The SGV fast detector simulation program

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ILD general meeting, Online, Feb 13, 20 24

CLUSTER OF EXCELLENCE
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PHYSICS AT THE TERA SCALE
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FTX

Outline


NEED FOR SPEED™
SPEEDHUNTERS
6666
Rocket Bunny
Rocket Bunny

Full SM simulation

Total cross-section @250 GeV for $e^+e^- \rightarrow$ 2f and 4f: $\mathcal{O}(1)$ nb (Whizard).

- $\int \mathcal{L}dt \sim = 5$ ab$^{-1} \rightarrow 5 \star 10^9$ events are expected.
- $\sim$ 1-20 ms to generate one event.
- $\sim$ 2 ms to fastsim (SGV) one event.

$\sim 5 \times 10^7$ s of CPU time is needed, ie around 1 year. But:This goes to 2000 years with full simulation. And this is just to simulate as many events as the data...

This does not include all bhabha's and $\gamma\gamma$ events $\sim$ an order of magnitude more $\Rightarrow$ without FastSim skimming, many of our results risk to be systematics dominated by lack of MC statistics!

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SUSY parameter scans

Simple example:

- MSUGRA: 4 parameters + sign of μ
- Scan each in eg. 20 steps
- Eg. 5000 events per point (modest requirement: in sps1a' almost 1 million SUSY events are expected for 500 fb^{-1} !)
- = $20^4 \times 2 \times 5000 = 1.6 \times 10^9$ events to generate...

Slower to generate and simulate than $\gamma\gamma$ events

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Fast simulation types, and the choice for ILC

Different types, with increasing level of sophistication:

- 4-vector smearing.
- Parametric, needing input from FullSim: Traditional Delphes
  - Hard to treat correlations, eg. between p measurement and ip:s.
  - Hard to handle confusion in high granularity calorimeters.
  - No dE/dx, secondary vertices, effect of hit level inefficiencies ....
  - But very fast, and very condensed output.
  - By theorists, for theorists.
- Covariance matrix machines, not needing input from FullSim:SGV
  - Full covariance matrix available for each track-helix.
  - Individual shower shape and position generated ⇒ can approximate confusion.
  - Hit patterns known ⇒ dE/dX and hit-level efficiencies doable.
  - Covariance matrices available ⇒ vertex fitting.
  - Anything up to DST-level detail can be output.
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For ILC:

Only Covariance matrix machines have sufficient detail. Here, I'll cover "la Simulation à Grande Vitesse", SGV.

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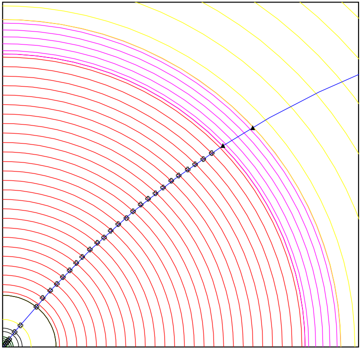
SGV: How tracking works

SGV is a machine to calculate covariance matrices

Tracking: Follow track-helix through the detector.



- Calculate cov. mat. at perigee, including material, measurement errors and extrapolation. NB: this is exactly what Your Kalman filter does!
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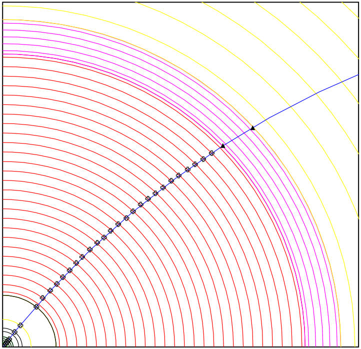

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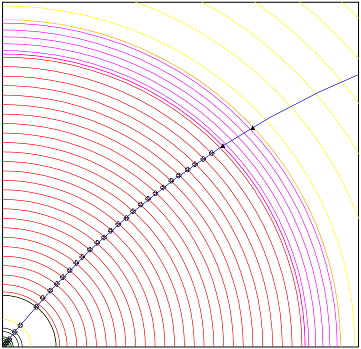

