The CLiC benchmarks and a status report of h → mu mu

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The CLiC benchmarks

- List of benchmarking channels chosen to test physics performance of the detectors
  - Physics case for linear colliders has been made elsewhere
- Should give good coverage of different detector components in presence of realistic (or worse) backgrounds
- Tried to keep the LHC physics reach in mind
- Both validated detector concepts are covered
  - Complementarity rather than competition

Heavy Higgs production

(ILD_CLIC)

$$e^+e^- \to H^+H^-$$
$$e^+e^- \to H^0A^0$$
$$m_h = 119.13 \text{ GeV}$$
$$m_{A^0} = 902.6 \text{ GeV}$$
$$m_{H^0} = 902.4 \text{ GeV}$$
$$m_{H^\pm} = 906.3 \text{ GeV}$$

Final states:

$$H^+H^- \to tb\bar{t}\bar{b}$$
$$H^0A^0 \to b\bar{b}b\bar{b}$$

Marco Battaglia's talk

Branching ratios:

$$H^+ \to t\bar{b}\ (81.8\%), \tau^+\nu_\tau\ (18.2\%)$$
$$H^0 \to b\bar{b}\ (81.8\%),\ \tau^+\tau^-\ (17.3\%),\ t\bar{t}\ (0.9\%)$$
$$A^0 \to b\bar{b}\ (81.7\%),\ \tau^+\tau^-\ (17.3\%),\ t\bar{t}\ (1.0\%)$$

Light Higgs production
(SID_CLIC)

$$e^+e^- \to h\nu_e\bar{\nu}_e$$
$$m_h = 120\ \mathrm{GeV}$$

Final states:

$$h \to \mu^+\mu^-$$
$$h \to b\bar{b}$$

Right-handed squarks production

(ILD_CLIC)

$$e^+e^- \to \tilde{q}_R\bar{\tilde{q}}_R$$

$$m_{\tilde{u}_R} = m_{\tilde{c}_R} = 1125.7 \text{ GeV}$$
$$m_{\tilde{d}_R} = m_{\tilde{s}_R} = 1116.1 \text{ GeV}$$

Frank Simon's talk

Final states:

$$\tilde{q}_R\bar{\tilde{q}}_R \to q\bar{q}\tilde{\chi}_1^0\tilde{\chi}_1^0 \to \text{jets} + \not{E}$$

Branching ratios:

$$\tilde{q}_R \to q\tilde{\chi}_1^0 \ (99.7\%)$$

Chargino and neutralino pair production

(SID_CLIC)

$e^+e^- \rightarrow \tilde{\chi}_i^+\tilde{\chi}_j^-$

$e^+e^- \rightarrow \tilde{\chi}_i^0\tilde{\chi}_j^0$

$$m_{\tilde{\chi}^0_{1,\,2,\,3,\,4}} = 340.3,\ 643.1,\ 905.5,\ 916.7\ \text{GeV}$$

$$m_{\tilde{\chi}^\pm_{1,\,2}} = 643.2,\ 916.7\ \text{GeV} \qquad m_h = 118.52\ \text{GeV}$$

Final states:

$$\tilde{\chi}_1^+\tilde{\chi}_1^- \rightarrow W^+W^-\tilde{\chi}_1^0\tilde{\chi}_1^0$$

$$\tilde{\chi}_2^0\tilde{\chi}_2^0 \rightarrow hh\tilde{\chi}_1^0\tilde{\chi}_1^0$$

$$\tilde{\chi}_2^0\tilde{\chi}_2^0 \rightarrow hZ\tilde{\chi}_1^0\tilde{\chi}_1^0$$

Tim Barklow's talk

Branching ratios:

$$\tilde{\chi}_1^\pm \rightarrow W^\pm\tilde{\chi}_1^0$$

$$\tilde{\chi}_2^0 \rightarrow h\tilde{\chi}_1^0\ (90.6\%),\ Z\tilde{\chi}_1^0\ (9.4\%)$$

$$h \rightarrow b\bar{b}\ (68.8\%),\ \tau^+\tau^-\ (21.0\%),\ W^+W^-\ (11.8\%),\ ZZ\ (0.9\%)$$

$$W^\pm \rightarrow \text{hadrons}\ (67.6\%)$$

Slepton production

(ILD_CLIC)

$$e^+e^- \rightarrow \tilde{\ell}^+\tilde{\ell}^-,\ \ell = e,\ \mu$$

$$m_{\tilde{e}_R} = m_{\tilde{\mu}_R} = 1010.8\ \mathrm{GeV}$$
$$m_{\tilde{e}_L} = m_{\tilde{\mu}_L} = 1100.4\ \mathrm{GeV}$$

Final states:

$$\tilde{\ell}^+\tilde{\ell}^- \rightarrow \ell^+\ell^-\tilde{\chi}_1^0\tilde{\chi}_1^0$$

Branching ratios:

$$\tilde{\ell}_R \rightarrow \ell\tilde{\chi}_1^0\ (100\%)$$
$$\tilde{\ell}_L \rightarrow \ell\tilde{\chi}_1^0\ (100\%)$$
$$\tilde{\nu}_\ell \rightarrow \nu_\ell\tilde{\chi}_1^0\ (100\%)$$

Generator-level analysis shown at LCWS 2010. Moving to full simulation with overlays next.

$t\bar{t}$ at 500 GeV

(ILD_CLIC)

$$e^+e^- \to t\bar{t}$$

Final states:

