Rejection of Rock Muon Background with ECAL

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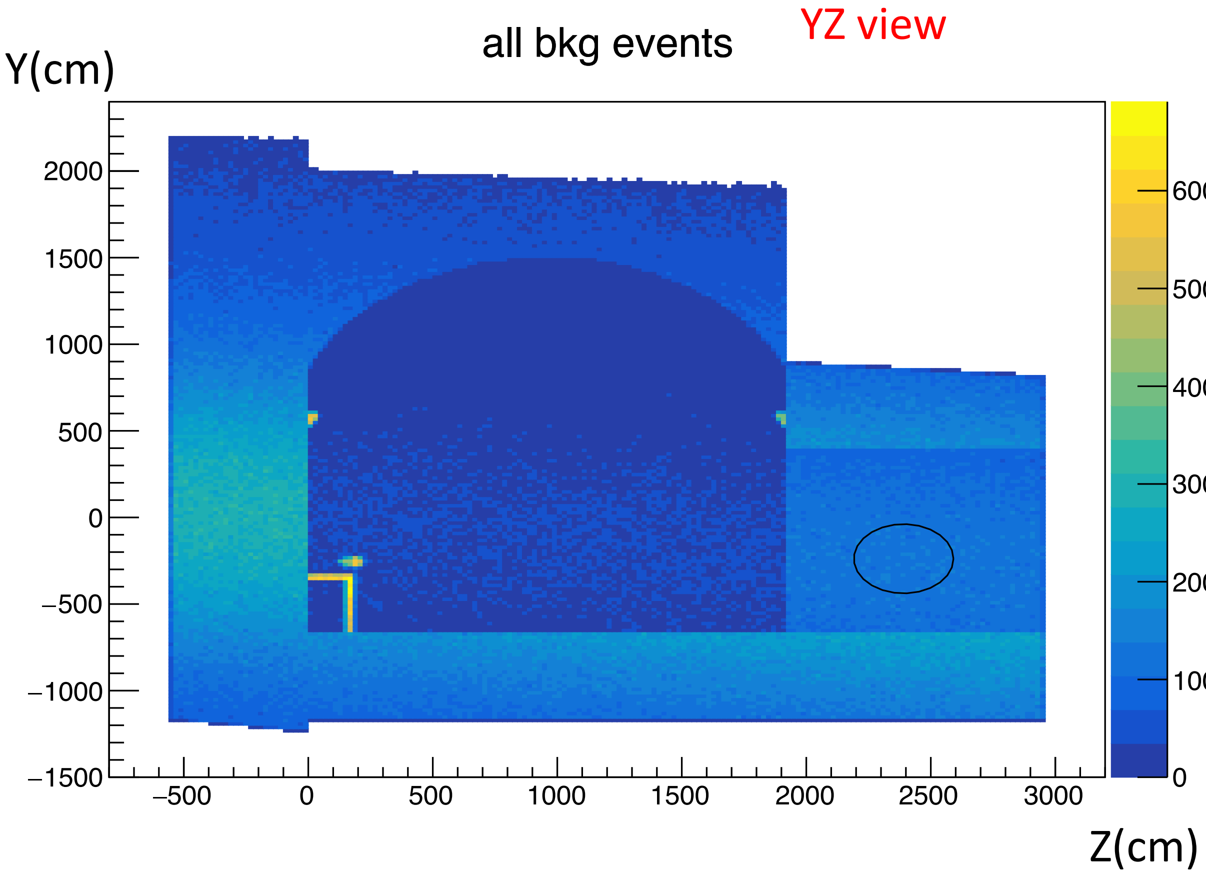
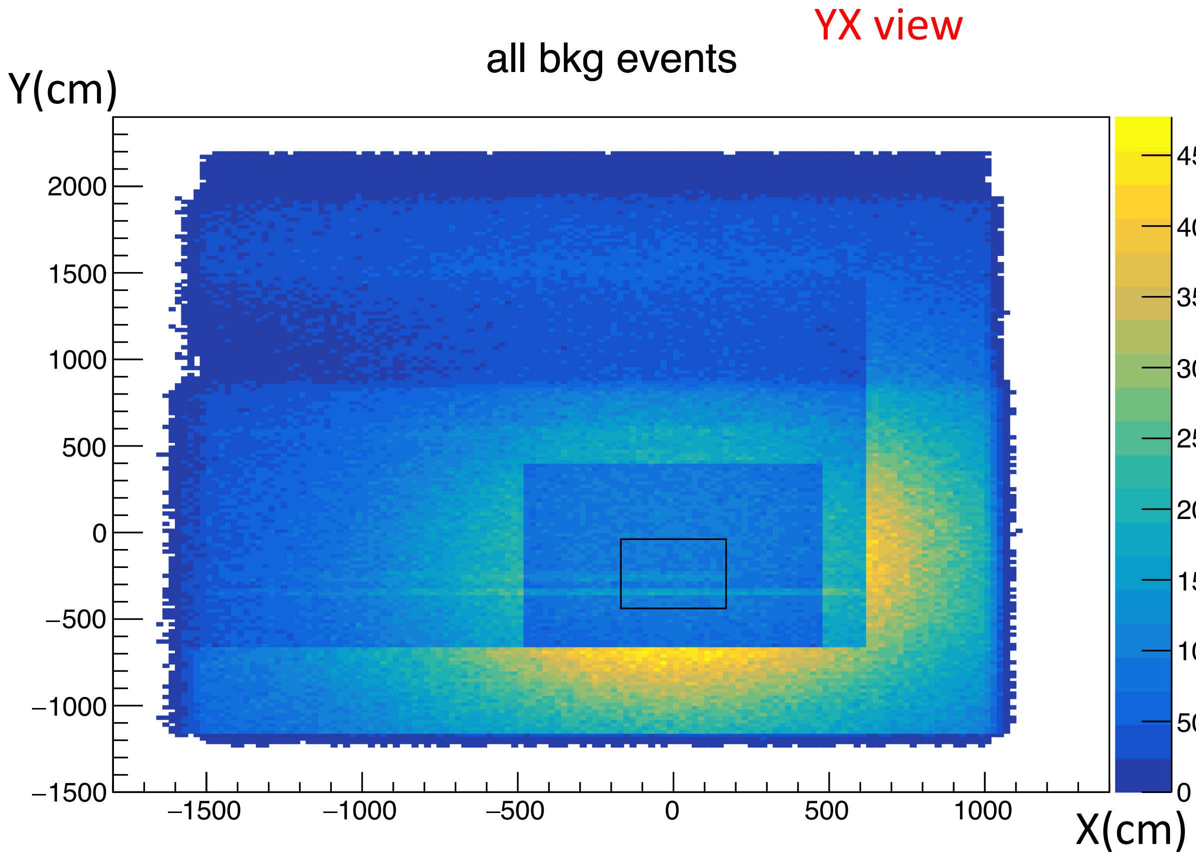
Analysis Framework

- This background study is focused on beam monitoring using Ecal
- ECAL+STT detector configuration as in docdb # 13262
- Signal: Ecal events in "Front Ecal FV"
  - Front Ecal FV: Z<Z0, |x|<1.69m, |y|<2.0m
- Background: muons from CC interactions in surrounding rocks of ND hall
- Analysis chain: GENIE-> Edep-sim(Geant4)->reconstruction smearing from hits

