Particle Flow Reconstruction "under the hood"

Some technical details aiming for stronger contributions from JME

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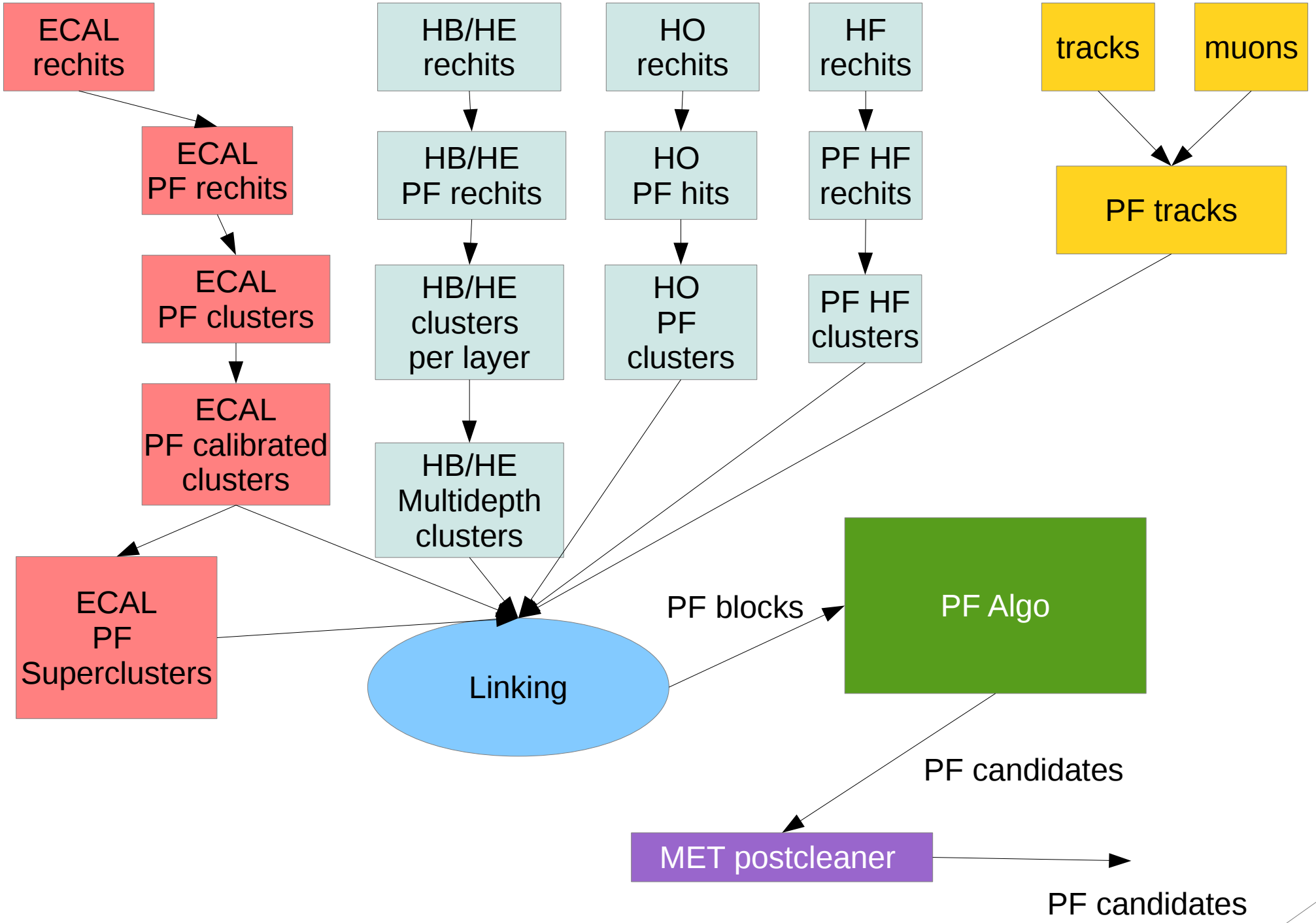
Introduction

- JME = **local reco** + PF + **algorithms**+**calibrations**
  - Significant contributions to HCAL reco in the shutdown
  - A lot of work on algorithms/substructure
  - Marathon on JECs and hadron calibrations
  - Not a lot of contributions in PF reconstruction
- Wishlist
  - JME experts should be able to improve change particle flow if issues in lower level reco arise
    - e.g fake tracks → MET tails
  - Based on the experience with Jet reco contribute to improvements in the core algorithms
- This talk: Mostly intended to describe “where is done what” to help the developers
  - You should also read the PF paper!
  - **The description is still simplified**

