# Fast Tracking Simulations in ATLAS and CMS

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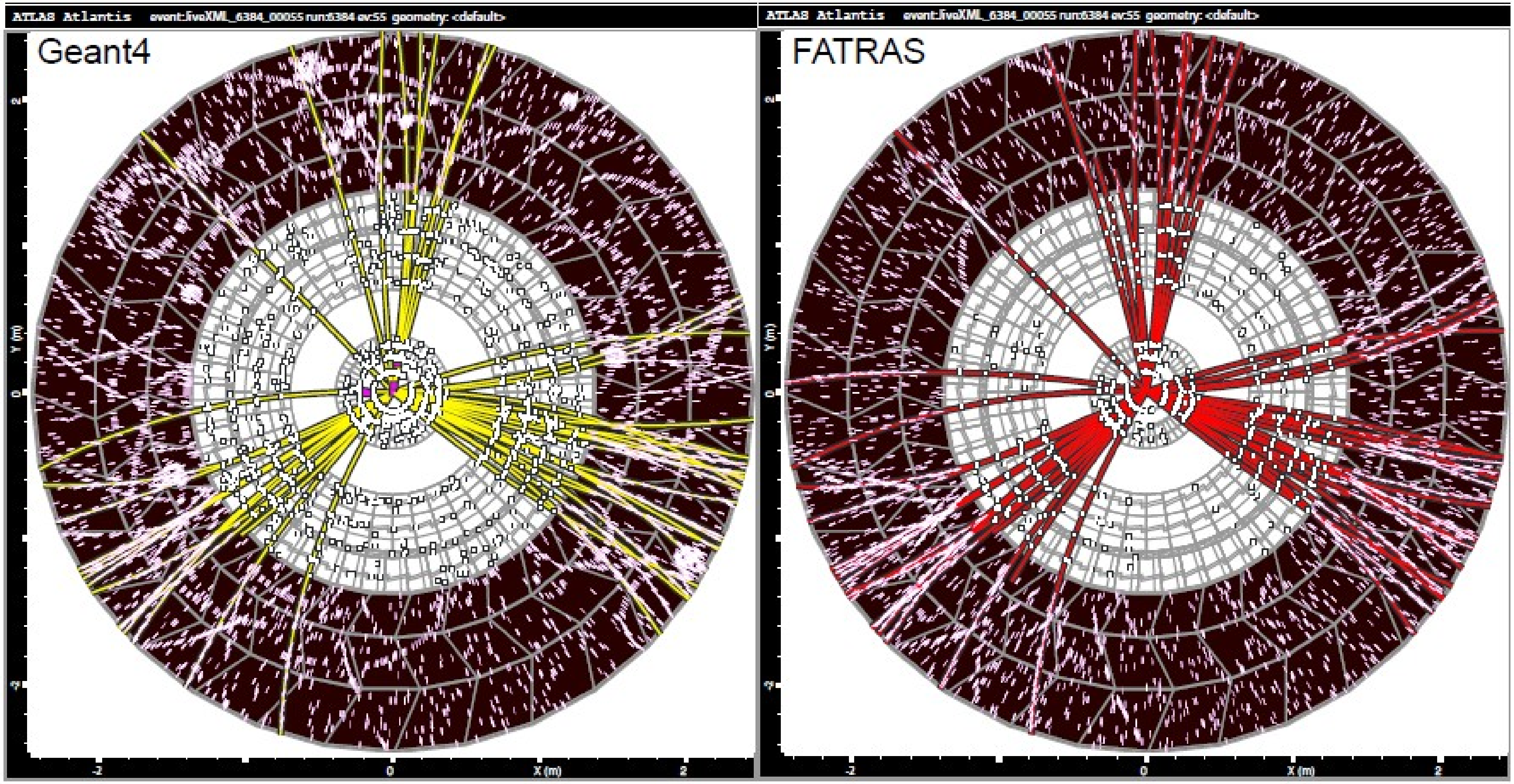


# Outline

- Tracking in ATLAS and CMS
- How this is fast-simulated in ATLAS and CMS
- Performances

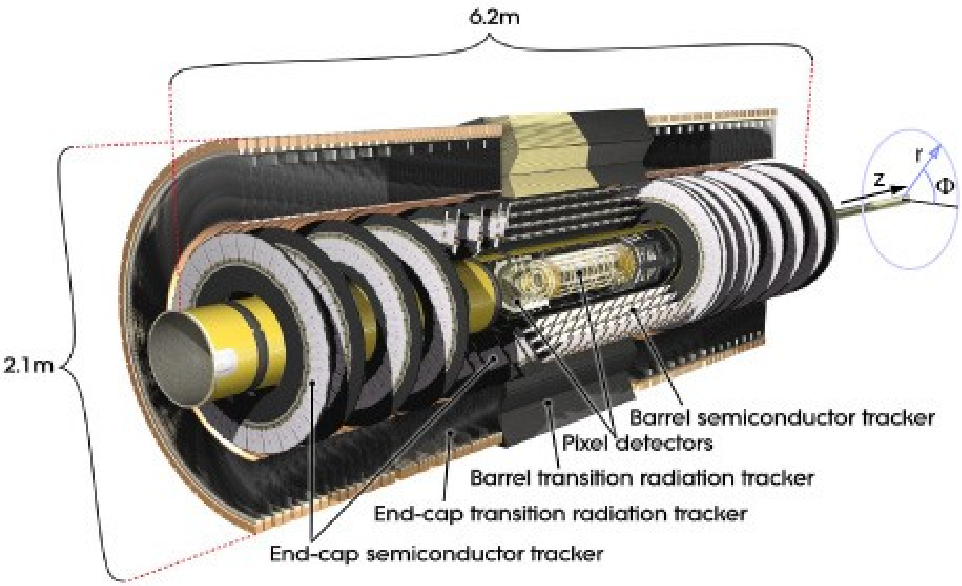
**Note:** I will focus mostly on the inner tracking systems of the two experiments, although the muon systems and their simulations will be presented too

**Acknowledgements:**
I got material or suggestions from Andreas Salzburger, Markus Elsing, Boris Mangano, Kevin Stenson, Giuseppe Cerati

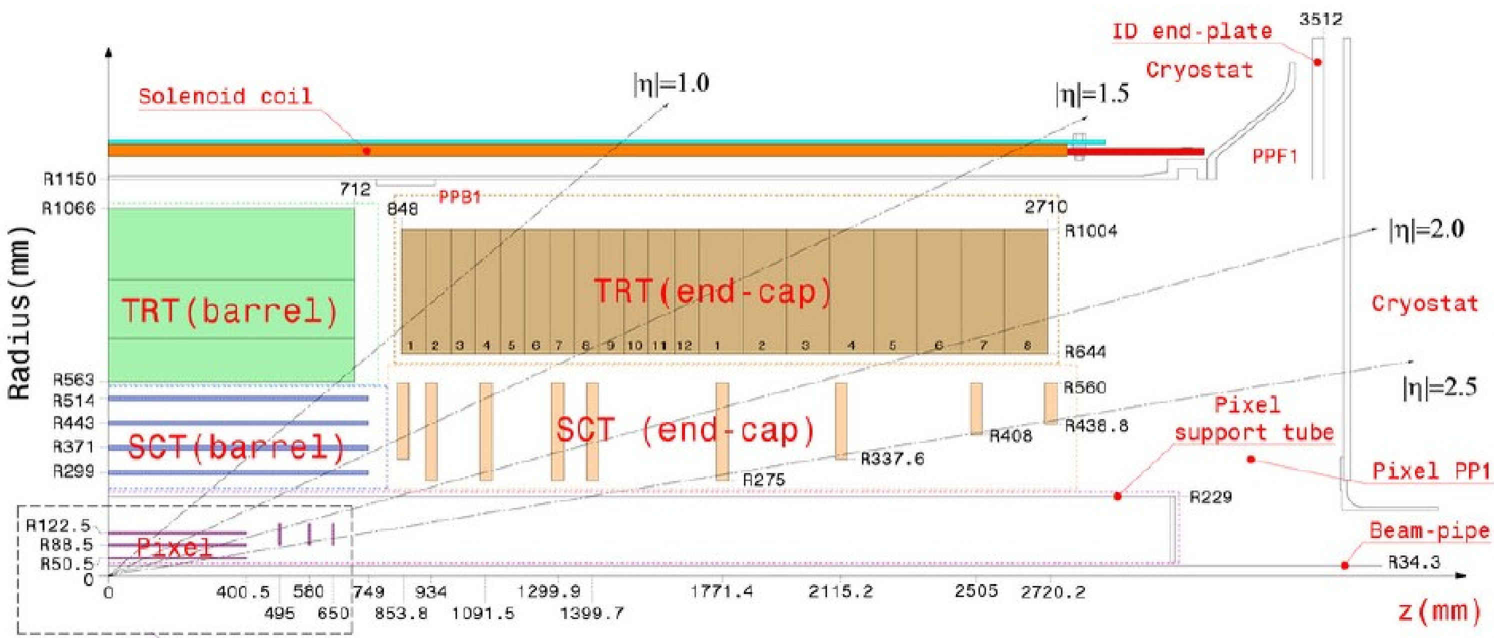
# Part 1

Tracking in ATLAS and CMS

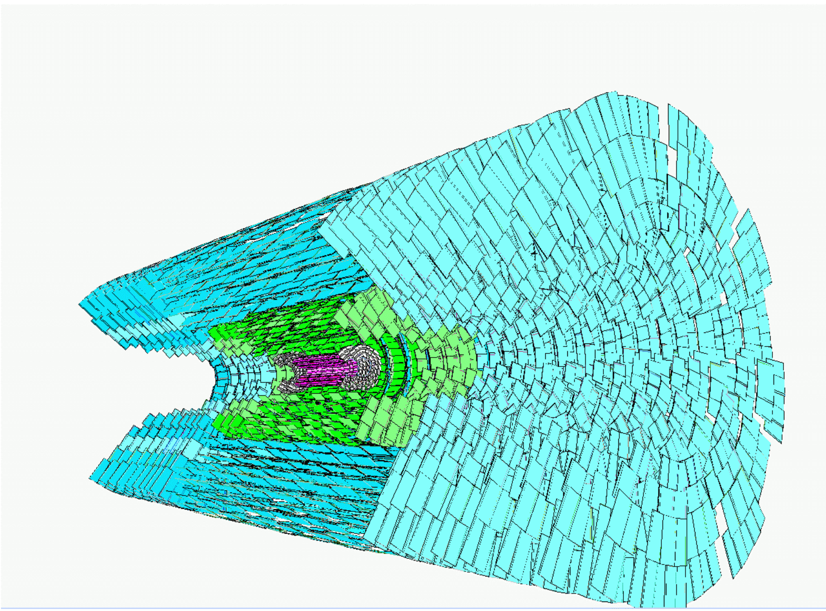
# ATLAS Inner Detectors



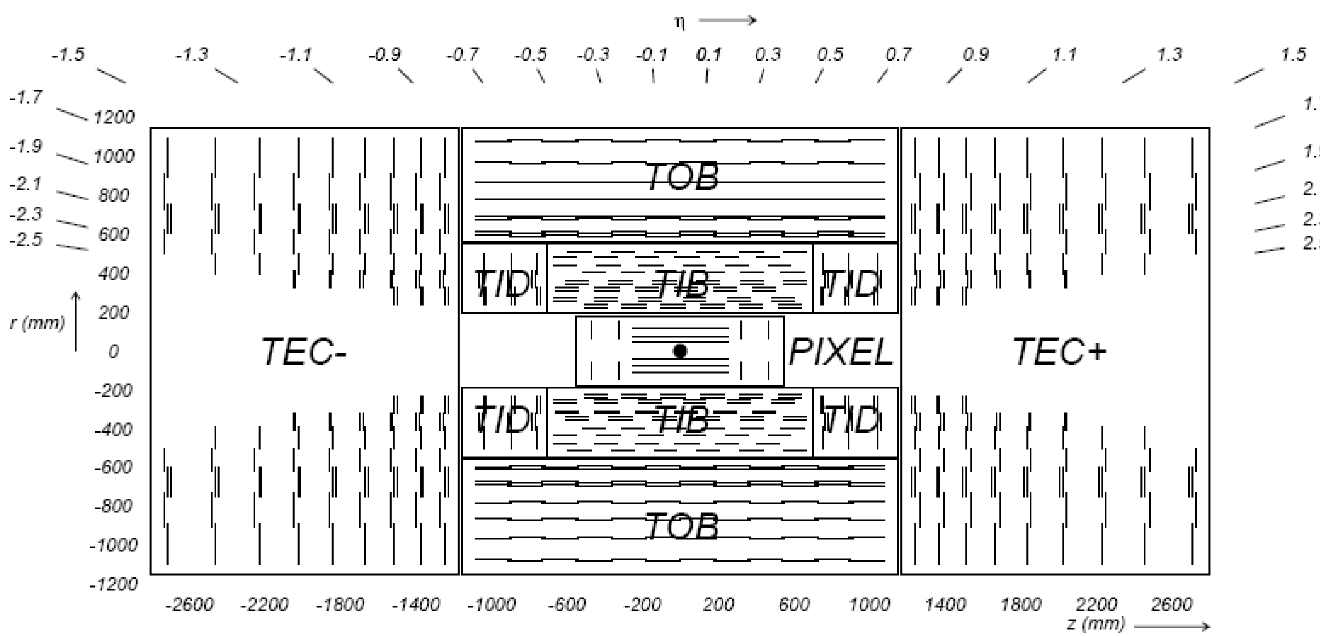

- Silicon and drift tube technologies
  - Pixels (PIX), $80 \times 10^6$ channels
  - Strips (SCT), $6.3 \times 10^6$ channels
  - Transition radiation detector with straw tubes (TRT), $3.5 \times 10^5$ channels
- Solenoidal field, B = 2 T



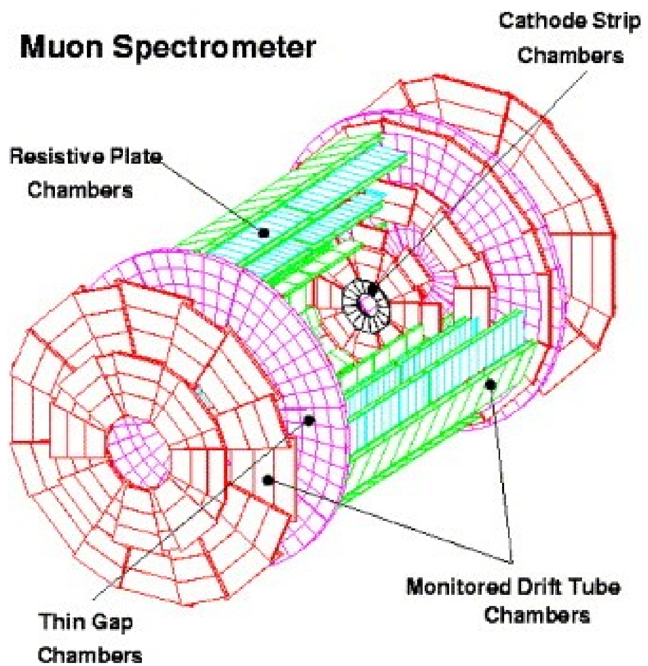
# CMS Inner Detectors



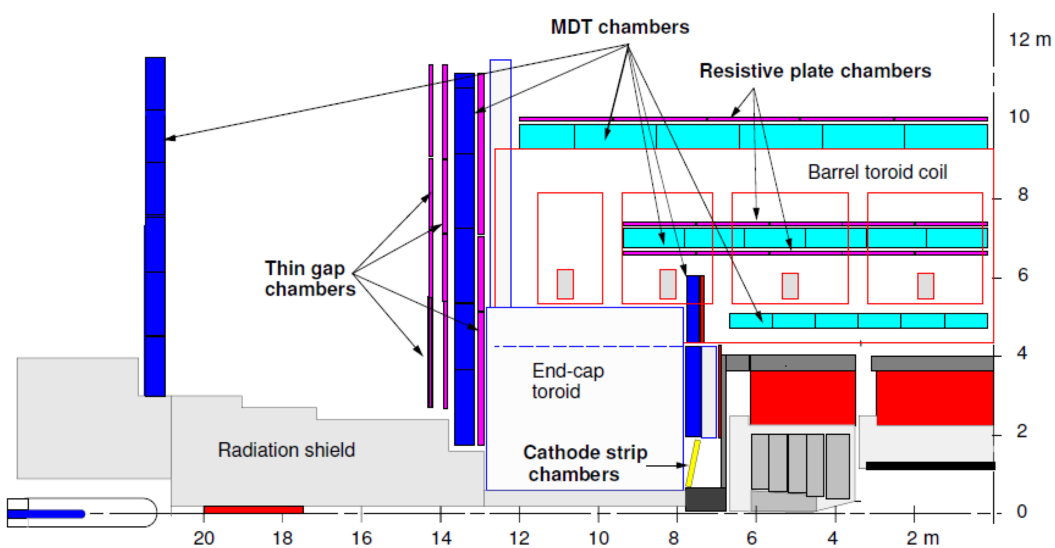
- All-silicon tracker
  - Pixels (PIX), $66 \times 10^6$ channels
  - Strips (TRK), $11 \times 10^6$ channels
- Solenoidal field, B = 3.8 T

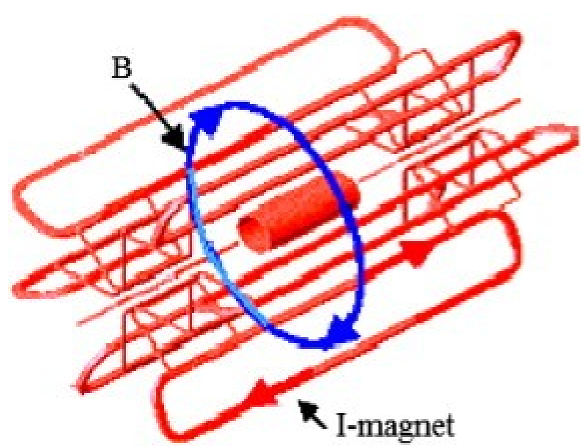


# ATLAS Muon System

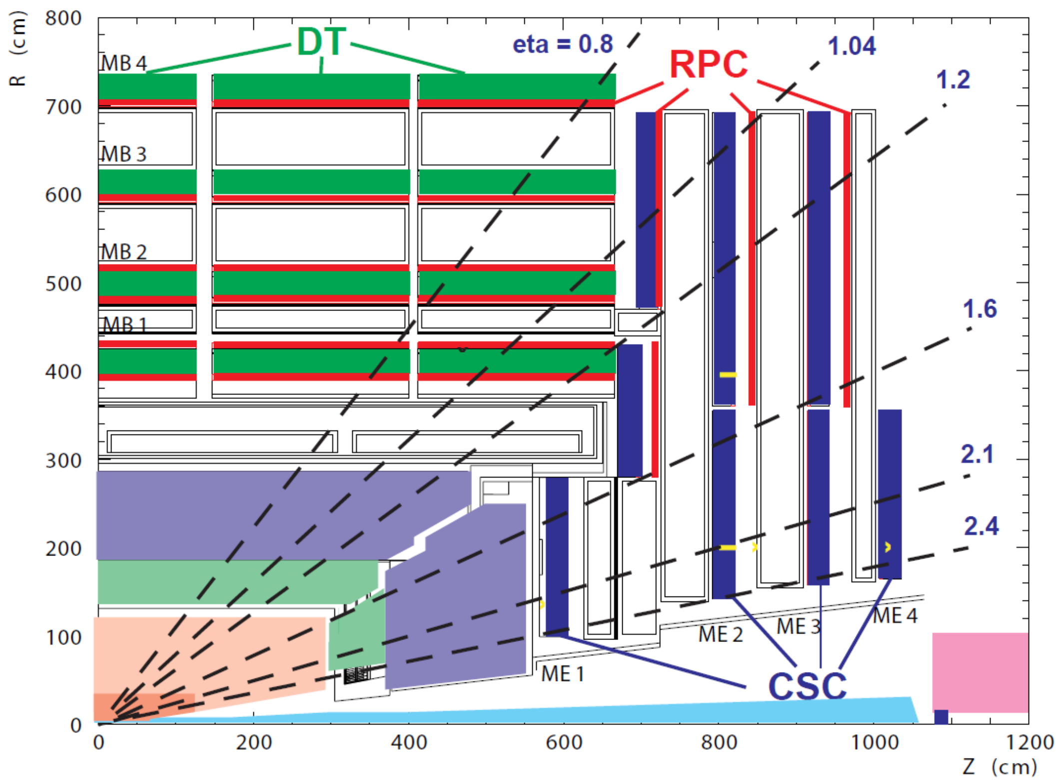



- 4 different technologies
  - MDT, CSC, RPC, TPC
  - 1M channels overall
- Toroidal field
  - Large B variations in a toroid
  - B = 4 T near coils

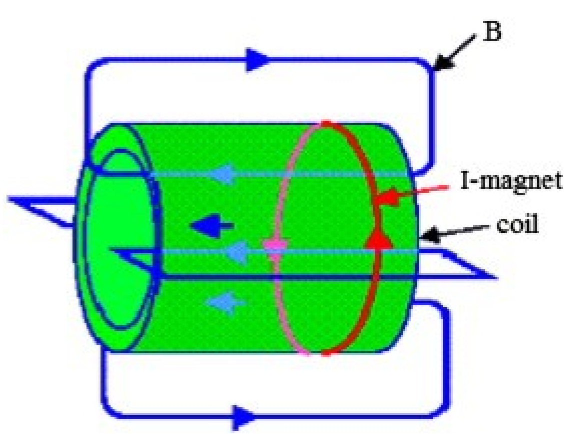


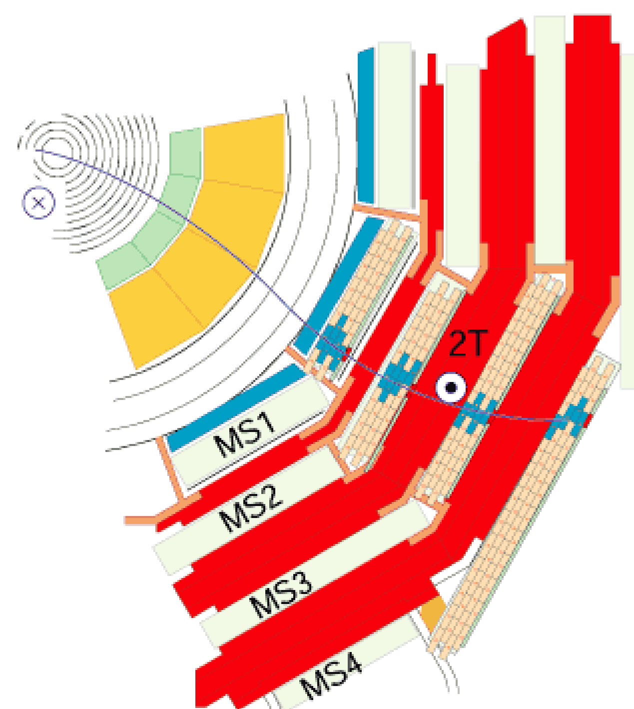



# CMS Muon System




- 3 different technologies
  - DT, CSC, RPC
  - 1M channels overall
- Solenoidal field from return yoke
  - B = 2 T in the iron, 0 T in the chambers
  - Large variation in the endcap



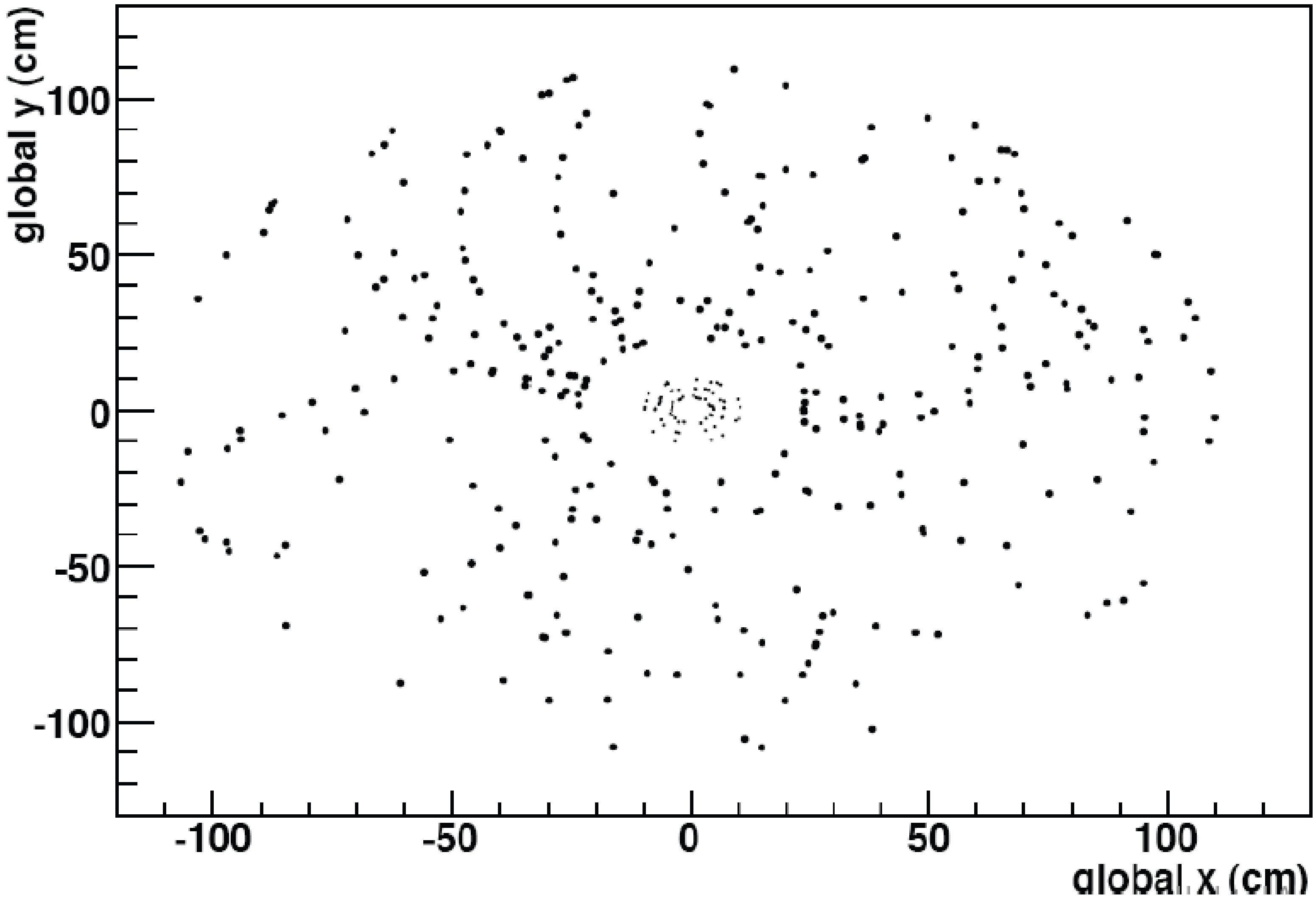



# How all this is represented in ATLAS&CMS Full Simulations

- Geometry and propagation
  - Extremely detailed description of active and inactive volumes
  - Note: the geometry used in reconstruction is, instead, a simplified one
  - Detailed **magnetic field** map is used for propagation
- Signal formation
  - **Geant4** is used to simulate all particle-matter interactions
  - Output: “SimHits” with given energy deposit, position, and time
- Electronic effects (“digitization step”)
  - Charge drift and diffusion, cross-talk, etc: simulated or parametrized
  - **Noise** is added; realistic **gain** miscalibration for signal and noise
  - Time delay (wrt in-time particles with v=c) affects signal strength
  - Energy is translated into **ADC counts**; saturation is considered
  - Dead channels can be taken into account at this stage (or later in reco)

