Production studies for Cosmic Ray Physics

LHCb on a Space Mission

Giacomo Graziani
(INFN Firenze)

on behalf of the LHCb Collaboration

Workshop on
LHCb Ion and
Fixed Target Physics

CERN, Jan 9, 2017

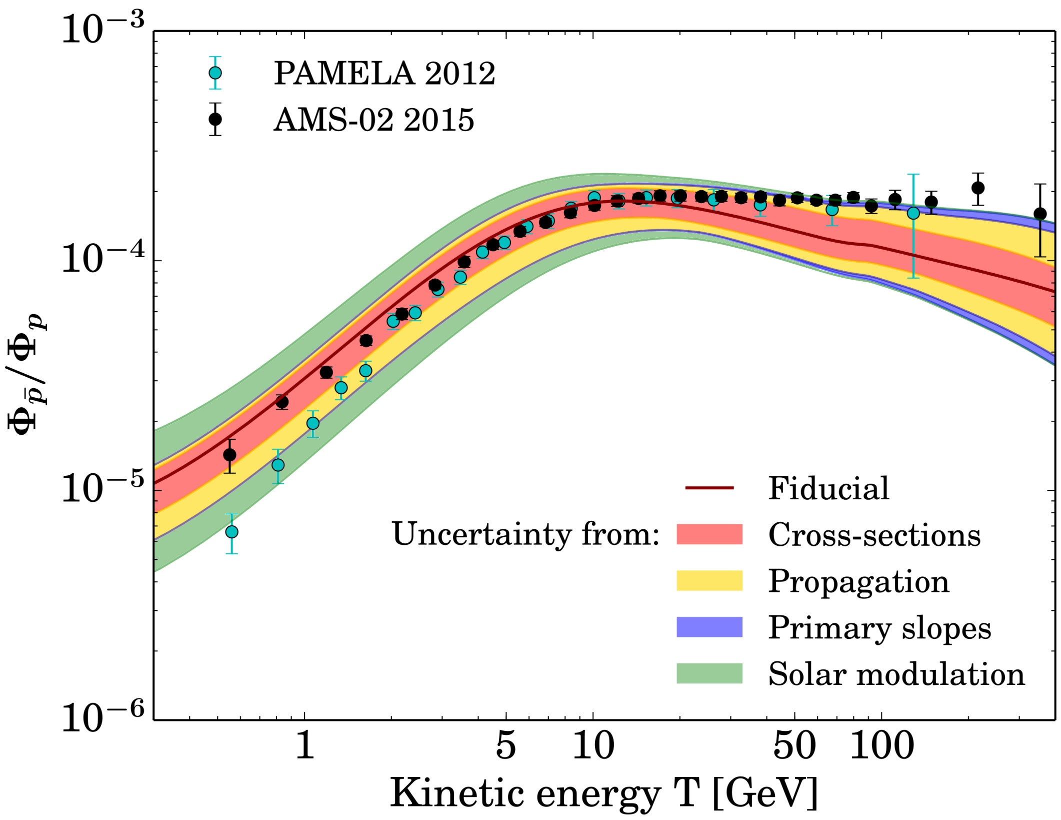
LHCb as a Cosmic Rays Experiment

- LHCb in fixed target configuration allows to access particle production at large x
- Important to better model backgrounds for high-p_{T} collider physics
- Some measurements can also have great impact to **astroparticle physics** through understanding of particle production from cosmic rays interactions in cosmos and atmosphere:
  - Production of **antimatter from cosmic rays collisions** ($\overline{\mathrm{p}}$, e^+, $\bar{d}$, $\bar{t}$, $\overline{He}$) on interstellar medium (H, He)
  - Secondary gamma production is main background for **gamma ray astronomy**
  - Interpretation of **high energy neutrino astrophisics** results (notably by IceCube) requires understanding of charm production.

