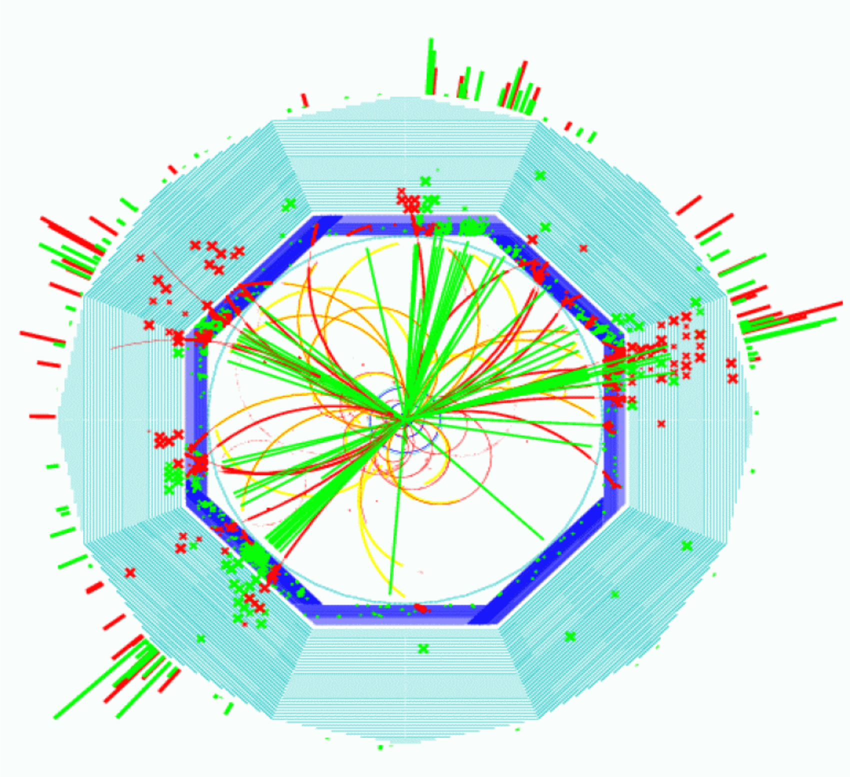
Review of PFlow Algorithms



Alexei Raspereza, DESY

Simulation Workshop, DESY, June 27 2005

Particle Flow :

Concept of Event Reconstruction @ LC

- PFlow concept : reconstruction of every particle in event

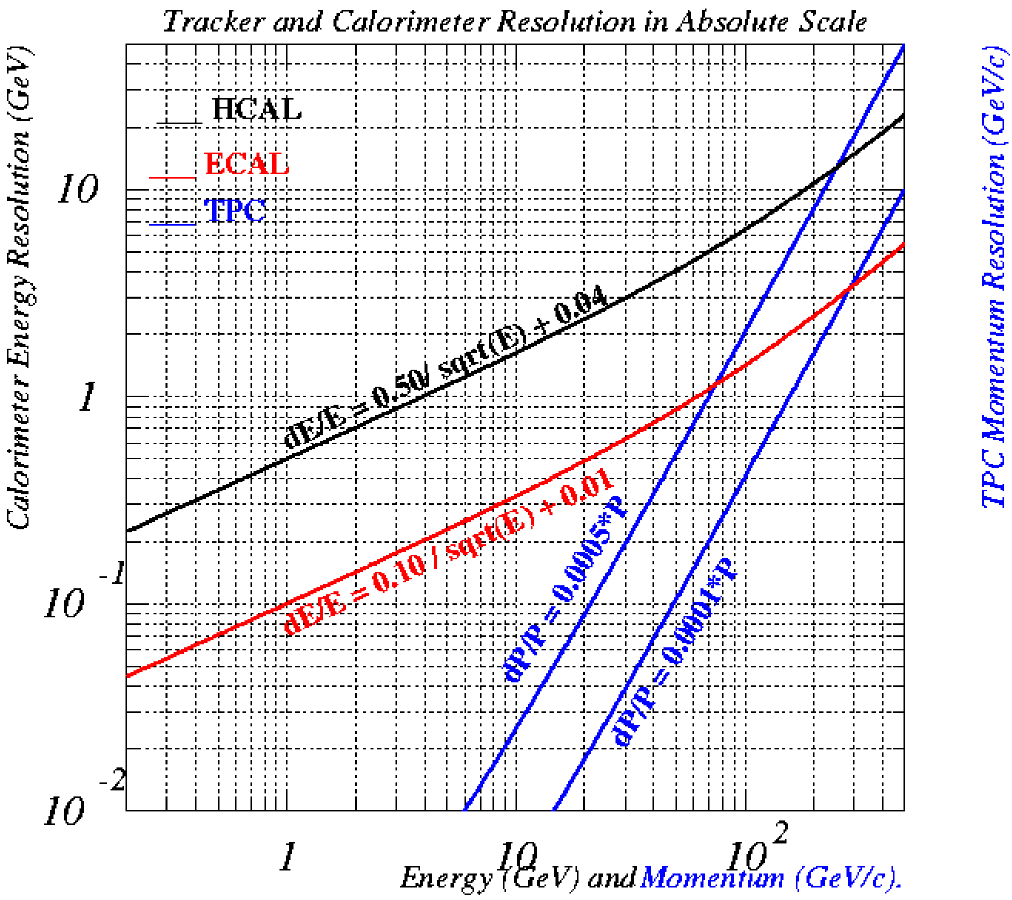
- Over energy range up to ~100 GeV tracker is superior w.r.t. calorimeter → use tracker to reconstruct charge objects ($e^{\pm}$, $\mu^{\pm}$ and $h^{\pm}$)

- Ecal : γ reconstruction

- Ecal + Hcal : h^0 reconstruction

- Efficient separation of showers is crucial

- Detector optimization is driven by PFlow



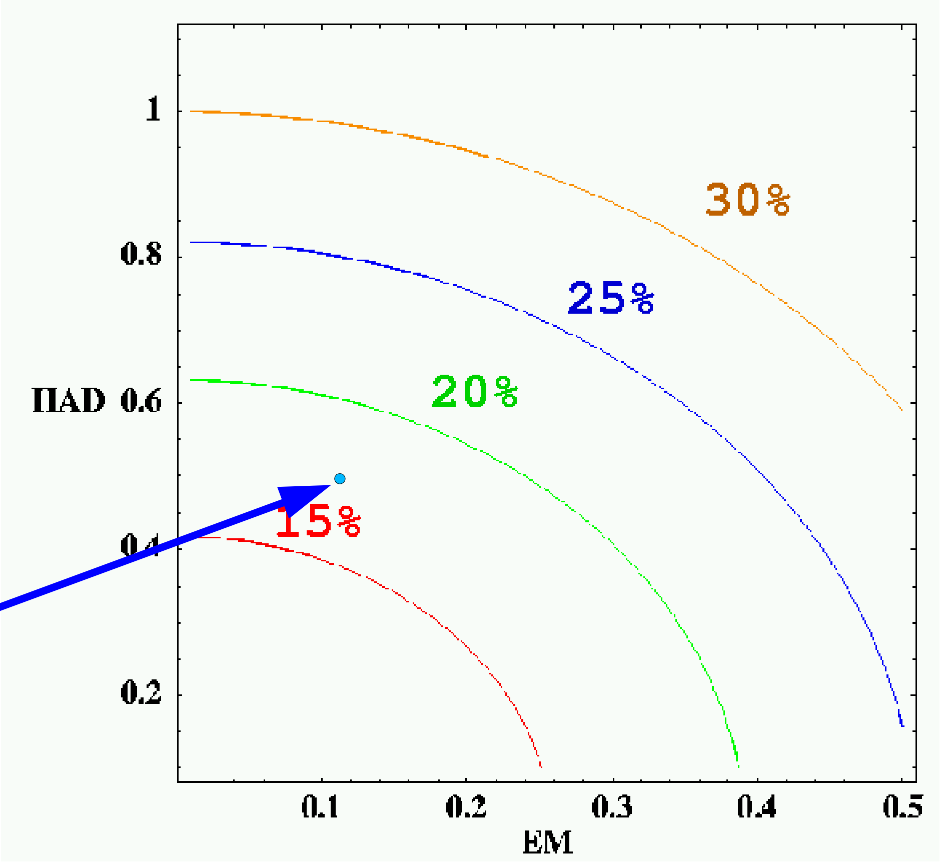
Perfect Particle Flow :

Jet Energy Resolution

- Theoretical computation :
  - $\sigma^2(E_j)=\sigma^2(\text{charg.})+\sigma^2(\gamma)+\sigma^2(h^0)+\sigma^2(\text{conf.})$

- TPC momentum resolution is much better than energy and angular resolution of calorimeters $\Rightarrow$ $\sigma^2(\text{charg.})$ is negligible

- Perfect Pflow : $\sigma(\text{conf.}) = 0 \Rightarrow$
  - $\sigma^2(E_j) = f_\gamma\,(0.11)^2\,E_j + f_{h0}\,(0.50)^2\,E_j$



- Typically $f_\gamma = 0.25$; $f_{h0} = 0.12 \Rightarrow$
  - $\sigma^2(E_j) = (0.17)^2\,E_j$

More on this topic in the talk by Predrag

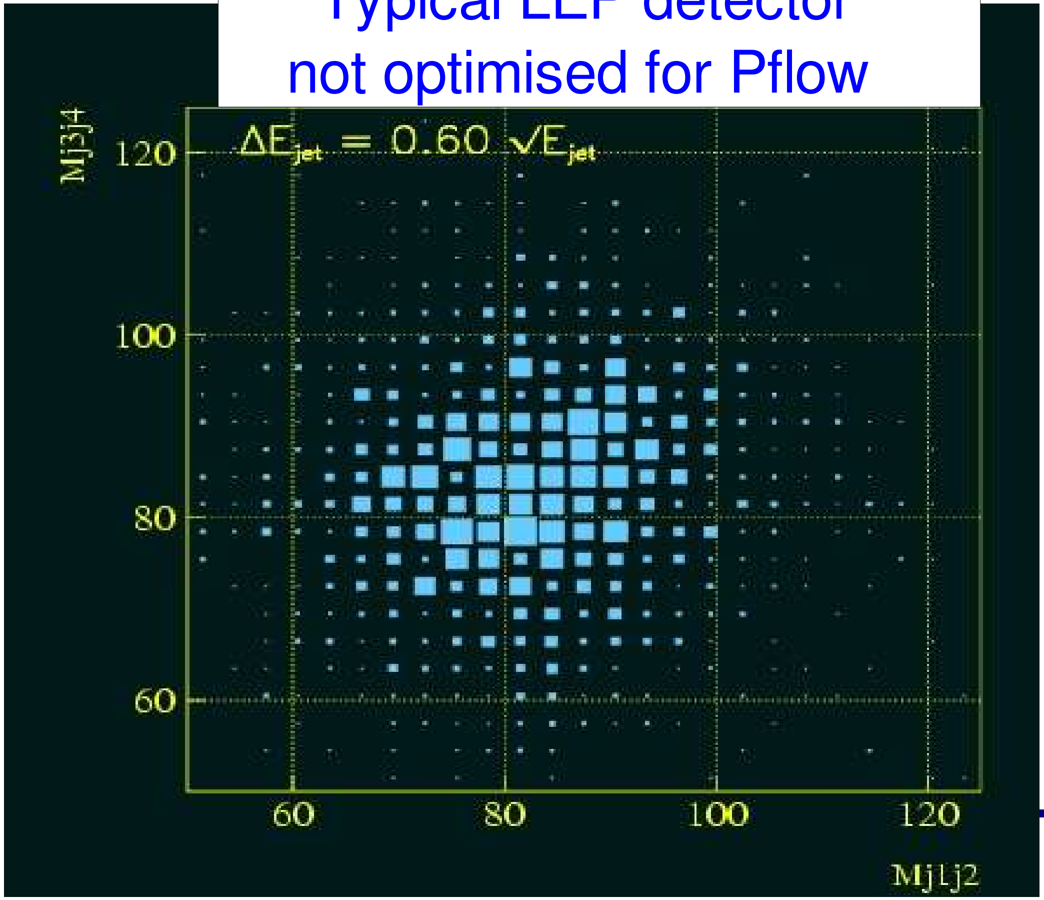
Implications of Pflow :

