Performance Study of Digital ECAL in ILD

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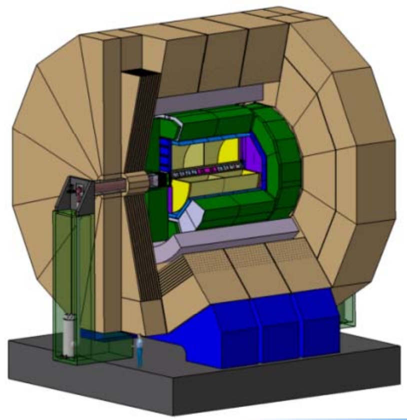
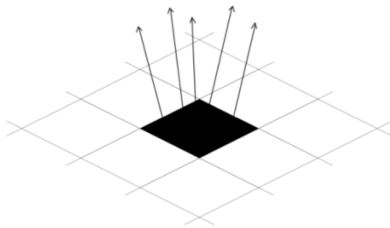


Outline

- DECAL overview
- Goal of study and context
- Simulations
- Results
- Conclusions and Outlook

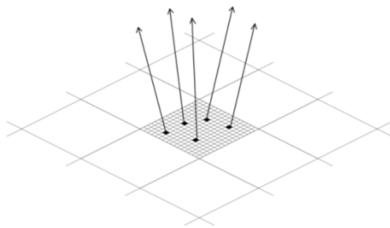
Overview of Digital ECAL

- Novel approach to EM calorimetry, not (yet) proven, therefore only an option
- Based on relatively small pixels, **50 x 50 μm^2**

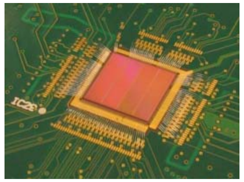


- **Binary readout, pixel size optimised for 1 MIP/pixel**

  even in EM shower core



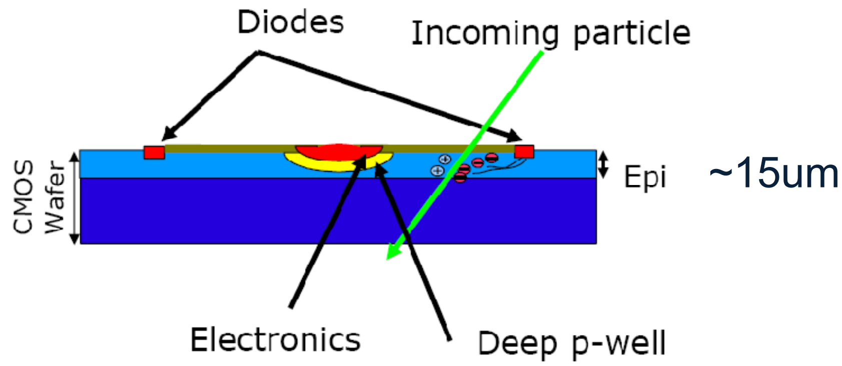
- EM shower energy is proportional to the number of pixels hit
- Ability to timestamp pixel hits
- Implemented in CMOS MAPS in hardware studies (SPIDER, CALICE): TPAC sensors, as tested at DESY, CERN



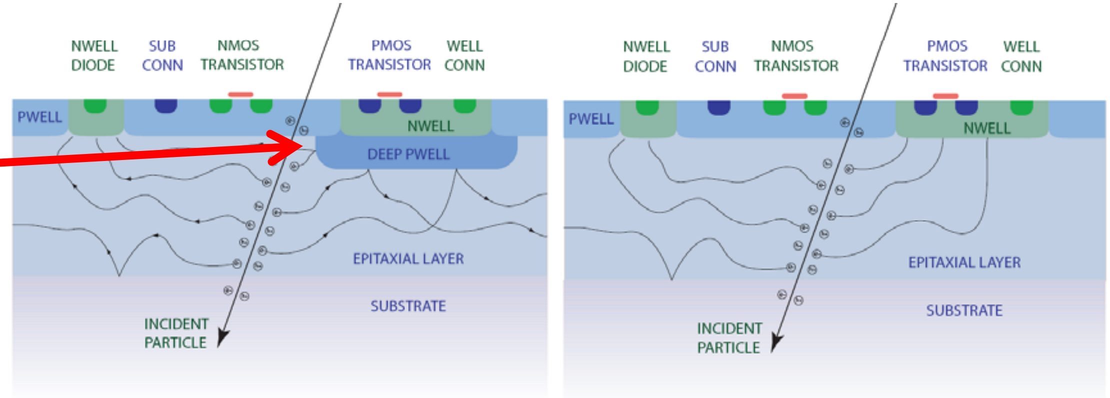
- Underlying motivations
  - CMOS so relatively low cost compared to conventional analogue Si
  - Electronics embedded in the sensor itself