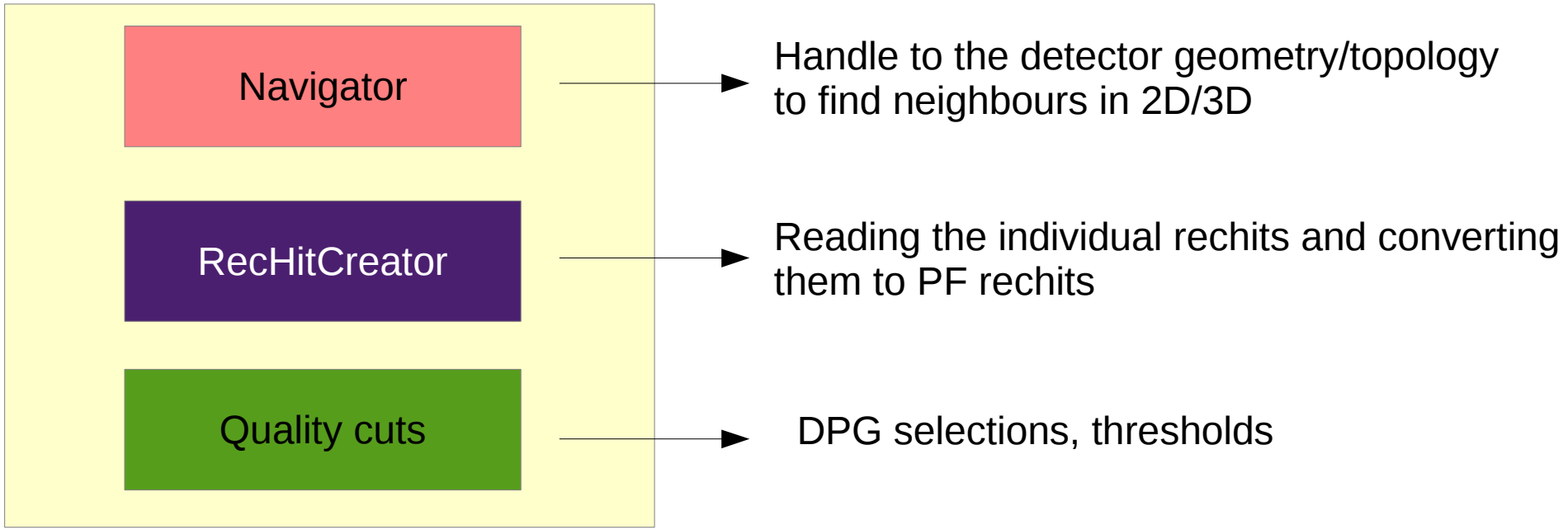
The PF sequence



The PF rechits(I)

- Common data format for all rechits in PF
- Essentially keeping energy, depth and time information along with navigation information (neighbours)
  - Navigation needed for clustering
- The PFRechit producer applies also selection criteria defined by the DPGs

PFRecHit producer



Modular code allows to write new rechit creators, navigators /q cuts with minimal coding

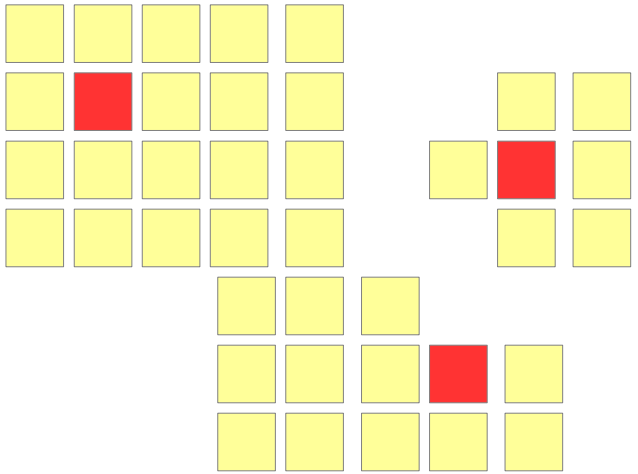
The PF rechits (II)

- ECAL/HBHE/HO
  - Just passes the information adding the navigation+ quality cuts
- HF
  - At rechit level read both layers of HF and apply dual readout to estimate the EM/HAD energy from the Long and short fibres
  - Then output rechits with (depth 1 , EM energy) and (depth 2 ,HAD energy)

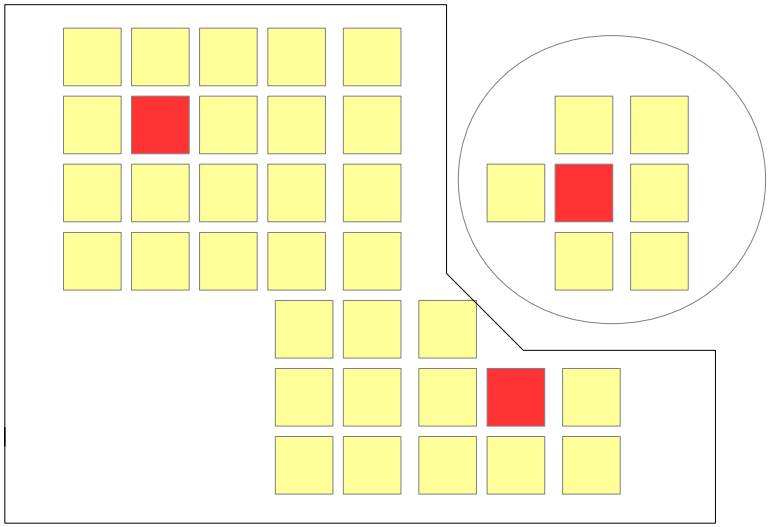
PF clustering (I)

