Interactions of hadrons in the SiW ECAL
Towards paper

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Physique des 2 Infinis et des Origines

LABORATOIRE DE L'ACCÉLÉRATEUR LINÉAIRE

Aim

- CALICE Analysis Note CAN-025:
  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 and revise the analysis presented in the Analysis Note on the FNAL 2008 SiW ECAL testbeam data and prepare the publication

CAN-025

Interactions of hadrons in the CALICE SiW ECAL prototype

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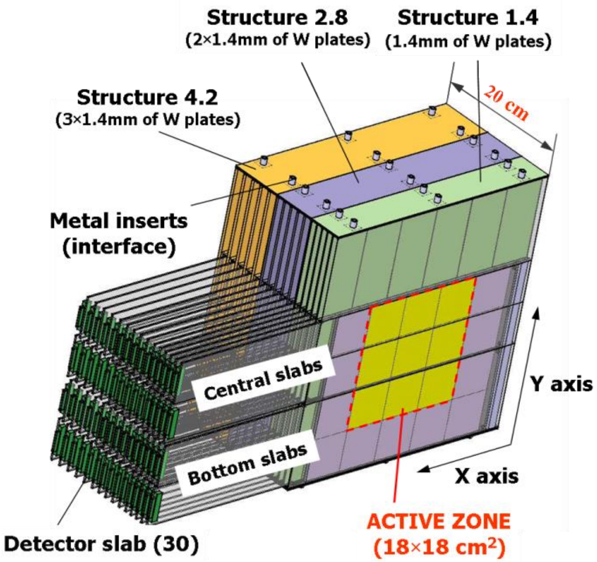
This note contains preliminary CALICE results, and is for the use of members of the CALICE Collaboration and others to whom permission has been given.

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

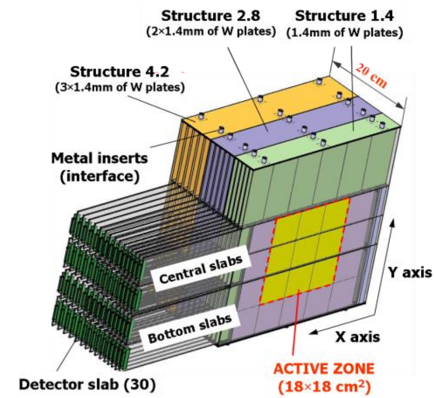
- Event sample:
  - SiW ECAL physics prototype
  - 2008 FNAL testbeam of π^- at 2, 4, 6, 8 and 10 GeV
  - Matching Monte Carlo (physics lists: FTFP_BERT, QGSP_BERT, LHEP, CHIPS, FTF_BIC, QGSP_BIC, QGS_BIC)
- Event cuts:
  - correct trigger, minimum number of hits (25), hits in correct region of Ecal (centre), minimum hit energy (0.6 mip), no noisy layers, muon rejection, multiple particle event rejection, electron rejection
- Sample size:
  - 500 k MC events (accepted 25 k – 300 k)
  - 150 k – 700 k data events (accepted 20 k – 450 k)