$$t\bar{t} \to (bq\bar{q})(\bar{b}q\bar{q}), \text{ i.e. 6 jets}$$

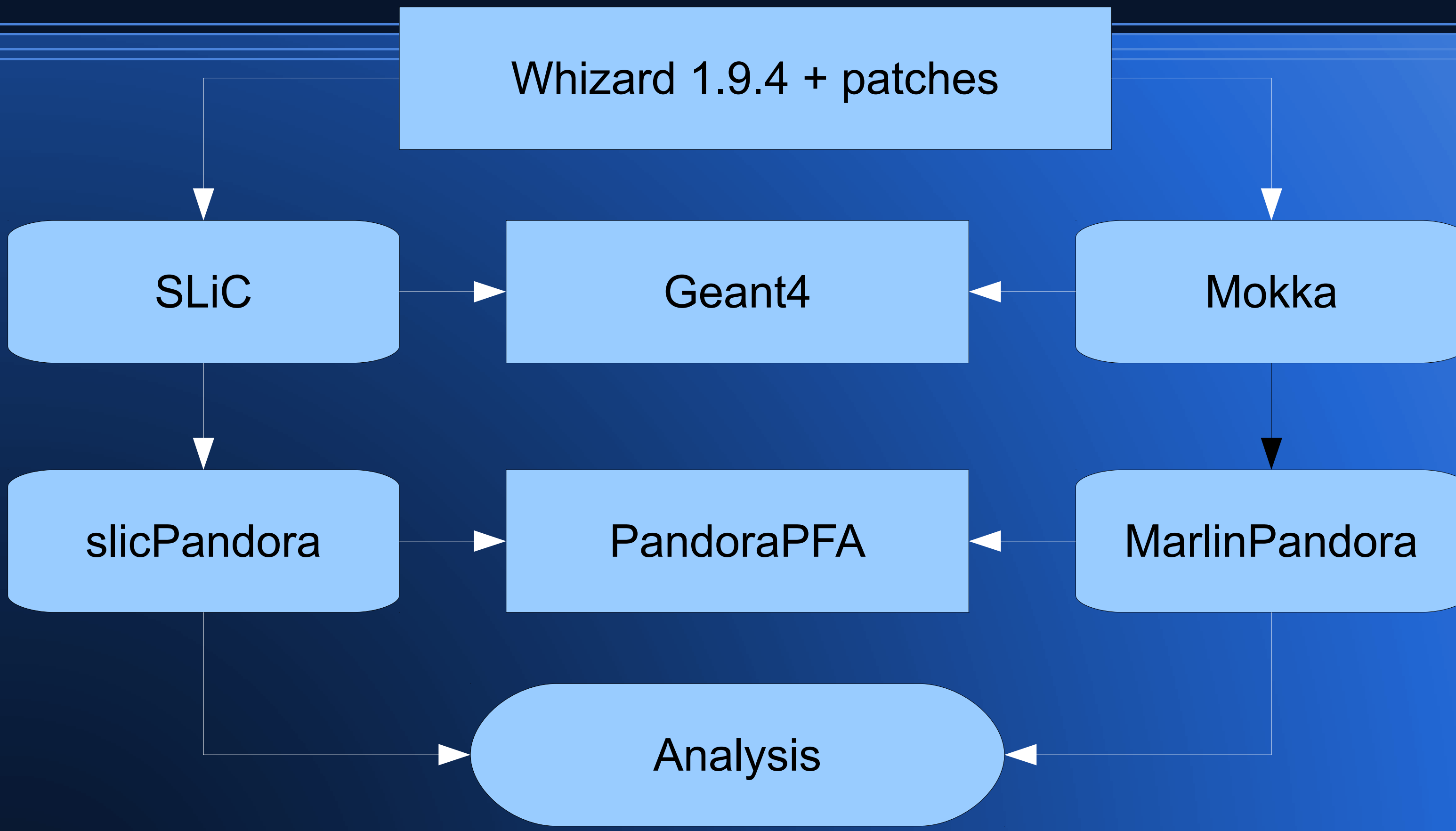
$$t\bar{t} \to (bq\bar{q})(\bar{b}\ell\nu_\ell), \quad \text{where } \ell = e,\ \mu, \text{ i.e. 4 jets} + \ell + \not{E}$$

Analysis just started. Strategy same as LOI

Analysis status

- Analysis strategies finalized
  - Most of them iterations of previous analyses or at least ready at FastMC level
- Currently validating the reconstruction
  - Our detectors and reconstruction software are entering new territory
  - PFA at 3 TeV(!)
  - PFA at CLiC(!)

Two reconstruction chains



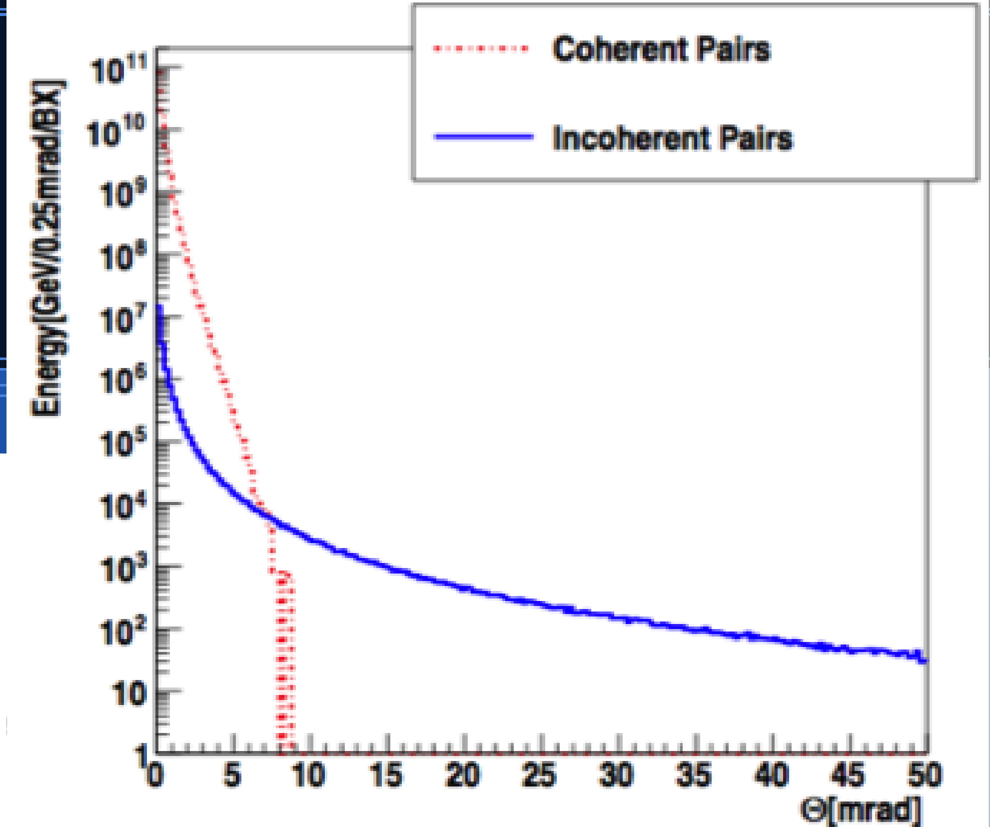
Event records are interchangable at each step !

Machine Backgrounds

Deposited energy from gg → hadrons

Pythia 2010 sample (D. Schulte)   3.2 events / bx

Section	CLIC_ILD_CDR E_{vis}/bx [GeV]	CLIC_SiD_CDR E_{vis}/bx [GeV]
no cuts	1365.2	1365.2
LUMI-CAL	101.5	120.2
CAL-Endcap	35.4	45.3
CAL-Barrel	3.6	4.4
CAL-all	37.8	47.5