Reconstruction of Multi-jet Events

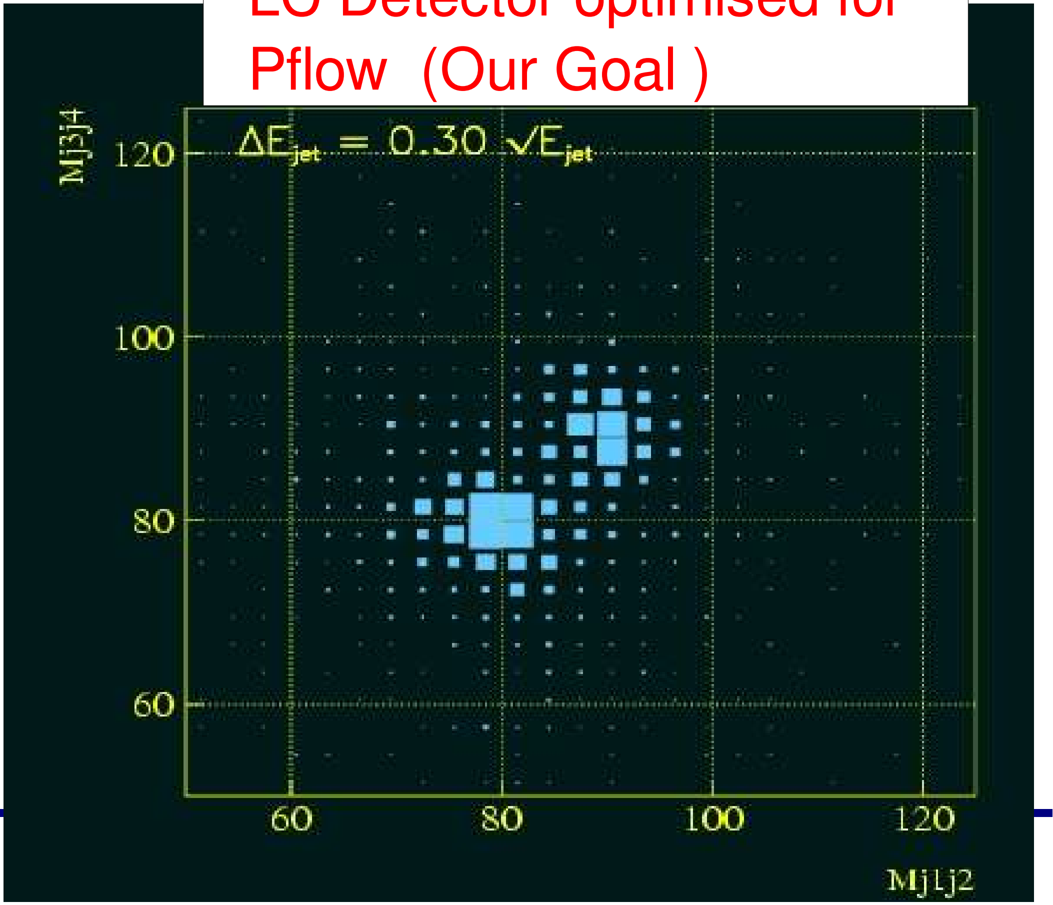
Separability of WW and ZZ ; 4-jets + missing E

$e^+e^- \rightarrow ZZ\nu\nu, WW\nu\nu$ @ 1 TeV (Signals for strong EWSB !)

Typical LEP detector
not optimised for Pflow



LC Detector optimised for
Pflow (Our Goal)

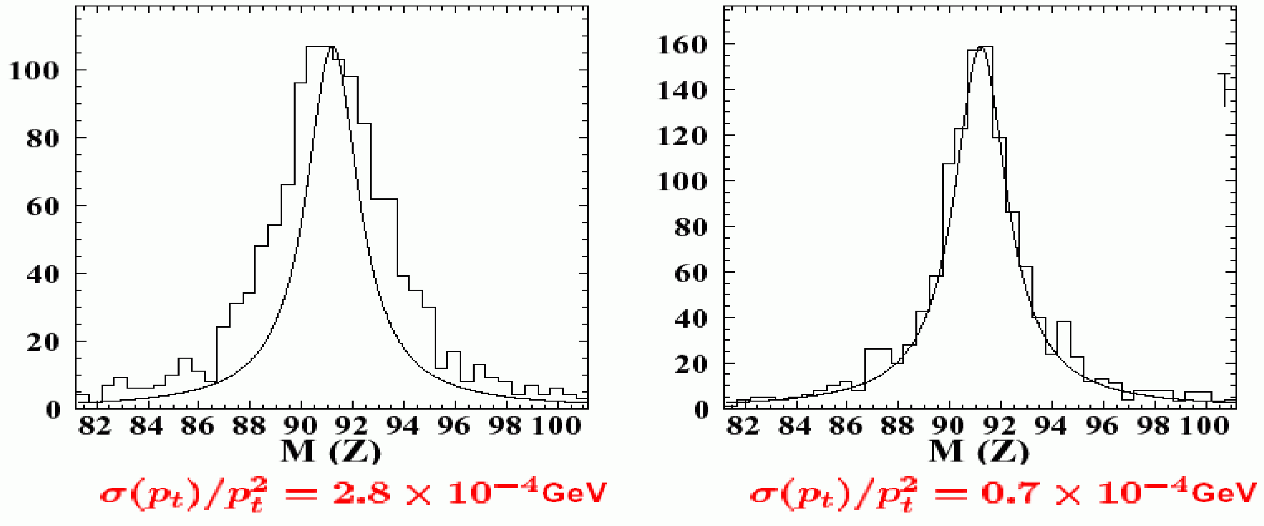


Detector Design in the Light of PFlow

Tracker Design. TPC Option

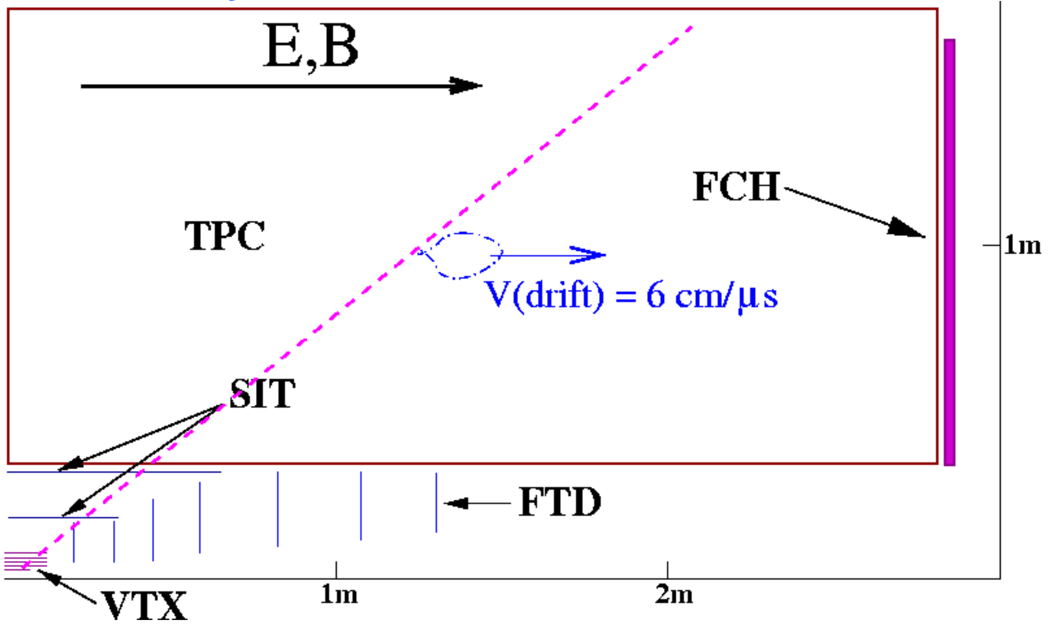
Benchmark conditions :

- Good momentum resolution such that σ_{mZ}(detector) $\ll \Gamma_Z$ in Z→ ee, μμ decays
- Efficient pattern recognition in multijet events



$\sigma(p_t)/p_t^2 = 2.8 \times 10^{-4}$GeV

$\sigma(p_t)/p_t^2 = 0.7 \times 10^{-4}$GeV

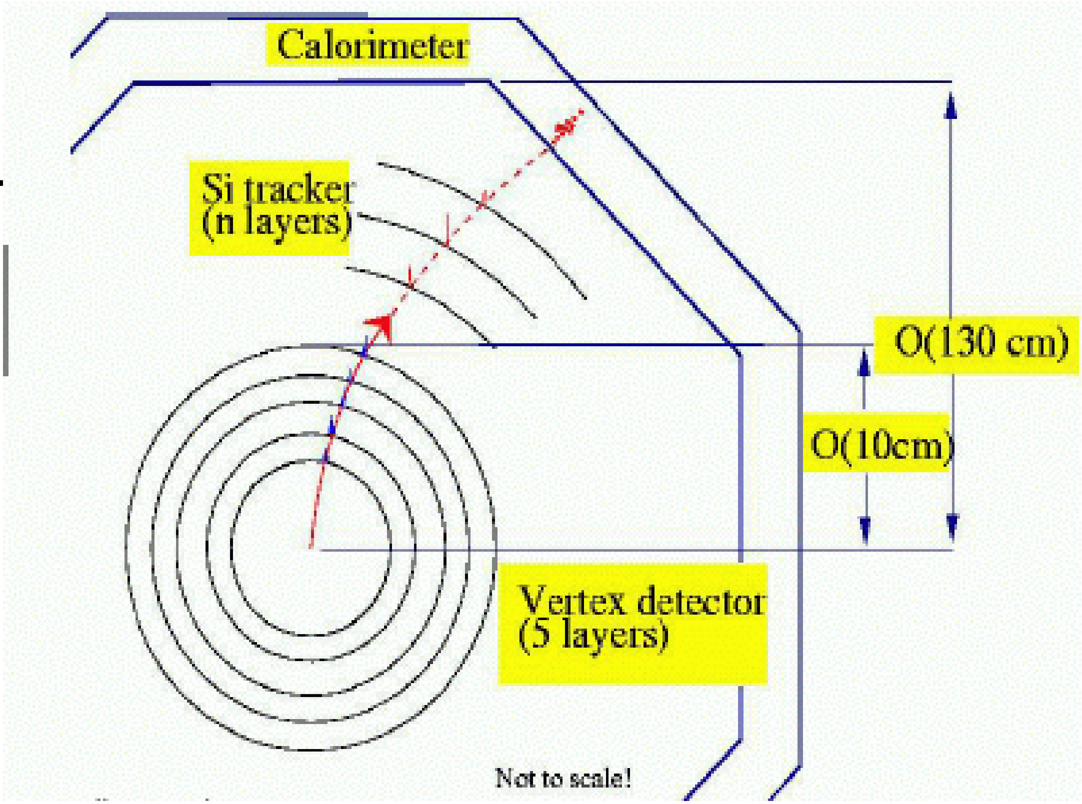


TPC : promising choice

- tracking to large radius → sensitivity to long lifetimes
- many space-points → large redundancy
- true 3D reconstruction (1 time, 2 space coordinates)
- gaseous detector, no wires → not much material
- particle ID through dE/dx

Tracker Design.
Silicon Tracker Option.