# The tracking problem

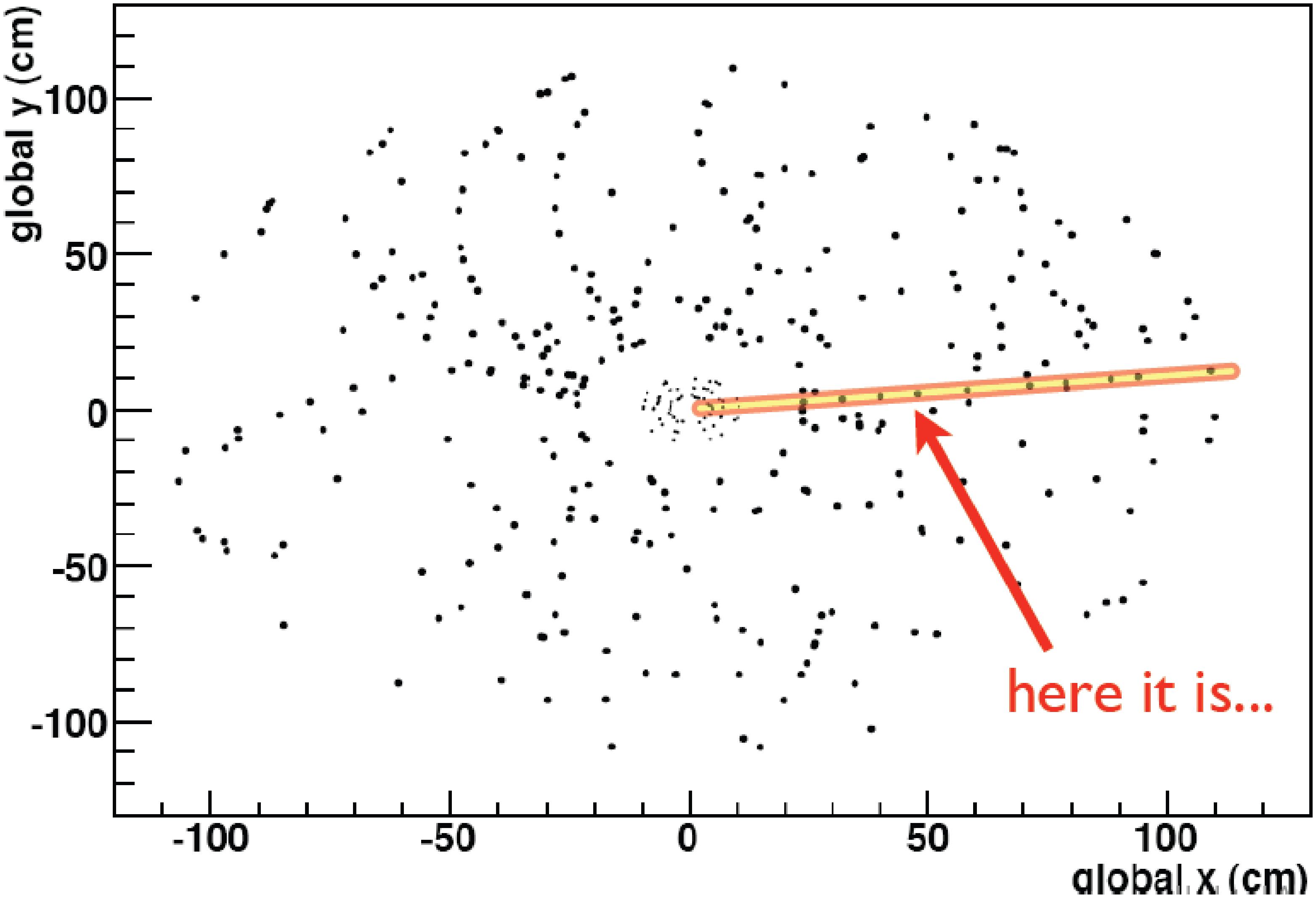
cf Aaron Dominguez



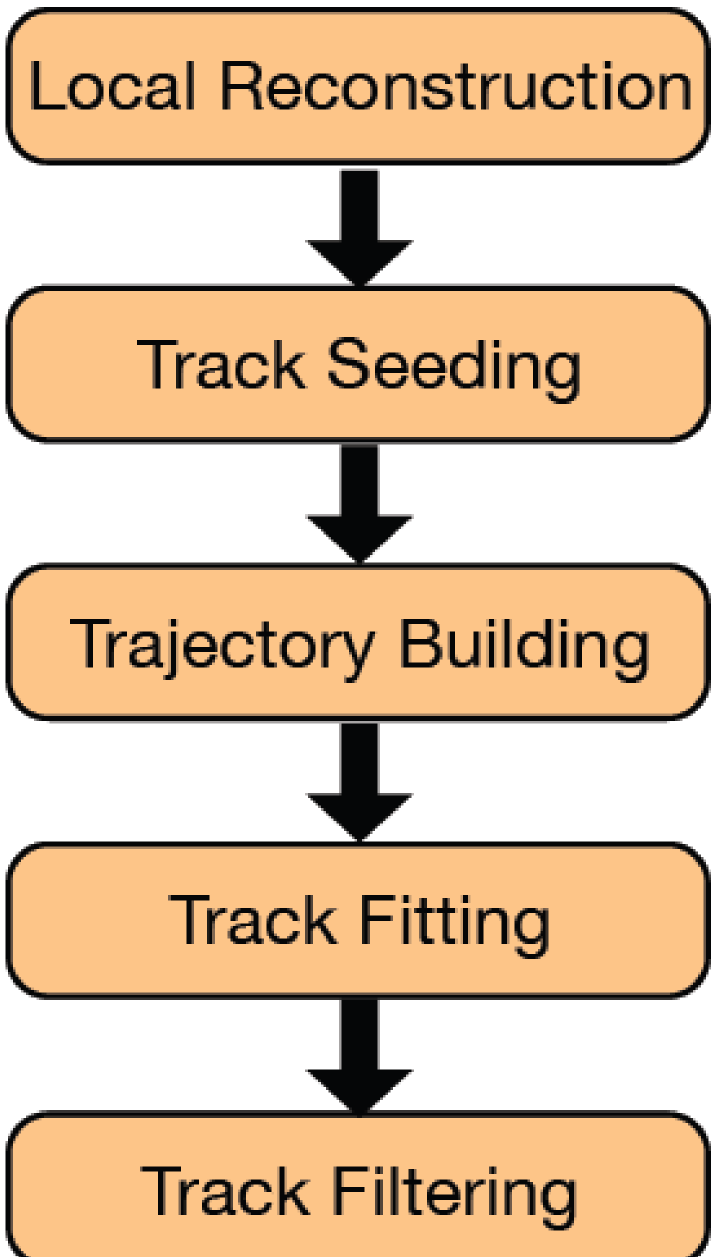

Where is the 50 GeV track?

# The tracking problem

cf Aaron Dominguez



# Tracking basics




Channels (strips, pixels, …) giving signal are clustered into "**hits**"

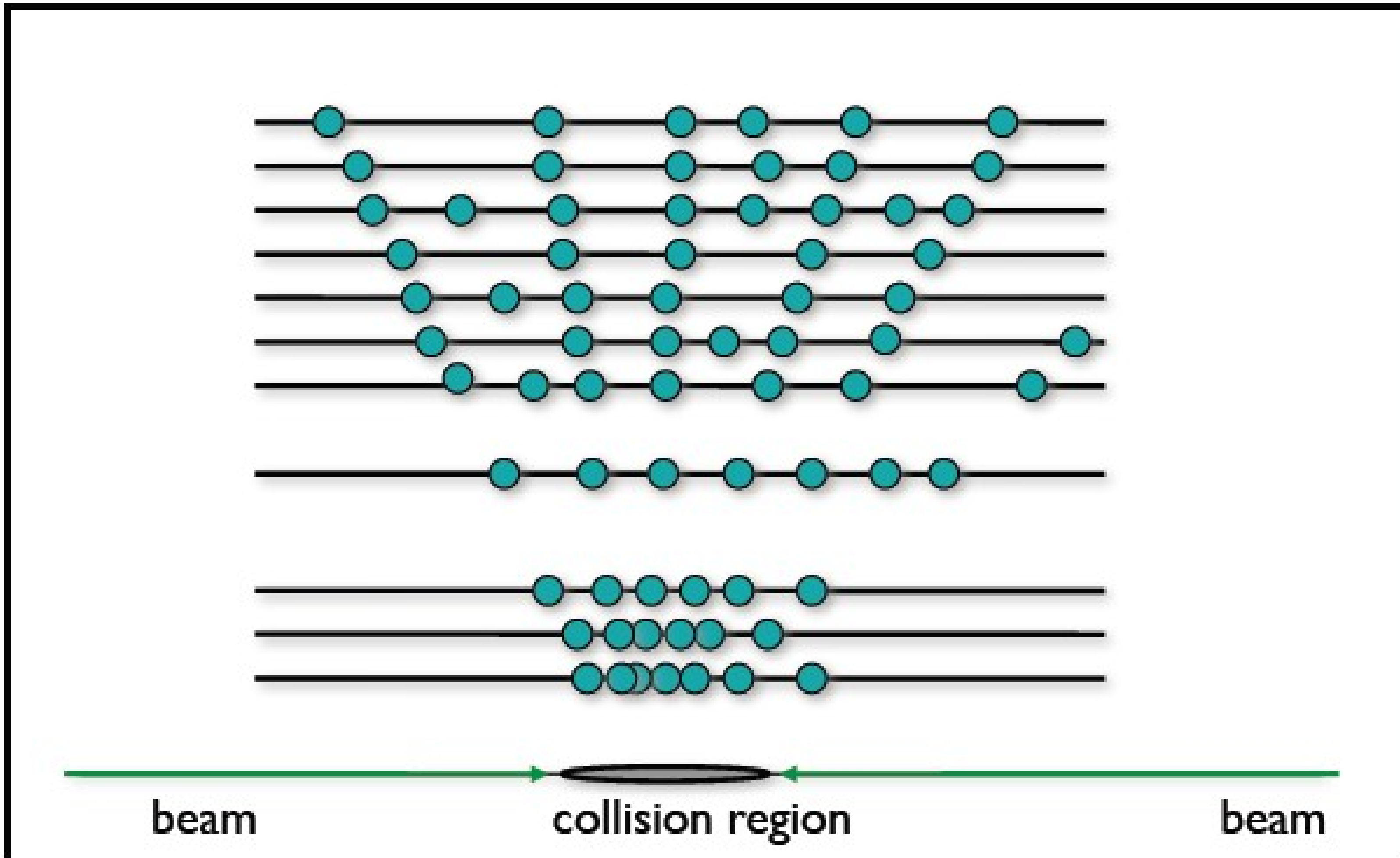
A minimal number of hits (or, in special cases, information from another detector) is used for an **initial estimate of track direction**

**Pattern recognition** step: all available hits are used to infer the particle trajectory

**Final estimate** of the track parameters using the full set of associated hits

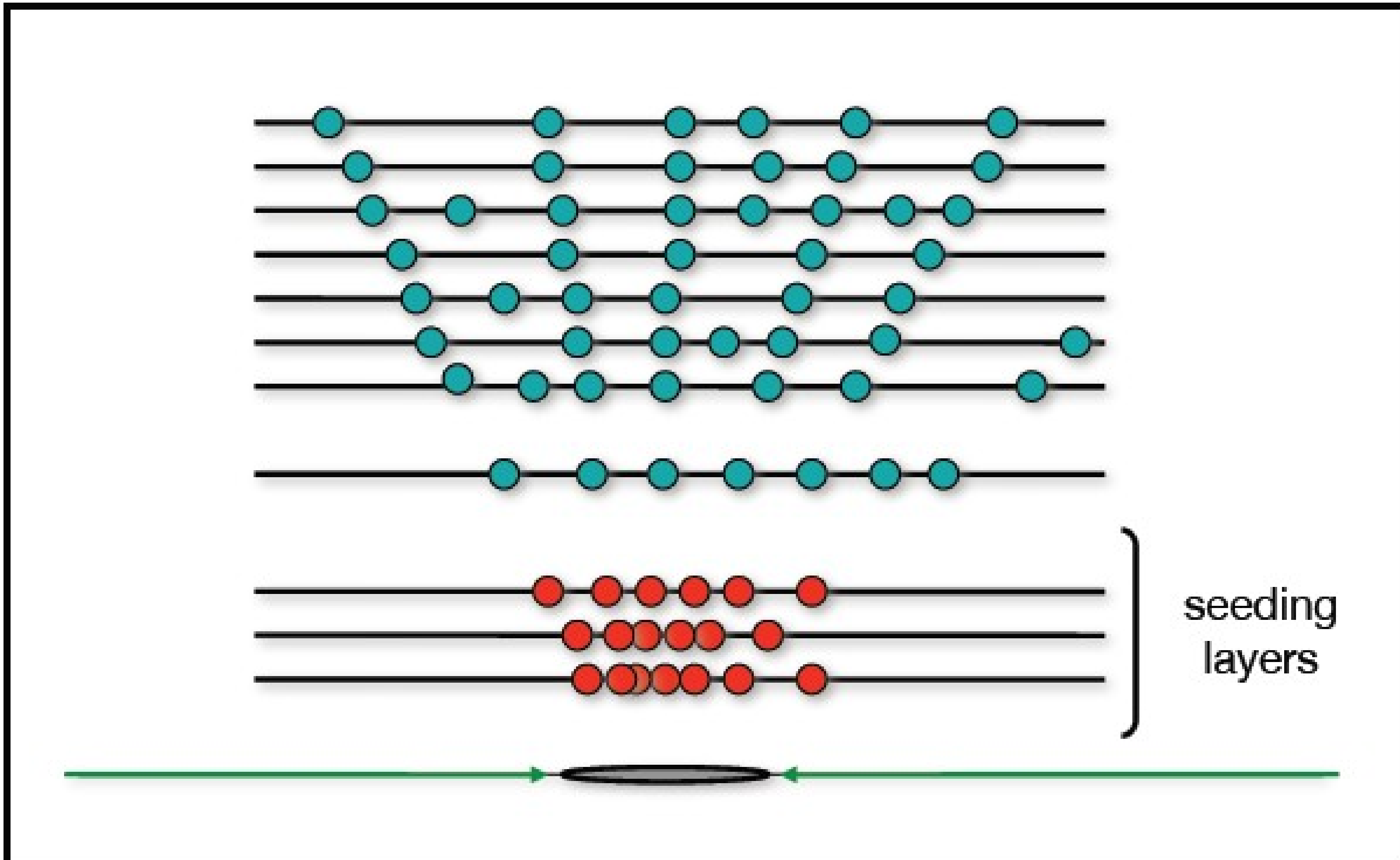
Removal of low-quality tracks, likely to be fakes

# After local reconstruction



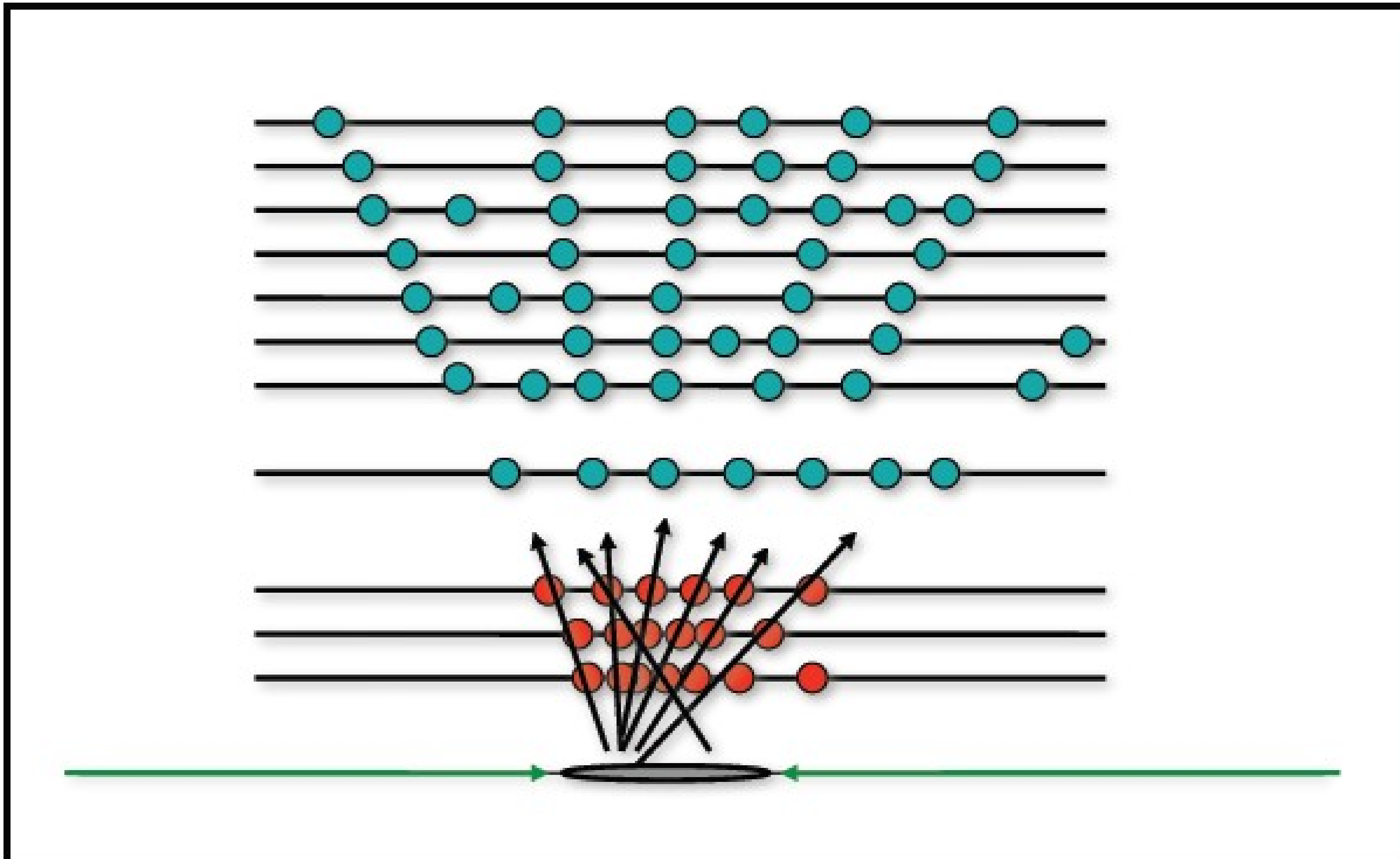

We start from a collection of hits, associated to a position and an uncertainty

# Seeding




Note: the seeding layers (or disks, in the endcaps) are not necessarily the innermost ones; seeds can even come from outer detectors (TRT, calorimeters, muon system)

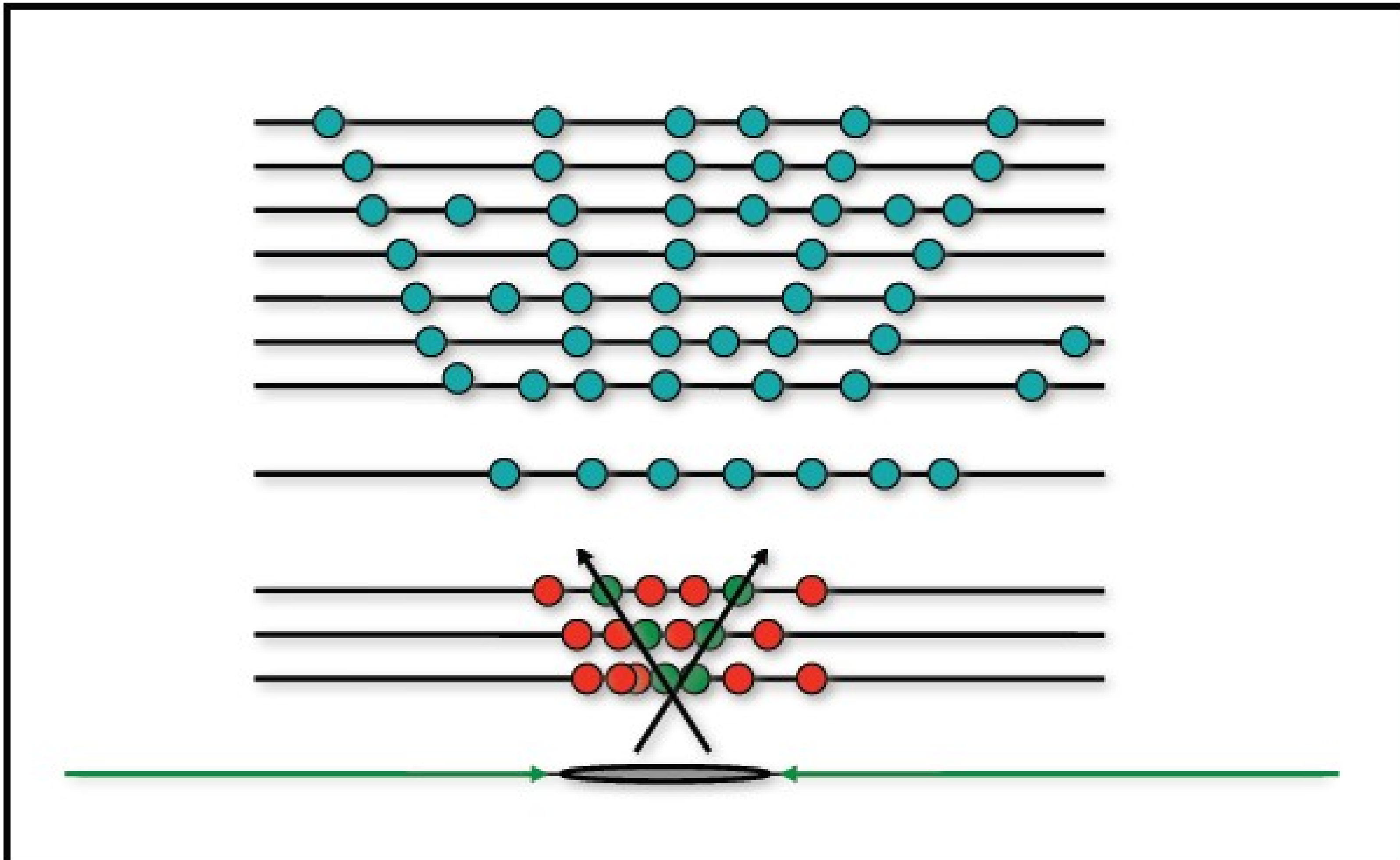
# Seeding



Fast helix fit to get initial trajectory
(5 parameters, e.g. $d_0$, $z_0$, $\phi$, $\theta$, $p_T$)

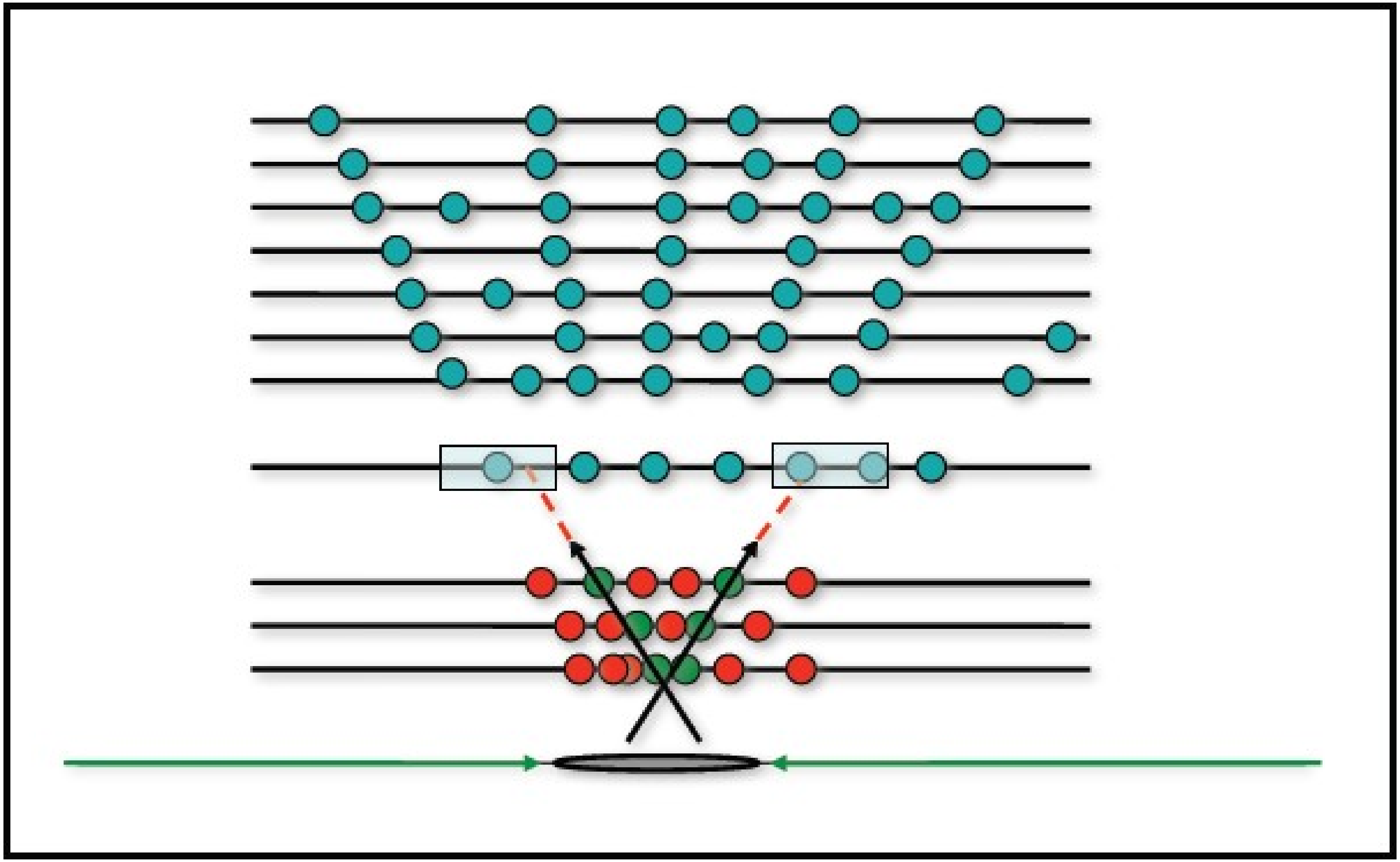
The beam spot or a volume around the center of the detector can be used as a constraint

