Fast detector simulation at the ILC: Simulation á Grande Vitesse - SGV

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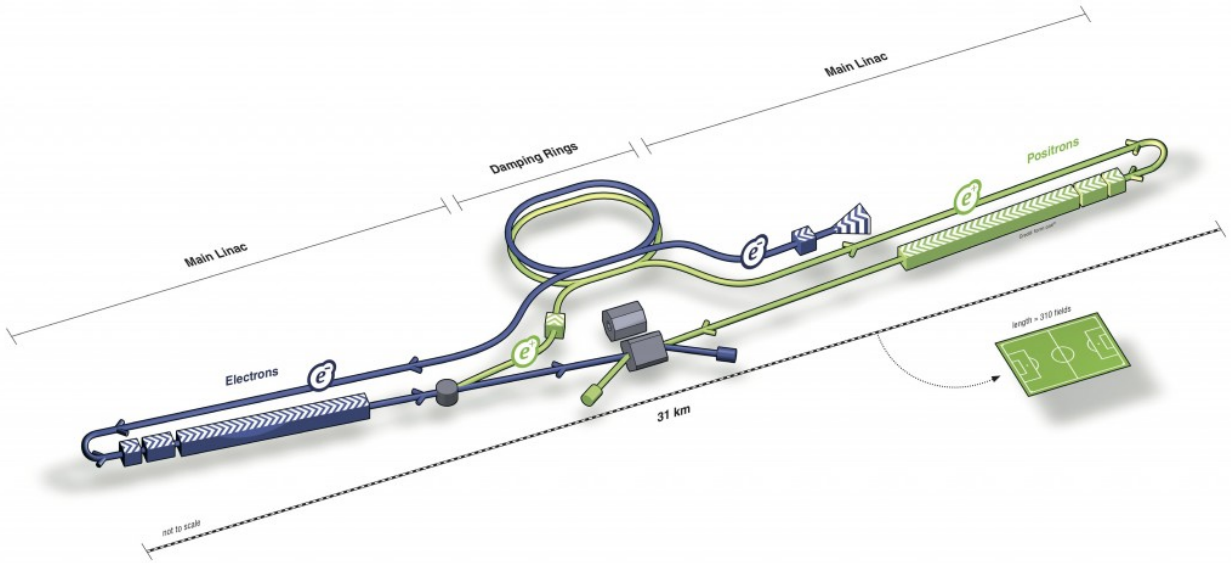
Outline

1. ILC
2. Fast simulation
   - The need for fast simulation at ILC
   - Ex1: $\gamma\gamma$ cross-sections
   - Ex2: SUSY scans
   - Fast simulation types
3. SGV
   - Working priciples
   - Technicalities
   - Usage
   - Use-cases, Comparisions
     - SGV for detector design
     - SGV and FullSim
4. Outlook and Summary

The ILC



- A linear e^+e^- collider.
- E_{CMS} tunable between 200 and 500 GeV, upgradable to 1 TeV.
- Total length 31 km
- $\int \mathcal{L} \sim 500$ fb^{-1} in 4 years
- Polarisation e$^-$: 80% (e$^+$: $\geq$ 30%)
- 2 experiments, but (possibly) only one interaction region.
- Concurrent running with the LHC

The ILC is not LHC

- Lepton-collider: Initial state is known.
- Production is EW $\Rightarrow$
  - Small theoretical uncertainties.
  - No "underlaying event".
  - Low cross-sections wrt. LHC, also for background.
  - Trigger-less operation.
  - High precision (sub-%) measurements needed, to extend our knowledge beyond LEP, Tevatron, LHC.
  - Interesting physics at low angles: t-channel di-boson production ...
- Extremely small beam-spot: 5 nm $\times$ 100 nm $\times$ 150 μm.
- High luminosity: 2×10^{34} cm^{-2} s^{-1}. Single pass operation $\Rightarrow$ this is the lumi for every bunch-crossing.

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The ILC is not LEP, either

- Small beam-spot $\Rightarrow$ Beam-beam interactions $\Rightarrow$
  - Large amounts of synchrotron photons ...
  - ... that get Compton back-scattered ...
  - They might create e^+e^- pairs when interacting with the field: The pairs-background.
  - Or interact with each other: mini-jets
- Single pass operation, ondulator positron-source, beam-beam effects: Beam-spectrum is not a δ-function.
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The ILC : Detectors

- Low background $\Rightarrow$ detectors can be:
  - Thin : few % X_0 in front of calorimeters
  - Very close to IP: first layer of VXD at 1.5 cm.
  - Close to 4π: holes for beam-pipe only few cm = 0.2 msr un-covered = Area of Suisse Romande (or Schleswig-Holstein) relative to earth.
- High precision measurements:
  - Extremely high demands on tracking.
  - Tracking to low angles
  - Identify and measure every particle in the event = Particle-flow:
    - Measure charged particles with tracker, not ECAL, which is second best.
    - Need to separate neutral hadrons from charged in calorimeters.
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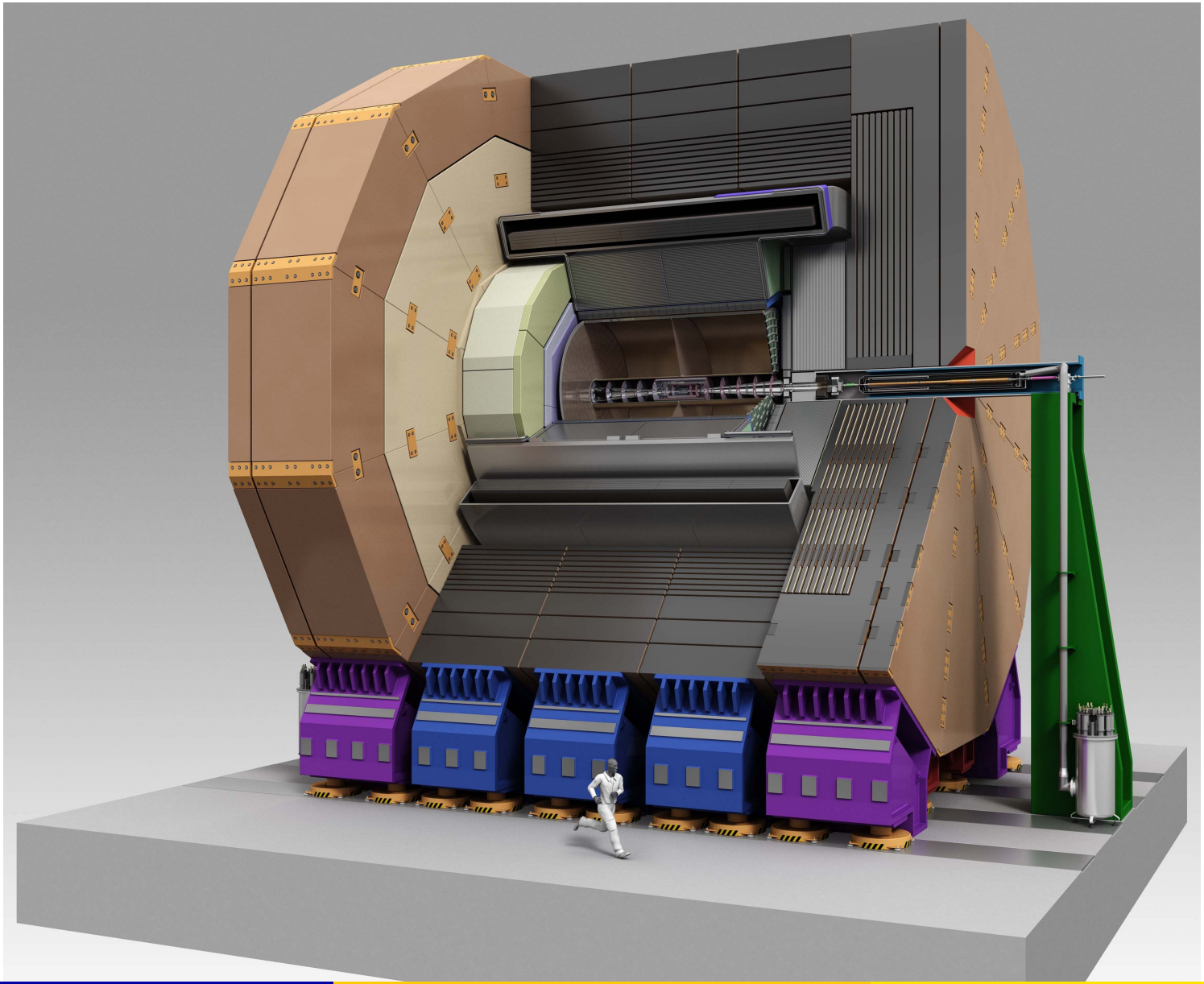
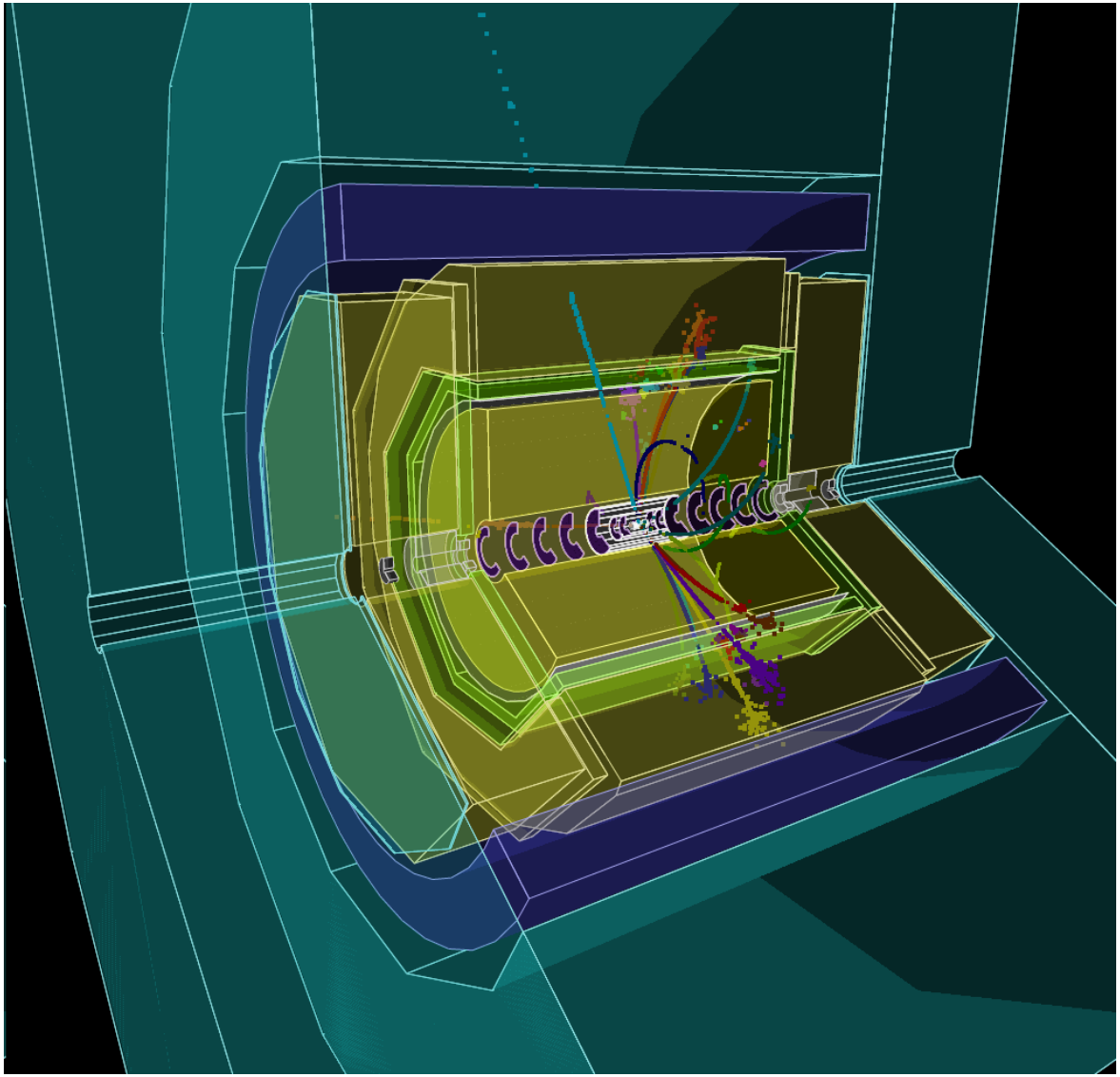
The ILD Detector



Example: $Zh \to \mu\mu q\bar{q}$ at 250 GeV



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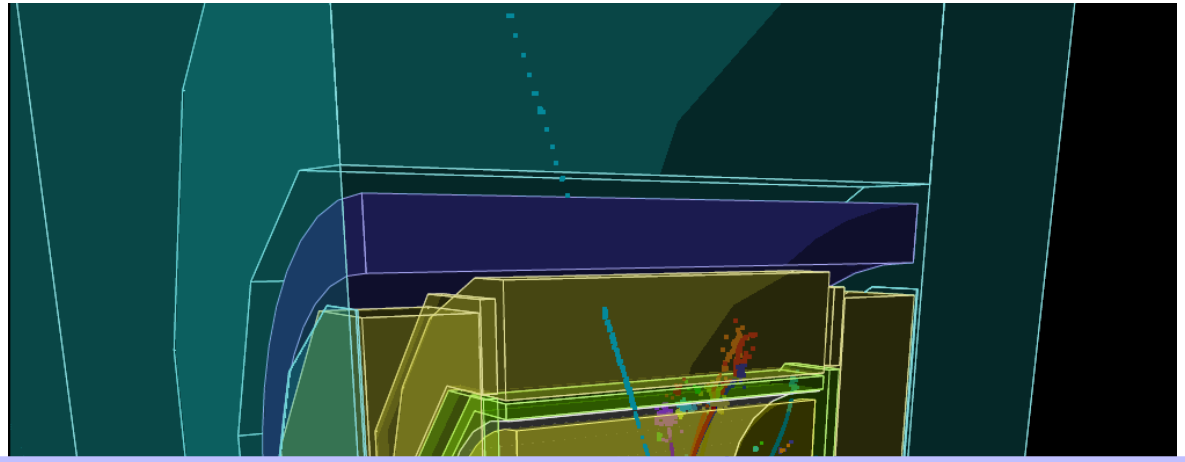
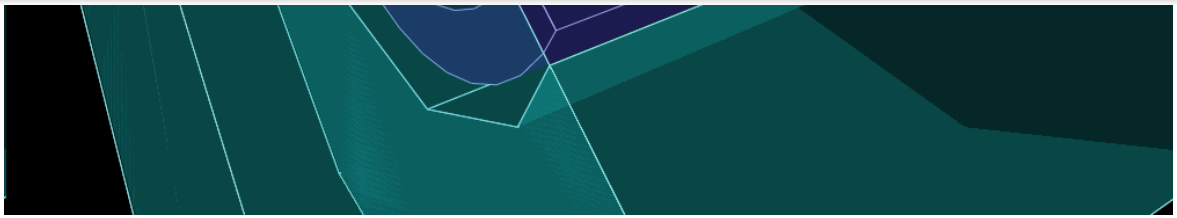


Topic: Model independent Higgs mass

Recoil mass measurement:

- Only reconstruct the $Z \to \mu\mu$
- Using E & p conservation the Higgs mass can be measured from the recoil independent of the decay mode



