Fixed Target Physics at LHCb

LHCb on a Space Mission

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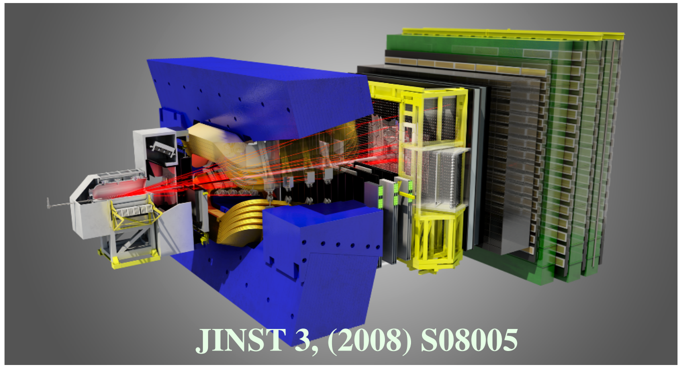
on behalf of the LHCb Collaboration

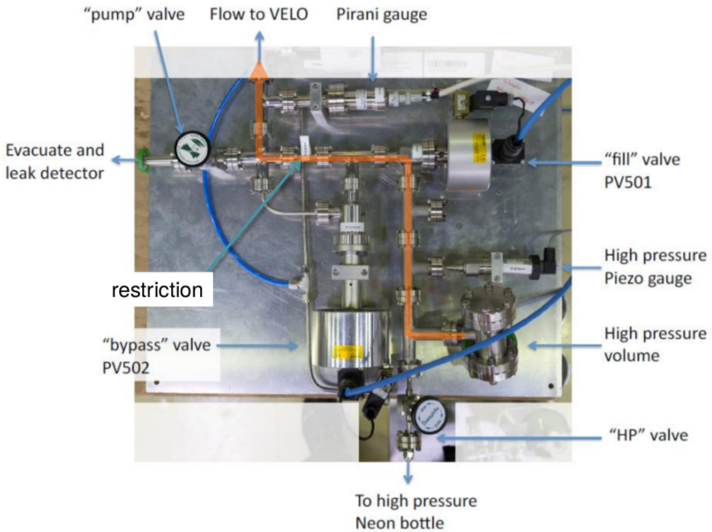
52nd Rencontres de Moriond on Electroweak Interactions and Unified Theories
La Thuile, Italy
Mar 22, 2017

SMOG: the LHCb internal gas target

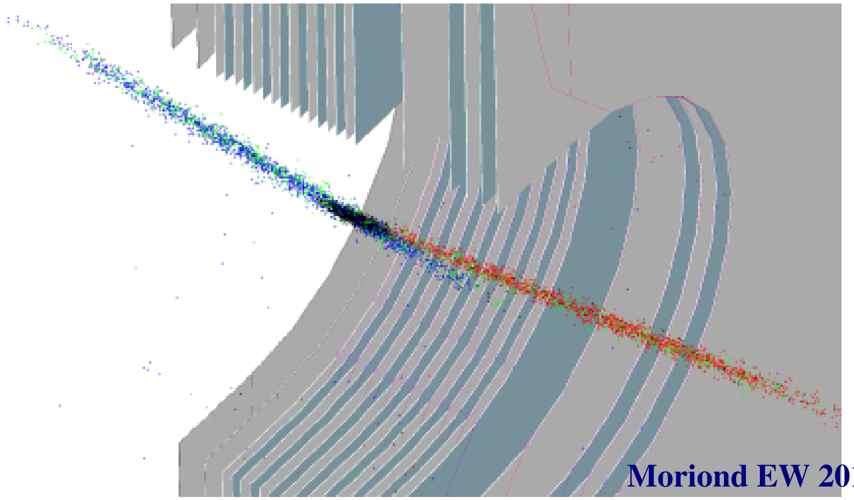
- LHCb is the LHC experiment with “fixed-target like” geometry
- very well suited for. . . fixed target physics!



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

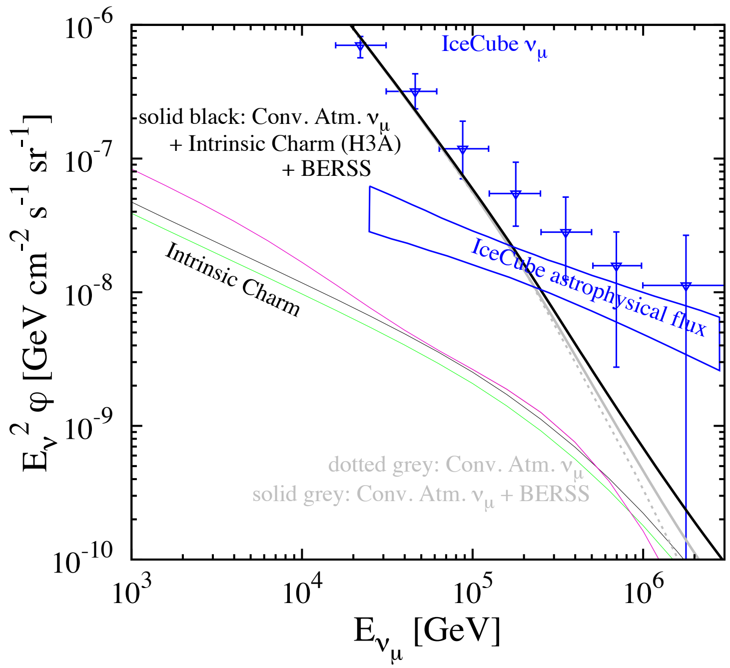


- Originally conceived for the luminosity determination with beam gas imaging **JINST 9, (2014) P12005**
- Became the LHCb internal gas target for a rich and varied fixed target physics program

Fixed target physics @ LHCb

Many things to learn from studying hadronic collisions in fixed target mode at the relatively unexplored scale of $\sqrt{s_{\rm NN}} \sim 100$ GeV:

- Nuclear effects, by changing the target atoms:
  - study Cold Nuclear Matter effects in Heavy Flavour production, to distinguish from QGP effects occurring at higher scales
- Access the large-x (target fragmentation) region, to better constrain (n)PDFs
  - possible contributions of intrinsic charm
    - important for LHC: can affect high-Q^2 processes, e.g. Higgs production
    - very important for high-energy neutrino astrophysics: background for the ICECUBE experiment is dominated by charm production in atmospheric showers



