INFN Firenze
Istituto Nazionale di Fisica Nucleare

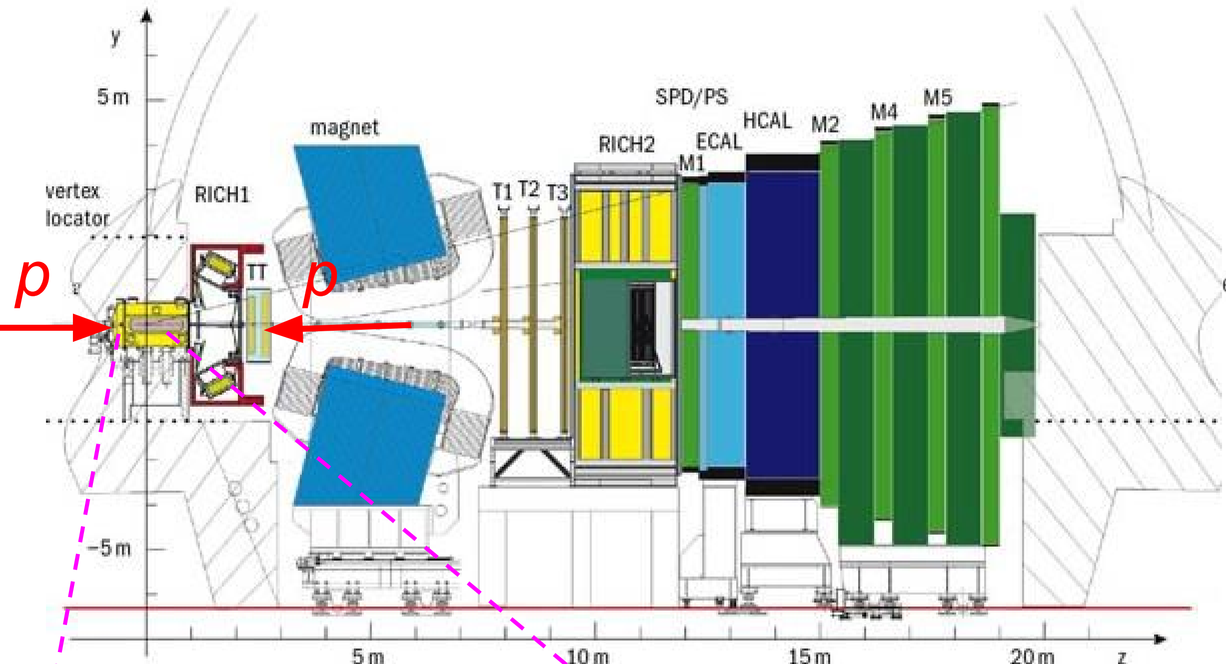
Fixed target collisions with the LHCb experiment

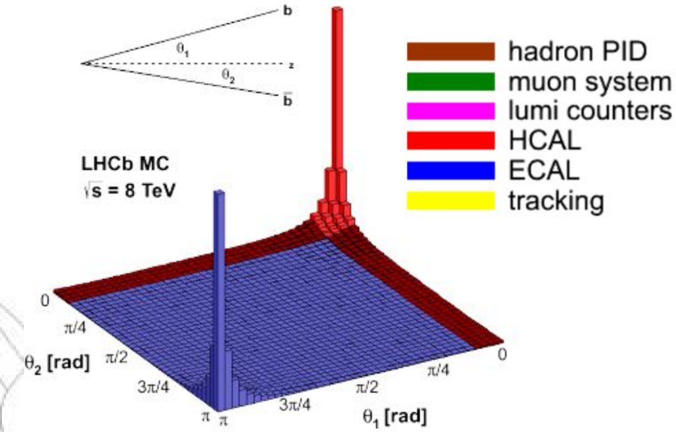
Lucio Anderlini
on behalf of the LHCb Collaboration

Thursday July 6th, 2017
Venice, Italy

The LHCb detector: *designed for heavy flavour physics*

Single arm spectrometer, fully instrumented in $2 < \eta < 5$

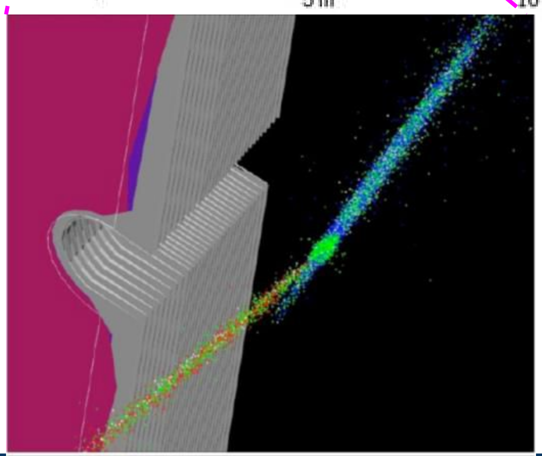




Excellent vertex, IP and decay time resolution

Very good momentum resolution

Excellent particle identification



SMOG. *A system for measuring overlap with gas*

Injecting gas in LHCb VELO region

- Designed to improve the luminosity measurement
- Exploited today also as an **internal gas target**
- Allows measurements p-gas and ion-gas collisions

Fixed-target mode. *Motivation and data-taking*

- An interesting intermediate region of $\sqrt{s_{NN}}$ between 20 (SPS) and 200 GeV (RHIC)
- Access the large Bjorken-x region of the target (backward rapidity)
- Conditions emulating CR collisions with atmosphere, and the interstellar medium
- Test intrinsic-charm in the proton

$\sqrt{s_{NN}}$ between 90 and 110 GeV

$\sqrt{s_{NN}} \sim 69$ GeV

System	Duration	CMS energy	Protons on target
2015			
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 (To be analyzed)	100h	69 GeV	2×10^{20}
2016			
pHe	*18h*	*110 GeV*	3×10^{21}
pHe (to be analyzed)	87h	87 GeV	4×10^{22}

Presented today:

- Results on heavy flavour production in pAr collisions at $\sqrt{s}$ = 110 GeV (LHCb-CONF-2017-001)
- Results on anti-proton production in *p*He collisions at $\sqrt{s}$ = 110 GeV (LHCb-CONF-2017-002)

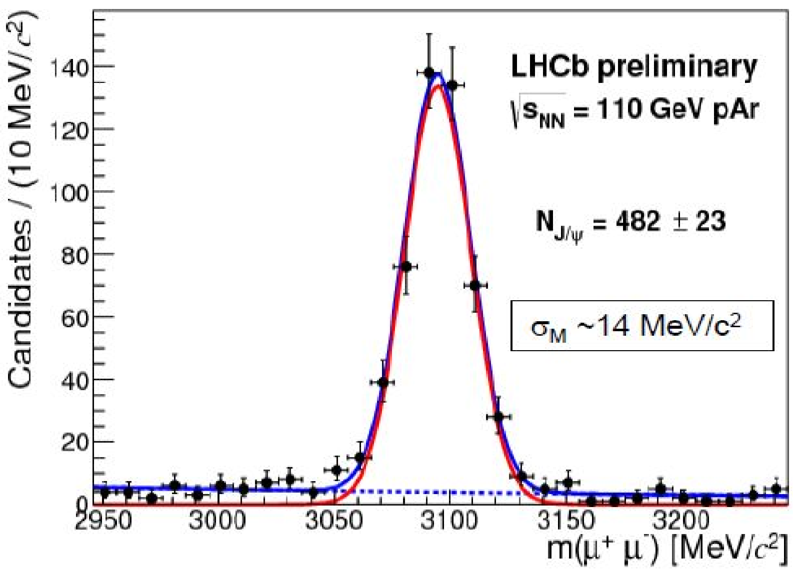
Heavy flavour production in *p*Ar collisions in fixed target mode

