Measurement of the $\bar{p}$ production cross-section in pHe collisions with the LHCb experiment at CERN

Lucio Anderlini
on behalf of the LHCb Collaboration

Istituto Nazionale di Fisica Nucleare
Sezione di Firenze

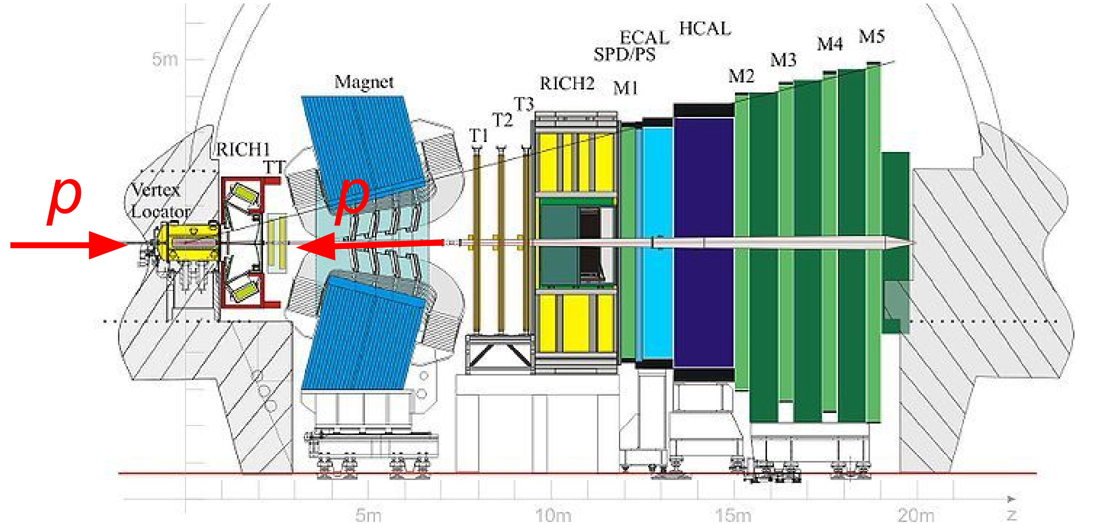
LHCb: fixed-target geometry installed at a collider

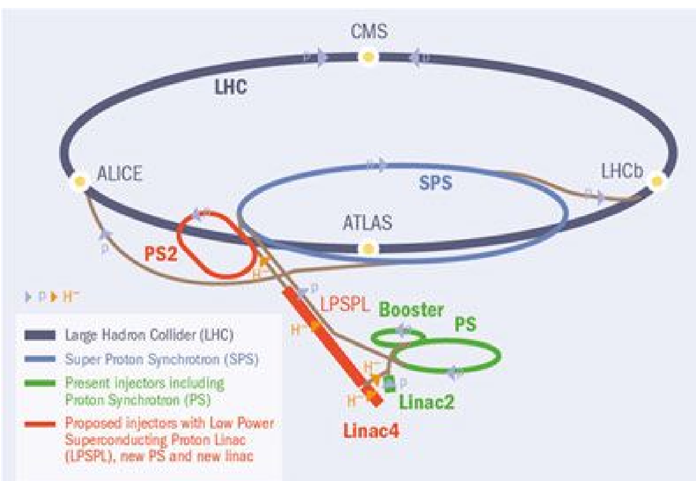
The LHC *pp* collisions are the most intense *b*-quark source on Earth.

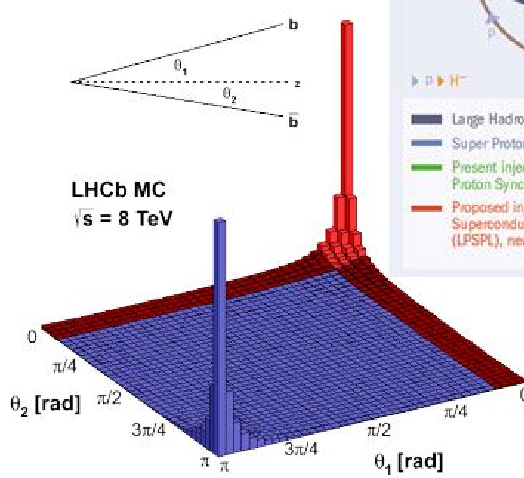
LHCb is the LHC experiment originally designed for heavy flavour physics.

Today considered a "general purpose detector" in the forward region.

To enhance acceptance for heavy hadrons (with *b* and *c* quarks), LHCb has a "forward" geometry customary at fixed-target experiments.

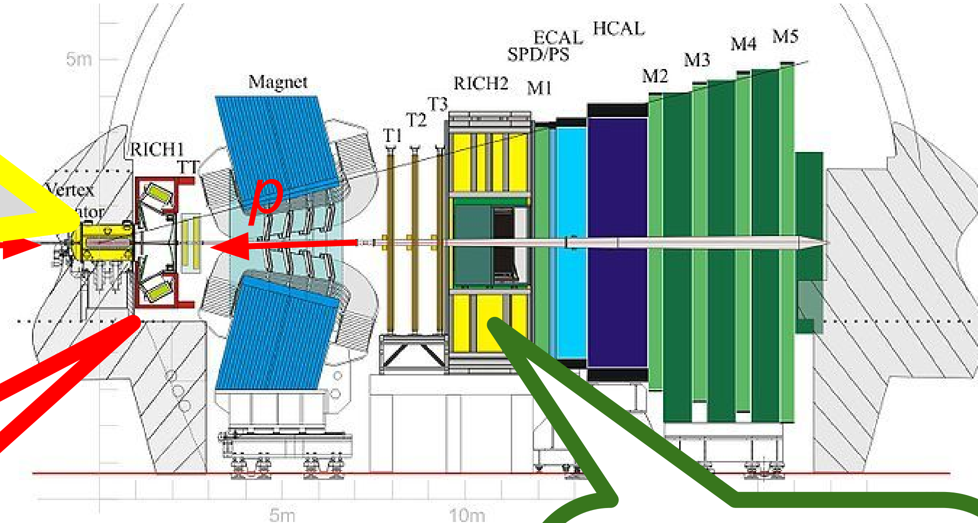


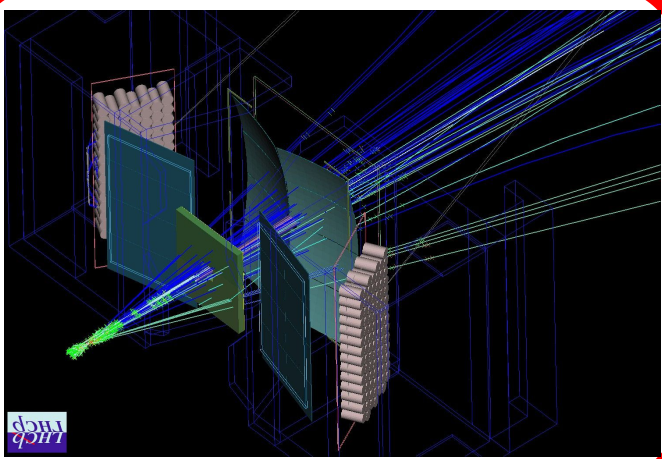


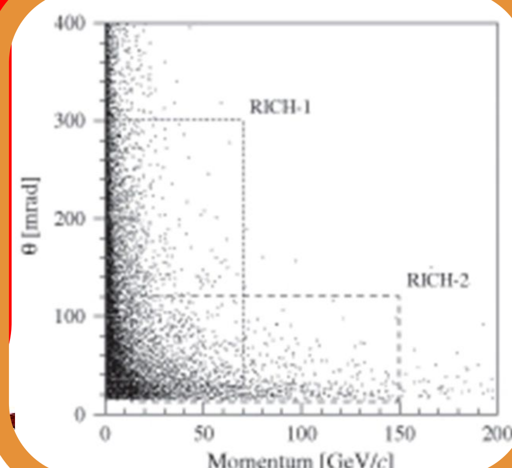


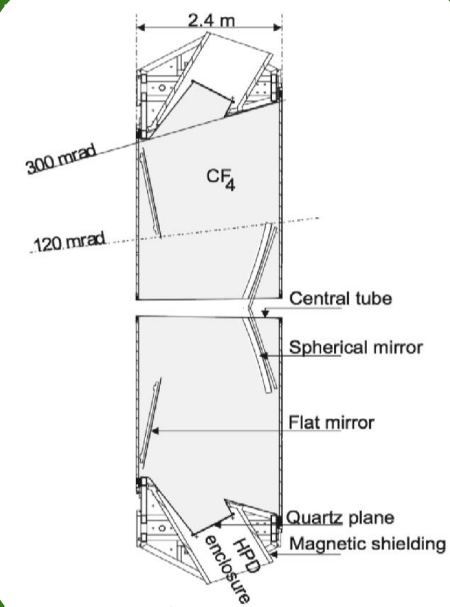
JINST 3 (2008) S08005

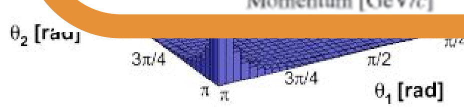
LHCb: fixed-target geometry installed at a collider











