ND280-ECAL

NEUTRINO GROUP MEETING

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TODAY

- Calorimetry
- Calorimeter Types
- Introduction to ND280 ECal
- TECal:
  - Design
  - Physics objectives
  - Cluster reconstruction
  - Electron and photon energy measurement
  - Reconstruction of π0
  - Particle identification
  - Processes
- Pion PID
- Pion PID ECal
- Muon PID ECal

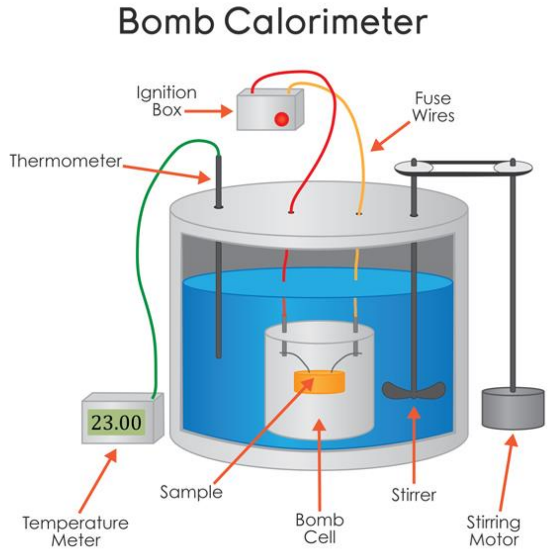
CALORIMETRY

Calorimetry originated in thermo-dynamics

- The total energy released within a chemical reaction can be measured by measuring the temperature difference.

In particular physics:

- Measurement of the energy of a particle by measuring the total absorption.



- Calorimetry is a “destructive” method. The energy and the particle get absorbed!
- Detector response $\propto E$
- Calorimetry works both for charged and neutral particles !

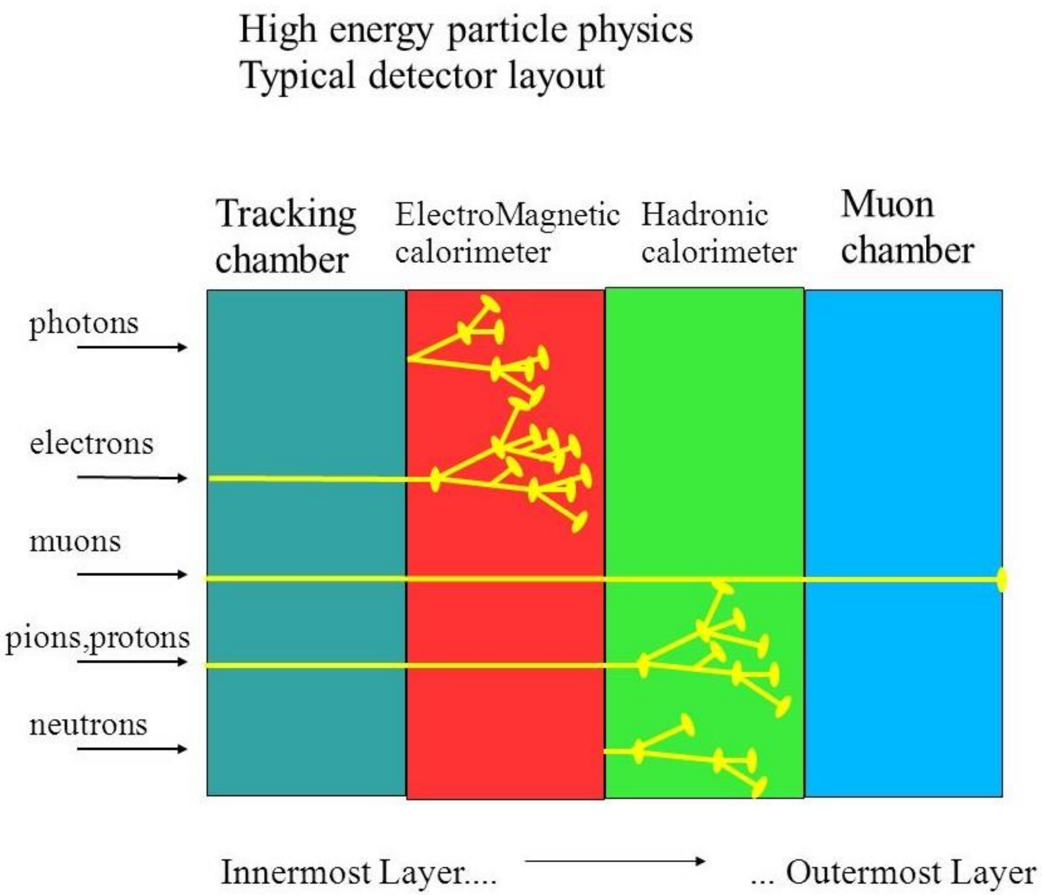
CALORIMETRY

Basic mechanism for calorimetry in particle physics:

- Electromagnetic,
- Hadronic.

The energy is converted into ionization or excitation of the matter.

Charge | **Scintillation light** | **Cerenkov light**

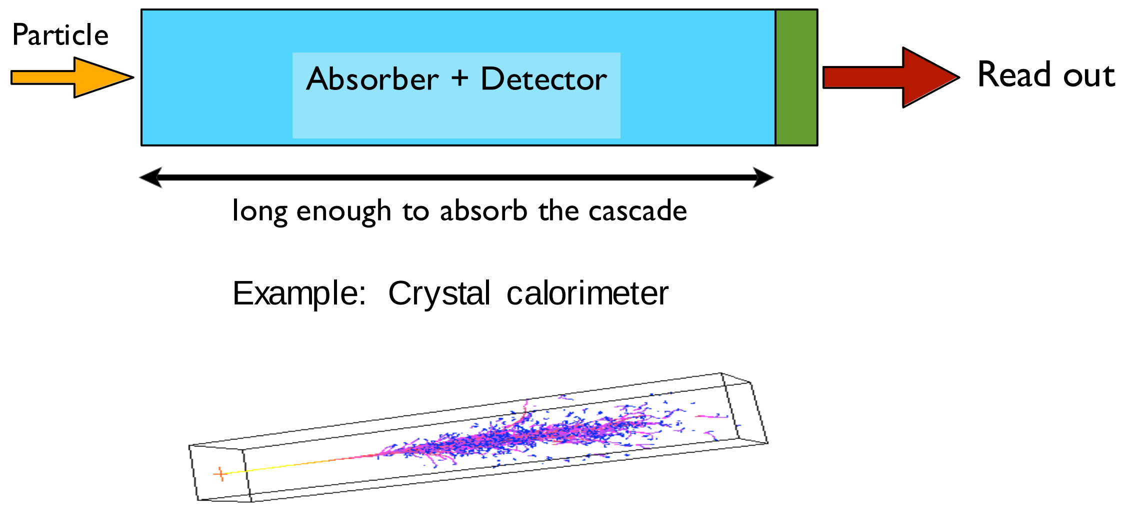


- Calorimeter measure the energy of the particle
- Particles enter the calorimeter can interact inside, starting a particle shower