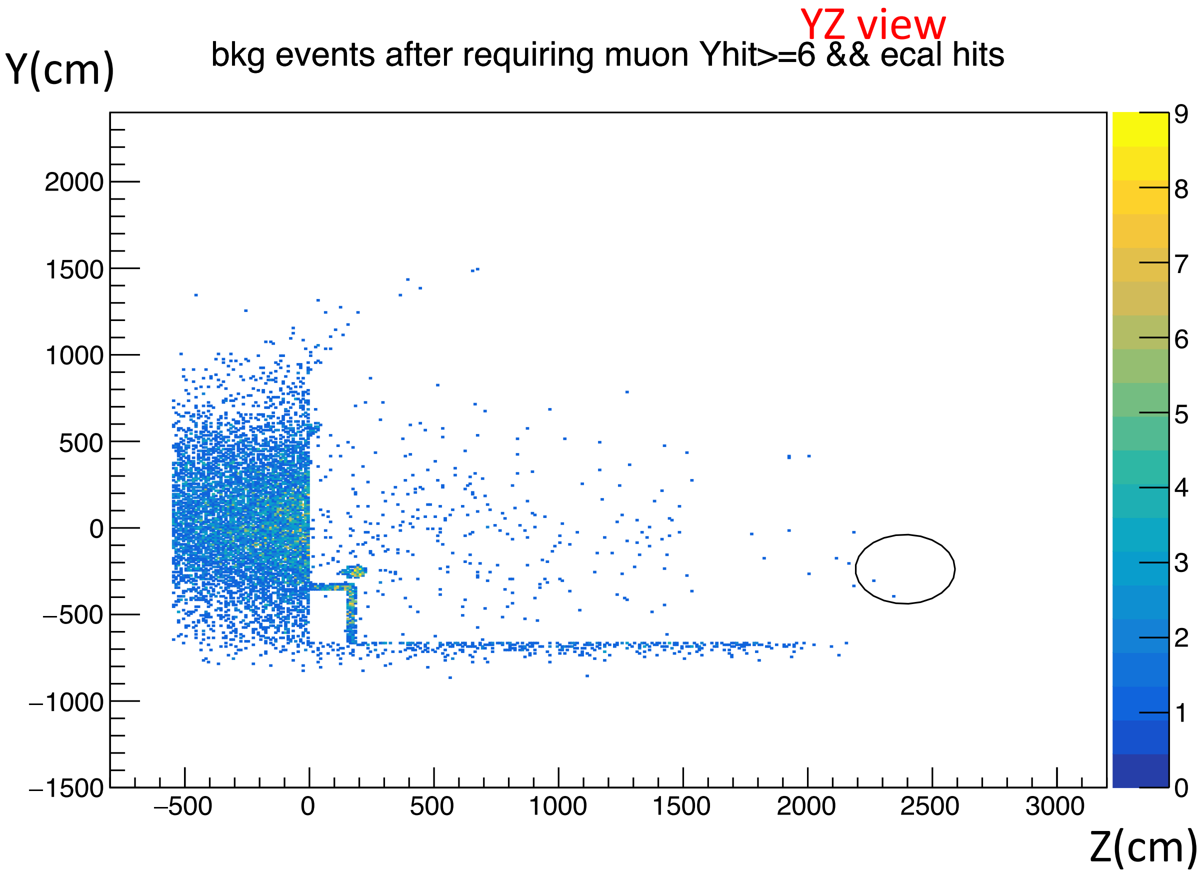
Rock Events

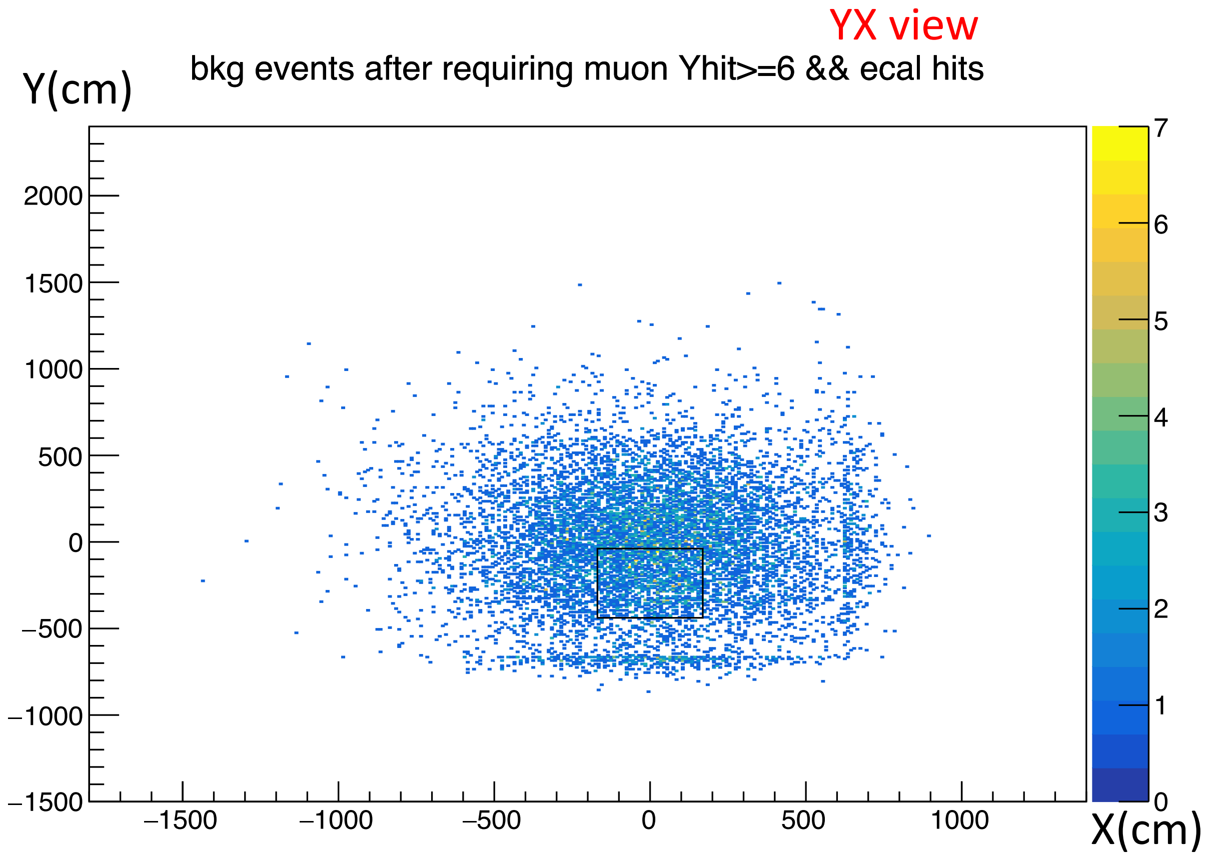




Initial vertex distribution of simulated events

Rock events reconstructed in SAND





- Reconstructed muon in STT with N(Y) hit >=6 (YZ: bending plane) ,
- Reconstructed hits in FV of front ECAL with deposited energy in (active) cell >= 100 keV

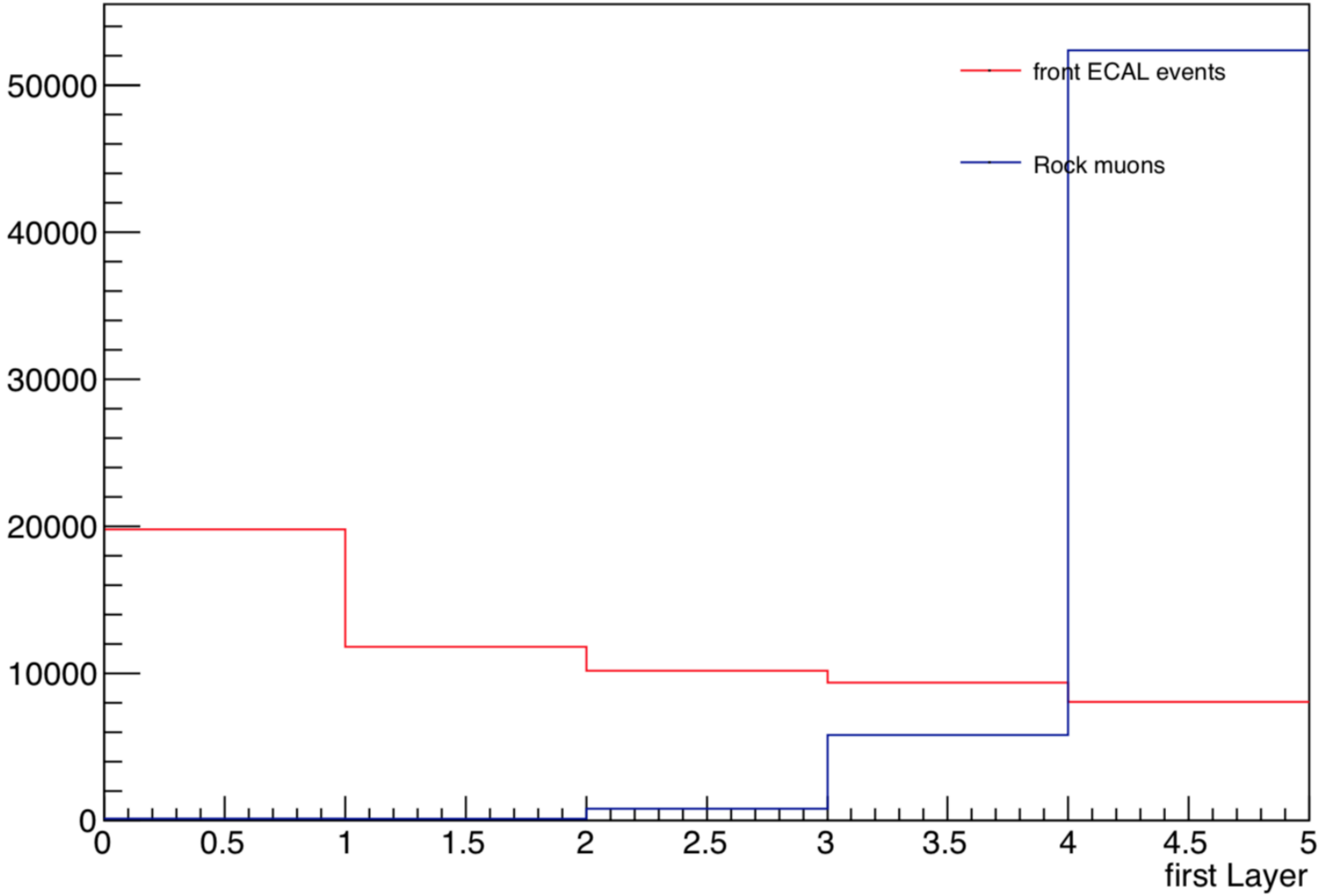
Reconstruction and selection efficiency

- Events from the side and downstream rocks result in negligible background in front ECAL FV
- Background from rock muons almost entirely from rocks & materials in front of SAND
- Background reconstructed in STT and ECAL: 2%
- Signal reconstructed in STT and ECAL : 77%

Ecal timing

Earliest Hit:	Layer 0	Layer 1	Layer 2	Layer 3	Layer 4
Ecal events	33.4%	20.0%	17.2%	15.8%	13.6%
Rock muons	0.22%	0.20%	1.35%	9.81%	88.4%

(distribution normalized to same area , for illustration)