- N Layers of Si detector (5 layer option is currently considered)
- Decrease in number of points per track is compensated by higher precision of the single point measurements
- Heavily relies on vertex as track "seeder"
- Reconstruction of V0's, kinks and low p_T particles provides a challenge

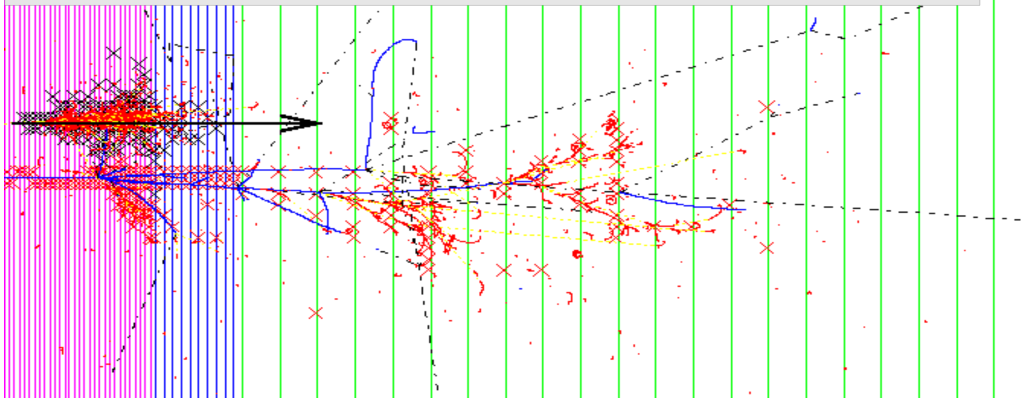


ECAL Design

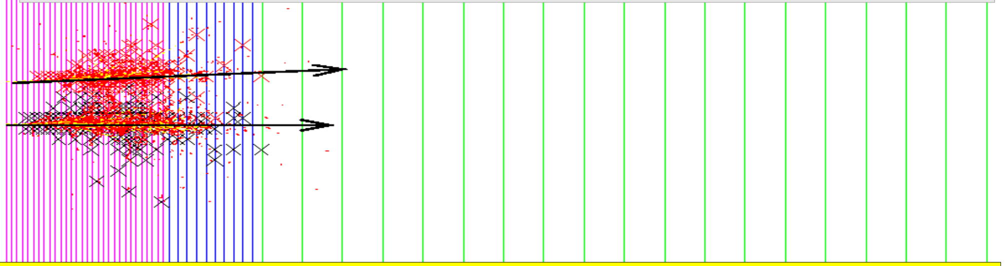
- PFlow favors sampling calorimeter with fine transverse segmentation : cell size ~ R_M
- Low X_0 / $\lambda_{nucl.}$ for absorber material → longitudinal separation of EM and hadronic showers
- Small R_M → transverse separation of particles
- Small spacings between absorber layers to keep effective R_M small
- W – Si sandwich seems to be optimal choice
- ~ 40 layers : few mm W plate + 0.5 mm Si layer ; total depth of 24 X_0

Good γγ , γh and γμ separation down to few cm distance

8 GeV γ & 6 GeV π^+ @ 4 cm distance



5 GeV γ & 4 GeV γ @ 3 cm distance π^0 decay



Energy resolution : 11% /√E for EM particles

Angular resolution : 68 mrad /√E + 8 mrad Identification of photons non-pointing to IP !

HCAL Design

- The same requirement as for ECAL : sampling device with fine transverse segmentation. Two options :

- Analogue HCAL :
  - ➔ Fe absorber plates; 2 cm thick (W absorber option also considered)
  - ➔ Sci tile as an active element; 5 mm thick
  - ➔ Amount of light → measure of energy (analogue approach)
  - ➔ Transverse granularity : technical/cost limitation ~3×3 cm^2

- Digital HCAL : read out in a fine granular way
  - ➔ Fe or W absorber plates
  - ➔ RPC as an active element (few mm thick chamber including gas volume & glass plates)
  - ➔ Counting # of fired cells → measure of energy (digital approach)
  - ➔ 1×1 cm^2 cell size
  - ➔ tile DHCAL is technically difficult to construct

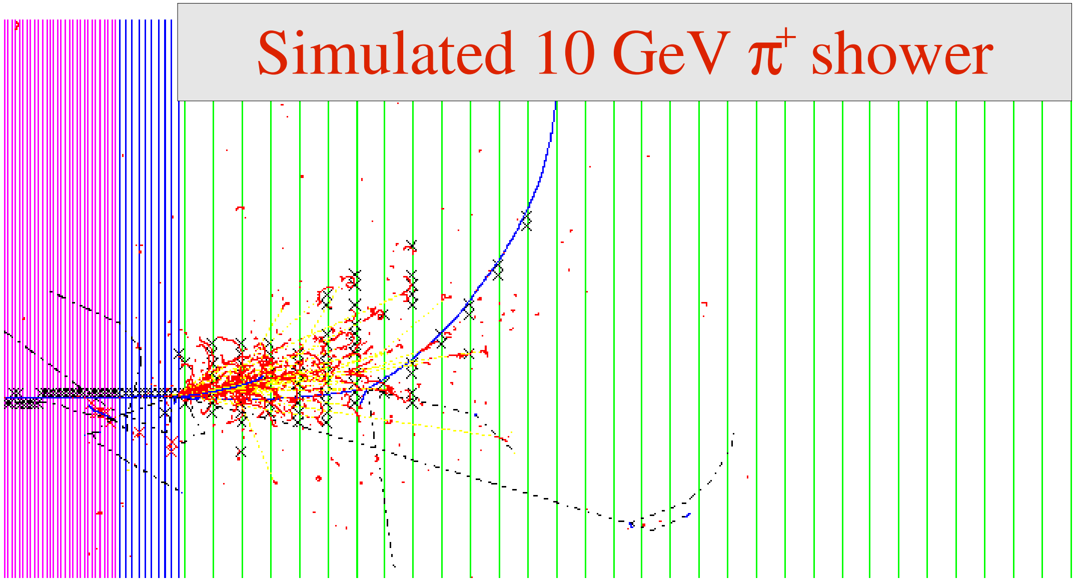
Particularities of Hadronic Showers

- Shapes of hadronic showers depend on number and position of nuclear interactions and number and 4P vectors of secondaries produced in these interactions.

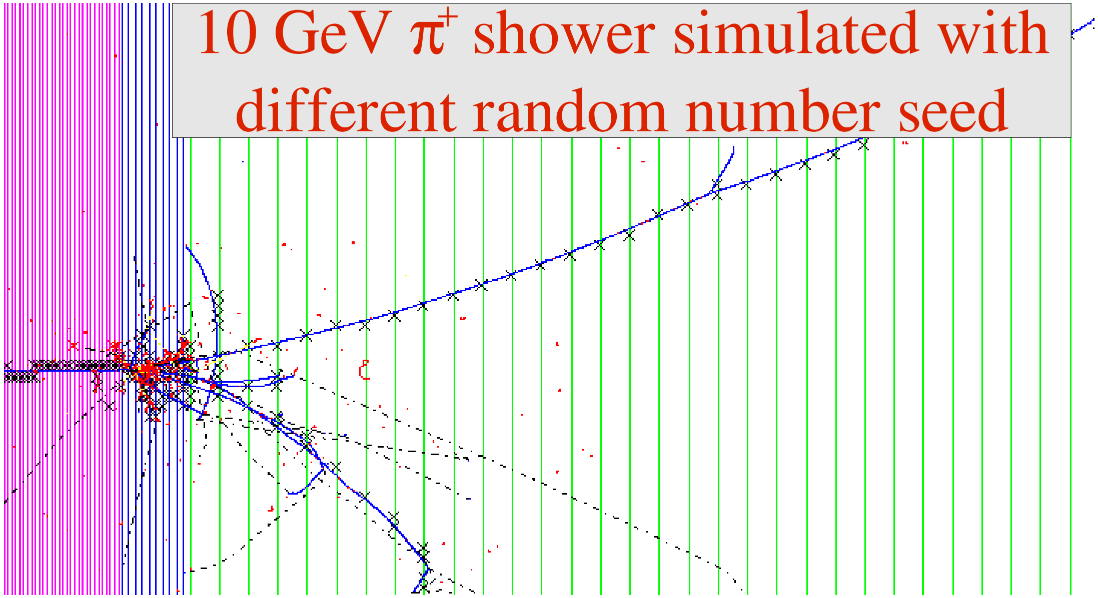
- Each of these factors largely fluctuates from shower to shower

- Shape of showers is ill-defined

⇒ **No a priori knowledge on shower shape can be used**



Simulated 10 GeV π^+ shower



10 GeV π^+ shower simulated with different random number seed

PFlow : General Scheme

Reconstruction : Track Finding

- Find track clusters; Cluster : set of spatially continuous measurement points (hits) compatible with helix hypothesis

- For each cluster found, fit set of points with helix (optionally correction for energy loss)

