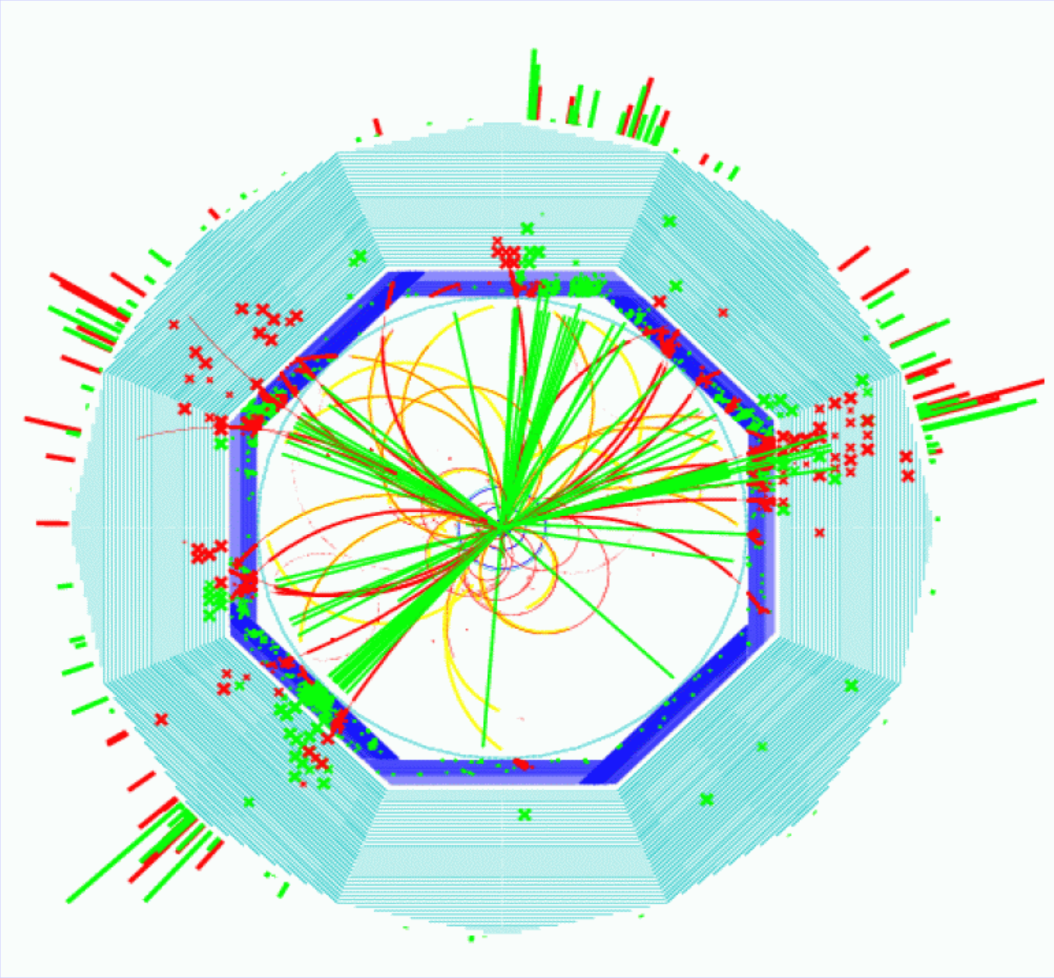
Particle Flow Issues

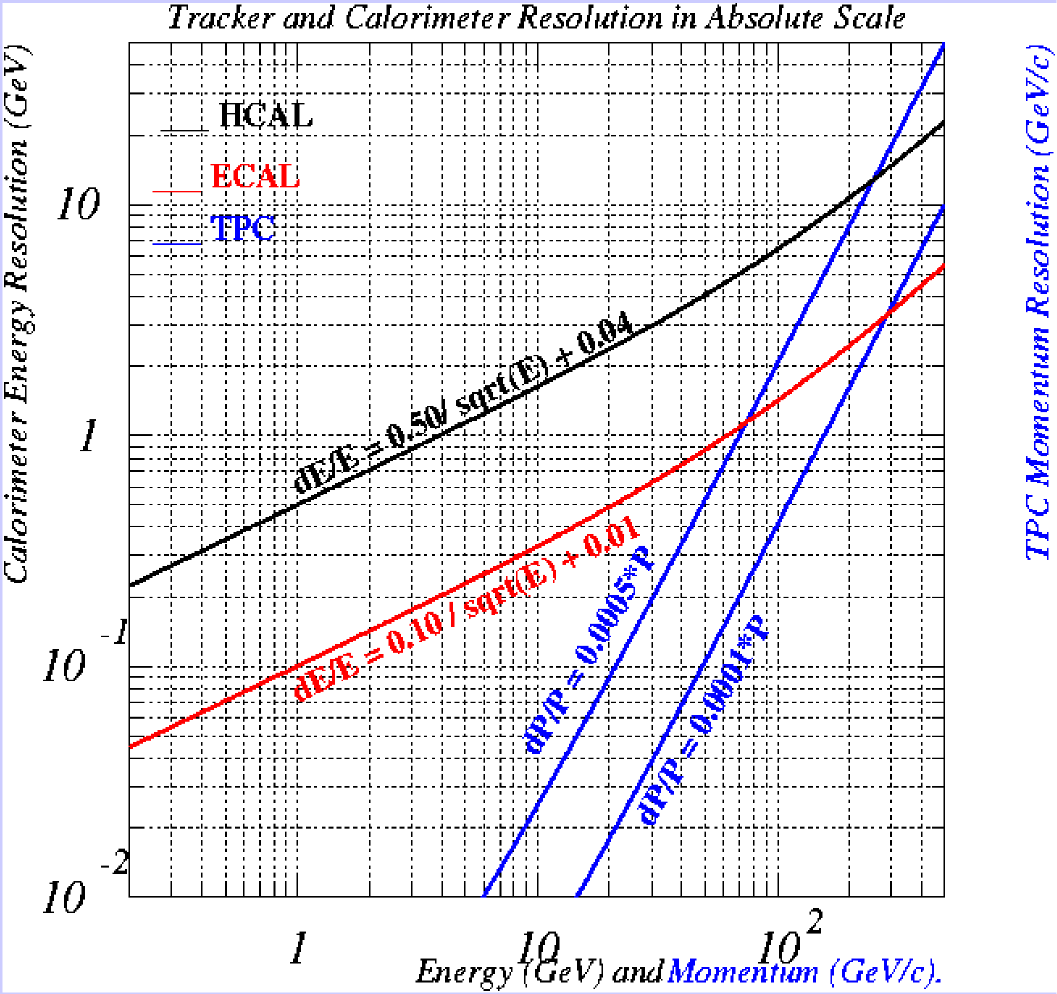


Alexei Raspereza, DESY

Hcal Main Meeting, 28/04/2005

Particle Flow Concept

- P-flow concept : attempt to reconstruct every single particle in event $\rightarrow$ best possible jet resolution
- Exploits superiority of tracker w.r.t. calorimeters in measuring charged particles
- Tracker information $\rightarrow$ 4P vectors of charged objects
