

# PODECaI Study



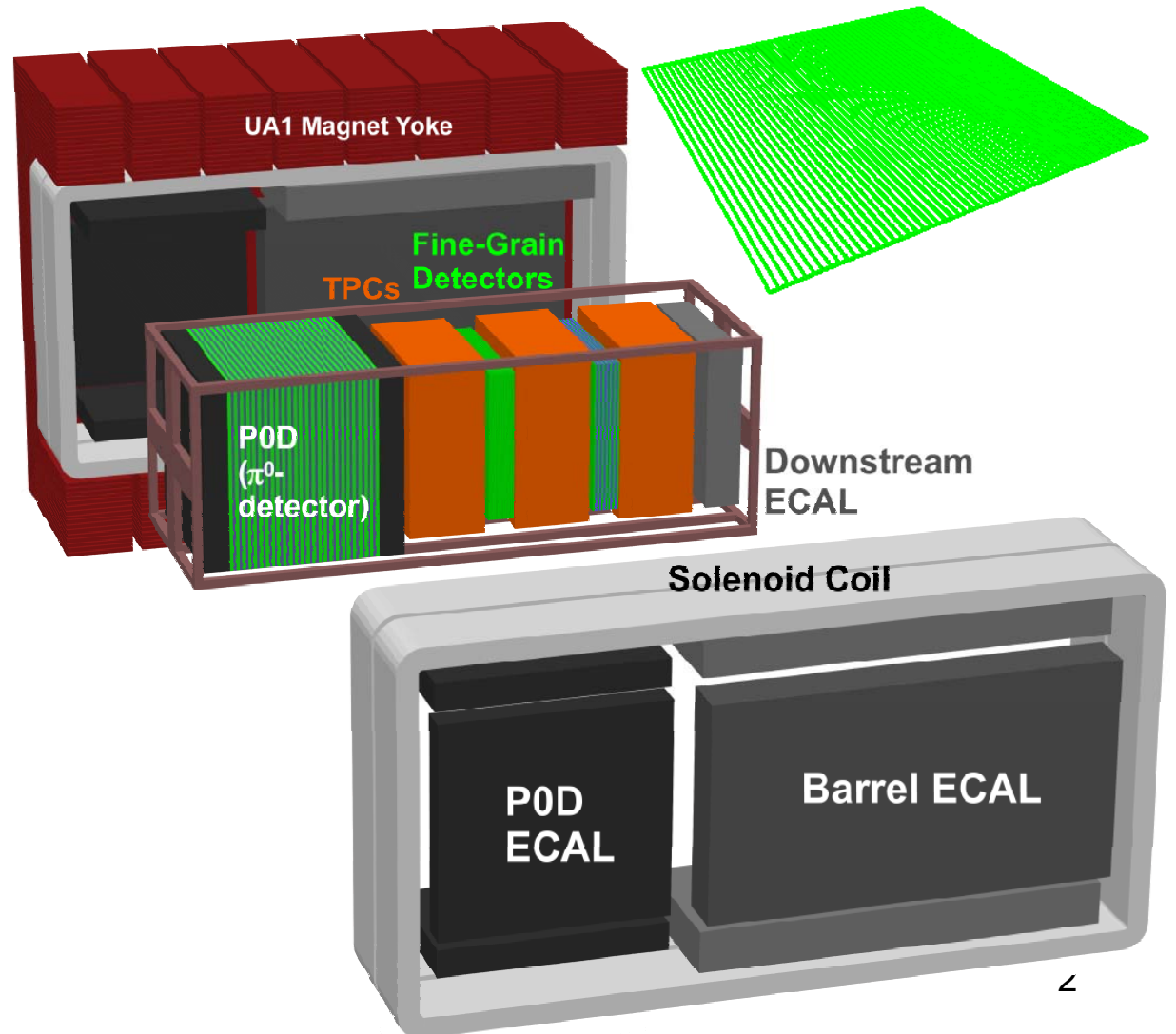
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University of Sheffield

# PODECAL in the ND280

Baseline:

- 6 Scint Layers, 4x1cm Bars
- 5 Pb Absorber Layers
- Single Ended Readout
- Bars Aligned along Beam Axis





# P0DECaI Physics

Photon tagger to improve the  $\pi^0$  reconstruction of the P0D.

- Convert Photons escaping the P0D
- Contain photon showers
- Tag photons and Muons (CC-NC Discrimination)



# MC Data

## Parameters for MC in this Talk (Other parameters have been investigated)

- Used nd280mc v3r4, elecSim v3r4 and ecalRecon v2r0
- Varying lead thickness, 1mm - 5mm over 5 Layers.
- Perpendicular incidence, vertex in the CarbStruct.
- ~10,000 Single photons 65MeV - 1GeV flat distribution
- ~5,000 Single Muons 100MeV - 1GeV flat distribution



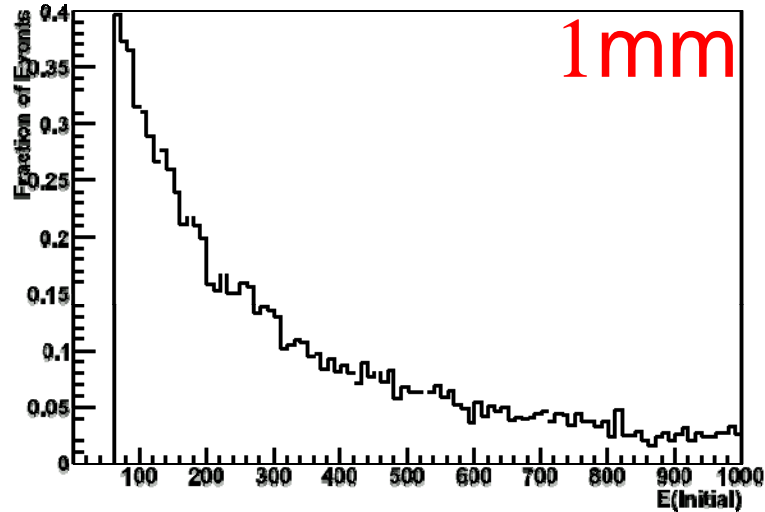
# Energy Containment

- Investigate events where photons pass through P0DECAL unnoticed.
  - Trajectory enters P0DECAL but no charge is deposited.
- Investigate fractional energy loss as a function of energy.
  - Sum the energy of all trajectories that exit the P0DECAL.
- Investigate layer of photon conversion.
  - Note first active layer in which the photon shower is first detected.

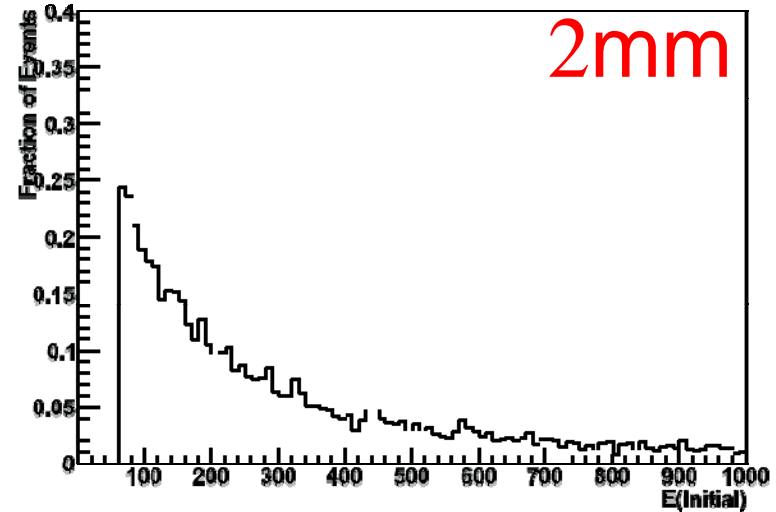


# Fraction of Escaping Photons

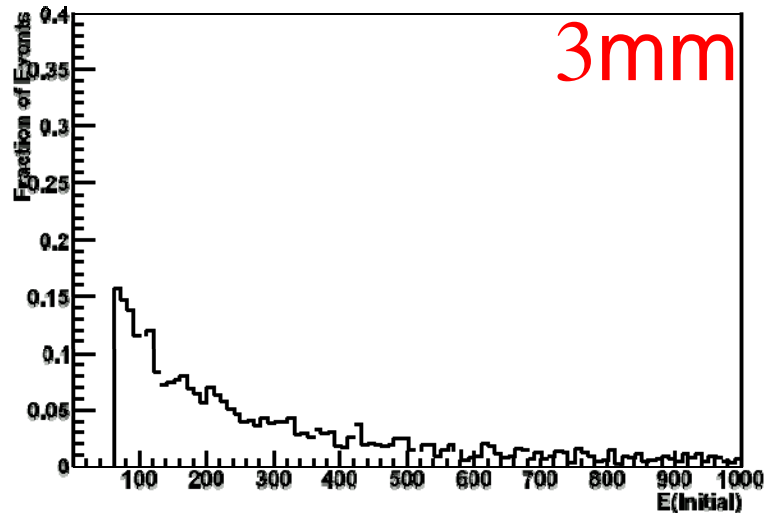
1mm Lead Fraction of Photons Escaping Detection



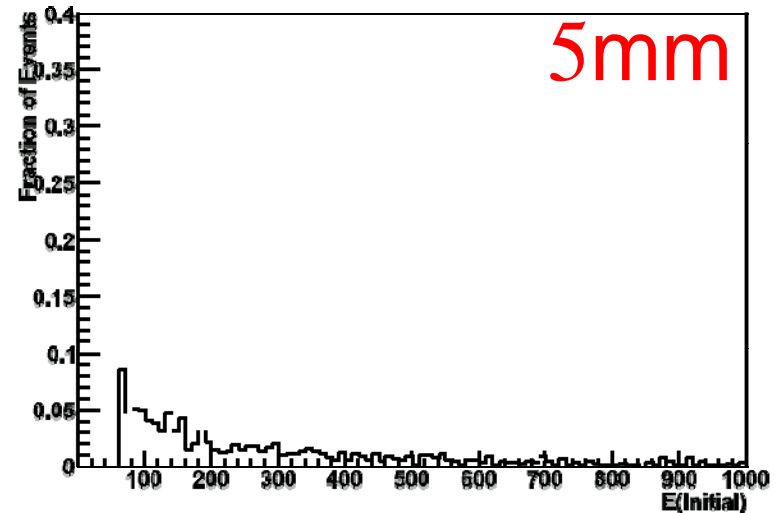
2mm Lead Fraction of Photons Escaping Detection



3mm Lead Fraction of Photons Escaping Detection



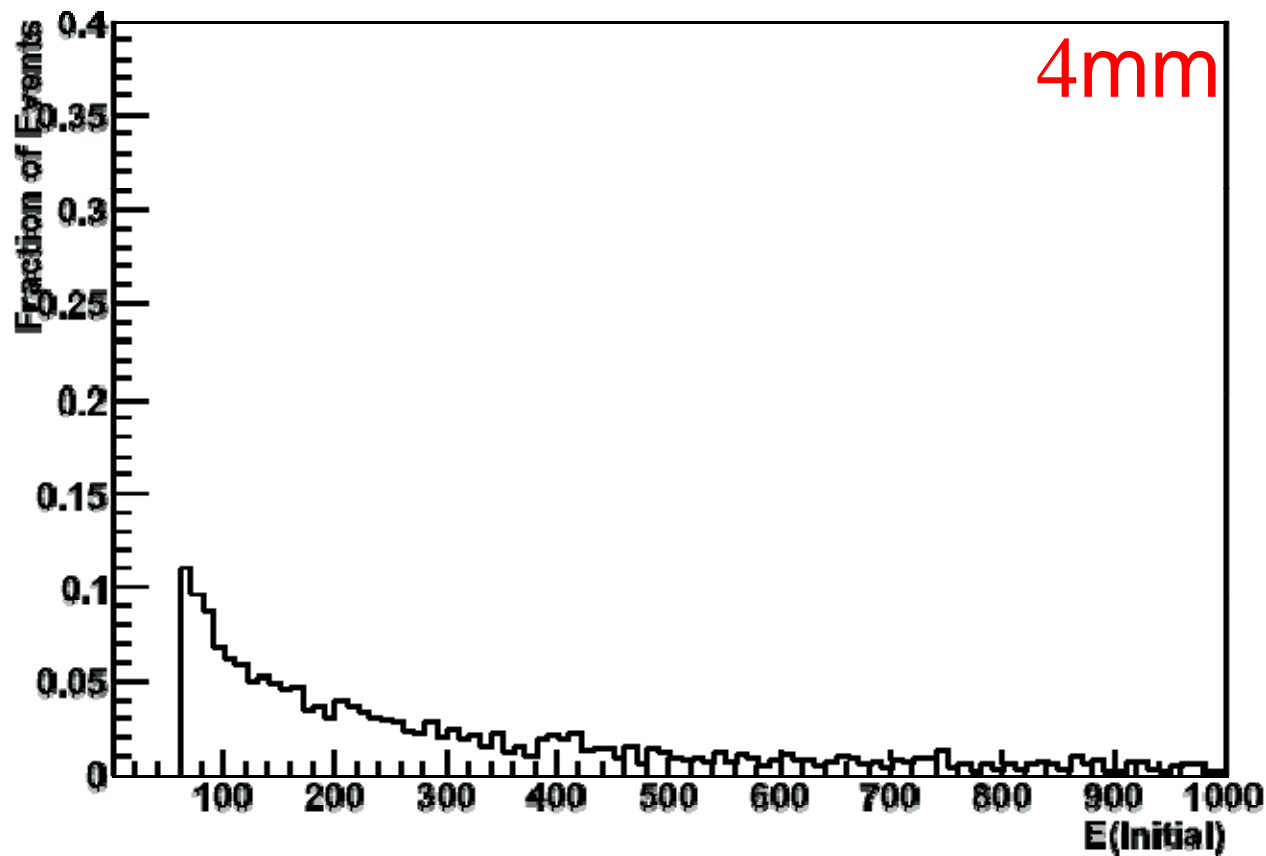
5mm Lead Fraction of Photons Escaping Detection





# Fraction of Escaping Photons

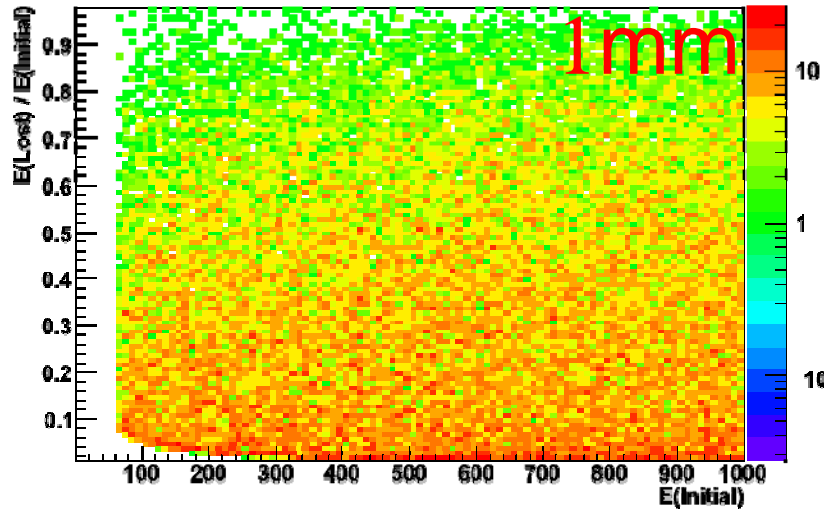
4mm Lead Fraction of Photons Escaping Detection



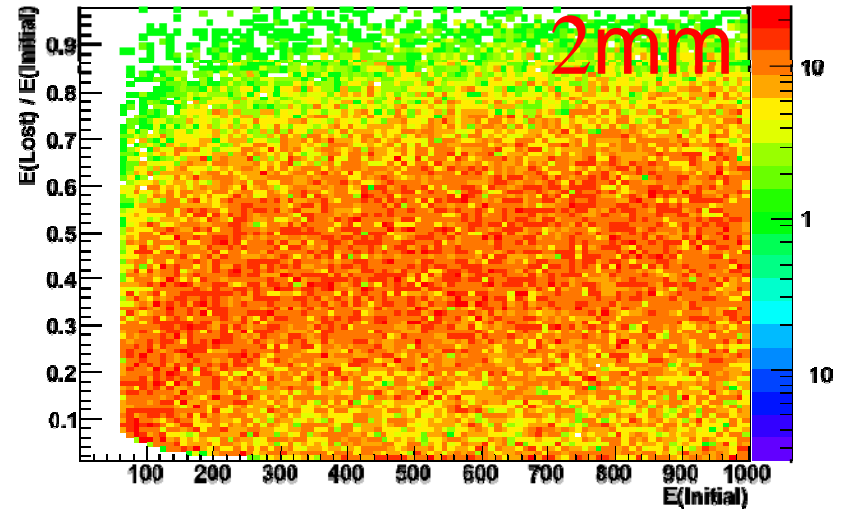


# True Uncontained Energy

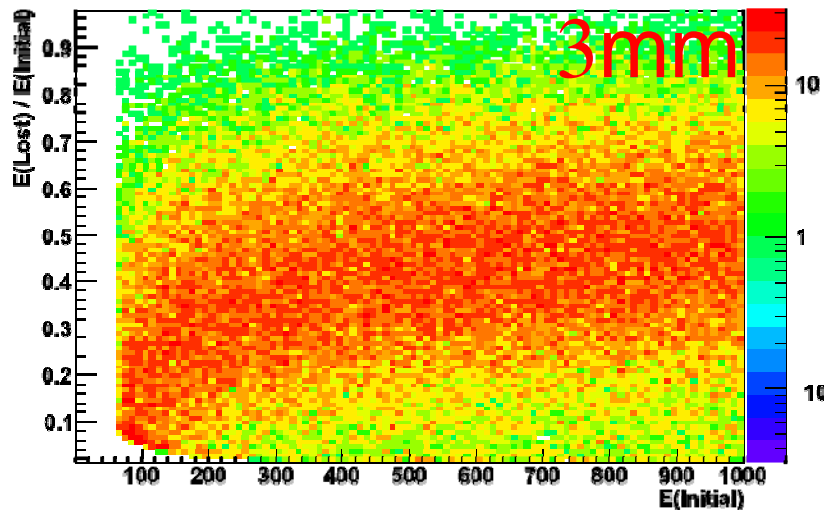
1mm Lead Energy Loss from PDECal All Primary Photons



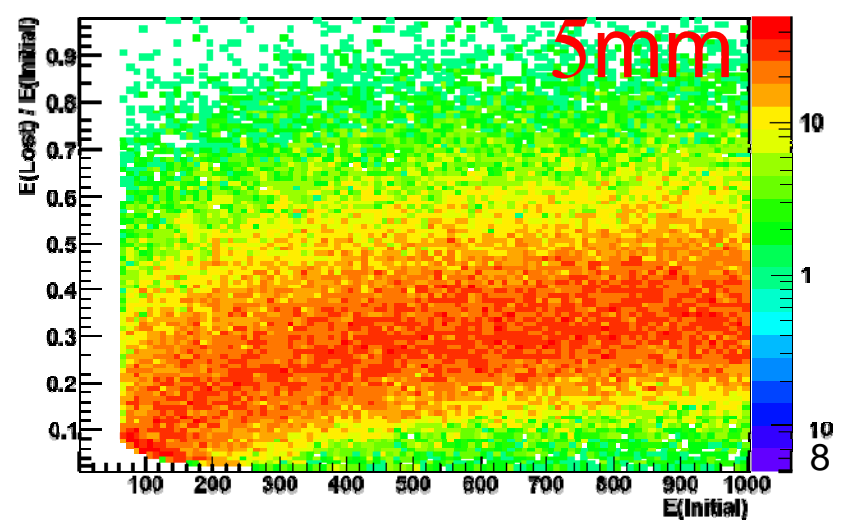
2mm Lead Energy Loss from PDECal All Primary Photons



3mm Lead Energy Loss from PDECal All Primary Photons



5mm Lead Energy Loss from PDECal All Primary Photons

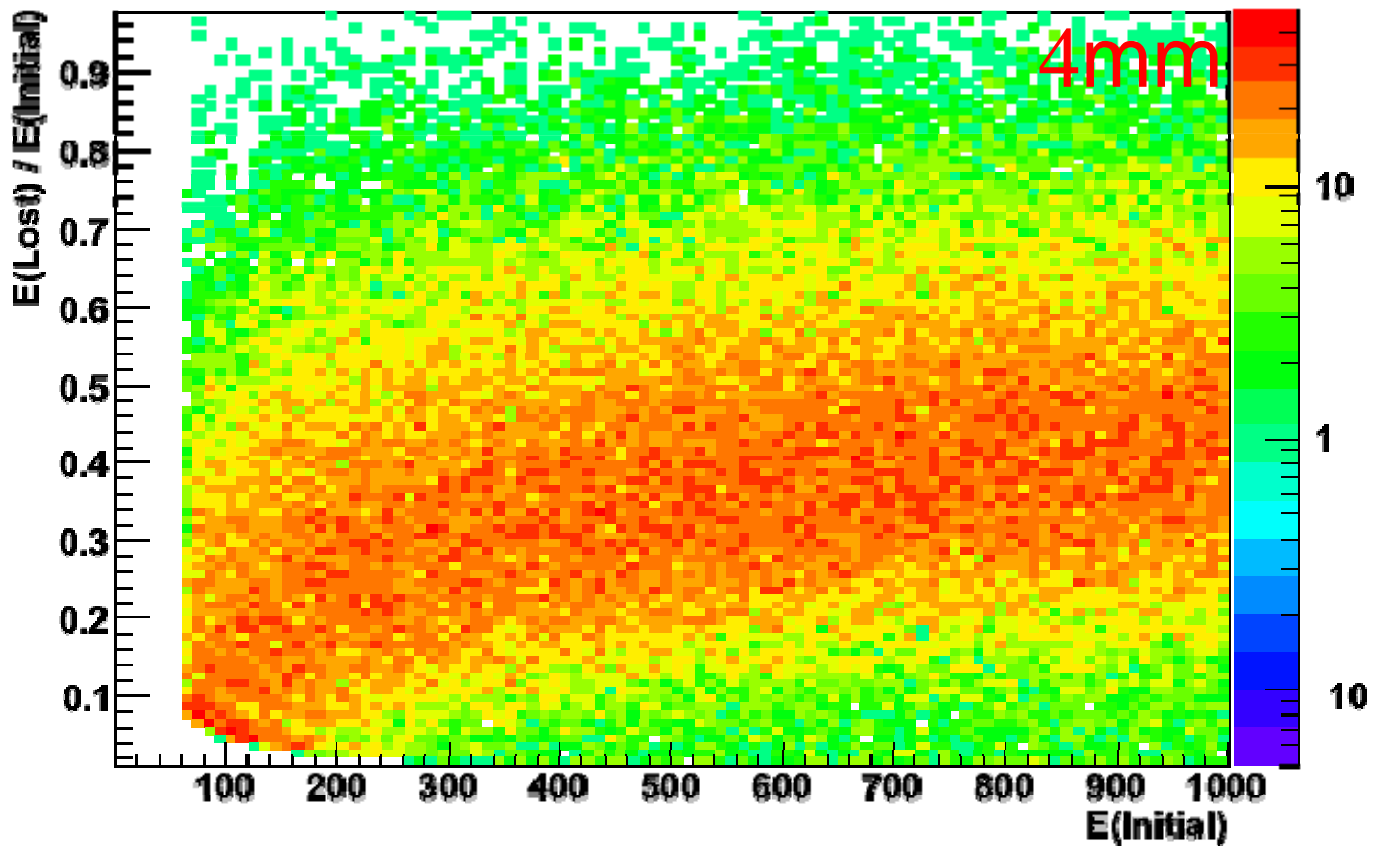






# True Uncontained Energy

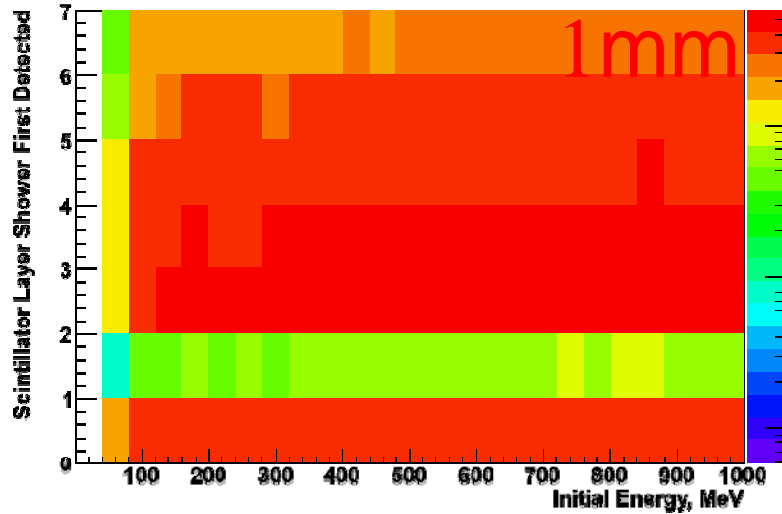
4mm Lead Energy Loss from P0DECa1 All Primary Photons