- Common algorithm that clusters ECAL, HO and HB/HE per layer

1.Identify local maxima as seeds

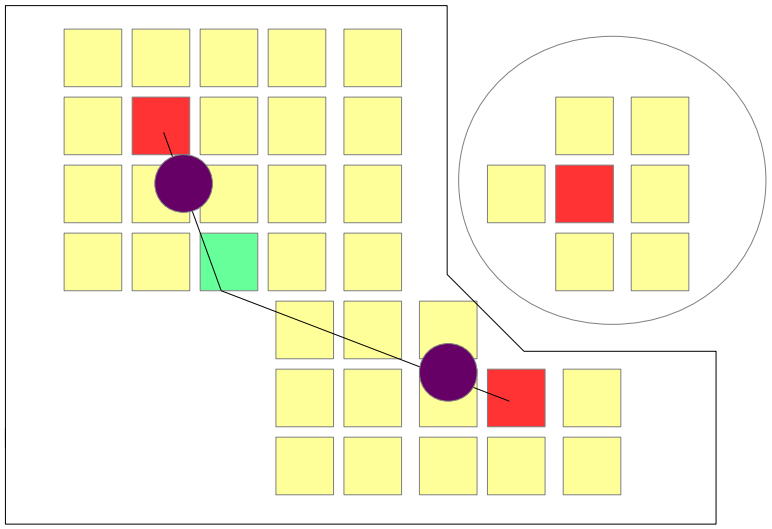


2.Grow topoclusters around seeds

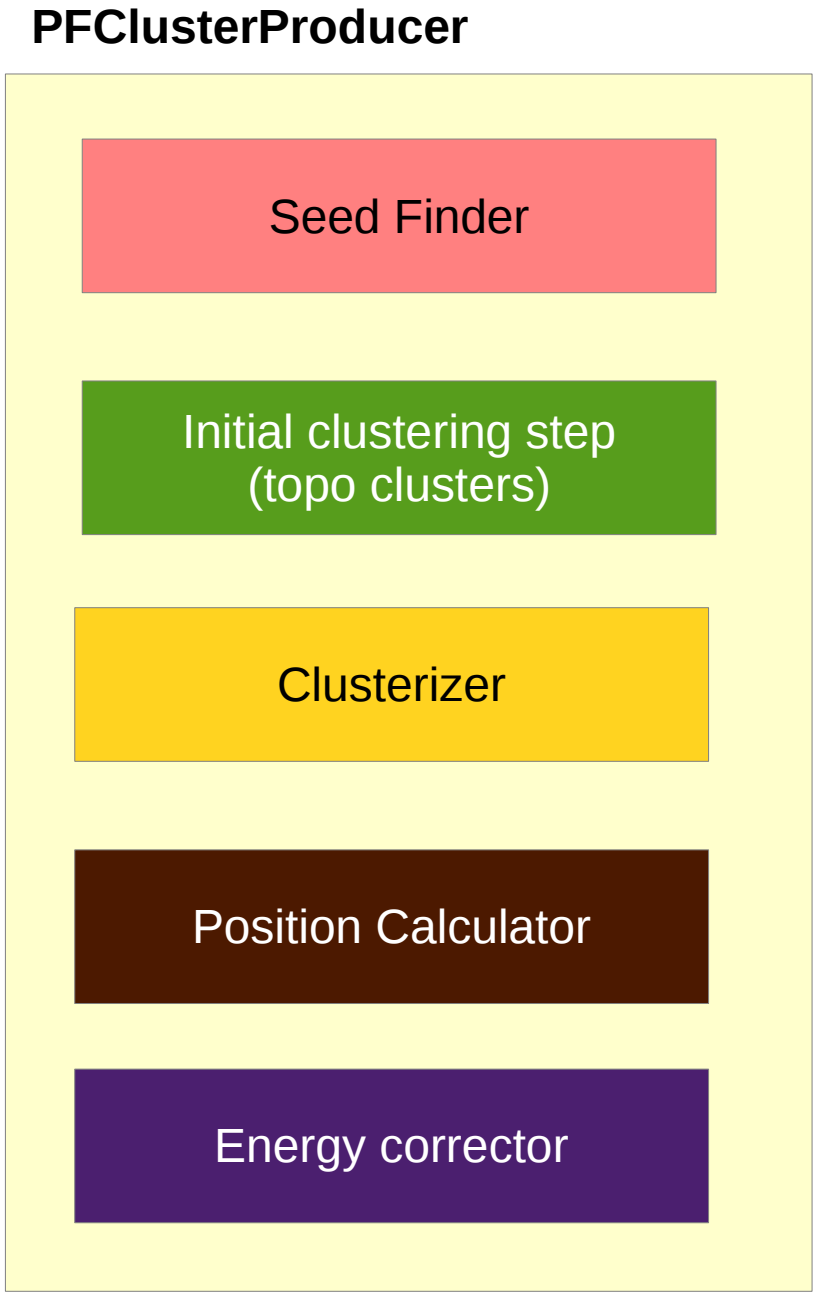


- Hits are shared in topo clusters
- Gaussian profile assumed ~ Moliere radius
  - Optimal for many deposits inside jets
- Iterative “fit” of position and energy

3.Make clusters from seeds and share hits in the same topo cluster



PF clustering (II)



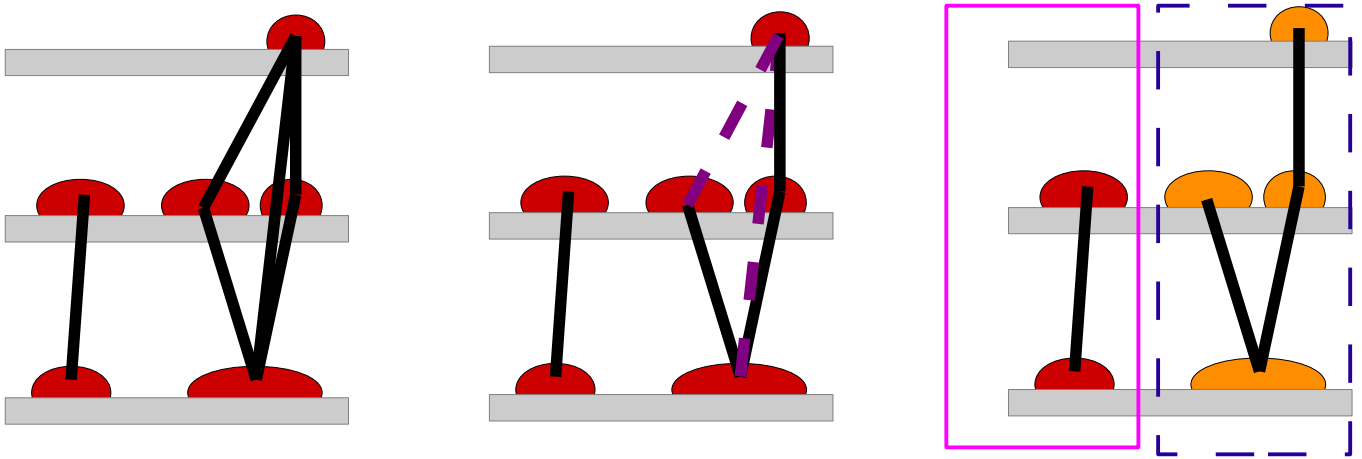
- ECAL:
  - clusters corrected by EGM including the PS information
- HB/HE/HO
  - No cluster level corrections
- HF
  - Clustering showed degradation of jet angular resolution
  - Hits are pass through as clusters (EM or HAD)

Modular code allows to write new clusterizers, seeders, position calculators, energy correctors with minimal coding

HCAL multidepth clustering

- Implemented in Sashlik +HE, default in Run II, ideas also from initial Phase I developments
  - Using the only two HE layers (3 depths in one tower in overlap)

