LHCb inputs to astroparticle physics

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INFN Cagliari and CERN

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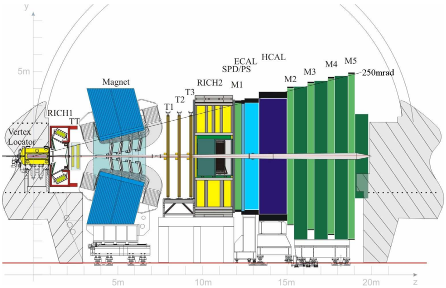
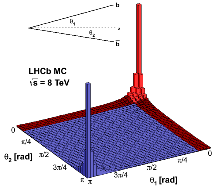
The LHCb detector

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



LHCb is an experiment dedicated to the study of heavy flavors

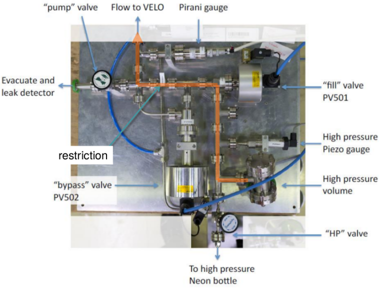
- Biggest *b* and *c* factory so far
- Search for CP violation and rare decays



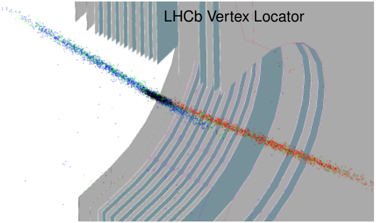
- Typical **geometry of a fixed target experiment**, to optimise the $b\bar{b}$ acceptance
- Good vertex resolution and tracking
- Excellent particle identification (RICH: π, K, p - CALO: e, γ, π^0 - MUON)
- Fast, efficient and flexible high bandwidth trigger system

The SMOG system

- The uncertainty on the integrated luminosity plays a role in the cross-section measurements
- LHCb introduced the **SMOG** (System for Measuring the Overlap with Gas) to complement the van der Meer scan luminosity measurement with a very precise determination (1.2%)
- The proton collisions with the noble gas atoms (He, Ne, Ar) in the beam-pipe allow the 3D beam reconstruction
- It can be used as an internal gas target for a rich physics programme
    - Coverage in the SPS - LHC energy: pA interactions at $\sqrt{s} \sim 100$ GeV
    - Probing large-x nPDF (intrinsic charm): also relevant for neutrino astronomy
    - Soft QCD: relevant for modelling of cosmic ray showers in the atmosphere



JINST 9, (2014) P12005



Charm x-sec in *p*-Ar collisions

- First result from the LHCb fixed target program
- Few nb^{-1} p-Ar collision data sample
- Measurement limited by statistics but proof of principle for future developments
- High-x PDF can be already constrained

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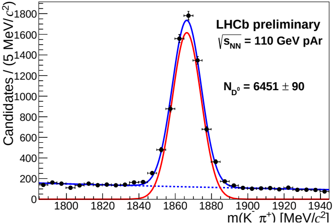
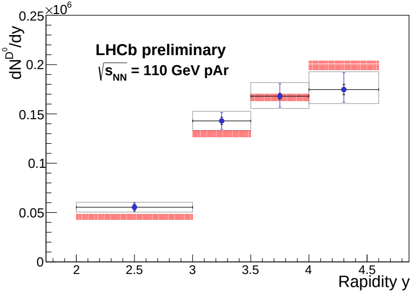
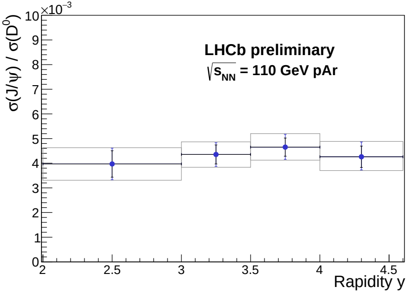


