ATLAS Performance for Different Luminous Region Scenarios

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Introduction

- LHC experiments want maximal integrated luminosity in the shortest possible time with the least impact on the detector and physics performance
  - Requires finding the optimal trade-off between high instantaneous luminosity, luminous region configuration, leveling schemes and detector degradation with pile-up
- New “Experimental Data Quality” HL-LHC working group formed together with ATLAS and CMS
  - Investigate the characteristics of the luminous region
  - Define and rank figures of merit relevant for the detector performance
  - Assess the HL-LHC baseline and possible variants, making recommendations where needed

Will report on some first results from ATLAS in context of this working group
Luminous Region

- Complex set of machine parameters define luminous region ($\beta^*$, bunch length, crossing angle, etc.)
- Experiments just see spatial and temporal distribution and the evolution within fill
  - Transverse distribution not a concern as is small
  - Most detectors blind to spread in time (<1ns), but precision timing detector under evaluation
- Primary concern is pile-up density in $z$ (events per mm) and overall pile-up level
- Note: luminous region is not always Gaussian shaped

Luminous region examples:
Luminous Region Scenarios

- Different running scenarios presented in previous talk
- Luminous region evolve during each fill
  - Primarily due to luminosity leveling
- Mostly consider detector performance at worst moment, i.e. at peak overall pile-up and peak pile-up densities
  - No longer necessarily worst at start of fill
- Should evaluate if limit is from overall pile-up or pile-up density
  - Limit determines what parameter to use for leveling
Impact of Pile-up Level

- Impact of overall pile-up level was studied in the past
  - Increased detector occupancy degrades resolution, increases combinatorics and requires additional readout bandwidth
  - Non-linear increase of trigger rates and fakes as well
- Pile-up can be partly mitigated for physics performance:
  - Increased detector granularity
  - Subtracting measured pile-up contribution (event-by-event or average)
  - Use of tracking (and timing) to associate signals to primary vertices

![Calorimeter cell-level noise](image)
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Jet response

B-tagging performance

A few earlier studies of different luminous region scenarios showed little impact of pile-up density, but are now being revisited
Pile-up Density Studies

- In last few months studied impact of pile-up density in more detail – *still work in progress*
- Have studied different Gaussian shaped lumi regions
  - Consider wide (50mm) and narrow (34mm) width
  - Two different pile-up levels, 140 and 200, studied for each

Note \( \mu=140, \sigma=34\text{mm} \) and \( \mu=200, \sigma=50\text{mm} \) scenarios have almost identical peak and average pile-up density
Pile-up mitigation relies heavily on use of tracking.

Designs of the upgraded ATLAS tracker under heavy optimization and evaluation:
- See presentations on Wednesday morning for more details.

In the following studies used recent version of “Extended Barrel” design:
- 5 Pixel layers
- 50x50 μm$^2$ pixel size
- $\eta$ coverage up to 4, but only use tracks with $|\eta|<2.9$ and $p_T>900$ MeV
- Hermetic for tracks in $|z|<15$ cm

Expect performance to improve further.
Primary Vertex Finding

- Reconstructing and identifying primary vertex of hard-scatter collision, critical first step in most analyses
- Could potentially get confused at high pile-up density
- Identify vertex with the highest $\Sigma p_T^2$ as hard-scatter

Efficiency as function of hard-scatter z-position

Primary vertex efficiency pretty independent of z-position
→ Pile-up density is not critical for efficient primary vertex
Primary Vertex Finding

- Primary vertex efficiency does depend on pile-up and physics process under consideration:

**Note:** for $H \rightarrow \gamma \gamma$ can use pointing of calorimeter to increase efficiency of identifying the correct vertex.
Vertex-Track Association

- Quality of primary vertex also important
- Study the tracks associated to primary vertex:

Pick up the same number of tracks from $t\bar{t}$ event independent of $z$ and hence pile-up density

Clear increase in pile-up tracks with increased pile-up density
Vertex-Track Association

Can convert vertex z-position to local pile-up density:

- Completely linear dependence on pile-up density
  - no break down of algorithm even at very high pile-up density
  - No dependence on overall pile-up in this case

**ATLAS Simulation Preliminary**

$t\bar{t}$ $\sqrt{s}=14$ TeV, ITk Extended

- $\sigma_z = 50$ mm, $\langle \mu \rangle = 140$
- $\sigma_z = 34$ mm, $\langle \mu \rangle = 140$
- $\sigma_z = 50$ mm, $\langle \mu \rangle = 200$
- $\sigma_z = 34$ mm, $\langle \mu \rangle = 200$

Up to 50% increase in tracks from pile-up at highest pile-up density

Completely linear dependence on pile-up density
- no break down of algorithm even at very high pile-up density
No dependence on overall pile-up in this case
Vertex-Track Association

- Most of the pile-up are very soft particles
- Study instead the $p_T$ sum of the additional particles:

> Only up to 15% increase over hard-scatter ($tt$) contribution

Again see only linear dependence on pile-up density
Lepton Isolation

- Pile-up tracks can spoil track-based lepton isolation
  - Studied tracks from primary vertex in cone around high-\(p_T\) muon in \(t\bar{t}\) events
  - Require no other tracks above 900 MeV around muon (tight isolation):

\[\text{See just a few \% degradation with pile-up density and no dependence on pile-up level}\]

Note: for calorimeter isolation, only the pile-up level matters
Pile-up Jet Rejection

- As pileup grows, we find more and more calorimeter lowish $p_T$ jets from pile-up – causes more background
  - Can suppress these using tracks to confirm they are coming from hard-scatter primary vertex
  - Different methods, most robust is simple
  - All methods will be affected by pileup tracks being associated to primary vertex

\[
R_{pT} = \frac{\sum_i (p_{T,\text{track},i})}{p_{T,\text{jet}}}
\]

![ATLAS Simulation](attachment:image.png)

- $p_{T,j} > 30$ GeV, $\mu=200$, $\epsilon_{PU} = 2\%$

Before pile-up jet rejection

After pile-up jet rejection
Pile-up Rejection

- Can vary pile-up rejection and hard-scatter jet efficiency by varying cut on $R_{pT}$
  - Note use all tracks within $\Delta z$ of primary vertex, with $\Delta z$ depending on the jet angle
- Scenarios with same pile-up density have similar performance:

Note jet resolution is worse at $\mu=200$ than $\mu=140$, so physics impact still worse at $\mu=200$, even if pile-up density is unchanged
Summary and Outlook

- The high pile-up at HL-LHC will have a significant impact on physics performance of ATLAS
  - Eventually will not gain in physics from increasing luminosity
  - Many of the planned upgrades aim to reduce this
- The impact of pile-up can in some cases be reduced with by lowering the overall pile-up density
  - Gain from better separation of tracks from pile-up vertices
  - Dependence on pile-up density largely linear in studies so far, with no critical pile-up density where performance breaks down
- Further studies are on-going
  - Will study pile-up and pile-up density dependence of additional physics measures, like b-tagging and $E_{T\text{miss}}$

Aim to eventually compare performance differences with luminosity differences for different machine running scenarios