1.Linking **2.Pruning** **3D clusters**



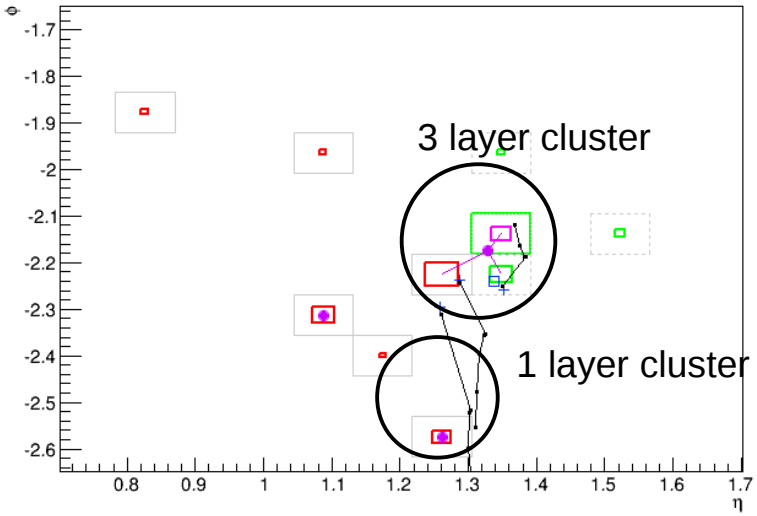
- Link clusters in different layers
- Requirements for link

$$\frac{\Delta\eta_{ab}}{\sqrt{\eta^a_{RMS}+\eta^b_{RMS}}} < N_\eta$$

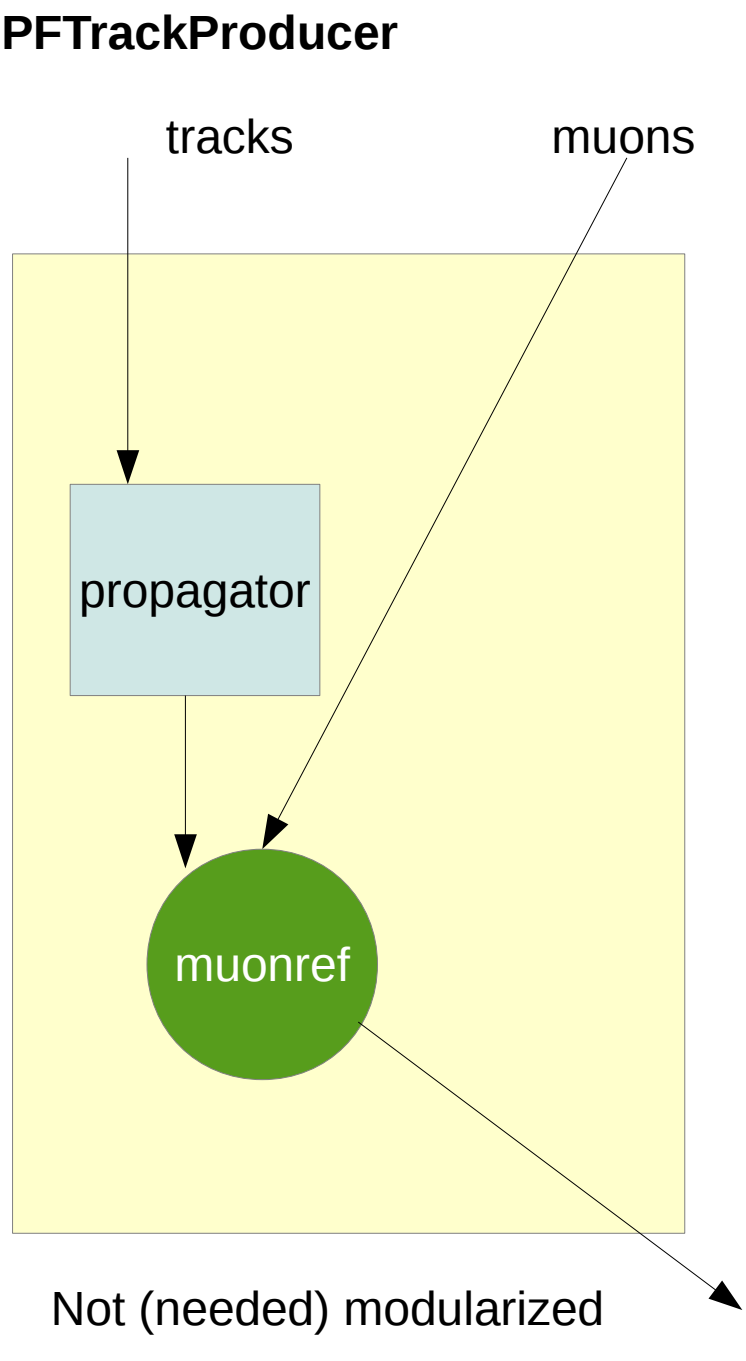
$$\frac{\Delta\phi_{ab}}{\sqrt{\phi^a_{RMS}+\phi^b_{RMS}}} < N_\phi$$

- Prefer links from nearest depths
- If same depth prefer smaller Nη+Nφ
- If same prefer high energy link