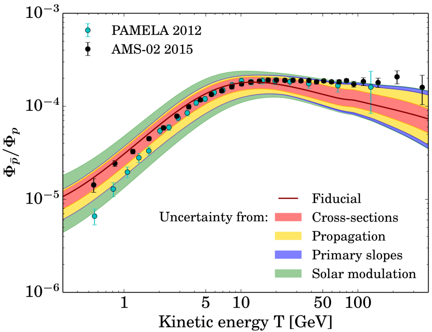


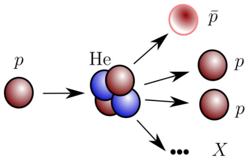


Cosmic antiprotons

- The fraction of antiprotons in cosmic rays has been measured with high precision by AMS-02 [PRL 117, 091103 (2016)]
- This confirmed the measurement by PAMELA [Nature 458 (2009) 607-609]
- Some dark matter models favour this scenario, but the uncertainty is big
- The biggest uncertainty is due to primary cosmic ray (protons) collisions with interstellar matter (H and He)
- The antiproton cross-section in p-He collisions has never been measured
- Predictions based extrapolating measurements at low energy (SPS)

JCAP 1509 (2015) no.09, 023





The p-He collisions

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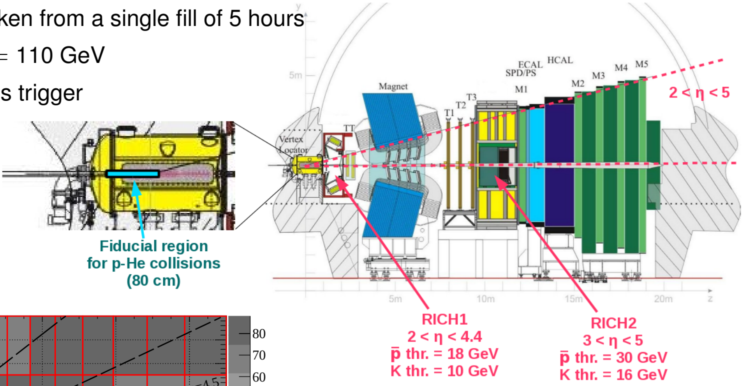
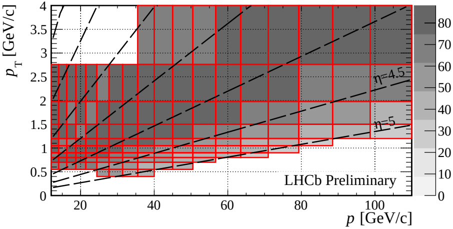
- Data taken on May 2016
- Most data taken from a single fill of 5 hours
- Energy $\sqrt{s} = 110$ GeV
- Minimum bias trigger



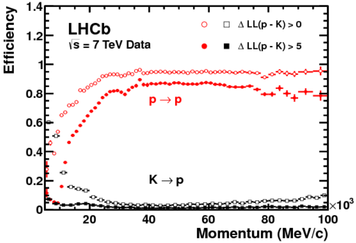


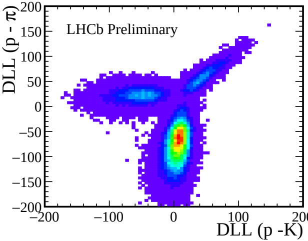
- Total efficiency: acceptance x reconstruction
- Cross-check of tracking efficiency from data
- Kinematical region: $12 < p < 110$ GeV
  $p_T > 0.4$ GeV

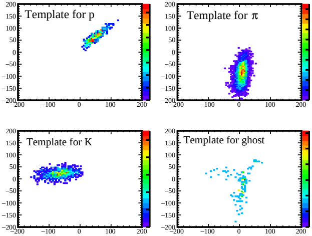
Antiproton identification

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

- Use RICH information to build likelihood function for particle hyphothesis
- Use difference of log likelihood (DLL) between $\bar{p}$ and $K(\pi)$
- Fit the 2D DLL distributions with templates from the calibration samples