# Trajectory building



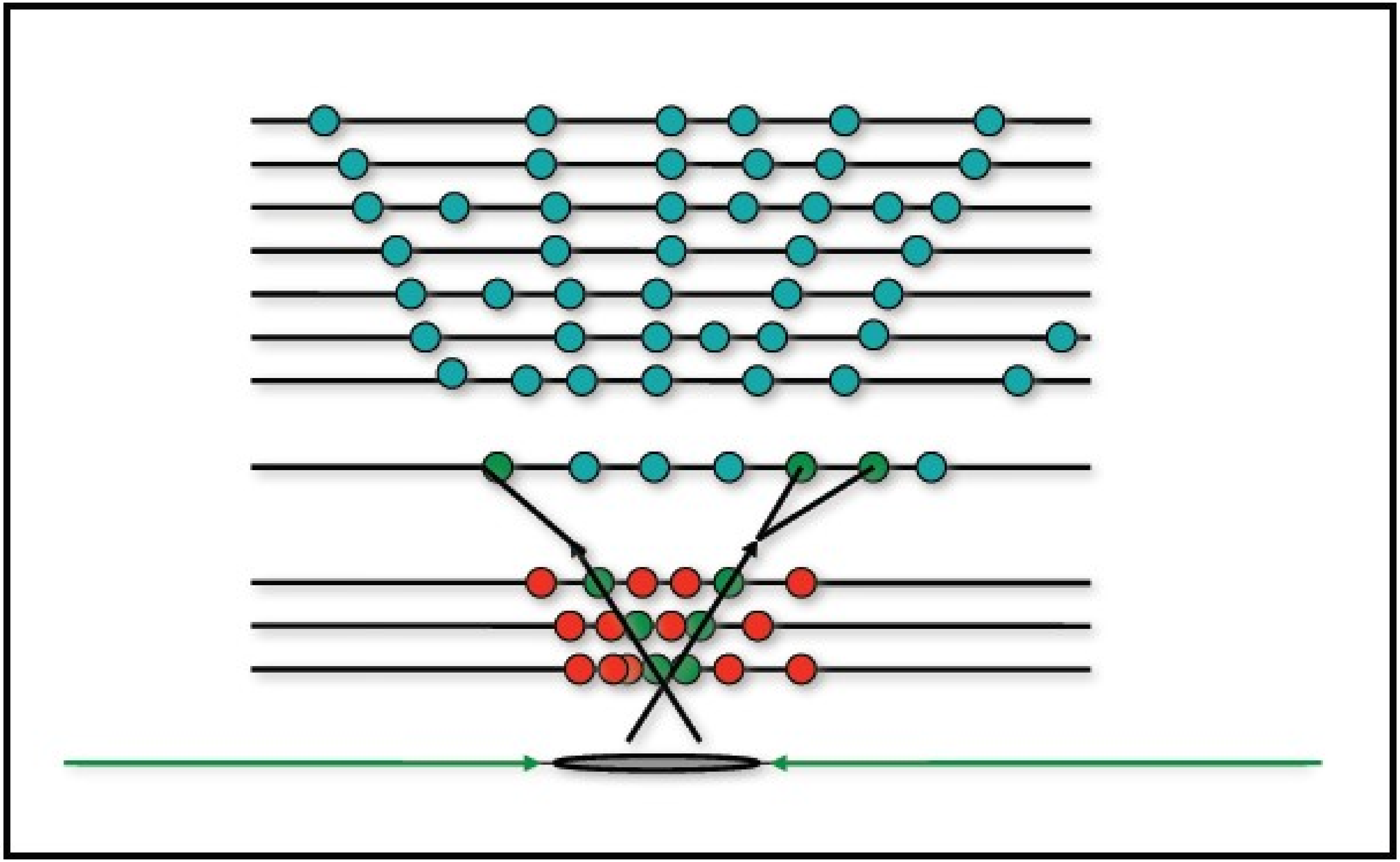
For illustration, let's consider these two seeds and let's see how trajectories are built from there. In CMS, all trajectories are propagated in parallel; in ATLAS, propagation is sequential.
Note: this particular example is inside-out; outside-in tracking is possible.

# Trajectory building

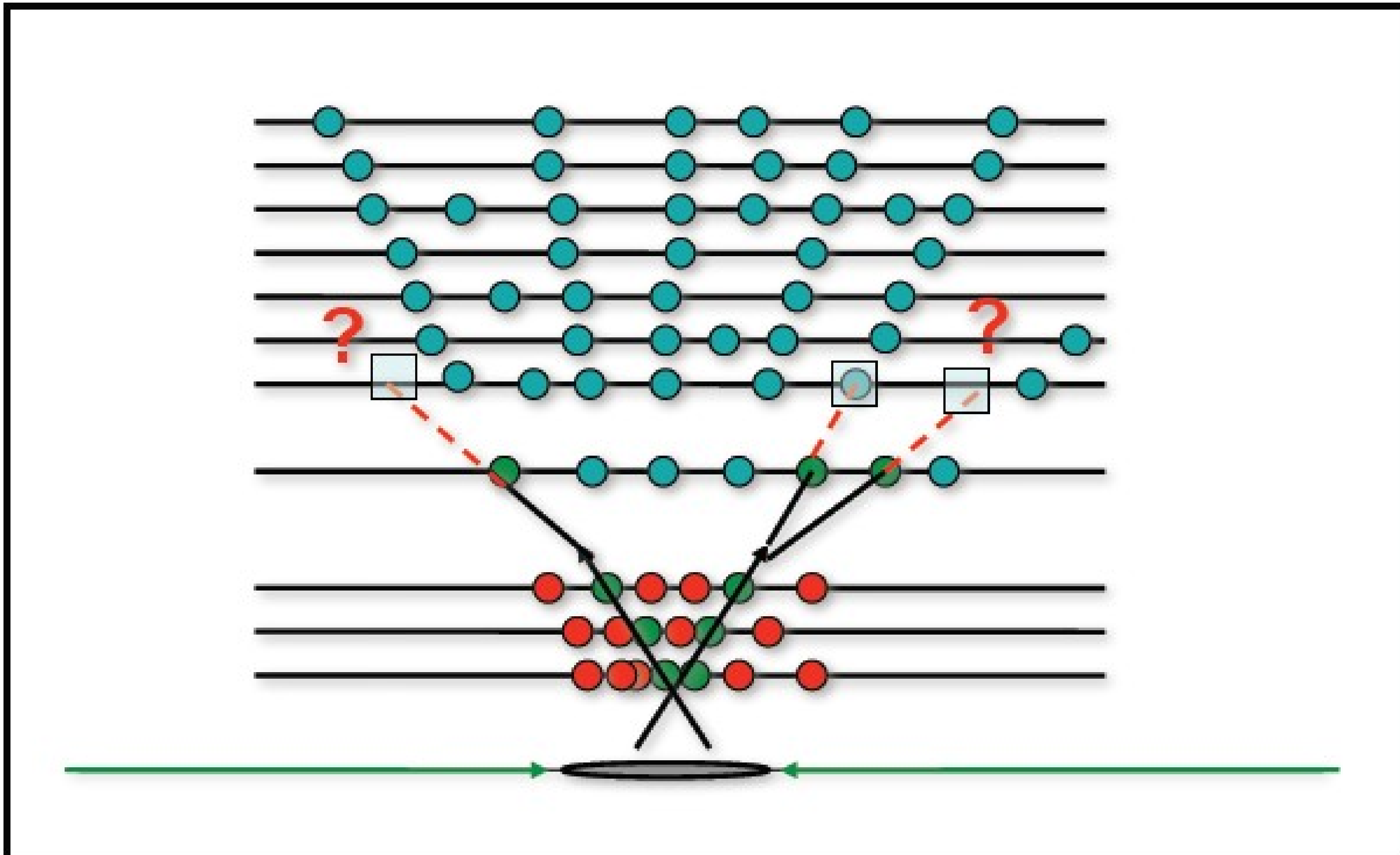


Trajectory is propagated from layer to layer taking into account the uncertainties on the hit positions, energy loss, multiple scattering. The combinatorial Kalman Filter technique is usually employed
(this talk doesn't mention special cases like electrons)

# Trajectory building

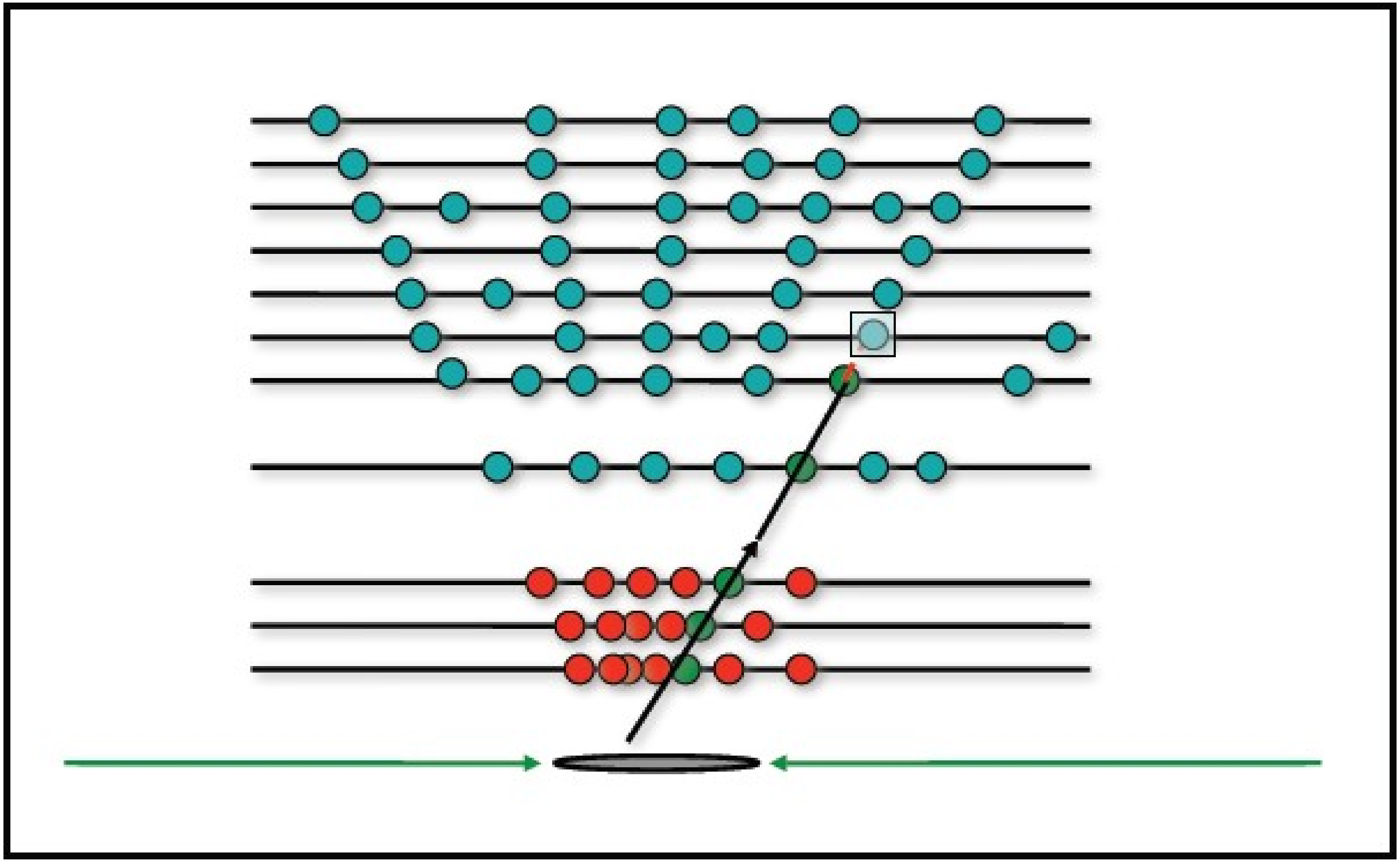


# Trajectory building

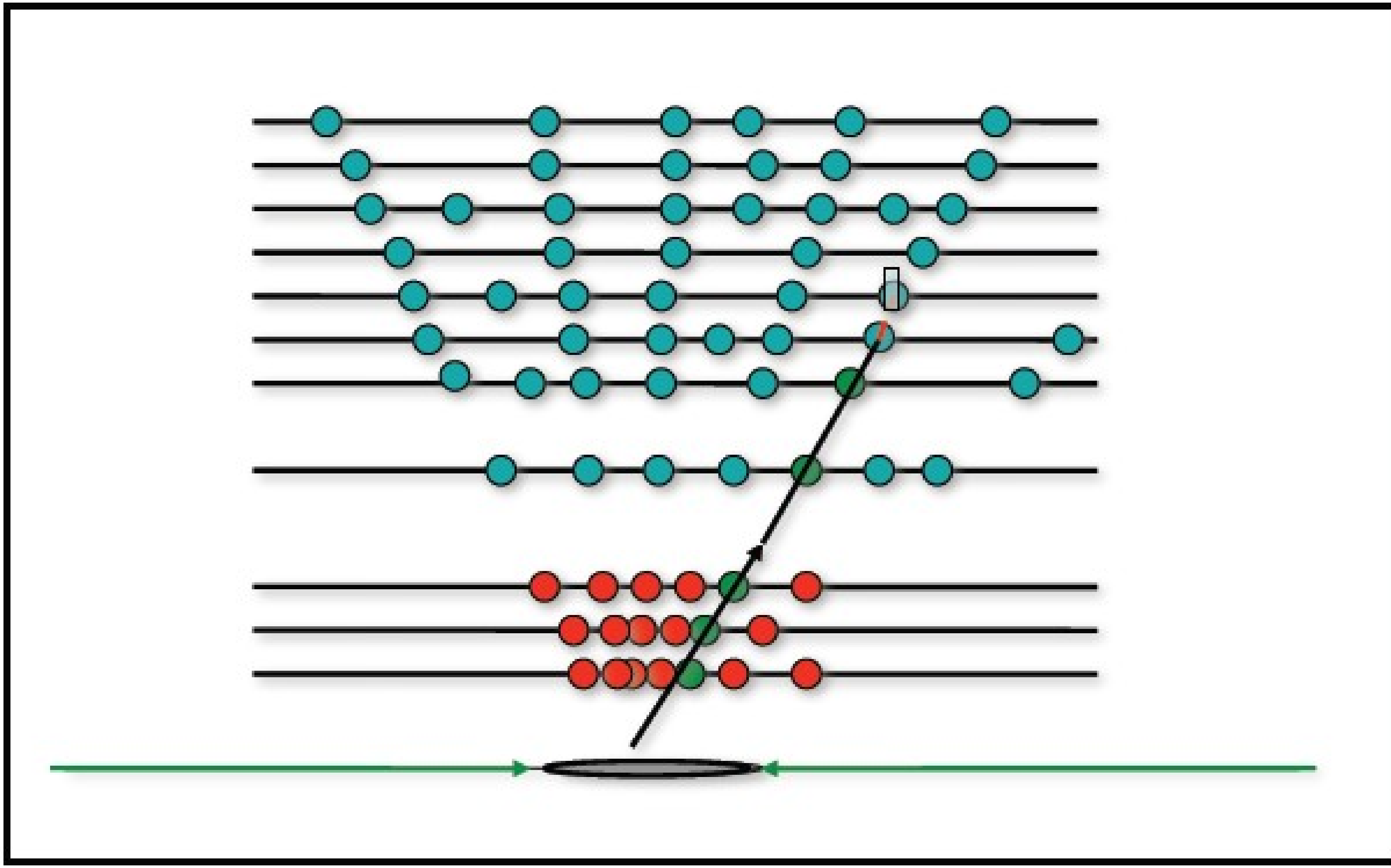



When no hits are found, track is probably fake

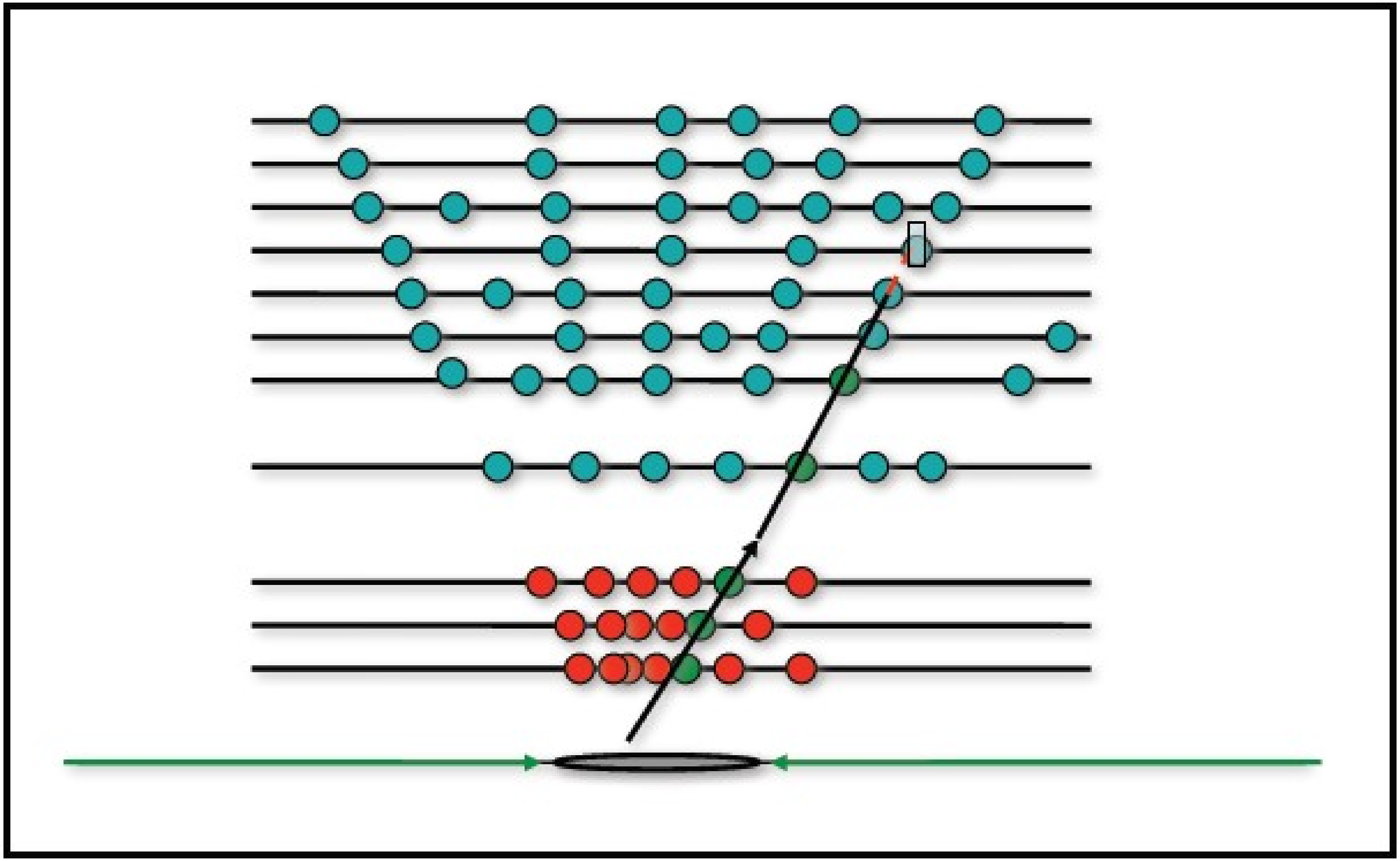
# Trajectory building



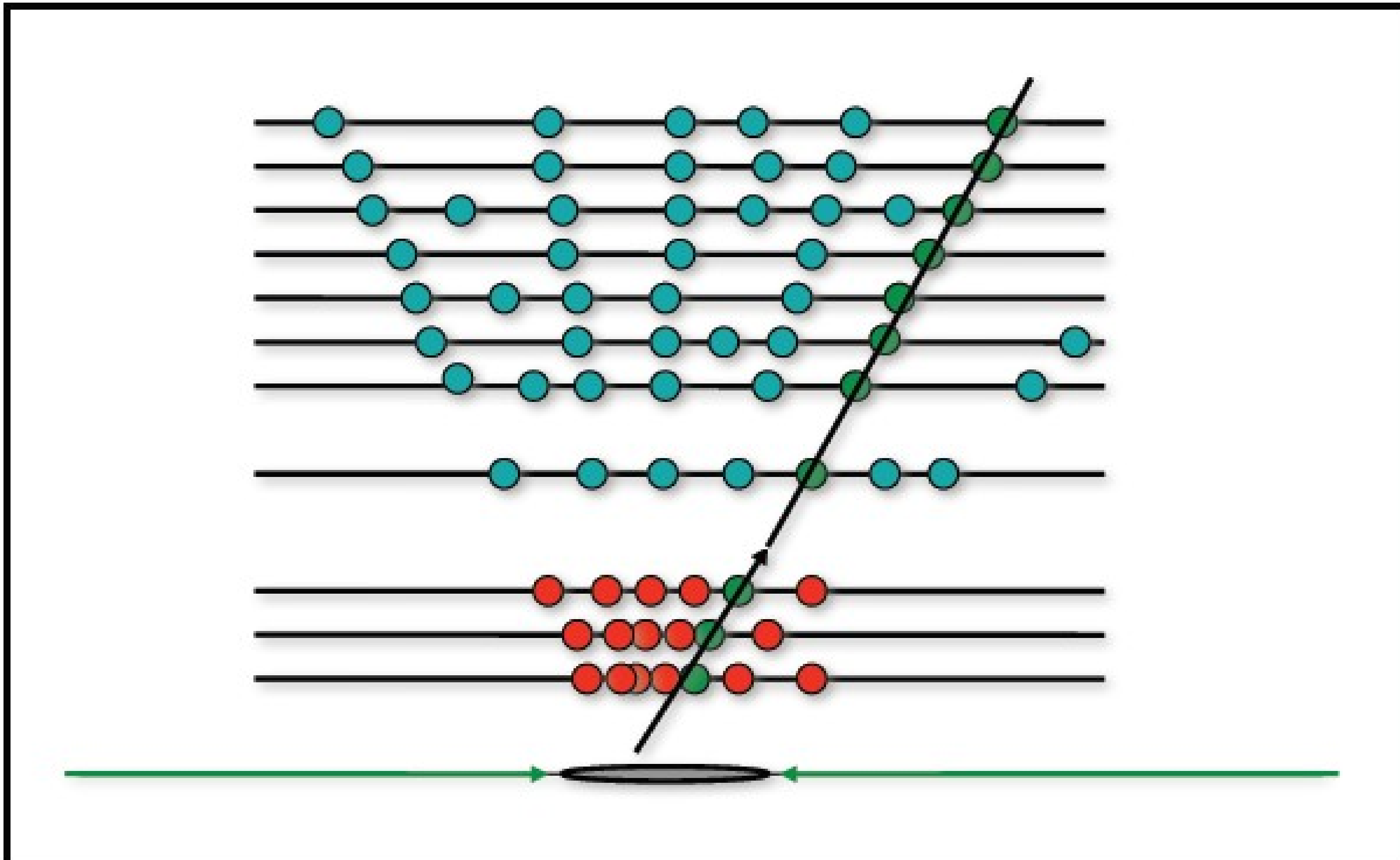
# Trajectory building



# Trajectory building



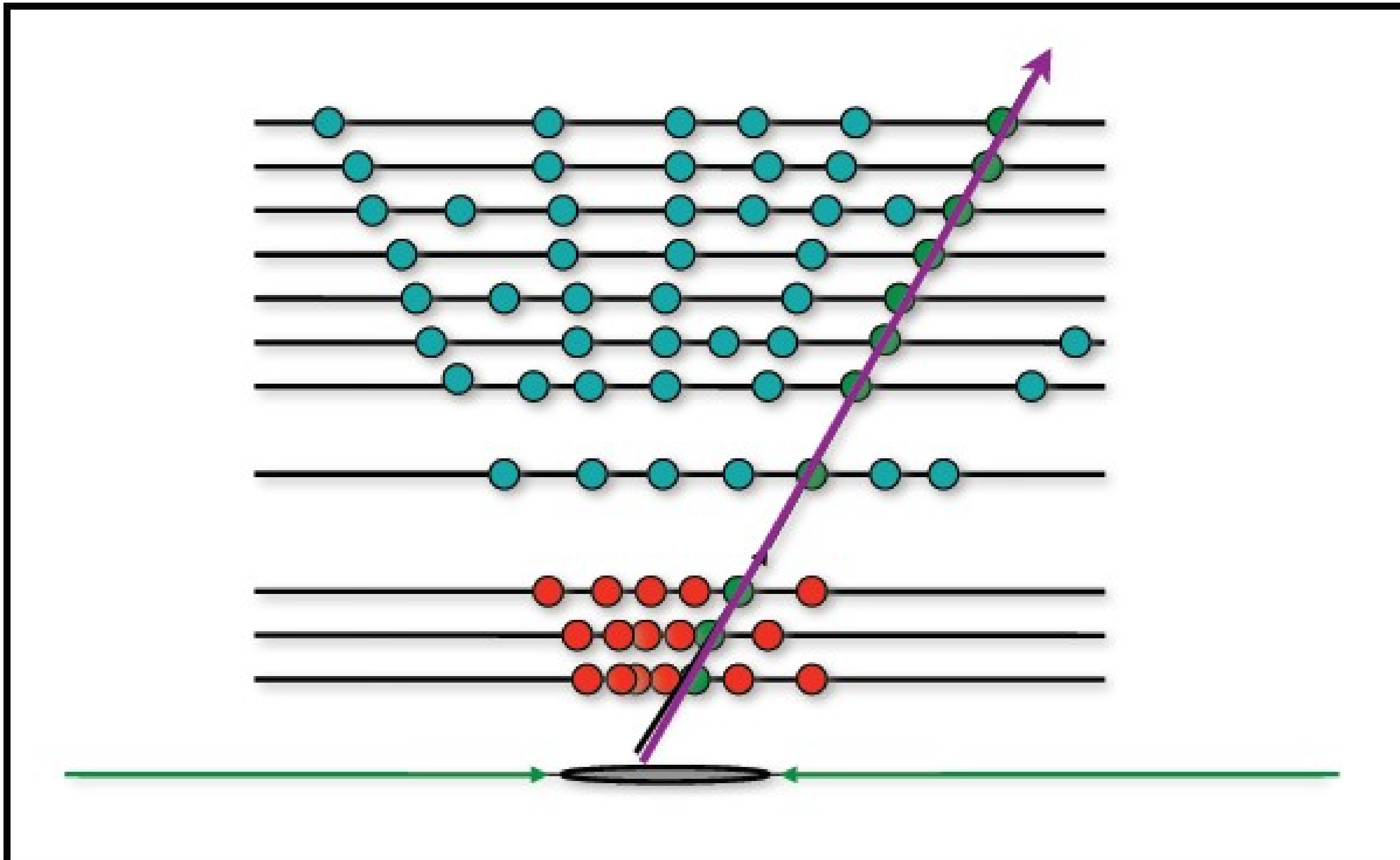
# Trajectory building



Now we have a track, and a preliminary estimate of its parameters; but this estimate can be biased by constraints applied at seeding stage, hence a final fit must be done.

