Interactions of hadrons in the SiW ECAL

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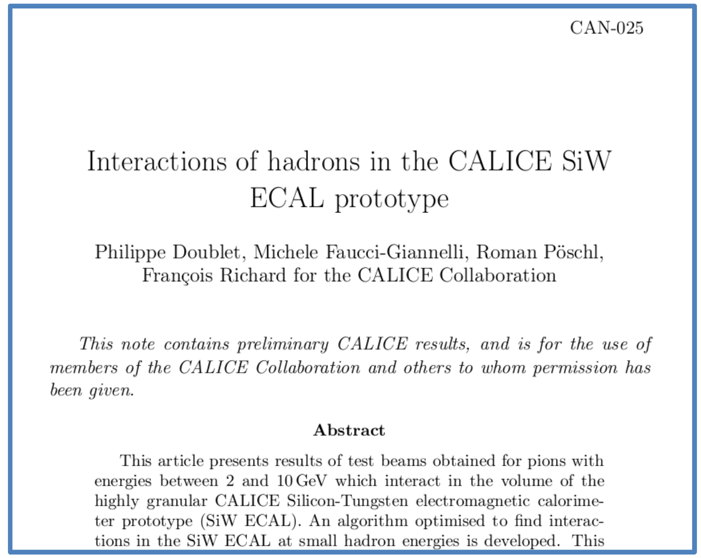
Aim

- Revise the analysis presented in CALICE Analysis Note CAN-025 on the FNAL 2008 SiW ECAL testbeam data
- Analysis Note: Study the interactions of π^- in the SiW ECAL at low energies (2 – 10 GeV) and compare various Monte Carlo Models (physics lists) to this data
- Check the analysis and make minor improvements and adjust the note to make it into a publication



CAN-025

Interactions of hadrons in the CALICE SiW ECAL prototype

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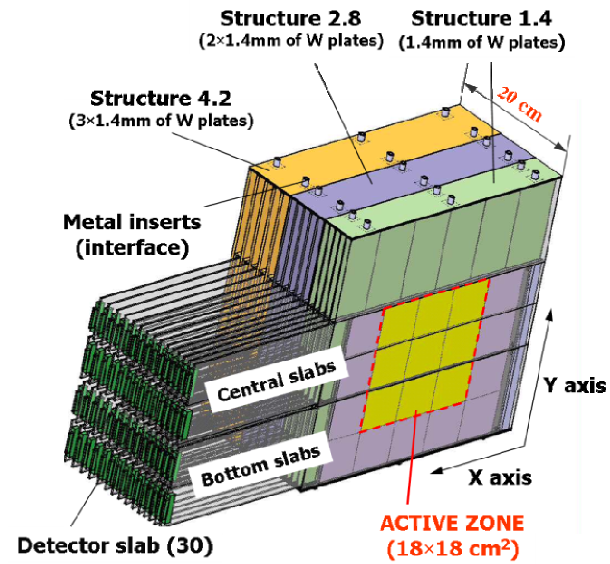
This note contains preliminary CALICE results, and is for the use of members of the CALICE Collaboration and others to whom permission has been given.

Abstract

This article presents results of test beams obtained for pions with energies between 2 and 10 GeV which interact in the volume of the highly granular CALICE Silicon-Tungsten electromagnetic calorimeter prototype (SiW ECAL). An algorithm optimised to find interactions in the SiW ECAL at small hadron energies is developed. This

Analysis setup

- Event sample:
  - SiW ECAL physics prototype
  - 2008 FNAL testbeam of π^- at 2, 4, 6, 8 and 10 GeV
  - Matching Monte Carlo with FTFP_BERT, QGSP_BERT and LHEP physics lists (add more)
- Event cuts:
  - correct trigger, minimum number of hits (25), hits in correct region of Ecal (centre), minimum hit energy (0.6 mip), no noisy layers, muon rejection



Energy (GeV)	Events processed MC	Accepted events QGSP_BERT	Accepted events FTFP_BERT	Accepted events LHEP	Events processed Data	Accepted events Data
2	500000	24824	24729	26806	146649	19893
4	500000	124932	124164	121182	267988	121027
6	500000	199830	204490	204496	114702	71615
8	500000	258129	260870	257141	327404	229058
10	500000	291970	292921	288504	738356	446059

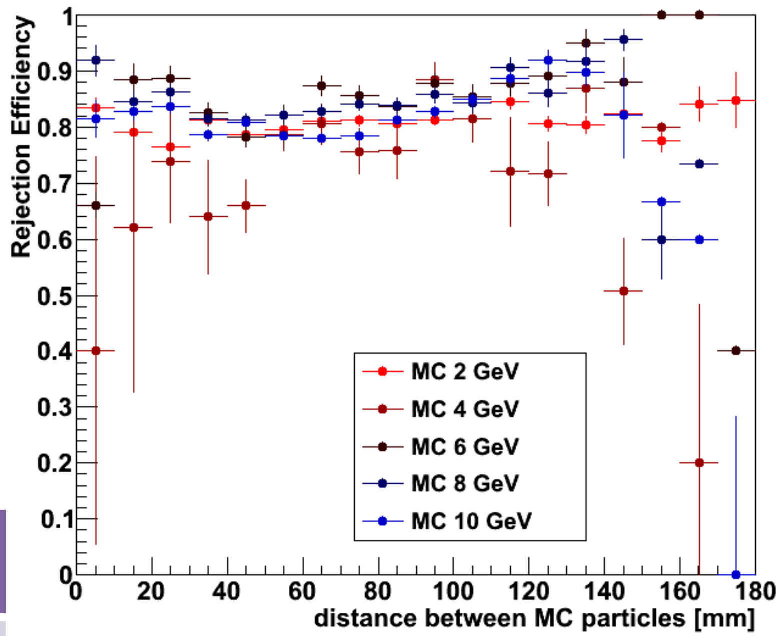
Event Classification

- Event classification based on 4 interaction types:
  - Interacting: FireBall (inelastic hadronic interaction) and Peaked (inelastic interaction with low energy transfer)
  - Non-interacting: Scattered (elastic scattering) and Mip
- The absolute and relative energy increase in subsequent layers defines the interaction point.
  - FireBall -> absolute increase and long range relative increase
  - Peaked -> short range relative increase
  - Scattered -> Displaced outgoing track
  - Mip -> all the rest
- Focus on interacting/non-interacting for the publication and refine the event classification with machine learning techniques

