Detector Simulation/ Higgs studies

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MAP14

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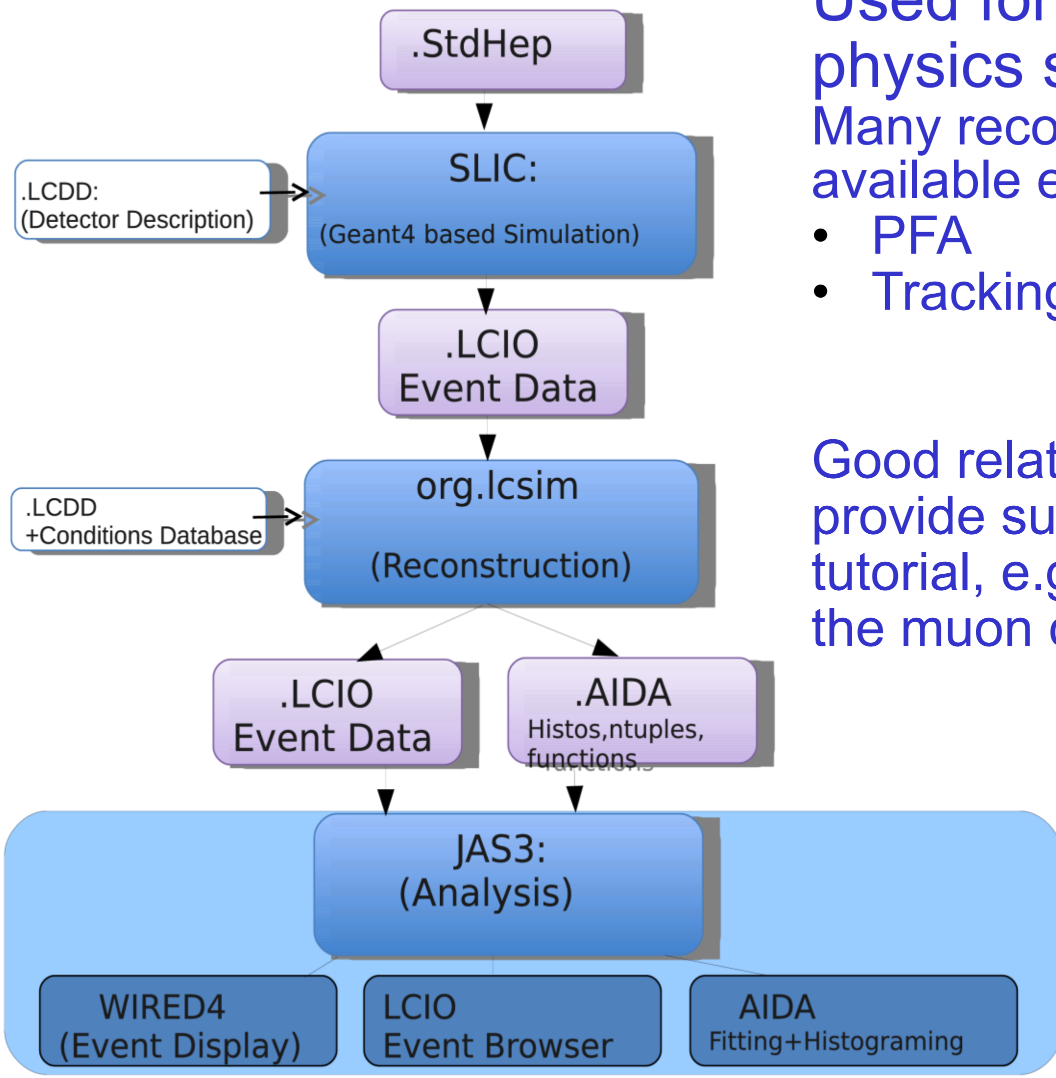
U.S. DEPARTMENT OF ENERGY

Fermilab

Outline

- Existing computing infrastructure (**If You Build It Will They Come?)**
- The mcdrcal01 detector
  - **Performance of a homogenous, total absorption, dual read out calorimeter**
- **Short overview of Higgs studies**
- **Future plans (or the lack thereof)**

Software framework



Used for ILC and CLIC physics studies:

Many reconstruction modules available e.g.

- PFA
- Tracking, Vertexing, B-tagging

Good relations with SLAC group provide support, contribute to the tutorial, e.g. changes specific to the muon collider

MCDRD (Muon Collider Detector R&D): computing resources

- Virtual Organization (VO): mcdrd
  - Sign up at: https://voms.fnal.gov:8443/voms/mcdrd
  - (we have 250 dedicated slots + opportunistic on fermigrid and we are part of OSG)
- reference machine on the fermicloud: mcdrd.fnal.gov
  - To get an account contact service desk and request a fermicloud account and request access to mcdrd.
  - Grid submission software installed

TBs of dedicated disk space on bluearc: /grid/data/mcdrd

- software installed in: /grid/data/mcdrd/sw
- detectors jas-assembly-0.9.9 jdk1.7.0_21 mac slic
- data available in: /grid/data/mcdrd/data

MCDRD: computing resources (cont.)

- 100TB in fermilab mass storage system (dcache, enstore)
  /pnfs/mcdrd/Higgsfactory/
- --> software(dccp) installed on mcdrd to move data in and out of mass storage
- Many thanks to the FermiGrid team!!!!!

Muon Collider Documentation

Created Confluence page:

https://confluence.slac.stanford.edu/display/MCPDS/Home

Look for:

Documentation for Accessing MCD R&D Computing Resources.

Tutorial:

https://confluence.slac.stanford.edu/display/ilc/Installing+lcsim+software+for+the+Winter+2012+tutorial

You can sign up here:

https://jira.slac.stanford.edu/signup/

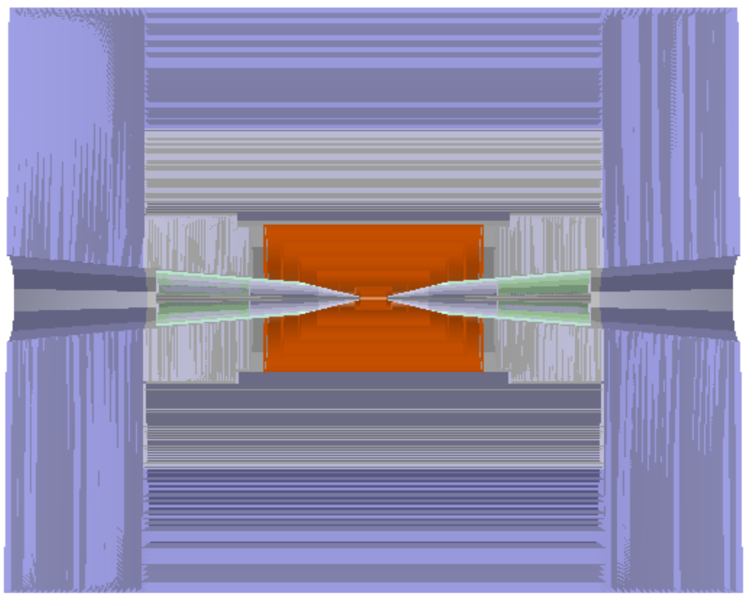
Changes to slic, LCDD and Geomconverter

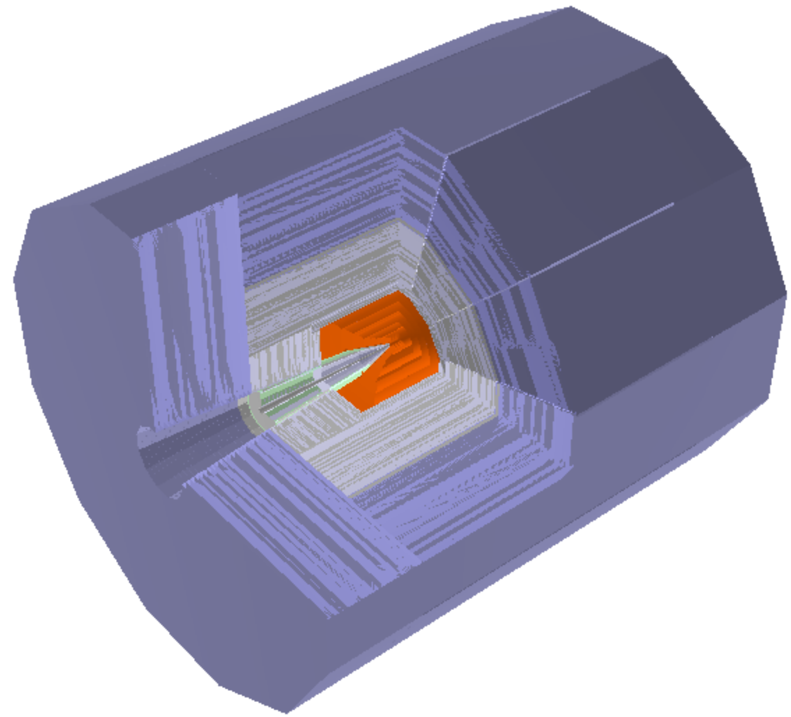
- Slic now uses recent version of geant 4 and new build system (cmake).
- optical properties can be specified in compact.xml and propagate to .lcdd and .gdml files.
- Optical dual readout (scint. And Cerenkov) calorimeter now available. We (Alex, Jeremy, myself) implemented fast calculation of Cerenkov contribution(instead of using Geant 4 (slow)) → makes simulation time acceptable.
- Can kill particles entering a specific volume (e.g. the tungsten cone)