Details of sensor geometry

- Charge collection diodes and CMOS electronics
- Thin (~15um) epitaxial layer for charge generation
- Substrate (~few hundred um)



- Enabling technology R&D was “deep P well”

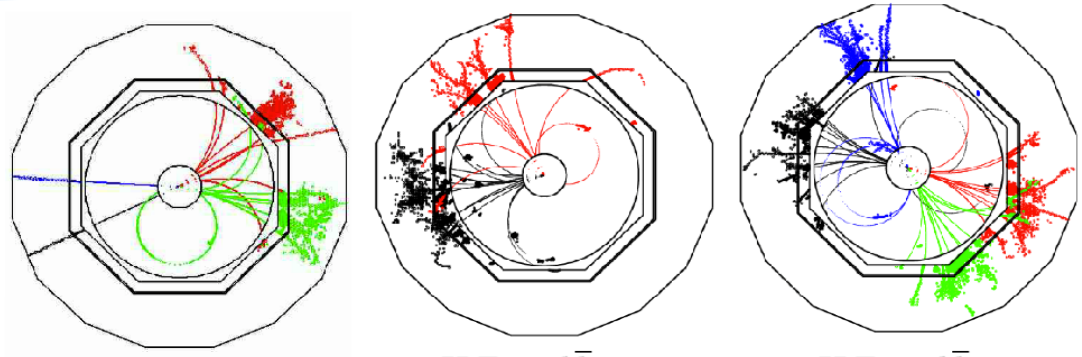


- In Mokka we do not model microscopic details, only:
  - Substrate, epi layers as separate sensitive detector volumes
  - 50um pitch as virtual cells
  - Single threshold applied in IldCaloDigi

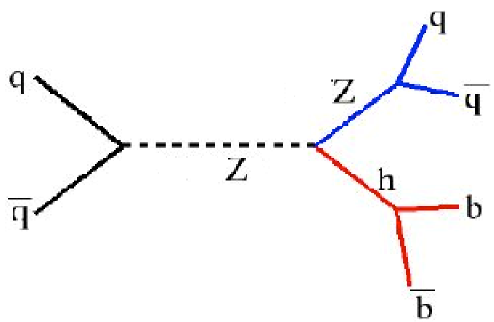
Without deep p well, charge Absorbed by n well electronics not collected by diodes

Search for the Higgs

- At ILC energy range Higgs will decay majoritly to b-bbar by Higgs-strahlung

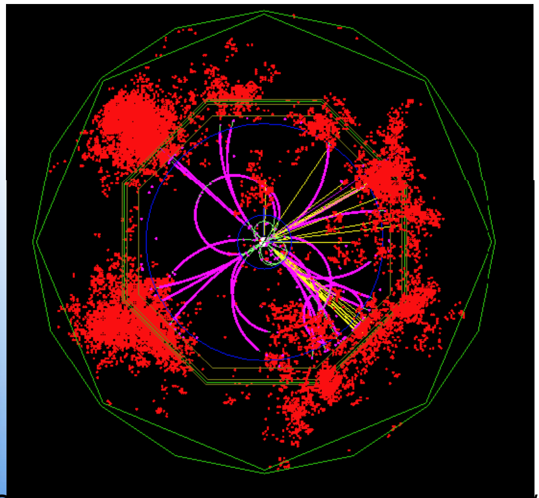


$HZ \rightarrow b\bar{b}\mu^+\mu^-$ $HZ \rightarrow b\bar{b}\nu\bar{\nu}$ $HZ \rightarrow b\bar{b}q\bar{q}$