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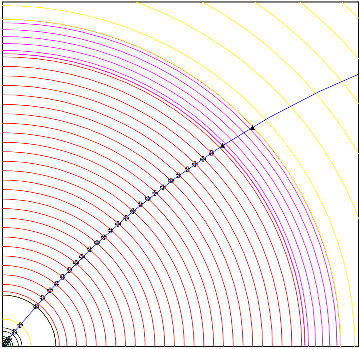

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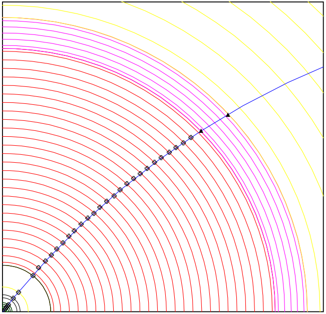
Calorimeters: Follow particle to intersection with calorimeters.



- Response type: MIP, EM or hadronic shower, below threshold, etc.
- Simulate single particle response from parameters.
- Easy to plug in more sophisticated shower-simulation. More in a minute...

Other stuff:

- EM-interactions in detector material simulated
- Plug-ins for particle identification, track-finding efficiencies,...
- Information on hit-patterns accessible to analysis.

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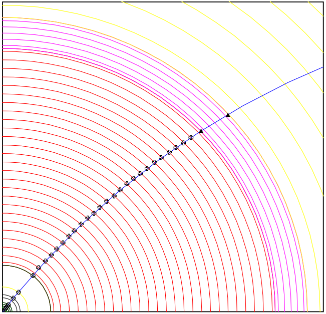

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  - Extended 4-vectors .
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  - Calorimetric clusters.
  - When relevant: true values.
  - Auxiliary information on particle history, detector-elements used etc.
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- User Analysis tasks :
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- Concentrate on what really matters:
  - True charged particles splitting off (a part of) their shower: double-counting.
  - True neutral particles merging (a part of) their shower with charged particles: enetgy loss.
- Don't care about neutral-neutral or charged-charged merging.
- Nor about multiple splitting/merging.
- Then: identify the most relevant variables available in fast simulation:
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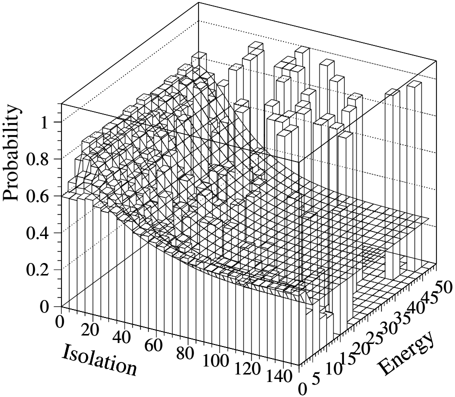
Observed distributions

- Probability to split (charged had or γ)
- Fraction the energy vs distance
- ... and vs E
- Fit of the Distribution of the fraction
- Average fraction vs. E and distance.



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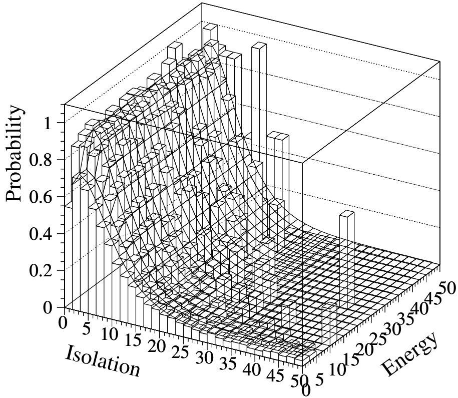

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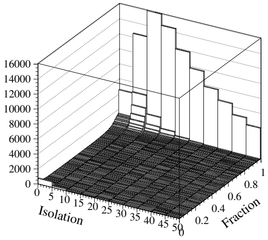

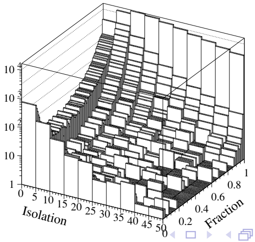

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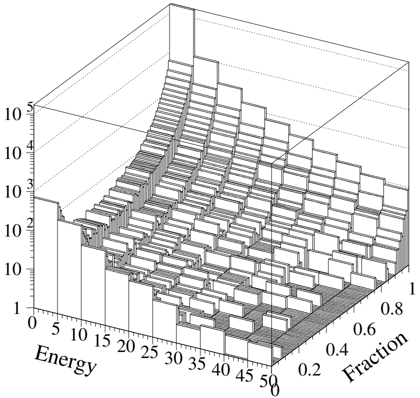

