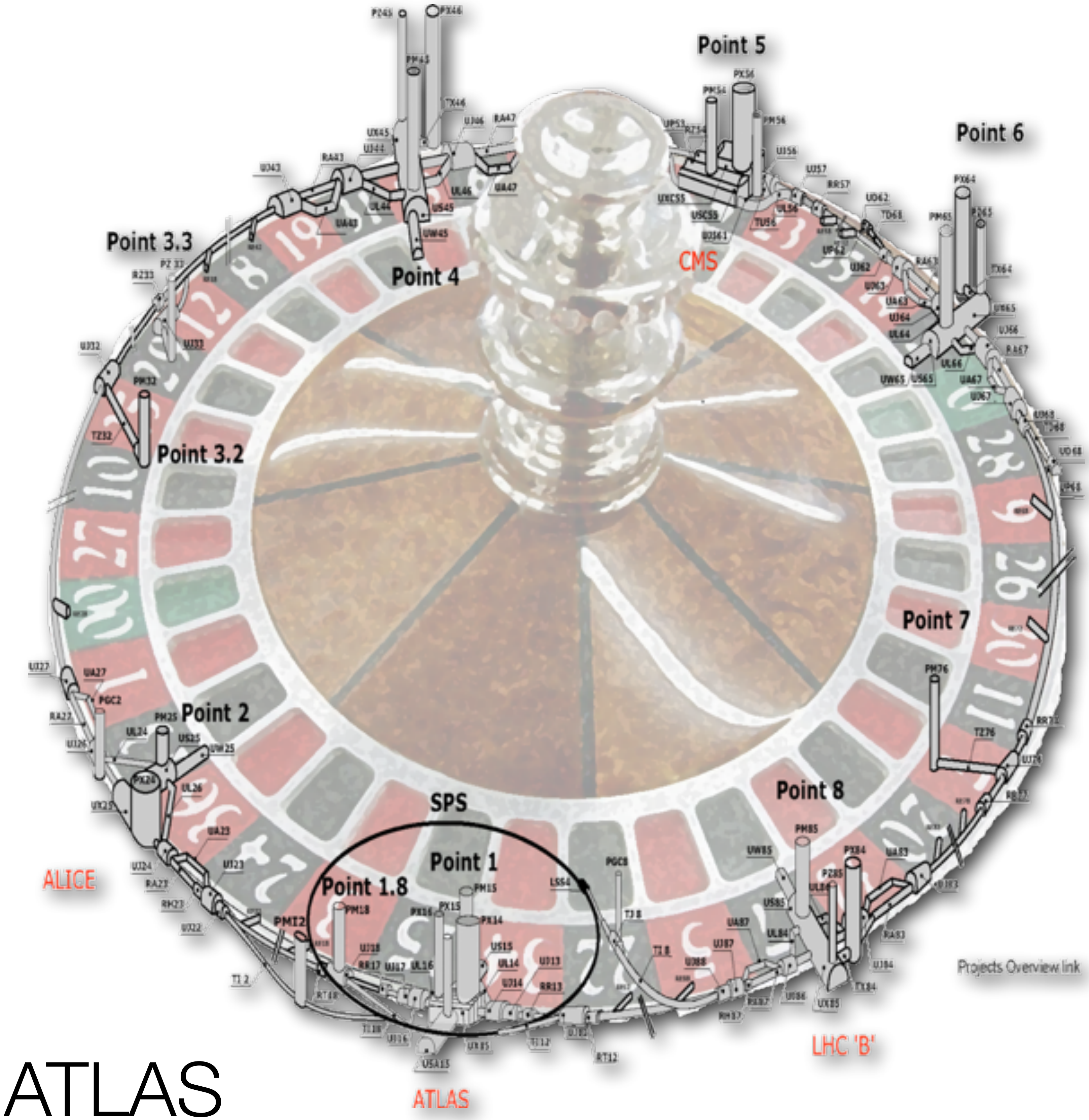
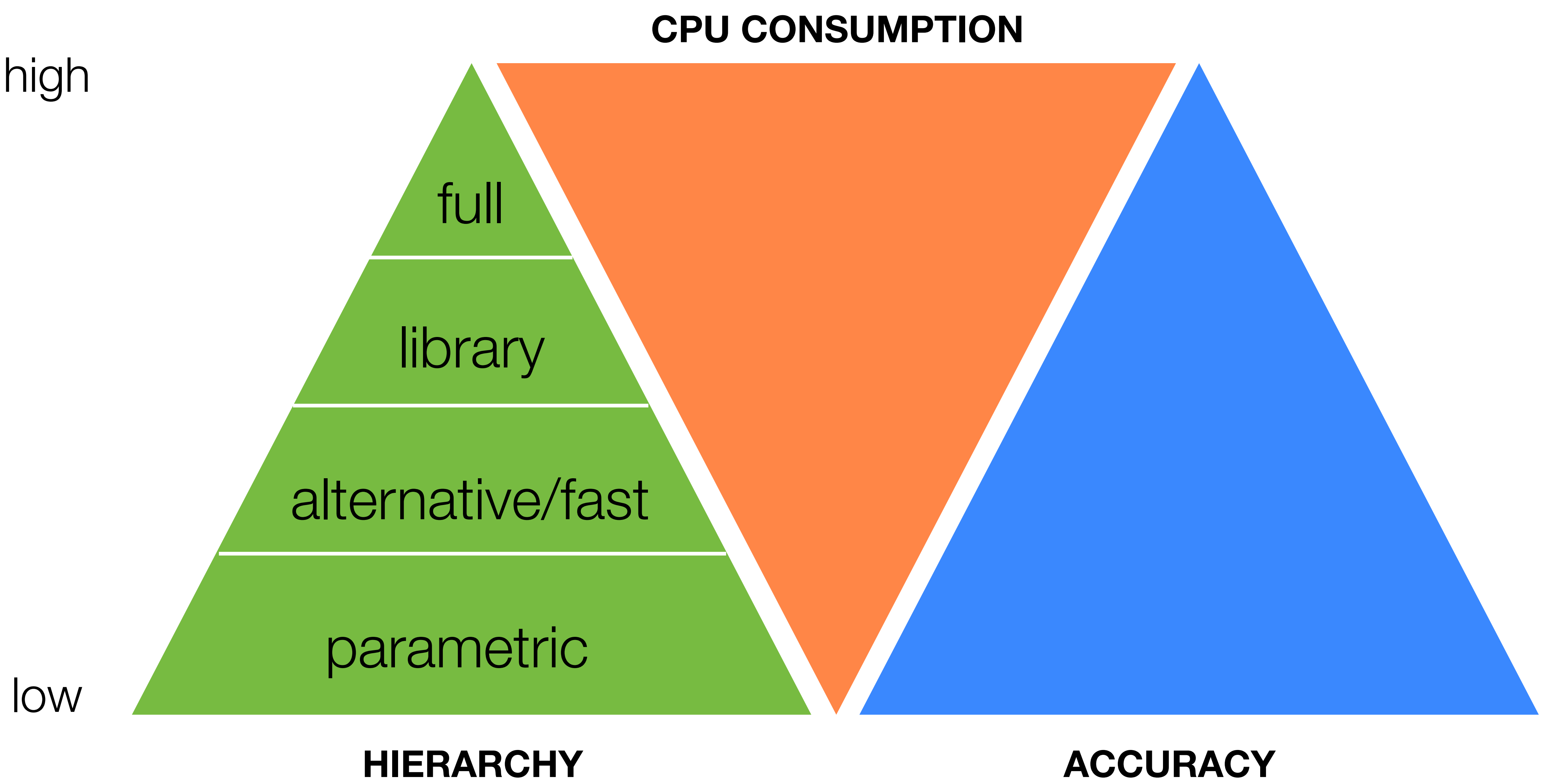


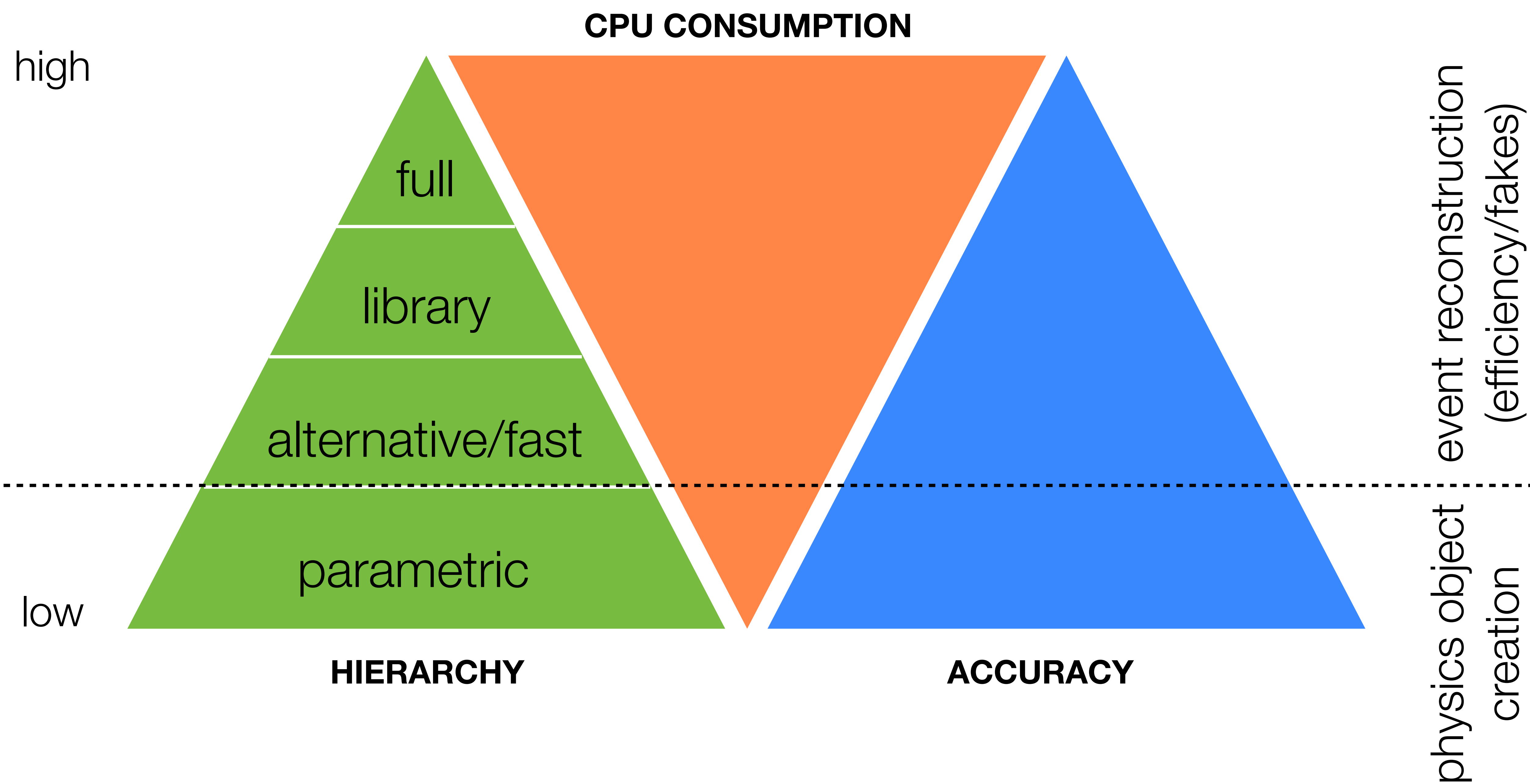
Fast simulation in ATLAS

A. Salzburger (CERN) for the ATLAS Simulation Team

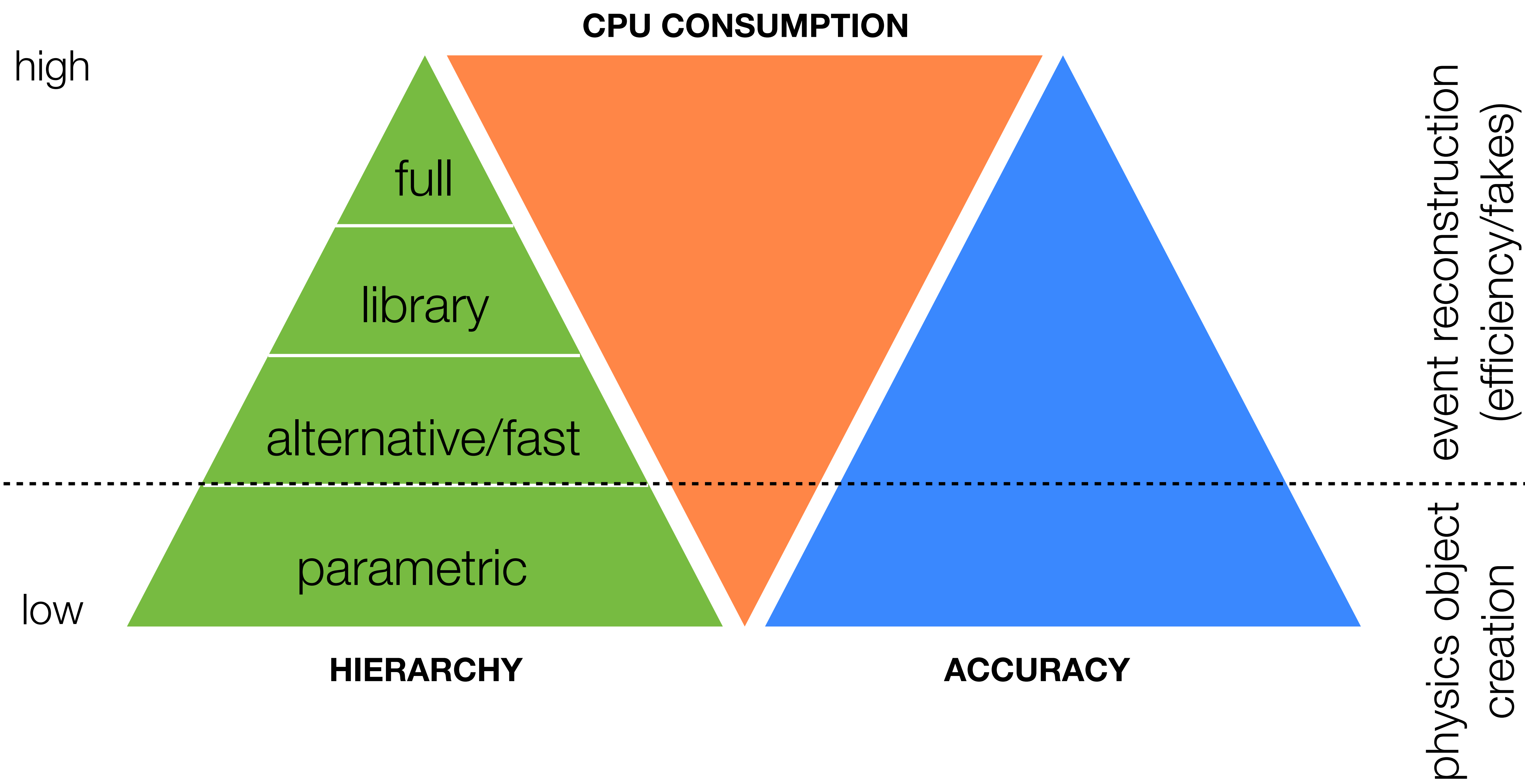
The simulation hierarchy pyramid



The simulation hierarchy pyramid

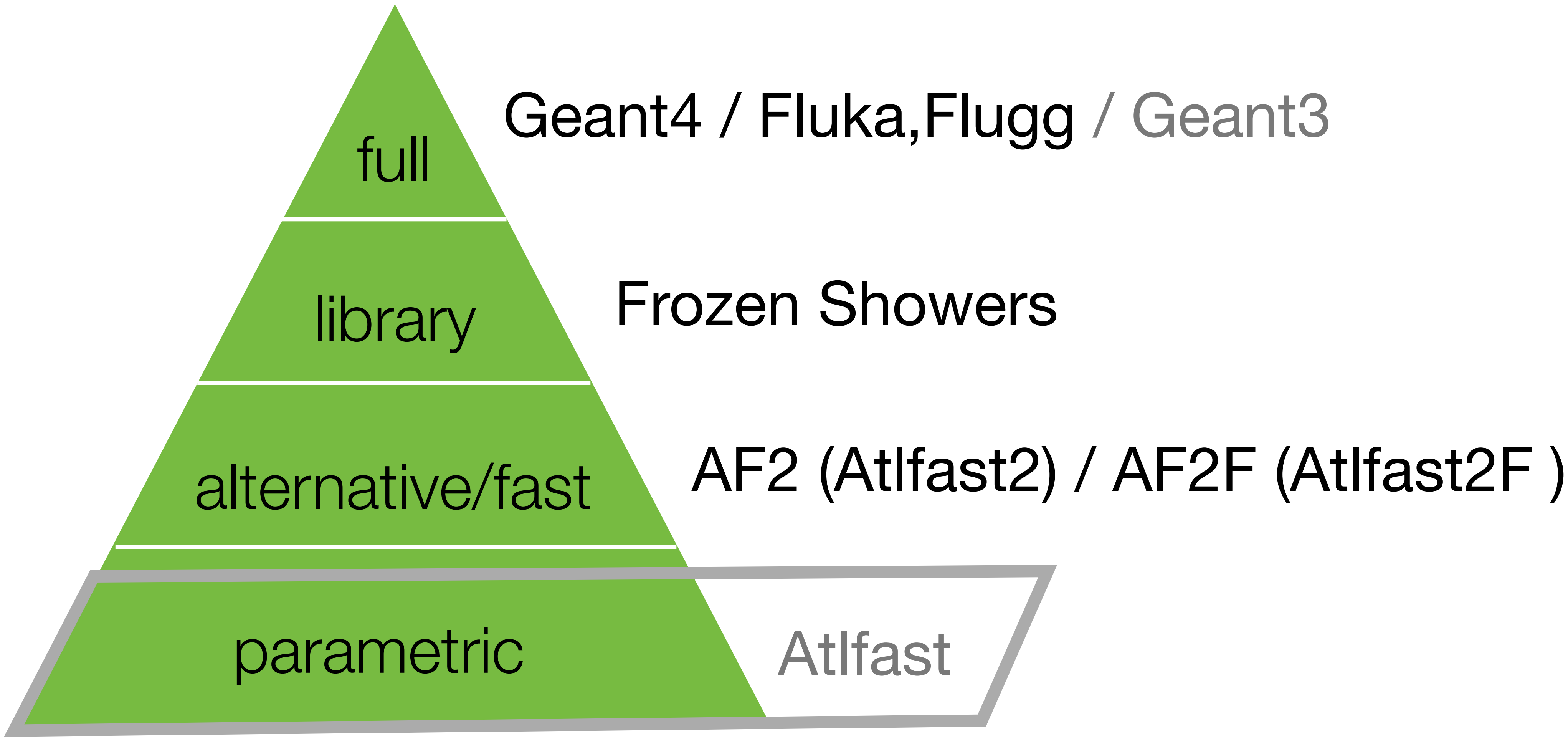


The simulation hierarchy pyramid



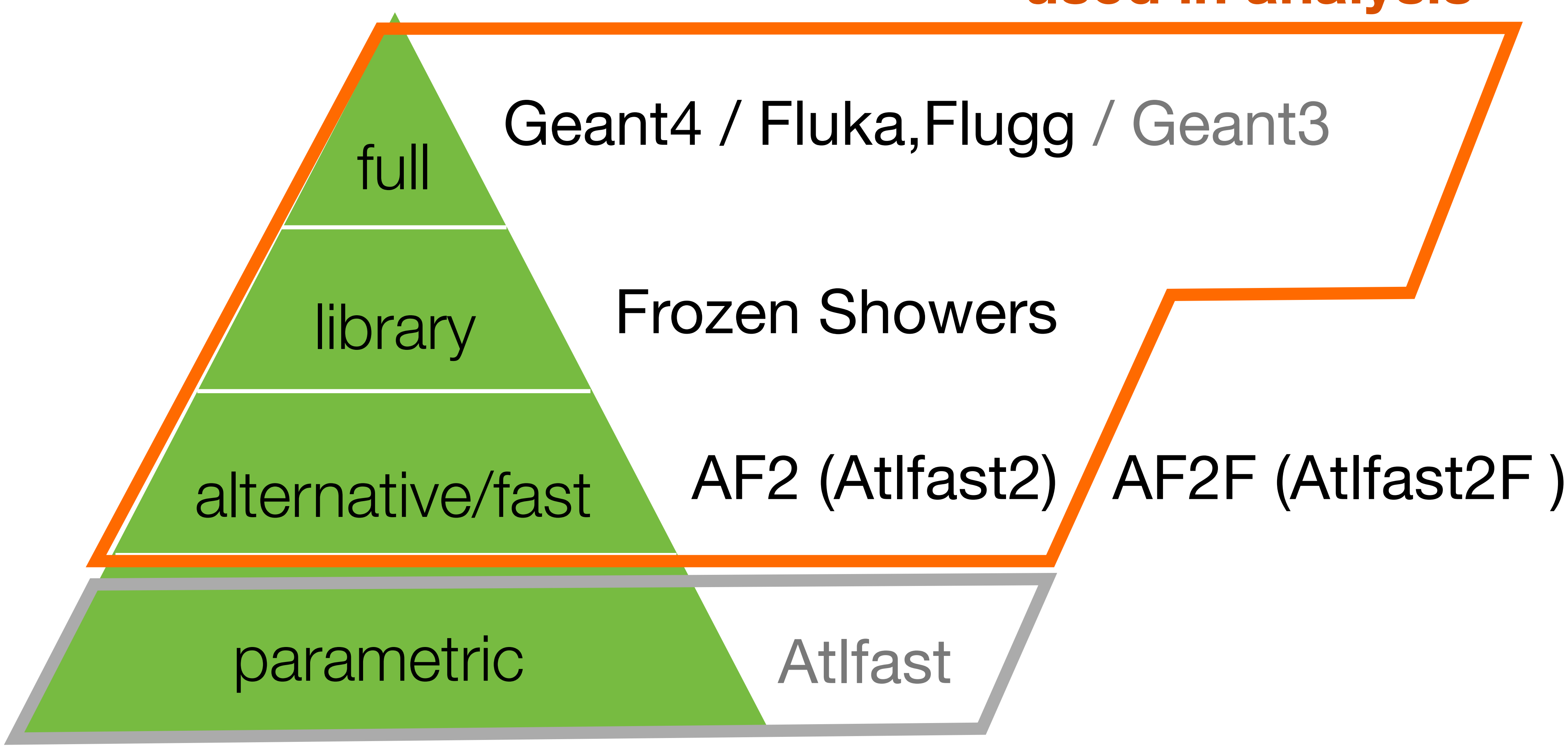
*the picture is quite trivial, finding the optimal working point is NOT !

