Generating CLIC Events

From a Feynman Diagram to a CLIC Event

Marco Battaglia
UCSC and CERN

CLIC WG-1
CERN, 11 January 2011

An attempt to give a review of issues in converting fundamental physics questions into realistic observables taking into account accelerator and detector parameters through analysis and application examples;

- Not a LC software primer;
- Not a CLIC detector performance manual;
- Not a valid reference for your study and next paper;

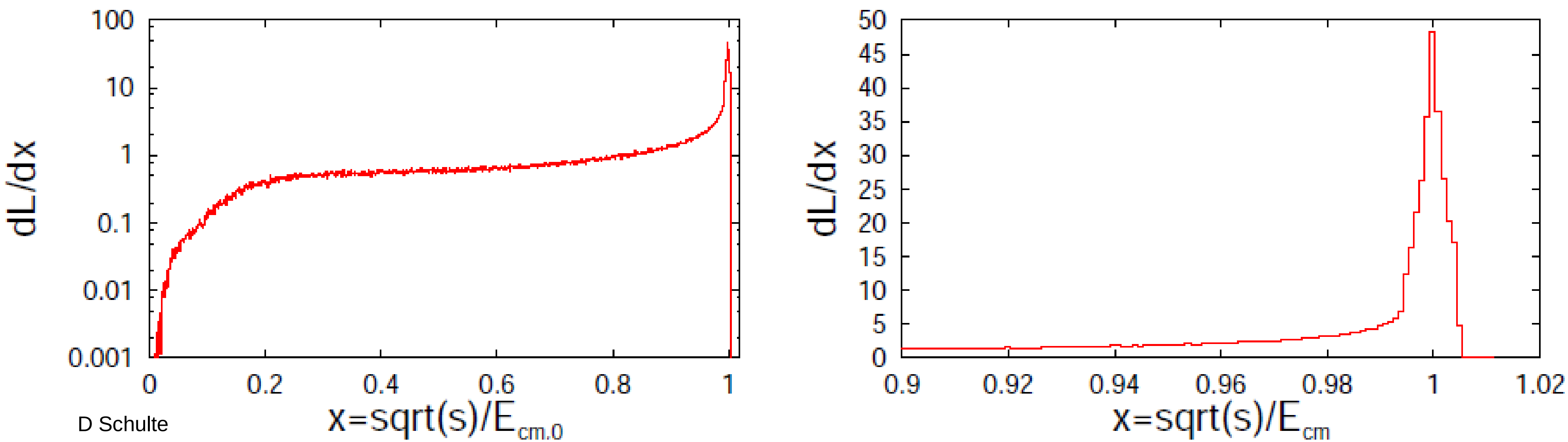
CLIC physics and detector effort organised around topical WGs (see http://lcd.web.cern.ch/LCD/Home/Organisation.html)

WG6: CLIC Detector Benchmark Studies
(http://lcd.web.cern.ch/LCD/Home/WG6.html)
(conveners: L Linssen, M Thomson, F Teubert)

Central production of events on the GRID (S. Poss, JJ Blaising et al.)

Realistic CLIC beams

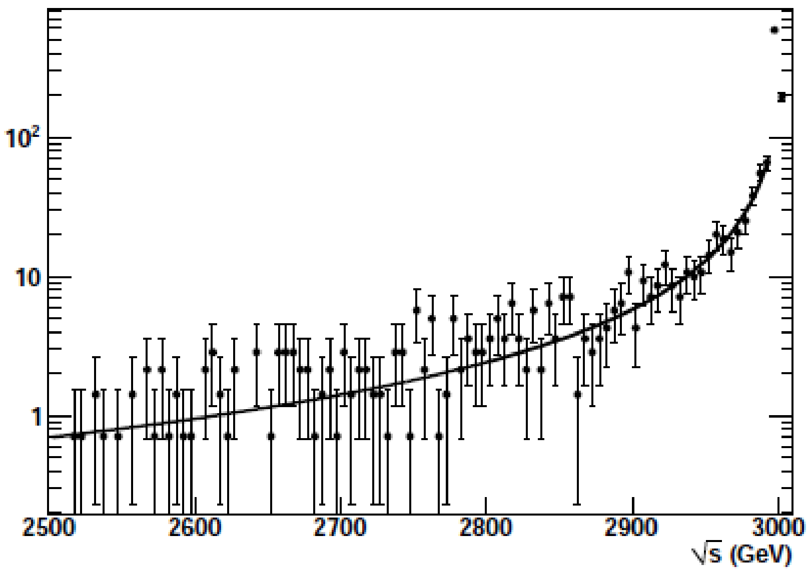
Beam-beam interactions cause radiation of incoming e+e- before annihilation:
- beamstrahlung (BS) (tail in luminosity spectrum below nominal energy)
- background particles



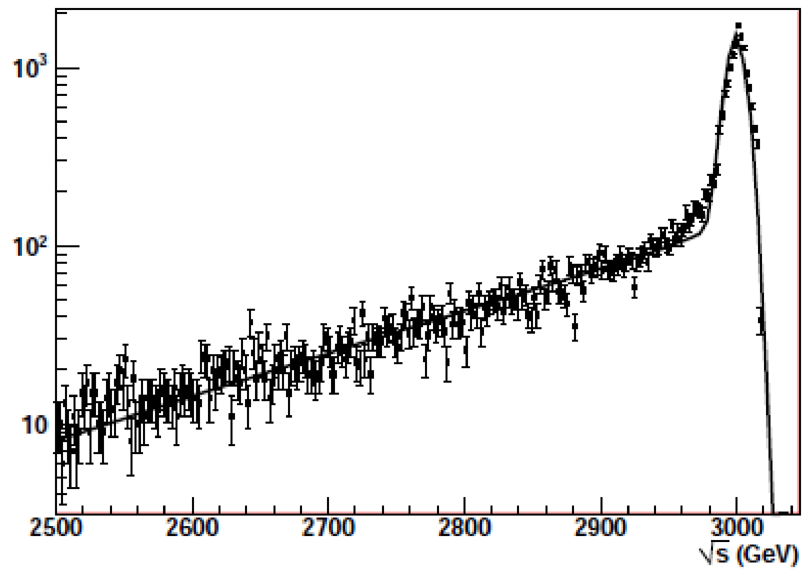
Due to beam-beam correlation, necessary to use colliding particles from GUINEA-PIG beam simulation, CALYPSO program extracts them from input file and interfaces with event generators.
Input files and interface programs available at:

http://clic-beam-beam.web.cern.ch

Realistic CLIC beams



(a) ISR



(b) Beamstrahlung

CERN-LCD-Note-2010-005

Implementing CLIC BS in Event Simulation with CALYPSO

CALYPSO interface (author: D Schulte) provides energy of colliding e+e- for event generation.