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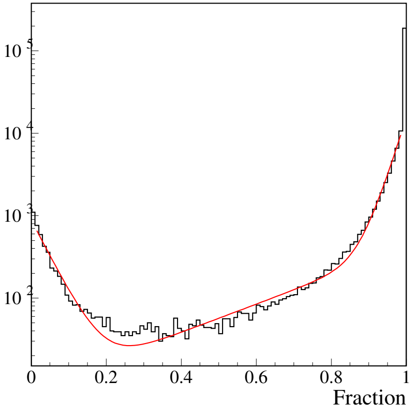

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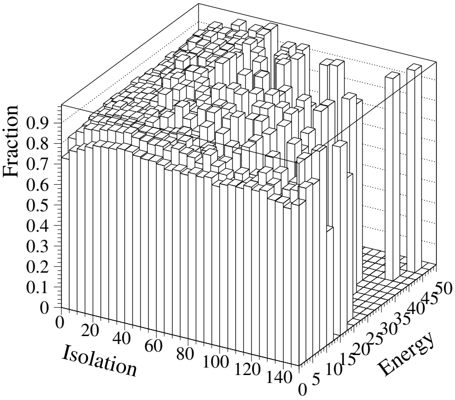

Observations

- Identify and factorise:
  1. Probability to split
  2. If split, probability to split off/merge the entire cluster.
  3. If split, but not 100 %: Form of the p.d.f. of the fraction split off.
- Observations:
  1. Depnds on the isolation - strongly for merging, slightly for splitting - but can be treated in two energy bins with no energy dependence in the bin. %5 over-all dependence on barrel/endcap.
  2. Depends only on energy. Is small for splitting, important for merging at low E.
  3. Depends on both energy and isolation (very little for splitting), but only via the average.
- All cases (EM/had - split/merge - Barrel/endcap) can be described by the same functional shapes.
- Functions are combinations of exponentials and lines.
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Steering SGV

Two steering files...

- Program steering:
  - Single file, with sections for general, generator, detector and analysis steering.
  - Many examples included.
  - Extensive comments in these.
- Geometry description:
  - Described by cylinders and planes.
  - Attach material properties (rad. length, material, int. length, ...)
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Example Geometry:TPC simplified and full

```
BF: BFIELD=3.5

TYPE:  BARREL_TRACKING
         .
         .

      LAYER : TPC
         REPEAT : TIMES=26, DELTA_R=5.448

            GEOMETRY:  R=39.5  , ZMIN=0.0, ZMAX=230.25
            MATERIAL:    X0=0.00047
            MEASUREMENT: CODE=1, SIG_RPHI=0.00301, SIG_Z=0.09,
                          SIG_RPHI_SLOPE=-0.0000058
         ENDREPEAT :
         .
         .
TYPE:  FORWARD_TRACKING
         .
         .

TYPE: BARREL_CALORIMETRY
         .
         .

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Example Geometry:TPC simplified and full

```
BF: BFIELD=3.5

TYPE:  BARREL_TRACKING
         .
         .

      LAYER : TPC
         REPEAT : TIMES=225, DELTA_R=0.6

            GEOMETRY:  R=39.5  , ZMIN=0.0, ZMAX=230.25
            MATERIAL:    X0=0.000052222
            MEASUREMENT: CODE=1,SIG_RPHI=0.0050,SIG_Z=0.04,
                          SIG_RPHI_BETA=0.090,
                          DIFFUSION=0.0053,
                          MOBILITY=3.0
         ENDREPEAT :
         .
         .