pu
reg

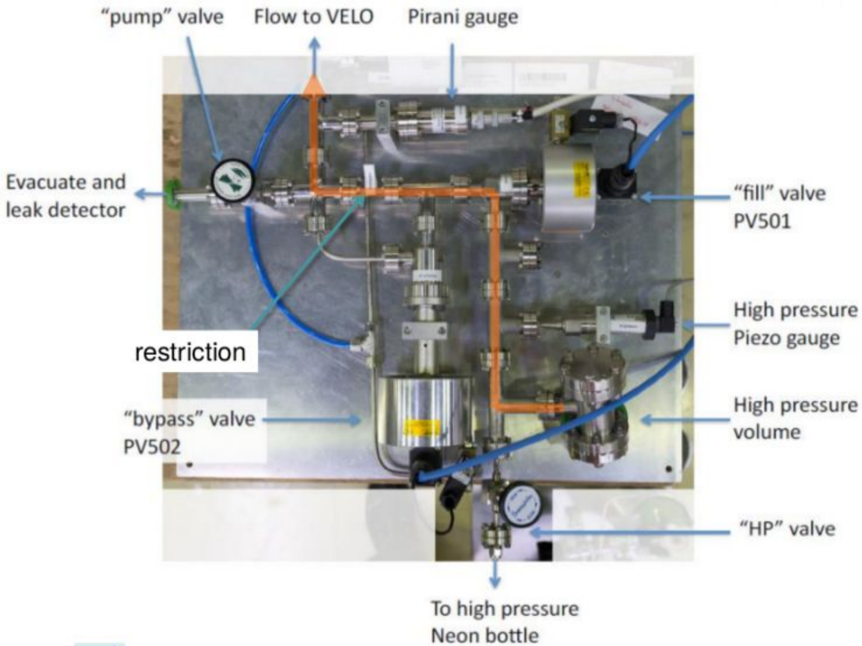
To
ha
LH
cu
expe

Best luminosity measurement with *beam-gas* collisions

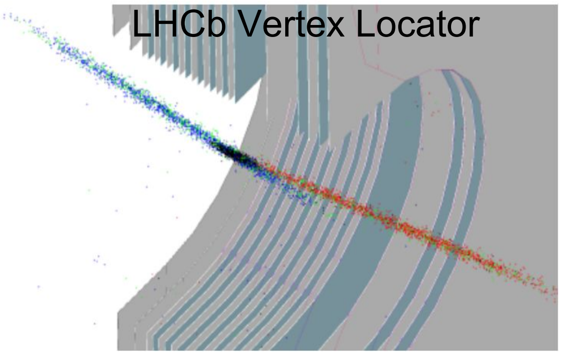
The uncertainty on the integrated luminosity affects **all** production measurements in *pp* collisions: **precision on the lumi measurement is important!**

The SMOG *(System for Measuring the Overlap With Gas)* system was introduced in LHCb as a complement to Van der Meer scans.

The collisions of protons with noble gases injected in the *beam-pipe* allows 3D reconstruction of the beams.



2014 JINST 9 P12005



Uncertainty combining the two methods:
1.12%
Best luminosity measurement achieved at a "*bunched*" collider.

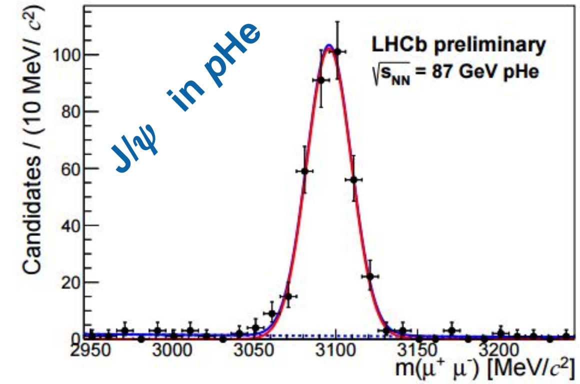
Physics with SMOG

System	Duration	$\sqrt{s_{NN}}$	Protons on target
pHe	7h	110 GeV	2×10^{21}
pNe	12h	110 GeV	1×10^{21}
pAr	17h	110 GeV	4×10^{22}
pAr	11h	69 GeV	2×10^{20}
PbAr	100h	69 GeV	2×10^{20}
pHe	18h	110 GeV	3×10^{21}
pHe	87h	87 GeV	4×10^{22}

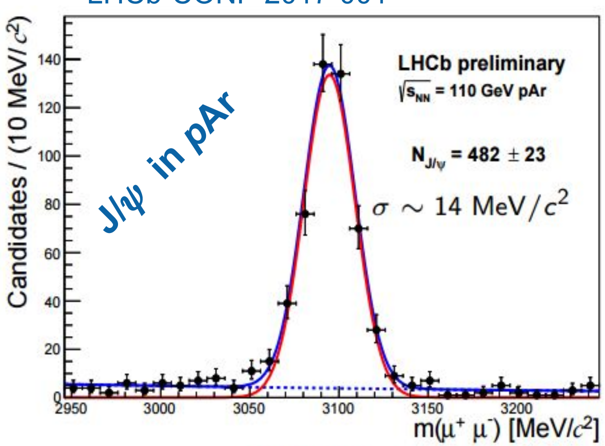
SMOG collisions became interesting also for nuclear physics:

- intermediate energy between SPS and LHC $\sqrt{s}$ = [69 , 115] GeV
- Variety of gases injectable in the beam pipe

Exploits *bunch crossings* with a filled bunch in beam 1 (towards LHCb) and an empty bunch in beam 2: *beam-empty* collisions.

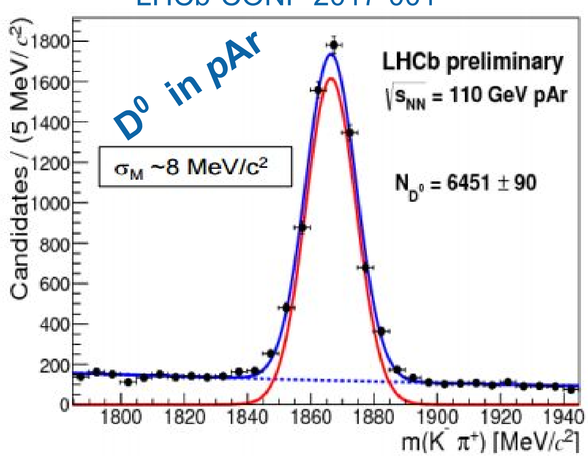


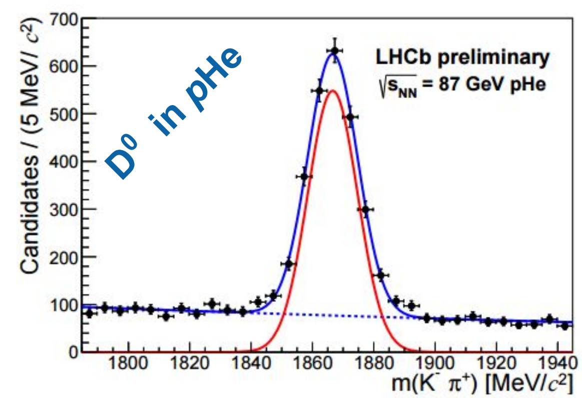
LHCb-CONF-2017-001



$\sim 500\ J/\psi \to \mu^+\mu^-$

LHCb-CONF-2017-001





Antiprotons from cosmos

A measurement of the antiproton component of cosmic rays was recently achieved by AMS-02 [PRL 117, 091103 (2016)].

It confirms the earlier observations from PAMELA [Nature 458 (2009) 607-609].

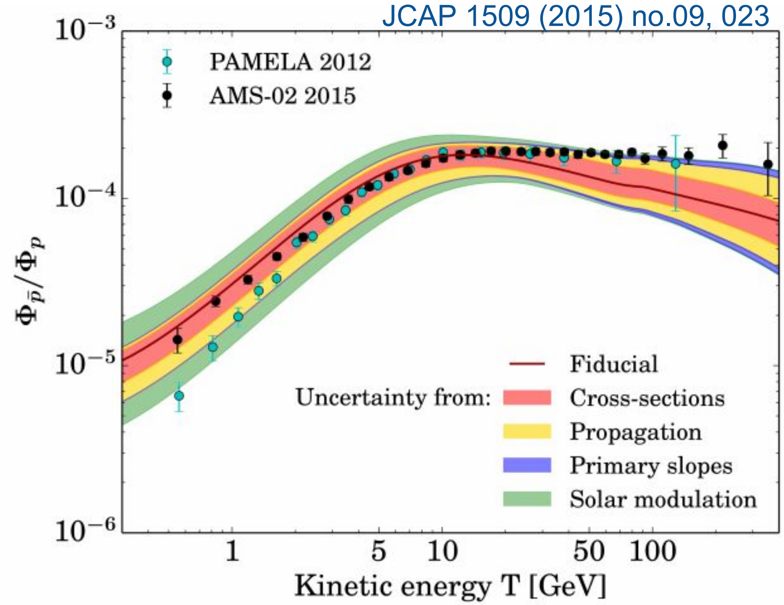
BSM models describing the annihilation of dark-matter predict an increase in the flux of antiprotons at high energy [link].

