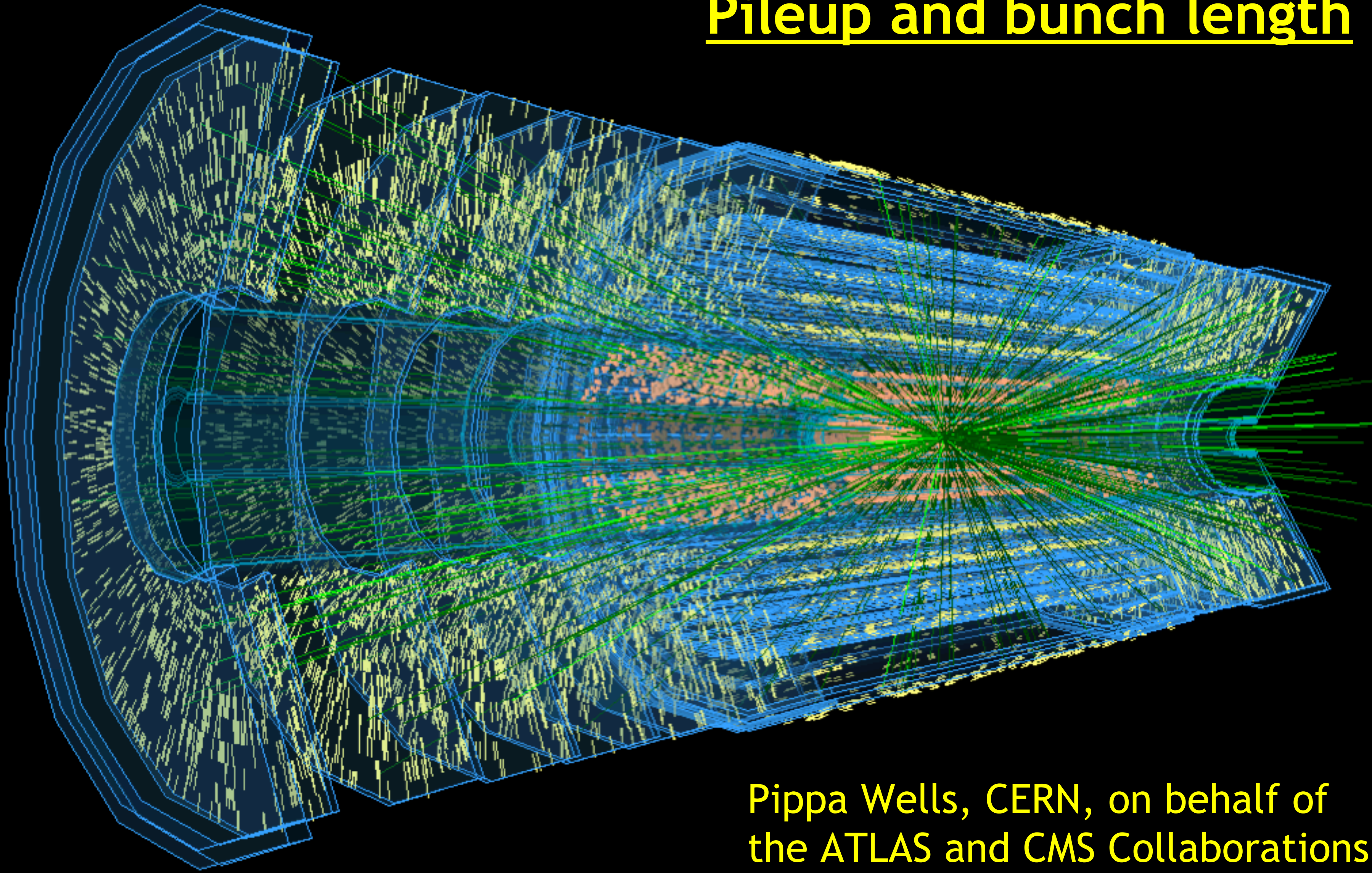
Pileup and bunch length



Pippa Wells, CERN, on behalf of the ATLAS and CMS Collaborations

5th Joint HiLumi LHC-LARP Annual Meeting, CERN, 2015

Pileup and bunch length/time structure

- Pileup and detector configurations
- Performance as a function of pileup:
  - Primary vertex finding
  - b-tagging
    - Variation with bunch length for PV and b-tagging
  - [e/γ/μ/τ]
  - Jets and E_T^{miss}
    - Pileup mitigation with tracking information
    - First prospects using timing information
- Conclusions and outlook

Pileup values

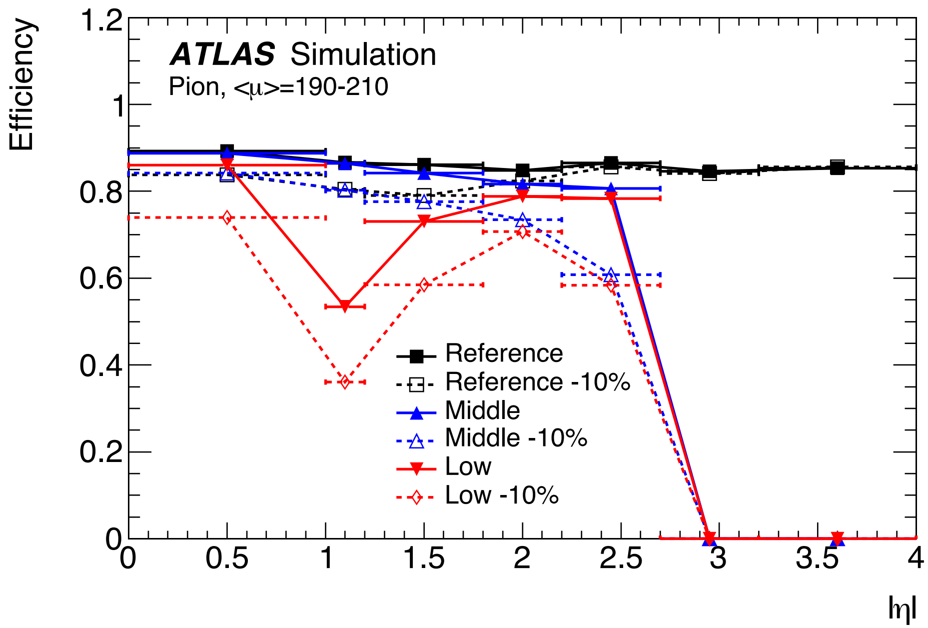
- Aim to upgrade the detectors to maintain the same or better performance with HL-LHC levels of pileup
- Luminosity of 5 (7.5) x10^{34} $cm^{-2}s^{-1}$ corresponds to *average* pileup, μ, of 140 (200) events per bunch crossing
  - Rounded up a few % to reflect variation from bunch-to-bunch
  - Simulation then includes Poisson fluctuations around the mean
  - Typical Run 3 (= Phase I) value expected to be around 50
- Pileup mitigation a critical element of detector designs
  - ATLAS and CMS scoping documents include performance comparisons at these two μ values
  - ATLAS [CERN-LHCC-2015-020], CMS [CERN-LHCC-2015-019]
- The scoping documents extend previous studies:
  - ATLAS Phase II LoI [CERN-LHCC-2012-022], CMS Technical Proposal [CERN-LHCC-2015-010]
  - Links to additional public results:
    https://twiki.cern.ch/twiki/bin/view/AtlasPublic/UpgradePhysicsStudies
    https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsFP
    ECFA HL-LHC workshop 2014: https://indico.cern.ch/event/315626/