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         .
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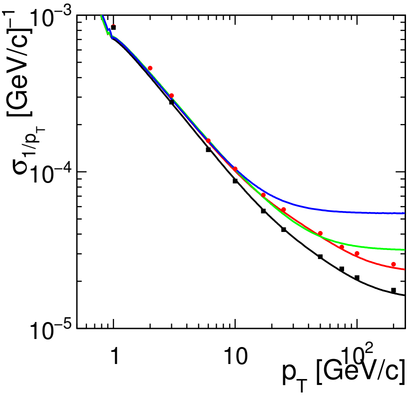
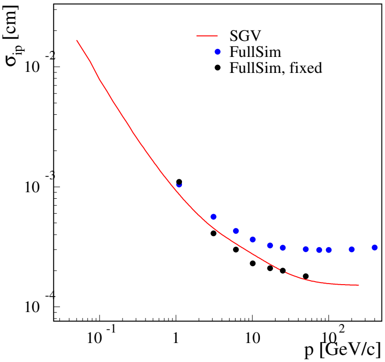
SGV and FullSim ILD: Tracking

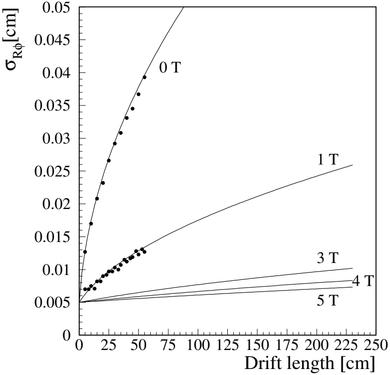




Lines: SGV, dots: Mokka+Marlin

TPC point-resolution vs. Z and B in SGV and test-beam

- Points: Prototype measurements (from DBD/DBD SVN)



- Lines: Formula used in SGV: $\sigma^2_{R\phi} = \sigma^2_0 + (\beta_{slope} \sin\phi)^2 + \frac{D^2_{0T}}{1+(\mu B)^2} \sin\theta Z$, $\Rightarrow$ complicated relation, but gets better with shorter drift-length and higher B.

SGV and FullSim ILD: Jets and events

Feed exactly the same physics events through FullSim or SGV.

- Overall:
  - Total seen energy
- $e^+e^- \to ZZ \to$ four jets:
  - Reconstructed M_Z at different stages in FullSim.
  - Seen Reconstructed M_Z, FullSim and SGV.
  - Jet-Energy resolution (NB: r.m.s., including jet-finding uncertainties ⇒ not the standard plot for JER!)
- *Zhh* at 1 TeV:
  - Visible E
  - Higgs Mass
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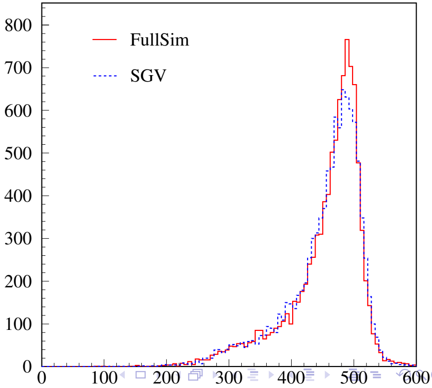

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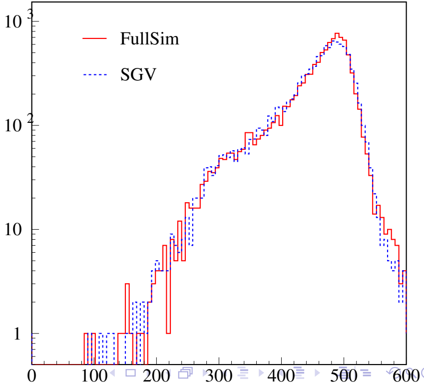

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Feed exactly the same physics events through FullSim or SGV.

