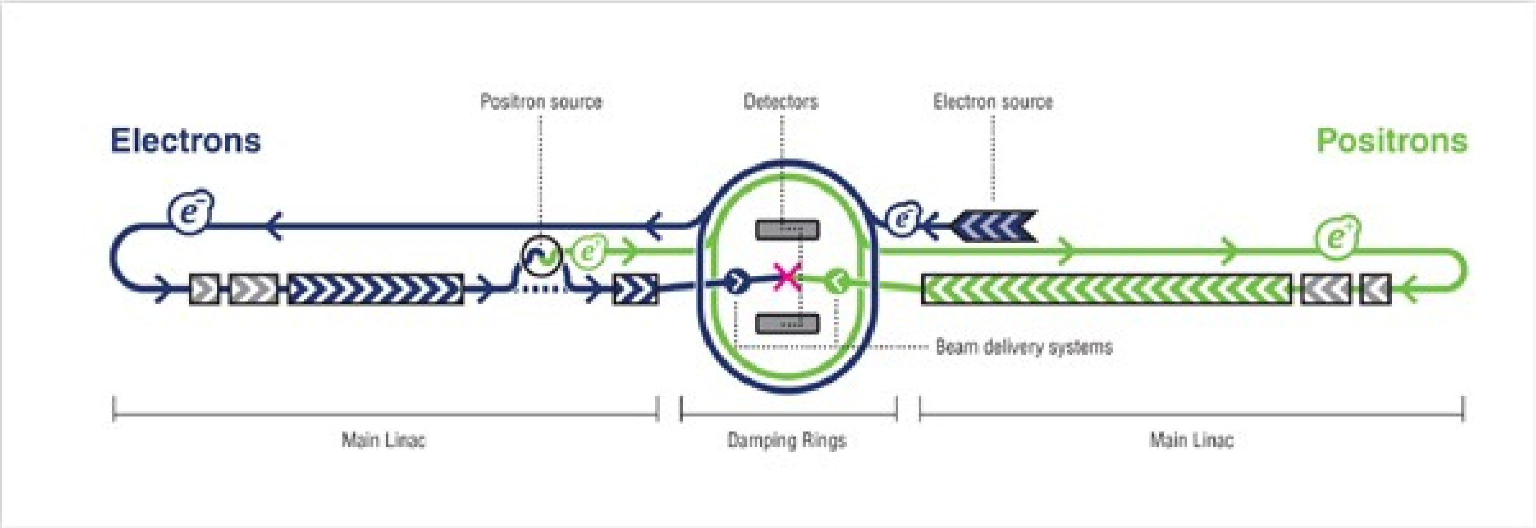
Study of SUSY particles properties at the future International Linear Collider with the International Large Detector

- Short introduction to International Linear Collider (ILC) and International Large Detector (ILD)
- SUSY studies at ILC
- Beam induced backgrounds and their influence on physics events

