Z production in pPb collisions at LHCb

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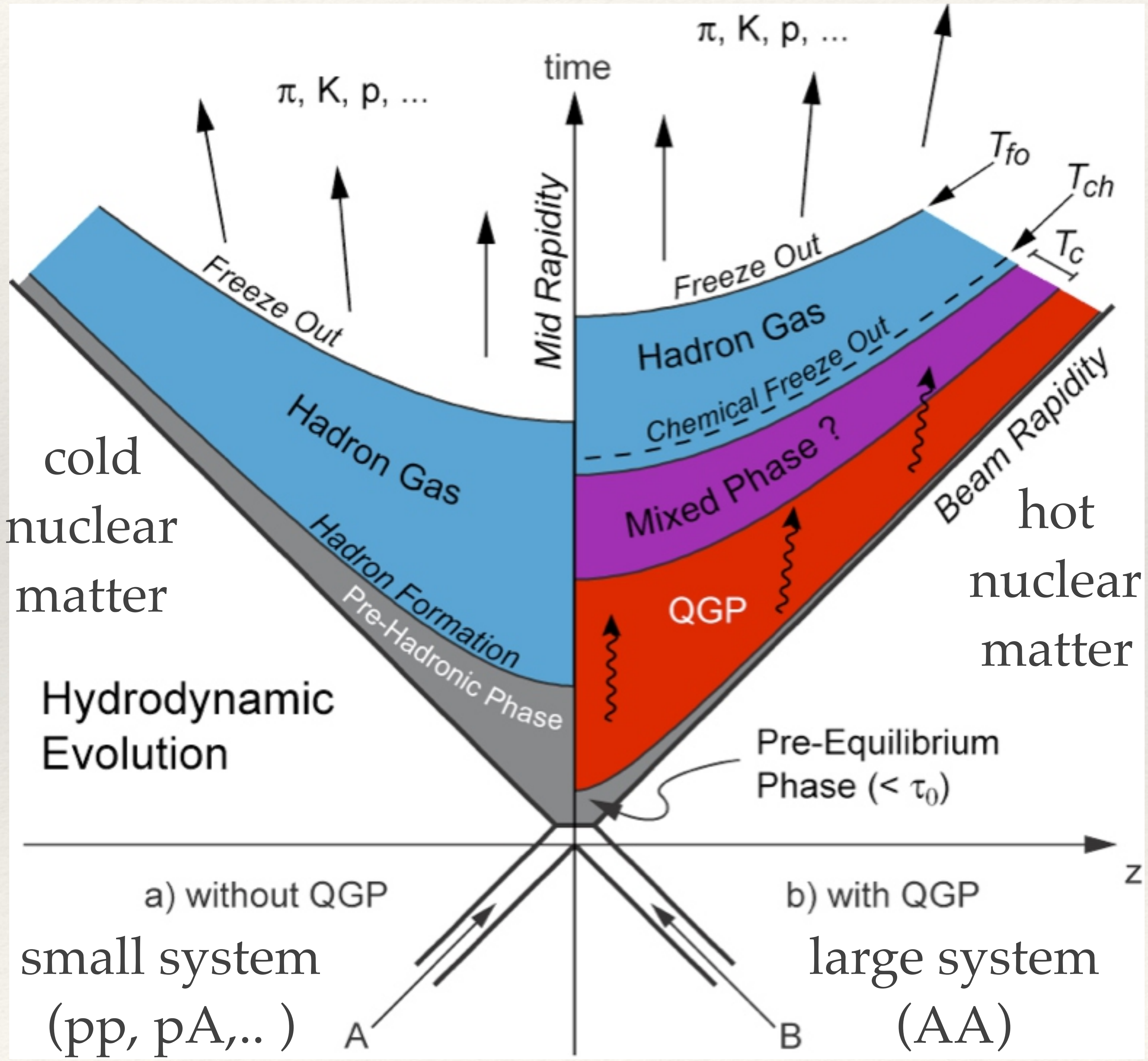
The nuclear matter effects

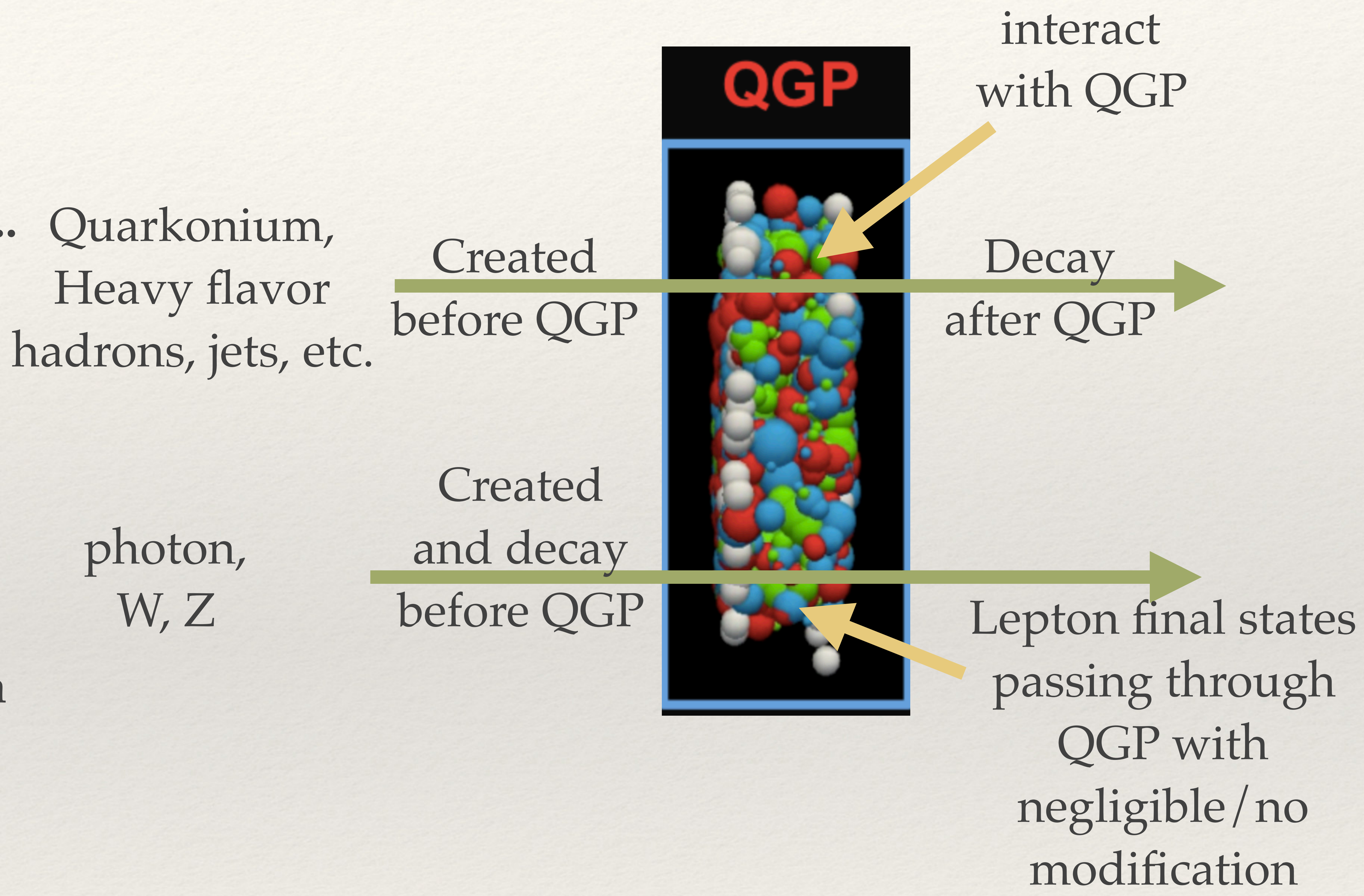
- Ultra-relativistic heavy ion collisions can help us to:
  - Explore phase diagram of nuclear matter
  - Large systems (AA):
    - Study QCD matter under extreme conditions (hot nuclear matter effects)
      - E.g. formation of Quark Gluon Plasma (QGP) at high temperature and/or energy density.
  - Small systems (pp, pA, ..):
    - Nucleon structure, intrinsic charm, reflected in the nuclear modifications (cold nuclear matter effects)
    - also QGP?
  - Many other things: QED at extreme field strengths, diffractive processes...