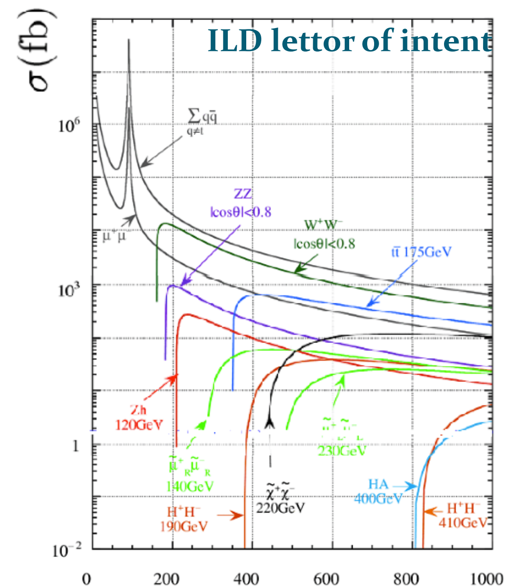


- Concentrate on HZ-> quarks topology!
  - Challenging to distinguish from ZZ -> qqqq decays

Ratio of Cross sections ZZ/HZ ~2

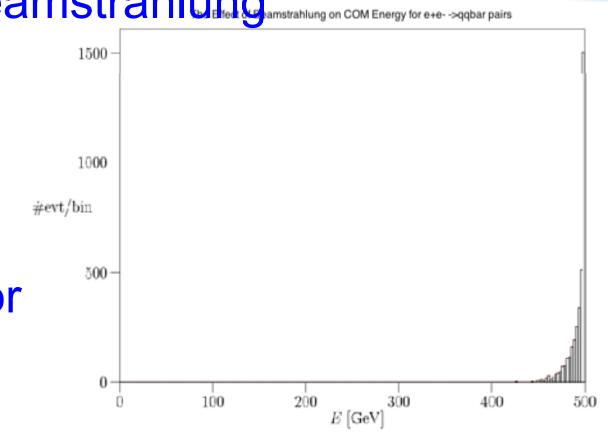


Performance of each ECAL determined by **Jet Energy Resolution** and its **Separation** of these very similar events



Event Generation

- **WHIZARD (1.96)**
  - Specified initial and final states, and decays, incl. beamstrahlung
  - 6k **HZ,** 6k **ZZ** decays at 500 GeV
  - **H** forced to decay to cc or bb, **Z** to all flavour quarks
  - Pythia fragmentation
  - Chose these channels as realistic jet environment for physics studies, not well separated Z→qq~



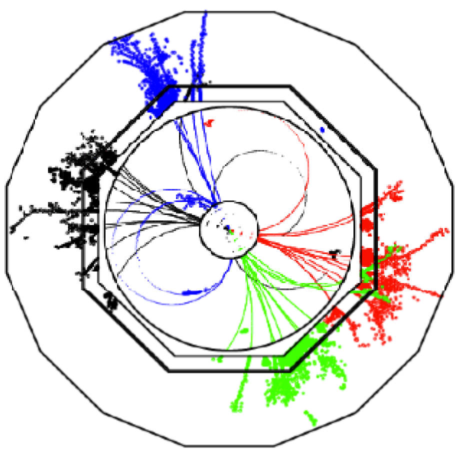
- Mokka 07-06
  - Changes for simple DECAL model implemented in SEcal03
  - This was last version of SiW analogue ECAL before very realistic details implemented (services, etc.)
  - For our purpose, older version preferable as allows “like with like” comparison
  - We do not have effort, and would be premature, to implement more sophisticated geometry for DECAL

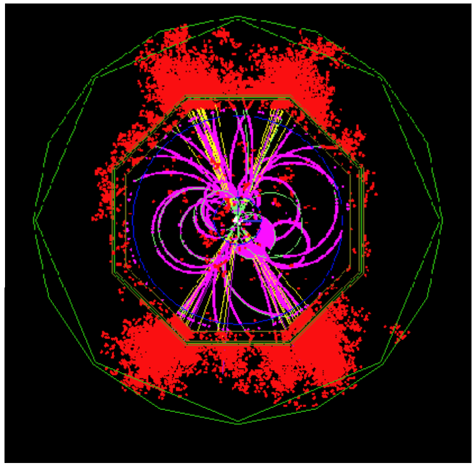
Simulation

- **Geant4** - Monte Carlo framework used to simulate particle interaction through detector matter
  - **Mokka** is the particular simulation for the ILD
- Each detector type has specific Geometry file
  - Specifying silicon pixel sizes, detector dimensions etc.
- Hadrons 4-vectors from WHIZARD are input and their motion and energy deposits are modeled