The simulation history in ATLAS (until recently)



- Unfortunately these all have "grown" indepdently
  - different configuration, steering
  - different output format

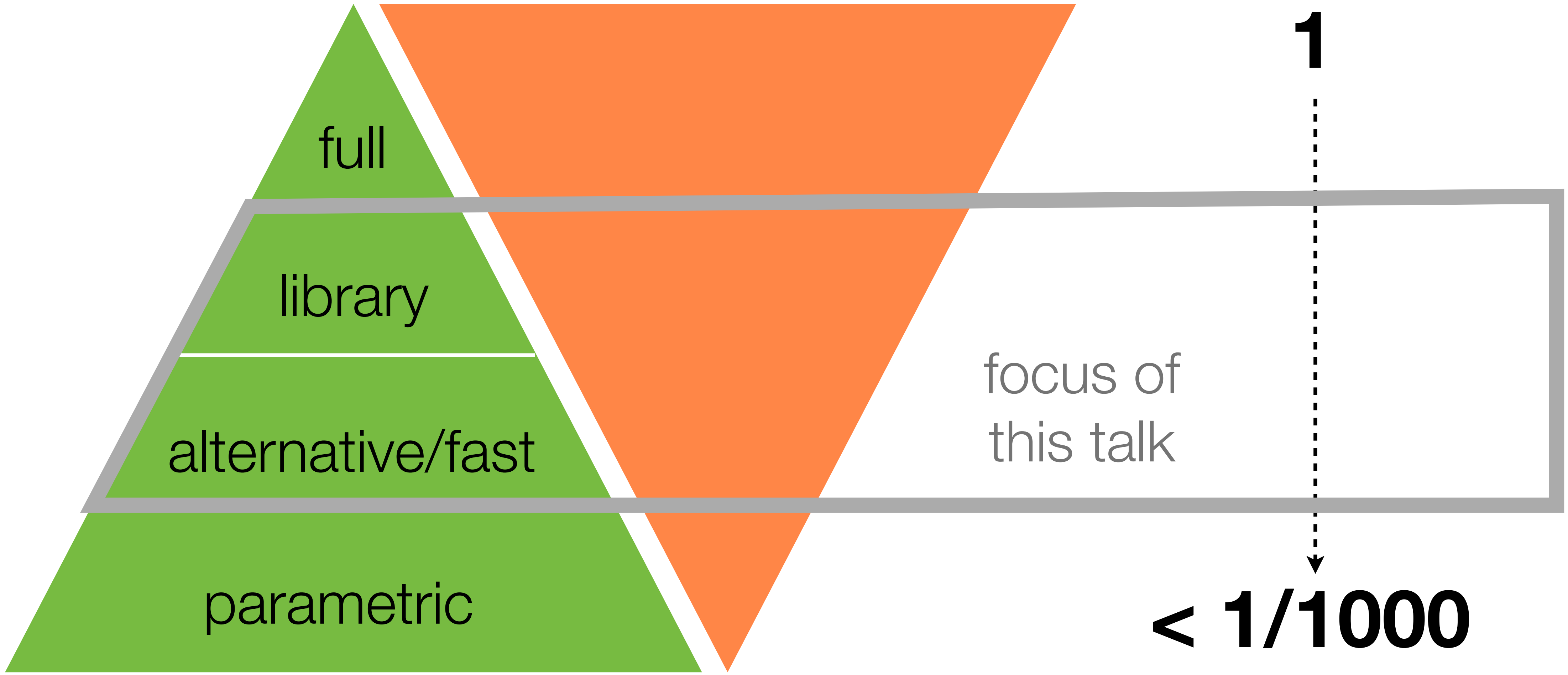
The simulation history in ATLAS (until recently)



used extensively for the TDR (late 1990's)

- Unfortunately these all have "grown" indepdently
  - different configuration, steering
  - different output format

Potential speed-ups: simulation



- Fast simulation sets the simulation into the ~ Hz level regime
- Has many more consequences (see later)

A few comments on **Geant4**

- Also Geant4 can be/should be speed-optimised

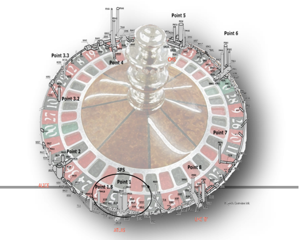
- Atlas imported its Runge-Kutta-Nystroem propagator into Geant4
  - is significantly faster
  - showed a higher accuracy in long extrapolation tests

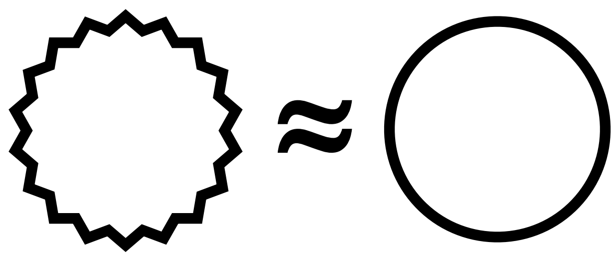
- Complete rework of Magnetic field access in ATLAS
  - including cell caching to optimise memory lookup: reduced cache misses dramatically
  - field access from above 10-15 % down to 2 %

- Very careful cut setting to avoid following low momentum particles

How to speed up simulation (1)

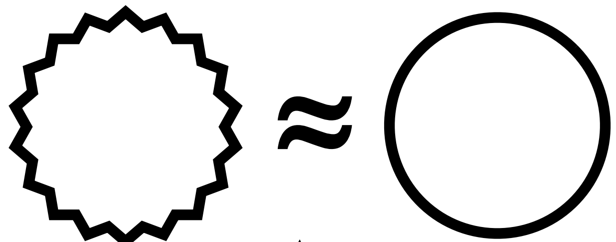
How to speed up simulation (1)



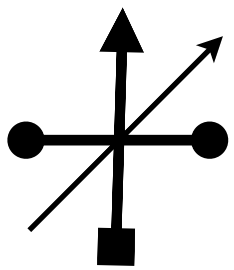


approximate geometry

How to speed up simulation (1)

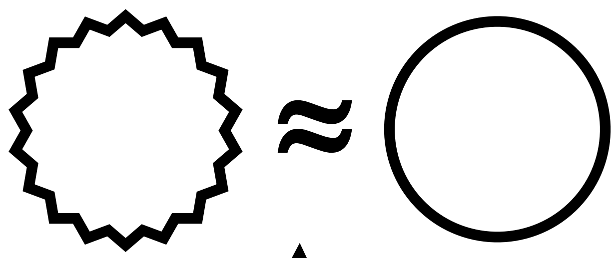


approximate geometry

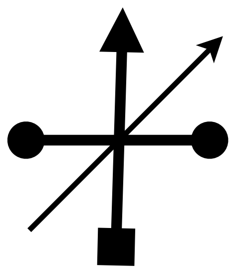


optimise transport and navigation

How to speed up simulation (1)



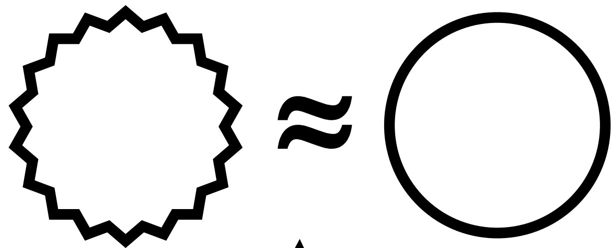
approximate geometry



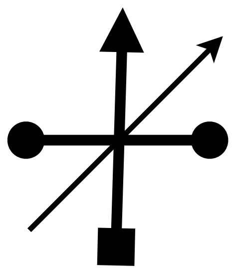
optimise transport and navigation

$\pi \approx 3$ approximate models

How to speed up simulation (1)

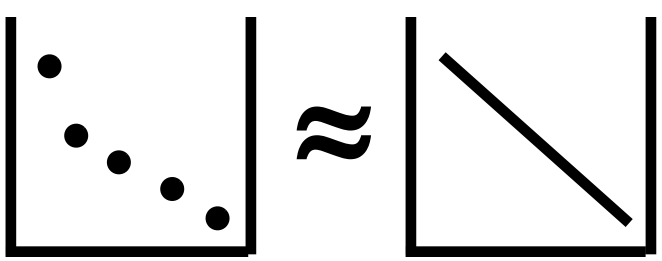


approximate geometry



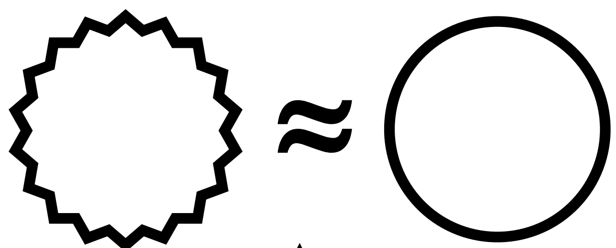
optimise transport and navigation

$\pi \approx 3$ approximate models

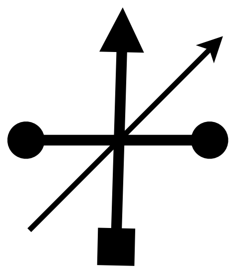


parameterisations

How to speed up simulation (1)



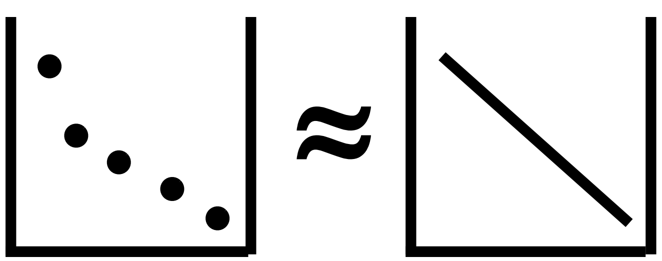
approximate geometry



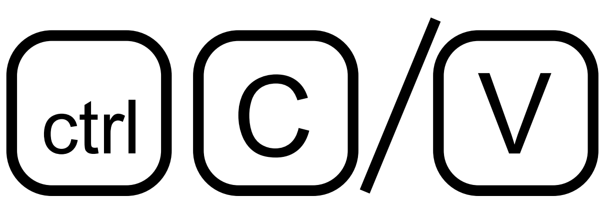
optimise transport and navigation

$\pi \approx 3$

approximate models

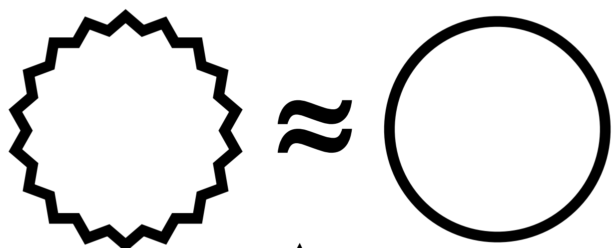


parameterisations

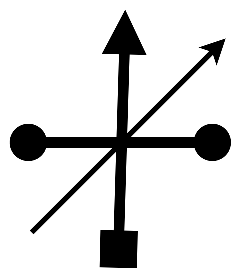


take shortcuts

How to speed up simulation (1)



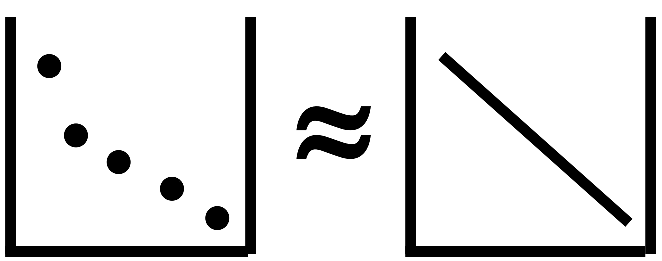
approximate geometry



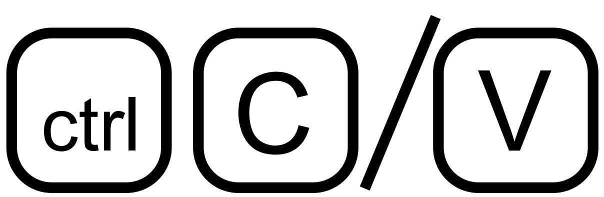
optimise transport and navigation

$\pi \approx 3$

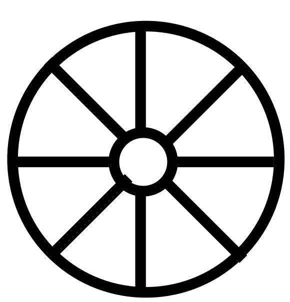
approximate models



parameterisations



take shortcuts

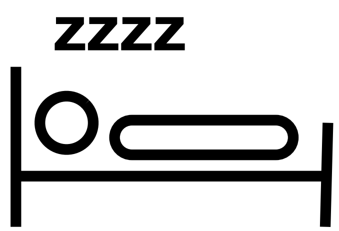


use new technologies

How to speed up simulation (2)

...

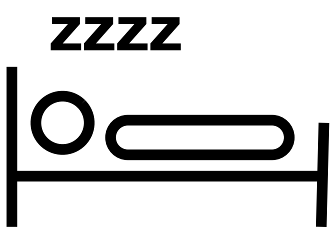
How to speed up simulation (2)



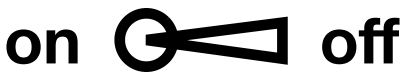
don’t do anything

...

How to speed up simulation (2)



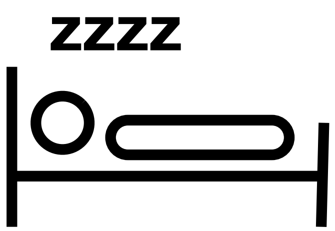
don’t do anything



work only on demand

...

How to speed up simulation (2)



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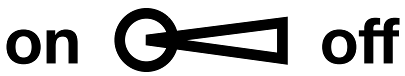


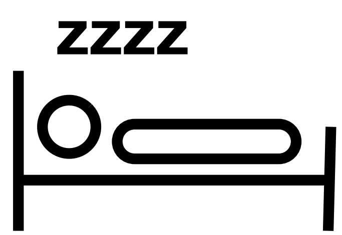
work only on demand

1 €	2 DM
2 €	4 DM

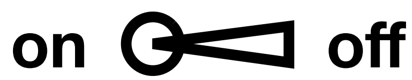
use look-up tables

...

How to speed up simulation (2)



don’t do anything



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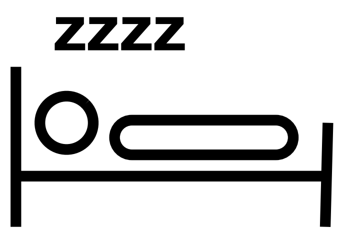
use look-up tables

throw away things

...

How to speed up simulation (2)



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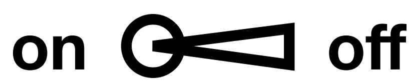

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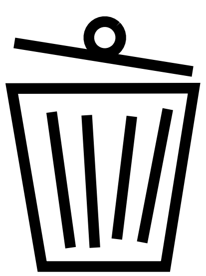
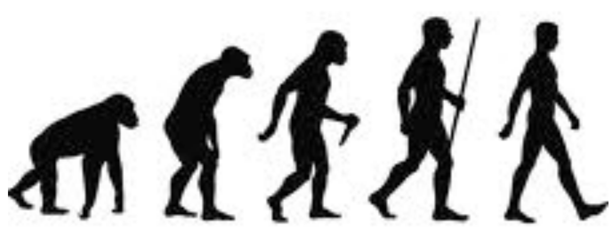


throw away things



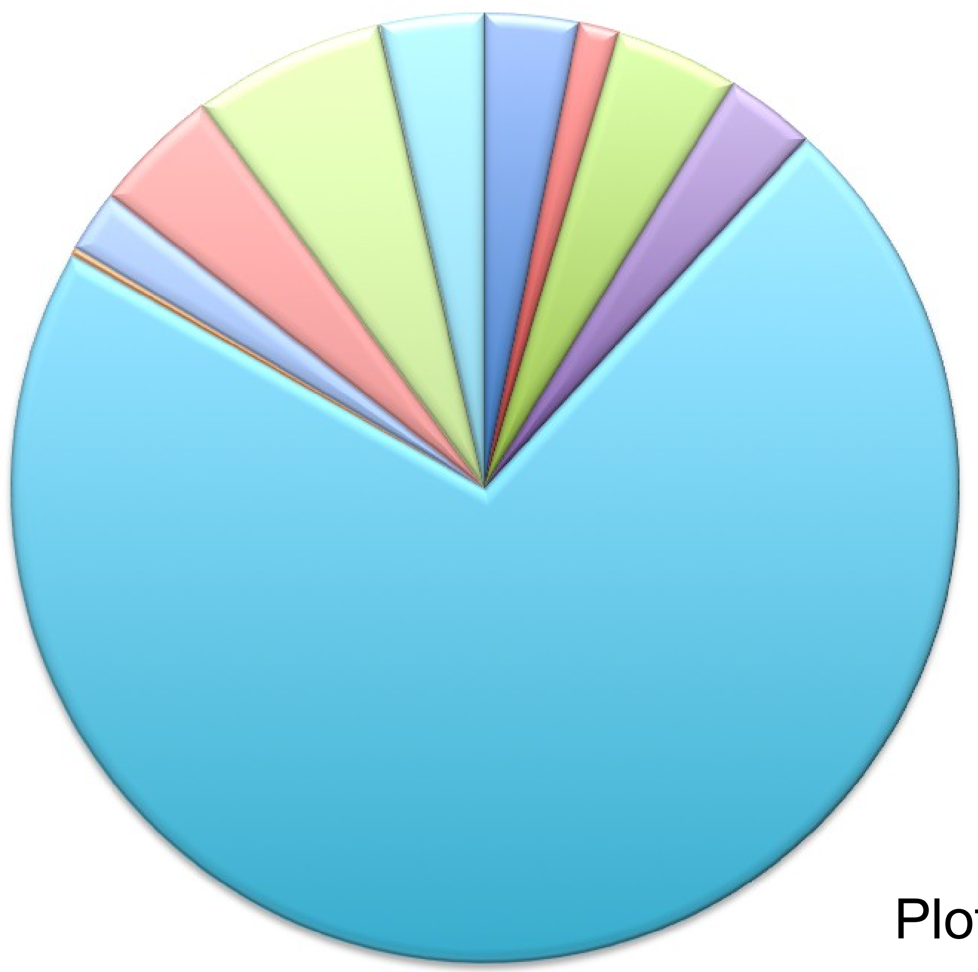
ignore the truth

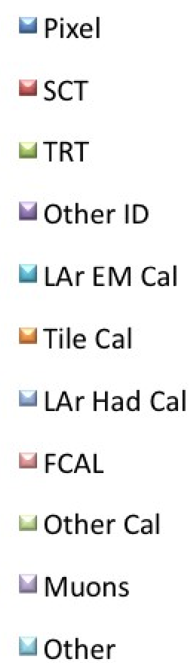
...

CPU time spent in ATLAS Calorimeter

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

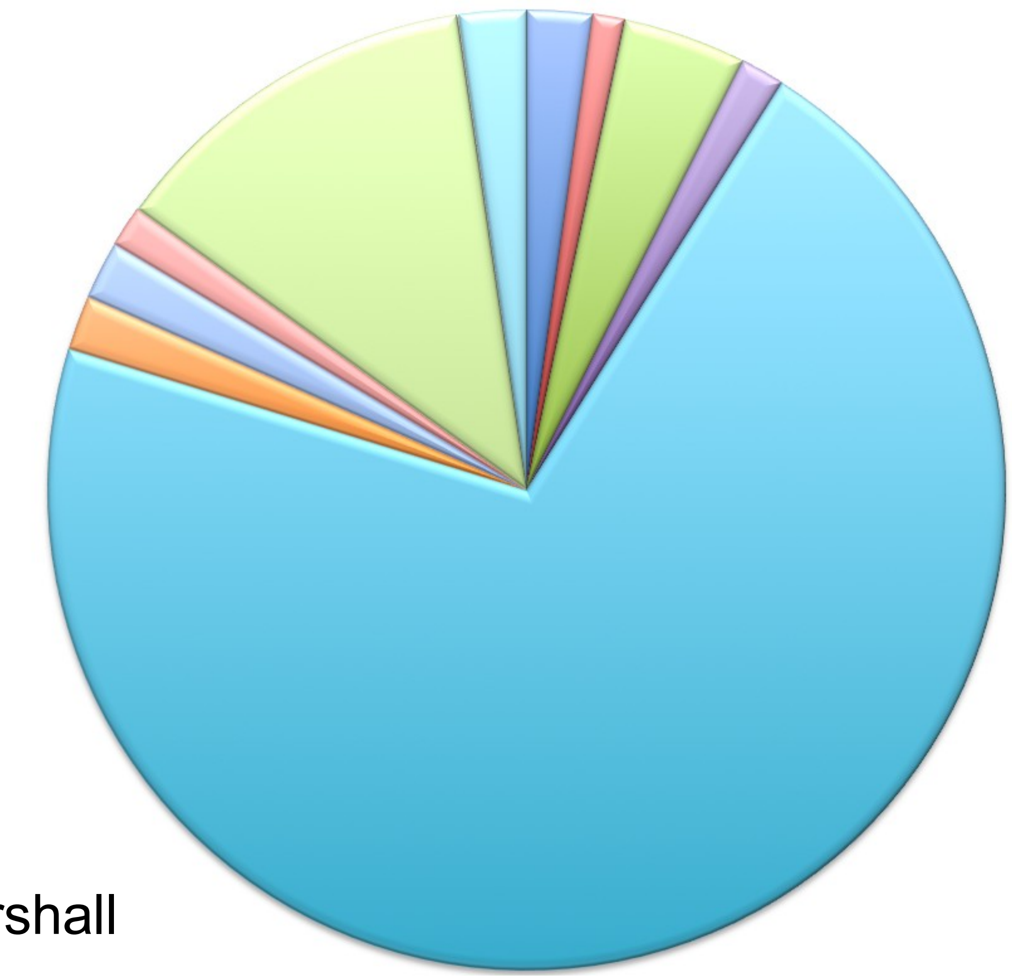
i686-slc5-gcc43-opt





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

i686-slc5-gcc43-opt



Plots by Z Marshall

Oct 2011

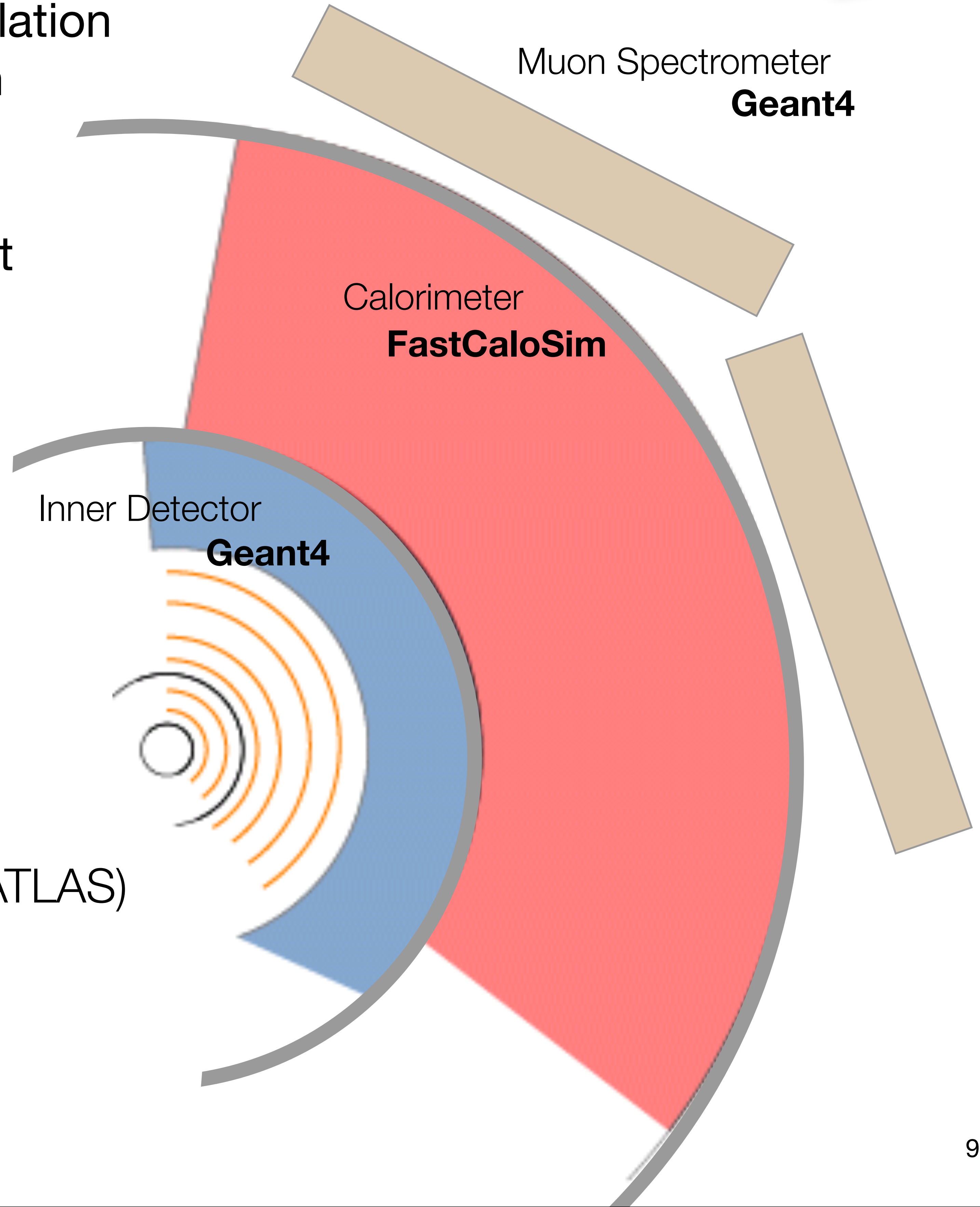
Replacing the slowest module - **AF2**

- Replacement of calorimeter simulation with parameterised **FastCaloSim**

- Relative CPU speed improvement w.r.t full Geant4 simulation:

  ~ 20

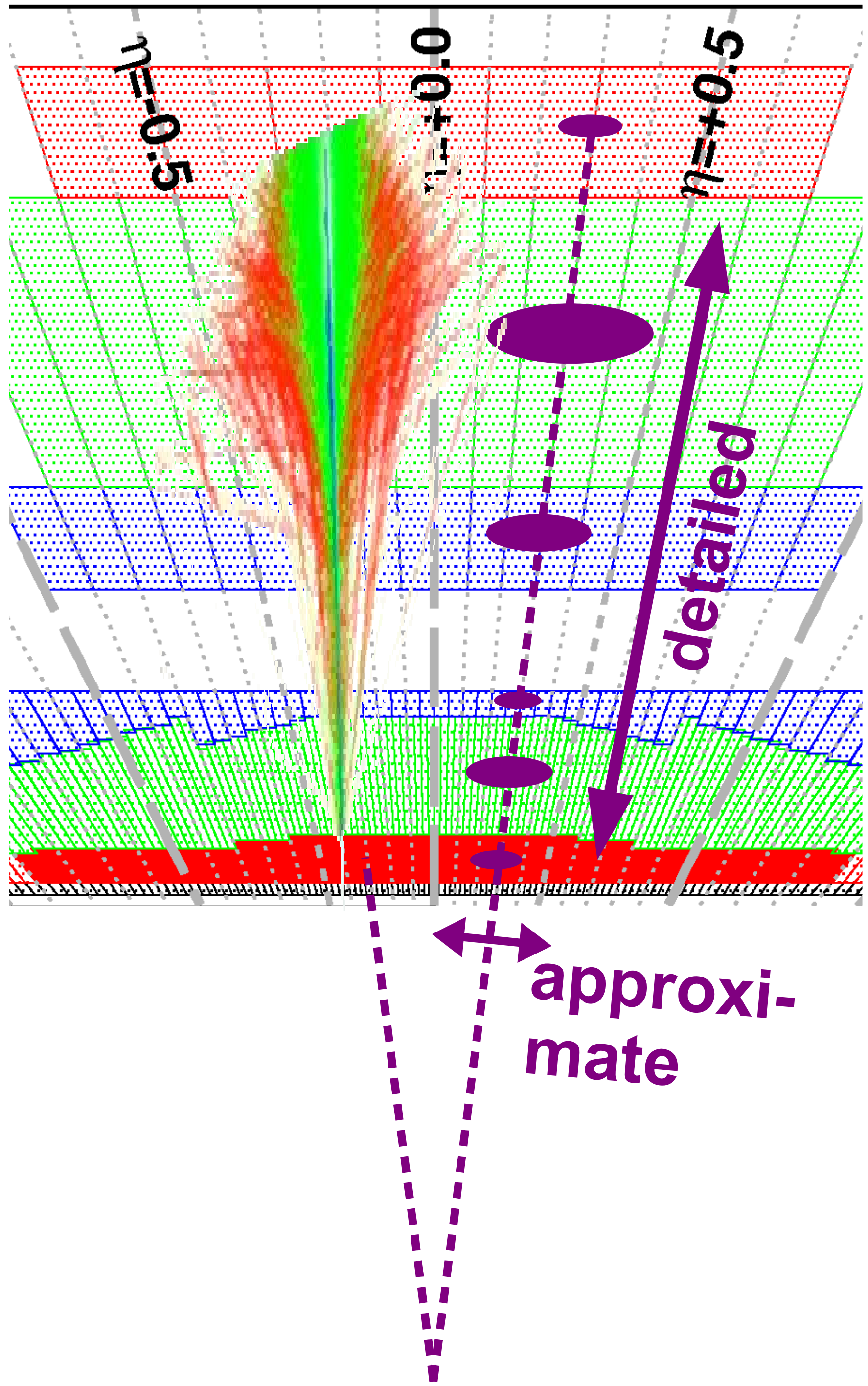
- **Drawbacks:**
  - simplifications in shower shapes (less fluctuations)
  - per se no hadronic leakage into Muon Spectrometer (can be and is parameterised in ATLAS)