- Space-time evolution of the collision



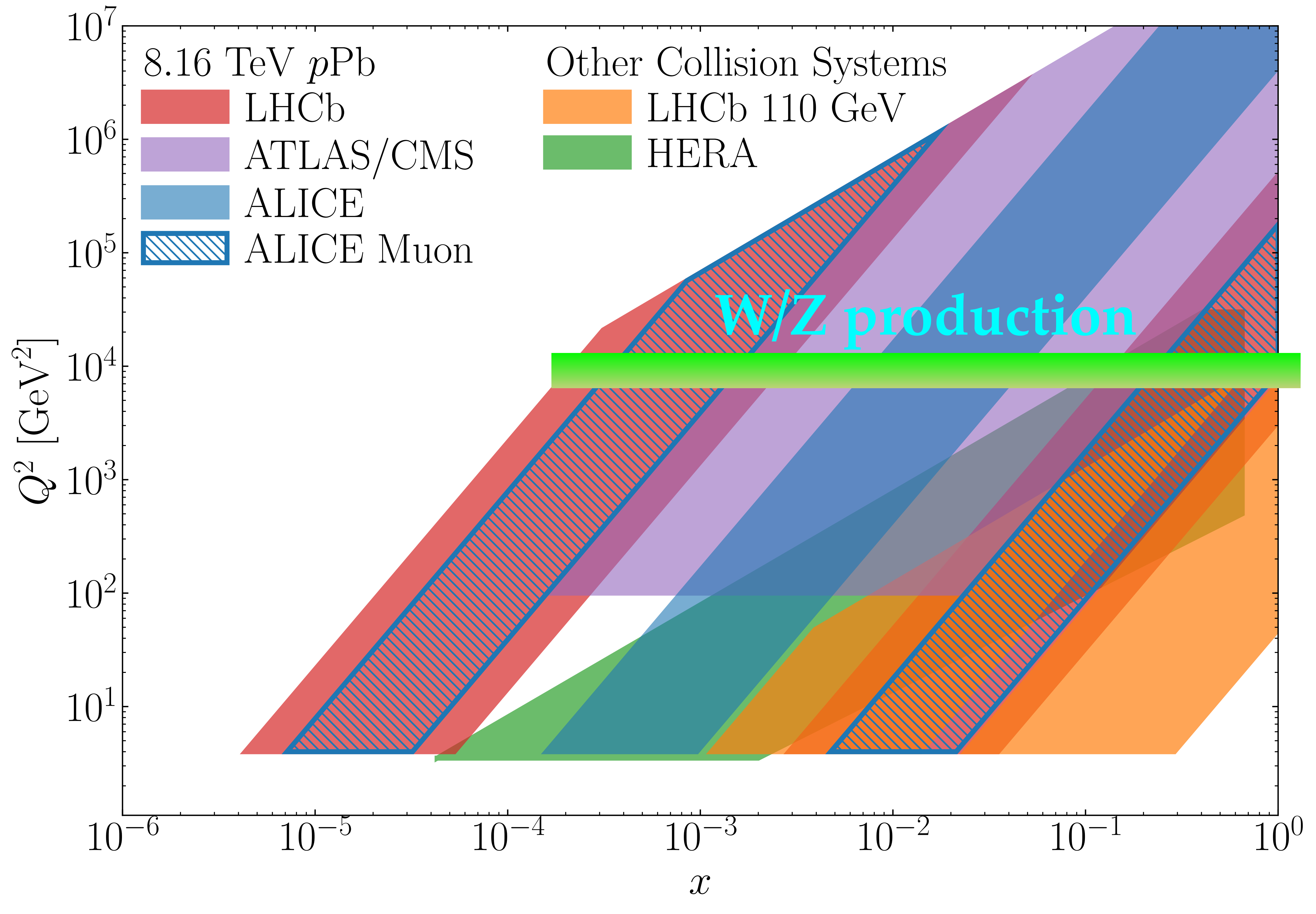
Soft probes, hard probes, EW probes

- Soft probes:
  - study the QGP medium itself: global characteristics such as multiplicities, correlations, azimuthal asymmetries, etc..
- Hard and electroweak probes:
  - using hard scatterings (pQCD controlled) created before the QGP medium formation, which propagated through the medium, to "probe" (study) the nuclear matter effects of the medium.
  - Heavy flavor hadrons, quarkonium, jets, etc., interact with QGP medium,
  - photon and W/Z bosons, decay before QGP formation, leptonic final states w/o impact by the medium ==> reference for hard probes.



Z boson production in pPb

- Electroweak bosons are unmodified by the hot and dense medium created in heavy ion 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 of other processes such as heavy quark production

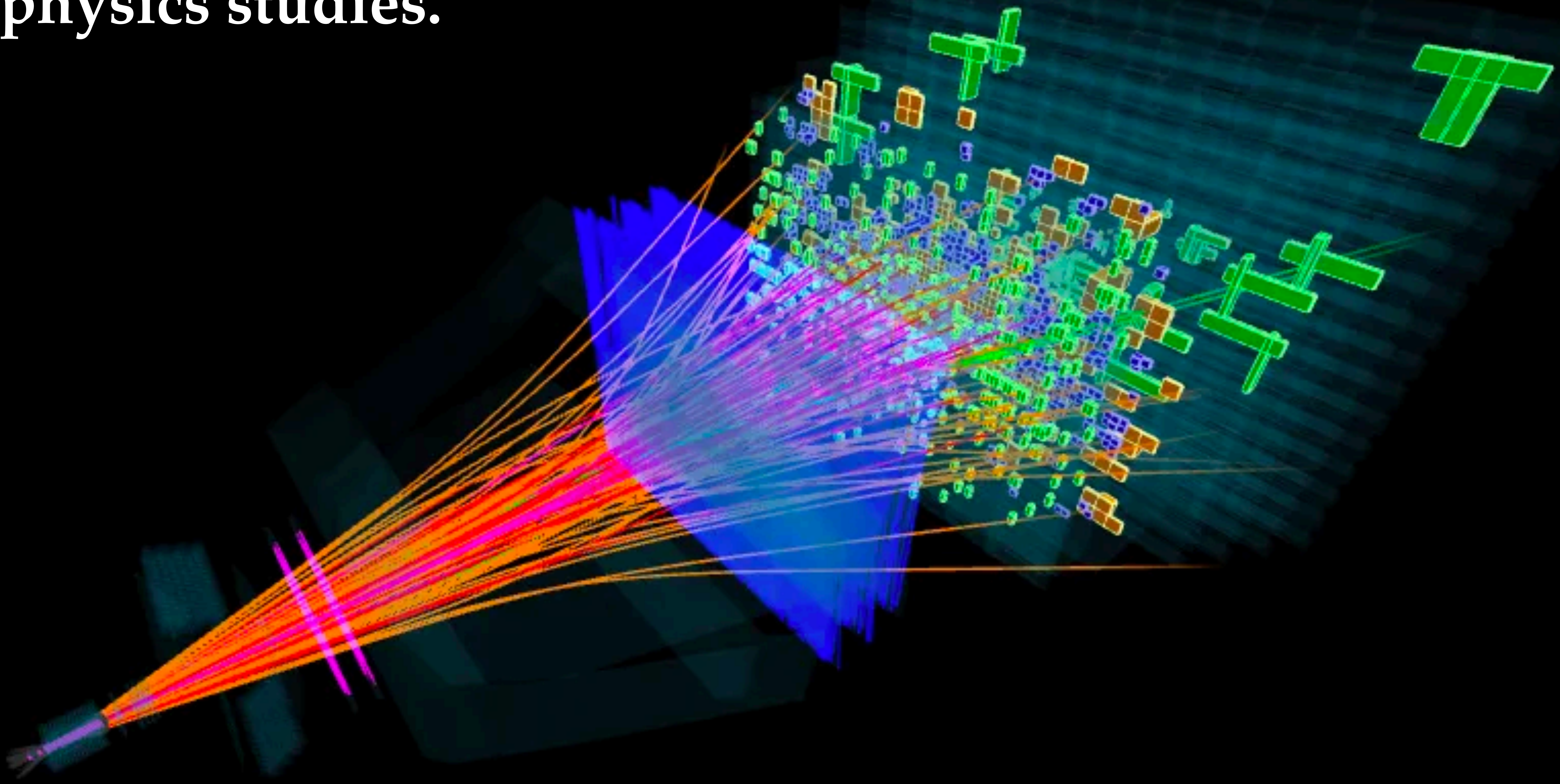


LHCb provides unique datasets for Heavy Ion physics studies.