This talk will focus on the first CR-inspired analysis in LHCb:
measurement of antiproton producton in p-He collisions

Antiproton production in pHe: motivation

- recent results from AMS-2 above 10 GeV lie above predictions from secondary production in the interstellar medium (mostly $p-He$, $p-p$, $He-p$ to $\bar{p}X$) and exhibit flatter energy dependence than expected
- conservative estimates on the related uncertainties show that the results could still fit with secondary production



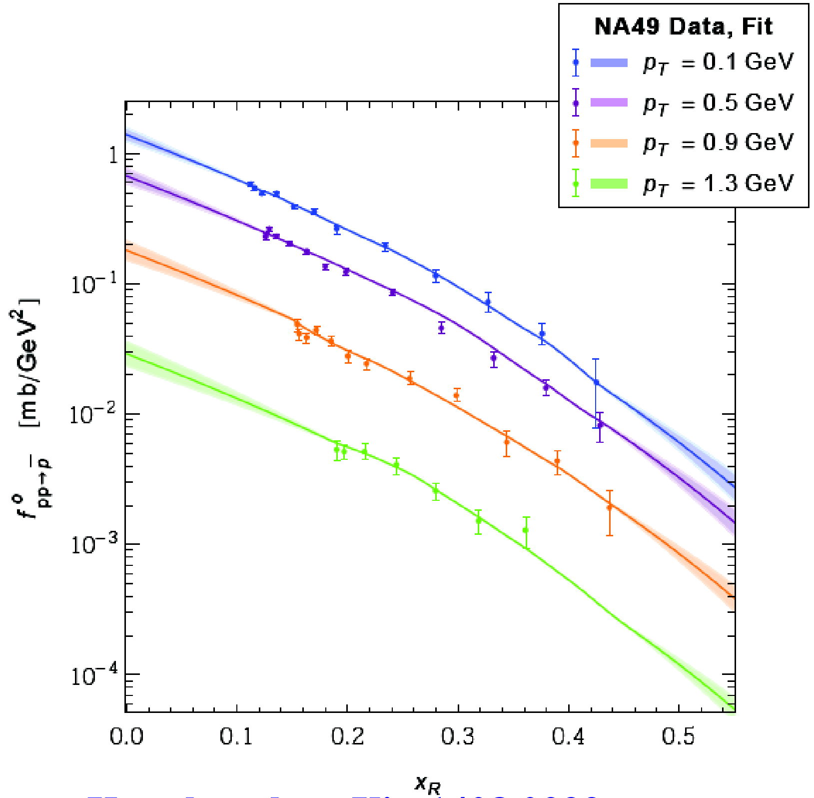
Giesen et al., arXiv:1504.04276

- **uncertainty on production cross section, notably $\sigma(pHe \rightarrow \bar{p}X)$, is still limiting the interpretation in the 10 - 100 GeV range (primary proton energy $\sim$ TeV)**

Fixed target configuration with LHC beam ideal to perform these production measurements!

Prediction of secondary production

- Most calculations are extrapolating direct measurements of $p + p \to \overline{p} + X$. The most important data are those from NA49, taken at $\sqrt{s} = 17.3$ GeV and covering only $x_R > 0.11$ (where $x_R = E_{\overline{p}}^{LAB}/max(E_{\overline{p}}^{LAB})$ is an alternative scaling variable, preferred to x_F in this case as scaling vs $\sqrt{s}$ is less broken)



Kappl et al., arXiv:1408.0299

- largest error on $p + p$ comes from the extrapolation at low x_R, and the uncertainty on hyperon contribution;
- **no** $p + He$ **measurement available**, difference wrt pp estimated from NA49 data on $p + C$

- "first principle" calculations based on effective models have larger uncertainties, but can also be improved by measuring differential distributions of all particles pp datasets currently used:

LHCb potential contribution

from Di Mauro et al., arXiv:1408.0288

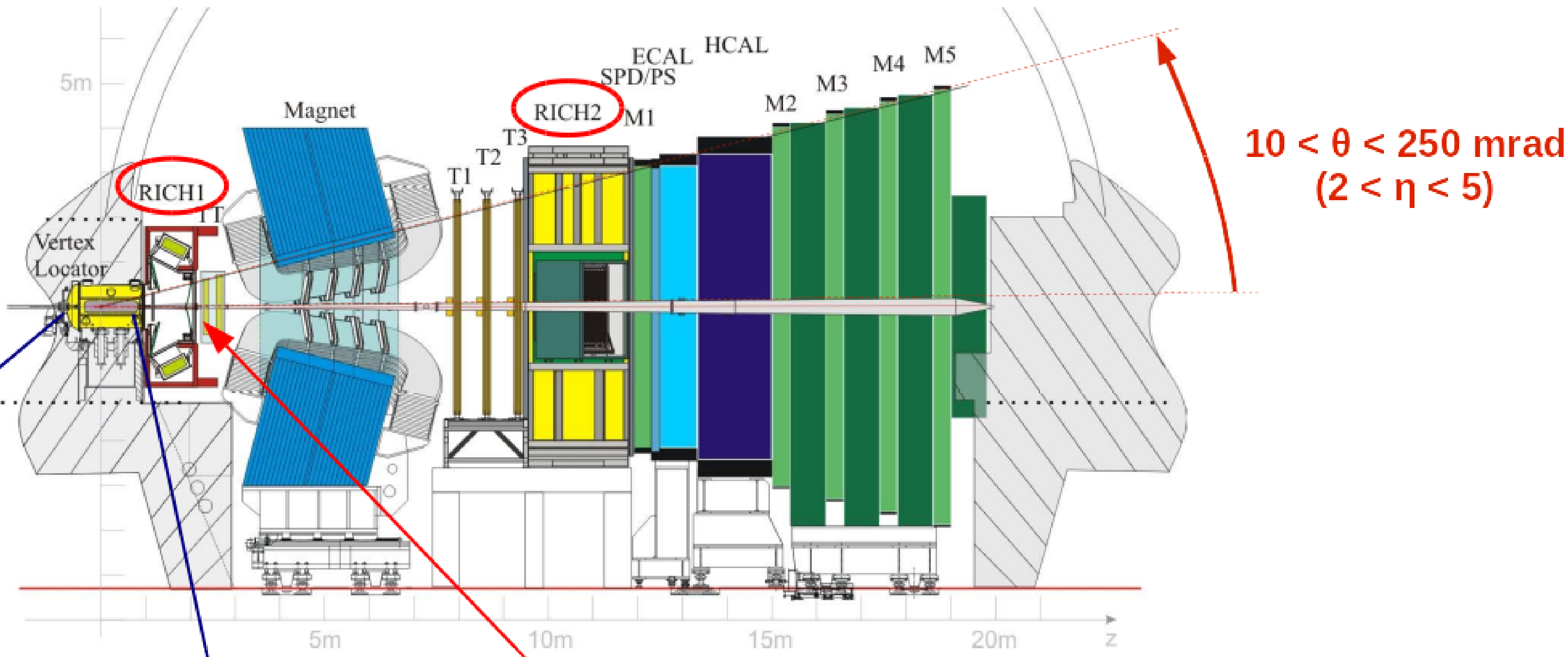
Experiment	$\sqrt{s}$ (GeV)	p_T (GeV)	x_R
Dekkers *et al*, CERN 1965 [18]	6.1, 6.7	$(0., 0.79)$	$(0.34, 0.65)$
Allaby *et al*, CERN 1970 [19]	6.15	$(0.05, 0.90)$	$(0.40, 0.94)$
Capiluppi *et al*, CERN 1974 [20]	23.3, 30.6, 44.6, 53.0, 62.7	$(0.18, 1.29)$	$(0.06, 0.43)$
Guettler *et al*, CERN 1976 [21]	23.0, 31.0, 45.0, 53.0, 63.0	$(0.12, 0.47)$	$(0.036, 0.092)$
Johnson *et al*, FNAL 1978 [22]	13.8, 19.4, 27.4	$(0.25, 0.75)$	$(0.31, 0.55)$
Antreasyan *et al*, FNAL 1979 [23]	19.4, 23.8, 27.4	$(0.77, 6.15)$	$(0.08, 0.58)$
BRAHMS, BNL 2008 [13]	200	$(0.82, 3.97)$	$(0.11, 0.39)$
NA49, CERN 2010 [14]	17.3	$(0.10, 1.50)$	$(0.11, 0.44)$
LHCb pHe	110	(0.1, 5.0)	(0.02, 0.30)
			$(-0.30 < x_F < 0.02)$

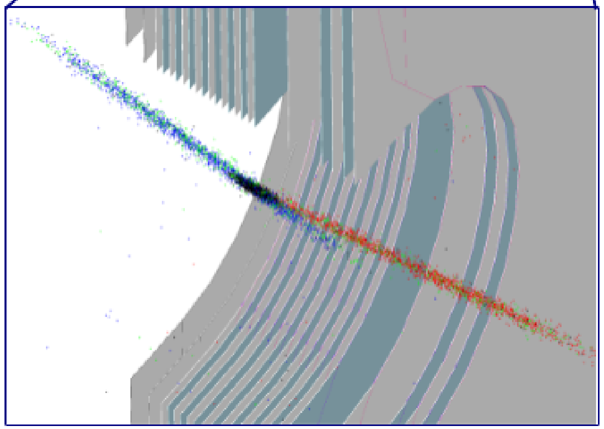
expected total pHe cross section is ~190 mb,