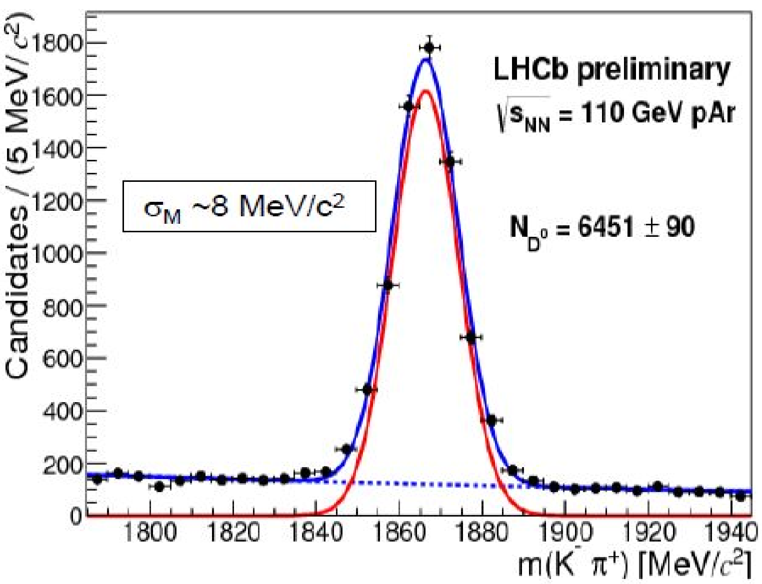
based on LHCb-CONF-2017-001

Heavy Flavour Production in pAr collisions

- A "thermometer for QGP" in ion-ion collisions
- proton-ion collisions, with different ions, is the baseline: *cold nuclear matter*

So far from LHCb: **abundant** and **pure** J/ψ and D^0 signal.





Used to measure the **efficiency-corrected yields** in bins of p_T and η.
Luminosity measurement for absolute cross-section determination is on the way.

Comparison of J/ψ spectra with NRQCD predictions

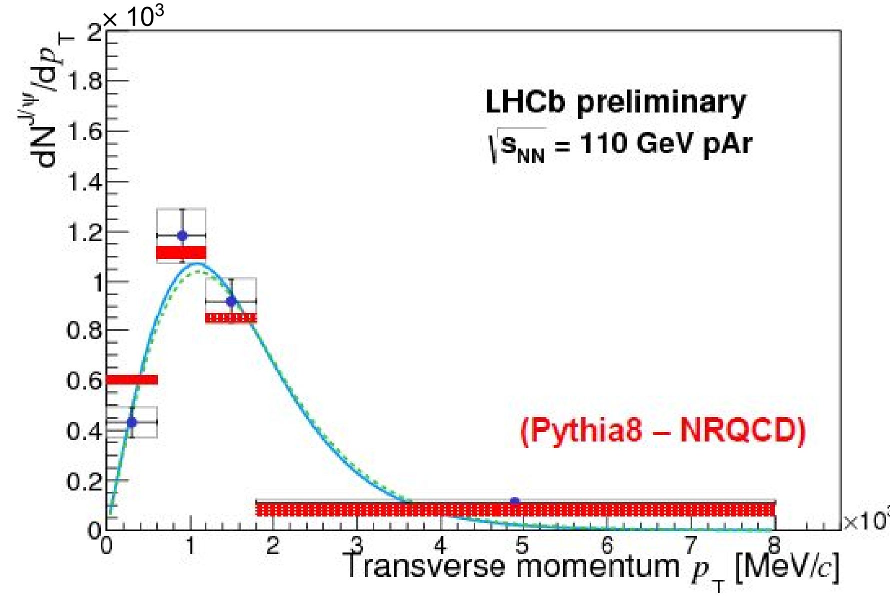
Error bars: *statistical uncertainty*

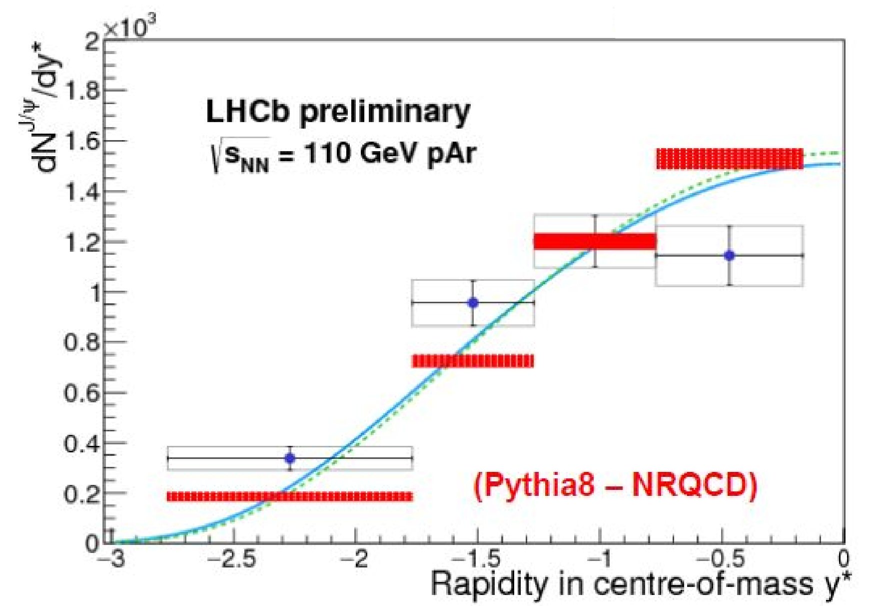
White boxes: *Systematic uncertainty*
found to be negligible

Red boxes: *Pythia8-NRQCD results*
using CT09MCS/NRQCD

Blue curves:

- Arleo, F. and Peigné, S. JHEP (2013) 2013:122
- Arleo, F. et al. JHEP (2013) 2013: 155



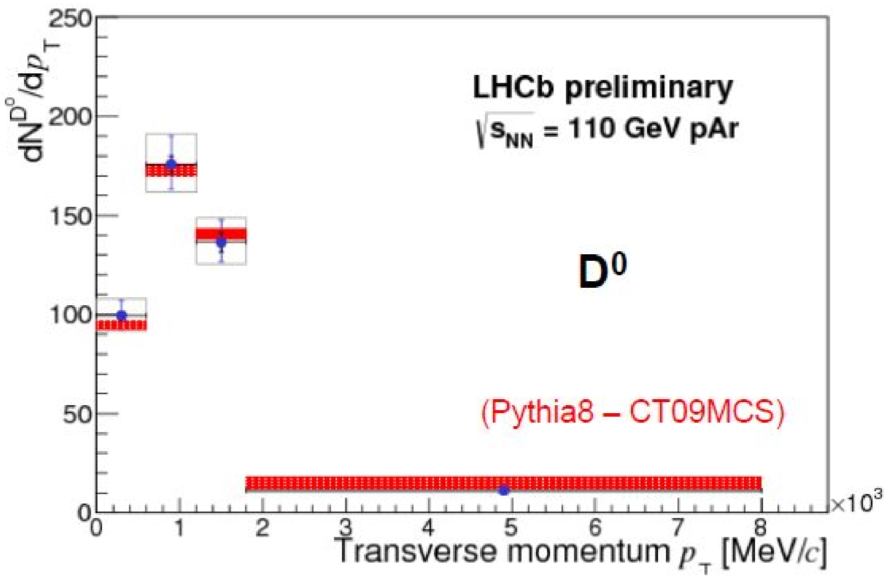


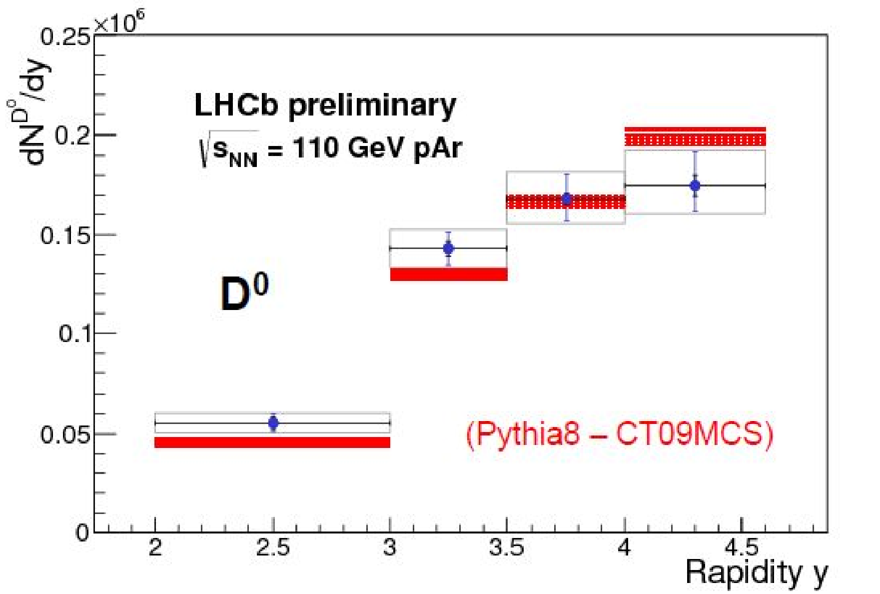
Comparison of D^0 spectra with NRQCD prediction

Larger statistics and hadronic final state makes systematic uncertainty non-negligible.