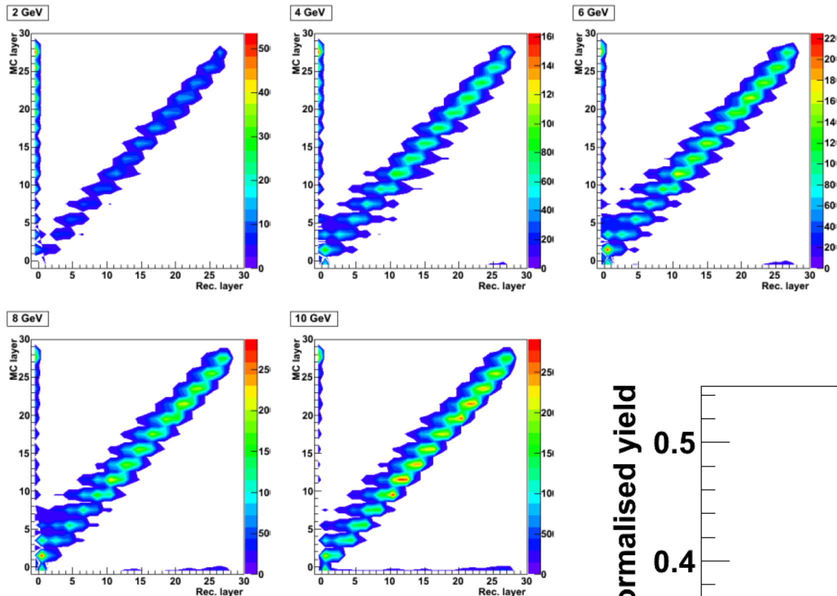


Event Classification

- Classify events as interacting or non-interacting
  - The absolute and relative energy increase in subsequent layers defines the interaction point
- In the note each category was again subdivided, but these criteria depended strongly on event cuts and will not be applied for the paper
- We will refine the event classification with machine learning techniques (more independent criteria) in future

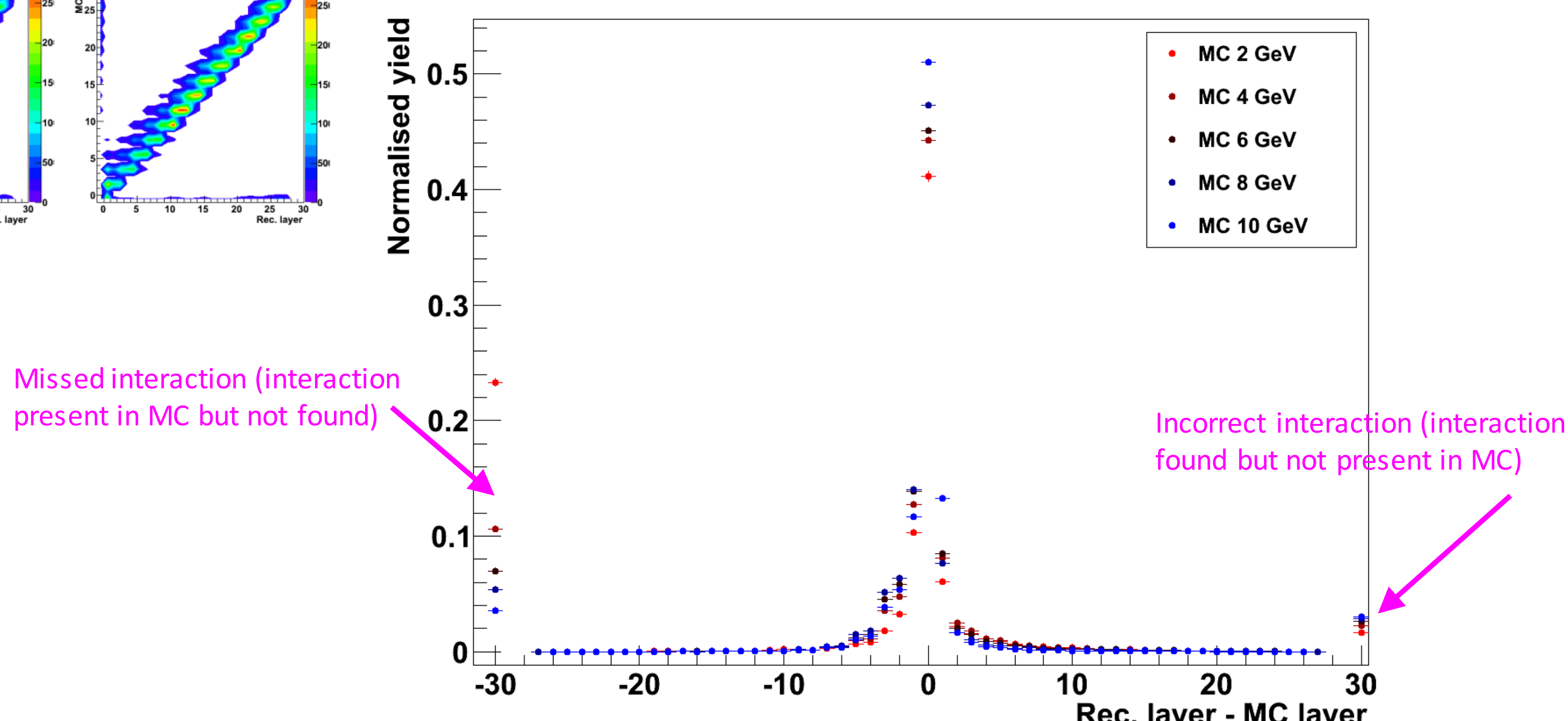
Interaction Layer





Monte Carlo π^- events (QGSP_BERT)