$\sigma(pHe \to \bar{p}\,\mathrm{X};\ 2.5 < \eta < 5,\ p > 10\ \mathrm{GeV/c}) \sim 8$ mb

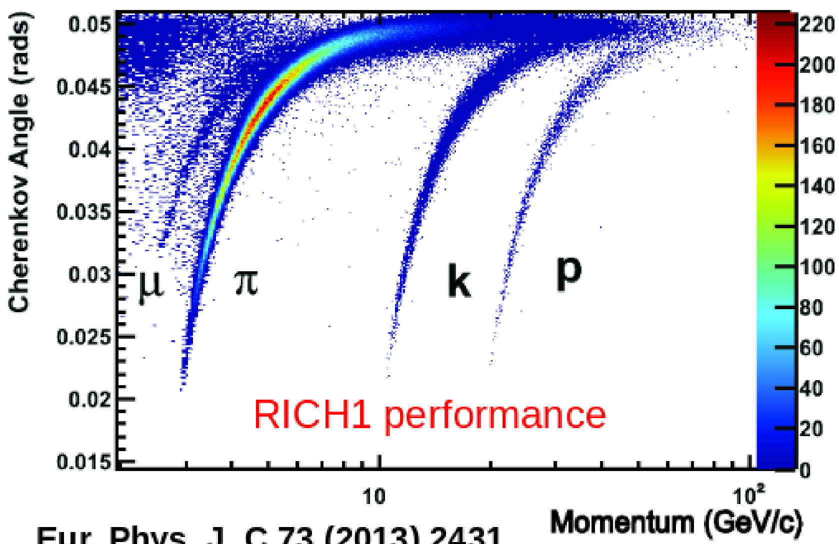
A valuable measurement can be performed with ~ 1/nb of data,
i.e. in a few hours with LHC beam on the SMOG He target