CALORIMETER TYPES

<u>Homogeneous Calorimeter</u>

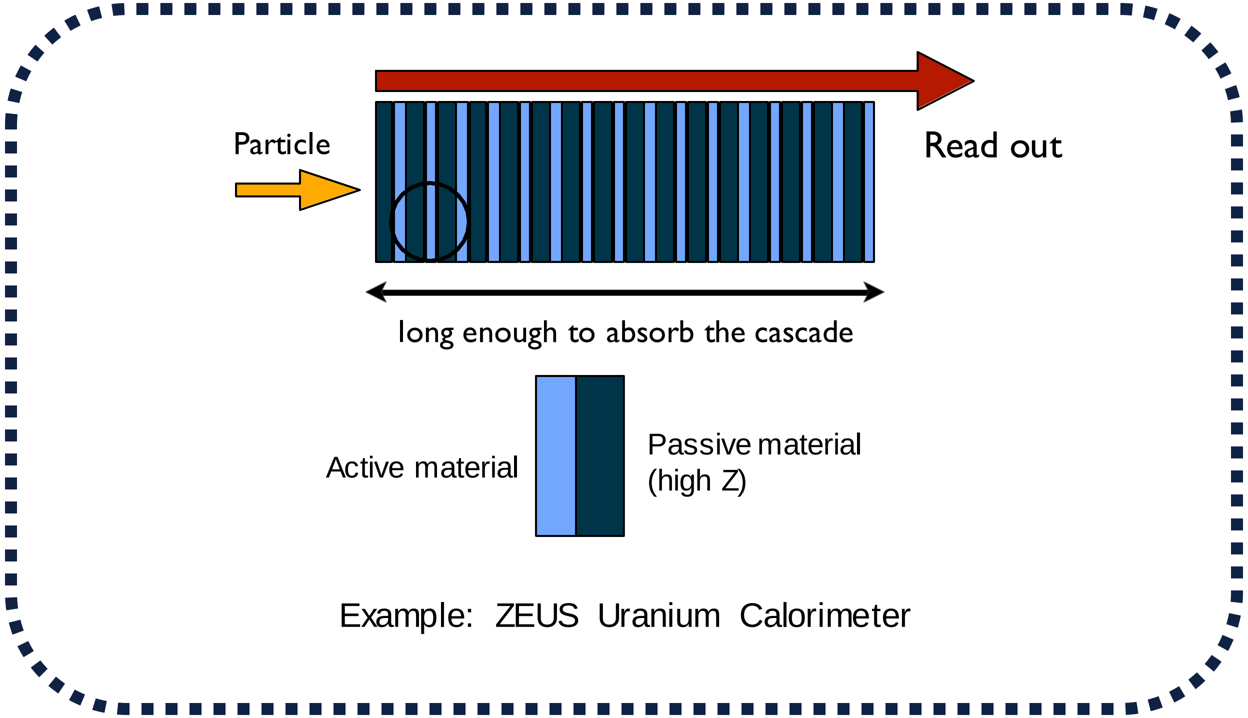
- The absorber material is active;
- The overall deposited energy is converted into a detector signal;
- Pro:
  - very good energy resolution;
- Contra:
  - Segmentation difficult,
  - selection of material is limited,
  - difficult to build compact calorimeters.



CALORIMETER TYPES

Sampling Calorimeter

- A layer structure of passive material and an active detector material;
- A fraction of the deposited energy is "registered ";
- Pro:
- Segmentation (transversal and lateral), compact the detectors by the usage of dense materials;
- Contra:
  - Energy resolution is limited by fluctuations.



Important parameter: Sampling Fraction
The fraction of the energy of a passing particle seen by the active material. Typically in the percent range

INTRODUCTION TO ND280-ECAL

The Electromagnetic Calorimeter comprises two sections.

1. **The Tracker ECAL (TECAL)** surrounds the FGDs and TPCs.

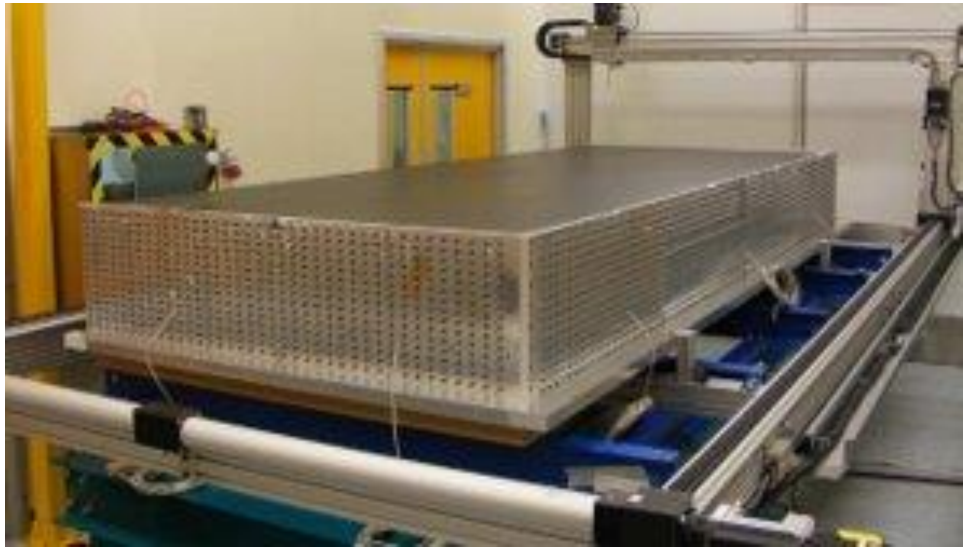
- to detects, reconstructs, and identifies particles leaving the tracking volume.

1. **The P0D ECAL** is a simpler device that surround the P0D

- to measure photons, primarily from π0 production,
- to distinguish e and μ escaping the P0D.

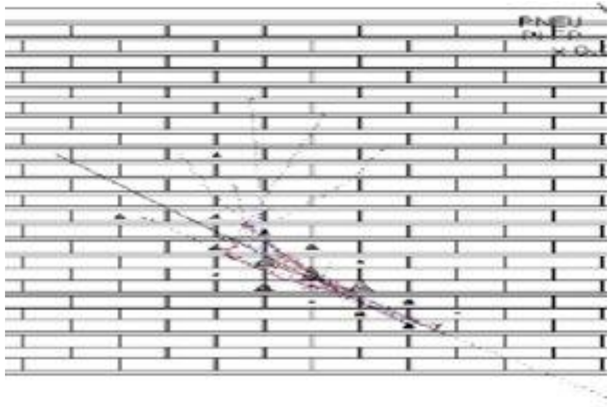
Note: Both ECAL sections tag interactions occurring outside the inner detectors, which produce event signatures that can resemble those of signal neutrino interactions in the fiducial volumes of the inner detectors.

The good cluster and MIP reconstruction capabilities of the ECALs will allow satisfactory background rejection to be performed.



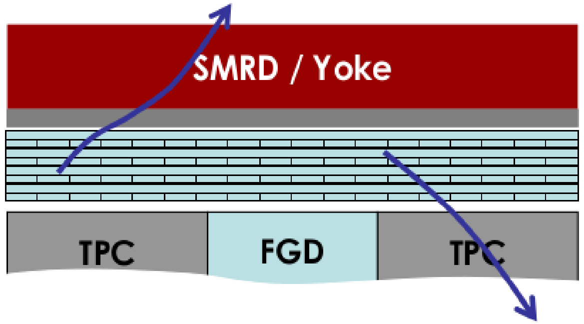
TECAL: DESIGN

- The ECAL consists of lead-scintillator sandwich sampling calorimeter modules located around the ND280 inner detectors on all four sides and at the downstream end of the magnet.



- The TECAL modules are made of 4cm-wide, 1cm-thick plastic scintillator bars arranged in 32 layers and separated by 31 layers of 1.75mm-thick lead sheets.

- The orientation of the bars alternates between layers so that the bars in any layer are perpendicular to the bars in the two adjacent ones.