Before the final fit, **ambiguities** (>1 tracks for the same seed) are solved

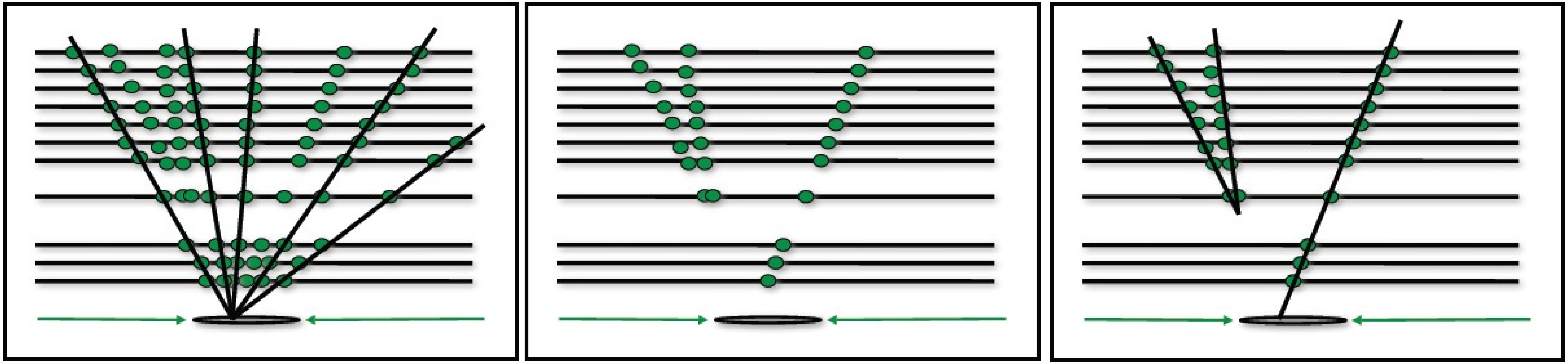
# Track fitting



Final fit to the hits, to get the tracks parameters. Outlier hits are rejected.
CMS: Kalman Filter (in-out & out-in), ATLAS: $\chi^2$ fit
After this step, cuts are applied ($\chi^2$, number of hits, etc.) to remove tracks that are very likely to be fake

# Iterative Tracking in CMS

N-th step: Remove associated hits: (N+1)-th step:



Iterative steps in 2011 reconstruction:

| Iteration | Seeds | $p_T$ cut | d0 cut | dz cut |
|---|---|---|---|---|
| 0 | pixel triplets | 0,8 GeV/c | 0,2cm | 3,0$\sigma$ |
| 1 | pixel pairs | 0,6 GeV/c | 0,2cm | 0,2cm |
| 2 | pixel triplets | 0,075 GeV/c | 0,2cm | 3,3$\sigma$ |
| 3 | pixel,TIB,TID,TEC | 0,35 GeV/c | 1,2cm | 10,0cm |
| 4 | TIB,TID,TEC | 0,5 GeV/c | 2,0cm | 10,0cm |
| 5 | TOB,TEC | 0,6 GeV/c | 5,0cm | 30,0cm |

# Tracking in ATLAS

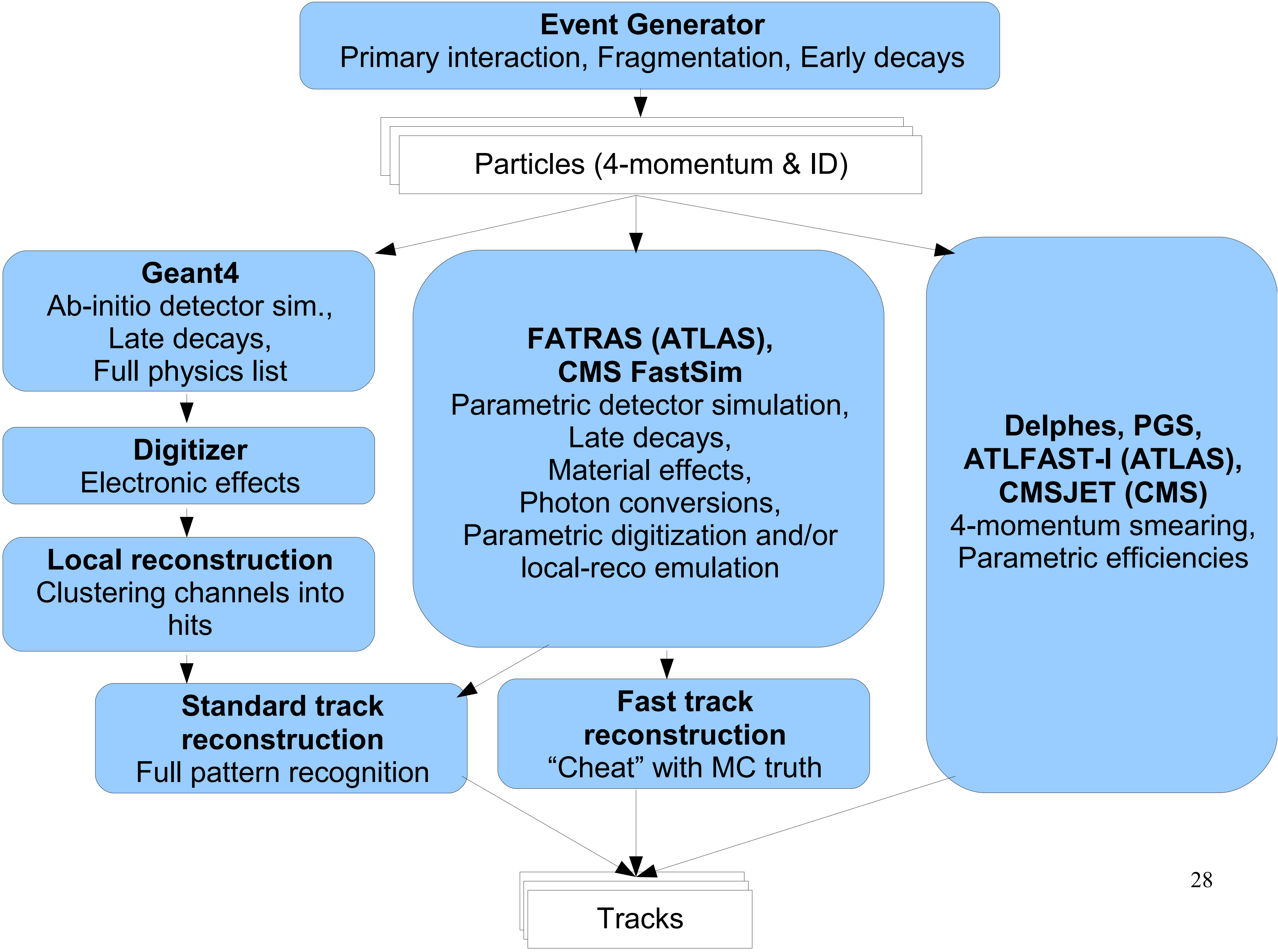
- Sequence of algorithms:
  - Iterative inside-out tracking
    - Each iteration starts from 3-hit seeds in silicon detectors
    - Add hits moving away from the interaction point
    - Ambiguities in the track candidates are resolved
    - Tracks extended to the TRT
    - Cut $p_T$>0.4 GeV
  - Back-tracking
    - Find segments reconstructed in the TRT
    - Extend them inwards adding hits in silicon detectors
  - TRT standalone
    - Add TRT segments without extension into the silicon detectors

# Muon candidates in ATLAS/CMS

- Algorithms are similar in the two experiments:
  - Standalone Muons
    - Tracks are found in the muon system and extrapolated to beam line
  - Combined/Global Muons
    - Standalone Muons are matched to tracks from the inner detector
    - Momentum measurement from combination
  - Tagged/Tracker Muons
    - Inner detector tracks are extrapolated to the muon system, searching for nearby hits
  - Calorimeter Muons
    - Inner detector tracks are extrapolated to the calorimeters, searching for signal compatible with MIP deposition

# Part 2

Fast tracking simulations


Event Generator
Primary interaction, Fragmentation, Early decays
Particles (4-momentum & ID)
Geant4
Ab-initio detector sim.,
Late decays,
Full physics list
Digitizer
Electronic effects
Local reconstruction
Clustering channels into hits
FATRAS (ATLAS),
CMS FastSim
Parametric detector simulation,
Late decays,
Material effects,
Photon conversions,
Parametric digitization and/or local-reco emulation
Delphes, PGS,
ATLFAST-I (ATLAS),
CMSJET (CMS)
4-momentum smearing,
Parametric efficiencies
Standard track reconstruction
Full pattern recognition
Fast track reconstruction
“Cheat” with MC truth
Tracks

# Decays in the detector volume

- Detector simulation (full or fast) has to take over the decay of unstable particles from the generator
  - Otherwise, you would have the decay products of particles that disappeared before decay, e.g. in a nuclear interaction
  - Moreover, generators don't know about magnetic fields
- The boundary between the “generator world” and the detector simulation is R = 1 cm in CMS, and based on $\tau_0$ in ATLAS
- Geant4 has its own particle-decay routine
- FATRAS (ATLAS tracking fast sim) uses Geant4's routine
- CMS FastSim uses a Fortran (*) routine adapted from Pythia6 (with magnetic bending); plans to use Pythia8 (C++)

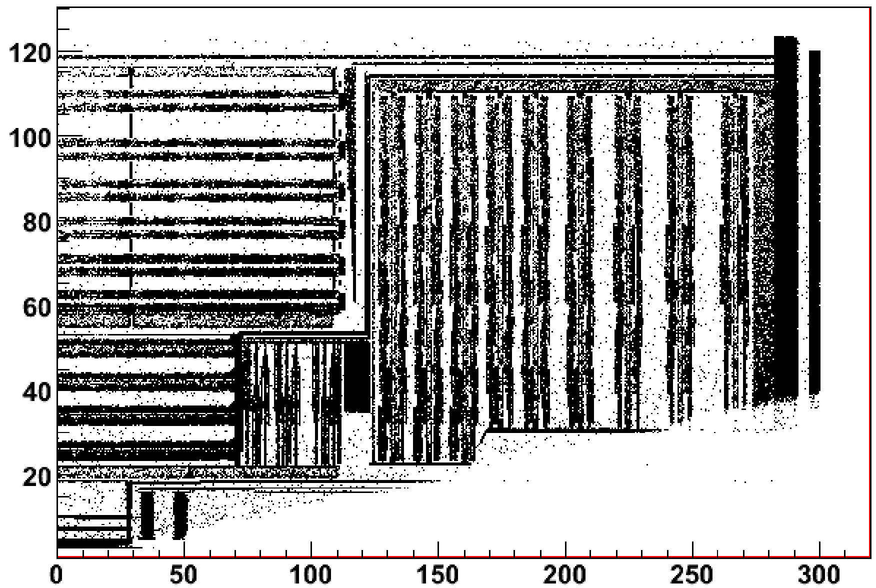


(*) It is the only Fortran code remnant in FastSim and one of the few in CMSSW

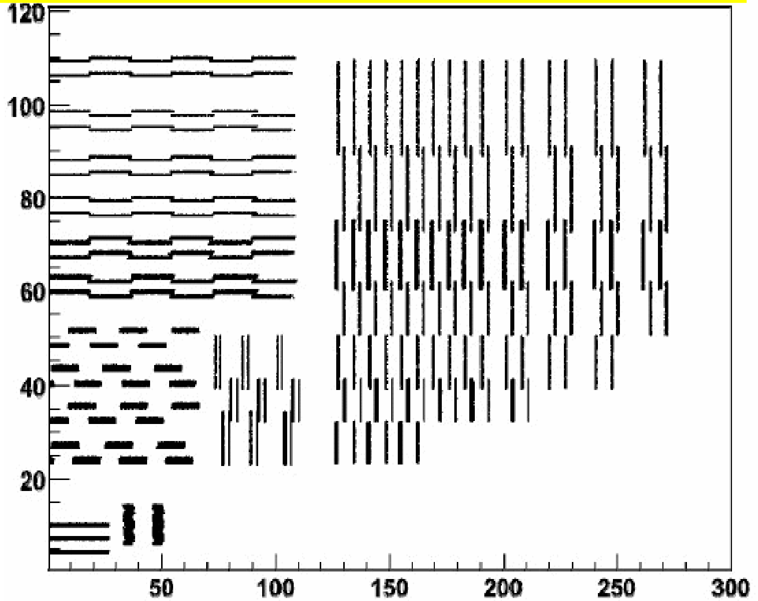
# Geometry and propagation

- Great gain in time by simplified geometry (same as in reconstruction)
- Connected cylindrical volumes, navigated from a layer to the next, keeping an exact description of sensitive elements
- Material is mapped onto layers
- Direct propagation between volume boundaries, but taking into account detailed magnetic field map

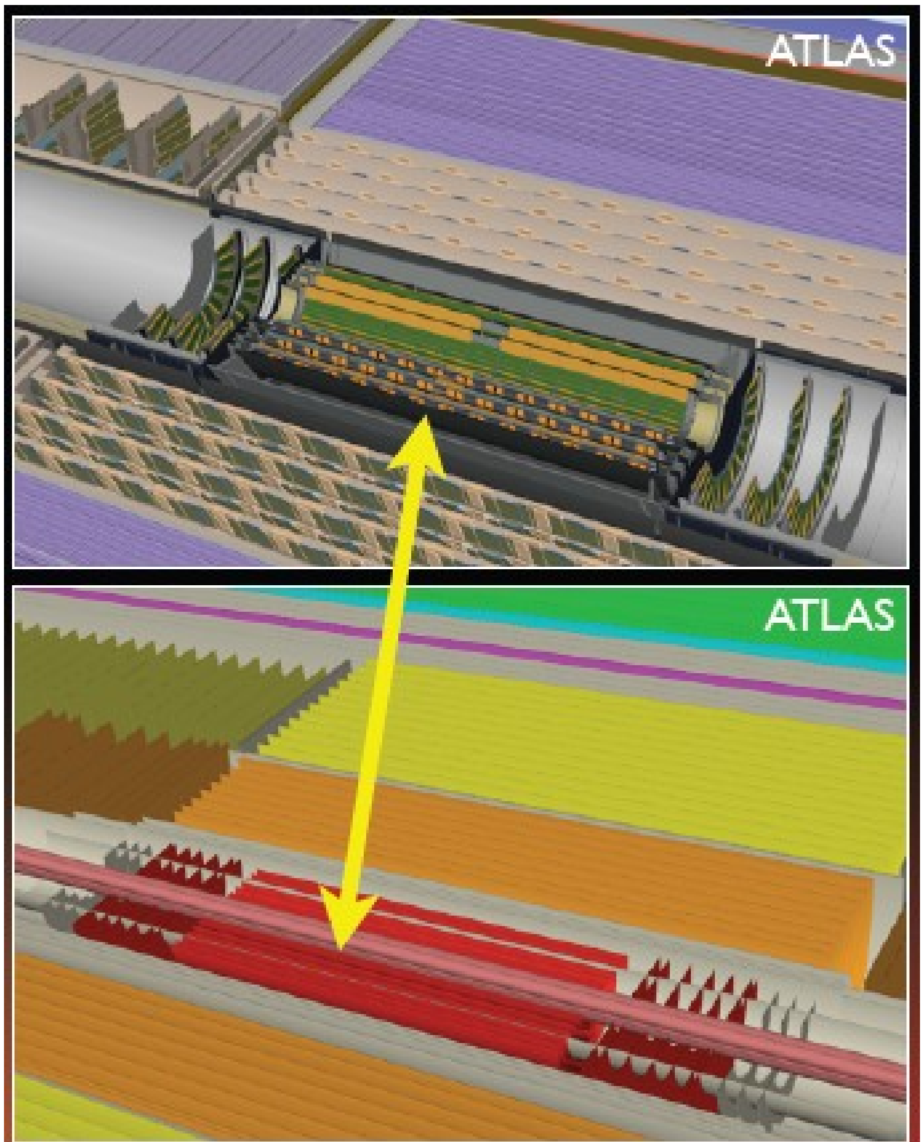
CMS-tracker “tomography” with FullSim geometry

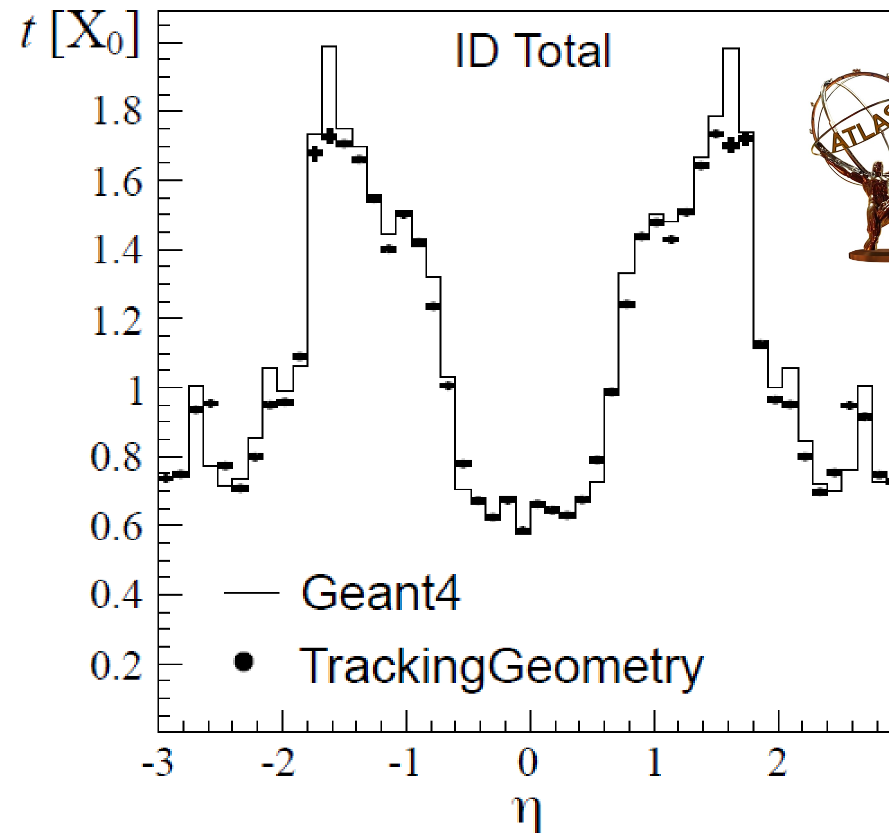



...and with reconstruction/FastSim geometry



# Geometry and propagation




| ATLAS | G4 | tracking | ratio |
|---|---|---|---|
| crossed volumes in tracker | 474 | 95 | 5 |
| time in SI2K sec | 19.1 | 2.3 | 8.4 |

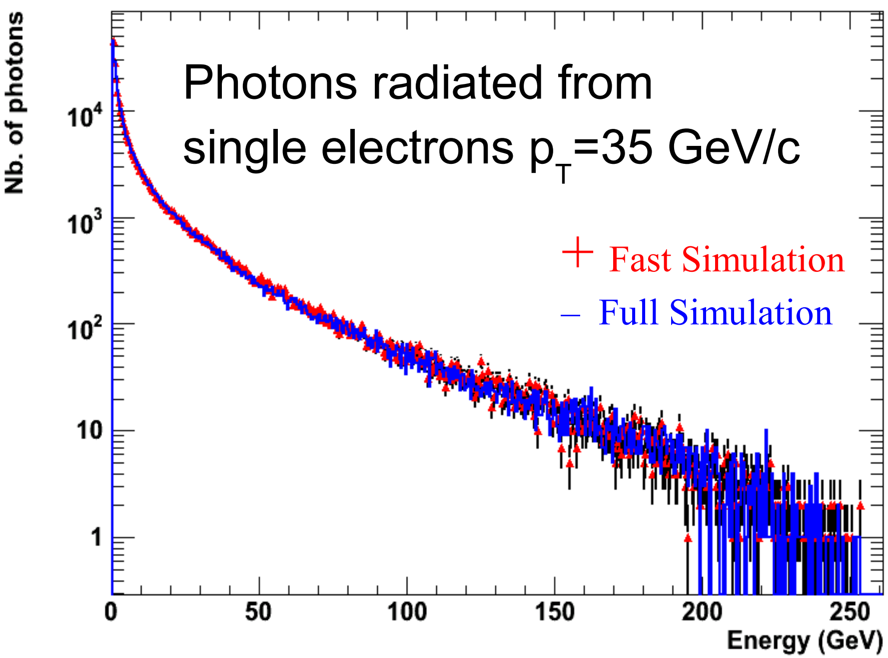
(neutral geantinos, no field lookups)

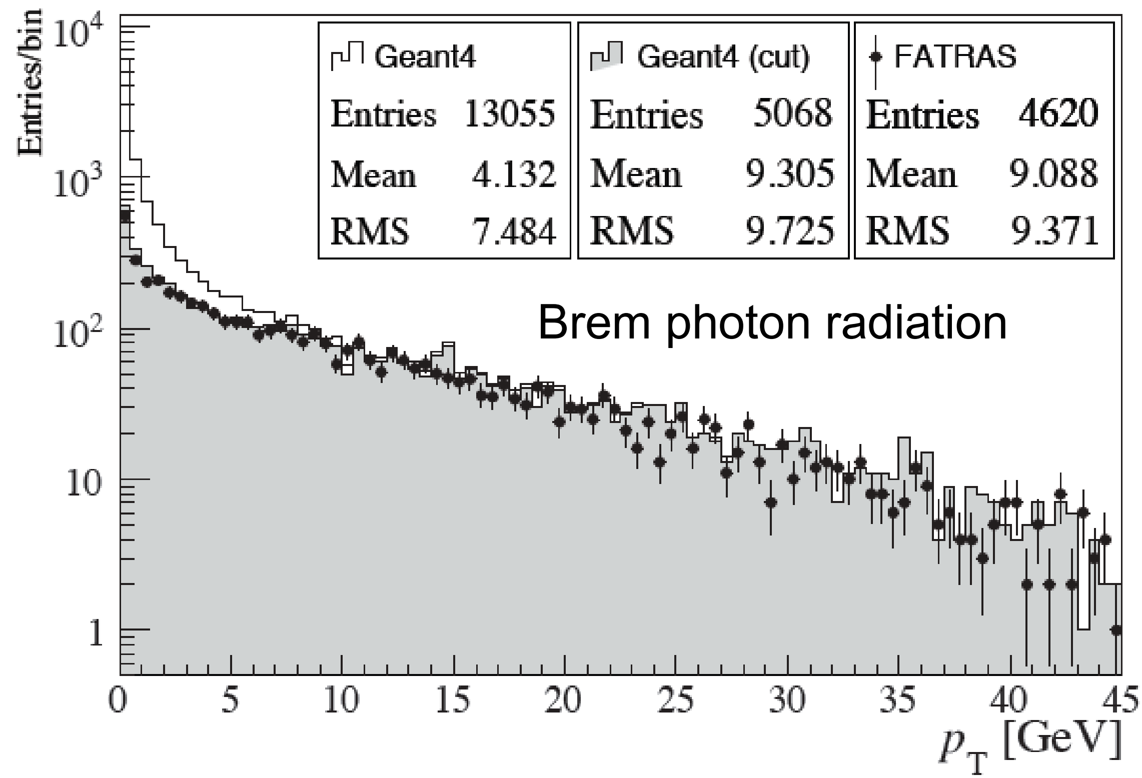
# Material effects

- All material effects are simulated when crossing a layer (point-like approach, as opposed to cumulative effects in the bulk)
- The interactions considered in the fast simulations of tracks:
  - Electron Bremsstrahlung (inner tracker)
  - Photon conversion (inner tracker)
  - Charged particle energy loss by ionization
  - Charged particle multiple scattering
  - Nuclear interactions (inner tracker)
- $\delta$-rays are ignored (their effects are absorbed in energy loss, or parametrized elsewhere)