Detector configurations

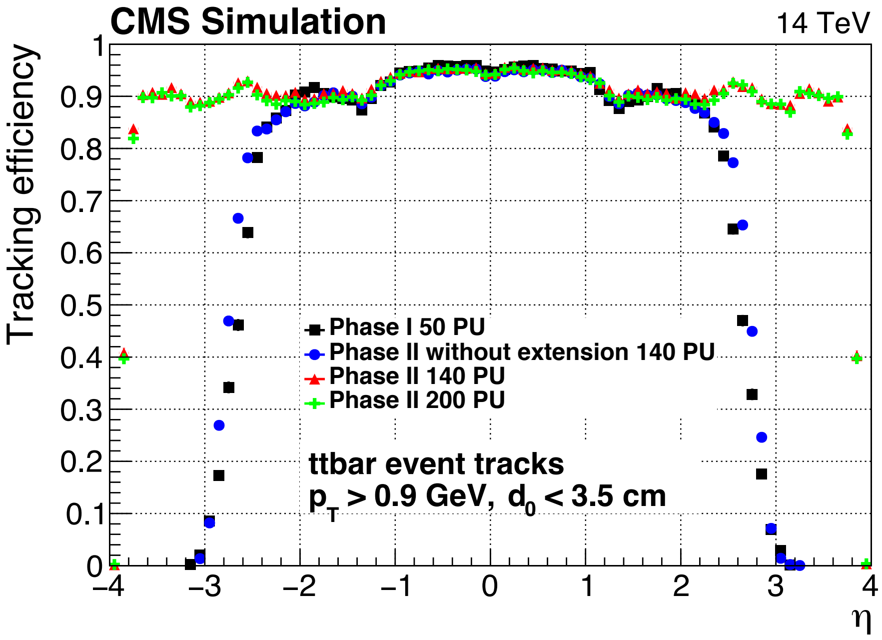
- Both experiments have made full simulations of their Phase II detectors to study performance. Caveats:
- Trackers
  - Pixel detectors extended to $|\eta|= 4.0$ (ATLAS), 3.8 (CMS)
  - For both, there will be a further reduction in pixel size (i.e. improvement in resolution) compared to the present simulations, and further optimisation of the layout
- Calorimeter upgrades
  - CMS will fully replace the end cap calorimeter ($1.5 < |\eta| < 3.0$), with precise timing information from each layer, plus improved timing information in the barrel region
  - ATLAS propose a high granularity timing detector between the barrel and endcap LAr calorimeter cryostats ($2.4 < |\eta| < 4.3$)
  - For both experiments, the timing aspects are not yet fully integrated in simulation and/or reconstruction algorithms
  - ATLAS may also replace the forward calorimeter ($3.2 < |\eta| < 4.9$)

Tracking extended to large |η|

- Pion tracking efficiency in ttbar events for ATLAS full and reduced scenarios, PU of 200



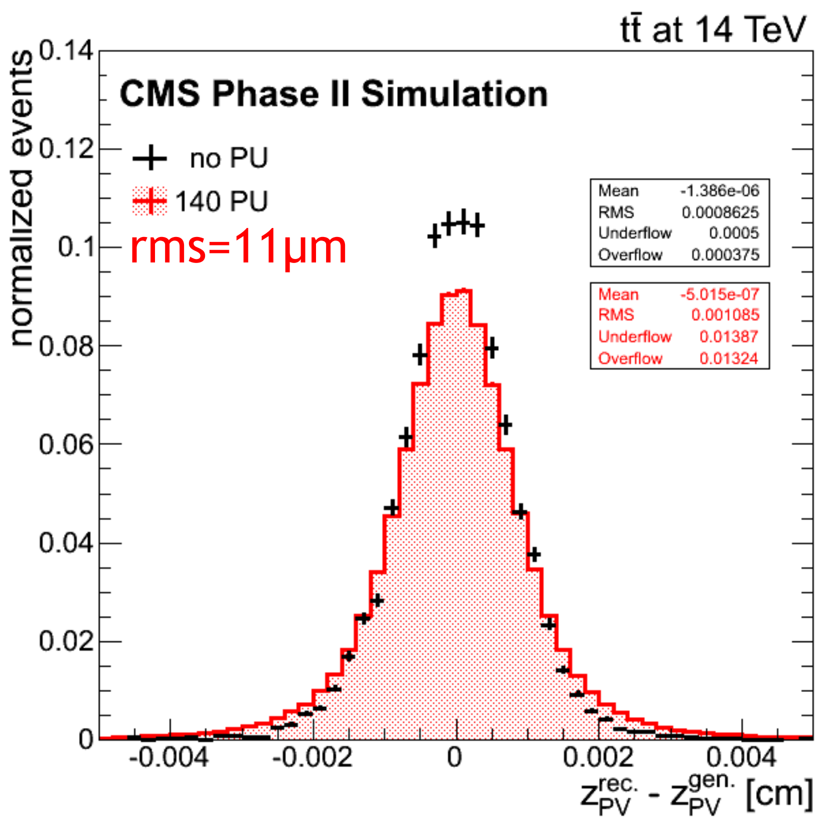
- Tracking efficiency with η extension in CMS for 140 PU or 200 PU

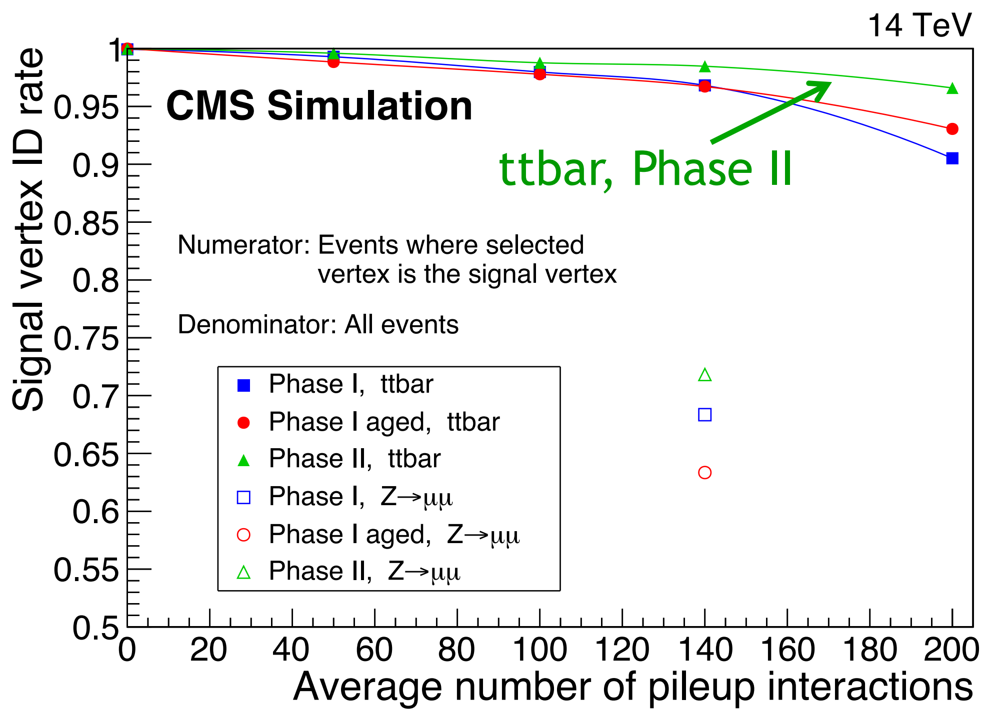


- For both experiments, fake rates are well under control
- Muon tracking efficiency is uniformly high (about 99%)

Primary vertex finding

- ttbar events reconstructed with the CMS Phase II detector
- rms resolution 11μm for this high multiplicity hard-scatter process
- Efficiency for picking the right vertex about 98% (96%) for μ=140 (200)