$HZ \rightarrow bbqq$

ILC Simulation





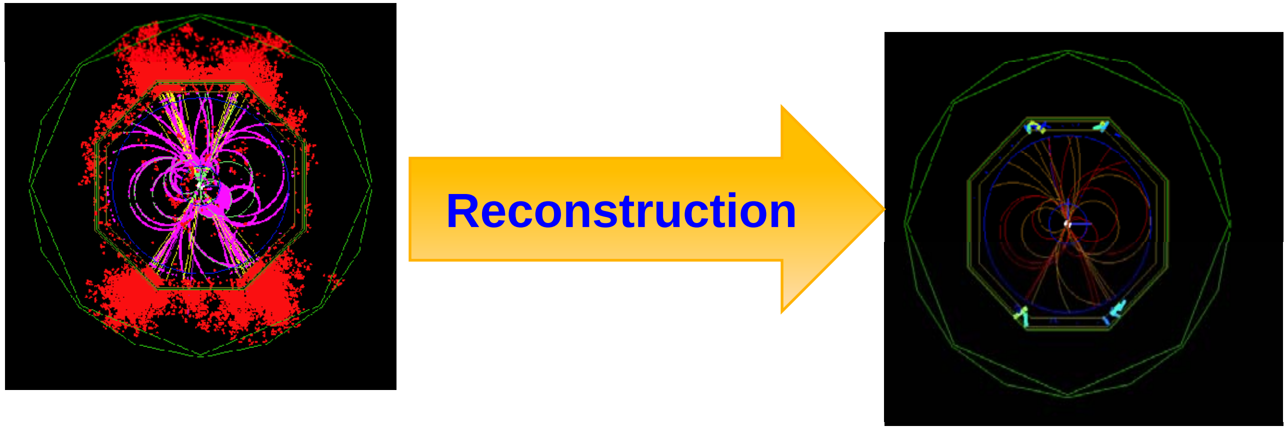
$HZ \rightarrow qqqq$

My Simulation

Critical to keep simulation software separate for each ECAL

Reconstruction

- **MARLIN**
  - **Illsoft v01-10,MarlinReco v00-19, IldCaloDigi, PandoraPFANew v00-04**
  - Single threshold energy cut for all pixels



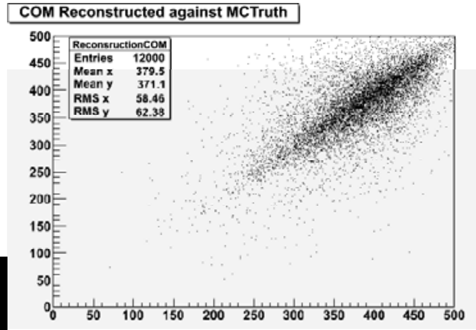
- Forced **HZ and ZZ,** to four jets
- Use natural variation in jet energies within sample at fixed centre-of-mass energy to estimate jet energy resolutions

Reconstruction Problems I

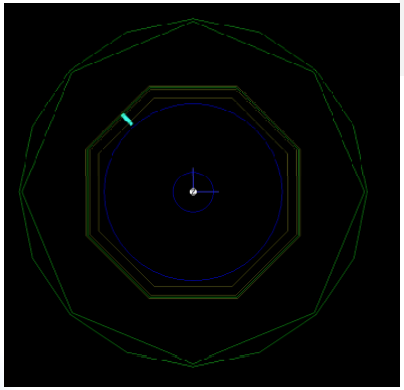
- **Reconstructed event energy ~20%** lower than expected
  - Up to 10% from Beamstrahlung
  - Standard Reconstruction Model changed, still energy discrepancy
  - Possible problem with model calibration?