Other physics lists have a very similar distribution



Interaction finding Efficiency

Depends on MC physics list, especially at low energy,
Bertini/Fritiof based models have the lowest efficiency

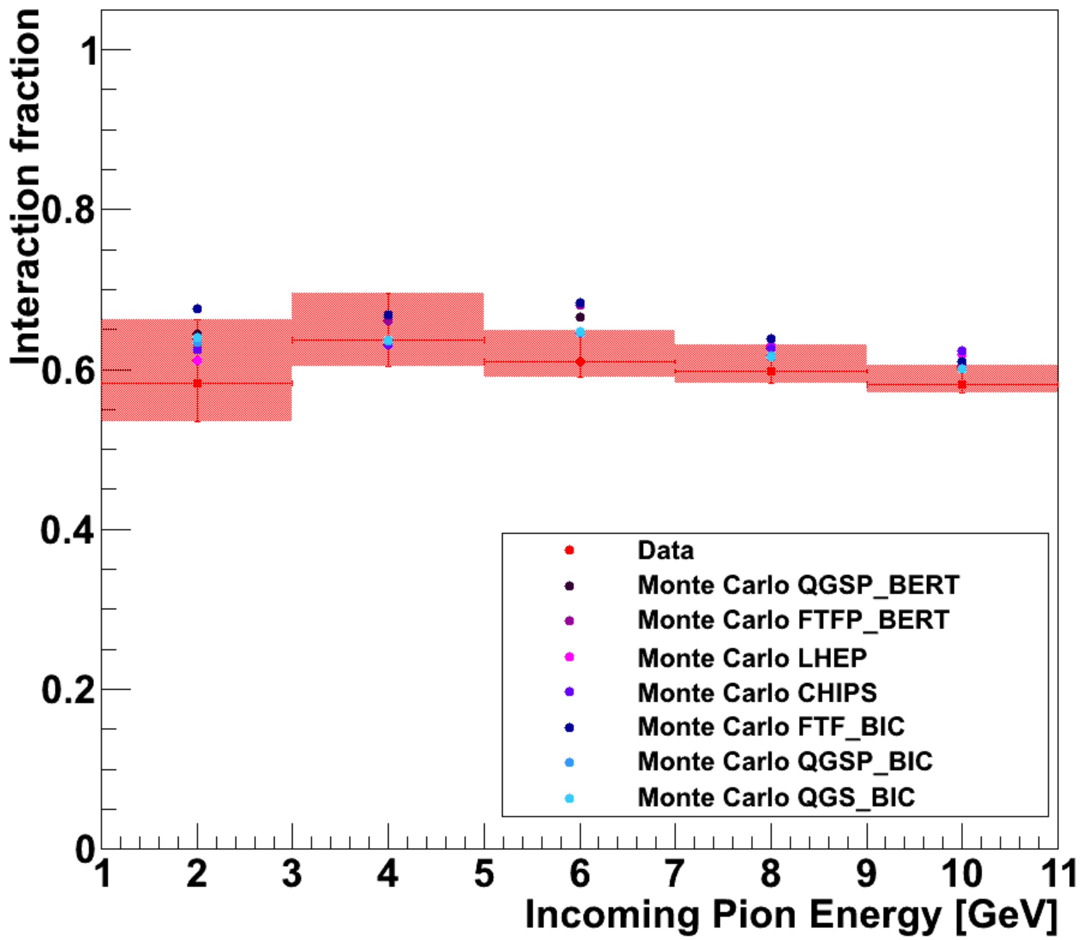
Energy (GeV)	QGSP_BERT	FTFP_BERT	FTF_BIC	QGSP_BIC	QGS_BIC	LHEP	CHIPS
2	0.65	0.66	0.66	0.75	0.75	0.79	0.76
4	0.84	0.84	0.77	0.88	0.88	0.92	0.89
6	0.90	0.95	0.86	0.93	0.94	0.96	0.94
8	0.92	0.95	0.90	0.96	0.96	0.96	0.96
10	0.94	0.95	0.93	0.96	0.96	0.96	0.96