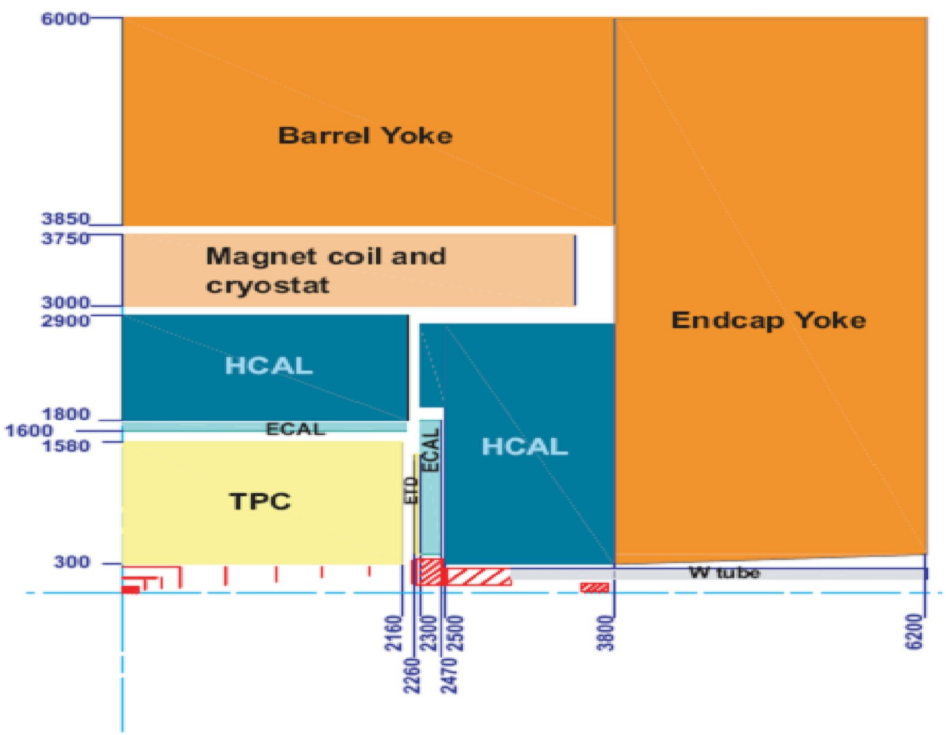
International Linear Collider

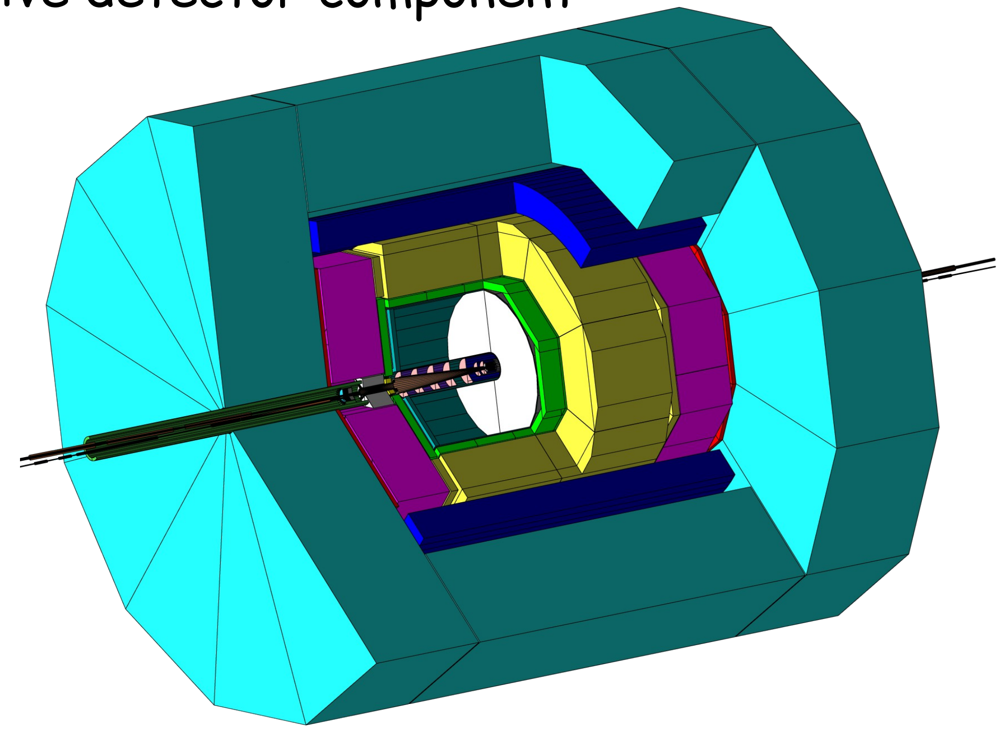
- ILC – International Linear Collider
  - next large high-energy project
  - linear e^+e^- collider, up to CMS = 500 GeV (1000 GeV)
  - luminosity of $2.10^{34}/cm^2/s$
  - polarized beams: electrons 80%, positron 30% (up to 60%)
- build for detailed studies of Higgs, SUSY, and other new physics particles & interactions



International Large Detector Concept

- Intended precision measurements at ILC require detectors of unprecedented performance – huge challenge for detector and reconstruction methods
    - vertex resolution, tracking resoution, jet energy resolution – better than in any existing detectors so far
- 'Particle Flow' - proposed approach for reconstruction
    - reconstruct 4-momenta of ALL particles in an event
    - for each particle use most effective detector component





Physics Studies @ ILD

- chosen reactions most challenging for the detector
  - allow to study detector performance & guide detector development
- full detector simulation Mokka (GEANT4)
- full reconstruction of over 30 million Monte Carlo events
- presented analyzes for CME of 500 GeV

- Letters of Intent (LoI) for ILC detector concepts recently submitted
- selection of ILD LoI physics studies is presented here

benchmark reactions for ILC

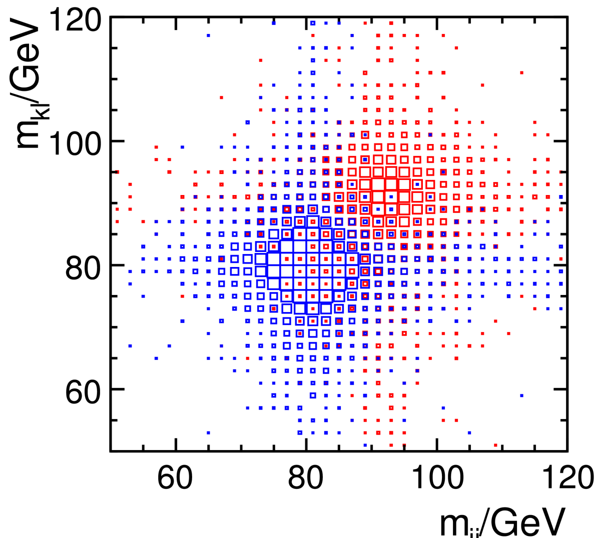
  - physics studies
  - detector design and optimization

Neutralino and Chargino Production

- mSugra "Point5" scenario:

$$e^+e^- \rightarrow \tilde{\chi}_1^+\tilde{\chi}_1^- \rightarrow W\,\tilde{\chi}_1^0\,W\,\tilde{\chi}_1^0$$
$$e^+e^- \rightarrow \tilde{\chi}_2^+\tilde{\chi}_2^- \rightarrow Z\,\tilde{\chi}_1^0\,Z\,\tilde{\chi}_1^0$$

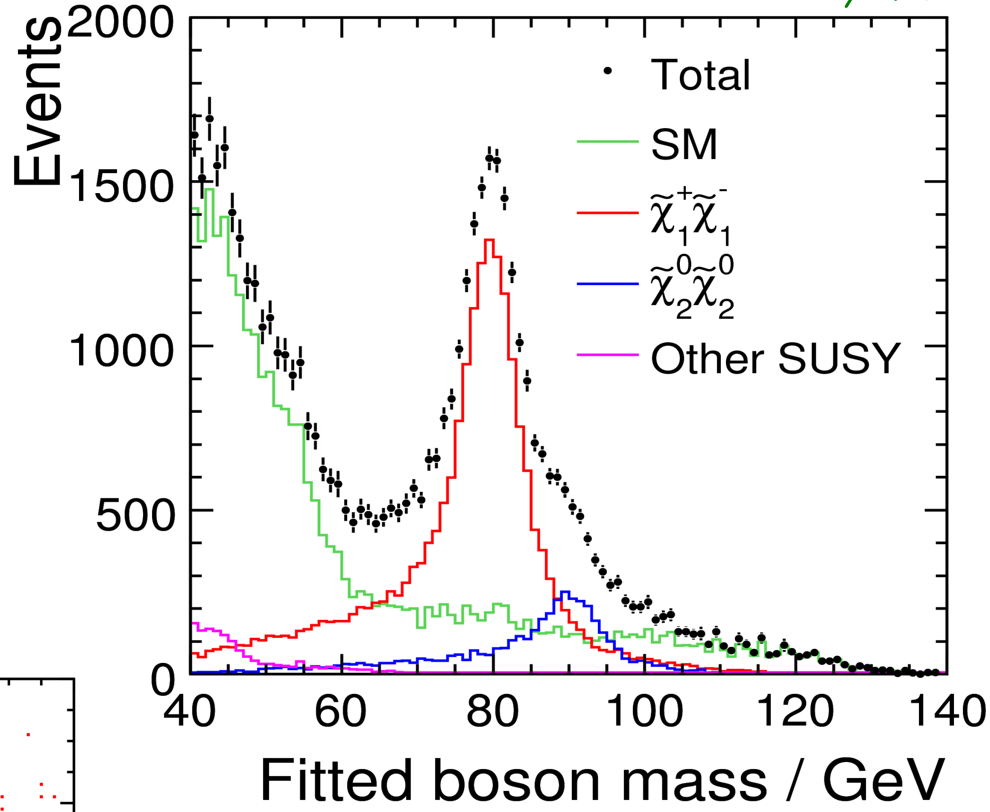
- hadronic W and Z decays
  - final state – 4 jets and missing energy
  - good W/Z separation essential
    - tests jet energy resolution
    - tests particle flow based jet reconstruction



