Benchmarking SiD

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SiD meeting in Paris, 11 Feb 2008

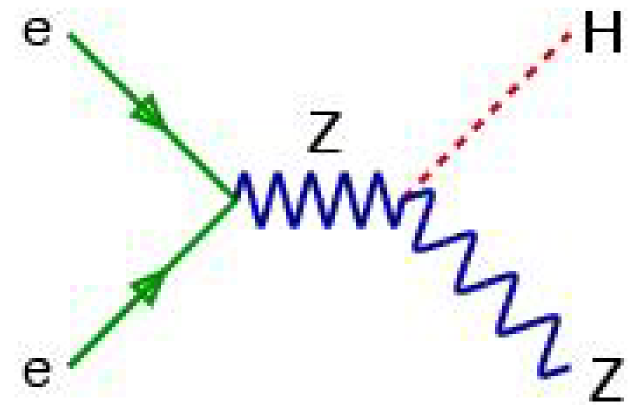
Physics at LC

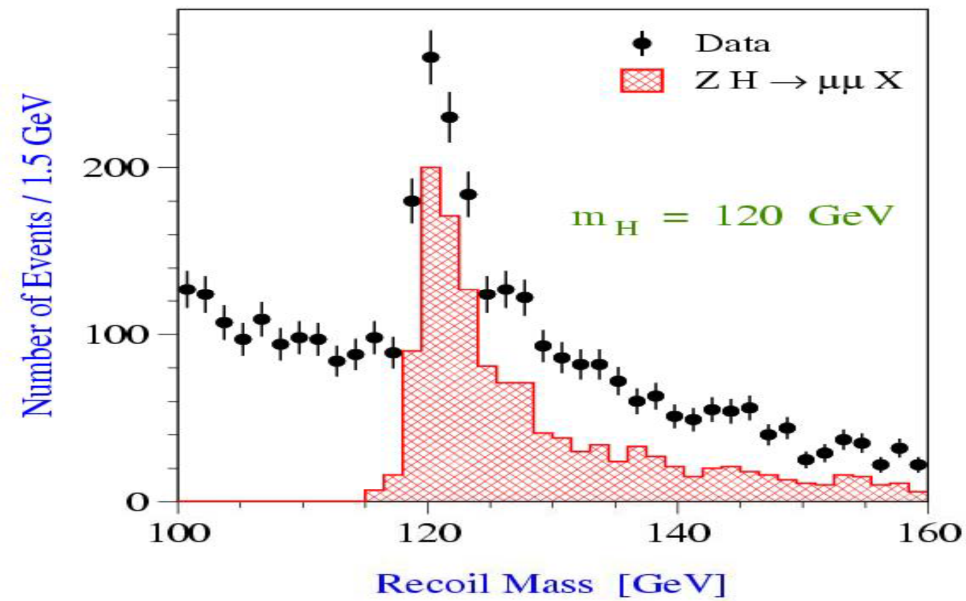
- Emphasis on
  - Higgs properties
  - Precision of measurements
  - SUSY parameters

But many other things are interesting and important

ZH

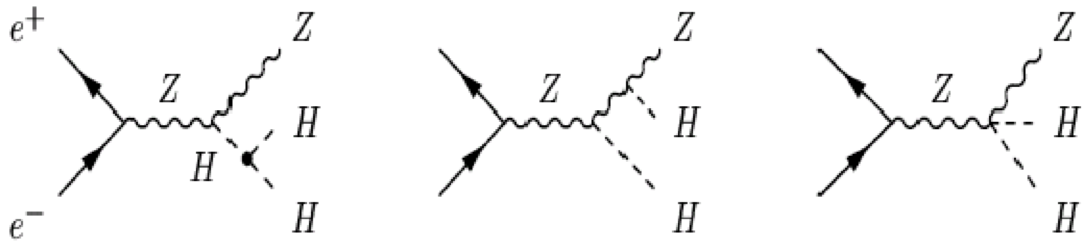
- Higgs:
  - Higgs can be reconstructed through recoil mass independently of its decay channel
  - Even for invisible decays





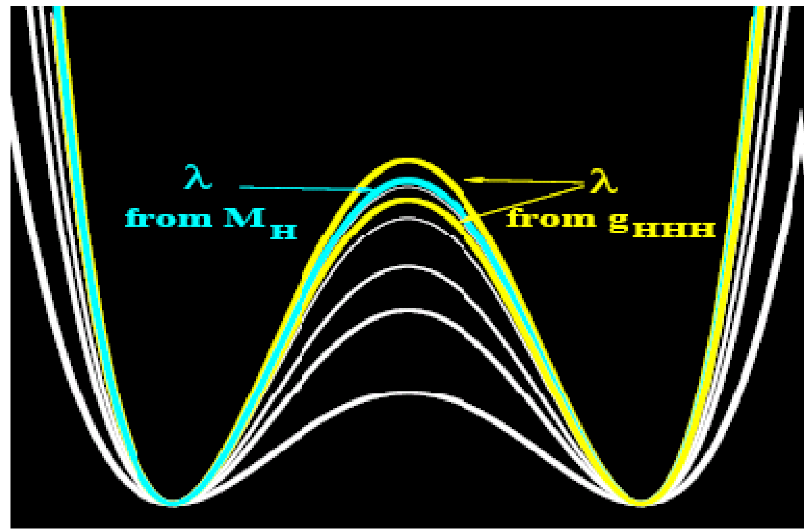
ZHH

Double Higgstrahlung: $e^+e^- \rightarrow H^0 H^0 Z^0$



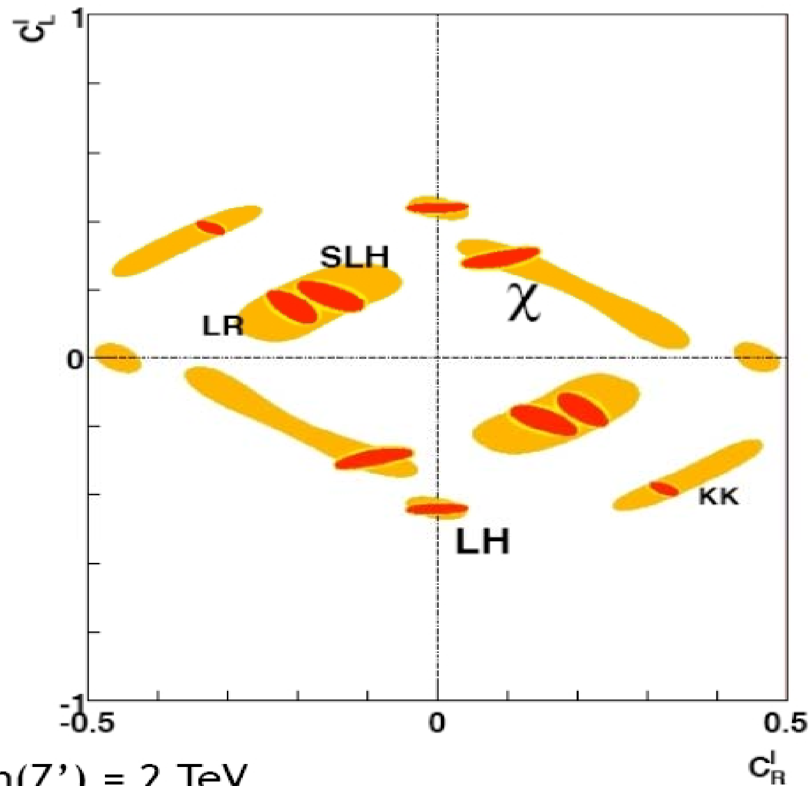
- Key to understanding of Higgs potential – mechanism of symmetry breaking

