Simulations for the Energy Frontier

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HEP/ANL
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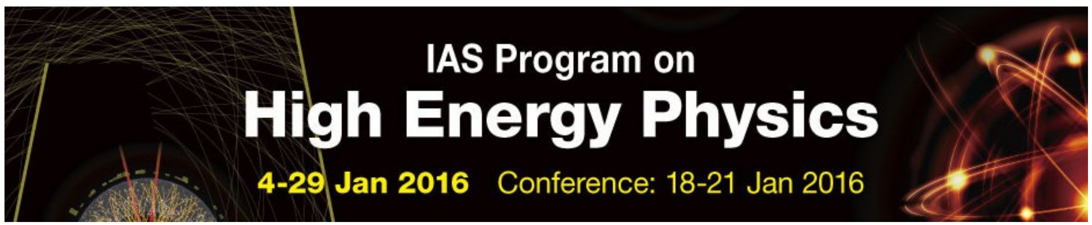


Future of particle collisions

High-Luminosity LHC

ILC (International Linear Collider)

FCC (Future Circular Collider). FCC-ee and FCC-hh

CEPC (Circular Electron Positron Collider)

SPPC (Super Proton-Proton Collider)

EIC (Electron Ion Collider)

In the next decade we will deal with explorations of physics reach, detector parameters and new technology options for post-LHC era

Requires detailed simulation of physics processes and detector responses

Simulations at the Energy Frontier

Process modeling

- Known particle properties
- Standard Model (SM) is well established (QCD & QED)
- Event generators at LO, NLO, NNLO, etc., NLO matched to NLO, ..
- Models beyond the SM with detailed implementation in event generators

Detector response

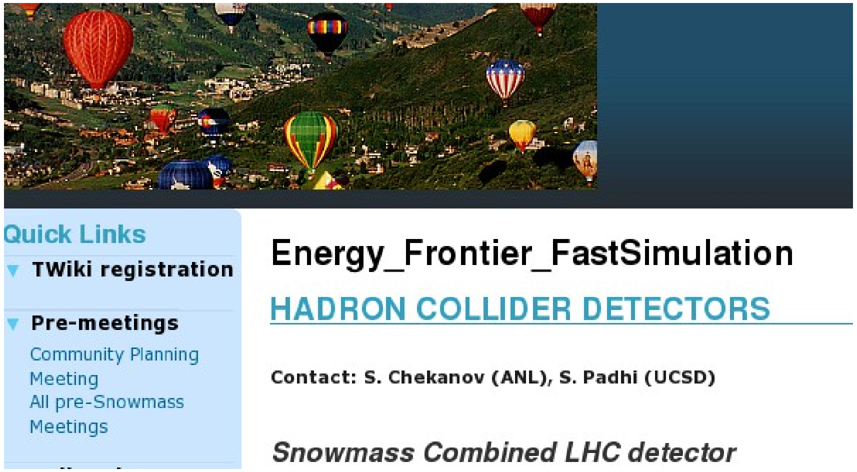
- Interactions of particles with materials
- Many parametrized cross sections (when exact theory is unknown)
- Simulation packages (Geant4,etc.)

Computing

- Fast progress in computer technology
- Open Science HPC and Grid (OSG)

Monte Carlo simulation for DPF (Snowmass 2013)

- First Snowmass meeting with large-scale MC production with open data access
  - ~billion events with Delphes fast simulation
  - 140 pileup scenarios for HL-LHC
- Open-science grid (OSG) and other resources



Described in the report "Snowmass Energy Frontier Simulations" ***(arXiv:1309.1057)***

Learned Lessons:

- General community (especially theorists) is reluctant to use grid to access data
  - security certificate & approvals are too complicated? → *use HTTP?*
- Limited file storage & large EVGEN event files when using pileup
  - EVGEN files & LOG files removed, ROOT files slimmed

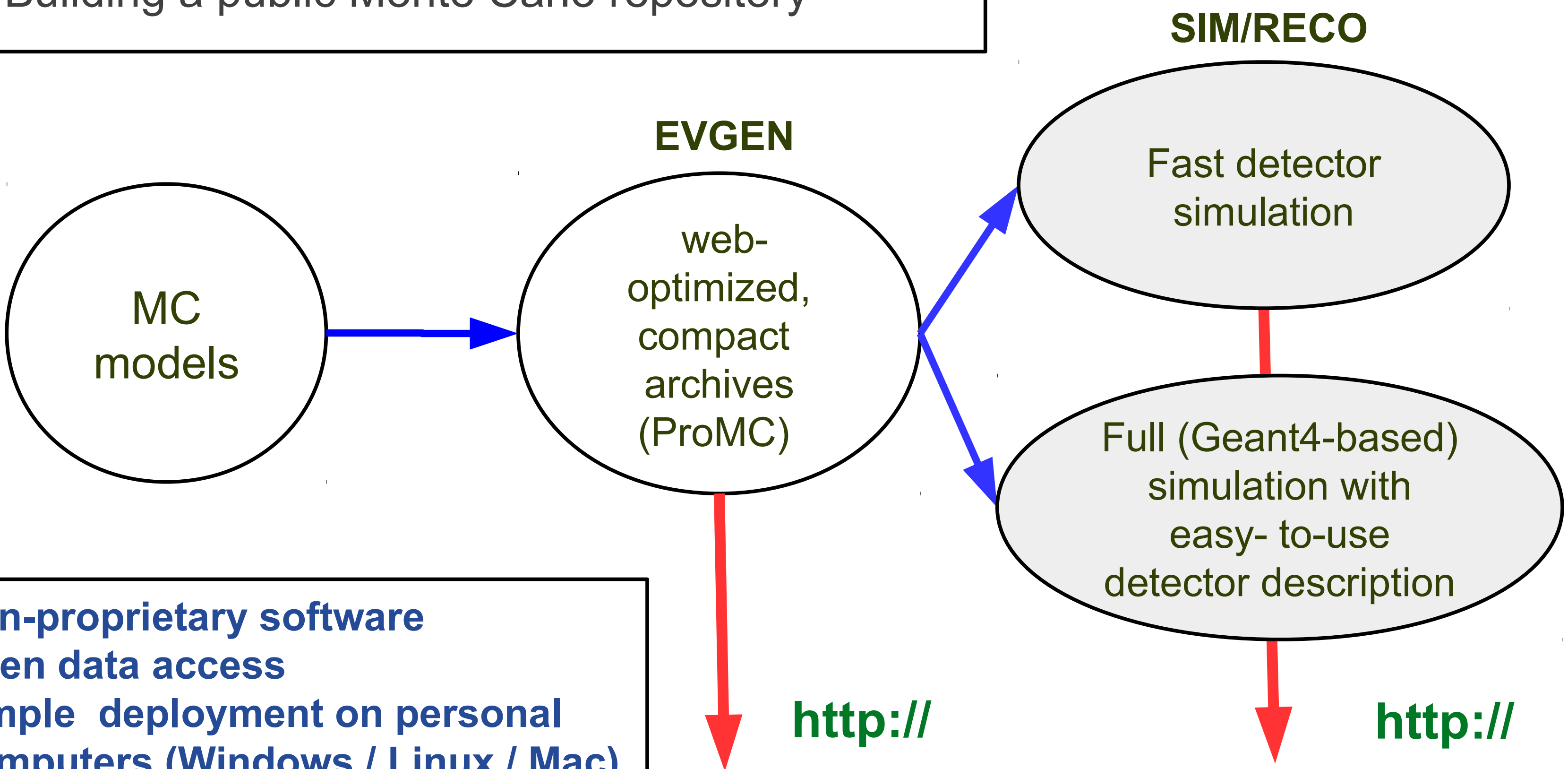
    → *Insufficient information for archiving*
- No sustainable data servers for long-term preservation

    → *Most files cannot be accessed any longer*

Each experiment has its own resources & proprietary tools.
How to share resources using project-specific infrastructure?

Moving forward: Public Repository with Simulations

- Learning from DPF
- Building a public Monte Carlo repository



→ Non-proprietary software
→ Open data access
→ Simple deployment on personal computers (Windows / Linux / Mac)

OPEN ACCESS

Long-term availability & preservation

Software choices for post-DPF event repository

- **Output from Monte Carlo generators (EVGEN)**
  - STDHEP, HEPMC, LHE, formats etc → **new ProMC format**
    - NLO, logfiles etc. in a single format → everything for **long-term archiving**

- **Fast detector simulation: DELPHES**
  - DELPHES 3.3 as for DPF 2015. Maintained by Université catholique de Louvain
    - Available ATLAS, CMS, ILD, LHC-B and "HERA-like" detectors
    - Open source
  - Output: **ROOT files**

- **Full detector simulation: Geant4**
  - no project or R&D money to develop → reuse the existing software
  - Use: Simulator For The Linear Collider (SLIC) developed at SLAC
    - Easy to use and configure detectors
    - Open source
  - Output: **SLCIO files**

- **Analysis: C++/ROOT, CPython/ROOT, Jython/Java**

New data format for EVGEN: **ProMC**

S.C., E.May, K. Strand, P. Van Gemmeren, Comp. Physics Comm. 185 (2014), 2629

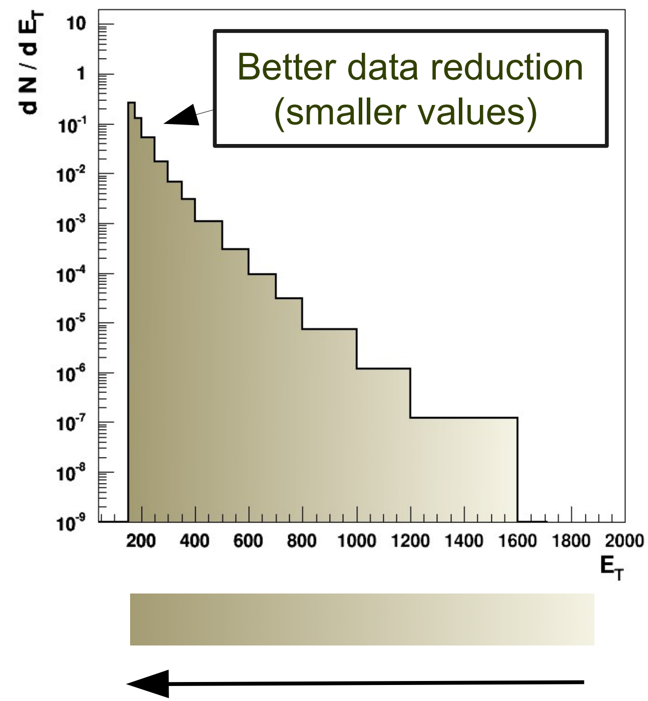
protobuf
Protocol Buffers - Google's data interchange format

- Based on Google's Protocol buffers
- 30% smaller files than existing formats after compression
  - Uses "Varint" for int64 instead of "fixed bytes"

> Number of used bytes depends on values.
> Small values use small number of bytes

- ~20 times faster than XML and 3-10 times smaller
- "Archive" format to keep:
  - Event records, original logfiles, PDG tables etc.
  - NLO simulations
- Separate events can be streamed as "records"
  - similar to avi frames for web video players
- Key for data reduction for large pile-up
  - Particles with small momenta → less bytes used
  - effective compression of pile-up particles

http://atlaswww.hep.anl.gov/asc/promc/



compression strength keeping precision of representation constant

Benchmarks for EVGEN files

ProMC files are 12 times smaller than HEPMC and 30% smaller than ROOT and ~30% faster to process

File sizes for 10,000 $t\bar{t}$ events for pp at LHC

File format	File Size (MB)	C++ (sec)	CPython (sec)	Java (sec)	Jython (sec)
ProMC	307	15.8	980	11.7 (12.1 +JVM startup)	33.3 (35 +JVM startup)
ROOT	423	20.4	66.7 (PyROOT)	-	-
LHEF	2472	84.7	30.4	9.0 (9.6 +JVM startup)	-
HEPMC	2740	175.1	-	-	-
LHEF (gzip)	712	-	-	-	-
LHEF (bzip2)	552	-	-	-	-
LHEF (lzma)	513	-	-	-	-
HEPMC (gzip)	1021	-	-	-	-
HEPMC (bzip2)	837	-	-	-	-
HEPMC (lzma)	802	-	-	-	-

Table 1. Benchmark tests for reading files with 10,000 ttbar events stored in different file formats. For each test, the memory cache on Linux was cleared. In case of C++, the benchmark program reads complete event records using appropriate libraries. CPython code for ProMC file is implemented in pure CPython and does not use C++ binding (unlike PyROOT that uses C++ libraries). In case of LHEF files. JAVA and CPYTHON benchmarks only parse lines and tokenize the strings, without attempting to build an event record, therefore, such benchmarks may not be accurate while comparing with ProMC and ROOT.

https://atlaswww.hep.anl.gov/asc/wikidoc/doku.php?id=asc:promc:introduction

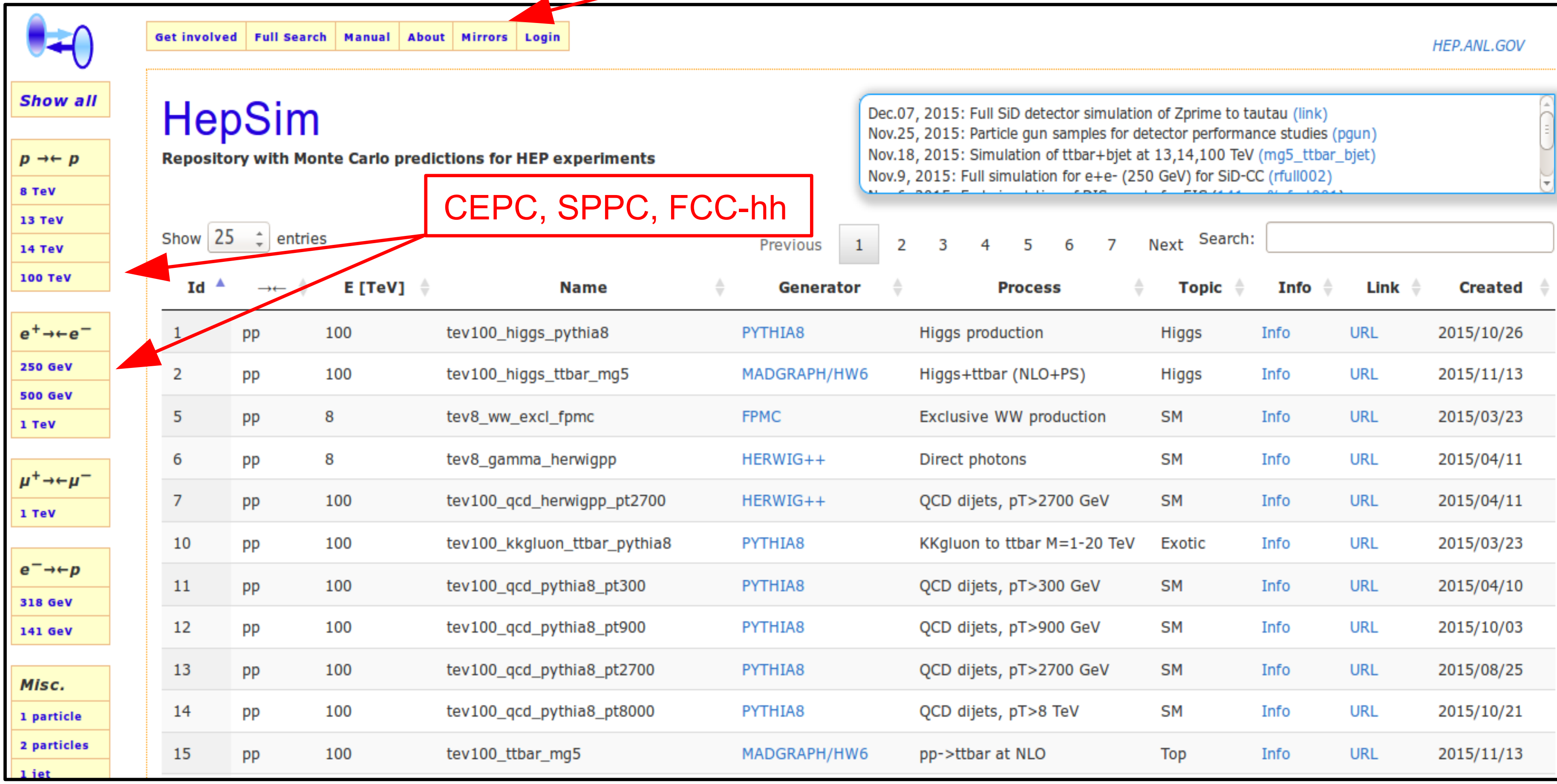
HepSim project

http://atlaswww.hep.anl.gov/hepsim/

- **2013-14: A community project to keep EVGEN files**
- **2015-now: Stores fast and full simulations using "tags"**
- **Maintained at HEP-ANL**
- **Used for future circular collider studies (ANL/Fermilab/CERN):**
  - LHC physics
  - Phase-II LHC upgrade
  - HL-LHC (pp 14 TeV 3000 fb-1)
  - FCC-hh studies (100 TeV pp, 3 ab-1)
  - HGCAL for CMS
  - Circular Electron Positron Collider studies
  - EIC
- **Theorists can add their simulations:**
  - .. and analyze events the way experimentalists do!
- **Can be used for outreach too**