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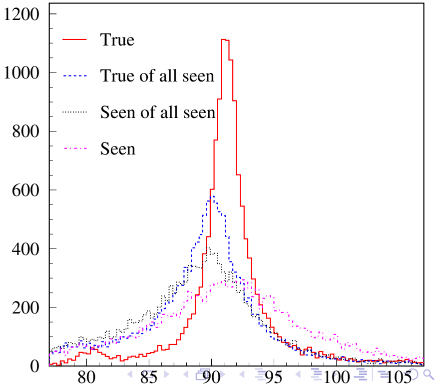

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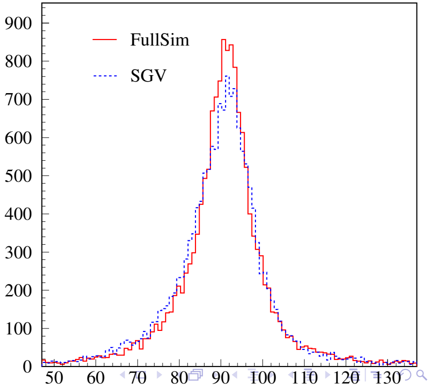

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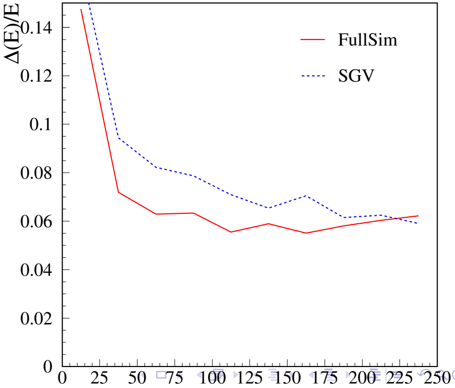

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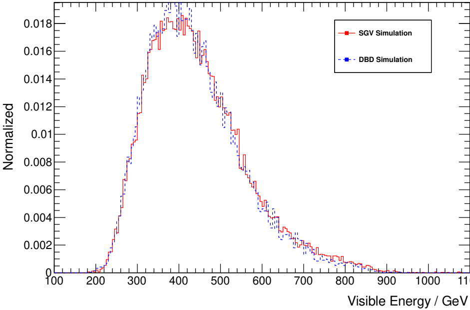

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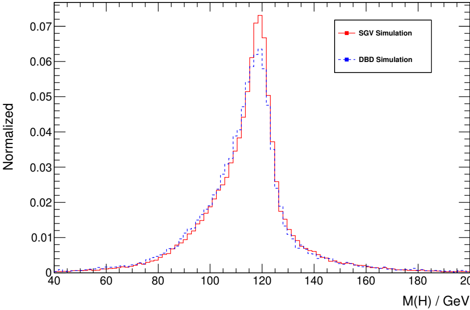

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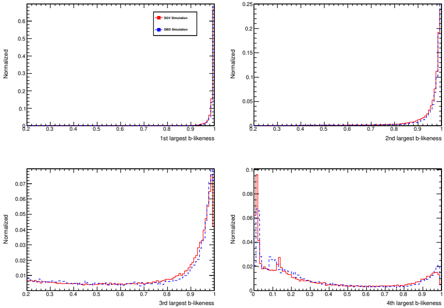

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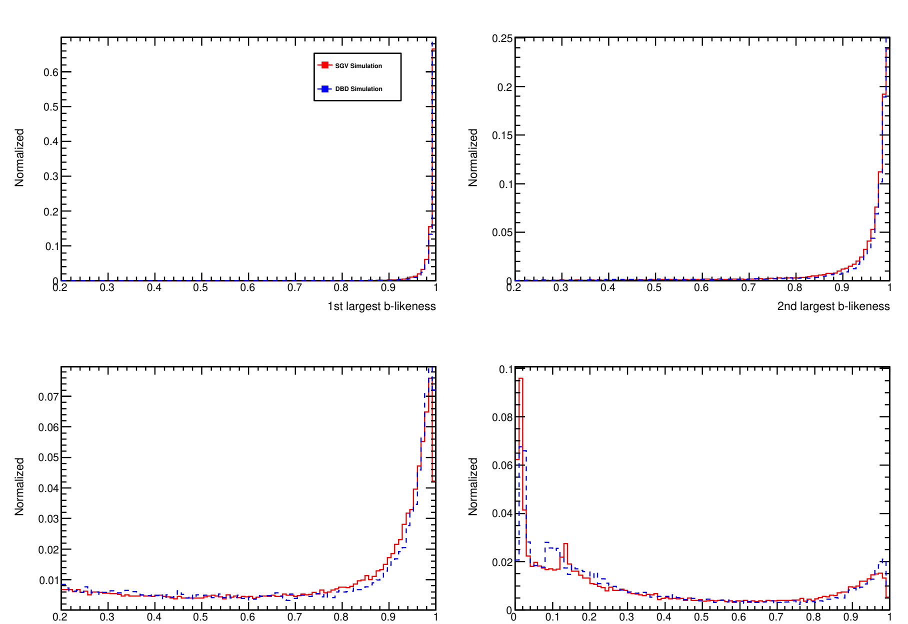

