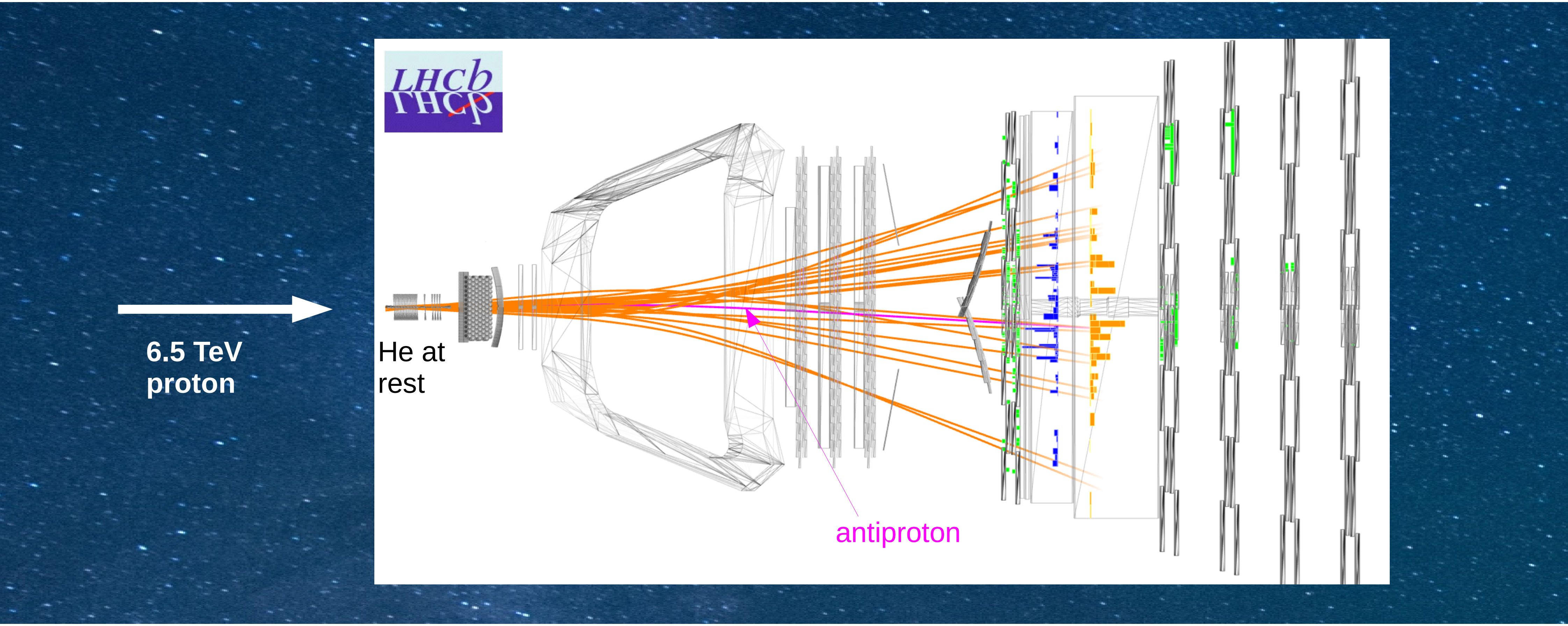
Measurement of antiproton production in p-He collisions at LHCb to constrain the secondary cosmic antiproton flux



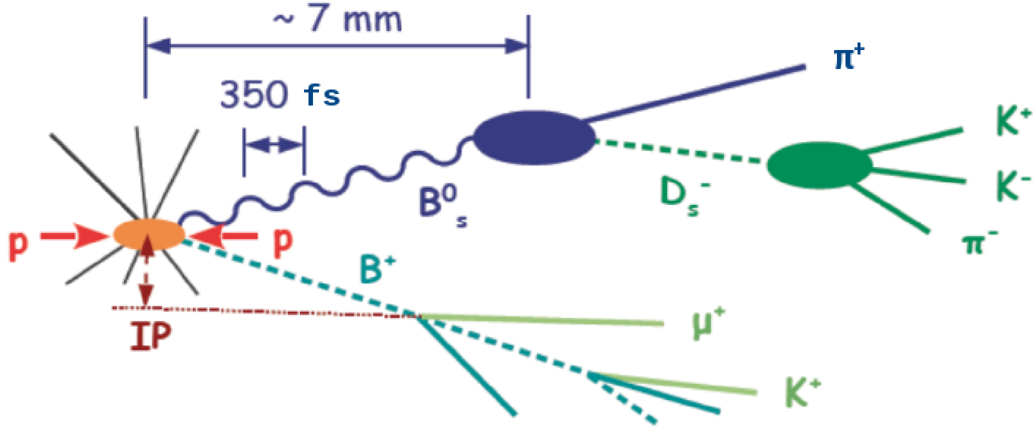
Giacomo Graziani (INFN Firenze)
on behalf of the LHCb Collaboration

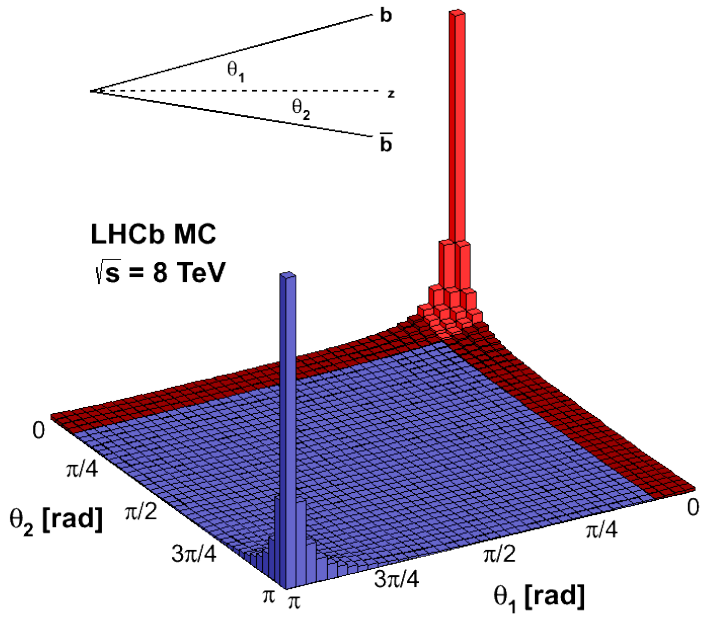
STARS2017, La Habana, Cuba   May 7, 2017

The LHCb Experiment

LHCb is the experiment devoted to heavy flavours at the LHC

- Focused on CP violation and rare signatures in b and c decays
- Exploiting LHC as the biggest b and c factory on earth





Detector requirements:

Forward geometry optimize acceptance for $b\bar{b}$ pairs

Tracking : best possible proper time and momentum resolution

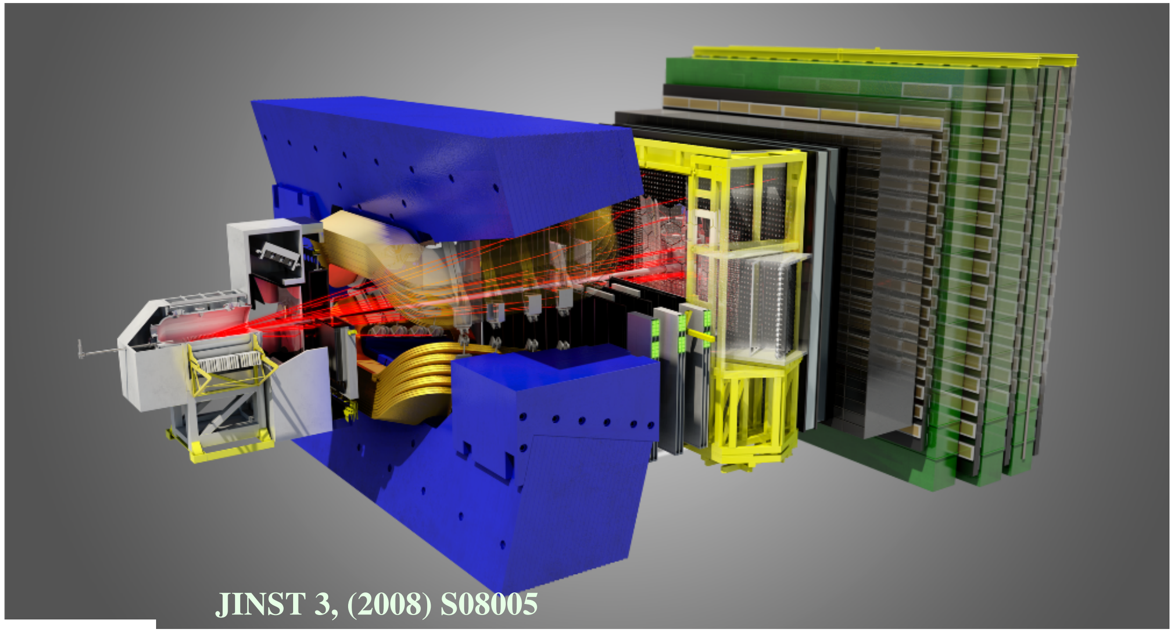
Particle ID : excellent capabilities to select exclusive decays

Trigger : high flexibility and bandwidth (up to 15 kHz to disk)