Example in PYTHIA:

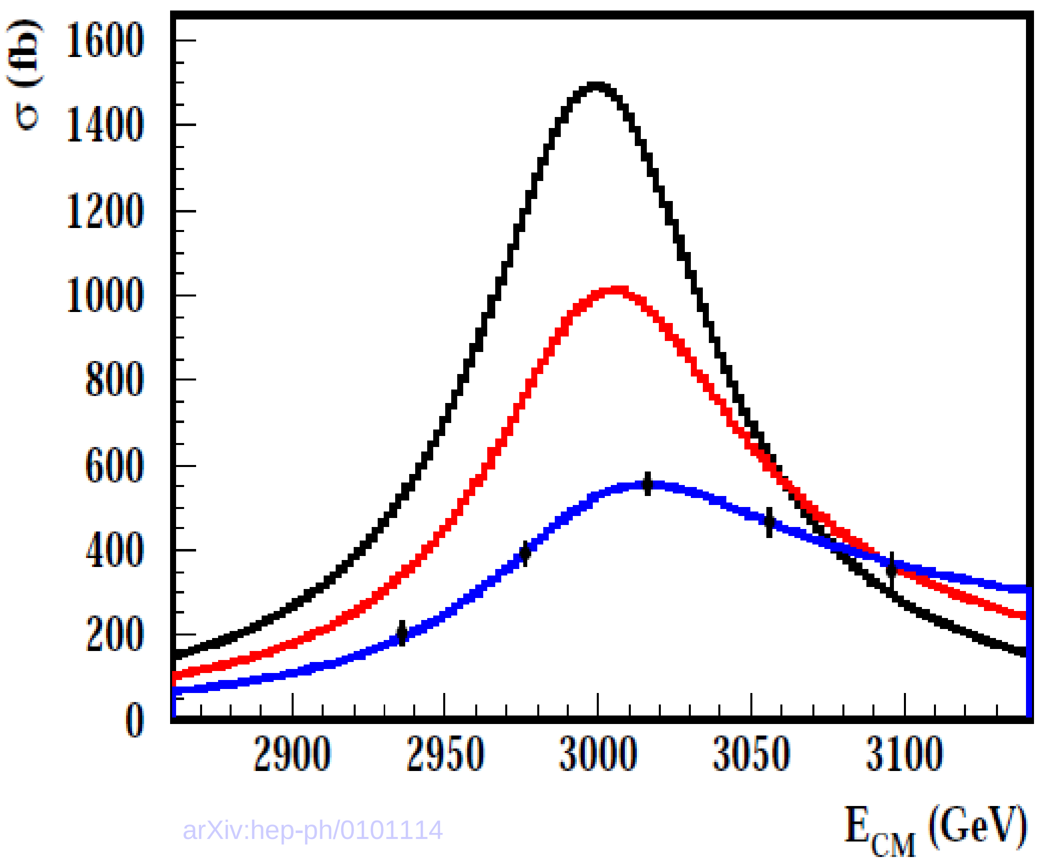
```
CALL CALYP0(lumfname,'e-','e+',1000.0,E1,E2,R)
CALL PYINIT('3MOM','e-','e+',dble(ecm))

…

* --- Event loop

CALL CALYP(E1,E2,Z,RAND)

P(1,3)=DBLE(E1)
P(2,3)=DBLE(E2)

CALL PYEVNT
```

http://clic-beam-beam.web.cern.ch

Effects of Beam Radiation

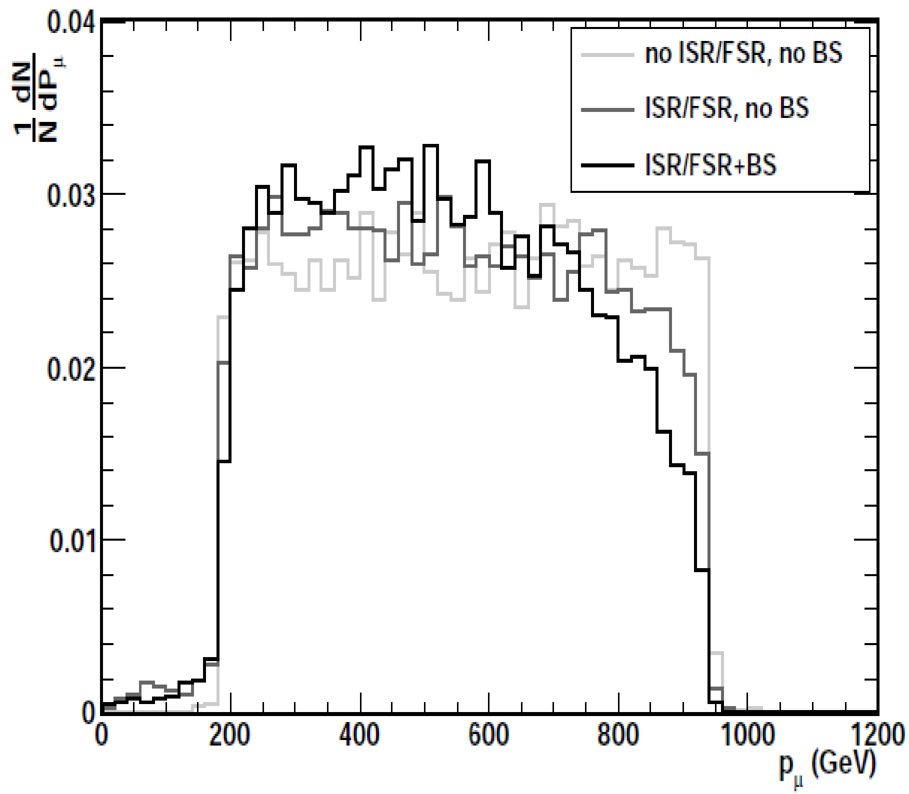
Examples of beam radiation (ISR + BS) effects on observables:

S-channel Resonance σ



arXiv:hep-ph/0101114

Sparticle kinematics

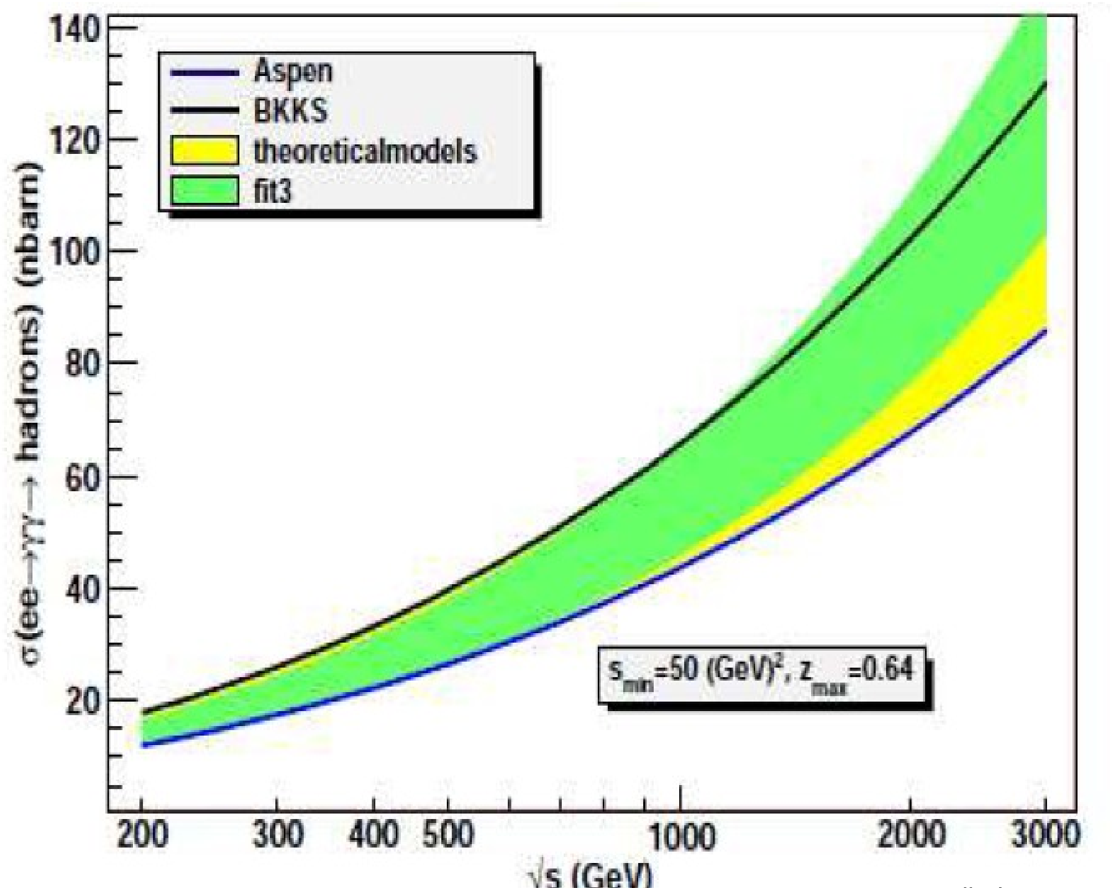


CERN-LCD-Note-2010-005

Machine-induced Backgrounds: $\gamma\gamma \rightarrow$ hadrons

gg $\rightarrow$ hadrons at 3 TeV has sizeable uncertainty on cross section, i.e. number of background events occuring per BX;

Estimates so far use one specific parametrisation, important to define range allowed by data and effect of variation of $\sigma_{\gamma\gamma}$ on event reconstruction.



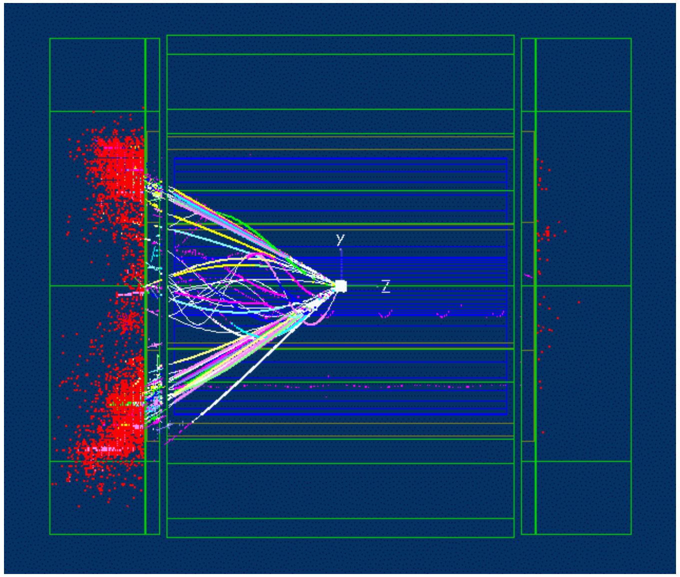
R Godbole

Machine-induced Backgrounds

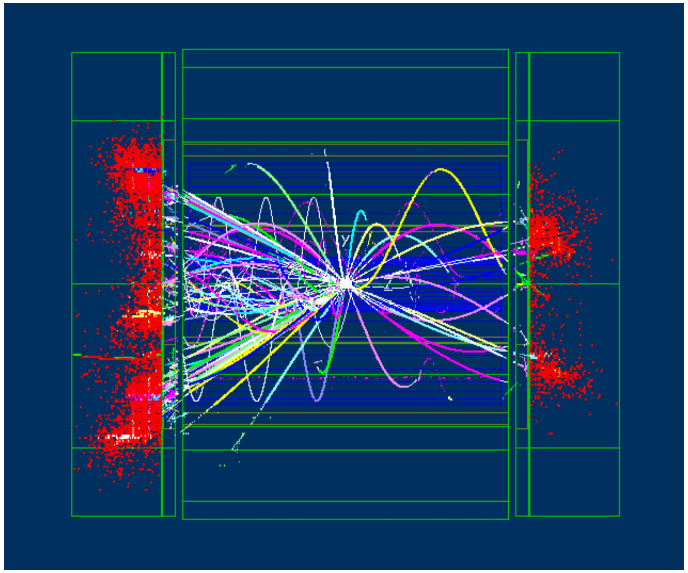
$\gamma\gamma \to$ hadrons background most important for event reconstruction due to large energy overlayed to original products of e+e- collision:

An $e^+e^- \to h^0\,\nu\nu \to bb\nu\nu$
with overlayed $\gamma\gamma \to$ hadrons