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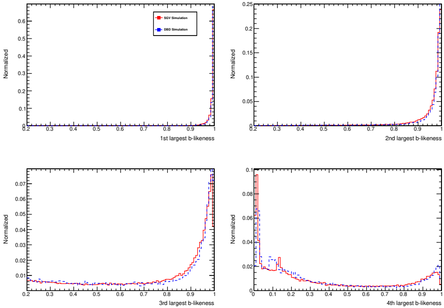

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For the "IDR" detector optimisation effort, SGV was used to change the ILD baseline geometry in many ways, in total 300 different models. Details in backup and AWLC-KEK 2015.

Construct metrics on performance
- both low level and physics output
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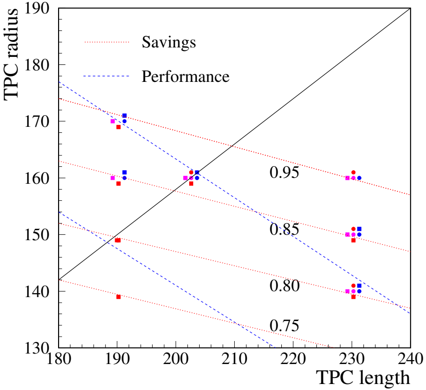

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  - On-demand memory allocation.
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To learn more about SGV:

Follow the ▸ tutorial! (There is an introduction first - The actual tutorial starts a 20:50.)

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... a tool for rapid LC studies?

Peer-reviewed papers using SGV

- Phys. Rev D101 (2020) 7, 075053
- ILD-PHYS-2019-001 (Accepted by Phys. ReV. D)
- Eur.Phys.J.C 76 (2016) 4,183
- Eur.Phys.J.C 75 (2015) 12, 617
- Phys. Rev D 91 (2015) 113007
- Phys. Rev D 90 (2014) 114029
- Phys. Rev D 89 (2014) 11, 113006
- Eur.Phys.J.C 73 (2013) 12,2660
- Eur.Phys.J.C 72 (2012) 2213
- Phys. Rev. D 82 (2010) 055016
- NIM A 579 (2007) 750
- Eur. Phys. J. C 31 (2003) 421
- Eur. Phys, J. direct (2000) 1

+ innumerable theses, reports, arXiv submissions and conference proceedings. Including the Tesla TDR, LoI, TDR, the IDR and ILC/ILD inputs to EPPSU and Snowmass 2013.

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SGV was used for

- Defining the forward tracking geometry of LDC:
  - Vienna 2005. ▸ LDC and ▸ tracking
- The utility (or not) of the silicon envelope
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Thank You !

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Backup

BACKUP SLIDES

LCIO Collections with DST output

- Added sensible values to all collections that will (probably) be there on the DST from the fullSim production.
  - BuildUpVertex
  - BuildUpVertex_RP
  - MarlinTrkTracks
  - PandoraClusters
  - PandoraPFOs
  - PrimaryVertex
  - RecoMCTruthLink
  - MCParticlesSkimmed
  - V0Vertices
  - V0RecoParticles
  - BCALParticles
  - BCALClusters
  - BCALMCTruthLink
  - PrimaryVertex_RP
- Also added more relation links:
  - MCTruthRecoLink
  - ClusterMCTruthLink
  - MCTruthClusterLink
  - MCTruthTrackLink
  - TrackMCTruthLink
  - MCTruthBcalLink

Comments

Secondary vertices (as before):

- Use true information to find all secondary vertices.
- For all vertices with ≥ 2 seen charged tracks: do vertex fit.
- Concequence:
  - Vertex *finding* is too good.
  - Vertex *quality* should be comparable to FullSim.

