Clustering-Based Two Particle Separation

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Introduction

- two particle separation is a key factor in the particle flow concept
- understanding the confusion term (i.e. wrong assignment of calorimeter energy to reconstructed particles) is needed to proof the particle flow concept working

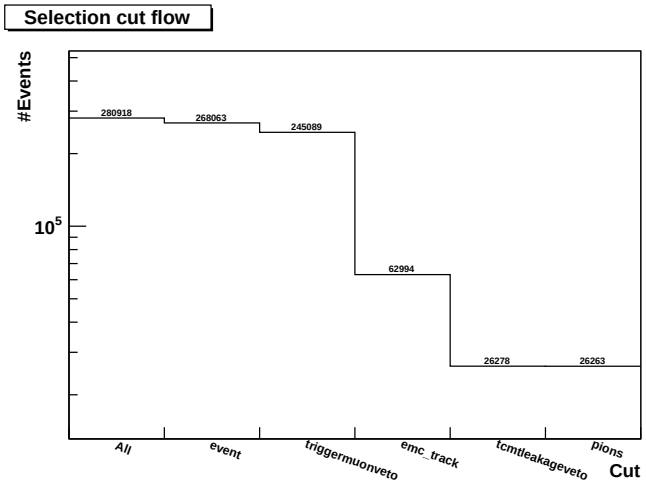
- comprehensive two particle separation study based on test-beam data: combine two single particle events to one virtual two particle event
  - increases statistics of events with larger impact position distance
  - allows to study events with different particle energy
  - provides the true single particle response of the particles

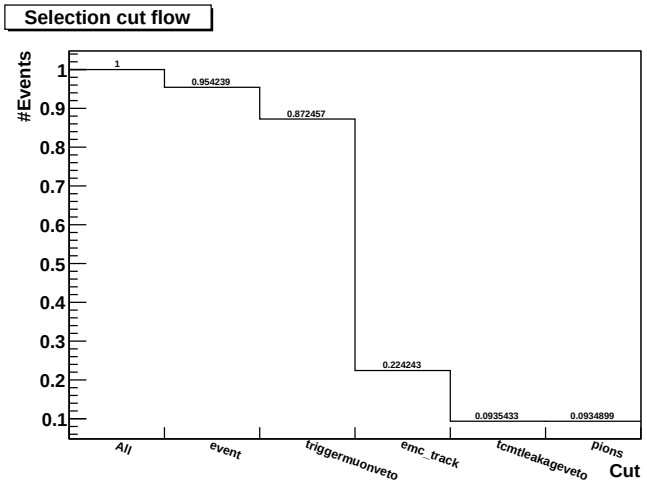
Data Set

E_{beam} [GeV]	run numbers	number of events
6	300628 300629 300630 300631 300669	1.0 10^6
8	300643 300647 300648 300652 300663	1.3 10^6
10	300613 300618 300660 300667	1.4 10^6
12	300644 300649 300653 300664	1.2 10^6
15	300619 300659	0.7 10^6
18	300645 300646 300650 300654 300665	1.5 10^6
20	300620 300658	0.6 10^6

- data taken October 2006 at CERN
- selected π^- runs
  - stable beam condition
  - stalbeambient temperature

Pion Selection



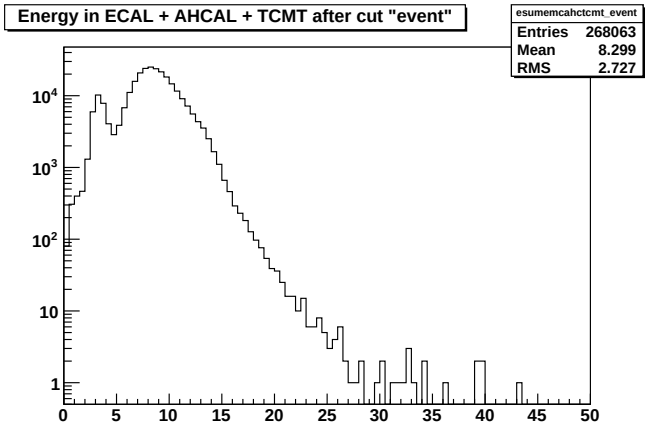


Cuts to select AHCAL contained pions

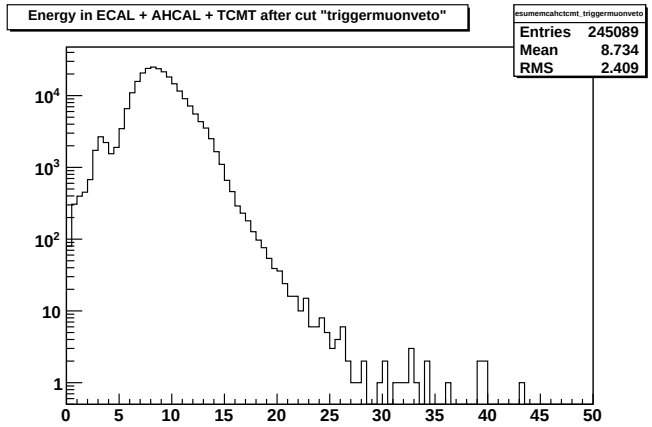
- cuts with focus on high purity (for all impact positions)
- only one cut on AHCAL to avoid biased selection
  - *event*: beam is "on", no calibration, ...
  - *trigger muon veto*: 100 $\times$ 100cm scintillator plate behind TCMT does not trigger (veto muons and punch through events)
  - *ECAL mip-like track*: require mip-like signal in 3$\times$3 ECAL-cell tower; only noise in the rest of ECAL; be strict on noise in last layers
  - *tcmt cuts*: only noise in TCMT; be strict on first 4 TCMT layers
  - HCAL cut: require at least 30 hits in HCAL

Pion Selection "at work"

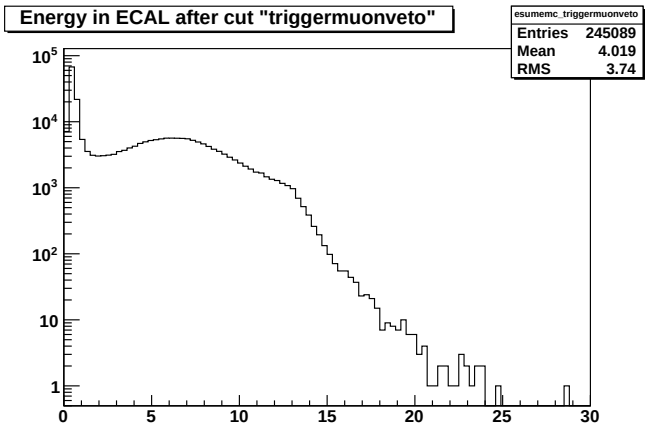
- total energy (ECAL+HCAL+TCMT): number of nuons gets reduced