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

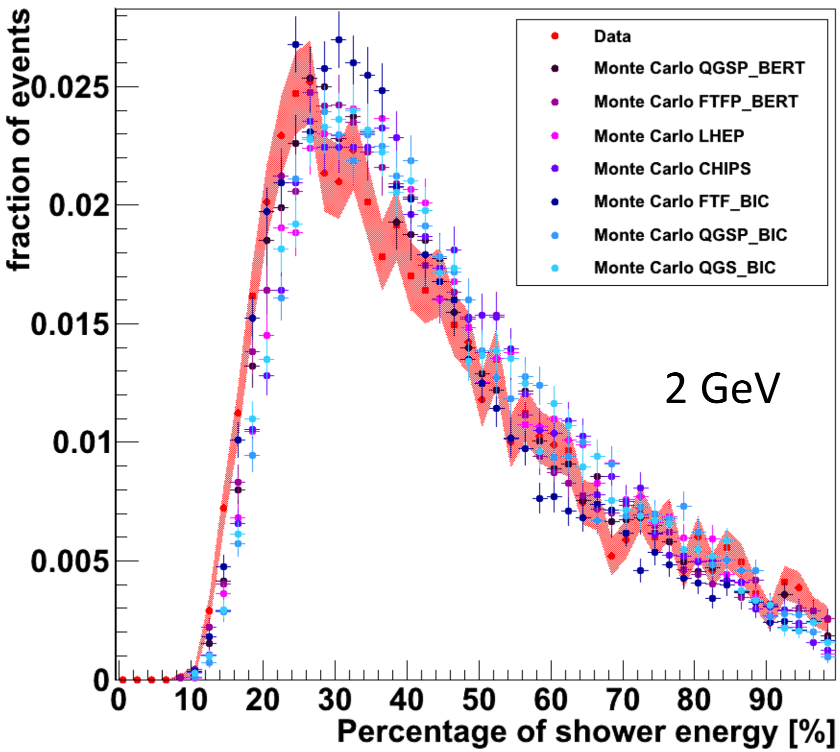
Contamination = fraction of all events classified as interacting that is non-interacting
Between 0.03 at 2 GeV and 0.05 at 10 GeV

Interaction Fraction

The interaction fraction is rather constant with beam energy
The error on the data is based on the spread in MC interaction finding efficiency