Example:3 prong tau in endcap

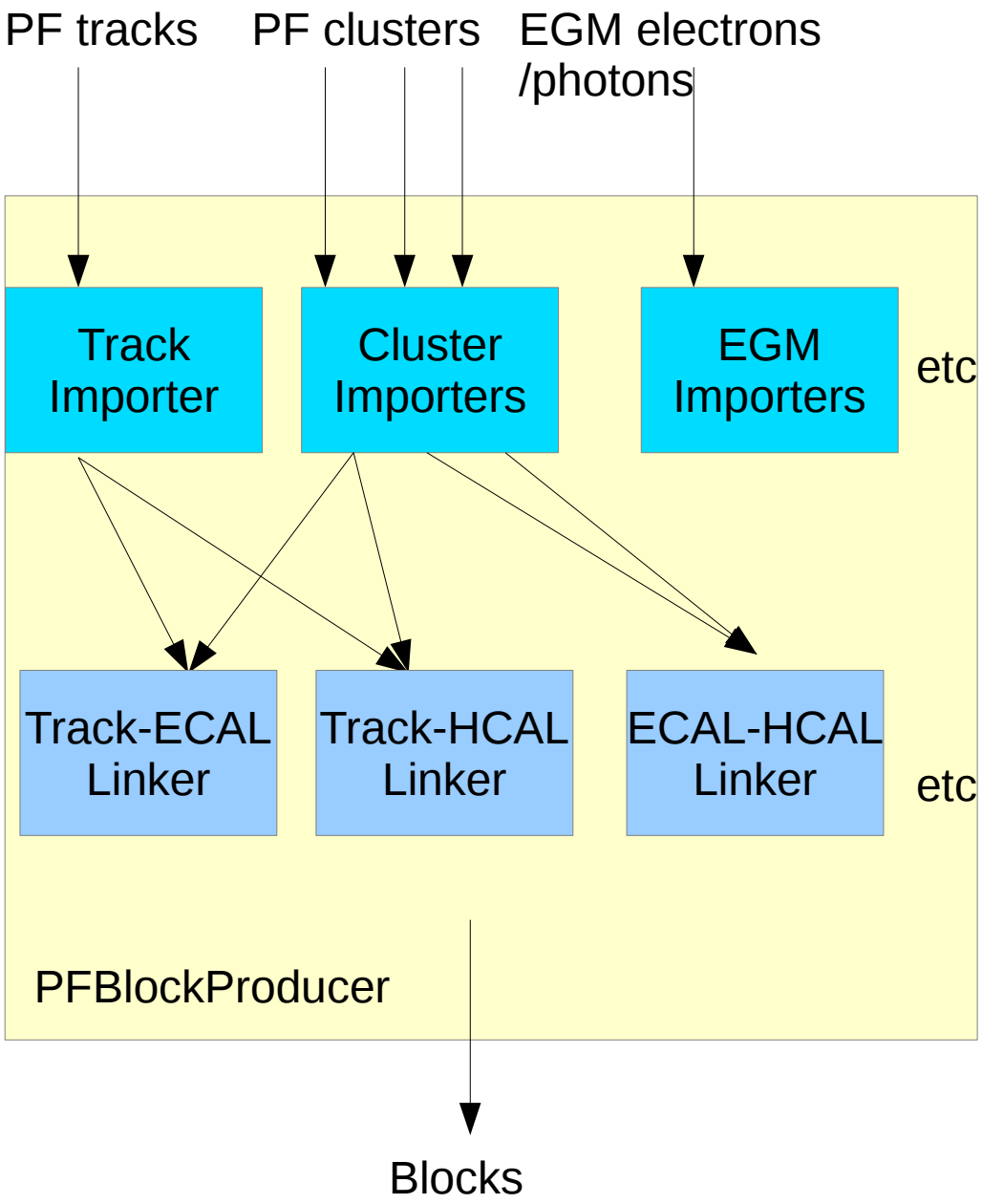


PF Tracks



- GeneralTracks are used
  - Including propagation Info
    - Using analytic propagator
  - Only high purity
- Muons are included
  - Tracks from muons always accepted in preselection
    - Since even if the inner track might be bad a global track can be OK therefore we dont want to kill the muon
  - MuonRef() is saved for each track

Linking



- Objects are imported using importers
  - Applying quality cuts
- Linkers link different objects
  - KD trees used for fast processing
- Blocks of objects as output

Modularity allows to write new importers+linkers

General Tracks importing

- A track is imported in PF if it satisfies one of the two
  - Is the inner track of a muon that passes PF-muon ID- therefore will become a PF muon
  - It is a “high purity” track that satisfies a σ_{Pt}/Pt cut depending on the track algorithm used
- Example: Recent 81X fixes
  - We were not enforcing high purity when a track from a muon failed ID [only Dpt/pt were applied -fixed]
  - We didnt have a Dpt/pt for some iterations [which is fine given that we didnt have fakes from those]
    - In 2016 we have more fake tracks therefore we added very loose requirements – that in fact could be tuned better