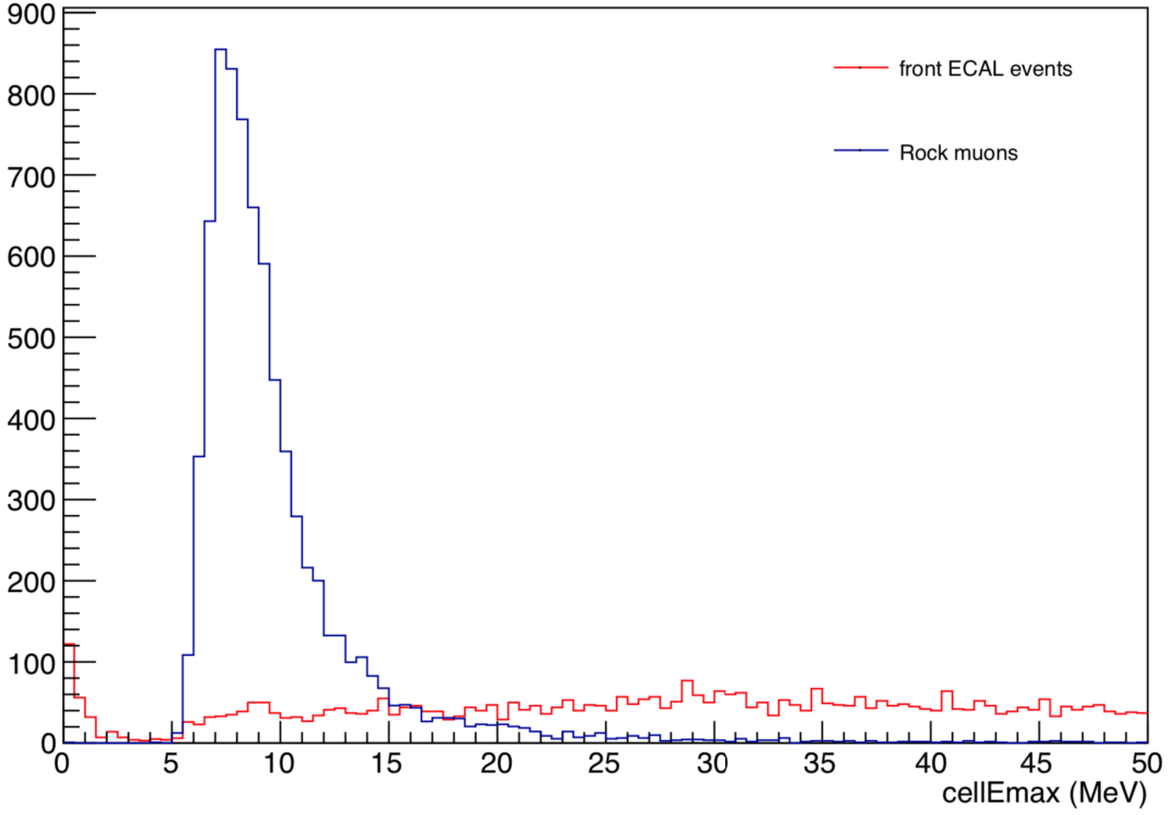
- Apply smearing according to average ECAL timing resolution sigma=260ps (to be improved with 54ps/sqrt(E) $\oplus$ 50ps)
- select the ECAL layer (out of 5) with the earliest detected signal

Strategy for event selection

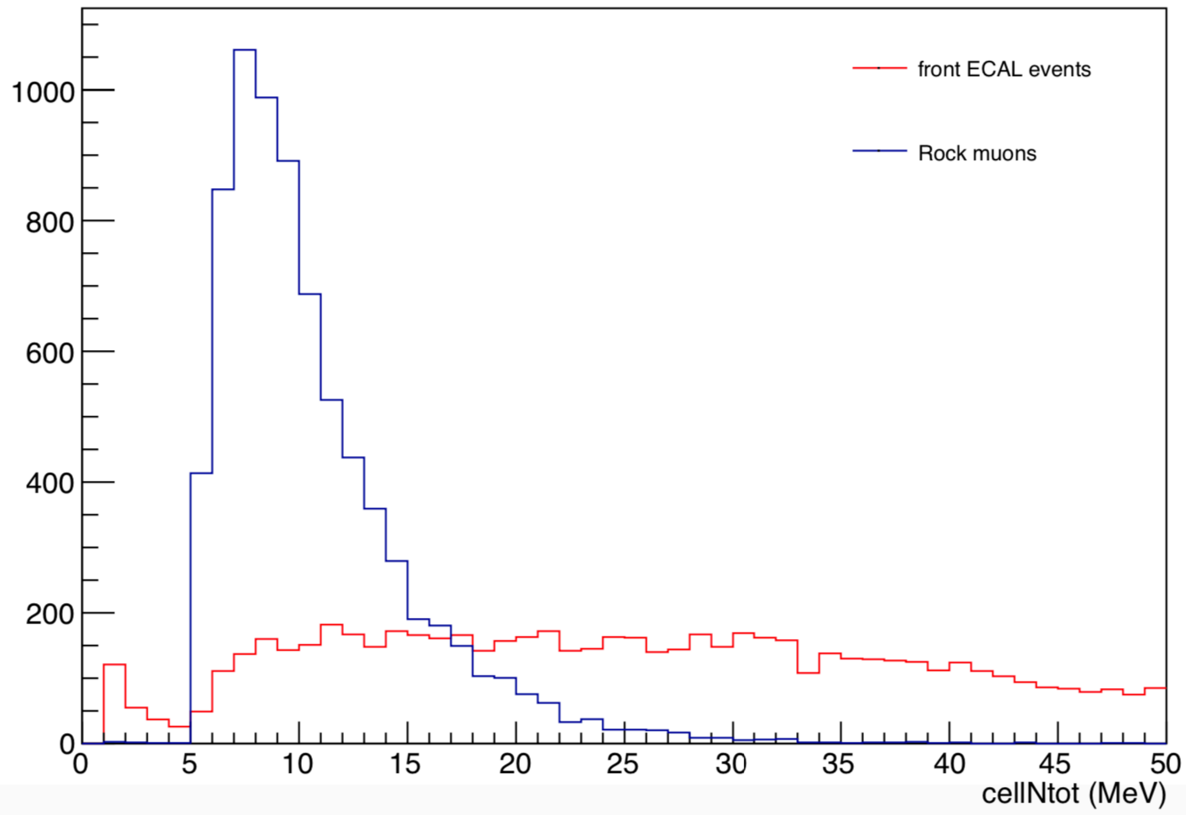
- Select events with the earliest hit in layer == 4 (outermost plane)
- Study the energy depositions and cell topology in ECAL
- Choose various discriminating variables to be used as input of neural network
- Optimize the NN architecture, train and select cut
- Repeat all of the above steps for each of the remaining layers ==3,2,1,0