In addition: Decide from parent pdg-code if it goes into BuildUpVertex or V0Vertices !

MCParticle :

- There might be some issues with history codes in the earlier part of the event (initial beam-particles, 94-objects, ...)

Comments

Clusters:

- Are done with the Pandora confusion parametrisation on.
- Expect $\sim$ correct dispersion of jet energy, but a few % to high central value.
- See my talk three weeks ago.
- Warning: Clusters are always only in one detector , so don't use E_{had}/E_{EM} for e/π: It will be $\equiv$ 100 % efficient !

Navigators

- All the navigators that the TruthLinker processor makes when all flags are switched on are created:
  - Both Seen to True and True to Seen (weights are different !)
  - Seen is both PFOs, tracks and clusters.
  - The standard RecoMCTruthLink collection is as it would be from FullSim ie. weights between 0 and 1.

SGV for Detector optimisation

For the “IDR” detector optimisation effort, SGV was used to change the ILD baseline geometry in many ways. For each of these modifications in 5 steps were done:

1. Keep baseline aspect ratio.
2. Keep baseline radius.
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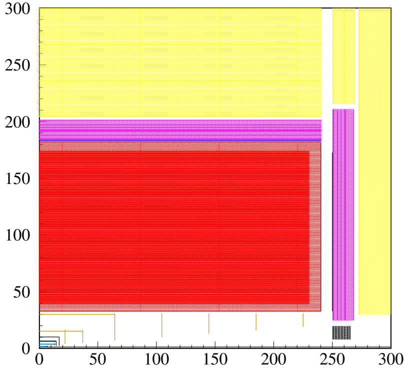

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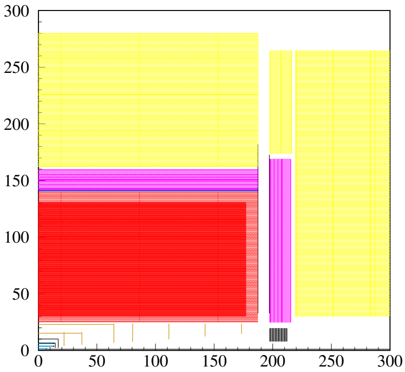

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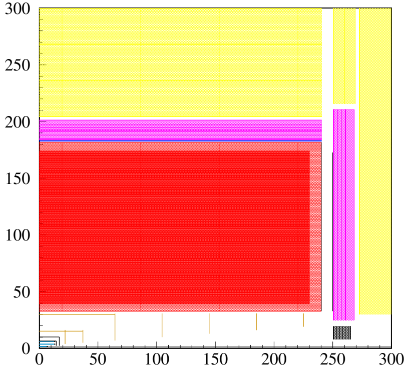

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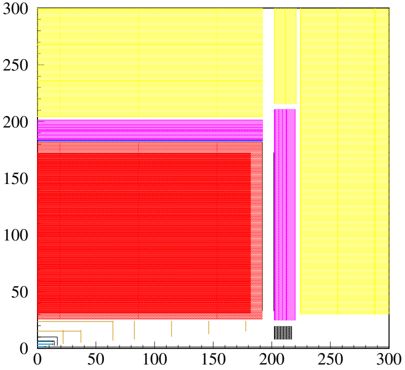

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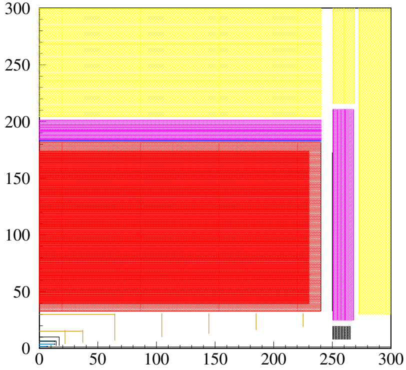

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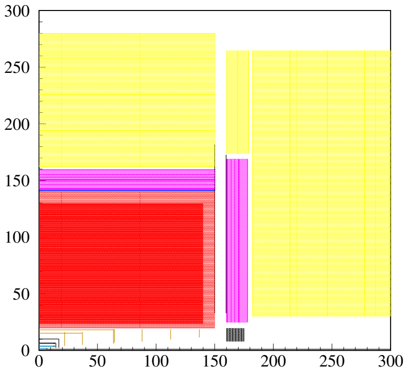
3. Keep aspect ratio = 1
4. Keep baseline length.
5. Keep length = baseline-40 cm.