Rejection efficiency for events with multiple incoming particles

- A muon may coincide with a pion
- Reject such events from the analysis by rejecting events with two large clusters of hits in the first 8 layers that have a small slope.
- Simulate "double events" -> Overlay pion events with muon events
  (add the hit collections together)
- Eff = #rejected/#total

Energy (GeV)	Eff for double events (pion + muon)	Eff for single events (pion)
2	0.806	0.123
4	0.74	0.139
6	0.852	0.149
8	0.838	0.155
10	0.810	0.156



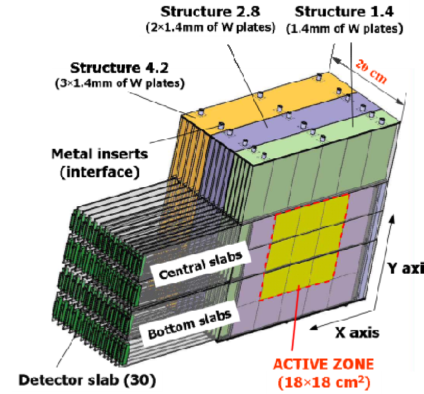
MC physics list FTFP_BERT

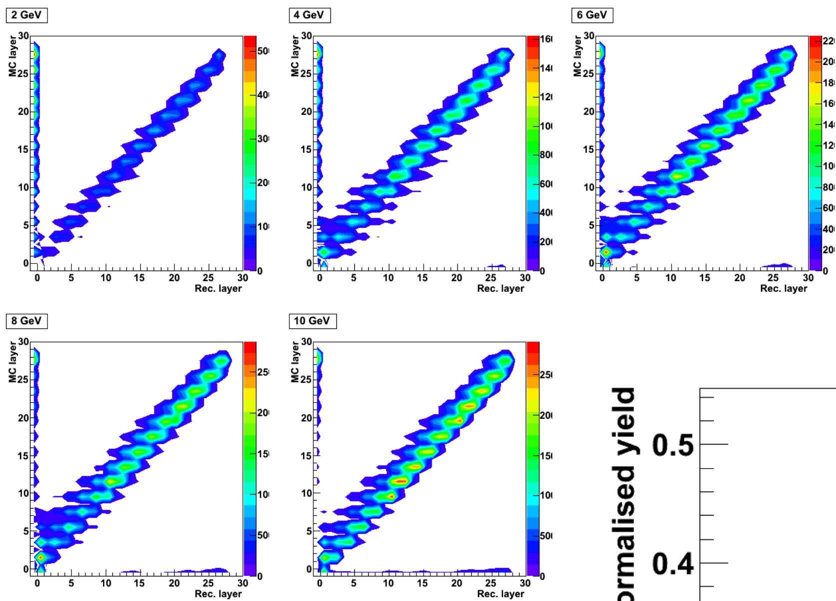
Estimate the contamination of "double events" in the accepted event sample in data

- Upper limit: Assume all rejected events were real double events
  contamination = $(1\text{-eff}_d)/\text{eff}_d * \text{rejected}$
- Estimate: rejected events are the sum of double and single events
  contamination = $(1\text{-eff}_d) * (\text{rejected} - \text{eff}_s * \text{total})/(\text{eff}_d - \text{eff}_s)$

Energy (GeV)	Upper limit	Contamination	Original fraction
2	0.155	0.125	0.393
4	0.166	0.116	0.305
6	0.058	0.028	0.142
8	0.086	0.053	0.225
10	0.059	0.017	0.070

Interaction Layer

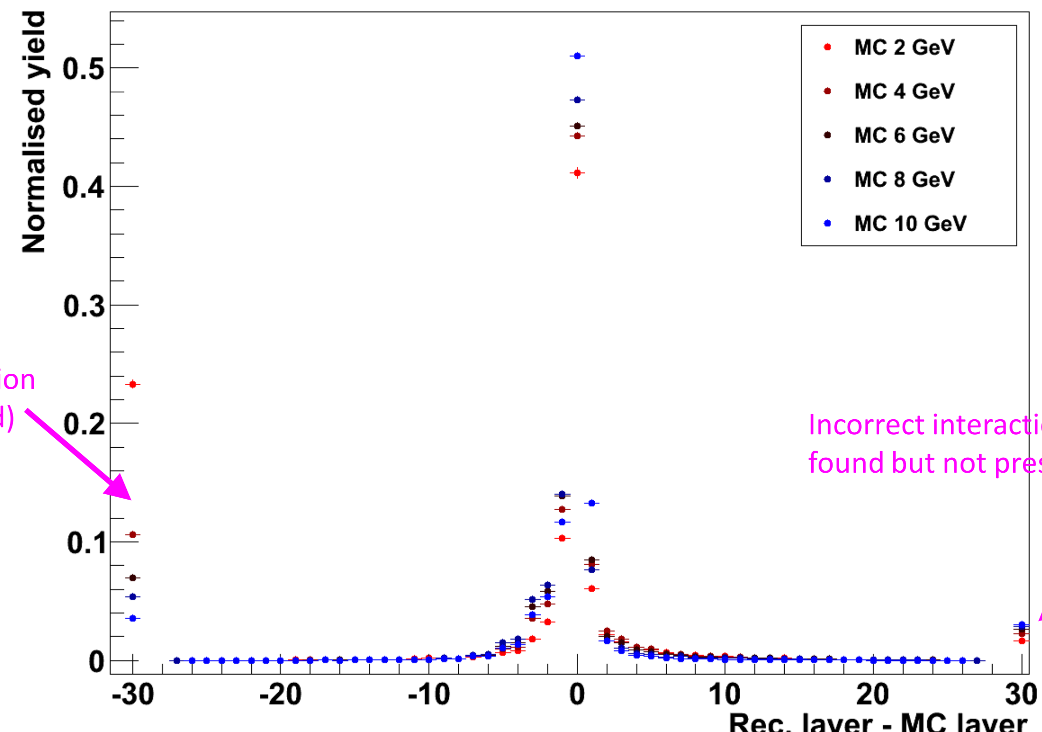




Monte Carlo π^- events (QGSP_BERT)