- Ecal $\rightarrow$ 4P vectors of photons
- Ecal + HCal $\rightarrow$ 4P vectors of neutral hadrons
- Efficient separation of neutral and charged objects is an issue $\rightarrow$ highly granulated calorimeters are required



Perfect Particle Flow. Simple Considerations.

- Theoretical computation :

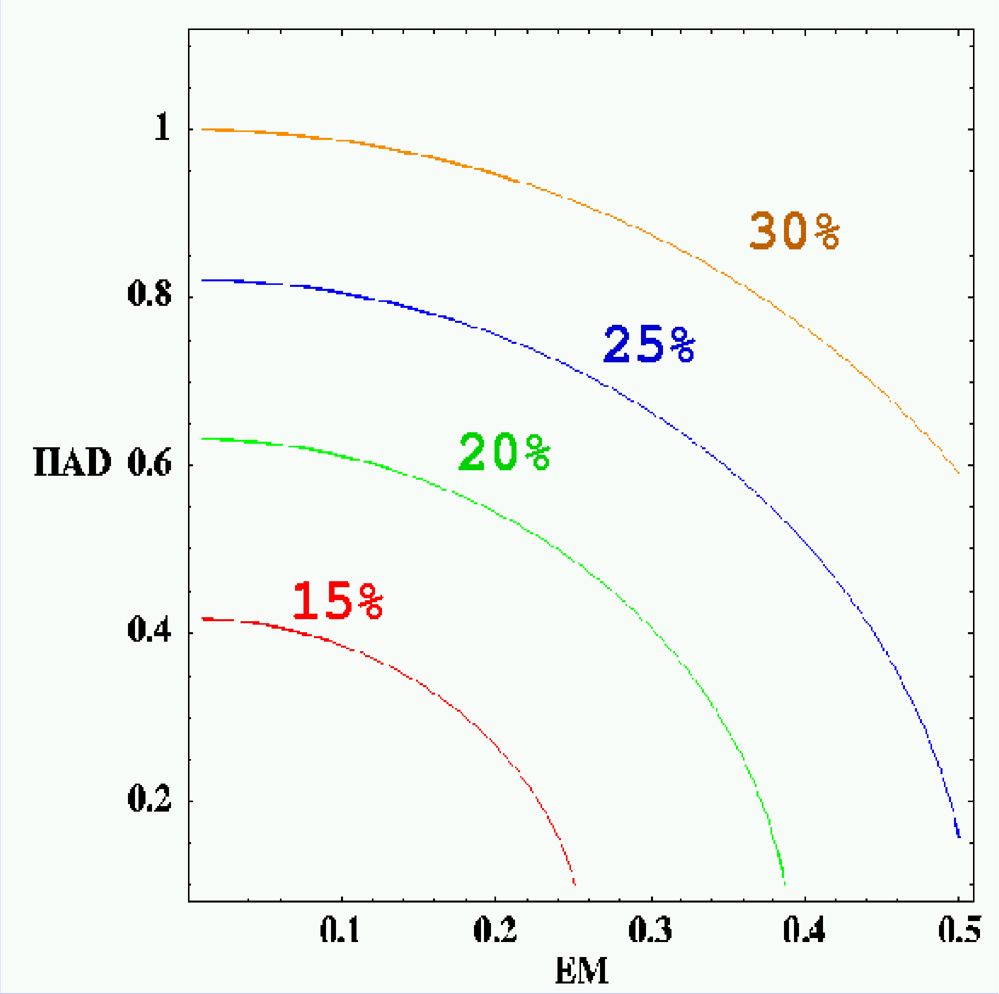
$$\sigma^2(E_j) = \sigma^2(\text{charg.}) + \sigma^2(\gamma) + \sigma^2(h^0) + \sigma^2(\text{conf.})$$