back

SGV for Detector optimisation

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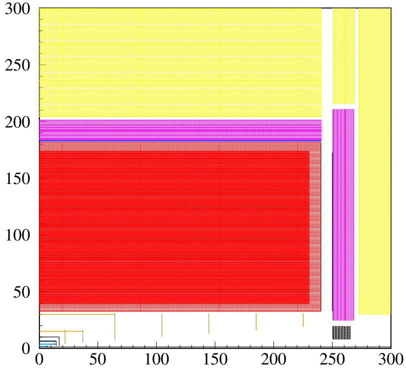

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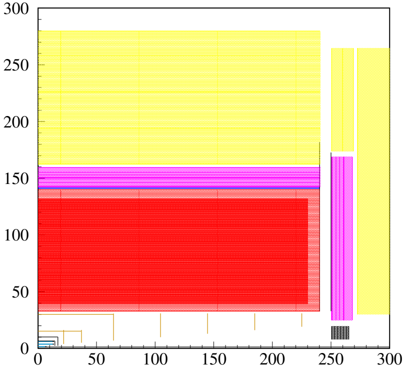

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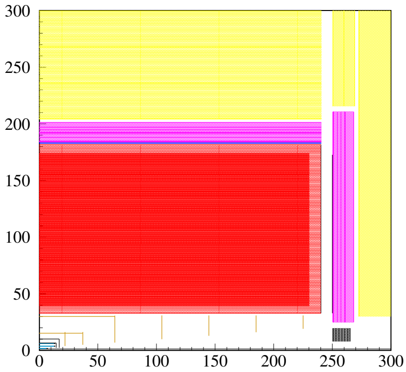

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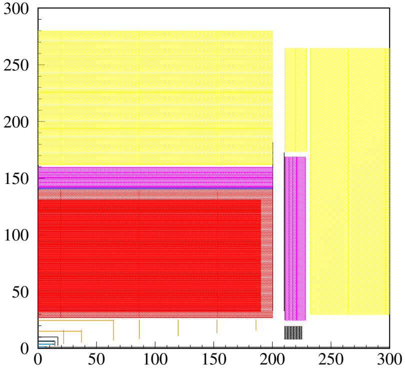

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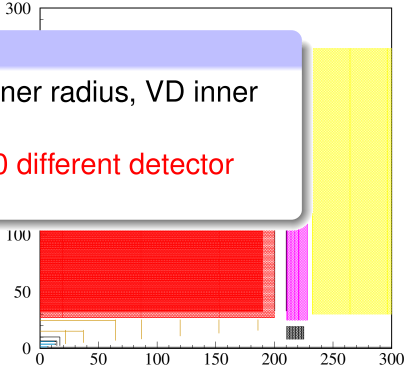


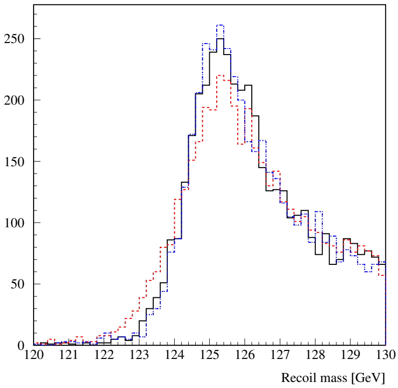
In addition:

Vary B-field, TPC inner radius, VD inner radius, ...

$2 \times 5 \times 5 \times 6 = 300$ different detector models !

Detector optimisation: The good, the bad, the ugly

- Higgs recoil-mass @350 GeV for the nominal ILD (black), the worst case (red) and the best case (blue)
- Simple b-tagger with two observables:
  - $\ln(-\ln(P(\text{All are primary})))$
  - Sum of 2:d to 5:th largest ip/σ_{ip}.
  - Optimise the cuts (on- the-fly) for best $S/\sqrt{S+B}$.
- $S/\sqrt{S+B}$ vs radius of inner layer of the VD



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