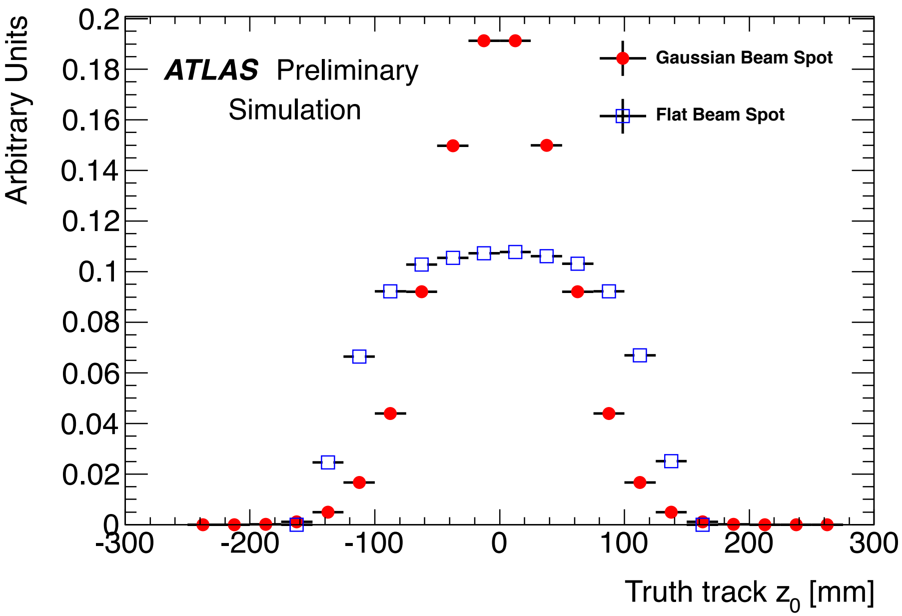




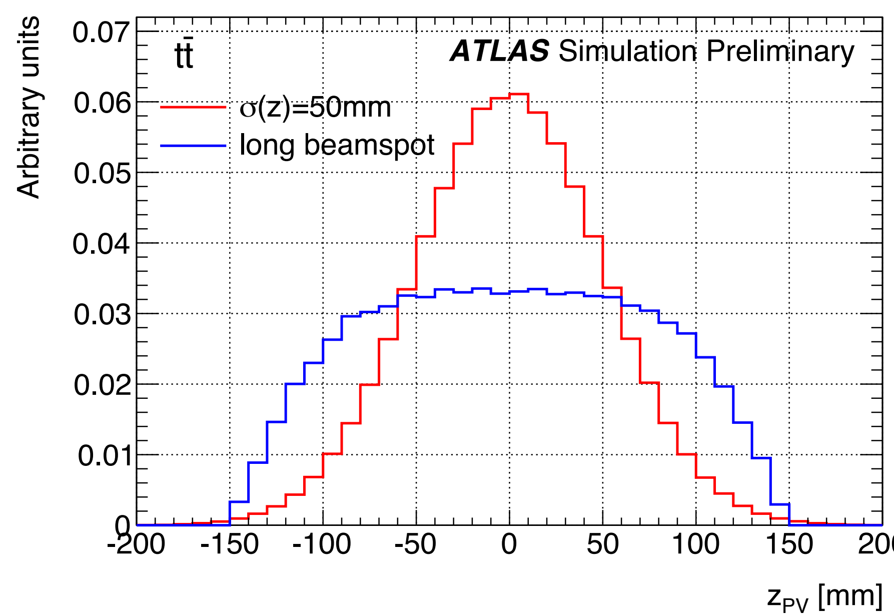
Effect of a longer beam spot

- Both experiments have investigated different longitudinal (z) beam spot profiles.
  - Gaussian with σ=5cm
  - Long beam spot, ~flat to ±11cm, falling off to ±15cm
- ATLAS tracker required to be hermetic for vertices in ±15cm
- CMS tracker optimised for hermeticity over ± 7cm, with no performance degradation seen out to ±11cm

Generated tracks

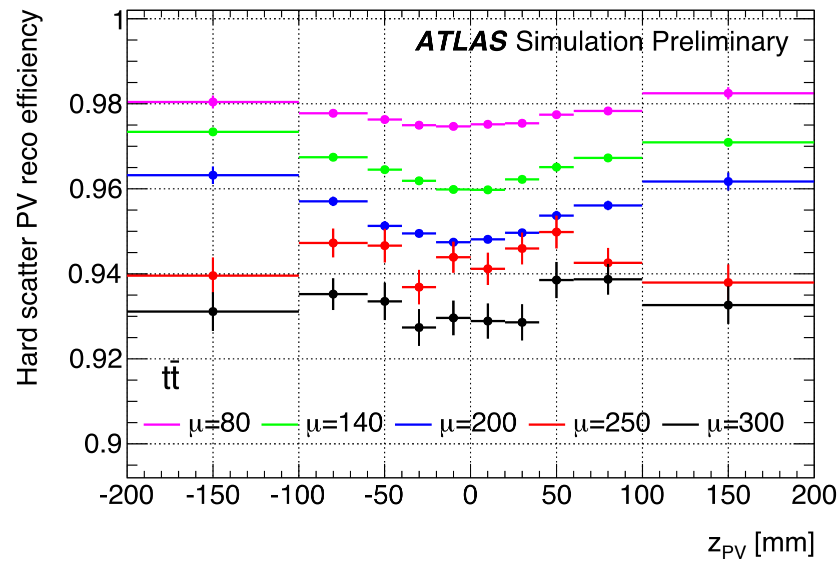


Reco primary vertices

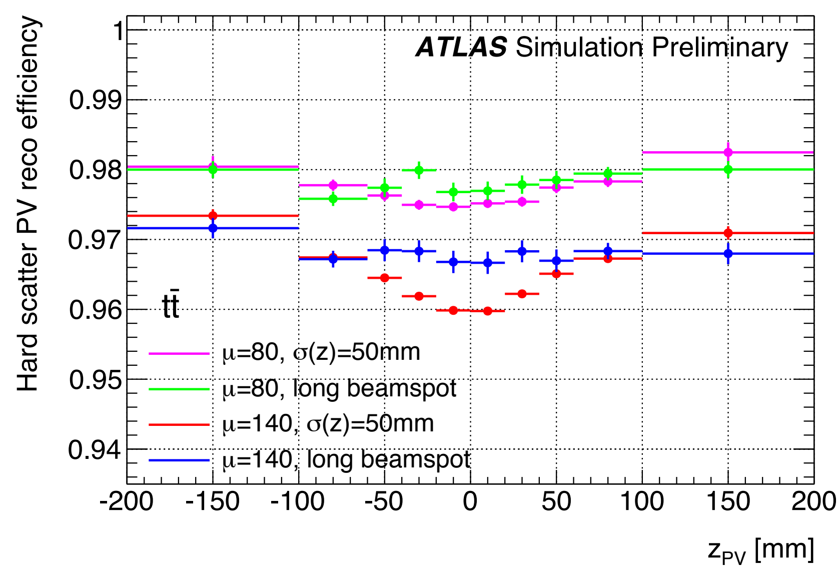


Effect of varying PU and beam spot shape

- Hard scatter reconstruction efficiency for ttbar events
- Non-optimised algorithms, larger pixel sizes than now planned



- Gaussian beam spot, σ=5cm, μ [80,140 … 300]



- Gaussian σ=5cm or long beam spot, μ=140: about 1% higher efficiency for long beam spot
- Much less difference for μ=80
- (No samples were made yet with long beamspot, μ=200)