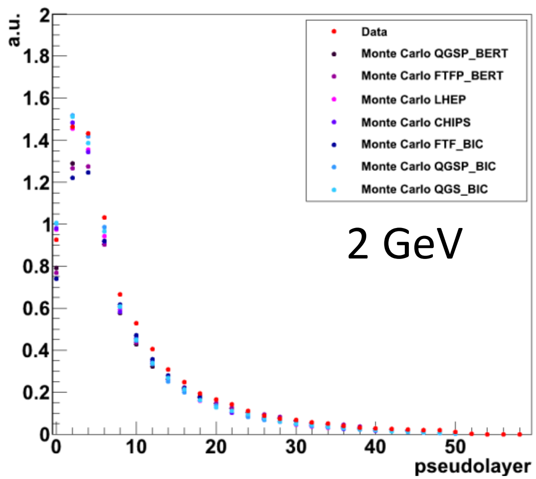


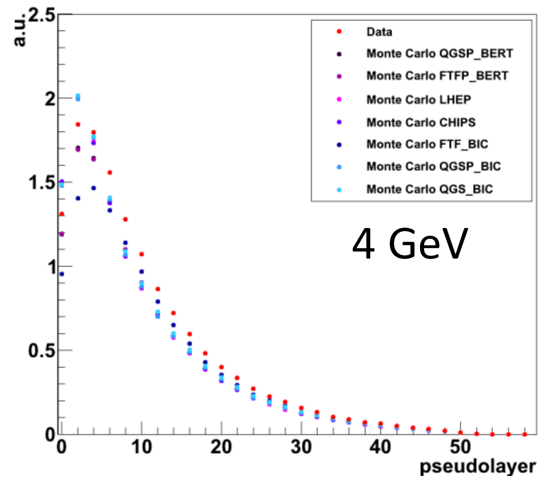
High energy fraction in single layers

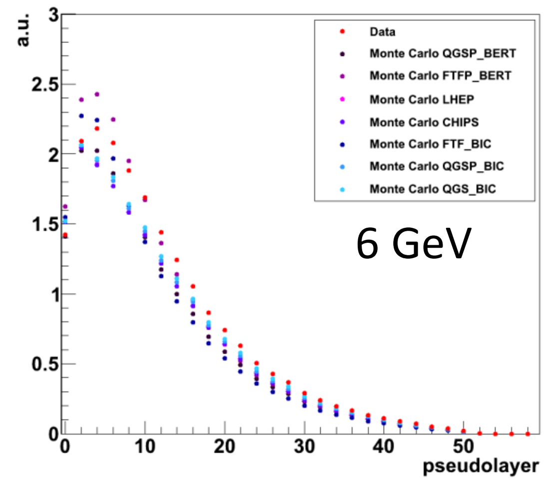


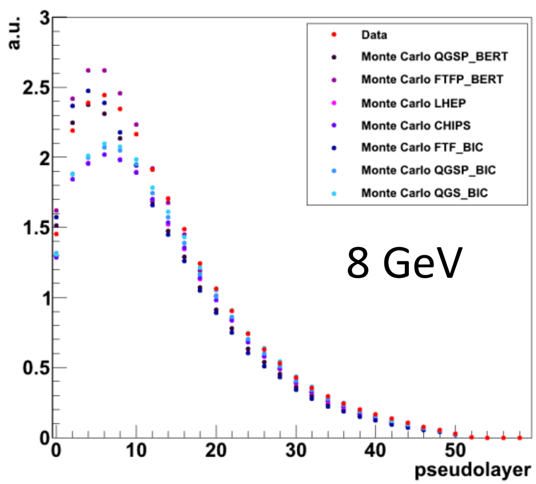
At 2 GeV for 21% of events more than 60% of the energy is deposited in a single layer!
At 10 GeV this is only 3%
Similar observation reported by Tohru Takeshita
at the last CALICE collaboration week at Desy.

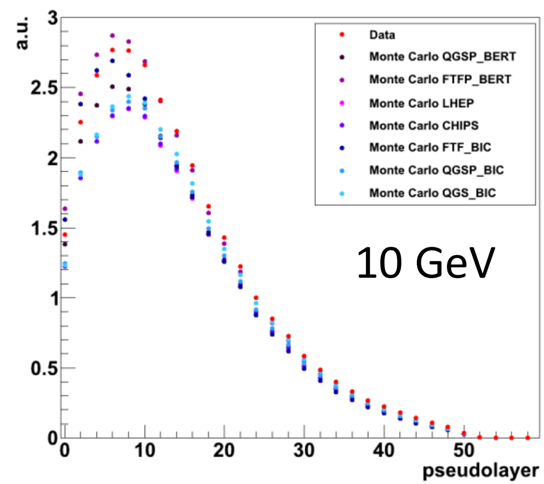
Longitudinal Energy Profile for events classified as interacting









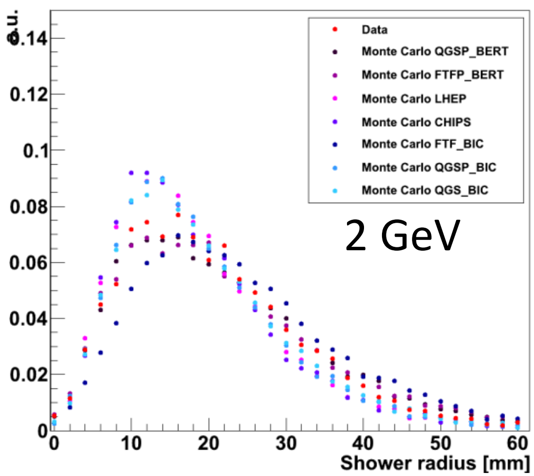


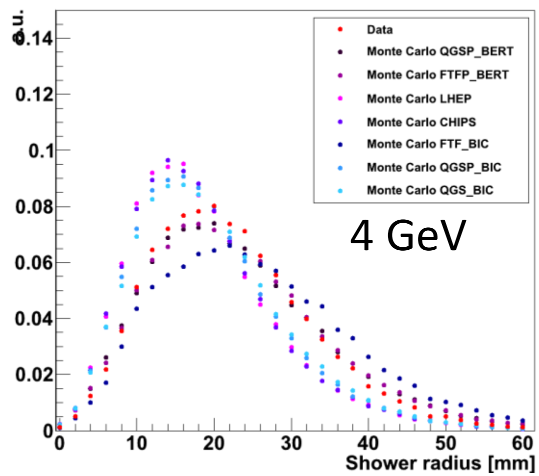
The data is not well described by the MC. Fritiof based models fit best.