Event 351483885

Run 187340

Fri, 02 Dec 2016 20:56:29



Event display from the proton-lead collisions in 2016

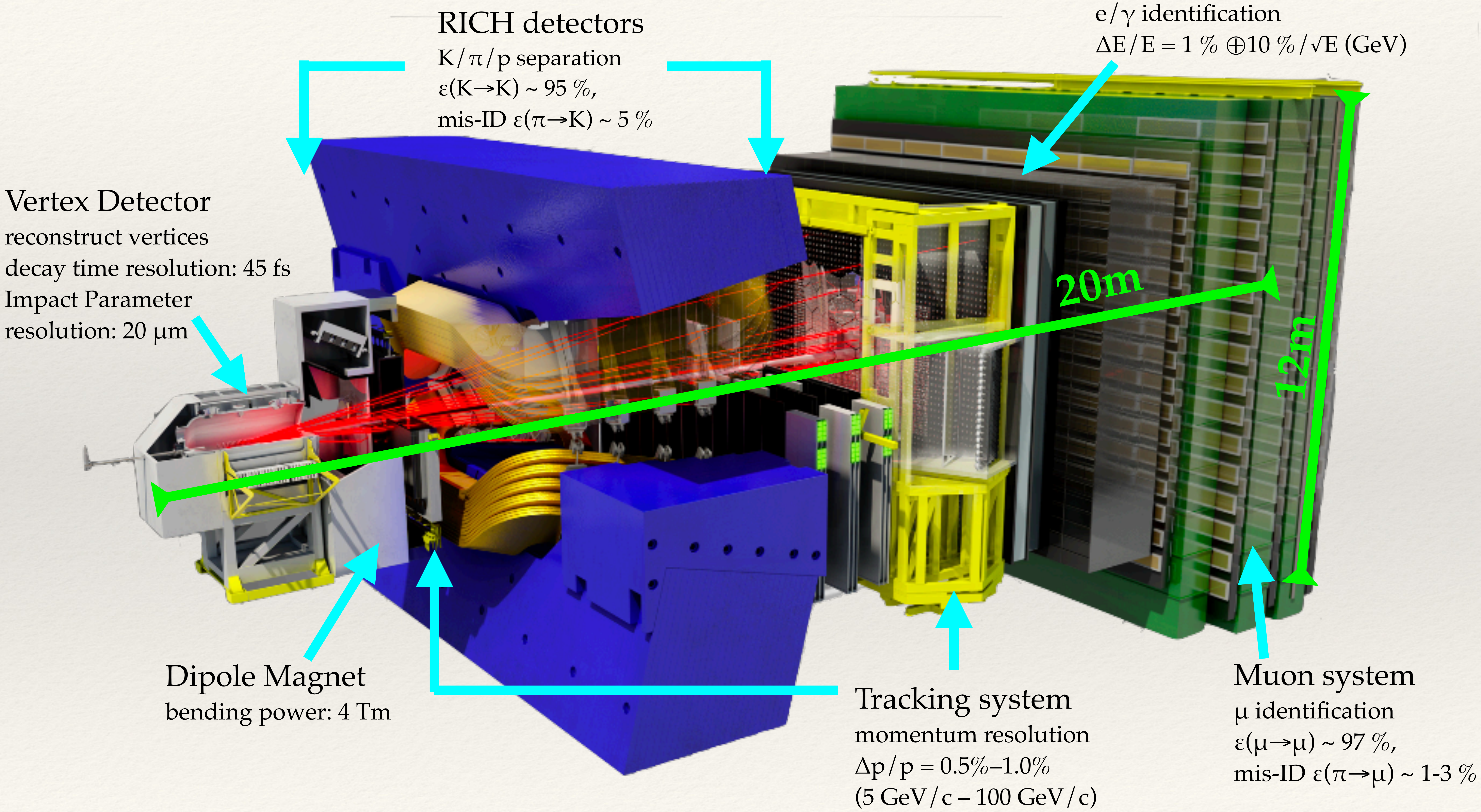
The LHCb detector is special

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

- LHCb is the only dedicated detector (at LHC) fully instrumented in forward region
- Unique kinematic coverage