# Bremsstrahlung

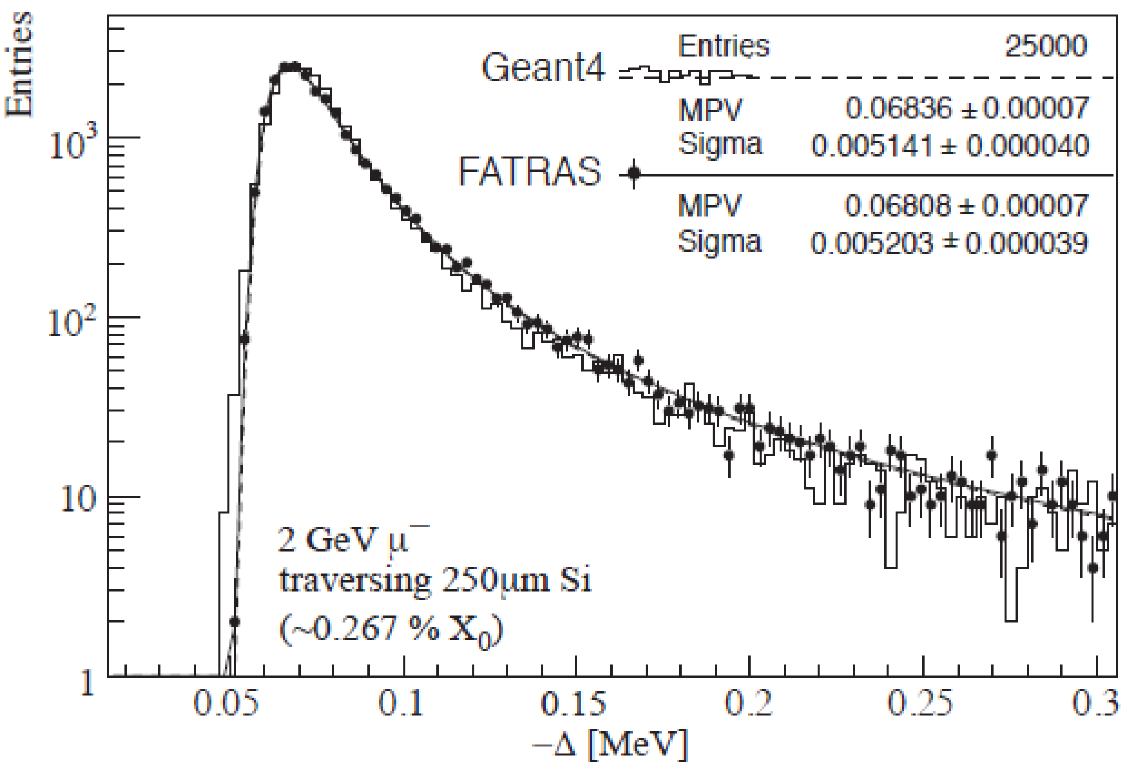
Photon emission probabilities, spectra and angular distributions from analytical formulas

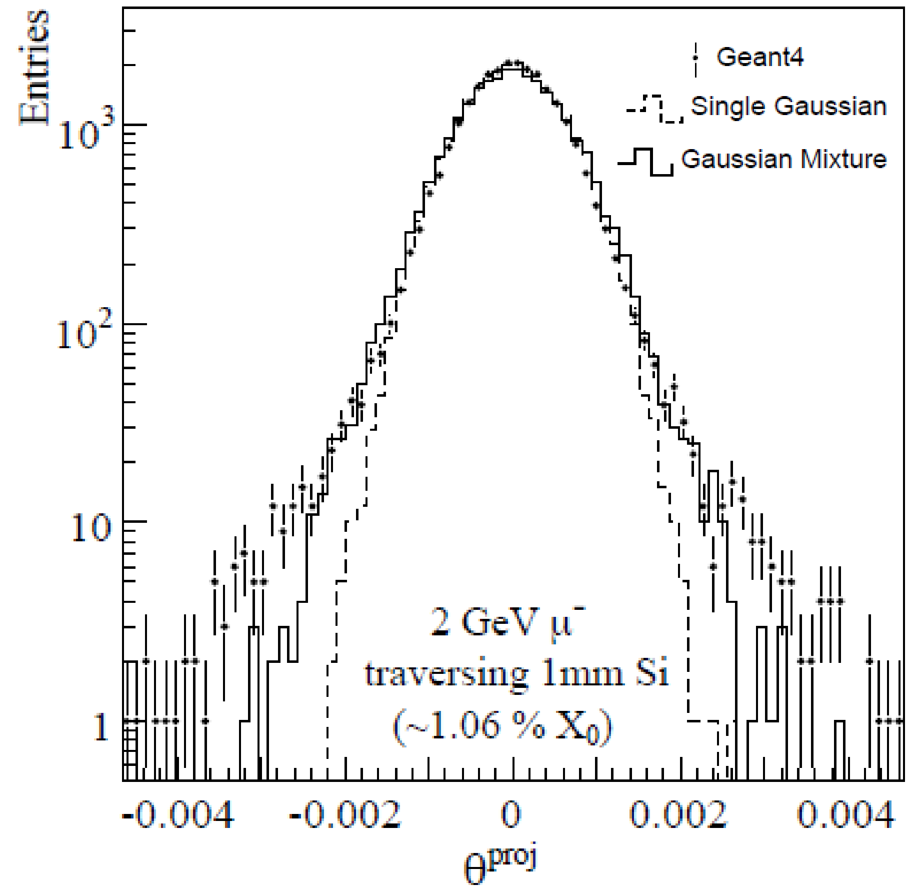


# Energy loss, multiple scattering

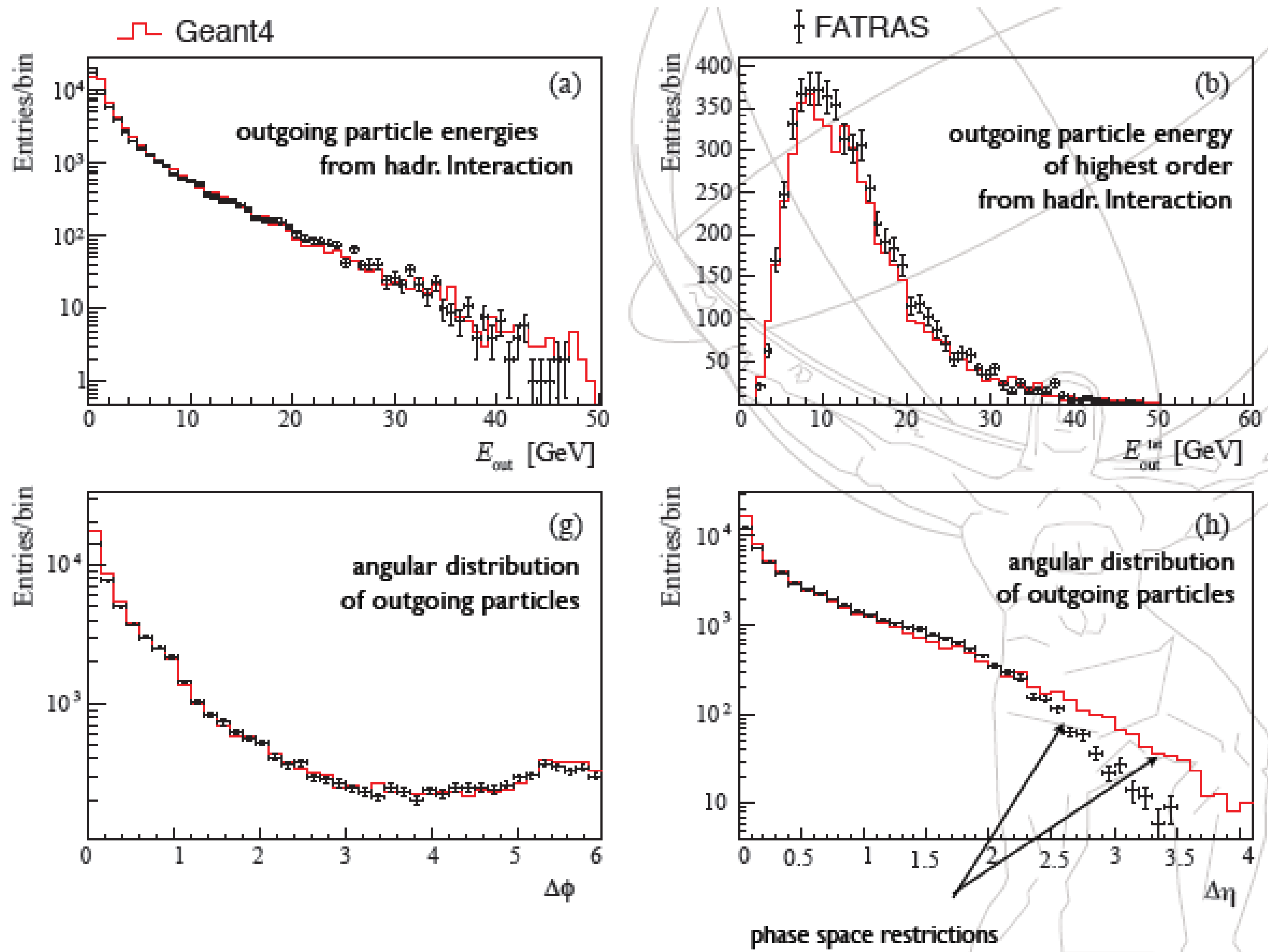
ΔE and Δθ diced from Landau and Gaussian Mixture distributions



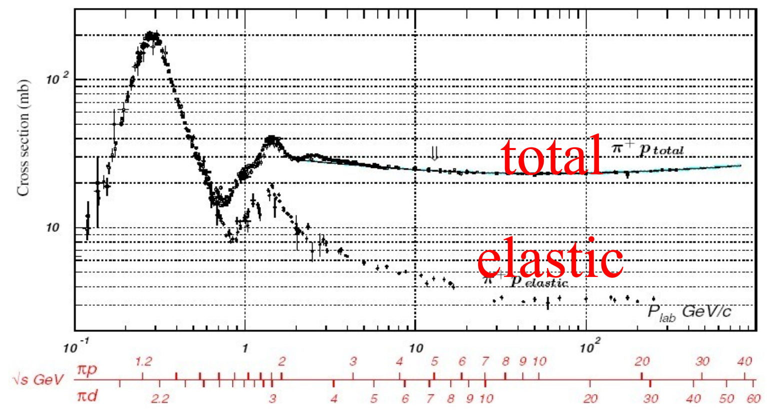
# Nuclear interactions, ATLAS

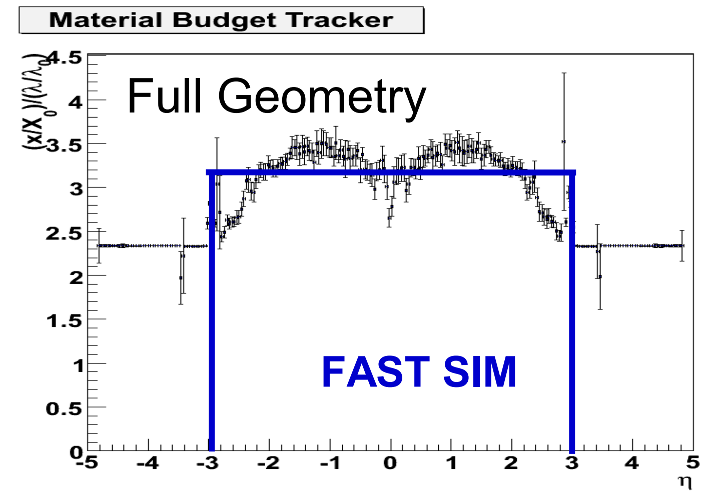
Fully parametric model: interaction probability, shower multiplicity, spectra and angular distributions of outgoing particles fitted to Geant4

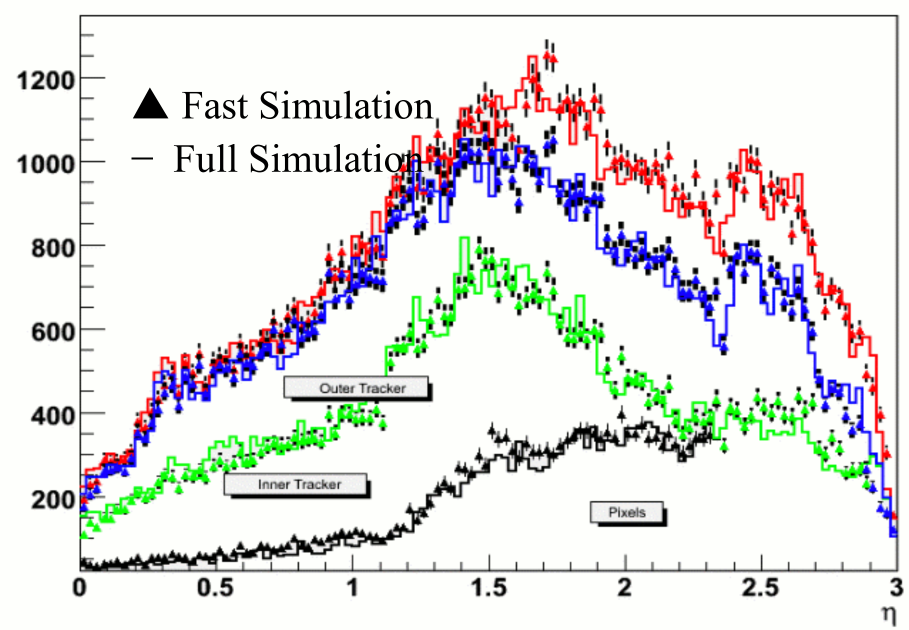


# Nuclear interactions, CMS

- Interaction probability parametrized from PDG
- Layer thickness considered constant in η
- Shower library used for the interaction products
- Libraries available for 9 different hadrons, several bins in range 1<E<1000 GeV




Number of nuclear interactions for 500K 15 GeV pions

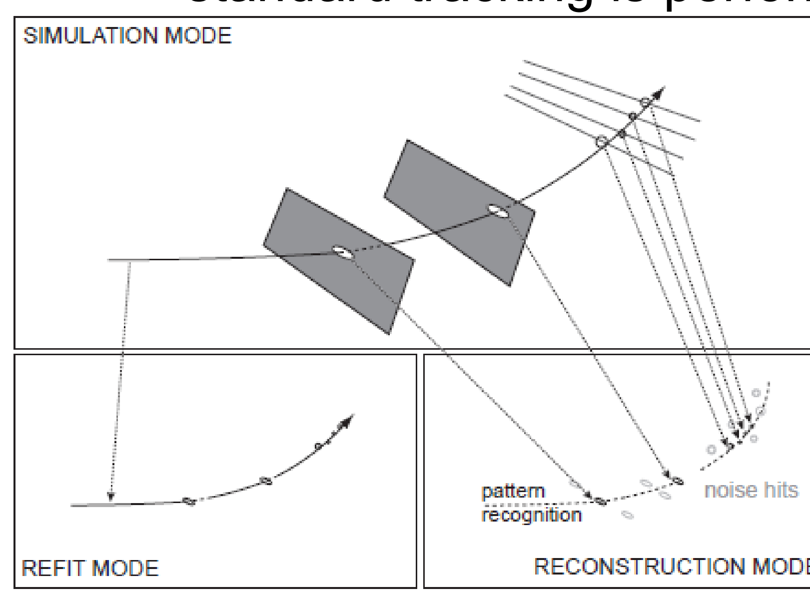
# To digitize, or not to digitize?

- In principle, the SimHits from the fast simulation can be fed to the same digitizers as in FullSim
- But this means an additional loop over a collection of inputs that can have a very large multiplicity (especially with large pile-up), see Federica's talk
- FATRAS (ATLAS): a parametric FastDigitizer is run
- CMS FastSim: the FullSim digitizer is run for the muon candidates (low hit multiplicity) and the same has been done also in the inner tracking in some Upgrade studies, where full tracking was also used; otherwise, SimHits are smeared into RecHits directly

# Fast tracking simulation in ATLAS (FATRAS); also for muon system

- Generator particles flagged as unstable are processed by the ParticleDecay module
  - Geant4 decayer (default) or own simplified module
- Photons are extrapolated through the detector
  - Conversion probability is calculated and pair production is performed
- Hits are created
  - Material effects are applied to all charged particles
  - This module is applied several times to allow for an iterative treatment of secondary particles

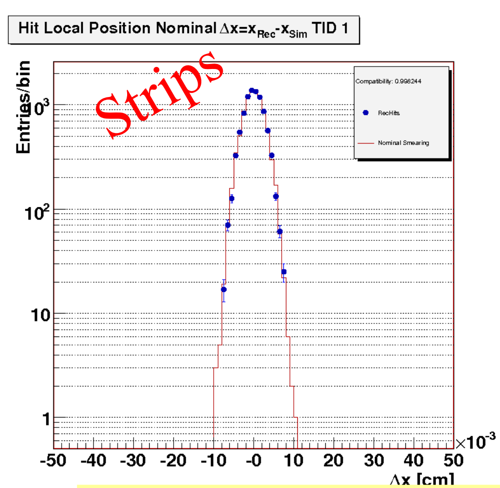
- Option 1: use MC truth
  - Final fit on the hits associated to MC particles
  - Track measurement is smeared before fit, to avoid bias given by seeding the fit with the true initial track momentum
- Option 2: full tracking
  - Noise hits are added, then standard tracking is performed

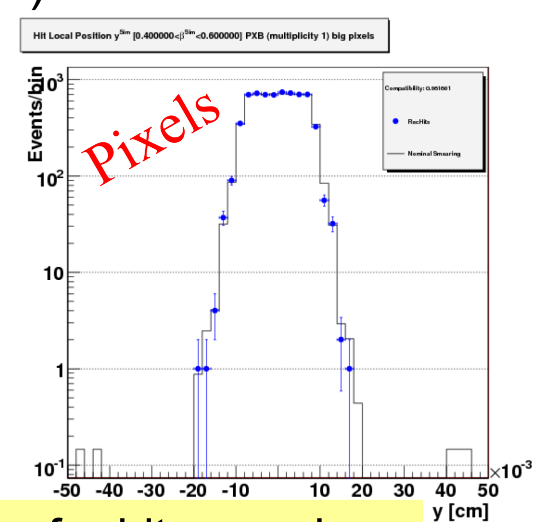


# Fast inner tracking simulation in CMS

- Generator particles flagged as unstable are processed by the ParticleDecay module
  - Own module adapted from Pythia6
- All material effects are simulated
  - Including photon interactions
- Hits are created
  - SimHits then smeared into RecHits:
  - Strips: layer-dependent Gaussian
  - Pixels: we smear by position resolution distributions extracted from FullSim (might be from data) as functions of cluster multiplicity and track incidence angle

- Option 1: use MC truth
  - Seeding: if the hits from the particle are on the seeding layers, a seed is created
  - Fitting and filtering are taken from standard tracking
  - Iterations as in standard tracking
- Option 2: full tracking
  - Standard tracking is performed (no noise hits)




Resolution functions for hit smearing

# Fast muon simulation in CMS

- Muons are the only generated particles propagated to the muon chambers
  - Multiple scattering and dE/dx by ionization
  - Muons from hadron decays propagated only if the decay is in the tracker volume; no late decays and no punch-through
  - Calorimeter deposits are parametrized
  - No bremsstrahlung, no $\delta$-rays
  - Hit inefficiency due to $\delta$-rays is parametrized as a function of log(P) for DT and CSC; not in RPC (coarse resolution)
- Same geometry as modelled in Geant4
- Standard digi+reco is applied to the muon SimHits
  - No need for short-cuts in outer tracking: multiplicity is low

# CPU time, an example from CMS

- Numbers are in **ms/event** for ttbar at 8 TeV, Pythia, no pileup
- CMS software release used for 2012 reconstruction and analysis (CMSSW 5.3)
- CERN's dedicated machine, same characteristics as production machines, 64 bits, 8 cores, Scientific Linux 5, gcc 4.6.2

| | **FullSim** | **FastSim** |
|---|---|---|
| **Generator** | 12 | 12 |
| **Detector simulation** | $84 \times 10^3$ | 169 |
| **Digitization** | 753 | 67 (*) |
| Strip digi only | 360 | - |
| Pixel digi only | 73 | - |
| **Reconstruction** | $1.9 \times 10^3$ | $1.2 \times 10^3$ |
| Inner Tracks | $1.0 \times 10^3$ | 295 |

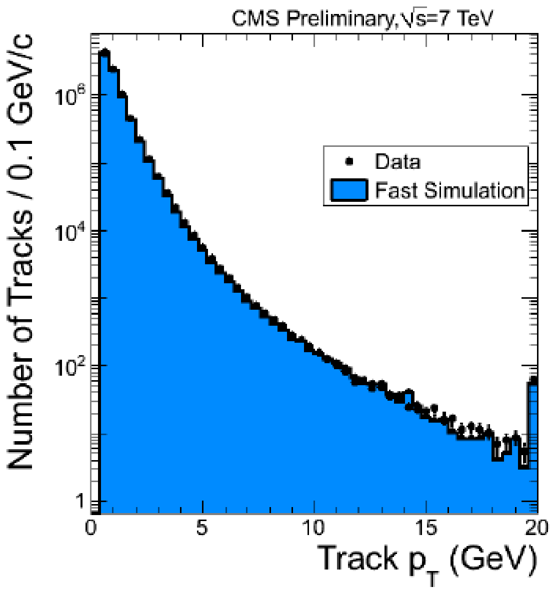
(*) see Federica Primavera's talk

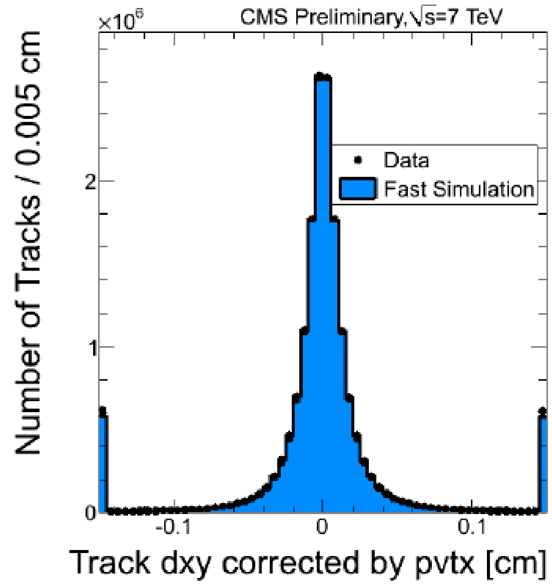
Even without pileup, inner tracking accounts for half of digitization time and half of reconstruction time in FullSim; and in FastSim, despite all short-cuts, it contributes more than detector simulation

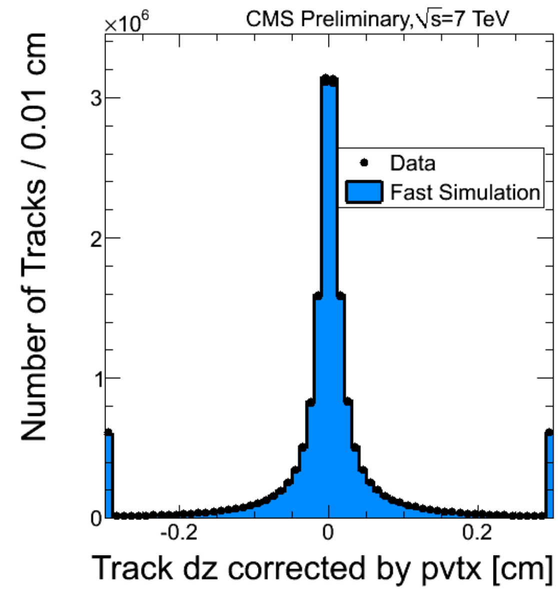
# Part 3

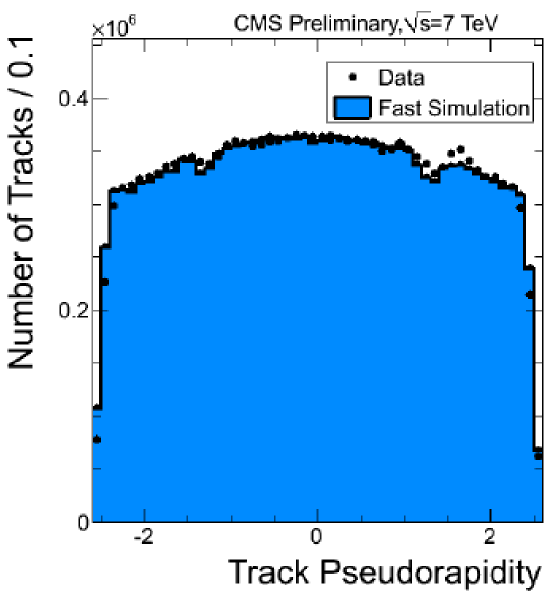
Performances

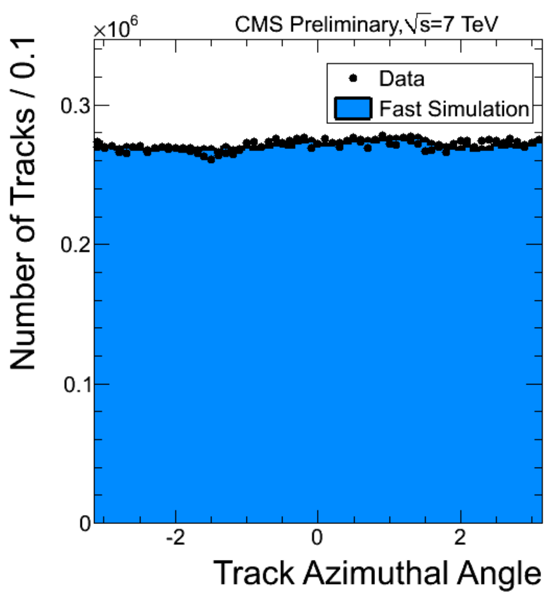
# Track kinematics, CMS



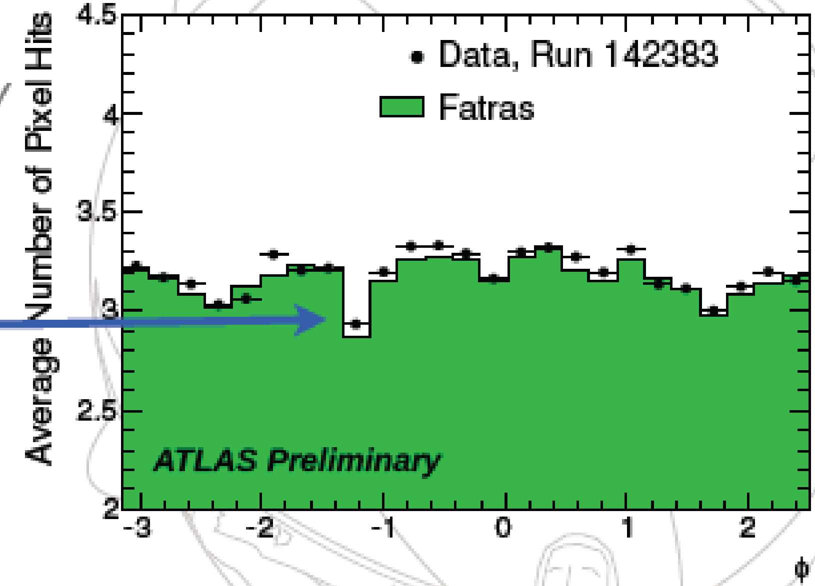

Comparison to early 2010 data collected with a minimum-bias trigger; track selection:
- $p_T$>0.5 GeV
- “high quality” flag
- $\Delta p_T/p_T$<5%
- within 10 sigma of beam spot