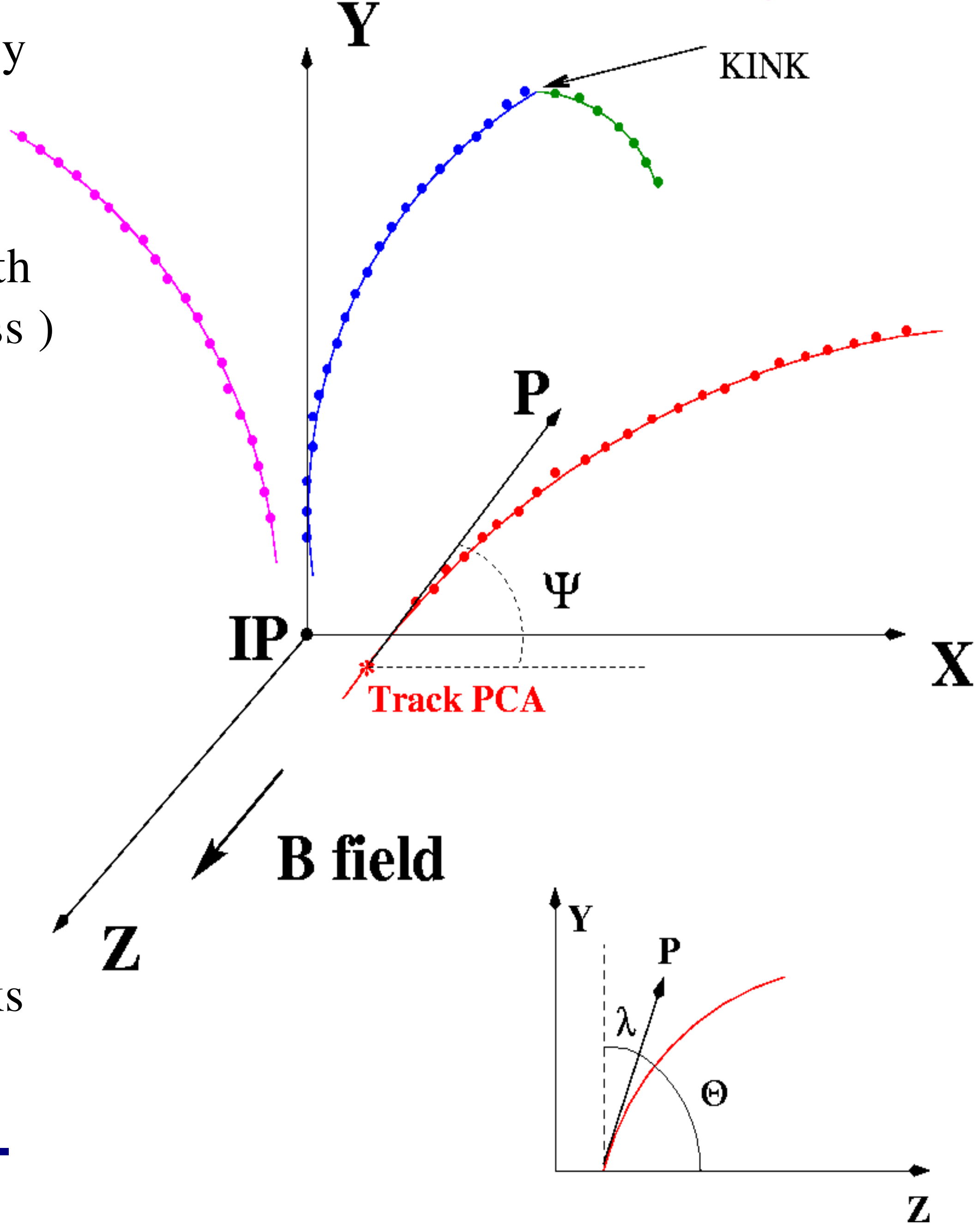
$X=X_0+R\cdot\cos\phi$; $Y=Y_0+R\cdot\sin\phi$; $Z=Z_0+b\cdot\phi$

- For each fitted track find point of closest approach (PCA) to IP (0.,0.,0)

- Determine momentum @ PCA :
  - $P_T\,[\mathrm{GeV/c}]=0.3\cdot B[\mathrm{T}]\cdot R[\mathrm{m}]$

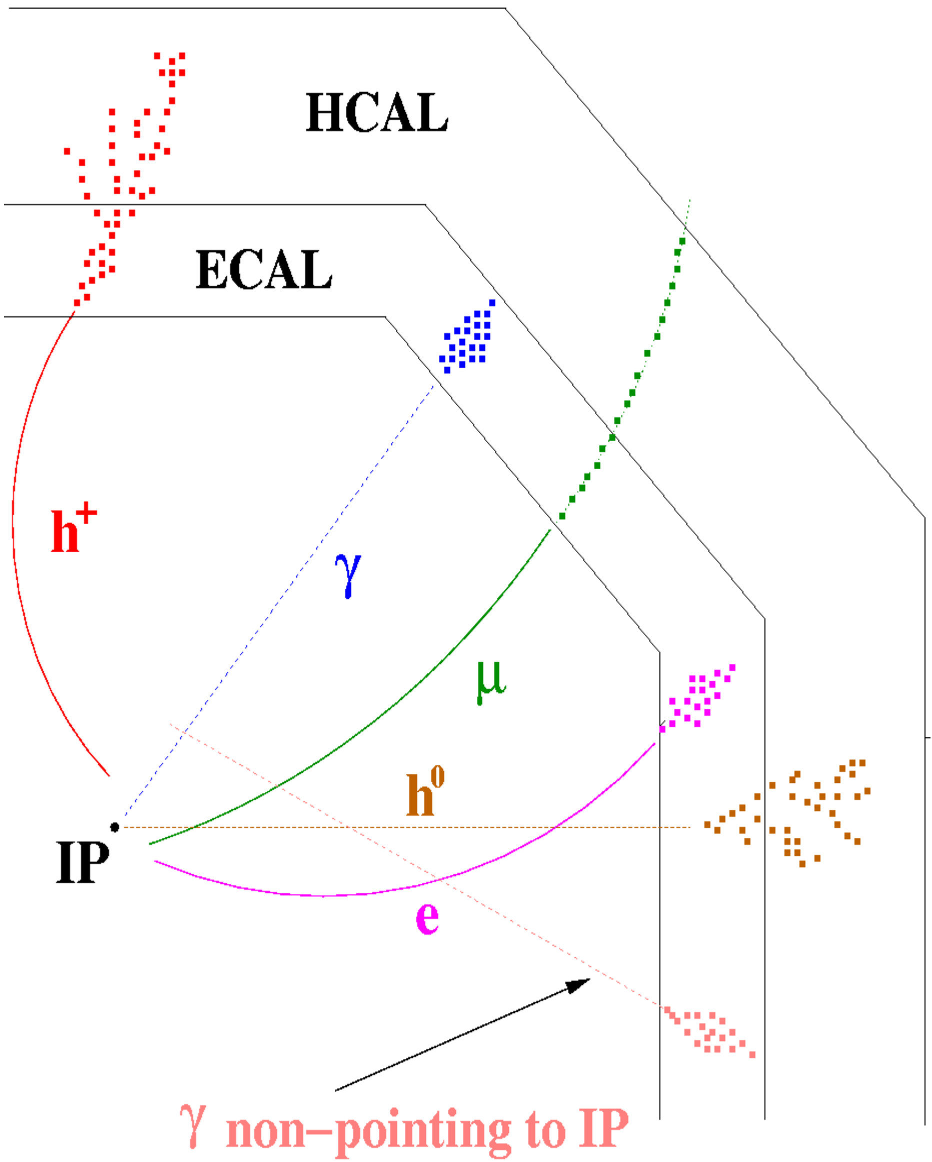
$P_x=P_T\cdot\cos\Psi$; $P_y=P_T\cdot\sin\Psi$; $P_z=P_T\cdot\tan\lambda$

- Special handle of neutral vertices and kinks (explained later on)



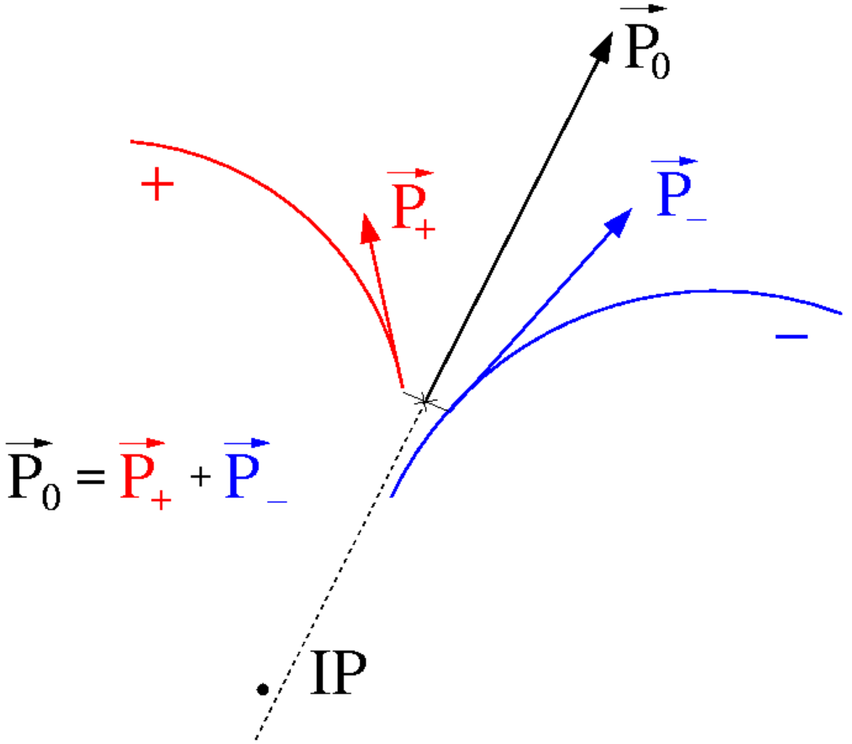
Calorimeter Clustering. Neutrals. Particle ID

- Find clusters in ECAL and HCAL
- Attempt to match calorimeter clusters with tracks
- If matched track found → charged object → 3-momentum from tracker
- If no matched track → neutral object (γ or h^0)
- Find centre-of-gravity of neutral cluster, connect IP to C-o-G position → direction of momentum
- Identify photons non-pointing to IP, use cluster directional information to estimate 3-momentum of photon (tough for hadrons)
- Energy of calorimeter cluster => energy of neutral particle
- $\vec{P} = |E| \cdot \vec{n}$ for γ , $\vec{P} = \sqrt{E^2 - m^2} \cdot \vec{n}$ for h^0



V0's and Kinks

V0's : γ conversions; Λ^0 , K^0 decays



$\vec{P}_0$

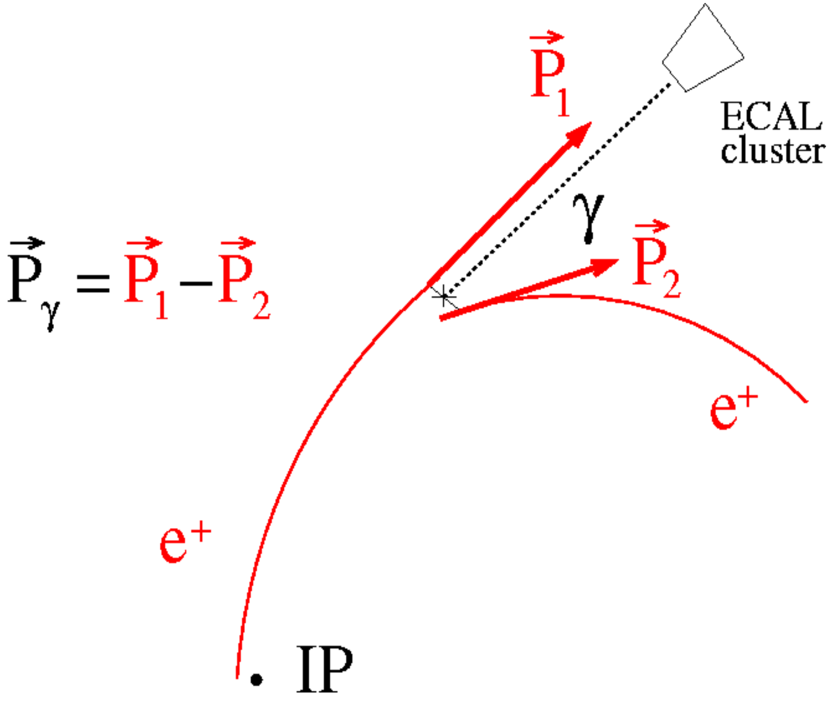
$\vec{P}_+$

$\vec{P}_-$

$$\vec{P}_0 = \vec{P}_+ + \vec{P}_-$$

Replace charged tracks {secondary objects} by reconstructed neutral particle {primary object}