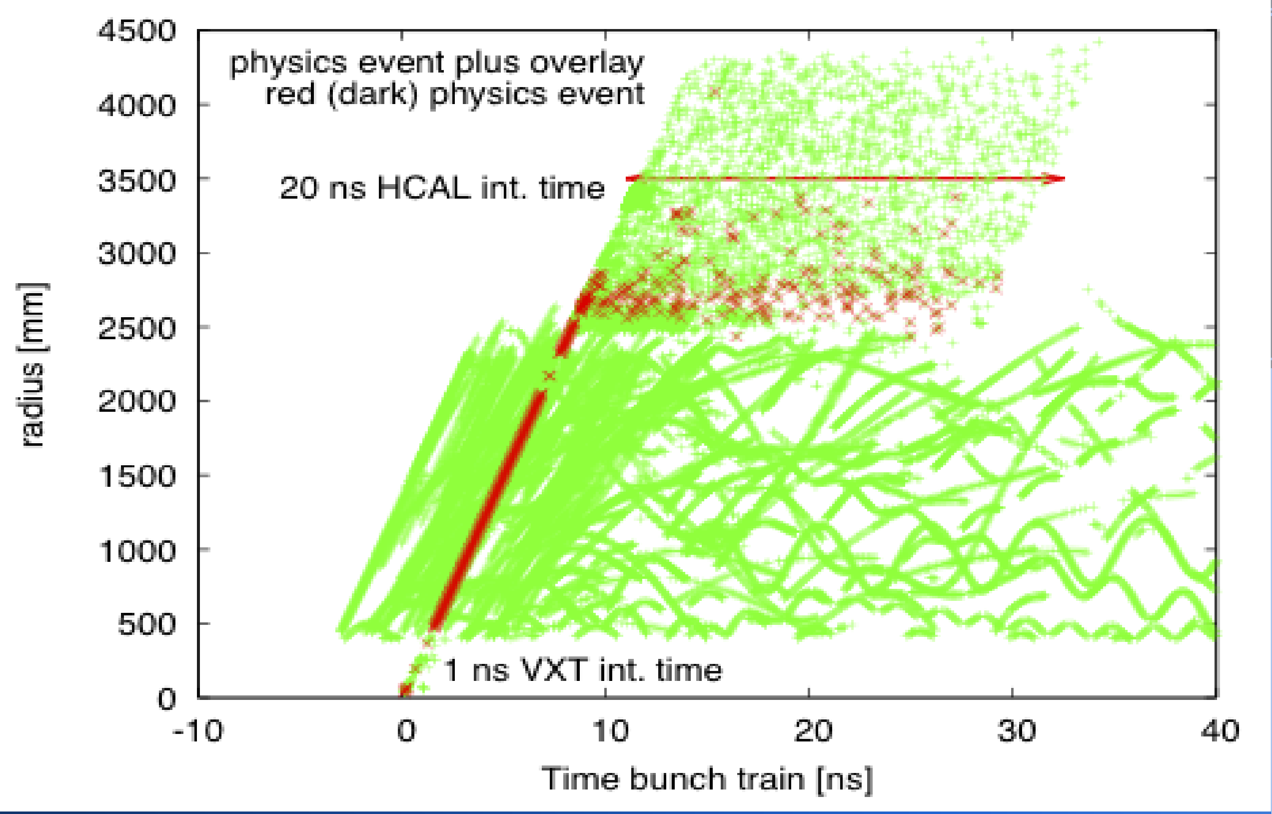


6 x 10E8 coherent particles / bx
3 x 10E5 incoherent particles / bx

For more on backgrounds and occupancies see Dominik Dannheim's talk

Full simulation of gg → hadrons

Overlay Processor



- Take physics event
  - Red points
- Randomly select gg->hadron events
  - 3.2 evts / BX
- Shift their hits in time (tof corrected)
- Apply readout window 20 ns

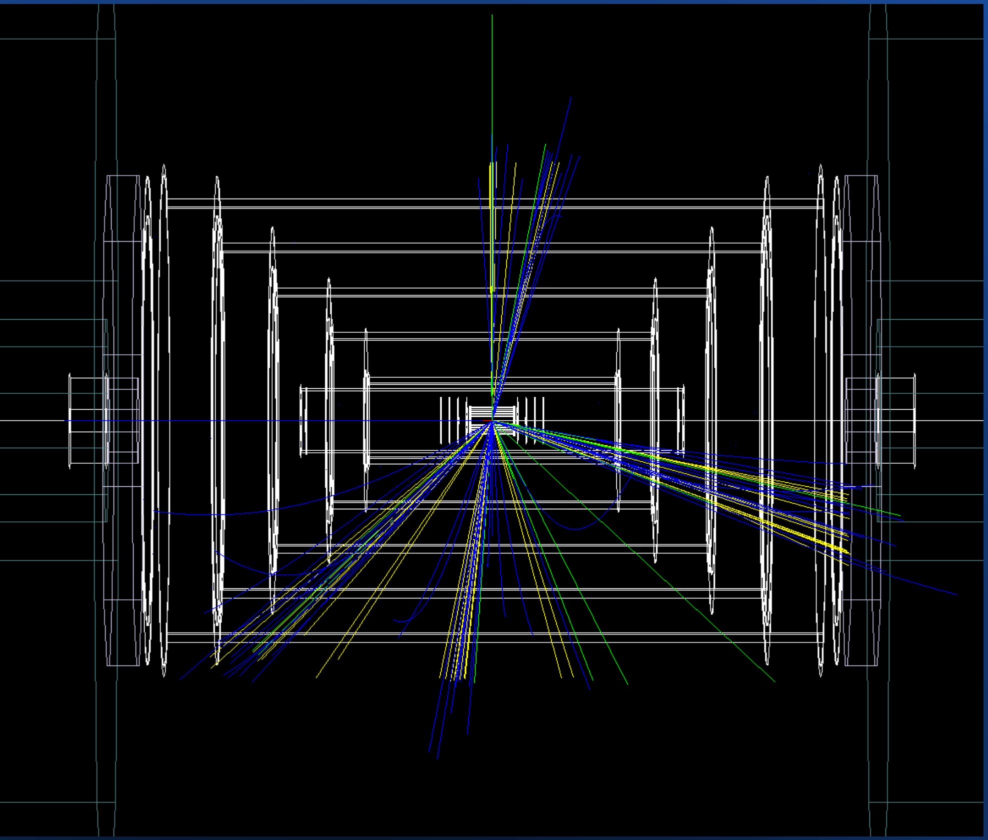
  → late hits from previous BX added

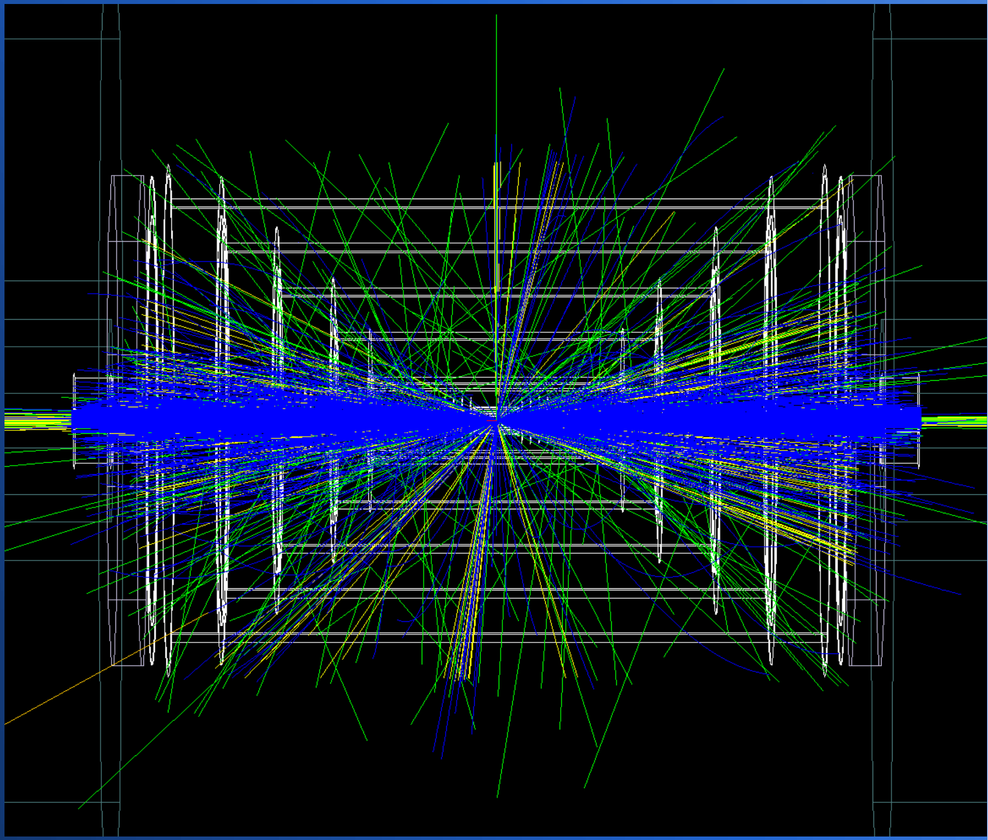
  → late hits from physics event lost (W Hcal)