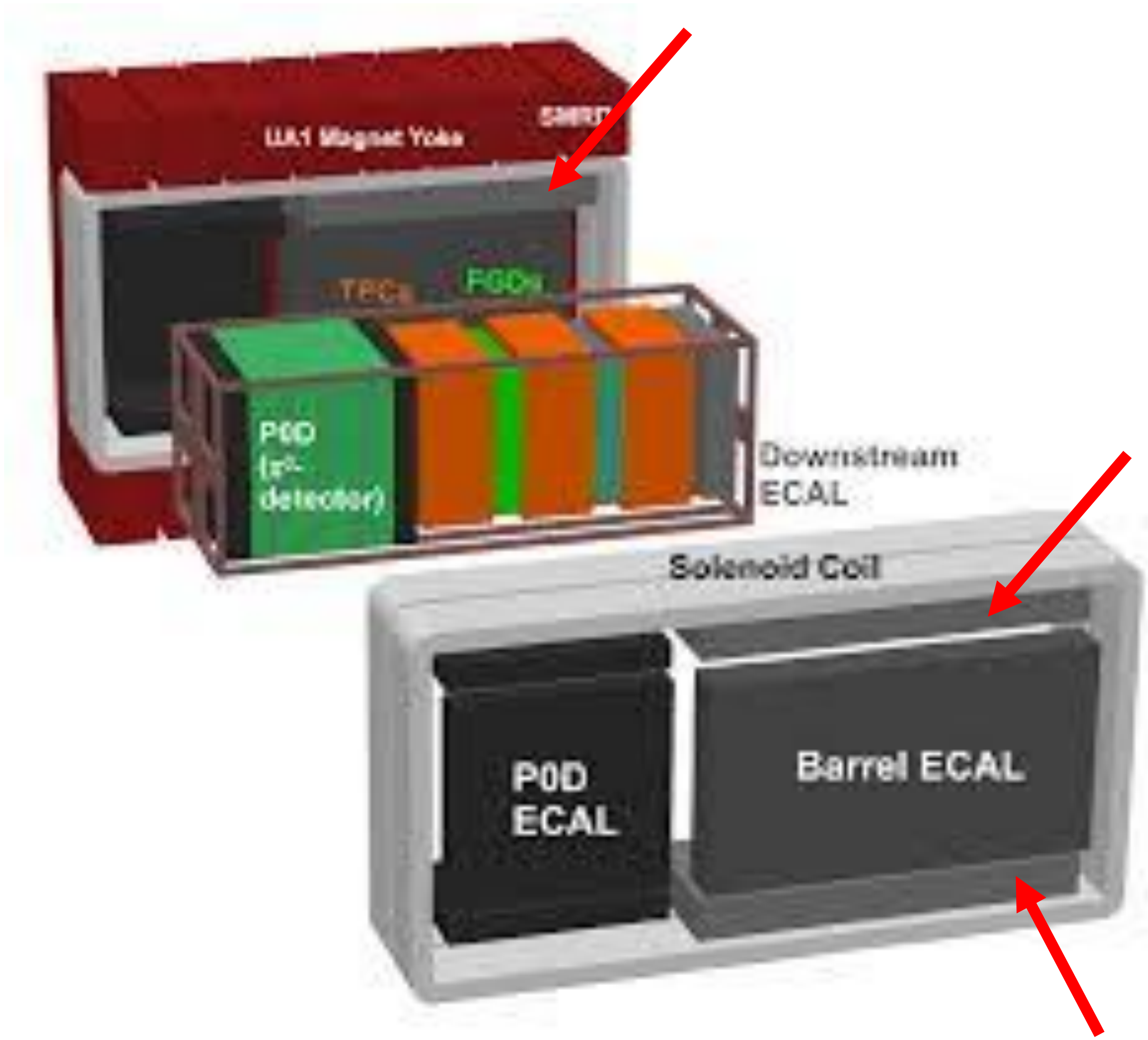


- Each module is located outside the Basket and is fixed independently to the iron of the magnet yokes.

TECAL: DESIGN

Bar length	Number of bars	Readout	Number of channels
3840 mm	4320	Double end	8640
2040 mm	1734	Double end	3468
1520 mm	6144	Single end	6144
2360 mm	3072	Single end	3072
Total	15270		21324

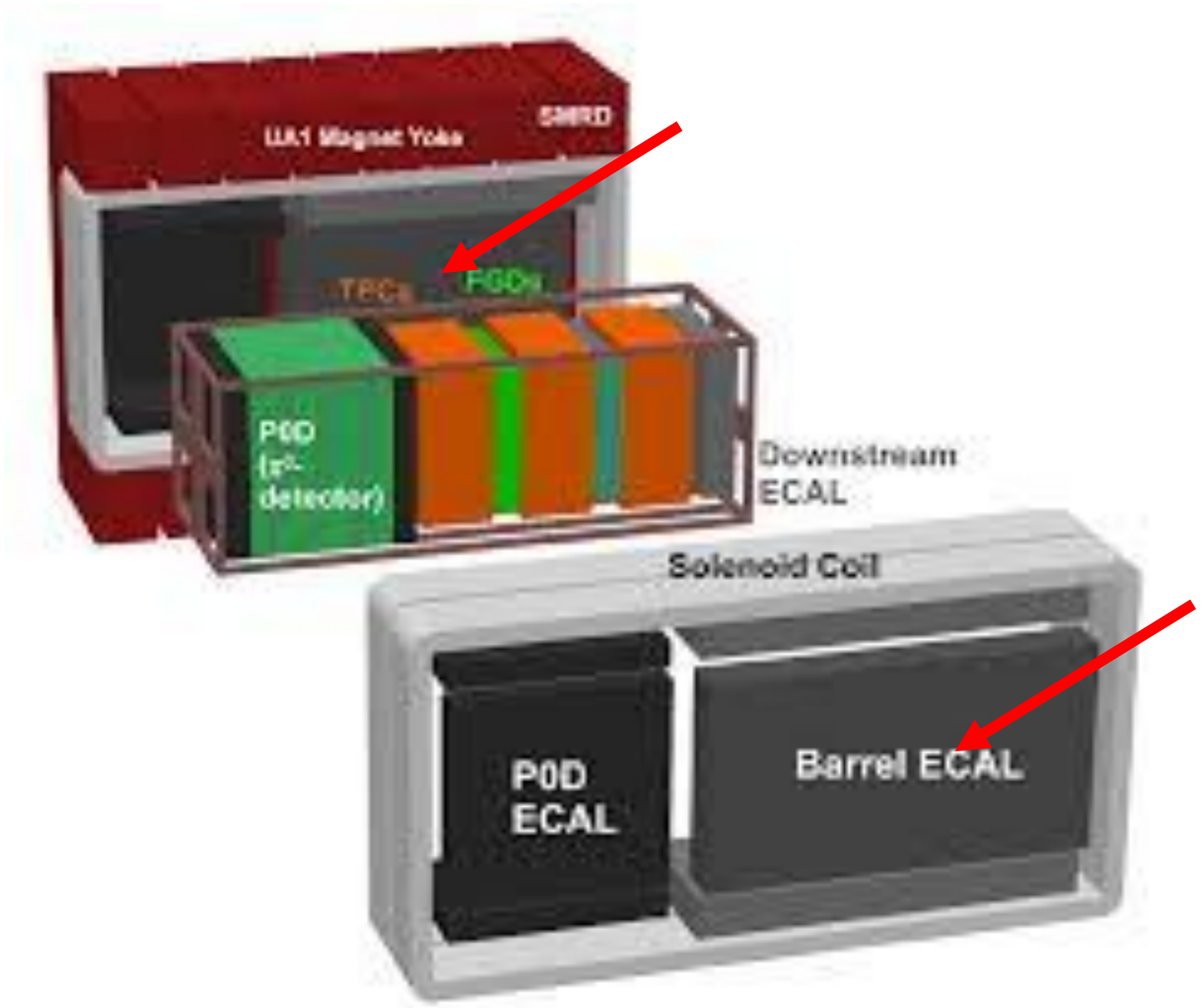
- All scintillator bars have a hole in the center with a 1mm wavelength-shifting (WLS) fiber running in it.
- All bars have simple or double-end readout .