Kinks : bremstrahlung ; $\pi^\pm$ $K^\pm$ $\Sigma^\pm$ ... decays



$\vec{P}_1$

$\vec{P}_2$

$$\vec{P}_\gamma = \vec{P}_1 - \vec{P}_2$$

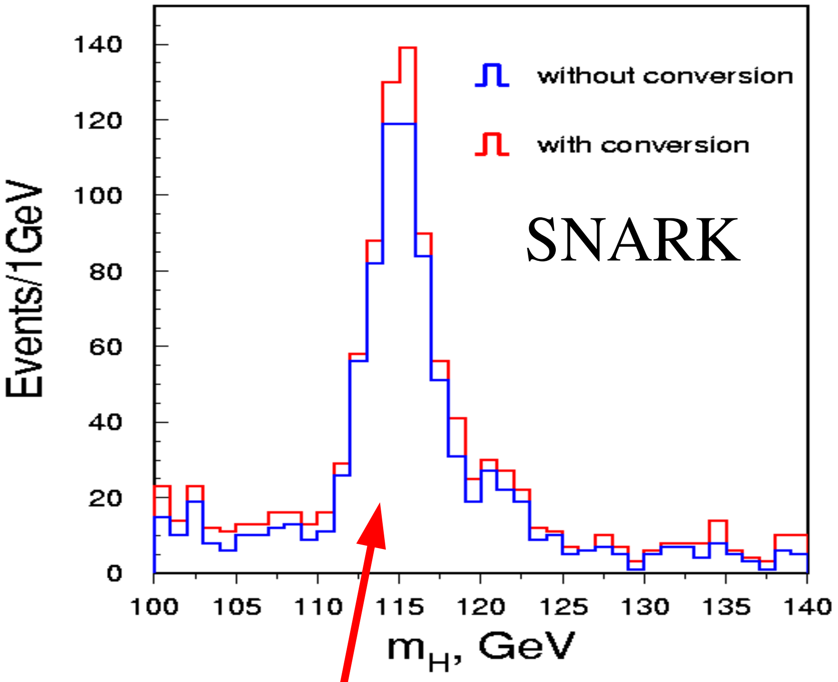
Replace outgoing track and associated neutral cluster (if any) {secondary objects} by incoming track {primary object}

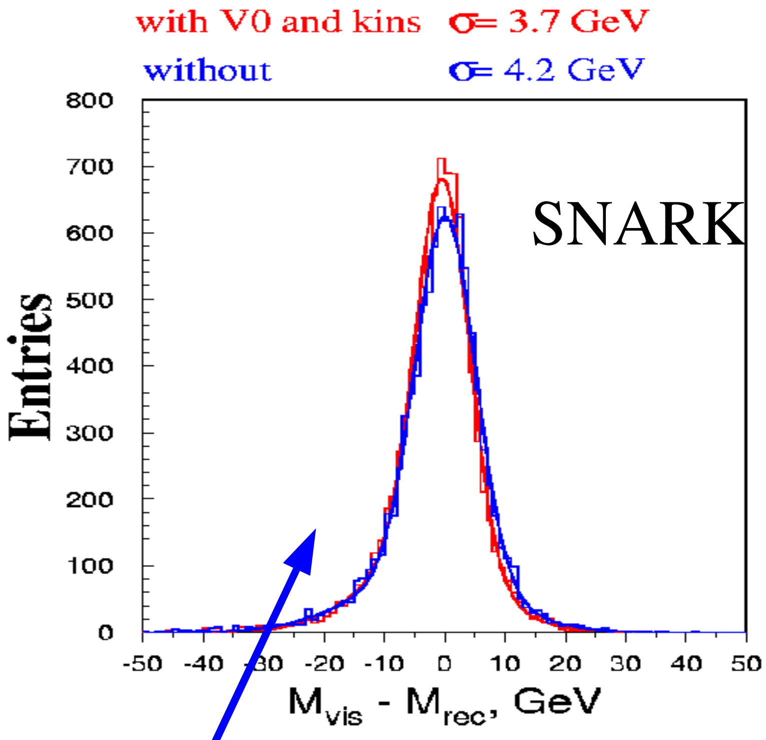
Implications of V0 and Kink Finding

$HZ \to \gamma\gamma qq$ @ $\sqrt{s} = 350$ GeV, $m_H = 115$GeV

In ~20% of events at least one γ undergoes conversion

$Z \to qq$ @ $\sqrt{s} = 91.2$ GeV





15% efficiency recovery with dedicated V0 finding procedure

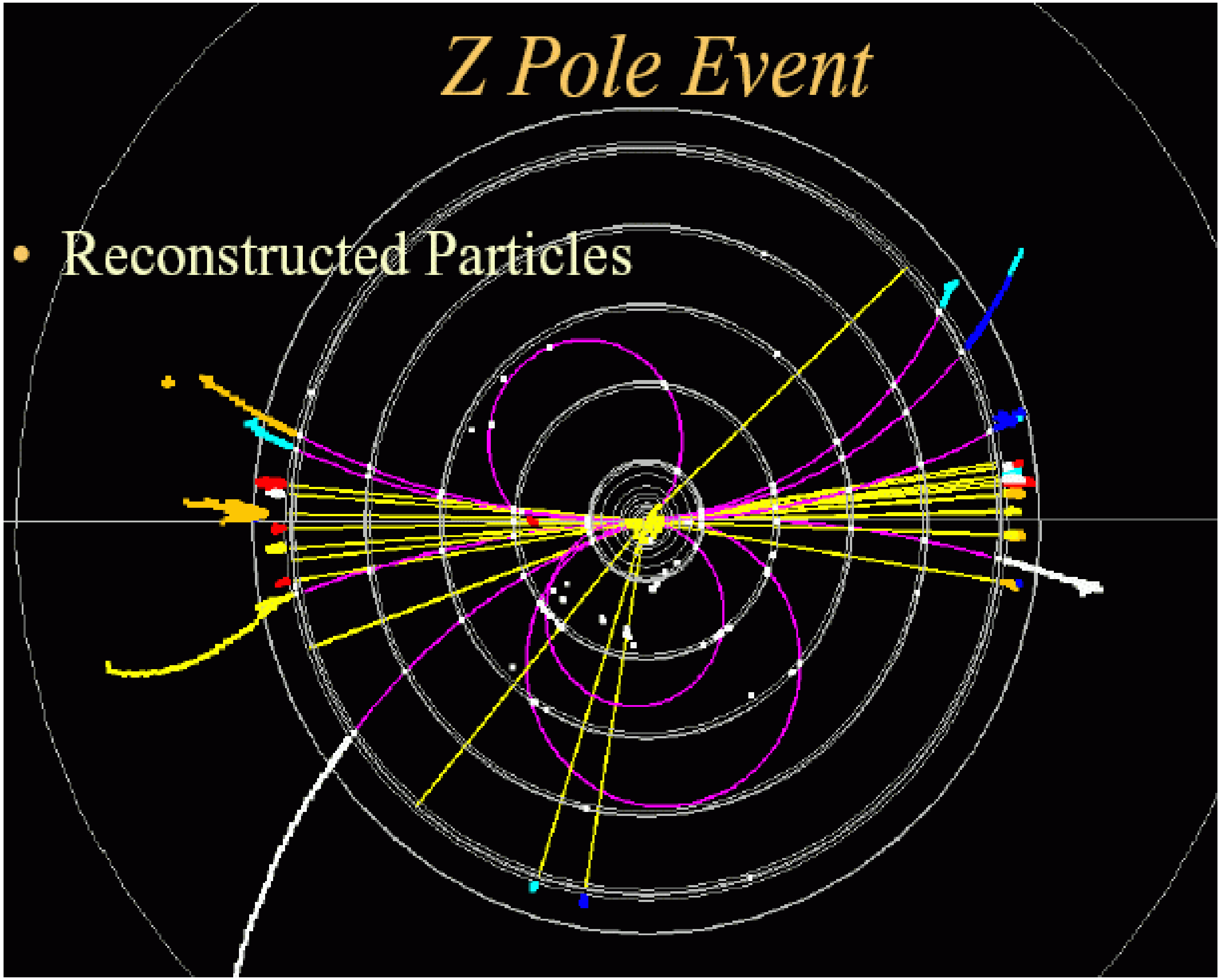
Dedicated V0 & kink finding procedure improves resolutions on boson masses

Pflow Algorithms : North America

Reconstruction is applied to SiD option:

- Si Tracker (5 layers)
- W-Si ECAL
- Fe-RPC HCAL

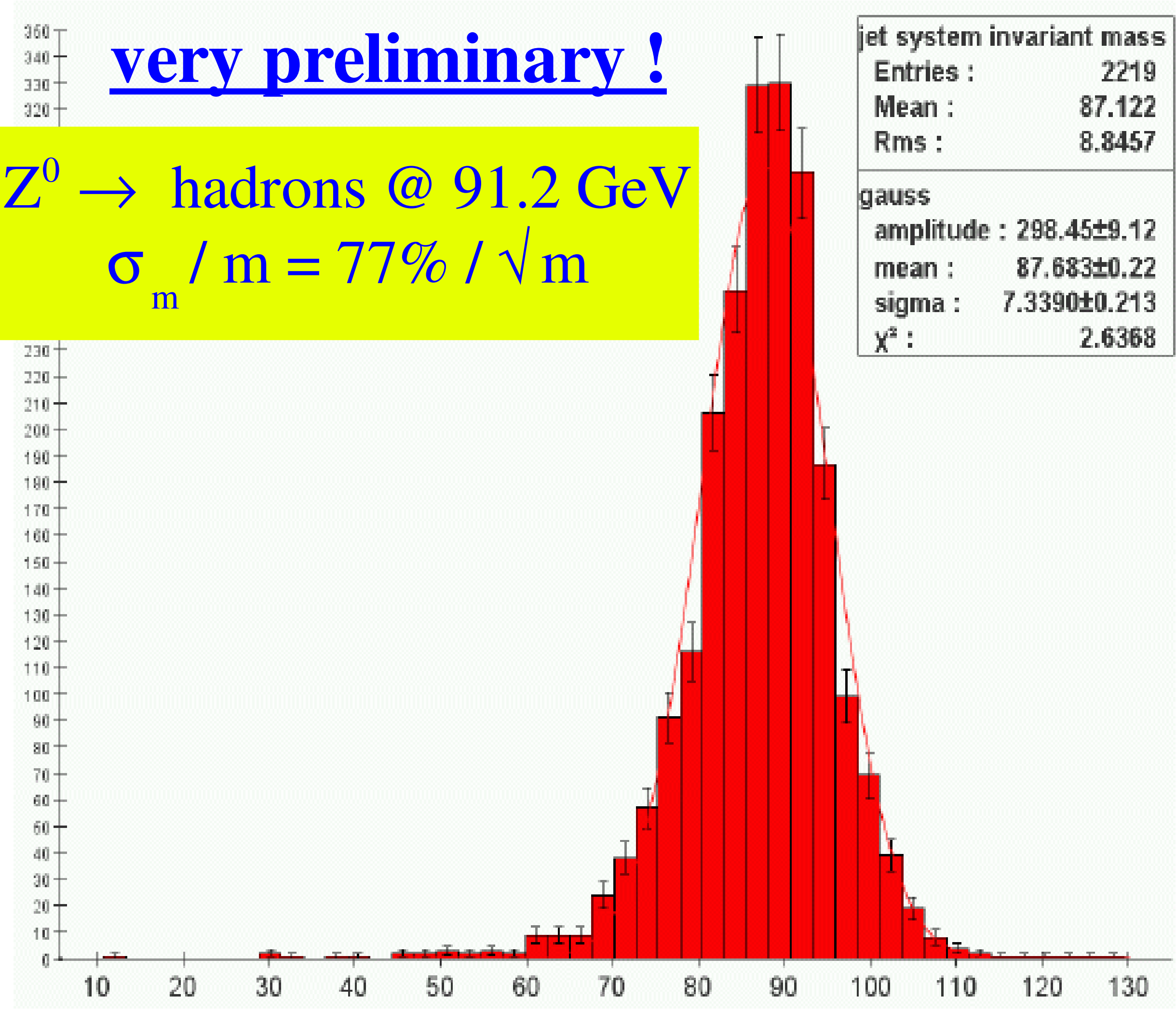
Talk by N.Graf
LCWS'05



Pflow Algorithms : North America

Procedure :