Laha and Brodsky, arXiv:1607.08240

Charm in p-Ar collisions @ 110 GeV

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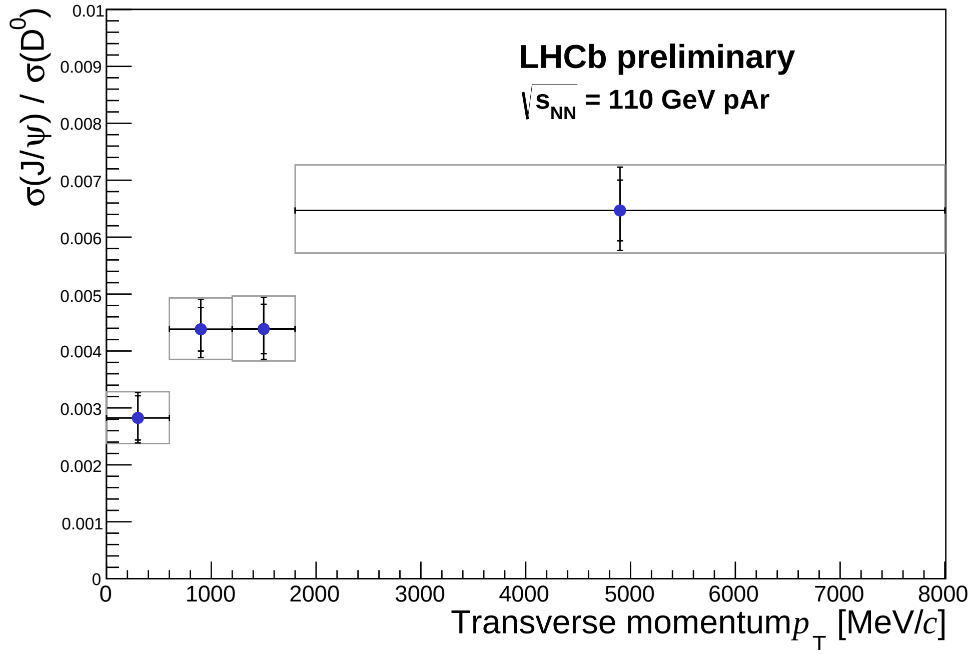
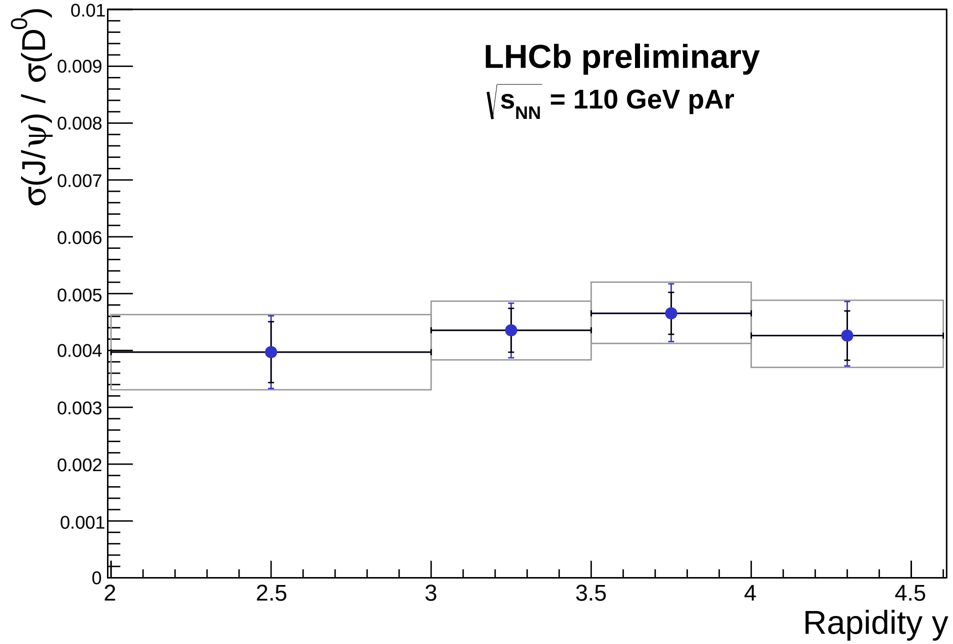
J/ψ / D^0 ratio vs transverse momentum and pseudorapidity

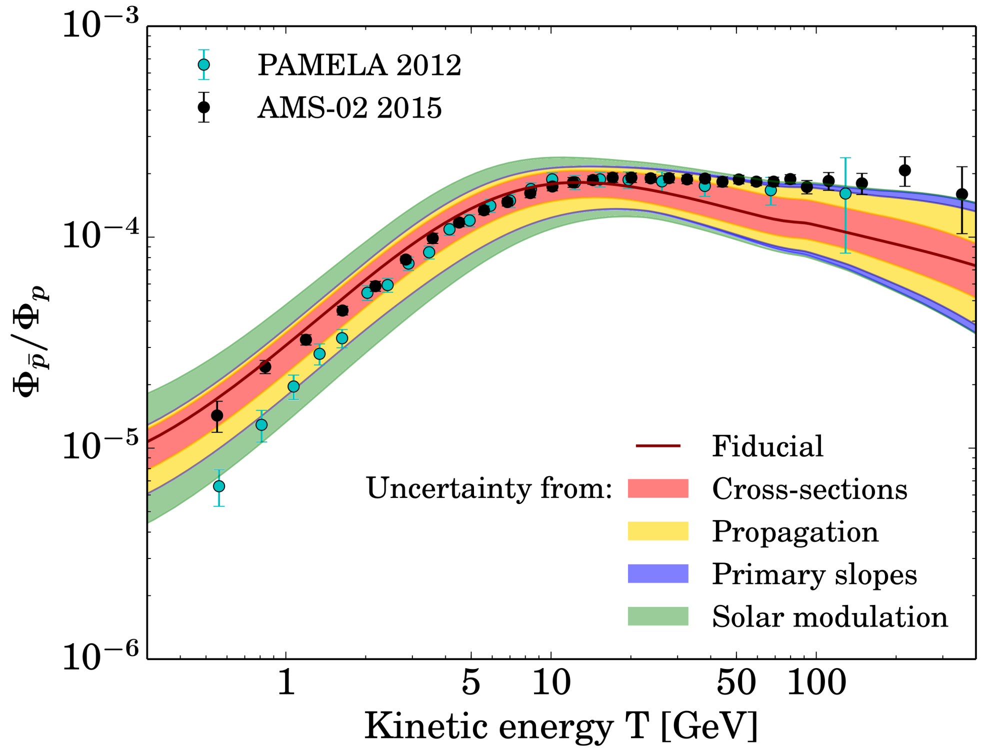




- First result from the LHCb fixed target program, presented at the Quark Matter conference last month
- Obtained from the first small (few nb^{-1}) p-Ar data sample
- Result limited by statistics, but demonstrates the physics potential
- Differential shapes can already test differences among models