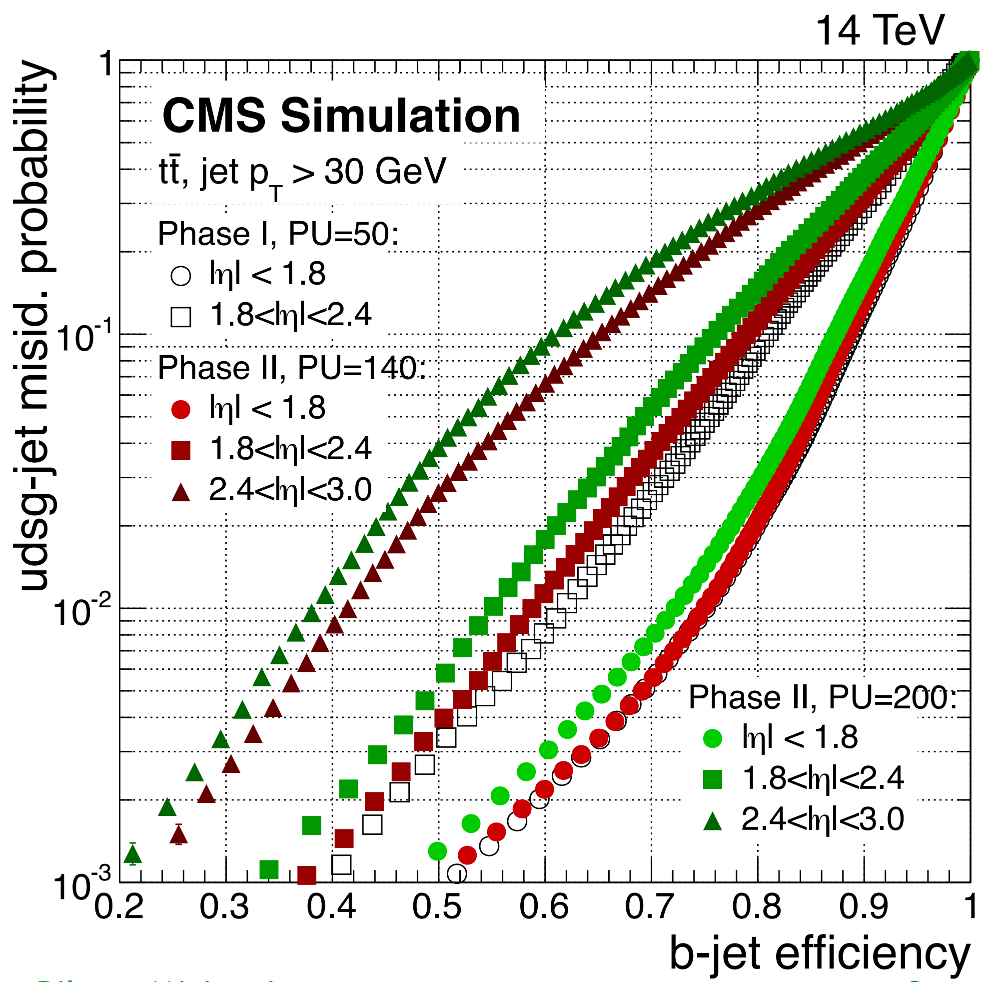
b-tagging

- Efficiency to tag a b-jet from ttbar decay vs the light-jet misid probability (for events with correct PV identified)

- μ=140
- μ=200
- μ=50 (Phase I)

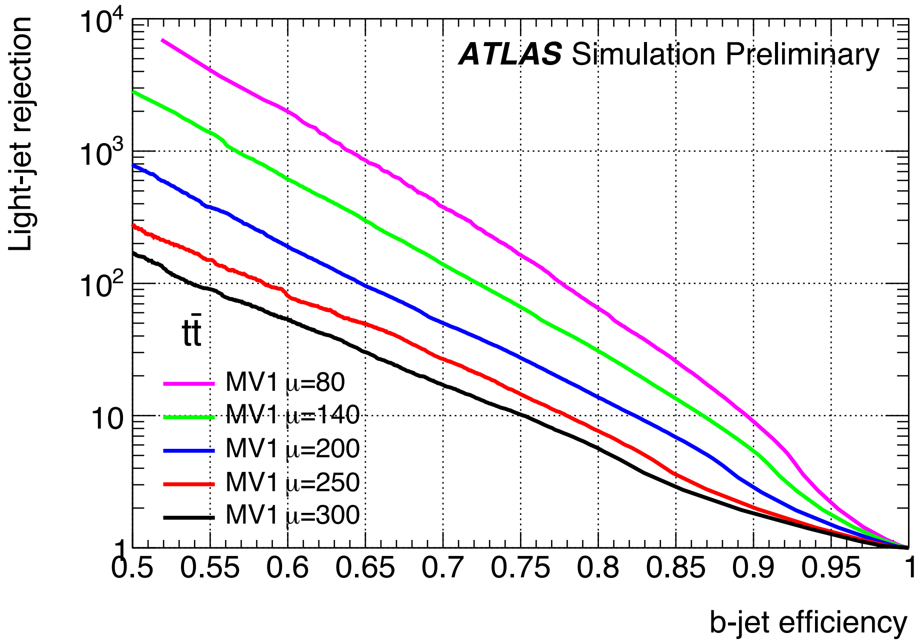
- Phase II detector gives useful performance up to |η|<3.0

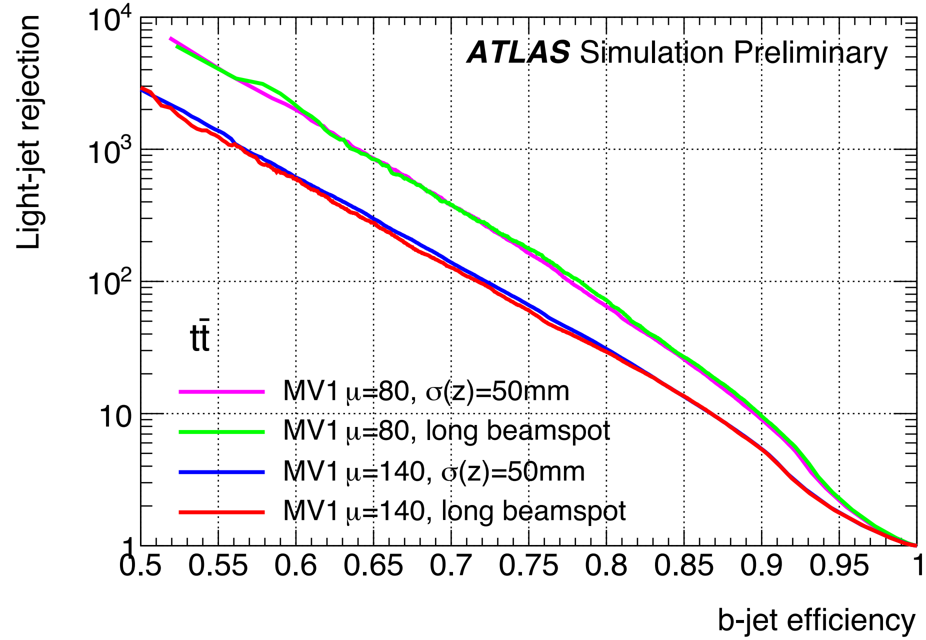
- Few % decrease in b-tag efficiency for fixed misid rate going from 140 to 200



b-tagging – beam spot shape

- b-tagging degrades gradually with higher μ (left plot)
- If the correct PV is selected, the b-tagging is insensitive to the beam spot shape (right plot)
    - Plots using the LoI detector averaging over |η|<2.5
    - (Exact results sensitive to layout, tracking algorithms, jet energy scale. No tests made yet with μ=200, long beamspot)