courtesy of M. Beckmann

- cross section determined from di-jet mass distributions

courtesy of J. List

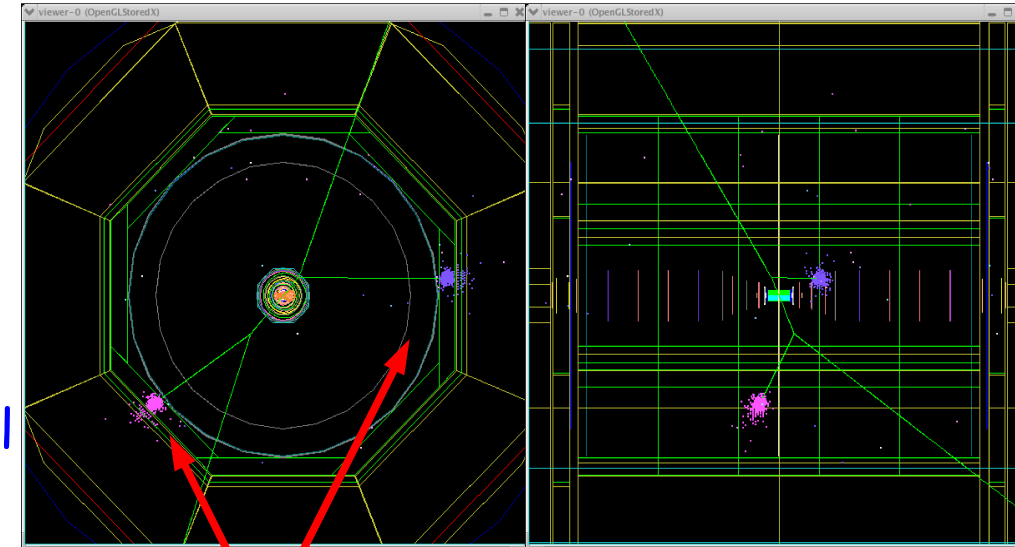


- statistical errors depend on method
  - **0.64%-0.95% for chargino**
  - **2.1%-2.9% for neutralino**

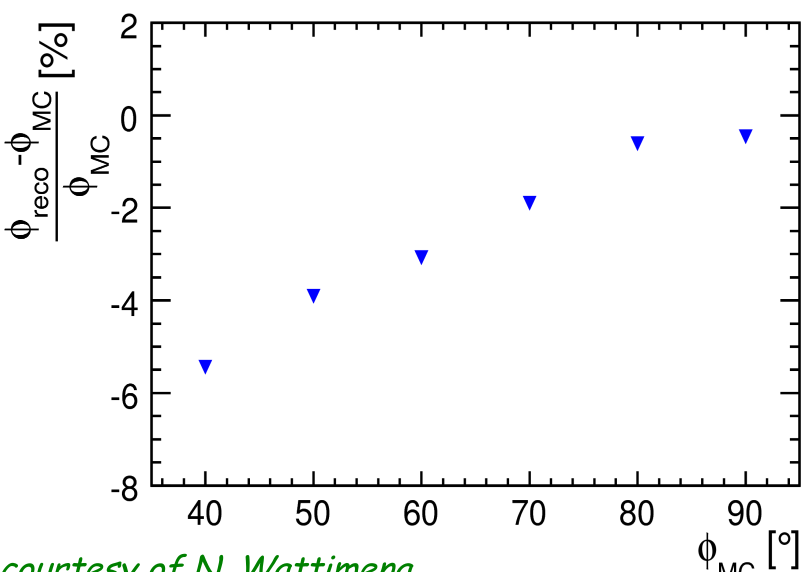
Long-lived Neutralinos in GMSB

$$e^{+}e^{-}\rightarrow\tilde{\chi}_{1}^{0}\tilde{\chi}_{1}^{0},\quad \tilde{\chi}_{1}^{0}\rightarrow\tilde{G}\,\gamma$$

- energetic, non-pointing γs $\rightarrow$ big challenge for electromagnetic calorimeter (ECAL)
- high granularity & resolution essential
- photons from ECAL clusters
  - efficiency: 84% for 1-200 GeV γ
  - angular resolution of photons:



non-pointing photons



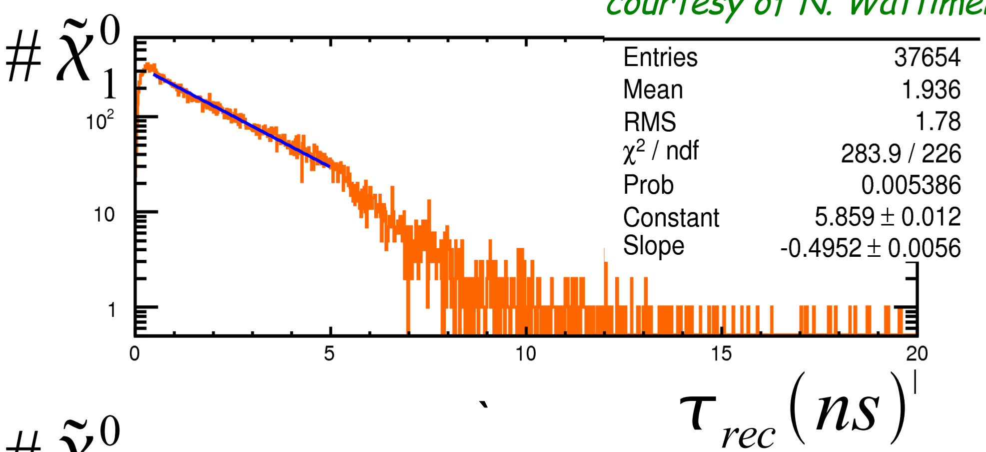
courtesy of N. Wattimena

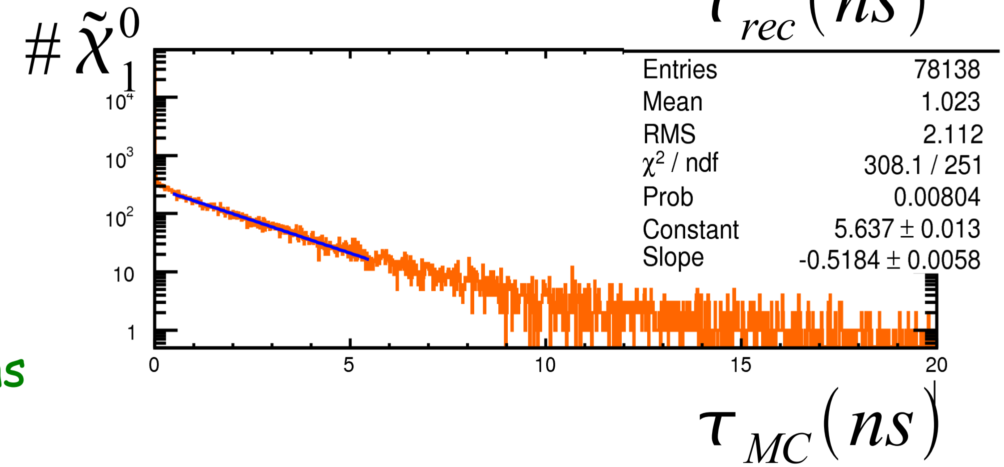
highly granular electromagnetic calorimeter $\rightarrow$ excellent angular resolution of single photons

Long-lived Neutralinos in GMSB

- investigating capability of ECAL for different neutralino life times
  - 0.2 ns corresponding to ~10 cm decay distance
  - 2 ns corresponding to ~100 cm decay distance
- $\tilde{\chi}_1^0$ mass and life time estimated from γ energy and τ distributions

courtesy of N. Wattimena





<u>0.2 ns sample</u>

- τ_{reco}=0.333±0.003 ns, τ_{MC}=0.480±0.009 ns

<u>2 ns sample</u>

- τ_{reco}=2.02±0.02 ns, τ_{MC}=1.9±0.02 ns

- neutralino lifetime measured to 1%
- neutralino mass determined with 2%

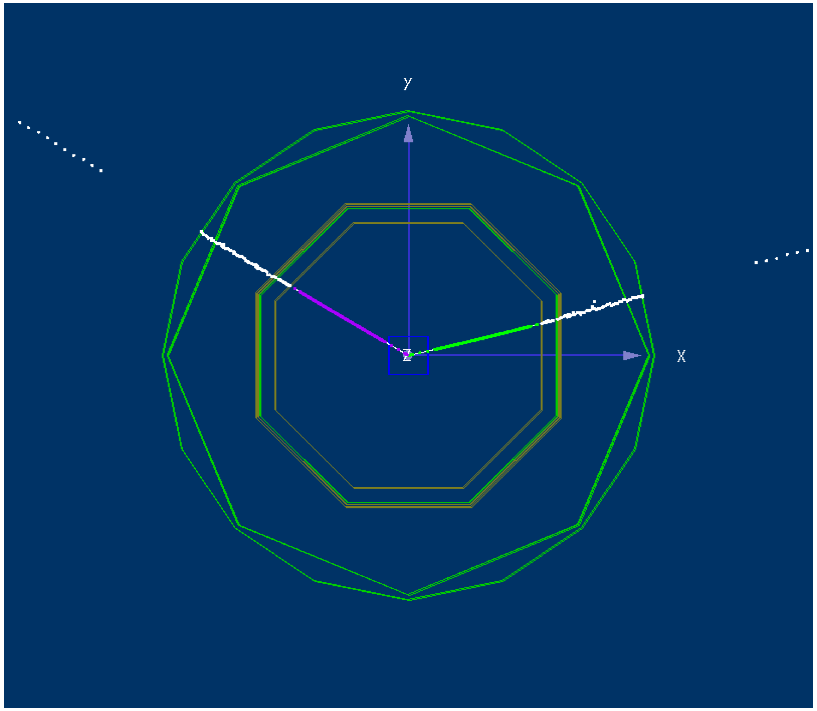
SUSY Sps1a': Neutralino System

- mSugra SUSY with Sps1a' parameter set

$$\tilde{\chi}^0_2 \tilde{\chi}^0_1 \rightarrow \mu\,\mu\,\tilde{\chi}^0_1 \tilde{\chi}^0_1 (\sigma = 4.1\ fb)$$
$$\tilde{\mu}_L \tilde{\mu}_L \rightarrow \mu\,\mu\,\tilde{\chi}^0_1 \tilde{\chi}^0_1 (\sigma = 54\ fb)$$

- signature: 2 energetic muons + missing E

excellent tracking performance (μ) and hermeticity of detector (E_{miss}) essential



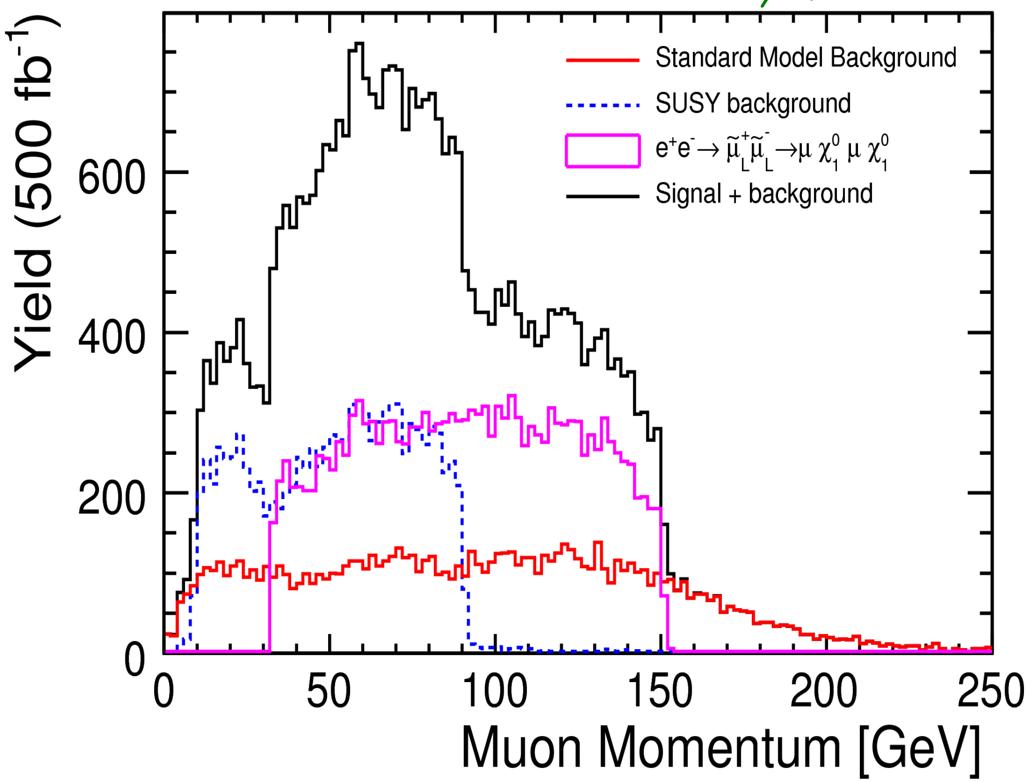
- muons identified with 95% efficiency using track, HCAL & muon chamber

