Geant4 simulation of a high-granular calorimeters for performance studies

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FCC hadron detector meeting

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Requirements for the FCC-hh hadronic calorimeter

(what we know already)

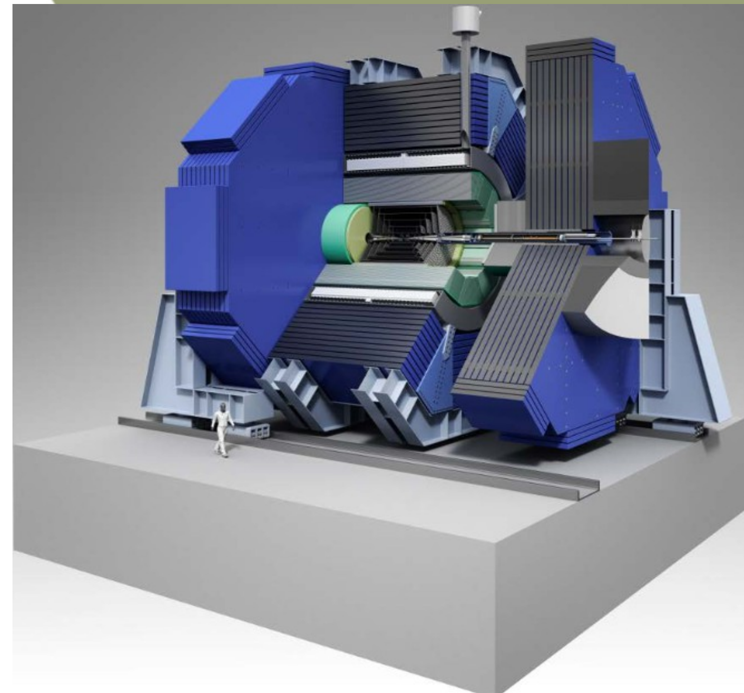
- **Good containment up to 30 TeV jets**
  - affects jet energy resolution & leakage biases
  - 12 λ_I is baseline for FCC-hh
- **Good longitudinal segmentation**
  - Realistic Gean4 simulation helps to determine
- **Good transverse segmentation for resolving boosted particles**
  - baseline 5x5 cm for FCC-hh (from previous Delphes studies)

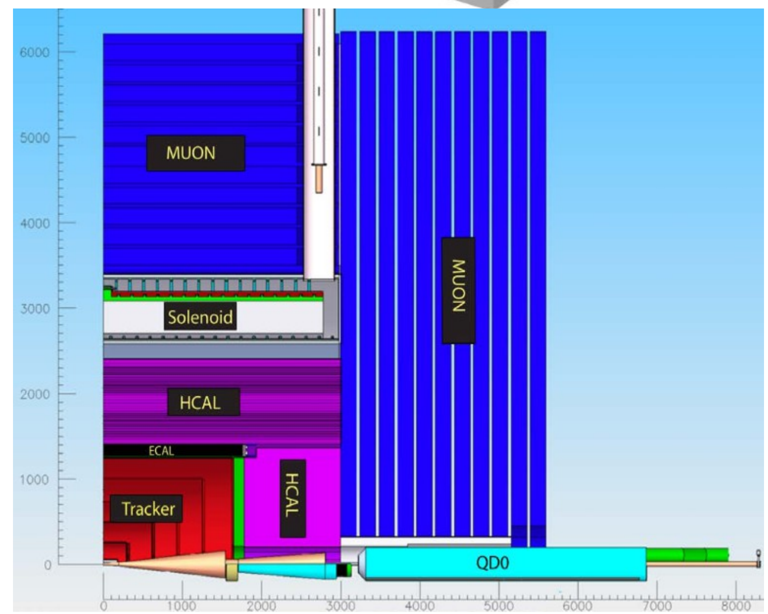
Optimize performance and sensitivity to new physics using appropriate technologies

Require detailed Geant4 simulations

SiD detector for ILC

- Multi-purpose detector for the ILC
- The key characteristics of the SiD detector:
  - 5 Tesla solenoid
  - Silicon tracker: 50 um readout pitch
  - ECAL: (0.35 cm cell size, W / silicon)
  - HCAL:
    - 1x1 cm cell size (RPC)
    - 40 layers for barrel (HCAL) ~4.5 λ_I
- Optimized for particle-flow algorithms (PFA)
- Fully configurable using SLIC software