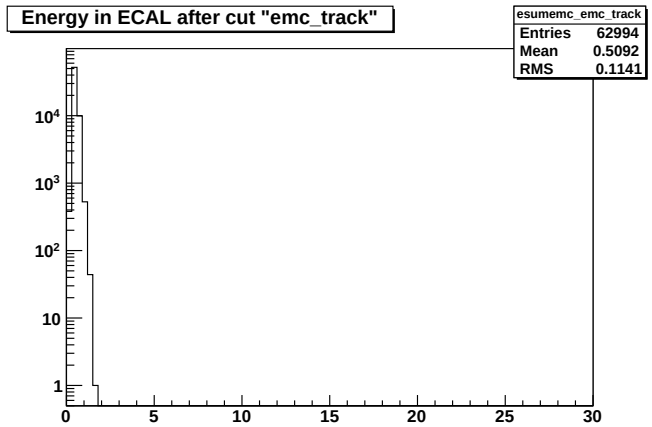
→ trigger → muon veto →



- Energy in ECAL: removes electron contamination and early starting showers

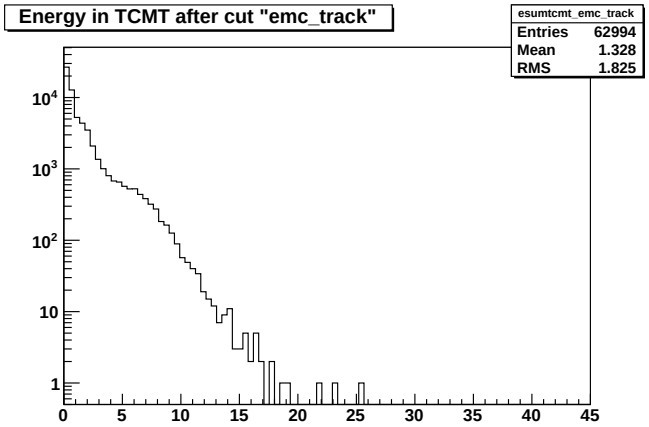


→ mip-like ECAL →

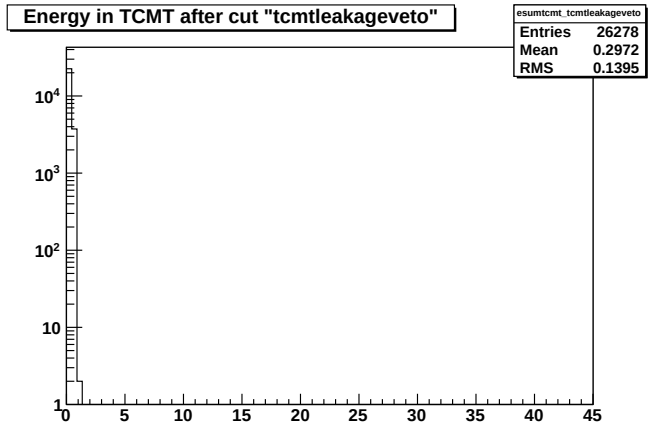


Pion Selection

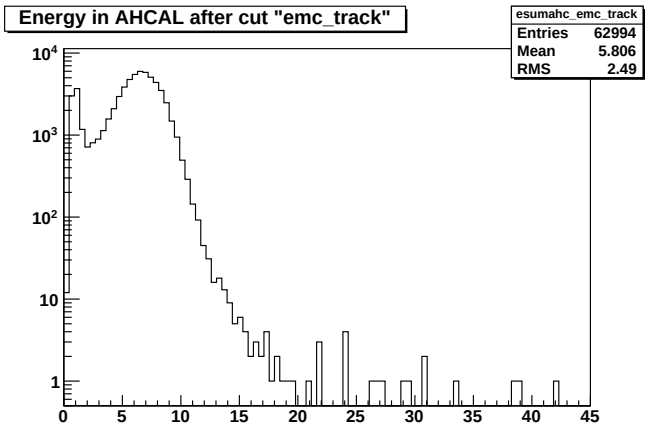
- Energy in TCMT: remove showers leaking into TCMT