- Fast MC smearing to emulate tracks; high track finding efficiency is assumed
- Fitting of smeared tracks
- Clustering :
  - ✓ Nearest-neighbour technique
  - ✓ Cone (ϕ, θ)
- Cluster-track matching
- Particle ID (shower shapes)
- Track parameters -> 4P of charged particles (e, μ, π)
- Calorimeter information -> 4P of γ's and K0L's



very preliminary !

$Z^0 \rightarrow$ hadrons @ 91.2 GeV

$\sigma_m / m = 77\% / \sqrt{m}$

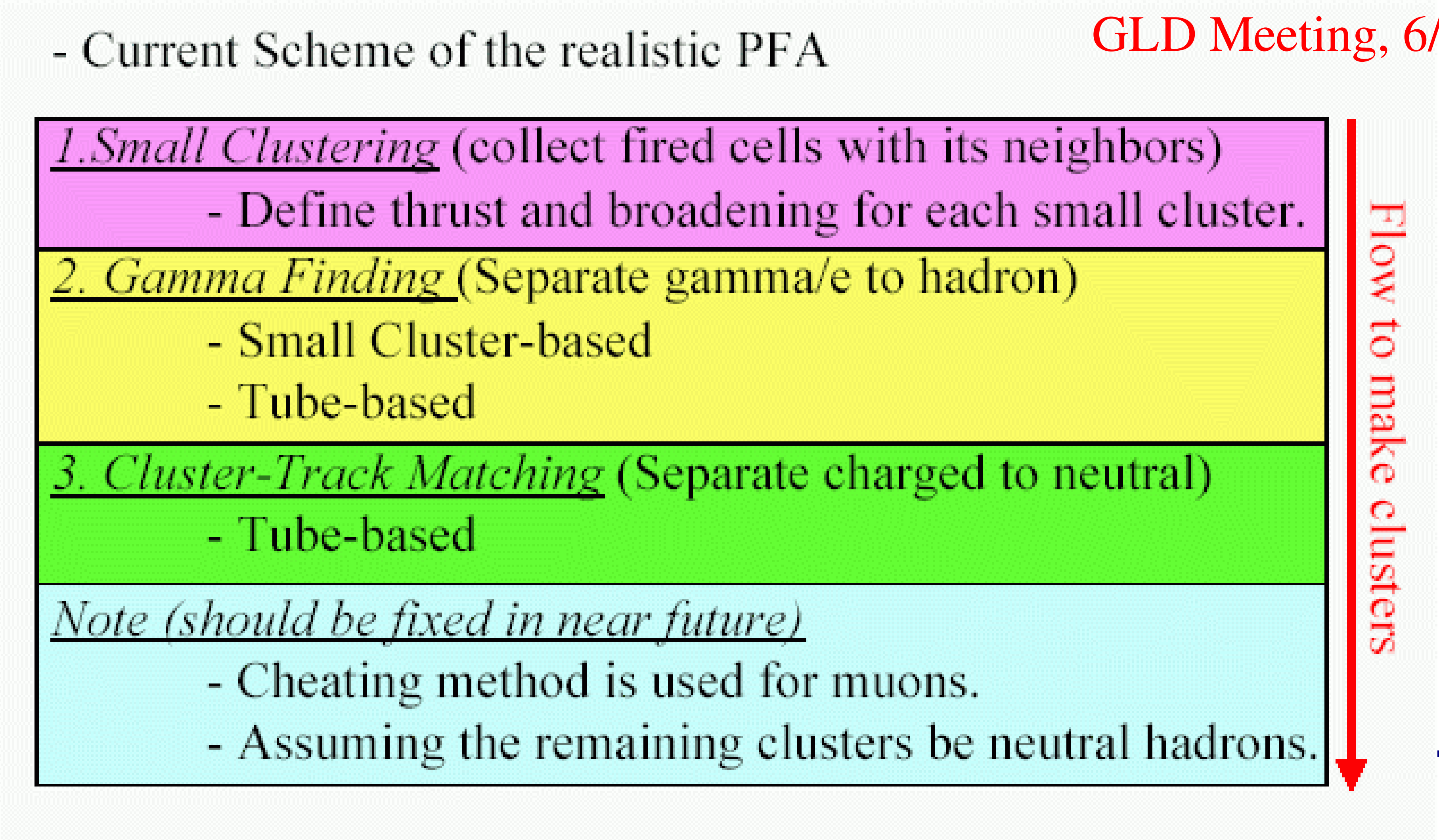
Pflow Algorithms : Asia

Reconstruction is applied on GL Detector option

TPC as a tracker; Lead – Sci compensating calorimeter (4x4 cm^2 tiles)

Fast MC smearing emulates tracks

Talk by T. Yoshioka
GLD Meeting, 6/22/2005



- Current Scheme of the realistic PFA

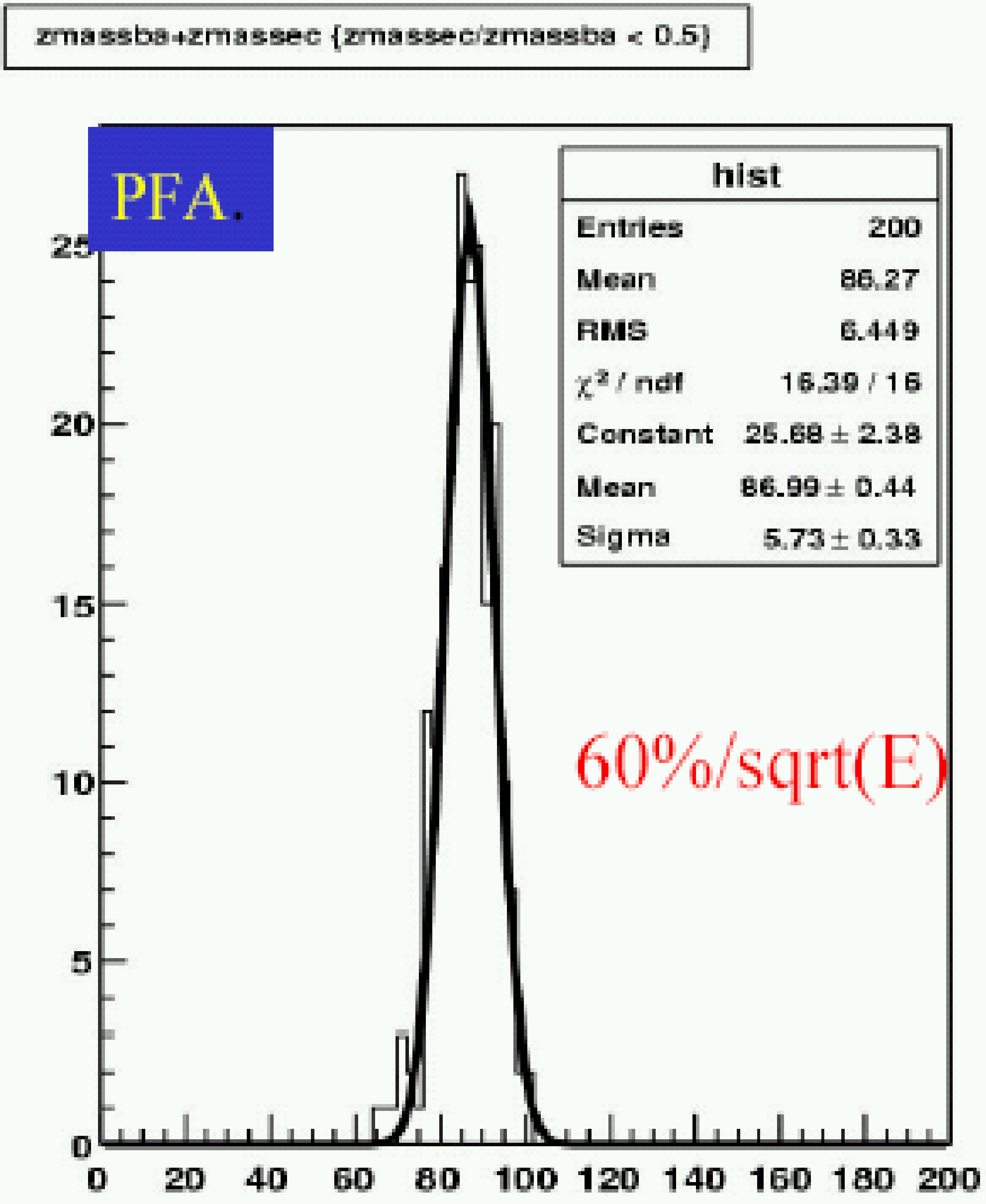
1.Small Clustering (collect fired cells with its neighbors)
- Define thrust and broadening for each small cluster.

