Chapter 3

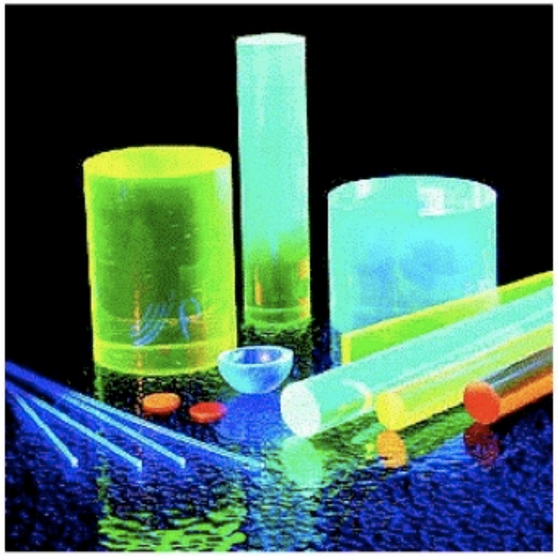
Particle Detection and Detector Layout

Basic considerations

Need to convert the presence of a particle into a measurable signal!

Historically: Angular distributions in scattering experiments measured by detecting light flashes with the human eye

1919 Evidence for hard nucleus in atom
Rutherford et al.



Visible light:

$E_{vis.light} \approx eV \Rightarrow$ Light creation by low energy parts of particle cascade

How is the light produced?

Scintillators

Convert dE/dx →Photons (light)

Anorganic:

High Z
High absorption for γ

Simple crystal structure

Radiation hard

EM-calorimetry

Compact (X_0, R_M)

Organic:

Low Z
Low absorption for γ

Complex organic molecules

Less radiation hard

Trigger, hodoscope

Charged particles, neutrons

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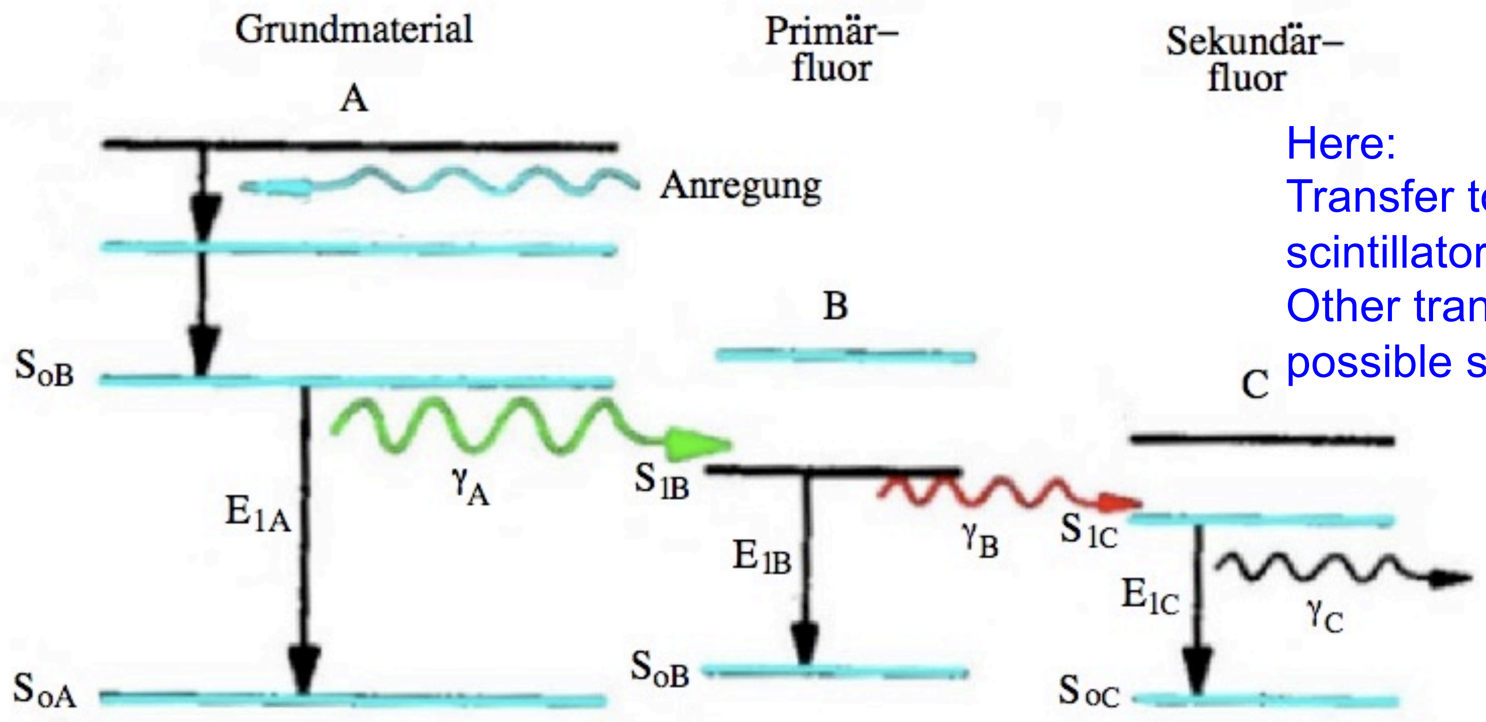
Multicomponent scintillator