- $\tilde{\chi}^0_1$ and μ_L masses measured from kinematic edges of muon momentum distribution in

$$\tilde{\mu}_L \tilde{\mu}_L \rightarrow \mu\,\mu\,\tilde{\chi}^0_1 \tilde{\chi}^0_1$$

  - $\tilde{\chi}^0_1$ mass up to 1.40%
  - μ_L mass up to 0.27%
  - σ up to 2.5%

courtesy of N. D'Ascenzo

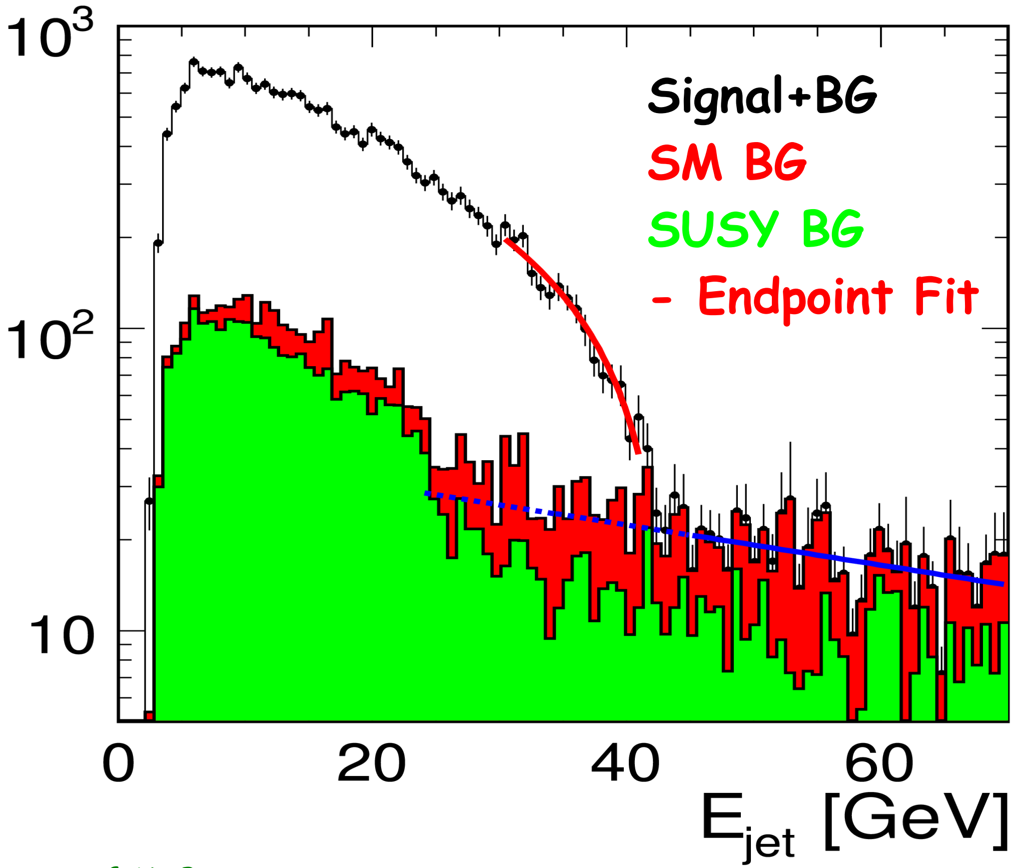


SUSY Sps1a': Stau Mass

$$e^+ e^- \rightarrow \tilde{\tau}\,\tilde{\tau} \rightarrow \tilde{\chi}_1^0 \tau\, \tilde{\chi}_1^0 \tau$$

- missing energy and 2 low multiplicity tau-jets
- τ mass extracted from end-point of tau-jet energy spectrum (assuming $\tilde{\chi}_1^0$ mass)

- requirements:
  - precision tracking
  - good particle identification
  - hermetic detector
  - low machine background



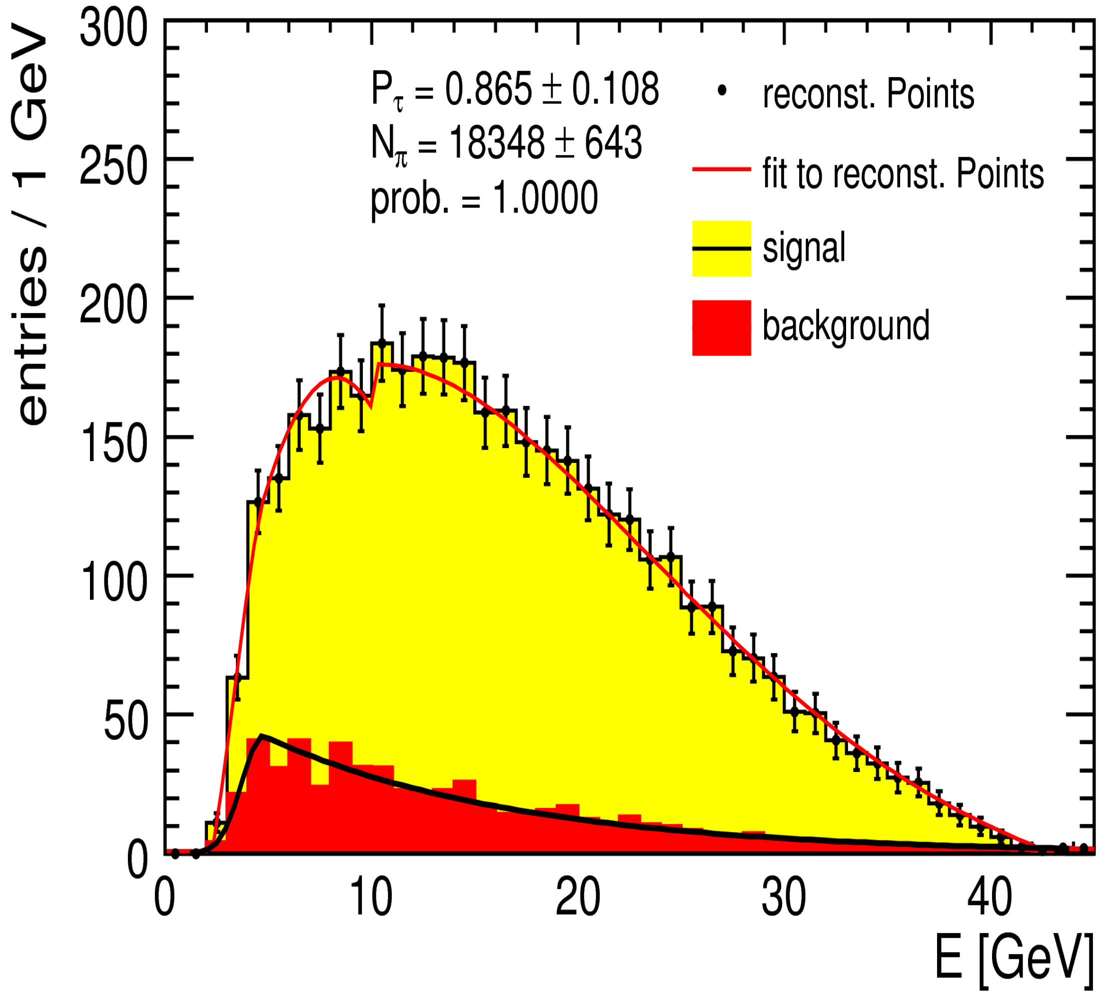
- stat. error on end-point: 0.1 GeV
- accounting for $\tilde{\chi}_1^0$ mass uncertainty: $0.1\ \text{GeV} \oplus 1.3\sigma_{LPS}$

