New measurements in fixed-target collisions at LHCb

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• The LHCb fixed-target program: SMOG

• **New SMOG results:**
  ‣ Charmonia production in \( p\)Ne collisions at \( \sqrt{s_{NN}} = 68.5 \) GeV  [LHCb-PAPER-2022-014]
  ‣ \( D^0 \) and \( J/\psi \) production in PbNe collisions at \( \sqrt{s_{NN}} = 68.5 \) GeV  [LHCb-PAPER-2022-012]
  ‣ Detached antiproton production in \( p\)He collisions at \( \sqrt{s_{NN}} = 110 \) GeV  [LHCb-PAPER-2022-006]

• SMOG2 upgrade for Run3
SMOG

- SMOG: System for Measuring Overlap with Gas
- A noble gas (He, Ne, Ar) at \( \sim 2 \times 10^{-7} \) mbar pressure injected into the LHC vacuum around the LHCb interaction region
- Originally used to determine luminosity, since 2015 started to collect fixed-target collision data

- \( \sqrt{s_{NN}} = 69-110 \) GeV between SPS & RHIC
- \(-3.0 < y^* < 0\)
- Access nPDF anti-shadowing region
- Probe intrinsic charm content in the nucleon
- Inputs to astrophysics
SMOG datasets and results

**New results:**

- Charmonia production in $p$Ne collisions at 68.5 GeV
- $J/\psi$ and $D^0$ production in PbNe collisions at 68.5 GeV
- Detached antiproton production in $p$He collisions at 110 GeV

**New technical publication:**

- A Neural-Network-defined Gaussian Mixture Model for PID with SMOG data (JINST 17 (2022) P02018)
- Centrality determination in heavy-ion collisions with the LHCb detector (arXiv:2111.01607)

**Previous SMOG results:**

Charmonia in $p$Ne collisions at 68.5 GeV

- Charmonium production modified by initial and final state effects in proton-nucleus collisions
  - Modification of PDFs inside nuclei, CGC
  - Nuclear absorption, multiple scattering, energy loss
  - Comovers

- Dataset: collisions of 2.5 TeV protons and neon nuclei at rest $\Rightarrow \sqrt{s_{NN}} = 68.5$ GeV
- Luminosity $21.7 \pm 1.4$ nb$^{-1}$
- Center-of-mass rapidity coverage: $-2.3 < y^* < 0$
Charmonia in $p$Ne collisions at 68.5 GeV

Differential $J/\psi$ production cross-section

- HELAC-ONIA using CT14NLO and nCTEQ15 under predicts the data
- Good agreement with predictions with (1%) and without an Intrinsic Charm contribution [PRC103 (2021) 035204]
Charmonia in $p$Ne collisions at 68.5 GeV

LHCb-PAPER-2022-014
In preparation

- Total $J/\psi$ cross-section: extrapolation to full phase space using Pythia8+CT09MCS PDF, assuming forward-backward symmetry.
  - shows a power-law dependency with the center-of-mass energy $\sqrt{s_{NN}}$
- $\psi(2S)$ to $J/\psi$ production ratio in good agreement with other proton-nucleus measurements at small values of target atomic mass number, $A$.
- The first measurement of $\psi(2S)$ to $J/\psi$ production ratio with SMOG
$D^0$ and $J/\psi$ in PbNe collisions at 68.5 GeV

- The first measurement of $J/\psi$ and $D^0$ production in fixed-target nucleus-nucleus collisions at the LHC
- Search for the potential formation of quark-gluon plasma. Look for the onset of the transition from ordinary hadronic matter to the QGP.
- Suppression of charmonium $c\bar{c}$ bound states due to presence of the hot and dense medium
- Dataset: 2.5 TeV lead ions incident on neon nuclei $\Rightarrow \sqrt{s_{\text{NN}}}$ = 68.5 GeV
- PbNe centrality determined by energy in ECal


![Graph 1: LHCb preliminary $D^0$ distribution with peak at 5.7k entries]

![Graph 2: LHCb preliminary $J/\psi$ distribution with peak at 550 entries]
$D^0$ and $J/\psi$ in PbNe collisions at 68.5 GeV

Production ratio $J/\psi / D^0$ vs. $p_T$ and $y^*$

- Depends strongly on $p_T$
- Compatible with no dependence on rapidity
- Suppression of $c\bar{c}$ bound states: measure charmonium together with the overall charm quark production
- The production of $D^0$ mesons reflects a large fraction of the overall charm quark production
- $D^0$ acts as a reference for studying quarkonium modification inside nuclear medium
**D⁰ and J/ψ in PbNe collisions at 68.5 GeV**

