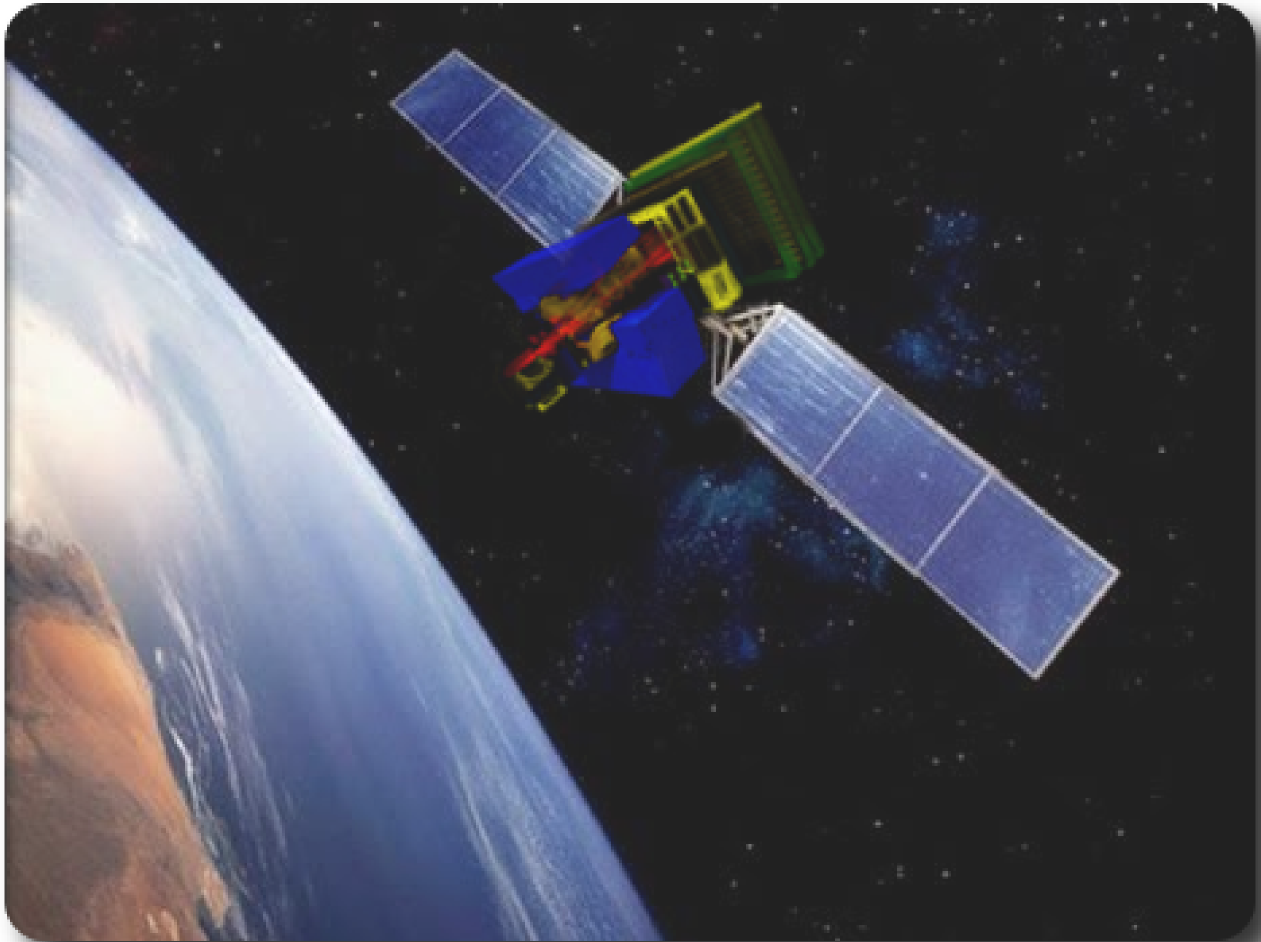
Antiproton production in p-He collisions at the LHC

LHCb on a Space Mission



Giacomo Graziani
(INFN Firenze)

Consiglio di Sezione
INFN Firenze
4 aprile 2017

A cosmic call to LHCb

A new idea!

- After the talk of F. Donato yesterday a new idea came to my mind
- The SMOG system has already been tested in 2012 in LHCb
  - Injection of noble gas atoms inside the beam pipe to:
    - Measure the beam profile
    - Measure the luminosity
- Why don't use SMOG to measure cross section relevant for Cosmic Ray Physics???
  - P-He→Antiprotons+X
- We could make use of 'perfect' Particle Identification Detectors
- We could make use of the highest possible energies
  - Direct access to protons in the most interesting energy region

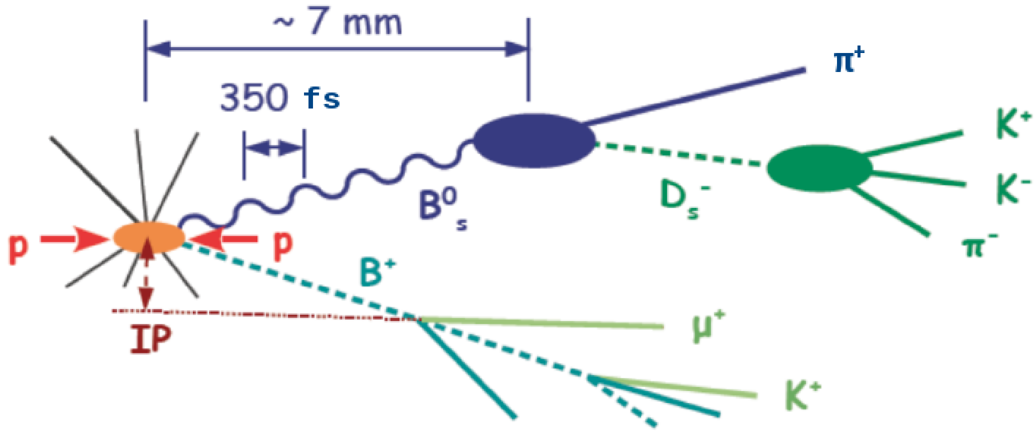
O. Adriani   Cosmic rays and accelerators: future   Cortona, April 21st, 2015

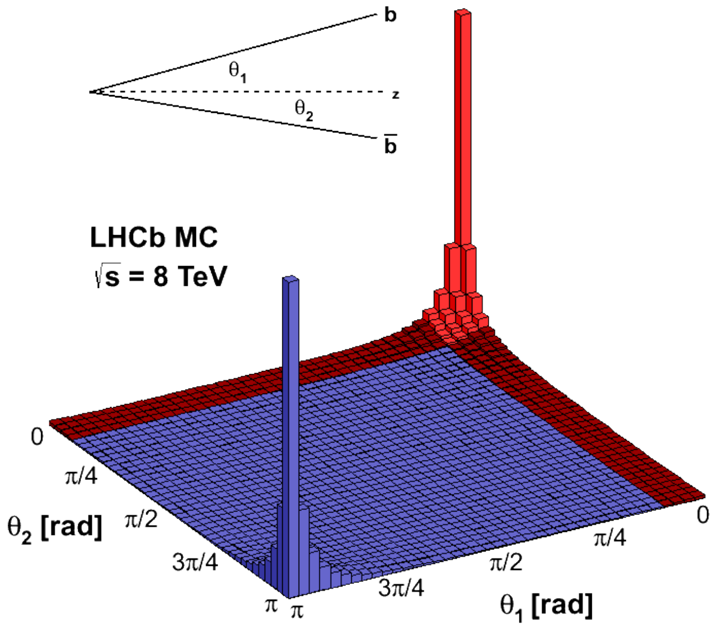
Idea from NPCQD2015 Workshop, April 2015 (from O. Adriani's talk)
Proposal to LHCb soon after (talk by L. Bonechi at LHCb Meeting, May 12 2015)

The LHCb Experiment

LHCb is the experiment devoted to heavy flavours at the LHC pp collider

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





Detector requirements:

Forward geometry optimize acceptance for $b\bar{b}$ pairs ($\sim 25\ \%$)

Tracking : best possible proper time and momentum resolution

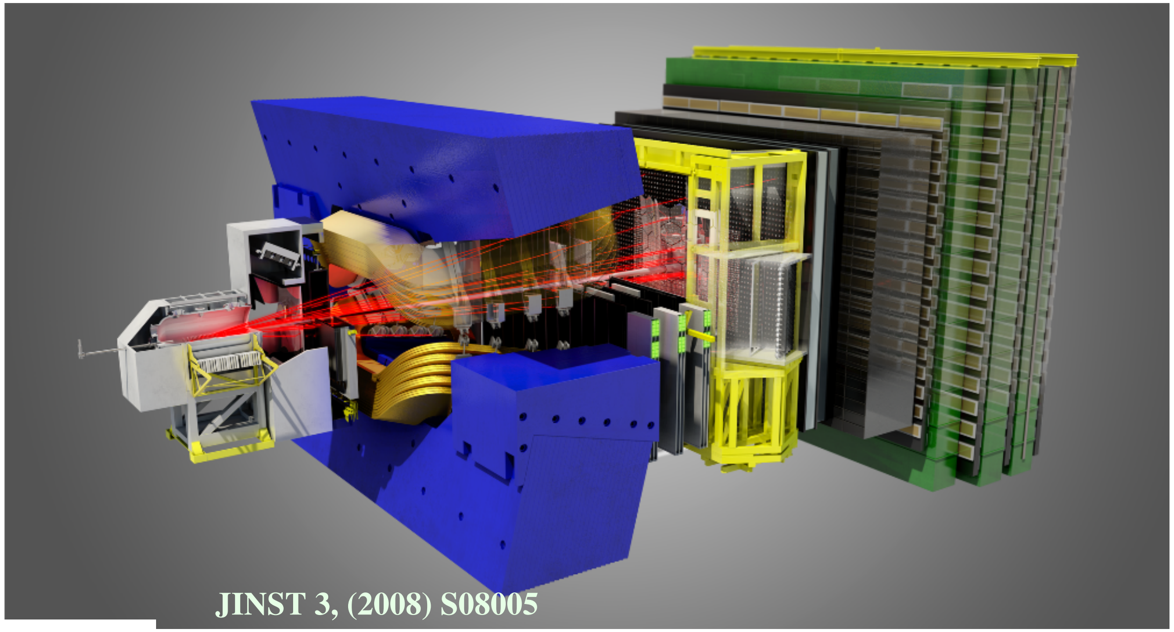
Particle ID : excellent capabilities to select exclusive decays