- Low xsection/ Large SM backgrounds
  - 0.2 fb HZZ vs 500 fb tt
- 4 b-jets in final state



Precision

- Precision measurements of A_{LR} and A_{FB} allows to distinguish between models: Little Higgs, Simplest Little Higgs, E_6, KK excitations, LR-symmetric

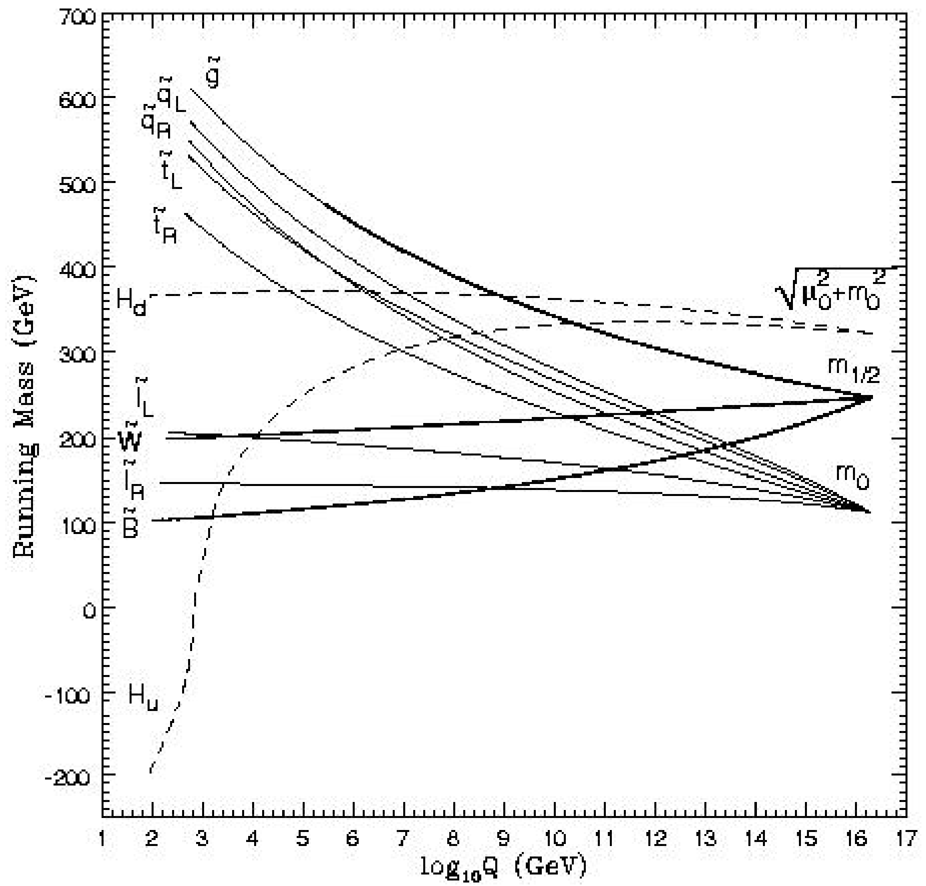


500 GeV, m(Z') = 2 TeV
1 ab-1, $e^+e^- \to \mu^+\mu^-$

Godfrey, Kalyniak, Tomkins

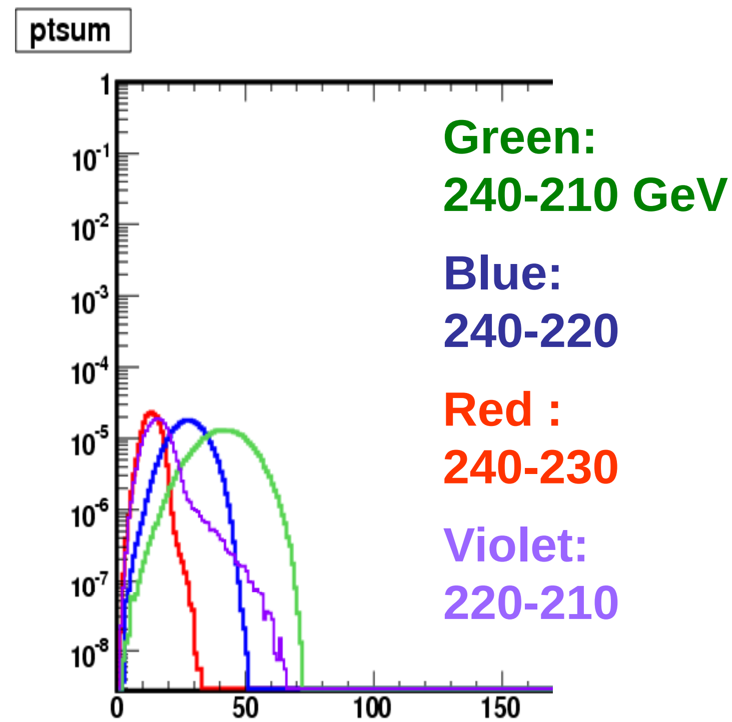
Supersymmetry

- Rich phenomenology
  - Mass spectrum and couplings are determined by several high mass scale parameters
  - They also define decay modes of SUSY particles → signatures
- Huge variety of signatures!