Soft QCD for Cosmic Rays Physics

- Fixed target data at the 100 GeV scale can also provide valuable inputs to MC models describing underlying event
- Very important for modeling cosmic ray showers in the atmosphere…
- …and in the cosmos, in particular for **antimatter production**
- AMS02 results provide unprecedented accuracy for measurement of $\overline{p}/p$ ratio in cosmic rays at high energies **PRL 117, 091103 (2016)**
- hint for a possible excess, and milder energy dependence than expected
- prediction for $\overline{p}/p$ ratio from spallation of primary cosmic rays on intestellar medium (H and He) is **presently limited by uncertainties on $\overline{p}$ production cross-sections, particularly for p-He**
- no previous measurement of $\overline{p}$ production in p-He, current predictions vary within a factor 2
- the LHC energy scale and LHCb +SMOG are very well suited to perform this measurement



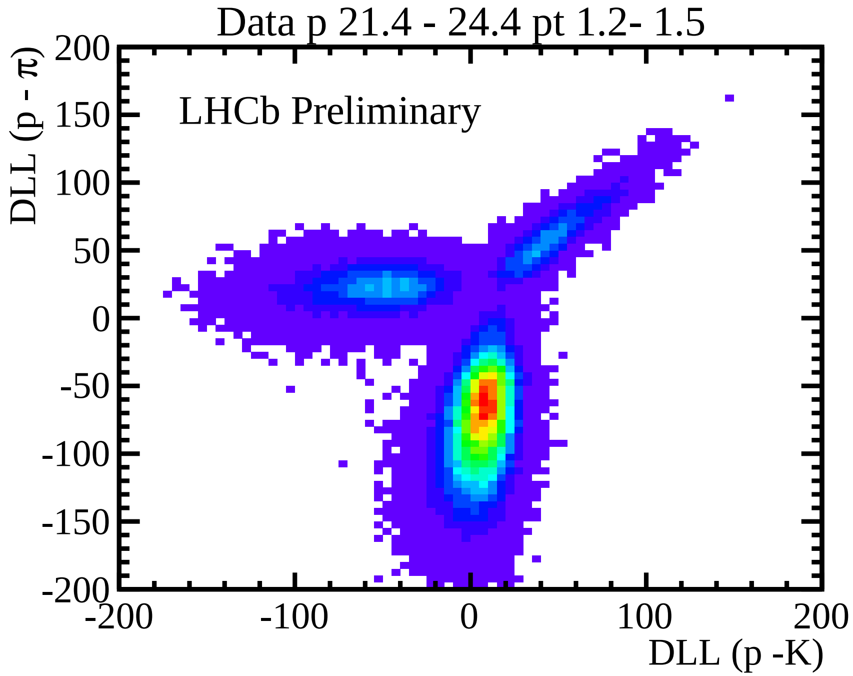
Giesen et al., JCAP 1509, 023 (2015)

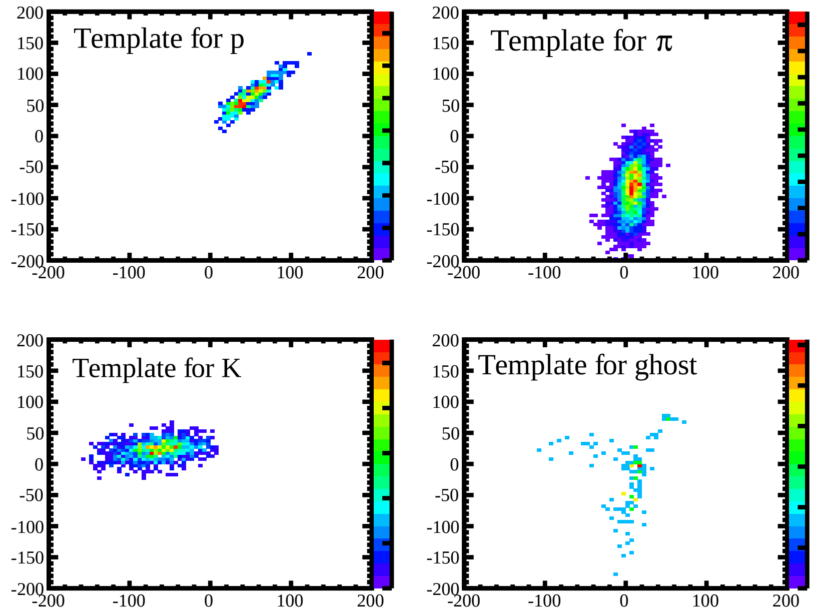
The p-He run

- Data collected in May 2016, with proton energy 6.5 TeV, $\sqrt{s_{\rm NN}} = 110$ GeV
- Using fill for Van der Meer scan (parasitic data taking)
- Most data from a single fill (5 hours)
- Minimum bias trigger, fully efficient on candidate events
- Exploit excellent particle identification (PID) capabilities in LHCb to count antiprotons in $(p,\ p_{\rm T})$ bins within the kinematic range