2. Gamma Finding (Separate gamma/e to hadron)
- Small Cluster-based
- Tube-based

3. Cluster-Track Matching (Separate charged to neutral)
- Tube-based

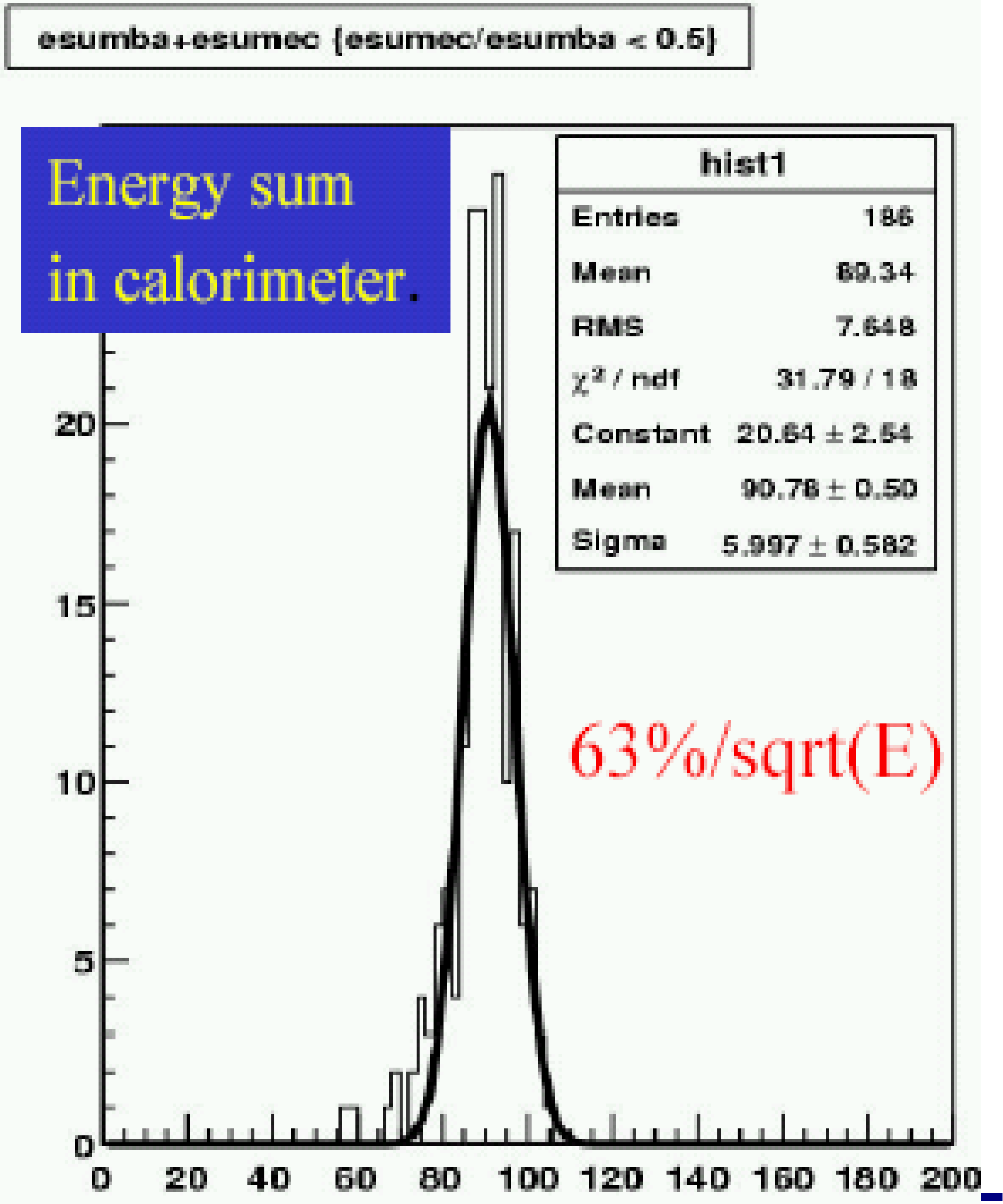
Note (should be fixed in near future)
- Cheating method is used for muons.
- Assuming the remaining clusters be neutral hadrons.

Pflow Algorithms : Asia



PFA.

60%/sqrt(E)



Energy sum in calorimeter.

63%/sqrt(E)

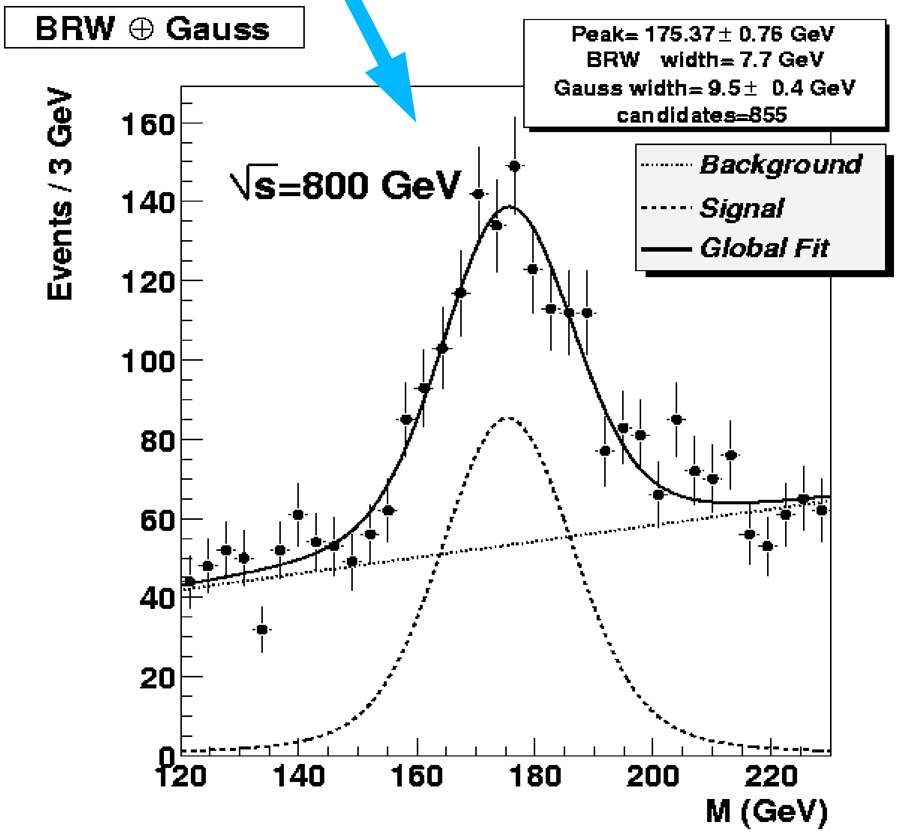
Pflow Algorithms : SNARK

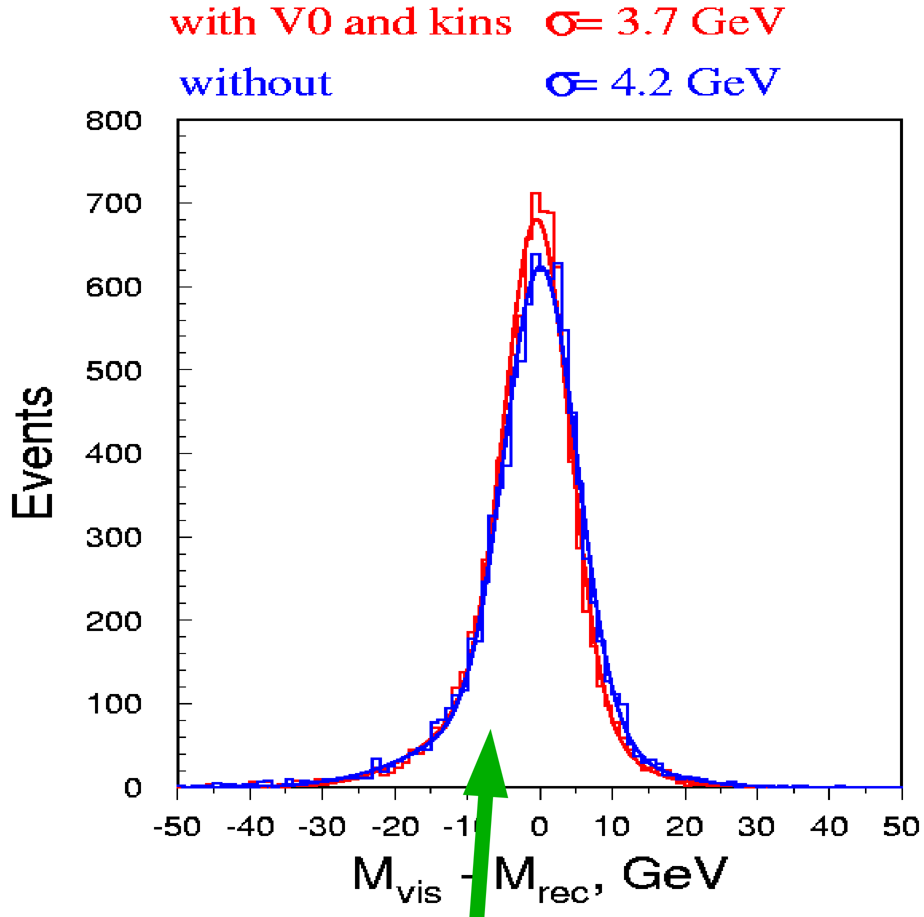
The most mature PFlow implementation today

- Features
  - ✗ Complete tracking (VTX+SIT+FTD+TPC) based on LEP software
  - ✗ Neutral vertex and kink finding procedures
  - ✗ Clustering, cluster-track matching, particle ID (SNARK package)
- Advantages
  - ✗ Fast, robust, highly performant
- Disadvantages
  - ✗ Written in old fashioned procedure-oriented manner (FORTRAN)
  - ✗ No LCIO compliance
  - ✗ Heavily optimised for TESLA detector geometry ⇒ can not be used for detector optimisation studies

SNARK Performance

Tested on complex events (tt →6jets)
V.Morgunov, S.Chekanov,
Phys. Rev. D 67, 074011





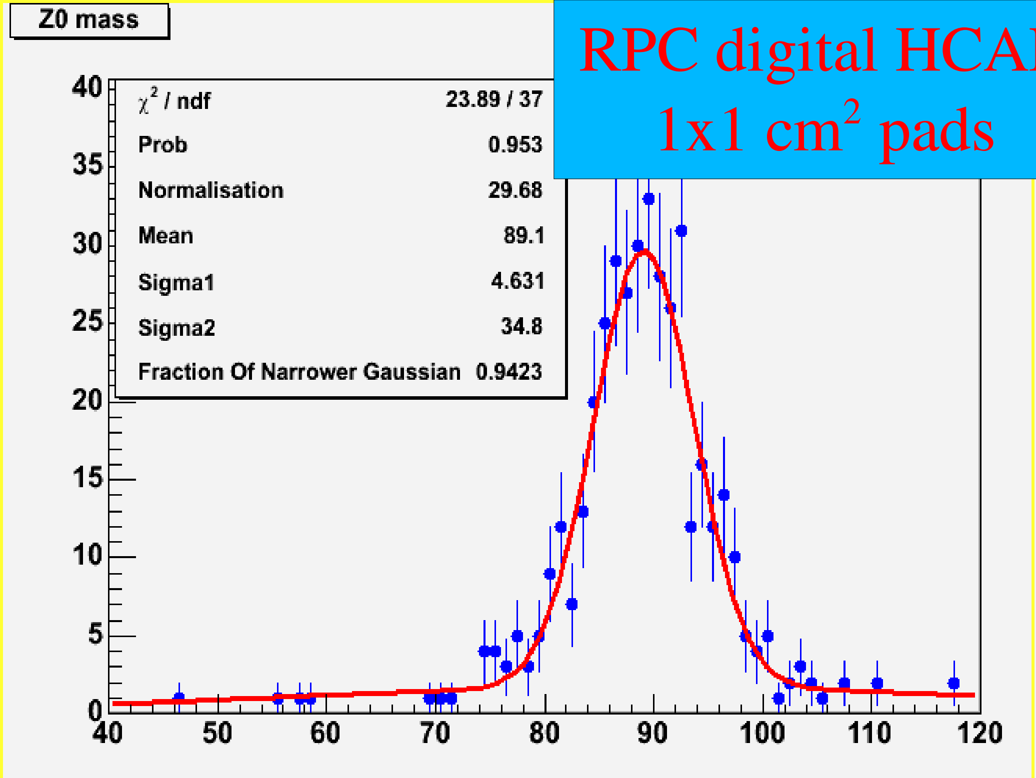
$Z^0 \to$ hadrons @ 91.2 GeV
$\sigma_m / m = 39\% / \sqrt{m}$

