High-$p_T$ measurements in p+Pb collisions with the ATLAS detector

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Motivation to study $p+\text{Pb}$ collisions

- Elements of proton-proton as well as HI collisions.
- Disentangle initial and final state effects.
- Probe nuclear wave function at small $x$.
- Investigate QCD at high gluon density: shadowing and gluon saturation.
- Study diffractive and photo-nuclear excitations.

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Eskola et al., JHEP 0904:065, 2009
p+Pb at LHC

- 4 TeV protons + 1.57 TeV/nucleon Pb ions.
- Boosted c.m.s system: $\Delta y=0.47$
- Pilot run in September 2012: $1 \mu b^{-1}$ of minimum bias data
- pPb Run in January/February 2013: total 30 nb$^{-1}$, including 17 $\mu b^{-1}$ of minimum bias data
- Sets of different triggers for different physics.
- Two periods:
  - p+Pb and Pb+p
  - systematic check
- pPb run was followed by pp run at 2.76 TeV: 4.5 pb$^{-1}$
  - Crucial reference for HI studies

![Graph showing ATLAS Online Luminosity and LHC Delivered (p+Pb) vs Day in 2013]
The ATLAS Detector

- ATLAS is a general-purpose p-p experiment, but it was proven to be well suited also for heavy ion physics!
- Large pseudorapidity coverage and full azimuthal acceptance.
- Fine granularity and longitudinal segmentation.
- Precise inner detector in a 2T solenoid field.
- Extensive system of muon chambers placed inside a 1T toroid field.
Centrality

- Characterize centrality by percentile of total cross-section using $E_T$ in forward region.
- Measured in Pb-going side of Forward Calorimeter (FCal).
- Particle density of UE is comparable to 80-90% peripheral Pb+Pb collisions or to p+p collisions with pile-up $\langle \mu \rangle \sim 5-10$. 

![Graph showing centrality distribution in Pb+Pb collisions with p+p collisions as reference. The graph displays the number of events per unit $E_T$ with the ATLAS collaboration's logo and data specifications: $p+Pb$, $s_{NN} = 5.02$ TeV, $L \approx 1 \mu b^{-1}$. The graph is color-coded with red for central and light blue for peripheral, showing a comparison of event distributions.](image-url)
Jet measurement

Event with two jets ($E_T=224$ GeV and $E_T=184$ GeV) near mid-rapidity with.
Mean UE contribution is subtracted

Fluctuations of UE will contribute to JER

Study of UE fluctuations is an independent check of jet energy resolution.

Fluctuations (1 standard deviation) of transverse energy measured in the area of \( R=0.4 \) jet are plotted as a function of FCal \( \Sigma E_T \) in the Pb-going side.

Comparison to Pb+Pb: fluctuations in central collisions are about 10 GeV in central midrapidity (\( |\eta|<2.8 \)) and mean \( E_T \) exceeds 100 GeV.
Triggering on pPb collisions

- Jets were recorded using HLT.
- Two configurations:
  - Standard pp jet triggers.
  - Standard HI jet triggers (UE subtracted).
- 75 GeV is the lowest unprescaled threshold!

Efficiency of HLT jet triggers in midrapidity.

Position resolution
Triggering on jets in p+Pb collisions

- Triggering on forward jets is important for low-\(x\) and saturation measurement.

\[
\int L \, dt = 17 \, \mu \text{b}^{-1}
\]

\(|n| > 3.2\)

Efficiency of forward jet trigger

\(\text{ATLAS preliminary} \quad \text{p+Pb 2013} \quad \sqrt{s_{\text{NN}}} = 5.02 \, \text{TeV}\)

HI anti-\(k_t\)\(^{\text{trigger}}\) \(R=0.4\)

\(\bigcirc\) EF FJ15 wrt. L1 FJ0, 80-97%

\(\square\) L1 FJ0, 80-97%

\(\bullet\) EF FJ15 wrt. L1 FJ0, 0-20%

\(\blacksquare\) L1 FJ0, 0-20%
Reconstruction algorithm is anti-$k_t$ with $R=0.4$.

We used standard pp and HI jet reconstruction.

HI jet reconstruction implies:

- Anti-$k_t$ reconstruction prior to a background subtraction.
- Underlying event estimated for each longitudinal layer and $\eta$ slice separately:
  \[ E_{Tsub}^{cell} = E_T^{cell} - \rho^{layer}(\eta) \times A^{cell} \]

- Jets with $D = \frac{E_{T_{tower}}^{max}}{\langle E_{T_{tower}} \rangle} > 4$ are excluded to avoid bias, but no jet rejection is based on $D$.

- Some parameters of the procedure were tuned for p+Pb.

- Small UE in p+Pb allows measuring larger kinematic range compared to Pb+Pb.

- No correction for the elliptic flow at this moment.
Effect of UE subtraction

**pp jets, $E_T > 30\text{GeV}$**

**HI jets (UE subtracted), $E_T > 30\text{GeV}$**

**pp jets yield:**

- some enhancement rate in the problematic region of the calorimeter and in Pb-going pseudorapidity region due to larger UE sensitivity to UE.
The UE subtraction is well under control:

- No jet $E_T$ dependence.
- Good proportionality to $E_T$ of UE.
Di-electron a di-muon mass distributions

ATLAS is fully capable to perform di-lepton measurement.

Study of cold nuclear effects via J/Ψ measurement.
Event $Z \rightarrow e^+e^-$ candidate. Invariant mass of electron pair is $m_{ee} = 94.9$ GeV.
Z measurement

Event $Z \rightarrow \mu^+\mu^-$ candidate. Invariant mass of electron pair is $m_{\mu\mu} = 91.2$ GeV.
The observation of Z production not accessible at RHIC energies.
Z production rate is a standard candle for other processes.
Test of nuclear PDFs.
Event with 107 GeV photon candidate and two energetic jets, one near mid-rapidity with $p_T=60$ GeV and one in the proton-going direction with $p_T=50$ GeV.
Conclusions

- Excellent performance of the LHC and ATLAS during 2013 p+Pb run!
- We have demonstrated our capabilities to measure various high-$p_T$ observables:
  - jets and photons
  - quarkonia
  - Z's and W's
- Harvest of important physics results is foreseen, analyses are ongoing.
- New exciting results from 2013 run are expected soon!
Backup
Subtracted $E_T$ in Pb+Pb

- Mean subtracted energy as a function of asymmetry

- No asymmetry dependence

- Amount of subtracted energy for leading and sub-leading jet is comparable