Initial-state in heavy-ion collisions at colliders: Experimental summary

Émilien Chapon

CERN

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Characterising the initial state of heavy-ion collisions:

- Spatial distribution: geometry (Glauber...)

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Initial state

Characterising the initial state of heavy-ion collisions:

- Spatial distribution: geometry (Glauber...)
- Momentum distribution: nuclear parton distribution functions
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Future experimental input
\( \nu_2 \) in Z-tagged events in pp

- Select higher \( Q^2 \) (smaller \( b \)? different \( \epsilon_2 \)?) with Z bosons
- First measurement of 2-particle correlations in high-pileup samples (up to 20% PU correction)
- \( \nu_2 \) in Z-tagged events shows no dependence on multiplicity
- \( 8 \pm 6\% \) larger than inclusive 13 TeV pp (but different \( p_T \) spectrum)
Collision geometry in PbPb: W and Z bosons

- W and Z bosons not expected to be affected by the strongly interacting QGP
- Use them for testing the initial state geometry (Glauber model)
- Measurement uncertainties smaller than normalisation \((T_{AA})\) ones! Could define \(Z_{AA} = \frac{N_{AA}^X \cdot \sigma_{pp}^Z}{N_{pp}^X \cdot \sigma_{AA}^Z}\)?
- Similar hint of excess in peripheral collisions for both W and Z
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**ATLAS** Preliminary

Pb+Pb, $\sqrt{s_{NN}}=5.02$ TeV, 0.49 nb$^{-1}$

$W \rightarrow \mu \nu$

$\mathbf{W}^*$: Data

POWHEG (CT10 NLO) $\times k_{NNLO}$

$\mathbf{W}$: Data

POWHEG (CT10 NLO) $\times k_{NNLO}$
Glauber in pPb

- Can also use $W$ bosons to test Glauber in pPb
- Centrality and $\langle N_{\text{coll}} \rangle$ estimated using neutron zero degree calorimeters + Glauber model with an “hybrid method”
- $W$ boson production consistent with geometric expectation

![Graphs showing $\sigma_{W} / \langle N_{\text{coll}} \rangle$ vs. centrality class](image)
Partonic content in the initial state

- Needed for $\sim$ any cross section or $R_{AB}$ prediction
- In pPb: correlation between measured kinematics and probed $x_{Pb}$
- PbPb can add some information
**CMS W bosons (8.16 TeV):**
- Experimental uncertainties smaller than nPDF ones
- Inconsistent with free proton PDF, better agreement with EPPS16 than nCTEQ15 (amount of shadowing)
- Consistency with 5.02 TeV data checked

**ALICE W and Z bosons (5.02 TeV):**
Inconclusive given current uncertainties
W and Z bosons in pPb

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H. Kim (CMS), A. Sarkar (ALICE)
- $R_{pAu}$ consistent with unity and EPPS16
- Inconclusive due to large uncertainties in the data
W and Z bosons in PbPb

- **ATLAS W bosons**: inconclusive (note also: NLO vs NNLO)
- **ALICE Z bosons**: hint of nuclear effects
Dijets in pPb

- Probing gluon nPDF over a wide range of $x_{Pb}$, from shadowing to anti-shadowing and EMC
- pPb data already included in EPPS16
- pPb/pp less sensitive to pp modelling
Interlude: free proton PDF

Free protons are the reference! But are they that well known?

- Some tension between dijet data and NLO pQCD
- NNLO pQCD with recent PDFs fails to reproduce ATLAS W/Z data at 5.02 TeV
  - Note1: 1.9% luminosity uncertainty!
Interlude: free proton PDF

Free protons are the reference! But are they that well known?

- Some tension between dijet data and NLO pQCD
- NNLO pQCD with recent PDFs fails to reproduce ATLAS W/Z data at 5.02 TeV
  - Note1: 1.9% luminosity uncertainty!
  - Note2: consistent ATLAS 5.02 and 7 TeV... but not CMS 8 TeV? Puzzle
Photons in pPb

- Photons also expected to be sensitive to initial state (isospin + nPDF)
- No nPDF constraints within current precision
- Also differential in multiplicity in ALICE
Ultra-peripheral collisions