LHCb Detector



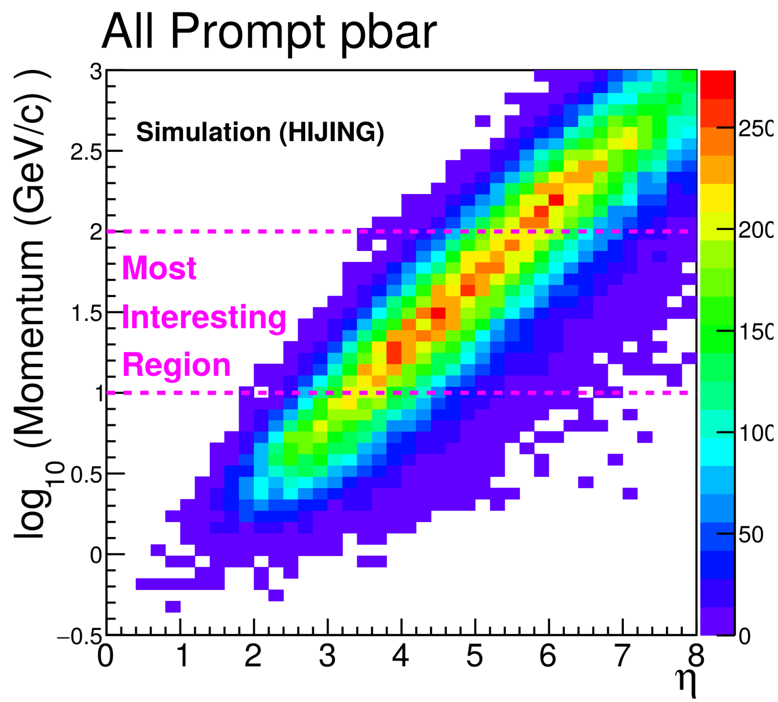


Beam-gas reconstructed vertexes
in the Vertex Locator

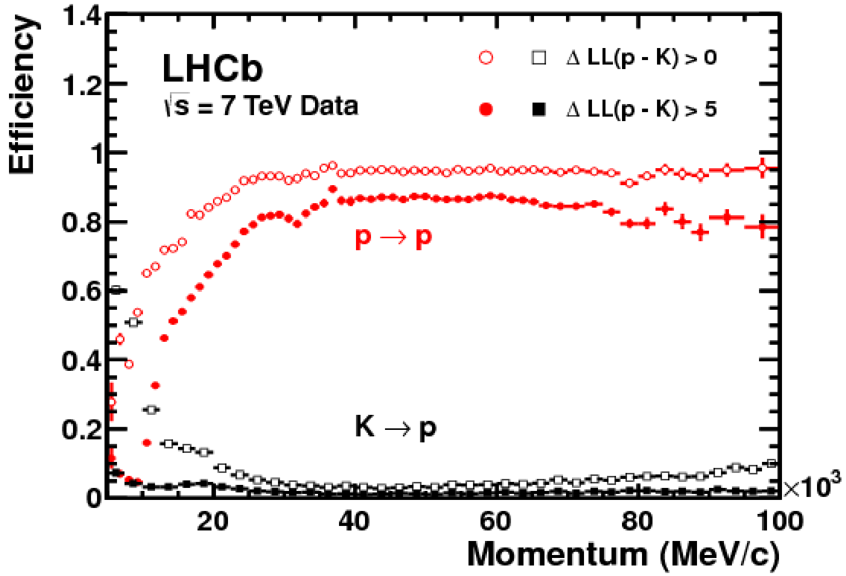


Eur. Phys. J. C 73 (2013) 2431

Expected reconstruction efficiency



Prompt $\overline{p}$ reconstruction with full MC simulation using HIJING



Proton identification performance

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

Identification efficiency and misid. probability can be precisely measured in data using control samples (Λ, K^0_S, D^0 decays)

LHCb covers the most interesting region (10 - 100 GeV) with high efficiency

Timeline of p-He Runs

May 2015, proposal to LHCb from "astroparticle" colleauges:
O. Adriani, L. Bonechi, A. Tricomi (LHCf, PAMELA), F. Donato (theory)

September 2015, 6.5 TeV pilot run
Using special LHC run (459 bunches, 87 non colliding) with 6.5 TeV protons

May 2016, 6.5 TeV run during runs for Van der Meer scans

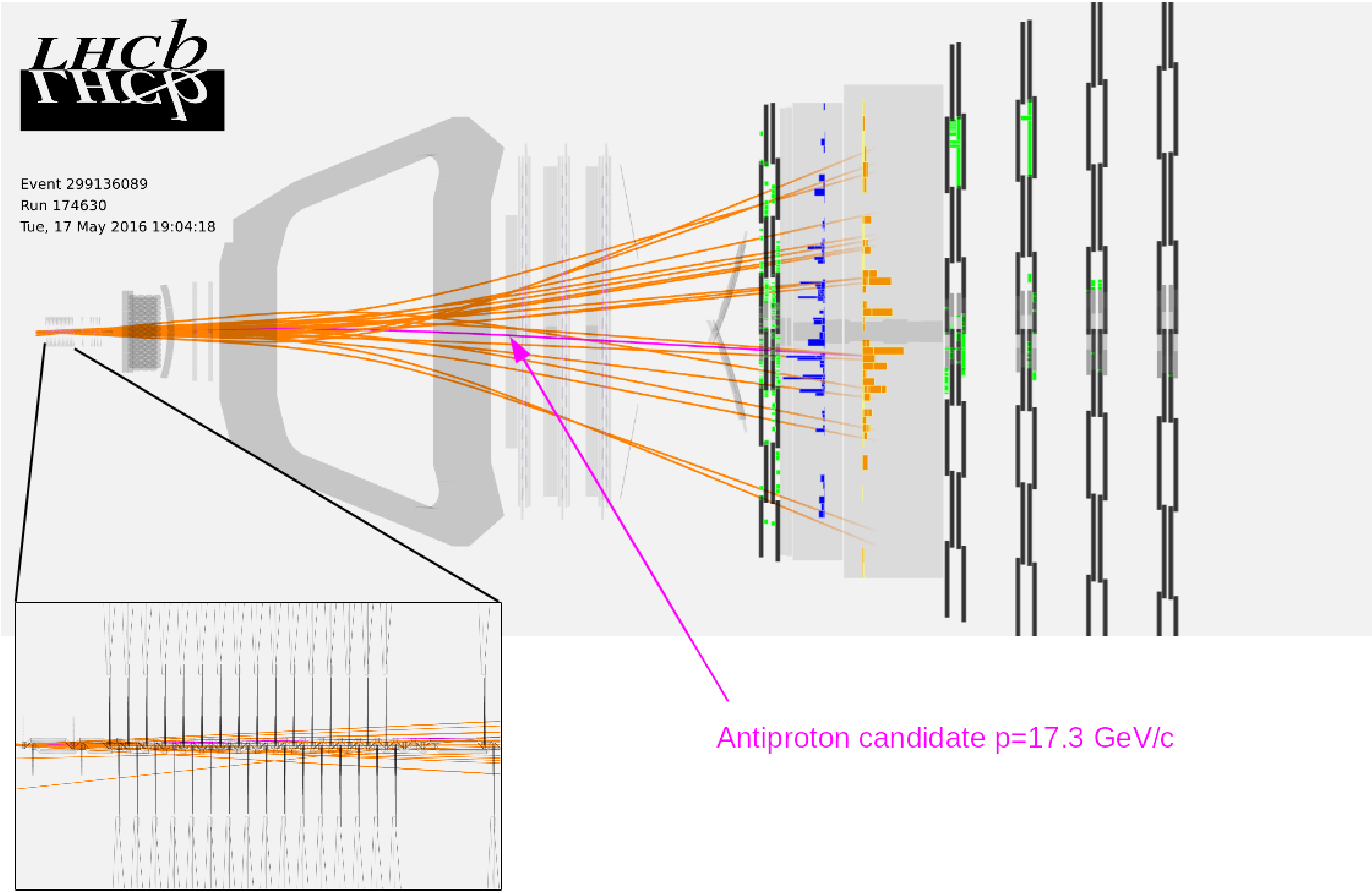
- acquired in better conditions (lower beam intensity, better control on gas contamination)
- more than 300M pHe minimum bias collisions recorded