HepSim simulation

http://atlaswww.hep.anl.gov/hepsim/



Id	→←	E [TeV]	Name	Generator	Process	Topic	Info	Link	Created
1	pp	100	tev100_higgs_pythia8	PYTHIA8	Higgs production	Higgs	Info	URL	2015/10/26
2	pp	100	tev100_higgs_ttbar_mg5	MADGRAPH/HW6	Higgs+ttbar (NLO+PS)	Higgs	Info	URL	2015/11/13
5	pp	8	tev8_ww_excl_fpmc	FPMC	Exclusive WW production	SM	Info	URL	2015/03/23
6	pp	8	tev8_gamma_herwigpp	HERWIG++	Direct photons	SM	Info	URL	2015/04/11
7	pp	100	tev100_qcd_herwigpp_pt2700	HERWIG++	QCD dijets, pT>2700 GeV	SM	Info	URL	2015/04/11
10	pp	100	tev100_kkgluon_ttbar_pythia8	PYTHIA8	KKgluon to ttbar M=1-20 TeV	Exotic	Info	URL	2015/03/23
11	pp	100	tev100_qcd_pythia8_pt300	PYTHIA8	QCD dijets, pT>300 GeV	SM	Info	URL	2015/04/10
12	pp	100	tev100_qcd_pythia8_pt900	PYTHIA8	QCD dijets, pT>900 GeV	SM	Info	URL	2015/10/03
13	pp	100	tev100_qcd_pythia8_pt2700	PYTHIA8	QCD dijets, pT>2700 GeV	SM	Info	URL	2015/08/25
14	pp	100	tev100_qcd_pythia8_pt8000	PYTHIA8	QCD dijets, pT>8 TeV	SM	Info	URL	2015/10/21
15	pp	100	tev100_ttbar_mg5	MADGRAPH/HW6	pp->ttbar at NLO	Top	Info	URL	2015/11/13

HepSim stores EVGEN files (LO,NLO, etc), fast simulations, full Geant4 simulations

Single dataset entry: http://atlaswww.hep.anl.gov/hepsim/

13 TeV
14 TeV
100 TeV

$e^+ \to \leftarrow e^-$
250 GeV
500 GeV
1 TeV

$\mu^+ \to \leftarrow \mu^-$
1 TeV
5 TeV
10 TeV

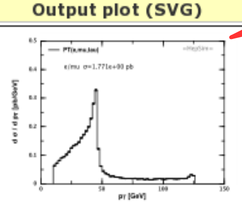
$e^- \to \leftarrow p$
318 GeV
141 GeV

Misc.
1 particle
2 particles
1 jet

Information about *"gev250ee_pythia6_zpole_ee"* dataset

Name:	*gev250ee_pythia6_zpole_ee*
Collisions:	e+e-
CM Energy:	0.25 TeV
Entry ID:	146
Topic:	SM
Generator:	PYTHIA6
Calculation level:	LO+PS+hadronisation
Process:	Z boson to e+e-
Total events:	2000000
Number of files:	100
Cross section (σ):	1.7765 ± 0.0126 pb
Luminosity (L):	1.126E+06 pb^{-1} *(or)* 1125.7948 fb^{-1} *(or)* 1.1258 ab^{-1}
Format:	ProMC
Submission date:	Tue Oct 13 14:28:55 CDT 2015
Download URL:	http://mc.hep.anl.gov/asc/hepsim/events/ee/250gev/pythia6_zpole_ee
Mirrors:	
MC truth size:	0.826 GB
Fast simulation:	rfast001 (info) |
Full simulation:	rfull002 (info) | rfull001 (info) |
Record slimmed:	No
Events weighted:	No
User description:	PYTHIA version 6.4. Z production (Zpole) with decays to e+e-. Other details in the log file.
File metadata:	**ProMC version:** 4; **Nr events:** 1000; **Varint E:** 1000000; **Varint L:** 10000; **Logfile:** logfile.txt; **Last modified:** 2015-10-15 20:31:08; **Settings:** PYTHIA-6.4.28; MSEL 0 0 0 ! mix events; NTOT 0 0 1000 ! Number of events; ECME 0 0 250.0 ! CM energy (GeV); IRND 0 0 839264 ! random seed; MSEL 0 0 0 ! all mixed events; PMAS 6 1 172.5 !; PMAS 23 1 91.1876 ! Z boson mass; PMAS 24 1 80.3850 ! W boson mass; PMAS 25 1 125. ! Higgs mass; MSUB 1 0 1 ! ffbar to Z; MSTP 43 0 2 ! Z only, no gamma; MDME 174 1 0 ! D D~; MDME 175 1 0 ! U U~; MDME 176 1 0 ! S S~; MDME 177 1 0 ! C C~; MDME 178 1 0 ! B B~; MDME 179 1 0 ! T T~; MDME 182 1 1 ! E- E+; MDME 183 1 0 ! NU_E NU_E~; MDME 184 1 0 ! MU+ MU-; MDME 185 1 0 ! NU_MU+ NU_MU-; MDME 186 1 0 ! TAU- TAU+; MDME 187 1 0 ! NU_TAU- NU_TAU+; PARJ 71 0 10 ! ctau=10mm; MSTJ 22 0 2 !;

Validation:

Nr	Analysis code	Output plot (SVG)	Output (XML)
1	pythia6_zpole_ee.py Launch Desktop: **hs-ide [URL]**		pythia6_zpole_ee.jdat

e+e- (250 GeV)

Z → e+e-

URL for EVGEN files (download or data streaming)

URL with fast or full simulations

Validation distribution created using Python scripts.

Also supports Java, Groovy, (J)Ruby, CPython and C++

The manual explains how to download or stream events using client-side analysis tool

Available Monte Carlo generators

- MG5/PY6 (NLO+PS+hadr): TTbar, Higgs+jj, Higgs+TTbar etc
- MG5/Herwig (NLO+PS+hadr)
- PYHIA8 (many processes)
- FPMC (exclusive WW, Higgs)
- HERWIG++ pp collisions (QCD dijets)
- SuperChic 2 - A Monte Carlo for Central Exclusive Production
- MCFM (NLO):: Higgs -> $\gamma\gamma$, Inclusive gamma, TTbar
- NLOjet++ (NLO) for inclusive jets (bins in pT)
- JETPHOX (NLO) for inclusive photons (bins in pT)
- PYTHIA6 for e+e and mu+mu- collisions
- LEPTO/PYTHIA for ep DIS
- LEPTO/ARIADNE for ep DIS
- Single particle guns (+ pileup)

~20% samples generated on BlueGene/Q (Mira) supercomputer (Jetphox, MCFM)
~40% HEP-ANL (mainly Madgraph)
~40% OSG-CI grid (ANL/UChicago) and USATLAS CI (for phase II)

Long-term preservation of theoretical calculations

- **Storing predictions in ntuples makes sense if:**

$$\frac{\text{time to download \& analyse on commodity computer}}{\text{CPU*h needed to create the prediction}} \equiv \varepsilon << 1$$

$\varepsilon \sim 0.01\text{-}1$ - for LO MC
$\varepsilon << 0.01$ - for NLO etc.

- **ε << 1:**
  - Madgraph5 etc. (NLO+PS+hadronisation), ALPGEN
  - Some fast-converging NLO calculations (MCFM, jetPHOX etc)
  - MC with ε ~ 1 but after mixing with pile-up (CPU intensive)
- **ε ~ 1:** Less appropriate approach for:
  - LO simulations (Pythia)
  - Some NLO programs with slow convergence
    - requires too large data volumes to keep weighted events

NLO calculations as “ntuples”

Theorists can use it too!

- Several NLO calculations are available (MCFM, JETPHOX, NLOjet++)
- Data structure is somewhat different compared to full parton-shower MC
- “Particle record”: Usually 4-momenta of 3-4 particles per events
- “Event record”:
  - Event weights (double)
  - Deviations from central weights for different PDF eigenvector sets for calculations of PDF uncertainties

$$\boxed{w_n = \left[1000 \times (1 - \frac{PDF(n)}{PDF(0)})\right]}$$

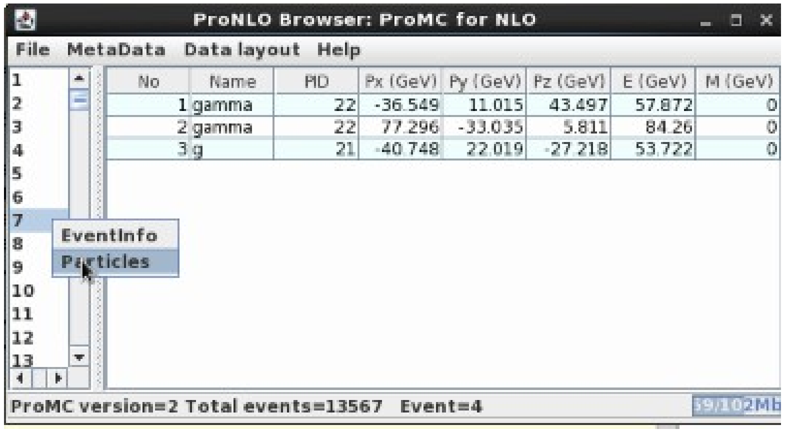
n=1...51 for CT10

Example: look at file structure of MCFM prediction for H(→ γγ)+jet

```
hs-view http://mc.hep.anl.gov/asc/hepsim/events/pp/100tev/higgsjet_gamgam_mcfm/hjetgamgam_0000000.promc
```

NLO calculations as “ntuples”

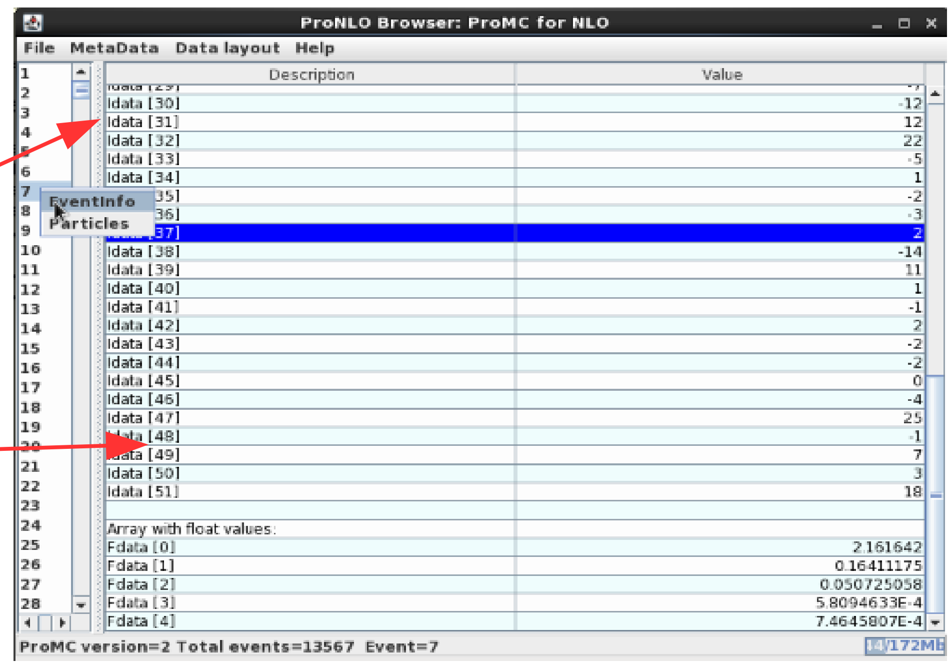
Some NLO samples using MCFM
have been created on Mira supercomputer
(BlueGene/Q)



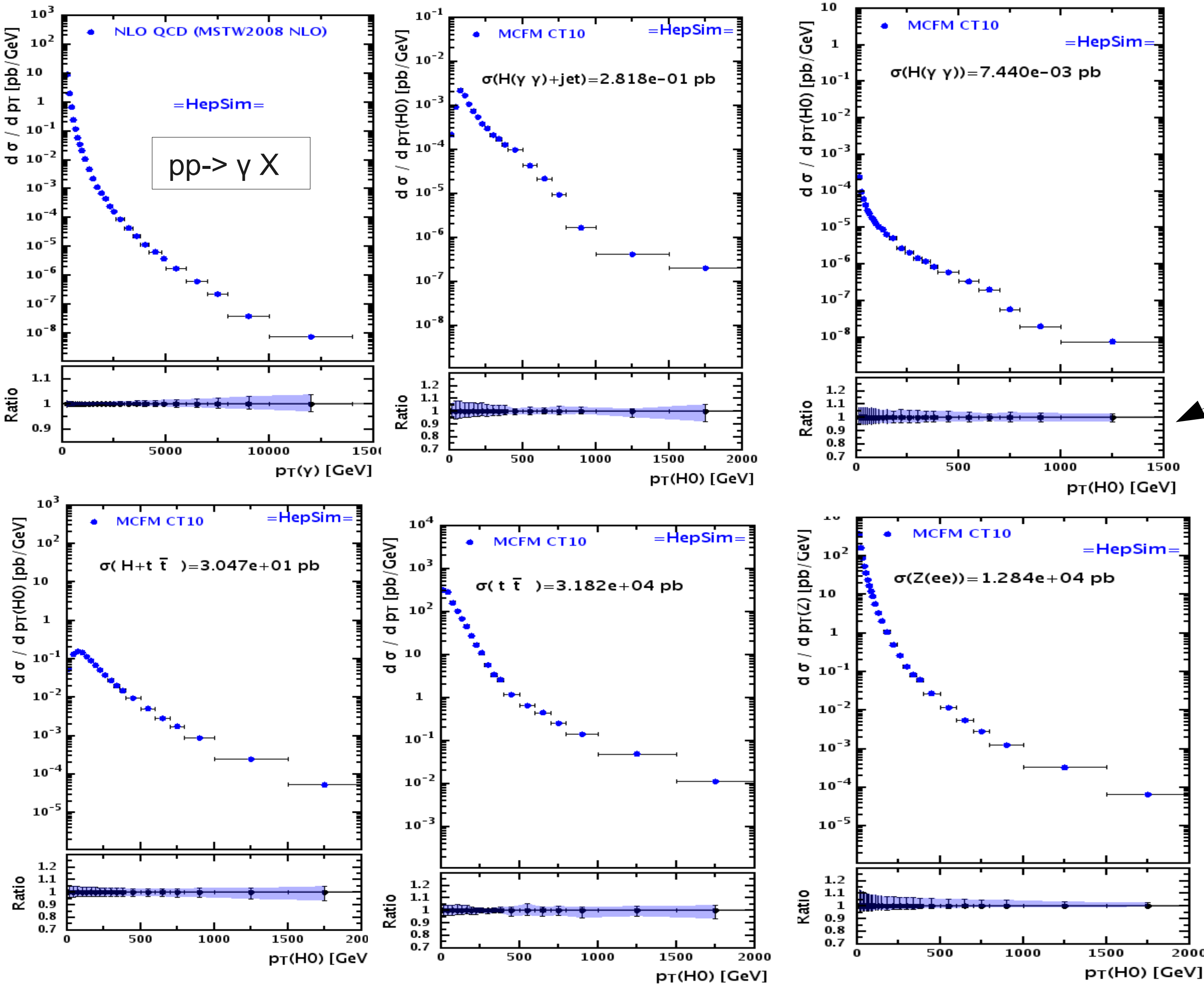
4-momenta of particles

Event weights

PDF variations for CT10 (51)



