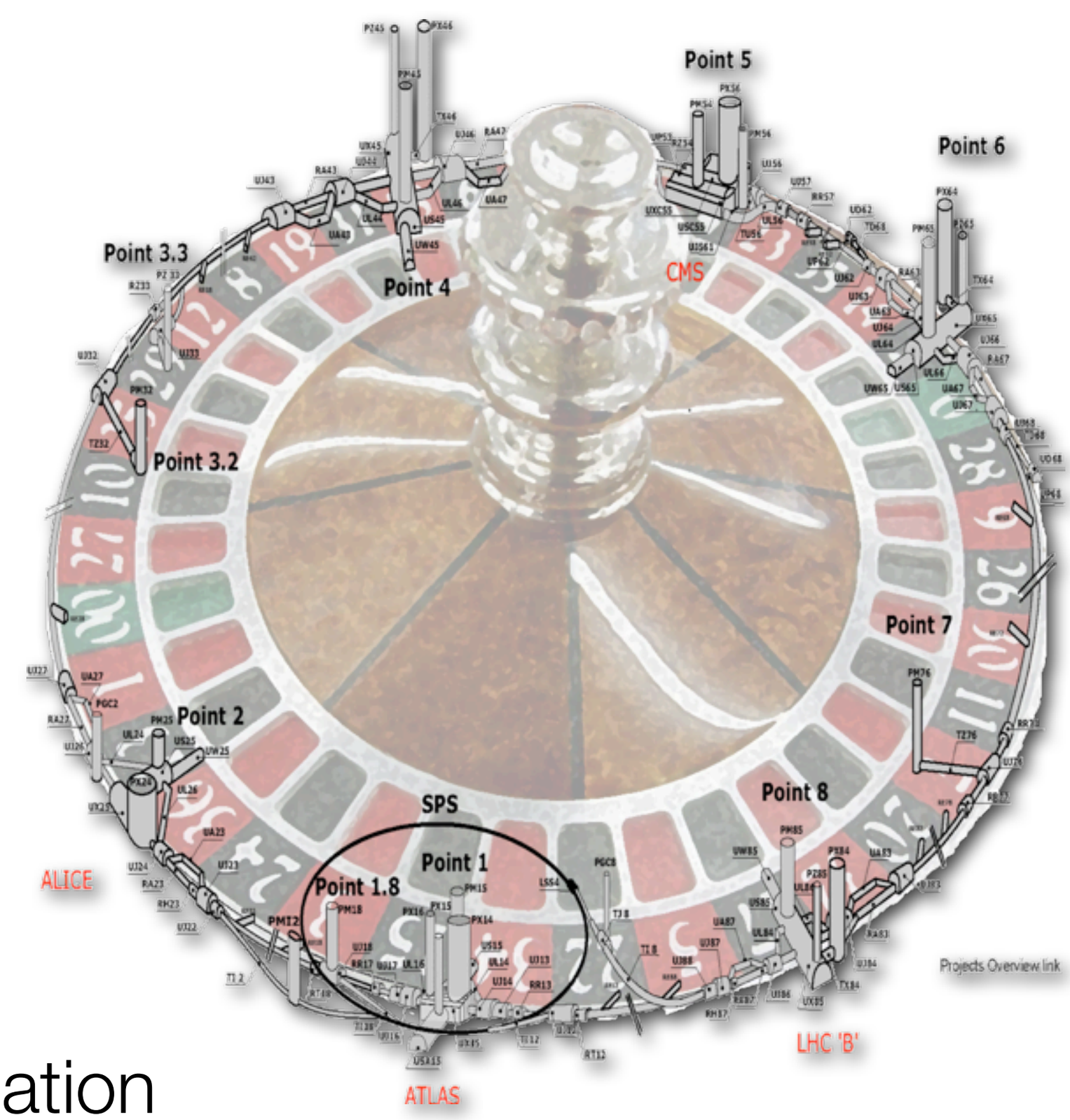
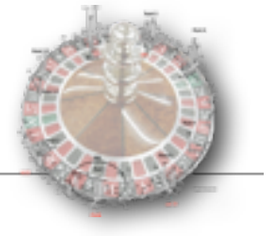


Fast and full simulation

A. Salzburger (CERN)

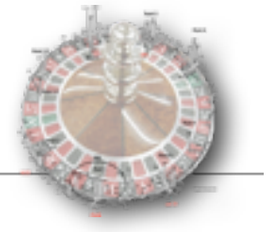
Disclaimers



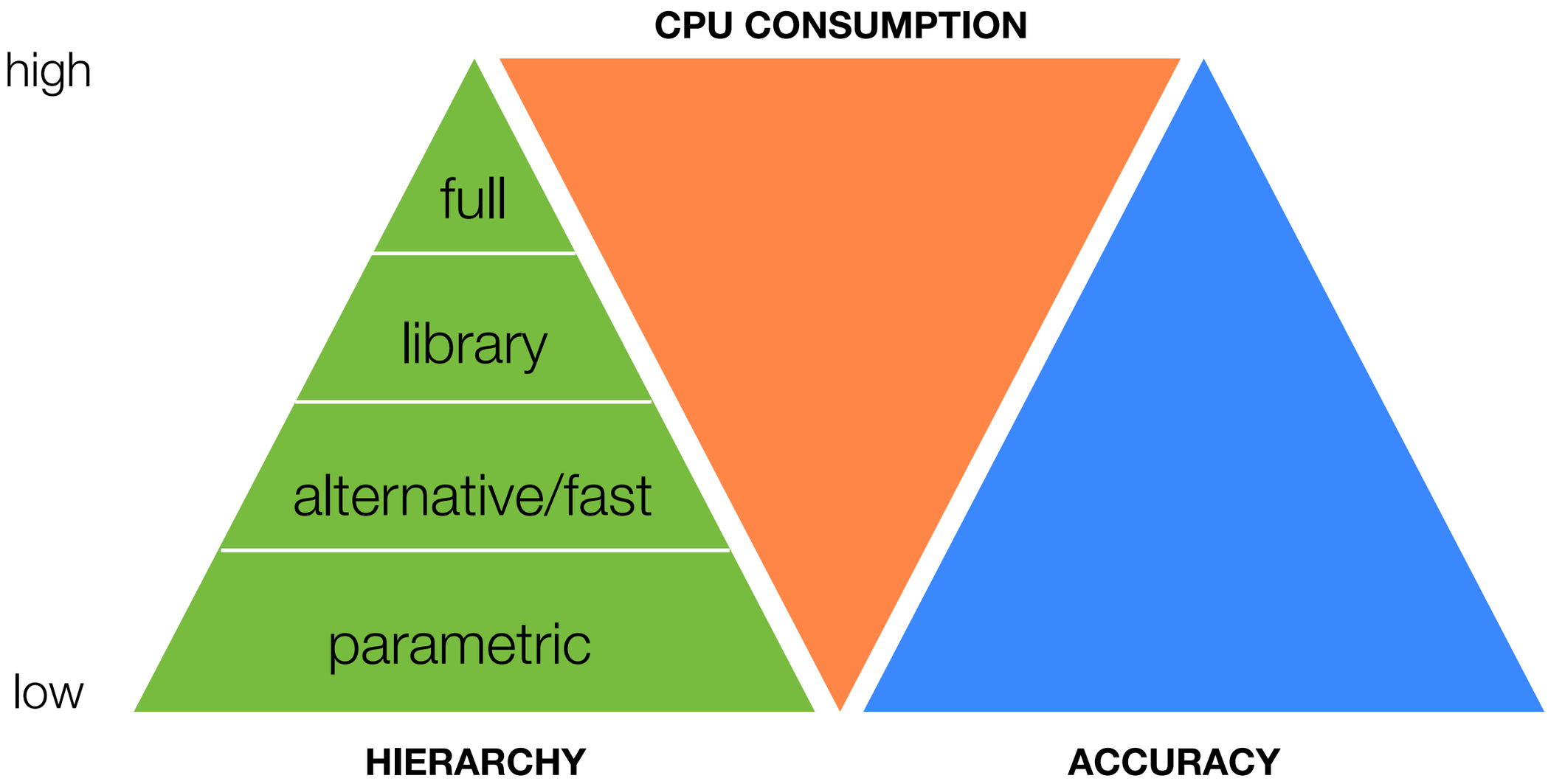
- My apologies for being rather ATLAS centric
- very similar plots & conclusions do exist for other experiments

  since I worked 11 weeks in CMS and 11 years on ATLAS it's just easier for me to find information on one side :-)
- main focus here is not to show specific results for experiments but rather demonstrate concepts & lessons
- will try to focus also on areas where fast simulation approaches have difficulties

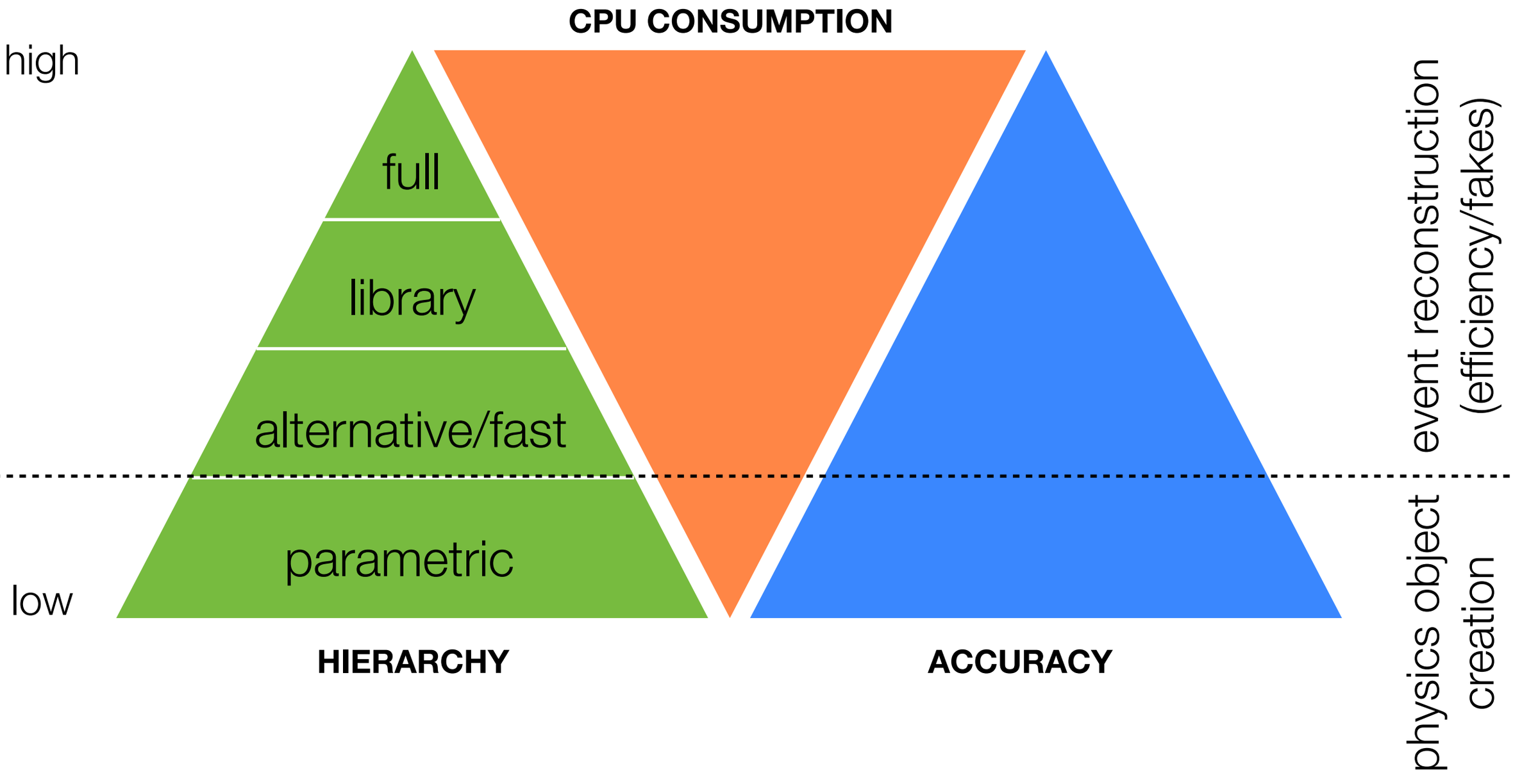
Part 1 - Concepts



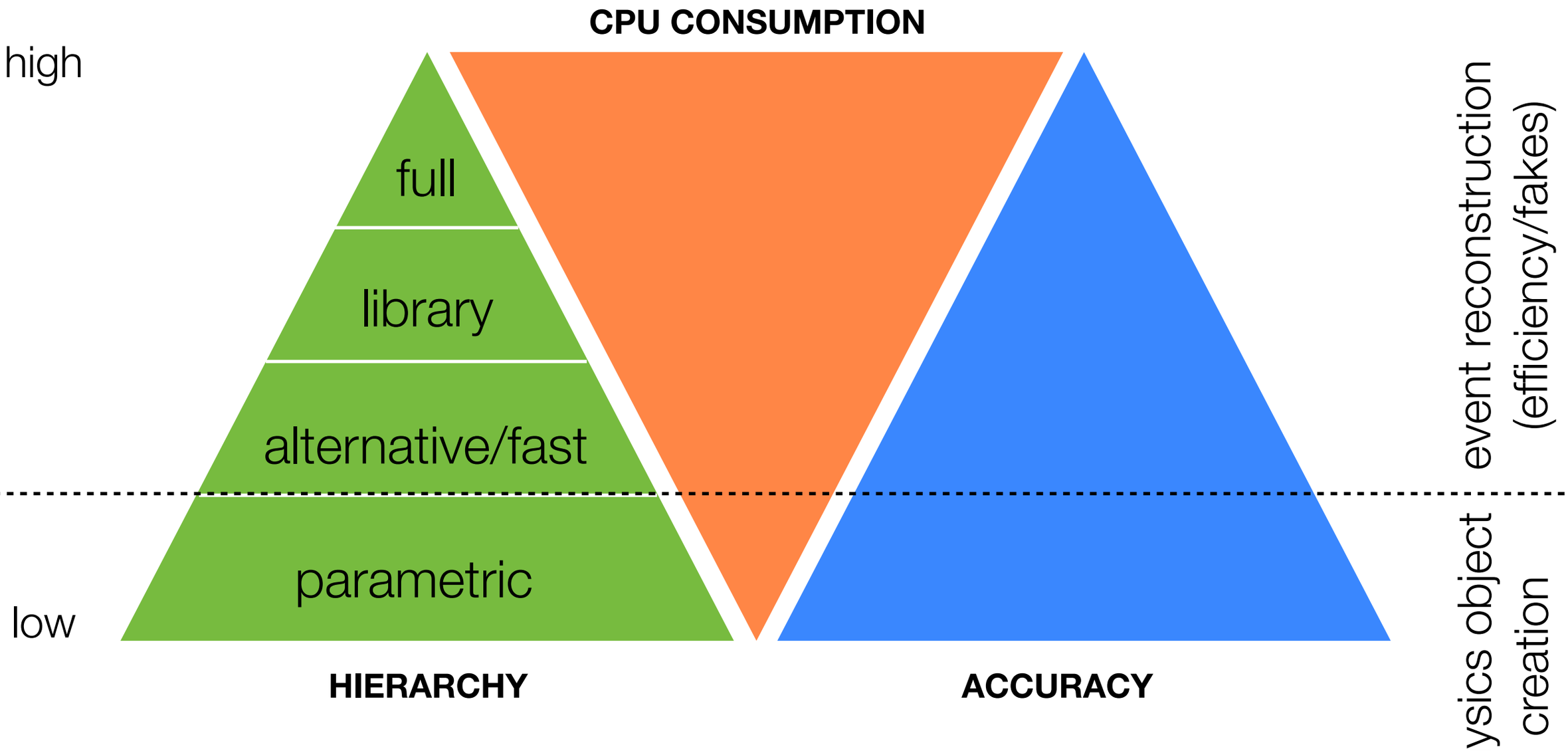
The simulation hierarchy pyramid



The simulation hierarchy pyramid

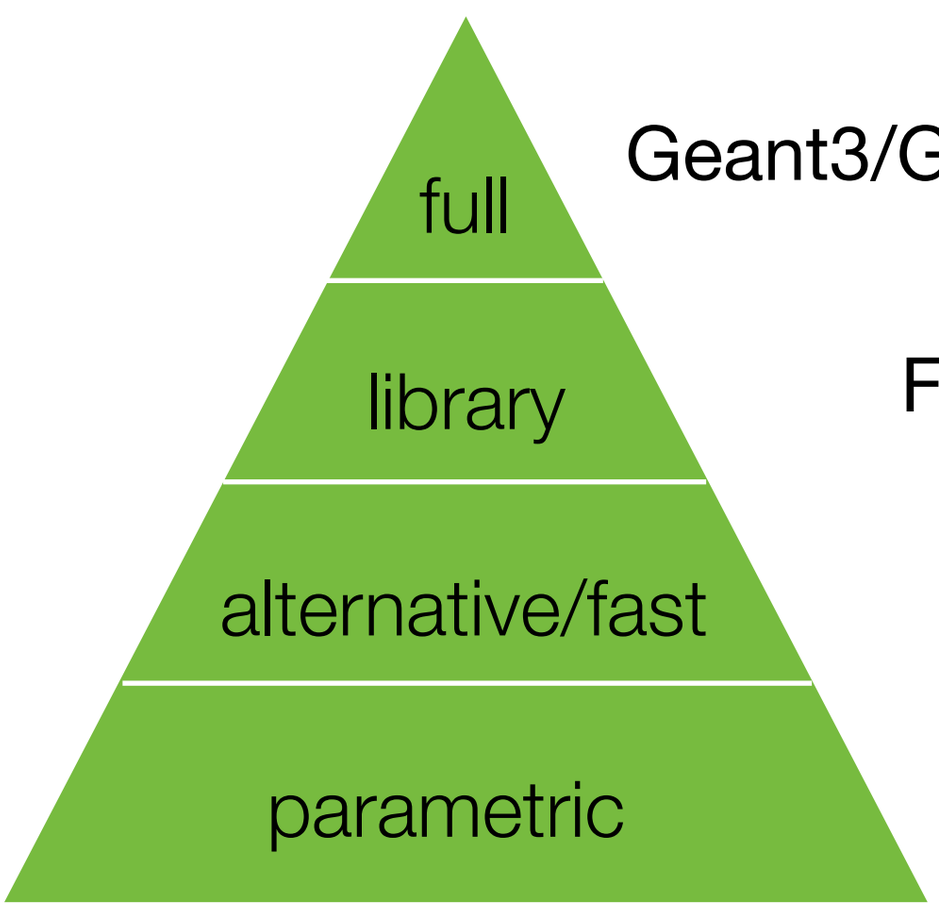


The simulation hierarchy pyramid



*the picture is quite trivial, finding the optimal working point is NOT !

