Heavy ion and fixed target results at LHCb

Pasquale Di Nezza

on behalf of the collaboration
LHCb is a unique spectrometer in HEP due to its forward geometry

Unique kinematics in heavy-ion collider and fixed target mode

**pPb run (2016) at $\sqrt{s_{NN}} = 8.16$ TeV:**
- $10^9$ minimum bias collisions in pPb and PbPb mode
- 34 nb$^{-1}$ luminosity acquired (i.e. $\approx 0.5$ million J/$\psi$ in pPb and PbPb each)

**Ion-ion:**
- 10 $\mu$b$^{-1}$ PbPb (2015) and 0.4 $\mu$b$^{-1}$ XeXe $\rightarrow$ 2018 PbPb a factor $>20$

Fixed target pp, pA, Pb-p or PbA collisions at the poorly explored energy of $\sqrt{s} \sim 100$ GeV and high Bjorken-x
D⁰ production in pPb collisions at 5.02 TeV

HF are unique probes in HI collision:
- \( m_\Psi \gg \Lambda_{QCD} \) allows perturbative calculations
- \( t_{prod} \ll t_{QGP} \) experiences the whole time evolution of the collision

Both cross section (left) and Nuclear Modification Factor (right) are fairly described by nPDFs and Color Glass Condensate calculations

LHCb data already used to constrain nPDFs in the unexplored region at low-x (PRL 121 (2018) 052004)
$\Lambda_c$ production in pPb collisions at 5.02 TeV


- $\Lambda_c$ 3-body decay: test of charm fragmentation
- In the ratio most of the nPDF uncertainties cancel out
- Important input for hadronization phenomenology: crucial comparison with other collision systems
- Hadronisation pattern of $c\bar{c}$ similar to model tuned to pp ($R \sim 0.3$), same discrepancy high-$p_T$ and forward rapidity
J/ψ production in pPb collisions at 8.16 TeV

**Prompt production**

- strong suppression at forward rapidity: increasing from 0.5 at lowest $p_T$ reaching 1 at highest $p_T$
- nPDFs & Color Glass Condensate calculations account for observations
- for rapidity dependence (not shown here) also the coherent energy-loss accounts for observation

**Non-prompt production**

- first precise b-production measurement in pPb down to $p_T \sim 0$
- suppression at forward rapidity, modification factor close to 1 at backward rapidity
- crucial input for the HI phenomenology

Very valuable constraint of nPDFs in unexplored area at low-$x$  

(PRL 121, 052004 (2018))
$\Upsilon$(nS) in HI: probe of deconfinement

Clean separation of the three nS states

$R_{PPb}$ for $\Upsilon$(1S)

$R_{PPb}$ for $\Upsilon$(2S)

$\Upsilon$(1S): suppressed forward, compatible with unity backward (within nPDF uncertainties)

$\Upsilon$(1S)/$J/\psi$-from-b similar in $pp$ & in $pPb/PbPb$:

- naive approximate expectation in pure nuclear PDF & coherent energy-loss
- ‘additional’ suppression for the ground state seems limited
Comovers theory model predicts large final-state effects, larger for excited states and in backward direction (JHEP 10 (2018) 094)

- Patterns observed in data support the comover picture
- Its understanding is crucial for the correct interpretation of the QGP-induced sequential suppression observed in PbPb collisions (CMS arXiv:1805.09215)
Ultra-Peripheral PbPb collisions: γ-probe of the nucleus

- Exclusive vector meson production via γ-pomeron scattering
- Sensitive to generalised gluon distributions for Bjorken-x ∈ 10^{-2} -10^{-5}
- For small quark at leading twist, leading ln(1/x), t→0: σ ∝ (gluon-PDF)^2
- LHCb well suited for exclusive production studies with Pb-beams: resolution, PID & very forward detector (HerSCheL)

Large cross-sections due to the large e.m. field (photon flux grows with Z^2) of the 2 nuclei
Coherent (whole nucleus) $J/\psi$ production can be well separated from incoherent ($\gamma$-nucleons) part

Coherent photo production cross section sensitive to nPDF

Covered rapidity range and precision can well constrain the models (2018 data taking gives a big boost)

Mantysaari model without subnucleonic fluctuations disfavoured —> crucial input for HI
LHCb is the only experiment able to run both in collider and in fixed-target mode
SMOG, a successful idea and a pseudo-target

System for Measuring Overlap with Gas (SMOG) has been thought for precise luminosity measurements by beam gas imaging, but then it served as a “pseudo-target” producing interesting results.