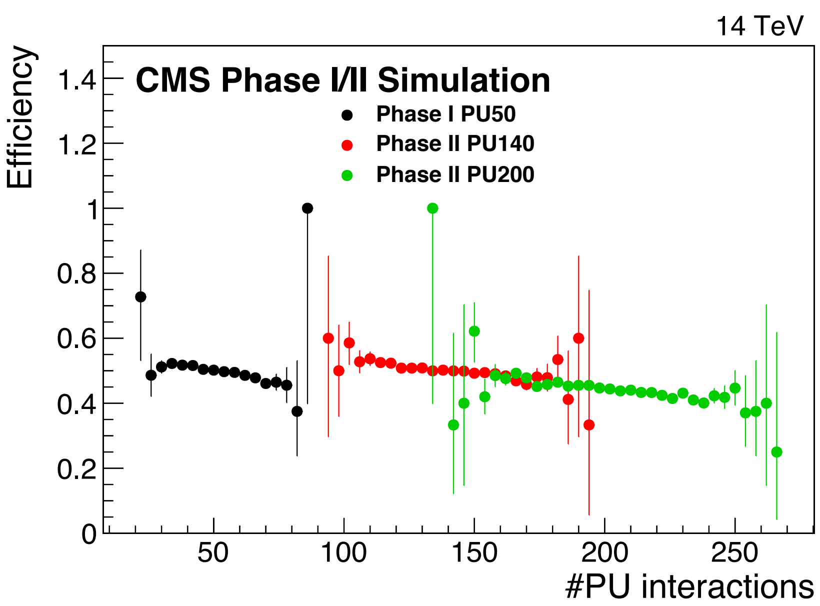


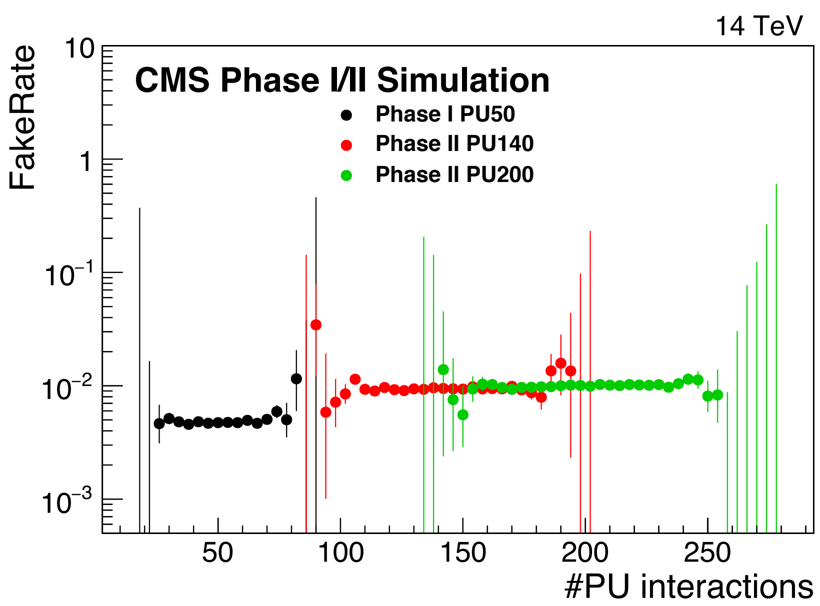


- NB: rejection = 1/(misid-prob)
- Non-optimised algorithms from Run 1

e/γ/μ/τ performance

- Muon track finding has high efficiency for ATLAS and CMS
  - Matching to muon spectrometer is only weakly affected by pileup
  - Isolation variables need corrections for pileup contribution
- Work is in progress to optimise e/γ/τ algorithms
  - Some degredation of id efficiency and resolution with pileup
- Example: τ efficiency and fake vs. number of events from CMS
  - Efficiency reduced if constant fake rate is chosen



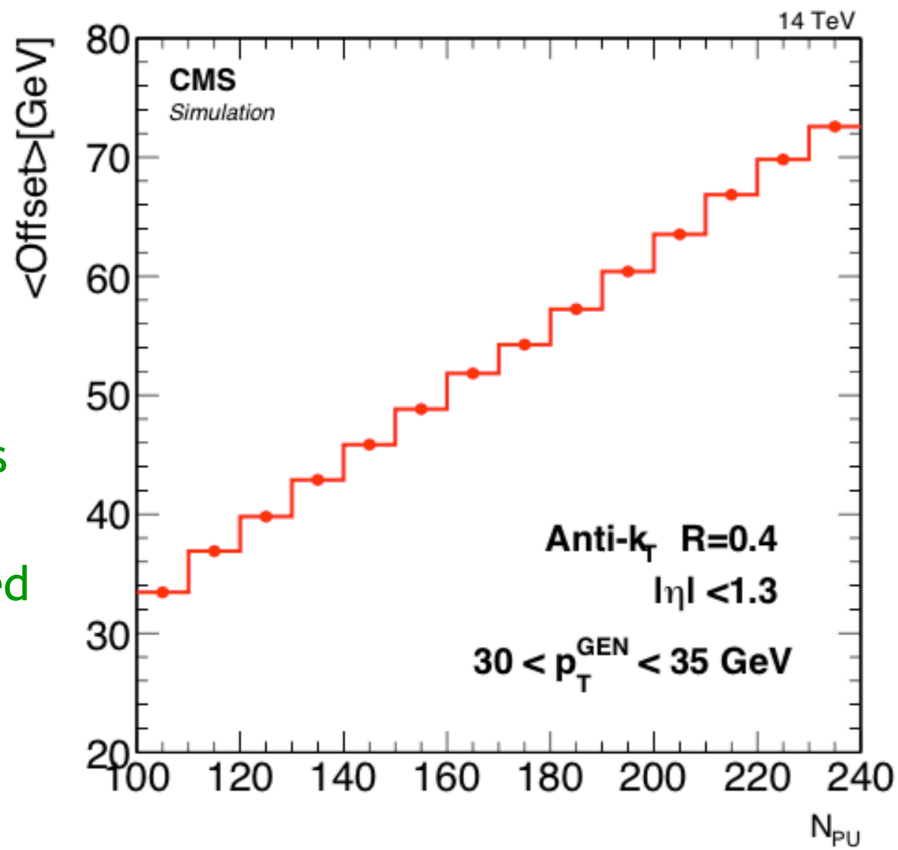


Jets and pileup

- Particles from pileup events make a significant contribution to the jet energy of true low p_T jets
- Pileup events can also produce additional QCD-like jets (usually at low p_T), and jets from random combinations of particles from several pileup events

- Plot shows additional energy from pileup overlaid on low energy QCD jets with radius 0.4 in η-φ space

- Reconstructed jet energy depends on detector specific algorithms
- Jet energy scale correction applied to estimate true jet energy

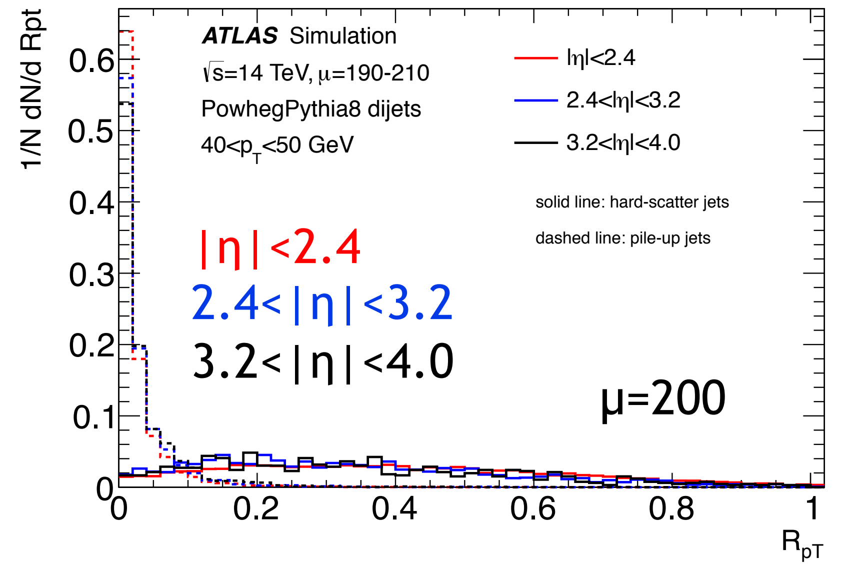


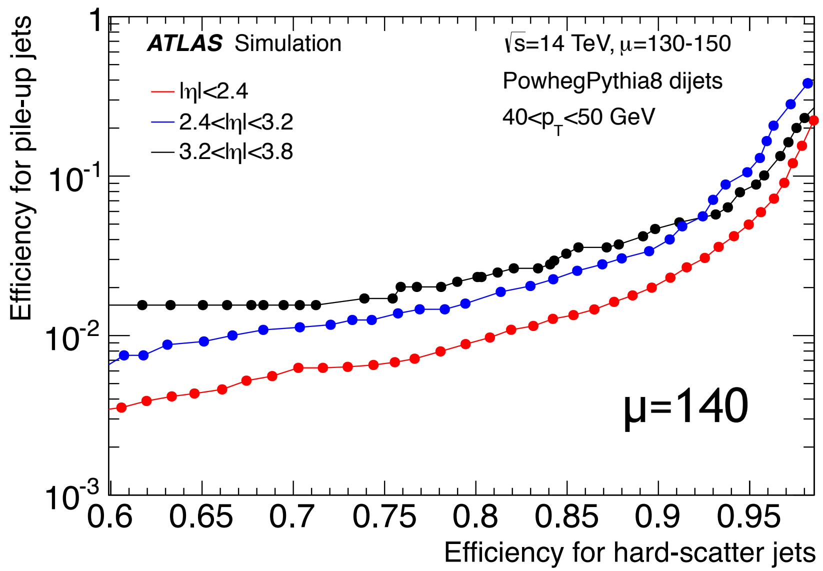
Pileup jet suppression with tracks - ATLAS