AECAL

E(GeV)

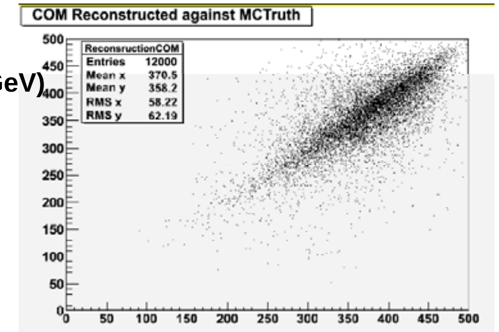


E(GeV)



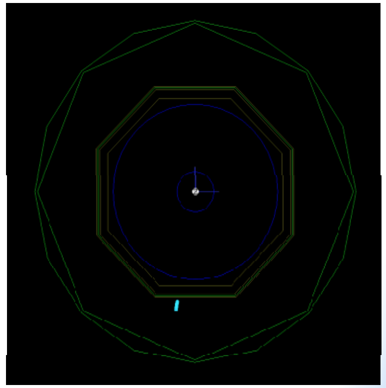
Photon successfully reconstructed

E(GeV)



E(GeV)

DECAL



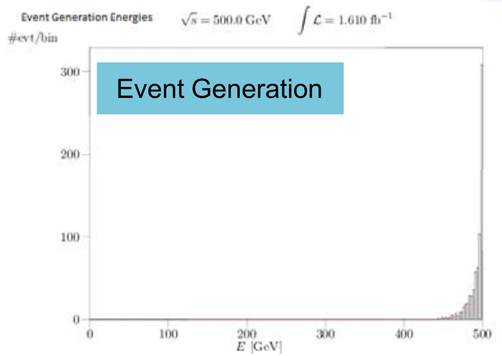
Kaon^0 successfully reconstructed

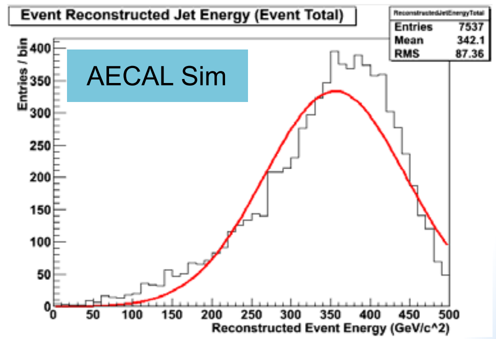
- **Comparison of two** ECALs so relative performance of most interest
  - **Assume results valid at required level**

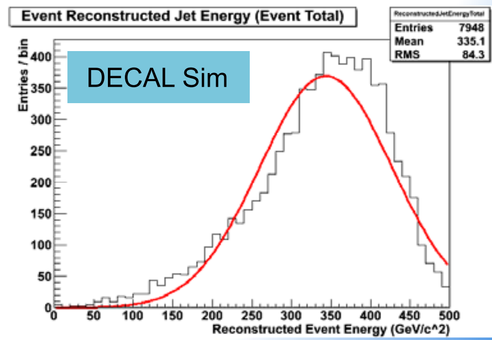
Reconstruction Problems II

- Reconstructed jet energies **lower** than Whizard as expected, up to 10% is lost as a result of **beamstrahlung**
- Reconstructed and truth jet energies are consistent
- **Problem with reconstruction?**
- Various ideas for cause, as of yet no solution
  - Reconstruction software problem
  - Simulation or model **calibration *** most likely!**
  - **Our misuse (abuse?) of PandoraPFA**? Pandora has only been tested with photons and K_L until now using DECAL
- For physics studies this is not an issue

