

Simulations for the Energy Frontier

S. Chekanov
HEP/ANL

IAS meeting

Jan 27, 2016



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)



Quick Links

- ▼ [TWiki registration](#)
- ▼ **Pre-meetings**
 - [Community Planning Meeting](#)
 - [All pre-Snowmass Meetings](#)

Energy_Frontier_FastSimulation
HADRON COLLIDER DETECTORS

Contact: S. Chekanov (ANL), S. Padhi (UCSD)

Snowmass Combined LHC detector

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

- 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

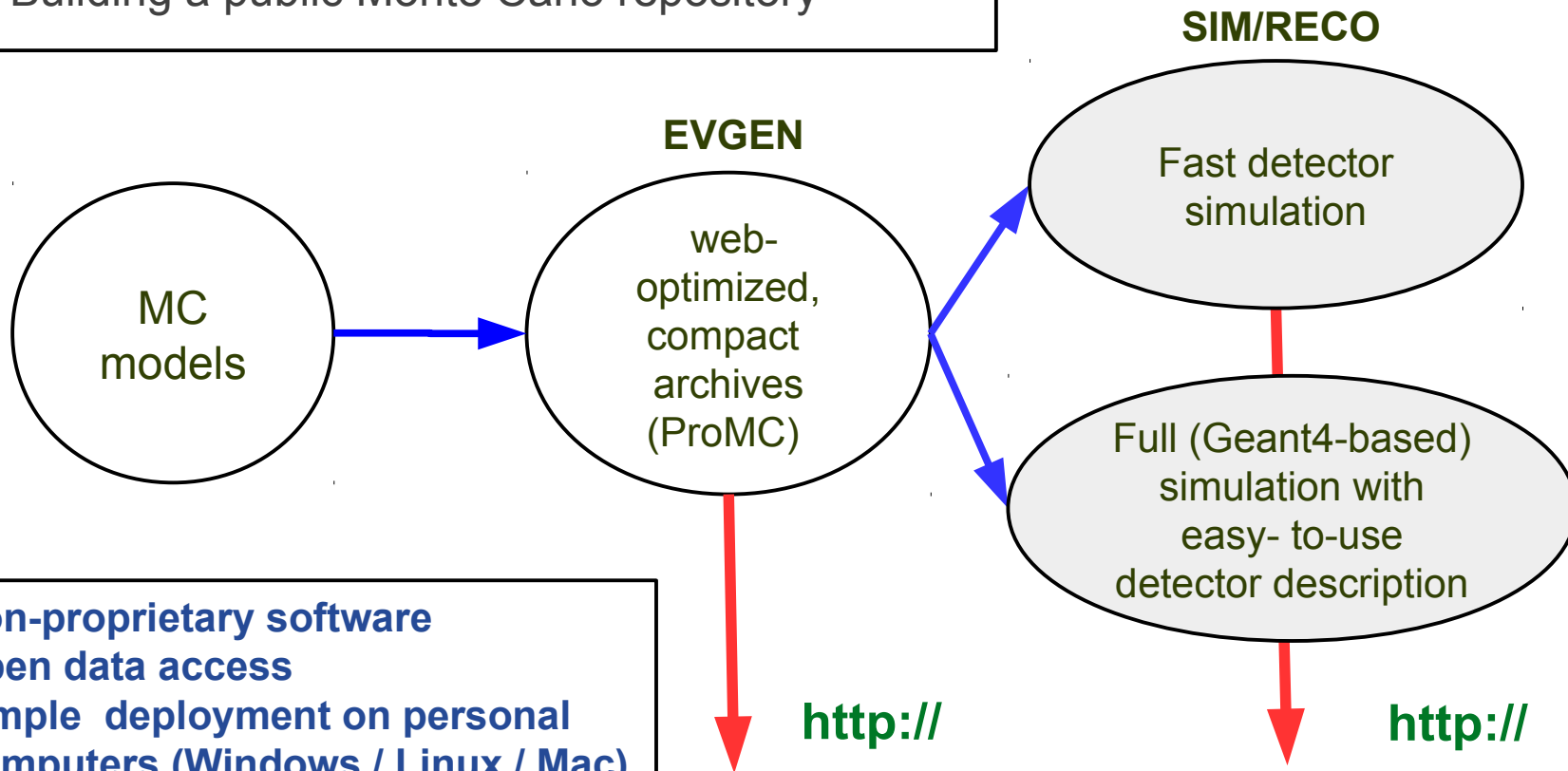
Learned Lessons:

- 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

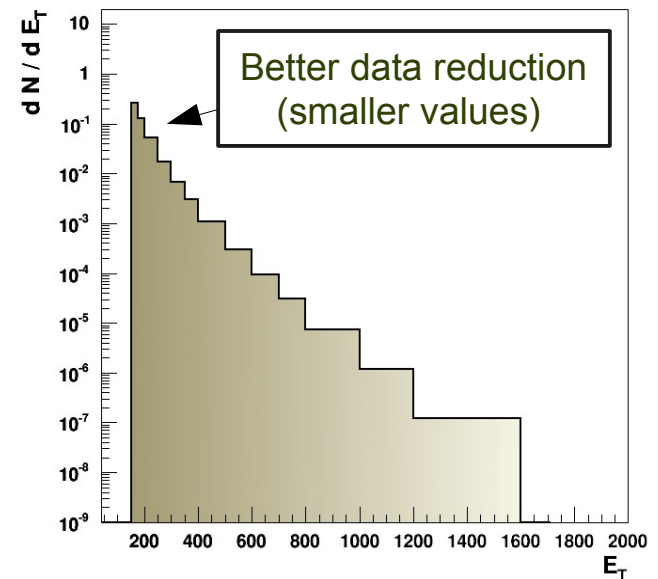
- Based on Google's Protocol buffers
- 30% smaller files than existing formats after compression
 - Uses "Varint" for int64 instead of "fixed bytes"



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 tt 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>



- **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/>

NERSC mirror

HepSim
Repository with Monte Carlo predictions for HEP experiments

Get involved Full Search Manual About Mirrors Login

HEP.ANL.GOV

Show 25 entries

Previous 1 2 3 4 5 6 7 Next Search:

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

Dec.07, 2015: Full SiD detector simulation of Zprime to tautau (link)
Nov.25, 2015: Particle gun samples for detector performance studies (pgun)
Nov.18, 2015: Simulation of ttbar+bjet at 13,14,100 TeV (mg5_ttbar_bjet)
Nov.9, 2015: Full simulation for e+e- (250 GeV) for SID-CC (rfull002)

CEPC, SPPC, FCC-hh

e⁺ to e⁻

p to p

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
- $e^+ \rightarrow e^-$**
- 250 GeV
- 500 GeV
- 1 TeV
- $\mu^+ \rightarrow \mu^-$
- 1 TeV
- 5 TeV
- 10 TeV
- $e^- \rightarrow p$
- 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.

e^+e^- (250 GeV)

$Z \rightarrow e^+e^-$



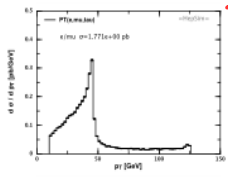
URL for EVGEN files
(download or data streaming)

URL with fast or full simulations

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; NTOF 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 ! fbar 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 distribution created using Python scripts.

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

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

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 $\rightarrow \gamma\gamma$, Inclusive gamma, TTbar
- NLOjet++ (NLO) for inclusive jets (bins in p_T)
- JETPHOX (NLO) for inclusive photons (bins in p_T)
- 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:

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

$\varepsilon \sim 0.01-1$ - for LO MC
$\varepsilon \ll 0.01$ - for NLO etc.

- $\varepsilon \ll 1$:
 - Madgraph5 etc. (NLO+PS+hadronisation), ALPGEN
 - Some fast-converging NLO calculations (MCFM, jetPHOX etc)
 - MC with $\varepsilon \sim 1$ but after mixing with pile-up (CPU intensive)
- $\varepsilon \sim 1$: 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

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

n=1...51 for CT10

Example: look at file structure of MCFM prediction for H($\rightarrow \gamma\gamma$)+jet

hs-view http://mc.hep.anl.gov/asc/hepsim/events/pp/100tev/higgsjet_gamgam_mcfm/hjetgamgam_000000.promc

NLO calculations as “ntuples”

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

No	Name	PD	Px (GeV)	Py (GeV)	Pz (GeV)	E (GeV)	M (GeV)
1	gamma	22	-36.549	11.015	43.497	57.872	0
2	gamma	22	77.296	-33.035	5.811	84.26	0
3	g	21	-40.748	22.019	-27.218	53.722	0

← 4-momenta of particles

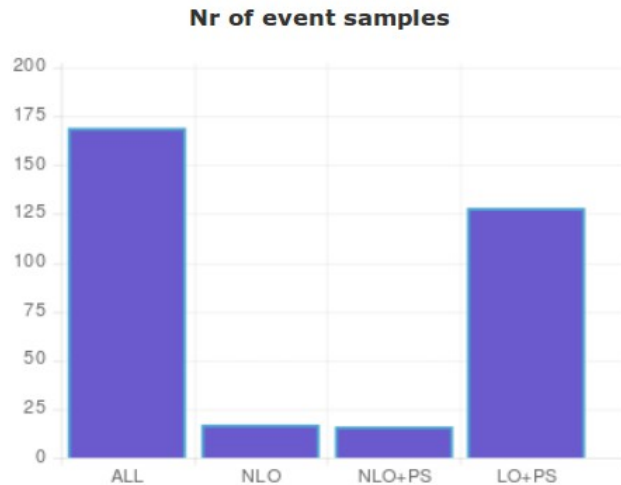
Event weights

PDF variations for CT10 (51)

Index	Description	Value
1	lodata [29]	-7
2	ldata [30]	-12
3	ldata [31]	12
4	ldata [32]	22
5	ldata [33]	-5
6	ldata [34]	1
7	ldata [35]	-2
8	ldata [36]	-3
9	ldata [37]	2
10	ldata [38]	-14
11	ldata [39]	11
12	ldata [40]	1
13	ldata [41]	-1
14	ldata [42]	2
15	ldata [43]	-2
16	ldata [44]	-2
17	ldata [45]	0
18	ldata [46]	-4
19	ldata [47]	25
20	ldata [48]	-1
21	ldata [49]	7
22	ldata [50]	3
23	ldata [51]	18
24	Array with float values:	
25	Fdata [0]	2.161642
26	Fdata [1]	0.16411175
27	Fdata [2]	0.050725058
28	Fdata [3]	5.8094633E-4
29	Fdata [4]	7.4645807E-4

HepSim statistics

(excluding fast and Geant4 simulations)



