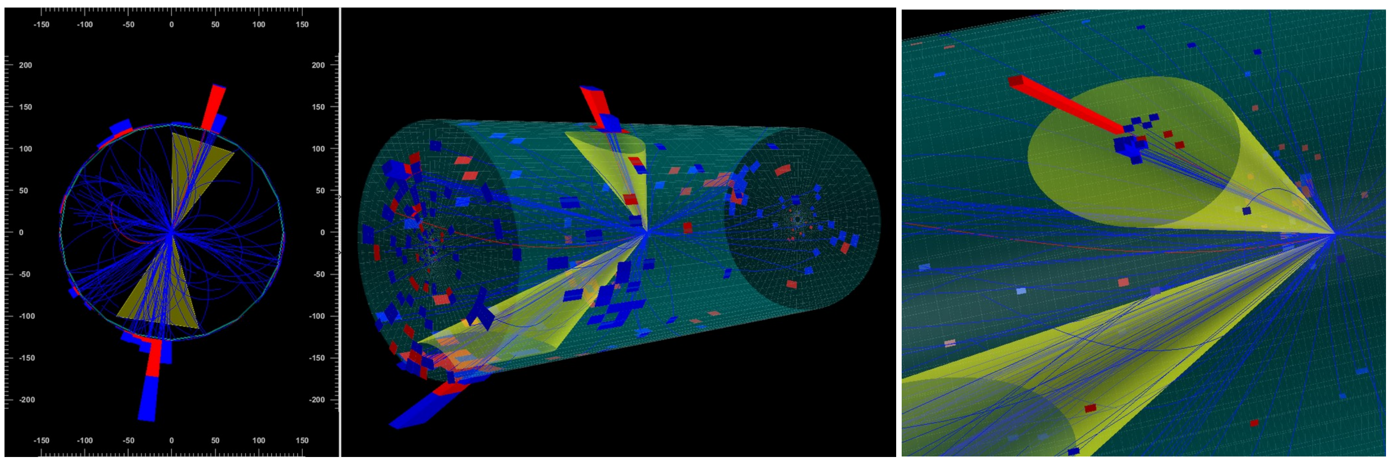
Monte Carlo repository for particle physics and studies of tens-of-TeV hadronic jets for post-LHC experiments

S.Chekanov (ANL)

Seminar, University of Maryland. Oct. 16, 2019

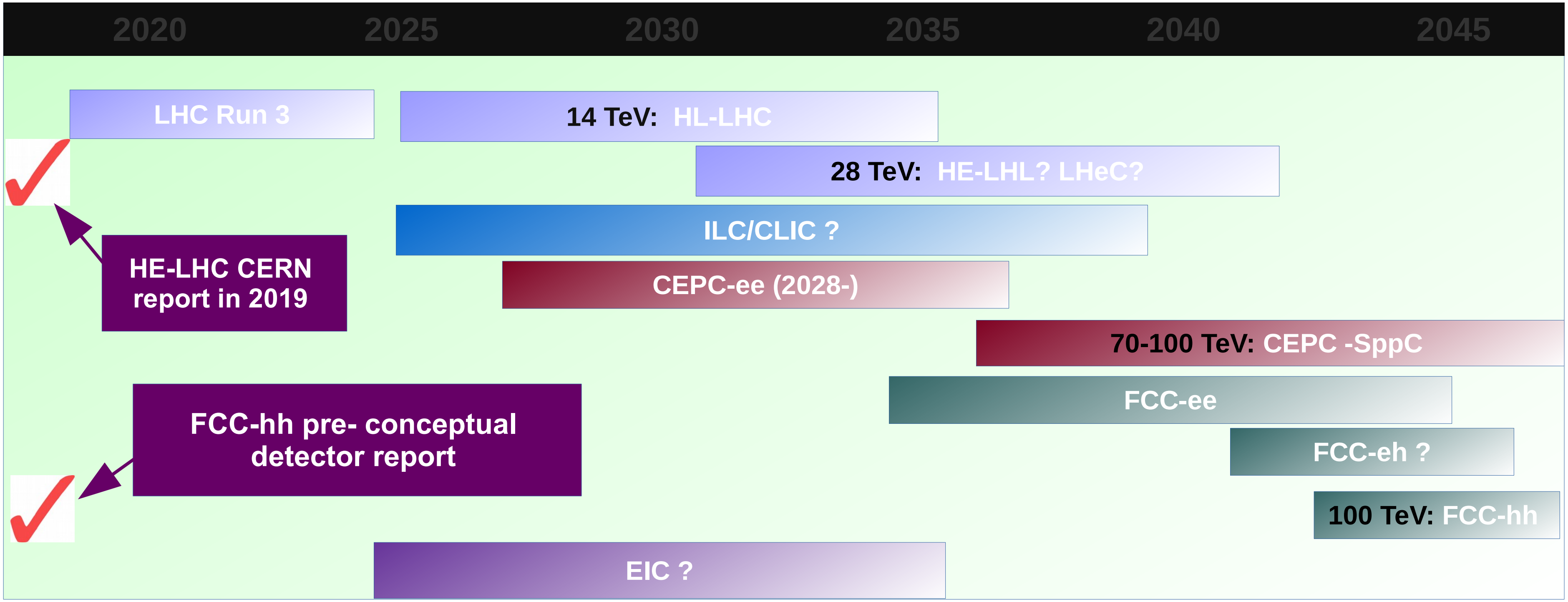


Z'(10 TeV) → $t\bar{t}$ → two jets

With contributions from:

D.Blyth (ANL), M.Demarteau (ANL), A.Kotwal (U.Duke), N.Tran (Fermilab)
S.Yu, (NCU), C.-H. Yeh (NCU), C.Solans, J.Repond (ANL), J.Proudfoot (ANL), A.Henriques (CERN)

Timeline of particle collision experiments



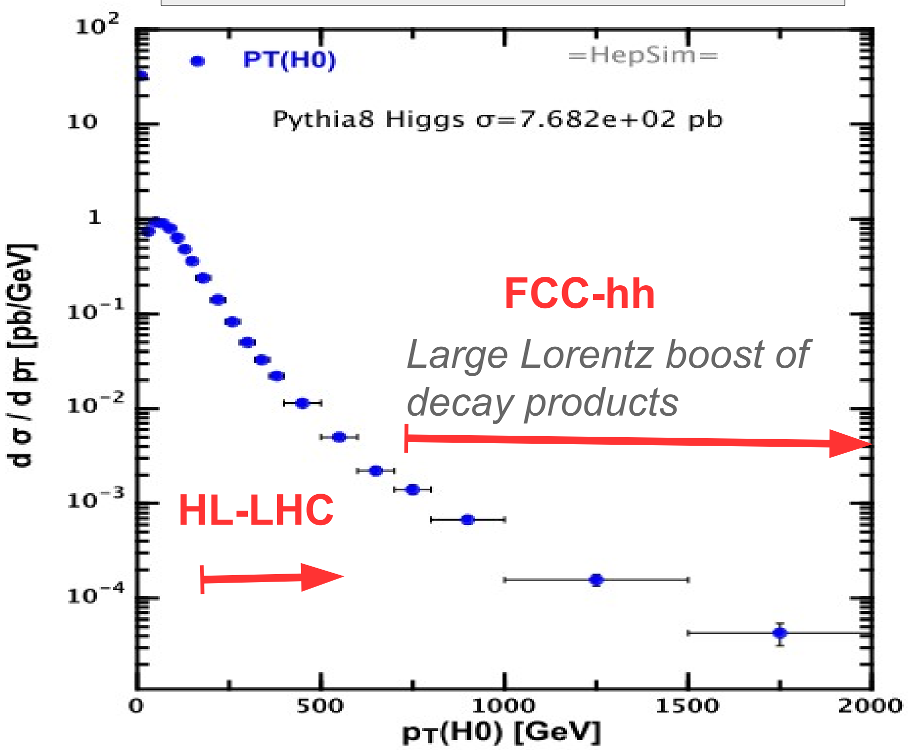
In the next decades we will deal with explorations of physics reach, detector parameters and new technology options for post-LHC era

Requires detailed simulation of physics processes and detector responses

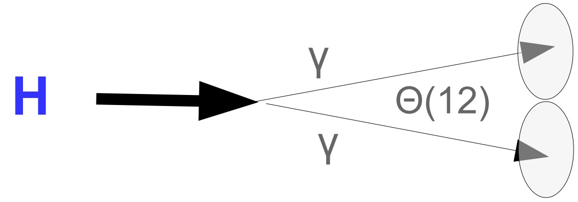
Why do we need simulations? Higgs example

- 100 TeV collider will hunt for M~30 TeV particles decaying to Higgs/W/Z bosons
- New kinematic regime → challenging for detector designs
- SM example: detectors must be optimized to reconstruct SM Higgs at large pT

100 TeV pp
Differential Higgs cross section



SM predictions: ~100,000 Higgs / ab^{-1} for pT>1 TeV



Just kinematics:
pT(H)>2 TeV → **~ 5 deg** between γ's
pT(H)>10 TeV → **~ 1 deg** between γ's

Instrumental challenges:
- identify 2 photons separated by 1 degree
- reject $\pi^0 \rightarrow \gamma\gamma$ background at the same time!
- similar problems for electron, b-jets decays

Spoiler alert:
← Calculation (+ NLO!) takes ~5 min using HepSim (+ can look at events in a detector too)

What is HepSim?

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

Repository with MC files and software toolkit for:

- Physics studies (discovery potential, future precision measurements, etc.)
- Exploration of general aspects of detectors using fast and full Geant4 simulations

NOT a file storage:

- i.e. files hosted where convenient using "https" and linked by HepSim
- for "baseline" detector simulations for CLIC, FCC-ee, FCC-hh, HE-LHC, EIC, CEPC etc.

Id	→←	E [TeV]	Dataset name	Generator	Process	Topic	Files	Created
286	e+e-	3	tev3ee_pythia8_qcdjets_tunes_qedoff	PYTHIA8	QCD dijet events with 7 tunes without ISR	SM	Info	2017/07/14
285	e+e-	0.38	gev380ee_pythia8_qcdjets_tunes_qedof	PYTHIA8	QCD dijet events with 7 tunes without ISR	SM	Info	2017/07/14
284	e-p	0.035	gev35ep_pythia8_dis1q2	PYTHIA8	DIS events at Q2>1 GeV2	SM	Info	2017/06/26
283	e-p	0.035	gev35ep_lepto6ard_dislowq2_jlab	LEPTO/ARIADNE	DIS events at Q2>1 GeV2 and W2>4 GeV2	SM	Info	2017/06/16
282	e+e-	0.5	gev500ee_pythia8_ttbar_tunes	PYTHIA8	top (ttbar) production with 7 tunes	SM	Info	2017/06/12
281	e+e-	14	tev14pp_pythia8_ttbar_tunes	PYTHIA8	top (ttbar) production with tune 14.	SM	Info	2017/06/09
280	e+e-	3	tev3ee_pythia8_ttbar_tunes	PYTHIA8	top (ttbar) production with 7 tunes	SM	Info	2017/06/03
279	e+e-	0.38	gev380ee_pythia8_ttbar_tunes	PYTHIA8	top (ttbar) production with 7 tunes	SM	Info	2017/06/03
278	e+e-	3	tev3ee_pythia8_qcdjets_tunes	PYTHIA8	QCD dijet events with 7 tunes	SM	Info	2017/05/20
277	e+e-	0.38	gev380ee_pythia8_qcdjets_tunes	PYTHIA8	QCD dijet events with 7 tunes	SM	Info	2017/05/19
276	e-p	0.035	gev35ep_lepto6ard_dislowq2	LEPTO/ARIADNE	DIS events at Q2>1 GeV2 and W2>4 GeV2	SM	Info	2017/05/17
275	e-p	0.035	gev35ep_lepto6_dis1q2	LEPTO/PYTHIA	DIS events at Q2>1 GeV2 and W2>5 GeV2	SM	Info	2017/05/01
274	e+e-	3	tev3ee_pythia8_higgs_ww	PYTHIA8	Higgs to WW	SM	Info	2017/04/29
273	e+e-	3	tev3ee_pythia8_higgs_bbar	PYTHIA8	Higgs to bbar	SM	Info	2017/04/29
272	e+e-	3	tev3ee_pythia8_qcdjets	PYTHIA8	QCD dijet events	SM	Info	2017/04/29
271	e-p	0.035	gev35ep_lepto6ard_dis1q2	LEPTO/ARIADNE	DIS events at Q2>1 GeV2 and W2>5 GeV2	SM	Info	2017/04/19
270	pp	13	tev13pp_pythia8_wh2l	PYTHIA8	WH2 with W to l+nu	Exotics	Info	2017/03/16
269	pp	13	tev13pp_pythia6_rho_techni	PYTHIA6	Technicolor rho_T to pi_T W	Exotics	Info	2017/02/26
268	pp	14	tev14pp_pythia8_higgs2mumu	PYTHIA8	Higgs to mu+mu-	Higgs	Info	2017/02/24
267	pp	13	tev13pp_pythia8_wprimezprime	PYTHIA8	Wprime to Zprime plus W	Exotics	Info	2017/02/23

What is HepSim?

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

- Consists of a web interface, distributed web storage, command-line tools, Jas3pp event browser, containerized software (docker/singularity image)
- Began at Snowmass 2013-2014
- Used for physics and detector studies for future experiments (HL-LHC, HE-LHC, FCC, CLIC, CEPC, EIC, etc.) and several ATLAS papers
- Contributed to ~30 articles, ~40 talks (see public results)

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285	e+e-	0.38	gev380ee_pythia8_qcdjets_tunes_qedof	PYTHIA8	QCD dijet events with 7 tunes wothout ISR	SM	Info	2017/07/14
284	e-p	0.035	gev35ep_pythia8_dis1q2	PYTHIA8	DIS events at Q2>1 GeV2	SM	Info	2017/06/26
283	e-p	0.035	gev35ep_lepto6ard_dislowq2_jlab	LEPTO/ARIADNE	DIS events at Q2>1 GeV2 and W2>4 GeV2	SM	Info	2017/06/16
282	e+e-	0.5	gev500ee_pythia8_ttbar_tunes	PYTHIA8	top (ttbar) production with 7 tunes	SM	Info	2017/06/12
281	e+e-	14	tev14pp_pythia8_ttbar_tunes	PYTHIA8	top (ttbar) production with tune 14.	SM	Info	2017/06/09
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279	e+e-	0.38	gev380ee_pythia8_ttbar_tunes	PYTHIA8	top (ttbar) production with 7 tunes	SM	Info	2017/06/03
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276	e-p	0.035	gev35ep_lepto6ard_dislowq2	LEPTO/ARIADNE	DIS events at Q2>1 GeV2 and W2>4 GeV2	SM	Info	2017/05/17
275	e-p	0.035	gev35ep_lepto6_dis1q2	LEPTO/PYTHIA	DIS events at Q2>1 GeV2 and W2>5 GeV2	SM	Info	2017/05/01
274	e+e-	3	tev3ee_pythia8_higgs_ww	PYTHIA8	Higgs to WW	SM	Info	2017/04/29
273	e+e-	3	tev3ee_pythia8_higgs_bbar	PYTHIA8	Higgs to bbar	SM	Info	2017/04/29
272	e+e-	3	tev3ee_pythia8_qcdjets	PYTHIA8	QCD dijet events	SM	Info	2017/04/29
271	e-p	0.035	gev35ep_lepto6ard_dis1q2	LEPTO/ARIADNE	DIS events at Q2>1 GeV2 and W2>5 GeV2	SM	Info	2017/04/19
270	pp	13	tev13pp_pythia8_wh2l	PYTHIA8	WH2 with W to l+nu	Exotics	Info	2017/03/16
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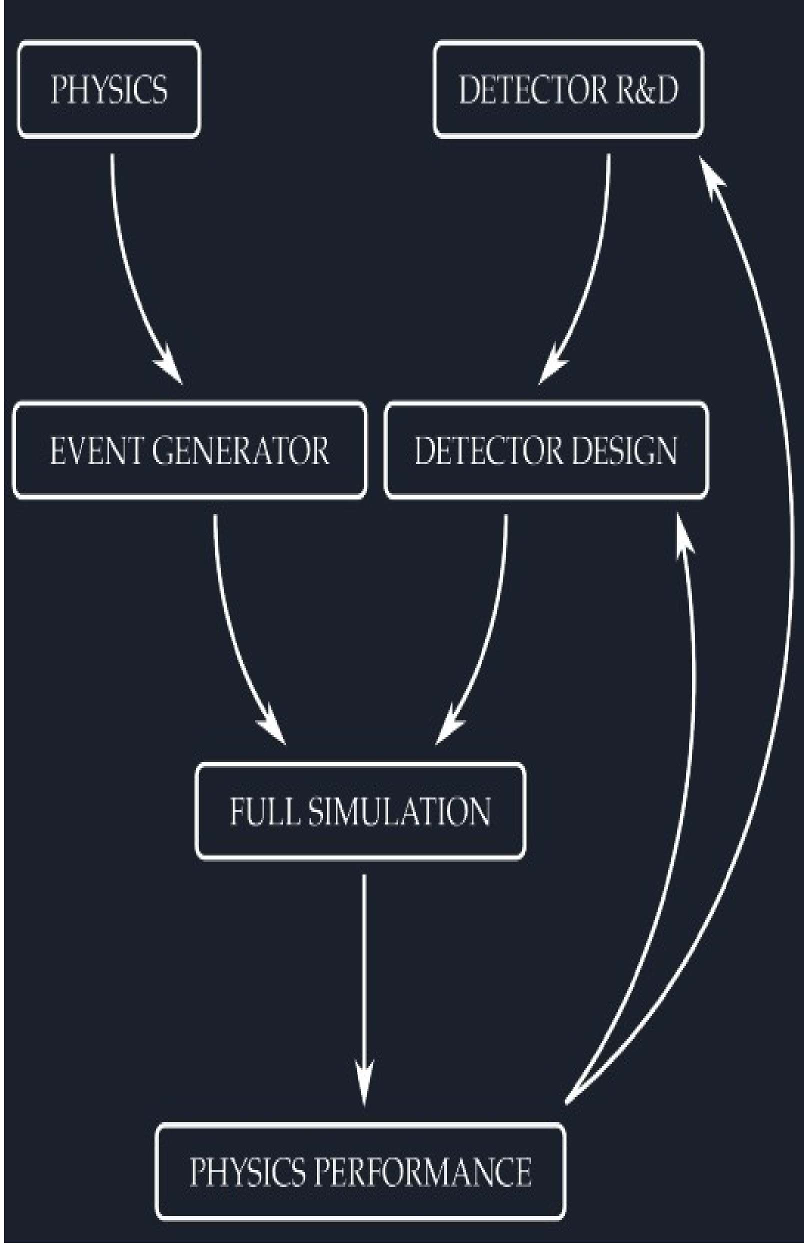
268	pp	14	tev14pp_pythia8_higgs2mumu	PYTHIA8	Higgs to mu+mu-	Higgs	Info	2017/02/24
267	pp	13	tev13pp_pythia8_wprimezprime	PYTHIA8	Wprime to Zprime plus W	Exotics	Info	2017/02/23

Why HepSim?