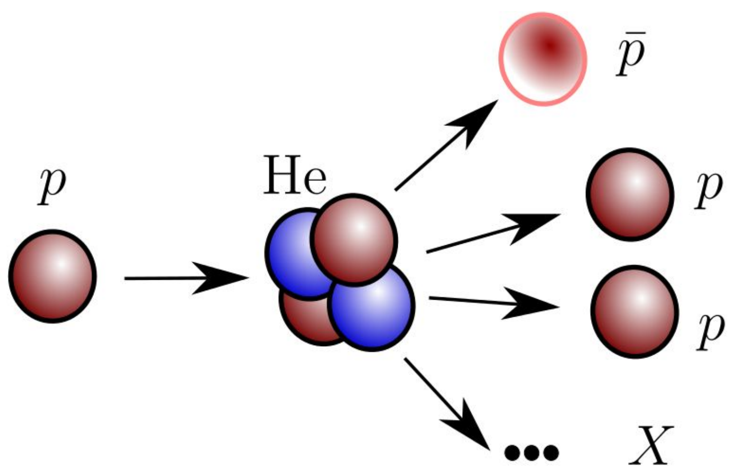
The uncertainties are dominated by component of antiprotons produced in the collisions of primaries (protons) with **interstellar matter** (H and He).

Antiproton production cross-section in *p*He collision was never measured.

The available prediction are based on *p*-H and *p*-C collisions at lower energies.

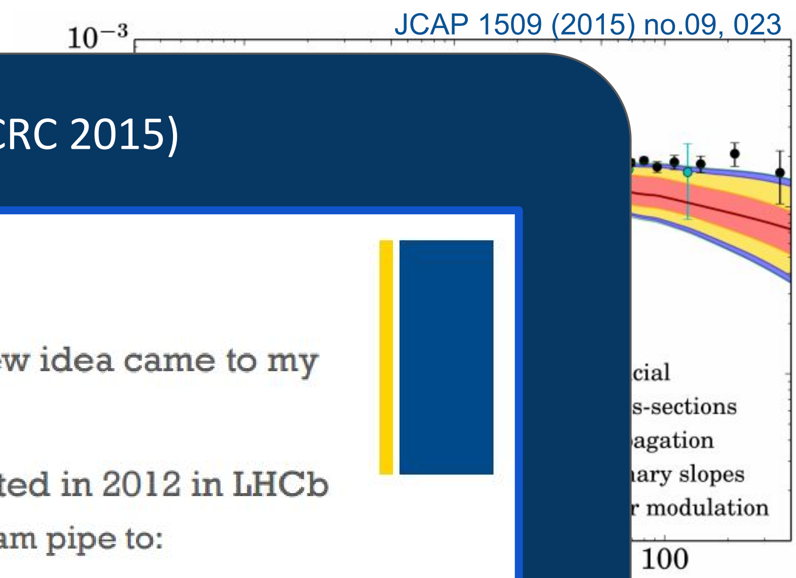
JCAP 1509 (2015) no.09, 023





Antiprotons from cosmos

JCAP 1509 (2015) no.09, 023



A me
cosm
[PRL

It co
[Natu

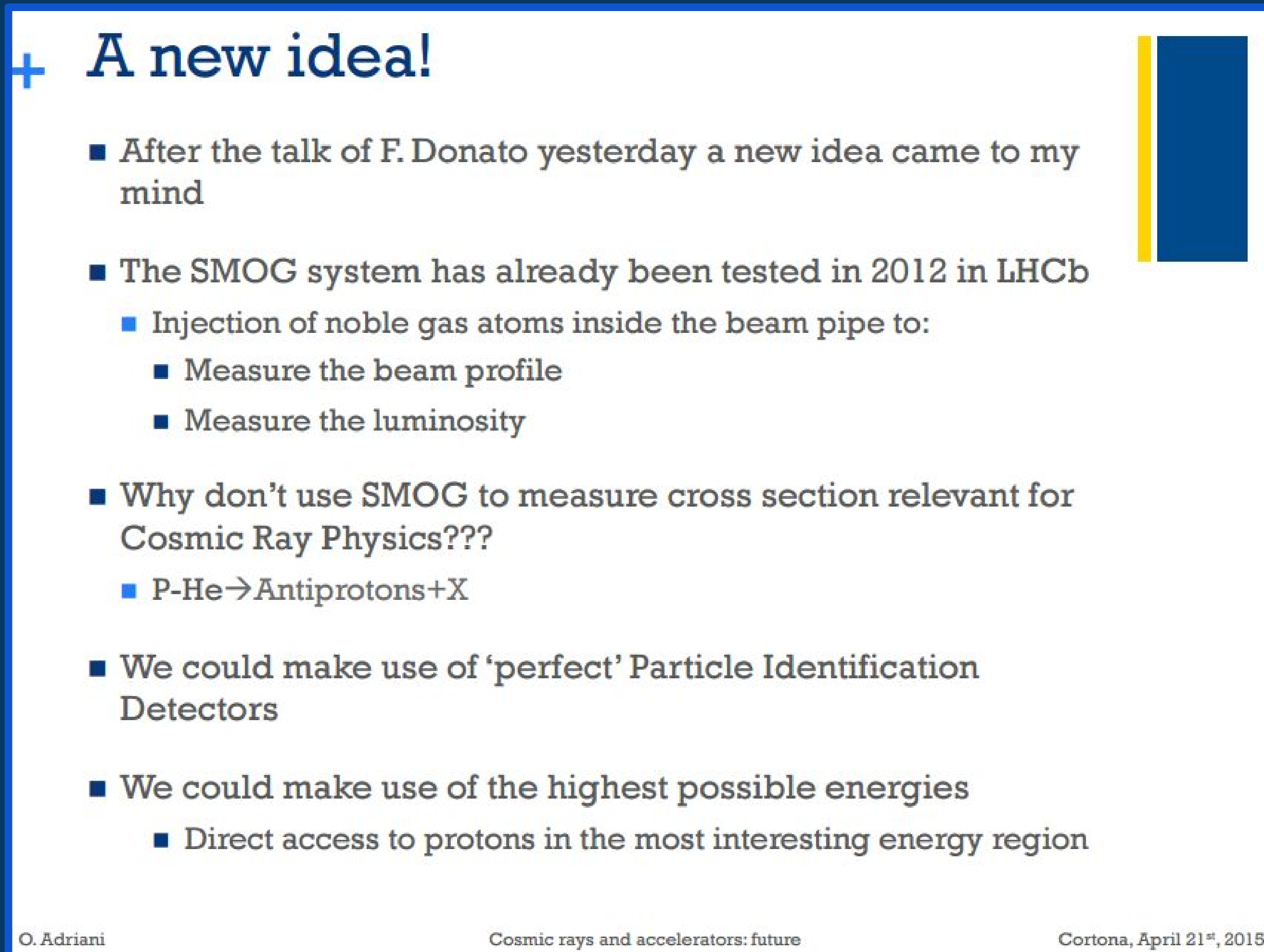
BSM
dark-
antip

The u
antip
(prot

Antip
collis

The a
collisions at 'lower energies.

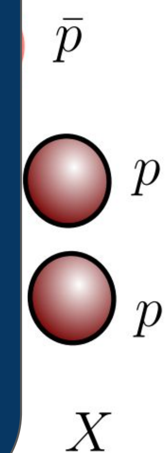
From a presentation by Oscar Adriani (XSCRC 2015)



A new idea!

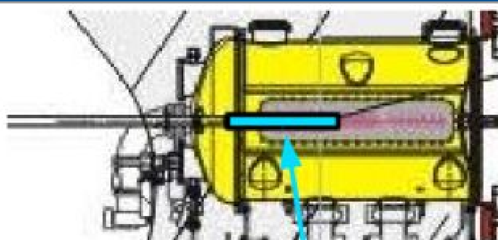
- After the talk of F. Donato yesterday a new idea came to my mind
- The SMOG system has already been tested in 2012 in LHCb
  - Injection of noble gas atoms inside the beam pipe to:
    - Measure the beam profile
    - Measure the luminosity
- Why don't use SMOG to measure cross section relevant for 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

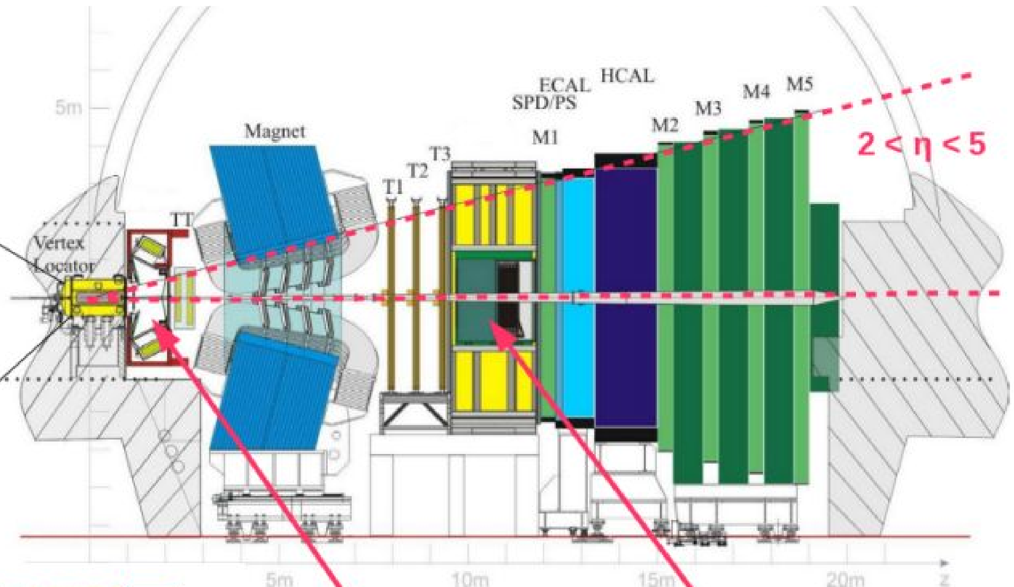
O. Adriani — Cosmic rays and accelerators: future — Cortona, April 21st, 2015