The simulation hierarchy pyramid



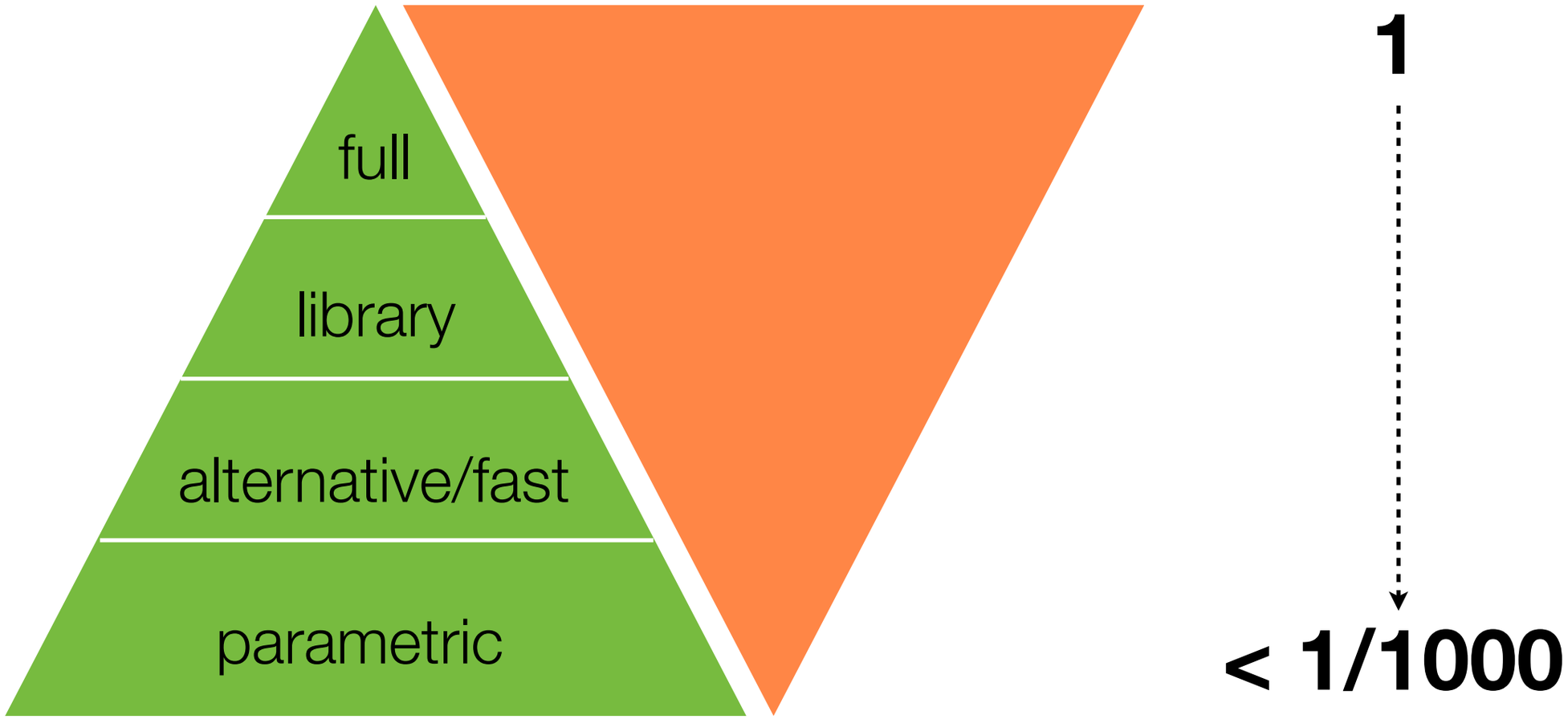
Geant3/Geant4/Flugg/Fluka

Frozen Showers/

Atlfast2(F) / GFlash /
CMS Fast Simulation

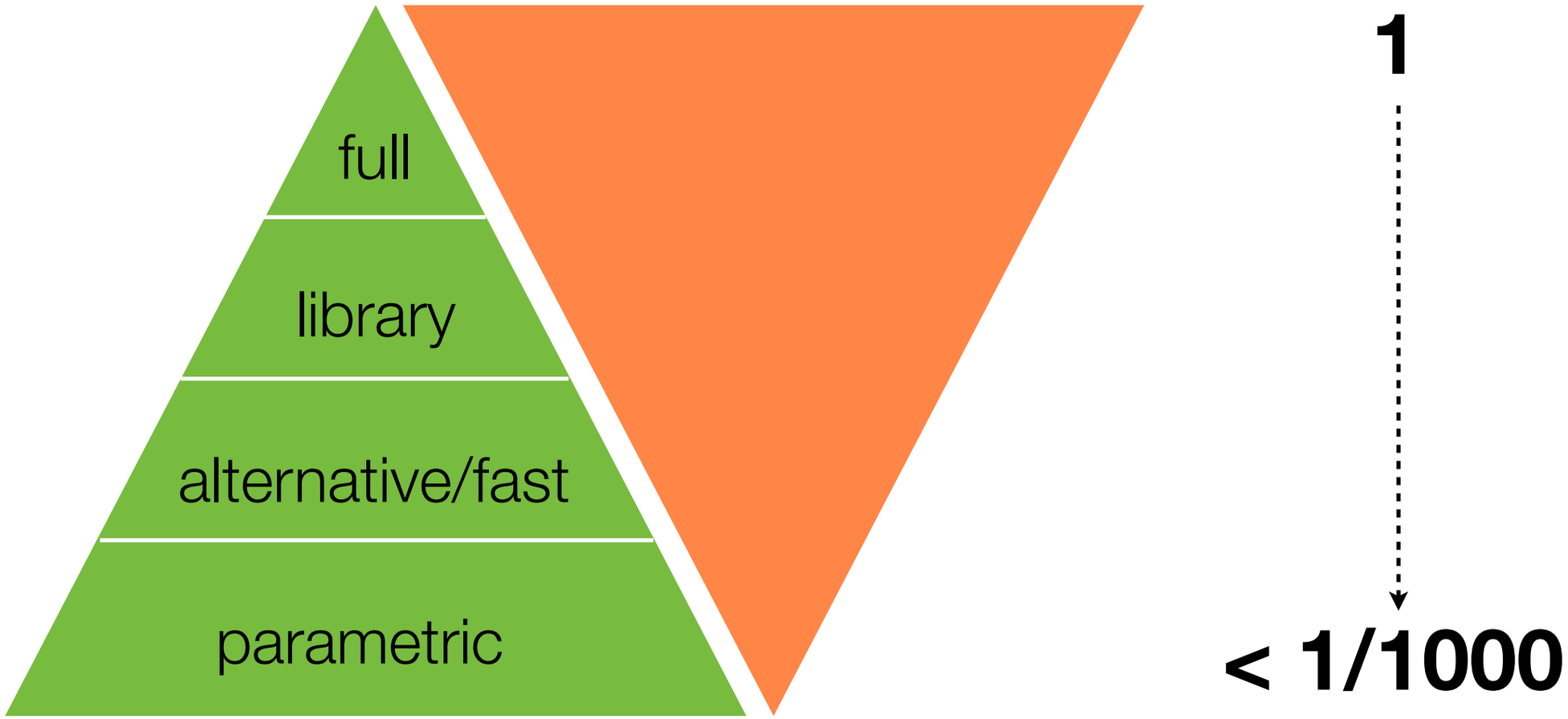
Atlfast, Delphes

Potential speed-ups: simulation



- This sets the simulation into the ~ Hz level regime*

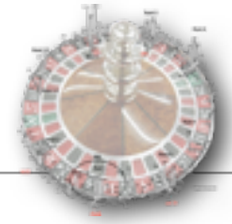
Potential speed-ups: simulation



- This sets the simulation into the ~ Hz level regime*

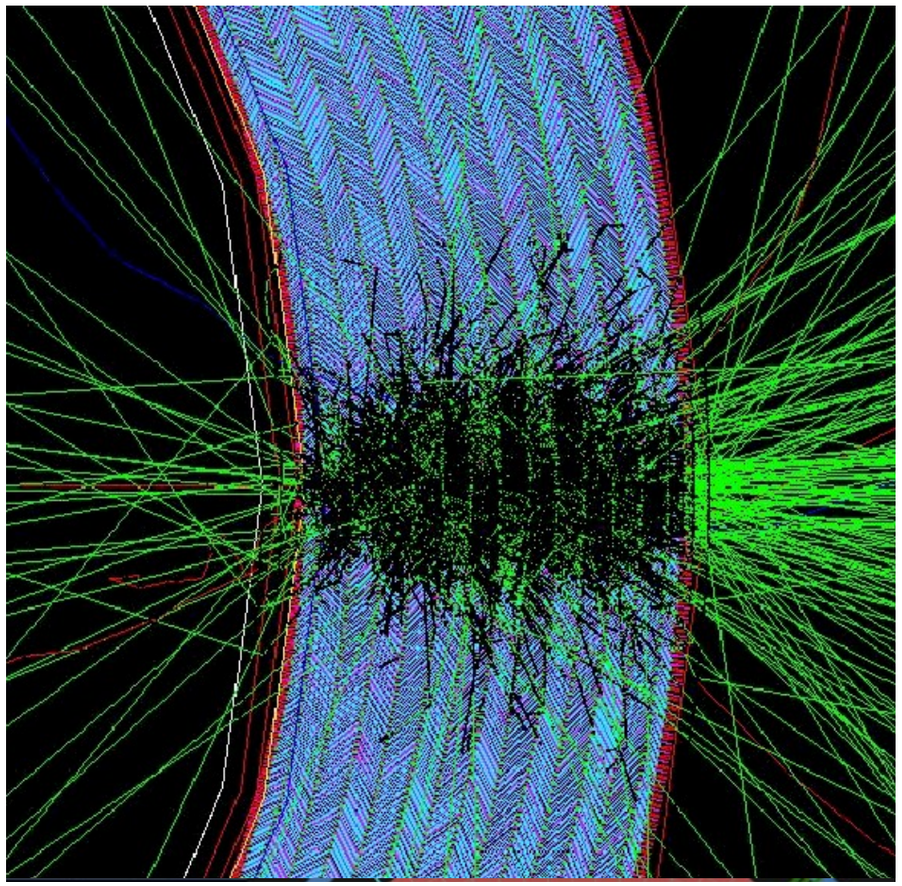
*I will speak about the consequences of this in my thursday contribution

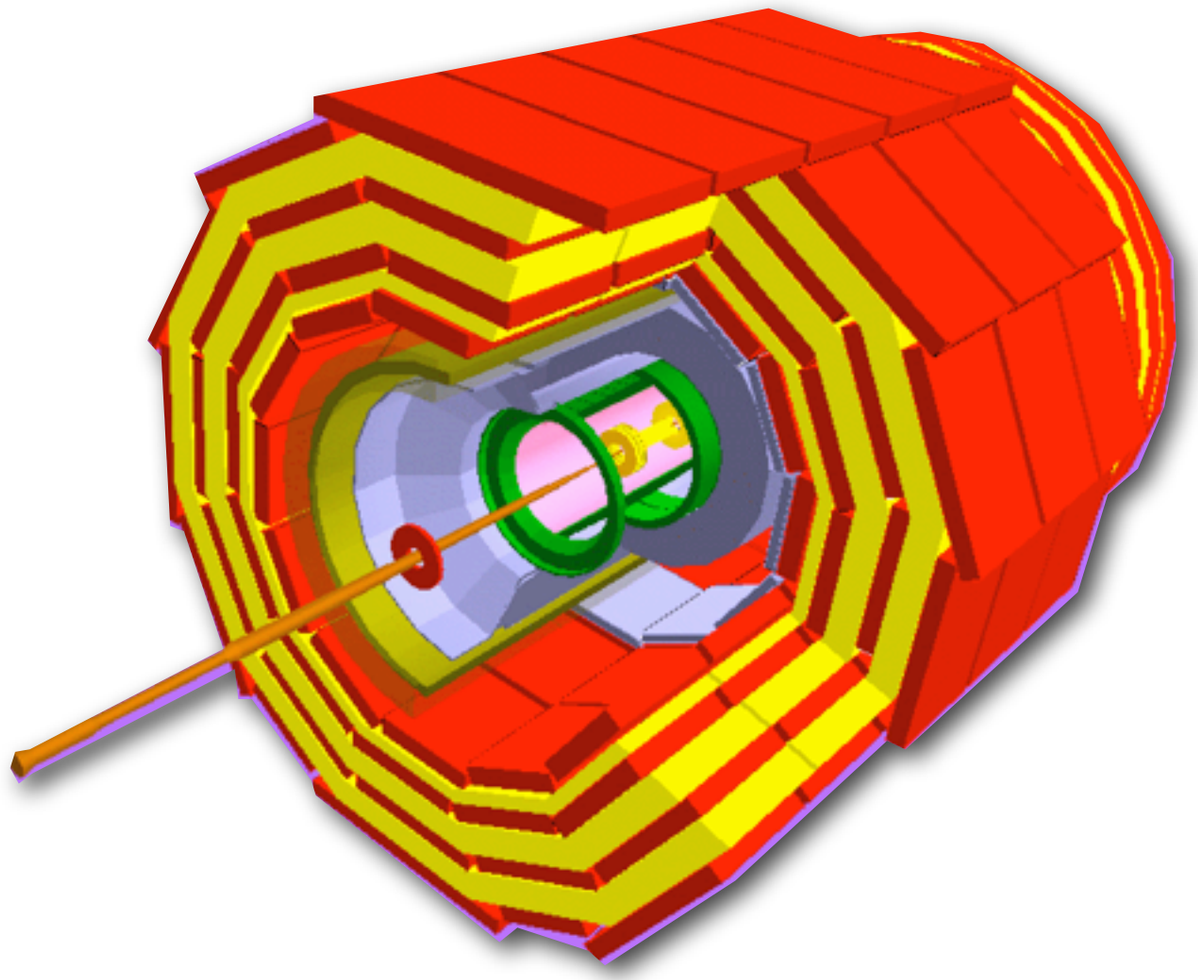
Full simulation: Geant4



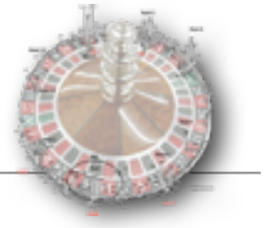
- The state of the art detector simulation
- Concept:
  - very detailed description of the detector geometry (> 10^6 nodes)
  - precise simulation of physics processes when propagating through detector material
  - stepping through material in very fine steps

  this is of course time consuming

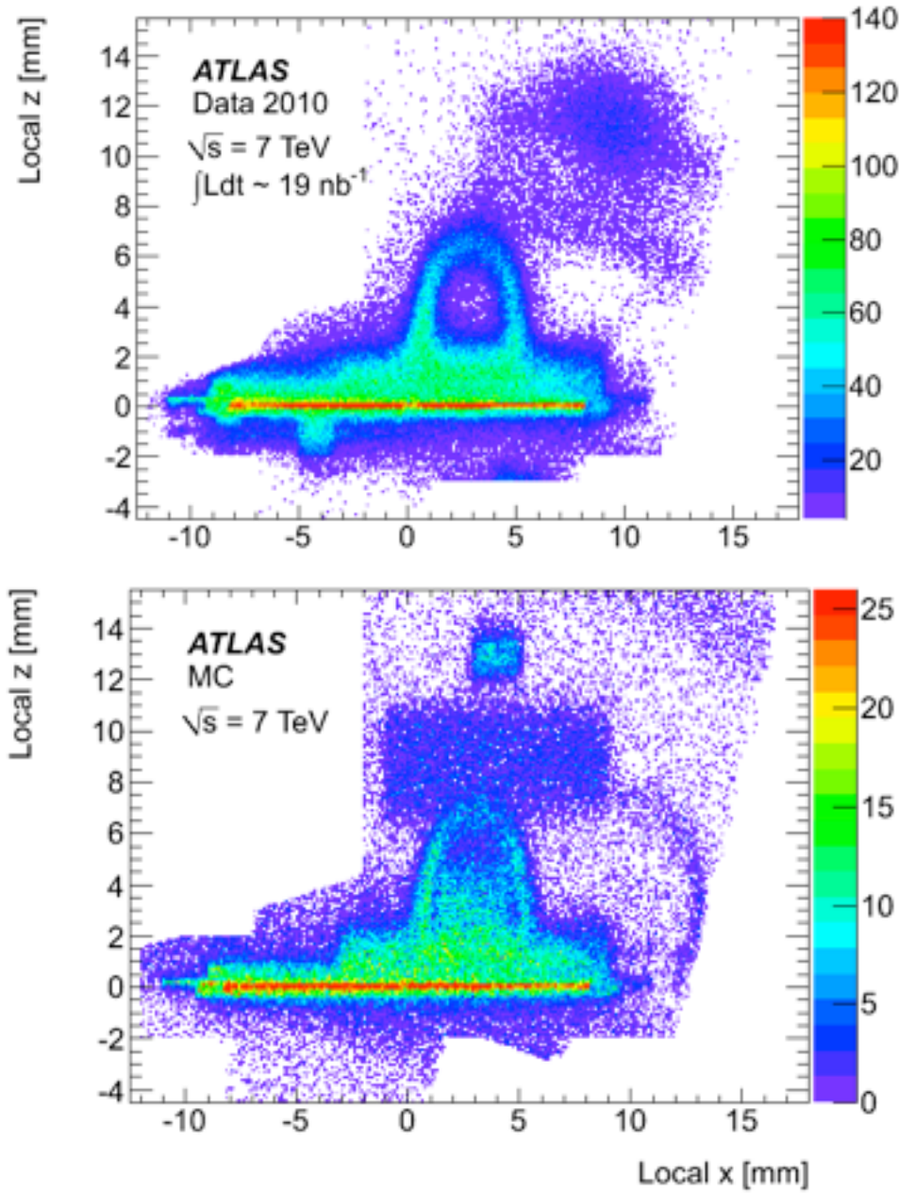


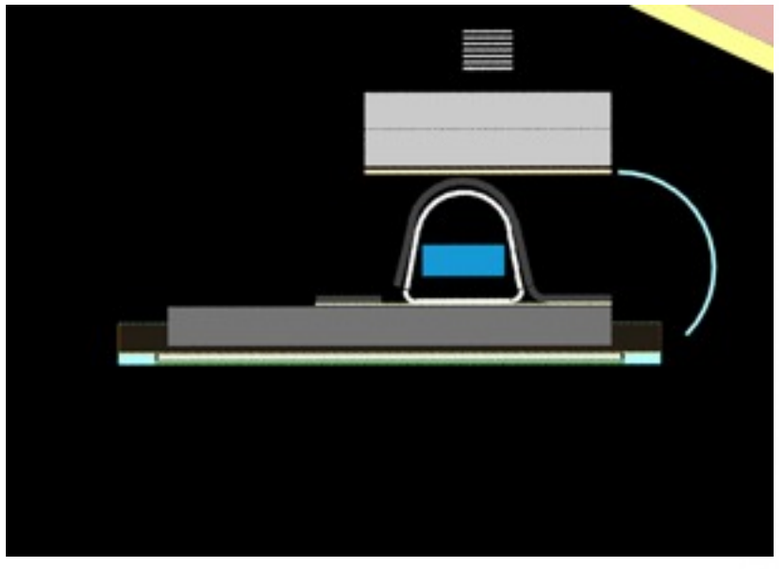


Full simulation: Geant4



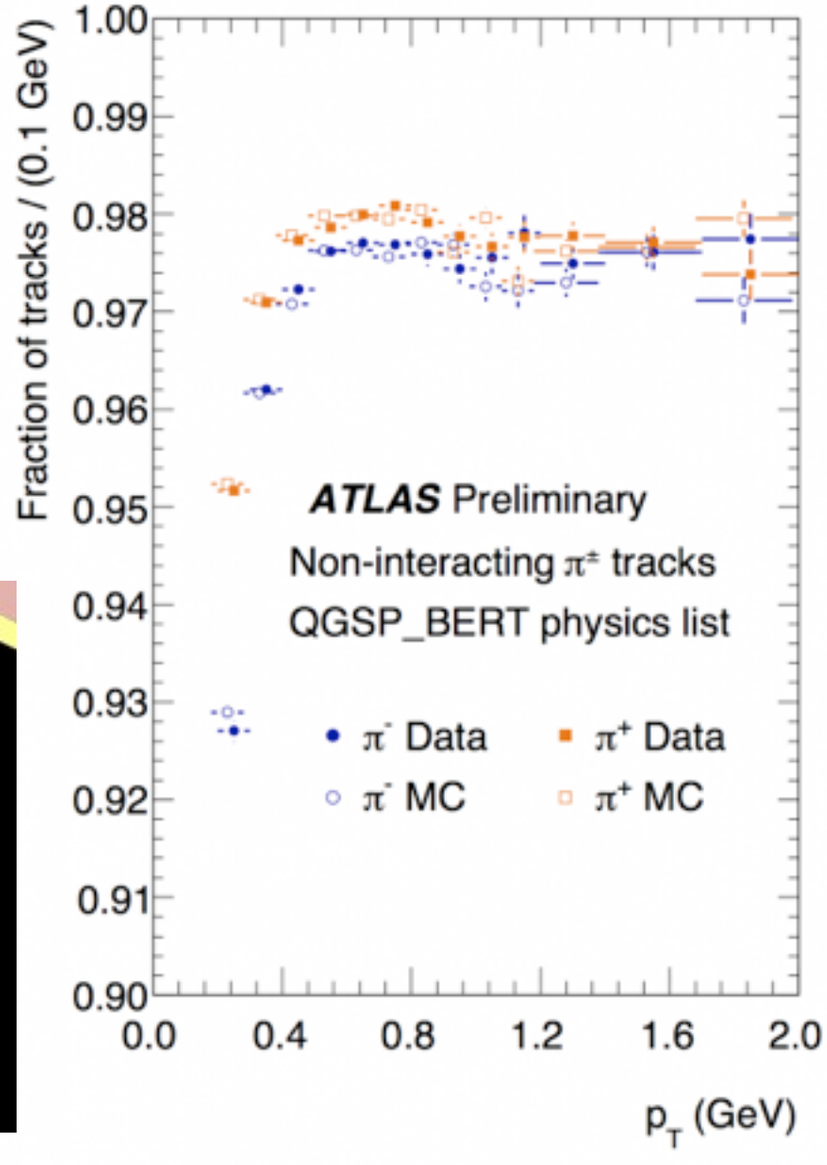
- Amazing amount of validation using data of LHC experiments & test beam setups
- remarkable modeling of physics processes can be achieved



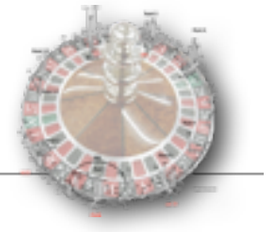


- Geant4 validation page

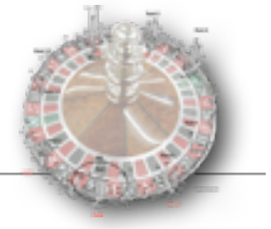
http://sftweb.cern.ch/validation/

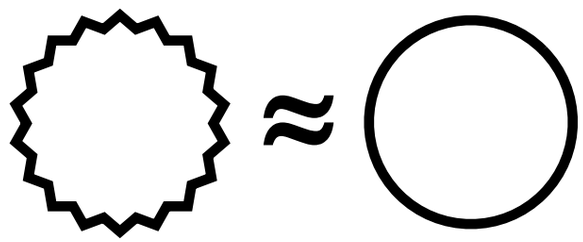


How to speed up simulation (1)



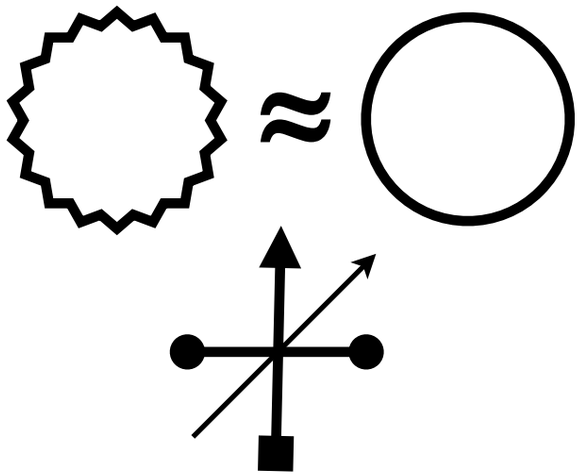
How to speed up simulation (1)





approximate geometry

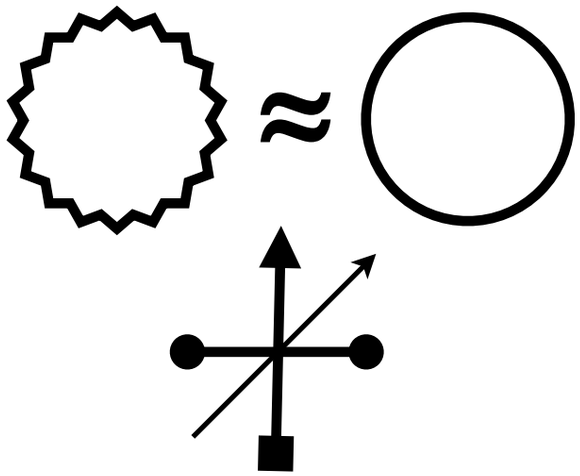
How to speed up simulation (1)



approximate geometry

optimise transport and navigation

How to speed up simulation (1)



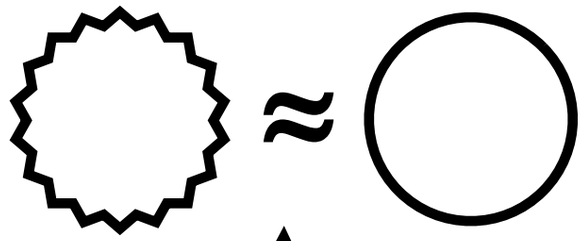
approximate geometry

optimise transport and navigation

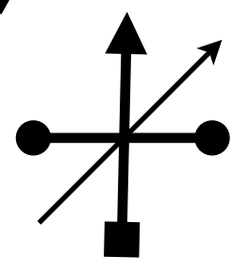
$\pi \approx 3$

approximate models

How to speed up simulation (1)



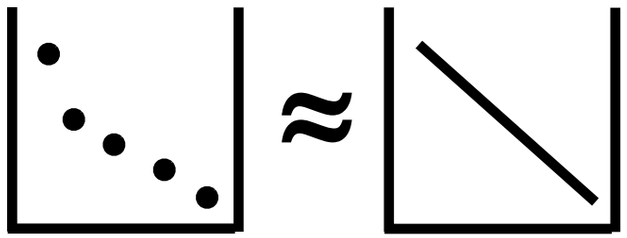
approximate geometry



optimise transport and navigation

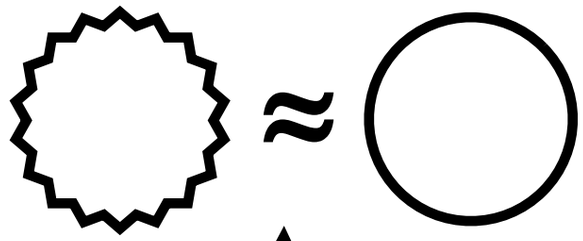
$\pi \approx 3$

approximate models

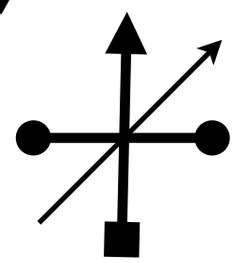


parameterisations

How to speed up simulation (1)



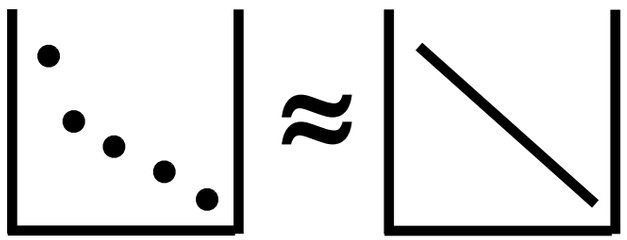
approximate geometry



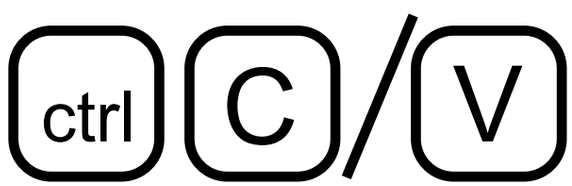
optimise transport and navigation

$\pi \approx 3$

approximate models

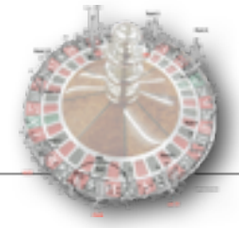


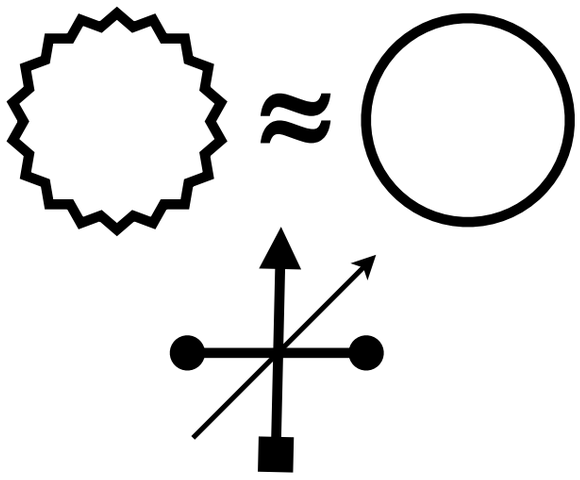
parameterisations



take shortcuts

How to speed up simulation (1)



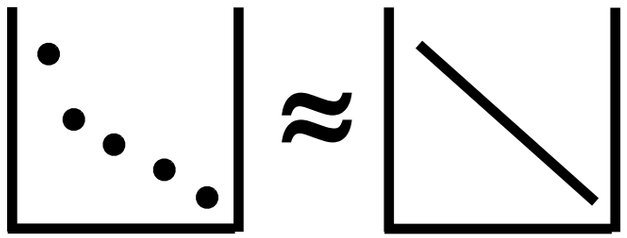


approximate geometry

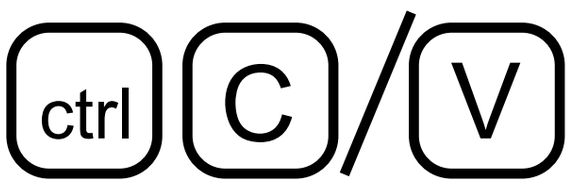
optimise transport and navigation

$\pi \approx 3$

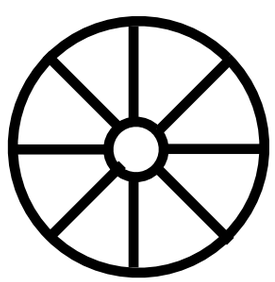
approximate models



parameterisations

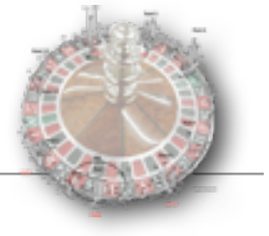


take shortcuts



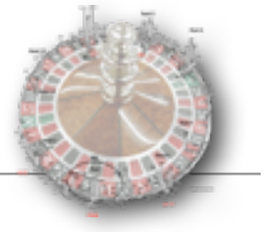
use new technologies

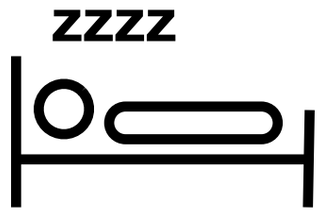
How to speed up simulation (2)



...