The mcdrcal01 detector in org.lcsim

5T solenoidal field,
radius=3.075m

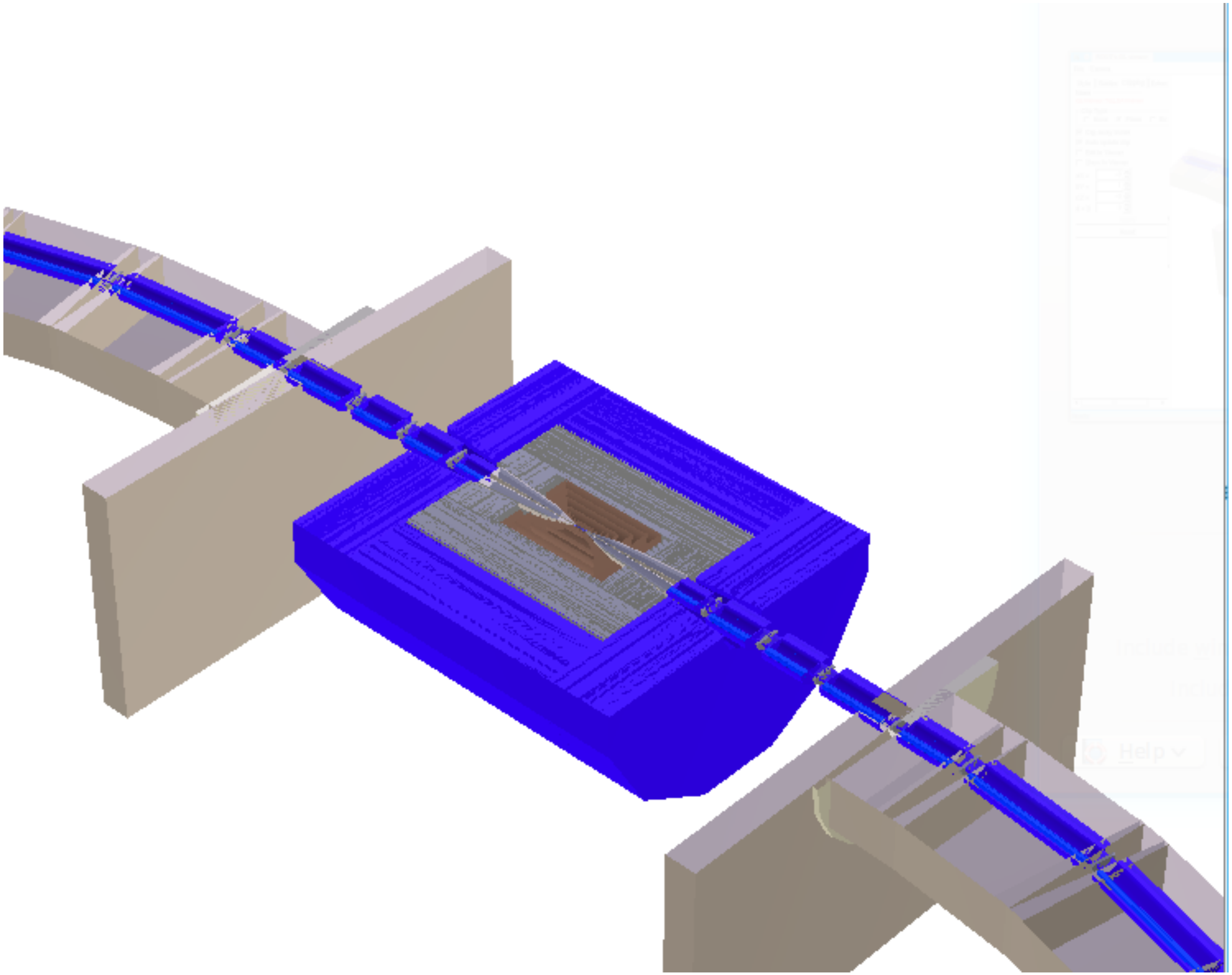
Calorimeter dimensions:
Rmin: 1.36 m
Rmax: 3.07 m
Length: 2x3.702 m





Good relation with accelerator group,
Easy to change detector design if e.g. shielding/MDI changes. Declared DMZ.

HF IR MARS15 Model: 3D View



Motivation for calorimeter choice

- Precise:
  - total absorption (no sampling fluctuations),
  - dual readout correction,
  - Homogeneous;(no difference in ECAL and HCAL response) → results in excellent energy resolution and linearity.
- Fast:
  - Cerenkov light is prompt, new photon detectors like SiPM show excellent timing capabilities → provides handle to get muon decay backgrounds under control.
- Finely granulated:
  - Improve reconstruction even further with PFA algorithms.

Calorimeter Properties for Barrel and Endcaps

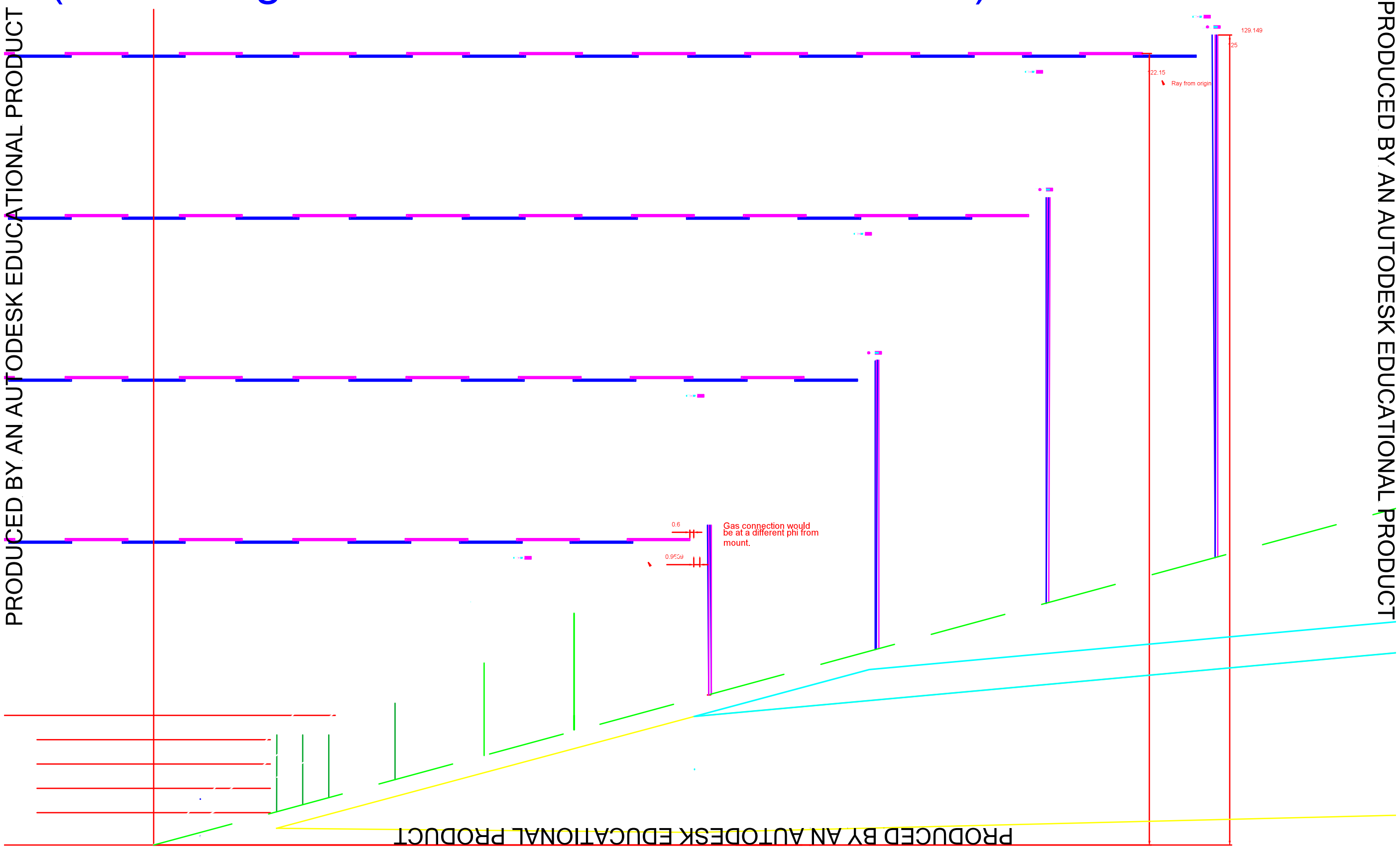
	EM	Hadron	Muon
Material	BGO/PbF_2/$PbWO_4$	BGO/PbF_2/$PbWO_4$	Iron
Density [g/cm^3]	7.13/7.77/8.29	7.13/7.77/8.29	7.85
Cell size [cm^3]	1x1x2	2x2x5	10x10x10
Layers	10	30	22
Detector Depth [cm]	20	150	220
Radiation Length [cm]	1.1/0.93/0.89	1.1/0.93/0.89	1.76
Nuclear Interaction Length [cm]	22.7/22.4/20.7	22.7/22.4/20.7	16.8
Total Nr of IA length (em +had)	**7.5 /7.6/8.2**		

Motivation for tracker choice

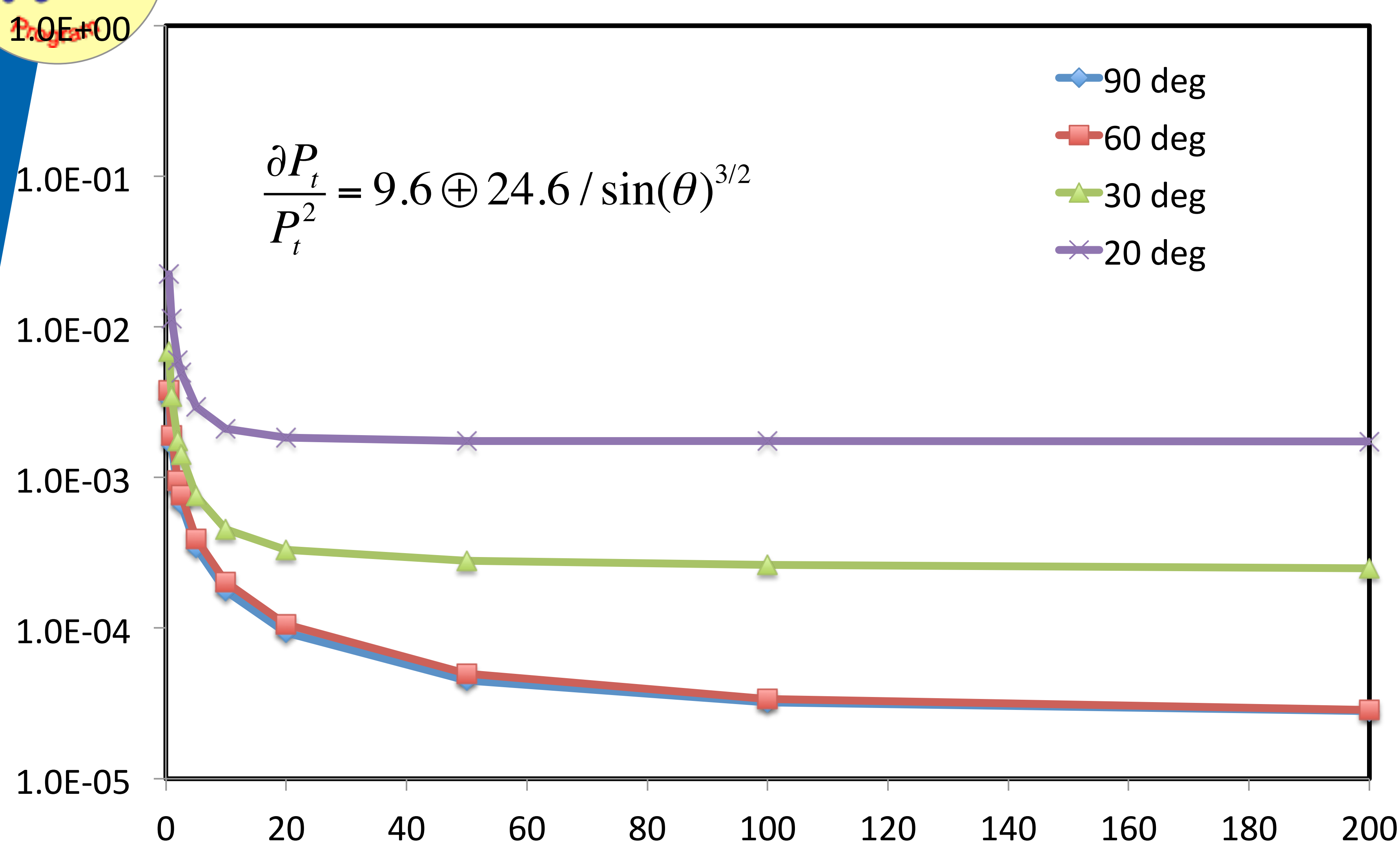
- Precise:
  - To achieve the tracking goals (driven by b-tagging,PFA) while keeping the tracker compact we require a high solenoidal magnetic field of 5 Tesla and use silicon tracking paired with a pixel vertex detector for high precision low mass tracking.
  - Fast timing and fast readout requires extra power and cooling and R&D will be necessary to achieve this while keeping detectors and support at the required low mass. (more CMS than ILC like)

