Detector Basics II

Introduction
Energy loss mechanisms
Scintillators and Lead Glass
Amplification using photomultiplier tubes

See Particle Data Group at http://pdg.lbl.gov/

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Hall D Engineering Meeting
March 23, 2012

What do we want to know?

- Properties of all particles produced in the interaction of the photon beam and the target (Hydrogen)
- For each particle
  - Determine what kind of particle it is (particle identification "pid"), i.e. determine the charge and mass M.
  - Determine its momentum p (magnitude and direction) $E = \sqrt{P^2 + M^2}$

Measures of thickness

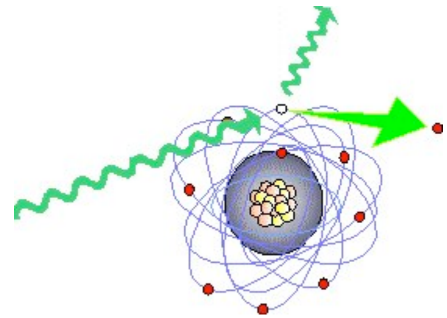
Material	Thickness (cm)	Density (g/cm^3)	Thickness (g/cm^2)	Radiation Length (g/cm^2)	Thickness (rad. Lengths)
Water	1	1	1	36.1	0.028
Scintillator	1	1.03	1.03	43.9	0.023
Carbon	1	2.2	2.2	42.7	0.052
Aluminum	1	2.7	2.7	24.0	0.113
Iron	1	7.9	7.9	13.8	0.572
Lead	1	11.4	11.4	6.4	1.78

Particle Spectrum

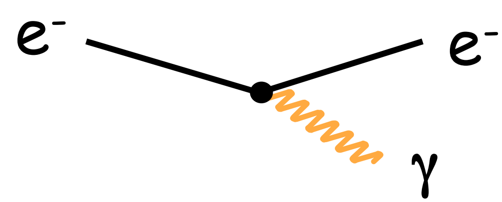
Particle	Mass (GeV)	Charge	
Proton	0.94	Positive	
Pion	0.14	Pos and neg	heavy
Muon	0.11	negative	
Electron	0.0005	negative	light
Photon	0	neutral	
Neutron	0.94	neutral	

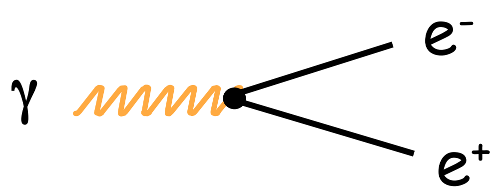
In regard to how particles lose energy as they traverse material, there are four types of particles

Energy loss mechanisms



- Ionization Losses
  - All charged particles and energetic photons
- Bremsstrahlung (radiation)
  - Electrons and photons

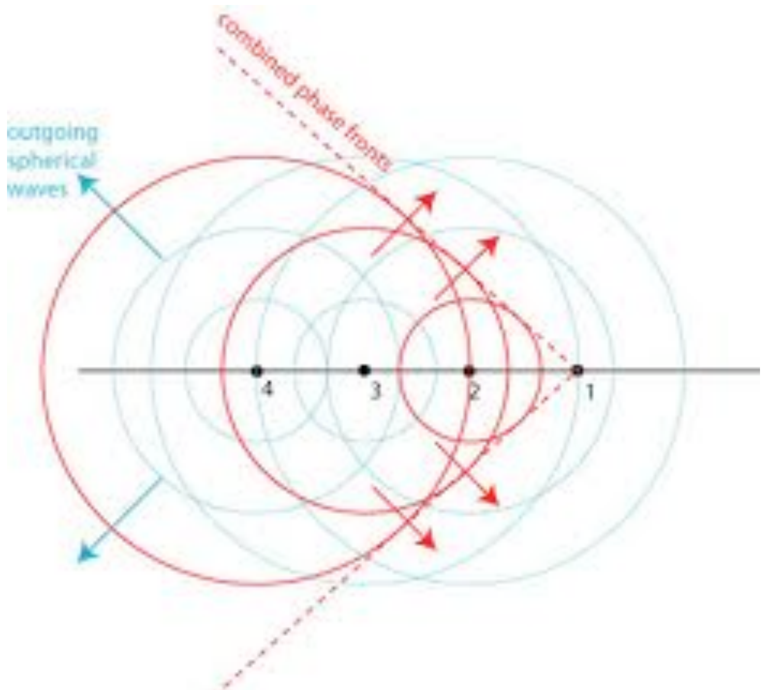




- "Billiard ball" interactions with nuclei
  - Protons, neutrons, pions

Energy loss mechanisms

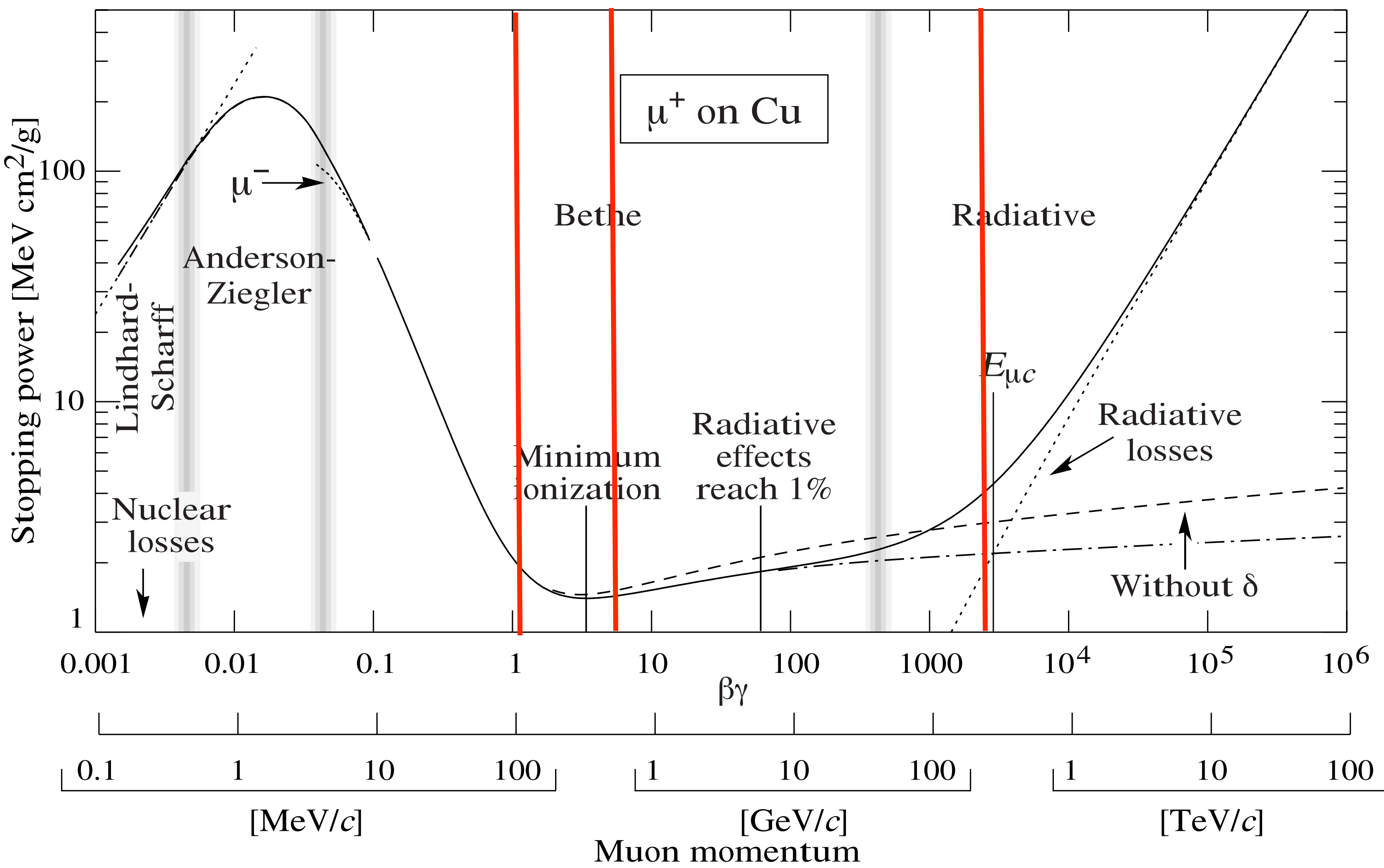
- Cerenkov radiation
  - All charged particles traveling $\beta > c/n$
  - "Sonic boom" (shock wave) for light



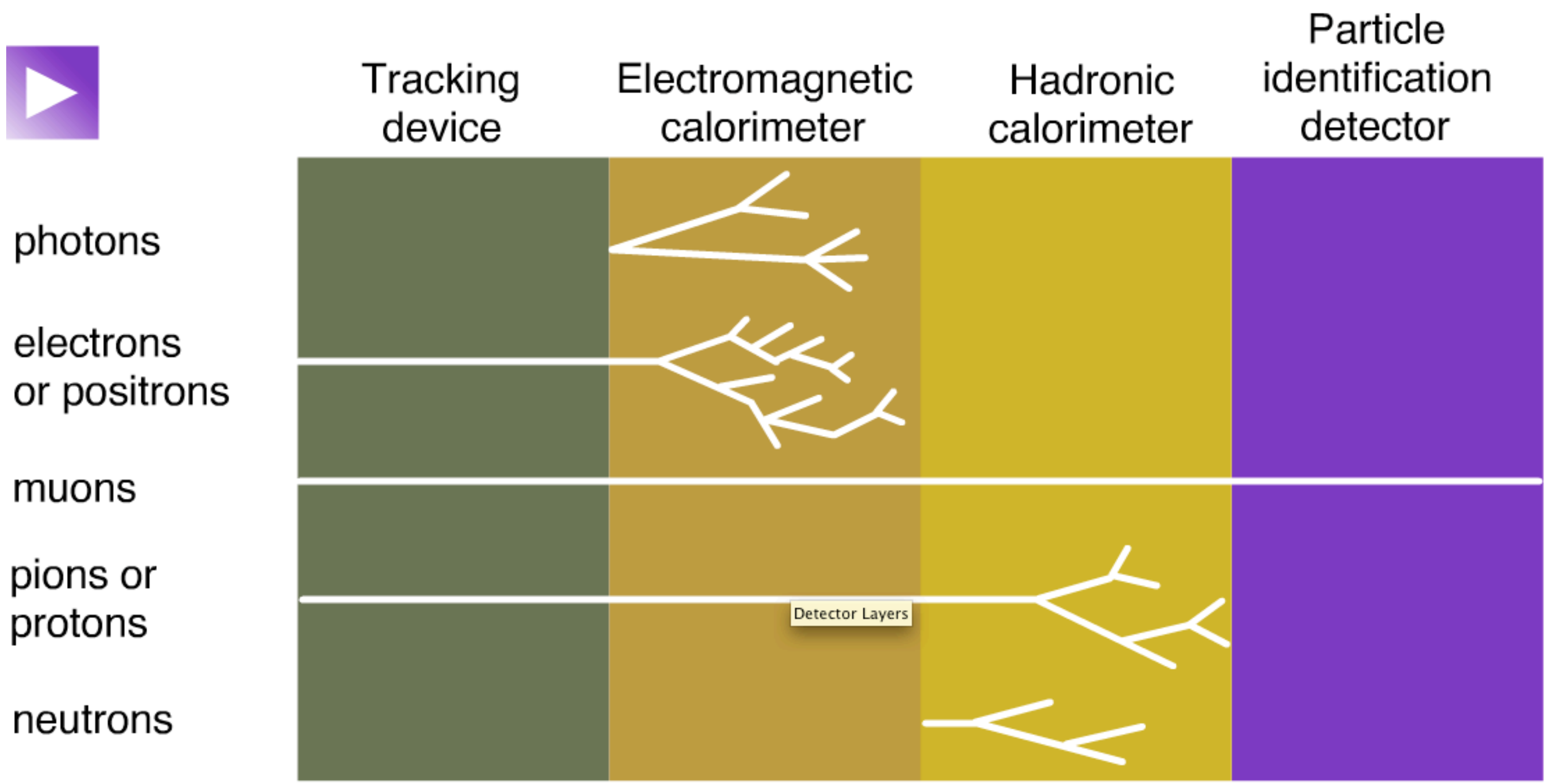
Regions of energy loss

$$\beta = \frac{v}{c} \quad \gamma = \frac{1}{\sqrt{1-\beta^2}}$$

$$(\beta\gamma)_p = 1.1 \; (\beta\gamma)_\pi = 7.1 \qquad (\beta\gamma)_e = 2000$$



Penetration of particles in various detectors



How do we measure these quantities?