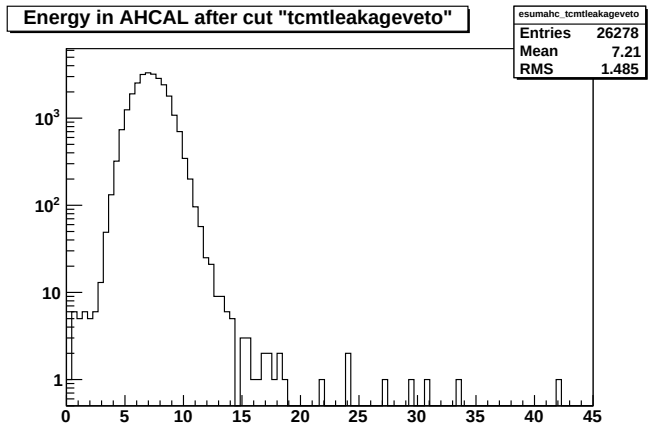
→ TCMT cuts →



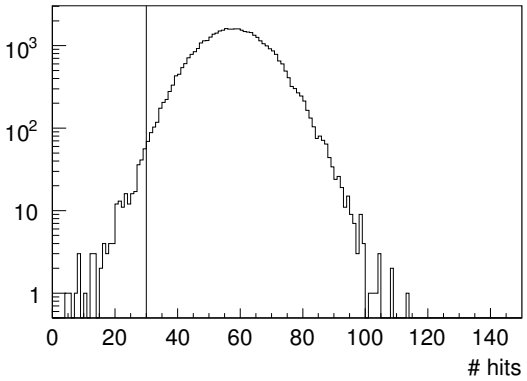
- Energy in HCAL: remove residual muons



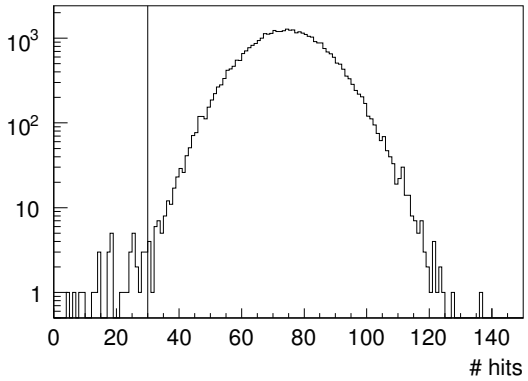
→ TCMT cuts →



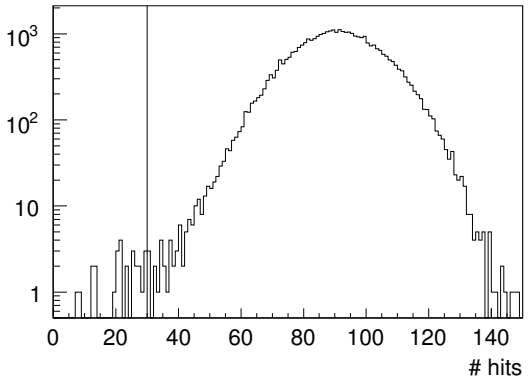
HCAL cut



6 GeV pions



8 GeV pions

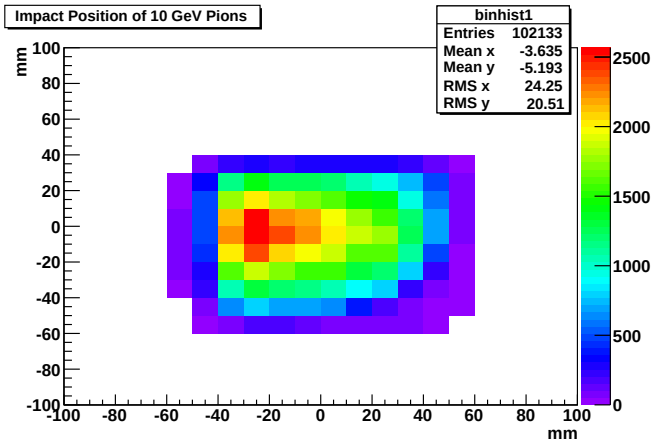


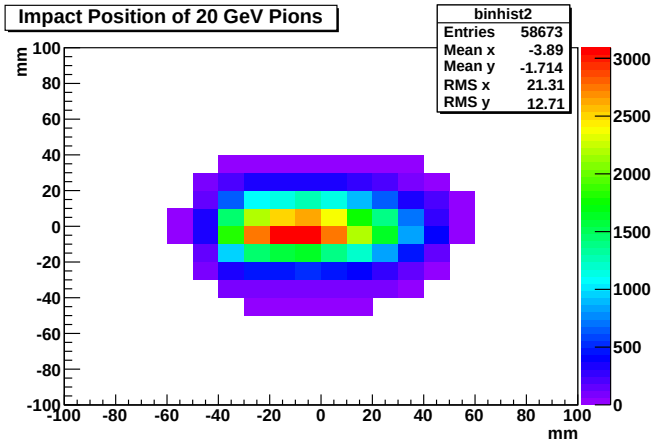
10 GeV pion

- removes muons scattered in HCAL (miss TCMT)
- strange events; might be fragments of showers upstream in beamline
- total number of "strange" events is low, but impact position tends to be at the edge of trigger acceptance (next slides)

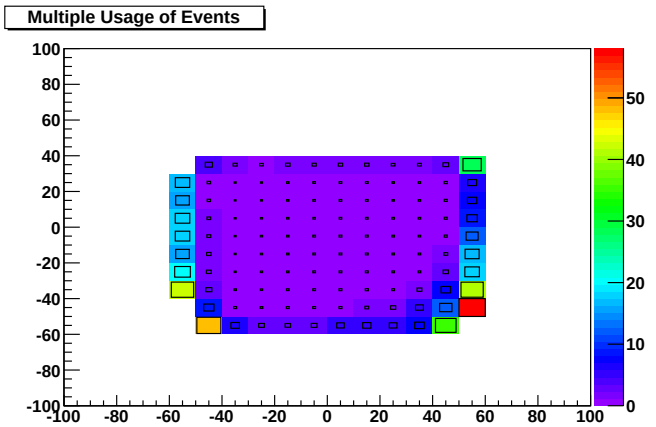
Event Pairing

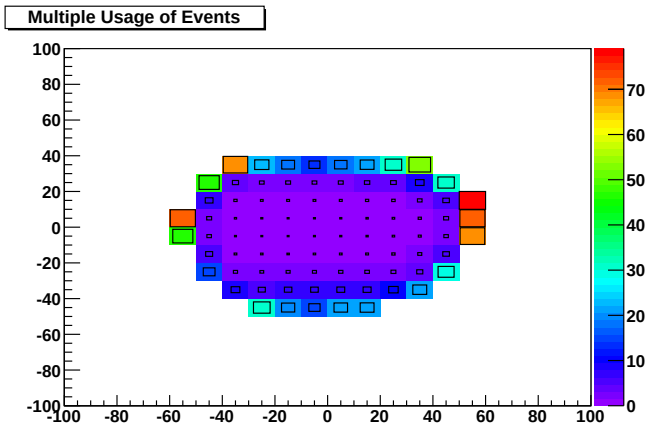
- beam profile and trigger acceptance limit impact position



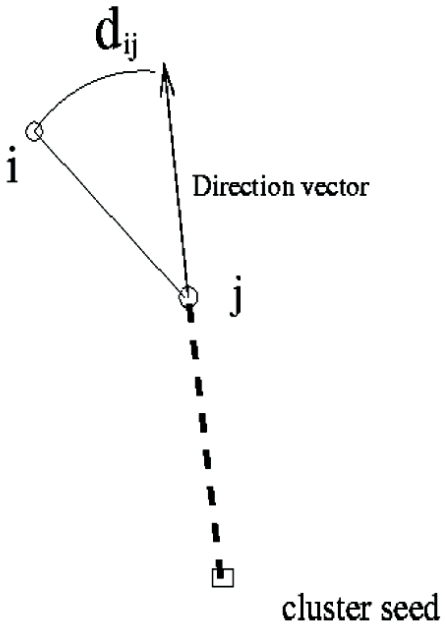


- events have to be "reused" to get statistics with "large" distance
- mix event A with B is different to mix event A with C