FTFP_BERT and LHEP have a very similar distribution

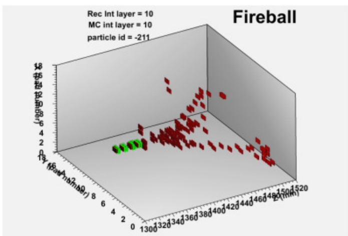
Missed interaction (interaction present in MC but not found)

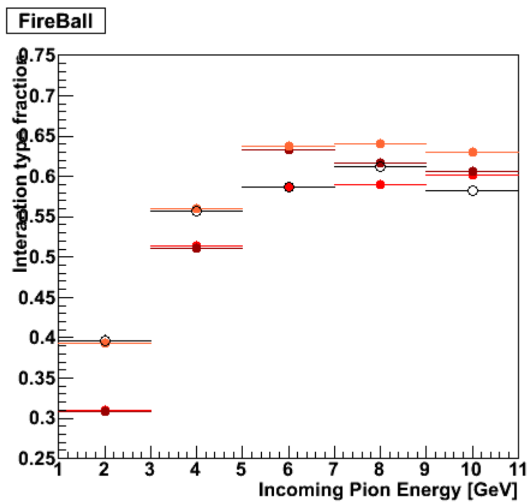


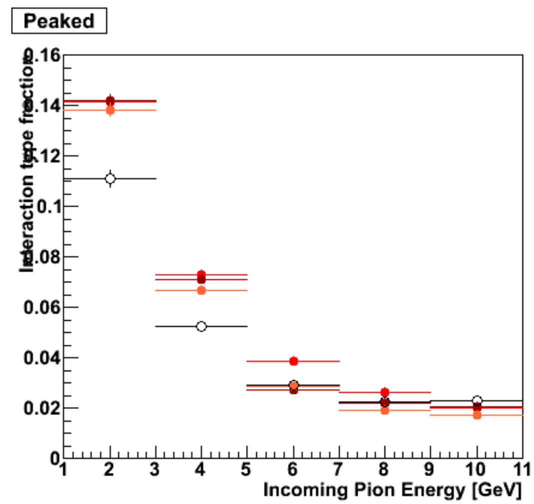
Incorrect interaction (interaction found but not present in MC)

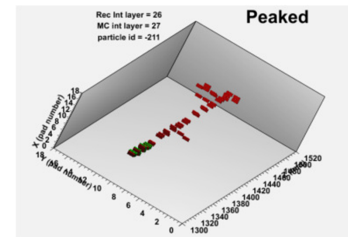
Event type fractions

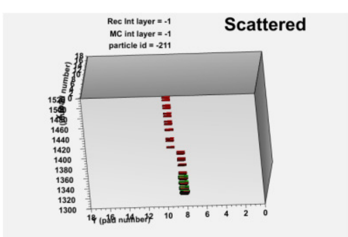
π^- data and Monte Carlo (QGSP_BERT, FTFP_BERT and LHEP)

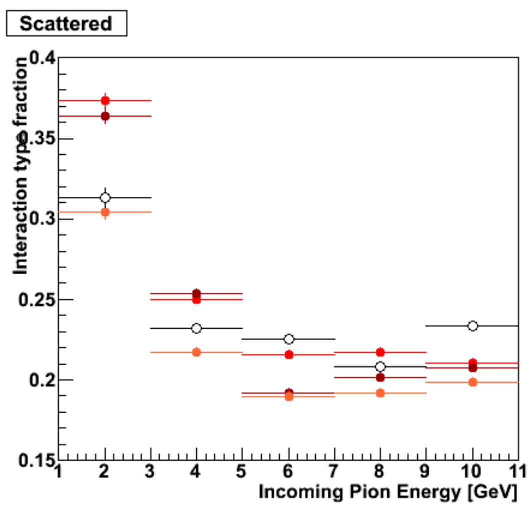


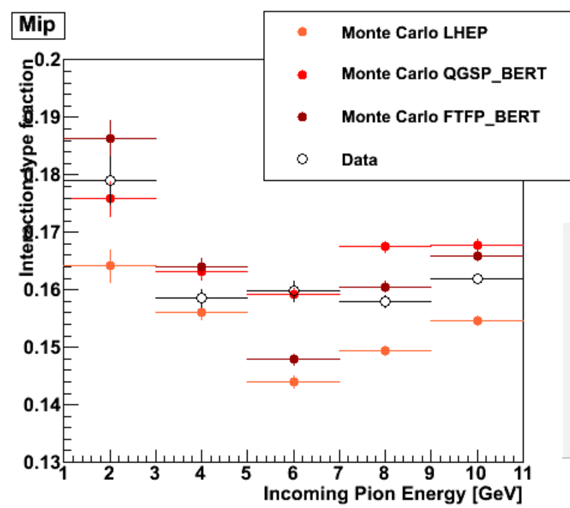


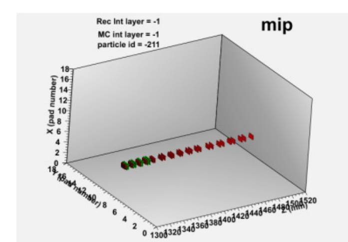












Interaction finding Efficiency

Monte Carlo π^- events (QGSP_BERT, FTFP_BERT and LHEP)