- Charged particles
  - Momentum and directions are determined by measuring the radius of curvature in a magnetic field

$$P(GeV) = 0.3B(T)R(m)$$

- Neutral particles
  - Energy is measured in the calorimeters
  - Directions are determined by using the location of impact on the calorimeter and the target vertex.

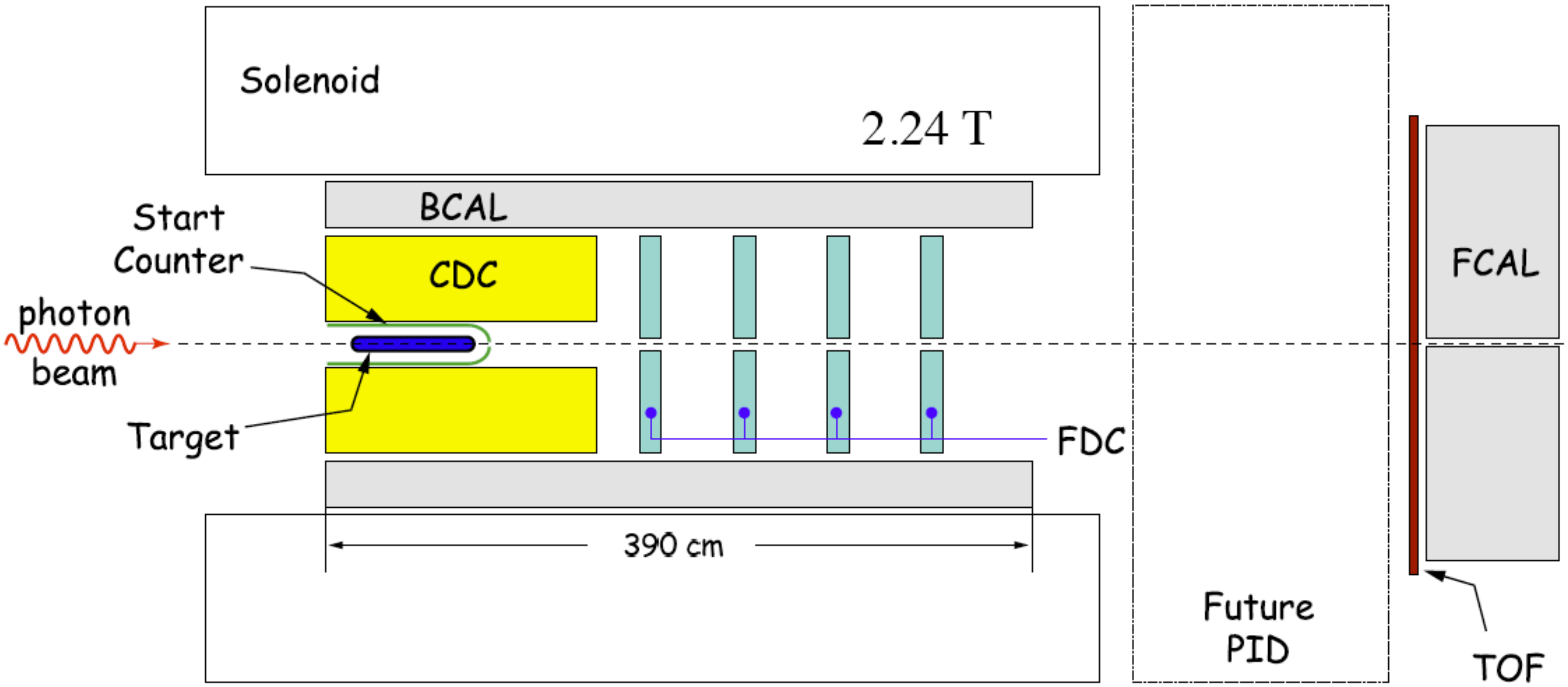
Required amplification and Nobels

- Signal from a single electron or ion

$$V \sim \frac{1.6 \times 10^{-19} C}{100 ns} 50\Omega \sim 10^{-10} volts$$

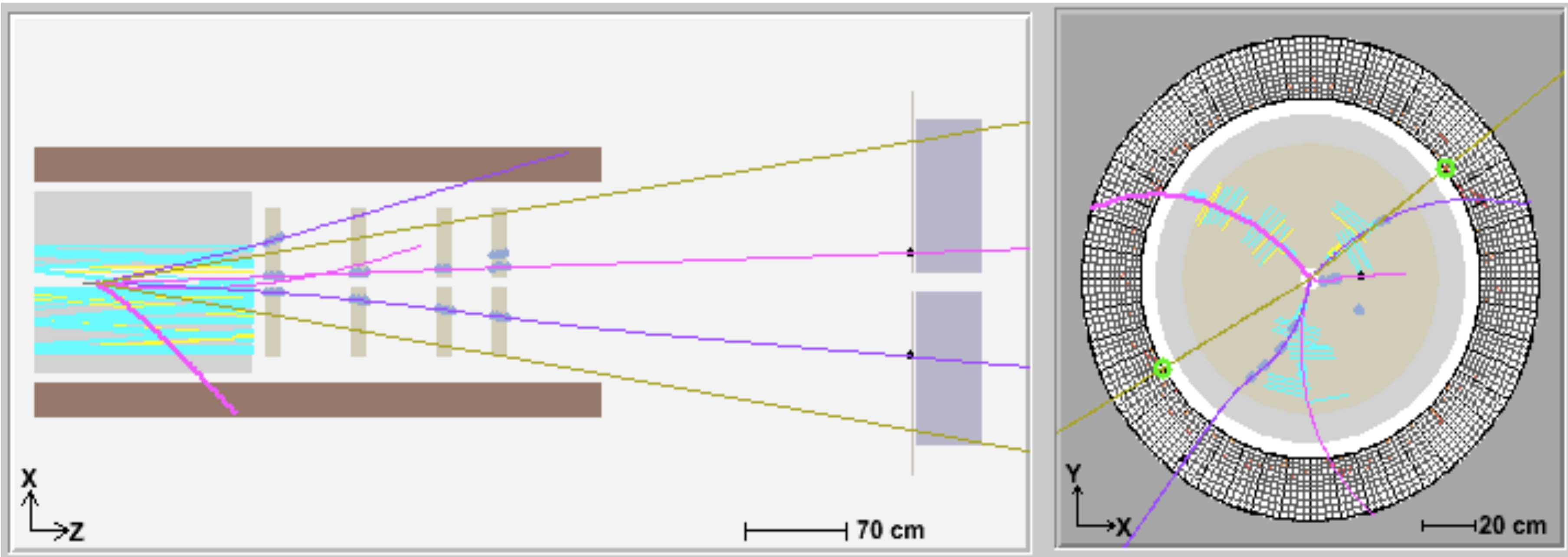
- So.... to have a mV signal, need a gain of 10^7
- For charged particles, charge amplification occurs in wire chambers
- For neutrals, sensitivity to generated light is achieved using photomultiplier tubes.

GlueX detector



Detector is cylindrically symmetric about the beamline

"typical" $\gamma p \rightarrow 2\pi^+ 2\pi^- \pi^0\, p$



Thrown

trk:	type:	p:	theta:	phi:	z:
1	pi+	1.269	22.85	4.426	59.79
2	pi-	2.277	8.827	4.541	59.79
3	gamma	0.42	12.12	0.6316	59.79
4	gamma	0.2729	10.89	3.712	59.79
5	pi+	2.43	2.242	5.92	59.79
6	pi-	2.08	16.22	0.8233	59.79
7	proton	0.6965	46.83	2.234	59.79