Trackwise Clustering



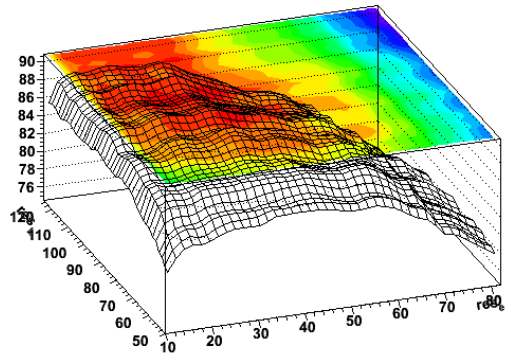
Trackwise Clustering algorighm

- Trackwise searches from calorimeter surface to the back for clusters
- axis of found cluster seeds defines search direction
- additional hits might be added to cluster seed if "distance" is below threshold
- "distance" is combination of distance in forward direction and length of arc d_ij
- tunable parameters are values for "forward" and "arclength" distance to pick up new hits

Parameter Tuning

parameter scan to tune particle flow

- tune to find two clusters for two particle events
- values 25 "forward" and 92 for "arclenght" have been choosen (default values are 20 and 80)
- parameter get to large, clusters are connected
- if "forward" parameter gets to small, neighboured cells cannot be connected

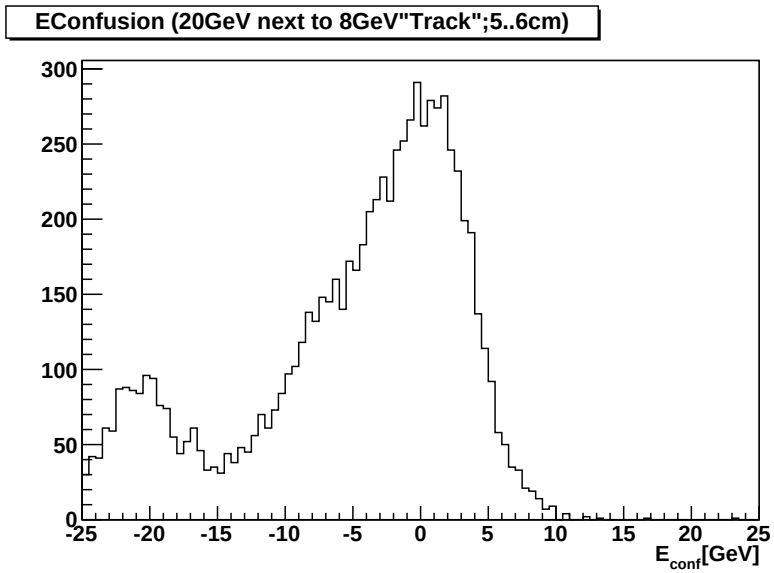


Confusion (Definition)

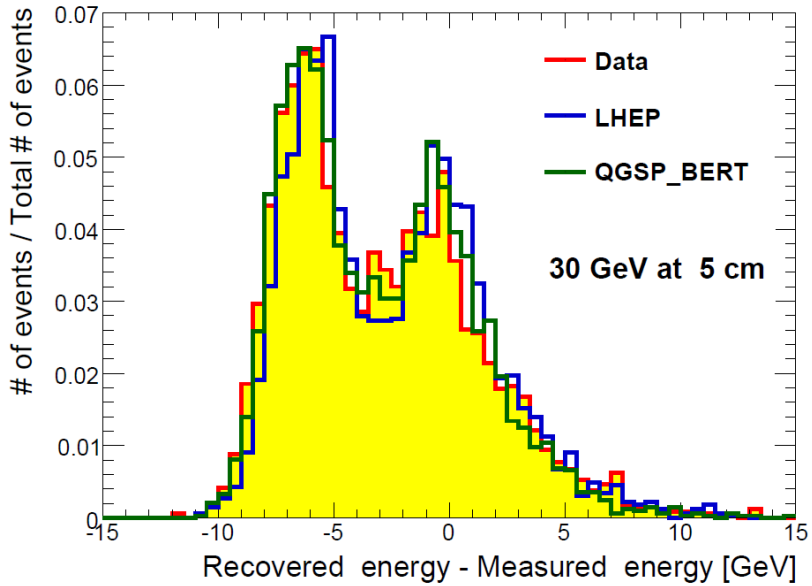
overlaid events:

- single particle events: energy deposition/measurement of particles is known
- virtual two particle events:
  - do clustering (particle reconstruction)
  - assume true particle energy (here beam energy) is known for *one* particle; I will call this one "track"
  - match "track" to one cluster/reconstructed particle
  - sum up the energy of all clusters, that are not the "track" particle
- confusion:
  - per event: $E_{\text{confusion}} := E_{\text{not track}} - E_{\text{sp event}}$
  - perfect particle separation: $E_{\text{confusion}} = 0$
  - worst case: $E_{\text{confusion}} := -E_{\text{sp event}}$

Confusion

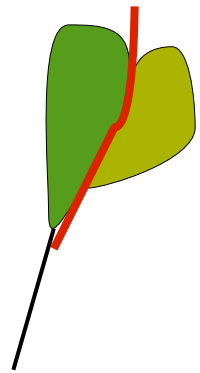


example of two particle confusion term with *trackwise clustering*



example of two particle confusion term with *PandoraPFA* (O. Markin paper draft)

- confusion shape characterises particle separation capability
- different aspects:
  - e.g. bias if separation works
  - fraction of events with one reconstructed particle
- *particle flow* is more than clustering (forces consitency with track information)