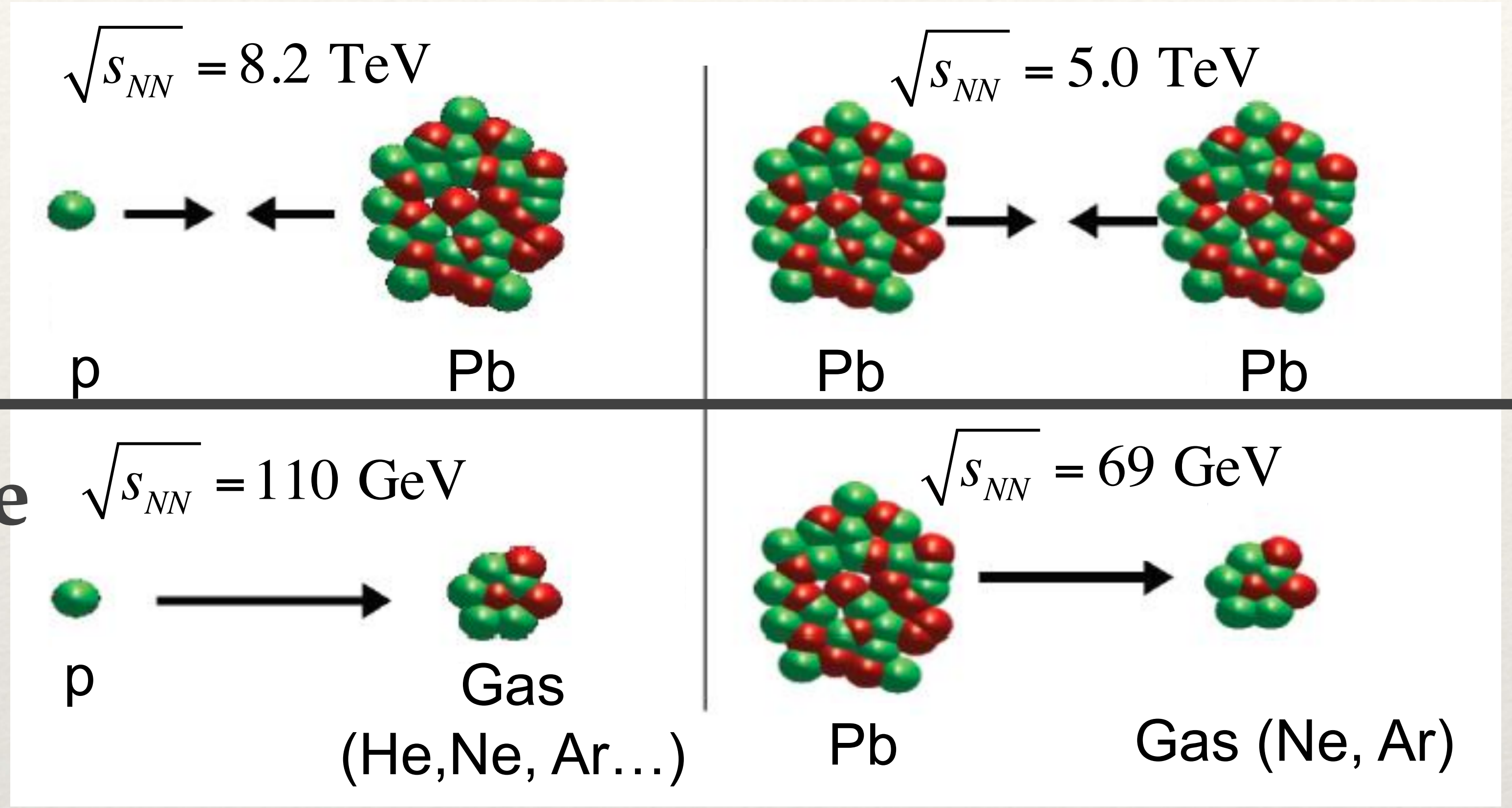
  $2 < \eta < 5$

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

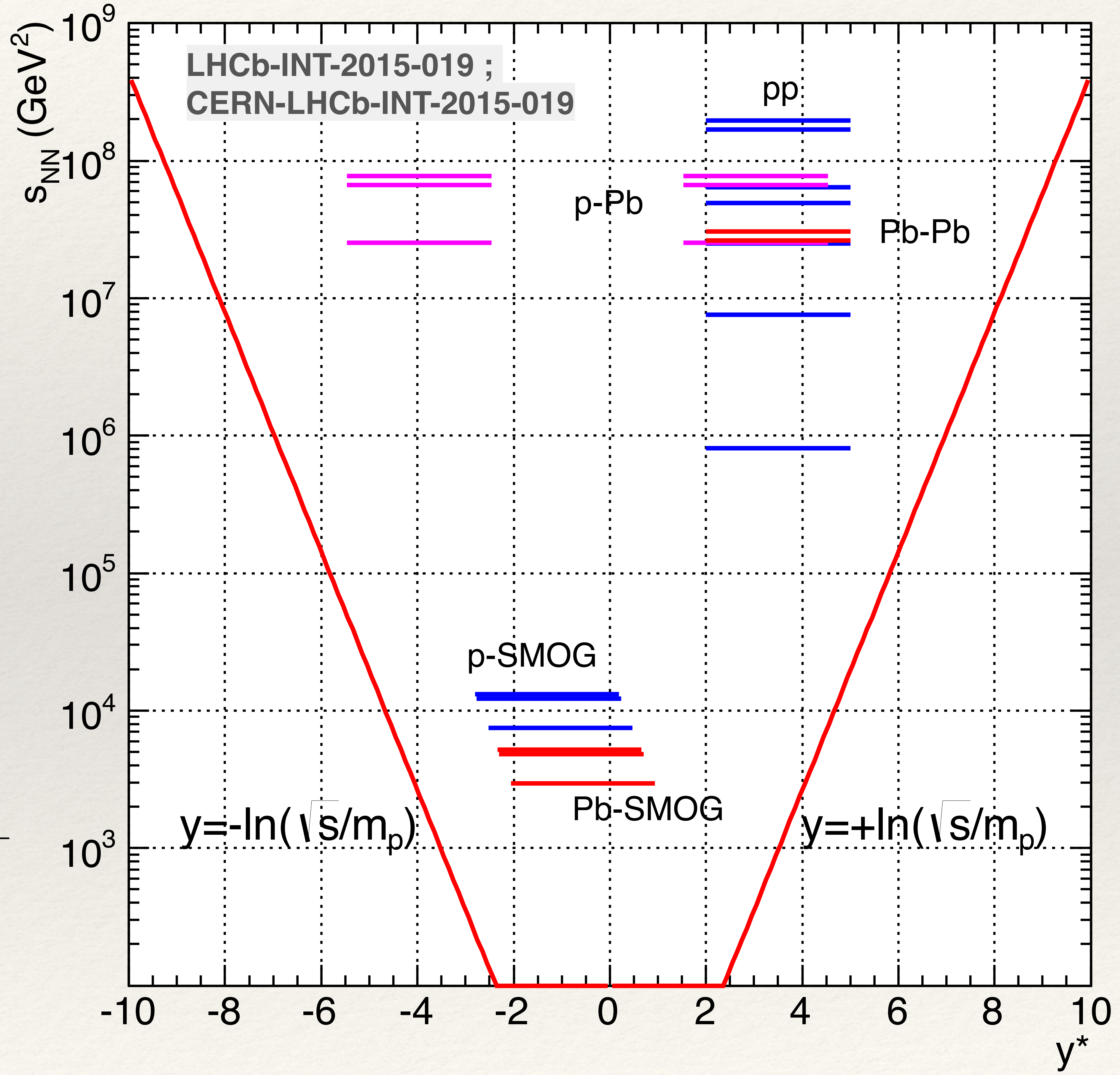


LHCb running modes and kinematic coverage

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



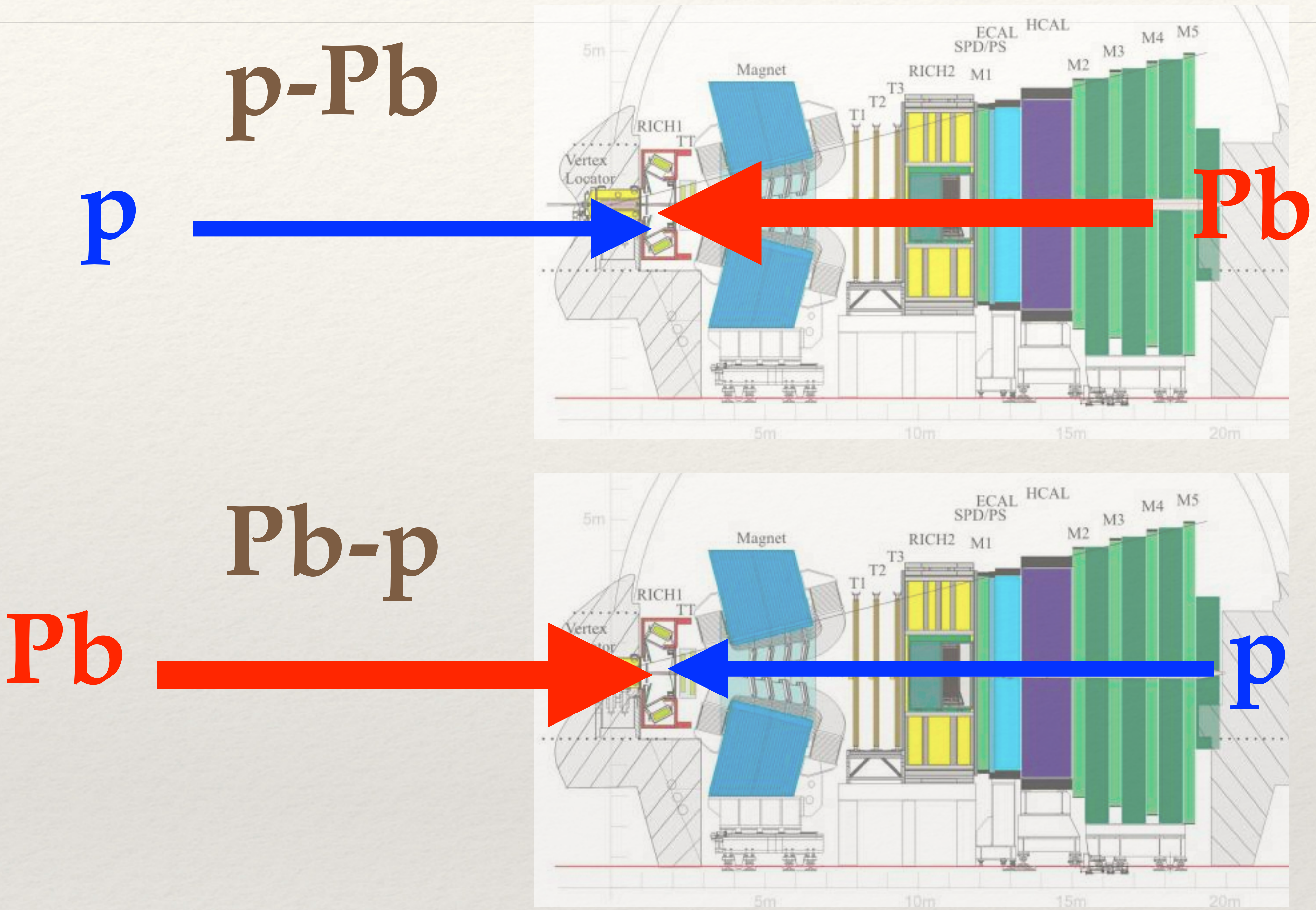
Kinematic Acceptance



- **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 μb^{-1}	0.4 μb^{-1}	$\sim$ 210 μb^{-1}

