ATLAS Upgrade Simulation.

Monte Carlo approaches for Inner Tracker Upgrade Studies

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Fast Monte Carlo in HEP Workshop
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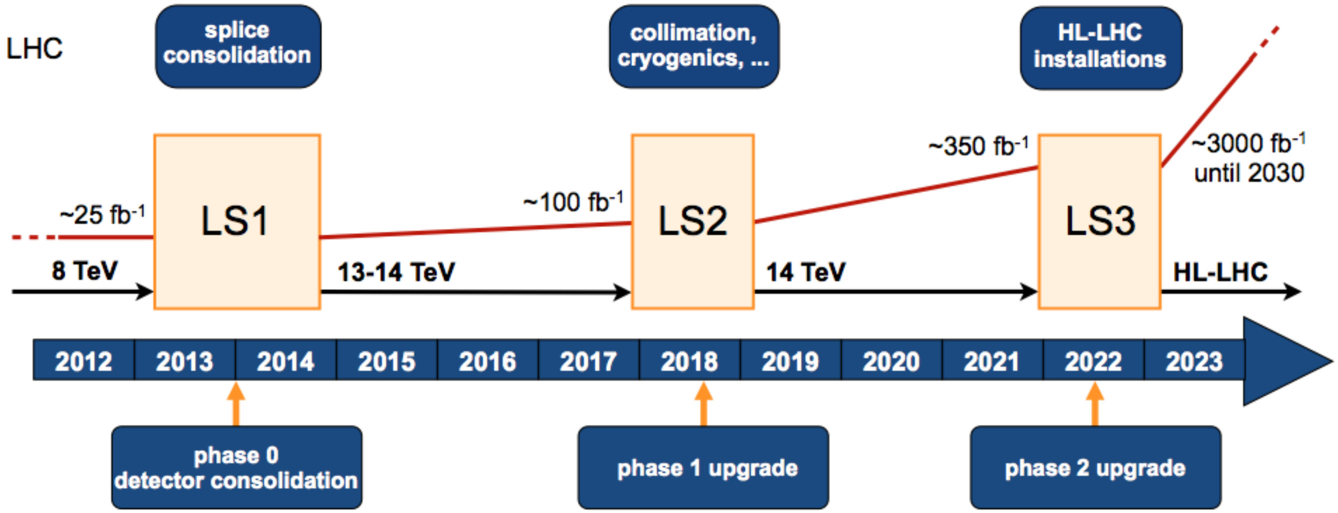
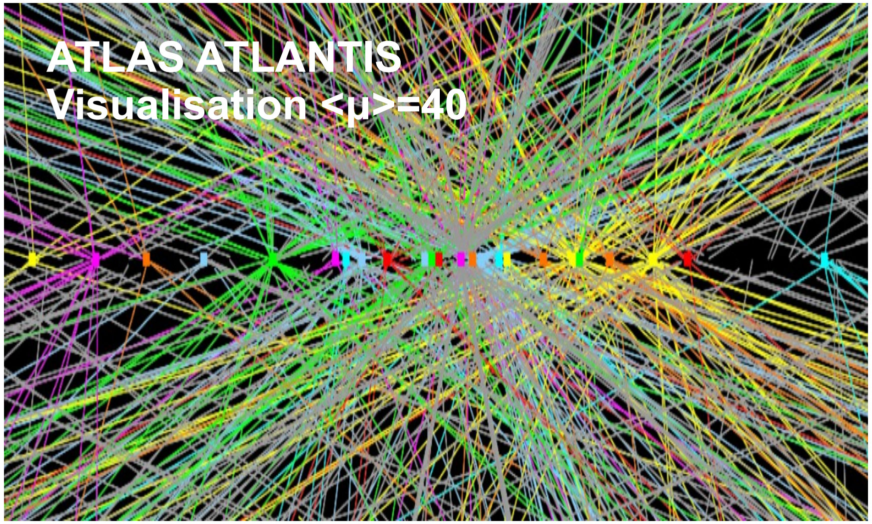
Introduction – High Luminosity LHC

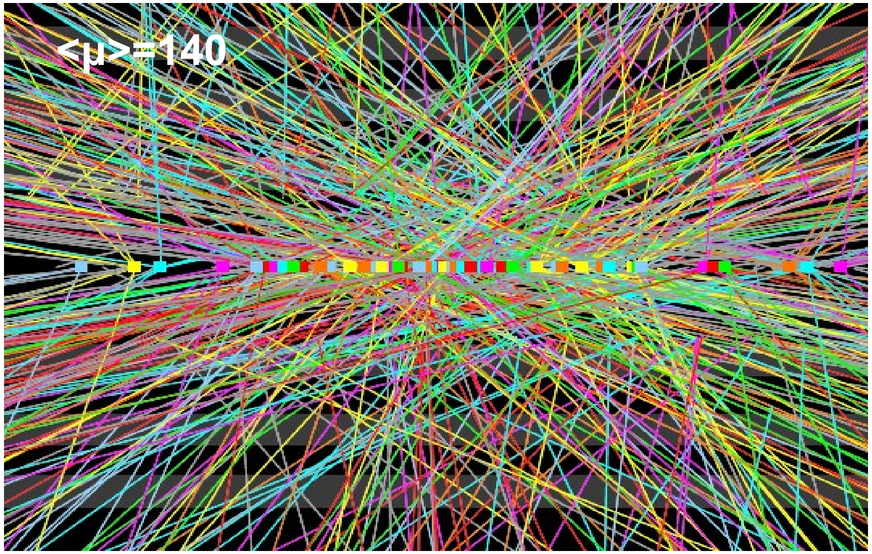
- High Luminosity LHC (HL-LHC) planned to start operation after long shutdown 3
  - Will provide ~3000 fb^{-1} $\sqrt{s}$ = 14 TeV p-p collisions
  - Will operate at an instantaneous luminosity of 5×10^{34} $cm^{-2}s^{-1}$
  - Rich experimental landscape, Challenging experimental conditions...



