Track-Based Particle Flow

Outline:

- Introduction
- Details of the Algorithm
- Performance of Track-Based Particle Flow
- Conclusions and Outlook

Introduction

Goal for precision physics:

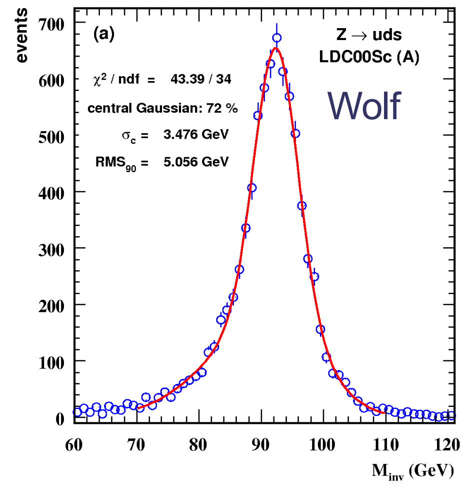
- Jet-Energy Resolution **0.30**/$\sqrt{E_{jj}}$ in hadronic decays of Z^0 and $W^{+/-}$
- → corresponds to a boson mass resolution of approx. $\Gamma_{Z/W}$
- 'Particle Flow Concept' is able to **reach** this goal

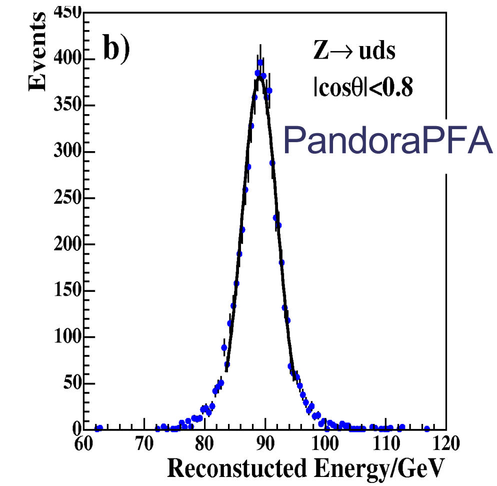
Particle Flow Algorithms for LDC (Marlin/MarlinReco):

1. Wolf: $\Delta E/E \approx$ **0.53**/$\sqrt{E}$ for $Z^0 \rightarrow$ uds for E_{Jet}= 45 GeV
2. PandoraPFA: $\Delta E/E \approx$ **0.30**/$\sqrt{E}$ for $Z^0 \rightarrow$ uds up to E_{Jet}= 100 GeV
3. TrackBased PFlow: $\Delta E/E \approx$ **0.41**/$\sqrt{E}$ for $Z^0 \rightarrow$ uds for E_{Jet}= 45 GeV

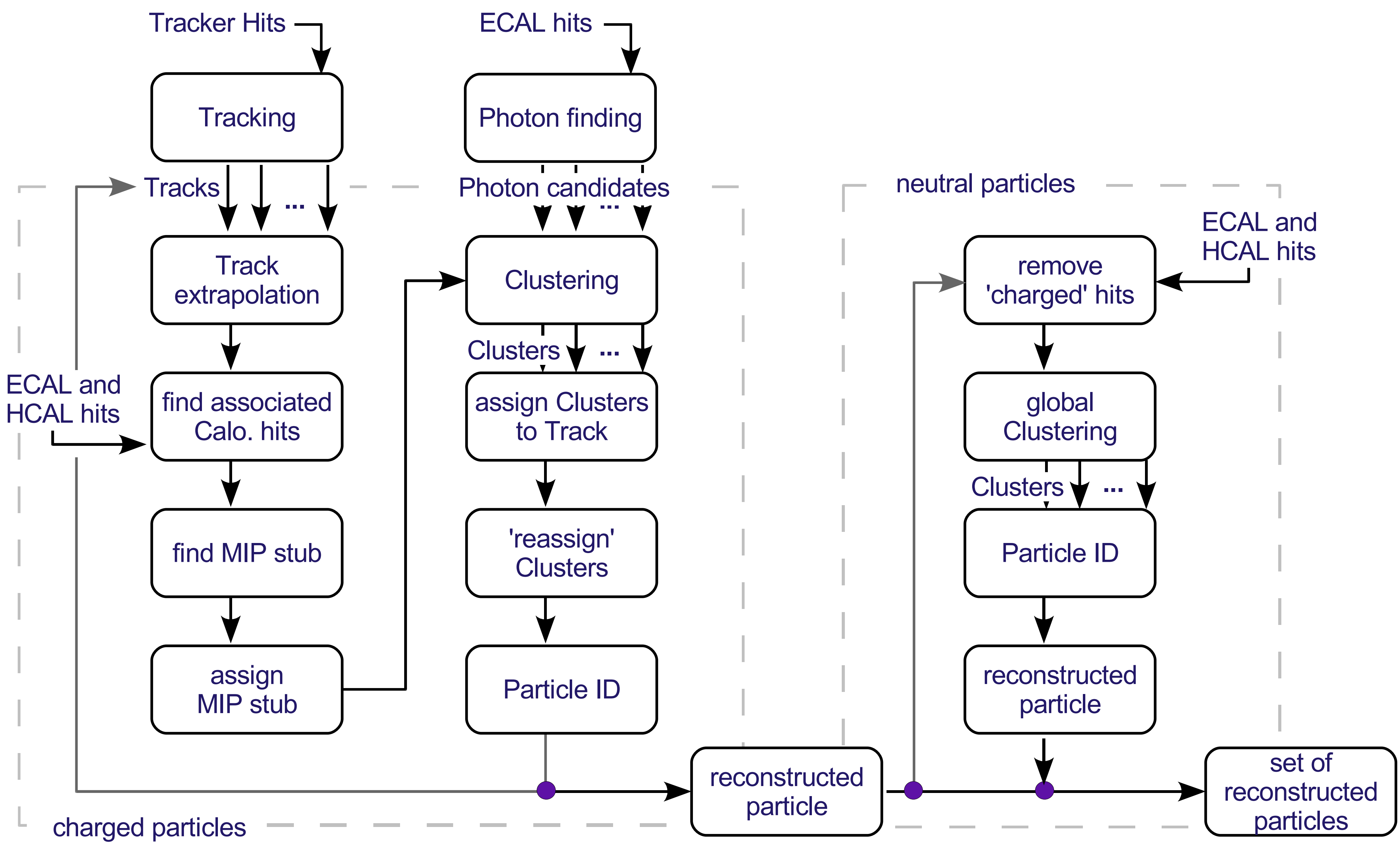
'Philosophy' of TrackBased PFlow:

- tracking system offers the **most accurate** measurement in detector
- → start from tracks, use as much track information as possible (extrapolation, direction, momentum, dE/dx, PID, ...)
- try to establish a **modular** track-based PFlow algorithm in Marlin
- → base on modules and experience made with Wolf (started mid/end 2006)





Track-Based Particle Flow Algorithm



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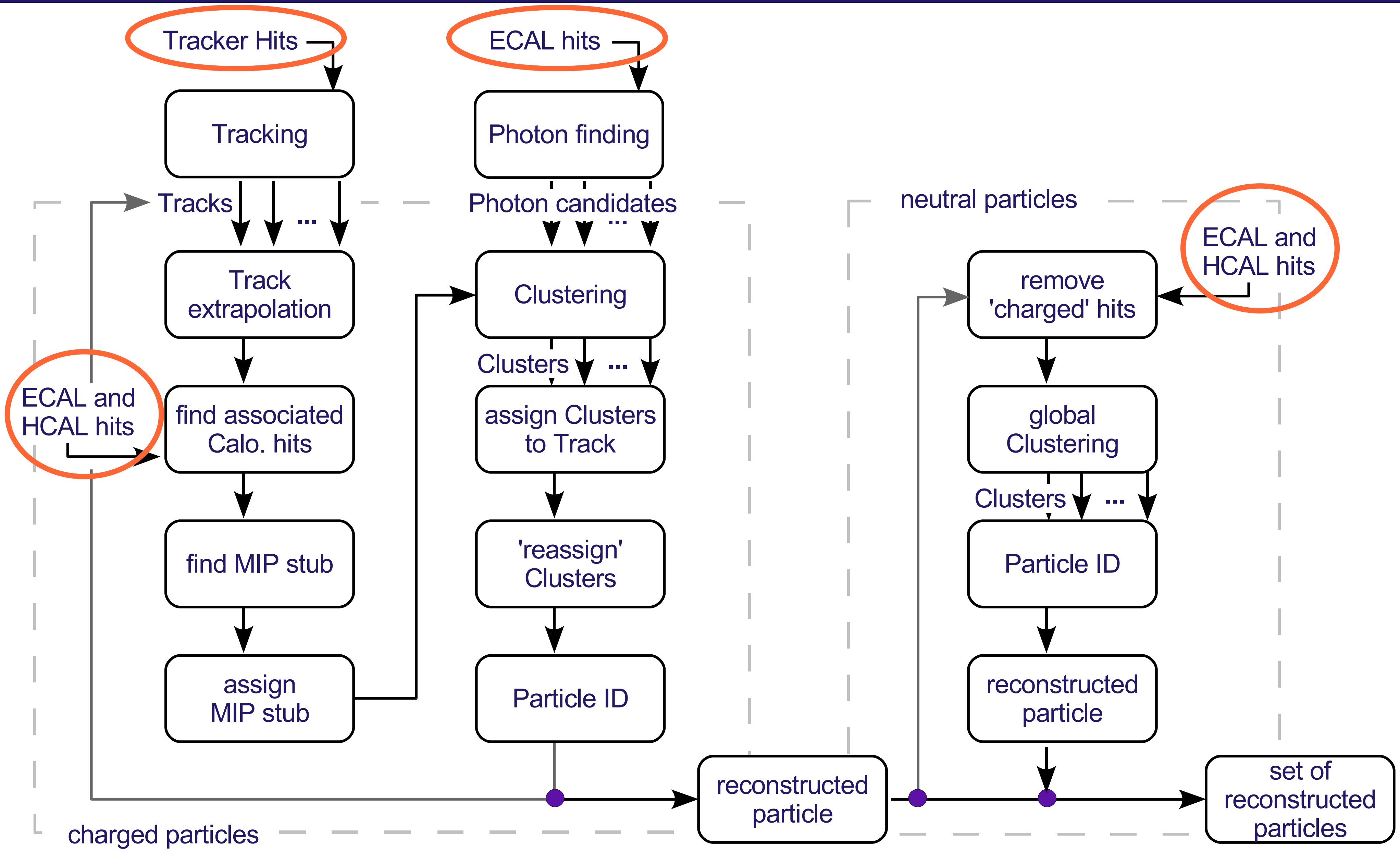

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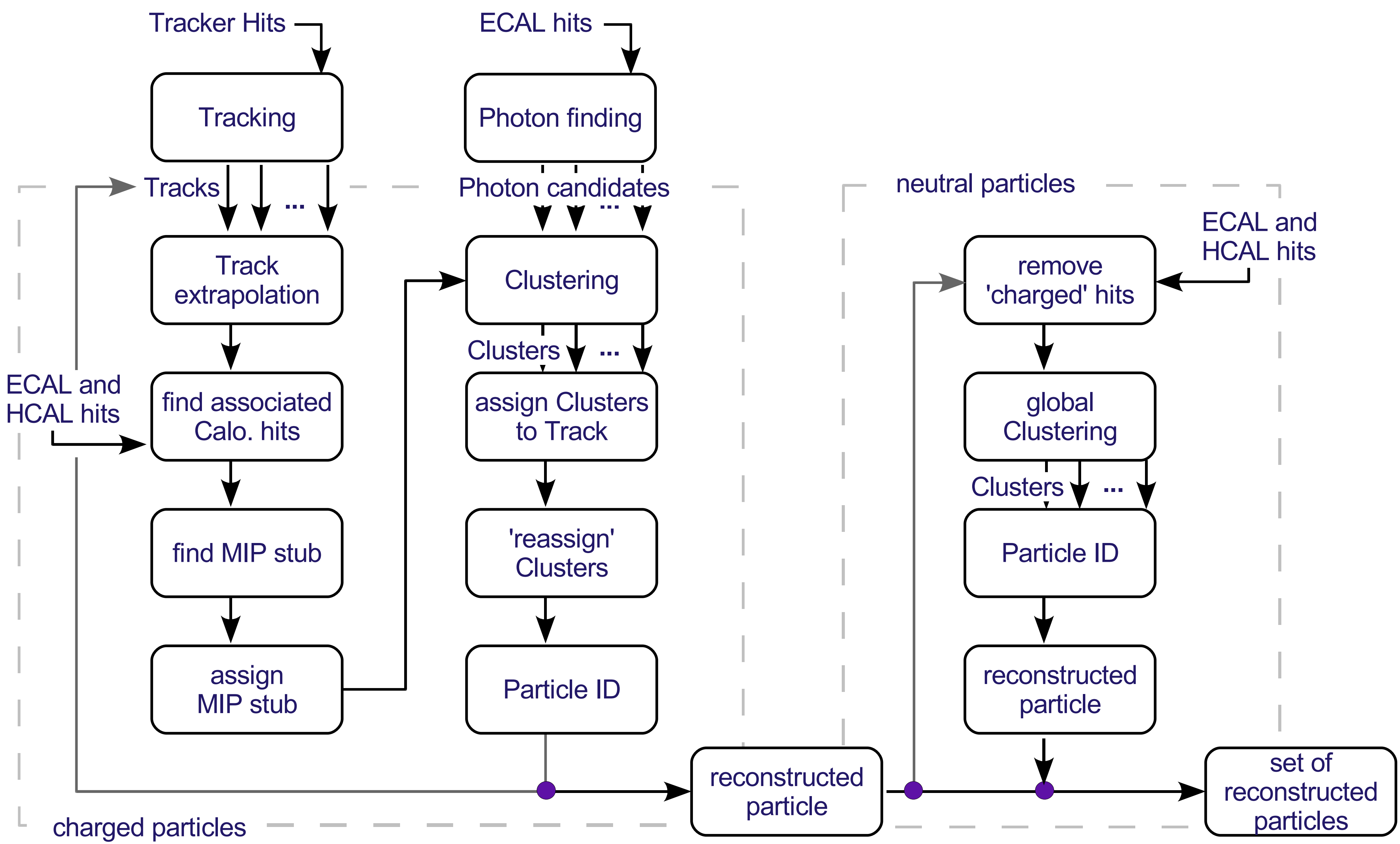
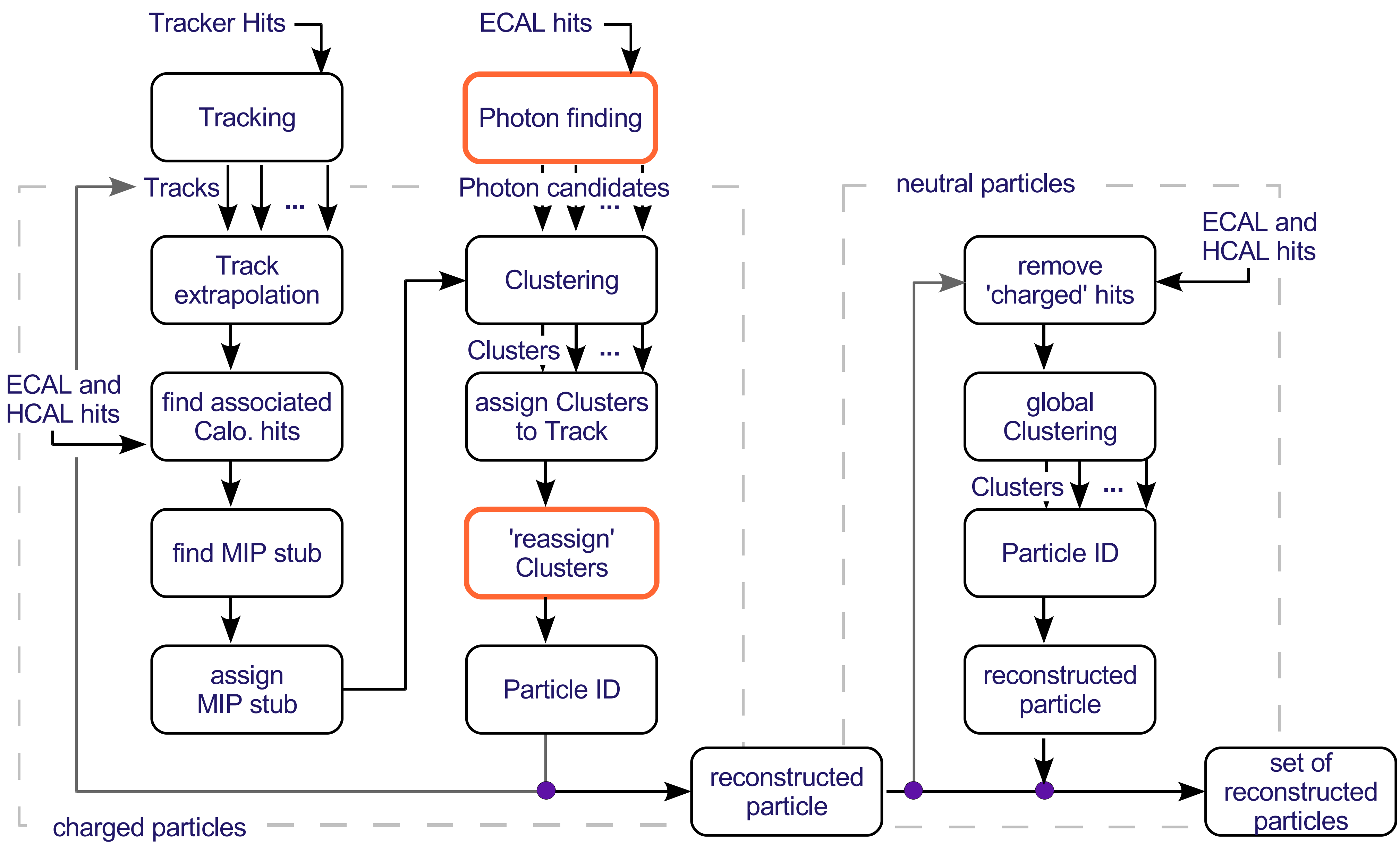


New Modules


Tracker Hits
ECAL hits
Tracking
Photon finding
Tracks
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Photon candidates
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Track extrapolation
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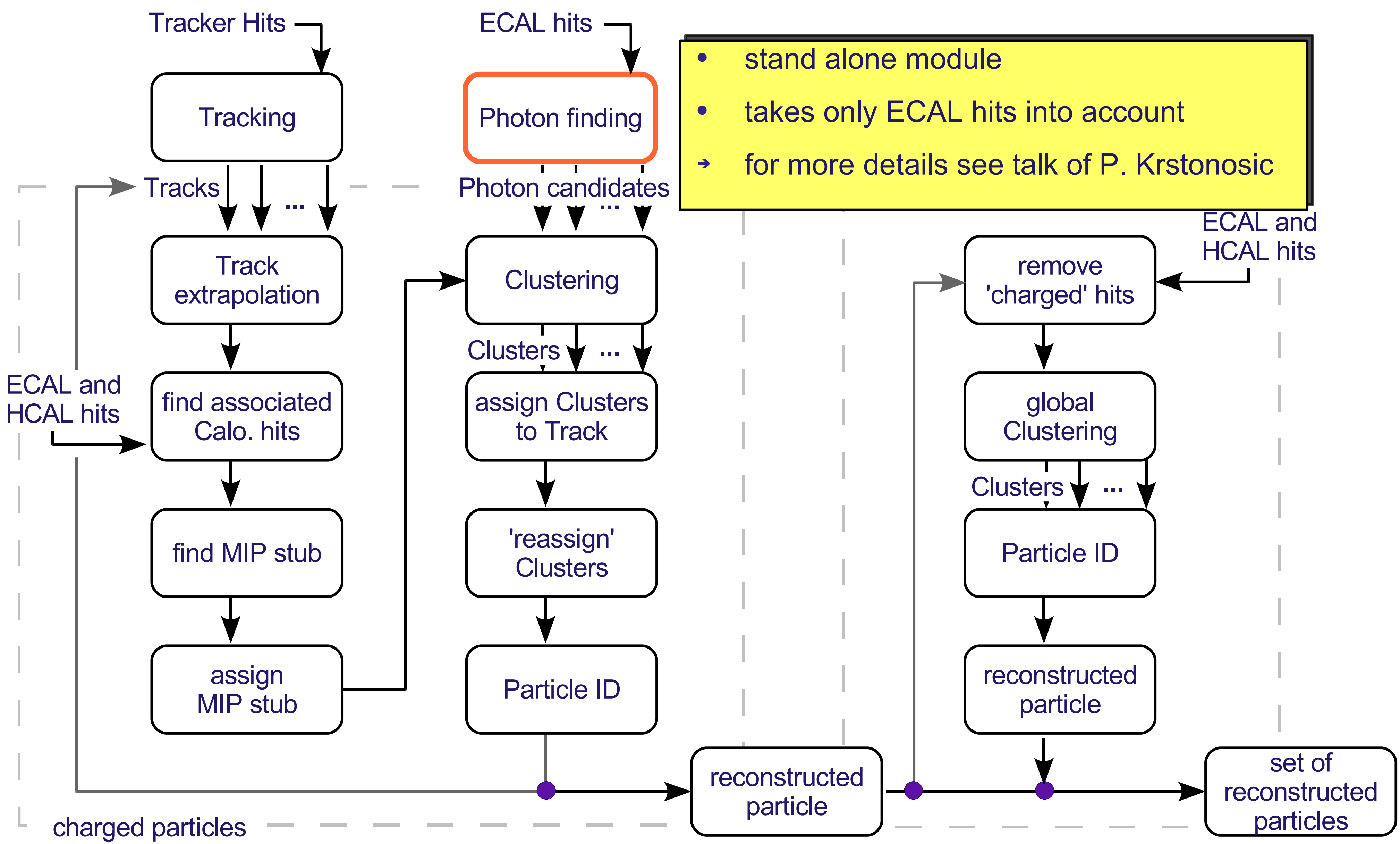
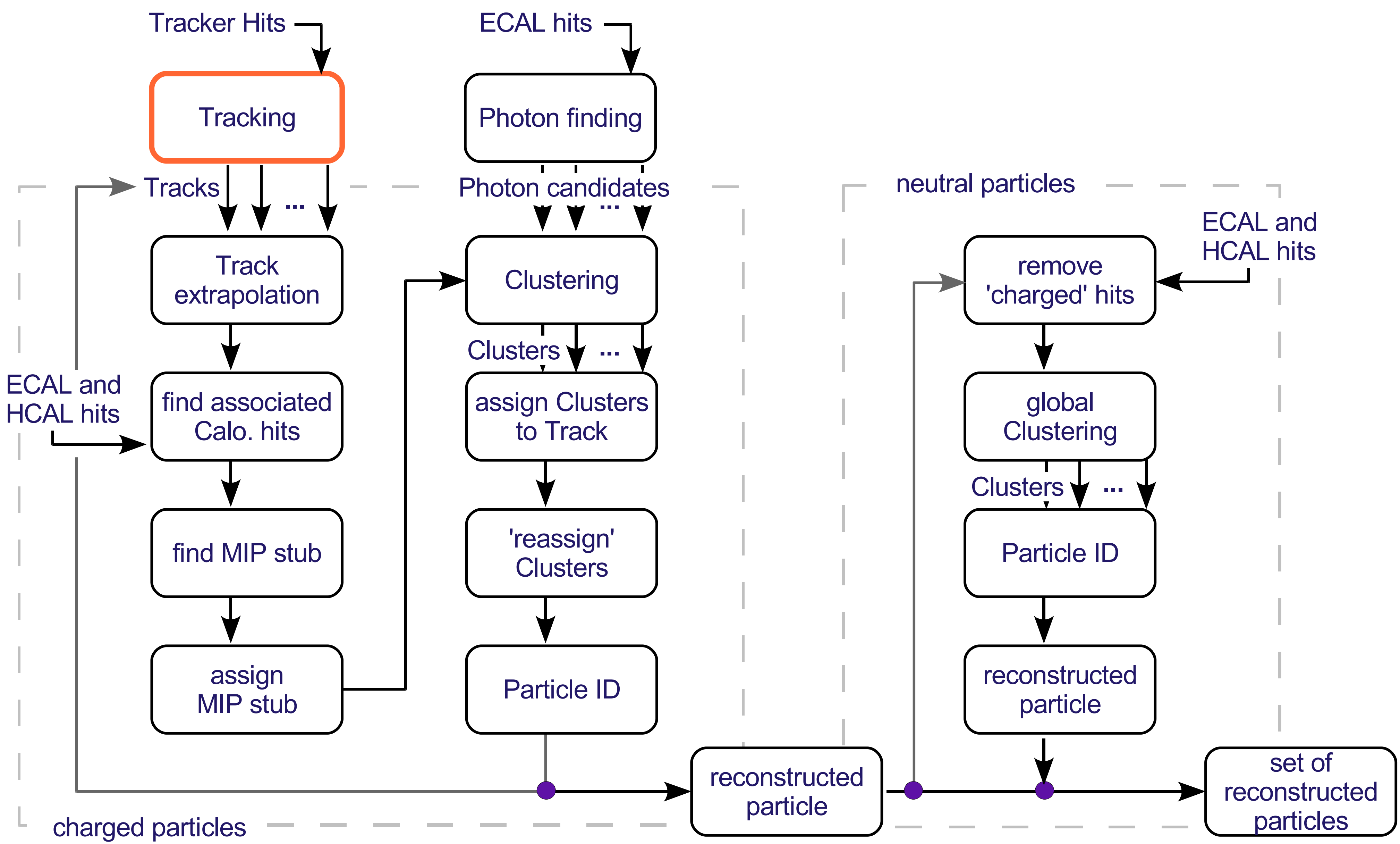
find MIP stub
'reassign' Clusters
Particle ID
assign MIP stub
Particle ID
reconstructed particle
reconstructed particle
set of reconstructed particles
charged particles

Photon Finding

- stand alone module
- takes only ECAL hits into account
- → for more details see talk of P. Krstonosic