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

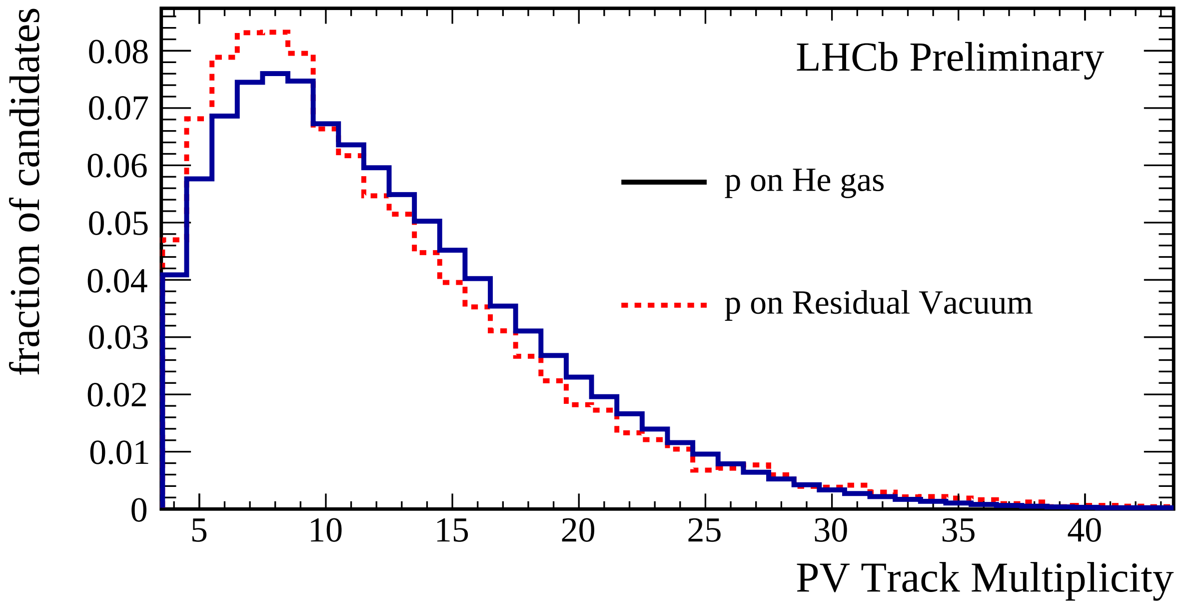
$$p_{\rm T} > 0.4\,{\rm GeV}/c$$





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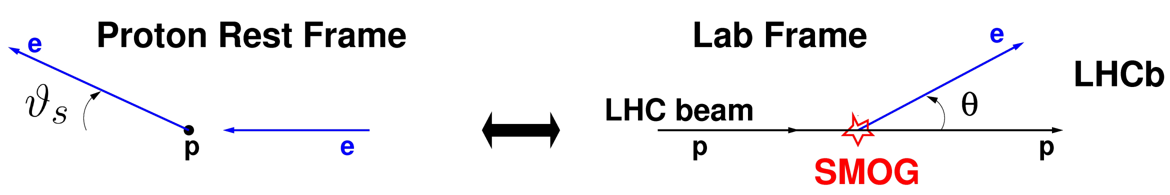
- Gas impurity found to be small: $0.6 \pm 0.2\%$
- PV multiplicity in residual vacuum events is **lower** than in He events, but has longer tails ➡ confirm findings from Rest Gas Analysis that residual vacuum is mostly H_2, with small heavy contaminants

Normalization

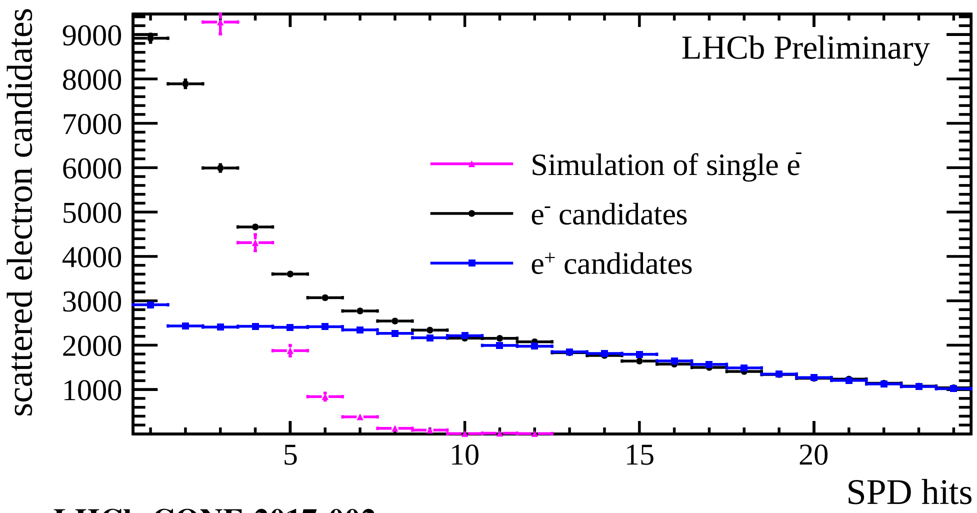


Using p-e$^-$ elastic scattering.