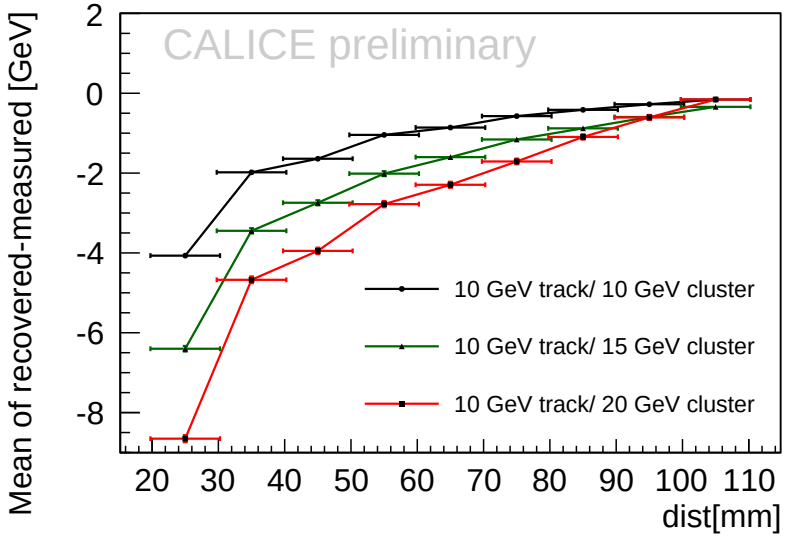


Figures of Merit

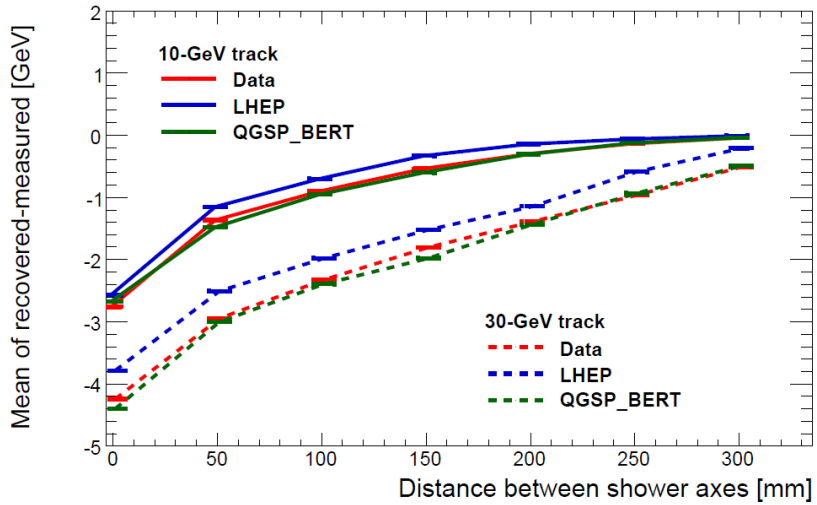
- mean of confusion distribution: energy bias of hadrons next to "known" hadrons
- RMS/RMS90 of confusion distribution: confusion width as source of additional jet-energy error in "jet" particle flow
- fraction of hadrons reconstructed within $n\,\sigma$ of natural HCAL resolution: $\approx$ "how often does pflow help"

Confusion Bias

mean of confusion distribution



two charged hadrons; trackwise clustering

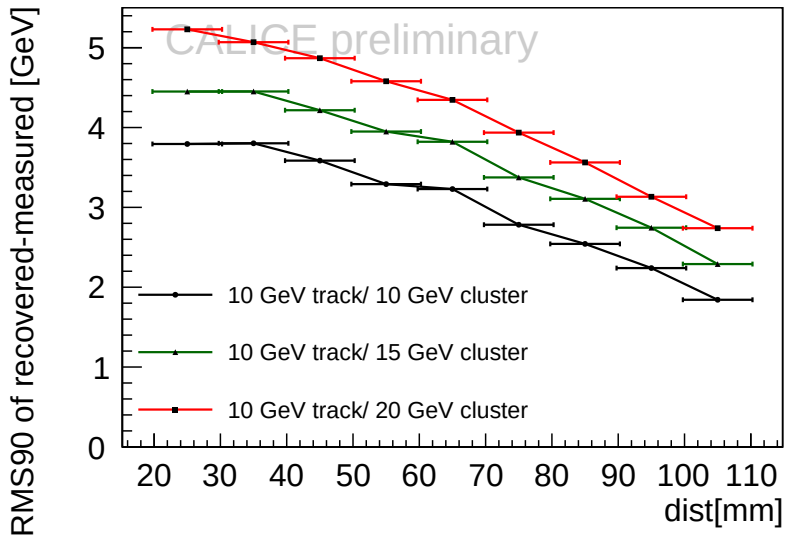


10 GeV neutral hadron; PandoraPFA (O. Markin)

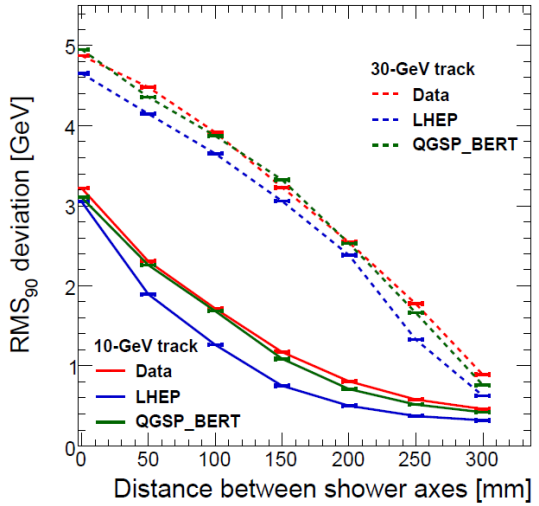
- PFA still has "limited" confusion bias at 0 distance
- confusion bias would drop to -E at 0 distance
- left: apply clustering to two charged hadrons
  - (possible) seed of all clusters "known" to clustering due to mip stub.
  - PFA has to "search" possible cluster position, but will search if track information inconsistent with clustering
  - might be a reason for smaller bias at 10 cm

