ATLAS Heavy Ion program in the LHC runs 3 & 4

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HI town meeting - October 24, 2018
• Significant upgrades of the ATLAS detector are expected for the Run 3 & Run 4
• Completely **new tracker** will be installed **before Run 4**
**ATLAS Inner Tracker (ITk)**

- η coverage of 8 units and all silicon design
- ~15 hits per track, approximately uniform across the η acceptance

**Diagram Description:**
- R [mm] axis ranging from 0 to 1400
- z [mm] axis ranging from 0 to 3500
- Graph labeled "ATLAS Simulation" showing Inclined Duals with η coverage at 1.0, 2.0, 3.0, and 4.0

- 5 pixel and 4 double-sided barrel layers
- 6 strip endcap disks
- Pixel endcap disks in the forward direction
Excellent efficiency for the charged particles reconstruction

- **Improvement** of about **20% for** $|\eta| < 1$ and **30% for** $|\eta| \sim 2$
  with respect to current tracker
- Based on the HIJING Pb+Pb simulation at 5.02 TeV
- Full simulation of the ITk using Geant4

**ITk designed to cope** with the **p+p collisions at** $<\mu> = 200$
Collectivity

Great progress in understanding the **nature of collectivity** and the **experimental techniques** over past years

- Precise measurements of $v_n$ harmonics, flow harmonics fluctuation and correlations between flow harmonics of different orders
- Importance of the initial state fluctuation
- Properties and space-time evolution of the produced matter
- Collectivity in **small systems** - small QGP droplets?
Heavy-flavor flow

- Flow of muons from heavy flavor - study the interactions of the heavy quarks with QGP
- Projections assuming 10 nb\(^{-1}\) of Pb+Pb
- Statistical **precision improved by a factor of 8**
- With the better precision could be sensitive to non zero higher harmonics \(v_3\) and for \(v_4\)
Flow decorrelation

• Breakdown of the factorization of two-particle flow into single-particle flow harmonics

• **Increased ITk acceptance** allow to extend the measurement **to forward rapidity**

  • Explore the non-linear behavior of flow decorrelation in the most central collisions
Flow in small system

• Precise measurement of the higher order harmonics with multi-particle correlations and subverts method to suppress non-flow
Energy loss in the QGP

Jet quenching observed from the earliest days of HI running at LHC

Rich experimental program to address the questions

• How much energy is lost by the jets in QGP?
• How is the parton shower modified with the interaction with the medium?
Inclusive Jets

- Projections account only for improvement of the statistical precision due increase of the integrated luminosity

- Extend the kinematic range to improve precision of the measurement
  - Probing possible saturation of $R_{AA}$
  - Explore $\eta$ dependence of $R_{AA}$ - fraction of quark jets increases with $|y|$ at fixed jet $p_T$
Jets Fragmentation

Jet structure modification observed in 
\textbf{Pb+Pb @ 2.76 \& 5.02 TeV}

\begin{equation}
D(z) \equiv \frac{1}{N_{\text{jet}}} \frac{dN_{\text{ch}}}{dz} \quad z \equiv p_T \cos \Delta R / p_T^{\text{jet}}
\end{equation}

\begin{equation}
R_{D}(z) \equiv \frac{D(z)/\text{PbPb}}{D(z)_{pp}}
\end{equation}

- Enhancement at high and low $z$
- Suppression around $\sim 0.1$
- Independent of $\sqrt{s_{\text{NN}}}$

- Improvement in precision especially for hard fragments ($\text{high } z$)
Rapidity dependence in 2015 data is statistically limited

$R_D(z)$ studied in rapidity intervals with respect to the reference at central rapidity

Measurement benefits from the large cancelation of systematic uncertainties

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  - Measurement benefits from the large cancelation of systematic uncertainties
Photon tagged jet fragmentation allows to study flavor composition.
- Sample dominated by quark-initiated jets.