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

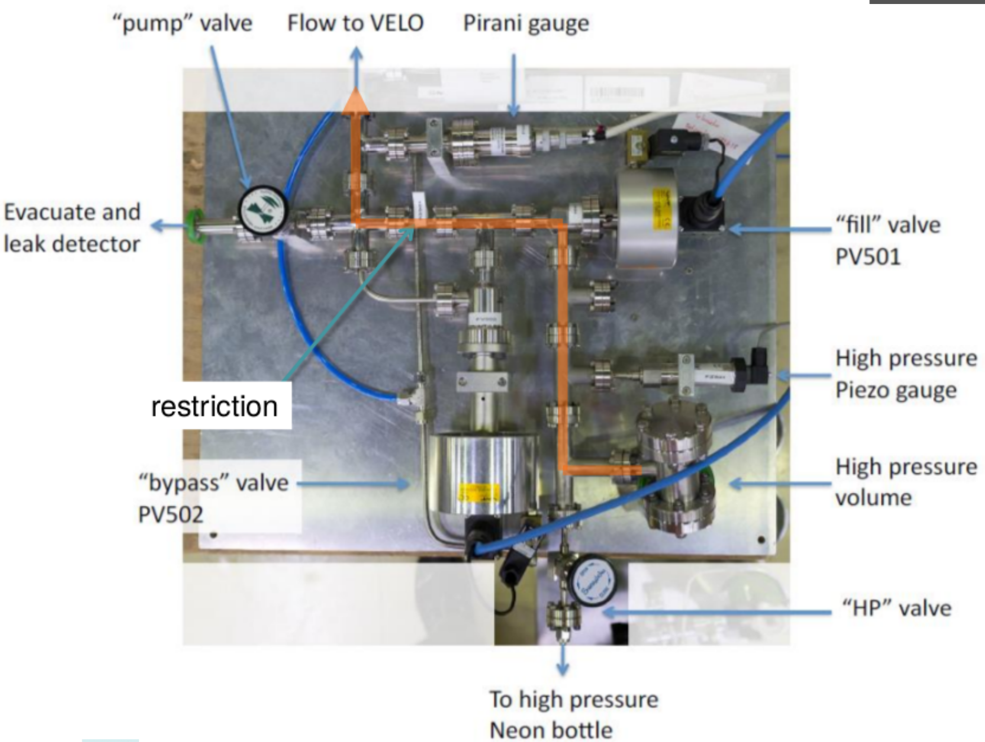
➨ allowed to widen our physics program to include hadron spectroscopy, EW physics, kaon physics, heavy ion physics. . .

SMOG: the LHCb internal gas target

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



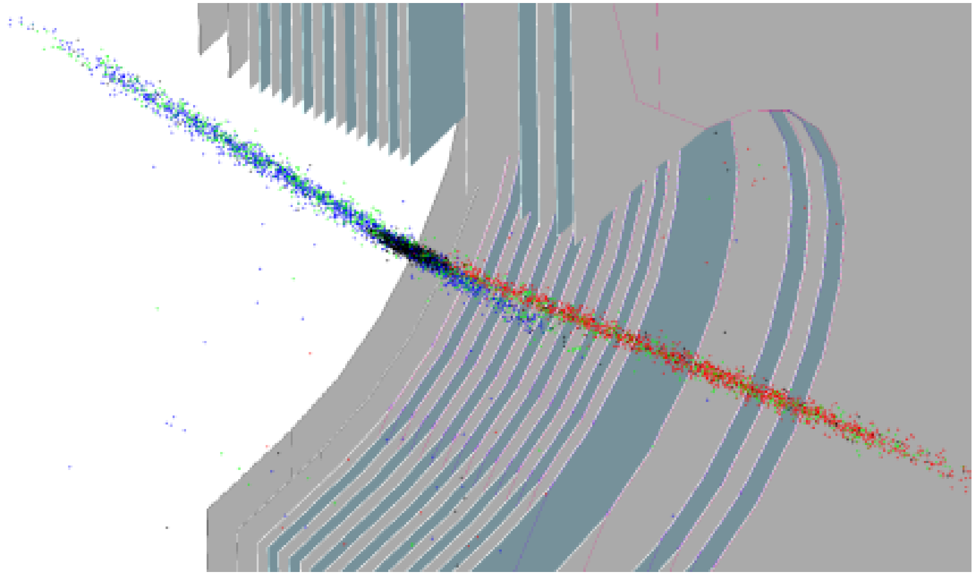
Int.J.Mod.Phys.A30 (2015) 1530022



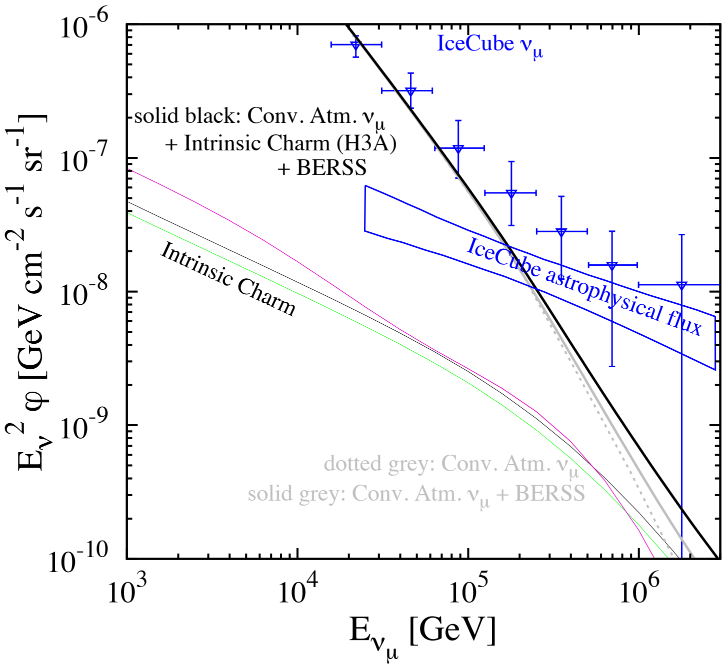
- The System for Measuring Overlap with Gas (SMOG) allows to inject small amount of noble gas (He, Ne, Ar, …) inside the LHC beam around ($\sim \pm 20$ m) the LHCb collision region
  Expected pressure $\sim 2 \times 10^{-7}$ mbar

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



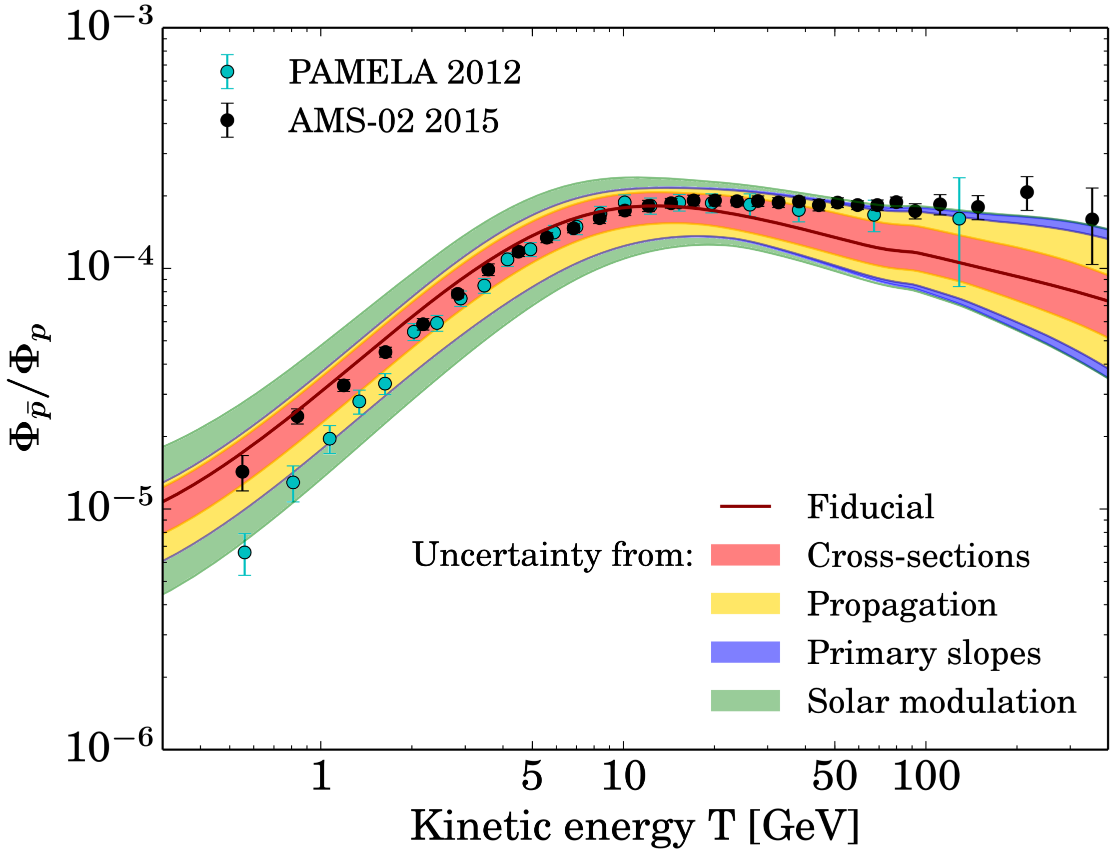
- Became the LHCb internal gas target for a rich and varied fixed target physics program:
  - pA interactions @ 100 GeV scale: exploring cold nuclear matter effects in heavy flavour production
    see talk tomorrow by F. Fleuret
  - probing large-x nPDF (intrinsic charm): also relevant for neutrino astronomy
  - soft QCD: relevant for modeling of cosmic ray showers in the atmosphere and in cosmos



Laha and Brodsky, arXiv:1607.08240

Cosmic antiprotons

- The recent 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** (see F. Donato's talk at the NPCQD2015 Workshop)
- no previous measurement of $\overline{p}$ 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



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

The p-He run

- 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)
- 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