Inner error bars represent the statistical uncertainty.

Source of uncertainties	D^0 y	D^0 p_T
Corr. between bins		
Signal selection	2.2%	2.2%
Signal extraction	2.3%	2.7%
Uncorr. between bins		
MC smaple	(1.0 – 1.9)%	(1.0 – 1.5)%
Tracking	(2.7 – 3.4)%	(2.8 – 3.6)%
PID	**(4.1 – 8.8)%**	**(4.8 – 6.9)%**
Stat. uncertainties	*(0.7 – 3.7)%*	*(0.6 – 3.4)%*





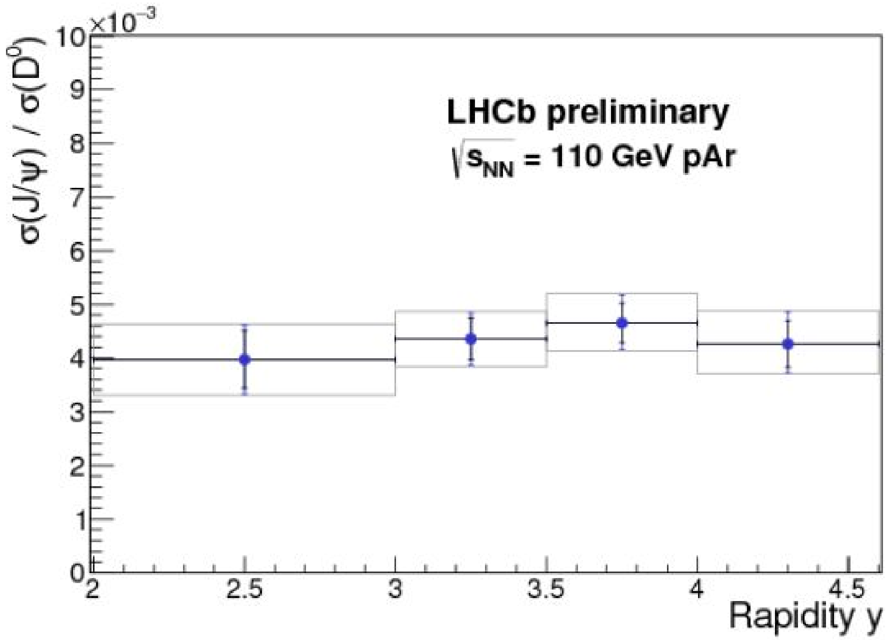
Ratio of corrected yields: *or relative cross-section*

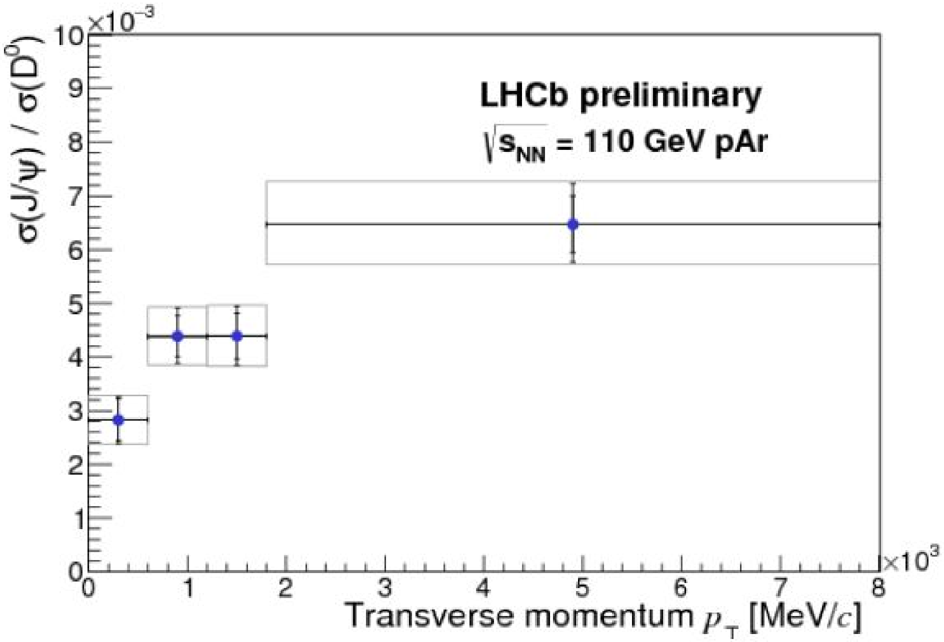
Luminosity L cancels out in the ratio

$$\left(\frac{\sigma(J/\psi)}{\sigma(D^0)} = \frac{Y(J/\psi)}{\mathcal{L}} \times \frac{\mathcal{L}}{Y(D^0)}\right)$$

No significant dependence of the ratio in rapidity.

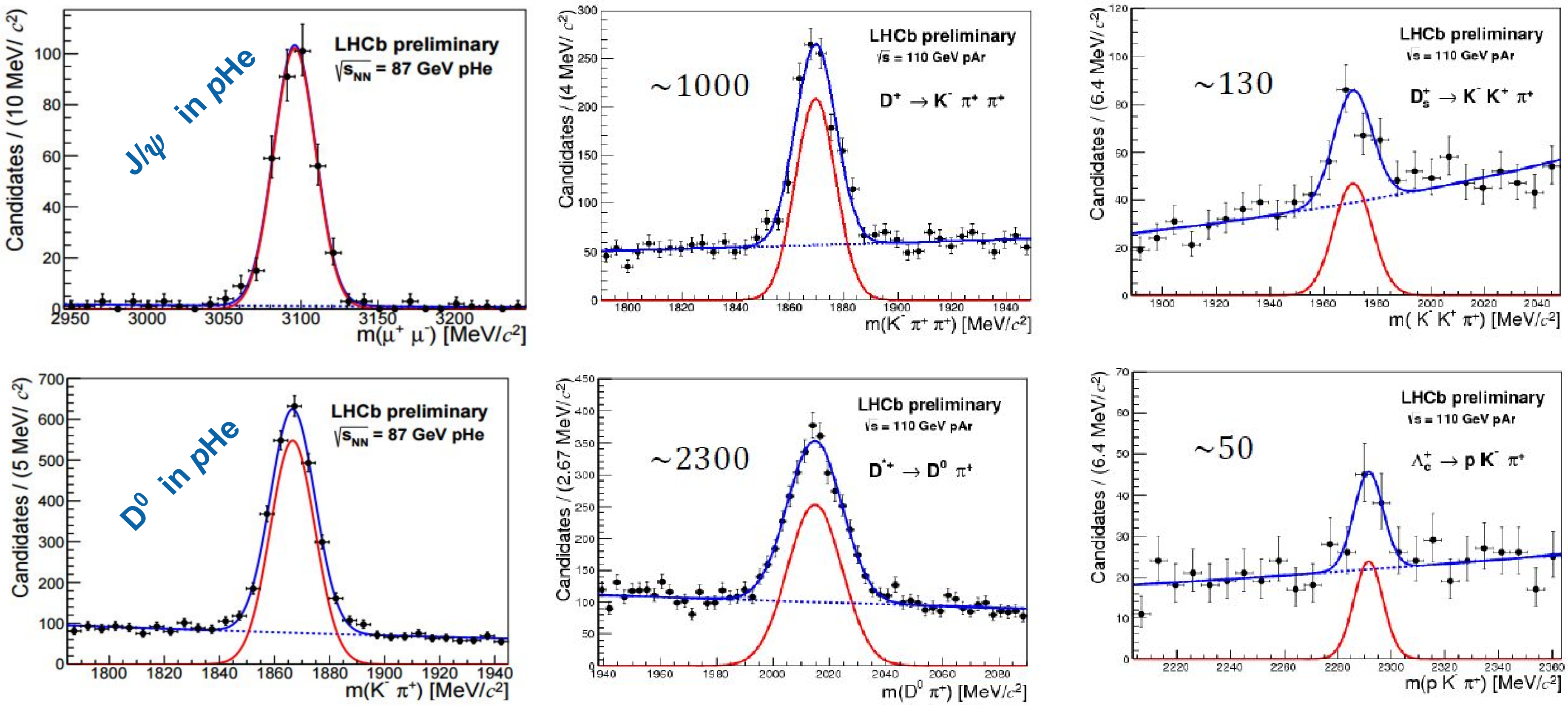
While J/ψ production increases faster with p_T





Outlook on heavy flavours

More to come with other runs and other heavy hadrons.