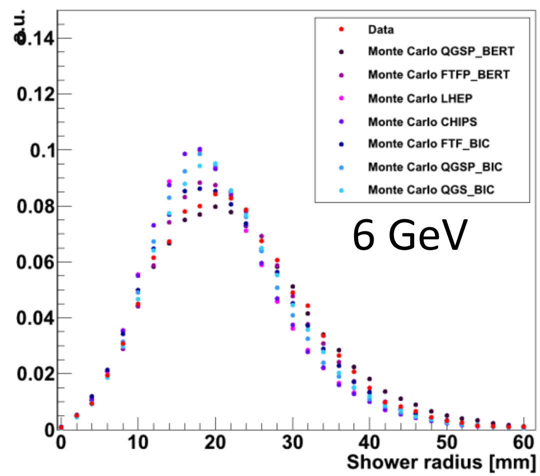
For non-interacting events the profile is approximately flat.

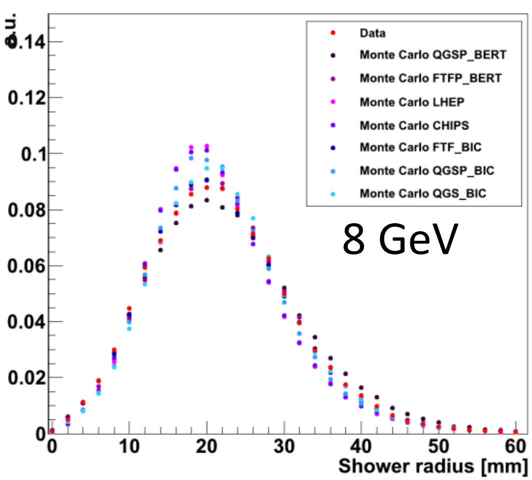
Mean Shower Radius for events classified as interacting

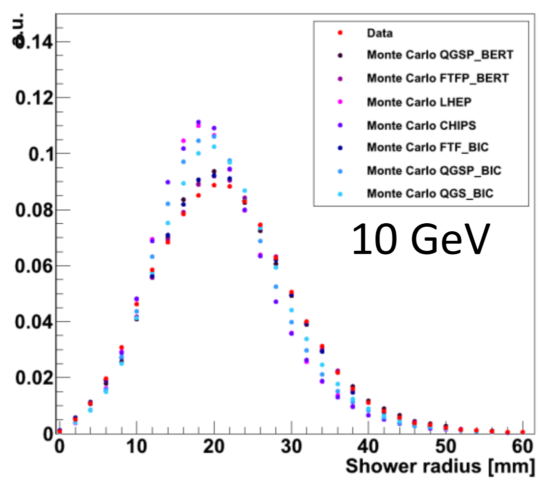
$$< r >_E = \sqrt{\sigma_{E,x}^2 + \sigma_{E,y}^2}$$











Clear difference between data and MC especially at low energy.
Fritiof/Bertini models have a similar peak position, others models have on average a smaller shower radius.

Summary

- Interacting events can be identified with an efficiency above 65%.
- These are compared to MC physics lists.
- Fritiof and Bertini based models seem to describe the data best.

- Next:
  - Finalize the paper by evaluating the error contributions

- Since October 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]

