Particle Flow

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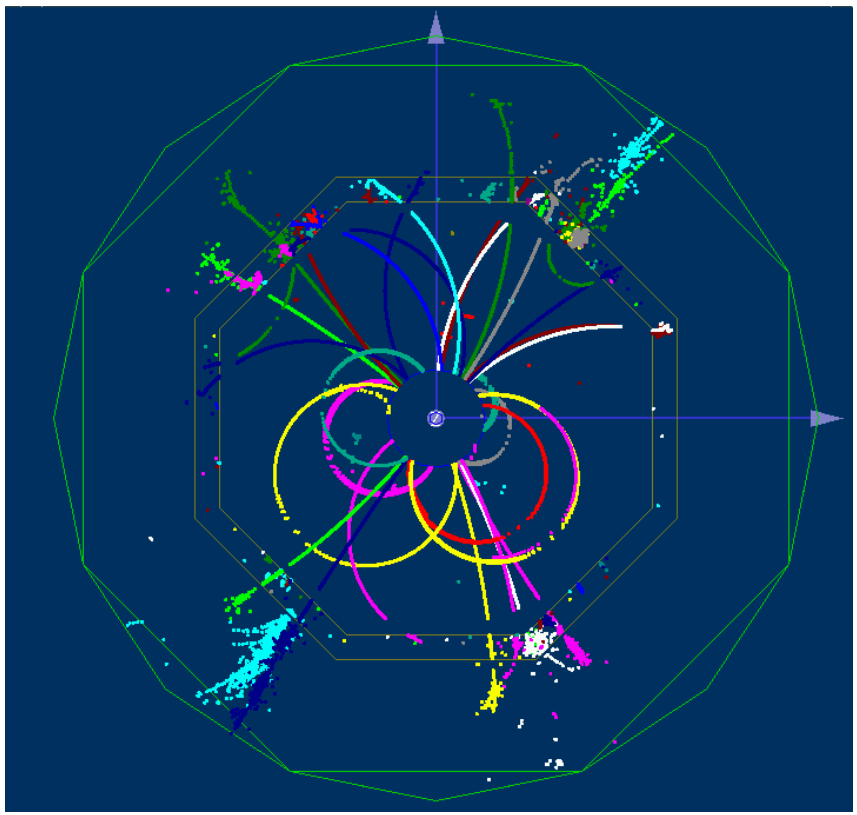


This Talk:

- ★ Software needs for Detector Optimisation
- ★ Particle Flow Algorithms
- ★ Current Results
- ★ Conclusions/Outlook

❶ Detector Optimisation

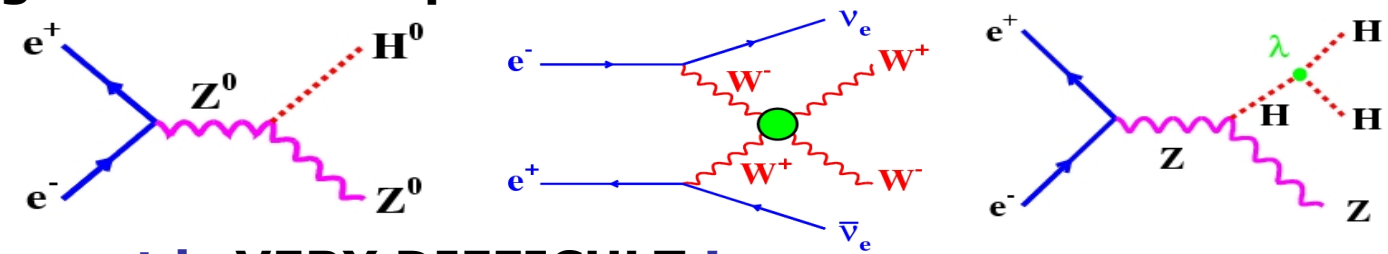
General consensus that Calorimetry and PFA drives overall ILC detector design

BUT: Don't really know what makes a good detector from point of view of PFA (plenty of personal biases – but little hard evidence)

How to optimise compare ILC detector design(s)

- ★ **Optimize** detector design using key physics processes
- ★ Need to choose the key "benchmark" processes (DONE)

  e.g. the usual suspects + ...



- ★ The rest is **VERY DIFFICULT !**
- ★ Need unbiased comparison
  - Same/very similar reconstruction algorithms
    - these need to realistic (i.e. start-of-art)
  - Need Multiple PFAs : avoid trap of optimising detector to flaws of particular algorithm
  - This is a lot of work – need user friendly software

Detector Optimisation : Software Tools

- Until very recently we did not have the software tools to optimise the detector from the point of view of **Particle Flow**
- This has changed !
- **The basic tools are mostly there:**
  - **Mokka :** now has scalable geometry for the LDC detector
  - **MARLIN:** provides a nice (and simple) reconstruction framework
  - **LCIO:** provides a common format for worldwide PFA studies
  - **Reconstruction:** in MARLIN framework already have **ALGORITHMs**

What is needed in MARLIN:

- **Digitisation:** (take simulated hits → hits)
  - ✓ simple **MARLIN** processors exist (more work needed)
- **Tracking:** (two options currently in MARLIN)
  - ✓ **Full LEP like fit:** TPC hits + currently being extended to VTX..
  - ✓ **"Cheated" tracks:** TPC/FTD/VTX use MC to assign hits to track. Track parameters from a Helix fit
- **Clustering:** (two options)
  - ✓ **TrackWiseClustering** (Alexei R. et al)
  - ✓ **MAGIC** (Chris Ainsley)
- **PFA:** now (nearly) have two algorithms !
  - ✓ **Wolf** (Alexei R.)
  - ✓ **PandoraPFA** (Mark Thomson) – will be released in January

★ **All the necessary tools exist !**

- **that doesn't mean that its time to stop work...**
- **things aren't perfect yet**

We are now in the position to start to learn how to optimise the detector for PFA

But first...

learning from ongoing studies of Perfect Particle Flow (P. Krstonosic)

