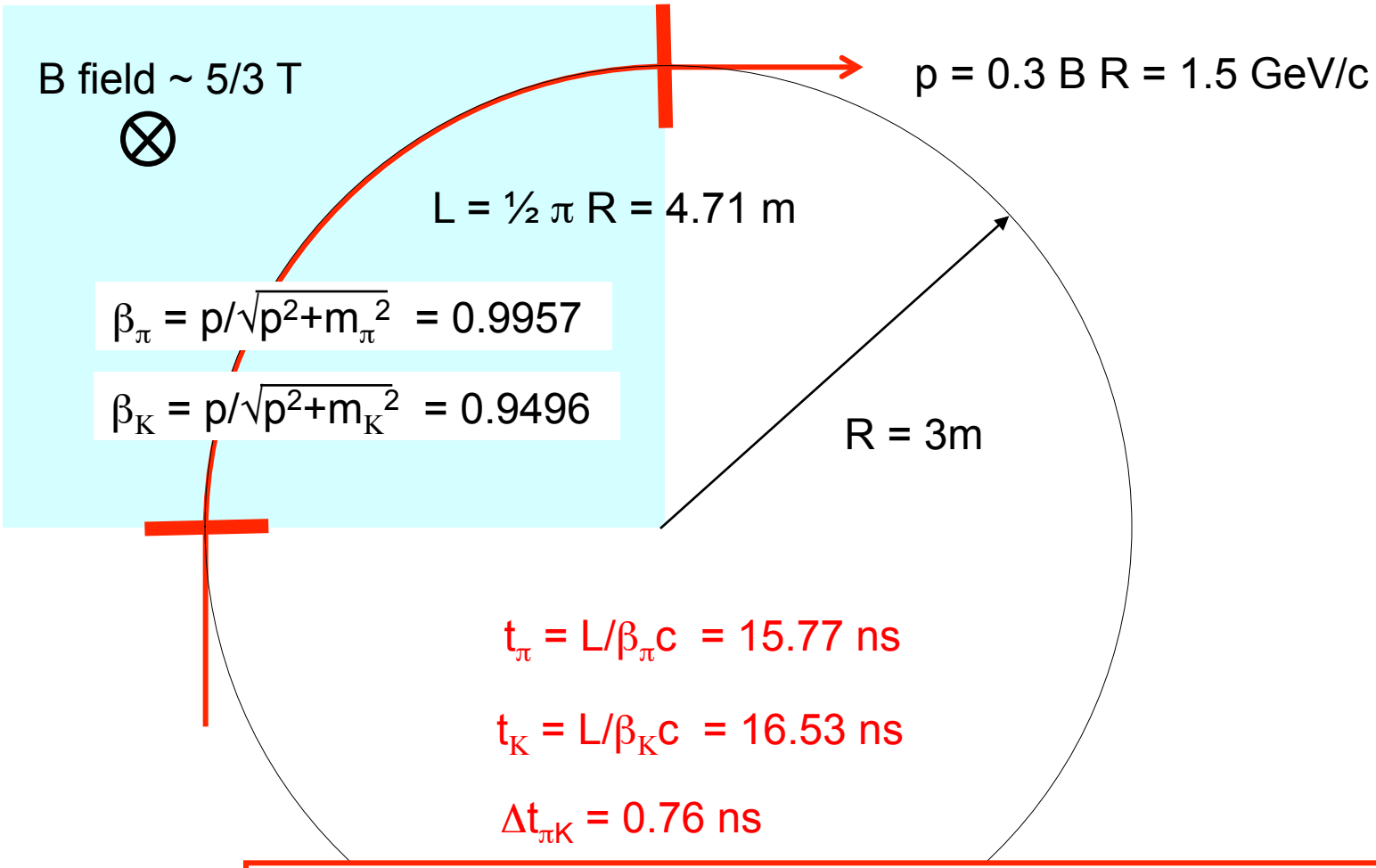
Scintillation Detectors

Introduction
Components
- Scintillator
- Light Guides
- Light Sensors
  - Photomultiplier Tubes
  - Silicon Photomultipliers

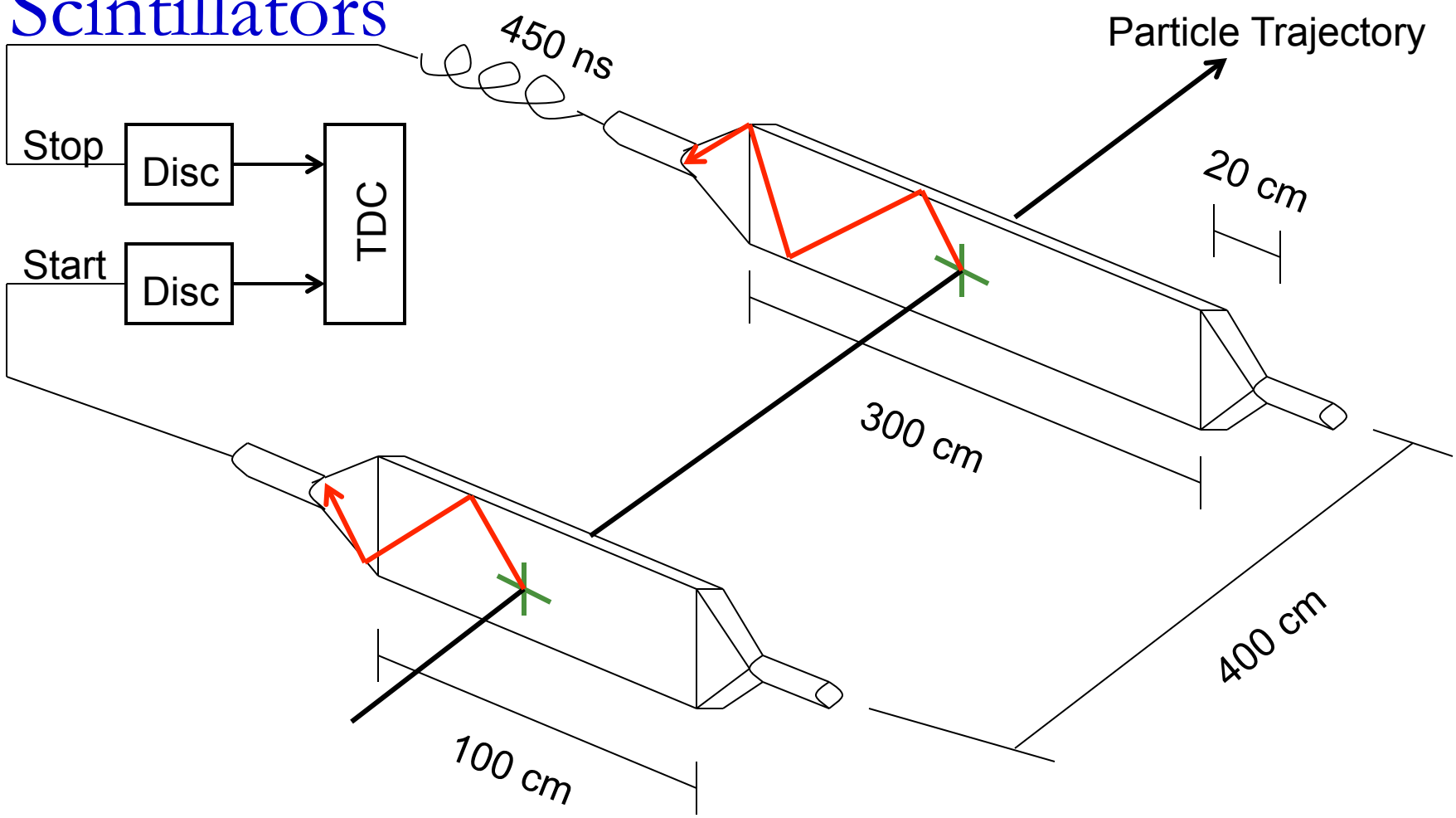
Formalism/Electronics
Application to Particle Identification

Experiment basics



Particle Identification by time-of-flight (TOF) requires Measurements with accuracies of ~ 0.1 ns

Measure the Flight Time between two Scintillators



Propagation velocities

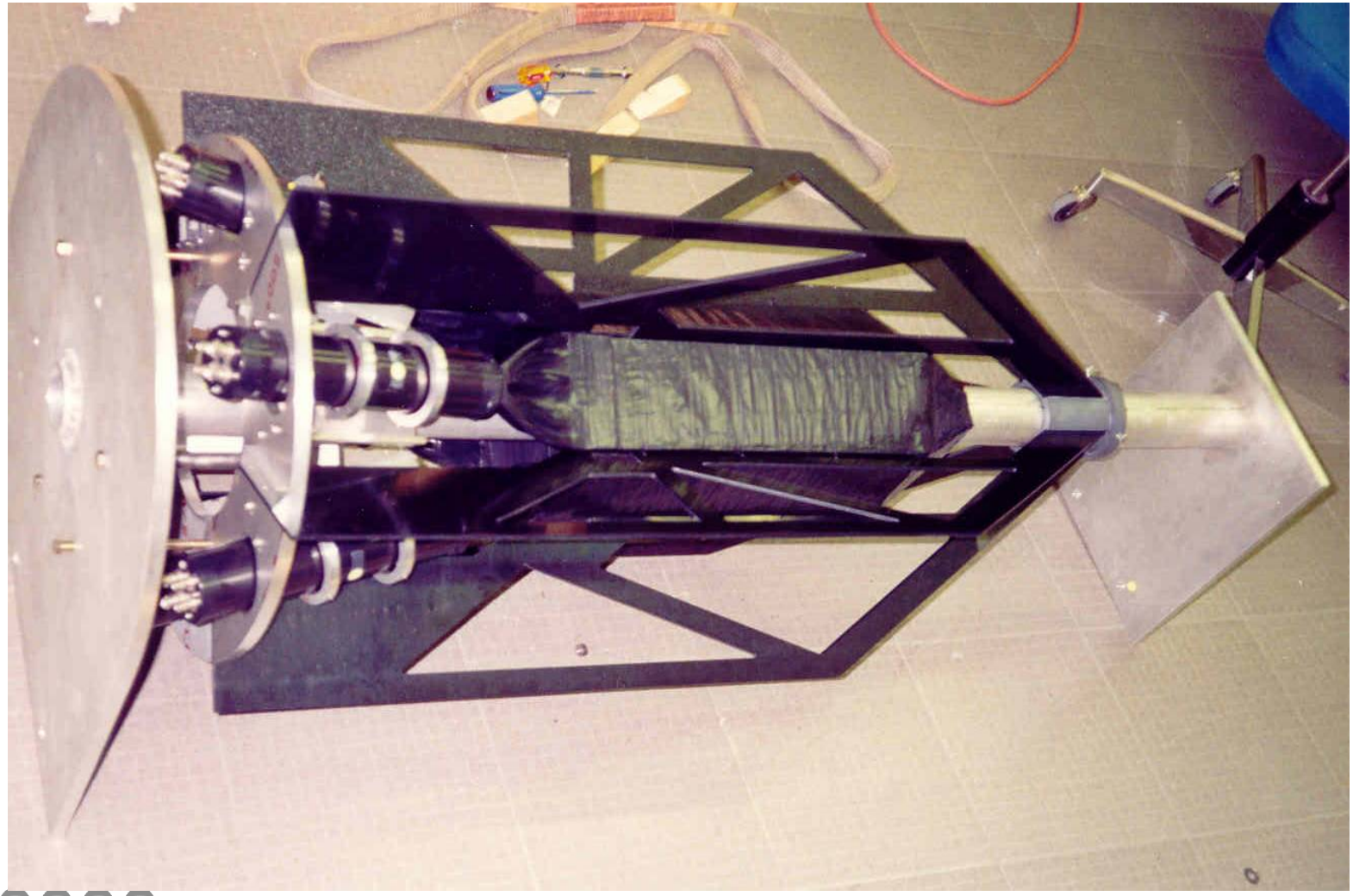
- $c = 30$ cm/ns
- $v_{scint} = c/n = 20$ cm/ns
- $v_{eff} = 16$ cm/ns
- $v_{pmt} = 0.6$ cm/ns
- $v_{cable} = 20$ cm/ns