Leverage large investments to R&D and software designs

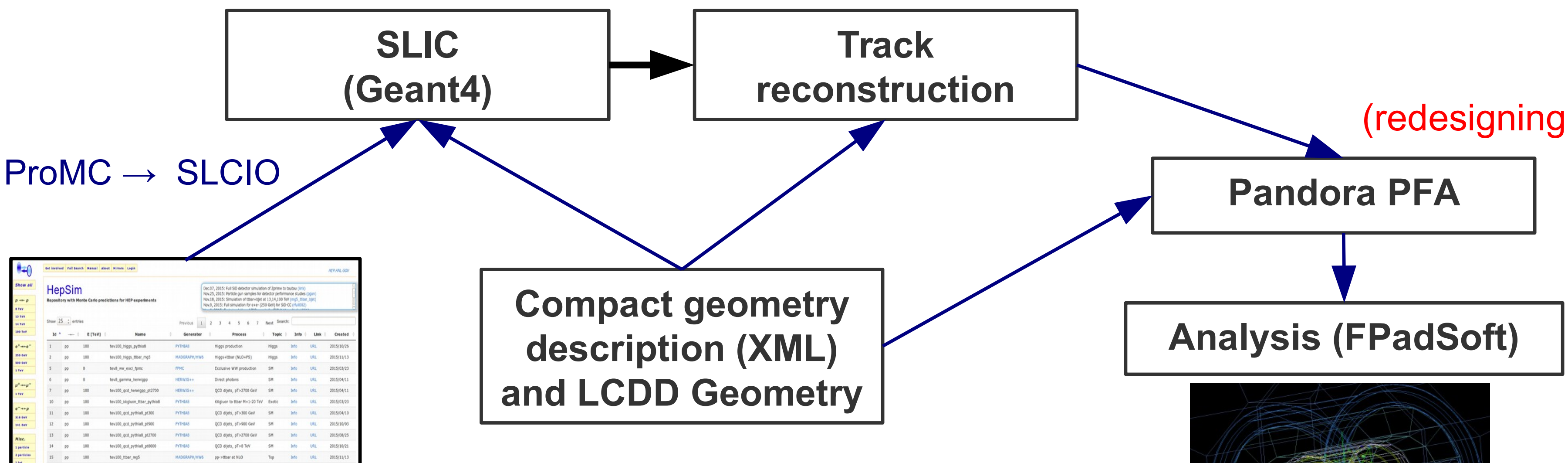
Re-purpose SLIC software for FCC-hh performance studies

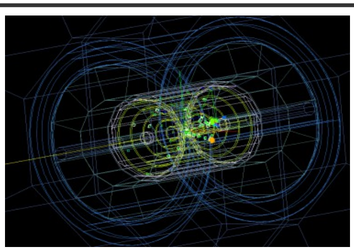
Software for future circular colliders

Re-purposing the Simulator for the Linear Collider (SLIC)

- Developed for the ILC.
- Optimized for the SiD detector at SLAC (T.Johnson, N.Graf, J.McCormick, J.Strube)
- Optimizing for future pp collider studies (S.C., A.Kotwal, J.Strube)
  - Integrated with **HepSim.** Output files are publicly accessible
  - Deployed on Open-Science Grid (OSG)

Analysis package: FPaDsoft - software for "Future Particle Detector" studies





URL with manual/examples:

https://atlaswww.hep.anl.gov/asc/wikidoc/doku.php?id=fcs:fpad

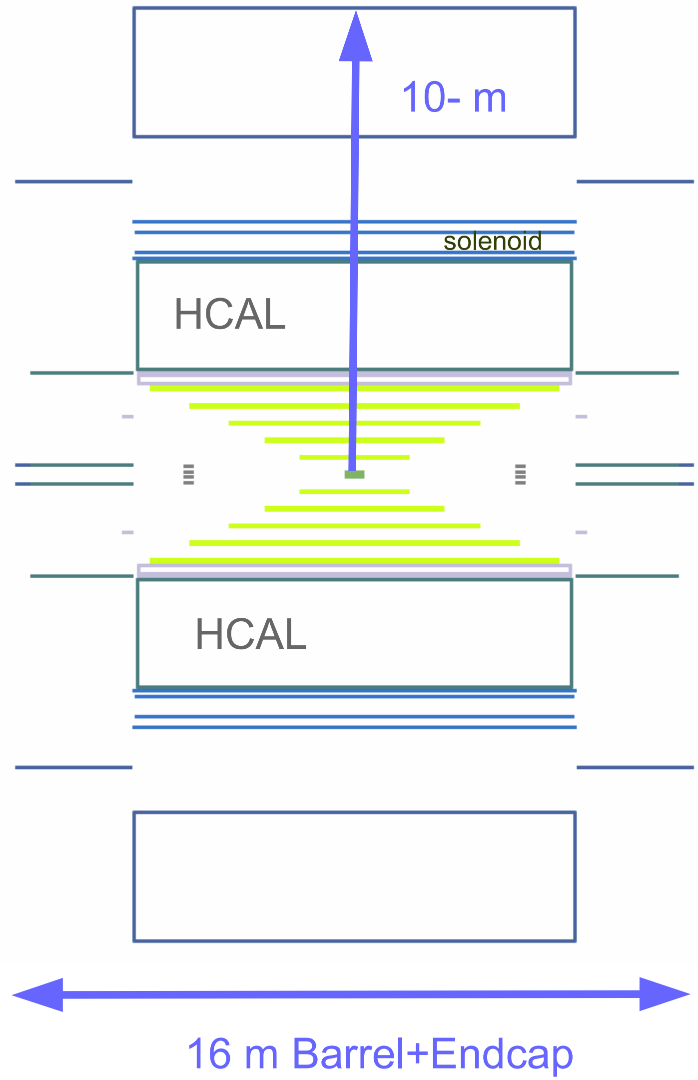
Designing calorimeters for FCC-hh

SiFcch2

http://atlaswww.hep.anl.gov/asc/hepsim/detectors/sifcch2.html

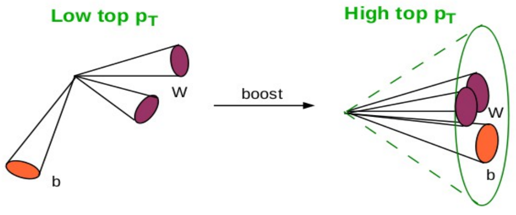
- **SiFcch2** geometry:
  - 5 T solenoid as for SiD
  - Increase Z-position of outer tracking, vertex detector and ECAL/HCAL by a factor 3
    - |eta|<1.7 for barrel calorimeter
  - Increase the outer radius of ECAL, HCAL, solenoid and muon detector by a factor ~2
  - **HCAL (Scint+Fe)**: ~ FCC baseline
    - 5x5 cm cells + analog readout
    - 12 lambda depth. 40 layers (as for SiD)
    - 5 cm absorber / layer (Fe)
  - **ECAL (Si/W)**:
    - 1x1 cm cells + analog readout
    - 32 layers, ~58 X0 (need optimization!)

- *Note: SiFcc1 geometry with "imaging" calorimeter was presented previously by S.Sen*



Physics processes for boosted jet studies

- Avoid complications due proton beams
- Processes for benchmarks using Pythia6:
  - μ+μ- → Z' → W+W-
  - μ+μ- → Z' → qq
  - μ+μ- → Z' → $t\bar{t}$
  - μ+μ- → Z' → tau+tau-



- LCIO reconstructed samples assuming:
  - ΔΓ(Z')~ 1 MeV
  - Z'(20 TeV), Z'(30 TeV), Z'(40 TeV)
- Apply favorite jet substructure techniques to identify W+W-, $t\bar{t}$ (and compare with Z' → $q\bar{q}$)

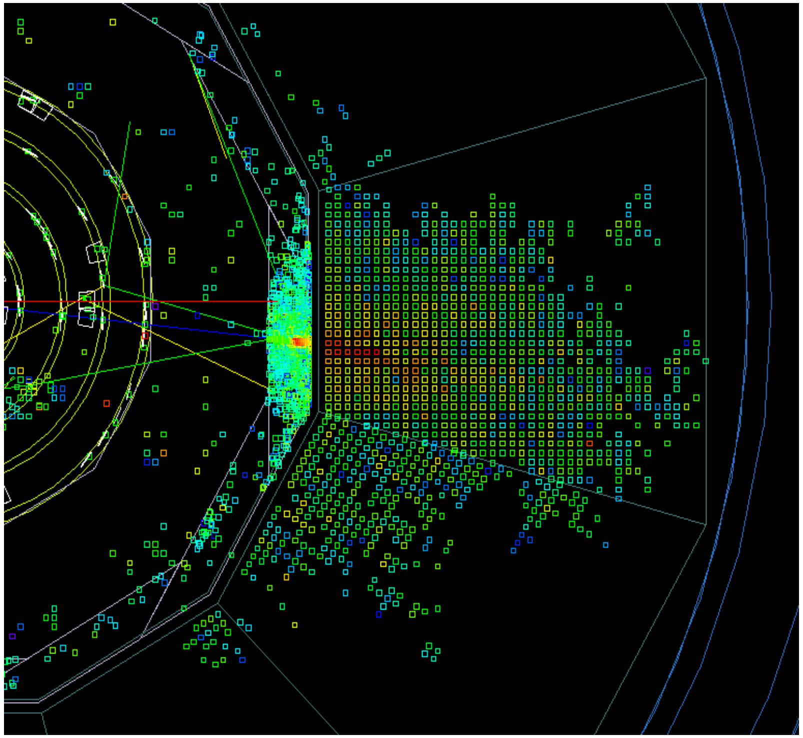
Response to 1 TeV pions

SiFcch2

- 1 TeV pions are important for "benchmarking" (C.Helsens & C.Solans studies)
  - ~10% will be carried by 1 TeV hadrons (~9 hadrons/jet) for pT(jet)>30 TeV