Reconstructed

trk:	type:	p:	theta:	phi:	z:	chisq/Ndof:
1	pi-	2.07	16.15	0.8262	59.45	N/A
2	pi+	1.438	22.85	4.458	59.94	N/A
3	proton+	0.6619	44.42	2.237	59.53	N/A
4	pi-	2.343	8.786	4.541	59.4	N/A
5	pi+	2.306	2.13	5.861	59.3	N/A
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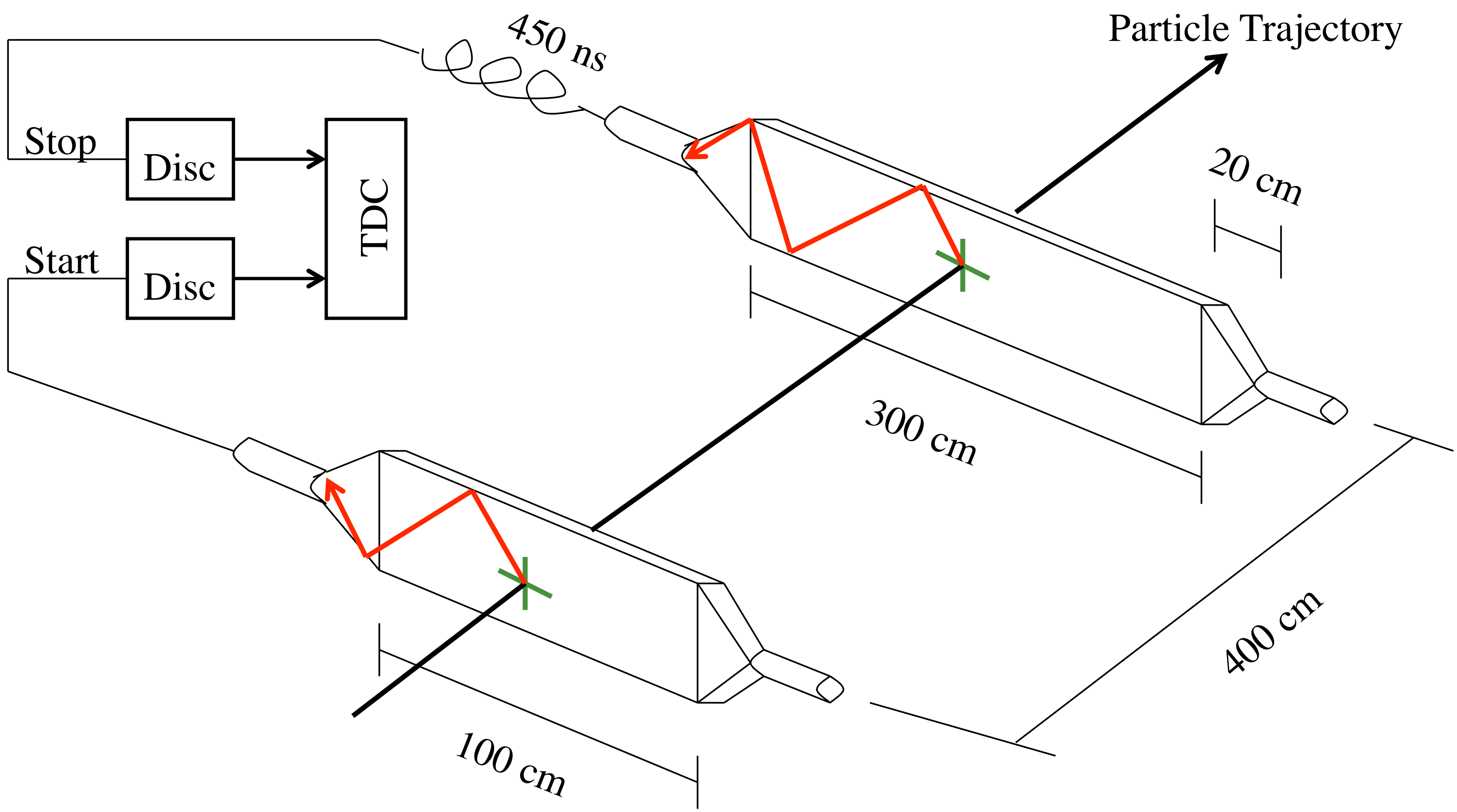
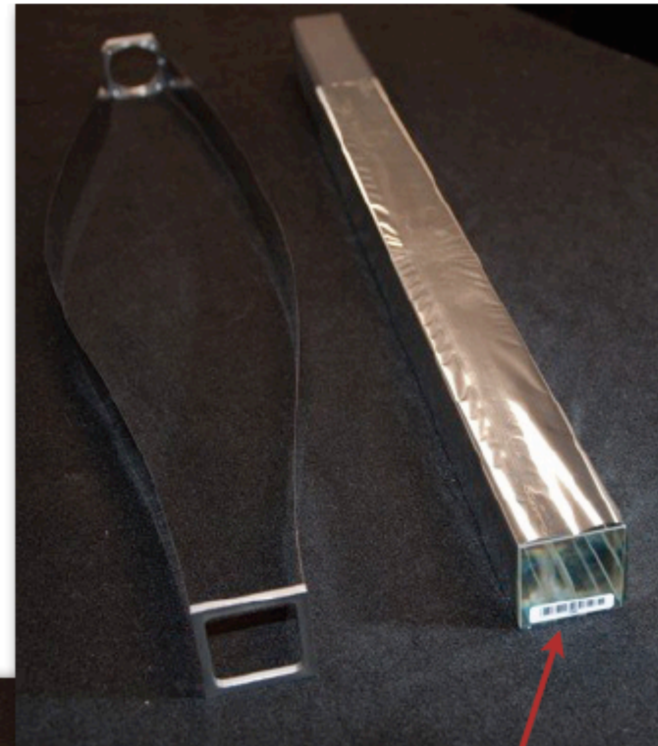
Plastic Scintillators (TOF, start counter)



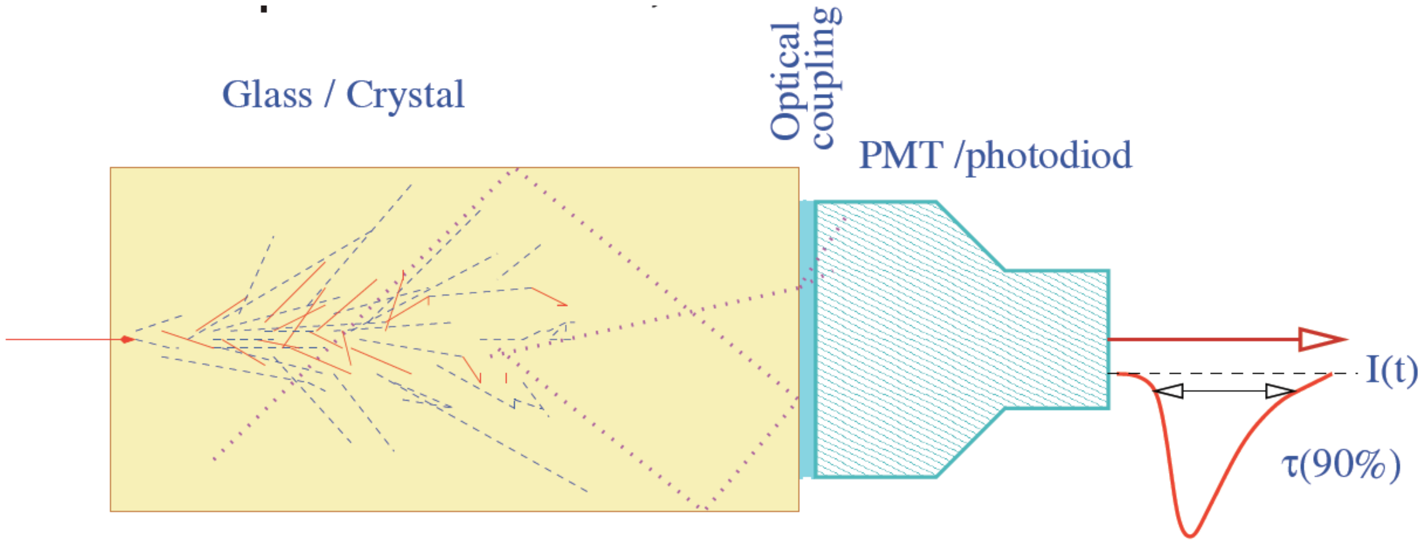
FCAL Lead Glass block unit

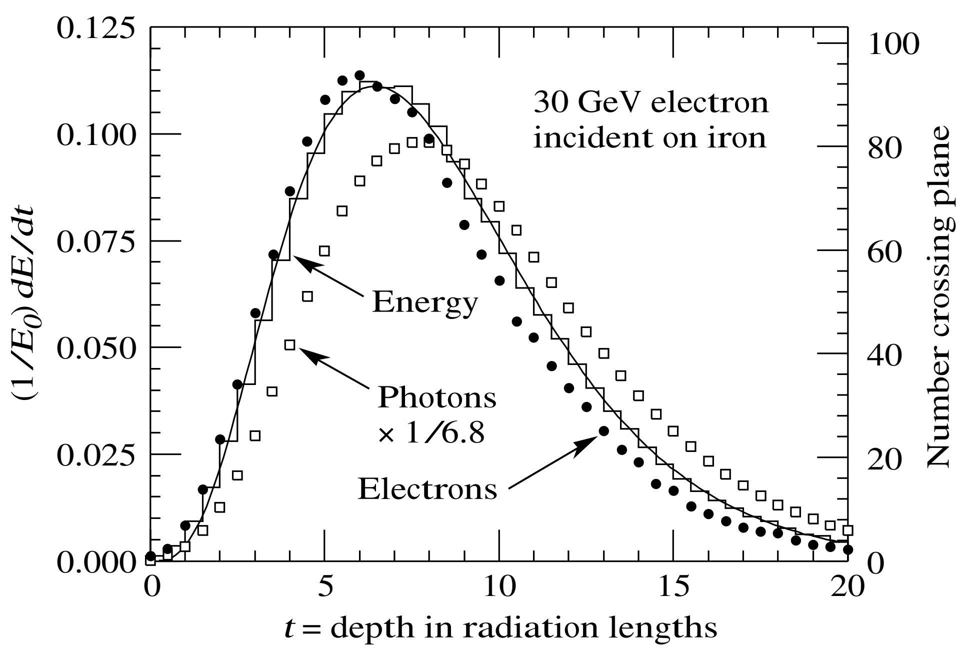
- Photomultiplier tube and housing
- Strap for mechanical support
- Pb glass bar 4x4x45 cm^3



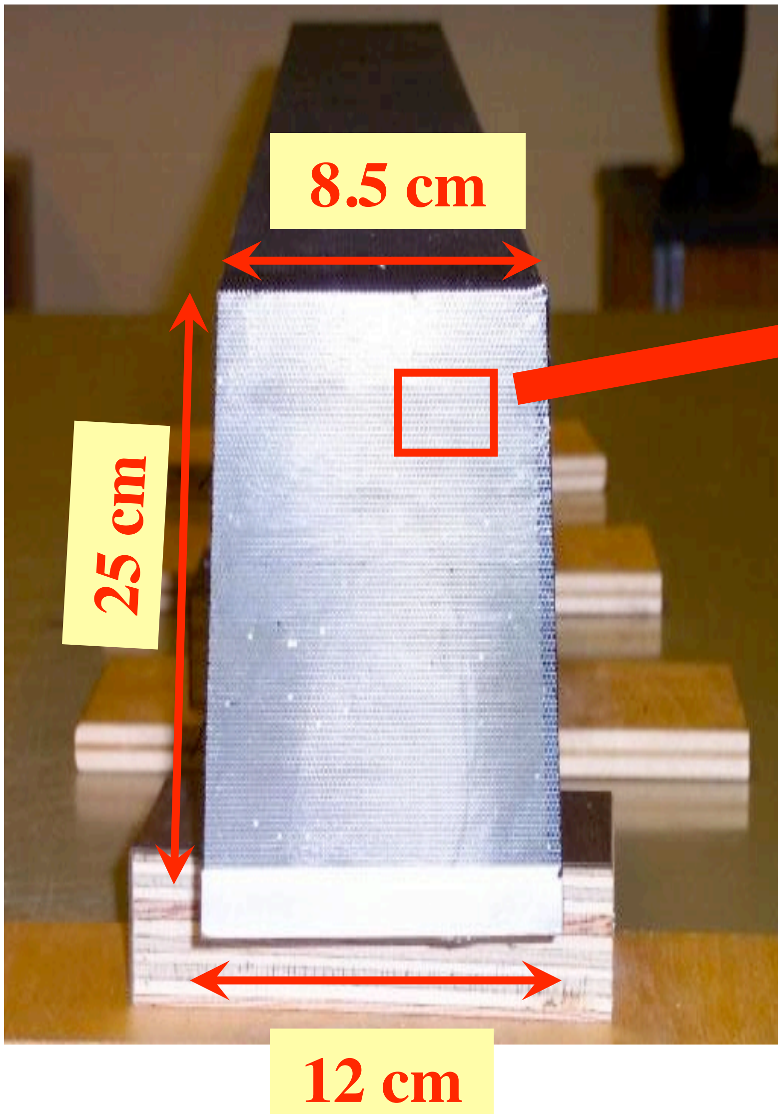
Tracking Barcode

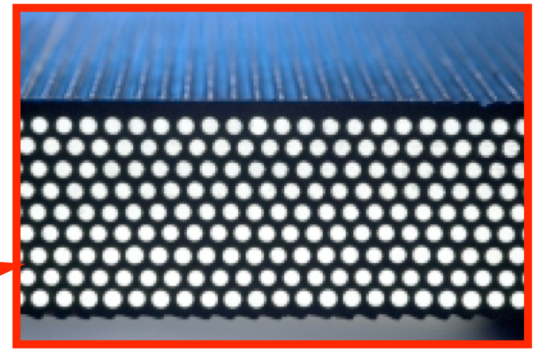
Homogeneous calorimeter (Fcal)