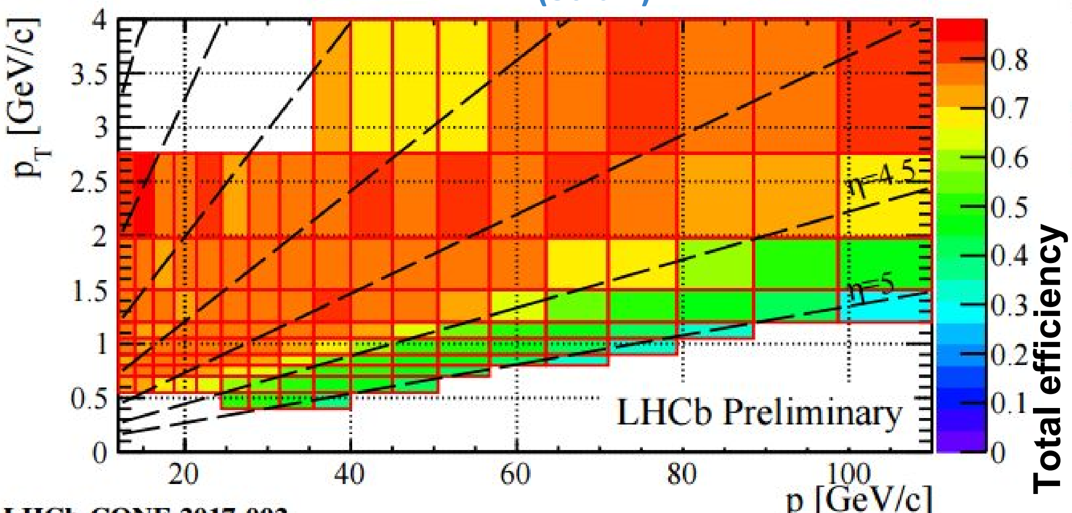
5 hour datataking with Helium in the beam-pipe

When:	May 2016
How long:	5 ore
Energy:	$\sqrt{s}$ = 110 GeV
Trigger:	Minimum Bias (ε = 100%)





Fiducial region for pHe collisions (80 cm)



LHCb-CONF-2017-002

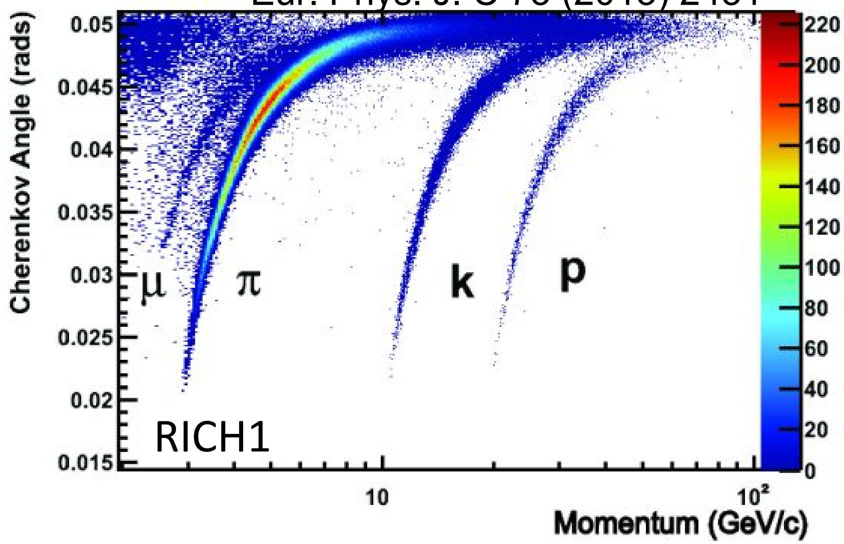
Acceptance (of tracking and RICH systems)

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

$$p_T > 0.4\ \mathrm{GeV}/c$$

Antiproton identification with Cherenkov radiation

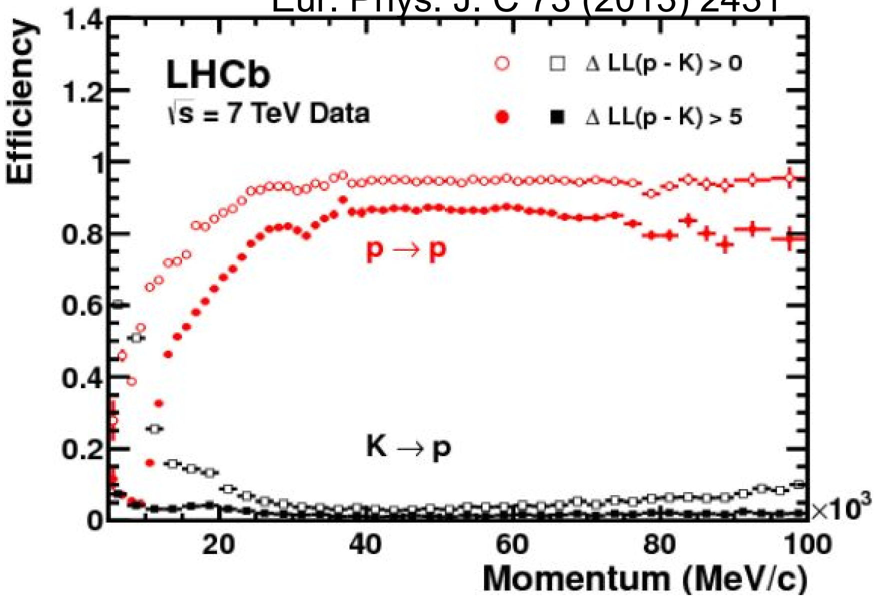
Eur. Phys. J. C 73 (2013) 2431

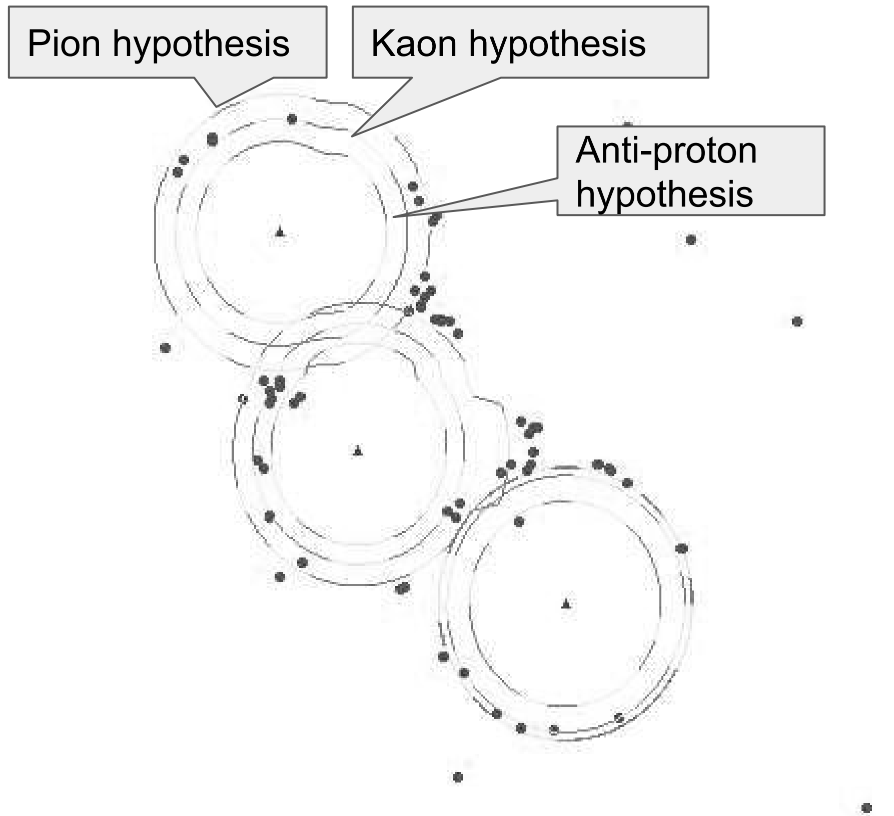


Likelihood for the three mass hypotheses (π, K and p) is computed from the Cherenkov photons produced in the two RICH detectors.

All the other likelihoods are referred to the pion hypothesis and expressed as log: differential log likelihoods.

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

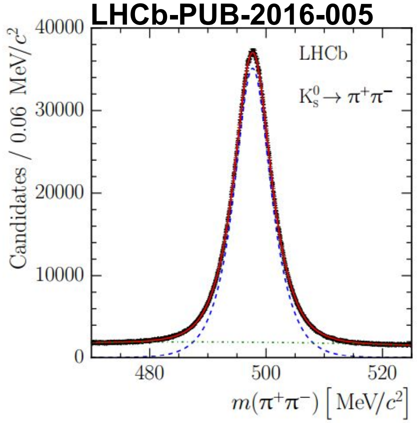




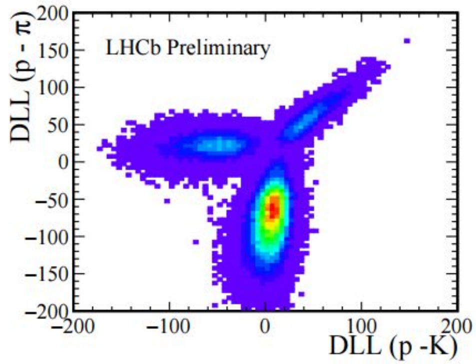
Antiproton identification with Cherenkov radiation

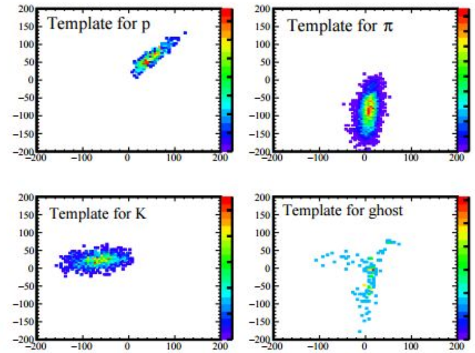
Negative tracks are statistically compared to template distributions of background-subtracted samples of **pions**, **kaons** and **antiprotons** collected in ***pp*** and ***pHe*** collisions and ***simulation***.