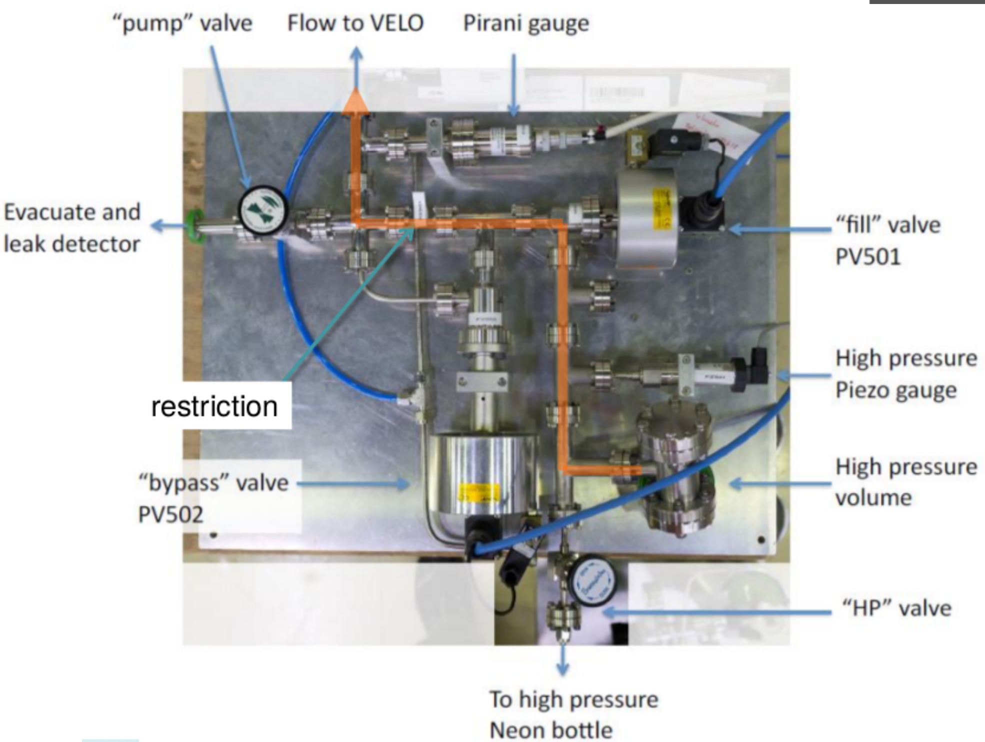
➡ allowed to widen our physics program to include hadron spectroscopy, EW physics, kaon physics, **heavy ion physics (pPb and PbPb collisions)** . . .

SMOG: the LHCb internal gas target

- LHCb is the LHC experiment with "fixed-target like" geometry
- very well suited for…fixed target physics!



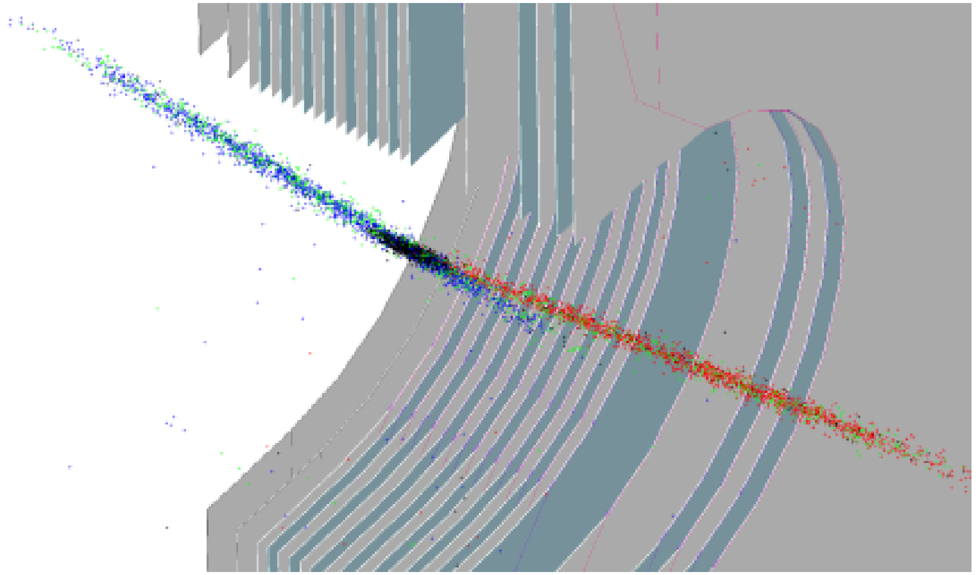
Int.J.Mod.Phys.A30 (2015) 1530022



- The System for Measuring Overlap with Gas (SMOG) allows to inject small amount of noble gas (He, Ne, Ar, …) inside the LHC beam around ($\sim \pm 20$ m) the LHCb collision region

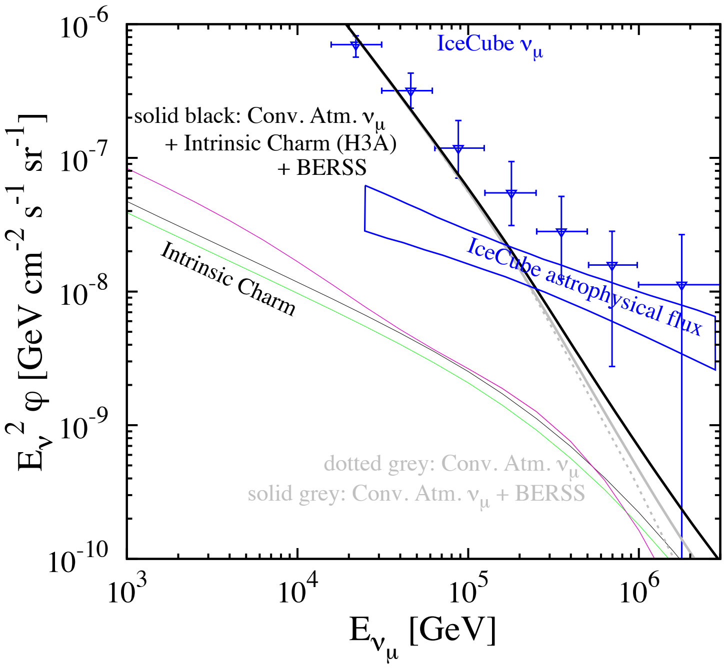
  Expected pressure $\sim 2 \times 10^{-7}$ mbar

SMOG applications



- Originally conceived for the luminosity determination with beam gas imaging
  JINST 9, (2014) P12005
  allows the most precise luminosity determination (1.2%) among the LHC experiments

- Became the LHCb internal gas target for a rich and varied fixed target physics program:
  - pA interactions @ 100 GeV scale: exploring cold nuclear matter (CNM) effects in **heavy flavour production**
    Bridging the gap between SPS and RHIC/LHC energy scales!
  - probing large-x nPDF (intrinsic charm): also relevant for neutrino astronomy
  - soft QCD: relevant for modeling of cosmic ray showers in the atmosphere and in cosmos



Laha and Brodsky, arXiv:1607.08240

Charm in p-Ar collisions @ 110 GeV

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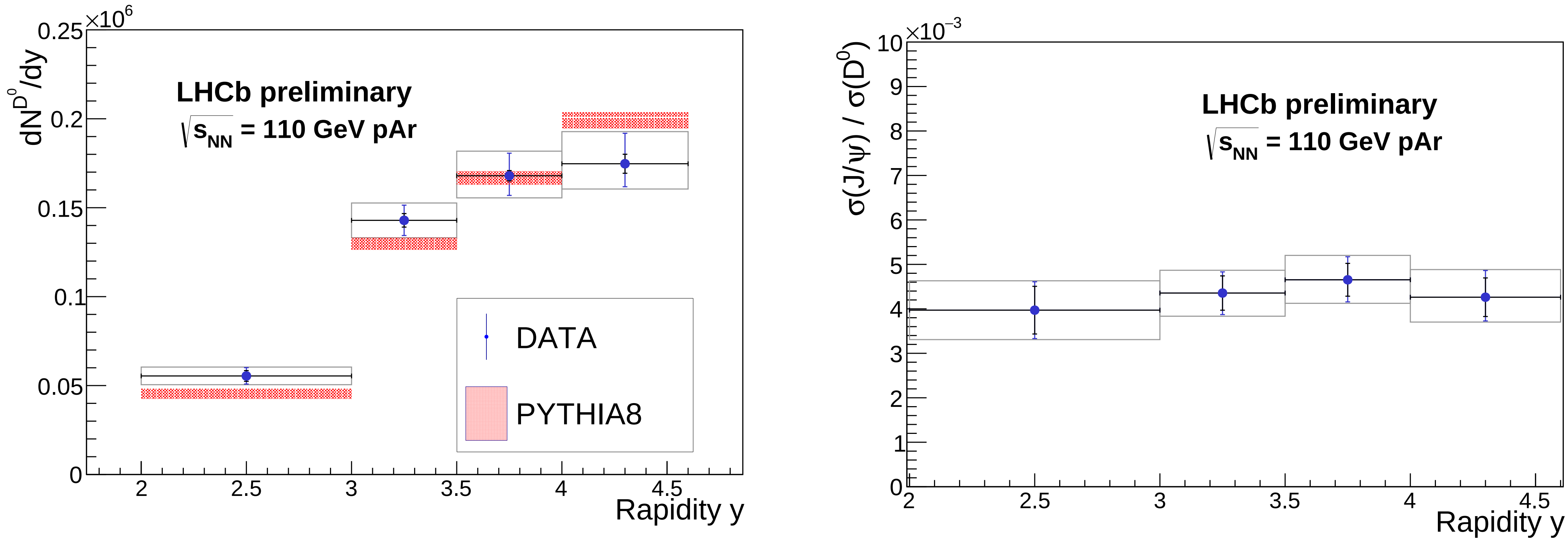
D^0 yield and J/ψ / D^0 ratio vs pseudorapidity

