Lecture # 3

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Introduction

- Gaseous detectors
- Greater → mobility of electrons
- Obvious medium
- Charged → particles detection
- Particle information easily → transformed
- Efficiency
- Time resolution
- Rate capability
- cheap

Ionization detectors

- Instruments based on → direct collection of
- Ionization chamber
- Proportional counter
- Geiger-Muller counter
- Multi-wire proportional chamber
- Capable of localizing particle trajectory in less than → a mm

Ionization mechanisms

- Energy loss → excitation, ionization

$$X + p \rightarrow X^{*} + p$$

- Excitation, → resonant reaction, exact amount of energy transfer
- Cross-section → $\delta = 10^{-17}\ \mathrm{cm}^2$
- No free electron-ion pair

$$X + p \rightarrow X^{+} + p + e^{-}$$

- Primary ionization, secondary ionization
- Penning effect → metastable states are excited
- Large spin-parity unable to → deexcite immediately

- Molecular ion → + gas ion → interacts neutral atom of same type → to form molecular ion
- Mean no. of electron-ion pair created
- Ionization reactions → statistical in nature
- Two particles → not same → electron-ion par
- For gases 1 e-i pair → 30 eV
- Average energy determines efficiency and time resolution of detector
- Recombination and electron attachment
- Electron affinity

$$R = 2.35\sqrt{Fw/E}$$

Energy resolution of a particle

Working principle

- Ionization mechanism
- Working under different voltage conditions
- Exploiting different phenomenon
- Gas cylinder
- Noble gas
- Mean number of electron-ion pair created
- Recombination and electron attachment

Simple gaseous detector

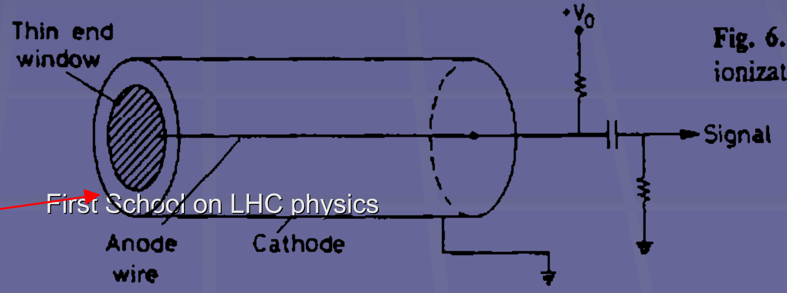


Fig. 6.1. Basic construction of a simple ionization detector

- Radial electric field →

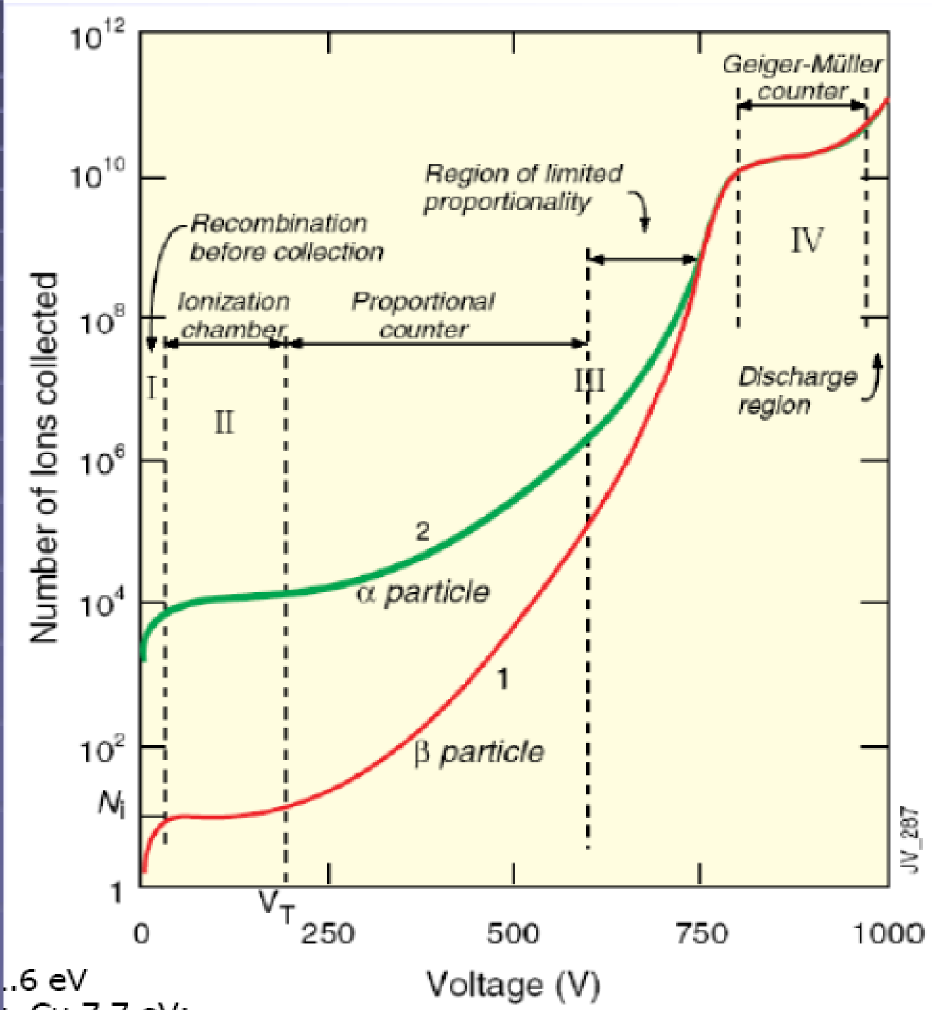
$$E = \frac{1}{r}\frac{V_0}{\ln\left(b/a\right)}$$