Events with earliest hit in layer 4

Maximal energy deposition in a cell



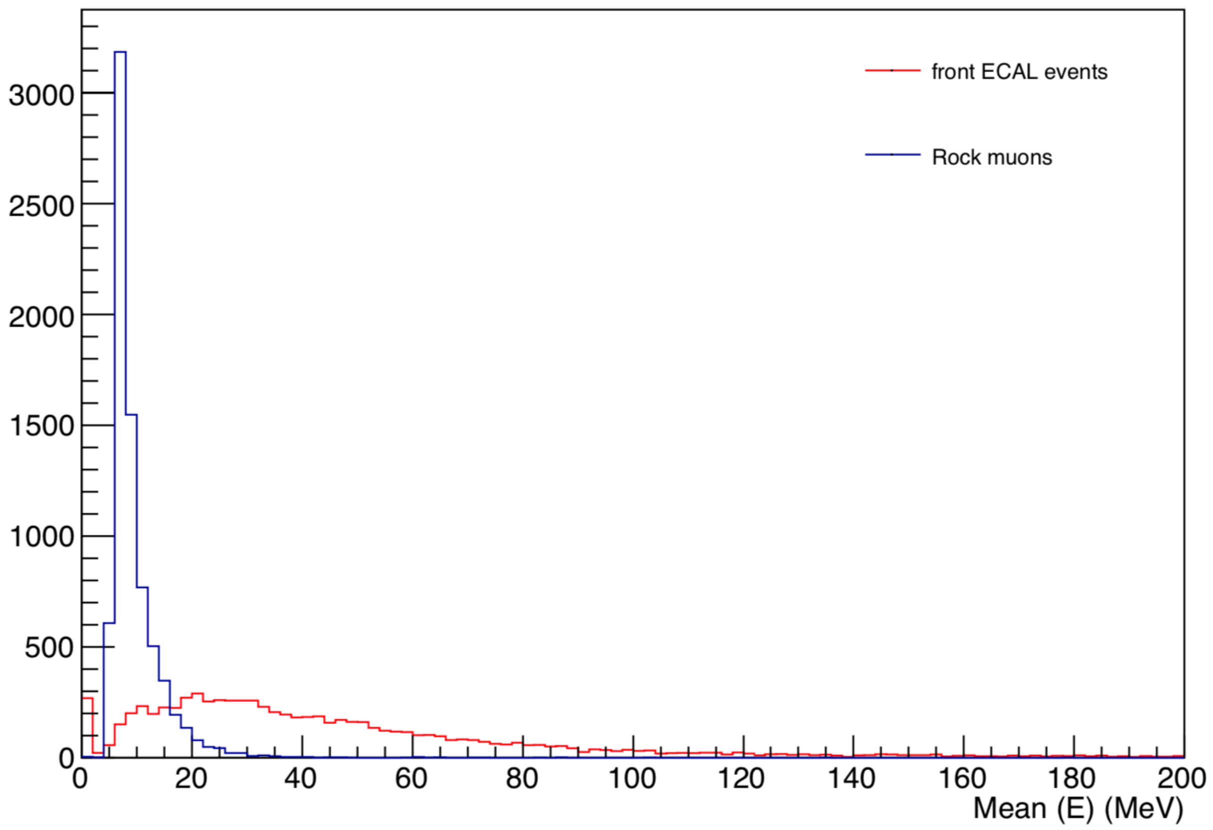
Total number of cells



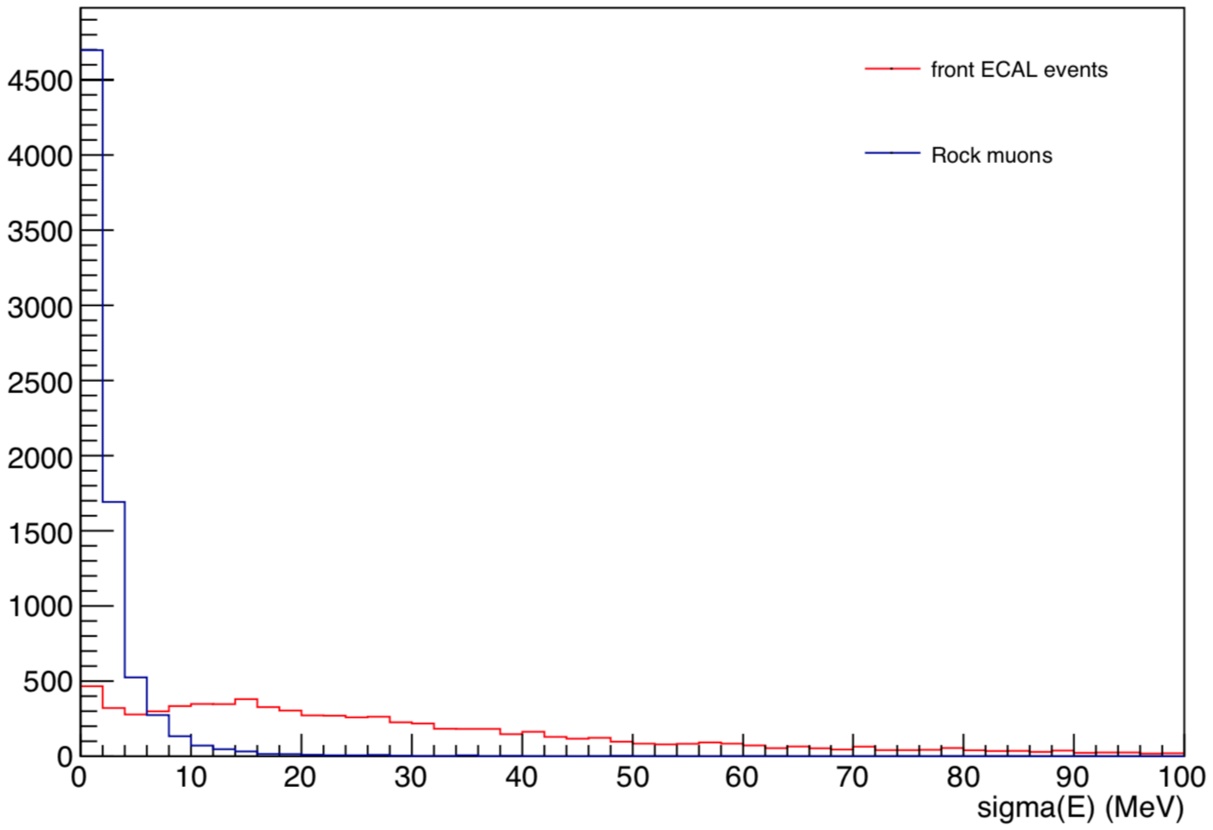
All distribution normalized to same area (for illustration)