Cosmology Motivated SUSY Scenarios

- Dark Matter is 25% of Universe – how to explain?
- In SUSY : small mass split between LSP and NLSP = small visible energy in the detector
  - ee → stops, sbottoms, staus
  - Important case to motivate the massless Tracker with zero P_T cutoff
- Large two –photon backgrounds
  - Need to veto electron/positron in forward systems



Small mass split of sbottom and neutralino produce soft particles – difficult to track and to tag

From Physics Studies to Benchmarking

- Emphasis of physics studies will shift towards
  - Evaluation and comparison of detector choices
  - Realities required by engineering: material (amount and distribution)
  - Realities required by reconstruction algorithms: tracking & PFA

Compulsory LOI Benchmarking List

At a Dec 7 meeting between Sakue Yamada and representatives of SiD, ILD, 4th Concept, an agreed that the following reactions will be used for LOI Physics Benchmarking:

1. $e^+e^- \to Zh, \to \ell^+\ell^- X, l = e, \mu;\ \ m_h = 120$ GeV at $\sqrt{s}$=0.25 TeV

2. $e^+e^- \to Zh,\ Z \to q\bar{q}, \nu\bar{\nu};\ \ h \to c\bar{c},\ \mu^+\mu^-;\quad m_h = 120$ GeV at $\sqrt{s}$=0.25 TeV

3. $e^+e^- \to \tau^+\tau^-$, at $\sqrt{s}$=0.5 TeV

4. $e^+e^- \to t\bar{t}$ at $\sqrt{s}$=0.5 TeV

5. $e^+e^- \to \tilde{\chi}_1^+\tilde{\chi}_1^- / \tilde{\chi}_2^0\tilde{\chi}_2^0 \to W^+W^-\tilde{\chi}_1^0\tilde{\chi}_1^0$ / $ZZ\tilde{\chi}_1^0\tilde{\chi}_1^0$ at $\sqrt{s}$=0.5 TeV

N.B.: The physics observables that are to be measured have not yet been determined.

Additional SiD Benchmarking Studies for LOI

6. $e^+e^- \to c\bar{c}, b\bar{b}$, at $\sqrt{s}$=0.5 TeV;

   $A_{FB}^{LR}(c)$ & $A_{FB}^{LR}(b)$

7. $e^+e^- \to Zhh$, $m_h = 120$ GeV at $\sqrt{s}$=0.5 TeV;

   g_{hhh}

8. $e^+e^- \to \tilde{\tau}_1\tilde{\tau}_1$, at Point 3 at $\sqrt{s}$=0.5 TeV;

   $M_{\tilde{\tau}_1}$ $\sigma(e^+e^- \to \tilde{\tau}_1\tilde{\tau}_1)$

9. $e^+e^- \to \tilde{t}_1\tilde{t}_1^* \to c\bar{c}\tilde{\chi}_1^0\tilde{\chi}_1^0$, $m_{\tilde{t}_1} = 120$ GeV, $m_{\tilde{\chi}_1^0} = 100$ GeV, at $\sqrt{s}$=0.5 TeV

   $M_{\tilde{t}_1}$, $\sigma(e^+e^- \to \tilde{t}_1\tilde{t}_1^*)$, $\cos\theta_{\tilde{t}}$

10. $e^+e^- \to \tilde{b}_1\tilde{b}_1^* \to bb\tilde{\chi}_1^0\tilde{\chi}_1^0$, at $\sqrt{s}$=0.5 TeV

    $M_{\tilde{b}_1}$, $\sigma(e^+e^- \to \tilde{b}_1\tilde{b}_1^*)$

11. $e^+e^- \to \mu^+\mu^-$, at $\sqrt{s}$=0.5 TeV

    Luminosity Weighted $\sqrt{s}$

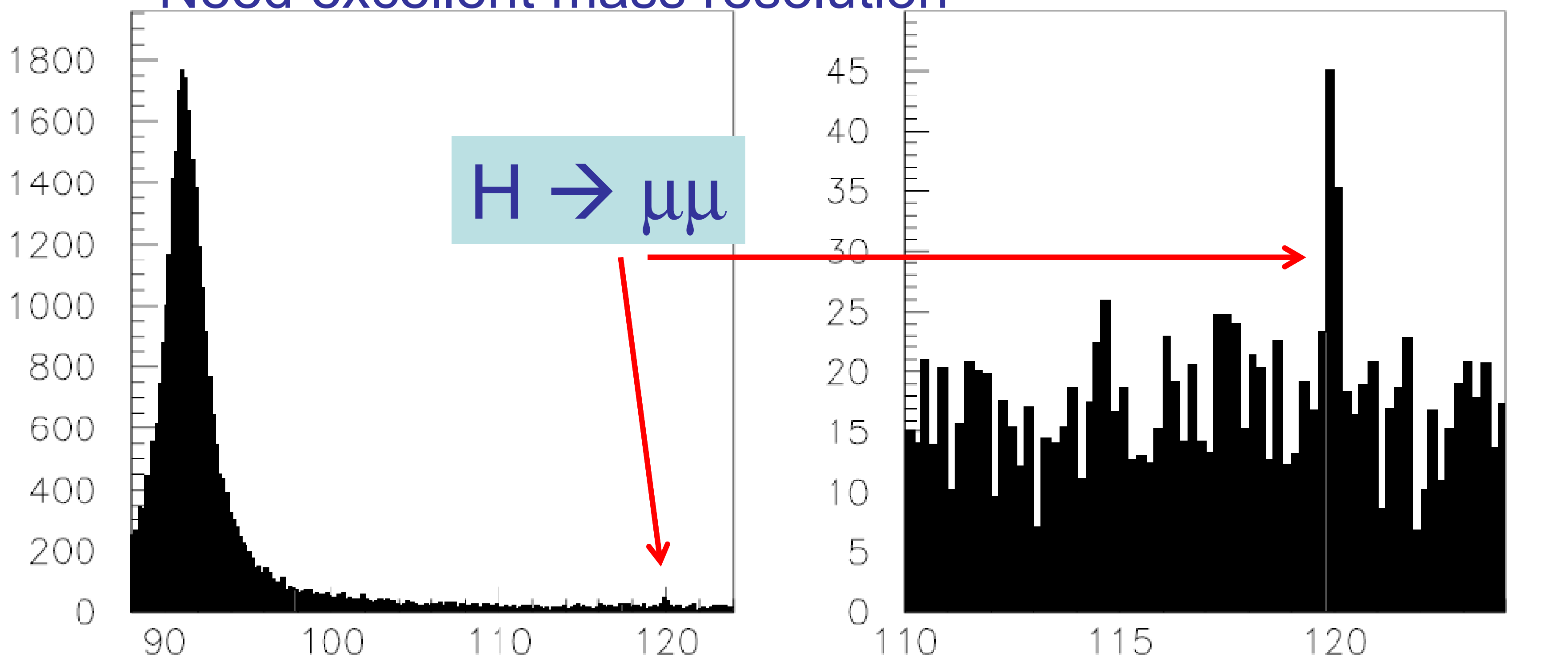
12. H→ γγ

Benchmarking Processes

- Compulsory and additional processes will allow to benchmark subsystems
  - Vertexing
  - Tracking
  - EM and HAD Calorimetry
  - Muon system
  - Forward system
- and to compare SiD to other concepts

H→μμ

- One of important Higgs Br
- $M_{\mu\mu}$ distributions for NN>0.95 for signal and background summed
  - Need excellent mass resolution