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

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

Nr of simulated 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



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

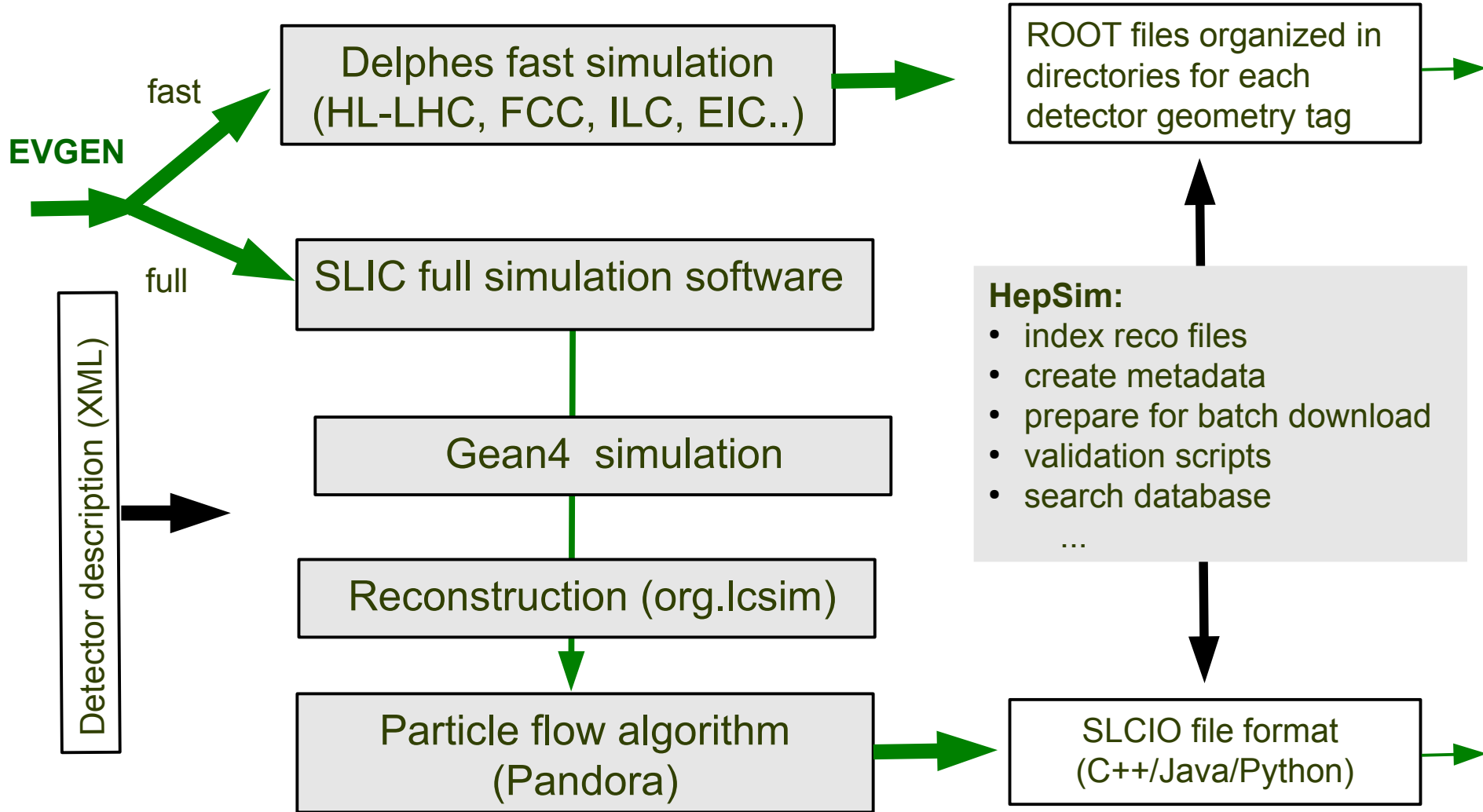
Data hosted by:

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

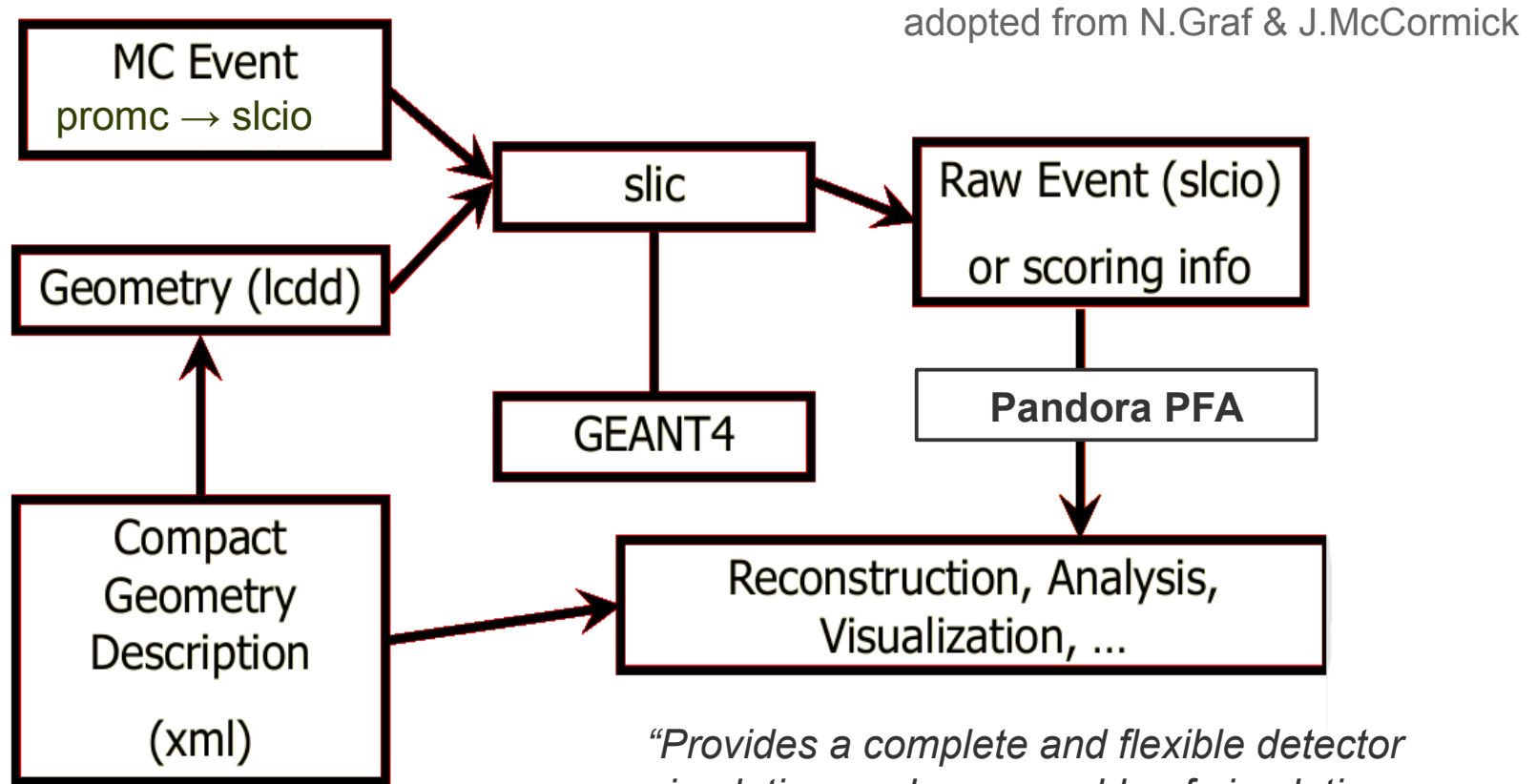


Full G4 simulation & analysis

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)



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

Software for future circular colliders

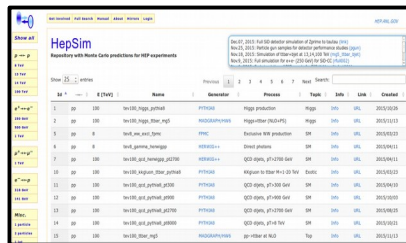
Created for future collider studies (S.C., A.Kotwal, J.Strube):

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

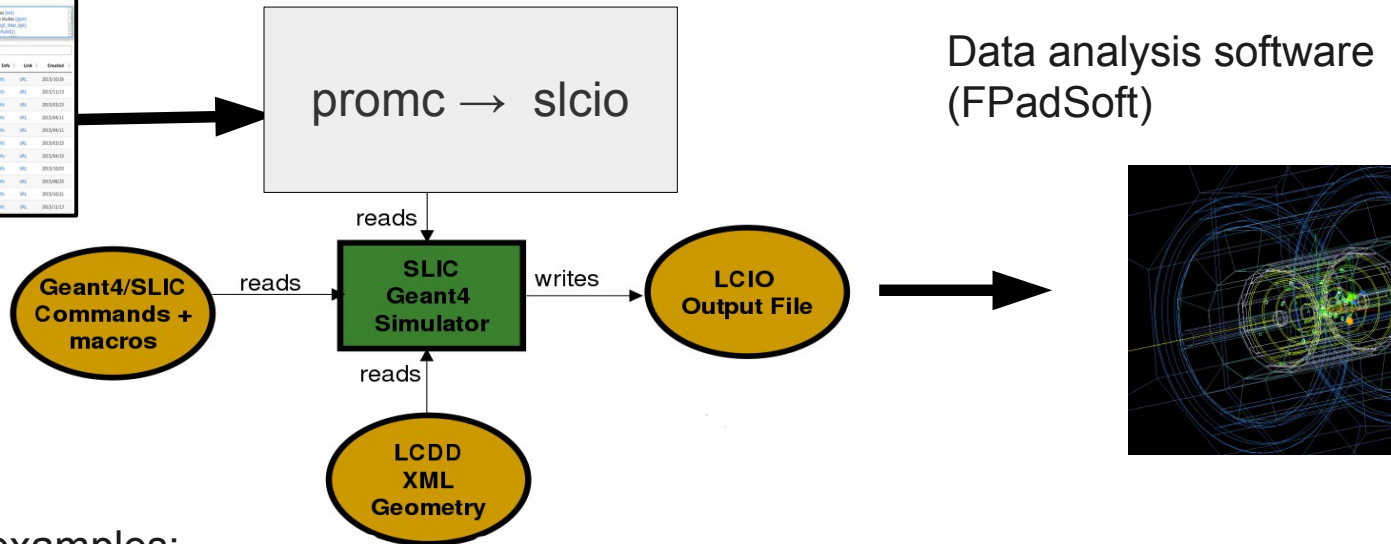
User analysis package: FPaDsoft - software for “Future Particle Detector” studies

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

HepSim repository at ANL



Job ID	Name	Priority	Age	State	Created
1	hep100_hep_production	100	100	Done	2012/02/04
2	hep100_hep_production	100	100	Done	2012/02/04
3	hep100_hep_production	100	100	Done	2012/02/04
4	hep100_hep_production	100	100	Done	2012/02/04
5	hep100_hep_production	100	100	Done	2012/02/04
6	hep100_hep_production	100	100	Done	2012/02/04
7	hep100_hep_production	100	100	Done	2012/02/04
8	hep100_hep_production	100	100	Done	2012/02/04
9	hep100_hep_production	100	100	Done	2012/02/04
10	hep100_hep_production	100	100	Done	2012/02/04
11	hep100_hep_production	100	100	Done	2012/02/04
12	hep100_hep_production	100	100	Done	2012/02/04
13	hep100_hep_production	100	100	Done	2012/02/04
14	hep100_hep_production	100	100	Done	2012/02/04
15	hep100_hep_production	100	100	Done	2012/02/04
16	hep100_hep_production	100	100	Done	2012/02/04
17	hep100_hep_production	100	100	Done	2012/02/04
18	hep100_hep_production	100	100	Done	2012/02/04
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20	hep100_hep_production	100	100	Done	2012/02/04

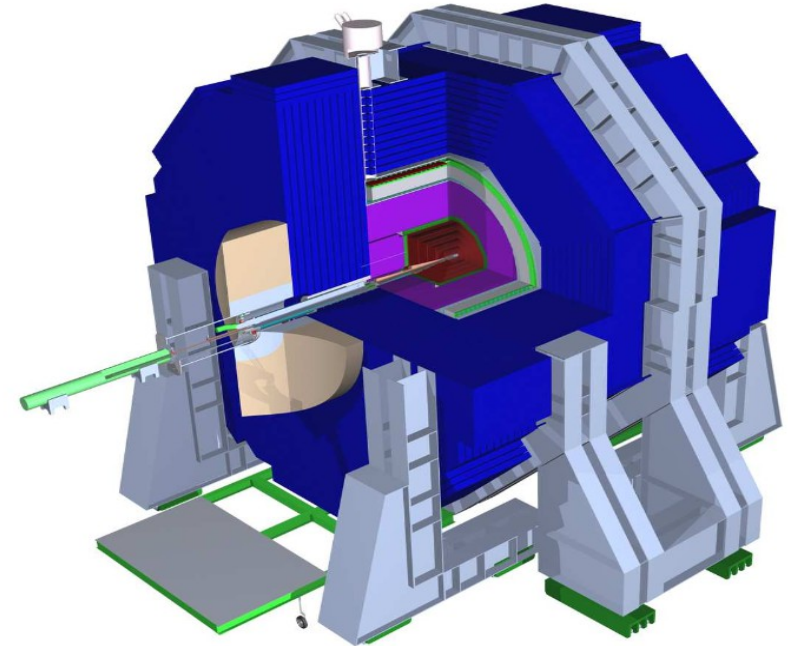


URL with manual/examples:

<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
 - Steel (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?