Mcdrcal01: Tracker

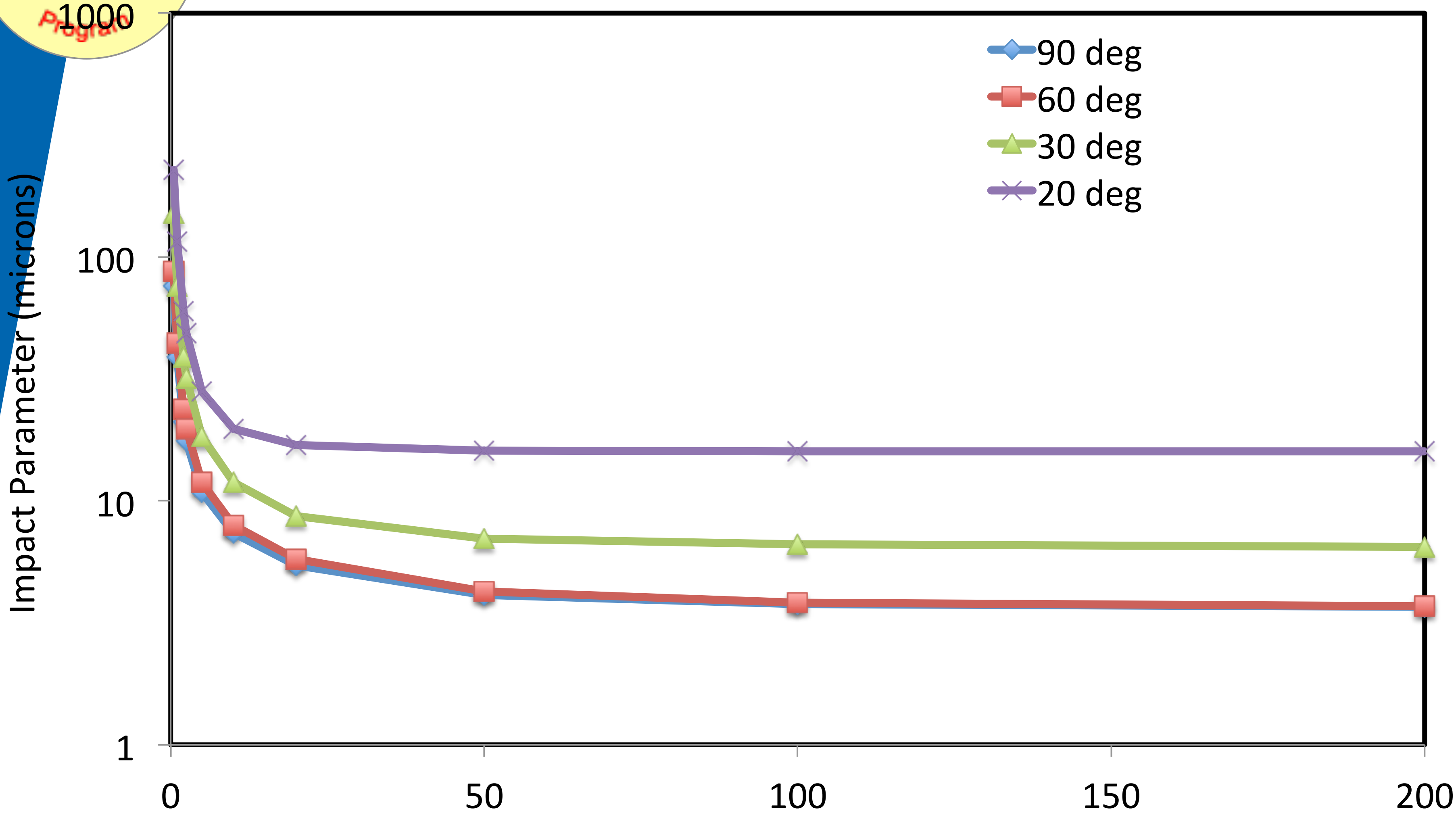
Simplified geometry: cylinders and disk no segmentation
(virtual segmentation used in reconstruction)