How to speed up simulation (2)

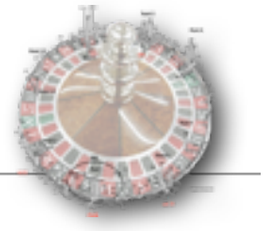


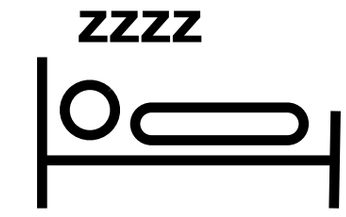


don’t do anything

...

How to speed up simulation (2)



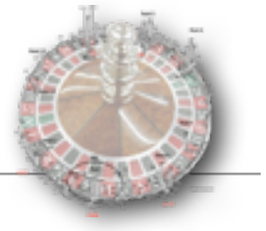


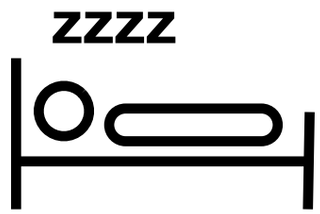
don’t do anything

work only on demand

...

How to speed up simulation (2)





don’t do anything

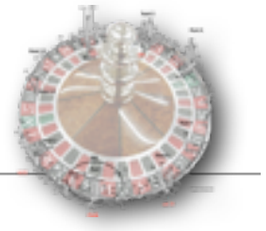
work only on demand

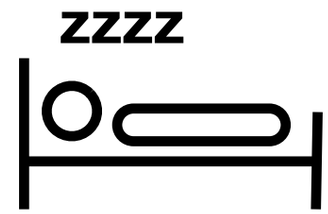
1 €	2 DM
2 €	4 DM

use look-up tables

...

How to speed up simulation (2)





don’t do anything

work only on demand

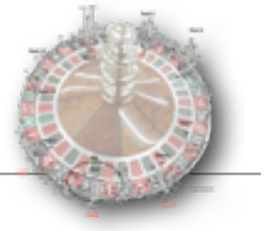
1 €	2 DM
2 €	4 DM

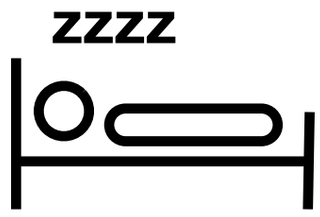
use look-up tables

throw away things

...

How to speed up simulation (2)





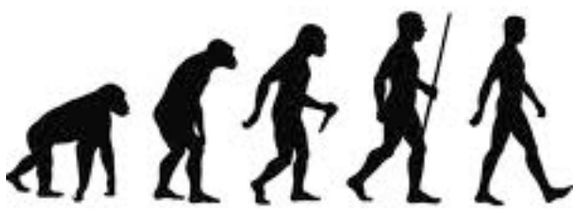
don’t do anything

work only on demand

1 €	2 DM
2 €	4 DM

use look-up tables

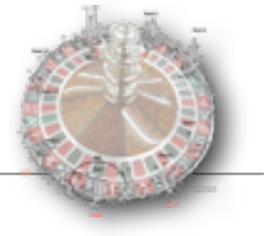
throw away things



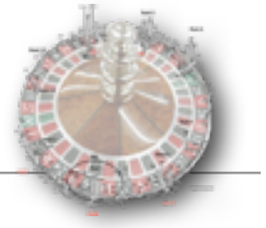
ignore the truth

...

Part 2 - The past



A look back into the past - ATLAS (1)



- **ATLAS Physics TDR (1999):**
  - mixture of Geant3 and ATLFAST
    (detector response parameterized from Geant3)

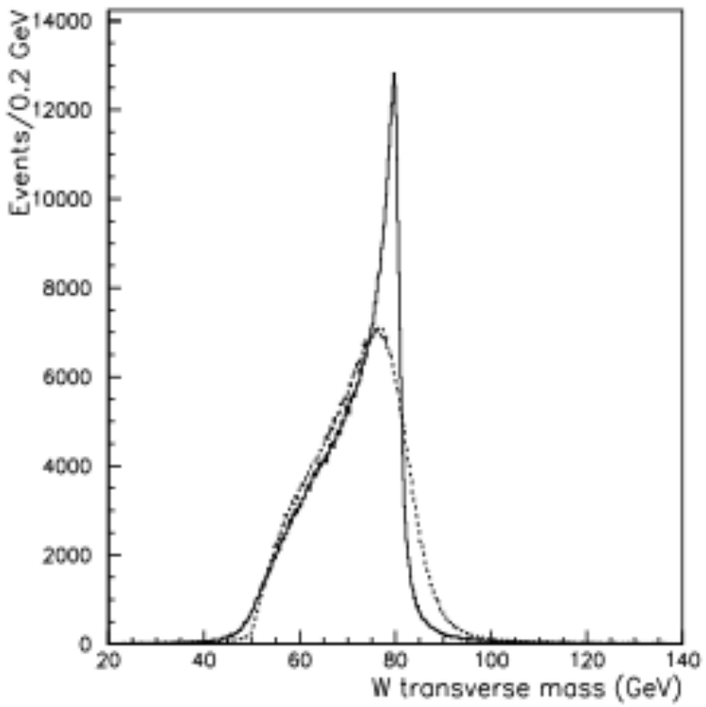
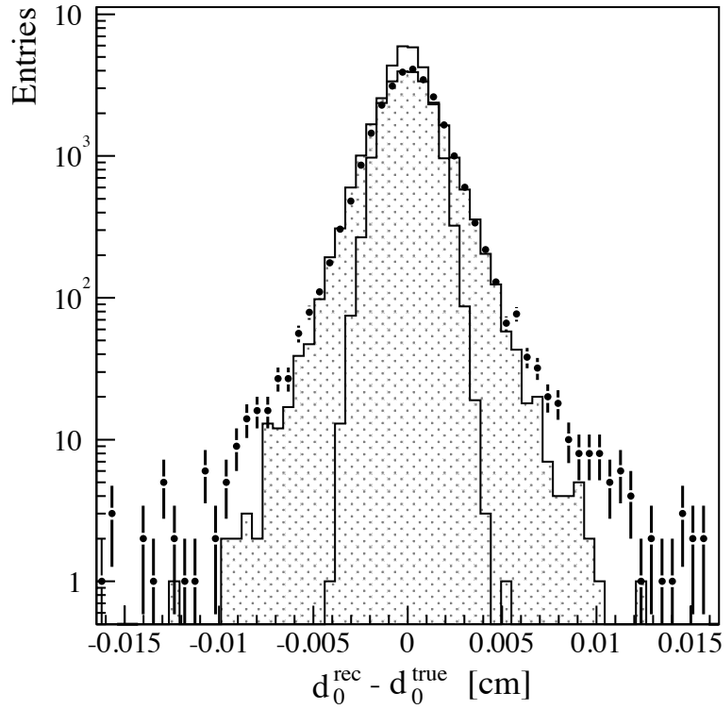
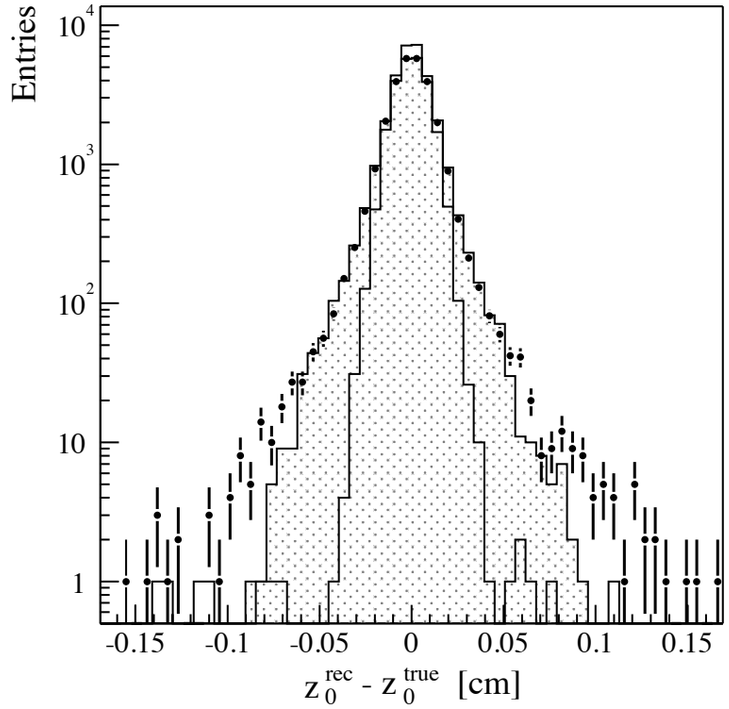


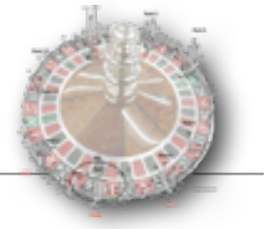
Figure 2-25 The generated (solid) and reconstructed (dashed) W transverse mass from $W \rightarrow l\nu$ events and after simple kinematical cuts. (Courtesy F. Gianotti)



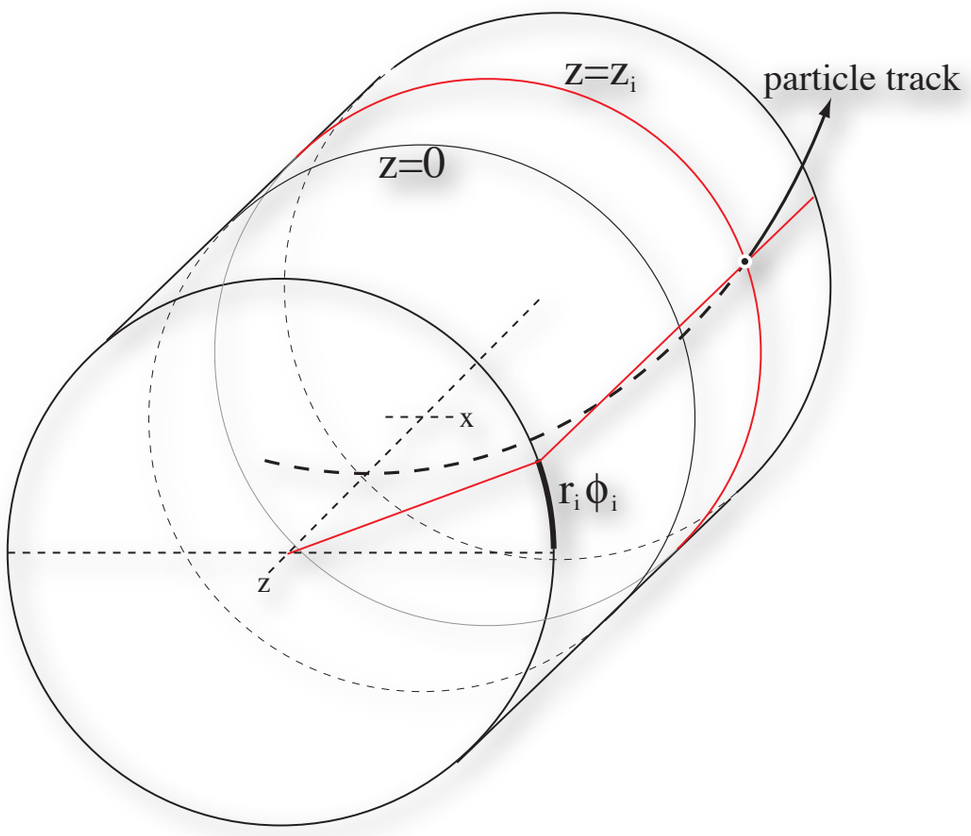


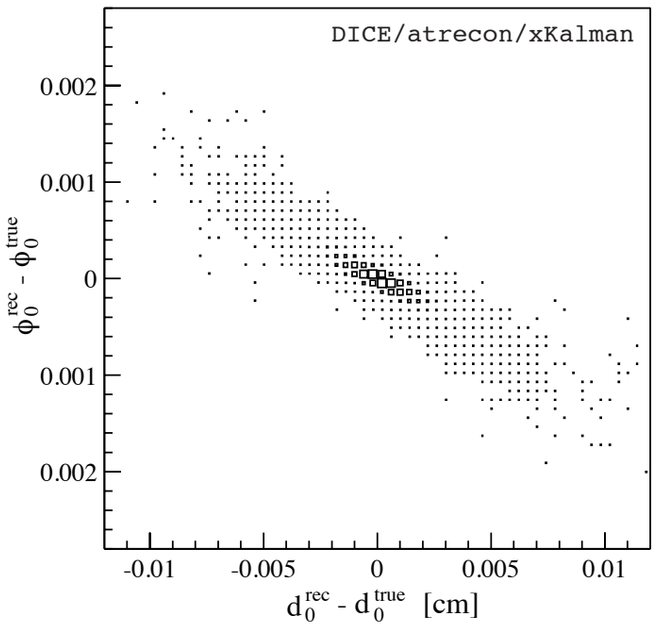
- with dedicated care (lots of work) a real good description of measured quantities could be achieved

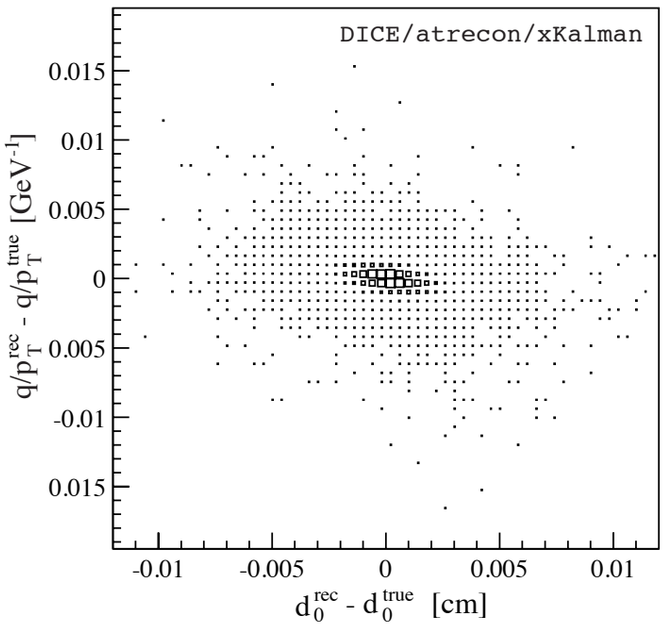
A look back into the past - ATLAS (2)

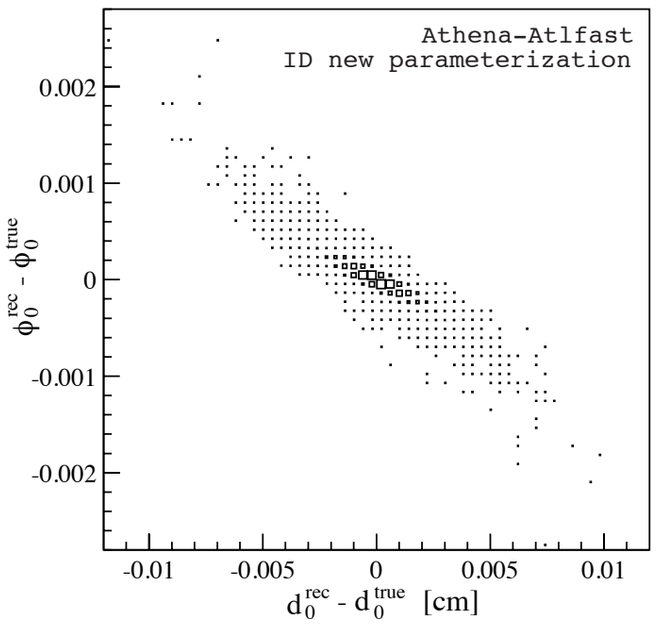


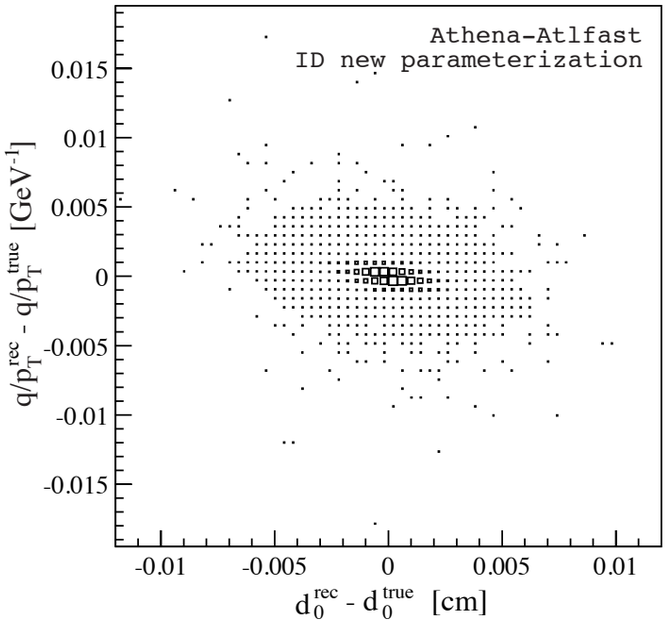
- **ATLFAST ID/MS Tracking:**
  - even correlations have been parameterised successfully
  - this is important for upstream reconstruction (e.g. vertexing)



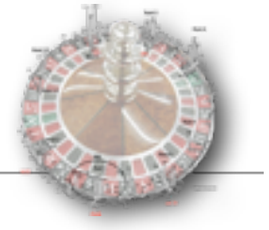








A look back into the past - CMS (1)



- **CMS Physics TDR (2006), 7 years later than ATLAS**
  - based on Geant4 (+GFlash) and CMS fast simulation (FAMOS) yielding high level objects, a simplified tracking similar to FATRAS
  - similar to ATLAS, a lot of work needed to derive parameterisations
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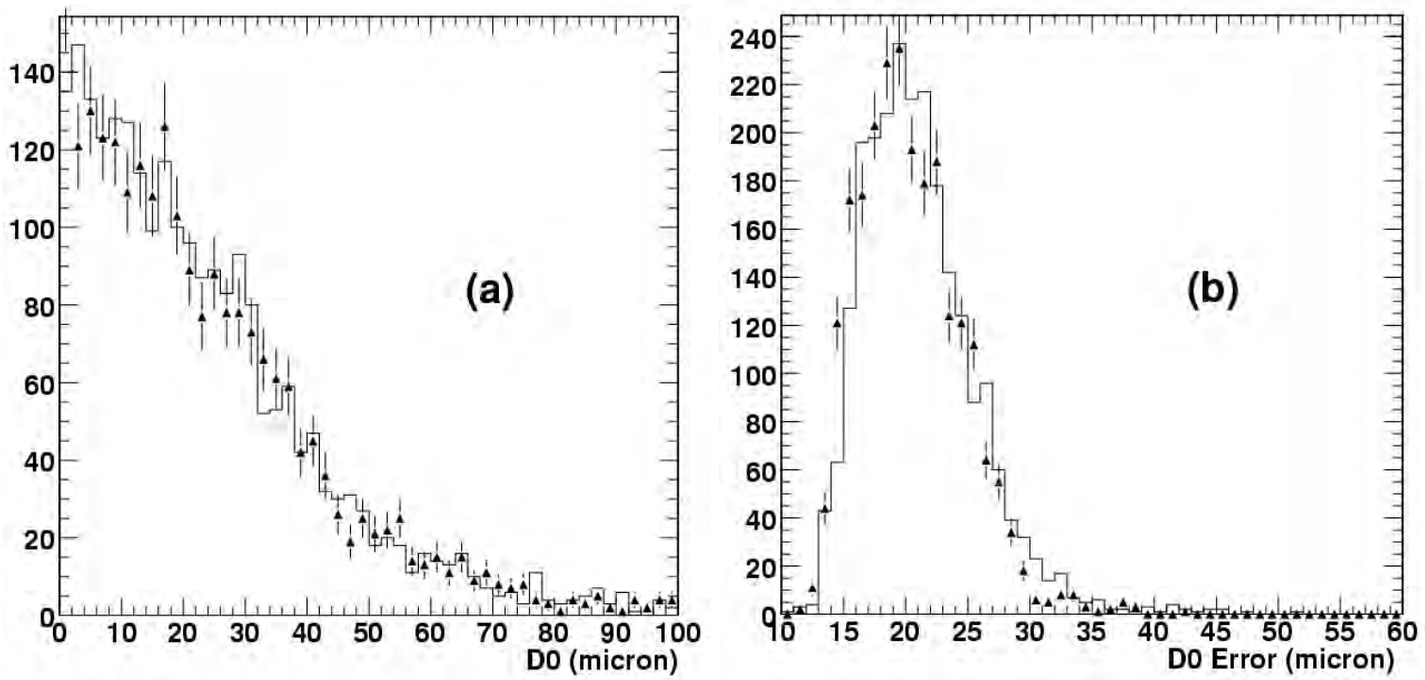

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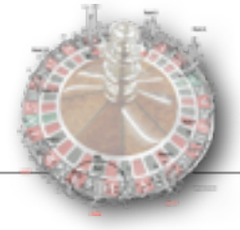