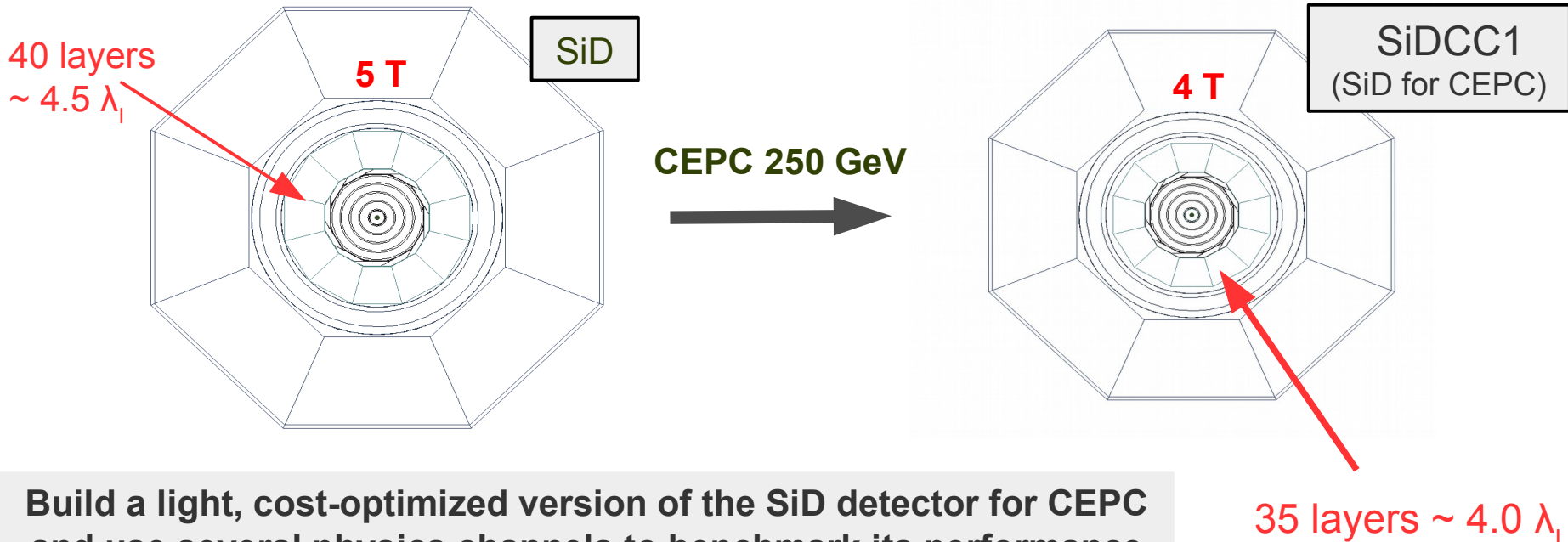
Designing a detector for CEPC (e+e- 250 GeV)

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: $4.5 \lambda_1$ (40 layers) \rightarrow **$4.0 \lambda_1$ (35 layers)**
endcap: $5 \lambda_1$ (45 layers) \rightarrow **$4.0 \lambda_1$ (35 layers)**
- Tracking: 5 Tesla \rightarrow **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))

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** → **e+e-**
 - **Z** → **tau tau**
 - **Z** → **mu+mu-**
 - **Z** → **b \bar{b}**
 - **H(125)** → **b \bar{b}**
 - **H(125)** → **$\gamma\gamma$**
 - **H(125)** → **ZZ* → 4l**
 - **H(125)** → **tau tau**

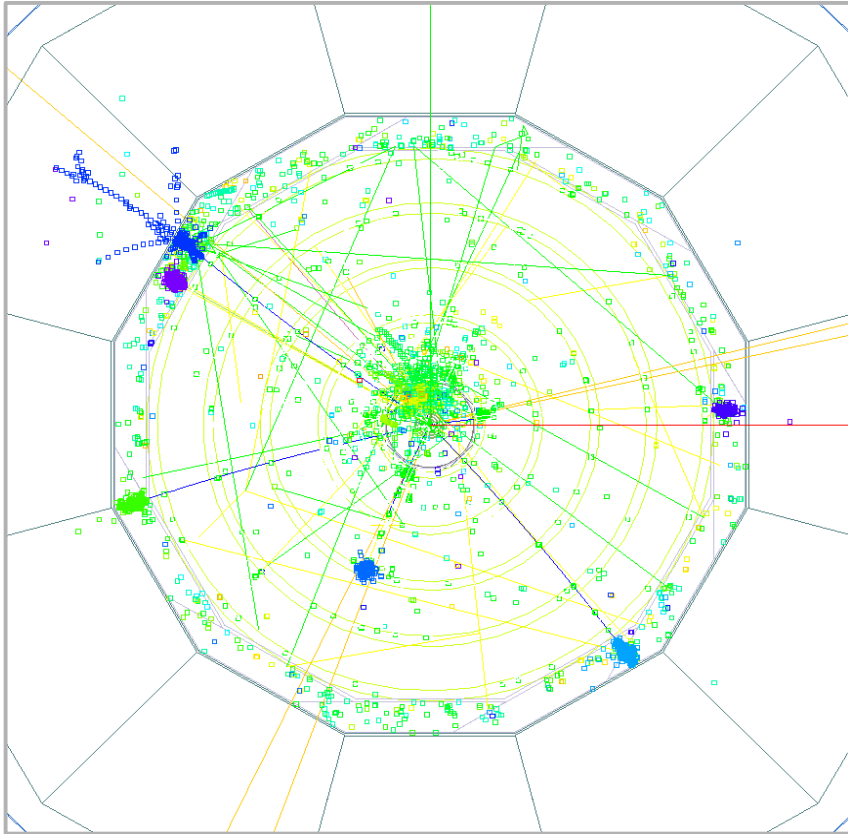
~ 10,000 reconstructed events for each physics channel after PFA (Pandora) reconstruction

URL with manual/examples:

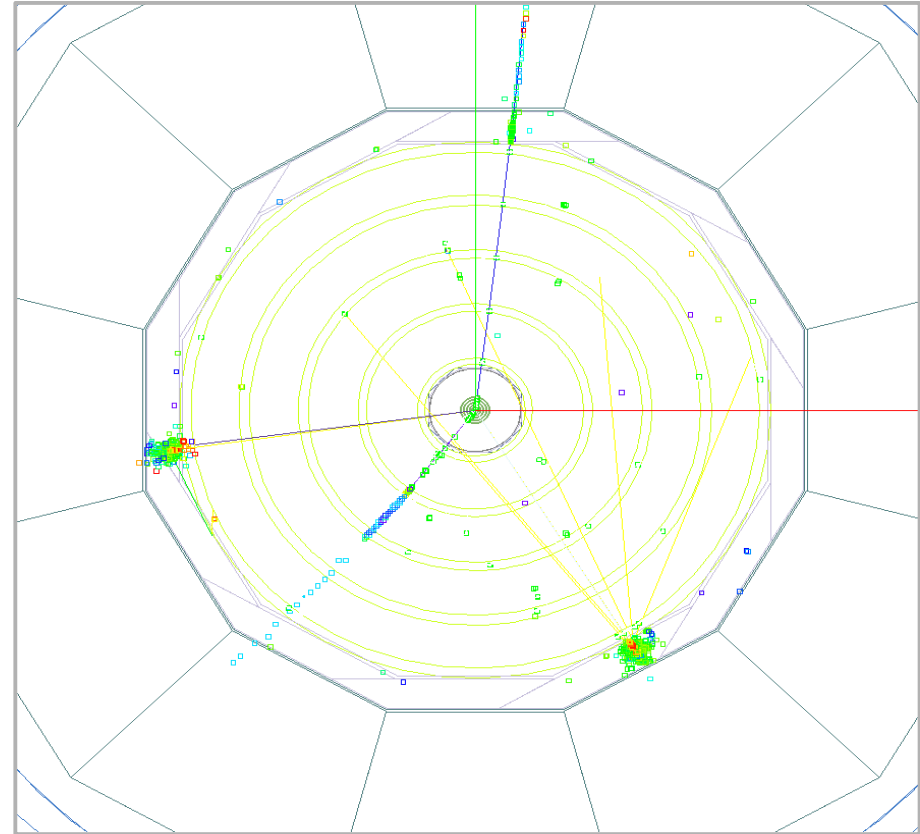
<https://atlaswww.hep.anl.gov/asc/wikidoc/doku.php?id=fcs:cepc>

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

SiDCC1 detector



$H(125) \rightarrow 4e$

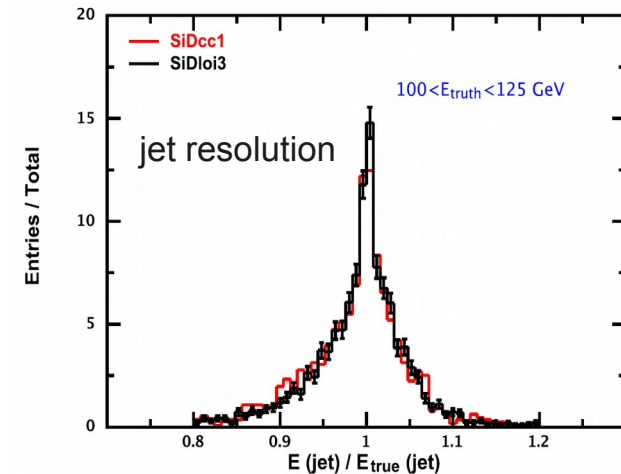
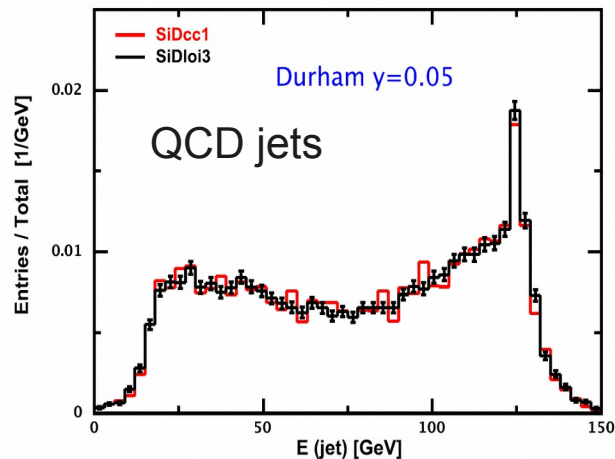
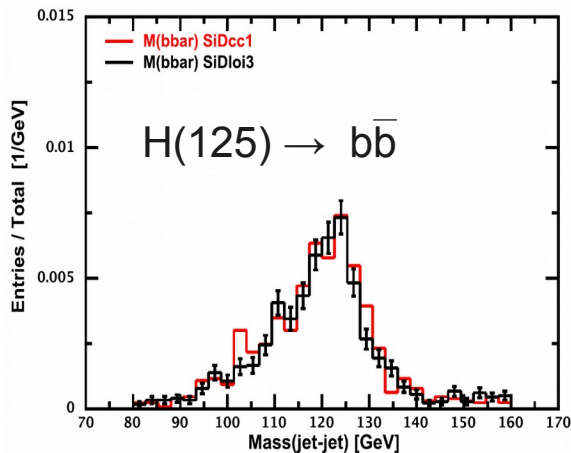
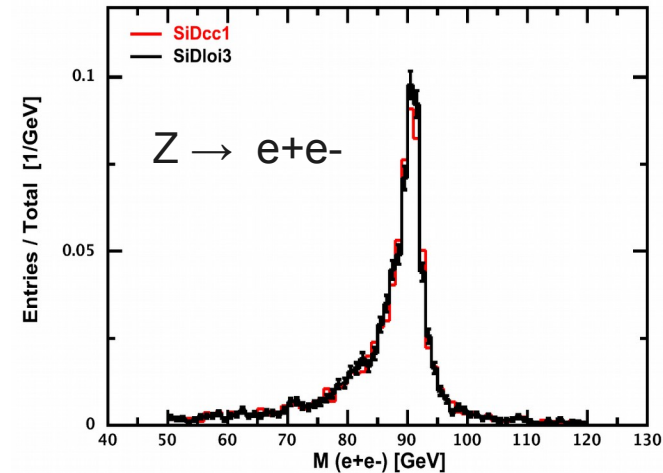