November 2016, 4 TeV run during p Pb run at $\sqrt{s}$ =5 TeV (proton beam energy of 4 TeV)

- additional data at different energy

All data acquired with very low-bias trigger, only requiring one reconstructed track in the vertex detector and any activity in the SPD scintillator counter

p He Event Display



Analysis strategy

Goal is to measure $\sigma(pHe \rightarrow \bar{p}\,\mathrm{X})$ in bins of p, p_{T}, $x_{F(R)}$, with **error within 10 %** (current estimated uncertainty is $\sim 20\%$)

Reconstruction and identification performance for antiprotons well demonstrated in LHCb

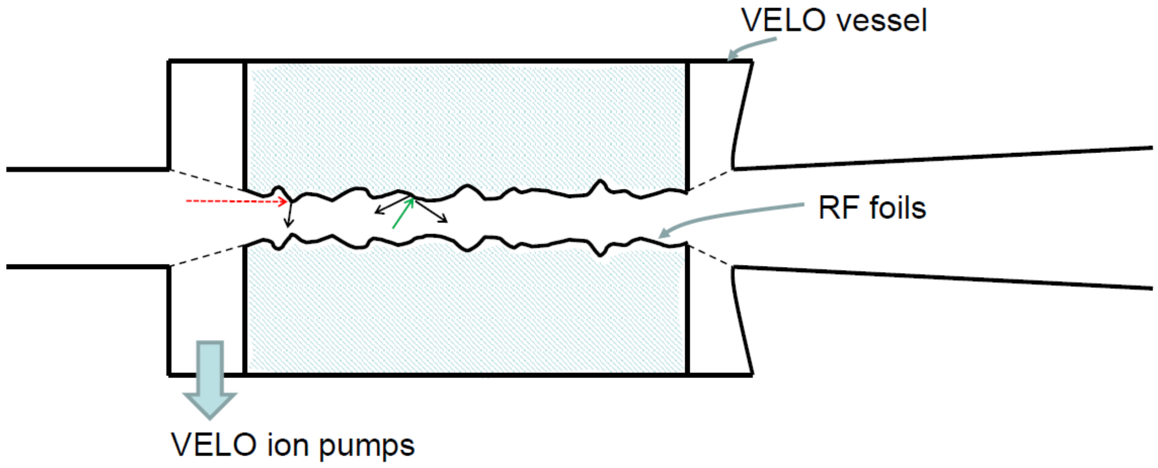
Two non-standard concerns:

1. Purity of Helium target: gas injected by SMOG at pressure $\sim 2 \times 10^{-7}$ mbar, residual gas in the LHC pipe, notably high-Z contaminants, can produce non negligible background
2. Normalization for cross-section measurement, since He density in SMOG is not precisely known

1. Helium Purity

Possible target contamination:

- Static beam vacuum effects: Rest Gas Analysis performed by CERN Beam Vacuum group after the runs.
- Dynamic beam vacuum effects (beam-induced outgassing from RF foils) are also possible.