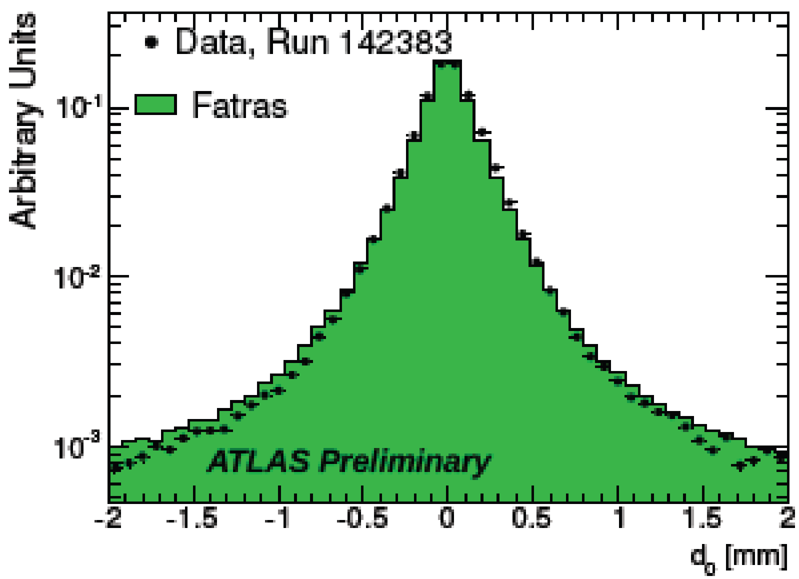
CMS-DPS-2010-039

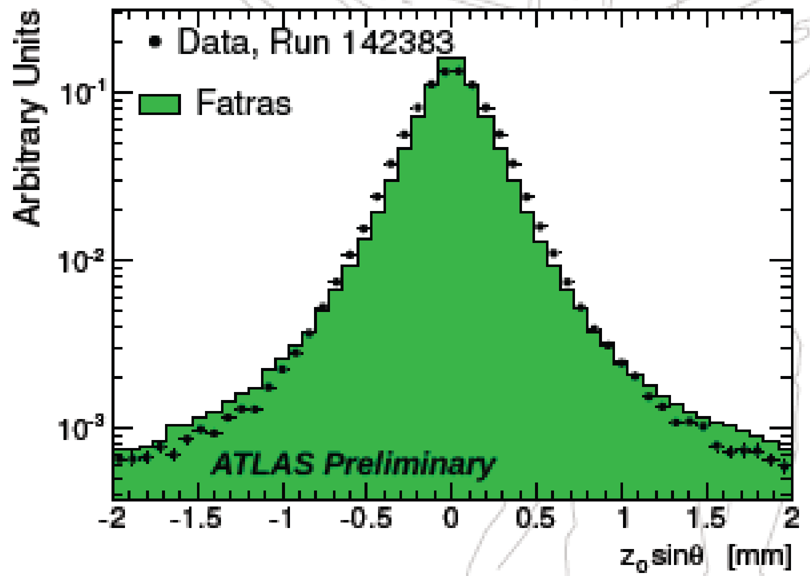
# FATRAS in comparison to data

- *ID reconstruction, tracks with $p_T > 500$ MeV*

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



# b-tagging, CMS

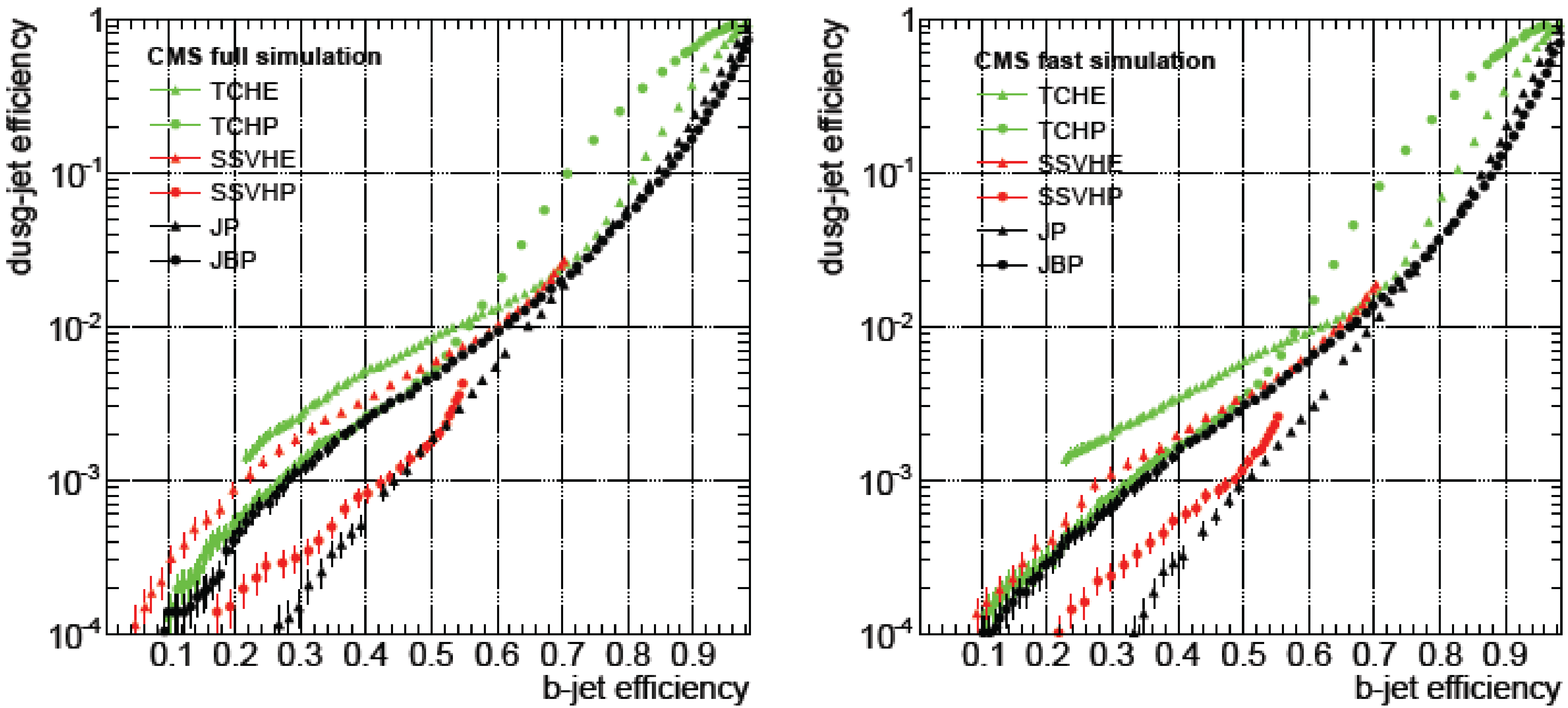
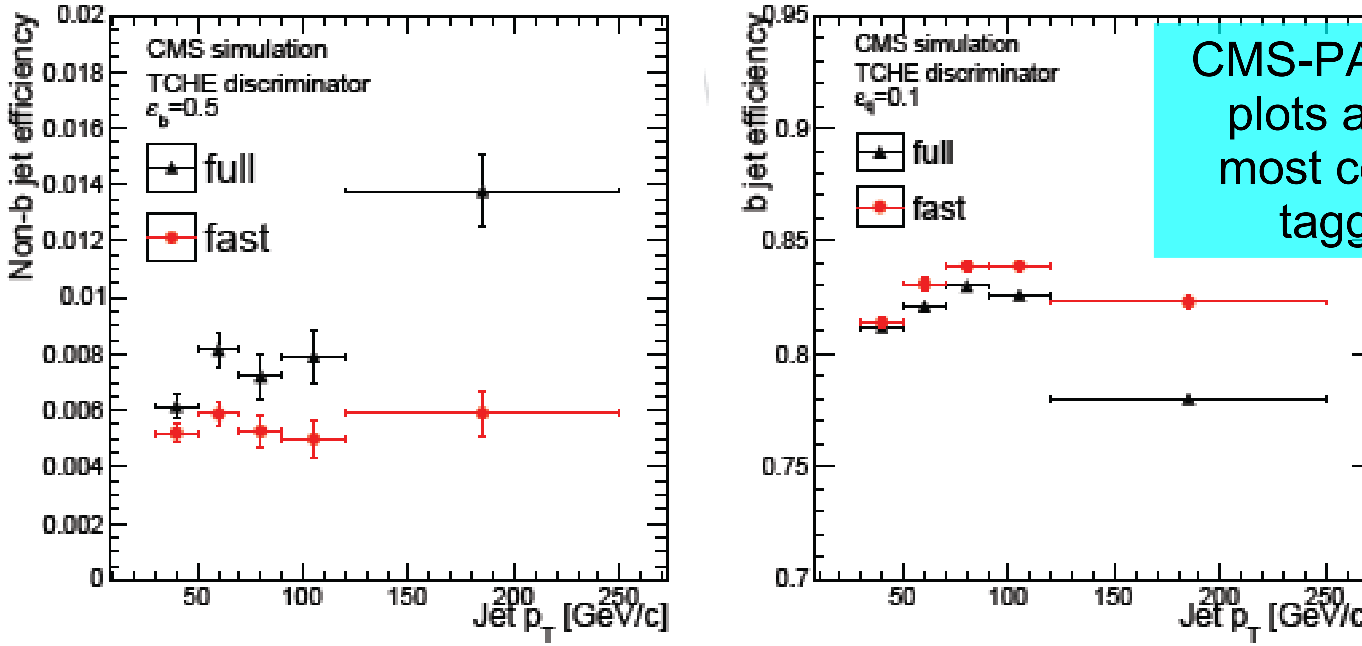



Figure 22: Light flavor mistag efficiency versus b-tagging efficiency in comparison for several b-tagging algorithms. On the left: full simulation, on the right: fast simulation.

CMS-PAS-BTV-11-002

# b-tagging, CMS

**Fake rate: generally lower** **Efficiency: generally higher**




CMS-PAS-BTV-11-002; plots available for all most commonly used taggers in CMS

Figure 24: Comparison of the b-tagging performance between full and fast detector simulation for the track counting high efficiency algorithm. Left: mistag rate versus jet $p_T$ at fixed b-tag efficiency of 50%. Right: b-tag efficiency versus jet $p_T$ at fixed light flavor mistag rate of 10%.

- Discrepancies attributed to:
  - No fake tracks
  - No cluster merging/splitting (important in dense high-momentum jets)

# So, should we discard FastSim when b-tagging is important?

Table 7: Values and total uncertainties for the efficiency scale factors $SF_b$ obtained in multijet and $t\bar{t}$ events for b jets in the expected $p_T$ range of $t\bar{t}$ events. For the $t\bar{t}$ results with the JP and JBP algorithms the profile likelihood ratio values [5] are quoted as they correspond to the same calibration as for the multijet results.

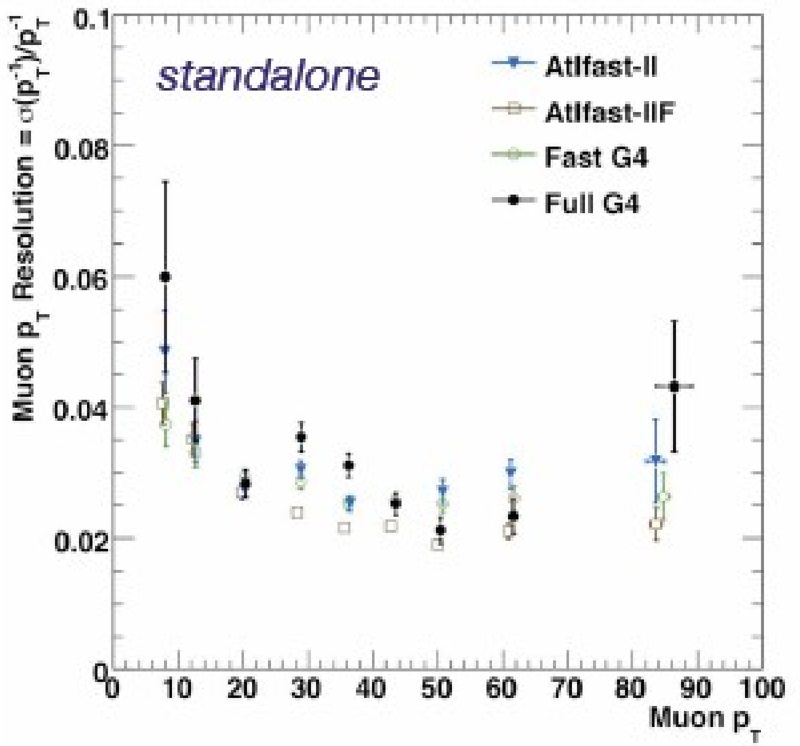
| b tagger | $SF_b$ in multijet events | $SF_b$ in $t\bar{t}$ events |
|---|---|---|
| JPM | $0.92 \pm 0.03$ | $0.95 \pm 0.03$ |
| JBPM | $0.92 \pm 0.03$ | $0.93 \pm 0.04$ |
| TCHEM | $0.95 \pm 0.03$ | $0.96 \pm 0.04$ |
| TCHPM | $0.94 \pm 0.03$ | $0.93 \pm 0.04$ |
| SSVHEM | $0.95 \pm 0.03$ | $0.96 \pm 0.04$ |
| CSVM | $0.95 \pm 0.03$ | $0.97 \pm 0.04$ |

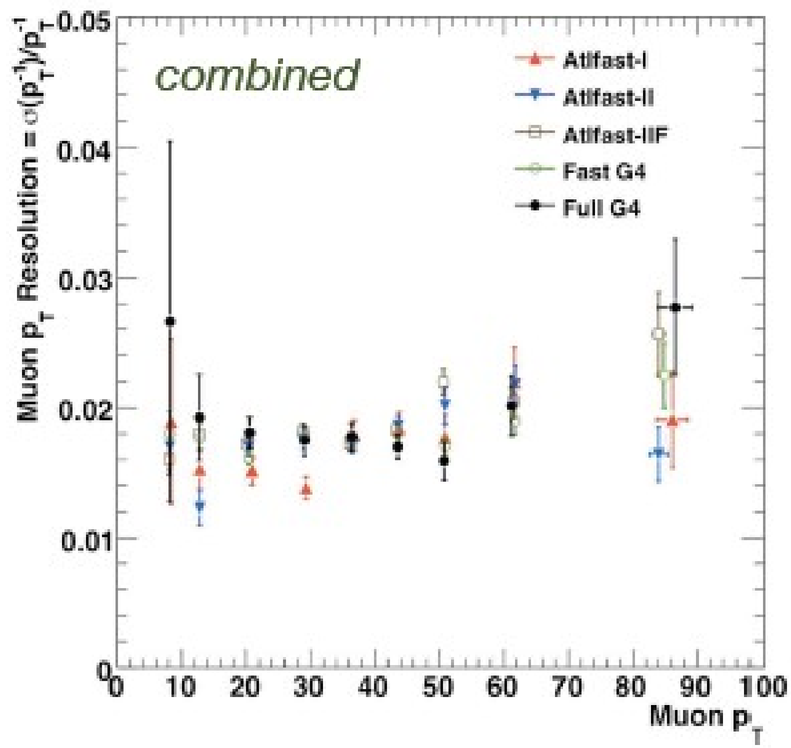
CMS-PAS-BTV-11-004:
data-driven efficiencies
and fake rates

Even FullSim overestimates efficiencies; most MC-to-data scale factors are ≠ 1 at 1-2σ level with the current precision

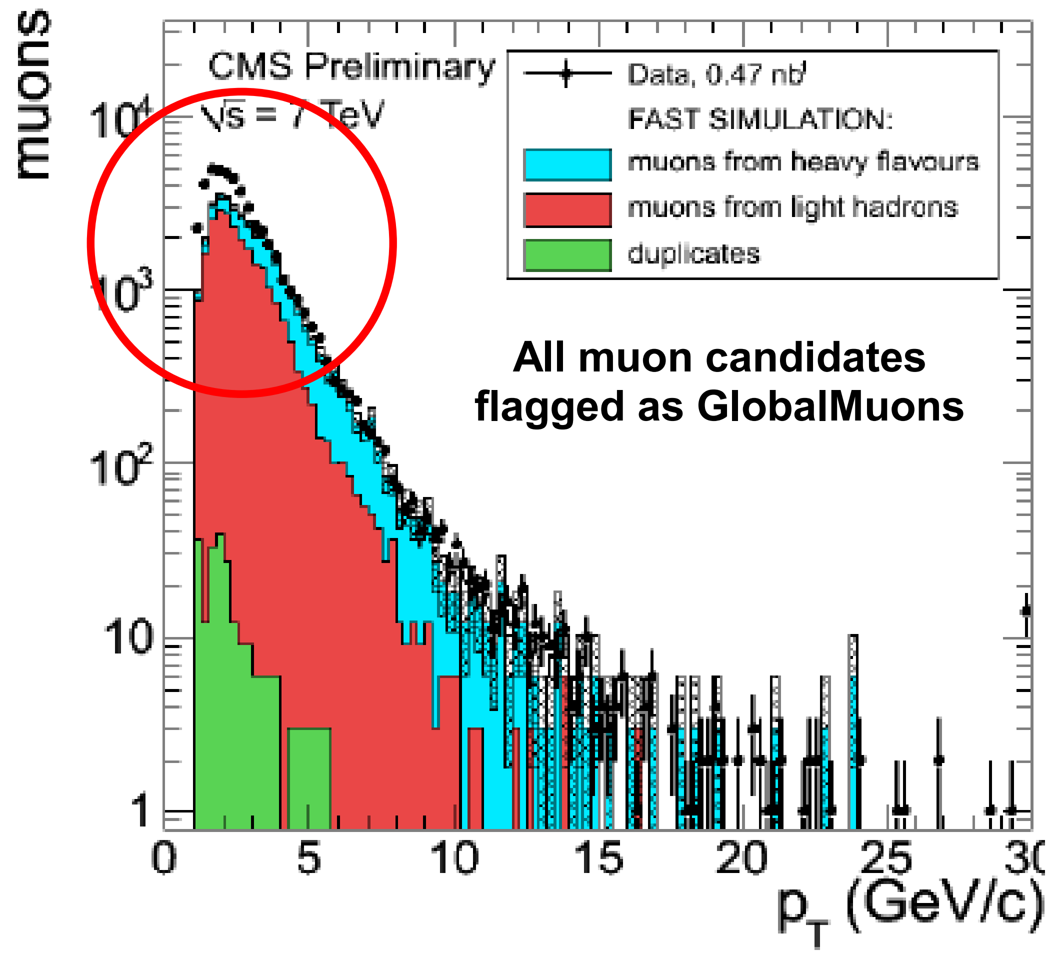
# Muon candidates, ATLAS

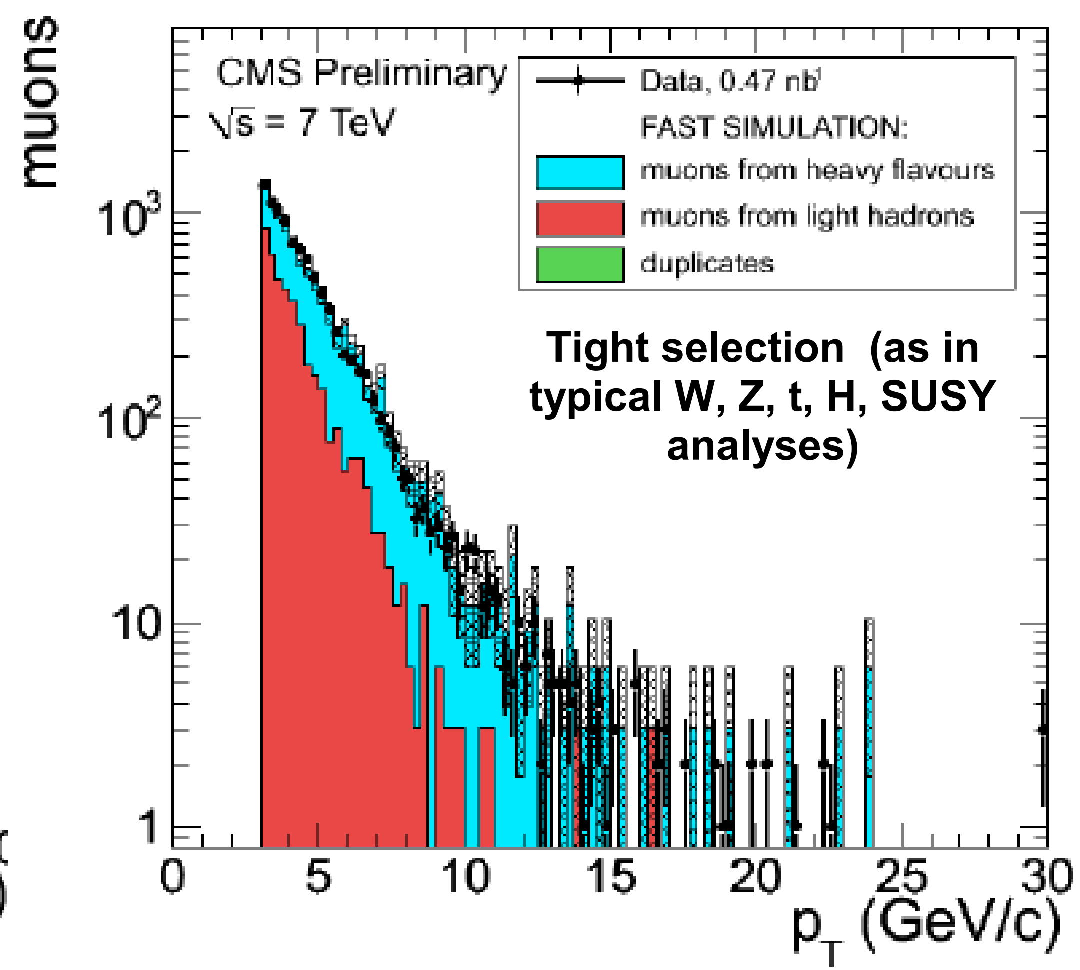
- *ATLAS standalone Muon System and combined (ID/MS) muon reconstruction*



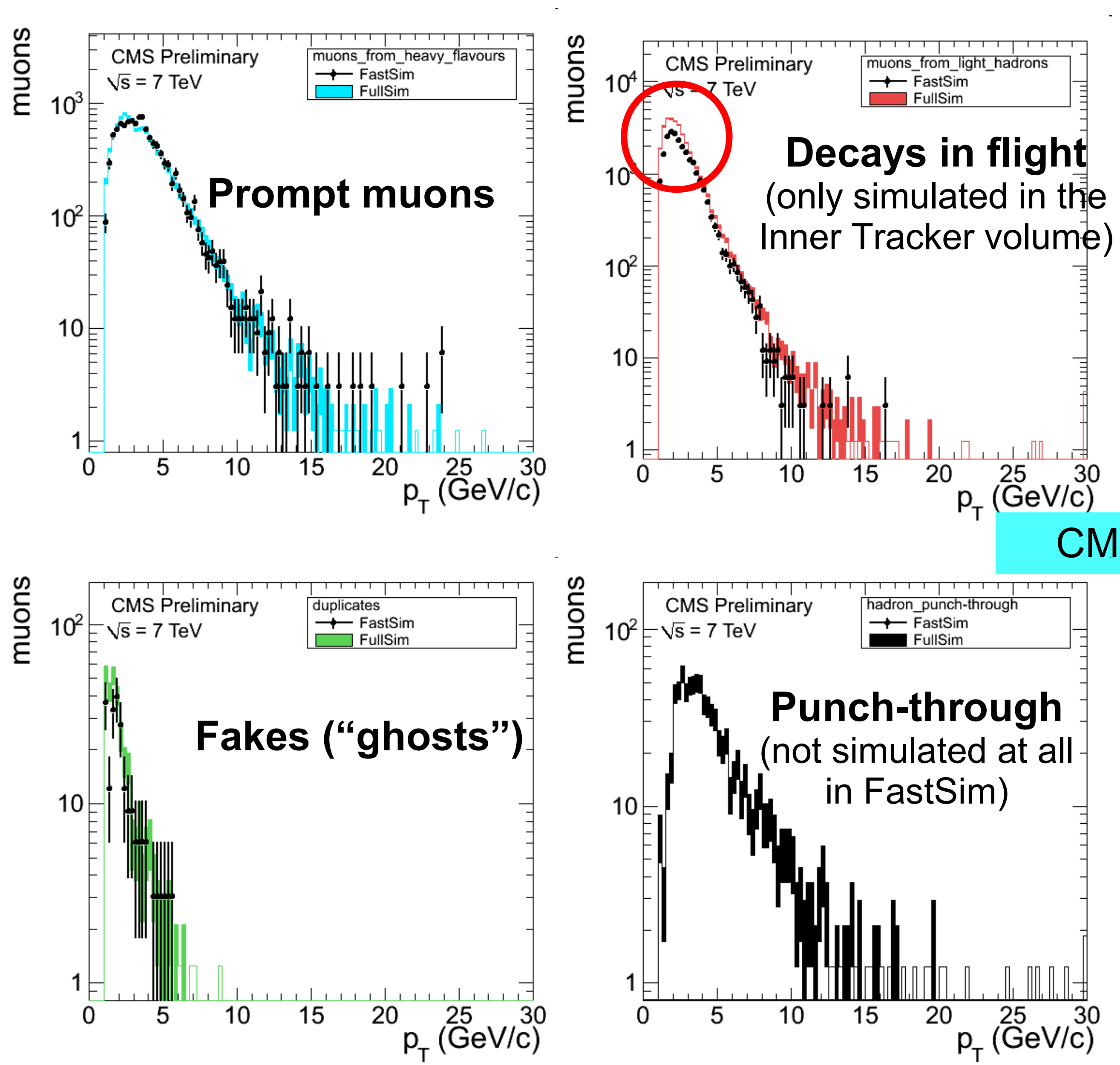
# Muon candidates, CMS




CMS-DPS-2010-039

# Breakdown of the $p_T$ distribution according to the origin of the muon




CMS-DPS-2010-039

# Summary

- Tracking is a challenging computational problem for the multi-purpose LHC experiments
- The fast simulations of ATLAS and CMS have the mission to get a %-level accuracy with a O(1s) cpu time in dense track environments
- This compromise is achieved by feeding the simulation output to standard reconstruction algorithms, with one major exception in both experiments: Tracking
- Short-cuts have been devised to avoid that tracking time jeopardizes the speed of the simulation