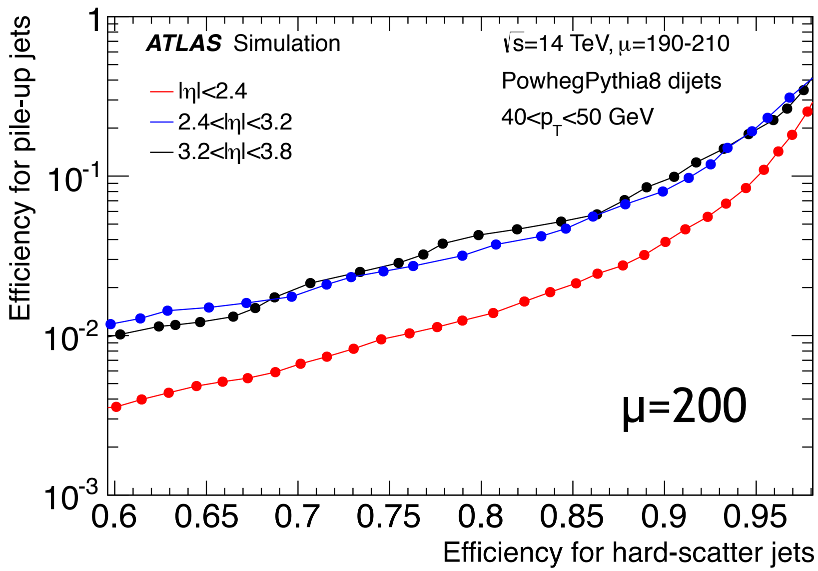
- Use a tracking variable, R_{pT}, to distinguish between hard-scatter and pile-up jets. Sum over tracks in the jet which come from the hard scatter PV

$$R_{pT} = \frac{\Sigma_i (p_T^{\mathrm{track},i})}{p_T^{\mathrm{jet}}}$$

- Scan value of R_{pT} to find efficiency for PU vs. HS jets (40-50 GeV jets shown)

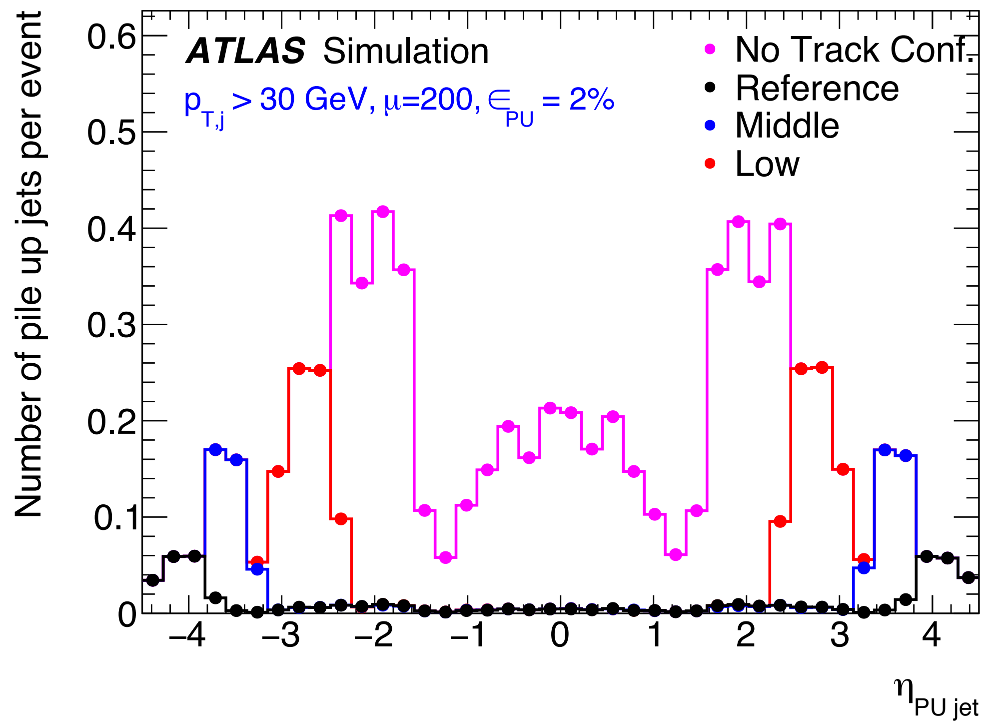






Pileup jet suppression with tracks

- Example: R_{pT} cut selected to keep <2% PU jets (μ = 200)



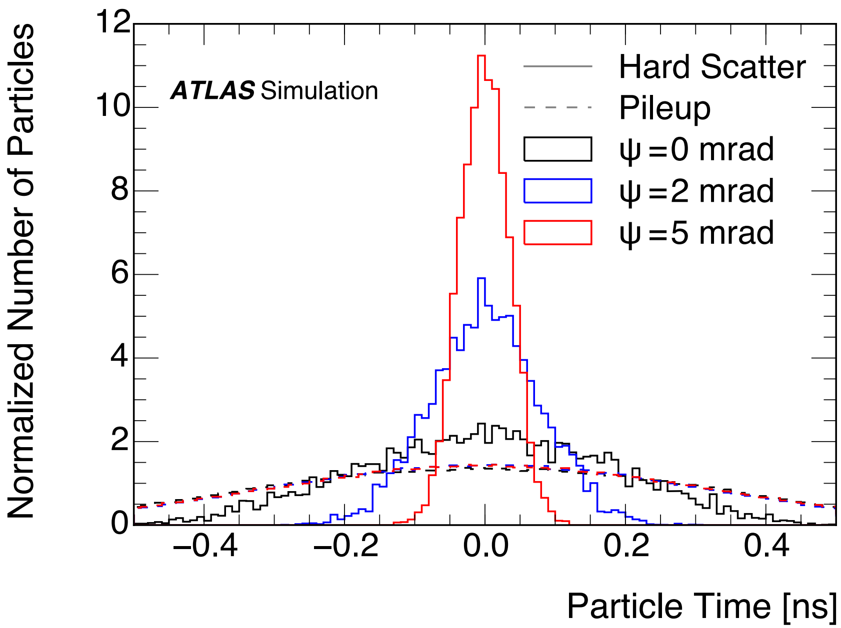
- CMS uses particle flow objects to make optimum use of track and calorimeter information
  - PUPPI algorithm to evaluate the weight for each PF object to be from hard-scatter or pileup event
  - Resolution improved by extended tracker coverage