Anti-proton production in *p*He collisions at $\sqrt{s}$ = 110 GeV

based on LHCb-CONF-2017-001

Anti-protons 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].

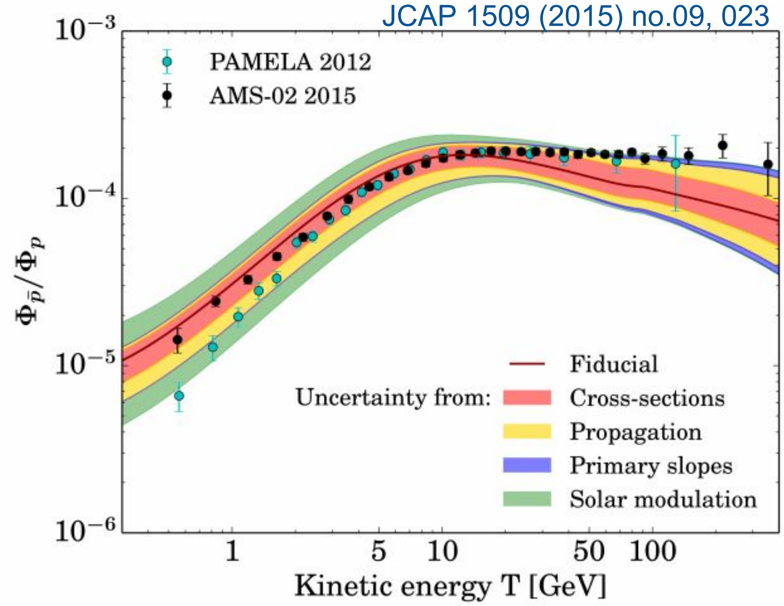
BSM models describing the annihilation of dark-matter predict an increase in the flux of antiprotons at high energy [link].

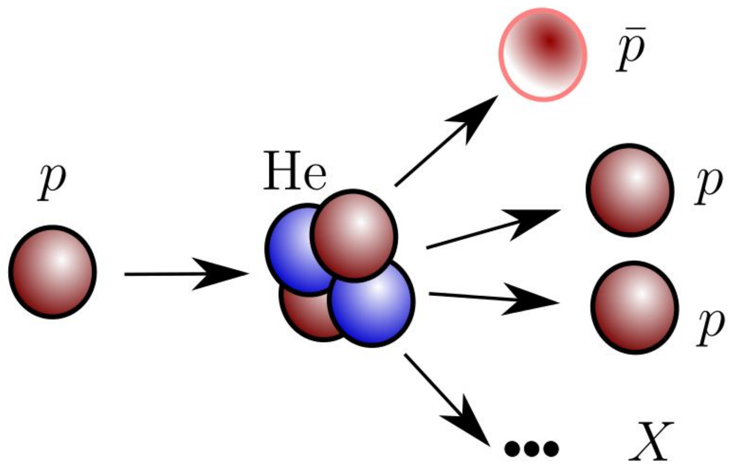
The uncertainties are dominated by component of antiprotons produced in the collisions of primaries (protons) with **interstellar matter** (H and He).

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





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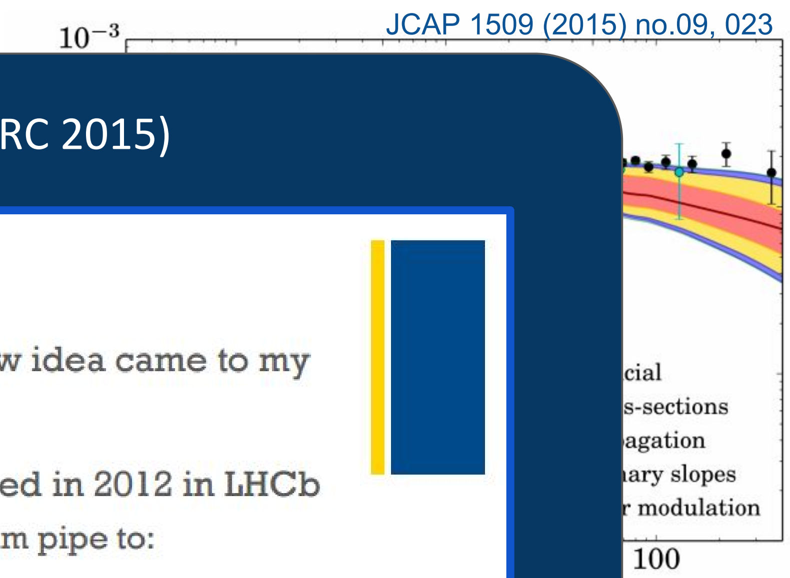

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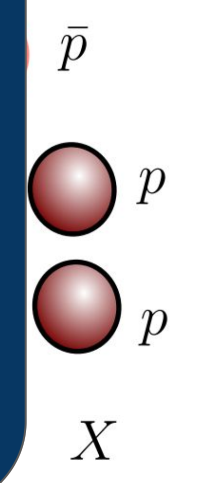
From a presentation by Oscar Adriani (XSCRC 2015)

A new idea!

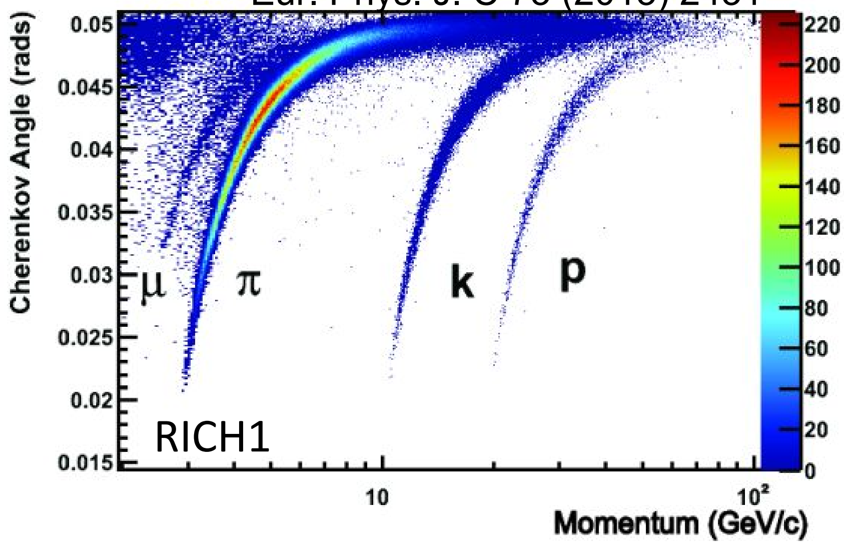
- After the talk of F. Donato yesterday a new idea came to my mind
- The SMOG system has already been tested in 2012 in LHCb
  - Injection of noble gas atoms inside the beam pipe to:
    - Measure the beam profile
    - Measure the luminosity
- Why don't use SMOG to measure cross section relevant for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