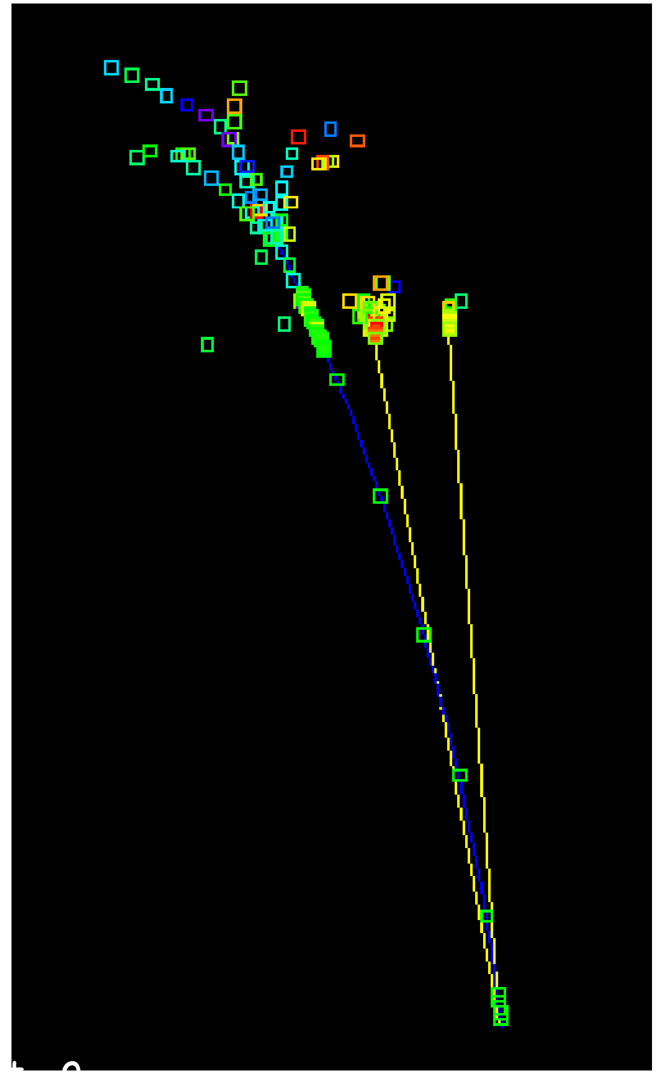
$a = 2\times10^{-5}$

$b = 1\times10^{-3}$

$$\frac{\delta p_t}{p_t^2} = a \oplus \frac{b}{p_t \sin\theta}$$

Importance of π^0

- $H \rightarrow \tau\tau$ process
- Tau polarization (from $\tau \rightarrow \rho\nu \rightarrow \pi^+\pi^o\nu$) allows to determine CP properties of Higgs
- Separation of clusters and reconstruction of π^o requires excellent segmentation of EMCAL (MAPS EMCAL)
- Also : using π^0 to constrain the vertex mass → improvements in b-tagging



Tools for Benchmarking

Java based lcsim.org framework

- lcsim.org FastMC
  - Smeared MC informaiton
- lcsim.org full MC: SLIC
  - GEANT based
- Perfect PFA

- Vertexing / Flavour tagging : LCFI package

- Track reconstruction and Full PFA – ready soon

Analysis Model

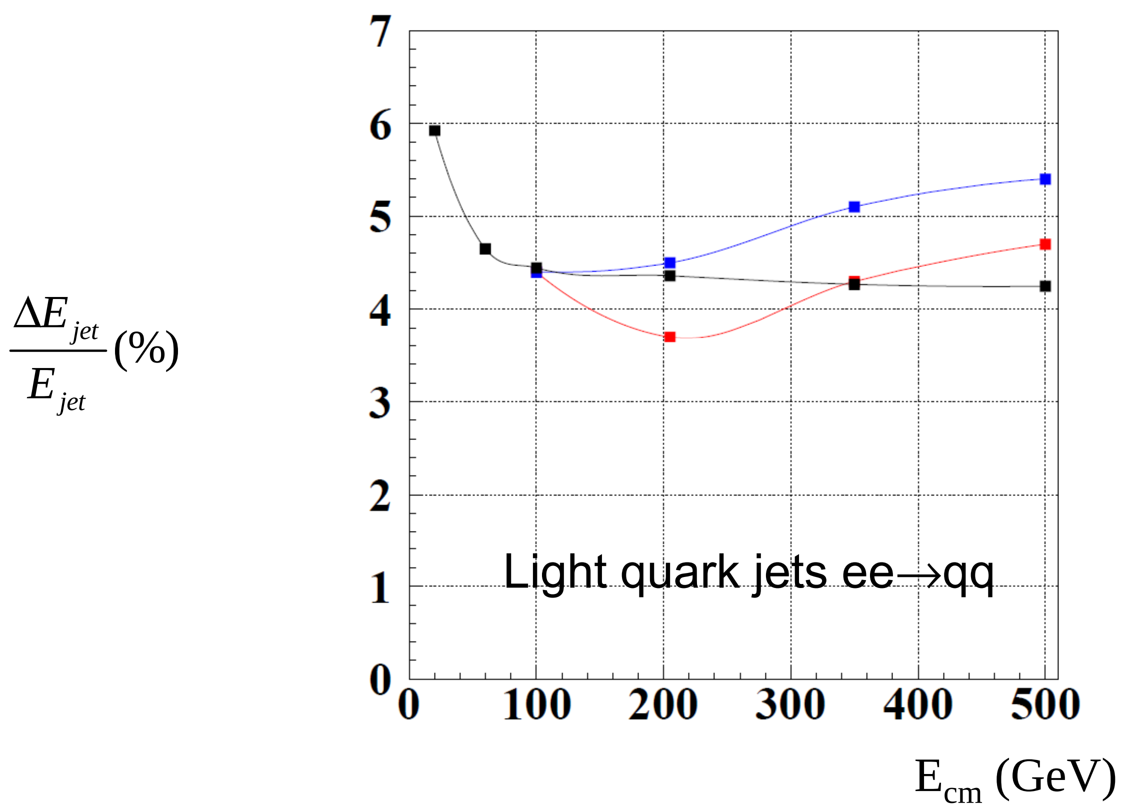
- Use FastMC to develop analysis algorithms
- Use full MC and Perfect PFA as intermediate step to develop a realistic analysis
- Use realistic tracking and PFA for the analysis when ready
  - A drop-in replacement of algorithms

org.lcsim FastMC simulation of Calorimeter/PFA output

Use tracker momentum for all charged tracks within acceptance;
account for confusion term by blowing up single particle resolution for neutral hadrons

GLD PFA — LDC PFA — org.lcsim FASTMC with

$$\frac{\Delta E_\gamma}{E_\gamma} = \frac{0.18}{\sqrt{E_\gamma}} \qquad \frac{\Delta E_{n,K_L^0}}{E_{n,K_L^0}} = 0.28$$



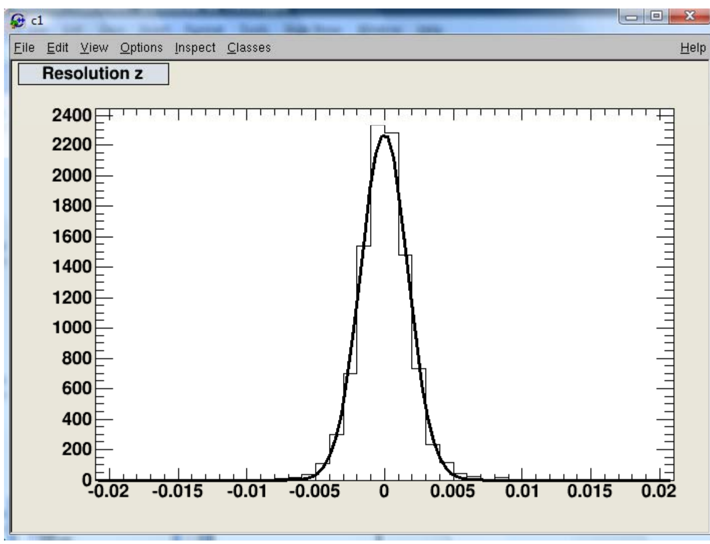
What does Perfect PFA do?