Using the lead ions as a source of quasi-real photons

- Can be used as a probe of the projectile structure
- Sensitivity to nPDF

**Photon-pomeron:**
production of vector mesons (sensitivity to nPDF)

**Photo-nuclear:**
jet photoproduction (probe nPDF directly)
Quarkonia in $\gamma p$ collisions

- Exclusive $J/\psi$ and $\psi(2S)$ in 13 TeV pp (LHCb)
- Exclusive $\Upsilon(1S)$ in 5.02 TeV pPb (CMS)
- Good agreement with models (NLO pQCD, gluon saturation)
\( \gamma \text{Pb} \) collisions

- LHCb: coherent \( J/\psi \) production
- ALICE: coherent \( J/\psi \) production with nuclear overlap (in two centrality bins)
- Models implement different initial state (gluon saturation...) and quarkonium production mechanisms
Photonuclear dijets

- Selecting $\gamma$Pb interactions using ZDC + rapidity gaps
- Comparison with PYTHIA ($\gamma$ spectrum reweighted to STARLIGHT)
- Sensitivity to nPDF
Open heavy flavour hadrons

C. Terrevoli (ALICE), Y. Zhang (LHCb), M. Dumancic (ATLAS)

- Many precise open heavy flavour measurements
  - $D^0$,
Open heavy flavour hadrons

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Open heavy flavour hadrons

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- Many precise open heavy flavour measurements
  - $D^0$, $\Lambda_c^+$, $B^+$, $J/\psi \leftarrow b$...
- Being considered for constraining nPDF
  - Precise measurements, access to low $x$ (down to $<10^{-6}$)!
  - Some theoretical issues being discussed

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**ATLAS Preliminary**

$p+Pb$ | $\sqrt{s_{\text{NN}}} = 8.16$ TeV, 76.3 $\mu$b

**Prompt $D^0$ Production**

- Data $\times 10^3$, $0.0 < y^* < 0.5$
- Data $\times 10^2$, $-0.5 < y^* < 0.0$
- Data $\times 10^1$, $-1.0 < y^* < -0.5$
- Data $\times 10^0$, $-1.5 < y^* < -1.0$

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**ALICE**

$p+Pb$, $\sqrt{s_{\text{NN}}} = 5.02$ TeV

$-0.96 < y < 0.04$

- $\Lambda_c^+$
- $D$ mesons (average $D^0$, $D^+$, $D^\star$)
- $D^0$ meson

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**LHCb**

$pPb$, $\sqrt{s_{\text{NN}}} = 5$ TeV

- Prompt $D^\star$, $J/\psi$
- $p_T < 10$ GeV/c

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**LHCb**

$pPb$, $\sqrt{s_{\text{NN}}} = 5$ TeV

- Prompt $D^\star$, $J/\psi$
- $1.5 < y^* < 4.0$

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**LHCb**

$pPb$, $\sqrt{s_{\text{NN}}} = 8.16$ TeV

- Prompt $D^\star$, $J/\psi$
- $2 < p_T < 20$ GeV/c
Quarkonia

Also quarkonia:

- Many precise quarkonium measurements
- Some theoretical complications
Large-\(x\): intrinsic charm

- Probing large \(x\) with LHCb in fixed-target mode (SMOG)
- No evidence for substantial valence-like intrinsic charm contribution
Future experiments

Forward photons in ALICE

- **FoCal**: new forward calorimeters for installation in 2024-2025
- Probing low $x$ nPDF using photons
- Complementary to forward heavy flavour measurements

**x-distributions from NLO pQCD**

- $\sqrt{s} = 8.8$ TeV
- $5 < p_T < 20$ GeV
- $4 < \eta < 5$

**NPDF3.1 NNLO, $Q^2 = 5$ GeV**

- **DIS+DY baseline**
- **DIS+DY baseline + FoCal**
Future facilities

A. Kusina, C. Hadjidakis, J.-P. Lansberg (AFTER), A. Deshpande, R. Yoshida (eIC), A. Dainese (FCC-AA)

Uncharted kinematic territory and precision:

- **AFTER@LHC** (fixed target with ALICE or LHCb):
  - high-$x$ frontier

- **eIC, LHeC, FCC-eh**:
  - large ($x, Q^2$) coverage, high precision
Future experiments

Initial-state in heavy-ion frog collisions

https://abstrusegoose.com/156

FUN FACT: Ex-particle-physicists make the worst biologists.