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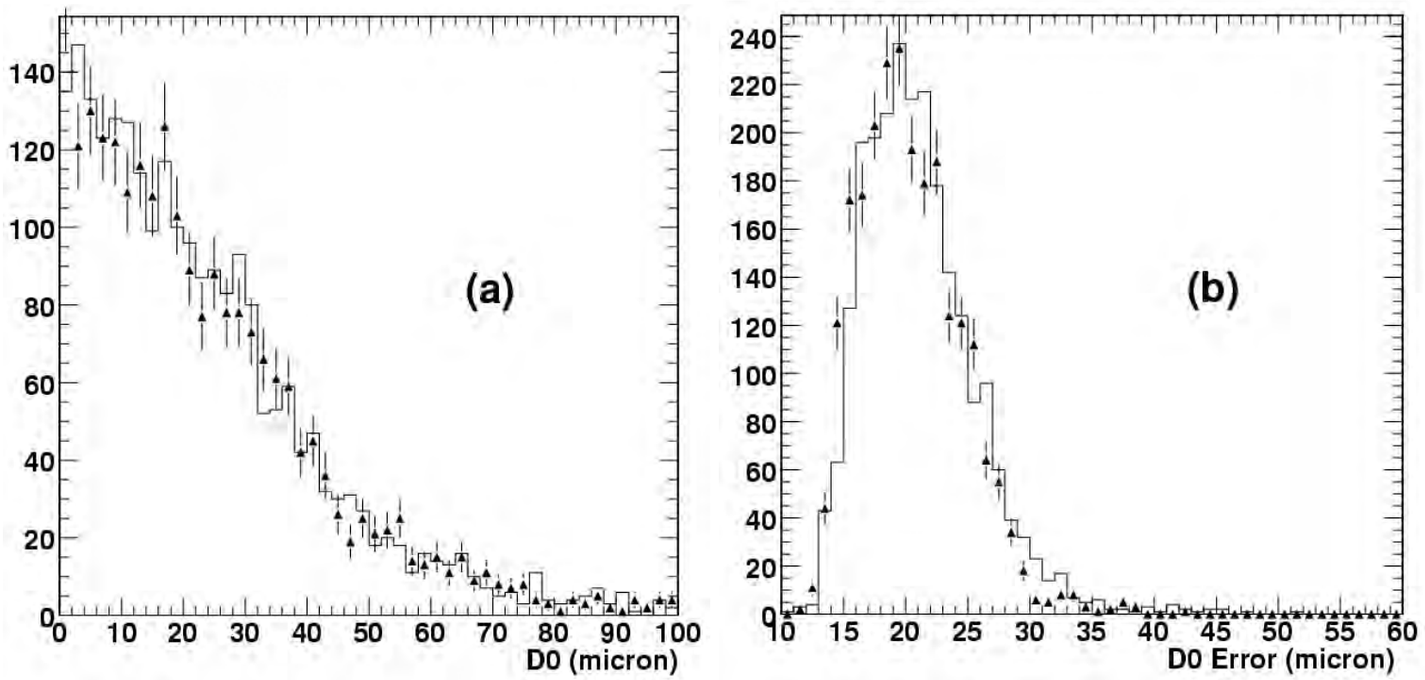
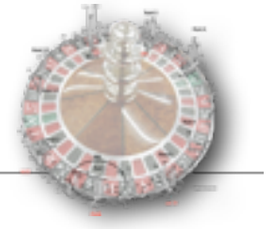


*there will be talks/contributions covering more of this during the WS

A look back into the past



- ATLAS & CMS developed very similar concepts for simulation in TDR times
  - Full simulation for detailed studies
  - Fast simulation (mainly parametric) based on full simulation results

    high level object creation as output of fast simulation

- TDR studies also showed limitations of (parametric) fast simulation
  - how to model efficiencies/inefficiencies
  - how to create fake objects
  - usually, one needs a full simulation first to derive parameters*

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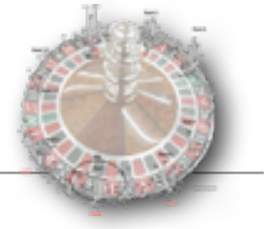

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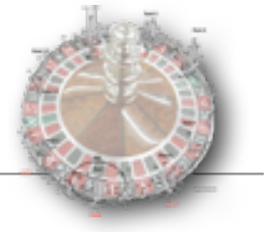
- TDR studies also showed limitations of (parametric) fast simulation
  - how to model efficiencies/inefficiencies
  - how to create fake objects
  - usually, one needs a full simulation first to derive parameters*

*not always necessary:

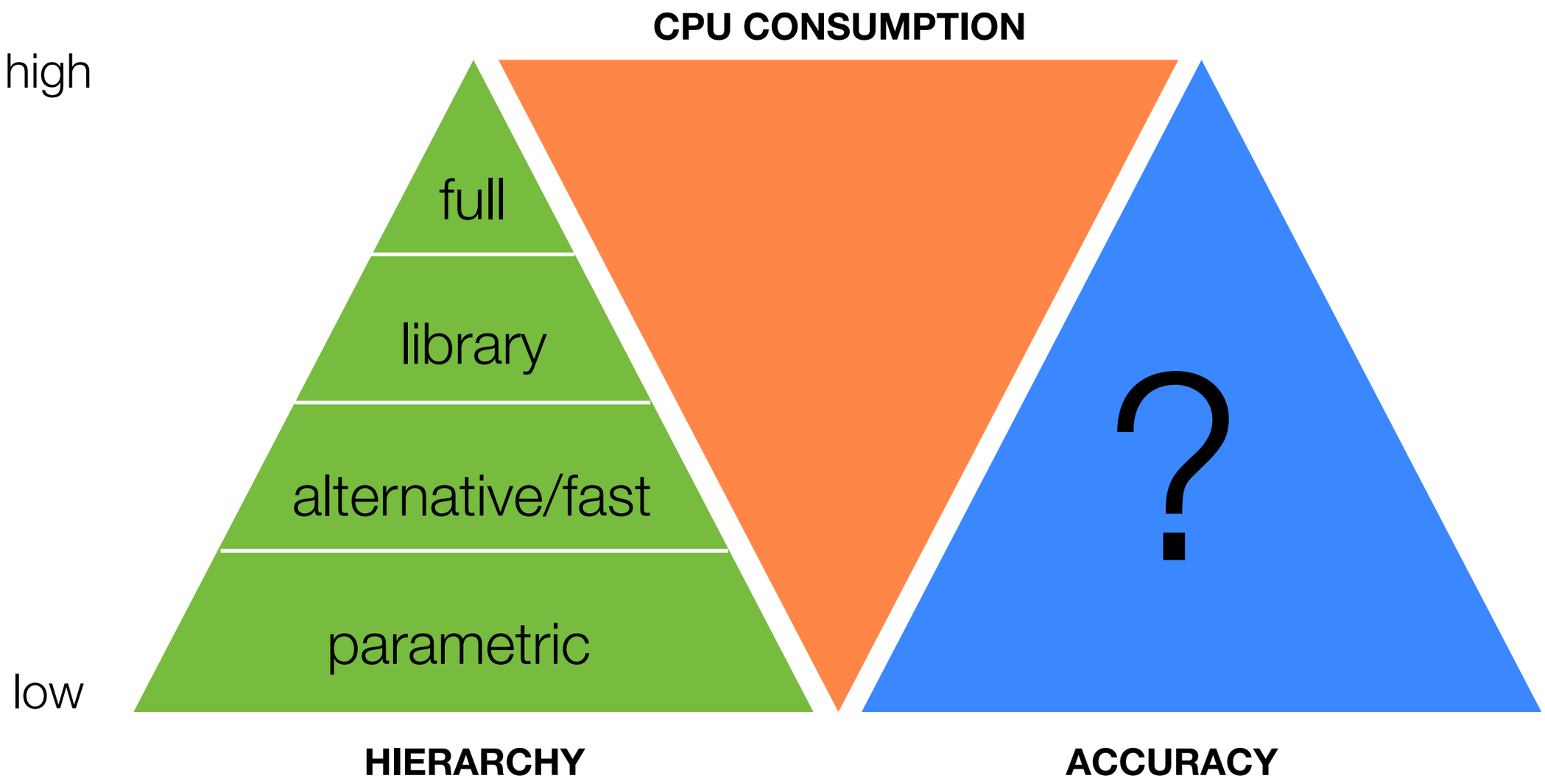
- e.g. impact parameter resolution can be rather well estimated using the 2-layer approximation

$$\sigma_{z_0} = A_{z_0} \oplus \frac{B_{z_0}}{p_{\mathrm{T}}} = \frac{r_1\sigma_{2,z} \oplus r_2\sigma_{1,z}}{r_2 - r_1} \oplus \frac{k_{1,z}r_1}{p_{\mathrm{T}}}.$$

Part 3 - A running LHC

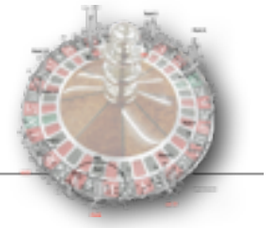


Accuracy



- What accuracy is actually needed ?
- Is it the same for every analyses/aspect ?

LHC experiments: Calorimetry dominates



- **Simulation time (CPU) consumption is dominated by calorimeter simulation**
  - obviously the shower simulation in dense material takes longer than propagation through tracking devices (low material budget)

- **Calorimeter simulation was the first to be fully replaced by fast components**
  - Frozen showers (ATLAS)
  - GFlash (CMS) / FastCaloSim (ATLAS)

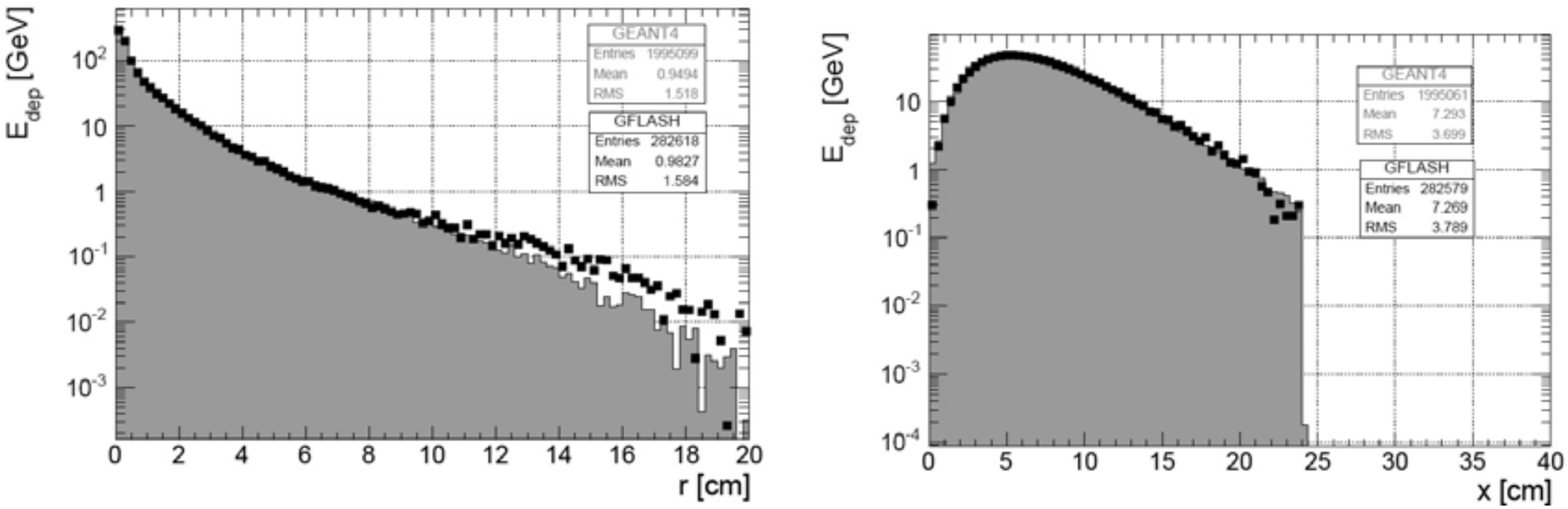
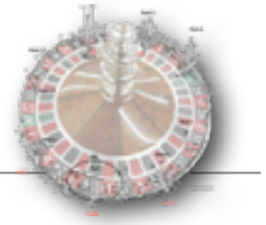


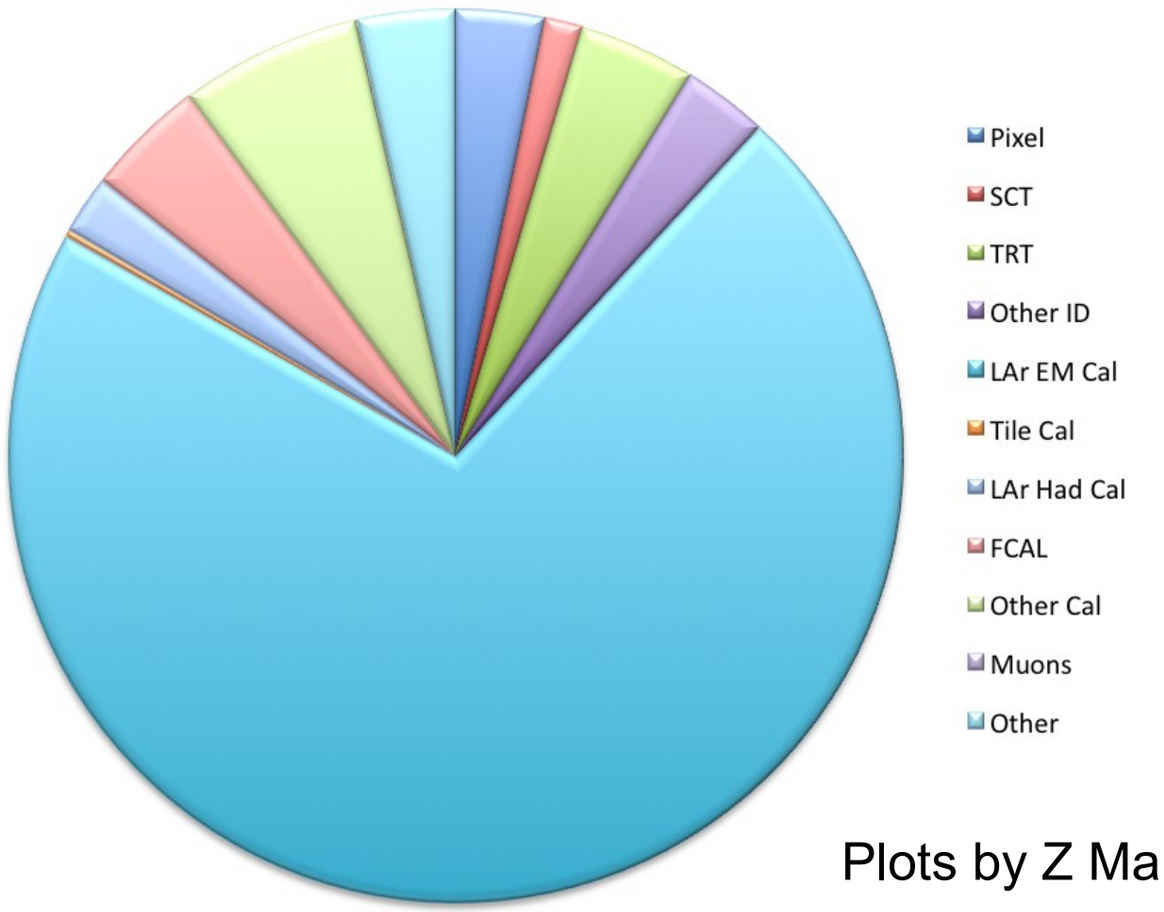
Figure 2.8: Transverse (left) and longitudinal (right) shower profiles for 50 GeV photons.

CPU time spent in ATLAS Calorimeter



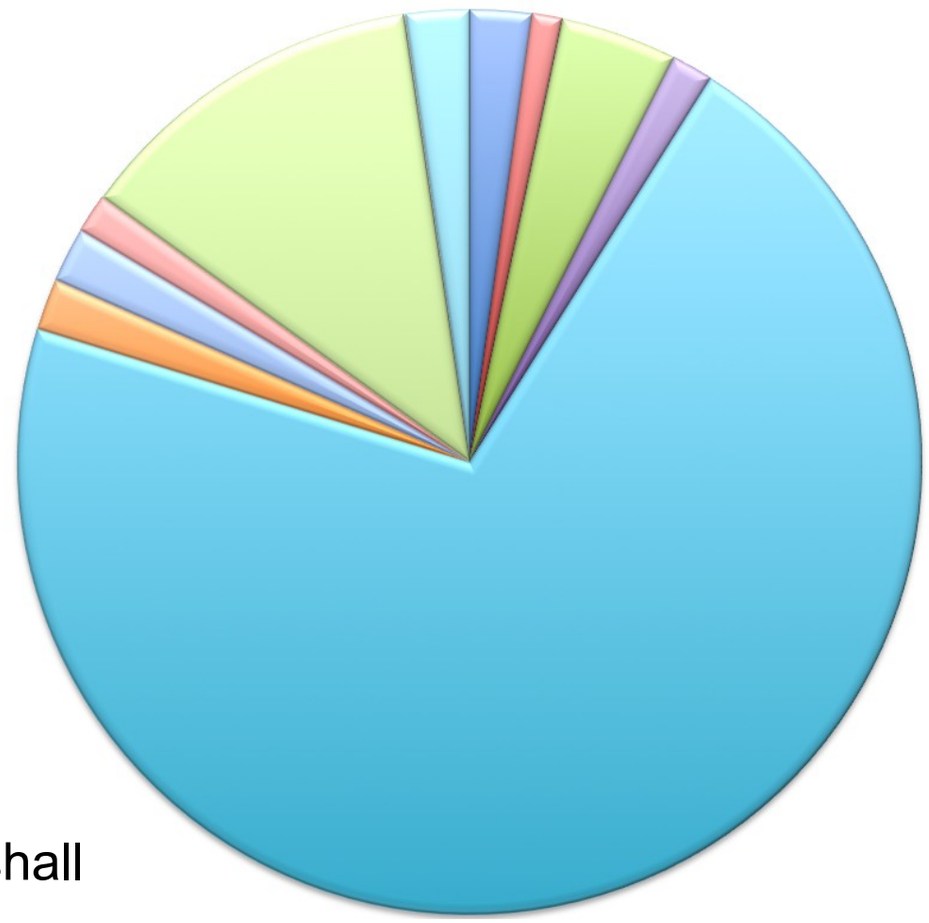
Minimum bias Simulation (with Frozen Showers)
Total CPU per event = 71.7 s

i686-slc5-gcc43-opt



tt Simulation (with Frozen Showers)
Total CPU per event = 346.1 s

i686-slc5-gcc43-opt



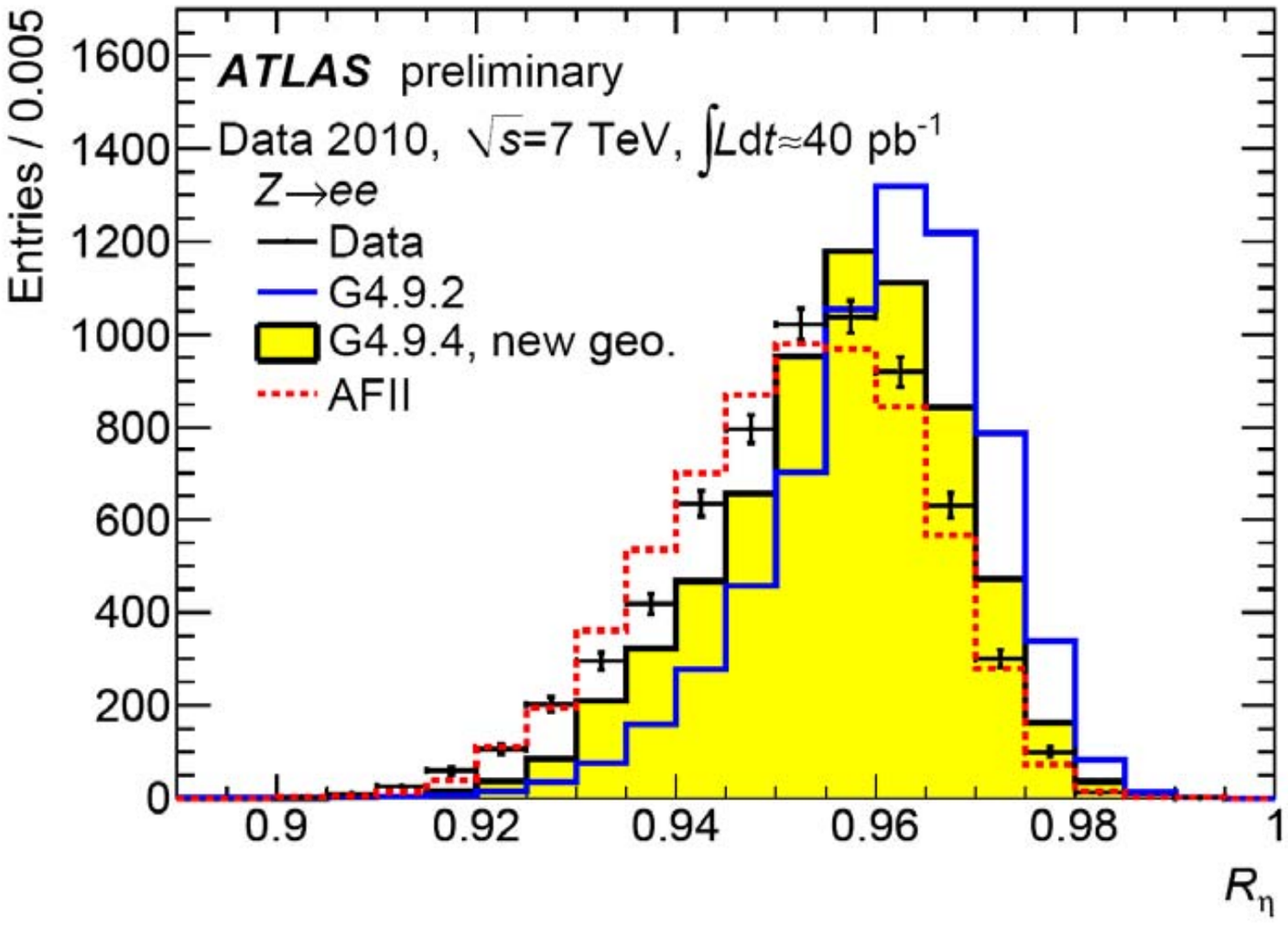
Plots by Z Marshall

Oct 2011

How to not lose accuracy ?