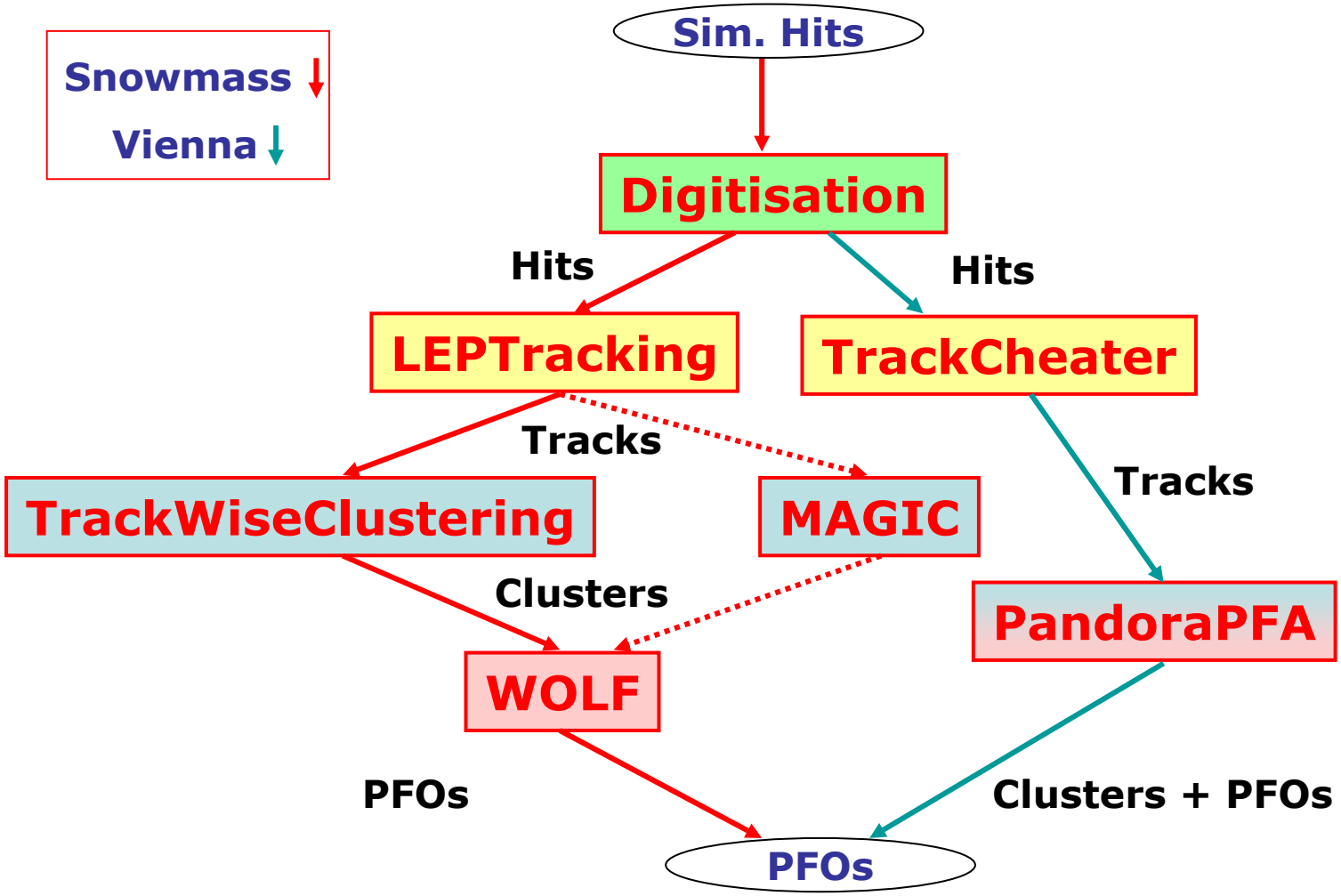
e.g. $e^+e^- \rightarrow Z \rightarrow qq$ **at 91.2 GeV**

To be reviewed

Effect	σ[GeV] separate	σ[GeV] not joined	σ[GeV] total ($\%/\sqrt{E}$)	σ % to total
$E_\nu > 0$	0.84	0.84	0.84 (8.80%)	12.28
$Cone < 5^o$	0.73	1.11	1.11(11.65%)	9.28
$P_t < 0.36$	1.36	1.76	1.76(18.40%)	32.20
σ_{HCAL}	1.40	1.40	2.25(23.53%)	34.12
σ_{ECAL}	0.57	1.51	2.32(24.27%)	5.66
M_{neutral}	0.53	1.60	2.38(24.90%)	4.89
M_{charged}	0.30	1.63	2.40(25.10%)	1.57

(assumed sub-detector resolutions: ECAL 11%/√E, HCAL 50%/√E +4%)

❷ Particle Flow Algorithms in MARLIN

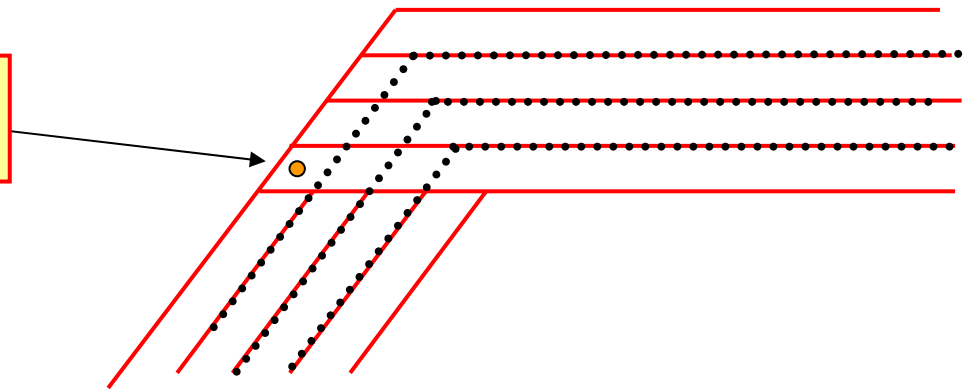


★ PandoraPFA/WOLF/MAGIC share many common features
★ Will briefly discuss some of the main points of the new Algorithm

PandoraPFA Clustering I

- ★ All current **MARLIN** clustering algorithms are "forward projecting"
  - Form clusters starting from inner CAL layer – working outwards
- ★ Arrange hits into **PSEUDOLAYERS** (same done in MAGIC)
  - **i.e.** order hits in increasing depth within calorimeter
  - PseudoLayers follow detector geometry