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

- **Open access**
  - No authentication for use of event files
  - Grab data with *hs-toolkit, wget, curl*, etc… your choice!
- **Preservation of MC data, MC settings and detector geometries**
- **Mitigate reproducibility problem in publications**
  - Published papers can cite HepSim samples
- **Platform-independent analysis**
  - Linux/Mac/Windows
  - Data streaming over URL
- **Cache for iterative experiment design process**



by W.Armstrong

Leveraging large-scale computing

Event Generators

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

osg connect

ATLAS CONNECT

NERSC

PETREL
Data Management and Sharing Pilot

MIRA

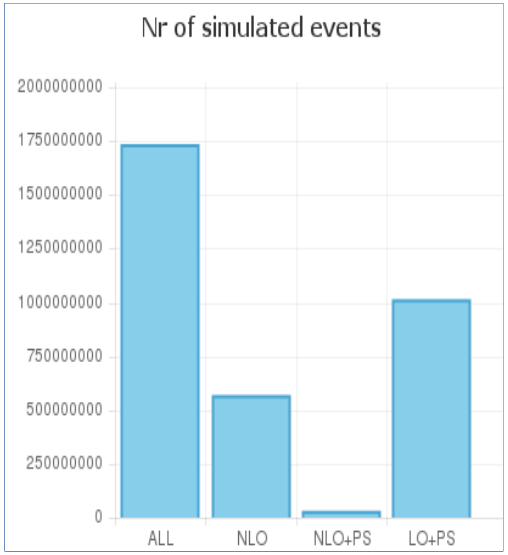
EVGEN

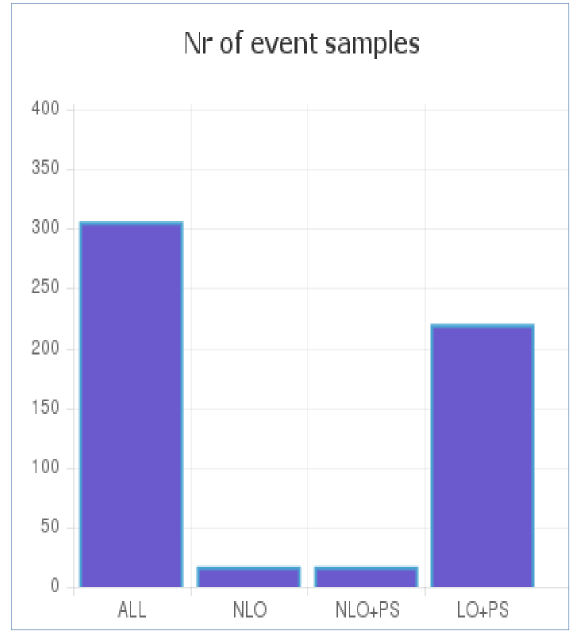
fast → Delphes fast simulation (ROOT files)

full → Geant4 full simulation and reconstruction software

- **Integrated with Chicago-area computing:**
  - CPU: OSG Connect, UChicago, LCRC, ALCF
  - File storage: PETREL Data Management and Sharing Pilot
- **HepSim FrontEnd mirrored at JLab, NERSC, CERN**
- **Easy to link self-managed external file storage**

HepSim event statistics (excluding fast and Geant4 detector simulations)



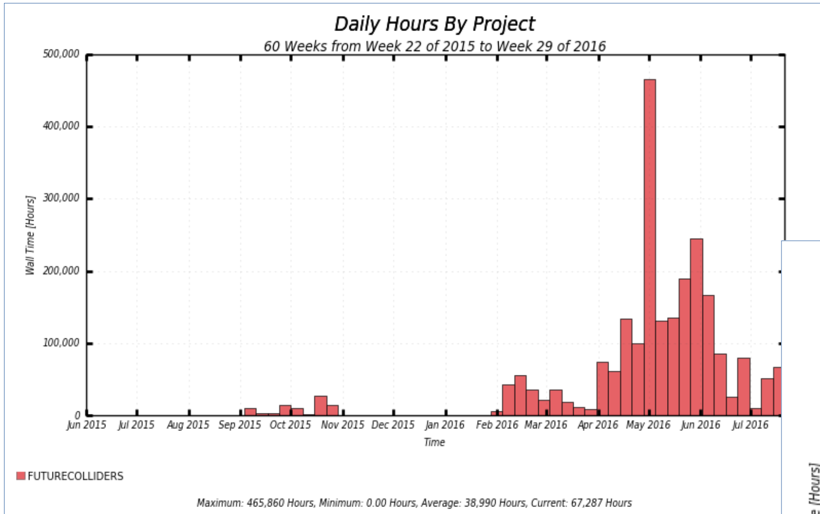


~ 340 Monte Carlo samples (LO, NLO, NLO+PS, LO+PS)
~ 2 billion stored EVGEN events
  ~ 10% after fast simulations(Delphes)
  ~ 0.1% after Geant4 simulations

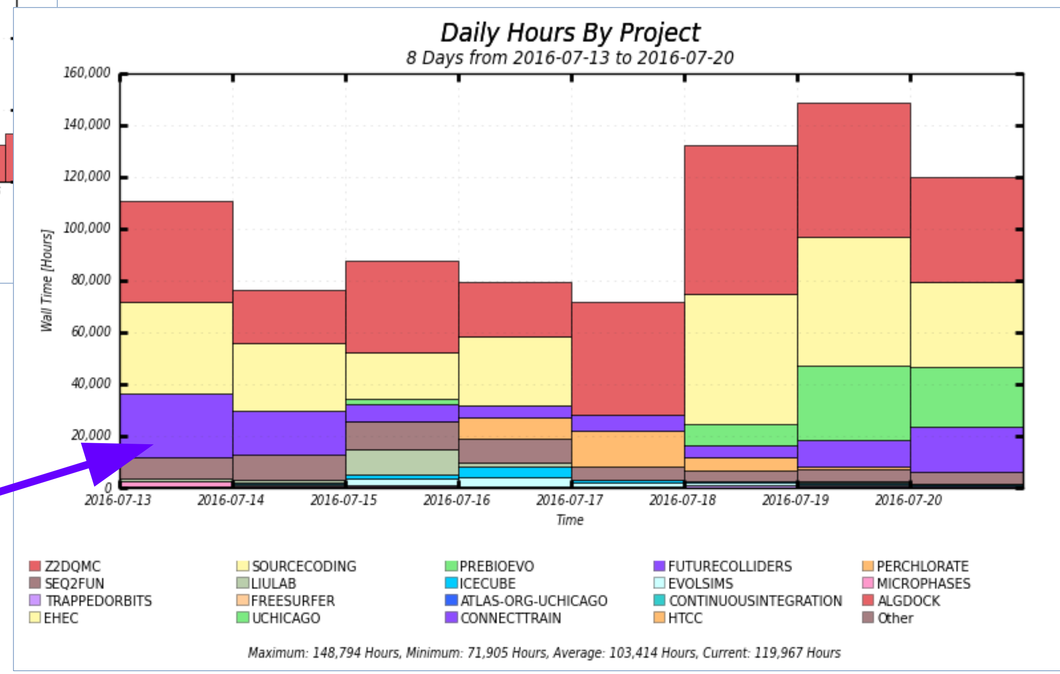
Number of public file servers	6
Number of event samples	306
Number of NLO samples	17
Number of NLO+PS samples	17
Number of LO (+PS) samples	220
Number of events	1736160679
NLO events	570440248
NLO+PS events	32860595
LO (+PS) events	1015127136
Total size (GB)	7373.477
NLO size (GB)	238.099
NLO+PS size (GB)	348.696
LO (+PS) size (GB)	6761.413
Number of files	344922

Usage of computational platforms:
- 10% → BlueGene/Q (ANL/Mira) (Jetphox, MCFM)
- 50% → HEP-ANL (mainly Madgraph)
- 40% → OSG-CI grid and USATLAS CI (for phase II)

CPU usage for HepSim simulations



CPU*h OSG-Connect



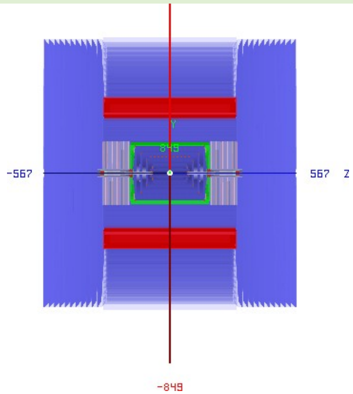
HepSim simulations (SLIC/Geant4)

HepSim uses:

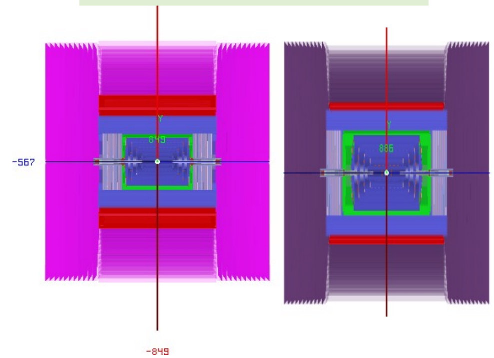
- OSG “Future Collider” project (20 M CPU*h in 2016)
- OSG “EIC” (electron ion collider) project (starting from 2017)

‘All-silicon’ design concepts supported in HepSim

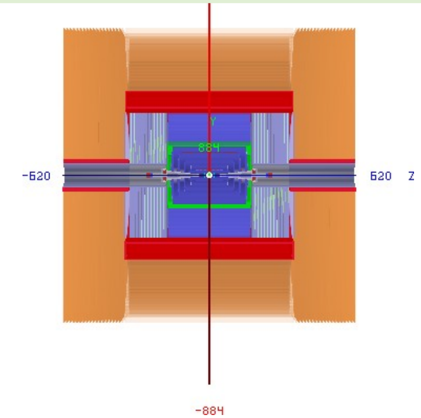
SiD (SiD LO3)
($e^+ e^-$ up to 1 TeV)



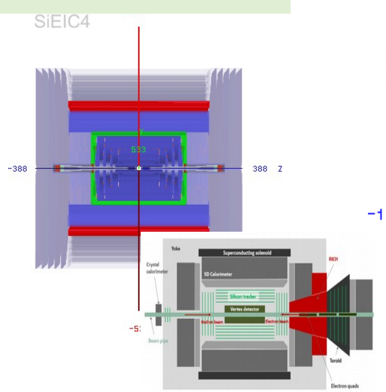
SiCPEC, SiDB
($e^+ e^-$ 250 GeV)



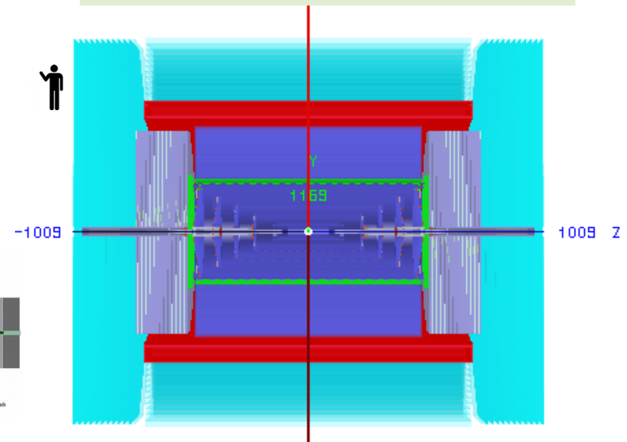
CLIC-SiD (CDR)
($e^+ e^-$ up to 3 TeV)



SiEIC, TopSide
(ep, 35-141 GeV)



SiFCC + 7 variations
(FCC-hh, pp 100 TeV)



Performance detectors:

- Physics reach studies using Geant4 simulations & full reconstruction
- Playground for various technologies and detector optimizations
- Fast turnover to modify detector & create events samples

Share similar design, but differ in sizes, calorimeter readouts etc
Interfaced with common Monte Carlo samples

Bringing innovations to I/O: ProMC and ProIO

http://atlaswww.hep.anl.gov/asc/promc/ and https://github.com/proio-org

- HepSim uses new event formats: ProMC and ProIO
- Archive self-described format to keep events
- 30% smaller files than ROOT I/O

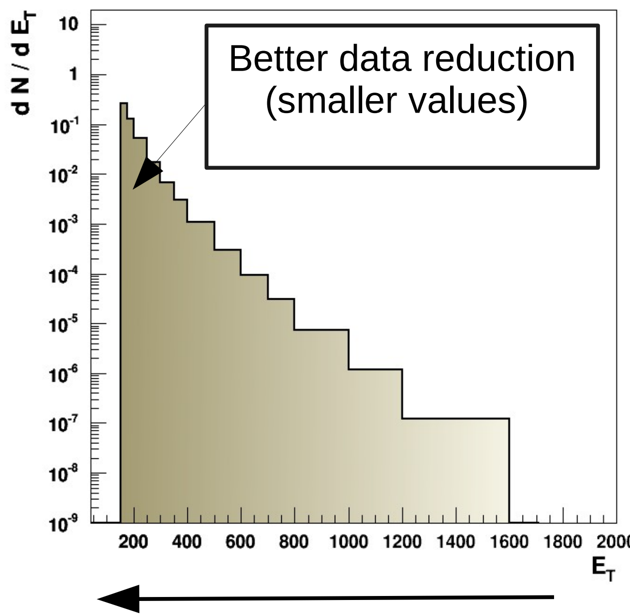
8-bytes → varint

Google's Protocol buffers

protobuf

Protocol Buffers - Google's data interchange format

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



compression strength keeping precision of representation constant

- Effective file size reduction for pile-up events
  - Particles with small momenta → less bytes used
- Separate events can be streamed over the Internet
- ProMC is being replaced by **ProIO** data format
  - *Comm. Phys. Comm. 241 (2019) 98*
  - *F*lexible, modern API for reconstructed events, support for C++/Java/Python/GO languages
- Other HepSim formats: **ROOT** and **LCIO** (full simulation)

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

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p →← *p*
- 8 TeV
- 13 TeV
- 14 TeV
- 27 TeV
- 33 TeV
- 100 TeV

$e^+ \rightarrow\leftarrow e^-$
- 250 GeV
- 380 GeV
- 500 GeV
- 1 TeV
- 3 TeV

$\mu^+ \rightarrow\leftarrow \mu^-$
- 1 TeV
- 5 TeV
- 10 TeV
- 20 TeV
- 40 TeV

HepSim

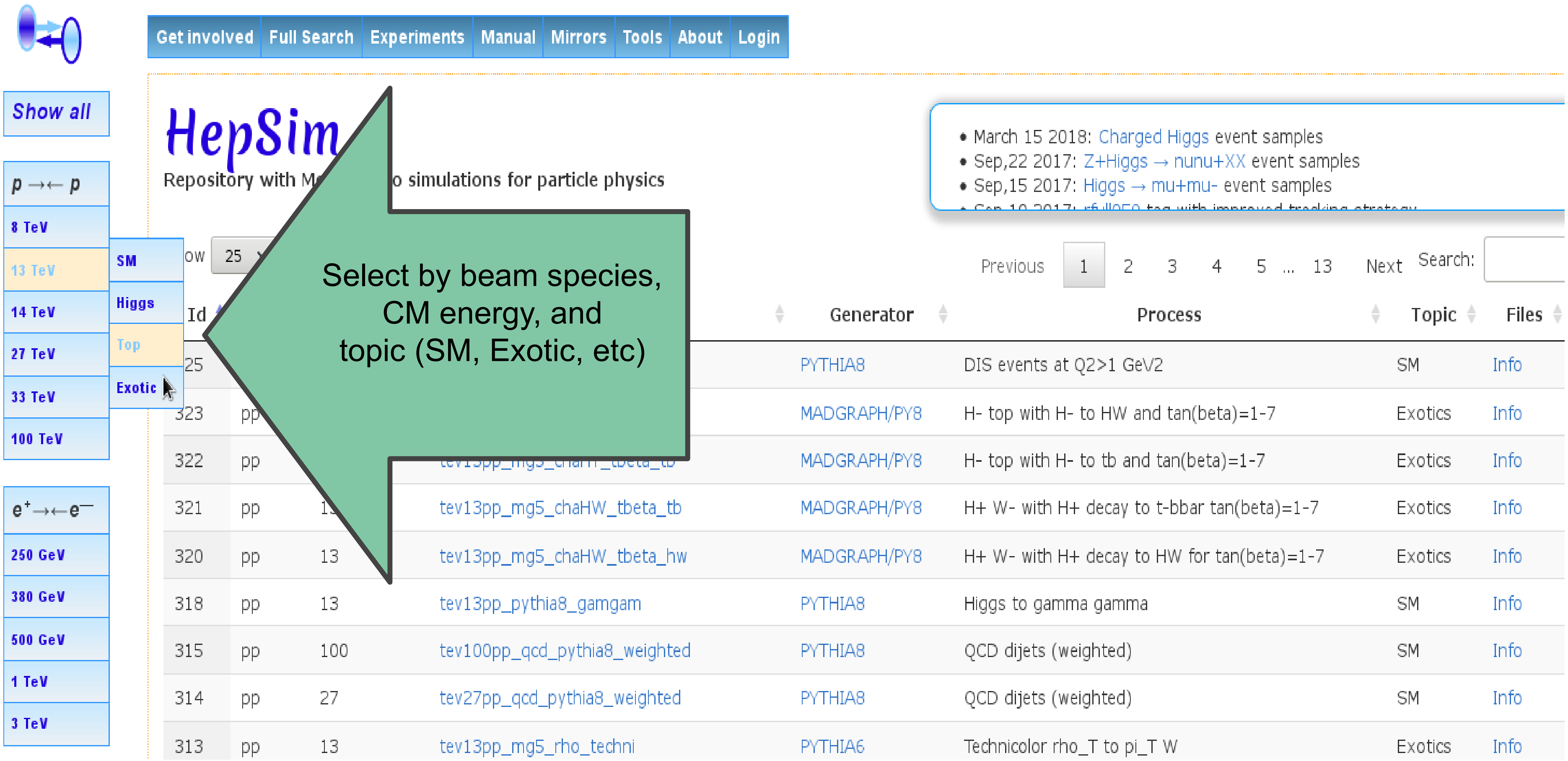
Repository with Monte Carlo simulations for particle physics

- Apr 15, 2019: Moving to globus (petrel)
- Sep.10 2018: Zprime/DM event samples
- Mar.15 2018: Charged Higgs event samples

Show 25 entries

Previous 1 2 3 4 5 ... 13 Next Search:

Id	→←	E [TeV]	Dataset name	Generator	Process	Topic	Files	Created
338	pgun	1	pgun_eta0_b0	PARTICLE GUN	Single particles at Eta=Phi=0 with B-field=0	Single particles	Info	2019/09/03
337	pp	14	tev14pp_pythia8_gammajet_weighted	PYTHIA8	Direct photon production	SM	Info	2018/12/16
336	pp	13	tev13pp_pythia8_minbias_a14	PYTHIA8	MinBias (ND+SD+DD) A14	SM	Info	2018/11/23
335	pp	14	tev14pp_pythia8_minbias_a14	PYTHIA8	MinBias (ND+SD+DD) A14	SM	Info	2018/11/22
334	pp	13	tev13pp_mg5_chaH4FNS	MADGRAPH/PY8	Charged Higgs (H+t) production in 4FNS	Exotics	Info	2018/11/10
333	pp	13	tev13pp_pythia8_qcd_jz	PYTHIA8	QCD multijets with filtered in pT slices	SM	Info	2018/10/31
332	pp	13	tev13pp_pythia8_qcd_em	PYTHIA8	QCD multijets with filtered leptons	SM	Info	2018/10/26
331	pp	13	tev13pp_pythia8_ttbarwz_wgt	PYTHIA8	SM EW and top processes	SM	Info	2018/10/25
330	pp	13	tev13pp_mg5_dm_a_boson	MADGRAPH/PY8	Zprime for dijet+W/Z events and interference	Exotics	Info	2018/10/09
329	pp	13	tev13pp_mg5_dm_boson	MADGRAPH/PY8	Zprime for dijet+W/Z events	Exotics	Info	2018/09/26
328	pp	13	tev13pp_pythia8_rmm	PYTHIA8	Various SM/BSM process for ML	SM	Info	2018/09/16
327	pp	13	tev13pp_qcd_pythia8_proio	PYTHIA8	QCD dijets for ProIO tests	SM	Info	2018/08/27
326	pp	13	tev13pp_qcd_pythia8_proio_tests	PYTHIA8	QCD dijets for tests of ProIO	SM	Info	2018/08/20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14 TeV
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1 TeV
3 TeV
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Higgs
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Exotic
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o simulations for particle physics
March 15 2018: Charged Higgs event samples
Sep,22 2017: Z+Higgs → nunu+XX event samples
Sep,15 2017: Higgs → mu+mu- event samples
Previous 1 2 3 4 5 ... 13 Next
Search:
Select by beam species, CM energy, and topic (SM, Exotic, etc)
Id
Generator
Process
Topic
Files
25 PYTHIA8 DIS events at Q2>1 GeV2 SM Info
323 pp MADGRAPH/PY8 H- top with H- to HW and tan(beta)=1-7 Exotics Info
322 pp MADGRAPH/PY8 H- top with H- to tb and tan(beta)=1-7 Exotics Info
321 pp tev13pp_mg5_chaHW_tbeta_tb MADGRAPH/PY8 H+ W- with H+ decay to t-bbar tan(beta)=1-7 Exotics Info
320 pp 13 tev13pp_mg5_chaHW_tbeta_hw MADGRAPH/PY8 H+ W- with H+ decay to HW for tan(beta)=1-7 Exotics Info
318 pp 13 tev13pp_pythia8_gamgam PYTHIA8 Higgs to gamma gamma SM Info
315 pp 100 tev100pp_qcd_pythia8_weighted PYTHIA8 QCD dijets (weighted) SM Info
314 pp 27 tev27pp_qcd_pythia8_weighted PYTHIA8 QCD dijets (weighted) SM Info
313 pp 13 tev13pp_mg5_rho_techni PYTHIA6 Technicolor rho_T to pi_T W Exotics Info


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HepSim
Repository with Monte Carlo simulations for particle physic
Choose dataset based on generator and process descriptions
Charged Higgs event samples
Z+Higgs → nunu+XX event samples
Higgs → mu+mu- event samples
8 TeV
13 TeV
14 TeV
27 TeV
33 TeV
100 TeV
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25 entries
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Search:
Id
E [TeV]
Dataset name
Process
Topic
Files
e-p 0.035 gev35ep_pythia8_dis1q2ct14lo PYTHIA8 DIS events at Q2>1 GeV2 SM Info
323 pp 13 tev13pp_mg5_chaHT_tbeta_hw MADGRAPH/PY8 H- top with H- to HW and tan(beta)=1-7 Exotics Info
322 pp 13 tev13pp_mg5_chaHT_tbeta_tb MADGRAPH/PY8 H- top with H- to tb and tan(beta)=1-7 Exotics Info
321 pp 13 tev13pp_mg5_chaHW_tbeta_tb MADGRAPH/PY8 H+ W- with H+ decay to t-bbar tan(beta)=1-7 Exotics Info
320 pp 13 tev13pp_mg5_chaHW_tbeta_hw Exotics Info
318 pp 13 tev13pp_pythia8_gamgam SM Info
315 pp 100 tev100pp_qcd_pythia8_weighted SM Info
314 pp 27 tev27pp_qcd_pythia8_weighted PYTHIA8 SM Info
313 pp 13 tev13pp_mg5_rho_techni PYTHIA6 Exotics Info
Then click on data set name to look at more closely

Show all

p →← p
- 8 TeV
- 13 TeV
- 14 TeV
- 27 TeV
- 33 TeV
- 100 TeV

e+ →← e−
- 250 GeV
- 380 GeV
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- 1 TeV
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μ+ →← μ−
- 1 TeV
- 5 TeV
- 10 TeV
- 20 TeV
- 40 TeV

HepSim

Repository with Monte Carlo simulations for particle physics

- Apr 15, 2019: Moving to globus (petrel)

This brings up information page for dataset. Starting with basic parameters, integrated luminosity, and a link to the download page

Dataset: *"tev100pp_qcd_pythia8_ptall"*

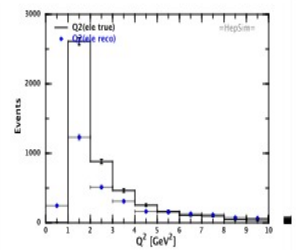
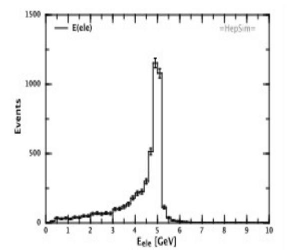
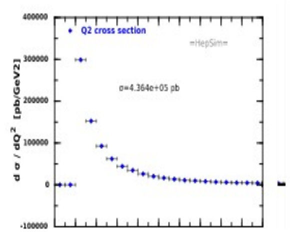
	Summary	
Name:	*tev100pp_qcd_pythia8_ptall*	
Collisions:	pp	
CM Energy:	100 TeV	
Entry ID:	219	
Topic:	SM	
Generator:	PYTHIA8	
Calculation level:	LO+PS+hadronisation	
Process:	QCD dijets in bins of pT	
Total events:	490000	
Number of files:	490	
Cross section (σ):	4.582E+07 ± 7.751E+05pb	Estimated from file Nr 1
Luminosity (L):	0.0107 pb^{-1} *(or)* 1.069E-05 fb^{-1} *(or)* 1.069E-08 ab^{-1}	
Format:	ProMC	
Download URL:	http://mc.hep.anl.gov/asc/hepsim/events/pp/100tev/qcd_pythia8_ptall	Status: Available
Mirrors:	http://portal.nersc.gov/project/m1758/data/events/pp/100tev/qcd_pyth[illegible]	
EVGEN size:	36.169 GB	
	Tags:	
Fast simulation:	rfast005 | Info 100 / 1.56 GB 10/16/2016	
Full simulation:	rfull015 | Info 341 / 15.85 GB 06/06/2017 rfull009 | Info 434 / 57.82 GB 06/23/2017	

```
parameter EVGEN:ProcessID [int]
parameter EVGEN:DIS:Q2 [float]      // Truth-level Q^2
parameter EVGEN:DIS:W [float]       // Truth-level W
parameter EVGEN:DIS:XBJ [float]     // Truth_level x_bjorken
parameter EVGEN:DIS:YBJ [float]     // Truth_level y_bjorken
```