TECAL: DESIGN

Top and bottom TECAL

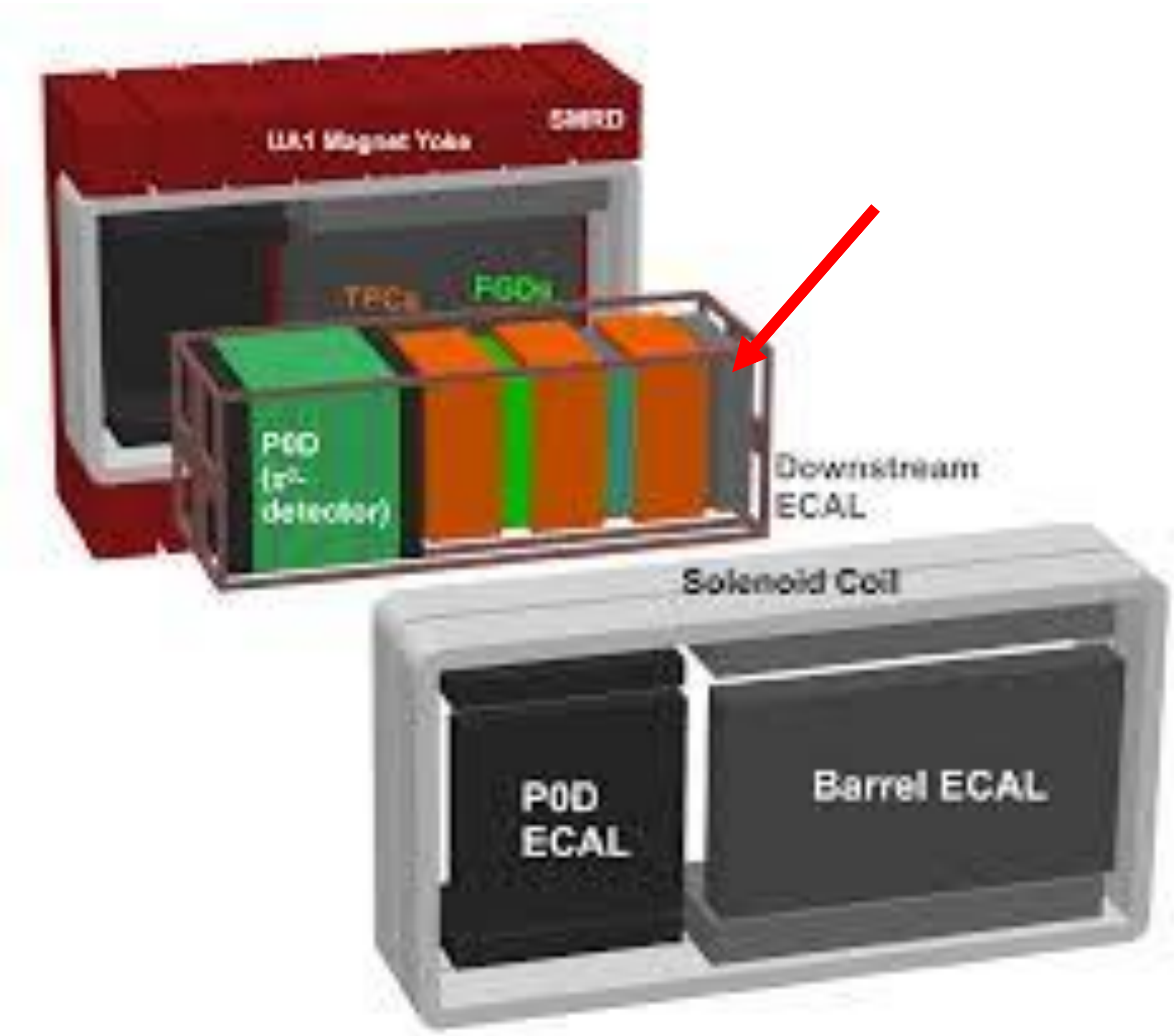
- Four modules, each top and bottom is split in two (left and right),
- The active width of each module is 1520 mm,
- Each modules has 16 layers with 38 3840mm-long bars per layer, and 16 layers with 96 1520mm-long bars per layer,
- The combined weight of lead and scintillator in each module is 5.6tons.



TECAL: DESIGN

Side modules

- Two modules, one on each side of the magnet,
- The active width of each module is 2360 mm,
- Each modules has 16 layers with 59 3840mm-long bars per layer, and 16 layers with 96 2360mm-long bars per layer,
- The combined weight of lead and scintillator in each module is 8.6tons.



TECAL: DESIGN

Downstream modules

- Single module taking up the last 50cm at its downstream end,
- The active surface transverse to the beam direction is (2040 x 2040) mm,
- The length of each bar is 2040mm, giving a square active cross-section,
- The combined weight of lead and scintillator in the Downstream module is 4.2tons.

TECAL: PHYSICS OBJECTIVES

- The main purpose of the TECAL is to aid the Tracker in fully reconstructing neutrino interactions in the FGDs.
- The photon shower reconstruction capabilities of the TECAL have been chosen to allow it to point back from photons created from $\pi 0$ decays.
- The TECAL geometrical coverage and its particle identification capability improve the reconstruction efficiency for interactions.
- The TECAL is able to positively identify muons and improve the energy measurement of electrons.
- Measurement of CCQE muon interactions in the TECAL itself.

TECAL: PHYSICS OBJECTIVES

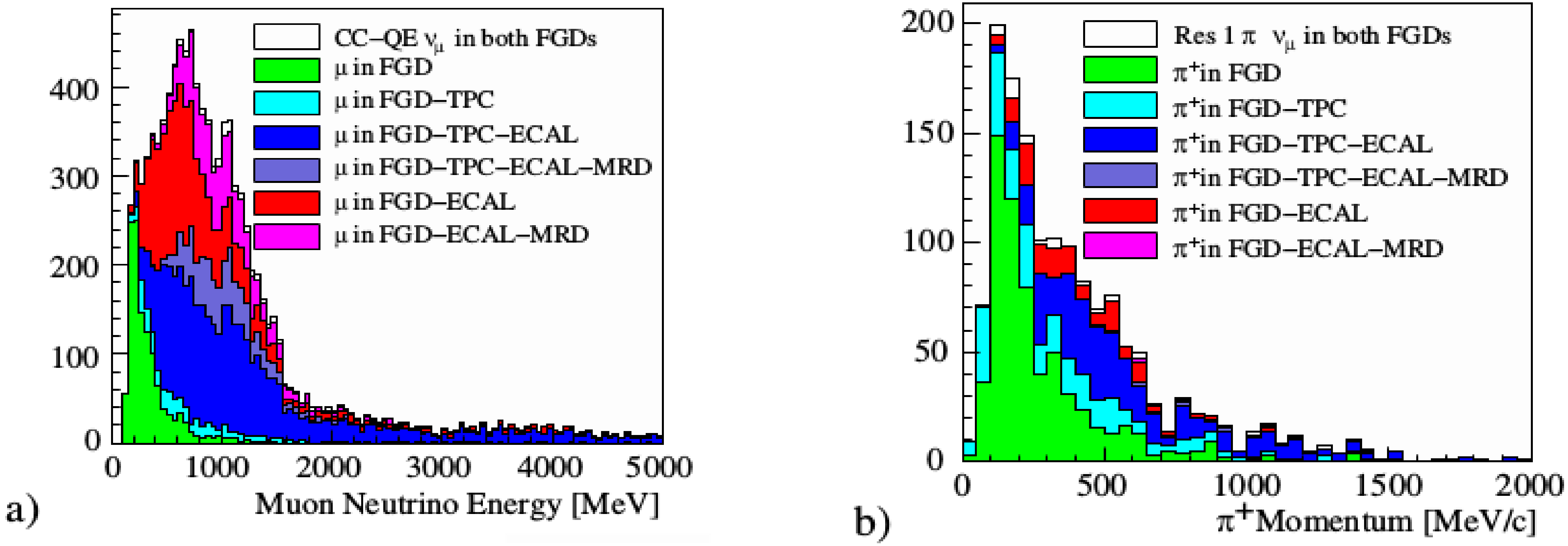


Fig 1: a) True neutrino energy distributions for CCQE interactions for different outgoing muon path categories through the sub-detectors b) Similar to a), but for CC1π + pion momentum distributions.