Events with earliest hit in layer 4

Average of summed energy in layers

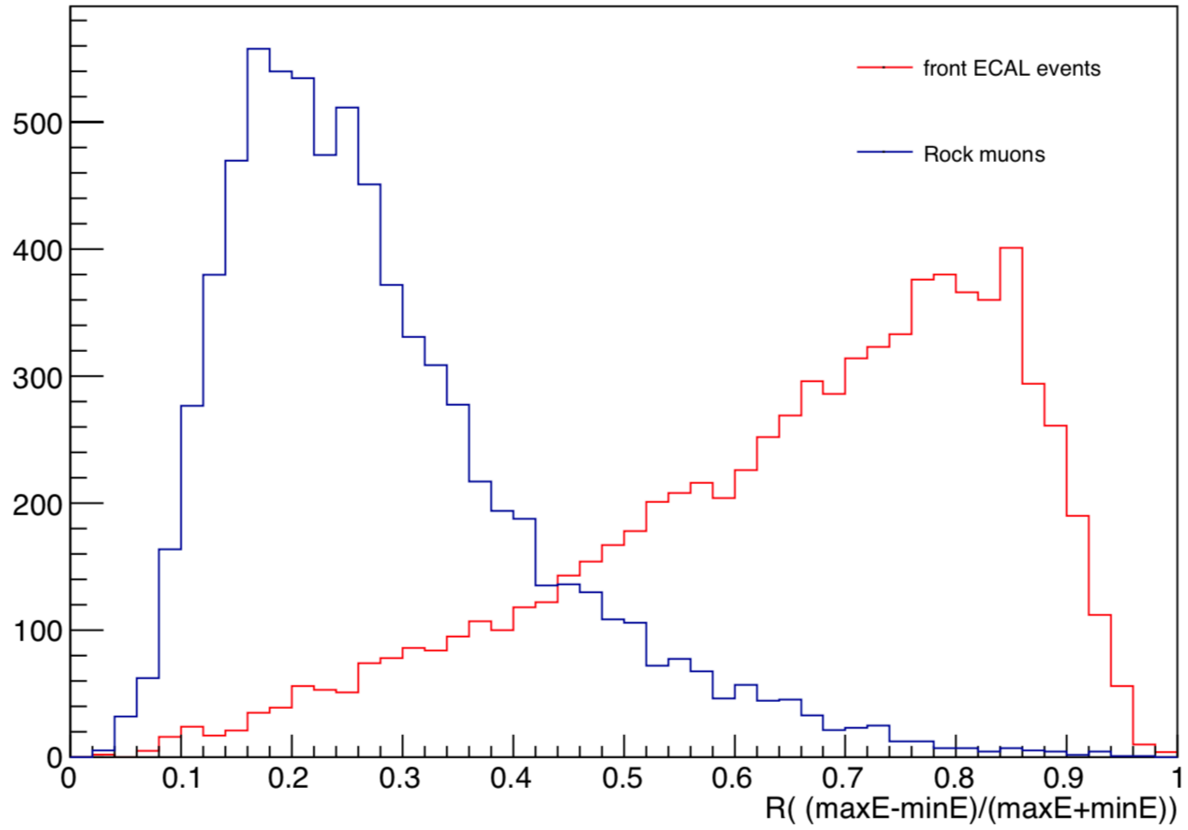


RMS of summed energy in layers

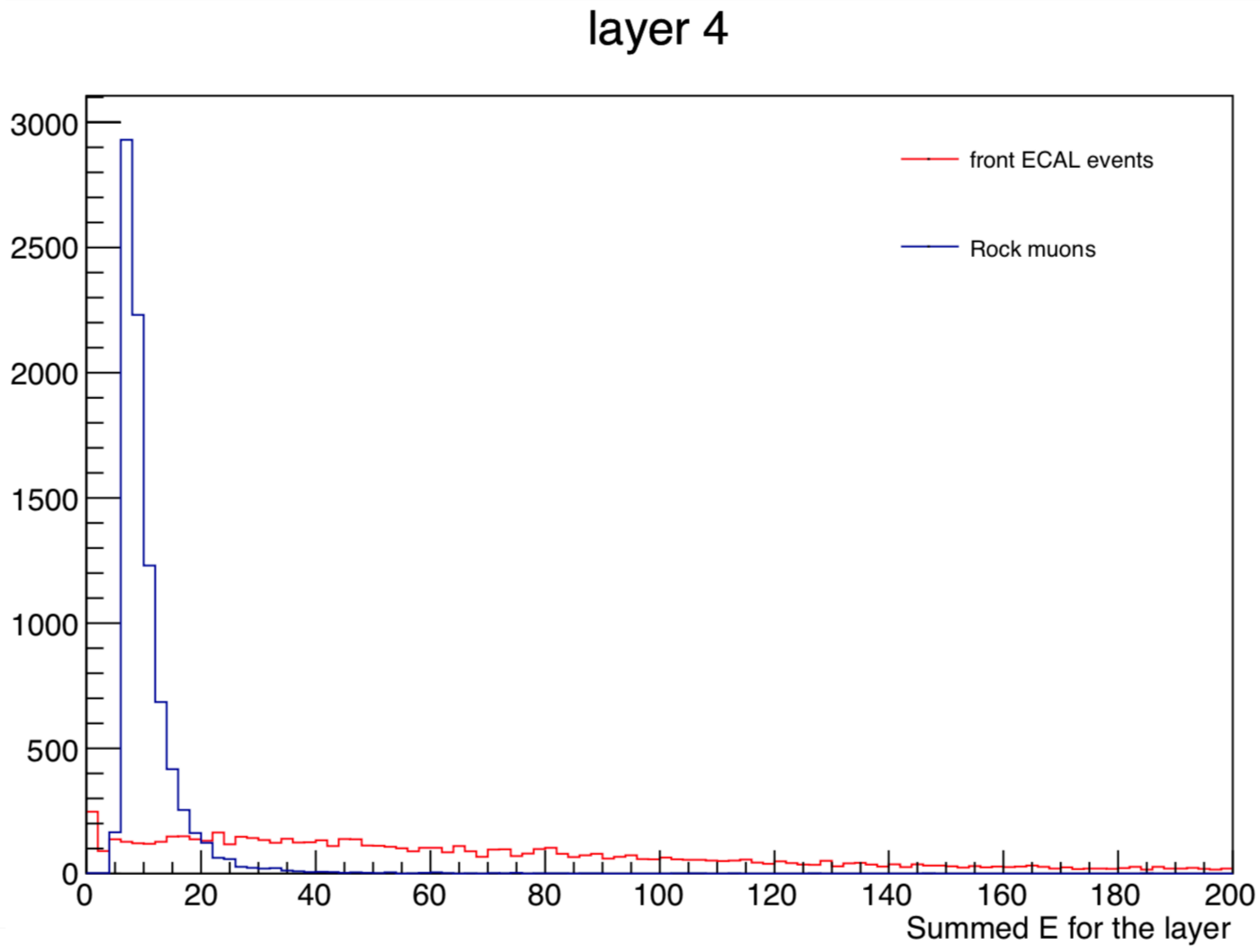


Events with earliest hit in layer4

Energy Asymmetry in different layers

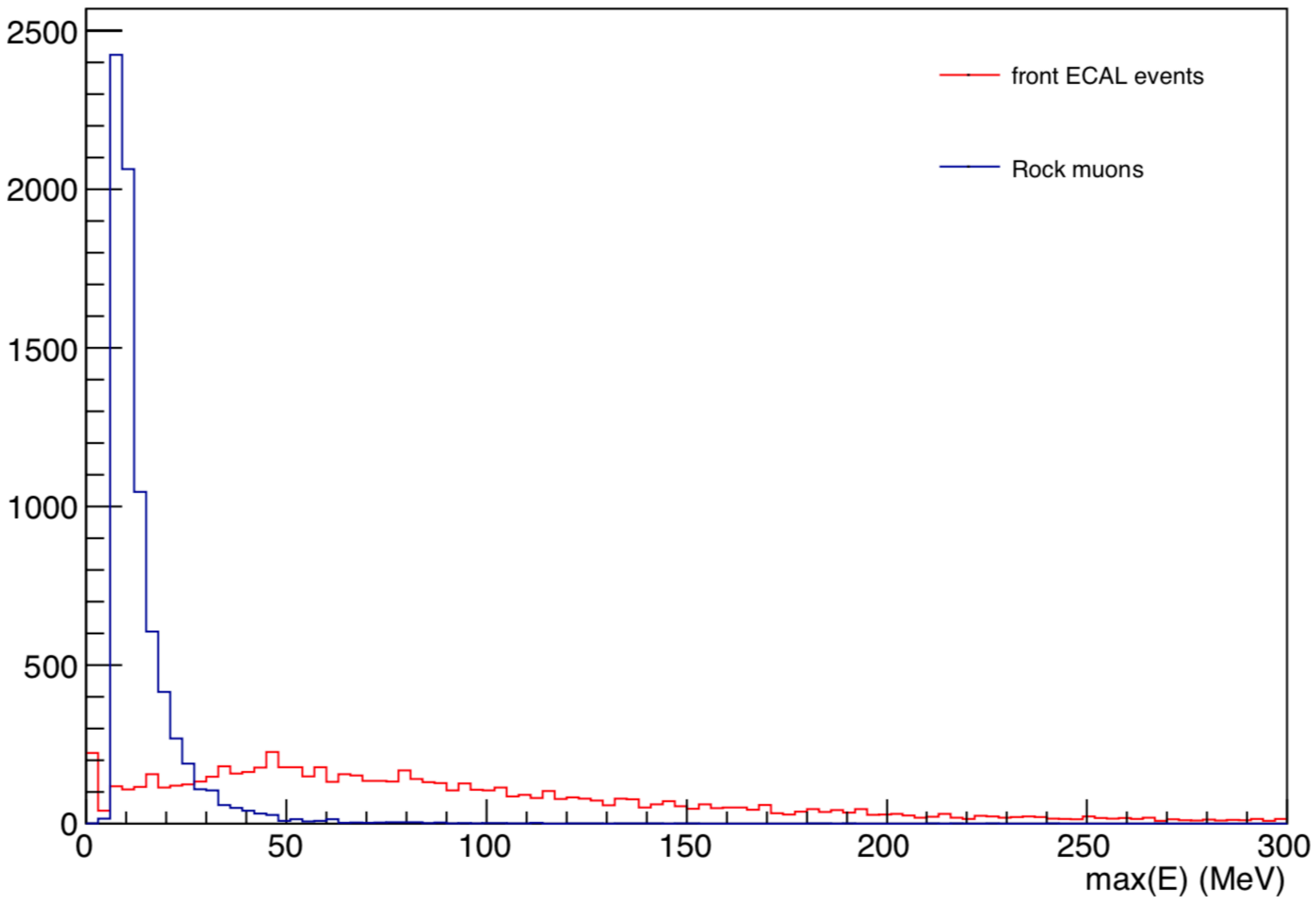


Energy depositions in layer 4

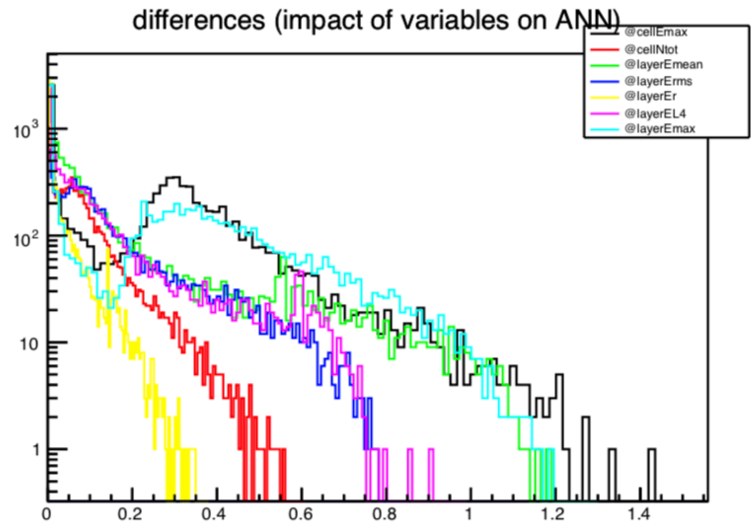


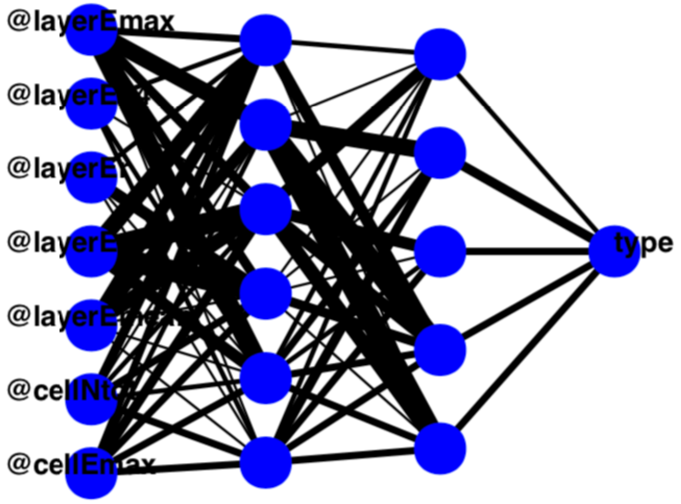