Please refer the HepSim manual

File metadata: Show

Validation:

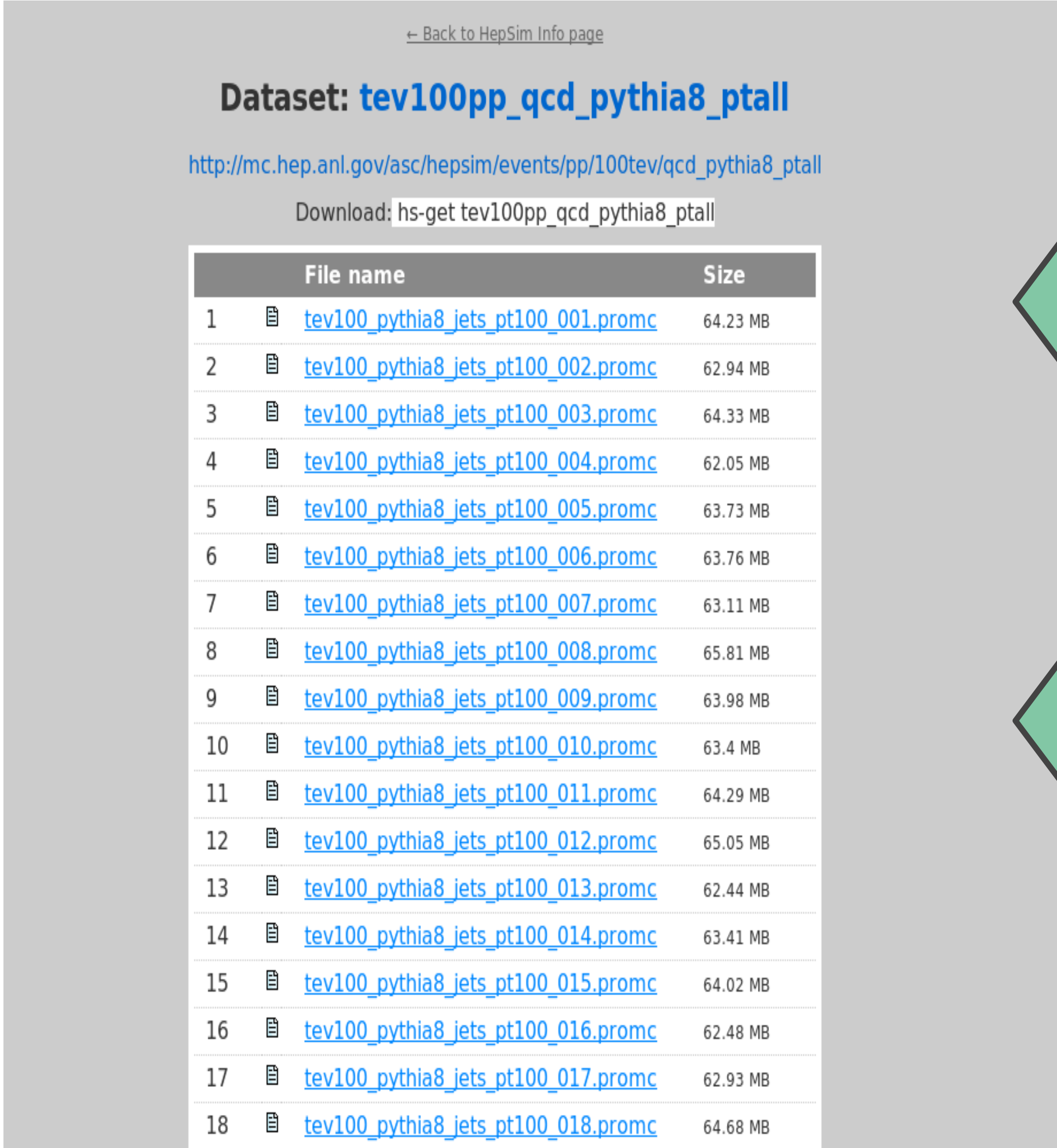
Nr	Analysis code	Output image	Output data
1	truth_q2_dislowq2_lcio.py Run		JDAT file
2	truth_ele_dislowq2_lcio.py Run		JDAT file
3	lepto6ard_dislowq2.py Run		JDAT file

Validation scripts and plots

Uses Python (Jython) scripts

Can be executed on Web browsers, Windows etc

Web Interface - Truth Level Navigation


← Back to HepSim Info page

Dataset: tev100pp_qcd_pythia8_ptall

http://mc.hep.anl.gov/asc/hepsim/events/pp/100tev/qcd_pythia8_ptall

Download: hs-get tev100pp_qcd_pythia8_ptall

	File name	Size
1	tev100_pythia8_jets_pt100_001.promc	64.23 MB
2	tev100_pythia8_jets_pt100_002.promc	62.94 MB
3	tev100_pythia8_jets_pt100_003.promc	64.33 MB
4	tev100_pythia8_jets_pt100_004.promc	62.05 MB
5	tev100_pythia8_jets_pt100_005.promc	63.73 MB
6	tev100_pythia8_jets_pt100_006.promc	63.76 MB
7	tev100_pythia8_jets_pt100_007.promc	63.11 MB
8	tev100_pythia8_jets_pt100_008.promc	65.81 MB
9	tev100_pythia8_jets_pt100_009.promc	63.98 MB
10	tev100_pythia8_jets_pt100_010.promc	63.4 MB
11	tev100_pythia8_jets_pt100_011.promc	64.29 MB
12	tev100_pythia8_jets_pt100_012.promc	65.05 MB
13	tev100_pythia8_jets_pt100_013.promc	62.44 MB
14	tev100_pythia8_jets_pt100_014.promc	63.41 MB
15	tev100_pythia8_jets_pt100_015.promc	64.02 MB
16	tev100_pythia8_jets_pt100_016.promc	62.48 MB
17	tev100_pythia8_jets_pt100_017.promc	62.93 MB
18	tev100_pythia8_jets_pt100_018.promc	64.68 MB

hs-toolkit helper command

Direct HTTPS download links

Web Interface - Truth Level Navigation

Get involved | Full Search | Experiments | Manual | Mirrors | Tools | About | Login

HEP.ANL.GOV

Show all

p →← *p*
- 8 TeV
- 13 TeV
- 14 TeV
- 27 TeV
- 33 TeV
- 100 TeV

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

$\mu^+ \to\leftarrow \mu^-$

HepSim

Repository with Monte Carlo simulations

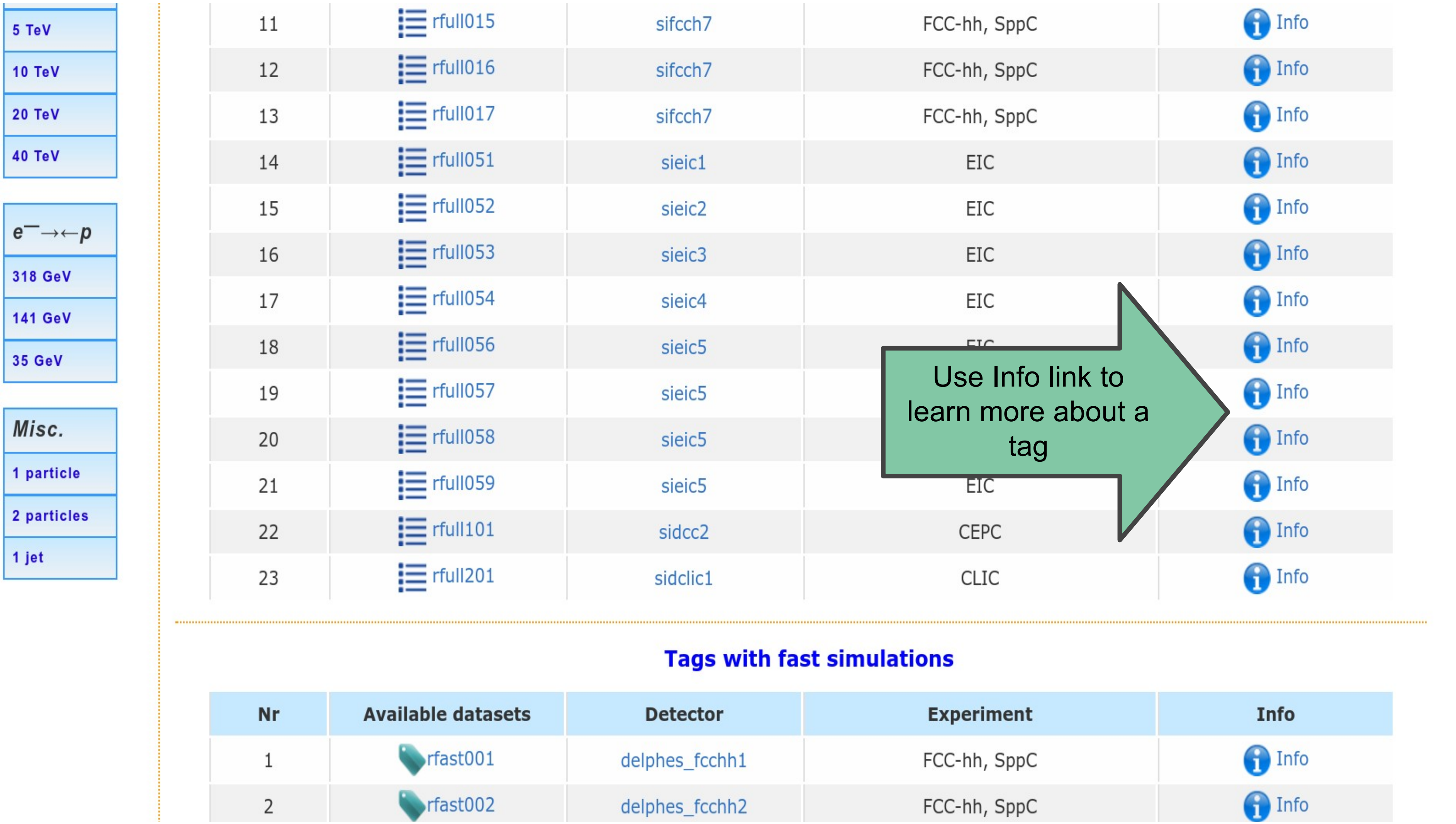
Navigate by detector and/or experiment

un.29, 2017: rfull058 tag with improved tracking strategy from
.Blyth
un.20, 2017: rfull057 tag with alternative tracking strategy from
Blyth

Here is a list of tags with simulation of detectors.

Tags with full simulations

Nr	Find data	Detector	Experiment	Description
1	rfull001	sidloi3	ILC	Info
2	rfull002	sidcc1	CEPC	Info
3	rfull003	sidloi4	ILC	Info
4	rfull006	sifcch4	FCC-hh, SppC	Info
5	rfull009	sifcch7	FCC-hh, SppC	Info
6	rfull010	sifcch8	FCC-hh, SppC	Info
7	rfull011	sifcch9	FCC-hh, SppC	Info
8	rfull012	sifcch10	FCC-hh, SppC	Info
9	rfull013	sifcch11	FCC-hh, SppC	Info

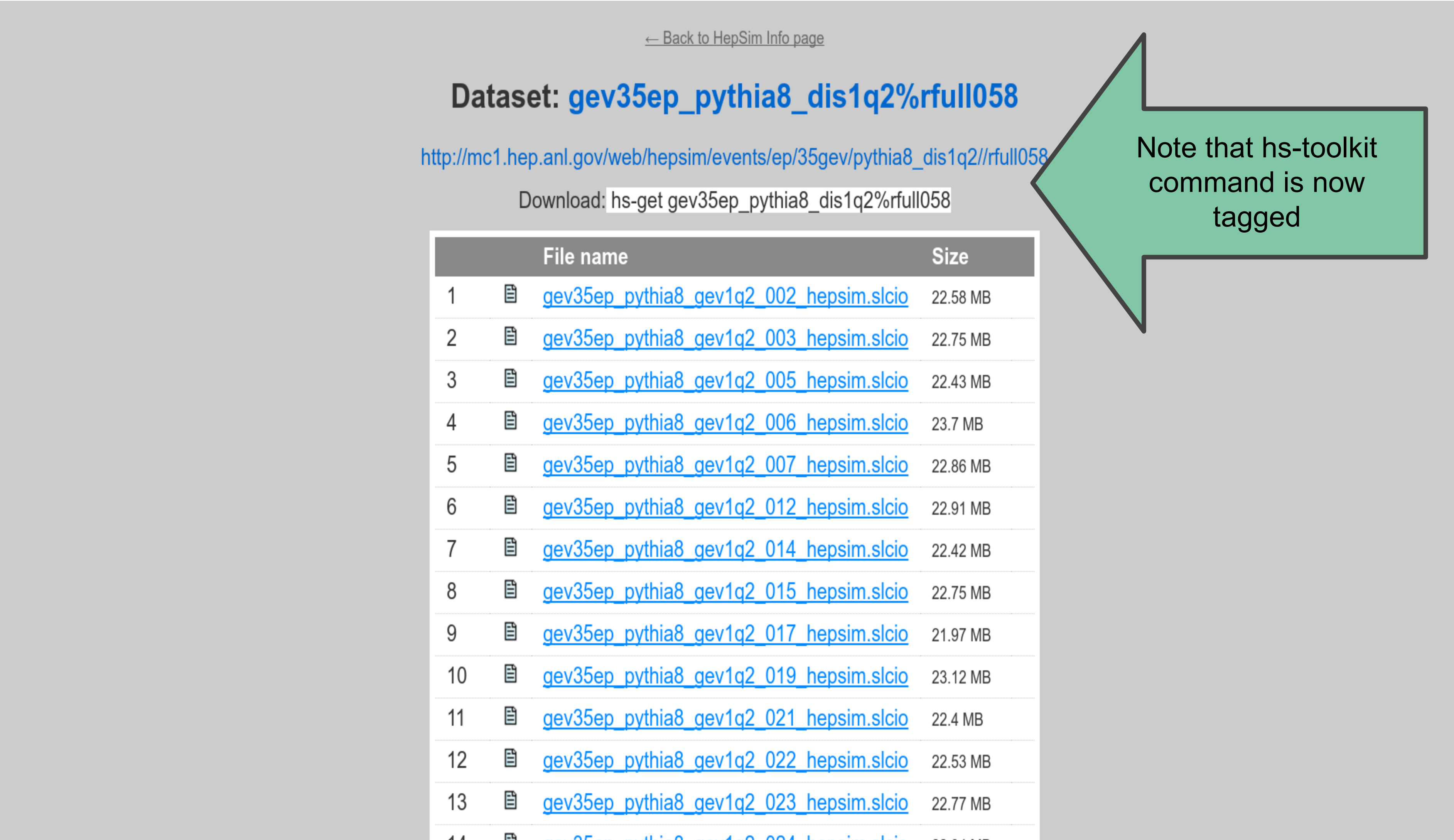


Nr	Available datasets	Detector	Experiment	Info
11	rfull015	sifcch7	FCC-hh, SppC	Info
12	rfull016	sifcch7	FCC-hh, SppC	Info
13	rfull017	sifcch7	FCC-hh, SppC	Info
14	rfull051	sieic1	EIC	Info
15	rfull052	sieic2	EIC	Info
16	rfull053	sieic3	EIC	Info
17	rfull054	sieic4	EIC	Info
18	rfull056	sieic5	EIC	Info
19	rfull057	sieic5		Info
20	rfull058	sieic5		Info
21	rfull059	sieic5	EIC	Info
22	rfull101	sidcc2	CEPC	Info
23	rfull201	sidclic1	CLIC	Info

Tags with fast simulations

Nr	Available datasets	Detector	Experiment	Info
1	rfast001	delphes_fcchh1	FCC-hh, SppC	Info
2	rfast002	delphes_fcchh2	FCC-hh, SppC	Info

Web Interface - Simulation Tag Navigation



← Back to HepSim Info page

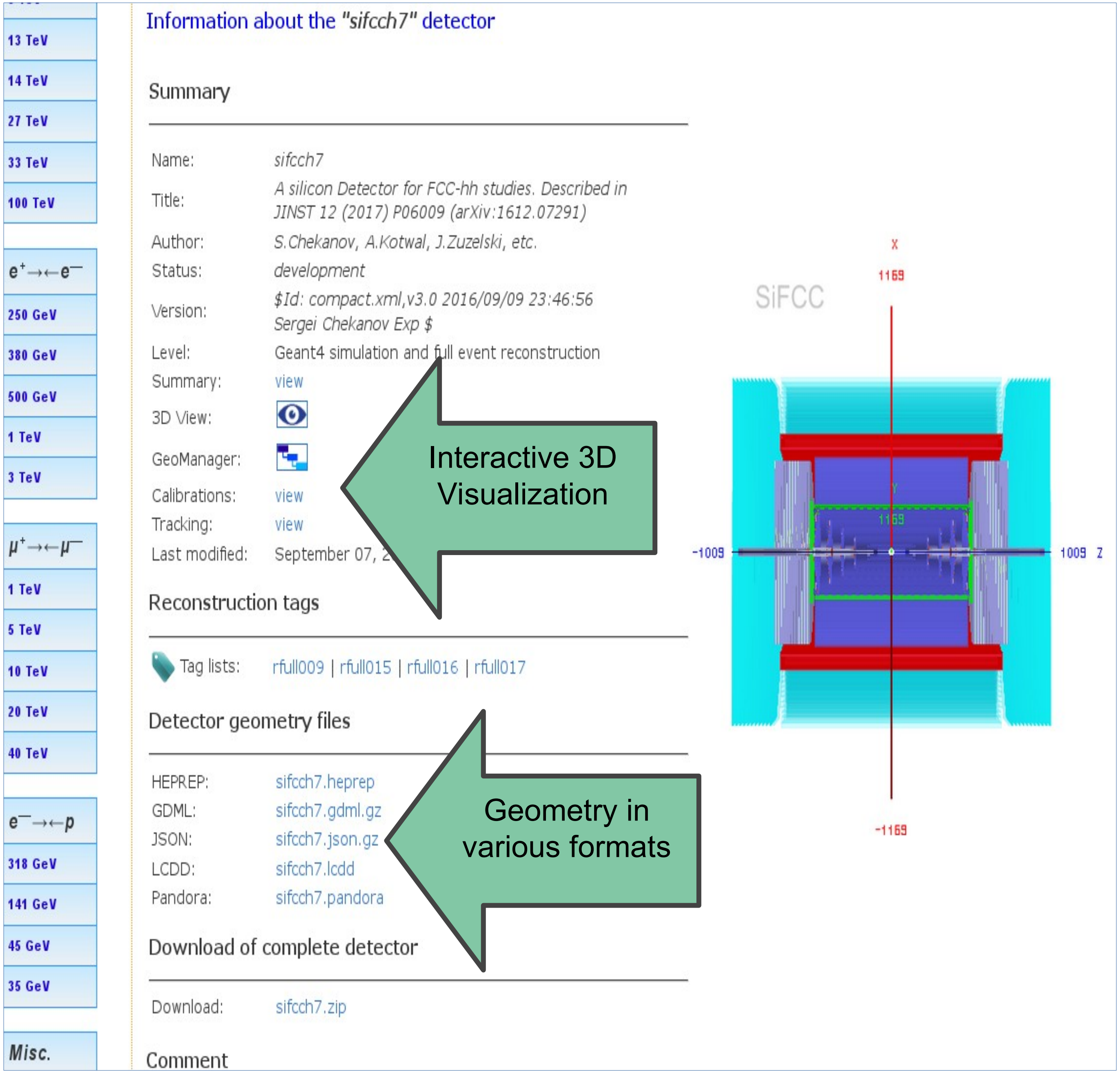
Dataset: gev35ep_pythia8_dis1q2%rfull058

http://mc1.hep.anl.gov/web/hepsim/events/ep/35gev/pythia8_dis1q2//rfull058

Download: hs-get gev35ep_pythia8_dis1q2%rfull058

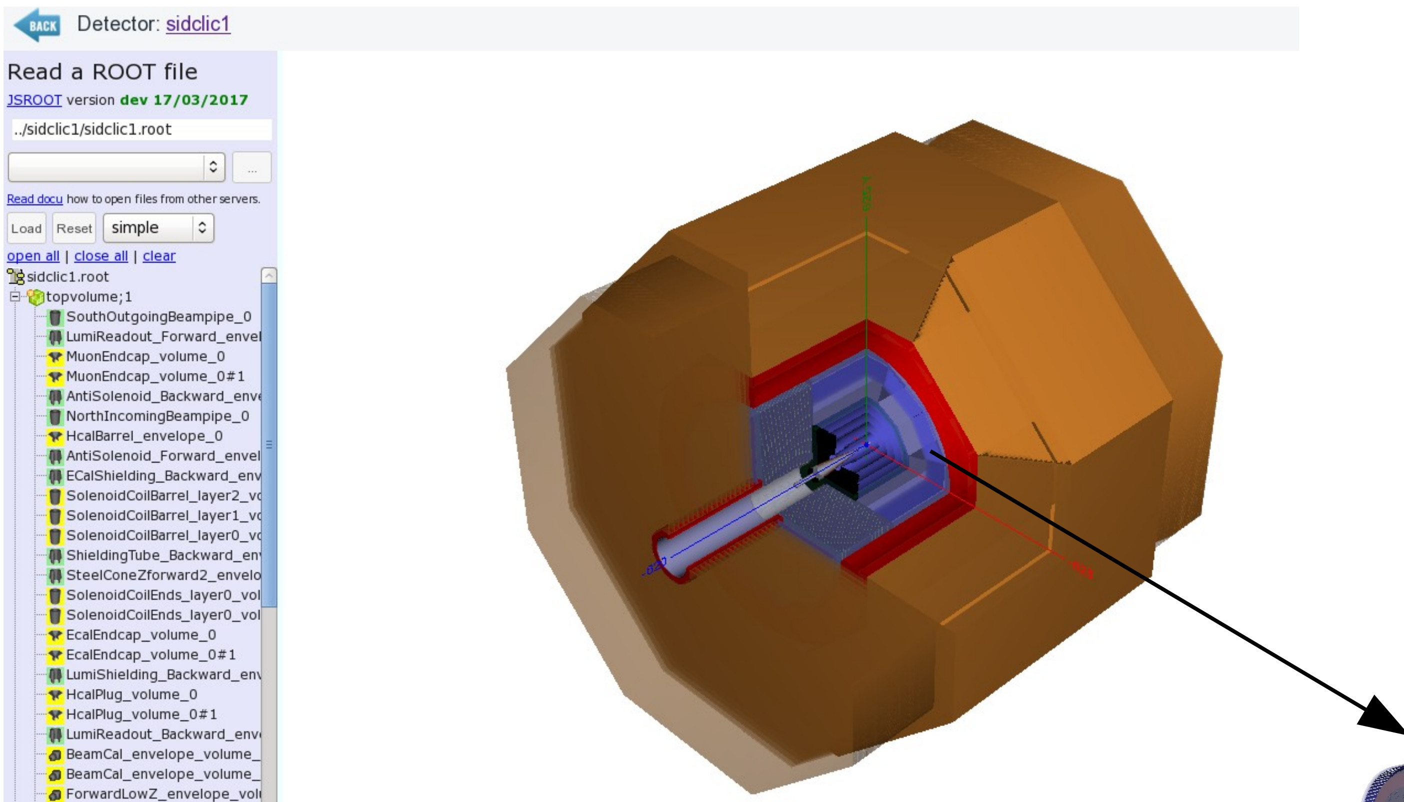
		File name	Size
1	🗎	gev35ep_pythia8_gev1q2_002_hepsim.slcio	22.58 MB
2	🗎	gev35ep_pythia8_gev1q2_003_hepsim.slcio	22.75 MB
3	🗎	gev35ep_pythia8_gev1q2_005_hepsim.slcio	22.43 MB
4	🗎	gev35ep_pythia8_gev1q2_006_hepsim.slcio	23.7 MB
5	🗎	gev35ep_pythia8_gev1q2_007_hepsim.slcio	22.86 MB
6	🗎	gev35ep_pythia8_gev1q2_012_hepsim.slcio	22.91 MB
7	🗎	gev35ep_pythia8_gev1q2_014_hepsim.slcio	22.42 MB
8	🗎	gev35ep_pythia8_gev1q2_015_hepsim.slcio	22.75 MB
9	🗎	gev35ep_pythia8_gev1q2_017_hepsim.slcio	21.97 MB
10	🗎	gev35ep_pythia8_gev1q2_019_hepsim.slcio	23.12 MB
11	🗎	gev35ep_pythia8_gev1q2_021_hepsim.slcio	22.4 MB
12	🗎	gev35ep_pythia8_gev1q2_022_hepsim.slcio	22.53 MB
13	🗎	gev35ep_pythia8_gev1q2_023_hepsim.slcio	22.77 MB
14	🗎	gev35ep_pythia8_gev1q2_024_hepsim.slcio	22.94 MB