- **Let's face it**

- all of these approximations/shortcuts will almost necessarily cause a loss of accuracy
- usually this would lead to a worse data/MC compatibility
- some of them, however, will also open possibilities, **e.g. tuning of parameterisations**



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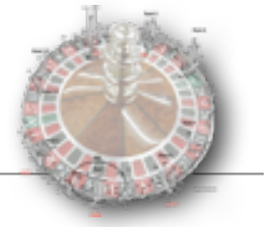

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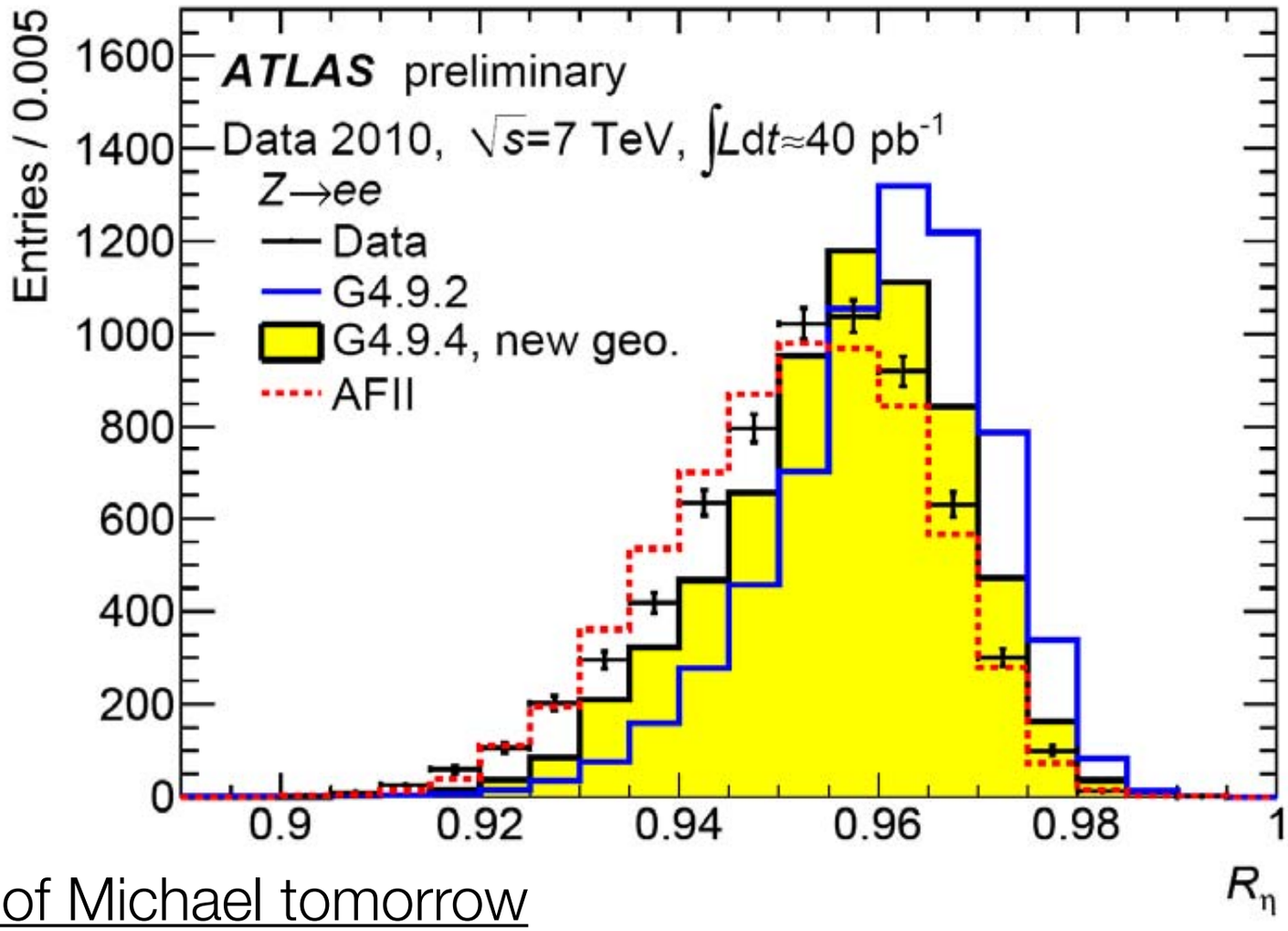
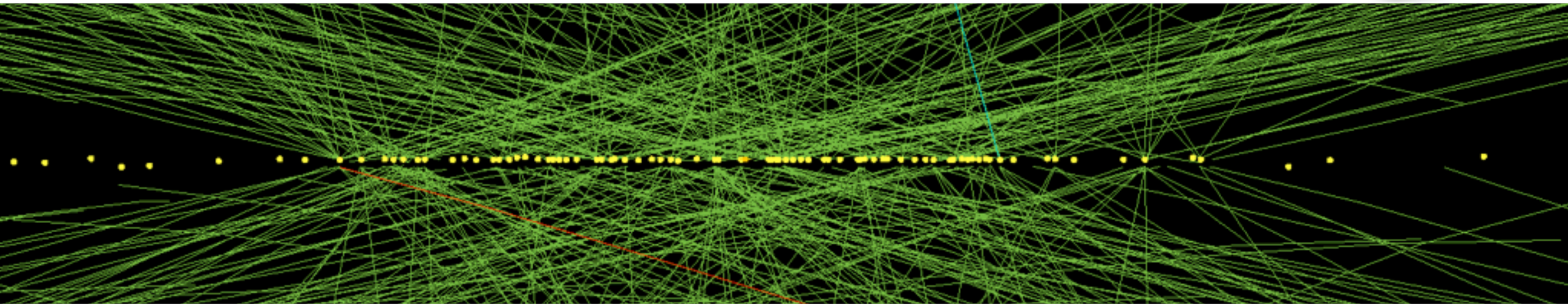
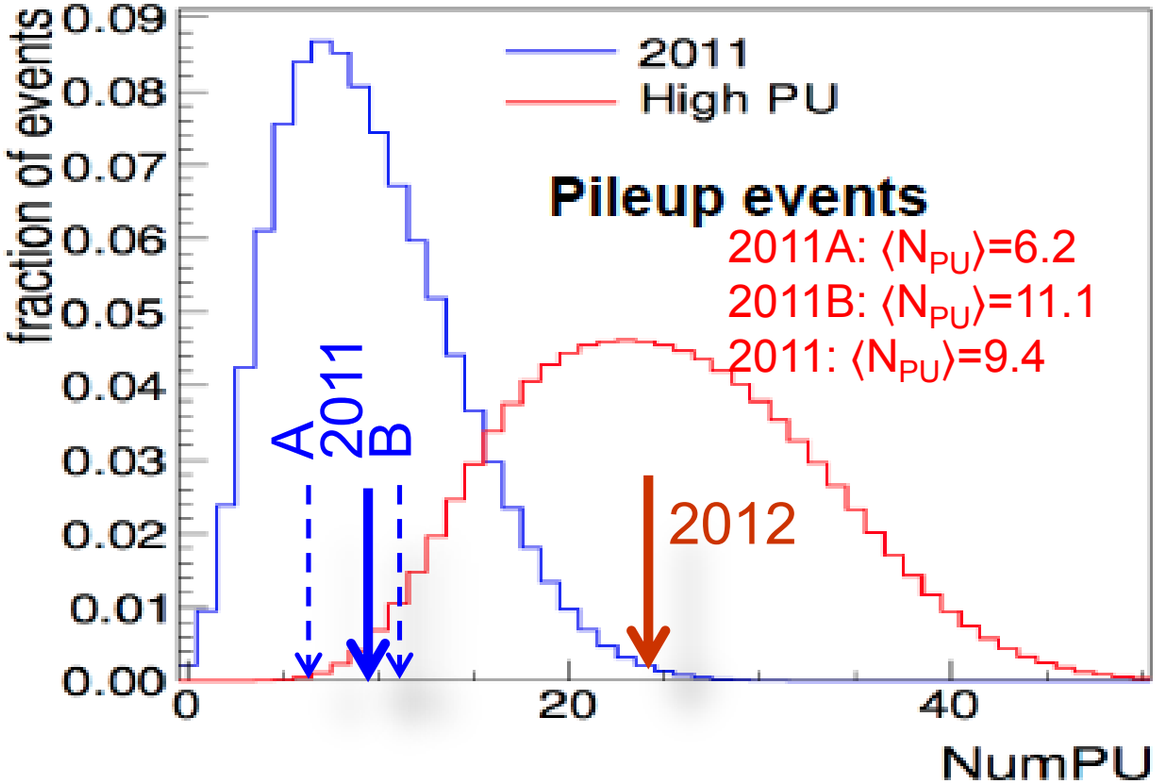


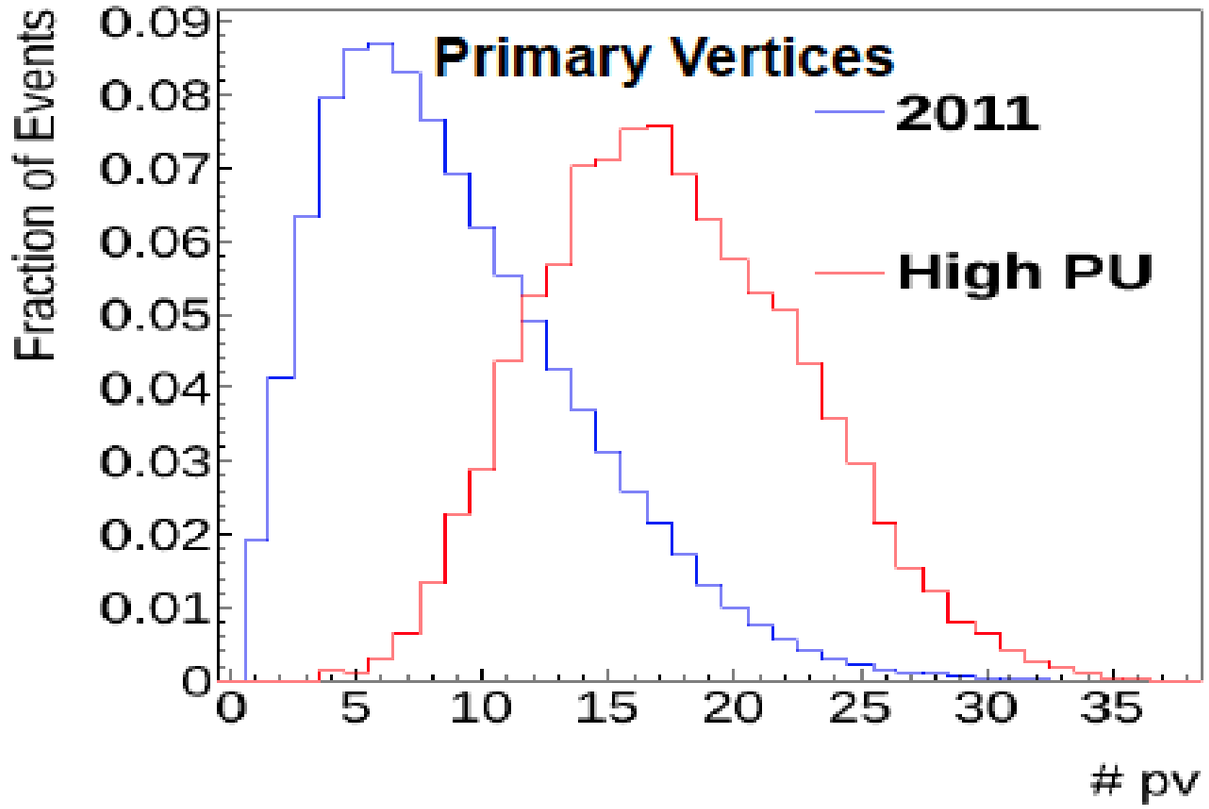
*see talk of Michael tomorrow

LHC conditions: pile-up



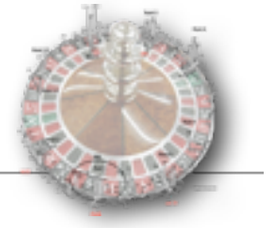
- Already in Run 0 of LHC the design pile-up numbers were exceeded
- having a simulation in place that could predict this was vital for ATLAS/CMS



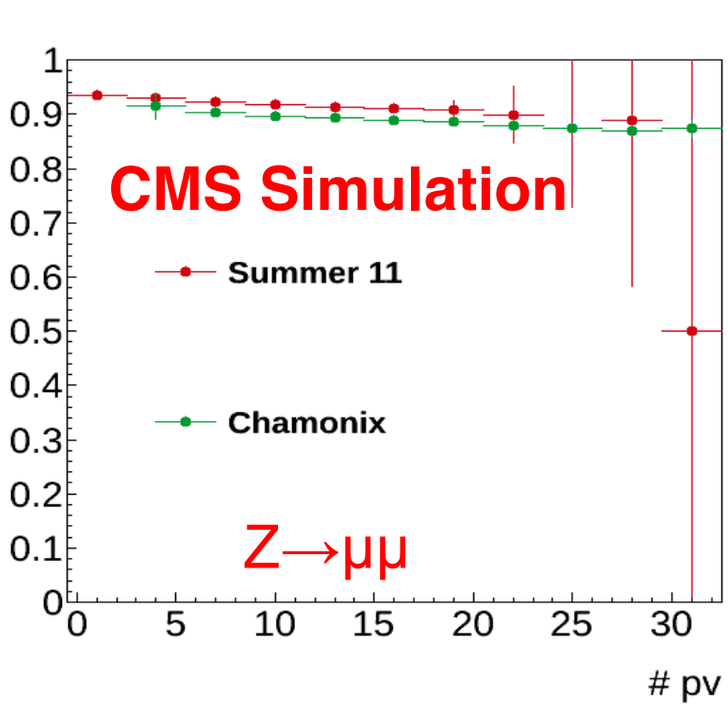


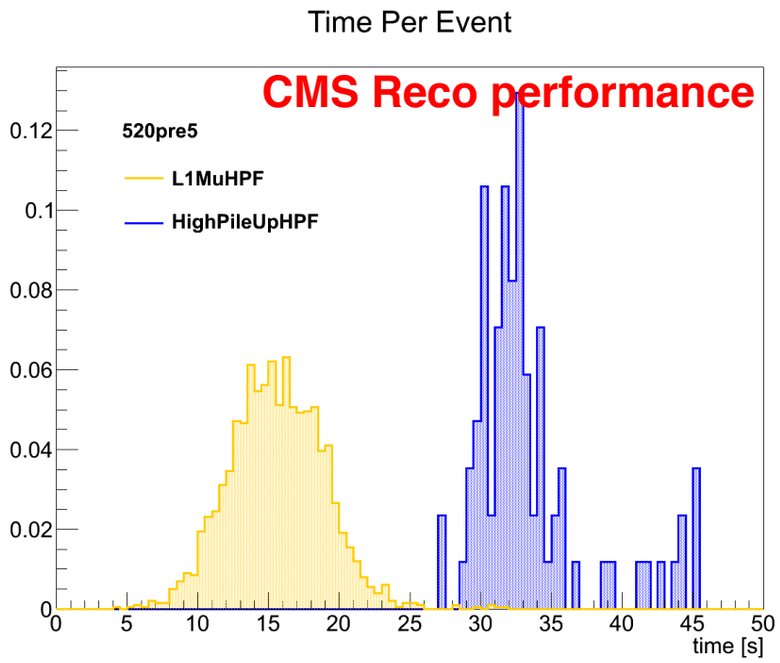
CMS Simulation

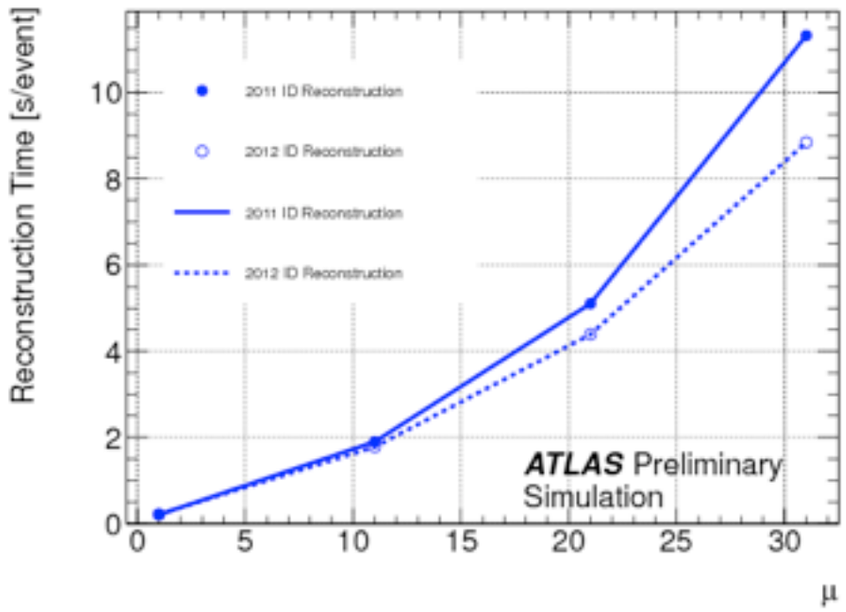
LHC conditions: pile-up



- Not only physics performance needed to be tested
- in the run-up of 2012 data taking, both CMS & ATLAS ran dedicated programs to get CPU time of reconstruction under control
- high pile-up simulation samples were necessary for this
- **this will become even more important for the HL-LHC preparations**

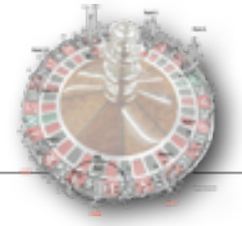






- Can fast simulation provide a good pile-up handling?
- strictly speaking, pile-up is NOT a simulation issue*

LHC conditions: pile-up



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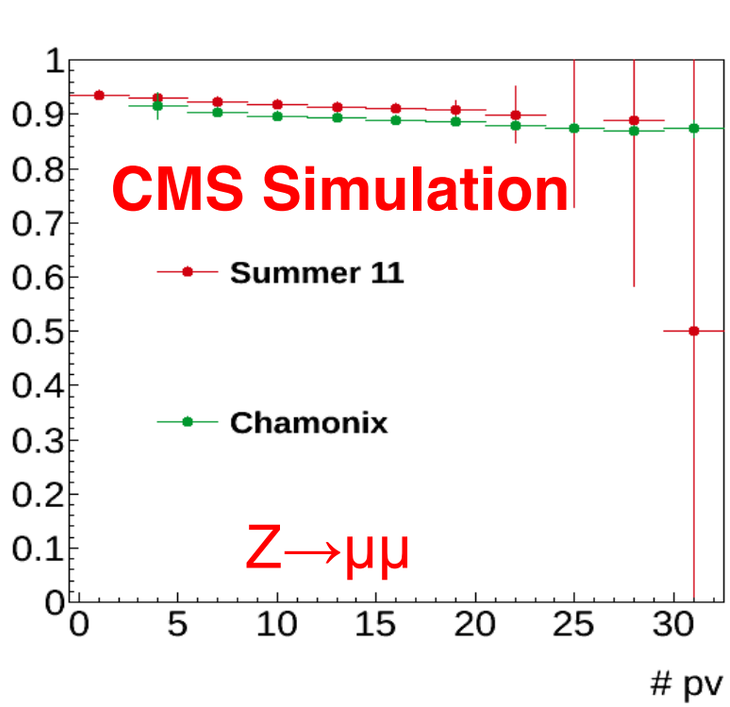

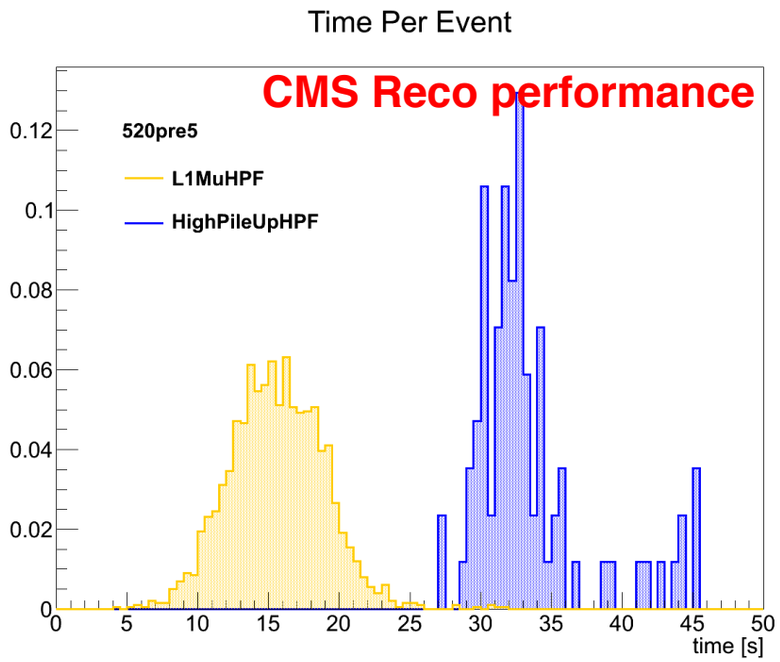

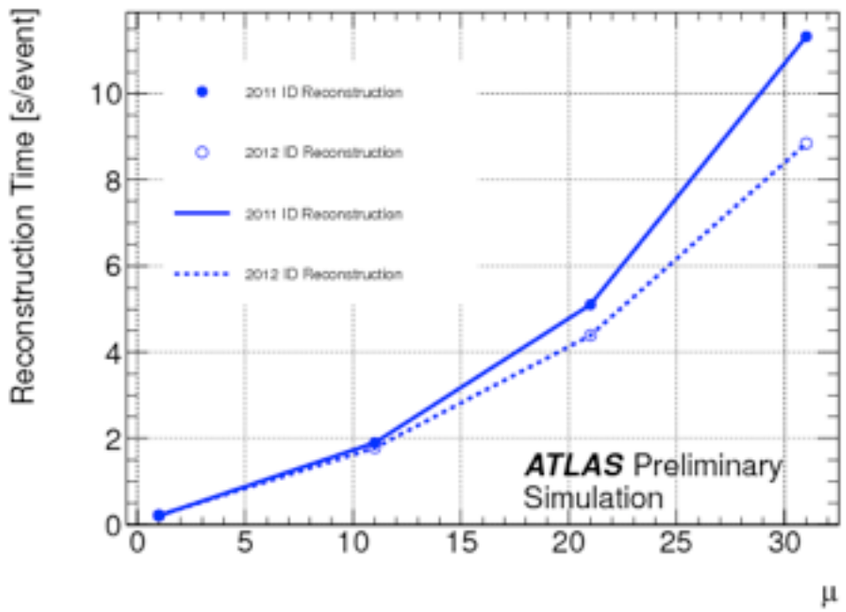

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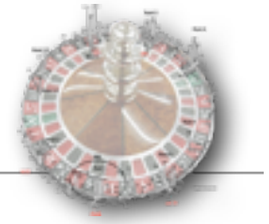
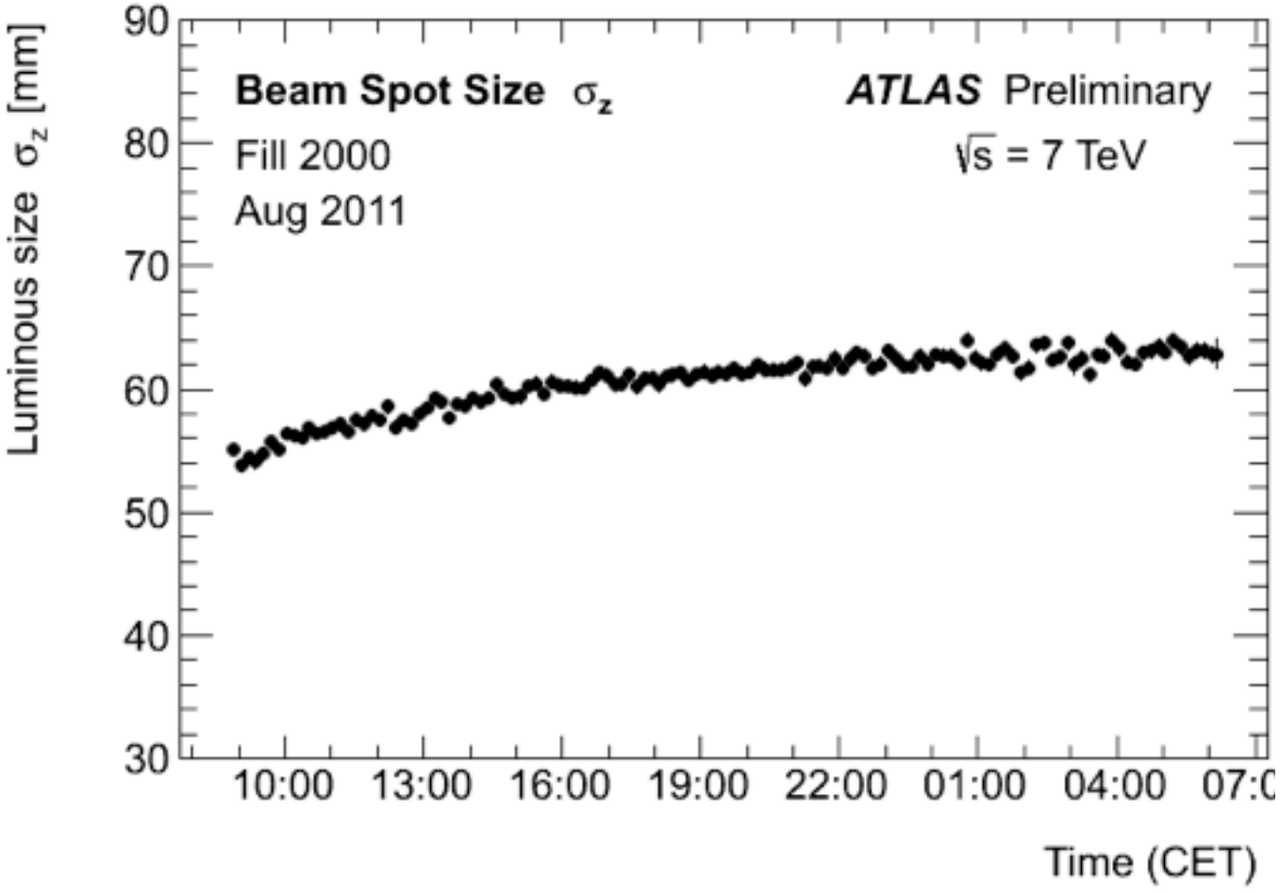
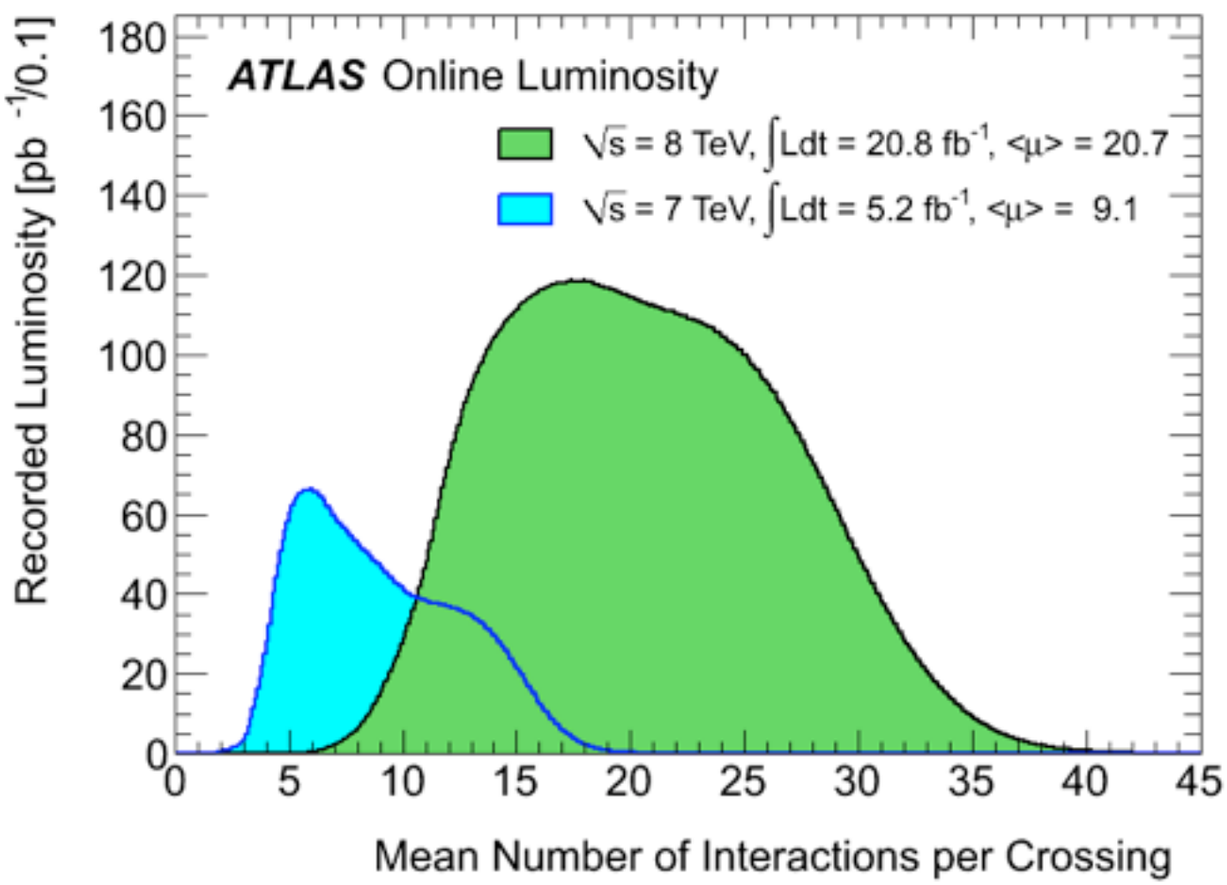
*I will contradict this message in my thursday contribution ...