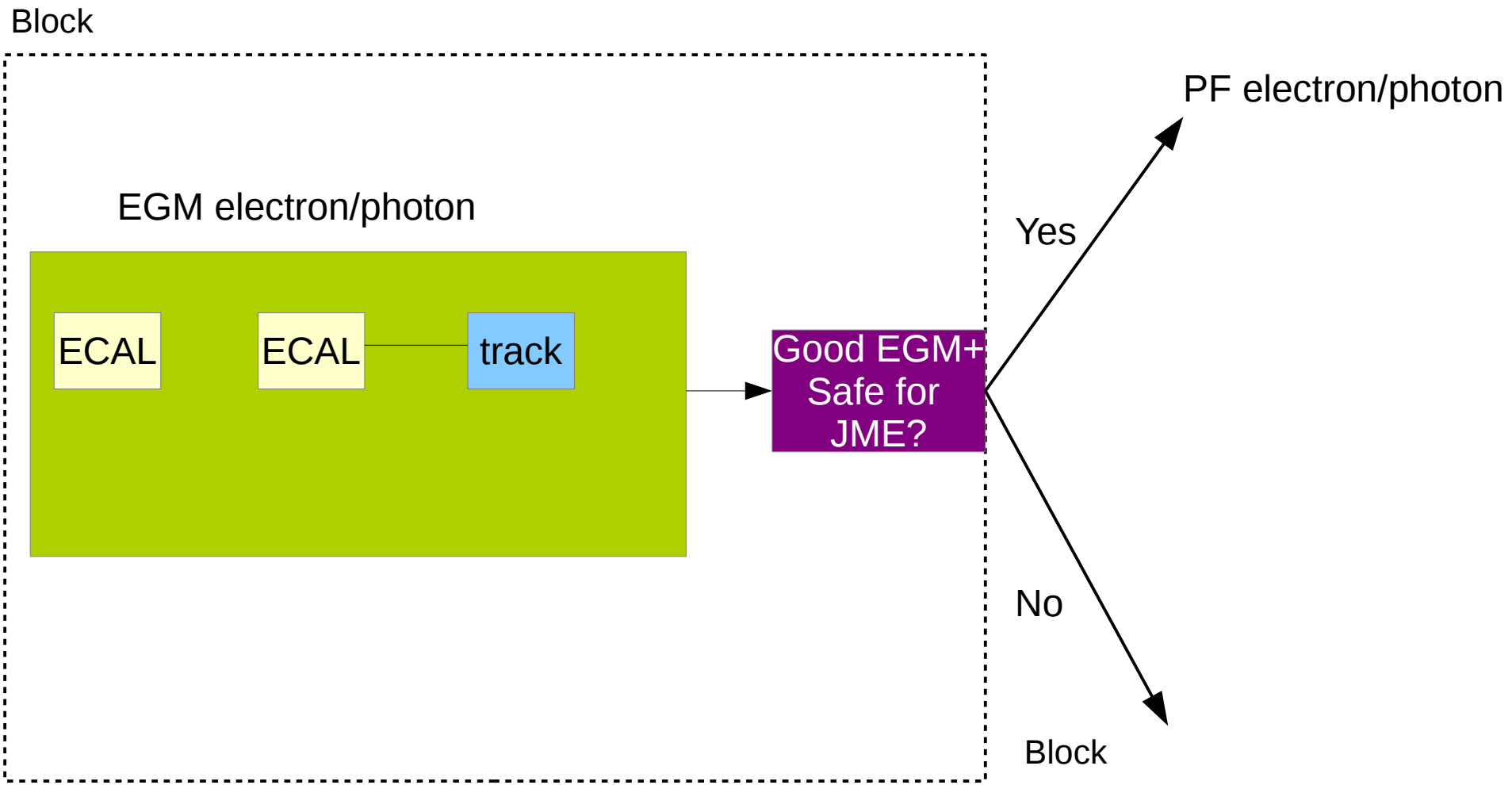
ECAL+HCAL linking

- There is a special treatment of ECAL/HCAL linking
  - Inside the tracker coverage (η<2.5) if there is no track we never link ECAL +HCAL clusters
    - We do of course link ECAL+track or HCAL+track tehrefore we can have Track+ECAL+HCAL
  - The reason is that in the tracker coverage the ECAL cluster will be most probably a photon since the charged hadrons(65%) have been ID (and neutral hadrons are only 10%)
  - On the other hand, outside the tracker coverage a hadron is more probable than a photon so we link ECAL+HCAL and make neutral hadrons with both

The PF Algo

- Processes blocks and builds PF candidates
- The core of PF reconstruction
- Main (over-simplified) idea:
  - Start from the tracks linked to calorimeter clusters
  - If calorimeter energy compatible with track (within resolution) absorb energy
  - If excess of energy create additional neutral particles

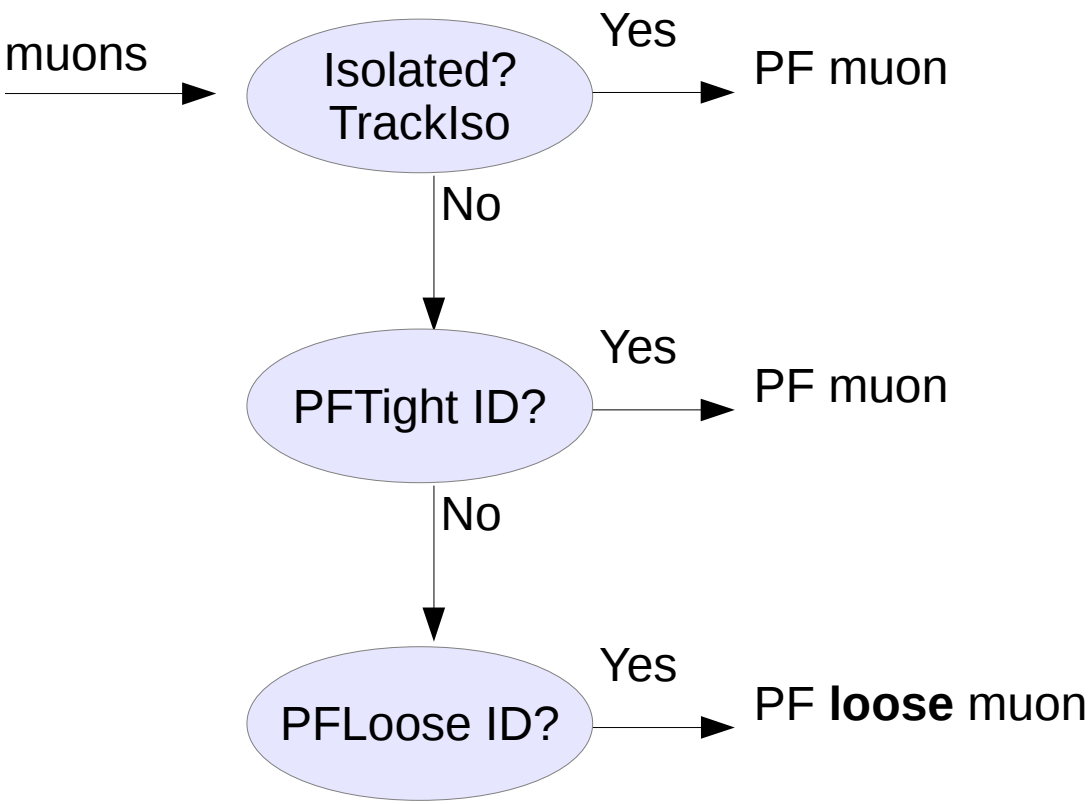
EGM in PF



- If the block looks more like jet
  - no PF ID for EGM
- Map between original EGM candidate and final PF candidates