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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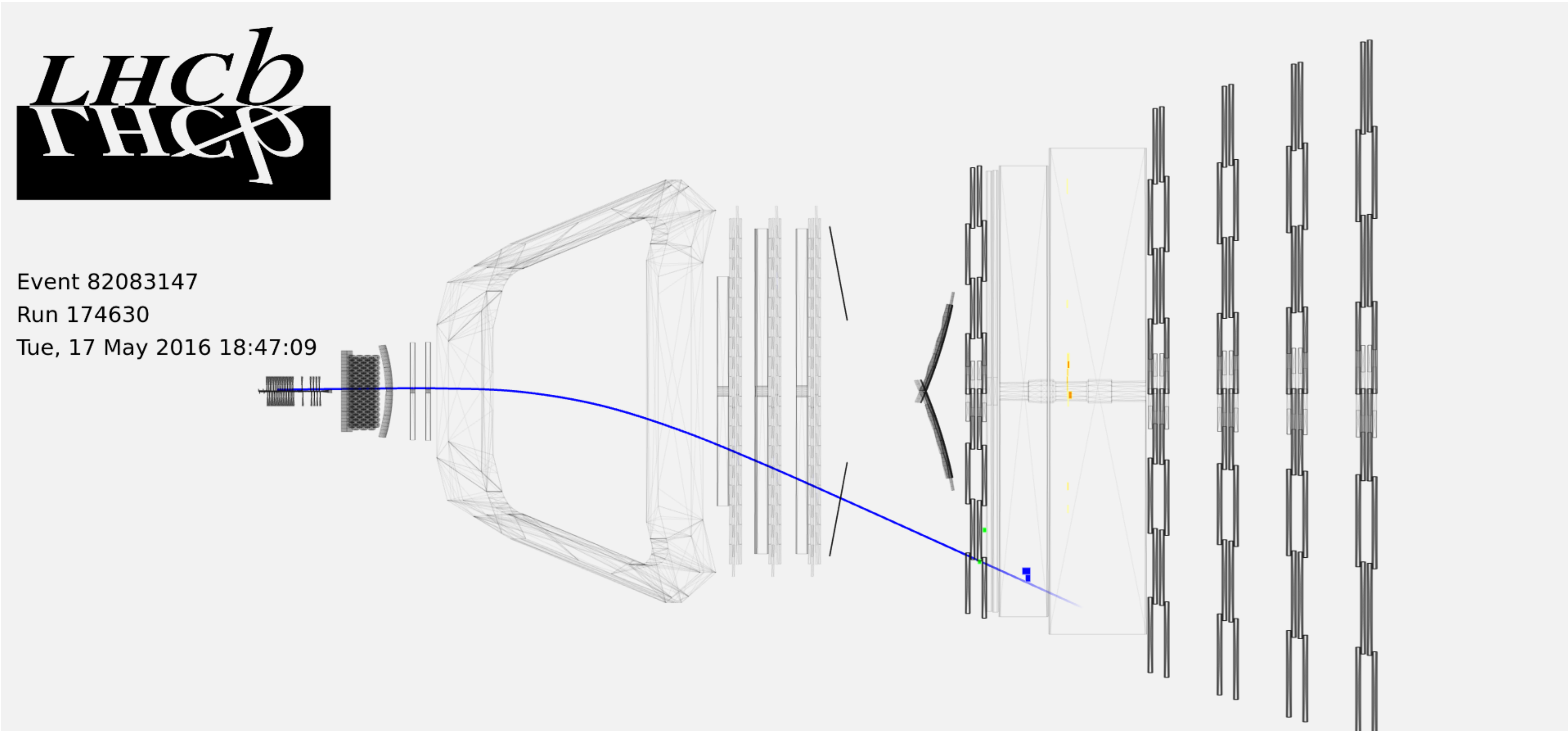
Cons:

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

Event display of a candidate scattered electron



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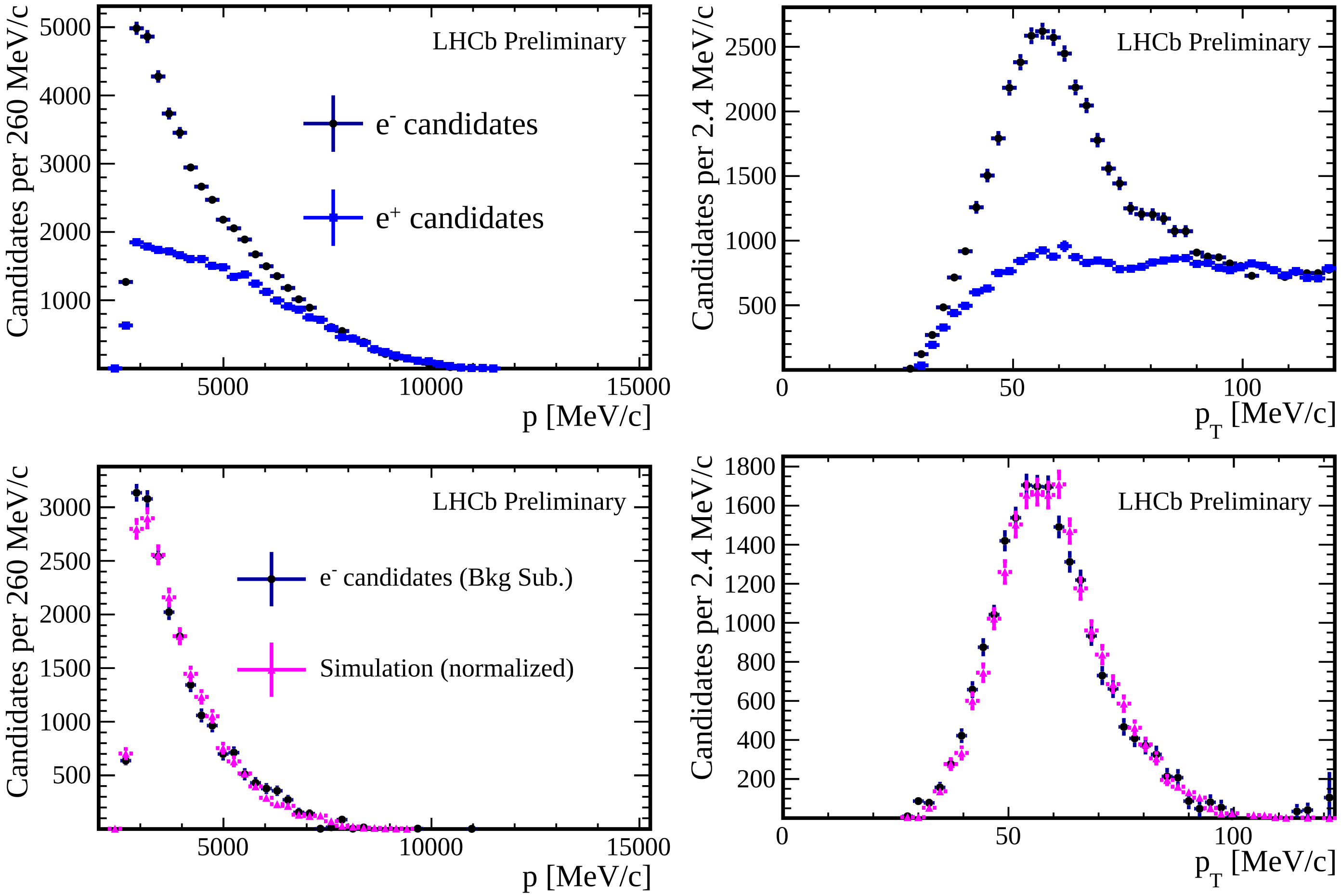
Electron spectra