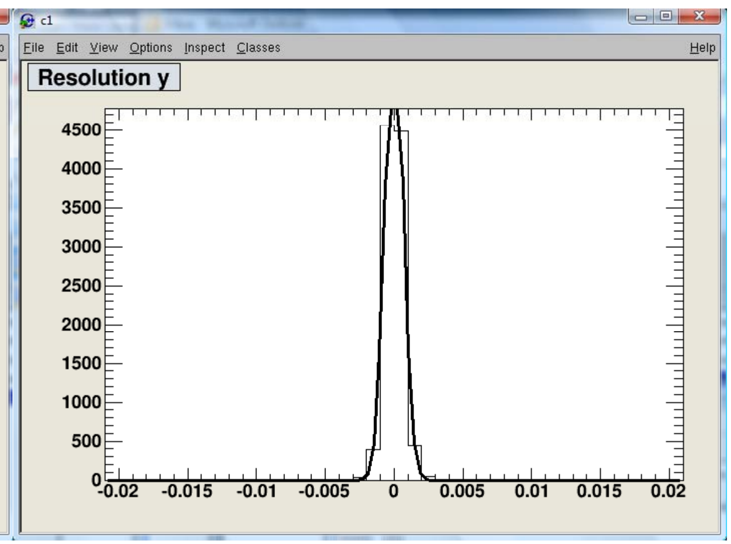
- Tracking
  - Define “trackable” charged particles
  - Smear as in FastMC
  - Full material effects (interactions and decays) before the calorimeter are taken into account in deciding which particles are actually tracked
- Neutrals
  - For all “non-trackable” particles, assign energy deposits in the calorimeters
  - Do neutral particle reconstruction using those deposits using perfect pattern recognition (no confusion term)
  - Use actual detector responses for energy and direction - so most of the nasty nonlinear, nongaussian effects are included

Primary Vertex Reconstruction with org.lcsim FastMC

LCFI vertexing package can be used with lcsim.org

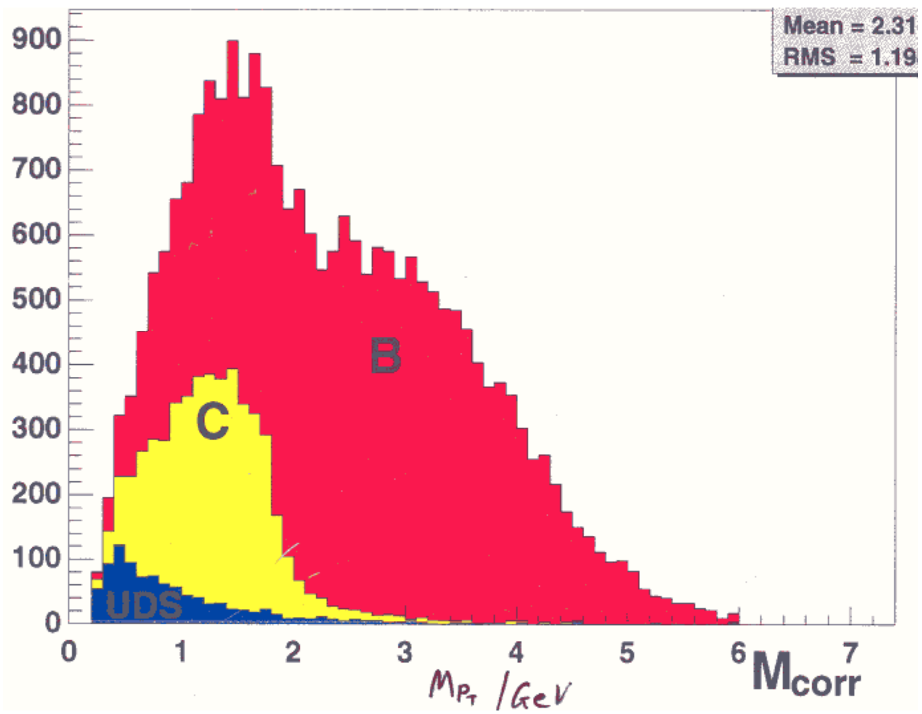
- Resolution for primary vertex in ZHH events:
  - 2 μm in z-direction
  - <0.8 μm in x-y plane (beamspot constr.) 2 μm (no beamspot constr.)
  - Resolution pulls are nice Gaussians with σ ~ 1.1 for all x,y and z





LCFI Flavour Identification

- Combine several variables into Neural Net
  - **Vertex mass**
  - Vertex momentum
  - Decay length
  - Decay length significance
  - Jet Probability
- Main contributors are Vertex Mass and Jet Probability



Standard Model Samples

- Full 2 ab^{-1} SM Data Sample is available at SLAC via ftp
- Each file corresponds to a particular initial e-/e+ pol. and final state
- Web documentation
- Will be used by all concepts
- Need to add 250 GeV samples

Data Sample

Stdhep files for an Ecm=500 GeV SM data sample assuming a 120 GeV Higgs mass are available at ftp://ftp-lcd.slac.stanford.edu/ilc/ILC500/StandardModel/ .
There are 487,603,537 events (250 fb -1 luminosity) with -80% electron/ +30% positron polarization, and 474,837,805 events (250 fb -1 luminosity) with +80% electron/ -30% positron polarization.
The WHIZARD Monte Carlo version 1.40 is used for parton generation. The Makefile and build log files for this implementation of WHIZARD can be found in ftp://ftp-lcd.slac.stanford.edu/ilc/ILC500/StandardModel/whizard-v1r4p0 .

Event Weight

Due to the presence of some high cross section processes the events are not completely unweighted.
The event weight must therefore always be considered when analyzing events.
This weight is stored in the variable EVENTWEIGHTLH in the stdhep common block HEPEV4.

Process Identification

Events corresponding to hundreds of different processes are stored in random order in the stdhep files.