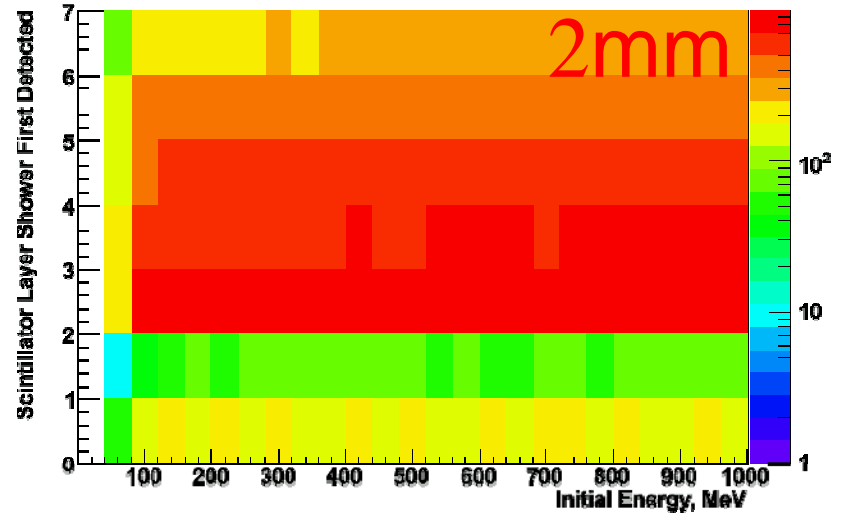


# First Active Layer with Hits

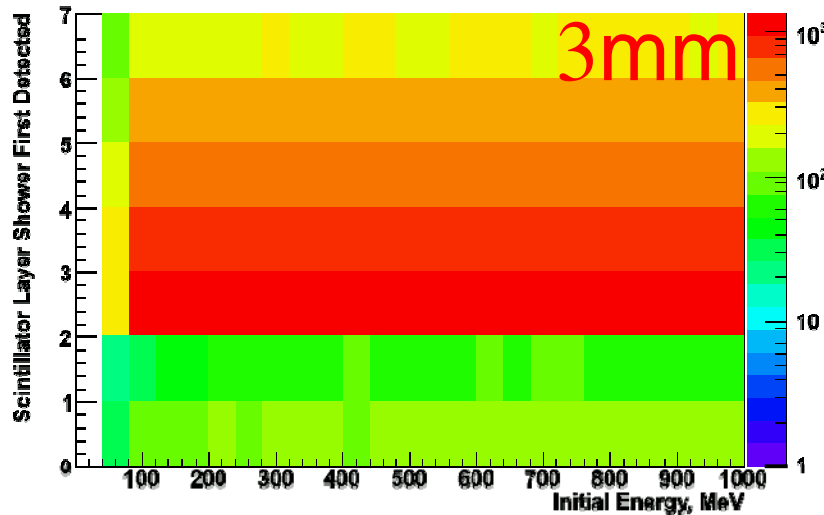
1mm Lead POEGal Layer Conv ~ InitialEnergy, perpendicular



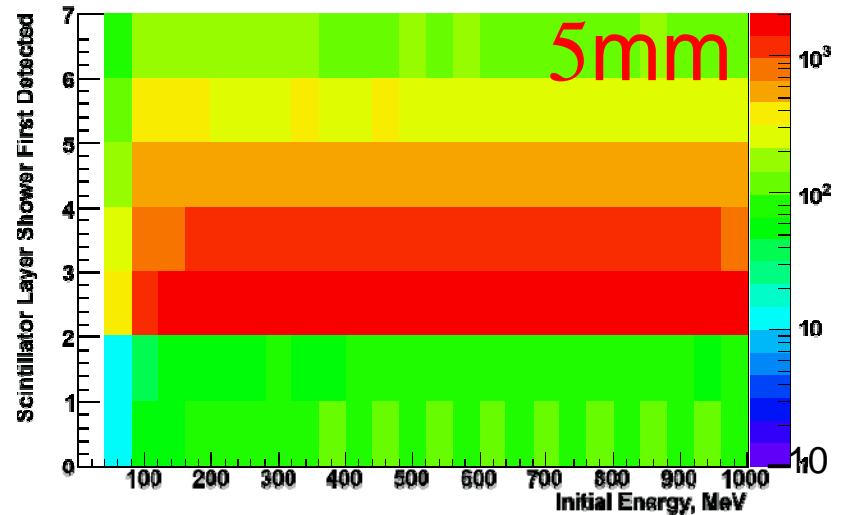
2mm Lead POEGal Layer Conv ~ InitialEnergy, perpendicular



3mm Lead POEGal Layer Conv ~ InitialEnergy, perpendicular



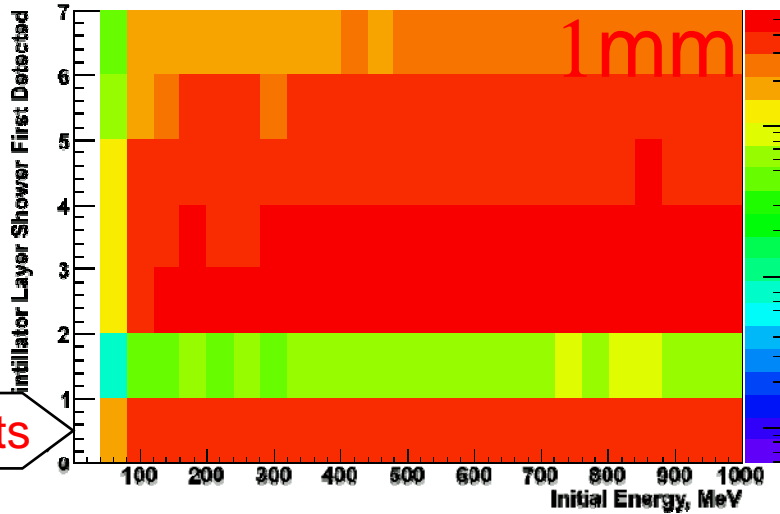
5mm Lead POEGal Layer Conv ~ InitialEnergy, perpendicular



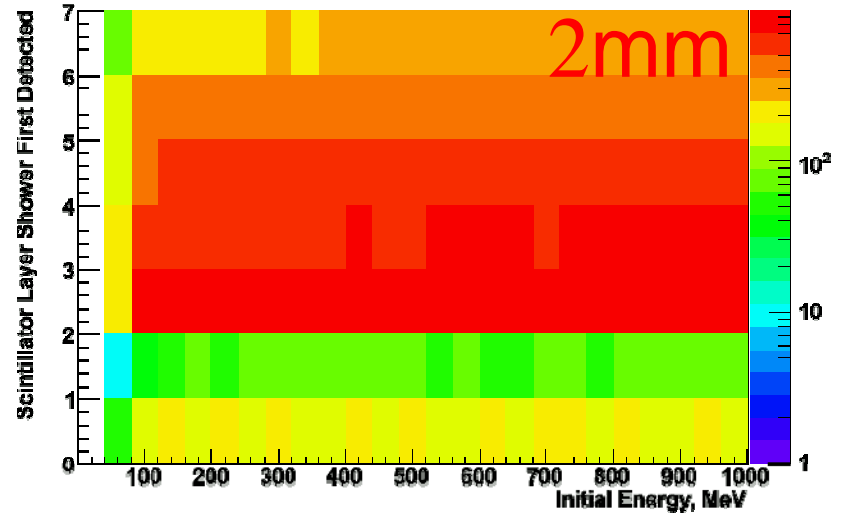


# First Active Layer with Hits

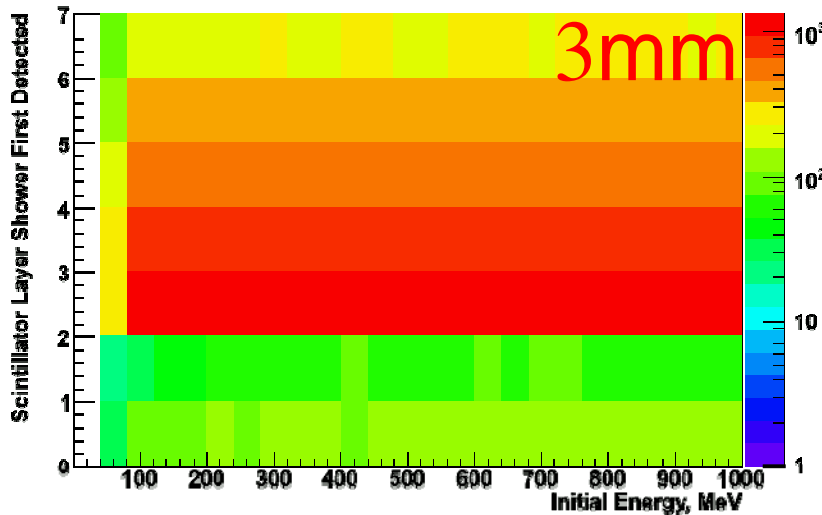
1mm Lead POEGal Layer Conv ~ InitialEnergy, perpendicular



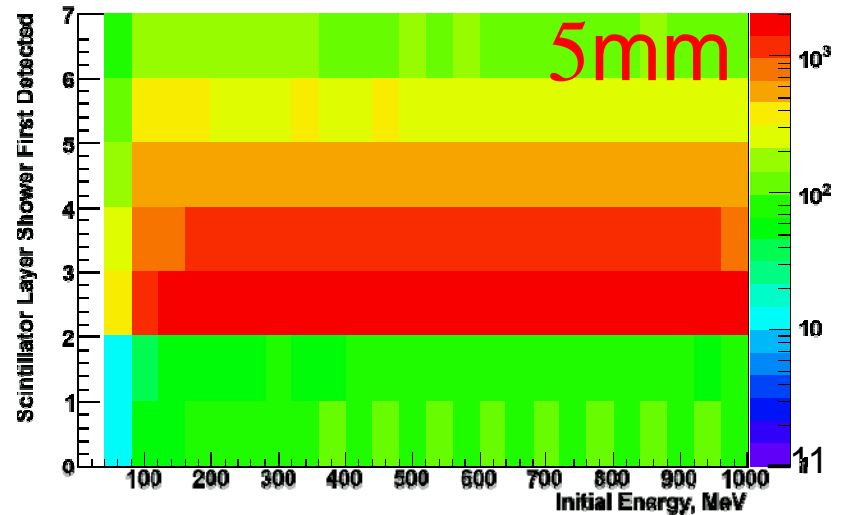
2mm Lead POEGal Layer Conv ~ InitialEnergy, perpendicular



3mm Lead POEGal Layer Conv ~ InitialEnergy, perpendicular



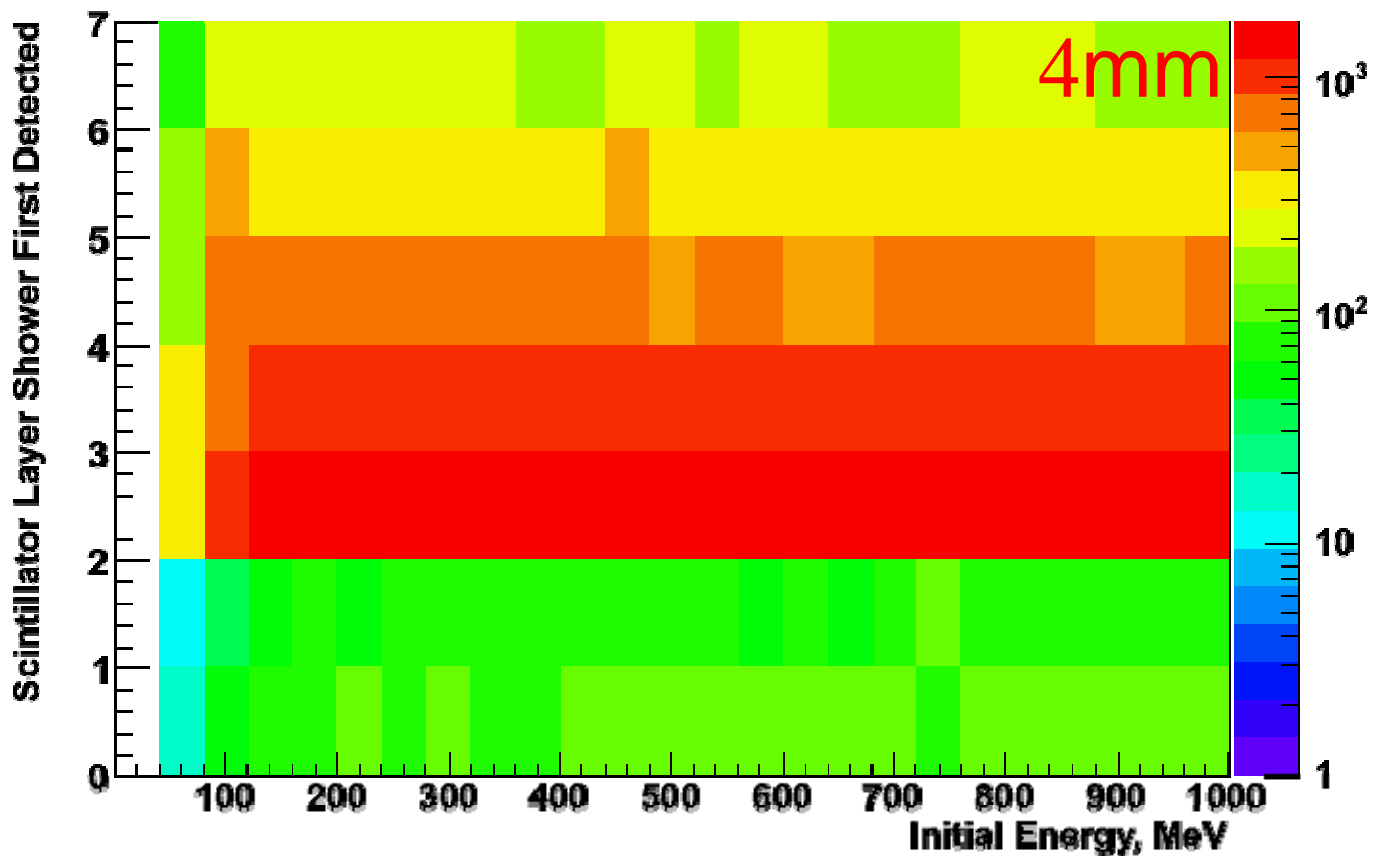
5mm Lead POEGal Layer Conv ~ InitialEnergy, perpendicular





# First Active Layer with Hits

4mm Lead P0DECal Layer Conv ~ InitialEnergy, perpendicular





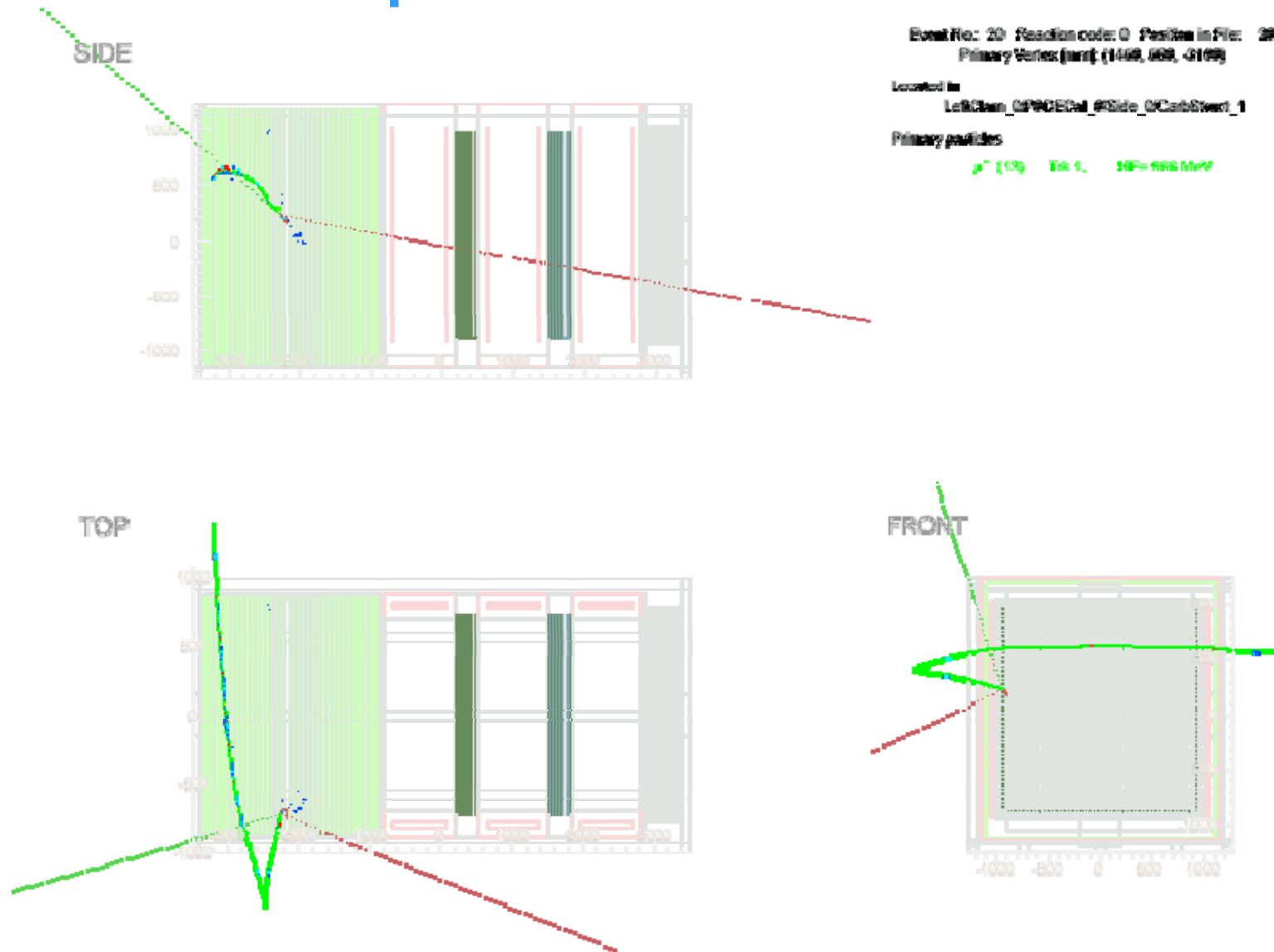
# PID Parameters

Here we have chosen to investigate how various data, used in PID techniques, alter with lead thickness. For a subset we chose:

- Number of Layers Hit
- Number of Bars Hit
- Average Charge Deposited per Layer

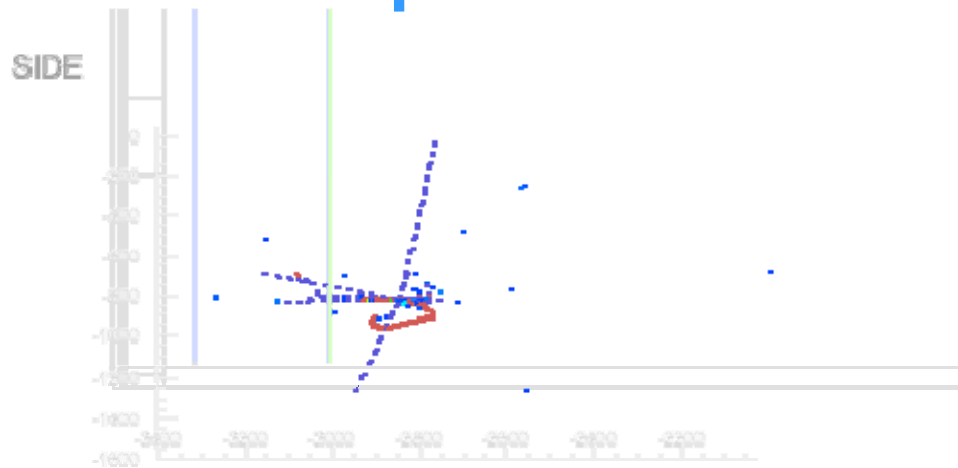


# Example Event - Muon





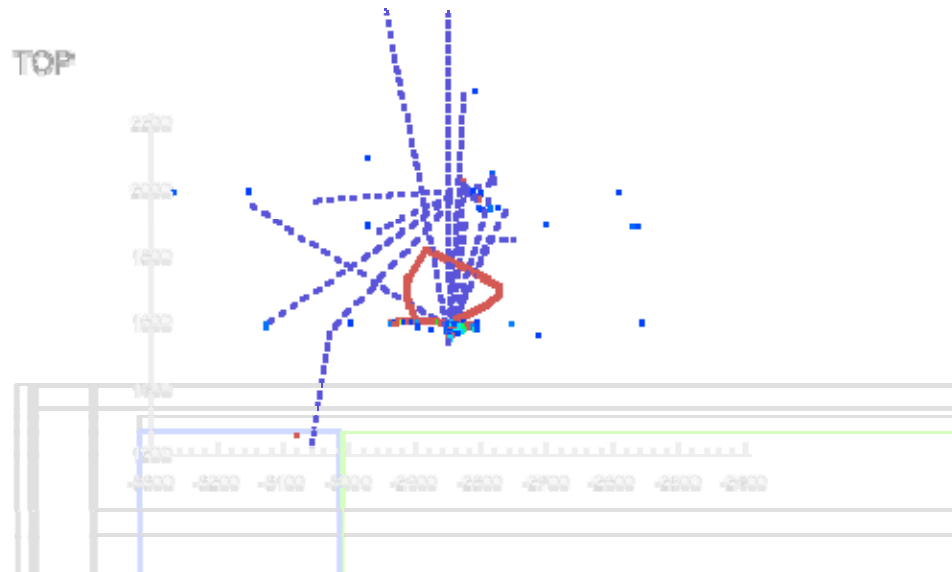
# Example Event - Photon



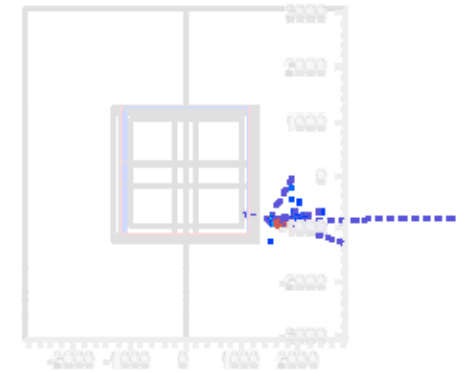
Event No.: 0 Reaction code: 0 Position in File: 0  
Primary Vertex (mm): (14.98, -6.28, -951.9)

Located in  
LeRClean\_03PDECAL\_#Side\_0\_Cat0West\_1

Primary particles  
 $\gamma$  (22)  $\pi^0$  (1)  $N^0$  (1)  $M^0$  (1)



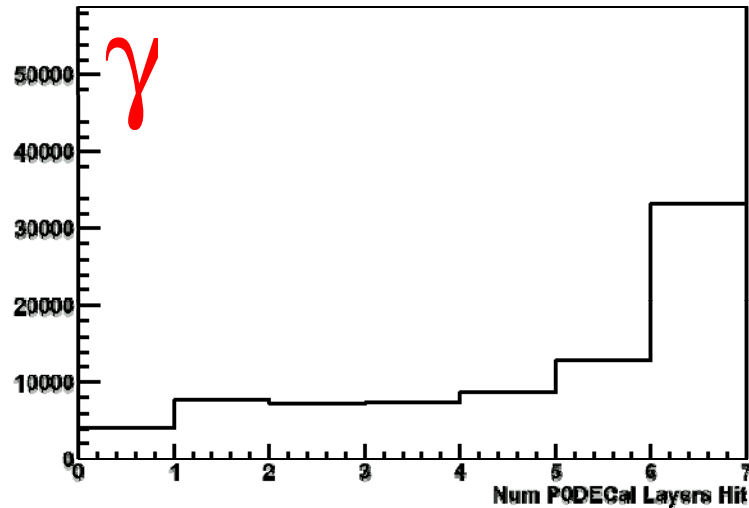
FRONT



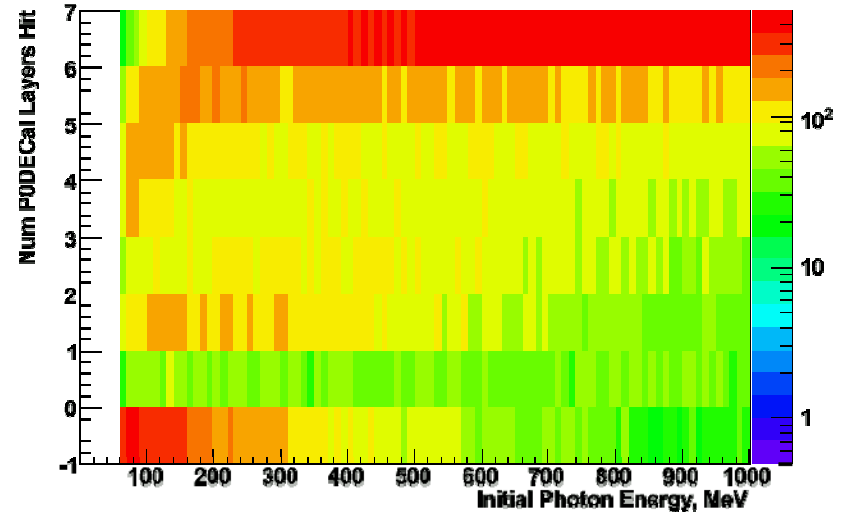


# Num of P0DECAL Layers Hit – 1mm

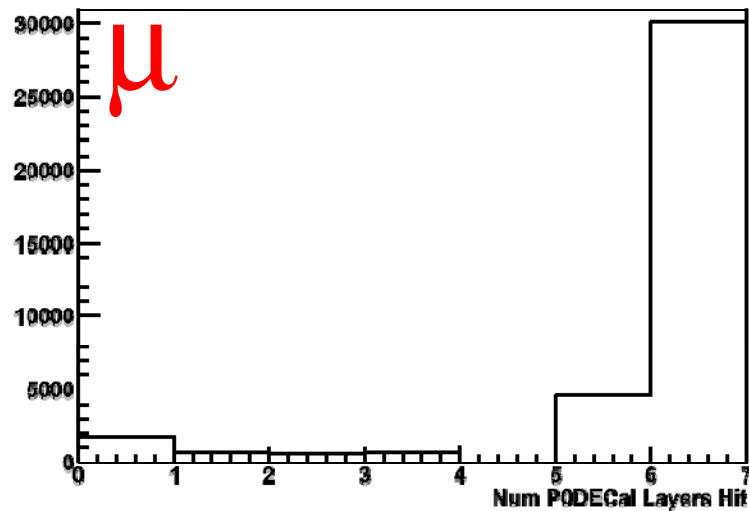
1mm Lead Num P0DECAL LayersHit, perpendicular