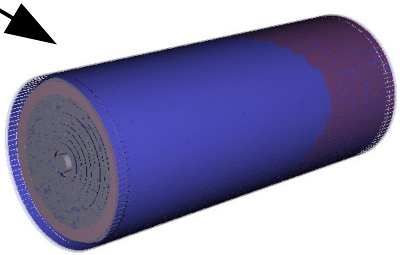
Note that hs-toolkit command is now tagged


13 TeV
14 TeV
27 TeV
33 TeV
100 TeV
e⁺→←e⁻
250 GeV
380 GeV
500 GeV
1 TeV
3 TeV
μ⁺→←μ⁻
1 TeV
5 TeV
10 TeV
20 TeV
40 TeV
e⁻→←p
318 GeV
141 GeV
45 GeV
35 GeV
Misc.
Information about the "sifcch7" detector
Summary
Name: sifcch7
Title: A silicon Detector for FCC-hh studies. Described in JINST 12 (2017) P06009 (arXiv:1612.07291)
Author: S.Chekanov, A.Kotwal, J.Zuzelski, etc.
Status: development
Version: $Id: compact.xml,v3.0 2016/09/09 23:46:56 Sergei Chekanov Exp $
Level: Geant4 simulation and full event reconstruction
Summary: view
3D View:
GeoManager:
Calibrations: view
Tracking: view
Last modified: September 07, 2
Reconstruction tags
Tag lists: rfull009 | rfull015 | rfull016 | rfull017
Detector geometry files
HEPREP: sifcch7.heprep
GDML: sifcch7.gdml.gz
JSON: sifcch7.json.gz
LCDD: sifcch7.lcdd
Pandora: sifcch7.pandora
Download of complete detector
Download: sifcch7.zip
Comment
SiFCC
X
1169
-1009
1009 Z
-1169
Interactive 3D Visualization
Geometry in various formats

Web-based 3D browser for detector geometries

- Detector volumes can **interactively** be studied in 3D using GeoManager
- Functionality since 2017





Design a detector → create LCIO files → performance studies

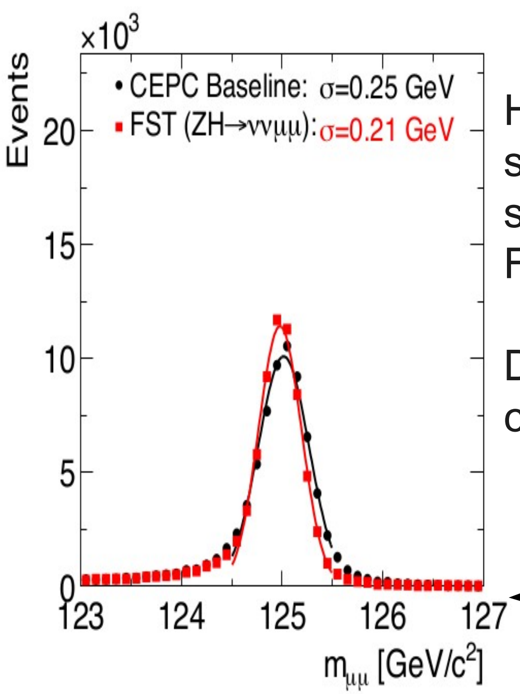
How your work can benefit from HepSim

- **Physics studies:**
  - Use truth-level Monte Carlo samples
  - Use fast detector simulations using *Delphes program*
- **Detector design: full simulation and reconstruction software chain**
  - Using HepSim’s truth-level samples as input
  - Produce simulated/reconstructed samples at key points
  - Simulation tags serve as a means to distribute and organize samples
  - Each geometry iteration is documented with simulation tags
  - Collaboratively assesses change in detector performance by referencing tags

Example: Studies of CEPC silicon tracker option

https://atlaswww.hep.anl.gov/hepsim/detectorinfo.php?id=sidcc3

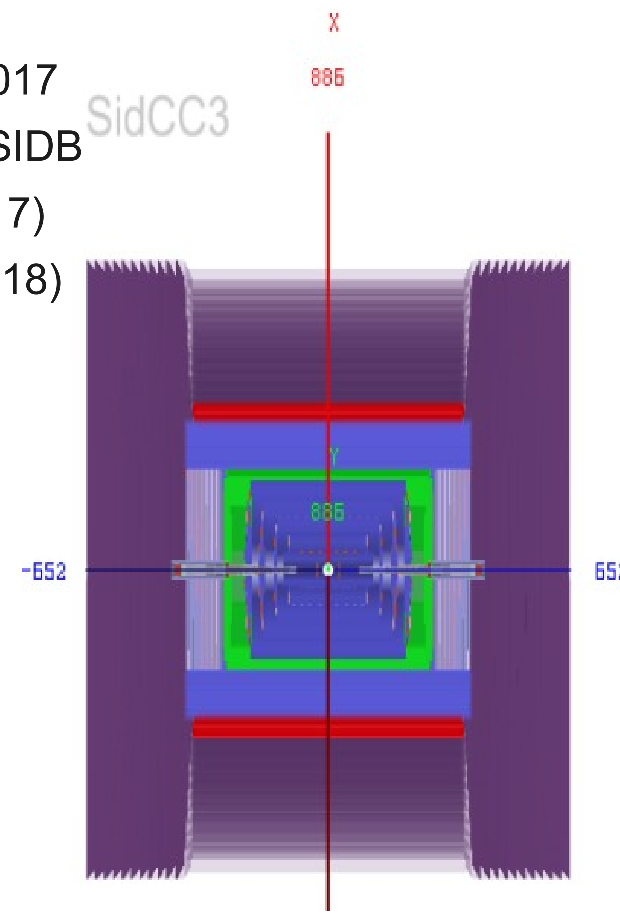
- SiD modified design to match CEPC goals (250 GeV) proposed in 2016 (S.C. & M. Demarteau IJMPA 31 644021-1)
- Silicon concept tuned by Wei-Ming Yao and Manqi Ruan in 2017
  - ✔ expanding the SID design to full CEPC tracking volume → SIDB
  - ✔ CEPCSIDV6 vs SIDB: W.M. Yao, Workshop on CEPC (2017)
- Included to Sect. "Full silicon tracker" (FST) in CEPC CDR (2018)



from CEPC CDR (2018) page 179

HepSim archives 12 Monte Carlo samples for e+e- (250 GeV) after full simulation and reconstruction with FST CEPC design

Data include complete events (with calorimeter, muon tracker etc.)



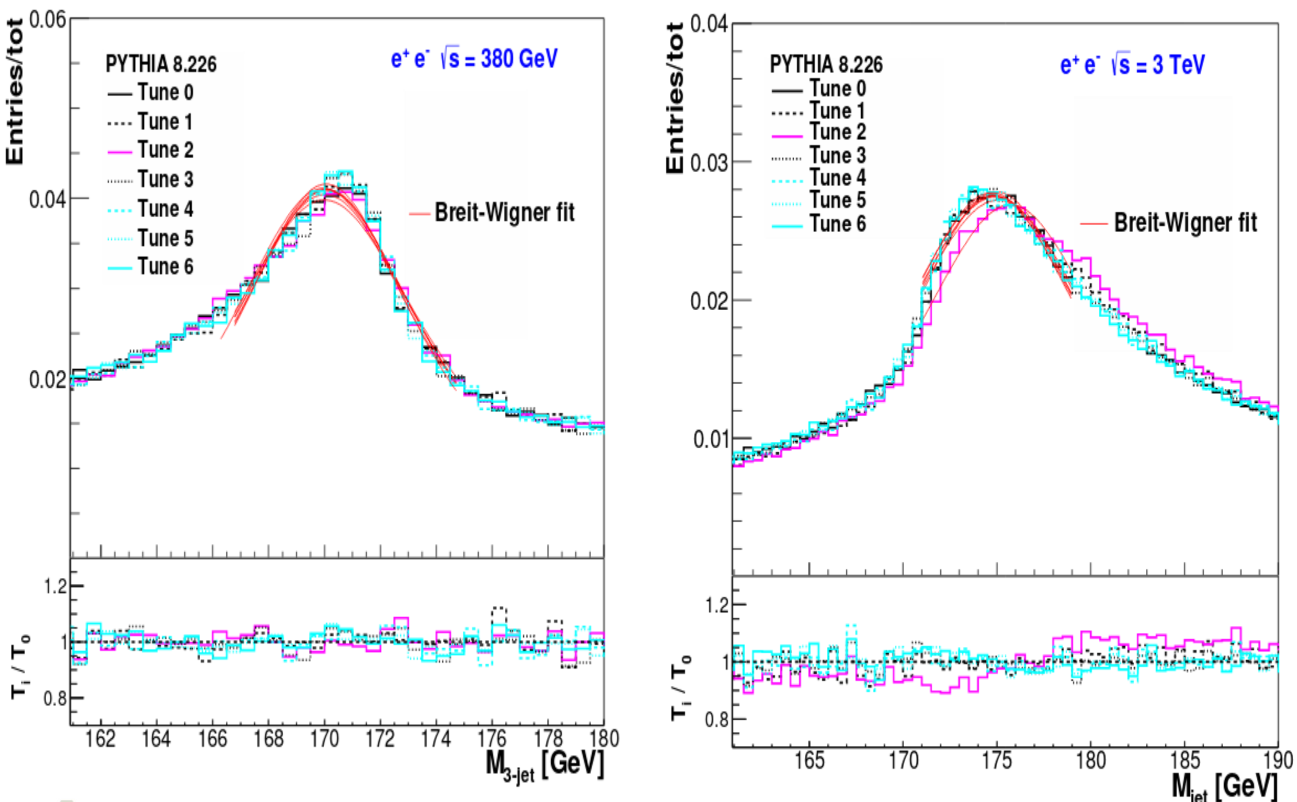
SiDB detector design

Example: Studies of physics at CLIC

CLICdp-Note-2017-005 (2018) M. Demarteau, S.C., A. Fischer, J. Zhang

At CLIC energies of 380 GeV, e+e- collision can produce $t\bar{t}$ pairs

Can modeling non-perturbative phase in Pythia8 affect top mass reconstruction, event shapes etc?



80 MeV shift was observed for top mass from 3-jet events

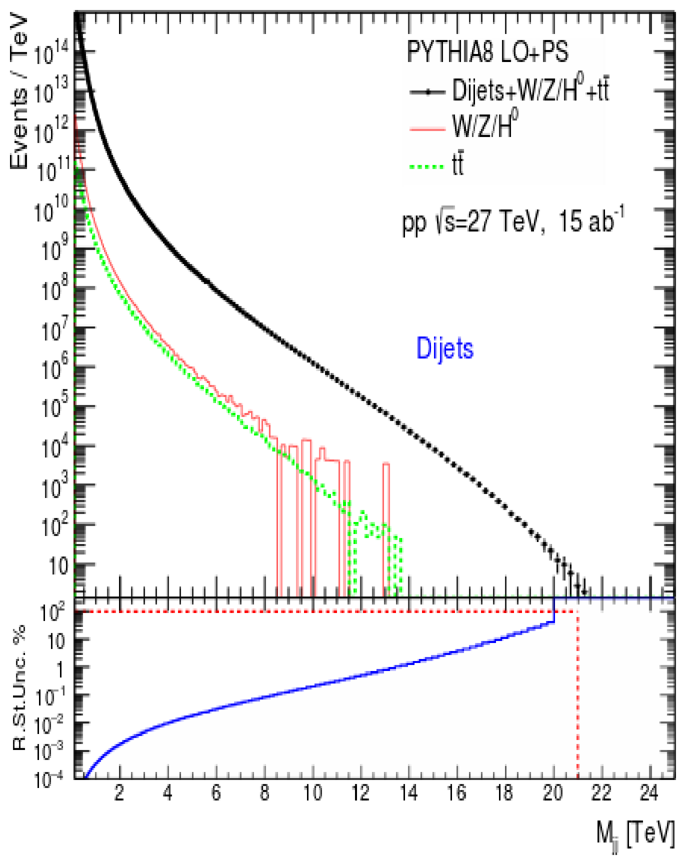
700 MeV for boosted mass (dominated by Montull tune)

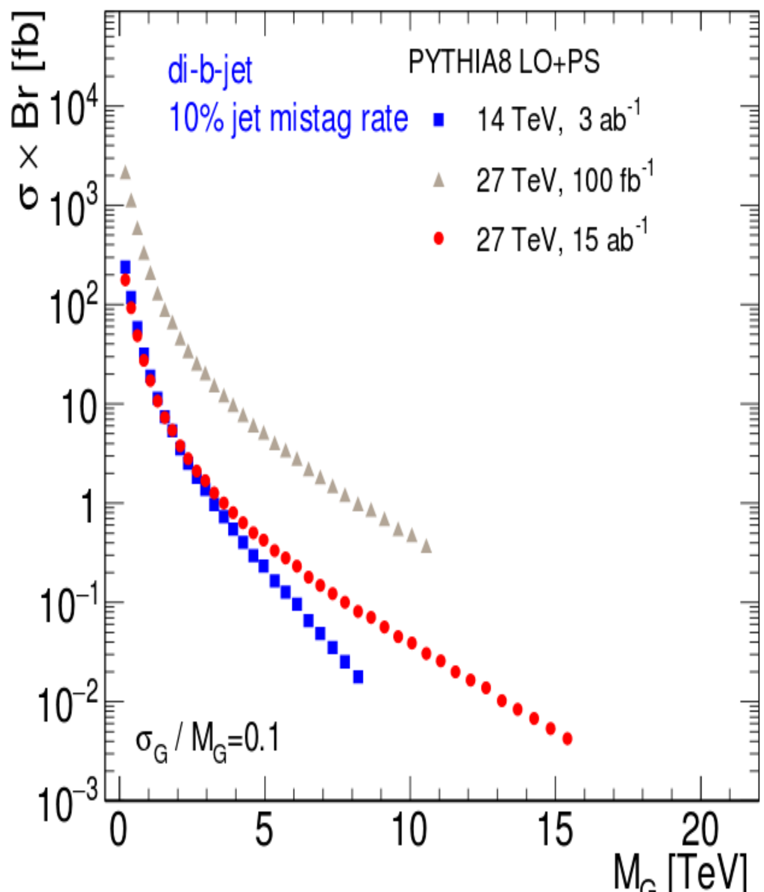
All samples for different tunes available from HepSim

HL-LHC and HE-LHC studies

JINST 13 (2018) P05022
CERN-LPCC-2018-05

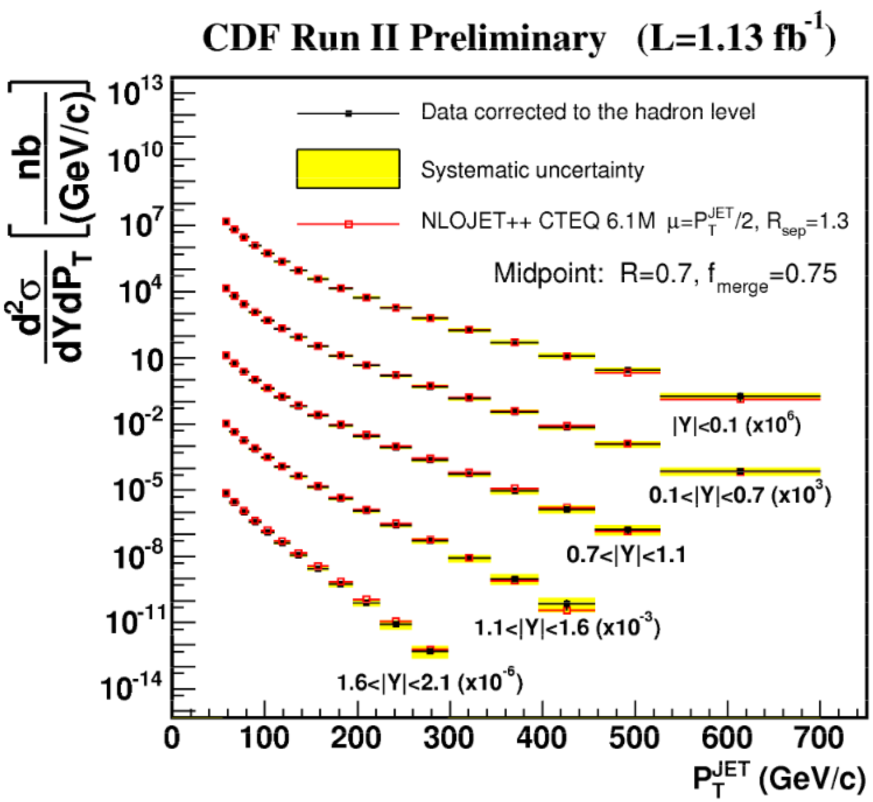
- Searches for high mass states in dijets (b-jets)
- 100 billion events created using HepSim singularity image at NERSC
- Event files cannot be stored .. but histograms can be saved





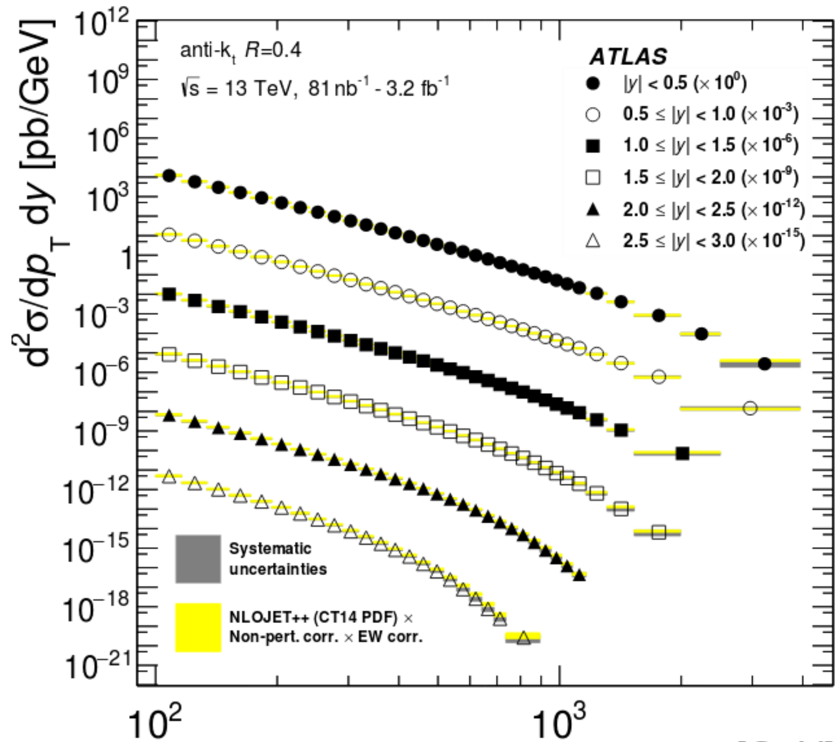
Studies of high-pT jets for 100 TeV colliders

Some history



Max p_T ~ 700 GeV

LHC



Max p_T ~ 4 TeV

Projections: for pT max:

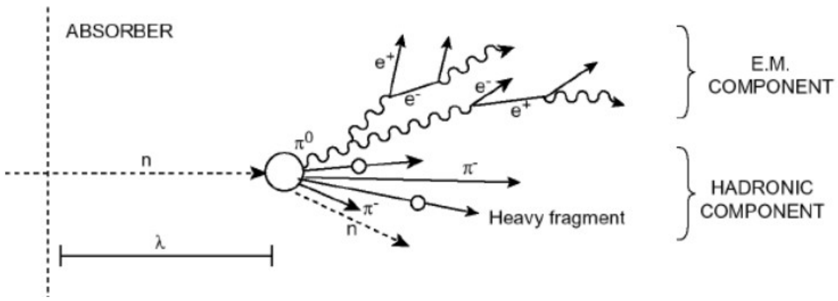
HE-LHC: $\sqrt{s}$ = 27 TeV **~ 10 TeV jets**

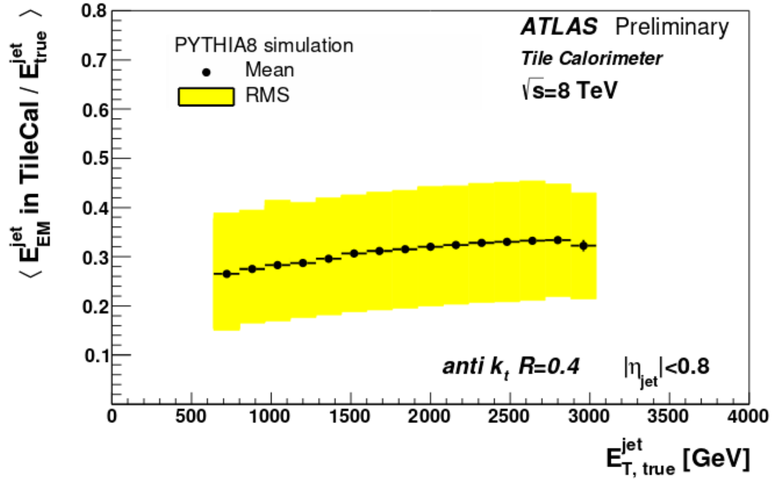
FCC/SppS: $\sqrt{s}$ = 100 TeV **~ 30 TeV jets**

What are technology challenges to reconstruct such jets?