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

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

- 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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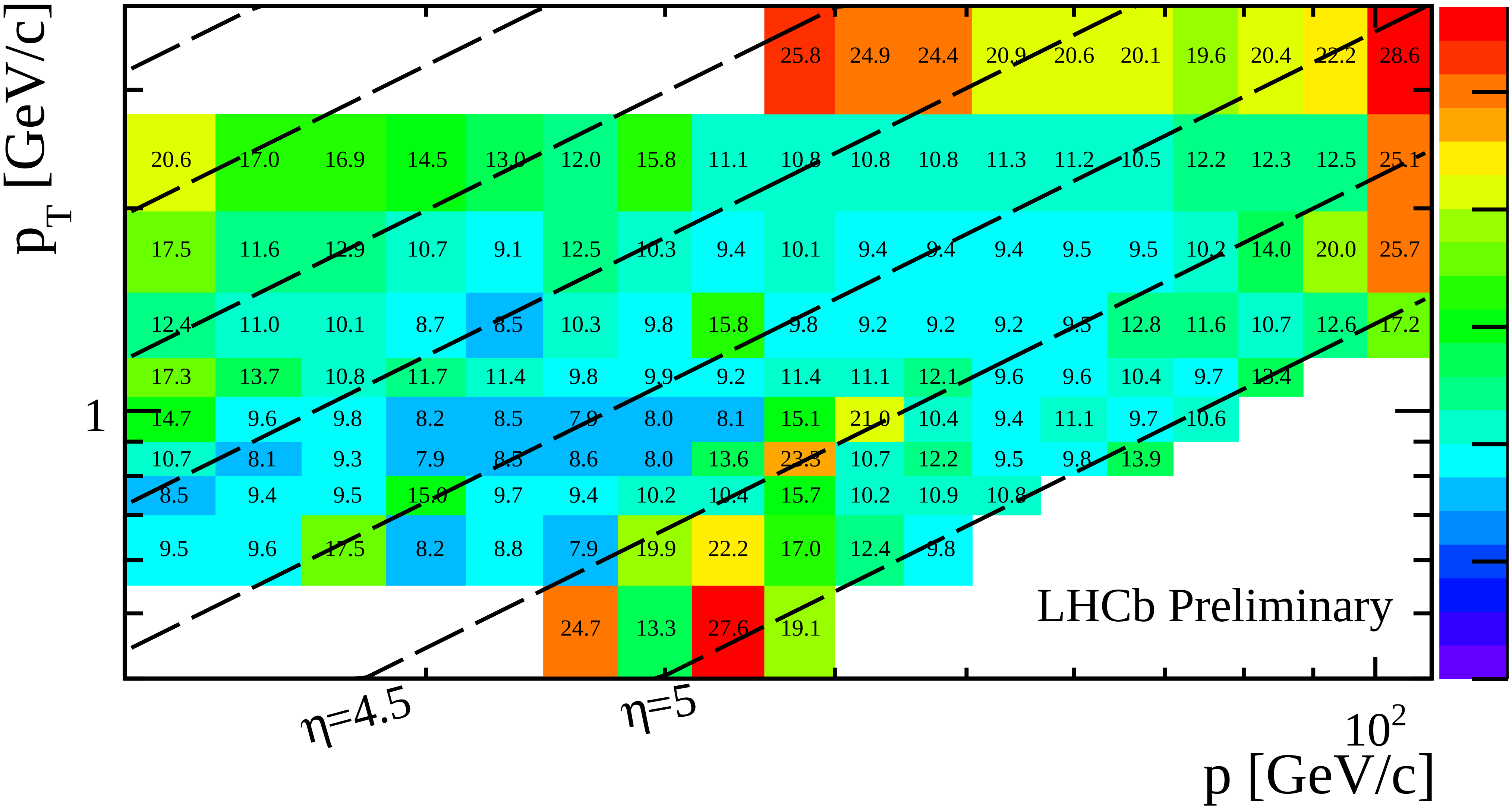

Result for cross section, compared with EPOS LHC

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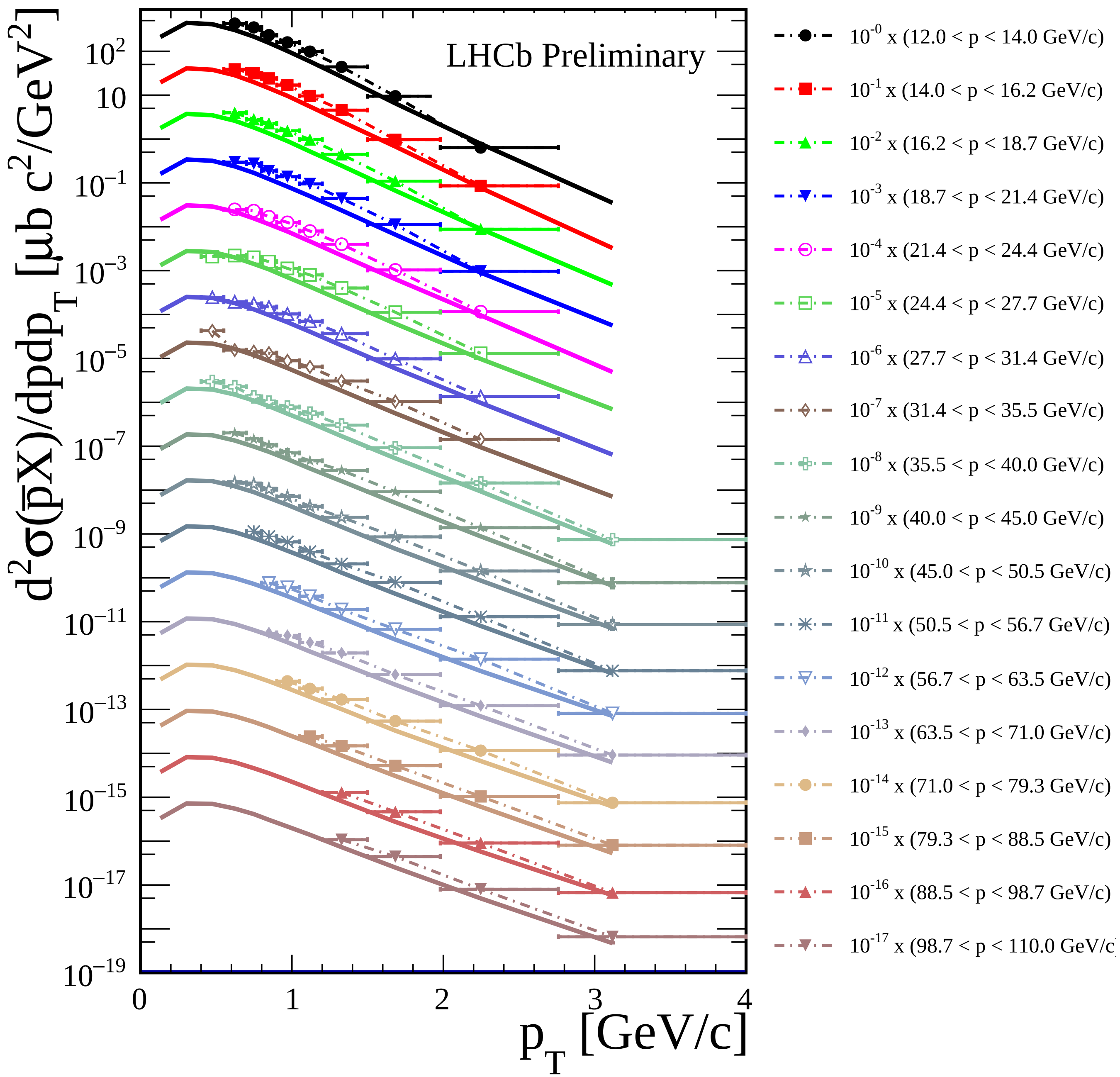