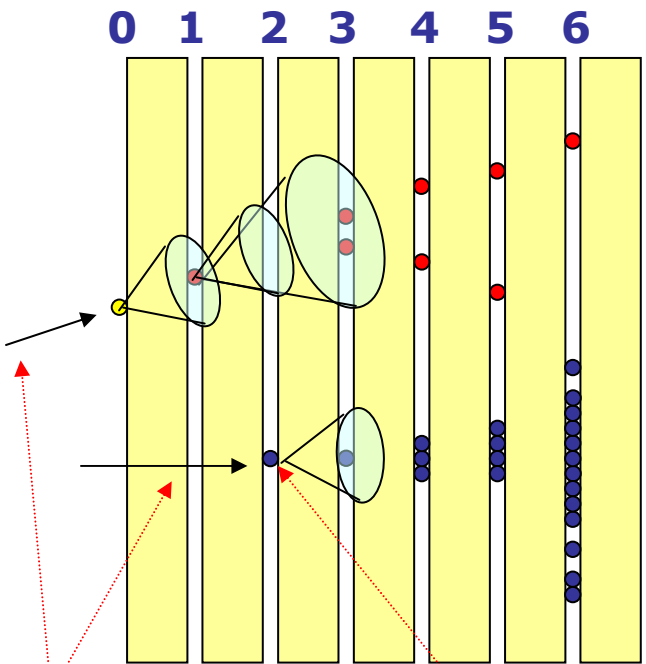
- Hit in early layer
- But high PseudoLayer

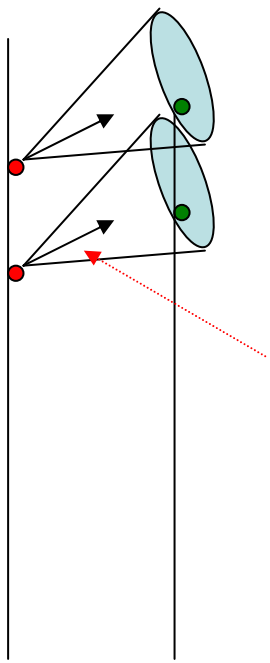


(WOLF orders hits by distance from IP)

PandoraPFA Clustering II

- ★ Start at inner layers and work outward
- ★ Associate Hits with existing Clusters
- ★ If multiple clusters "want" hit then Arbitrate
- ★ Step back **N** layers until associated
- ★ Then try to associate with hits in current layer (M pixel cut)
- ★ If no association made form new Cluster
- ★ + tracks used to seed clusters





Simple cone algorithm based on current direction + additional N pixels

Cones based on either: initial PC direction or current PC direction

WOLF/MAGIC do things slightly differently but same basic idea

Initial cluster direction

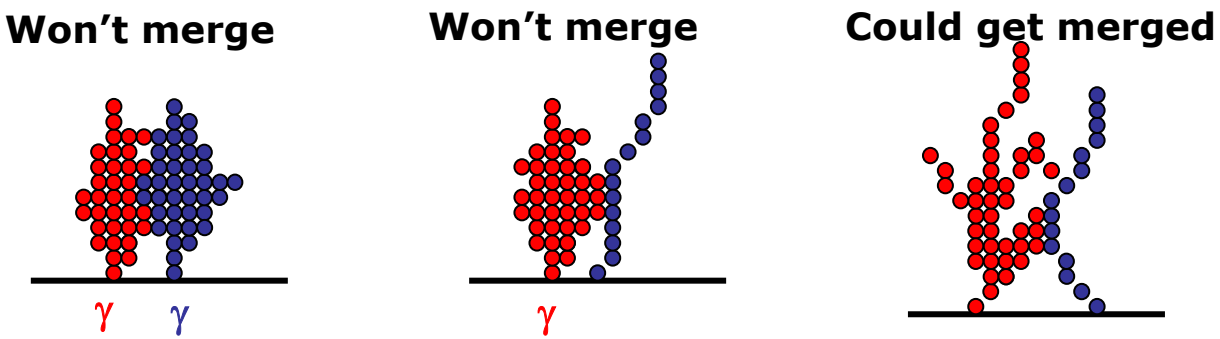
Unmatched hits seeds new cluster

PandoraPFA Cluster Association

- By design clustering errs on side of caution
  i.e. clusters tend to be split
- **Philosophy:** easier to put things together than split them up
- Clusters are then associated together in two stages:
  - 1) Tight cluster association - clear topologies
  - 2) Loose cluster association – catches what's been missed but rather crude

Photon ID

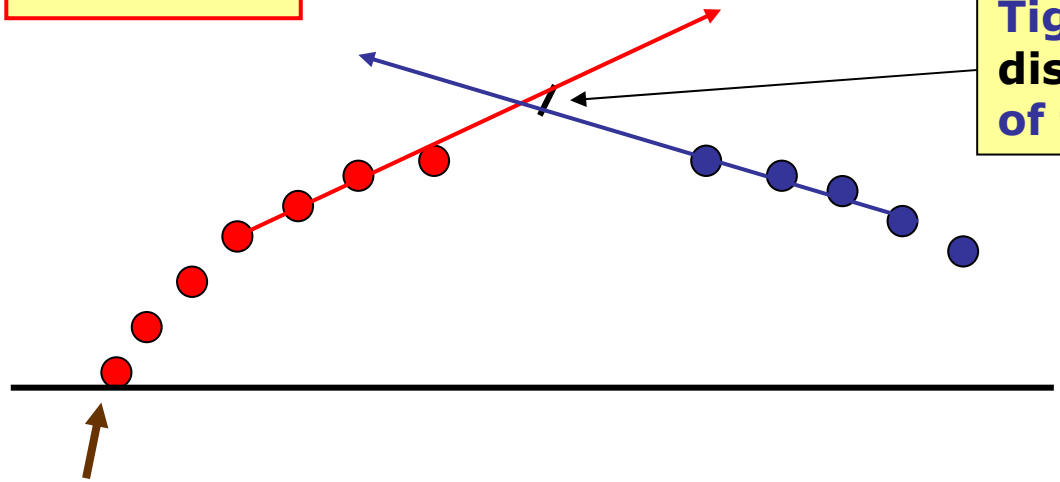
- Photon ID plays important role
- Simple "cut-based" photon ID applied to all clusters
- Clusters tagged as photons are immune from association procedure – just left alone