Tracking



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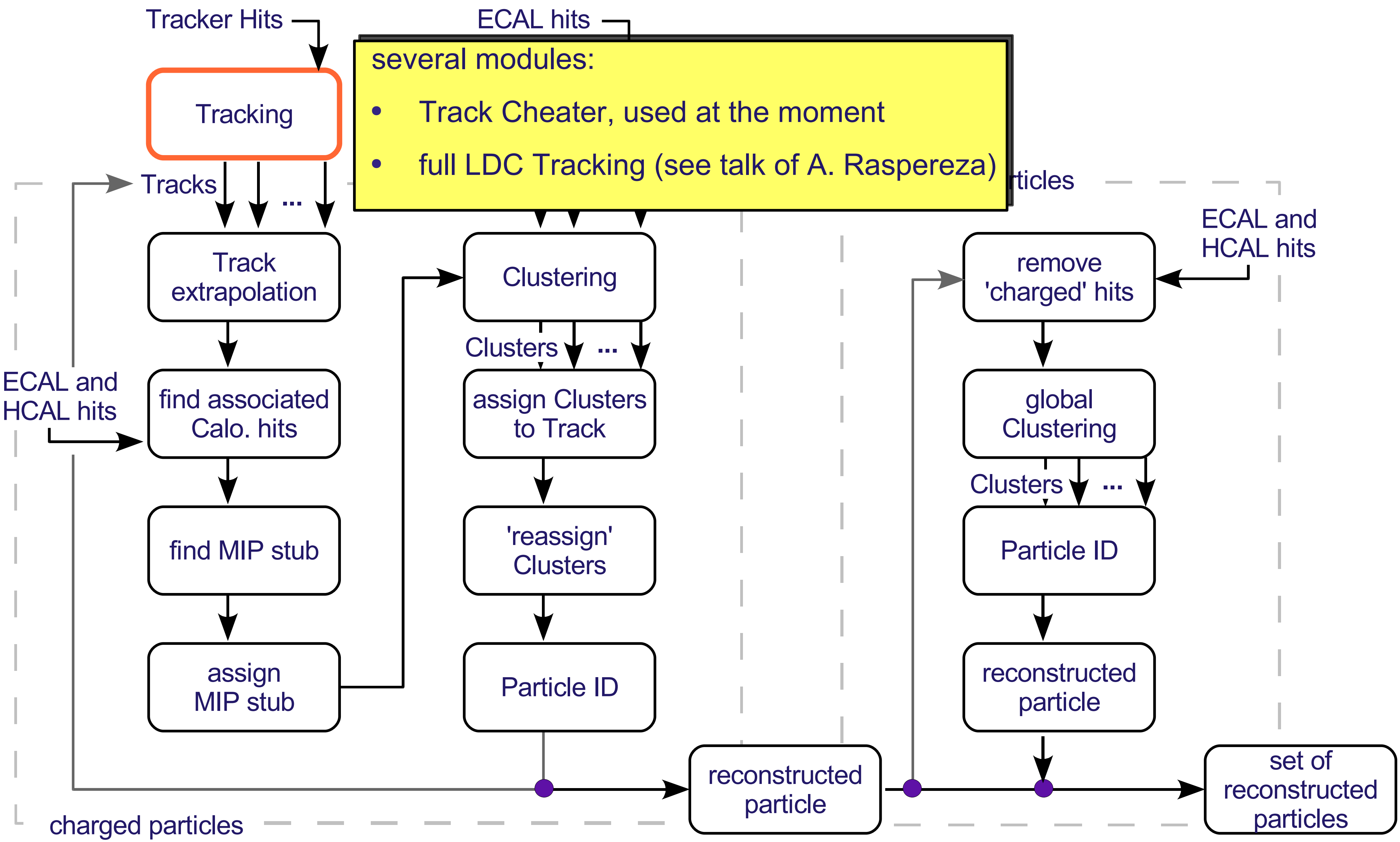
charged particles

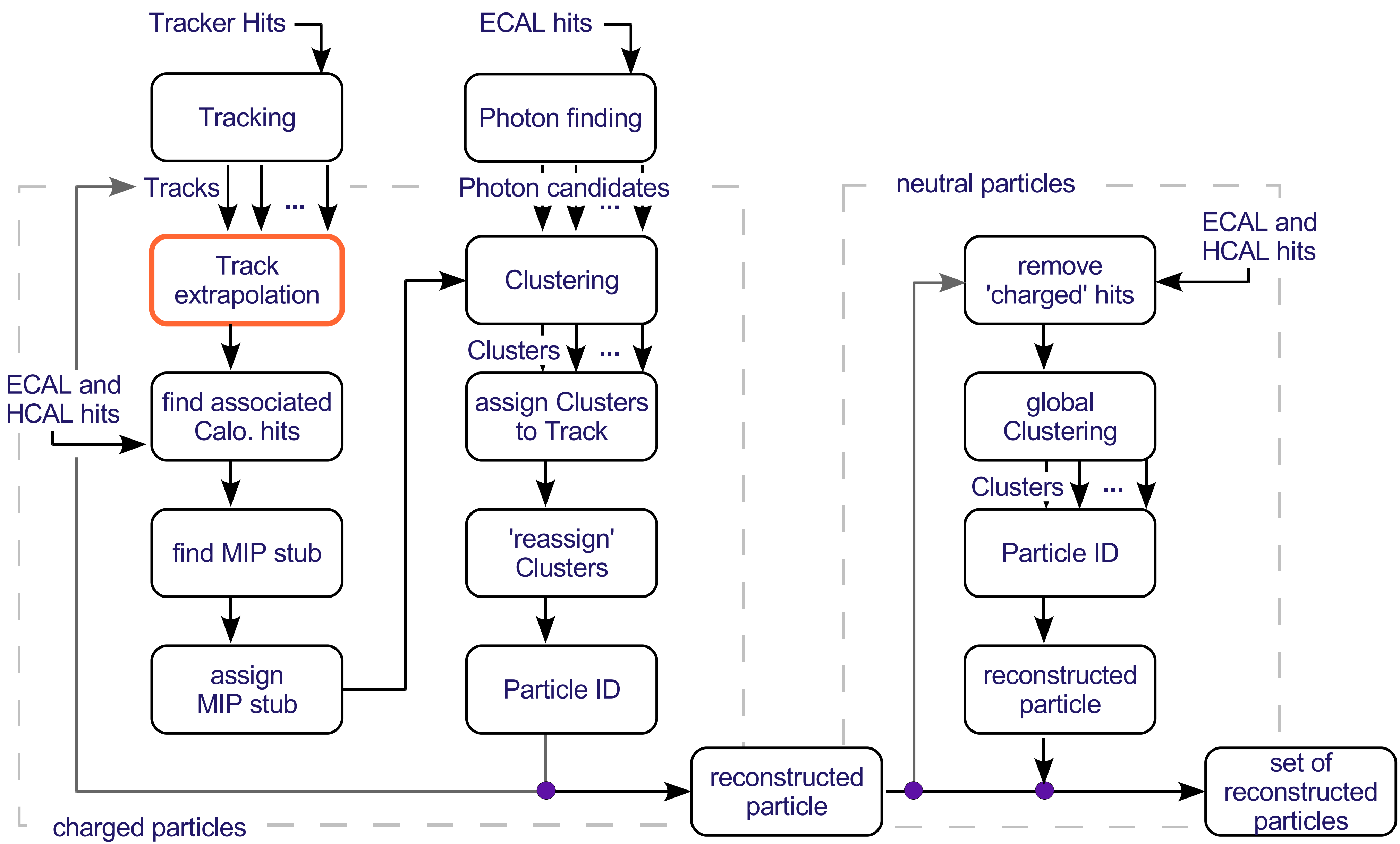
Tracking

several modules:

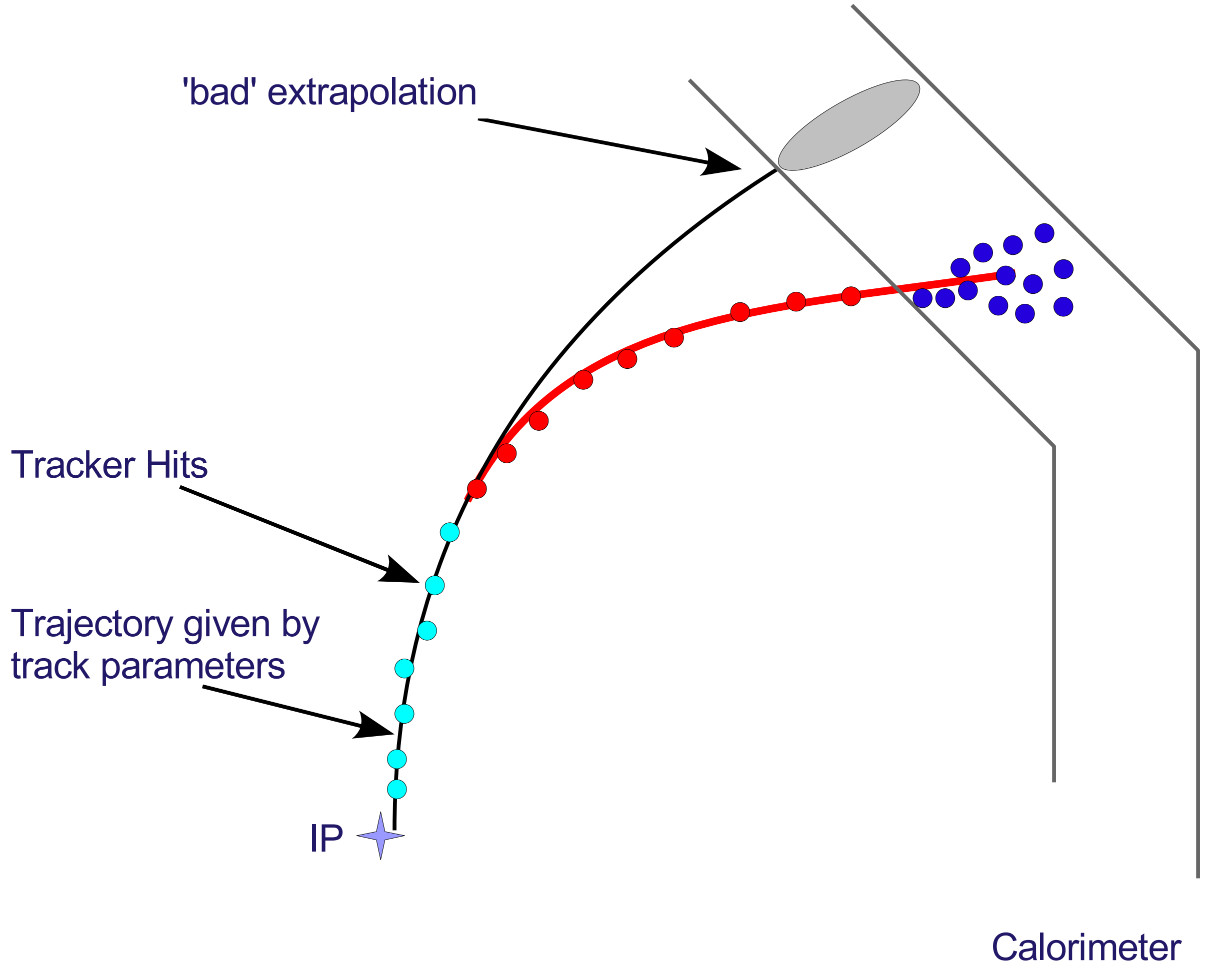
- Track Cheater, used at the moment
- full LDC Tracking (see talk of A. Raspereza)



Track Extrapolation



Track Extrapolation



- Track parameters might give a 'bad' extrapolation into the Calorimeter

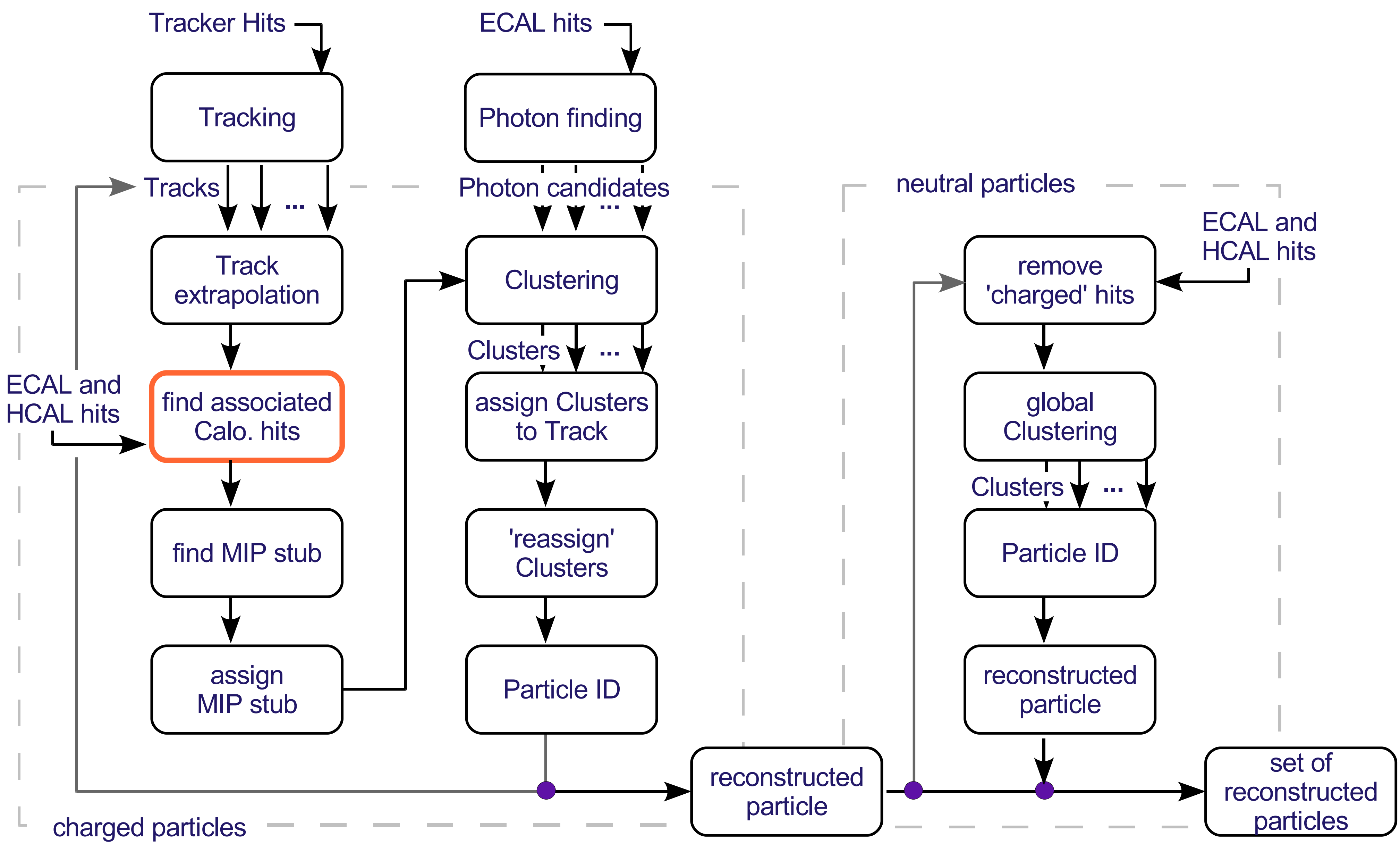
<u>Algorithm:</u>

- take the outermost n Tracker hits (w.r.t path-length)
- fit trajectory on these hits
- ➔ at the moment done with a simple helix model (w/o energy loss, multiple scattering, ...)

<u>Technicalities:</u>

- based on the Trajectory interface in MarlinUtil
- fitting based on GSL using canonical track parametrisation
- ➔ more general fitting module for different Trajectory 'models' needed

Find associated Calorimeter Hits



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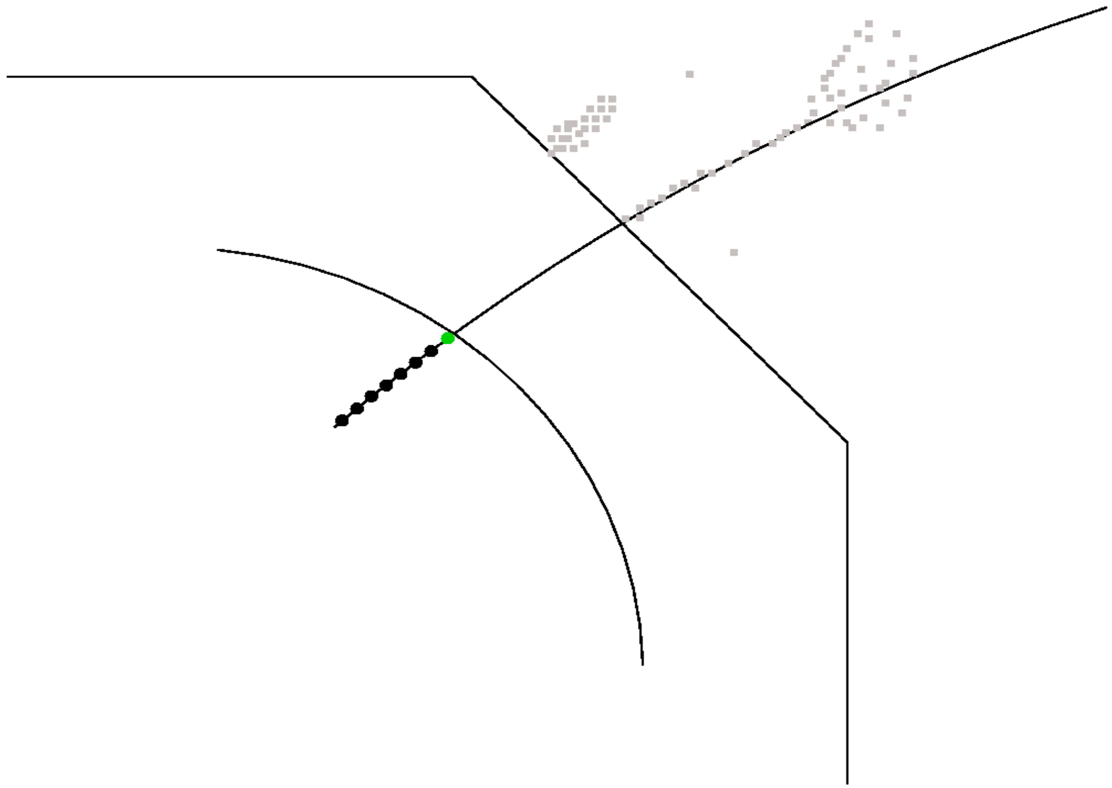
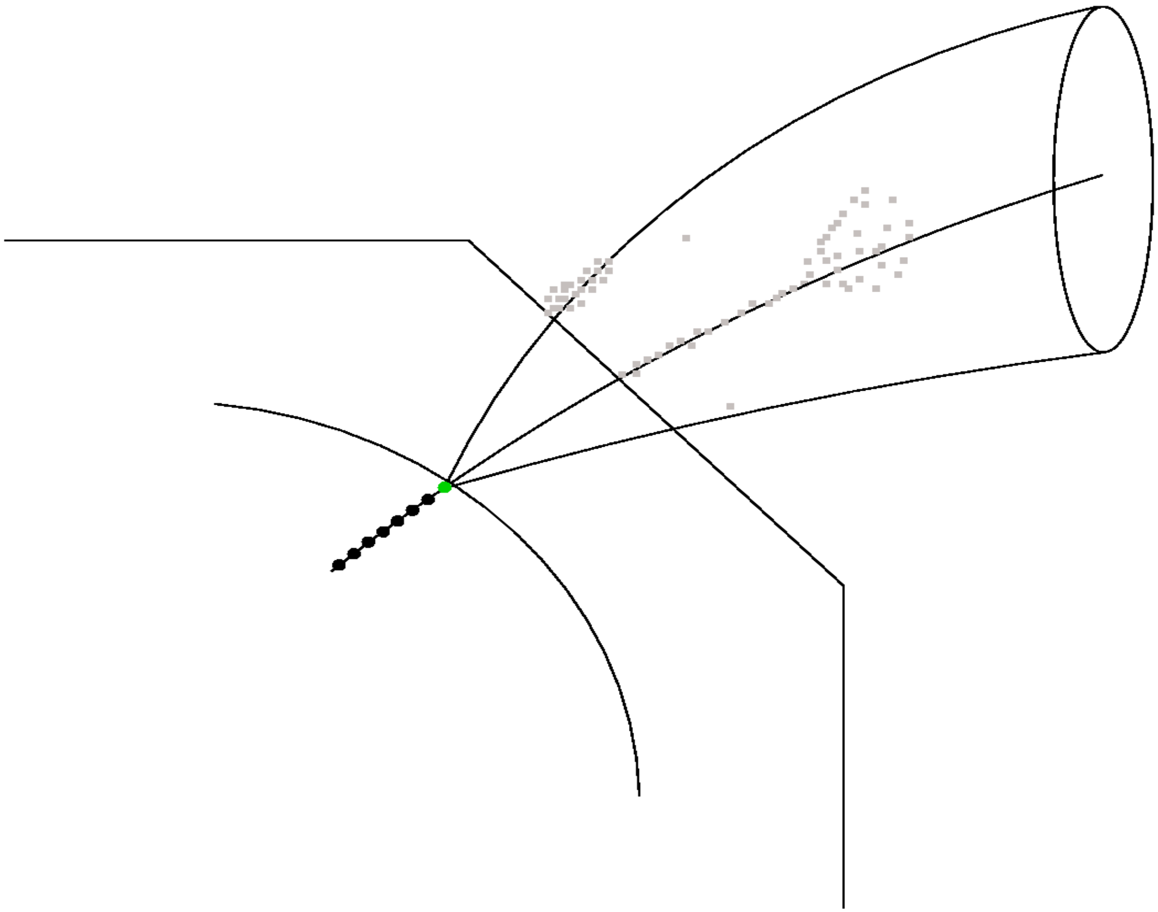


Find associated Calorimeter Hits

<u>Algorithm:</u>

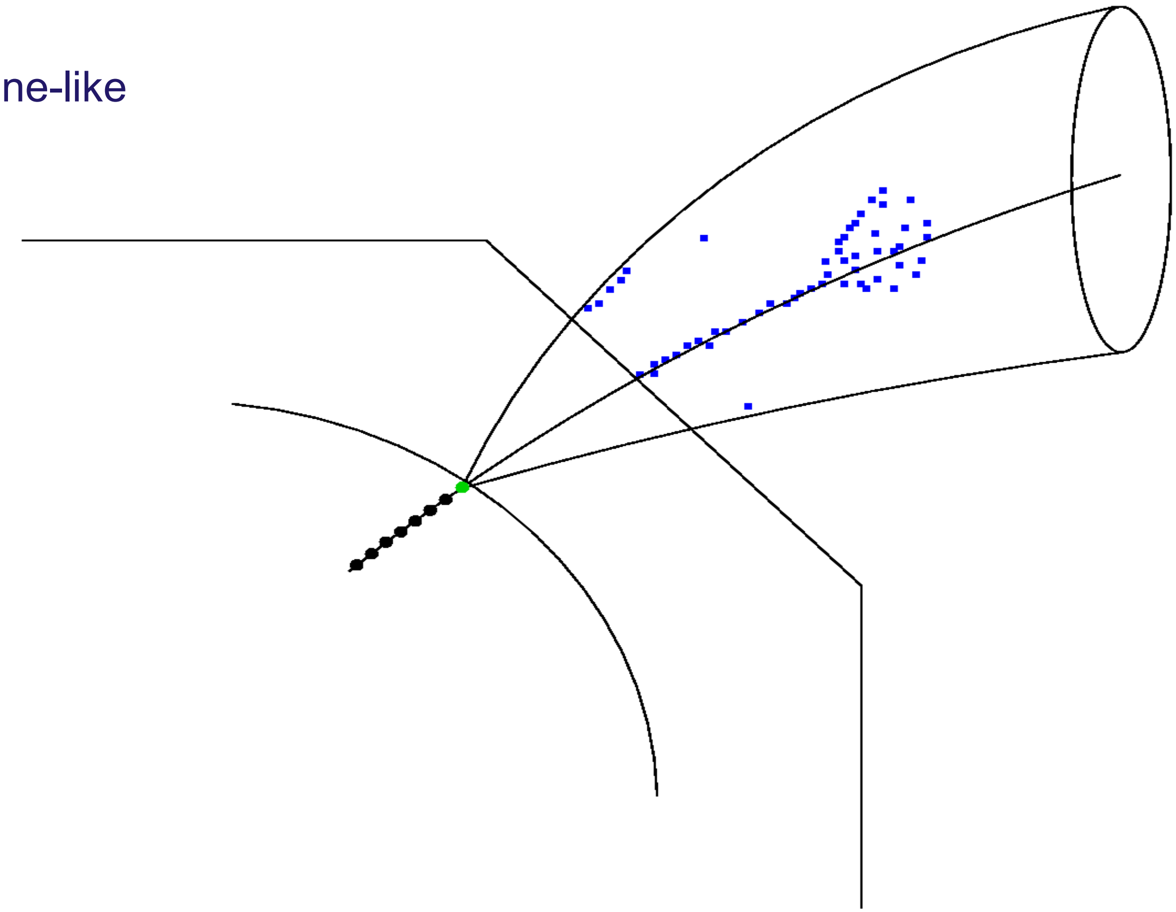
- put cone-like tube around extrapolated trajectory



Find associated Calorimeter Hits

Algorithm:

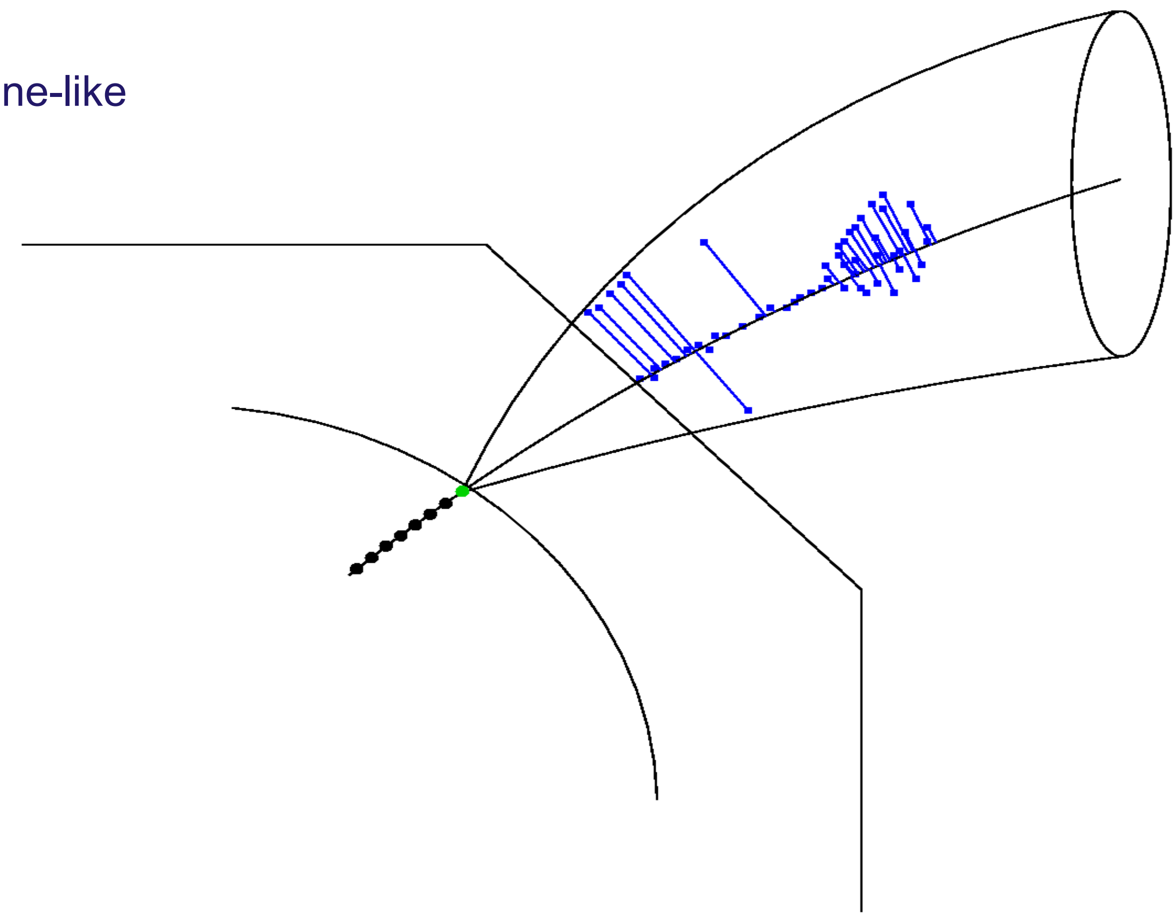
- put cone-like tube around extrapolated trajectory
- cut calorimeter hits outside cone-like tube