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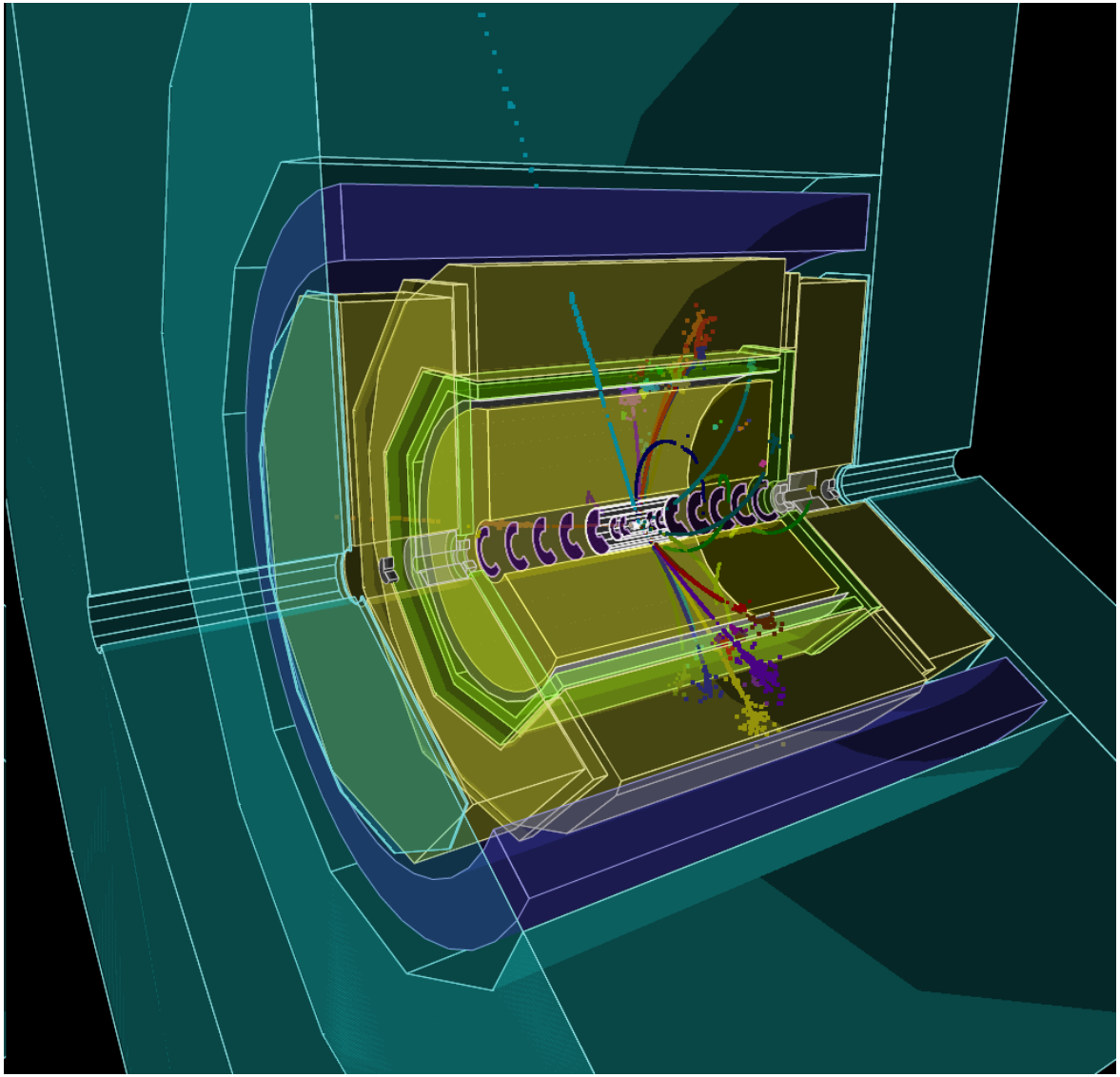
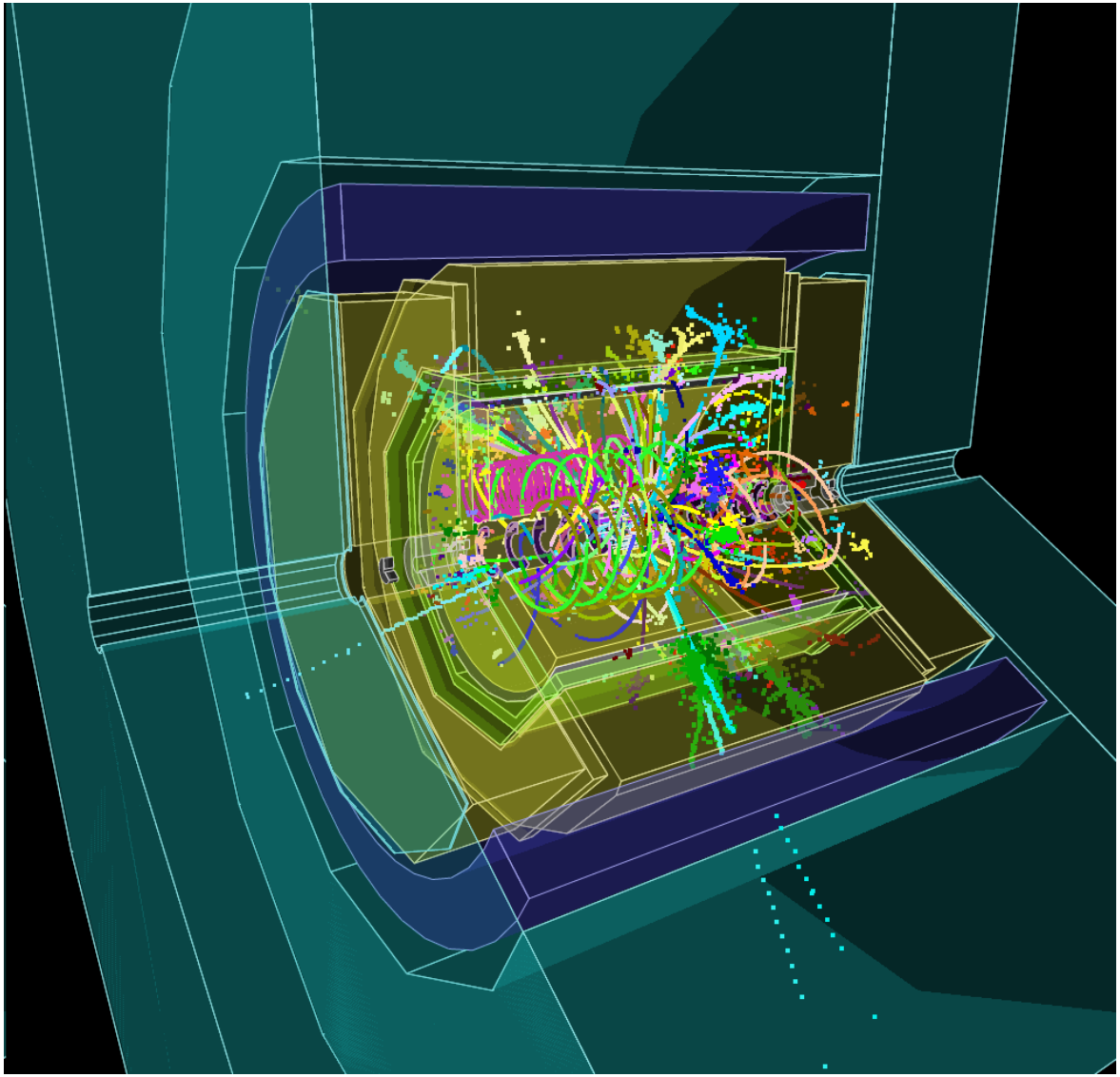


Example: $tth \rightarrow$ 8 jets at 1 TeV



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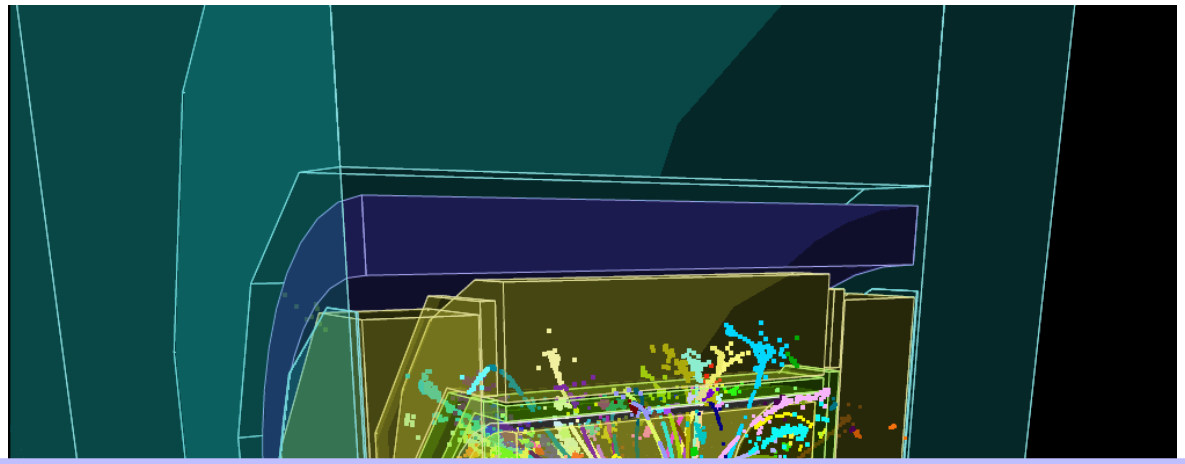
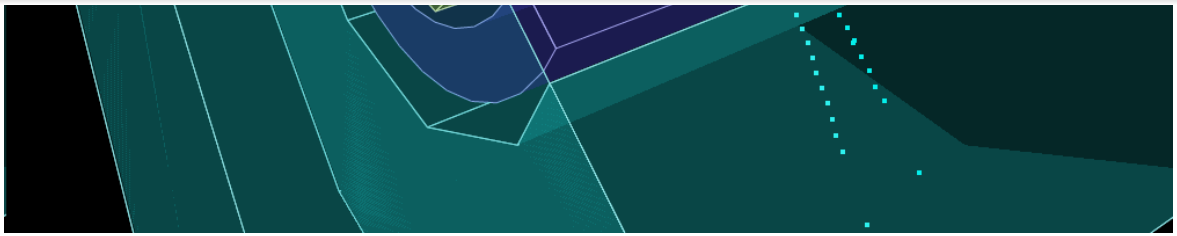


Topic: Higgs-top coupling

- Find all 8 jets.
- Find the jets from each top-decay and from the Higgs decay $\Rightarrow$
  - Flavour-tagging and jet-energy resolution.
- Find cross-section.



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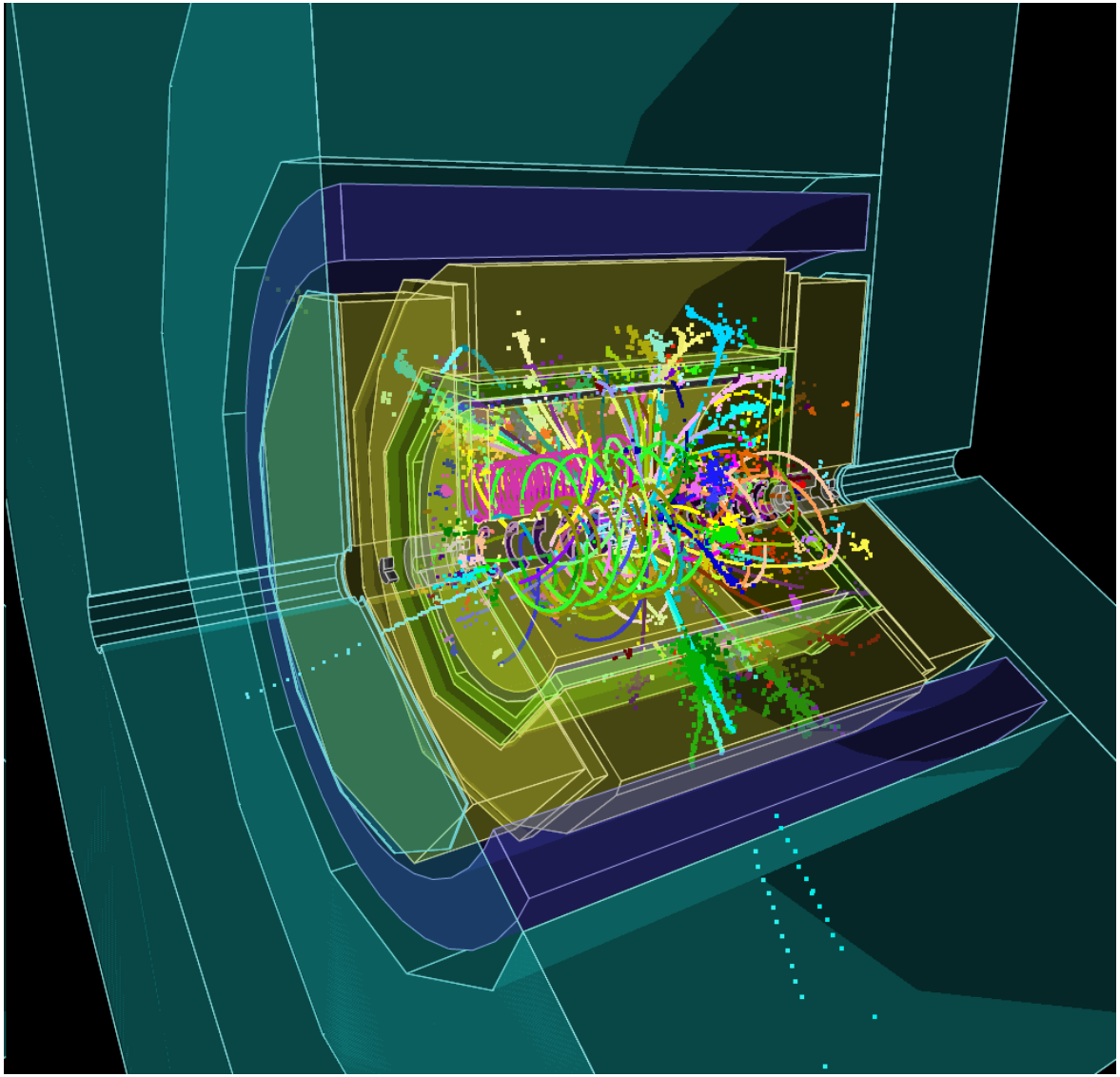

The need for fast simulation at ILC

- We have very good full simulation now.
- So why bother about fast simulation ?
- Answer:
  - R. Heuer at LCWS 2011: *We need to update the physics case continuously*.
  - Light-weight: run anywhere, no need to read tons of manuals and doxygen pages.
  - Anyhow, the Letter Of Intent exercise in 2009 showed that for physics, the fastSim studies were good enough.

But most of all:

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Total cross-section for $e^+e^- \to \gamma\gamma e^+e^- \to q\bar{q}e^+e^-$: 35 nb (PYTHIA)

- $\int \mathcal{L}dt = 500$ fb^{-1} $\to$ 18 $\star 10^9$ events are expected.
- 10 ms to generate one event.
- 10 ms to fastsim (SGV) one event.

10^8 s of CPU time is needed, ie more than 3 years. But:This goes to 3000 years with full simulation.

- And that's only to keep up with the real data ...
- For MC-statistics not to be the dominating systematic error one would like to to have at least 5-10 times the data.

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SUSY parameter scans

Simple example:

- Modest pMSSM scan with 10 parameters.
- Scan each in eg. 10 steps
- Eg. 1000 events per point (also a modest requirement: in eg. sps1a' almost 1 million SUSY events are expected for 500 fb^{-1} !)
- = $10^{10} \times 1000 = 100 \times 10^9$ events to generate...

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Fast simulation types

Different types, with increasing level of sophistication:

- 4-vector smearing. ILC Ex. SimpleFastMCProcessor.
- Parametric. ILC ex.: SIMDET
- Covariance matrix machines. ILC ex.: LiCToy, SGV

Common for all:

Detector simulation time $\approx$ time to generate event by an efficient generator like PYTHIA 6

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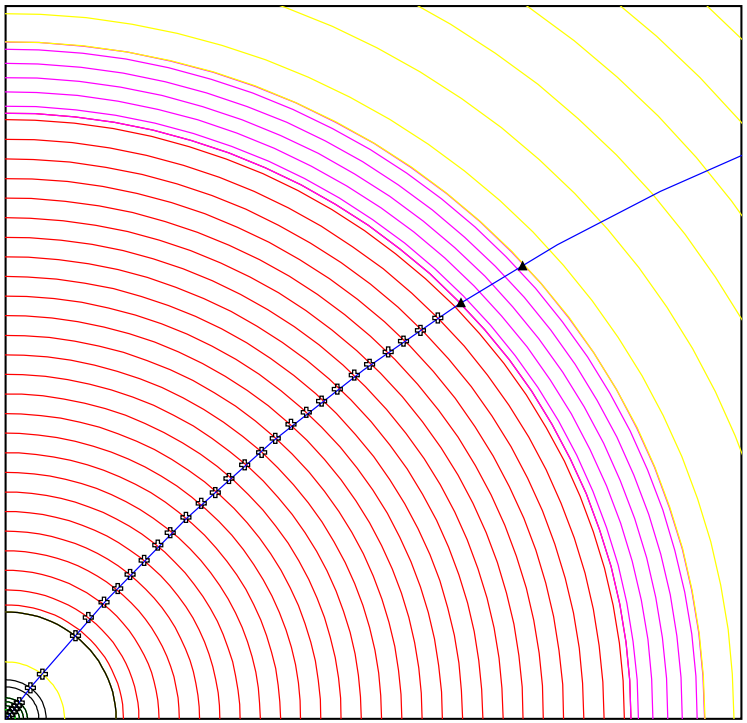
SGV: How tracking works

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 track fit does!
- Smear perigee parameters (Choleski decomposition: takes all correlations into account)
- Helix *parameters* exactly calculated, *errors* with one approximation: helix moved to (0,0,0) for this.