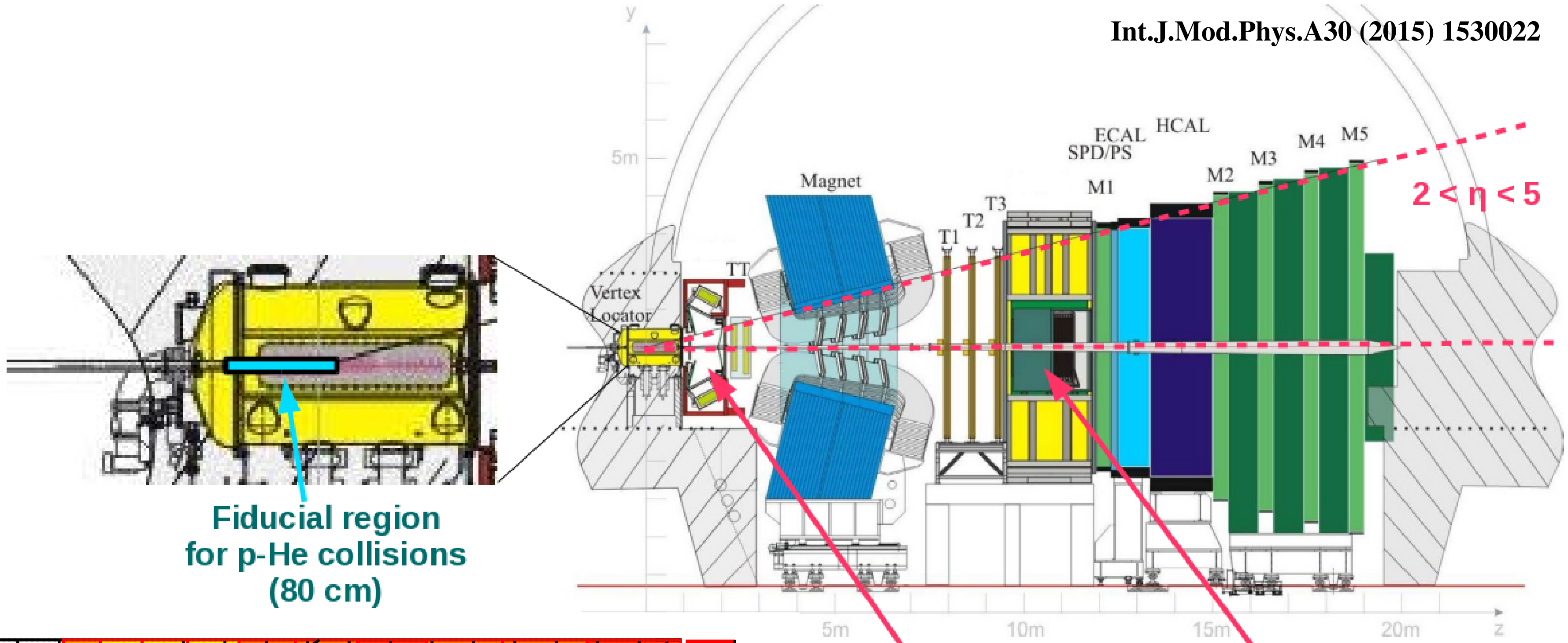
$$12 < p < 110\,\mathrm{GeV}/c$$

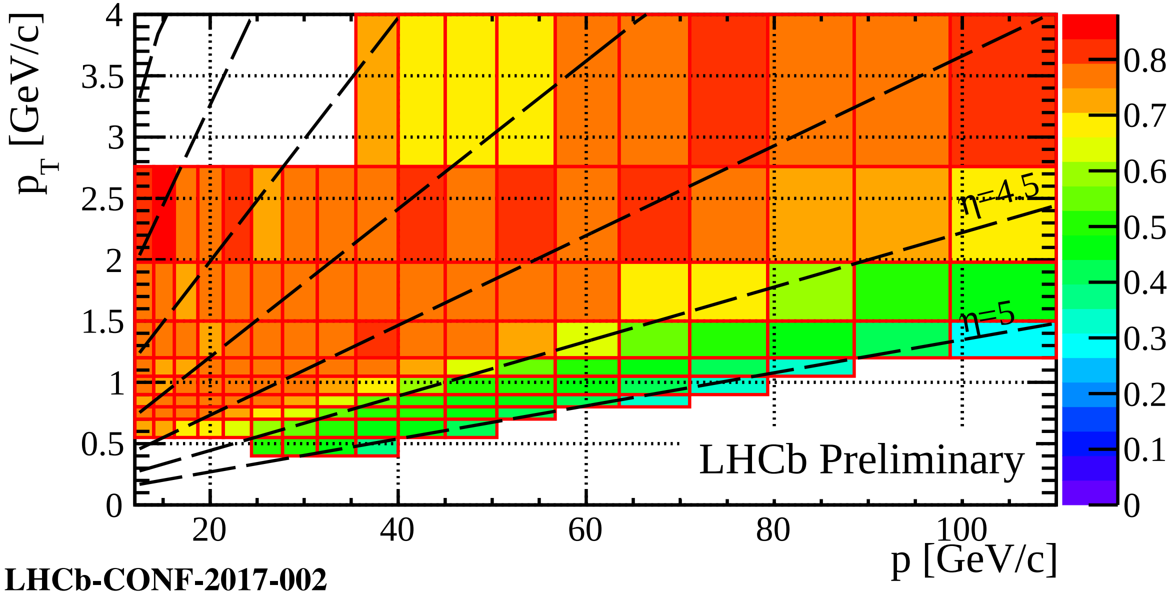
$$p_{\mathrm{T}} > 0.4\,\mathrm{GeV}/c$$

Detector and Acceptance

JINST 3, (2008) S08005

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





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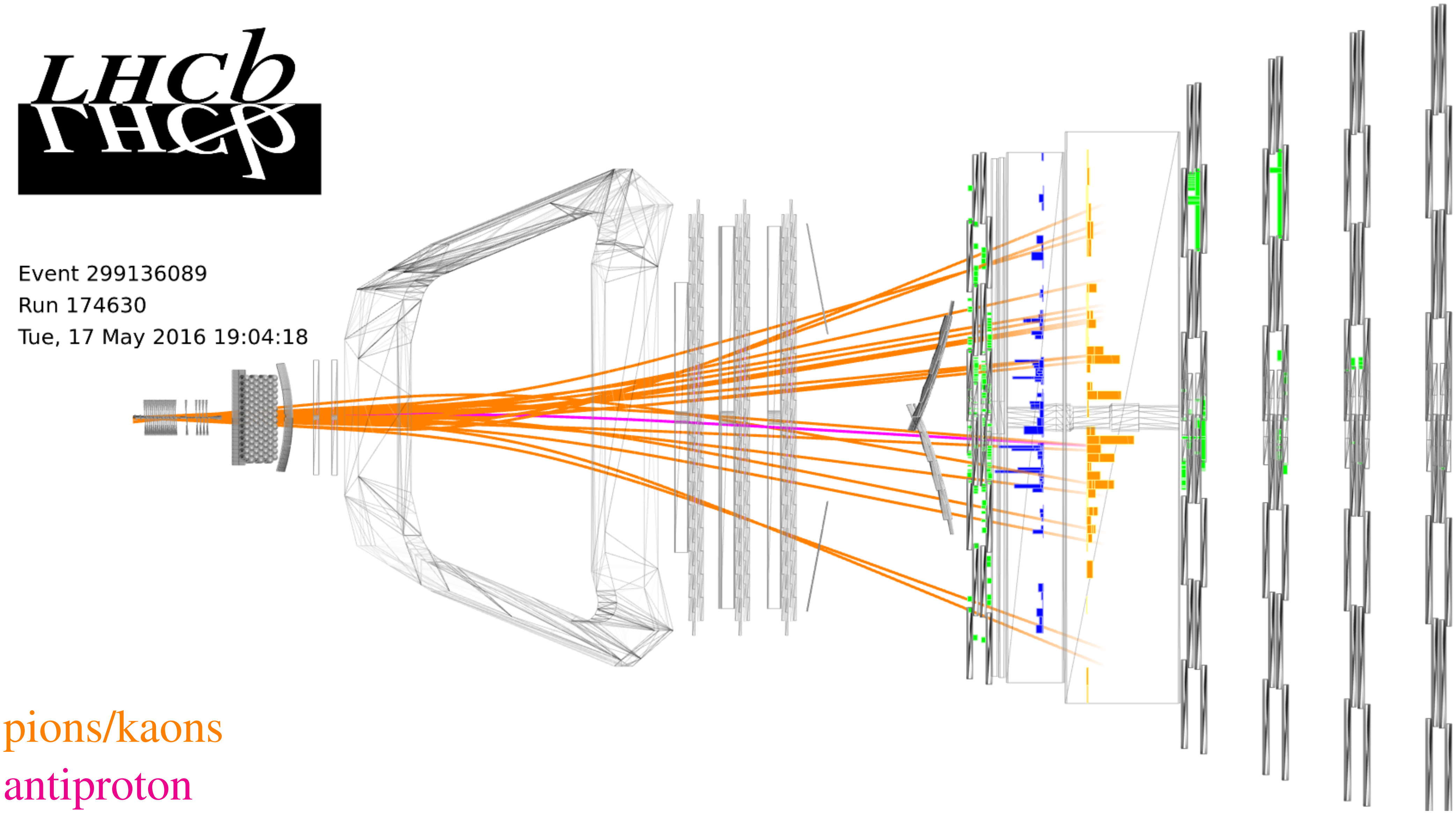
Total acceptance × reconstruction efficiency for antiprotons