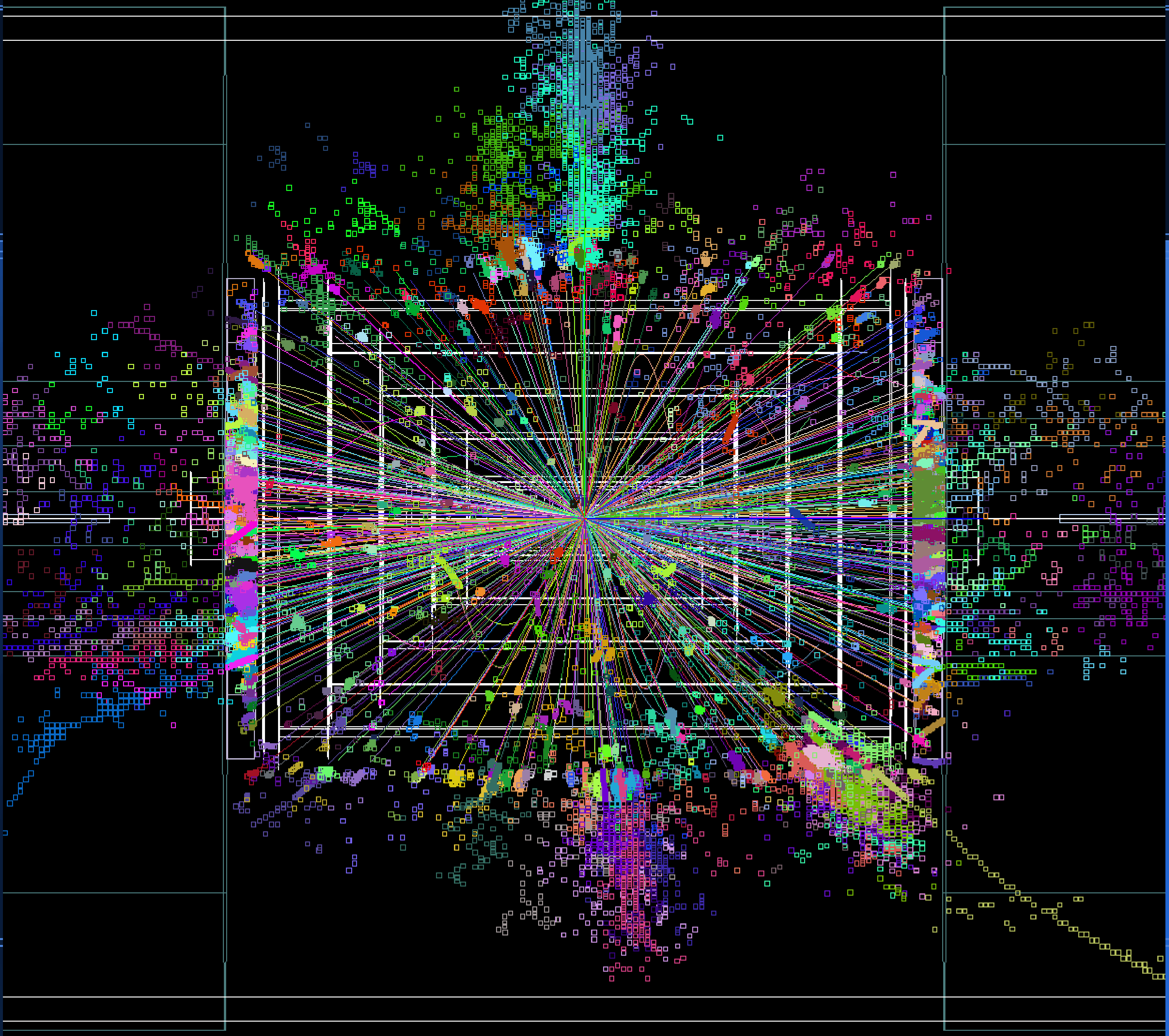
Reconstructing Overlaid Events

- To simulate machine backgrounds, use 60 BX
  - HCAL shower development (tungsten)
    - integrate over 100 ns
  - TPC would “see” full bunch train
    - 312 BX
  - Time stamping in the tracker 10 ns
  - Time stamping in the calorimeters ~2 ns
    - Multi-hit separation 20 ns
  - Means we have to deal with at most 20 BX in tracker
    - Make it a bit more realistic for the reconstruction

Reconstruction Performance in presence of backgrounds







Reconstruction times

Sample		Production step	Wall clock time
bb		generation	4 min
bb @ 500 GeV (SiD)		simulation	7 1/2 min
bb @ 3 TeV (ILD)		simulation	30 min
		reconstruction	52 min
HA (ILD)	qqqq	simulation	15 1/2 h
	bbbb	simulation	15 h
cc @ 500 GeV (SiD)		simulation	7 min
tt @500 GeV (ILD)		simulation	95 min
		reconstruction	9 min
Z → uds @ 1 TeV (SiD)		tracking	11 min (was 37.5 min)
Z → uds @ 3 TeV (SiD)		tracking	25 1/2 min