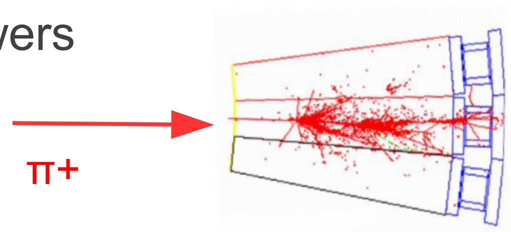
Hadronic calorimeter (HCAL) and nuclear interaction length

- Contains ~40% of jet energy pT> 3 TeV. Performance improves with energy!
- Measures neutral and changed particles
- Strong interaction , messy hadronic showers
- Typical scale is the interaction length λ_I





- λ_I ~ longitudinal and transverse (?) profile of hadronic showers
- "Rule of thumb": transverse cell size ~ λ_I
  - » Example: **λ_I ~18 cm for Fe**



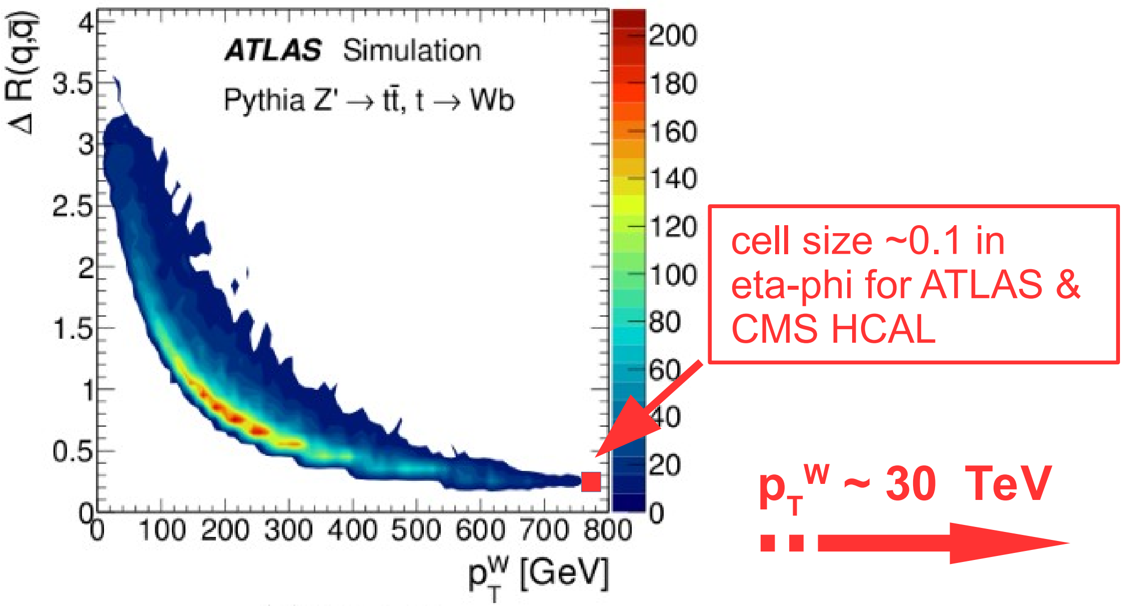
- ~20 cm transverse size of HCAL cells for LHC and (pre)LHC experiments
- **Is any preferential transverse direction in hadronic shower created by jets that can be detected by reducing cell sizes below λ_I ?**
- **Can TeV-scale physics benefit from small cell sizes of HCAL?**

Instrumentation challenges beyond the LHC era

- What are detector requirements for physics beyond the LHC (HE-LHC, FCC-hh etc)?
  → Jets and particles up to **30 TeV** in transverse momentum (vs 3 TeV at LHC)
- Are the current technologies sufficient and affordable?

  We know how to measure cosmic rays with energy several magnitude larger than at the LHC, but post-LHC colliding experiments are something else:

- Controlled collision environment
- High-precision measurements
- Complex subdetectors
- Large collision rate
- Super-boosted objects with small angular separation of decay products (W,top, etc).



(b) $W \to q\bar{q}$

Detector requirements driven by physics at 100 TeV

- **Good containment up to pT(jet)~30 TeV: 12 λ_I for ECAL+HCAL**
  - affects jet energy resolution
  - leakage biases, etc.
- **Small constant term for energy resolution: $c < 3\%$**
  - dominates jet resolution for pT>5 TeV
  - important for heavy-mass particles decaying to jets
- **Longitudinal segmentation**
  - **??**
- **Sufficient transverse segmentation for resolving boosted particles:**
  - Current LHC experiments: $\Delta\eta \times \Delta\varphi = 0.1 \times 0.1$
  - For FCC-hh: suggested $\Delta\eta \times \Delta\varphi = 0.025 \times 0.025$ using fast simulation (Delphes)

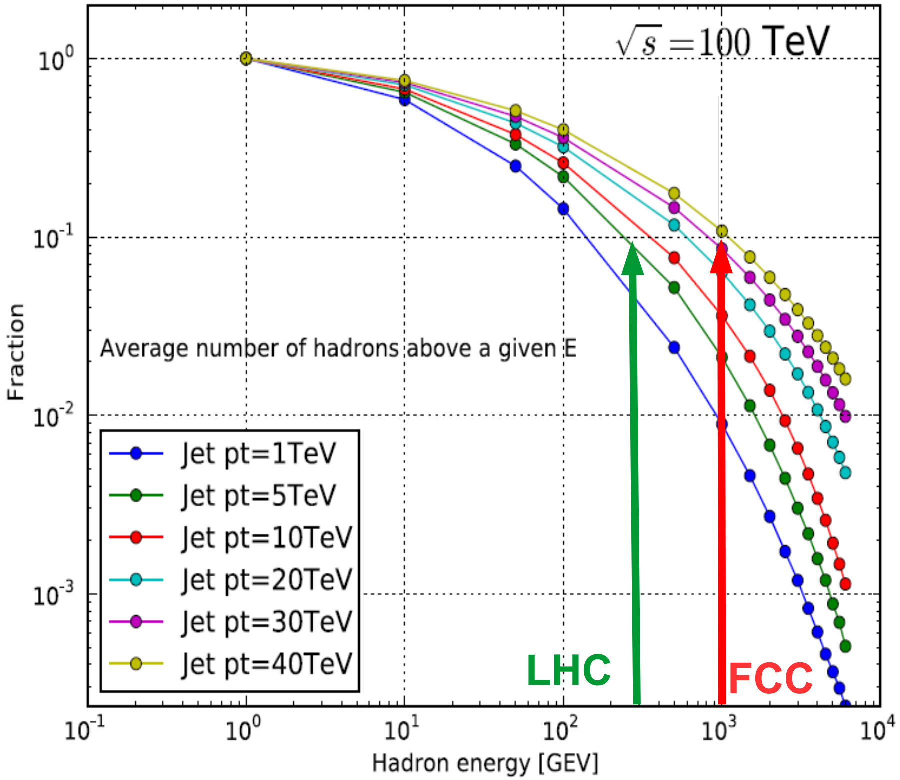
Study these questions using realistic Geant4 simulations and reconstruction

See: The Hadron Collider: "Future Circular Collider Conceptual Design Report" Volume 3. Eur. Phys. J. Spec. Top. (2019) 228, 755

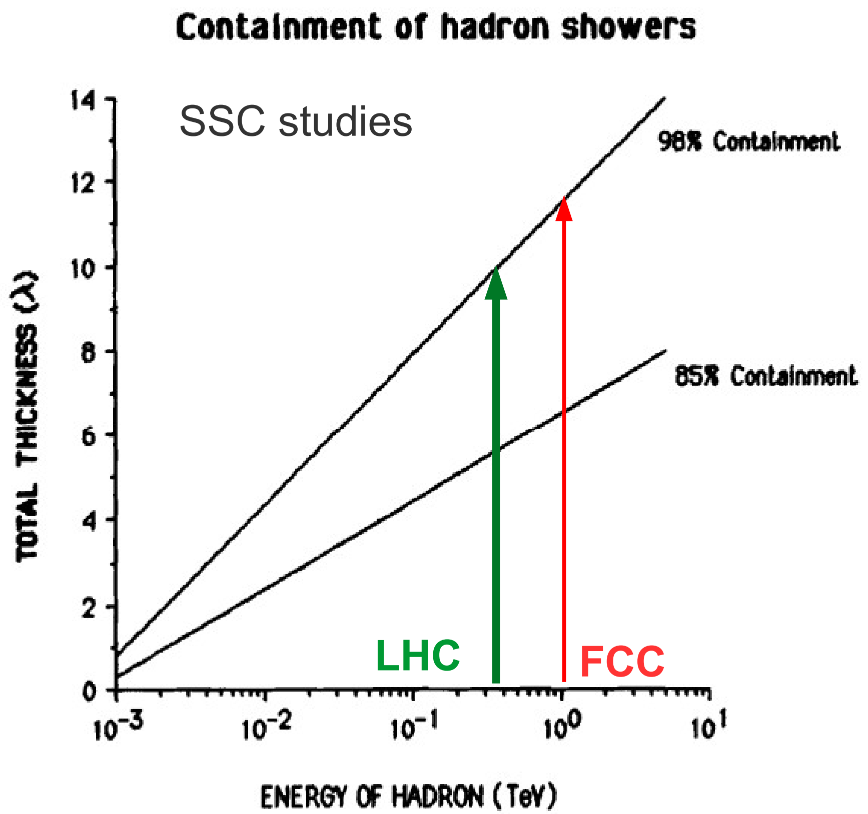
Estimating HCAL depth

Leading particles in high-pT jets

C.Helsens,C.Solans



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



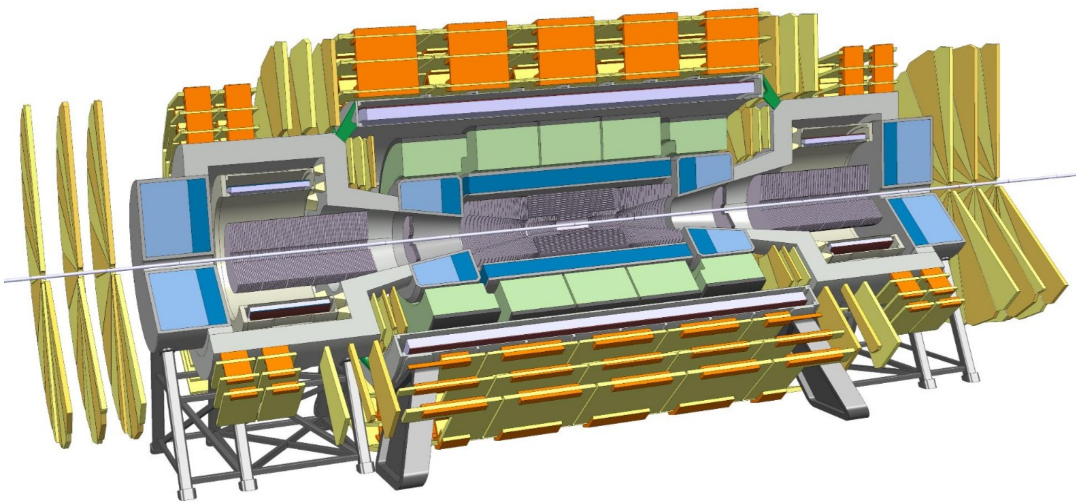
pT(jet)>30 TeV: ~10% will be carried by 1 TeV hadrons (~9 hadrons/jet)

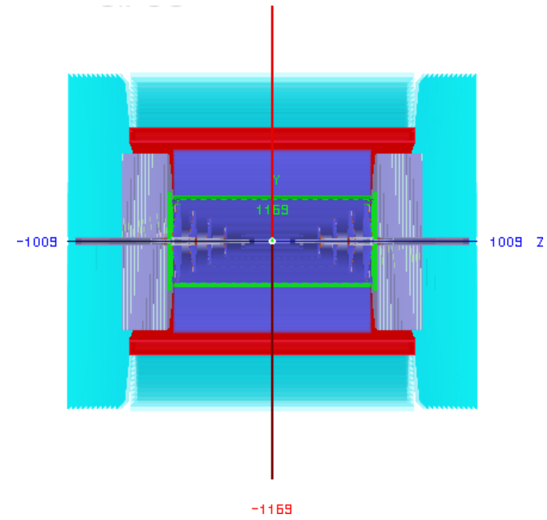
12 λ_I is needed to contain 98% of energy of a 1 TeV hadron

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

Detector simulations for 100 TeV physics

FCC-hh reference detector	**SiFCC: performance detector**
Eur. Phys. J. Spec. Top. (2019) 228, 755	JINST 12 (2017) P06009





- Larger than ATLAS
- Optimized forward region
- Twin solenoid + forward dipoles
- Fast detector simulations

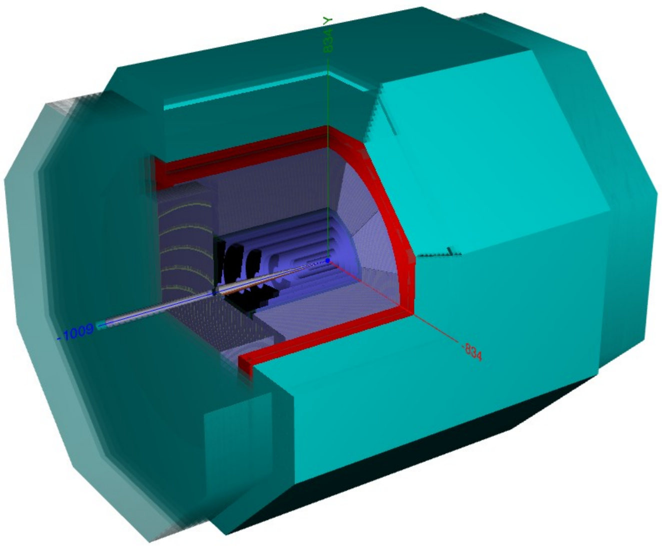
- Derived from the SiD/CLIC "all silicon" concept
- Compact (~20% smaller than ATLAS + muon det.)
- $|\eta|<2.5$ optimized for 100 TeV collisions
- Playground for various designs and technologies
- Fast turnover to modify the detector & create Monte Carlo events
- Geant4 simulation & reconstruction since 2016
- All simulations are archived in HepSim repo

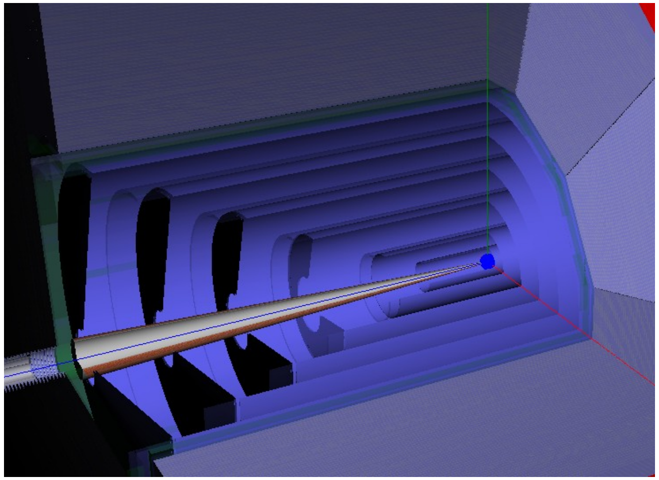
Characteristics of SiFCC

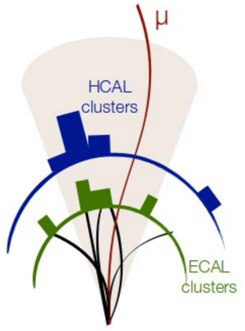
WWW link to explore this detector

http://atlaswww.hep.anl.gov/hepsim/detectorinfo.php?id=sifcch7

- **5 T solenoid outside HCAL**
- **Si pixel and outer trackers (5 + 5 layers):**
  - 20 μm pixel (inner), 50 μm (outer)
- **ECAL (Si/W):** 2x2 cm. 32 layers, ~35 X0
- **HCAL (Scint. / Fe)** **~ FCC-hh reference**
  - 5x5 cm cells: $\Delta\eta \times \Delta\varphi = 0.022 \times 0.022$
    x4 smaller than for CMS & ATLAS
  - 64 longitudinal layers → 11.3 λ_I
  - 3.1% sampling fraction
- > 150 M non-projective cells (ECAL+HCAL)







JINST 12 (2017) P06009
https://arxiv.org/abs/1612.07291

Event simulation and reconstruction

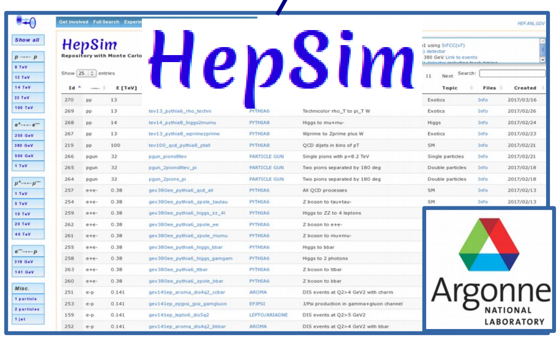
- **SLIC** simulation v5: updated for Geant 10.3p1 (J.McCormick, D.Blyth, W.Armstrong, S.C, etc)
  - *updated for Geant 10.3p1, decoupled from ILCSOFT*
- Fast **LCSIM** track reconstruction: (D.Blyth, J.McCormick, N.Graf, etc.)
  - *3-4 speed increase compared to the previous releases*
- Fast **PandoraPFA** (J.Marshall, M.Thomson)
- Integrated with **HepSim** repository. Analysis: C++/Root or **Jas4pp**
- ~20 M CPU*h using Open Science Grid (OSG)

ongoing optimization

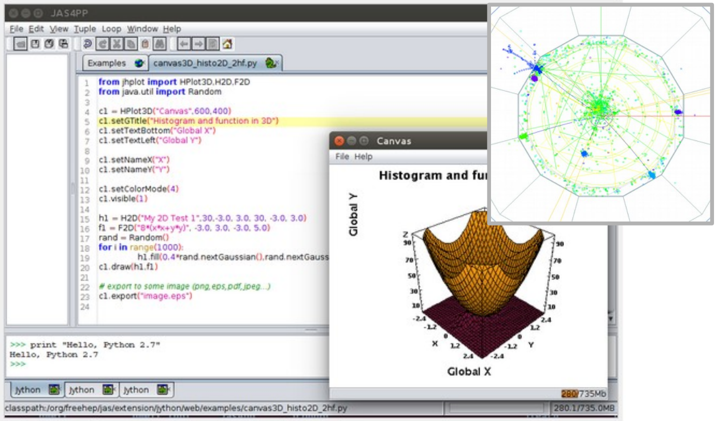
SLIC 5.1 (Geant4, version 10.3p1) → **LCSIM track reconstruction** → **SlicPandora and Pandora PFA** → **Event display + Analysis (C++/ROOT or Jas4pp)**

ProMC → SLCIO

Compact geometry description (XML)



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



Energy reconstruction in SiFCC

SLIC 5.0.1 with Geant4 10.3p1
Inelastic physics list for pi+/p/n
(validated<400 GeV):
QGSP_BERT 4.0
QGSP: 12 GeV - 100 TeV
FTFP: 9.5 GeV - 25 GeV
BertiniCascade: 0 eV - 9.9 GeV
Elastic: ElasticLHEP/ Gheisha: 0 eV-100 TeV

↓

raw hits

↓

slicPandora: Sampling fractions, hit cuts ..