TECAL: PHYSICS OBJECTIVES

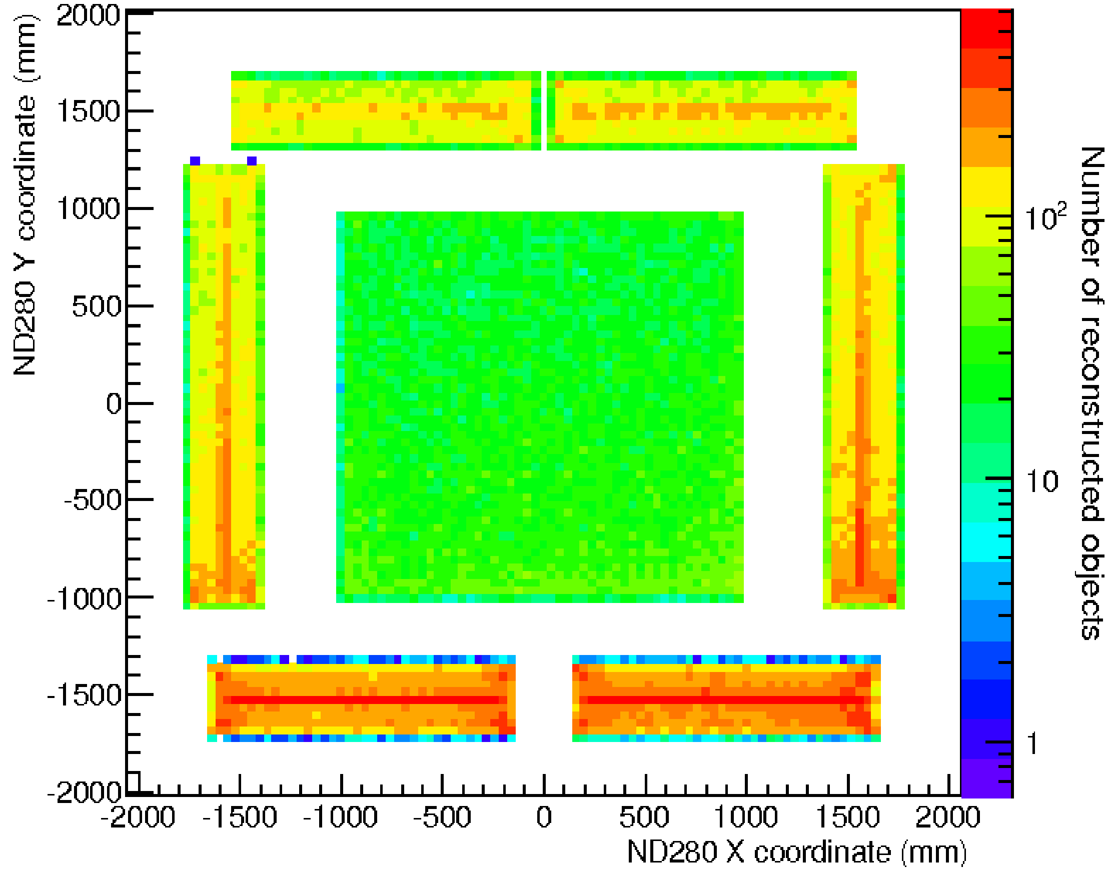
ECALs large mass

- results in a high rate of interactions,
- identifying the outgoing muons and high energy protons,

Neutrino interactions in the ECal are about 50/50 on Lead and scintillator.

- Not so great for cross-section studies but fine for flux measurements.

The position of reconstructed ECal objects in the ND280 XY plane



TECAL: CLUSTER RECONSTRUCTION

- Hits in adjacent ECAL scintillator bars are grouped into clusters.
- The position of a cluster in three dimensions is estimated using information from the two projections.
- For double-end readout bars, pulse height comparison and timing.
- Clusters are then matched with charged tracks reconstructed in the other subsystems.
- Clusters which appear to be unrelated to the charged tracks are considered to be photon candidates.

TECAL: ELECTRON AND PHOTON ENERGY MEASUREMENT

The basic energy measurement of electromagnetic showers in the simulation is performed as a simple weighted sum of the energy deposited in the TECAL scintillator bars of a cluster:

$$E_{rec} = \sum_i \frac{\rho_{bar} d_{bar} + \rho_{Pb} d_{Pb}}{\rho_{Pb} d_{Pb}} E_i \tag{8.1}$$

with ρ_{bar} and d_{bar} being the density of plastic scintillator and thickness of the bar, ρ_{Pb} and d_{Pb} respectively the density and thickness of the lead layer and E_i the individual bar hit energy in MeV. This formula assumes that the energy loss in the bar comes solely from ionisation. To properly reconstruct the shower energy, the so-called e/mip and γ/mip ratio respectively for electron and γ shower is applied on E_{rec}.

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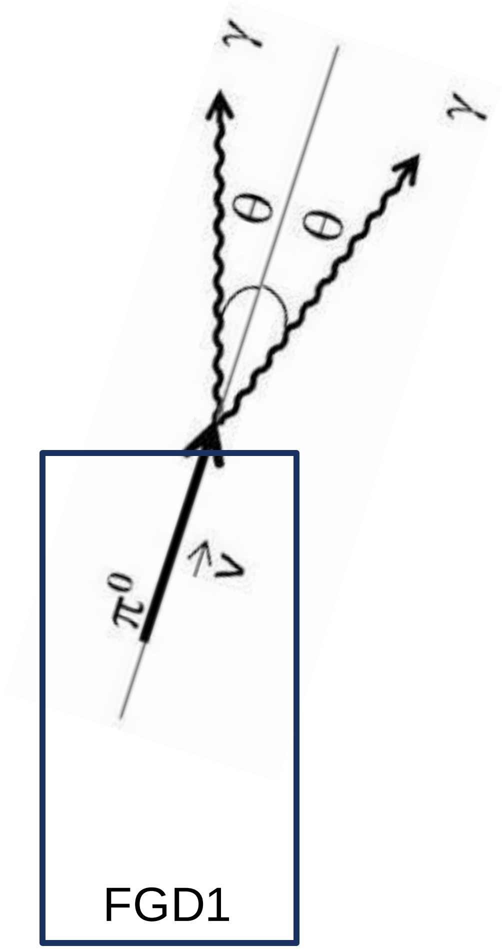
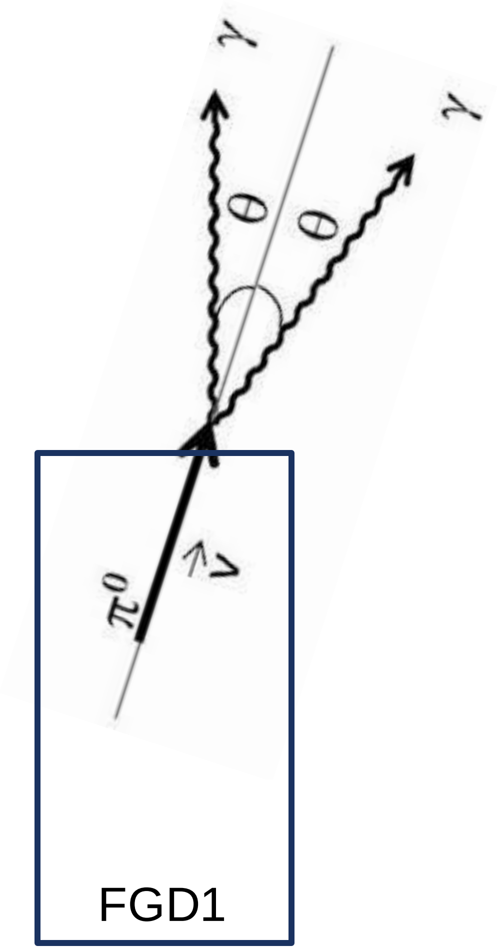