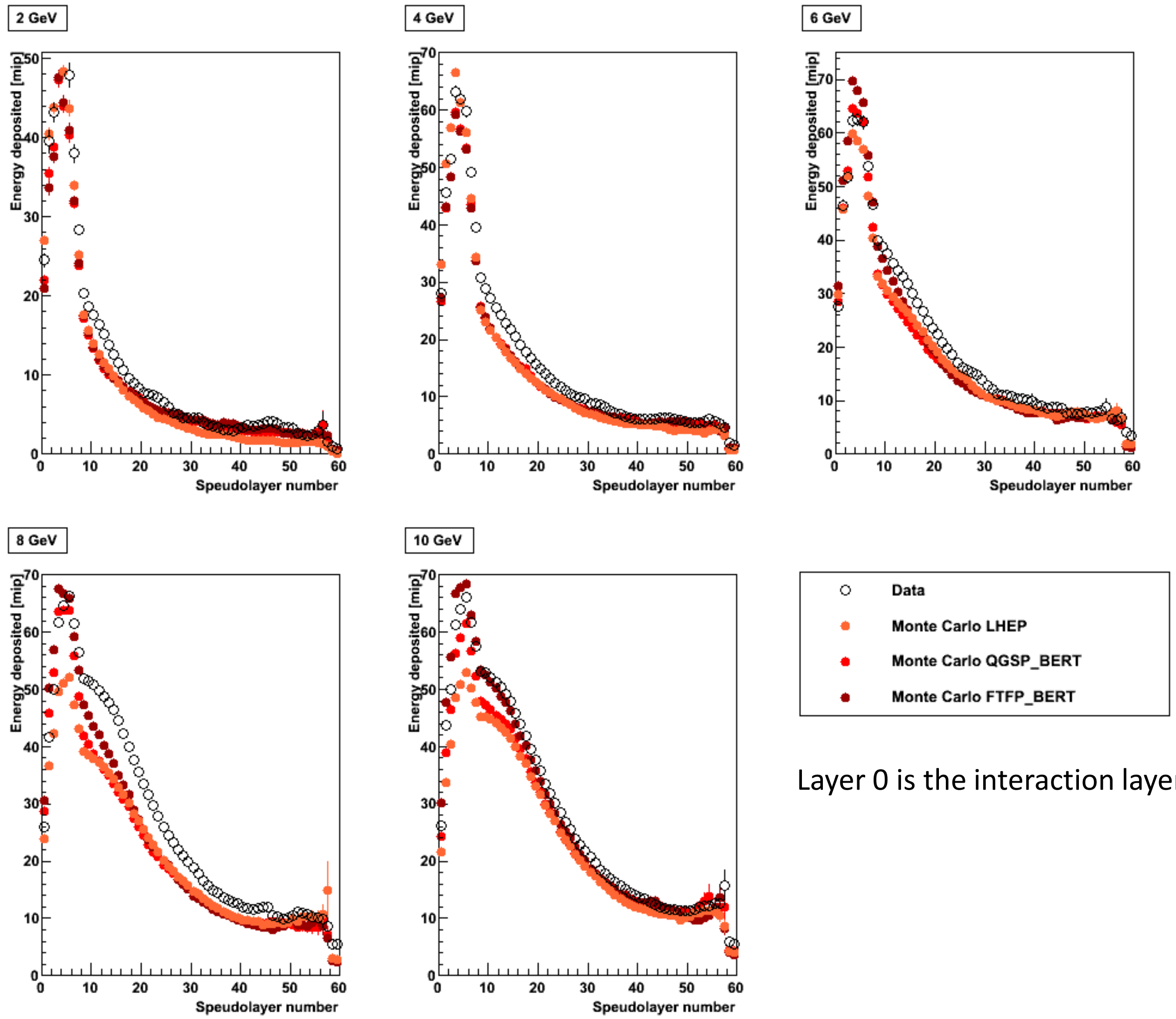
Energy (GeV)	Efficiency QGSP_BERT / FTFP_BERT / LHEP			Contamination QGSP_BERT / FTFP_BERT / LHEP		
2	0.651	0.656	0.786	0.036	0.023	0.033
4	0.841	0.839	0.915	0.038	0.033	0.036
6	0.895	0.945	0.956	0.042	0.040	0.042
8	0.916	0.952	0.962	0.047	0.045	0.045
10	0.944	0.952	0.957	0.049	0.048	0.044

Efficiency
=
fraction of all true interacting events that is classified as interacting

Contamination
=
fraction of all events classified as interacting that is non-interacting