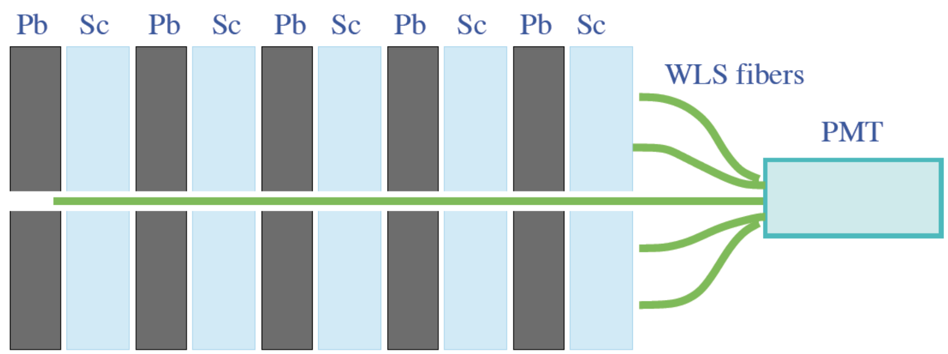




Sampling calorimeter (Bcal)



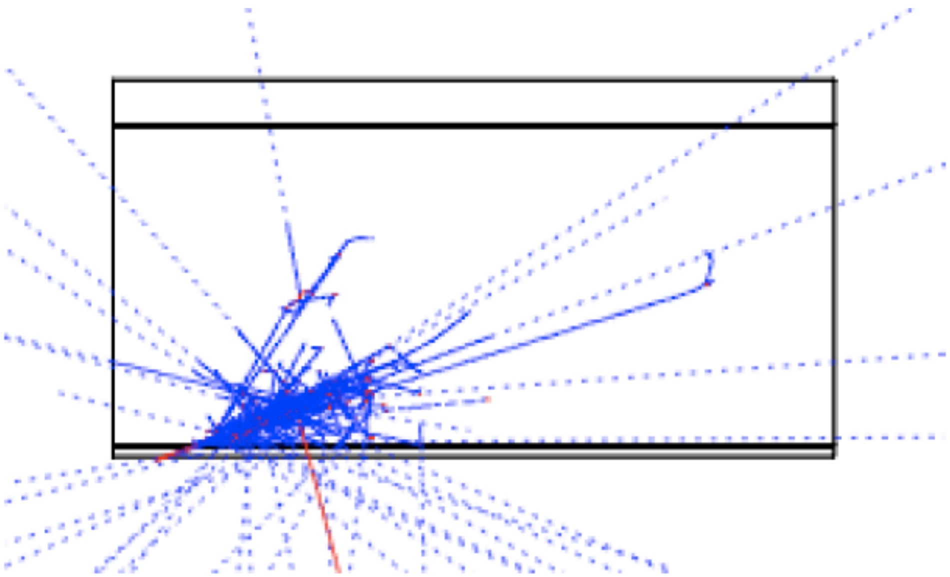




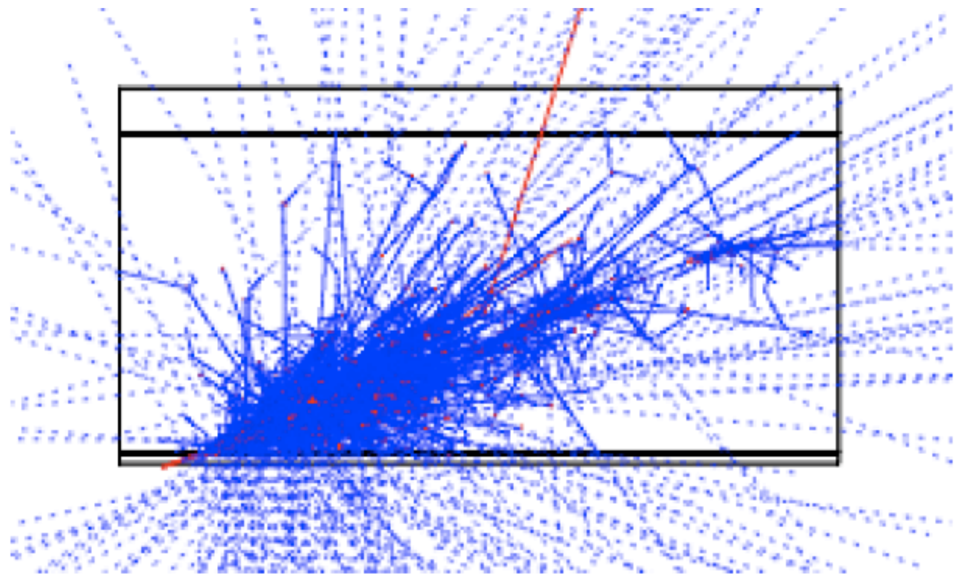
Electrons showering in mini-Bcal

Electrons incident at 20°

E_e = 0.25 GeV



E_e = 1.6 GeV

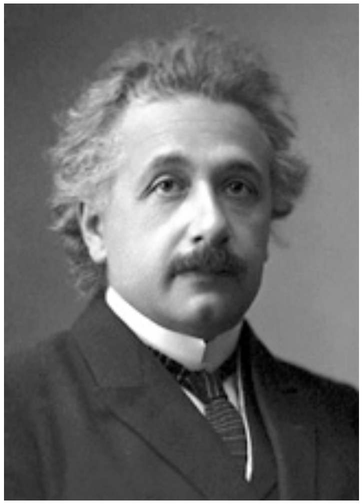


The BCAL is a sampling calorimeter

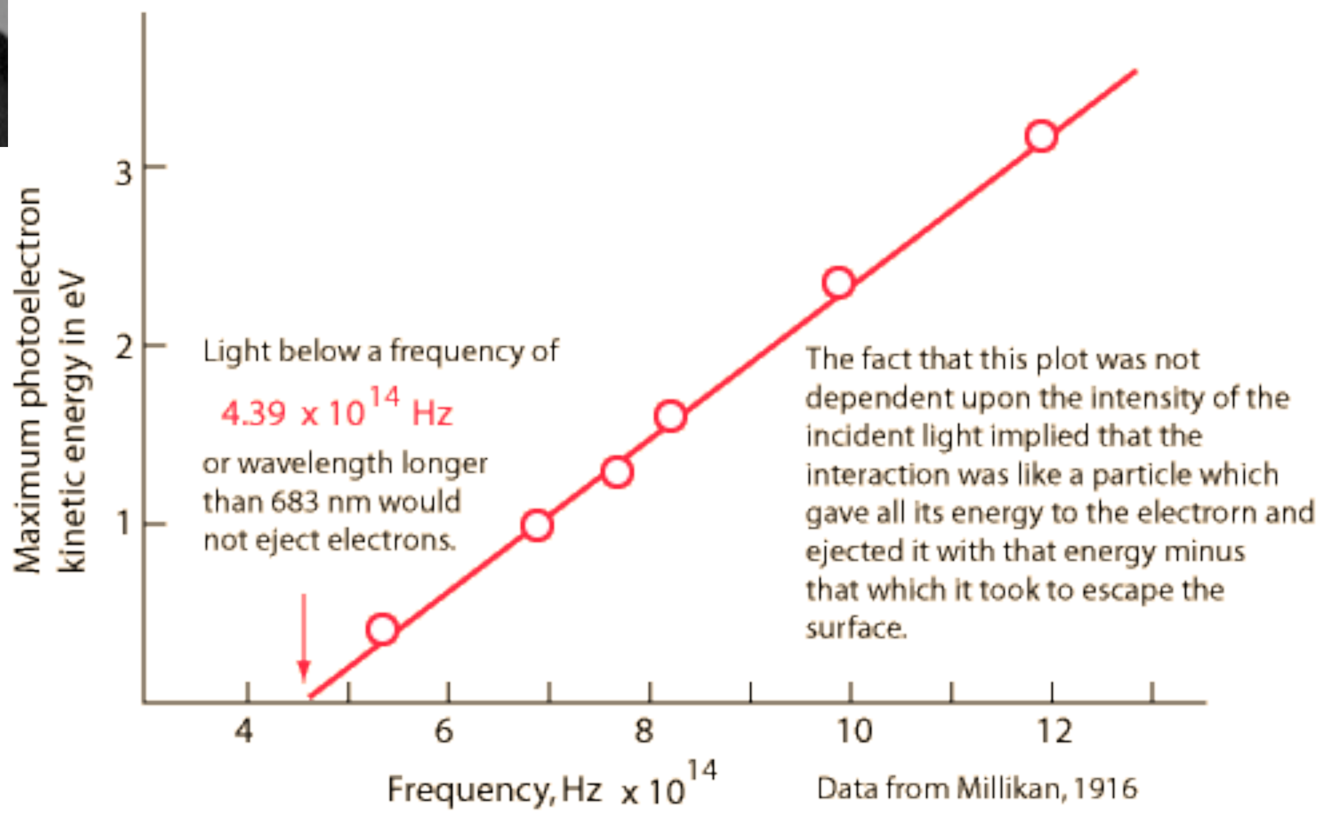
Detection of light

- Light is produced by charged particles when they traverse scintillation materials and lose energy through ionization (TOF)
- Light is produced by showering electrons when they lose energy in the Bcal scintillating fibers
- Cerenkov light is generated by showering electrons in the Fcal lead glass detectors.

Photoelectric Effect

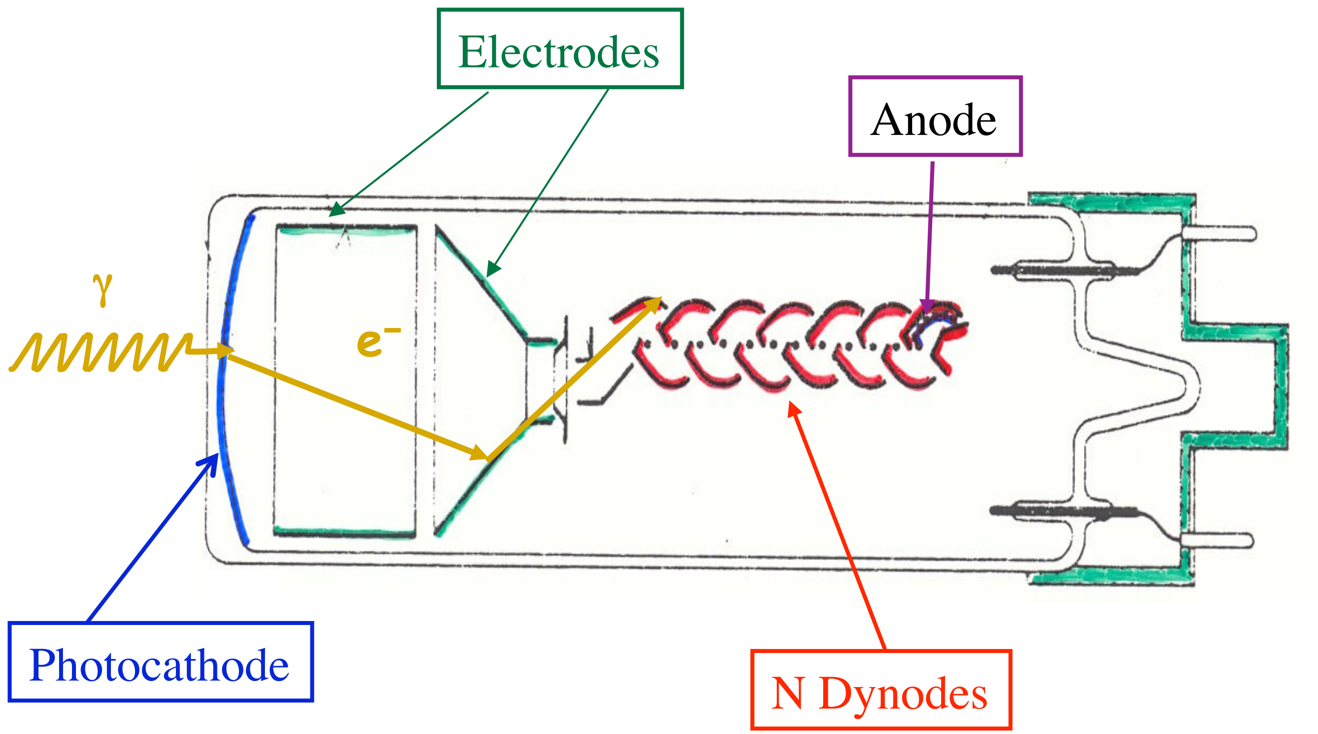


Albert Einstein received the Nobel Prize in 1921"for his services to Theoretical Physics, and especially for his discovery of the law of the photoelectric effect”.