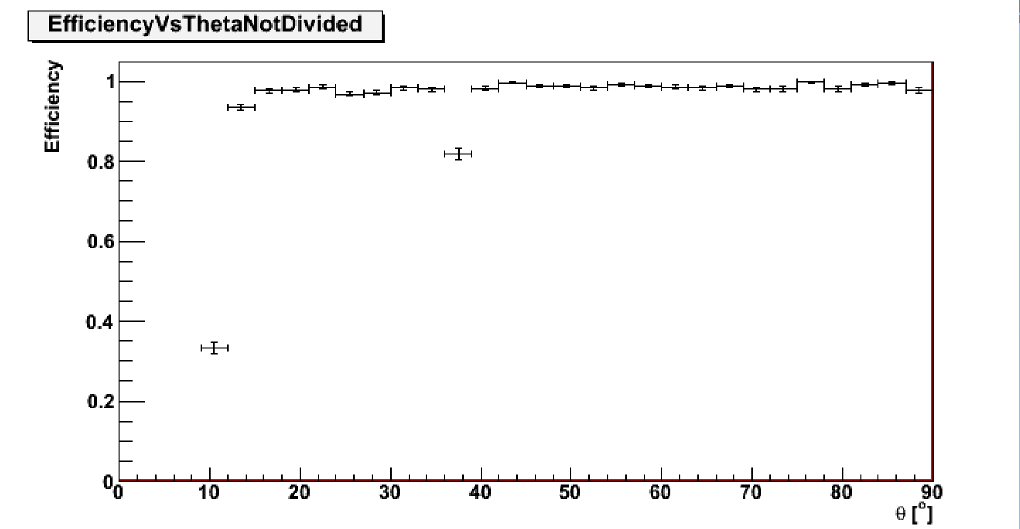
Event Overlay

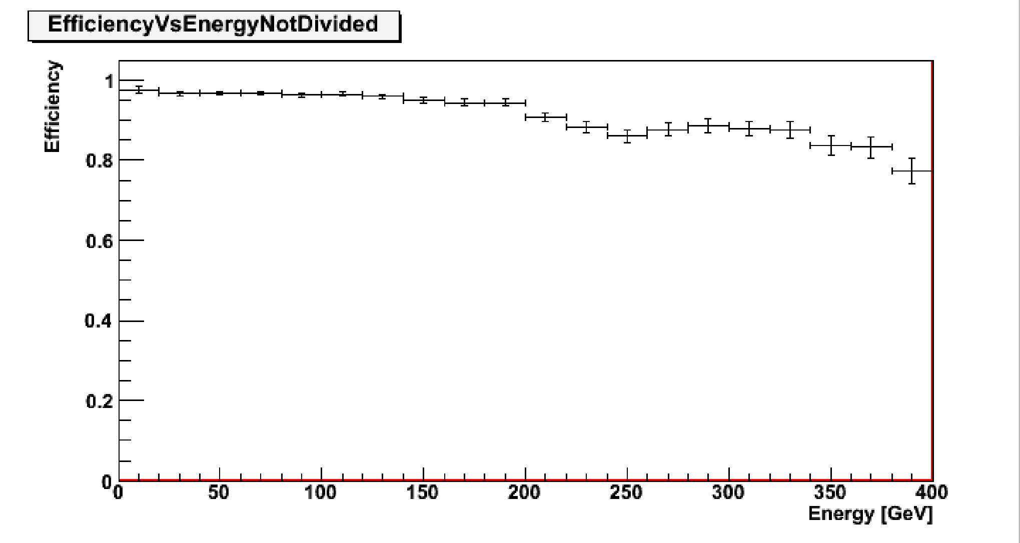
Reconstruction time determines job splitting. The Grid simply kills the job at the limit.
Long tails could bias your event selection

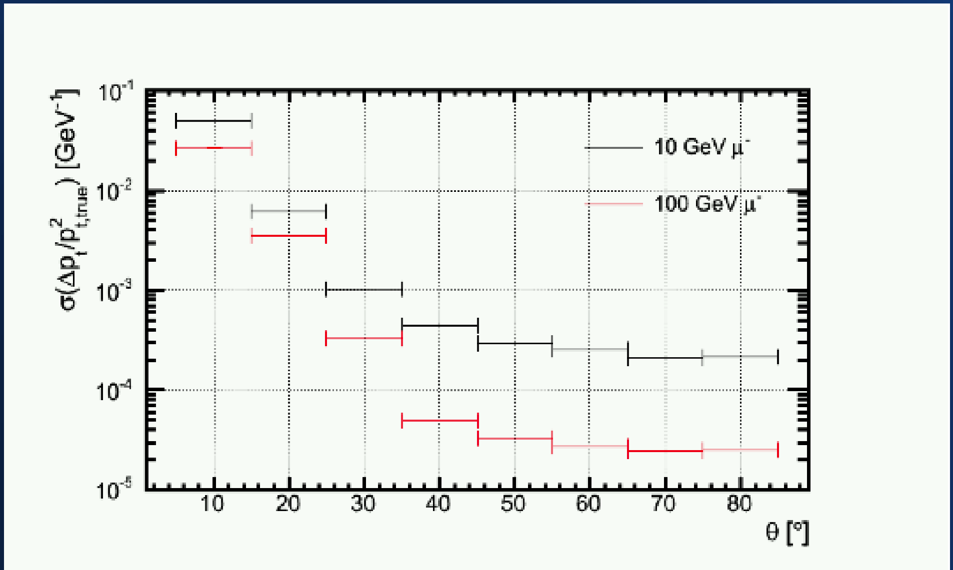
Muon Reconstruction Performance

Taking advantage of better reconstruction in the barrel:

Both muons in barrel 51%
One barrel, one endcap 38 %
Both forward 11 %

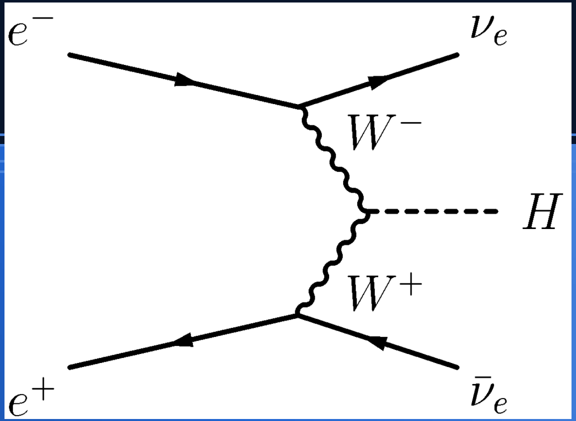






H → mu mu + backgrounds in Whizard 2.0

$\nu\nu H : 503\,\mathrm{fb}\left(\times 2.82 * 10^{-4} = 142\,\mathrm{ab}\right)$



$\mu\mu\nu\nu : 157.1\,\mathrm{fb}$

$\mu\mu e e\left(|\cos(\theta_e)| > 0.995,\ |\cos(\theta_\mu)| < 0.87,\ (100\,GeV < M_{\mu\mu} < 130\,GeV\right):$
$29.2\,\mathrm{fb}$

Note: 20% less in production, due to BES

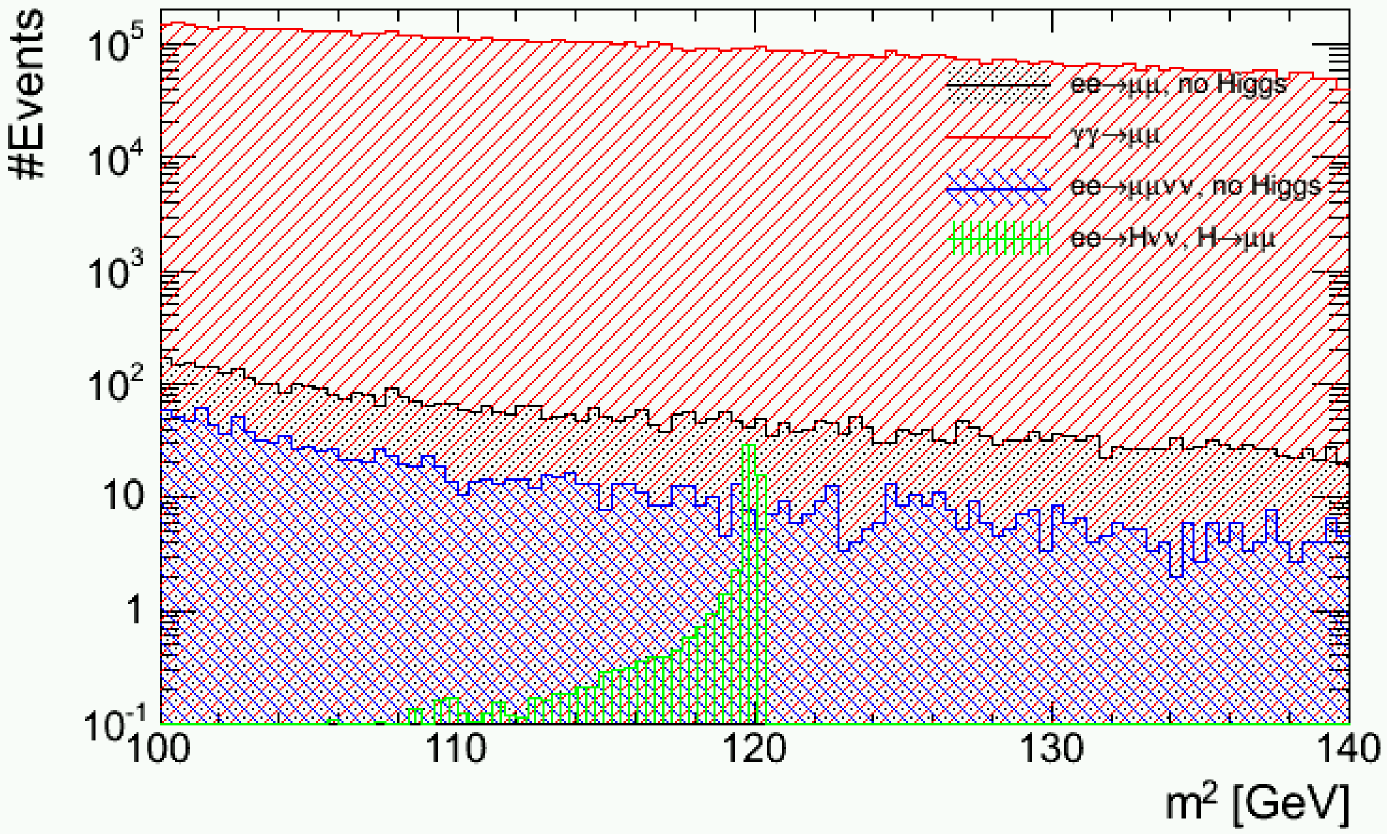
$\tau\tau\gamma : 49.2\,\mathrm{fb}\left(\times 0.03 = 1.42\,\mathrm{fb}\right)$