Pile-up at HL-LHC

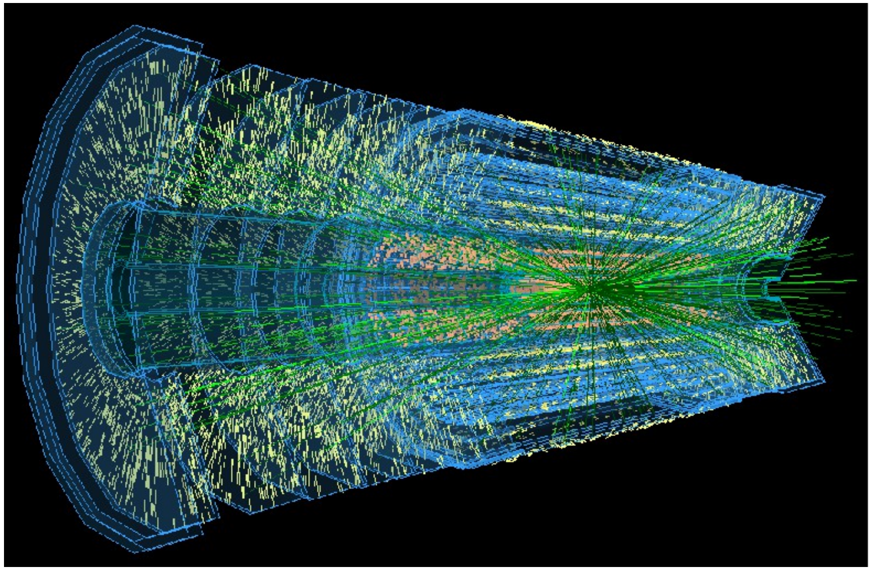
- Increase in instantaneous luminosity implies increased pile-up
  - Standard assumption for performance studies $<\mu>=140$
  - Some studies being performed up to pile-up of 400!
  - Beam spot parameters (length, profile) affect track/vertex density
- Consequences for Phase-II Upgrade Tracker design must be considered
  - Granularity: IP resolution and track/vertex separation
  - Material: Minimize multiple scattering and bremsstrahlung
  - Occupancy: Avoid readout dead time

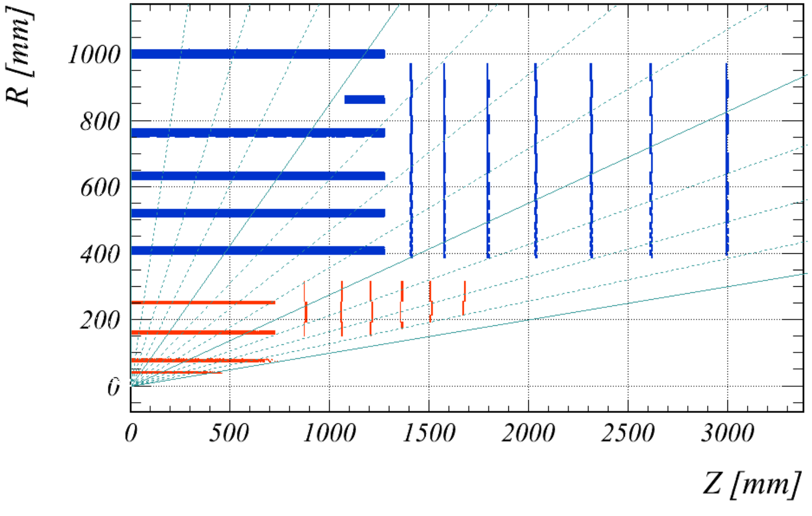




Baseline ATLAS Phase-II Tracker - ITK

- Baseline design for ATLAS Phase-II Tracker
  - All-silicon tracker; TRT (straw tracker) occupancy too high under HL-LHC conditions
  - Radiation damage of current Tracker will necessitate replacement, even if no upgrade were to take place
  - Aim of upgraded tracker – maintain at least current physics performance under high pile-up conditions
- Extensive design phase ahead of Letter of Intent
  - Design may be revisited ahead of Technical Design Report