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

Event display for a p-He collision

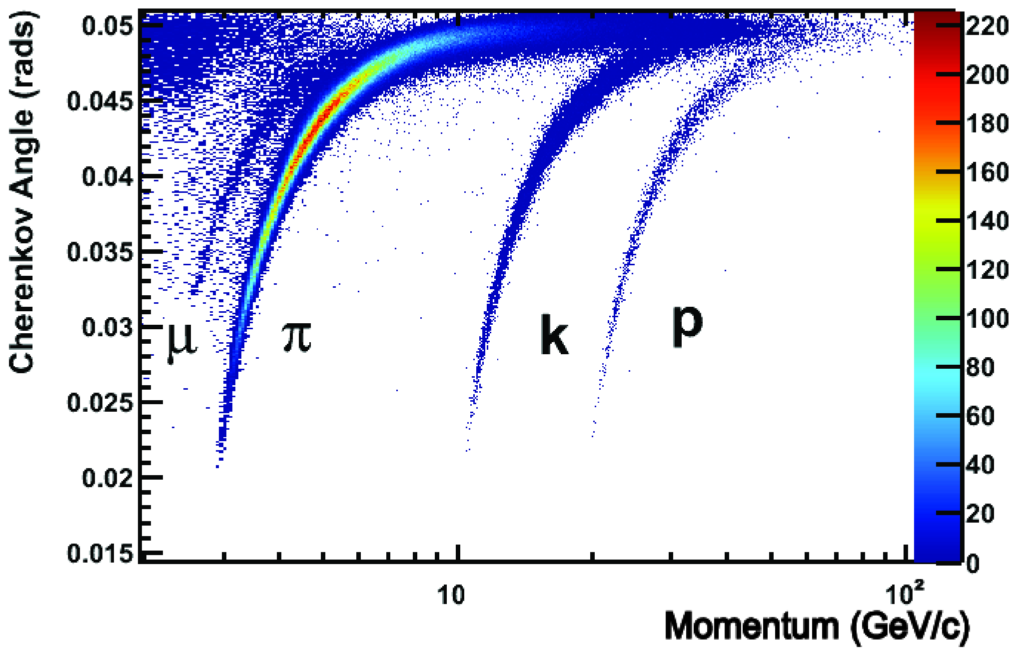


pions/kaons

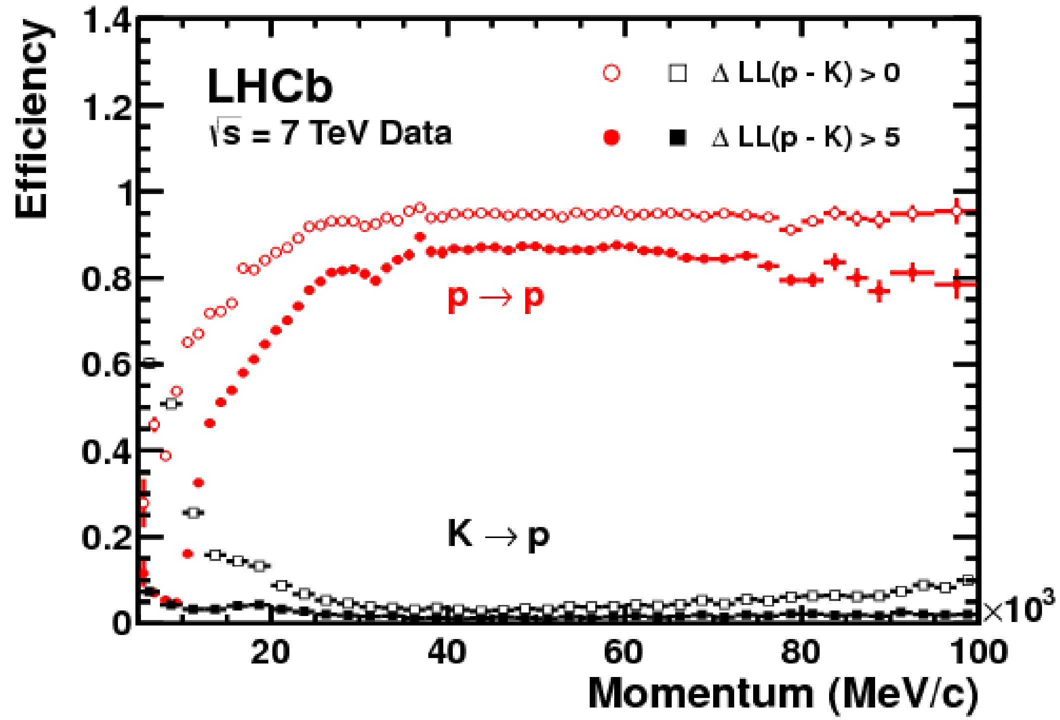
antiproton

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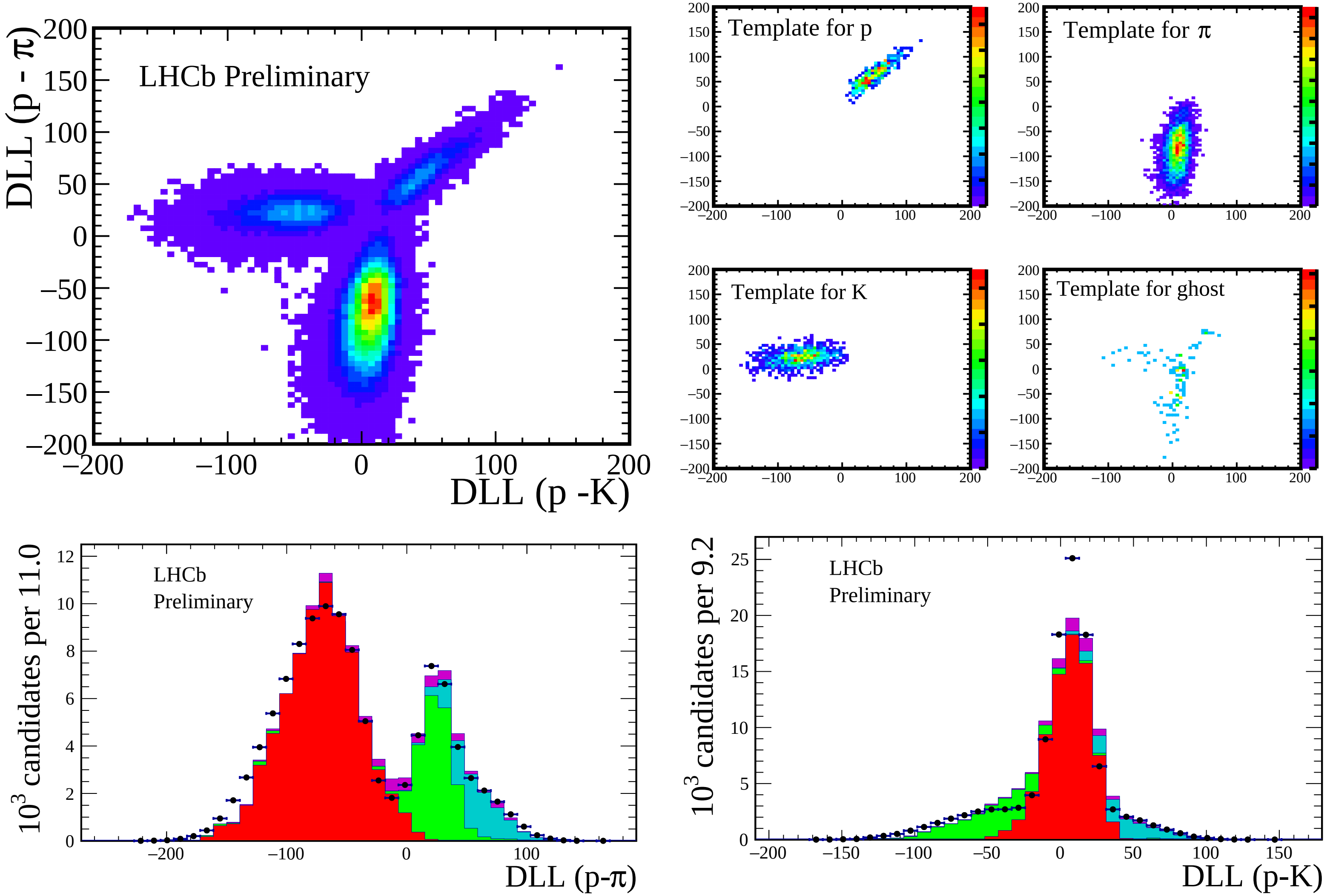
- Build likelihood function for particle hypothesis using RICH response
- Use difference of log likelihood (DLL) between $\overline{p}$ and K^- and $\overline{p}$ and π^-
- Fit the 2-dimensional $(\mathrm{DLL}(p-K), \mathrm{DLL}(p-\pi))$ distributions using templates from calibration samples in each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



Raw yield for antiprotons

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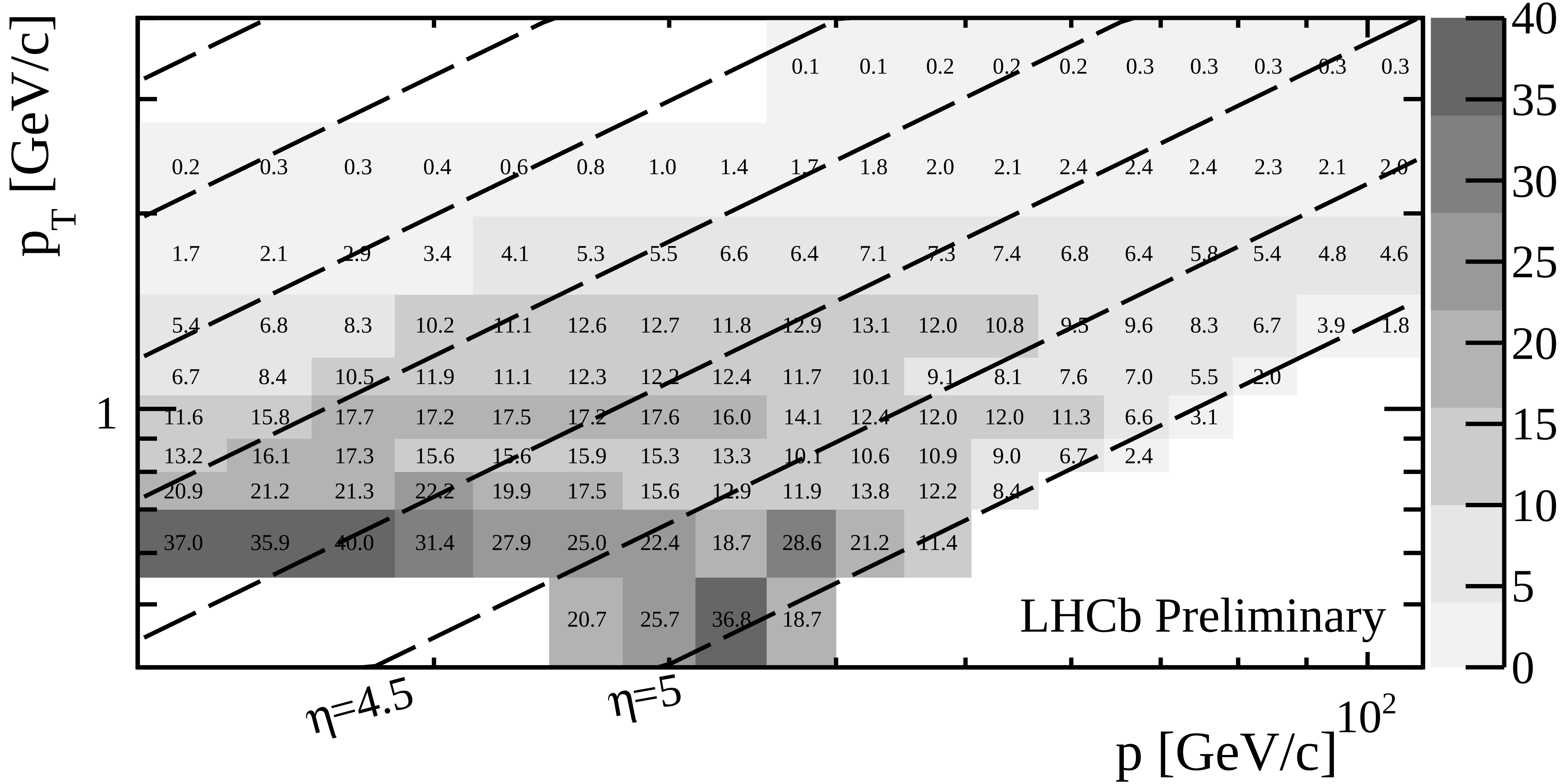
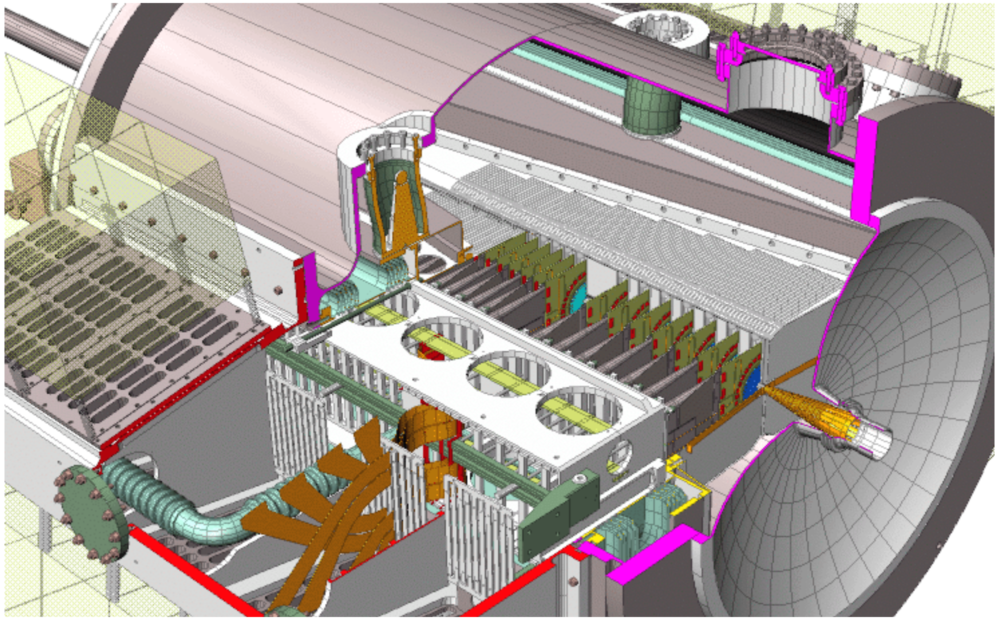
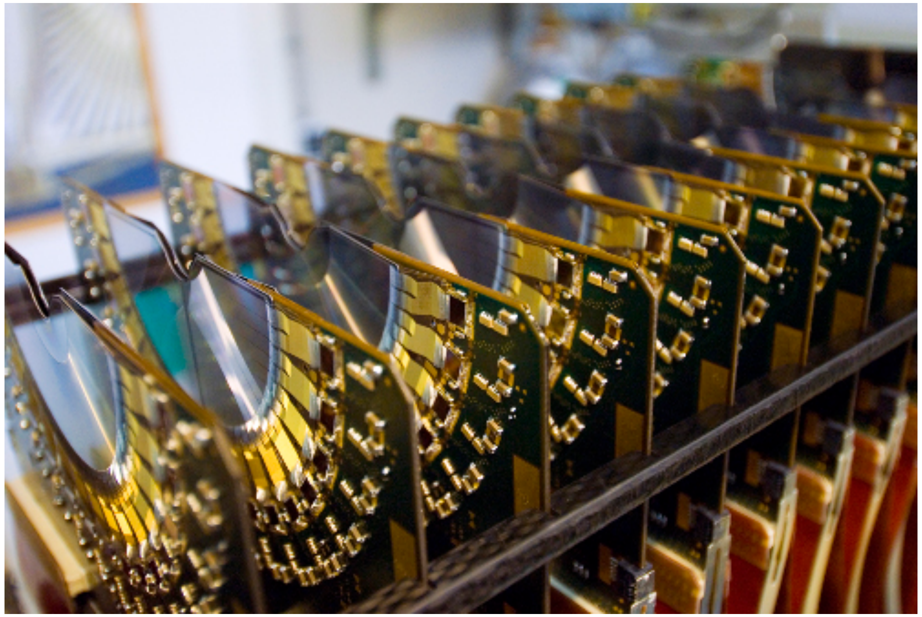
Units 10^3