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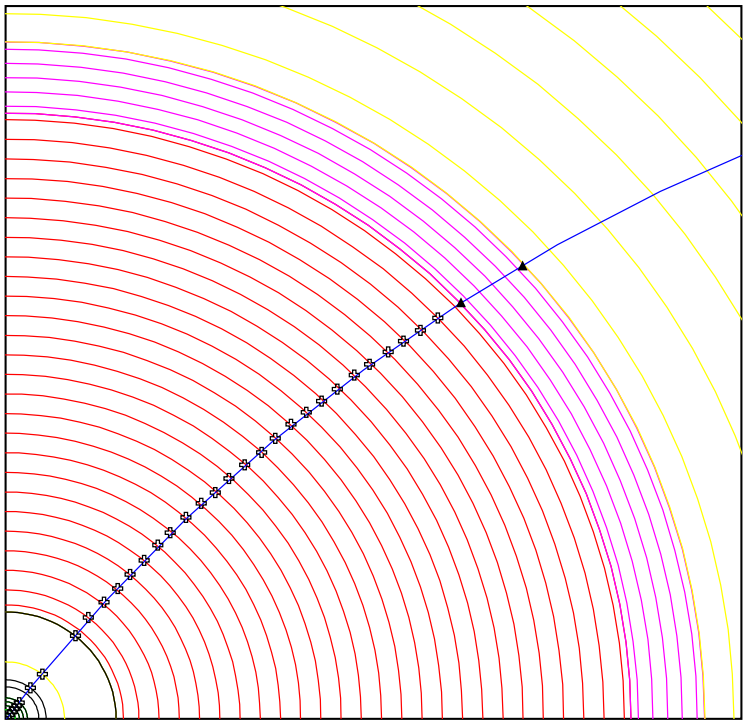

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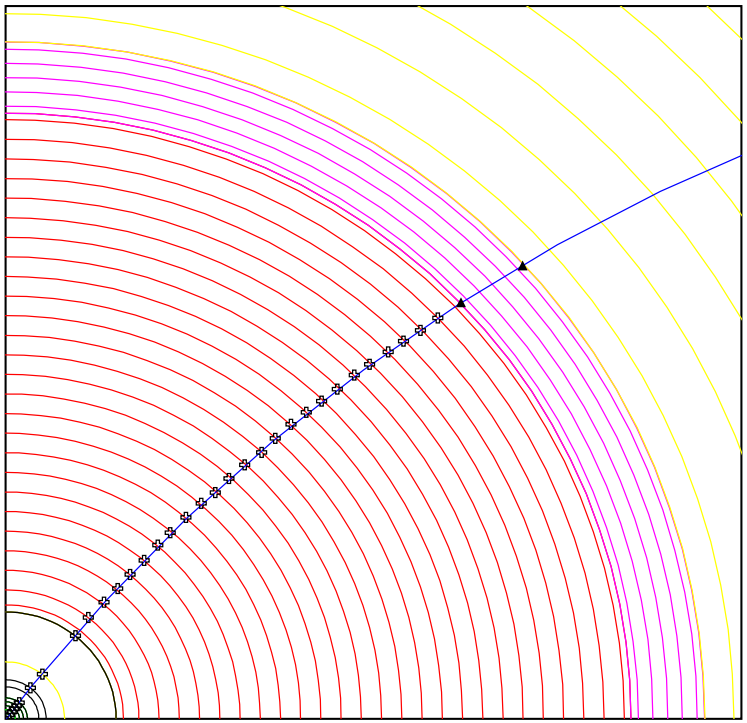

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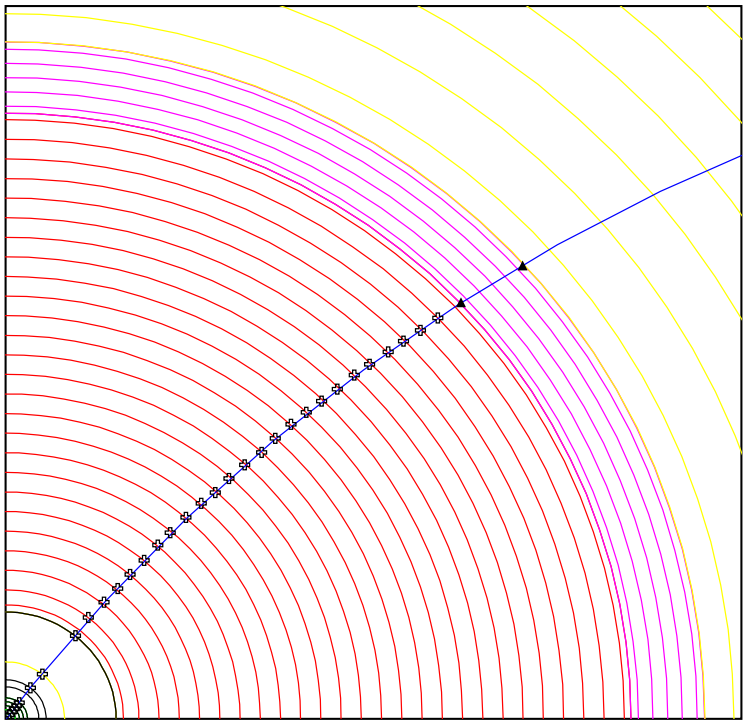

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  - Response type: MIP, EM-shower, hadronic shower, below threshold, etc.
  - Simulate single particle response from parameters.
  - Easy to plug in other (more sophisticated) shower-simulation. See Madalina Chera's talk tomorrow.

Other stuff:

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- Plug-ins for particle identification, track-finding efficiencies,...
- Information on hits accessible to analysis.

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Technicalities

- Written in Fortran 95, a re-write of the Fortran77-based SGV2 series, battle-tested at LEP.
- Some CERNLIB dependence. Much reduced wrt. old F77 version, mostly by using Fortran 95's built-in matrix algebra. Just one core dependence (Choleski decomposition), so in a future version, the dependence will be optional.
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- samples subdirectory with steering and code for eg. scan single
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Stucture

SGV is made of six loosely connected parts:

- The Steering, which takes care of initialisation and ending, and runs the event loop.
- In the event loop,
  - The Event Generator, which either calls the external generator, or reads in pre-generated events.
  - The Detector Simulation
  - The Event Dispatcher

  is called.
- The Detector Simulation calls
  - The Covariance Matrix Machine
  - The Calorimeter response simulation.

Stucture

- The Event Dispatcher trasferes the data directly to the Event Analysis, and/or writes to an file / FIFO / shared memmory (RZ/FZ).
- Communication between parts - steering *and* data - is by arguments only (except for Event Generator → Detector Simulation → Event Dispatcher.)
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  - Many more complicated examples in the "samples" sub-directory.
- User data, delivered in Module-global arrays:
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Ex: ILD tracker-system design (Vienna 2005).

- I: The divergence in the TDR: Once the last disk is hit, the $1/\sqrt{\tan\theta}$ is back !
- II: The step: End of The Vertex Detector
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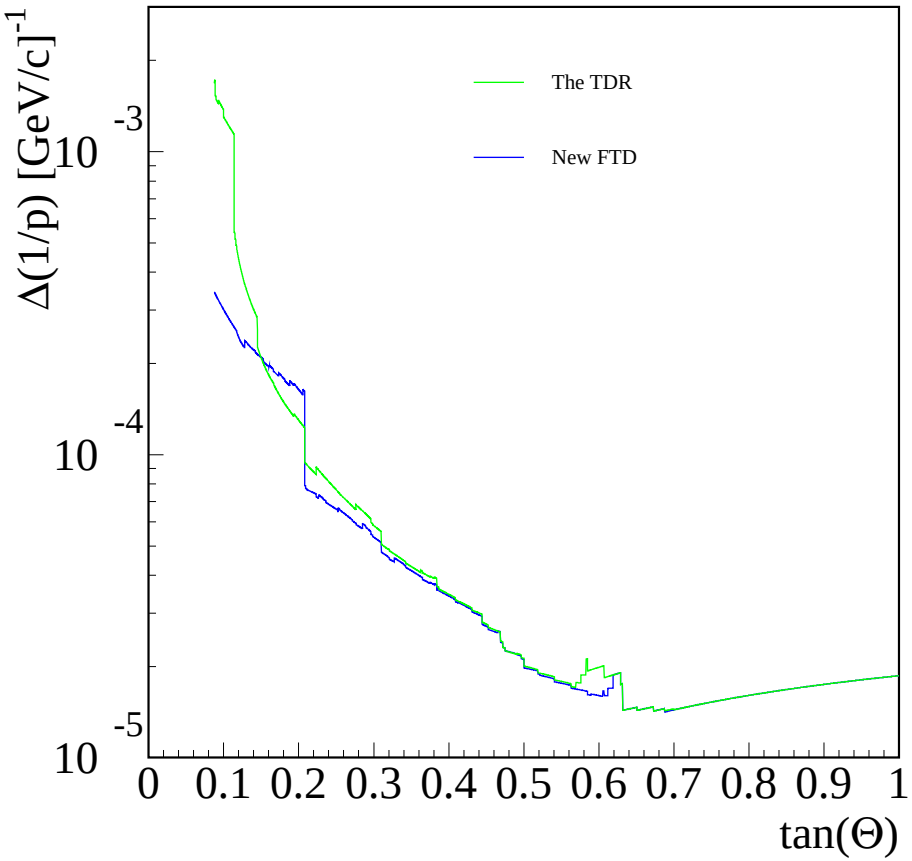

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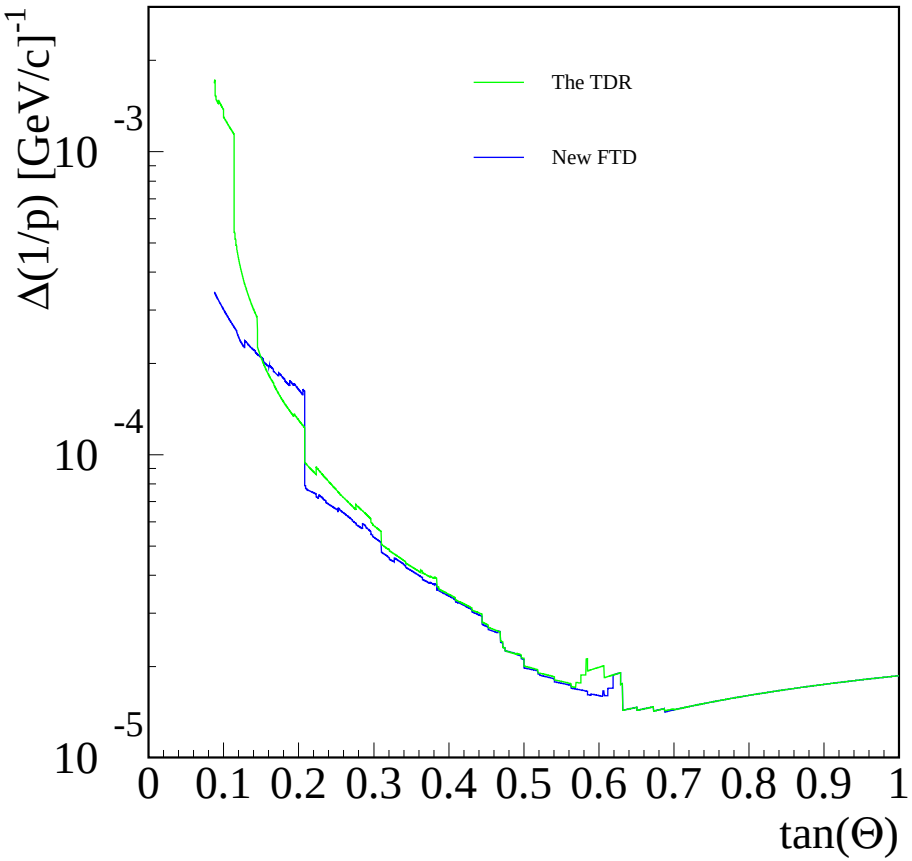

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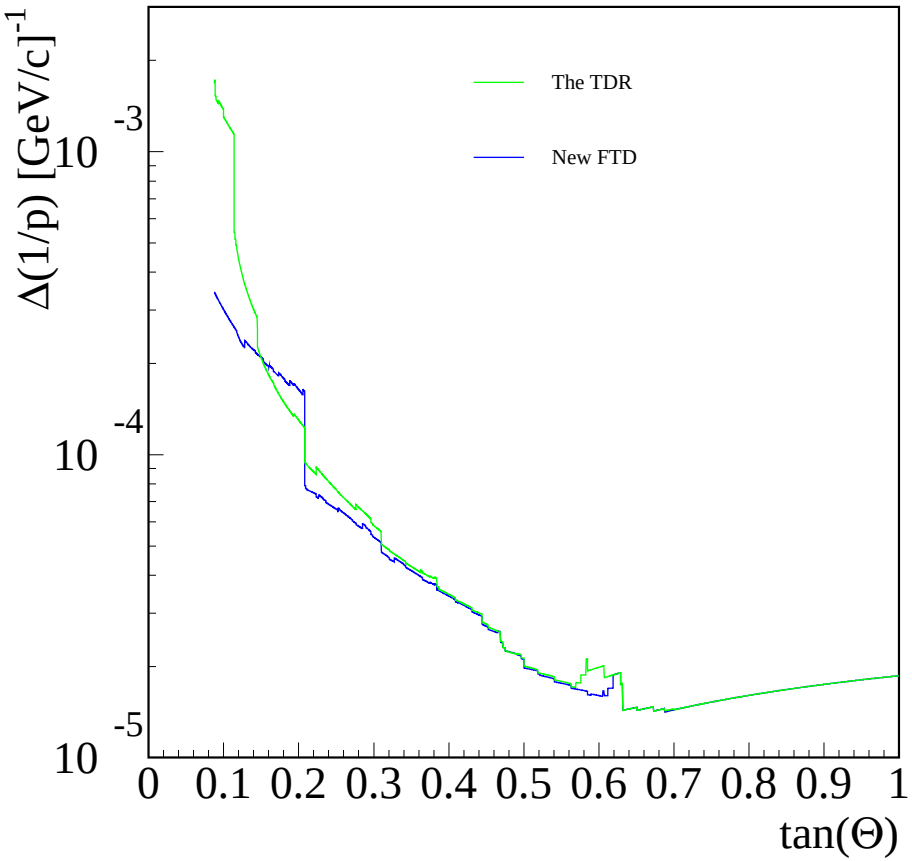

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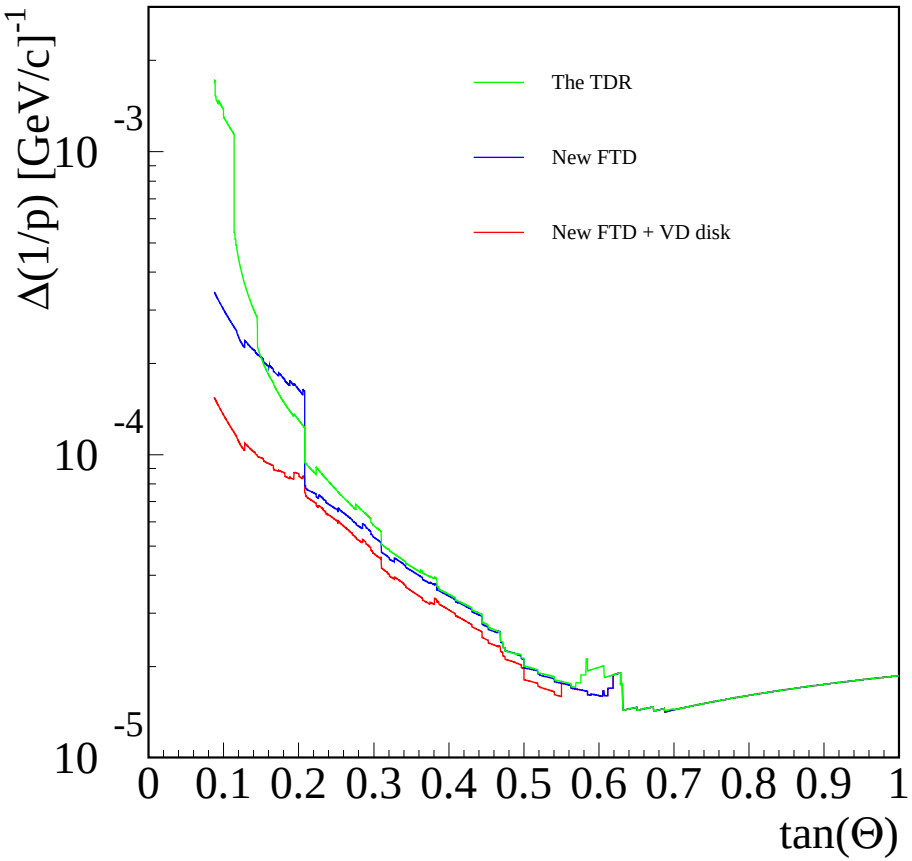
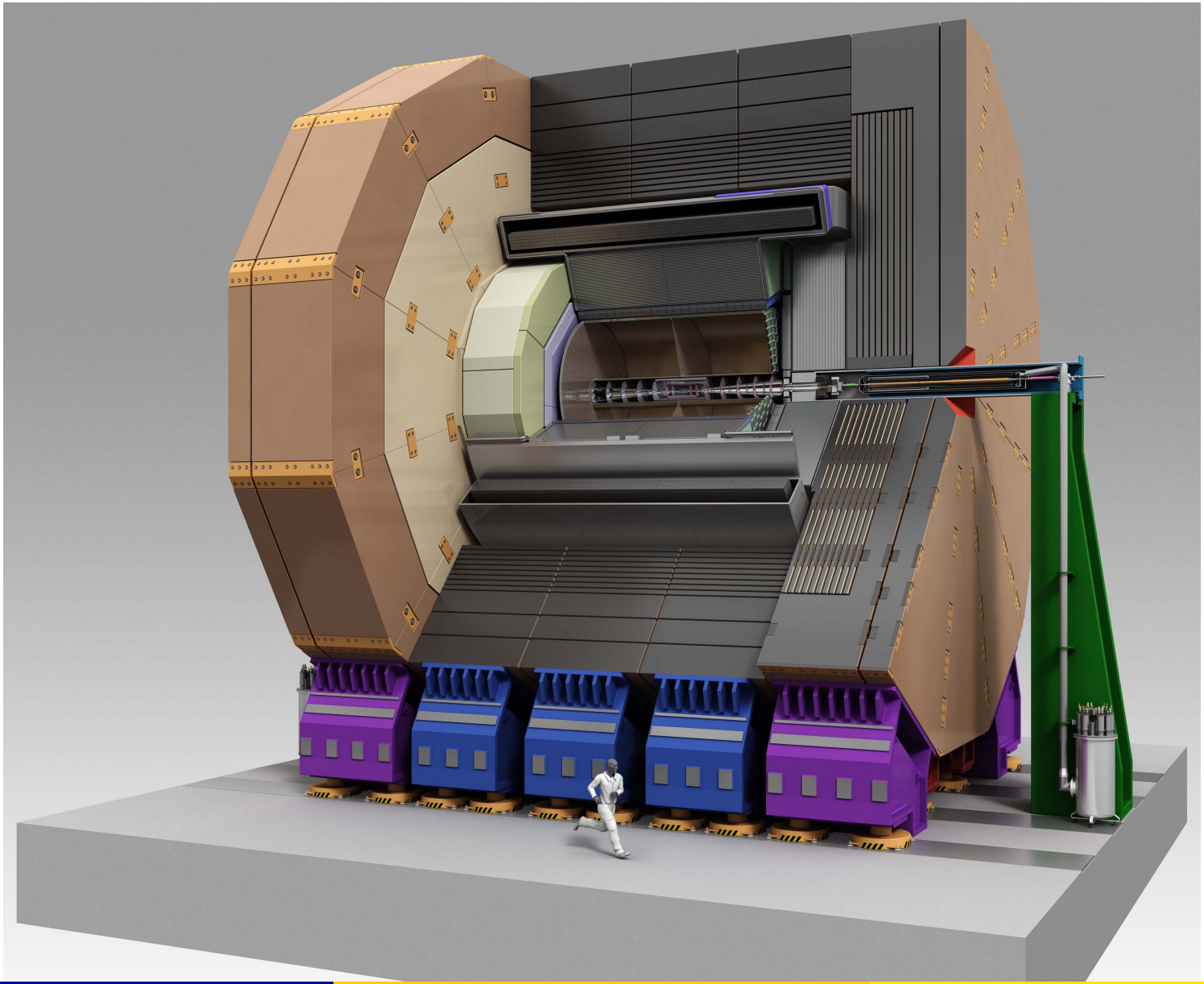
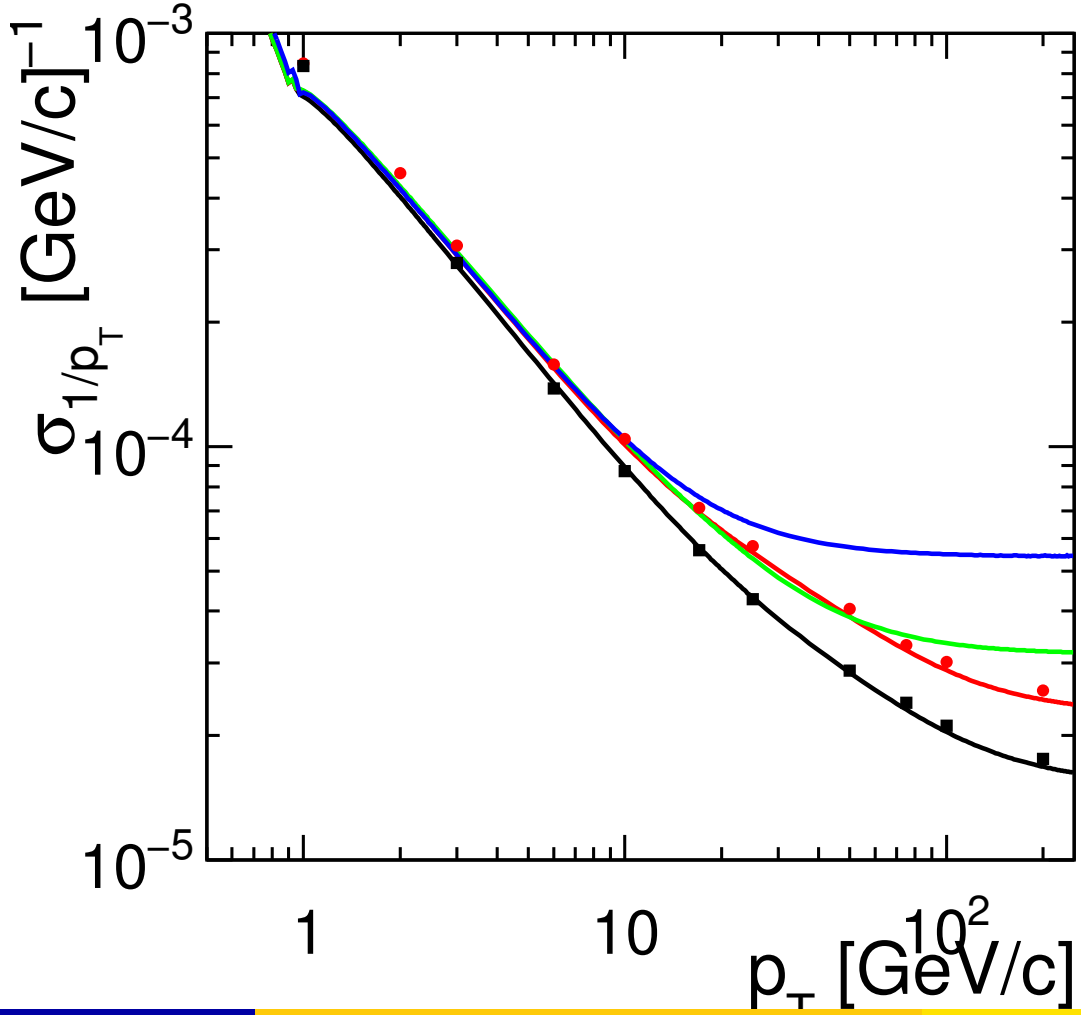