courtesy of M. Berggren

SUSY Sps1a': Stau Polarization

- tau polarization, P_τ, provides sensitivity to many SUSY parameters
- cleanest measurement from $\tau \rightarrow \pi\nu$
  - slope of $\pi^\pm$ energy spectrum proportional to P_τ
- fit to energy spectrum very sensible to spectrum shape
  - particle identification crucial
    - likelihood based on CAL info
  - background (21%) subtracted
  - beam background not taken into account for now

- estimated uncertainty 13-16%
  - depends on positron beam polarization

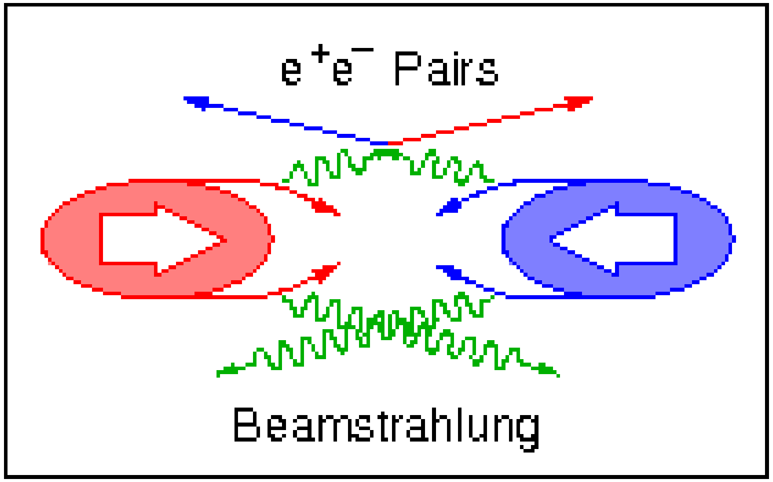


courtesy of P. Schade

Beam Induced Backgrounds

<u>novel problem faced by linear colliders – beam induced backgrounds</u>

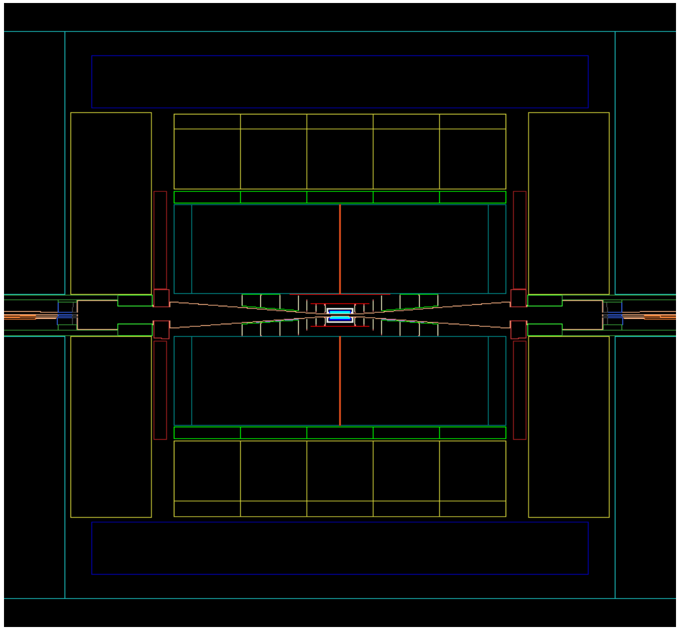
- machine induced backgrounds -> most important source of unwanted interactions

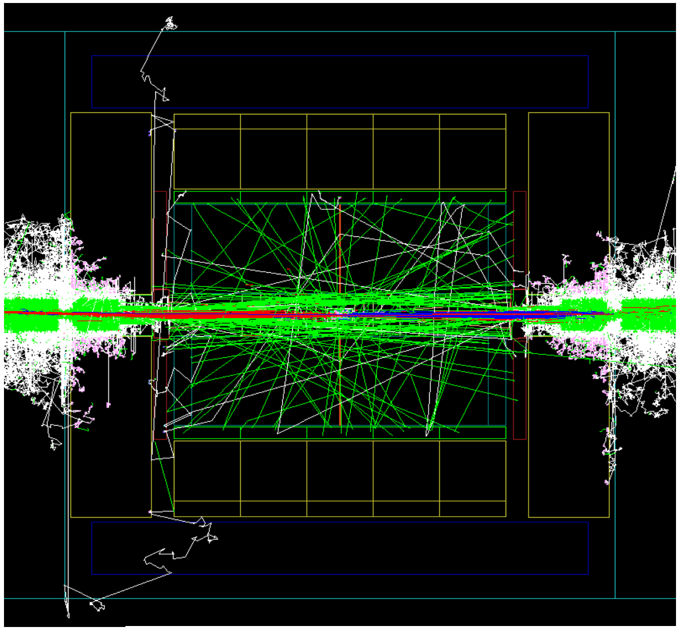


  - beamstrahlung (photons) & e^+e^- pair production
  - photons strongly focused in forward direction – exit through beam tube
  - e^+e^- pair production: direct and scattered particles in the detector
  - 10^5 pairs per bunch crossing, total energy ~1TeV, average few GeV per particle
- mostly affected – vertex detector (VTX) and forward detectors
- electron-positron pairs are unavoidable backgrounds