LHCb-PUB-2016-005

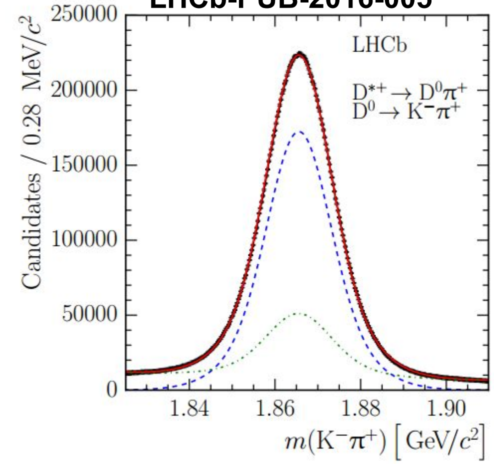


LHCb-CONF-2017-002

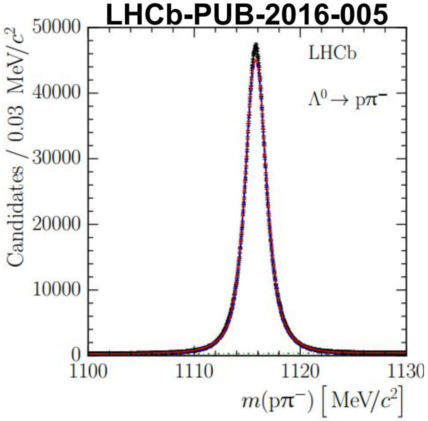


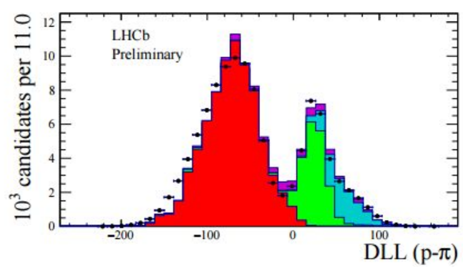


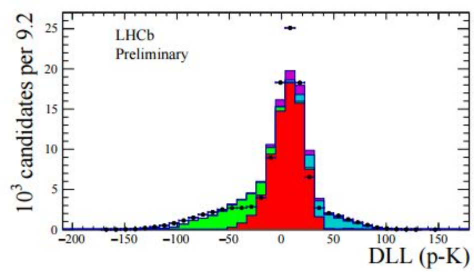
LHCb-PUB-2016-005

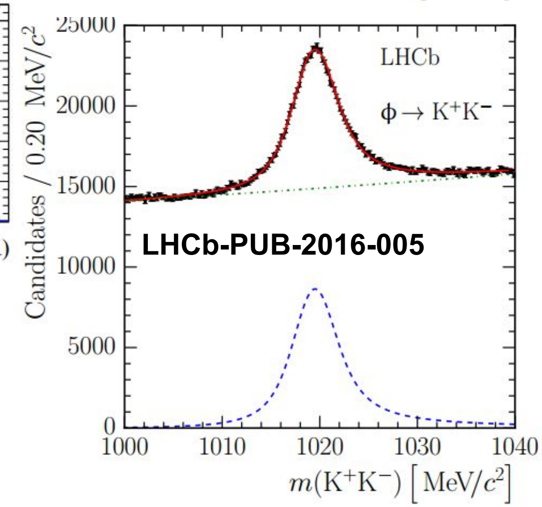


LHCb-PUB-2016-005





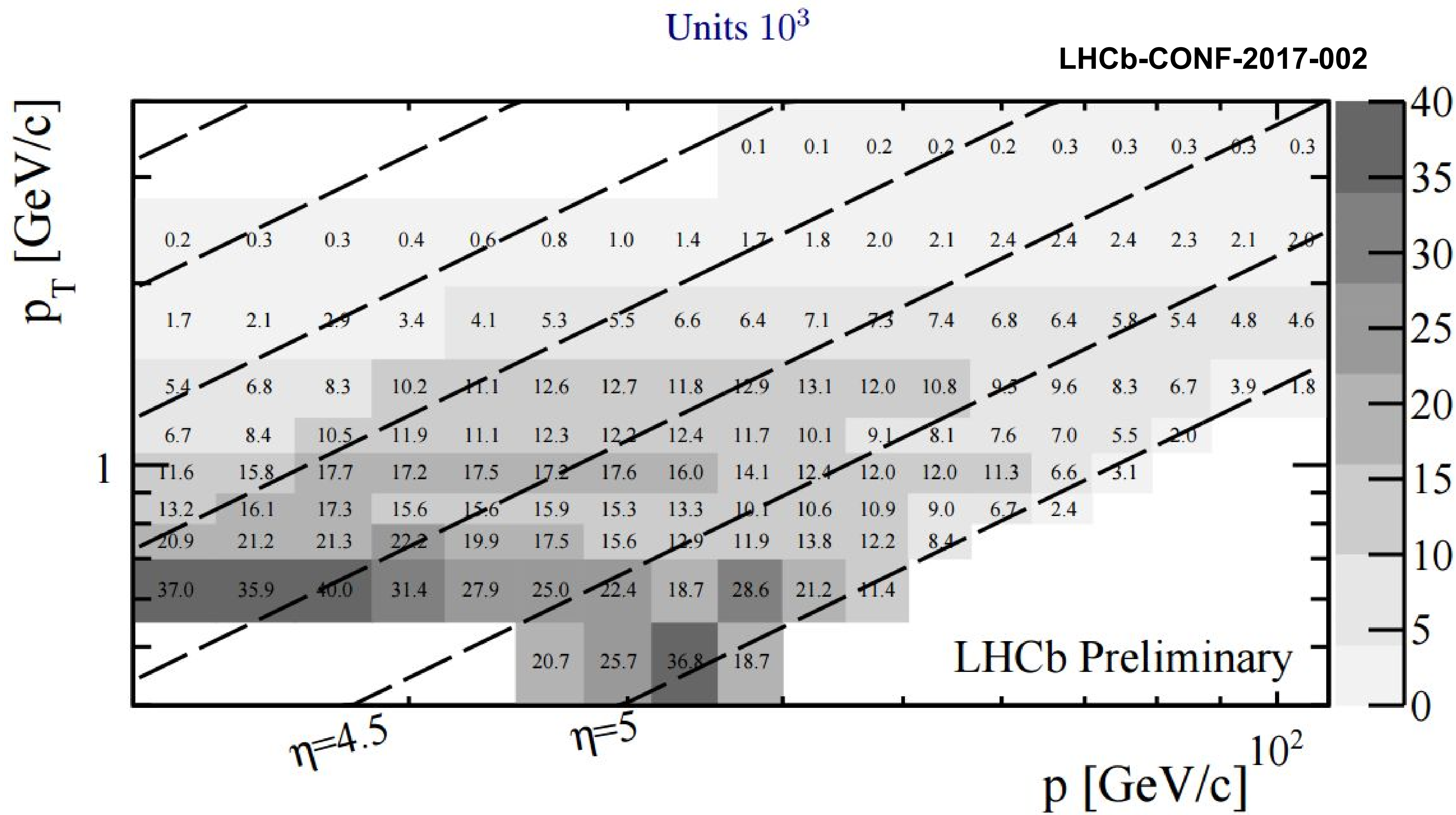




Systematic uncertainty from the comparison of the results with different templates.
Smaller than 10% in most bins; smaller than 30% also in bins at the acceptance boundaries.