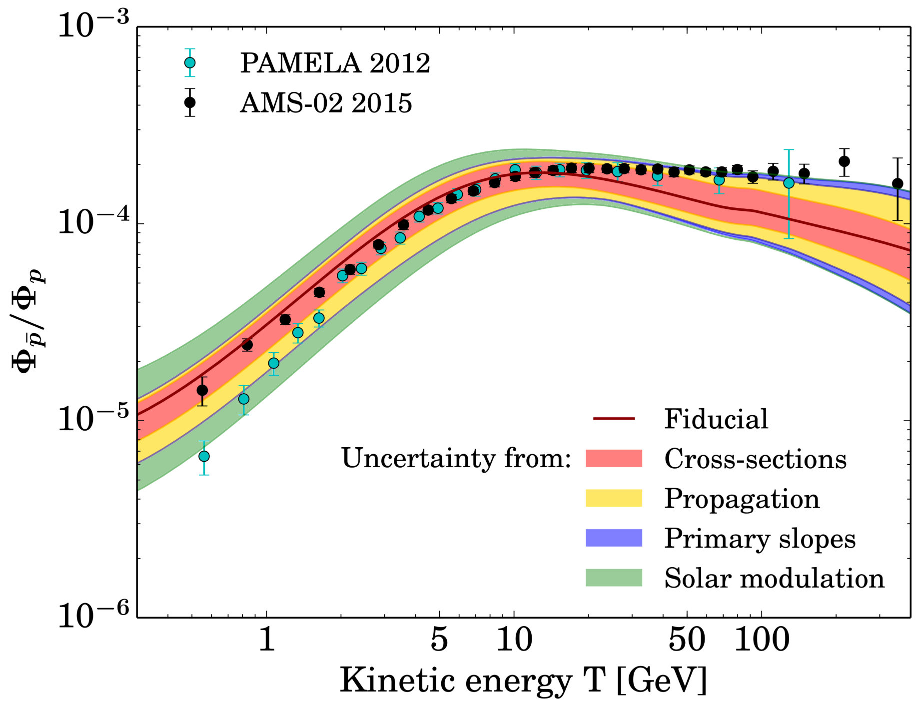


- First result from the LHCb fixed target program, presented at the last Quark Matter conference
- Obtained from the first small (few nb^{-1}) p-Ar data sample
- Result limited by statistics, but demonstrates the physics potential
- Differential shapes can already constrain high-x PDFs

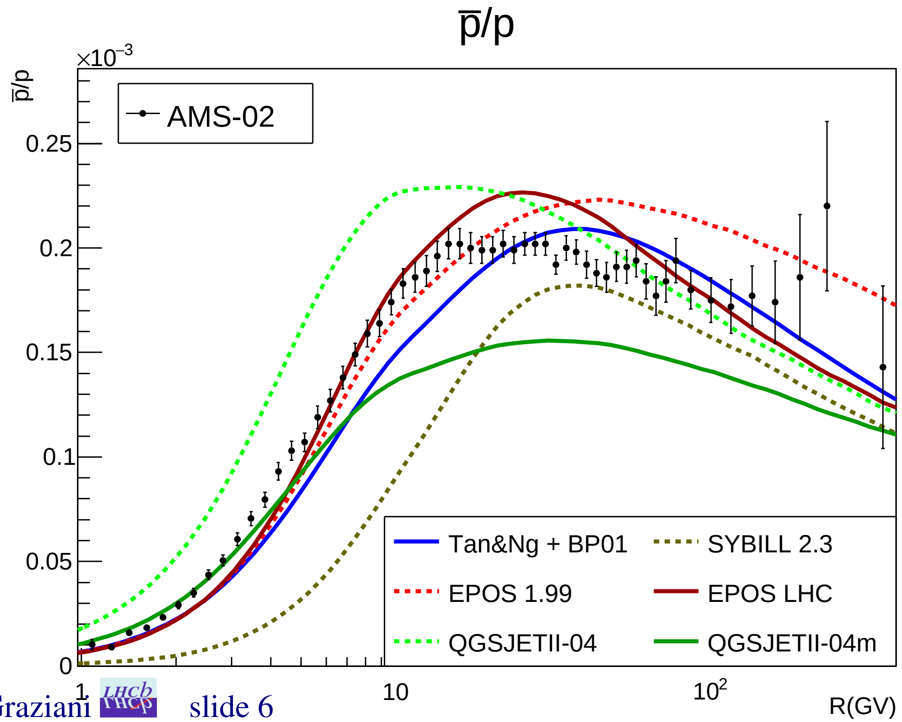
Cosmic antiprotons

- The recent AMS-02 results provide unprecedented accuracy for measurement of $\bar{p}/p$ ratio in cosmic rays at high energies **PRL 117, 091103 (2016)**
- hint for a possible excess, and milder energy dependence than expected
- prediction for $\bar{p}/p$ ratio from spallation of primary cosmic rays on intestellar medium (H and He) is **presently limited by uncertainties on $\bar{p}$ production cross-sections, particularly for p-He**

Giesen et al., JCAP 1509, 023 (2015)



Lin et al., arXiv:1612.04001



- no previous measurement of $\bar{p}$ production in p-He, predictions from soft QCD models vary within a factor 2
- the LHC energy scale and LHCb +SMOG are very well suited to perform this measurement

The p-He run

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- Data collected in May 2016, with proton energy 6.5 TeV, $\sqrt{s_{\mathrm{NN}}} = 110$ GeV
- Using fill for Van der Meer scan (parasitic data taking)
- Analysis from 9×10^{20} protons on target
- Most data from a single fill (5 hours)
- Minimum bias trigger, fully efficient on candidate events
- large control samples (random triggers) to check trigger efficiencies, deadtime, pileup
- Exploit excellent particle identification (PID) capabilities in LHCb to count antiprotons in (p, p_{T}) bins within the kinematic range

