Particle Flow Status

<u>Outline</u>:
- Basic Concept and Limits of Particle Flow
- Full Detector Simulation and Performance of Particle Flow Algorithms
- 'Track-Based' Particle Flow in Marlin
- Summary and Outlook

Basic Concept of Particle Flow

Particle Flow

- is a method to reconstruct events

goal: reconstruct four-momenta of all particles in an event

- 'mostly' particles with energies < 100 GeV
- better resolution in tracking system

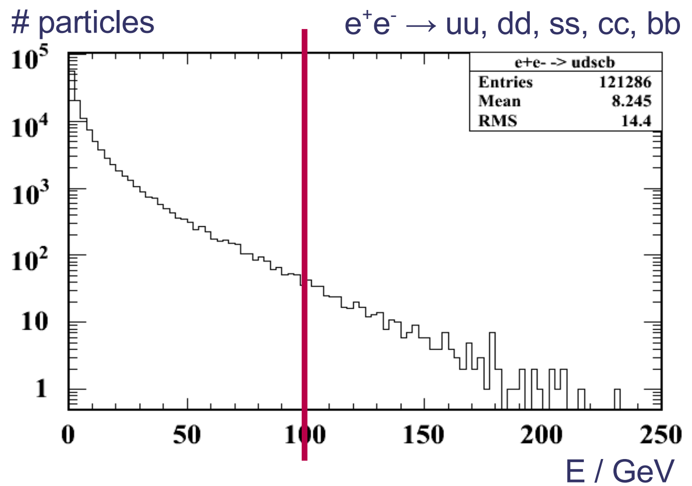
➔ use tracker to reconstruct $e^{+/-}$, $\mu^{+/-}$, $h^{+/-}$

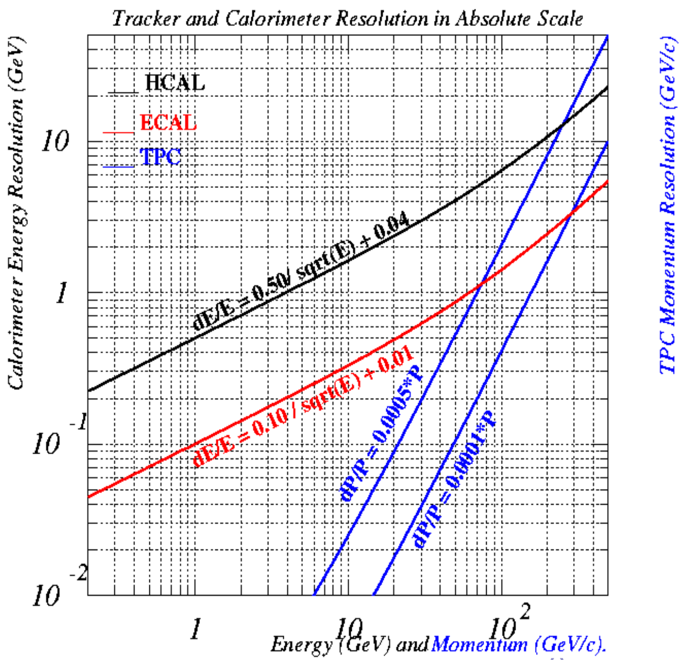
- **'find'** their ECAL/HCAL hits

➔ use ECAL to reconstruct gammas

➔ use ECAL + HCAL to reconstruct h^0

goal: **30% / √E** (jet) energy resolution to meet high precision physics goals





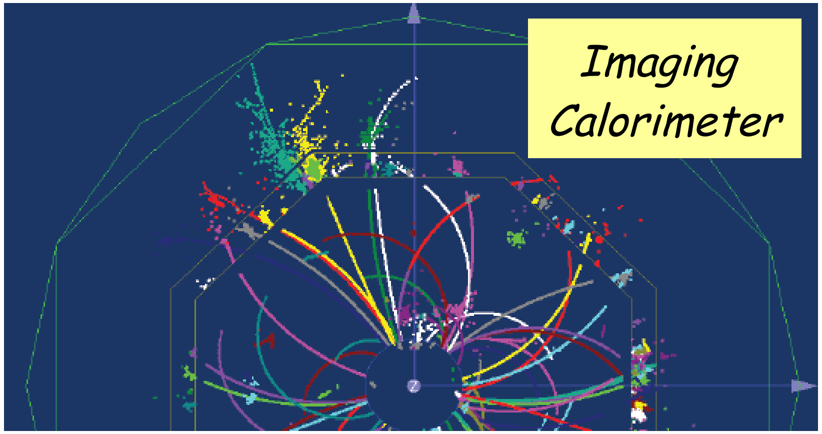
Basic Concept of Particle Flow

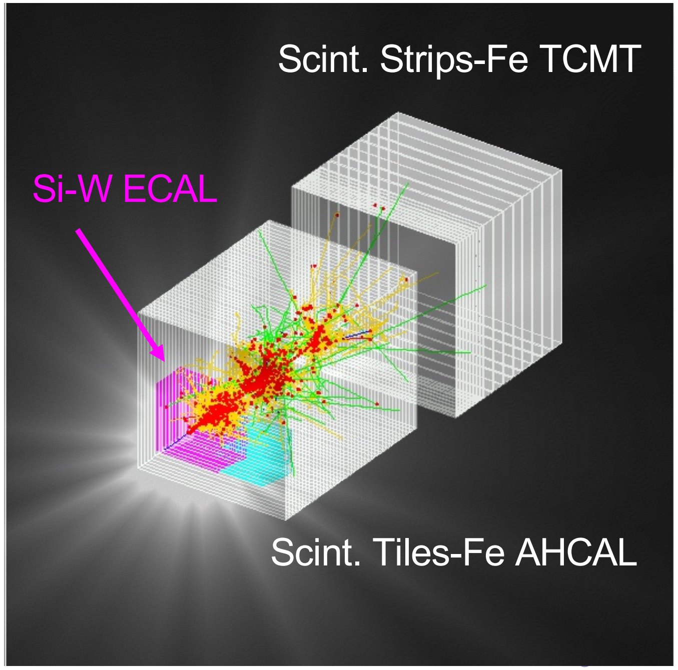
Implications of PFlow for the detector layout:

- **excellent** momentum resolution
- **high** calorimeter **granularity** (transv. **and** longitudinal)
    - ➔ assign energy to tracks
    - ➔ separate charged from neutral particles

➔ all this is incorporated in the layout of LDC (**simulation**)

➔ CALICE HCAL offers a prototype (**reality**)





use PFlow as a tool for **detector optimisation**

- length and radius of TPC and Calorimeter
- segmentation, number of layers and absorber material in Calorimeter
- B field ...

➔ performance vs. cost

Basic Concept of Particle Flow

jet energy composition at the ILC:

- $e^+e^- \rightarrow$ hadrons @ 90 – 500 GeV
- $E_{h+/-} \approx 0.6 \cdot E_{det}$ $\sigma_{h+/-} \approx 10^{-4} \cdot E^2_{h+/-}$
- $E_g \approx 0.3 \cdot E_{det}$ $\sigma_g \approx 0.11 \cdot \sqrt{E_g}$
- $E_{h0} \approx 0.1 \cdot E_{det}$ $\sigma_{h0} \approx 0.50 \cdot \sqrt{E_{h0}}$

ideal jet energy resolution:

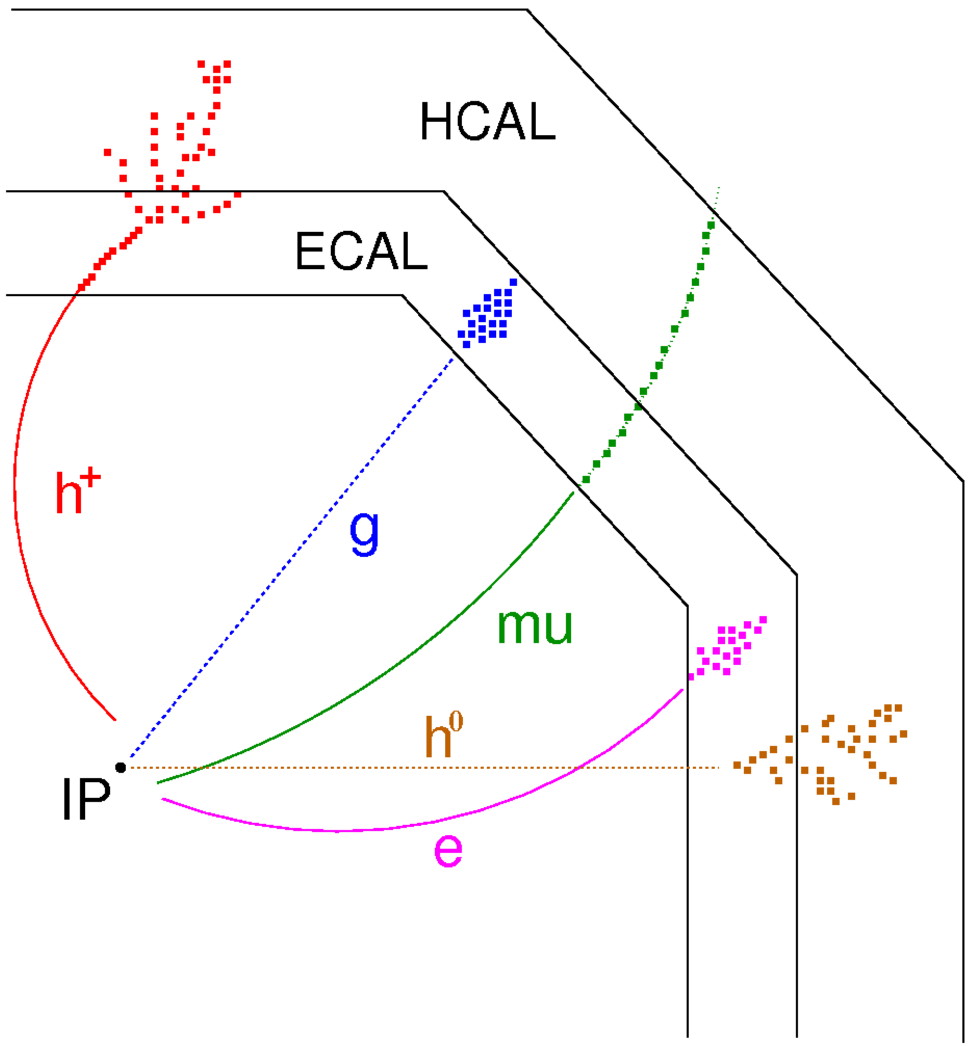
- $(\sigma_{Ejet})^2 = (\sigma_{h+/-})^2 + (\sigma_g)^2 + (\sigma_{h0})^2$
- $\sigma_{Ejet}/E_{jet} \approx \mathbf{0.20/\sqrt{E_{jet}}}$

➔ but there are **inefficiencies** (confusion)

➔ $(\sigma_{Ejet})^2 = (\sigma_{h+/-})^2 + (\sigma_g)^2 + (\sigma_{h0})^2 + (\sigma_{conf})^2$

➔ confusion term dominates

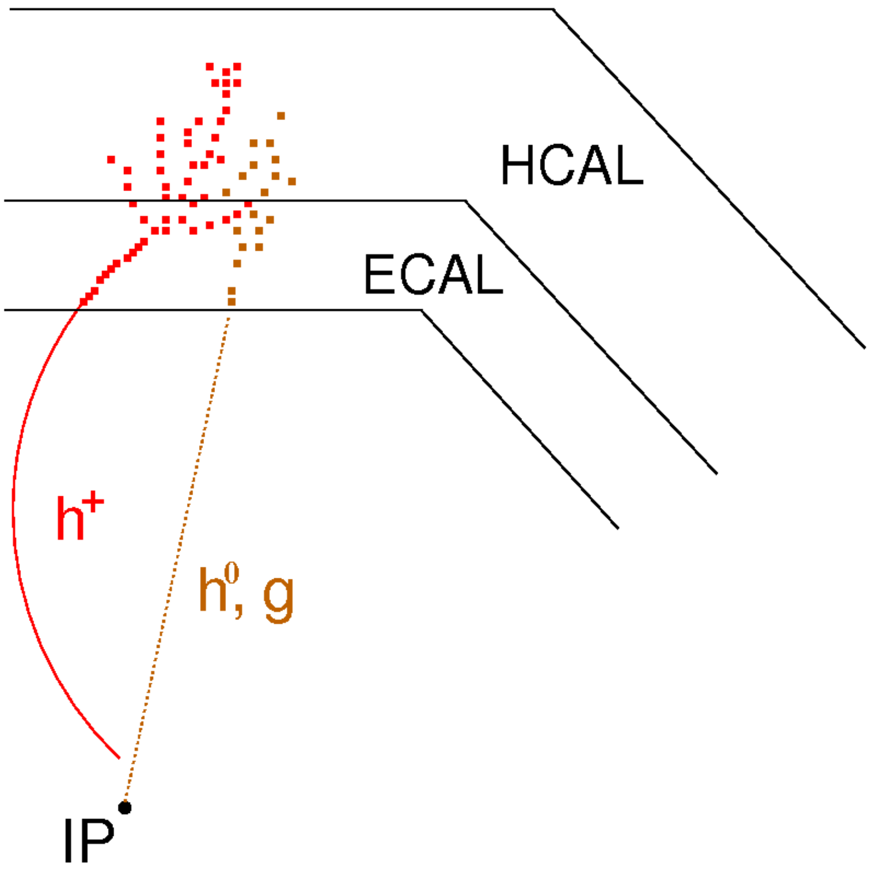
- 2 effects: 'wrong assignment' and 'double counting'