- TPC momentum resolution is much superior w.r.t. energy and angular resolution of calorimeters $\rightarrow \sigma^2(\text{charg.})$ is negligible
- Perfect Pflow $\rightarrow \sigma(\text{conf.}) = 0$

$$\sigma^2(E_j) = f_\gamma \times (0.11)^2 E_j + f_{h0} \times (0.35)^2 E_j$$

Typically $f_\gamma = 0.25$, $f_{h0} = 0.15 \rightarrow$

$$\sigma^2(E_j) = (0.14)^2 E_j$$



Open Questions

- Ways of defining jet energy resolution :
  - ✗ w.r.t. to sum of true energies of all particles assigned to given jet (reflects solely detector resolution effects)
  - ✗ w.r.t to energy of primary parton (quantifies combined effect : detector resolution ⊕ fragmentation, imperfection of jet clustering
- Benchmark resolution of $dE_{jet}/E_{jet} = 14\%/\sqrt{E_{jet}}$ corresponds to the first definition
- How is it reflected on the Z/W/H mass resolutions?
- Theoretical computations are done by fixing f_{γ} and f_{h0} to some averaged values. But what is the effect of f_{γ} and f_{h0} fluctuations on dE_{jet}/E_{jet}?

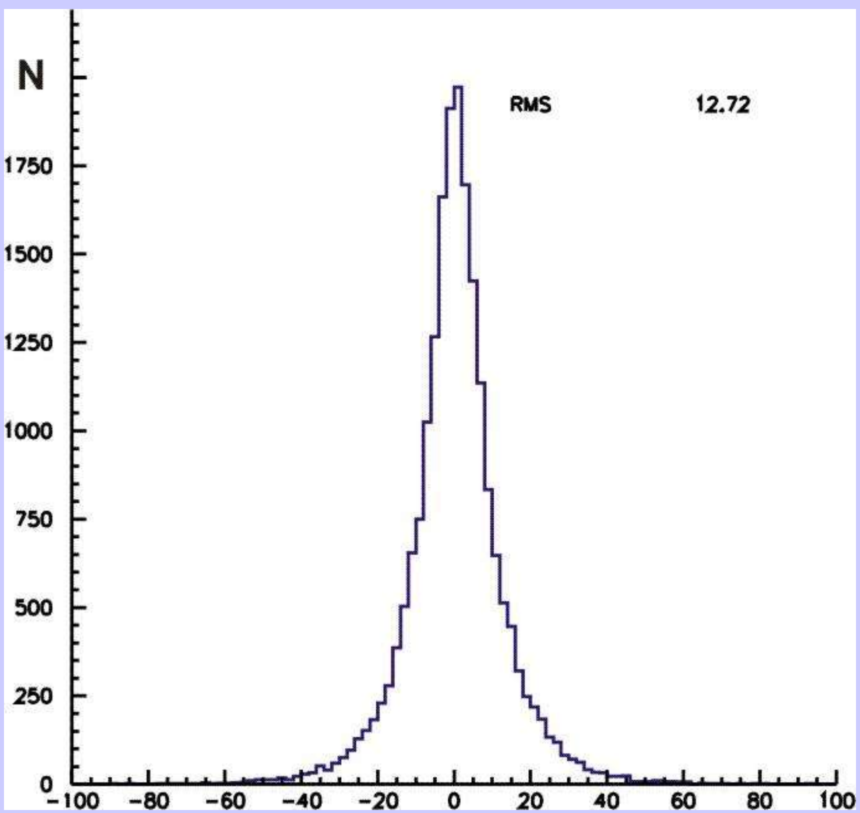