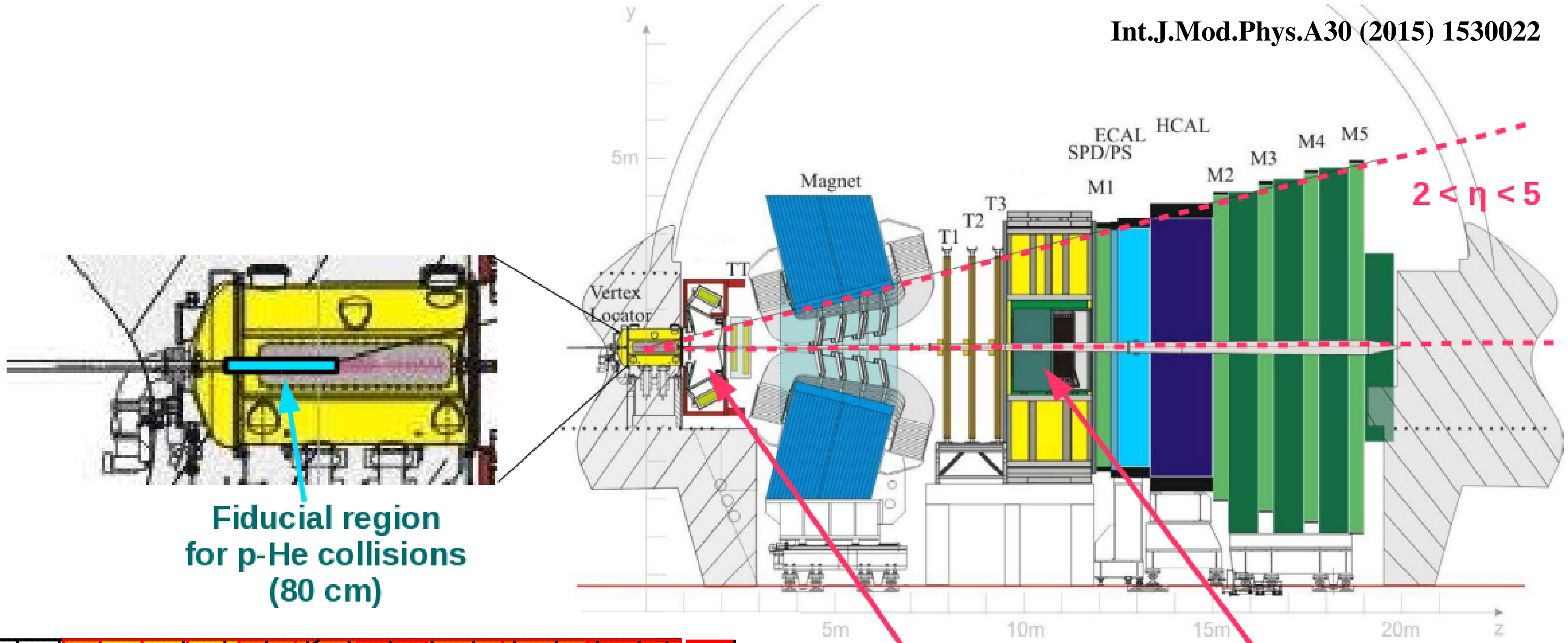
$$12 < p < 110\,\mathrm{GeV}/c$$

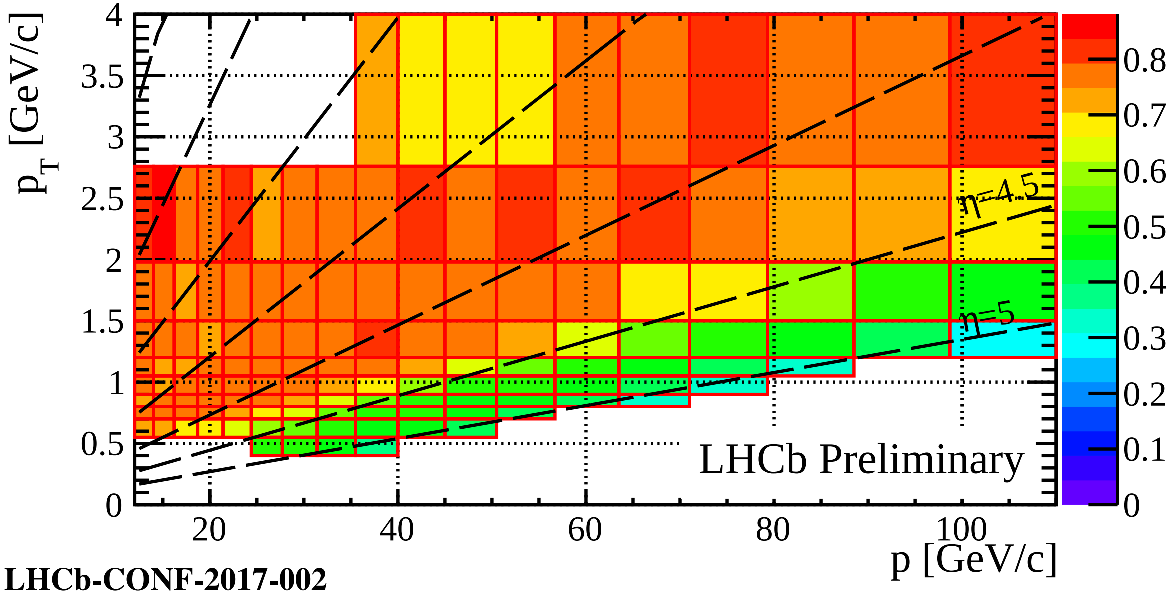
$$p_{\mathrm{T}} > 0.4\,\mathrm{GeV}/c$$

Detector and Acceptance

JINST 3, (2008) S08005

Int.J.Mod.Phys.A30 (2015) 1530022





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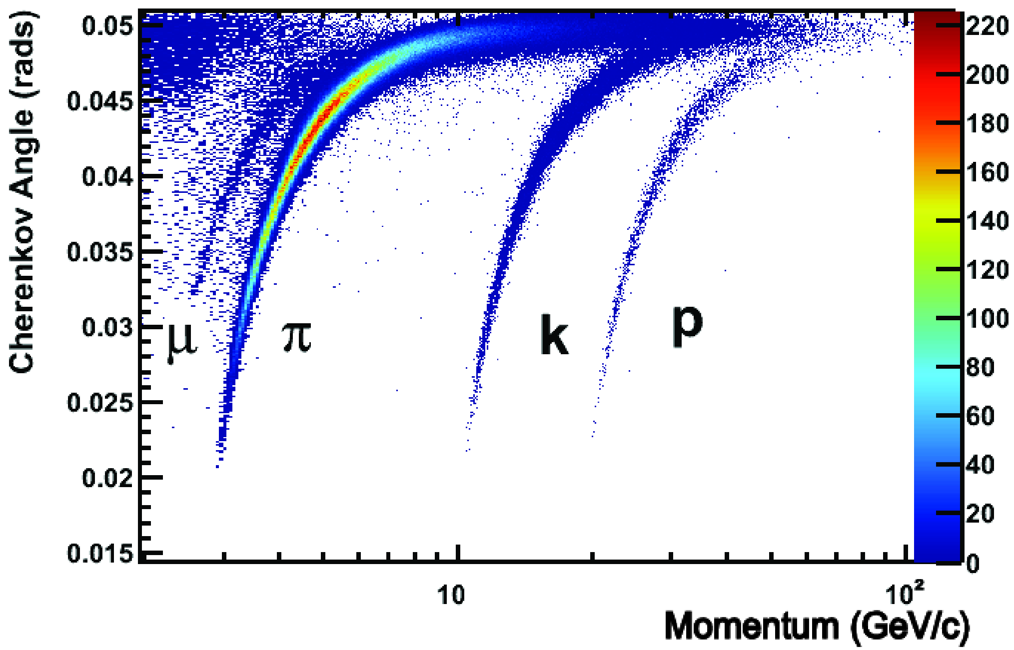
Total acceptance × reconstruction efficiency for antiprotons

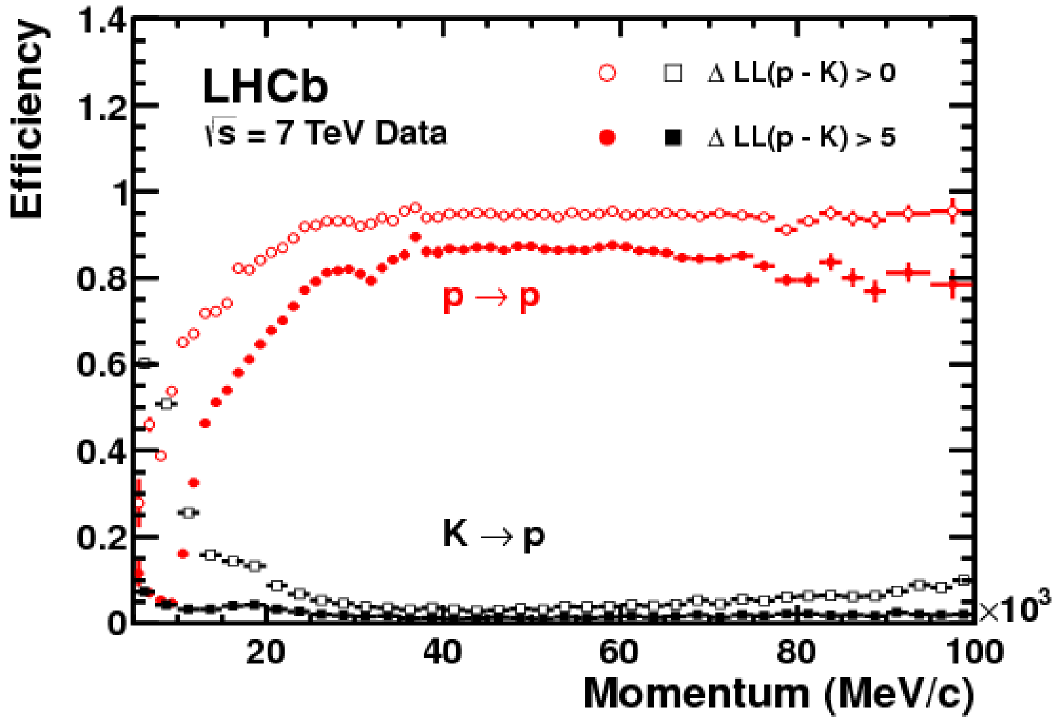
Tracking efficiency estimated from simulation, validated on (pp) data