Result for **prompt** production (excluding weak decays of hyperons)

The total inelastic cross section is also measured to be

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

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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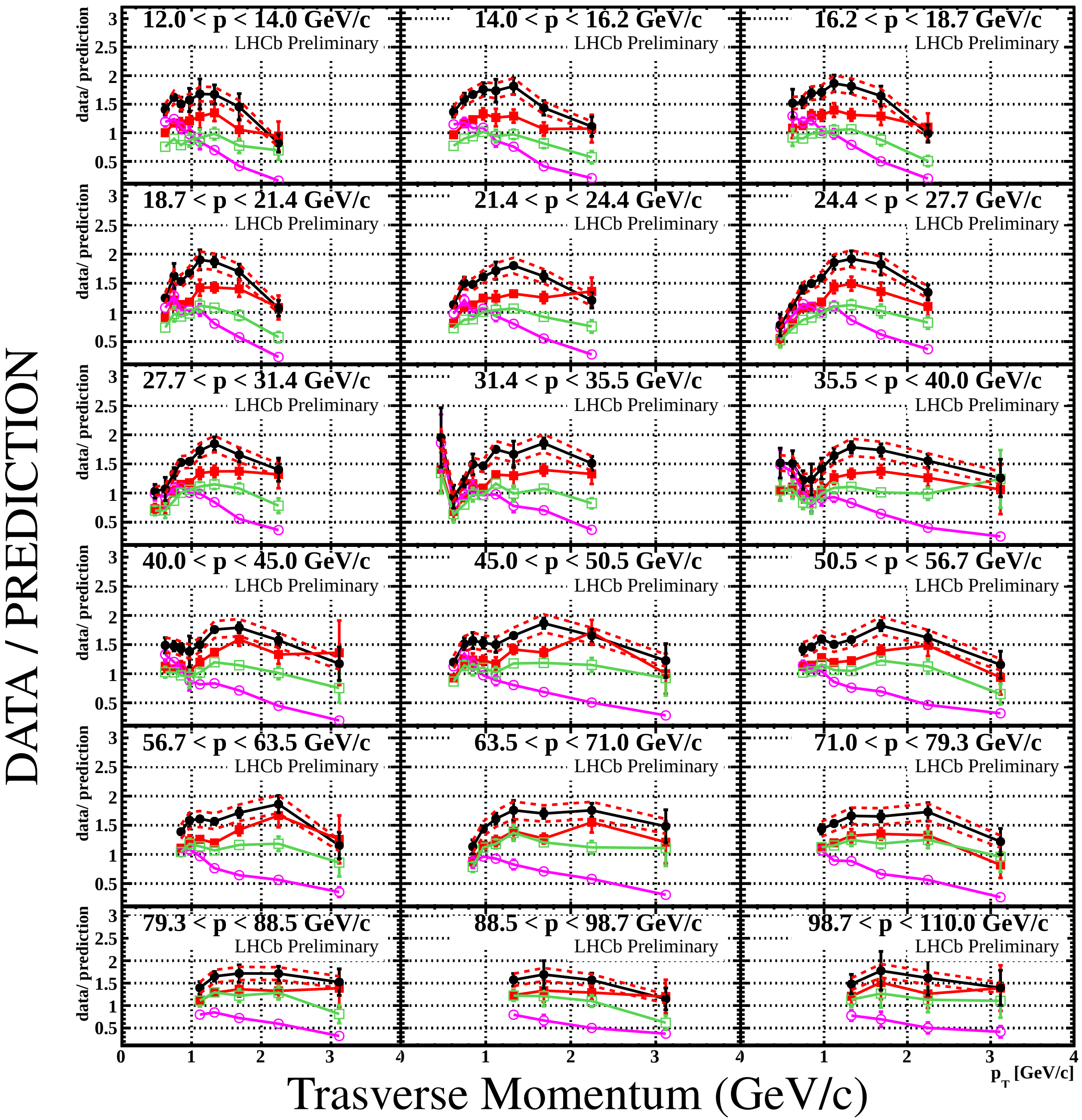
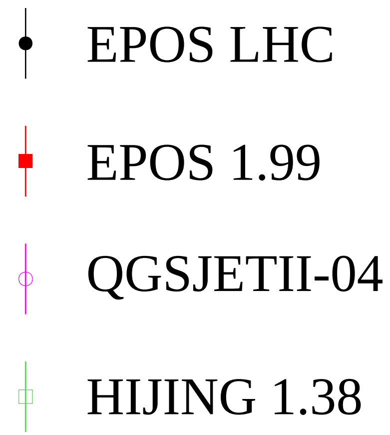