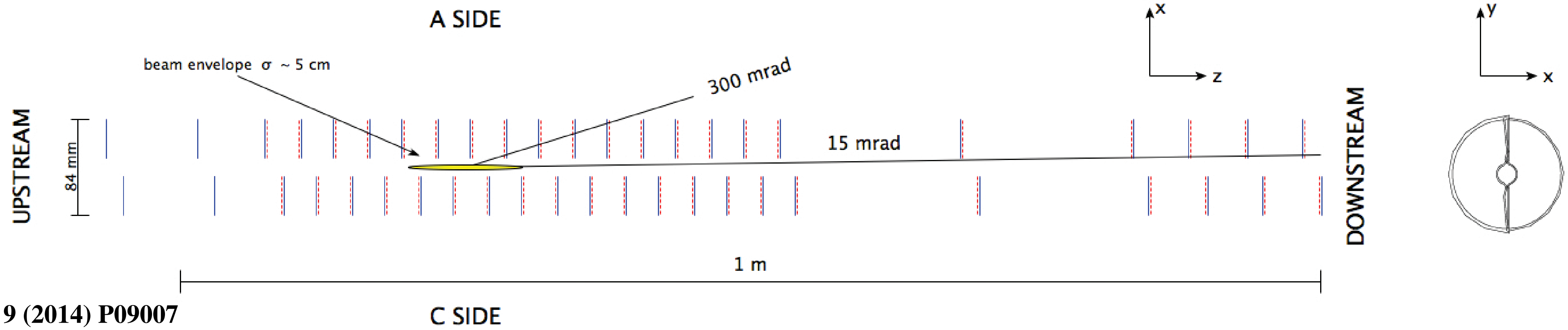


Selection of prompt component: the Vertex Detector

- 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





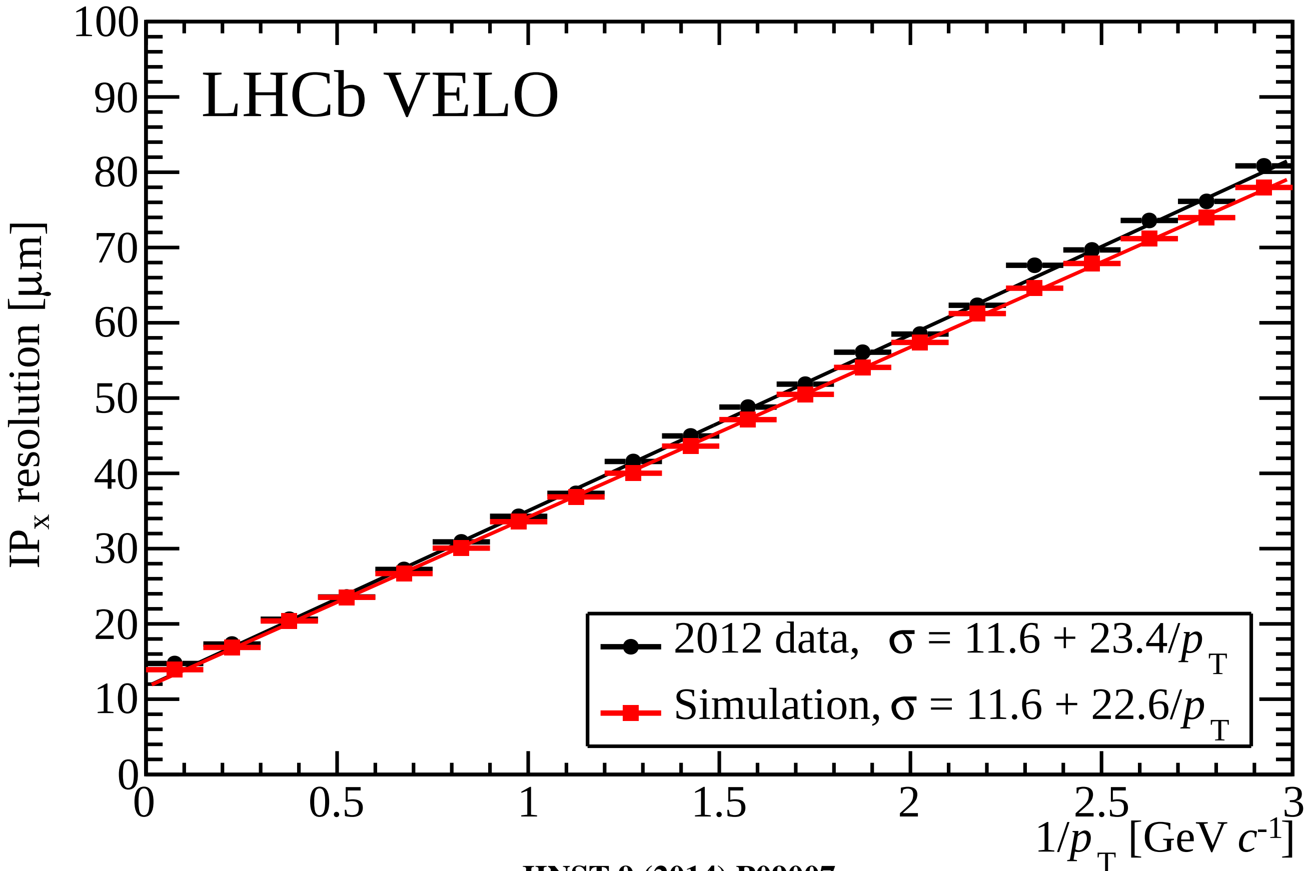


JINST 9 (2014) P09007

Background from weak hyperon decays

- detached component from weak decays of hyperons is treated as a background

- suppressed by requiring small impact parameter (IP)

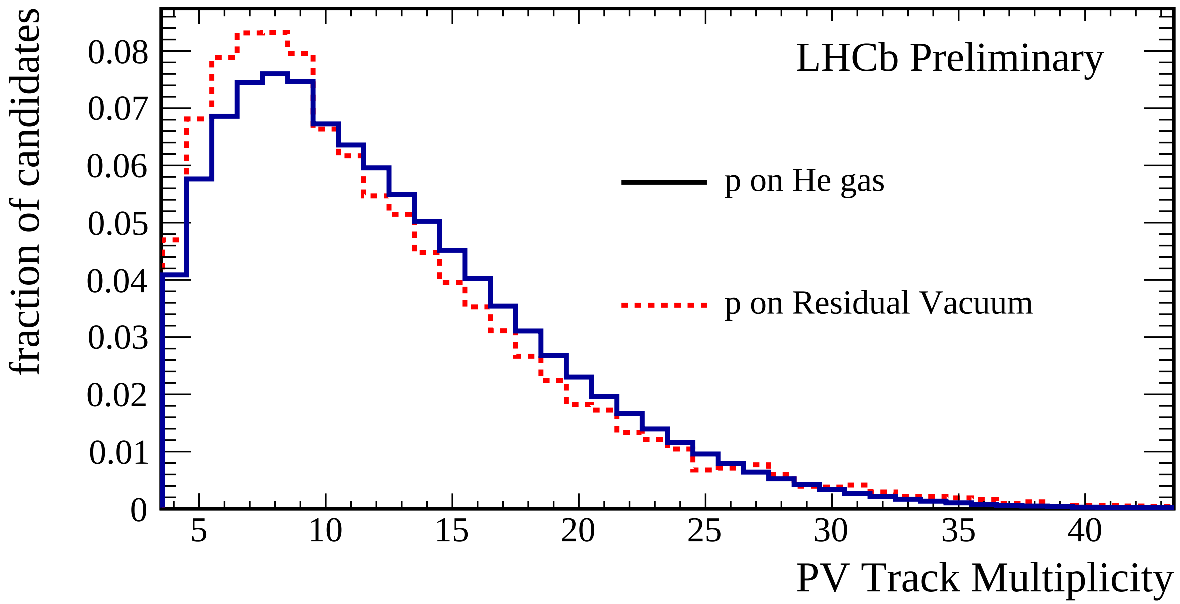


JINST 9 (2014) P09007

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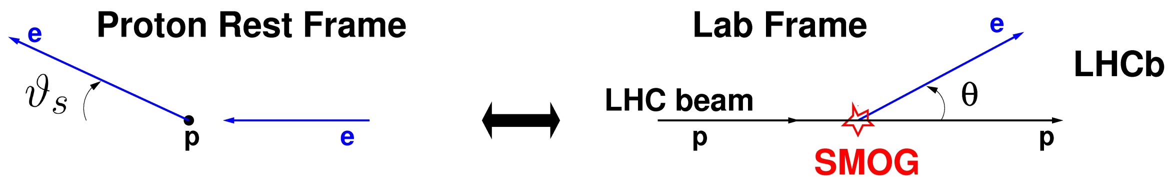
- Gas impurity found to be small: $0.6 \pm 0.2\%$
- PV multiplicity in residual vacuum events is **lower** than in He events, but has longer tails ➨ confirm findings from Rest Gas Analysis that residual vacuum is mostly H_2, with small heavy contaminants