Toy MC Analysis

- Consider benchmark reactions :
  $Z \rightarrow qq$ @ 91.2 GeV; HZ,WW,vvZZ$\rightarrow$ 4jets @ higher energies
- Smear 4P momenta of each stable (measurable) particle in event according to its type and anticipated detector resolutions:
  - char. particles : $\delta p/p = 7 \cdot 10^{-5} p$, $\delta(\Theta,\phi) \sim 1$mrad
  - photons : $\delta E/E = 11\%/\sqrt{E}$, $\delta(\Theta,\phi) \sim 3$mrad
  - h^0 : $\delta E/E = 30\%/\sqrt{E}$, $\delta(\Theta,\phi) \sim 5$mrad
- Jet clustering with smeared objects => reconstruct jet energies
- Consider two possible definitions of jet energy resolution
  - $\delta E_j = E_{j,\,\text{reconstr-smeared}} - E_{\text{parton}}$
  - $\delta E_j = E_{j,\,\text{reconstr-smeared}} - E_{j,\,\text{gen}}$
- $\Rightarrow$ Resolution expected for perfect Pflow

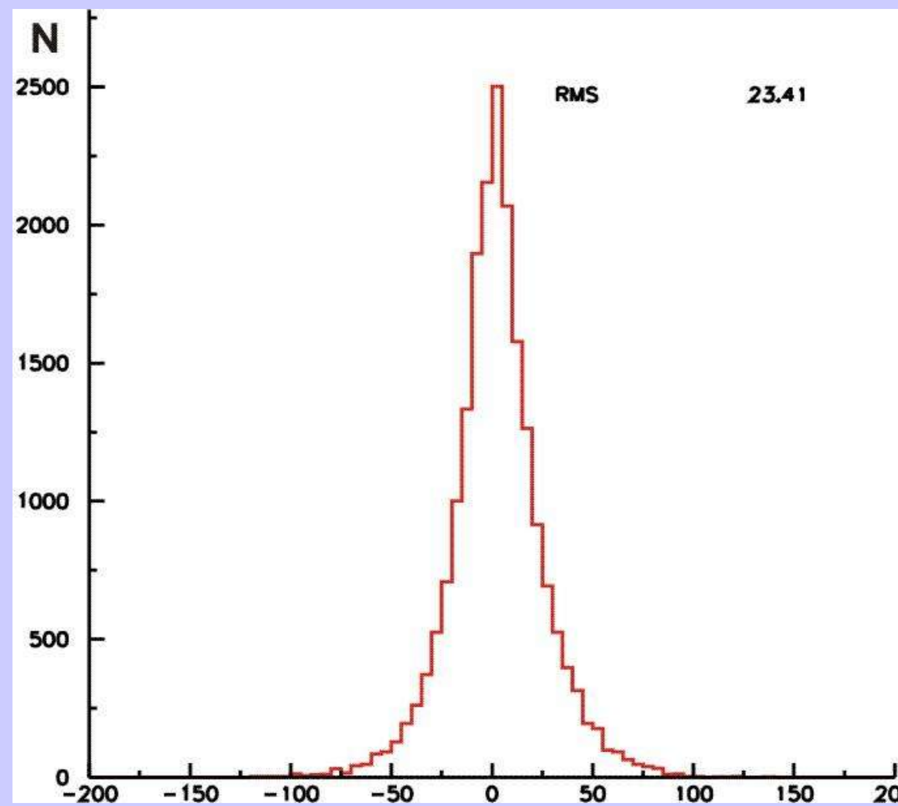
Hadronic Z Decays @ 91.2 GeV

- Studies done by Predrag for hadronic Z decays at 91.2 GeV
- ISR, beamstrahlung are off ⇒ perfect MC probe of pure detector effects on jet/mass resolution