AF2 - FastCaloSim

Full simulation

- Detector as built with all complications
- All physics processes for all primary and secondary particles.
- Tracking of shower development through the calorimeter in fine steps

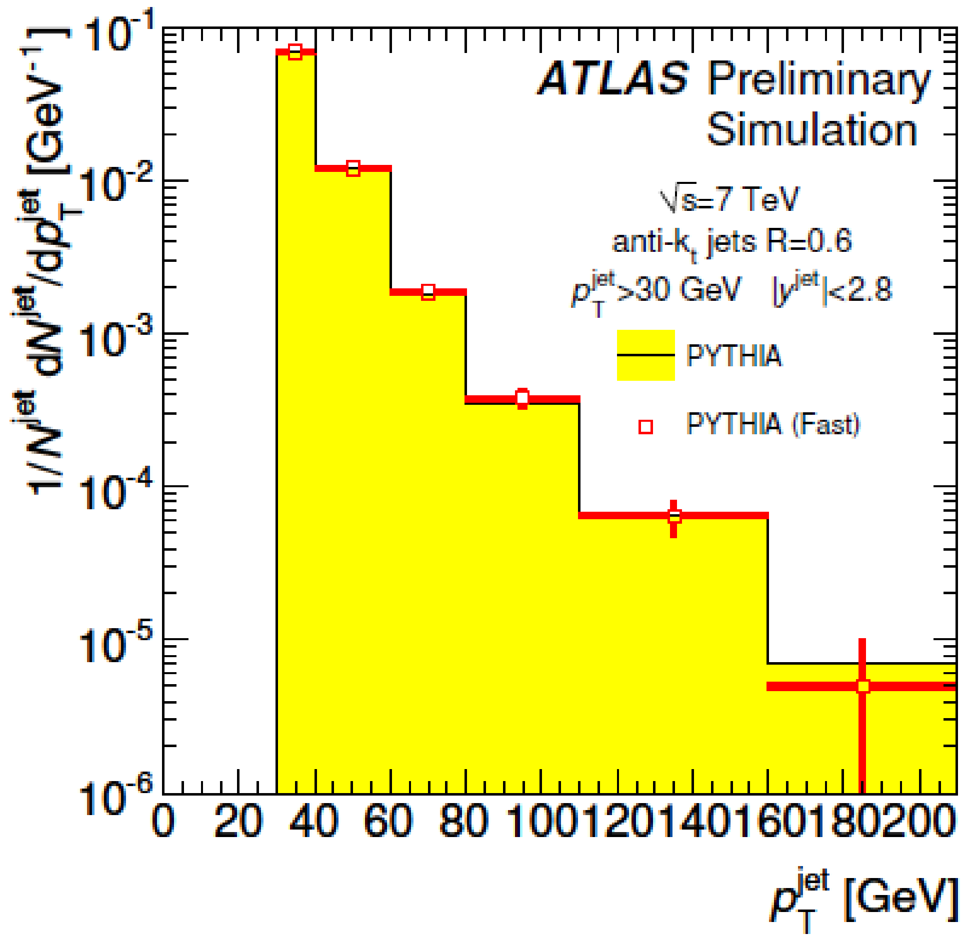


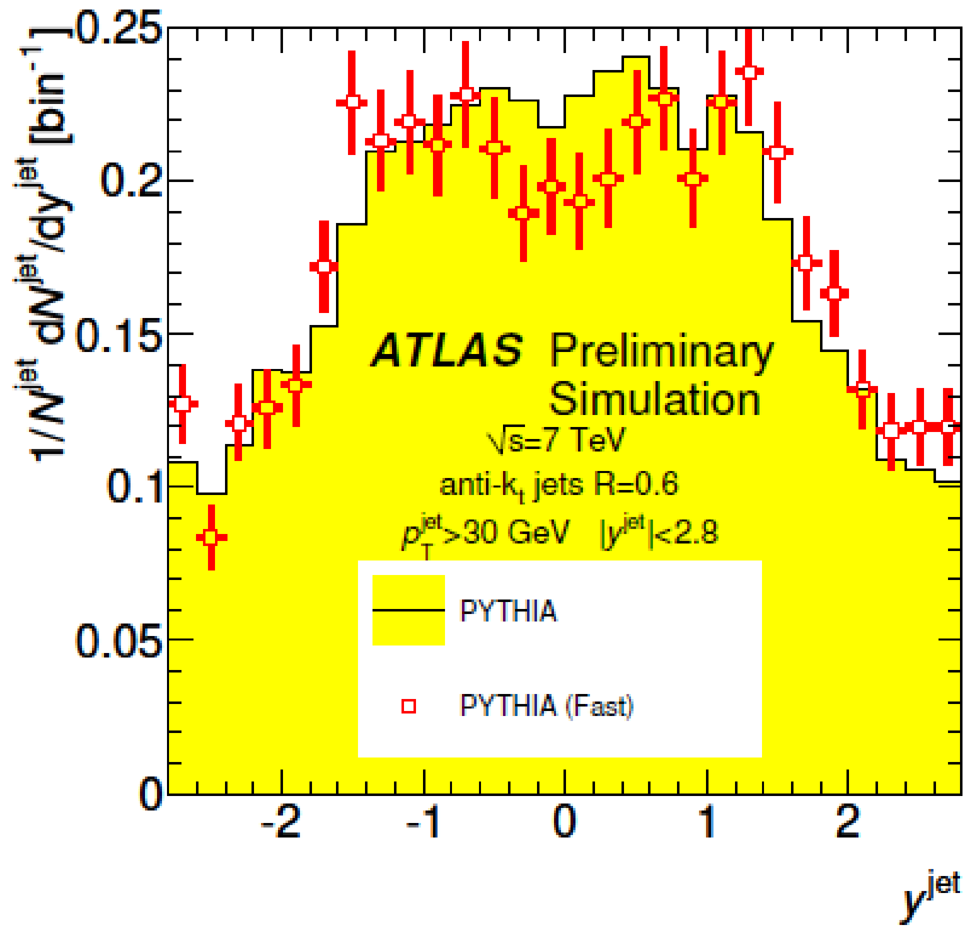
FastCaloSim

- Simple reconstruction geometry with only ~185000 cells
- Energy and shape parametrization only for photons and charged pions. Parametrization derived from ~30M fully simulated single particle events
- Deposition of the particle energy in each calorimeter layer in one step.

AF2 - Jets

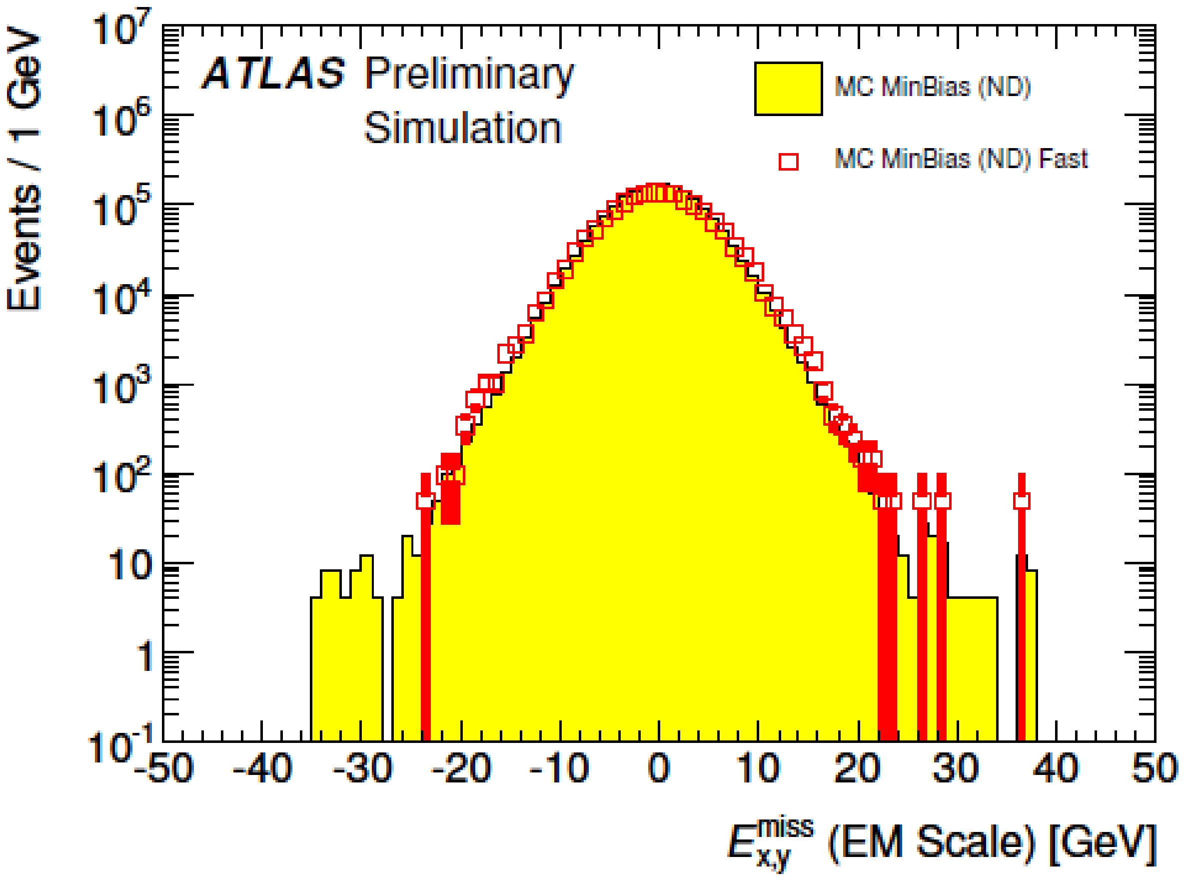
- **Agreement for inclusive jet quantities within a few % of full simulation out of the box**
- **Improved by now by**
  - using dedicated jet calibrations for Atlfast-II
  - having pileup which “smears” full and fast simulation in the same way – removes many small differences!

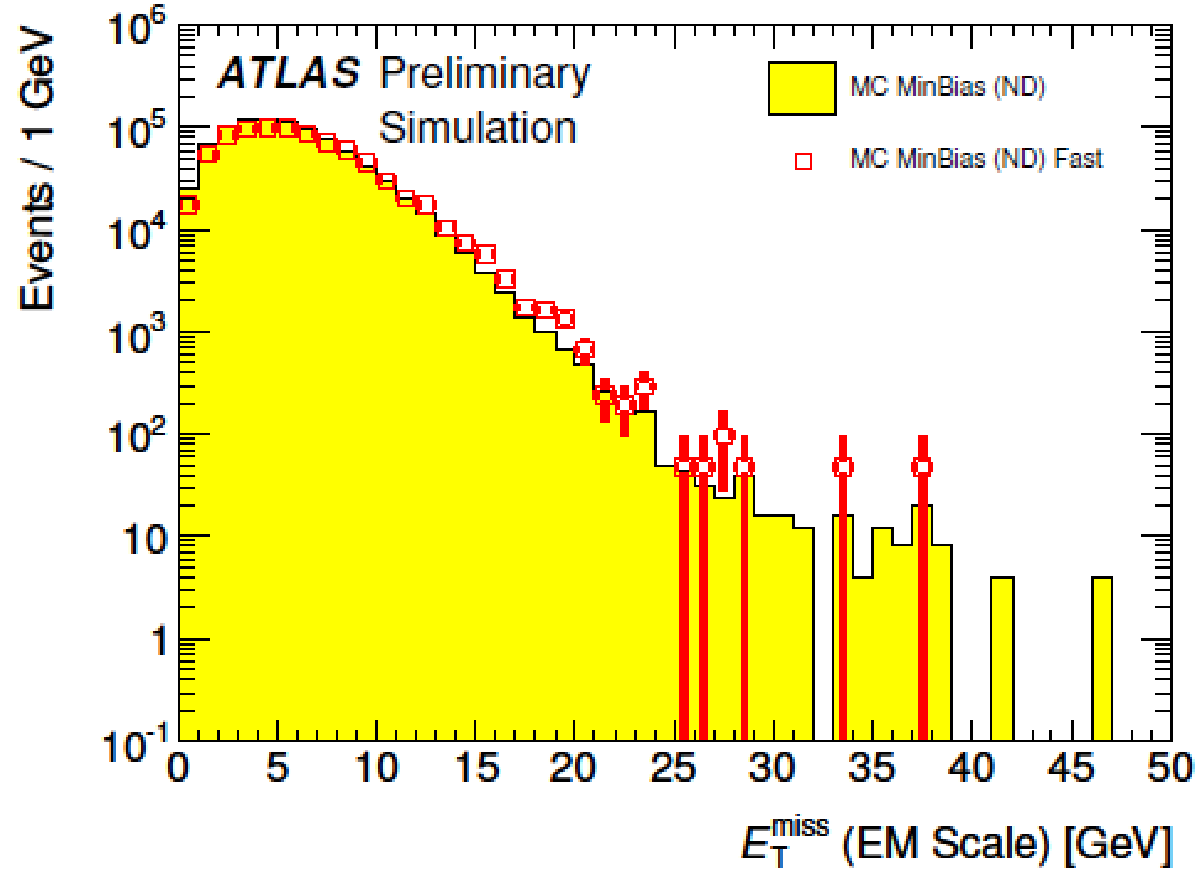




AF2 - MET

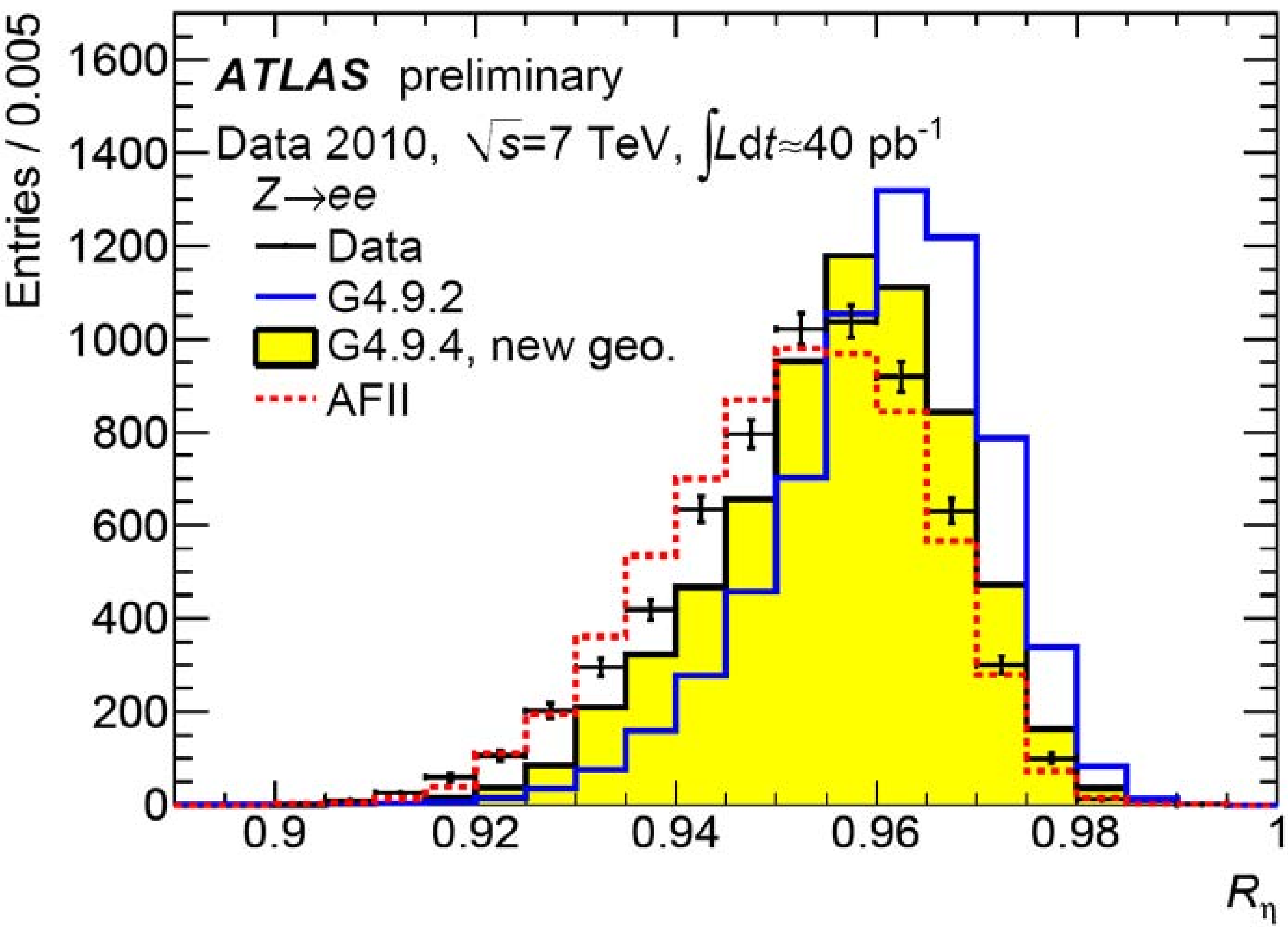
- **Good agreement for the bulk of the distributions, but differences appear in the tails**
- **Improved by now by**
  - using dedicated jet calibrations for Atlfast-II
    → removes most tails
  - Pileup actually dominates MET in 2012
    → including pileup causes MET to be in very good agreement





AF2 - Accuracy & Tuning

- 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**

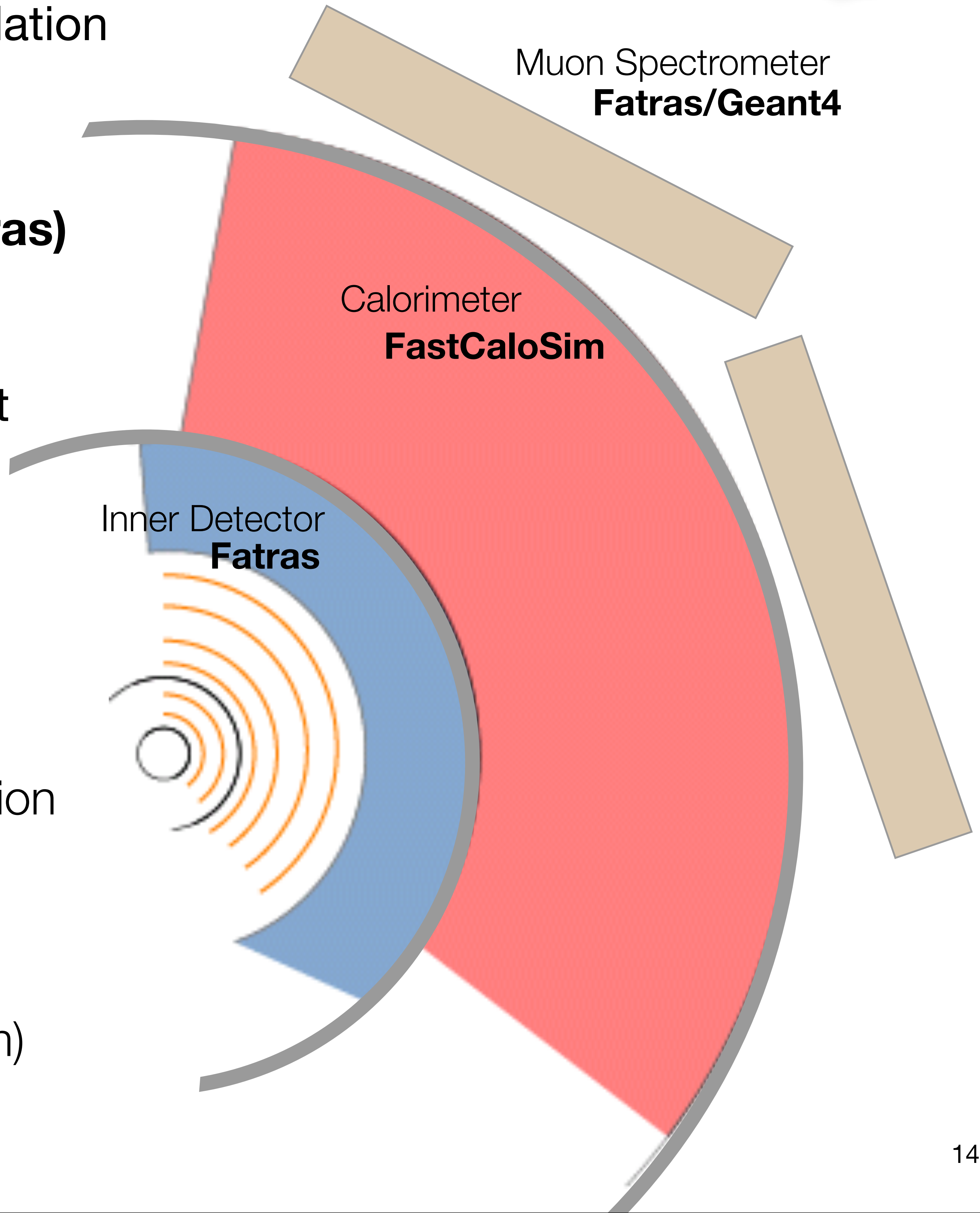


The next step - **AF2F/G**

- Replacement of calorimeter simulation with parameterised FastCaloSim
- Replacement of Track simulation with **Fast Track Simulation (Fatras)**
- Relative CPU speed improvement w.r.t full Geant4 simulation:

  > 100

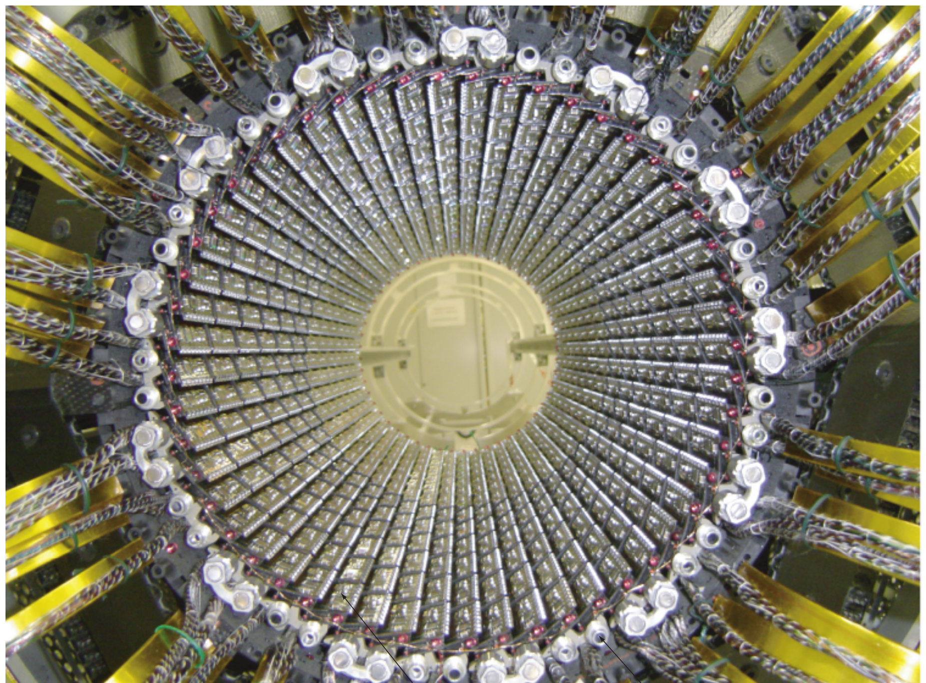
- **Drawbacks:**
  - simplifications of material integration (less tail effects in resolutions)
  - usually slightly higher simulation thresholds (affects hand-over to FastCaloSim)



Fatras - Tracking Geometry with navigation

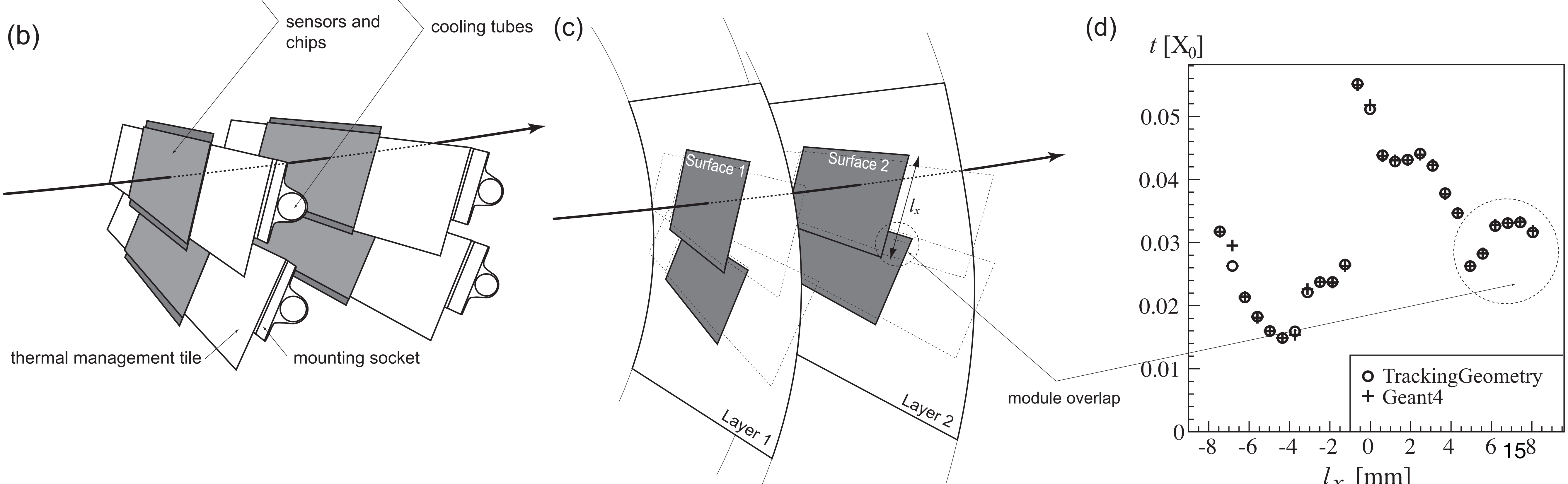
ATLAS TrackingGeometry

- Inner Detector & Calorimeter: simplification to layers and cylindrical volumes keeping the exact description of sensitive elements