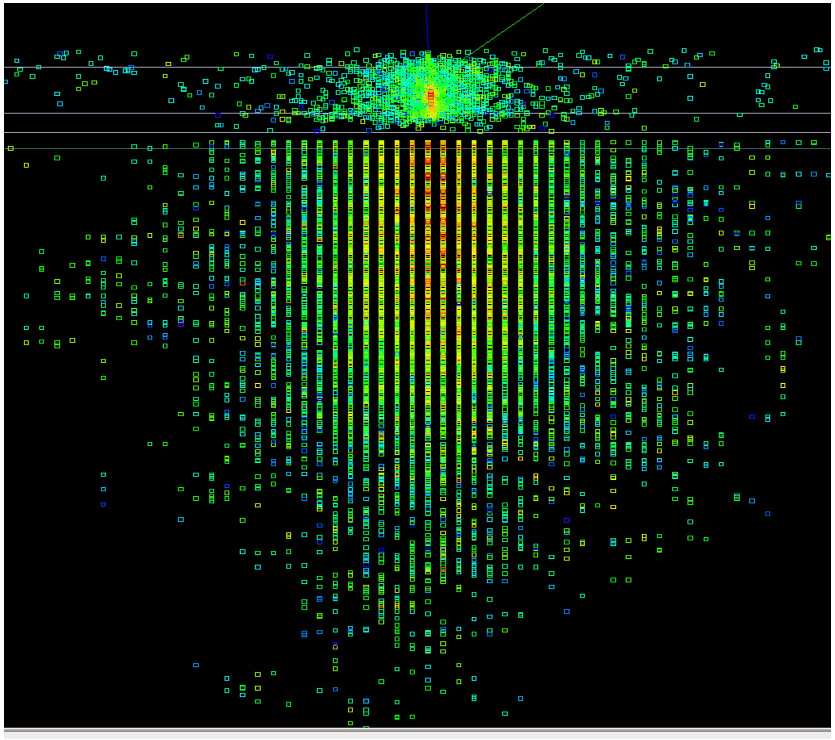
pi+ 1 TeV

X-Y view



pi+ 1 TeV

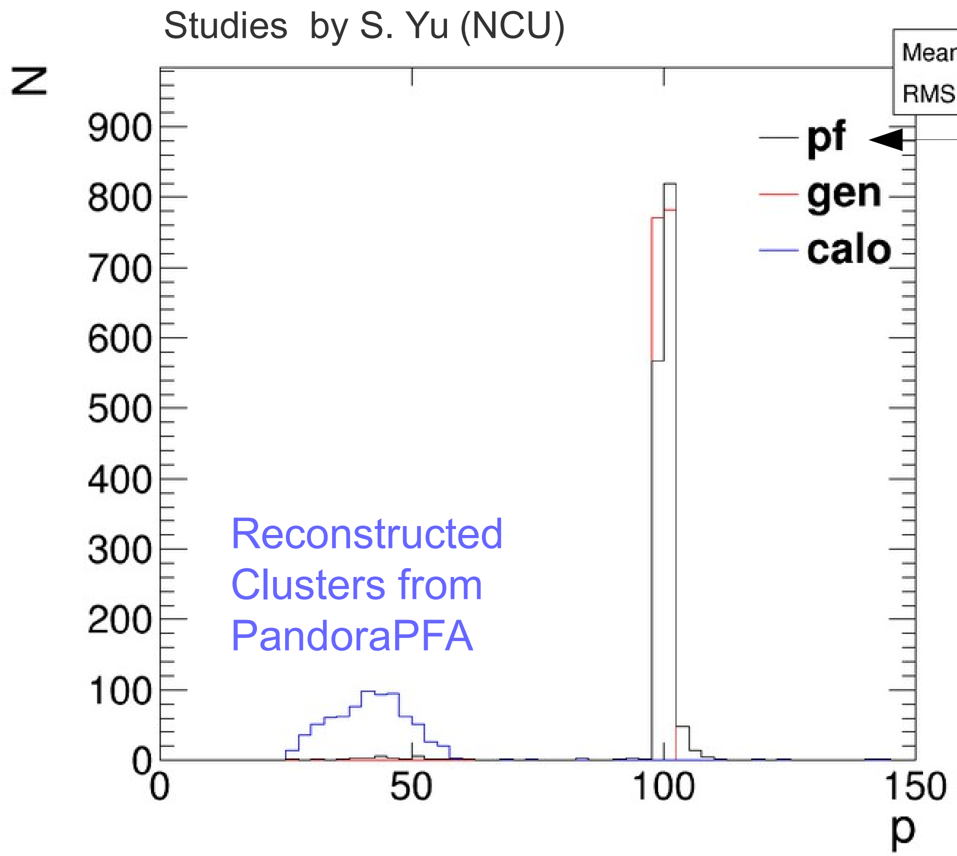
rho-Z view



Based on http://atlaswww.hep.anl.gov/hepsim/info.php?item=182

Response to 100 GeV pions

SiFcch2