Events with earliest hit in layer4

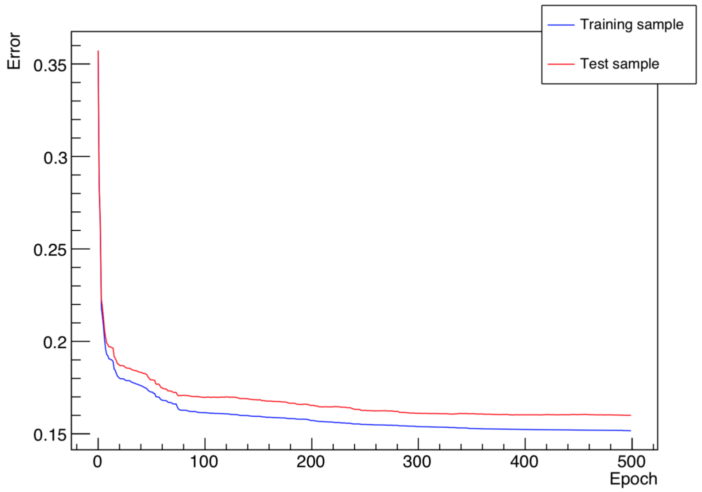
Maximal energy depositions in layers

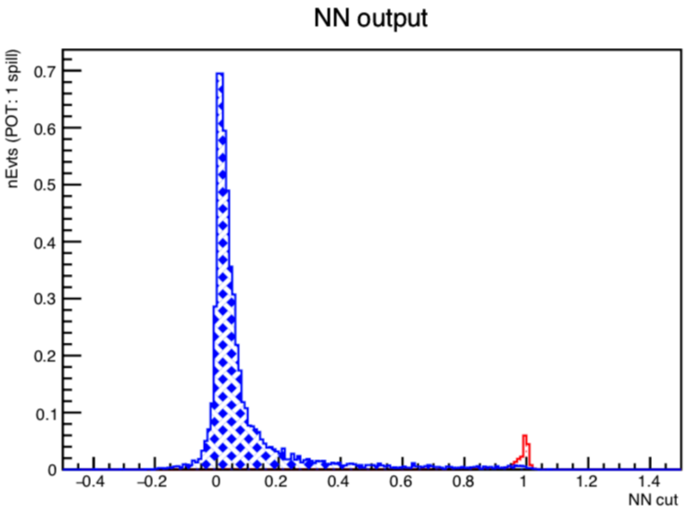


Neural Network results



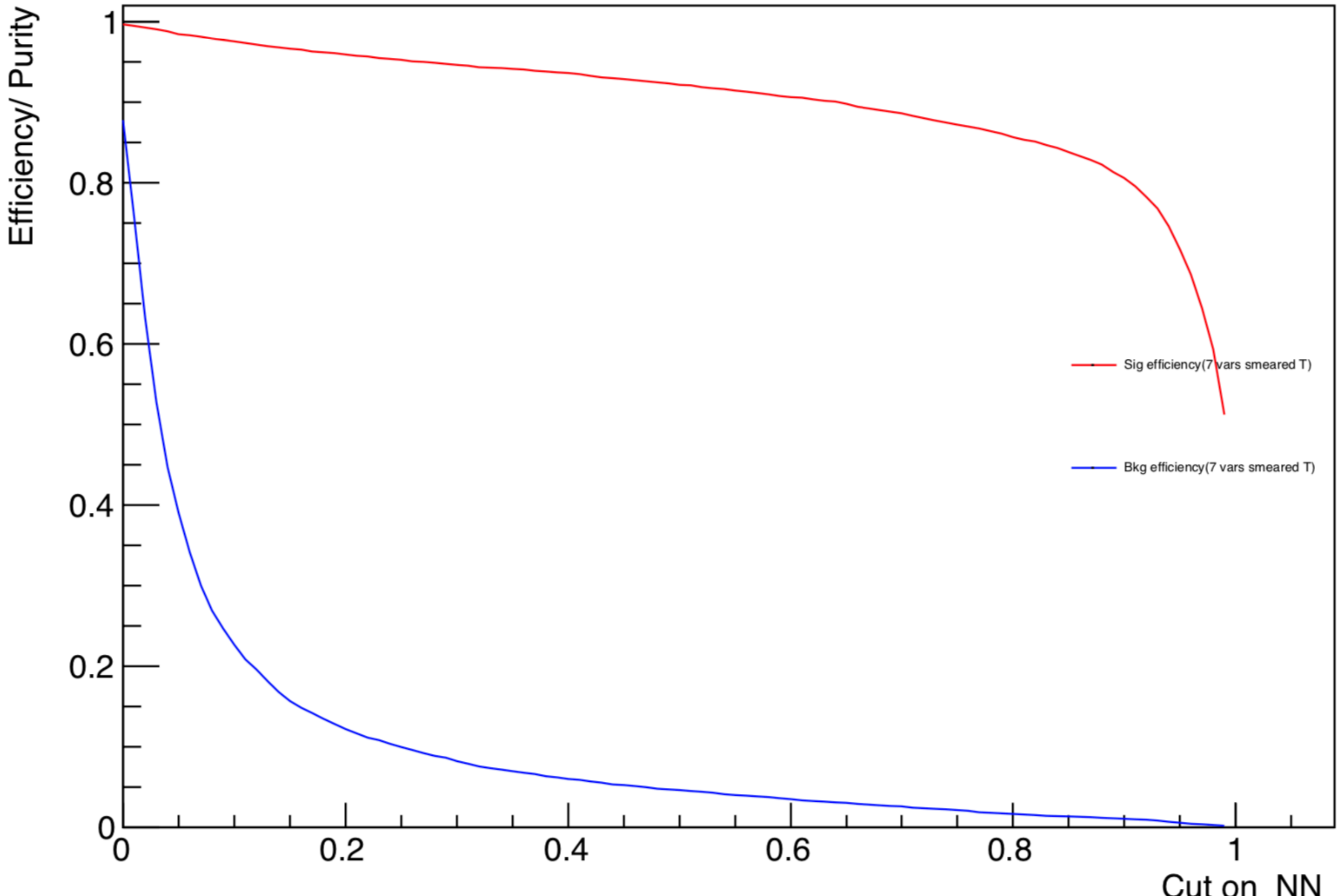






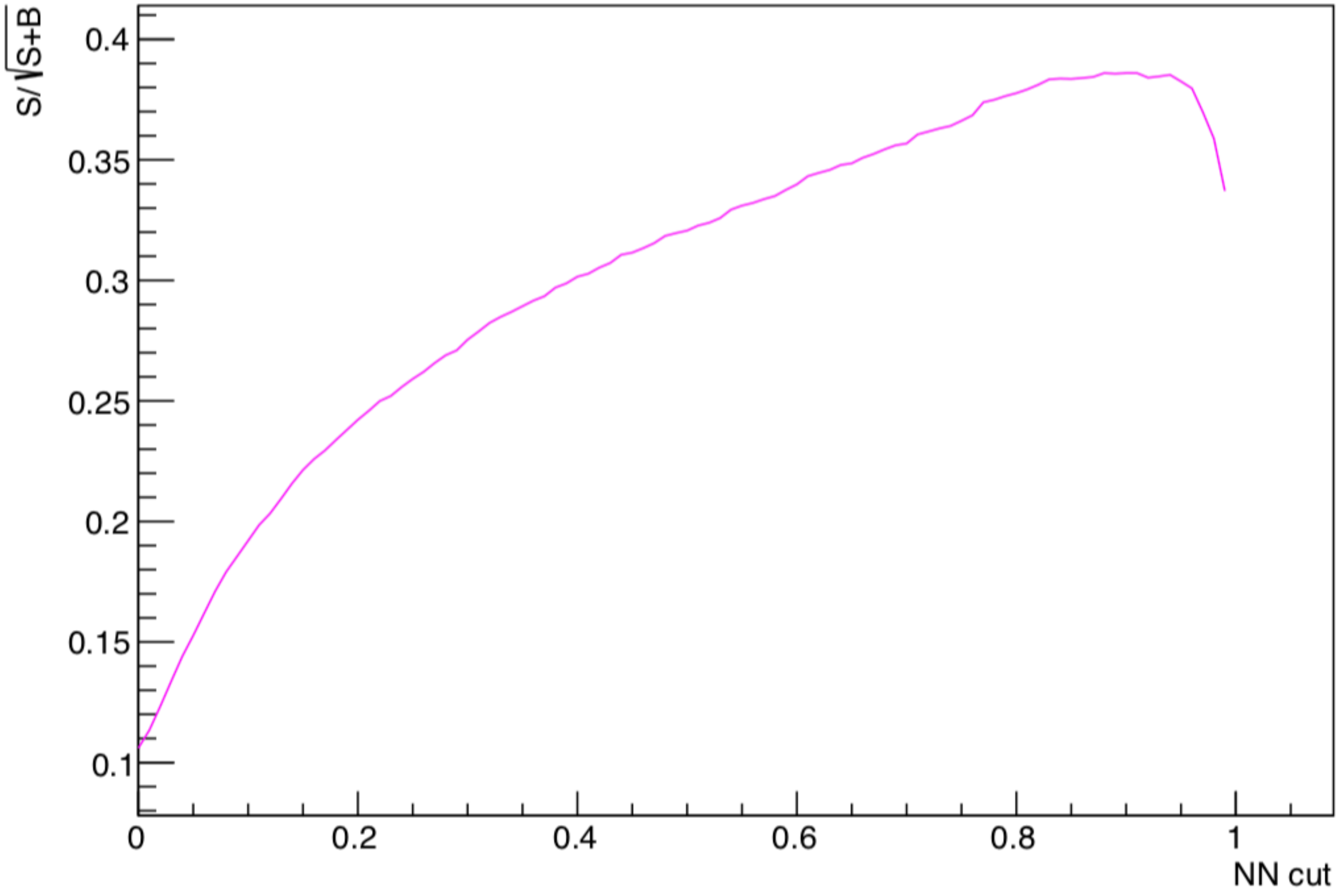
- 8284 train and 8285 test entries, 8063 signal and 8506 background events.
- Events normalized to expected POT per spill : 7.5E13