↓

cells

↓

PandoraPFA: Topological 3D RecoClusters

↓

clusters

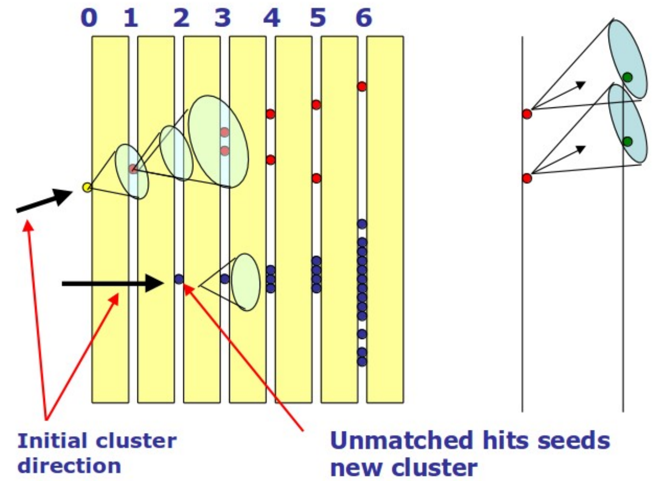
↓

antiKT R=0.5 jets from RecoClustes

↓

Data analysis

From M.Thomson



Cone algorithm
Start from inner layer and work outward

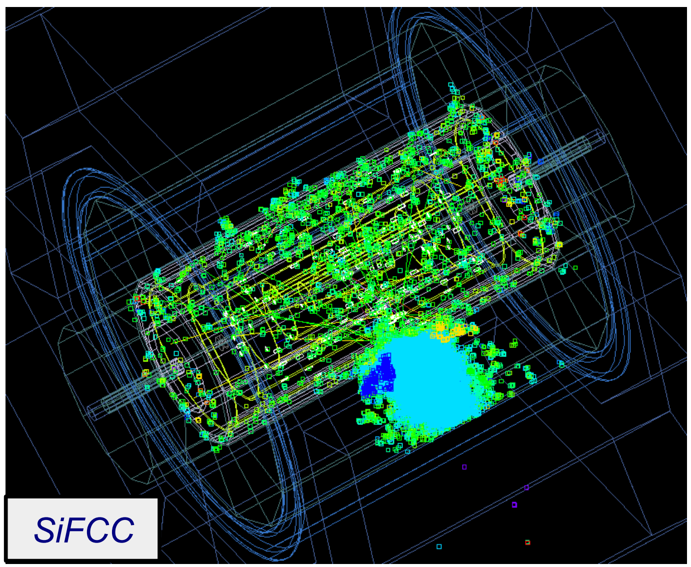
Notes:
- *Birks' effect was not included*
- *Min mip cut was applied on hits*
- *100 ns for fastest hit contribution*
- *No PFA for this study*

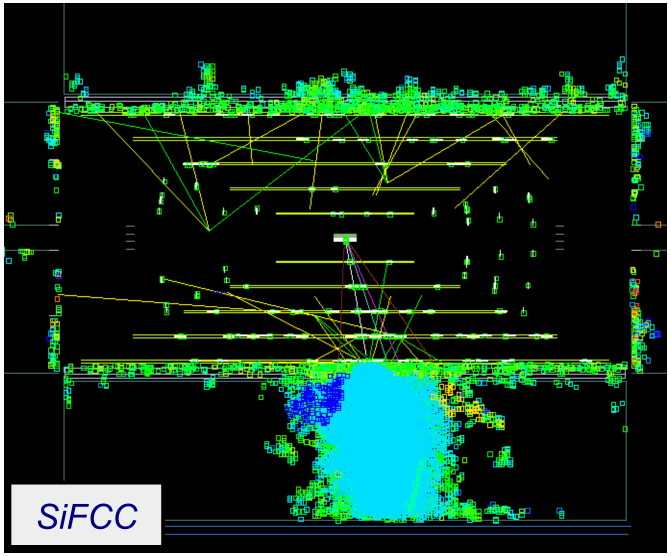
Response to single particles: 8 TeV pions

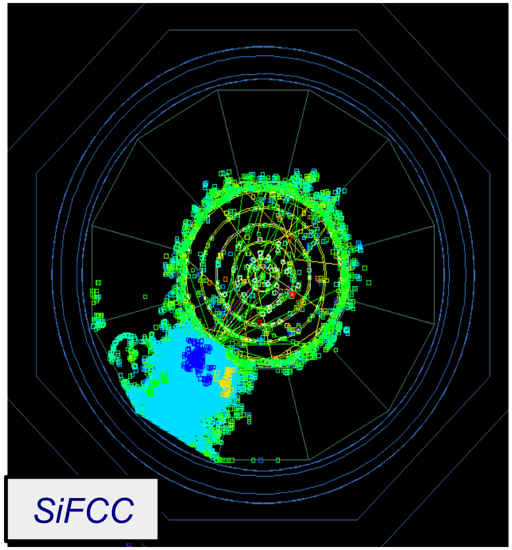
Example: True momentum of π+ : 8.16 TeV

After SiFCC reconstruction (>1.5 M HCAL cells):

- ~30000 calorimeter hits, ~500 SiTracker hits
- 1 reconstructed PFA (pi+) P=8.97 TeV
- 1 reconstructed CaloCluster at P=8.40 TeV
- Many back-splash interactions



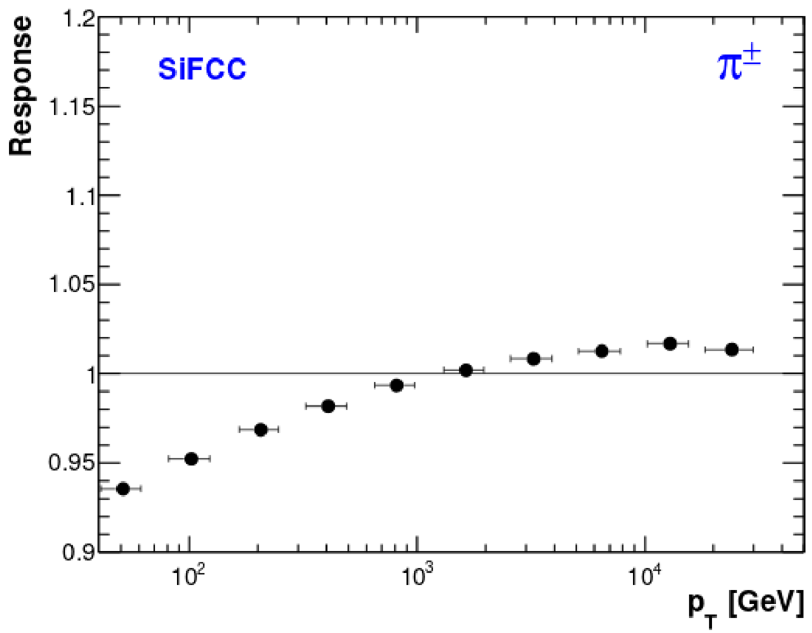


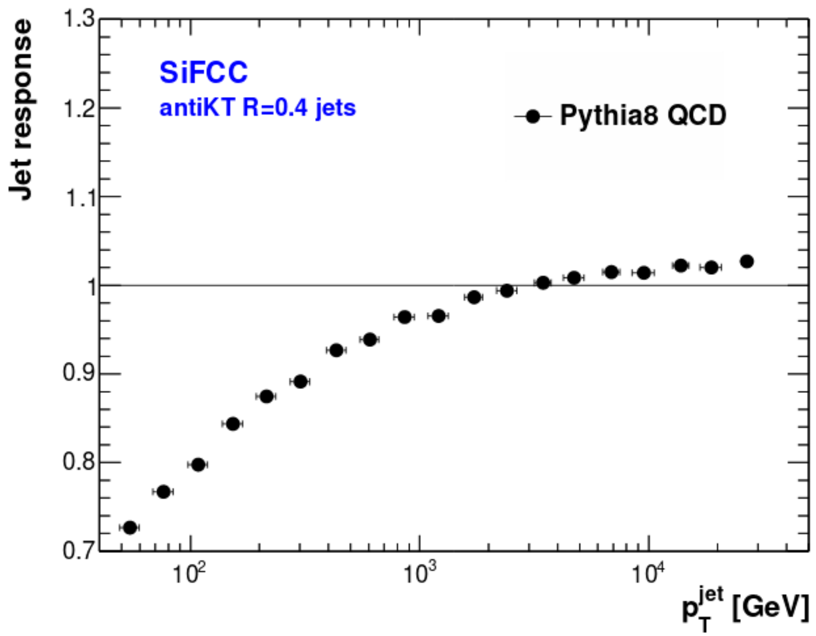


Based on **HepSim**:   http://atlaswww.hep.anl.gov/hepsim/info.php?item=201

Particle response using calorimeter clusters

Energy Response: ratio between the reconstructed jet energy (or p_T) and the corresponding truth-particle jet energy (or p_T) in the simulation, i.e. $<p_T/p_{T,\ truth}>$





Response is non-linear (as expected) → non-compensation due difference in response between electromagnetic and hadronic showers, energy losses in inactive regions of the detector etc. etc. → require jet energy correction

Important:

no downward trend, i.e. no leakage outside the HCAL for 20 TeV single pions

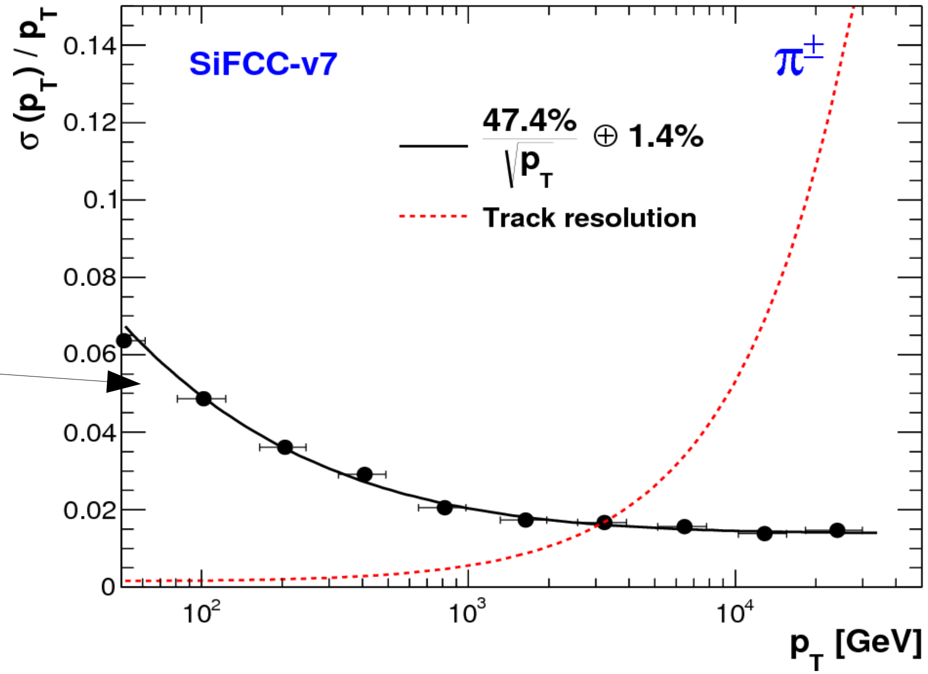
Resolution for single hadrons ($\pi^{\pm}$)

JINST 12 (2017) P06009
https://arxiv.org/abs/1612.07291

- Single pi+ randomly distributed in eta & phi
- pT is reconstructed by collecting energies from all RecoClusters

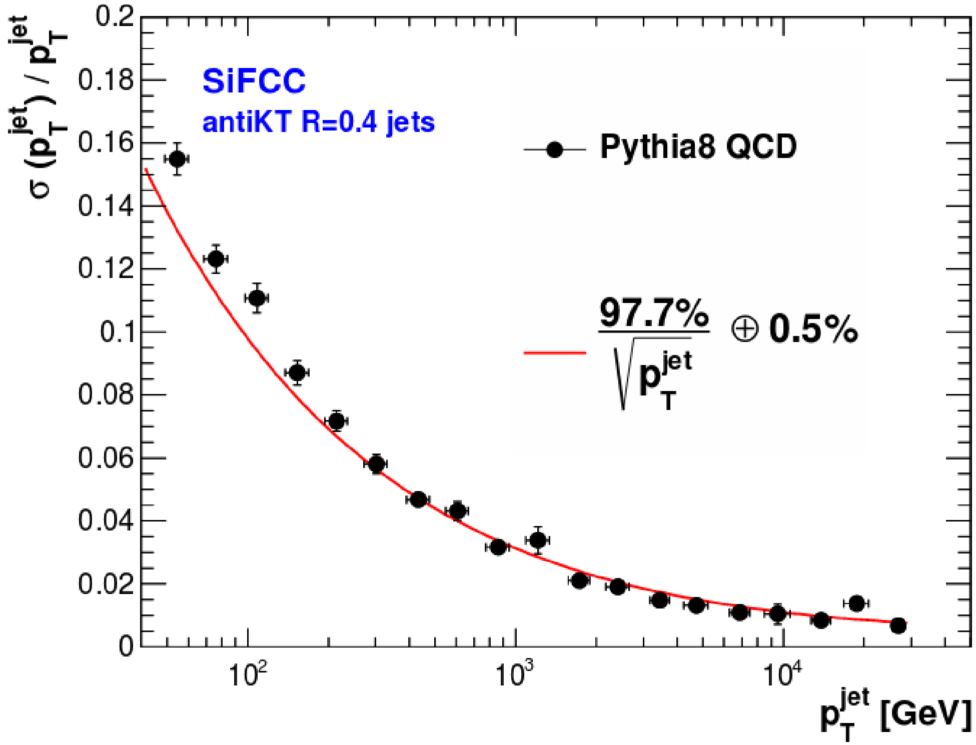
$$\frac{\sigma(p_T)}{p_T} = a/\sqrt{p_T} \oplus b$$

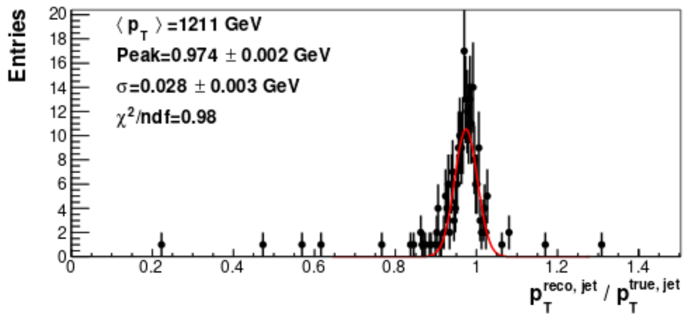
a – stochastic/sampling term,
b- constant term



- ~47% sampling term, 1.4% constant term
  - sampling term is consistent with ATLAS-like setup (arXiv:1604.01415)
- Calorimeter resolution is better than for SiTracker for pT>3 TeV
  - Tracker: outer radius R=2.1 m, 5 T solenoid, 25 um pixel size

Jet resolution and response. AntiKT R=0.4 jets





Spread is determined using Gaussian fits

$$\frac{\sigma(p_T)}{p_T} = a/\sqrt{p_T} \oplus b$$

- Jet energy resolution is similar to ATLAS jets (“EM” scale) for pT(jet)<1 TeV
- Fit with the sampling and constant term is not perfect (χ^2/ndf ~ 2.5)
- Fixing constant term to 1-2% leads to a similar fit quality
  - Constant term < 2% can be achieved

With contributions from:
J.McCormick (SLAC)
A.Dotti (SLAC)
A.Ribon (CERN)

High granularity HCAL for 100 TeV physics

- Baseline for past & operational detectors:
  - **transverse cell size is similar or larger than nuclear interaction length: λ_I**
- **Conclusion from CALICE R&D:**
  - 2x2 or 1x1 cm cell sizes required to reconstruct PFA for separate particles
- **Question for post-LHC colliders:**

Can reconstruction of jets and particles at tens-of-TeV scale benefit from small HCAL cells?

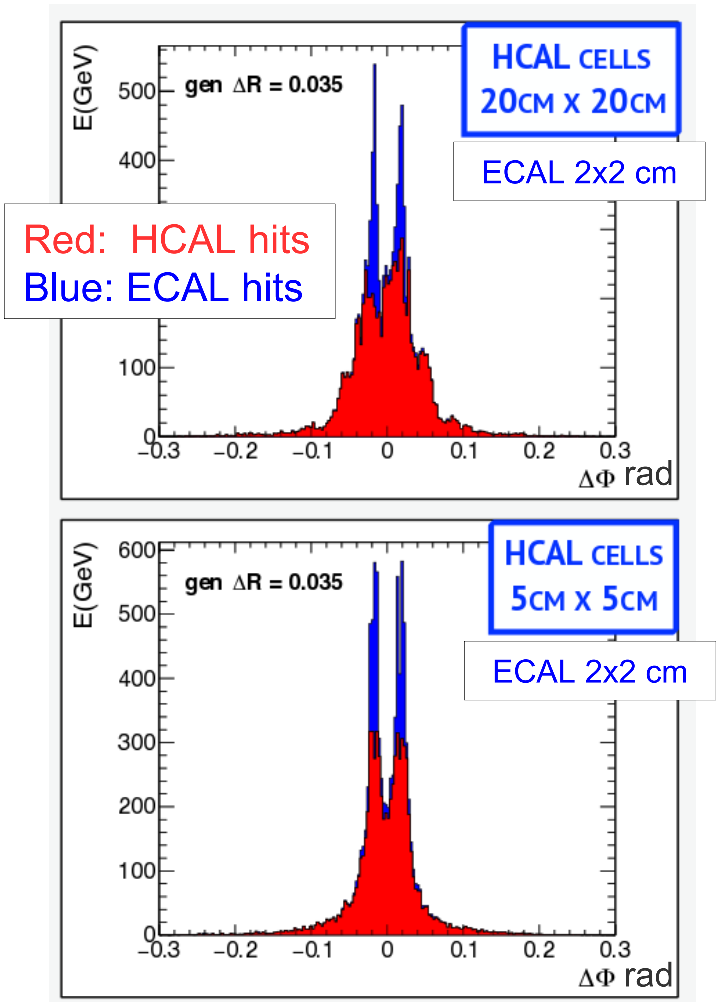
Several simulations with ECAL cells 2x2 cm while HCAL cell sizes were varied:

SiFCC detector version (Fe/Scin. HCAL)	Transverse size of HCAL cells (cm or $\Delta\eta x\Delta\varphi$)	Transverse size of HCAL cells in λ_I	Simulation tag in HepSim
SiFCC-v7 (baseline)	5X5 cm ($\Delta\eta x\Delta\varphi$ = 0.022 x 0.022)	~ $\lambda_I/4$	rfull009
SiFCC-v8 (traditional)	20x20 cm ($\Delta\eta x\Delta\varphi$ = 0.1 x 0.1)	~ λ_I	rfull010
SiFCC-v9 (as ECAL)	2x2 cm ($\Delta\eta x\Delta\varphi$ = 0.01 x 0.01)	$\lambda_I/8$	rfull011
SiFCC-v10 (fine)	1x1 cm ($\Delta\eta x\Delta\varphi$ = 0.005x 0.005)	$\lambda_I/17$	rfull012

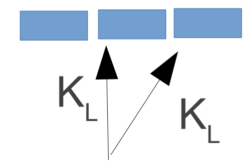
HCAL segmentation: double particles

JINST 12 (2017) P06009
https://arxiv.org/abs/1612.07291

- Look at hits associated with two close-by particles (before any clustering)



truth-level separation between 2 K_L is 0.035 rad (2 deg)



- Generate two K_L (E=100 GeV) particles at η=0.
  - First K_L is always at $\Phi^{true}=0$
  - Second is shifted by $\Delta\Phi^{true}=2$ deg
- Calculate energy of hits in Φ with respect to Φ=0
- Repeat for different HCAL cell sizes

Small HCAL cells (~ λ_I /4) helps separate hits in hadronic showers from two K_L separated by 2 deg

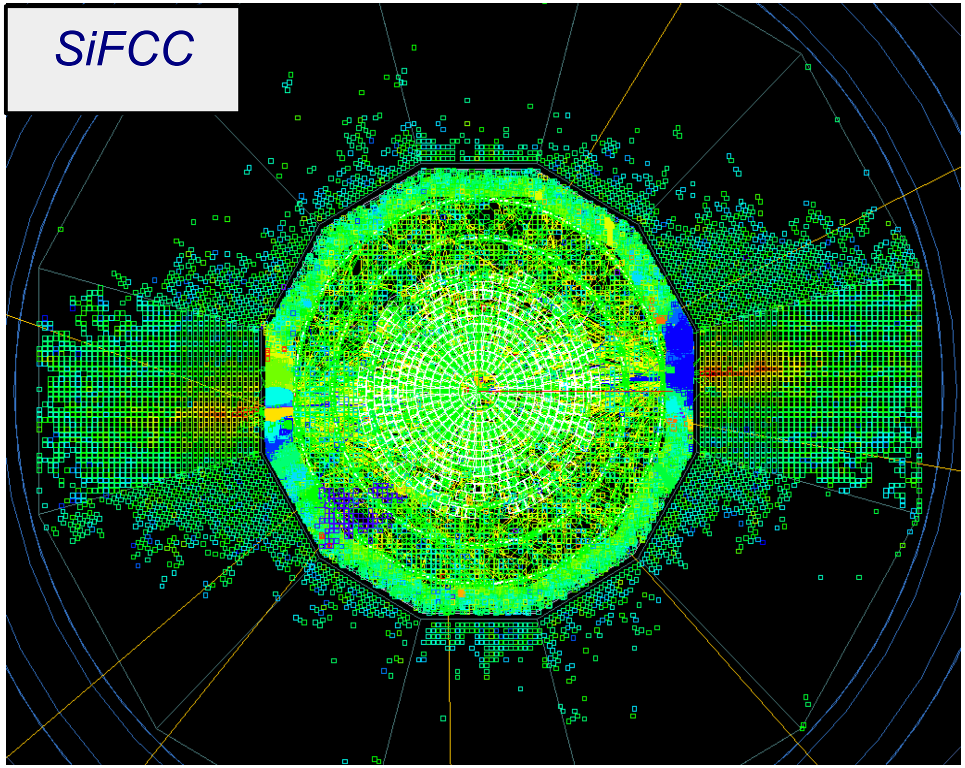
Extends CALICE observation to high energies (1 TeV)

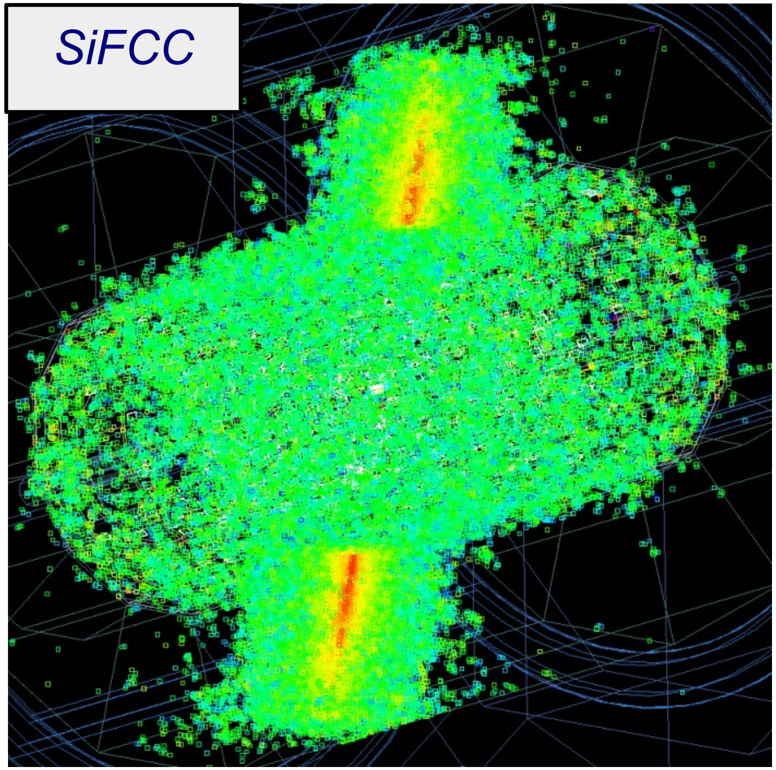
Are small cells useful for multi-TeV jets?