PFA (particle flow algorithm)

Calorimeter clusters are miscalculated

Lost calibration for HCAL during the transition "imaging → analog"?

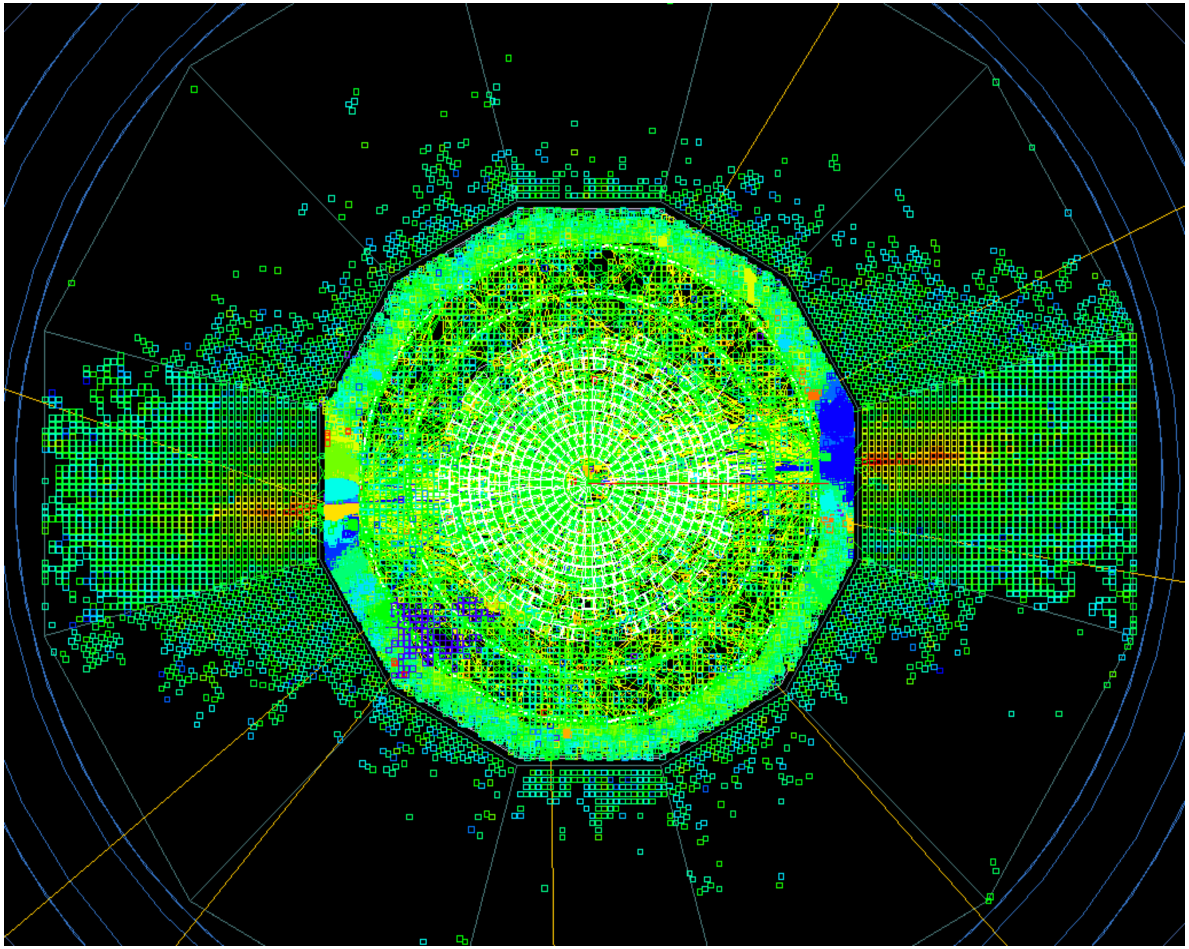
Working on PandoraPFA reconstruction to recalibrate hits and clusters