RICH Performance

Eur. Phys. J. C 73 (2013) 2431



Particle separation in RICH1



K/p separation vs momentum

Antiproton identification strategy

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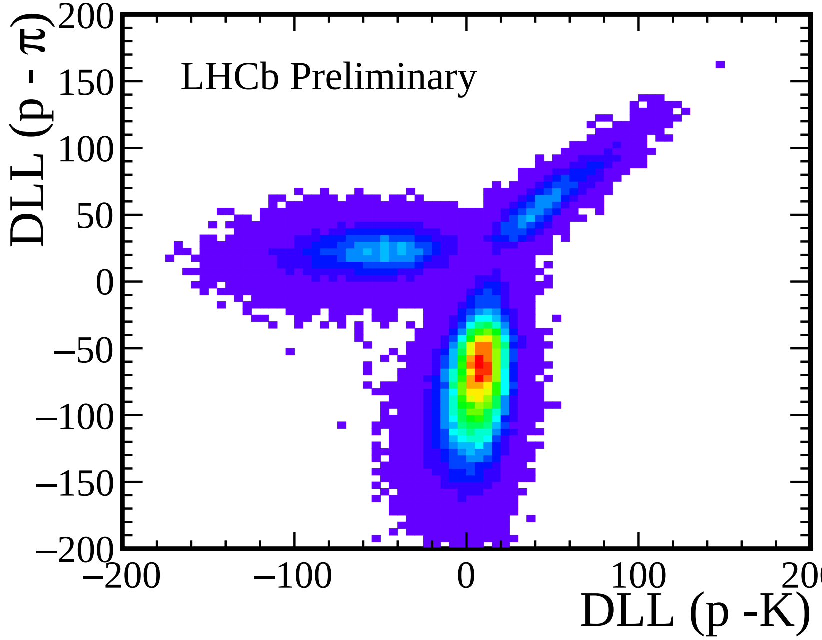
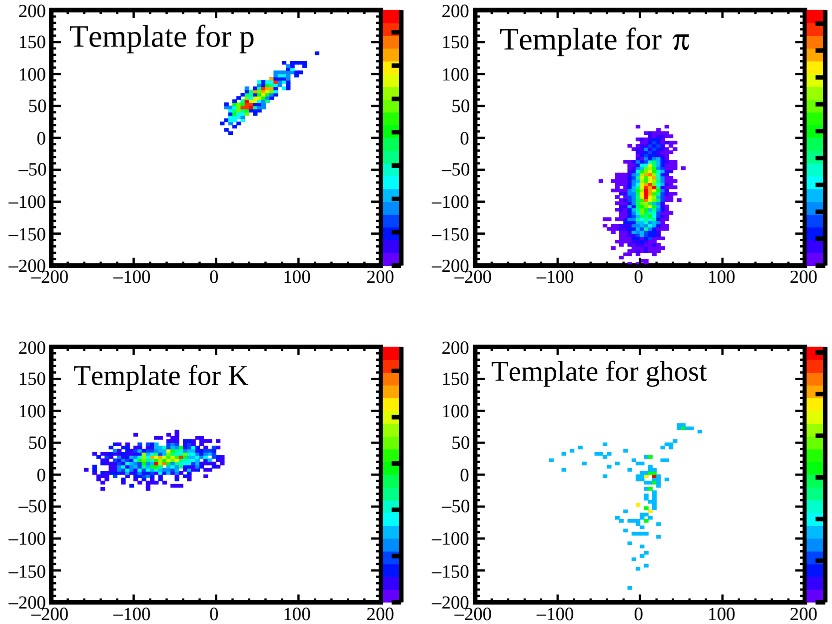
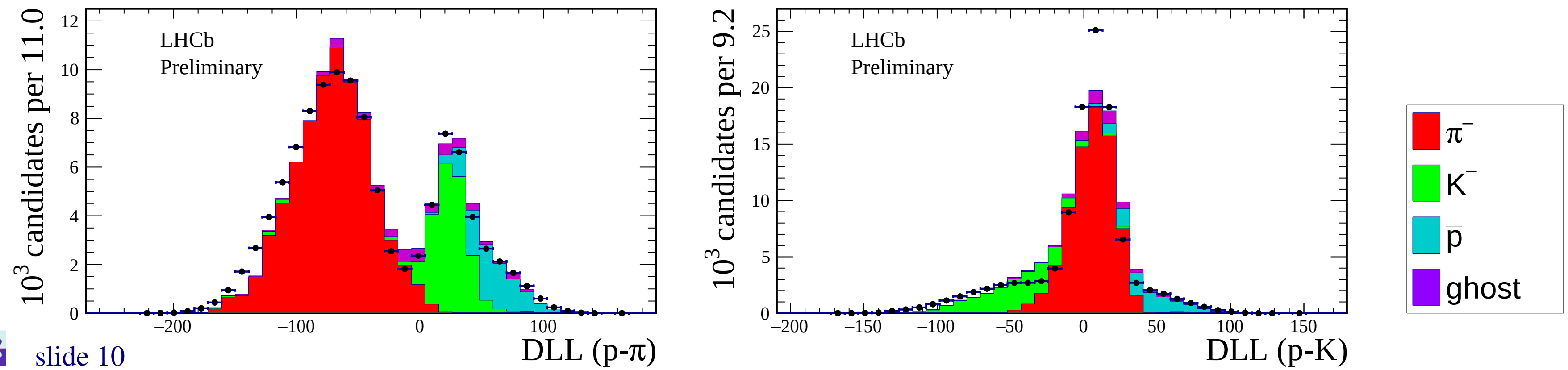
- Build likelihood function for particle hypothesis using RICH response
- Use difference of log likelihood (DLL) between $\overline{\mathrm{p}}$ and K^- and $\overline{\mathrm{p}}$ and π^-
- Fit the 2-dimensional (DLL($\mathrm{p}-\mathrm{K}$), DLL($\mathrm{p}-\pi$)) distributions using templates from calibration samples in each kinematic bin







Raw yield for antiprotons

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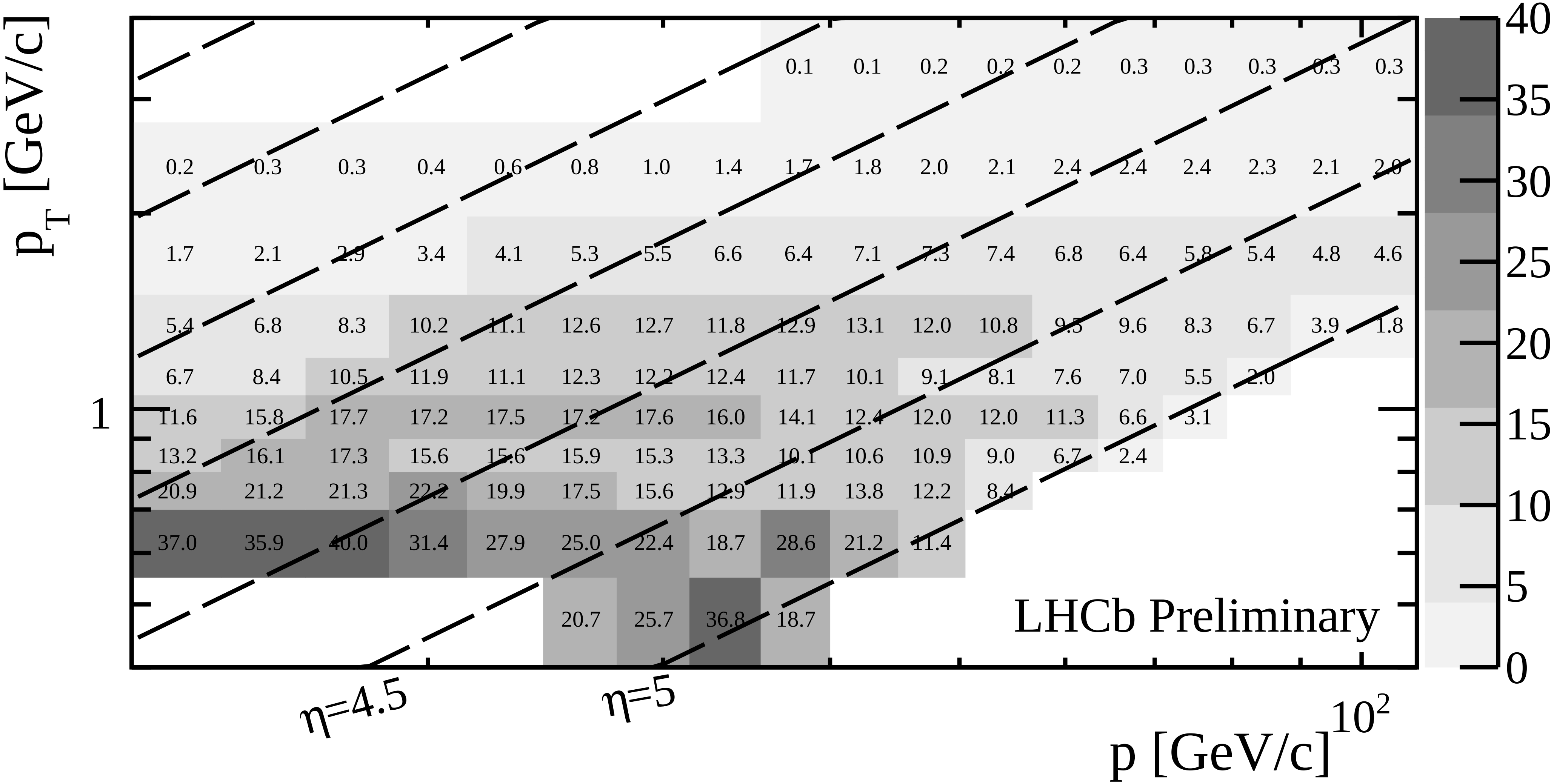
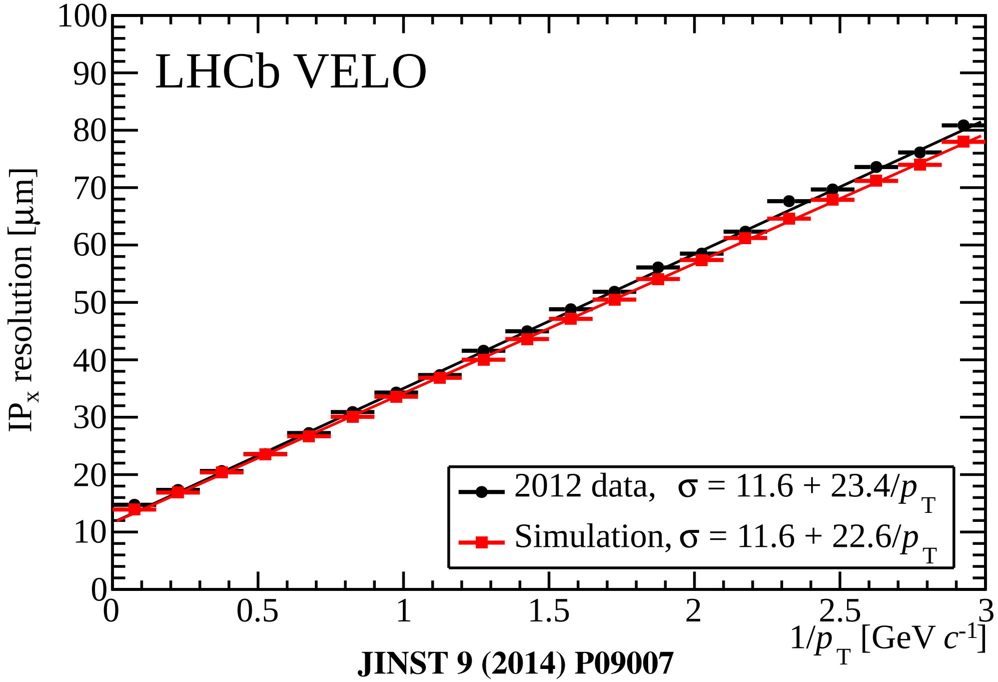
Units 10^3



Background from hyperon decays

- Current analysis limited to "prompt" component (direct production and $\overline{p}$ from strong resonance decays)
- Can be distinguished from $\overline{p}$ produced by weak decays of hyperons and secondary interactions using the excellent LHCb vertexing capabilities
- Non-prompt component is suppressed by requiring small impact parameter (IP)