Combine different materials to optimise light yield of scintillator
Avoid identical absorption and emission levels



Here:
Transfer to primary scintillator by radiation
Other transfer mechanisms possible see literature

Requirements to additional component(s):

- Good solvability in ground material
- large fluorescence yield
- Absorption edge of component = Emission edge of ground material

Detectors based on semi-conduction

Employed in: High precision gamma spectroscopy
Measurement of charged particles with E < 1 MeV

Vertex finding, I.e. determining the interaction of a high energy reaction ...

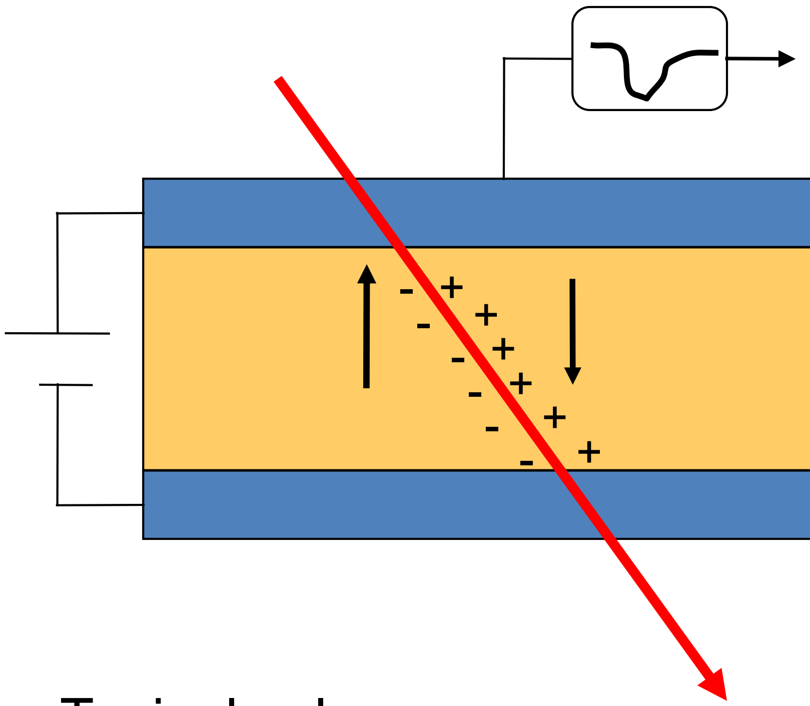
... but also in modern calorimeters

Takes relatively small energy deposition to create a signal

Comparison: O(100 eV) to create a γ-quant in a scintillator
3.6 eV to create a electron-hole pair in silicon

Principle of particle detection

Base material e.g. Si
doted with e.g. As → n-doted (Donator)
B → p-doted (Acceptor)



Typical values:
Dotation $N_D = 10^{12}$ cm^{-3}, $N_A=10^{16}$ cm^{-3}
Extension of depletion zone 300 μm
Specific resistance of depletion zone 10kΩm