The ILD Detector



SGV and FullSim ILD: momentum resolution

Lines: SGV, dots: Mokka+Marlin



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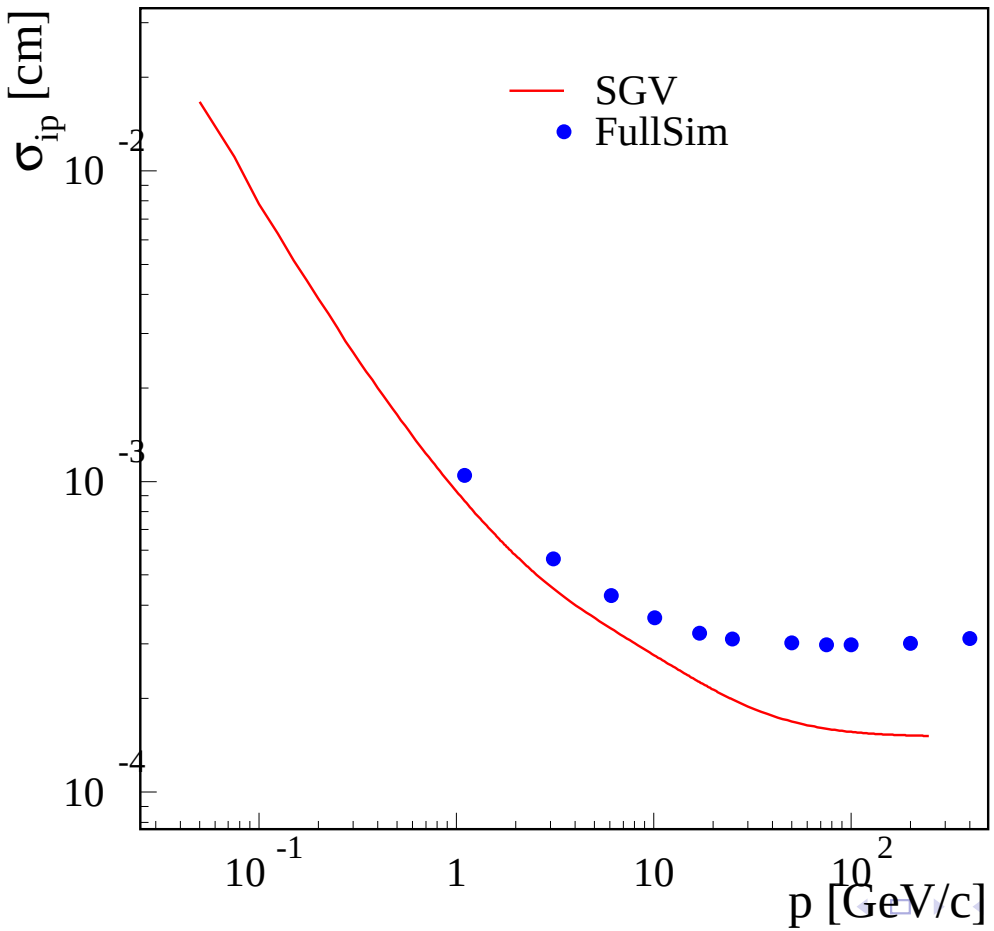

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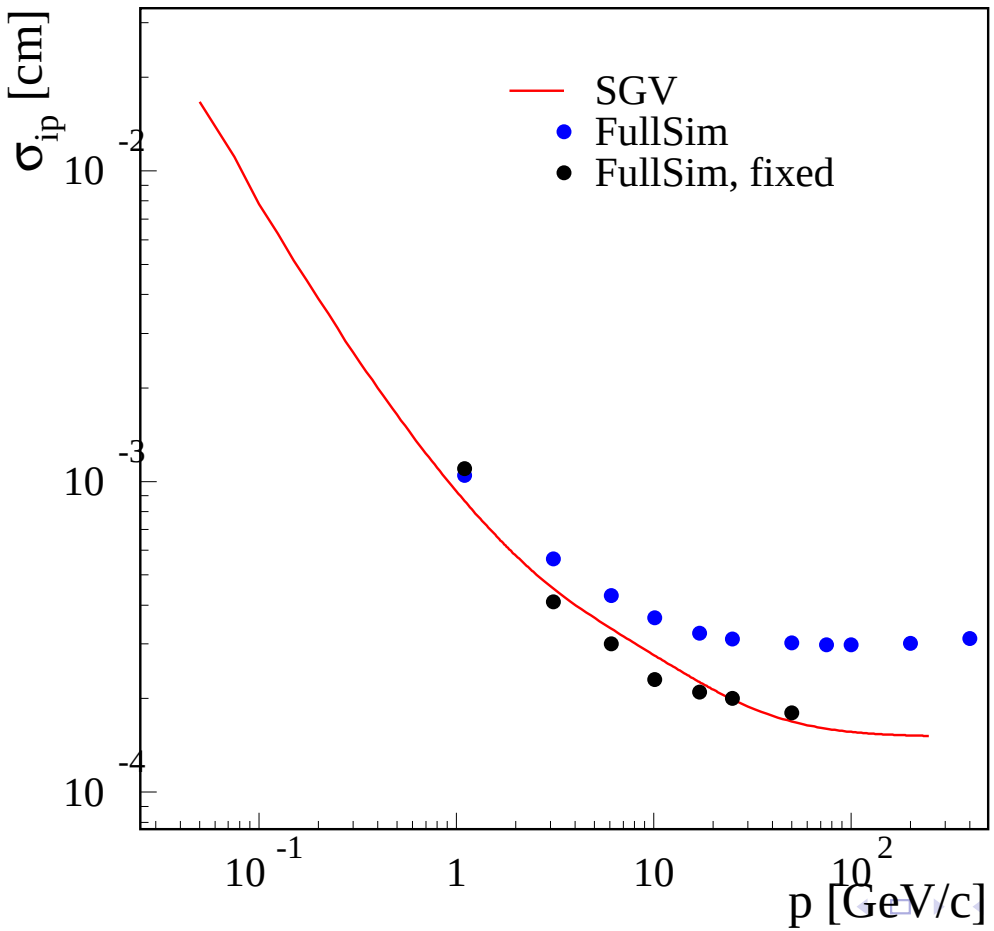

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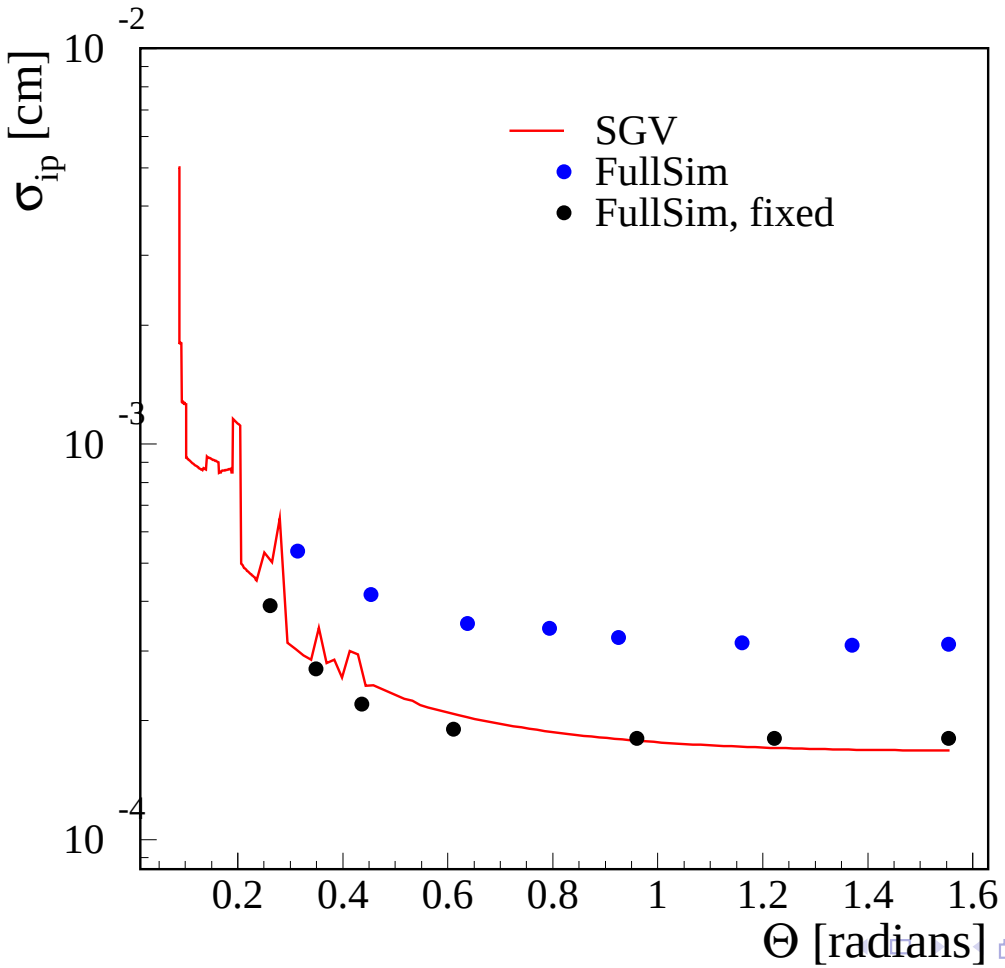

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Feed exactly the same physics events through FullSim or SGV.

- Overall:
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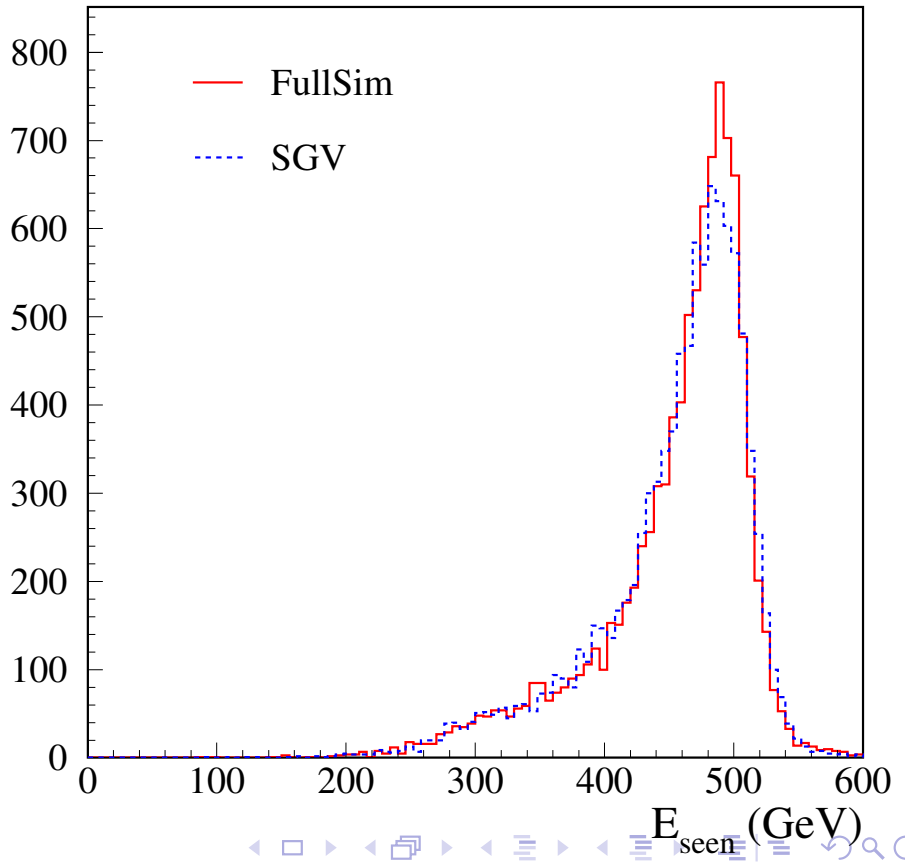

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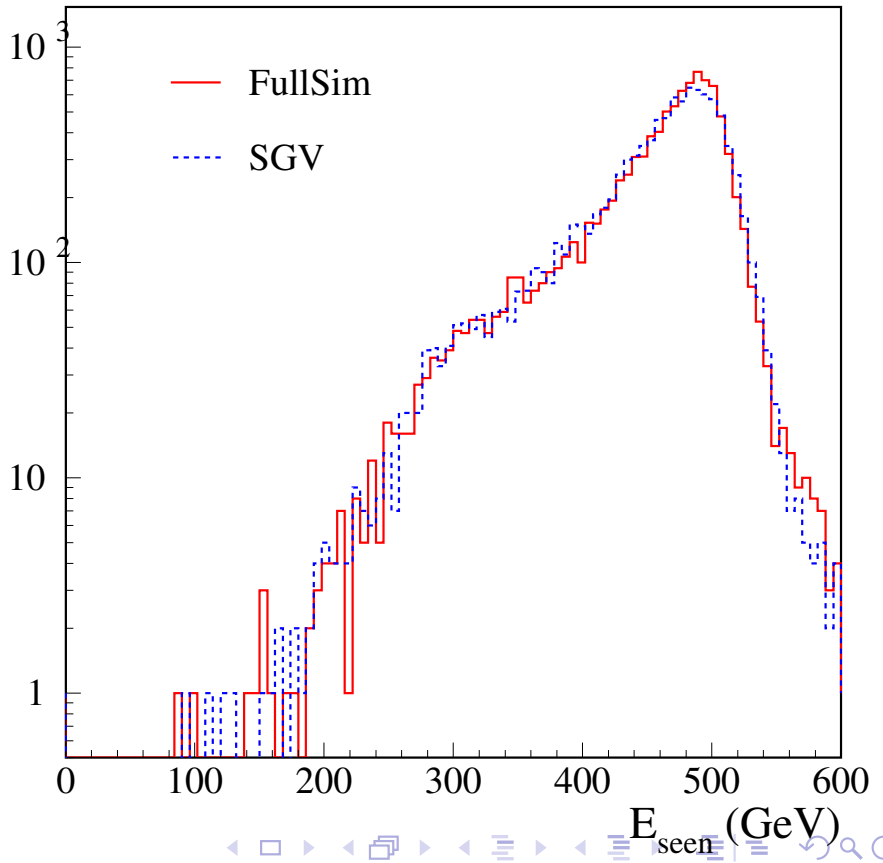

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- Find initial hadrons from each colour-singlet (string).
- Find the quarks at each end of the string.
- Group hadrons to jets by which quark they are closest to.
- Follow the decay-chains and assign all particles in the event to the jet of their respective ancestor hadron.