Find associated Calorimeter Hits

Algorithm:

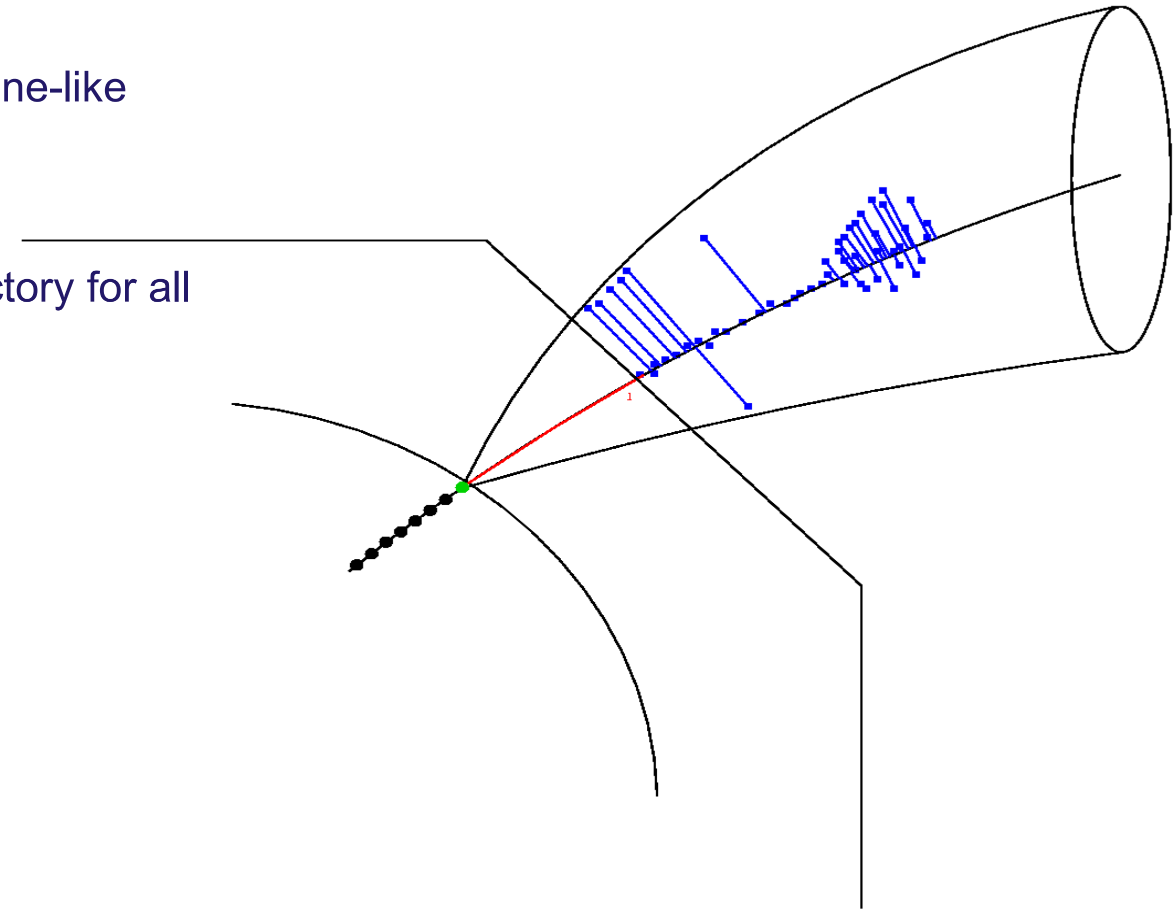
- put cone-like tube around extrapolated trajectory
- cut calorimeter hits outside cone-like tube
- project all hits on trajectory



Find associated Calorimeter Hits

Algorithm:

- put cone-like tube around extrapolated trajectory
- cut calorimeter hits outside cone-like tube
- project all hits on trajectory
- calculate path length on trajectory for all hits



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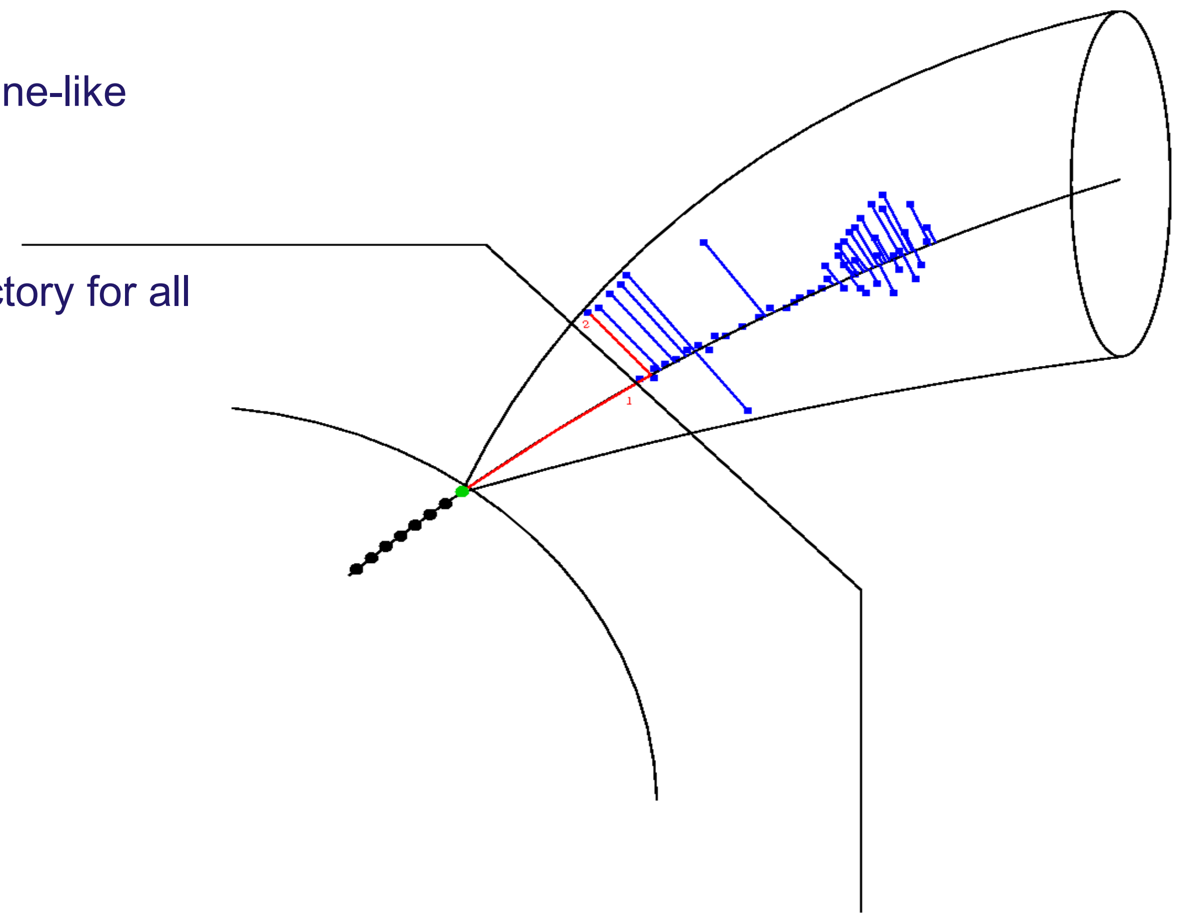
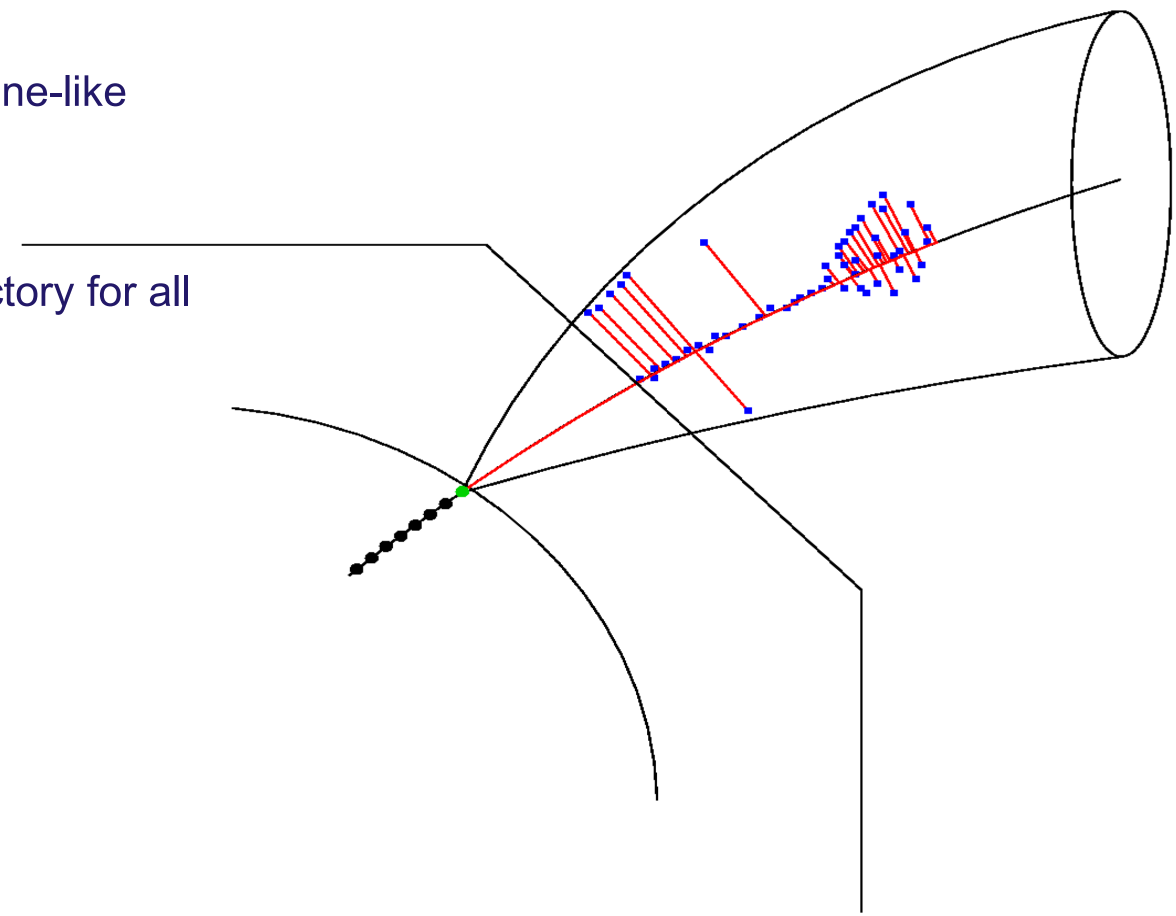


Find associated Calorimeter Hits

<u>Algorithm:</u>

- put cone-like tube around extrapolated trajectory
- cut calorimeter hits outside cone-like tube
- project all hits on trajectory
- calculate path length on trajectory for all hits
- sort hits by their path lengths

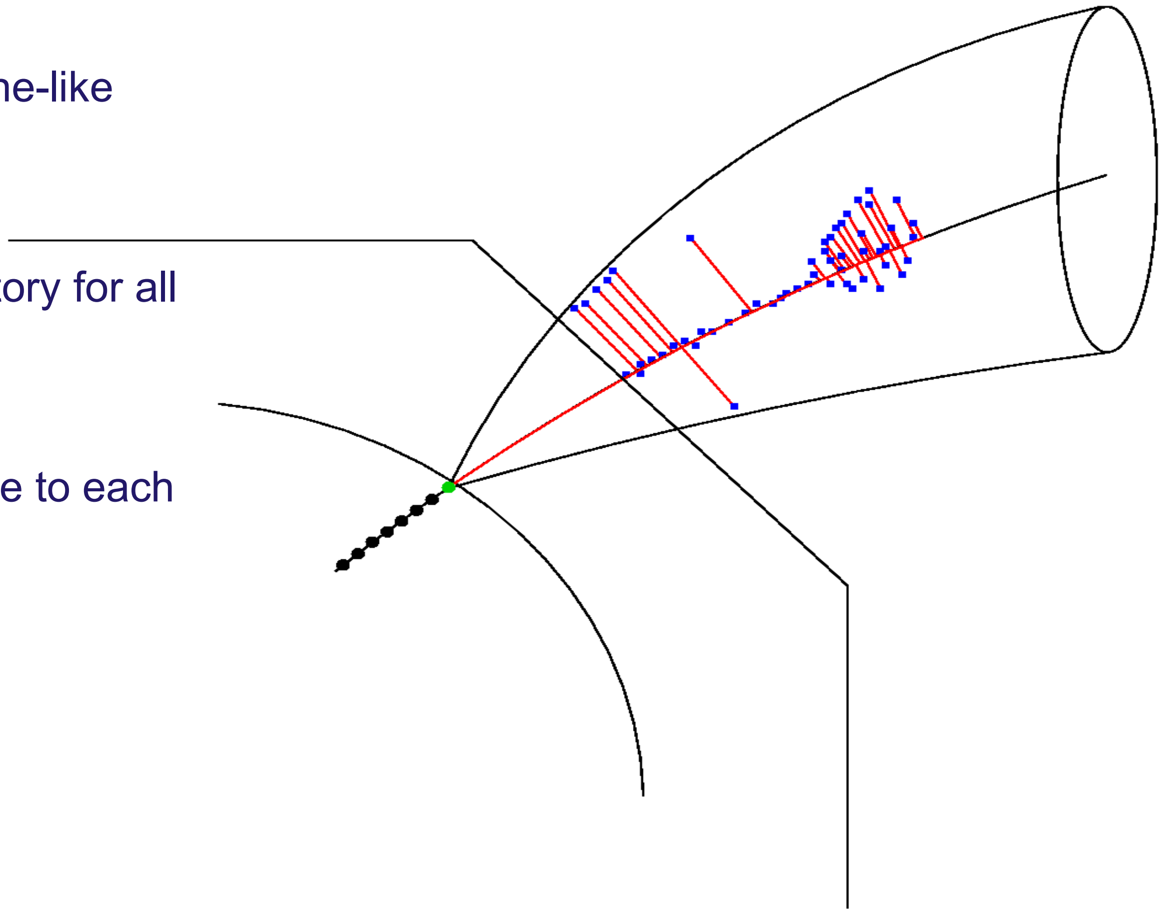


Find associated Calorimeter Hits

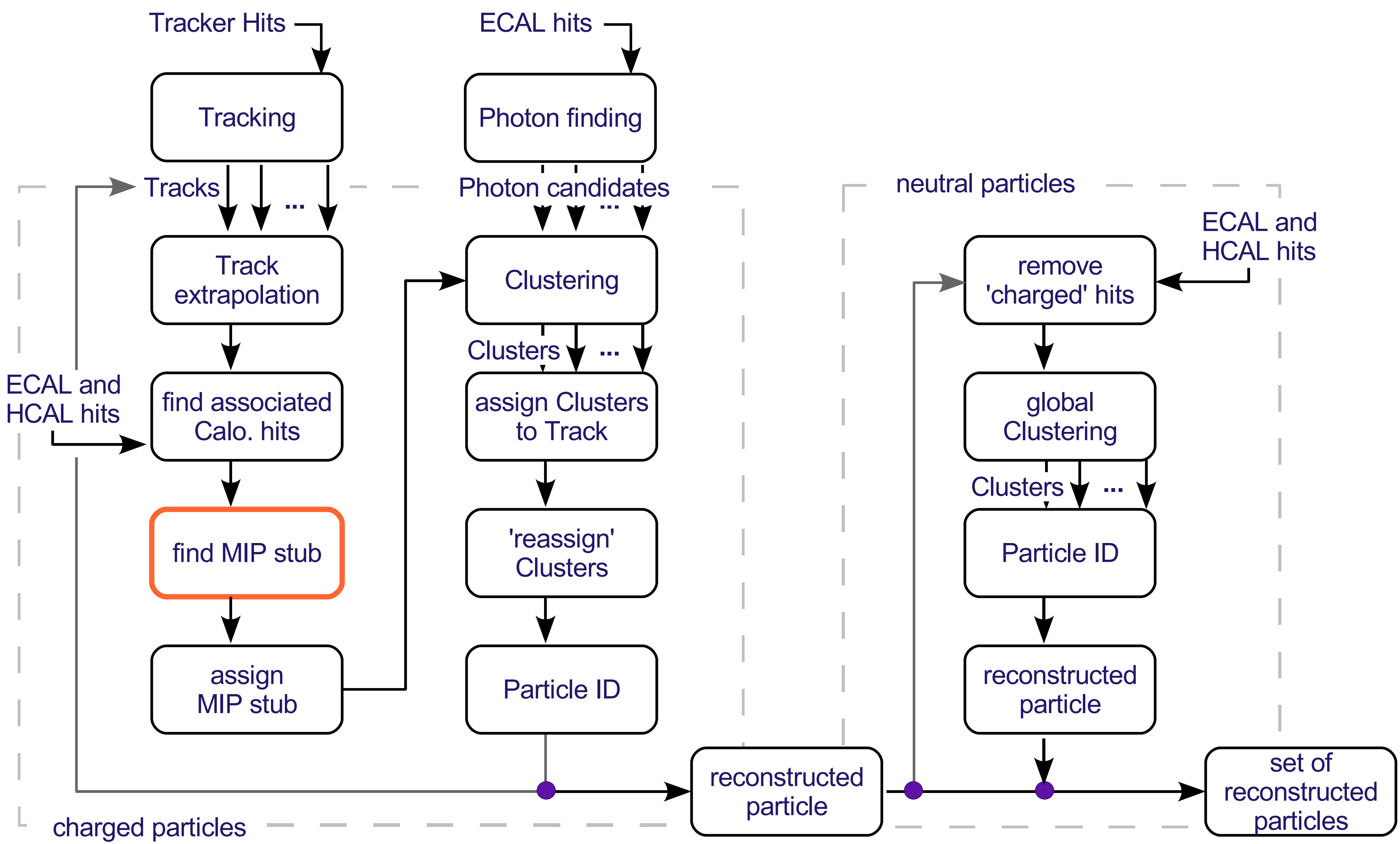
Algorithm:

- put cone-like tube around extrapolated trajectory
- cut calorimeter hits outside cone-like tube
- project all hits on trajectory
- calculate path length on trajectory for all hits
- sort hits by their path lengths

➔ assign path length and distance to each hit



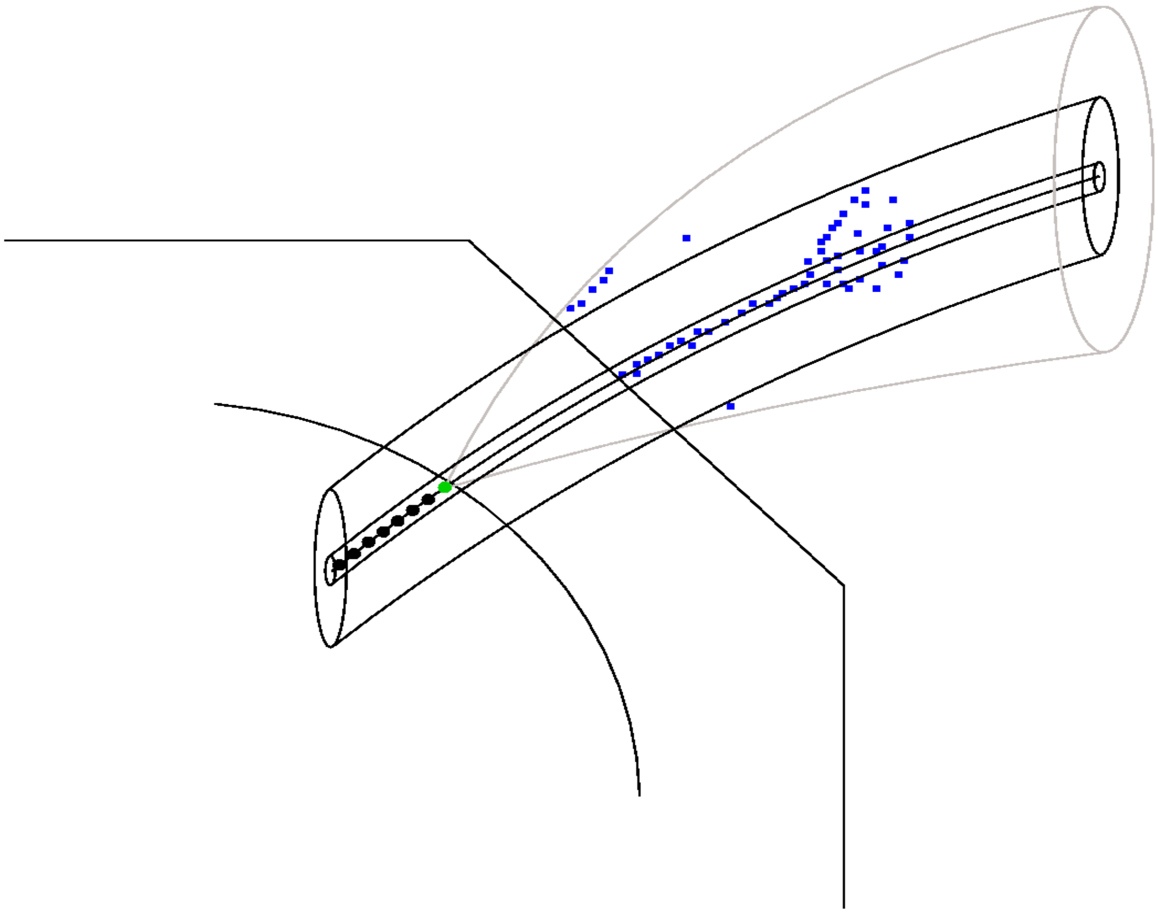
Find MIP Stub



Find MIP Stub

Algorithm:

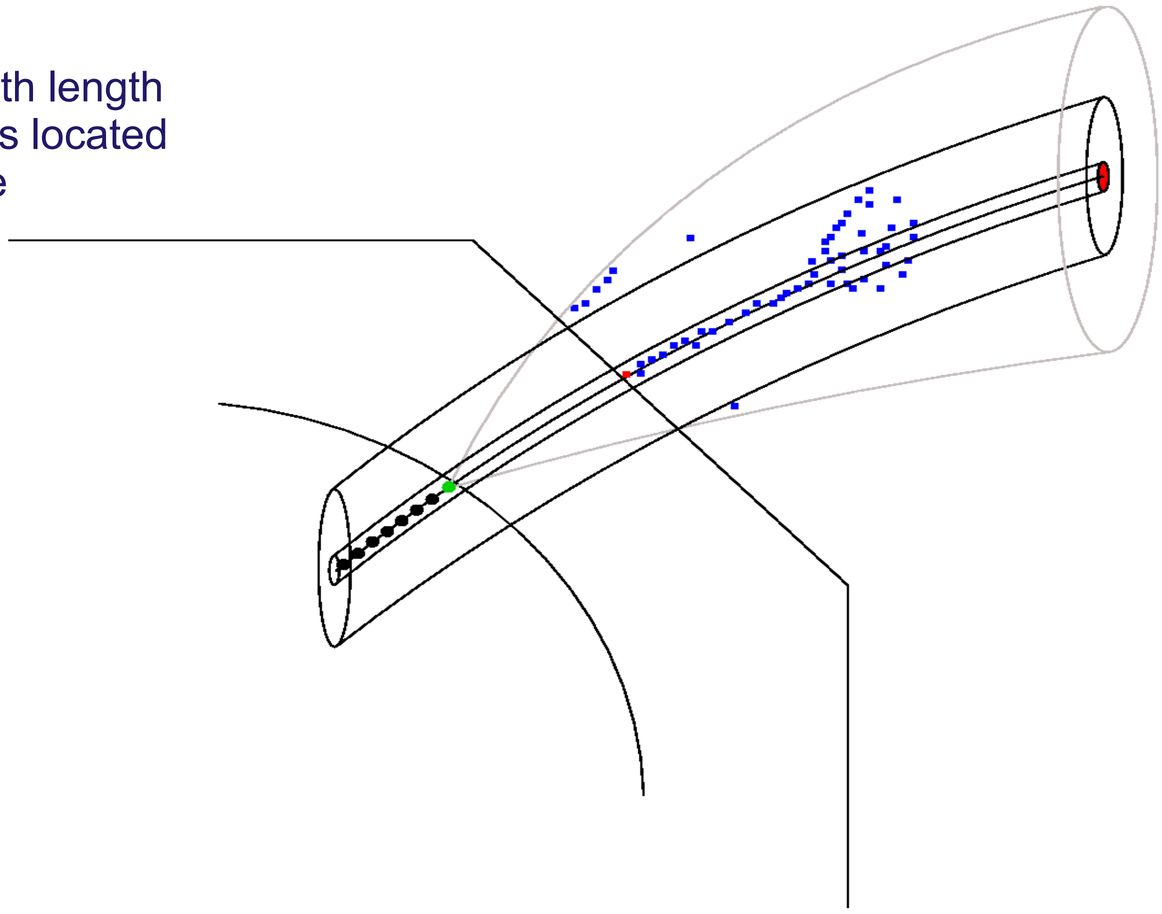
- put two cylindrical tubes around extrapolated trajectory



Find MIP Stub

Algorithm:

- put two cylindrical tubes around extrapolated trajectory
- take first hit according to its path length and add it to the MIP stub if it is located inside the inner cylindrical tube