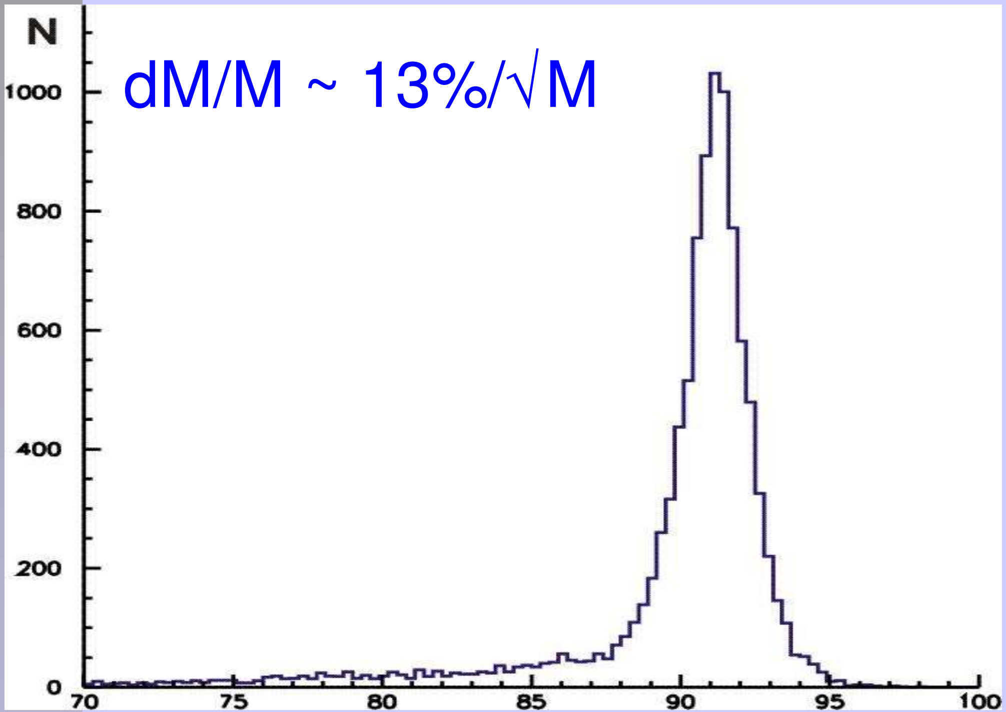
EM = 11%, HAD = 30%

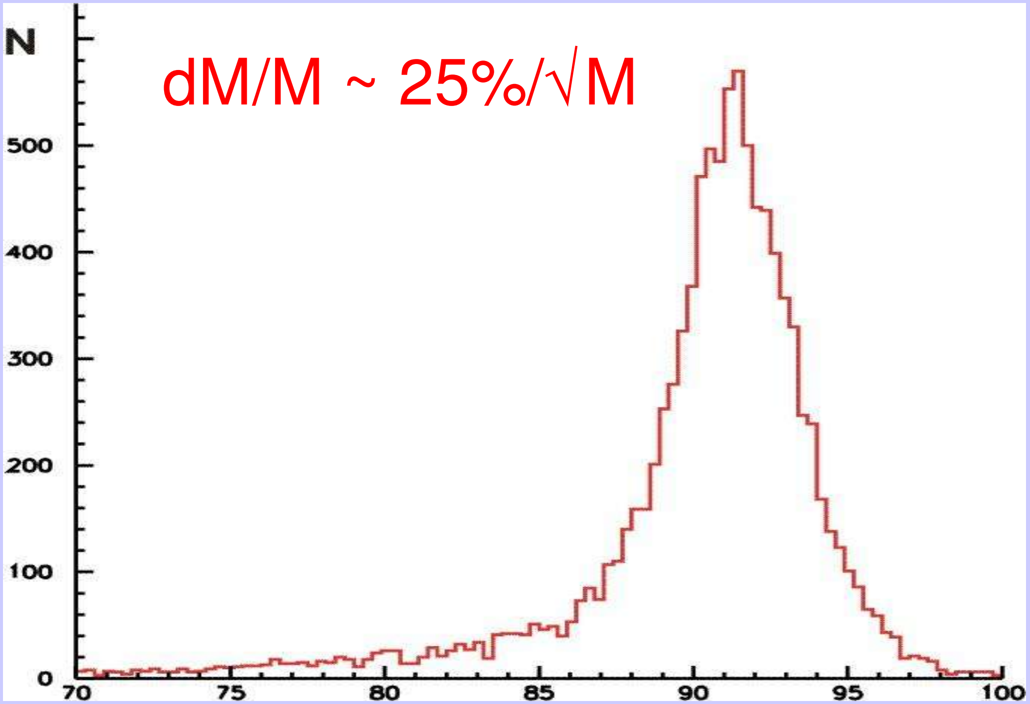


EM = 20%, HAD = 60%



Z Mass Resolution





Jet energy resolution directly translates in mass resolution
But simple topology : two jets in opposite hemispheres =>
No big effect from fragmentation / jet clustering is expected

- Further studies with HZ,WW,vvZZ,vvWW samples are foreseen
- Studies with full detector simulation (Mokka) assuming perfect hit->cluster assignment and cluster->track linking are also planned

Realistic PFlow

- SNARK – the only complete and self-consistent Pflow implementation available nowadays on the market
- Includes :
  - Realistic tracking (based on algorithms used in LEP experiments)
  - Clustering of calorimeter hits
  - Cluster – track linking
  - Neutral vertex / kink finding & particle propagation
- Advantages
  - Fast, robust, efficient
- Disadvantages
  - No LCIO compliance
  - Heavily optimized for TDR geometry with HCAL tile size ranging from 5x5 to 25x25 cm^2 => reduced flexibility, no real use of imaging capabilities of HCAL