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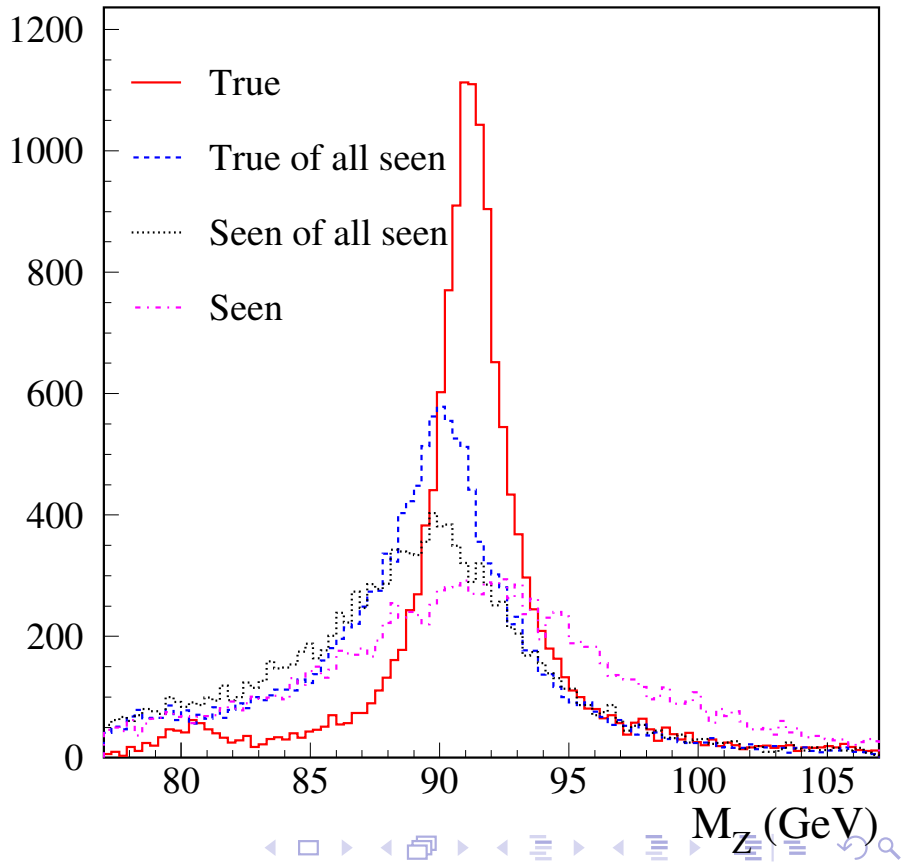

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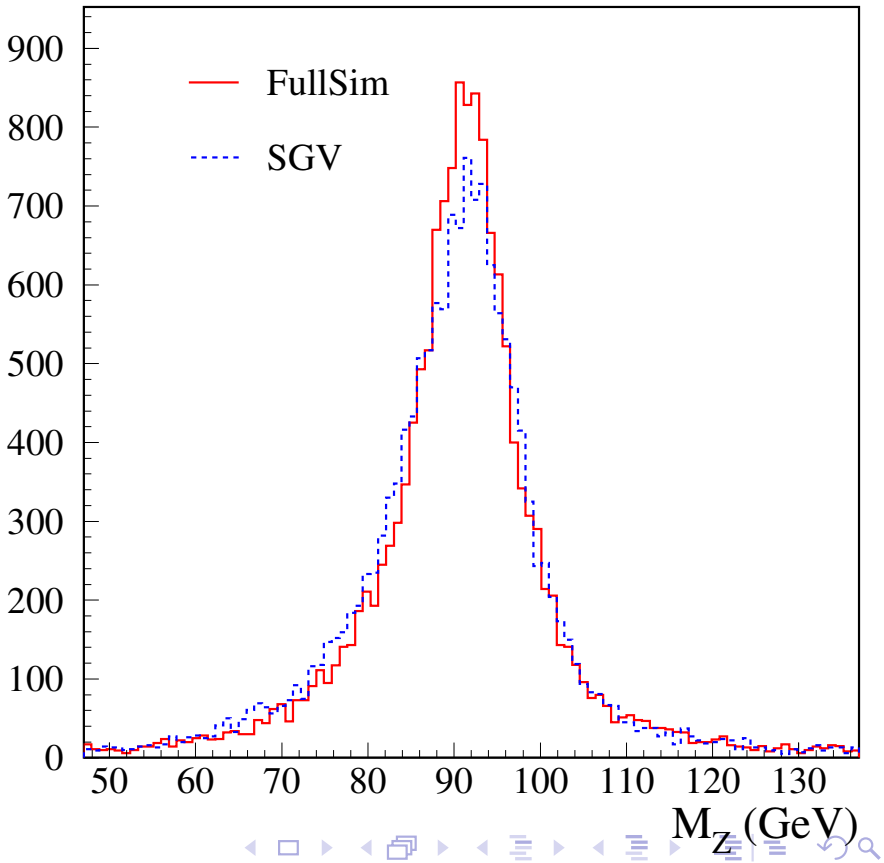

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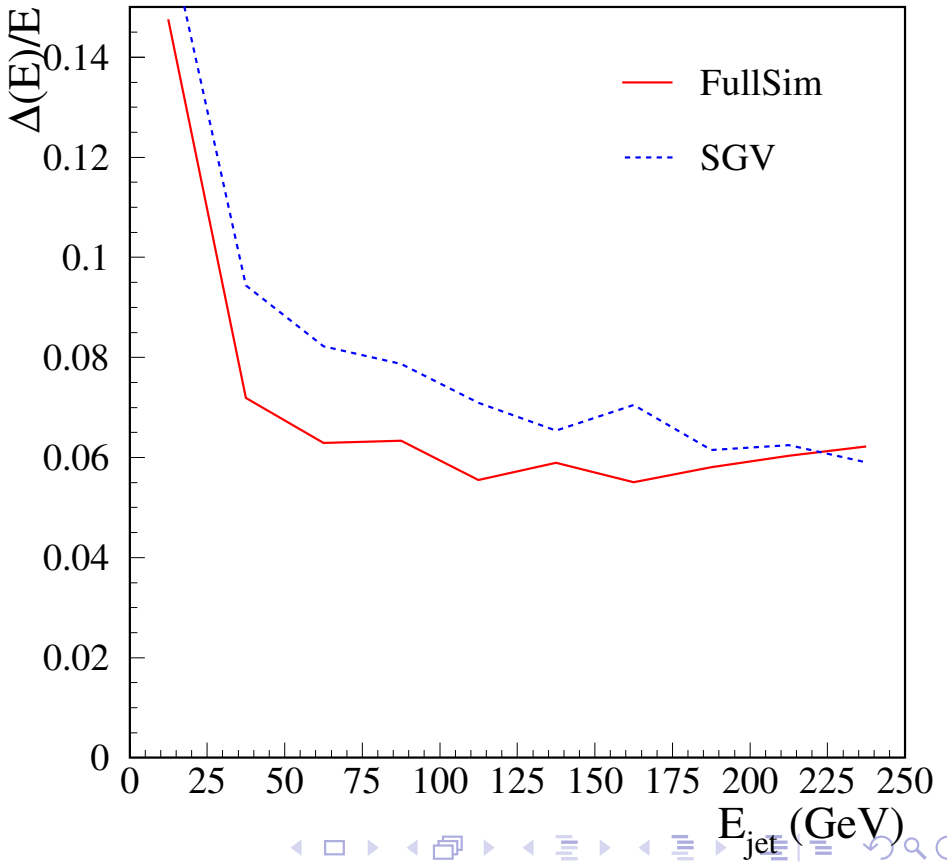

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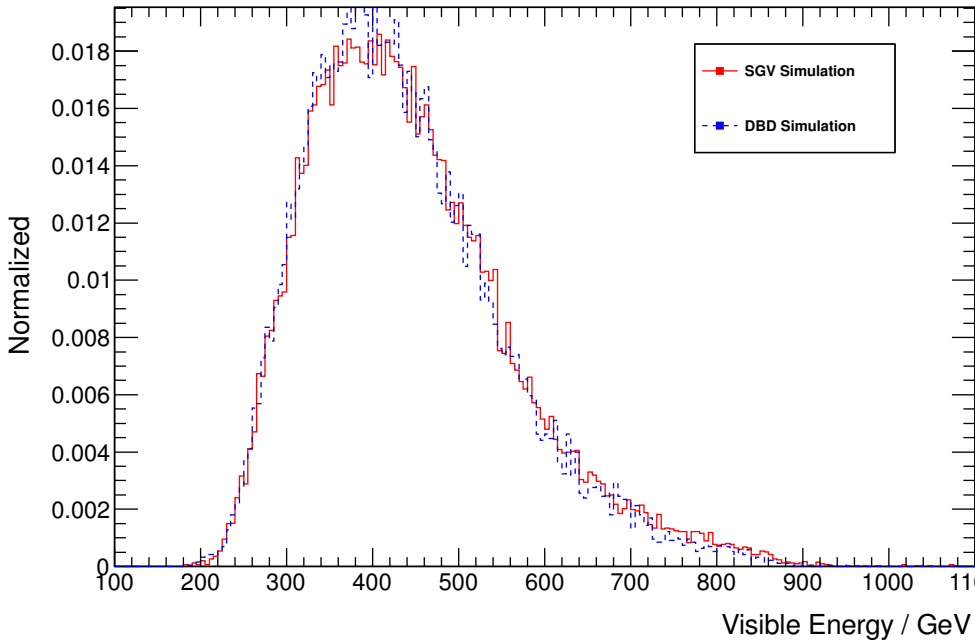

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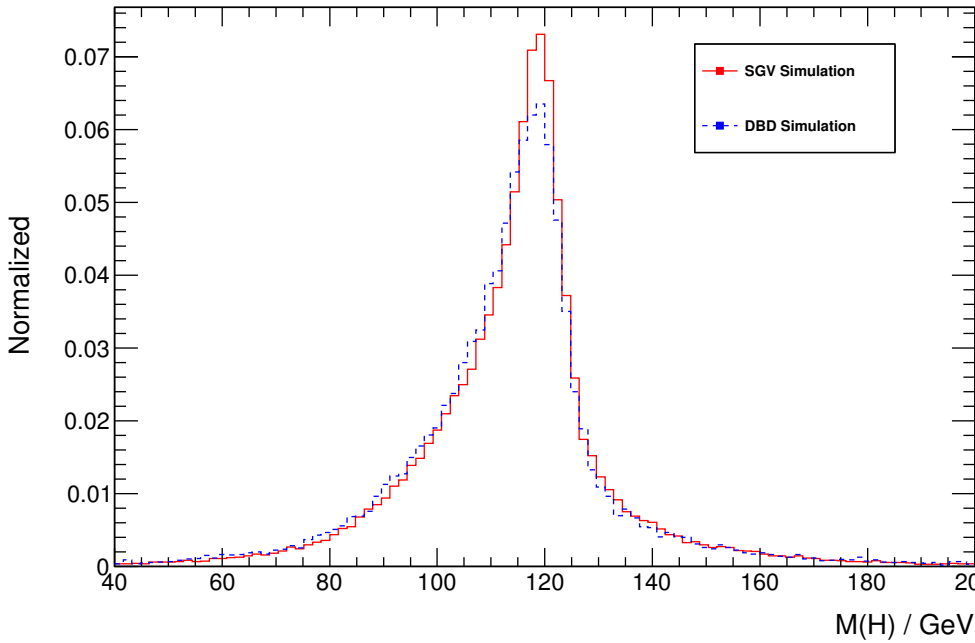

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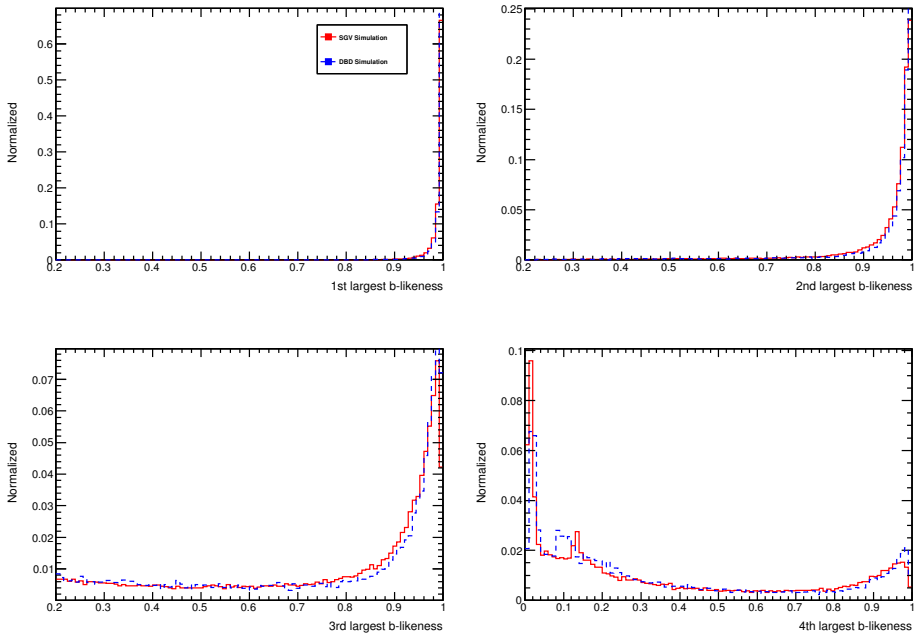
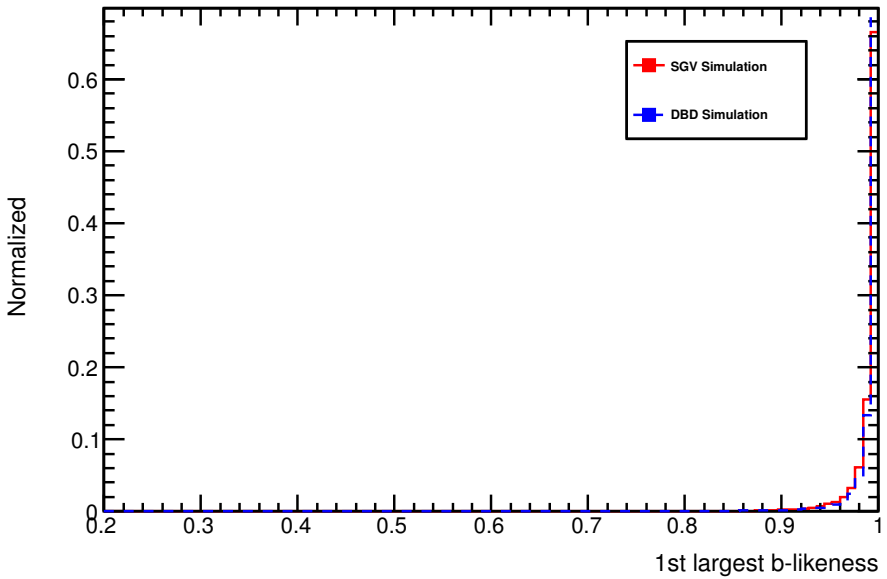
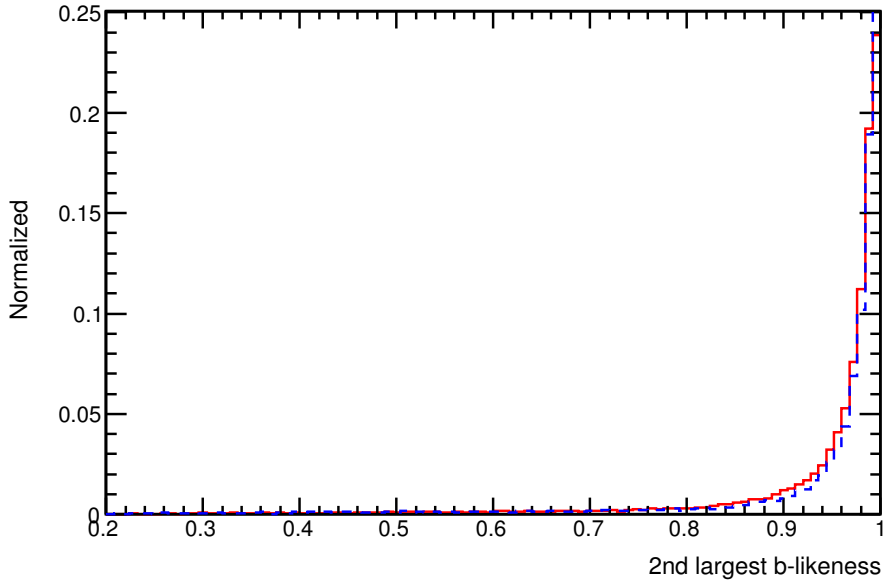
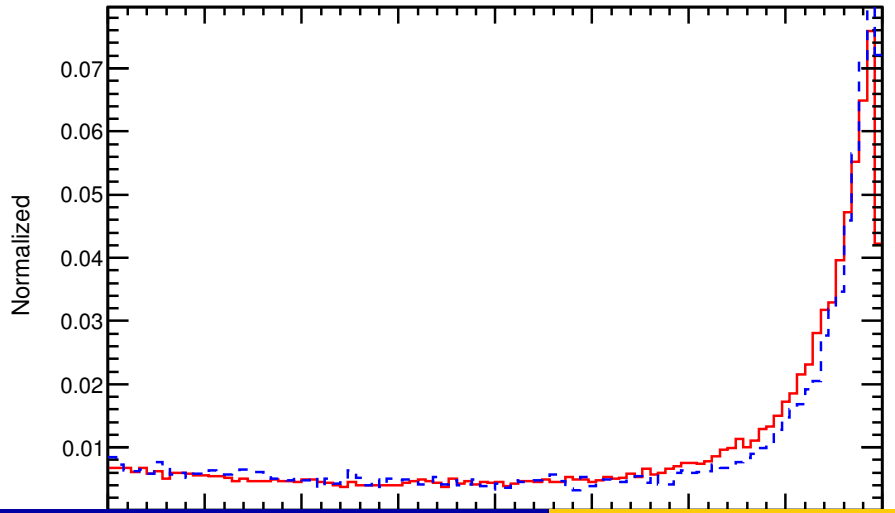