WOLF/MAGIC do things differently but both perform cluster merging

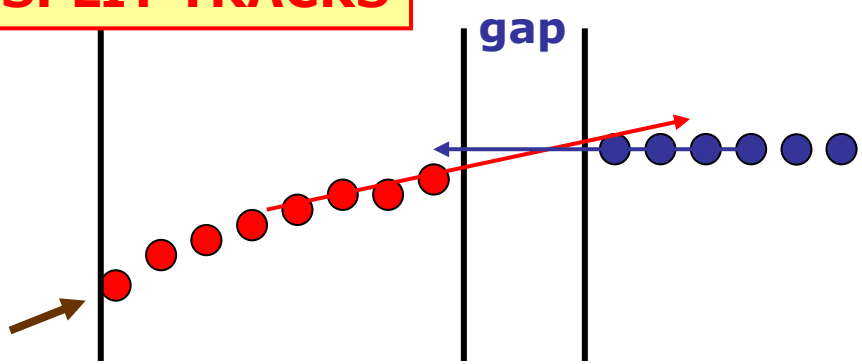
Cluster Association I : track merging

LOOPERS



Tight cut on extrapolation of distance of closest approach of fits to ends of tracks

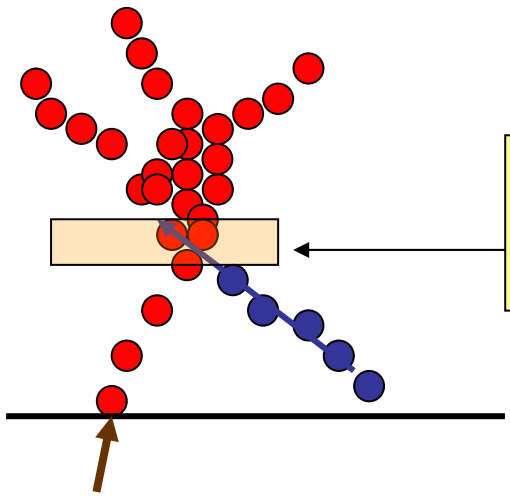
SPLIT TRACKS



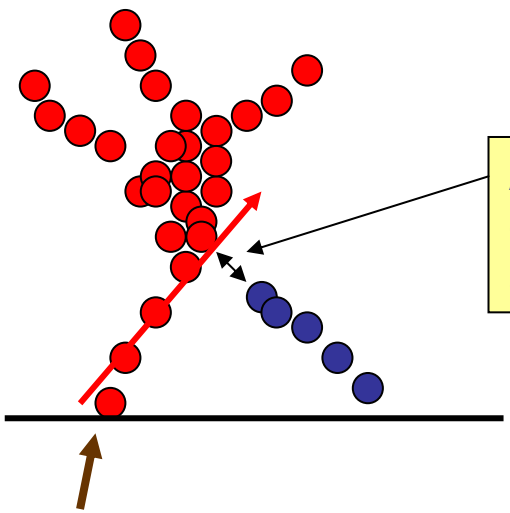
Tight cut on extrapolation of distance of closest approach of fits to end of inner tracks and start of outer track

Cluster Association II : Backscatters

- **Forward propagation clustering algorithm has a major drawback: back scattered particles form separate clusters**



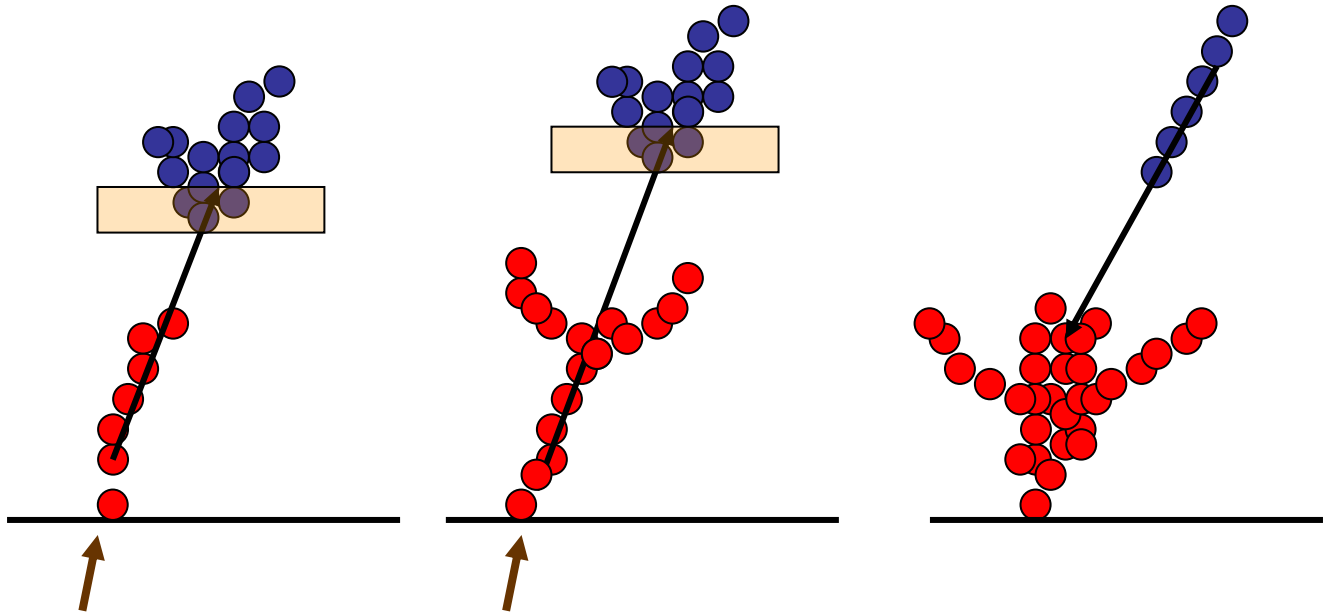
Project track-like clusters forward and check distance to shower centroids in subsequent N layers



Also look for track-like segments at start of cluster and try to match to end of another cluster