**J/ψ / D⁰ ratio as a function of N_{coll}**

• Assuming \( \sigma_{J/\psi} \propto \langle N_{coll} \rangle^{\alpha'} \) and \( \sigma_{D^0} \propto \langle N_{coll} \rangle \)

\[ \Rightarrow \sigma_{J/\psi}/\sigma_{D^0} \propto \langle N_{coll} \rangle^{\alpha'-1} \]

• \( \alpha' = 0.82 \pm 0.07 \)

• Agree with measurements from proton-nucleus collisions by NA50  

• \( J/\psi \) production affected by additional nuclear effects compared to \( D^0 \)

• No anomalous \( J/\psi \) suppression is observed that could indicate the formation of QGP
Detached antiproton in $p$He collisions at 110 GeV

SMOG input to astrophysics


- PAMELA and AMS-02 measurements of $\bar{p}/p$ in cosmic rays sensitive to a possible dark matter contribution
- Interpretation of $\bar{p}/p$ measurements require precise $\bar{p}$ production cross-section in spallation of cosmic rays in the interstellar medium (H and He)
- A first measurement of prompt $\bar{p}$ production in $p$He collisions at 110 GeV using SMOG
  
  - Extending the first measurement: antiproton from anti-hyperon decays (detached $\bar{p}$)

- Detached $\bar{p}$ can be distinguished from prompt $\bar{p}$ in LHCb by the separation of their original vertex and the primary $p$He collision vertex.
- Study strangeness production enhancement at $\sqrt{s} \sim 100$GeV

Uncertainty still dominated by XS


Martin Winkler at 2nd LHCb Heavy Ion workshop

LHCb-data would be very helpful
Detached antiproton in $pHe$ collisions at 110 GeV

Exclusive measurement:

- Dominant anti-hyperon contribution from $\bar{\Lambda}$ exclusively reconstructed
- $\bar{\Lambda} \rightarrow \bar{p}\pi^+$: $(50.7 \pm 0.3) \times 10^3$ candidates

$$R_{\bar{\Lambda}} \equiv \frac{\sigma(pHe \rightarrow \bar{\Lambda}X \rightarrow \bar{p}\pi^+X)}{\sigma(pHe \rightarrow \bar{p}_{\text{prompt}}X)}$$

Inclusive measurement:

- Anti-hyperon $H = \Lambda, \Sigma, \Xi, \Omega$
- template fit of $\bar{p}$ impact parameter:
  - Prompt, detached, secondary collisions from materials

$$R_H \equiv \frac{\sigma(pHe \rightarrow HX \rightarrow \bar{p}X)}{\sigma(pHe \rightarrow \bar{p}_{\text{prompt}}X)}$$
Detached antiproton in $p$He collisions at 110 GeV

**Exclusive**
- All considered generators significantly underestimate the $\bar{\Lambda}$ contribution to the $\bar{p}$ production

**Inclusive**
- Generators underestimate the anti-hyperon contribution to $\bar{p}$ production

- The results confirm an increased $H$ contributions compared to $\sqrt{s_{NN}} \sim 10$ GeV
- Indicate a sizable underestimation of detached $\bar{p}$ contribution in most hadronic production models used in cosmic ray physics
SMOG2: Storage Cell for the gas upstream of the nominal IP (z in [-500, -300] mm) and precisely calibrated Gas Feed System.

- Gas density increased by up to two orders of magnitude ==> much higher luminosity
- More gas targets: H₂, D₂, He, N₂, O₂, Ne, Ar, Kr, Xe
- beam-beam and beam-gas separate luminous regions:
  ==> simultaneous pp-SMOG2 data-taking
  ==> large statistics

Physics:
- Intrinsic heavy-quark
- p-Gas collisions: nPDFs, gluon anti-shadowing at large x, cold nuclear matter effects
- Pb-Gas collisions: QGP formation, rapidity scan at lower energy, quarkonium sequential suppression
- Astrophysics

More details: talk by S. Mariani 06/04, 11:30
Conclusion

Thanks for your attention!

• The LHCb fixed-target program SMOG offers rich physics opportunities
• New results from SMOG data:
  • Charmonia production in $p$Ne at 68.5 GeV: first $\psi(2S)$ result from SMOG
  • $D^0$ and $J/\psi$ production in PbNe collisions at 68.5 GeV: first result from SMOG AB collisions
  • Detached $\bar{p}$ production in $p$He at 110 GeV: key inputs to astrophysics
• Promising SMOG2 upgrade in Run3
• And much more to come from the SMOG/SMOG2