Ionization of the detector material - Bethe Bloch

Charge collection in an electrical field

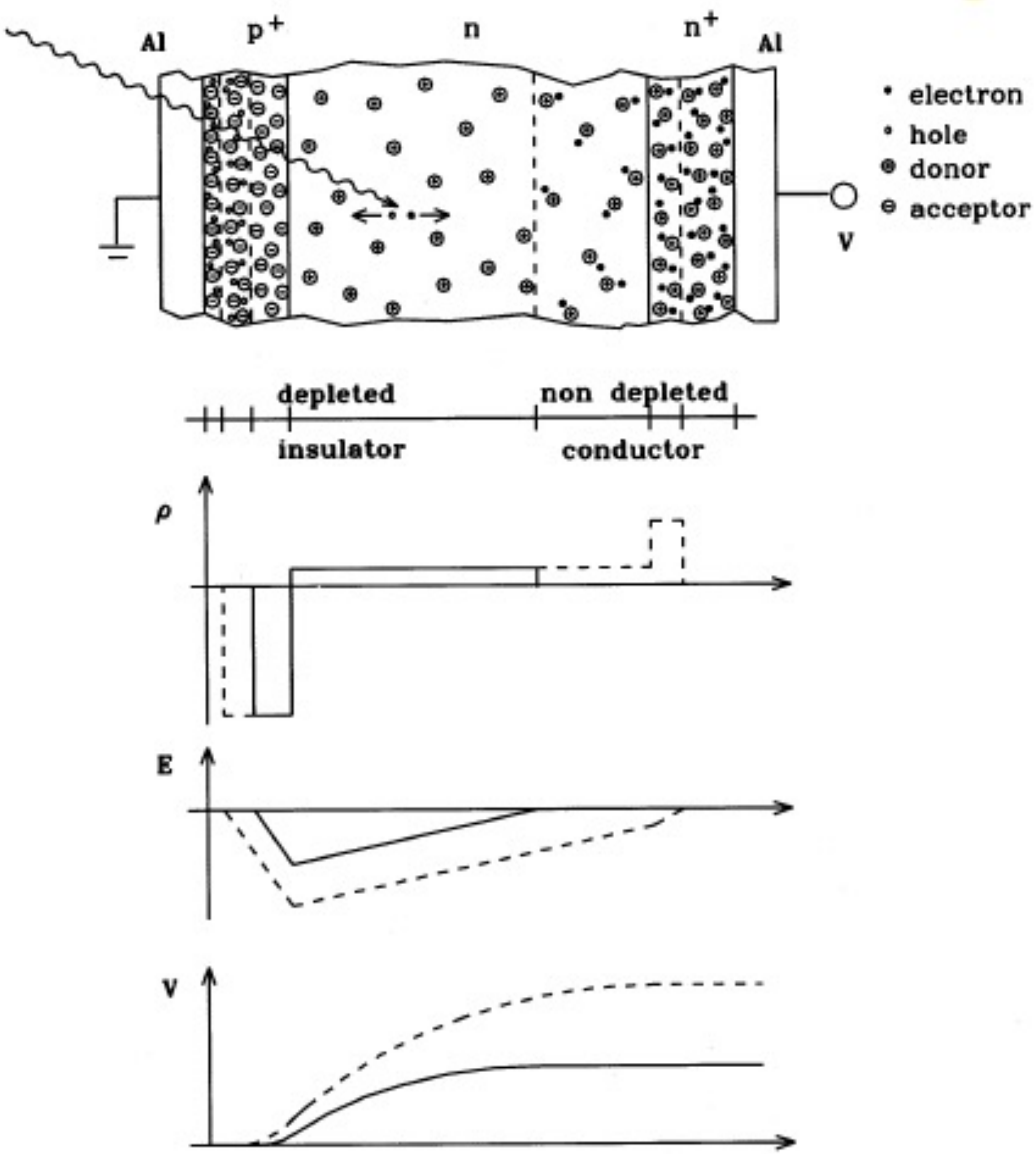
(E-Field extends over depletion zone, capacitance)

Electronic amplification and measurement of the signal

Number of charges is proportional to deposited energy

Segmentation of electrodes allows for high spatial resolution

pn-transition in reverse biasing mode



- Semiconducting detectors based in pn-transition which is connected in reverse-biasing

- E-Field is given by Poissonian Equation

$$\frac{d^2\phi}{dx^2} = \frac{e}{\varepsilon\varepsilon_0}(N_A - N_D + x_p - x_n)$$

N_A = Acceptor Concentr.
N_D = Donator Concentr.
x_p = Thickness of depletion region p+-side
x_n = Thickness of depletion region n-side

Linear in region of depletion zone

- For a highly doted p type layer on a n-type substrate the total thickness of the depletion zone is given by