Cluster association III : MIP segments

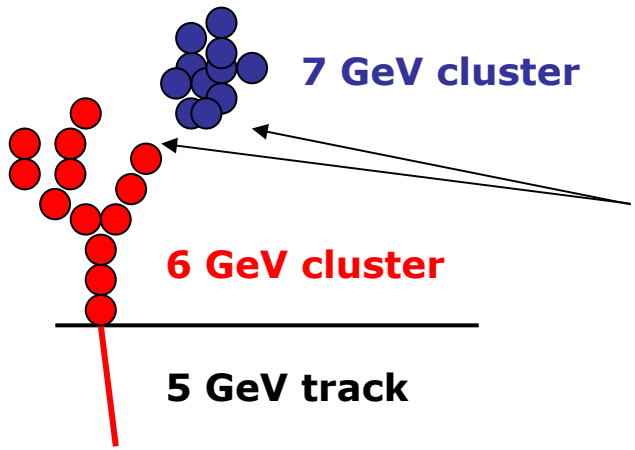
- Look at clusters which are consistent with having tracks segments and project backwards/forward



- Apply tight matching criteria on basis of projected track [NB: + track quality i.e. chi2]

Cluster Association Part II

- Have made very clear cluster associations
- Now try "cruder" association strategies
- **BUT** first associate tracks to clusters (temporary association)
- Use track/cluster energies to "veto" associations, e.g.



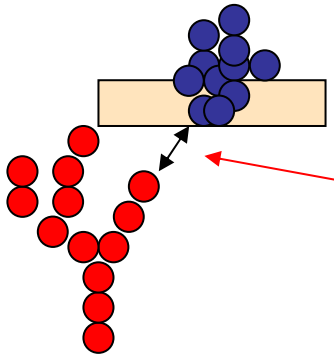
This cluster association would be forbidden if $|E_1 + E_2 - p| > 3\,\sigma_E$

Provides some protection against "silly" mistakes

★ Clustering and PFA not independent

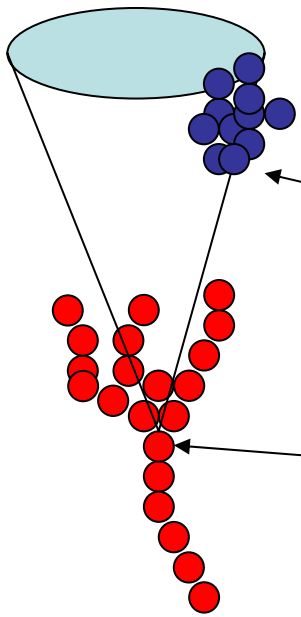
Sledgehammer Cluster Association

Proximity



Distance between hits -limited to first layers

Shower Cone



Associated if fraction of hits in cone > some value

Shower start identified

+Track-Driven Shower Cone

Apply looser cuts if have low E cluster associated to high E track

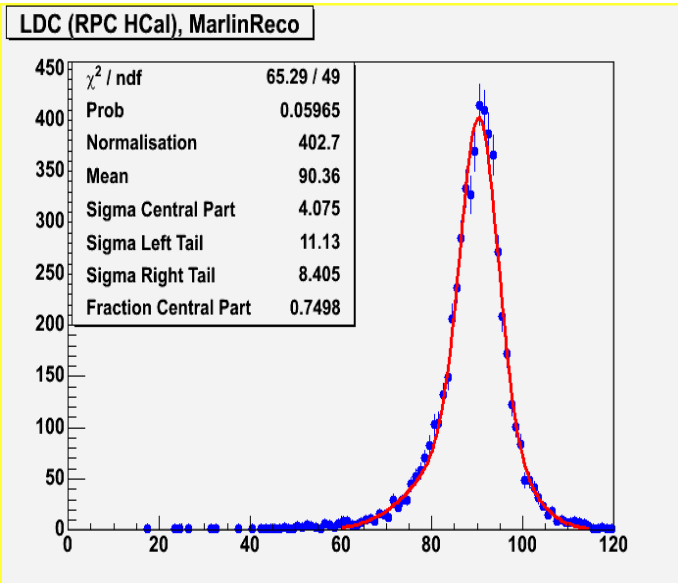
❸ PFA Results

★ Currently PFA performance only investigated for **Z→qq** at 91.2 GeV
- Good place to start as relatively simple (spread out jets)

★ Need to define figure of merit

Snowmass-style

Fit central Gaussian + asymmetric tails

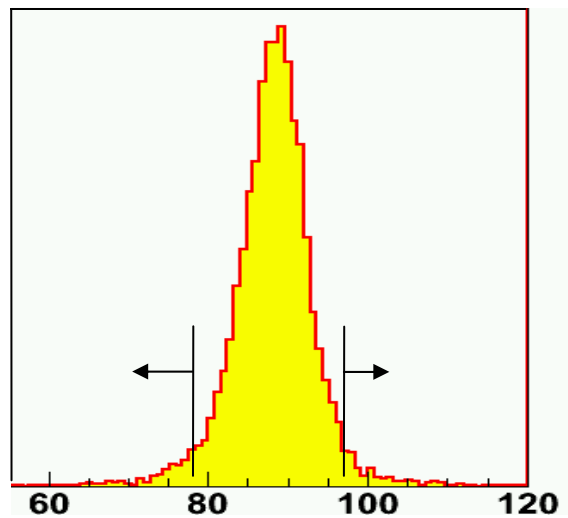


OK, but requires care:
- ⇒ sigma + fraction in peak
- + results will depend on fit region

New Proposed Figure of Merit:

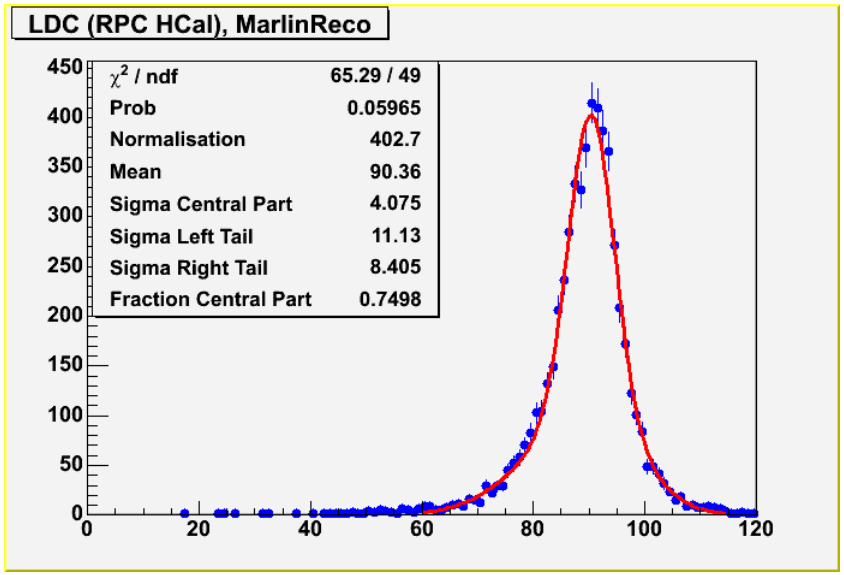
★ **Find smallest region containing 90 % of events**