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

First realistic Geant4 simulation of ~20 TeV jets (FCC week, Apr 2016)

High-granularity HCAL, 10k hits in ECAL, 46k hits in HCAL, 12k/1k hits in the outer/inner tracker





Busy event, large number of back-splash interactions in ECAL/HCAL/Tracker

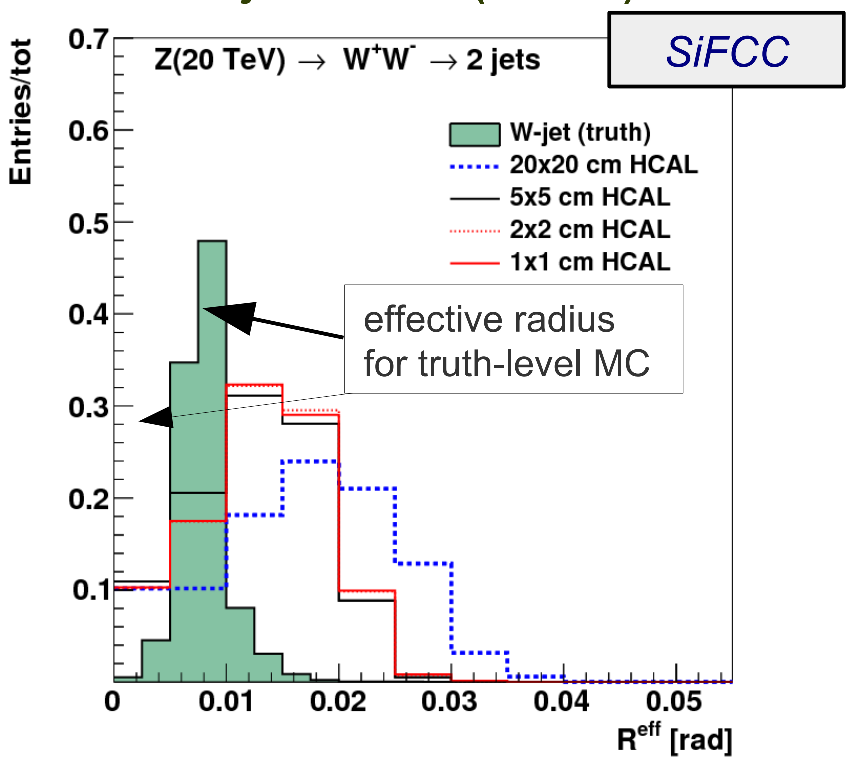
What about 5, 10, 20 TeV jets?

See: C.-H. Yeh et al, JINST 14 (2019) , P05008

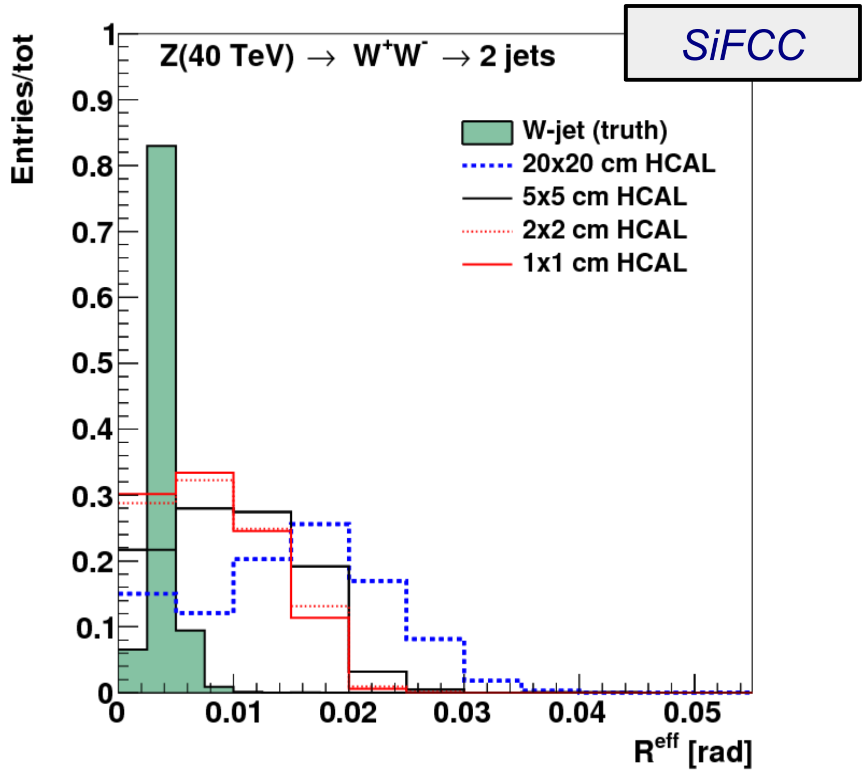
Effective jet radius of antiKT5 jets

Sum over all distances between energy deposits and jet center, weighted with E(const) / E(jet)

W-jets from Z'(20 TeV)



W-jets from Z'(40 TeV)

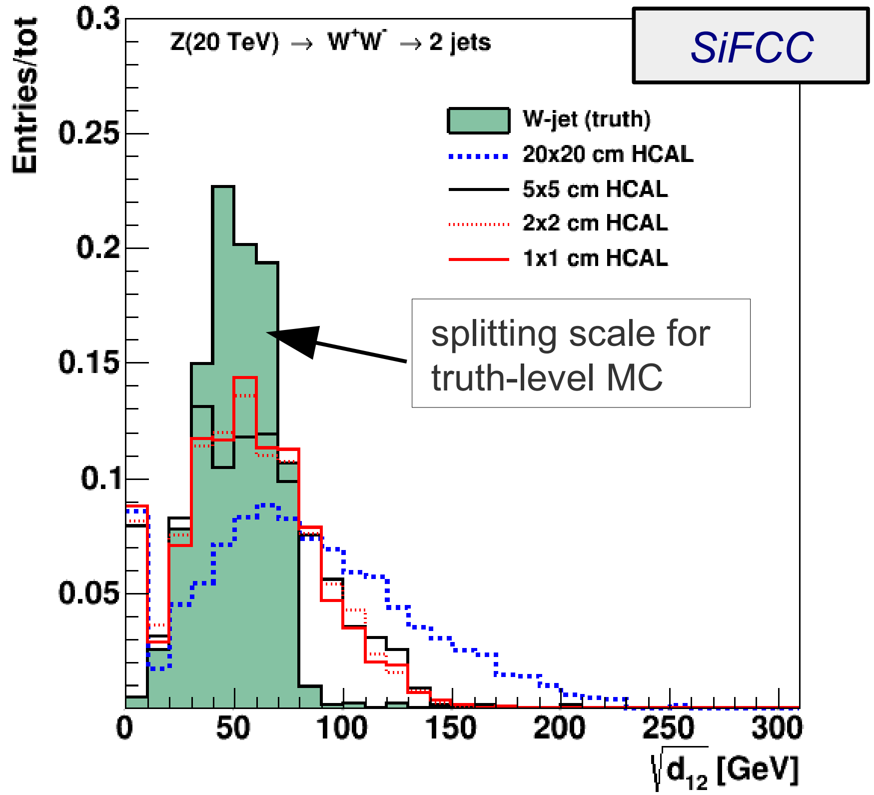


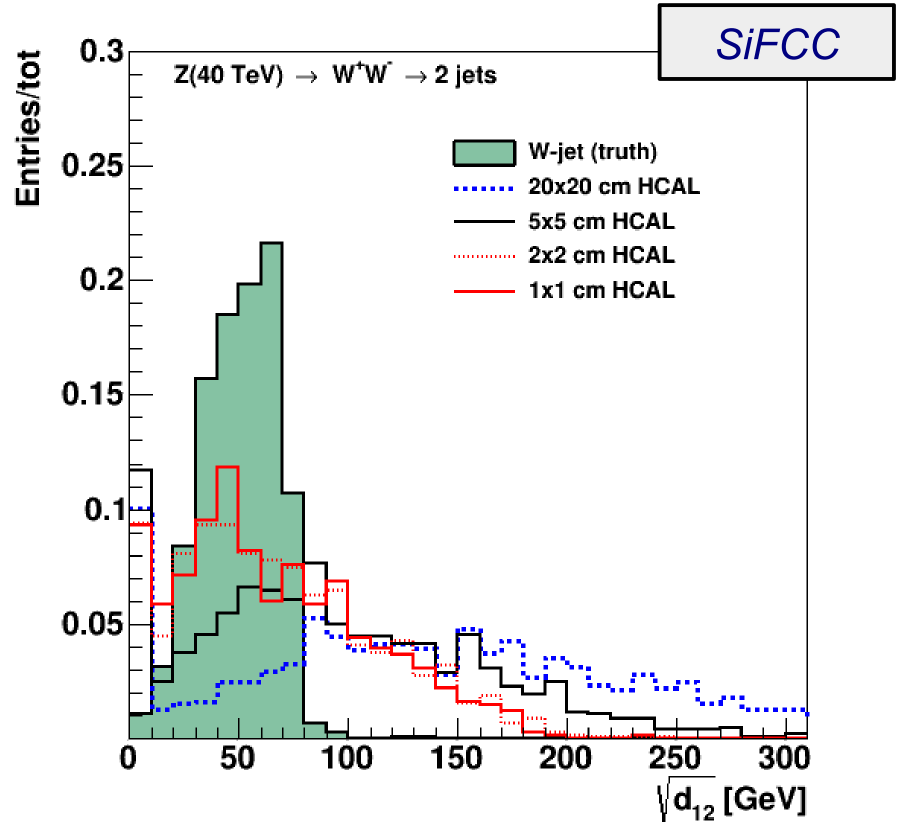
- Jets with pT>10,20 TeV, each from $W \to q\bar{q}$
- Narrow ($\Delta R \sim 2^* pT / M(W)$) compared to QCD jets (not shown)
- 5x5 cm cells ($\Delta\eta x \Delta\varphi$ = 0.022x 0.022) show improvement compared to $\Delta\eta x \Delta\varphi$ = 0.1x 0.1 (ATLAS)
- Small difference between 2cm and 1cm cell sizes

Jet splitting scale: d_{12}

K_T scale at which a jet splits into 2. Used to differentiate QCD jets from 2-body decays (W,H,etc)

W-jets from Z'(20 TeV) **W-jets from Z'(40 TeV)**

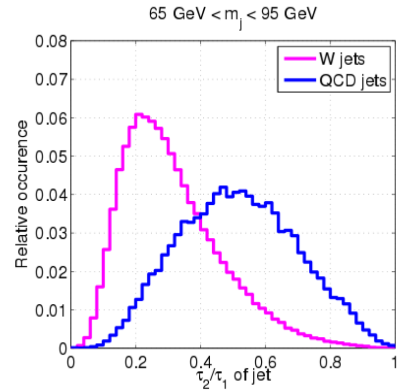




- Jets with pT>10,20 TeV, each from W decays ($q\bar{q}$)
- 5x5 cm cells ($\Delta\eta x \Delta\varphi$ = 0.022x 0.022) show improvement compared to $\Delta\eta x \Delta\varphi$ = 0.1x 0.1 (ATLAS)
- Small difference between 2cm and 1cm cell sizes

Studies of N-subjettiness using SiFCC

J.Thaler and K. Van Tilburg, JHEP 1103 (2011) 015

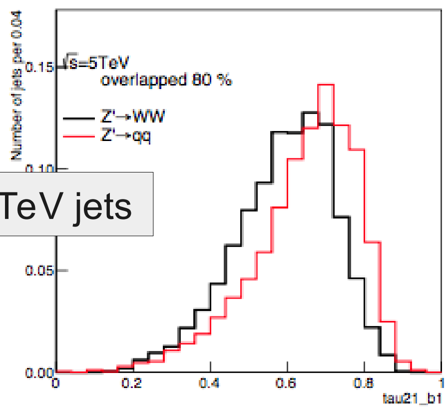


- Jesse Thaler, Ken Van Tilburg (JHEP 1103:015,2011)
  - $\tau_{21} = \tau_2/\tau_1$ – used for boosted W studies
- Use overlap between QCD and W jets as a benchmark for effectiveness of tau21 for boosted W reconstruction
- Use different HCAL granularity from 20x20 cm to 1x1 cm (ECAL same)

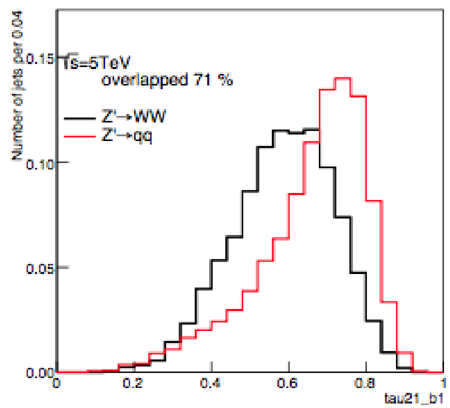
Conclusion: 2.5 TeV jets show reduction in overlap (80% →71% → 66%) going from 20x20 cm to 1x1 cm for HCAL cells

2.5 TeV jets

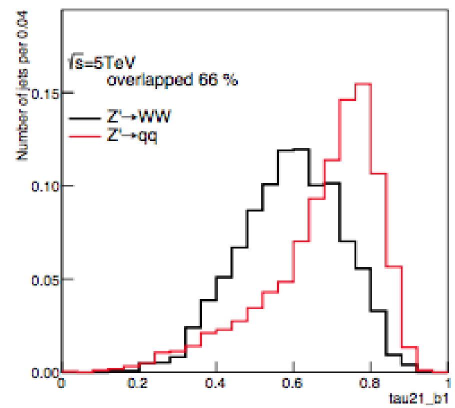
$\Delta\eta \times \Delta\varphi = 0.1 \times 0.1$ (20x20 cm)



$\Delta\eta \times \Delta\varphi = 0.022 \times 0.022$ (5x5 cm)

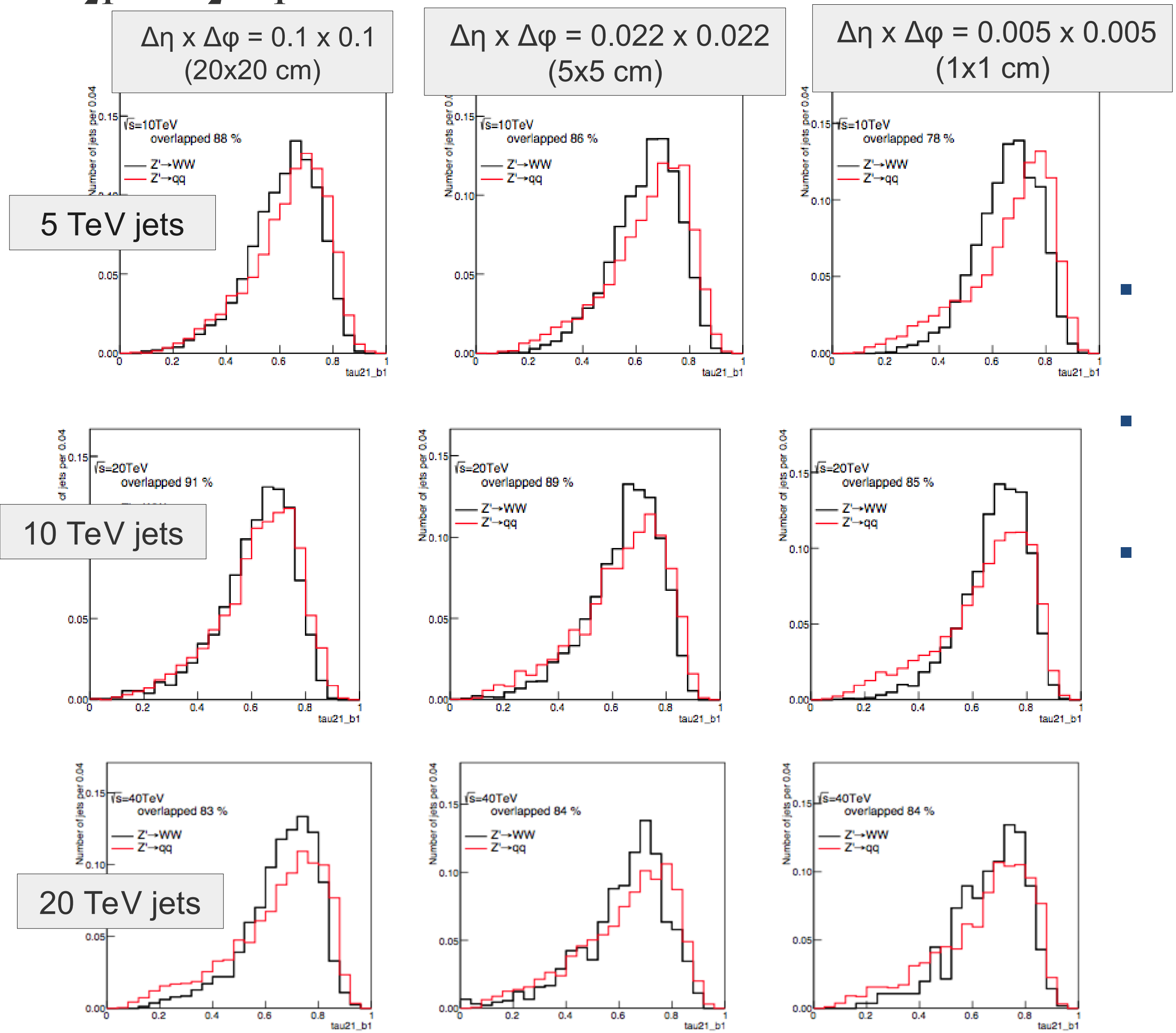


$\Delta\eta \times \Delta\varphi = 0.005 \times 0.005$ (1x1 cm)



Also see the poster: "The importance of calorimetry in highly boosted jet substructure" by Evan Coleman et al. describing N-subjettiness for fast simulations using for 100 TeV

$\tau_{21} = \tau_2/\tau_1$ for different HCAL granularity

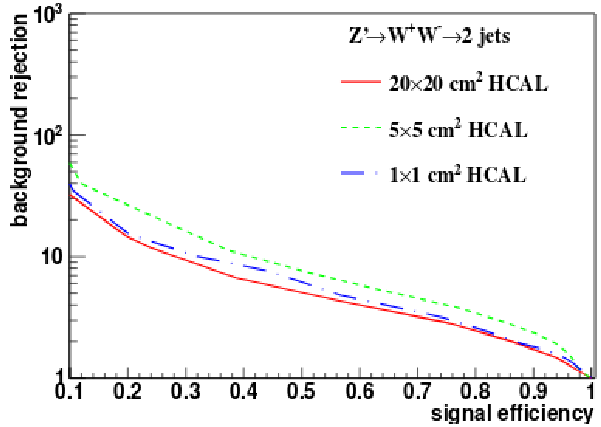


- 5 TeV jets:
  - 88% → 78% overlap
- 10 TeV jets:
  - 91% → 85% overlap
- 20 TeV jets:
  - change in HCAL granularity does not modify overlap

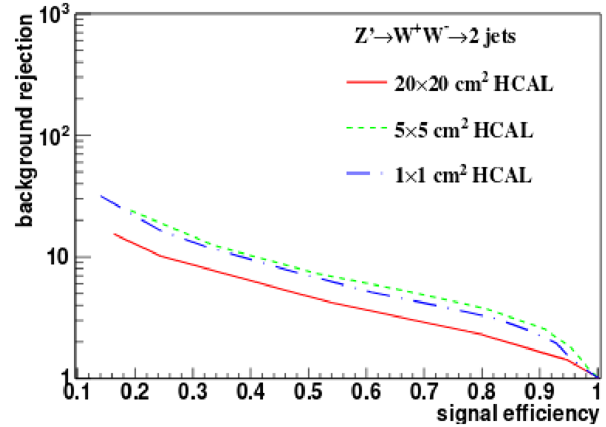
Efficiency vs background rejection for different cell sizes

C.-H. Yeh JINST 14(2019) P05008

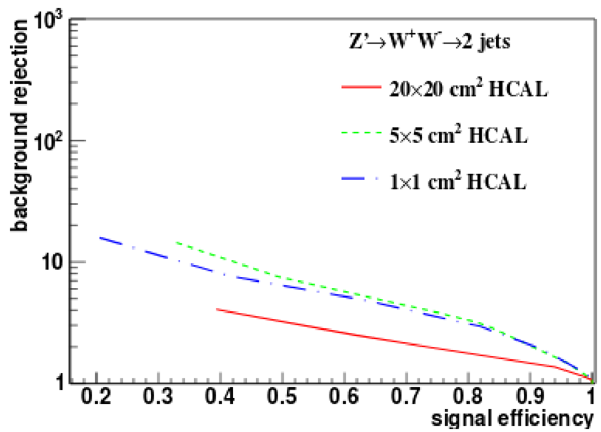
$$\tau_{21} = \tau_2/\tau_1$$



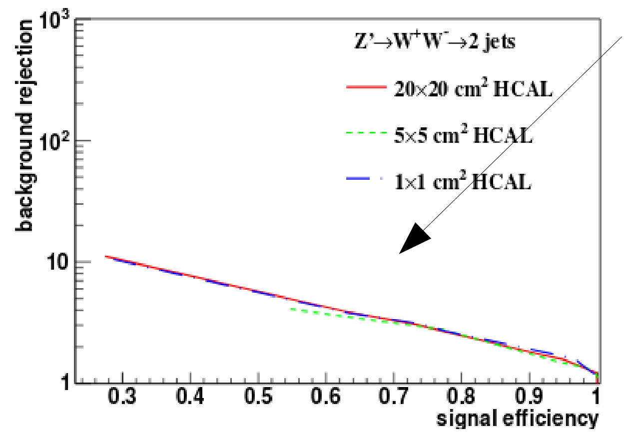
(a) $M(Z') = 5$ TeV



(b) $M(Z') = 10$ TeV



(c) $M(Z') = 20$ TeV



(d) $M(Z') = 40$ TeV

no separation between different cell sizes

Summary

- **Boosted jets are studied up to 30 TeV in transverse momentum using Geant4 simulation with realistic reconstruction (from HepSim)**
  - Constant term of <2% for jet energy resolution (with simplified readout)
  - Calorimeter is primary instrument for tens-of-TeV physics (compared to tracker)
- **Separation of hits from close-by large pT particles in high-granularity HCAL**
- **Reconstruction of jet substructure benefits from HCAL granularity:**
  - Optimal HCAL cell size is $\Delta\eta \times \Delta\varphi = 0.022 \times 0.022$ (vs $\Delta\eta \times \Delta\varphi = 0.1 \times 0.1$ for ATLAS) for jet radius and splitting scale
  - W reconstruction using τ_{21} benefits from 1x1 cm cells ($\Delta\eta \times \Delta\varphi = 0.005 \times 0.005$). But challenging to see this for 20 TeV jets
- **R&D focused on cost-effective options for signal readout of high-granularity calorimeters for pp colliders is required**

Thanks!