Total number of antiprotons

LHCb-CONF-2017-002



Residual Vacuum Background

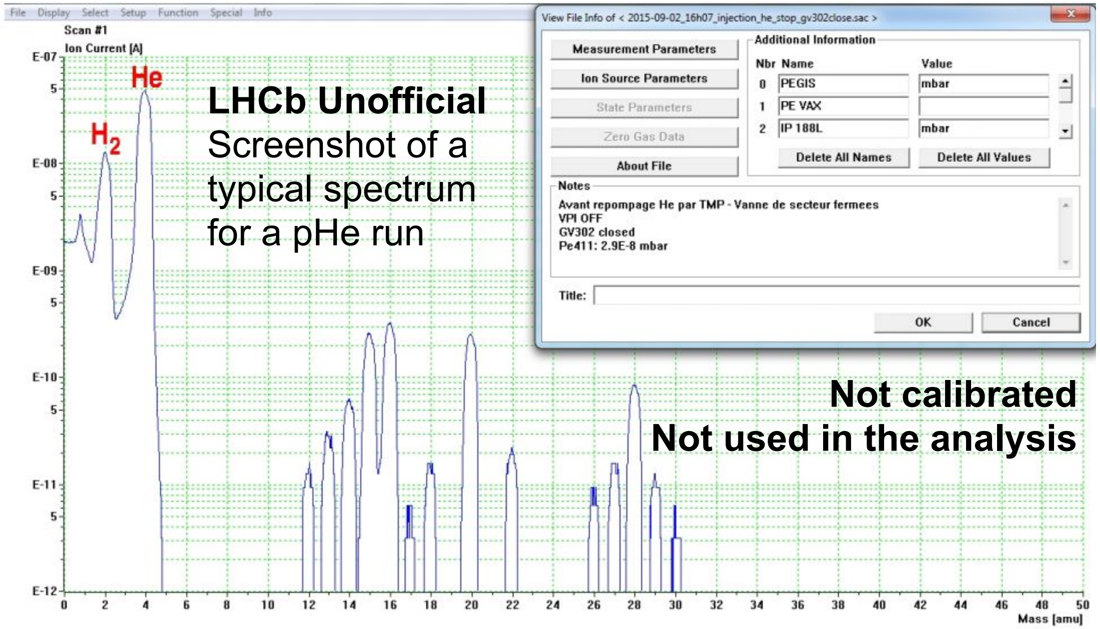
Dedicated "no-gas" data-taking to study the collisions of the proton beam with the residual vacuum within the beam-pipe.

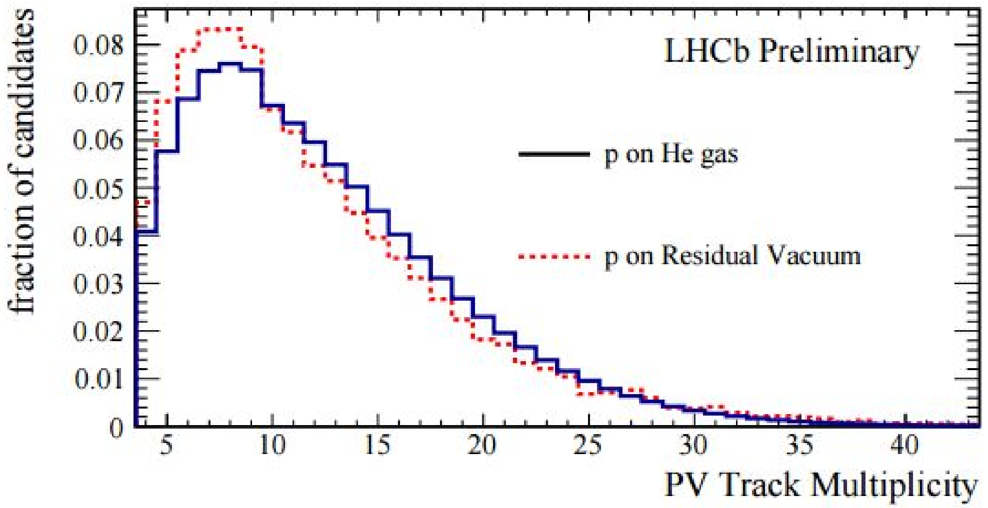
The residual gas is dominated by hydrogen: *lower average track multiplicity.*

The small contribution from proton-hydrogen collisions

0.66 ± 0.06 %

is subtracted.





Luminosity and normalization

Cross-section $\sigma(p\text{He} \to \bar{p}X)$

Observed antiprotons in a 5-hour run

$$\frac{\mathrm{d}N_{\bar{p}}}{\mathrm{d}t} = \sigma_{\bar{p}}\rho\ell \times \frac{\mathrm{d}N_p^{(\mathrm{beam})}}{\mathrm{d}t}$$

Number of protons of the LHC traversing the gas target in a 5-hour run.

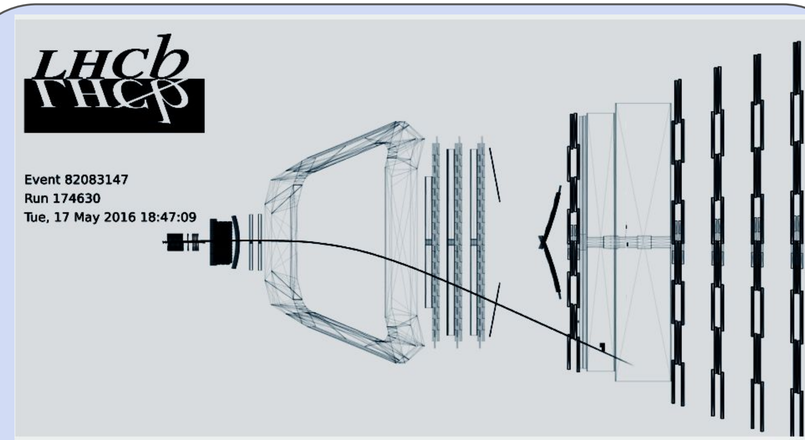
Gas density.
Known up to large uncertainties.
Order 10^{-7} mbar

Target length (80 cm)

To avoid uncertainties from gas density, use a normalization channel: **elastic *pe* scattering**

$$\frac{\mathrm{d}N_{\bar{p}}}{\mathrm{d}t} = \frac{\sigma_{\bar{p}}}{\sigma_{e^-}} \frac{\mathrm{d}N_{e^-}}{\mathrm{d}t}$$

Theoretical cross-section of elastic *pe* scattering known with great precision.



Luminosity and normalization

Cross-section $\sigma(pHe \rightarrow \bar{p}X)$

Observed antiprotons in a 5-hour run

$$\frac{\mathrm{d}N_{\bar{p}}}{\mathrm{d}t} = \sigma_{\bar{p}} \rho \ell \times \frac{\mathrm{d}N_p^{(\mathrm{beam})}}{\mathrm{d}t}$$

Number of protons of the LHC traversing the gas target in a 5-hour run.

Gas density. **Known up to large uncertainties. Order 10^{-7} mbar**

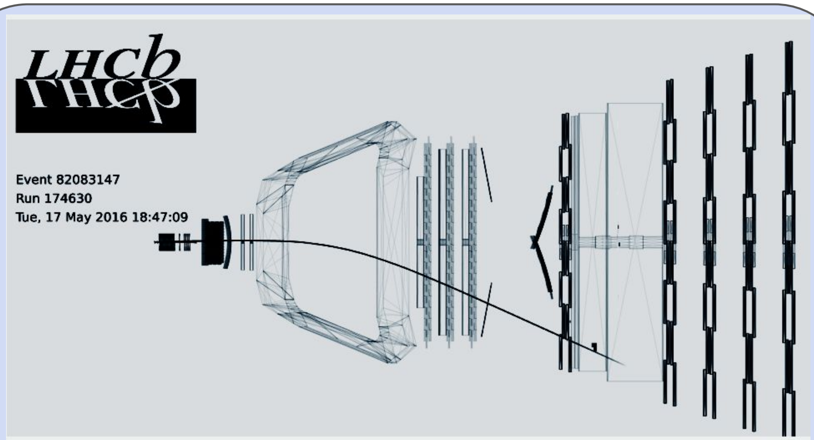
Target length (80 cm)

To avoid uncertainties from gas density, use a normalization channel: **elastic *pe* scattering**

$$\frac{\mathrm{d}N_{\bar{p}}}{\mathrm{d}t} = \frac{\sigma_{\bar{p}}}{\sigma_{e^-}} \frac{\mathrm{d}N_{e^-}}{\mathrm{d}t}$$

$\mathcal{L}$

Theoretical cross-section of elastic *pe* scattering known with great precision.



Background to the normalization channel

Gamma conversions in the detector material and **soft pion pairs** produced in diffractive *pp* collisions can mimic the elastic scattering if the negative leg is lost.

However, both processes are **charge-symmetric**: observed single-positive-track events are used to subtract the background.

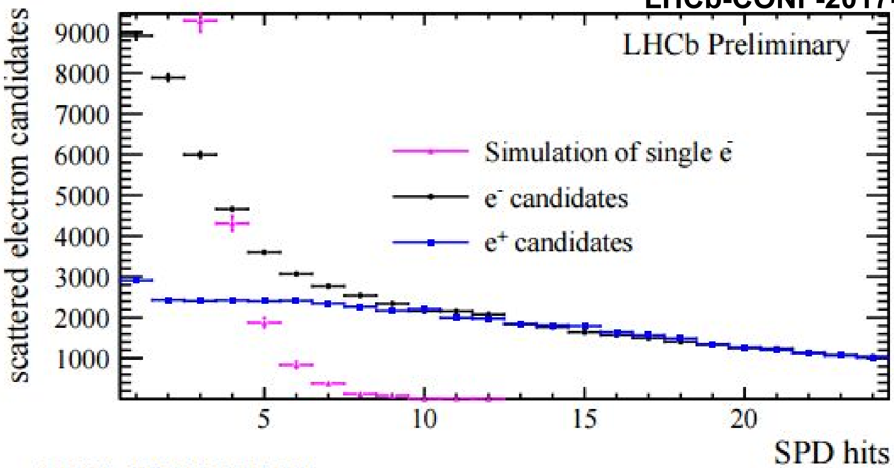
Excellent agreement with the **simulation** is achieved.