$\Delta t \sim 0.1$ ns

$\Delta x \sim 3$ cm

CLAS detector with FC pulled apart

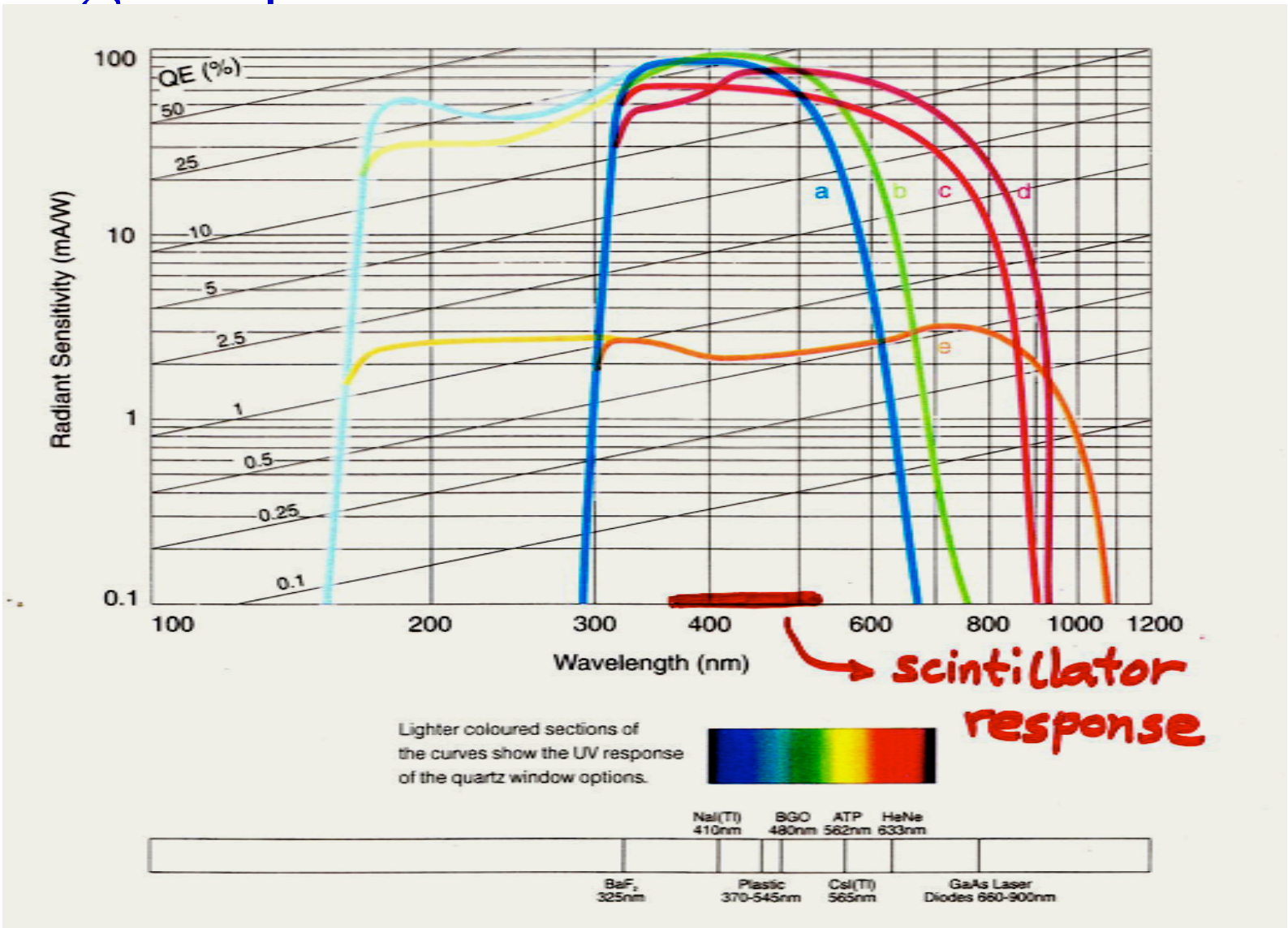
Start counter assembly



Scintillator types

- Organic
  - Liquid
    - Economical
    - messy
  - Solid
    - Fast decay time
    - long attenuation length
    - Emission spectra
- Inorganic (crystals)
  - Anthracene
    - Unused standard
  - NaI, CsI
    - Excellent γ resolution
    - Slow decay time
  - Lead Tungstate ($PbWO_4$)
    - High density and resolution

Light Spectrum

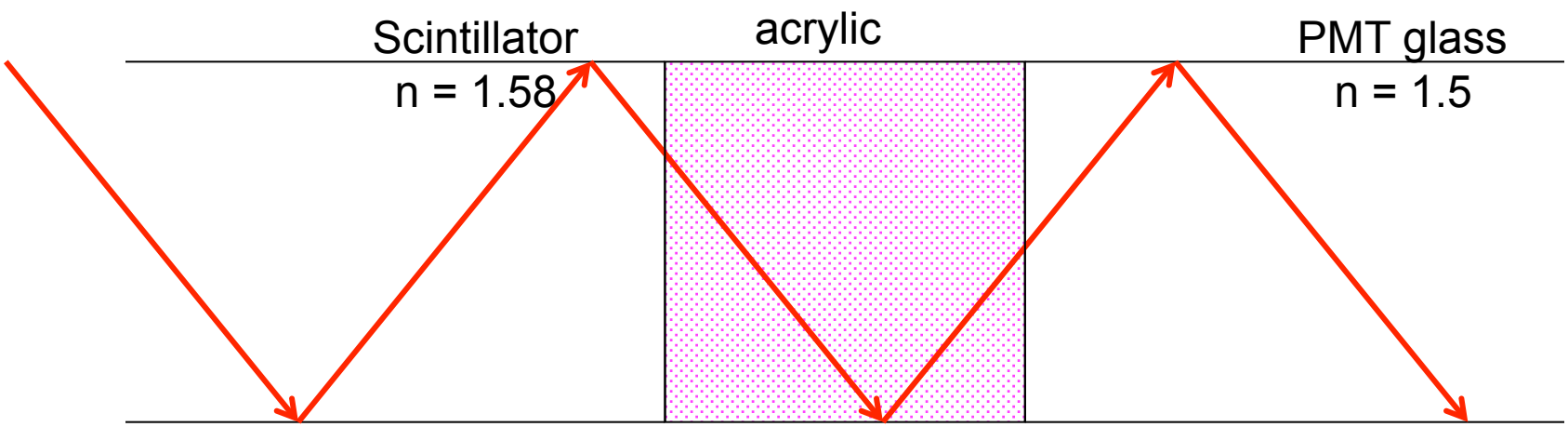


Light Collection: Light guides

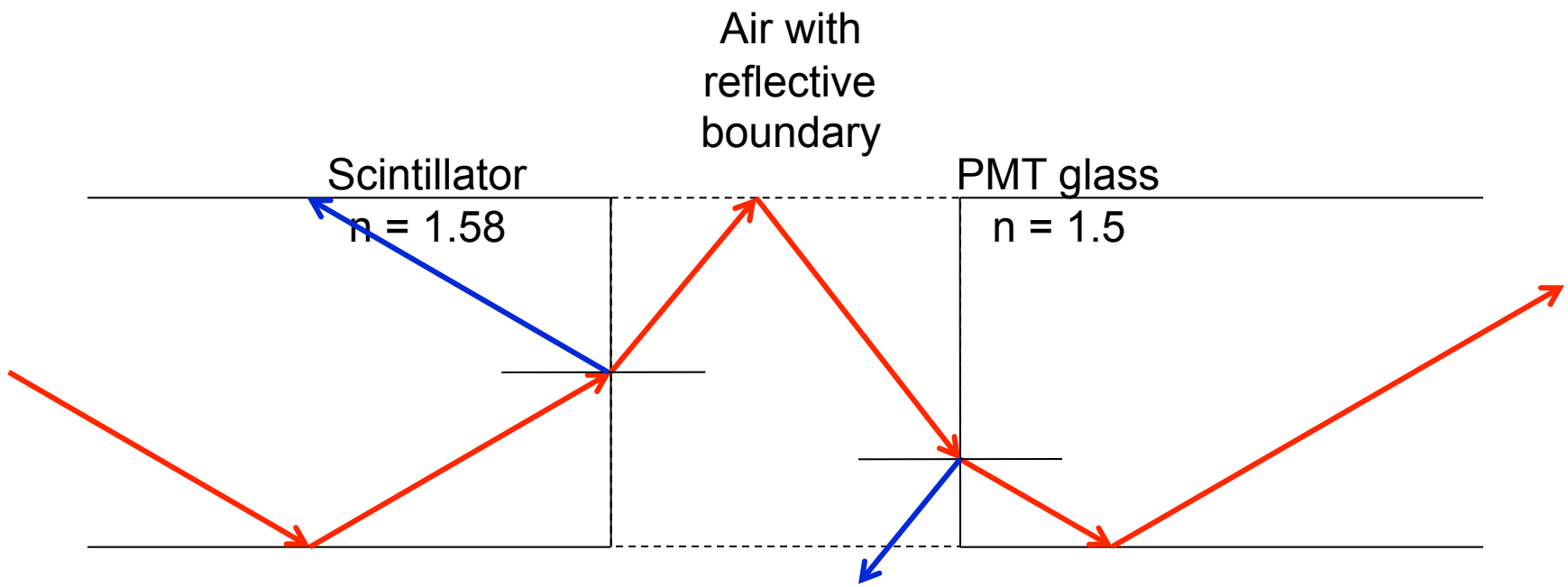
- Goals
  - Match (rectangular) scintillator to (circular) pmt
  - Optimize light collection for applications

- Types
  - Plastic
  - Air
  - None
  - “Winston” shapes

Reflective/Refractive boundaries



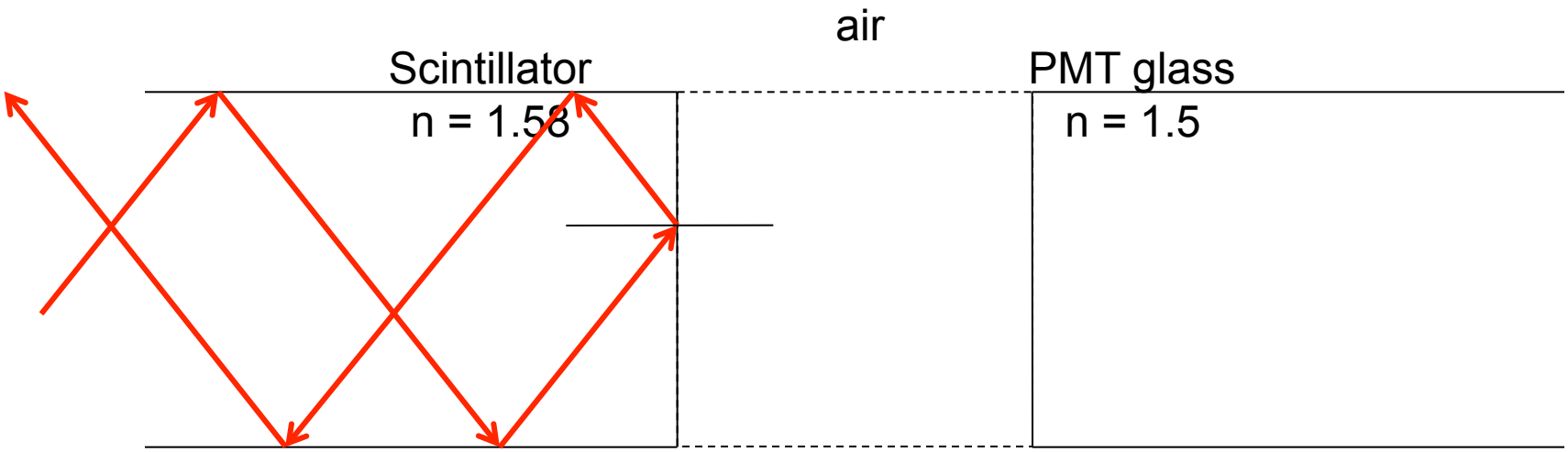
Reflective/Refractive boundaries



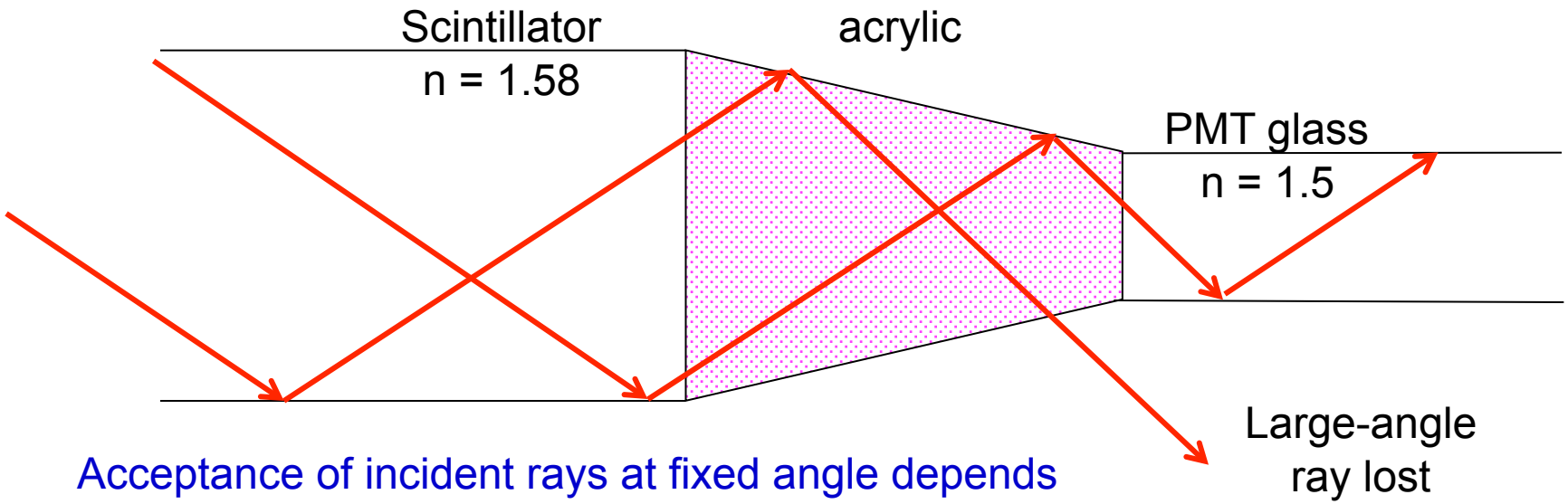
$$\mathbf{R_{air}} = \left(\frac{\mathbf{1-n}}{\mathbf{1+n}}\right)^{\mathbf{2}} \approx \mathbf{4-5\%}$$