Normalization

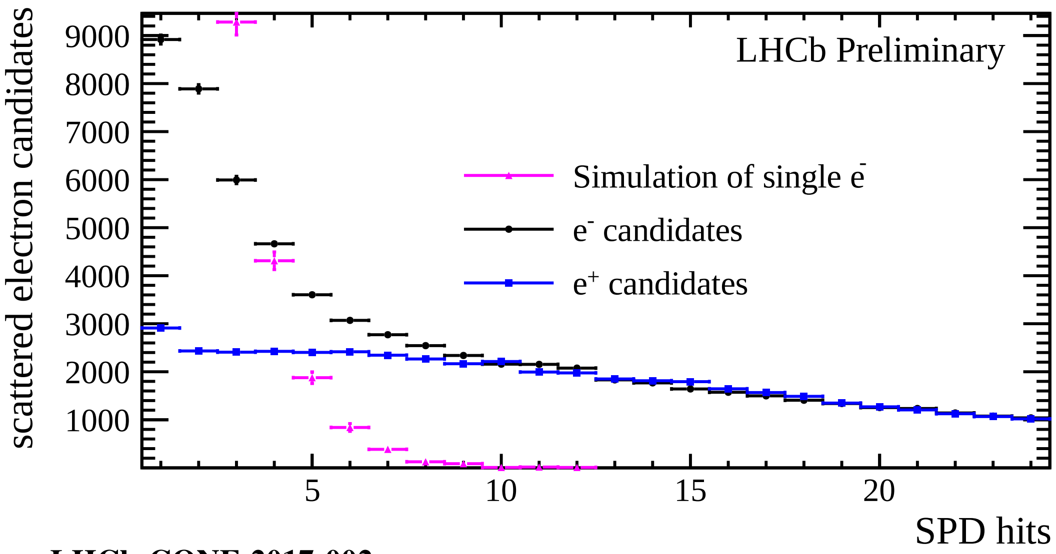


Using p-e$^-$ elastic scattering.

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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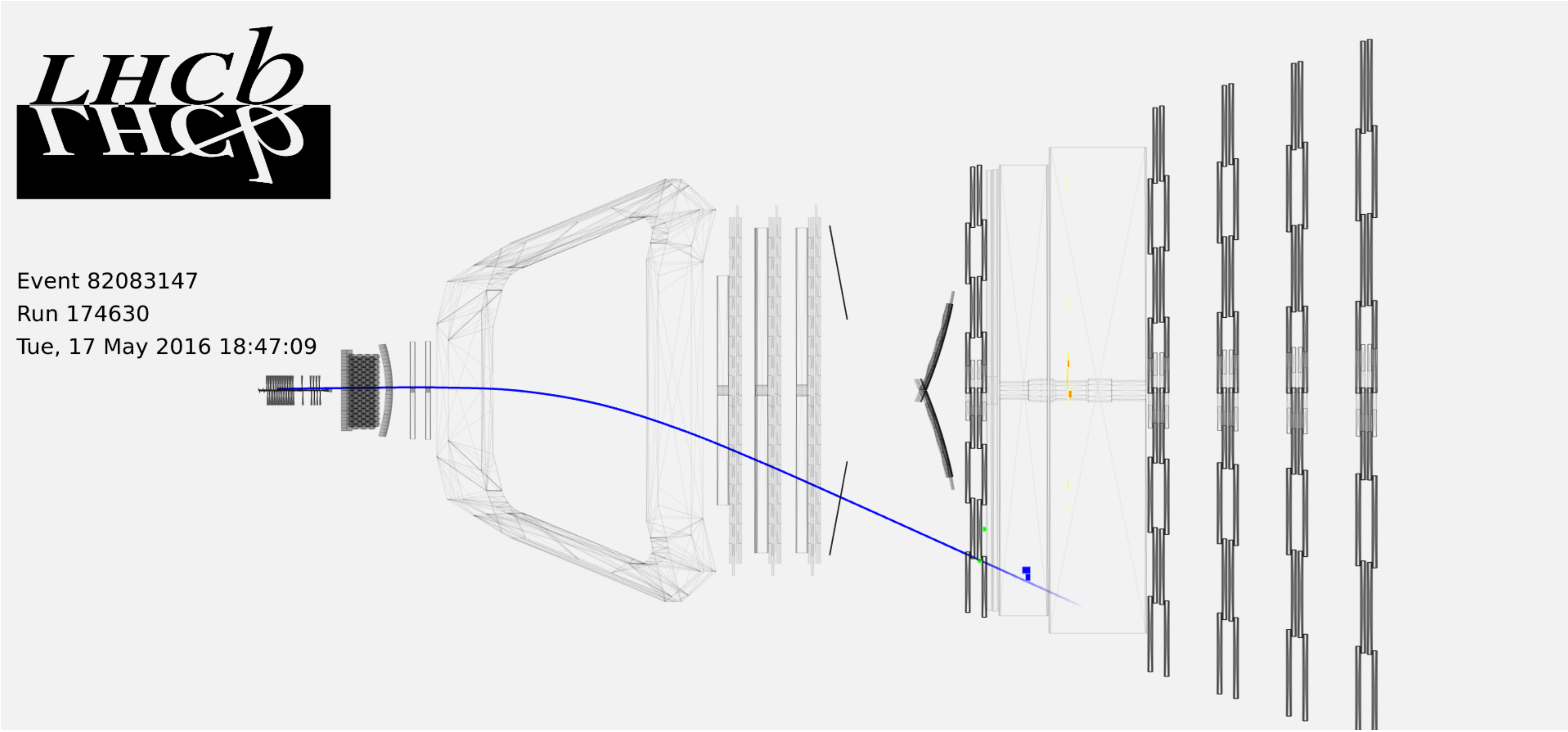
Cons:

- 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



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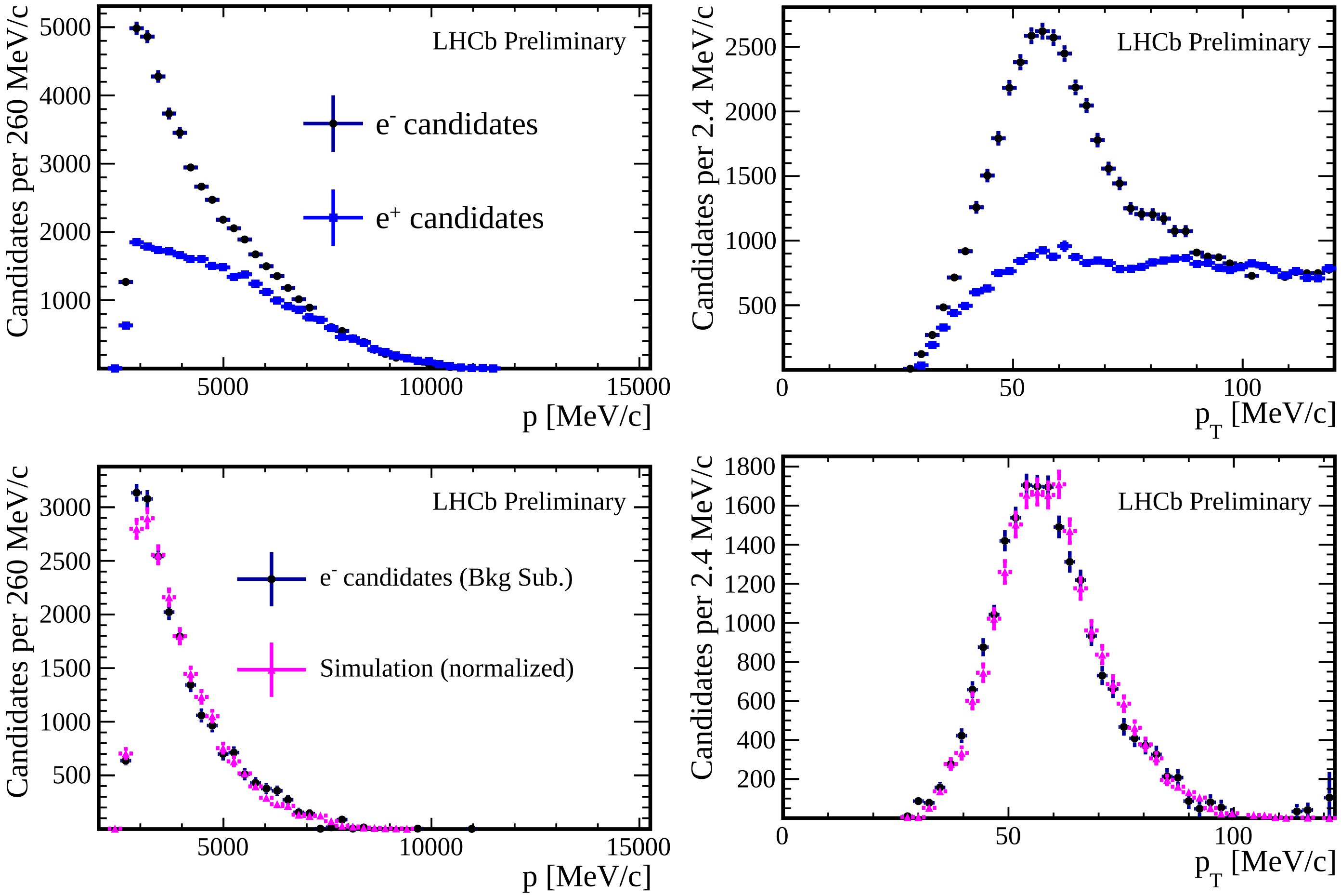
Electron spectra