Longitudinal Energy Profile for events classified as interacting

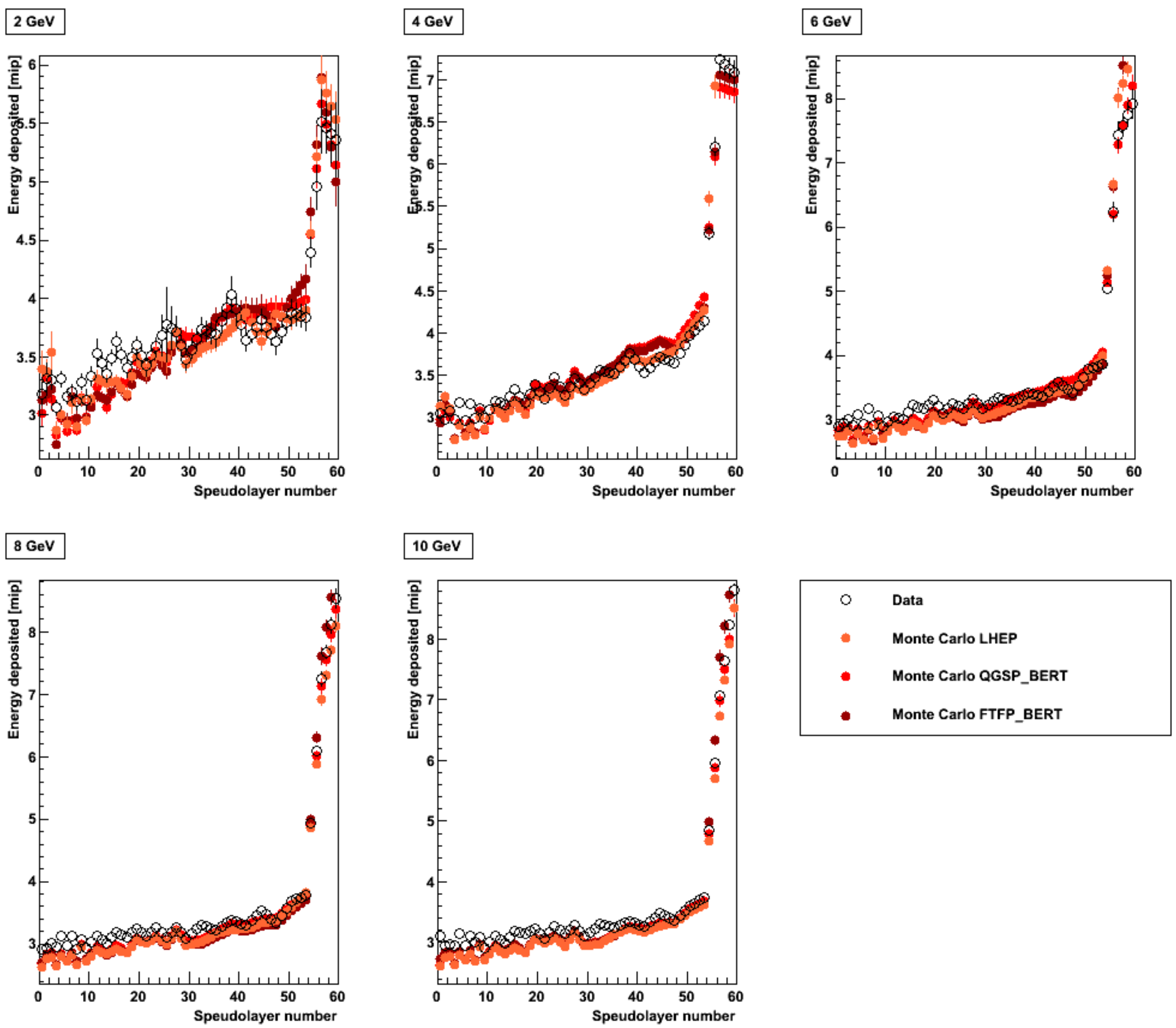
π^- data and Monte Carlo (QGSP_BERT, FTFP_BERT and LHEP)



Layer 0 is the interaction layer

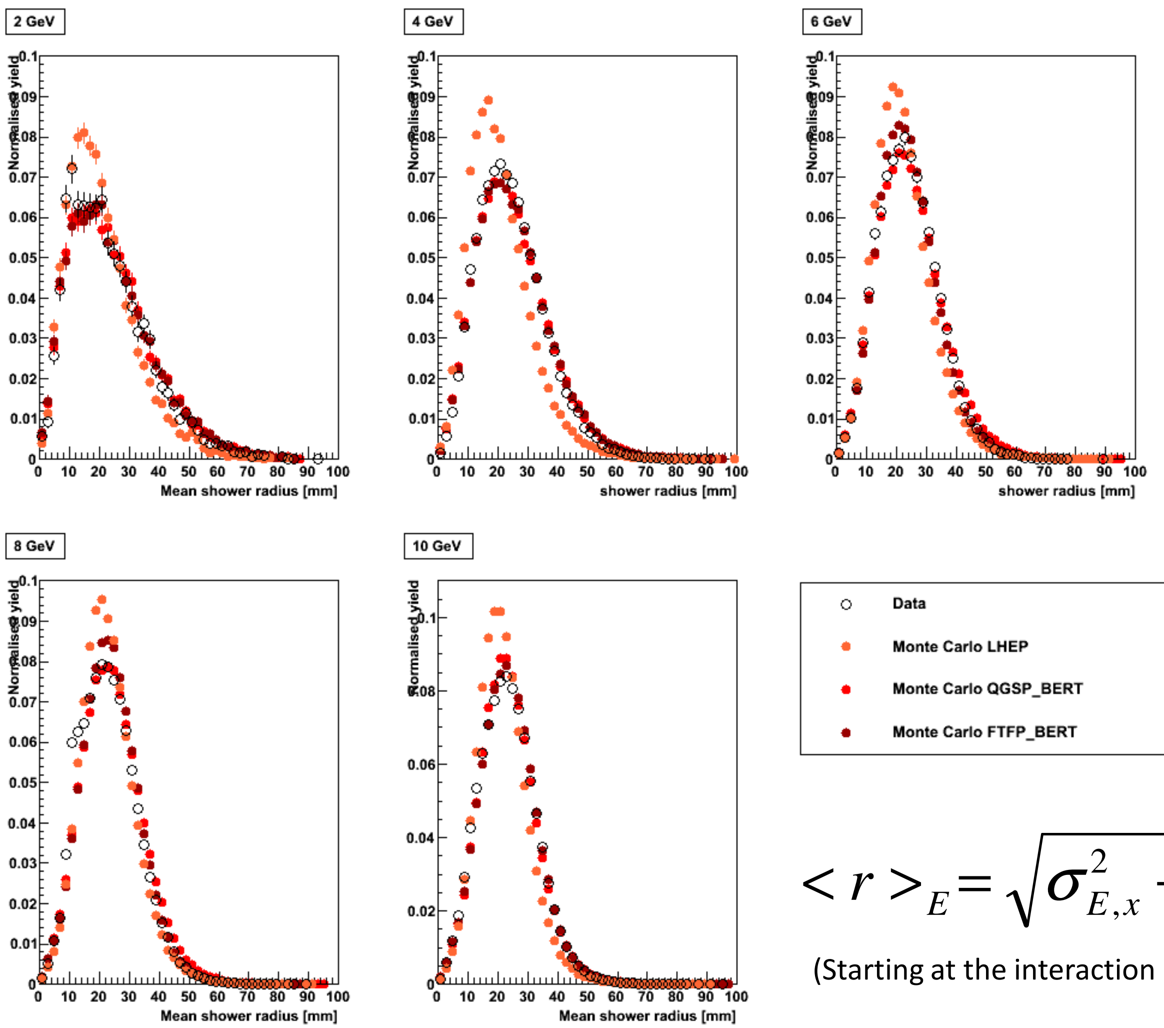
Longitudinal Energy Profile for events classified as non-interacting