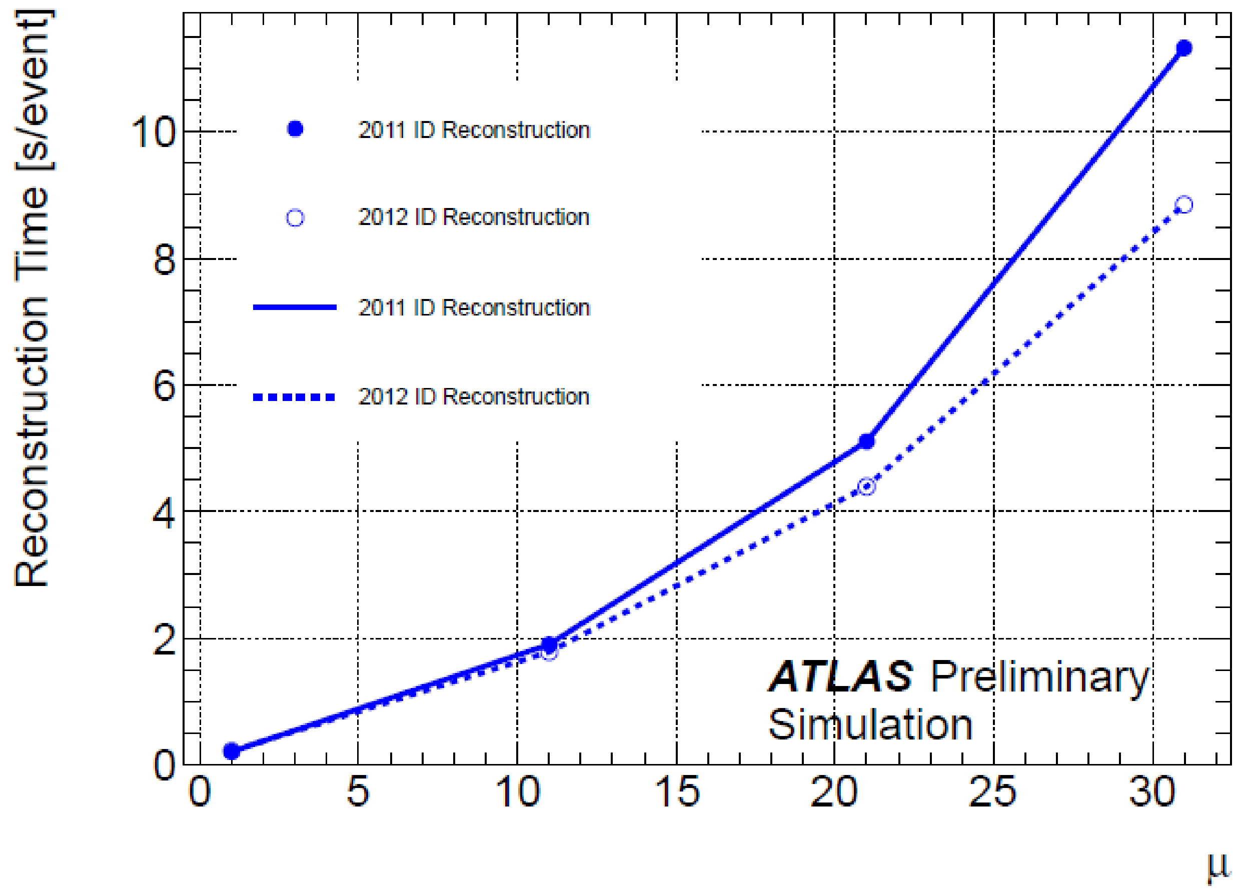
# Bibliography

- Simulation descriptions:

  - K.Edmonds, A.Salzburger, et al., “The Fast ATLAS Track Simulation (FATRAS)”, ATL-SOFT-PUB-2008-001
  - R.Rahmat, A.Giammanco, “The Fast Simulation of the CMS Experiment”, Proceedings of CHEP2012, J. Phys.: Conf. Ser. 396 (2012) 062016

# Backup

# Full tracking or short-cuts?




And the situation becomes much worse with PU.
In this graph: cpu time versus number of minimum-bias interactions in the same event.

| Component | Parameter | CMS | ATLAS |
|---|---|---|---|
| Magnetic field | | 4T | 2T |
| **Pixel** | Technology | $n^+$-in-n | $n^+$-in-n |
| | Pixel size | 100 x 150$\mu$m$^2$ | 50 x 400$\mu$m$^2$ |
| | # of pixels | 66M | 80M |
| | Active area | 1m$^2$ | 1.7m$^2$ |
| | Read-out | Analogue | Time-over-threshold |
| | Res. r$\phi$ x z | 15-20$\mu$m both | 10$\mu$m x 115$\mu$m |
| **Silicon strips** | Technology | p-in-n | p-in-n |
| | Pitch in barrel | 80-183$\mu$m | 80$\mu$m |
| | # of channels | 9.3M | 6.3M |
| | Active area | 200m$^2$ | 63m$^2$ |
| | Stereo angle | 100mrad<br>Some modules | 40mrad<br>All modules |
| | Read-out | Analogue | Binary |
| | Res. r$\phi$ x z (binary) | 23-35$\mu$m x 230/530$\mu$m | 17$\mu$m x 580$\mu$m |
| **TRT** | Resolution r$\phi$ | | 130$\mu$m |

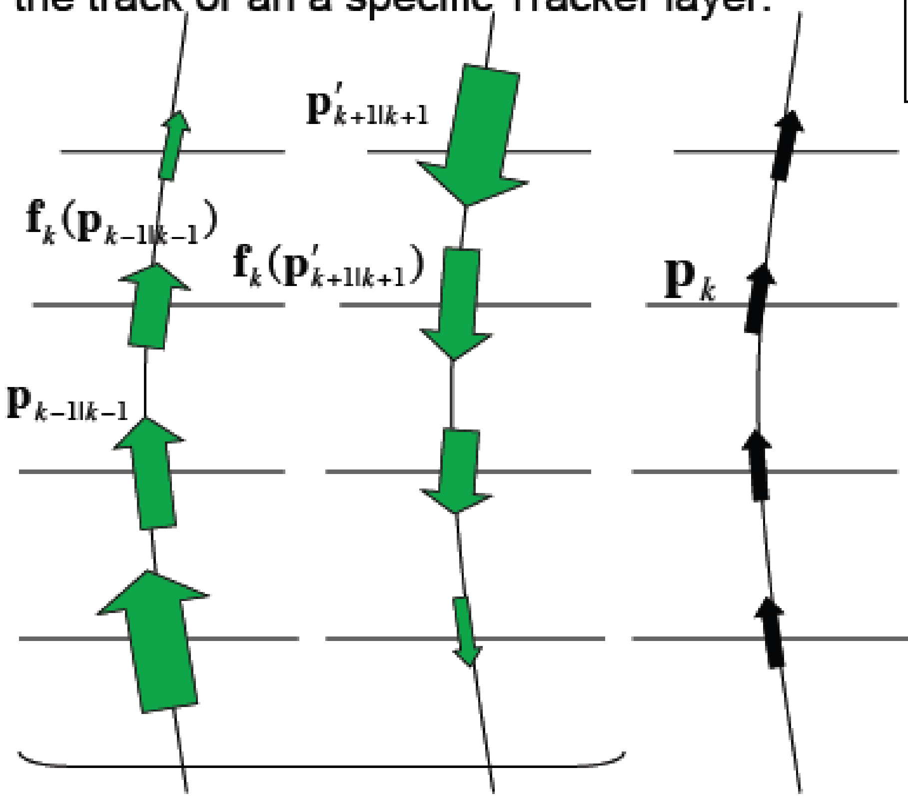
Table from Katja Klein

# Track fit with Kalman Filter

Once the set of hits that defines a trajectory are identified, the next step is to fit the positions of the hits to extract the particle parameters: at vertex, at the end of the track or an a specific Tracker layer:

$$\mathbf{p}_k = \mathbf{p}_{k|k} \oplus \mathbf{f}_k(\mathbf{p}'_{k+1|k+1})$$

A statistically correct *weighted mean:* **Kalman *smoother***




Both in-out filter and out-in one are run

$\mathbf{p}_{k|k}$ — Contains information from measurements: 1,2,..,k

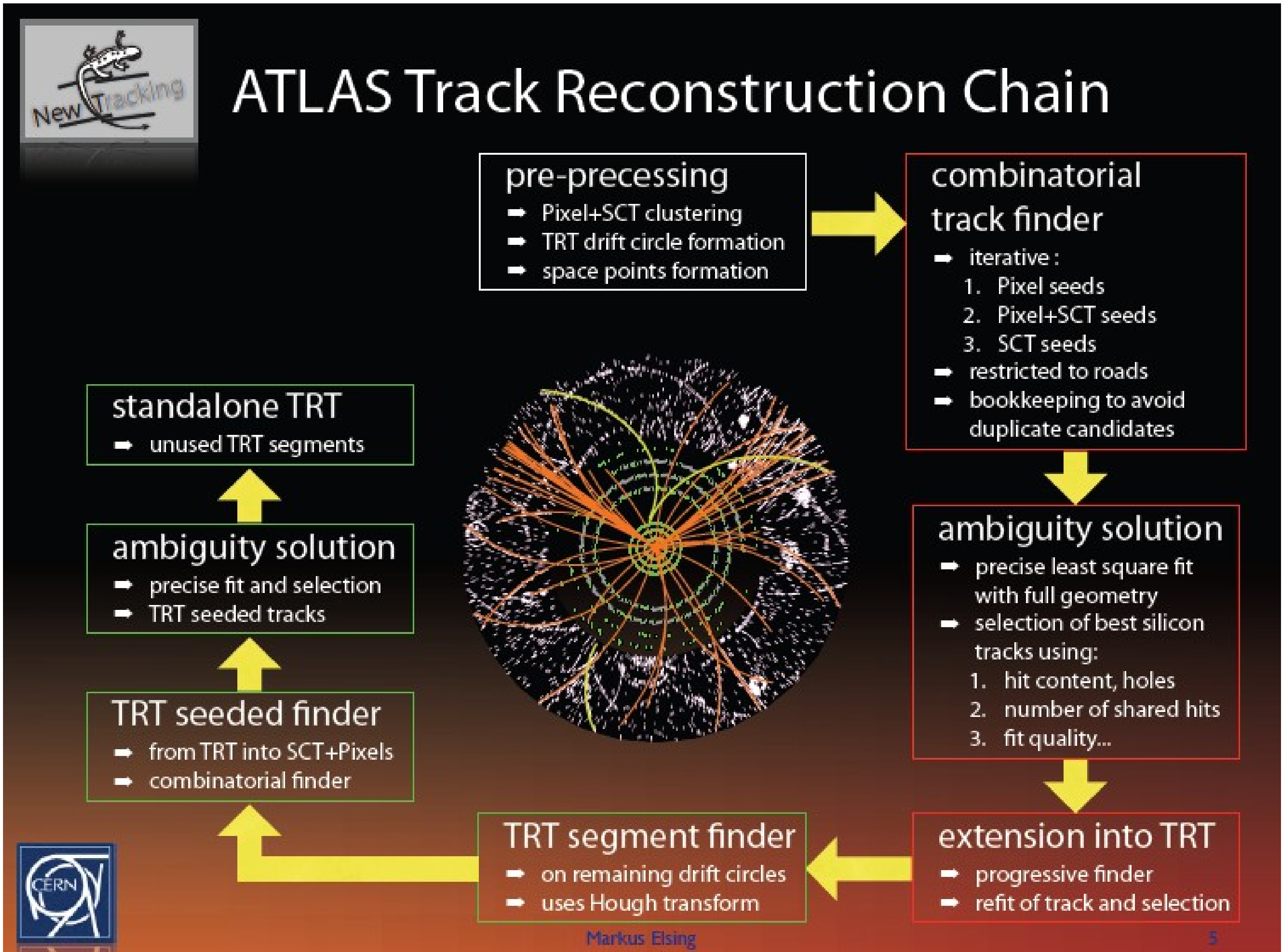
$\mathbf{p}'_{k+1|k+1}$ — Contains information from measurements: n,n-1,…,k+1

$\mathbf{p}_k$ — Contain the full information. All measurement from 1 to n are used.

All math details in book from R.Fruhwirth: “Data Analysis Techniques for High-Energy Physics”

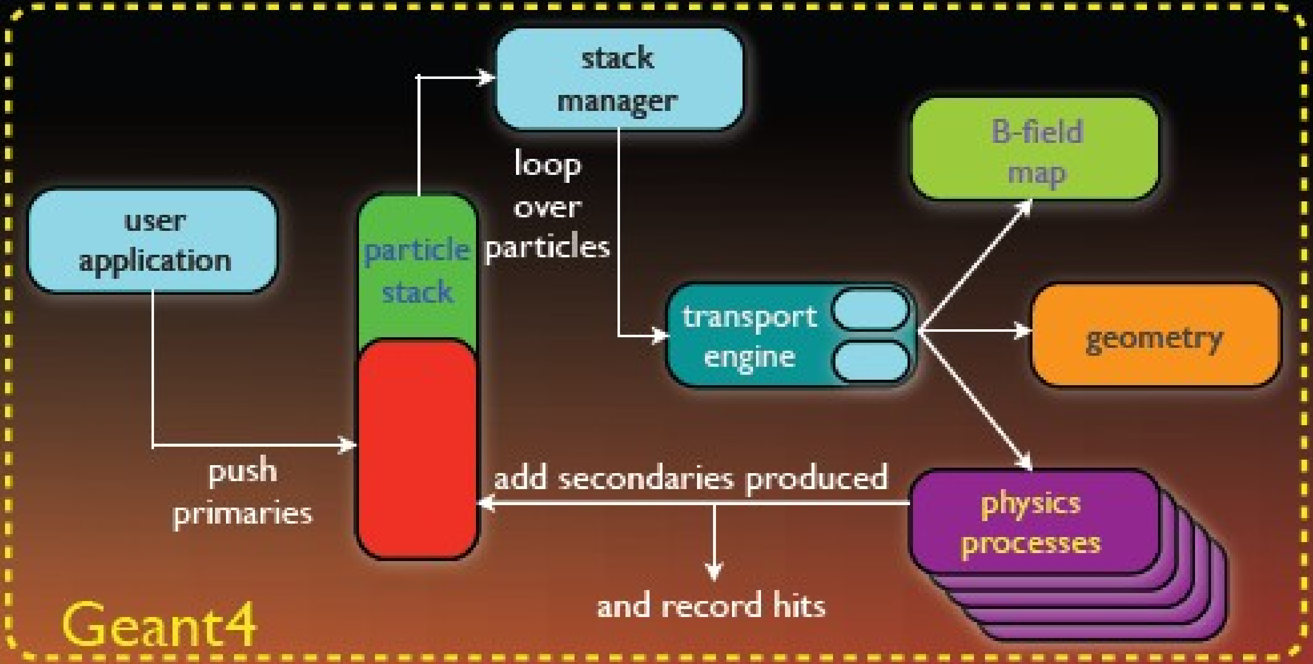
Slide from Boris Mangano

# Tracking in ATLAS



# Some Remarks on Simulation: Geant4

- Geant4 is based upon
  - ➡ **stack** to keep track of all particles produced and stack manager
  - ➡ **extrapolation system** to propagate each particle:
    - transport engine with navigatoin
    - geometry model
    - B-field
  - ➡ set of **physics processes** describing interaction of particles with matter
  - ➡ a user application interface, ...



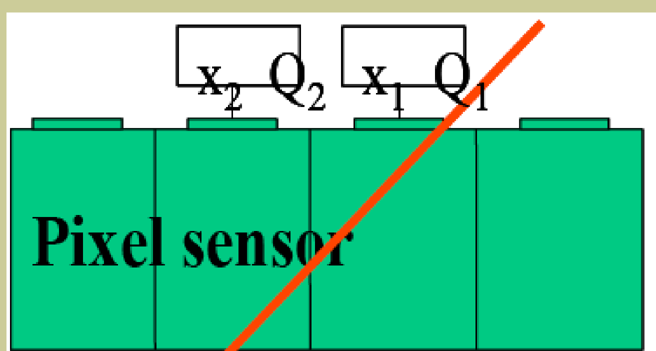
# Geant 4 — Pixel/SCT — fatras

**Geant 4**

- simulates charge deposition in **single pixel/strip** in steps of O(50 µm), followed by

**DIGITISATION**

- collect charge in single silicon elements, estimate cluster position

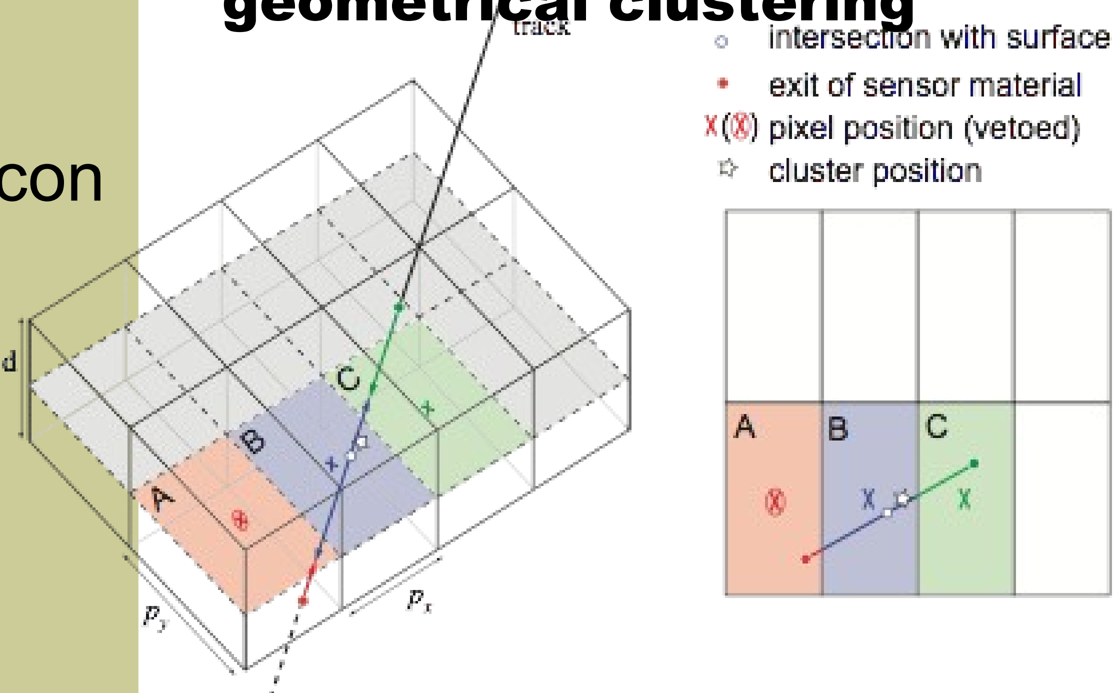



analog clustering using the charge deposition in the individual pixels

**fatras**

- charge deposition not simulated:

**geometrical clustering**




- model parameter:

**minimal path in pixel**
(to achieve minimal charge deposition)

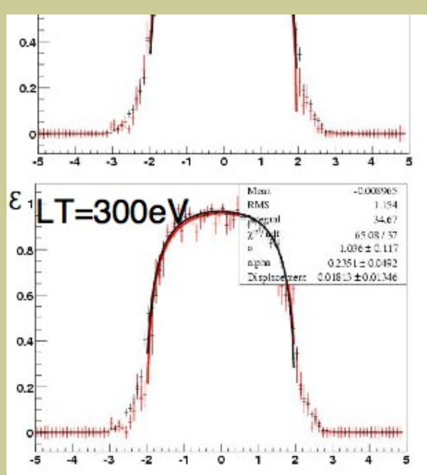
# TRT

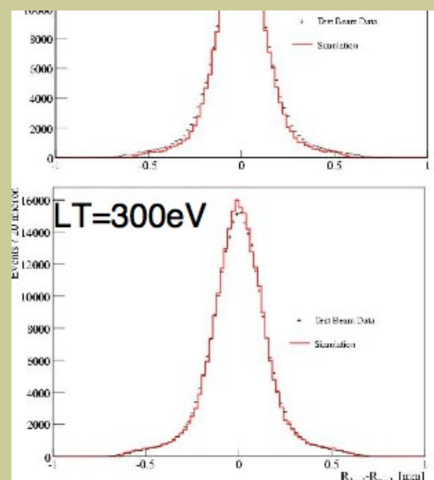
## Geant 4

**DIGITISATION**

- **LowTreshold tuning with data**

*Major effort in simulation tuning:*
*- efficiency (CombinedTestBeam)*
*- resolution (TestBeam)*
*- Time over threshold (TestBeam)*



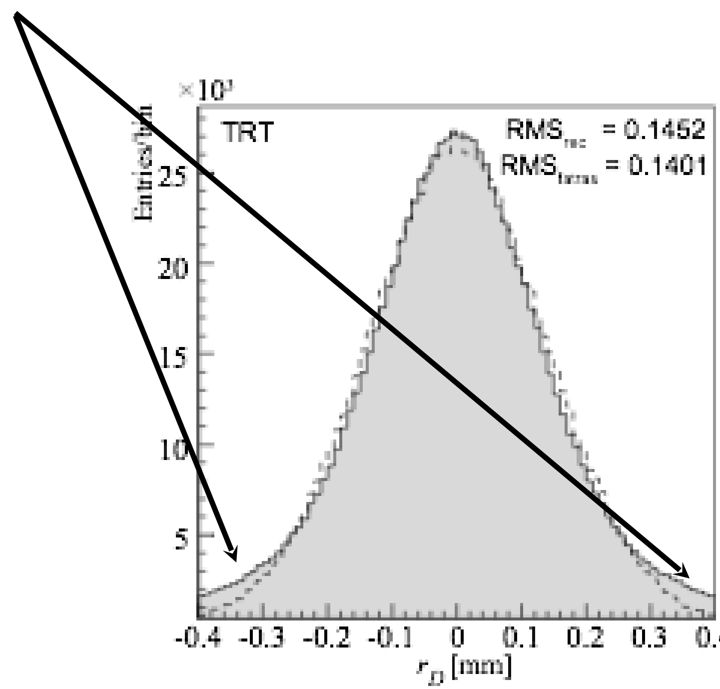

*all three variables favor ~300 eV (taken as default now)*

## fatras

- **gaussian smearing**

*Fatras uses first modules from the full simulation (digitisation), since they are fast enough ...*

*... plans to take the tuned setup. Expect improvement in tails.*

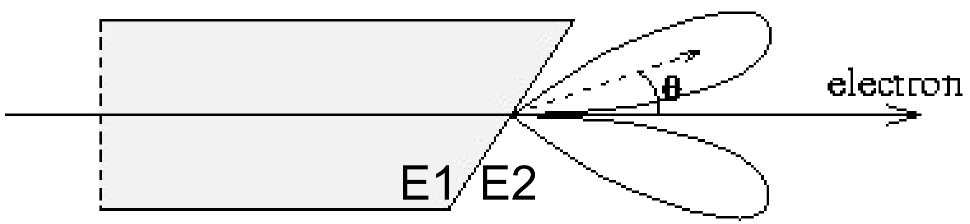


Geant 4

TRT

**DIGITISATION**

- **HighThreshold (HT) tuning (Transition radiation)**



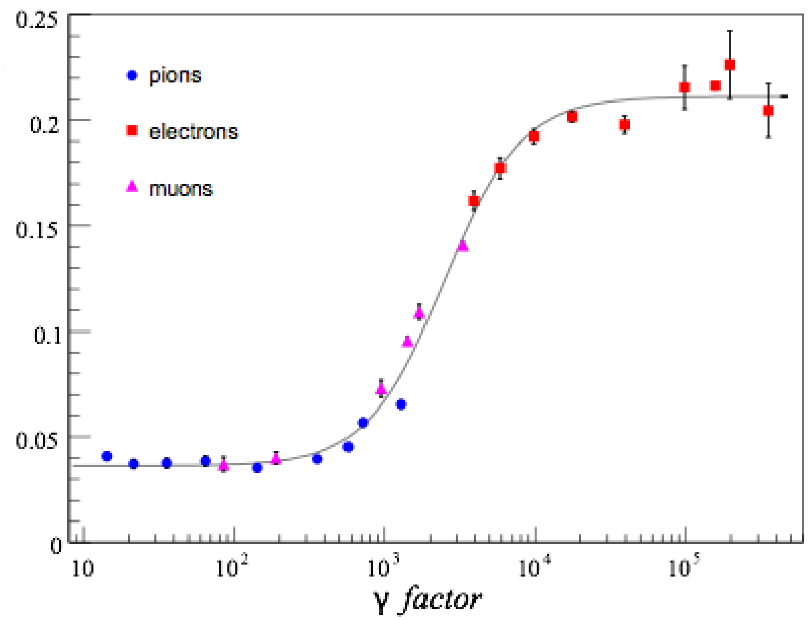

when particle traverses two materials, with rapidly changing dielectric constants (E1,E2), it emits
so-called *transition* radiation depending on Lorentz factor
This results in higher charge collection (HT)

again used for tracking-only PID information

fatras

- **HT simulation**

uses generic function obtained from CTB data (currently)




example how we can tune Fatras from data.