- Electron-ion pair produced
- Direct ionization → charged particles
- Indirect ionization → neutral particles
- Mean number of pair produced → directly proportional to → energy deposited by particle
- At zero voltage, recombination
- Recombination forces overcome → current increase
- All created pair collected → voltage increase no effect

- Detector working in this range → ionization chamber
- Voltage increase beyond region II
- Strong electric field → accelerate freed electrons → ionization
- Electrons liberated in secondary ionization accelerate → more ionization
- Ionization avalanche or cascade
- Strongest electric field near anode wire
- Number of electron-ion pair directly proportional to primary electrons

- Proportional amplification → as high 10^6
- Working in this range → Proportional chamber
- Further voltage increase
- Space charge distorts electric field about anode
- Proportionality begins to lost
- Region of limited proportionality
- Further V increase → discharge
- Chain reaction of many avalanche
- Secondary avalanche caused by → photons emitted by deexciting molecules

- Output current completely saturated
- Same amplitude regardless of particle energy
- To stop discharge → quench gas
- Working is this range → Geigger-Muller or break-down
- Further voltage increase → continuous breakdown



..6 eV

ı. Cu 7.7 eV:

The total charge collected as function of V

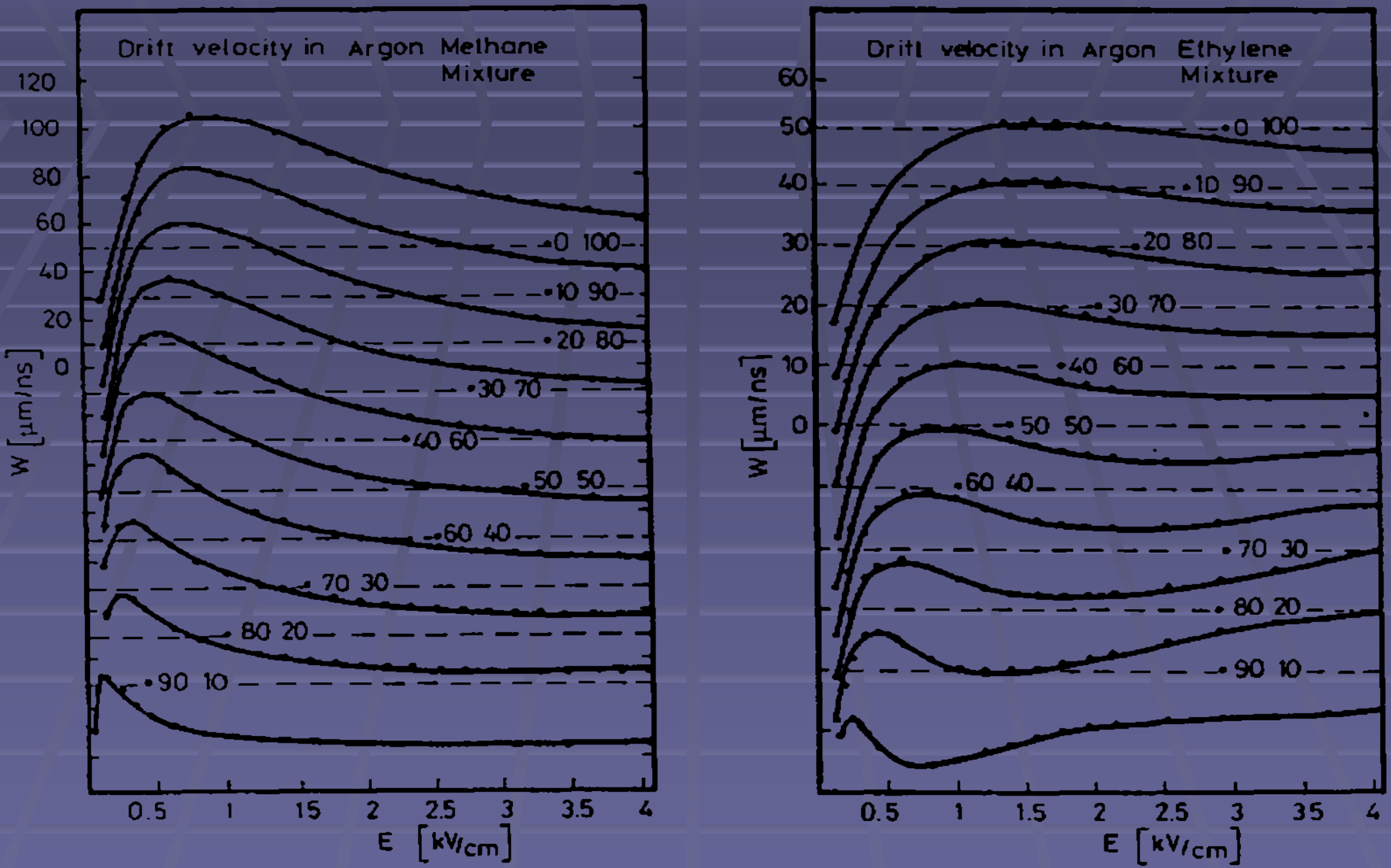
Transport of electrons and ions i gases

- Understanding → motion of electrons and ions
- Determine operating characteristic
- Two parameters → diffusion, drift
- Diffusion: at thermal energy → $v = \sqrt{\frac{8kT}{\pi m}}$
- Electron speed → 10^6 cm/s
- Spherical spread → $\sigma(r) = \sqrt{6Dt}$
- Diffusion coefficient → $D = \frac{2}{3\sqrt{\pi}} \frac{1}{p\sigma_0} \sqrt{\frac{(kT)^3}{m}}$
- Drift and mobolity

$$\mu = \frac{u}{E}$$

$$\frac{D}{\mu} = \frac{kT}{e}$$

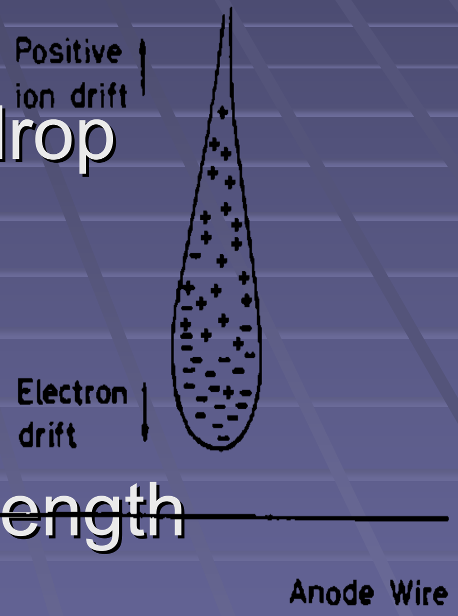
- Drift and mobility
- Electrons accelerate along field lines
- Acceleration interrupted by collision
- Average velocity attained → drift velocity
- Superimposed upon normal random movement
- Mobility → $\mu = u/E$
- Einstein relation → $D/\mu = kT/e$
- Electron velocity → 10^6 cm/s, E → 1 kV/cm-atm
- Gas mixture affects rate capability



Drift velocities of electrons in various gas mixtures as a function of electric field

Avalanche Multiplication

- Multiplication in gas detectors occurs
- Primary electrons gain sufficient energy
- Secondary, tertairy ionization
- Greater mobility of electrons → liquid-drop like shape
- Electrons grouped near head
- Slower ions trailing behind
- $\alpha = 1/\lambda$, prob. of ionization per unit path length also called first Townsend coefficient
- Multiplication factor or → Gas gain is of fundamental importance