$\mu\mu\nu\nu\nu\nu : 2.6\,\mathrm{fb}$

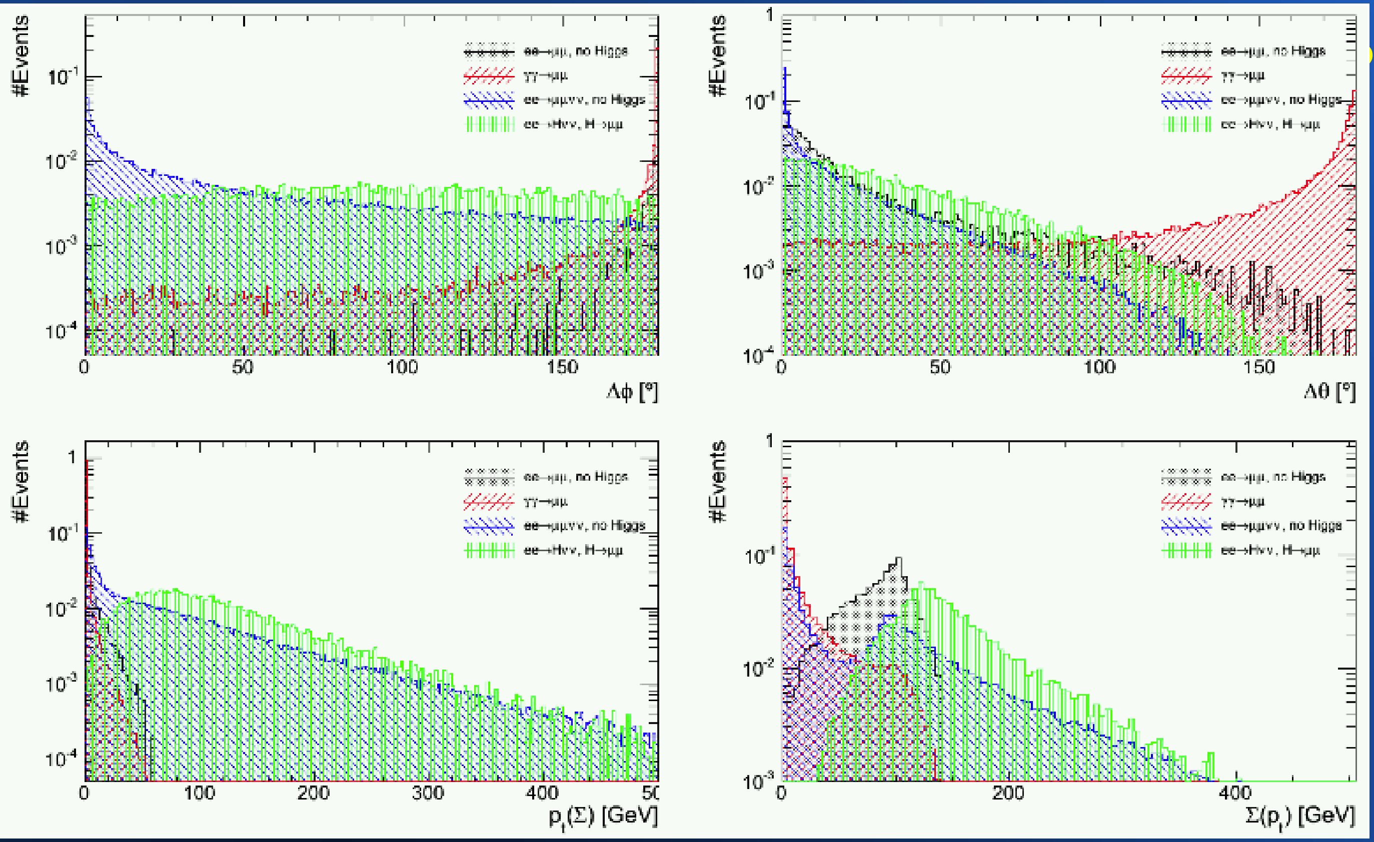
$\tau\tau\nu\nu : 137.7\,\mathrm{fb}\left(\times 0.03 = 4.15\,\mathrm{fb}\right)$