Current activities @ DESY: Reconstruction in MARLIN

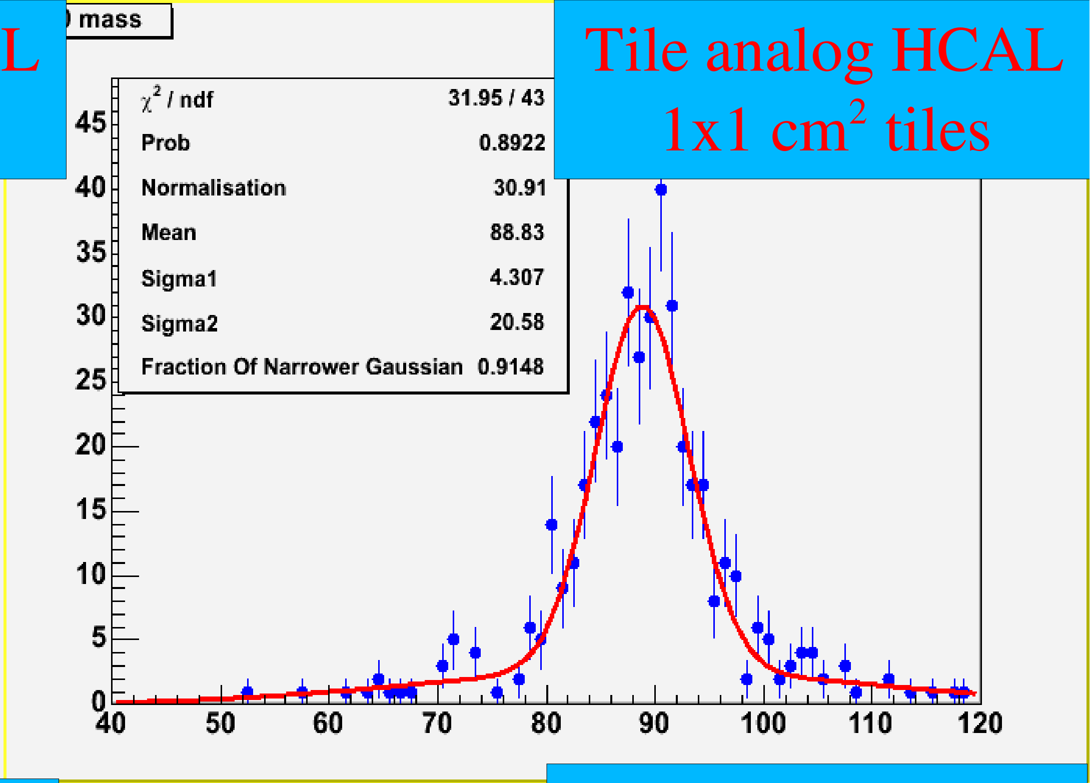
- Modular, object-oriented framework : MARLIN (Frank Gaede)
- **Realistic tracking** (**not just fast MC smearing**) (Steve Aplin)
  - currently includes only TPC
  - C++ wrappers of LEP code; optimisation of code for LC detector
  - Procedure relies on large number of points per track; not applicable for Si tracker
- Track wise calorimeter clustering, cluster-track matching, PFlow (A.Raspereza)
  - Relies on imaging capabilities of calorimeters; not applicable in case of coarse calorimeter segmentation
  - Minimal dependence on calorimeter geometry
  - Works with both analogue and digital readout schemes
- Calorimeter cluster shape analysis, particle ID (D.Martsch, O.Wendt)
- Event shape analysis, jet clustering (P.Krstonosic, T.Kraemer)

Fast Check of Performance

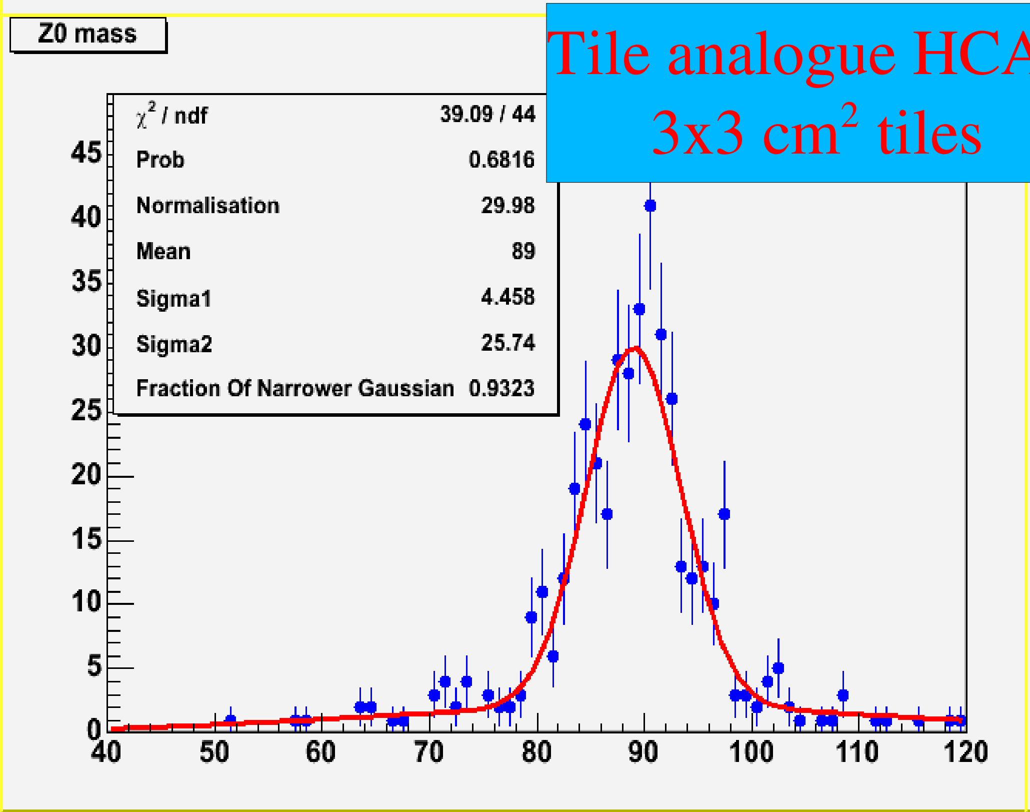
- Performance is checked with limited statistics of 500 $Z^0 \rightarrow$ uds events @ Z pole; no special selection, all events are accepted
- Detector response is simulated with Mokka for two detector models : D10 (RPC digital HCAL) & D10scint (tile analogue HCAL) ; W-Si ECAL
- Tracks are reconstructed using only TPC
- No realistic digitization of calorimeter response is applied
- Calibration factors, converting energy deposited in active layers (analogue HCAL/ECAL) or number of hits (digital HCAL) into nominal energy, are extracted with single particle events (γ, π^+, n with 2, 5, 10, 20 GeV energies)
- Threshold on hit energy = 0.5 MIP
- Energy $= A_{\mathrm{ecal1\text{-}30}} E_{\mathrm{ecal1\text{-}30}} + A_{\mathrm{ecal\ 30\text{-}40}} E_{\mathrm{ecal\ 30\text{-}40}} + A_{\mathrm{hcal}} E_{\mathrm{hcal}}$ (analogue HCAL)
  $= A_{\mathrm{ecal1\text{-}30}} E_{\mathrm{ecal1\text{-}30}} + A_{\mathrm{ecal\ 30\text{-}40}} E_{\mathrm{ecal\ 30\text{-}40}} + D_{\mathrm{hcal}} N(\mathrm{hits})_{\mathrm{hcal}}$ (digital HCAL)



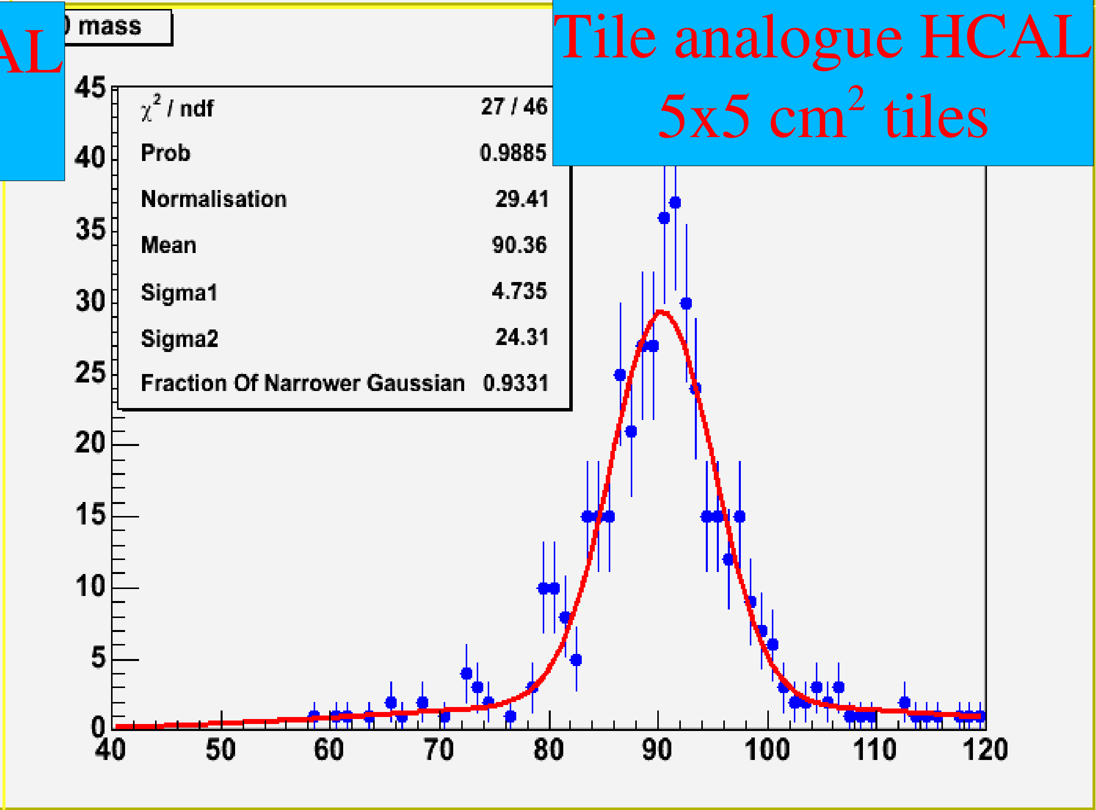
RPC digital HCAL
1x1 cm^2 pads



Tile analog HCAL
1x1 cm^2 tiles



Tile analogue HCAL
3x3 cm^2 tiles



Tile analogue HCAL
5x5 cm^2 tiles

Summary

- Pflow is widely accepted as an optimal approach for event reconstruction @ ILC
- Acitivies are ongoing worlwide aiming at development & implementation of PFlow algorithms for ILC experiment
- Detector optimization **must** be done with full simulation and realistic reconstruction : reconstruction software is one of the tools needed for detector optimisation as well as for physics studies
- Modular approach realised in MARLIN is very efficient way to unify efforts of different research groups working on PFlow algorithms
- Join our efforts in development of MARLIN based reconstruction tools