For more information, see the HepSim web manual and **hs-help** on the command line.

HepSim manual: https://atlaswww.hep.anl.gov/hepsim/doc/

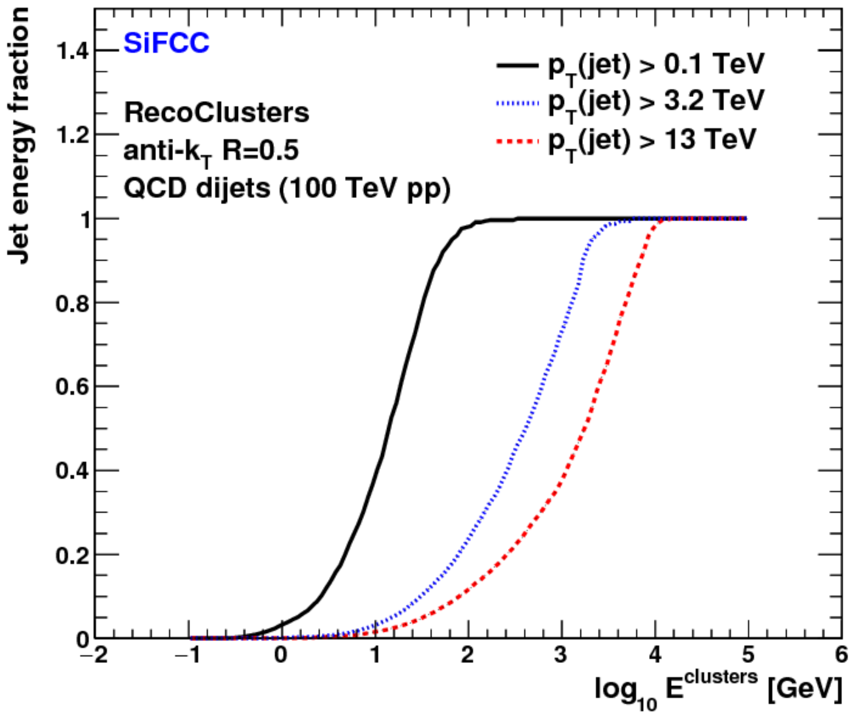
HepSim contributors:
https://atlaswww.hep.anl.gov/hepsim/doc/doku.php?id=hepsim:contributions

HepSim public results:
https://atlaswww.hep.anl.gov/hepsim/doc/doku.php?id=hepsim:public

Backup

Jet energy fraction

Jets from RecoClusters



Constituents of tens-of-TeV jets:

- span 4 orders of magnitude in energy
  - vs 2 orders for 100 GeV jets
- dependence on fragmentation function?

Hadronic calorimeter (HCAL)

- Strong interactions make jets
  - billions of jets with > 2 TeV at future colliders (28-100 TeV CM energy)

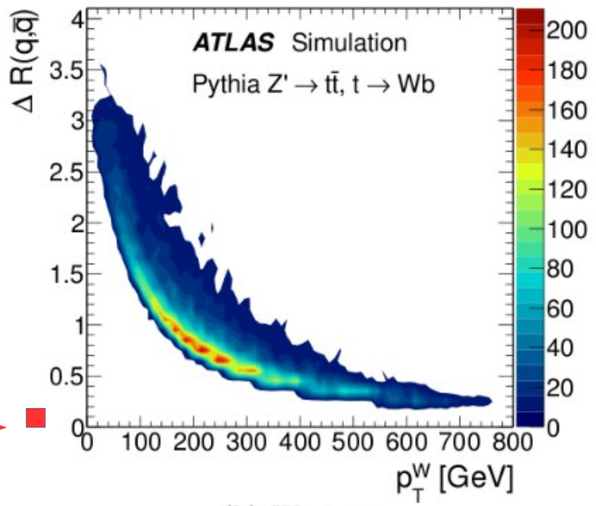
- Higgs, W, Z, top (pT>2 TeV) decay to narrow jets with jet radius smaller than 0.2 in $\varphi x \eta$. Such narrow jets have substructure (2 or 3 subjets)

- Physics goals of future colliders - search for particles with masses 10-50 TeV that can decay to Higgs, W, Z, top decays

  → narrow jets with pT>5-25 TeV from Higgs, W, Z, top

- How to build a HCAL that can:
  - measure jet energies (up to 30 TeV)?
  - resolve internal structure of narrow jets?

Typical cell size for ATLAS & CMS HCAL →



(b) $W \to q\bar{q}$

SiFCC detector

https://arxiv.org/abs/1612.07291

Table 1: Technology and dimensions of the SiFCC sub-detectors in the barrel region. The solenoid field is given inside and outside the solenoid, respectively.

Barrel	Technology	pitch/cell	radii (cm)	$\|z\|$ size (cm)
Vertex detector	silicon pixels/5 layers	25 μm	1.3 - 6.3	38
Outer tracker	silicon strips/5 layers	50 μm	39 - 209	921
ECAL	silicon pixels+W	2×2 cm	210 - 230	976
HCAL	scintillator+steel	5×5 cm	230 - 470	980
Solenoid	5 T (inner), -0.6 T (outer)	-	480 - 560	976
Muon detector	RPC+steel	3×3 cm	570 - 903	1400

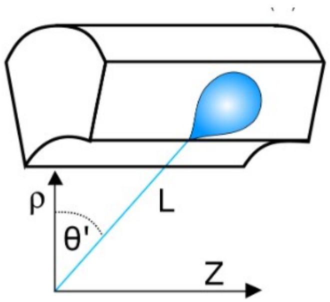
Table 2: Technology and dimensions of the SiFCC sub-detectors for the endcap region.

Endcap	Technology	pitch/cell	z extent	outer radius
			(cm)	(cm)
Vertex detector	silicon pixels	25 μm		
Outer tracker	silicon strips	50 μm		
ECAL	silicon pixels+W	2×2 cm	500 - 516	250
HCAL	scintillator+Steel	5×5 cm	518 - 742	450
Muon detector	RPC+Steel	3×3 cm	745 - 1010	895
Lumi calorimeter	silicon+W	3.5×3.5 mm	495 - 513	20
Beam calorimeter	semiconductor+W	3.5×3.5 mm	520 - 539	13

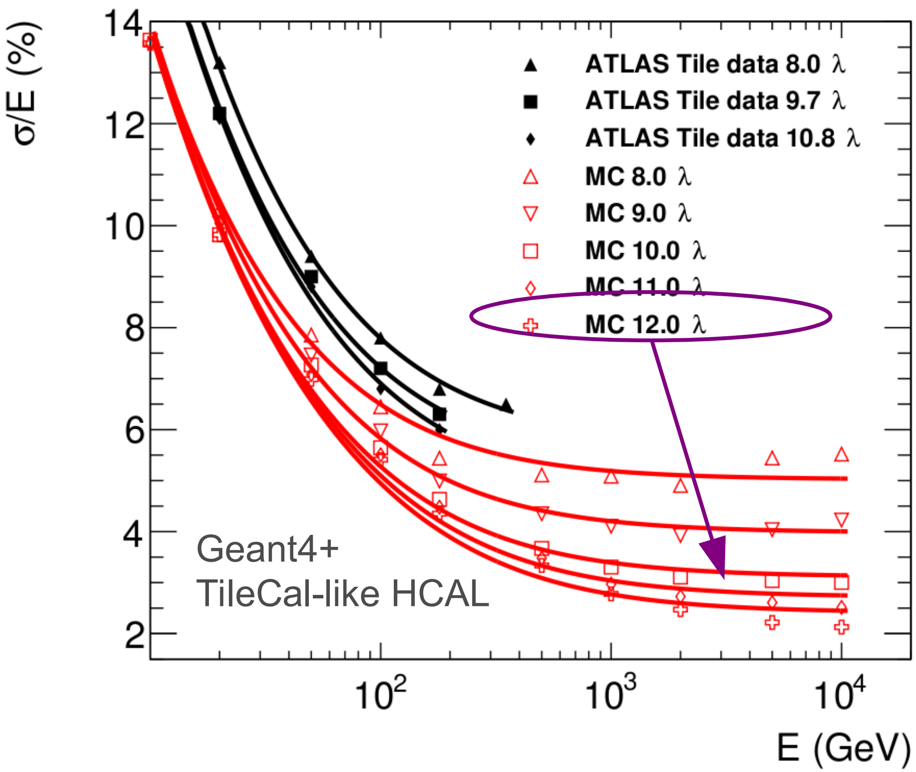
Resolution for single pions

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

ATLAS-like setup
based on Geant4



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



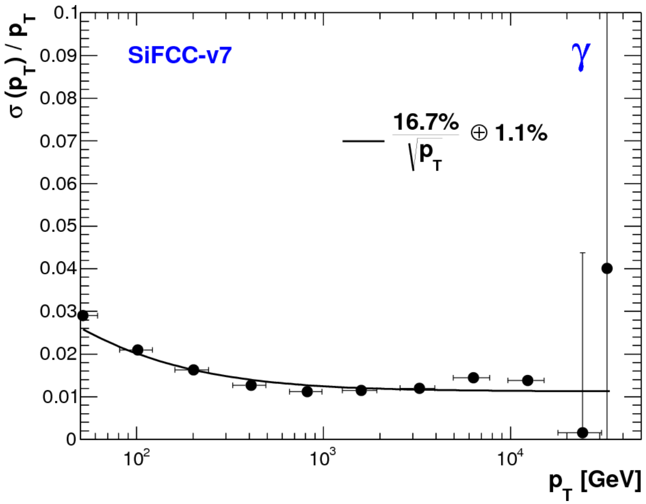
"c" dominates for jet with pT>5 TeV

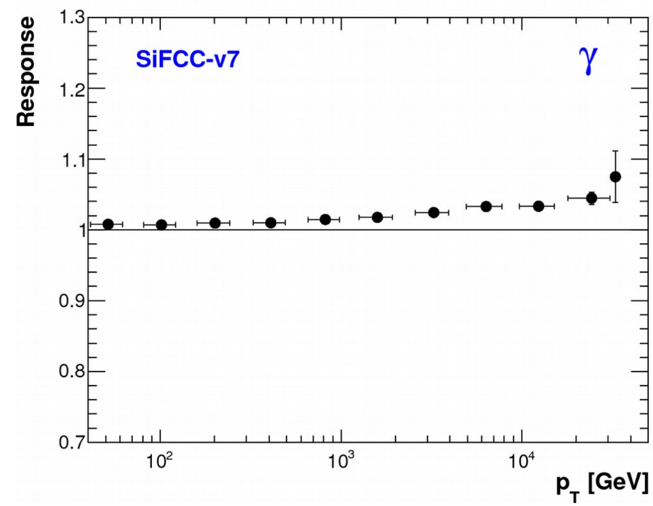
- Geant4 TileCal inspired simulation based on FTFP_BERT
- Calculate single-particle resolution
- Stochastic term is close to 45%/√E
- Constant term improves by ~20% with increase of **1λ_I**

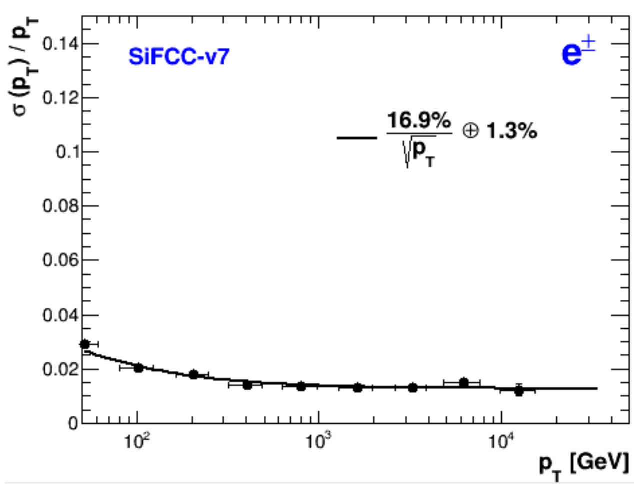
Constant term c~2.5% is achievable for 12 λ_I

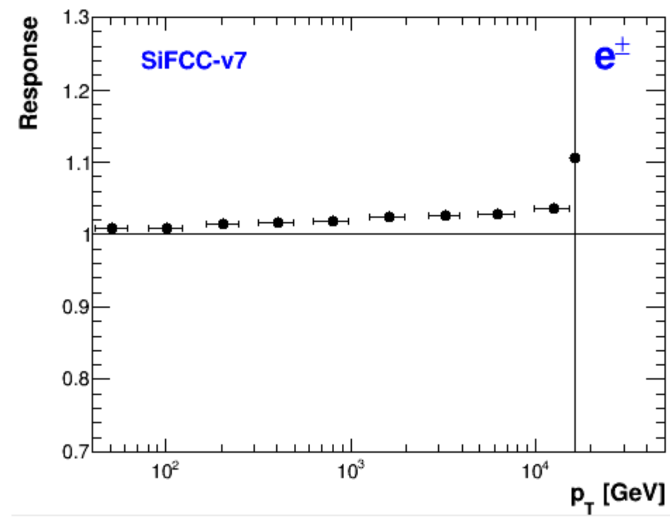
T.Carli, C.Helsens, A.Henriques Correia, C.Solans: arXiv:1604.01415

Single particle resolution and response (e/γ/π^0)



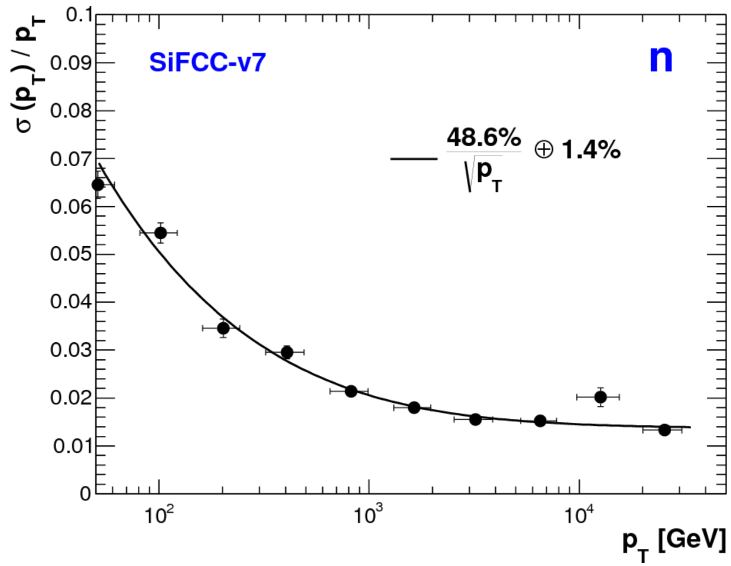


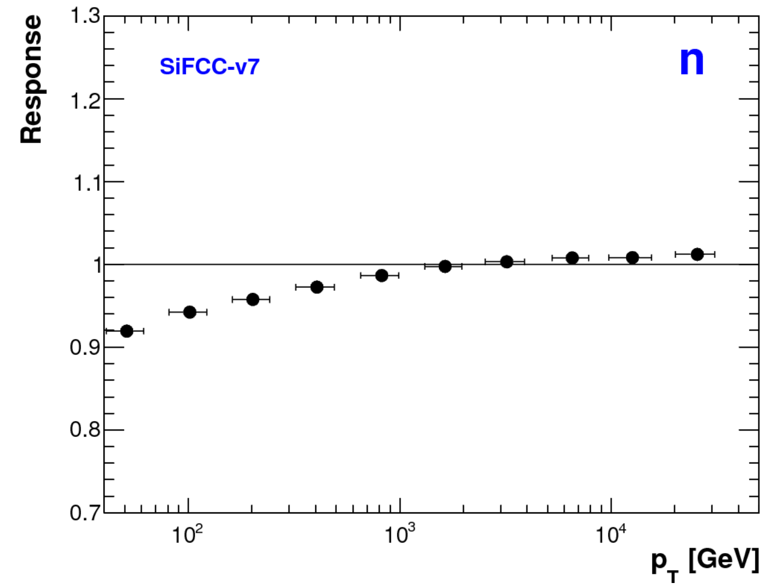


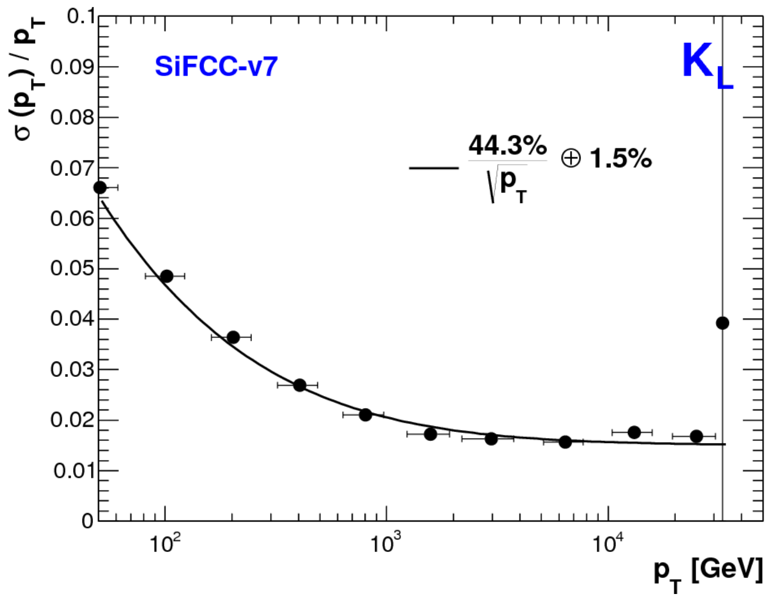


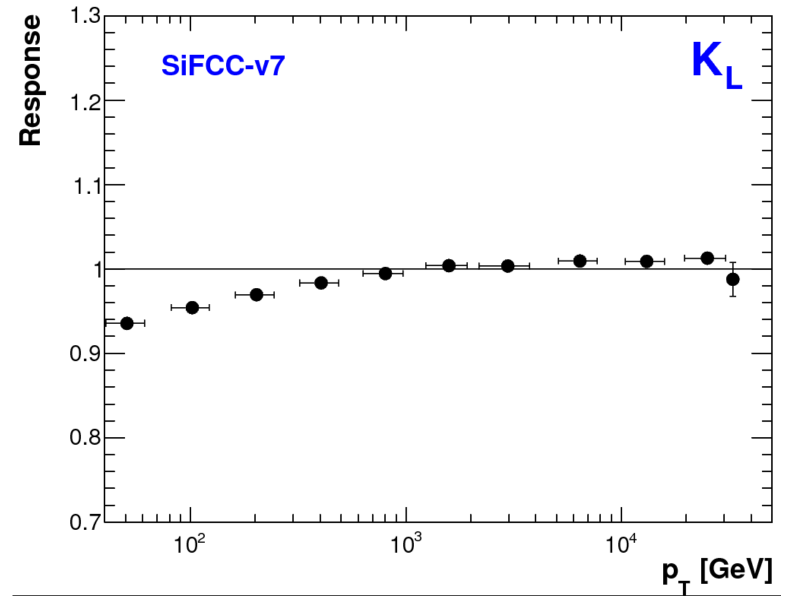
- Reasonable performance of ECAL: ~17% sampling term, 1.3% constant term
- Tracking is not used for electrons

Response to neutrons and K_L





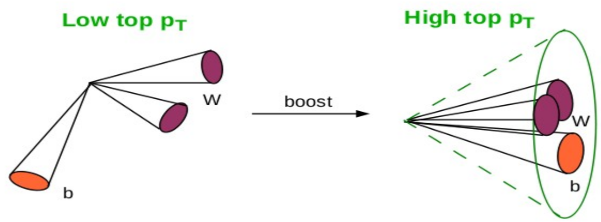


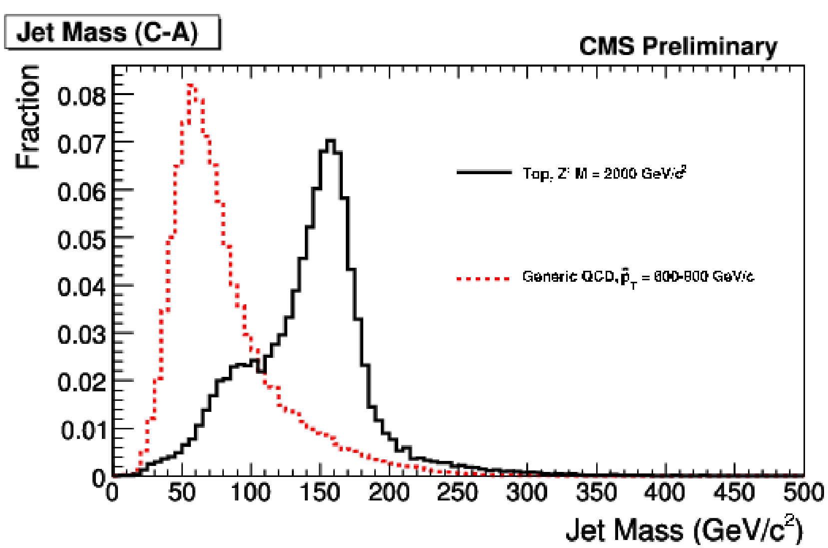


Jet masses for highly boosted jets

- Simple observable constructed from energies and positions of jet constituents
  - requires high spatial resolution of jet constituents
  - sensitive to calorimeter granularity
- Critical for many searches by ATLAS & CMS
  - signal extraction, background rejection etc: boosted W, top, Higgs etc.

$$m^2(jet) = \sum E_i^2 - \sum \boldsymbol{p}_i^2$$





$W \rightarrow q\bar{q} \rightarrow jet$