$\tau\tau : 11.8\,\mathrm{fb}\left(\times 0.03 = 0.34\,\mathrm{fb}\right)$

Starting Point



Fighting machine backgrounds



- Background from photon pairs goes mostly forward

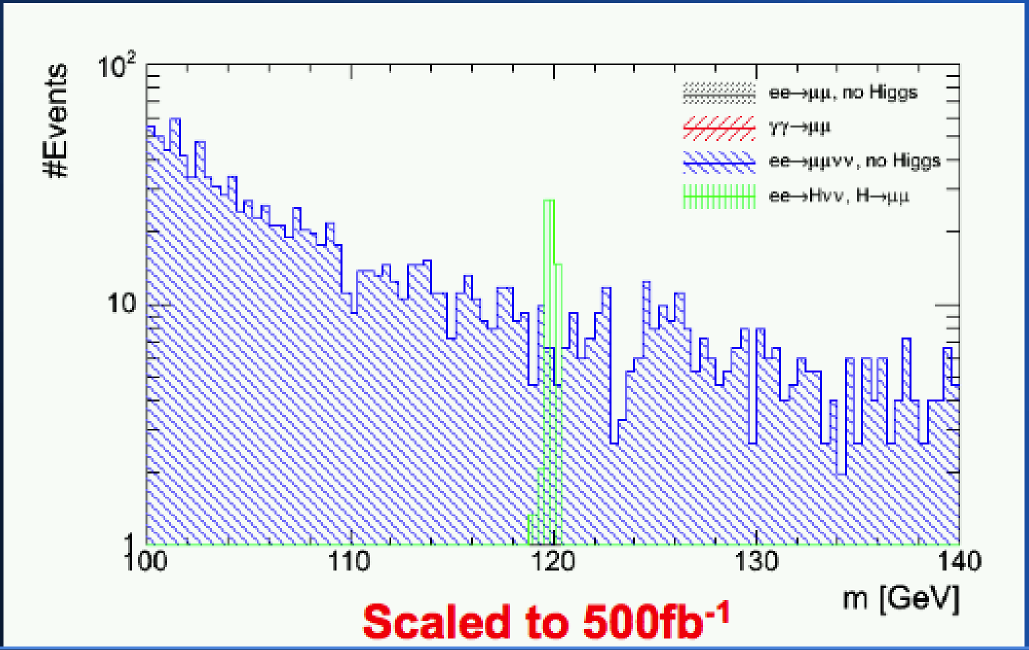
pt_mu1+pt_mu2 > 50GeV

pt_(mu_1+mu_2) > 20GeV

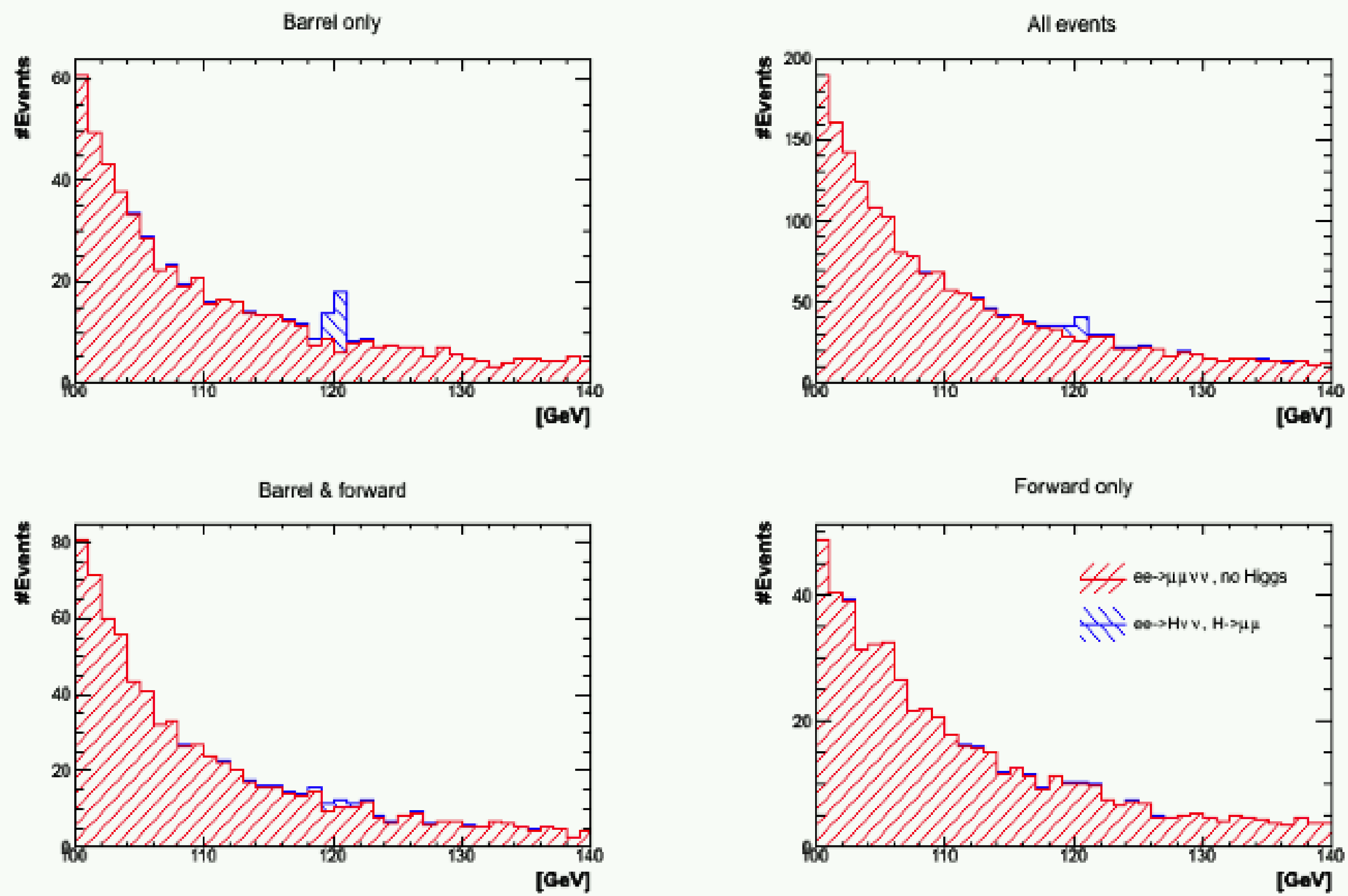
delta(phi) < 178deg

Current state

	gg → mu mu	ee → mu mu	ee → mumu	signal
100 GeV < m < 140 GeV	92.6 %	91.3 %	2.11 %	95.5 %
pt(mu1+ mu2)	0.006 %	< 0.01 %	2.01 %	90.6 %
pt(mu1) + pt(mu2)	< 0.001 %	< 0.01 %	2.00 %	90.3 %



Barrel vs. Endcap



Scaled to 500fb^{-1}

Work plan

- Look for improvements to muon reconstruction
- Likelihood fit method is being developed right now
- Determine luminosity necessary for discovery

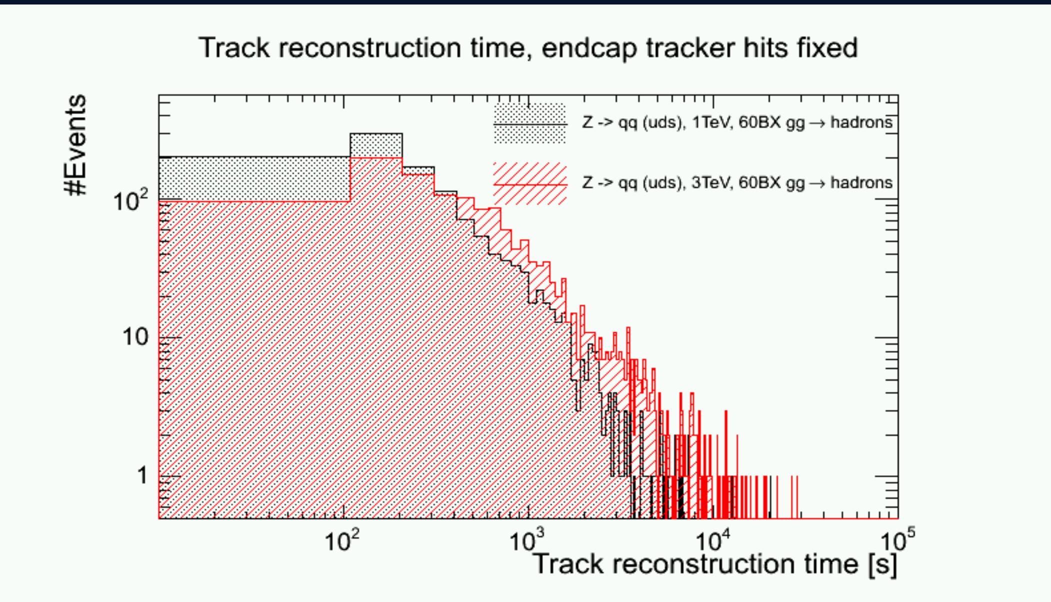
  → reconstruction performance in the different detector regions