(reflectance at normal incidence)

Reflective/Refractive boundaries



Reflective/Refractive boundaries



Acceptance of incident rays at fixed angle depends on position at the exit face of the scintillator

Rule of thumb: Acceptance is given by the ratio of output/input areas

Winston Cones - special geometry

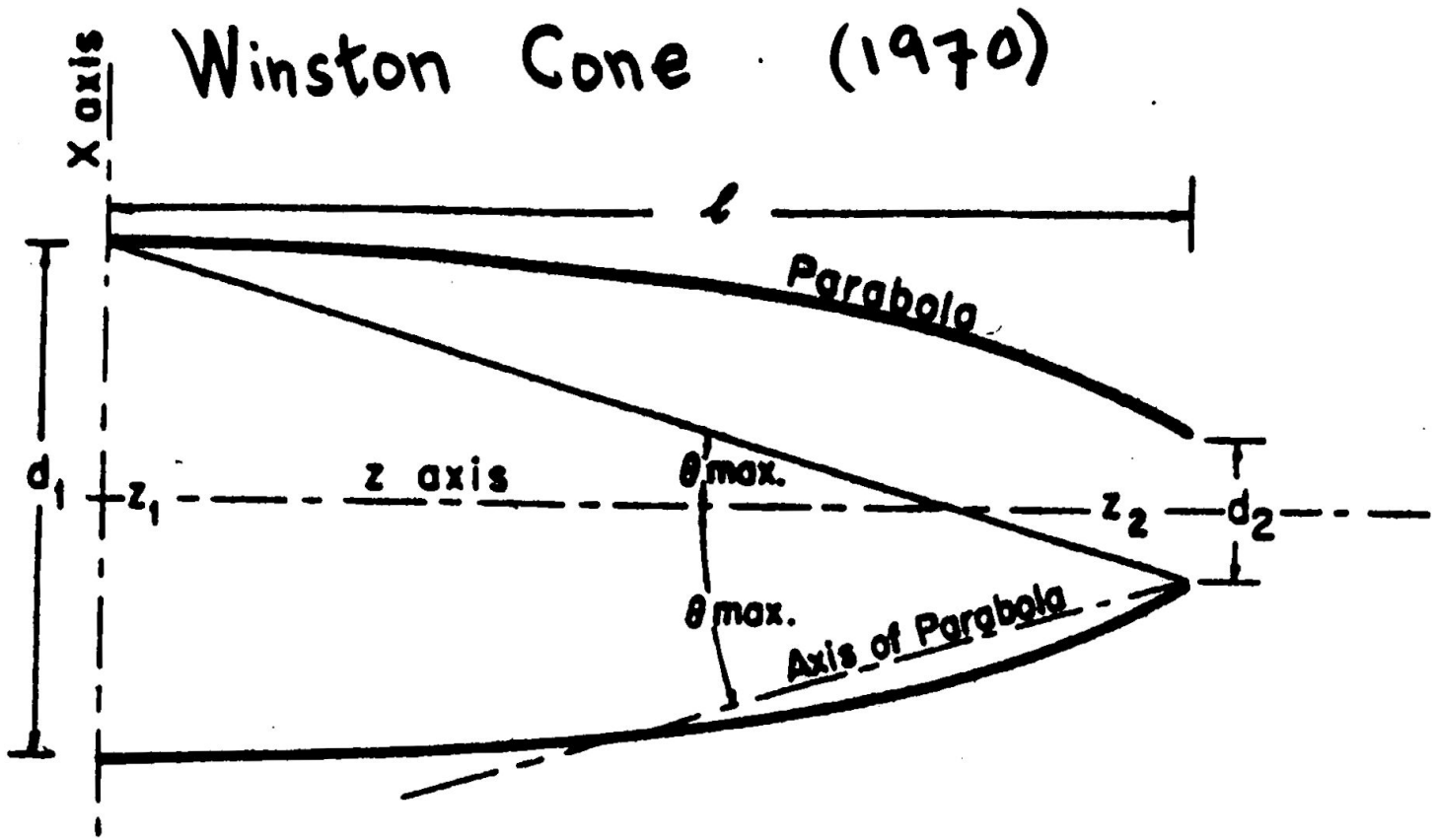
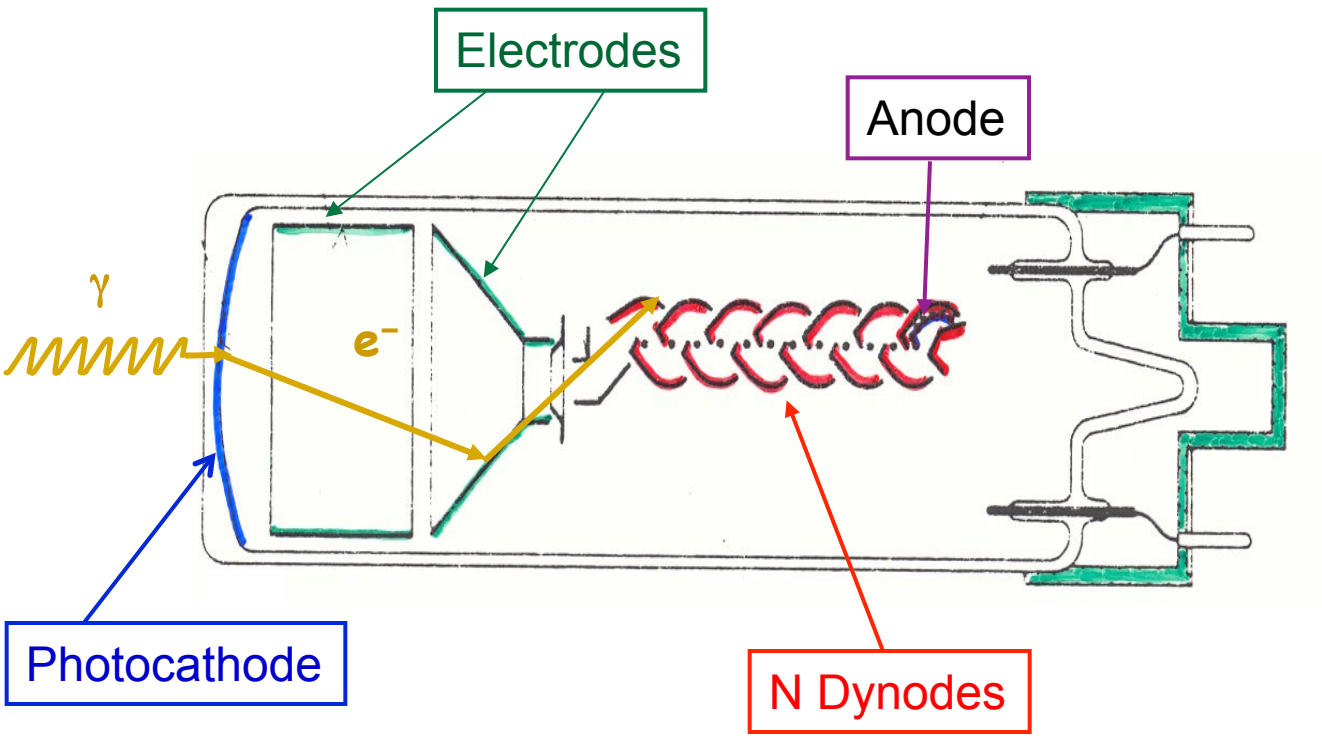


FIG. 2. Construction of an ideal light collector for the case of constant index of refraction. In this example, $\theta_{max} = 16°$.

