ATLAS Performance for Different Luminous Region Scenarios

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Introduction

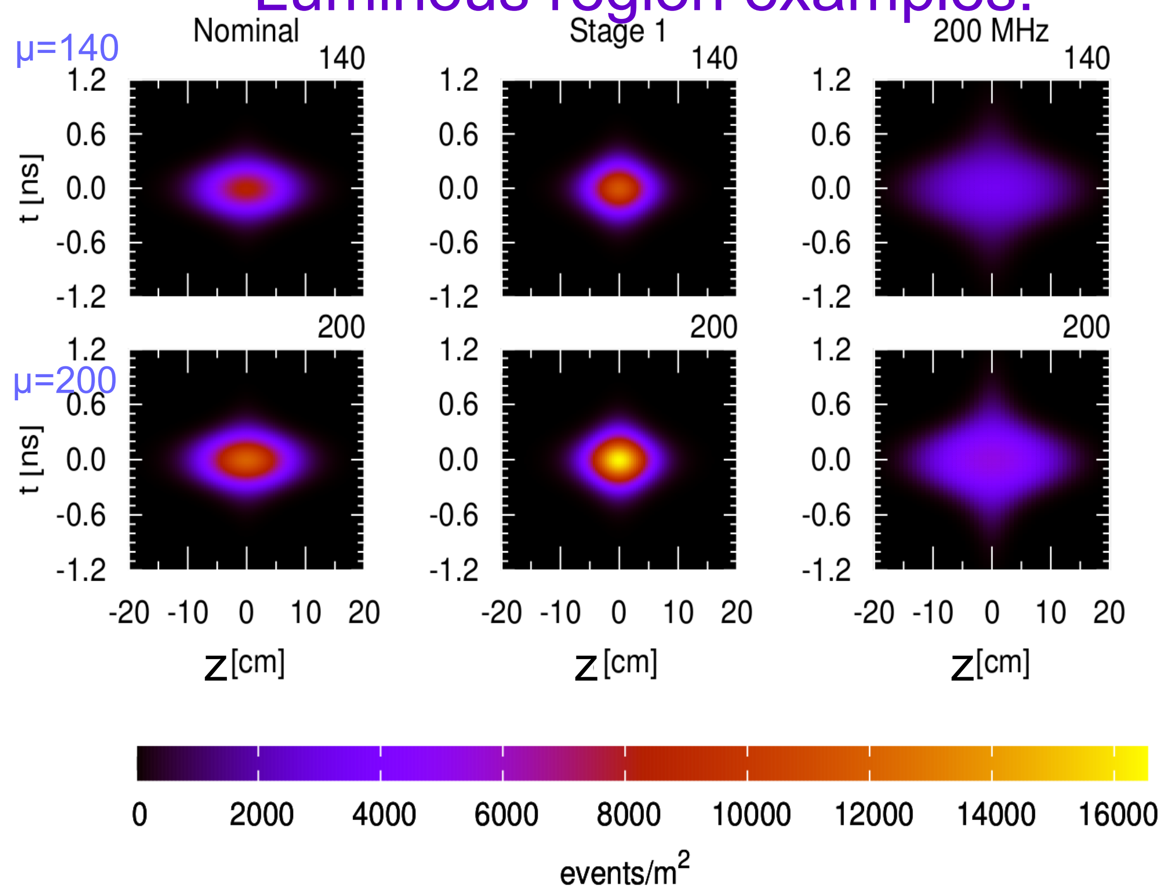
- LHC experiments want maximal integrated luminosity in the shortest possible time with the least impact on the detector and physics performance
  - Requires finding the optimal trade-off between high instantaneous luminosity, luminous region configuration, leveling schemes and detector degradation with 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

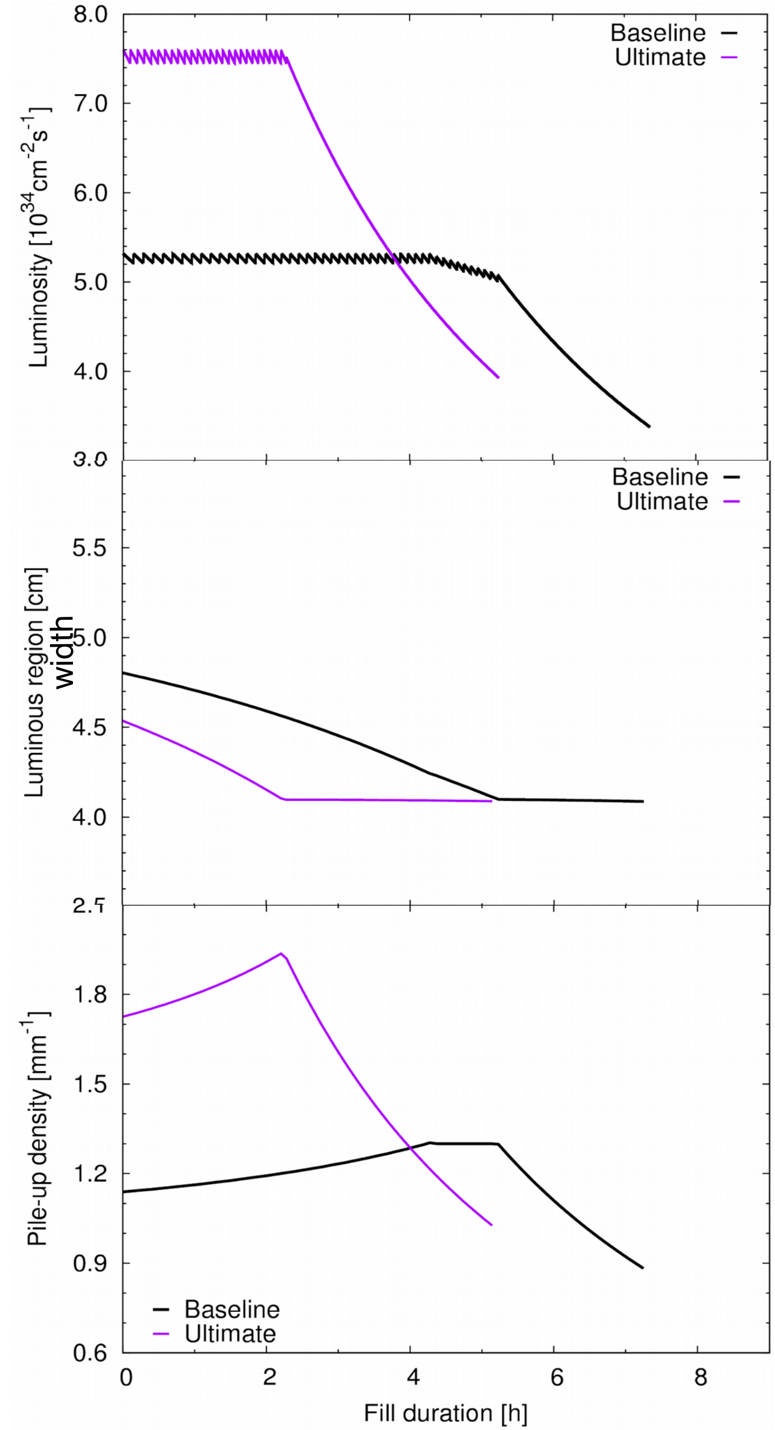
- Complex set of machine parameters define luminous region (β*, bunch length, crossing angle, etc.)
- Experiments just see spatial and temporal distribution and the evolution within fill
  - Transverse distribution not a concern as is small
  - Most detectors blind to spread in time (<1ns), but precision 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