Summary

- The CLiC CDR benchmarking process is in full swing
  - Realistic treatment of backgrounds is a lot of work
- Light higgs decays to muons are challenging at any energy
  - Larger cross-section somewhat offset by the backgrounds
- Thank you Angela Lucaci-Timoce, Christian Grefe, Stephane Poss, Jacopo Nardulli, Lucie Linssen and Felix Sefkow for sharing material and useful discussions

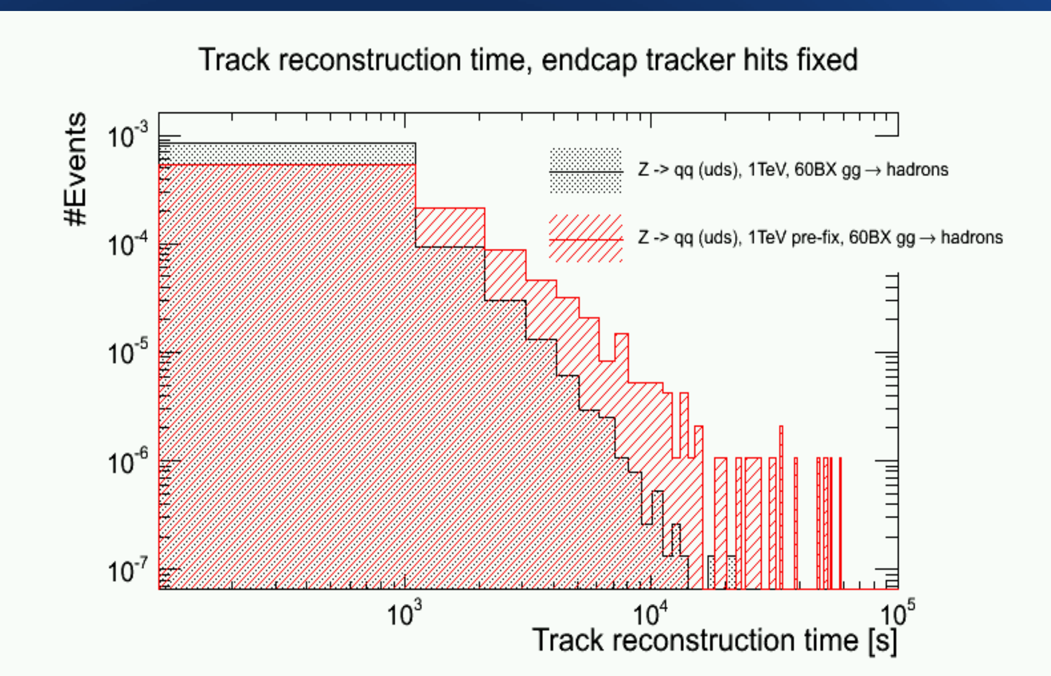
Backup

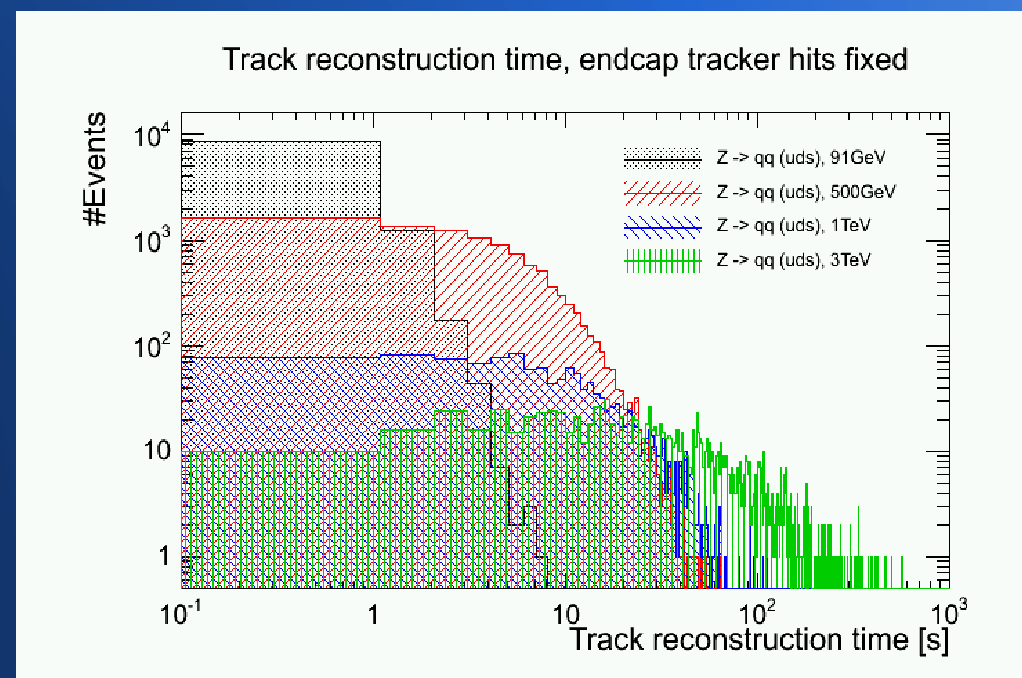
Reconstruction Times



Z → uds with overlays

Z → uds at different energies





Important to note: No tails!

H->mu mu backgrounds in Whizard 2.0

$$\nu\nu H : 503\,\mathrm{fb}\left(\times 2.82 * 10^{-4} = 142\,\mathrm{ab}\right)$$

$$\mu\mu\nu\nu : 157.1\,\mathrm{fb}$$

$$\tau\tau e e\left(|\cos(\theta_e)| > 0.995\right),\ |\cos(\theta_\tau) < 0.995| : 3.5\mathrm{e}4\,\mathrm{fb}\left(\times 0.03 = 1060\,\mathrm{fb}\right)$$

$$\tau\tau\nu\nu : 137.7\,\mathrm{fb}\left(\times 0.03 = 4.15\,\mathrm{fb}\right)$$

$$\tau\tau : 11.8\,\mathrm{fb}\left(\times 0.03 = 0.34\,\mathrm{fb}\right)$$

$$\tau\tau\gamma : 49.2\,\mathrm{fb}\left(\times 0.03 = 1.42\,\mathrm{fb}\right)$$

$$\mu\mu\nu\nu\nu\nu : 2.6\,\mathrm{fb}$$

$$\tau\tau\nu\nu\nu\nu : 2.6\,\mathrm{fb}\left(\times 0.03 = 78\,\mathrm{ab}\right)$$

$$\tau\tau e e\left(|\cos(Theta_e)| > 0.9\right) : 13.5\,\mathrm{fb}\left(\times 0.03 = 0.4\,\mathrm{fb}\right)$$

$$\mu\mu e e\left(|\cos(Theta_e)| > 0.9\right) : 39.5\,\mathrm{fb}$$

Note: 20% less in production, due to BES

$$\mu\mu e e\nu\nu\left(|\cos(Theta_e)| > 0.9\right) : 1.1\,\mathrm{fb}$$

Strategy

- Two background components
  - Exponential tail from Z peak
  - Flat sum of many contributions
- Likelihood fit of two bg components + signal
- CLs method to determine luminosity needed for discovery