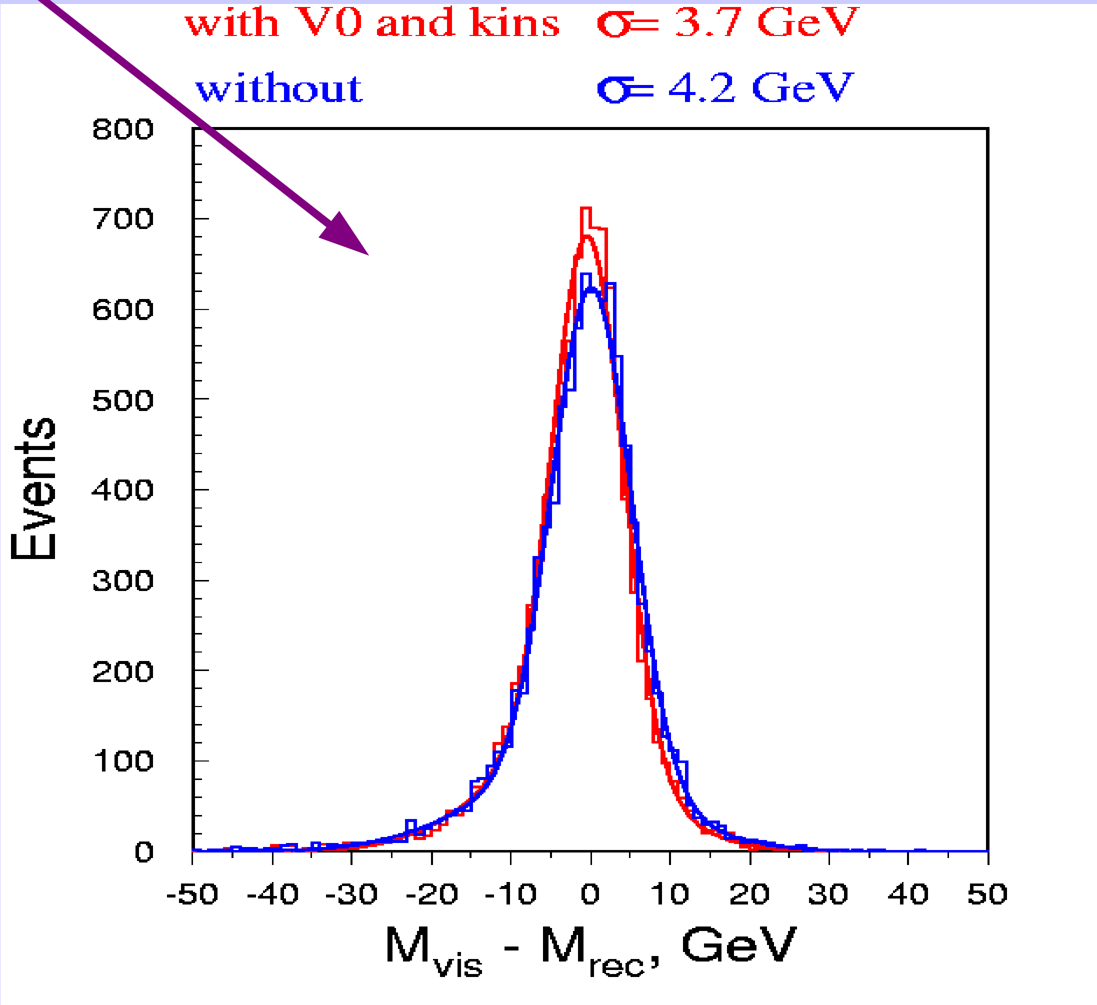
Performance of SNARK

- Tracking also influences jet energy resolution via efficient identification of V0 and kins

Z -> hadrons @ 91.2 GeV

Mass resolution
with BRAHMS :

$dM_Z / M_Z = 38\%/\sqrt{M}$



What We Need

- Complete / self-consistent reconstruction software designed in a modular object-oriented manner (MARLIN – ideal framework for that) $\rightarrow$ easy to maintain continuous development
- Worldwide study enters the phase of detector optimization where Pflow performance will be one of the criterion $\rightarrow$ software must be flexible (minimal dependence on detector configuration) in order to be used for detector optimization

What We Have

- A bunch of ideas inherited from SNARK (author : V.Morgunov)
- Logically disconnected pieces of code written independently by different people
  - Several separate clustering algorithms disentangled from tracking (MST Clustering by G.Mavromanolakis, layer-by-layer clustering by C. Ainsley)
  - Clustering algorithms using tracking information (track-wise clustering by A.Raspereza, Snark++ by V. Morgunov)
  - Are these algorithm are incompatible/exclusive w.r.t to each other or can they be used in a complementary way?
  - Tracking implemented within MARLIN (Steve Aplin) (FORTRAN wrapper)

Clustering Algorithms. Features.