$H(125) \rightarrow \gamma\gamma$



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 \sim 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

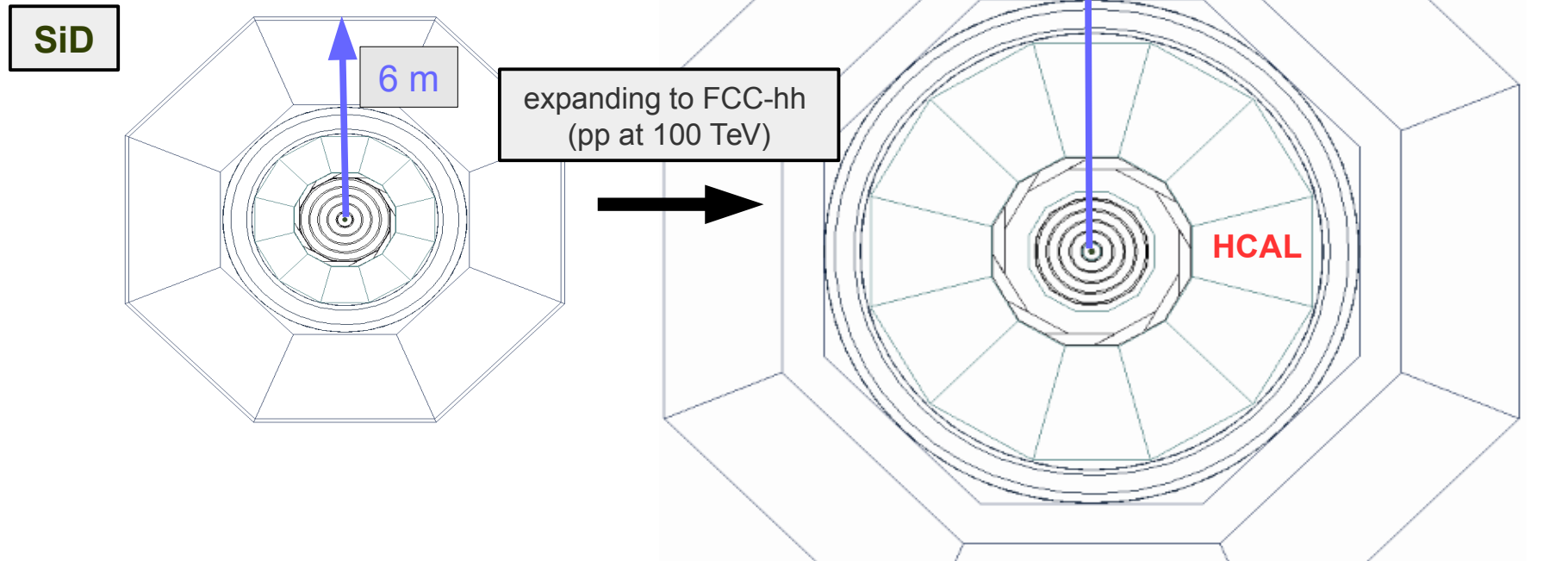
Require elaborate full simulations

Scaling up the SiD detector for tens-TeV energy (\sim 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 \sim tens TeV-scale particles/jets

Focus on performance studies of multi-TeV boosted objects



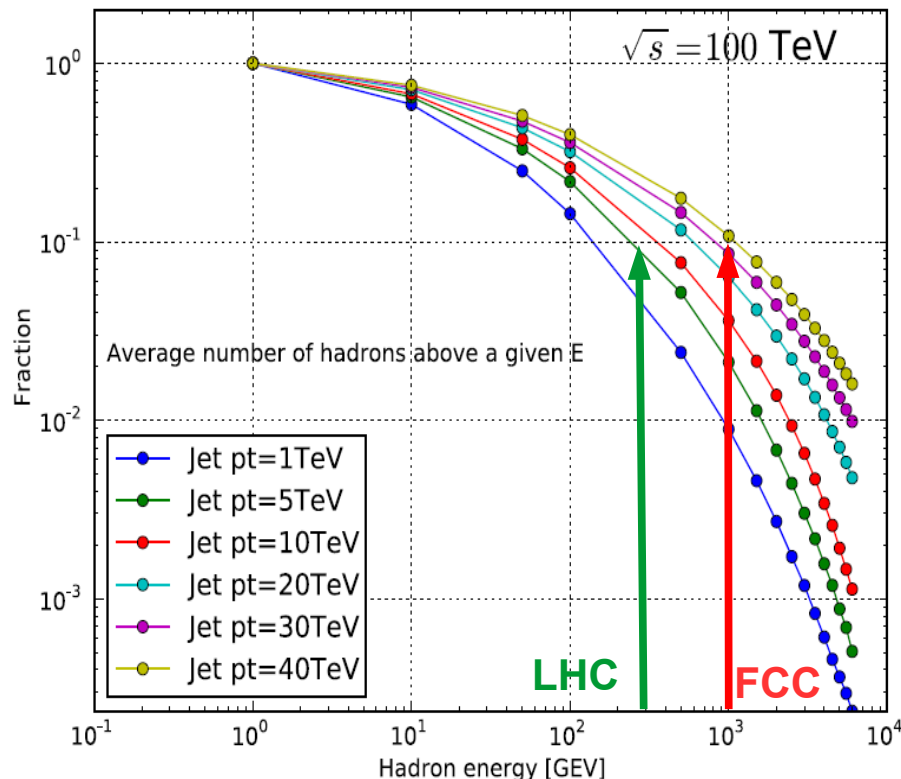
Designing a Geant4 simulation for high-granular calorimeter for \sim 20 TeV jets (particles)

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

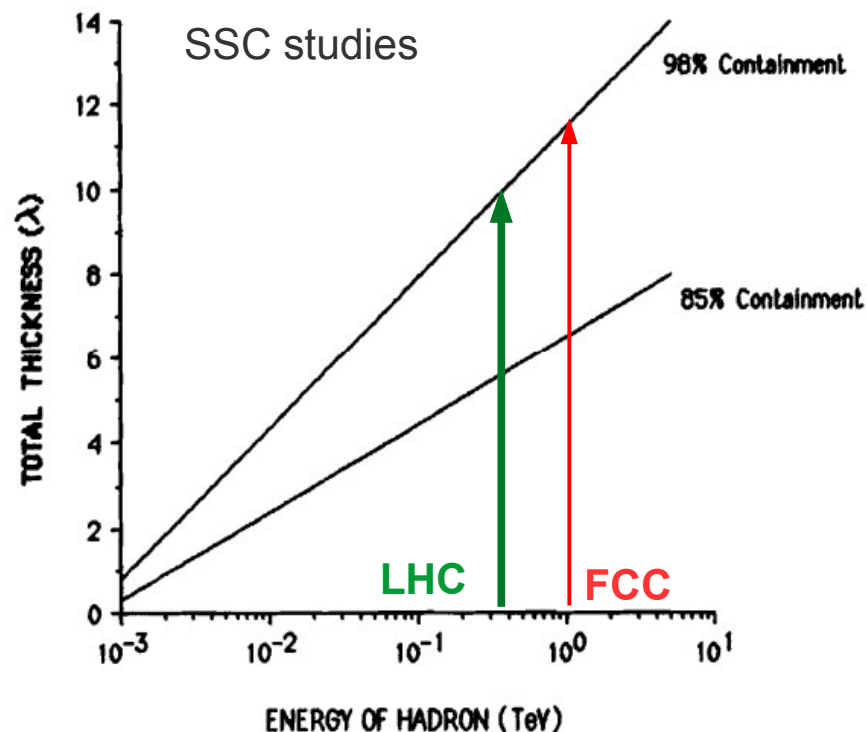
Leading particles in high-pT jets

C.Helsens, C.Solans



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

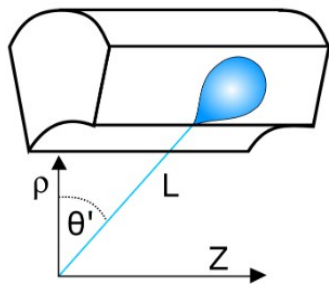
Containment of hadron showers



pT(jet)>30 TeV: ~10% will be carried by 1 TeV hadrons (~9 hadrons/jet)
12 λ_1 is needed to contain 98% of energy of a 1 TeV hadron

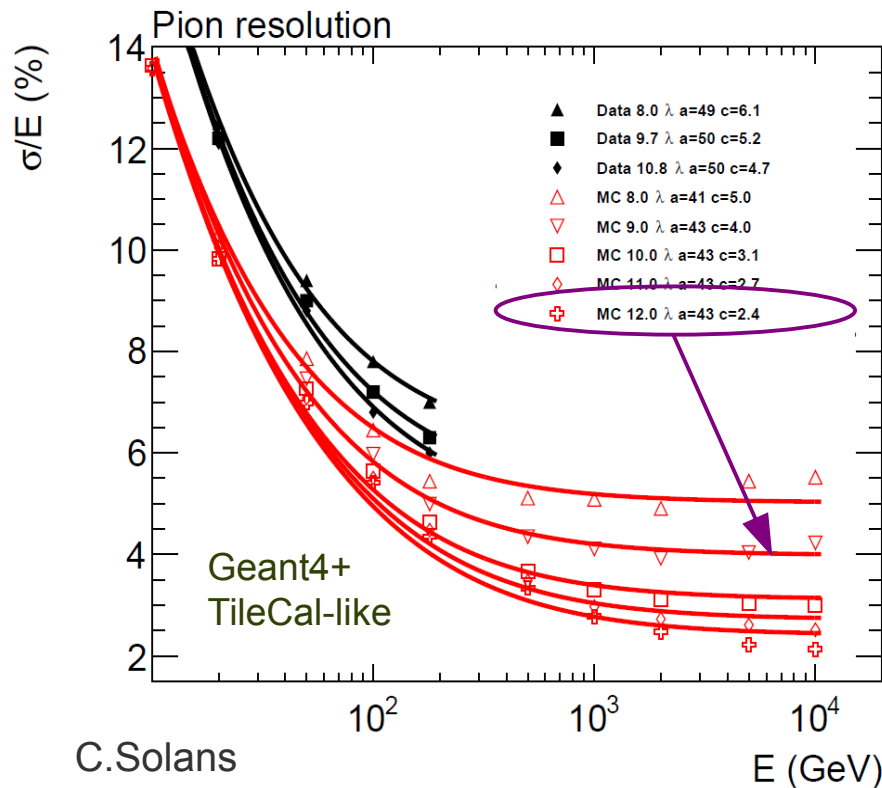
Geant4 simulation agrees with calculations for SSC (.. 1984 Gordon&Grannis. Snowmass)

Resolution for single pions



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

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



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

“c” dominates for jet with $p_T > 5$ TeV

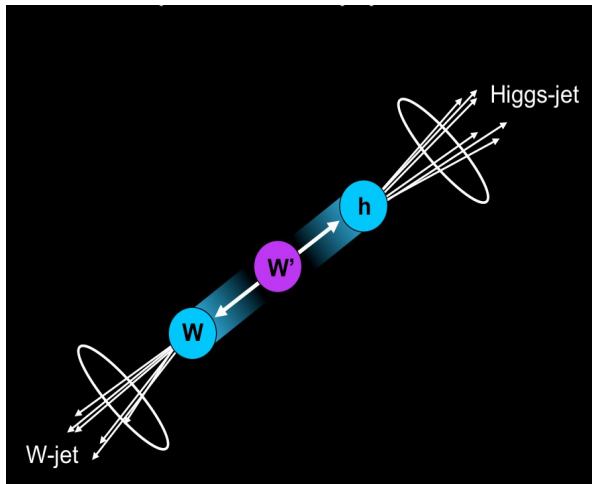
- Geant4 TileCal inspired simulation based on FTFP_BERT
- Calculate single-particle resolution
- Stochastic term is close to $45\%/\sqrt{E}$
- Constant term improves by $\sim 20\%$ with increase of $1\lambda_1$