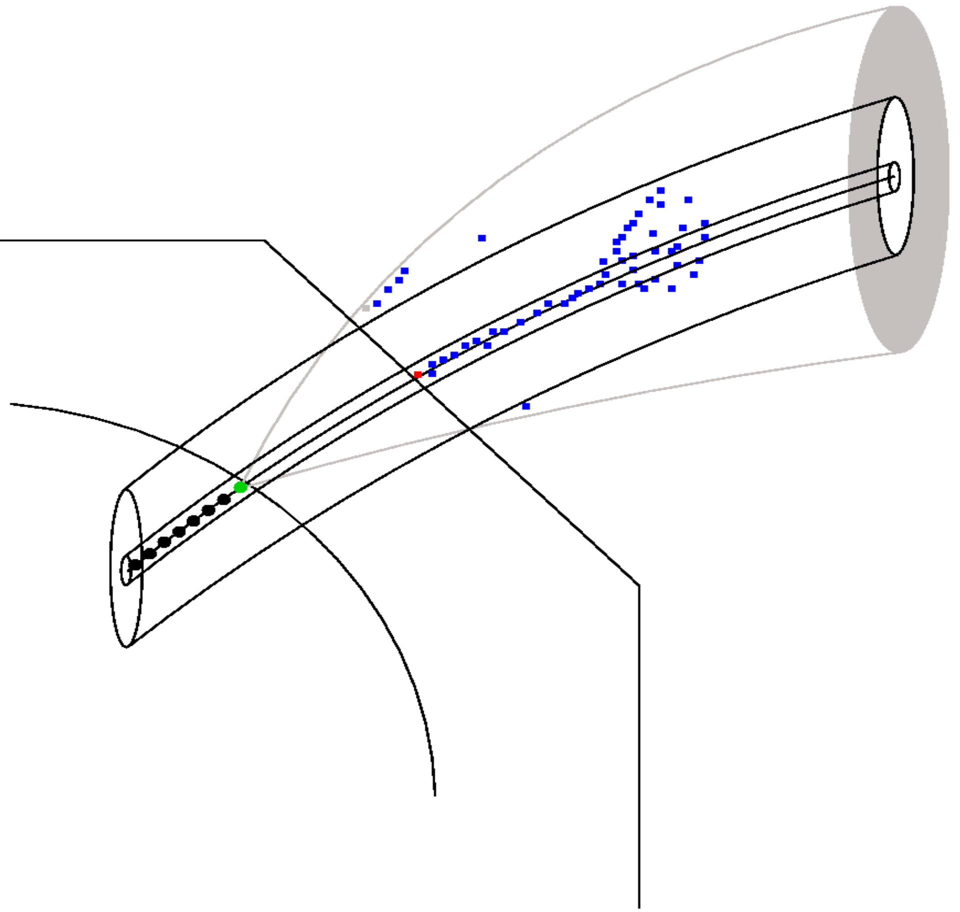


Find MIP Stub

Algorithm:

- put two cylindrical tubes around extrapolated trajectory
- take first hit according to its path length and add it to the MIP stub if it is located inside the inner cylindrical tube
- take the next hit and discard it if it is located outside the outer tube

→ amplitude information can be taken into account (MIP like)



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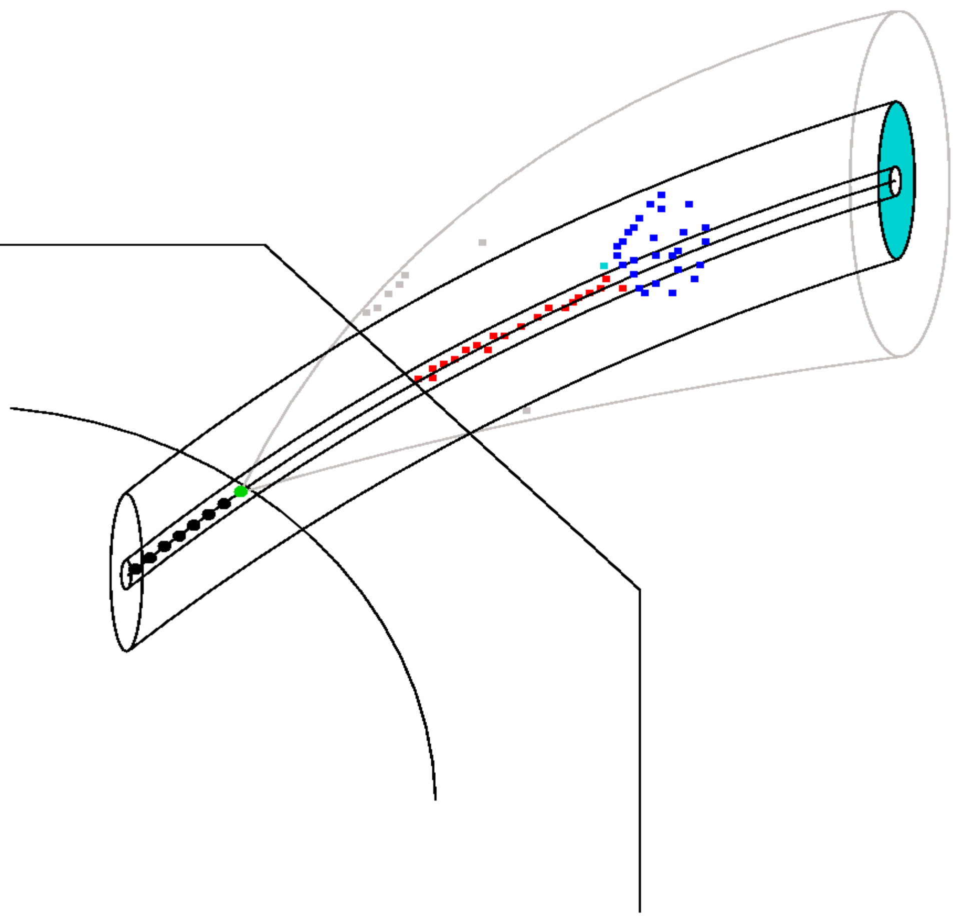
Algorithm:

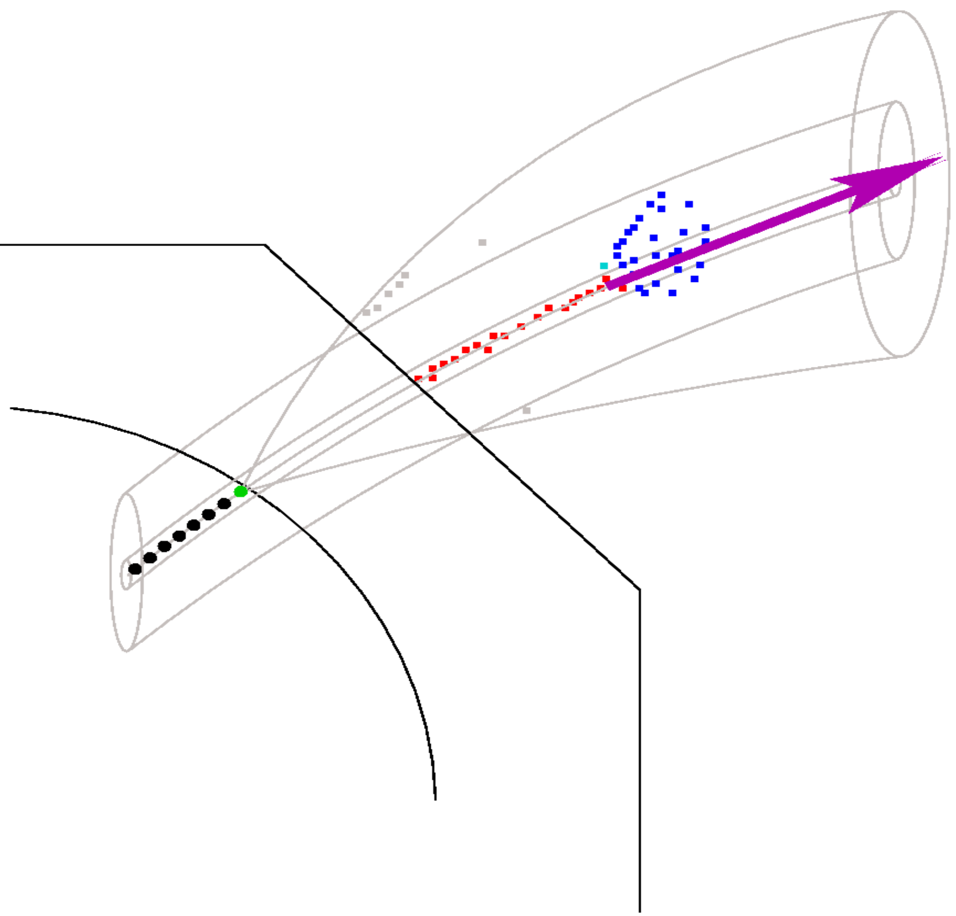
- put two cylindrical tubes around extrapolated trajectory
- take first hit according to its path length and add it to the MIP stub if it is located inside the inner cylindrical tube
- take the next hit and discard it if it is located outside the outer tube
- → amplitude information can be taken into account (MIP like)
- repeat this procedure for all hits until a hit outside the inner and inside the outer cylinder tube is found ('veto-cylinder')



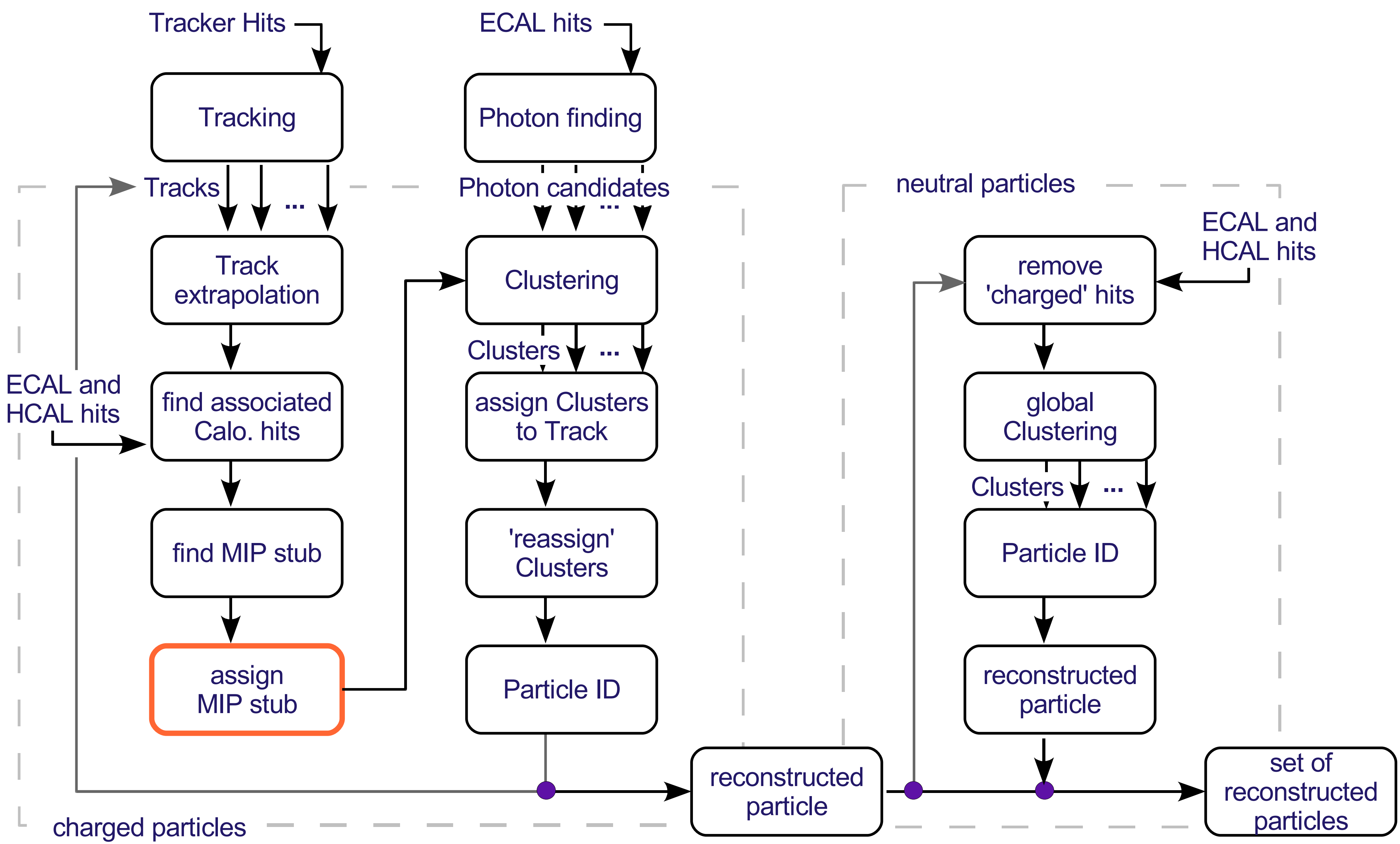
Find MIP Stub

<u>Algorithm:</u>

- put two cylindrical tubes around extrapolated trajectory
- take first hit according to its path length and add it to the MIP stub if it is located inside the inner cylindrical tube
- take the next hit and discard it if it is located outside the outer tube
- ➔ amplitude information can be taken into account (MIP like)
- repeat this procedure for all hits until a hit outside the inner and inside the outer cylinder tube is found ('veto-cylinder')
- ➔ stop the MIP stub finding
- take the projection of the last hit collected for the MIP stub as a start point for clustering
- take the direction (tangent) of this point as a start direction for clustering



Assign MIP Stub



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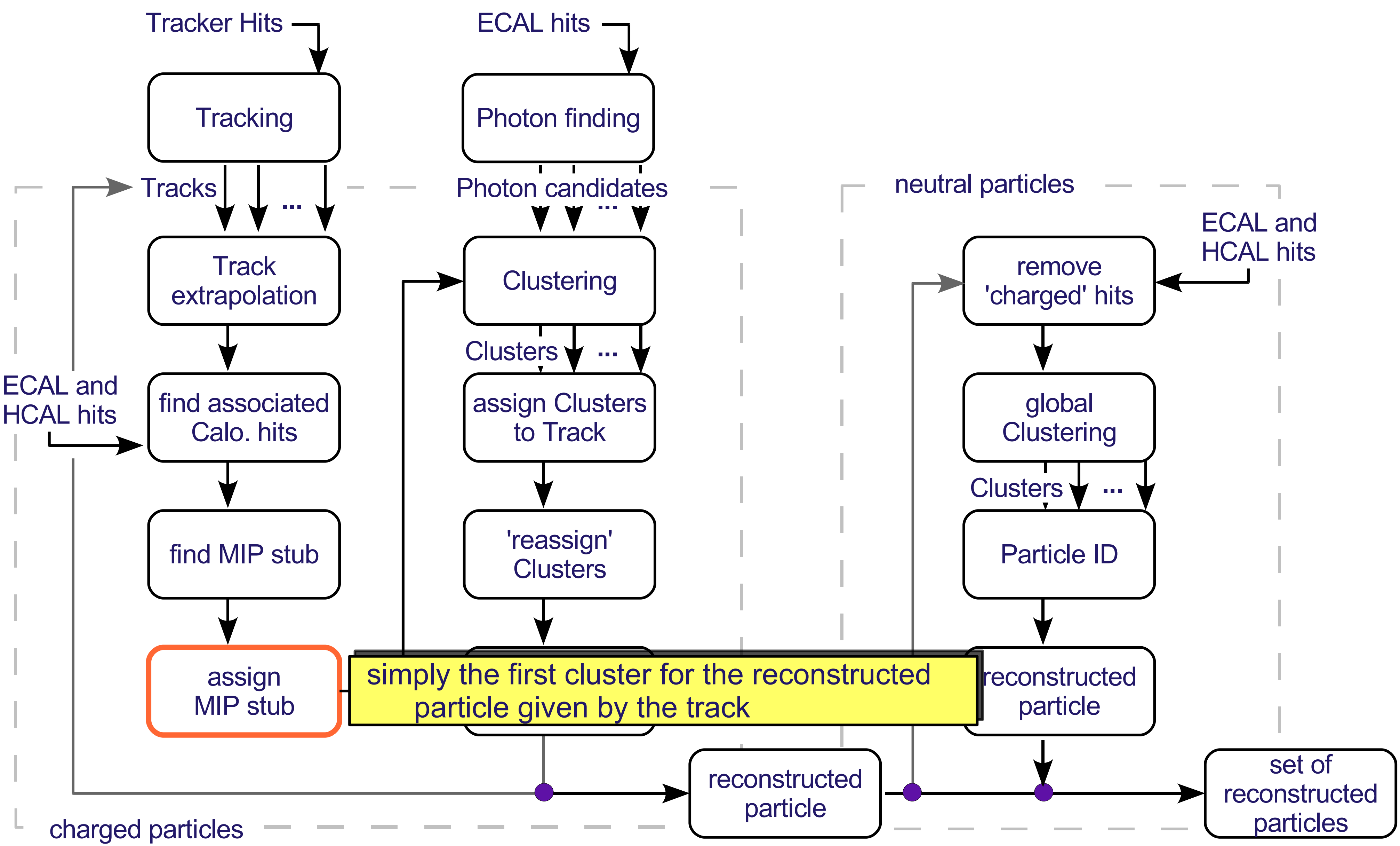
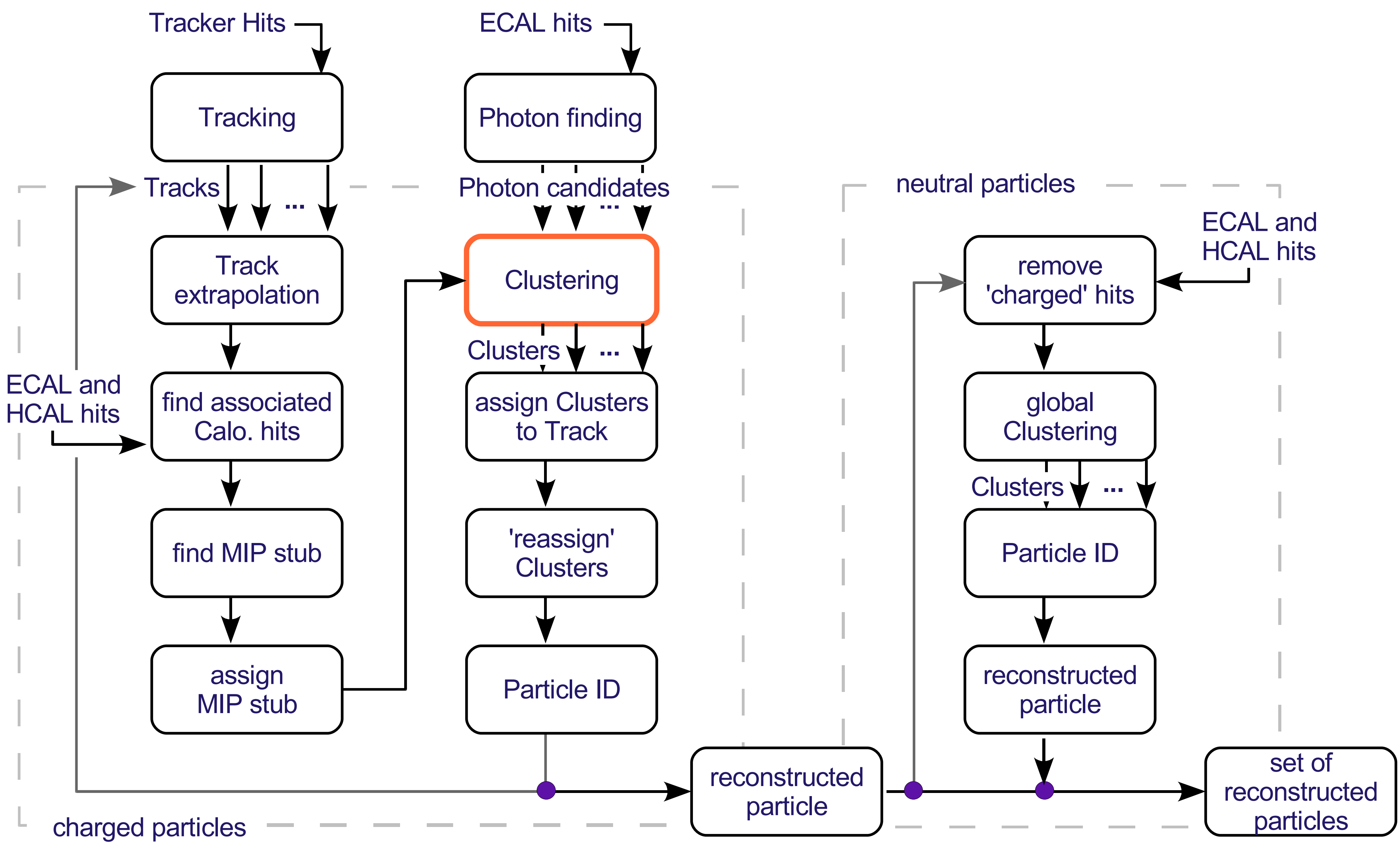


Clustering



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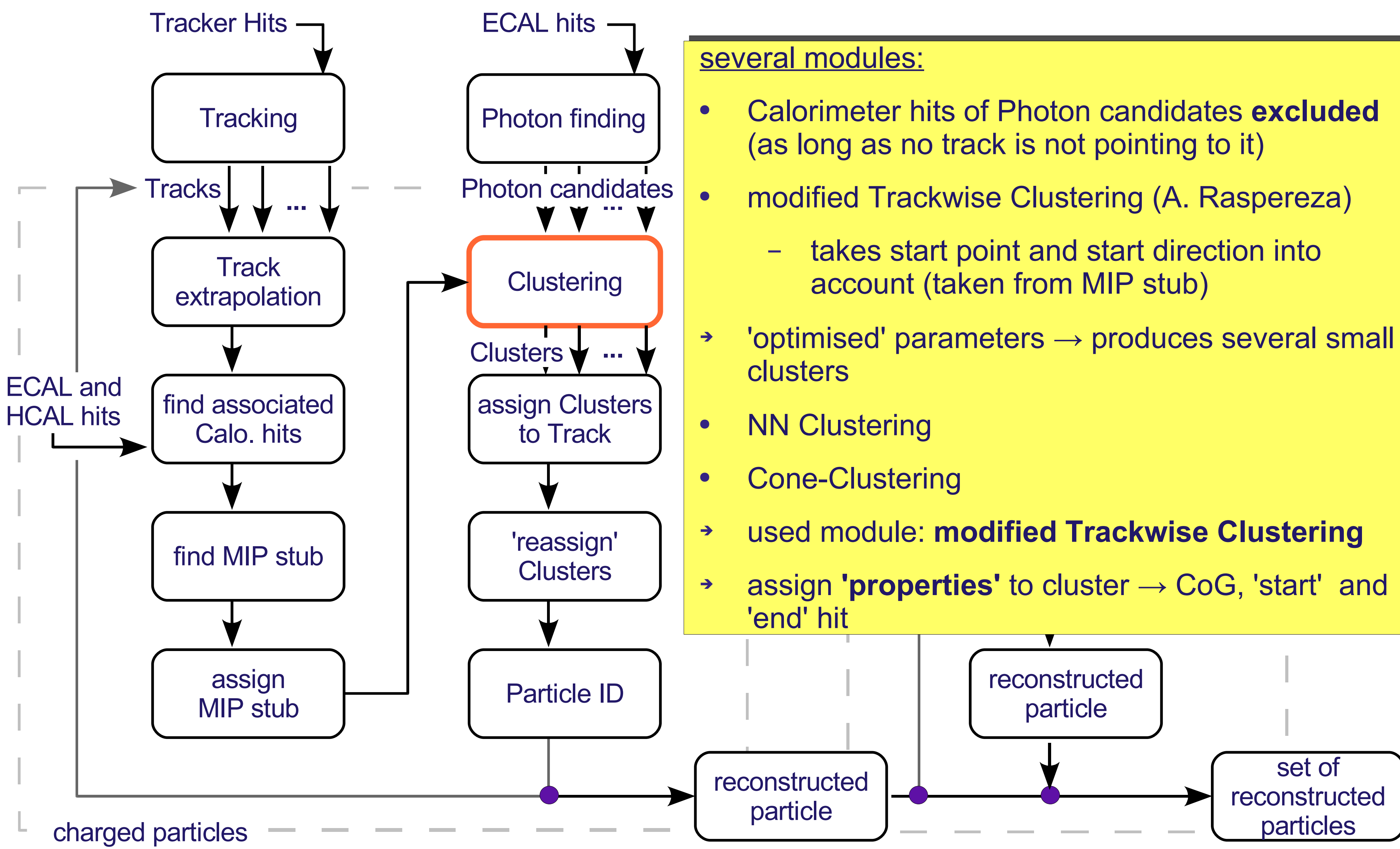
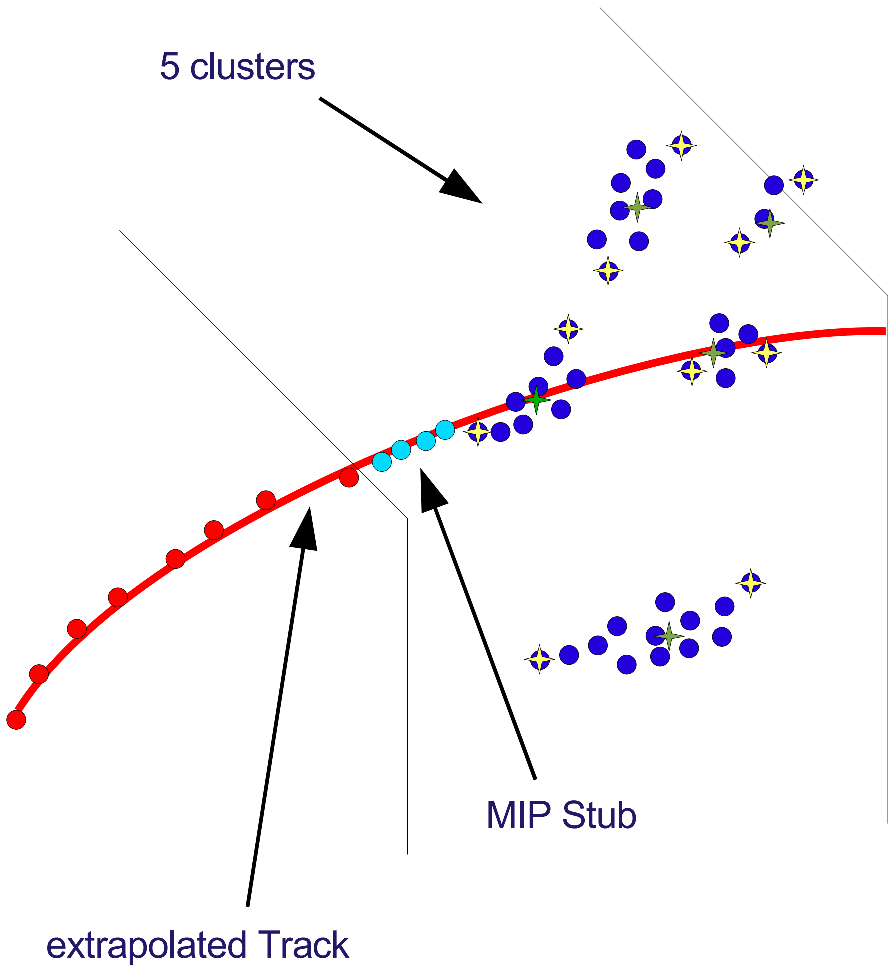
Clustering



several modules:

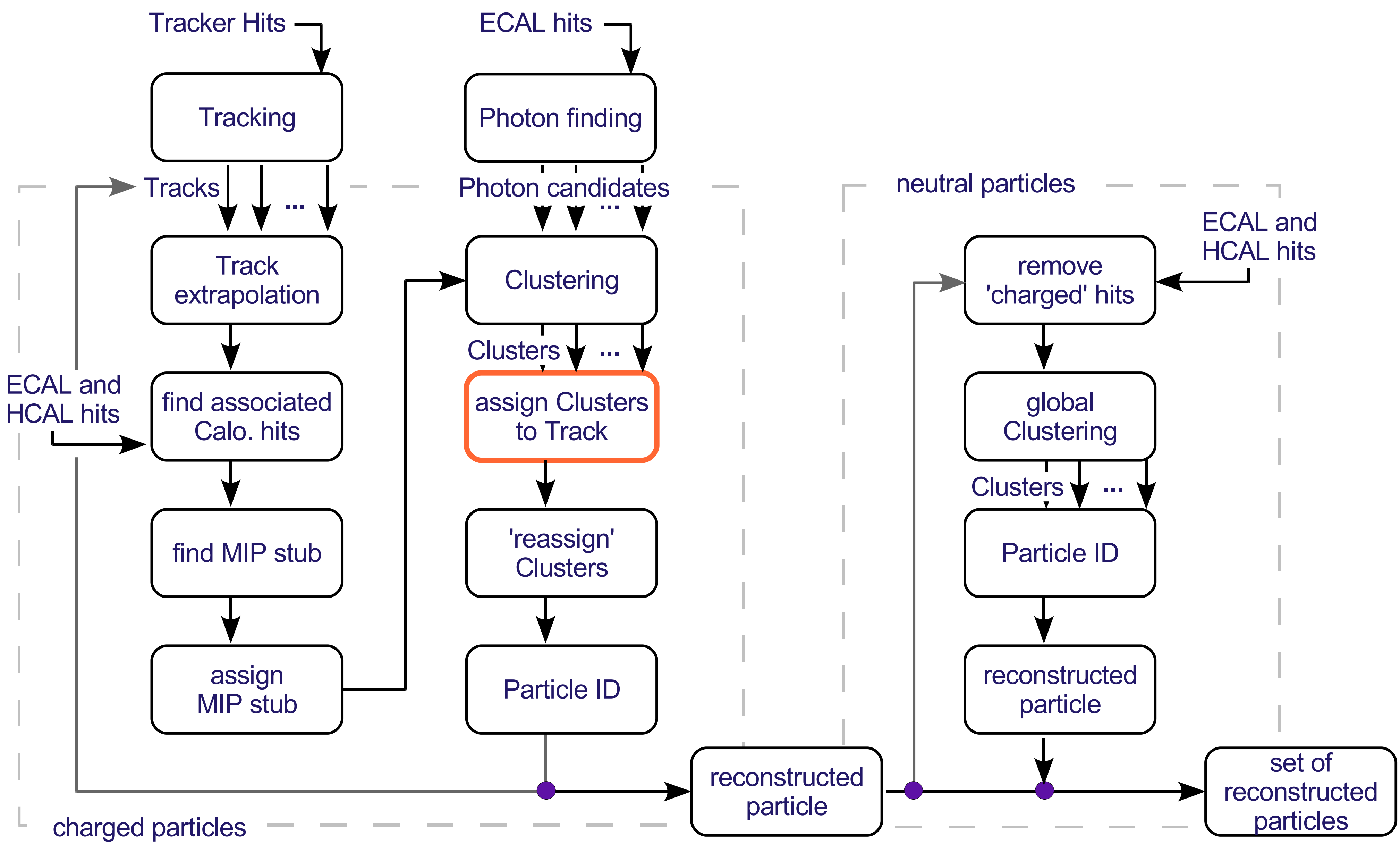
- Calorimeter hits of Photon candidates **excluded** (as long as no track is not pointing to it)
- modified Trackwise Clustering (A. Raspereza)
  - takes start point and start direction into account (taken from MIP stub)
- ➔ 'optimised' parameters → produces several small clusters
- NN Clustering
- Cone-Clustering
- ➔ used module: **modified Trackwise Clustering**
- ➔ assign **'properties'** to cluster → CoG, 'start' and 'end' hit

Properties of Clusters



- calculate Center of Gravity (CoG) for each cluster (✦)
- calculate start and end hit for each cluster (✦)
  - simply smallest and largest path length of Calorimeter Hit on trajectory/helix
  - these properties are assigned to each cluster

Assign Clusters to Track



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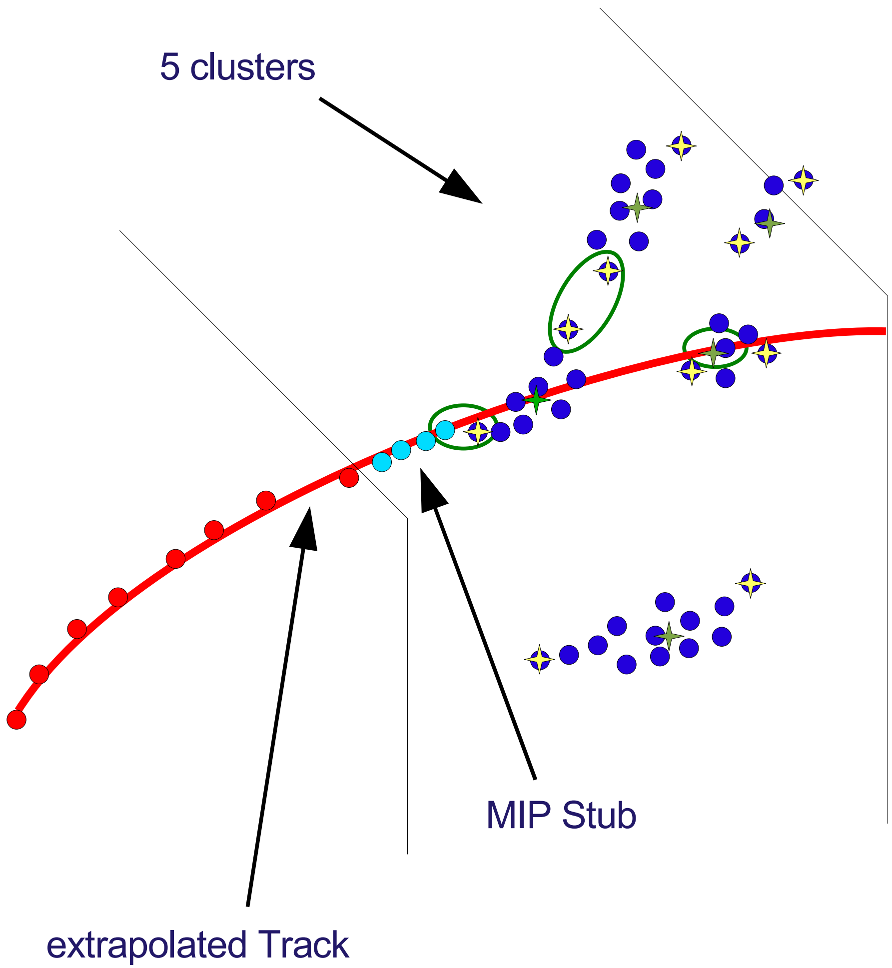
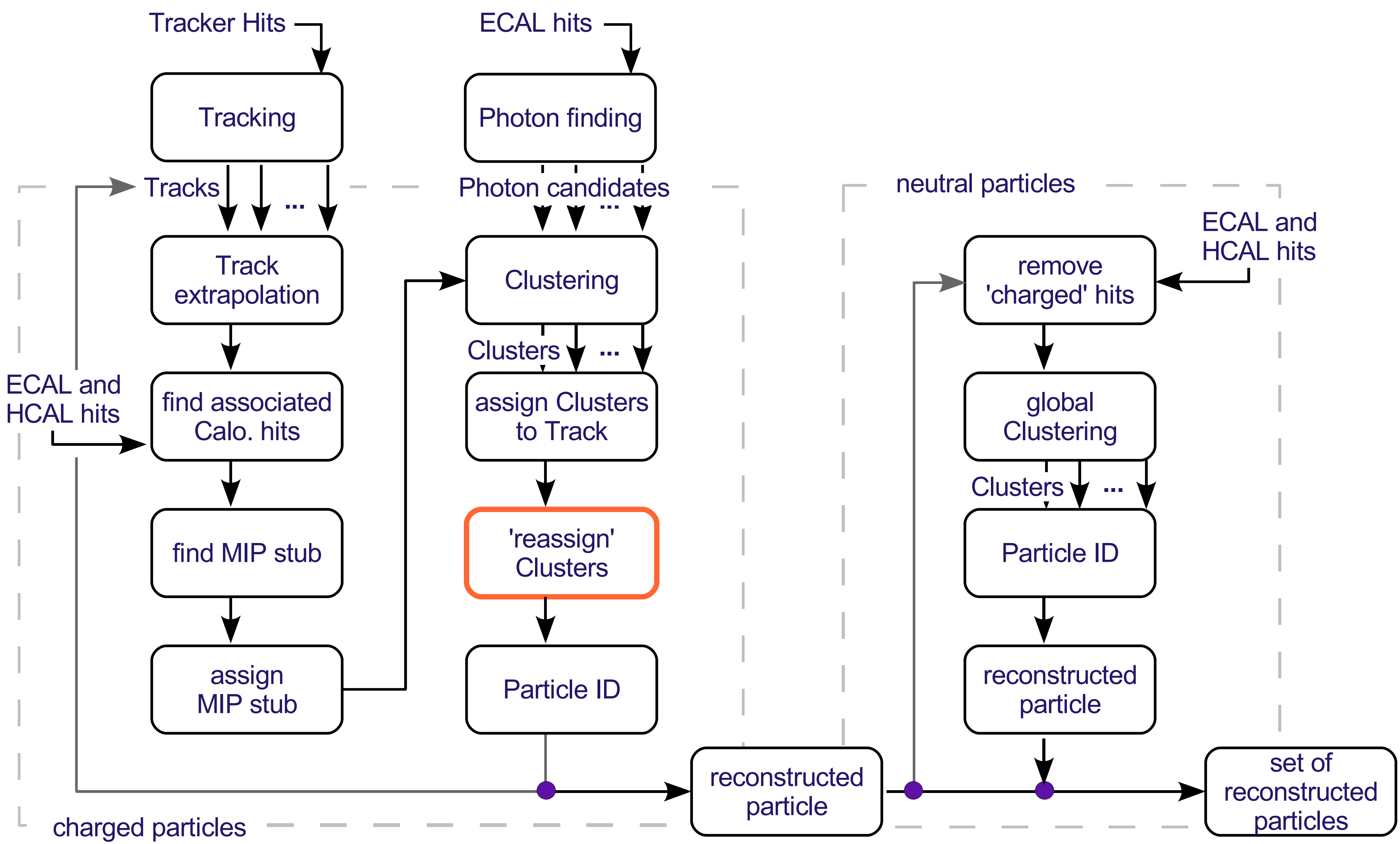


assign Cluster to track if

- distance between end point of cluster i to start point of cluster j is smaller than a given limit
- ➔ limit depends on sampling fraction
- distance of CoG to extrapolated track is smaller than a given limit
- some more geometrical conditions

'Reassign' Clusters



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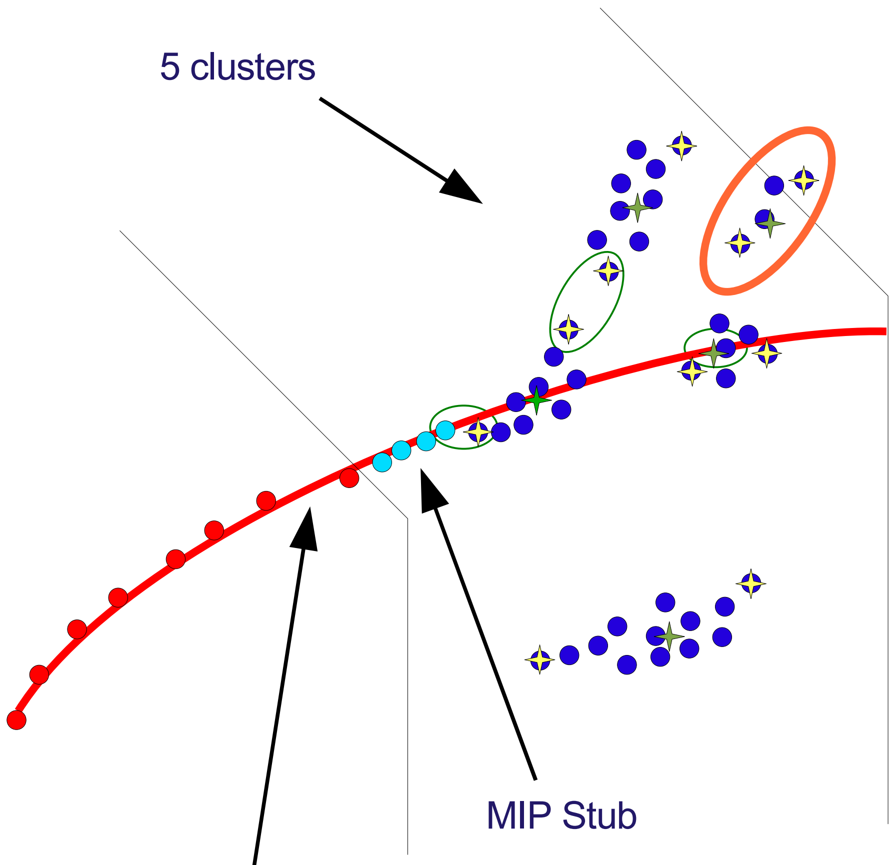
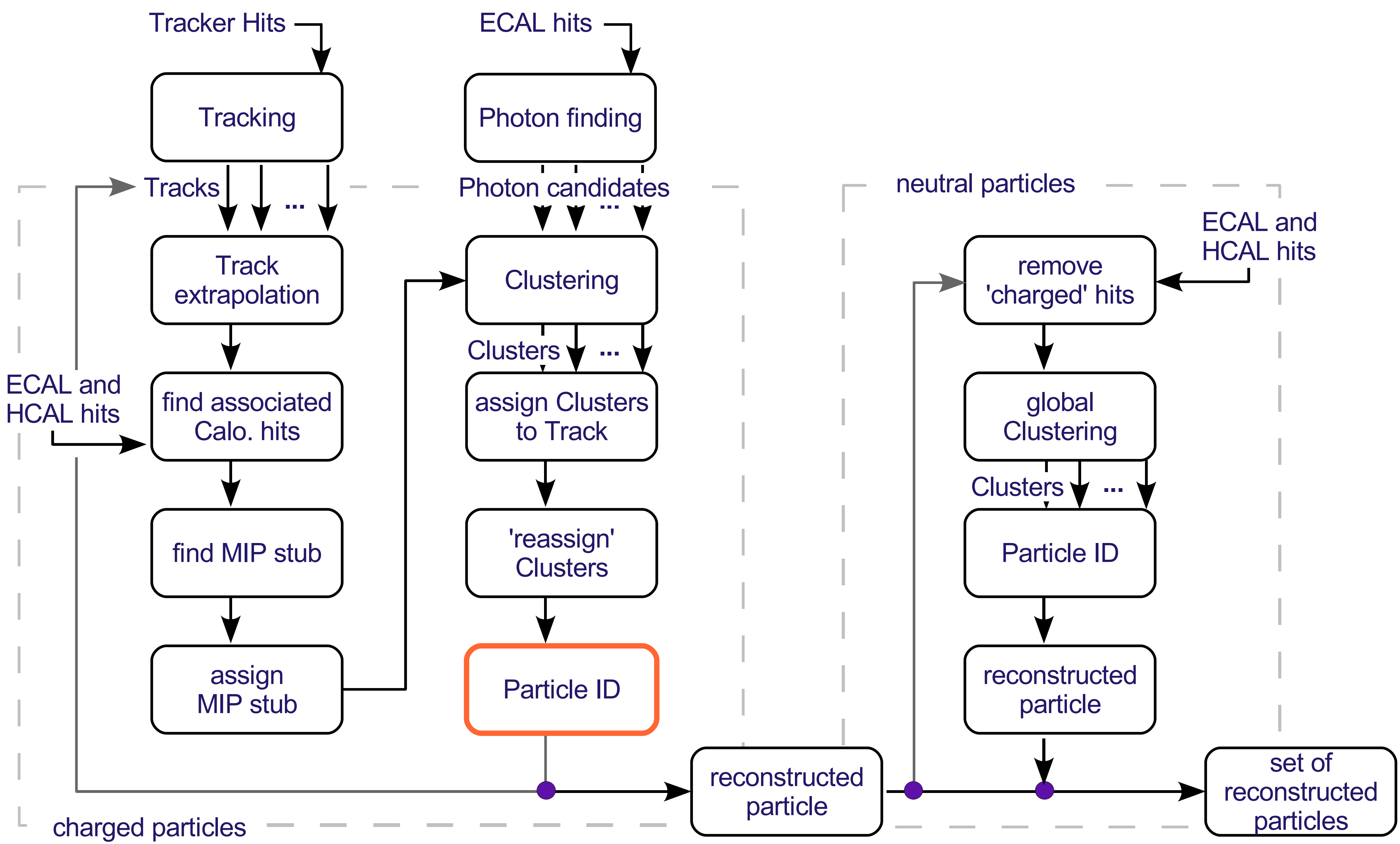


assign additional Clusters if

- distance of cluster is smaller than a certain limit
- $|E_1 + E_2 - E_{Track}| < 3\ \sigma_E$

→ very simple at the moment

Particle ID



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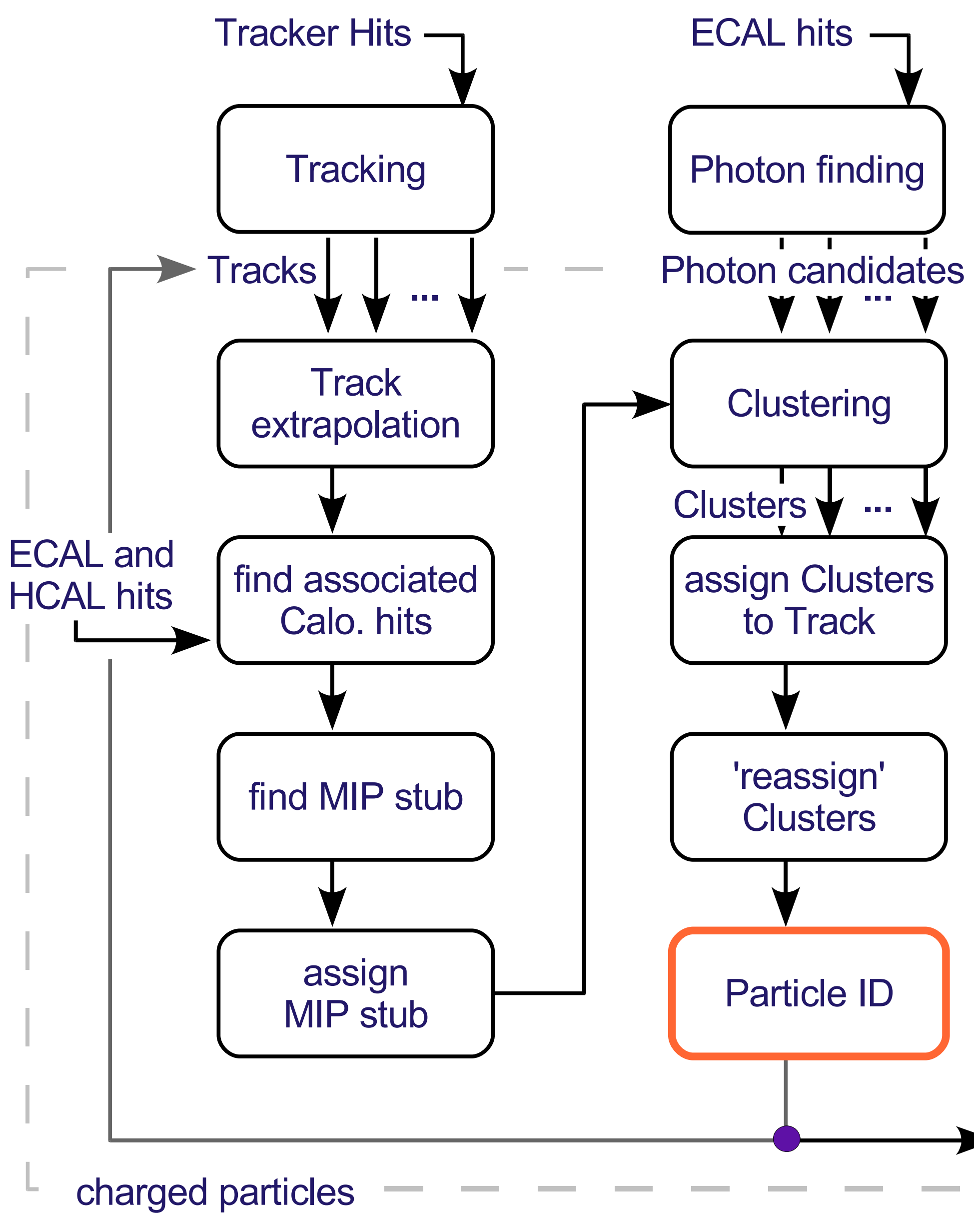


very simple procedure at the moment (adapted from Wolf):

- fraction of energy ECAL/HCAL, given by a steering parameter
  - if fraction > 95 % → particle is an electron
  - if fraction < 95 % → particle is a pion

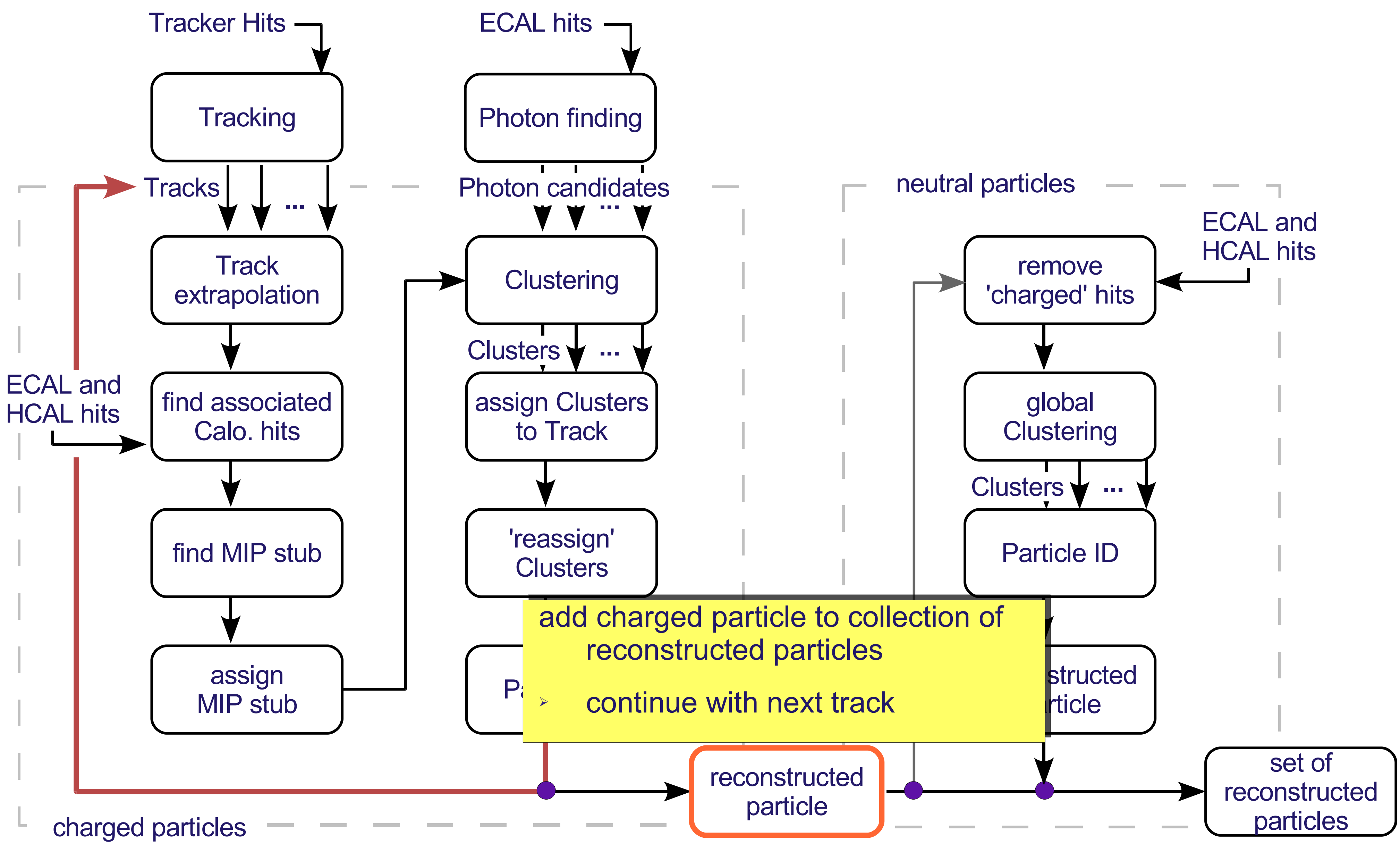
additionally:

- if there is only the MIP stub assigned to the track → particle is a muon

a lot of room for improvements:

- fit of the e.m. Shower Shape
- do 'real' electron (find 'photon' with corresponding track) and muon finding