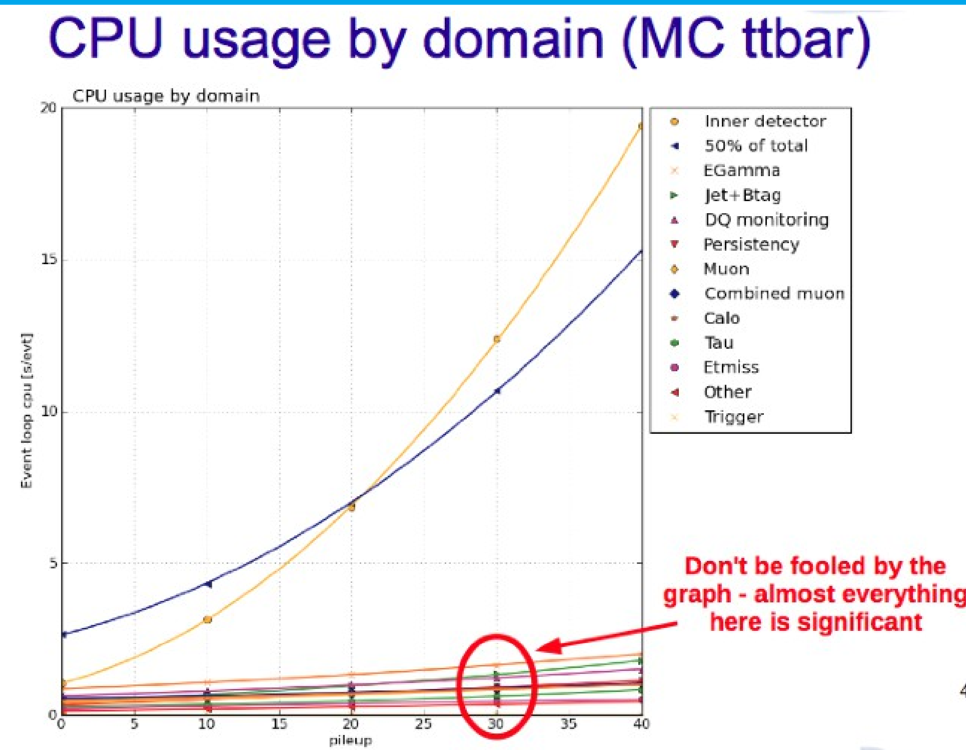


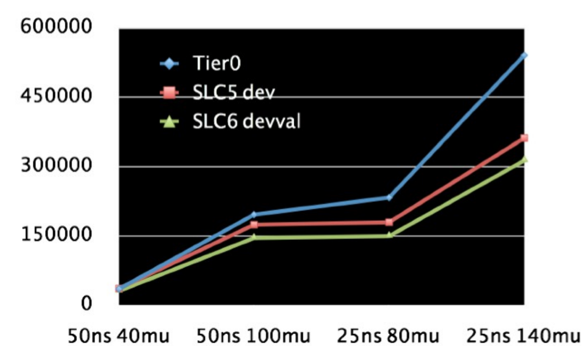
Simulation challenges for Phase 2 tracker design

- Simulation and Monte Carlo studies are an invaluable tool in designing a new detector
  - Both for overall global design choices/parameters, and very specific aspects of technology
- Detector design is a 'highly-coupled' problem
  - Many aspects to be explored which are interdependent, ideally studied in conjunction, and under realistic conditions
  - Turn-around time for developing/validating/running/analysing detailed simulation for each variation makes this unfeasible
- Different studies must use a variety of different approaches
  - To provide the appropriate level of detail to answer questions
  - To provide information on timescale required

Computing challenges

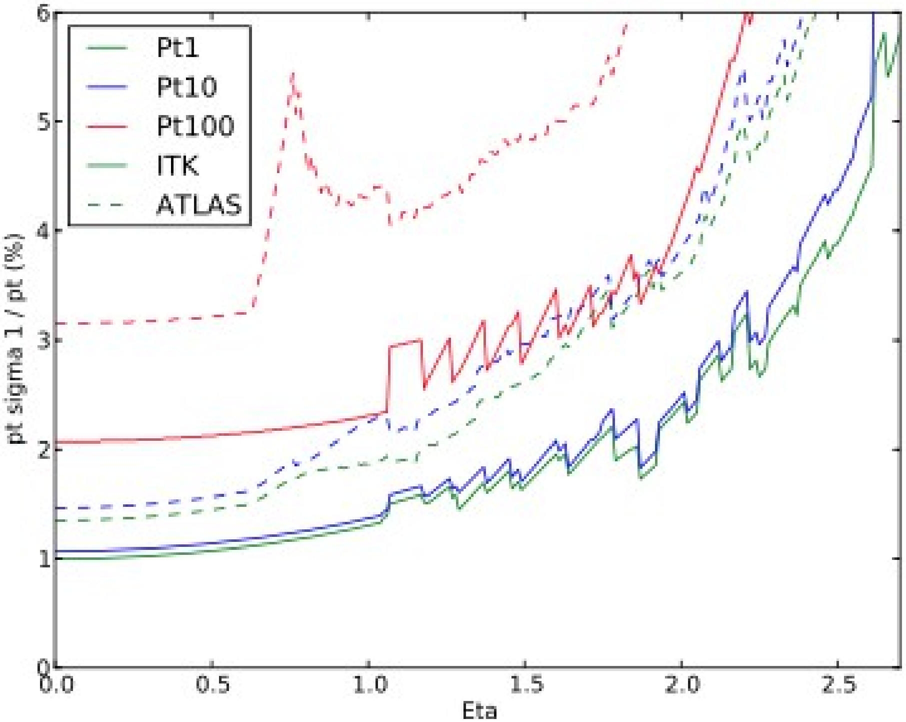
- Increased pile-up has significant consequences for CPU resources needed
  - Combinatorial complexity especially affects Inner Detector track reconstruction
  - Very large samples of minimum bias events must be simulated
- Expensive in terms of time, CPU cycles, manpower
  - Much work going in to software improvements
  - In future, new technologies and increased parallelisation will also help
  - Nevertheless, high threshold must be set for producing samples under such conditions

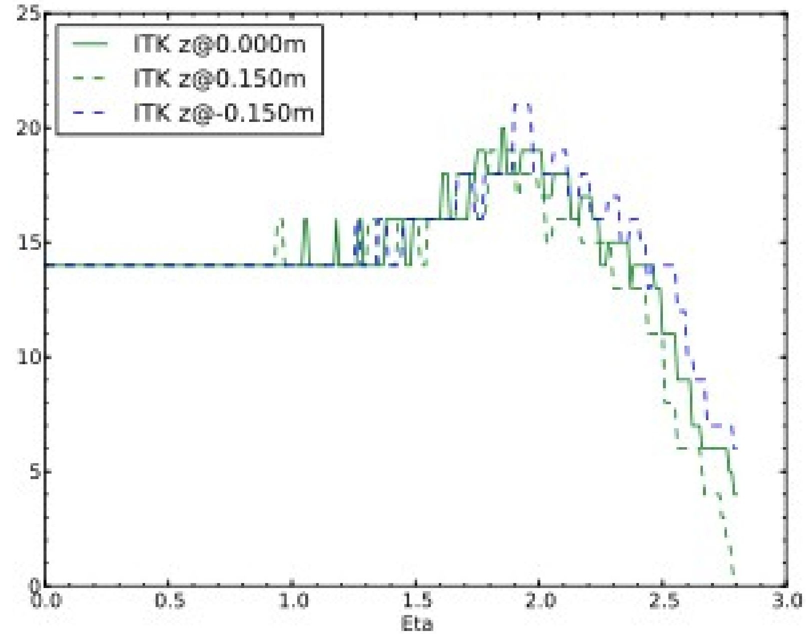




First design stages – analytical 'simulation'