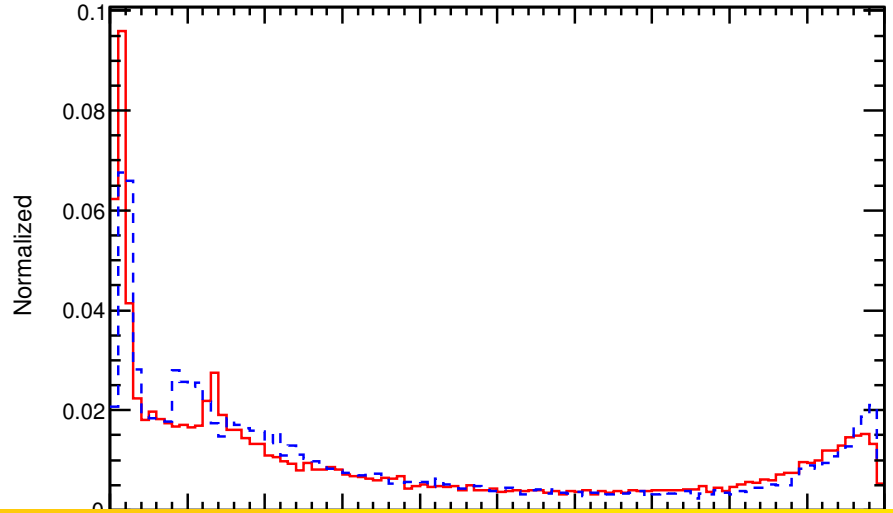
SGV and FullSim ILD: Full system

F









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Feed exactly the same physics events through FullSim or SGV.

- Overall:
  - Total seen energy
- $e^+e^- \rightarrow ZZ \rightarrow$ four jets:
  - Make "True Jets":
  - Reconstructed M_Z at different stages in FullSim.
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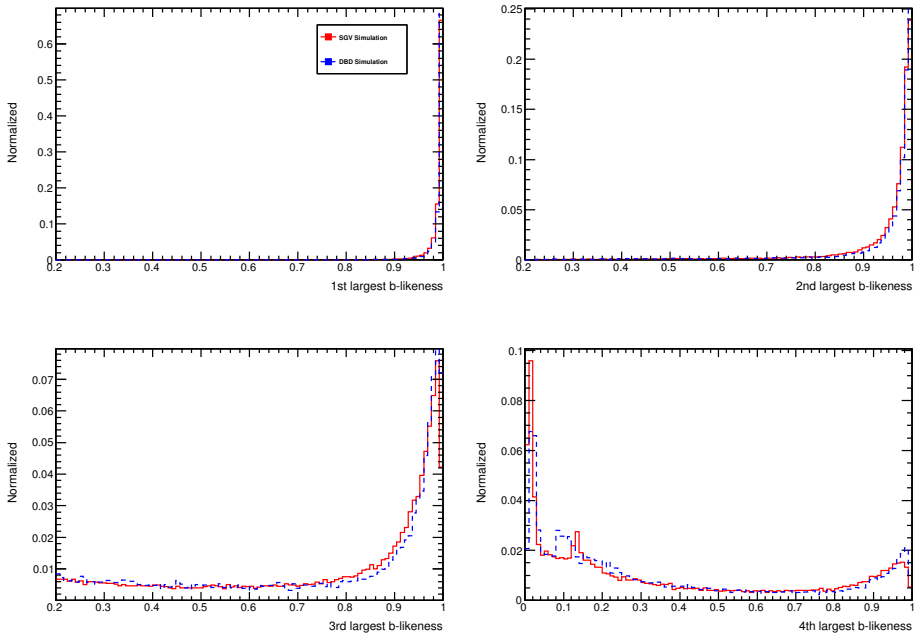

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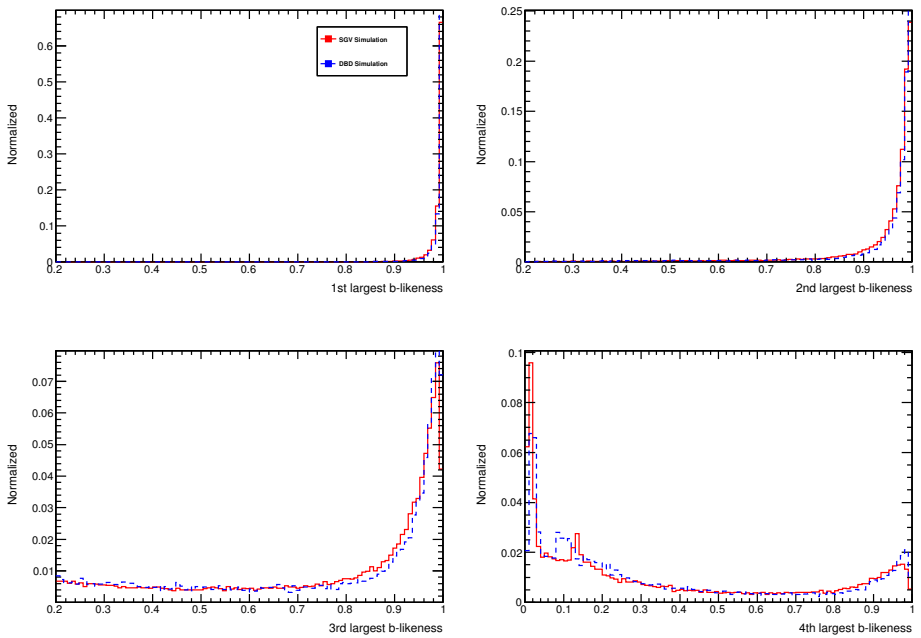

Near Future developments

- Finish up particle flow parametrisation:
  - Jet mass.
  - MIP signals.
  - Clusters from same true particle in both EM and hadronic calorimeters.
  - Cluster C.O.G (not just start point)
- Handling very large input and/or output files: File splitting etc.
- Handling very large *numbers* input files.
- Include a filter-mode:
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Not-So-Far Future developments

- Update documentation and in-line comments, to reflect new structure.
- Consolidate use of Fortran 95/203/2008 features:
  - Use of user-defined types.
  - Use of PURE and ELEMENTAL routines,
  - Optimal choice between pointer, allocatable and automatic and/or assumed-size, assumed-shape, and explicit arrays.
- I/O over FIFO:s to avoid storage and I/O rate limitations.
- The Grid.
- Investigate running on GPU:s.
- Possibly - when gcc/gfortran 4.4 (ie. Fortran 2003) is common-place - Object Orientation, if there is no performance penalty.

Summary

- The need for FastSim was reviewed:
- Large cross-sections ($\gamma\gamma$), or large parameter-spaces (SUSY) makes such programs obligatory, also at the ILC.
- The SGV program was presented, and (I hope) was shown to be up to the job, both in physics and computing performance.
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Installing SGV

svn co https://svnsrv.desy.de/public/sgv/trunk/ sgv/
Then
cd sgv ; . ./install

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Thank You !

Backup

BACKUP SLIDES

Some internals

Tracking:

- Module zt_tracking:
  - Higher-level functions: *"Particle with momentum $\bar{p}$ starts at $\bar{v}$ in detector i. Return helix-paramters and covariance at point $\bar{r}$"*
  - Initialises constants-of-motion for the track *once*.
  - Decides which helix-parametrisation is best at a given point, and transforms when needed.
  - Checks max and min layer that *could* be hit by particle, to avoid un-nessesary computations.
- Module zt_covaiance: The covariance machine:
  - Geometry worked out analytically.
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- Decide if particle is:
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  This reduces the size of loops later.
- Apply B-field: move decay verticies, tilt $\bar{p}$ of decay products.
- Loop "seeable" twice:
  - First: simulate brems and pair-creation; remove daugthers of particles that hit a calorimeter before decaying.
  - Second: actually simulate the responce.
    - Tracking: Call tracking to get unsmeared helix and covariance, then smear, which smears it using Cholesky decomposition method.
    - Calorimetry: Call ... which calls ... to get path of/coordinates of trajectory intersection points with calo ... parametrically.

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- Important issues in red.
- During f77 $\rightarrow$ Fortran95 transistion:
  - Avoid feature rot: Adding a cool feature that only add 10 % to the CPU time is OK, right ?
    - Well, yes, but ...
    - ... if you do that every two weeks ...
    - ... yor code runs 10 times slower after 1 year...
    - ... 100 times slower after 2 years ...
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Use-cases at the ILC

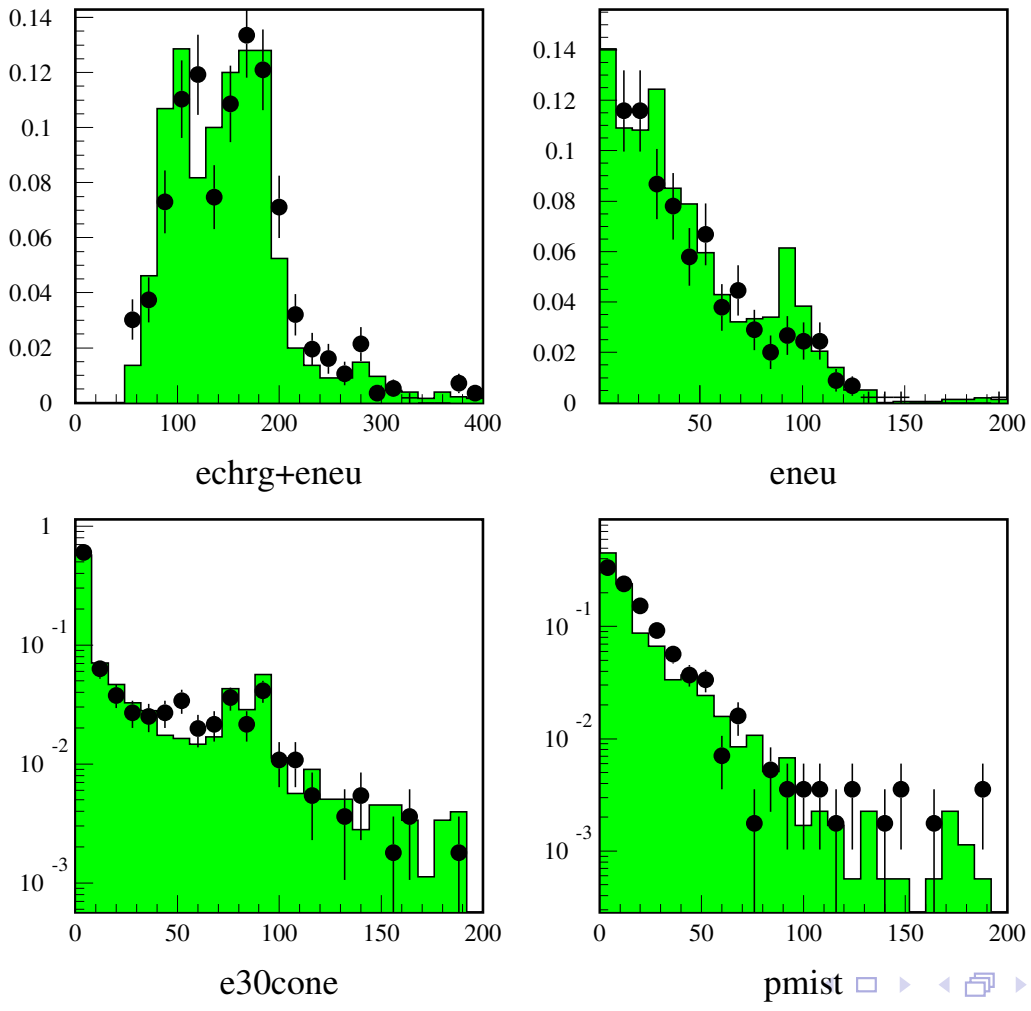
- Used for fastsim physics studies, eg. arXiv:hep-ph/0510088, arXiv:hep-ph/0508247, arXiv:hep-ph/0406010, arXiv:hep-ph/9911345 and arXiv:hep-ph/9911344.
- Used for flavour-tagging training.
- Used for overall detector optimisation, see Eg. Vienna ECFA WS (2007), See Ilcagenda > Conference and Workshops > 2005 > ECFA Vienna Tracking
- GLD/LDC merging and LOI, see eg. Ilcagenda > Detector Design & Physics Studies > Detector Design Concepts > ILD > ILD Workshop > ILD Meeting, Cambridge > Agenda >Sub-detector Optimisation I

The latter two: Use the Covariance machine to get analytical expressions for performance (ie. *not* simulation)

SGV physics performance

SGV and real data from DELPHI: Global variables

Histogram: SGV, Points: DELPHI data



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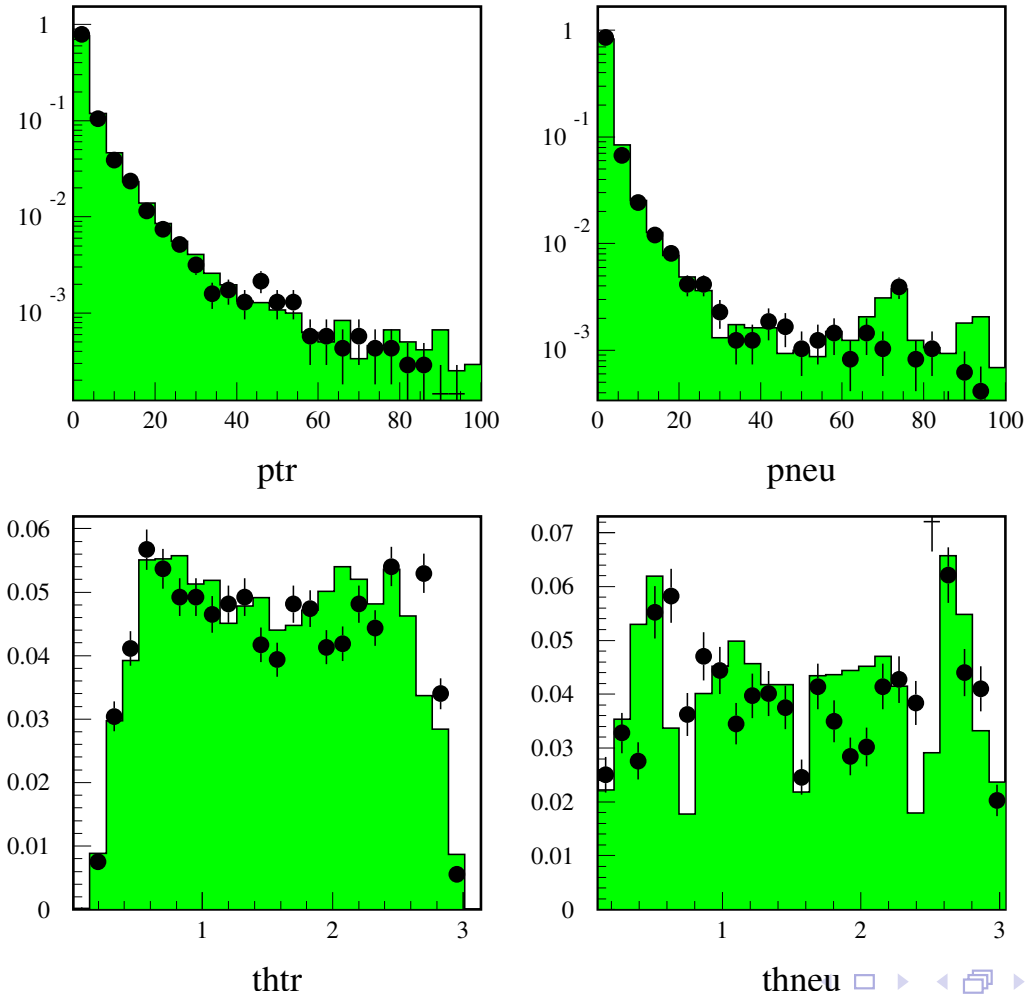
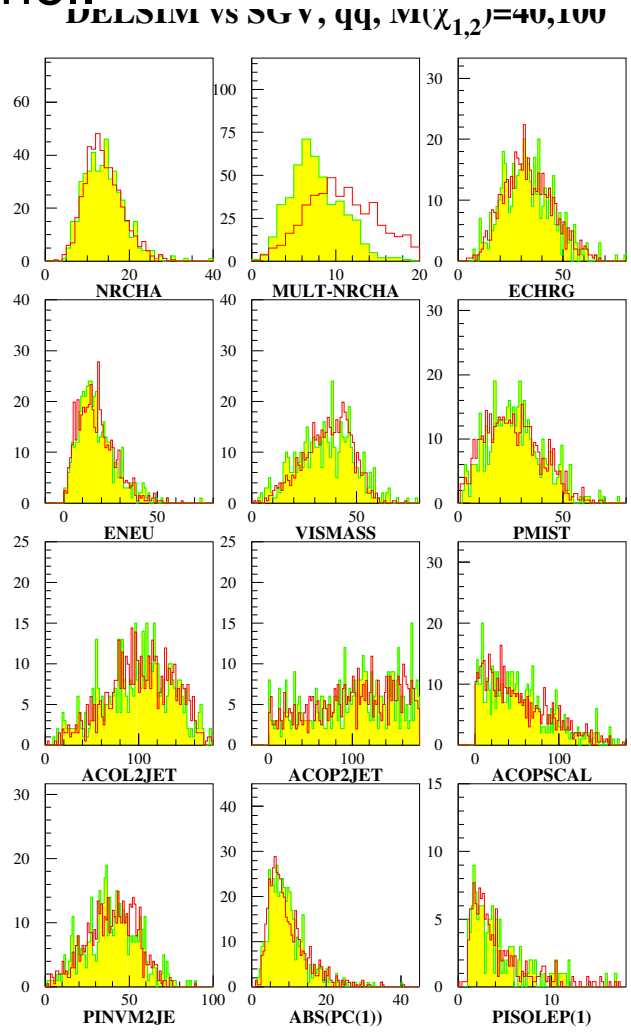
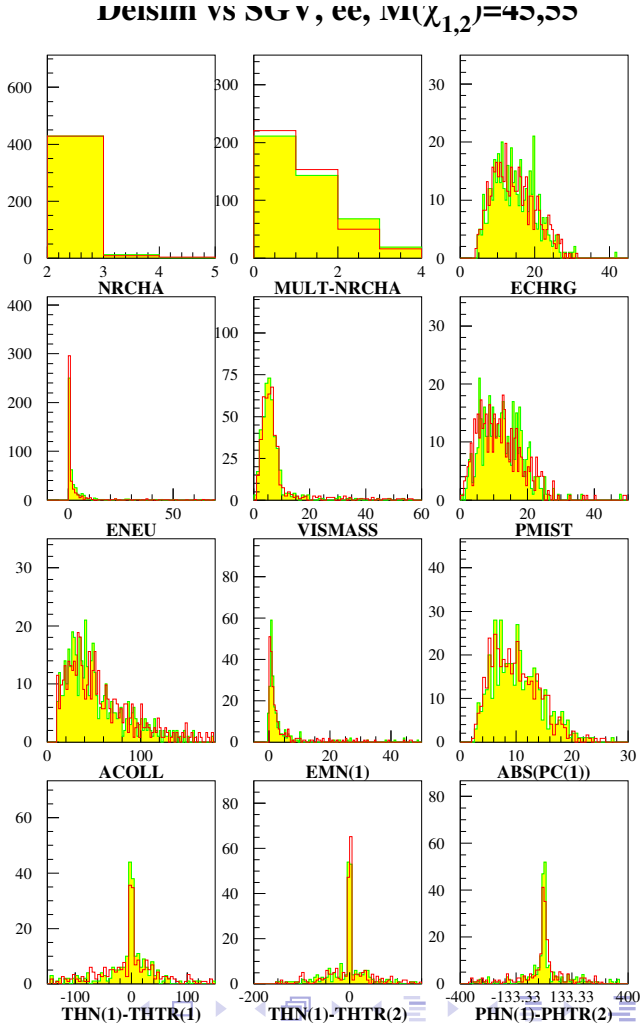