The luminosity,

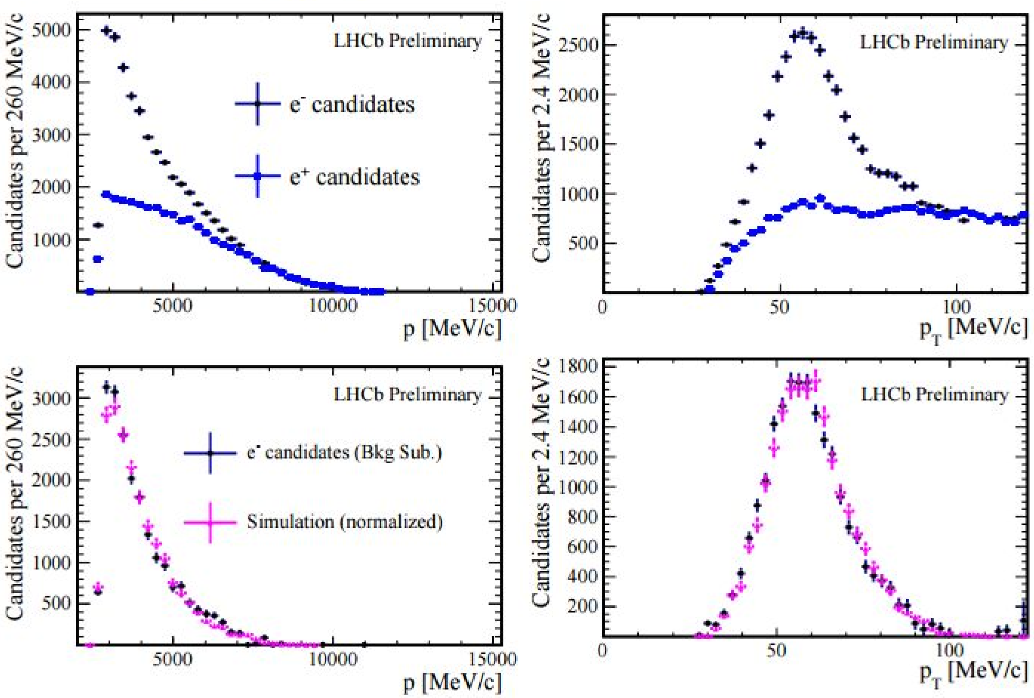
$$\mathcal{L} = 0.443 \pm 0.011 \pm 0.027\,\mathrm{nb}^{-1}$$

corresponds to 2.4 10^{-7} mbar, is in good agreement with SMOG design.

LHCb-CONF-2017-002



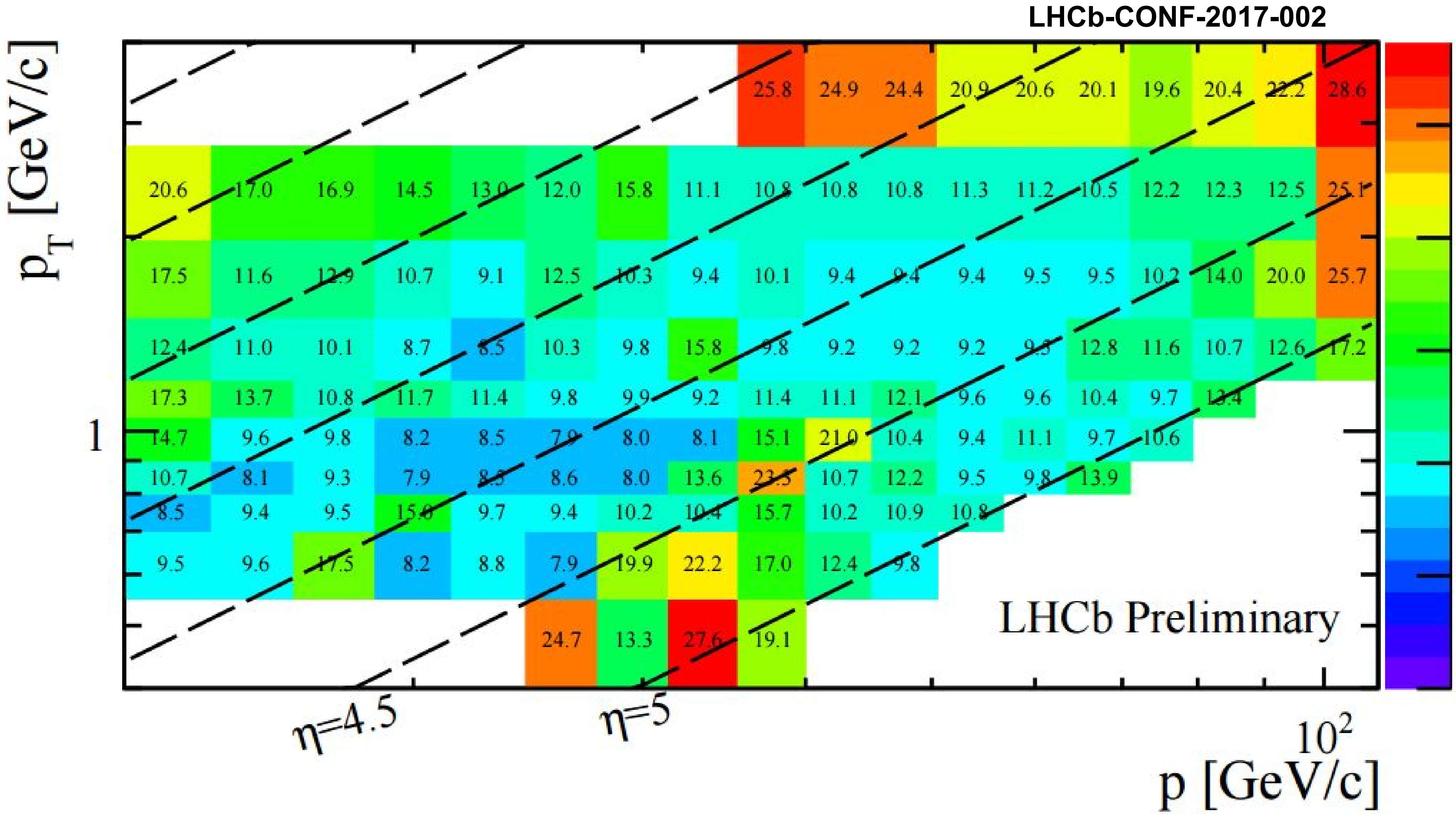
LHCb-CONF-2017-002



Budget of the uncertainties on $\sigma(p\,\mathrm{He} \to \bar{p}\,X)$

Number of antiprotons and PID samples	Statistics	0.7 - 10.8% (< 3% for most bins)
Normalization (number of scattered e^-)	Statistics	2.5 %
Normalization (reconstruction)	Correlated systematics	6.0 %
Selection	Correlated systematics	0.3 %
Primary vertex reconstruction	Correlated systematics	0.8 %
Track reconstruction	Correlated systematics	2.2 %
Residual vacuum background	Correlated systematics	0.1 %
Hyperon background	Correlated systematics	0.3 - 0.7 %
Track reconstruction	Uncorrelated systematics	3.2 %
Selection (impact parameter)	Uncorrelated systematics	1.0%
Antiproton identification	Uncorrelated systematics	0 - 26% (< 10% for most bins)
Statistics of the simulated samples	Uncorrelated systematics	0.8 - 15 % (< 4% for p_T < 2 GeV/c)

Total uncertainty, bin by bin (%)



Results

Prompt antiproton production cross-section.

Total inelastic cross-section

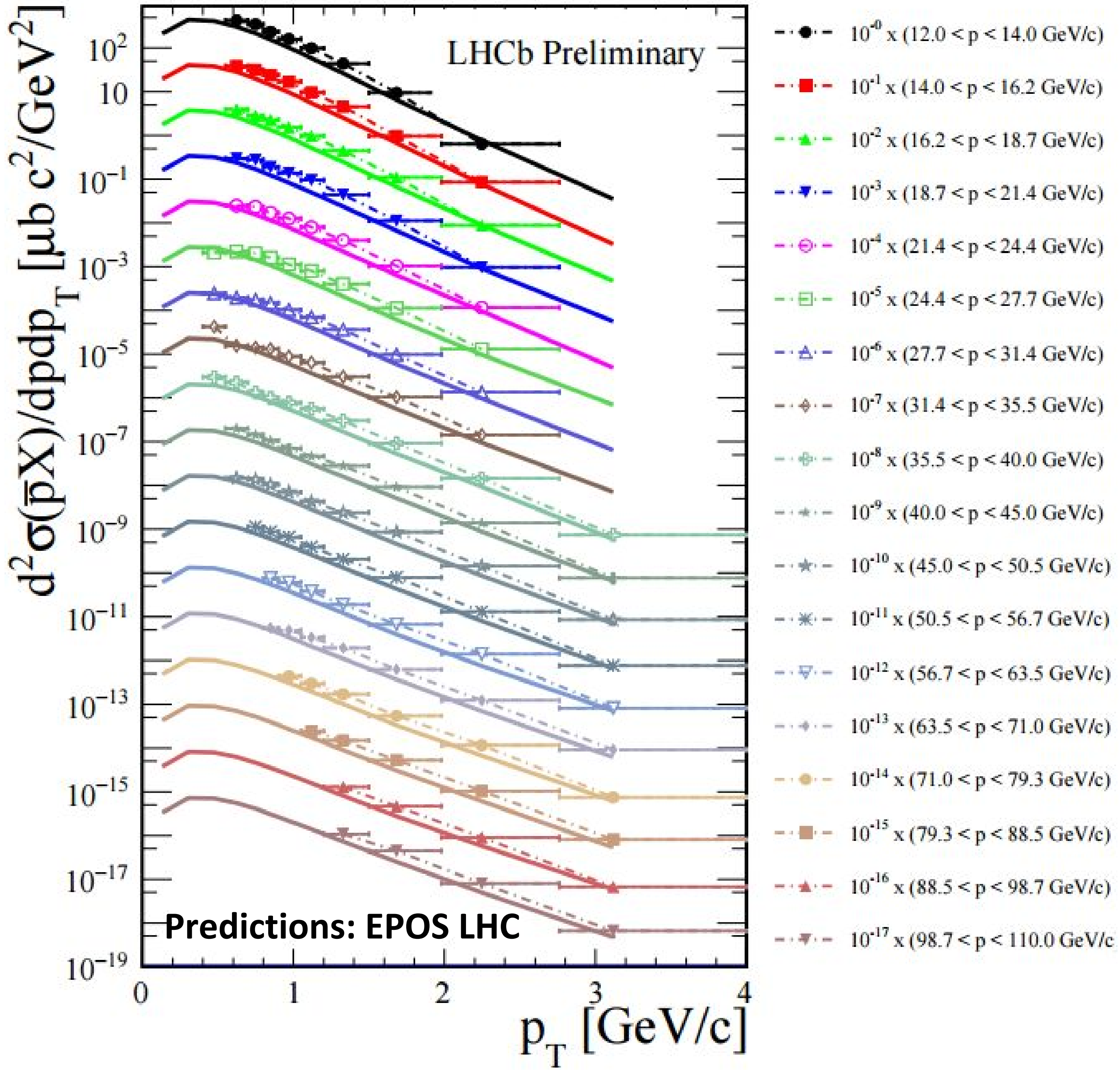
$$\sigma_{inel}^{\text{LHCb}} = (140 \pm 10)\ \text{mb}$$