Data taking SMOG 2015-2017

A very successful data taking just concluded
Cosmic Antiprotons

- Precision AMS-02 measurements of $\bar{p}/p$ ratio in cosmic rays at high energies is an indirect search for Dark Matter (PRL 117, 091103 (2016))

- Data hint for a possible excess, and milder energy dependence than expected

- Prediction for $\bar{p}/p$ ratio from spallation of primary cosmic rays on interstellar medium (H and He) is presently limited by uncertainties on $\bar{p}$ production cross-sections
  
  - Large uncertainties (~ factor 2) on cross-sections from models of hadronic interactions
  
  - Empirical parameterizations mostly based on SPS pp data, but no previous measurement of $\bar{p}$ production in p-He
  
  - Scaling violations at $\sqrt{s_{NN}} \sim 100$ GeV is poorly constrained

The LHC energy scale and LHCb +SMOG is very well suited to this measurement
Uncertainties are smaller than model spread

$\text{EPOS+LHC}\_\text{tuning}$ underestimate the $\bar{p}$-production

... but then the visible inelastic cross section is compatible with $\text{EPOS-LHC}$:

$$\frac{\sigma_{\text{LHCb}}}{\sigma_{\text{EPOS-LHC}}} = 1.08 \pm 0.07 \pm 0.03$$

$\rightarrow$ discrepancy: $\bar{p}$ yield/event

Fundamental contribution able to shrink the background uncertainties in dark matter searches in space

Natural $p\text{He}$ extensions:
- inclusive $\bar{p}$ from hyperon decays
- charged $\pi,K,p$ spectra
- $\sqrt{s_{\text{NN}}}=87\text{ GeV}$ data

Charm production in fixed targets

First LHCb charm samples from:
- pHe@69 GeV (7.6 ± 0.5 nb⁻¹) and
- pAr@110 GeV (few nb⁻¹)

First determination of c̅c cross-section at this energy scale

LHCb results in good agreement with NLO NRQCD fit (J/ψ, left) and NLO pQCD predictions (cc, right) and other measurements
Good agreement of phenomenological predictions with $y^*$-shape, poor in $p_T$ (not shown here) ... gluon dominance?

HELAC-ONIA, designed and tuned for collider data, underestimate the $J/\psi$ ($D^0$) pHe-cross section by a factor 1.78 (1.44)
- HELAC-ONIA does not contain intrinsic charm contribution
- No evidence for sizeable valence-like intrinsic charm contribution
A real storage cell - **SMOG2** - will be installed during the LHC LS2 and start taking data from 2021.

- Increase of the luminosity by up to 2 orders of magnitude using the same gas load as SMOG.
- Injection of $H_2, D_2, He, N_2, O_2, Ne, Ar, Kr, Xe$.
- New Gas Feed System will give a strong improvement on the luminosity determination.
- Well defined interaction region upstream the nominal IP: strong background reduction and also the possibility to run in parallel with pp collisions.
Conclusions

- LHCb developed a lively and fast growing heavy-ion program, with very specific capabilities and unique acceptance at a hadron collider.

- Much more data from Run 2 to be analyzed and substantial development of the program in the next future with an upgraded spectrometer and a real storage cell.
Conclusions

- LHCb developed a lively and fast growing heavy-ion program, with very specific capabilities and unique acceptance at a hadron collider

- Much more data from Run 2 to be analyzed and substantial development of the program in the next future with an upgraded spectrometer and a real storage cell

Heavy-Ion and Fixed-Target collisions at LHCb offer a unique opportunity for a laboratory for QCD and astroparticle in unexplored kinematic regions