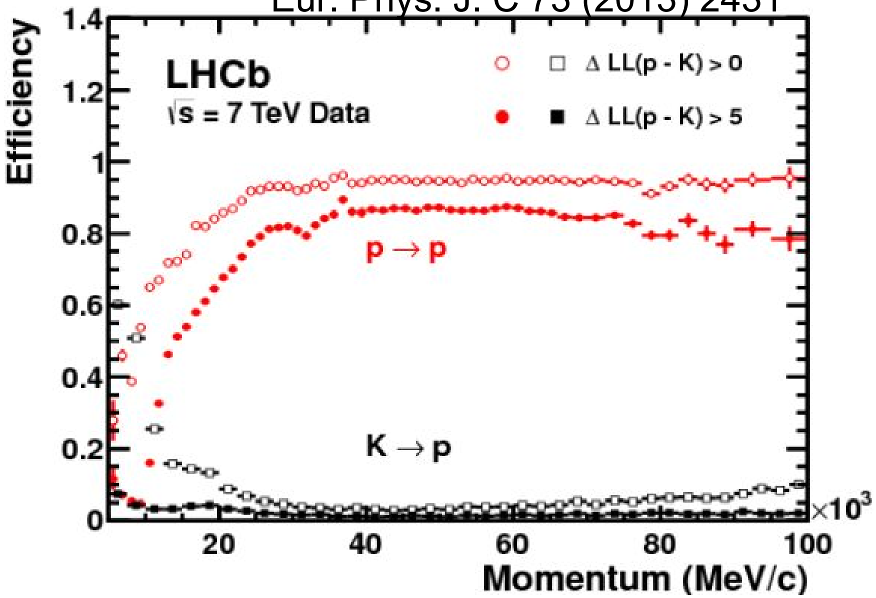


Antiproton identification with Cherenkov radiation

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

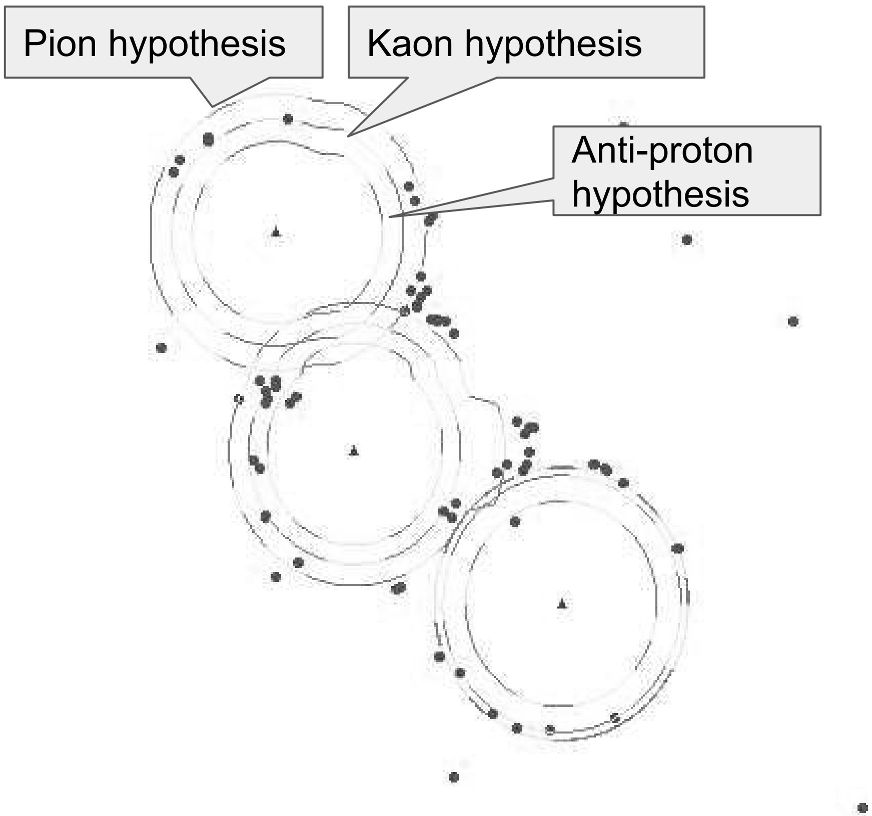


Eur. Phys. J. C 73 (2013) 2431



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

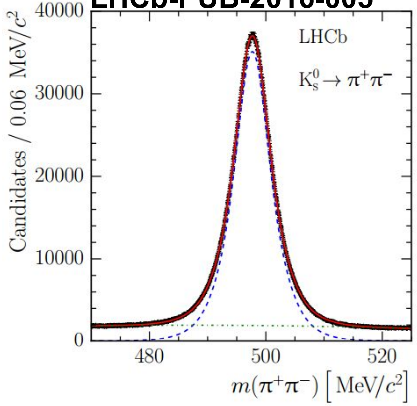
All the other likelihoods are referred to the pion hypothesis and expressed as log: differential log likelihoods.



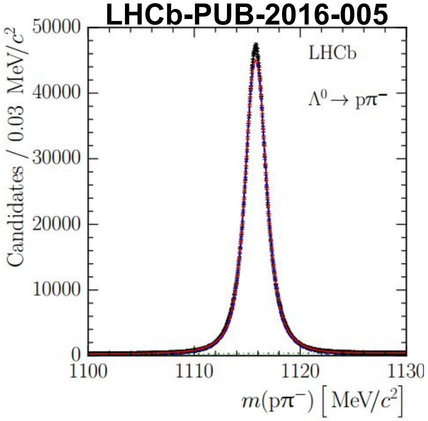
Antiproton identification with Cherenkov radiation

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***.

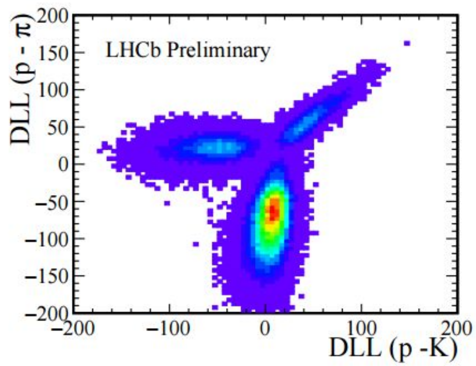
LHCb-PUB-2016-005

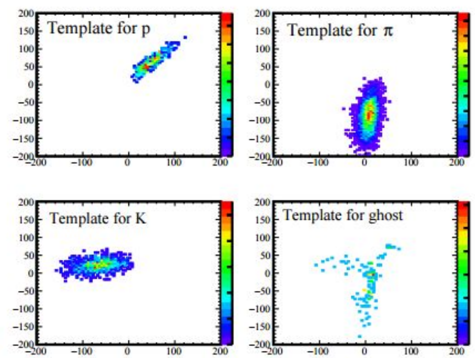


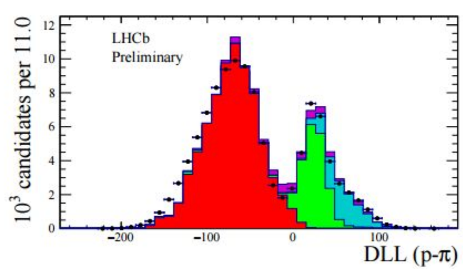
LHCb-PUB-2016-005

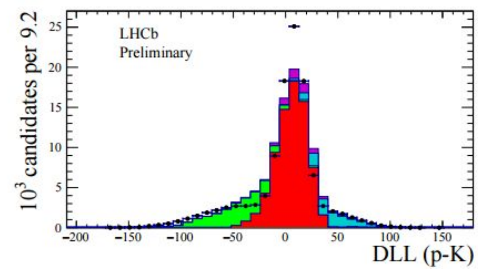


LHCb-CONF-2017-002









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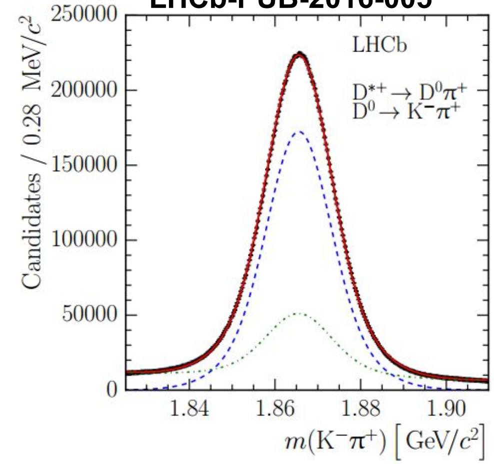
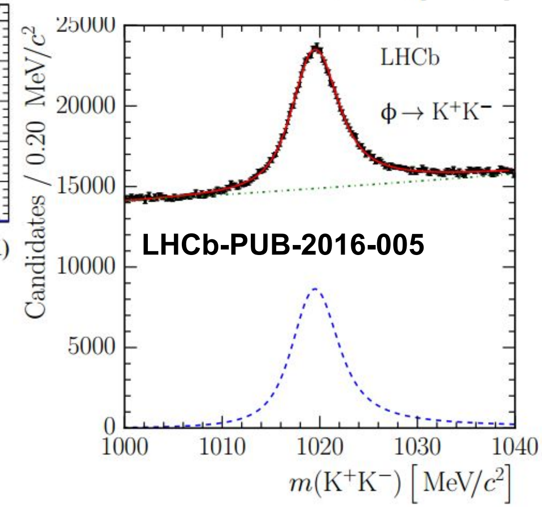