Confusion Width

RMS90 of confusion distribution



two charged hadrons; trackwise clustering

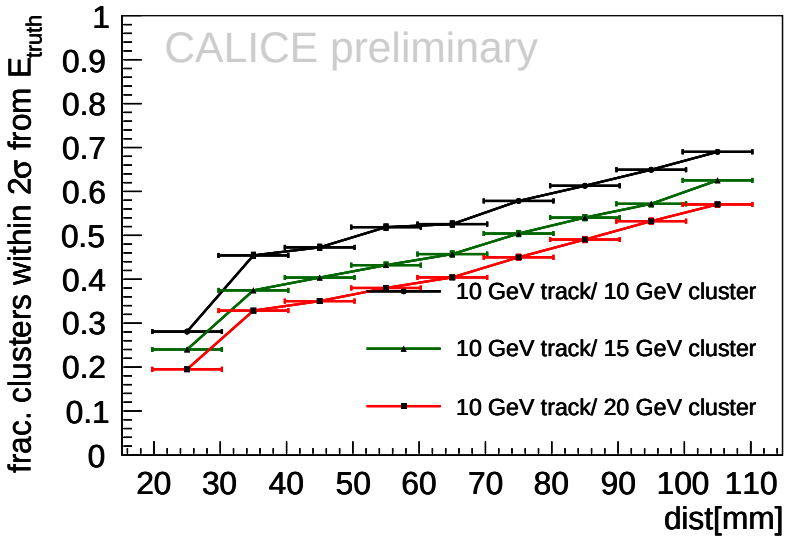


10 GeV neutral hadron; PandoraPFA (O. Markin)

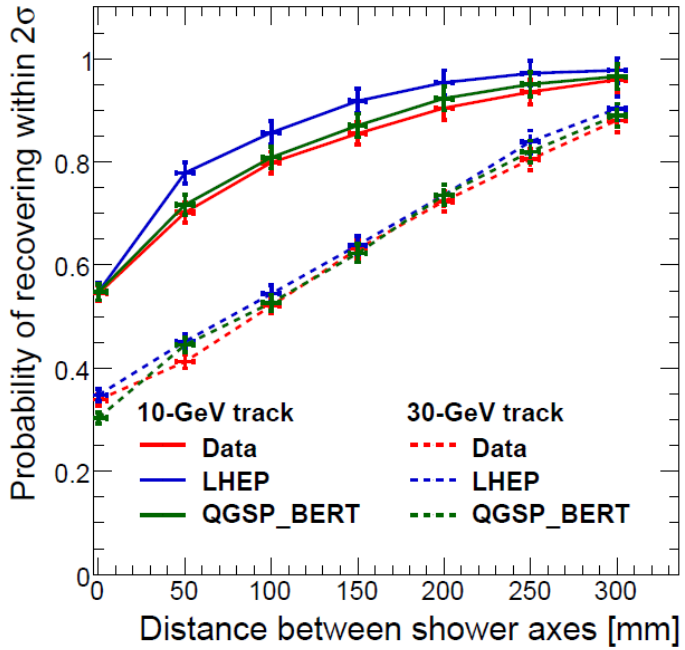
- RMS90 / RMS as figure of merit for width (confusion distribution not Gaussian)
- RMS differ more than RMS90 between "clustering" and "PFA" due to different position of "secondary peak"

Good Reconstruction Efficiency

fraction of reconstructed "unkown" hadrons within 2σ of HCAL resolution



two charged hadrons; trackwise clustering



10 GeV neutral hadron; PandoraPFA (O. Markin)

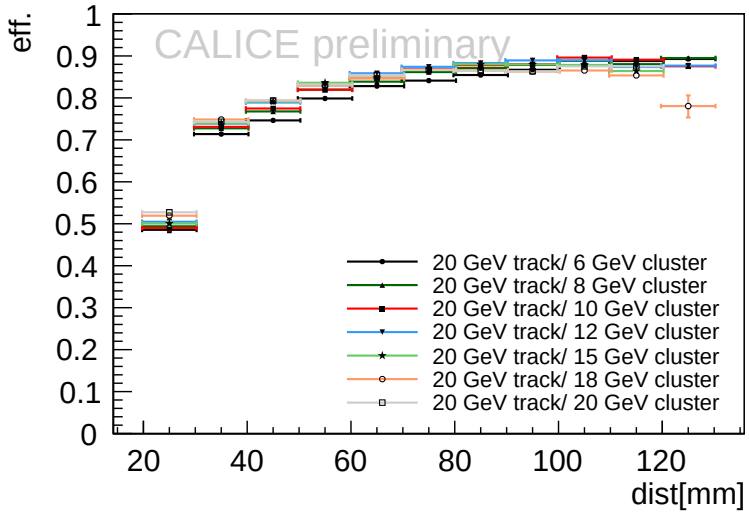
- small distance: part of "second peak" events for PFA within 2σ
- 10 cm: more accurate cluster finding due to second MIP-stub already compensates "lost" clusters

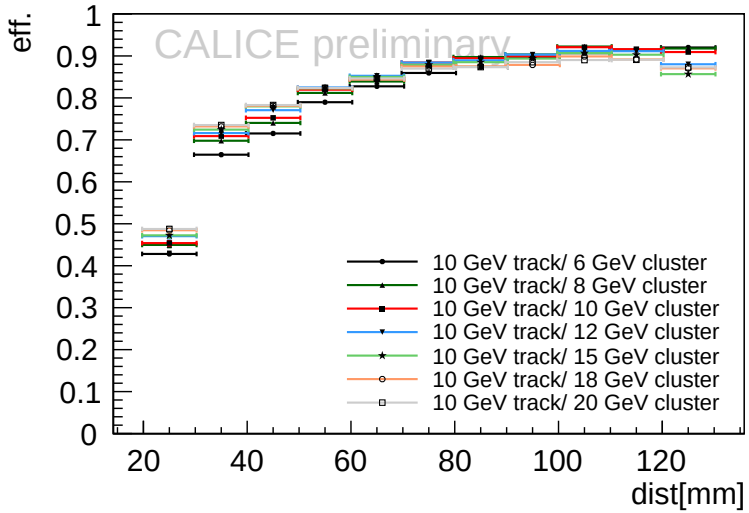
Summary

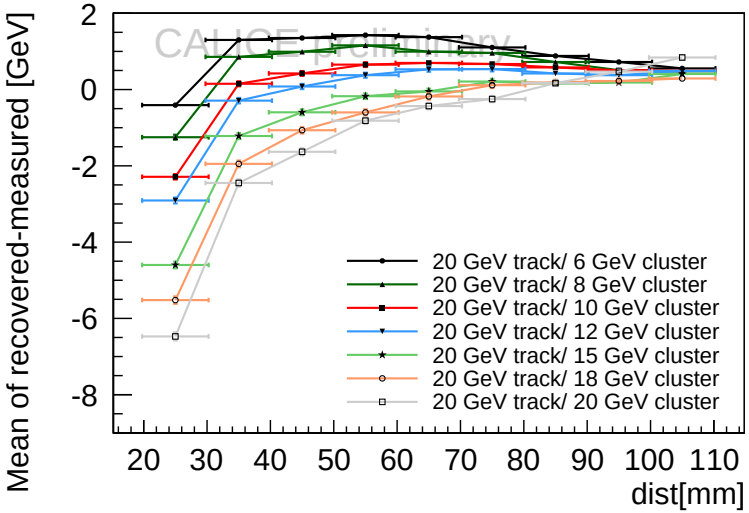
- particle flow algorithms are needed to recover from low particle separation efficiencies at small distances.
- mip-stub of charged hadron helps pure clustering algorithm to do what particle flow does on its own
- separation power of Pandora PFA and "MIP-stub-assisted" trackwise clustering seem to converge at $\gtrsim$ 10cm, however, trackwise clustering data $>$ 10cm missing to confirm assumption