Basic Concept of Particle Flow

main reason: **overlaps** → **two** contributing **effects**

1. missing neutral energy (**wrong assignment**):



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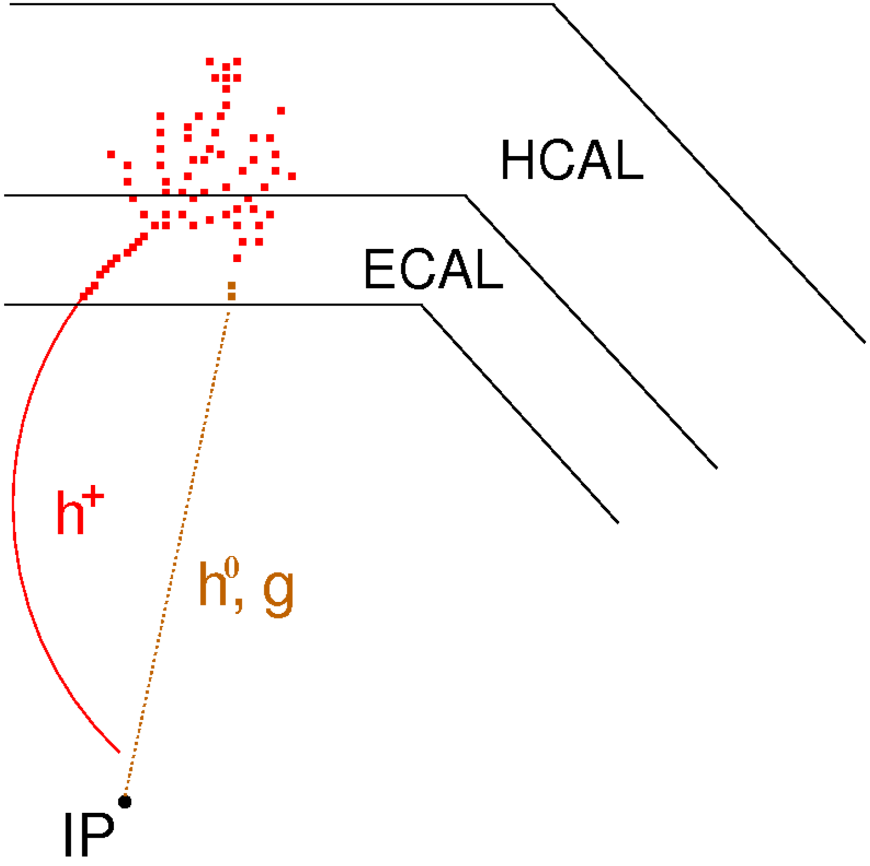

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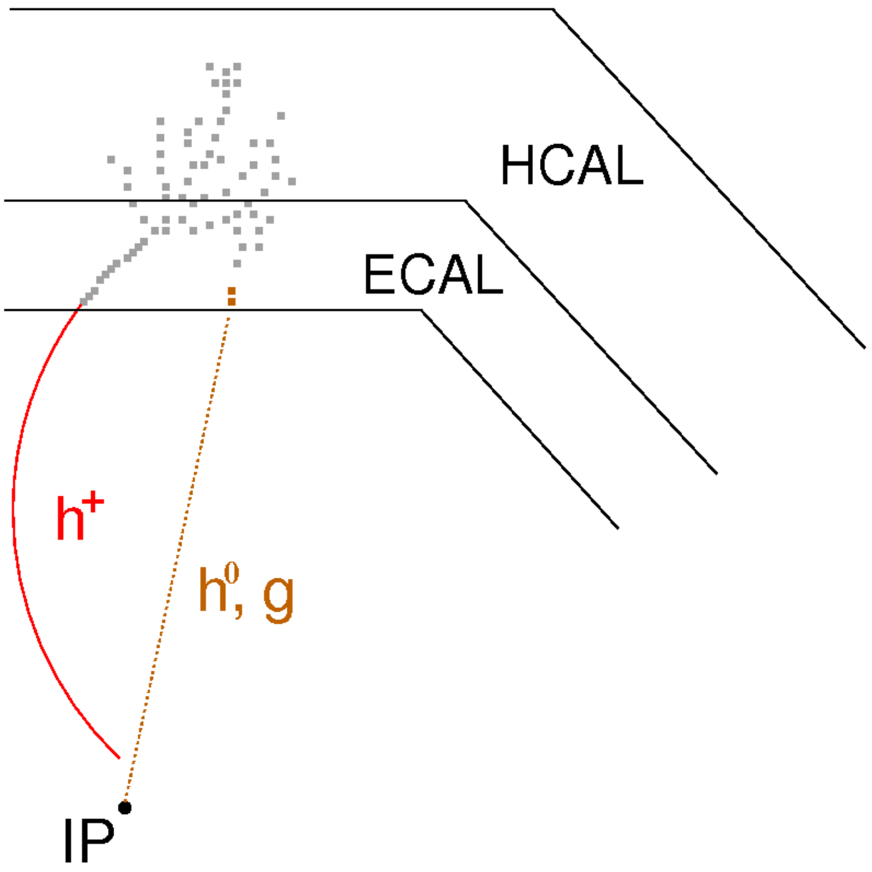
    - → four momentum of charged particle **reconstructed accurately**



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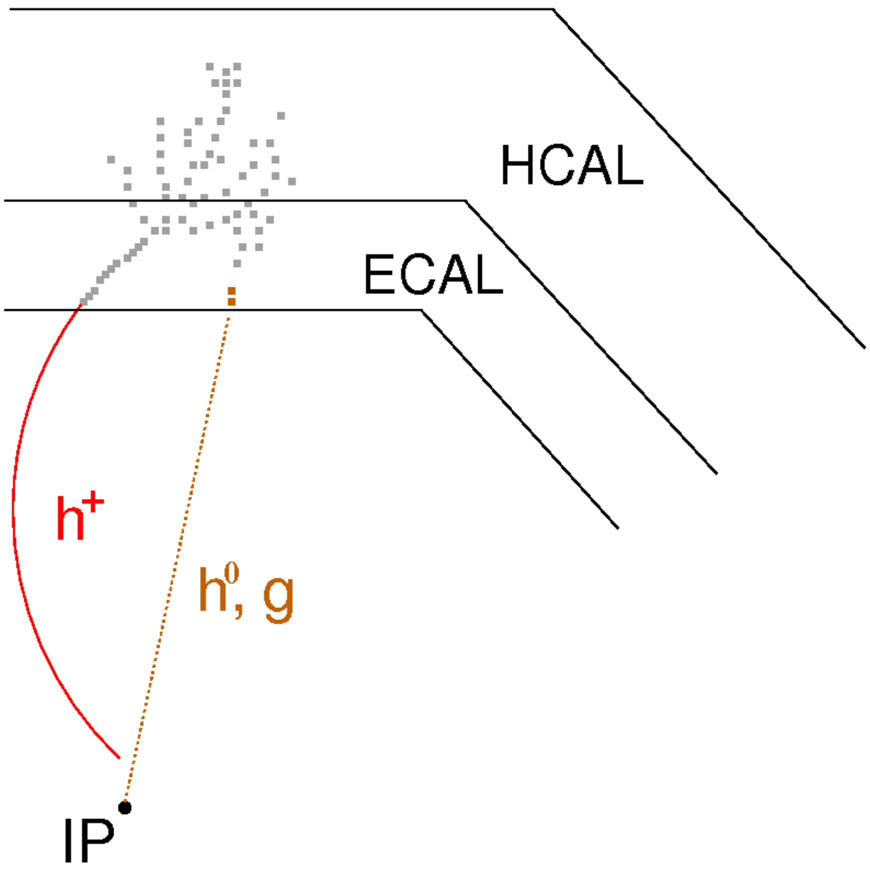
   - neutral particle reconstructed with **too small** energy or **not at all**
   - possibly problem to identify particle (h^0 or g → assign mass)



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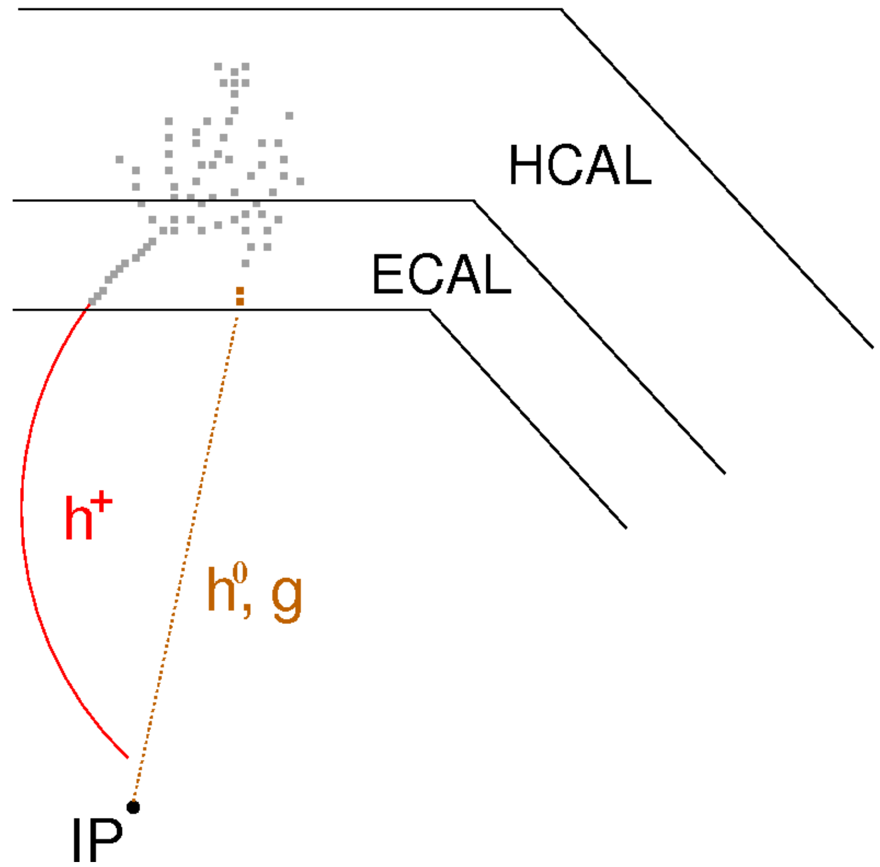
→ deteriorates (jet) energy to **smaller value**



Basic Concept of Particle Flow

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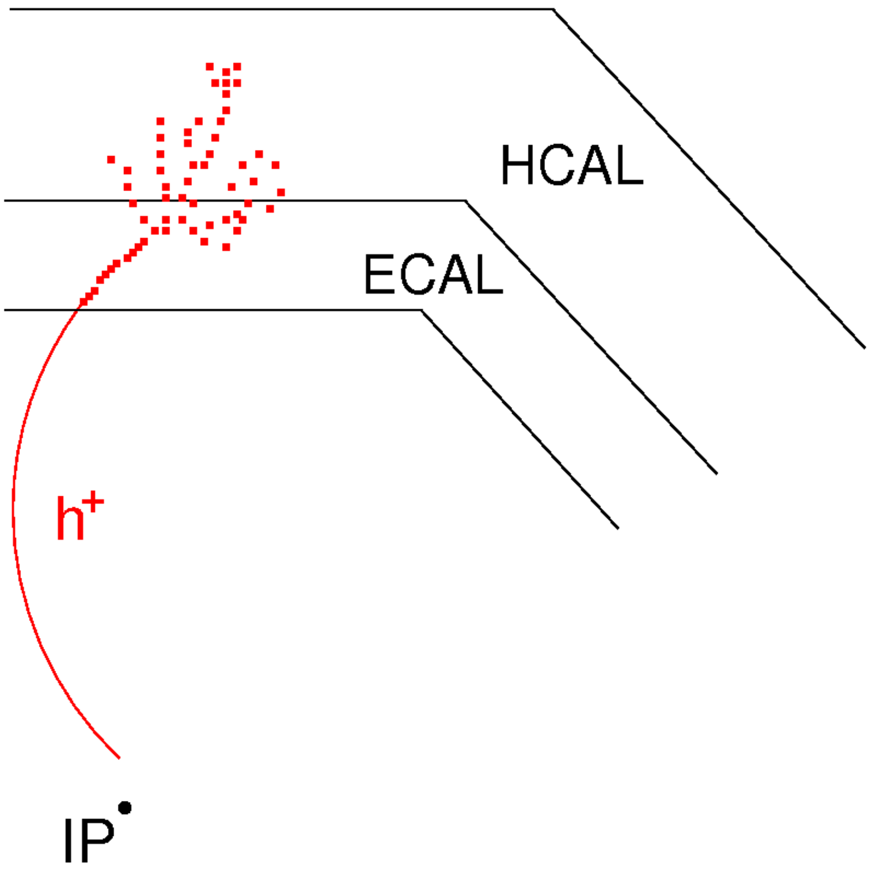