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Number of signal events

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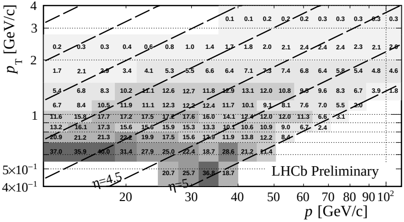
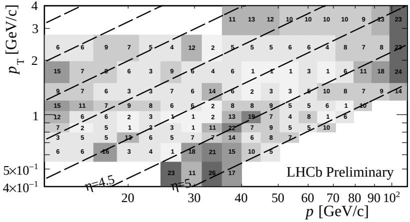
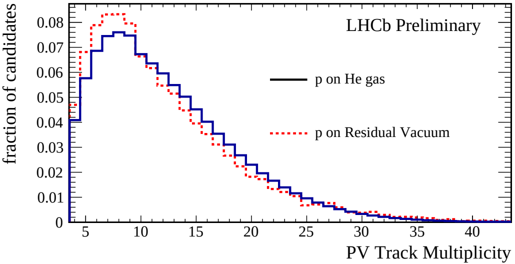
- The systematic uncertainty due to the PID analysis is dominating in most bins
- Large uncertainties (up to 26%) affect the bins at the border of the detector acceptance and for intermediate momentum and pseudorapidity region





Backgrounds

- **Non-prompt antiprotons**: LHCb-CONF-2017-002
  - 90%: hyperon decays, 10%: $\bar{p}$ coming from secondary collisions with detector material
  - Suppressed with impact parameter requirements
  - Residual $(2.6 \pm 0.6)\%$ subtracted
- **Residual vacuum**
  - Computed from the yields in no-gas data: about 15% of delivered p on target acquired before He injection (but with identical vacuum pumping configuration): $(0.6 \pm 0.2)\%$
  - Slightly lower multiplicity in no-gas data, but longer tail
  - Residual vacuum dominated by hydrogen, with small contribution from elements heavier than He



Normalisation

- **Elastic scattering of single electrons on proton beam**

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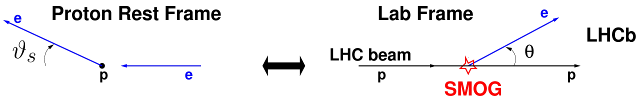
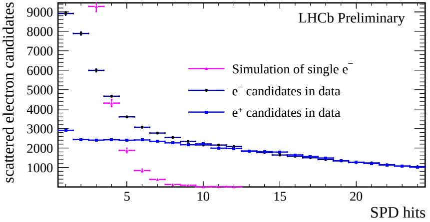


- Process with a well-know cross-section, though small (100μb)
- It can be observed within the LHCb acceptance (10 $< \theta <$ 250 mrad)
- Signature: single low-p and low-p_T electron track visible in the detector

- **Background**: soft nuclear interactions, with electrons coming from γ conversion or a light hadron from a Central Exclusive Production
- Charge symmetric $\rightarrow$ model in data with a single positron



- Reconstruction inefficiency due to bremsstrahlung energy loss
- Reduction in acceptance due to low momentum

Normalisation

- Excellent agreement with the simulation
- Validity of the charge symmetric background hypothesis

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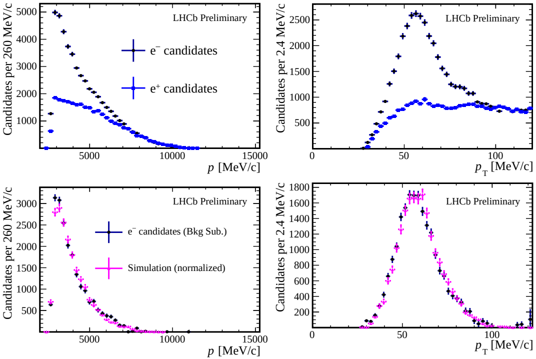

- The luminosity is determined as

$$\mathcal{L} = \frac{N_e}{Z_{He} \times \sigma_{pe^-} \times \varepsilon_e} = 0.443 \pm 0.011 \pm 0.027 \text{ nb}^{-1}$$

Uncertainties on the cross-section

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

- Precision of the **measurement limited by the systematic uncertainty**

Total relative uncertainty per bin (%)