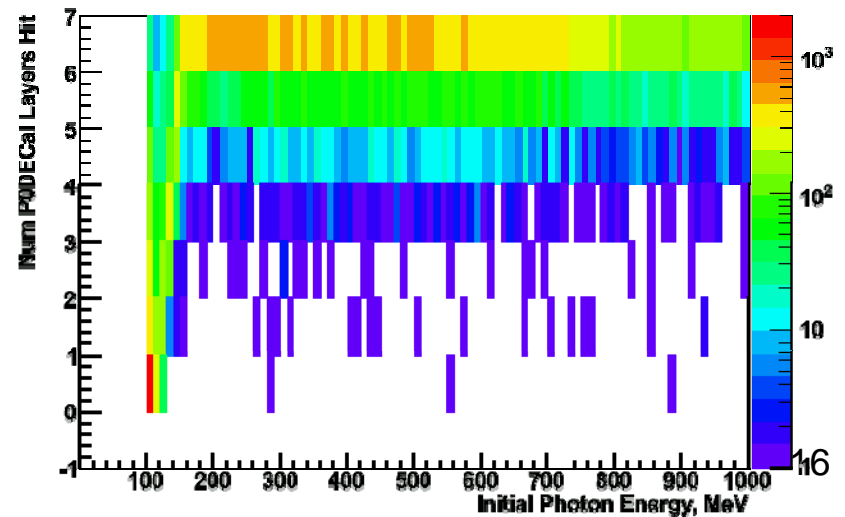
1mm Lead Num P0DECAL LayersHit ~ InitialEnergy, perpendicular



1mm Lead Num P0DECAL LayersHit, perpendicular



1mm Lead Num P0DECAL LayersHit ~ InitialEnergy, perpendicular

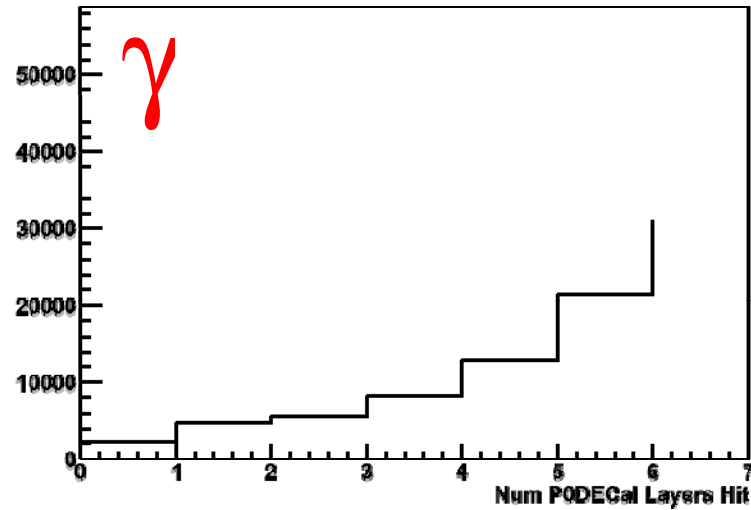




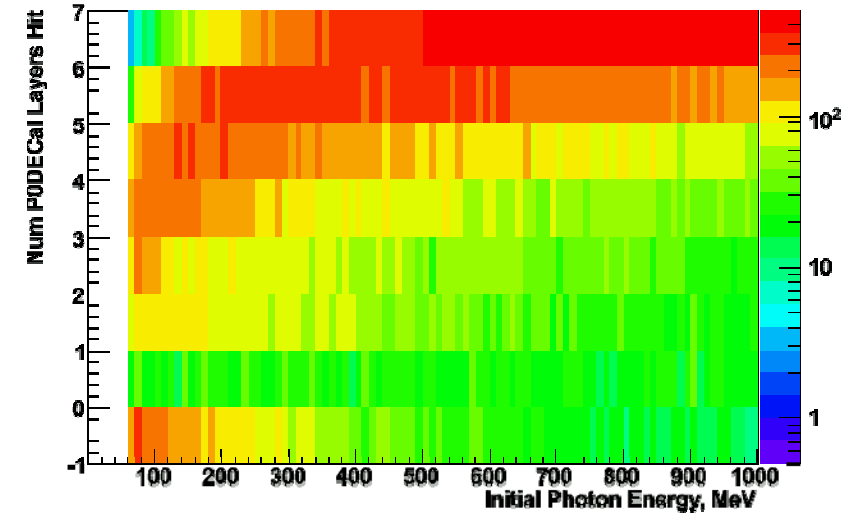


# Num of P0DECAL Layers Hit – 2mm

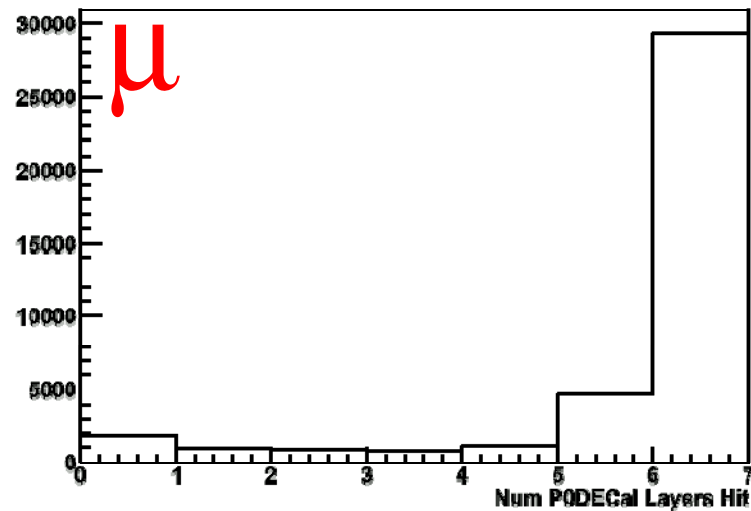
2mm Lead Num P0DECAL LayersHit, perpendicular



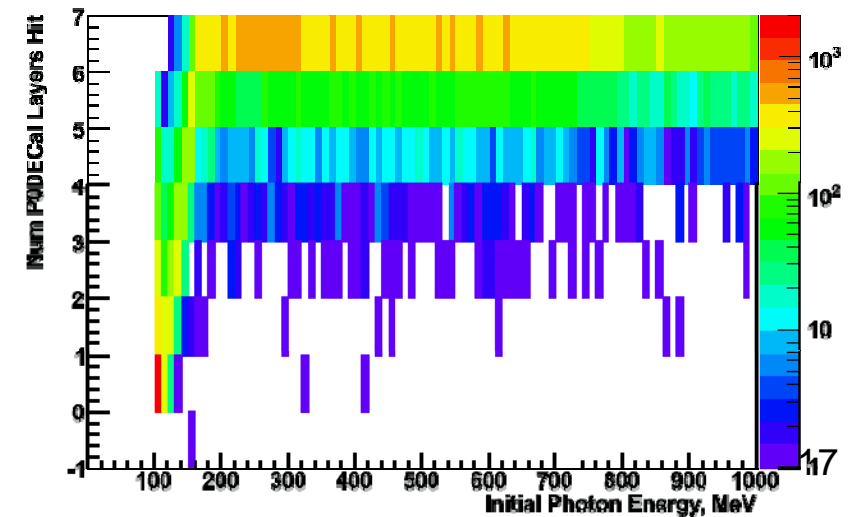
2mm Lead Num P0DECAL LayersHit ~ InitialEnergy, perpendicular



2mm Lead Num P0DECAL LayersHit, perpendicular



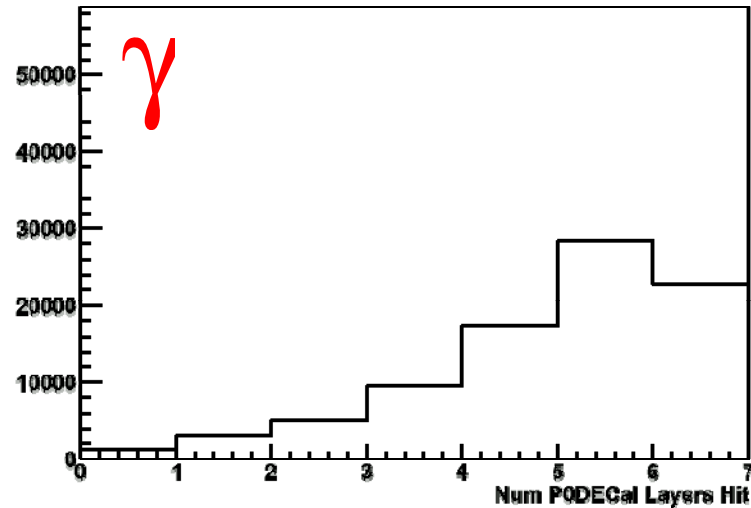
2mm Lead Num P0DECAL LayersHit ~ InitialEnergy, perpendicular



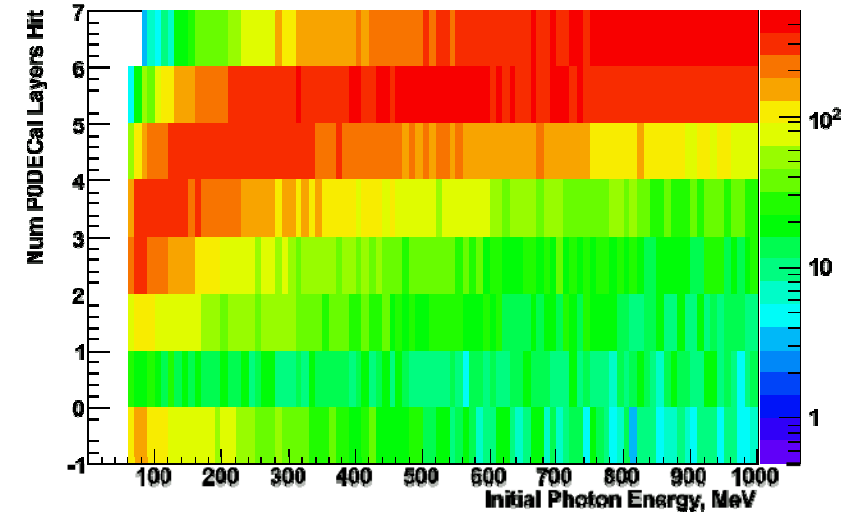


# Num of P0DECAL Layers Hit – 3mm

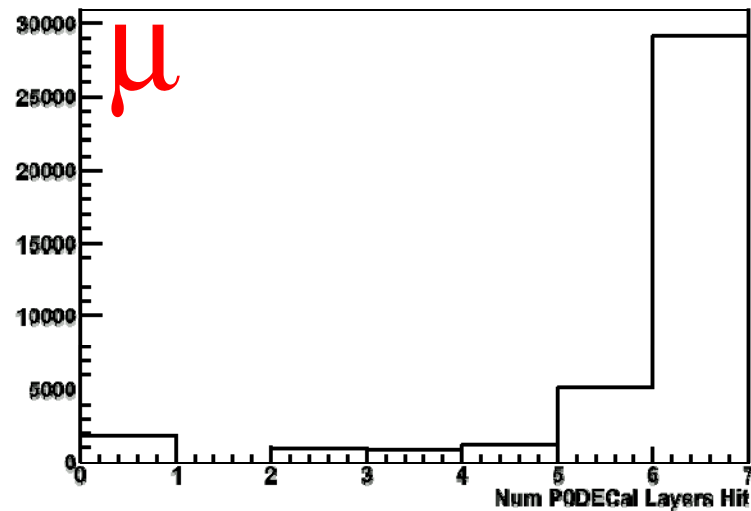
3mm Lead Num P0DECAL LayersHit, perpendicular



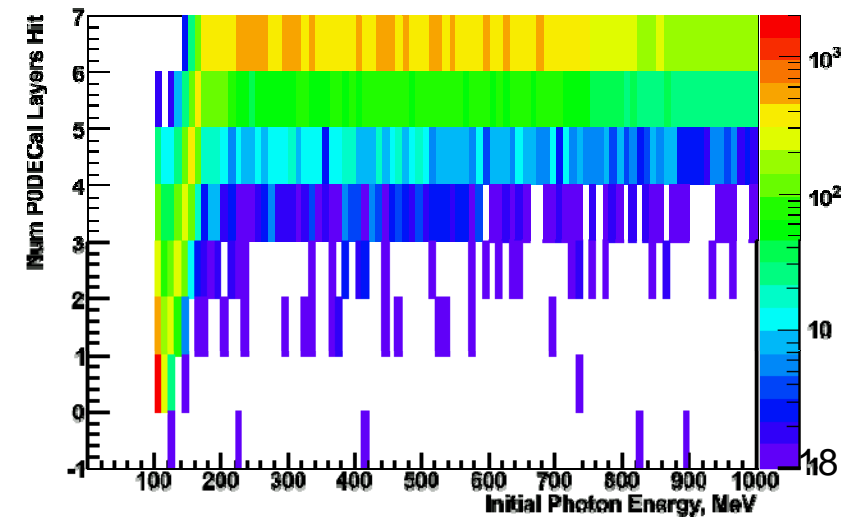
3mm Lead Num P0DECAL LayersHit ~ InitialEnergy, perpendicular



3mm Lead Num P0DECAL LayersHit, perpendicular



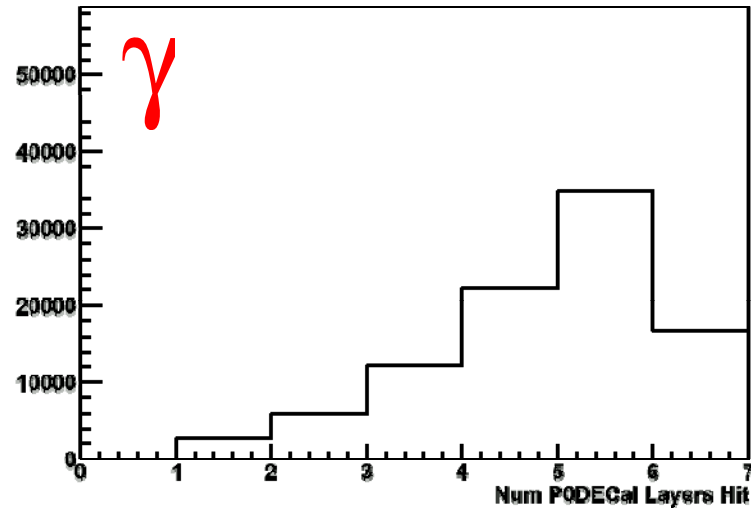
3mm Lead Num P0DECAL LayersHit ~ InitialEnergy, perpendicular



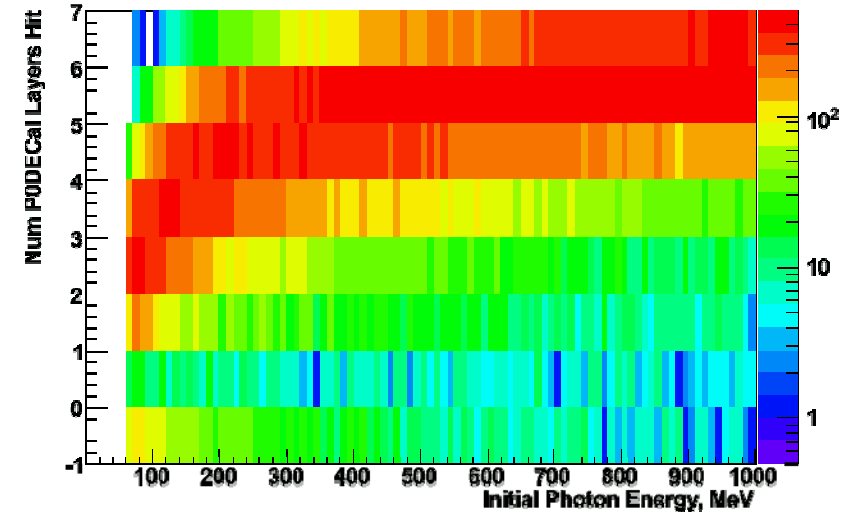


# Num of P0DECAL Layers Hit – 4mm

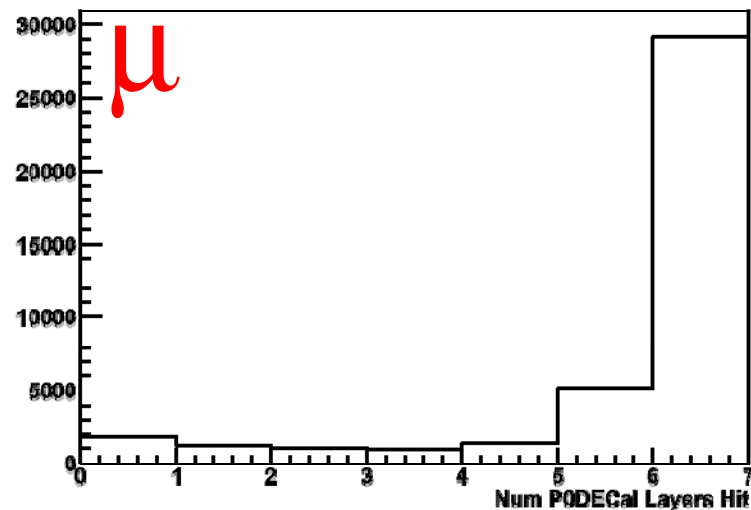
4mm Lead Num P0DECAL LayersHit, perpendicular



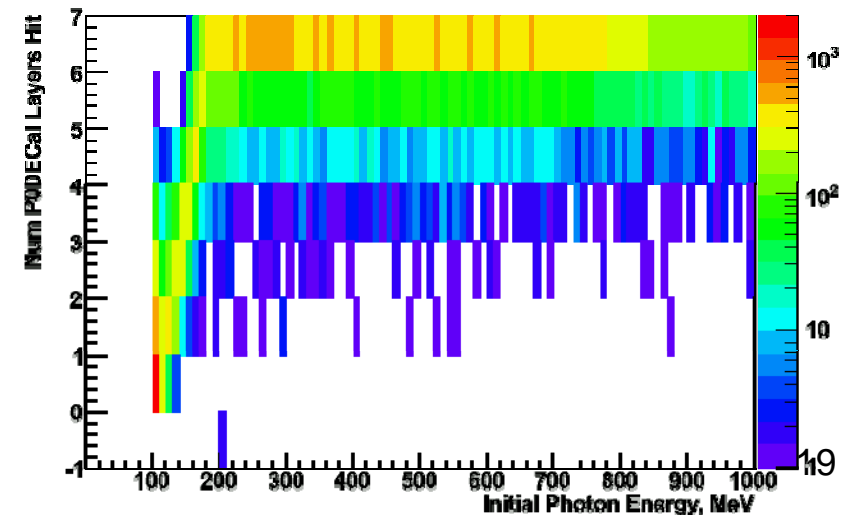
4mm Lead Num P0DECAL LayersHit ~ InitialEnergy, perpendicular



4mm Lead Num P0DECAL LayersHit, perpendicular



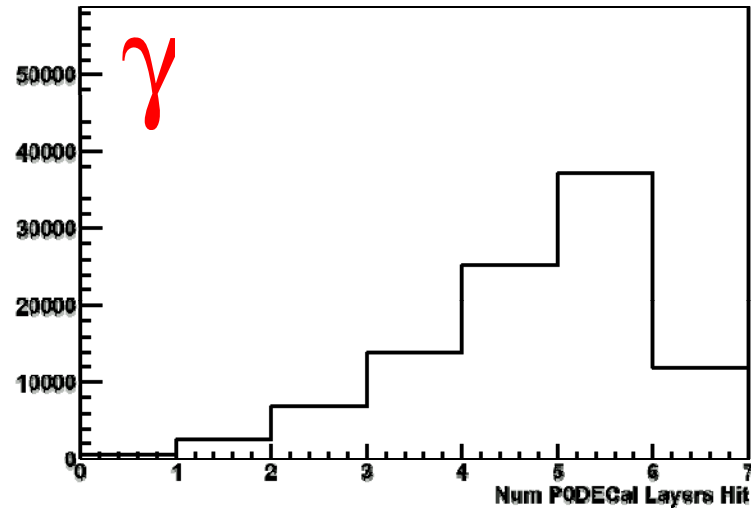
4mm Lead Num P0DECAL LayersHit ~ InitialEnergy, perpendicular



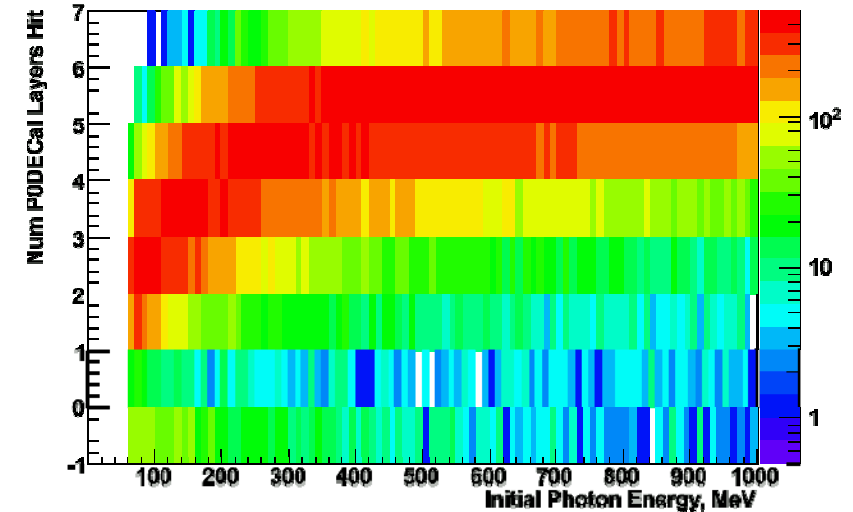


# Num of P0DECAL Layers Hit – 5mm

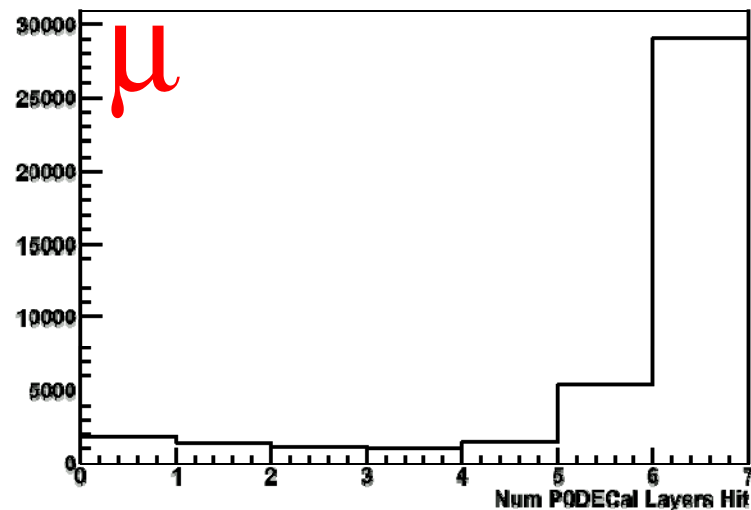
5mm Lead Num P0DECAL LayersHit, perpendicular



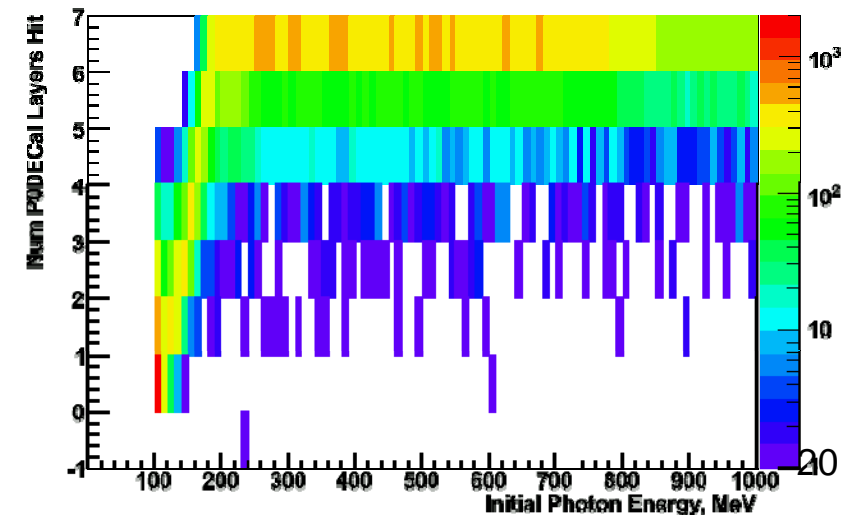
5mm Lead Num P0DECAL LayersHit ~ InitialEnergy, perpendicular