Constant term $c \sim 2.5\%$ is achievable for $12 \lambda_1$

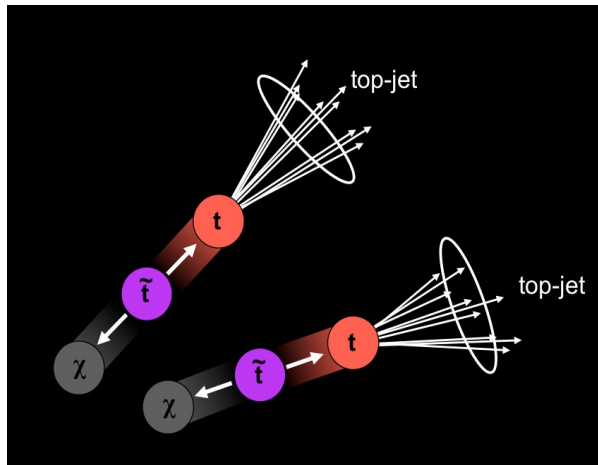
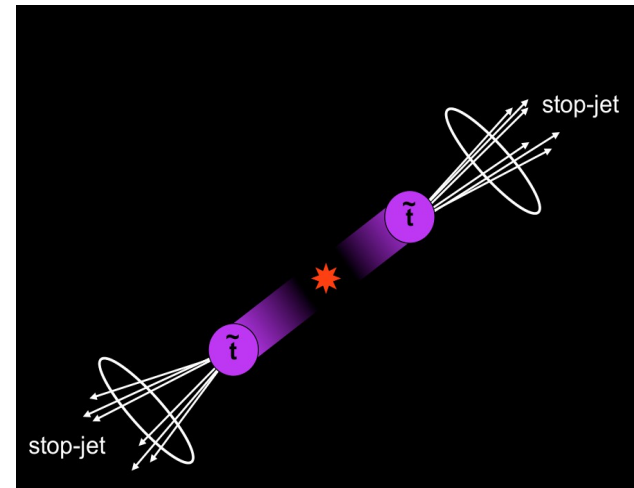
Lateral segmentation. Where does it matter..

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

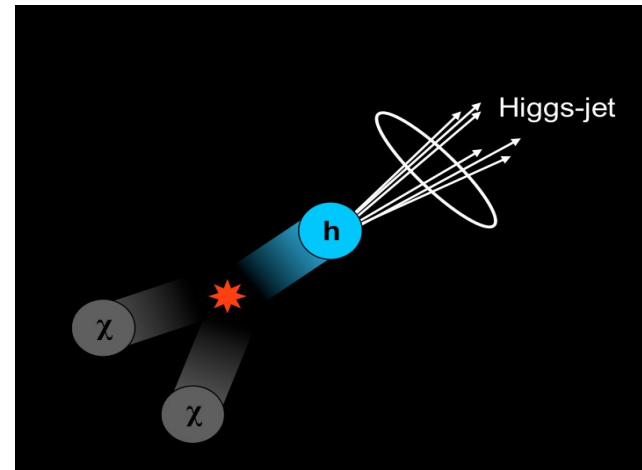
$X \rightarrow W / Z / \text{Higgs} / \text{top}$



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



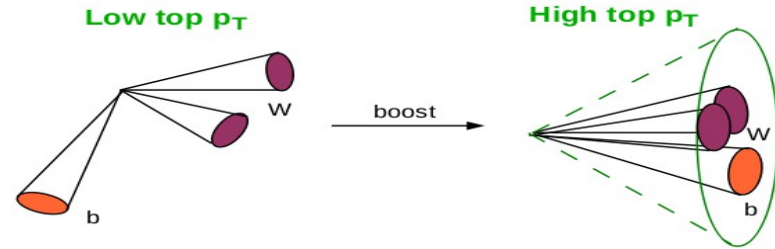
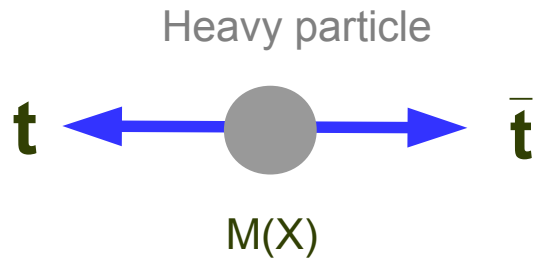
TeV-scale pair-produced



SM + dark matter

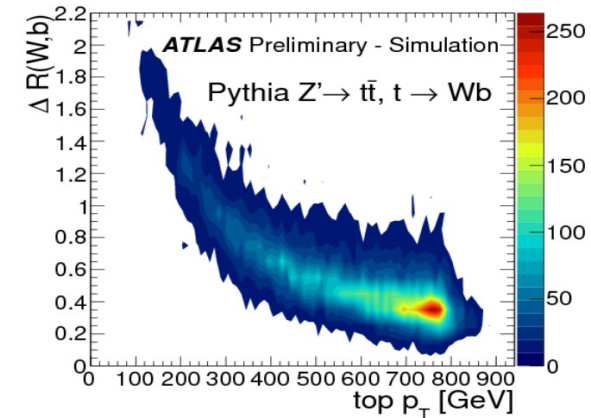
- Large mass \rightarrow large Lorentz boost \rightarrow large collimation of decay products

Boosted top from high-mass particles

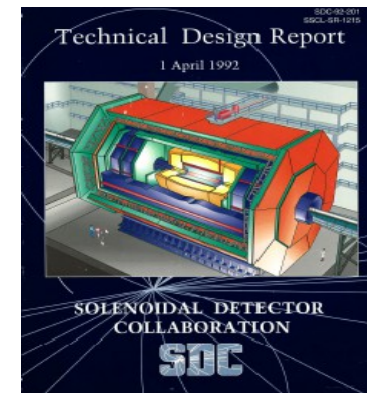


$$\Delta R \sim 2 p_T / m(\text{top})$$

www.quantumdiaries.org



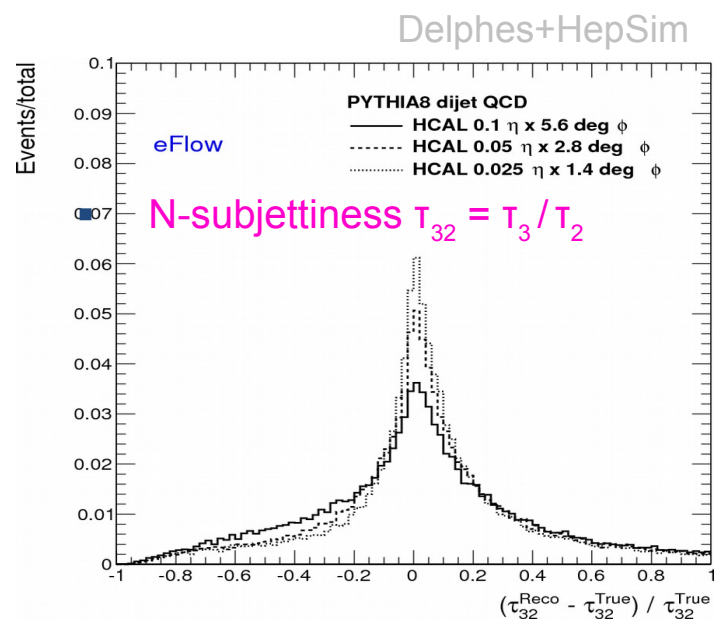
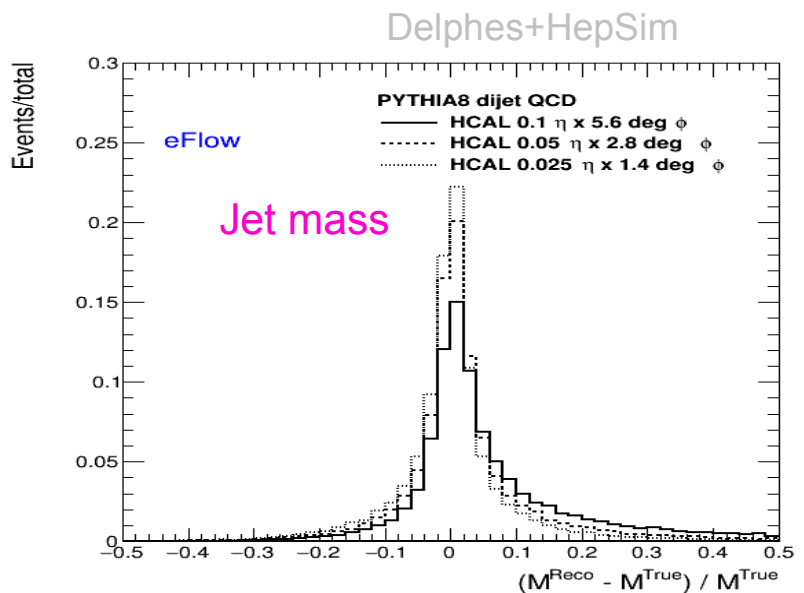
- $M(X) \sim 10 \text{ TeV} \rightarrow$ top quarks with $p_T(\text{top}) > 3\text{-}5 \text{ TeV}$
- ΔR distance between 2 particles (W, b) from top decay
- SM physics & 10 ab^{-1} for FCC-hh:
 - 5M top events with $p_T(\text{top}) > 3 \text{ TeV}$
- SSC TDR discussed substructure signatures and large 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 $p_T(\text{jet}) > 10$ TeV (fast simulation)

Presented at

Boost2015. Chicago, Aug. 10-15, 2015

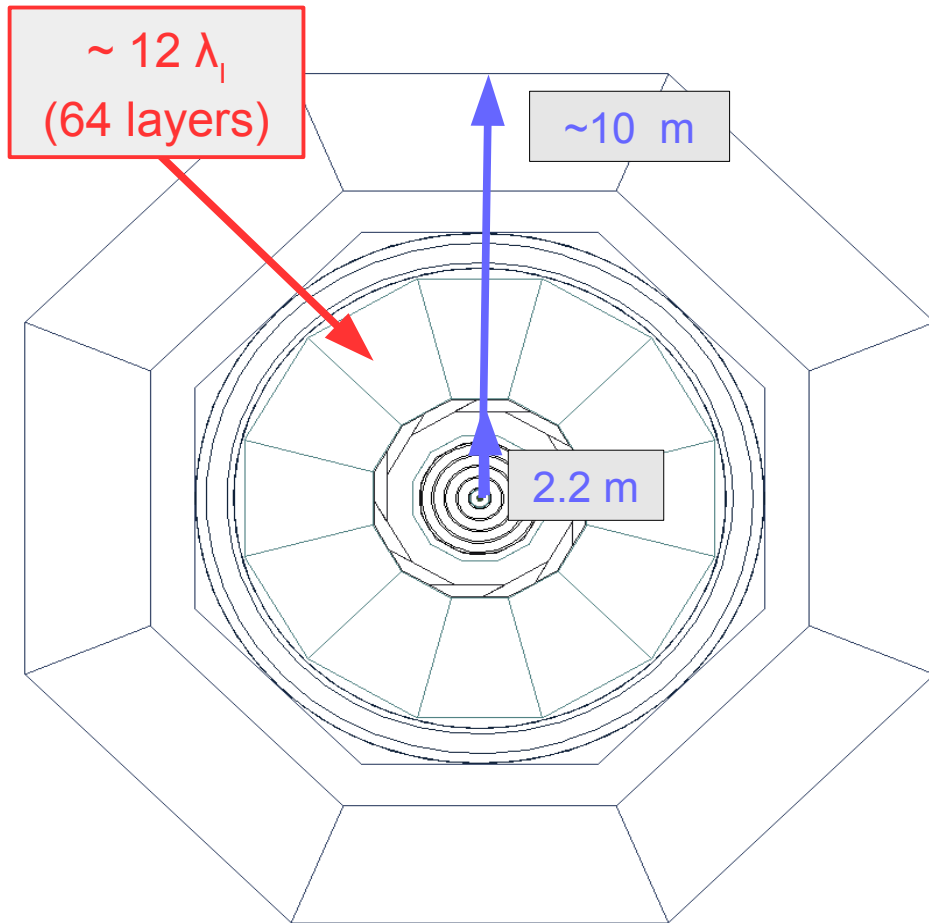


Decrease in RMS values compared to $\Delta\eta \times \Delta\phi = 0.1 \times 0.1$