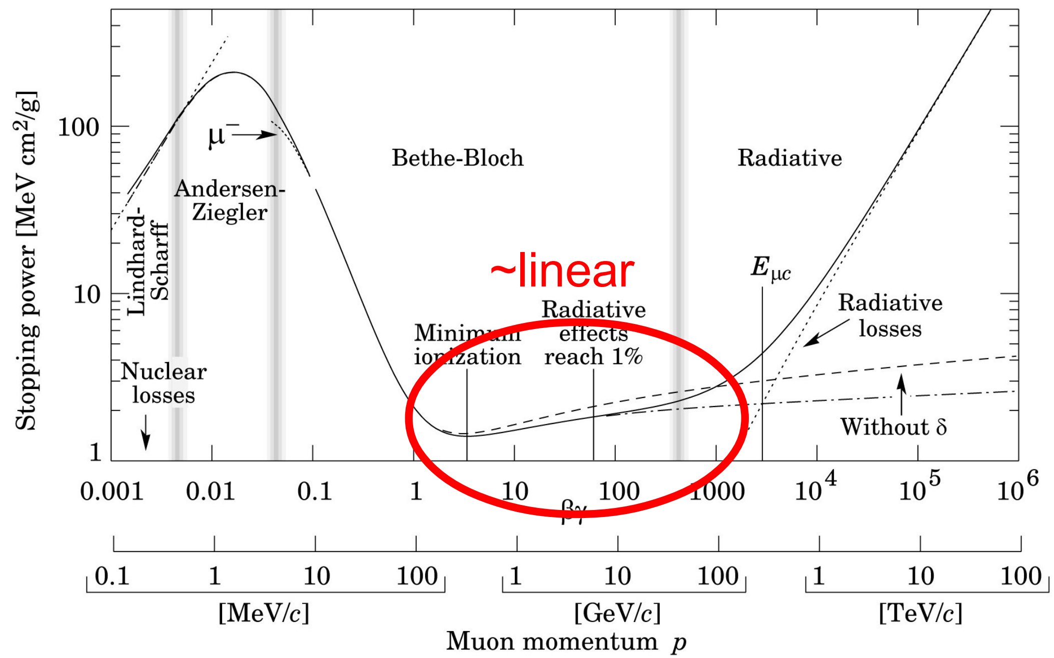
# CMS: tracking timing breakdown

- CPU times in seconds, from a high-PU special run in 2011 (similar average PU as in 2012, but 7 TeV data)

| **Iteration** | **Initial** | **LowPt** | **PixelPair** | **Detached** | **Mixed** | **PixelLess** | **TobTec** | **Conv** | **Total** |
|---|---|---|---|---|---|---|---|---|---|
| Seed time | 0.07 | 0.25 | 0.20 | 0.38 | 0.61 | 0.19 | 0.10 | 0.04 | **1.84** |
| Build time | 0.42 | 0.46 | 0.55 | 0.20 | 0.31 | 0.90 | 0.48 | 0.30 | **3.62** |
| Fit time | 0.18 | 0.19 | 0.19 | 0.12 | 0.12 | 0.10 | 0.04 | 0.02 | **0.96** |
| Select time | 0.005 | 0.004 | 0.003 | 0.004 | 0.002 | 0.002 | 0.001 | 0.0005 | **0.03** |
| **Total time** | **0.68** | **0.90** | **0.94** | **0.70** | **1.03** | **1.20** | **0.61** | **0.36** | **6.42** |
| Seeds | 470 | 850 | 2210 | 520 | 2670 | 8370 | 5340 | | |
| Tracks | 273 | 209 | 124 | 73 | 37 | 96 | 73 | | 885 |
| HP tracks | 267 | 153 | 56 | 47 | 21 | 46 | 40 | | 630 |

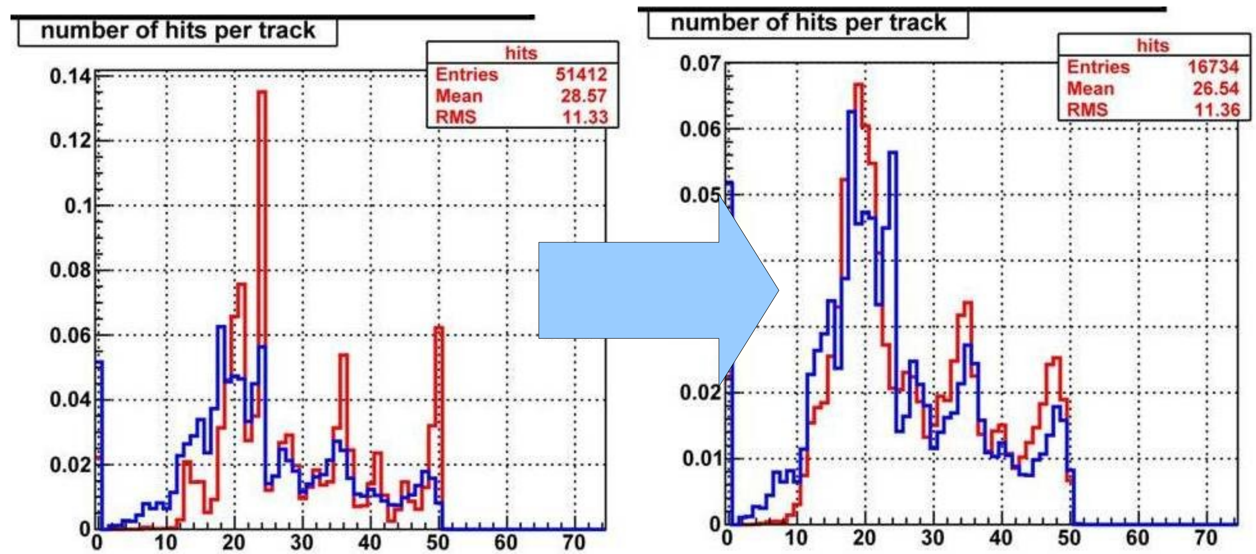
# CMS: Emulation of δ-rays effects for μ

- δ-rays emitted at the entry of a cell may cause the hit to get corrupted (⇒inefficiency) or an after-pulse (~harmless)
- Log of hit inefficiency is found to be pretty linear with log(P) for DT and CSC, as expected if the cause are δ-rays; almost no P dependence found in RPCs, as expected due to their coarser spatial resolution
- Hit inefficiency has been parametrized as a function of log(P) for DT and CSC

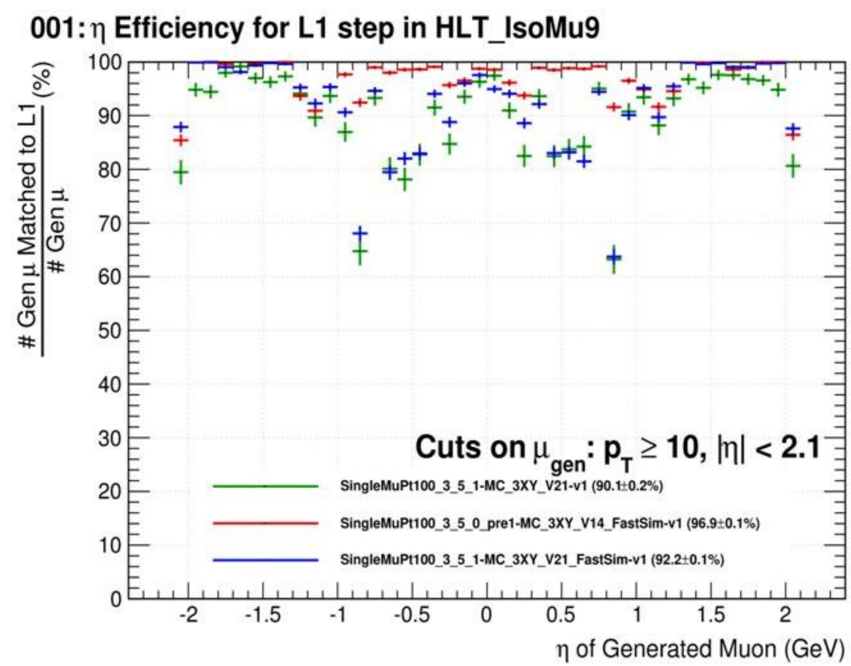


# Before and after

Rec hit multiplicity in the muon chambers for L2 muon trigger, without and with the parameterization of the inefficiency due to delta rays



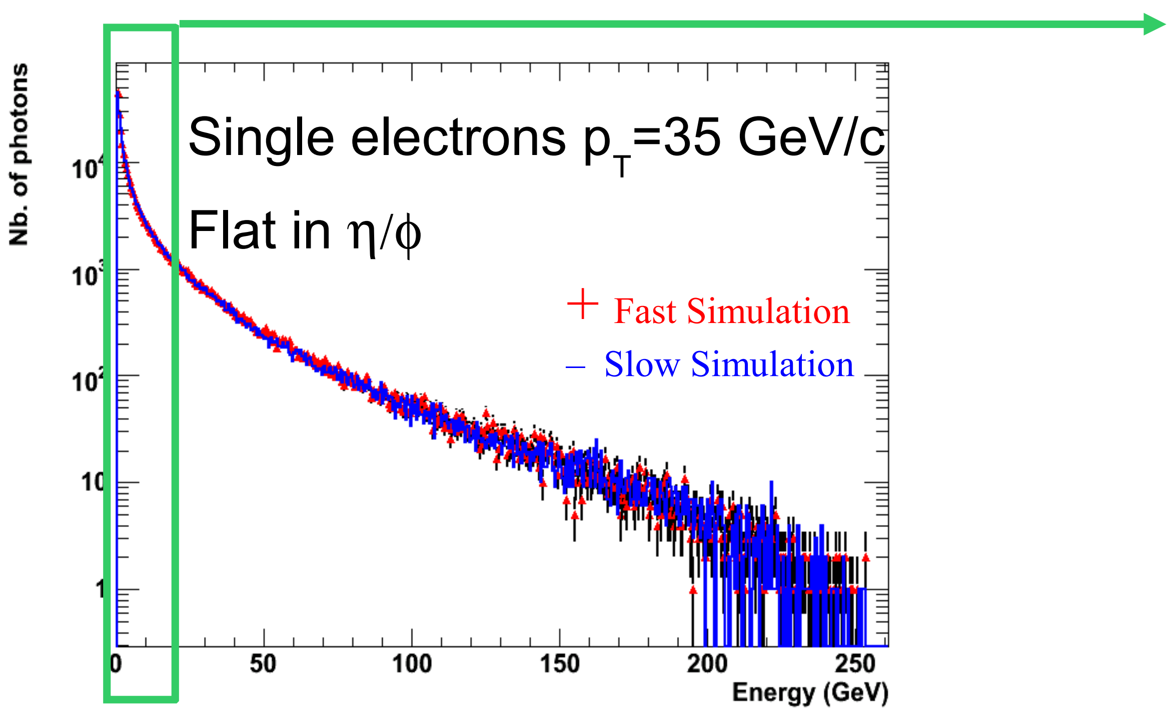

Taking the hit inefficiency into account yielded also a better description of reconstruction efficiencies, especially at trigger level




Private plots

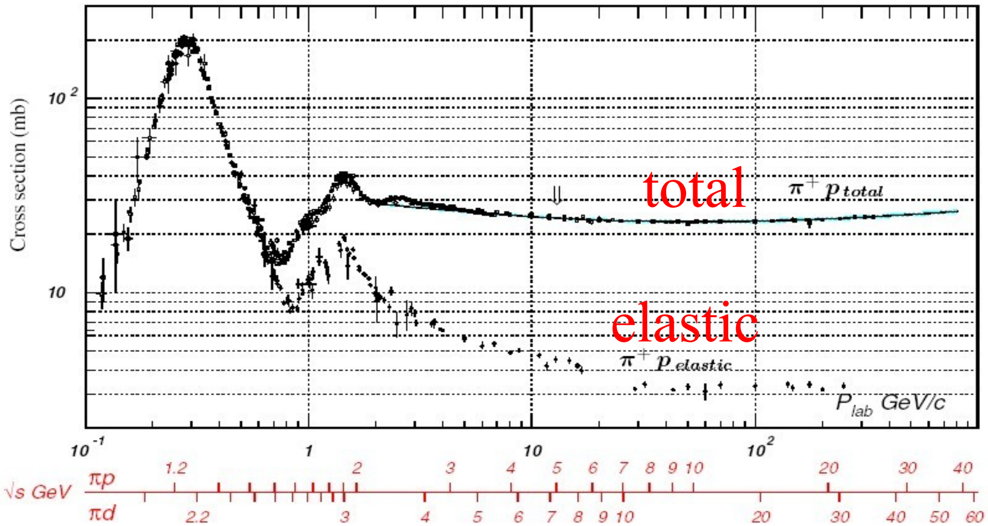
# Tuning layer thickness, CMS

- The Brem photon emission probability and spectrum are calculated analytically, layer by layer
- The layer thickness is tuned to reproduce the number of photons in the GEANT-based simulation:
  - the photon energy spectrum is beautifully reproduced...
  - (incidentally , this tuning reproduces the actual layer thickness in $x/x_0$)




Absolute normalization !

# Nuclear interactions, CMS

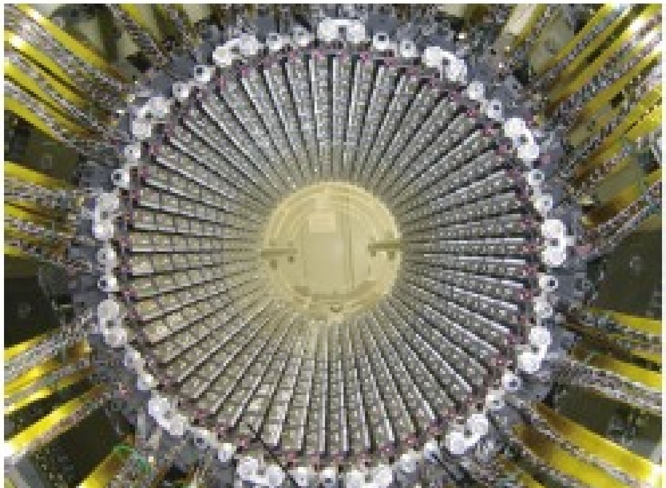



The elastic and inelastic cross sections come from experimental measurements (PDG)

- The tracker layer thickness is expressed in terms of $\lambda/\lambda_0$
  - 0.31 $x/X_0$ (total) or 0.25 $x/X_0$ (inelastic)
  - ➡ (not strictly true, but good approximation in the tracker acceptance)
- Data files of inelastic N.I have been created
  - 2.5 million N.I saved, 9 different hadrons, 1<E<1000 GeV
  - when a N.I occurs, a N.I is picked up randomly in the relevant energy range
  - a rotation around the particle direction is made (extra randomness)

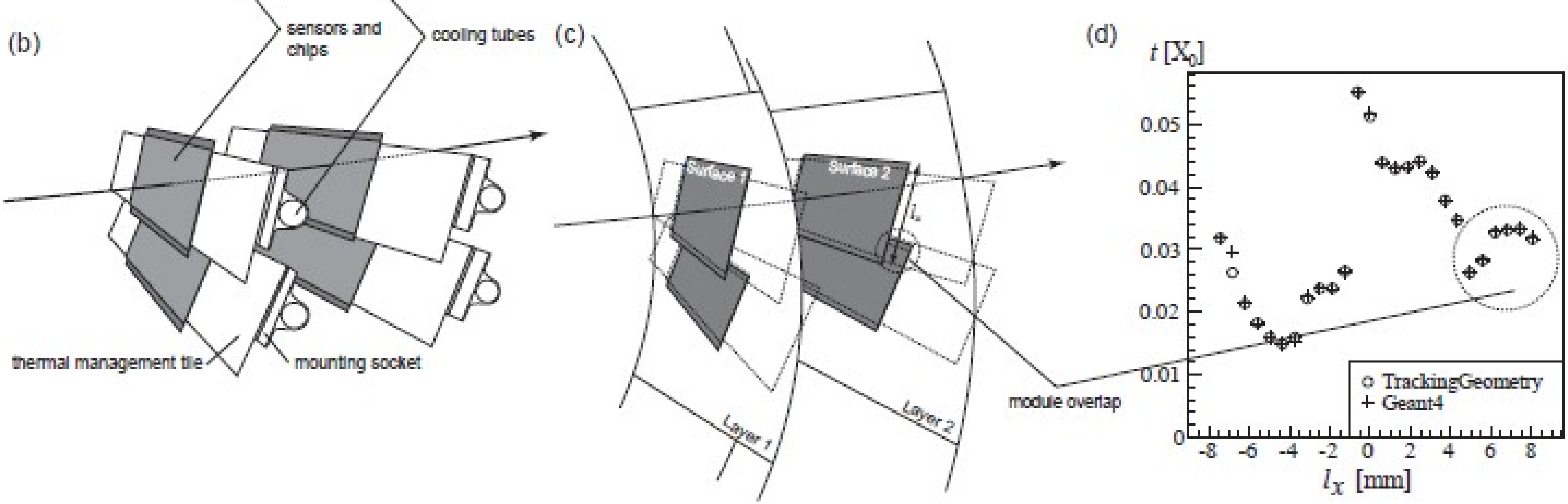
# ATLAS TrackingGeometry

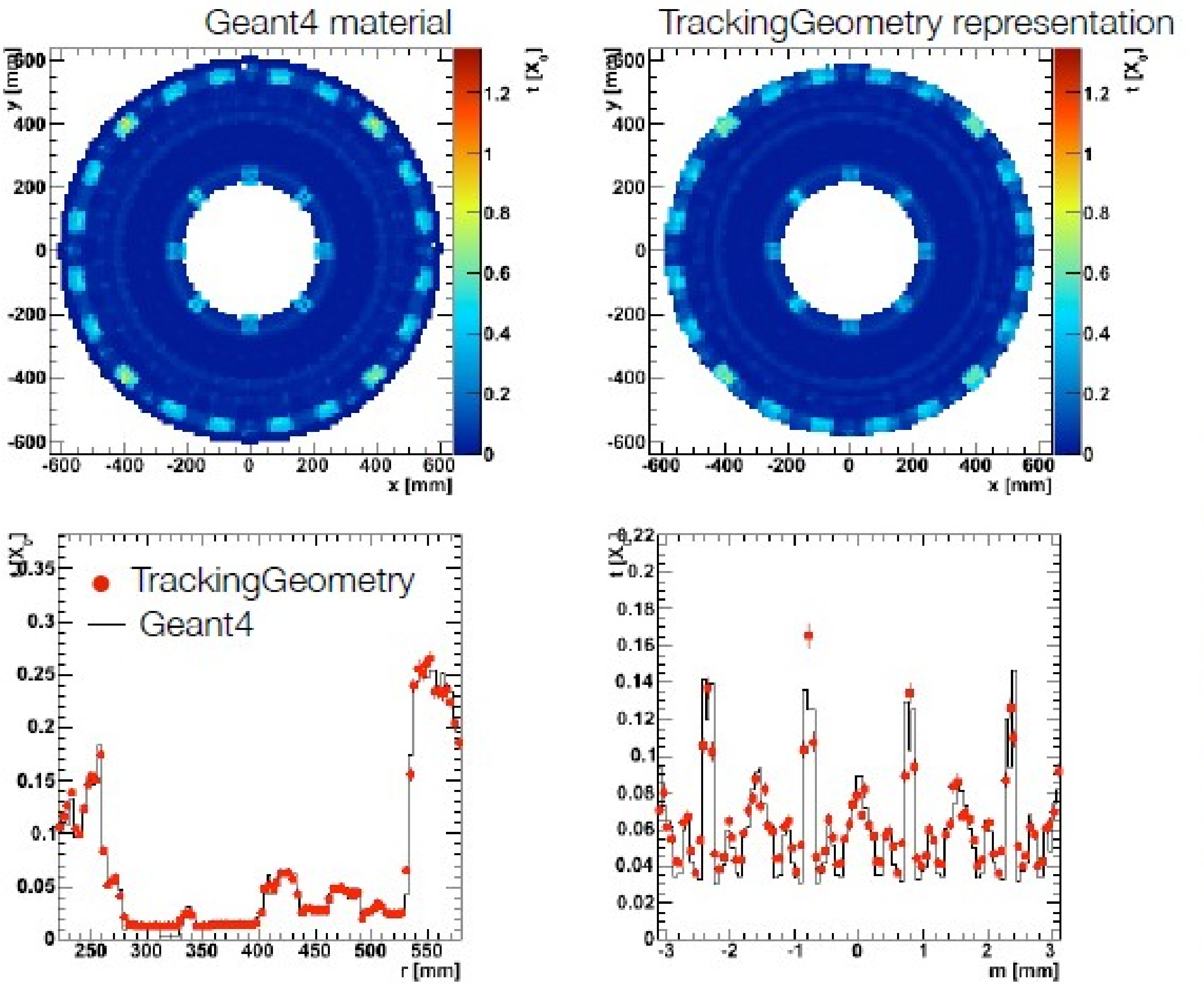
- *Inner Detector & Calorimeter:* *simplification to layers and cylindrical volumes keeping the exact description of sensitive elements*



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

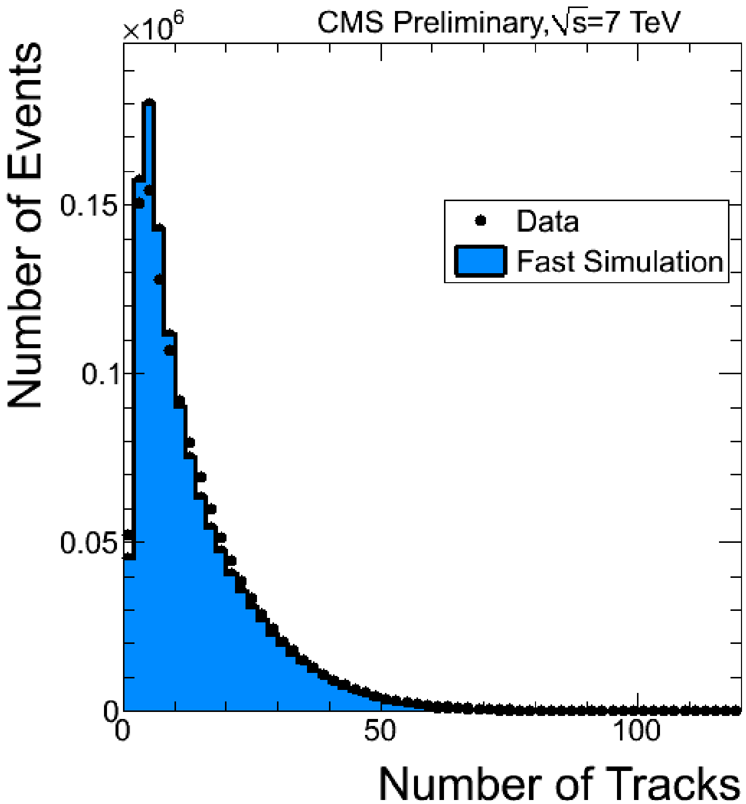
*material is mapped onto layers using Geant4 description and geantinos*

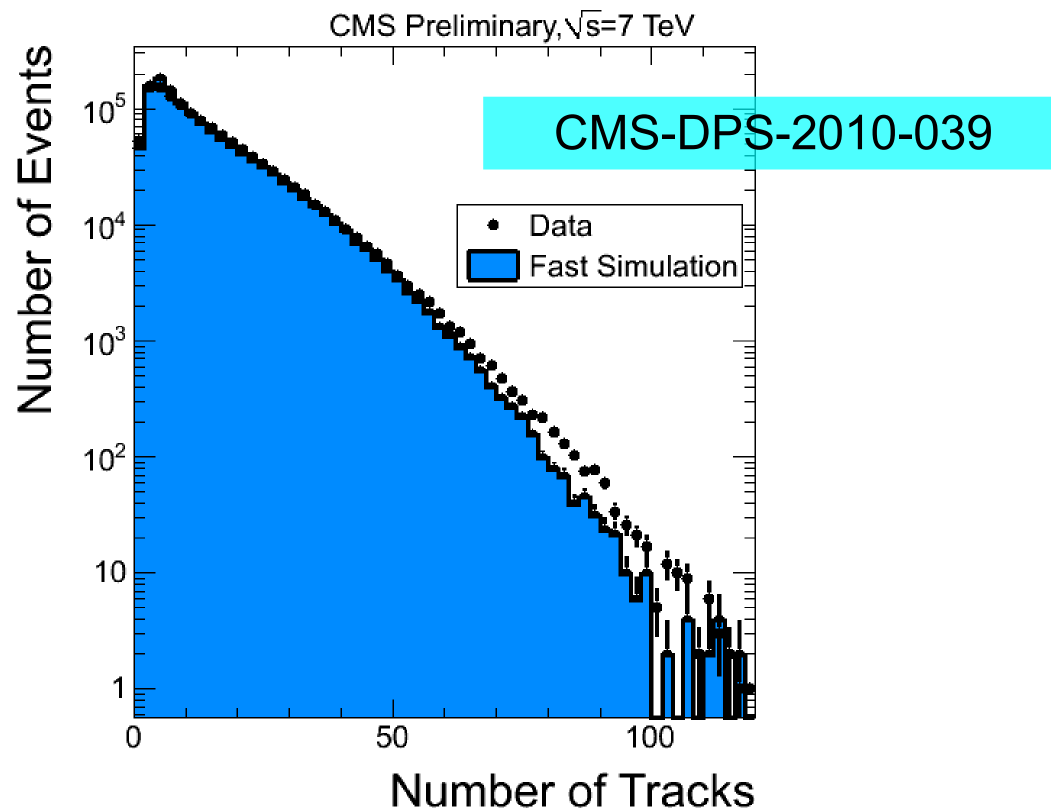





example for TrackingGeometry layer

# Number of reconstructed tracks, CMS




Lower number of events with high track multiplicity in the Fast Simulation with respect to the data. The same also happens in Full Simulation: Pythia tuning. (Improved in the meantime, but no new public plots for FastSim...)