficiency	Trigger efficiency	Matching efficiency	Cluster resolution	σ_{MB}
Forward	1%	4%	2%	1%	1.3%	3.2%
backward	2%	6%	2%	1%	0.2%	3%

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

Background Contribution