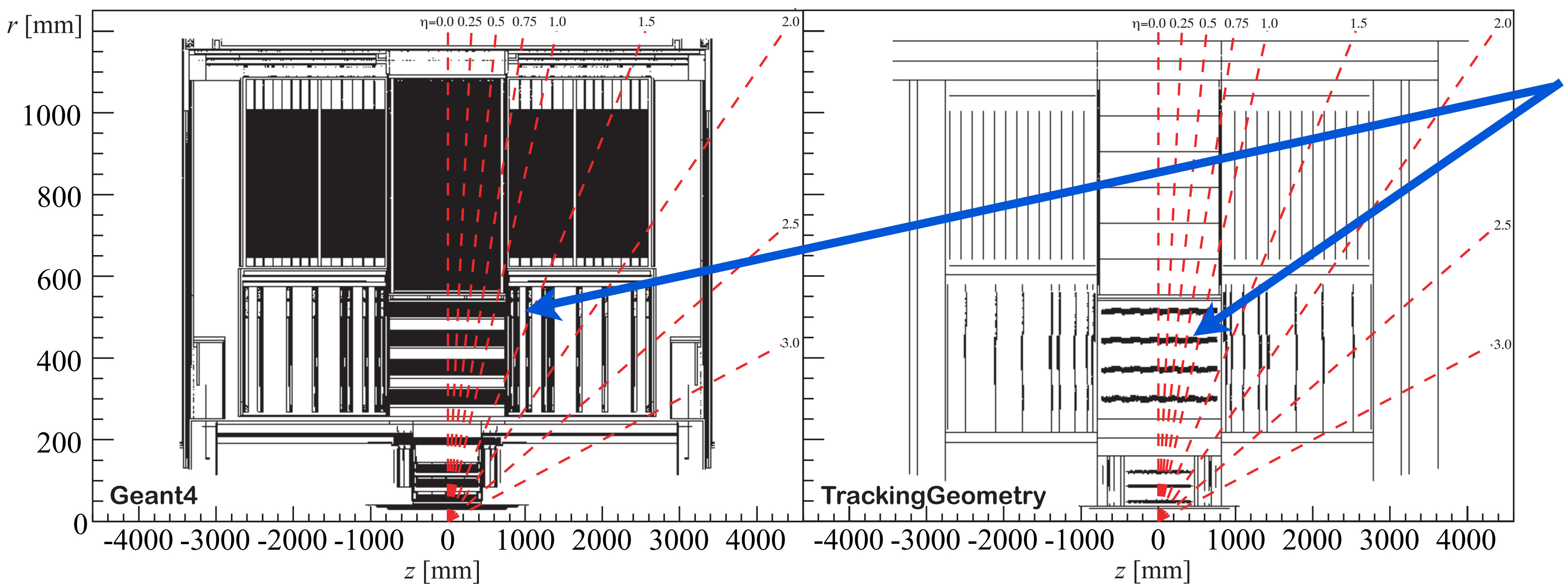
navigation through the geometry is only done using the layers and volume boundaries, modules are found by intersection with layer

material is mapped onto layers using Geant4 description and geantinos



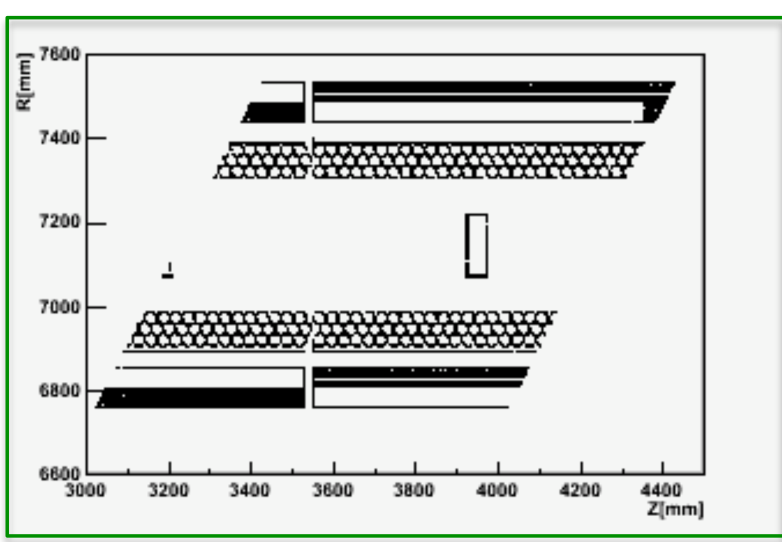
Fatras - Tracking Geometry with navigation

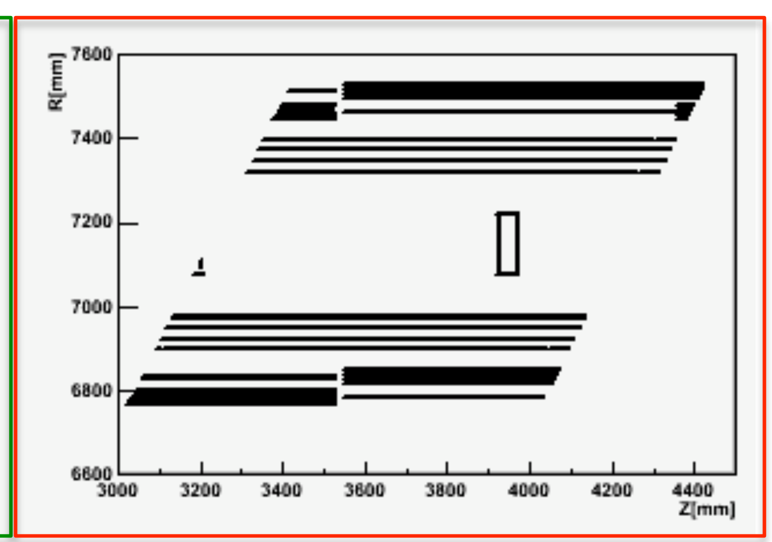
- *Example Inner Detector:*
  O(100) layers and detector boundaries

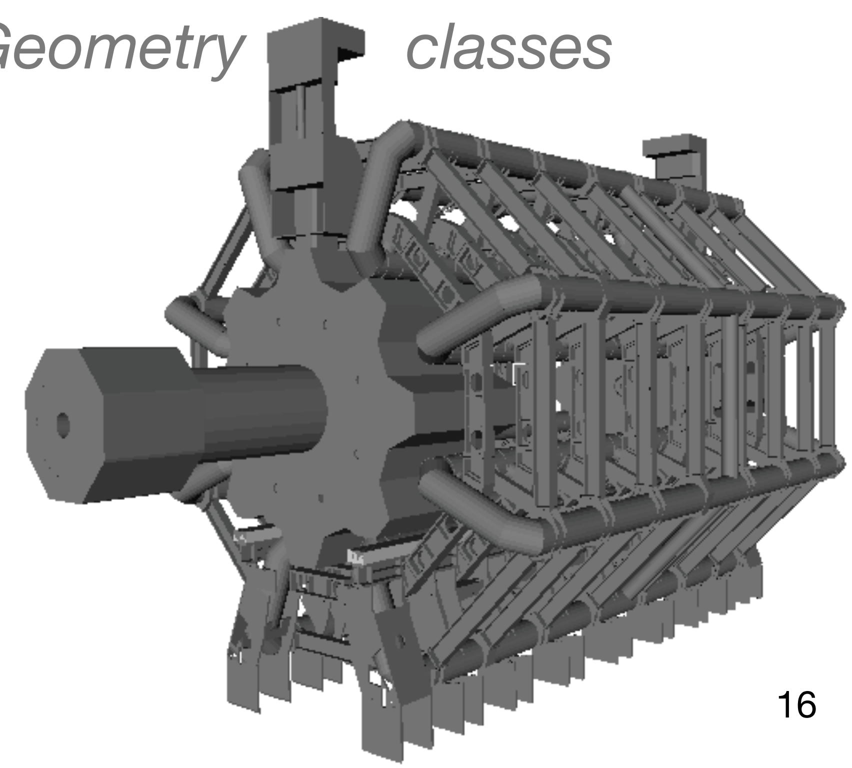


sensitive modules are identical

- *Muon System:*
  simplification of chambers & exact transcript into TrackingGeometry classes

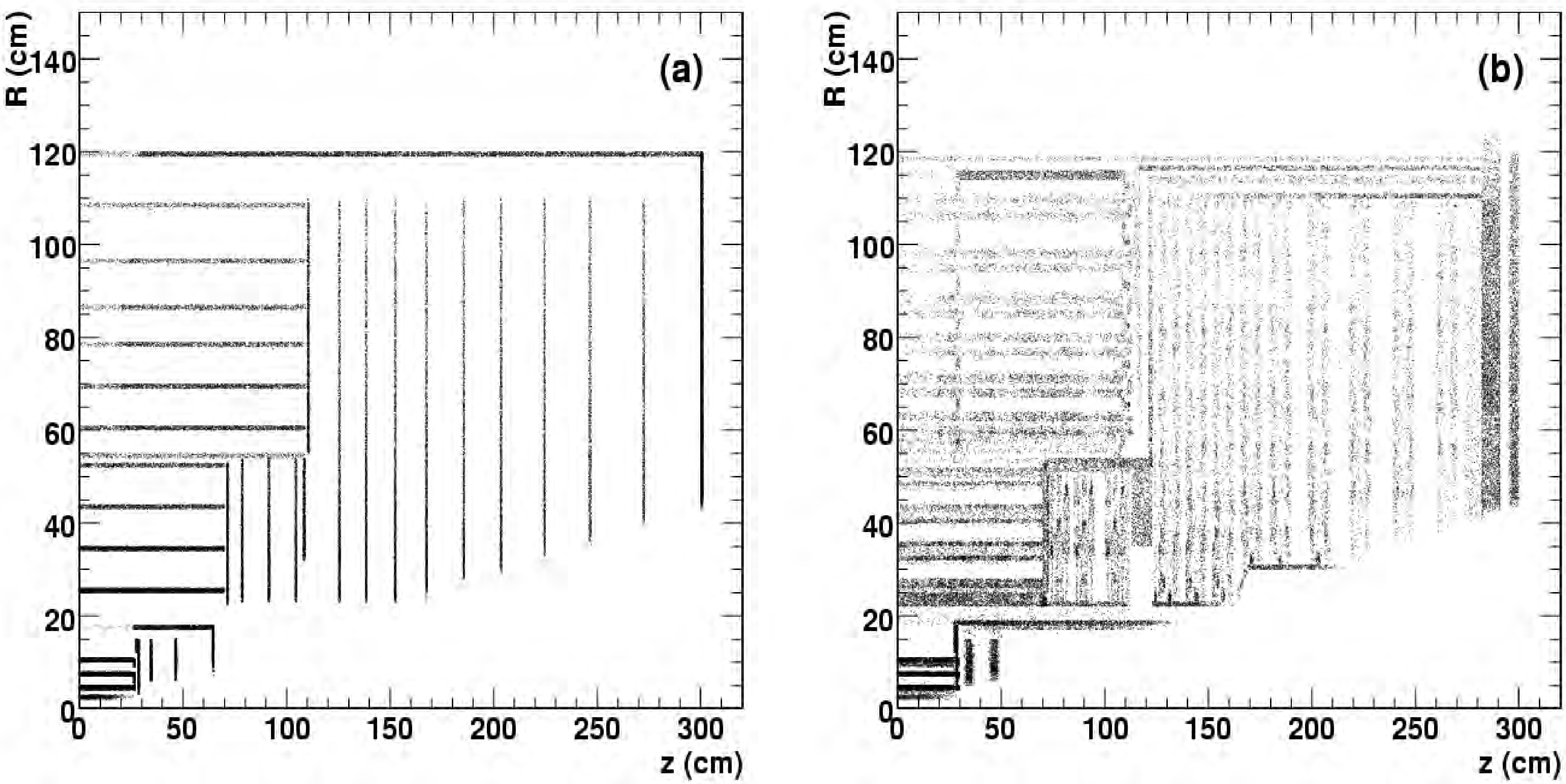






We're not the only smart ones: CMS

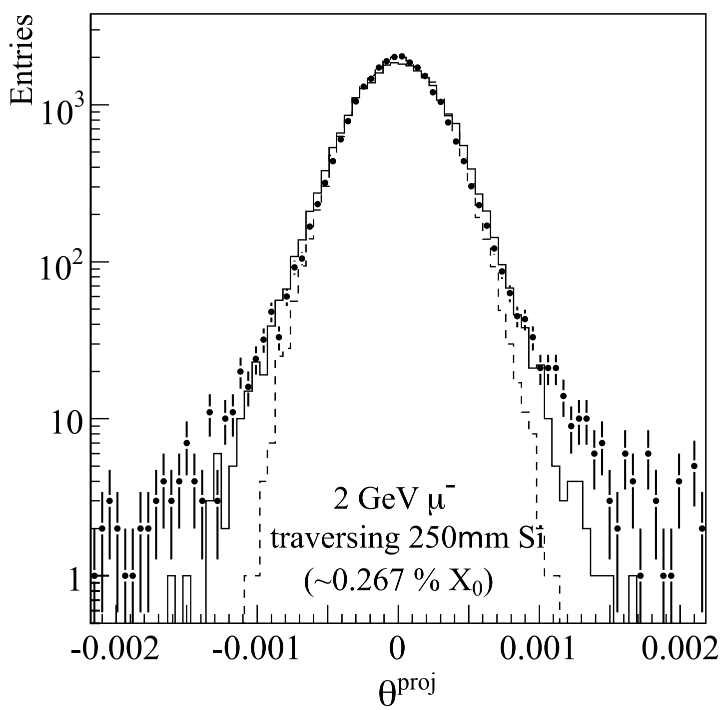
CMS



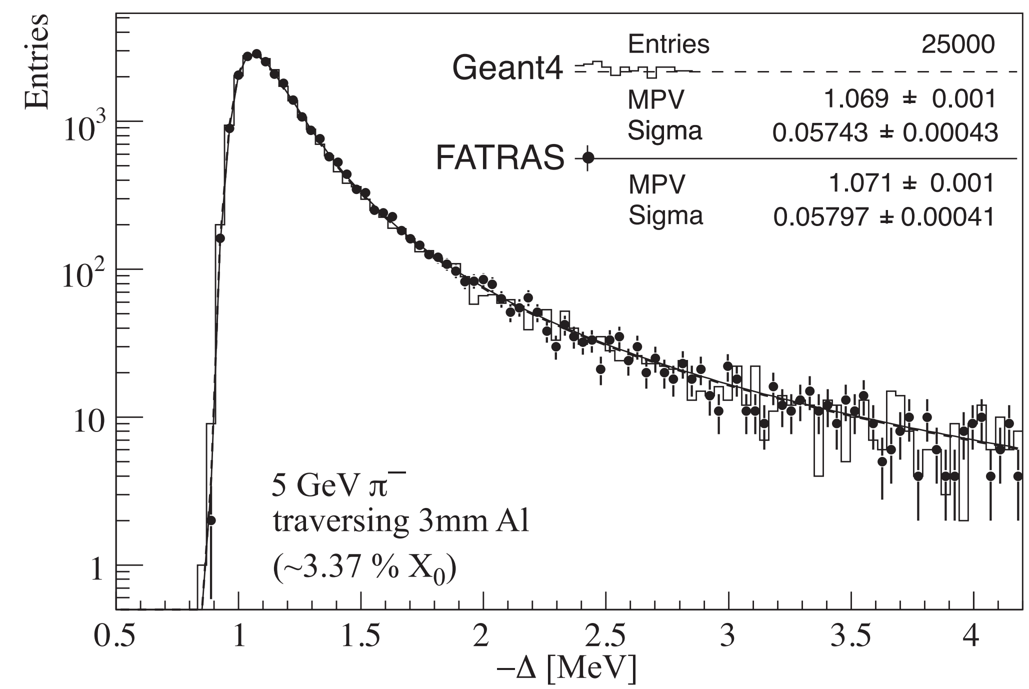
Fatras - simplified material effects

Parameterisation of material interactions

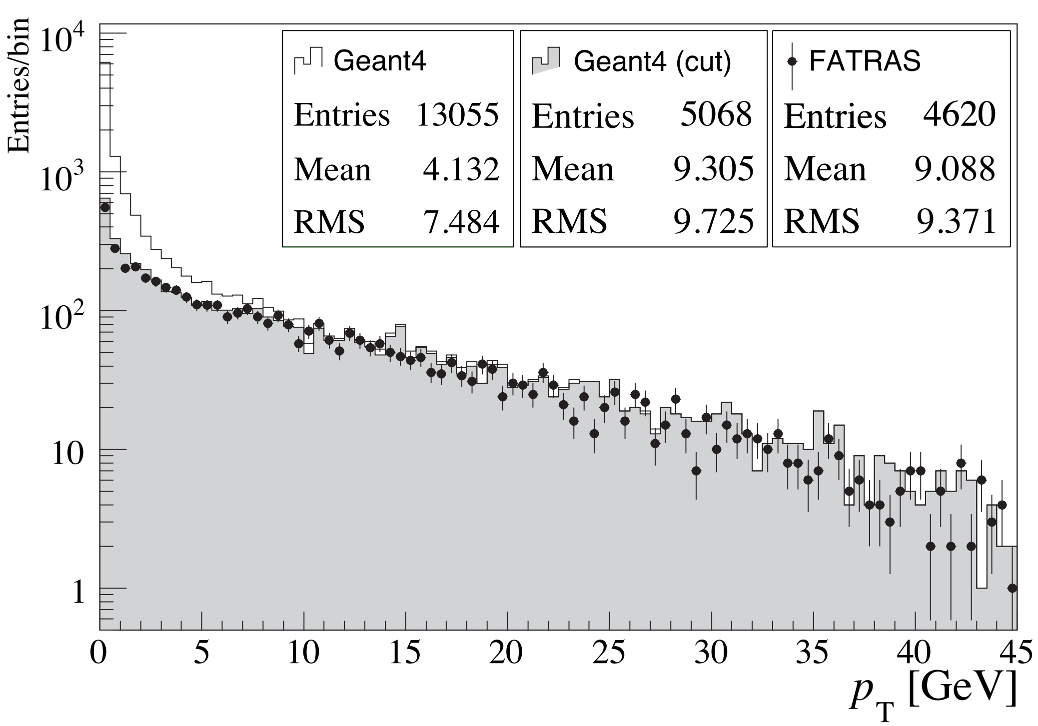
(a) multiple scattering



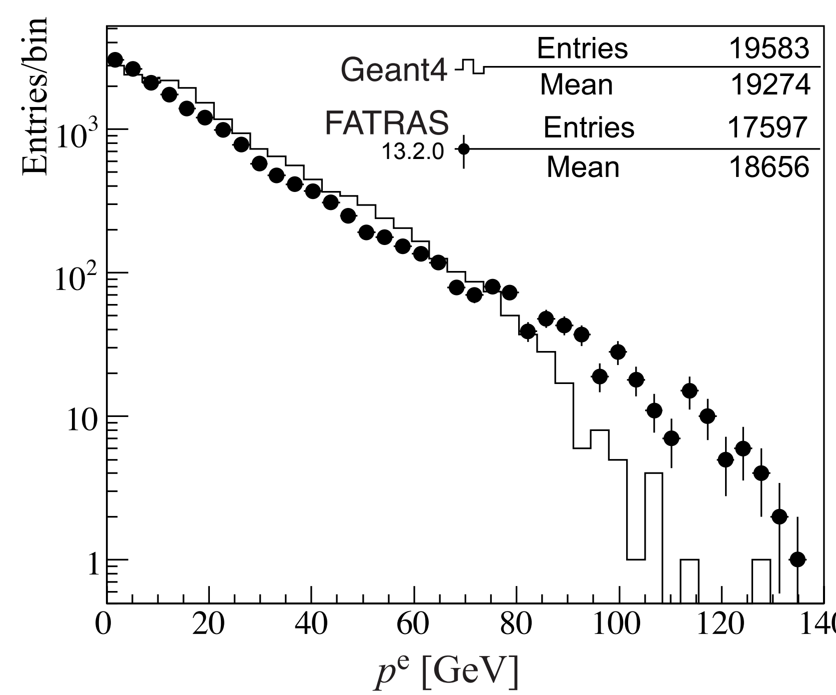
(b) ionisation energy loss



(c) brem photon radiation

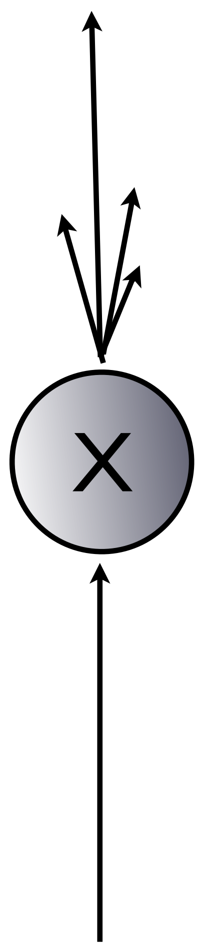


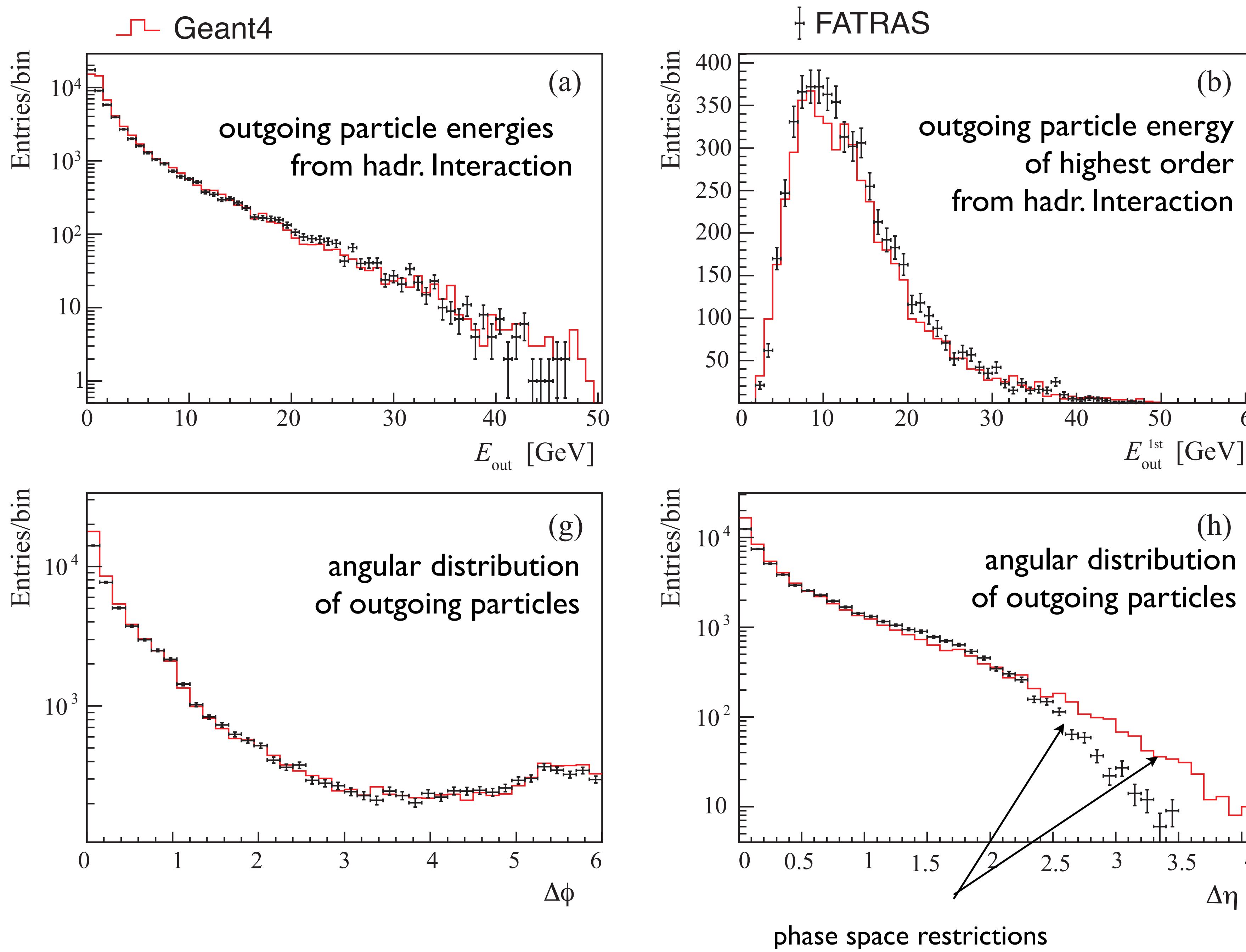
(d) brem photon conversion



Fatras - simplified material effects

(e) nuclear interactions (parametric model implemented)