$$x_n + x_p \approx \sqrt{\frac{2\varepsilon\varepsilon_0}{eN_D}V}$$

V = Bias Voltage

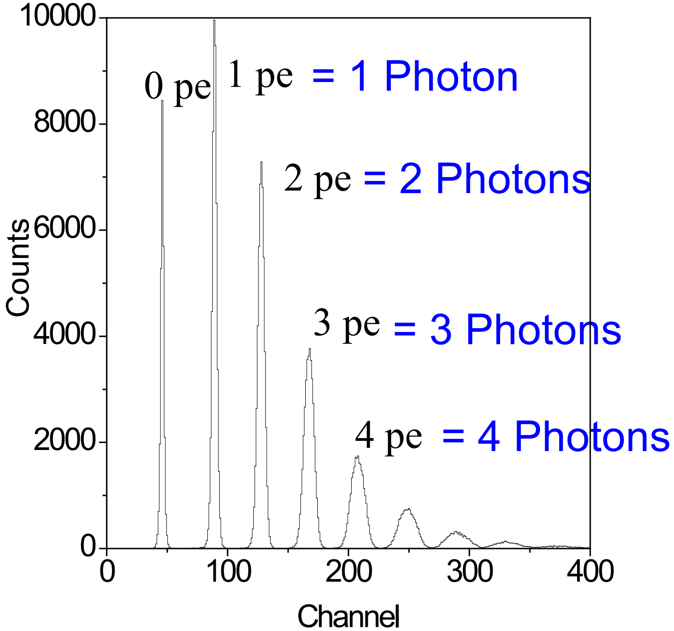
- Dark current by thermal fluctuations

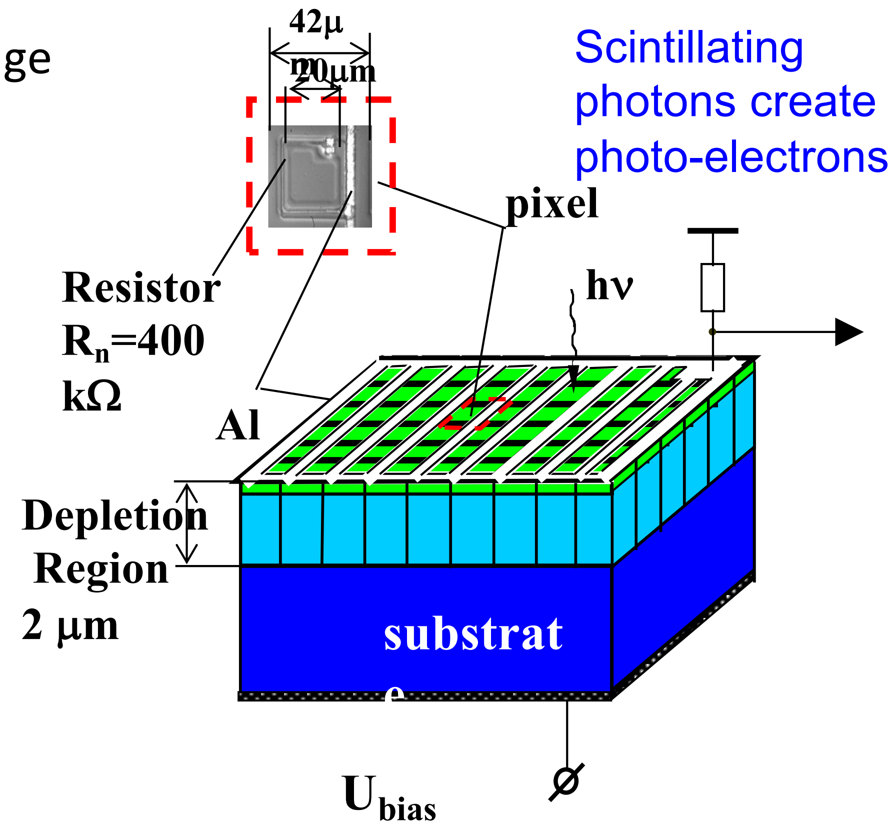
Silicon photomultipliers

- A pixelated solid state Geiger counter (semi-conducting)
  - 1000 pixels on 1mm^2
  - Gain 10**6, efficiency 10..15%
  - At 50 V typical bias voltage