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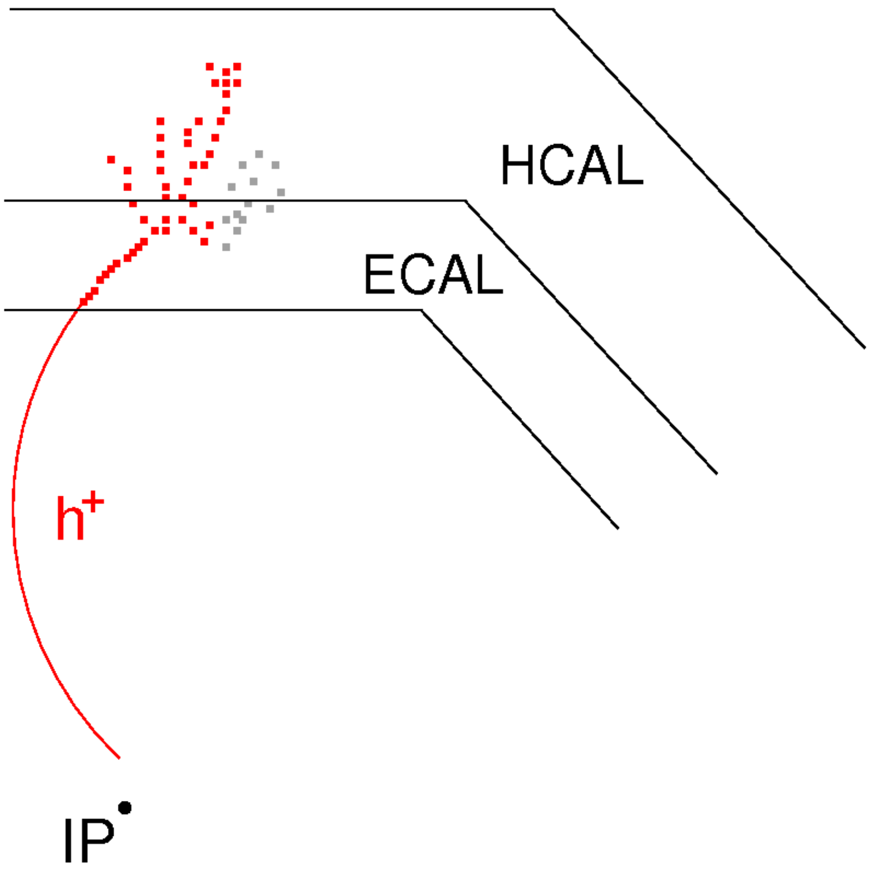

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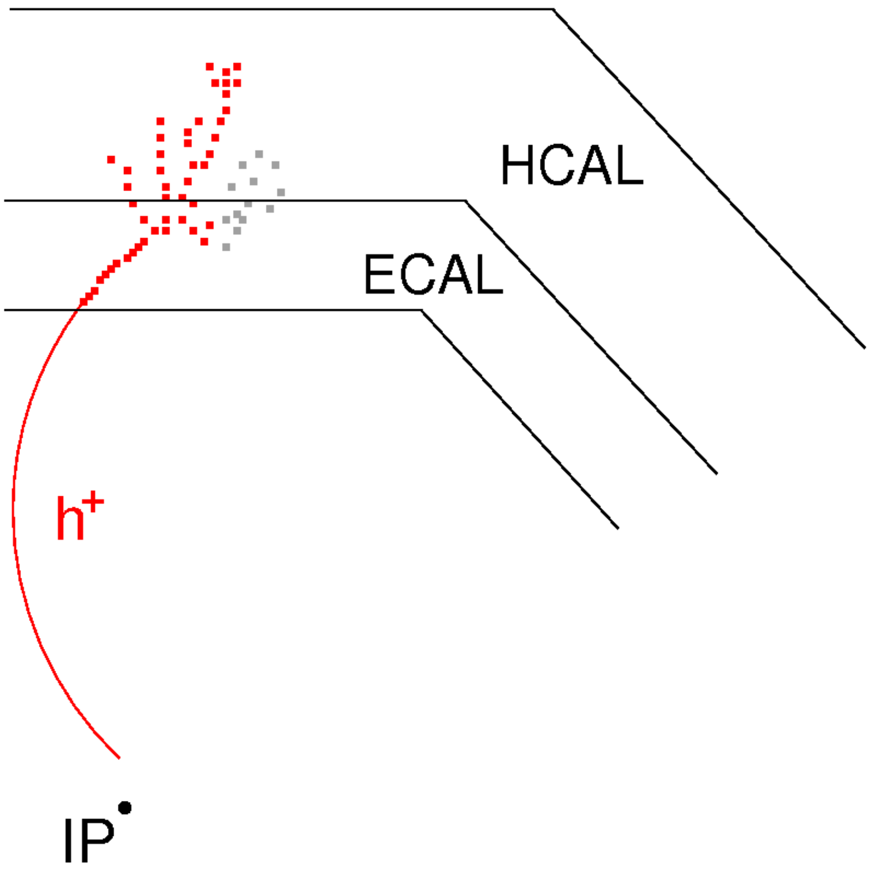

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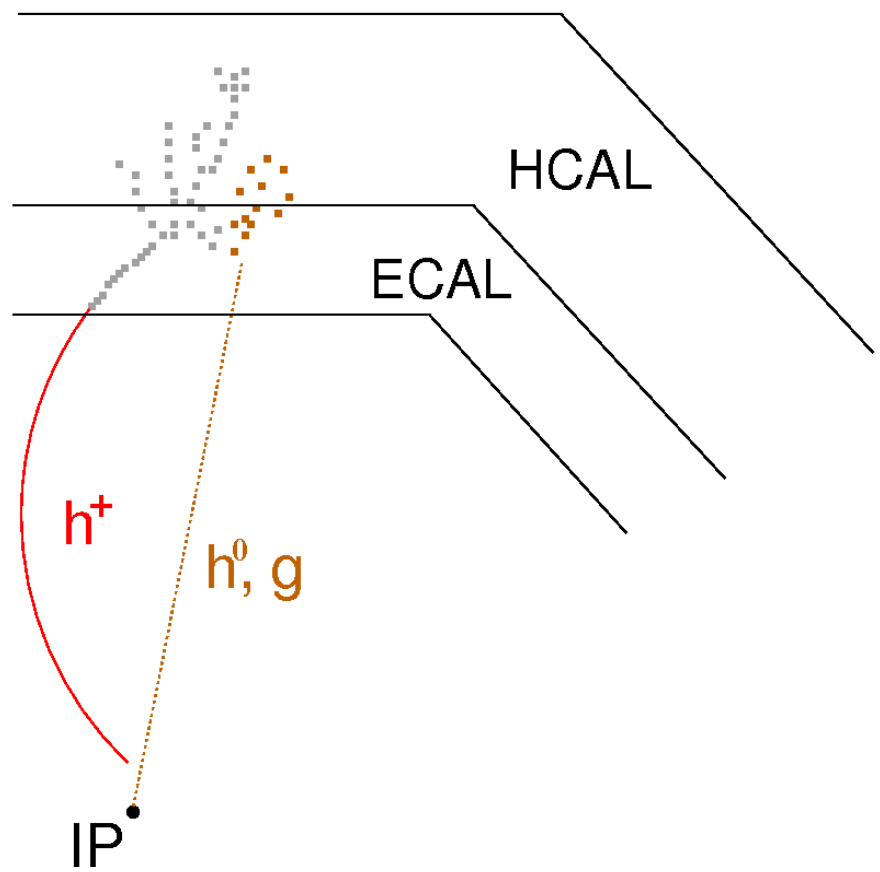

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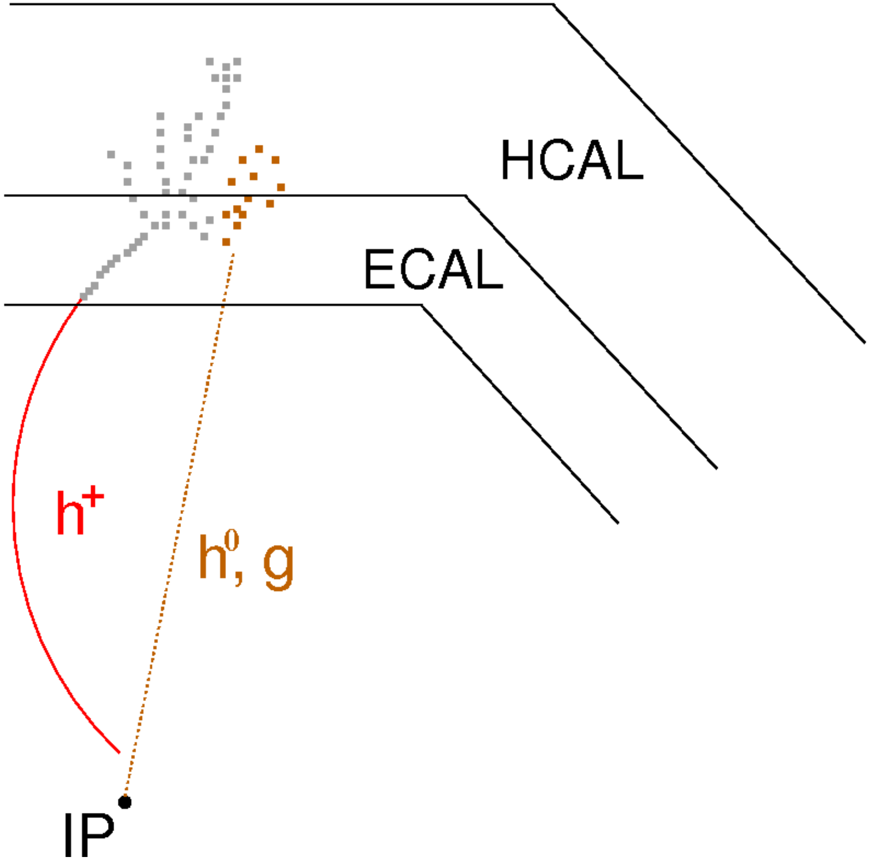
➔ deteriorates (jet) energy to **larger value**



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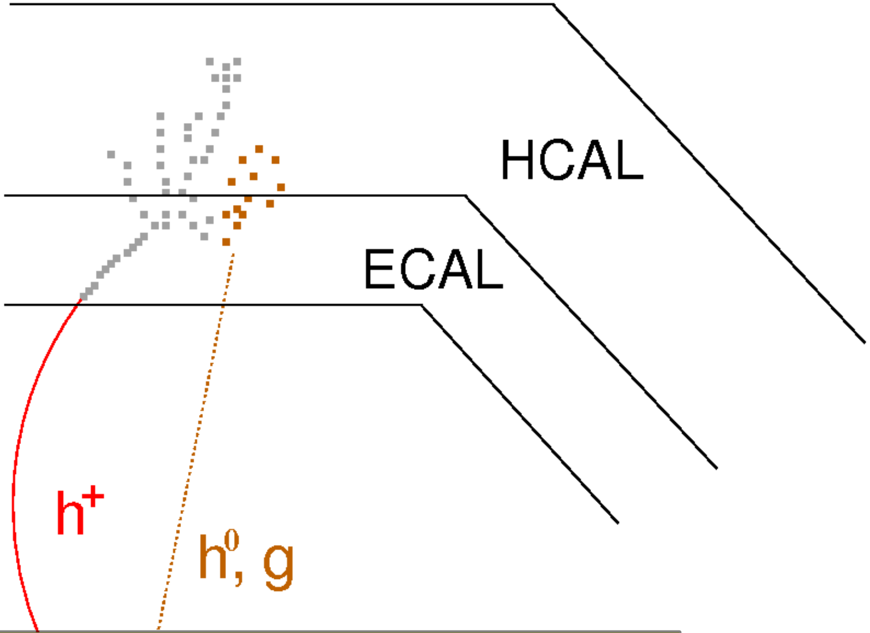


→ reconstructed (jet) energy resolution **easily** deteriorates to values of **$0.6/\sqrt{E_{jet}}$ ... $0.8/\sqrt{E_{jet}}$** depending on the occupancy and the jet density in an event

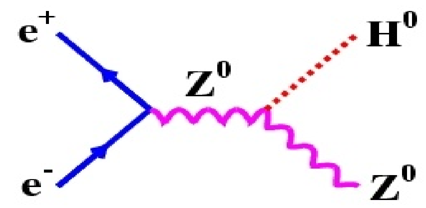
→ **highly accurate** treatment of the energy assignment needed

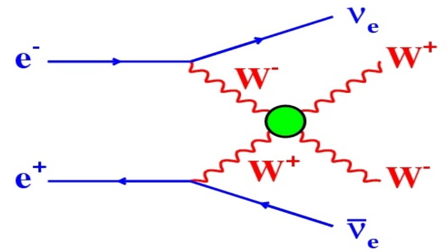
→ **ambitious goal** to reach $0.3/\sqrt{E_{jet}}$ with an 'theoretical' limit of $\approx 0.2/\sqrt{E_{jet}}$

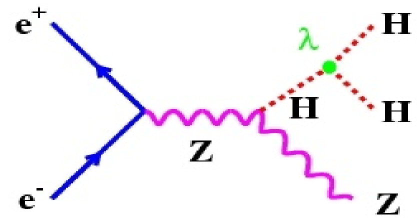
Basic Concept of Particle Flow

<u>benchmark processes</u> to check/optimise performance of detector **and** PFlow

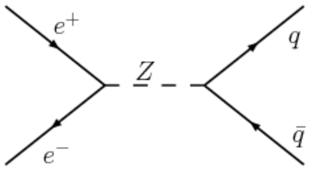
- choose **key physics** processes, such as:

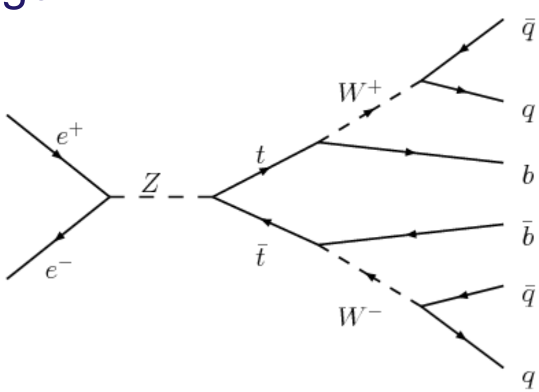


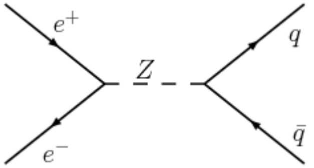




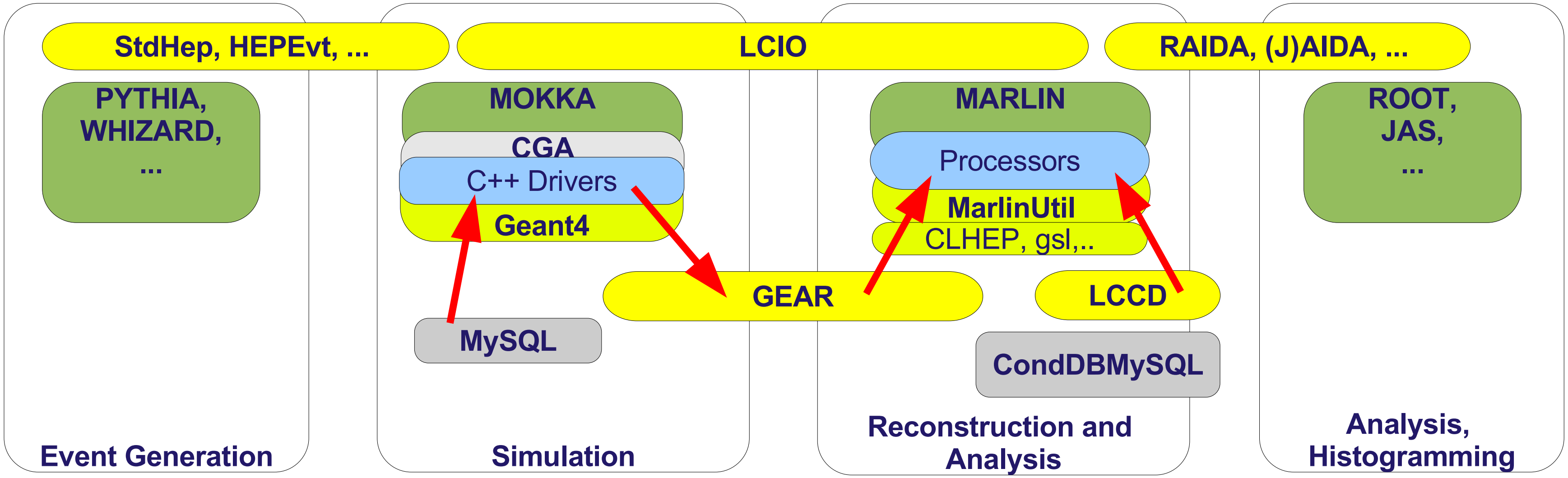
- start with **more simple** processes to study PFlow performance
  - $e^+e^- \rightarrow Z^0 \rightarrow$ uds @ 91.2 GeV:
    - only little 'overlaps', **good benchmark** for PFlow algorithm
  - $e^+e^- \rightarrow$ ttbar$\rightarrow$ 6 jets @ 360 ... 1000 GeV:
    - (relatively) low energetic jets, but many
    - especially at high energies **challenging** for PFlow algorithm
  - $e^+e^- \rightarrow Z^0 \rightarrow$ uds @ 200 ... 1000 GeV:
    - high energetic, dense and collimated jets
    - more an 'academic' process but also **challenging** for PFlow algorithm







Detector Simulation and Reconstruction



Simulation: **Mokka** (GEANT4 based simulation package)

Reconstruction: **MarlinReco** ('Wolf') and **'PandoraPFA'** (both **Marlin** based)

MarlinReco → full set of modules (Processors) for **event reconstruction**

Digitisation, Tracking, Clustering, PFlow and Analysis

http://www-flc.desy.de/ilcsoft

PandoraPFA → Clustering and PFlow (Cambridge University [M. Thomson])

→ will be released in MarlinReco as well

pre-release available at: http://www.hep.phy.cam.ac.uk/~thomson/pandoraPFA/

all software can be found at our portal: **http://ilcsoft.desy.de**

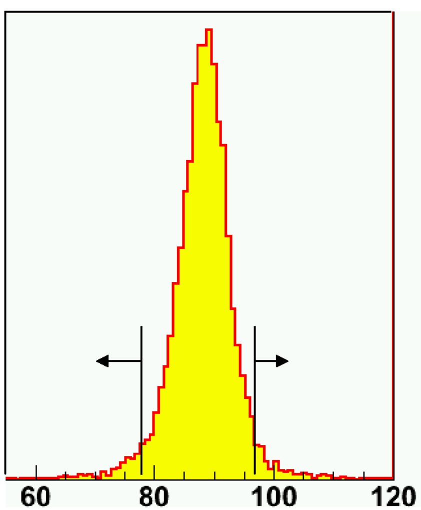
Performance of Particle Flow Algorithms

Wolf (A. Raspereza) and **PandoraPFA** (M. Thomson):

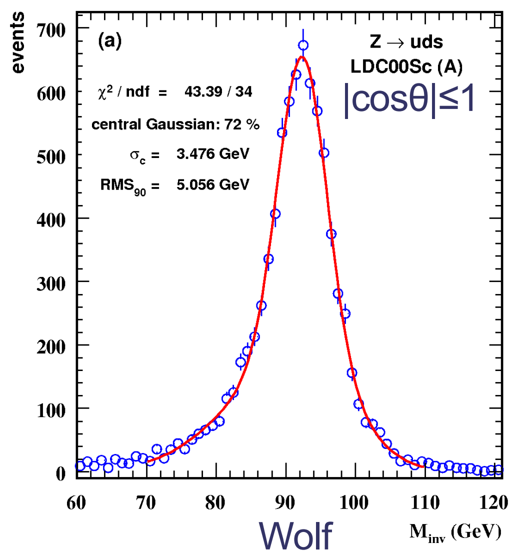
- Wolf: $\Delta E/E \approx$ **0.5**$/\sqrt{E}$ ($RMS_{90\%}$) for $Z^0 \rightarrow$ uds @ **91.2 GeV**
- PandoraPFA: $\Delta E/E \approx$ **0.3**$/\sqrt{E}$ ($RMS_{90\%}$) for $Z^0 \rightarrow$ uds @ **91.2 GeV**

✓ both perform **'reasonable'** @ 91.2 GeV, benchmark: PandoraPFA

Figure of Merit:

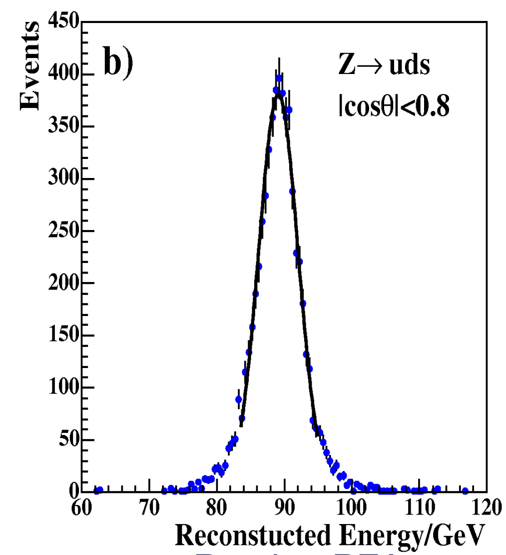


★ **Find smallest region containing 90 % of events**
★ **Determine rms in this region**



Wolf

RMS90% / E ≈ 0.5 / √E



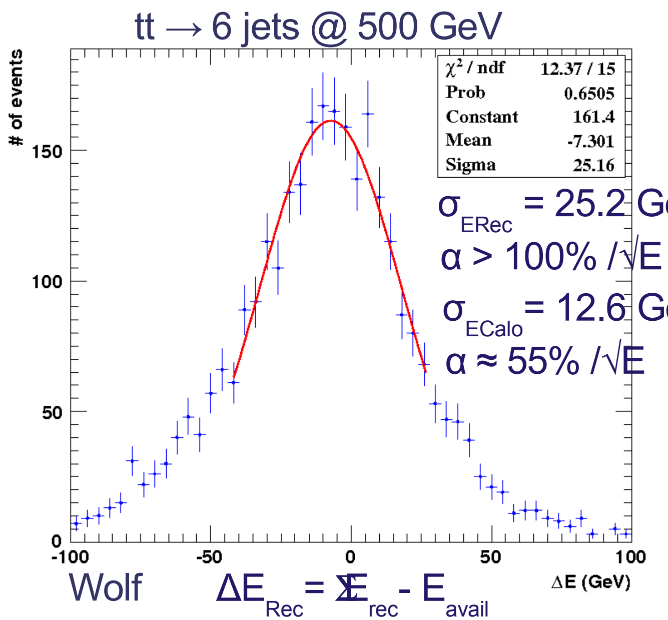
PandoraPFA

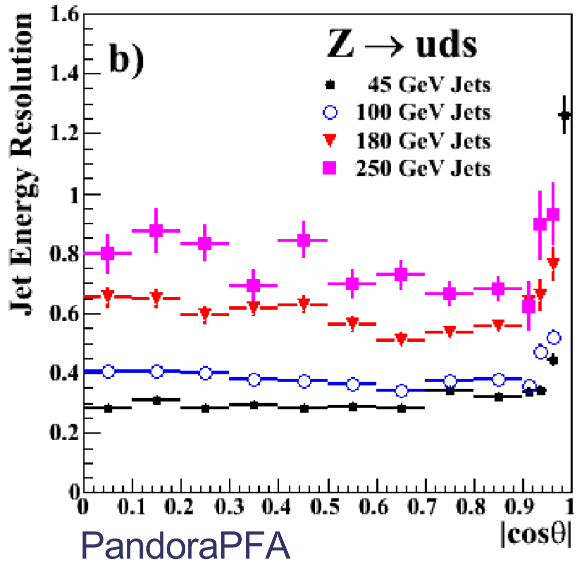
RMS90% / E ≈ 0.3 / √E

Performance of Particle Flow Algorithms

Wolf (A. Raspereza) and **PandoraPFA** (M. Thomson):

- performance of both **degrade rapidly** with increasing jet energy and overlaps

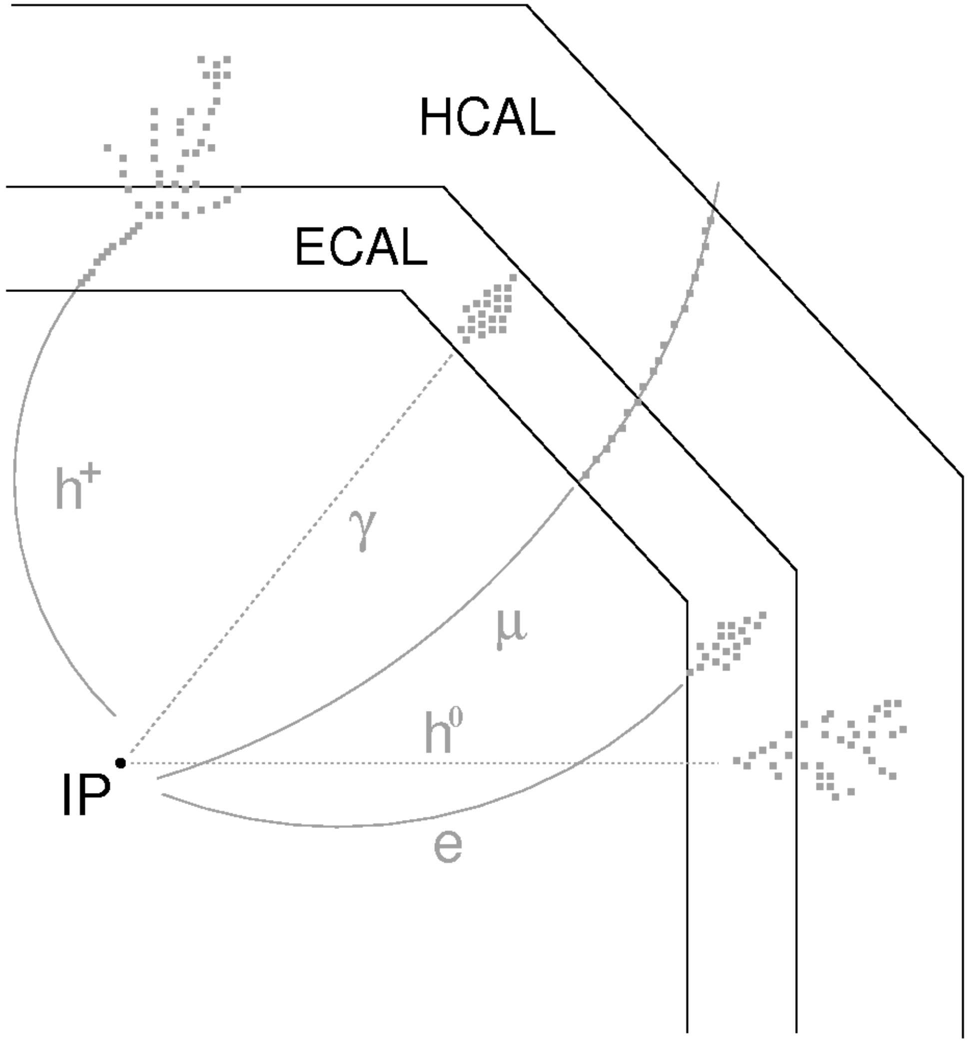




- both are **'cluster-based'** algorithms (PandoraPFA: tracks ↔ cluster-ass.)

