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 $2 < \eta < 5$

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

Excellent vertex, IP and decay time resolution
Very good momentum resolution
Excellent particle identification
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

<table>
<thead>
<tr>
<th>System</th>
<th>Duration</th>
<th>CMS energy</th>
<th>Protons on target</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>2015</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>pHe</td>
<td>7h</td>
<td>110 GeV</td>
<td>$2\times10^{21}$</td>
</tr>
<tr>
<td>pNe</td>
<td>12h</td>
<td>110 GeV</td>
<td>$1\times10^{21}$</td>
</tr>
<tr>
<td>pAr</td>
<td>17h</td>
<td>110 GeV</td>
<td>$4\times10^{22}$</td>
</tr>
<tr>
<td>pAr</td>
<td>11h</td>
<td>69 GeV</td>
<td>$2\times10^{20}$</td>
</tr>
<tr>
<td>PbAr (To be analyzed)</td>
<td>100h</td>
<td>69 GeV</td>
<td>$2\times10^{20}$</td>
</tr>
<tr>
<td><strong>2016</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>pHe</td>
<td>18h</td>
<td>110 GeV</td>
<td>$3\times10^{21}$</td>
</tr>
<tr>
<td>pHe (to be analyzed)</td>
<td>87h</td>
<td>87 GeV</td>
<td>$4\times10^{22}$</td>
</tr>
</tbody>
</table>

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 pHe collisions at $\sqrt{s} = 110$ GeV ([LHCb-CONF-2017-002](#))
Heavy flavour production in $p\text{Ar}$ collisions in fixed target mode

based on LHCb-CONF-2017-001
Heavy Flavour Production in pAr collisions

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

So far from LHCb: abundant and pure $J/\psi$ and $D^0$ signal.

Used to measure the efficiency-corrected yields in bins of $p_T$ and $\eta$. Luminosity measurement for absolute cross-section determination is on the way.
Comparison of $J/\psi$ 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. 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.

<table>
<thead>
<tr>
<th>Source of uncertainties</th>
<th>$D^0$ $y$</th>
<th>$D^0$ $p_T$</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Corr. between bins</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Signal selection</td>
<td>2.2%</td>
<td>2.2%</td>
</tr>
<tr>
<td>Signal extraction</td>
<td>2.3%</td>
<td>2.7%</td>
</tr>
<tr>
<td><strong>Uncorr. between bins</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MC smaple</td>
<td>(1.0 – 1.9)%</td>
<td>(1.0 – 1.5)%</td>
</tr>
<tr>
<td>Tracking</td>
<td>(2.7 – 3.4)%</td>
<td>(2.8 – 3.6)%</td>
</tr>
<tr>
<td>PID</td>
<td>(4.1 – 8.8)%</td>
<td>(4.8 – 6.9)%</td>
</tr>
<tr>
<td><strong>Stat. uncertainties</strong></td>
<td>(0.7 – 3.7)%</td>
<td>(0.6 – 3.4)%</td>
</tr>
</tbody>
</table>
Ratio of corrected yields: or relative cross-section

\[ \frac{\sigma(J/\psi)}{\sigma(D^0)} = \frac{Y(J/\psi)}{L} \times \frac{L}{Y(D^0)} \]

Luminosity L cancels out in the ratio

No significant dependence of the ratio in rapidity.
While \( J/\psi \) 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.
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The production cross-section in $p$-$\text{He}$ collisions was never measured. The available prediction are based on $p$-$\text{H}$ and $p$-$\text{C}$ 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???
  - $p$-$\text{He} \rightarrow $ 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, 2016
Antiproton identification with Cherenkov radiation

Likelihood for the three mass hypotheses ($\pi$, $K$ 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**.

**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.
Luminosity and normalization

Cross-section $\sigma(pHe \rightarrow pX)$

$$\frac{dN_{\bar{p}}}{dt} = \sigma_{\bar{p}} \rho \ell \times \frac{dN_p^{(\text{beam})}}{dt}$$

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

Target length (80 cm)

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

Observed antiprotons in a 5-hour run

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

$$\frac{dN_{\bar{p}}}{dt} = \frac{\sigma_{\bar{p}}}{\sigma_{e^-}} \frac{dN_{e^-}}{dt}$$

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

Prompt antiproton production cross-section.

Total inelastic cross-section

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

slightly exceeding the EPOS prediction:

118 mb

The ratio is

1.19 \pm 0.08

Predictions: EPOS LHC
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
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

<table>
<thead>
<tr>
<th>$E_{beam}(p)$</th>
<th>pp</th>
<th>p-SMOG</th>
<th>p-Pb/Pb-p</th>
<th>Pb-SMOG</th>
<th>Pb-Pb</th>
</tr>
</thead>
<tbody>
<tr>
<td>450 GeV</td>
<td>0.90 TeV</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.38 TeV</td>
<td>2.76 TeV</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.5 TeV</td>
<td>5 TeV</td>
<td>69 GeV</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3.5 TeV</td>
<td>7 TeV</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4.0 TeV</td>
<td>8 TeV</td>
<td>87 GeV</td>
<td>5. TeV</td>
<td>54 GeV</td>
<td></td>
</tr>
<tr>
<td>6.5 TeV</td>
<td>13 TeV</td>
<td>110 GeV</td>
<td>8.2 TeV</td>
<td>69 GeV</td>
<td>5.1 TeV</td>
</tr>
<tr>
<td>7.0 TeV</td>
<td>14 TeV</td>
<td>115 GeV</td>
<td>8.8 TeV</td>
<td>72 GeV</td>
<td>5.5 TeV</td>
</tr>
</tbody>
</table>
5 hour datataking with Helium in the beam-pipe

<table>
<thead>
<tr>
<th>When:</th>
<th>May 2016</th>
</tr>
</thead>
<tbody>
<tr>
<td>How long:</td>
<td>5 hours</td>
</tr>
<tr>
<td>Energy:</td>
<td>$\sqrt{s} = 110$ GeV</td>
</tr>
<tr>
<td>Trigger:</td>
<td>Minimum Bias ($e = 100%$)</td>
</tr>
</tbody>
</table>

Fiducial region for pHe collisions (80 cm)

Acceptance (of tracking and RICH systems)

\[ 12 < p < 110 \text{ GeV/c} \]

\[ p_T > 0.4 \text{ GeV/c} \]