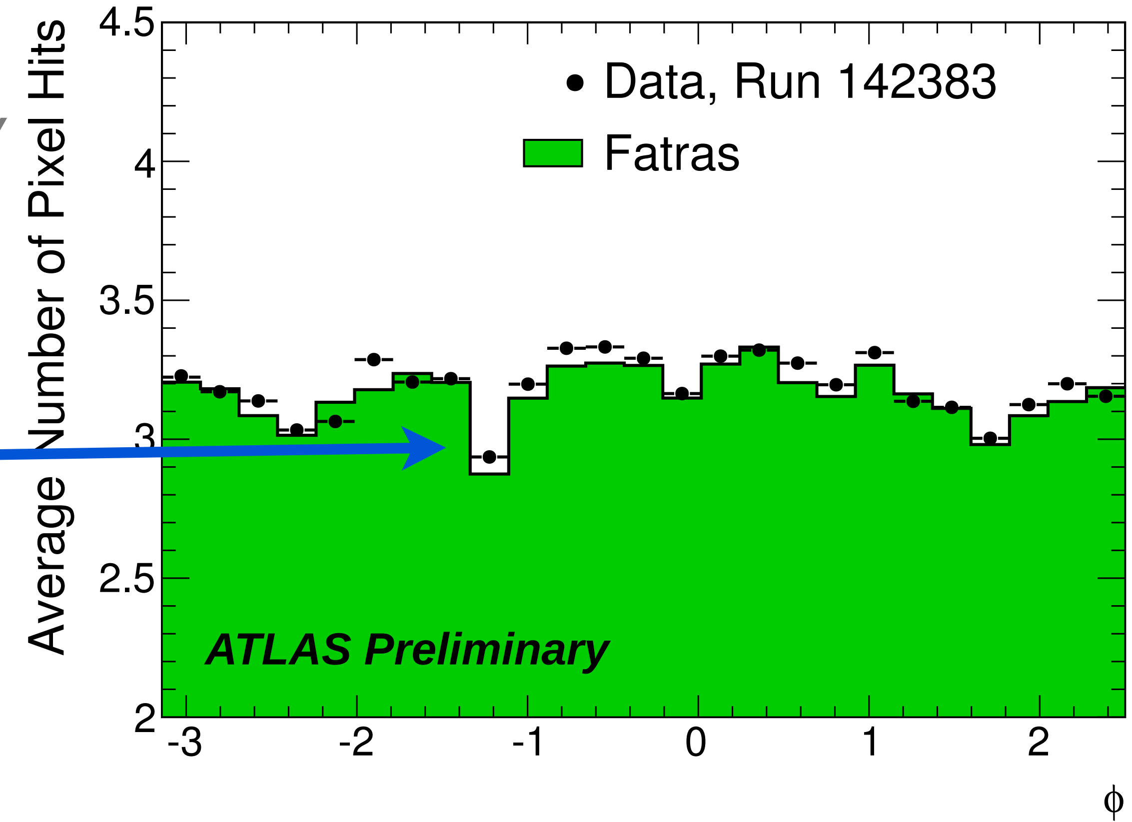
- Currently testing a Geant4 based hadronic interaction processor

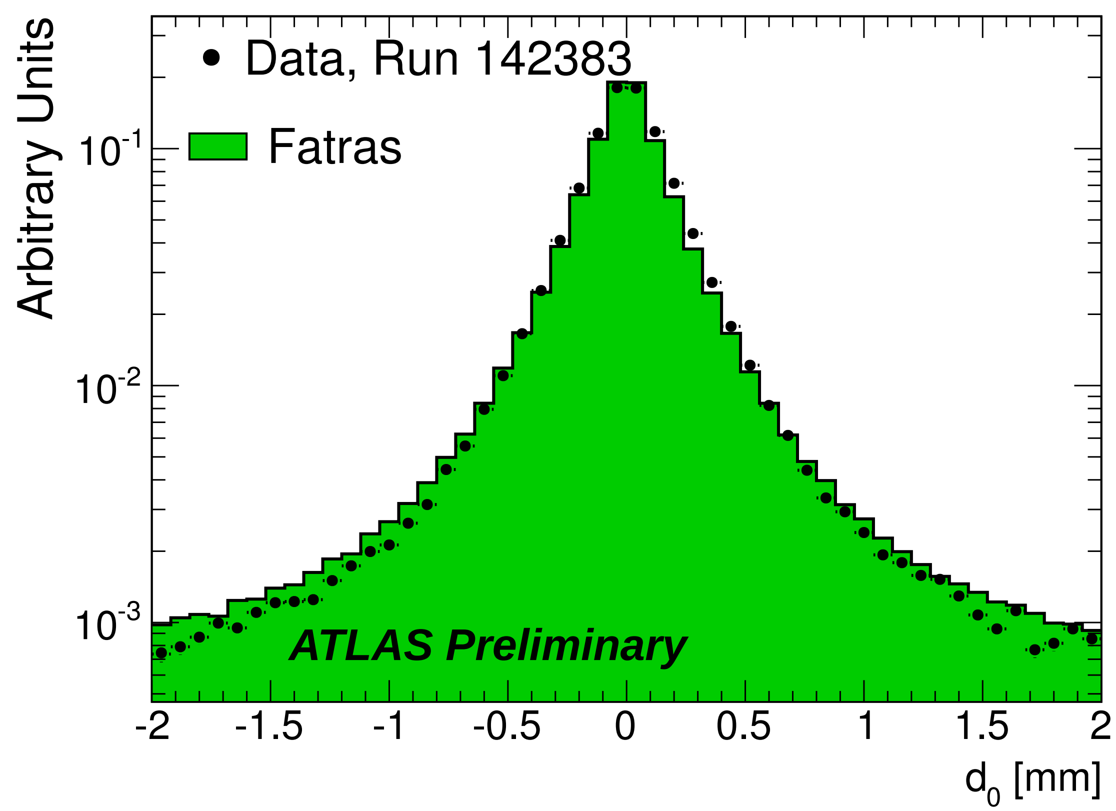
Fatras - performance

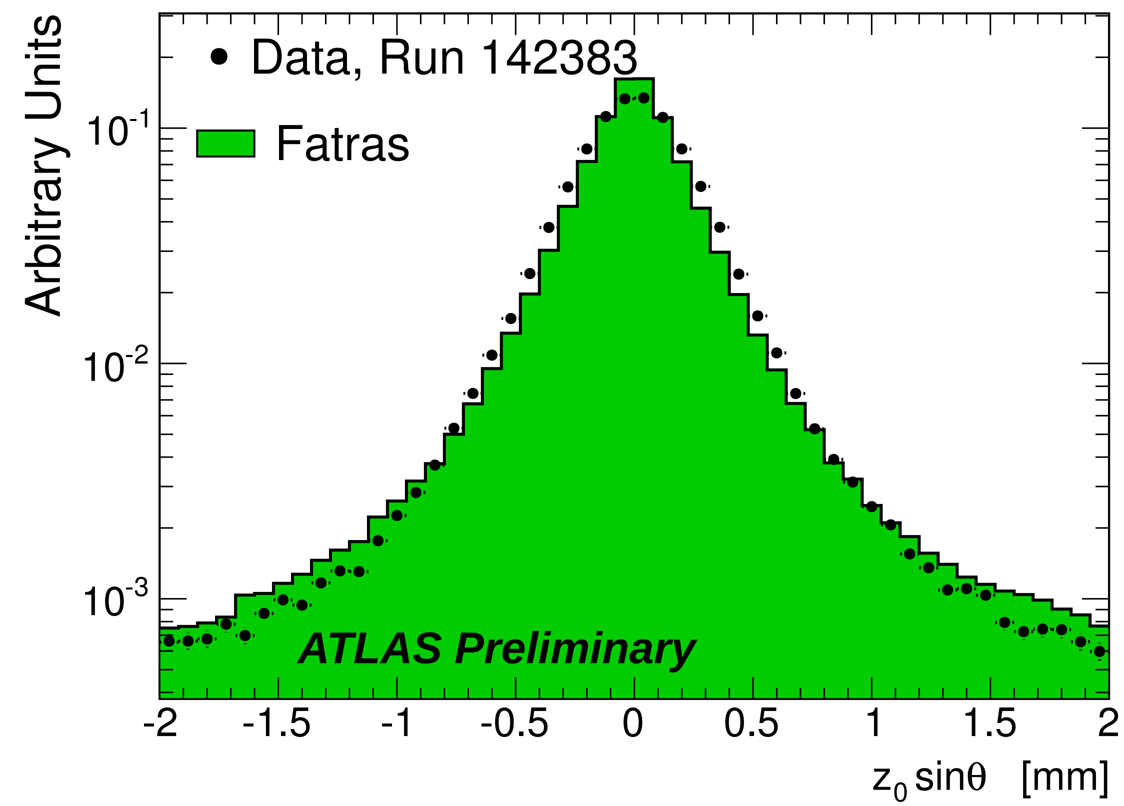
FATRAS in comparison to data

- ID reconstruction, tracks with p_T > 500 MeV

- using exact same sensitive detector elements:
conditions data being fully integrated

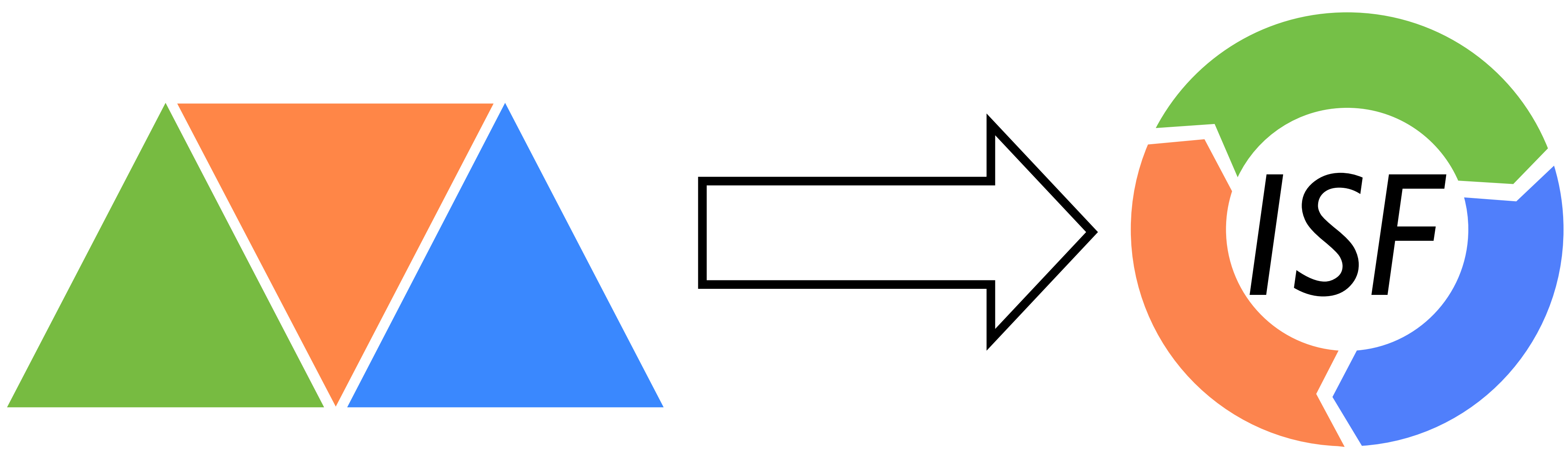






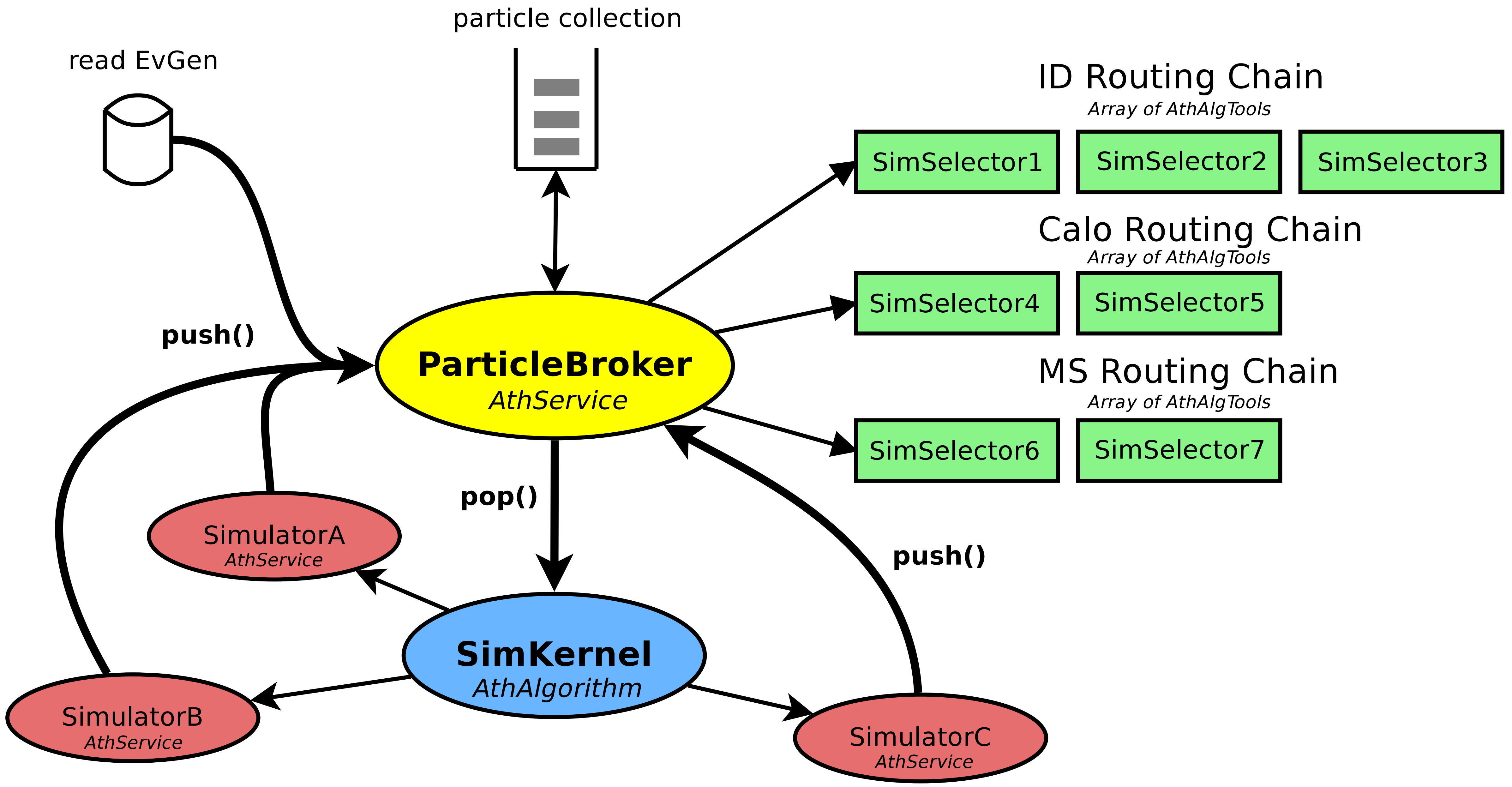
Breaking the pyramid - **ISF**

- Integrated simulation framework (**ISF**) aims to combine the different simulation approaches in ATLAS into one framework
  - output format is always the same **independent** of simulation chosen
  - configuration is done at one **central place** and standardized
  - fast and full simulation setup can be **mixed** and used **alongside**



ISF - Routing & centralised services

- One aim of the ISF was to bring all simulation flavours into one framework
  - central services handle common tasks



ISF - Commonalities

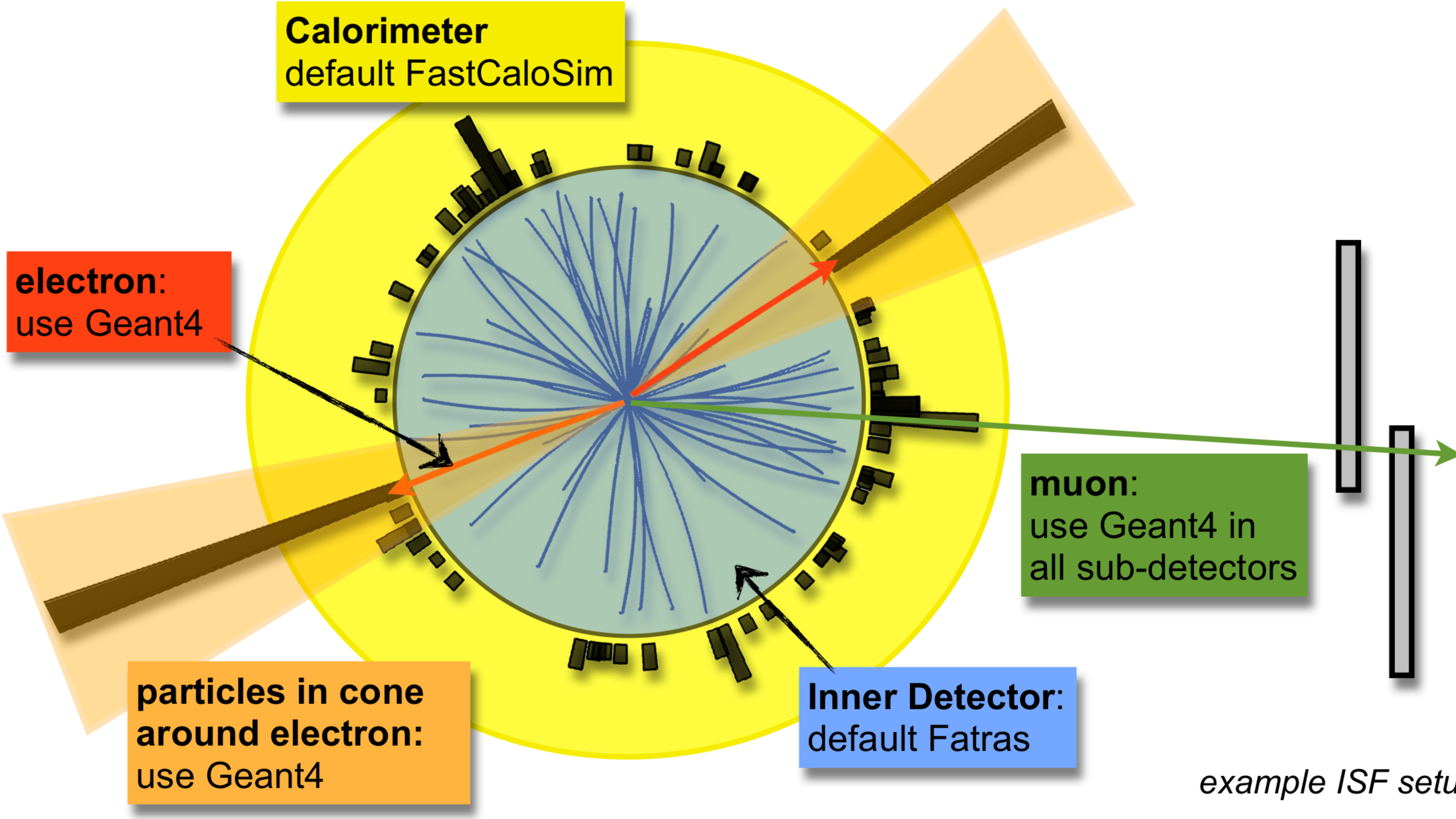
- All simulators within the ISF share common services
  - write common simulation output (ISF_Fatras rewritten for this purpose)
  - use same EVGEN feeding
  - use same Truth service & Barcode handling

- Simulators are defined for sub-detectors
  - particle routing organised/handled by ISF and handed over to simulators

- Multiple simulators can be defined for each sub-detector and routing rules allow to chose the simulation strategy
  - non-trivial question: simulation needs to be **reproducible** and **deterministic** at each time

- ISF allows side-by-side simulation with different setups: **flavour mixing**

ISF - Flavour mixing



example ISF setup

ISF - Flavour mixing example

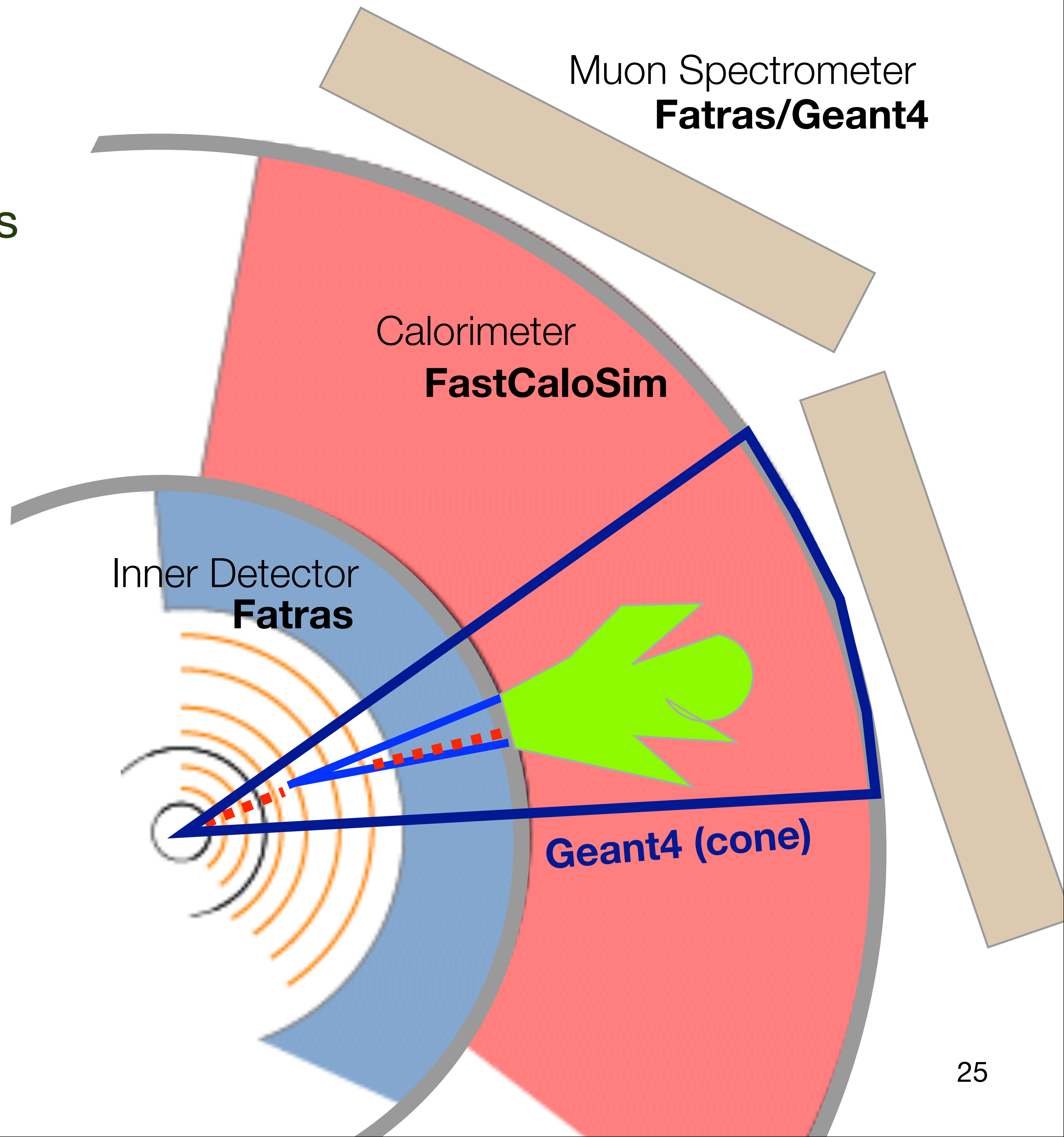
- Most elaborated test example in ATLAS
  - ISF H -> gamma gamma setup for background shape simulation
  - default simulation: **AF2F/G**

+ everything in a **cone** around the photons simulate with:

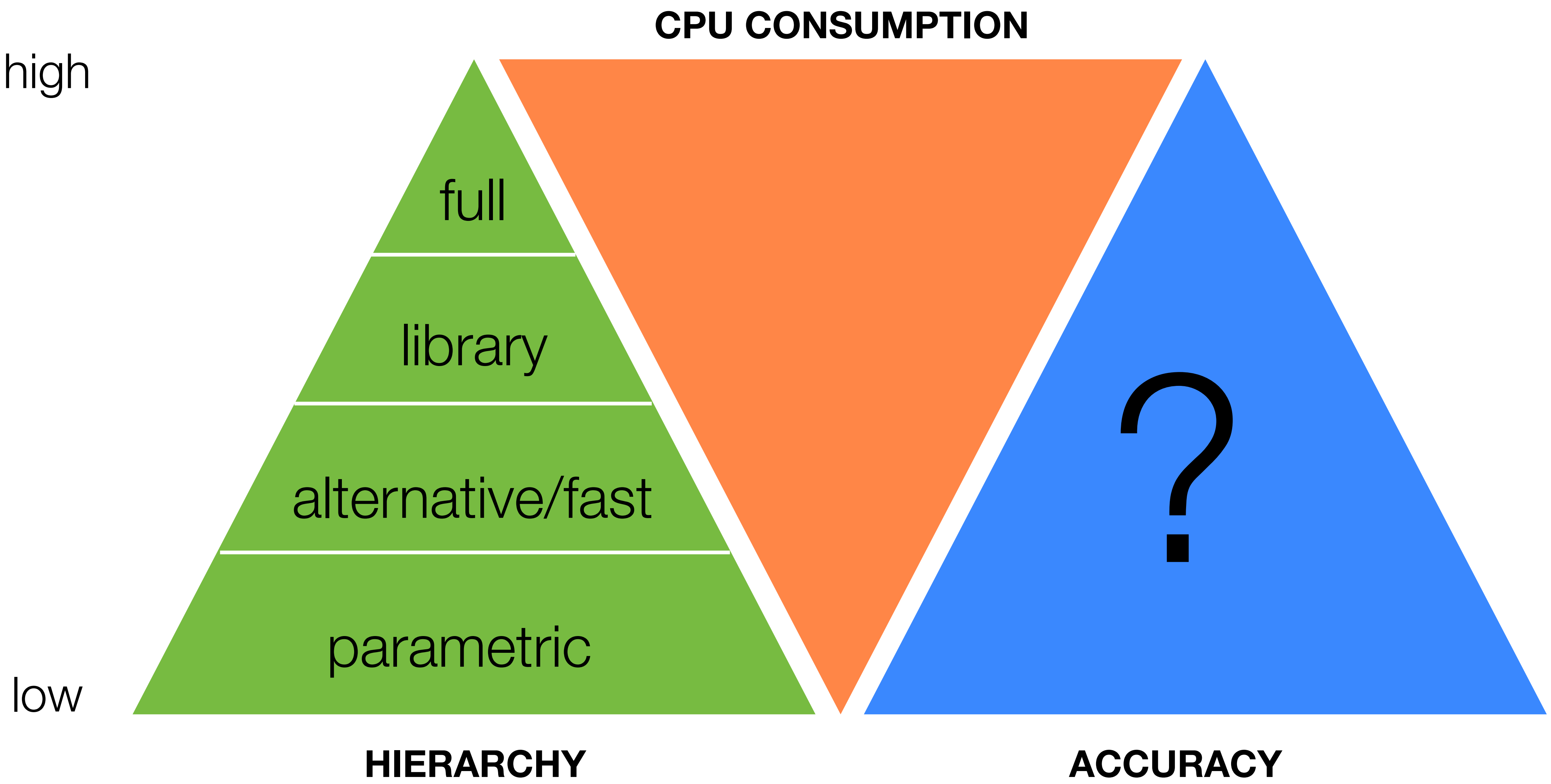
Geant4

- Relative CPU speed improvement w.r.t full Geant4 simulation:

~ 100



Accuracy

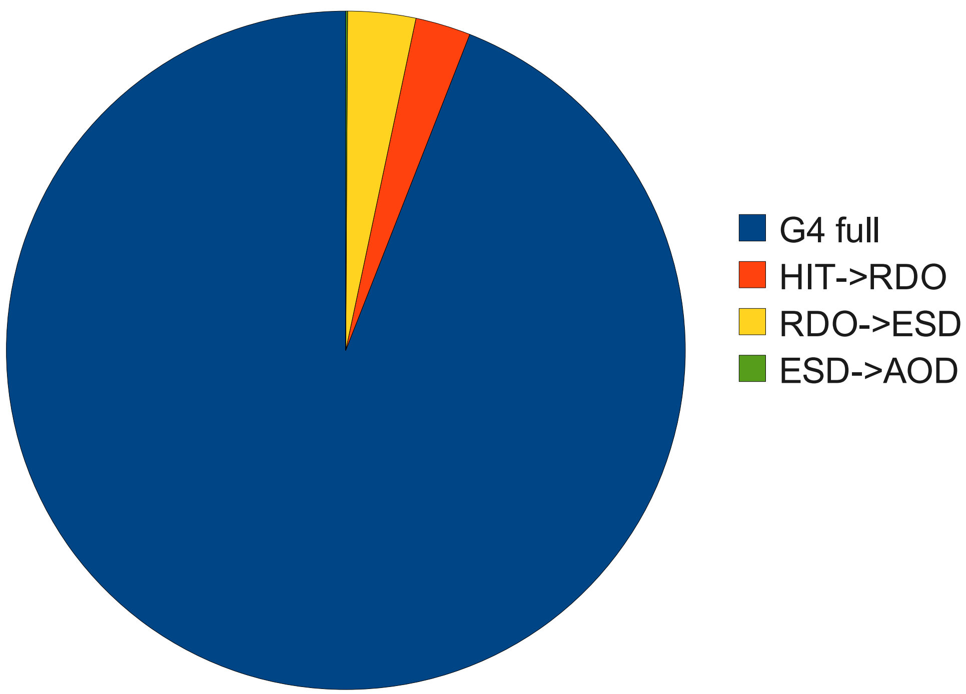


- What accuracy is actually needed ?
- Is it the same for every analyses/aspect ?

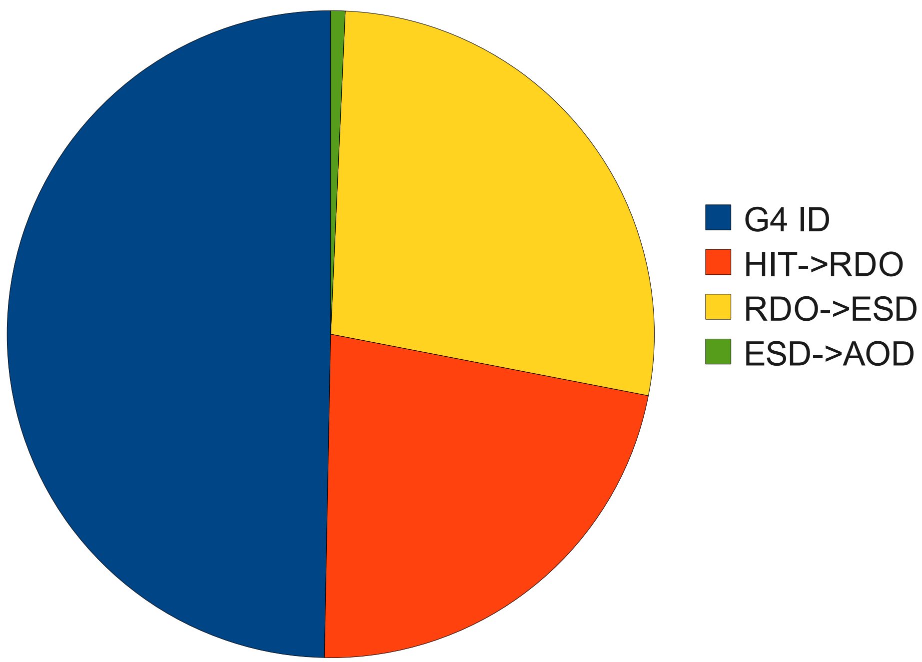
An ATLAS-centric world with (very) fast simulation

- A factor of 100 in simulation puts digitisation/reconstruction under extreme pressure

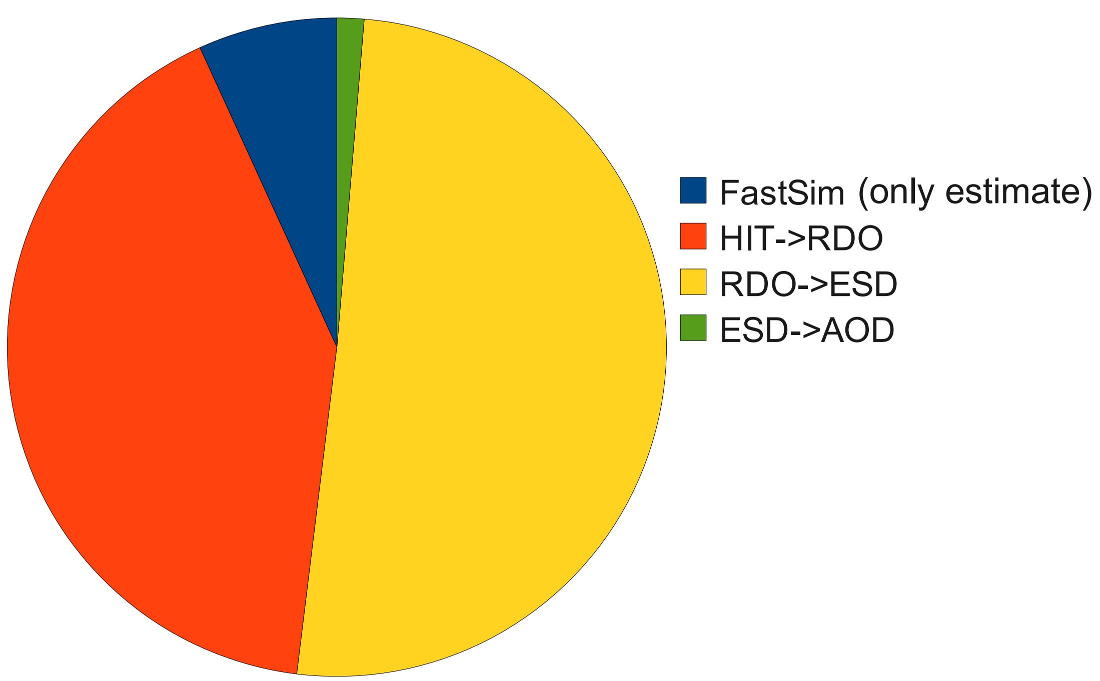
Estimate MC11a G4 full CPU time



MC11a AFII CPU time

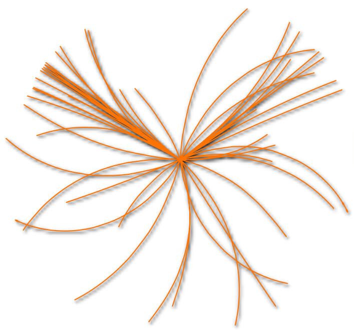


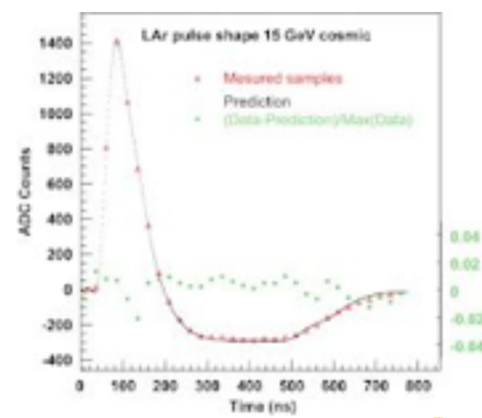
Estimate AFII-F CPU time

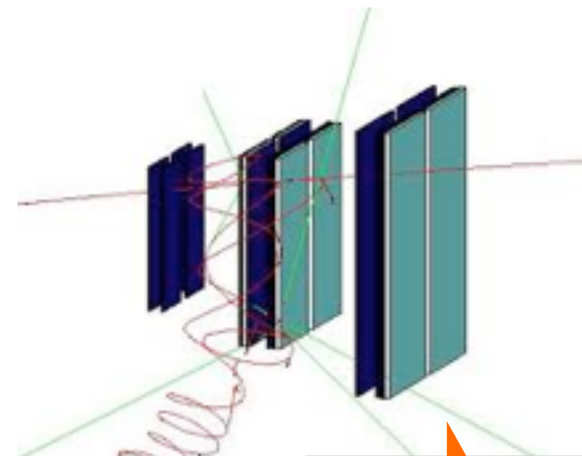


A fast Monte Carlo chain

- Of course, we need to factor pile-up into this picture







Event Generation → **Detector Simulation** → **Digitization** → **Reconstruction** → **Analysis**

A fast Monte Carlo chain

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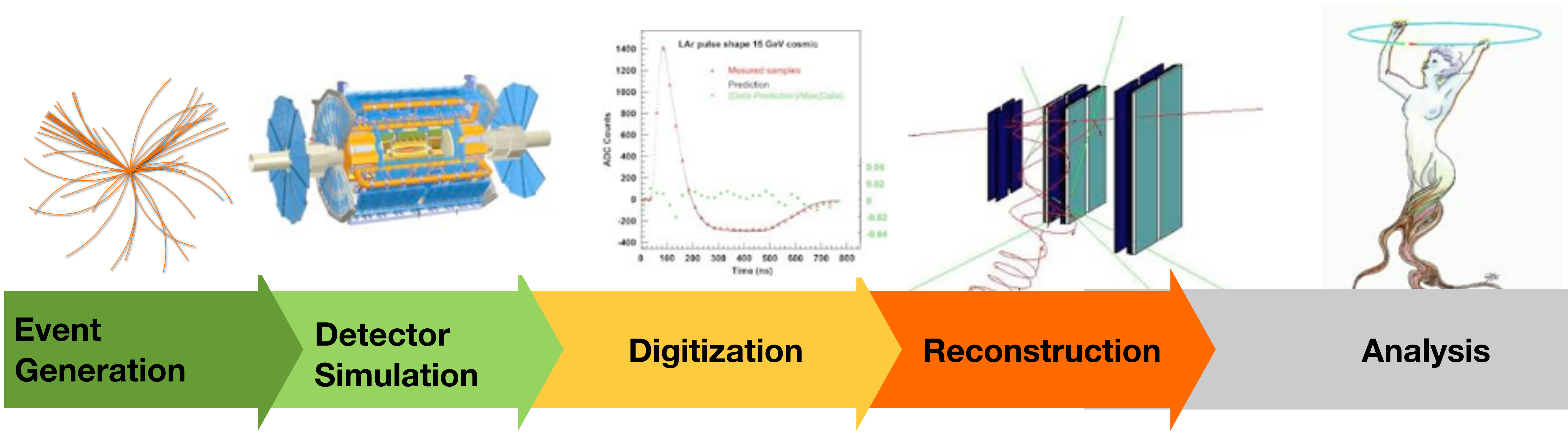

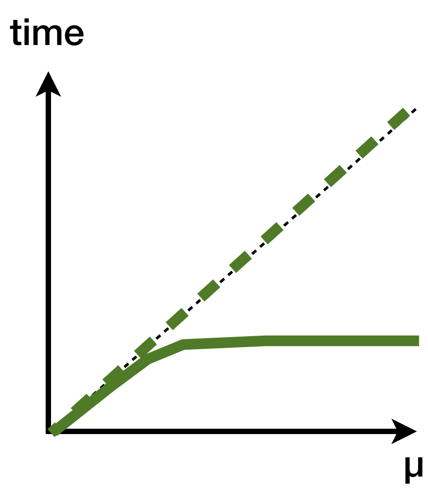

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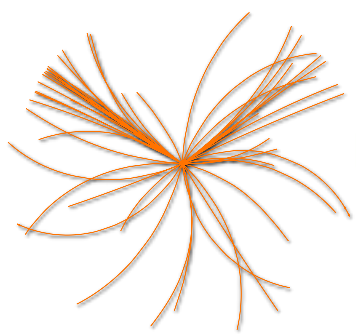
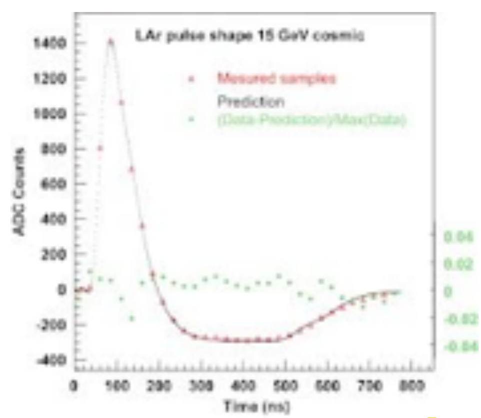
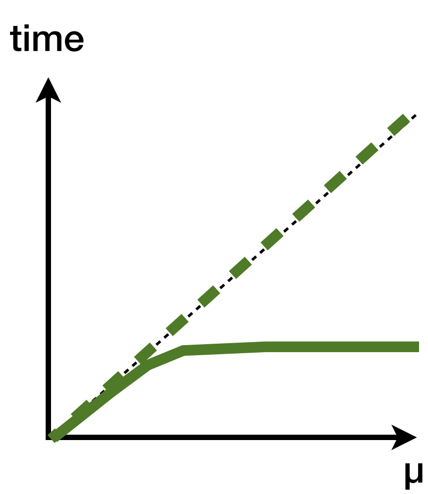
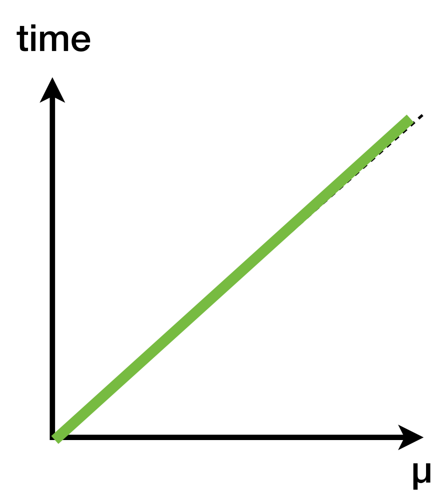




Event Generation → **Detector Simulation** → **Digitization** → **Reconstruction** → **Analysis**





A fast Monte Carlo chain

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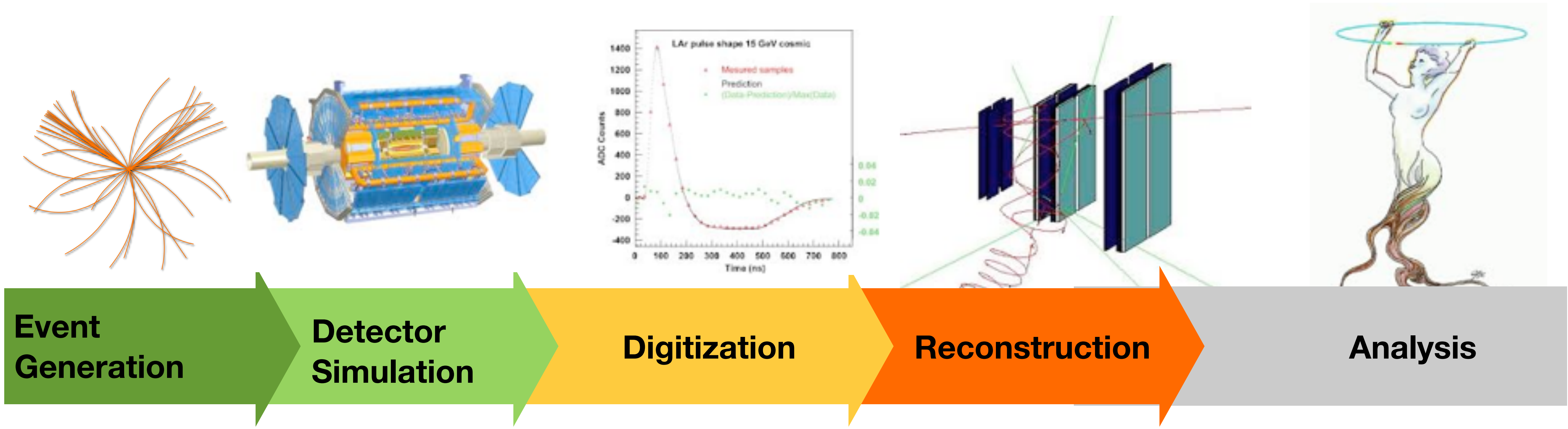

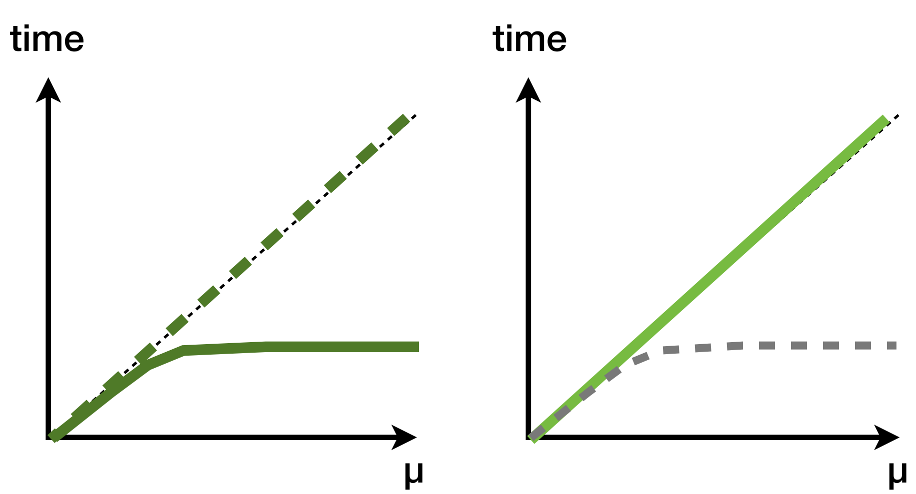

A fast Monte Carlo chain

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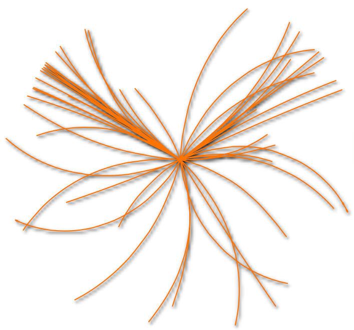
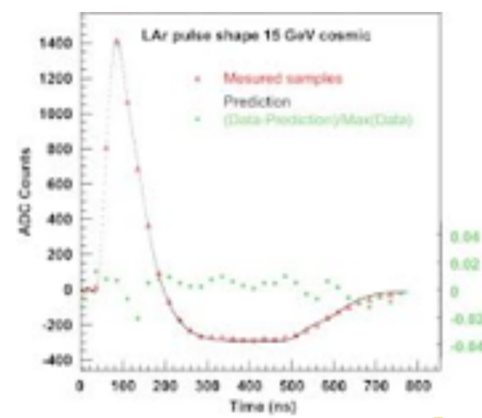
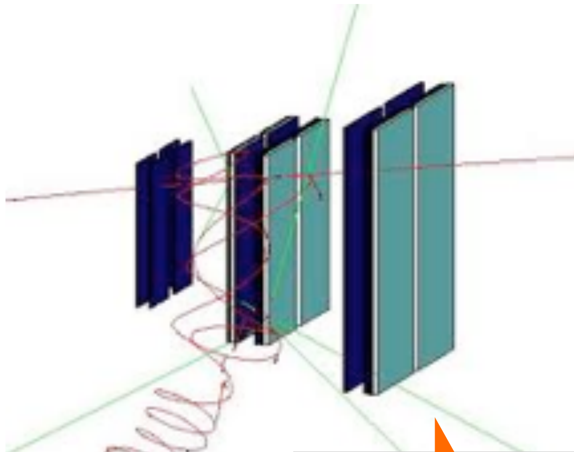
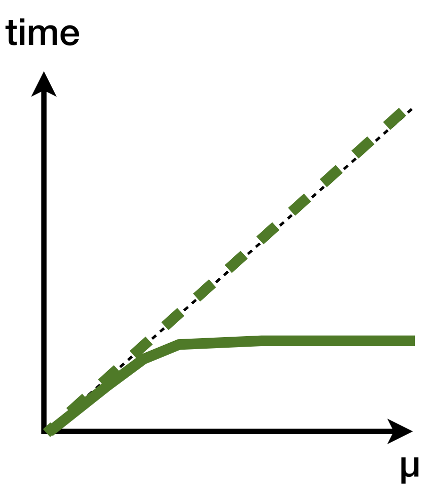
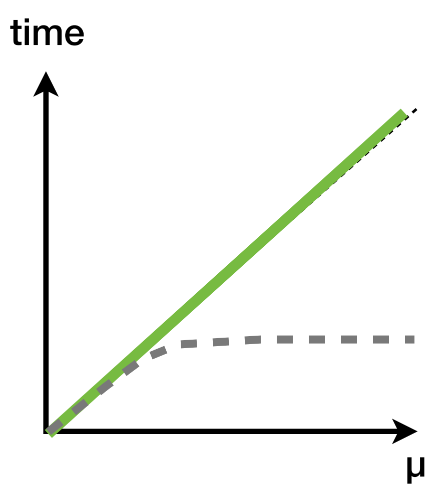


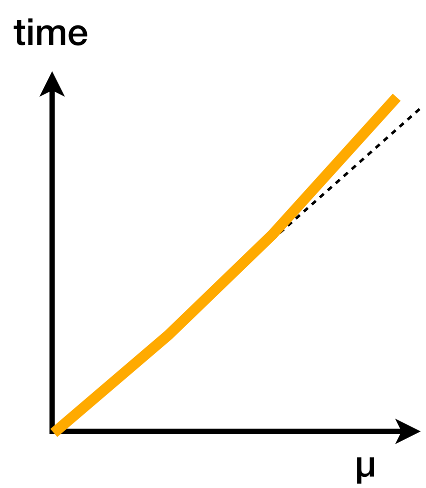




Event Generation → **Detector Simulation** → **Digitization** → **Reconstruction** → **Analysis**







A fast Monte Carlo chain

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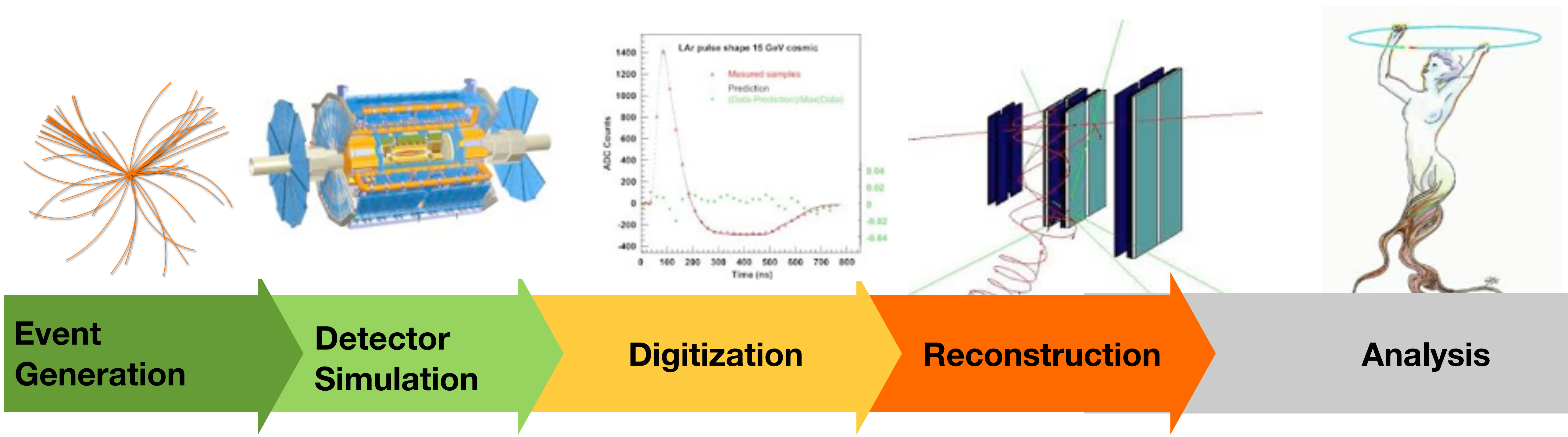