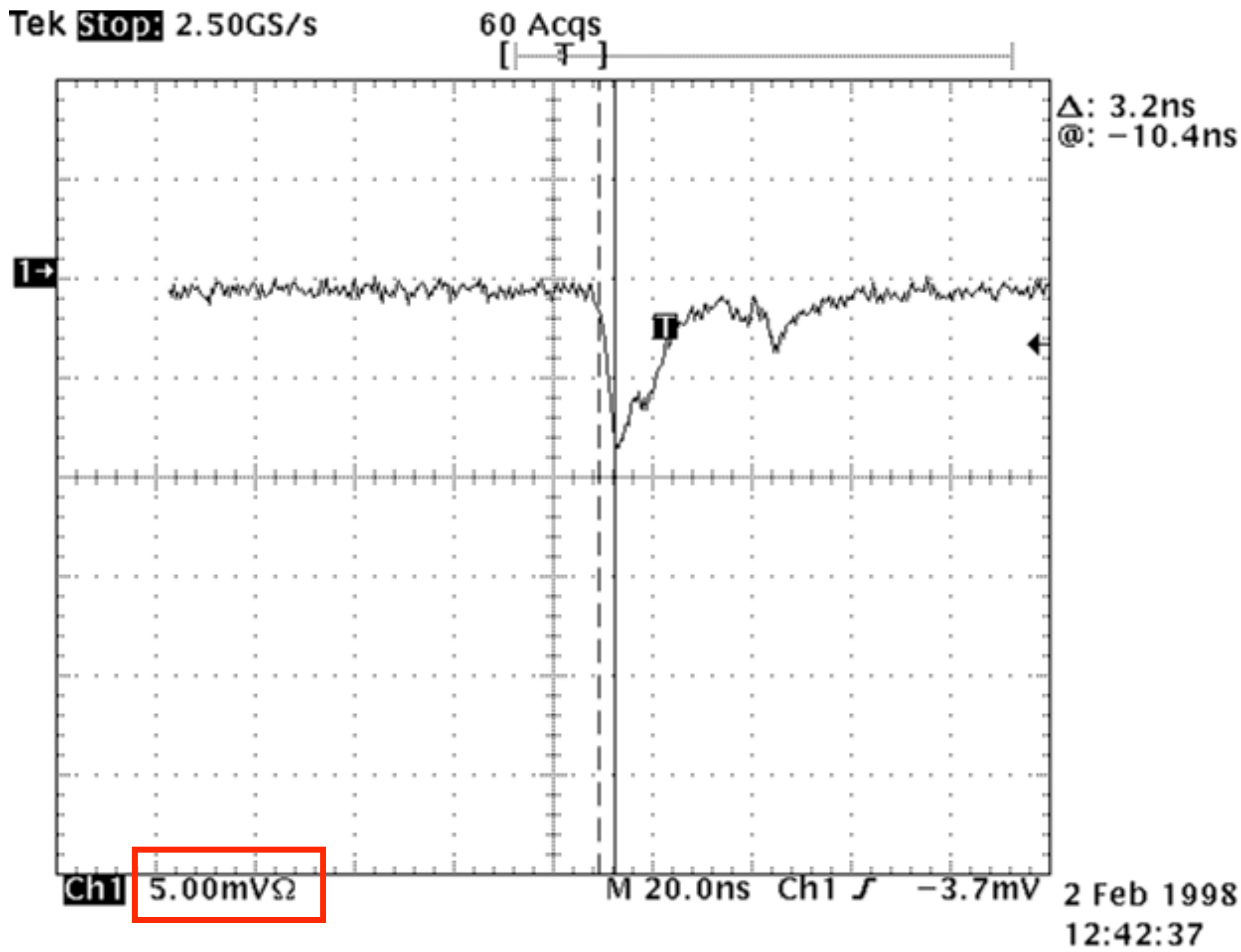
Photomultiplier tube, sensitive light meter

Gain ~ $V^{\alpha N}$ ~ 10^6 - 10^7

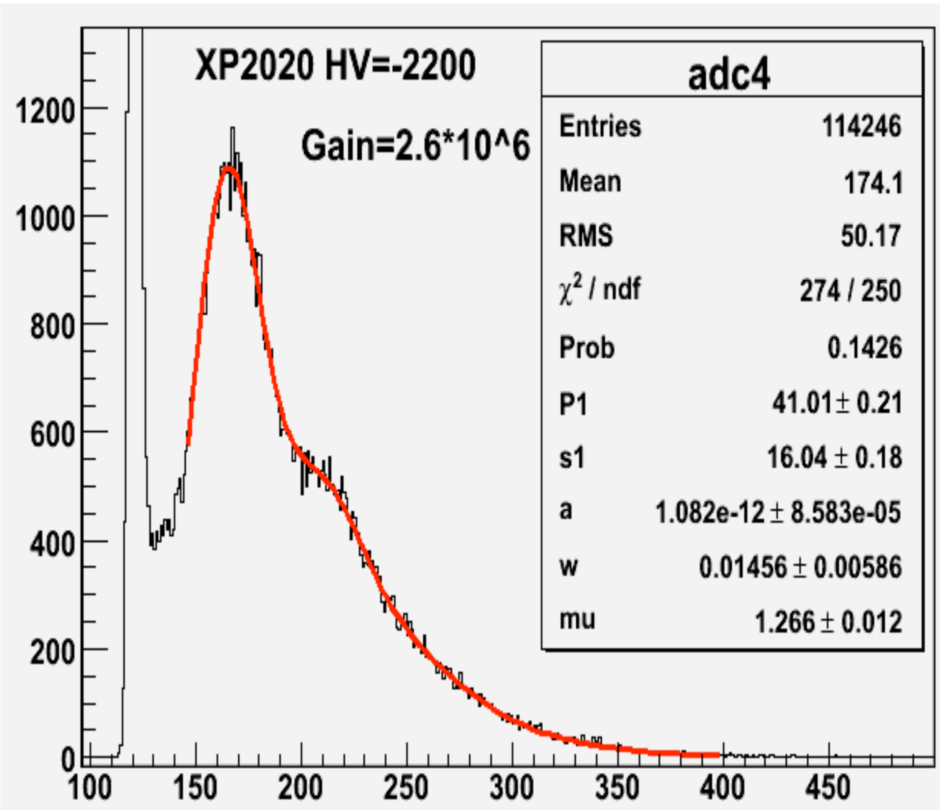


56 AVP pmt

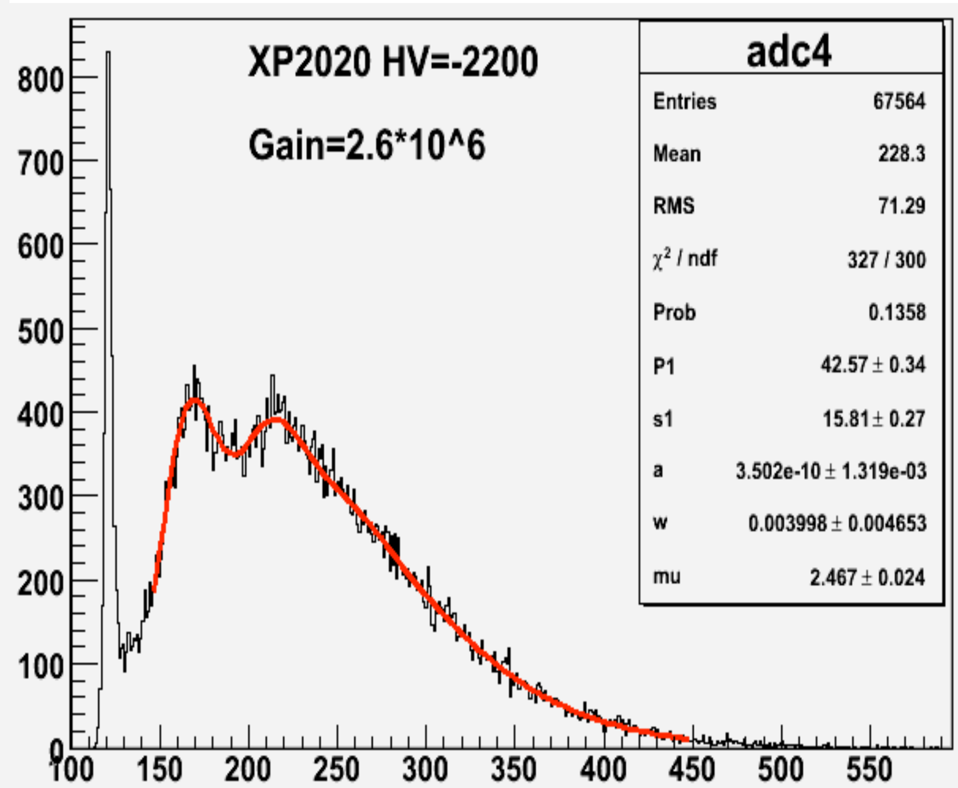
Single photoelectron signal



PMT single p.e. spectra (noise)