FTP directory /ilc/whizdata/ILC500/ at ftp-lcd.slac.stanford.edu

To view this FTP site in Windows Explorer, click **Page**, and then click **Open FTP Site in Windows Explorer**.

Up to higher level directory

```
09/16/2007 12:00AM      Directory .
03/14/2007 12:00AM      Directory ..
09/14/2007 09:12PM            144 copy.sh
09/14/2007 09:09PM         60,980 theoryDiskContents.txt
09/14/2007 06:15PM         60,911 tmp.txt
09/14/2007 09:16PM  2,138,688,564 w11715_01.stdhep
09/14/2007 09:19PM  2,138,688,564 w11715_02.stdhep
09/14/2007 09:22PM  2,138,688,564 w11715_03.stdhep
09/14/2007 09:23PM    243,273,156 w11715_04.stdhep
09/14/2007 09:23PM    573,450,716 w11715_05.stdhep
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09/14/2007 09:33PM  2,138,688,564 w11716_03.stdhep
09/14/2007 09:34PM    812,779,312 w11716_04.stdhep
09/14/2007 09:35PM    713,262,648 w11716_05.stdhep
09/14/2007 09:38PM  1,407,942,308 w11719_01.stdhep
09/14/2007 09:40PM  1,408,867,732 w11720_01.stdhep
09/14/2007 09:40PM    145,274,324 w11723_01.stdhep
09/14/2007 09:40PM    145,384,112 w11724_01.stdhep
09/14/2007 09:43PM  2,138,688,564 w11730_01.stdhep
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09/14/2007 09:57PM  2,138,688,564 w11731_01.stdhep
09/14/2007 10:01PM  2,138,688,564 w11731_02.stdhep
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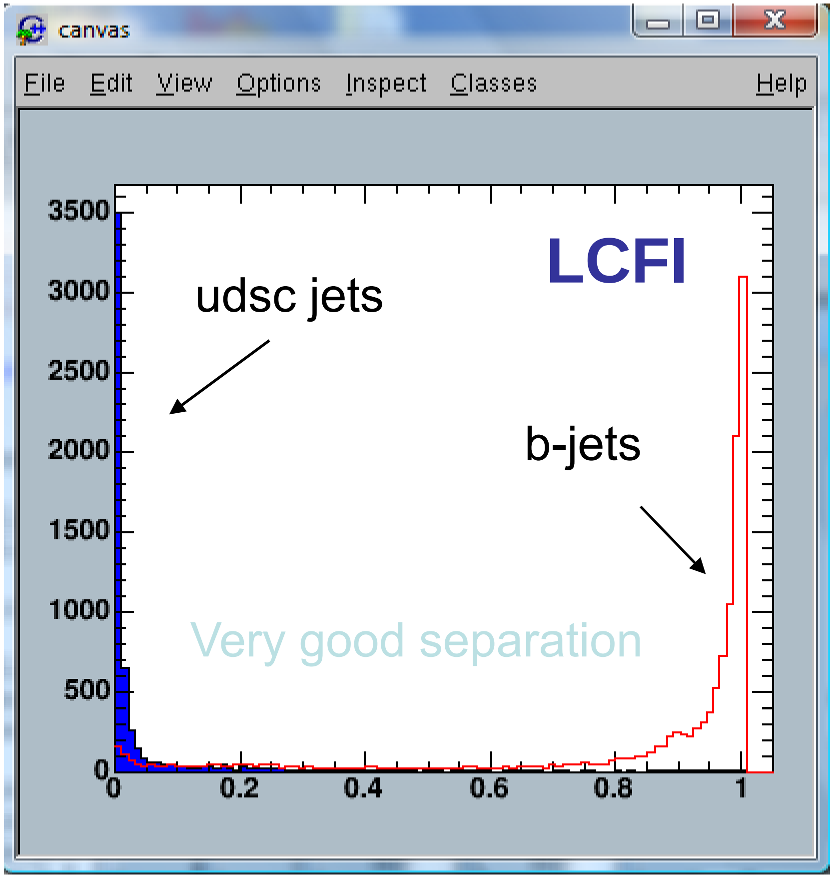
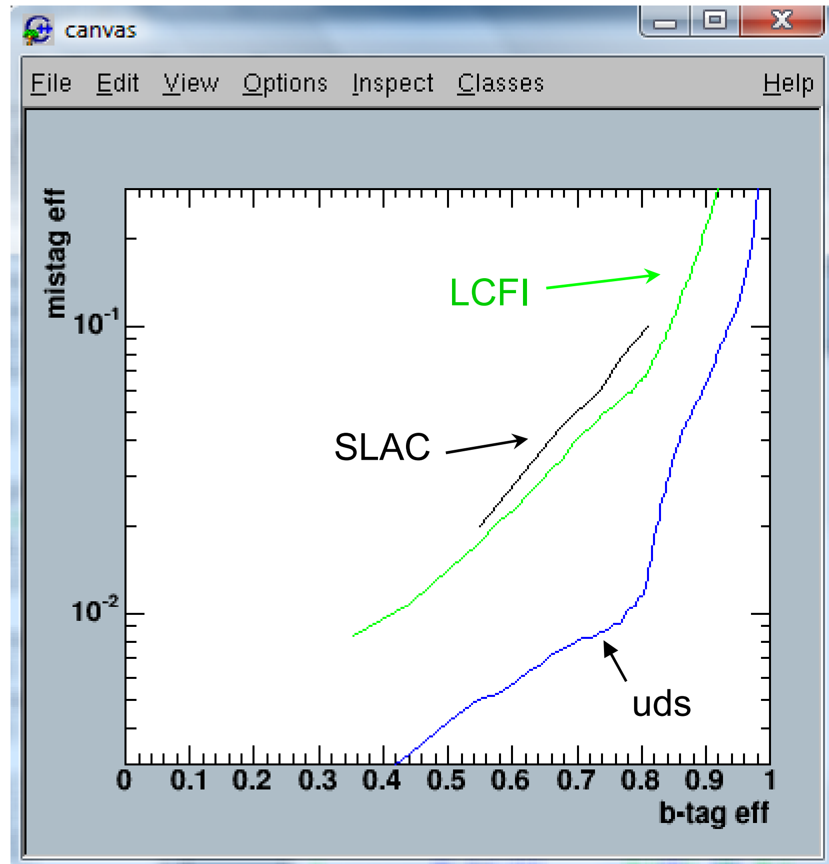
Some Results

- Several analyses done previously used both Fast and Full MC
  - ZH, ZHH, H→ $\mu\mu$, ttbar …
- Recent developments with tools
  - Used LCFI package with lcsim.org samples
  - Used Perfect PFA for ZHH analysis