Photon-tagged jet fragmentation is statistics hungry.
- 2015 measurement - broad centrality classes (0-30%, 30-80%)
- Much finer centrality selection with 10 nb⁻¹
Expected improvements in the analysis

Possible reduction of the systematic uncertainties in the Jets measurements

- **Jet Energy Scale** is a dominant source of systematic
  - Improvements on the proton-proton baseline
  - Use of MC generators which realistically simulate jet quenching

- **Uncertainty on track reconstruction** is expected to be reduced by the use of the upgraded tracker (ITk)

- Uncertainty on the **determination of the nuclear overlap function**
  - Data-driven techniques for the centrality determination

\[ \text{ArXiv:1805.05635} \]
Ultra-peripheral collisions (UPC)

Boosted nuclei are intense source of quasi-real photons
• Leads to **photon-photon and photon-nucleus collisions**
• Opens up the possibility for the **QED, QCD or event QGP studies**
Exclusive di-muons in UPC

- Expected exclusive production of di-muon pairs \( \gamma\gamma \rightarrow \mu^{+}\mu^{-} \) with the sample of 10 nb\(^{-1}\)
  - Provide calibration to other UPC processes

- Projection of the uncertainties for 0.5 nb\(^{-1}\) and 10 nb\(^{-1}\)

- Two scenarios for the nuclear geometry - realistic skin depth of the nucleus or a hard sphere
  - Increased precision at the highest \( m_{\mu\mu} \) will help in modeling
Differential cross section as a function of the di-photon rapidity for LbyL scattering and photon selection

- \( p_T^\gamma > 2.5 \text{ GeV} \)
- \( p_T^\gamma > 2.0 \text{ GeV} \)

**Light-by-light scattering**

**ATLAS Simulation Preliminary**

SuperChic2, \( \sqrt{s_{NN}} = 5.02 \text{ TeV} \)

\( \text{Pb+Pb} \rightarrow \text{Pb+Pb} \gamma\gamma \)

- \( p_T^\gamma > 2.0 \text{ GeV, } |h_\gamma^\gamma| < 4.0 \)
- \( p_T^\gamma > 2.5 \text{ GeV, } |h_\gamma^\gamma| < 4.0 \)

**Significant increase of cross section with lower photon \( p_T^\gamma \)**

- Measurement will benefit for the **improvement in the reconstruction**
- **Reduced amount of inactive material in new tracker** (smaller probability of photon conversion)
Light-by-light scattering

• Invariant mass distributions for the di-photons from LbyL signal and background components

• **Expected 640 events** in 5.02 TeV Pb+Pb collisions with an integrated luminosity of 10 nb⁻¹
  • **13 events observed** in the 2015
ALP (a) with masses above 1GeV could induce an anomalous contribution to the LbyL

- $\gamma\gamma \rightarrow a \rightarrow \gamma\gamma$
- Due to high enough electric field produced by ultra relativistic Pb

- Three ALP signal mass values, and the main background from LbyL
  - Could provide strong limits in the absence of signal
Collisions of light ions at LHC

Successful Xe+Xe run in 2017
- Few hours of data taking
- Precise measurements of bulk and jets

Similar short run with small ions like O+O
- Better constrain on small systems
- Measurable energy loss?

Lighter ions could provide more jets & rare probes at the LHC
- Detailed studies of energy loss in for example Ar+Ar

Gains in integrated nucleon-nucleon luminosity PER FILL wrt. Pb-Pb

From John Jowett QM18
Summary

• Expected integrated luminosity of **10 nb\(^{-1}\) in Run3&4** leads to improvements in precision for measurements which suffer from lack of statistics
  - Many interesting physics results to be delivered!
  - New discoveries maybe waiting around the corner!

• Significant improvement in the future measurements thanks to the installation of the ATLAS detector upgrade
  - **Looking forward for ITk in Run4**

ATLAS public results twiki - new Run3&4 pub notes: https://twiki.cern.ch/twiki/bin/view/AtlasPublic/HeavyIonsPublicResults

This work was supported in part by the National Science Centre, Poland grant 2016/23/B/ST2/00702
Backup