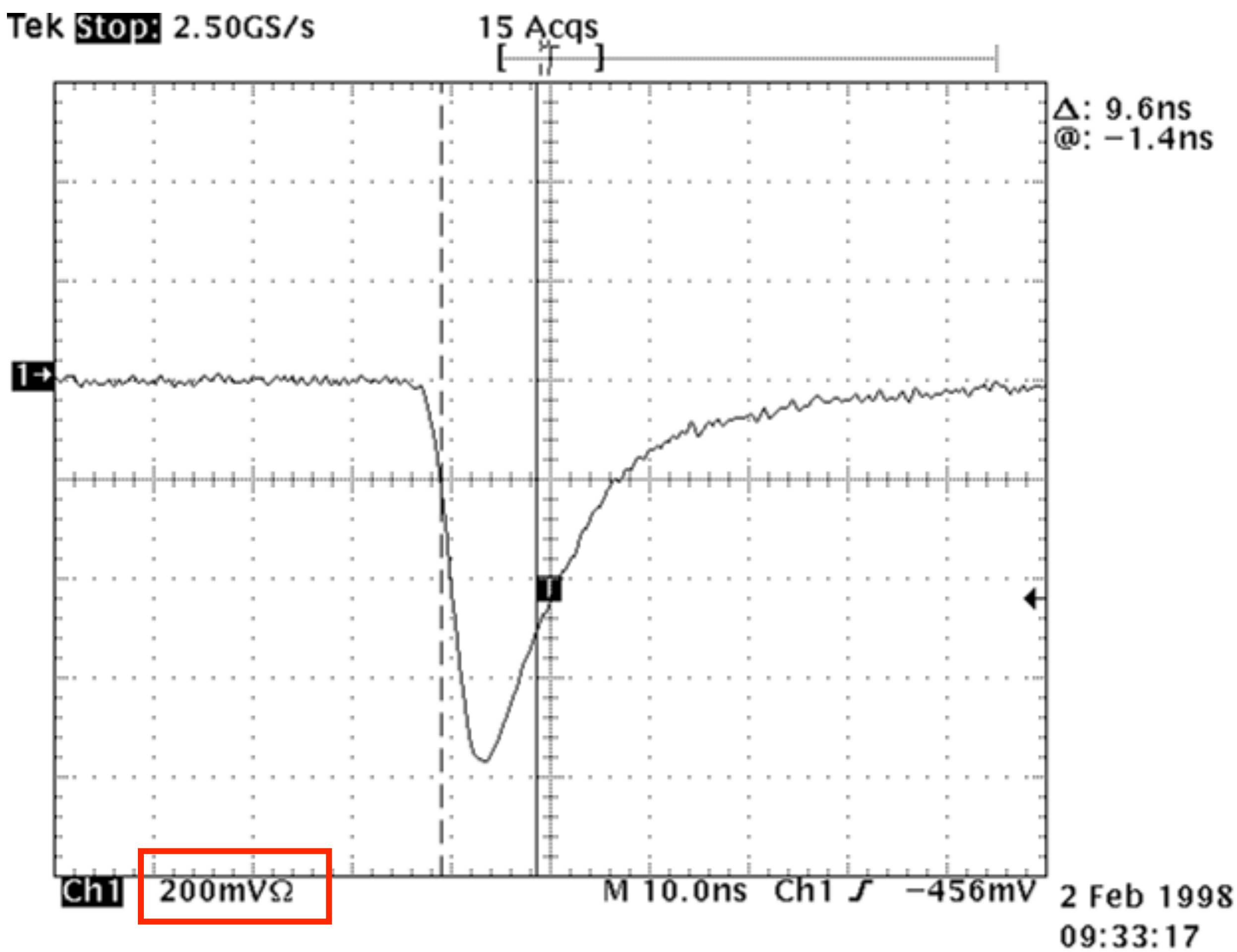


ADC (counts)

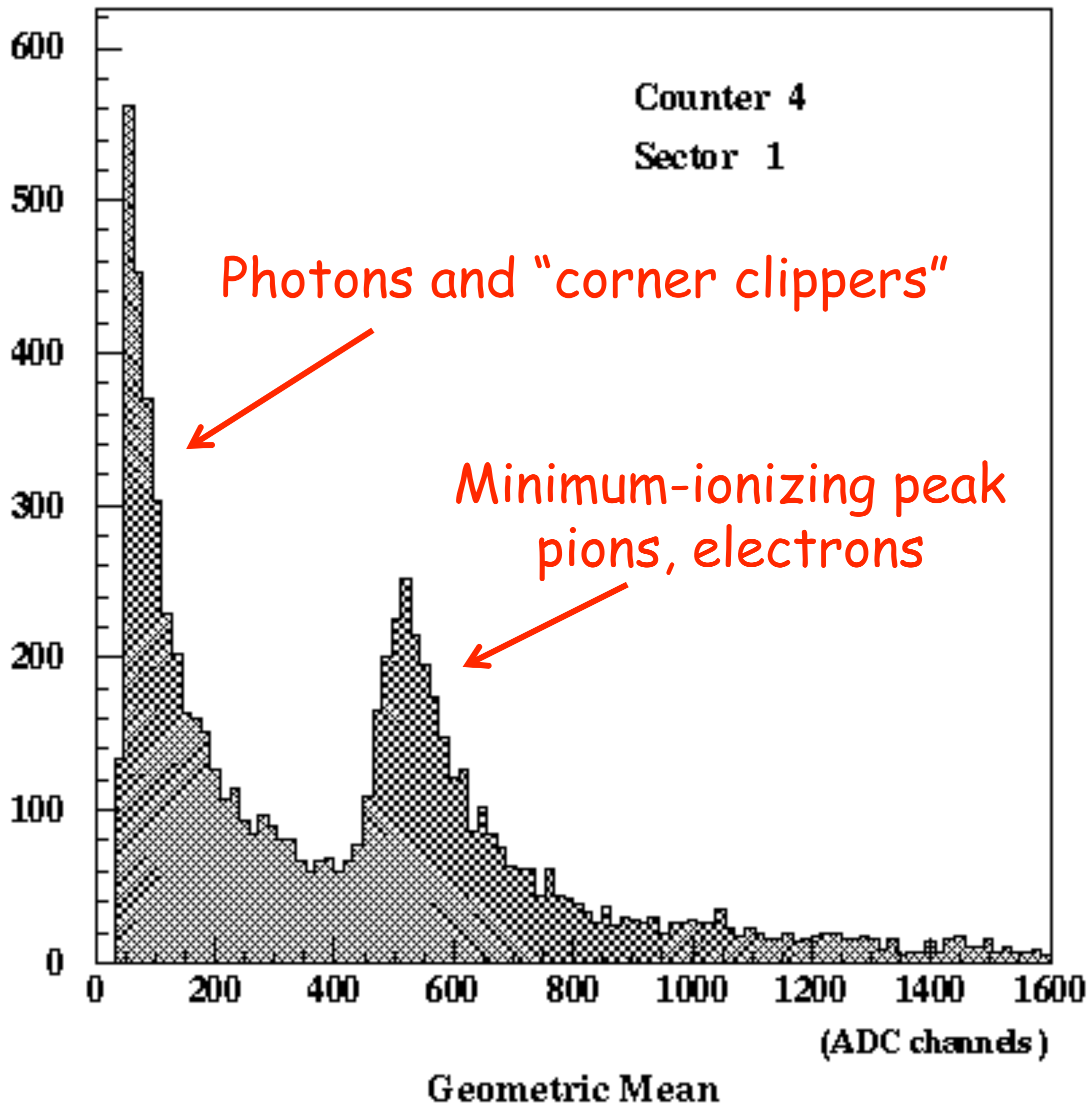


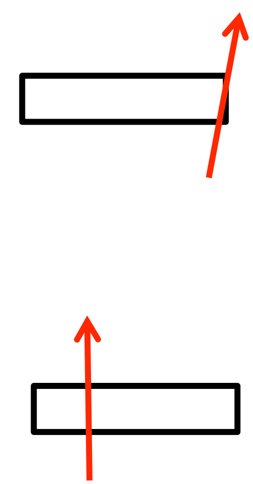
ADC (counts)

Signal for passing tracks



Energy deposited in scintillator





Effect of magnetic field on pmt

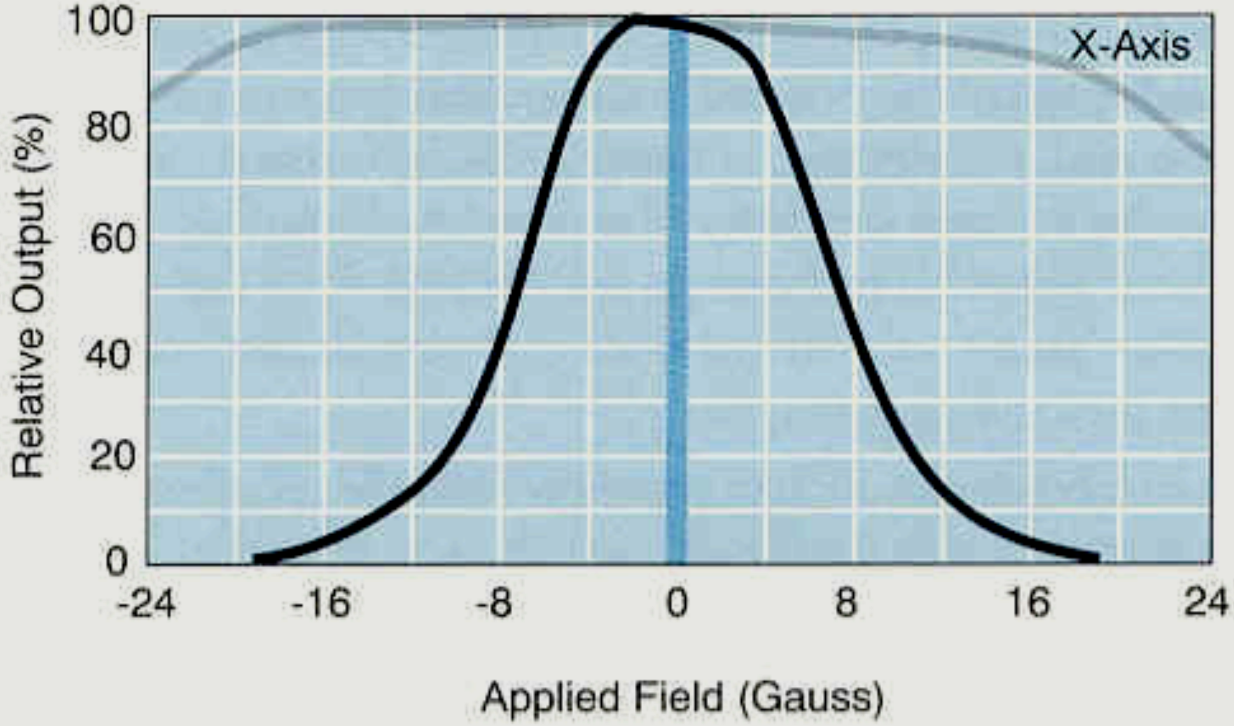
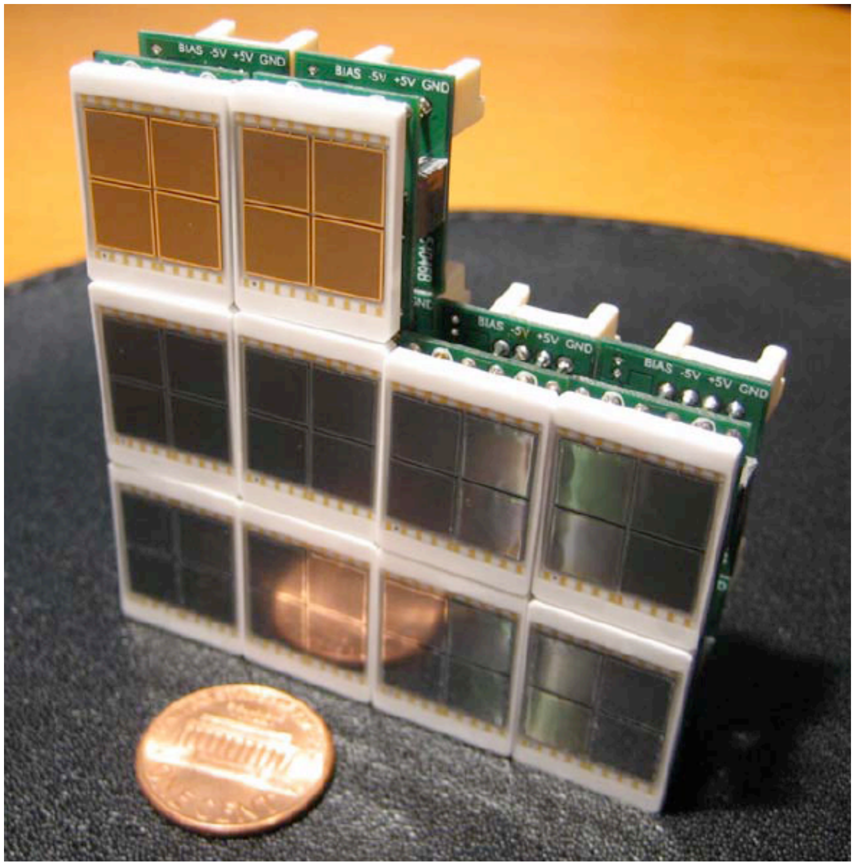
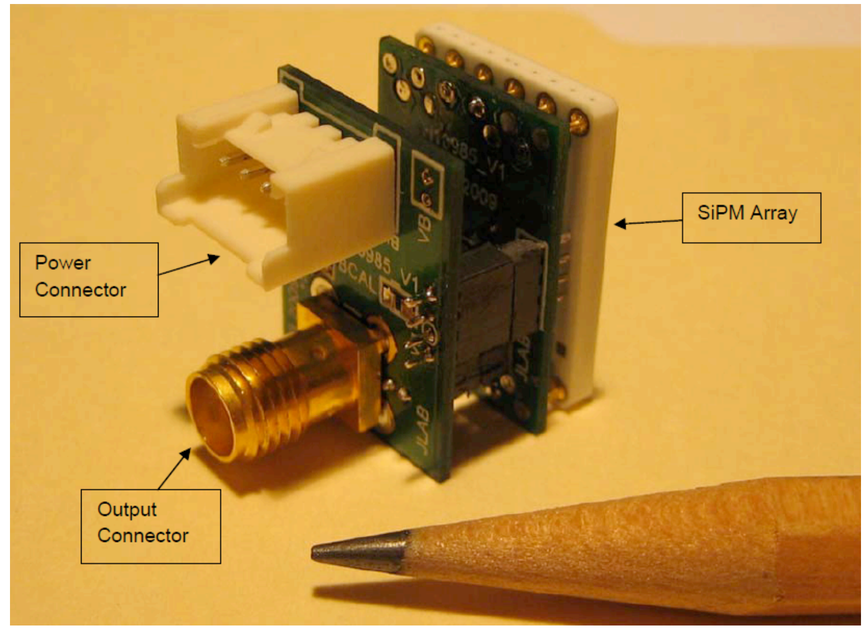