Based on: http://atlaswww.hep.anl.gov/hepsim/info.php?item=182

Event display of Z' (40 TeV) → $q\bar{q}$

SiFcch2

Known issues:
- HCAL hits are miscalibrated
- Graphics needs to be improved:
  - remove low-energy cells, correct cell sizes



Simulation & reconstruction of 1 event takes ~4h

Geant4 simulations for FCC calorimeter. S.Chekanov (ANL)

Preliminary MC reconstructed samples

SiFCCh2 geometry description. Reco tag rfull004
http://atlaswww.hep.anl.gov/asc/hepsim/detectors/sifcch2.html

- Available single-particle samples after full reconstruction:
  - Pions with P=10,100,1000,10000 GeV. Uniform Eta and Phi
  - http://atlaswww.hep.anl.gov/hepsim/info.php?item=182

- Z'(10 TeV) decaying to $q\bar{q}$, $t\bar{t}$, W+W-
  - ~2000 fully reconstructed events per sample (Tracks, PFA, CaloClusters, HITS)
  - created on Open-Science Grid (UChicago/ANL. ~100,000 CPU*h)
  - http://atlaswww.hep.anl.gov/hepsim/index.php?c=mupmum&e=10000&t=all

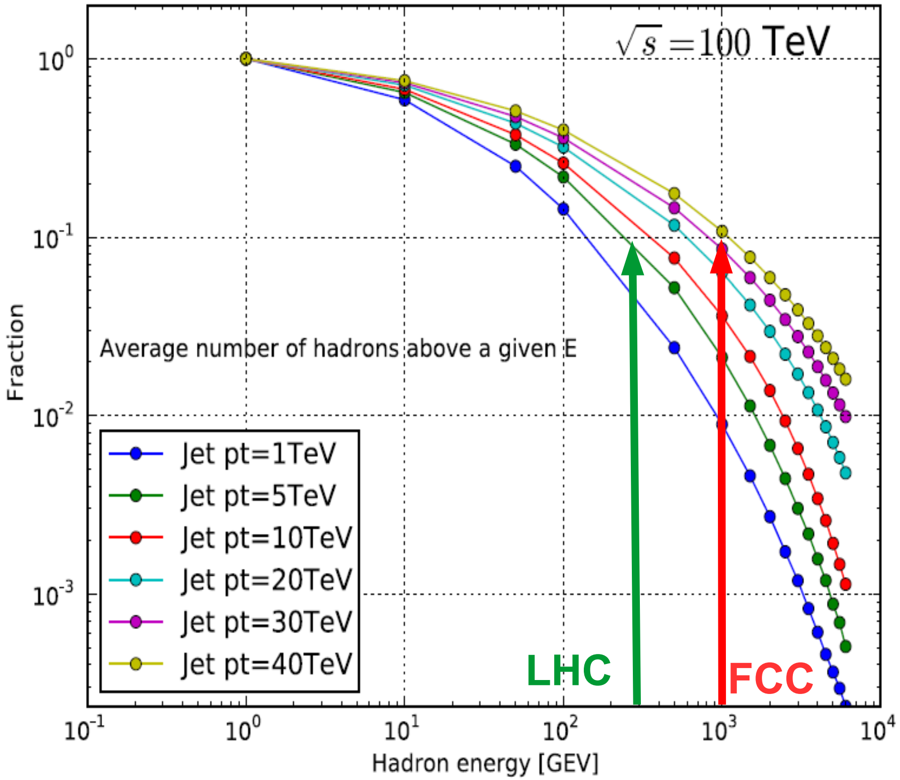
- Warning/known issues:
  - RecoCalor clusters are miscalibrated
  - Use HCAL HITs offline and apply sampling fractions / corrections?
  - Work in progress (changing the Pandora algorithm)