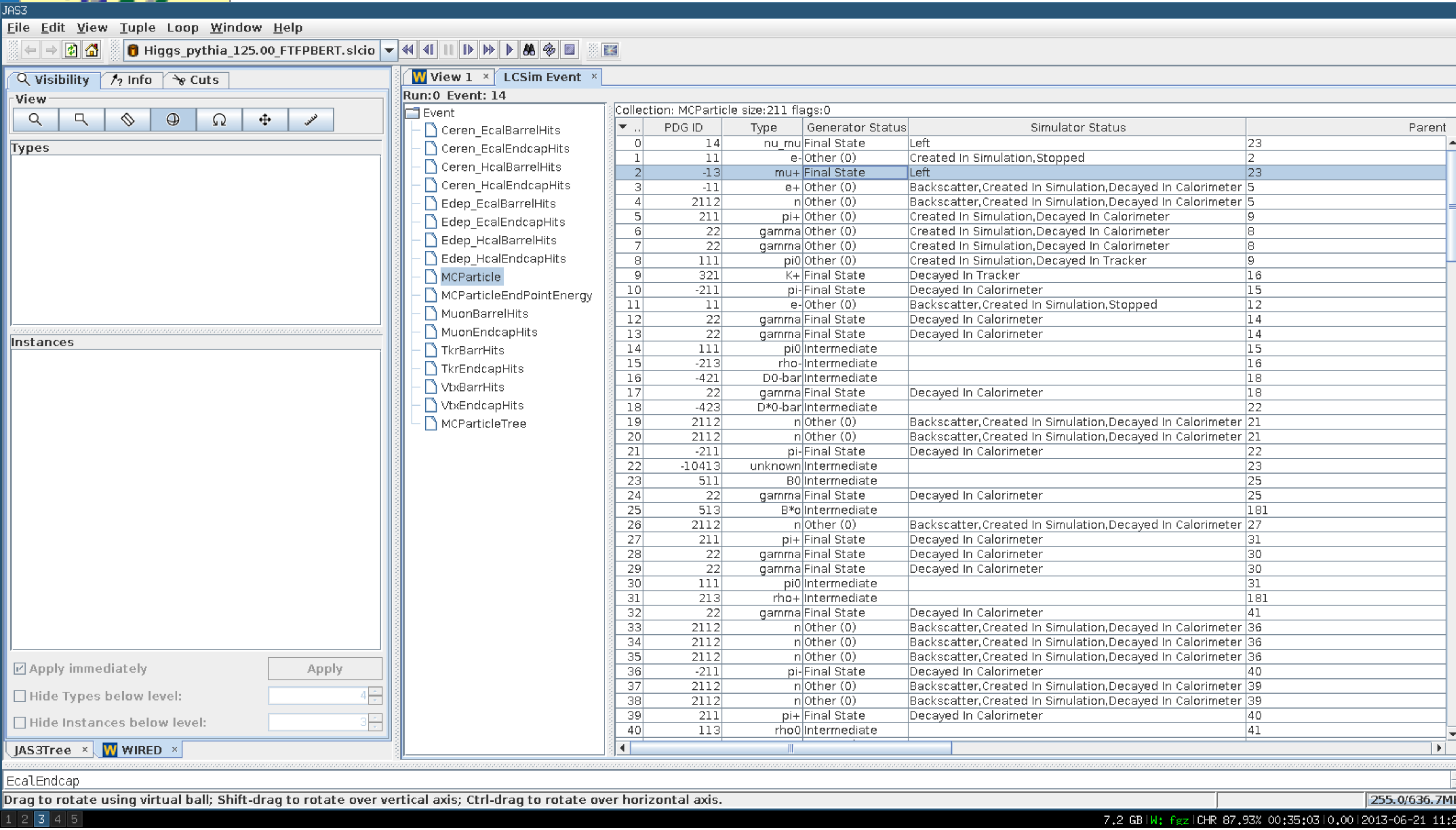
Predicted momentum resolution



Predicted: Impact Parameter resolution

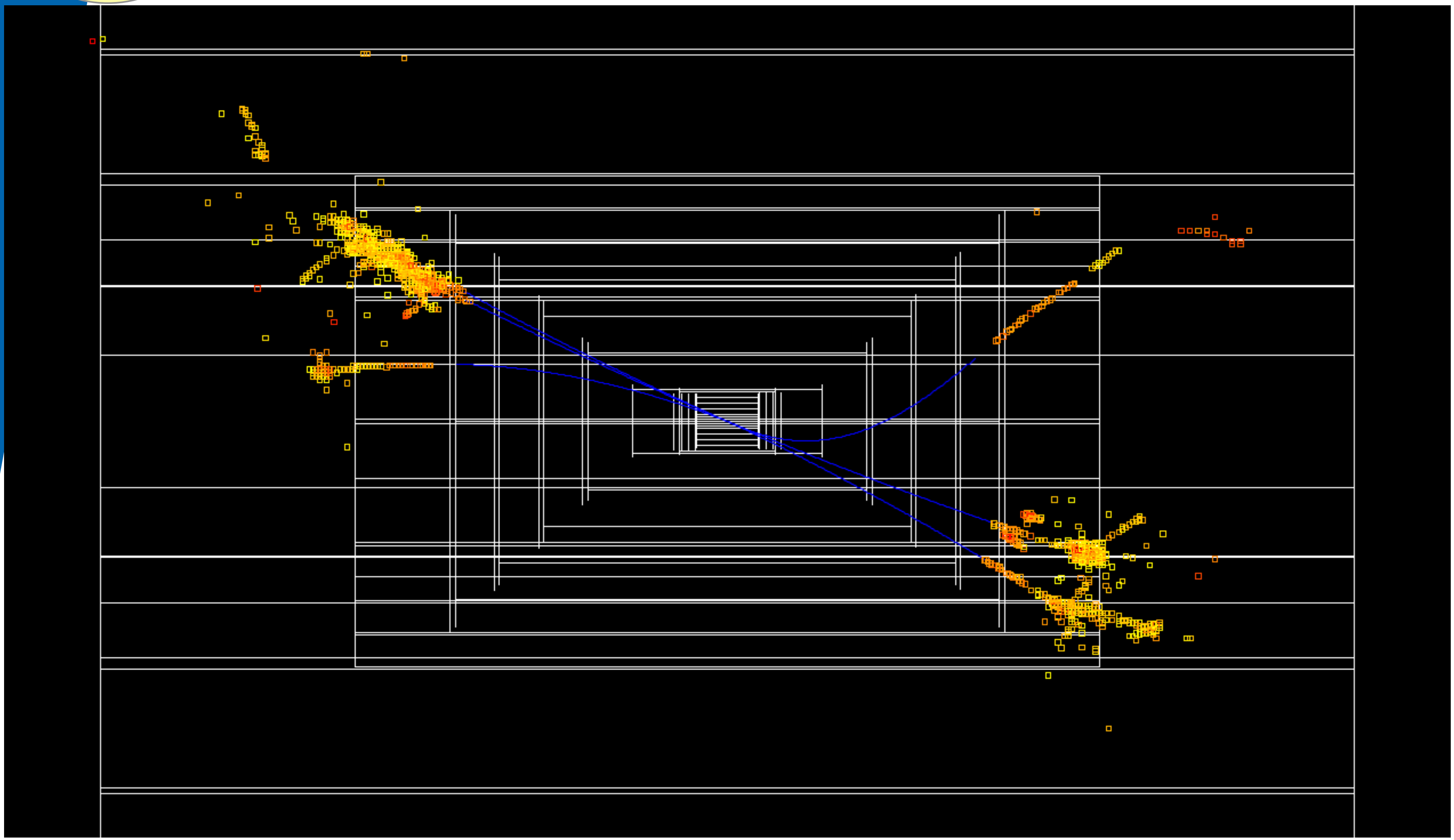


JAS3 – Event Browser

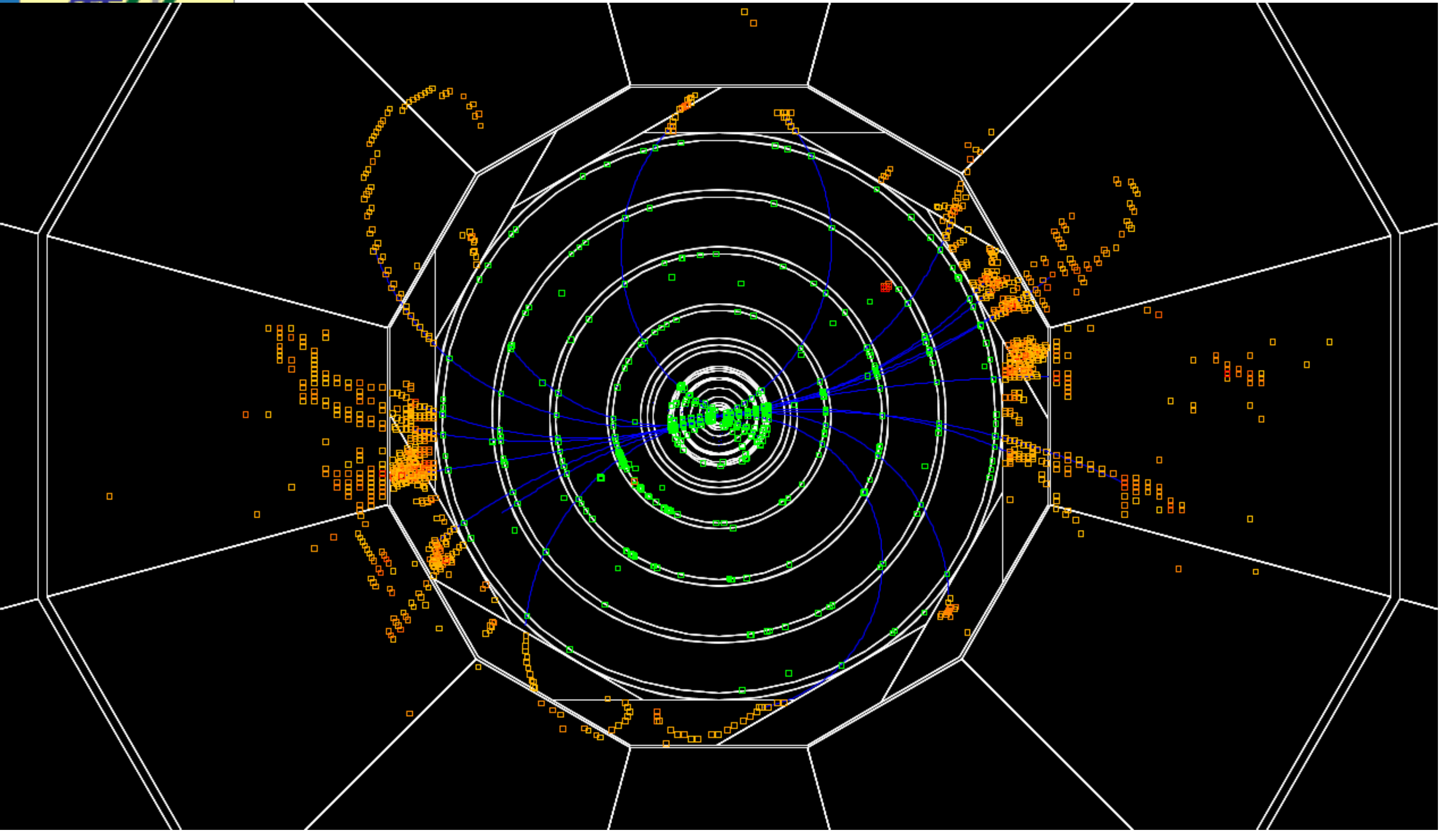


..	PDG ID	Type	Generator Status	Simulator Status	Parent
0	14	nu_mu	Final State	Left	23
1	11	e-	Other (0)	Created In Simulation,Stopped	2
2	-13	mu+	Final State	Left	23
3	-11	e+	Other (0)	Backscatter,Created In Simulation,Decayed In Calorimeter	5
4	2112	n	Other (0)	Backscatter,Created In Simulation,Decayed In Calorimeter	5
5	211	pi+	Other (0)	Created In Simulation,Decayed In Calorimeter	9
6	22	gamma	Other (0)	Created In Simulation,Decayed In Calorimeter	8
7	22	gamma	Other (0)	Created In Simulation,Decayed In Calorimeter	8
8	111	pi0	Other (0)	Created In Simulation,Decayed In Tracker	9
9	321	K+	Final State	Decayed In Tracker	16
10	-211	pi-	Final State	Decayed In Calorimeter	15
11	11	e-	Other (0)	Backscatter,Created In Simulation,Stopped	12
12	22	gamma	Final State	Decayed In Calorimeter	14
13	22	gamma	Final State	Decayed In Calorimeter	14
14	111	pi0	Intermediate		15
15	-213	rho-	Intermediate		16
16	-421	D0-bar	Intermediate		18
17	22	gamma	Final State	Decayed In Calorimeter	18
18	-423	D*0-bar	Intermediate		22
19	2112	n	Other (0)	Backscatter,Created In Simulation,Decayed In Calorimeter	21
20	2112	n	Other (0)	Backscatter,Created In Simulation,Decayed In Calorimeter	21
21	-211	pi-	Final State	Decayed In Calorimeter	22
22	-10413	unknown	Intermediate		23
23	511	B0	Intermediate		25
24	22	gamma	Final State	Decayed In Calorimeter	25
25	513	B*0	Intermediate		181
26	2112	n	Other (0)	Backscatter,Created In Simulation,Decayed In Calorimeter	27
27	211	pi+	Final State	Decayed In Calorimeter	31
28	22	gamma	Final State	Decayed In Calorimeter	30
29	22	gamma	Final State	Decayed In Calorimeter	30
30	111	pi0	Intermediate		31
31	213	rho+	Intermediate		181
32	22	gamma	Final State	Decayed In Calorimeter	41
33	2112	n	Other (0)	Backscatter,Created In Simulation,Decayed In Calorimeter	36
34	2112	n	Other (0)	Backscatter,Created In Simulation,Decayed In Calorimeter	36
35	2112	n	Other (0)	Backscatter,Created In Simulation,Decayed In Calorimeter	36
36	-211	pi-	Final State	Decayed In Calorimeter	40
37	2112	n	Other (0)	Backscatter,Created In Simulation,Decayed In Calorimeter	39
38	2112	n	Other (0)	Backscatter,Created In Simulation,Decayed In Calorimeter	39
39	211	pi+	Final State	Decayed In Calorimeter	40
40	113	rho0	Intermediate		41