Figure 32

Demostrating how a wrapped mu-metal shield reduces the sensitivity of a 9106 photomultiplier to external magnetic fiels. Solid line: unshield; grey line: wrapped shield; shaded region: earth's field. Field aligned across the first dynode, X axis.

Hamamatsu S12045 arrays





4x4 array of 3x3 mm^2 sensors
Area = 12.7 x 12.7 mm^2

Insensitive to Magnetic Fields!

SiPM (3x3 mm^2) single p.e. spectra

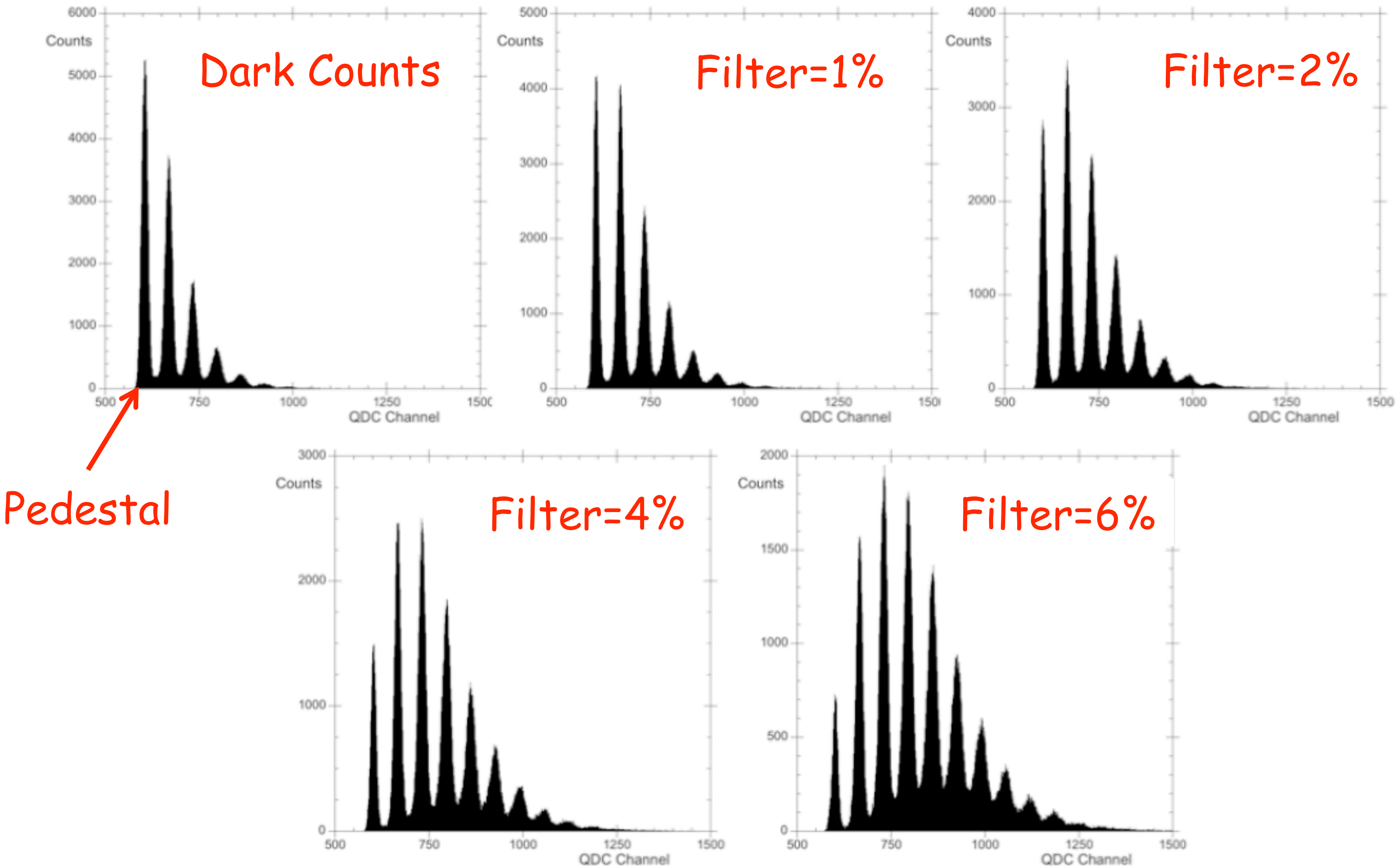


Figure 5: Examples of typical QDC data for one cell (3x3 mm^2) from a SiPM array.

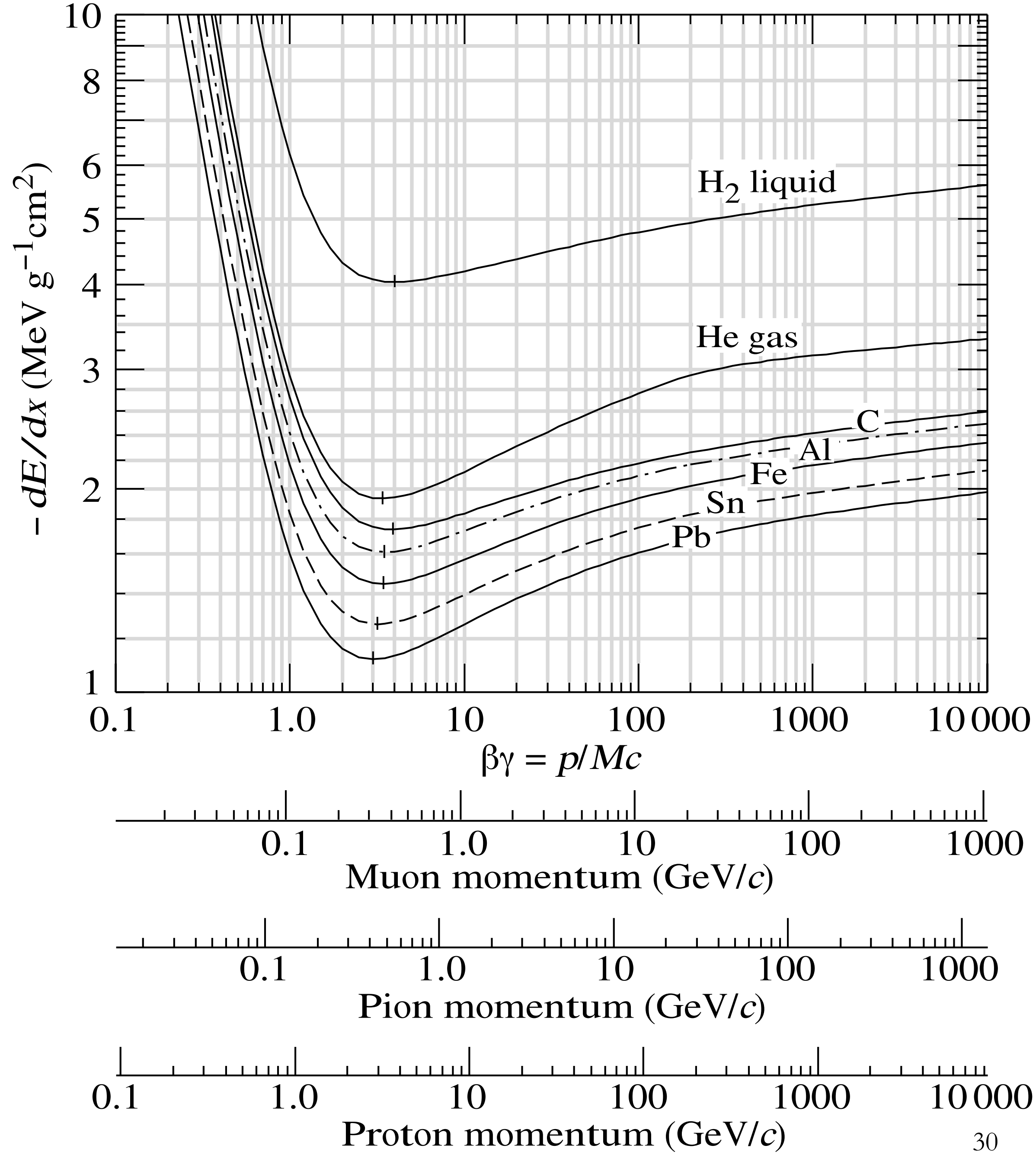
Summary

- We have explored how particles loose energy in matter
- The energy deposited in matter is used to detect traversing particles and measure their properties
- Scintillation counters and calorimeters convert deposited energy into light, which is detected and amplified using vacuum type and silicon type photomultipliers.