5mm Lead Num P0DECAL LayersHit, perpendicular



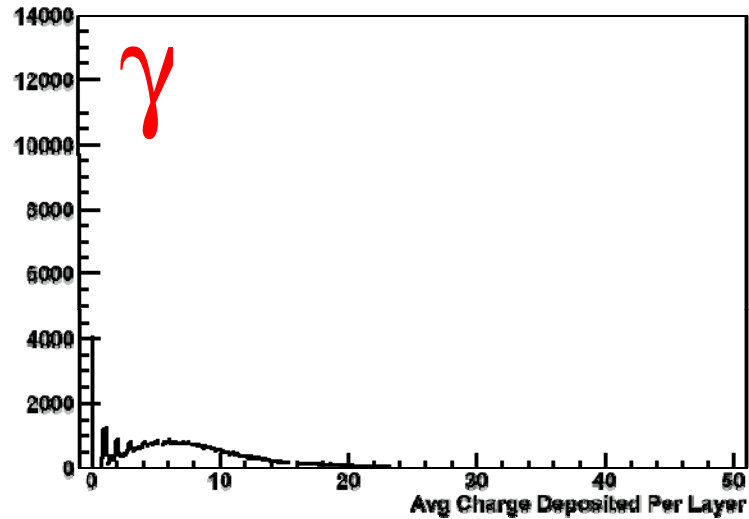
5mm Lead Num P0DECAL LayersHit ~ InitialEnergy, perpendicular



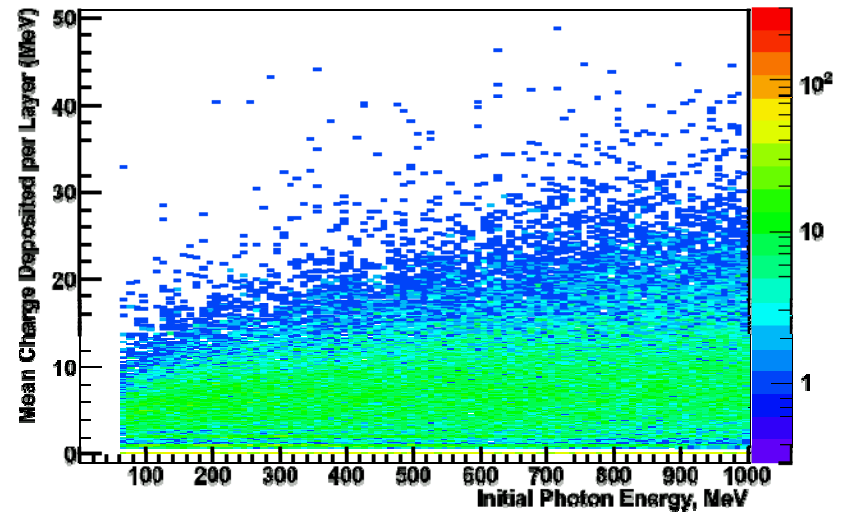


# Average Charge per Layer – 1mm

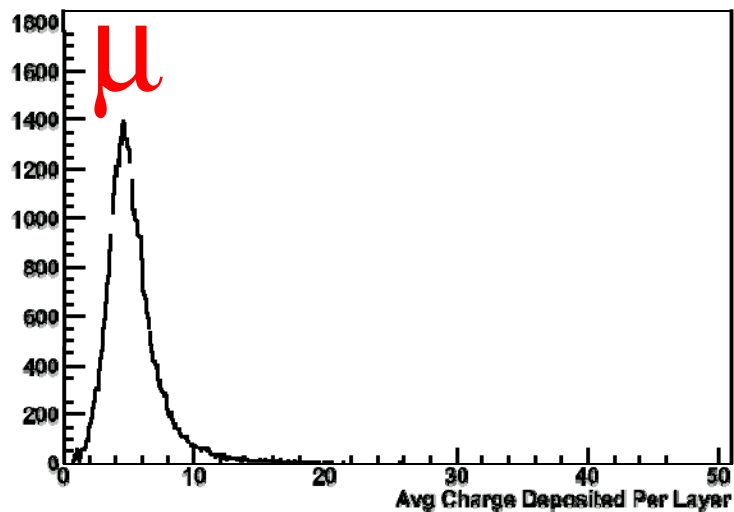
1mm Lead Avg Charge Deposited per Layer



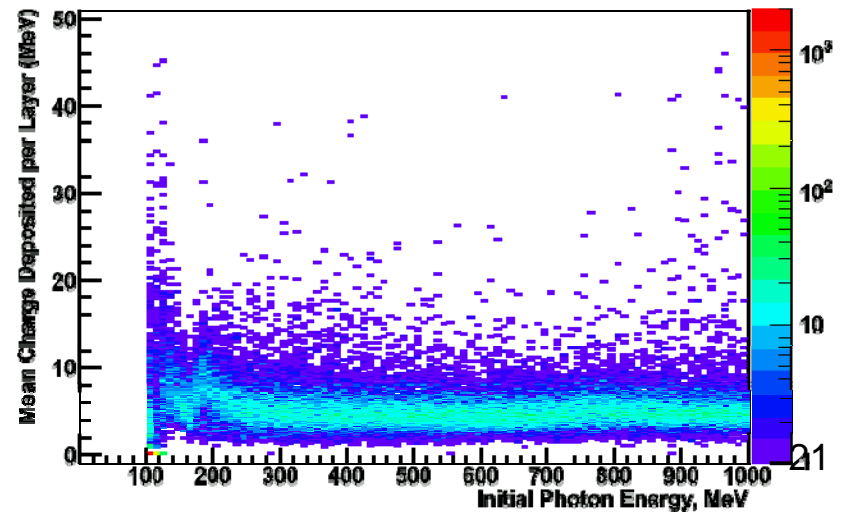
1mm Lead Avg Charge Deposited per Layer ~ InitialEnergy



1mm Lead Avg Charge Deposited per Layer



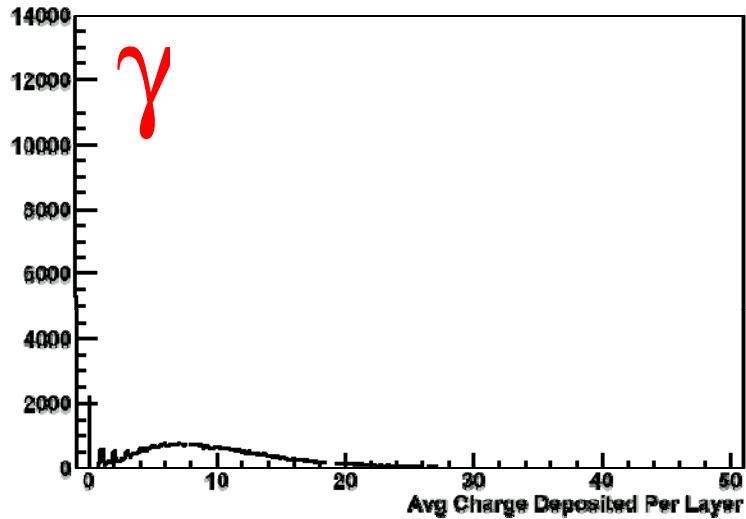
1mm Lead Avg Charge Deposited per Layer ~ InitialEnergy



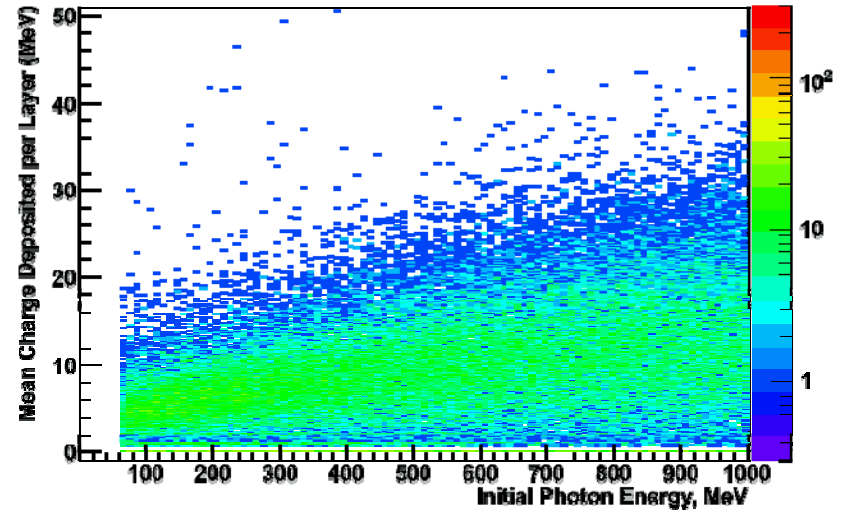


# Average Charge per Layer – 2mm

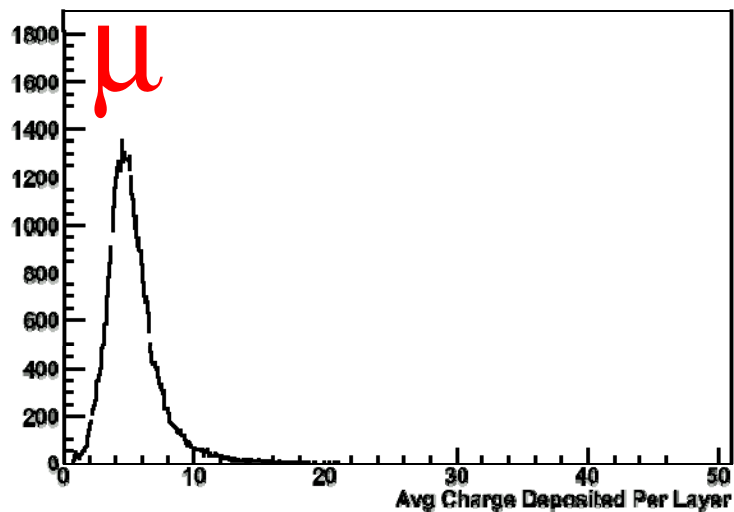
2mm Lead Avg Charge Deposited per Layer



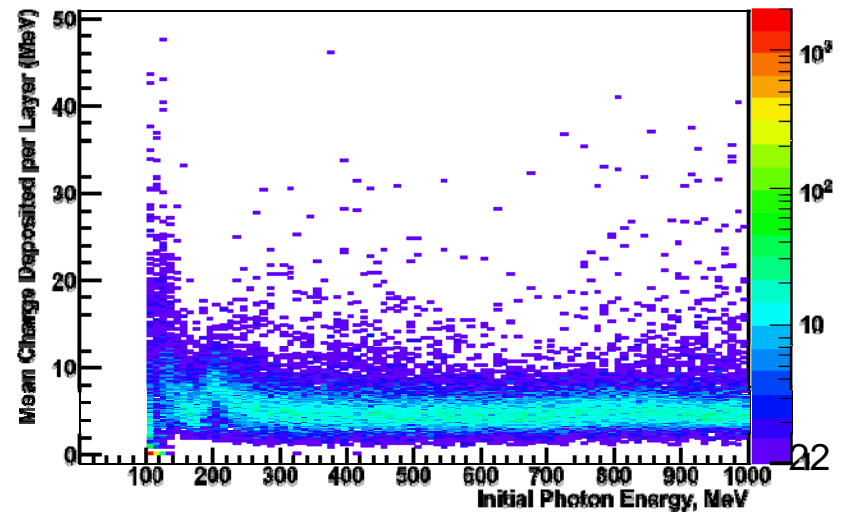
2mm Lead Avg Charge Deposited per Layer ~ InitialEnergy



2mm Lead Avg Charge Deposited per Layer



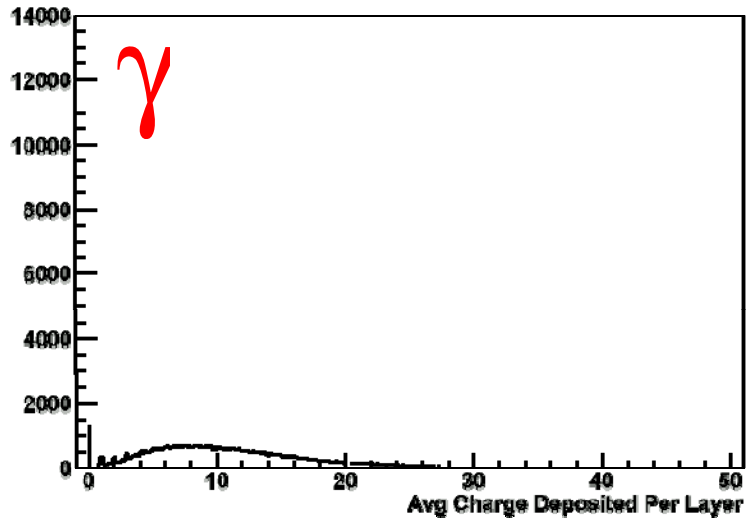
2mm Lead Avg Charge Deposited per Layer ~ InitialEnergy



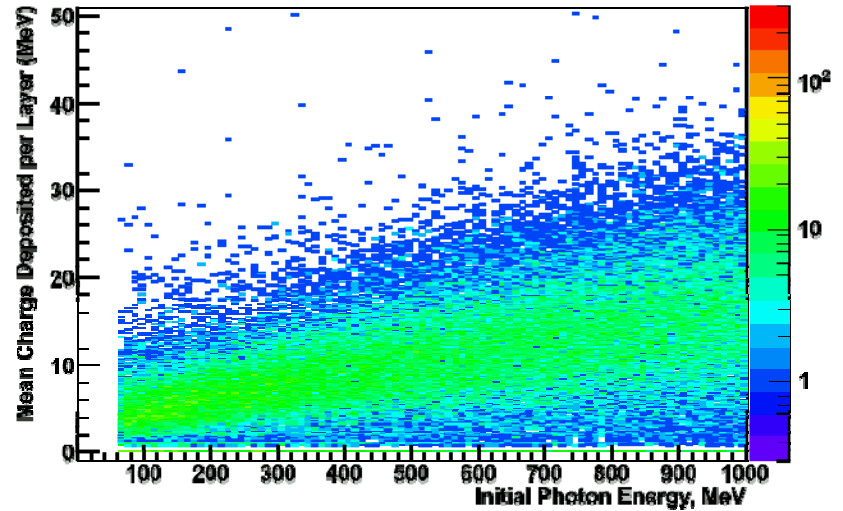


# Average Charge per Layer – 3mm

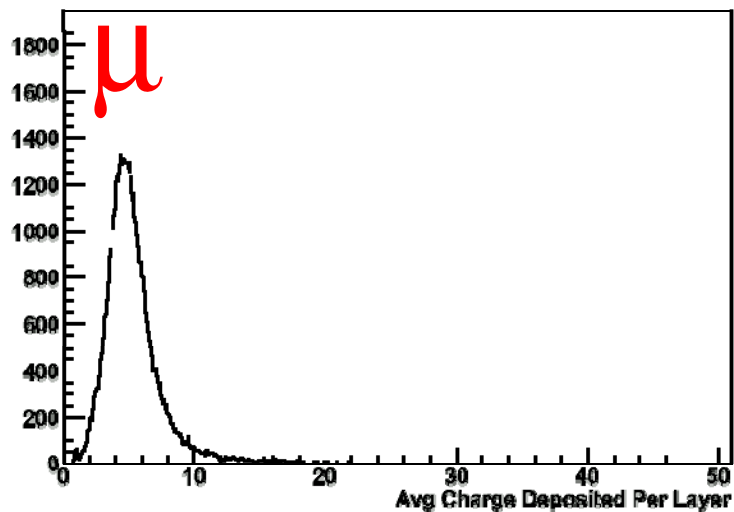
3mm Lead Avg Charge Deposited per Layer



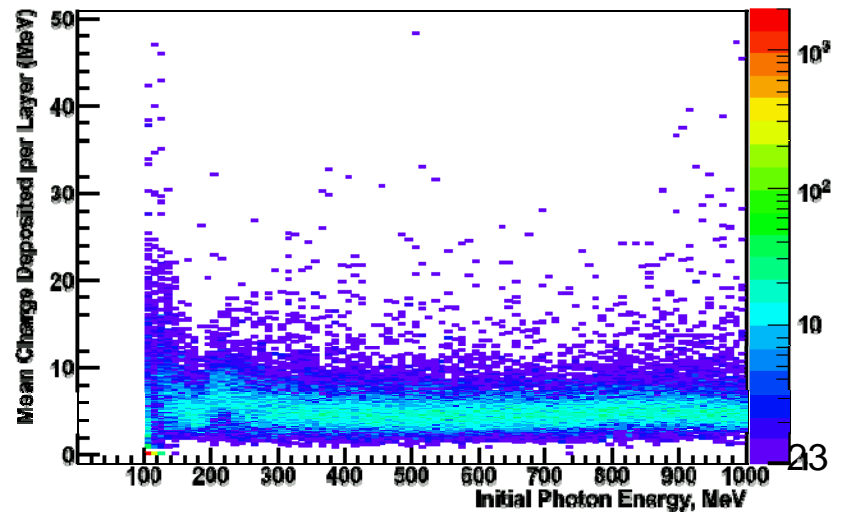
3mm Lead Avg Charge Deposited per Layer ~ InitialEnergy



3mm Lead Avg Charge Deposited per Layer



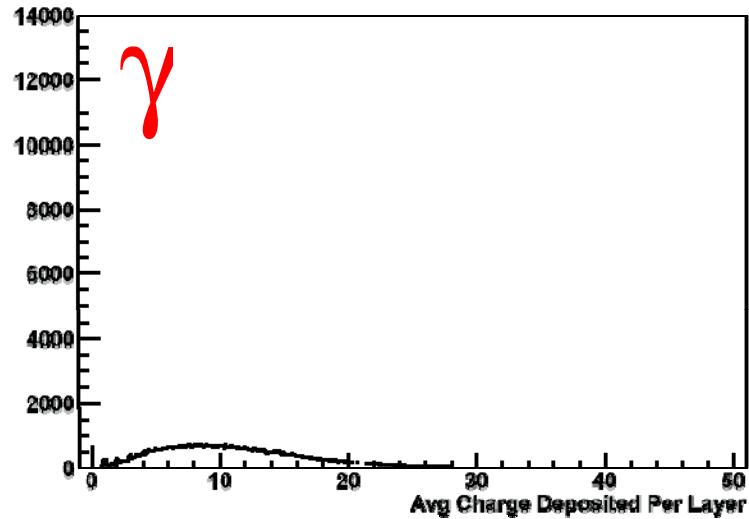
3mm Lead Avg Charge Deposited per Layer ~ InitialEnergy



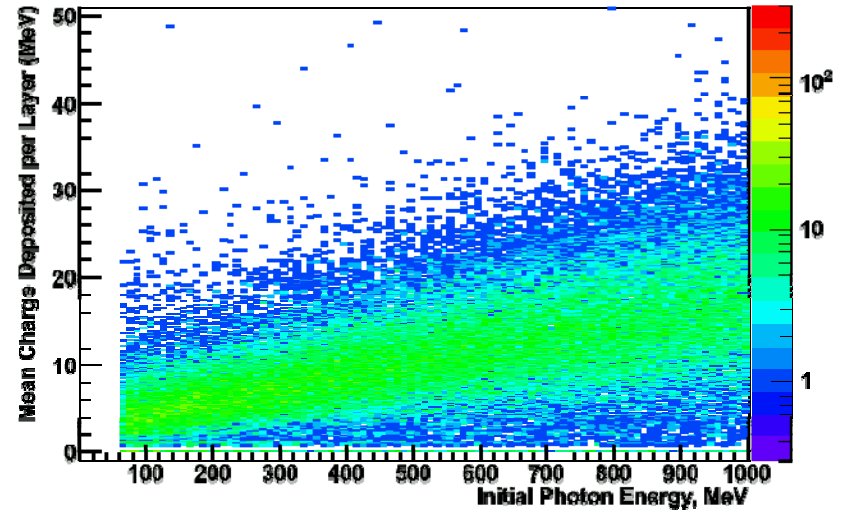


# Average Charge per Layer – 4mm

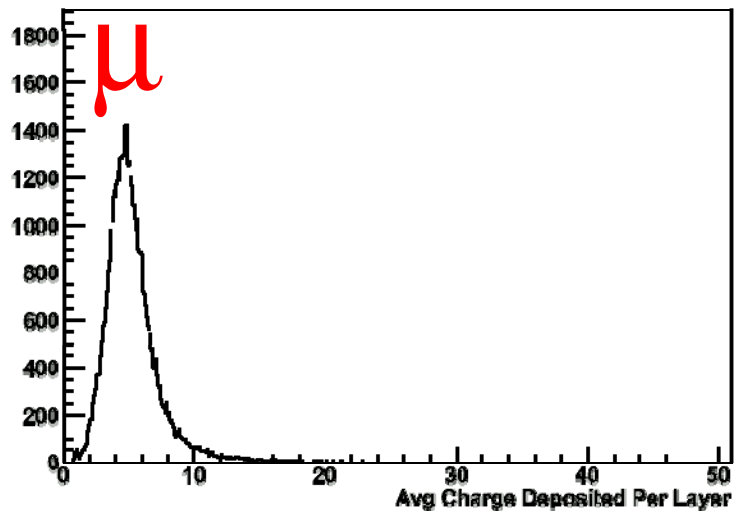
4mm Lead Avg Charge Deposited per Layer



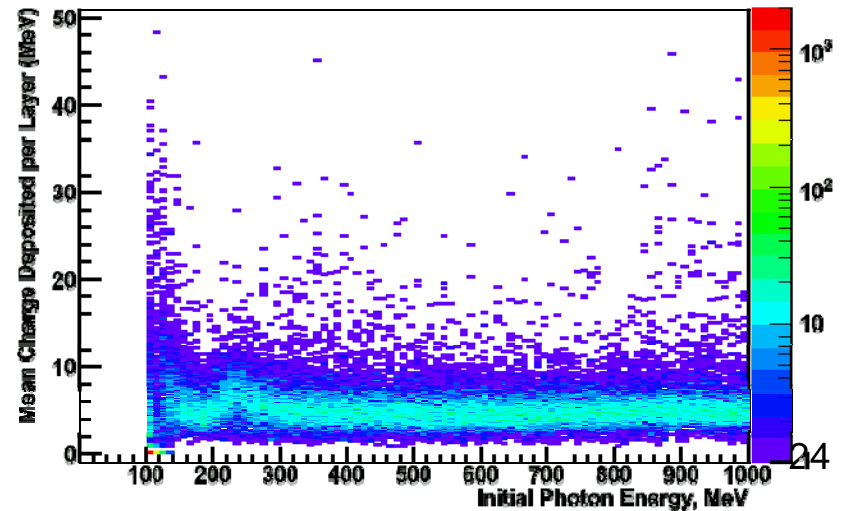
4mm Lead Avg Charge Deposited per Layer ~ InitialEnergy