TECAL: RECONSTRUCTION OF Π0

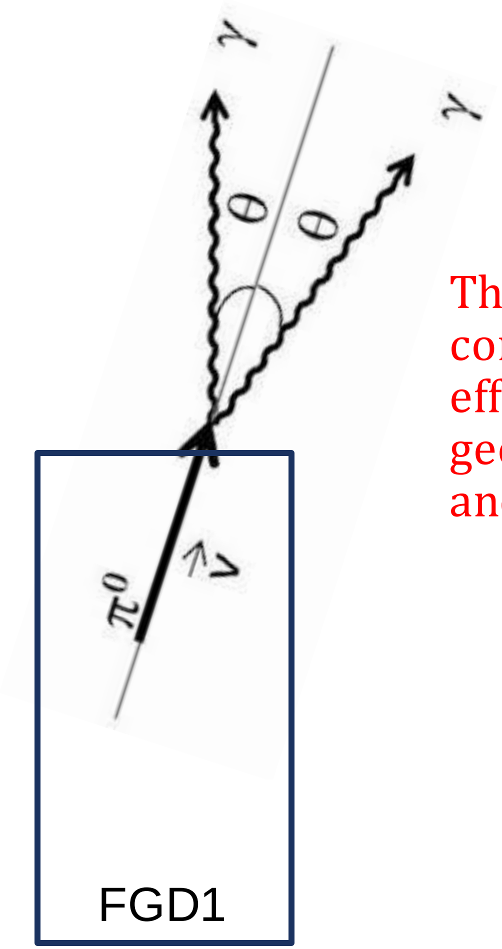
- Identify γ-cluster partners and to extrapolate back to the decay point of the π° in the FGD block,
- The TPCs are used as vetoes for charged particles,
- In the π° momentum range of particular interest (between 200 and 800 MeV/c), approximately one third of the FGD NC1π° events have both decay photons converting in the TECAL.



TECAL: RECONSTRUCTION OF Π0

A π° candidate is selected using the following requirements:

- low activity in the Tracker region,
- identification of γ-like clusters,
- good reconstruction of direction of one γ using a thrust analysis,
- intersection of γ direction with FGD fiducial volume,
- consistency of invariant mass formed with second γ with π°.



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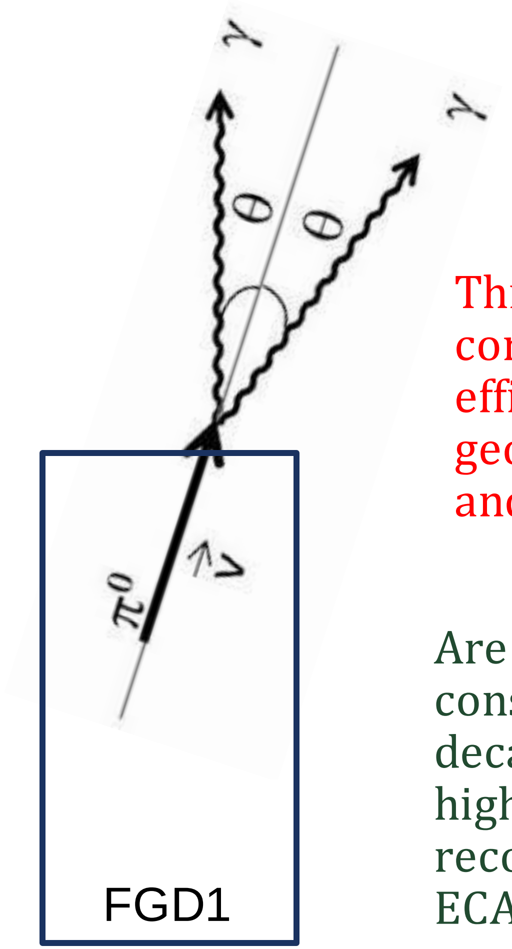

This first three requirements constitute a pre-selection, and their efficiency depends mostly on the geometry of the Tracker and ECAL, and basic ECAL properties.

Are then studied for their consistency with being from a π° decaying in the FGD. This step is highly dependent on the reconstruction capabilities of the ECAL.

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- low activity in the Tracker region,
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- intersection of γ direction with FGD fiducial volume,
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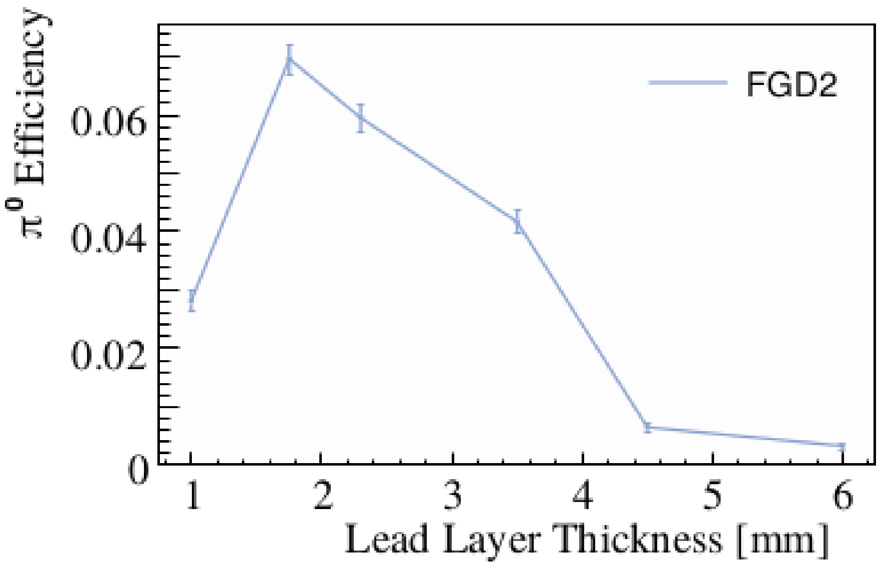
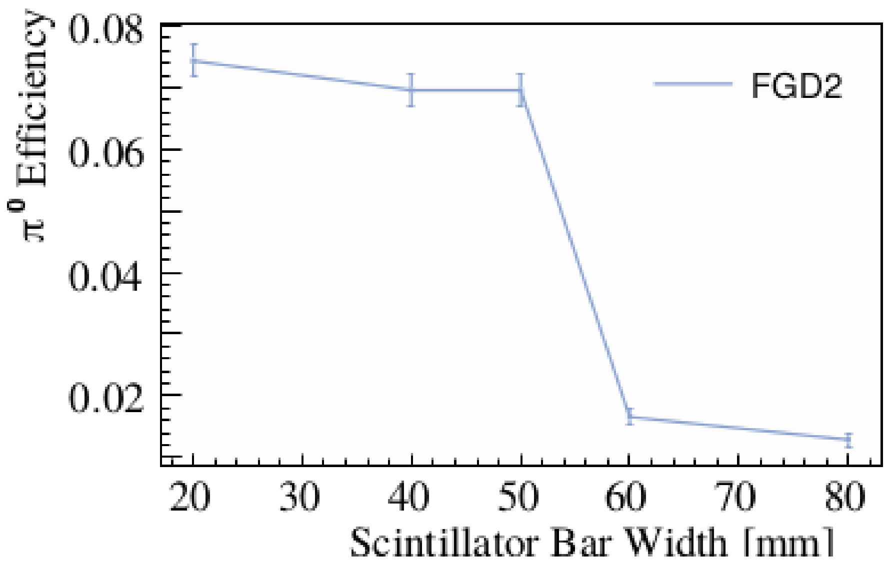
TECAL: RECONSTRUCTION OF Π°

The γ-cluster direction reconstruction and thus the π° efficiency is highly dependent on the Tracker ECAL design. To study the impact of the TECAL design parameters on the π° reconstruction efficiency, a range of values of the TECAL parameters was explored.



a)



b)

TECAL: PARTICLE IDENTIFICATION

Muon-Electron separation

The TECAL plays an important role in identifying charged particles. The finely segmented ECAL modules surrounding FGDs and TPCs allow shower characteristics to be used for the separation between hadrons (pions, protons), electrons, and muons over a large range of particle momenta (0.5 < p < 10 GeV/c).