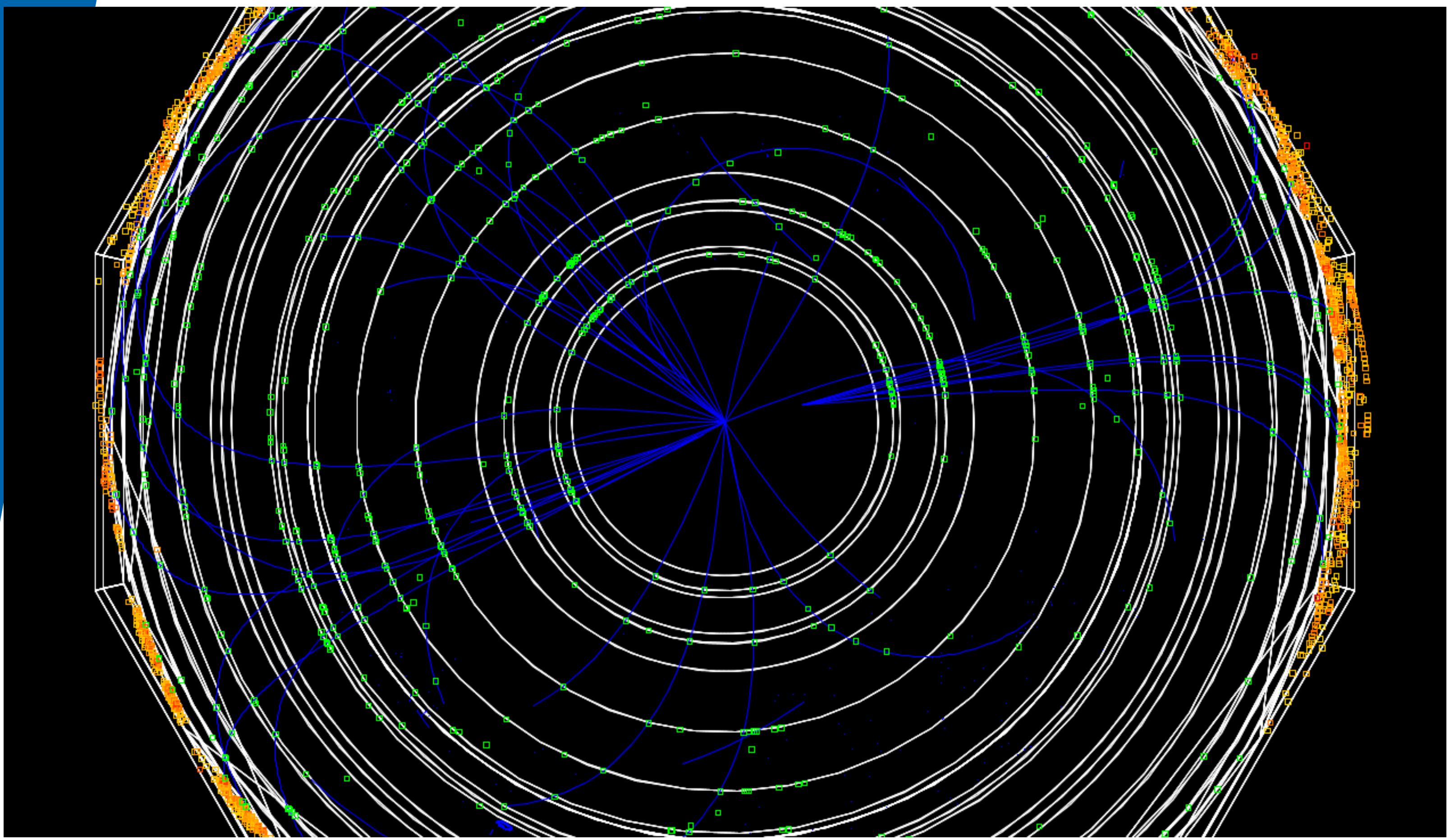
$H^0 \rightarrow \tau^+\tau^-$ event



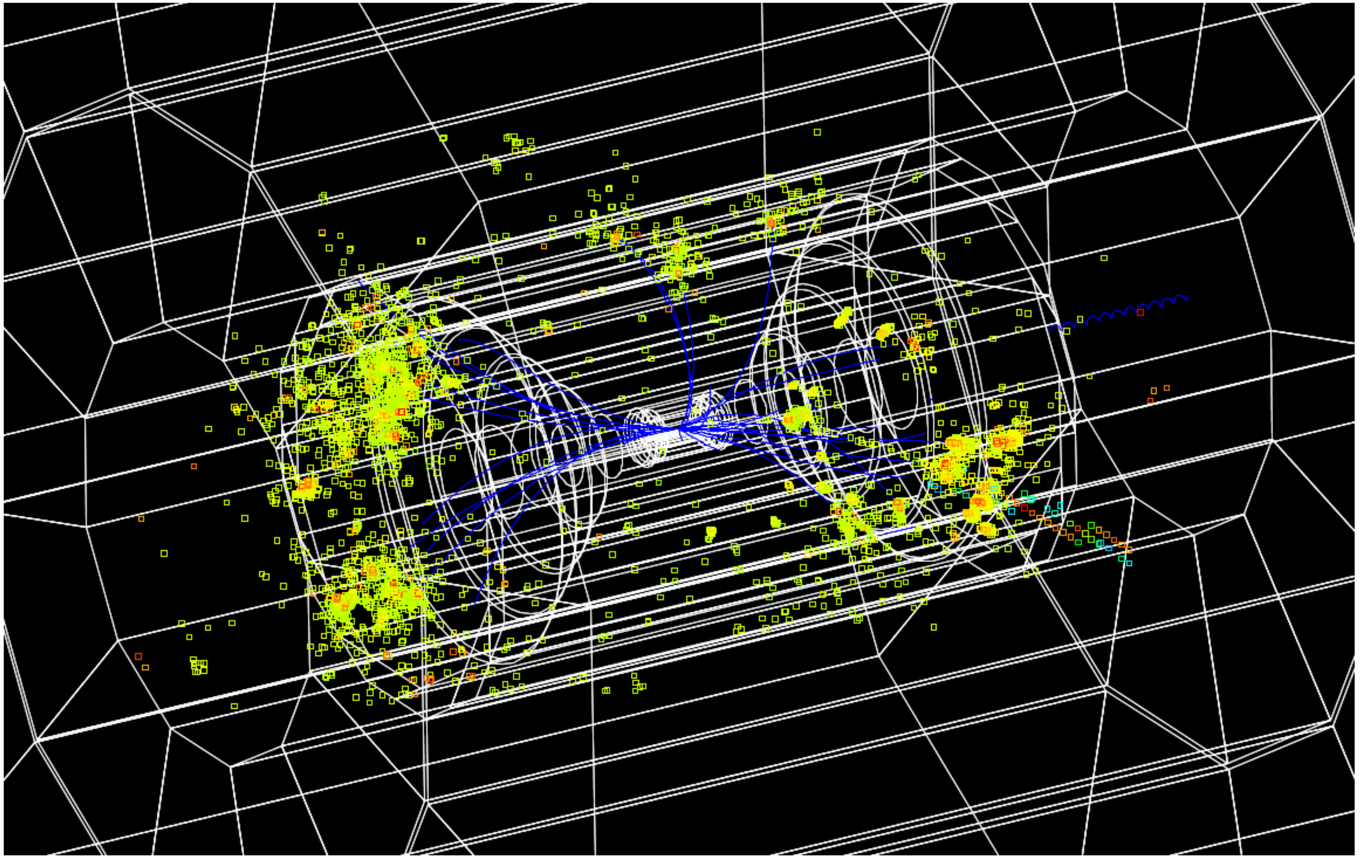
$H^0 \rightarrow$ bb event



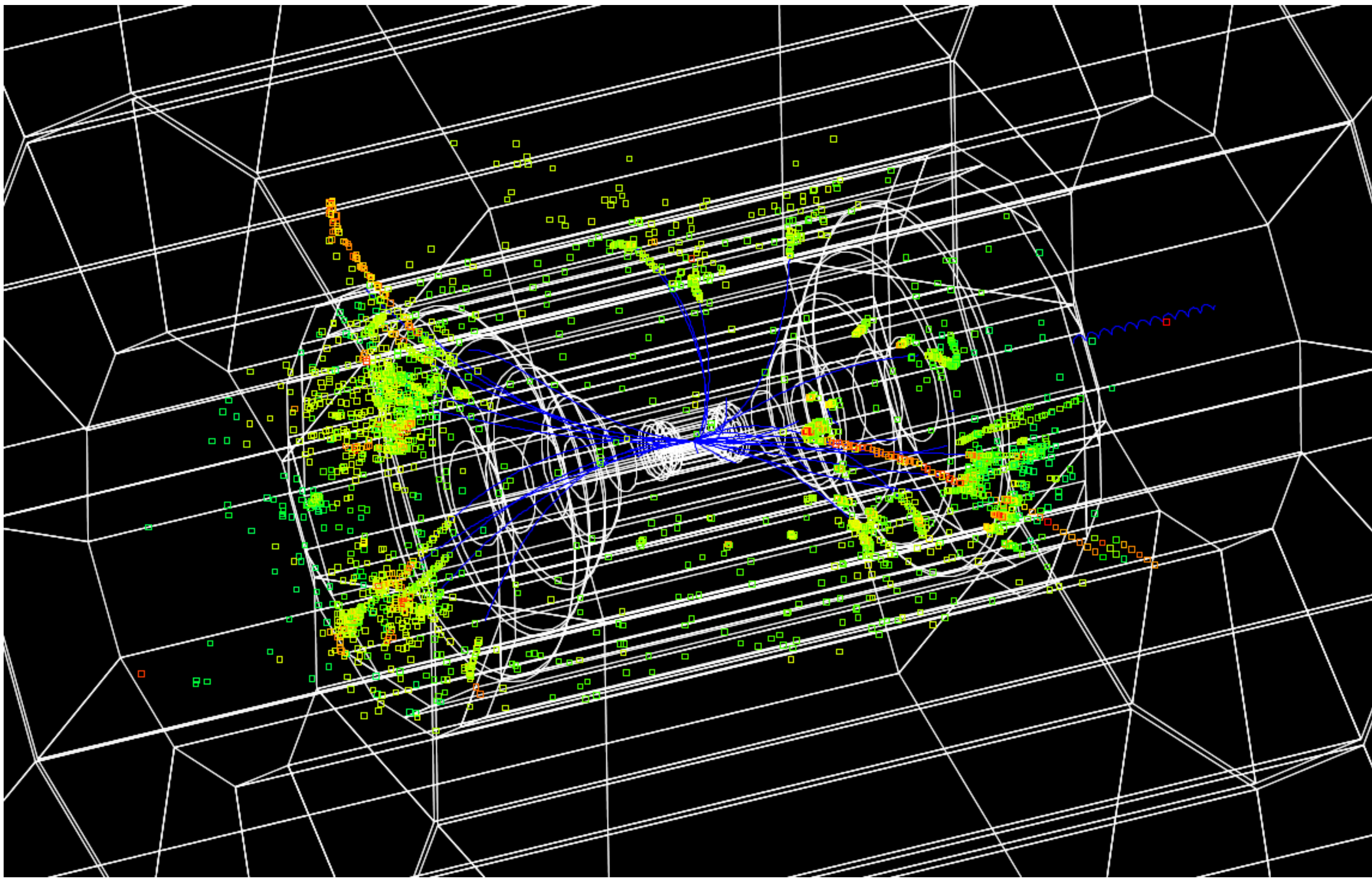
$H^0 \rightarrow$ bb event



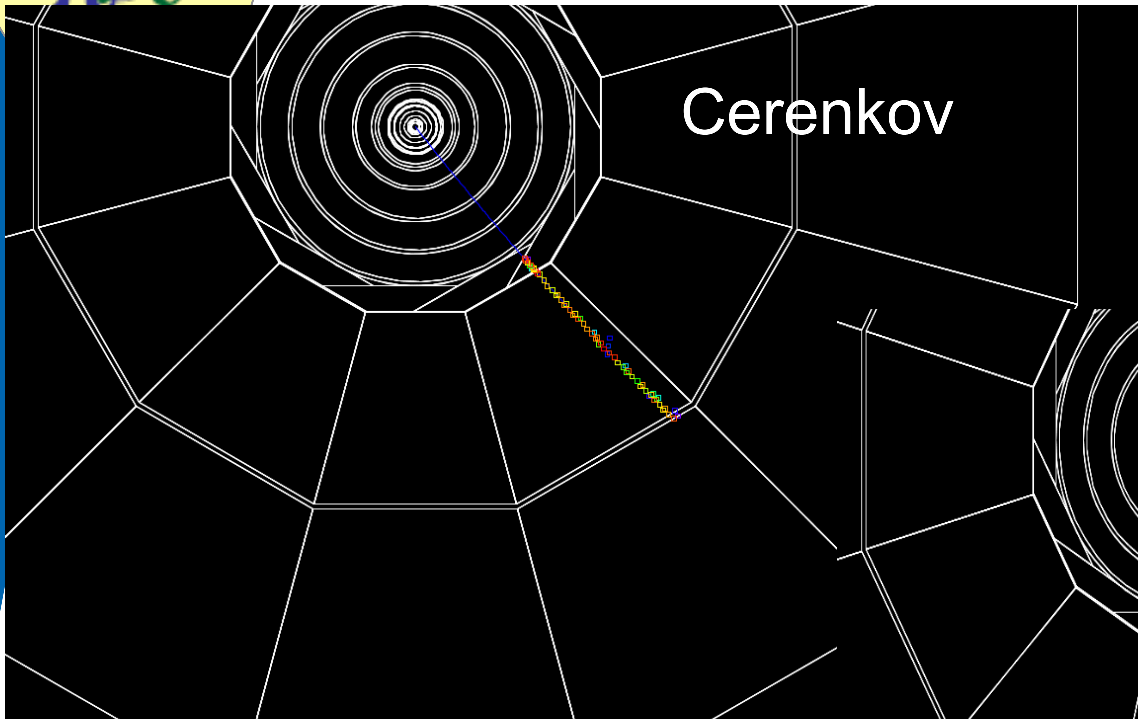
$H^0 \rightarrow$ bb event (Edep Hits)

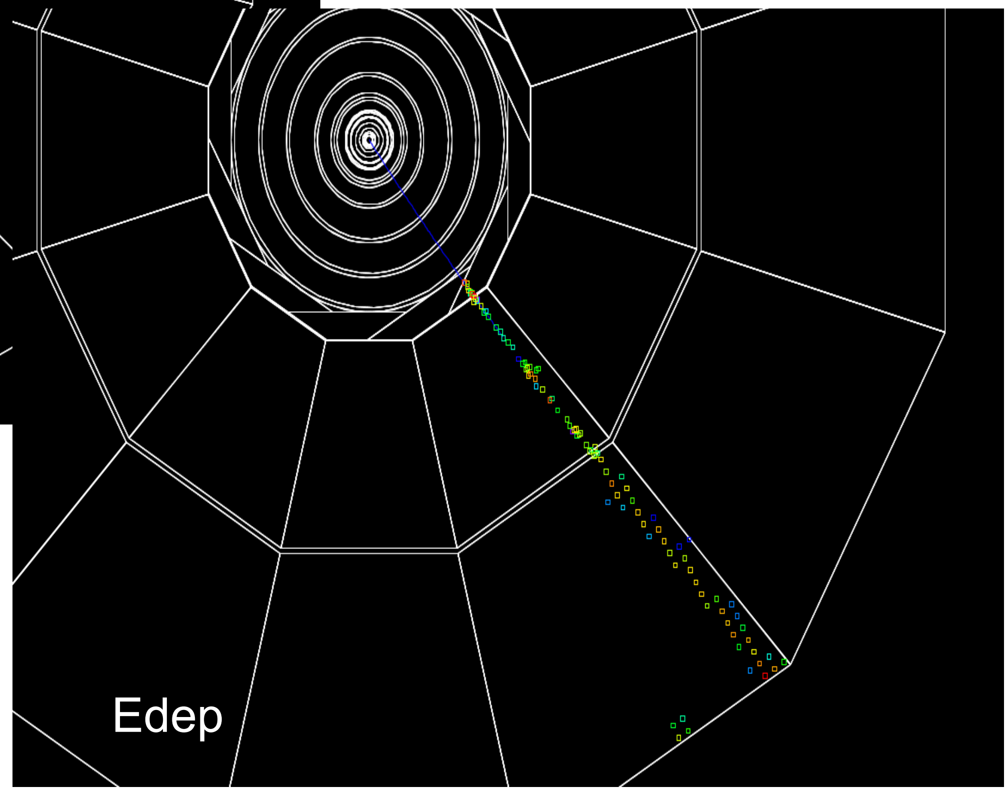


$H^0 \rightarrow$ bb event (cerenkov Hits)

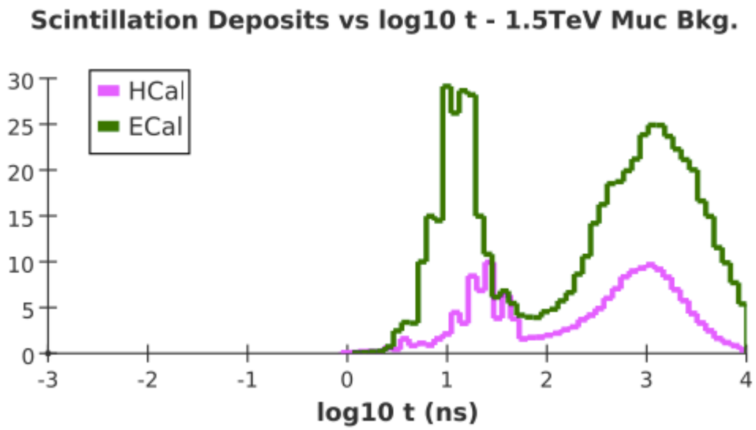


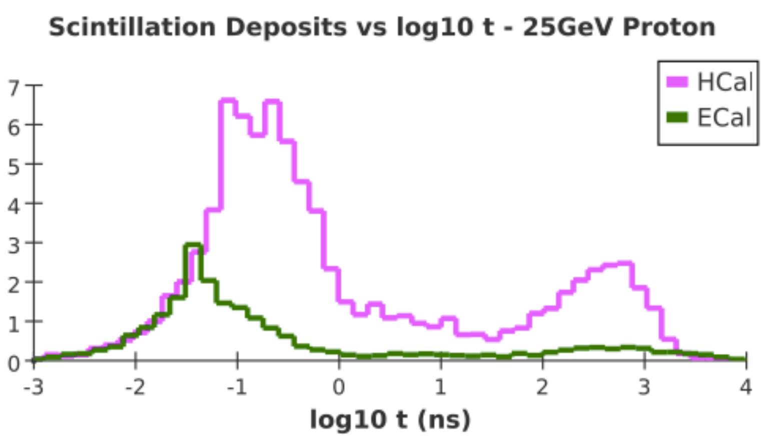
Single Muon





Time Cuts – MuC Example





Histograms weighted by energy.
$log_{10}t$ time axis.

Muon Collider Backgrounds:

- Machine backgrounds from muon beam decay.
- Mostly photons and neutrons.
- Background not normalized.
- Signal in HCal, bkg in ECal.

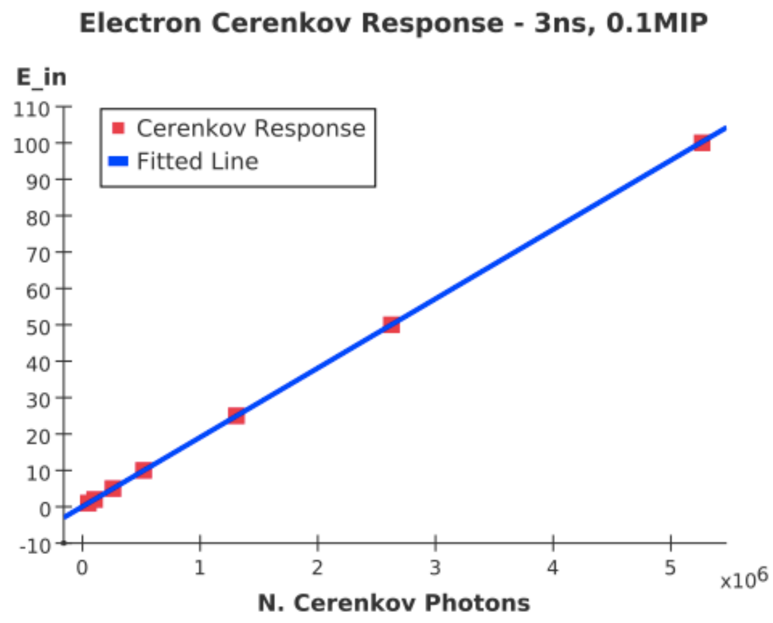
Time Cuts:

- Majority of signal in first ns.
- Cuts should be in 3–10ns range.
- 3ns cut eliminates 92% of background, 5% of proton signal compared to 10ns cut.

Cerenkov Calibration Using Electrons

Convert number of Cerenkov photons to an energy.

- Use electrons with range of energies.
- Fit Cerenkov response at each energy with Gaussian.
- Fit electron energy to Cerenkov responses with line.
- Slope gives conversion factor for number of photons to energy.
- Also do this with scintillation.



Slope: $1.9 \times 10^{-5} GeV/photon$

$\rightarrow \quad \sim 53,000 \; photons/GeV$

DR Correction With Protons

Plot (S)cintillation response fraction vs. (C)erenkov/(S)cintillation.

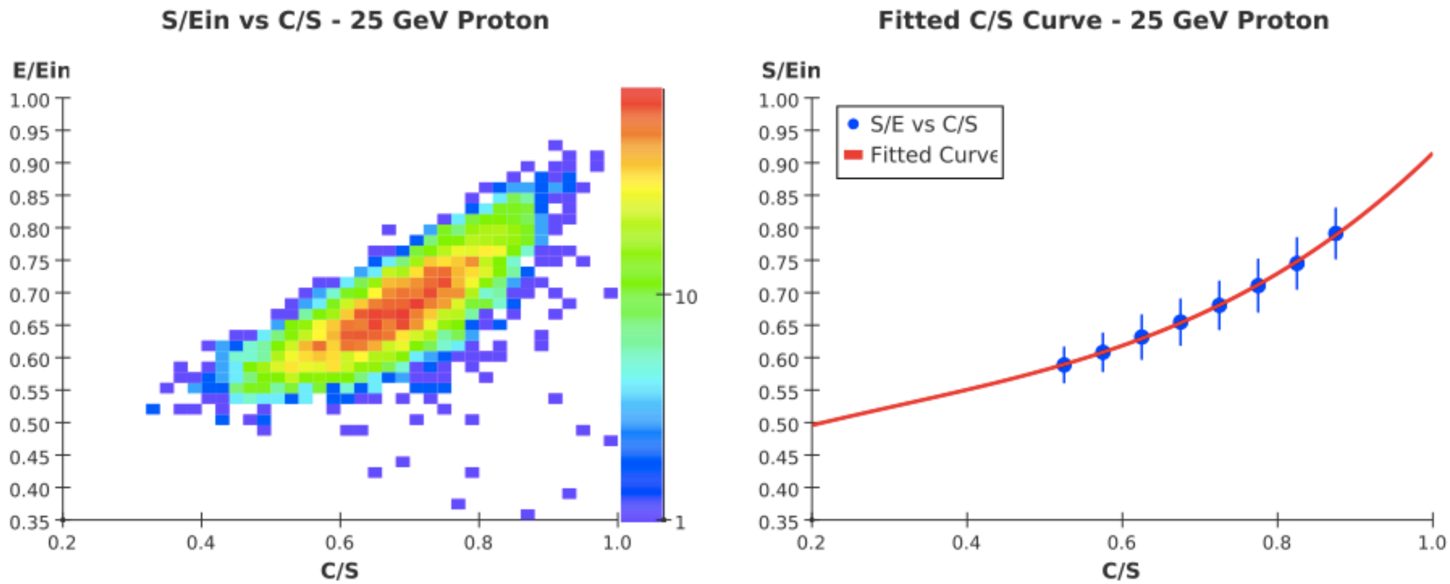


Figure: C/S histogram and fit for 25 GeV proton, 3ns, 1/10 MIP cuts.