Photomultiplier tube, sensitive light meter

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

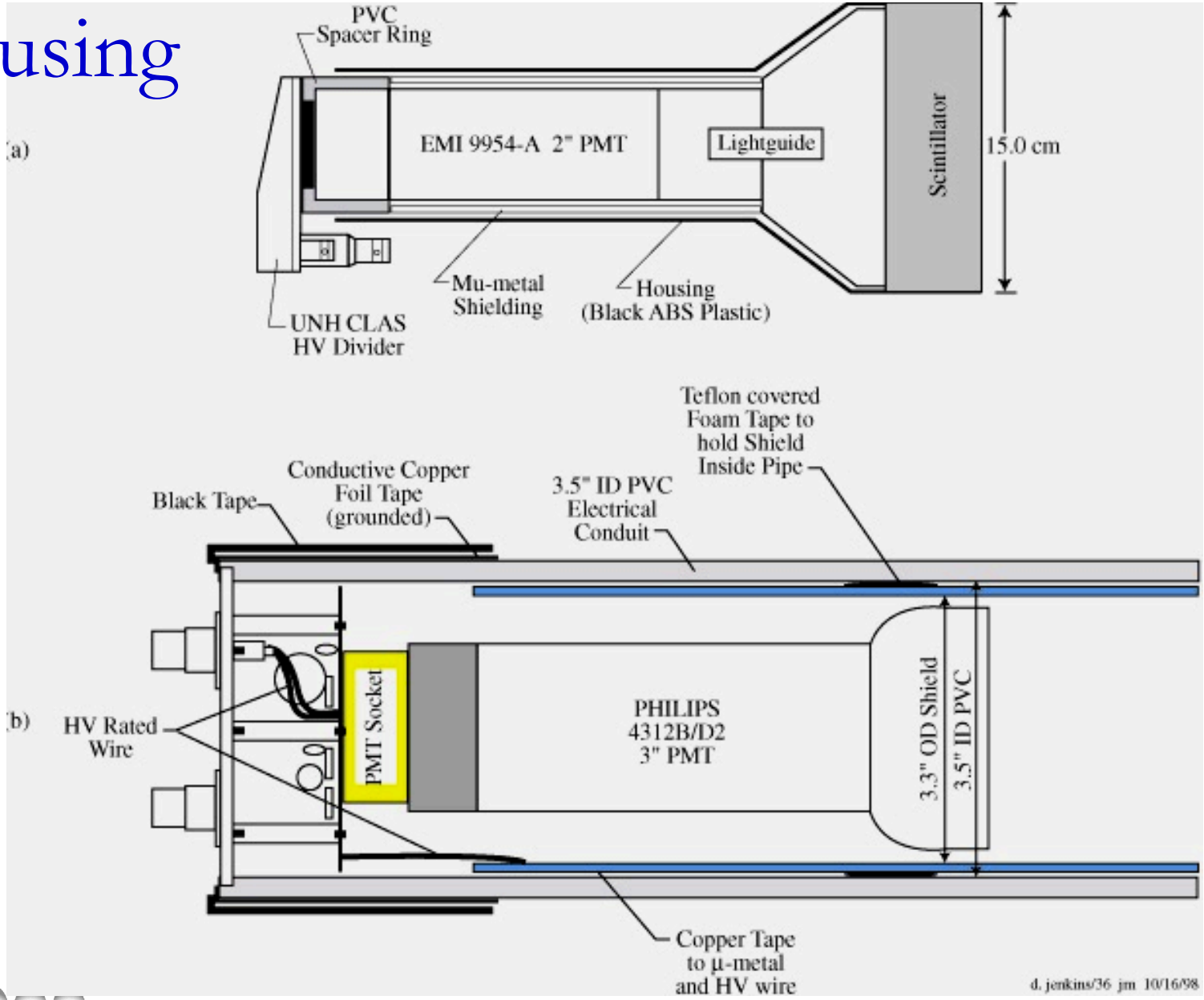


56 AVP pmt

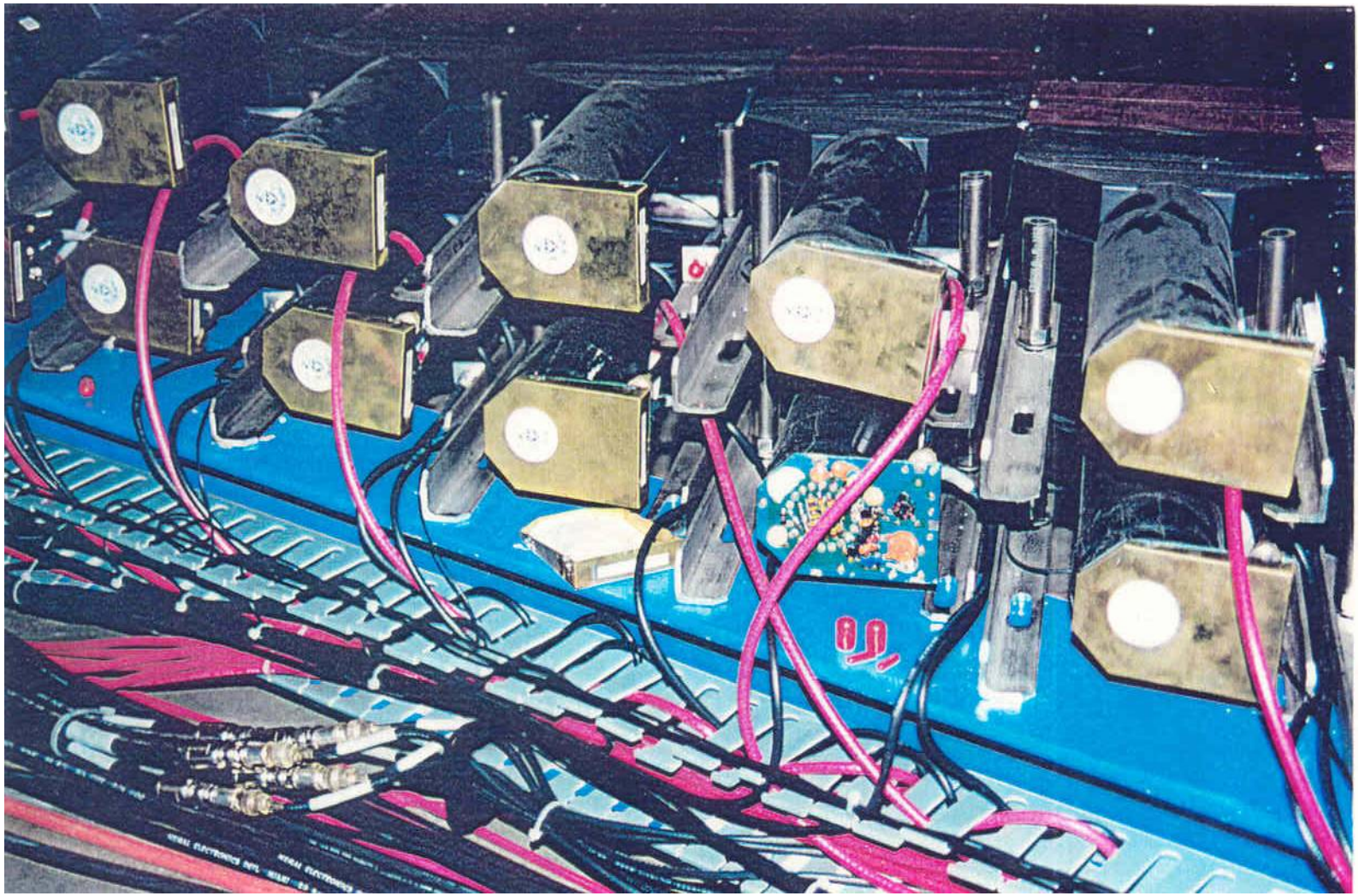
High voltage

- Positive (cathode at ground)
  - low noise, capacitative coupling
- Negative
  - Anode at ground (no HV on signal)
- No (high) voltage
  - Cockcroft-Walton bases

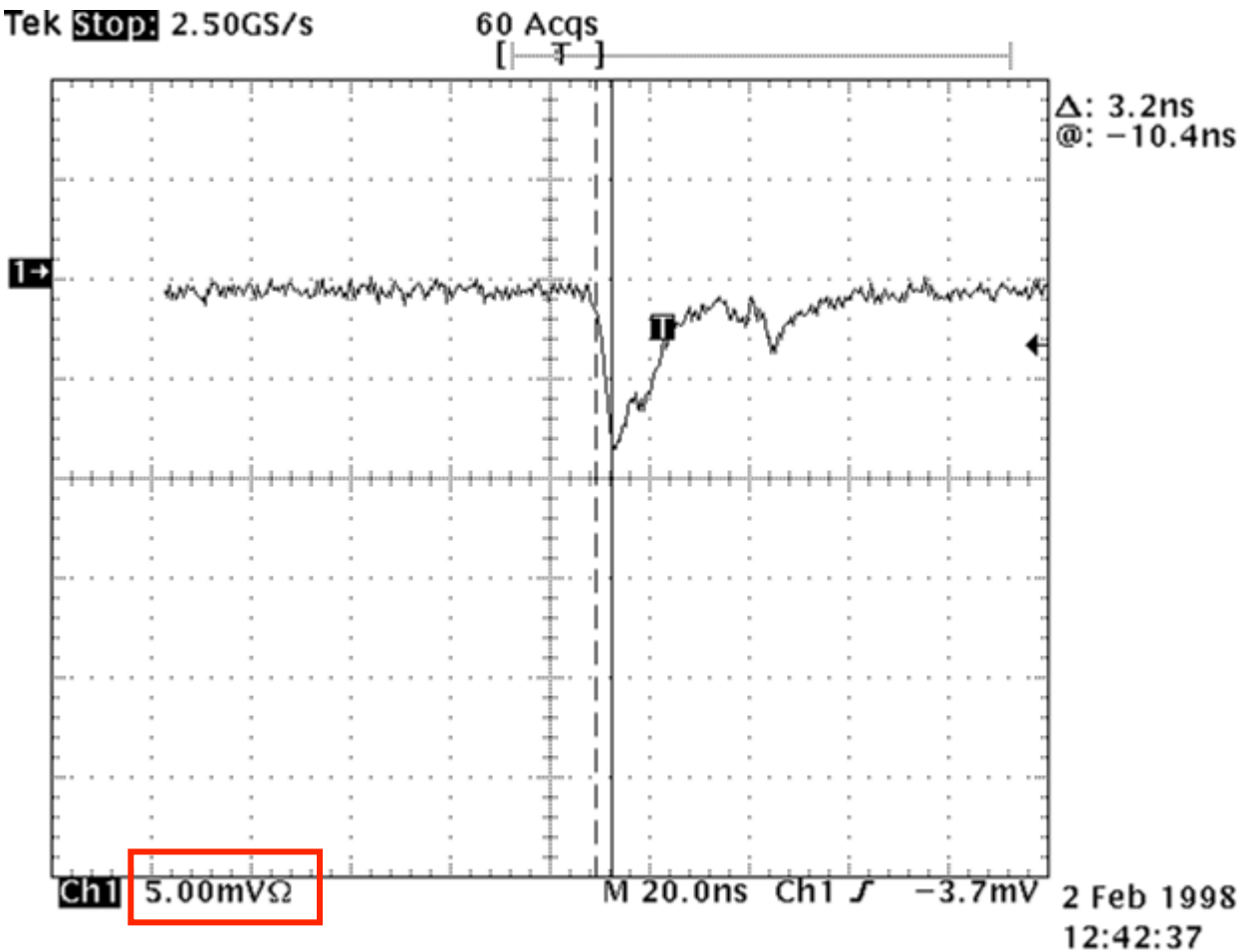
Housing


(a)
PVC
Spacer Ring
EMI 9954-A 2" PMT
Lightguide
Scintillator
15.0 cm
Mu-metal
Shielding
Housing
(Black ABS Plastic)
UNH CLAS
HV Divider
(b)
Teflon covered
Foam Tape to
hold Shield
Inside Pipe
Conductive Copper
Foil Tape
(grounded)
Black Tape
3.5" ID PVC
Electrical
Conduit
HV Rated
Wire
PMT Socket
PHILIPS
4312B/D2
3" PMT
3.3" OD Shield
3.5" ID PVC
Copper Tape
to μ-metal
and HV wire
d. jenkins/36 jm 10/16/98

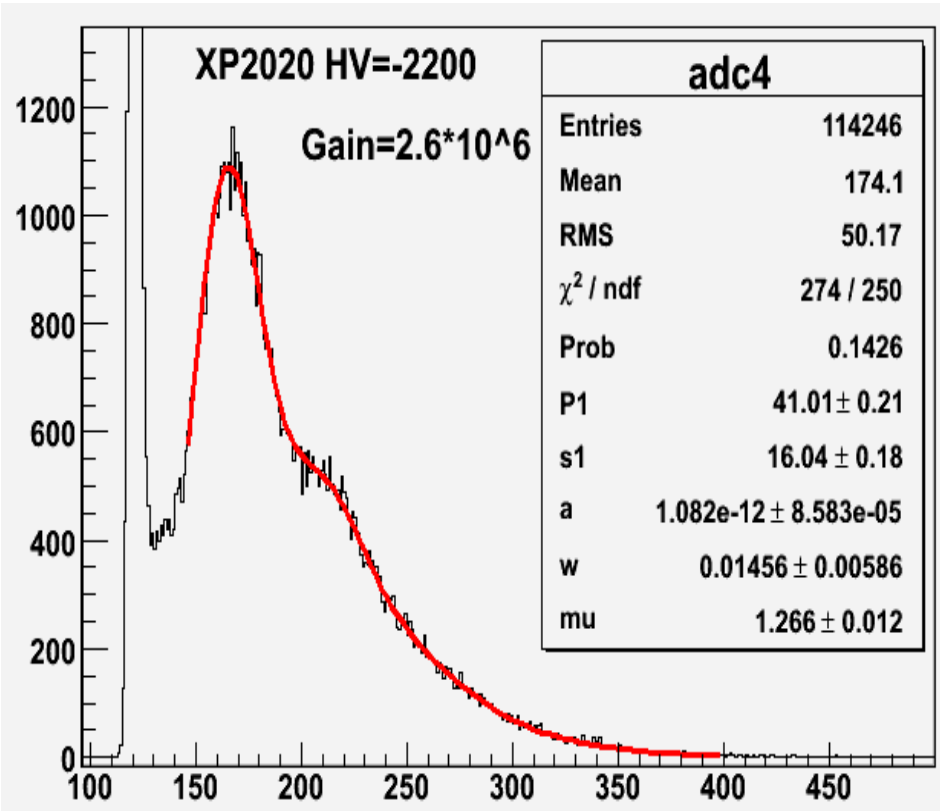
Compact divider design



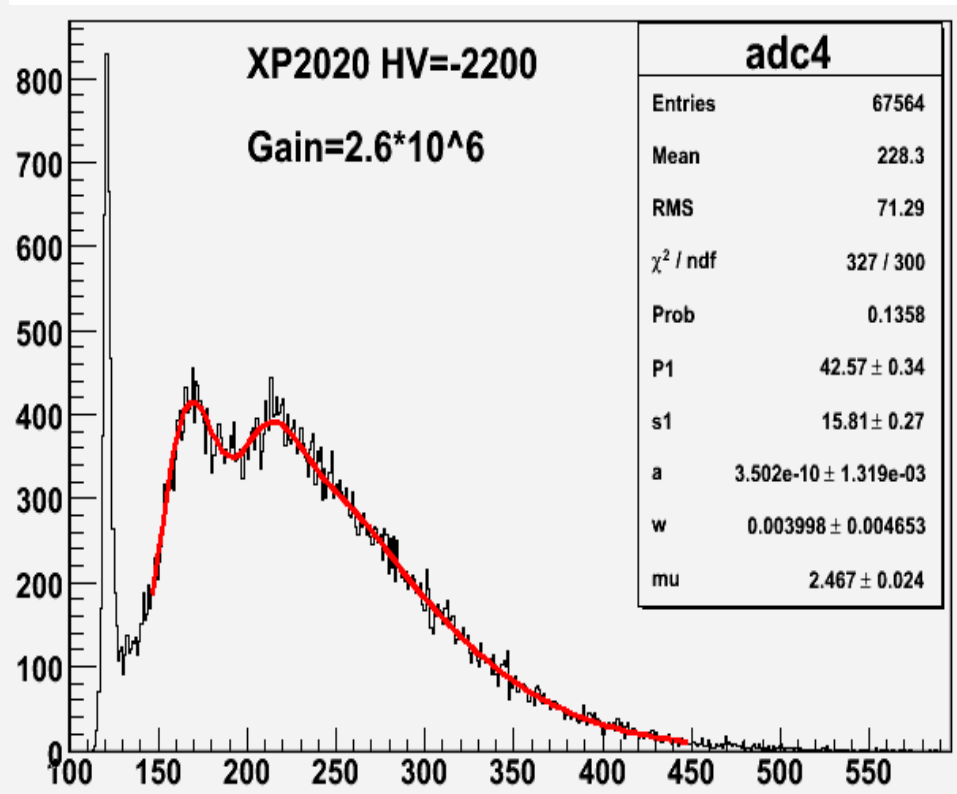
Single photoelectron signal



PMT single p.e. spectra (noise)