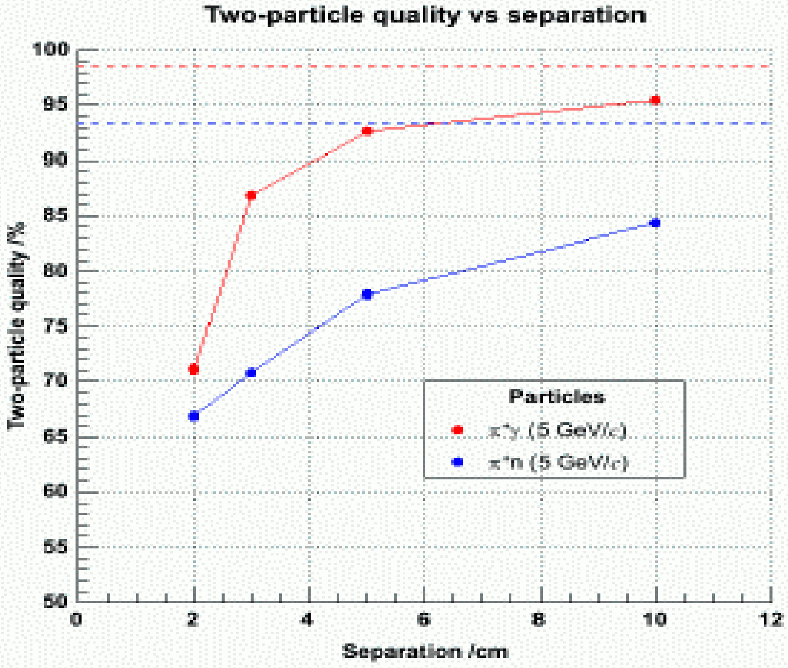
- Challenge : highly granulated calorimeters -> huge number of hits -> need in preclustering. Usually based on analysis of some generic metric (3D distance, angle between) defined by hit pairs. Time consumed by this procedure ~ n(n-1), n = number of hits in an event
- Three out of four methods (MST, layer-by-layer cluster propagation, track-wise clustering) primarily exploit geometrical information, minimal use of hit amplitude information => appropriate for both analogue and digital device
- Snark++ uses amplitude information for making subcluster hypotheses (e.g. MIP or EM cluster), primarily intended to be used for analogue device
- MST, layer-by-layer cluster propagation : currently no use of tracking information; at certain point track-cluster links must be established
- Track-wise clustering, Snark++ : use tracking information already at the stage of clustering, track intersection with calorimeter inner boundary -> cluster seed -> natural linkage between track and cluster.

5 GeV two-particle quality vs separation

- Goal: to distinguish charged clusters from neutral clusters in calorimeters *e.g.* $\pi^+\gamma$ / π^+n.
- Propose a figure of merit:

  Quality = fraction of event energy that maps in a 1:1 ratio between reconstructed and true clusters.

- Quality improves with separation (naturally).
- ∀ $\pi^+\gamma$ separation at 5 GeV seems to be pretty good; π^+n is somewhat tougher (n showers typically have relatively ill-defined shapes).



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General CALICE meeting
14-16 March 2005, NIU, De Kalb, IL, USA

Clustering algorithms have comparable performance in terms of their capability to separate two close-by showers, but were not really examined on real multi-jet events as a part of Pflow algorithm.

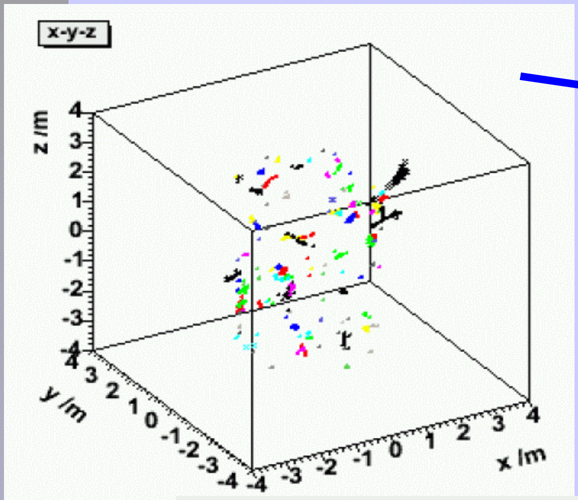
Our Short-Term Goal.

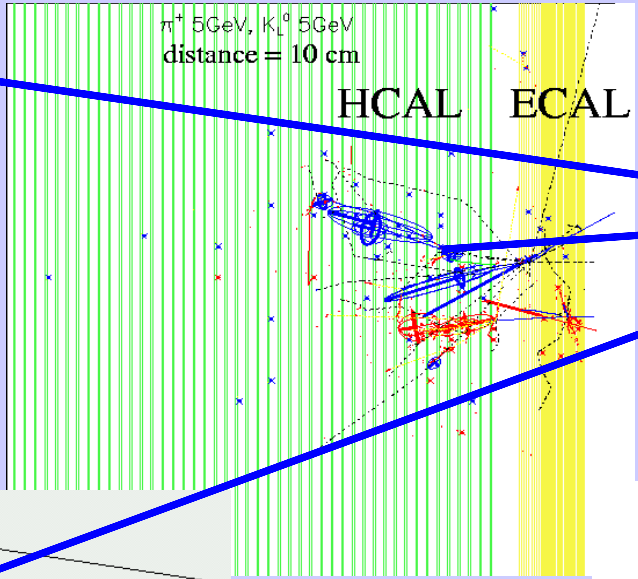
- Check / improve existing clustering methods; try to gain maxi-mal profit from ideas implemented in these methods