Fit to 4^{th} order polynomial in C/S. Use polynomial to obtain correction: $E_{corr} = S/Poly(C/S)$.

Single Hadron Resolution Curves

- Similar resolution curves per particle.
- Maintain high resolution with timing cuts.
- Correction curve changes, resolution doesn't.

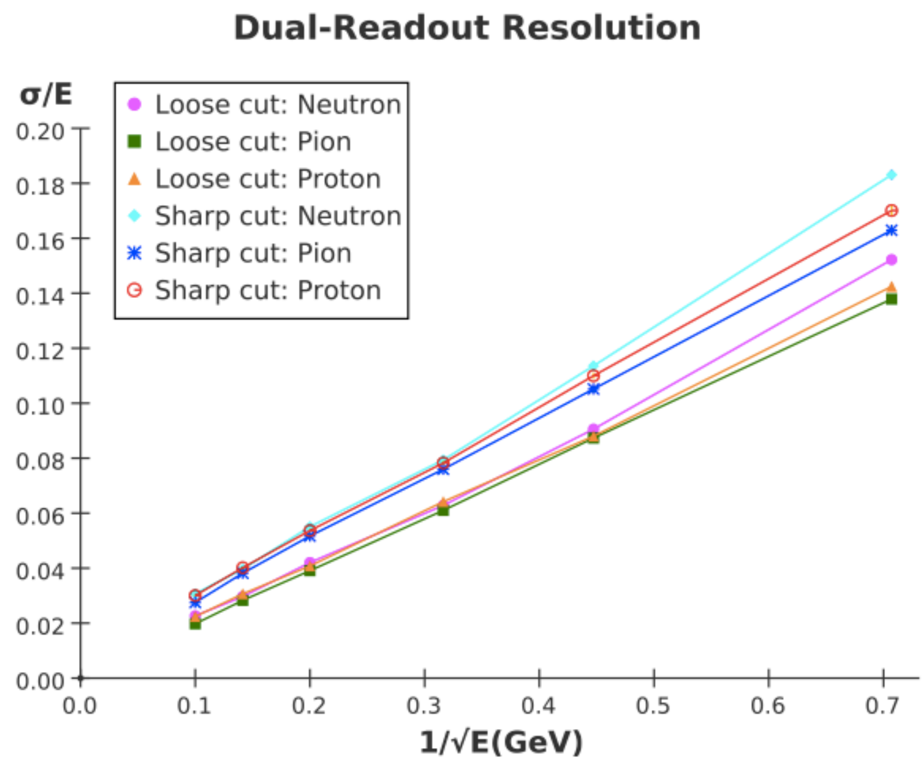
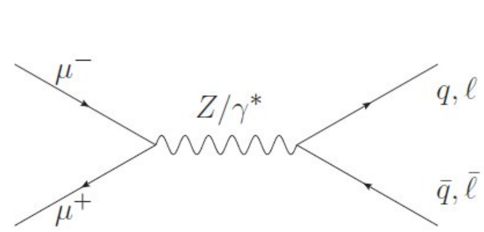


Figure: Resolution curves for protons, neutrons, and pions with 'loose cut' of 10ns, 1/50 MIP, 'sharp cut' of 3ns, 1/10 MIP.

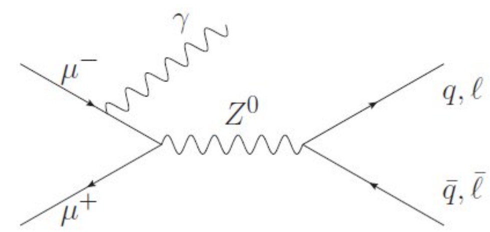
Higgs studies at a MUC-Higgs factory

- Generator level studies → no full detector simulation
- Precision of mass/width measurement →given by accelerator.
- Detector: classify events → optimize signal/ bgr.

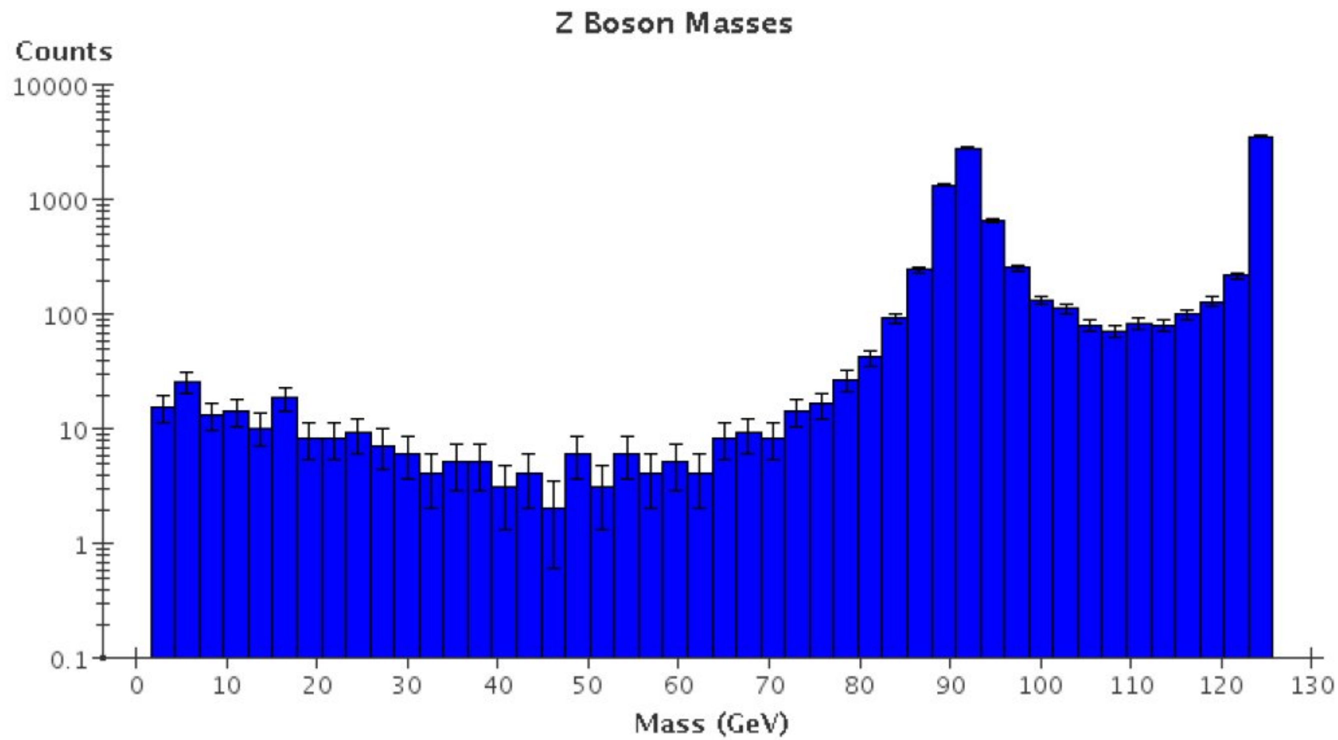
SM Background



(a) Irreducible background: $\mu^+\mu^- \to Z/\gamma^*$ with $M_{Z^*} = \sqrt{s}$.



(b) Reducible background: $\mu^+\mu^- \to Z^0, \gamma$ with $M_{Z^0} < M_{H^0}$.



Require:
Evis> 98GeV
in Detector

Branching ratios

Decay Mode	Z		H^0	
	BR	σ (pb)	BR	σ (pb)
$u\bar{u}$,$d\bar{d}$,$s\bar{s}$	0.427	160.6	0.0003	0.009
$c\bar{c}$	0.119	44.8	0.032	0.91
bb	0.152	57.2	0.584	16.5
e^+e^-	0.034	12.8	—	—
$\mu^+\mu^-$	0.034	12.8	—	—
$\tau^+\tau^-$	0.034	12.8	0.071	2.01
$\nu_\ell\bar{\nu}_\ell$	0.200	75.4	—	—
gg	—	—	0.053	1.50
$\gamma\gamma$	—	—	0.003	0.085
WW^*	—	—	0.226	6.39
Z^0Z^0	—	—	0.028	0.79
Total:	1.0	376.3	1.0	28.3