4mm Lead Avg Charge Deposited per Layer



4mm Lead Avg Charge Deposited per Layer ~ InitialEnergy

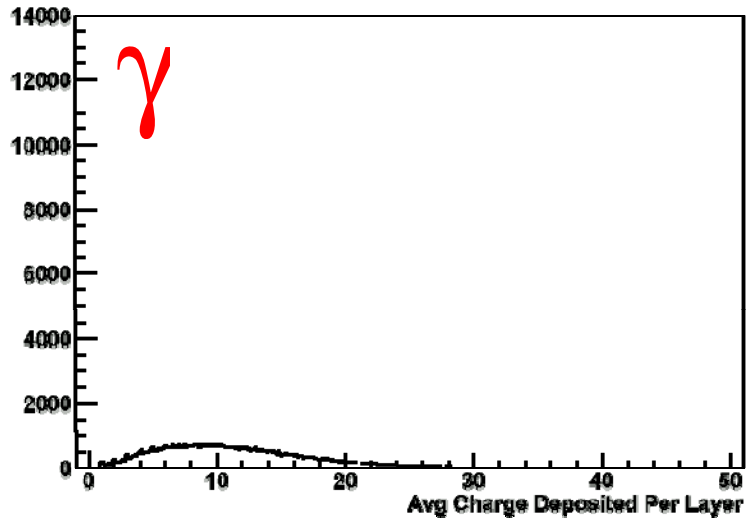




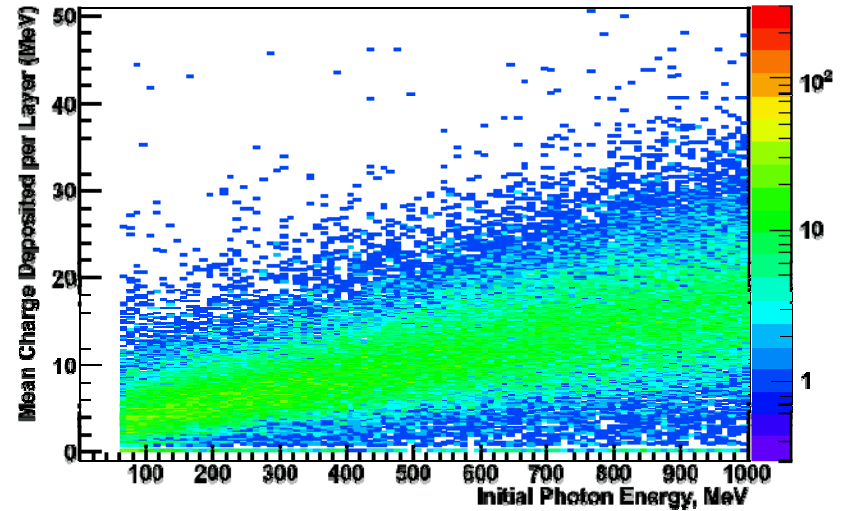


# Average Charge per Layer – 5mm

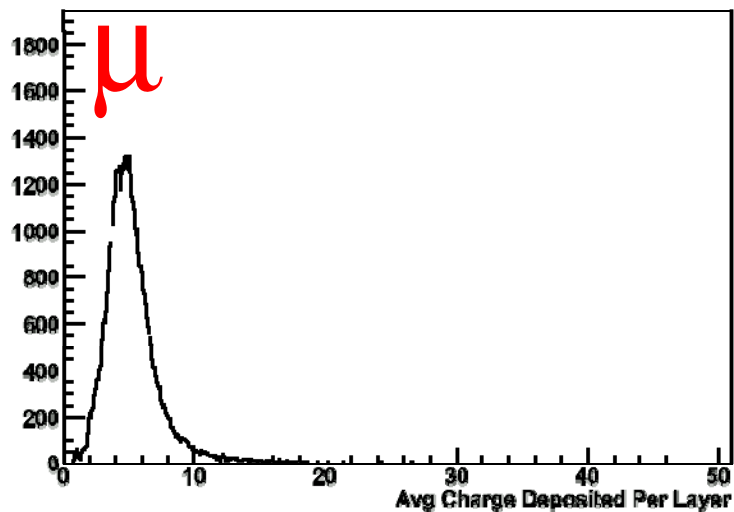
5mm Lead Avg Charge Deposited per Layer



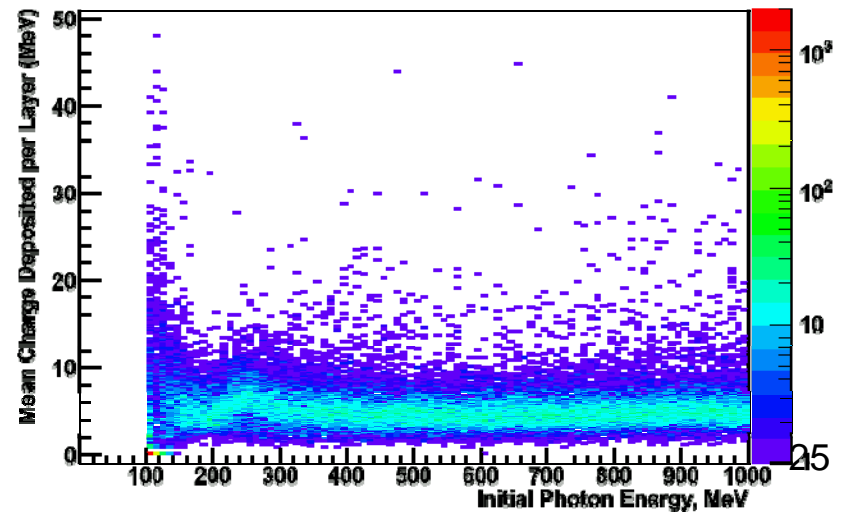
5mm Lead Avg Charge Deposited per Layer ~ InitialEnergy



5mm Lead Avg Charge Deposited per Layer



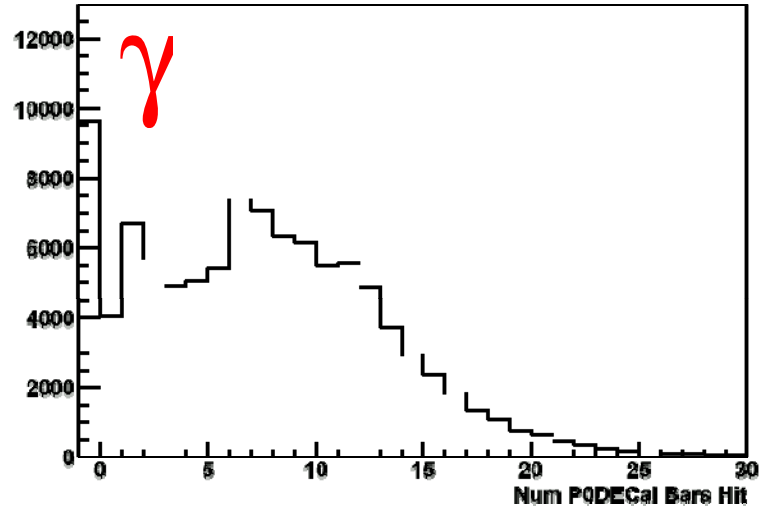
5mm Lead Avg Charge Deposited per Layer ~ InitialEnergy



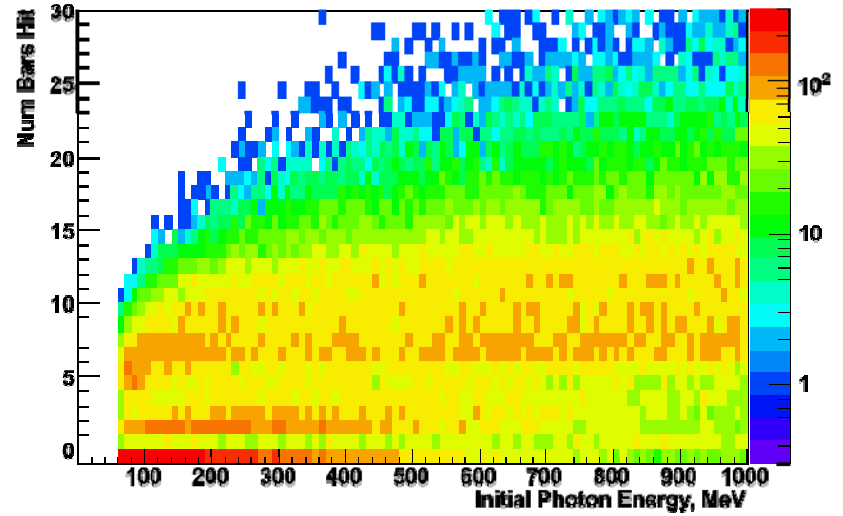


# Number Bars Hit – 1mm

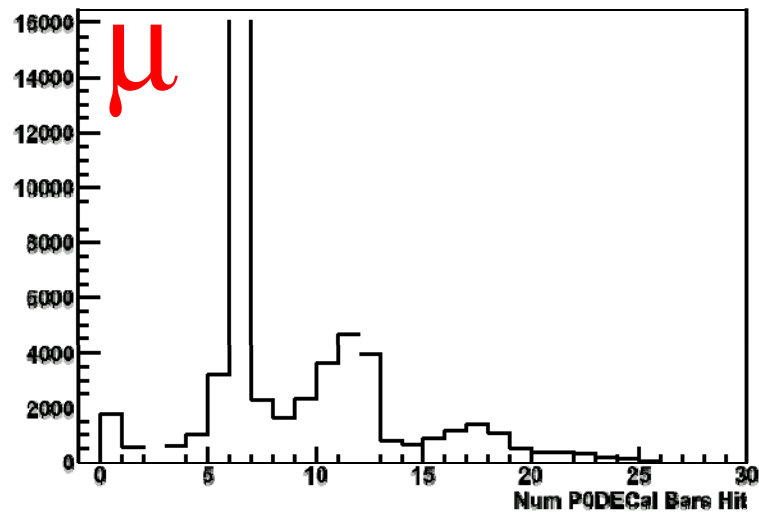
1mm Lead Number of Bars Hit



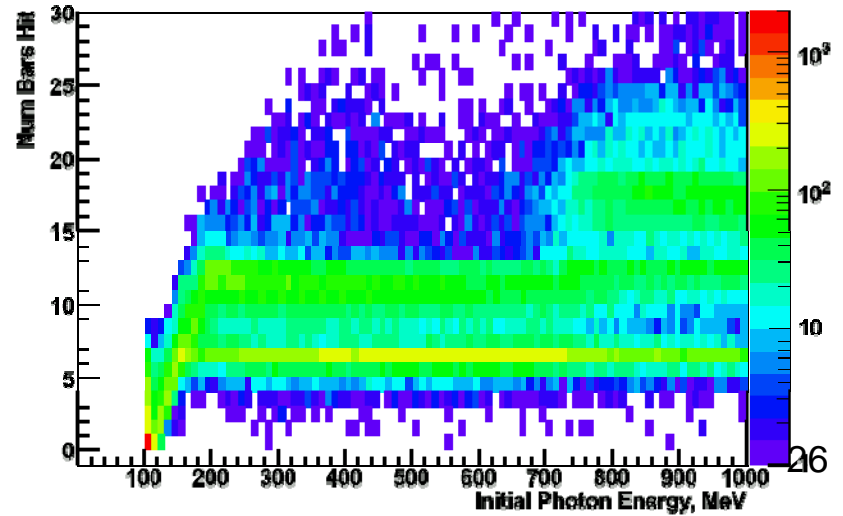
1mm Lead Number of Bars Hit ~ InitialEnergy



1mm Lead Number of Bars Hit



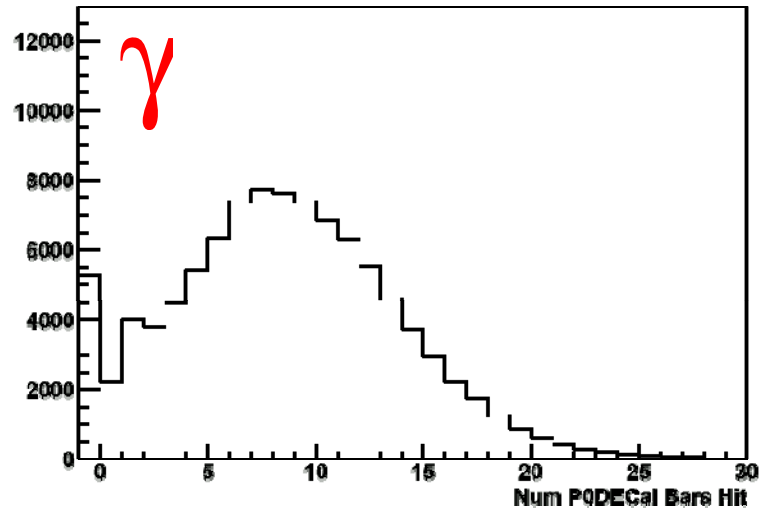
1mm Lead Number of Bars Hit ~ InitialEnergy



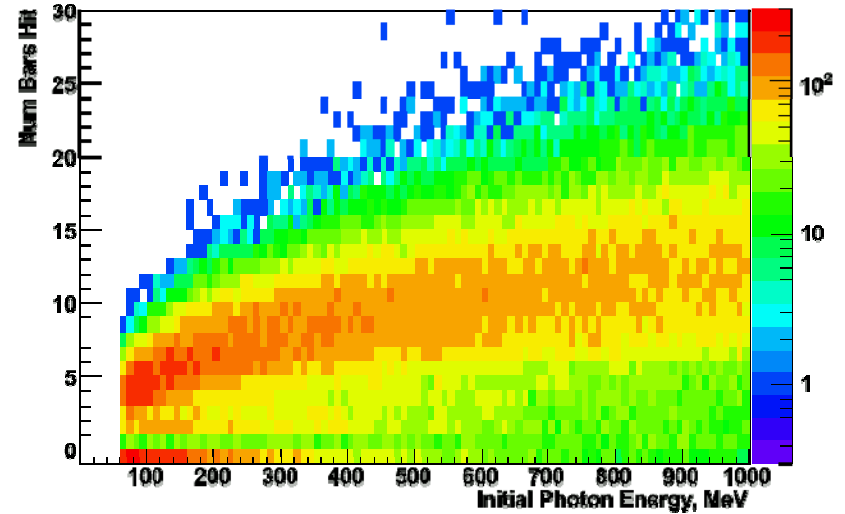


# Number Bars Hit – 2mm

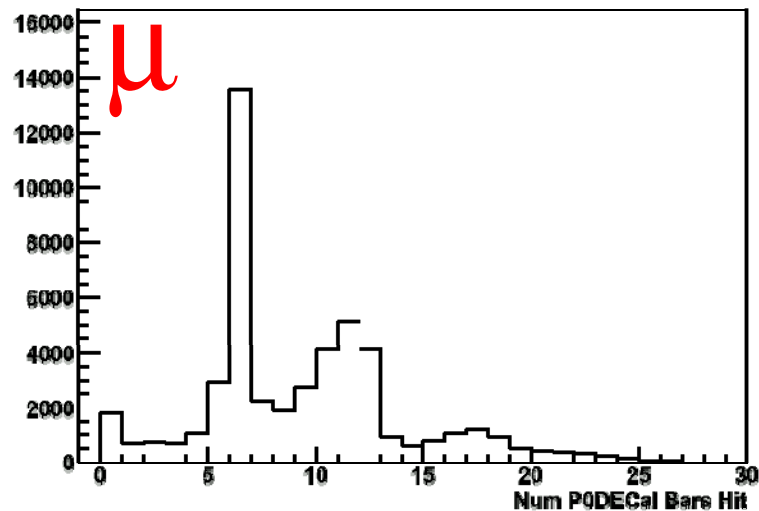
2mm Lead Number of Bars Hit



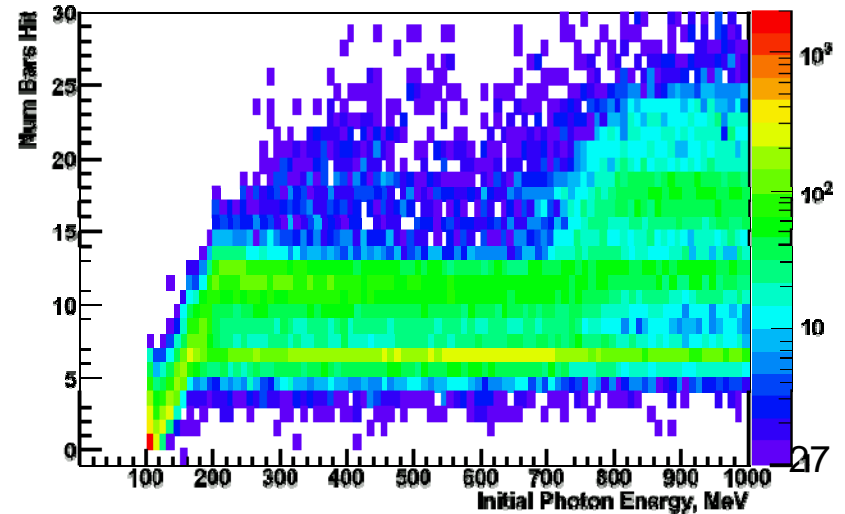
2mm Lead Number of Bars Hit ~ InitialEnergy



2mm Lead Number of Bars Hit



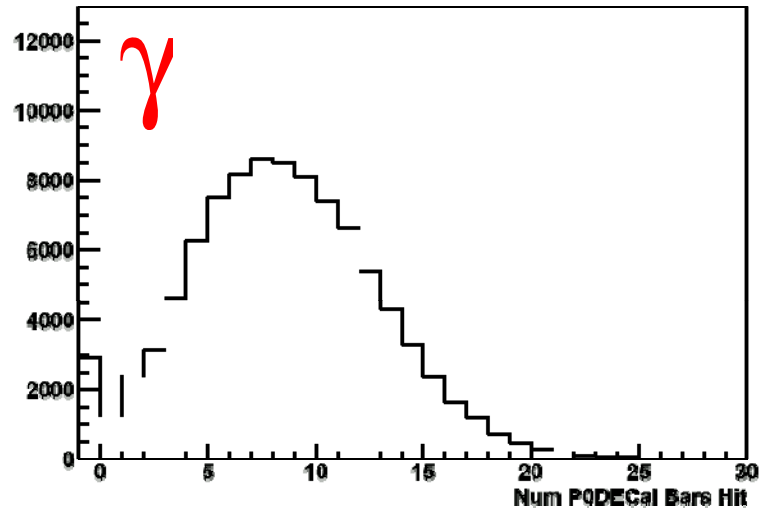
2mm Lead Number of Bars Hit ~ InitialEnergy



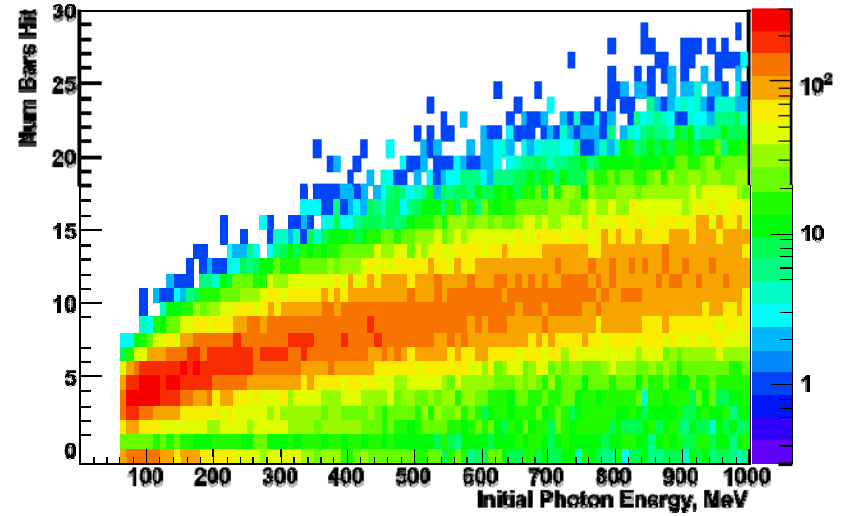


# Number Bars Hit – 3mm

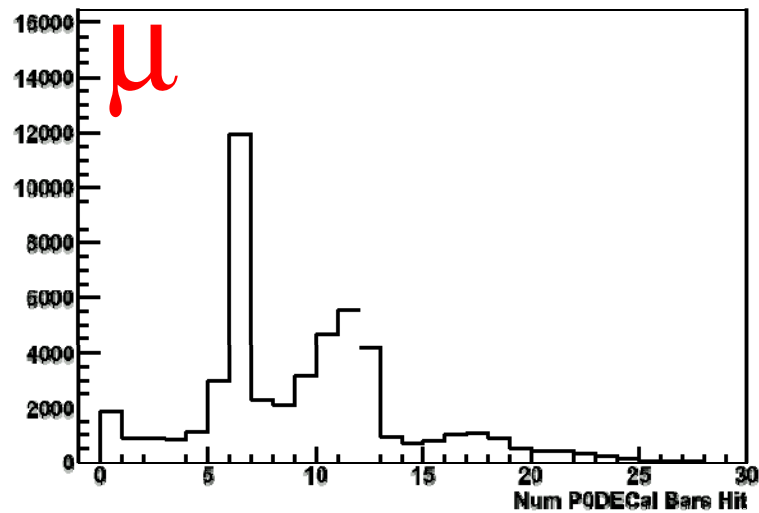
3mm Lead Number of Bars Hit



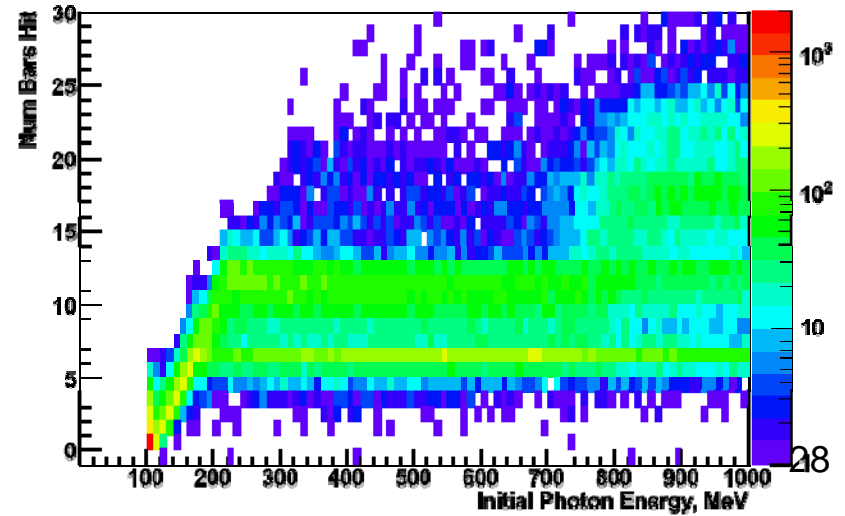
3mm Lead Number of Bars Hit ~ InitialEnergy



3mm Lead Number of Bars Hit



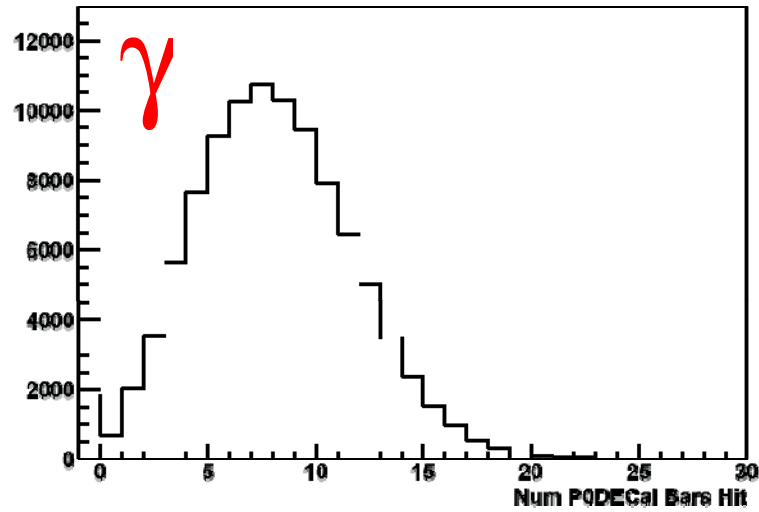
3mm Lead Number of Bars Hit ~ InitialEnergy



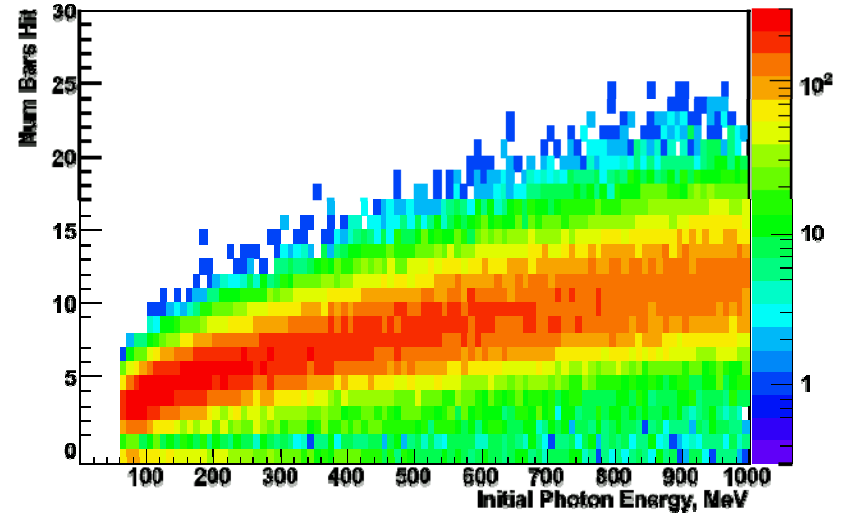


# Number Bars Hit – 4mm

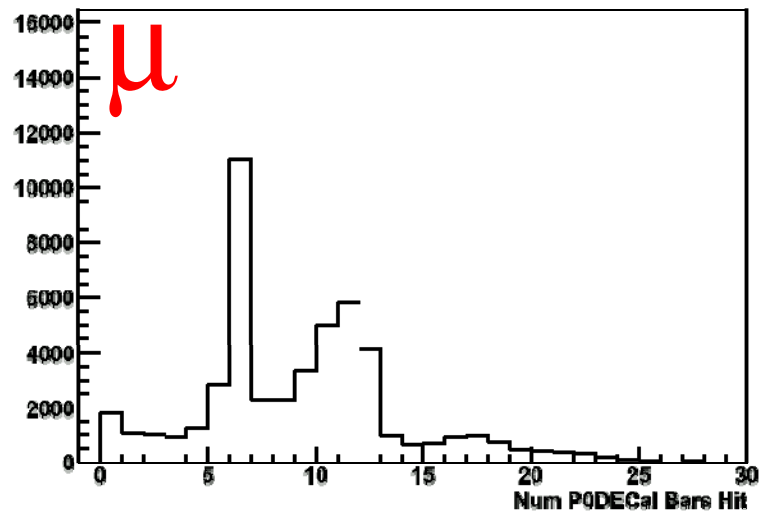
4mm Lead Number of Bars Hit



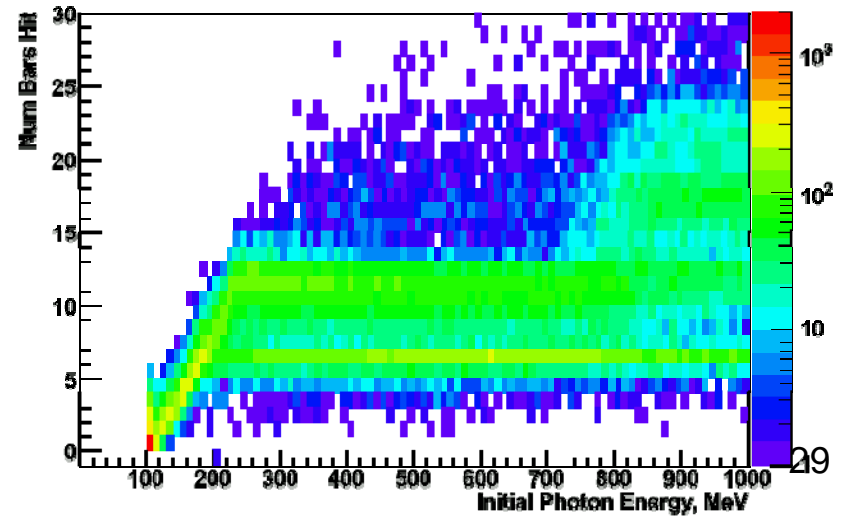
4mm Lead Number of Bars Hit ~ InitialEnergy