π^- data and Monte Carlo (QGSP_BERT, FTFP_BERT and LHEP)



Mean Shower Radius for events classified as interacting

π^- data and Monte Carlo (QGSP_BERT, FTFP_BERT and LHEP)



$$< r >_E = \sqrt{\sigma_{E,x}^2 + \sigma_{E,y}^2}$$

(Starting at the interaction layer)

Next…

- New MC production to add more physics lists to the comparison
- Error calculation wrt double event rejection and interaction finding efficiency
- Thorough check of all the cuts

- Since October a collaboration between LAL and LLR ILC groups and LAL AppStat group to better characterise and understand hadronic showers using machine learning techniques. First step: finding the most discriminating features (characteristics) of the shower and testing different machine learning techniques.
  - B. Kegl, F.Dubard,
    V. Boudry, M. Ruan, T.H. Tran,
    R. Poeschl, N. van der Kolk

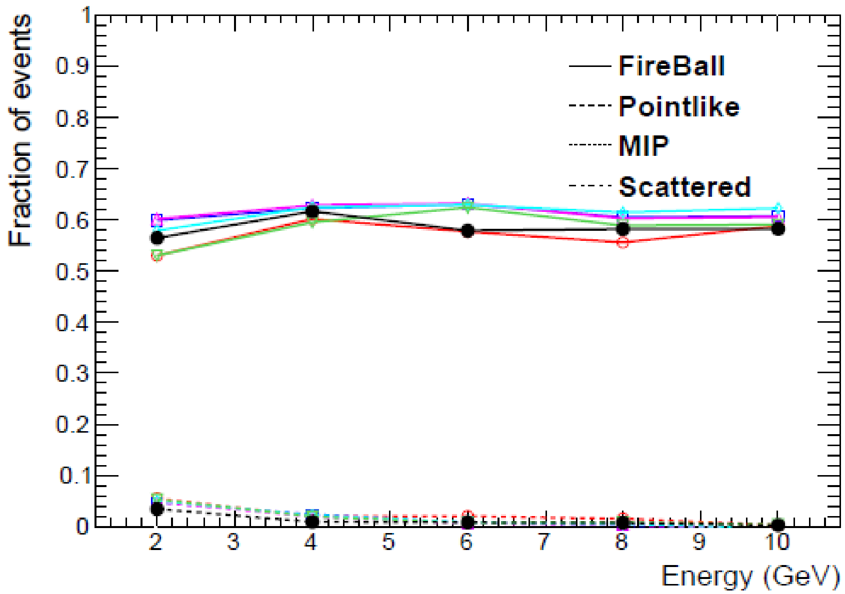
    Special thanks to T. Frisson and D. Benbouzid

[Backup]

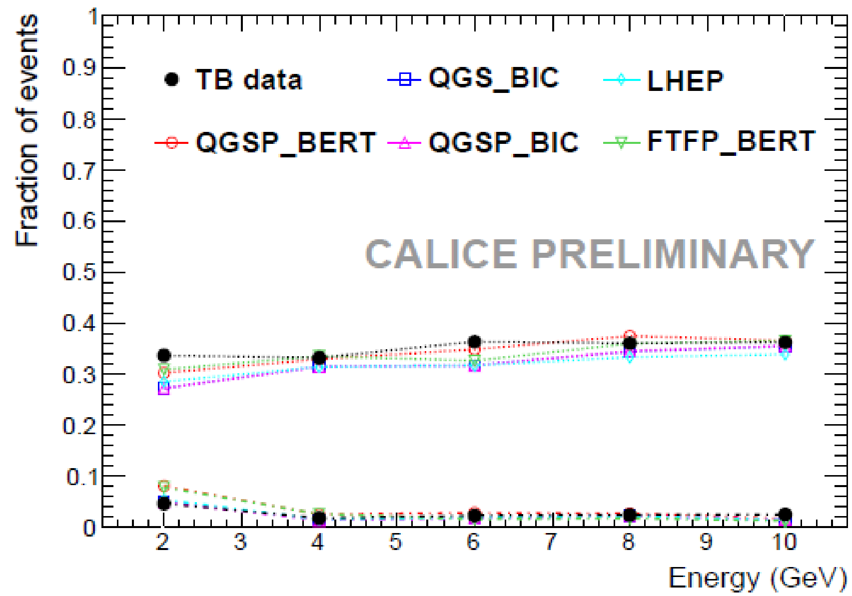
Selection criteria for event types

- Interacting
  - FireBall (inelastic hadronic interaction)
    - Absolute energy increase $E_i > E_{cut}$ && $E_{i+1}>E_{cut}$ && $E_{i+2}>E_{cut}$
    - Relative energy increase $F=(E_i+E_{i+1})/(E_{i-1}+E_{i-2})>F_{cut}$ && $F' = (E_{i+1}+E_{i+2})/(E_{i-1}+E_{i-2})> F_{cut}$ && $E_{aroundi}>0.5E_i$
  - Peaked
    - Local relative energy increase $F>F_{cut}$ && $F' > F_{cut}$ not valid anymore at layer i+3
- Non-interacting
  - Scattered (elastic scattering)
    - Lateral distance of two pixels or more between the incoming and outgoing track
  - Mip
    - All events which do not fit the other criteria