Cross section is larger by factor ~ 1.5 wrt EPOS LHC (mostly from larger $\overline{p}$ rate per collision).
Better agreement with EPOS 1.99 and HIJING 1.38

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

Conclusions

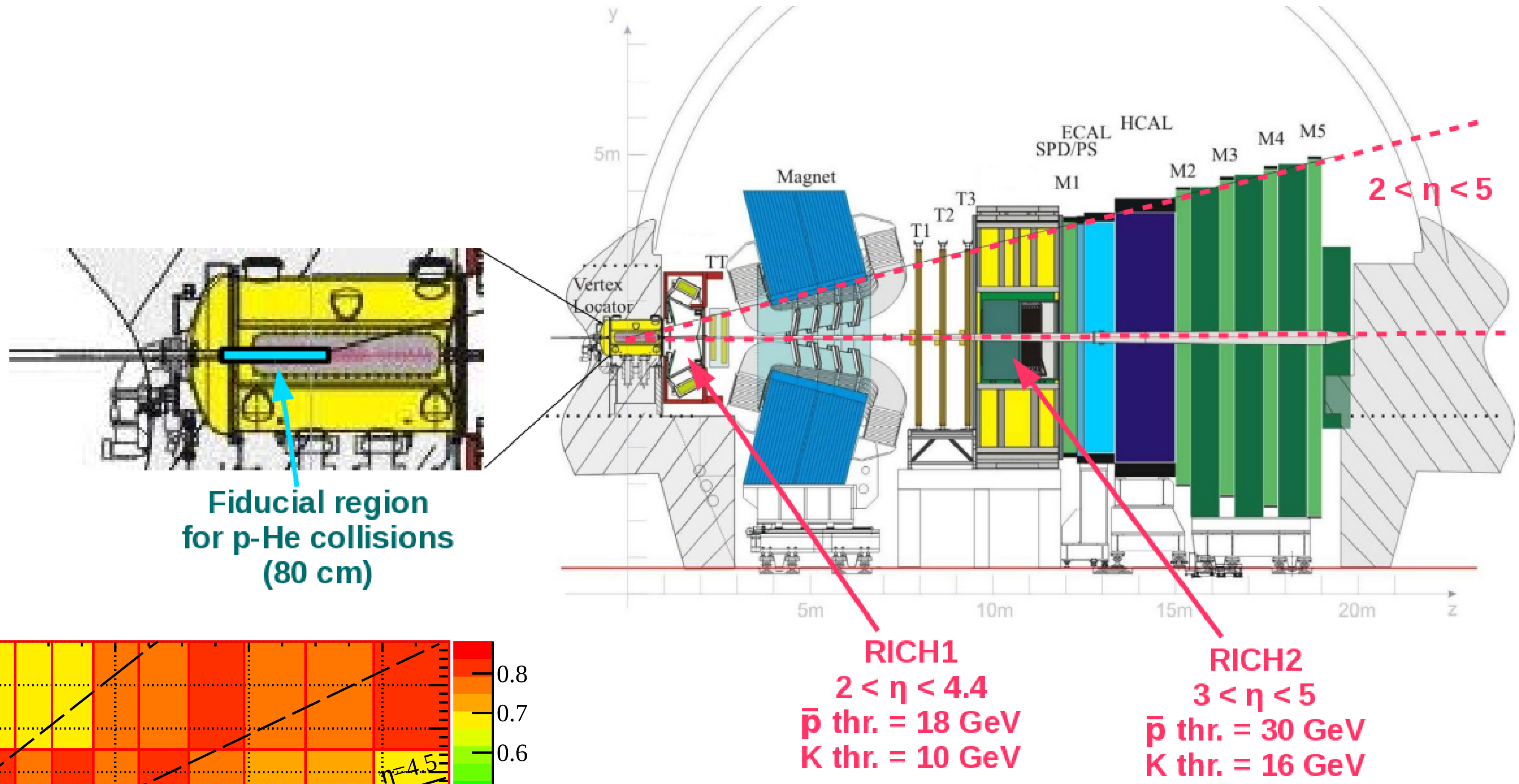
- LHCb started its fixed target program
- becoming an unexpected contributor to cosmic ray physics!
- The $\bar{p}$ production measurement in p-He collisions is expected to narrow down significantly the uncertainty on the $\bar{p}/p$ prediction for cosmic rays
- **Many thanks to our colleaugues in cosmic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

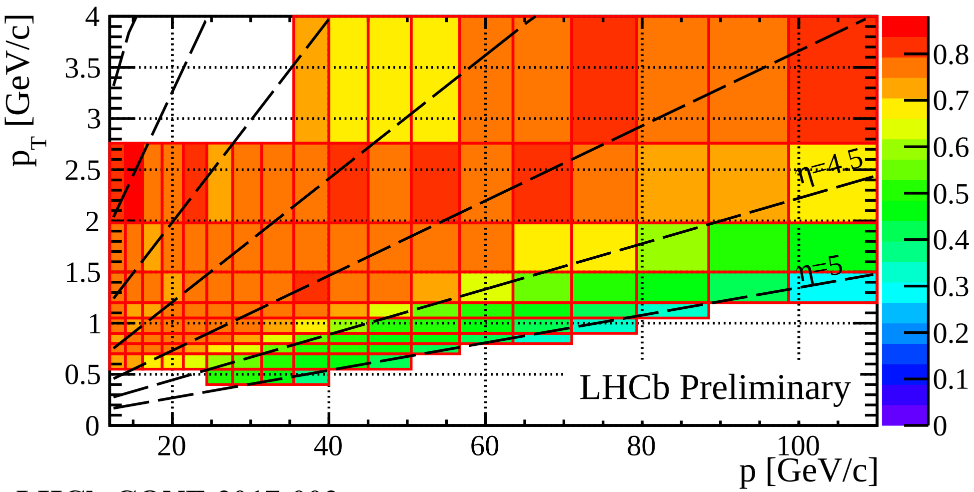
- More to come on $\bar{p}$ production:
  - dataset with beam energy of 4 TeV also collected
  - will also measure the detached (Λ decays) component
- and much more to harvest from the SMOG samples: charged particle yields, particle/antiparticle ratios, positrons, gamma, charm…

the LHCb space mission just started!

Additional Material

Detector and Acceptance





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Total acceptance × reconstruction efficiency for antiprotons