It is even more complicated (1a)



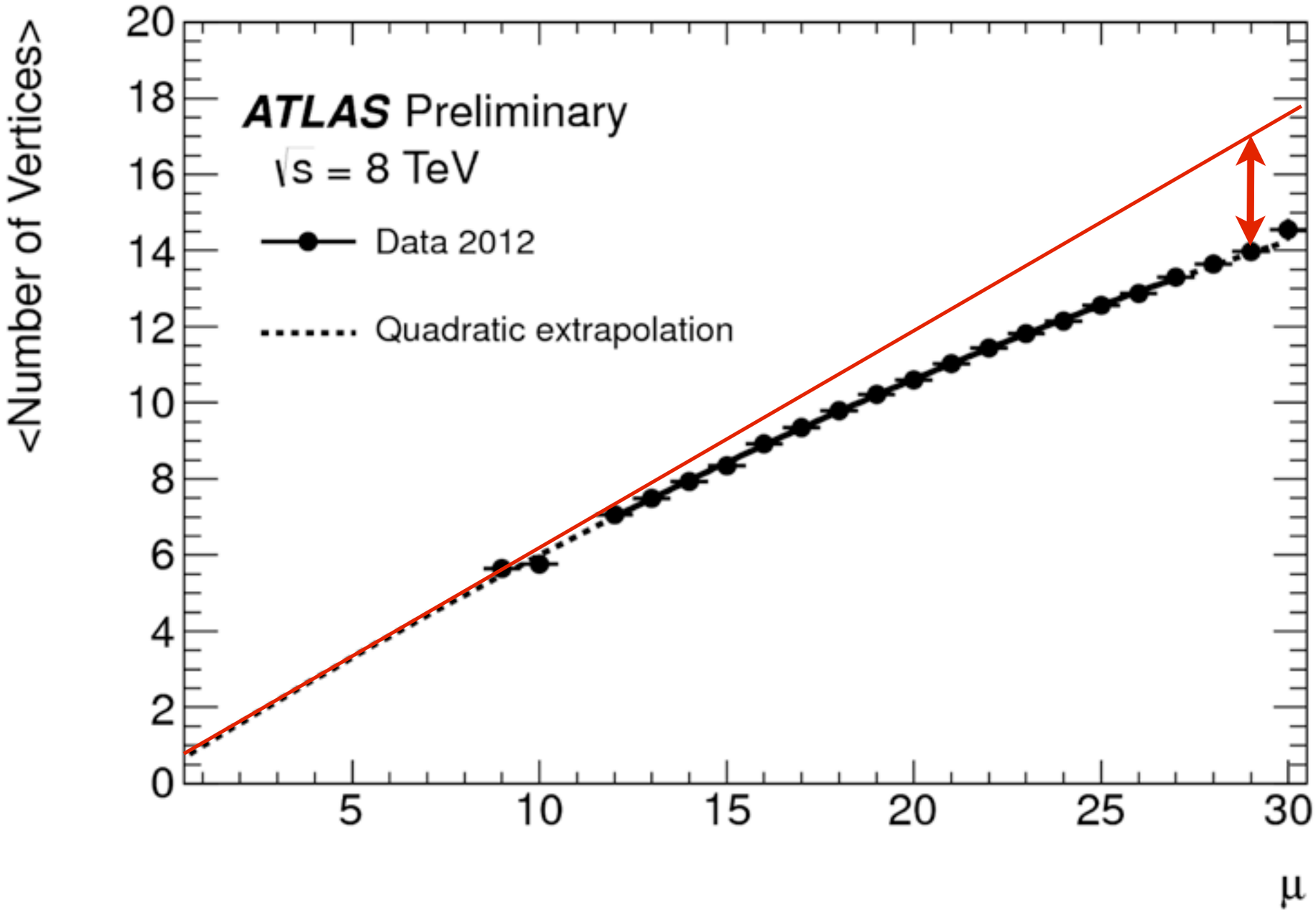
- There are many parameters when you want to describe the pile-up correctl
- In-time pile-up components
  - a correct modeling (in particular for tracking aspects) needs a good prediction of the number of interaction per X-ing & the size of the beam-beam X-ing region
  - this has been difficult in the past to get *a priori* from the machine



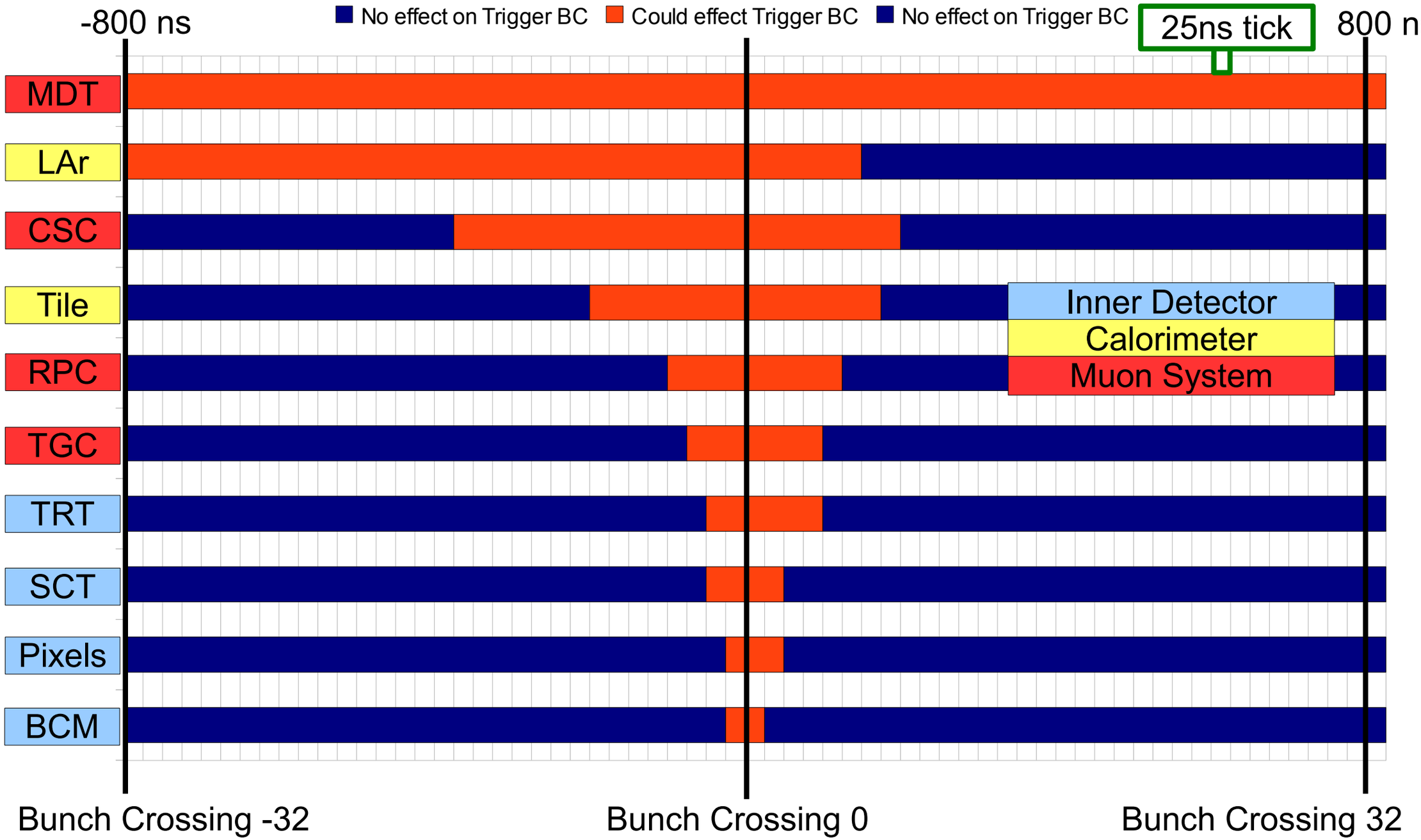


It is even more complicated (1b)

- Vertex reconstruction is very sensitive to these parameters
  - shadowing, merging, splitting effects are dependent on the vertex density

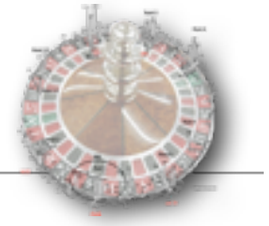


It's even one complicated (2)



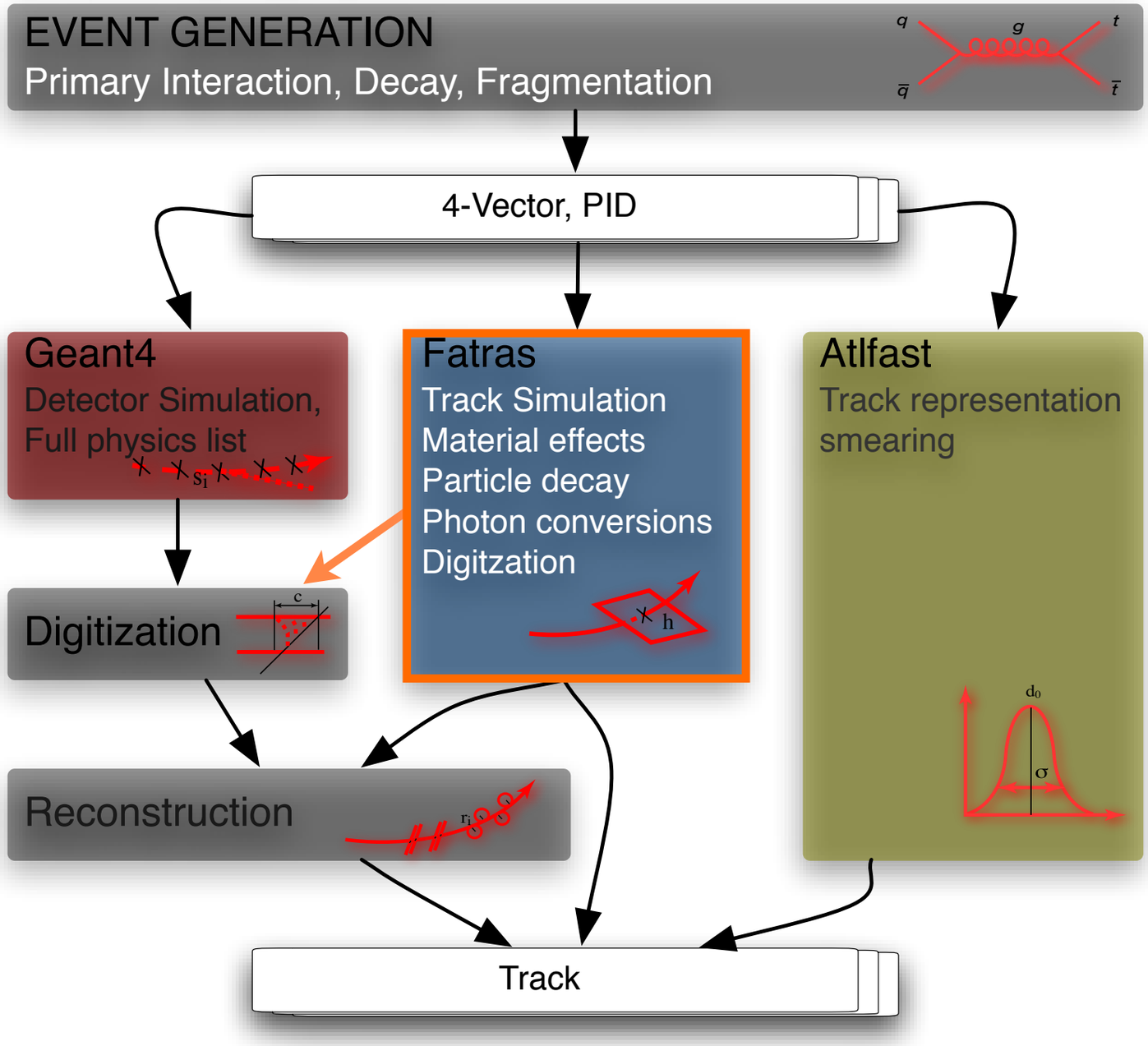
- A correct treatment of the pile-up structure is quite complex
- This will become one of the most important issues for upgrade simulation

Lessons learned



- **Fast simulation needs to be able to “emulate” pile-up**
- consequence in ATLAS: initially developed fast simulation approaches now feed in digitization

ISF_Fatras*



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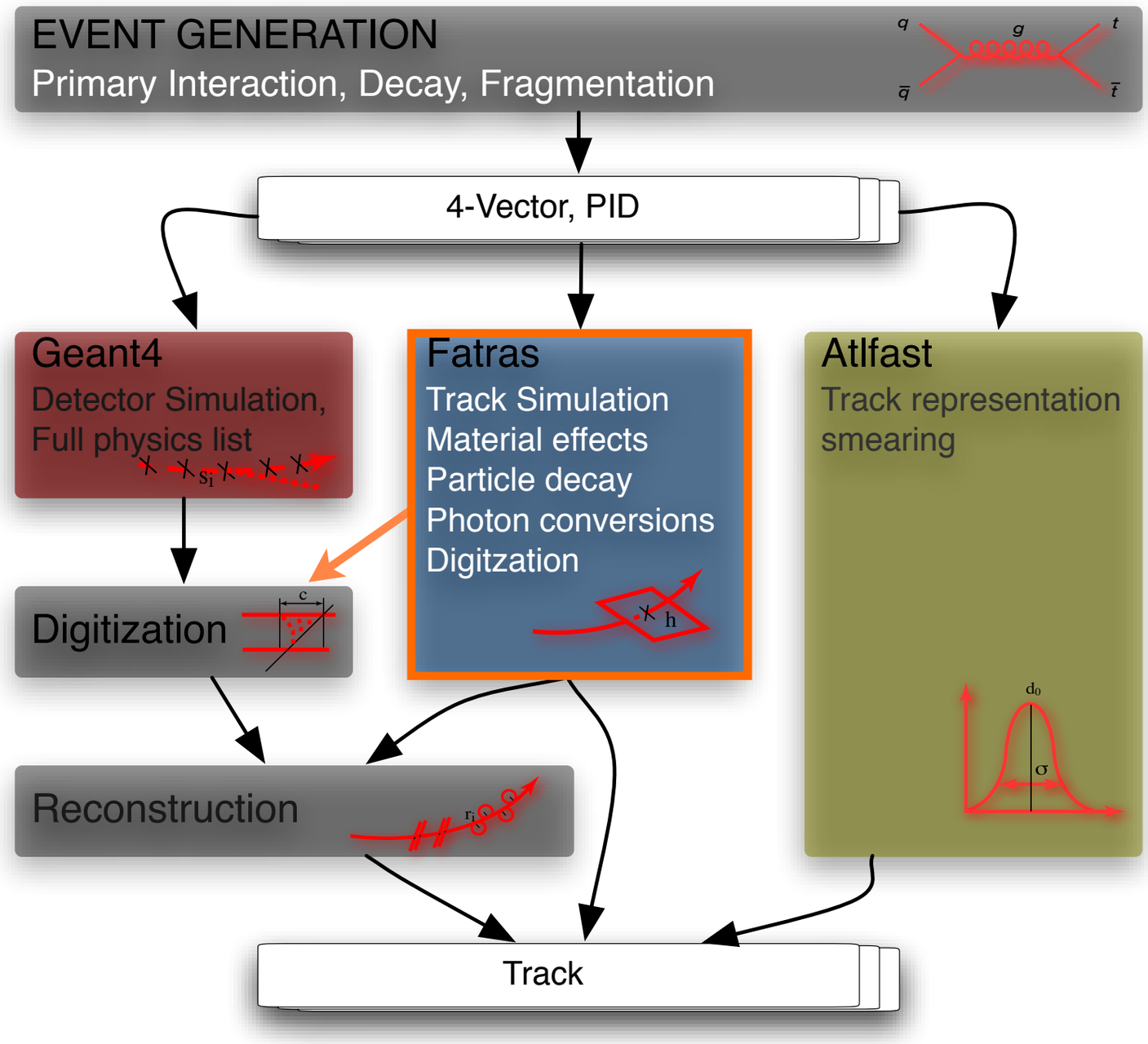
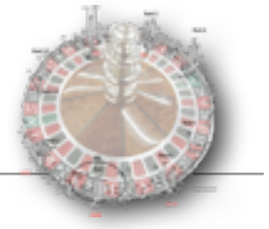