4mm Lead Number of Bars Hit



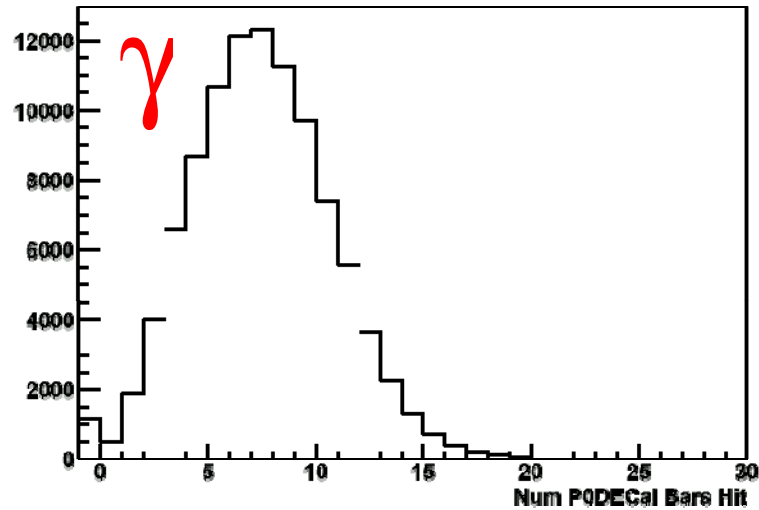
4mm Lead Number of Bars Hit ~ InitialEnergy



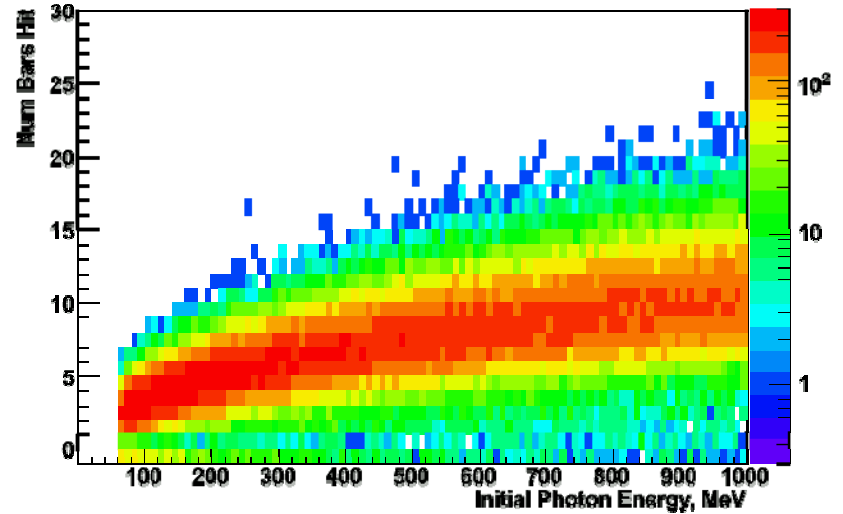


# Number Bars Hit – 5mm

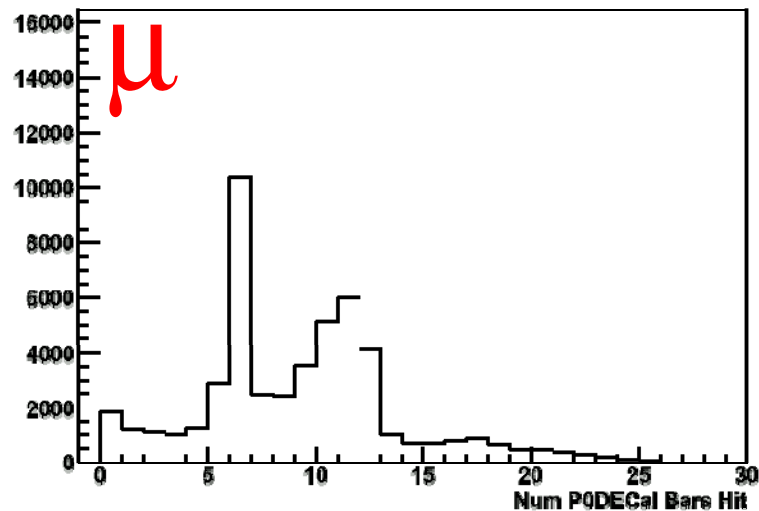
5mm Lead Number of Bars Hit



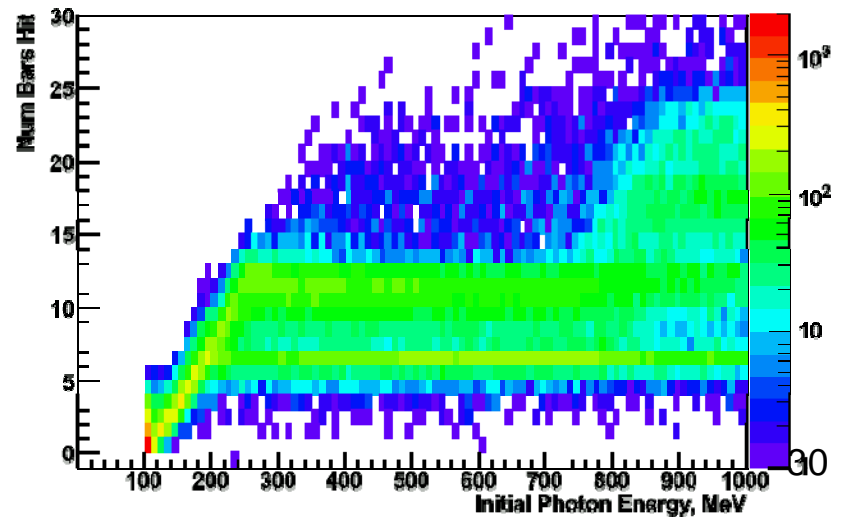
5mm Lead Number of Bars Hit ~ InitialEnergy



5mm Lead Number of Bars Hit



5mm Lead Number of Bars Hit ~ InitialEnergy





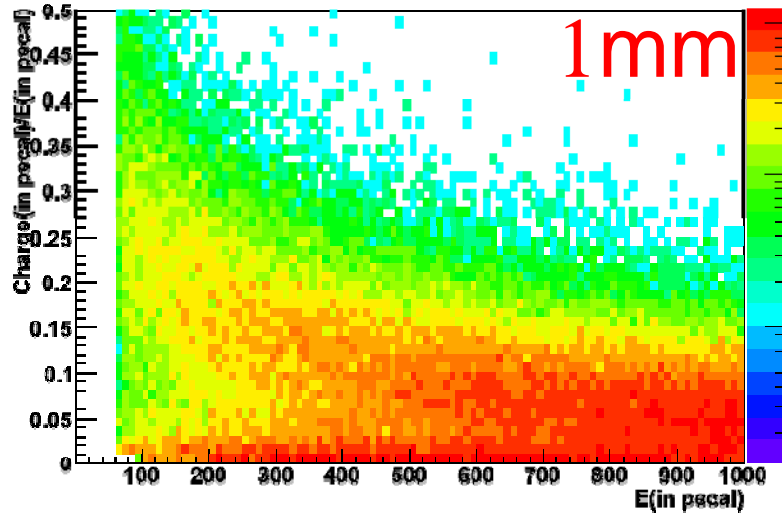
# Energy Resolution

- Energy resolution important in reconstructing  $\pi^0$ 's

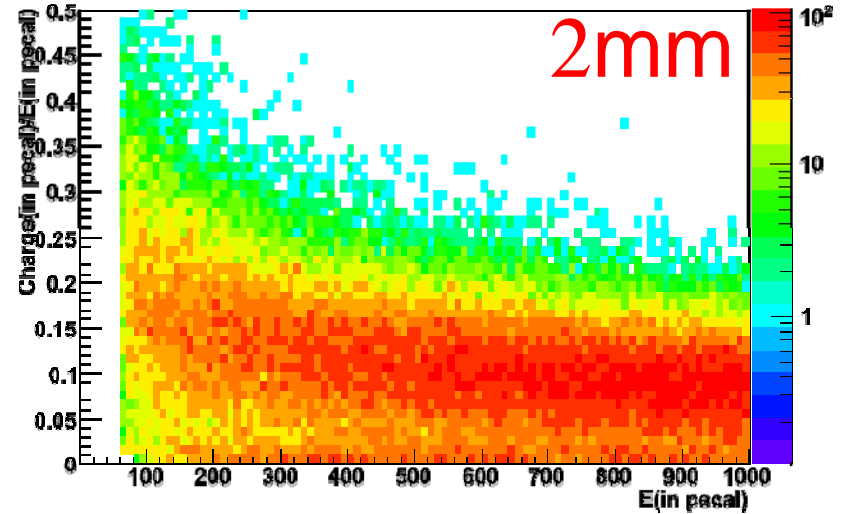


# Fractional Charge 'Seen' (au)

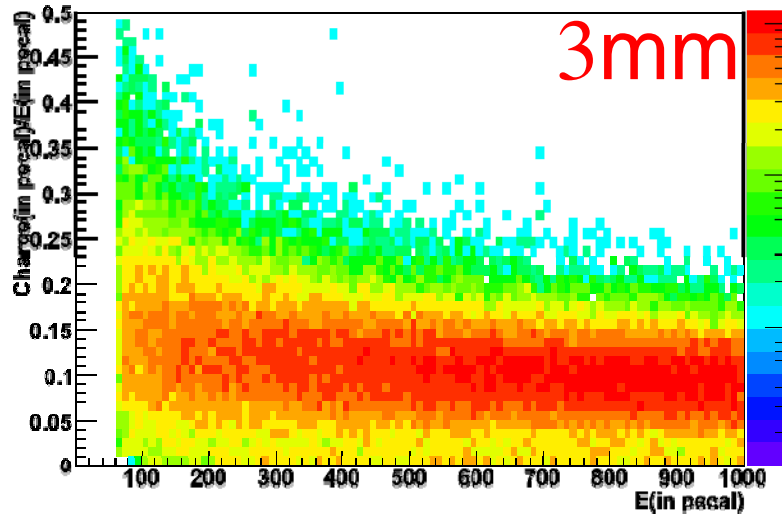
1mm Lead EnergyResoHist



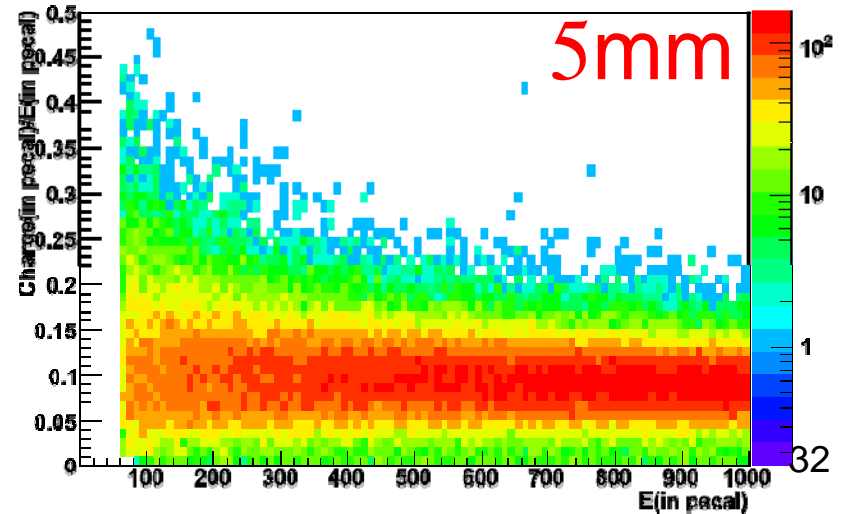
2mm Lead EnergyResoHist



3mm Lead EnergyResoHist



5mm Lead EnergyResoHist

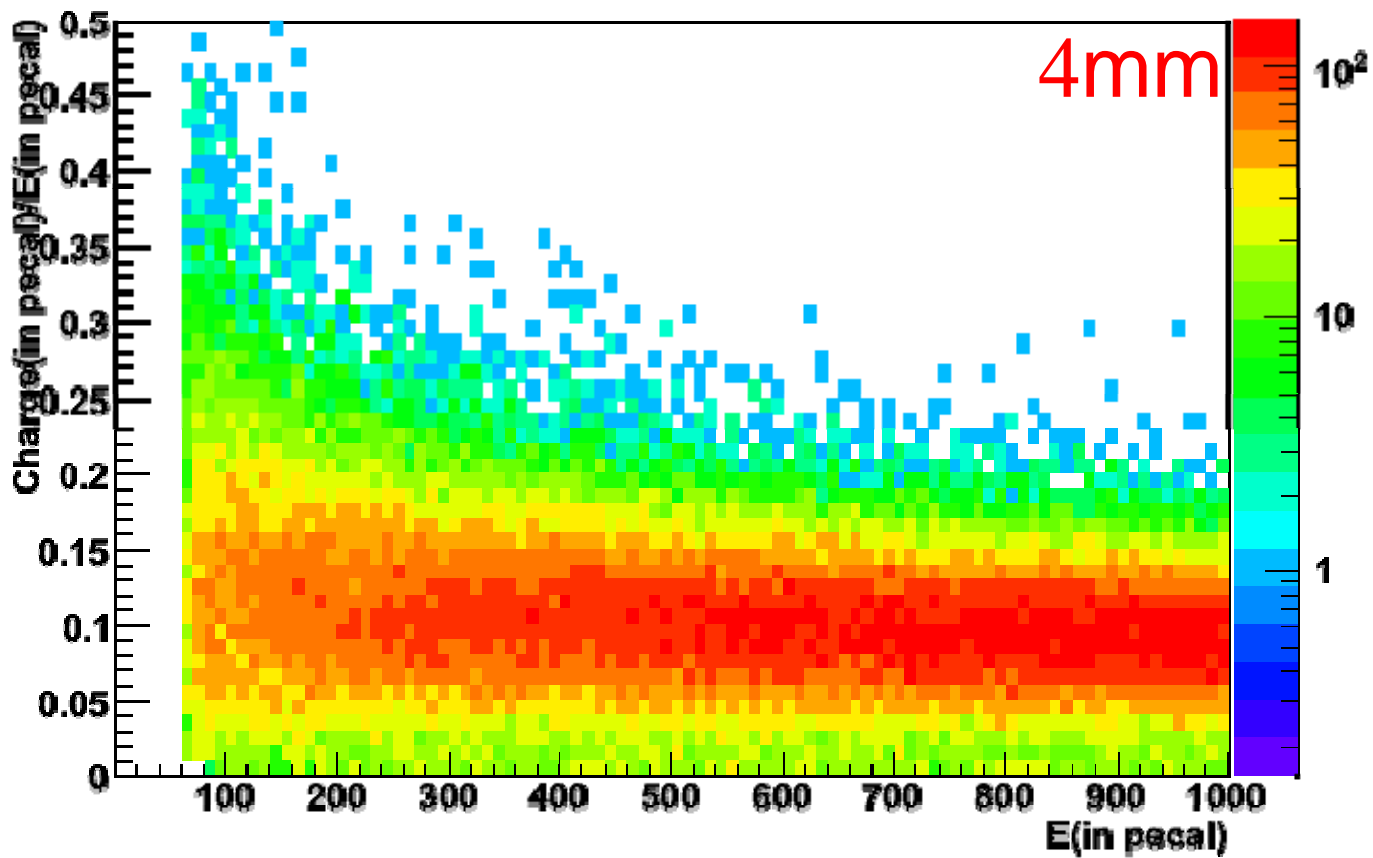






# Fractional Charge 'Seen' (au)

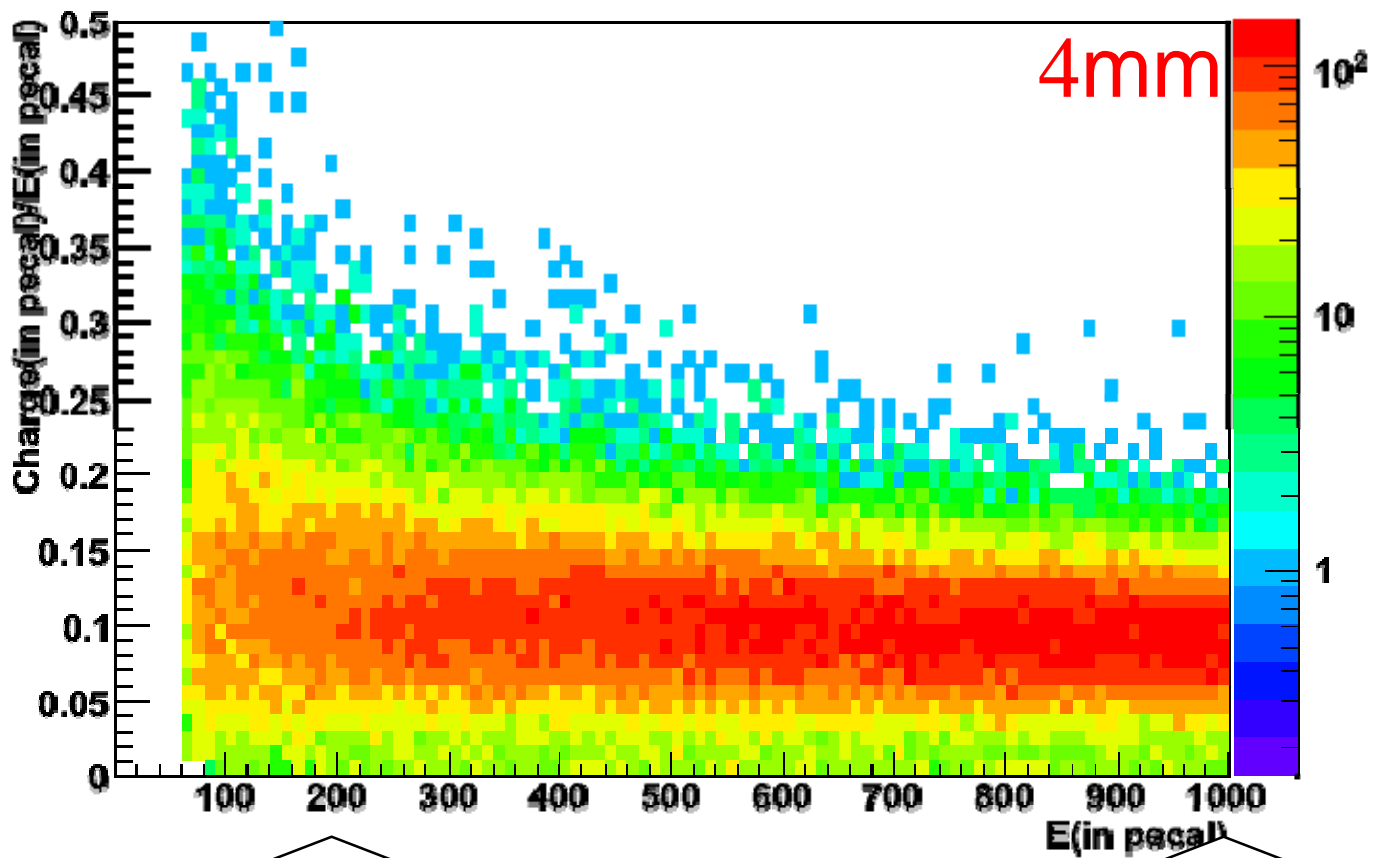
4mm Lead EnergyResoHist





# Fractional Charge 'Seen' (au)

4mm Lead EnergyResoHist



50%

40%



# Summary

- Set out to maximise photon shower containment and  $\mu$ - $\gamma$  tagging whilst also minimising the number of escaped photons.
- 5x1-3mm lead absorber layers are better for low energy behaviour but contains poorly.
- 4-5mm lead are comparable in containment with an increase in PID for 4mm.
- Chose to go with 4mm as oblique photons will 'see' a greater effective thickness.



# Comments or Suggestions

- Baseline design is thus 6 scintillator + 5 lead layers with 4 mm lead, all oriented along beam, with single-ended readout.
- Feedback? Especially if current design does not meet your expectations.

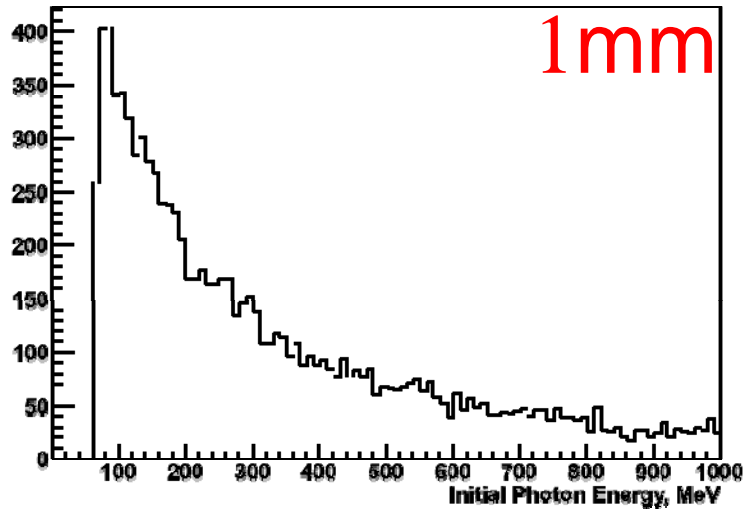


# Back-Up

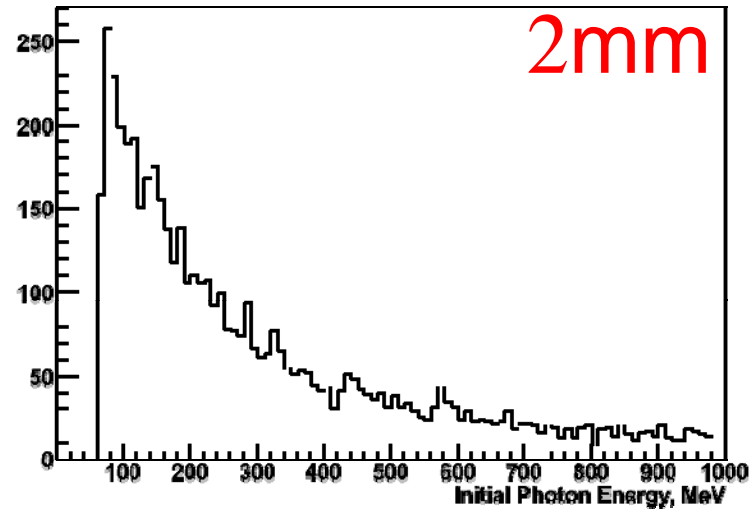
- Escaping Photons, raw stats.
- Fractional energy 'Seen' profile against initial energy axis, error bars == RMS (photons)
- Energy Resolution for photons
- Sample projection of an energy bin (photon)
- Fractional energy 'Seen' Against Initial energy for Muons
- Fractional energy 'Seen' profile against initial energy axis, error bars == RMS
- Energy 'Resolution' for Muons

# Energy Containment

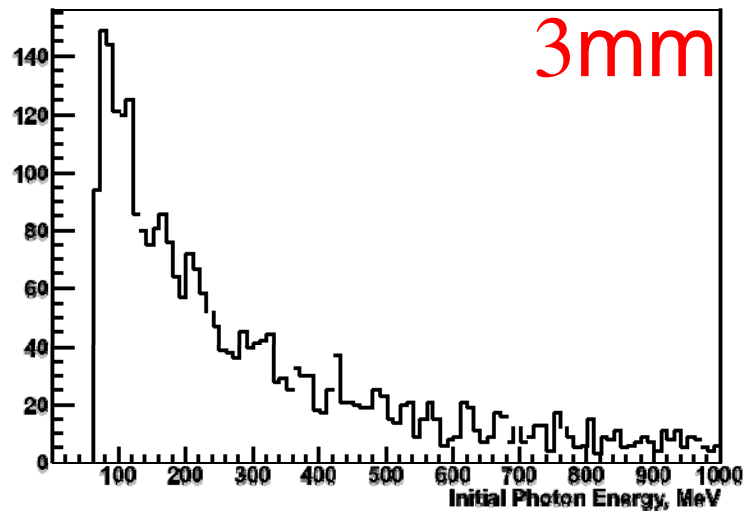
1mm Lead Histogram of PODECal Escaped Primary Photon Energy