slightly exceeding the EPOS prediction:

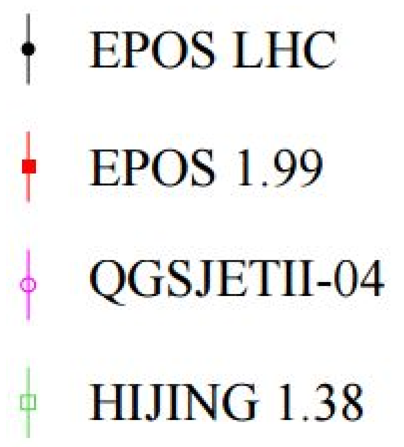
$$118\ \text{mb}$$

The ratio is

$$1.19 \pm 0.08$$

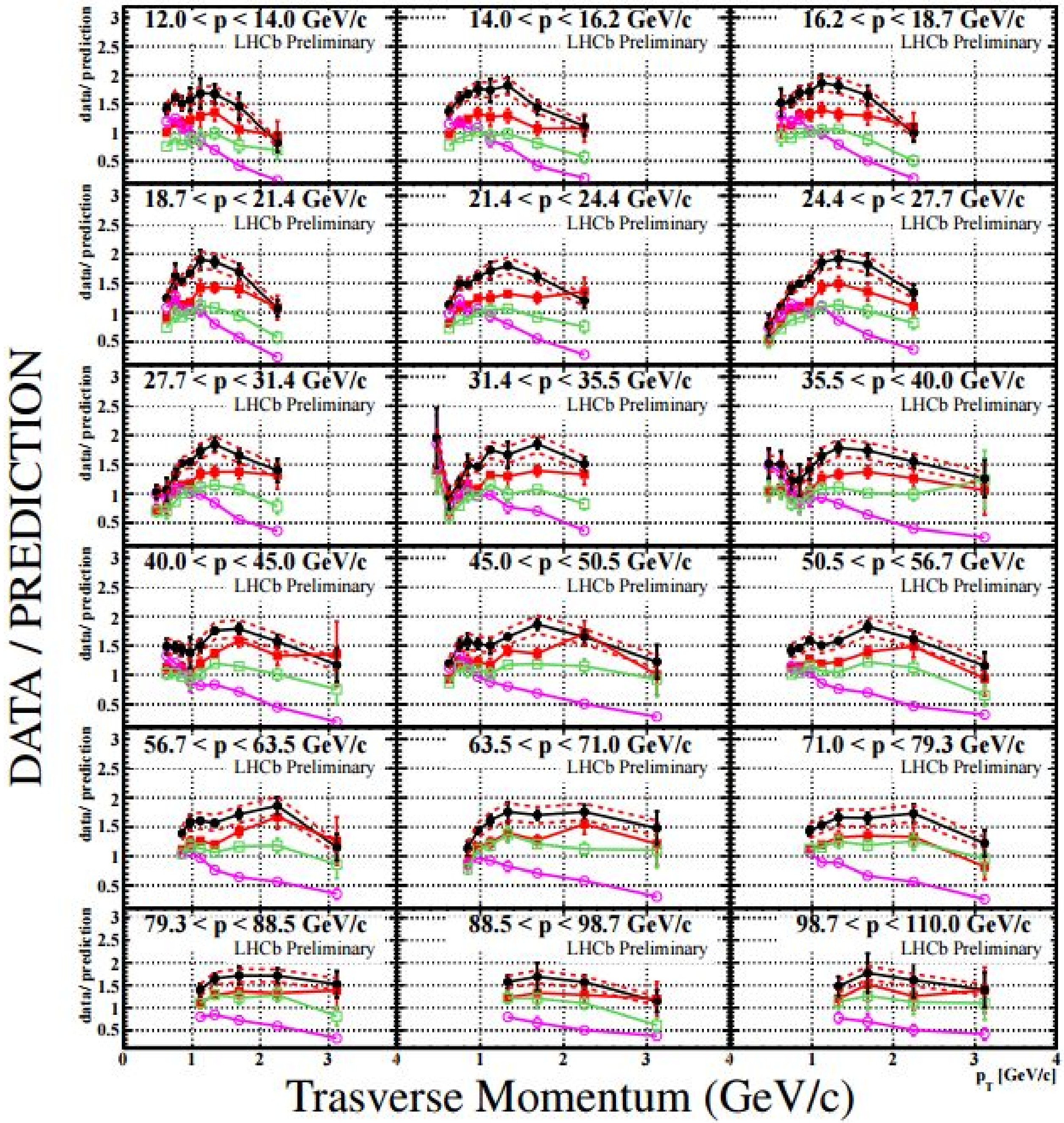


Ratio with models



EPOS LHC underestimates antiproton production by about 30%.

Better agreement with EPOS 1.99 and HIJING.



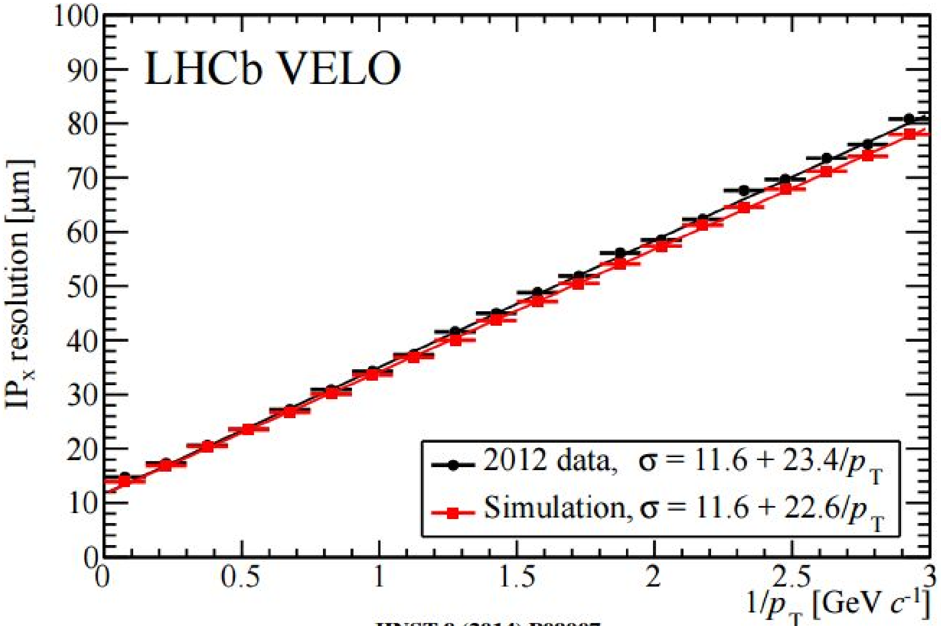
Outlook

On the antiproton production

- analyse the LHC data at 4 TeV (already taken)
- determine the production of antiprotons from hyperons (measuring at least Λ^0 production) stimata al (2.6 ± 0.6) % in the current analysis.

More to come from the LHCb-as-a-fixed-target-experiment experiment

- particle/anti-particle ratio
- charm, charmonia
- ...



JINST 9 (2014) P09007

Conclusion

The **SMOG** system for the luminosity measurement opened to new opportunities for studying **proton-gas collision physics** at the LHC energy

LHCb can study the *p*He collisions emulating the collisions of primary cosmic rays with **interstellar medium**.

The measurement of the antiproton production cross-section in *pHe* collisions is an unexpected contribution from LHCb to the **cosmic ray physics**.

We are grateful to **O. Adriani**, **L. Bonechi**, **F. Donato**, and **A. Tricomi** for having proposed and discussed with us this measurement!

The new information on the secondary production of antiprotons will **reduce significantly the uncertainties on the predictions for the $\bar{p}/p$ ratio** in cosmic rays.


THE END