Examples of differential cross sections for 100 TeV

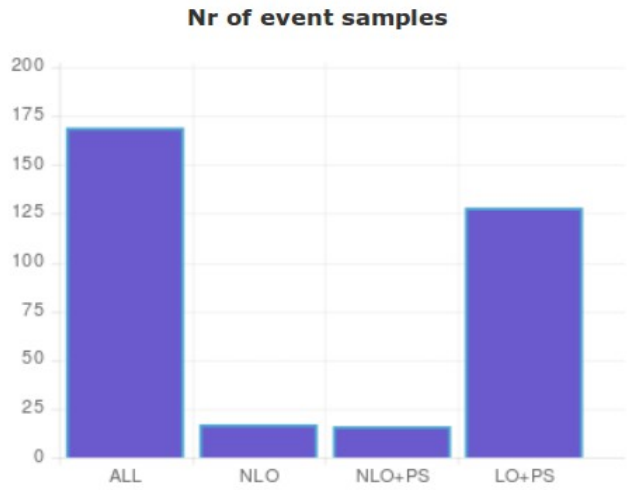


$$\frac{\sqrt{\sum_{i=1}^{N}(\sigma_i - \sigma_0)^2}}{\sigma_0}$$

PDF uncertainties are < 15% for all studied processes

HepSim statistics

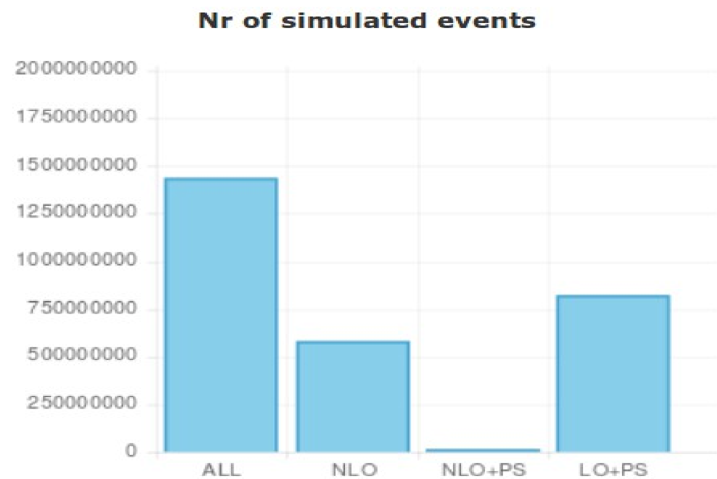
(excluding fast and Geant4 simulations)



Number of public file servers	4
Number of event samples	169
Number of NLO samples	17
Number of NLO+PS samples	16
Number of LO (+PS) samples	128
Number of events	1437939816
NLO events	583000000
NLO+PS events	15900595
LO (+PS) events	823536521
Total size (GB)	6486.634
NLO size (GB)	238.06
NLO+PS size (GB)	117.773
LO (+PS) size (GB)	6127.386
Number of files	306046

Data hosted by:

Nr	Data servers
1	mc.hep.anl.gov
2	raw.stash2.ci-connect.net
3	faxbox.usatlas.org
4	portal.nersc.gov



~ 170 data samples

(some are “compound”, i.e. consists of subsamples)

~1.4 billion events

How it works: EVGEN

Event Generators

- PYTHIA6
- PYTHIA8
- HERWIG++
- Madgraph5
- MCFM
- JetPhox
- FPMC
- NLOjet++
- LEPTO/Ariadne

Files created on
HEP servers, Mira,
OSG-grid (CI connect)
U Chicago / ANL comp. Institute
Or users

osg connect

CONNECT

EVGEN files stored on several public web servers (Apache)

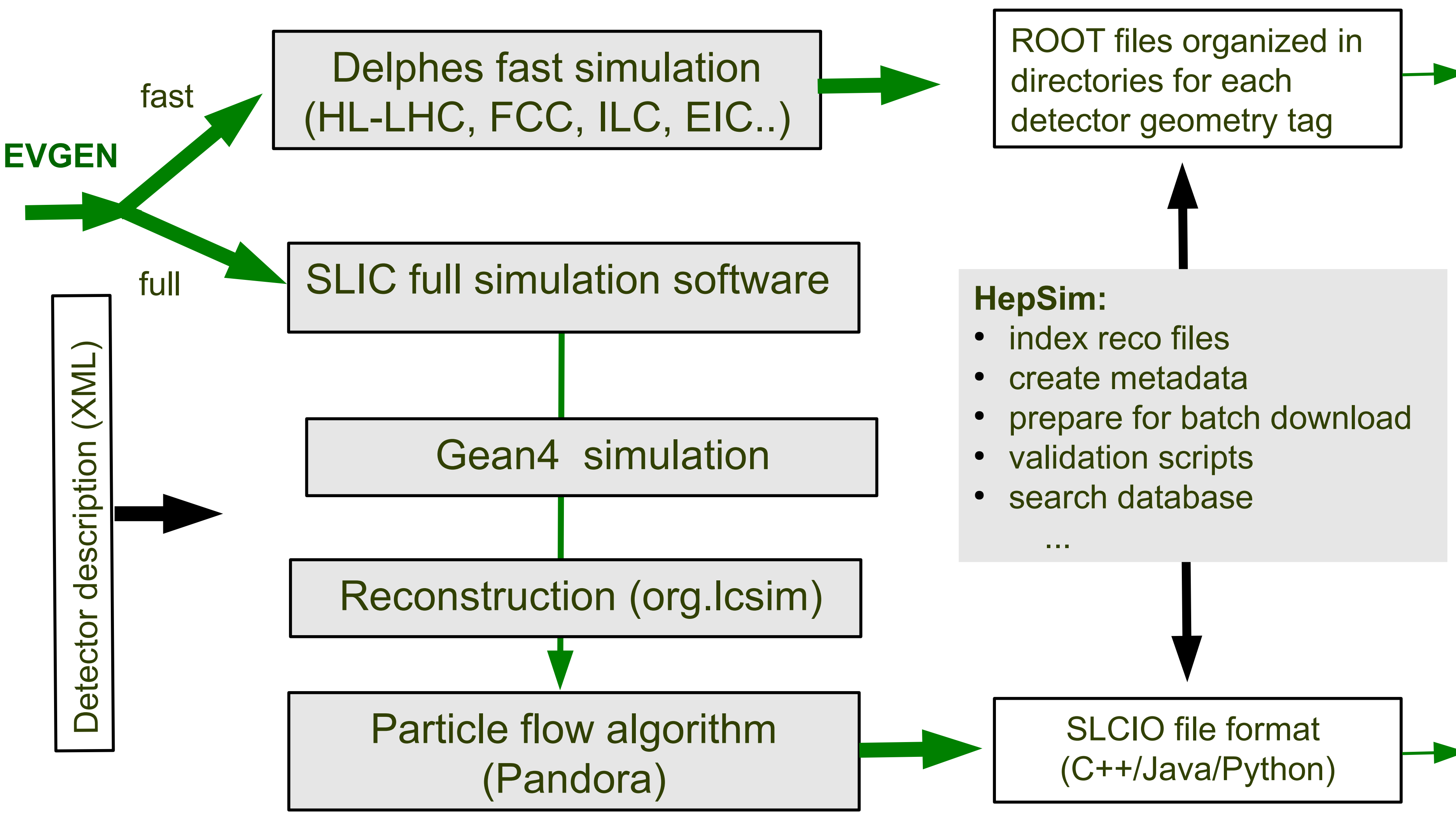
- **Unified ProMC format**
- varint encoding
- C++, Java, Python
- Web streaming
- Can be installed on BG/Q

Data hosted by:

Nr	Data servers
1	mc.hep.anl.gov
2	raw.stash2.ci-connect.net
3	faxbox.usatlas.org
4	portal.nersc.gov

HepSim:
- index files
- create metadata
- prepare for batch download
- validate with Jython scripts
- create search database

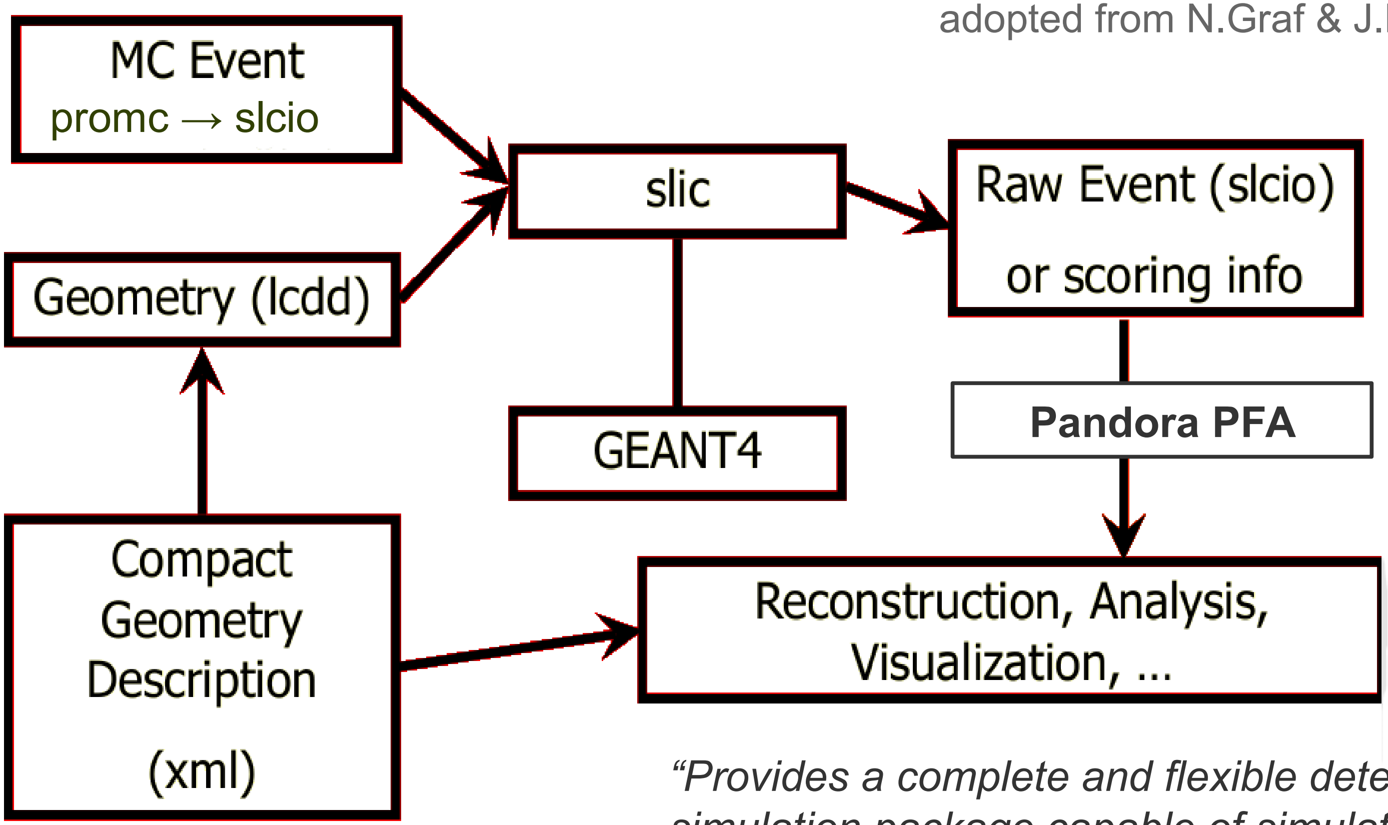
Simulation of detector response



Full G4 simulation & analysis

Developed at SLAC (T.Johnson, N.Graf, J.McCormick) for the SiD detector (ILC)
Included to ilcsoft (J.Srube, PNNL)
Includes analysis tools (Jas3, Wired4)

adopted from N.Graf & J.McCormick



"Provides a complete and flexible detector simulation package capable of simulating arbitrarily complex detectors with runtime detector description"..

Software for future circular colliders

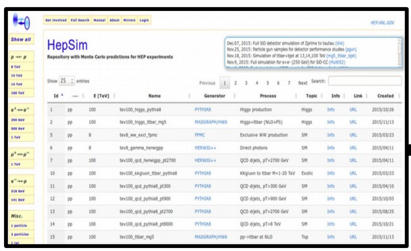
Created for future collider studies (S.C., A.Kotwal, J.Strube):

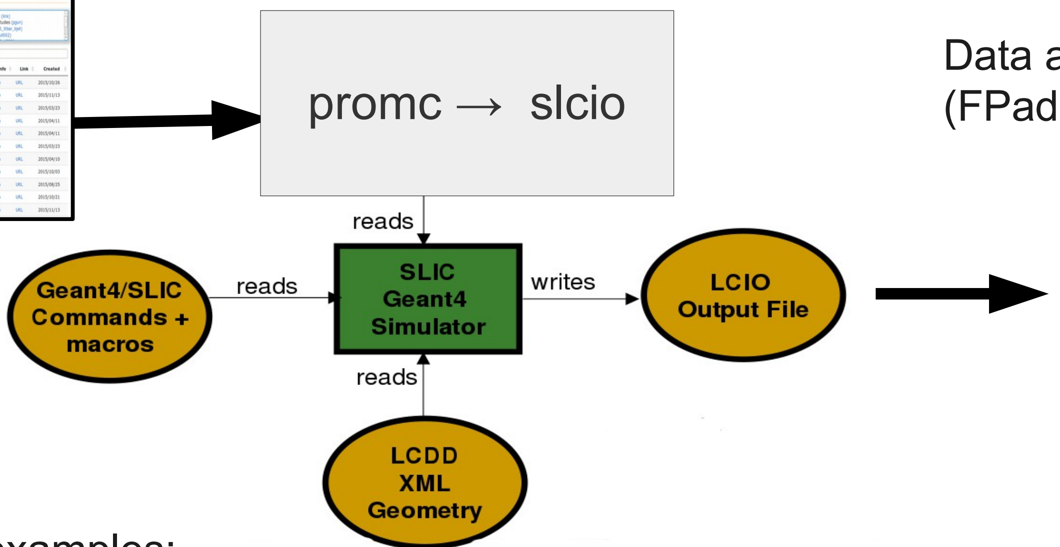
- Integrated with HepSim. Output files are publicly accessible
- Supported by HEP ANL and deployed on open-science grid (OSG)

User analysis package: FPaDsoft - software for "Future Particle Detector" studies

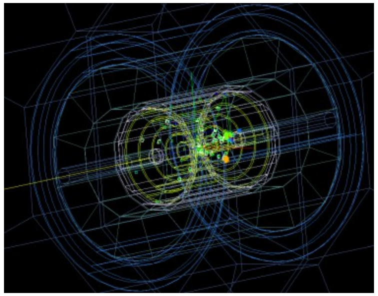
- Uses Python on the Java platform (C++ can be used too)