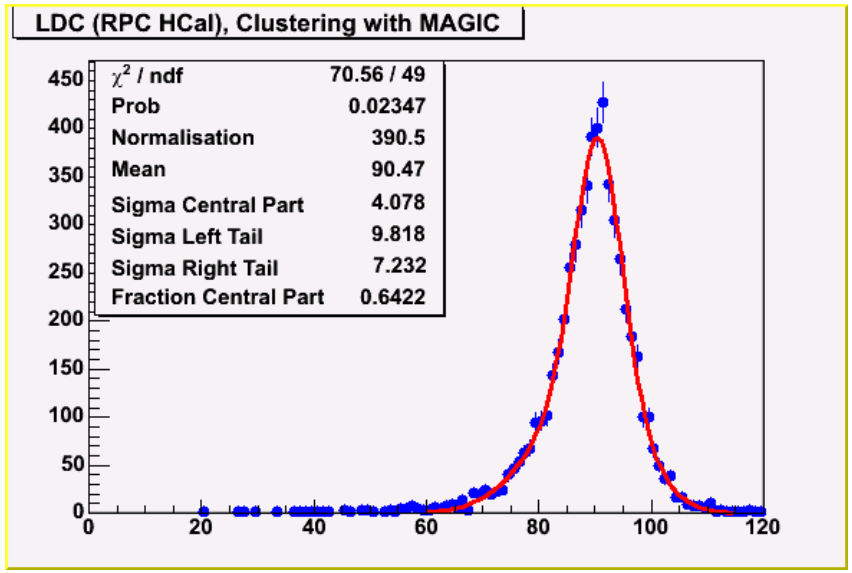
★ **Determine rms in this region**

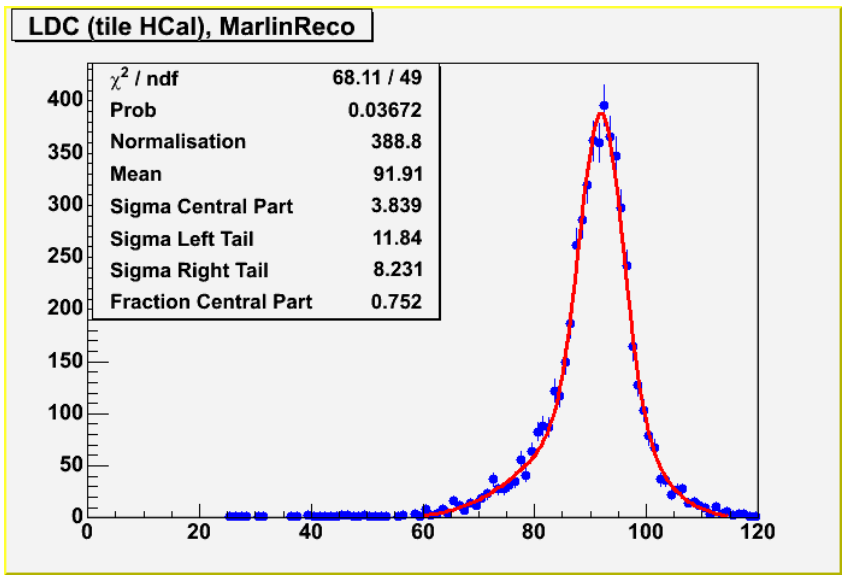


★ **More robust**

Wolf Results (Z →uds)