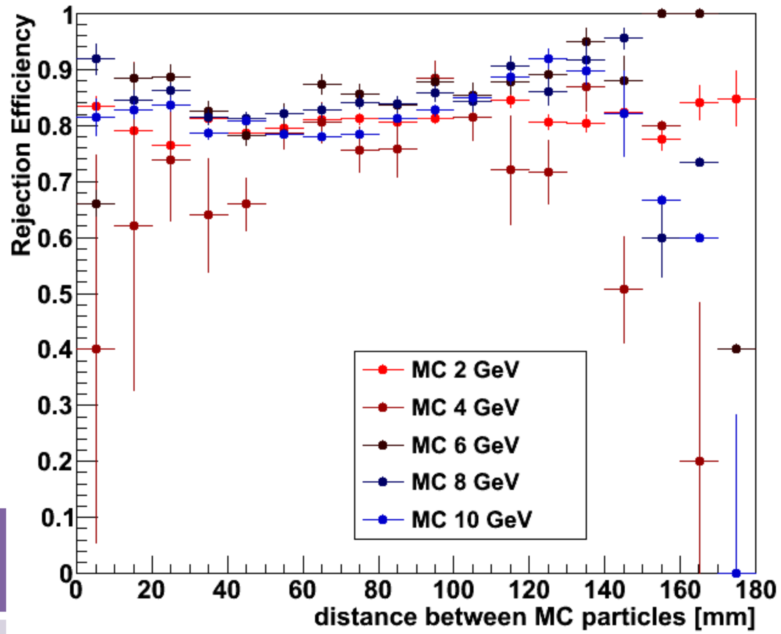
Selection criteria for event types

- 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

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



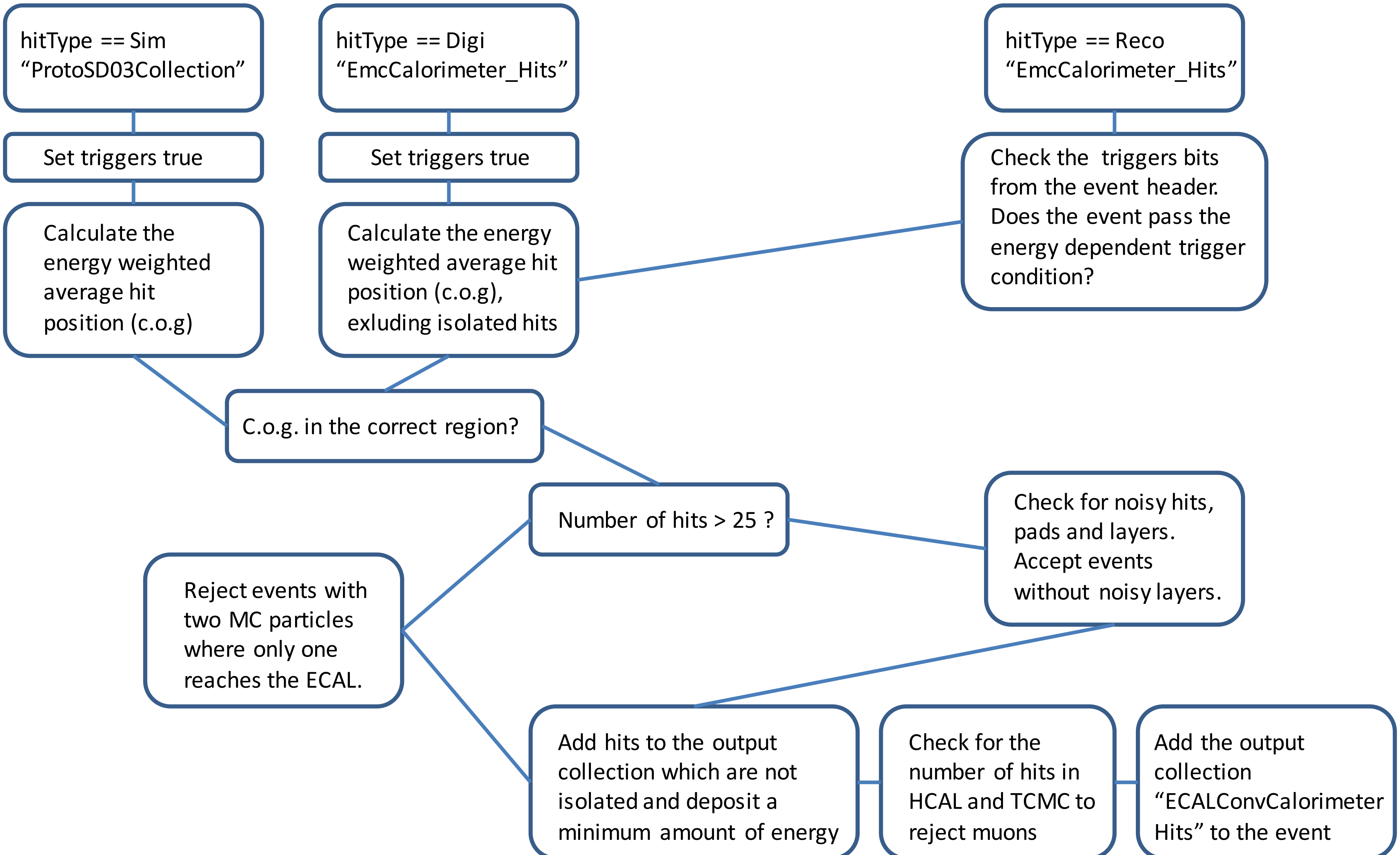
MC physics list FTFP_BERT

Estimate the contamination of “double events” in the accepted event sample in data