Setups for proton-ion collisions



- **Forward production:**
  - Center of mass rapidity coverage: $1.5 < y^* < 4.0$
- **Backward production:**
  - Center of mass rapidity coverage: $-5.0 < y^* < -2.5$

- 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: $2.5 < |y^*| < 4.0$

pPb Z boson production

- Cross-sections measured in fiducial volume for both pPb and Pbp:

$$\sigma_{Z\to\mu^+\mu^-} = \frac{N_{\text{cand}}\cdot\rho}{\mathcal{L}\cdot\epsilon_{\text{tot.}}}$$

- Forward-backward ratio measured in fiducial volume + common rapidity coverage:

$$R_{\text{FB}}^{2.5<|y^*|<4.0} = \left.\frac{\sigma_{Z\to\mu^+\mu^-,p\,\text{Pb}}}{\sigma_{Z\to\mu^+\mu^-,\text{Pb}\,p}}\right|_{2.5<|y^*|<4.0}$$

【JHEP09(2014)030】【LHCb-CONF-2019-003】

- Using pPb datasets at 5.02 TeV and 8.16 TeV

	2013		2016	
$\sqrt{s_{NN}}$	5.02 TeV		8.16 TeV	
	pPb	Pbp	pPb	Pbp
$\mathcal{L}$	1.1 nb^{-1}	0.5 nb^{-1}	13.6 nb^{-1}	20.8 nb^{-1}

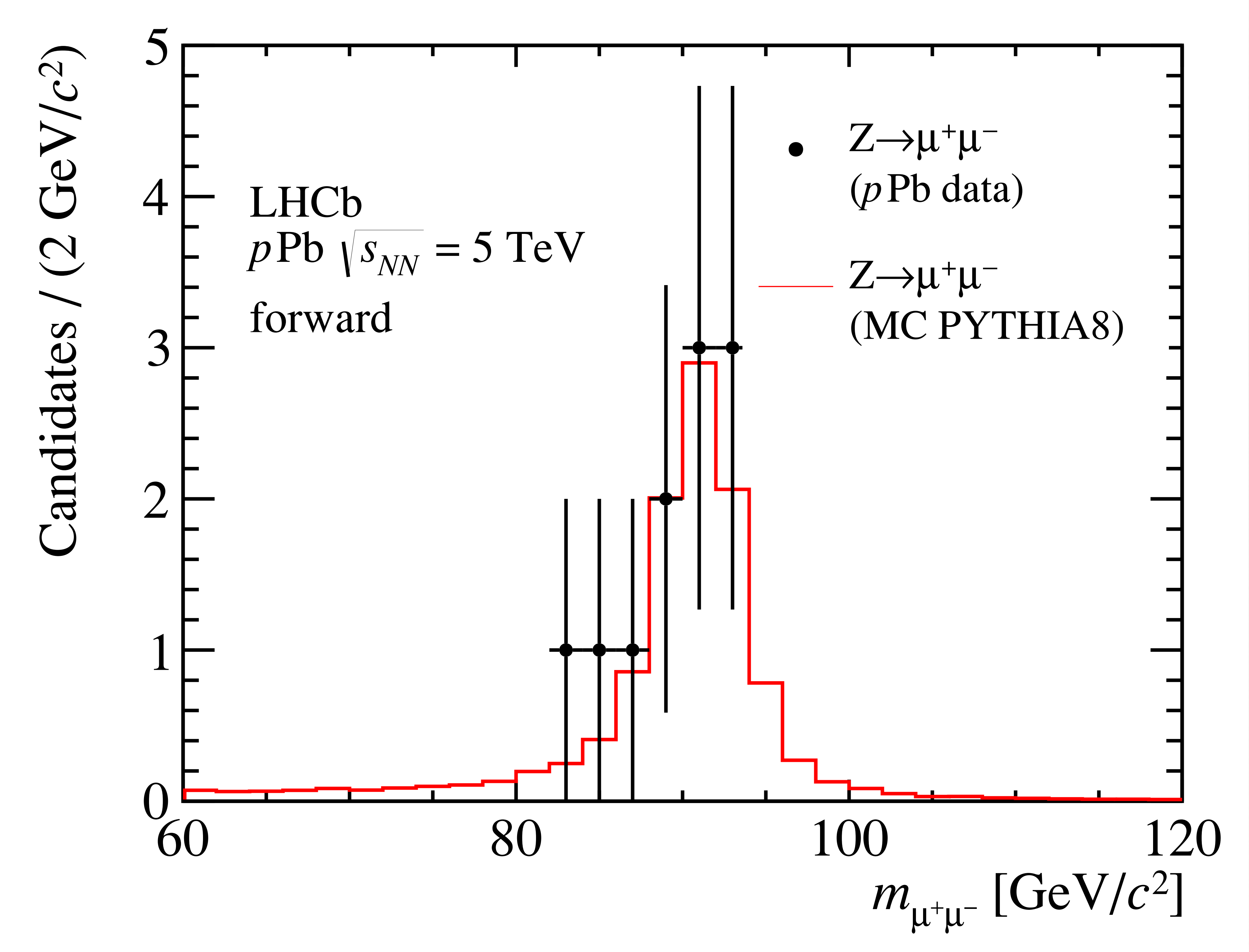
- Fiducial volume:
  $60 < m_{\mu\mu} < 120\,\text{GeV}$
  $2.0 < \eta^{\mu} < 4.5,\ p_T^{\mu} > 20\,\text{GeV}$

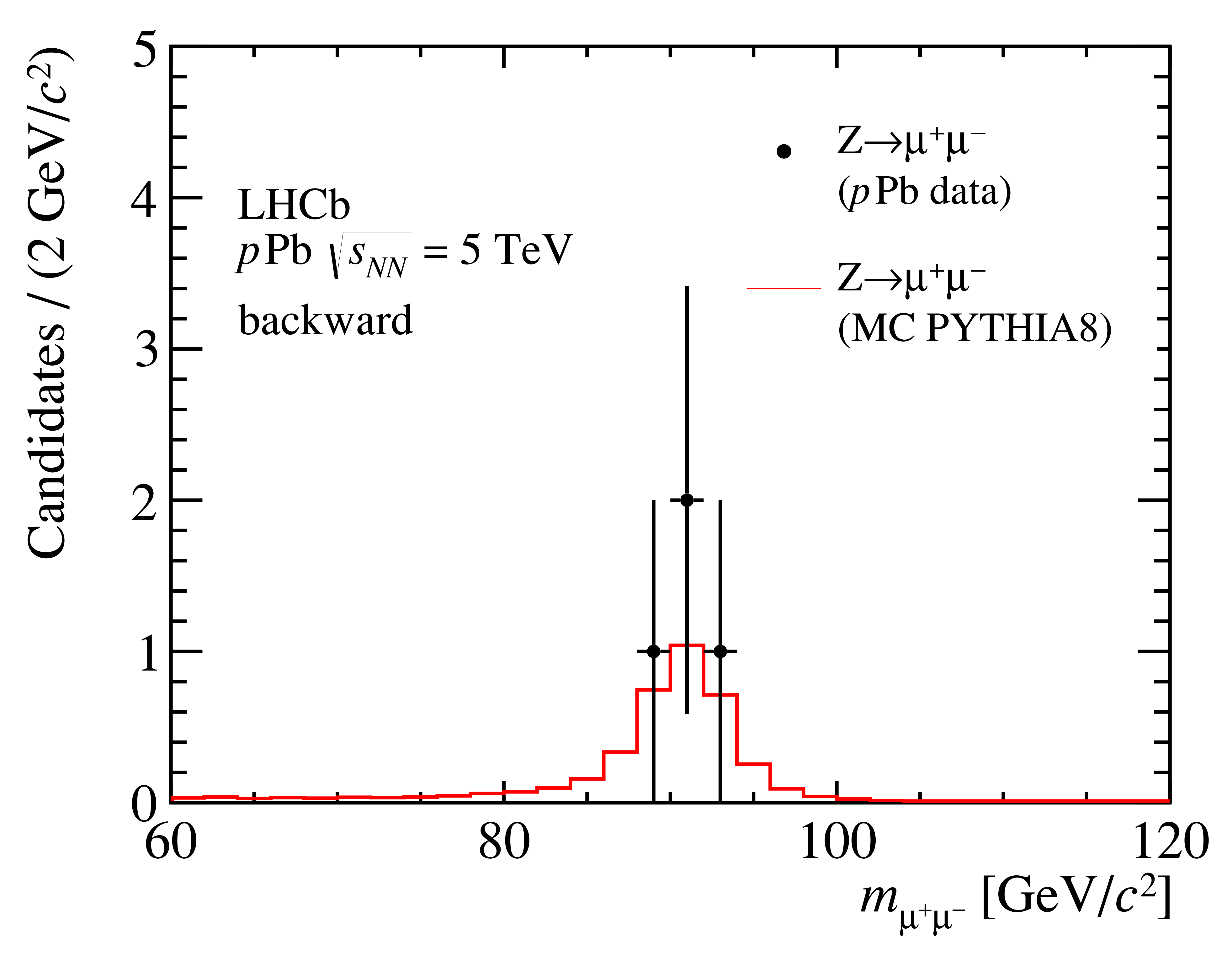
  - Purity ρ (signal fraction) is measured using same-sign muon pair and ABCD-method
  - Efficiencies are estimated using MC and tag-and-probe data-driven corrections