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

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

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 $pT(\text{jet}) > 20$ TeV
- Also try W instead of steal
- Keep the same pixel size: **1 x 1 cm**

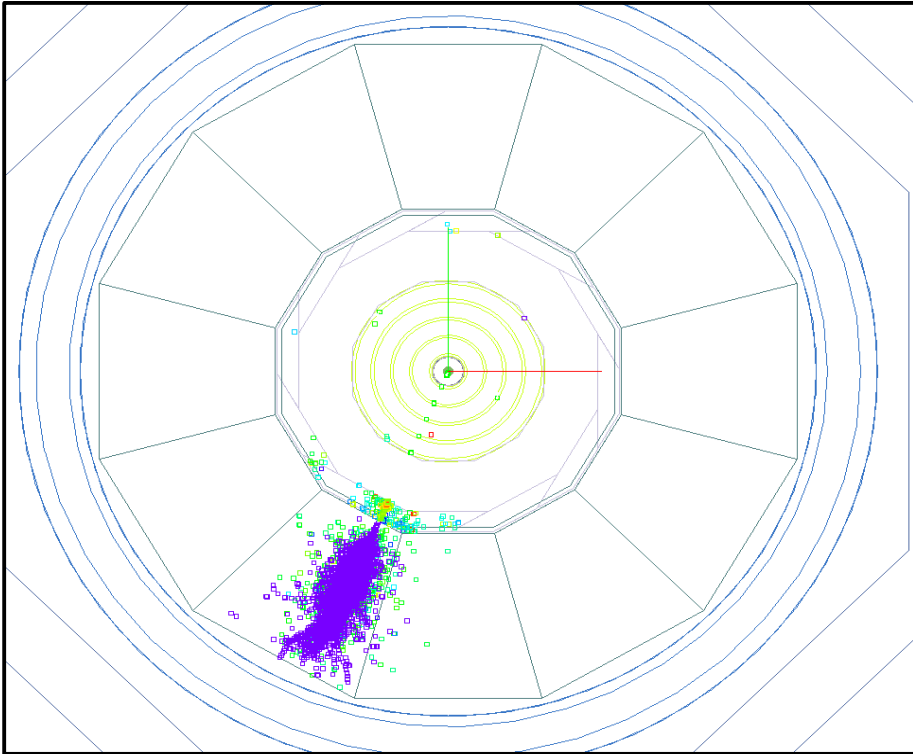
Calorimeter has about 80 million HCAL cells and a similar number for ECAL

“Imaging” (digital) HCAL calorimeter. Can be analog too

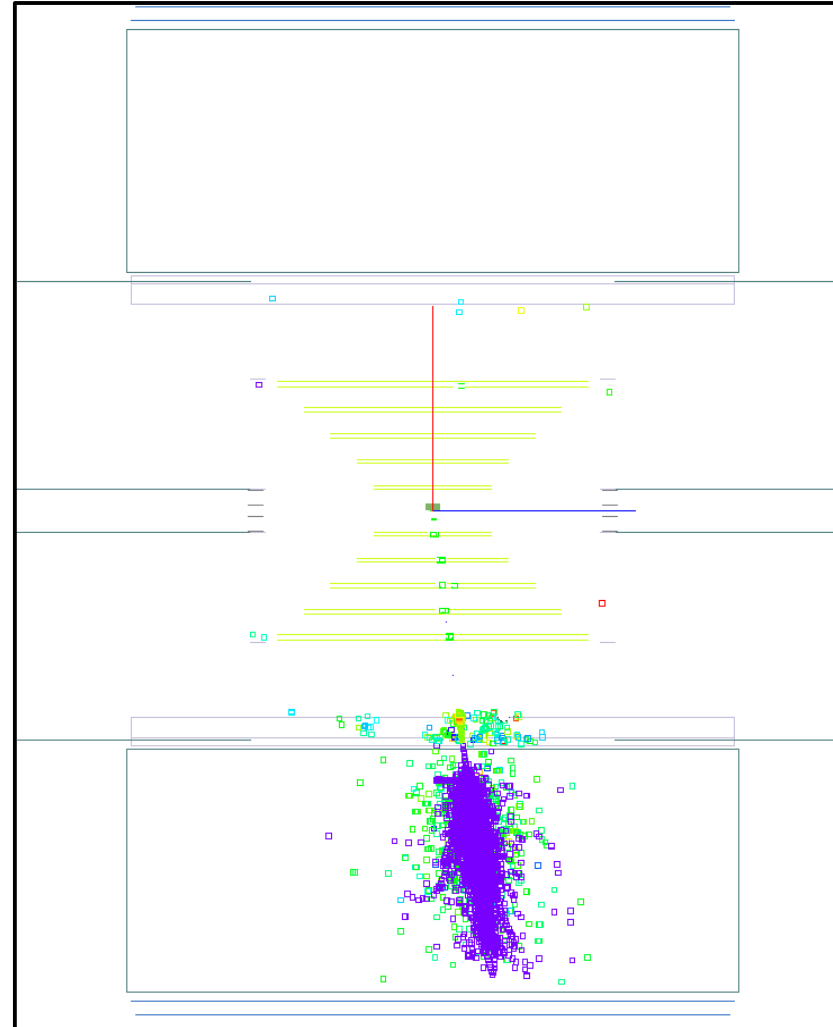
Event display for 1 TeV π^+

Remember: $\sim 10\%$ of energy will be carried by 1 TeV hadrons in a jet with $p_T > 30$ TeV

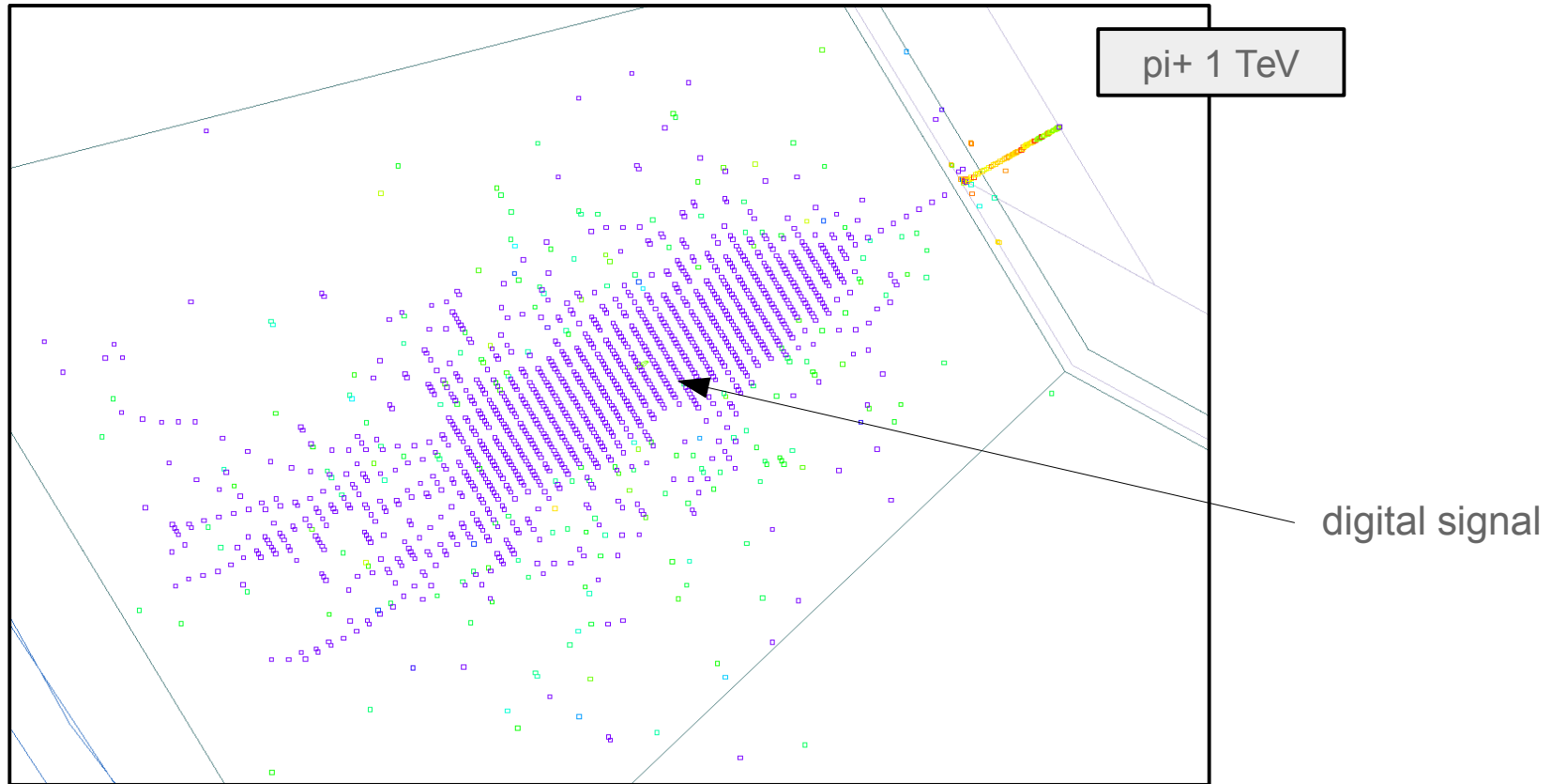
Use 1 TeV single particles for benchmarks



Reconstructed PFA with $E=1007$ GeV (charge +)



Event display for 1 TeV pion in HCAL

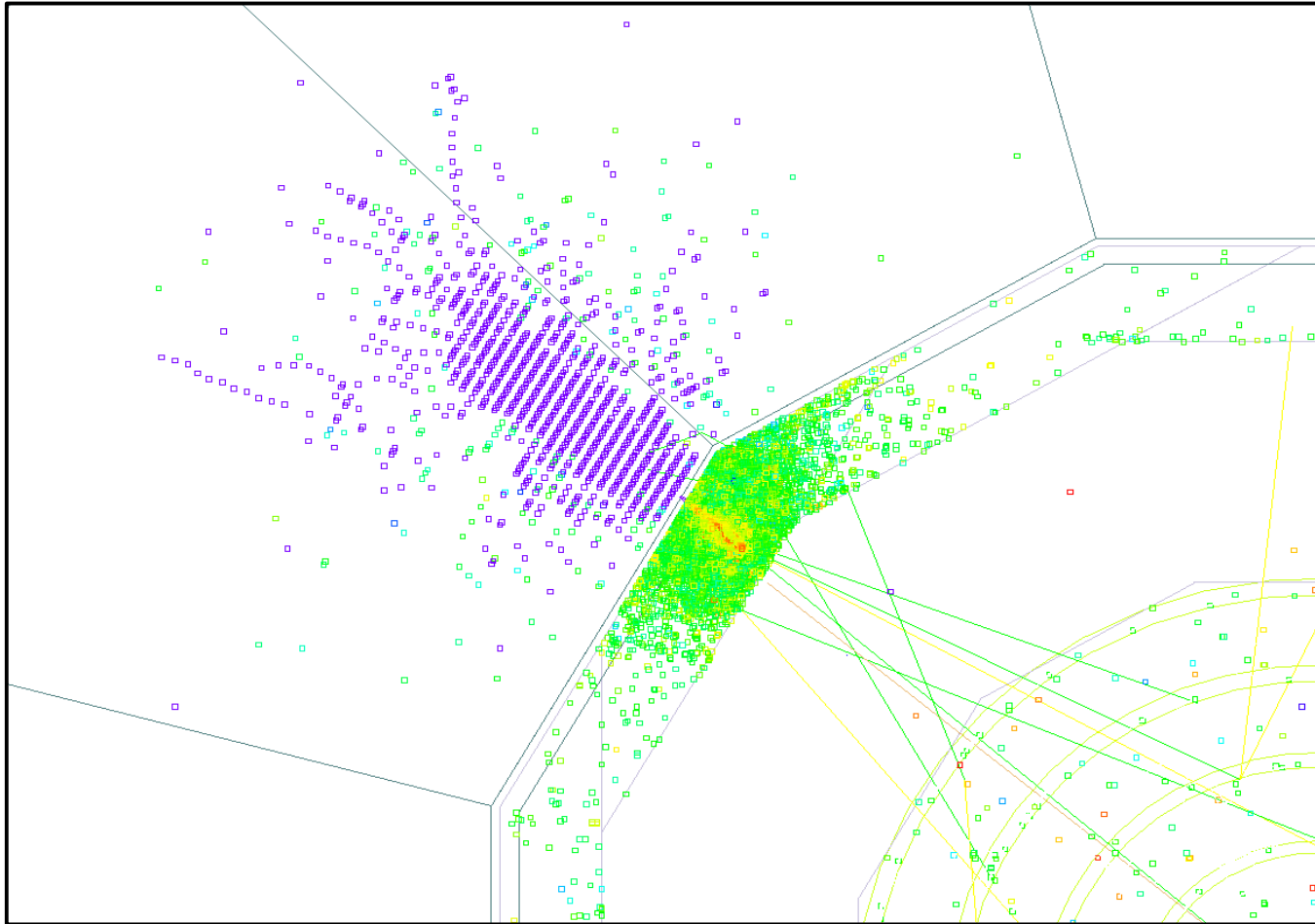


“imaging SiD” calorimeter with 1-bit (single threshold) and 1x1 cm cells designed for low rate environment of a future e+e-. 60 layers. ~80 M cells for HCAL and ECAL