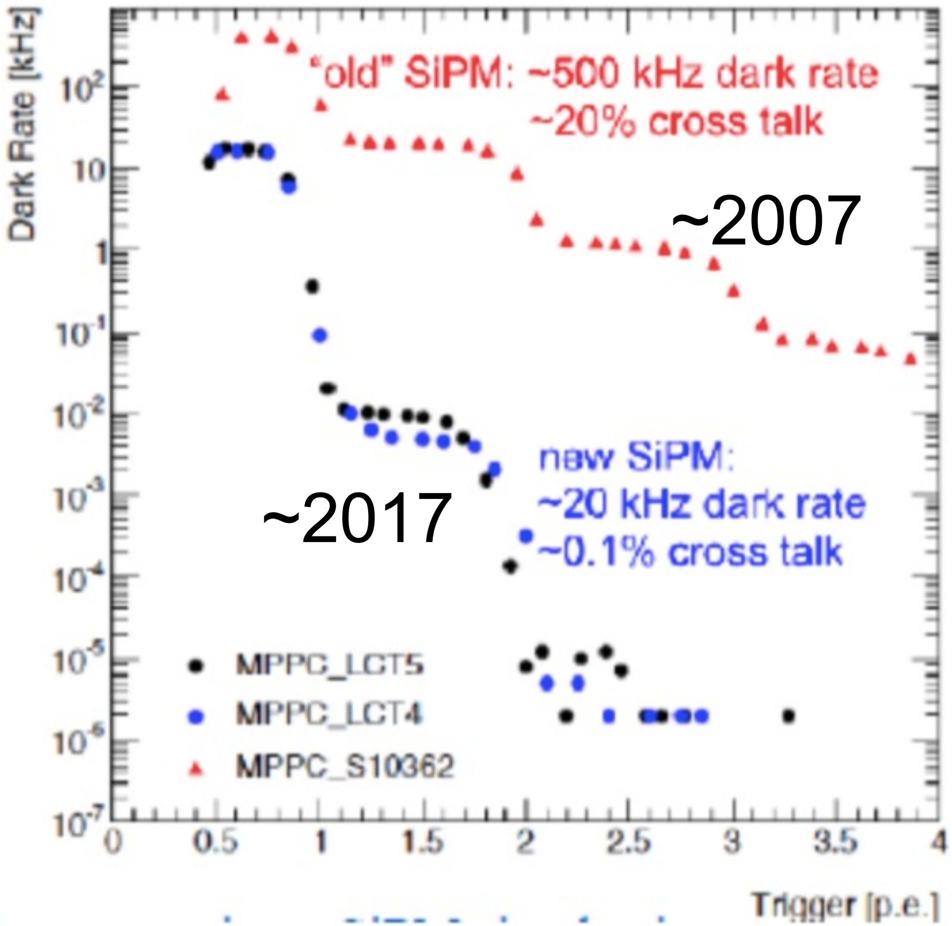
Single photon signals

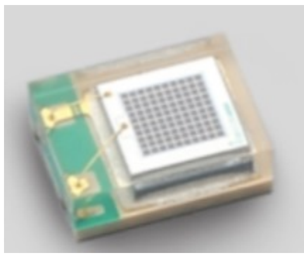
Signal - analog sum





Silicon photomultipliers cnt'd

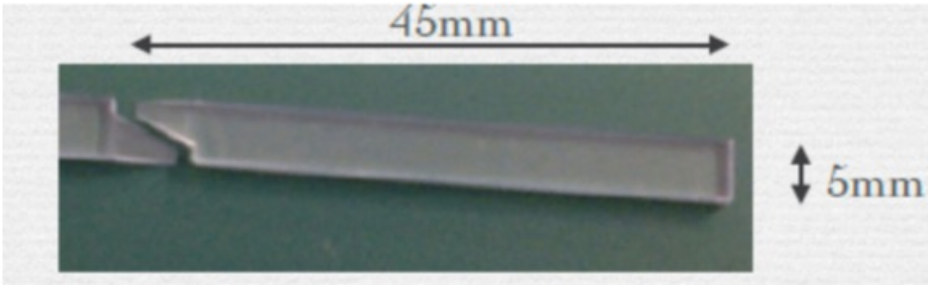




Huge step in quality of SiPM in last decade
- ~Since 2003 MePHI/Pulsar (RU)
- ~Since 2006 Hamamatsu
- Recently Chinese producers

Silicon photomultipliers have many applications Inside and outside of particle physics

- Calorimeters for future e+e- colliders Tile Hcal, Dual readout, Scintillator Ecal