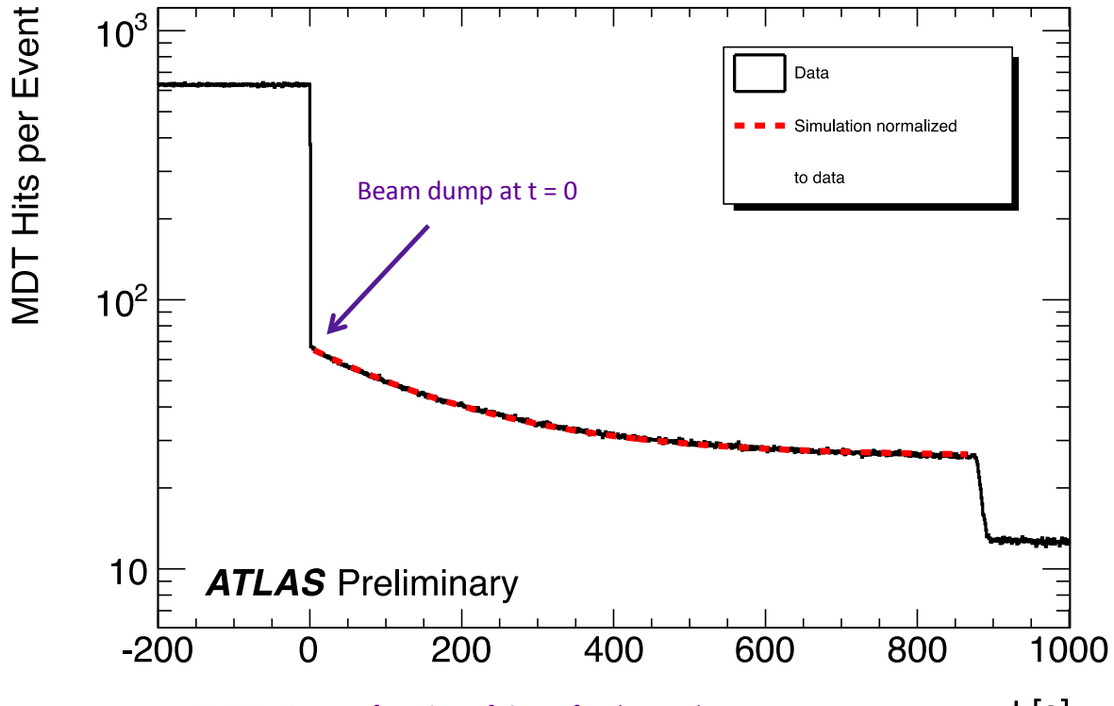
*see talk of Elmar tomorrow

Part 4 - We need **full** simulation



We need **fast** simulation

Full simulation usage: detector activation and cavern background

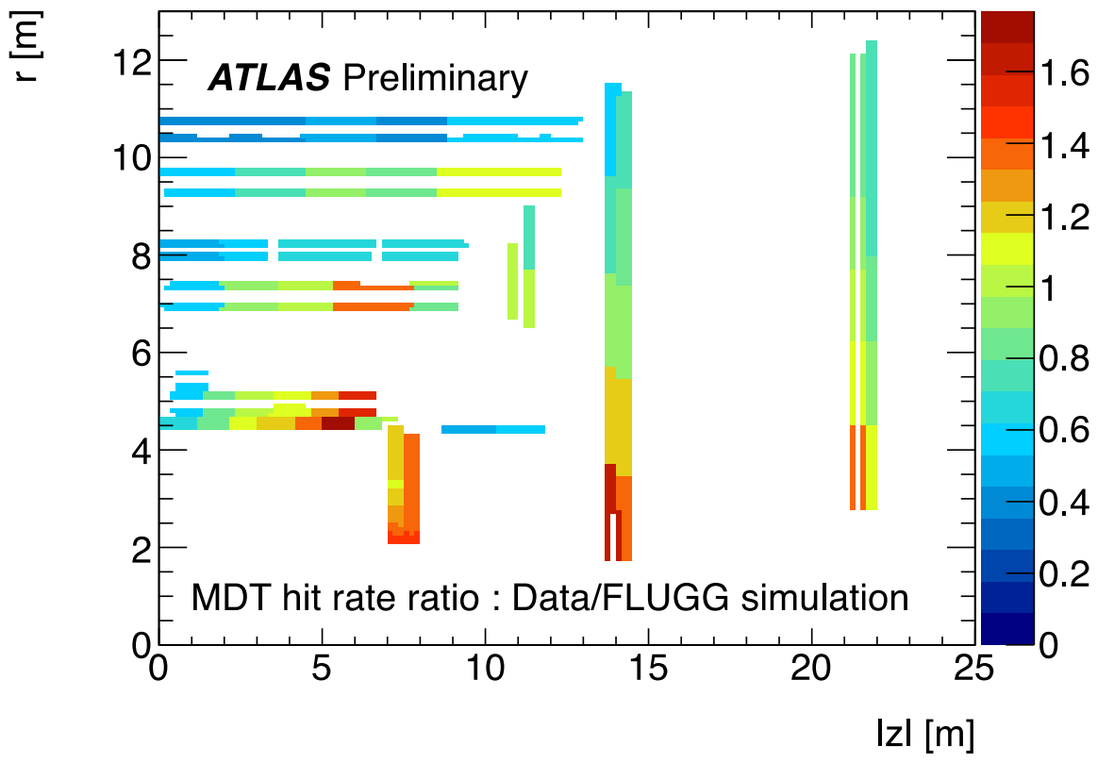


MDT Hits as a function of time after beam dump

- There are areas where fast simulation just won't work that easily

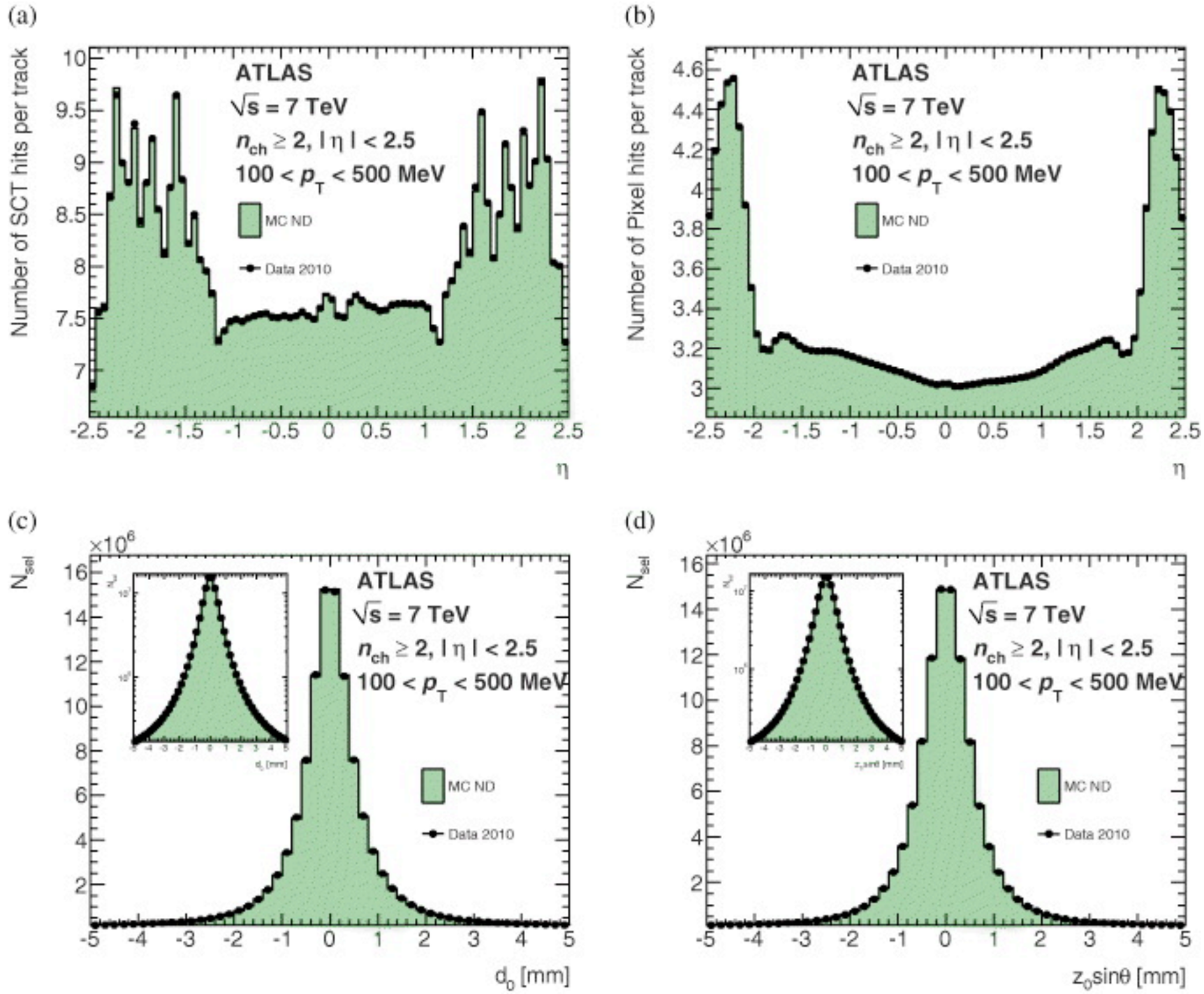
- in particular in the precise understanding of the detector (including activation, aging effects, etc.)

- Even full simulation has difficulties with describing the cavern activity

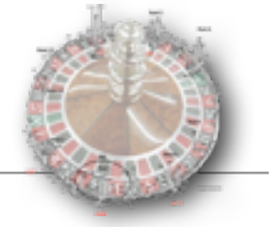


Full simulation usage: precise detector effects

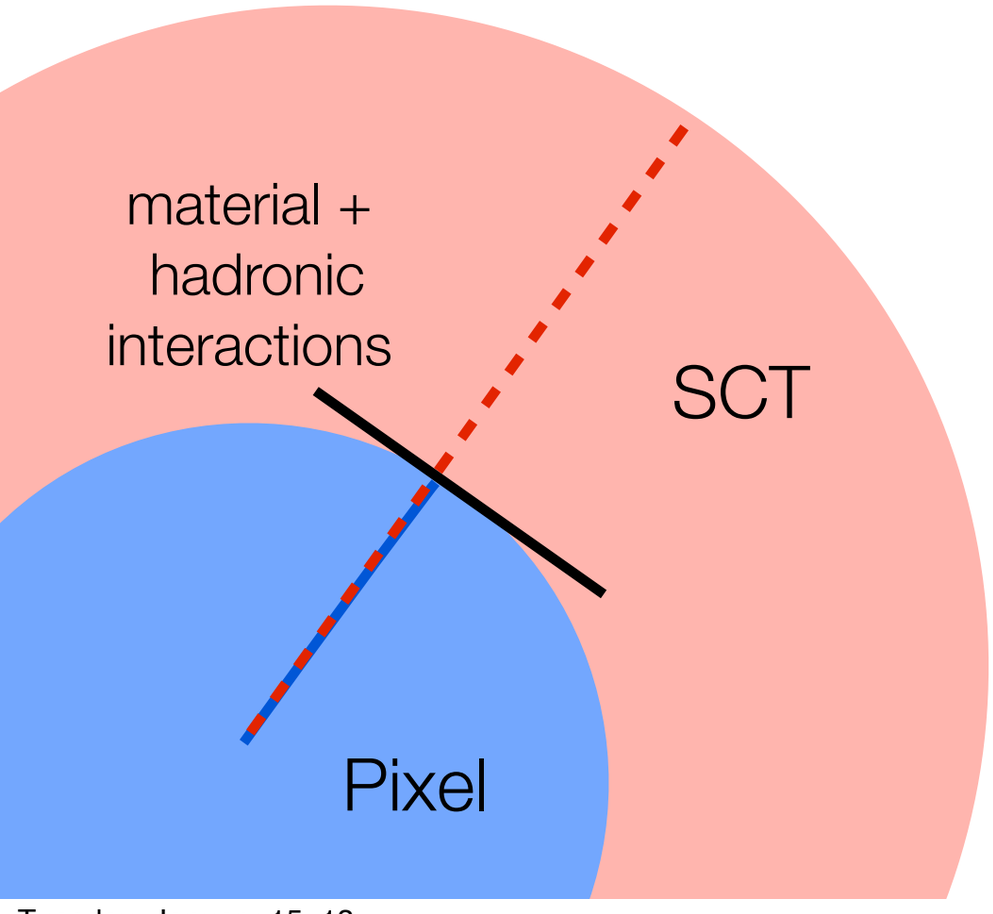
- Example: charged particle multiplicity measurements ATLAS/CMS
- Generic track reconstruction efficiency for hadrons is determining component

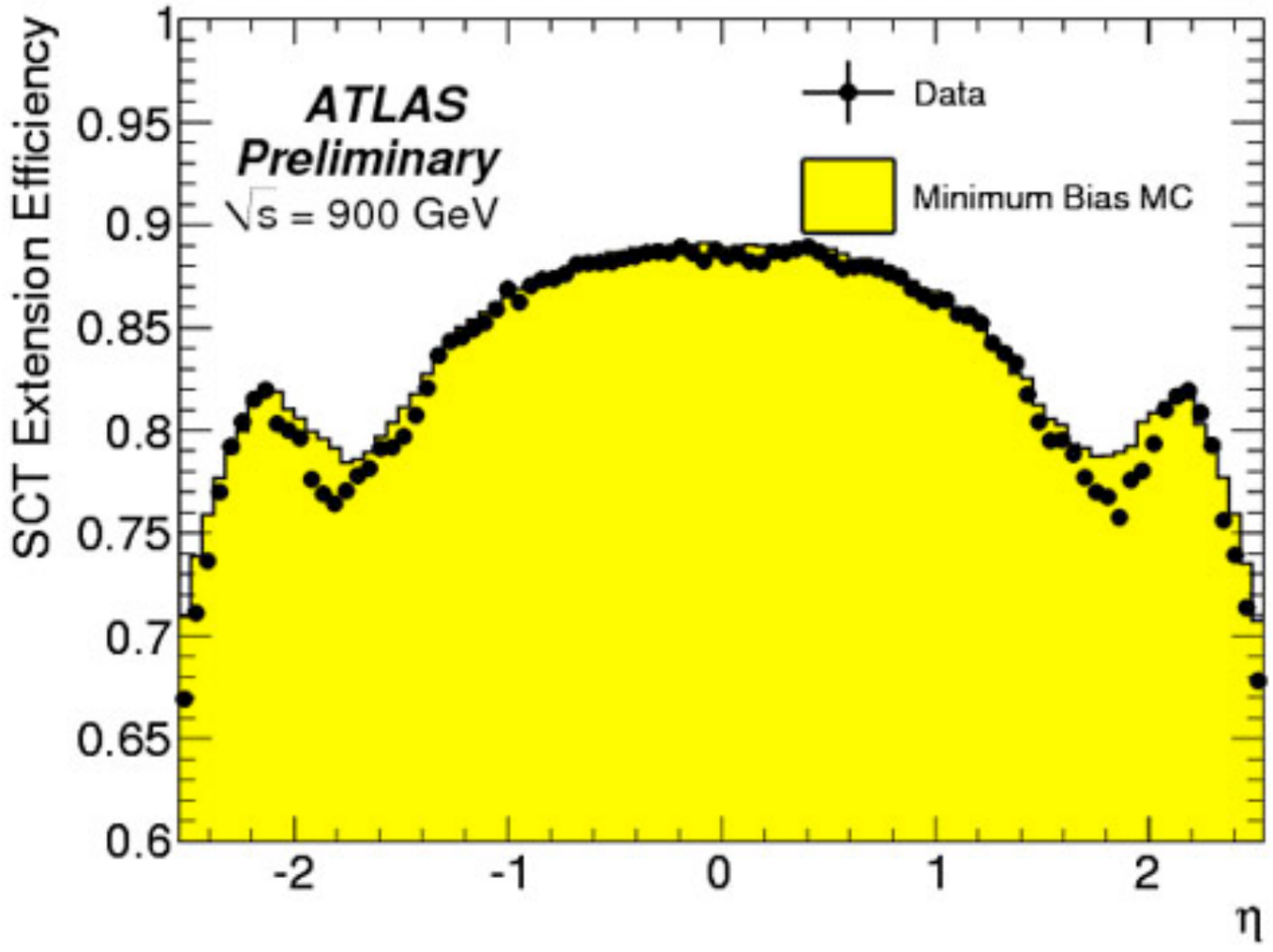


Full simulation usage: precise detector effects

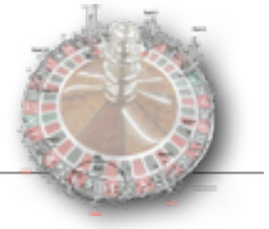


- Example: track reconstruction efficiency for hadrons from MC
- Requires an excellent **description of the detector & hadronic physics**
- Early 2009 data: cross-checks of detector description using SCT extension



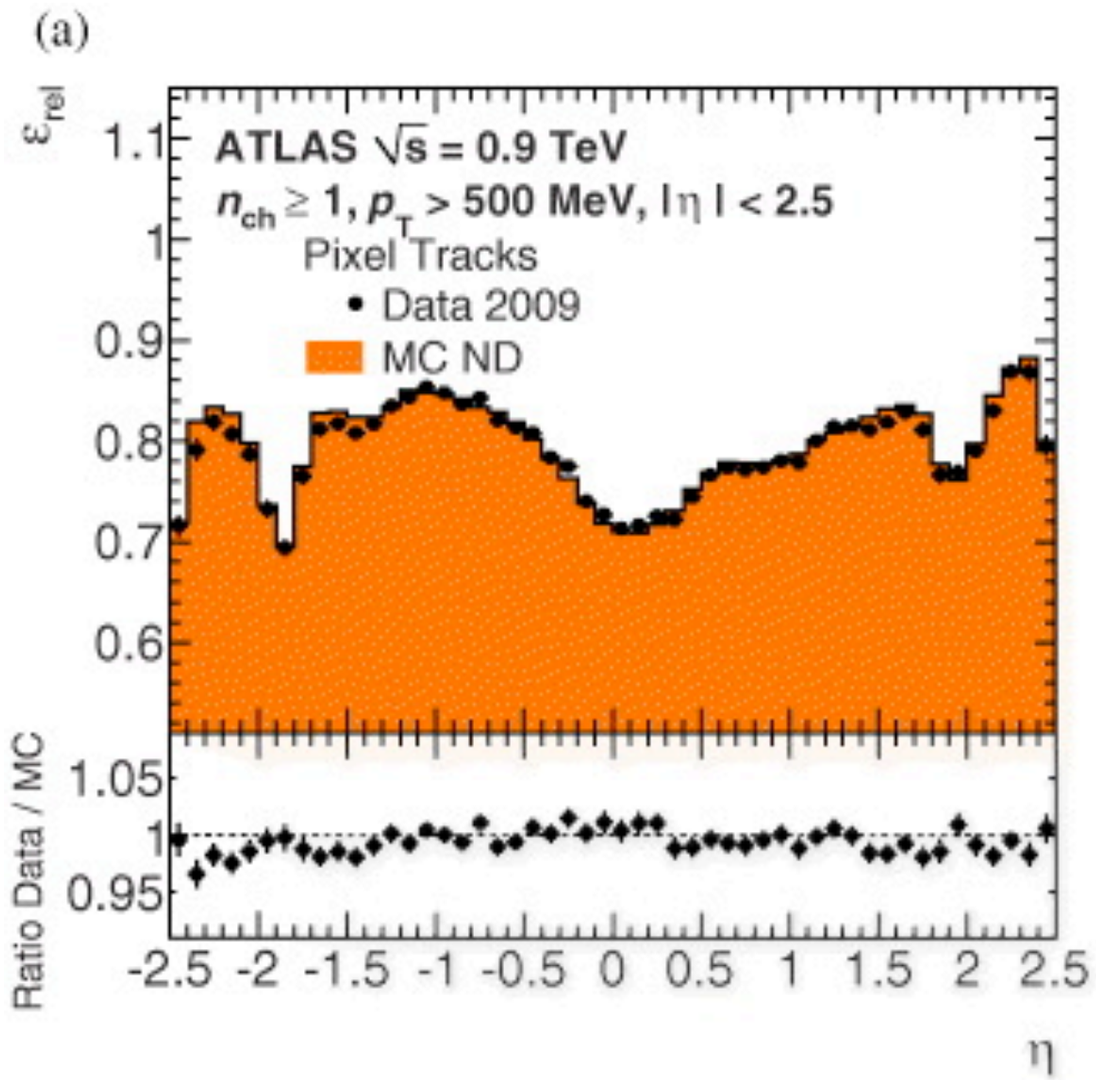


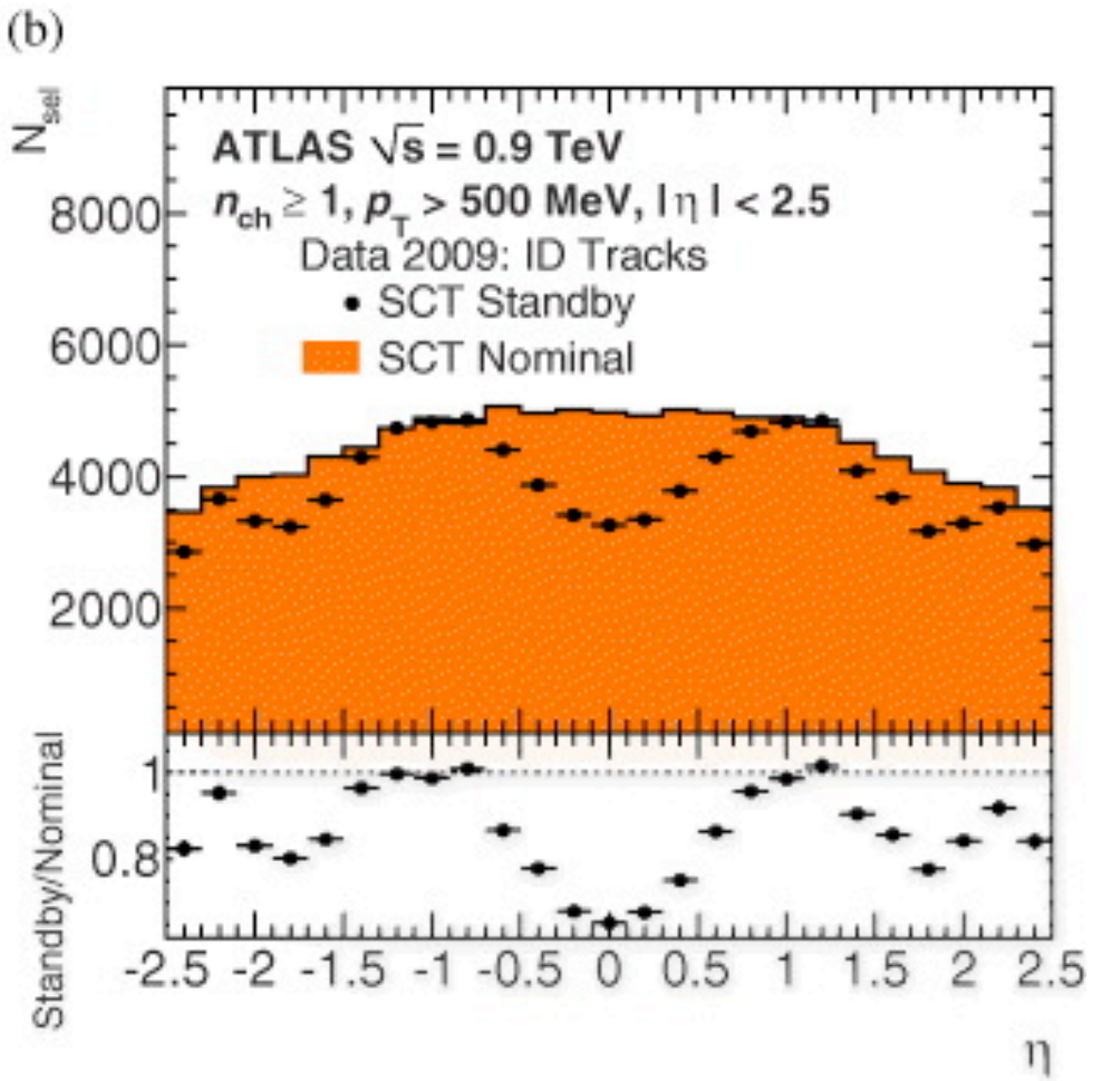
Transition: fast & full simulation



- Expanding the example:
  ATLAS' charged particle multiplicity measurement at 2.37 TeV

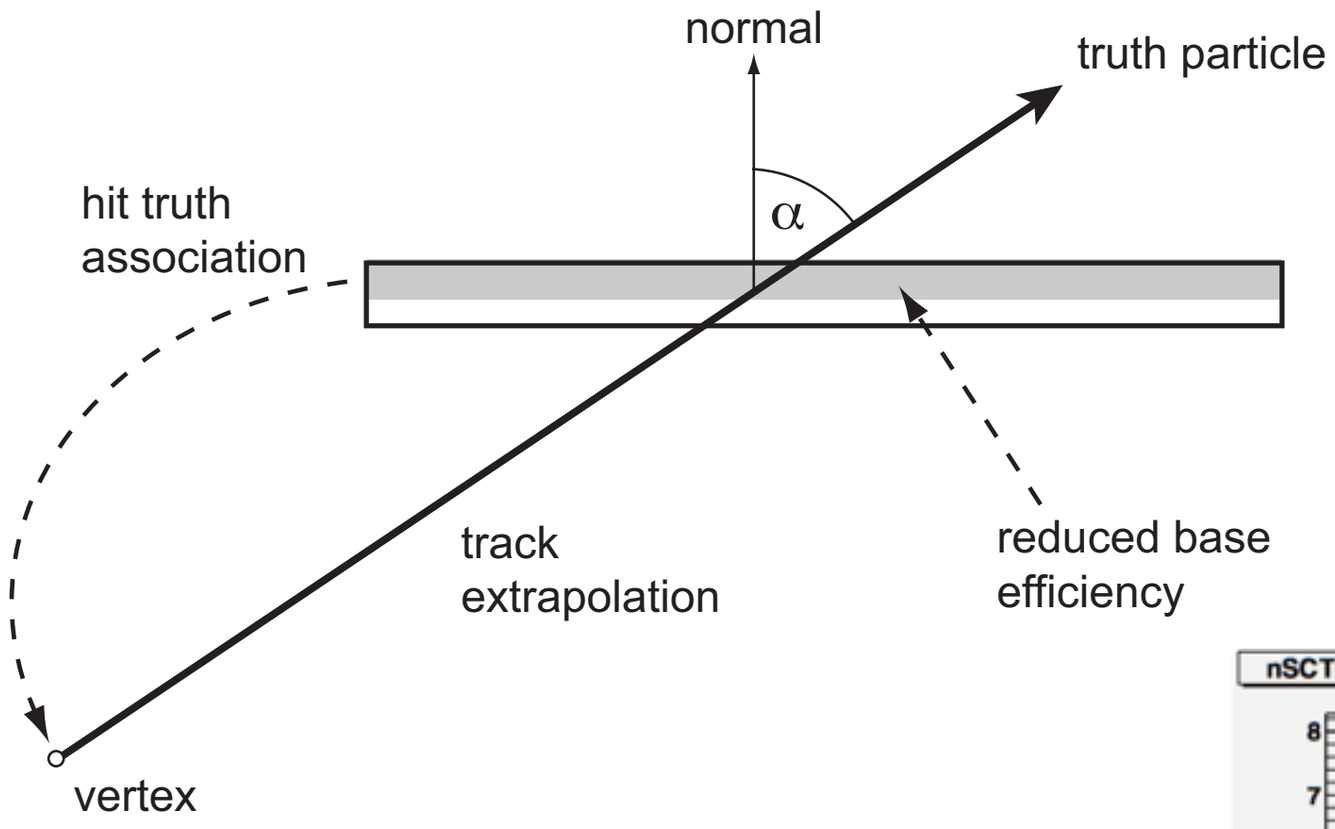
- LHC has not given "stable beam": ATLAS SCT detector was in stand-by