SGV physics performance: DELPHI

SGV and full simulation from DELPHI: Neutralino search in hadronic channel.





Checking the parametrisation

- Some overall distributions:
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- Jet properties in the SUSY benchmark point 5 ($\tilde{\chi}_1^{\pm}$):
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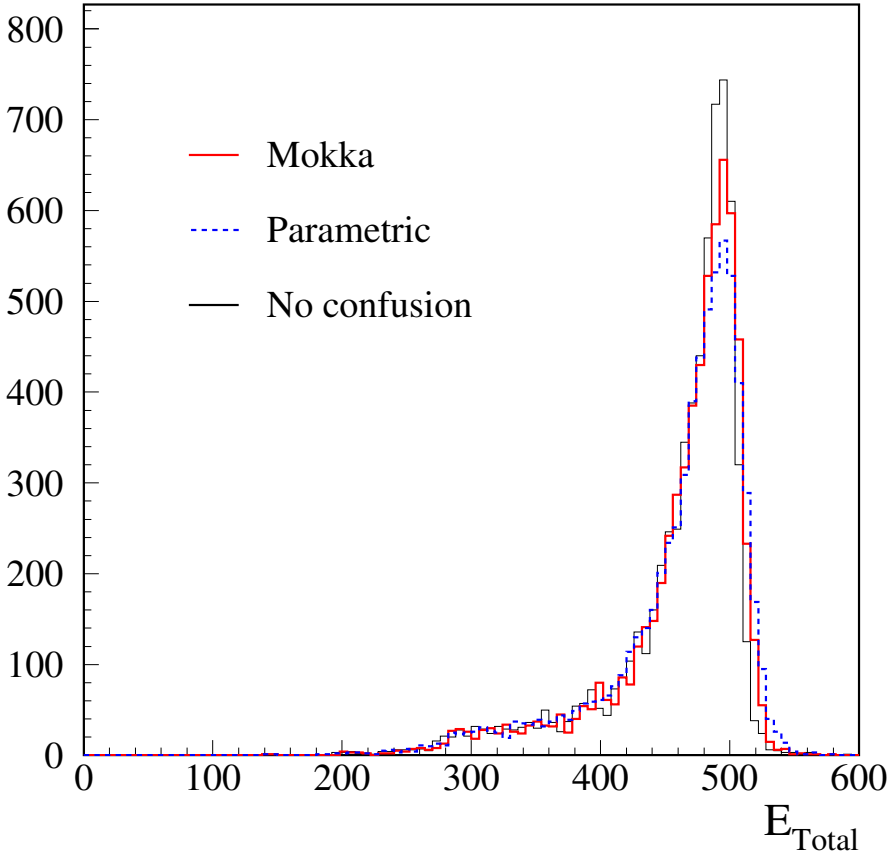

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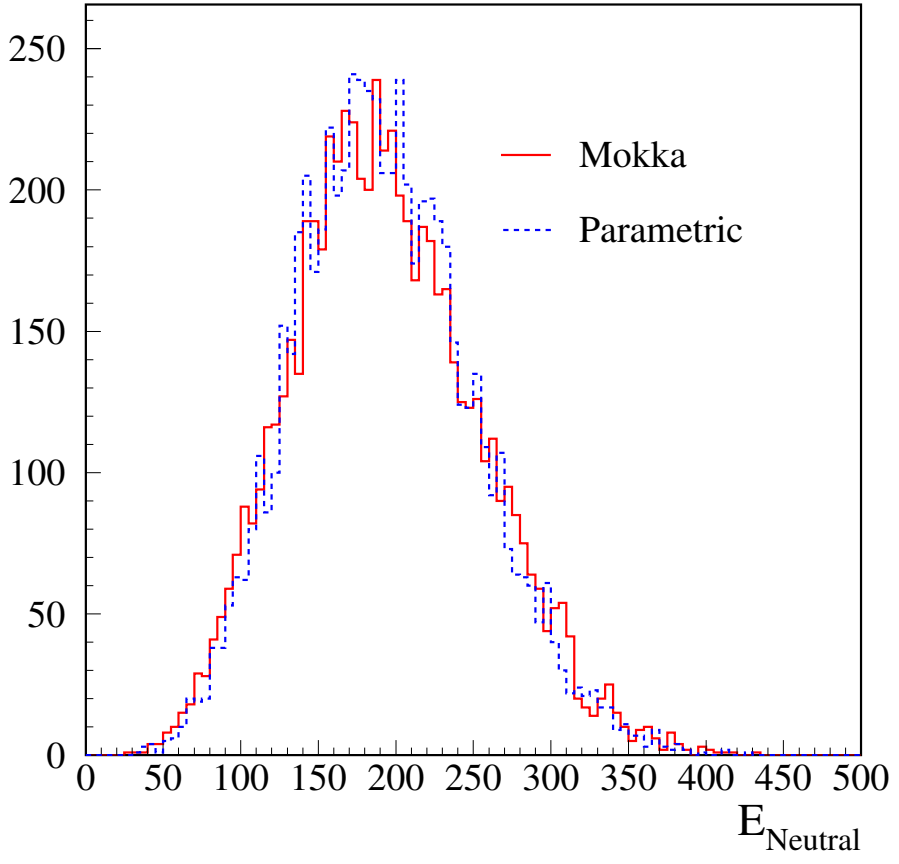

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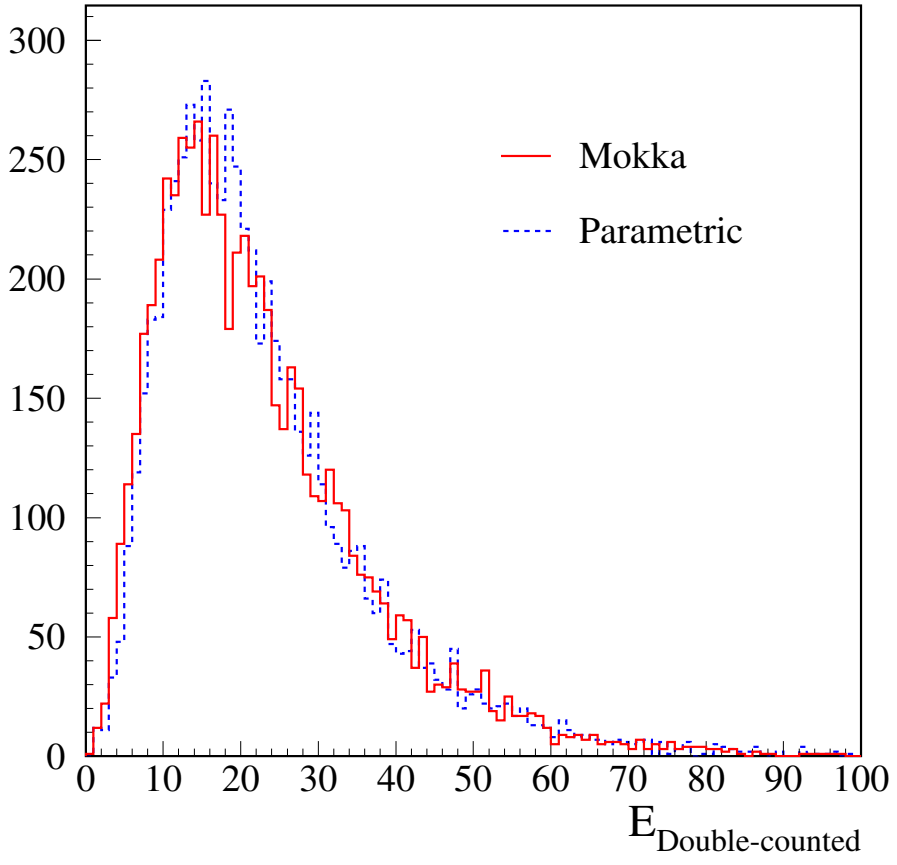

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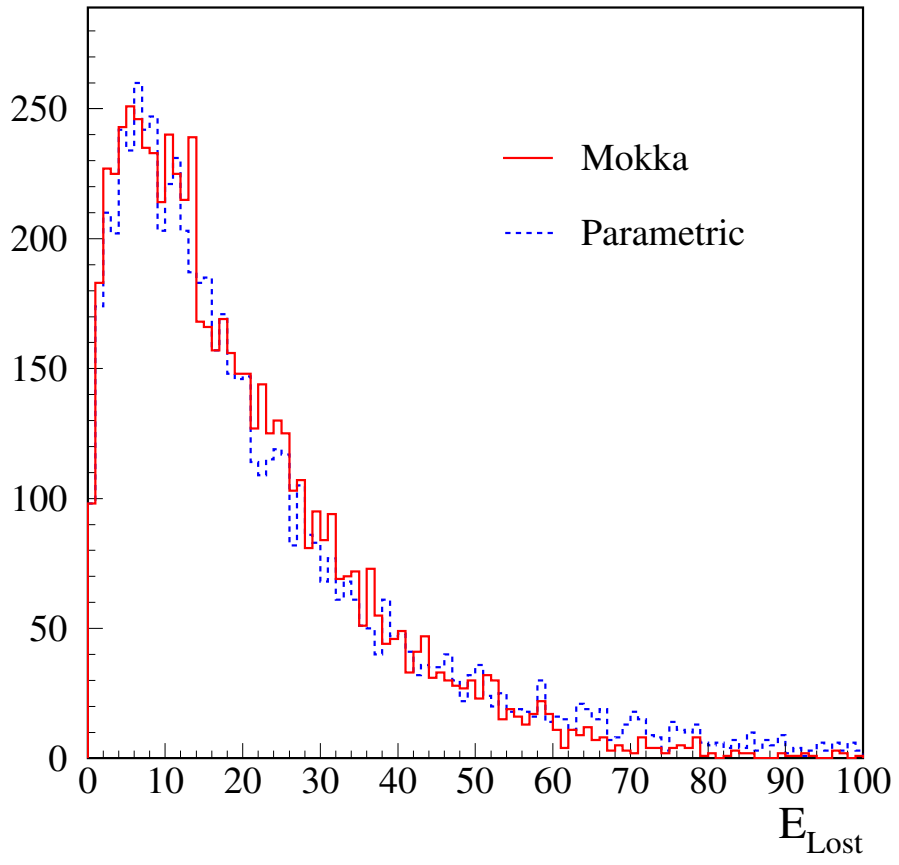

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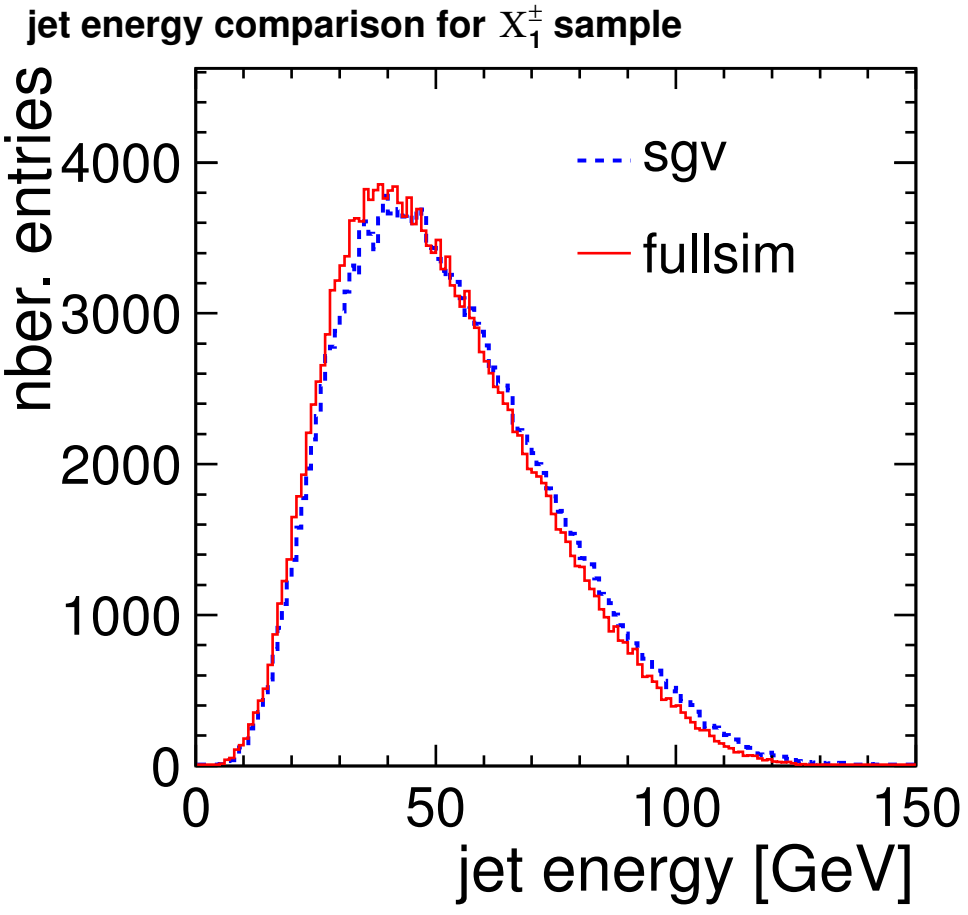

Checking the parametrisation

- Some overall distributions:
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  - Lost and double counted energy.
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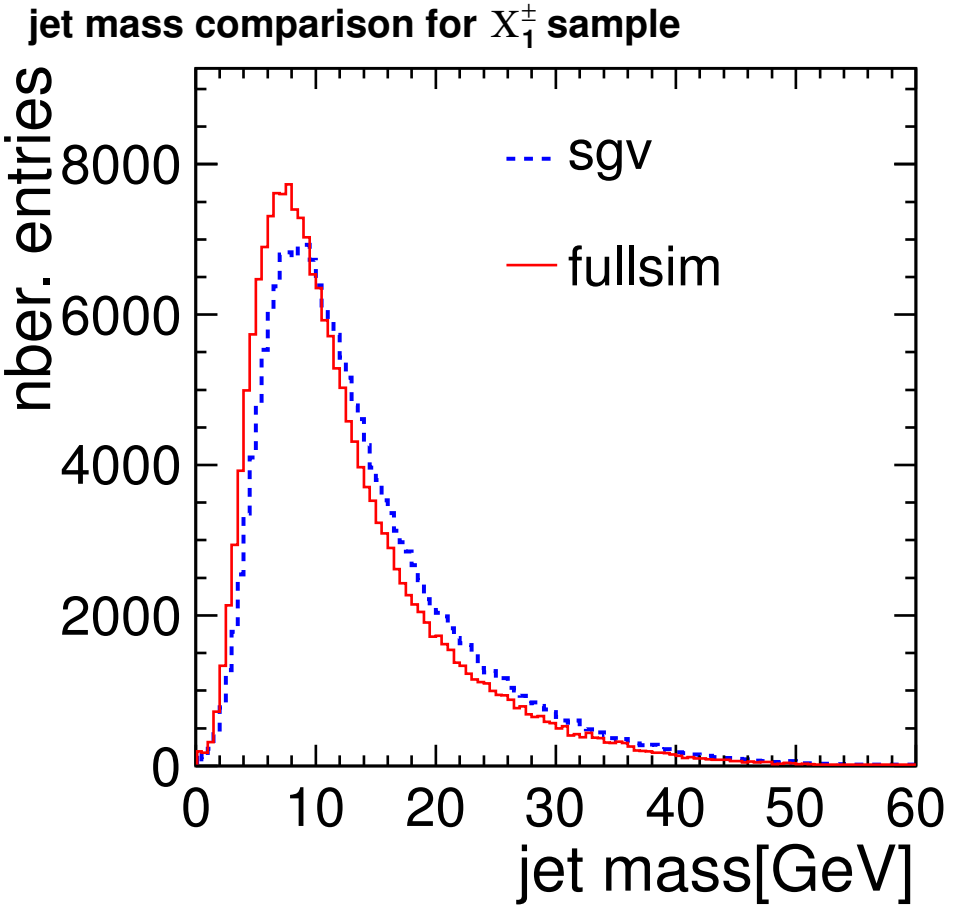