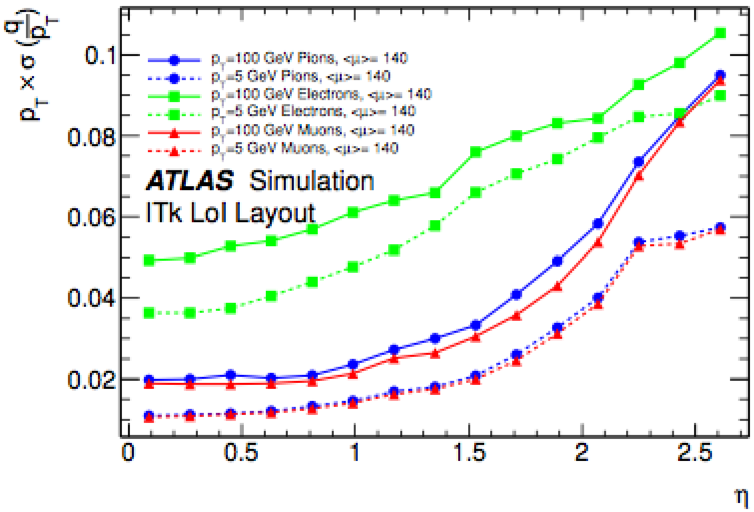
- For many initial design considerations, used 'IDRes' tool for analytical track resolution calculation
  - Useful for purely geometrical studies; hit coverage for given beam spot size, maximum distance between hit points, track resolutions for isolated muons
  - Used to develop layouts to be considered and studied further
  - Very fast, but not strictly even Monte Carlo simulation...

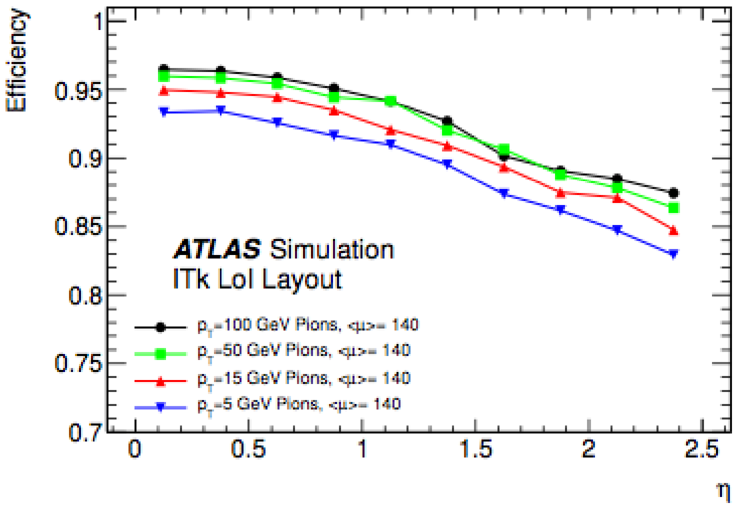




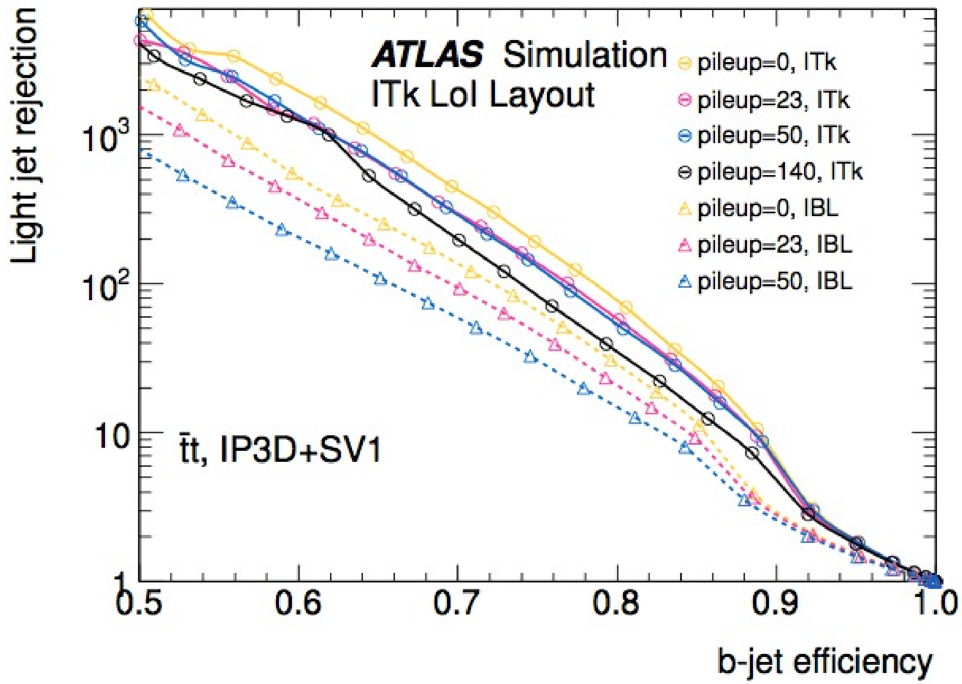
Initial simulation tests – single particle, tracker only

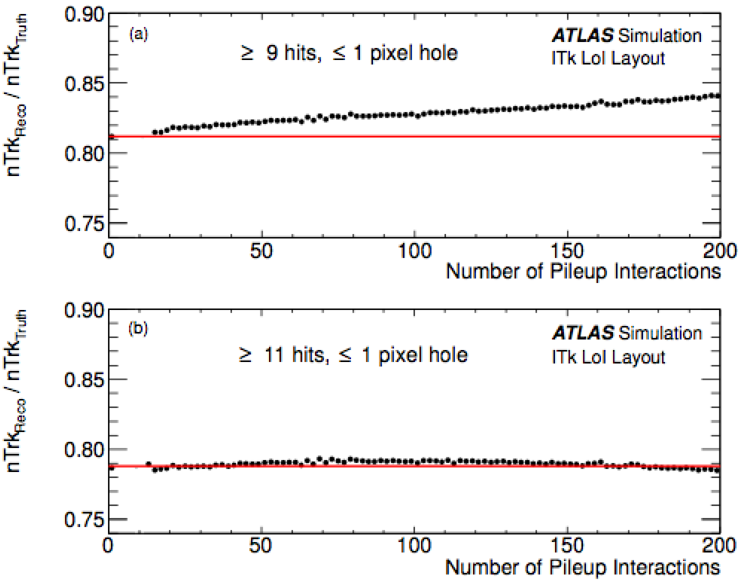
- Promising layouts can be tested further in Geant4
  - Simulated only tracker; no calorimeters or muons
  - Isolated single particles, no pile-up
  - Track efficiencies, confirm muons resolutions, electron/pion resolutions
- FATRAS has also been used in place of Geant4
  - Offers speed-up with respect to Geant4
  - Access to multiple simulation engines useful for debugging purposes