Z boson production in pPb at 5 TeV

- Integrated luminosity: forward (1.099 ± 0.021 nb^{-1}) / backward(0.521 ± 0.011 nb^{-1})
- Yields: forward (11 events) / backward (4 events)

【JHEP09(2014)030】





Z boson production in pPb at 5 TeV

- Fiducial cross-section results:
  - Forward:

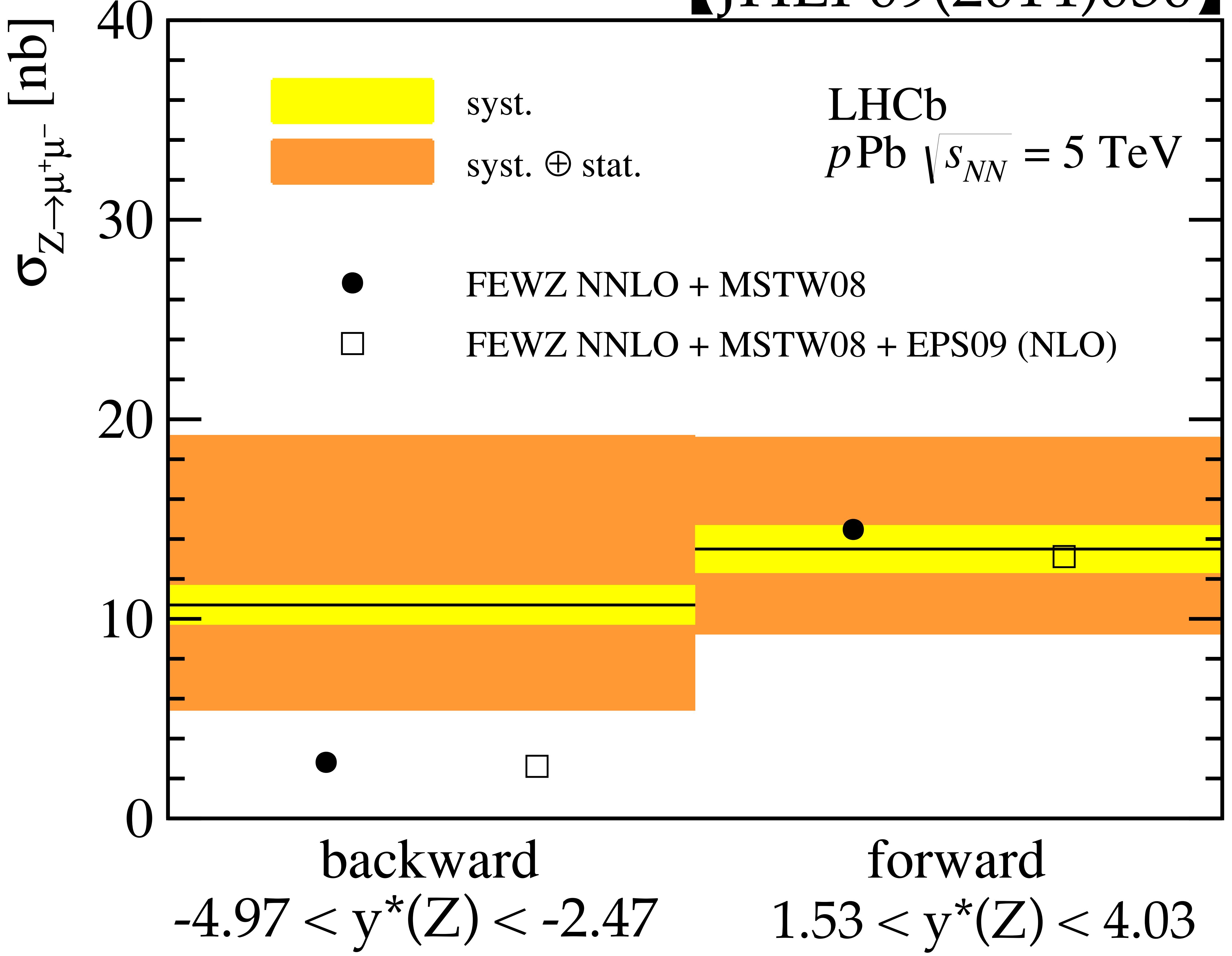
$$\sigma_{Z\to\mu^+\mu^-}(\text{fwd}) = 13.5^{+5.4}_{-4.0}(\text{stat.}) \pm 1.2(\text{syst.})\ \text{nb}$$

  - Backward:

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

- Compatible with theoretical predictions using FEWZ(NNLO pQCD+NLO pEW) with:
  - MSTW08(PDF) for both p and Pb
  - MSTW08(PDF) for p and EPS09(nPDF) for Pb