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

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

- 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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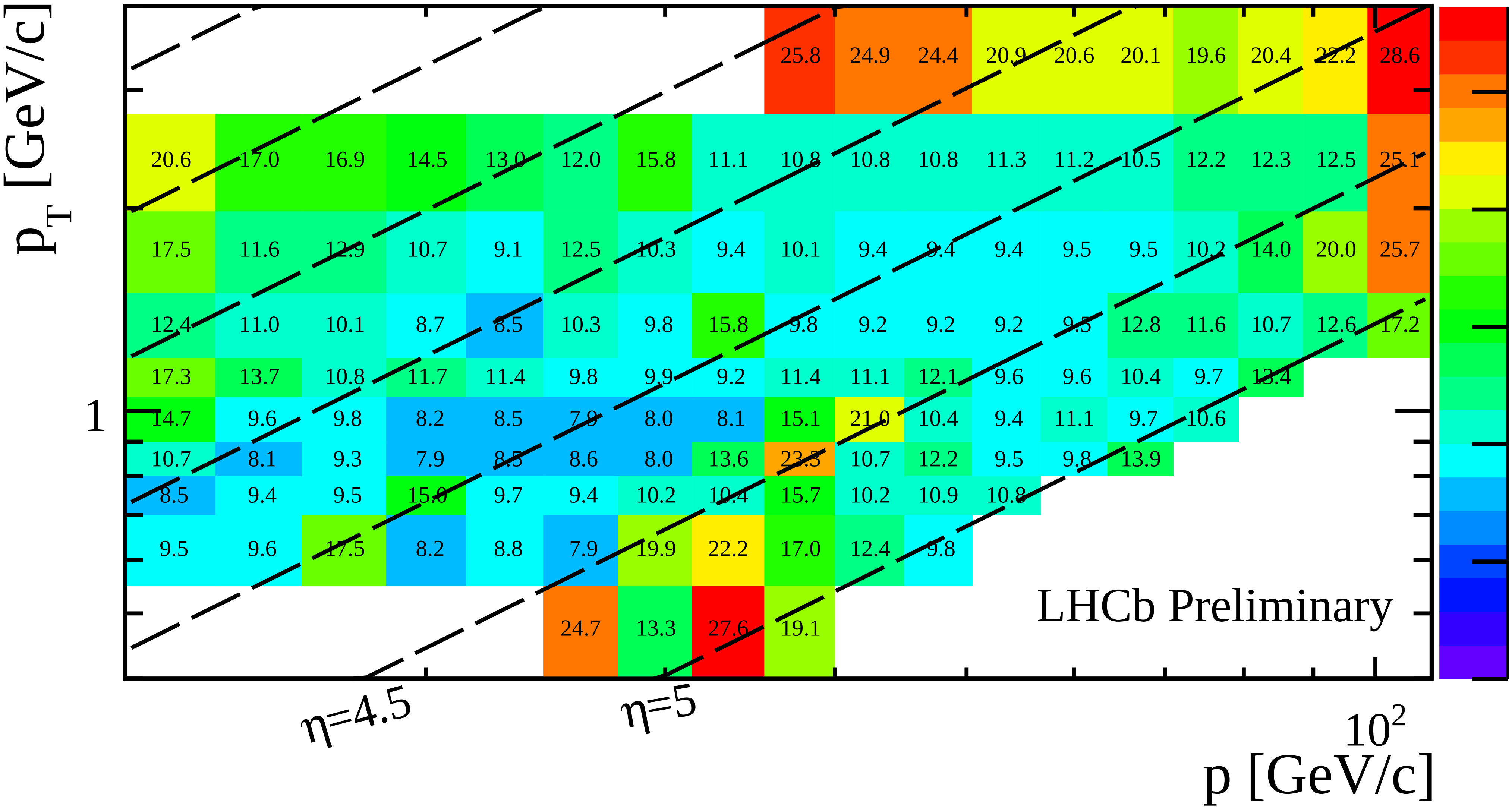

Result for cross section, compared with EPOS LHC

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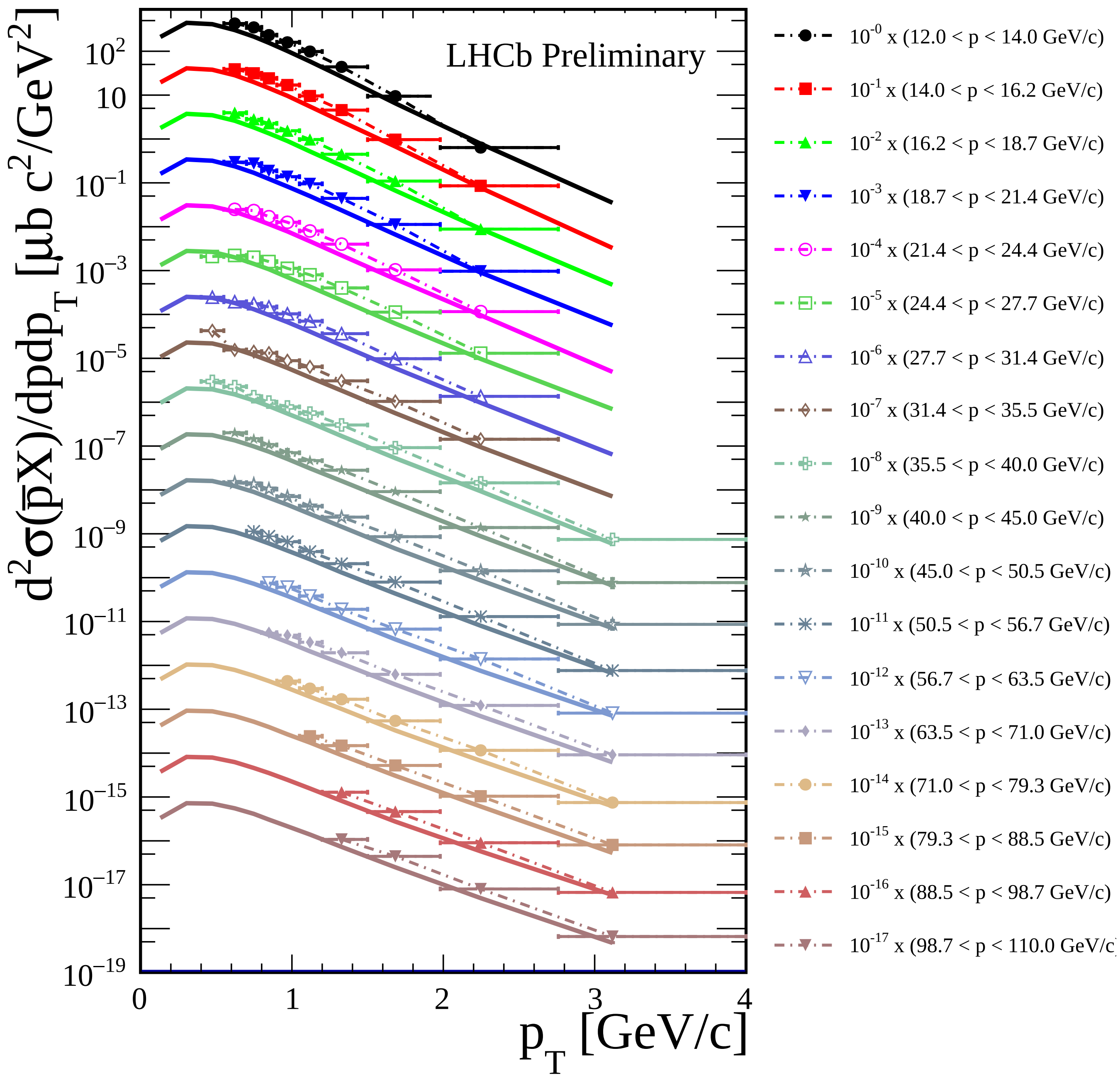

Result for **prompt** production (excluding weak decays of hyperons)

The total inelastic cross section is also measured to be

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

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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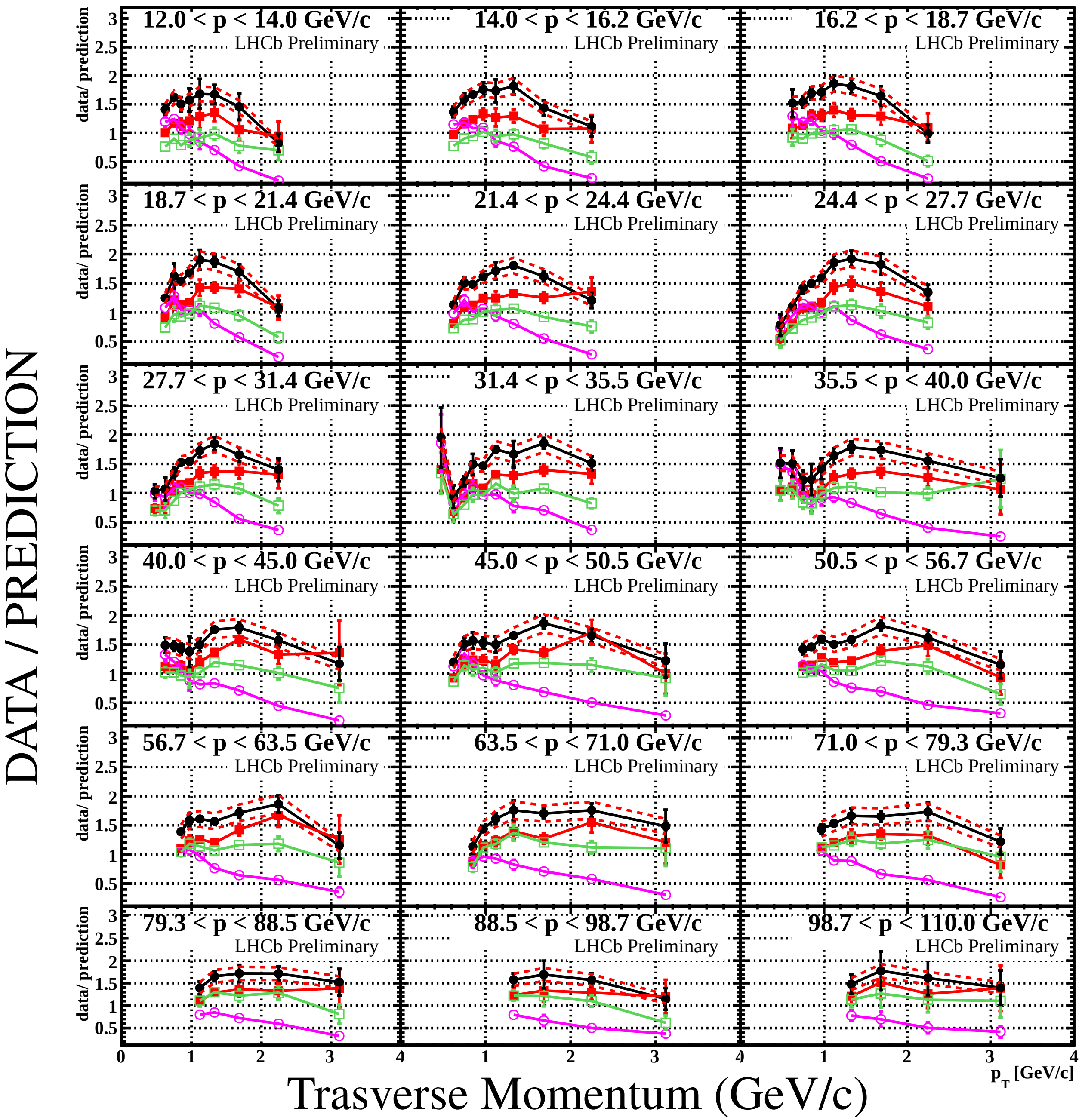

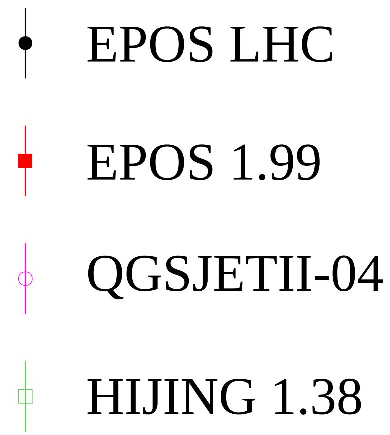

Cross section is larger by factor ~ 1.5 wrt EPOS LHC (mostly from larger $\overline{p}$ rate per collision).
Better agreement with EPOS 1.99 and HIJING 1.38

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 $\overline{\mathrm{p}}$ 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
- **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 $\overline{\mathrm{p}}$ 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!