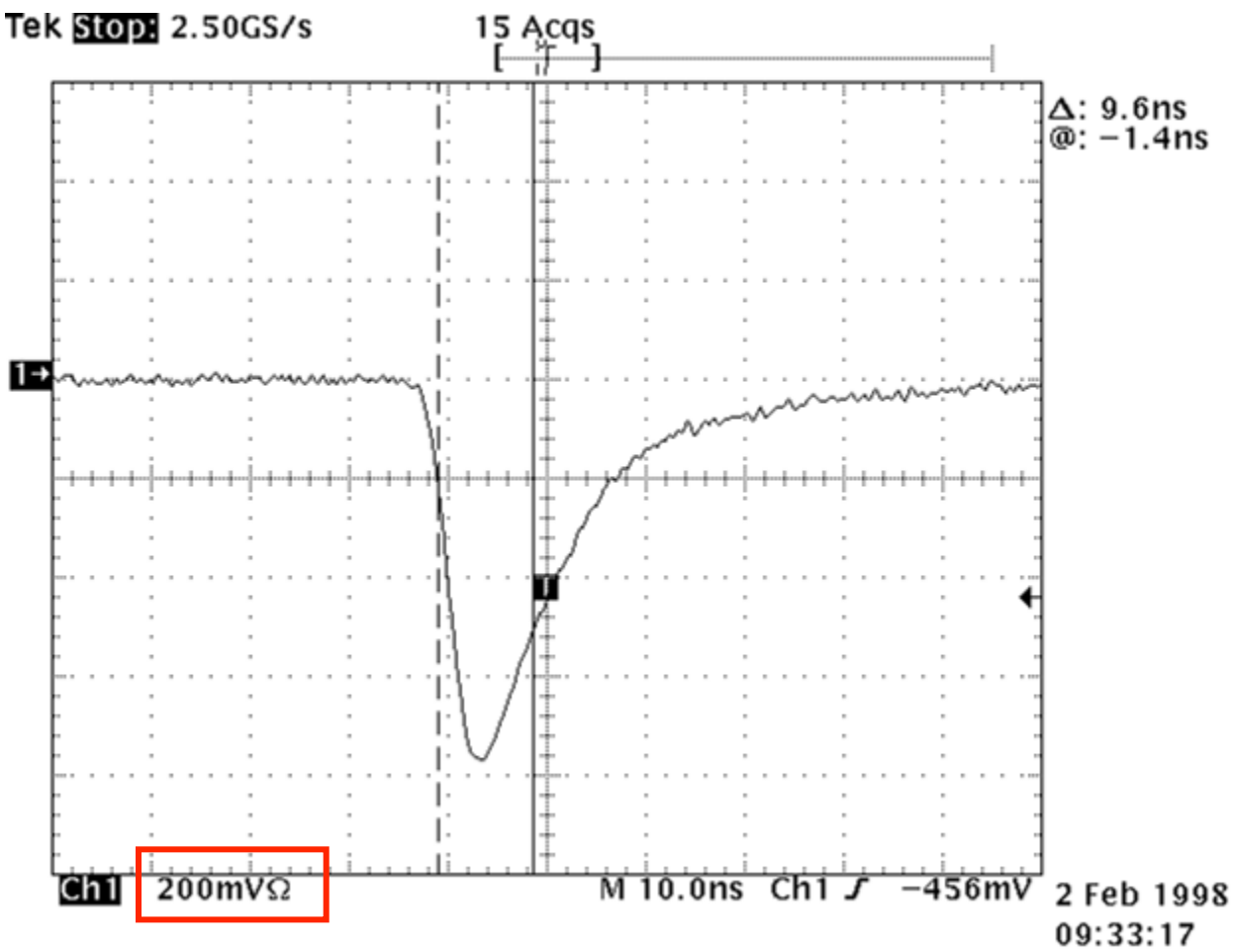


ADC (counts)

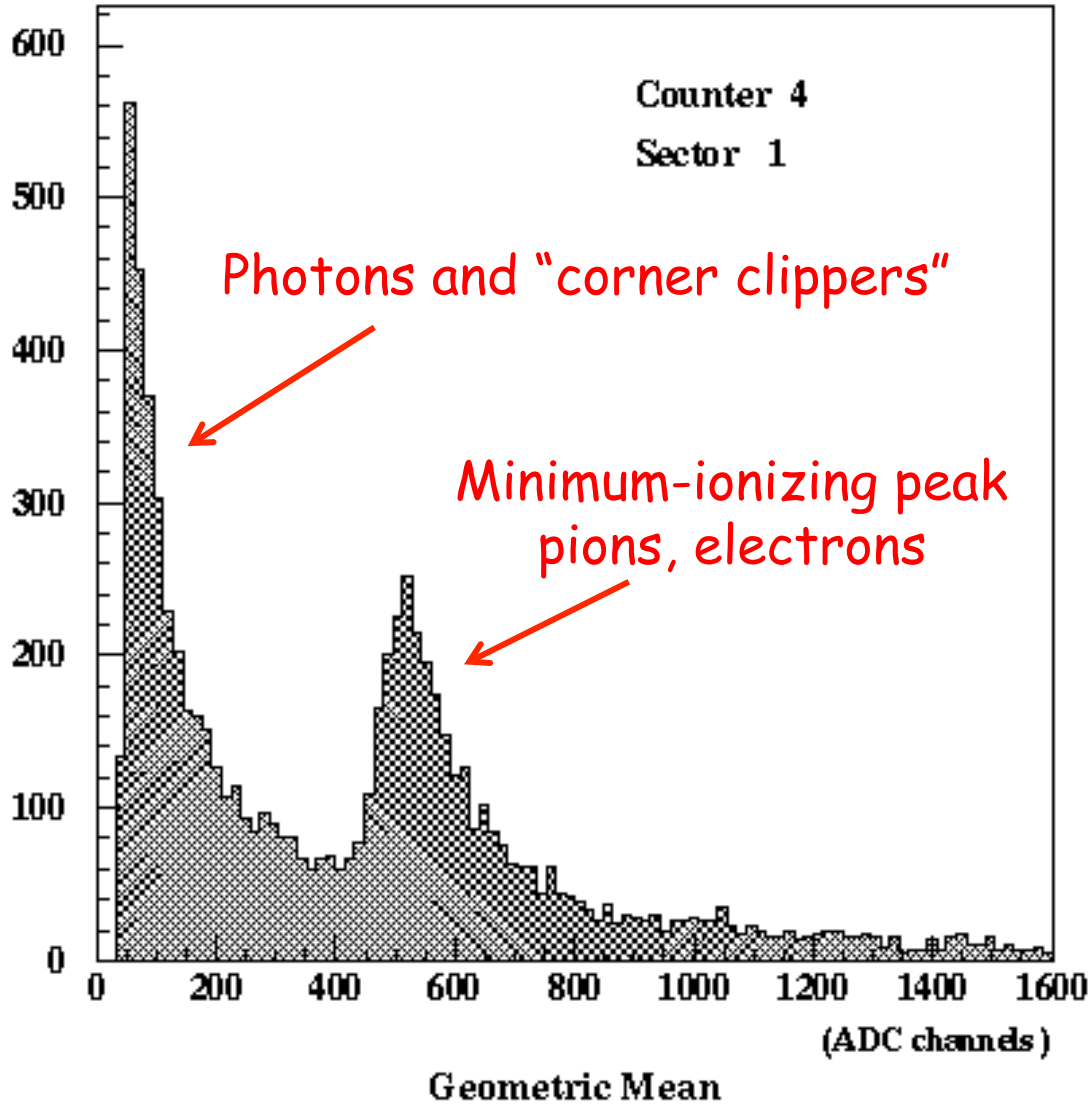


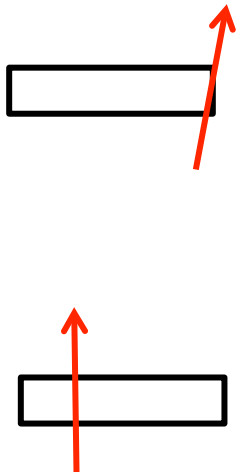
ADC (counts)

Signal for passing tracks



Energy deposited in scintillator





Effect of magnetic field on pmt

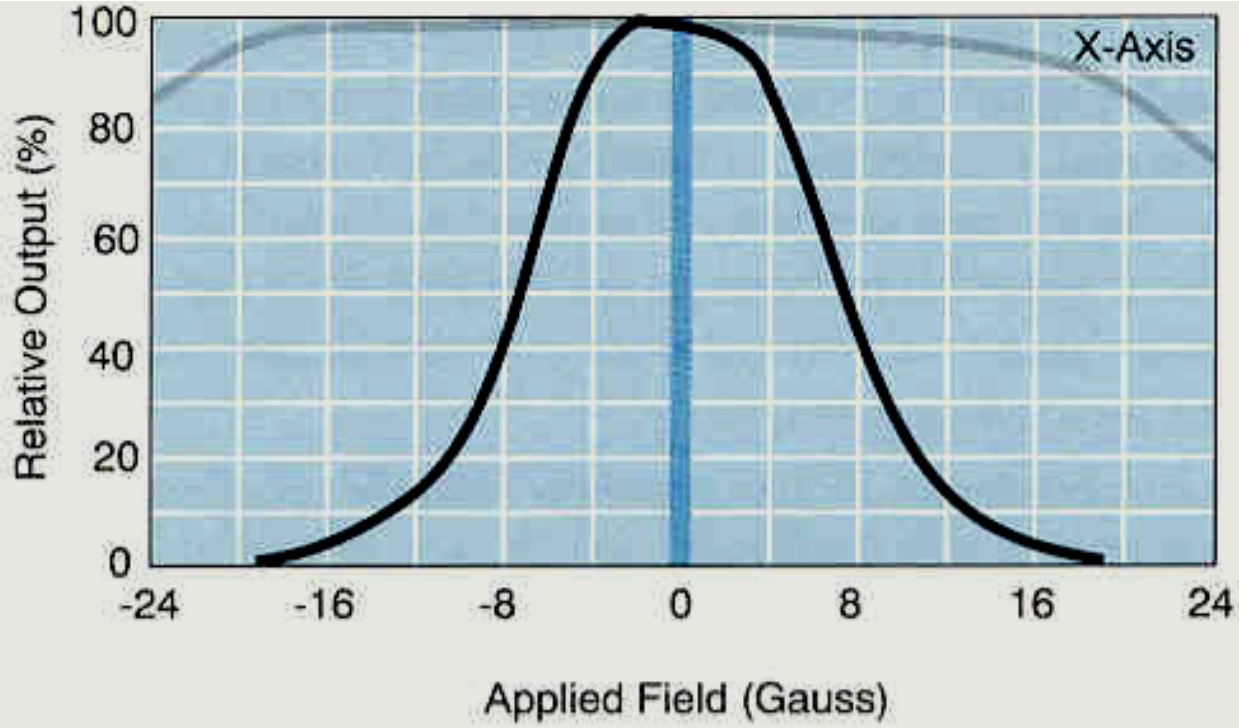


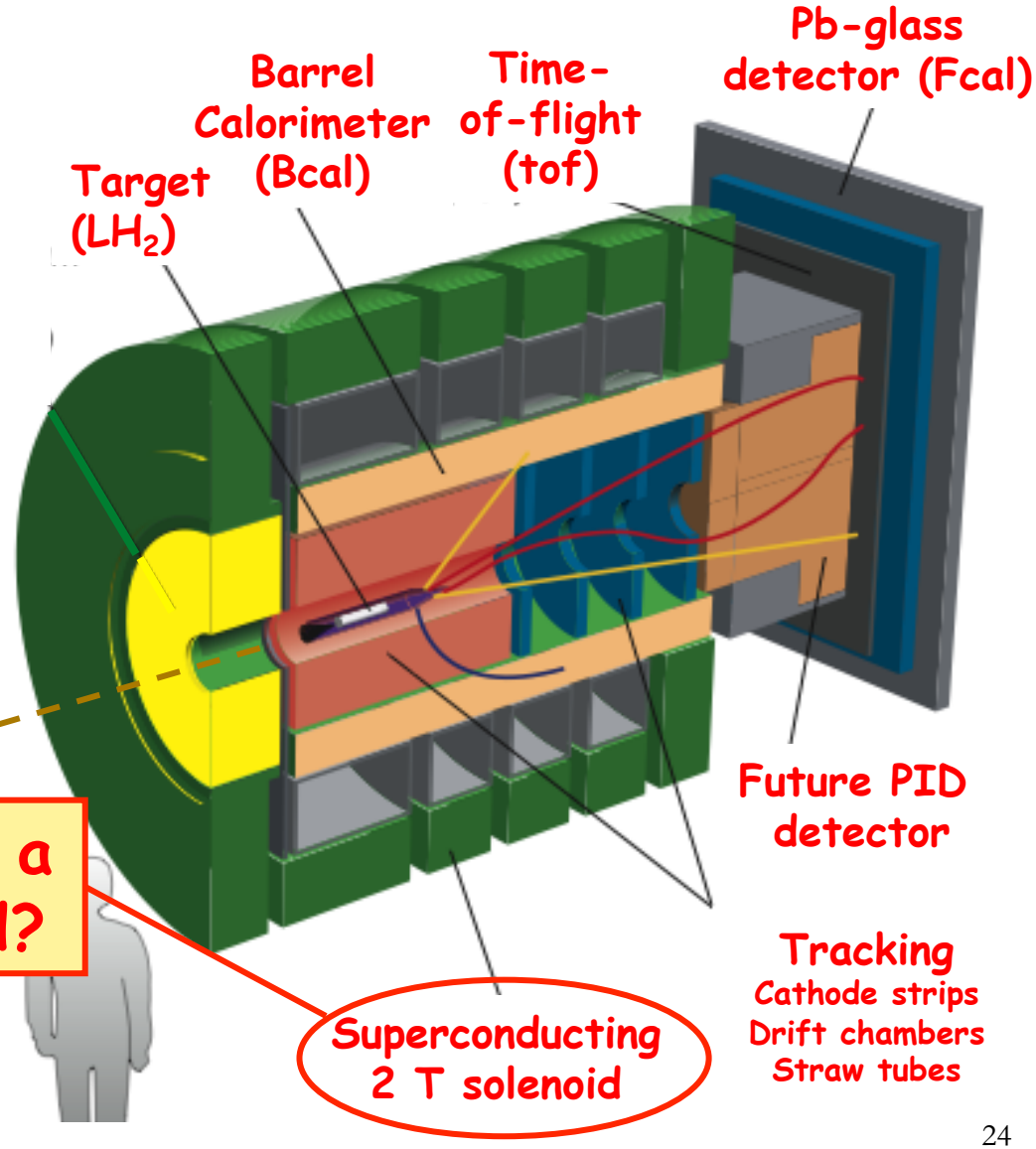
Figure 32

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.