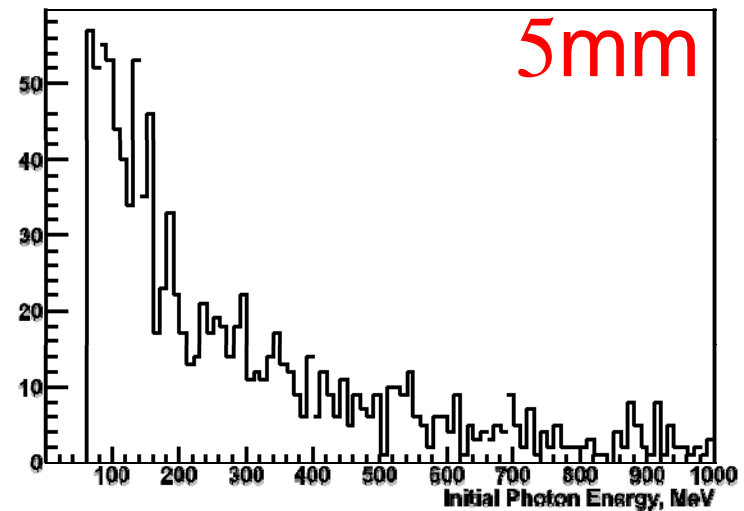
2mm Lead Histogram of PODECal Escaped Primary Photon Energy



3mm Lead Histogram of PODECal Escaped Primary Photon Energy



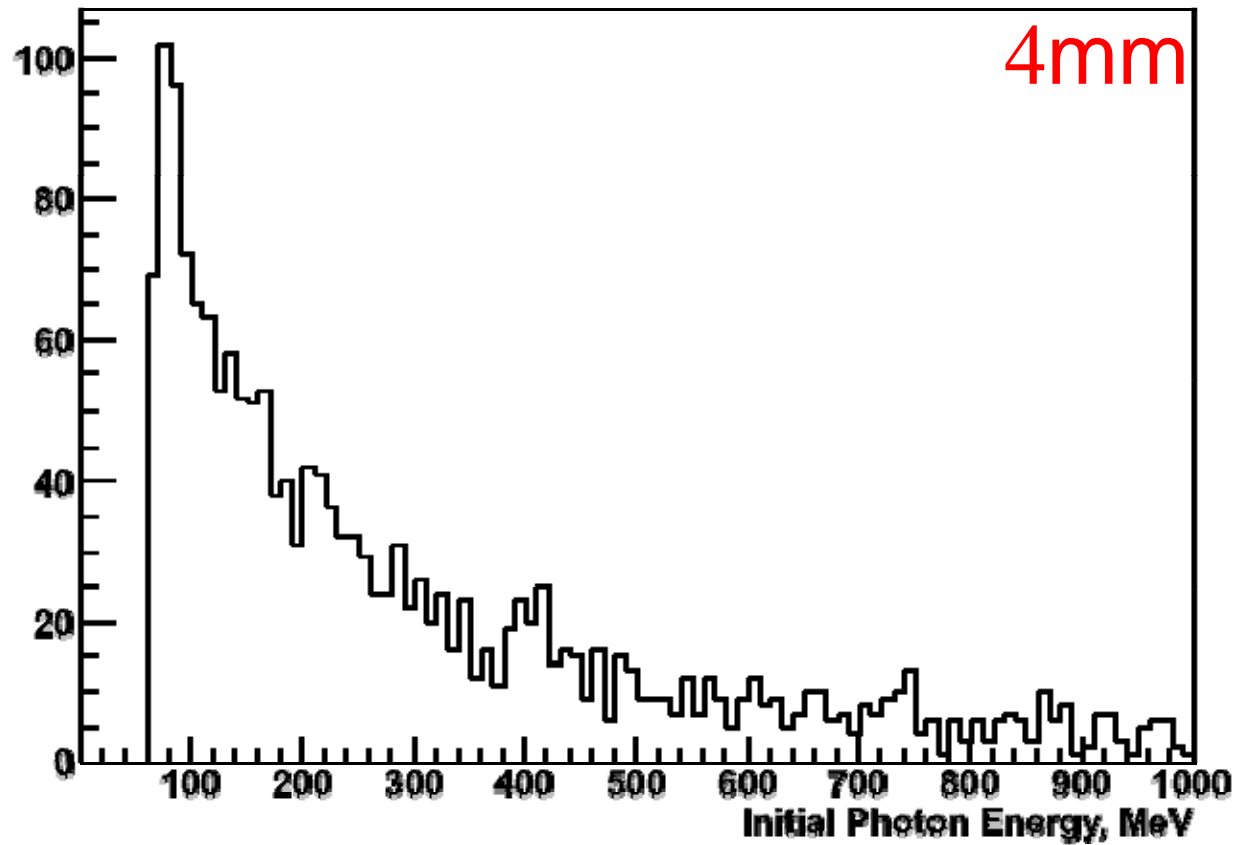
5mm Lead Histogram of PODECal Escaped Primary Photon Energy





# Energy Containment

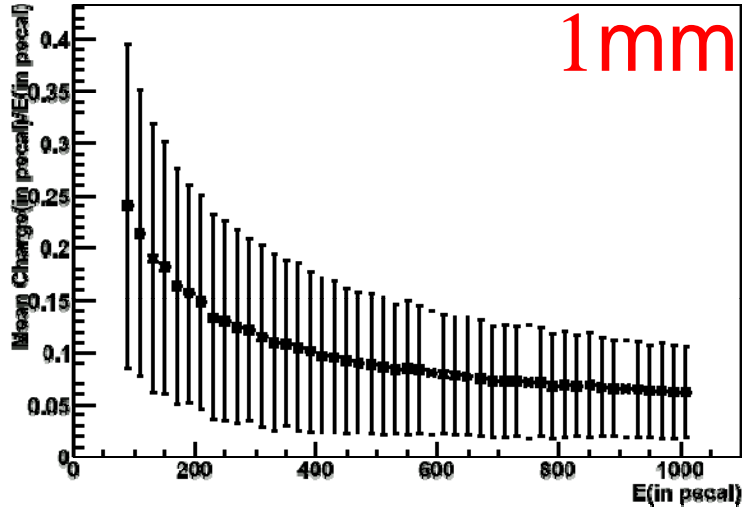
4mm Lead Histogram of P0DECAL Escaped Primary Photon Energy



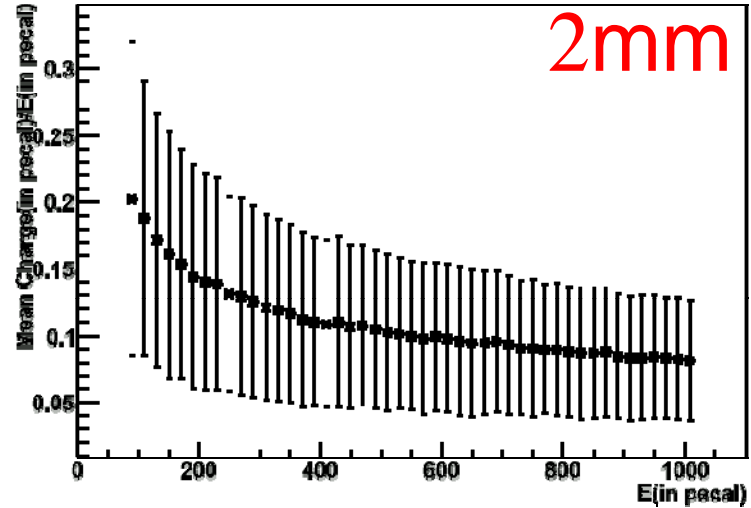


# Fractional Charge 'Seen' (au)

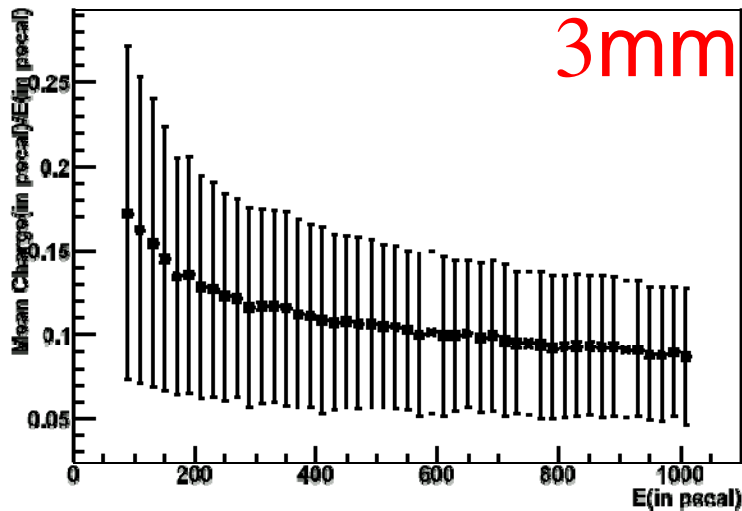
1mm Mean % Energy Deposited ~ Initial Energy, error bars=RMS



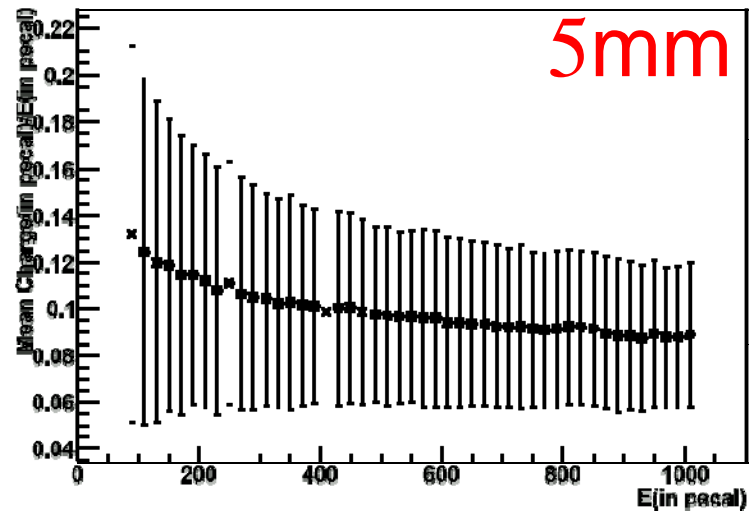
2mm Mean % Energy Deposited ~ Initial Energy, error bars=RMS



3mm Mean % Energy Deposited ~ Initial Energy, error bars=RMS



5mm Mean % Energy Deposited ~ Initial Energy, error bars=RMS

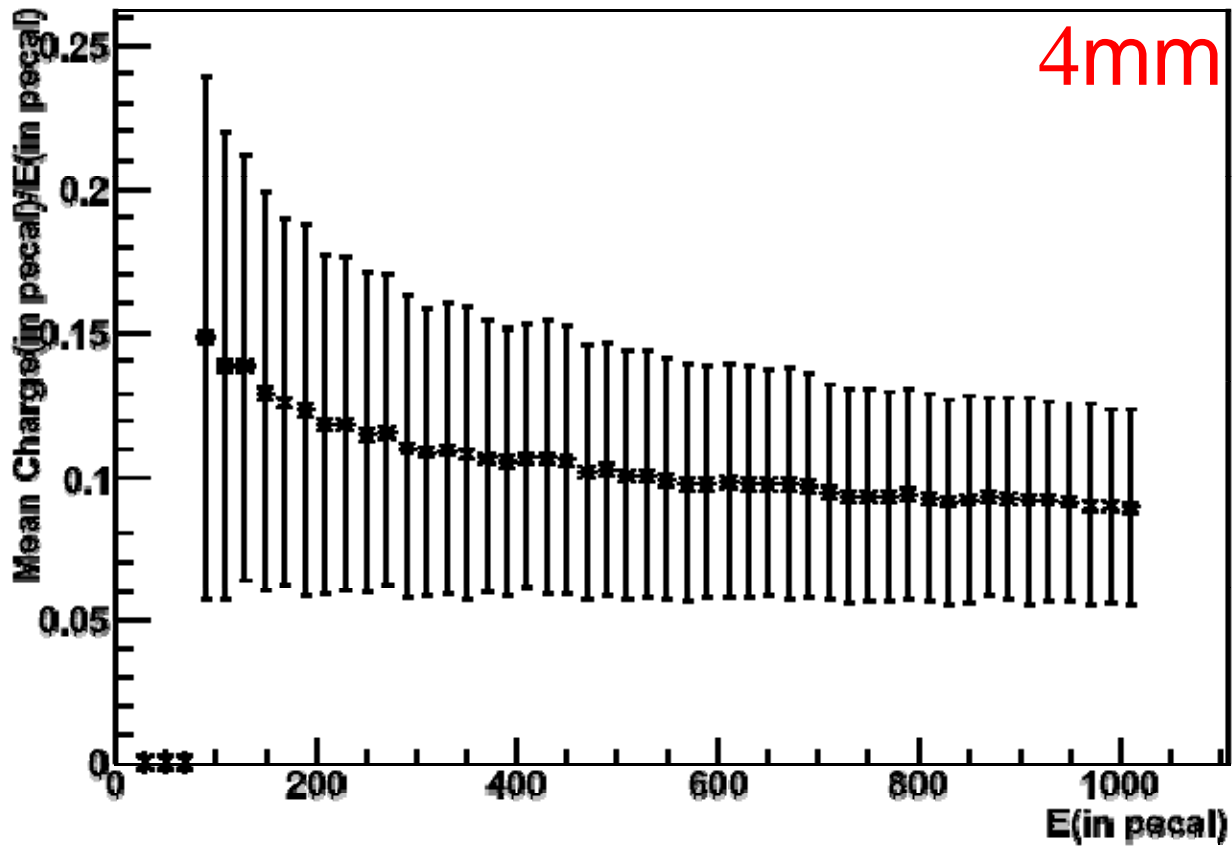






# Fractional Charge 'Seen' (au)

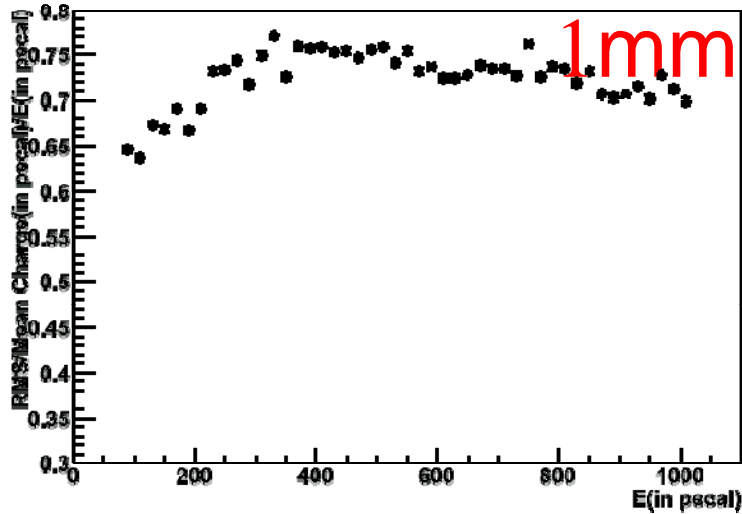
4mmMean % Energy Deposited ~ Initial Energy, error bars=RMS



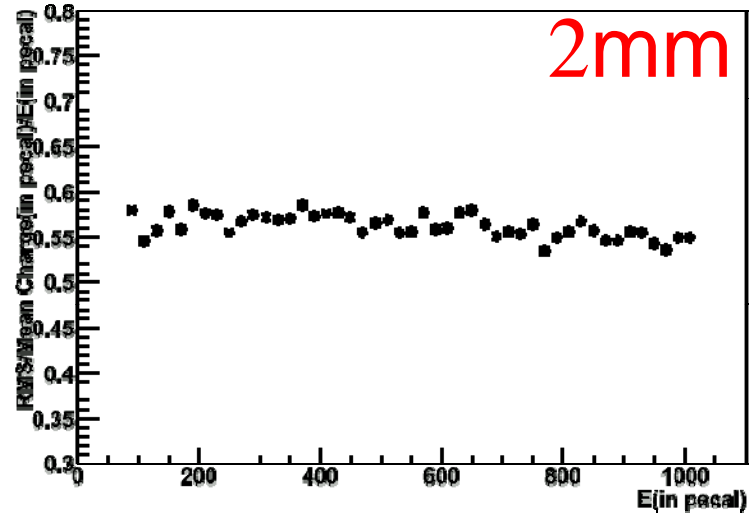


# Energy Resolution

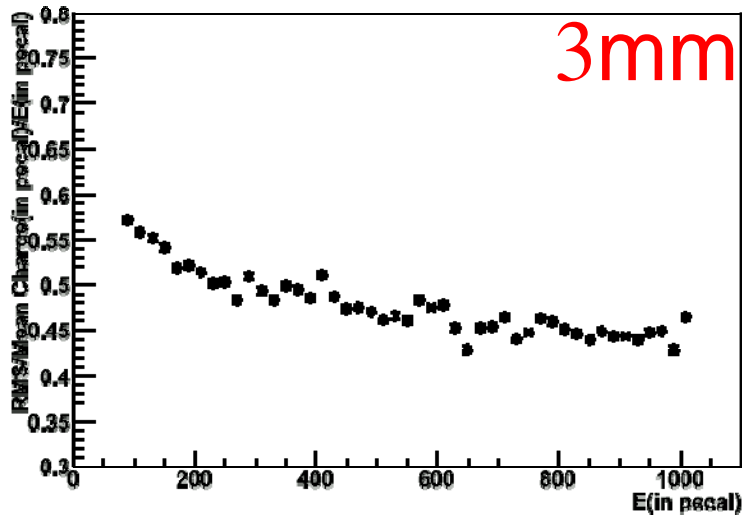
1mm Energy Resolution (RMS/Mean % Energy Deposited) ~ Initial Energy



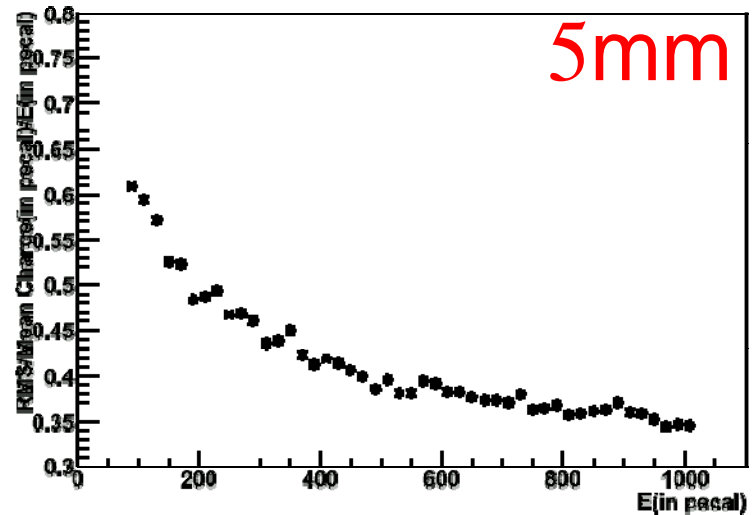
2mm Energy Resolution (RMS/Mean % Energy Deposited) ~ Initial Energy



3mm Energy Resolution (RMS/Mean % Energy Deposited) ~ Initial Energy



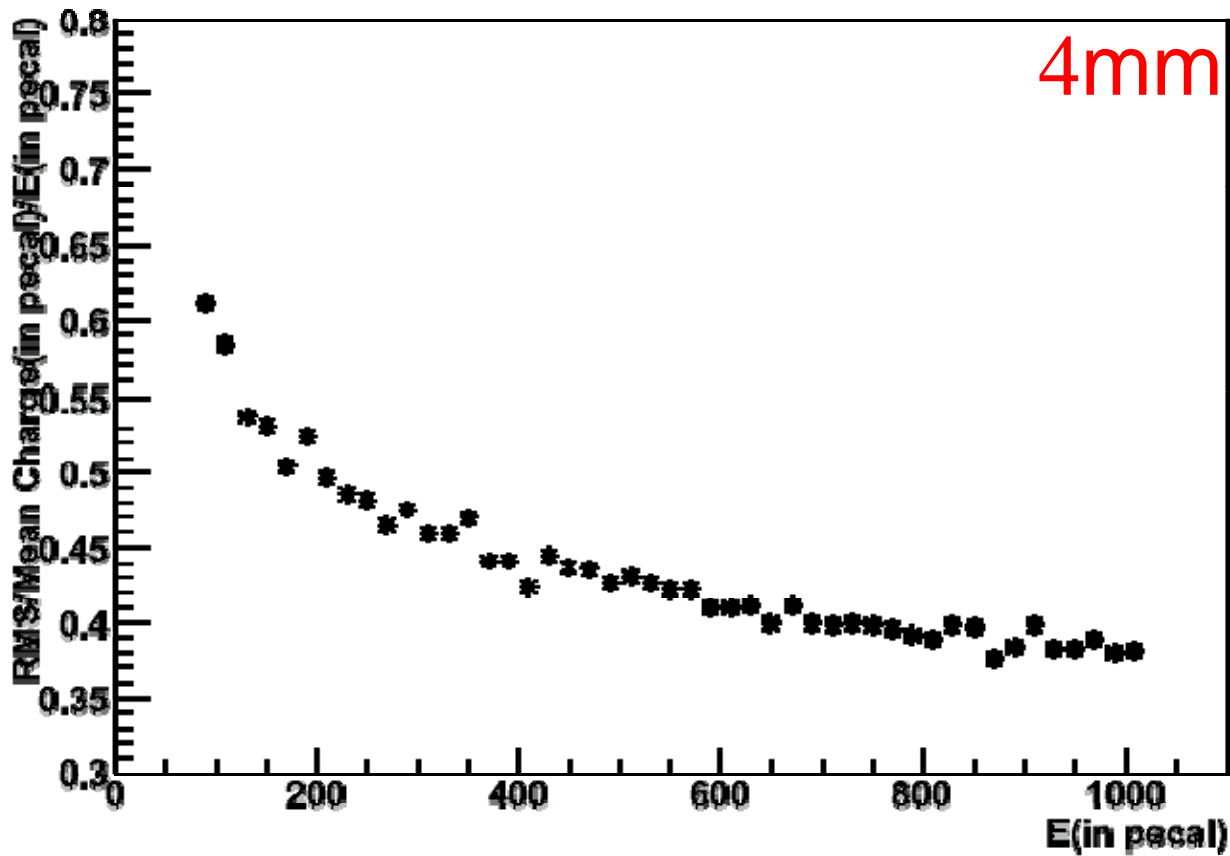
5mm Energy Resolution (RMS/Mean % Energy Deposited) ~ Initial Energy