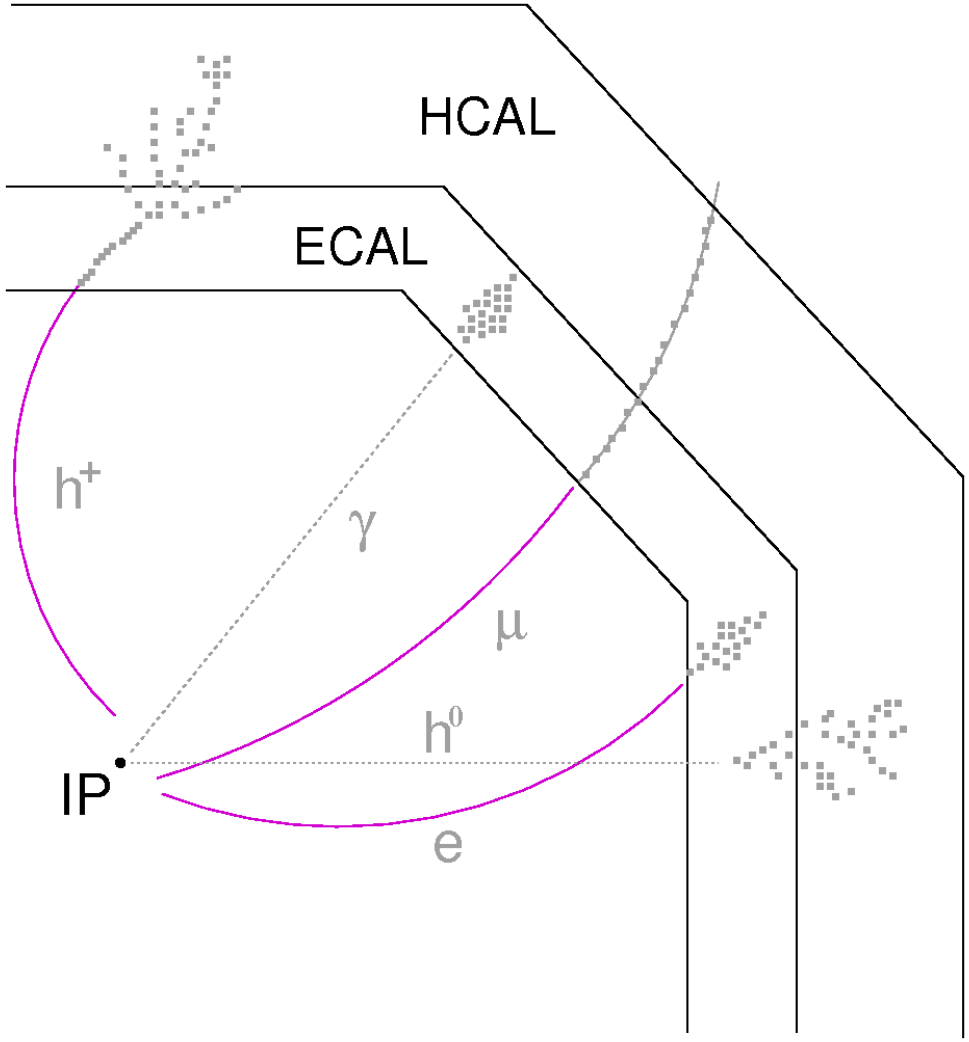
'track-based' algorithm should perform better → **more complex**

Particle Flow: 'Cluster-Based' Approach



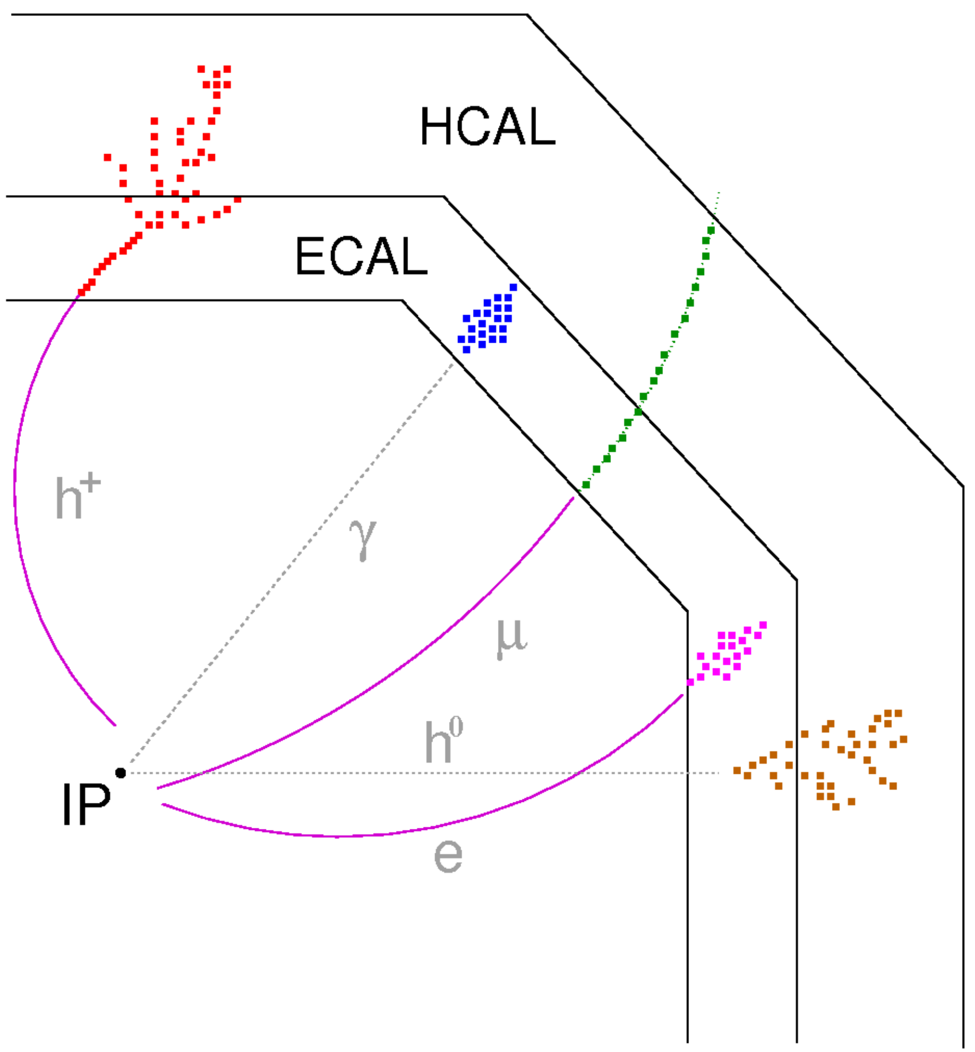
Particle Flow: 'Cluster-Based' Approach

1. tracking (VTX, SIT, TPC...)



Particle Flow: 'Cluster-Based' Approach

1. tracking (VTX, SIT, TPC...)
2. clustering (ECAL and HCAL)
   - independent
   - different algorithms



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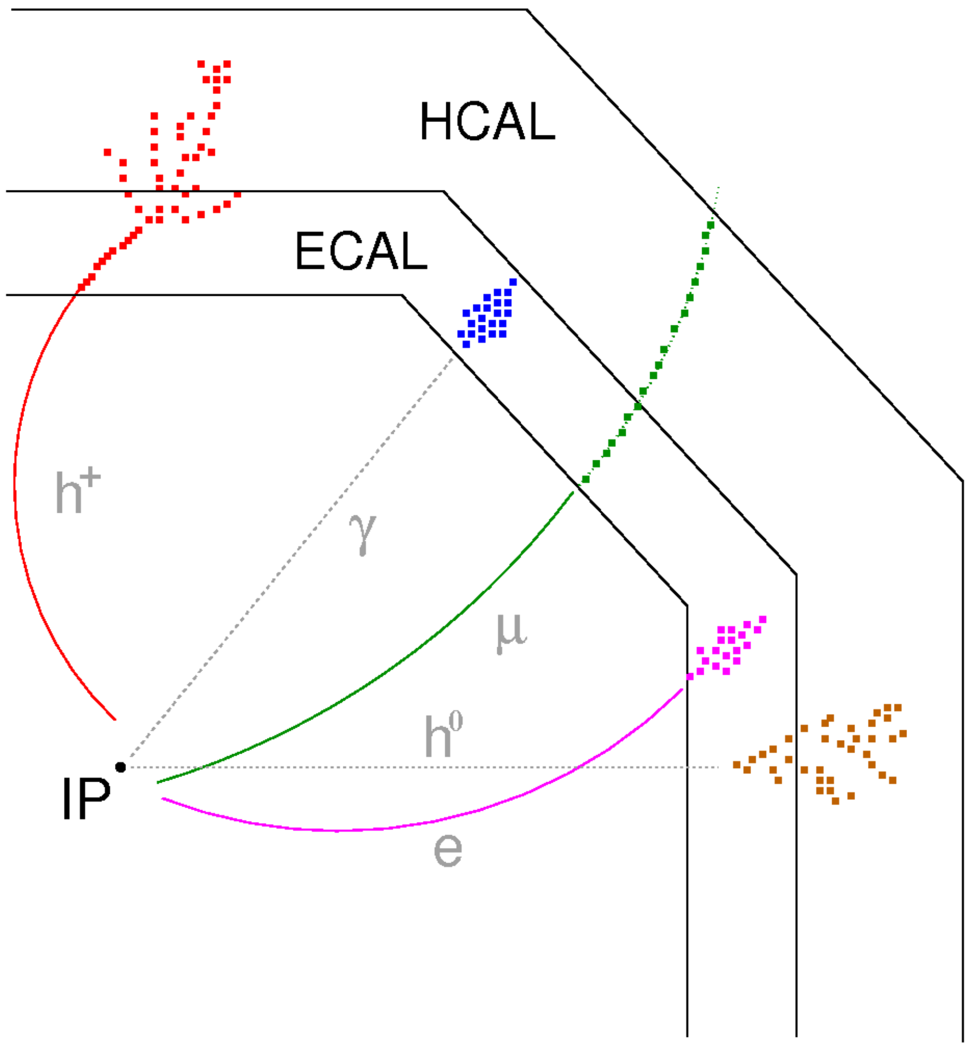
   - proximity criteria



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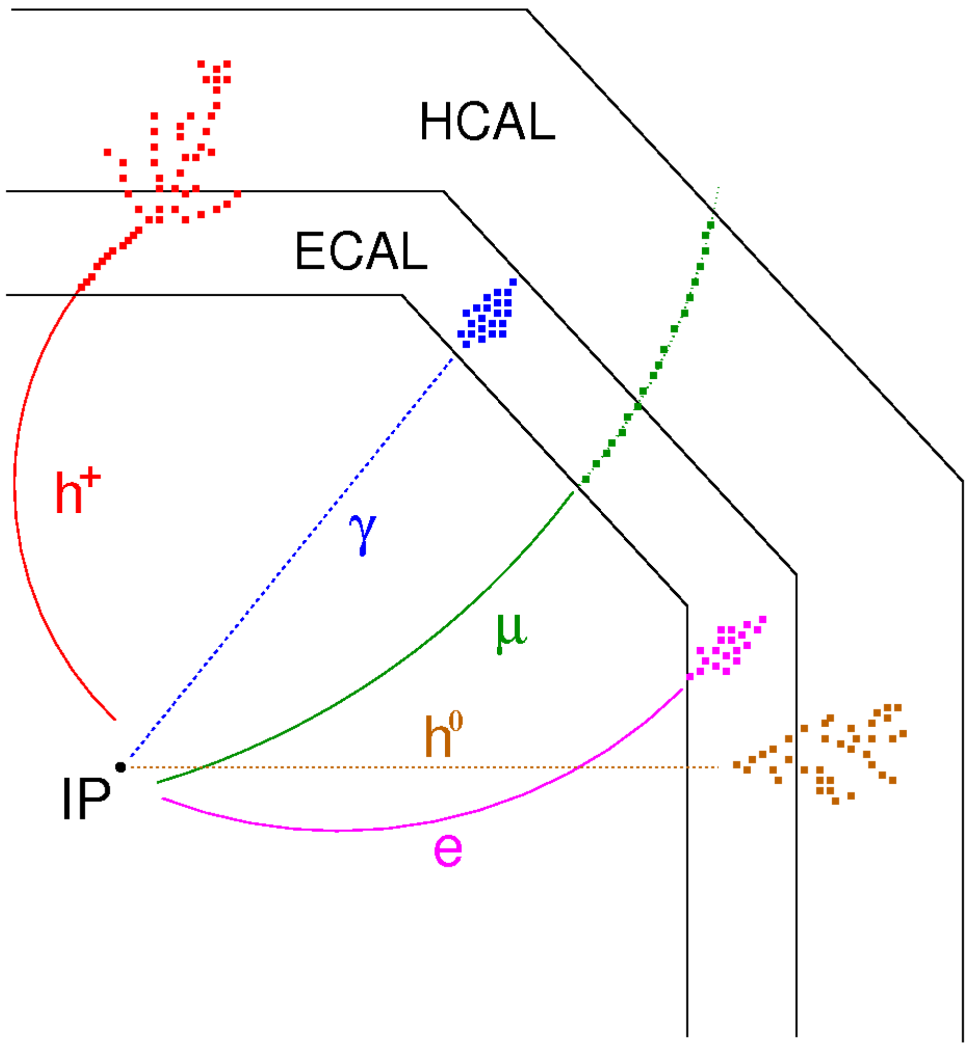
4. particle ID
   - e.g. fraction of energy in ECAL/HCAL
   - $e^{+/-}$, $mu^{+/-}$, $h^{+/-}$
   - assign clusters w/o tracks to neutral objects (g, h^0)