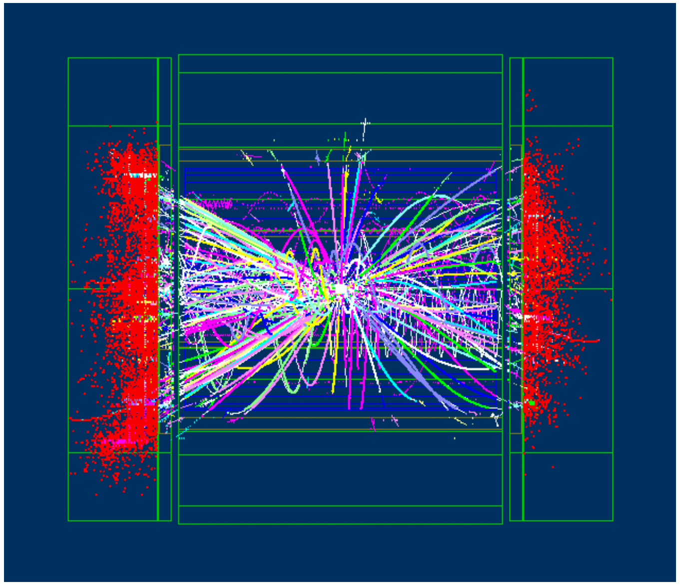
+0 BX



+ 20BX



+60BX



Overlaying Background Events in Event Simulation with HADES

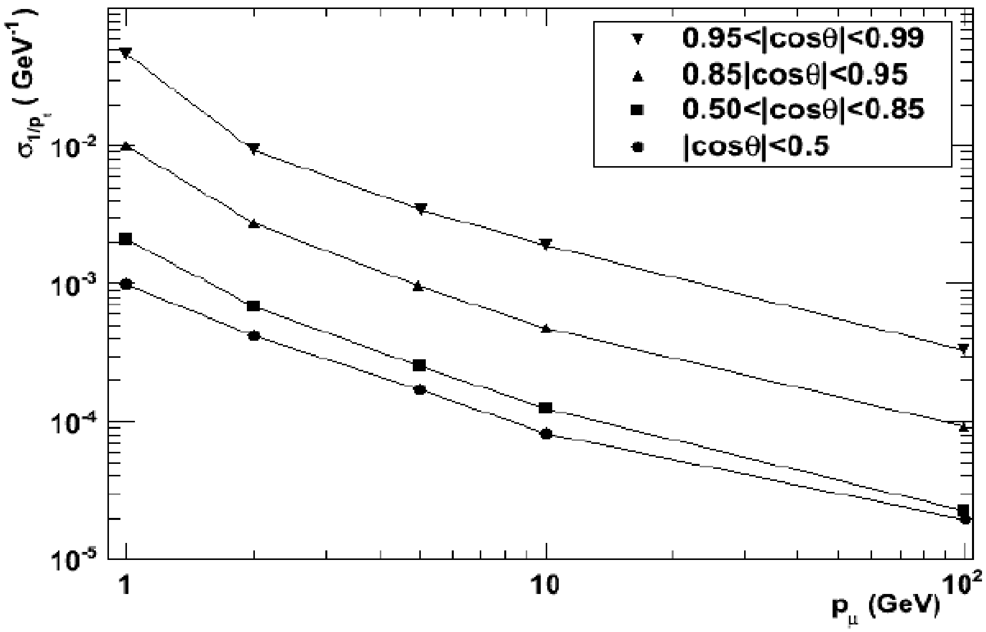
HADES interface (author: D Schulte) reads background events from file and appends particles to PYTHIA event record:

```
call hades0(iunit,bkgfname,rate,pt0,theta0,nch)

* Event loop

call hades
```