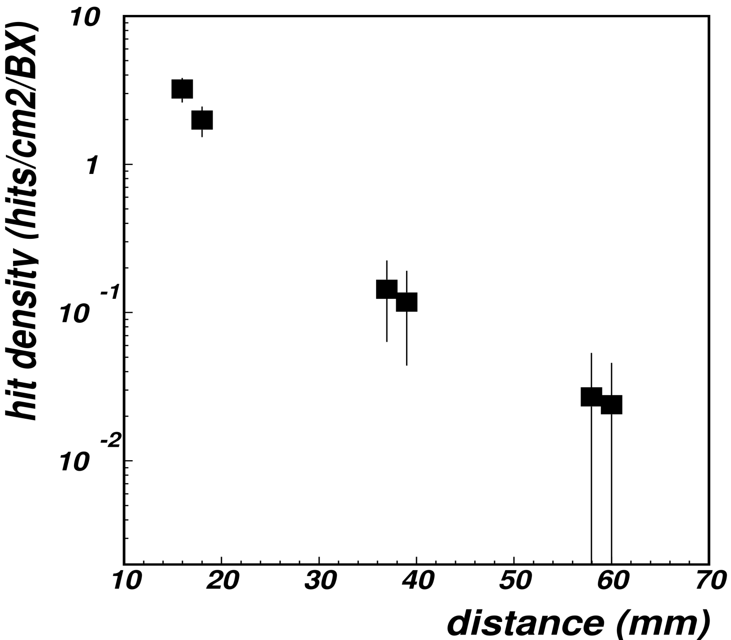
Beam Backgrounds in Detector

effect of 1/10th of bunch crossing





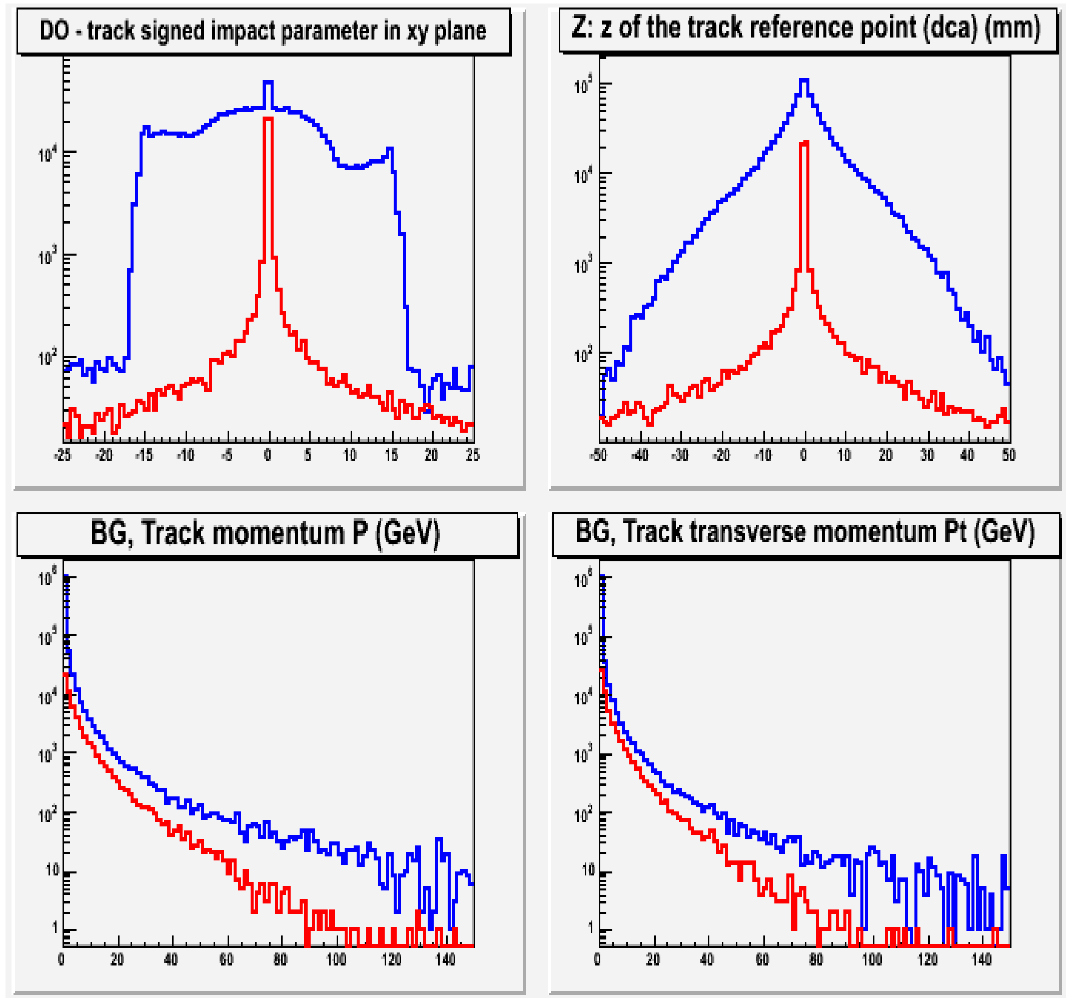
- Guinea Pig (GP) generator used to generate beam background + Mokka (full simulation)
- hit densities for VTX calculated from number of hits in detector layers for 1 bunch crossing (BX)