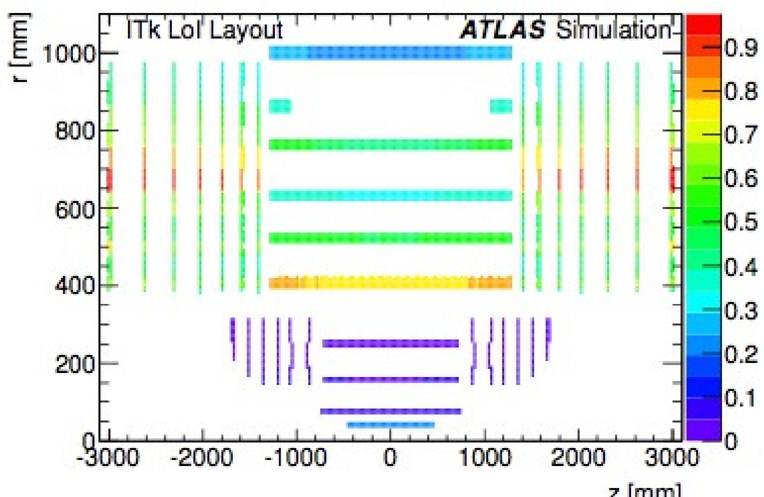




Pile-up, Tracker-only simulation







Occupancy (%) at <μ>=200

- Wide range of studies possible in this configuration
  - Effect of pile-up on reconstruction, channel occupancies...
  - B-tagging performance studies (using MC truth jets in place of reconstructed jets)

Going beyond the Inner Tracker...

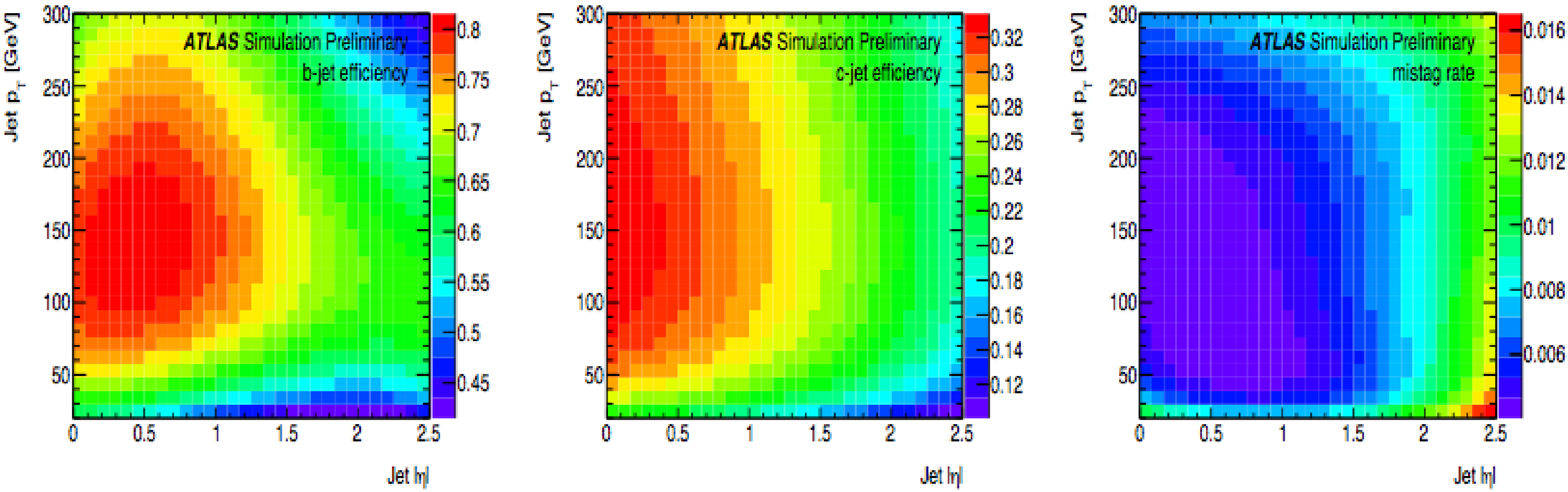
- Bulk of tracker performance studies for ATLAS Phase-II Letter of Intent produced as just described
  - Such a sample (tracker only, pile-up 140) can plausibly be produced by an individual user with their own grid quota, up to reasonable statistics (few hundred kEvents)
  - Reconstructing 100 events@pile-up 140 takes ~8 hours
- Tracker-only samples not sufficient to build HL-LHC and ATLAS Phase-II upgrade Physics case
  - Very few physics analyses rely solely on Inner Detector tracks; need also to be able to extrapolate tracks to Calorimeters and Muon System
  - Not feasible to produce full simulation of ATLAS+ITK at full HL-LHC conditions for each signal sample to be studied + backgrounds
  - Different approach needed for performing ATLAS Phase-II physics studies at this point
  - Will be outlined in coming slides...