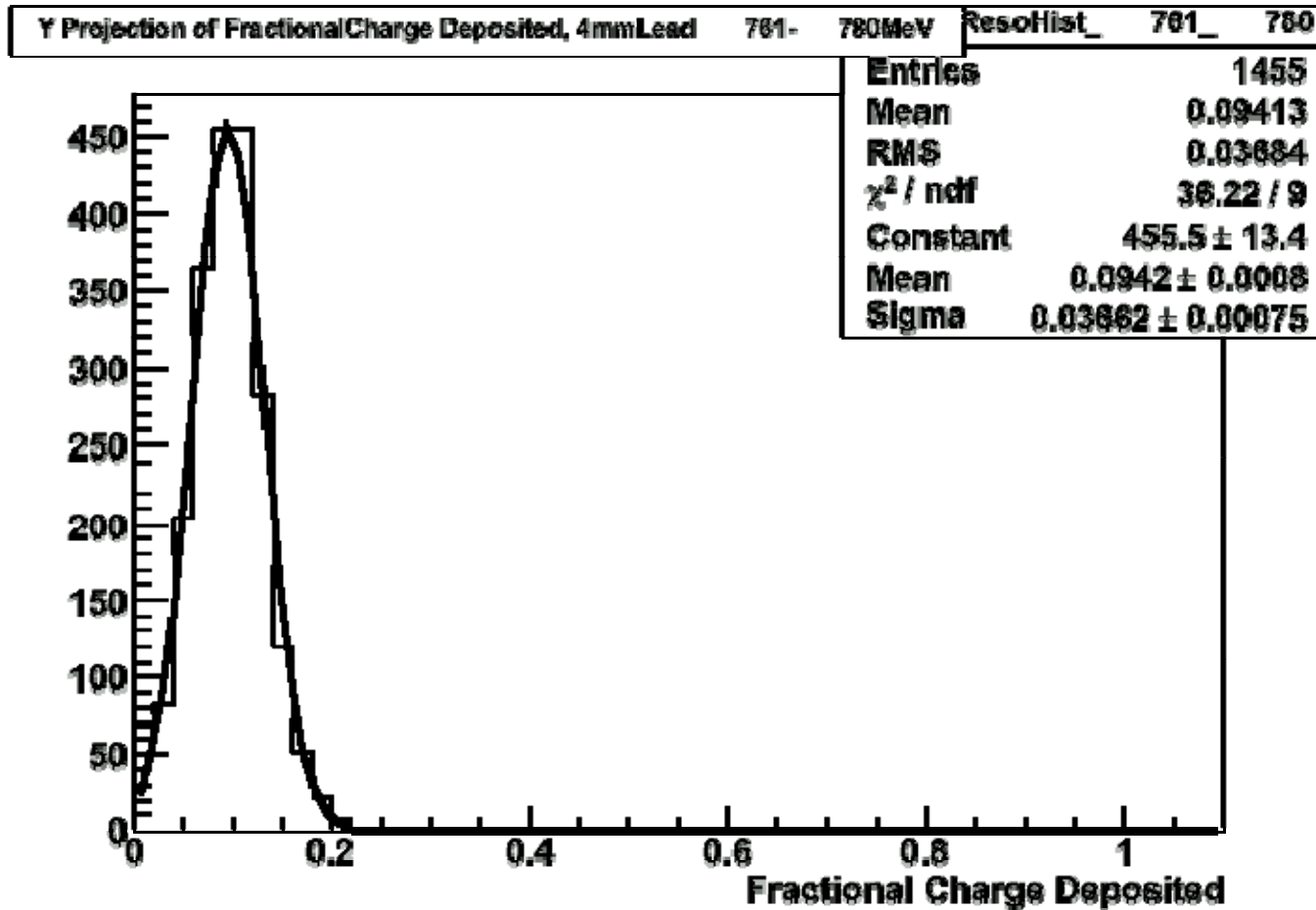
# Energy Resolution

4mm Energy Resolution (RMS/Mean % Energy Deposited) ~ Initial Energy





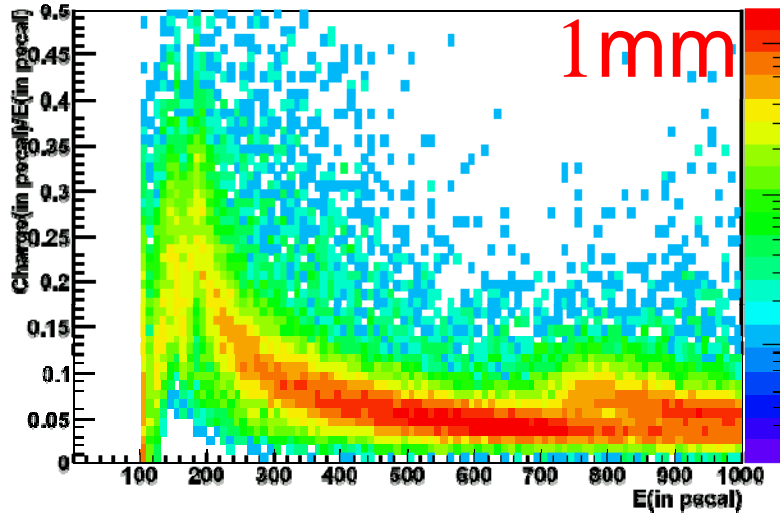
# Energy Resolution



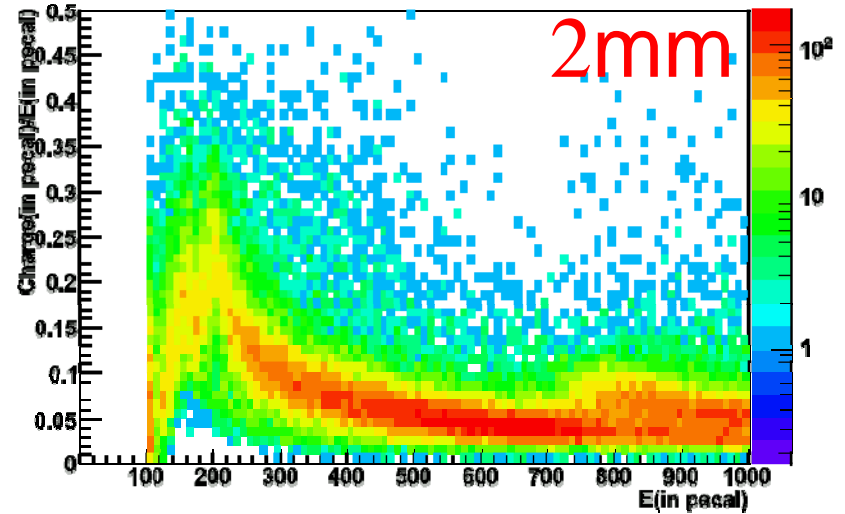


# Fractional Charge 'Seen' - Muons

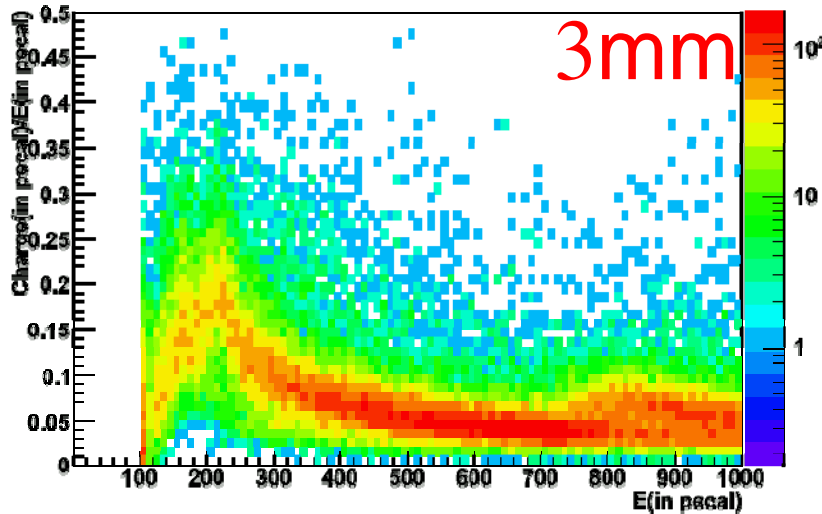
1mm Lead EnergyResoHist



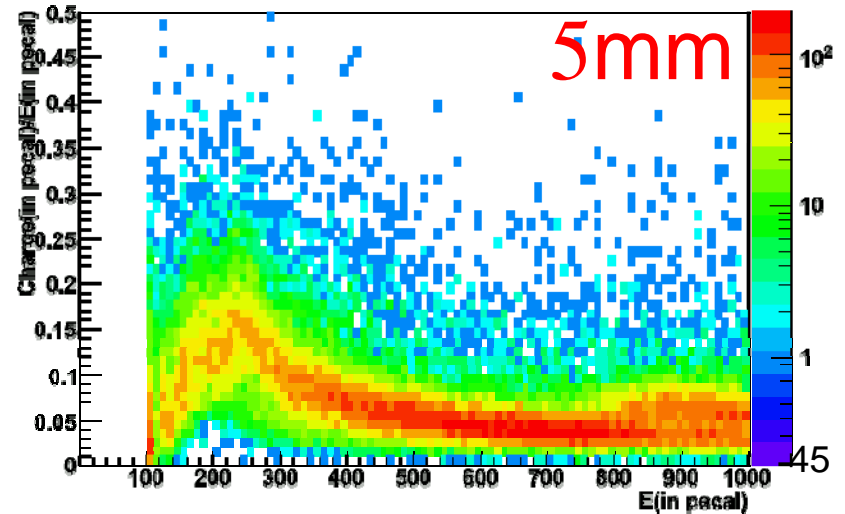
2mm Lead EnergyResoHist



3mm Lead EnergyResoHist



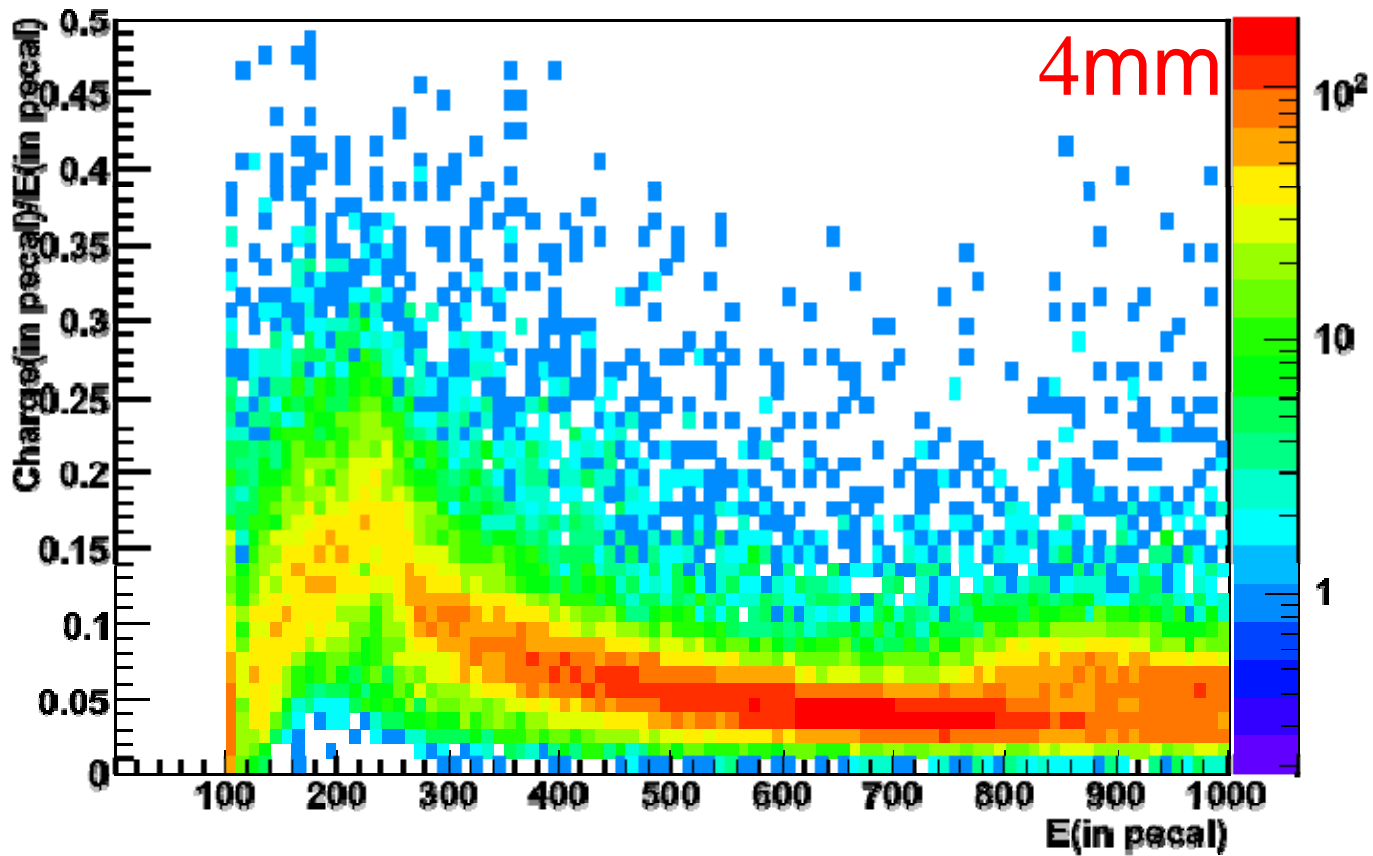
5mm Lead EnergyResoHist





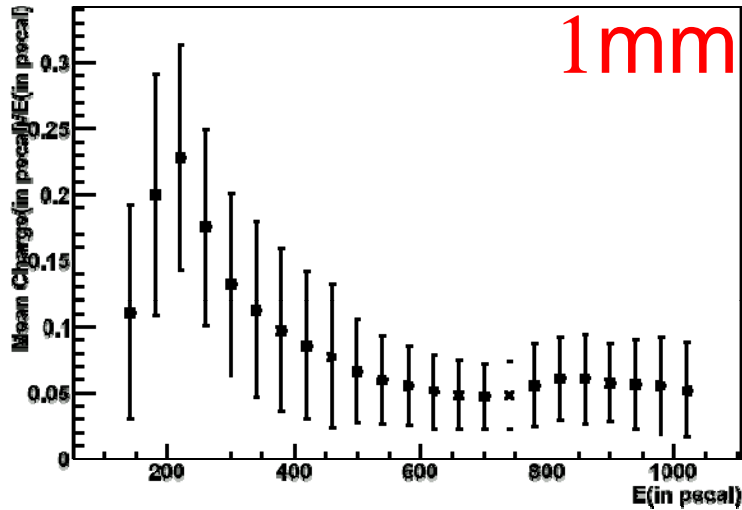
# Fractional Charge 'Seen' - Muons

4mm Lead EnergyResoHist

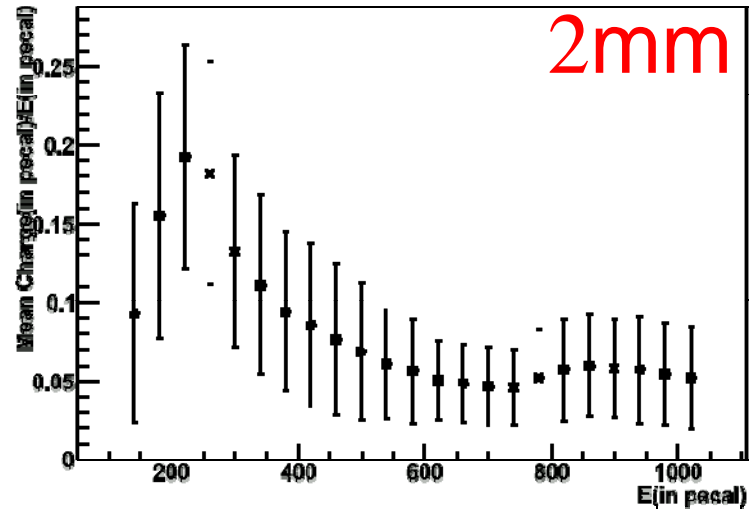


# Fractional Charge 'Seen' - Muons

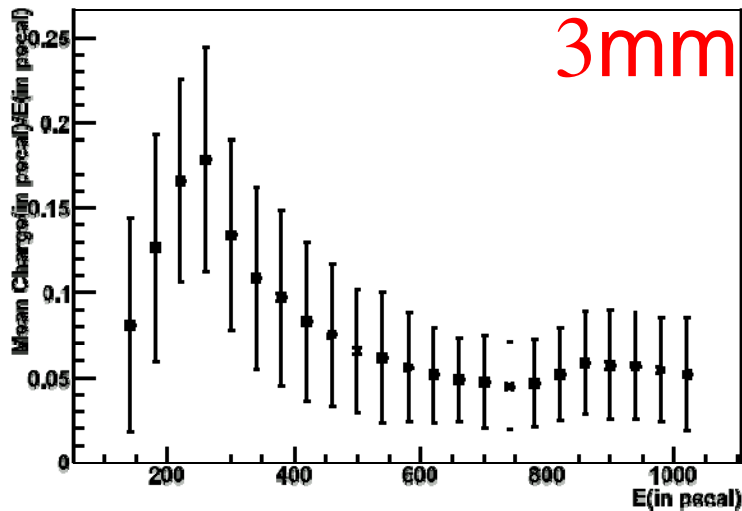
1mm Mean % Energy Deposited ~ Initial Energy, error bars=RMS



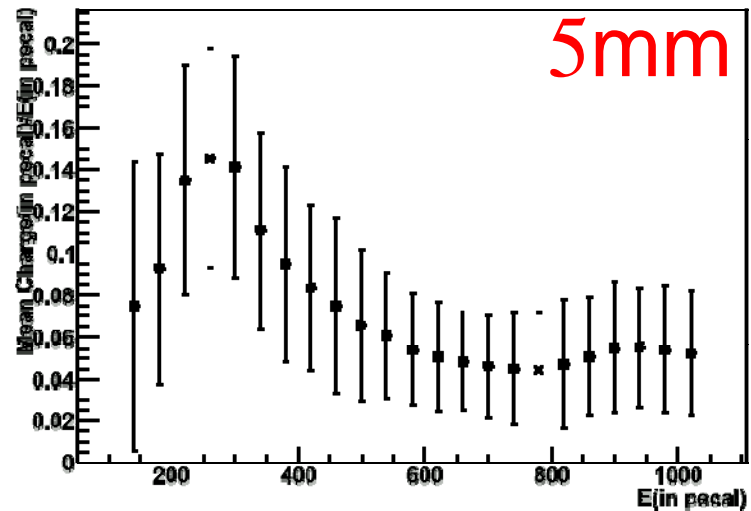
2mm Mean % Energy Deposited ~ Initial Energy, error bars=RMS



3mm Mean % Energy Deposited ~ Initial Energy, error bars=RMS



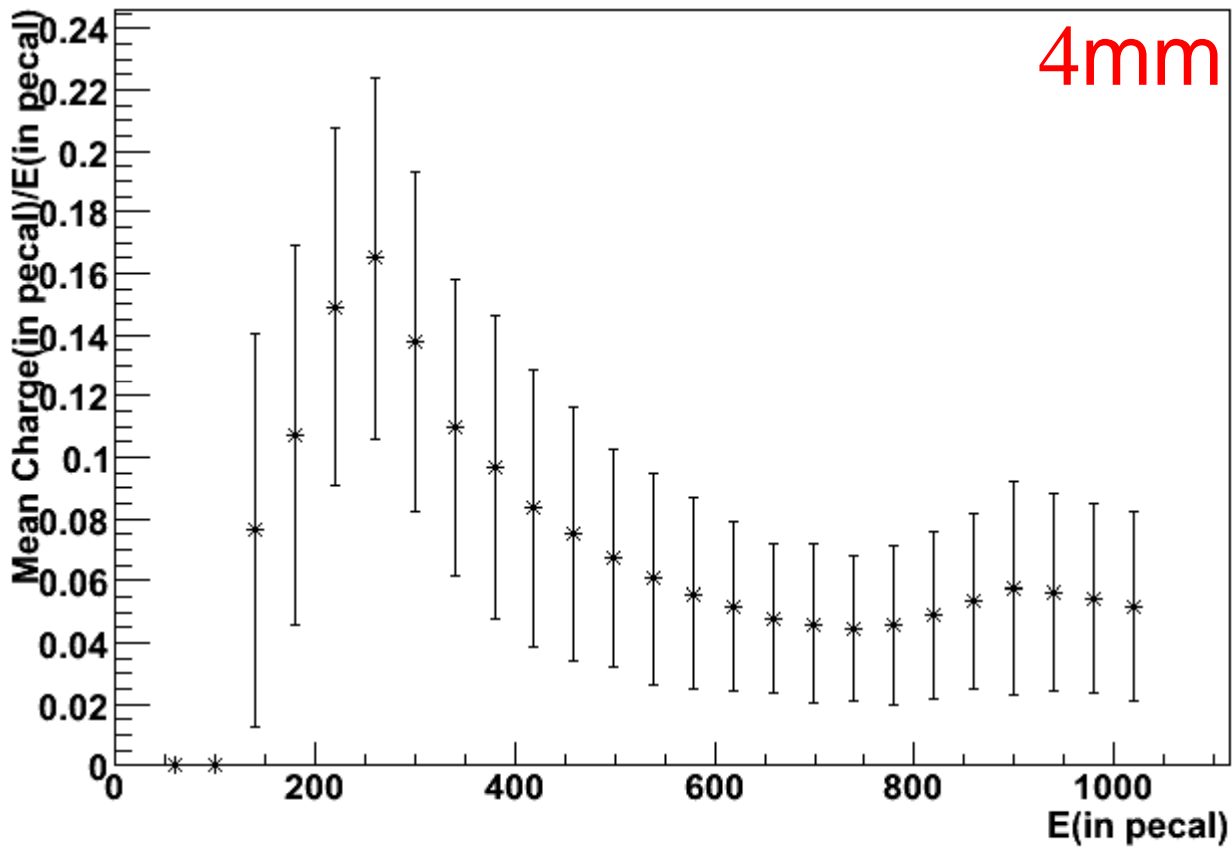
5mm Mean % Energy Deposited ~ Initial Energy, error bars=RMS





# Fractional Charge 'Seen' - Muons

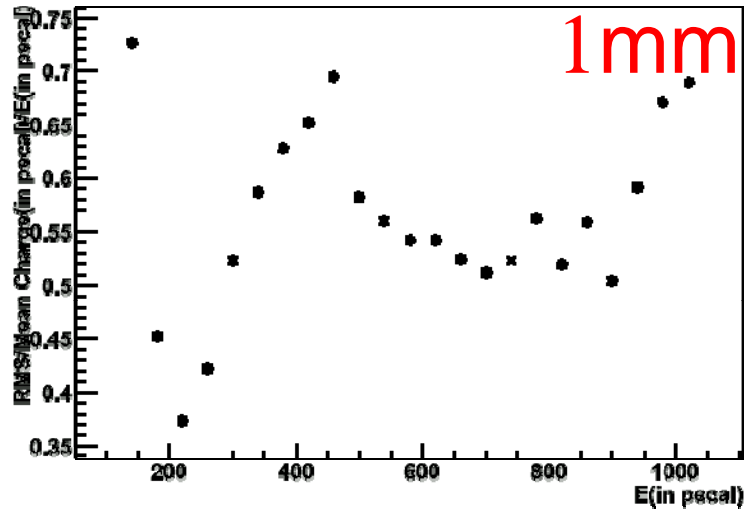
4mmMean % Energy Deposited ~ Initial Energy, error bars=RMS



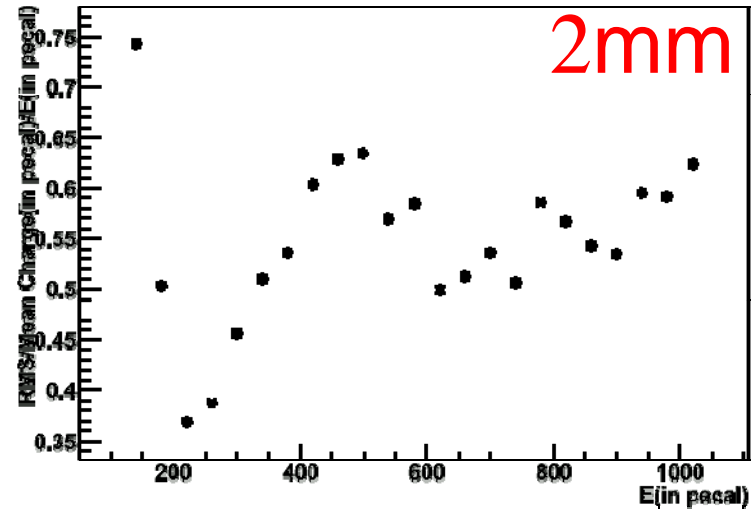


# Energy 'Resolution' - Muons

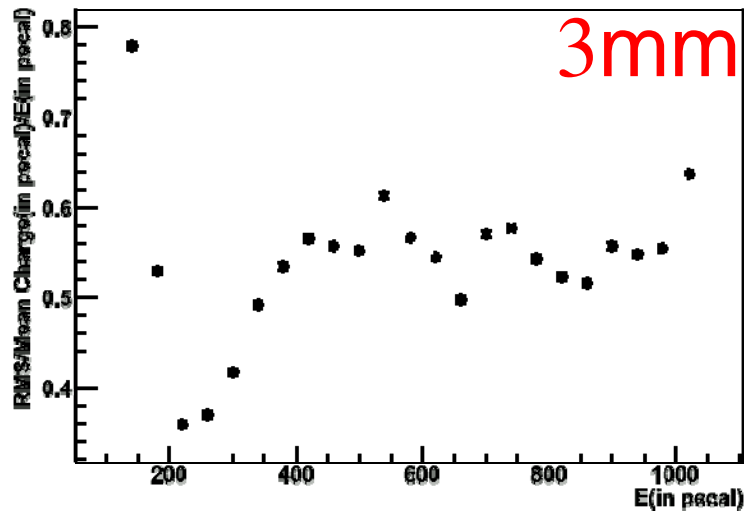
1mm Energy Resolution (RMS/Mean % Energy Deposited) ~ Initial Energy



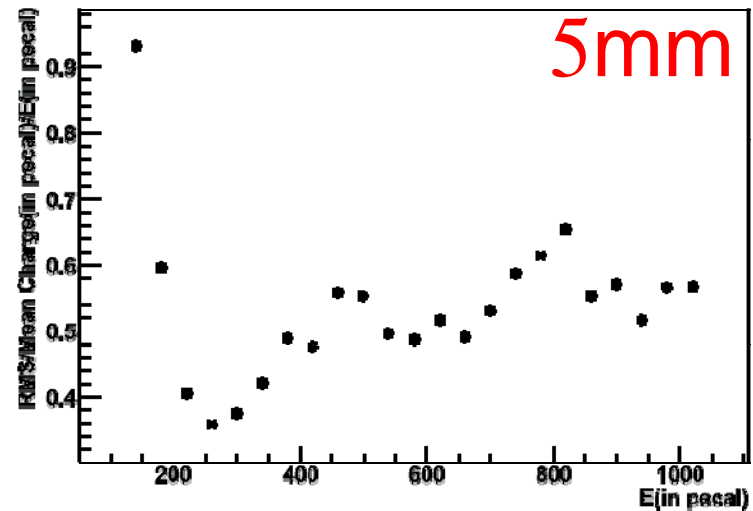
2mm Energy Resolution (RMS/Mean % Energy Deposited) ~ Initial Energy



3mm Energy Resolution (RMS/Mean % Energy Deposited) ~ Initial Energy



5mm Energy Resolution (RMS/Mean % Energy Deposited) ~ Initial Energy





# Energy 'Resolution' - Muons

4mm Energy Resolution (RMS/Mean % Energy Deposited) ~ Initial Energy