Matched clusters are first categorized as track-like or shower-like. The PID selection cuts are based on the shape and energy deposition characteristics of the cluster :

- The ratio between cluster view axis eigenvalues in a principal components analysis (Axis Maximum Ratio);
- The variation of energy deposits within the cluster;
- The variation and spatial distribution of the number of hits in the cluster.

Sample category	ECAL Barrel		ECAL Downstream	
	efficiency	purity	efficiency	purity
Shower-like electrons	0.43	0.78	0.84	0.86
Track-like muons	0.97	0.92	0.99	0.90

TECAL: PARTICLE IDENTIFICATION

Electron-Pion separation ???

Currently this is done using Neural Nets .Two different nets are used:

- first one -> truth information about the incoming particle (momentum, direction, position of intercept with the front of the calorimeter) is used to mimic clusters matched to charged tracks;
- second one-> such information isn't use, hence is a simulate the PID capabilities of the ECAL in the absence of any tracking information from other subsystems.

A large sets of GEANT4 simulated single-particle samples of electrons and pions with energies up to 6GeV and over the full angular range.

- 200,000 events are used in the training set,
- 200,000 as a comparison set to avoid over-training
- 600,000 are used for evaluation.

TECAL: PROCESSES

	Int./10^{21}POT/ton	TECAL	Reconstruction method
CC-QE ν_μ	65038 (0.38)		
CC-QE ν_μ μ^-		0.82(0.21)	PID/(Range)
CC-QE ν_μ proton		0.28(0.25)	PID
CC-Res1π	30029		
CC-Res1π μ^-		0.79(0.37)	PID/(Range)
CC-Res1π π^+		0.37(0.29)	(PID)
NC-Res1π^0	7455	0.22	
NC-Res1π^0 γ_1		0.55	Dir/PID/E
NC-Res1π^0 γ_2		0.54	Dir/PID/E
CC-QE ν_e	500		
CC-QE ν_e e^-		0.78	PID/E
CC-QE ν_e proton		0.33(0.28)	PID

Table 8.1: "TECAL" column: Fractions of particles crossing (stopping in) the TECAL for various neutrino processes occurring in the FGD. Neutrino interactions are as given by the NEUT generator. Event reconstruction methods are : PID = cluster shape particle identification, Dir = direction reconstruction, Range = muon ranging, E = energy measurement.

Questions?

PION PID

Particles with good quality TPC information:

- Positive Particle: tagged as the particle with highest likelihood, except if positrons with p > 900 MeV, which are tagged as protons.
- Negative Particle: pion if $L_{pion} /(L_{pion} + L_{el}) > 0.8$, otherwise e^-.

Pions contained in FGD1 (no TPC information):

- Track needs to start and stop in FGD1.
- -0.3 < cosine of track < 0.3
- $-2.0 < Pull_{pion} < 2.5$

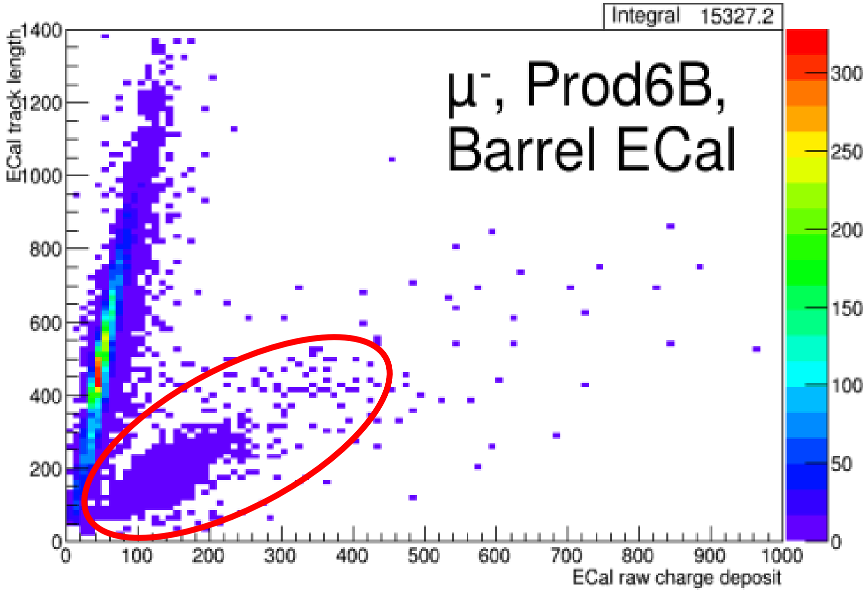
Electron from pi0 contained in FGD1 (if no charged pion found):

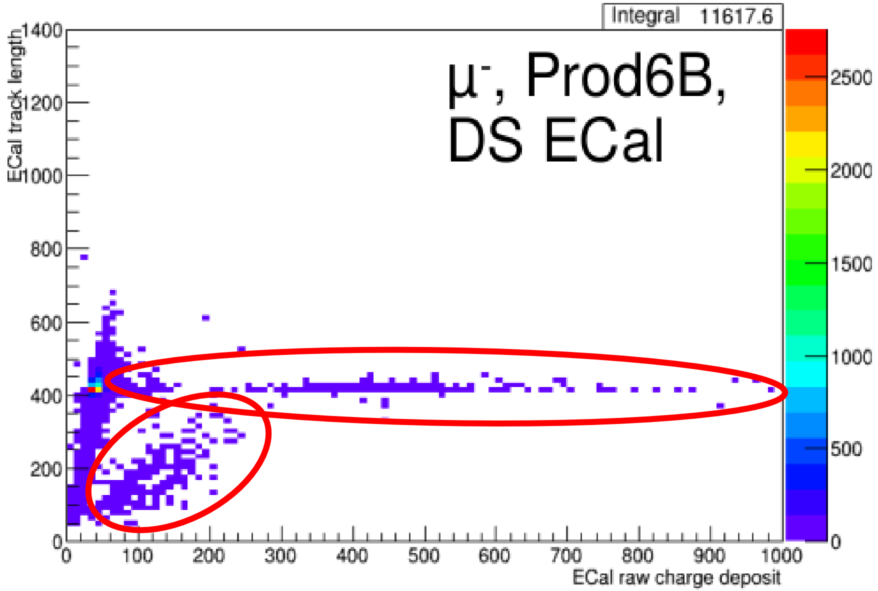
- Track needs to start and stop in FGD1.
- If there is at least one Michel electron: $Pull_{pion} < -3.0$
- If there is no Michel electron: $Pull_{pion} < -1.5$

PION PID ECAL

Waiting for output of MC from LxPlus to check pion PID ECal and start study HA systematics.

Working hard on this.