- Upper limit: Assume all rejected events were real double events
  contamination = $(1-eff_d)/eff_d*rejected$
- Estimate: rejected events are the sum of double and single events
  contamination = $(1-eff_d)*(rejected - eff_s*total)/(eff_d - eff_s)$

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

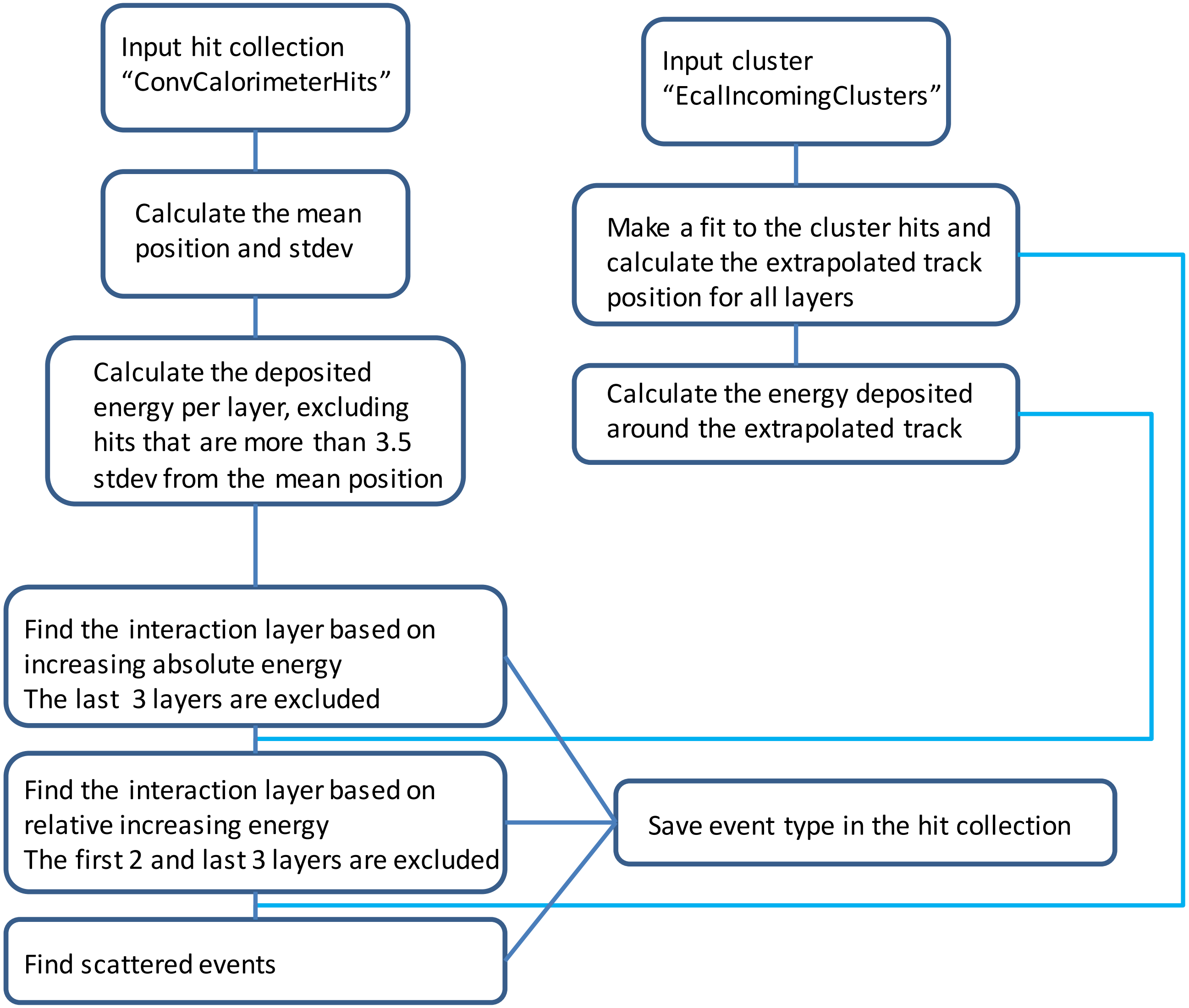
Step 1: SelectAndConvert



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