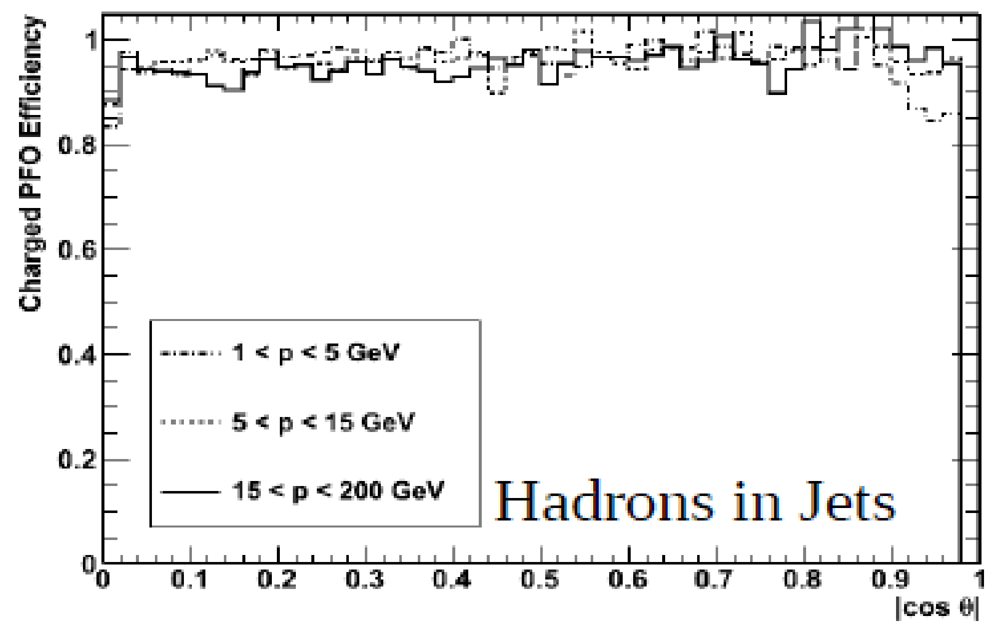
http://clic-beam-beam.web.cern.ch

Detector Effects

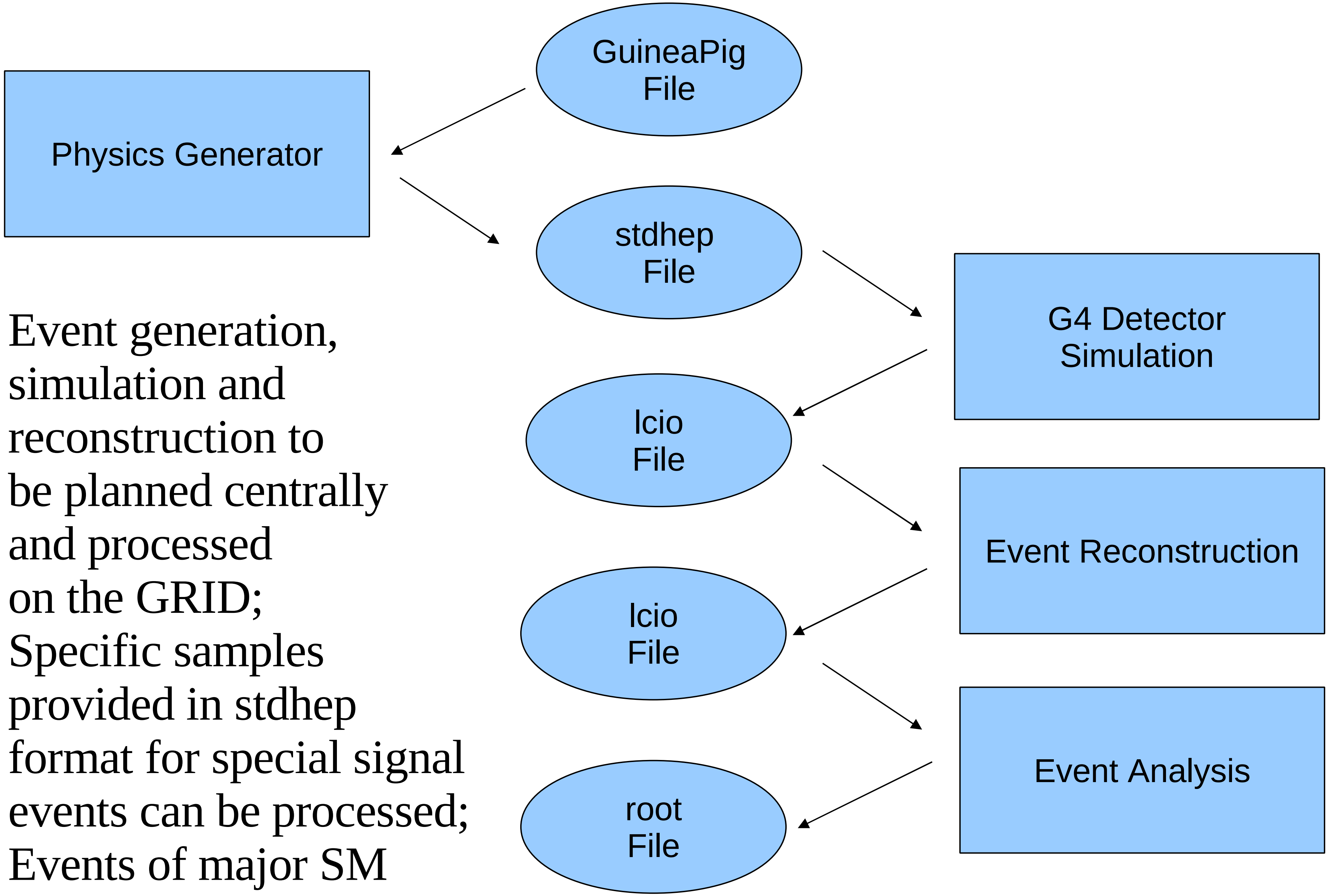
(p,E) Resolution vs p, θ



Efficiency vs p, θ

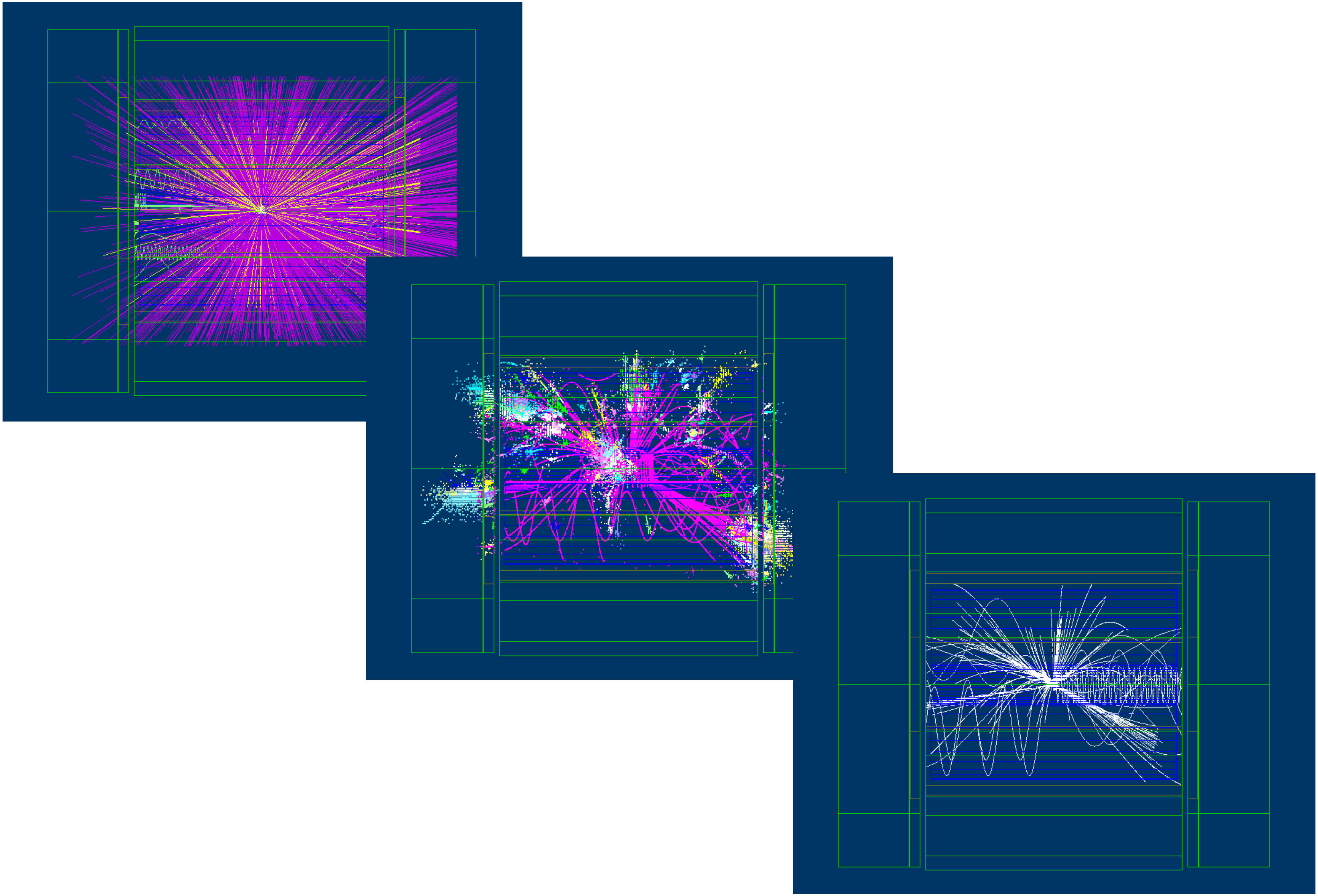


Detector Simulation Chain



Event generation, simulation and reconstruction to be planned centrally and processed on the GRID; Specific samples provided in stdhep format for special signal events can be processed; Events of major SM processes will be available.