HepSim repository at ANL





Data analysis software (FPadSoft)

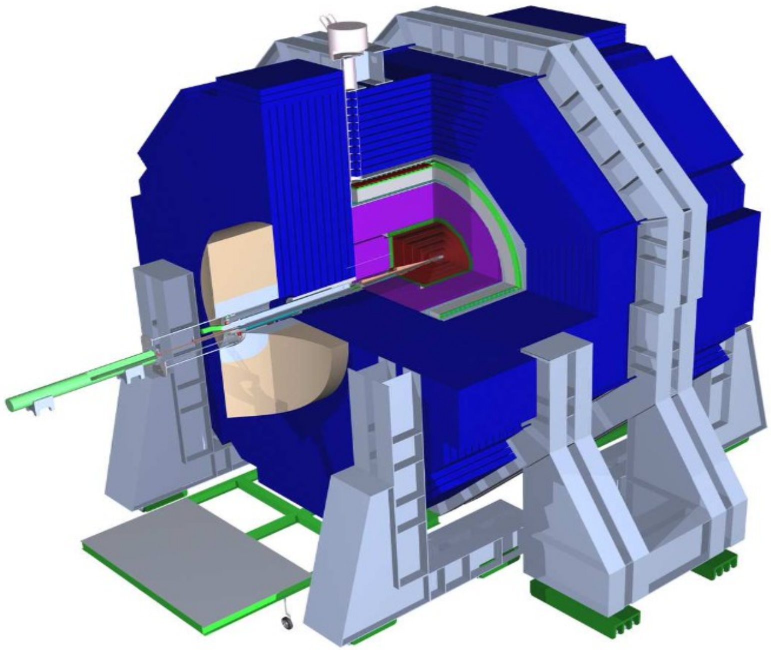


URL with manual/examples:

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

SiD detector for ILC

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



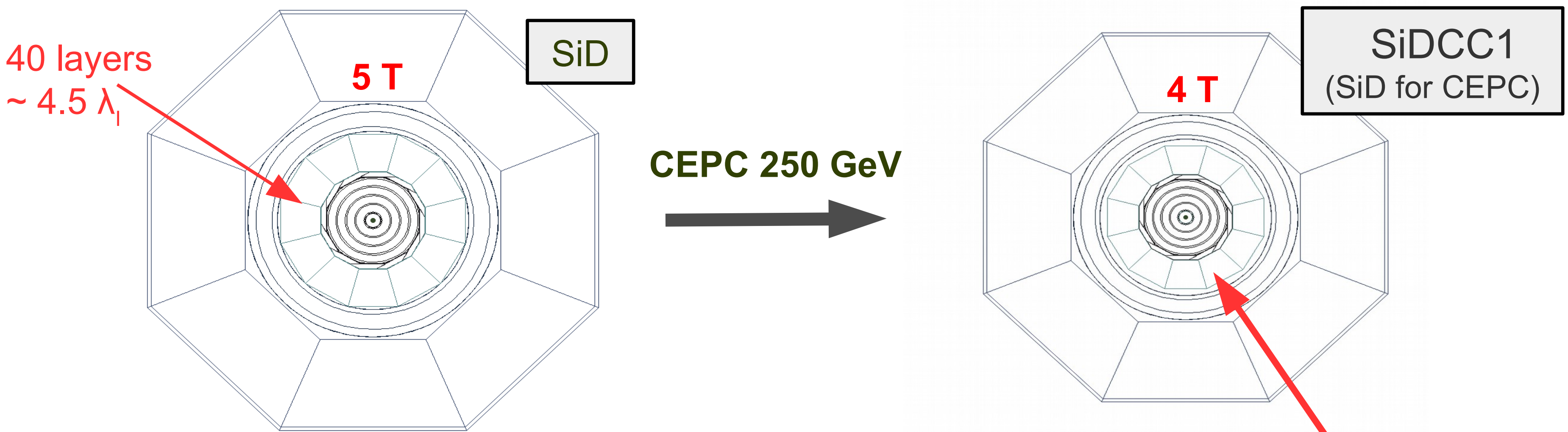
Possible choice for the second detector at **CEPC?**

Designing a detector for CEPC (e+e- 250 GeV)

SiD detector was designed for ~500 GeV jets
But CEPC will measure particles/jets up to 125 GeV. Possible changes:

jets/particles up to 125 GeV

- **HCAL:** barrel: 4.5 λ_I (40 layers) → **4.0 λ_I (35 layers)**
  endcap: 5 λ_I (45 layers) → **4.0 λ_I (35 layers)**
- **Tracking:** 5 Tesla → **4 Tesla**



Build a light, cost-optimized version of the SiD detector for CEPC and use several physics channels to benchmark its performance
(S.Chekanov (ANL), M.Demarteau (ANL))

35 layers ~ 4.0 λ_I

HepSim MC samples after full SLIC simulations

- **SiDCC** http://atlaswww.hep.anl.gov/hepsim/list.php?find=gev250%rfull002
- **SiD:** http://atlaswww.hep.anl.gov/hepsim/list.php?find=gev250%rfull001
- Event samples for SiDCC1 (rfull002) and the standard SiD (rfull001):
- Use particle flow algorithm (PFA) for reconstruction using Pythia6:
  - **$Z \to$ e+e-**
  - **$Z \to$ tau tau**
  - **$Z \to$ mu+mu-**
  - **$Z \to b\bar{b}$**
  - **$H(125) \to b\bar{b}$**
  - **$H(125) \to \gamma\gamma$**
  - **$H(125) \to ZZ^* \to 4l$**
  - **$H(125) \to$ tau tau**

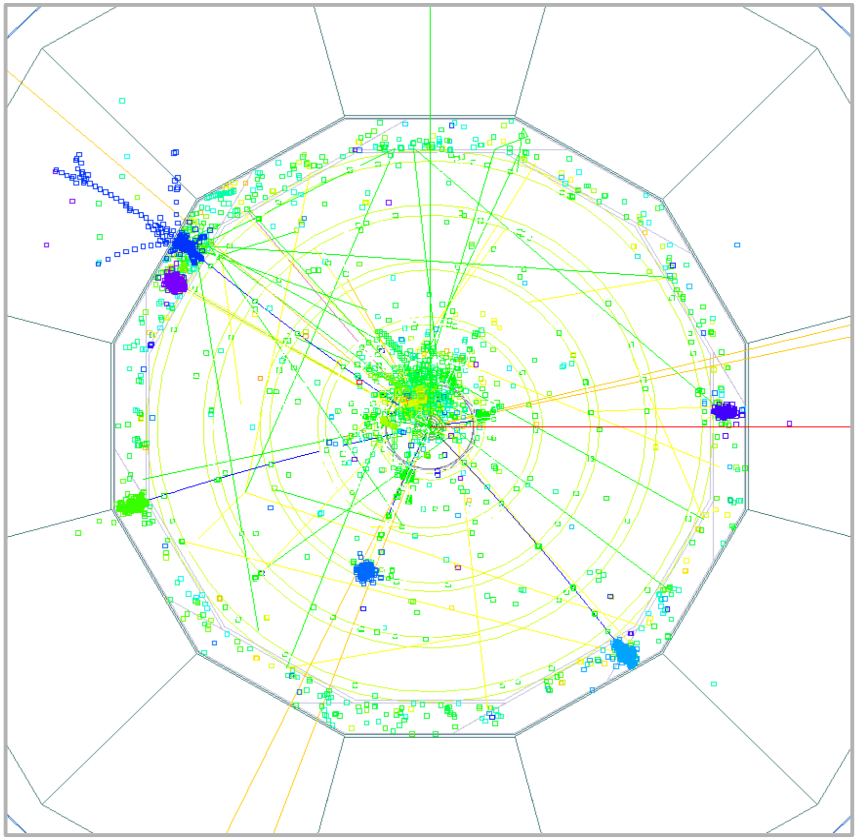
~ 10,000 reconstructed events for each physics channel after PFA (Pandora) reconstruction

URL with manual/examples:

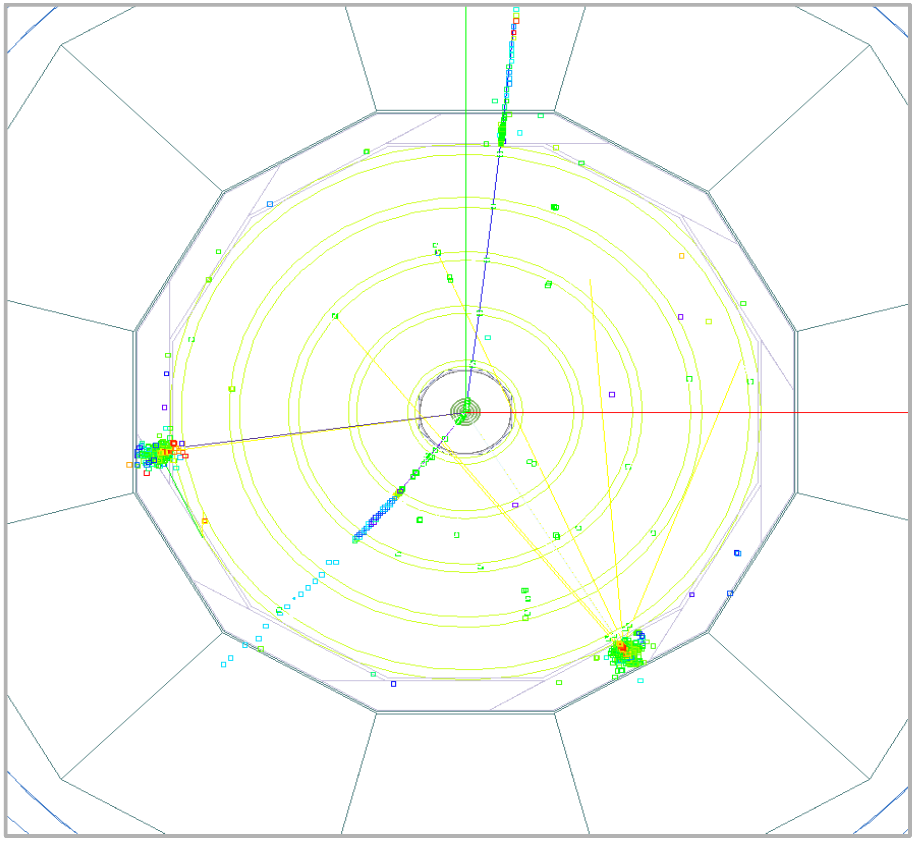
https://atlaswww.hep.anl.gov/asc/wikidoc/doku.php?id=fcs:cepc

Event display for e^+e^- (250 GeV CM energy)

SiDCC1 detector



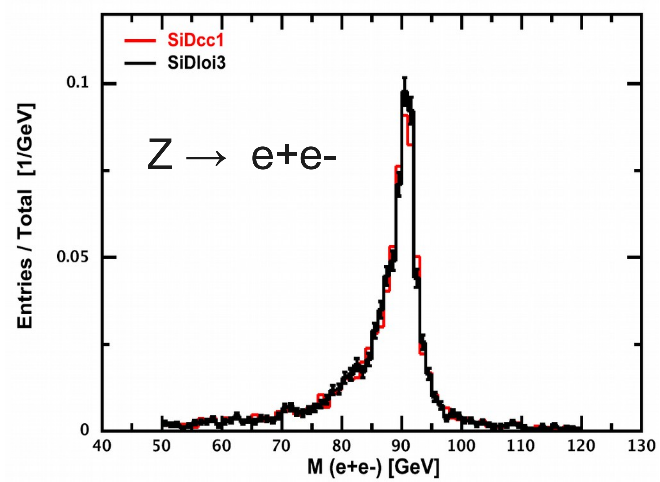
H(125) → 4 e

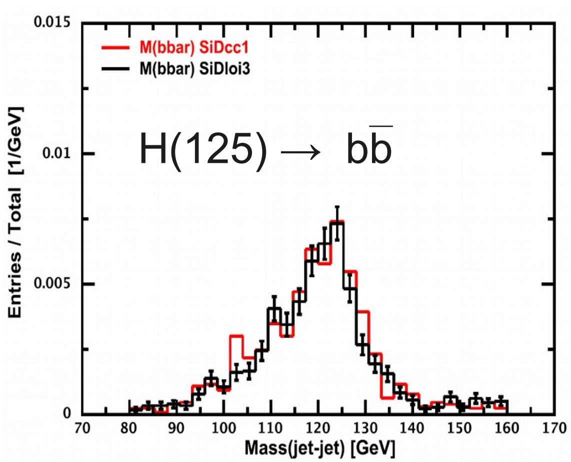


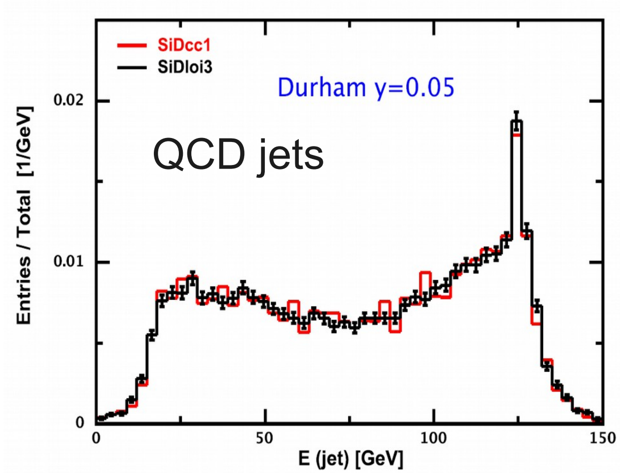
H(125) → γγ

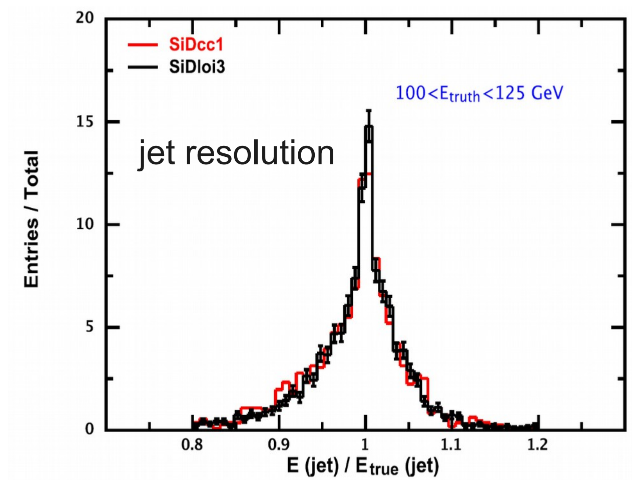
Comparing SiD with SiDCC1

- Benchmark processes for e+e- (250 GeV)
  - $Z \rightarrow$ e+e-, $Z \rightarrow b\bar{b}$, $Z \rightarrow$ tau+tau-, $H \rightarrow \gamma\gamma$
  - $H \rightarrow$ 4l, $H \rightarrow b\bar{b}$, QCD jets
- Use particle flow objects to reconstruct invariant masses and jet energy resolutions using the Durham jet algorithm









Simplification of the SiD detector does not compromise physics performance

Expanding the SiD detector to ~ FCC-hh energies

Requirements for the FCC-hh hadronic calorimeter

- **Good containment for 30 TeV jets**
  - affects jet energy resolution & leakage biases
- **Good longitudinal segmentation**
  - affects jet energy resolution
- **Good transverse segmentation**
  - for resolving boosted particles

Optimize performance and sensitivity to new physics using appropriate technologies

