Measurement of direct photons at forward rapidities in p-A collisions at LHC with ALICE

a probe for nuclear PDFs and saturation

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1. Low-x physics and gluon saturation in p/d+A
   • results from RHIC and LHC
2. Direct Photons
3. FoCal - an ALICE Upgrade Proposal
   • performance studies
   • detector R&D
Experimental results from RHIC and LHC

- **Gluon saturation**
  From DIS, HERA: 
  gluon density increases rapidly at low x 
  → problems with unitarity (finite cross sections)

- **Particle production in nuclear collision at forward rapidities**
  Observation: 
  suppression of hadron production in d+Au / p+Pb as compared to p+p 
  → nuclear modification factor

* Kinematics
  2→1 process
  y=rapidity of (x_L, k) system
  \[ x_{1,2} = \left( \frac{M}{s} \right) e^{2y} \]
Charged hadrons – $R_{dAu}$ at different pseudorapidities (RHIC)

$R_{dAu} = \frac{1}{<N_{coll}>} \frac{d^2N^{d+Au}}{dp_Td\eta} / \frac{d^2N^{pp}_{inel}}{dp_Td\eta}$

where $<N_{coll}> = 7.2\pm0.3$

- Clear suppression as $\eta$ changes from 0 to 3.2
- CGC model describes $R_{dAu}$ and $R_{CP}$

Experimental results from RHIC

Results from STAR

NMF

\[ \sqrt{s_{NN}} = 200 \text{ GeV} \]

\[ \pi^0 (\langle \eta \rangle = 4.0) \]

\[ \pi^- (\eta = 3.2) \]

\[ \pi^- (\eta = 2.2) \]

\[ \frac{R_{dAu}}{dAu} \]

\[ \text{STAR, PRL97, 152302} \]

\[ \text{dAu} \]

\[ \text{forward-forward correlations} \]

\[ \text{di-hadron correlations} \]

\[ \pi^0 \text{ mesons } \langle \eta \rangle = 4.0 \]

\[ \text{shadowing (KKP)} \]

\[ \text{shadowing (Kretzer)} \]

\[ \text{multiple scattering} \]

\[ \text{STAR preliminary} \]

\[ p + p \rightarrow \pi^0 \pi^0 + X \]

\[ d + Au \rightarrow \pi^0 \pi^0 + X \]

broadening/suppression of away-side peak in dAu

strong suppression of hadron yield

- qualitatively consistent with CGC expectations
- however, many open questions/alternative interpretations:
  e.g. effects of multiple interactions, beam energy loss, kinematic limits…
Results from p-Pb at LHC (1)

forward/backward ratio $R_{FB}$

$$R_{FB} = \frac{dN/dp_T(p \rightarrow \text{going})}{dN/dp_T(Pb \rightarrow \text{going})}$$

for Φ-mesons in ALICE (dimuons) and for open charm in LHCb

• Φ strongly suppressed at forward rapidity
  – interpretation unclear

• prompt $D^0$ suppressed
  – comparison with shadowing (EPS09): consistent, but data slightly more suppressed
Results from p-Pb at LHC (2)

nuclear modification factor $R_{pPb}$ for charmonium

- $J/\psi$ suppressed at forward rapidity
  - consistent with shadowing (EPS09)
  - not described by a specific CGC calculation

- More recent CGC calculation compatible with observed $J/\Psi$
  $\rightarrow$ inconclusive

$$R_{pA} = \frac{\frac{dN}{dp_T(pA)}}{<N_{coll}(pA)> \frac{dN}{dp_T(pp)}}$$
A probe for gluon density – direct photons

• Hadronic observables
  – interpretation inconclusive

• Electromagnetic probes
  – Deep-Inelastic Scattering (DIS)
    » classical PDF method
    » not sensitive to gluons at LO
    » gluons from NLO

  – Photon production in hadronic collisions
    » sensitive to gluons at LO
Direct photons - nPDF vs CGC

- **Direct photons**
  - large cross section
  - sensitive to small $x$ at forward rapidity: $x \approx 10^{-5}$ at $\eta=4-5$
    (narrow peak, however with a sizeable tail)

- **Two scenarios for forward $\gamma$ production in $p + A$ at LHC**
  - normal nuclear effects
    NLO and LO nPDFs
  - saturation/CGC

$\rightarrow$ strong suppression in direct $\gamma R_{pA}$
  - clean signal for isolated photons
  - signal expected at forward $\eta$, low-intermediate $p_T$
ALICE detector & upgrades