Backup

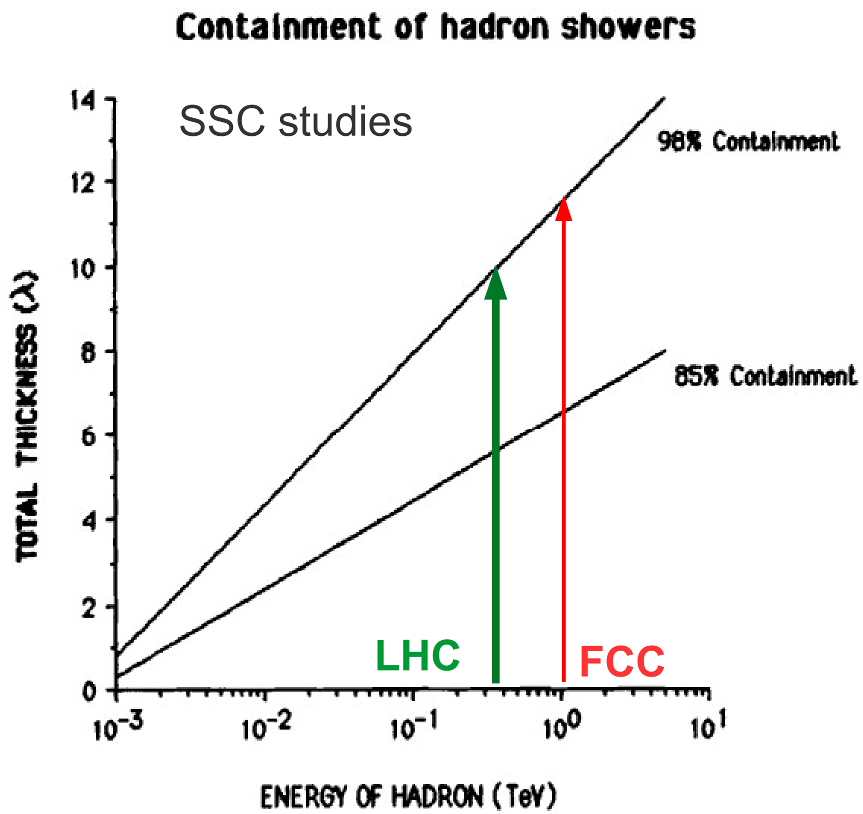
Estimating HCAL depth

Leading particles in high-pT jets

C.Helsens,C.Solans

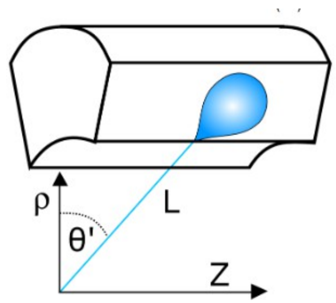


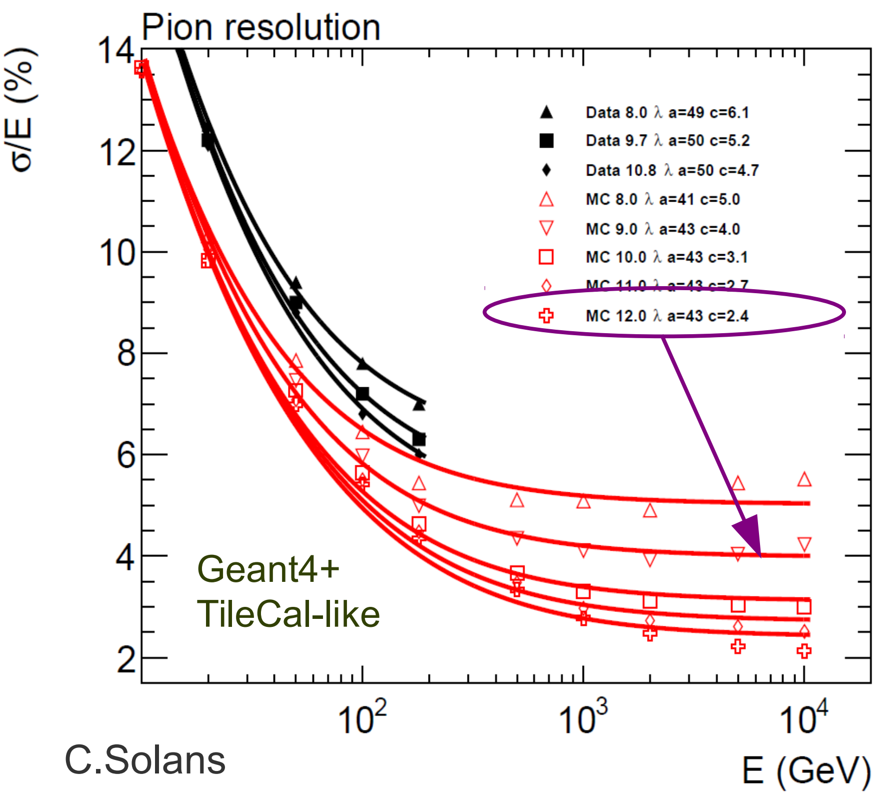
http://lss.fnal.gov/conf/C860623/p355.pdf



pT(jet)>30 TeV: ~10% will be carried by 1 TeV hadrons (~9 hadrons/jet)
12 λ_I is needed to contain 98% of energy of a 1 TeV hadron
Geant4 simulation agrees with calculations for SSC (.. 1984 Gordon&Grannis. Snowmass)