Hall D – GlueX detector

Hermetic detection of charged and neutral particles in solenoid magnet

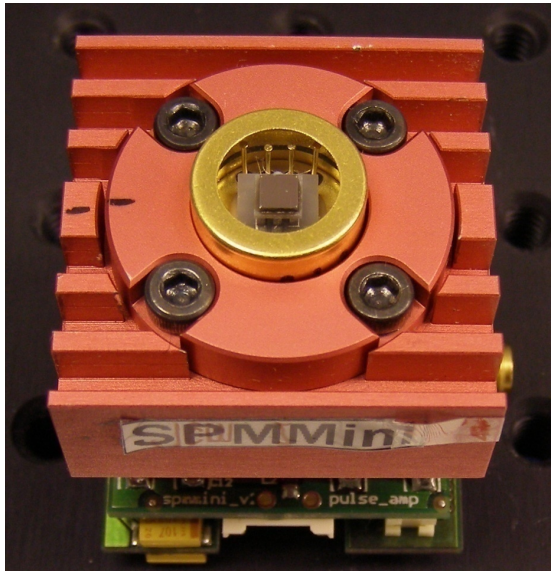
Initial Flux 10^7 γ/s
18,000 FADCs
4,000 pipeline TDCs
20 KHz L1 trigger
300 MB/s to tape

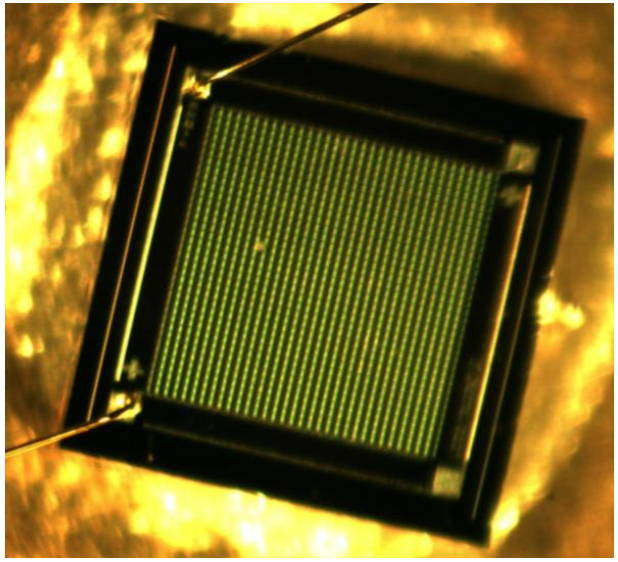


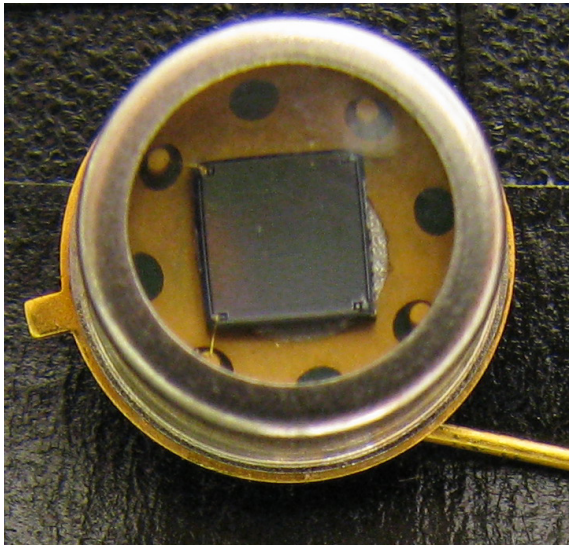
What to do in a Magnetic Field?

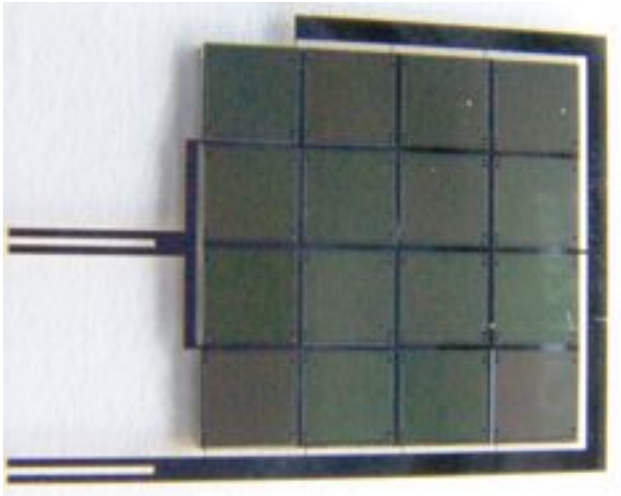
TAGGER S
(UPSTREA

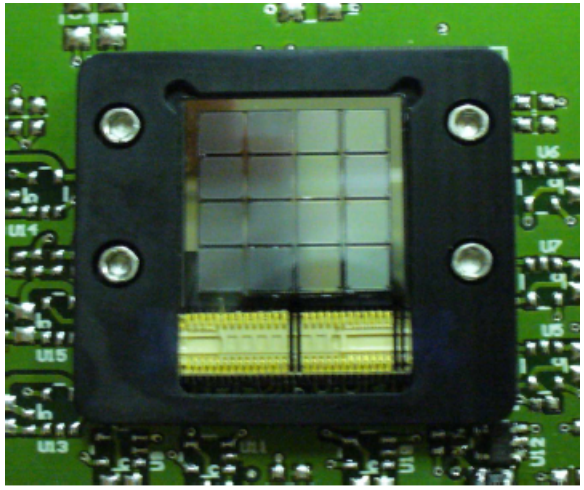
Some history in photos

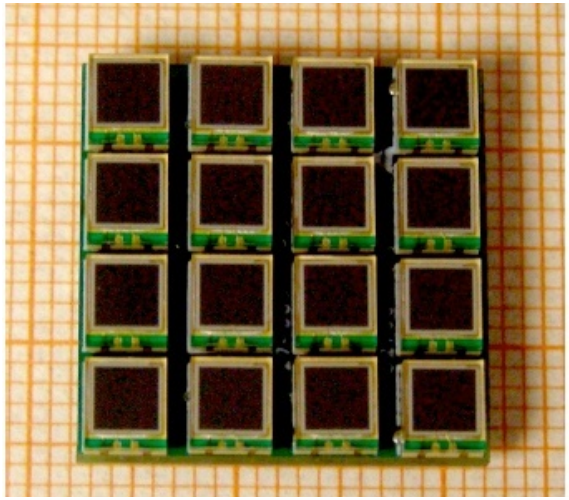




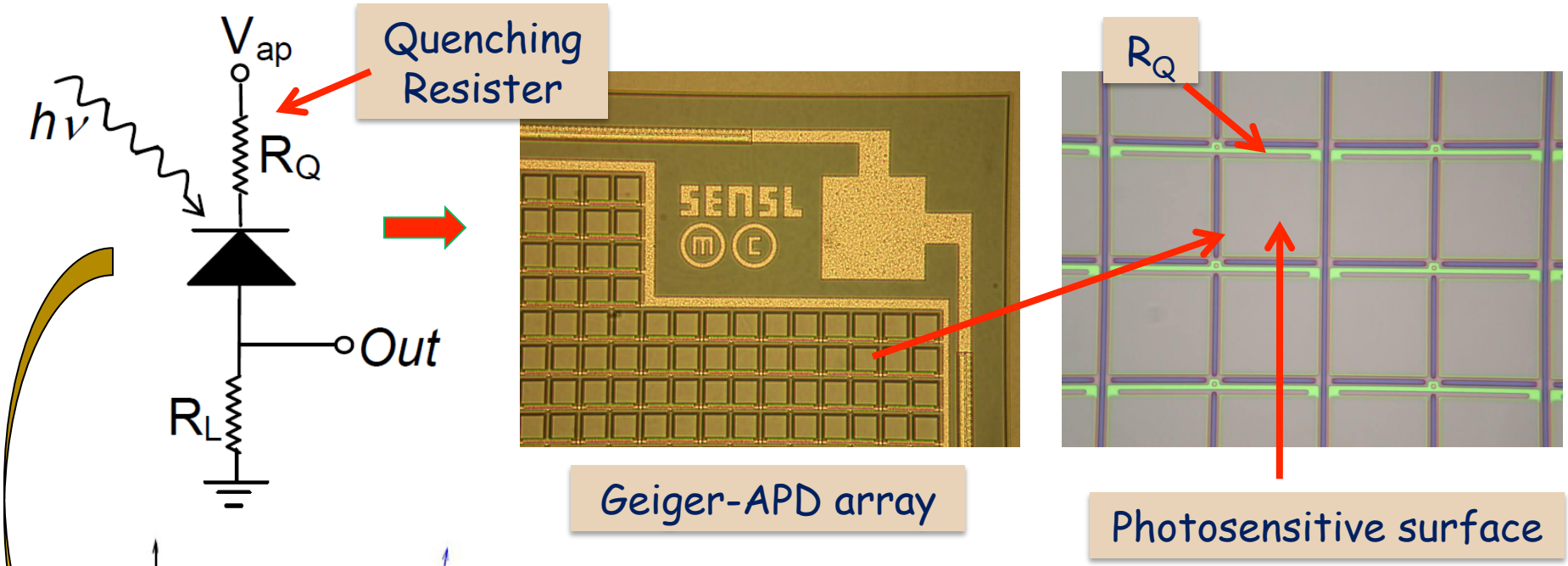


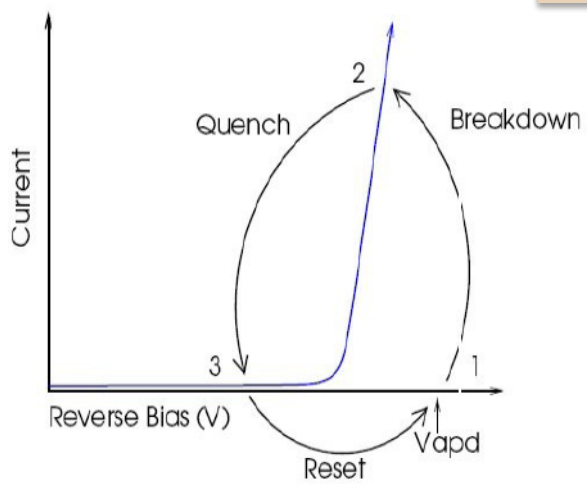






Multipixel Limited Geiger mode APD

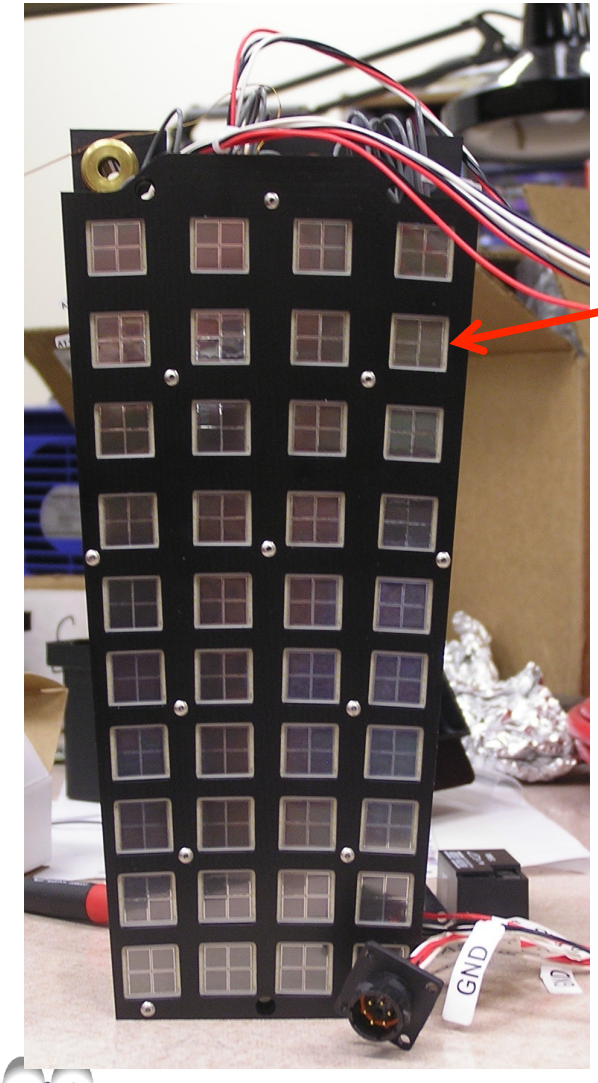




- 20-100 μm Geiger APD pixel
- Incident photon initiates avalanche
- Quenched by resister ➔ device reset
- Sum the pixels -> photon counter

Insensitive to Magnetic Fields!