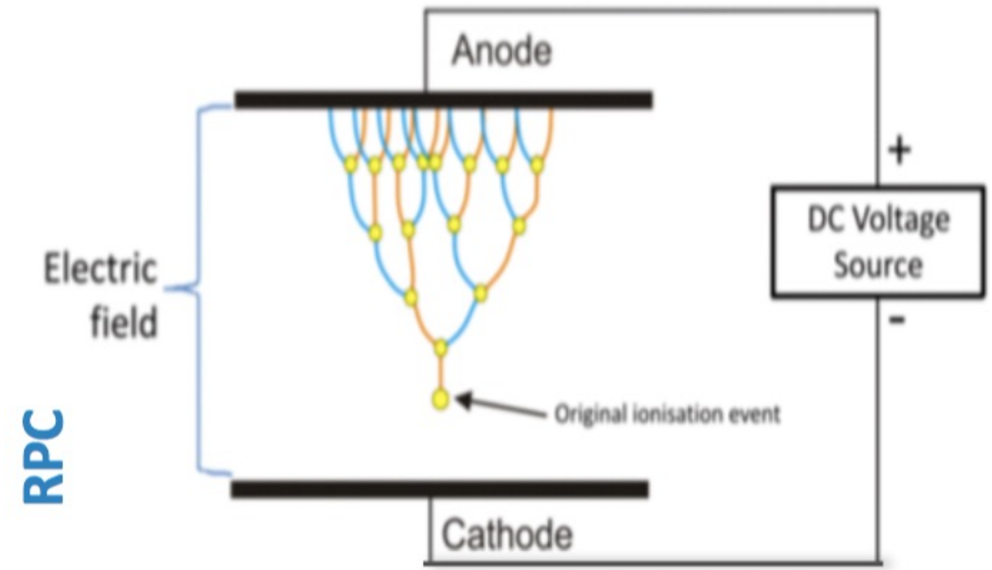


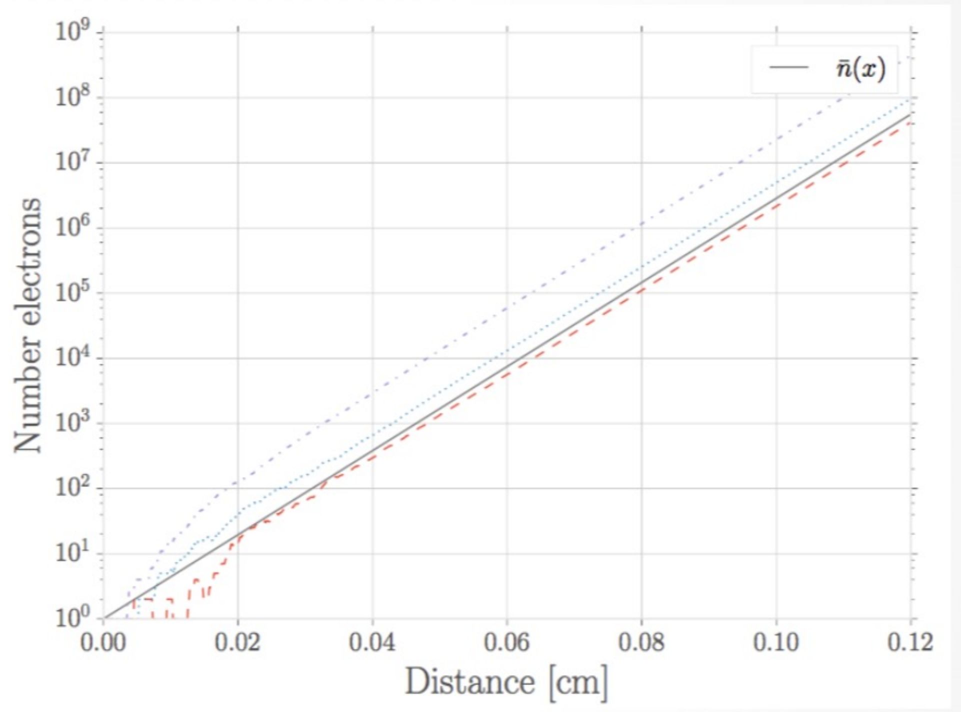
- HL-LHC Calorimeters

- Medical applications e.g. Endoscopy

Gaseous materials - RPC

RPC = Resistive Plate Chamber





D. Boumediene

- Primary Ionization in gas volume
- Acceleration in strong electric field (typically 5-10 kV between cathode and anode)