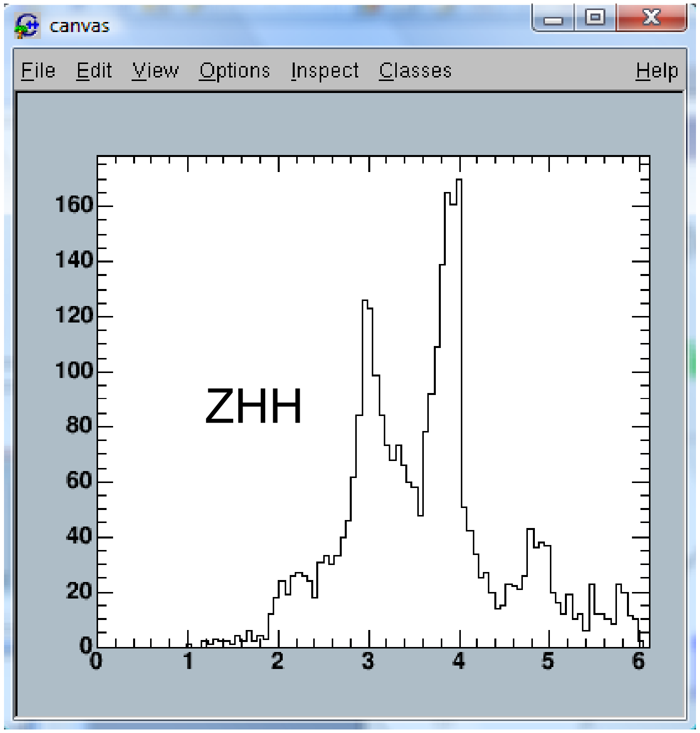
ZHH Analysis

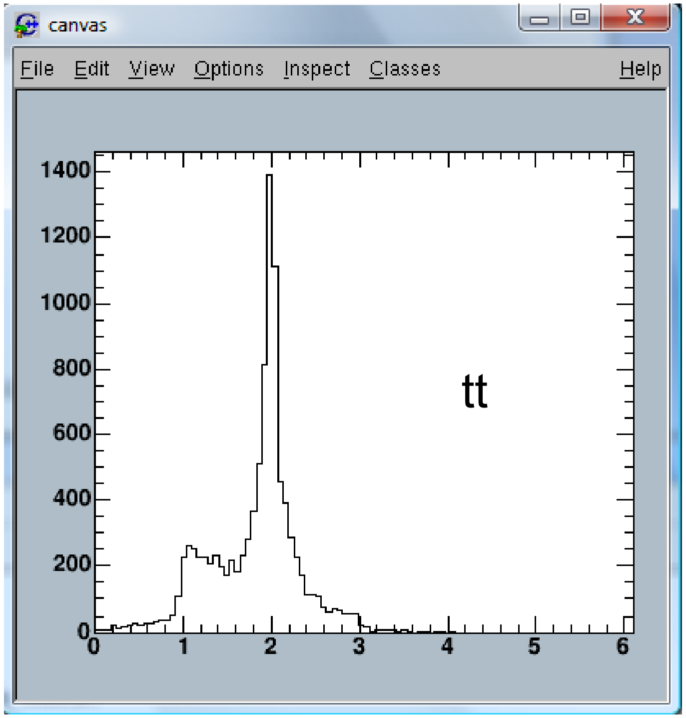




- Flavour ID Neural Net output
- c-mistag vs b-tagging eff

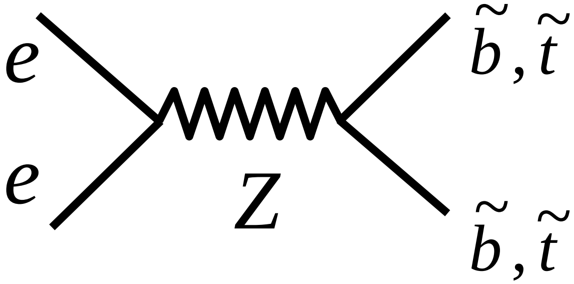
ZHH Analysis

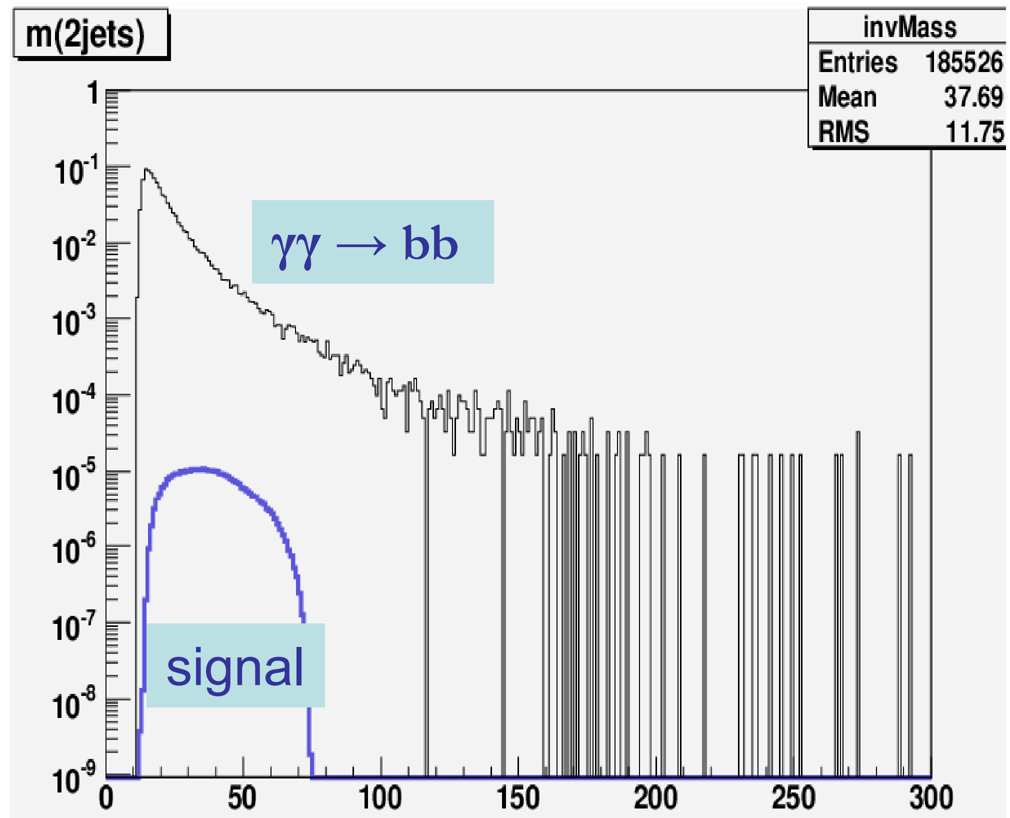




- Sum of neural net outputs for all six jets
- Developing ZHH selections
- The above is FastMC
- Checked first ZHH Perfect PFA sample

SUSY Sbottom Analysis





Invariant mass of two jets, GeV

- $\gamma\gamma$ is the main bkg
- Studying variables to separate signal and background
- b-tagging of soft jets

How to contribute

- We look for people to lead several analyses – both compulsory and additional
- Physics studies are ideal for newcomers, fast track way to contribute to LoI

Backups

Compulsory LOI Benchmark Observables - SiD Proposal

1. $e^+e^- \to Zh, \to \ell^+\ell^- X,\, l = e, \mu;\;\; m_h = 120$ GeV at $\sqrt{s}$=0.25 TeV

   M_h & $\sigma(e^+e^- \to Zh)$

2. $e^+e^- \to Zh,\, Z \to q\bar{q}, \nu\bar{\nu};\;\; h \to c\bar{c},\, \mu^+\mu^-;\;\; m_h = 120$ GeV at $\sqrt{s}$=0.25 TeV

   BR($h \to c\bar{c}$) & BR($h \to \mu^+\mu^-$)

3. $e^+e^- \to \tau^+\tau^-$, at $\sqrt{s}$=0.5 TeV

   Identification efficiency and purity for $\tau^- \to \pi^-\nu_\tau$, $\rho^-\nu_\tau$

4. $e^+e^- \to t\bar{t}$ at $\sqrt{s}$=0.5 TeV

   $\sigma(e^+e^- \to t\bar{t})$ & M_t (as defined in tree-level event generator such as WHIZARD)

5. $e^+e^- \to \tilde{\chi}_1^+\tilde{\chi}_1^- / \tilde{\chi}_2^0\tilde{\chi}_2^0 \to W^+W^-\tilde{\chi}_1^0\tilde{\chi}_1^0$ / $ZZ\tilde{\chi}_1^0\tilde{\chi}_1^0$ at $\sqrt{s}$=0.5 TeV

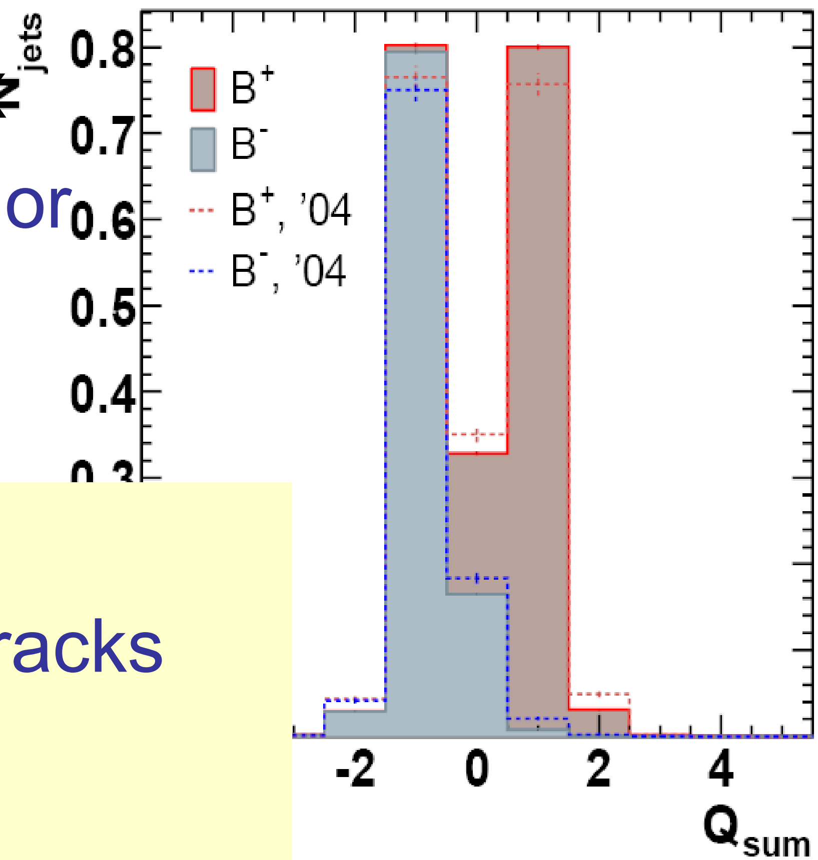