  like-with-like comparisons

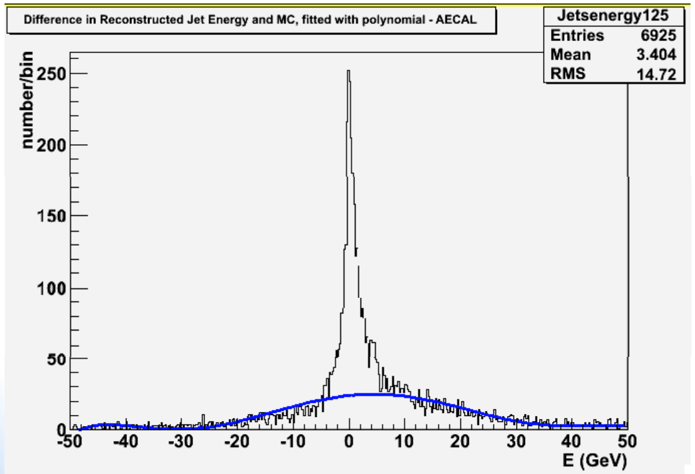


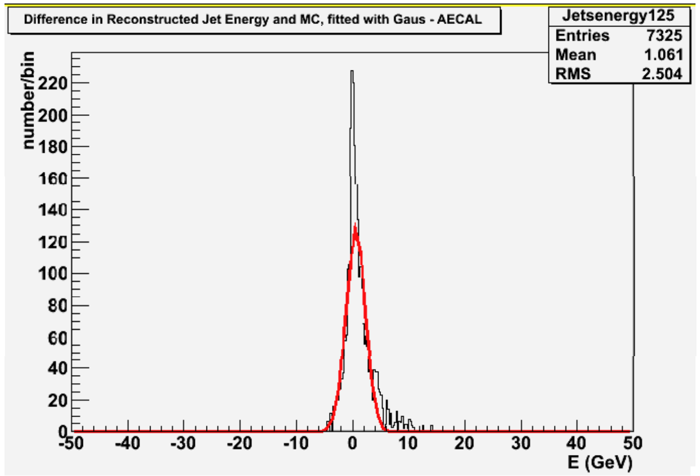




Analysis

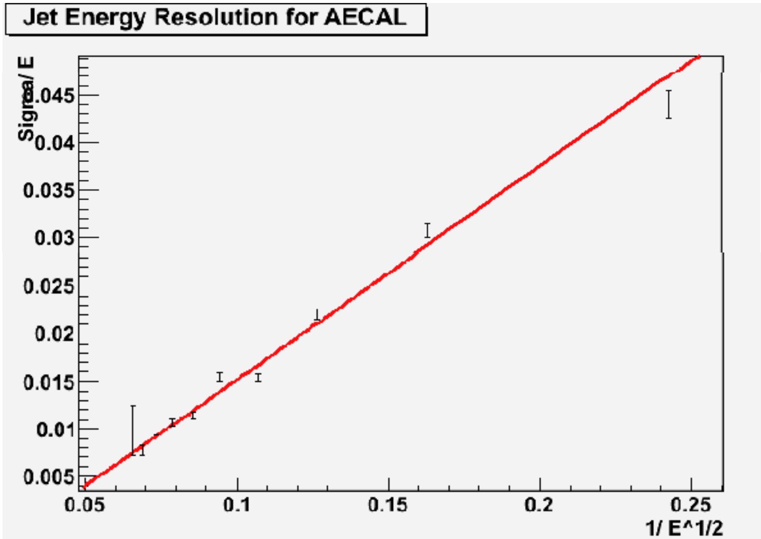
- **Compared reconstructed to MCTruth energies** for each jet
- Each jet binned according to MCTruth energy
  - 10 bins each at 25 GeV intervals
- **Polynomial fitted** to to remove outliers
  - Outliers assumed to be dominated by algorithm
  - Detector resolution categorized by peak



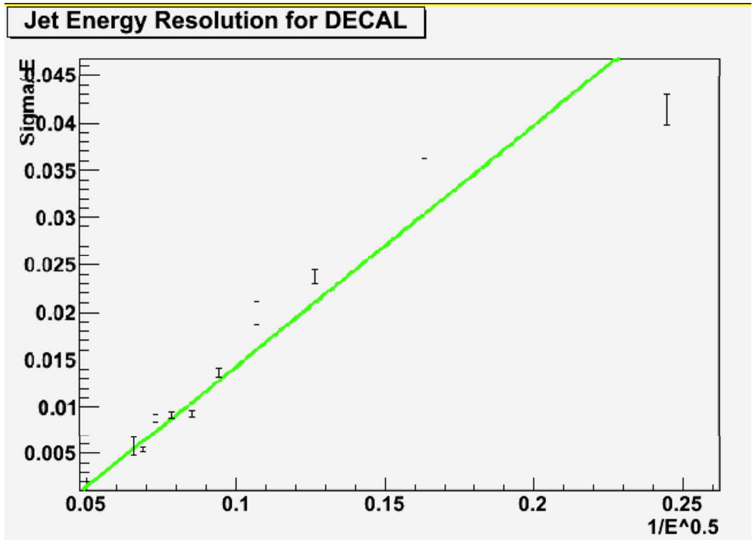


Resolution

- Each bins **sigma value** used alongside average MC energy to **calculate resolution**