⇒Lots of secondary ionisation

⇒Measurable charge

RPC cont'd

Why Resistive Plate Chambers

-High Efficiency
-Linearity
-Low background

} -> energy resolution

-Well contained avalanches -> fine granularity

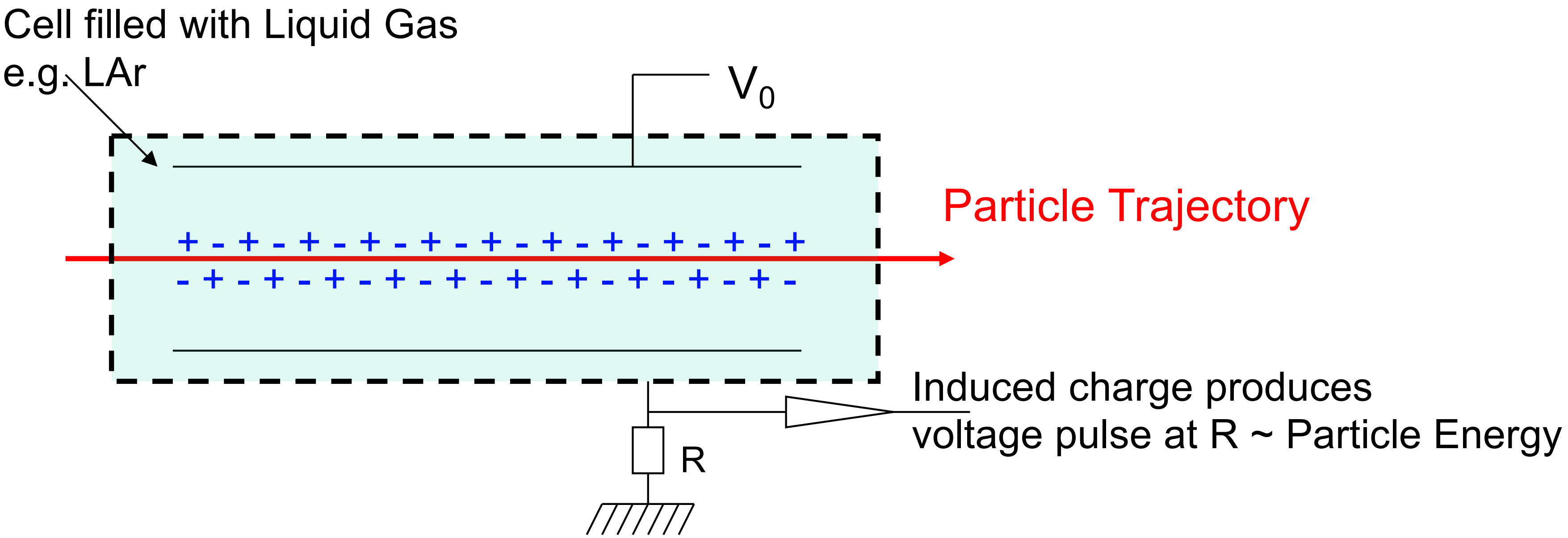
Requires

-Careful choice of resistive material (typically glass with resistive coating

-Control of the gas -> maintain avalanche mode, avoid saturation

Liquid Noble Gases

Basic Principle: Charged particle <u>ionizes</u> liquid gas embedded in an electrical field



Collection of Electrons at Anode: $v_{D,e-}$ = 4.5 mm/μs in LAr

$v_{D,Ion} = 10^4 * v_{De-}$

Liquie Noble gases have relatively small X_0, l int => compact detectors

Liquid Noble Gases have small electrongativity

i.e. no desire to capture drifting electrons since all atomic shells are filled

Energy Measurement - Charge Collection

Ionizing particle (electron) creates line charge in Noble Gas

Current induced at Anode: $I_{lin}(t) = N_e \bullet e \frac{1}{t_D^2}(t_D - t)$ $t_D = d_{gap}/v_D$

Charge collected after t_D: $Q_0^{lin} = \int_0^{t_D} I_{lin}(t)dt = \int_0^{t_D} N_e e \frac{1}{t_D^2}(t_D - t)dt = \frac{1}{2} N_e e$

Strongly ionizing particle with low energy creates point charge

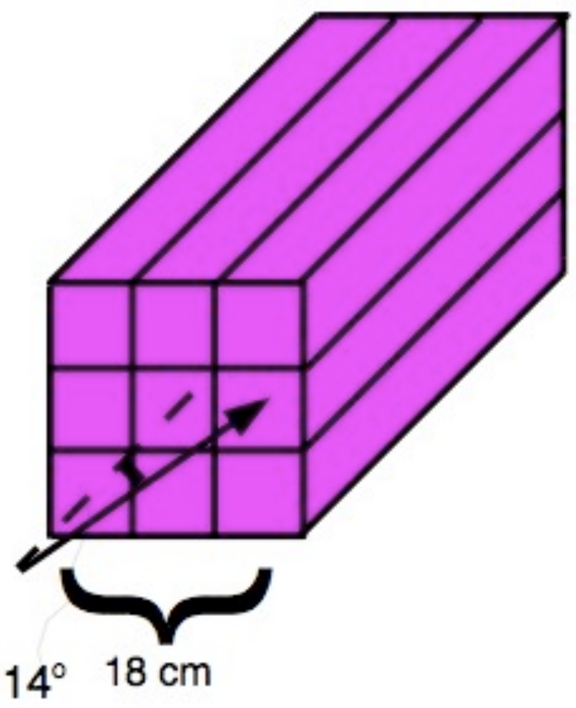
Current induced at Anode: $I_p = \frac{N_e e v_D}{d_p} = const.$