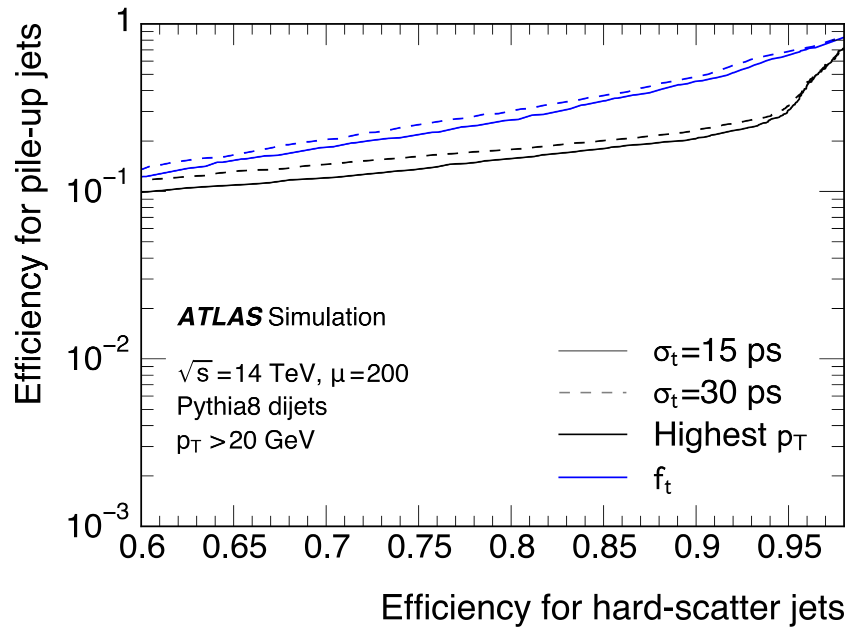
Use of precision timing information

- CMS end cap calorimeter will include precise timing information from active layers
  - Intrinsic ToT jitter expected to be 50ps per measurement. (Many individual measurements in a jet).
- ATLAS plan a high-granularity timing detector in front of the existing end-cap calorimeter
- In the forward region, a precise timing measurement with 20-30ps resolution gives about 1cm resolution on z(vertex)
  - Typical jet: 55% charged particles, 30% photons (from π^0 decay), 15% neutral hadrons (neutrons and K^0)
  - Timing information for neutral particles is complementary to vertex position information from tracking
  - Time of flight for lower energy charged particles is also affected by the path length. (Bending in axial magnetic field → longer path length. More significant in the barrel region)
  - In Run 1, the spread of collision times was about 220 ps

ATLAS high granularity timing layer

- Standalone analytical study assuming the crab-kissing scheme
  - Time spread of collisions depends on angle ψ. Plot shows particle time w.r.t. times from known hard scatter position.
  - With a simple algorithm, 90% efficiency for HS jets while retaining about 10% of pileup jets
  - Combined algorithm using tracking and timing to be studied
  - Use of relative timing of contributions to a jet to be studied

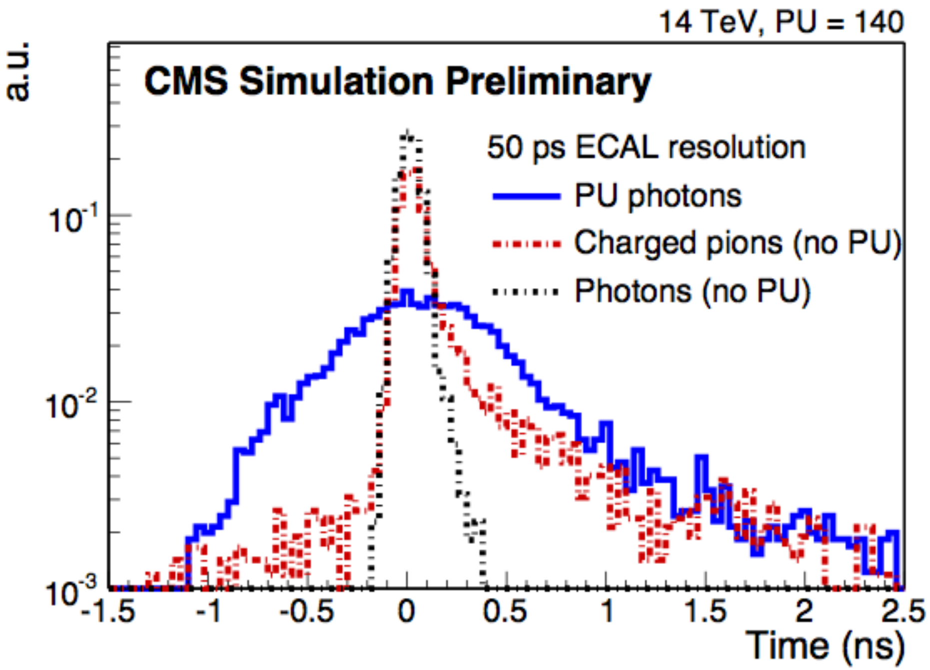


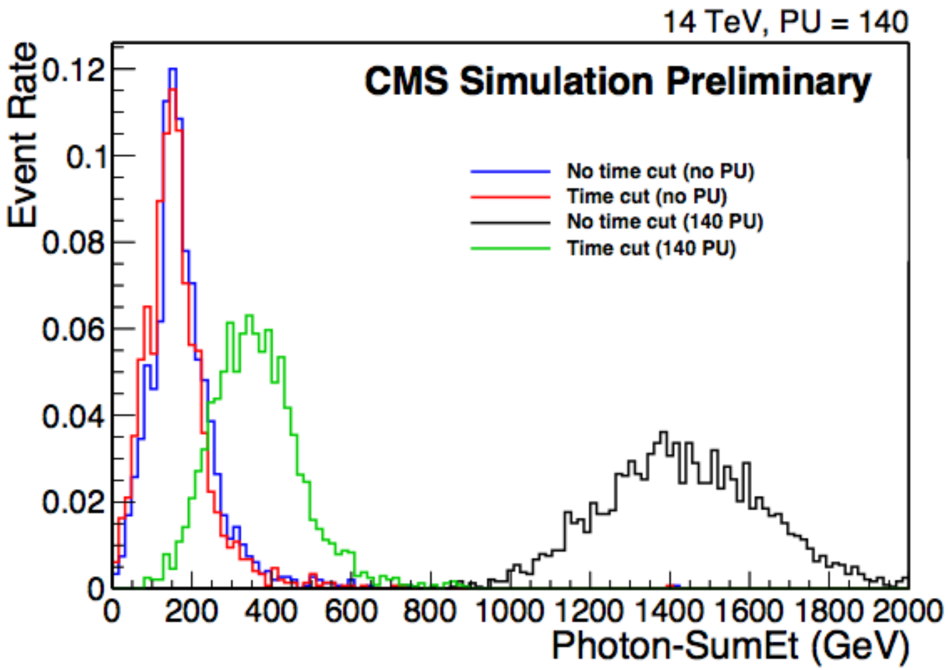


CMS studies with precise timing

- Reconstructed time for PFlow objects assuming new detector element with 50ps resolution
- Signal charged pions/photons and pileup photons

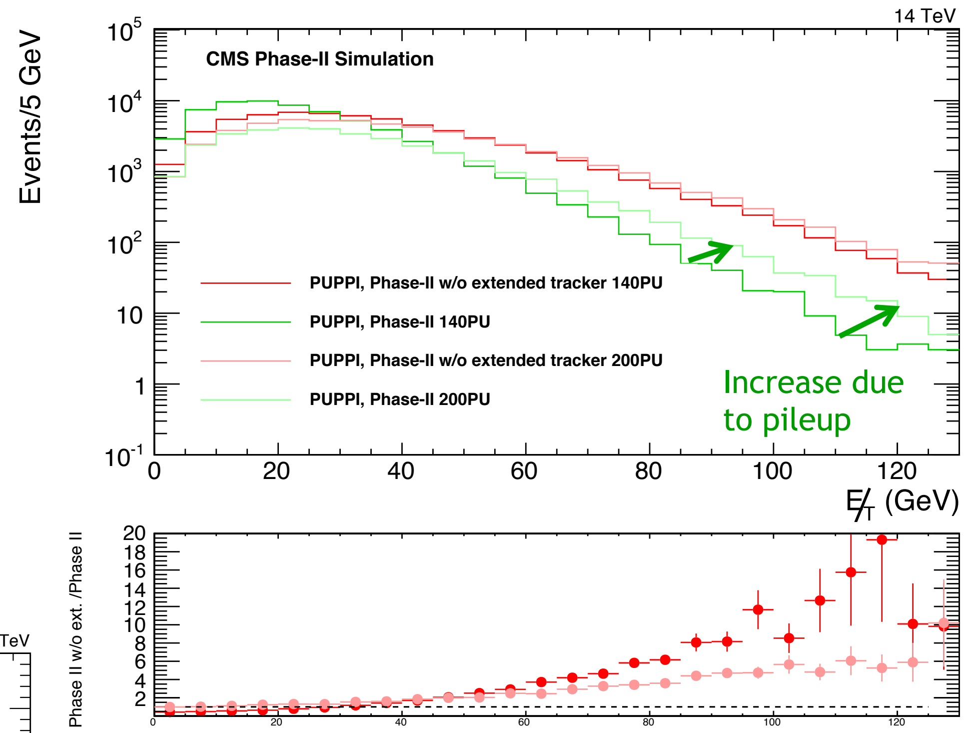
- Sum ET of PFflow photons for VBF H→γγ events
  - No pileup (red/blue)
  - Pileup 140 – no time cut
  - Pileup 140 – with time cut