Impact

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ANTIMATERIA COSMICA A LHC

L'esperimento LHCb, al Large Hadron Collider (LHC) del CERN, è riuscito a ricreare in laboratorio le collisioni cosmiche fra protoni, accelerati nell'anello a un'energia di 6,5 TeV, e atomi di elio a riposo. Si tratta della prima misura di produzione di antimateria in collisioni protone-elio, e rappresenta perciò un passo significativo verso una migliore comprensione della produzione secondaria di antiprotoni...

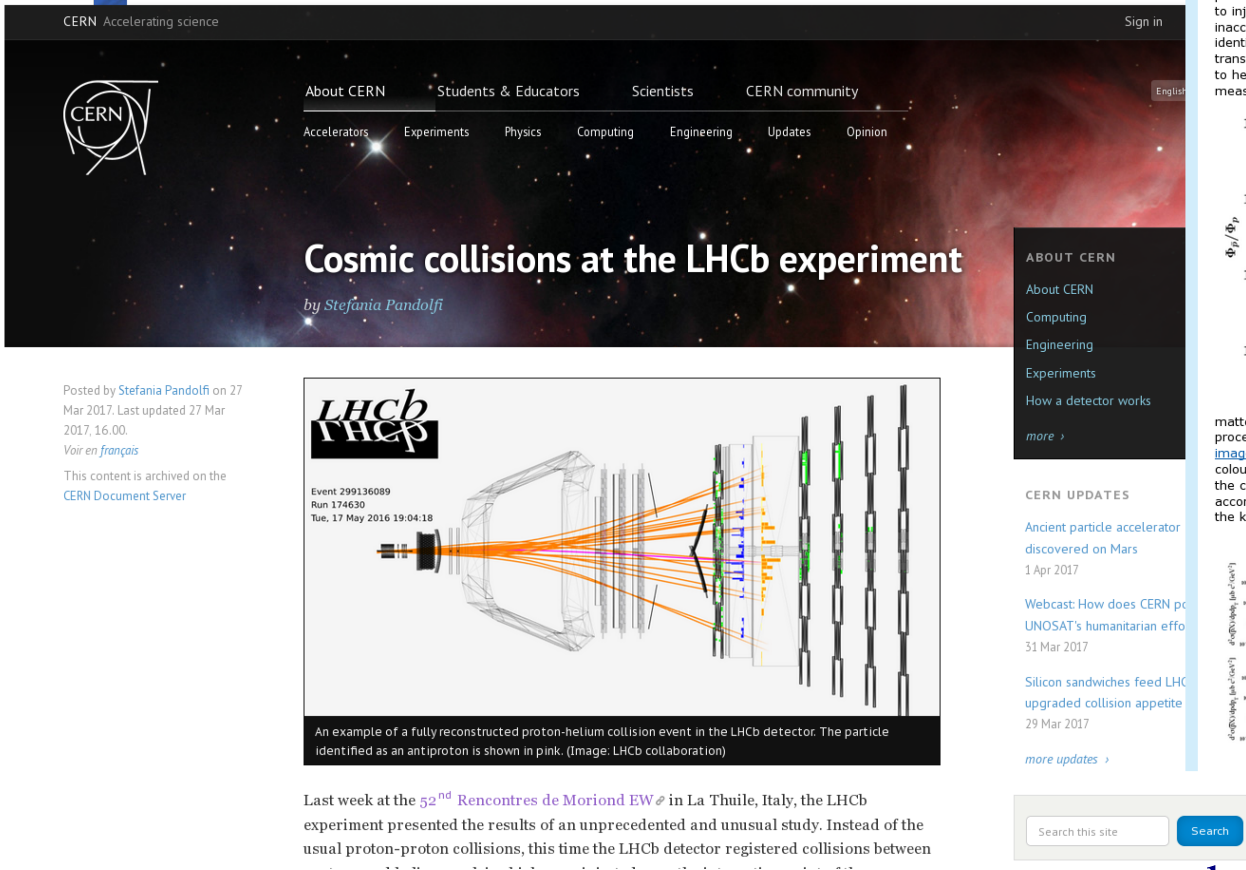
Read more

LINEE DI RICERCA

1 fisica delle PARTICELLE

2 fisica delle ASTROPARTICELLE

3 fisica NUCLEARE



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Cosmic collisions at the LHCb experiment

by Stefania Pandolfi

Posted by Stefania Pandolfi on 27 Mar 2017. Last updated 27 Mar 2017, 16.00.

Voir en français

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An example of a fully reconstructed proton-helium collision event in the LHCb detector. The particle identified as an antiproton is shown in pink. (Image: LHCb collaboration)

Last week at the 52nd Rencontres de Moriond EW in La Thuile, the LHCb experiment presented the results of an unprecedented and unusual study. Instead of the usual proton-proton collisions, this time the LHCb detector registered collisions between

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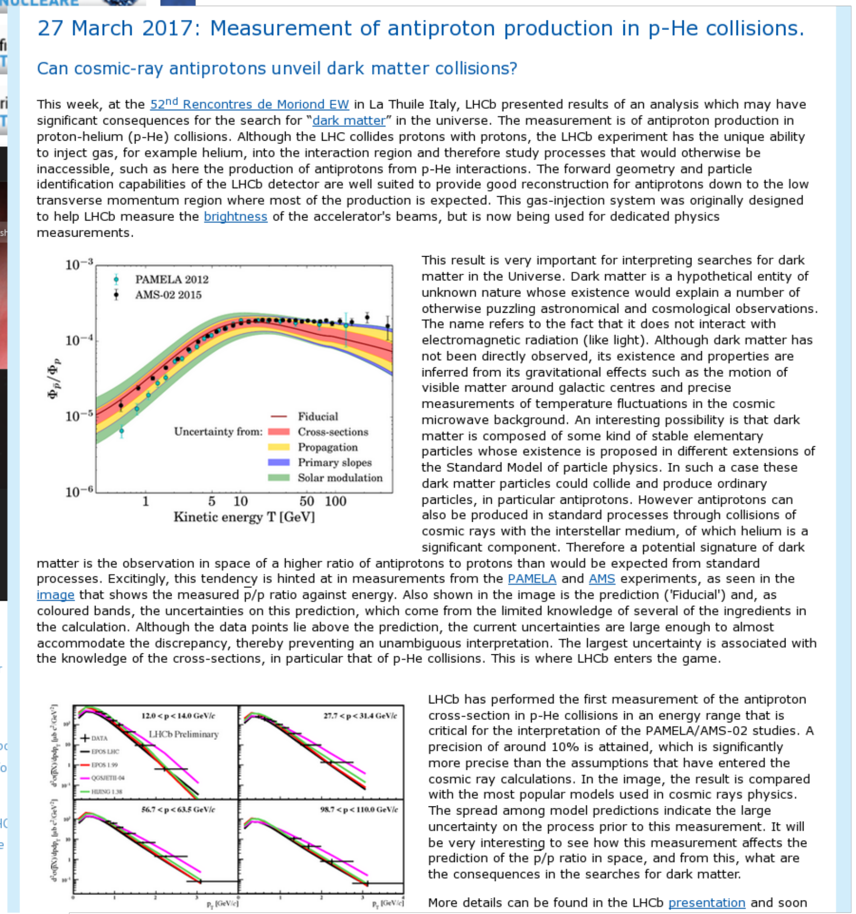

27 March 2017: Measurement of antiproton production in p-He collisions.

Can cosmic-ray antiprotons unveil dark matter collisions?

This week, at the 52nd Rencontres de Moriond EW in La Thuile Italy, LHCb presented results of an analysis which may have significant consequences for the search for "dark matter" in the universe. The measurement is of antiproton production in proton-helium (p-He) collisions. Although the LHC collides protons with protons, the LHCb experiment has the unique ability to inject gas, for example helium, into the interaction region and therefore study processes that would otherwise be inaccessible, such as here the production of antiprotons from p-He interactions. The forward geometry and particle identification capabilities of the LHCb detector are well suited to provide good reconstruction for antiprotons down to the low transverse momentum region where most of the production is expected. This gas-injection system was originally designed to help LHCb measure the brightness of the accelerator's beams, but is now being used for dedicated physics measurements.

This result is very important for interpreting searches for dark matter in the Universe. Dark matter is a hypothetical entity of unknown nature whose existence would explain a number of otherwise puzzling astronomical and cosmological observations. The name refers to the fact that it does not interact with electromagnetic radiation (like light). Although dark matter has not been directly observed, its existence and properties are inferred from its gravitational effects such as the motion of visible matter around galactic centres and precise measurements of temperature fluctuations in the cosmic microwave background. An interesting possibility is that dark matter is composed of some kind of stable elementary particles whose existence is proposed in different extensions of the Standard Model of particle physics. In such a case these dark matter particles could collide and produce ordinary particles, in particular antiprotons. However antiprotons can also be produced in standard processes through collisions of cosmic rays with the interstellar medium, of which helium is a significant component. Therefore a potential signature of dark matter is the observation in space of a higher ratio of antiprotons to protons than would be expected from standard processes. Excitingly, this tendency is hinted at in measurements from the PAMELA and AMS experiments, as seen in the image that shows the measured $\bar{p}/p$ ratio against energy. Also shown in the image is the prediction ('Fiducial') and, as coloured bands, the uncertainties on this prediction, which come from the limited knowledge of several of the ingredients in the calculation. Although the data points lie above the prediction, the current uncertainties are large enough to almost accommodate the discrepancy, thereby preventing an unambiguous interpretation. The largest uncertainty is associated with the knowledge of the cross-sections, in particular that of p-He collisions. This is where LHCb enters the game.

LHCb has performed the first measurement of the antiproton cross-section in p-He collisions in an energy range that is critical for the interpretation of the PAMELA/AMS-02 studies. A precision of around 10% is attained, which is significantly more precise than the assumptions that have entered the cosmic ray calculations. In the image, the result is compared with the most popular models used in cosmic rays physics. The spread among model predictions indicate the large uncertainty on the process prior to this measurement. It will be very interesting to see how this measurement affects the prediction of the $\bar{p}/p$ ratio in space, and from this, what are the consequences in the searches for dark matter.

More details can be found in the LHCb presentation and soon

and on the next CERN Courier issue…