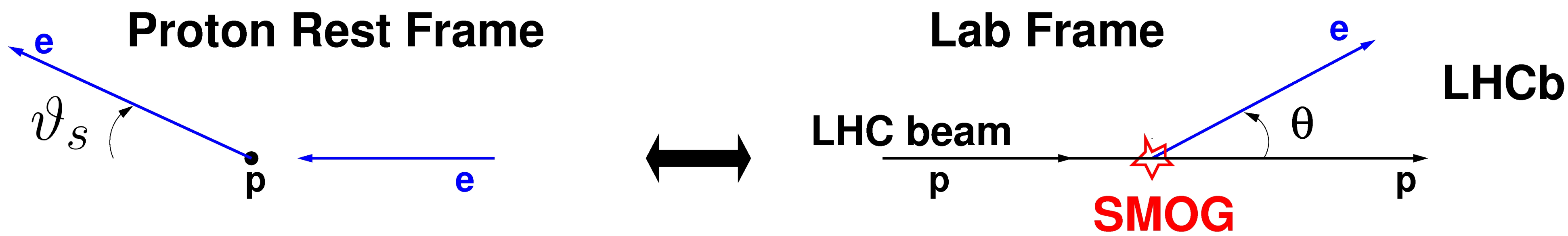


To measure the total background, about 1 hour of data was taken without He gas injected in SMOG, but with the same configuration of vacuum pumps/valves of the measurement.

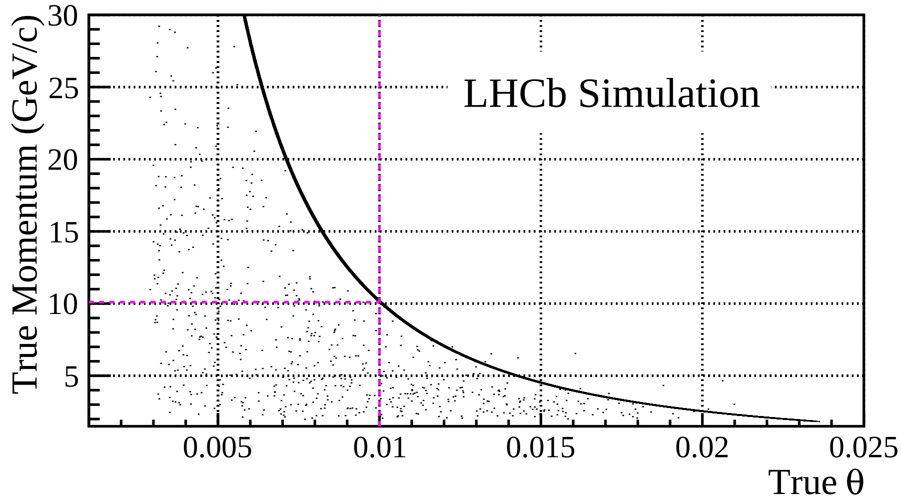
This allows to measure and subtract the background contribution.

2. Normalization: p-e^- elastic scattering

Since He pressure is not precisely known, a reference process with known cross-section is needed. Idea is to use **proton-electron scattering**