efficiency VS. NN cut



Example Cut = 0.64
Signal eff: 90%
Bkg eff: 3.3%

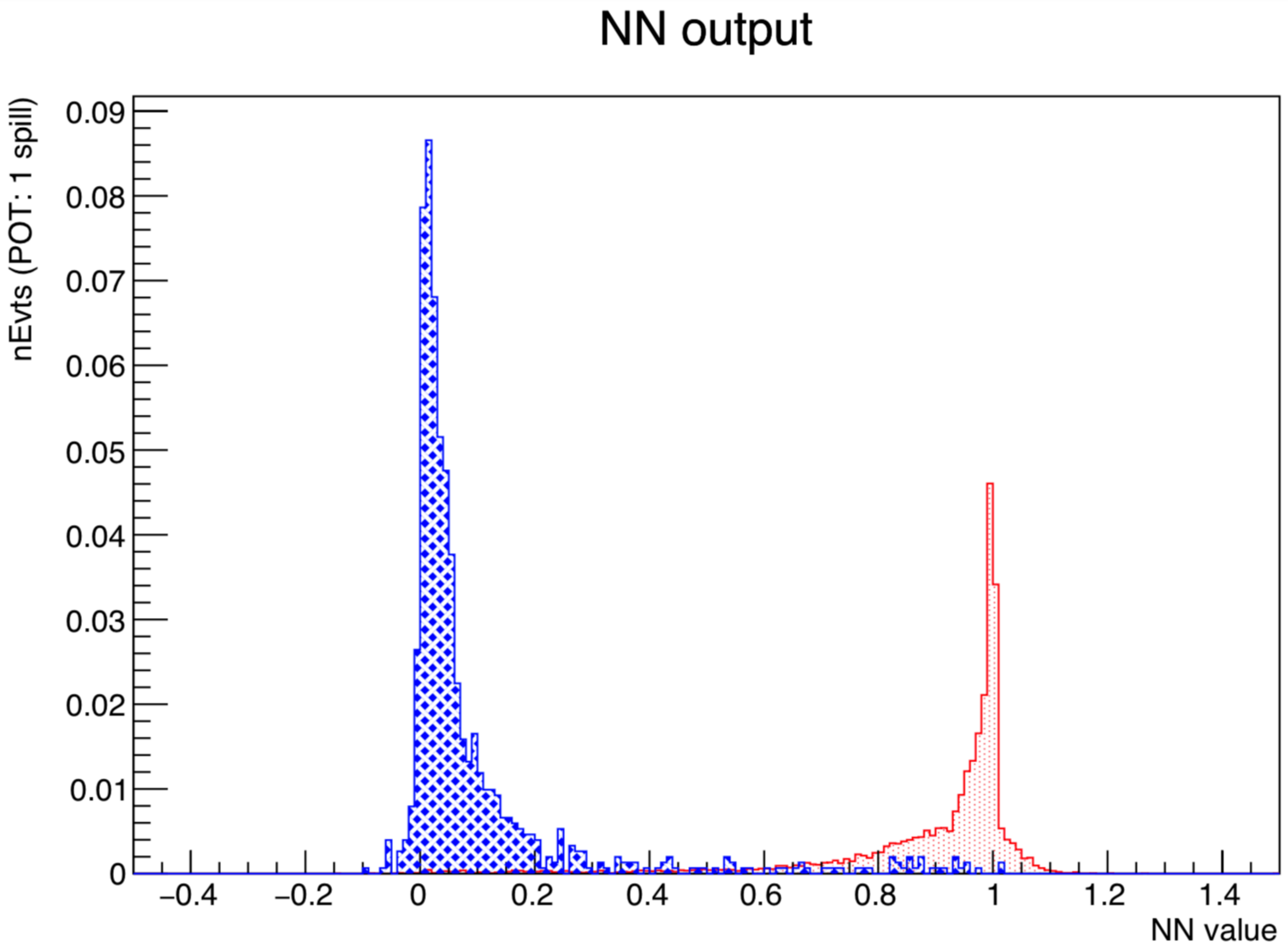
The final cut will be optimized



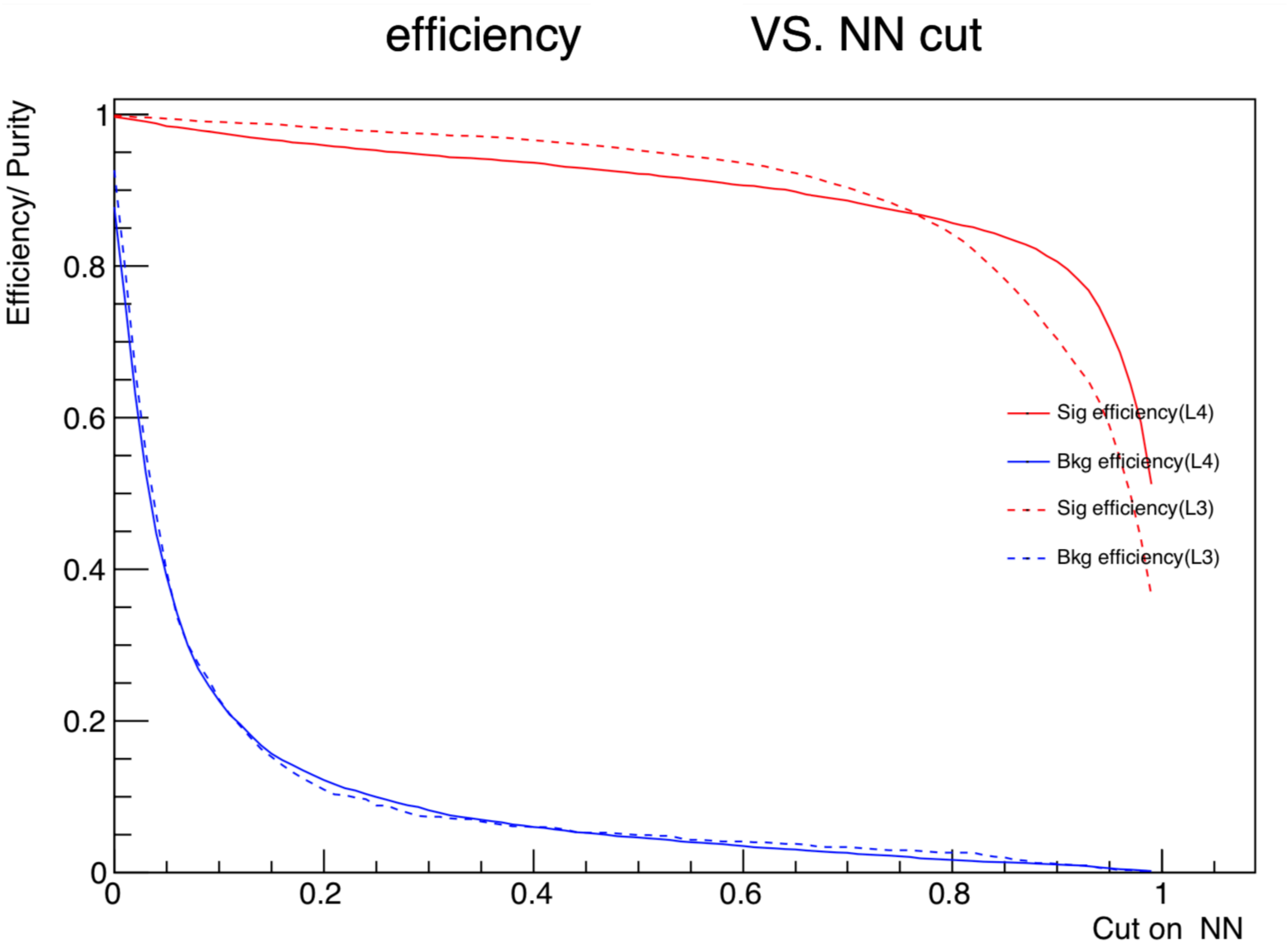
Samples normalized to expected POT per spill

Events with earliest hit in layer3

- Repeat same procedures used for events with earliest hit in layer4
- Due to limited statistics available from simulated events, use the same NN trained in layer4
- To be optimized and improved with higher statistics in future



- Neural network result without retraining
- Distribution normalized to expected POT in one spill



Distribution normalized to expected POT in one spill

Example Cut: 0.43
Signal eff: 95%
Bkg Eff: 5.3%
FOM: 94.2

Events with Earliest hit in layer==2,1,0

- Repeat same procedures described before for each layer : 2,1,0
- Very limited statistics available at the moment, don’t apply NN
- Will optimize in the future with enough statistics

Summary of event selection

Events Per spill (7.5E13POT)	Ecal events	signal efficiency	Rock events	bkg efficiency
No Cut	2.29	100%	1447.26	100%
Muon in ECAL FV	2.29	100%	11.51	0.795%
STT N(Y)>=6 & ECAL hits	1.78	77.5%	6.36	0.439%
NN cut	1.72	75.2%	0.25	0.017%

Final S/B=6.9

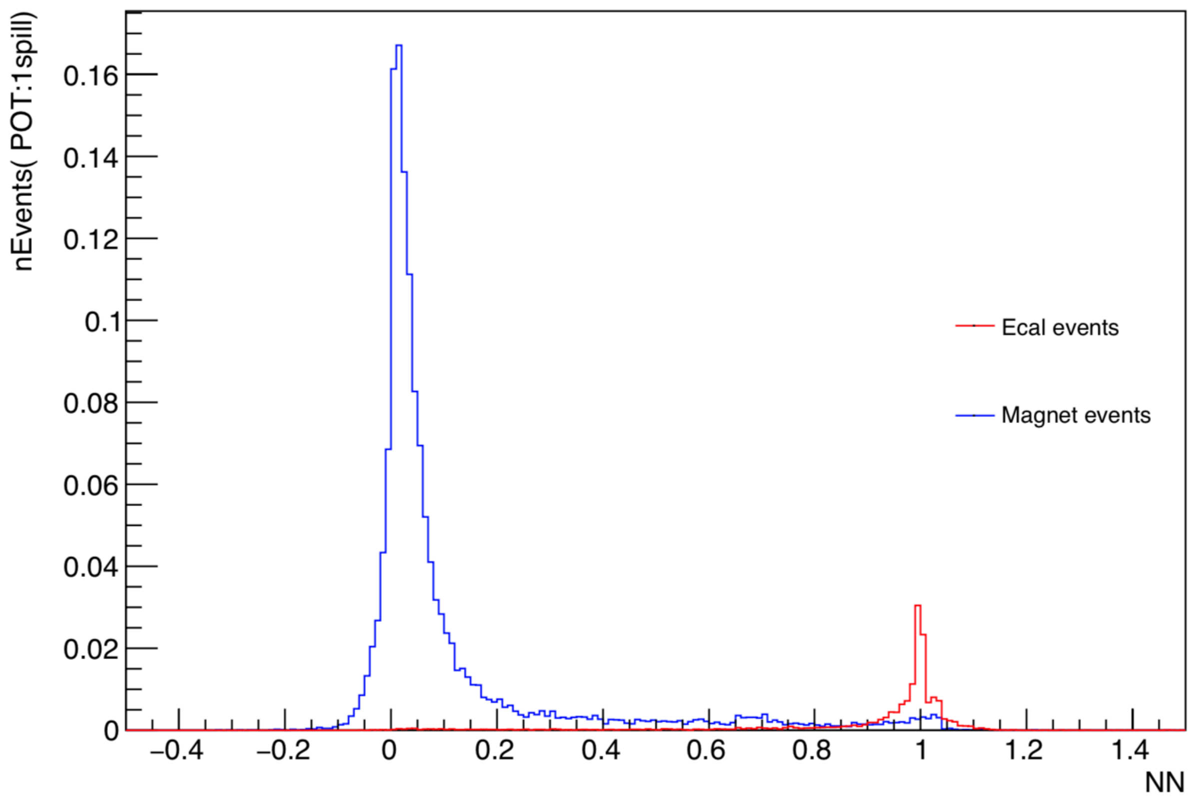
- Further improvements possible with optimization and increased simulated statistics

Rejection of Background from magnet

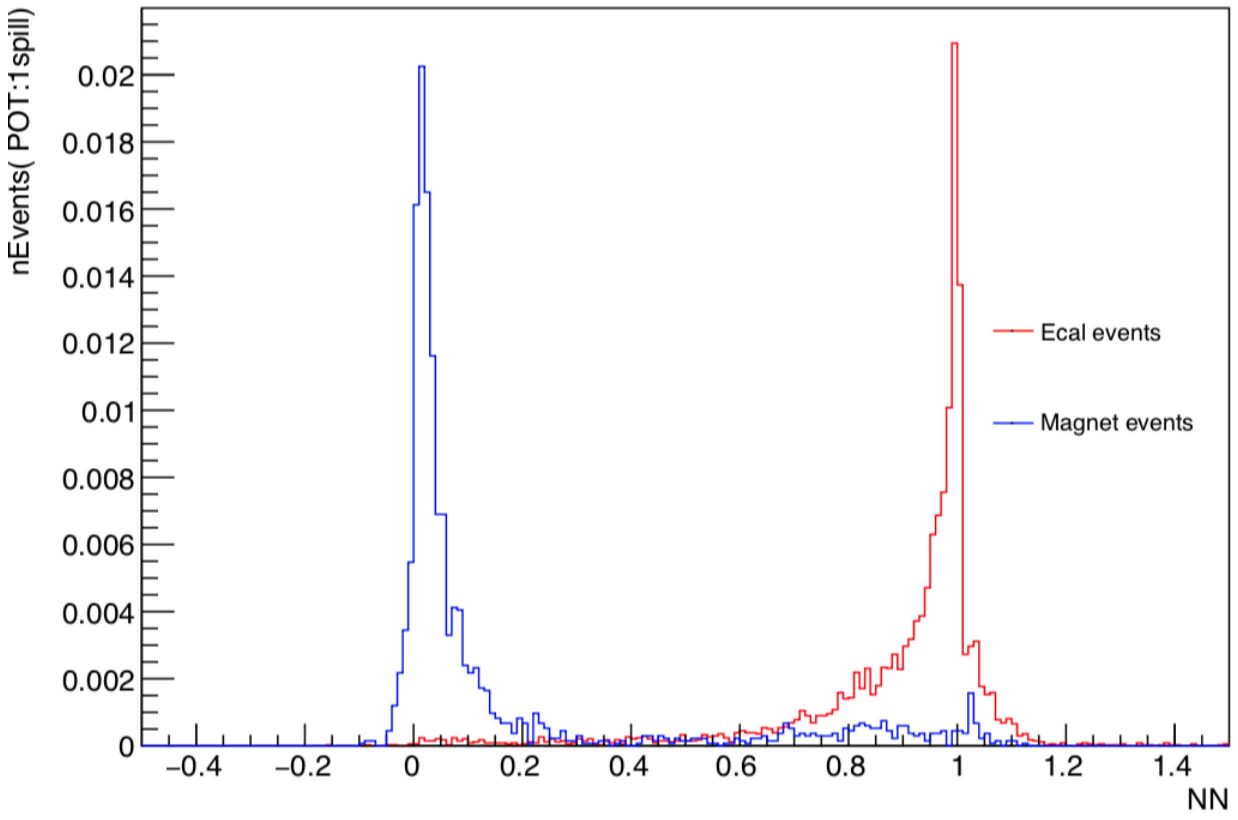
- Simulate CC events in the entire SAND magnet with GENIE + EdepSim(Geant4) + reconstruction smeared from hits
- Require a reconstructed muon in STT with N(Y)>=6 and hits in the front ECAL FV
- Apply exactly the same NN selection(same cuts without retraining) used to reject rock muons: no additional loss of signal efficiency
- Evaluate residual background from events in the SAND magnet and compare with rock muon background