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



Event display for 1 TeV neutron

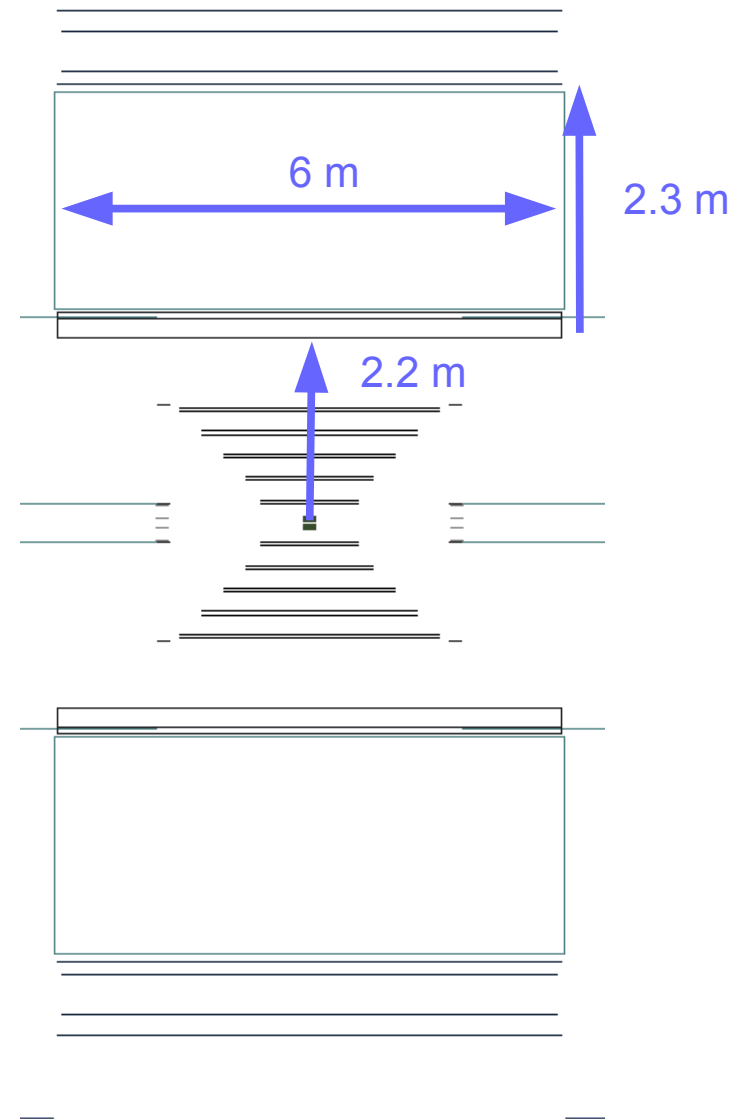


PFA energy: 951 GeV (from calorimeters)



Need simplifications for realistic pp events!

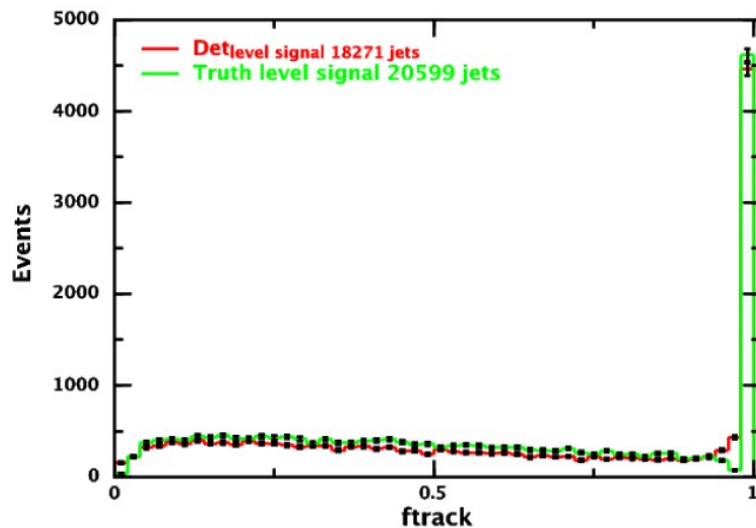
- pp collision events at 100 TeV are busy
- Running full calorimeter is CPU demanding
 - Number of cells > 150 million (ECAL+HCAL)
- Use Barrel ECAL/HCAL region $|\eta| < 0.7$
- Processes for benchmarks:
 - $\mu+\mu^- \rightarrow Z' (10 \text{ TeV}) \rightarrow W+W^-$
 - $\mu+\mu^- \rightarrow Z' (10 \text{ TeV}) \rightarrow qq$
 - $\mu+\mu^- \rightarrow Z' (10 \text{ TeV}) \rightarrow \text{tau}+\text{tau}^-$
- Set $\Delta\Gamma(Z')$ to a small value
- Or single particle guns up to 20 TeV
- Full simulation files are available from HepSim



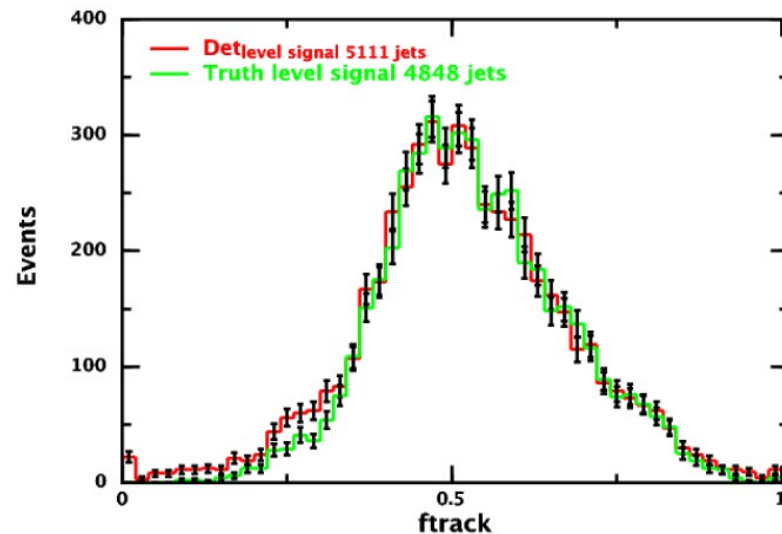
Z' (1 TeV) → tau+tau (<http://atlaswww.hep.anl.gov/hepsim/index.php?c=mupmum&e=1000&t=all>)

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



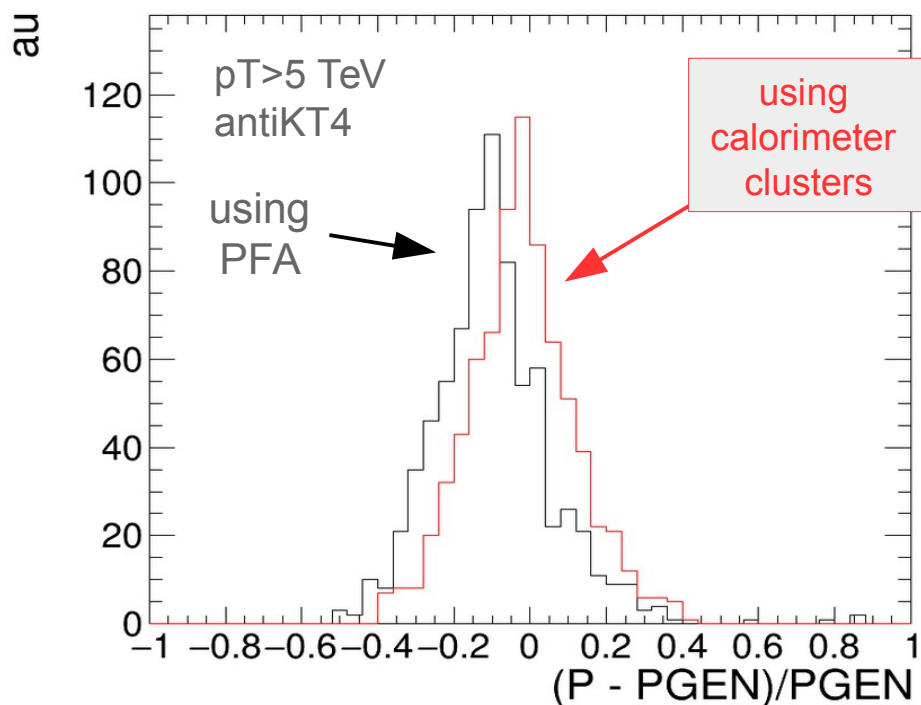
3 prong

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

$Z' (10 \text{ TeV}) \rightarrow W+W-$ (using width $< 1 \text{ GeV}$)

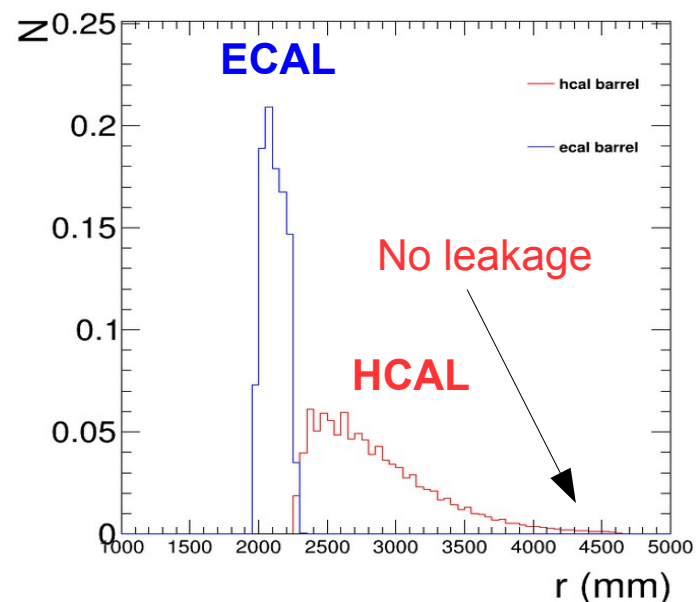
HepSim download: [tev10mumu_pythia6_zprime10tev_ww%rfull003](#)