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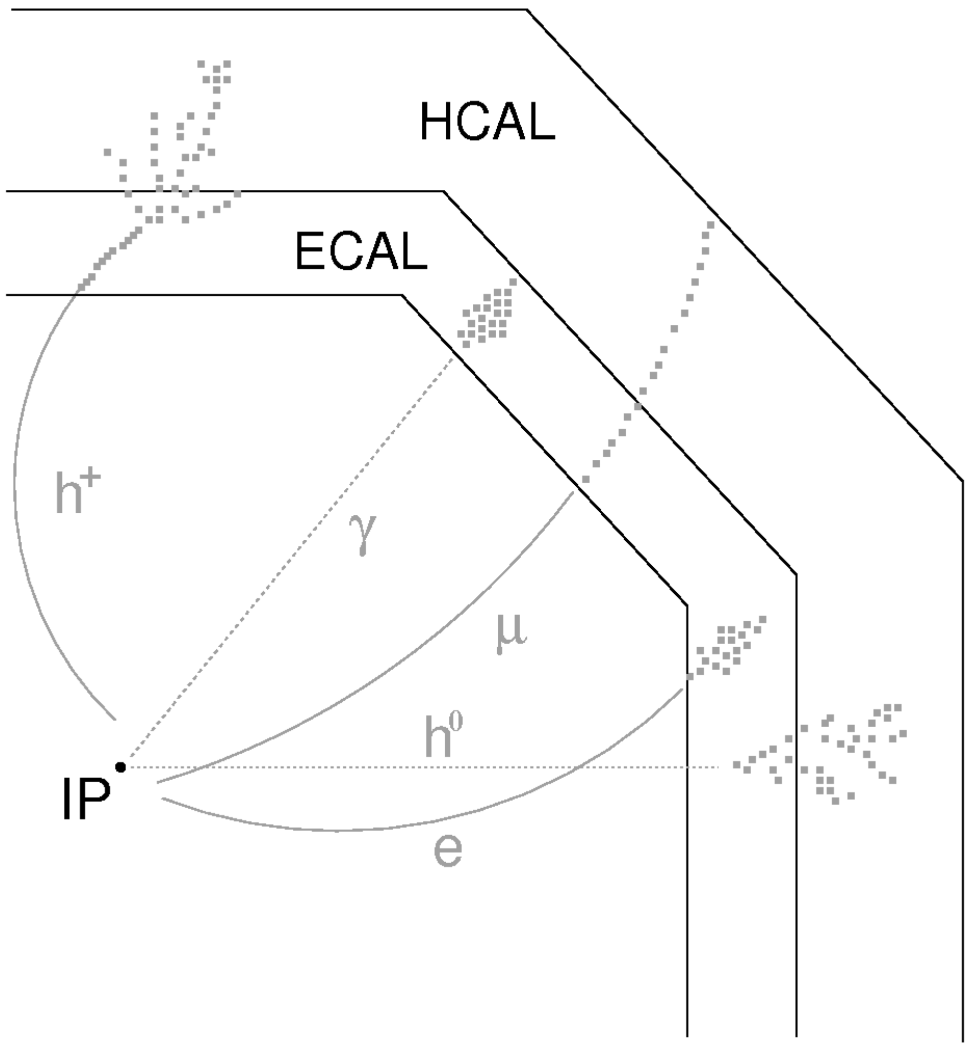

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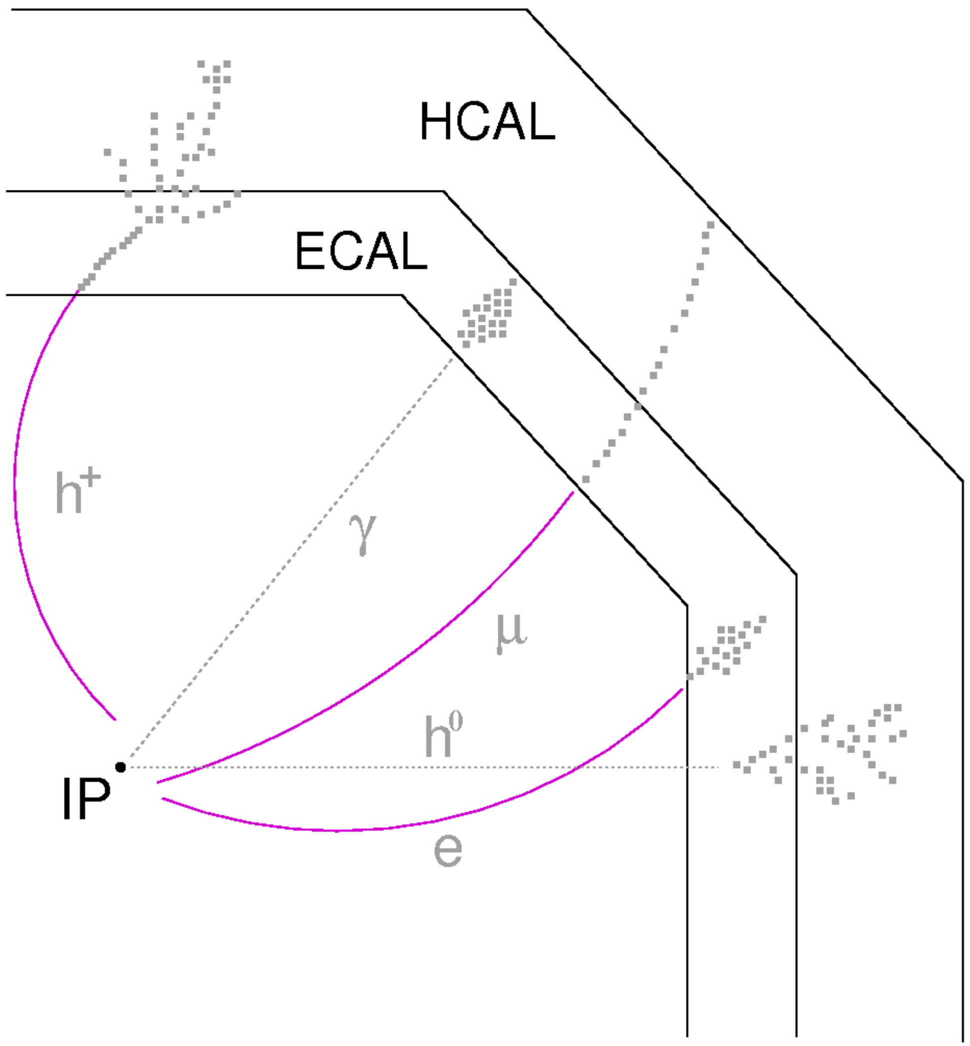
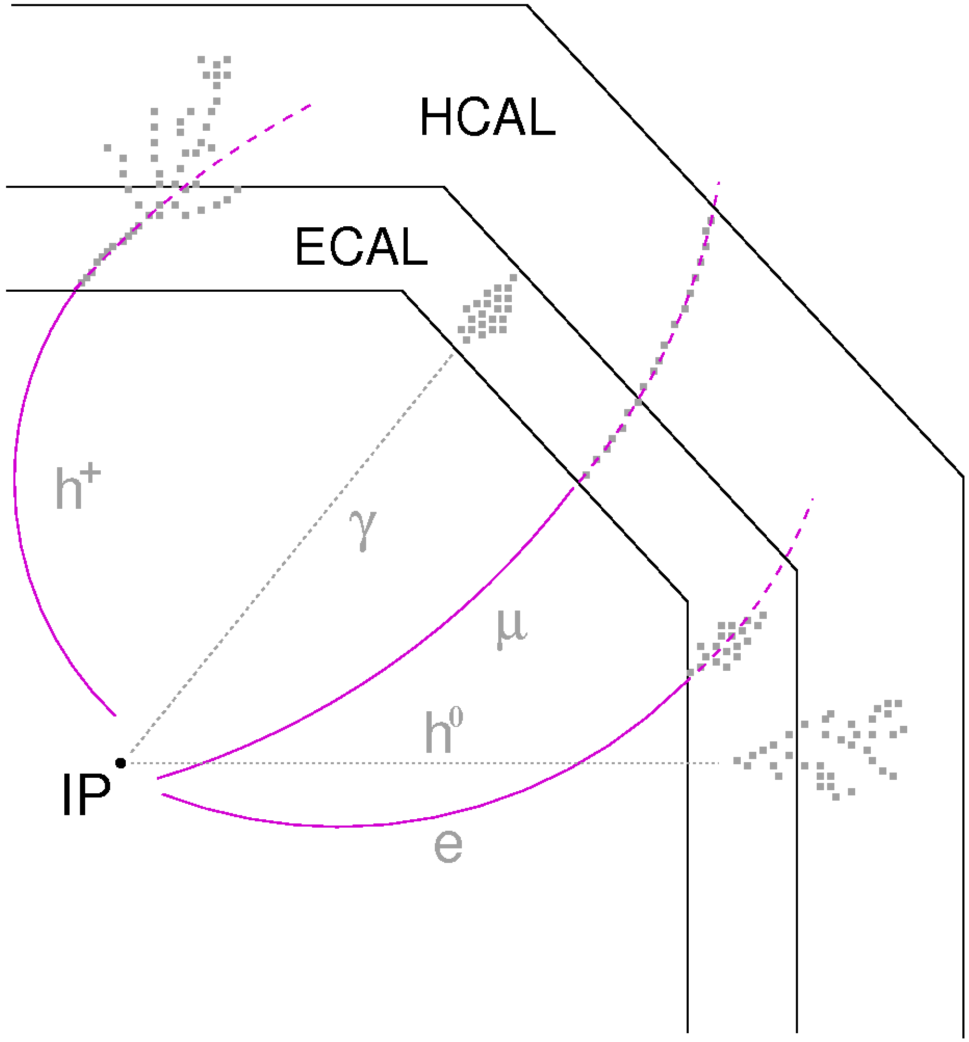


Particle Flow: 'Track-Based' Approach

1. tracking (VTX, SIT, TPC...)
2. extrapolate tracks into Calorimeter



Particle Flow: 'Track-Based' Approach

1. tracking (VTX, SIT, TPC...)
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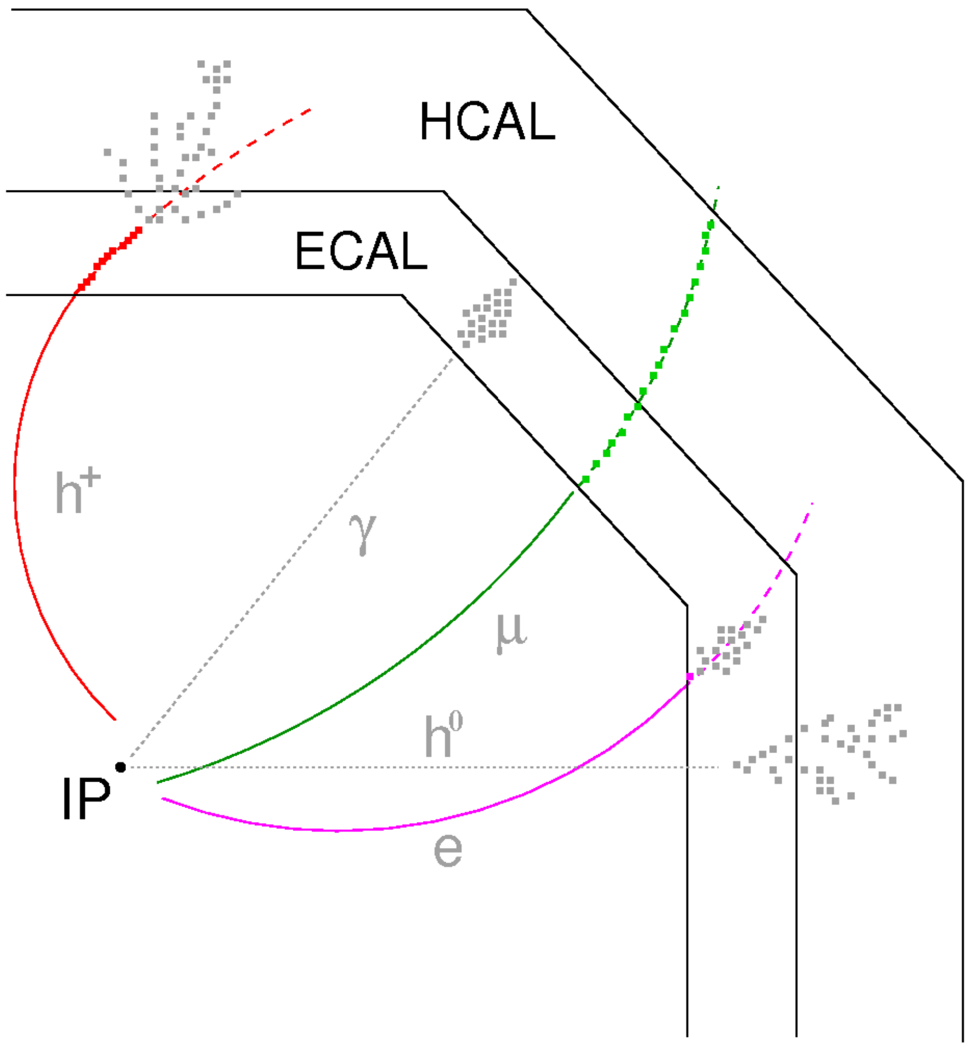
3. assign MIP stub to track
   - ➔ get mu$^{+/-}$ as well