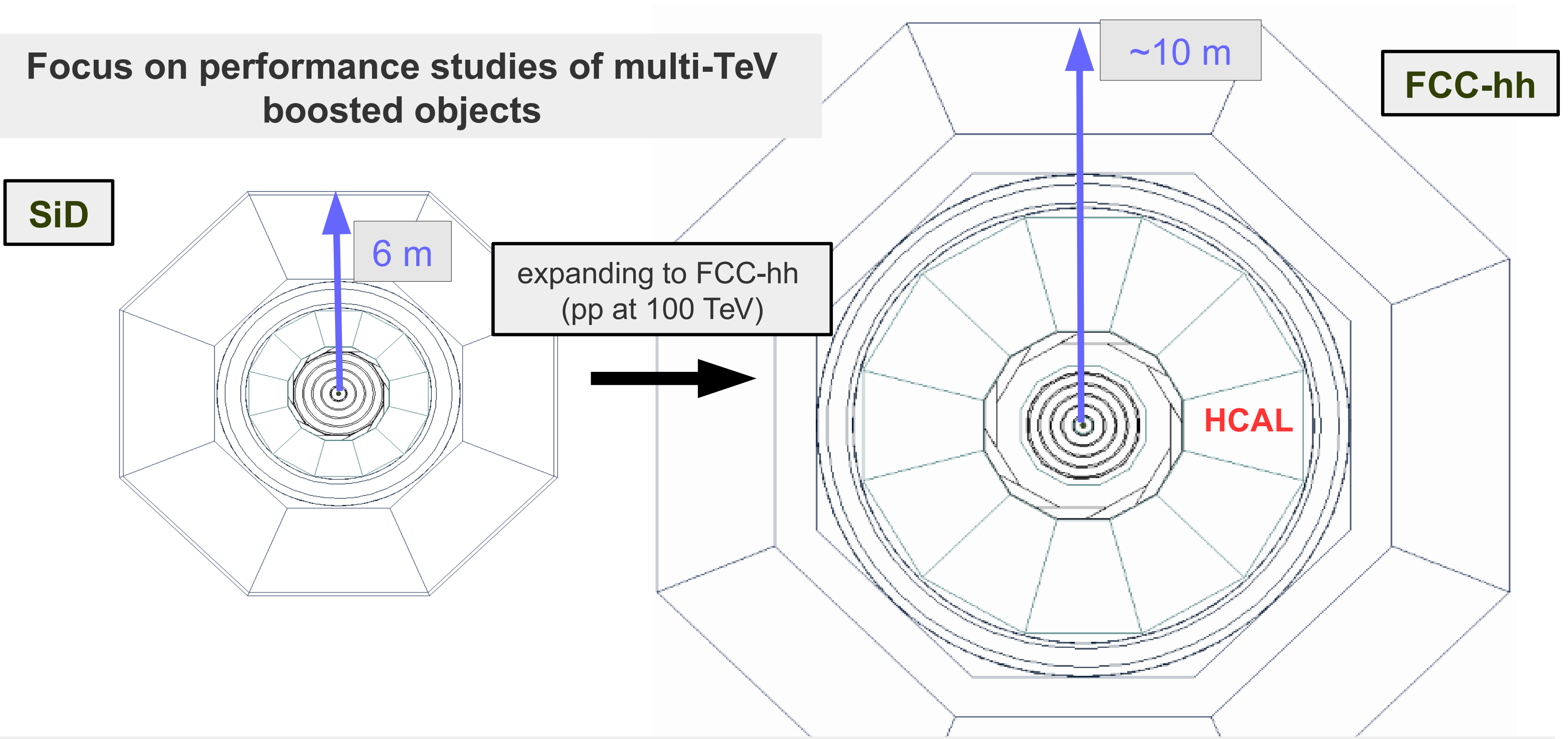
Require elaborate full simulations

Scaling up the SiD detector for tens-TeV energy (~ FCC-hh)

Build a FCC-like detector for studies of CAL transverse and longitudinal granularity, depth, material, magnetic fields, pixel sizes etc.

Use the SLIC setup for ~ tens TeV-scale particles/jets

Focus on performance studies of multi-TeV boosted objects



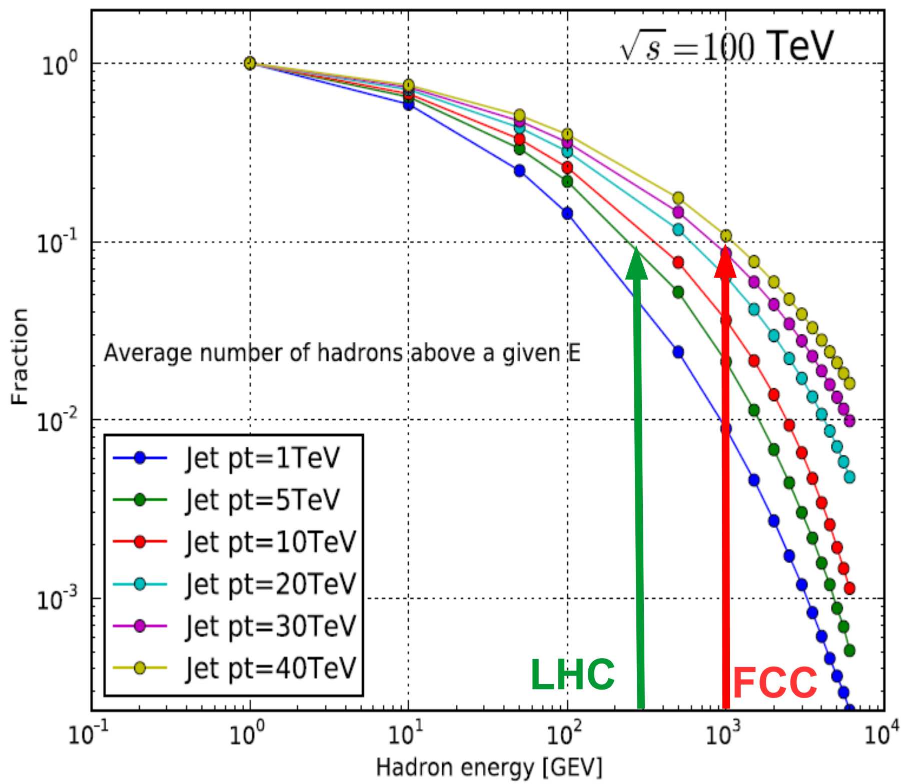
Designing a Geant4 simulation for high-granular calorimeter for ~20 TeV jets (particles)

A.Kotwal (Fermilab/Duke), L.Gray (Fermilab), S.Chekanov (ANL), J.Strube (PNNL), N.Tran (Fermilab), S-S. Yu (NCU), S.Sen (Duke)

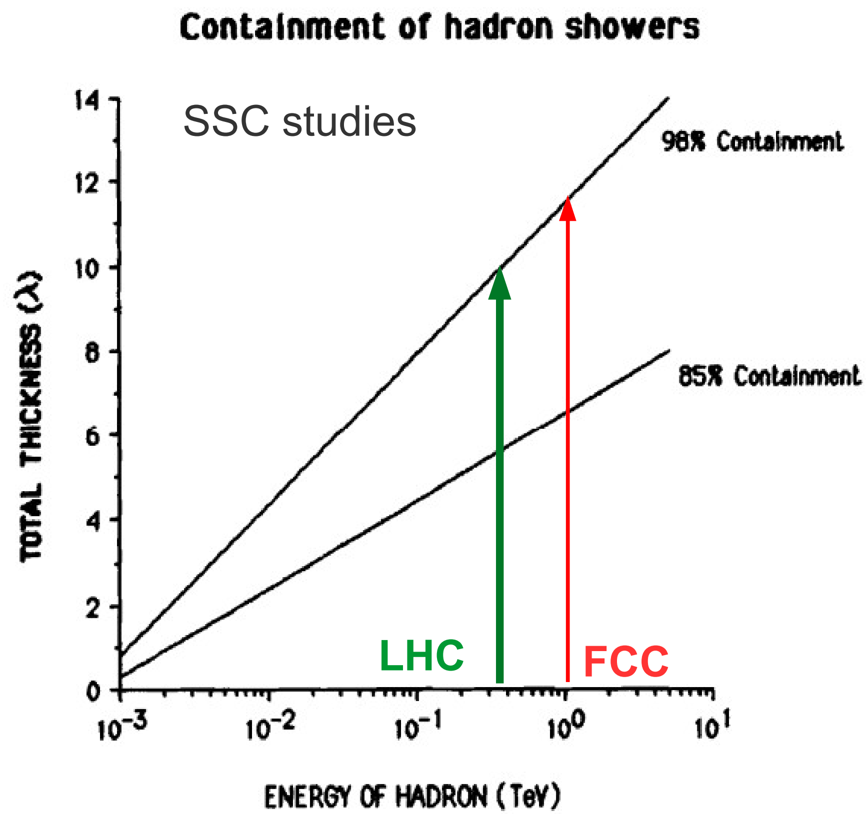
Estimating HCAL depth

Leading particles in high-pT jets

C.Helsens,C.Solans

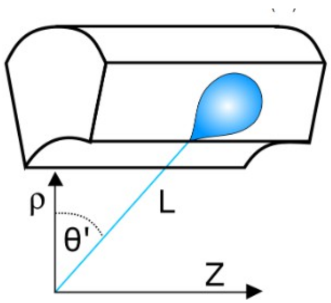


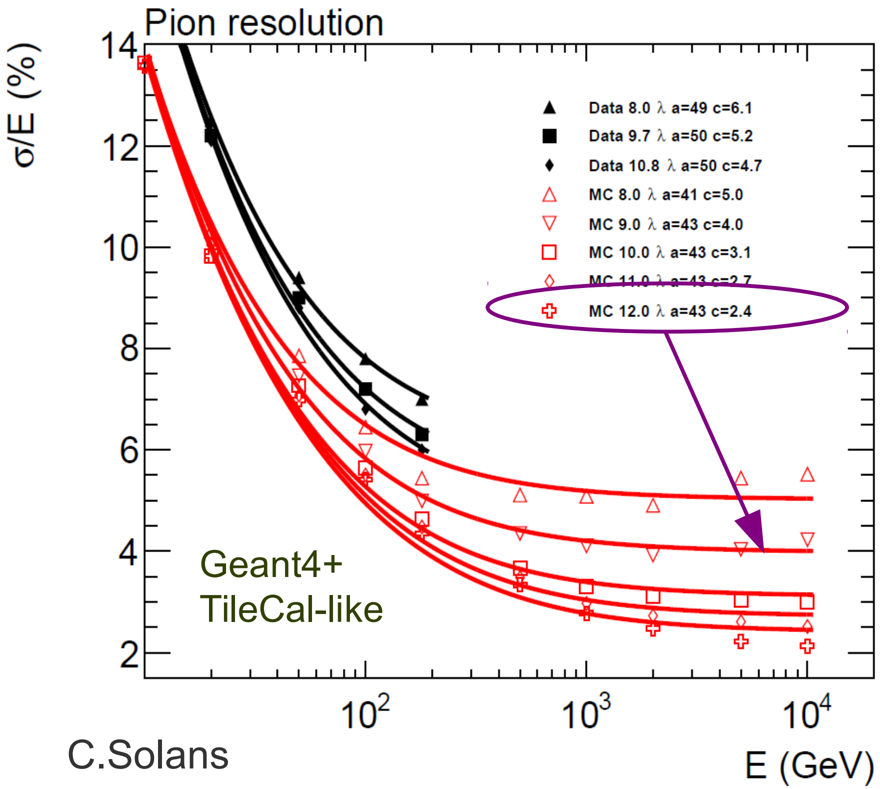
http://lss.fnal.gov/conf/C860623/p355.pdf



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

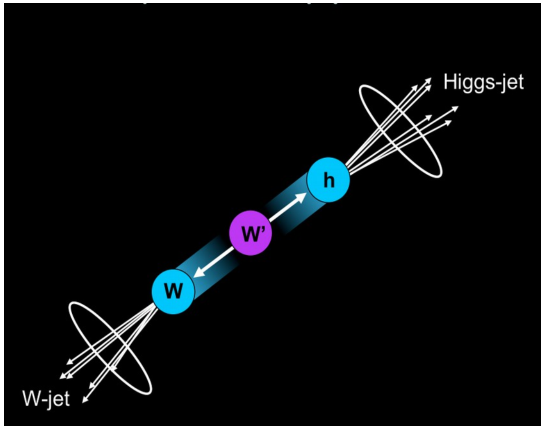
- Geant4 TileCal inspired simulation based on FTFP_BERT
- Calculate single-particle resolution
- Stochastic term is close to 45%/√E
- Constant term improves by ~20% with increase of **1λ_I**

Constant term c~2.5% is achievable for 12 λ_I

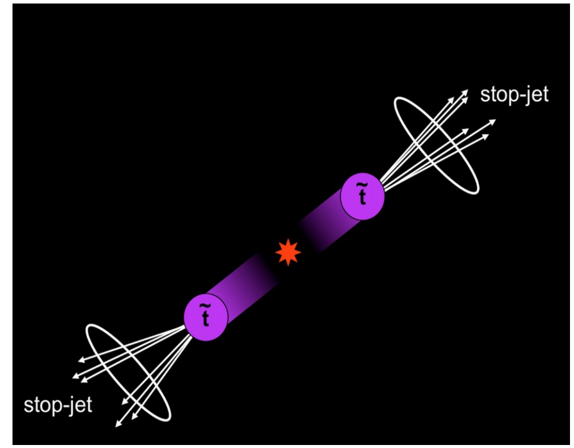
Lateral segmentation. Where does it matter..

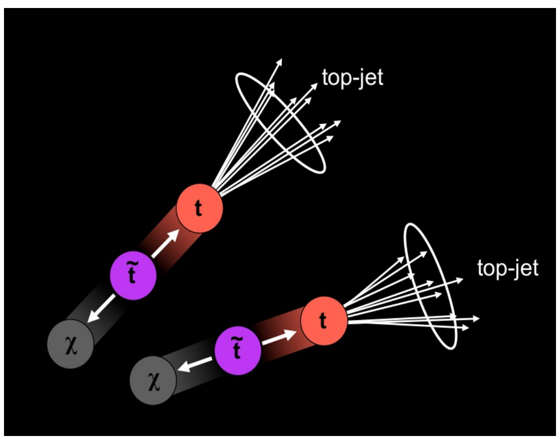
Brock Tweedie. Next steps in the Energy Frontier. LPC@FNAL. Aug. 24, 2014