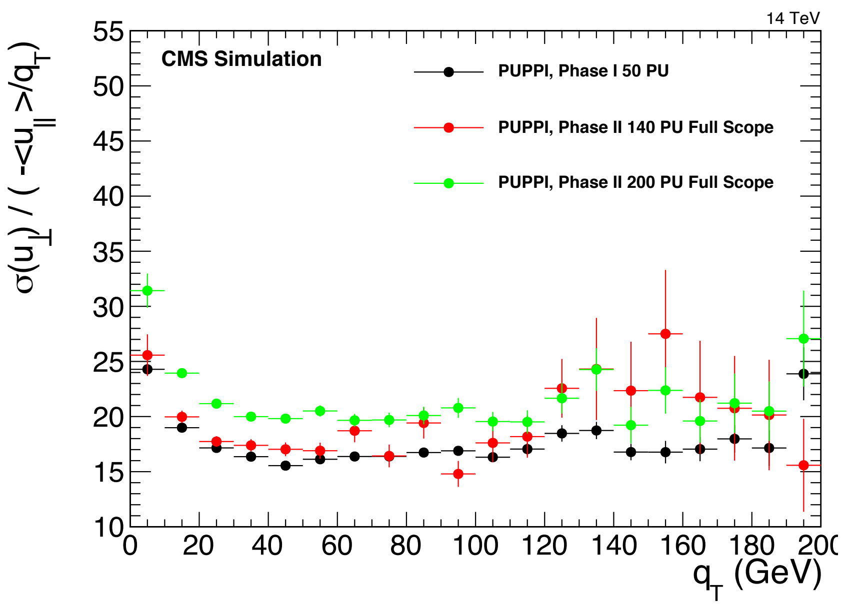




CMS E_T^{miss}

- Apparent E_T^{miss} in $Z/\gamma^* \rightarrow \mu\mu$ events, largely due to measurement of the recoiling hadronic system and pileup contributions
  - No tracker extension
  - With tracker extension

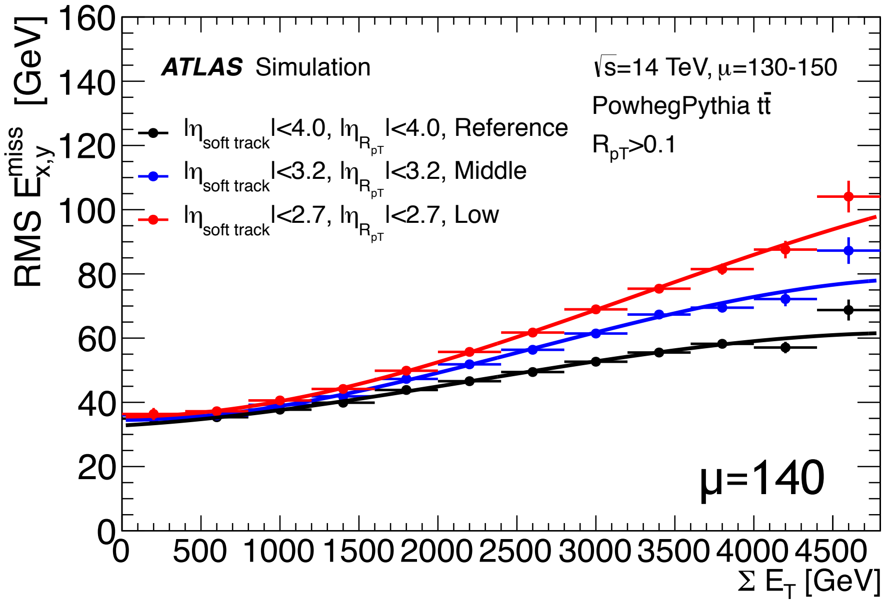


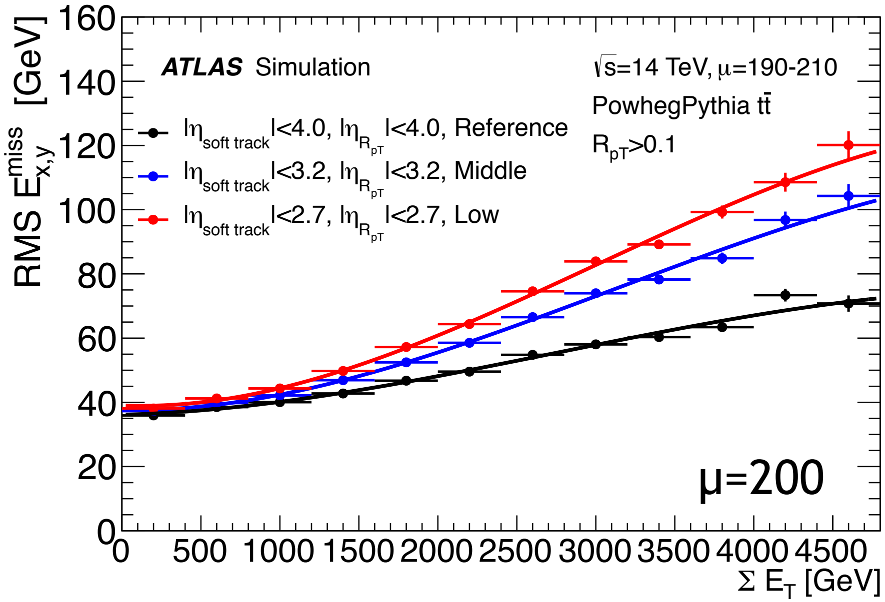


- E_T^{miss} resolution: the component of the hadronic recoil perpendicular to the Z direction in $Z \rightarrow \mu\mu$ events
  - PU 140
  - PU 200

E_T^{miss} with extended tracker - ATLAS

- E_T^{miss} resolution improves if tracking information is available for $|\eta|<4.0$ compared to 3.2 or 2.7
  - Degradation with pileup is also strongly reduced
  - Dominant effect is from rejection of pileup jets
  - Small additional contribution from improved estimate of soft term





Conclusion and outlook

- Improved understanding of pileup mitigation from recent studies
  - Relative performance with μ=140 and μ=200 evaluated. Improvements from optimised layouts and algorithms expected
  - Tracker extensions in η are a vital element
  - First results on the impact on physics analysis precision available. More in the pipe line. Optimum choice is analysis dependent.
- Tracking/vertex finding as a function of bunch length/shape
  - First indication from ATLAS was that long-flat bunch does not bring much benefit. Vertices may be merged if they are within a few 100 μm. Despite this, hard scatter PV resolution is 10-20 μm
  - Studies of an even longer beam spot have started in CMS
- Fully accounting for shape of luminous region in time and space (z,t) is in active development for precise timing detectors
  - From the machine side, which scenarios are plausible? (eg. Max length, variations in time structure, prospects for crab kissing)
  - Experiments could then give additional feedback on the time scale of Autumn 2016 (possible ECFA workshop)