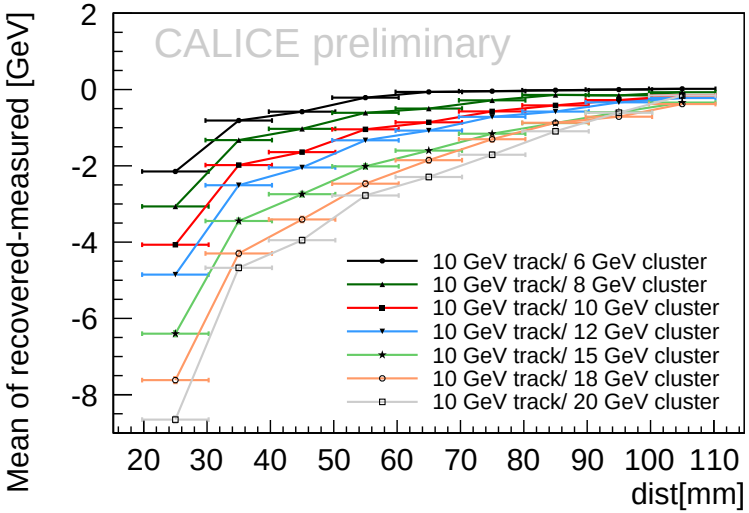
- real particle flow is needed to handle small impact distances
- above distances of 10cm pflow optimised hardware can be exploited/pflow can be done
- at smaller distances pflow algo does more eflow than pflow
- this is needed for good jet energy resolution