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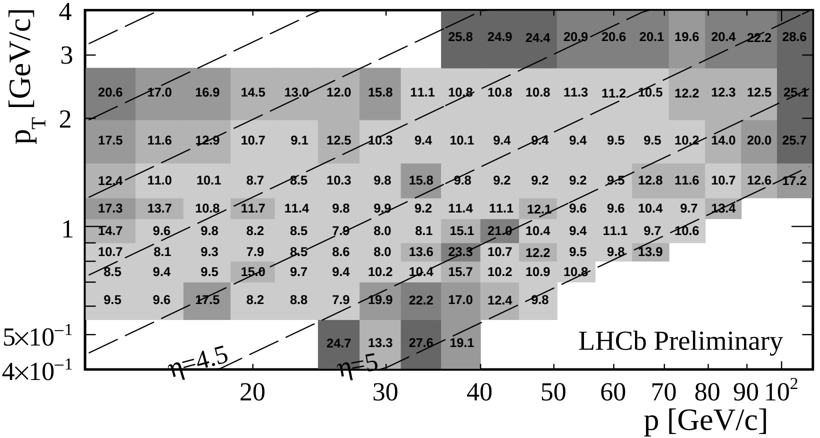

Results

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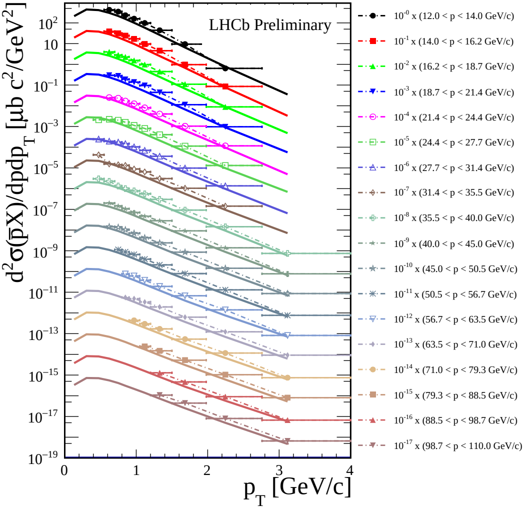
- Results compared to the EPOS LHC prediction
- Double differential shape in good agreement
- Absolute production rate larger of $\sim$ 1.5
- Inelastic cross-section

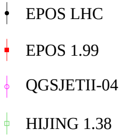
$$\sigma_{inel}^{LHCb} = (140 \pm 10)\ \text{mb}$$

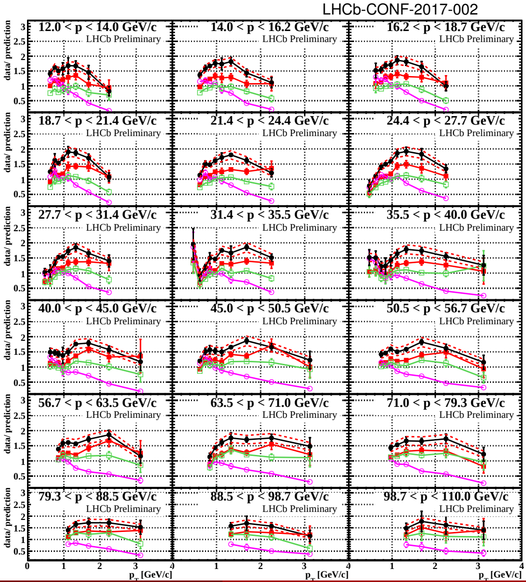
$$\sigma_{inel}^{EPOS} = 118\ \text{mb}$$

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



Ratio with models





- Results compared to other predictions
- Better agreement with EPOS 1.99 and HIJING 1.38

Conclusions and prospects

- The SMOG system started the possibility for LHCb to study proton collisions on a fixed gas target
- LHCb can study p-He collisions emulating cosmic ray interactions with interstellar medium
- The result is expected to have an important role on the accuracy of the prediction for the $p/\bar{p}$ ratio expected in cosmic rays from spallation of primary p with interstellar medium

- More to come:
  - Inclusion of data collected at $\sqrt{s_{NN}} = 86.6$ GeV in November 2016
  - Measurement of the contribution due to hyperon decays
  - Charged particle yields, particle/antiparticle ratios, positrons, gamma, charm, deuterons

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Thanks for your attention!

Backup