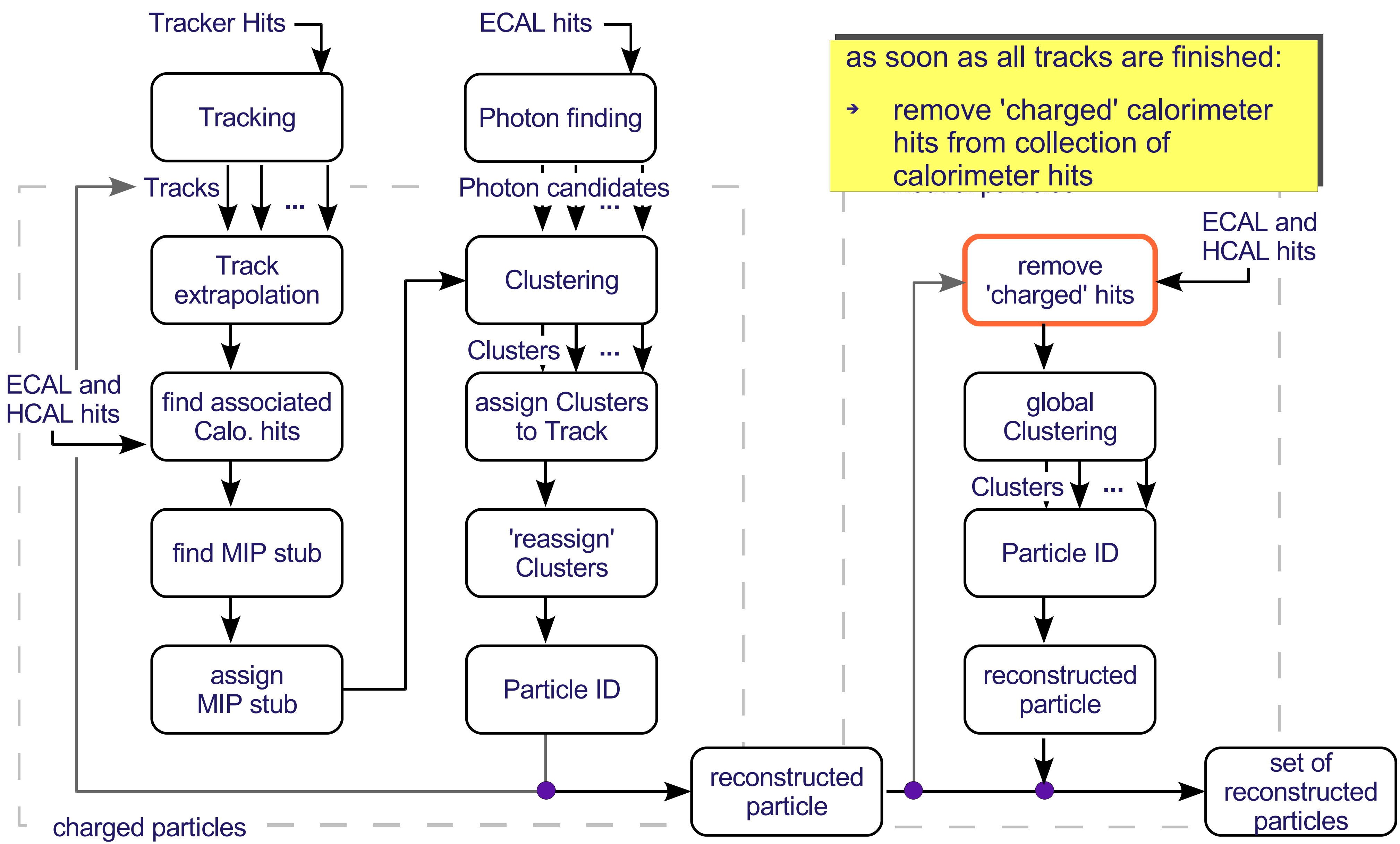
Charged Particle reconstructed



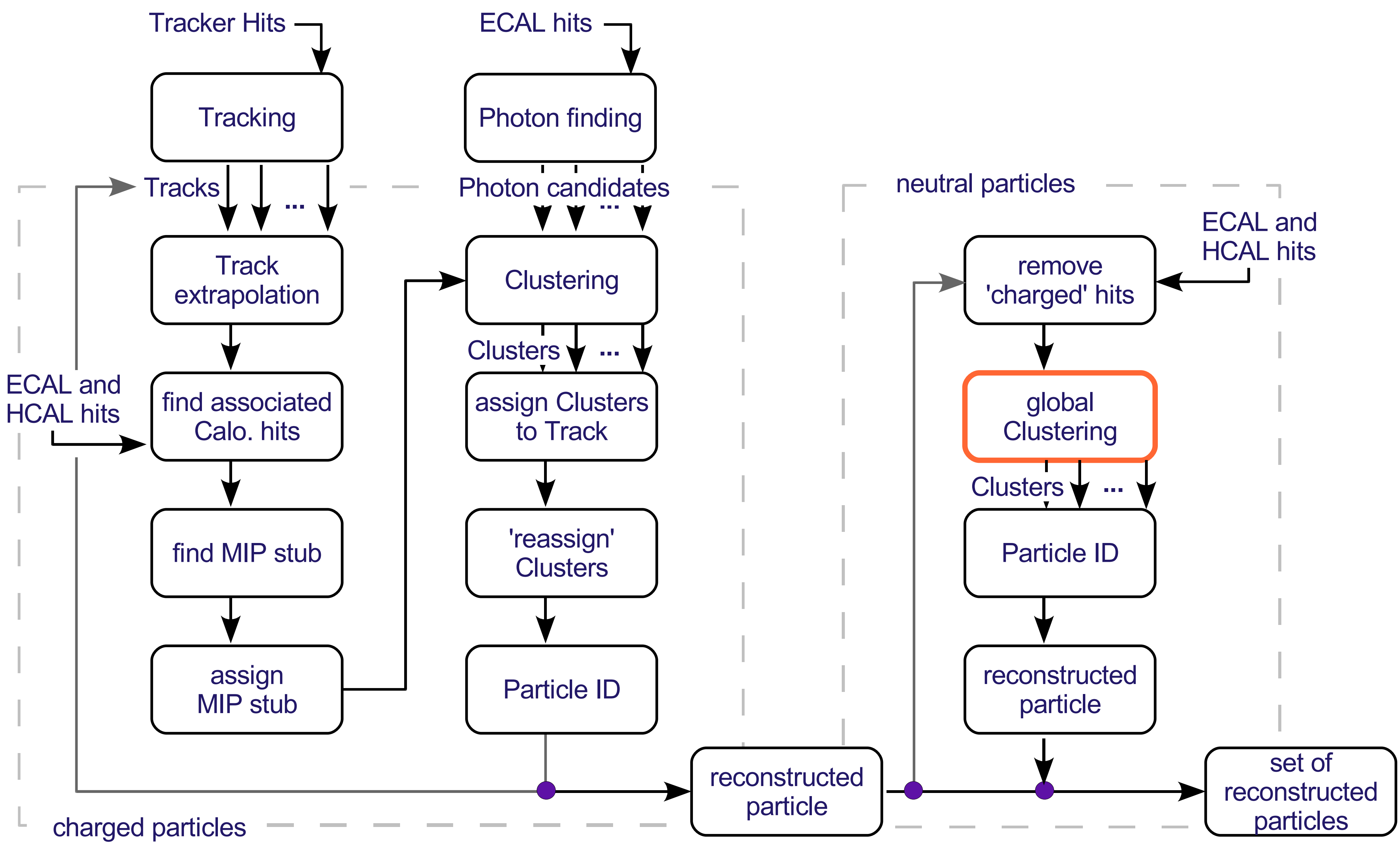
Remove 'Charged' Calorimeter Hits

as soon as all tracks are finished:

- remove 'charged' calorimeter hits from collection of calorimeter hits



Clustering on Neutral Hits



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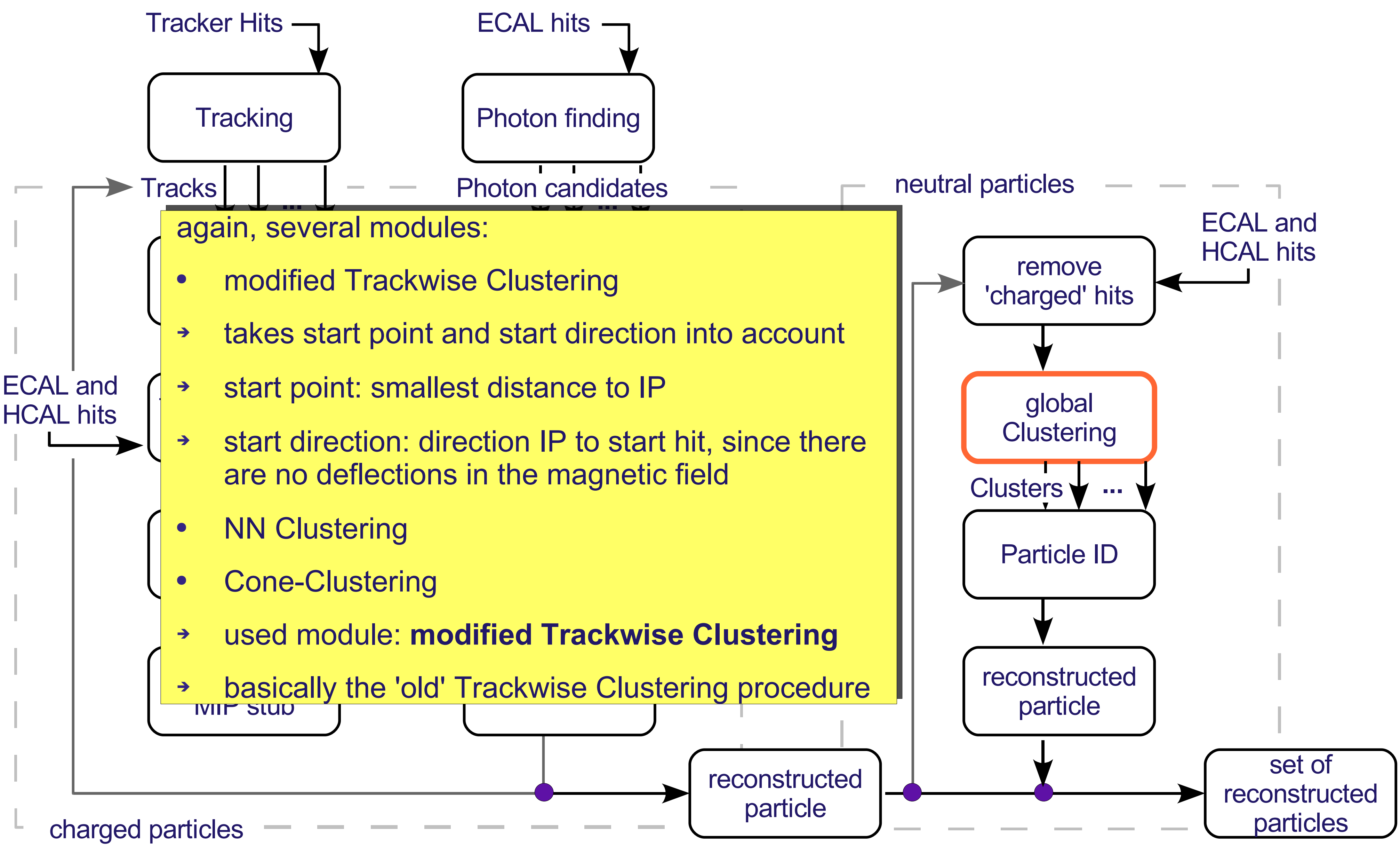
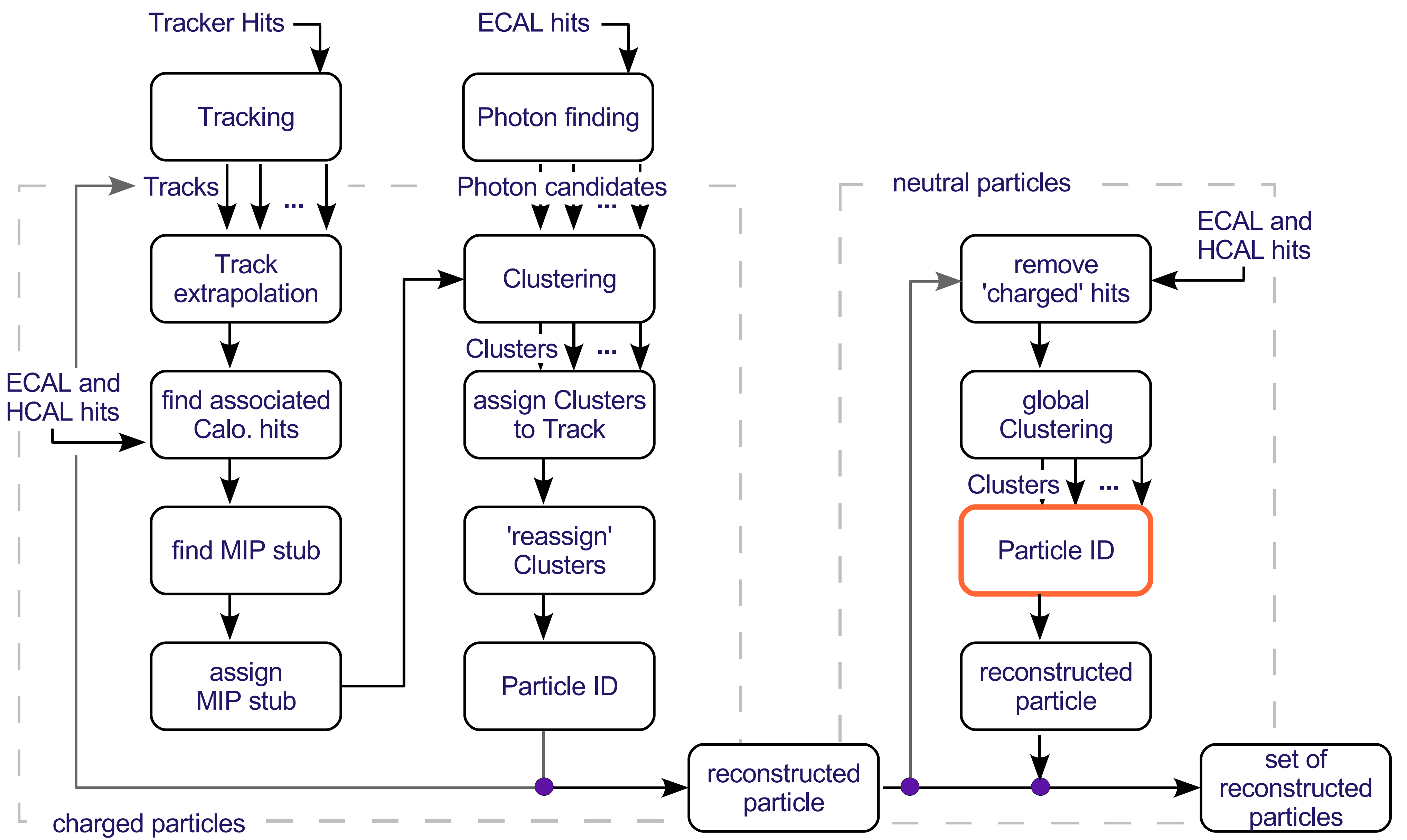


again, several modules:

- modified Trackwise Clustering
  - takes start point and start direction into account
  - start point: smallest distance to IP
  - start direction: direction IP to start hit, since there are no deflections in the magnetic field
- NN Clustering
- Cone-Clustering
  - used module: **modified Trackwise Clustering**
  - basically the 'old' Trackwise Clustering procedure

Particle ID for Neutrals



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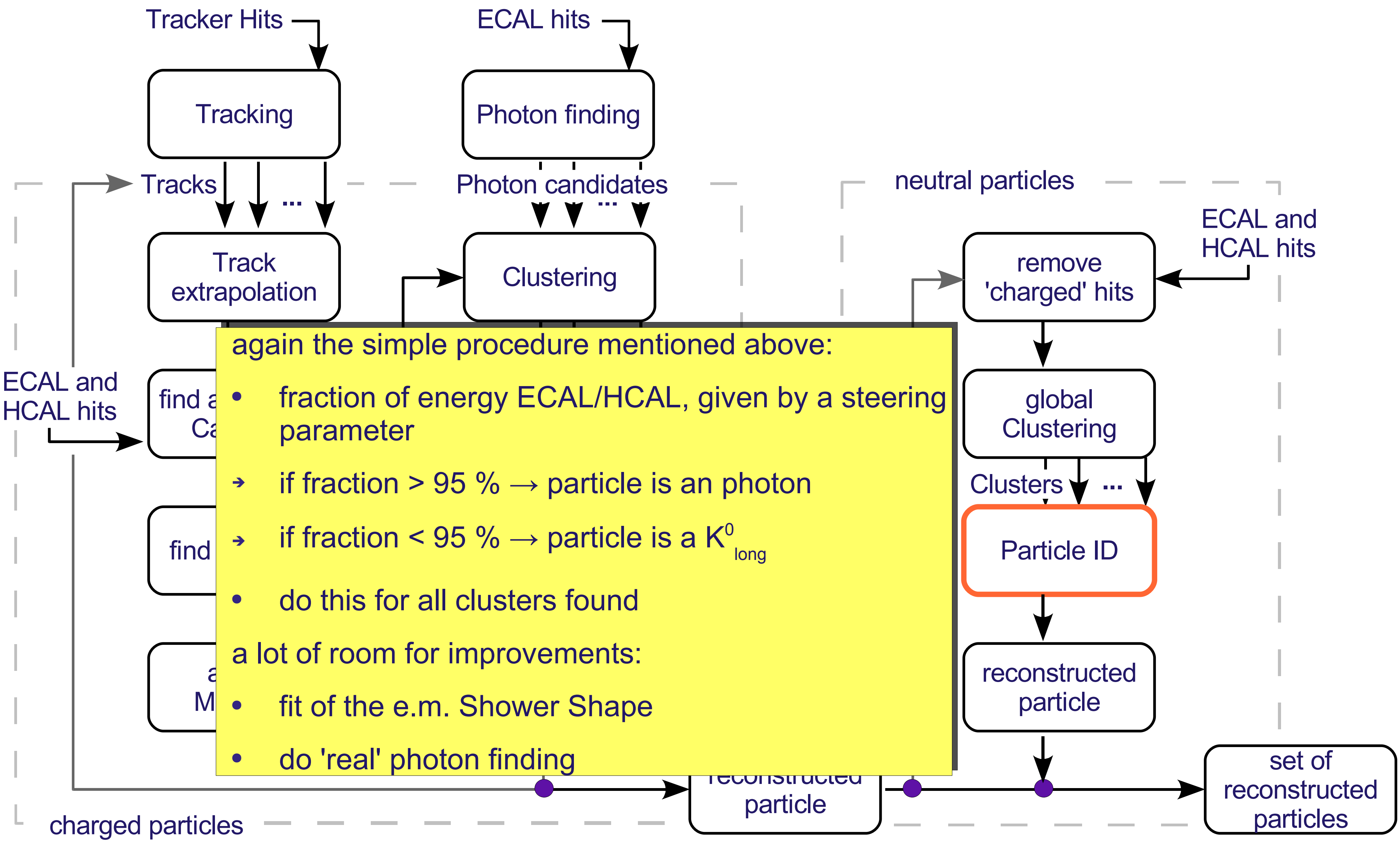


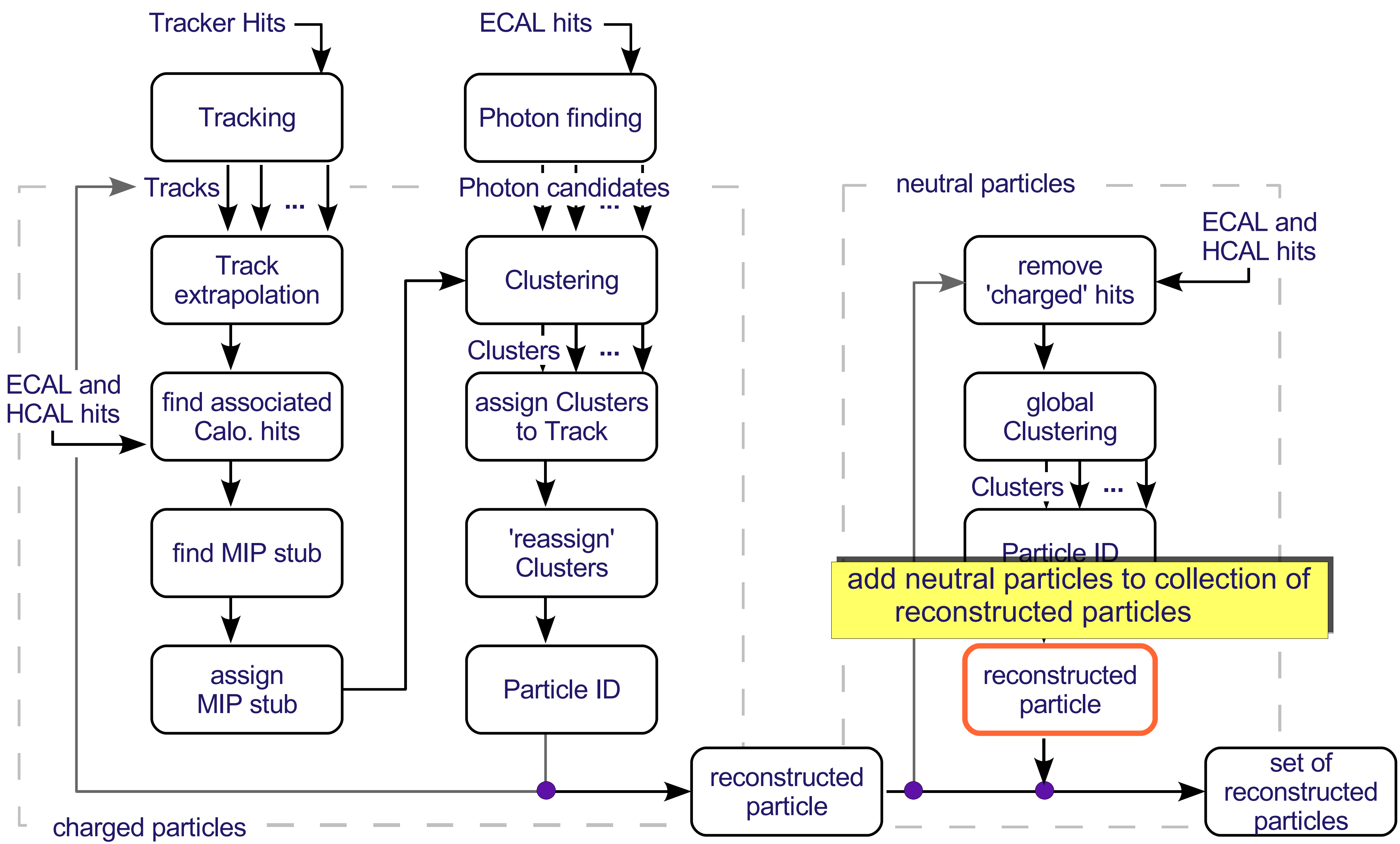
again the simple procedure mentioned above:

- fraction of energy ECAL/HCAL, given by a steering parameter
  - if fraction > 95 % → particle is an photon
  - if fraction < 95 % → particle is a K^0_{long}
- do this for all clusters found

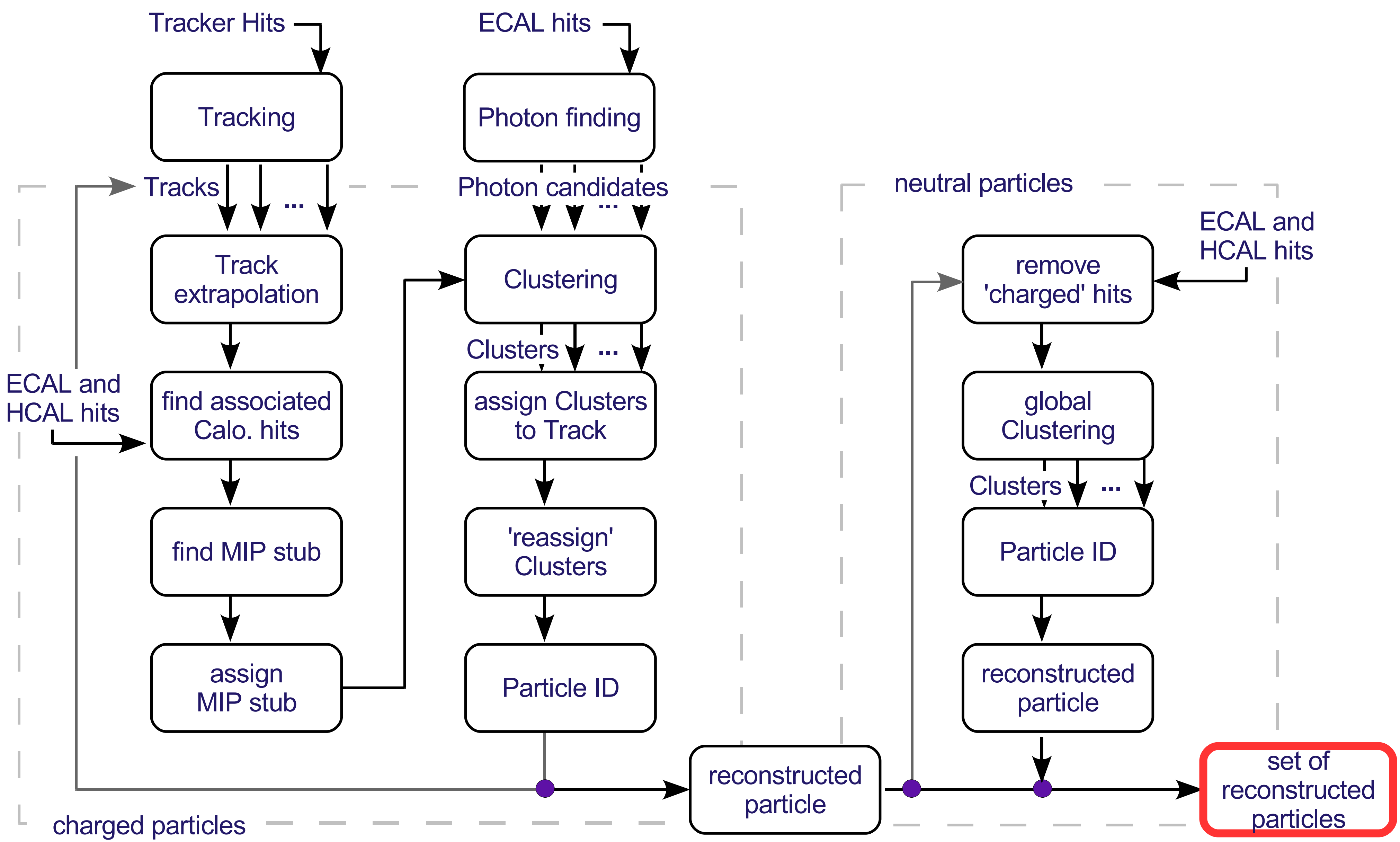
a lot of room for improvements:

- fit of the e.m. Shower Shape
- do 'real' photon finding

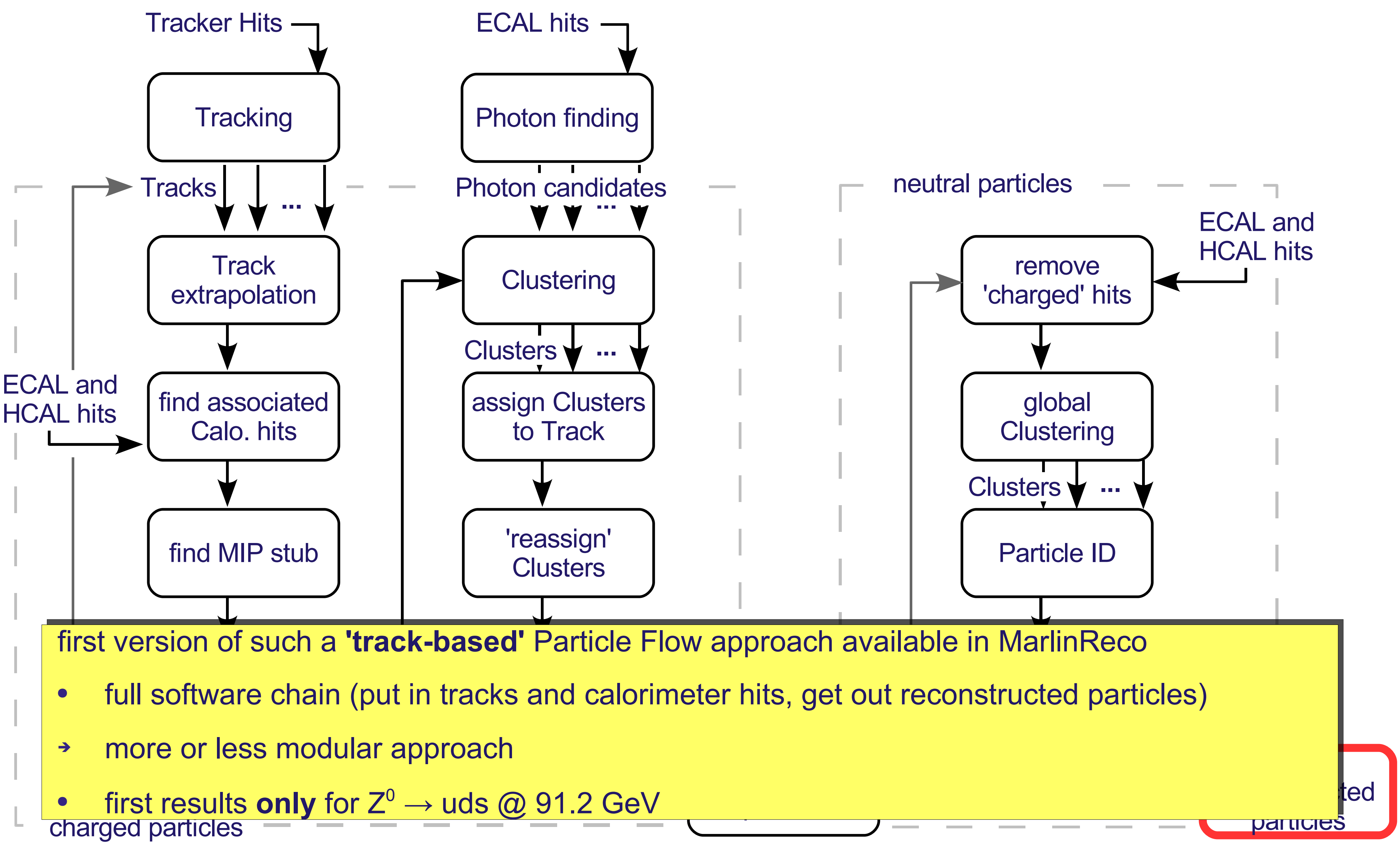
Neutral Particle reconstructed



End of Track-Based Particle Flow Algorithm



Track-Based Particle Flow Algorithm



first version of such a **'track-based'** Particle Flow approach available in MarlinReco

- full software chain (put in tracks and calorimeter hits, get out reconstructed particles)
- → more or less modular approach
- first results **only** for $Z^0 \rightarrow$ uds @ 91.2 GeV

Performance of Track-Based PFlow

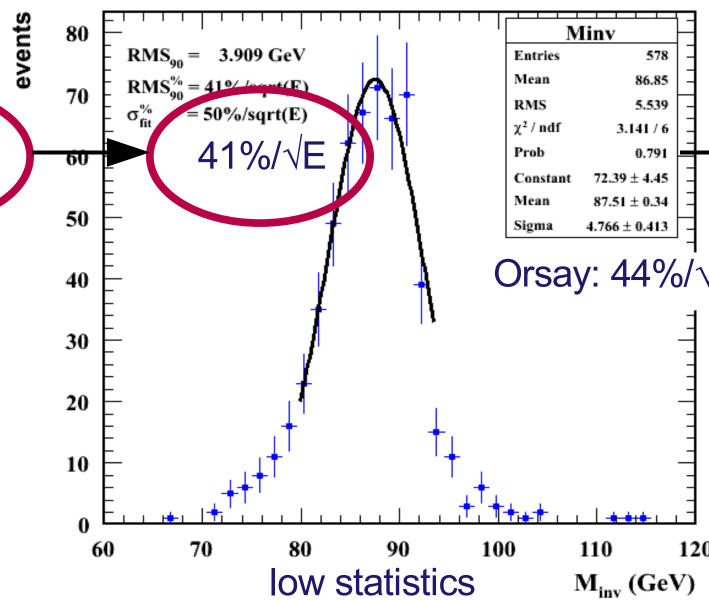
<u>some first results</u> for Z → uds @ 91.2 GeV, cos(θ) < 0.8, LDC00Sc, R(1690mm), L(2730mm):

Wolf

52%/√E

realistic **Track-Based PFlow**

41%/√E



low statistics

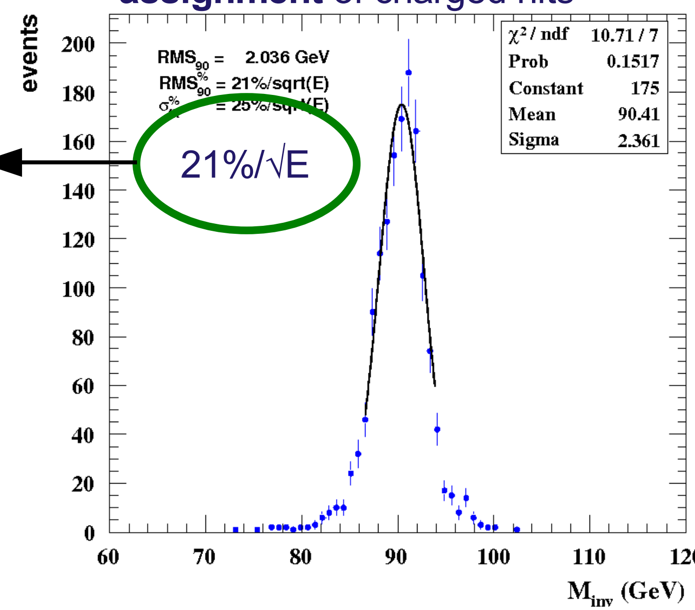
Orsay: 44%/√E

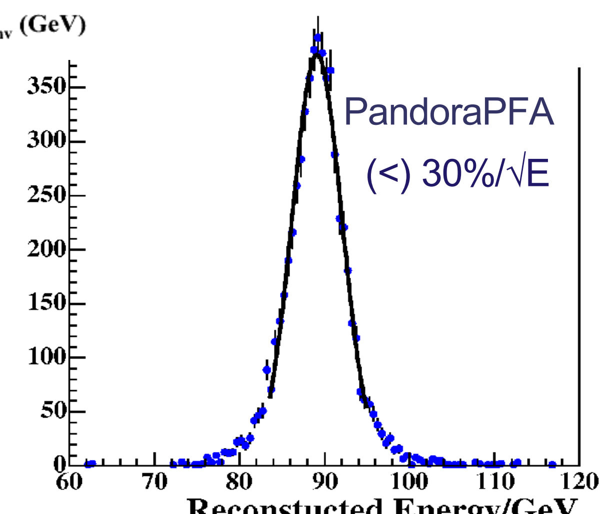
GOAL

30%/√E

Track-Based PFlow with **perfect assignment** of charged hits

21%/√E





PandoraPFA

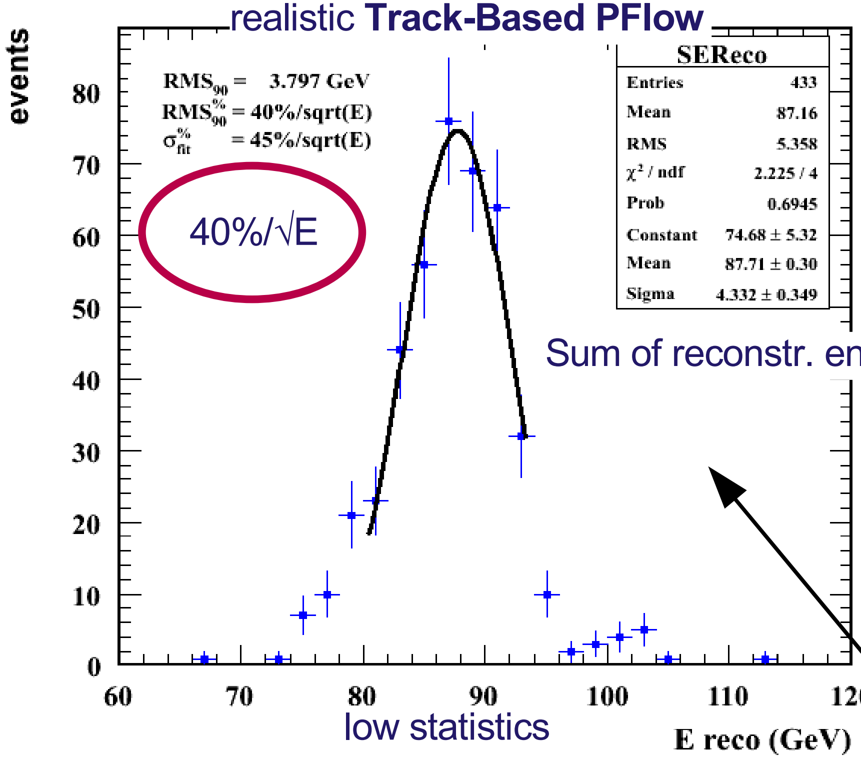
(<) 30%/√E

- **exceeds performance** of Wolf but still (significantly) worse than PandoraPFA
- perfect assignment comes close to 'theoretical' limit
- → no major bugs in the code

Performance of Track-Based PFlow

some first results for Z → uds @ 91.2 GeV, cos(θ) < 0.8, LDC00Sc, R(1690mm), L(2730mm):

realistic **Track-Based PFlow**



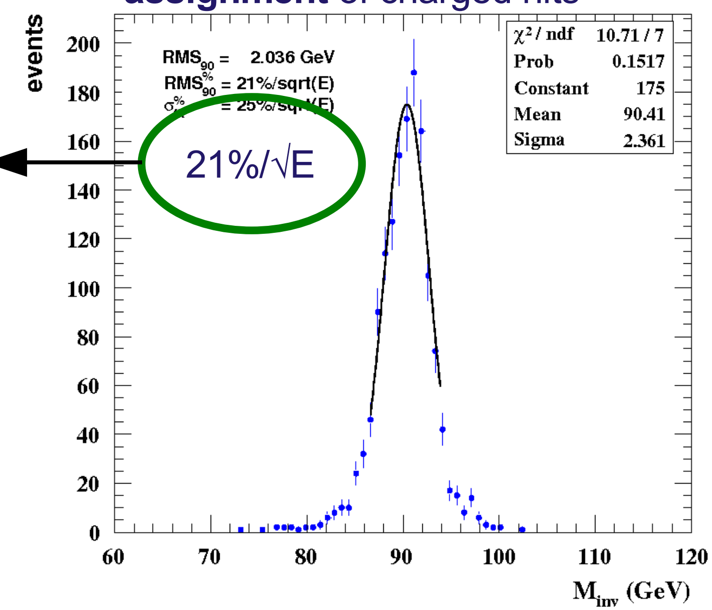
Sum of reconstr. energy

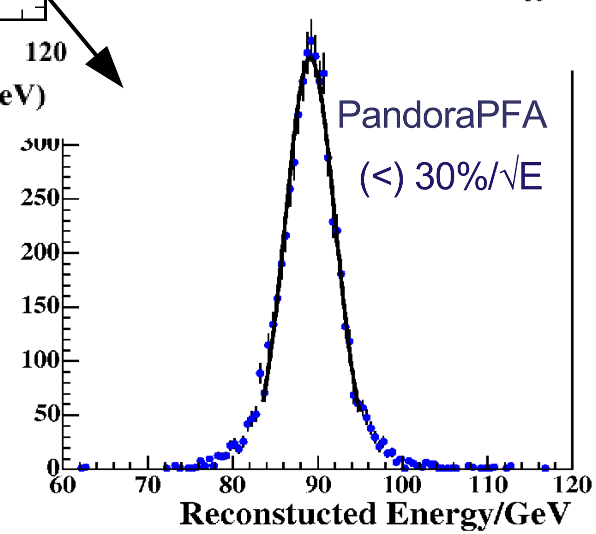
low statistics

GOAL

30%/√E

Track-Based PFlow with **perfect assignment** of charged hits





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- **exceeds performance** of Wolf but still (significantly) worse than PandoraPFA
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➔ no major bugs in the code

Conclusions and Outlook

Conclusions:

- Track-Based Particle Flow is evolving, **improvements** made since Valencia/Orsay
- performance **exceeds** performance of Wolf but still (significantly) worse than PandoraPFA
  - → algorithm is far perfect and not optimised in any direction (processing time)
  - → relatively 'young' approach, work in ongoing
- new modules (Photon finding and cluster 'reassignment') and bug-fixes since Orsay
- **initial** version of a Track-Based Particle Flow **available** in Marlin (in MarlinReco cvs)

→ first attempt to use it for higher energies (M. Faucci Giannelli and K. Wichmann)

- gain understanding of 'intrinsic' problems / properties of Particle Flow algorithms in general

➢ need **multiple/different** Particle Flow approaches to **disentangle** detector and algorithm effects on the reconstruction/physics performance

Outlook:

- go for $30\%/\sqrt{E_{jet}}$ @ 91.2 GeV first, then address higher energies
- follow the path given by PandoraPFA, do detector optimisation studies and **compare results**
- study **sub-structure** of hadronic showers (e.m., hadr. part) in Calice physics prototype
  - → apply results to 'clustering' of hadronic energy in the Track-Bases Particle Flow

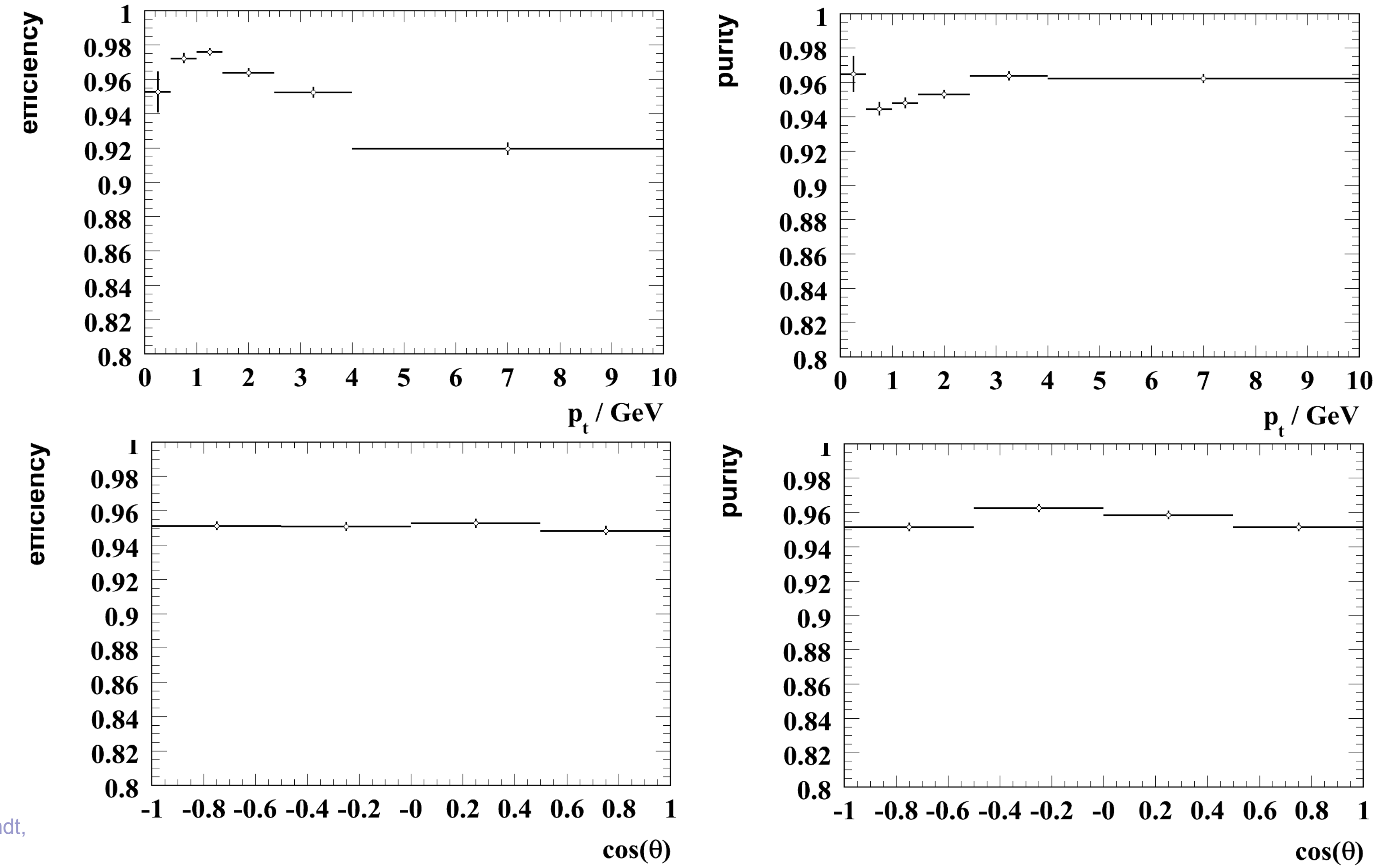
inputs / ideas / discussions are welcome

backup slides ...

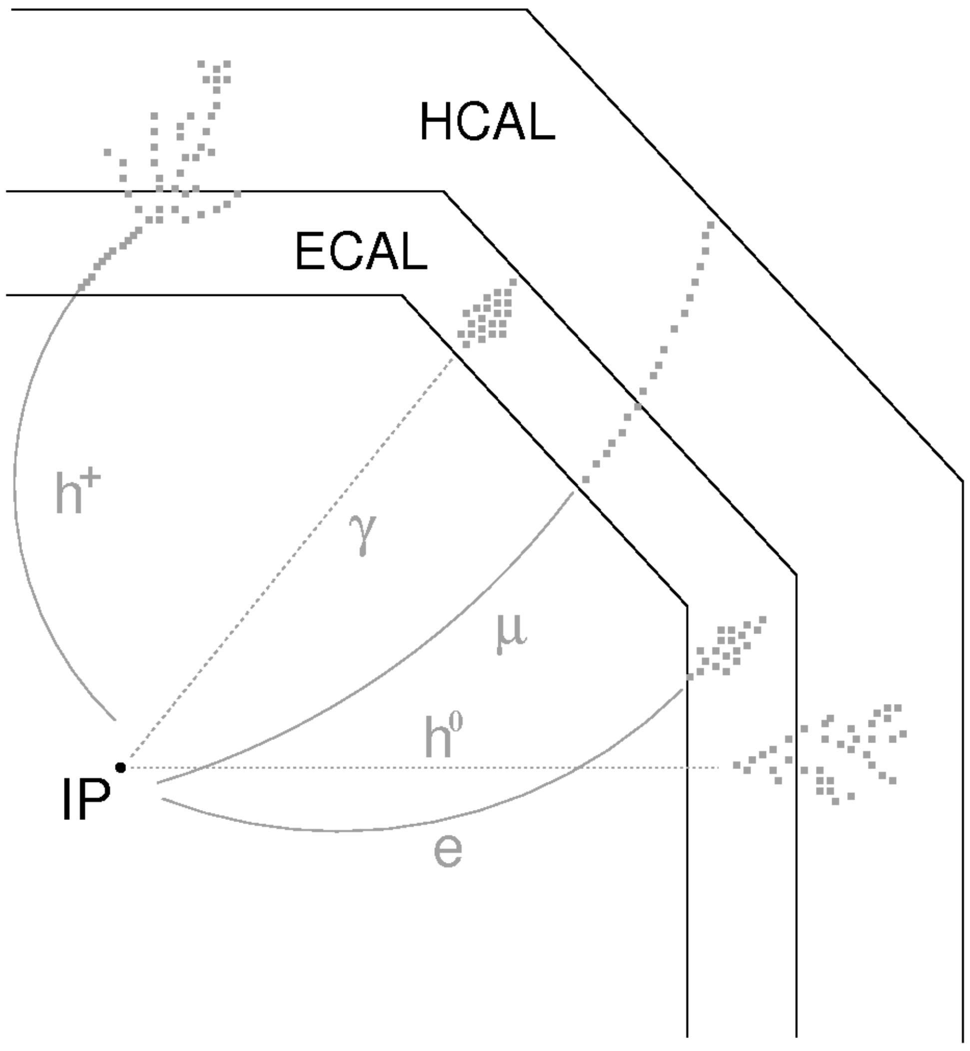
Details on MIP stub finding

Comparison with MC:

- efficiency and purity vs. p_t and cos(θ):
- overall efficiency >90%, overall purity >90%

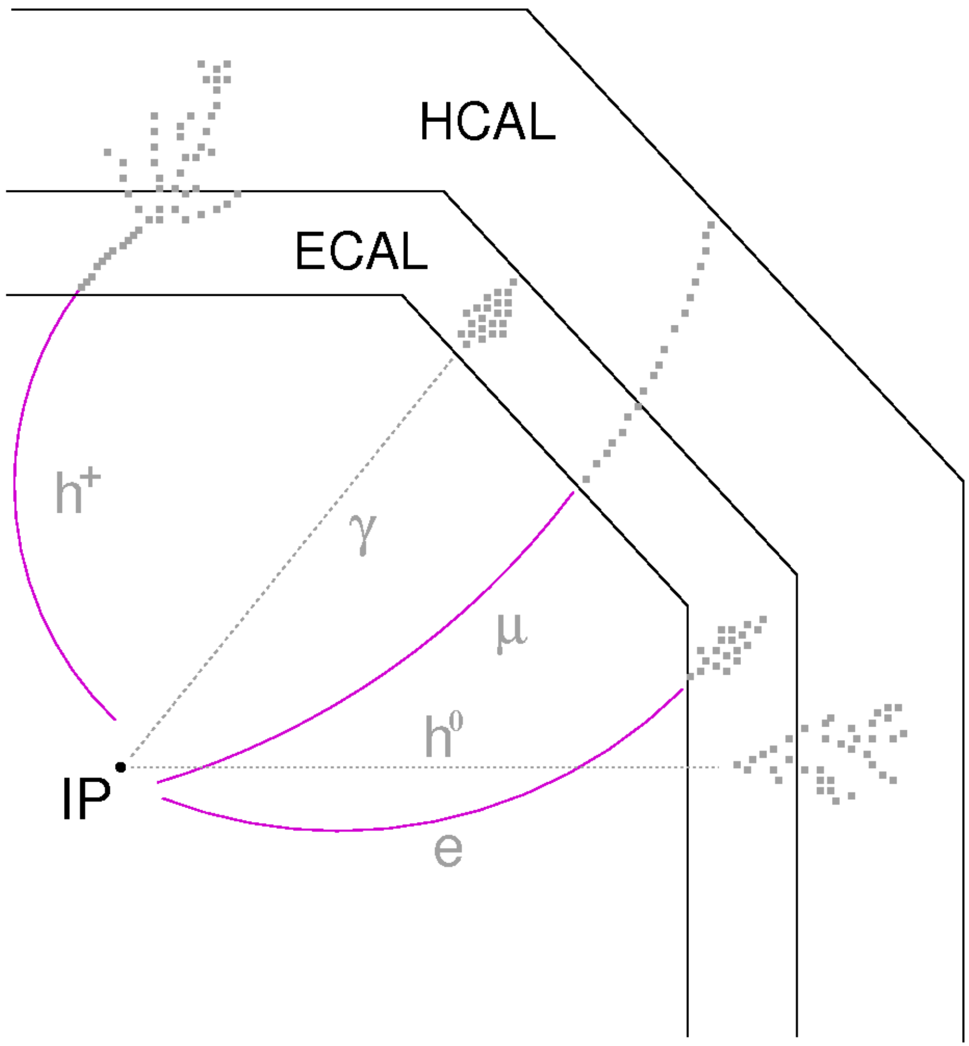


Track-Based Particle Flow Concept



Track-Based Particle Flow Concept

1. tracking (Silicon and TPC)



Track-Based Particle Flow Concept

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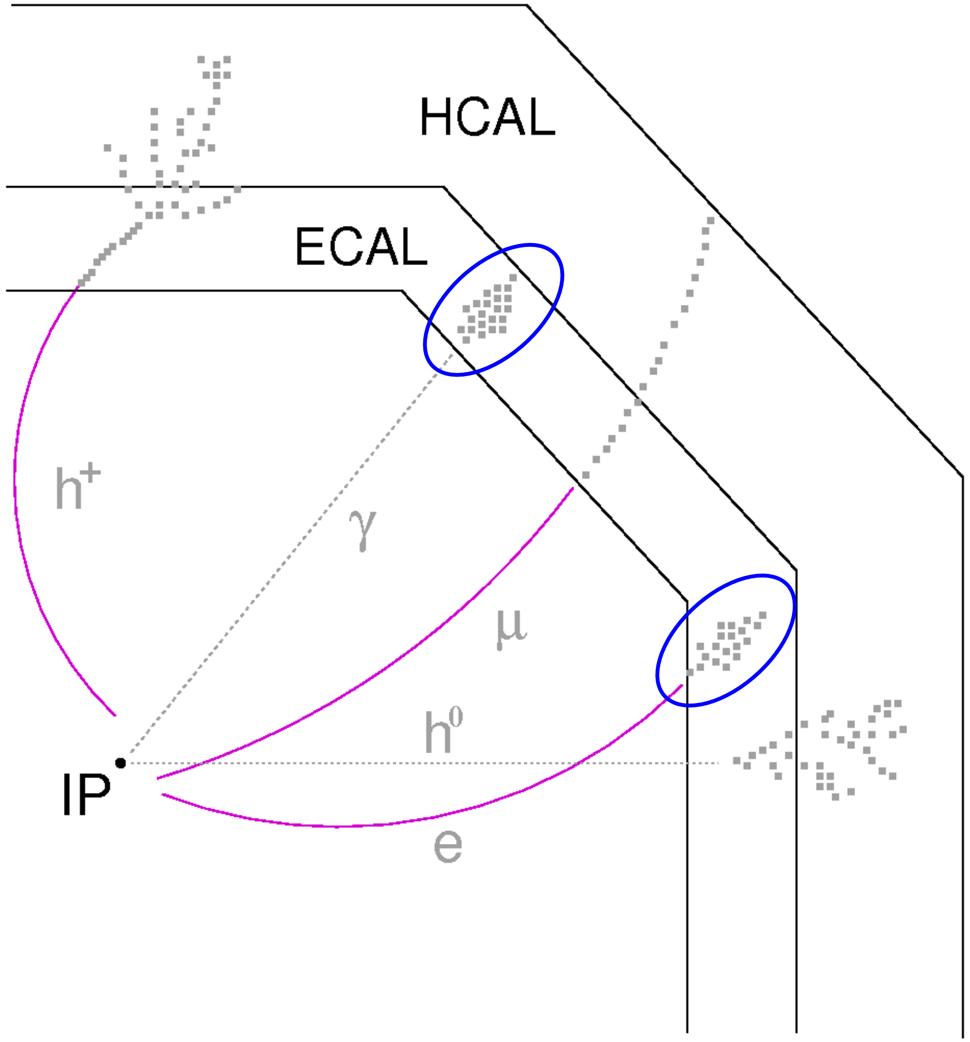
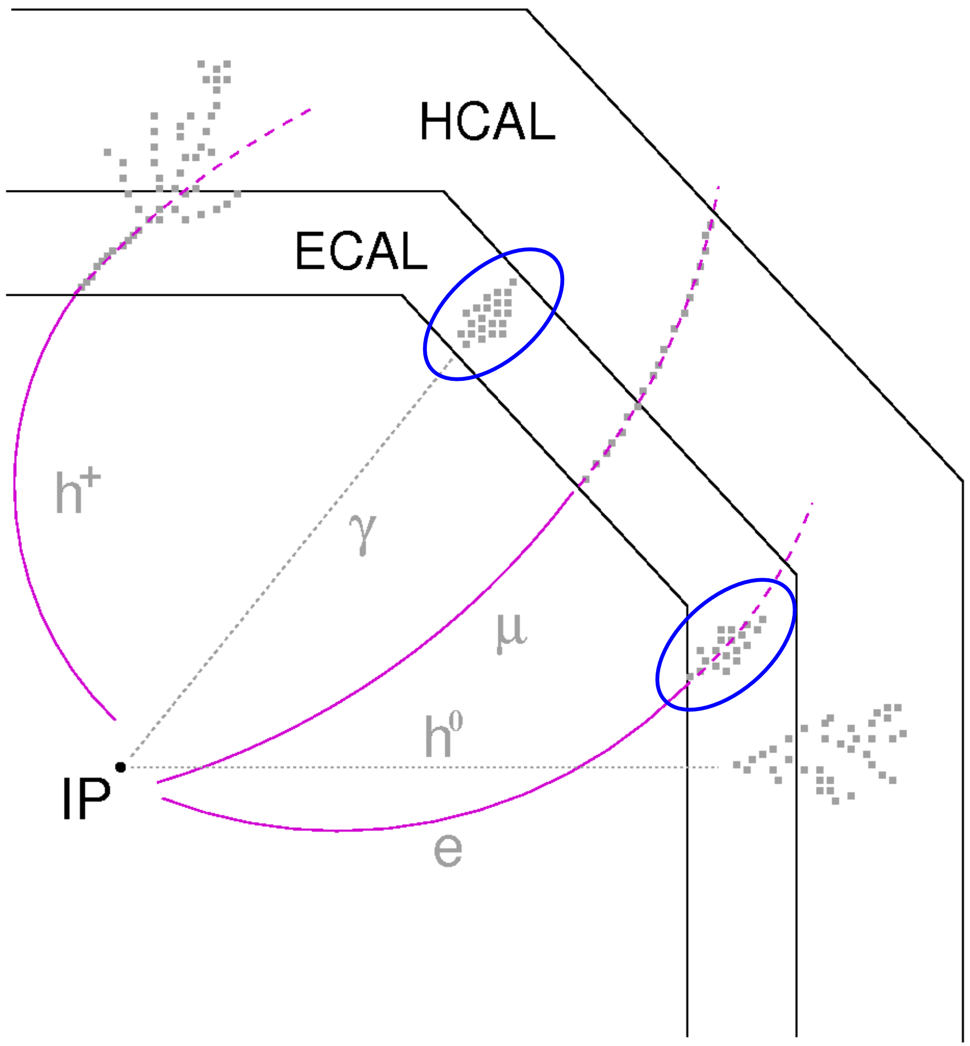
2. find photon candidates