ATLAS+ITK Simulation for ECFA Studies

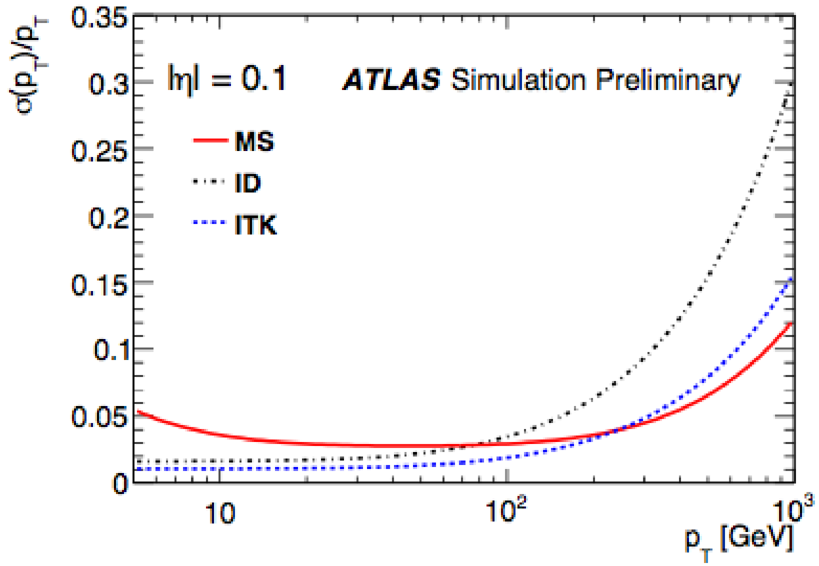
- Provided physics input to 2013 ECFA HL-LHC Workshop
  - Show the physics reach of an upgraded ATLAS at HL-LHC
  - Variety of benchmark measurements
- Selection of representative samples produced to estimate performance
  - ATLAS+ITK, high pile-up HL-LHC conditions
  - Performance groups analysed samples
  - Extracted paramterisations of ATLAS+ITK performance
  - Applied parameterisations to generated 4-vectors to produced 'smeared' Monte Carlo

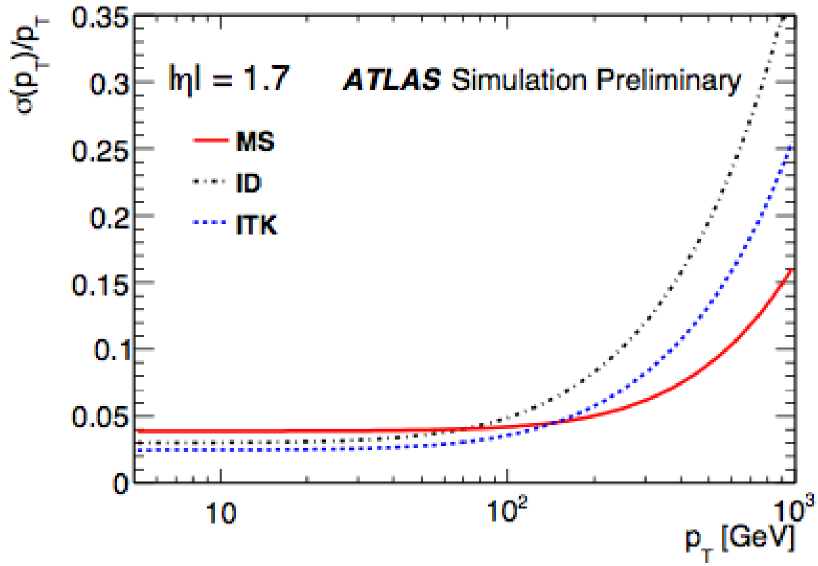
B-tagging

- Single operating point
  - Average b-tagging efficiency of 70%
  - Extracted from $t\bar{t}$ sample
- Parameterised in both eta and pT
  - B-tag efficiency, and mistag efficiencies for c-jets and light jets separately