Hamamatsu S12045 arrays



4x4 array of 3x3 mm^2 sensor

Area = 12.7 x 12.7 mm^2

57600 pixels

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

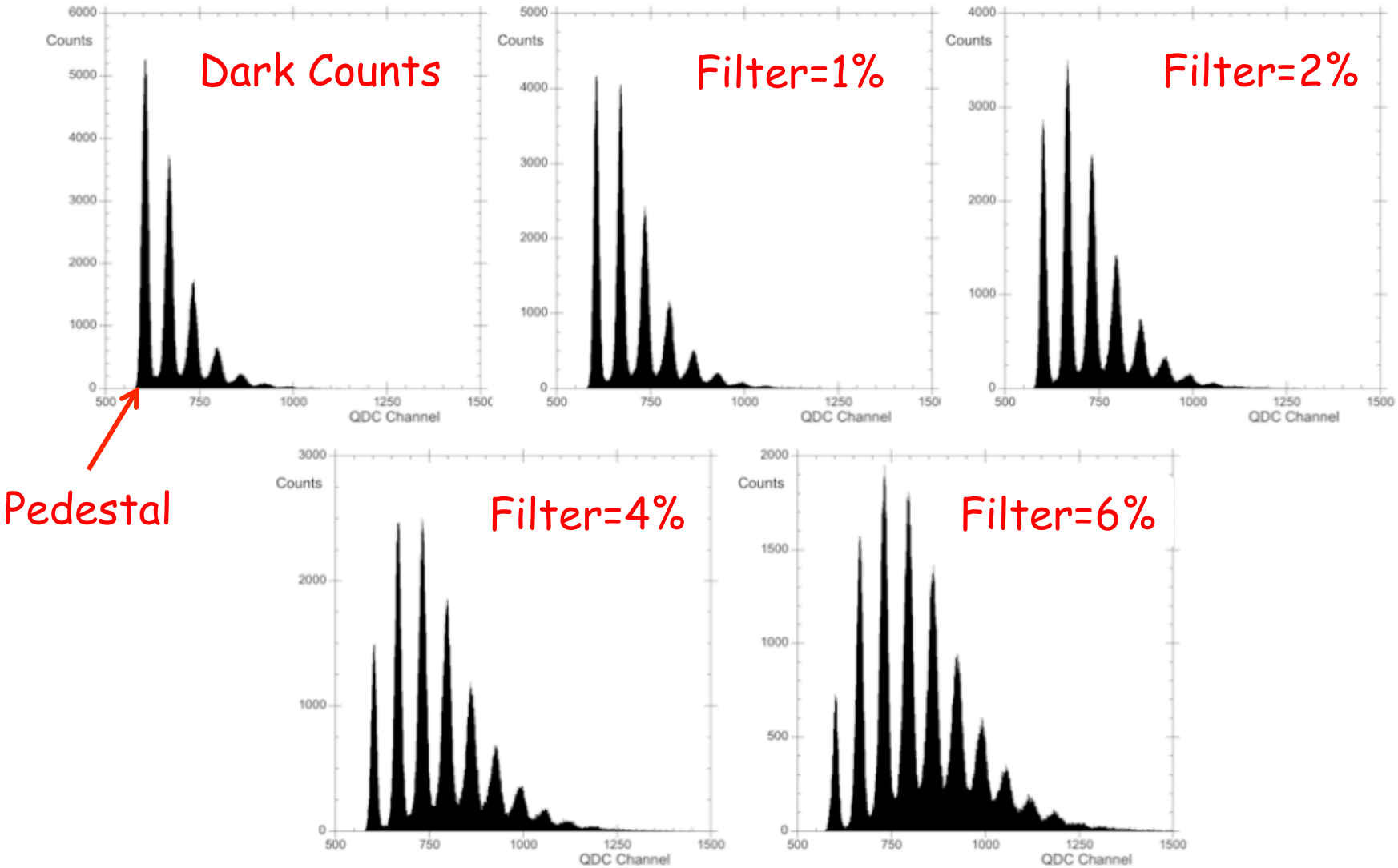
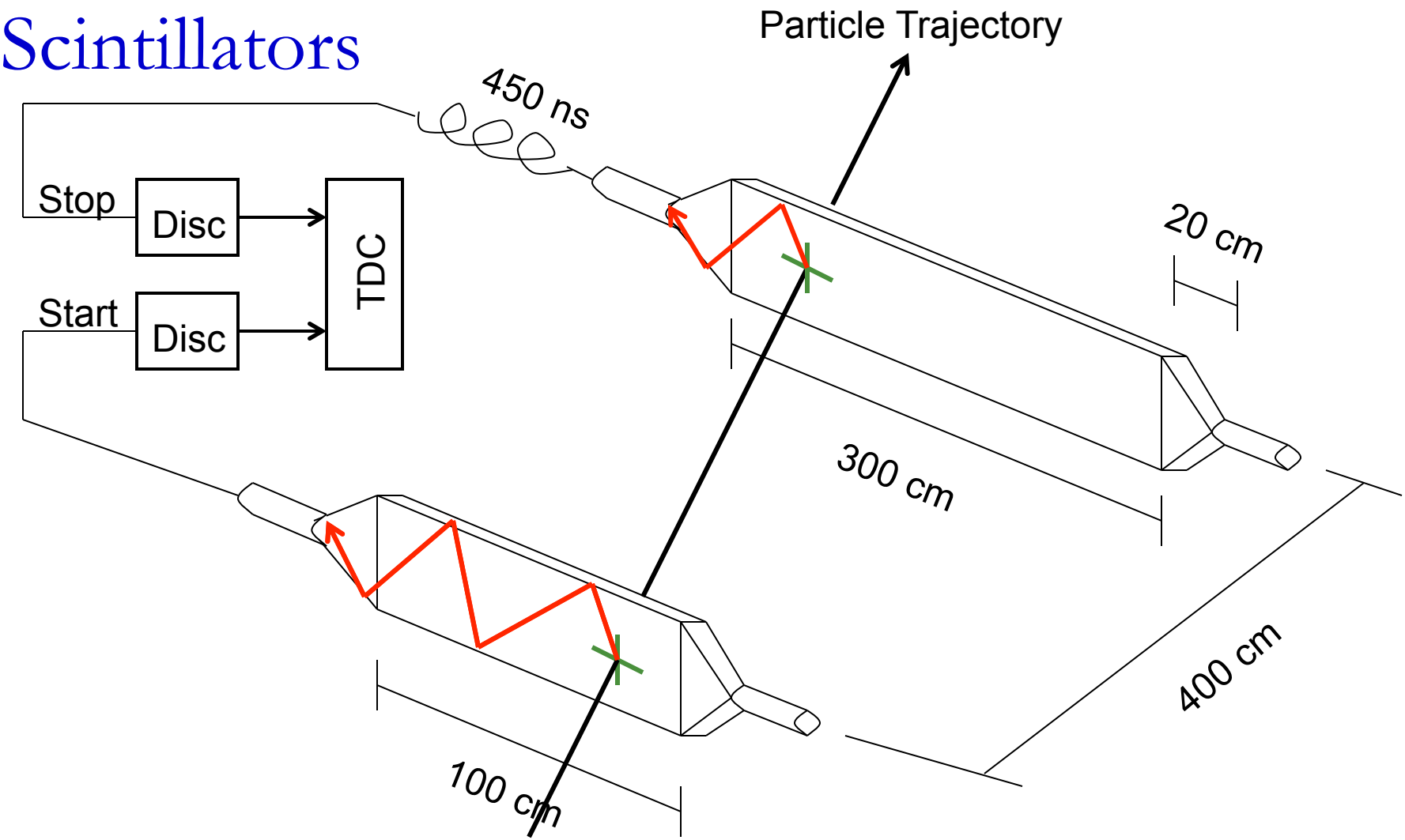
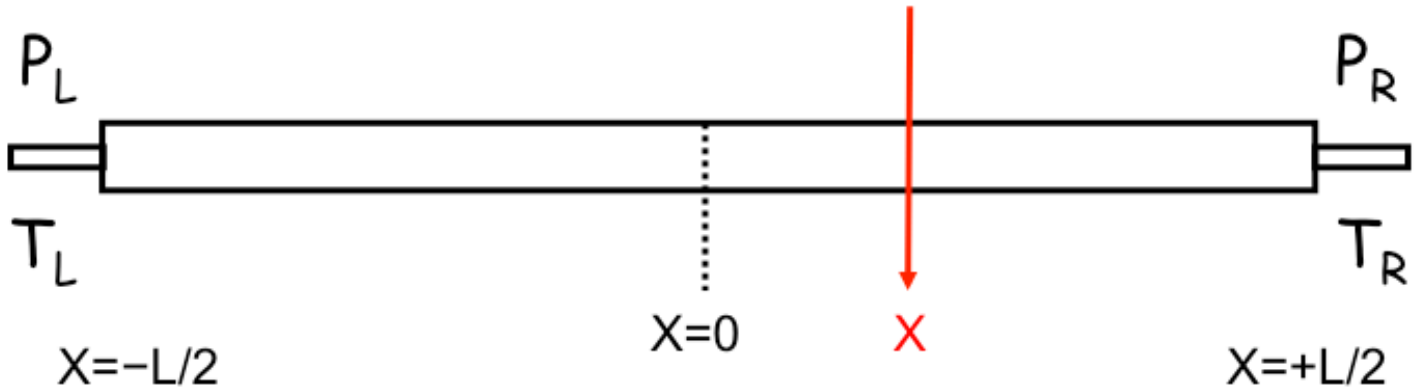


Figure 5: Examples of typical QDC data for one cell (3x3 mm^2) from a SiPM array.

Measure the Flight Time between two Scintillators



Formalism: Measure time and position



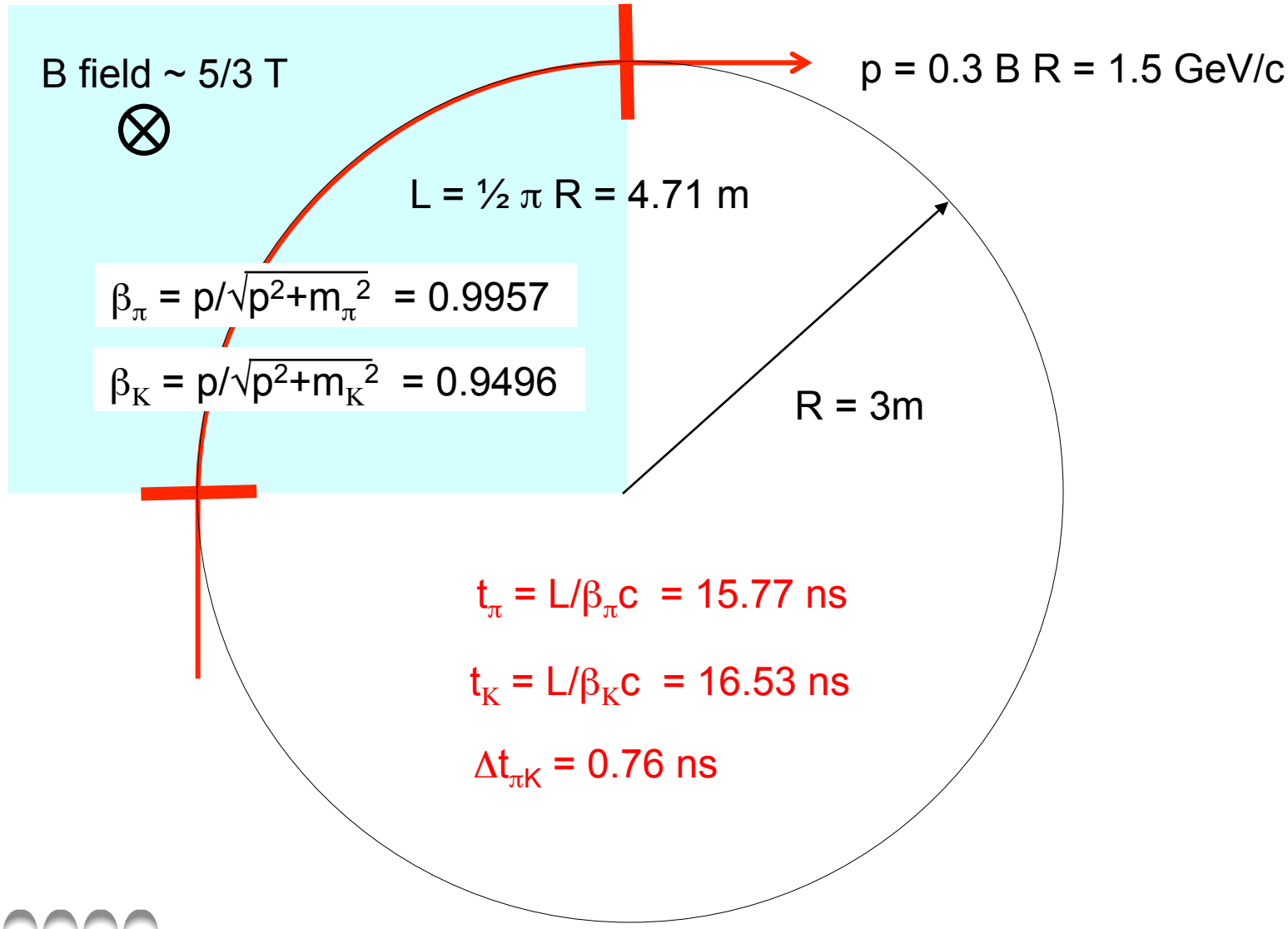
$$T_L = T_L(0) + x/v_{eff} \qquad T_R = T_R(0) - x/v_{eff}$$