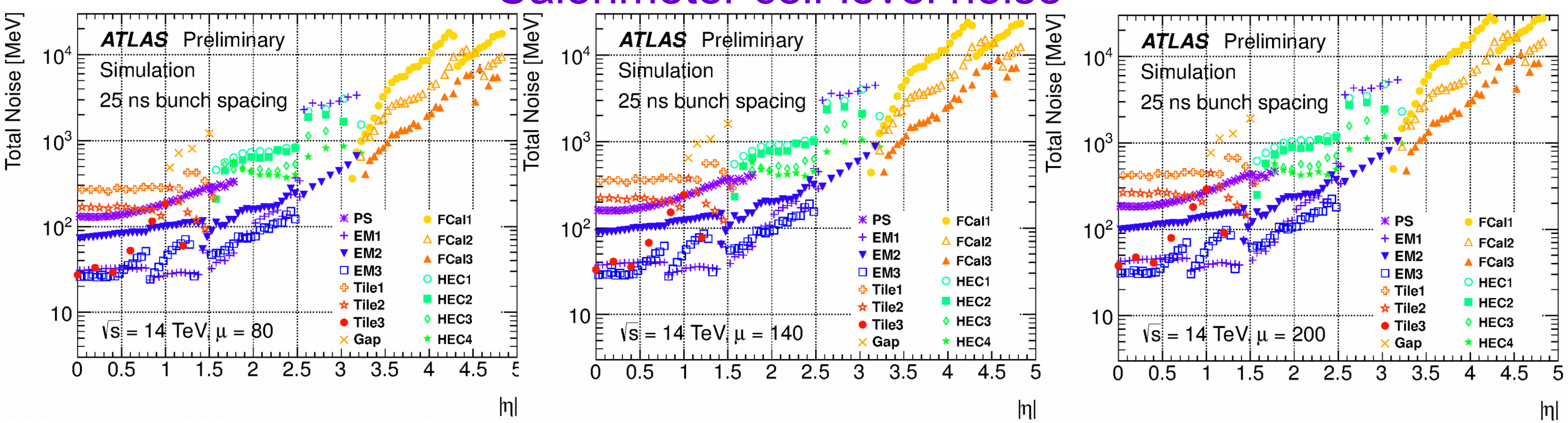
- Different running scenarios presented in previous talk
- Luminous region evolve during each fill
  - Primarily due to luminosity leveling
- Mostly consider detector performance at worst moment, i.e. at peak overall pile-up and peak pile-up densities
  - No longer necessarily worst at start of fill
- 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



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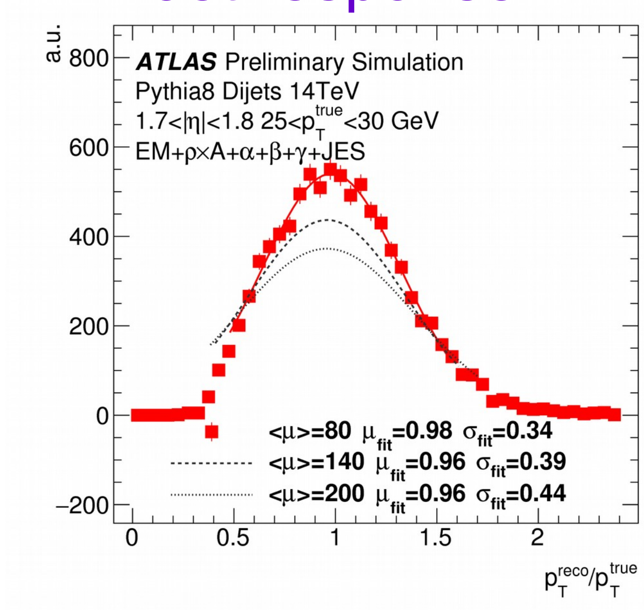
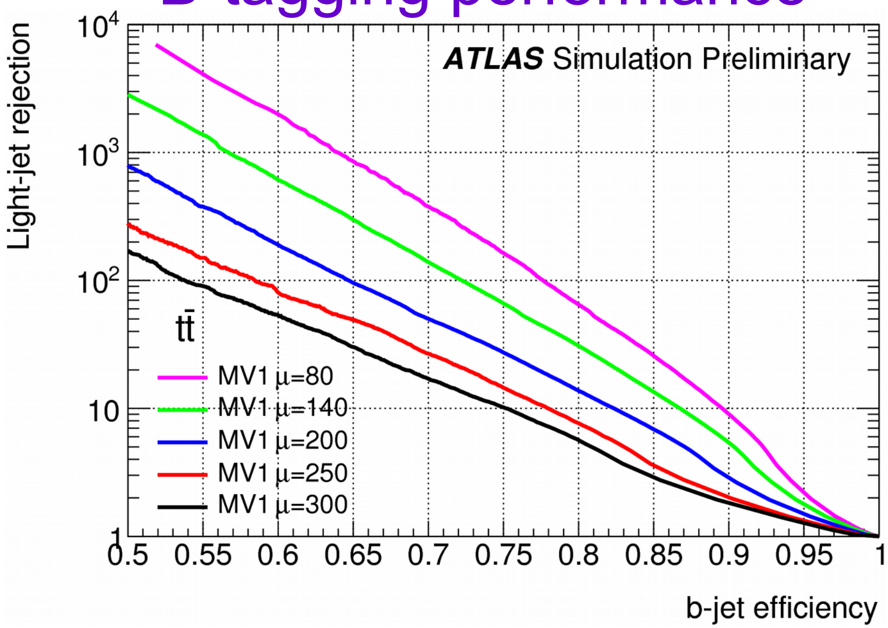
Jet response