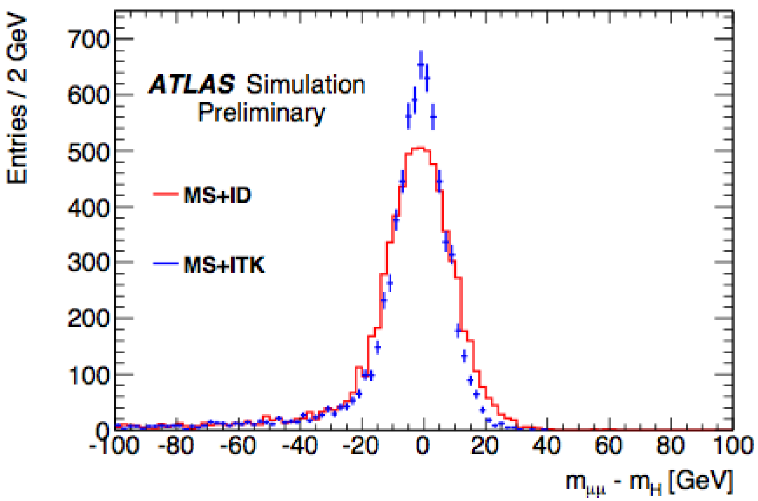


Muon Smearing

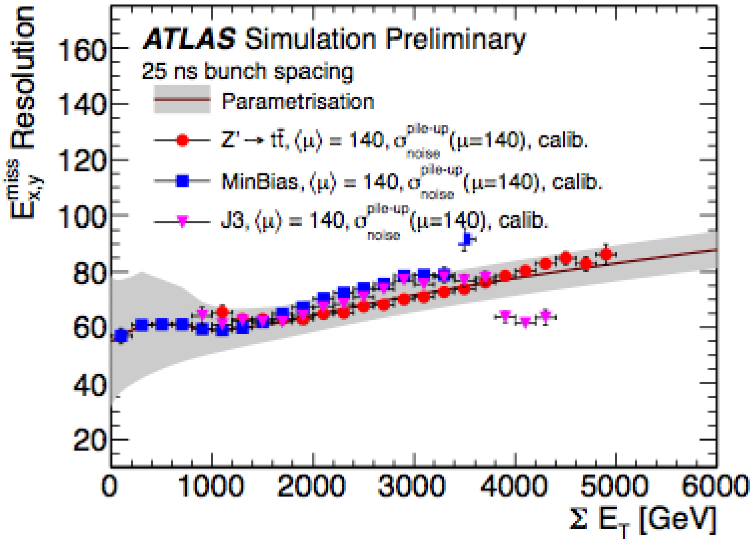




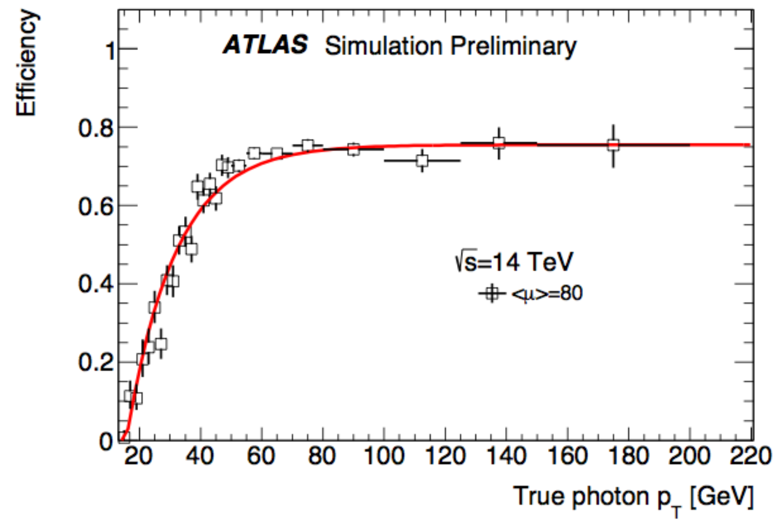
- Transverse momentum smearing only
  - Simple bin-by-bin eta dependent resolution function
  - Extracted ITK-only from isolated muon sample
- Muon efficiency very high
  - ~100%
  - Therefore no efficiency function required

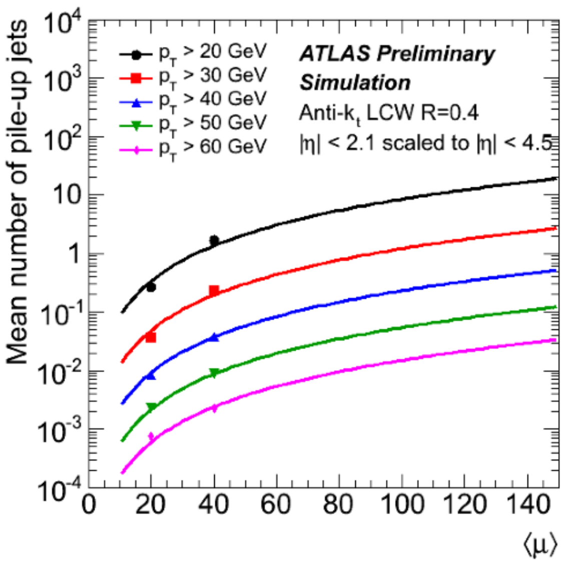


Other performance parameterisations



(c) $\langle\mu\rangle$=140, $\sigma_{\text{noise}}^{\text{pile-up}}(\mu$=140)



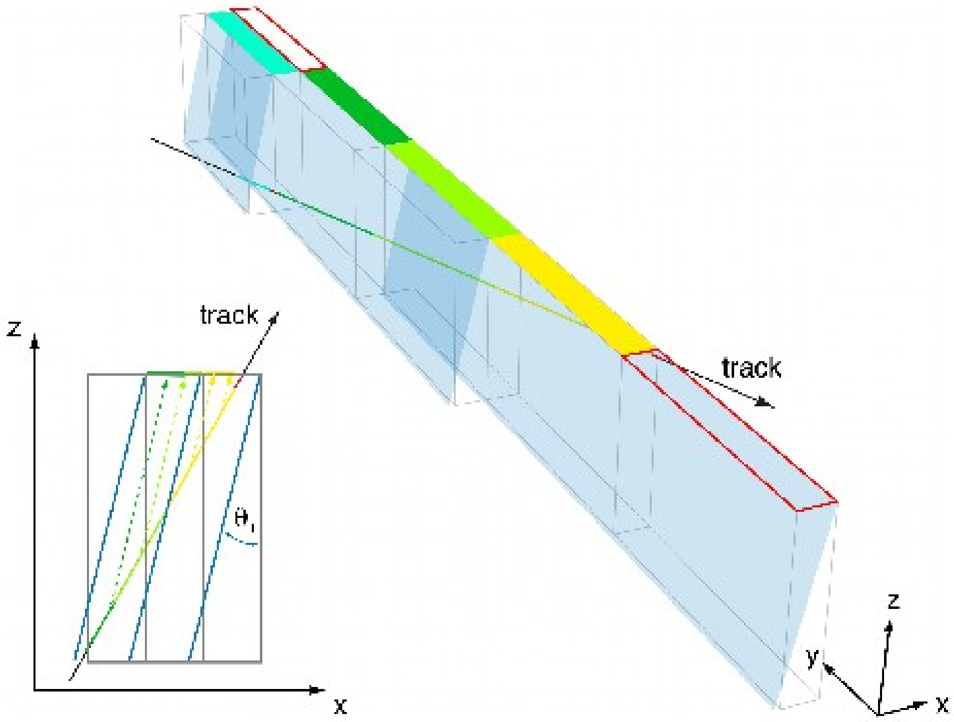


- Variety of further parameterised performance functions available
  - Electrons, photons, jets, missing E_T...
  - Some used ATLAS with current ID at lower pile-up to extract performance, and extrapolate
- Currently implemented as stand-alone functions
  - Could potentially be added as a further option in ISF

Future plans for Upgrade Simulation

- Up to this point, fast simulation techniques under-used for ATLAS Upgrade studies
  - Potential speed-up in layout testing + comparisons
  - Fully-detailed simulation often not really necessary for many studies
- Still early in the process
  - A lot more Monte Carlo productions to come
  - Not just for layout development
  - A lot of Monte Carlo will be needed for physics studies once layout is closer to final
- Opportunities to extend use of fast techniques
  - Will go over some particularly interesting examples in following slides