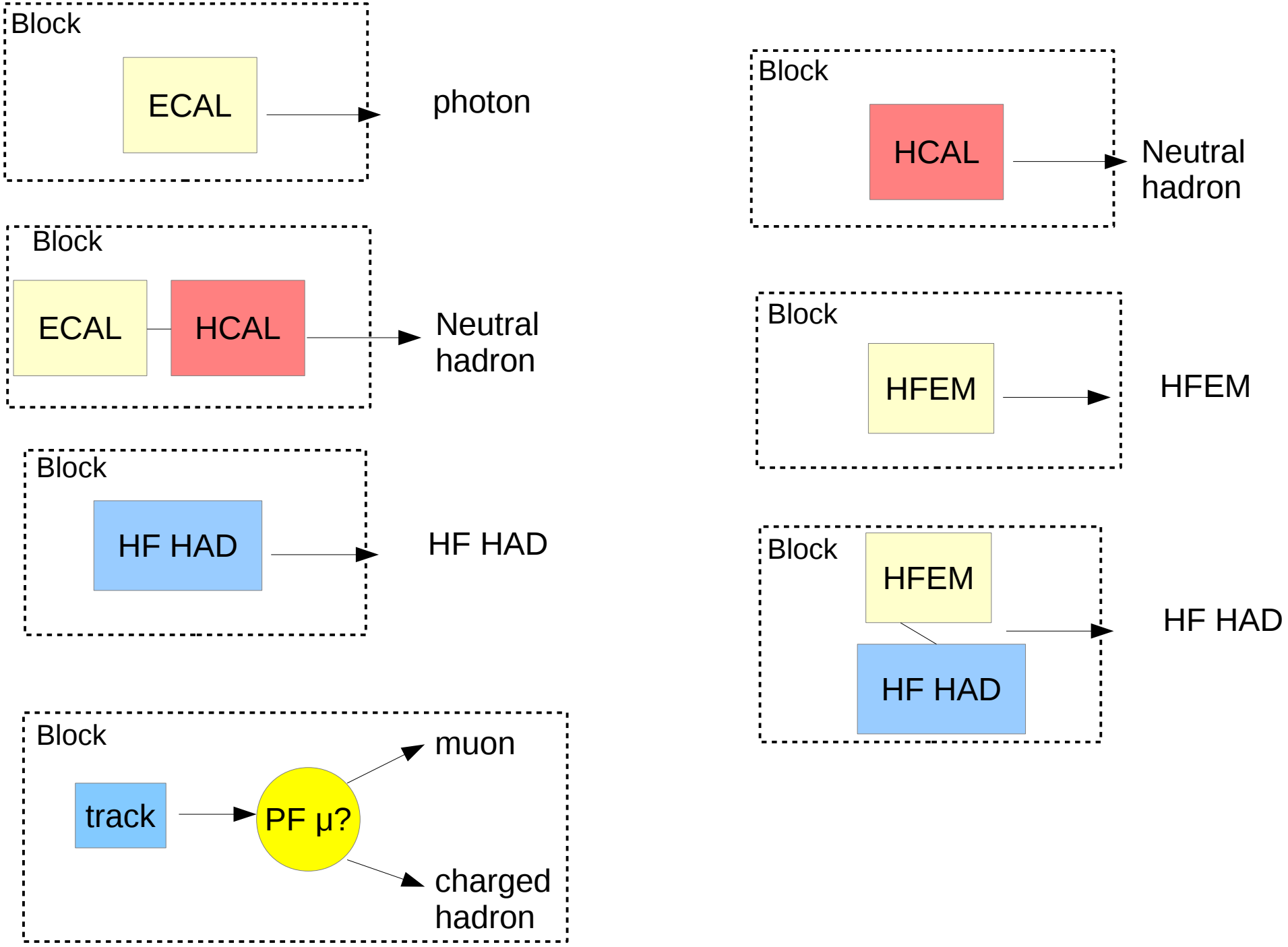
Muons in PF

- Specialized muon ID for PF with the following requirements:
  - Maintain high efficiency for isolated prompt muons
  - Reconstruct efficiently muons inside jets
  - Reject fakes and punch through

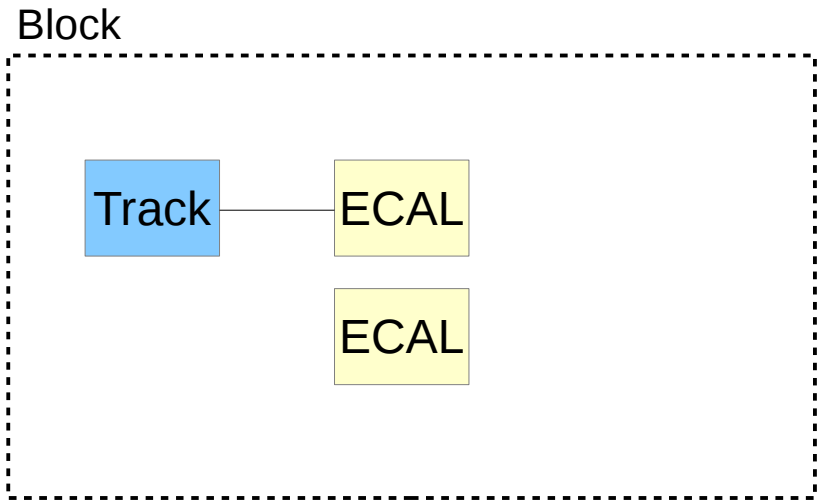


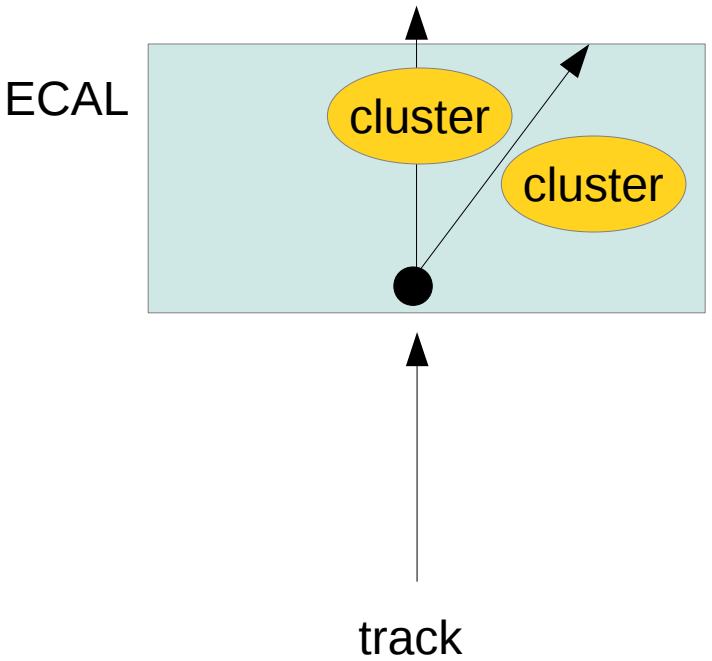
- Muon momentum assignment with TuneP algorithm
- 5 tracks considered
  - Inner track
  - Global Track
  - Picky Track
  - Tracker + first muon station
- TuneP decides which one based on track quality
- PF can rarely change the assignment (see later)