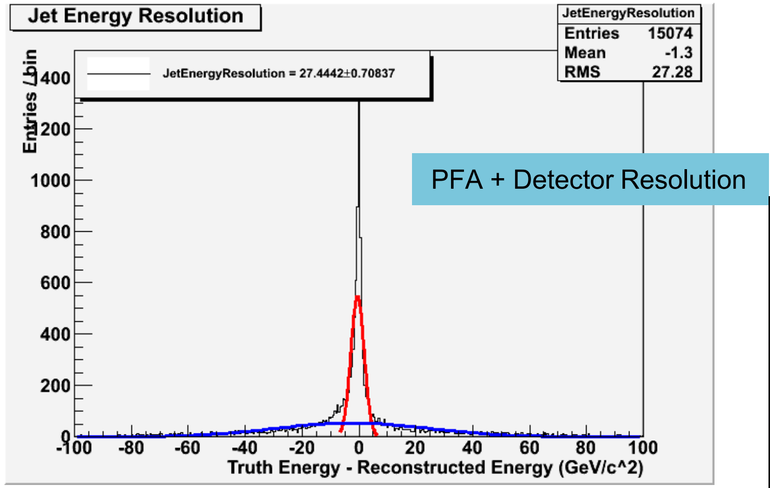
$$(22.3 \pm 0.5)\% / \sqrt{E(GeV)}$$

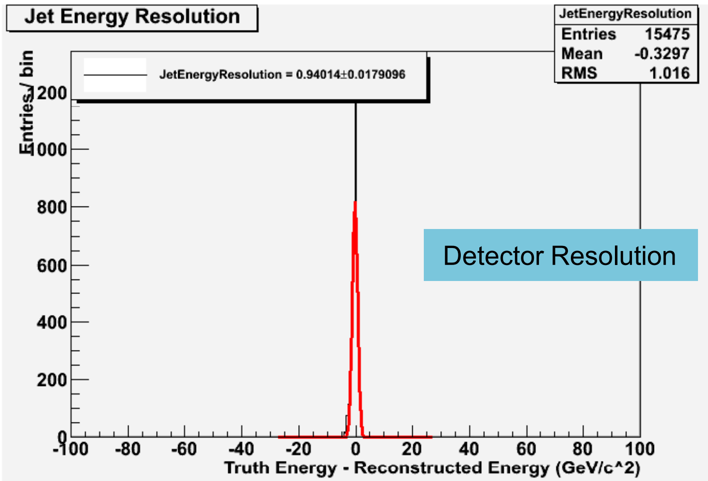


$$(25.5 \pm 0.6)\% / \sqrt{E(GeV)}$$

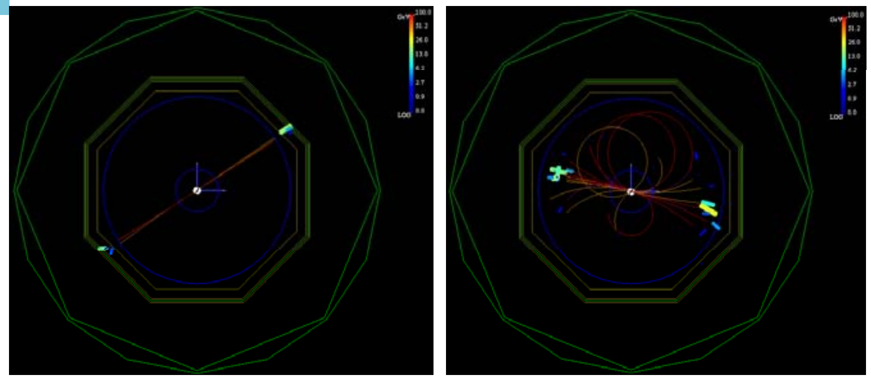
- **Comparable with required resolution**
- **AECAL –** compatible with earlier studies by others
- **DECAL -** resolution never been simulated this rigorously for ILD
  - **Idealized** case (9.52 ± 0.07)%/E(GeV)$^{1/2}$ – e-, photons

Detector Performance in Tau pairs





- Similar studies carried out for tau pair events, with background from light quarks, low mult. Hadronic jets