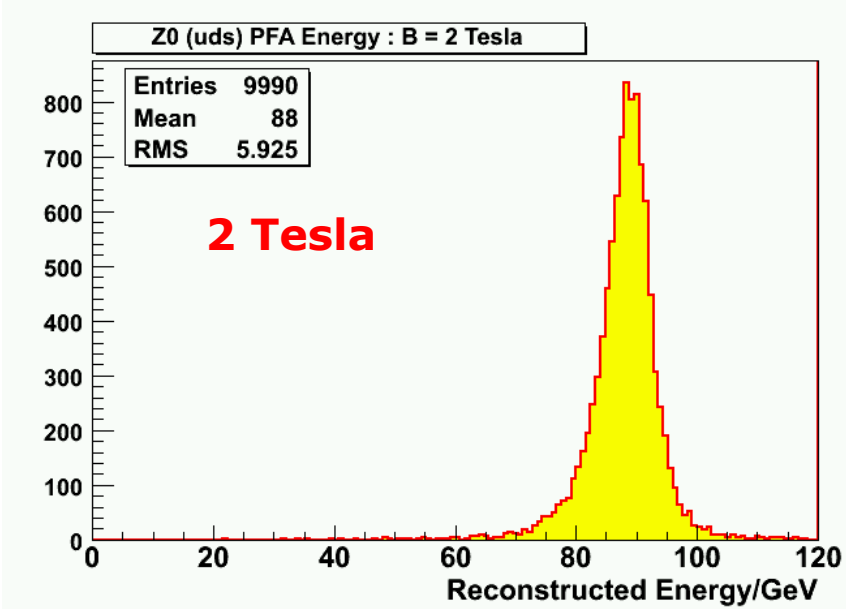
- **RMS of Central 90 % of Events**

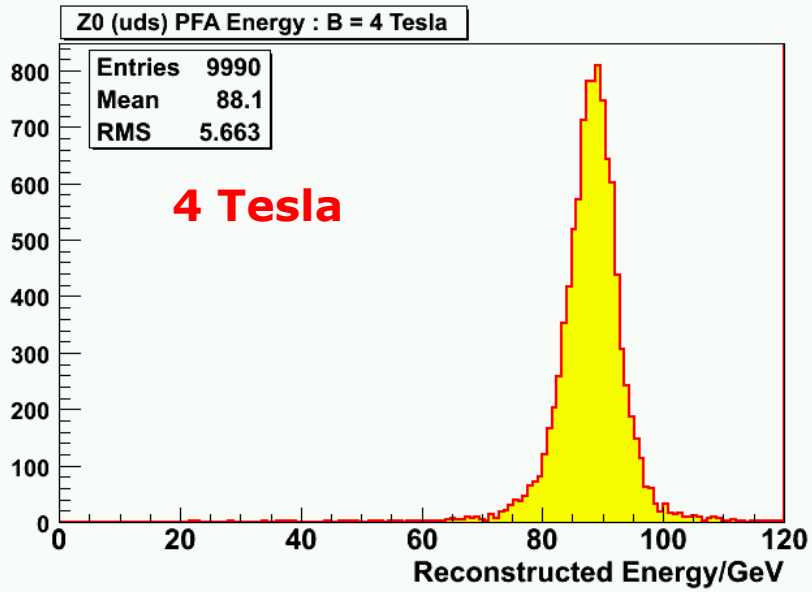
	RMS (90%)
RPC HCAL	4.3 GeV
Tile HCAL	4.1 GeV
RPC (MAGIC)	4.4 GeV

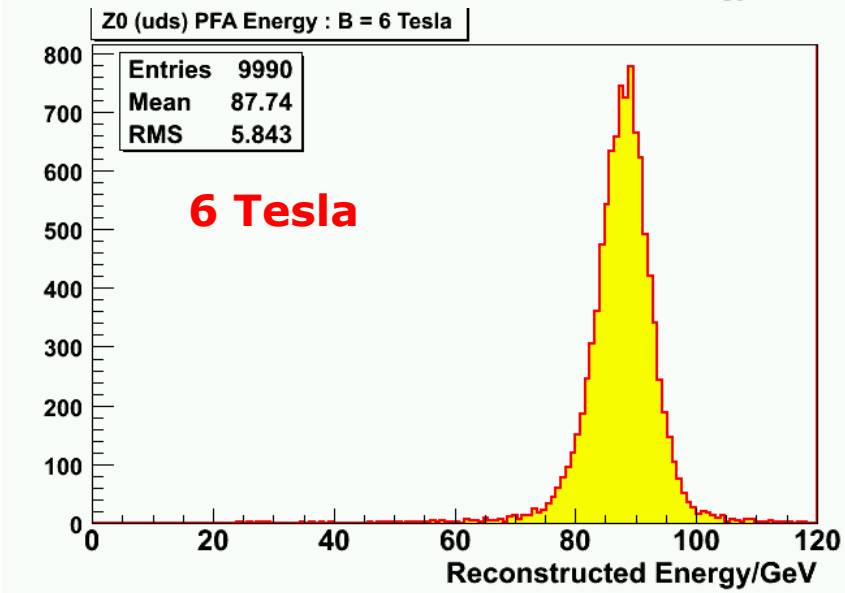
- **RMS (90 %) is somewhat larger than width of fitted peak**

(Results for Reco Tracks)

PandoraPFA Results (Z →uds)







✸ **RMS of Central 90 % of Events**

B-Field	$\sigma_E/E = \alpha\sqrt{(E/GeV)}$
2 Tesla	35.3±0.3%
4 Tesla	35.8±0.3 %
6 Tesla	37.0±0.3 %

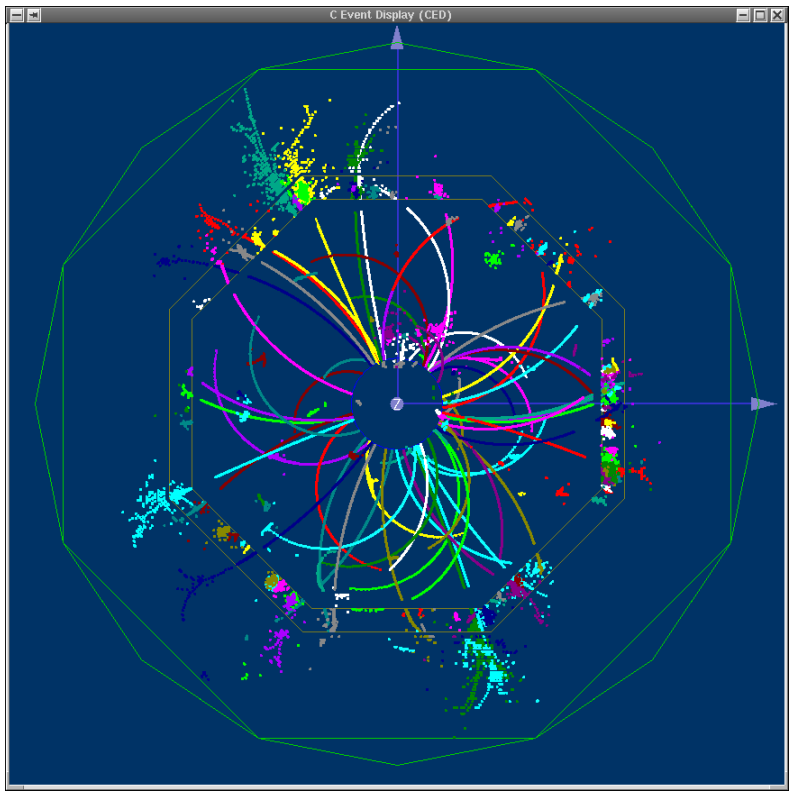
✦ **only weakly depends on B**

(Results for Cheated Tracks)