$X \rightarrow W / Z / \text{Higgs} / \text{top}$

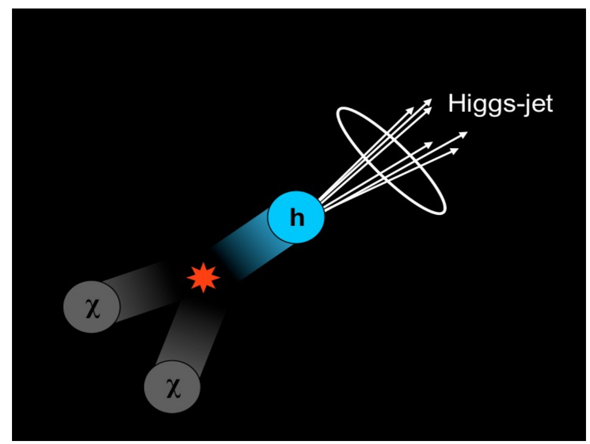


$X \rightarrow \text{quarks/gluons}$





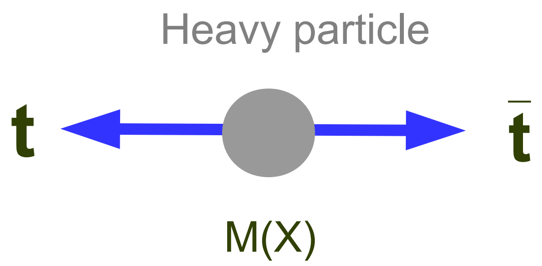
TeV-scale pair-produced



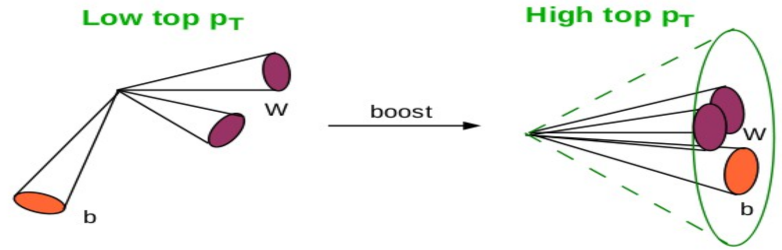
SM + dark matter

Large mass → large Lorentz boost → large collimation of decay products

Boosted top from high-mass particles

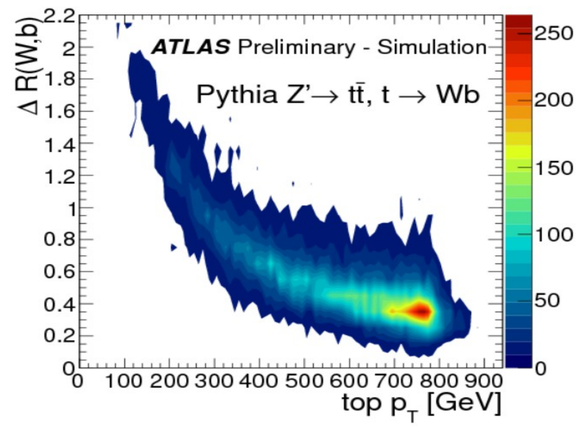


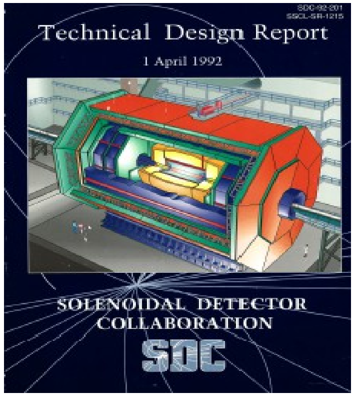
$\Delta R \sim 2$ pT / m(top)



www.quantumdiaries.org

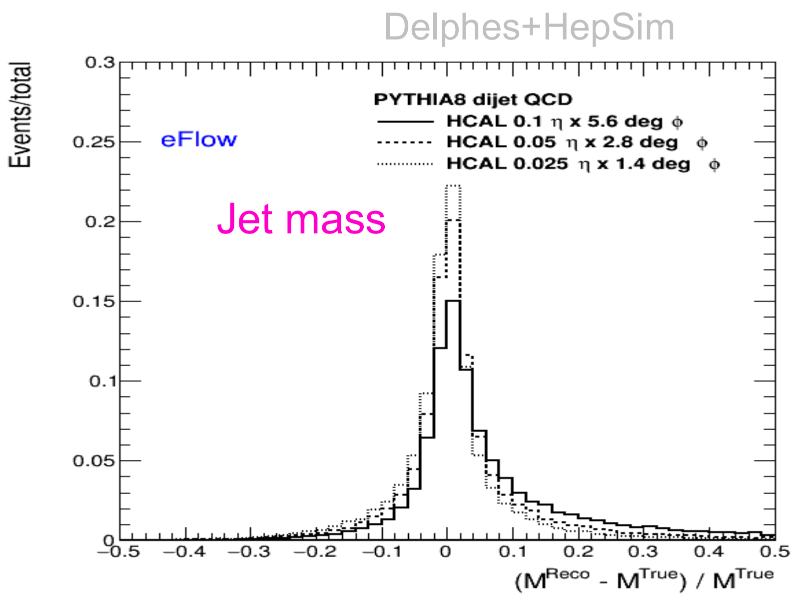
- M(X)~10 TeV → top quarks with pT(top) > 3-5 TeV
- ΔR distance between 2 particles (W,b) from top decay
- SM physics & 10 ab^{-1} for FCC-hh:
  - 5M top events with pT(top)>3 TeV
- SSC TDR discussed substructure signatures and large R-jets for boosted Z (SSC-SR-1217 TDR 1992 p 3-26)
- **FCC detector will be based on boosted signatures for top, Z/W, Higgs + modern techniques**

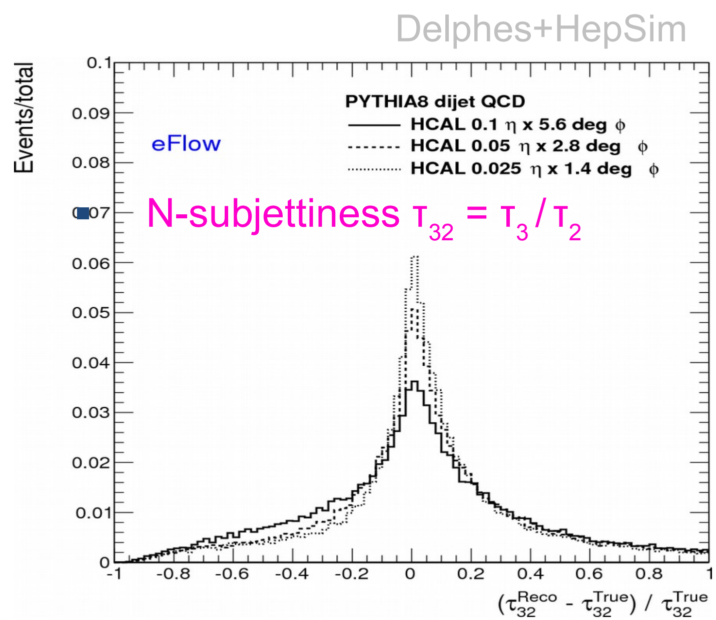




Resolutions for substructure variables for pT(jet)>10 TeV (fast simulation)

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



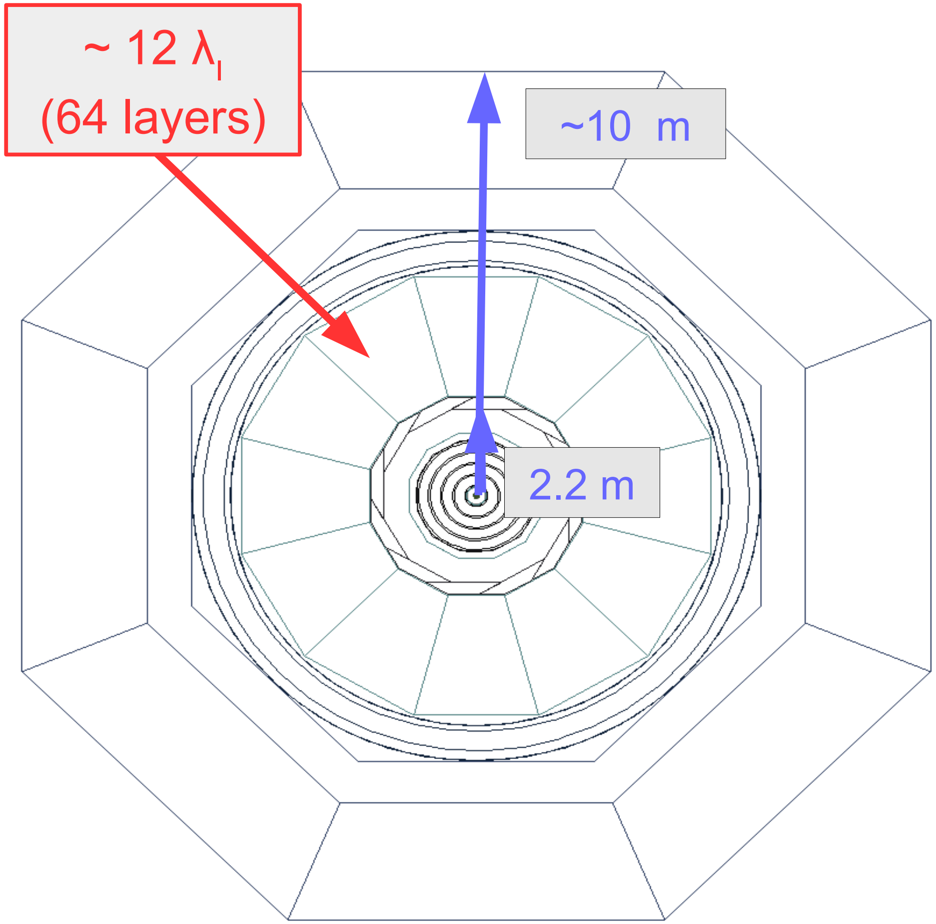


Decrease in RMS values compared to $\Delta\eta \times \Delta\varphi = 0.1 \times 0.1$

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

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

FCC-like calorimeter for performance studies



- Keep the same tracker & muon detector as for SiD
- 5 T solenoid
- Increase cell sizes for ECAL:
  - 40 layers
- Increase size of HCAL:
  - 64 longitudinal layers (original 40)
  - 2.8 cm steal layer (1.8 cm original)
  - RPC (no change) → "**digital**"
  - **12 λ_I** for pT(jet)>20 TeV
- Also try W instead of steal
- Keep the same pixel size: **1 x 1 cm**

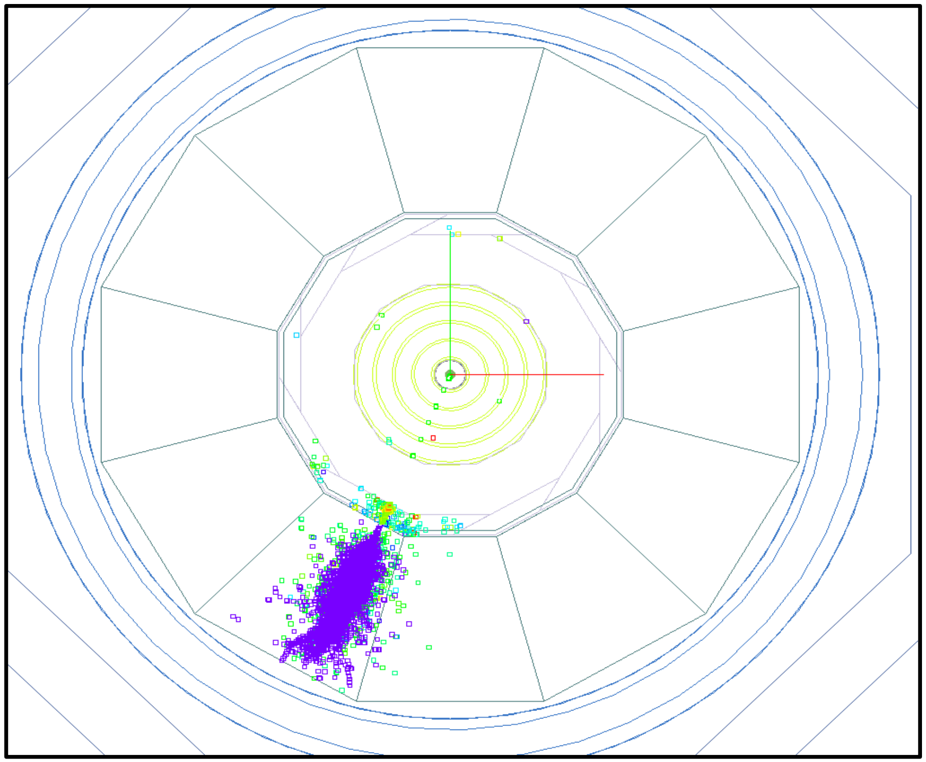
Calorimeter has about 80 million HCAL cells and a similar number for ECAL

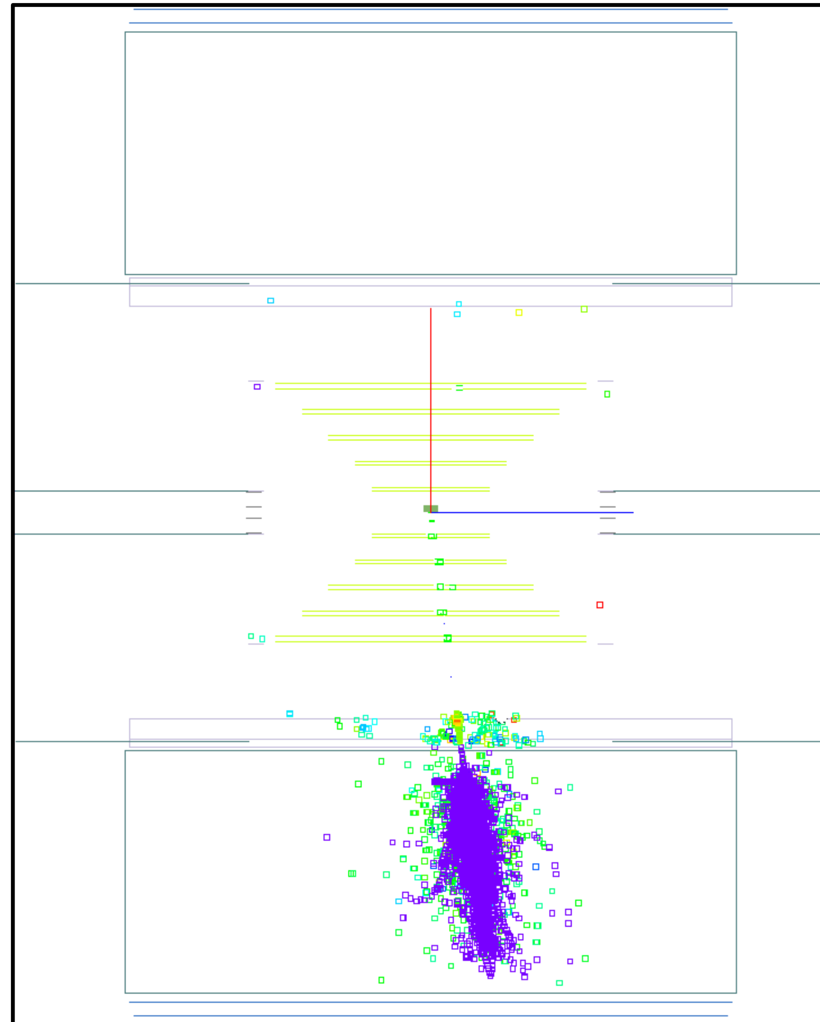
"Imaging" (digital) HCAL calorimeter. Can be analog too

Event display for 1 TeV π+

Remember: ~10% of energy will be carried by 1 TeV hadrons in a jet with pT>30 TeV