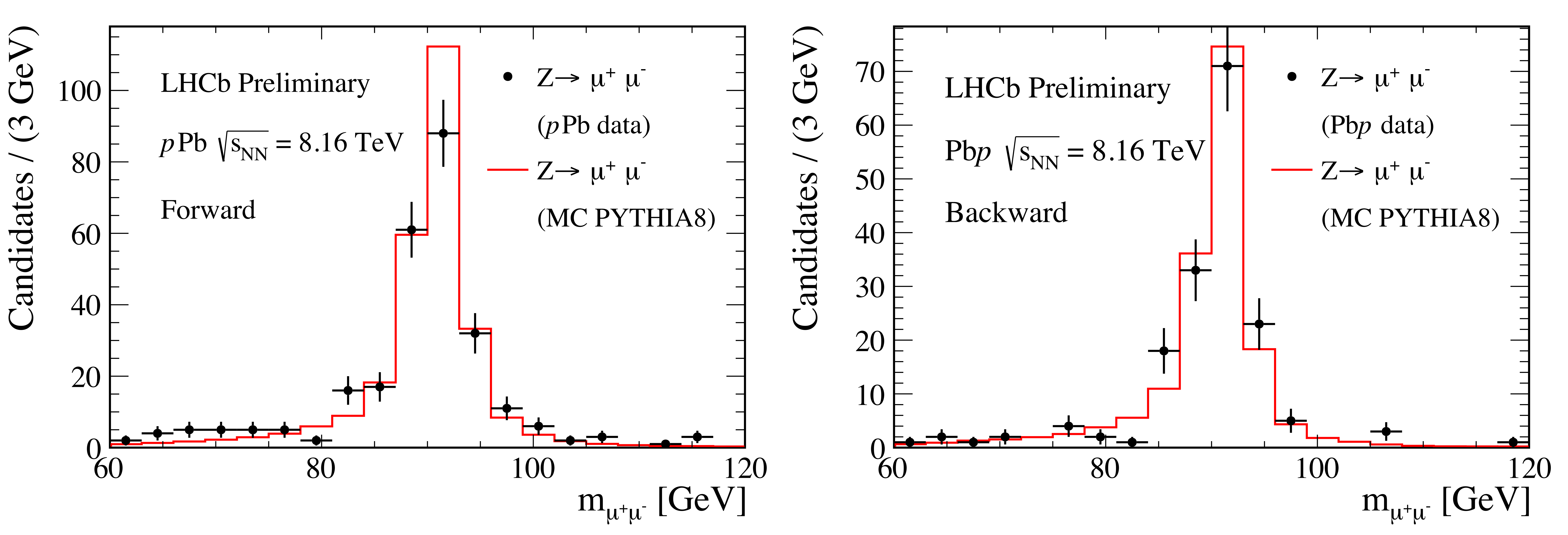
【JHEP09(2014)030】



Z boson production in pPb at 8 TeV

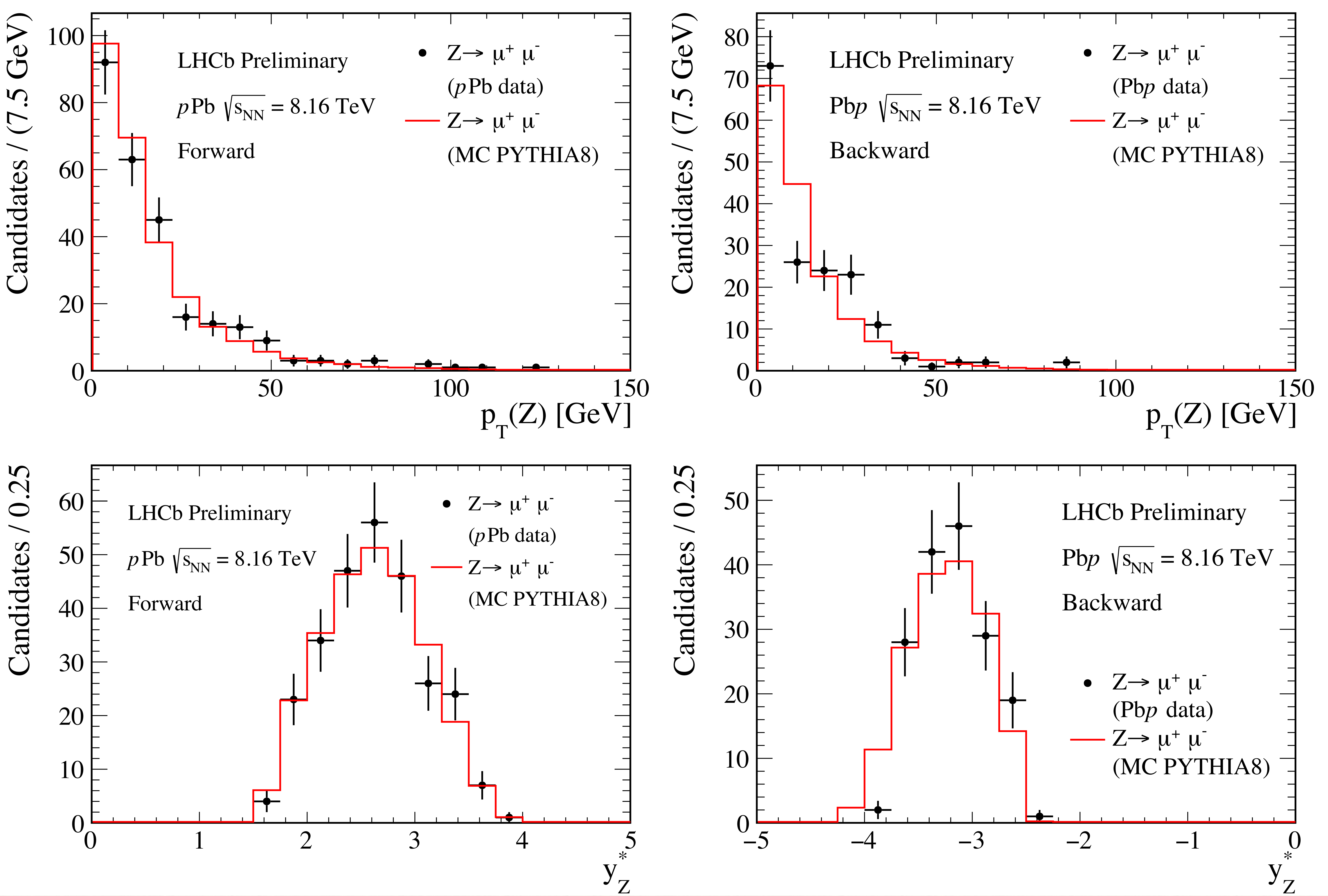
- Integrated luminosity: forward (12.2 ± 0.3 nb^{-1})   / backward(18.6 ± 0.5 nb^{-1})
- Yields: forward (268 events) / backward (167 events)

【LHCb-CONF-2019-003】



pPb Z boson production at 8 TeV

- Integrated luminosity:
  forward (12.2 ± 0.3 nb^{-1})
  backward(18.6 ± 0.5 nb^{-1})
- Yields:
  forward (268 events)
  backward (167 events)
- MC normalized to data yields



【LHCb-CONF-2019-003】

pPb Z boson production at 8 TeV

- Fiducial cross-section results:

  $\sigma_{Z\to\mu^+\mu^-,\ p\mathrm{Pb}}$ (forward)

  $= 28.5 \pm 1.7(\mathrm{stat.}) \pm 1.2(\mathrm{syst.}) \pm 0.7(\mathrm{lumi.})\ \mathrm{nb}$

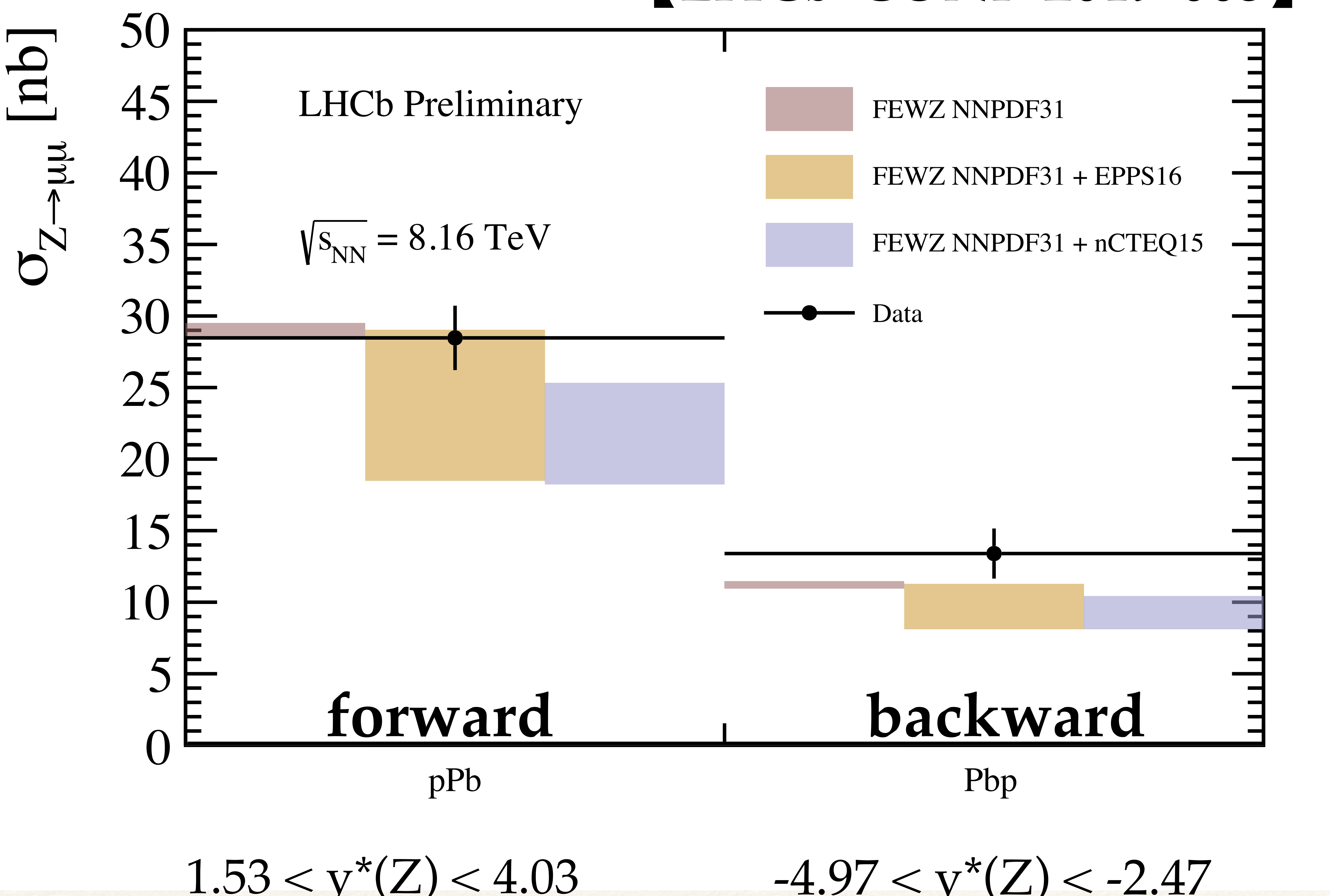
  $\sigma_{Z\to\mu^+\mu^-,\ \mathrm{Pb}p}$ (backward)