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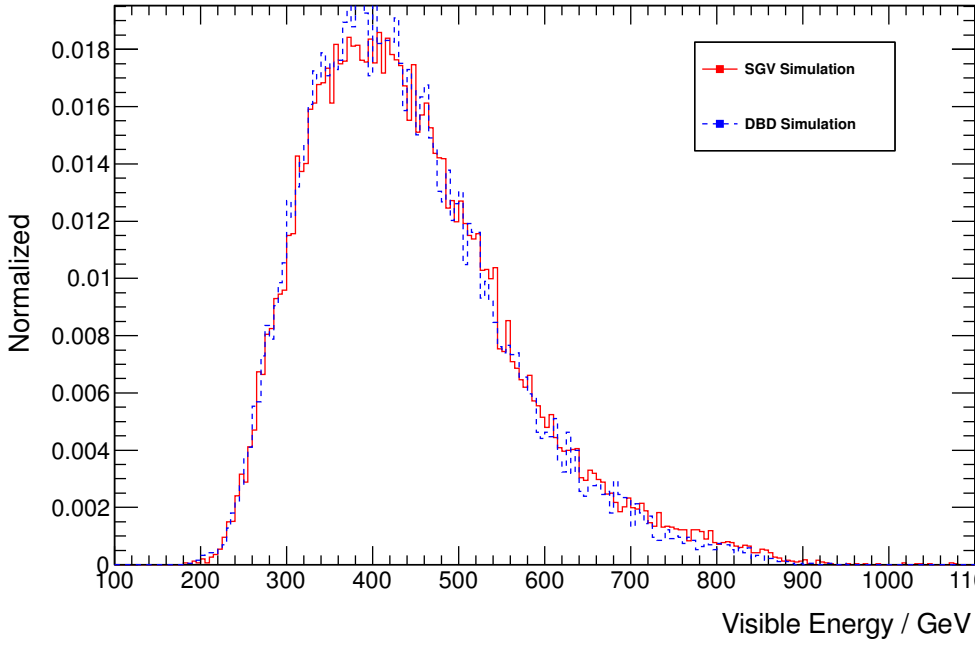

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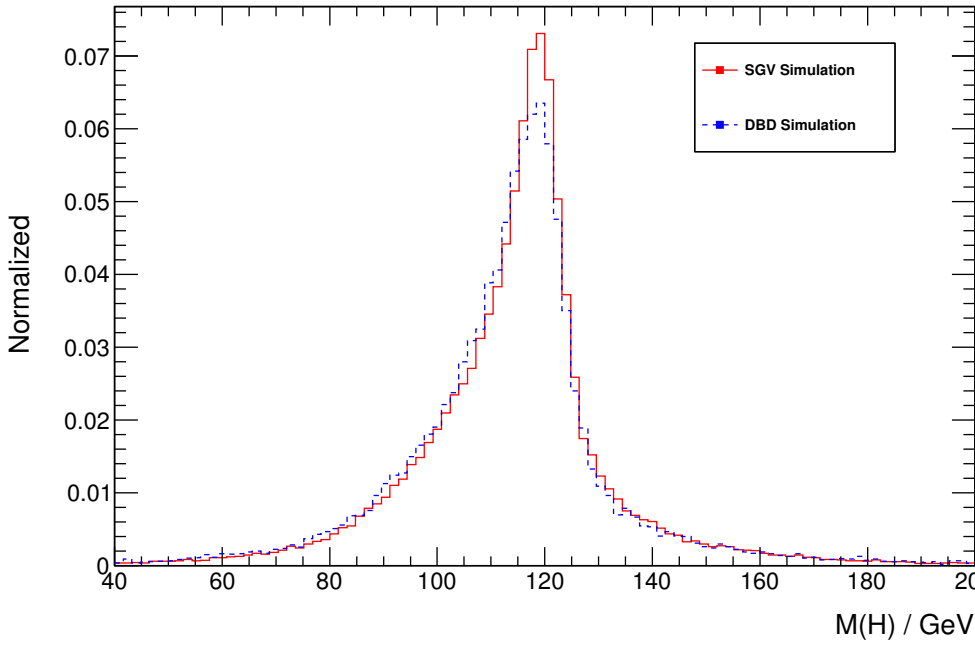

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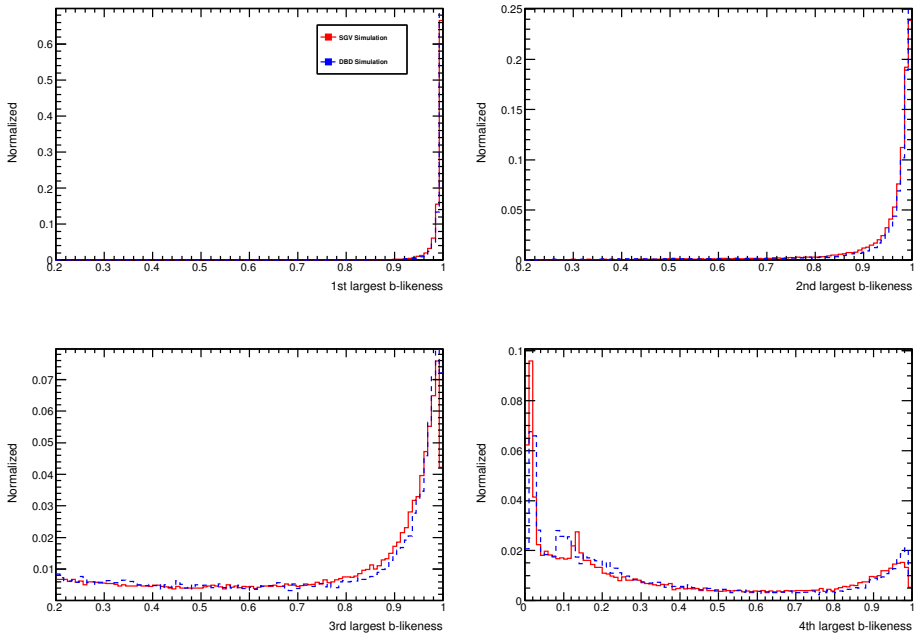
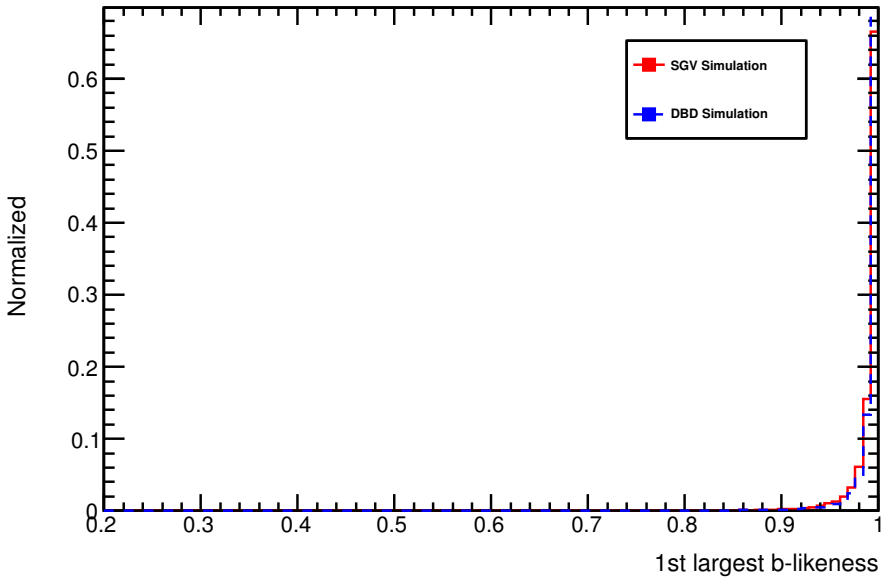
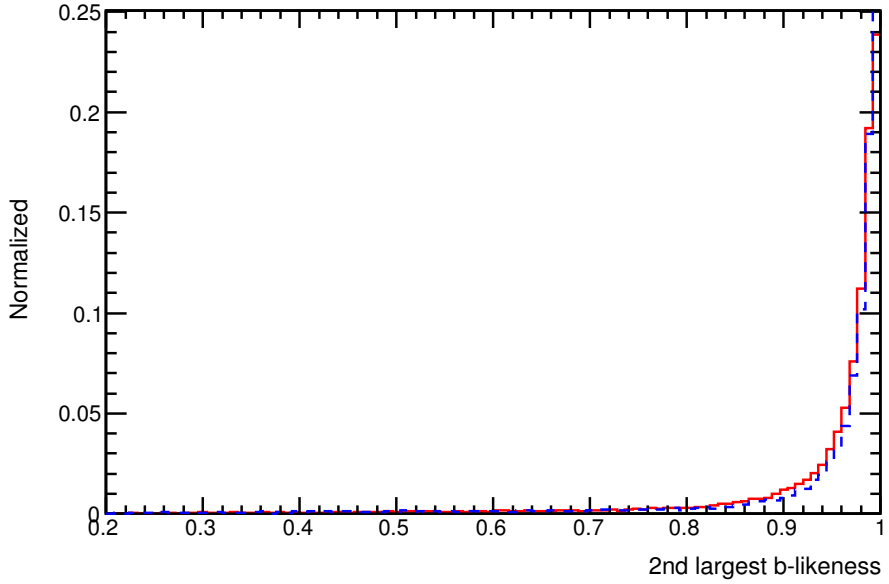
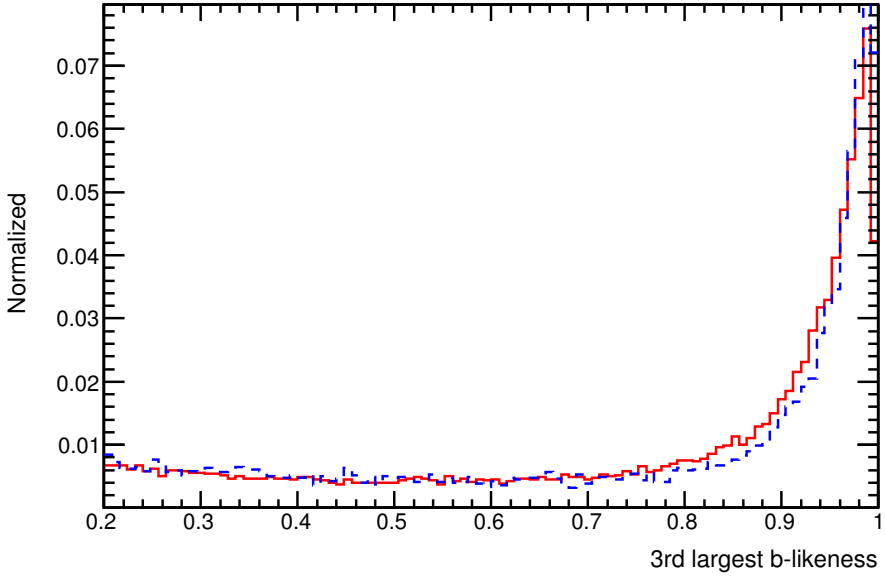
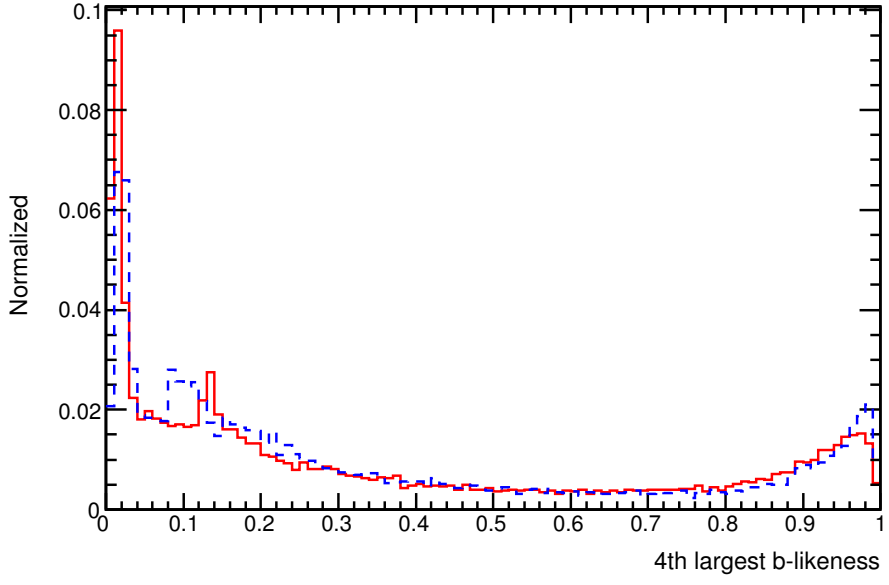


C


SGV Simulation
DBD Simulation
Normalized
1st largest b-likeness


Normalized
2nd largest b-likeness


Normalized
3rd largest b-likeness


Normalized
4th largest b-likeness

Checking the parametrisation

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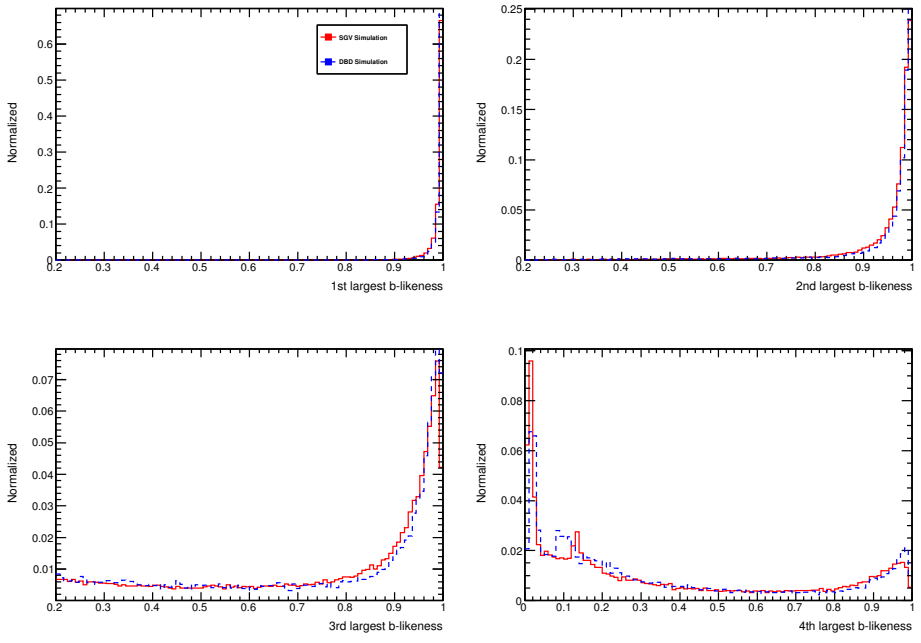

LCIO DST mass-production

SGV has been used to produce ILD DST:s for the full DBD benchmarks.

- *usesgvlcio.F95* in the *samples/lcio* directory extracts SGV data and fills all LCIO collections on the ILD DST:s
  - Clusters:
    - Are done with the Pandora confusion parametrisation on.
    - Expect $\sim$ correct dispersion of jet energy, but a few % to high central value of jet masses.
  - Navigators
    - All the navigators that the TruthLinker processor makes when all flags are switched on are created.
  - Secondary vertices:
    - Use true information to find all secondary vertices.
    - For all vertices with ≥ 2 seen charged tracks: do vertex fit.
    - Expect $\sim$ correct vertex fit-parameters, but too good vertex finding.

Mass production

- Done almost the full DBD samples - several times.
  - 34 Mevents.
  - $\sim$ 1 hour of wall-clock time (first submit to last completed) on the German NAF.
- $\gamma\gamma$ still missing: Logistics to figure out (Many thousands of input files !)

Collections

- 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.
- Consequence:
  - 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.

Outlook

- Include a filter-mode:
  - Generate event inside SGV.
  - Run SGV detector simulation and analysis.
  - Decide what to do: Fill some histos, fill ntuple, output LCIO, or better do full sim
  - In the last case: output STDHEP of event
- Update documentation and in-line comments, to reflect new structure.
- Consolidate use of Fortran 95/203/2008 features. Possibly - when gcc/gfortran 4.4 (ie. Fortran 2003) is common-place - Object Orientation, if there is no performance penalty.
  - Use of user-defined types.
  - Use of PURE and ELEMENTAL routines.
  - Optimal choice between pointer, allocatable and automatic and/or assumed-size, assumed-shape, and explicit arrays.
- I/O over FIFO:s to avoid storage and I/O rate limitations.
- The Grid.
- Investigate running on GPU:s.

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