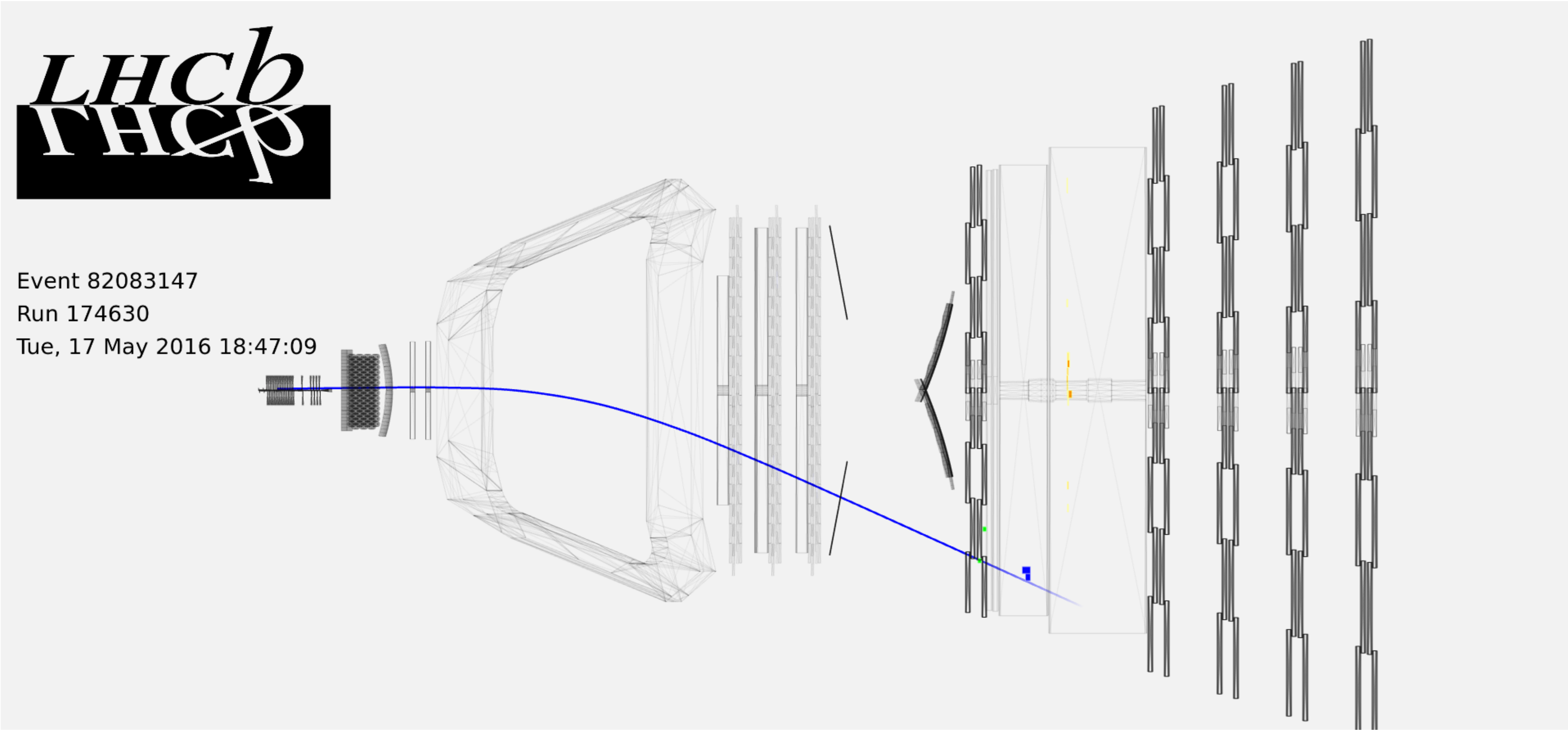


For a 6.5 TeV beam, LHCb acceptance $(10 < \theta < 250$ mrad) for scattered electrons corresponds to a scattering angle $\vartheta_s < 29$ mrad in proton rest frame
➡ $Q^2 < 1 \times 10^{-2}$ GeV^2, **elastic regime!**



Cross-section: $$Z_{He} \times \sigma(pe^- \rightarrow pe^-, 10 < \theta < 25\text{mrad}) = 0.26 \text{ mb}$$

Typical single electron event



single electron candidate with momentum of 3.0 GeV/c,
well identified in the ECAL

Expected Reconstruction performance

Reconstruction and identification of these events is quite challenging:

- Small angles and momentum: bremstrahlung losses and large acceptance effects due to the spectrometer field
  ➡ poor momentum reconstruction ($\sigma(p)/p \sim 20$ %)
  poor electron identification performance
- However, good polar angle reconstruction ($\sigma(\theta) = 1$ mrad) allows to know the position of the scattering with $\sim$ 10 cm accuracy along the beam direction

Background from p-nuclei scattering:

- Require no or low activity in the detector beyond e^- candidate
- Expected residual background from charge-symmetric contributions:
  - soft (diffractive) hadron production, with single $\pi^\pm$ in LHCb acceptance
  - γ conversion, with single $e^\pm$ in LHCb acceptance

  ➡ background can be subtracted relying on charge simmetry

Summary and Prospects

- LHCb has the potential to provide important, and unexpected, contributions to astroparticle physics
- The first of such production measurements, $\overline{\mathrm{p}}$ production in pHe collisions, is on its way:
  - data already acquired for 6.5 and 4.0 TeV proton energy ;
  - LHCb has good acceptance and reconstruction capabilities in the 10-100 GeV range;
  - He purity looks under control;
  - Proton - electron elastic scattering can provide the normalization with the required accuracy;
- We are starting to develop this program, many other production studies are possible
- Feedback from the astroparticle community is very welcome