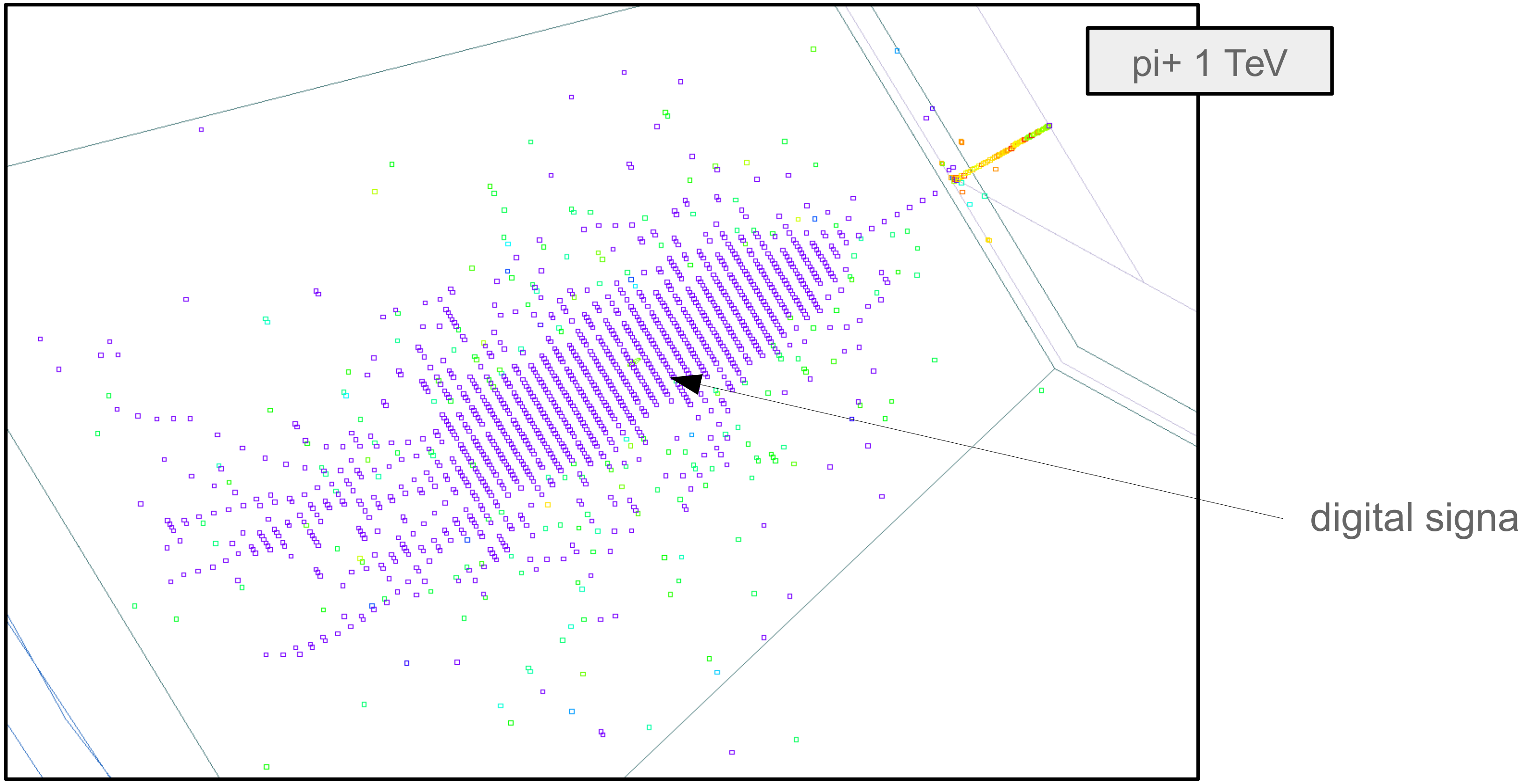
Use 1 TeV single particles for benchmarks





Reconstructed PFA with E=1007 GeV (charge +)

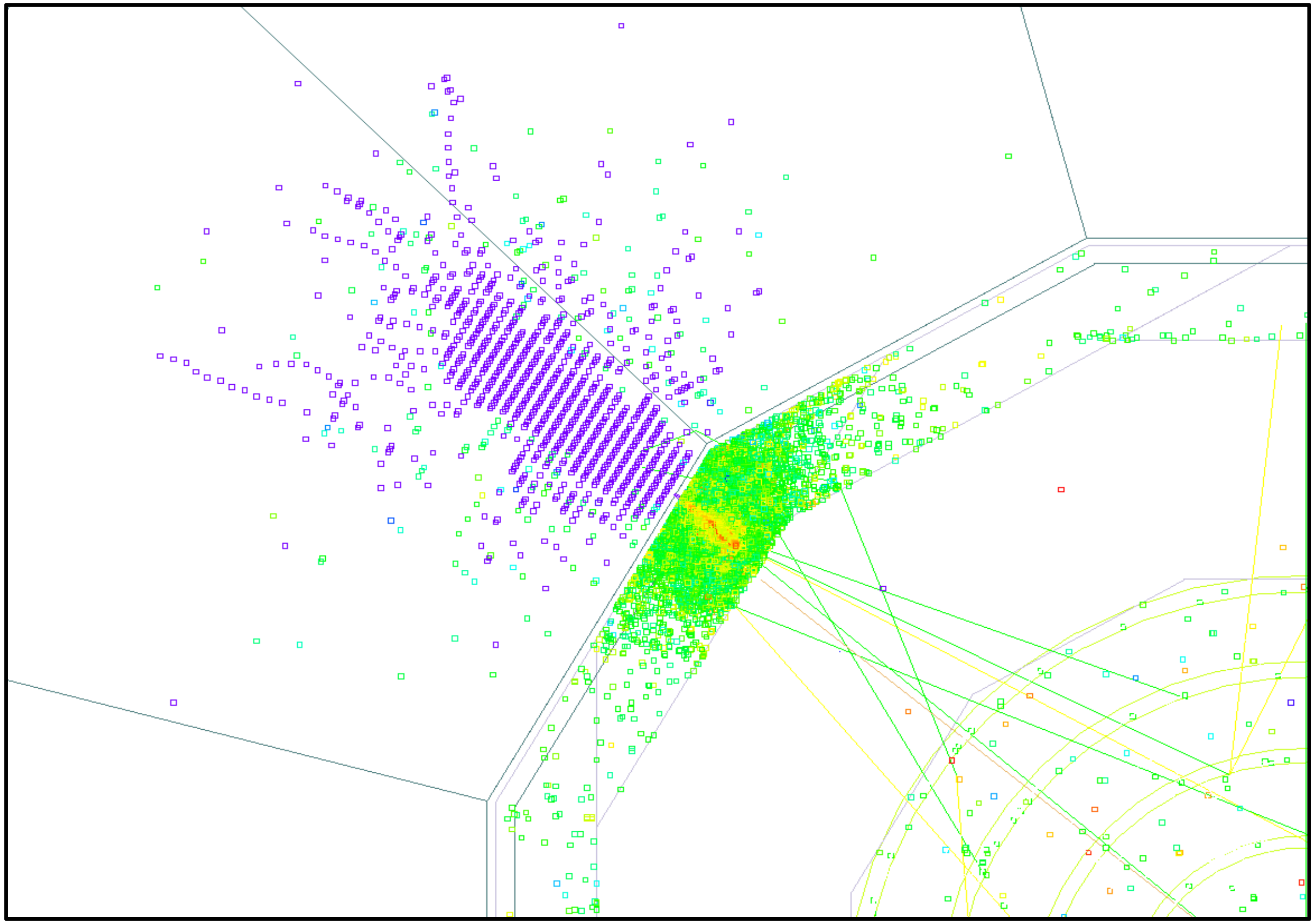
Event display for 1 TeV pion in HCAL



“imaging SiD” calorimeter with 1-bit (single threshold) and 1x1 cm cells designed for low rate environment of a future e+e-. 60 layers. ~80 M cells for HCAL and ECAL

Several options to study: decrease cell sizes, add multiple thresholds (analog) readout etc.

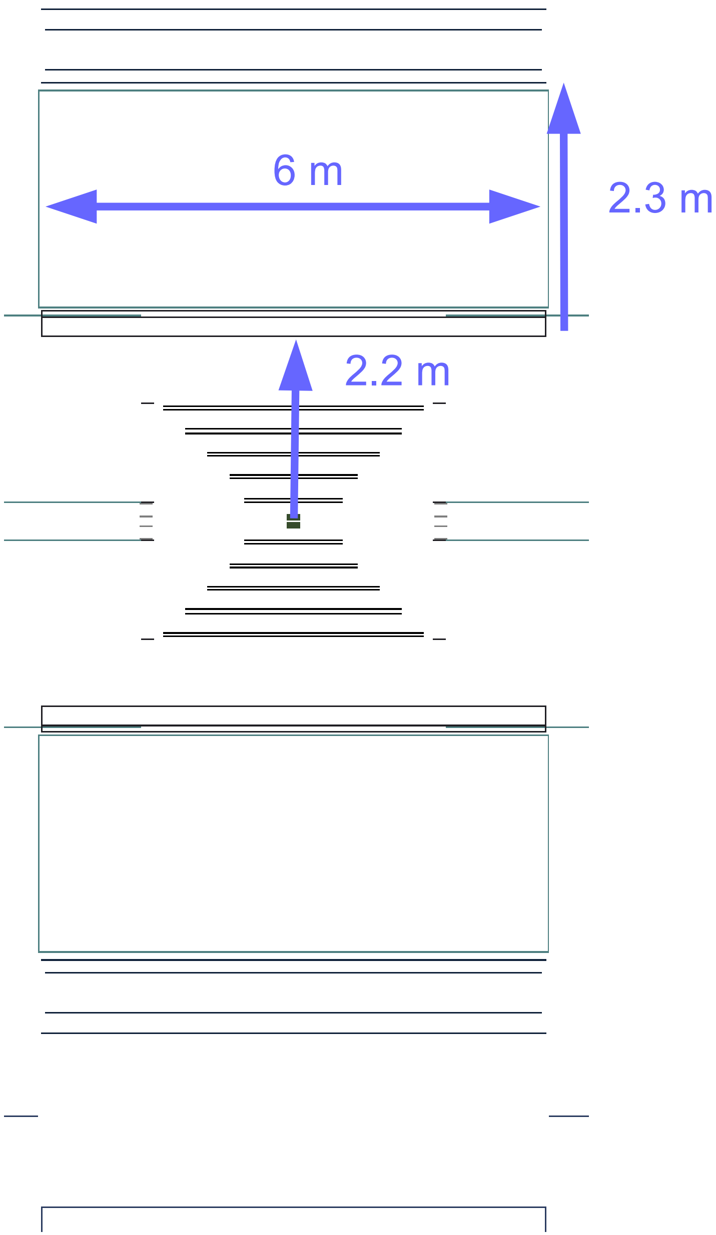
Event display for 1 TeV neutron



PFA energy: 951 GeV (from calorimeters)

Need simplifications for realistic pp events!

- pp collision events at 100 TeV are busy
- Running full calorimeter is CPU demanding
  - Number of cells > 150 million (ECAL+HCAL)
- Use Barel ECAL/HCAL region **|eta|<0.7**
- Processes for benchmarks:
  - μ+μ- → Z' (10 TeV) → W+W-
  - μ+μ- → Z' (10 TeV) → qq
  - μ+μ- → Z' (10 TeV) → tau+tau-
- Set ΔΓ(Z') to a small value
- Or single particle guns up to 20 TeV
- Full simulation files are available from HepSim

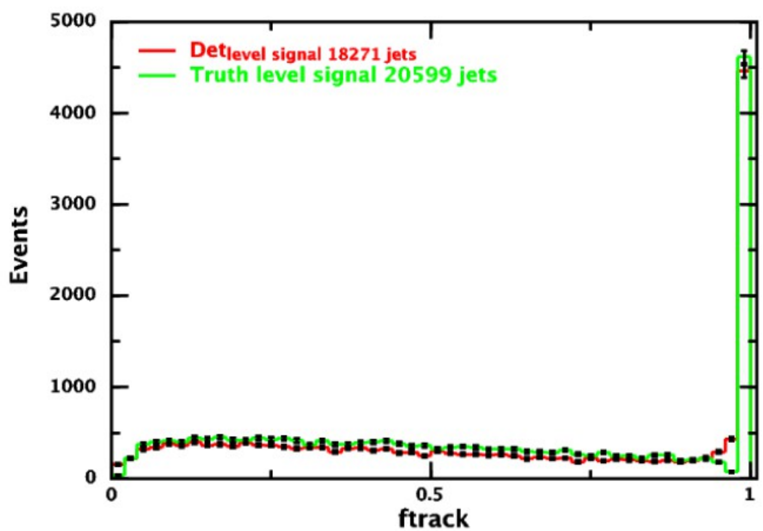


Looking at tau's after the full detector simulation

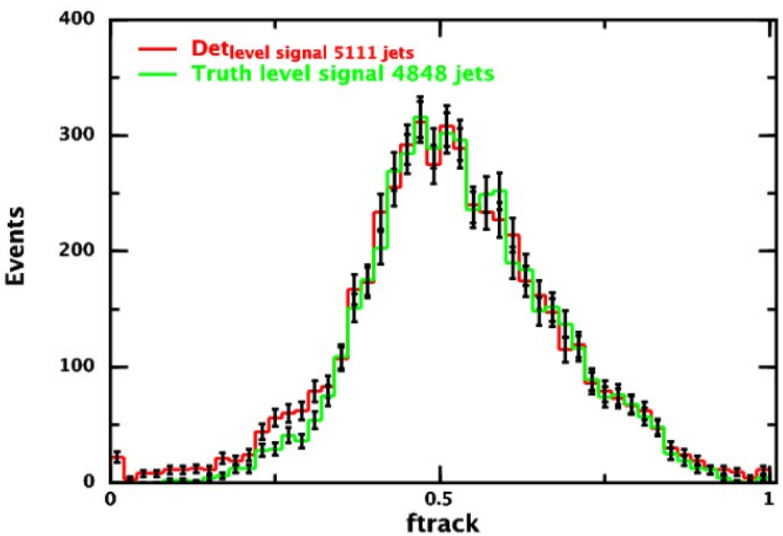
A.Kotwal, S.Sen

Z' (1 TeV) → tau+tau (http://atlaswww.hep.anl.gov/hepsim/index.php?c=mupmum&e=1000&t=all)

Calculate shape variables for 1 and 3-prong decays (ATLAS, arXiv:1412.7086 (2014)).
Checking performance of Si tracking (50 um pixels) and high-granular ECAL



1 prong



3 prong

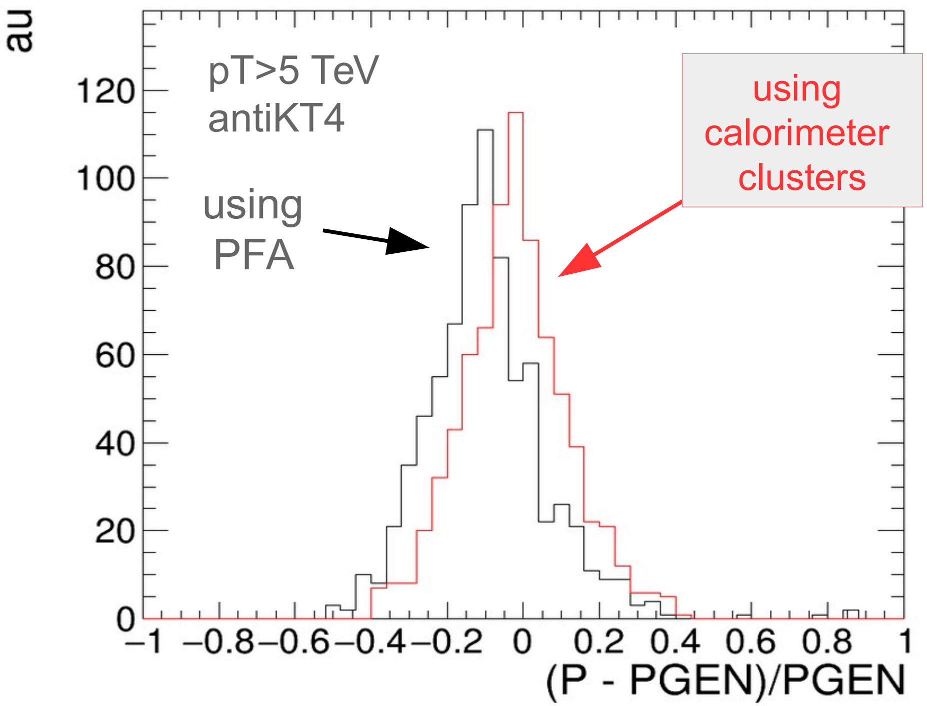
ftrack (leading track momentum fraction) =
(pT of highest pT track in core region ($\Delta R < 0.1$)) / (Total ET deposited in $\Delta R < 0.1$)