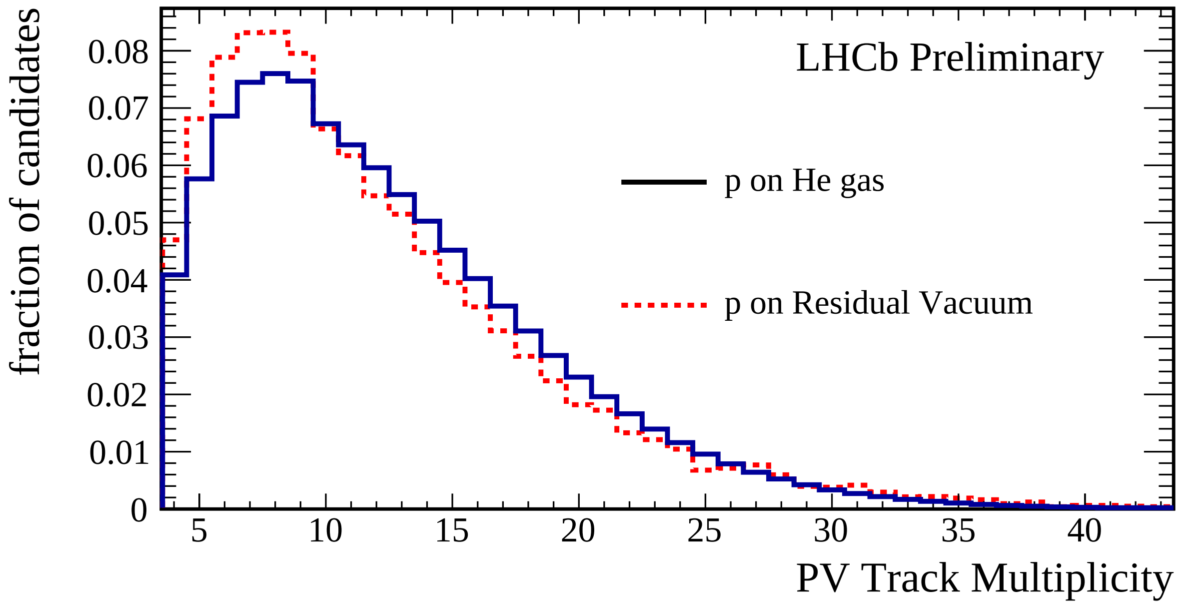


JINST 9 (2014) P09007

- Residual detached component estimated to be $(2.6 \pm 0.6)\%$ and subtracted
- Systematic uncertainty estimated from data/MC comparison of IP tails

Background from Residual Vacuum

- Residual vacuum in LHC is not so small ($\sim 10^{-9}$ mbar) compared to SMOG pressure
- Can be a concern, especially for heavy contaminants (larger cross section than He), and beam-induced local outgassing
- Direct measurement in data: about 15% of delivered protons on target acquired before He injection (but with identical vacuum pumping configuraton)



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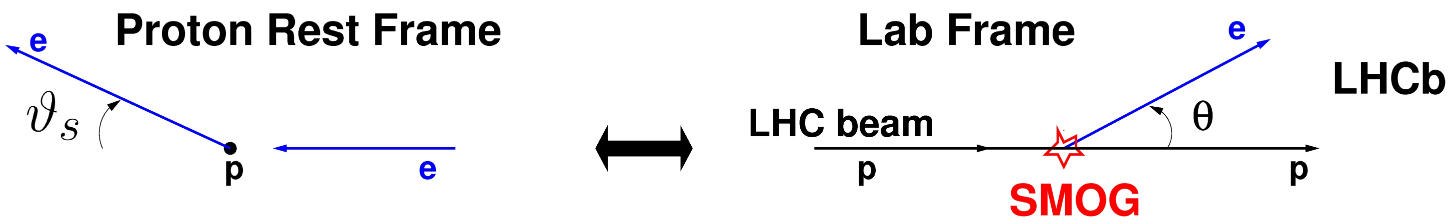
- Gas impurity found to be small: $0.6 \pm 0.2\%$
- PV multiplicity in residual vacuum events is **lower** than in He events, but has longer tails ➡ confirm findings from Rest Gas Analysis that residual vacuum is mostly H_2, with small heavy contaminants

Normalization

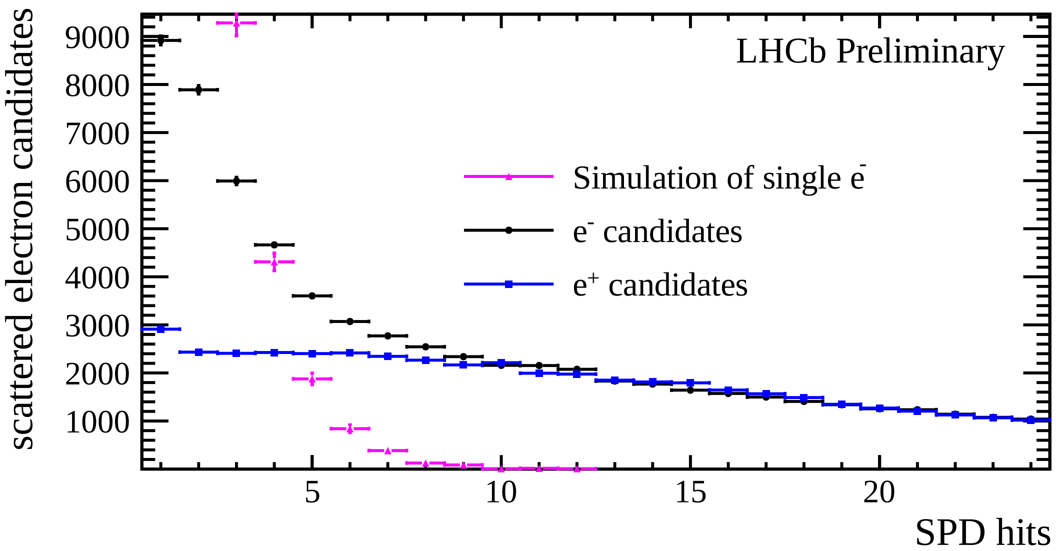


Using p-e$^-$ elastic scattering

Pro:

- LHCb sees the purely elastic regime: $\theta > 10$mrad ➡ $\vartheta_s < 29$ mrad, $Q^2 < 0.01$ GeV^2
  ➡ cross-section very well known

- distinct signature with single low-p and very low p_T electron track, and nothing else
- background events mostly expected form very soft collisions, where candidate comes from γ conversion or pion from CEP event
  ➡ **background expected to be charge symmetric**, can use "single positrons" to model it in data



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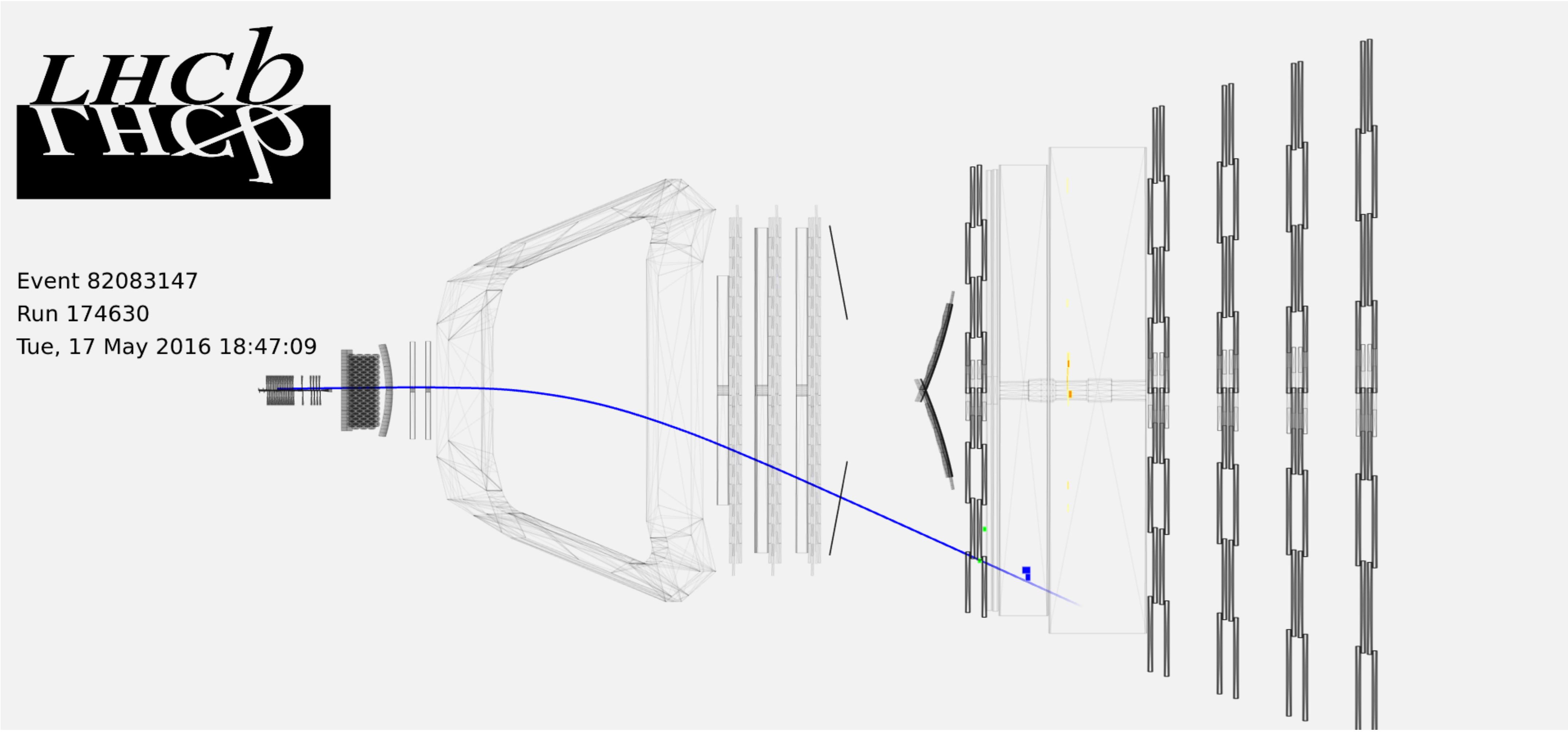
Cons:

- cross-section is small (order 100 μb, 3 orders of magnitude below hadronic cross section)
- electron has very low momentum and θ, it showers through beam pipe/detectors
  ➡ low acceptance and reconstruction efficiency

Event display of a candidate scattered electron



Electron spectra

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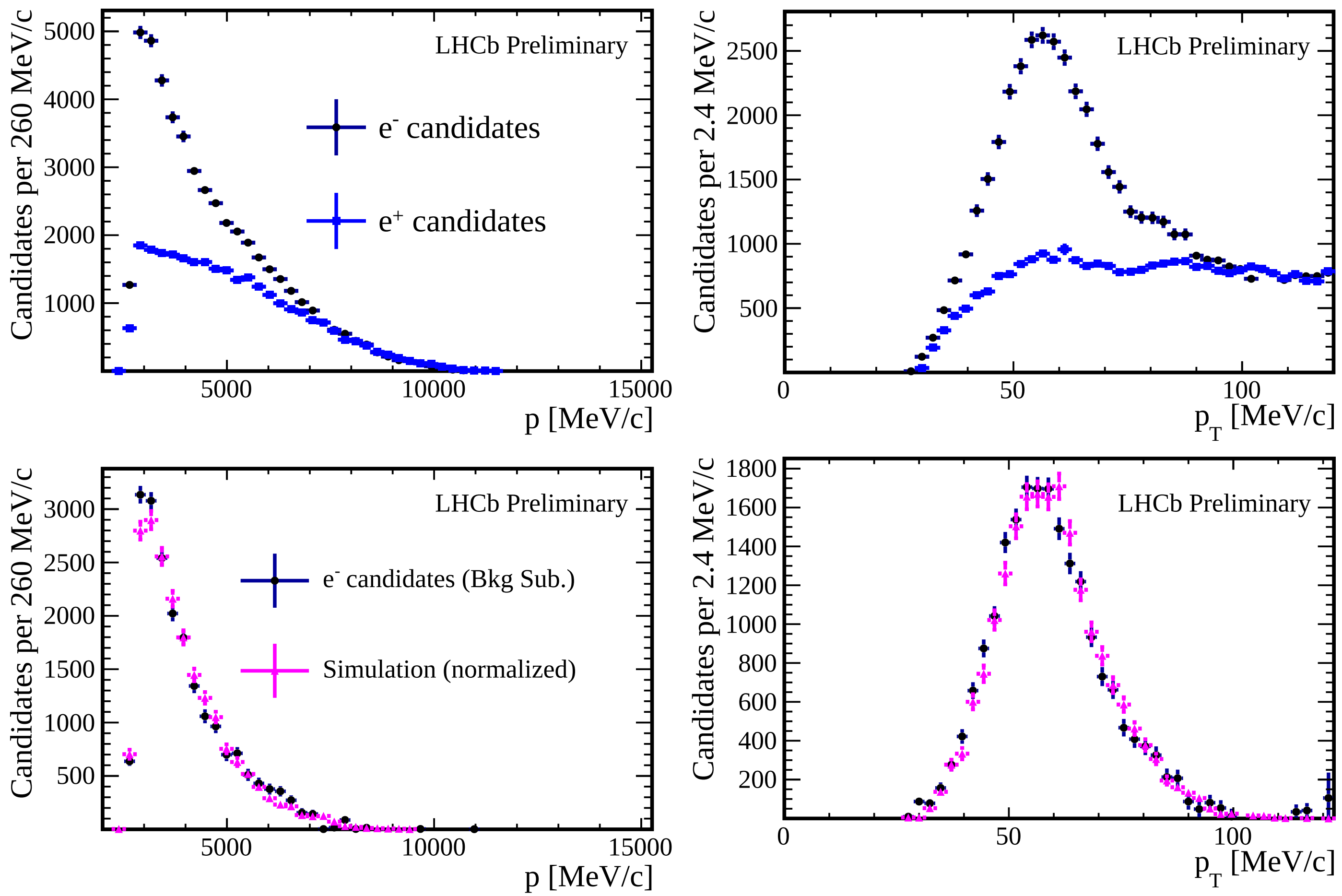

- Very good agreement with simulation of single scattered electrons
- Data confirm charge symmetry of background

$$\mathcal{L} = \mathbf{0.443 \pm 0.011 \pm 0.027}\,\mathrm{nb}^{-1}$$

- Systematic from variation of selection cuts, largest dependence is on azimuthal angle
- equivalent gas pressure is 2.4×10^{-7} mbar, in agreement with the expected level in SMOG

Result for cross section: final uncertainties (relative)

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Statistical:	
Yields in data/PID calibration	$0.7-10.8\%$ ($<3\%$ for most bins)
Normalization	2.5%
Correlated Systematic:	
Normalization	6.0%
GEC and PV cut	0.3%
PV reco	0.8%
Tracking	2.2%
Residual Vacuum Background	0.1%
Non-prompt background	$0.3-0.7\%$
PID	$1.2-5.0\%$
Uncorrelated Systematic:	
Tracking	3.2%
IP cut efficiency	1.0%
PID	$0-26\%$ ($<10\%$ for most bins)
MC statistics	$0.8-15\%$ ($<4\%$ for $p_{\mathrm{T}}<2$ GeV/c)

Total relative uncertainty per bin, in per cent

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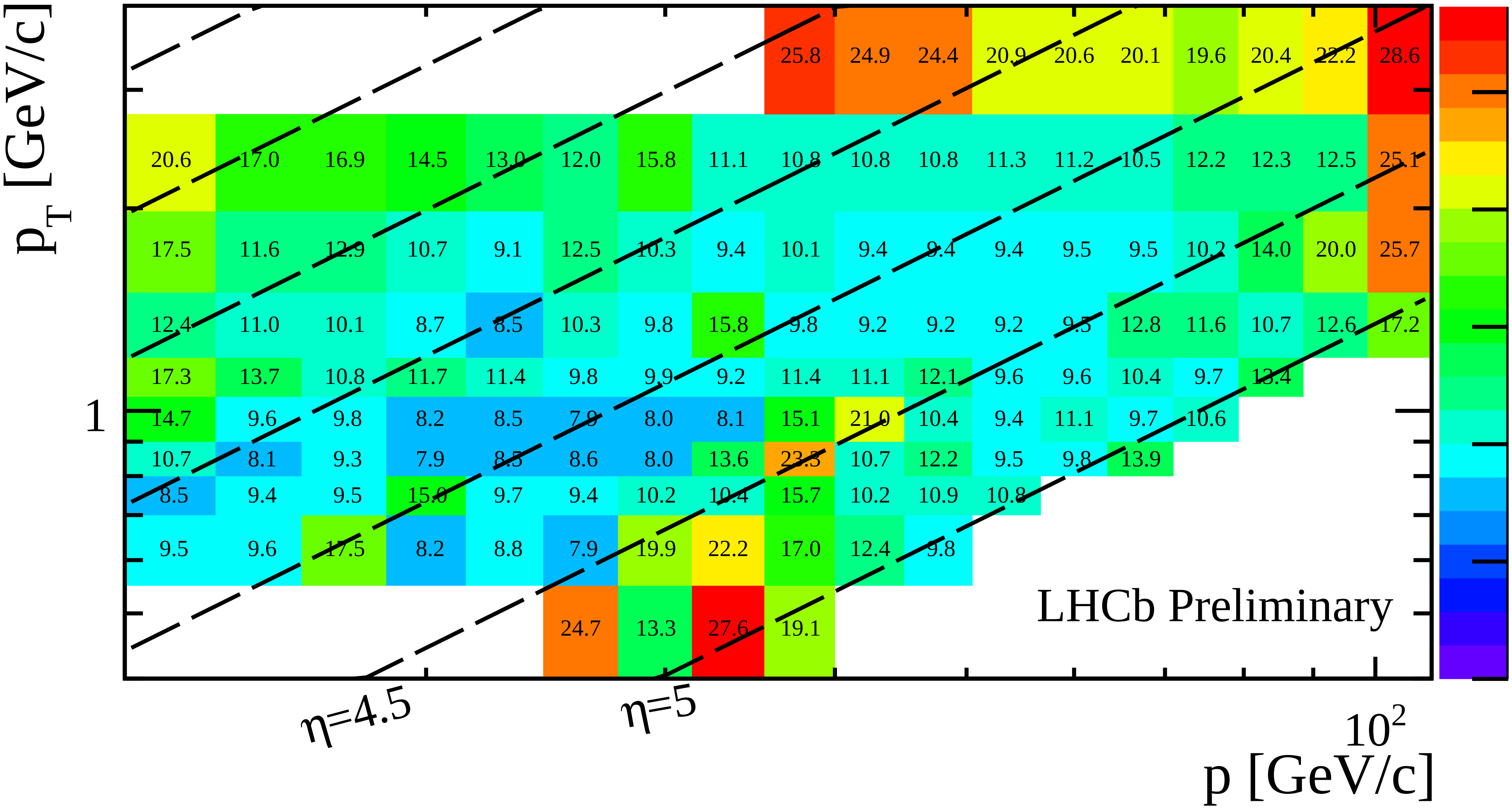