$$T_{ave} = \frac{1}{2}\left(T_L + T_R\right) = \frac{1}{2}\left(T_L(0) + T_R(0)\right)$$

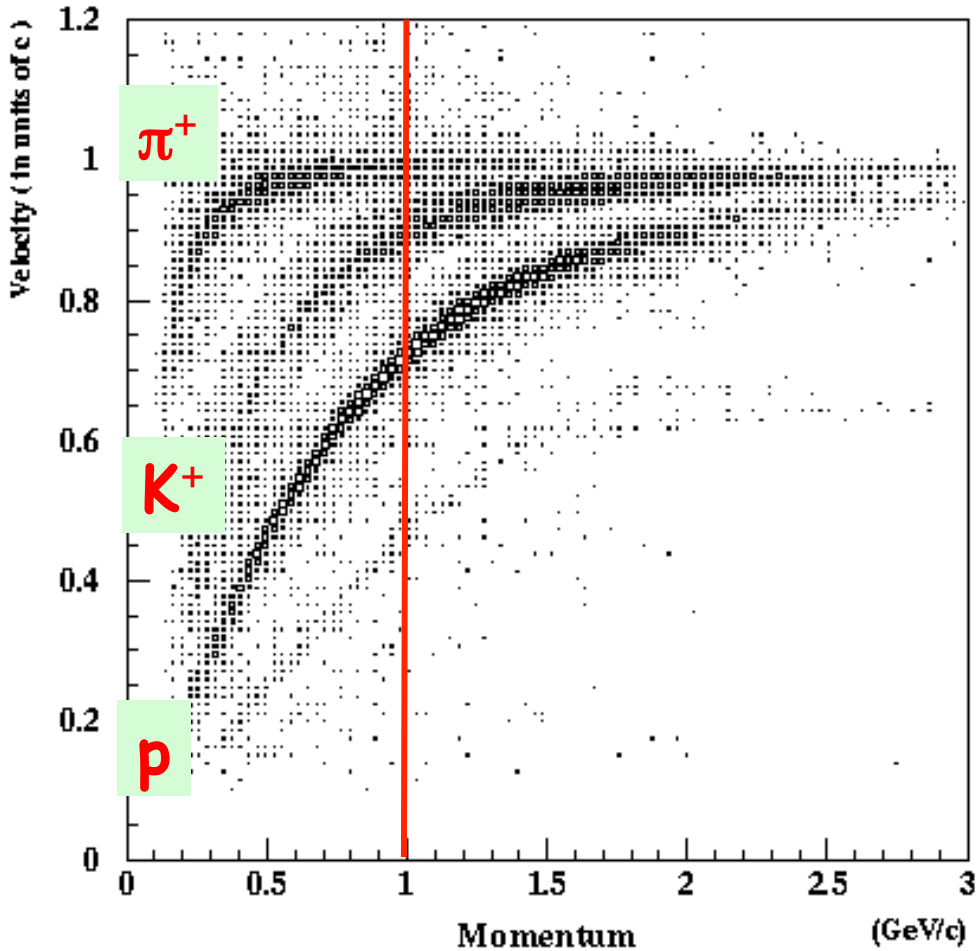
Mean is independent of position!

$$x = \frac{v_{eff}}{2}\left[(T_L - T_R) - (T_L(0) - T_R(0)\right] \rightarrow \frac{v_{eff}}{2}\left[T_L - T_R\right]$$

Experiment basics



Particle ID by "tof": β vs p plot

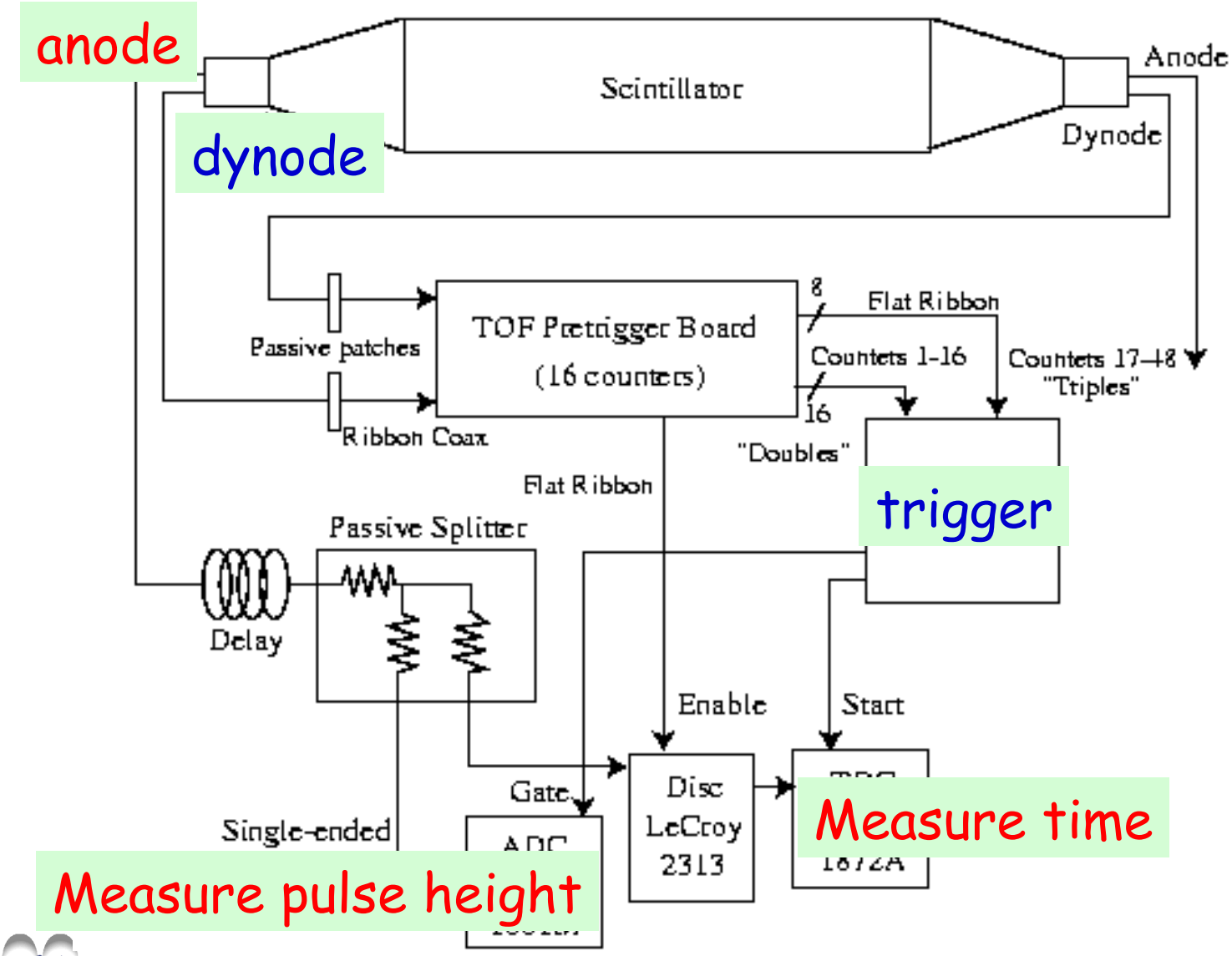


Summary

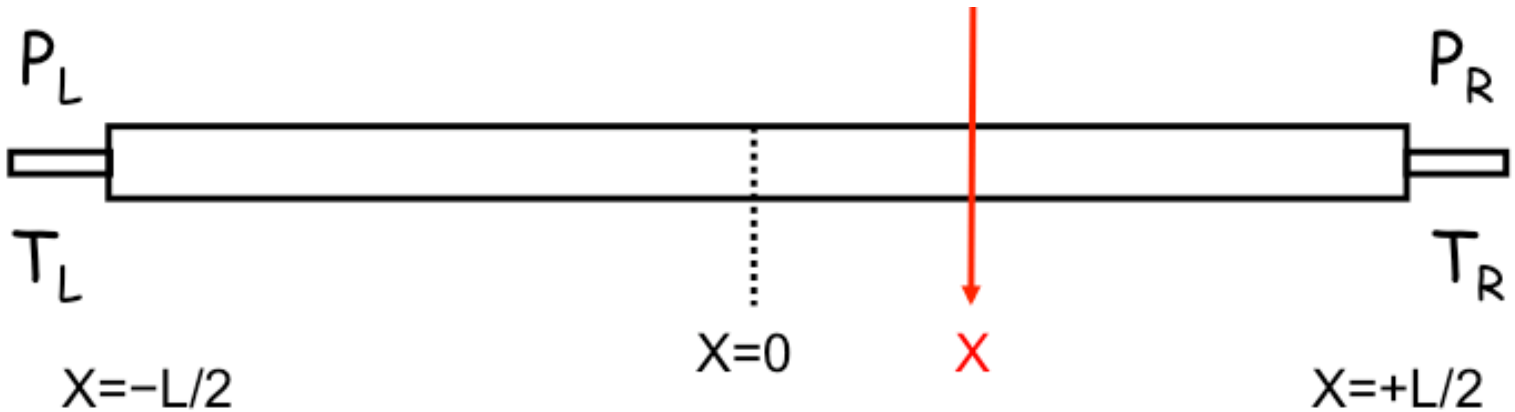
- Scintillation counters have a few simple components
- Trigger and time-of-flight systems are built out of these counters
- Fast response allows for accurate timing
- New solid-state light sensors are now available, which allow use in high magnetic fields
- Combining the timing information from scintillator detectors with momentum measurements from tracking detectors, one can determine the mass of passing particles.

Backup slides

Electronics



Formalism: Measure energy loss



$$\mathbf{P_L = P_L(0)\, e^{-x/\lambda}} \qquad \mathbf{P_R = P_R(0)\, e^{+x/\lambda}}$$

$$\mathbf{Energy = \sqrt{P_L \cdot P_R} = \sqrt{P_L(0) P_R(0)}}$$

Geometric mean is independent of position!

Example: Kaon mass resolution by TOF

$$P_K = 1\ \text{GeV} \qquad E_K = \sqrt{m_K^2 + P_K^2} = \sqrt{0.495^2 + 1} = 1.1161\ \text{GeV}$$

$$\beta_K = \left(\frac{P_K}{E_K}\right) = 0.896 \qquad \gamma_K = \left(\frac{E_K}{m_K}\right) = 2.26$$

For a flight path of d = 500 cm

$$t_K = \left(\frac{500\ \text{cm}}{0.896 \cdot 30\ \text{cm/ns}}\right) = 18.6\ \text{ns}$$

Assume experimental resolutions of

$$\delta t = 0.15\ \text{ns} \qquad \frac{\delta p}{p} = 0.01$$

$$\left(\frac{\delta m}{m}\right)^2 = 2.26^4 \left(\frac{0.15}{18.6}\right)^2 + (0.01)^2 = 0.042^2 \quad \rightarrow \delta m_K \approx 21\ \text{MeV}$$

$$\left(\frac{\delta m}{m}\right) \rightarrow \infty \quad \text{for } p \rightarrow \infty \text{ and fixed } \frac{\delta\beta}{\beta}$$