B-tagging performance

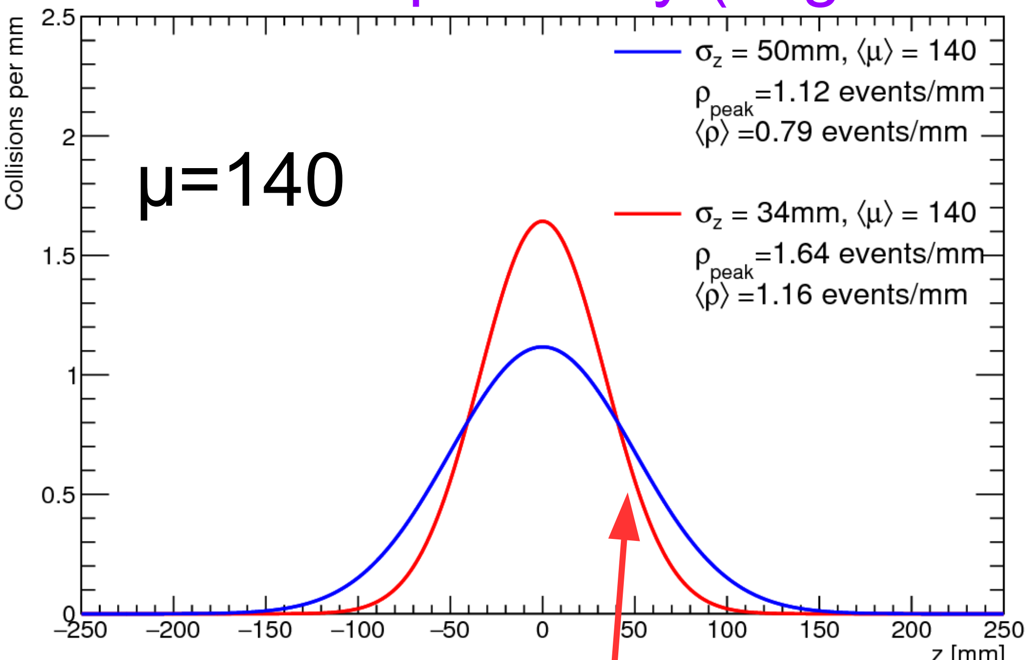


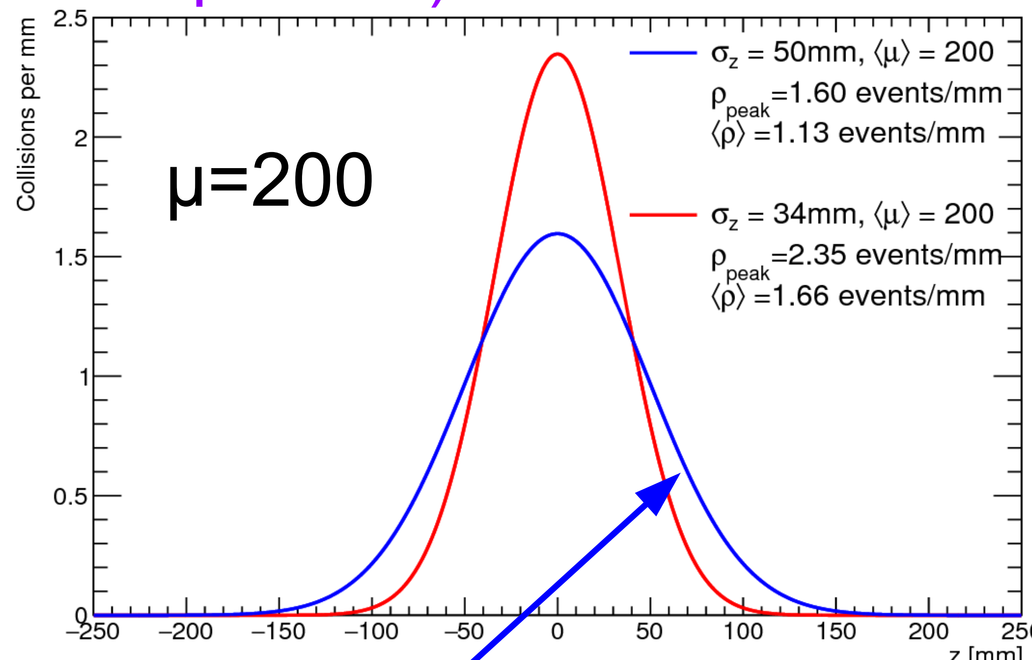
A few earlier studies of different luminous region scenarios showed little impact of pile-up density, but are now being revisited

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

Pile-up density (avg. #collisions per mm) vs z location:

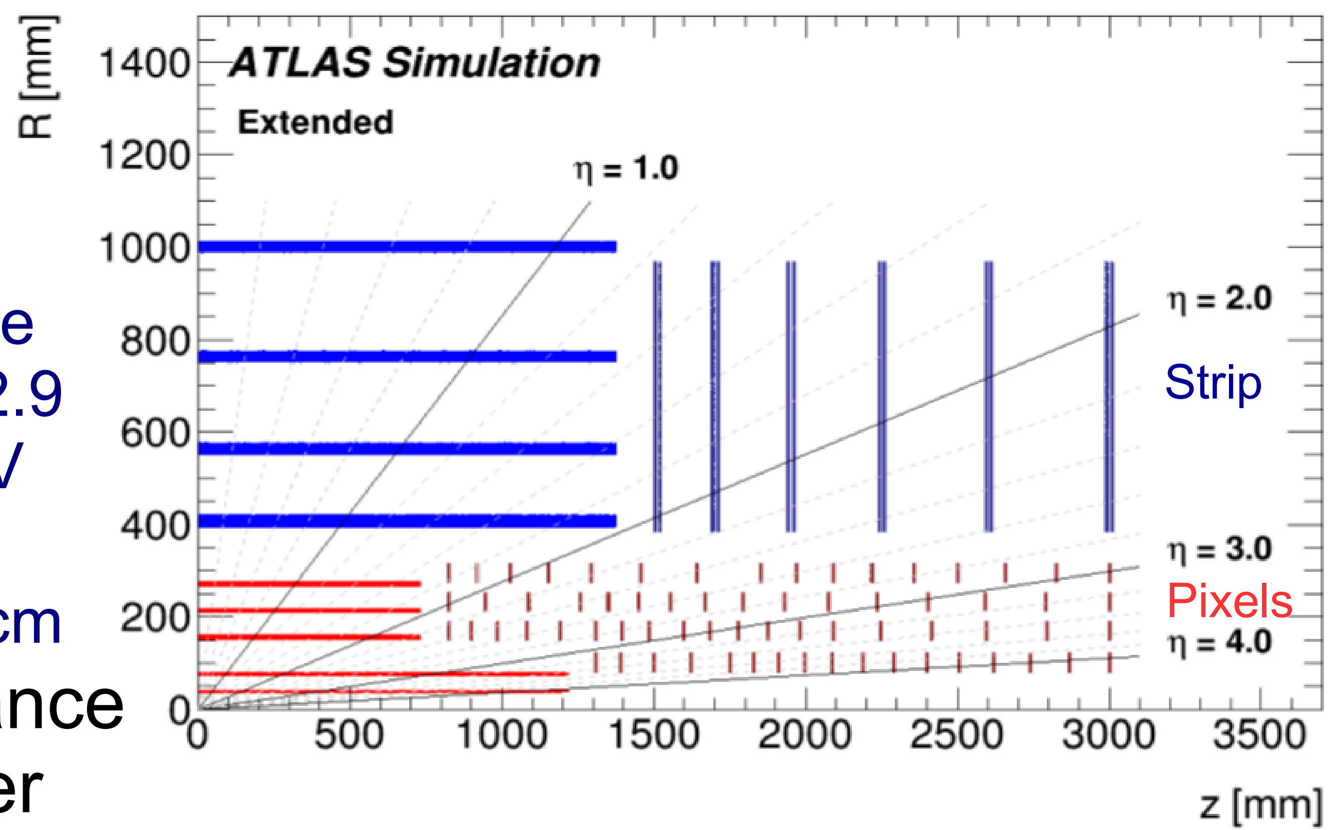




Note μ=140, σ=34mm and μ=200, σ=50mm scenarios have almost identical peak and average pile-up density