- Combine existing clustering methods with tracking procedure into Pflow algorithm
- Either find a way to use different clustering algorithms in a complementary manner or choose the one which provides the best Pflow performance in combination with tracking.
  Criteria for selecting clustering algorithm
  - ✗ Pflow efficiency in terms of jet energy / mass resolutions
  - ✗ Flexibility (minimal dependence on detector geometry)
  - ✗ Speed

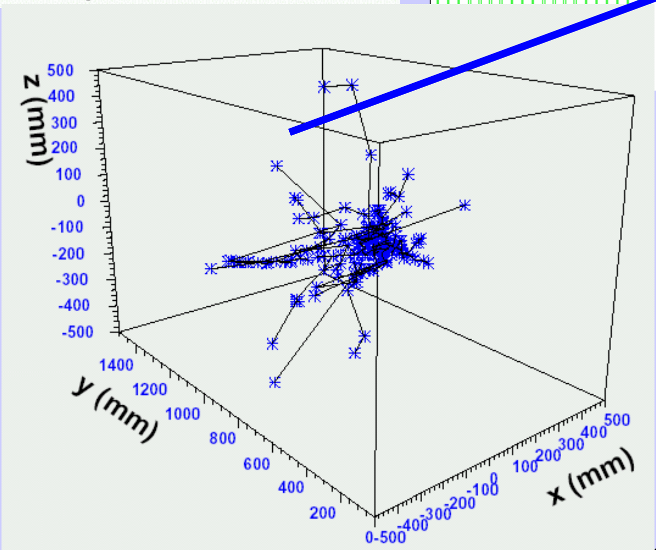
- Complete self-consistent flexible Pflow algorithm is **urgently** needed for detector optimization studies

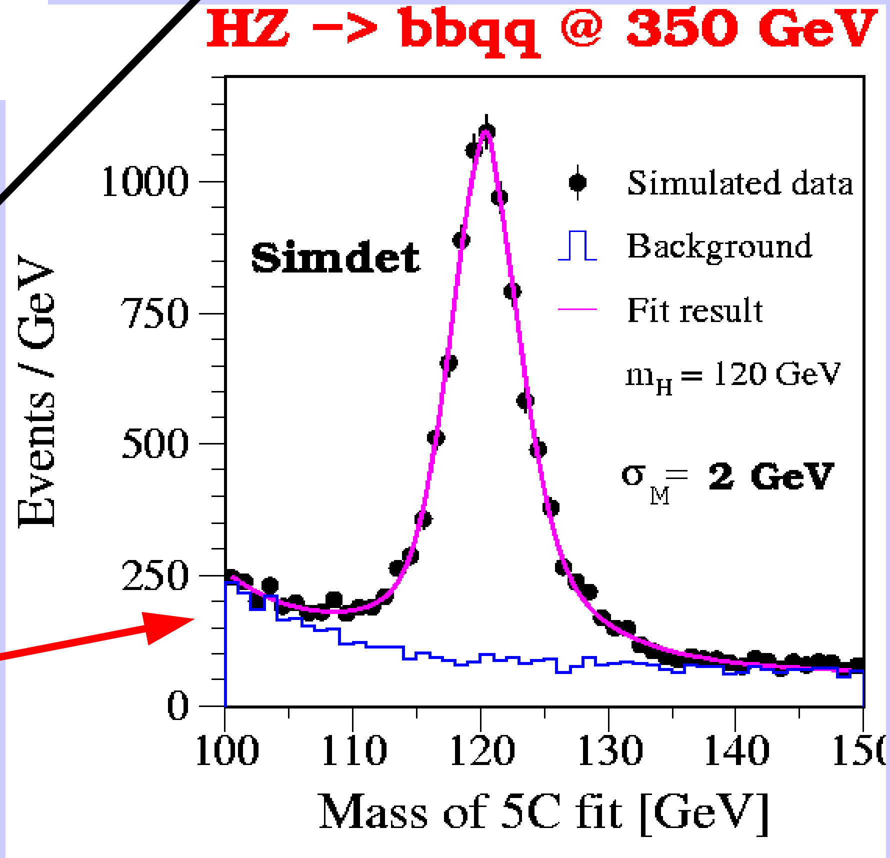
Ultimate Goal. Roadmap.





From individual diverse efforts





To unified efficient PFlow