PF algo: Trivial cases first



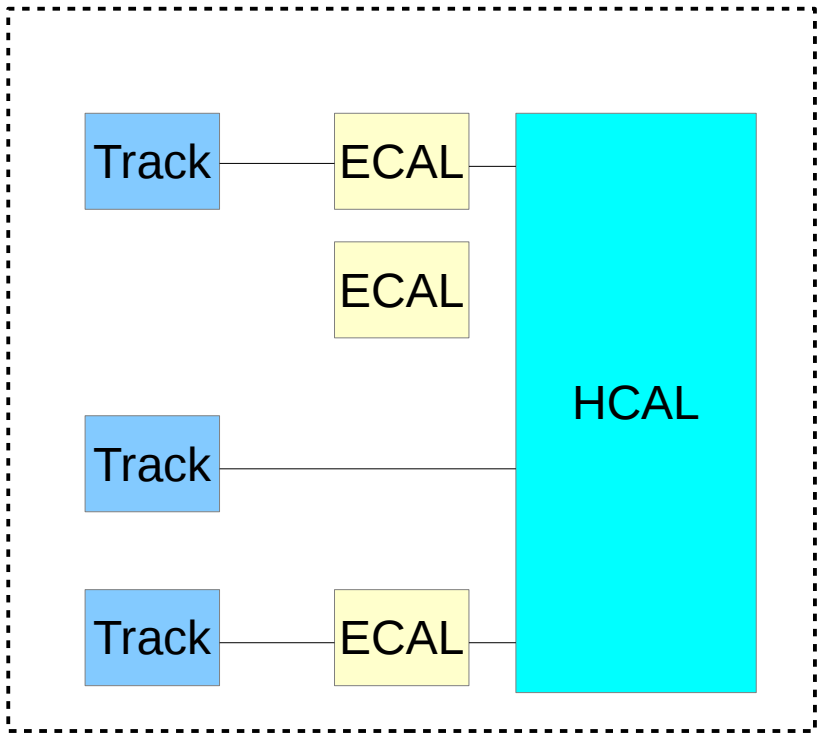
Track + ECAL





- If track is not a PF muon check compatibility of ECAL energy with track momentum using neutral hadron hypothesis
  - If compatible create charged hadron
  - If ECAL deficit collect nearby ECAL clusters not associated to other tracks in block
    - A charged hadron can give early interaction in the ECAL that due to the excellent granularity (and low thresholds) can appear as many clusters
  - If ECAL excess create a photon with the energy excess
- If track is a PF muon create a photon if the energy exceeds the expected MIP

More general: Tracks +ECAL+HCAL



- Total track momentum (excluding PF muons), ecal energy and hcal cluster energy calculated
- Calo Energy is calibrated for charged hadron hypothesis
- If track and calo compatible
  - Make charged hadrons
- If track> calo
  - Allow to accept PF loose muons to improve the compatibility
- If calo>track
  - Create additional photons and /or neutral hadrons

The post cleaners

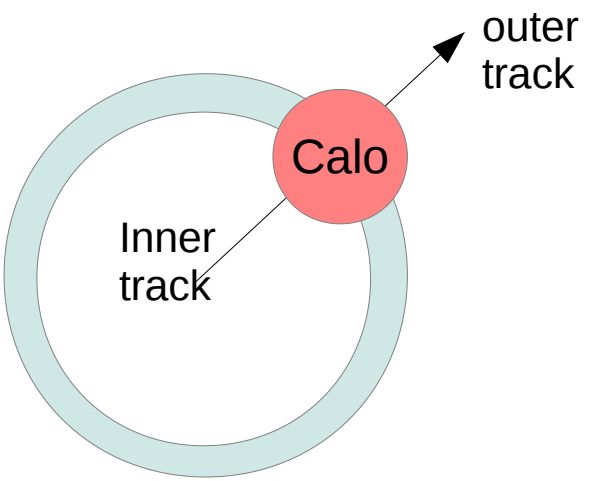
- Algorithms running after PF to cure events that create MET tails
  - Allowed to redefine particle content
  - Two algorithms: HF post cleaner and Muon post cleaner
- Algorithms revisited before Run II
  - HF post cleaner deactivated
  - Muon post cleaner still useful
- For Exotica lovers: All the post cleaned candidates are saved in separate collections however tests in MC samples have shown negligible impact on signal

Muon post cleaner(I)

- Cosmics
  - Find PF muons that are displaced (d_{xy}<1 cm)
    - If those tracks Sum ET fraction is significant and the MET^2 is reduced if removed, remove them
- Mismeasured
  - Find PF muons and check on the other global refits.
    - If the MET significance is large and a refit is reducing MET^2 by a factor while retaining some part of the Sum ET change the track
      - Adds MET info in momentum assignement
      - Robust against W' -sum ET is not allowed to be reduced
  - Allow to reject muons with tighter cuts

Muon post cleaner(II)

- Punch through
  - If a very energetic hadron becomes a muon, the calo energy will become additional neutral hadron
  - If this is dominating (and pointing at) the missing ET
    - merge the particles to a charged hadron including the calo energy
- Adding missing muons
  - In events with large MET if a muon has not been ID in PF try to add it if it reduces MET^2 by a large amount
    - This is the only case standalone tracks are allowed in PF



Summary

- PF in good shape but since it depends on low level information continuous attention is needed
  - e.g changes in tracking are always enforcing additional changes in PF
- A lot of areas to improve
  - Post cleaning
    - Include MET filters in PF but to repair the events instead of rejecting them?
  - Hadron calibration
    - Include HO instead of just summing the energy?
    - Use the HCAL cluster depth information?