Simulation Framework

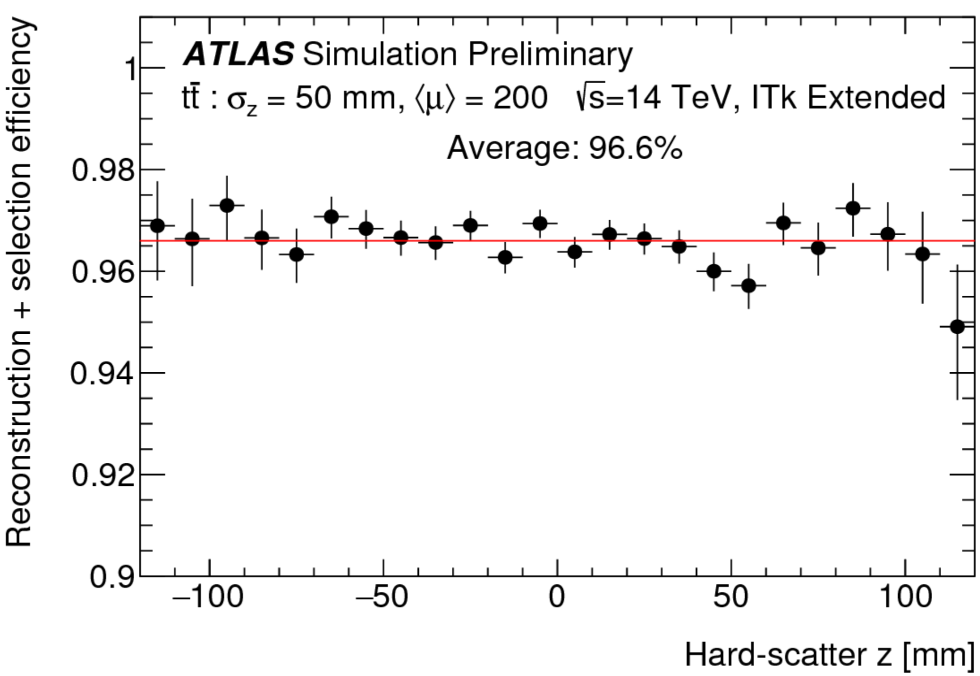
- Pile-up mitigation relies heavily on use of tracking
- Designs of the upgraded ATLAS tracker under heavy optimization and evaluation
  - See presentations on Wednesday morning for more details
- In the following studies used recent version of "Extended Barrel" design:
  - 5 Pixel layers
  - 50x50 μm^2 pixel size
  - η coverage up to 4, but only use tracks with |η|<2.9 and p_T>900 MeV
  - Hermetic for tracks in |z|<15cm
- Expect performance to improve further