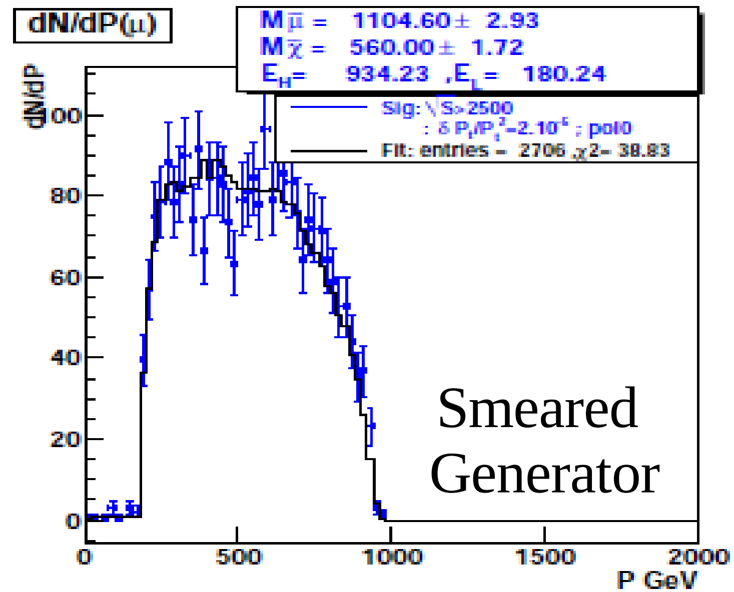
Detector Reconstruction



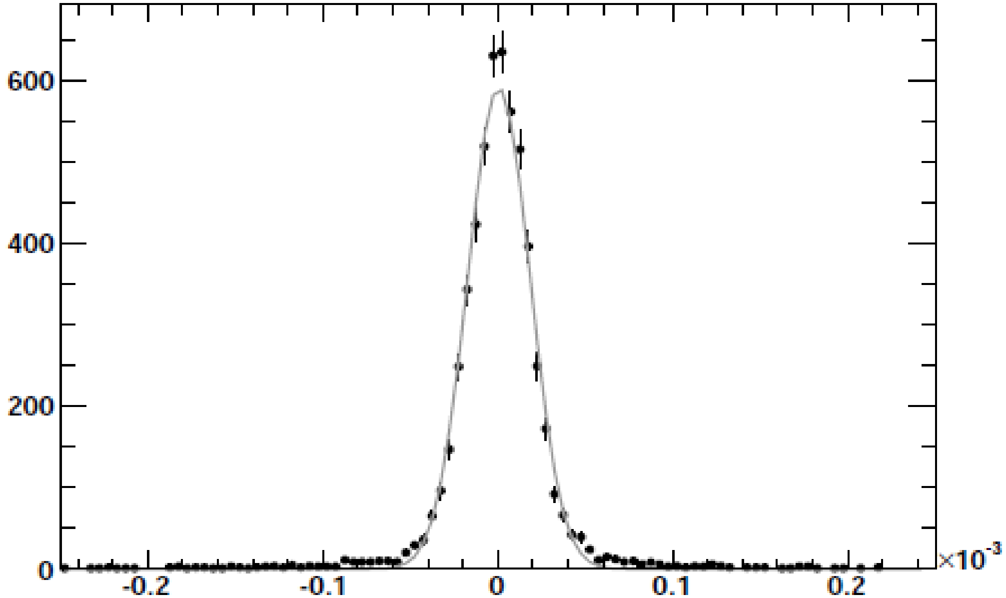
Detector Reconstruction Examples

$$e^+e^- \rightarrow \tilde{\mu}_R^+\tilde{\mu}_R^-$$

In energy spectrum of simple 2 μ final state, $\delta p_t/p_t$ smearing of generator-level p_μ spectrum gives excellent description of spectrum after full simulation and reconstruction

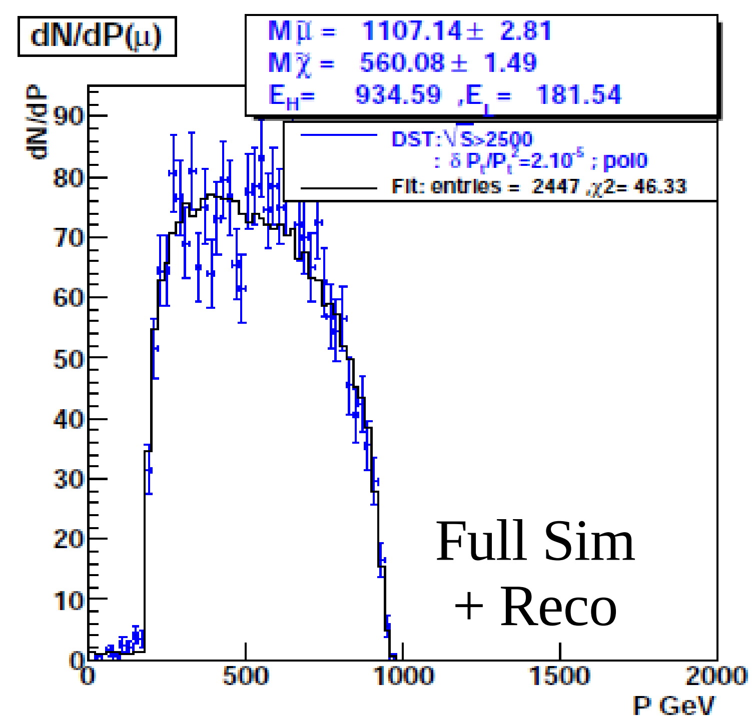


(a) $\delta p_t/{p_t}^2 = 2 \times 10^{-5}\ \mathrm{GeV}^{-1}$



CERN-LCD-Note-2010-005

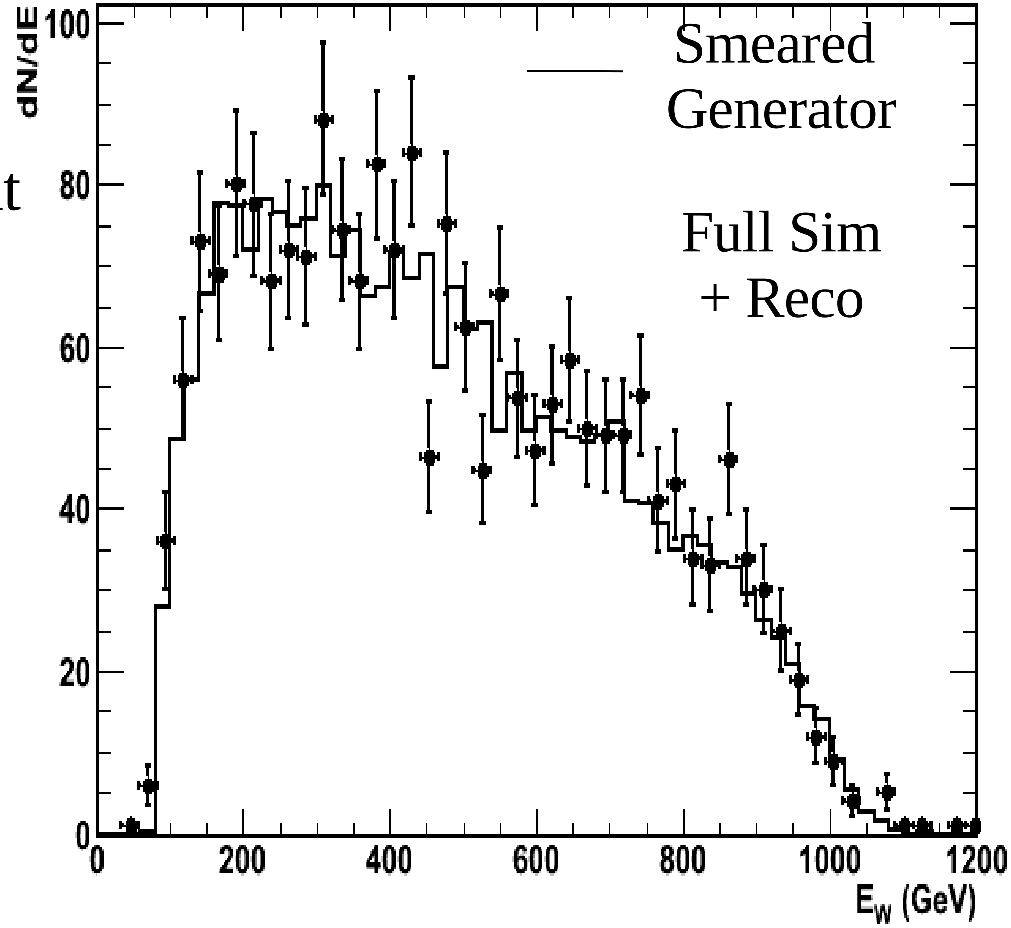
arXiv:1006.2547



Detector Reconstruction Examples

$$e^+e^- \rightarrow \chi_1^+\chi_1^- \rightarrow W^+\chi_1^0 W^-\chi_1^0;\, W \rightarrow q\bar{q}'$$