d_p = Point of creation of point charge

Charge collected after t_D: $Q_0^p(t) = N_e e$

Subdivision of Calorimeters

A Calorimeter is a block of Matter

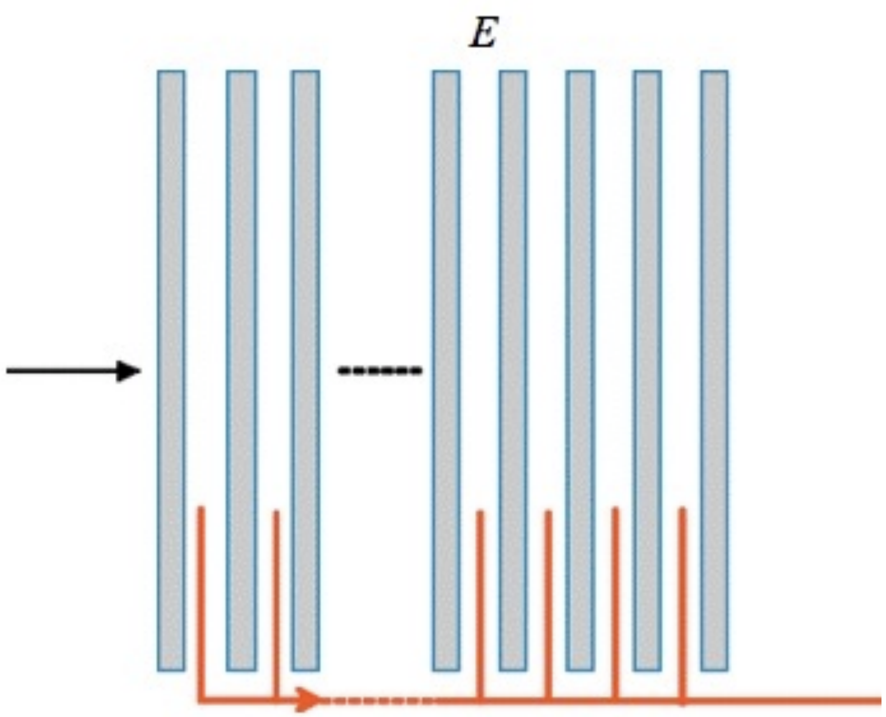


Typically it is subdivided into smaller
Units called calorimeter cells

- The subdivision is not necessary for the energy measurement
... and even not really desired to keep highest Precision
→ Homogeneous calorimeters

- But subdivision usually provides important spatial information on impact points
→ Homogeneous calorimeters typcially come in a « set of blocks »

Longitudinal Segmentation of a Calorimeter



Typically Calorimeters are subdivided longitudinally by alternating active and passive layers

'Sandwich Calorimeter'

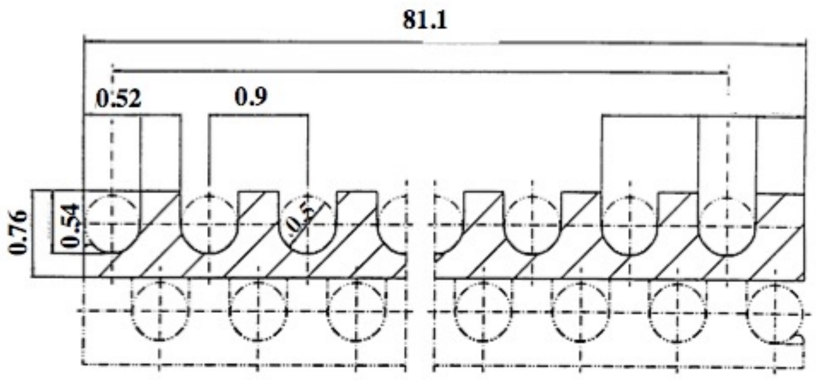
A suited twofold segmentation allows already for distinction between e,g and hadrons sinc $\lambda_{int} >> X_0$

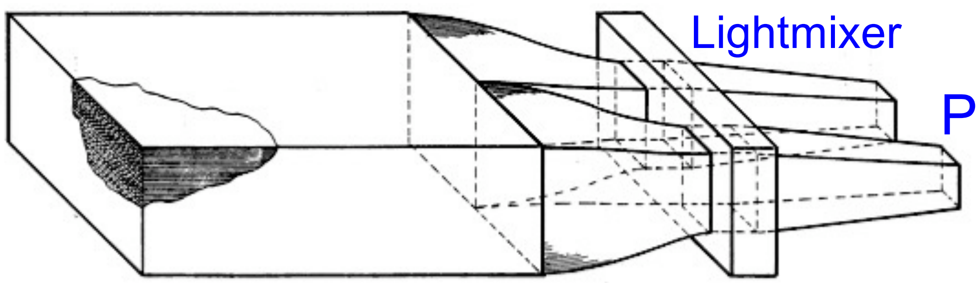
Typical for calorimeters with organic scintillators

longitudinal segmentation
technically diffcult for Crystal Calorimeters
Future calorimeters try to introduce
Longitudinal segmentation

SpaCal – "Spaghetti Calorimeter"

Example H1 Experiment (1992-2007 @ HERA)
Lead/Scintillating Fibre Matrix





Scintillating Files
embedded in lead
Ratio Lead/Fibre 2.27:1

Scintillation Light
from fibres guided to
PMT by lightmixers

⇒ Quasi homogenous Structure