Track-Based Particle Flow Concept

1. tracking (Silicon and TPC)
2. find photon candidates
3. extrapolate tracks into Calorimeter
   - different models, with and w/o energy loss, multiple scattering, ...
   - dedicated Geometry description needed



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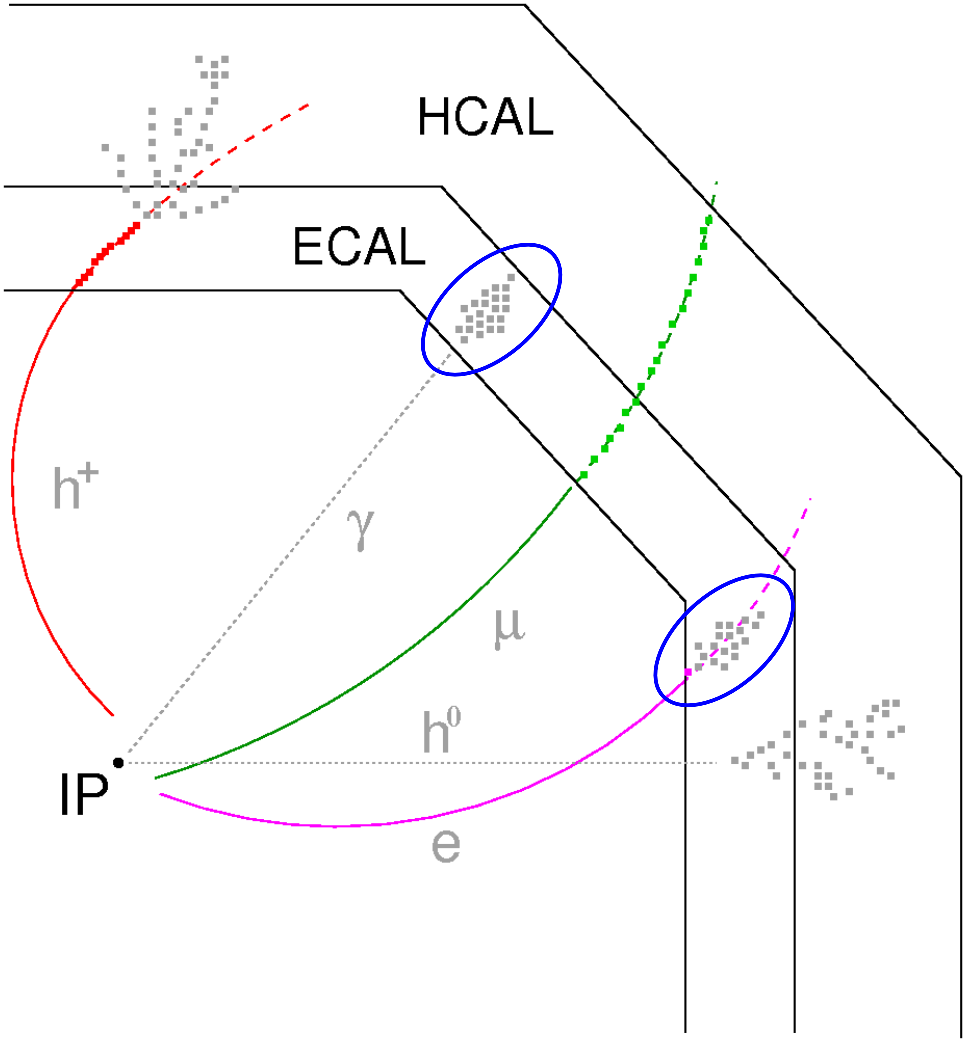

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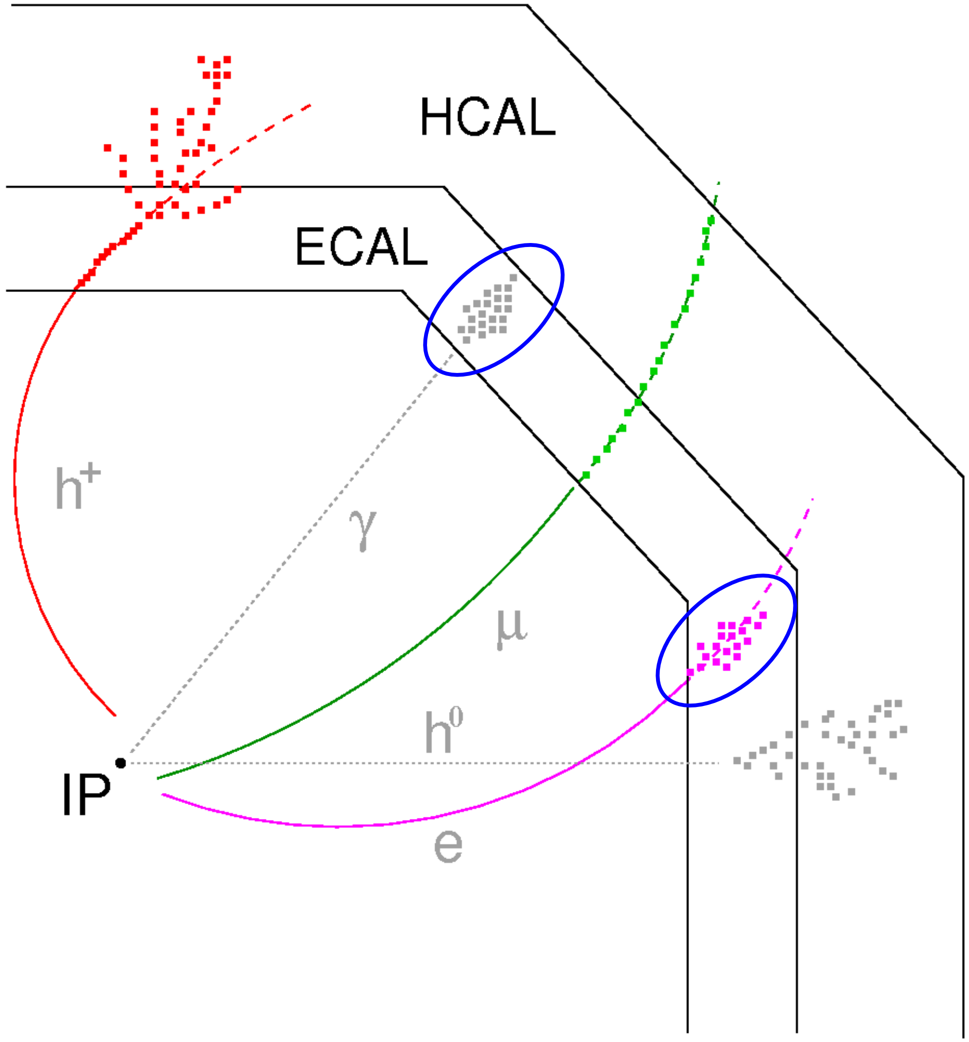
5. clustering (ECAL and HCAL)
   - variable, depending on track and photon candidates
   - different algorithms



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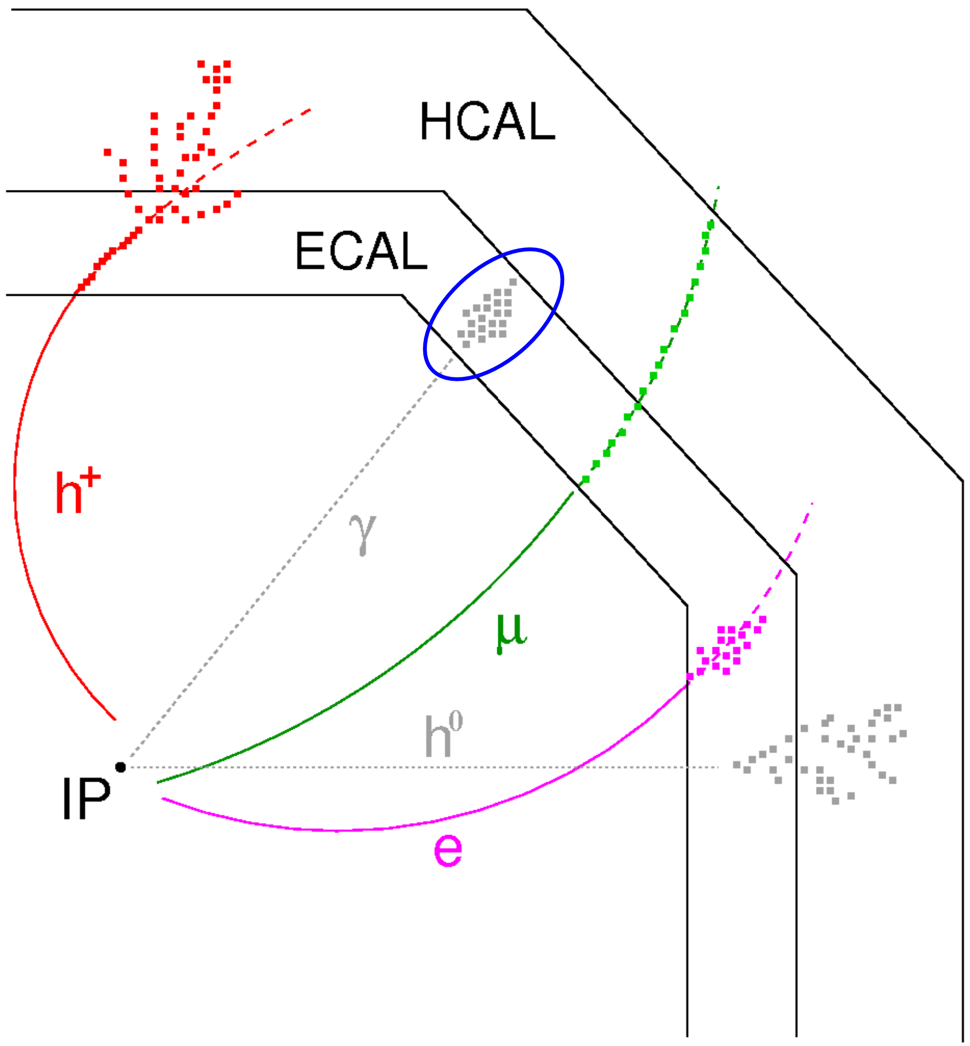
6. particle ID for $e^{+/-}$, $h^{+/-}$



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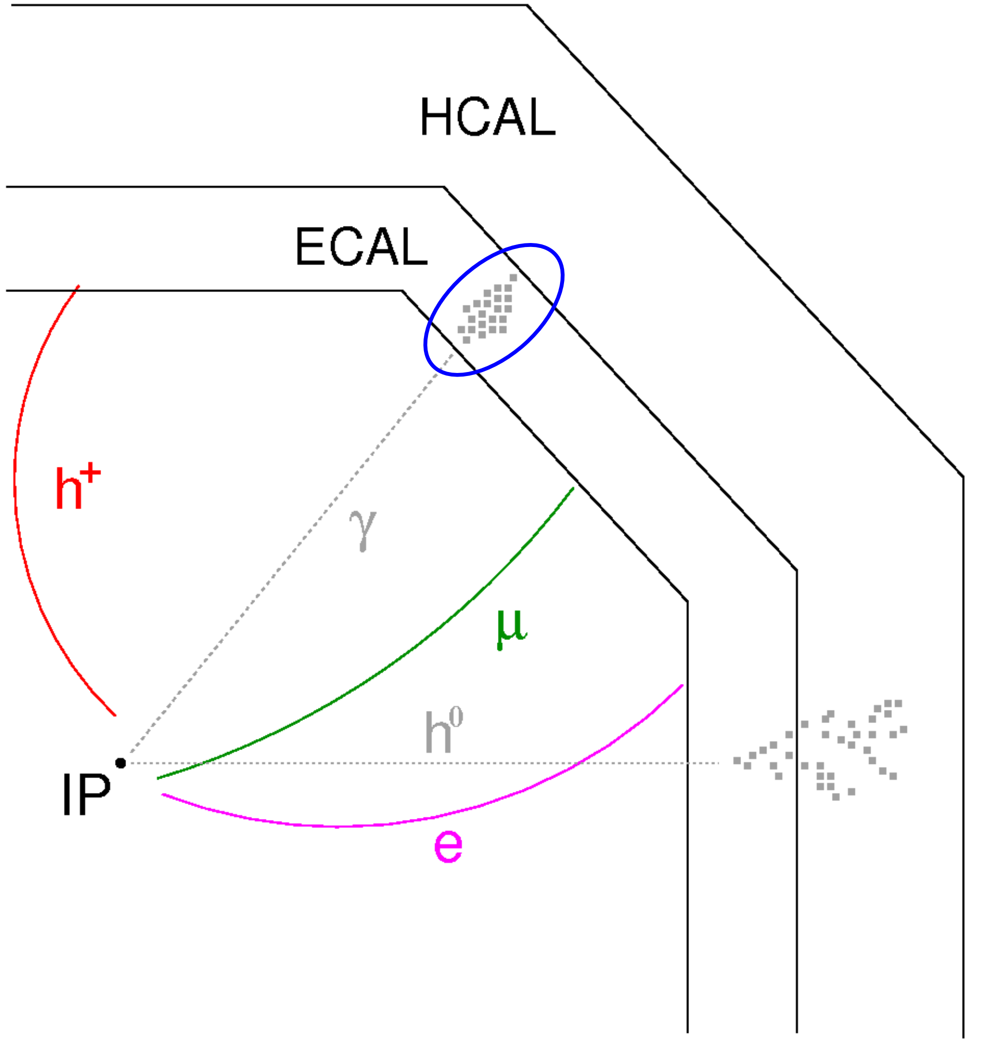
7. remove 'charged' Calorimeter hits



Track-Based Particle Flow Concept

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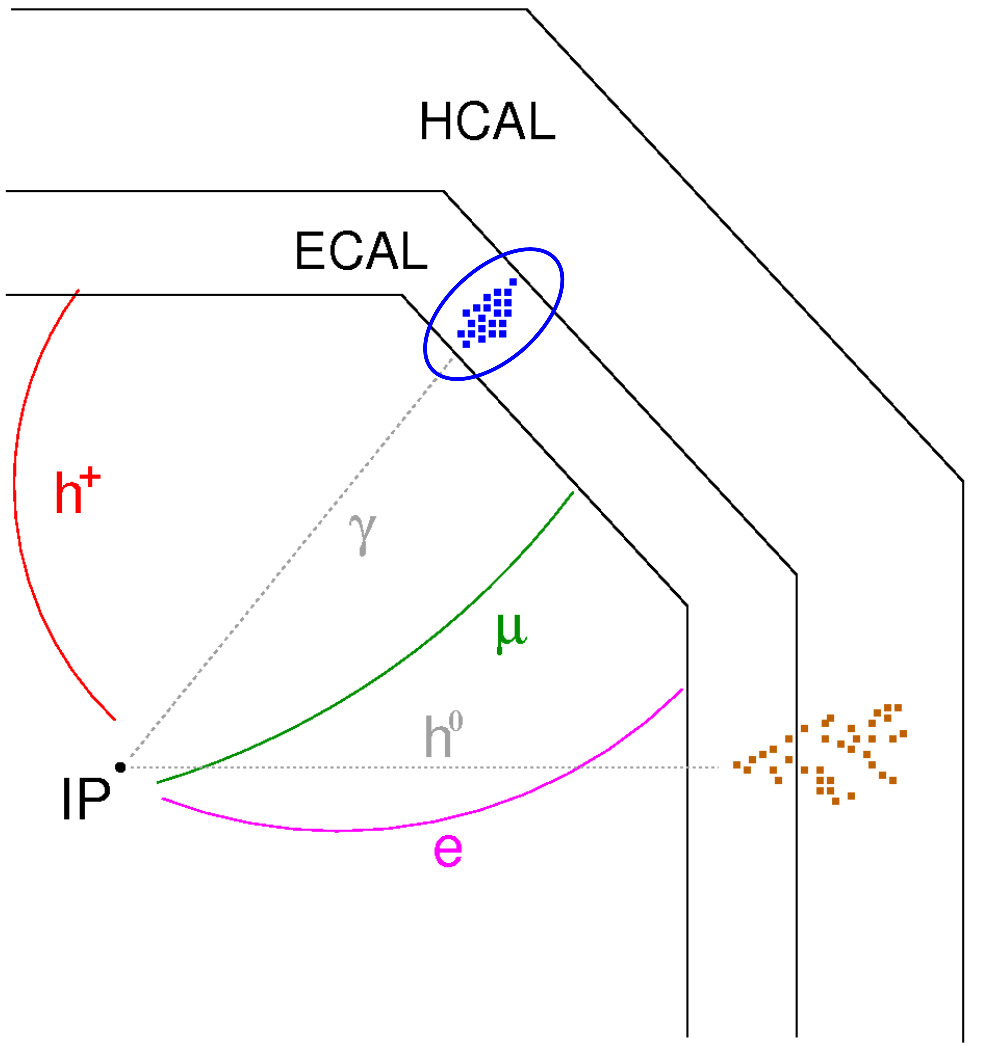
   - dedicated Geometry description needed
4. assign MIP stub to track, find muons
5. clustering (ECAL and HCAL)
   - variable, depending on track and photon candidates
   - different algorithms
6. particle ID for $e^{+/-}$, $h^{+/-}$
7. remove 'charged' Calorimeter hits
8. clustering on 'neutral' hits



Track-Based Particle Flow Concept

1. tracking (Silicon and TPC)
2. find photon candidates
3. extrapolate tracks into Calorimeter
   - different models, with and w/o energy loss, multiple scattering, ...
   - dedicated Geometry description needed
4. assign MIP stub to track, find muons
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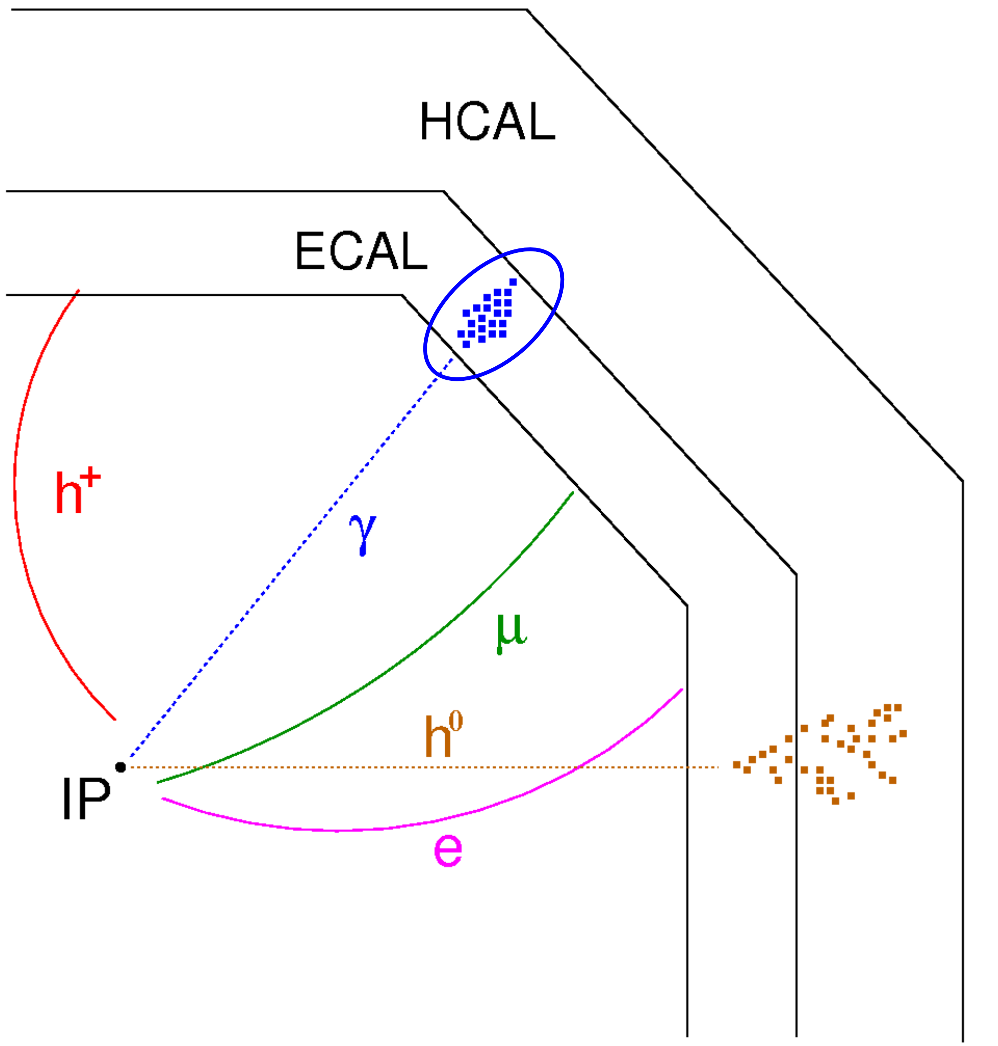
   - variable, depending on track and photon candidates
   - different algorithms
6. particle ID for $e^{+/-}$, $h^{+/-}$
7. remove 'charged' Calorimeter hits
8. clustering on 'neutral' hits
9. particle ID for photons and h^0



Track-Based Particle Flow Concept

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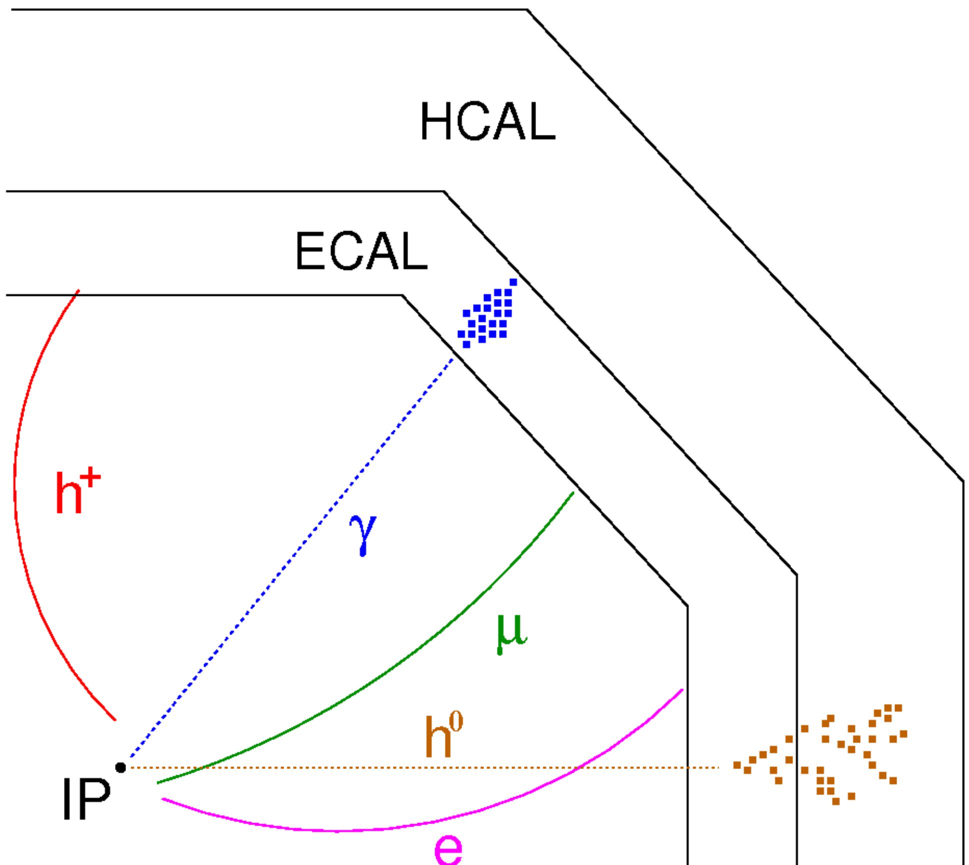

first version of such a **'track-based'** Particle Flow approach available in MarlinReco

- full software chain (put in tracks and calorimeter hits, get out reconstructed particles)
- more or less modular approach
- first results **only** for $Z^0 \rightarrow uds$ @ 91.2 GeV