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

Jet momentum response:
 $(P(\text{rec}) - P(\text{gen})) / P(\text{reco})$

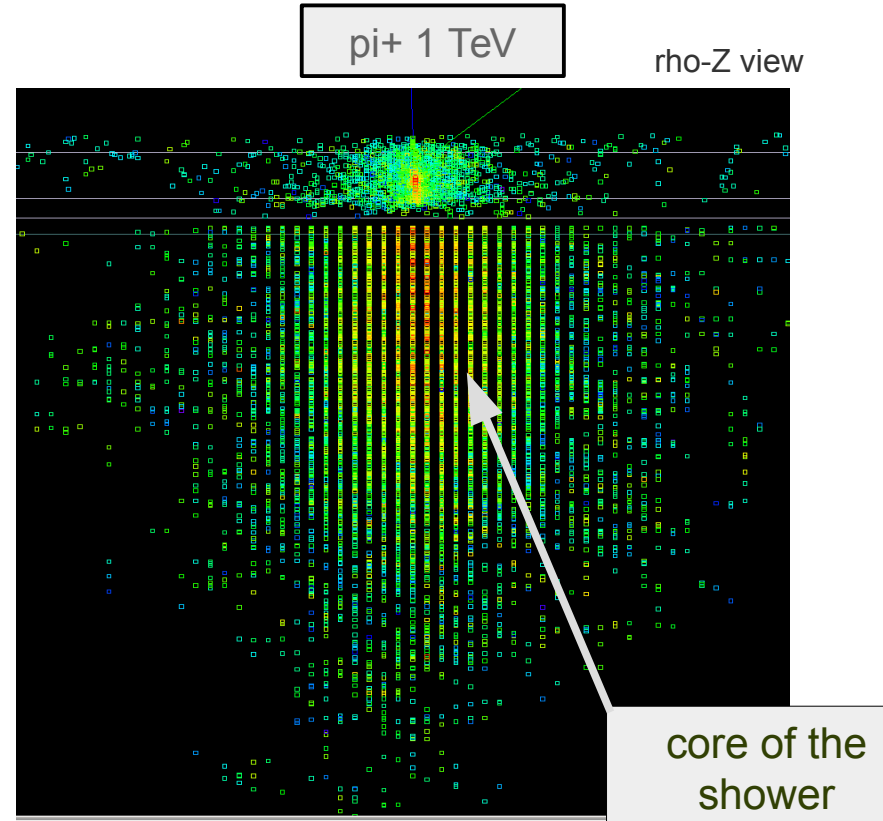
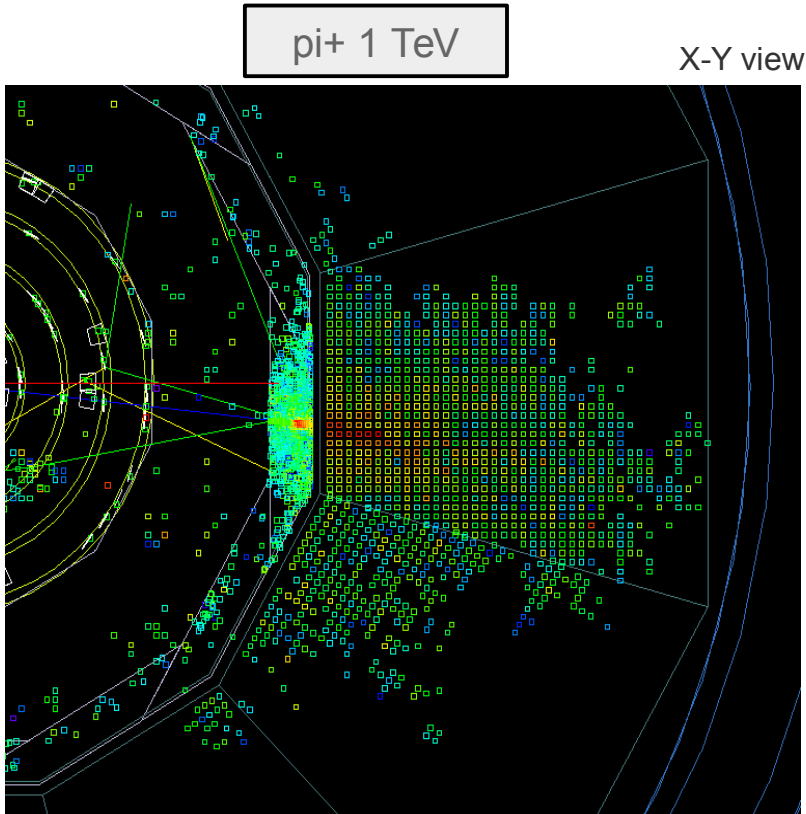
Distribution of calorimeter hits



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 $\lambda_1 \sim 17$ cm!



Can we improve boosted object reconstruction using cell sizes $< \lambda_1$?



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)

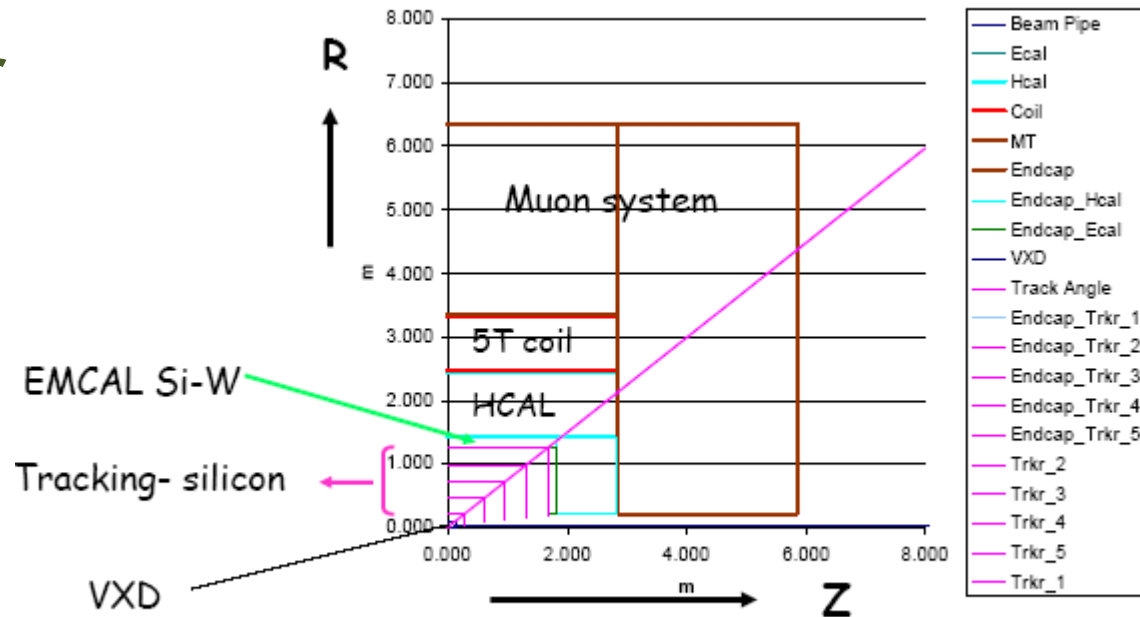
- HEPSIM integration, deployment, OSG-grid, EVGEN MC, fast sim etc.
 - ANL: S.C.
- Some support for SLIC software (used for ILC)
 - SLAC: N.Graf & J.McCormick
 - PNNL: J.Strube
- Configure detectors, physics, analysis package for circular colliders
 - ANL/Fermilab: S.C., A.Kotwal

Thanks!



Backup

SiD detector



NOT A SMALL DETECTOR

Barrel		Techno	nt		
Vertex detector	Silicon				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

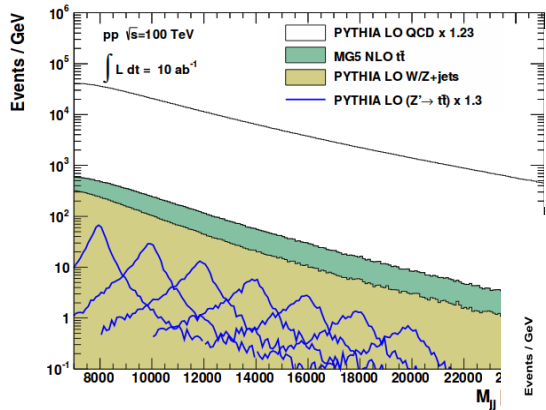
- **EVGEN: ProMC format → C++ (or) Java. Support for Fortran**
- **Delphes fast simulation → C++/ROOT**
- **SLIC software:**
 - Geant4 simulation → C++/C
 - Reconstruction → Java
 - Pandora particle flow algorithm → C++
- **Analysis: C++/ROOT or Jython/Java (Python on the Java platform)**
 - No manpower 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>

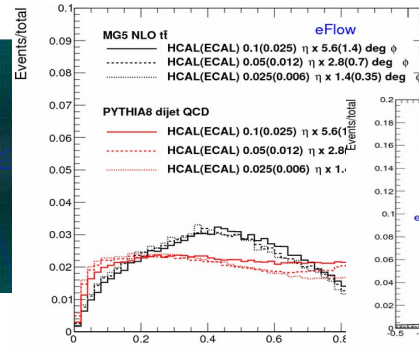
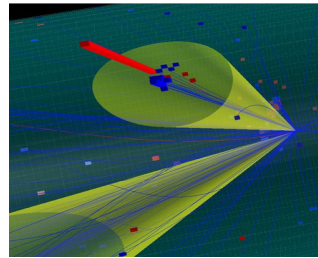
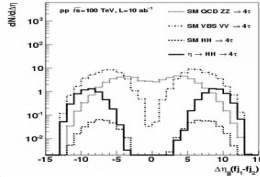


MC simulations for the HEP community

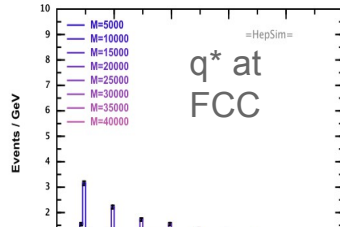
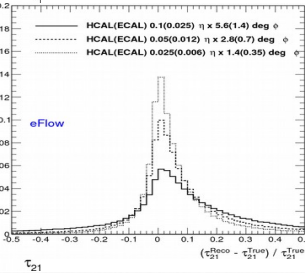
Phys. Rev. D 91 (2015) 034014



Phys. Rev. D 91,
114018 (2015)



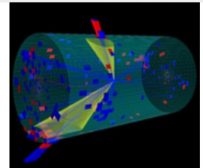
HCAL
segmentation
studies



Researchers create enormous simulation of proton collisions

BY JARED SAGOFF • DECEMBER 12, 2014

Like 0 Tweet 0 Share 0 Email Print



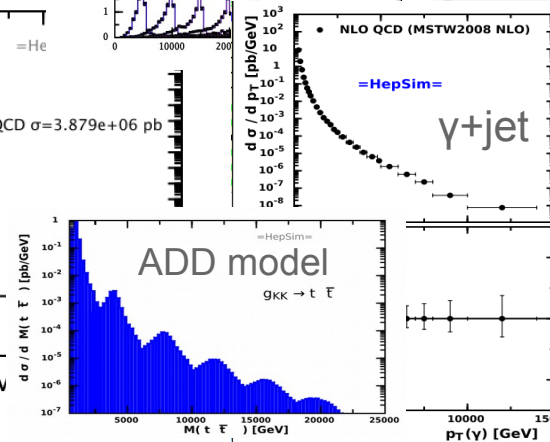
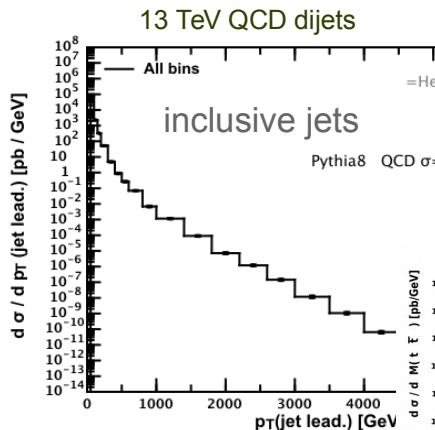
This image shows what happens in a detector after colliding two protons, each with an energy of roughly 50

Scientists from the U.S. Department of Energy's Argonne National Laboratory and the University of Chicago have created one of the world's largest

largest
data sam
particles
Each part
quantum

One of the world's largest public MC simulation for 100 TeV:
~40,000 CPU*h to create
~ 2 days for download & analyse

The creat
events wi
sample is
surpasses the Large Hadron Collider (LHC). This event sample provides
the background for potential new experiments to discover new physics at



Usage:

- Snowmass papers for HL-LHC
- ATLAS run I & II analyses: excl. H⁰, 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>