Beam Background in Detector

- effort to simulating backgrounds and study its effects on reconstruction
- detector swamped by additional hits
  - mostly affected VTX and Forward
  - more reconstructed tracks, Flow Objects, shifted energies
- needed ways to reduce backgrounds
  - detector design & machine parameters chosen to minimize beam background impact
  - beam background must be treated on analysis level as well

background (only in VTD), no background

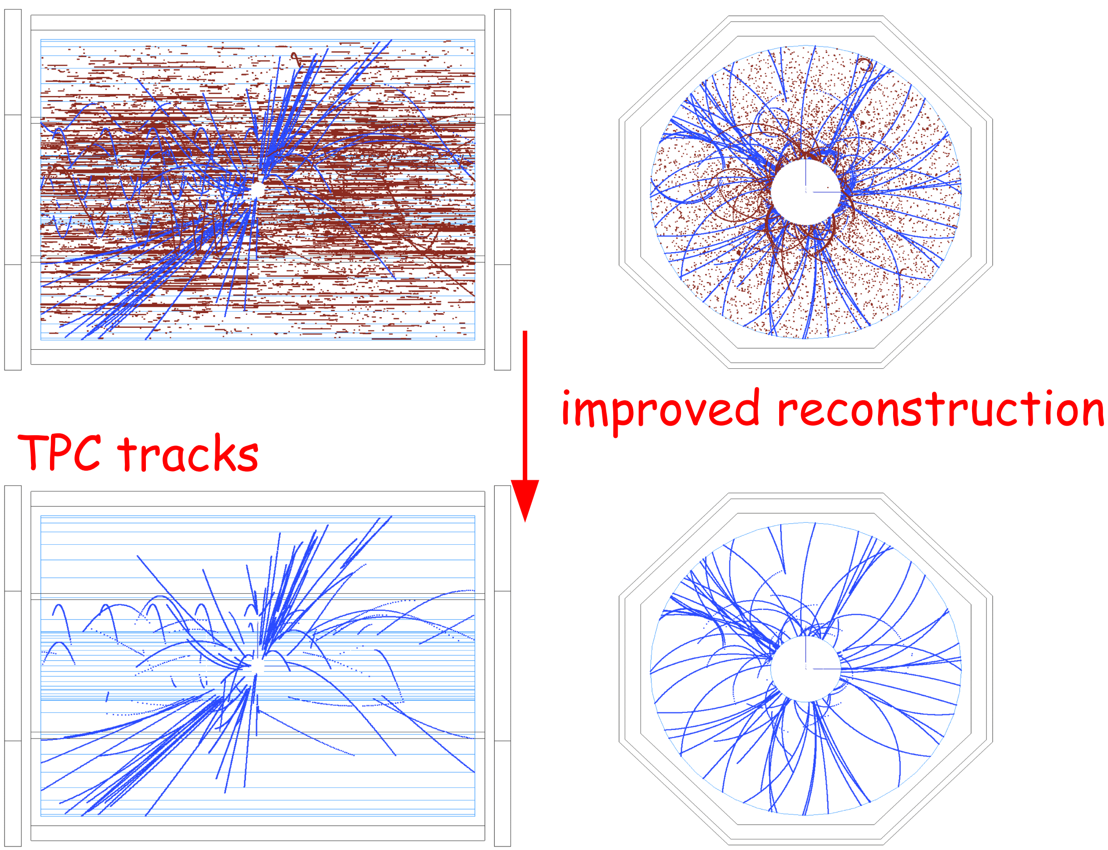


- in VTX ~100000 hits with beam backgrounds compared to ~400 without!
- ~3000 full tracks compared to ~60

Beam Background in Detector

- ways to reduce backgrounds
  - on the reconstruction level – huge progress
  - between reconstruction & analysis
    - set of 2D cuts on track variables gives background rejection of 97% and track efficiency of 1.5%, for pT>0.5 GeV
  - on the analysis level – example on next page

TPC hits for ttbar events overlayed with 150 BX of pair-background hits



courtesy of S. Aplin

SUSY Sps1a': Staus Revisited

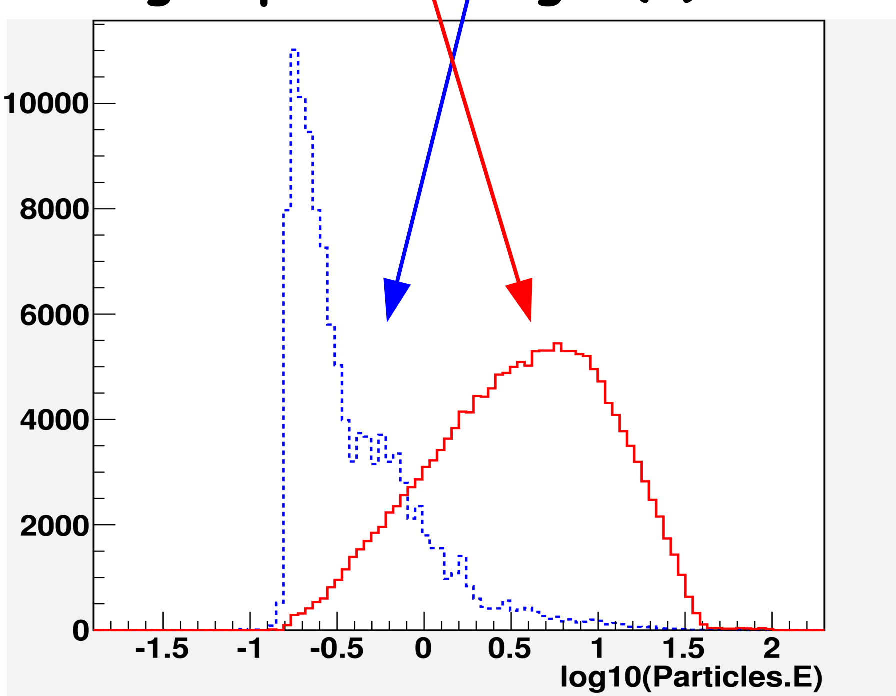
$$e^+ e^- \rightarrow \tilde{\tau}\,\tilde{\tau} \rightarrow \tilde{\chi}_1^0 \tau\, \tilde{\chi}_1^0 \tau$$

- studied with beam background present
  - missing energy and 2 low multiplicity tau-jets
- set of cuts to remove background
  - particle energy E > 0.5 GeV
  - at least 1 hit in TPC (charged and neutral)
  - special DELPHI jet algorithm used to find taus

no difference in τ mass extracted with beam background and without

- requirements:
  - good tracking, good particle identification, hermetic detector
  - low machine background (analyzed in mass measurement only)
    - each physics event overlayed with 1 BX of Guinea Pig pairs

charged particle log10(E)



courtesy of M. Berggren

Summary

- ILC- future linear collider offers unique chance for
- precise measurements of Higgs and new physics
- ILD Concept worked with wide set of benchmark reactions
  - to study physics
  - to work on detector design and optimization
- ILC faces novel problem of beam-related backgrounds
  - studies of pair background show methods to deal with it
- ILD Concept demonstrated in Letter of Intent that it is able to build detector sufficient to fulfill ambitious physics program