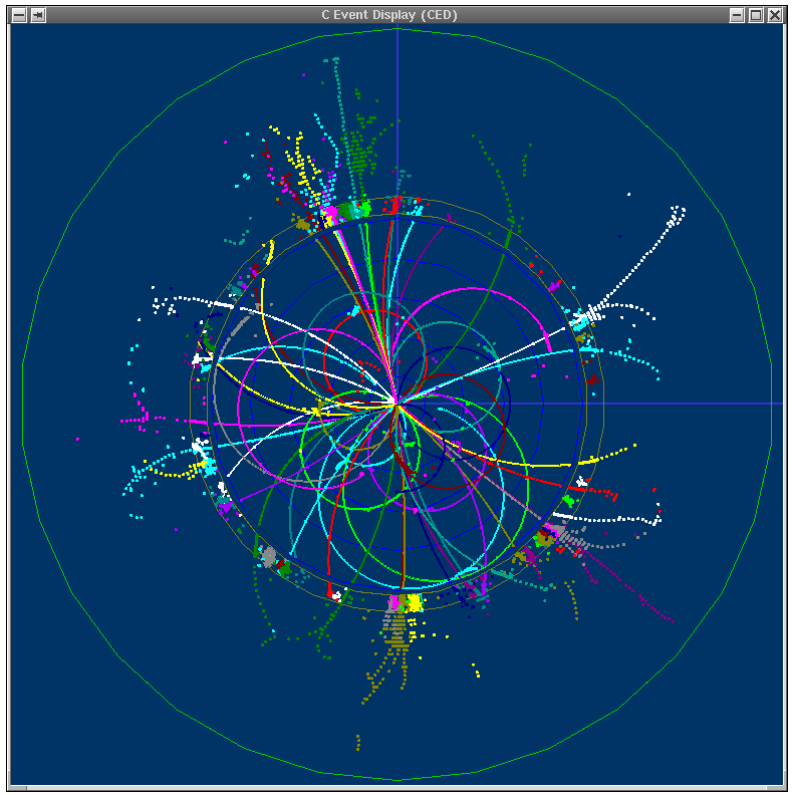
Towards detector optimisation

★ **Both WOLF and PandoraPFA designed to work for different detector parameters / detectors !**

e.g. tt event in LDC

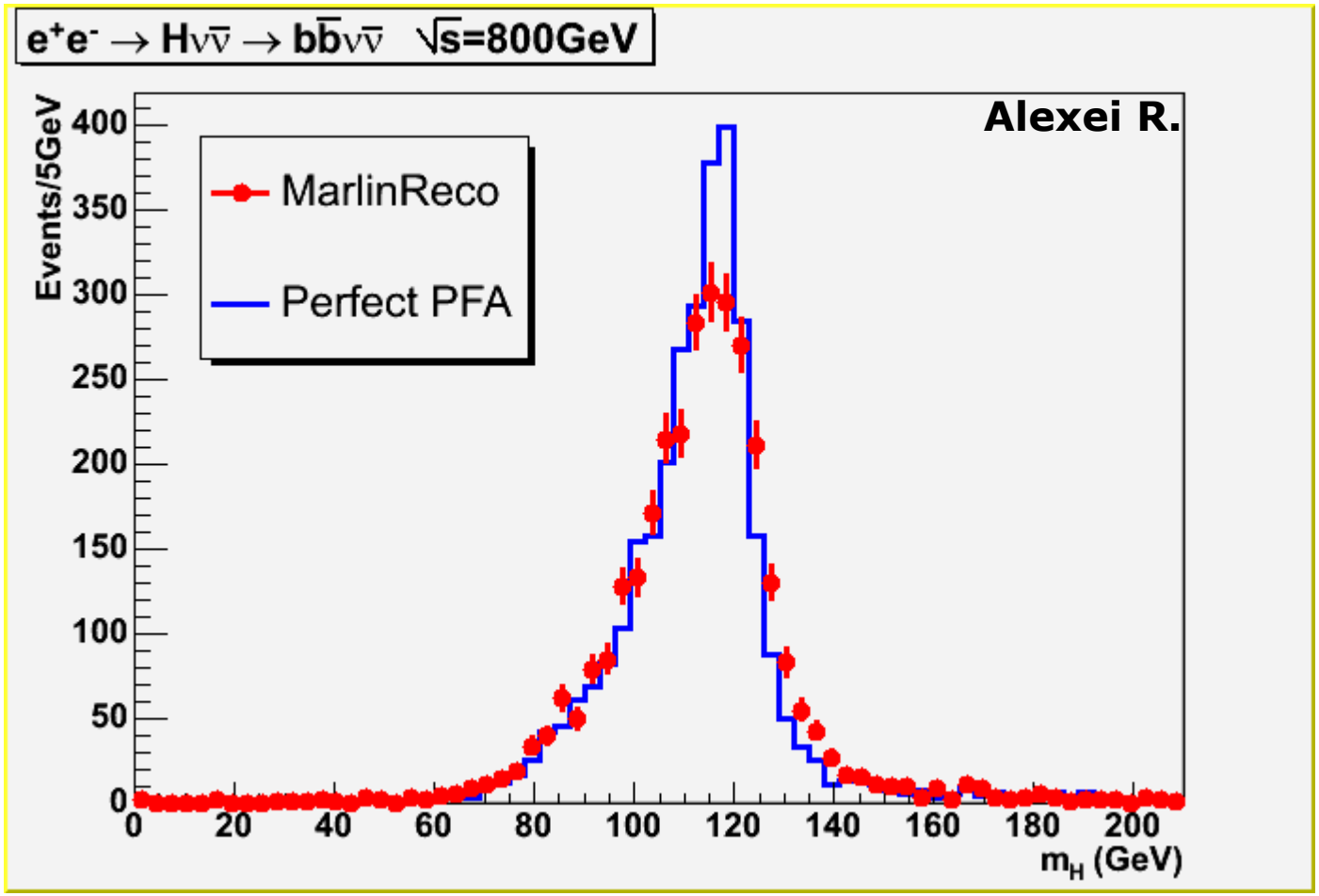


e.g. tt event in SiD



★ **really are in a position to start optimising the ILC detector design**

also possible to perform physics studies....



Reconstructed jet-jet mass

Conclusions

- ★ Huge amount of progress in the last year
- ★ MARLIN provides a very convenient framework to "plug in" reconstruction modules

- ★ Realistic PFAs now exist
  - plenty of room for development/improvement
- ★ Can now seriously start to optimise the ILC detector(s)
- ★ THIS NEEDS CARE – need to be sure not just seeing flaws in algorithms (Multiple Algorithms help)

- ★ + possible to pick up off-the-shelf software and perform full- simulation physics studies

- ★ Need to ensure that the software development and detector optimisation/physics studies are performed in a coherent manner

- ★ This is an excellent time to start using MARLIN
- ★ It is EASY to get going, you can be up and running in days !