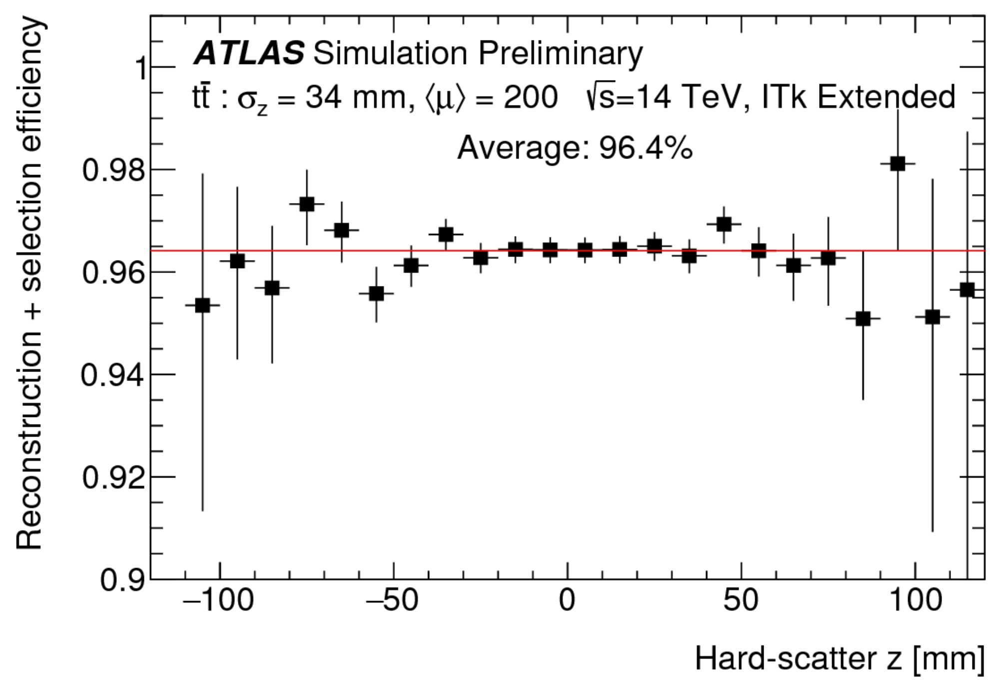


Primary Vertex Finding

- 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 Σp_T^2 as hard-scatter

Efficiency as function of hard-scatter z-position

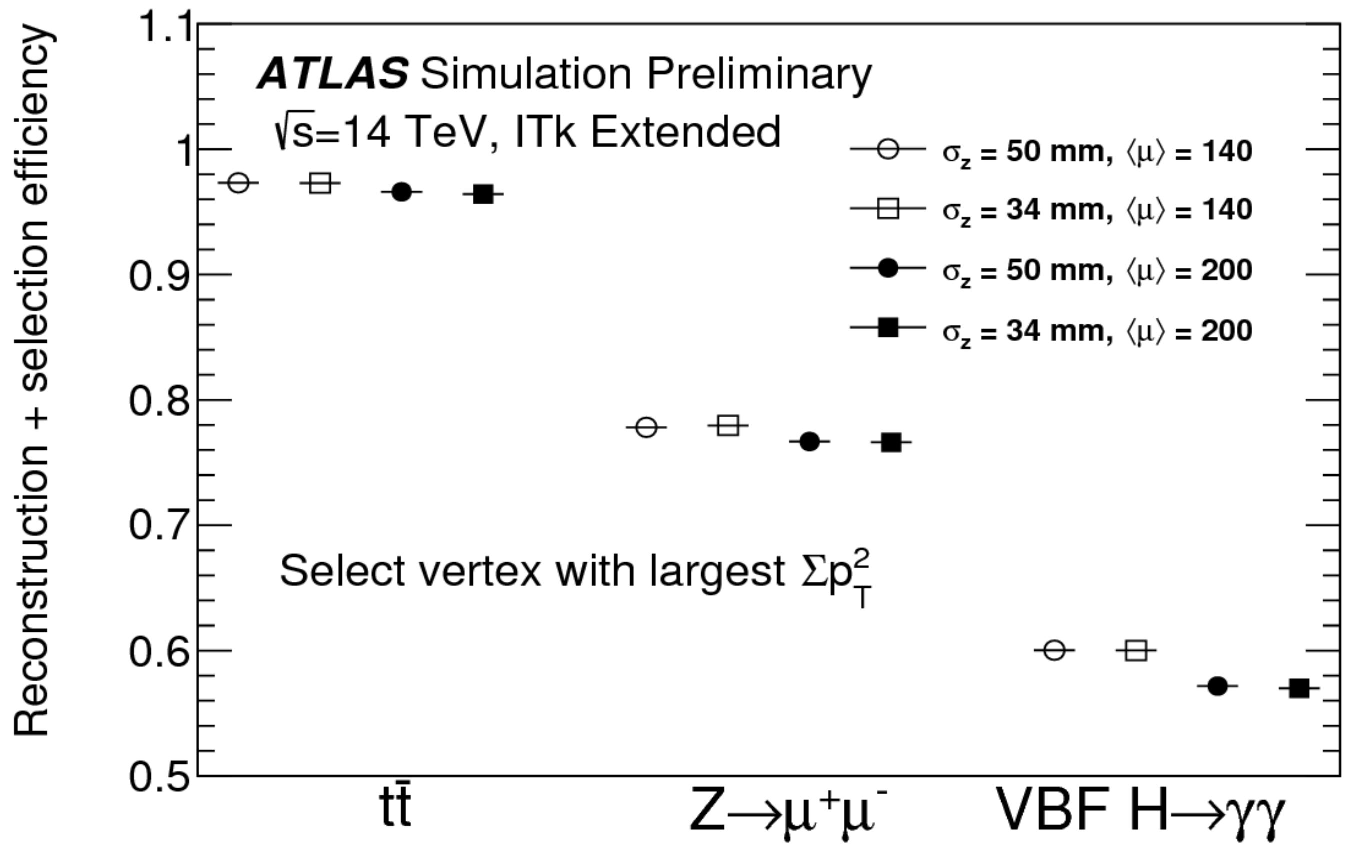




Primary vertex efficiency pretty independent of z-position
→ Pile-up density is not critical for efficient primary vertex

Primary Vertex Finding

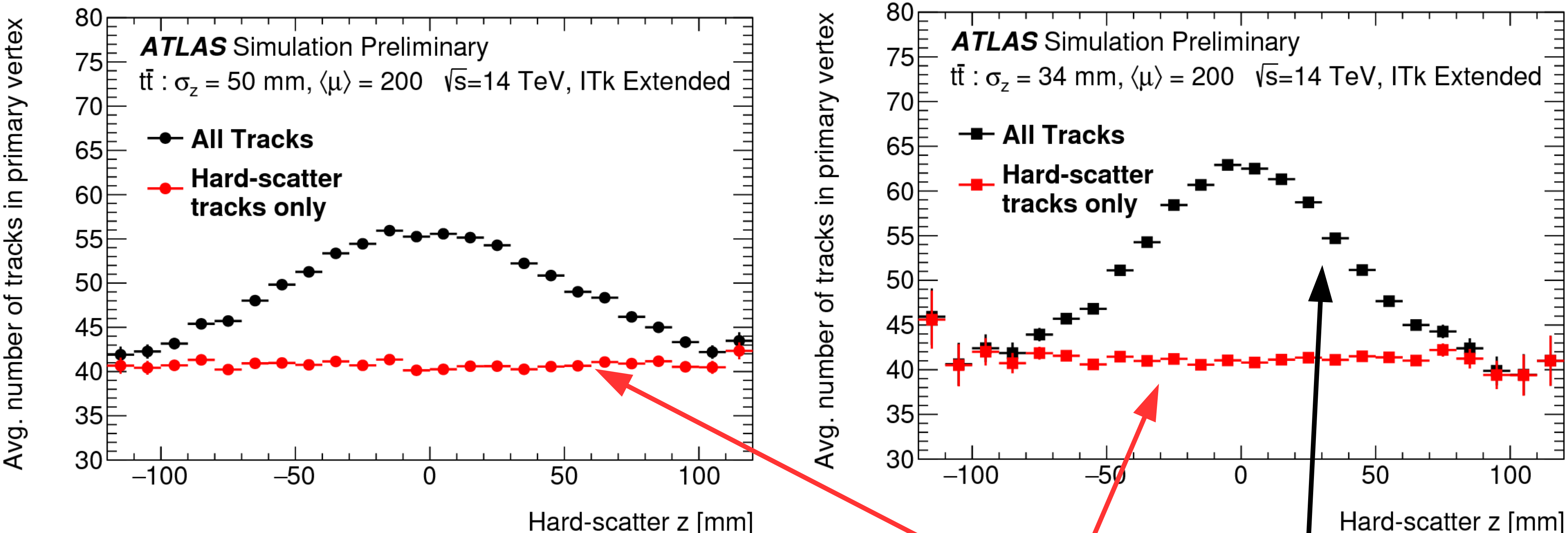
- Primary vertex efficiency does depend on pile-up and physics process under consideration:



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:

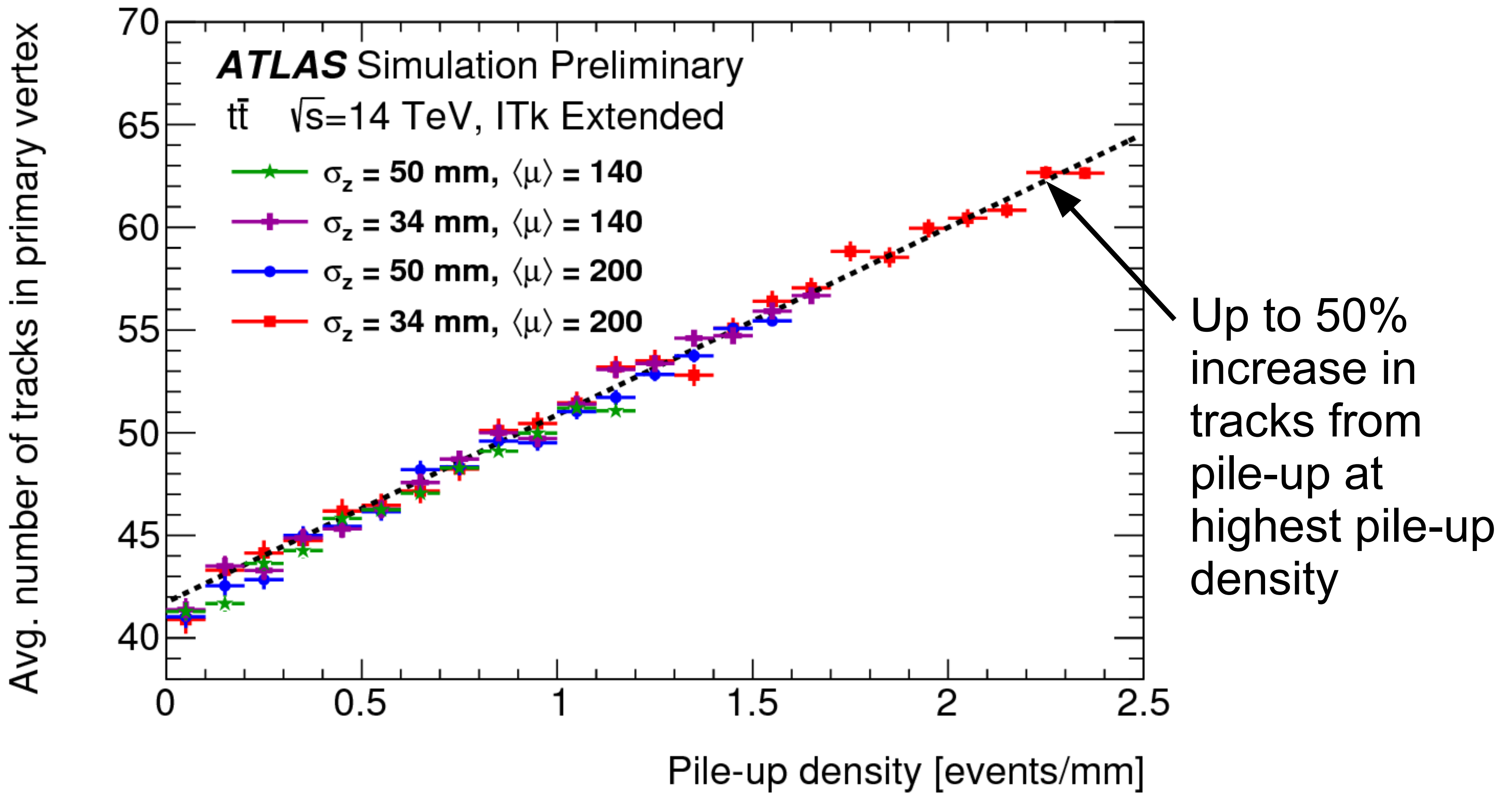


Pick up the same number of tracks from $t\bar{t}$ event independent of z and hence pile-up density

Clear increase in pile-up tracks with increased pile-up density

Vertex-Track Association

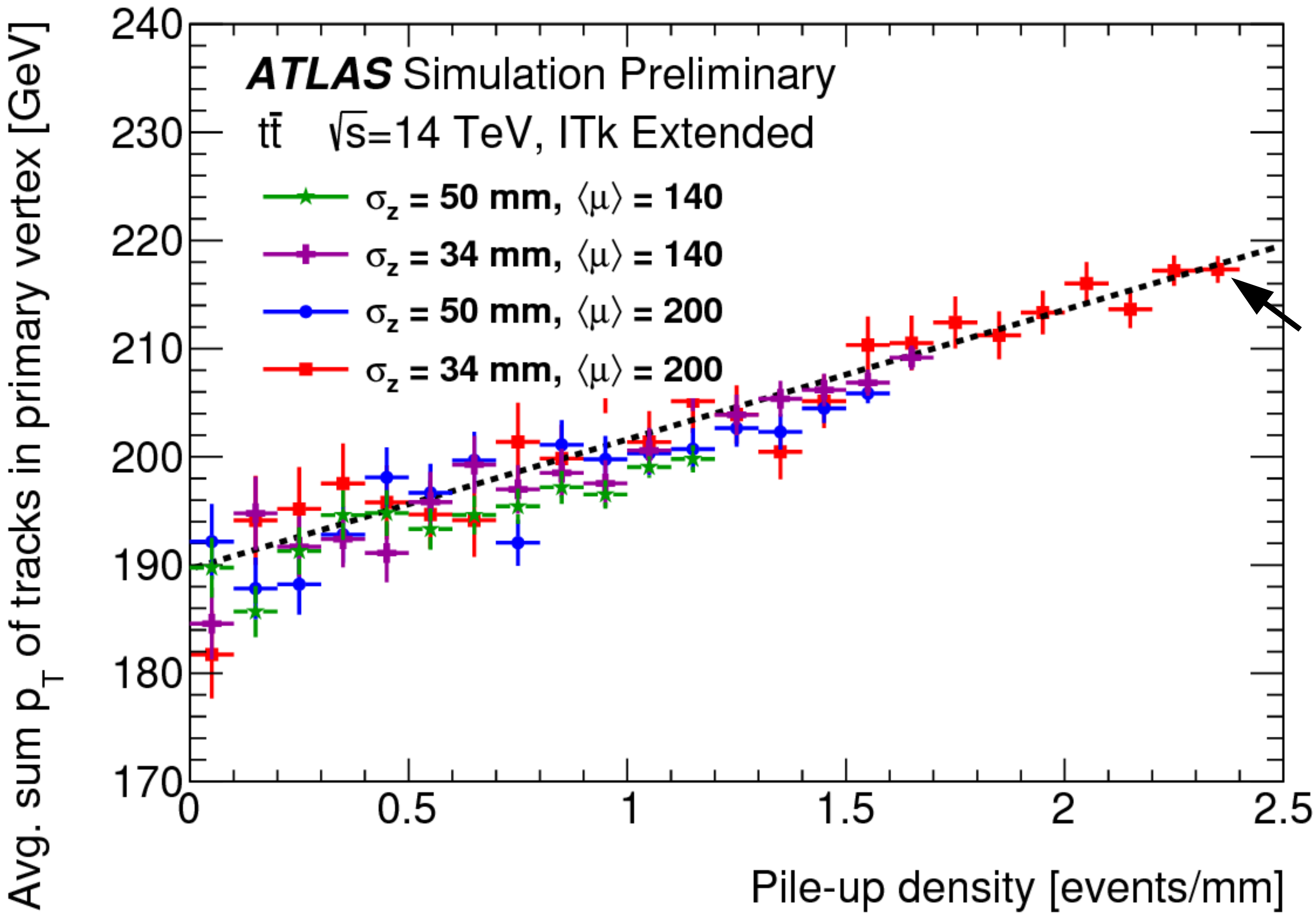
Can convert vertex z-position to local pile-up density:



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

Vertex-Track Association

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

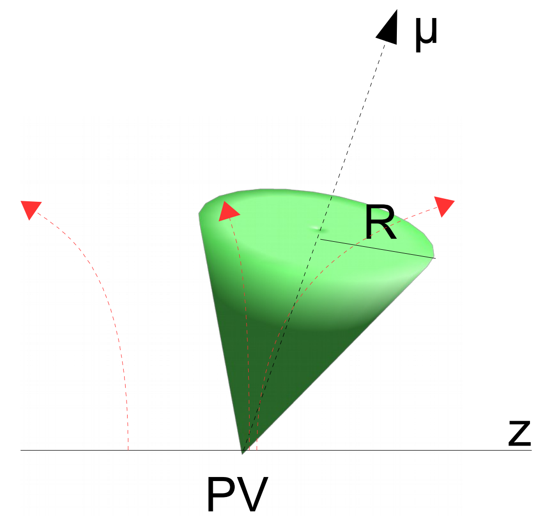


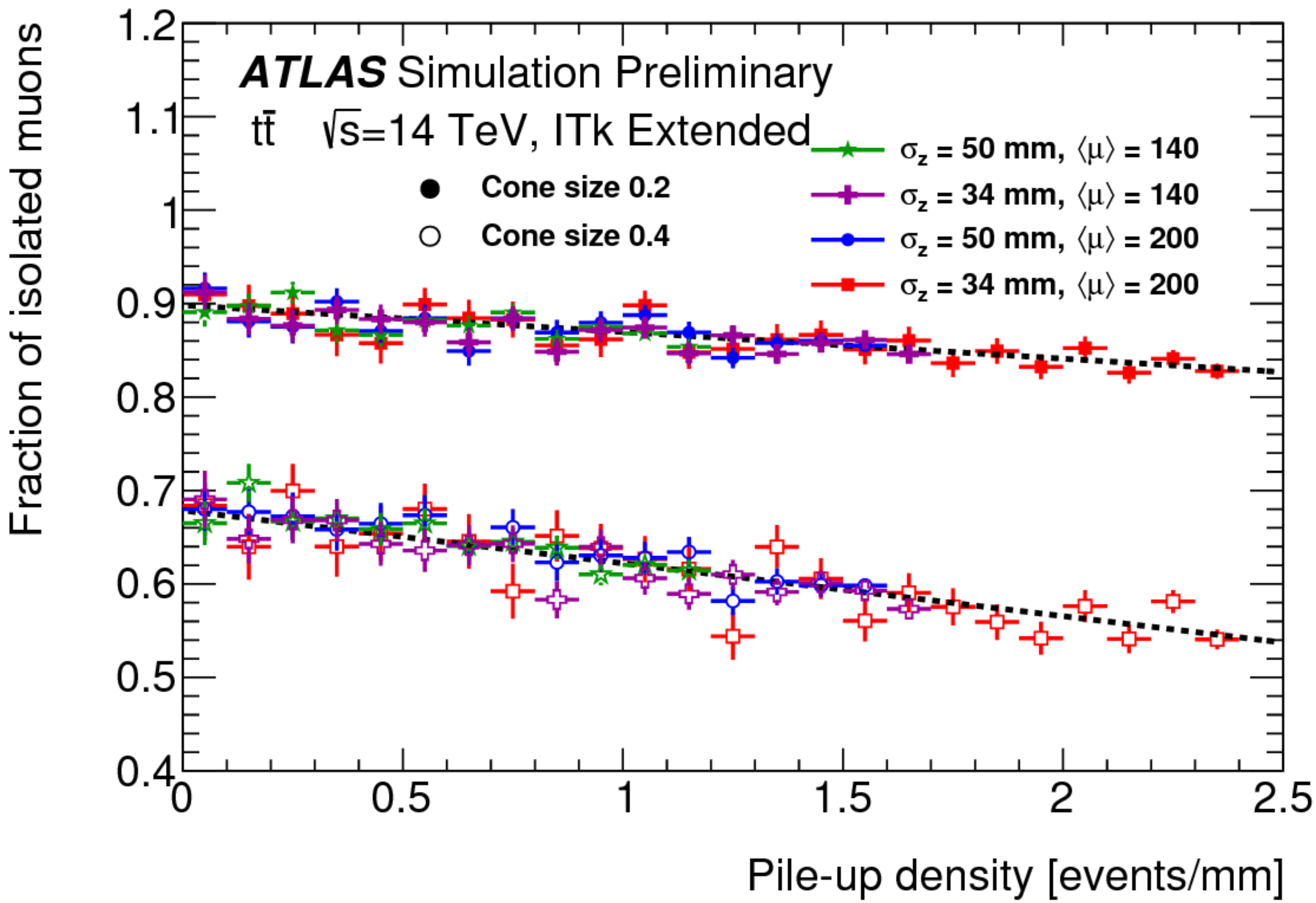
Only up to 15% increase over hard-scatter ($t\bar{t}$) contribution

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):