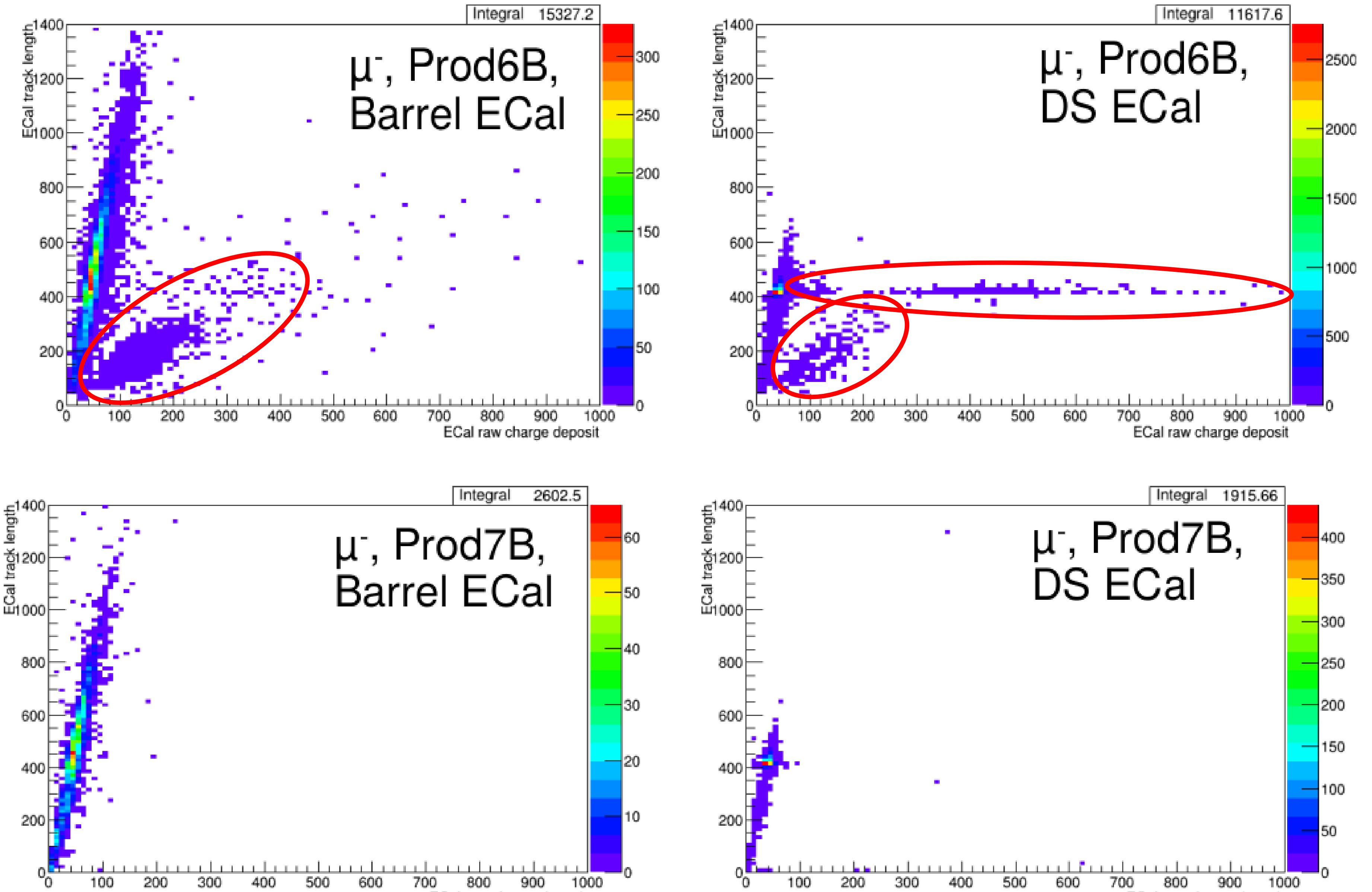




MUON PID ECAL

- Unexpected behavior seen in relationship between charge deposited in ECal and track length for true muons in Prod6B

MUON PID ECAL



- Unexpected behavior seen in relationship between charge deposited in ECal and track length for true muons in Prod6B
- Switching to Prod7B Monte Carlo appears to remove the unexpected behavior

THANK YOU

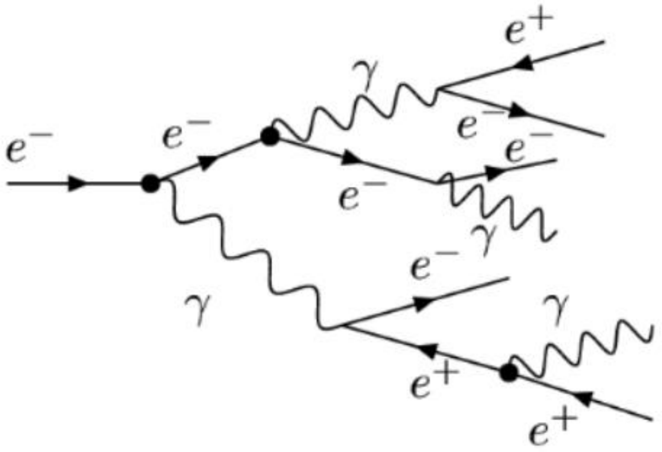
AND NOW …

ELECTROMAGNETIC SHOWERS

An avalanche!

- Can start with either a photon or e ±, electron brems
    - γ pair-produces
    - e ± brem

... until energies drop below pair-production threshold and/or Ec for electrons



Start with energy E_0

- Photon will convert after ~1 radiation length
    - E_0 /2 for each of e + , e -
- Divide energy per particle again by 2 after another radiation length
- After t radiation lengths,

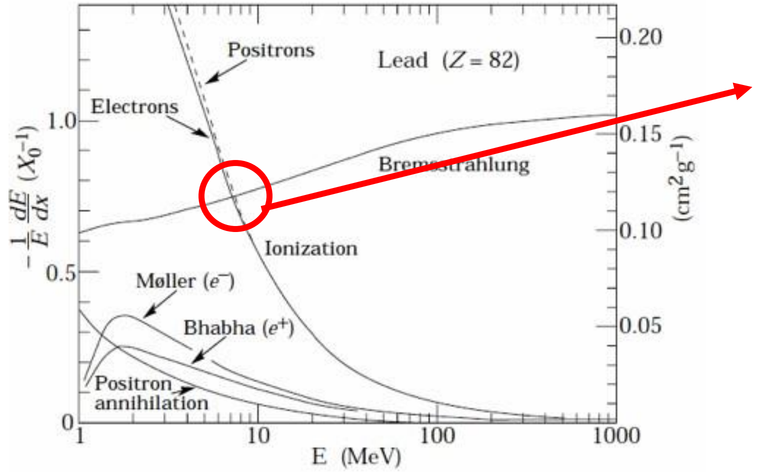
$N \sim 2^t$ so $E \sim E_0/2^t$ for each particle

$$E(t_{\max}) = E_0/2^{t_{\max}} = E_c$$

$$\rightarrow \boxed{t_{\max} = \frac{\ln(E_0/E_c)}{\ln 2}}$$

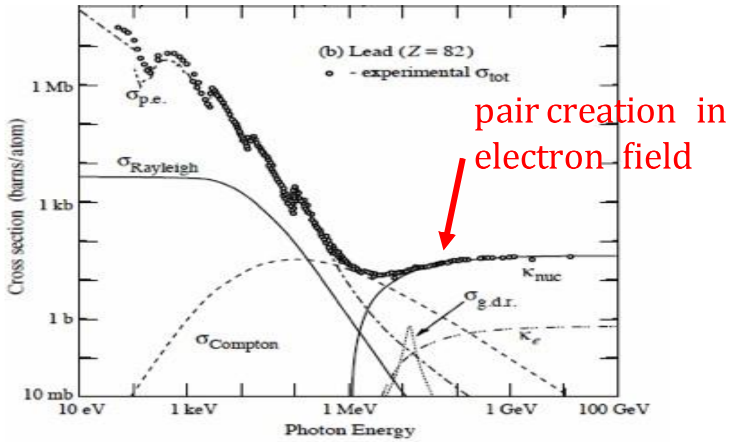
ECAL - ELECTROMAGNETIC CALORIMETER

Electrons



Critical energy: the energy at which the losses due to ionization and Bremsstrahlung are equal.

Photons



Radiation length: the amount of material a particle has to travel through until the energy of an electron is reduced by Bremsstrahlung to 1/e of its original.