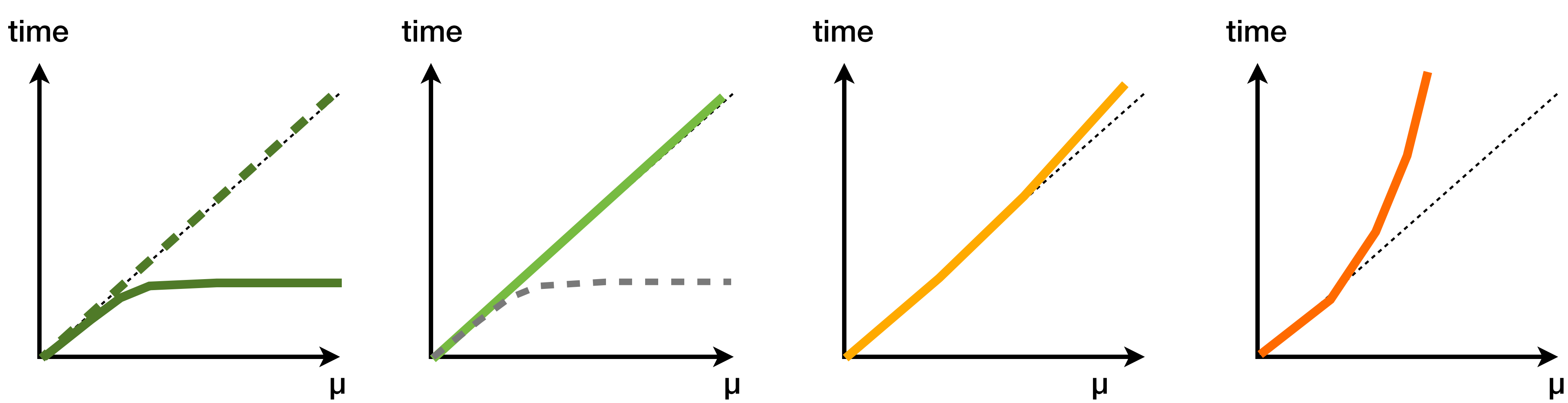

A fast Monte Carlo chain

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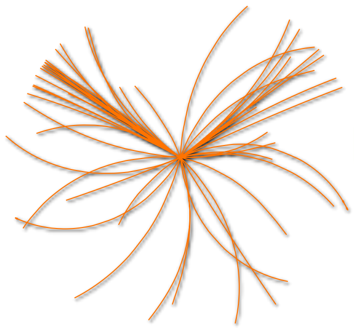
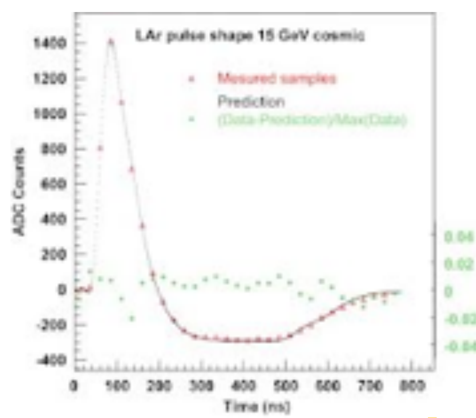
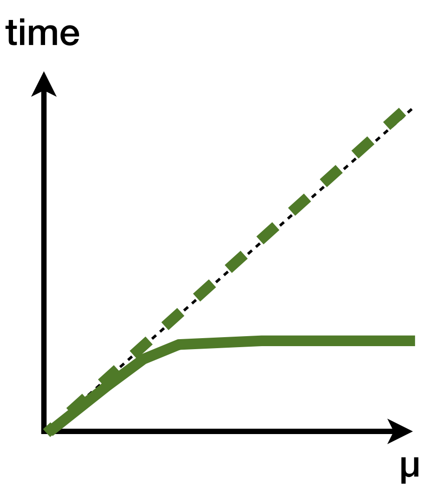
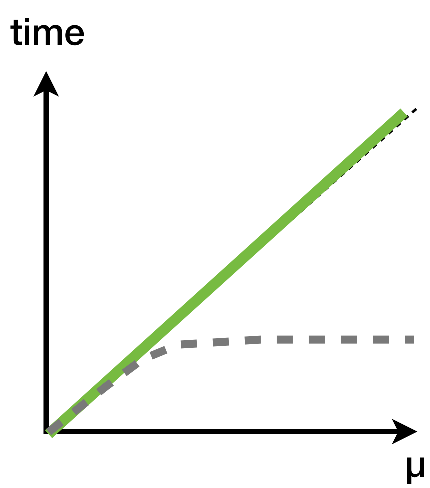
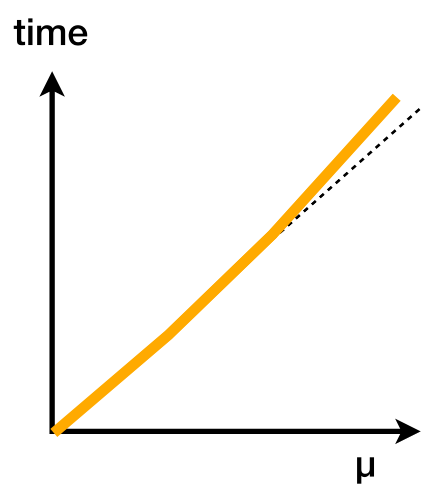


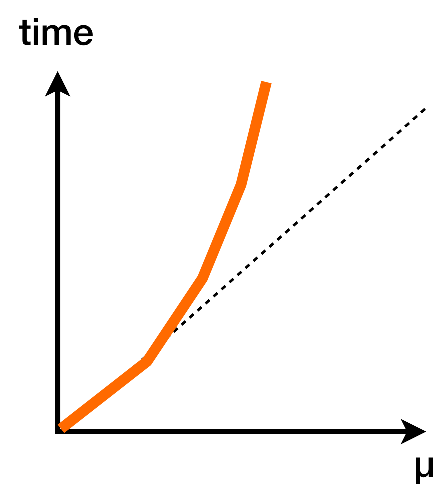


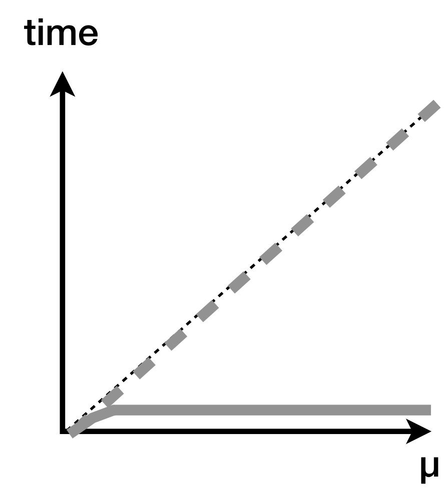
Event Generation → **Detector Simulation** → **Digitization** → **Reconstruction** → **Analysis**











A fast Monte Carlo chain

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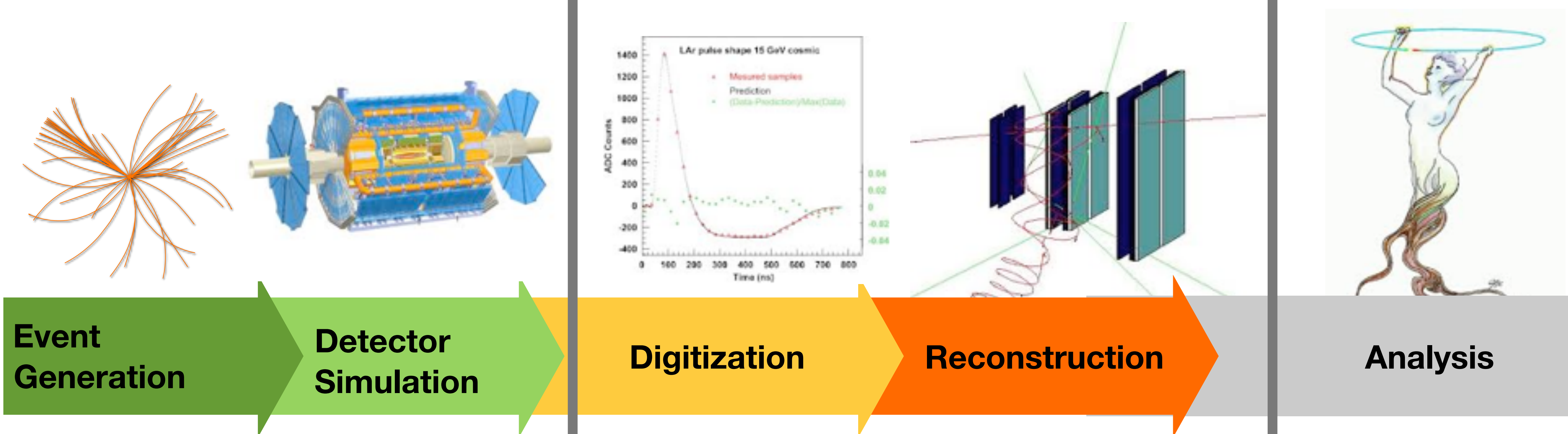
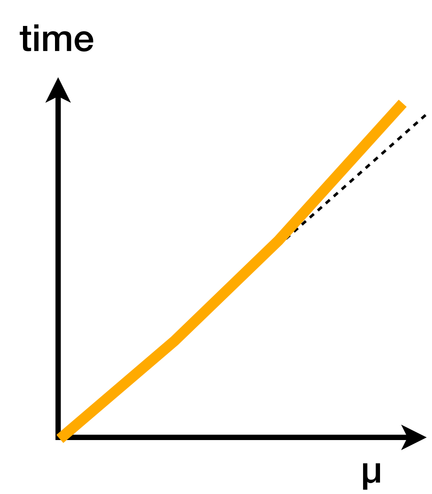
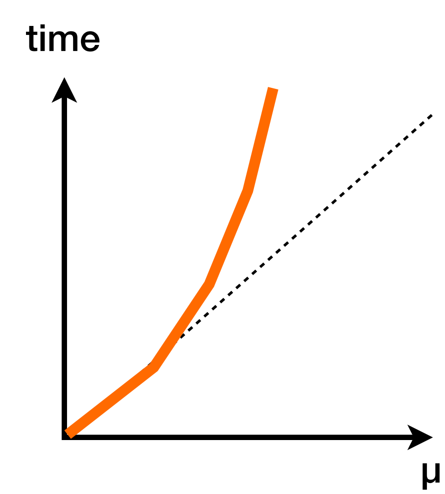


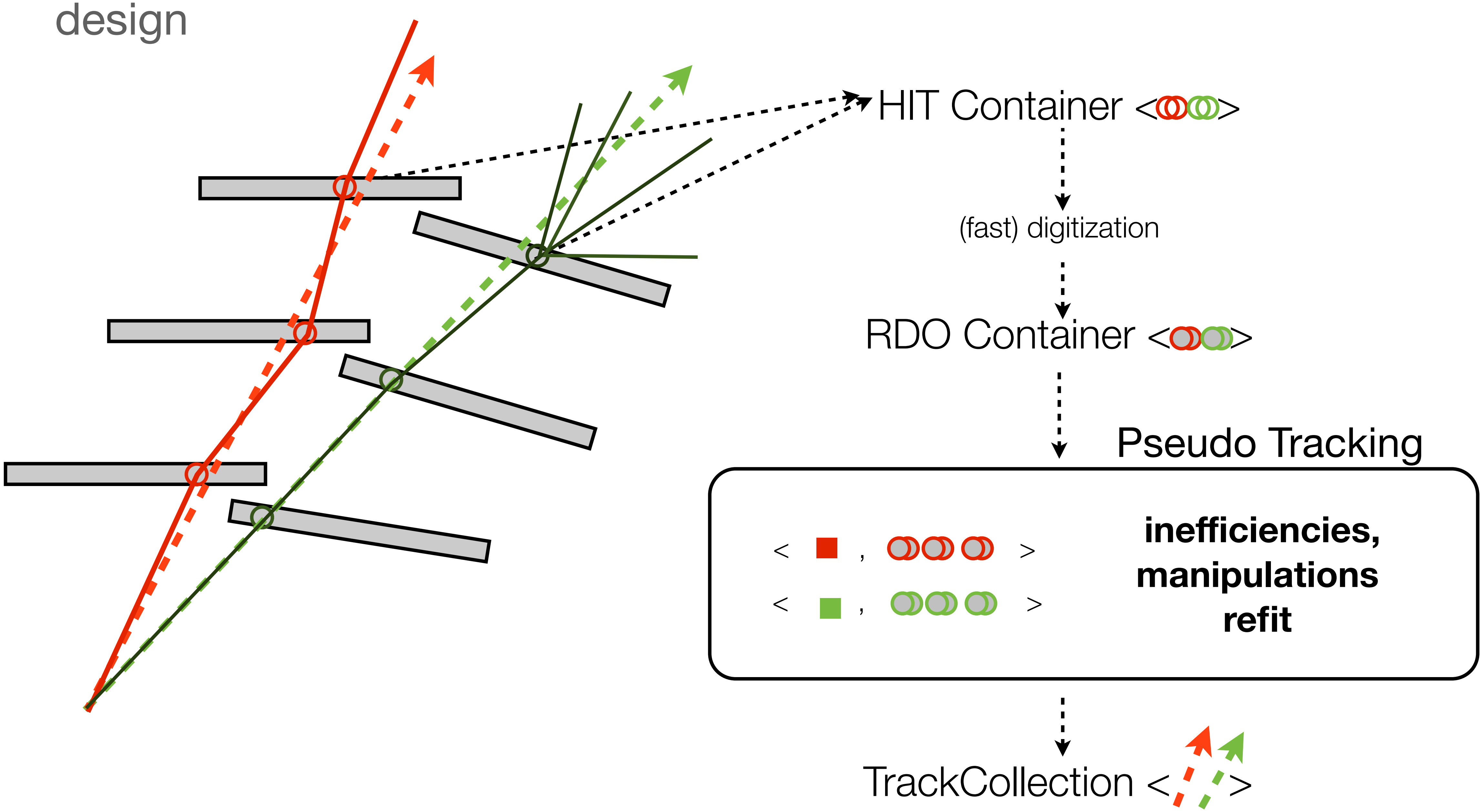




- ATLAS is working on fast digitisation & fast reconstruction
- This has to be handled with a lot of care !

Fast MC: truth tracking

- Truth tracking represents the optimal pattern recognition in presence of detector material
  - this is an ideal tool for detector design



Fast MC: truth tracking performance (1)

- To make it work for physics, we need to shape the truth tracks a bit
  - a set of manipulators are in place to do so

IMPACT PARAMETERS

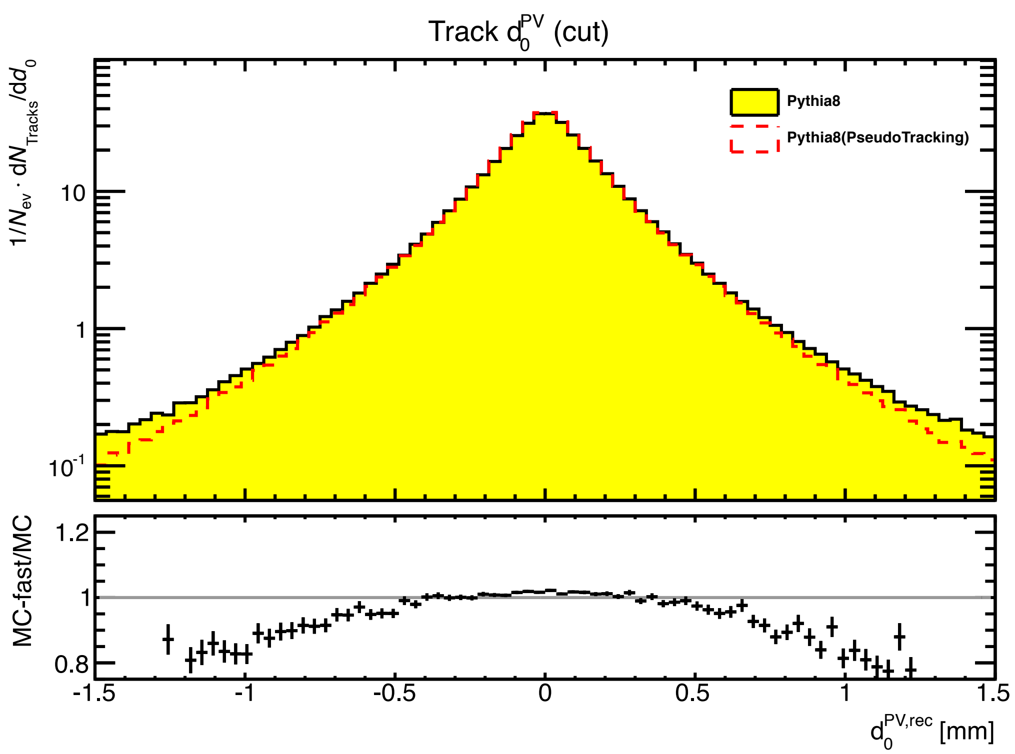


Figure 13: Transverse impact parameter distribution with respect to the primary vertex comparing NT with TT for fully simulated minimum bias events.

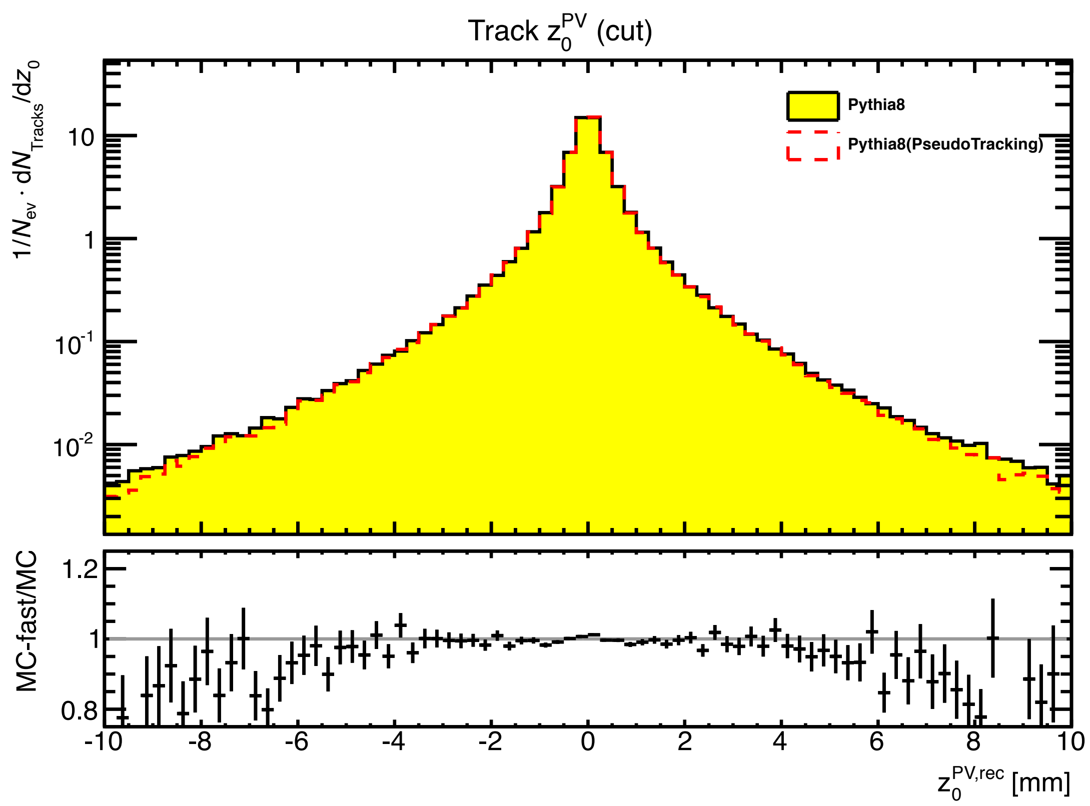
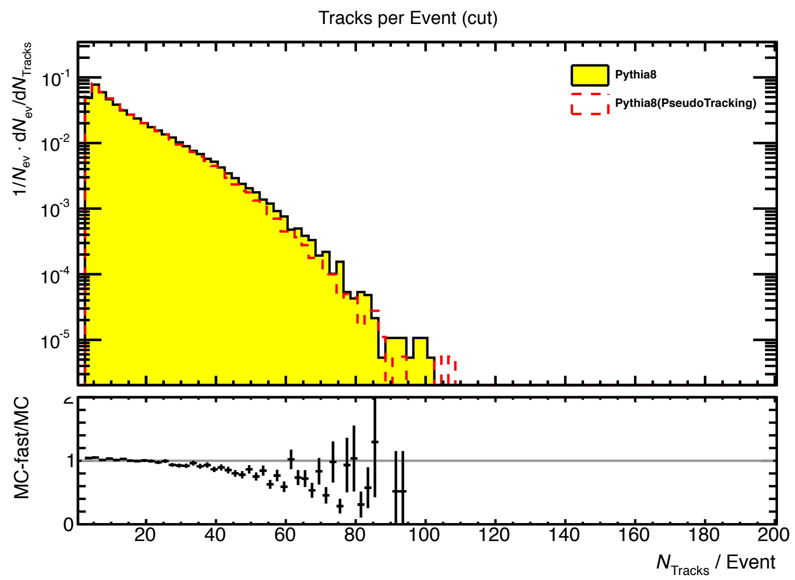


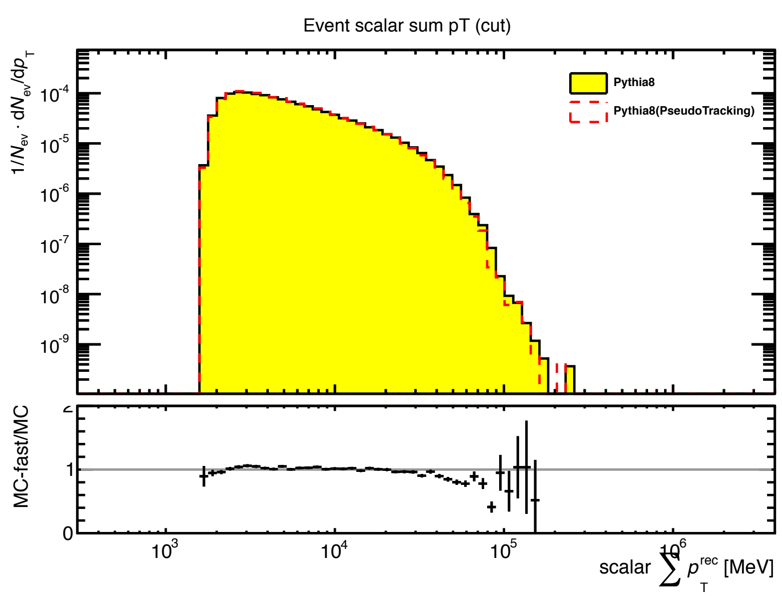
Figure 14: Longitudinal impact parameter distribution with respect to the primary vertex.