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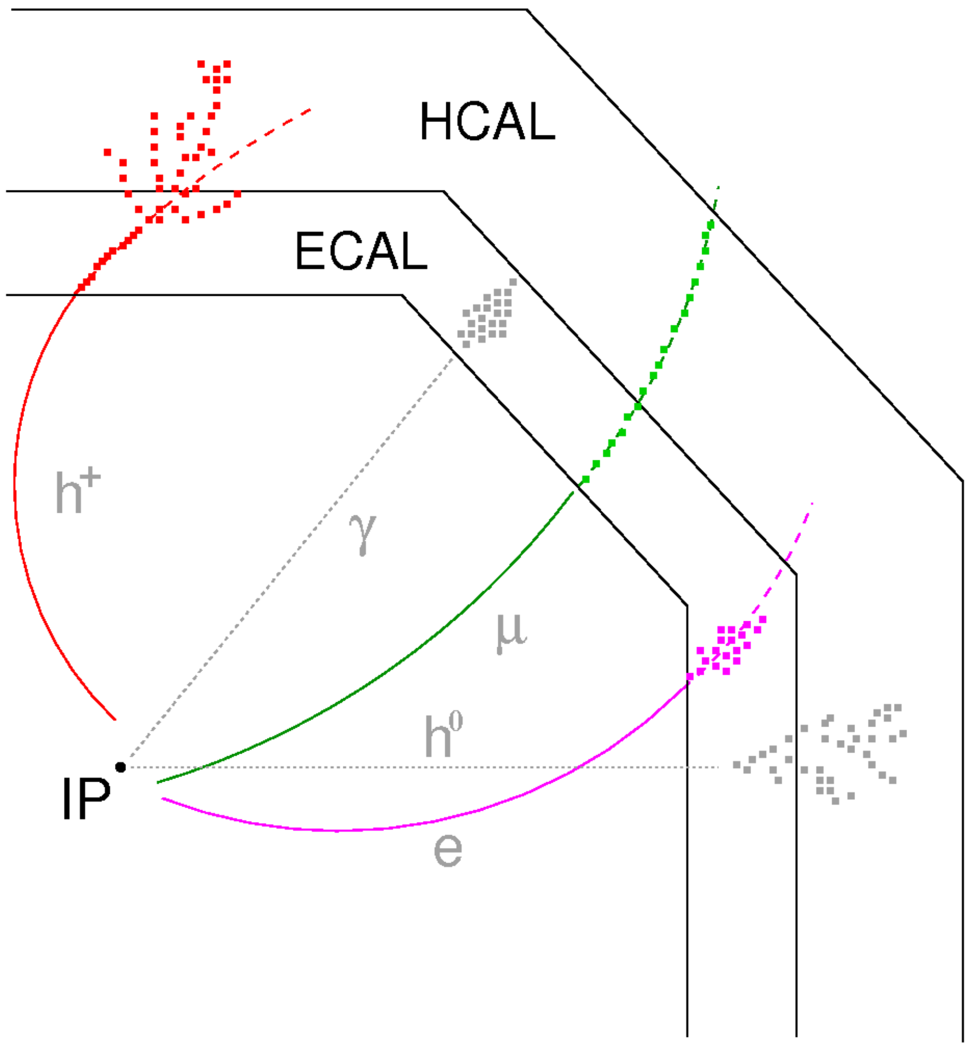

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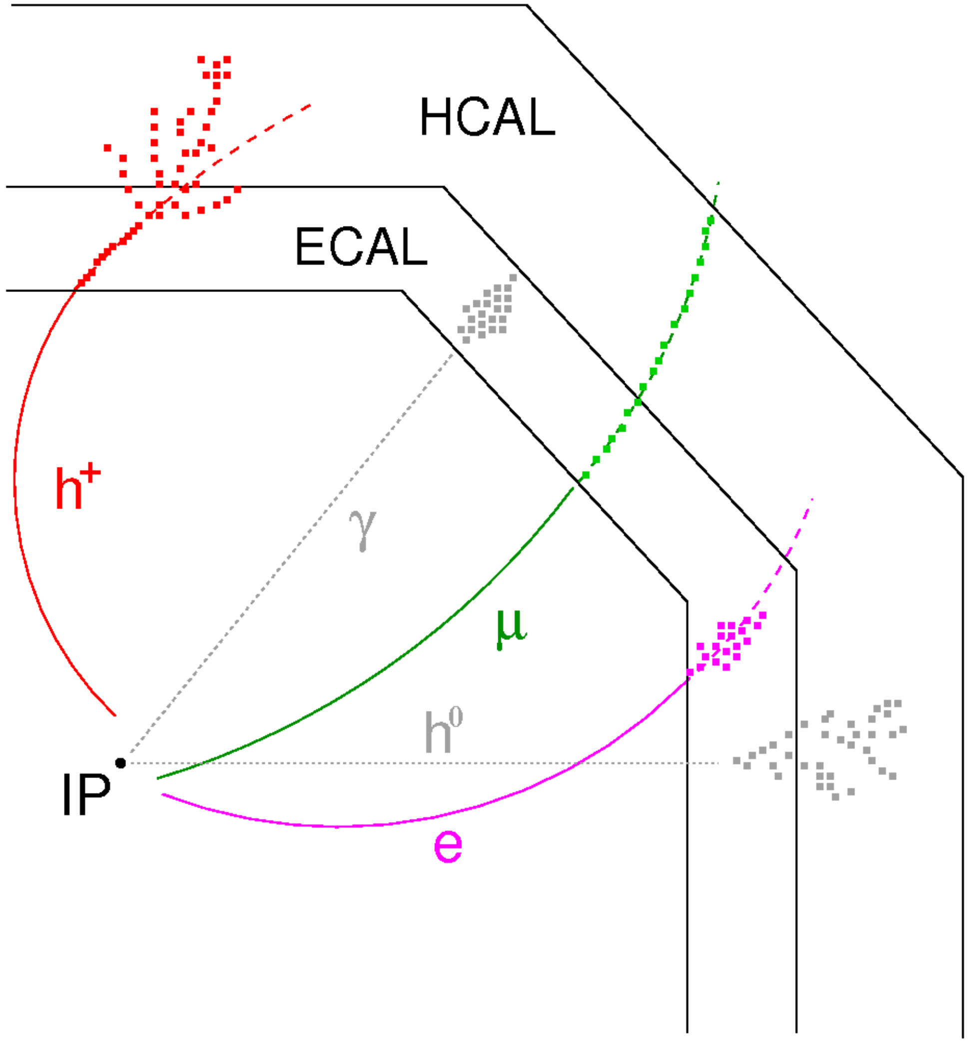

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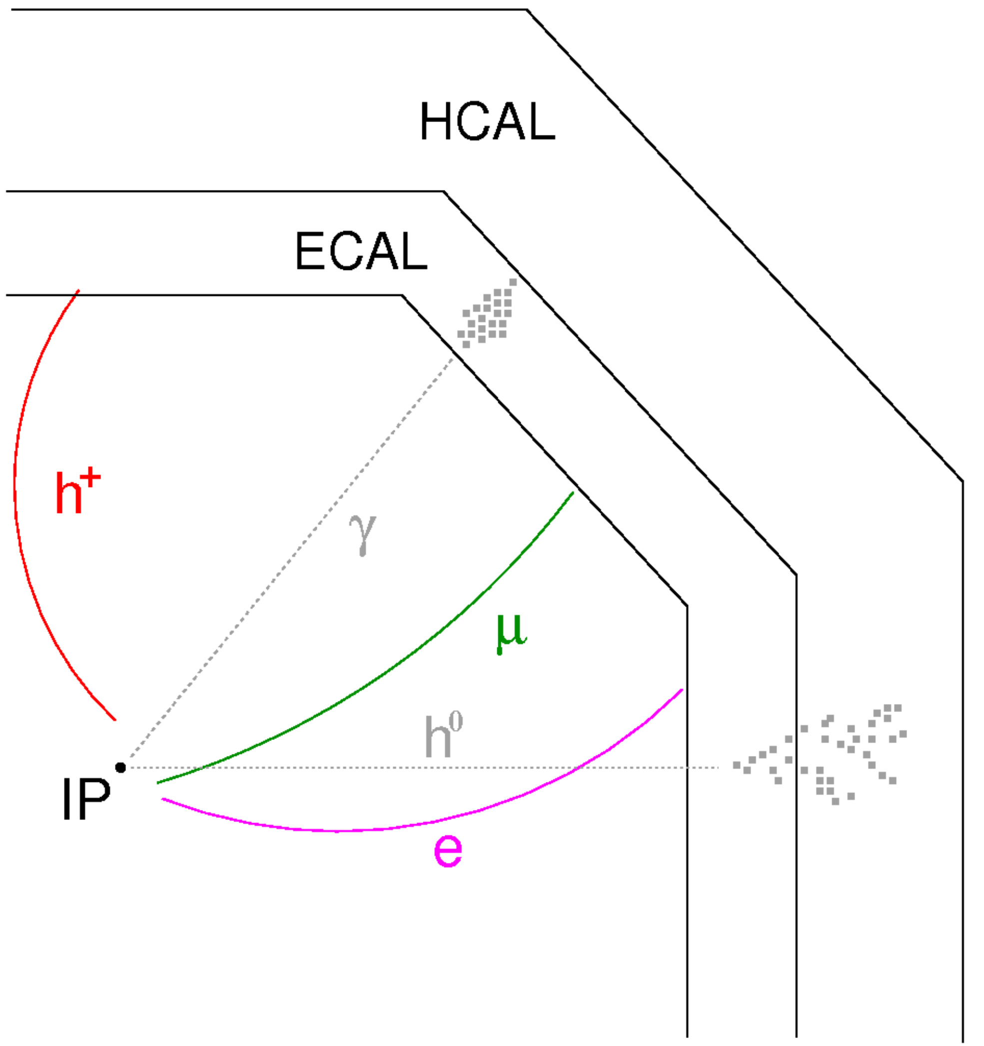
6. remove 'charged' Calorimeter hits



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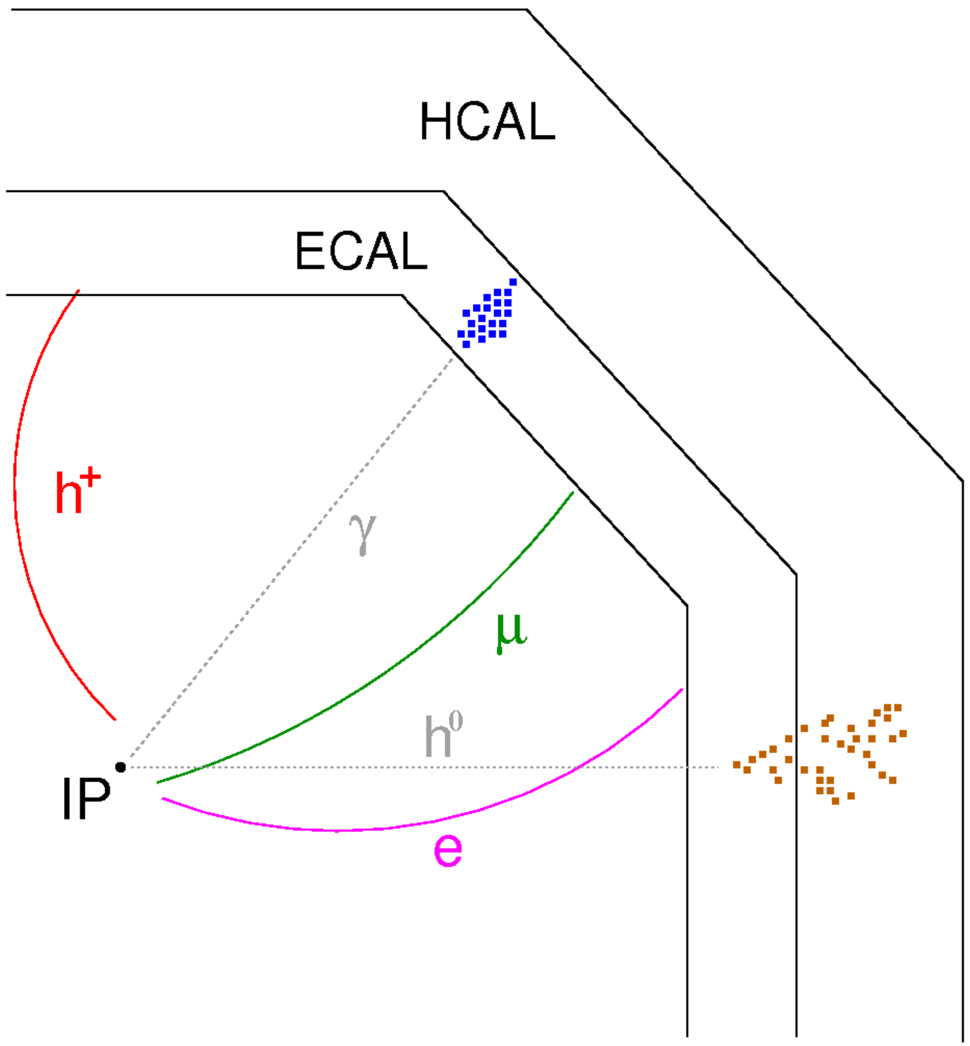
7. clustering on 'neutral' hits