NN for L4 & L3 with Rock muon NN training result

Events with earliest hit in Layer4



Events with earliest hit in Layer3



Summary of event selection

Event Per spill (7.5E13)	Ecal events	signal efficieny	Rock events	Rock efficiency	Magnet Events	Magnet efficiency
No Cut	2.29	100%	1447.26	100%	50.82	100%
Muon in ECAL FV	2.29	100%	11.51	0.795%	2.59	5.09%
STT N(Y)>=6 & ECAL hits	1.78	77.5%	6.36	0.439%	1.67	3.29%
NN cut	1.72	75.2%	0.25	0.017%	0.18	0.36%

- Further improvements possible with optimization and increased simulated statistics
- Same cuts rejecting rock muons also reject magnet events
- NN selection results in only 2% signal loss. A tighter cut (NN=0.85) on NN would give 3% signal loss with bkg reduction by a factor of 2

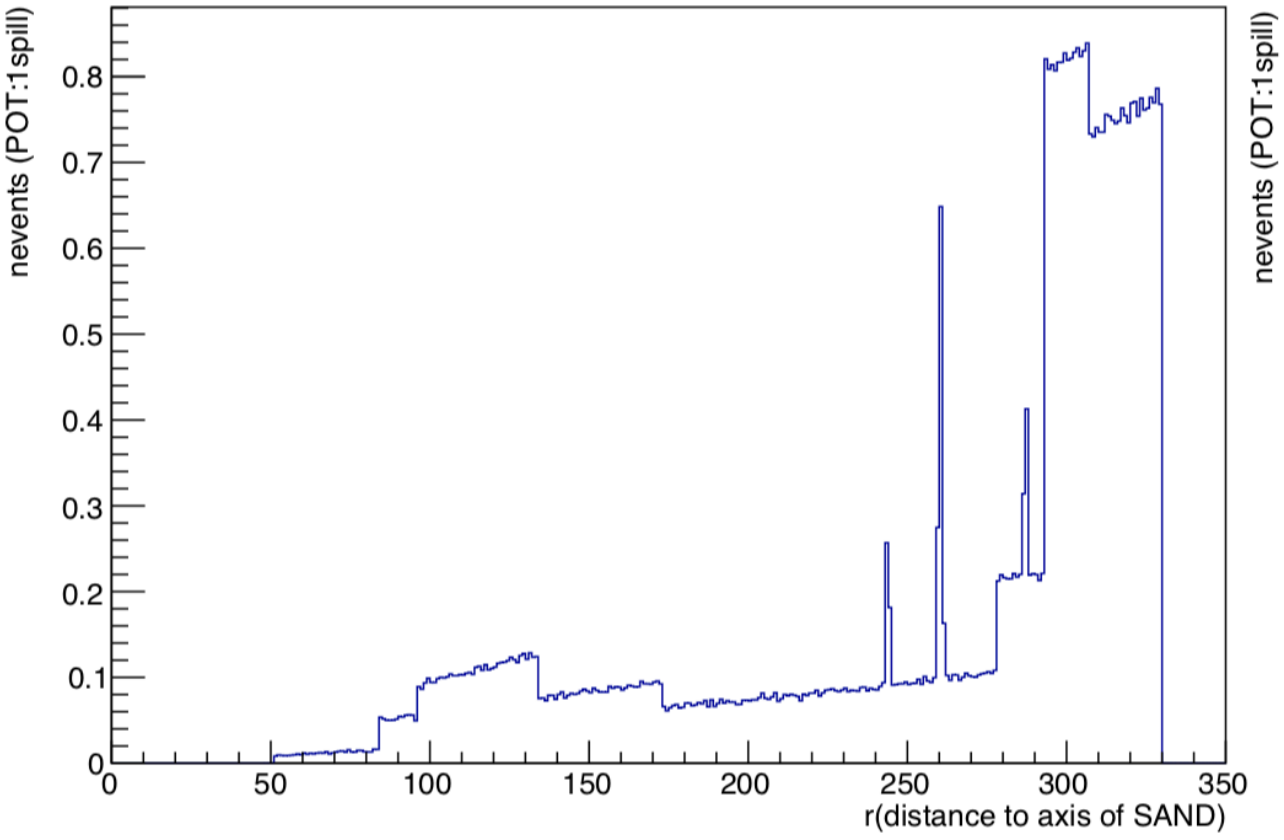
Summary

- Studied background from rock and magnet CC events with GENIE+EDEPSIM(GEANT4)+ reconstruction smearing from hits
- Method to separate rock and magnet events from genuine ECAL events developed using a combination of timing and topological information (NN) in ECAL
- Results indicate an efficient rejection of both rock muon and magnet backgrounds with minimal signal loss
- Implementation of active veto systems less critical

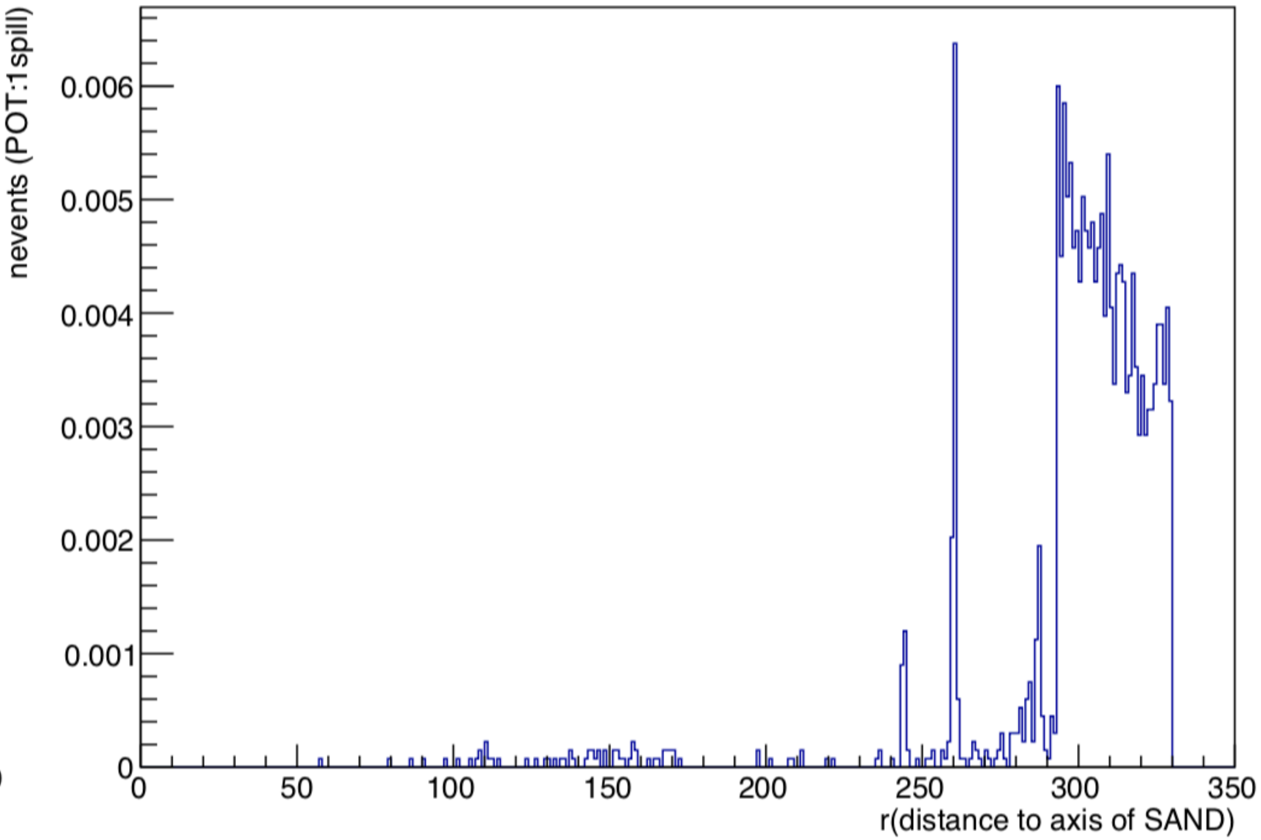
Backup

Magnet Events vertex distribution

No cut



After all the cuts



Distributions normalized to expected pot per spill