In highly constrained 2 W+$E_{missing}$ final state, $\delta E/E$ smearing of generator level E_W spectrum again gives excellent description of same spectrum after full simulation and reconstruction



Detector Reconstruction Examples

In complex hadronic events, such as e+e- $\rightarrow$ h$\nu\nu$ $\rightarrow$ bb$\nu\nu$, e+e- $\rightarrow$ H^0A^0 $\rightarrow$ bbbb, e+e- $\rightarrow$ H^+H^- $\rightarrow$ tbtb not only signal resolution but reconstruction efficiency determination requires study using detailed simulation:

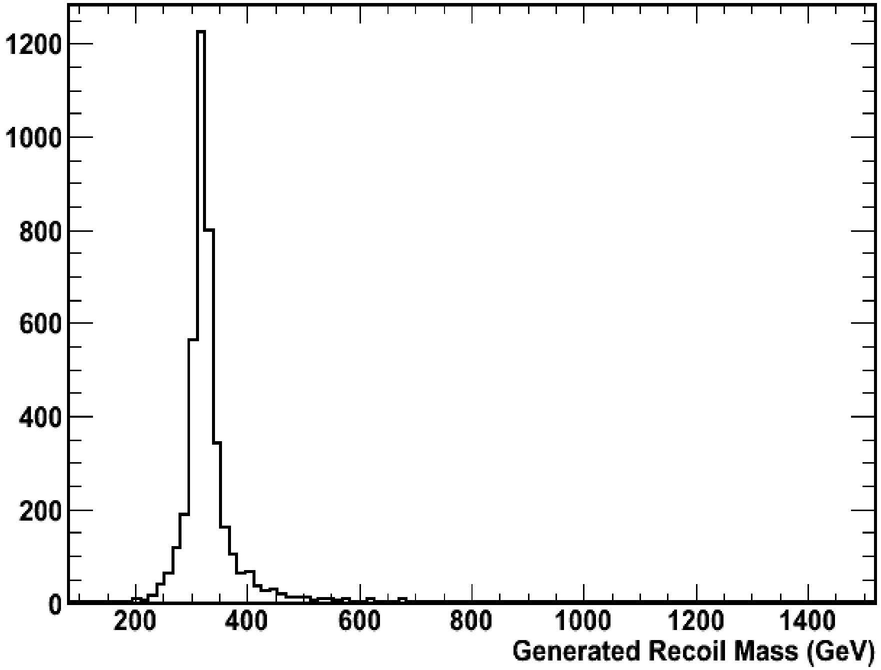
Channel	Final State	ε_{reco}
$e^+e^- \rightarrow \chi^+_1\chi^-_1 \rightarrow WW\chi^0_1\chi^0_1$	qqqq + $E_{missing}$	~0.80
$e^+e^- \rightarrow H^0A^0$	bbbb	~0.20
$e^+e^- \rightarrow H^+H^- \rightarrow tbtb$	bqqbbqqb	~0.07

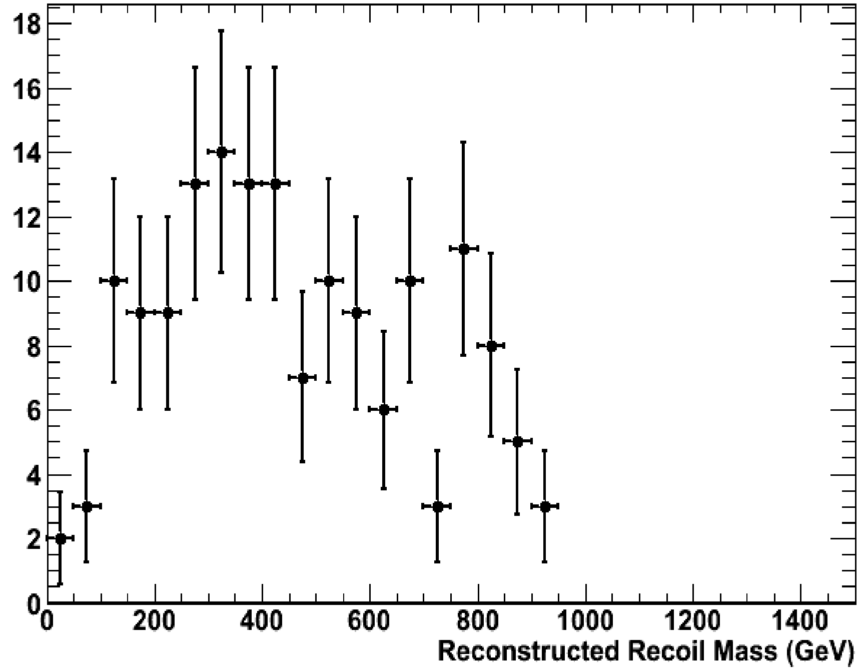
Detector Reconstruction Examples

Combination of beamstrahlung and energy resolution for complex hadronic final states may hinder the use some kinematic observables.

An example:

tt Recoil Mass in e+e- → ttZ' → ttN1N1 at 3 TeV





Analysis of Reconstructed Events

Result of event reconstruction is a collection of lcio objects, named ReconstructedParticle

Documentation at :

http://lcio.desy.de/v01-51/doc/doxygen_api/html/classEVENT_1_1ReconstructedParticle.html

Example of retrieving info on reco particle:

```
for(int iP = 0; iP < recoPtcColl->getNumberOfElements(); iP++){

  ReconstructedParticle * thisRecoPtc =
dynamic_cast<ReconstructedParticle*>(recoPtcColl-> getElementAt(iP));

   Energy = thisRecoPtc->getEnergy();
   Mass = thisRecoPtc->getMass();
   ...
}
```

ReconstructedParticle has link to original generated MCParticle:

```
MCParticle * thisMCPtc = getMCParticle(thisRecoPtc, relColl);
```

Analysis of Reconstructed Events

Large set of advanced event reconstructed tools available from the ILC studies and under constant development for ILC+CLIC:

<u>Event Reconstruction Tools</u>

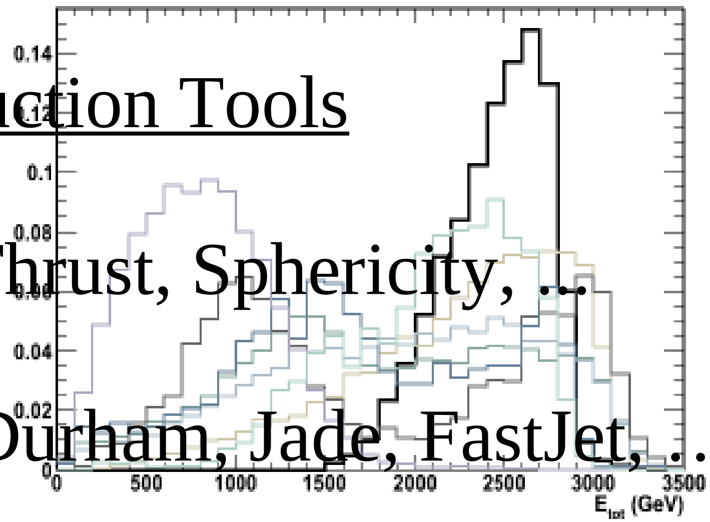
Event Shapes: Thrust, Sphericity, ...