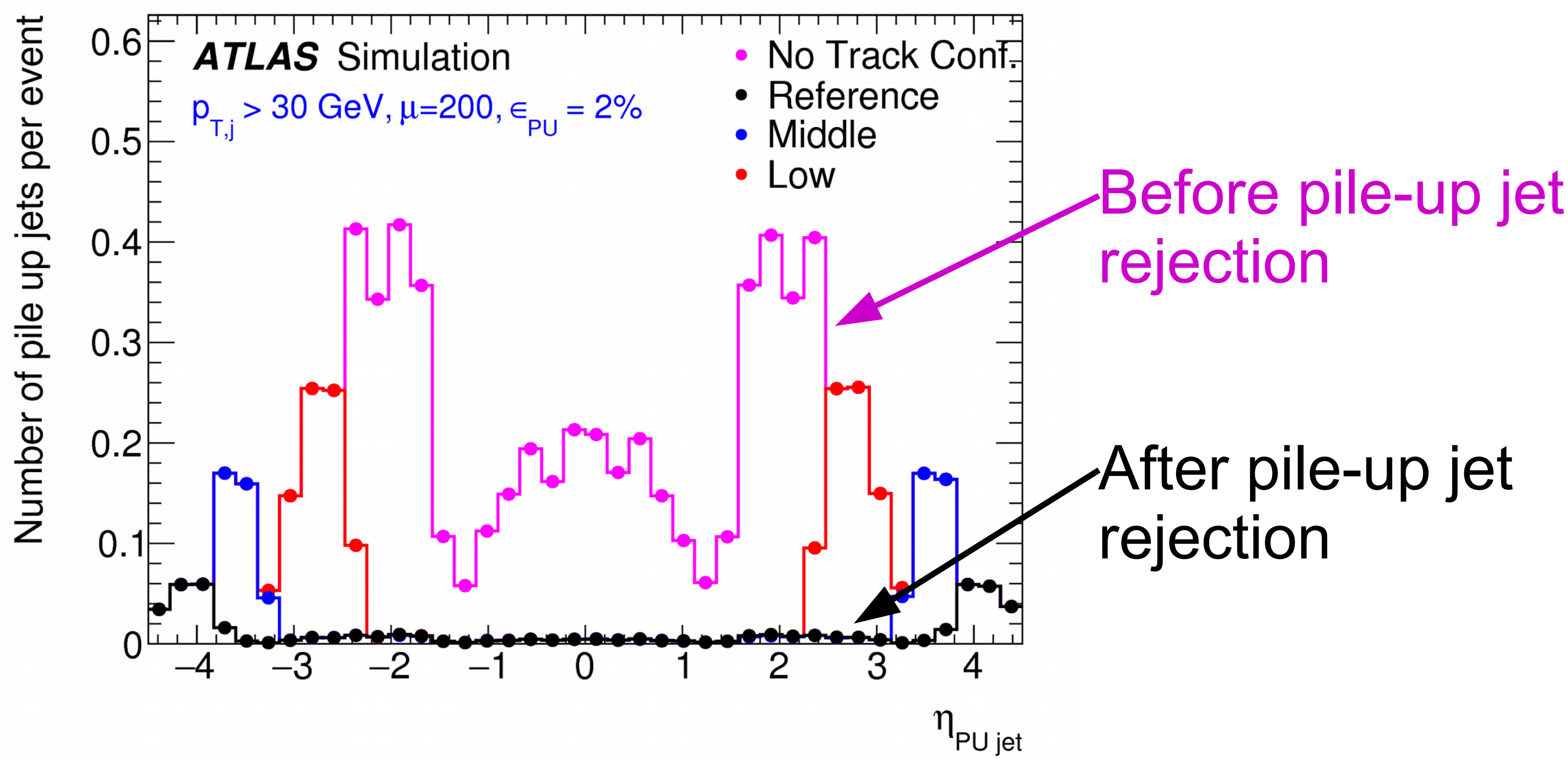


See just a few % degradation with pile-up density and no dependence on pile-up level

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

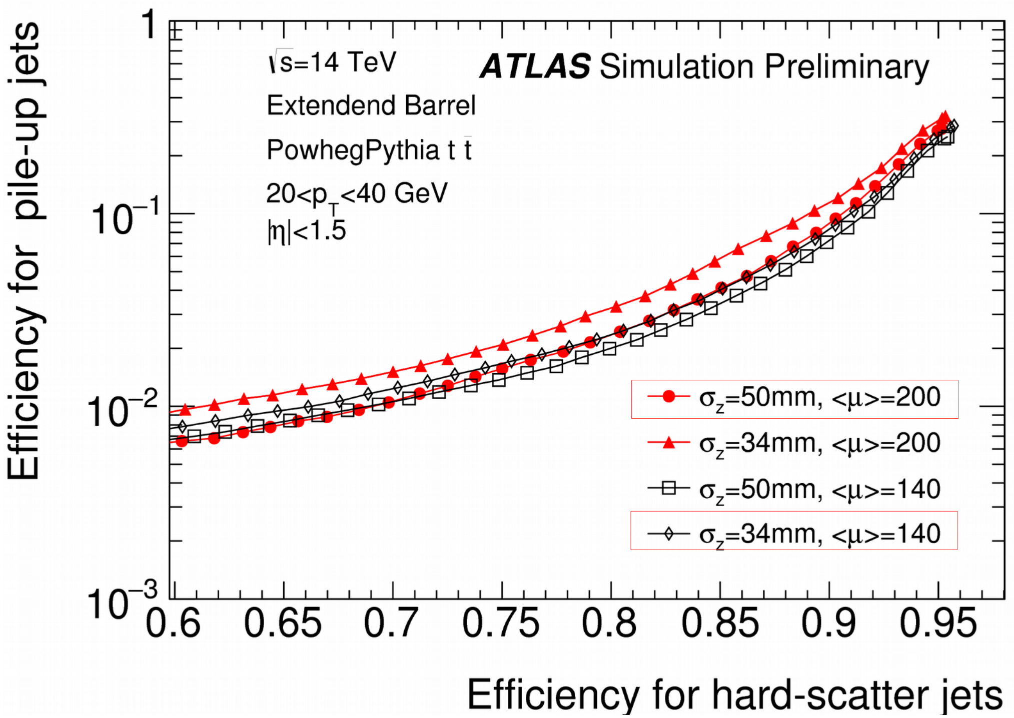
Pile-up Jet Rejection

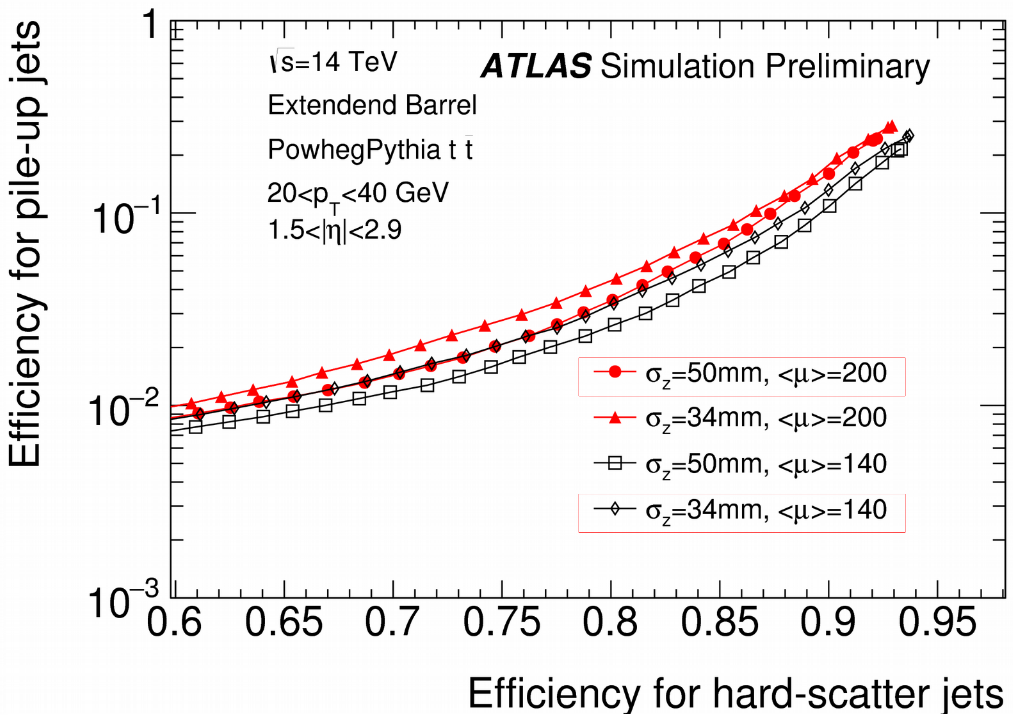
- As pileup grows, we find more and more calorimeter lowish p_T jets from pile-up – causes more background
  - Can suppress these using tracks to confirm they are coming from hard-scatter primary vertex
  - Different methods, most robust is simple $R_{pT} = \frac{\Sigma_i (p_T^{\mathrm{track},i})}{p_T^{\mathrm{jet}}}$
  - All methods will be affected by pileup tracks being associated to primary vertex



Pile-up Rejection

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





Note jet resolution is worse at μ=200 than μ=140, so physics impact still worse at μ=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_{Tmiss}

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