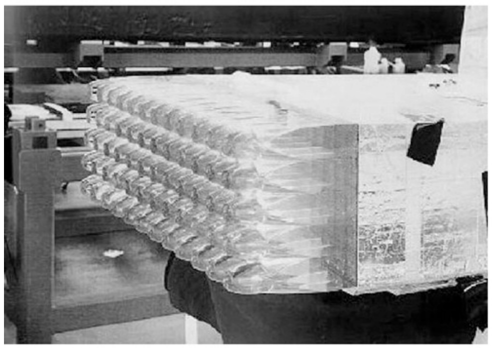
Backup Slides

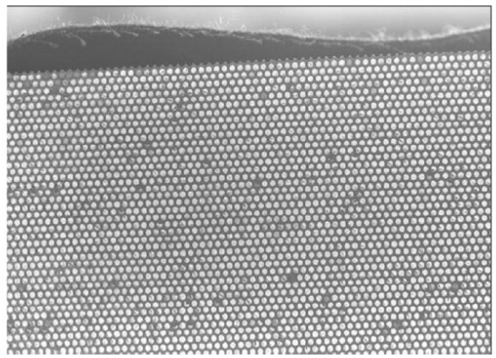
dE/dx (Ionization)

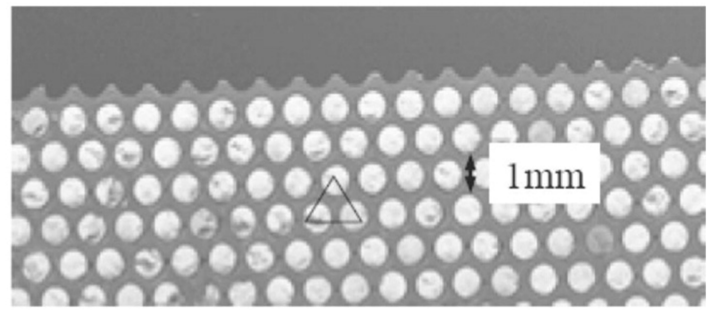
Rule of thumb:
Energy loss ~
2MeV/g/cm²



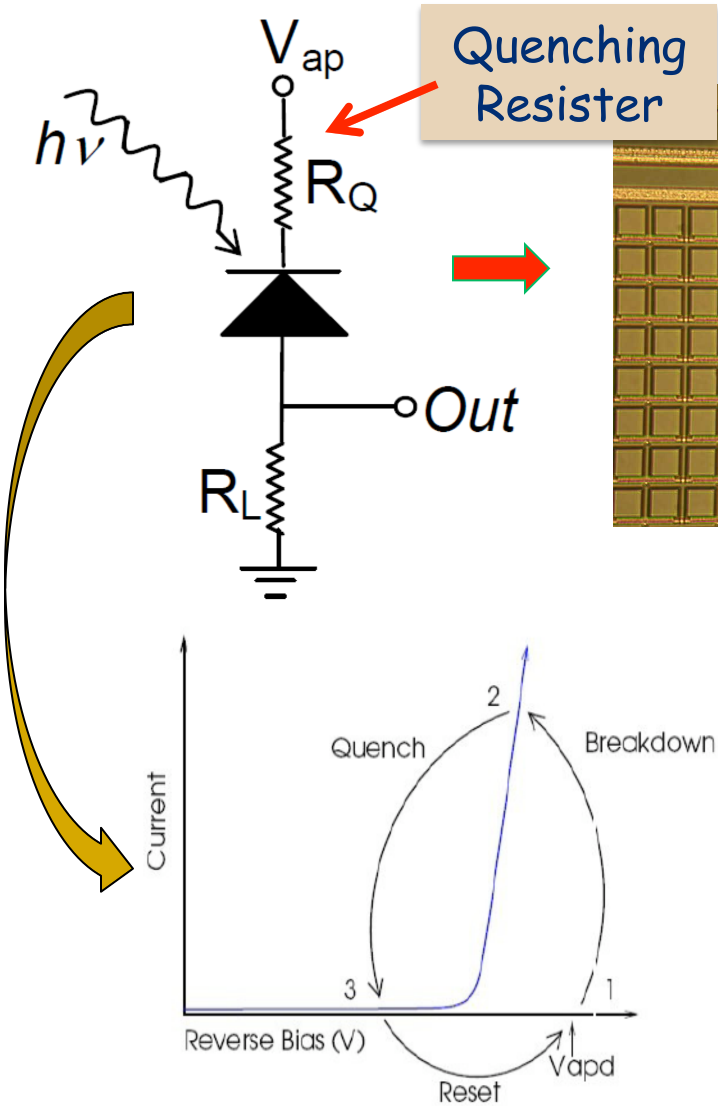
KLOE calorimeter

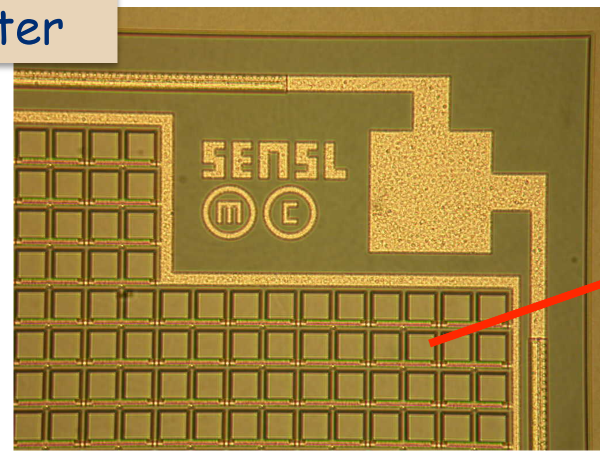




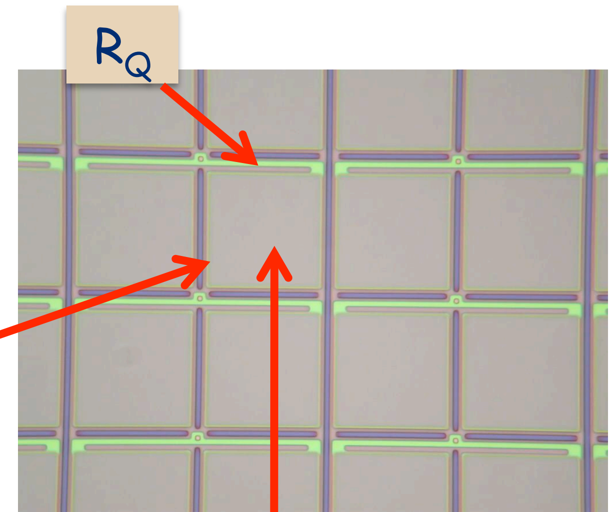


Multipixel Limited Geiger mode APD





G-APD array

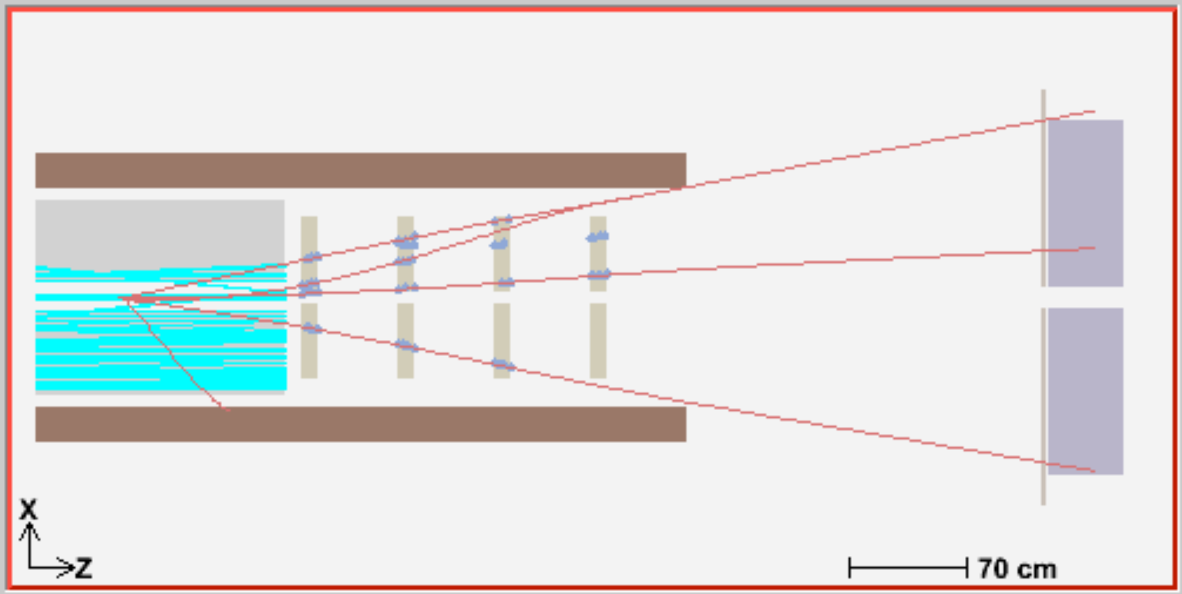


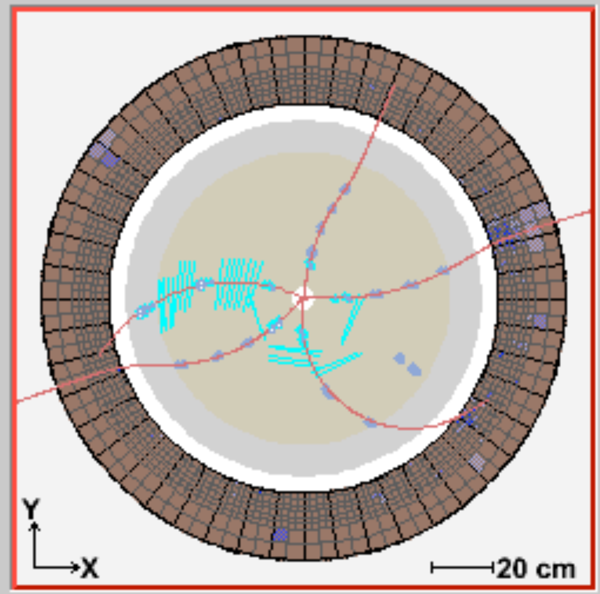
Photosensitive surface

- 20-100 μm G-APD pixel
- Incident photon initiates avalanche
- Quenched by resister ➔ device reset
- Sum the pixels -> photon counter

Insensitive to Magnetic Fields!

“typical” $\gamma p \rightarrow 2\pi^+ 2\pi^- p$





Track Info

Thrown

trk:	type:	p:	theta:	phi:	z:
1	pi+	2.722	12.07	6.203	69.55
2	pi+	0.8265	16.36	4.532	69.55
3	pi-	3.31	7.836	1.476	69.55
4	pi-	2.021	11.76	4.005	69.55
5	proton	0.4386	49.02	2.71	69.55
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Reconstructed

trk:	type:	p:	theta:	phi:	z:	chisq/Ndof:	Ndof:
1	pi-	3.267	7.771	1.494	67.3	1.935	31
2	pi-	1.985	11.69	4.021	69.56	3.604	31
3	pi+	2.753	11.96	6.191	68.38	3.65	20
4	pi+	0.8488	17.04	4.588	72.81	8.872	21
5	pi+	0.4221	50.56	2.703	69.18	11.66	27
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