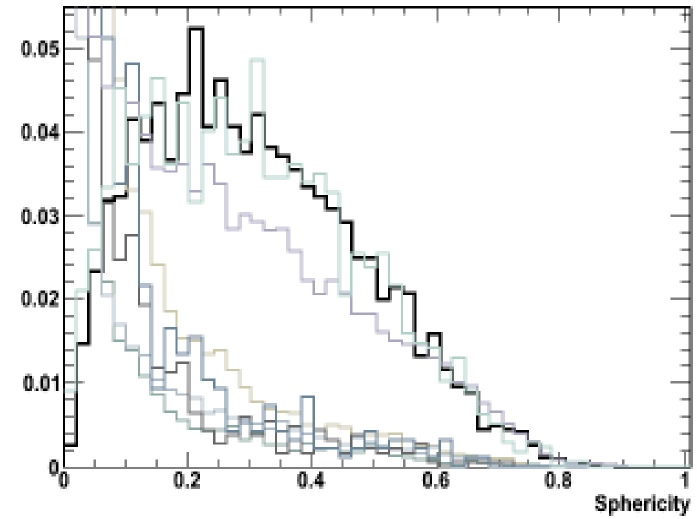
Jet Clustering: Durham, Jade, FastJet, …

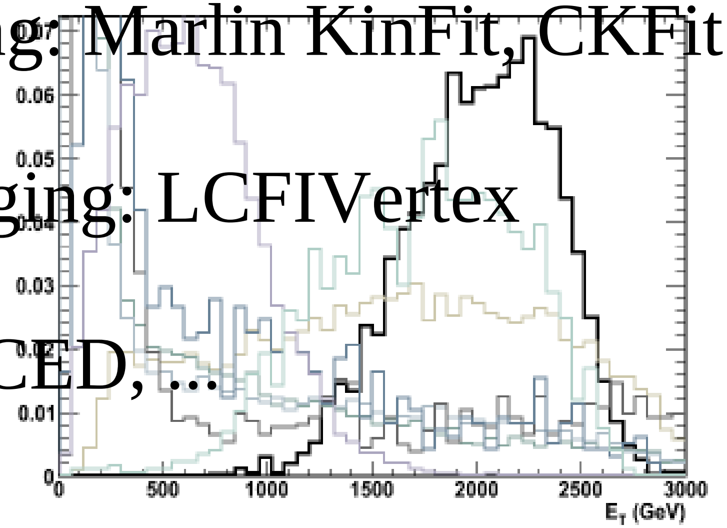
Kinematic Fitting: Marlin KinFit, CKFit

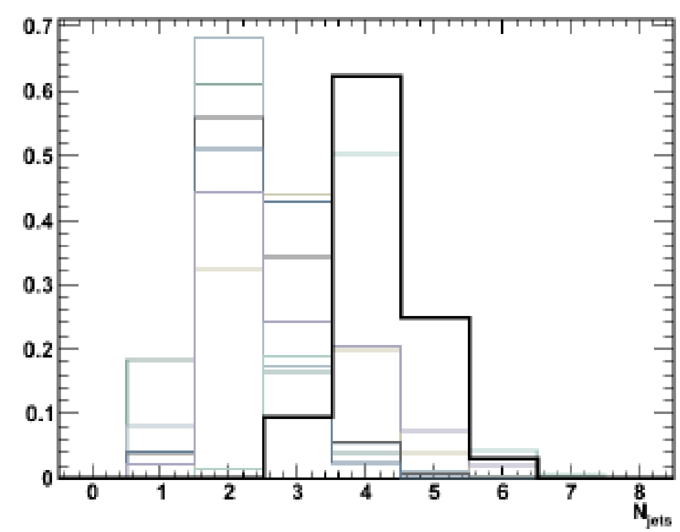
Jet Flavour Tagging: LCFIVertex

Event Display: CED, ...









Tuple Analysis

After event analysis values of observables of interest per event, jet, particle saved to ROOT tuple for final analysis and histogramming;

Tuples can be produced for various data sets (signal & bkg), with various analysis methods (fixed nb of hadronic jets and/or leptons, kin fitting, …) and analysed to extract quantities of interest. Reconstructed observables have values at generator level to estimate detector effects.

Useful to have std ntuples ?

```
*Baskets :       65 : Basket Size=      32000 bytes  Compression= 124.58     *
*............................................................................*
*Br   25 :jet2Vector : jet2Vector[10][2]/F                                    *
*Entries :     6382 : Total  Size=     512472 bytes  File Size  =     297250 *
*Baskets :       16 : Basket Size=      32000 bytes  Compression=   1.72     *
*............................................................................*
*Br   26 :jet2MCVector : jet2MCVector[6][2]/F                                 *
*Entries :     6382 : Total  Size=     307680 bytes  File Size  =     221897 *
*Baskets :       10 : Basket Size=      32000 bytes  Compression=   1.38     *
*............................................................................*
*Br   27 :jet2ParentVector : jet2ParentVector[3][2]/F                         *
*Entries :     6382 : Total  Size=     154123 bytes  File Size  =      19224 *
*Baskets :        5 : Basket Size=      32000 bytes  Compression=   7.99     *
*............................................................................*
*Br   28 :jet2ZVTOPVector : jet2ZVTOPVector[7][2]/F                           *
*Entries :     6382 : Total  Size=     358986 bytes  File Size  =       2951 *
*Baskets :       12 : Basket Size=      32000 bytes  Compression= 121.45     *
```

Outlook

Path from generator-level quantities to realistic observables accounting for beam physics and detector effects critically depends on observables of interest and topology of event;

Beam effects can be included at generator level using packages and data provided by the CLIC machine group (see http://clic-beam-beam.web.cern.ch)

In some cases BS+ISR and smearing of (p,E) of partons give an acceptable approximation of observables after full convolution of detector effects...

.. but often does not and reconstruction efficiency should always be checked, possibly on full simulation, as it scales with complexity of events;

Significant effort in the LCD group on simulation and reconstruction of large samples of events for SM and benchmark processes: opportunity for dedicated study of specific signals.

Most studies possible at the tuple level from fully reconstructed events: interesting opportunity to perform realistic analyses without overhead of production, event reconstruction and physics observable reconstruction.