   $M_{\tilde{\chi}_1^+}$, $M_{\tilde{\chi}_2^0}$, $\sigma(e^+e^- \to \tilde{\chi}_1^+\tilde{\chi}_1^-)$, $\sigma(e^+e^- \to \tilde{\chi}_2^0\tilde{\chi}_2^0)$

Benchmarking Plans, Andrei Nomerotski, 30 Jan 2008

1. $e^+e^- \to Zh, \to \ell^+\ell^- X$, $l = e, \mu$; $m_h = 120$ GeV at $\sqrt{s}$=0.25 TeV — SLAC
2. $e^+e^- \to Zh$, $Z \to q\bar{q}, \nu\bar{\nu}$; $h \to c\bar{c}, \mu^+\mu^-$; $m_h = 120$ GeV at $\sqrt{s}$=0.25 TeV — Michigan/Bristol ?
3. $e^+e^- \to \tau^+\tau^-$, at $\sqrt{s}$=0.5 TeV — Texas A&M ?
4. $e^+e^- \to t\bar{t}$ at $\sqrt{s}$=0.5 TeV — RAL/Oxford
5. $e^+e^- \to \tilde{\chi}_1^+\tilde{\chi}_1^- / \tilde{\chi}_2^0\tilde{\chi}_2^0 \to W^+W^-\tilde{\chi}_1^0\tilde{\chi}_1^0$ / $ZZ\tilde{\chi}_1^0\tilde{\chi}_1^0$ at $\sqrt{s}$=0.5 TeV — SLAC
6. $e^+e^- \to c\bar{c}, b\bar{b}$, at $\sqrt{s}$=0.5 TeV; — Oxford
7. $e^+e^- \to Zhh$, $m_h = 120$ GeV at $\sqrt{s}$=0.5 TeV; — Oxford
8. $e^+e^- \to \tilde{\tau}_1\tilde{\tau}_1$, at Point 3 at $\sqrt{s}$=0.5 TeV; — Texas A&M/Colorado ? /Montenegro
9. $e^+e^- \to \tilde{t}_1\tilde{t}_1^* \to c\bar{c}\tilde{\chi}_1^0\tilde{\chi}_1^0$, $m_{\tilde{t}_1} = 120$ GeV, $m_{\tilde{\chi}_1^0} = 100$ GeV, at $\sqrt{s}$=0.5 TeV — Lancaster
10. $e^+e^- \to \tilde{b}_1\tilde{b}_1^* \to b\bar{b}\tilde{\chi}_1^0\tilde{\chi}_1^0$, at $\sqrt{s}$=0.5 TeV — Oxford/Montenegro
11. $e^+e^- \to \mu^+\mu^-$, at $\sqrt{s}$=0.5 TeV — SLAC
12. $H \to \gamma\gamma$ — RAL

Example: Vertex Charge

- Total charge of tracks associated with a vertex
  - Binary behaviour : a lost or wrongly assigned track changes the charge → every track is important



Sensitive to low pT tracks

Sensitive to material

Where is it useful?