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5. particle ID for e$^{+/-}$, mu$^{+/-}$, h$^{+/-}$
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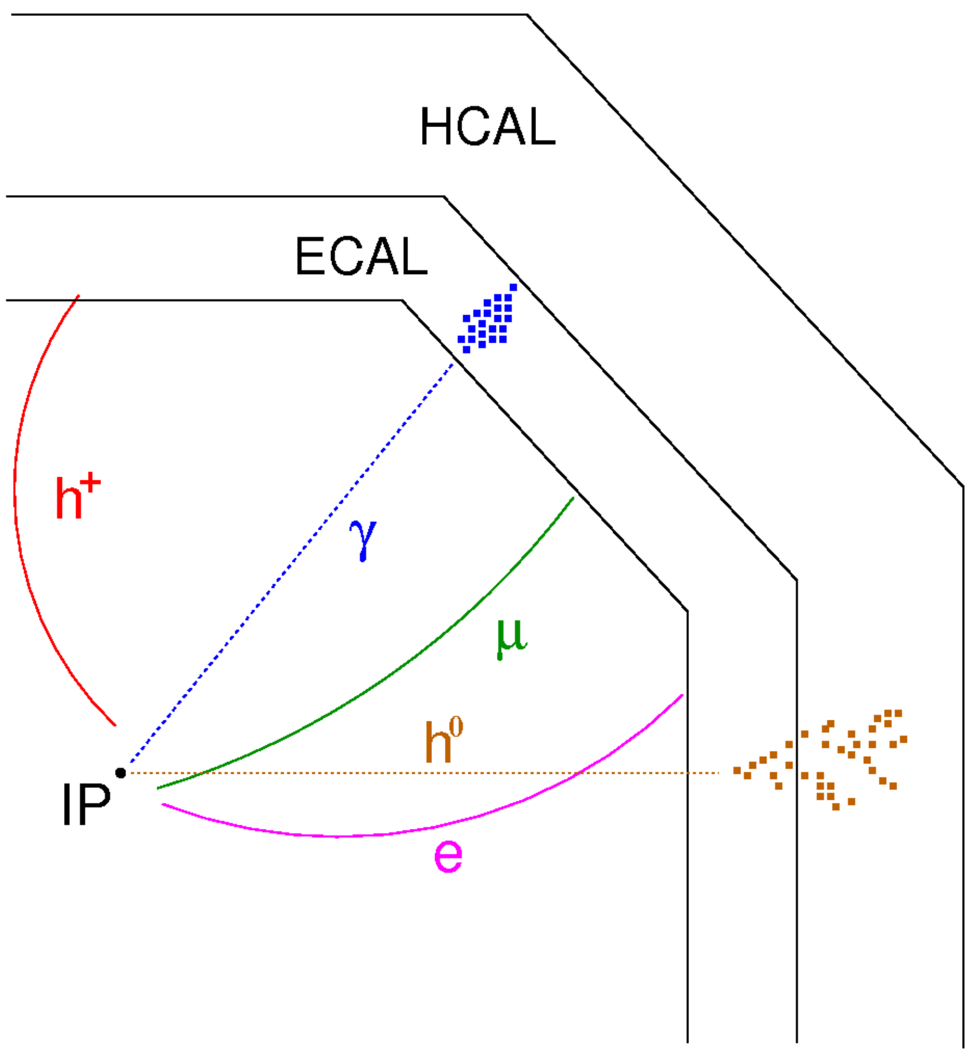
7. clustering on 'neutral' hits
8. particle ID for g, h^{0}



'Track-Based PFlow' in Marlin

First version of a **'track-based'** PFlow algorithm implemented in Marlin

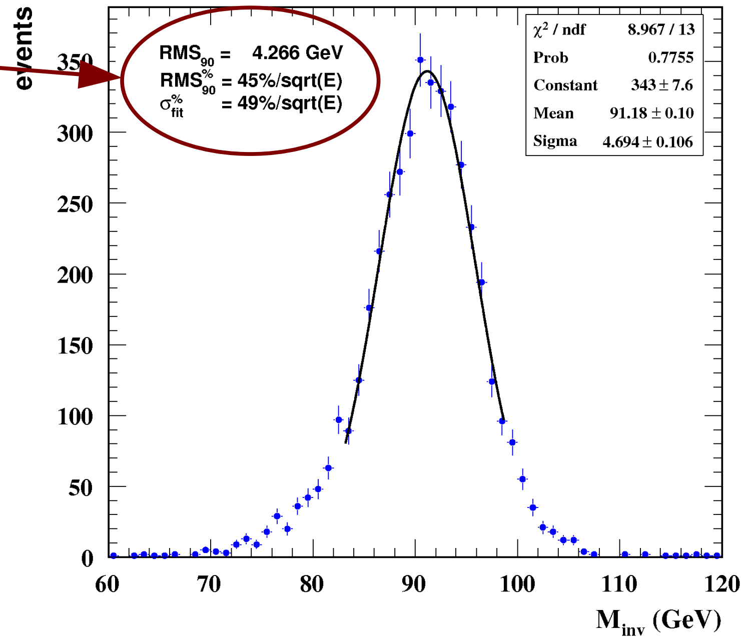
- full software chain established (tracks, calorimeter hits → reconstr. particles)
- first results for $Z^0 \rightarrow$ uds @ 91.2 GeV (preliminary, **work in progress):**

exceeds performance of Wolf

➔ still (significantly) worse than PandoraPFA

reasons:

➔ 'wrong assignment' and 'double counting' of calorimeter cells (studies ongoing)



'Track-Based PFlow' in Marlin

First version of a **'track-based'** PFlow algorithm implemented in Marlin

- full software chain established (tracks, calorimeter hits → reconstr. particles)
- first results for $Z^0 \rightarrow$ uds @ 91.2 GeV (preliminary, **work in progress):**

exceeds performance of Wolf

➔ still (significantly) worse than PandoraPFA

reasons:

➔ 'wrong assignment' and 'double counting' of calorimeter cells (studies ongoing)

check with perfect assignment (MC information)

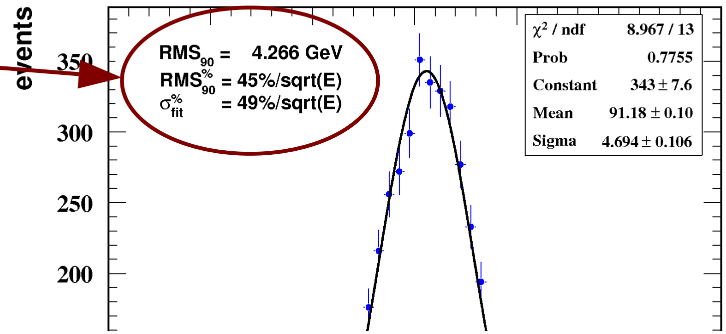
- reaches 'theoretical' limit of ≈ 20% / √E

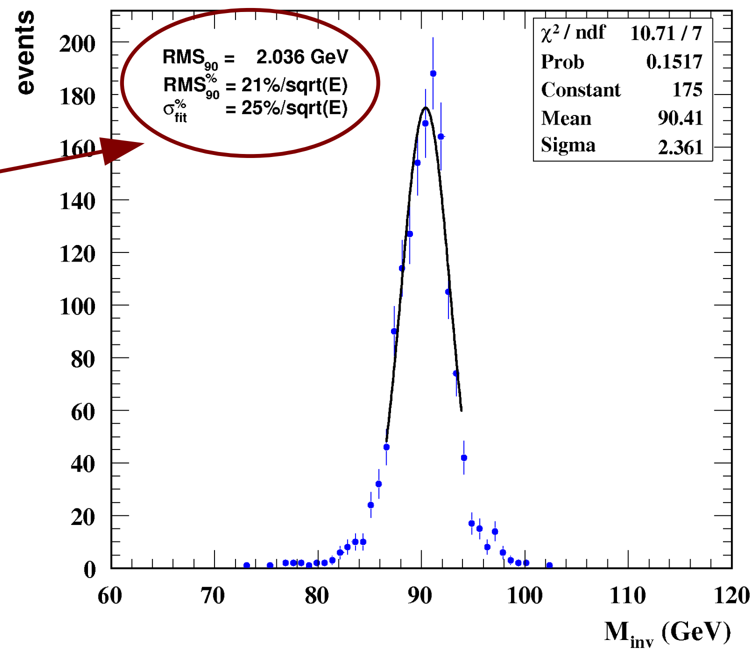
up to now: purely 'topological' clustering

future:

- study **sub-structure** of hadronic showers

➔ more sophisticated energy assignment

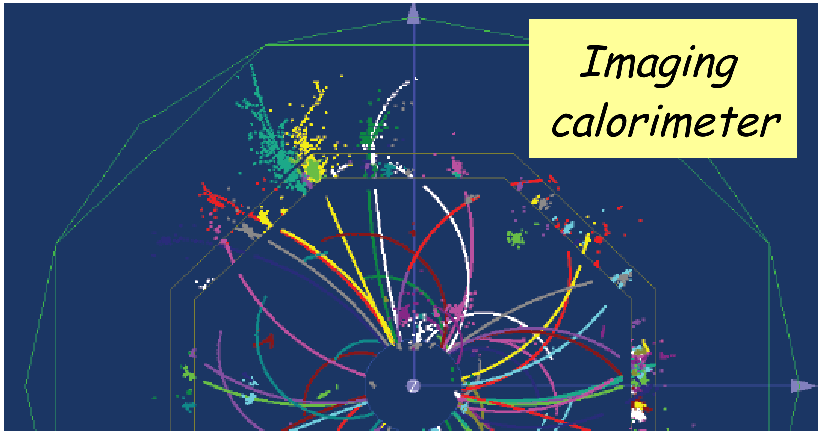


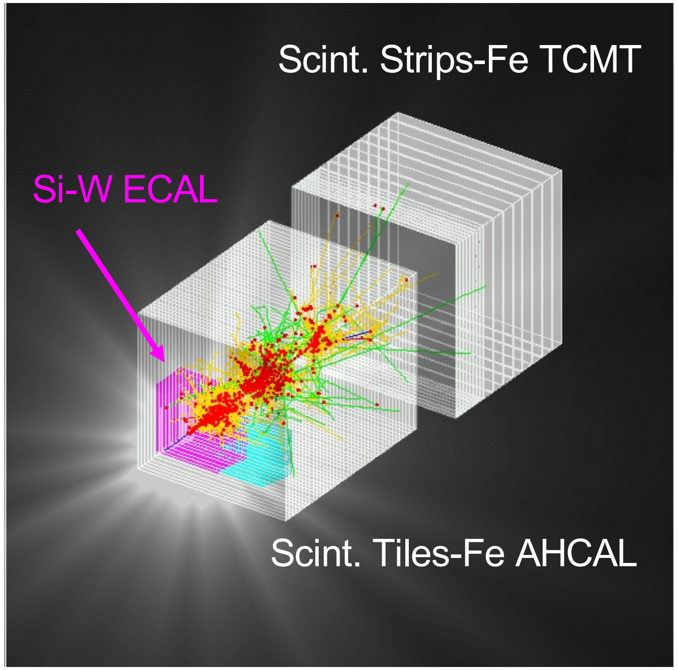


PFlow and Calice Test Beam Studies

study this with the Calice AHCAL and test beam data:

- take amplitude into account, RGB-clustering (V. Morgunov)
- study (hadronic) shower shapes in reality (geometry, topology)
- derive influence on PFlow performance (neighbouring showers, overlaps, ...)





Summary and Outlook

- ✔ First version of a **'track-based'** PFlow algorithm implemented in Marlin
- assignment of calorimeter energy to corresponding still the main problem
  - → need (better) tools to study this
- → **more sophisticated** clustering procedures needed (take amplitude into account)
  - → study (hadronic) **shower shapes** in Calice AHCAL (geometry, topology)
  - → neighbouring showers, overlaps, ...
- develop tools to study the performance and limits of available PFlow algorithms
  - → Perfect Particle Flow
- → detector optimisation studies

backup slides ...

Basic Concept of Particle Flow

charged particles ($e^{+/-}$, $\mu^{+/-}$, $h^{+/-}$):

- measure p in tracking system
  - ➔ direction at IP
- particle ID by dE/dx, fraction energy ECAL/HCAL, cluster shapes, ...
- calculate E by $E^2 = p^2 + m^2$

➔ four momentum reconstructed

neutral particles (g, h^0):

- measure E in Calorimeter
- particle ID by fraction energy ECAL/HCAL, cluster shapes, ...
- direction of p direction by 'cluster axis'
- calculate value of p by $p^2 = E^2 – m^2$

➔ four momentum reconstructed