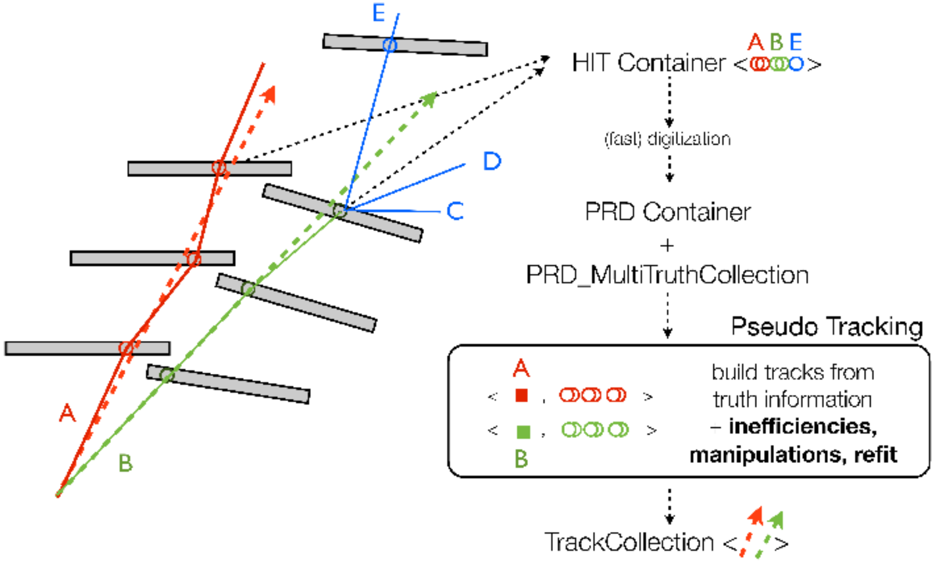
Fast Si Digitization



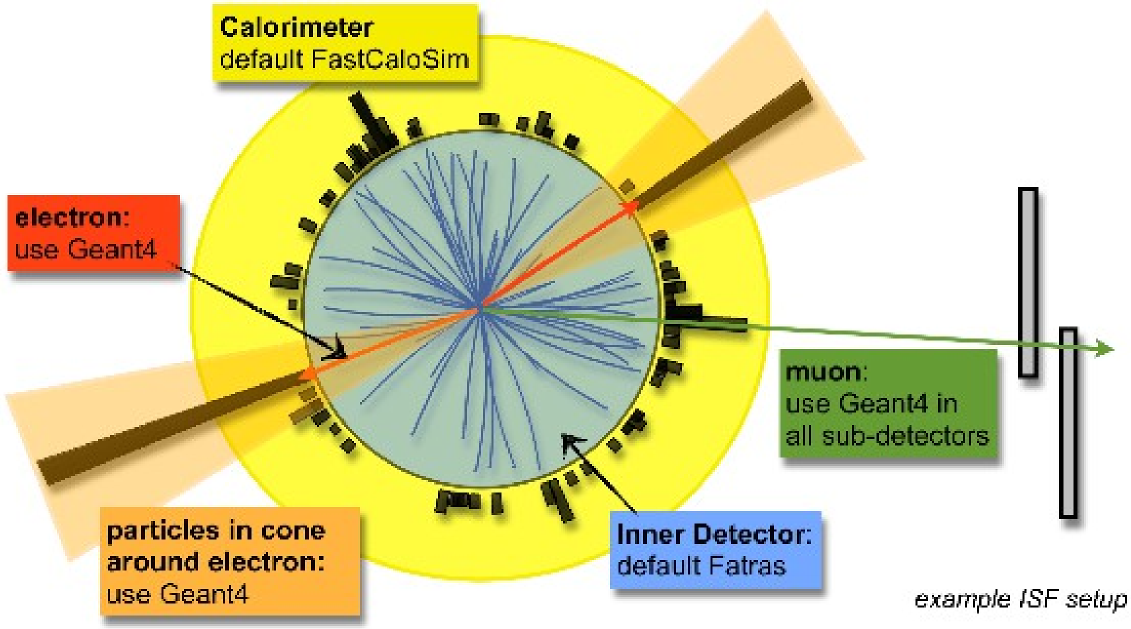
- Required granularity of pixel & strip sensors an open question
  - 'Trivial' change to layout
  - Implementation often has complications
  - Testing different granularities requires re-running simulation (signal and min bias)
- Fast digitization could help
  - Re-process the same simulation
  - Provide different granularities only at digitization stage

Truth-based Tracking

- Track reconstruction using MC truth info
  - In place of pattern recognition, track seeding, and ambiguity solving
  - Offers considerable speed-up, particularly in dense environments
- Limited to use for specific cases
  - Likely provides an unattainable upper bound on tracking performance
  - This can nevertheless be useful
  - Very valuable debugging tool



Integrated Simulation Framework



ISF Simulation Setup	Speedup	Accuracy
Full Geant4	1	best possible
Geant4 with FastCaloSim	~25	approximated calorimeter
Fatras with FastCaloSim	~750	all subdetectors approximated
Fatras with FastCaloSim only simulating particles inside cones around photons	~3000	all subdetectors approximated + partial event simulated

- Challenge of producing sufficient MC for 3000 fb^{-1} analyses, with HL-LHC conditions will necessitate use of fast simulation techniques
  - Very large CPU savings possible, and will be very welcome
- ISF designed to make selection of desired combination of simulation techniques straightforward
  - Will be invaluable for future production campaigns

Summary & Outlook

- Phase 2 Upgrade simulation can benefit greatly from more extensive use of fast simulation techniques
  - Both for studies of detector design and physics potential
- Care must be taken to choose the right combination of techniques to answers the necessary questions
  - Do not want to 'wash out' effects of certain design choices
  - In some case, advantage of fast techniques could be lost if a long validation or tuning process is needed for a new layout
- Some fast reconstruction techniques may also help to decouple effects of detector design and reconstruction algorithms
  - Using reconstruction optimized for ATLAS on a new detector may give non-optimal results
  - Tuning software for each layout variant unfeasible