Fast MC: truth tracking performance (2)

- Efficiencies well described
- Real appealing affect is when using truth tracking for pile-up only

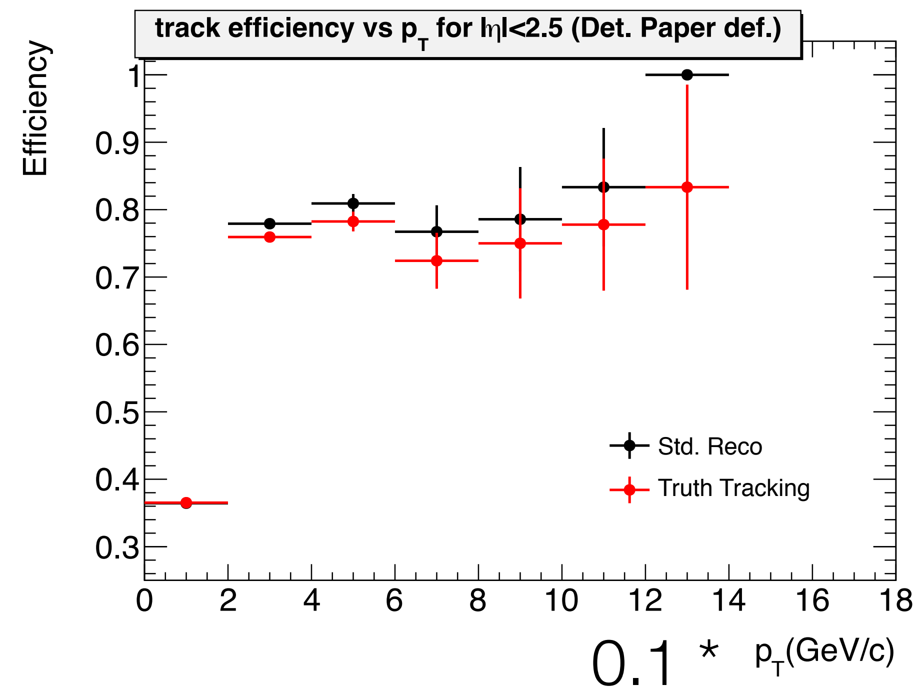


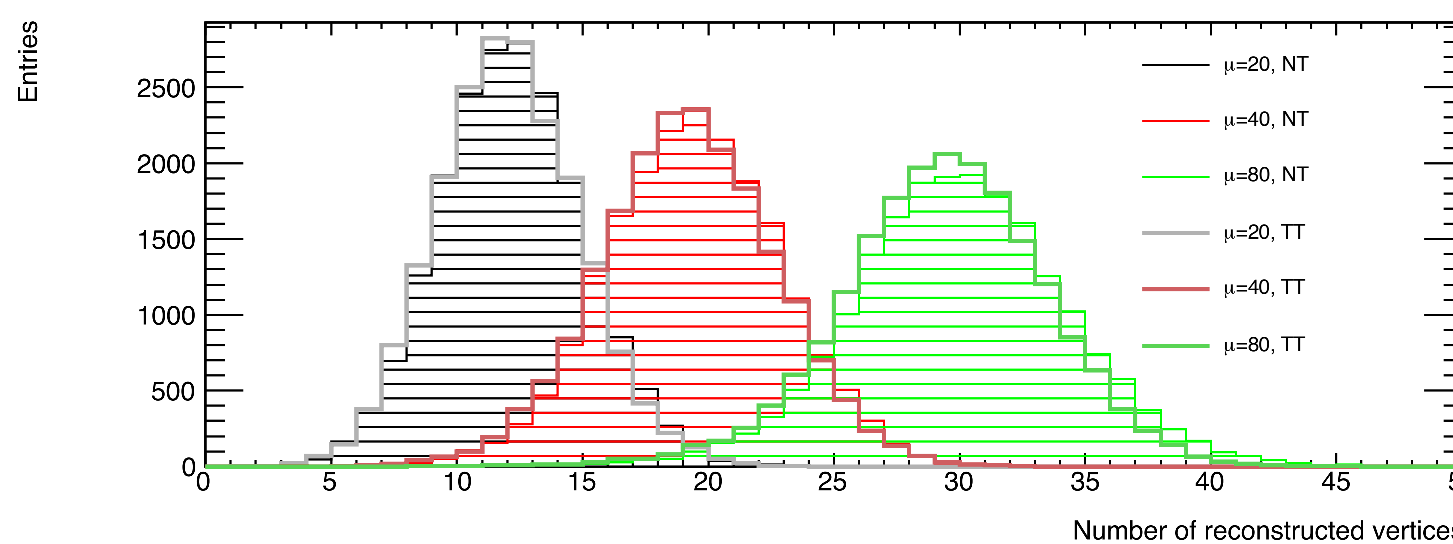
(a) Number of tracks per event



(b) Event scalar sum p_T distribution

EVENT CHARACTERISTICS





Fast MC: truth tracking speed

- That’s the really appealing plot

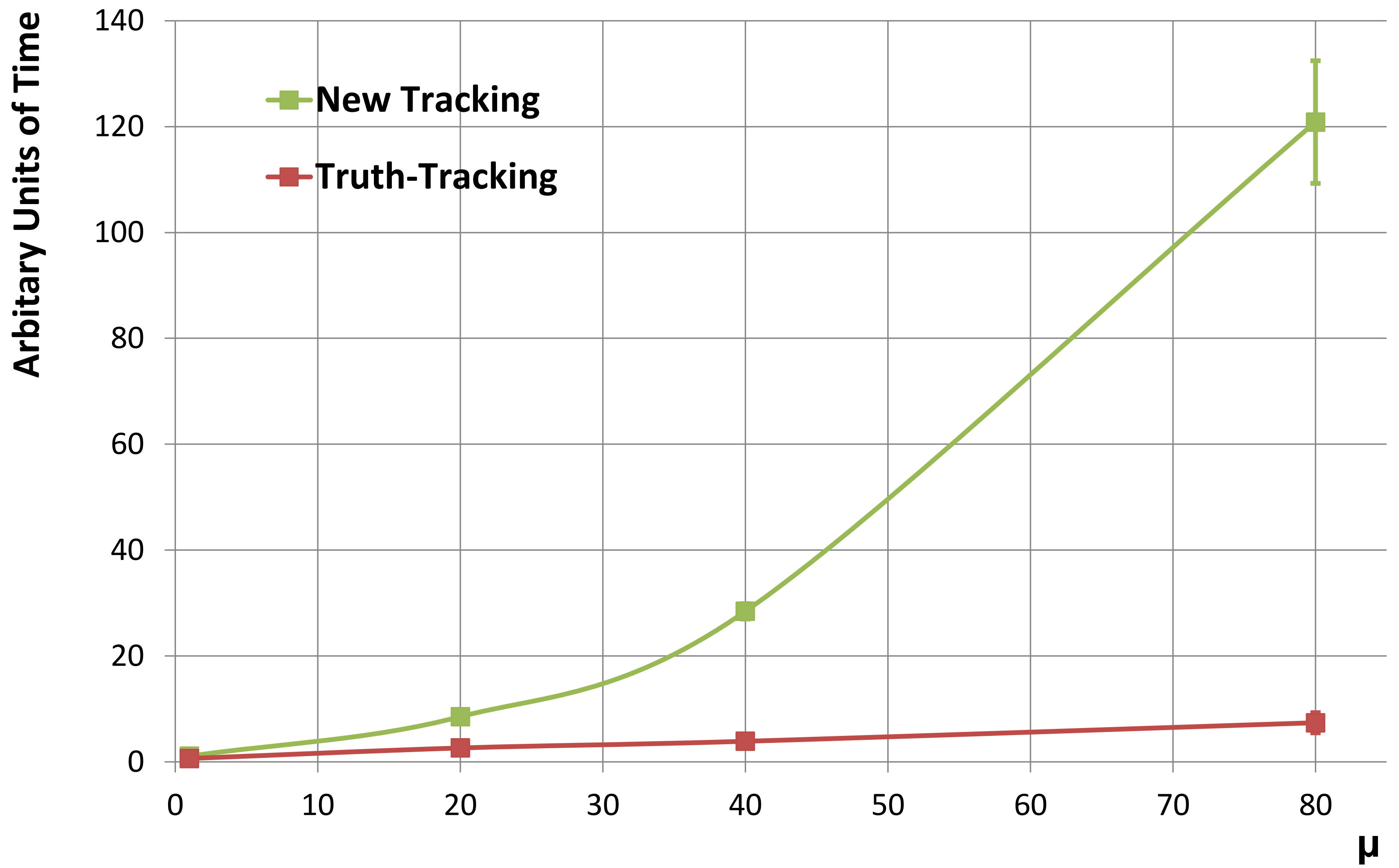


Figure 30: Overview of μ dependance of the reconstruction time for TT and NT.


TRUTH SEEDED RECONSTRUCTION FOR FAST SIMULATION IN THE ATLAS EXPERIMENT

ROLAND JANSKY

universität innsbruck

master thesis in physics

submitted to the Faculty for Mathematics, Computer Science and Physics of the University of Innsbruck

Supervisors:

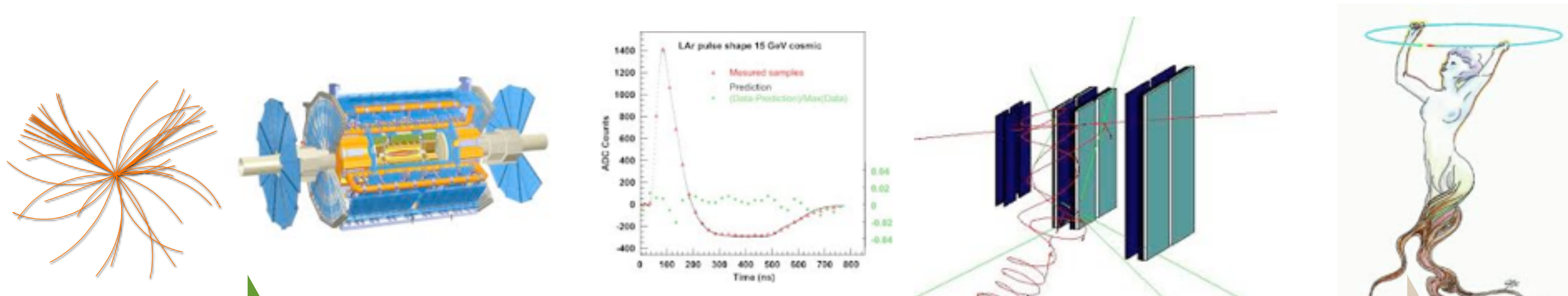
Emmerich Kneringer, Institute for Astro- and Particle Physics

Andreas Salzburger, CERN

September 2013

R. Jansky

A possible final product



Event Generation → **Detector Simulation** → **Digitization** → **Reconstruction** → **Rootification**

full simulation/digitization/reco on hard scatter event

HS **EVGEN ⟶ Hits A Hits B ⟶ Digits A Digits B ⟶ Objects** TTree/THist

Pile-Up

EVGEN ⟶ Hits A Hits B ⟶ Digits A Digits B

EVGEN ⟶ Hits B ⟶ Digits B

EVGEN ⟶ Hits B ⟶ Digits B

EVGEN ⟶ Hits B ⟶ Digits B

fast alternatives on the pile-up (event underlying event?)

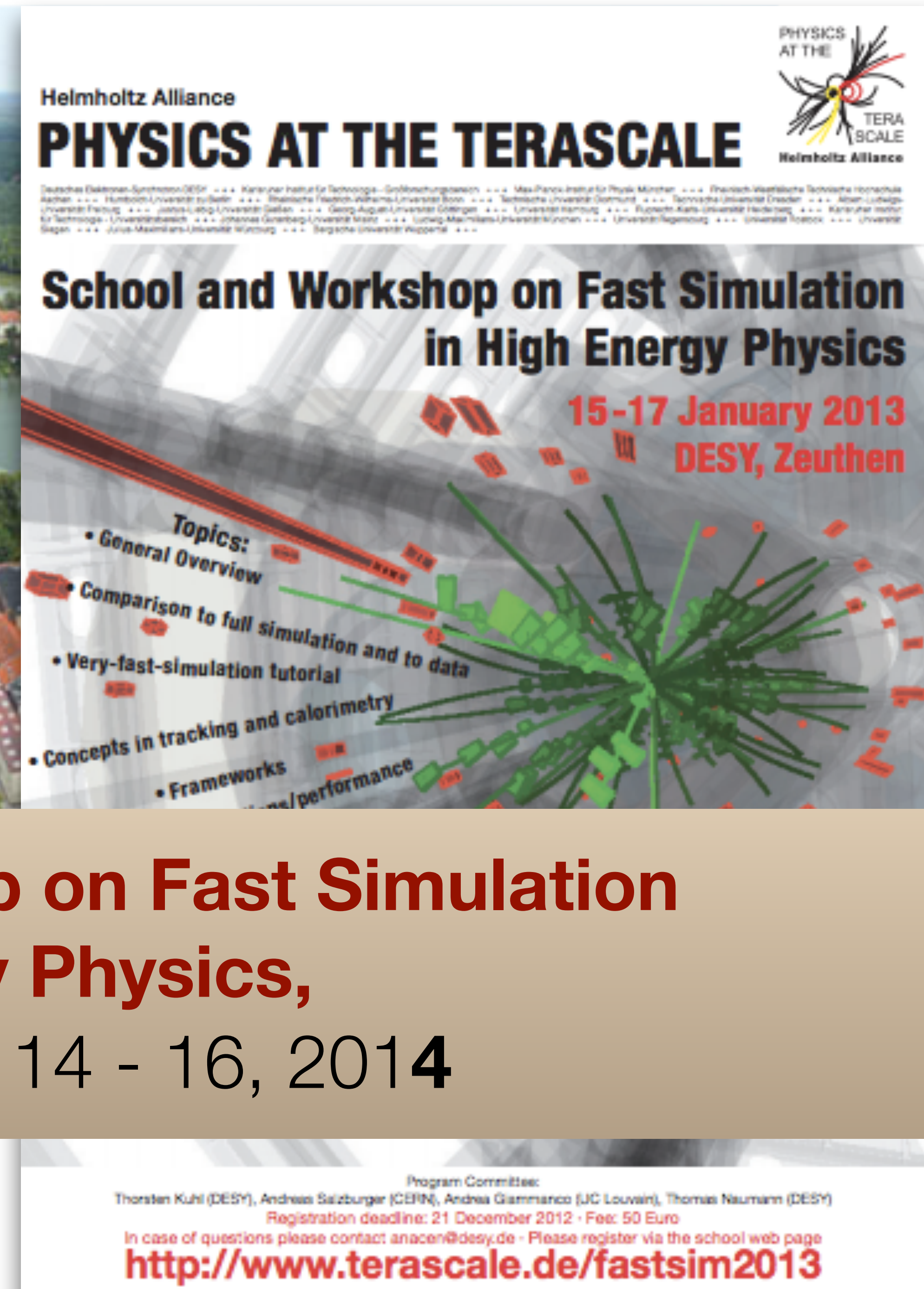
"Fast Detector Simulation in High Energy Physics"

15-17 January 2013 *Zeuthen*

Europe/Berlin timezone

Search

- **Overview**
- Organizers
- List of registrants
- Timetable
- Poster
- Group photo



2nd School and Workshop on Fast Simulation in High Energy Physics,

DESY, Zeuthen, Jan 14 - 16, 201**4**

https://indico.desy.de/conferenceDisplay.py?confId=6681

A look back into the past - ATLAS (1)

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

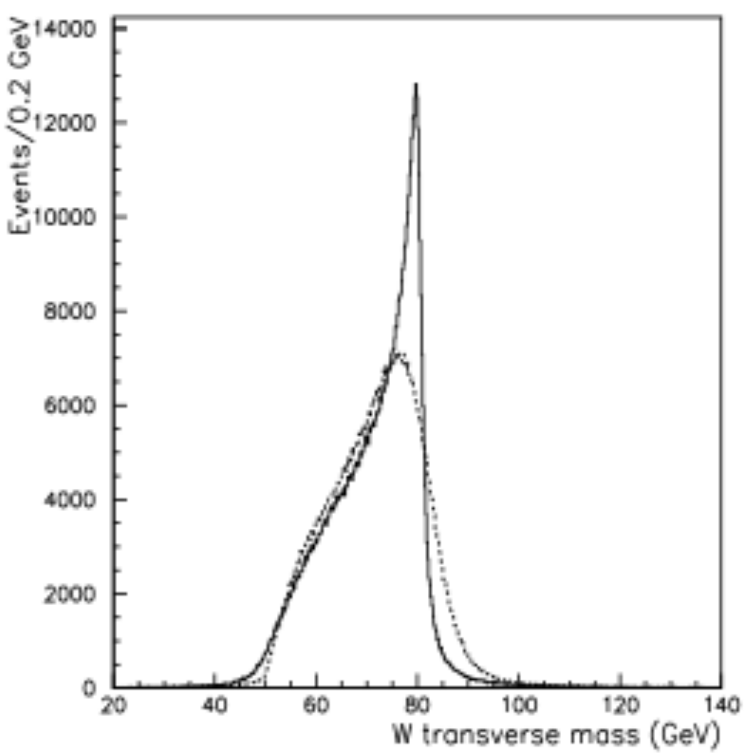
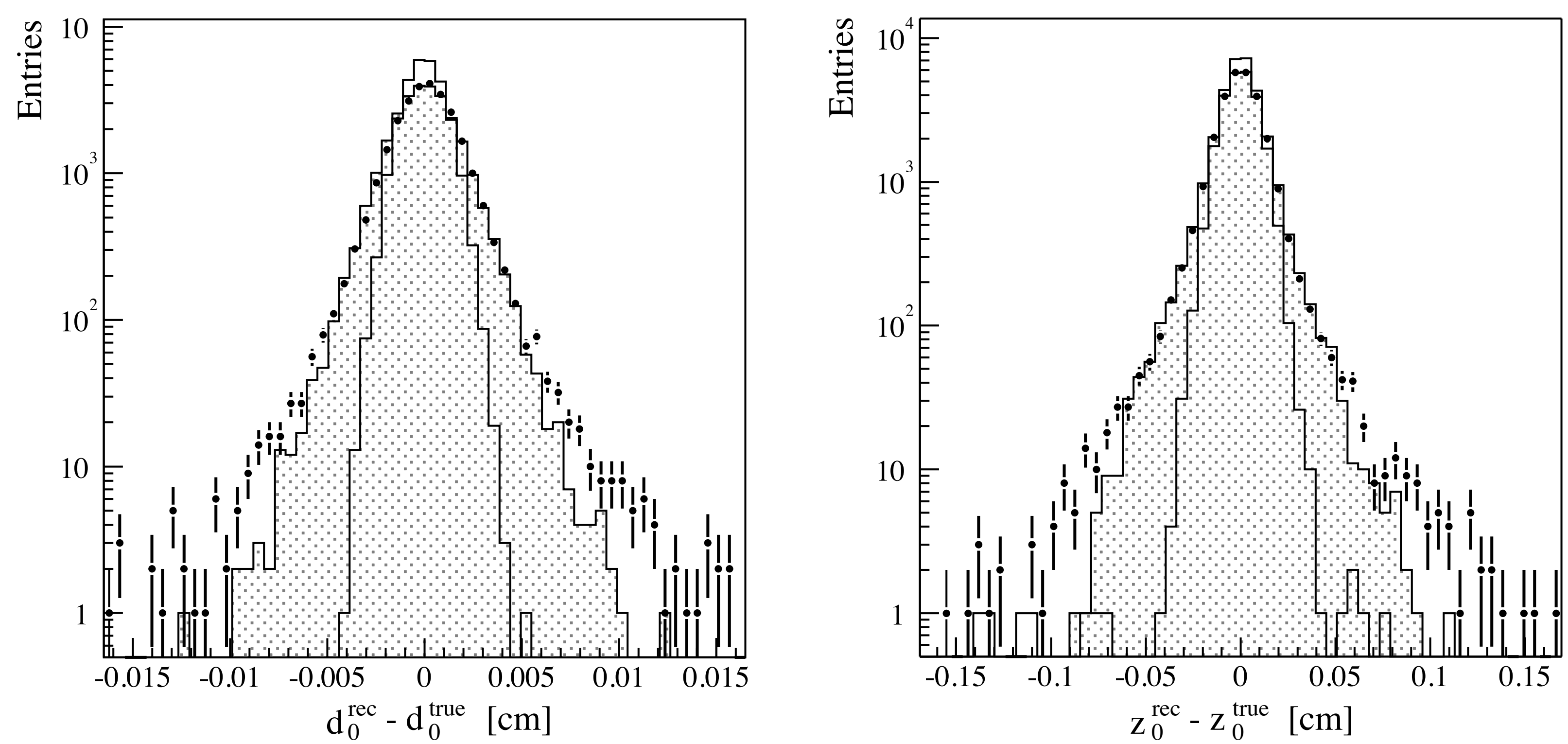


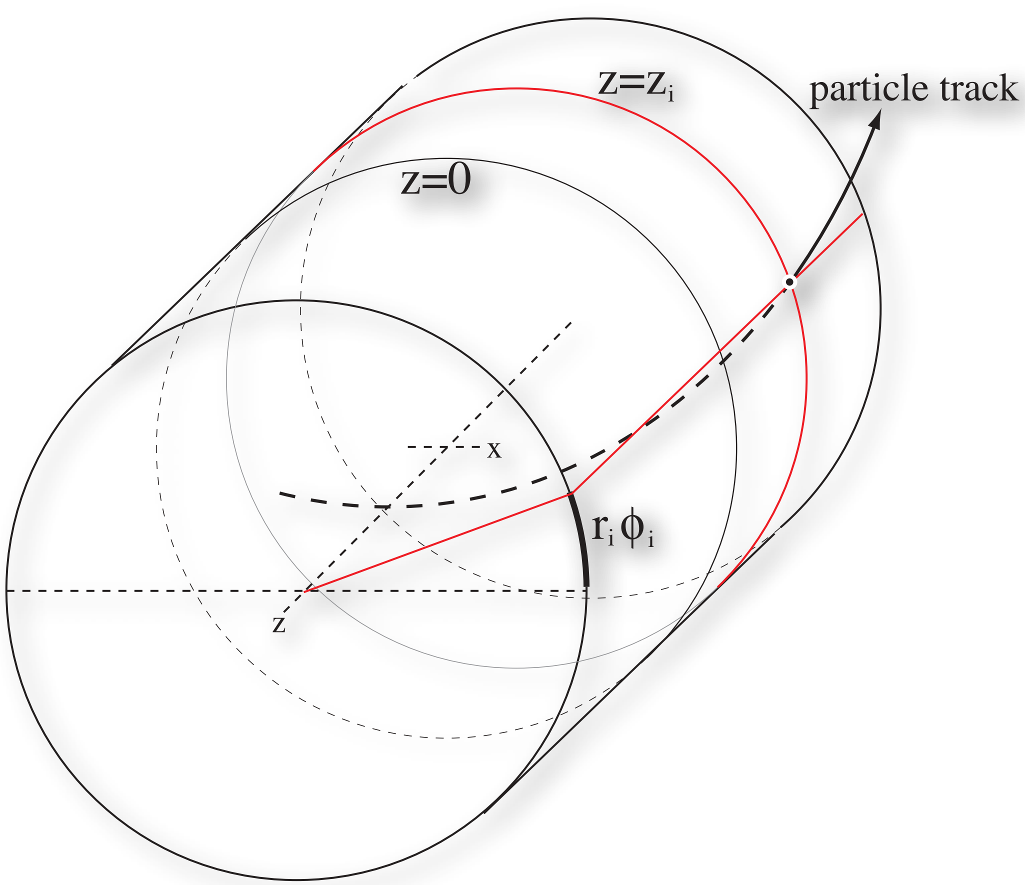
Figure 2-25 The generated (solid) and reconstructed (dashed) W transverse mass from W → lν events and after simple kinematical cuts. (Courtesy F. Gianotti)

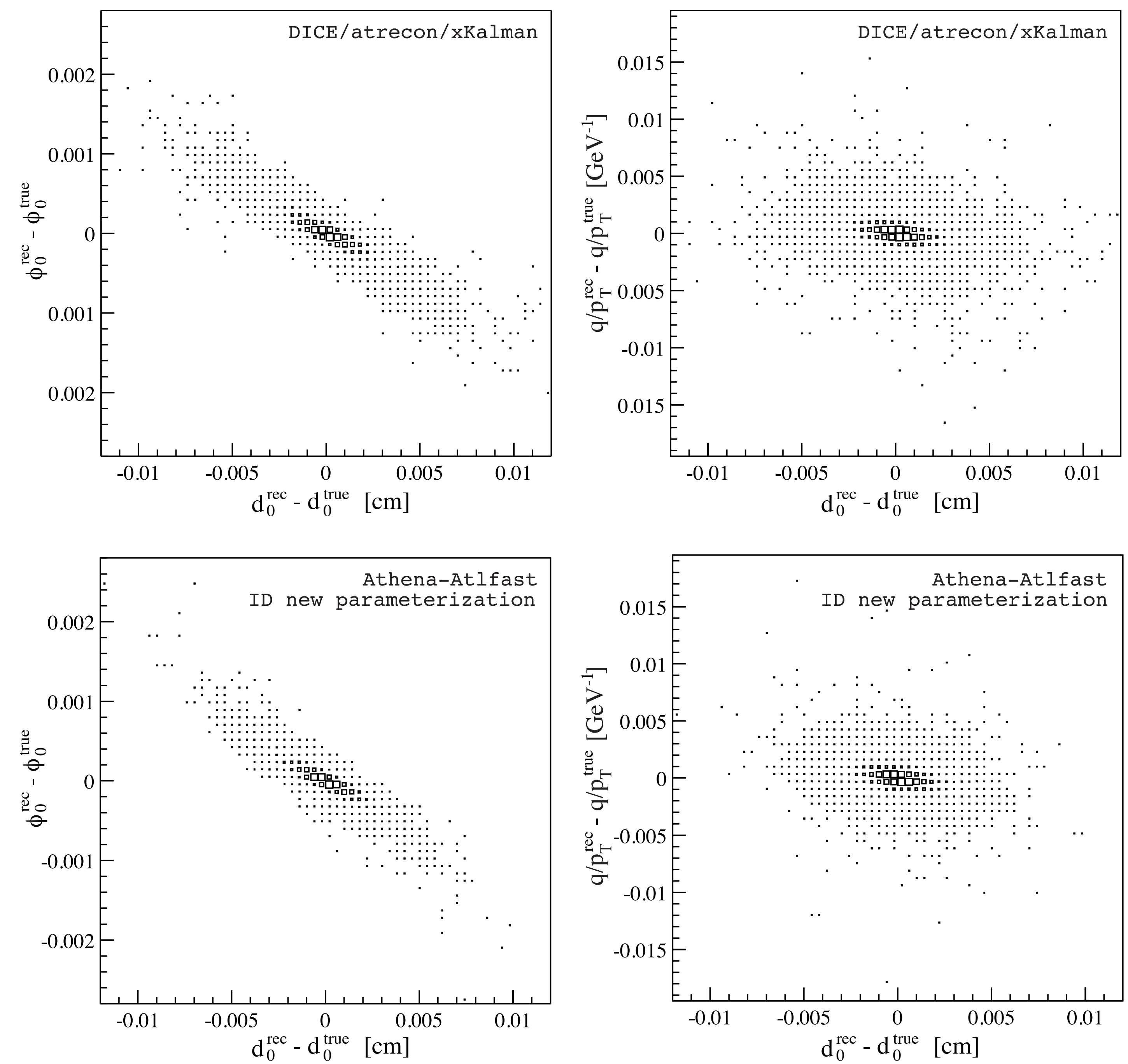


- with dedicated care (lots of work) a real good description of measured quantities could be achieved

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

- 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*

- This sort of mechanism appears again for Run 2+ studies

A look back into the past

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  - how to model efficiencies/inefficiencies
  - how to create fake objects
  - usually, one needs a full simulation first to derive parameters*

- This sort of mechanism appears again for Run 2+ studies

not always necessary:
- e.g. impact parameter resolution can be rather well estimated using the 2-layer approximation

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