Resolution for single pions





C.Solans

https://indico.cern.ch/event/404924/

$$\frac{\sigma(E)}{E} = \frac{a}{\sqrt{E}} \oplus \frac{b}{E} \oplus c$$

a – stochastic/sampling term,
b - electronic noise term
c - constant term

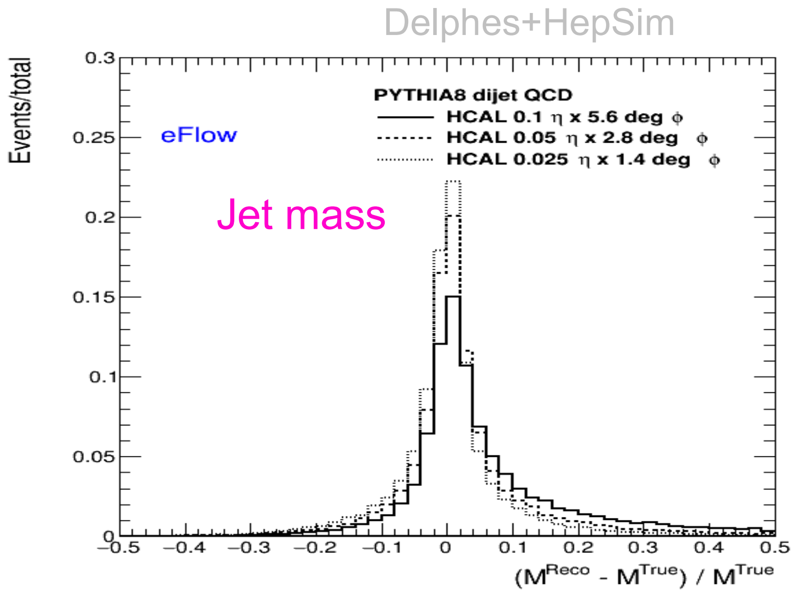
"c" dominates for jet with pT>5 TeV

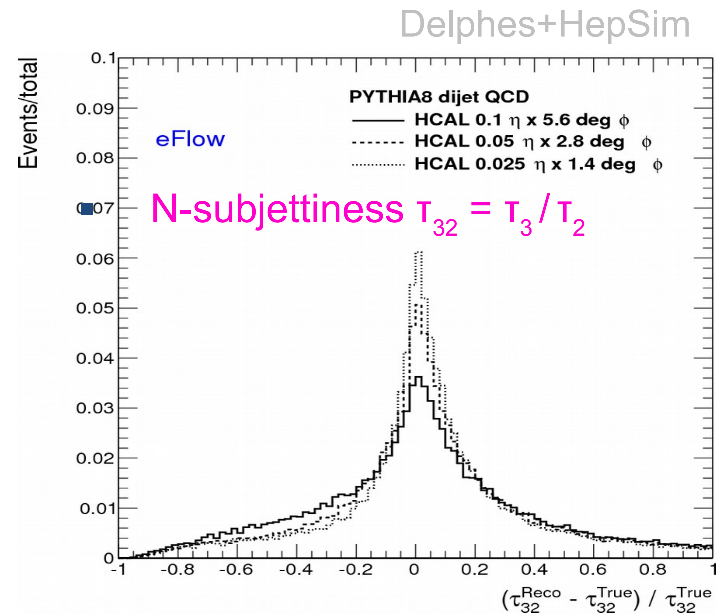
- Geant4 TileCal inspired simulation based on FTFP_BERT
- Calculate single-particle resolution
- Stochastic term is close to 45%/√E
- Constant term improves by ~20% with increase of **1**$\boldsymbol{\lambda_I}$

Constant term c~2.5% is achievable for 12 $\boldsymbol{\lambda_I}$

Resolutions for substructure variables for pT(jet)>10 TeV (fast simulation)

Presented at
Boost2015. Chicago, Aug. 10-15, 2015





Decrease in RMS values compared to $\Delta\eta \times \Delta\varphi = 0.1 \times 0.1$

	$\Delta\eta \times \Delta\varphi = 0.05 \times 0.05$	$\Delta\eta \times \Delta\varphi = 0.025 \times 0.025$
tau21	18%	28%
tau32	9%	13%
jet mass	80%	120%

Large improvement in resolution for $\Delta\eta \times \Delta\varphi = 0.025 \times 0.025$