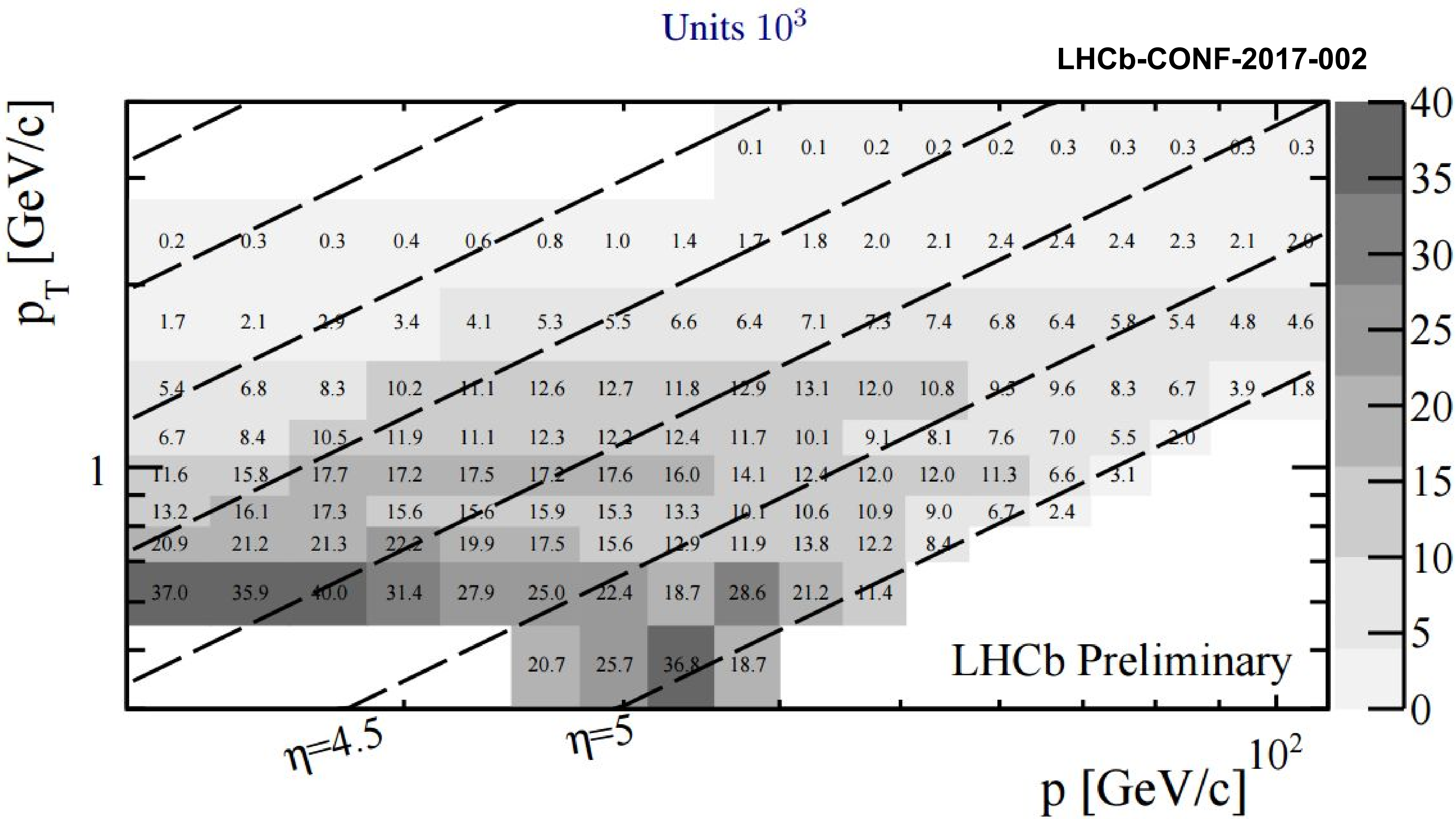


LHCb-PUB-2016-005

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



Luminosity and normalization

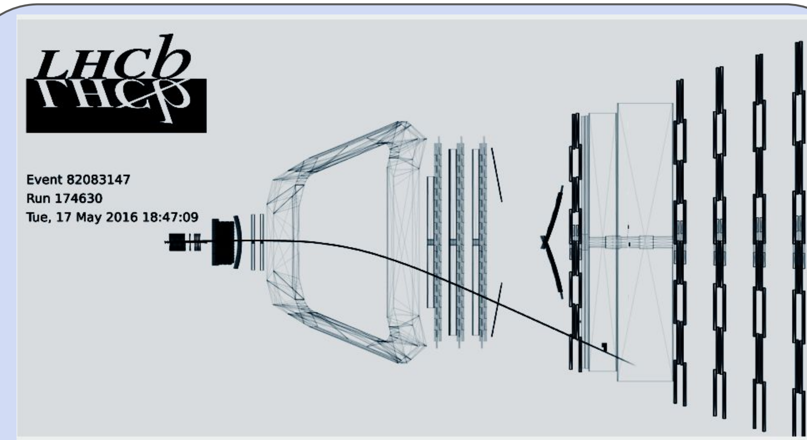
$$\frac{\mathrm{d}N_{\bar{p}}}{\mathrm{d}t} = \sigma_{\bar{p}}\rho\ell \times \frac{\mathrm{d}N_p^{(\mathrm{beam})}}{\mathrm{d}t}$$

- Cross-section $\sigma(p\mathrm{He} \to \bar{p}X)$
- Observed antiprotons in a 5-hour run
- Gas density. **Known up to large uncertainties. Order 10^{-7} mbar**
- Target length (80 cm)
- Number of protons of the LHC traversing the gas target in a 5-hour run.

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.



Results

Prompt antiproton production cross-section.