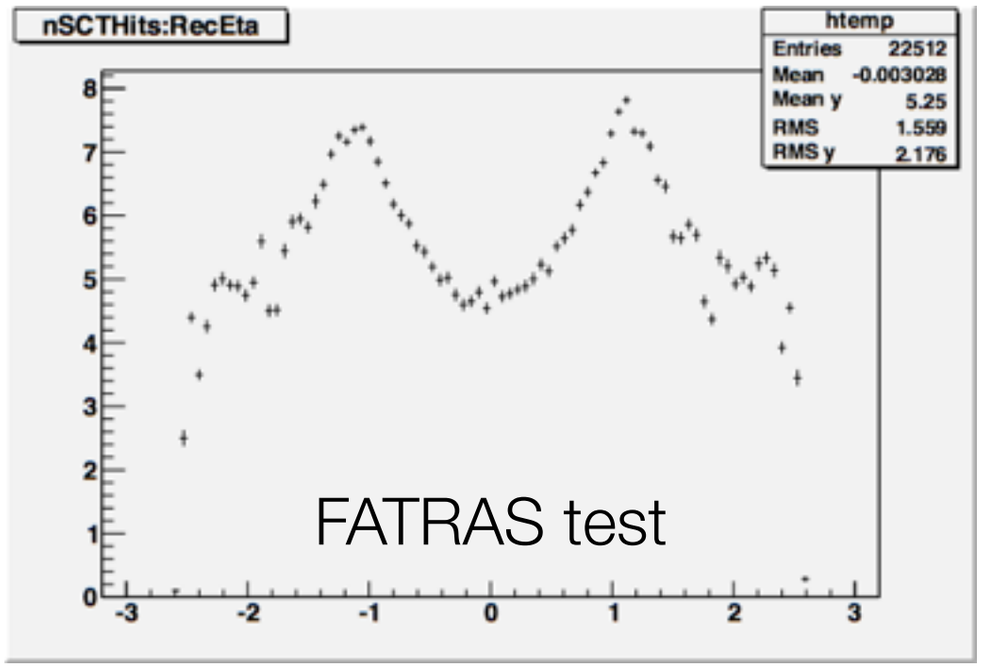




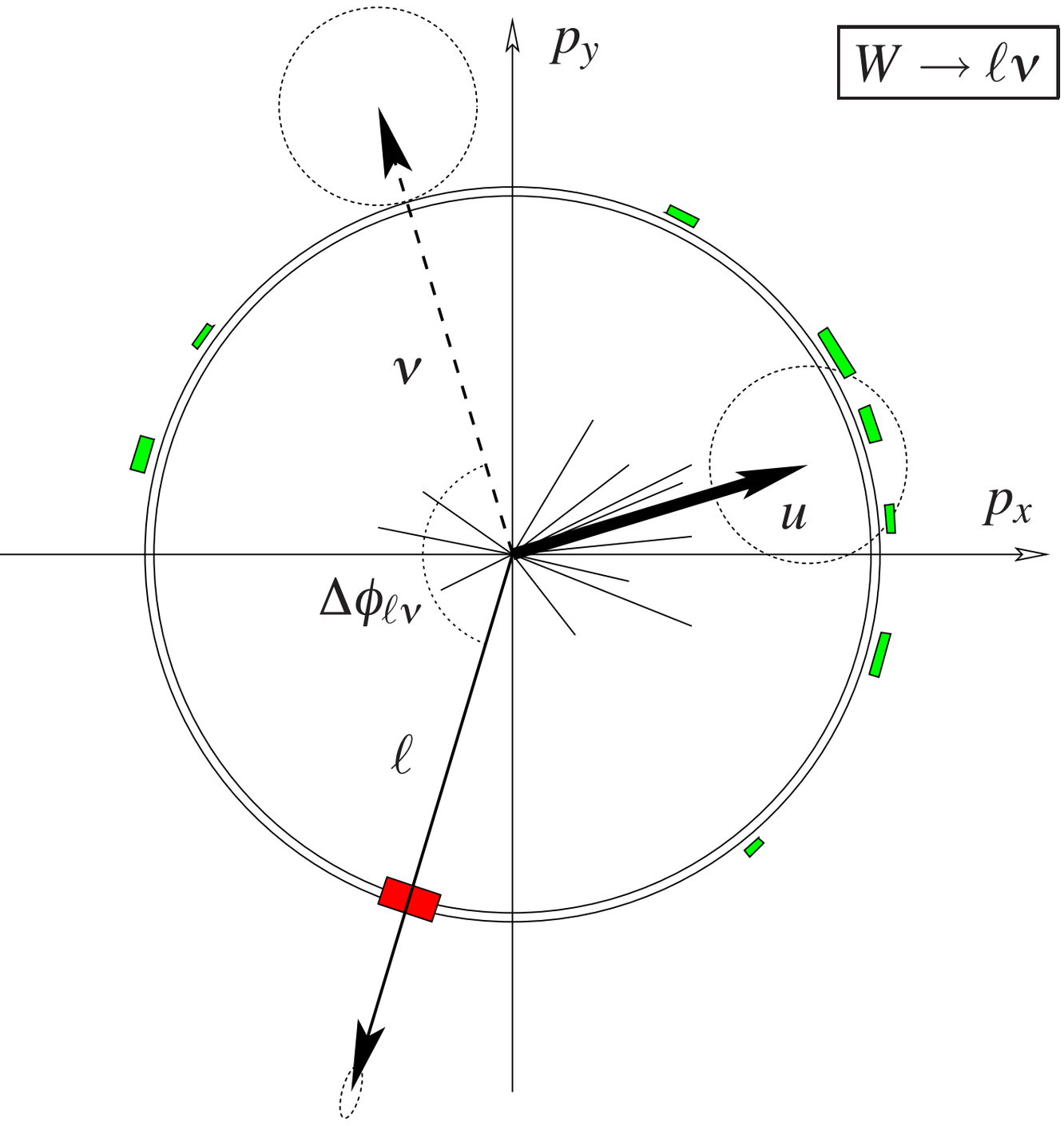
Transition: fast & full simulation

- Developed fast model of partly depleted detector and implemented in FATRAS





Fast simulation usage: precision measurement (1)



- m(W) measurement is one of the most challenging precision measurements to be done with the LHC
- Performed by template measurement to the transverse mass distribution
- Needs a very well understood MC modeling of
  - energy scale
  - lepton momentum scale
  - missing ET
  - hadronic recoil

- Can such a precise measurement be done using fast simulation ?

Fast simulation usage: precision measurement (2)

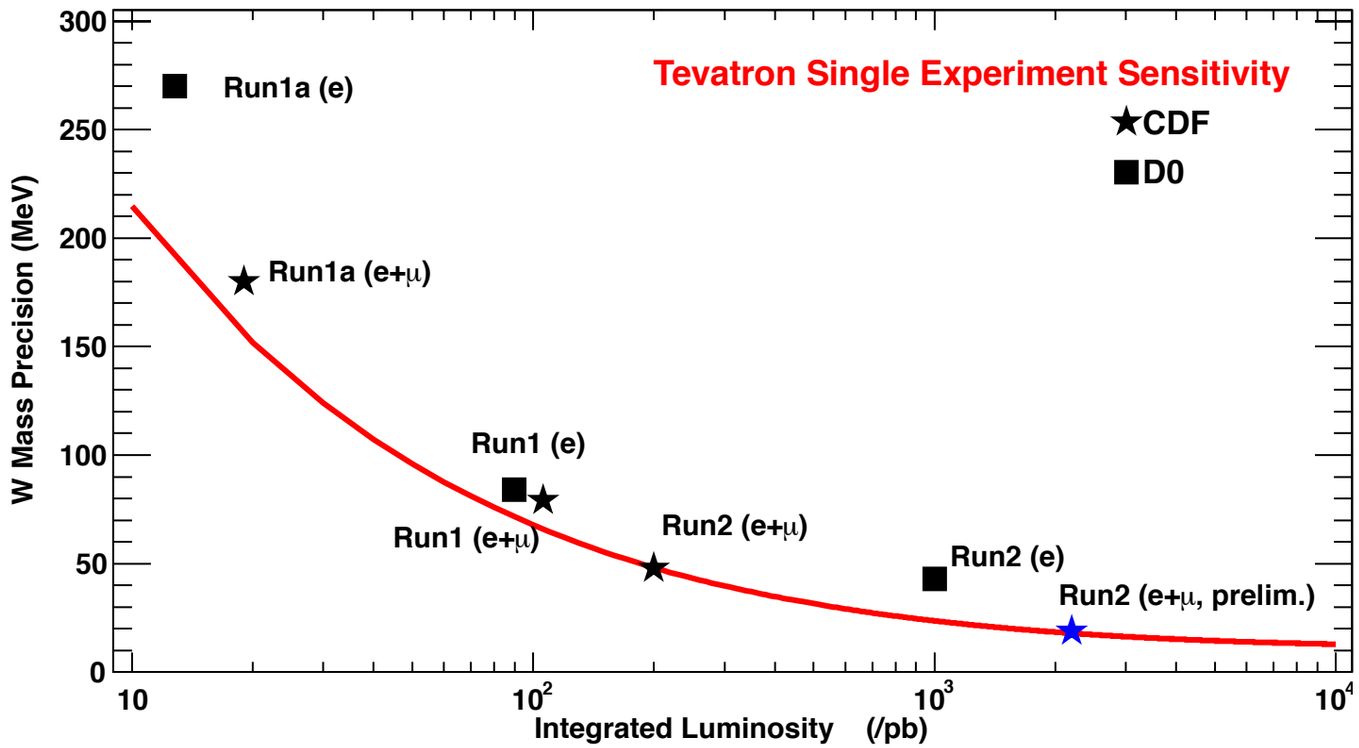
Abstract

We present a measurement of the W boson mass using 2.2 fb^{-1} of CDF Run II data. With 470,126 W→eν candidates and 624,708 W→μν candidates, we measure M_W = 80387 ± 19 MeV/c^2. This represents the most precise measurement of the W boson mass to date.

Measurement Technique

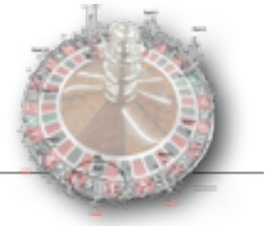
The W boson mass is extracted from a template fit to the transverse mass, transverse momentum and transverse missing energy distribution. We use a fast Monte Carlo simulation to predict the lineshape of the template distribution. These lineshape predictions depend on a number of physics and detector effects which we constrain from control samples or simulation. Important detector effects include external bremsstrahlung and ionization energy loss in the detector material, tracker momentum scale, calorimeter energy scale and resolutions of both detectors. Important physics effects include internal QED radiation, the intrinsic W boson transverse momentum and the proton parton distribution functions.

- energy scale tuning
- momentum scale tuning
- recoil calibration
- PDF variations
- **Up to 10 billion events, roughly 4 M/hour throughput on a single CPU**



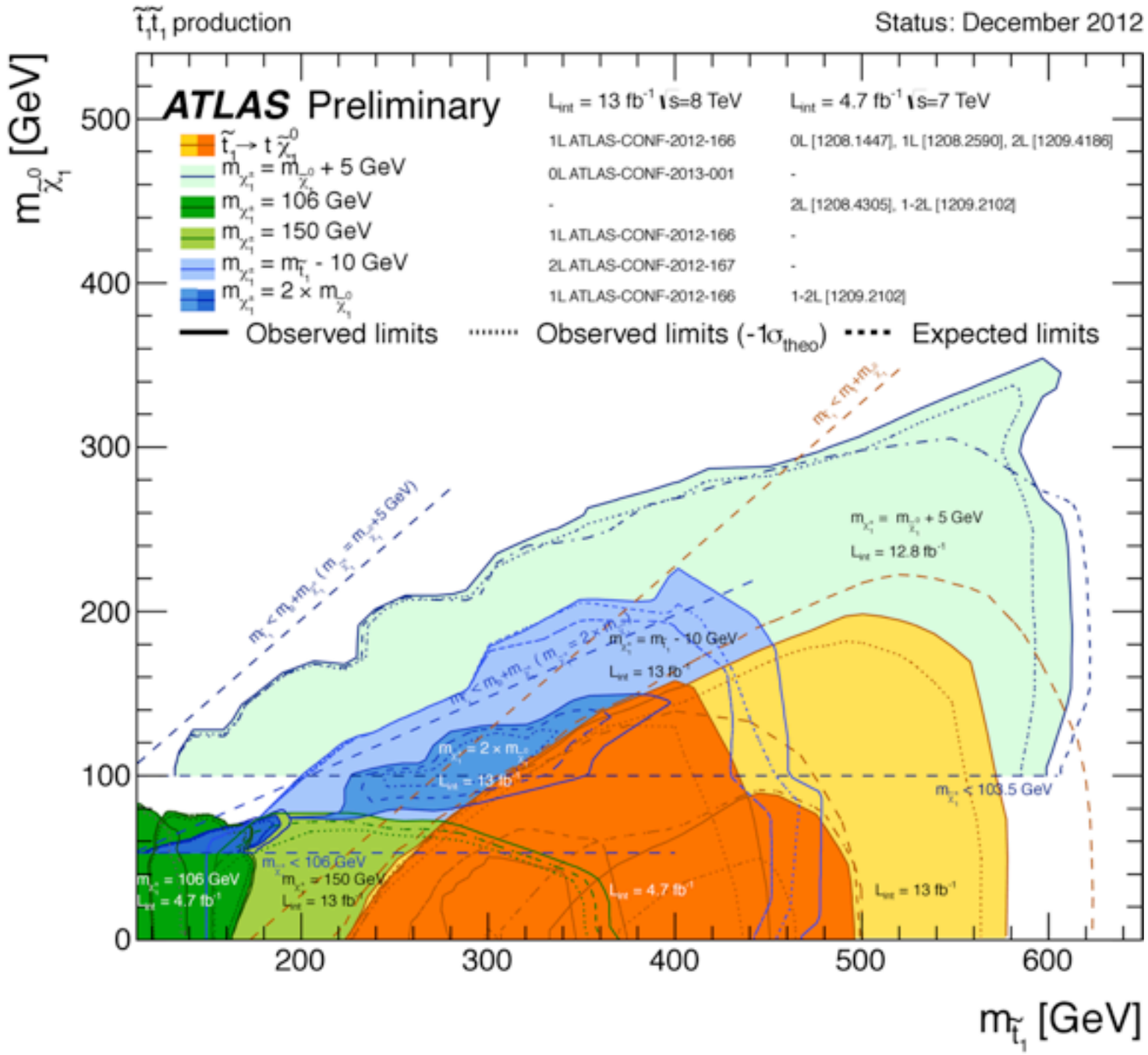
http://www-cdf.fnal.gov/physics/ewk/2012/wmass

Fast simulation usage: SUSY grids

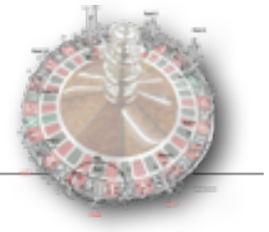


- Large theoretical uncertainties
- High statistics needed to cover the SUSY phase space
- A possible strategy:

- simulate the grid with fast simulation, but support it with with single full simulation bounds

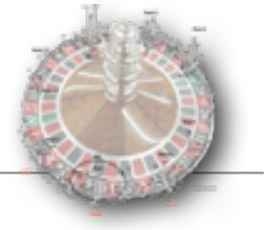


Part 5 - Commonalities



- A CMS/ATLAS centric view ... my apologies

Full simulation & first steps

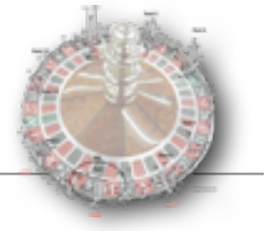


- **Full simulation is based on Geant4**
  - general improvement of Geant4 suite is in the interest of all
  - place for modern computing techniques
    e.g. auto-vectorization (CLHEP!), parallelism (Geant4MT), ...
    this is not the scope of this workshop

- **First attempt is to speed up the calorimeter**
  - CMS: GFlash (parameterised)
  - ATLAS: FrozenShowers (library for FCAL), FastCaloSim (parameterised)

- **Fast simulation started as stand-alone programs**
  - ATLFAST (199x) in ATLAS
  - FAMOS (early 2000's) in CMS

Towards fast simulation in LHC experiments

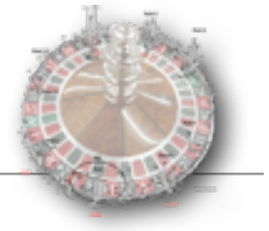


- **Next steps in fast simulation**
  - closer integration into the experiments framework:
    ATLAS: FATRAS, FastCaloSim & Frozen showers (as part of Geant4)
    CMS: Fast Simulation as part of CMSSW & GFlash

- **Common look & feel with fully simulated events is necessary**
  - simple analysis aspect: one **Event Data Model** to serve all

- Many concepts have been developed in **parallel but in very similar ways**
  - simplification of geometry
  - implementation of material effects (EM and HI for Tracking)*
  - shower shape parametrisation for calorimetry**
  - outsourcing of particle decay*

Towards fast simulation in LHC experiments



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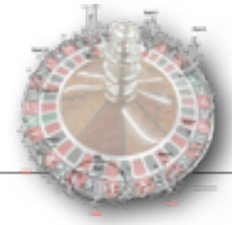
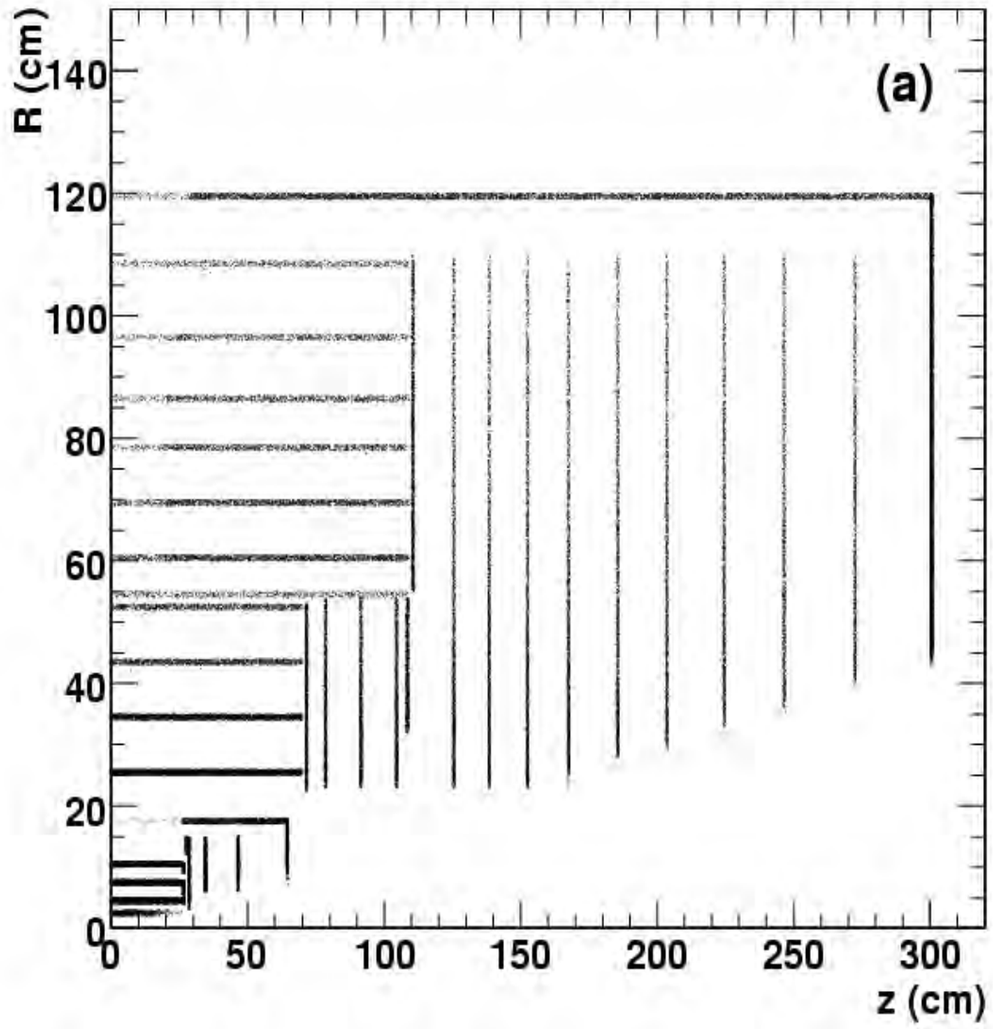
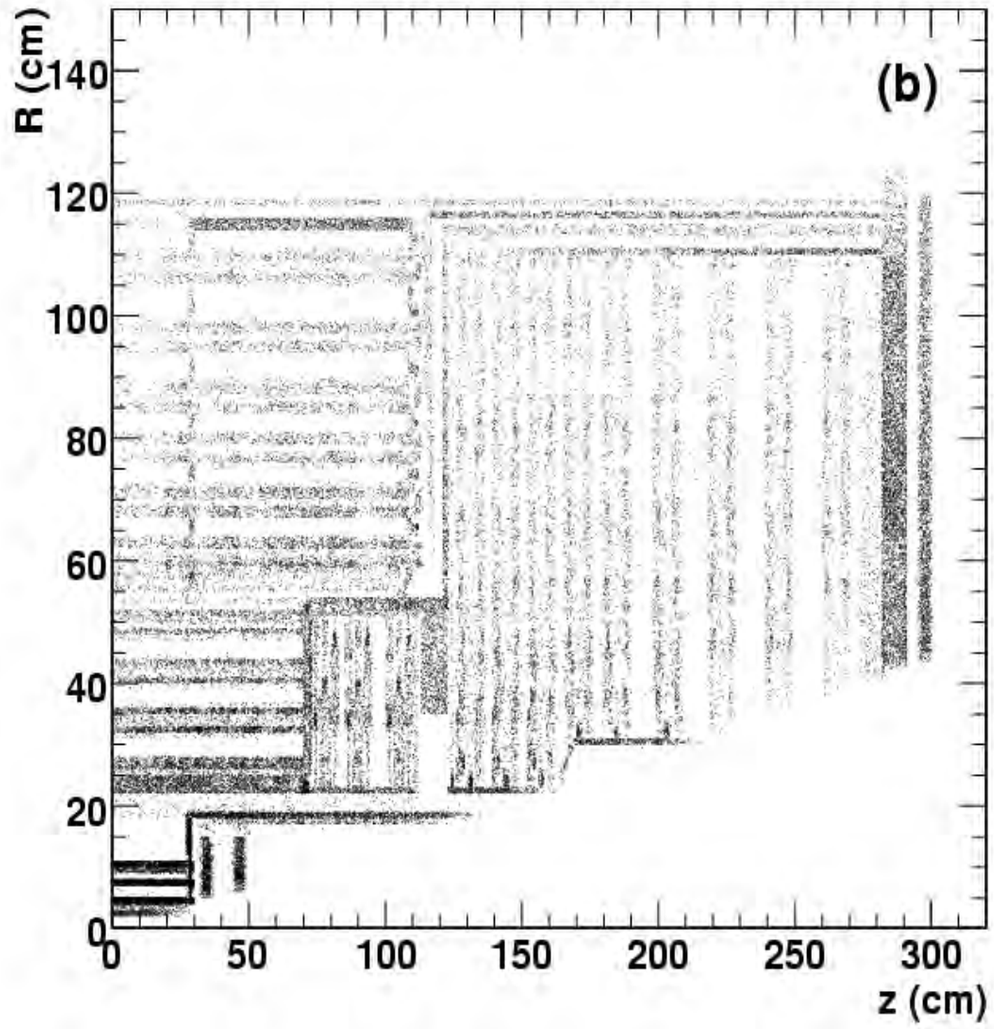
*see talk of Andrea tomorrow
**see talks during calorimetry session tomorrow

Example: Tracking simplification in Tracker (1)

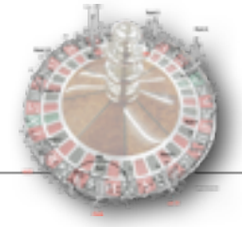


CMS





Example: Tracking simplification in Tracker (2)



ATLAS