Result for cross section, compared with EPOS LHC

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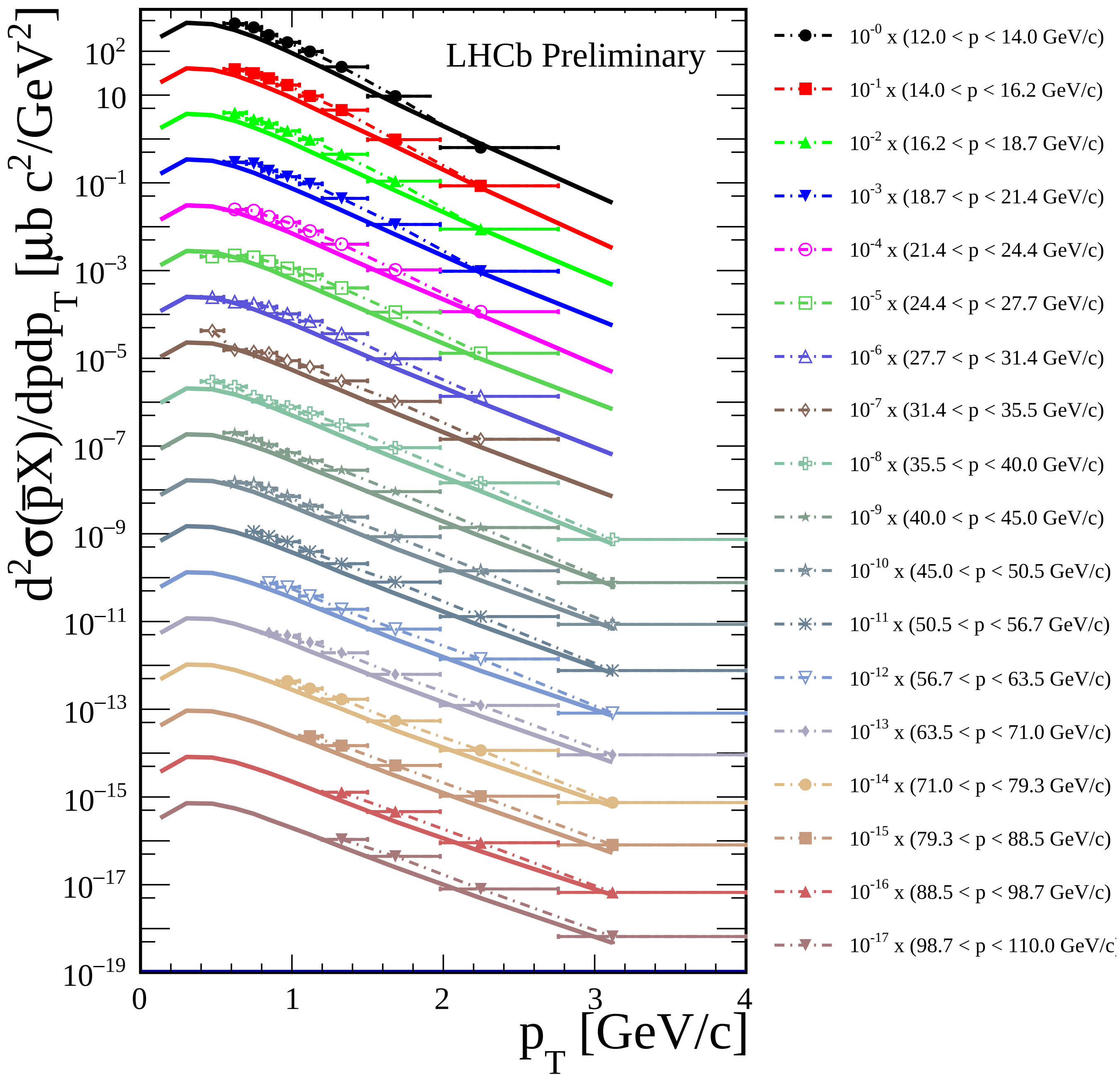

Result for **prompt** production (excluding weak decays of hyperons)

The total inelastic cross section is also measured to be

$$\sigma_{inel}^{\mathrm{LHCb}} = (140 \pm 10)\ \mathrm{mb}$$

The EPOS LHC prediction

[T. Pierog at al, Phys. Rev. C92 (2015), 034906]

is 118 mb, ratio is 1.19 ± 0.08.

Result for cross section, ratio with models

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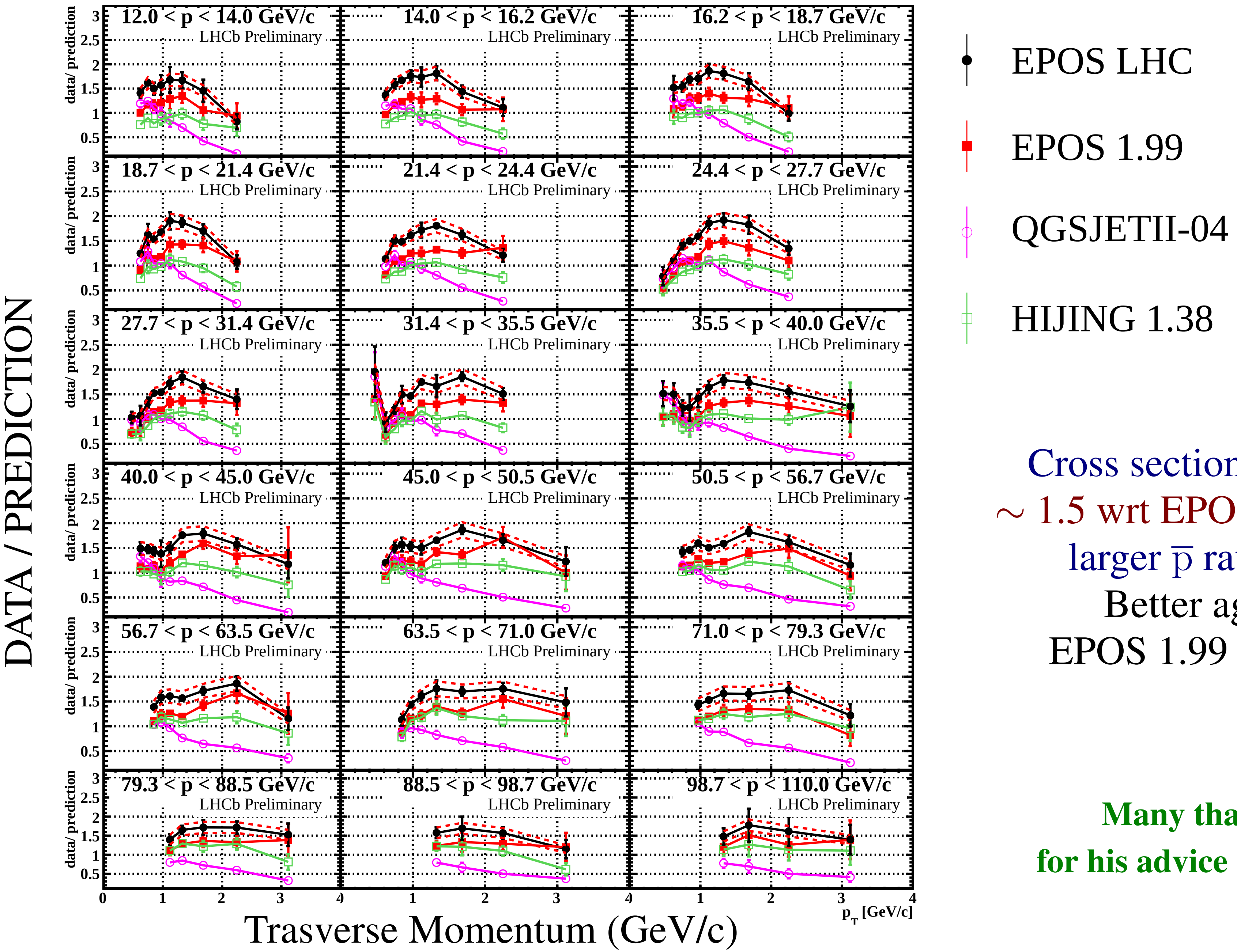

Cross section is larger by factor ~ 1.5 wrt EPOS LHC (mostly from larger $\overline{\mathrm{p}}$ rate per collision).
Better agreement with EPOS 1.99 and HIJING 1.38

Many thanks to T. Pierog for his advice with EPOS/CRMC!

Conclusions

- LHCb started its fixed target program
- becoming an unexpected contributor to cosmic ray physics!
- **Many thanks to our colleaugues in cosmic rays community, O. Adriani, L. Bonechi, F. Donato and A. Tricomi** for proposing this measurement
- The $\overline{\mathrm{p}}$ production measurement in p-He collisions is expected to narrow down significantly the uncertainty on the $\overline{\mathrm{p}}/\mathrm{p}$ prediction for cosmic rays
- **looking forward for updates of secondary $\overline{\mathrm{p}}$ calculations**

Outlook

- More to come on $\overline{\mathrm{p}}$ production:
  - dataset with beam energy of 4 TeV also collected
  - will also measure the detached (Λ decays) component
- much more to harvest from the SMOG samples: charged particle yields, particle/antiparticle ratios, positrons, gamma, charm, deuterons…
- the fixed target program will be further developed in the coming years: many possible unique measurements to better understand cold nuclear matter effects soft QCD physics

the LHCb space mission
just started!