Total inelastic cross-section

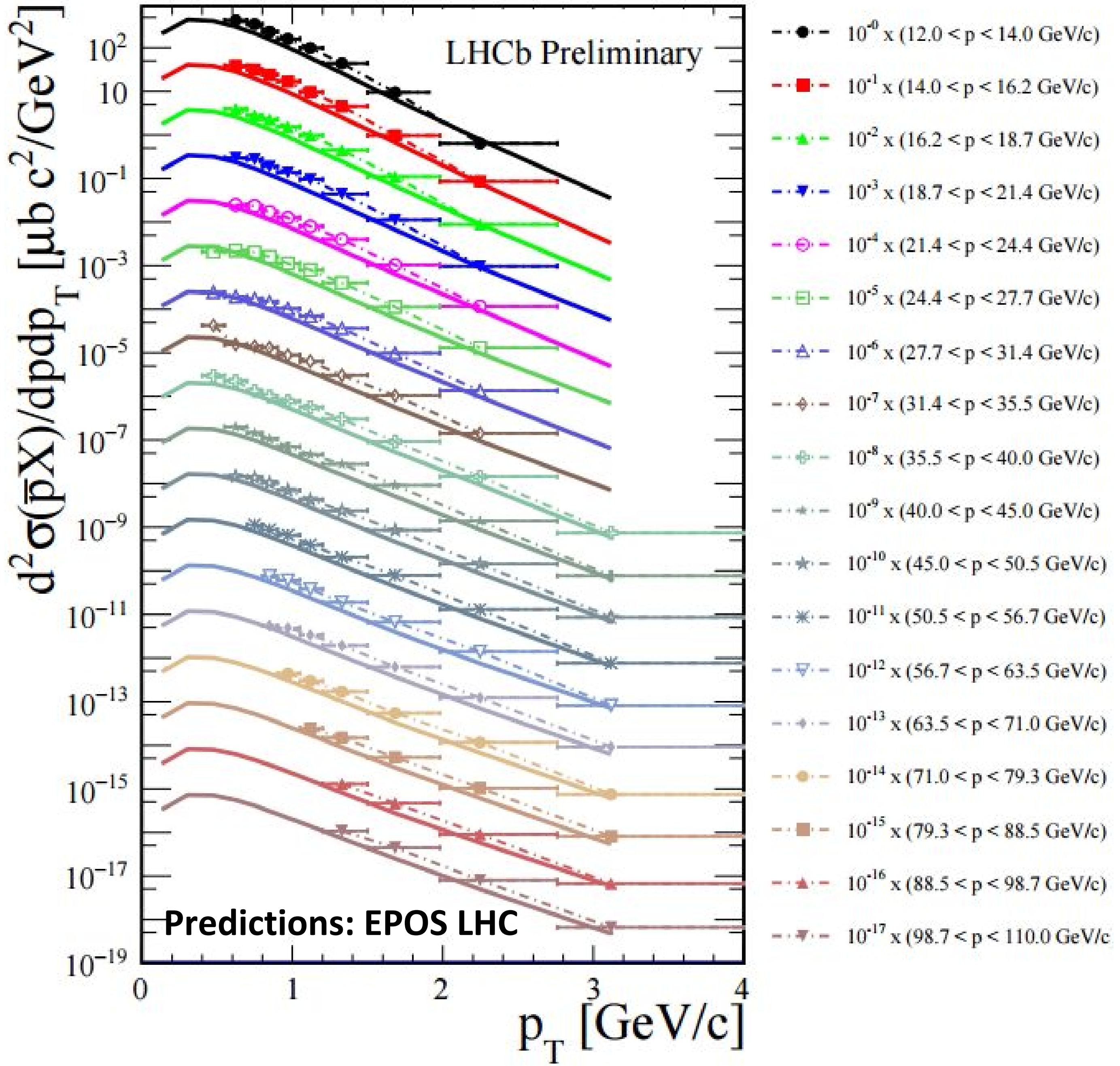
$$\sigma_{inel}^{\mathrm{LHCb}} = (140 \pm 10)\ \mathrm{mb}$$

slightly exceeding the EPOS prediction:

$$118\ \mathrm{mb}$$

The ratio is

$$1.19 \pm 0.08$$



Conclusive remarks

Dawning of a new way to see the LHCb detector

- Beam-gas collisions provide a very interesting system to study mid-energy proton-ion and ion-ion collisions for various targets and energies.
- Several production studies are ongoing to test Cold Nuclear Matter effects
- A link between cosmic-ray physics and HEP was clearly established with the anti-proton cross-section determination
- LHCb is evaluating several proposals to upgrade the SMOG system during LS2 (2019) or LS3 (2024).

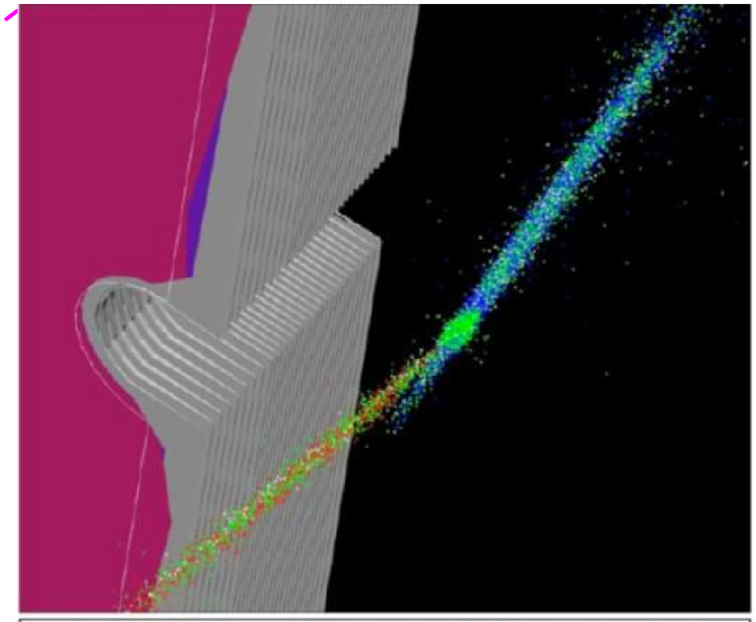
Spare slides

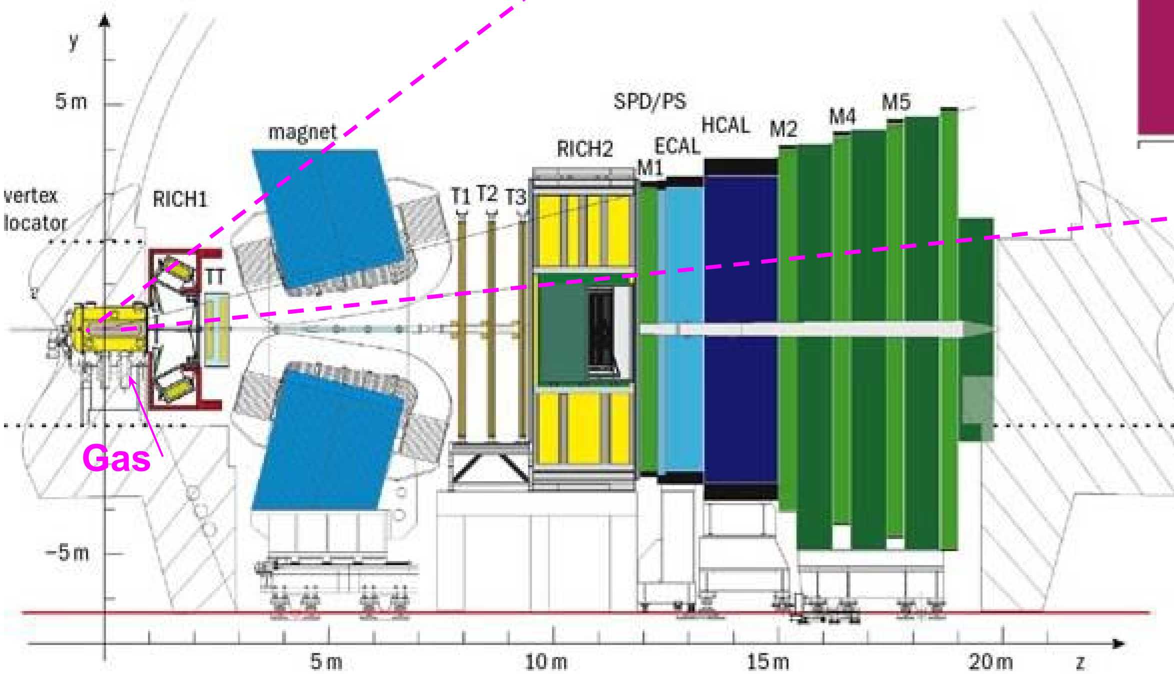
2014 JINST 9 P12005

SMOG. *System for Measuring Overlap with Gas*

Injecting gas in LHCb VELO region

- Designed to improve the luminosity measurement
- Exploited today also as an **internal gas target**
- Allows measurements p-gas and ion-gas collisions





Noble gas only:
(limit chemical reactivity)

✓	Helium	A = 4
✓	Neon	20
✓	Argon	40
✓	Kripton	84
✓	Xenon	131

A wide physics programme.