TPC: new GEM readout chambers, continuous readout

new ITS: high resolution, low material budget

TRD, TOF, PHOS, EMCal, Muon spectrometer: new readout electronics

MFT: secondary vertexing for muons

Upgrade of forward/trigger detectors (ZDC, VZERO, T0)

FoCal project

new beam pipe: smaller diameter

planned for installation in LS2 (2019), Letter of Intent: CERN-LHCC-2012-012

Proposed for LS3 upgrade (under internal discussion)
Forward measurements: RHIC vs LHC

RHIC: low $p_T$, kinematic limit at $p_T \approx 5$ GeV

LHC: $x = 10^{-4}$-$10^{-5}$ accessible with $p_T \approx Q \approx 3$-$5$ GeV
FoCal in ALICE

- **FoCal-E**
  high-granularity Si-W calorimeter for direct (isolated) $\gamma$, $e^+e^-$ ($J/\psi$) and $\pi^0$
- **FoCal-H**
  hadronic calorimeter for photon isolation and jets
- **location**
  $z \approx 7m$ (outside magnet) $\rightarrow 3.3 < \eta < 5.3$
- **main challenge**
  separate $\gamma/\pi^0$ at high energy
- **technology**
  - Si-W calorimeter, effective granularity $\approx 1\text{mm}^2$
  - small Molière radius, high-granularity read-out
FoCal strawman design

studied in performance simulations:

24 layers: W (3.5mm $\approx 1 \times X_0$) + Si-sensors (2 types)
- low granularity (LG), Si-pads
- high granularity (HG), pixels (e.g. CMOS-MAPS)

<table>
<thead>
<tr>
<th></th>
<th>LG</th>
<th>HG</th>
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</thead>
<tbody>
<tr>
<td>pixel/pad size</td>
<td>$\approx 1 \text{ cm}^2$</td>
<td>$\approx 30 \times 30 \mu\text{m}^2$</td>
</tr>
<tr>
<td>total # pixels/pads</td>
<td>$\approx 2.5 \times 10^5$</td>
<td>$\approx 2.5 \times 10^9$</td>
</tr>
<tr>
<td>readout channels</td>
<td>$\approx 5 \times 10^4$</td>
<td>$\approx 2 \times 10^6$</td>
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assuming $\approx 1 \text{ m}^2$ detector surface
Direct-$\gamma$ / decay-$\gamma$ separation in pp

Direct $\gamma$/all cluster ratio

- $pp$, $\sqrt{s} = 13$ TeV
- $4.0 < \eta < 5.0$
- 7m position
- ALICE simulation
- FoCal upgrade

Direct $\gamma$ uncertainty

- $pp$, $\sqrt{s} = 13.0$ TeV
- $4.0 < \eta < 5.0$
- Relative uncertainty

- Statistical
- Systematic (PYTHIA)
- Systematic (JETPHOX)

- $R_{iso}=0.4$, $p^{E+H}_{T,iso} < 3.0$ GeV

- $\gamma_{all}/all > 0.1$ for $p_T > 4$ GeV/c

- 20-40% uncertainty at $p_T = 4$ GeV/c, decreases with increasing $p_T$
20 layer pixel detector

- **Several groups involved**
  - full prototype with pixel detectors CMOS (MIMOSA) 39M pixels, 30µm pitch
  - use synergy with R&D for ALICE ITS upgrade (ALPIIDE)
  - full prototype with pad readout

- **Performed systematic tests**
  - test beam data from 2 to 250 GeV/c (DESY, CERN PS & SPS)
  - cosmic muons
R&D results - two shower separation

display of single event (with pile-up) from 244 GeV/c SPS mixed beam

evaluate separation capability: core energy
  - calculate shower energy in cylinder of finite radius
  - study as function of radius
R&D results: lateral profile and core energy

- extremely good spatial resolution \( R_{\text{Moliere}} \approx 11\text{mm} \) (estimated from cumulative distributions)
- good agreement with simulations using GEANT4 + charge diffusion

![Lateral profiles for 50 GeV/c electrons - comparison to GEANT4](image1)

- reasonable energy resolution of pixel calorimeter
- response and resolution for core energy hardly affected down to \( r = 5\text{mm} \)
Summary

- LHC forward measurements provide unique opportunity for low-x physics
- ALICE experiment has open space to instrument forward rapidities
- FoCal detector in ALICE – upgrade proposal for LS3
  - opportunity for forward direct photon measurement
  - particle density/kinematics require extremely high granularity: feasible with SiW pixel calorimeter
  - rich physics program
    » other observables: $\pi^0$, $e^+e^-$ ($J/\psi$), jets
    » p+Pb: gluon density, ridge
    » Pb+Pb: medium effects