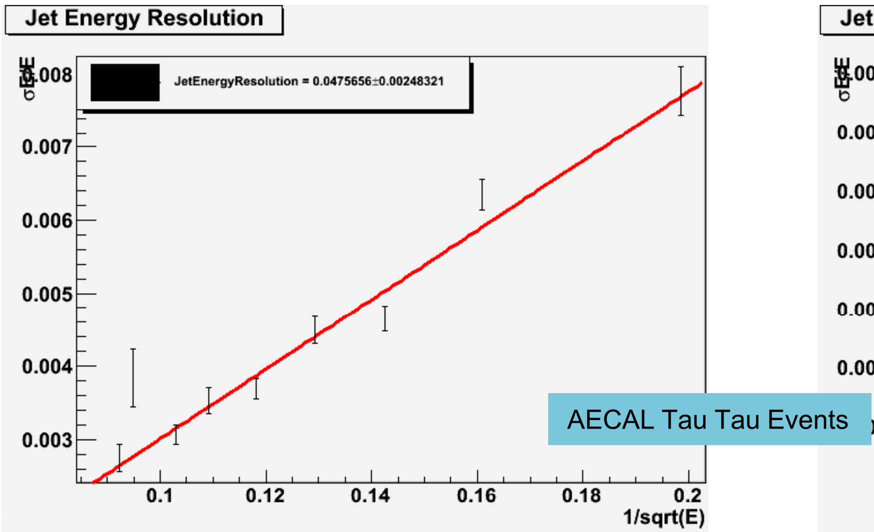


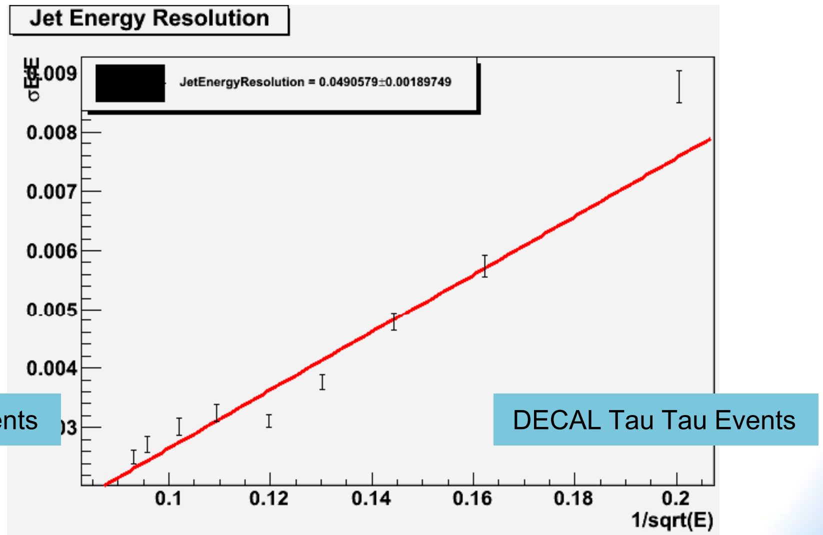
- Wide background found under central peak, fit only for central region, assert that **large divergence** from zero suggests association problems

- Left with a pure jet energy resolution for detector performance, compare DECAL with AECAL

Jet Energy Resolution Comparisons in tau pairs

- **Jet energy resolution** is calculated over wide range of jet energies, from 25 GeV – 250 GeV
- Approx. Linear, with some spread.
- Find jet energy resolutions for AECAL and DECAL are (4.76±0.24)%/√E, and (4.91±0.18)%/√E respectively





Summary

- Different stages of data production - like to like comparison
  - **Event generation** using **WHIZARD**, HZ & ZZ
  - **Simulation** of particles motion through ILD using **MOKKA**
  - **Reconstrustion** of particles using **MARLIN**
- The different methods to analyse data
  - **Jet energy comparison** to Truth energy, determine **Resolution**
  - **Minimum mass difference** between bosons to **separate signal**

Conclusions

- This like with like comparison project has shown:
  - Hadronic jets
    - **AECAL** resolution to be (22.3±0.5)
    - **DECAL** resolution to be (25.5±0.6)
  - Tau pairs
    - 4.76±0.24% **AECAL**
    - 4.91±0.18% **DECAL**

- DECAL (if it works) would be a valid choice for ILD, based on simulations so far…
- Successfully carried out a like-with-like comparison of AECAL and DECAL