Seaparation

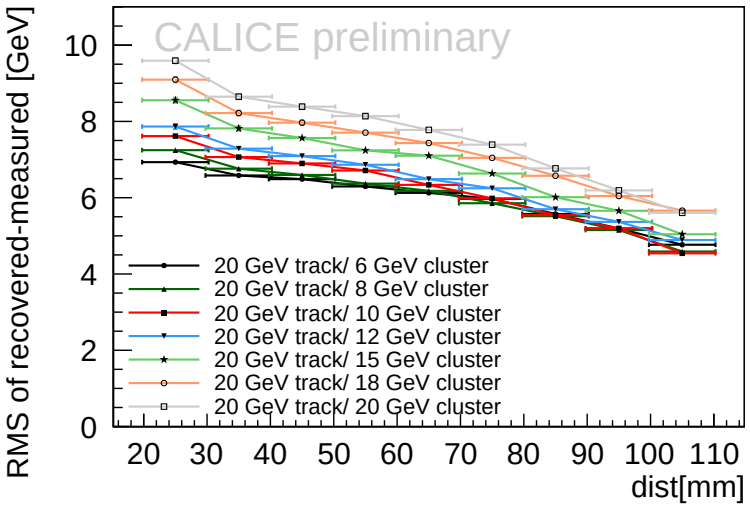


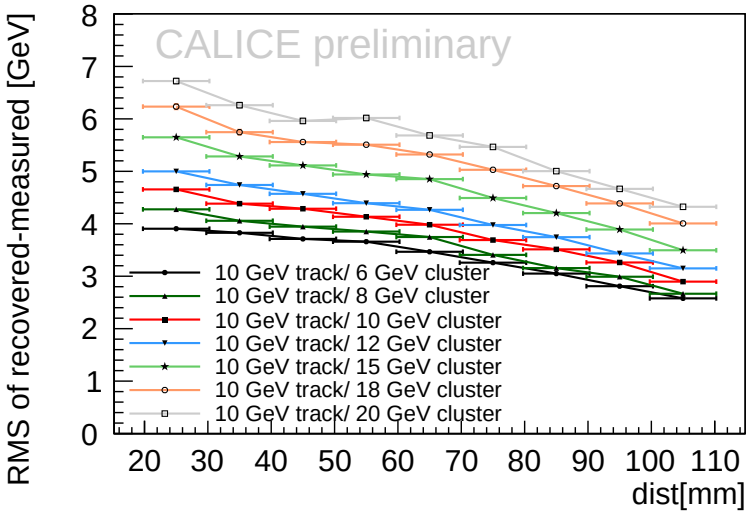






Separation


CALICE preliminary
RMS of recovered-measured [GeV]
dist[mm]
20 GeV track/ 6 GeV cluster
20 GeV track/ 8 GeV cluster
20 GeV track/ 10 GeV cluster
20 GeV track/ 12 GeV cluster
20 GeV track/ 15 GeV cluster
20 GeV track/ 18 GeV cluster
20 GeV track/ 20 GeV cluster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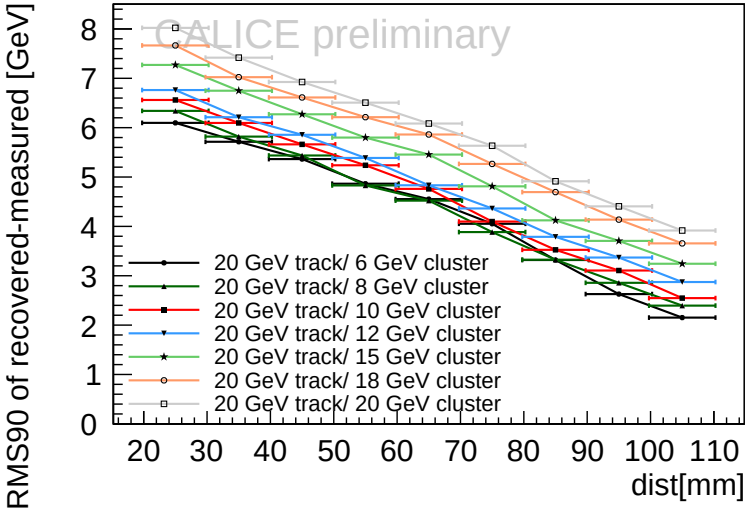
CALICE preliminary
RMS90 of recovered-measured [GeV]
dist[mm]
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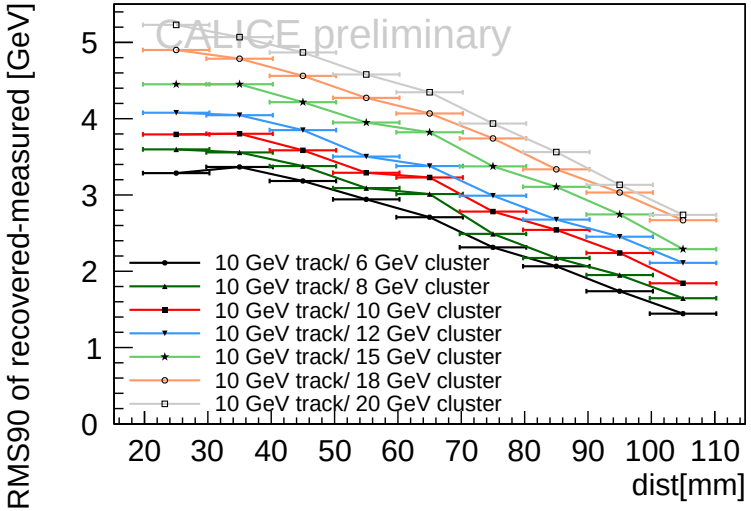
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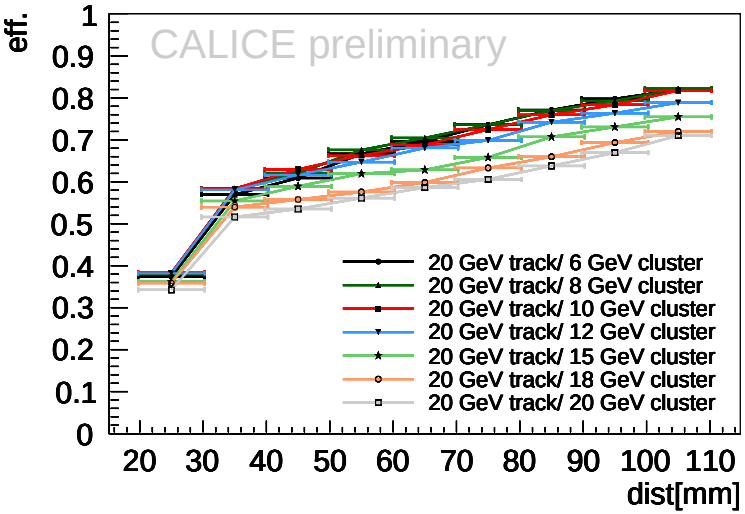
Separation


CALICE preliminary
eff.
dist[mm]
20 GeV track/ 6 GeV cluster
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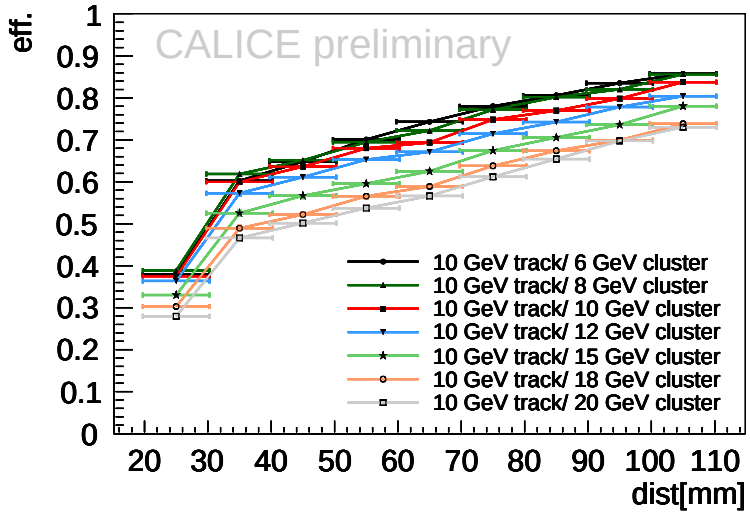
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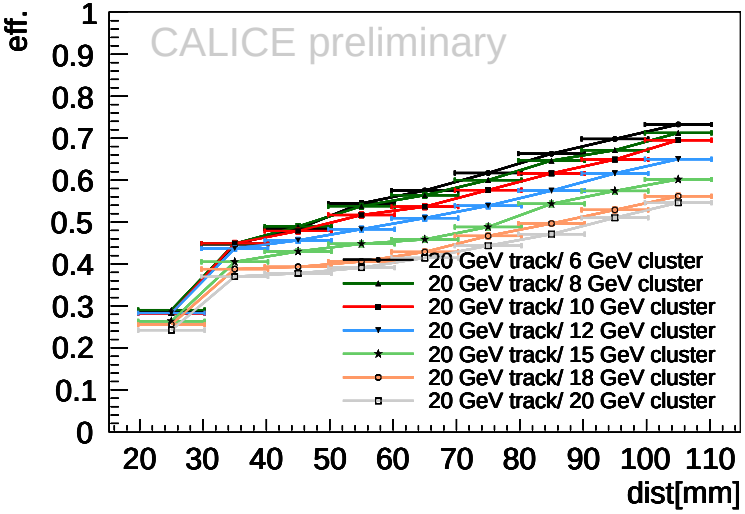
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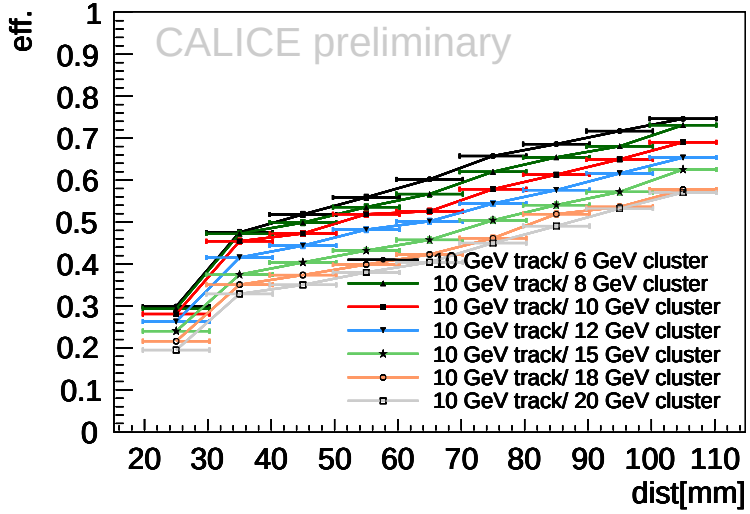
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Charged - Neutral vs. Charged Charged