Event shape variables

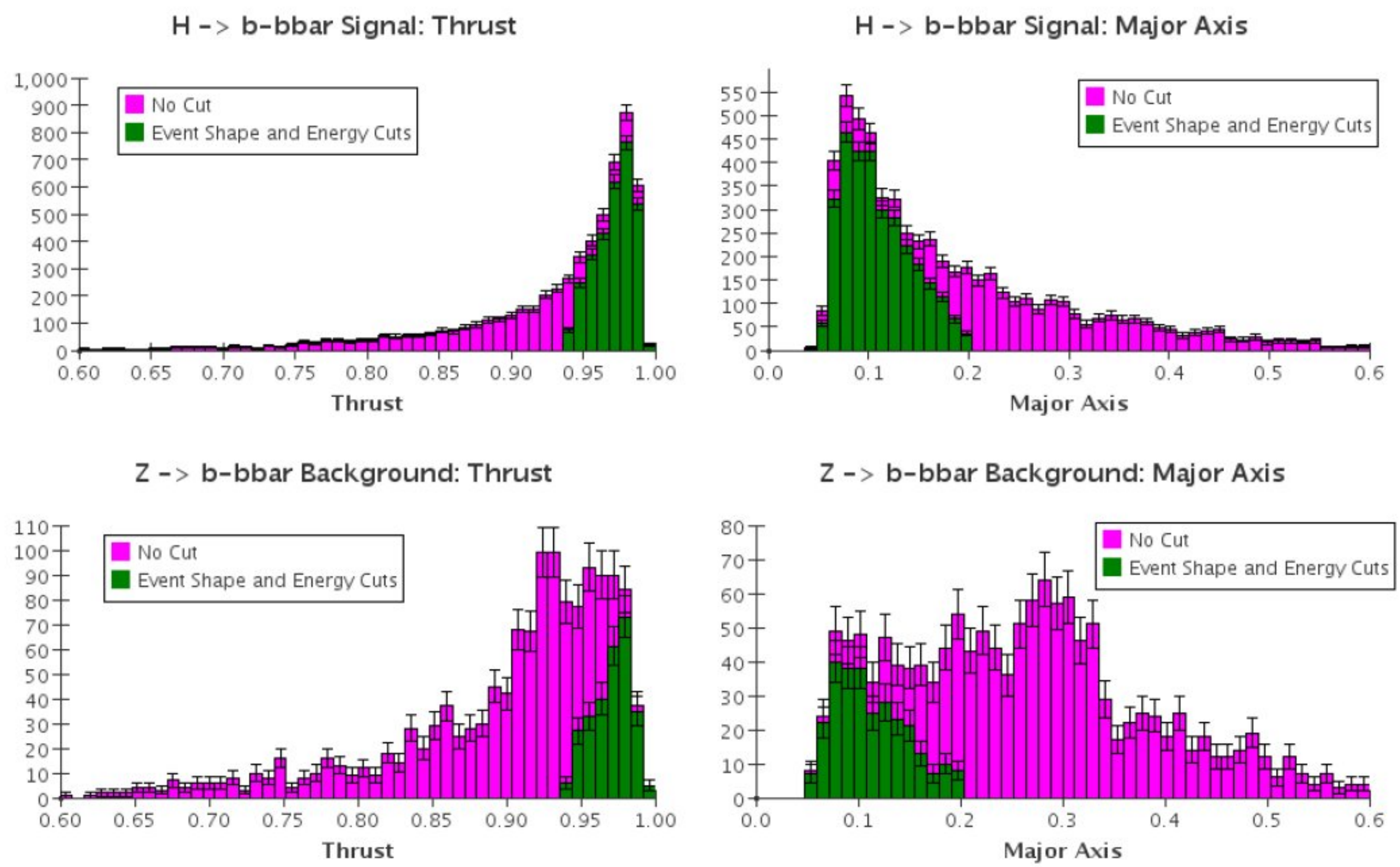


Figure 6: Effects of event shape and energy cuts on Higgs $b\bar{b}$ signal and background. Cuts were made by selecting events with total energy $E_{tot} > 98.0GeV$ visible to the detector, thrust between 0.94 and 1.0 and major axis between 0.0 and 0.2. The signal is reduced to 52% and the background to 15%.

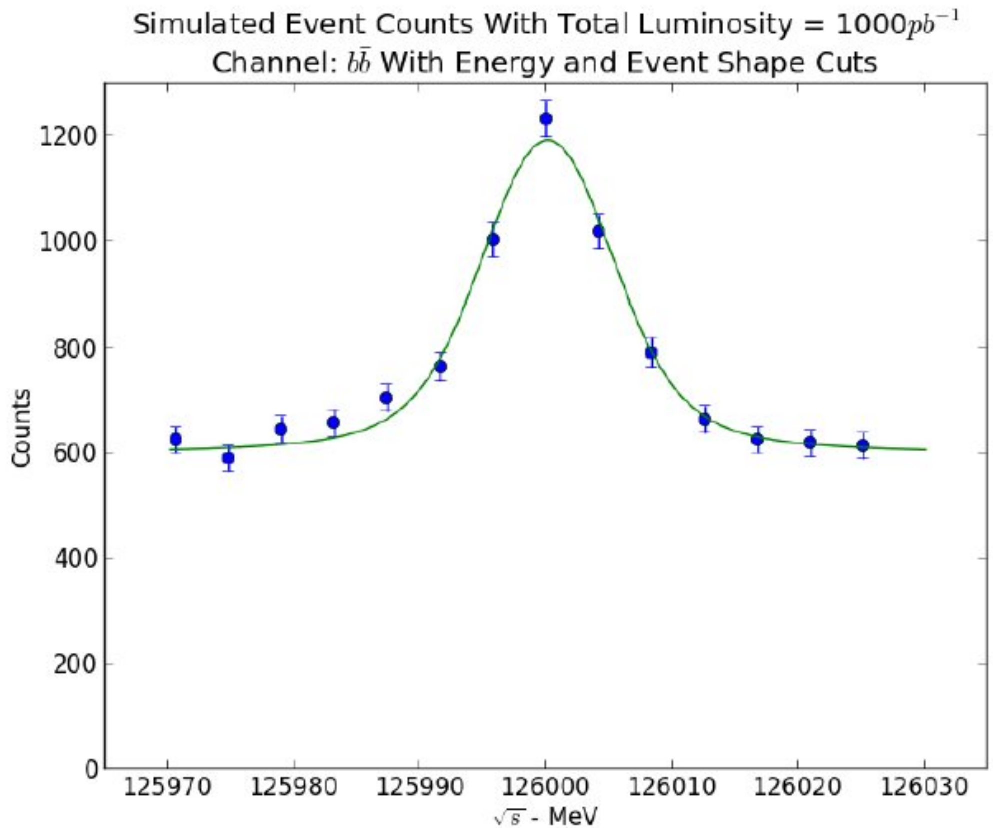


Figure 7: Simulated event counts for a scan across a 126.0 GeV Higgs peak with a 4.2 MeV wide Gaussian beam spread, counting $X \rightarrow b\bar{b}$ events with a total energy of at least 98.0 GeV visible to the detector and cutting on event shape parameters. Data is taken in a 60 MeV range centered on the Higgs mass in bins separated by the beam width of 4.2 MeV. Event counts are calculated as Poisson-distributed random variables and the data is fit to a Breit-Wigner convoluted with a Gaussian plus linear background. The fit width is 4.78 ± 0.48 MeV, the error in the mass measurement is 0.01 ± 0.05 MeV and the branching ratio is measured at 0.271 ± 0.001. Total luminosity is $1000pb^{-1}$, or $71.4pb^{-1}$ per point.

Channel		$\Gamma_{H\to X}(MeV)$	$\Delta M_H(MeV)$	$Br(H^0 \to X)$
Total	Raw	4.56 ± 1.52	0.13 ± 0.16	0.96 ± 0.04
	Cut	5.57 ± 1.33	-0.02 ± 0.14	0.65 ± 0.01
$b\bar{b}$	Raw	3.49 ± 1.83	-0.06 ± 0.19	0.67 ± 0.05
	Cut	4.78 ± 0.48	0.01 ± 0.05	0.271 ± 0.001
WW^*	Raw	4.06 ± 0.24	0.00 ± 0.07	0.217 ± 0.001
	Cut	3.96 ± 0.17	-0.16 ± 0.04	0.1271 ± 0.0002
$\tau^+\tau^-$	Raw	4.82 ± 4.46	-0.54 ± 0.47	0.0623 ± 0.0005
	Cut	0.84 ± 2.97	1.07 ± 0.30	0.24 ± 0.23
$\gamma\gamma$	Raw	2.85 ± 5.73	-0.6 ± 0.9	0.0035 ± 0.0001
	Cut	—	—	—

Table 3: Fitted values of Higgs decay width, mass and branching ratio from simulated data. Mass values are the difference between the measured mass and the true mass of 126,000 MeV. Total integrated luminosity was 1 fb^{-1}, or $71.4pb^{-1}$ per data point.

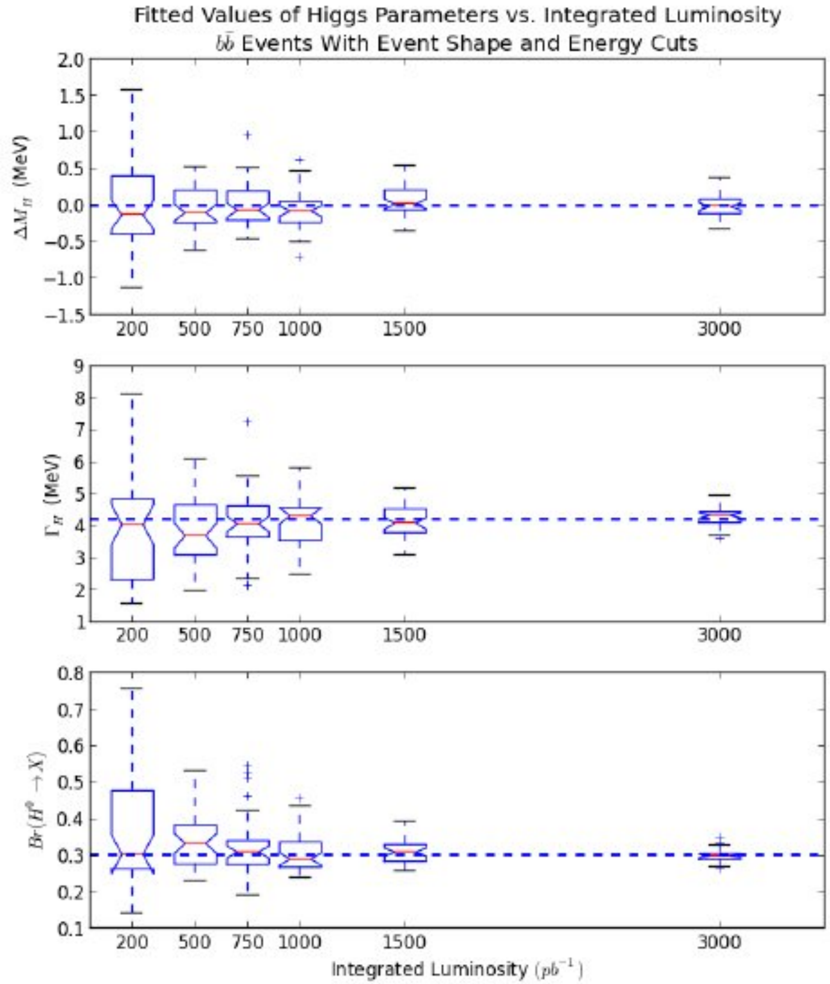


Figure 9: Box-and-whisker plots of fitted values of the Higgs mass, $b\bar{b}$ partial width and $b\bar{b}$ branching ratio for 40 experiments at each luminosity. Integrated luminosity is the total luminosity taken in 14 bins 4.2 MeV apart in a 60 MeV range centered on the Higgs mass. The boxes extend to the upper and lower quartiles of the data and the 'whiskers' extend to the most extreme value within 1.5 times the inner-quartile range.

Future plan

- Make sure the work isn't lost
- Maintain computing infrastructure?
- Archived detector descriptions/analysis programs.
- All modifications to the core software are part of the ILC software distribution.