  $= 13.4 \pm 1.0(\mathrm{stat.}) \pm 1.4(\mathrm{syst.}) \pm 0.3(\mathrm{lumi.})\ \mathrm{nb}$

- Much higher precision
- Compatible with theoretical predictions using FEWZ(NNLO pQCD+NLO pEW) with NNPDF3.1(PDF) for p and
  - NNPDF3.1(PDF)
  - EPPS16 (nPDF)
  - nCTEQ15 (nPDF)

  } for Pb

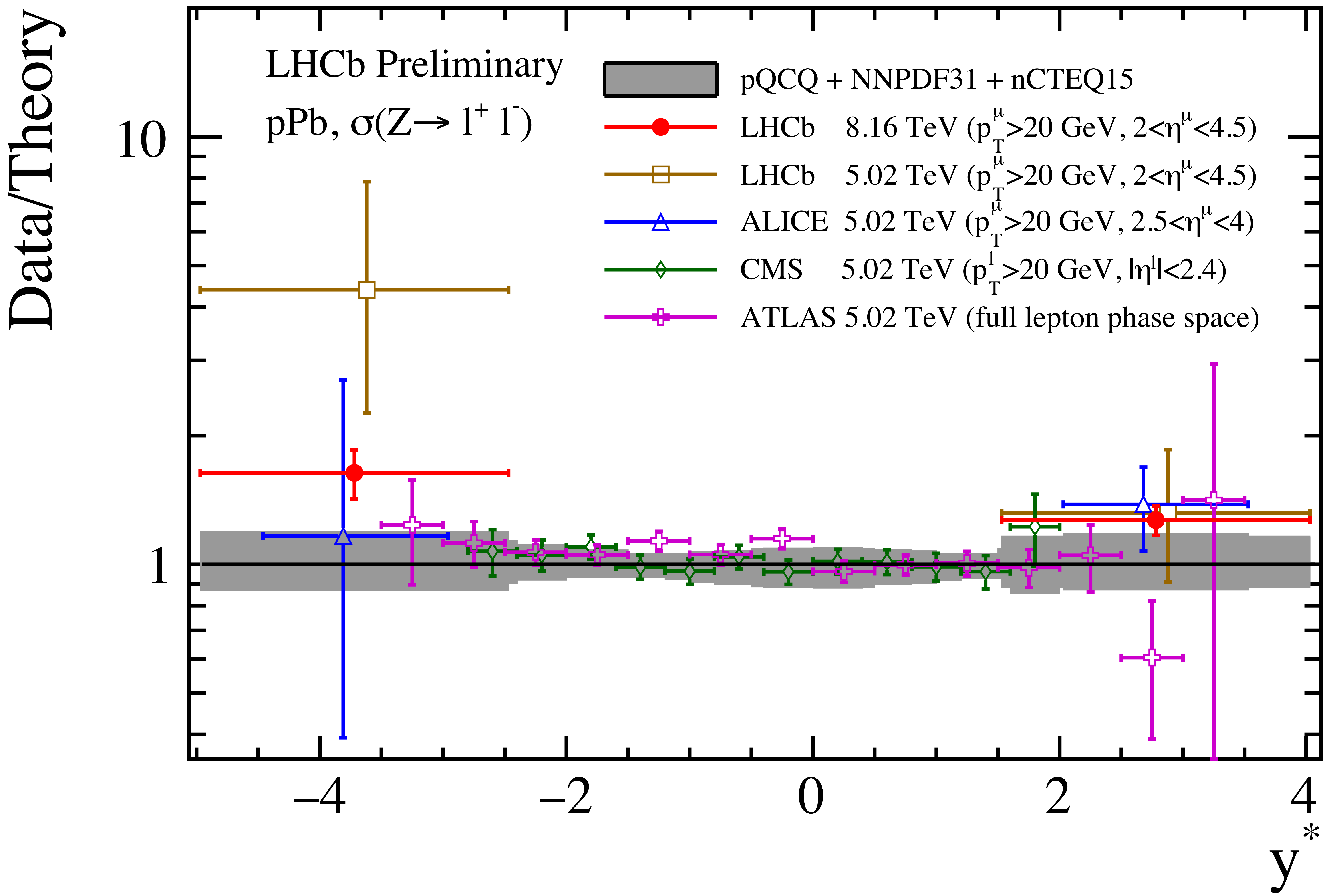
【LHCb-CONF-2019-003】



Compare with results at 5 TeV

- Results are compatible with previous 5 TeV results from various experiments
- The 20 times higher statistics bring higher precision in the measurements

【LHCb-CONF-2019-003】



* only exp. uncert. shown on data/theory ratio, theo. PDF uncert. shown separately on the line at one.

Forward-backward ratio

【LHCb-CONF-2019-003】

- Forward-backward ratio is derived based on cross-sections measured in the common rapidity range:

$$\sigma^{2.5<|y^*|<4.0}_{Z\to\mu^+\mu^-,\ p\text{Pb}} = 17.1 \pm 1.4(\text{stat.}) \pm 0.7(\text{syst.}) \pm 0.4(\text{lumi.})\ \text{nb},$$
$$\sigma^{2.5<|y^*|<4.0}_{Z\to\mu^+\mu^-,\ \text{Pb}p} = 13.3 \pm 1.0(\text{stat.}) \pm 1.4(\text{syst.}) \pm 0.3(\text{lumi.})\ \text{nb},$$

- Measured forward-backward ratio

$$R^{2.5<|y^*|<4.0}_{\text{FB}} = 1.28 \pm 0.14(\text{stat.}) \pm 0.14(\text{syst.}) \pm 0.05(\text{lumi.}).$$

- Compatible with theoretical predictions:

$$R^{2.5<|y^*|<4.0}_{\text{FB,NNPDF3.1}} = 1.59 \pm 0.10(\text{theo.}) \pm 0.01(\text{num.}) \pm 0.05(\text{PDF}),$$
$$R^{2.5<|y^*|<4.0}_{\text{FB,NNPDF3.1+EPPS16}} = 1.45 \pm 0.10(\text{theo.}) \pm 0.01(\text{num.}) \pm 0.27(\text{PDF}),$$
$$R^{2.5<|y^*|<4.0}_{\text{FB,NNPDF3.1+nCTEQ15}} = 1.44 \pm 0.10(\text{theo.}) \pm 0.01(\text{num.}) \pm 0.20(\text{PDF}).$$

Conclusion

- The LHCb detector is the only dedicated forward detector.
  - Capabilities can also be applied to relativistic heavy ion collisions.
- Recent results from LHCb on Z boson production have been discussed
  - Currently the most precise results at forward rapidity region
- Rich EW probe program is on going at LHCb:
  - W, Z, and low mass DY at pPb and PbPb collisions

	2013 pPb 1.6 nb^{-1}	2016 pPb 35 nb^{-1}	2015 PbPb 10 μb^{-1}	2018 PbPb 210 μb^{-1}
Z	**published**	**conf note->paper**	to be studied	to be studied
W		to be studied	to be studied	to be studied
D-Y		to be studied	to be studied	to be studied