Good agreement between EVGEN (truth level) and reconstructed objects

Looking at physics events after the full detector simulation

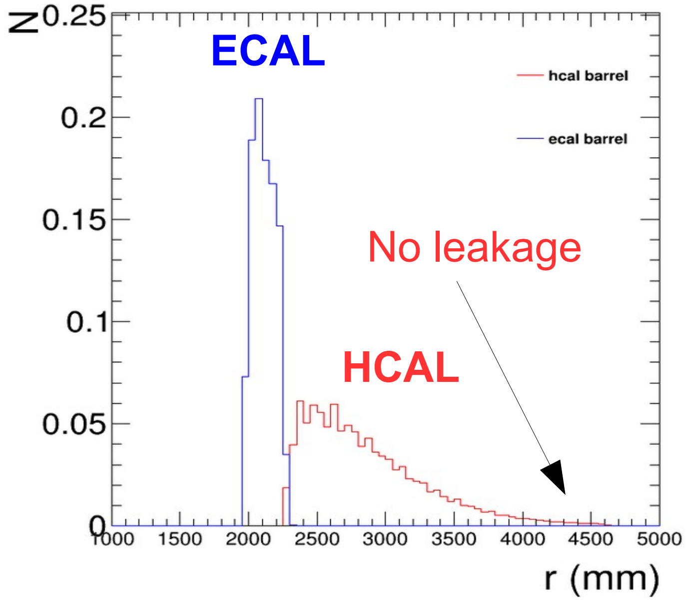
N.Tran, A.Kotwal

Z ' (10 TeV) → W+W- (using width < 1 GeV)
HepSim download: tev10mumu_pythia6_zprime10tev_ww%rfull003



Jet momentum response:
(P(rec) – P(gen)) / P (reco)

Distribution of calorimeter hits



Shift for PFA jets is due to tracking or imaging HCAL? (under investigation)

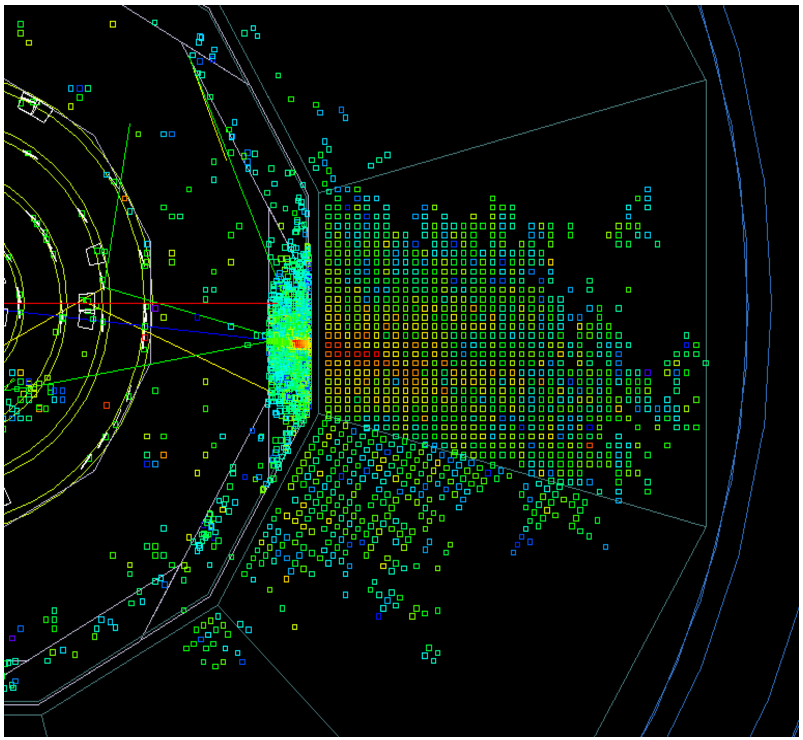
Analog calorimeter with small cell sizes

~ close to proposed for FCC-hh

- Extended SiD with traditional analog readout (scintillators)
- Cell sizes 5x5 cm are motivated by fast simulations (20x20 cm for ATLAS TileCal)
  - 40 layers (Fe ~ 5 cm layer): smaller than the interaction length λ_I **~17** cm!

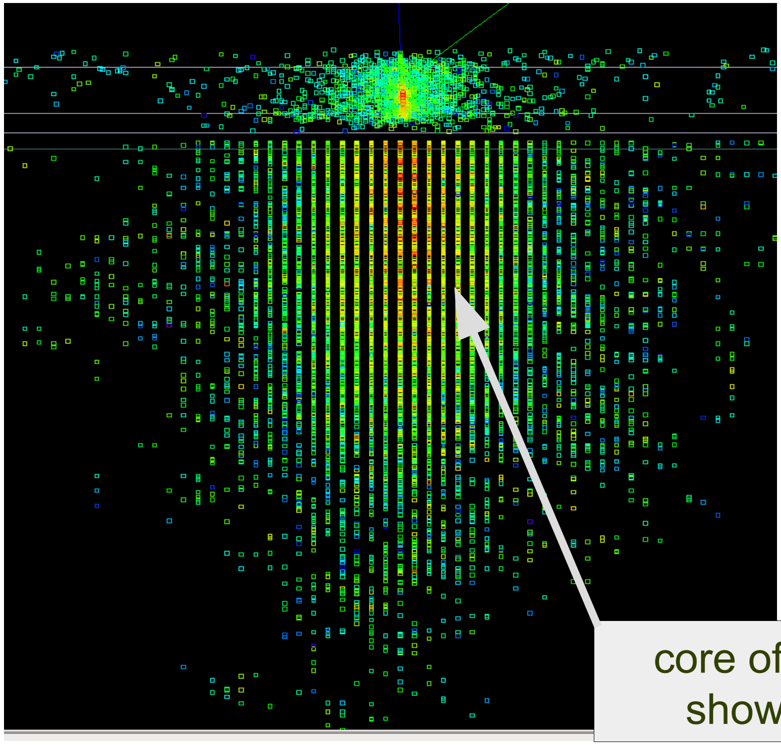
pi+ 1 TeV

X-Y view



pi+ 1 TeV

rho-Z view



core of the shower

Can we improve boosted object reconstruction using cell sizes < λ_I ?

Contributions to HepSim software

- E. May - ProMC format development, benchmarks on BlueGene/Q (ANL)
- K. Strand (SULI 2014) - ProMC conversion tools
- P. Van Gemmeren - testing ProMC format
- T. Sjöstrand - ProMC integration with Pythia8
- P. Demin - ProMC integration with Delphes
- I. Pogrebnyak - (U.Michigan) software validation toolkit, fastjet in Java
- D. Wilbern (SULI 2015) - Pileup mixing tool based on ProMC
- M. Selvaggi - Delphes card for ILD geometry and “**EIC”-like (requested by S.C.)**
- H. Gray - Delphes card for FCC-hh geometry
- J. Strube (PNNL) - LCIO/SLIC for full simulation
- A. Kotwal (Duke Univ.) - LCIO/SLIC for full simulation
- J. Adelman (NIU) – H+tt sample + post-Snowmass Delphes 3.3 card for 13/14 TeV
- S. Padhi - prototyping Snowmass Delphes 3.1 during Snowmass 2013
- K. Pedersen - alternative b-tagging for rfast003 in HepSim
- Shin-Shan Yu - Heavy Higgs MG5 simulations for HepSim

A lot of help / advise from J.McCormick and N.Graf (SLAC)

How to contribute to HepSim

- Generate EVGEN archive files with physics processes
- Validate using the HEPSIM tools (if you can)
- Contribute to the software tools
- Run a data server and maintain your own EVGEN & full simulation files

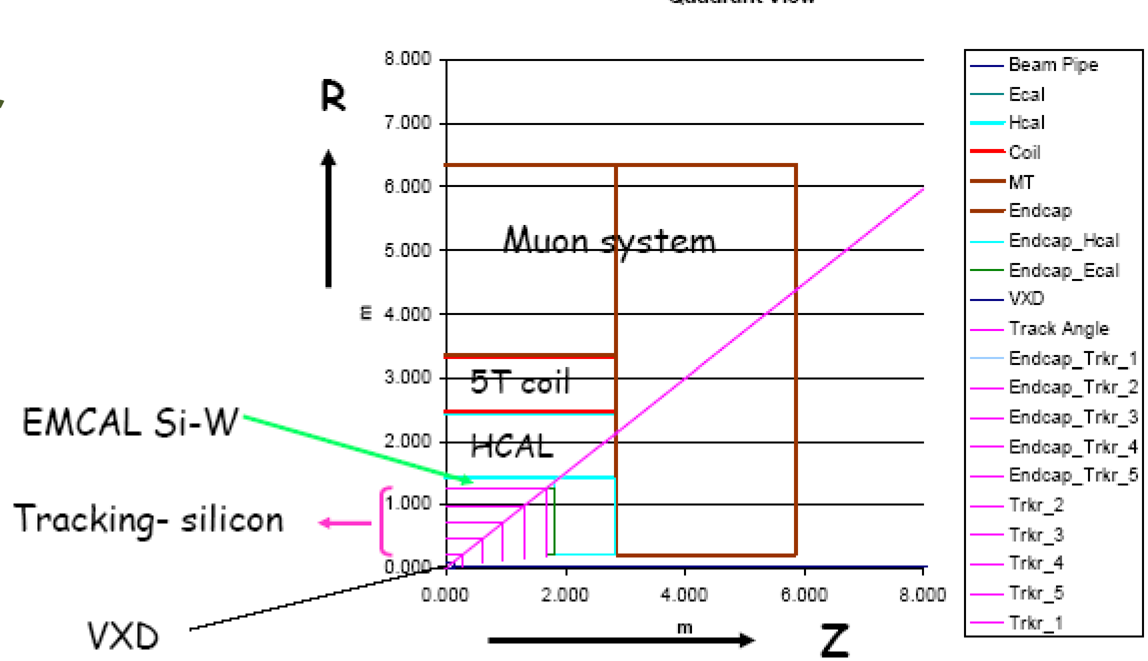
Support (limited, on a voluntary basis): (contact hepsim@anl.gov)

- HEPSIM integration, deployment, OSG-grid, EVGEN MC, fast sim etc.
  - ANL: S.C.
- Some support for SLIC software (used for ILC)
  - SLAC: N.Graf & J.McCormick
  - PNNL: J.Strube
- Configure detectors, physics, analysis package for circular colliders
  - ANL/Fermilab: S.C., A.Kotwal

Thanks!

Backup

SiD detector



NOT A SMALL DETECTOR

Barrel	**Techno**			**nt**
Vertex detector	Silicon p			25
Tracker	Silicon strips	21.7	122.1	+/- 152.2
ECAL	Silicon pixels-W	126.5	140.9	+/- 176.5
HCAL	RPC-steel	141.7	249.3	+/- 301.8
Solenoid	5 Tesla SC	259.1	339.2	+/- 298.3
Flux return	Scintillator-steel	340.2	604.2	+/- 303.3
Endcap	**Technology**	**Inner z**	**Outer z**	**Outer radius**
Vertex detector	Silicon pixels	7.3	83.4	16.6
Tracker	Silicon strips	77.0	164.3	125.5
ECAL	Silicon pixel-W	165.7	180.0	125.0
HCAL	RPC-steel	180.5	302.8	140.2
Flux return	Scintillator/steel	303.3	567.3	604.2
LumiCal	Silicon-W	155.7	170.0	20.0
BeamCal	Semiconductor-W	277.5	300.7	13.5

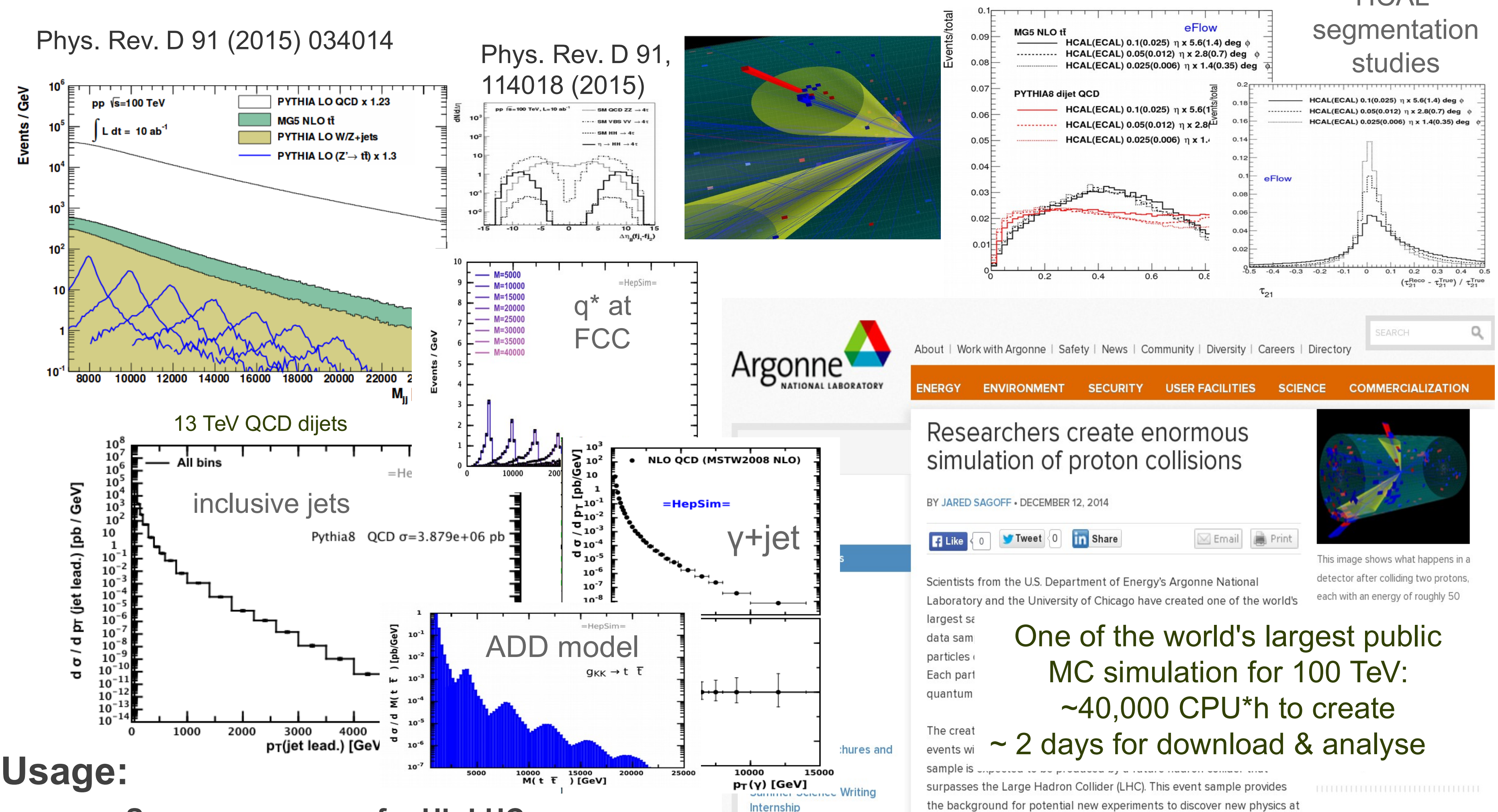
All of this can be changed using XML configuration files

Programming languages

- **EVGEN: ProMC format → C++ (or) Java. Support for Fortran**
- **Delphes fast simulation → C++/ROOT**
- **SLIC software:**
  - Geant4 simulation → C++/C
  - Reconstruction → Java
  - Pandora particle flow algorithm → C++
- **Analysis: C++/ROOT or Jython/Java (Python on the Java platform)**
  - No manpower to maintain platform specific libs → minimize the usage of C++
  - Currently, many studies are done using Python on the Java platform
    - can read PROMC and SLCIO files
    - easy to deploy, no LINUX specific libraries
    - runs on Windows/Mac

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

MC simulations for the HEP community



Usage:

- **Snowmass papers for HL-LHC**
- **ATLAS run I & II analyses:** excl. H^0, excl. WW, direct photons with MCFM NLO, JETPHOX NLO, Long-lived particles, ADD model for gravitons, H → φγ) → validated and shipped to ATLAS
- **FCC physics studies, CPEC (recently)**
- **Detector studies.** List of public talks/papers in **http://atlaswww.hep.anl.gov/hepsim/about.php**