Event type fraction
Previous version

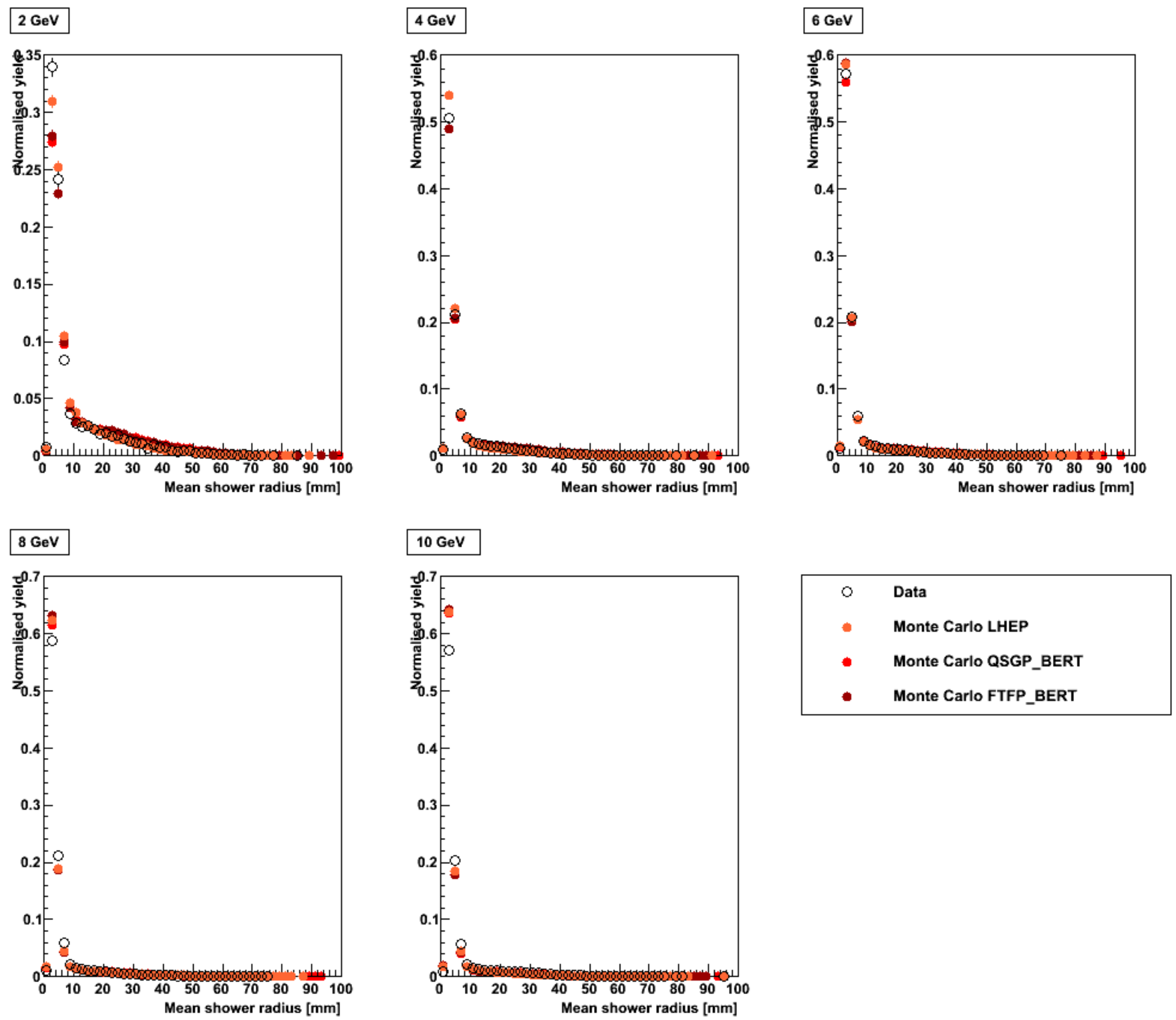


(a) Interaction classes

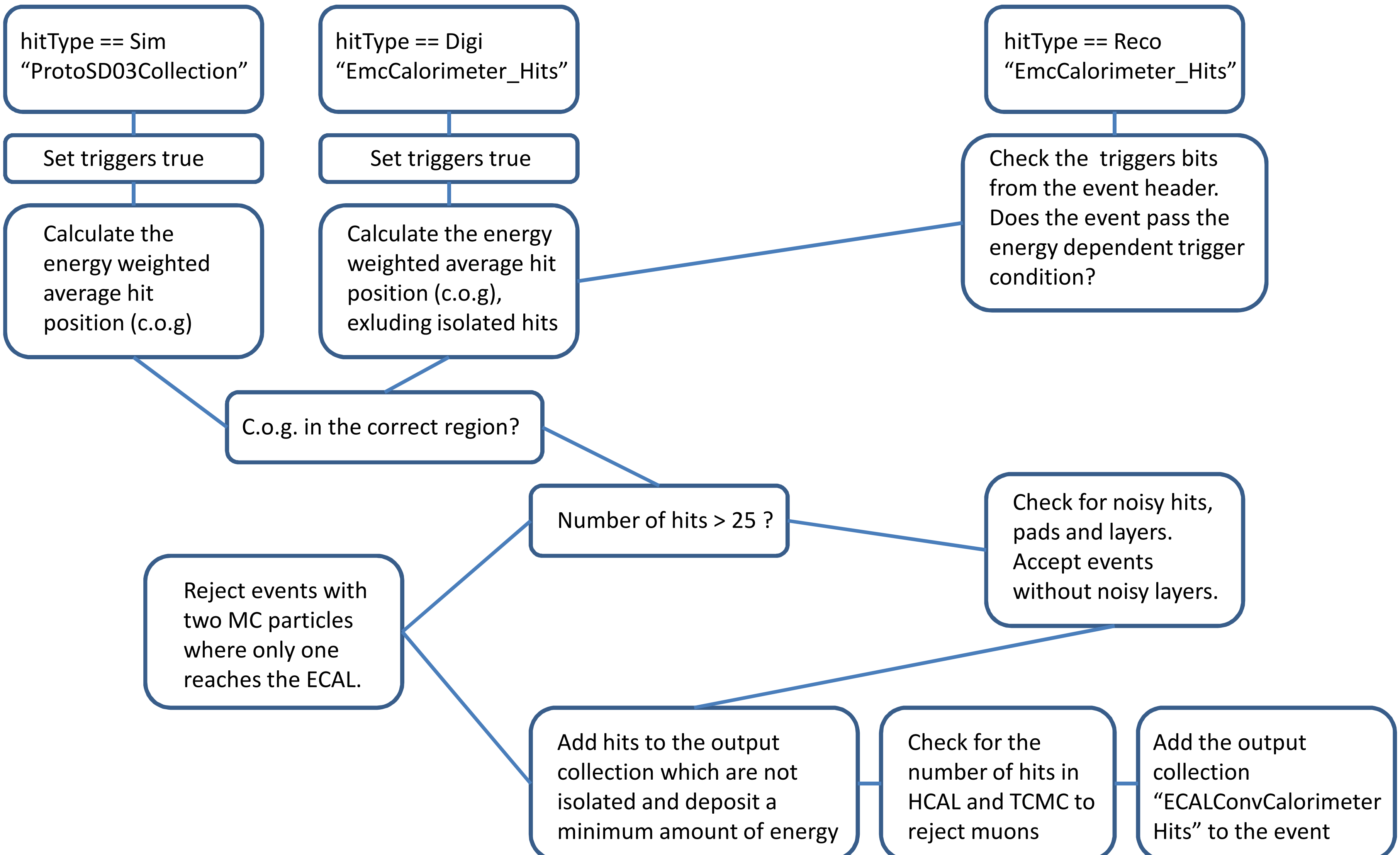


(b) Non interaction classes

Mean Shower Radius for events classified as non-interacting



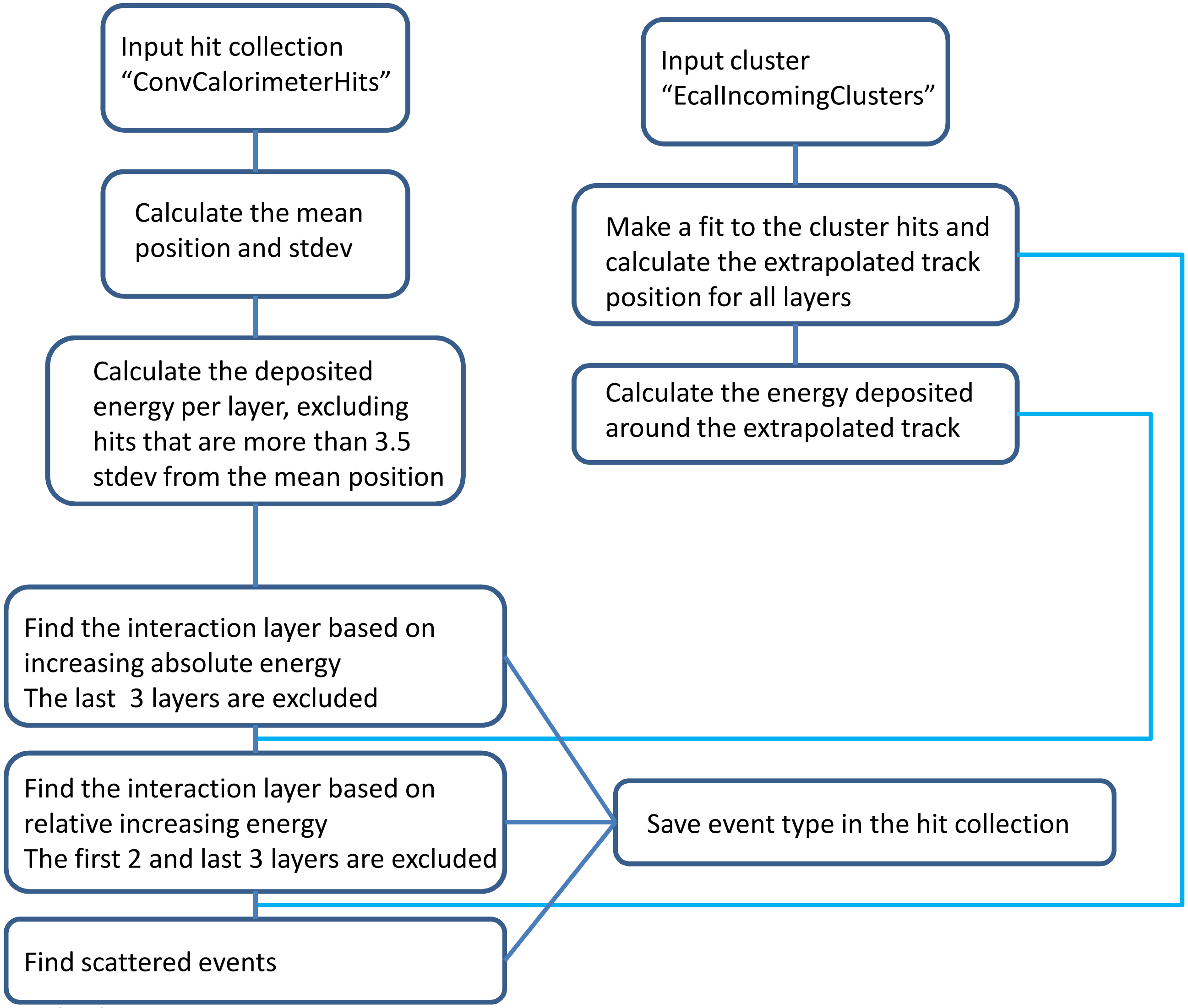
Step 1: SelectAndConvert



Step 2: MipFinder2

- Input collection "ConvCalorimeterHits"
- Assign each hit to its layer object
- Find the first layer with a hit
- Start clustering in the first layer up to the 8th layer. If hits are closer than a minimum distance they are added to that cluster. Else they seed a new cluster
- Merge clusters if they are close enough together
- Select the most likely candidate cluster (with more that 3 hits) based on the slope of a fit to the cluster hits
- Reject the event if there are two large clusters with a slope less than 0.7
- Add the cluster with the smallest slope to the output cluster collection "EcalClusters"

Step 3: InteractionFinder



Step 4: CaliceEcalHitInfo

Input hit collection "ECALConvCalorimeterHits"

Input cluster "EcalIncomingClusters"

Fill histograms and a TTree of event and hit properties

For MC calculate efficiency and contamination