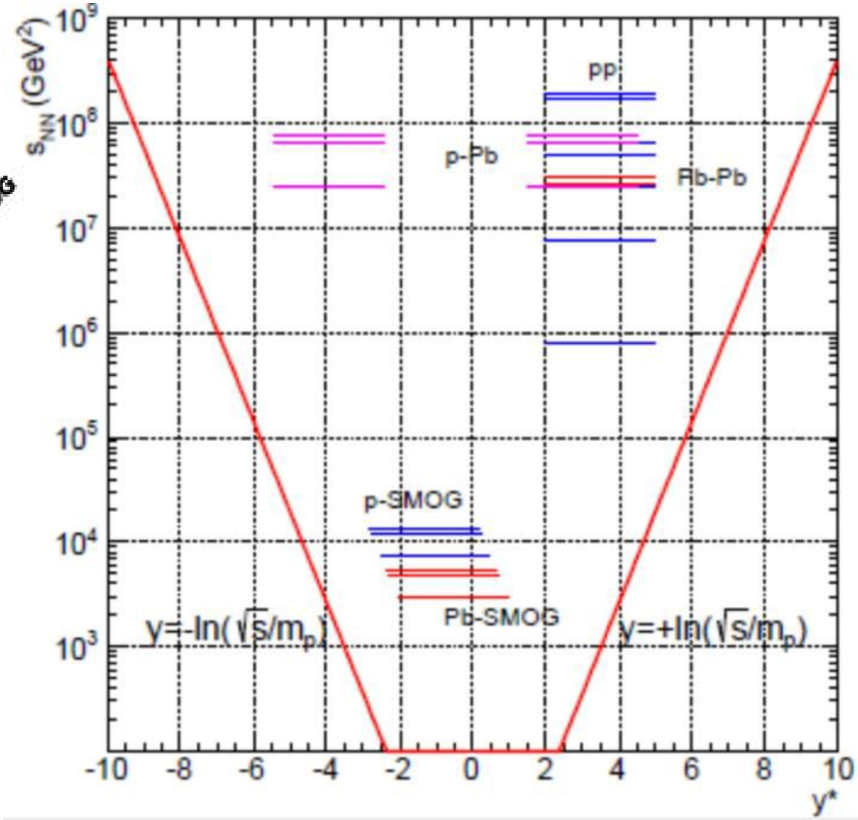
The fixed-target configuration allows to access

- An interesting intermediate region of $\sqrt{s_{NN}}$ between 20 (SPS) and 200 GeV (RHIC)
- The large Bjorken-x region of the target (backward rapidity)
- Conditions emulating cosmic rays collisions with atmosphere, and the interstellar medium
- Test intrinsic-charm in the proton

$\sqrt{s_{NN}}$ between 90 and 110 GeV

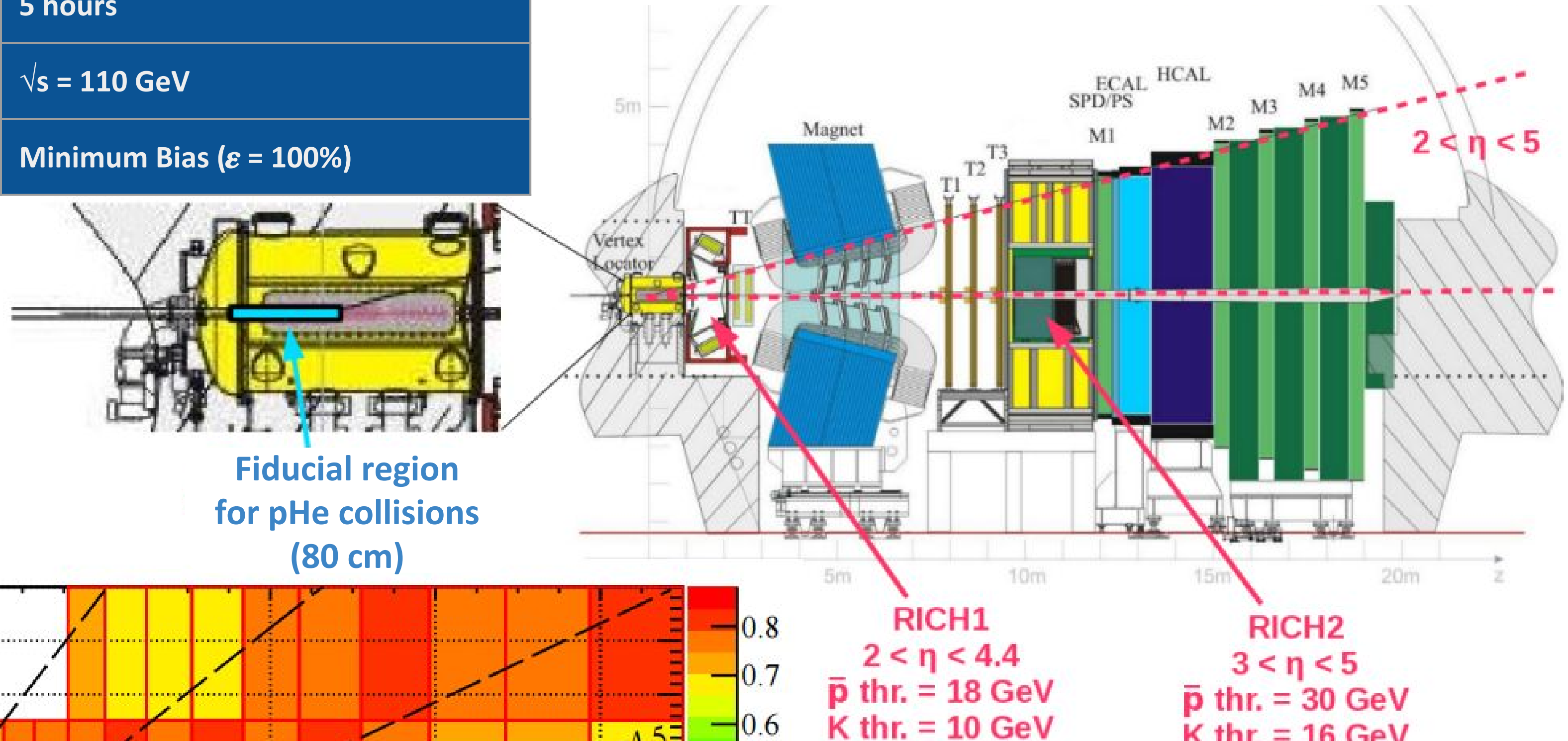
$\sqrt{s_{NN}}$ ≈ 69 GeV

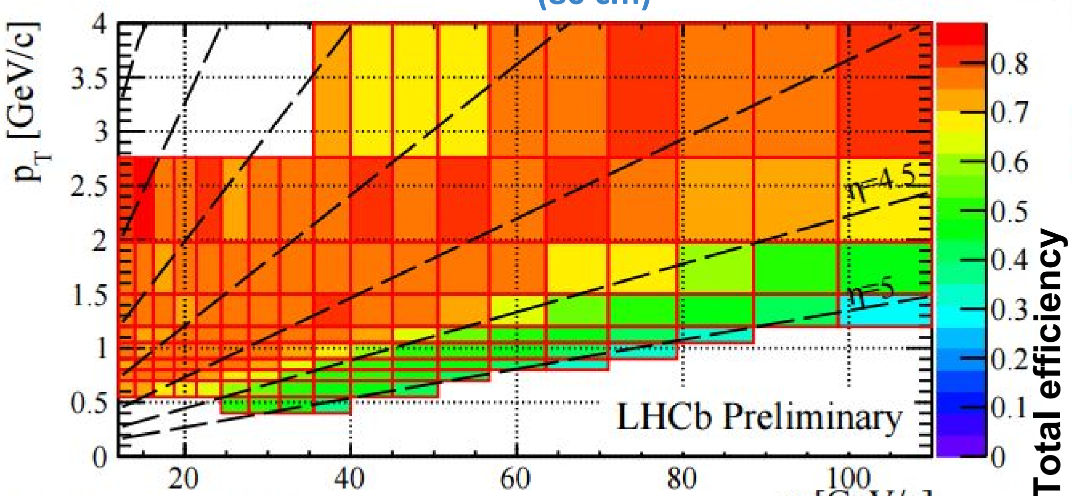
E_{beam}(p)	pp	p-SMOG	p-Pb/Pb-p	Pb-SMOG	Pb-Pb
450 GeV	0.90 TeV				
1.38 TeV	2.76 TeV				
2.5 TeV	5 TeV	69 GeV			
3.5 TeV	7 TeV				
4.0 TeV	8 TeV	87 GeV	5. TeV	54 GeV	
6.5 TeV	13 TeV	110 GeV	8.2 TeV	69 GeV	5.1 TeV
7.0 TeV	14 TeV	115 GeV	8.8 TeV	72 GeV	5.5 TeV



5 hour datataking with Helium in the beam-pipe

When:	**May 2016**
How long:	**5 hours**
Energy:	**√s = 110 GeV**
Trigger:	**Minimum Bias (ε = 100%)**





LHCb-CONF-2017-002

Acceptance
(of tracking and RICH systems)

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

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