in path *dx*, new electrons created are *dn*

$$dn = n \alpha dx$$

Integrate to obtain total electrons

$$n = n_0 \exp(\alpha x)$$

Multiplication factor

$$M = n / n_0 = \exp(\alpha x)$$

Gas gain

Multiplication factor in case of non-uniform field

$$M = \exp\left[\int_{r_1}^{r_2} \alpha(x) dx\right]$$

$M < 10^8$ or $\alpha x < 20$ Raether limit → breaks down

Value of α

$$\frac{\alpha}{p} = A \exp\left(-\frac{Bp}{E}\right)$$

Choice of gas

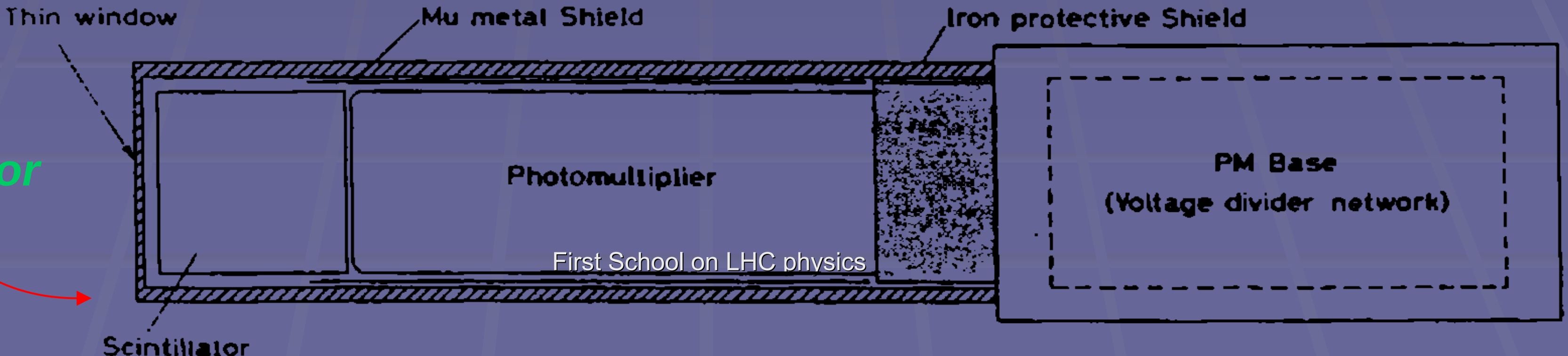
- Low working voltage
- High gain
- Good proportionality
- High rate capability
- Normally use gas mixture
- Noble gases → low electric field intensity for avalanche formation
- Argon → higher specific ionization, low cost
- Gas gain → 10^3-10^4
- High excitation energy

- Excited argon atoms form in avalanche
- De-excitation gives high energy photons
- Further avalanche formation
- Quenching gas
- Radiated photons absorbed
- Gain upto 10^6 is obtained
- 90 % Ar, 10% methane
- P10 gas
- Isobutane another quench gas

- Gas gain further increase → electronegative gas
- → also trap electrons extracted from cathode
- Gain of 10^7

Scintillators

- Scintillators → make use of the fact that certain materials when struck by a radiation , emit a small → flash of light i.e scintillation
- Scintillating material optically → coupled to photomultiplier
- The radiation → excites atoms and molecules causing light to be emitted transmitted → photomultiplier → converted weak current of photoelectrons → amplify by electron multiplier



scintllator

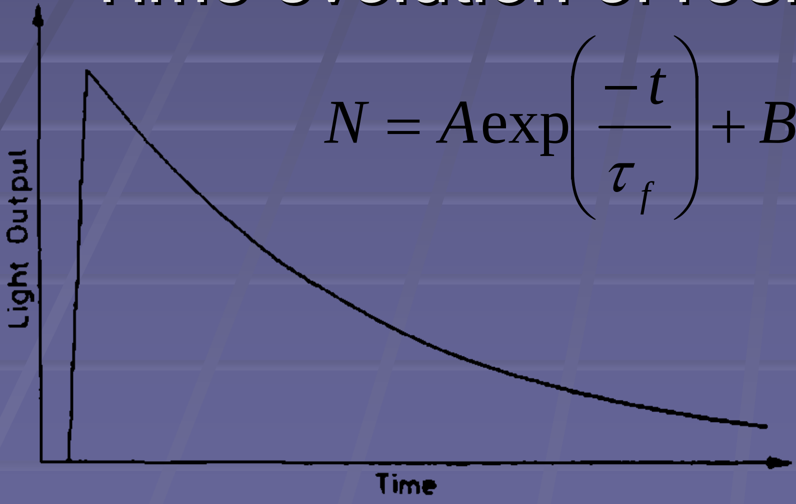
- Sensitivity of energy
- Above certain minimum level → most scintillators behave → linear fashion with respect to → energy deposited
- Light output → directly proportional to energy deposited
- Amplitude final electrical → prop. energy → of particle
- Fast time response
- Fast → response and → recovery time compared → to other detectors

- Timing information → of particles
- Time difference → b/w two events → greater precision
- Fast time → high count rate
- Pulse shape discriminator
- With certain scintillators → possible to distinguish → different particles → by analyzing → shape of emitted light
- This is due to excitation → of different → fluorescence mechanism by particles of different ionizing power.

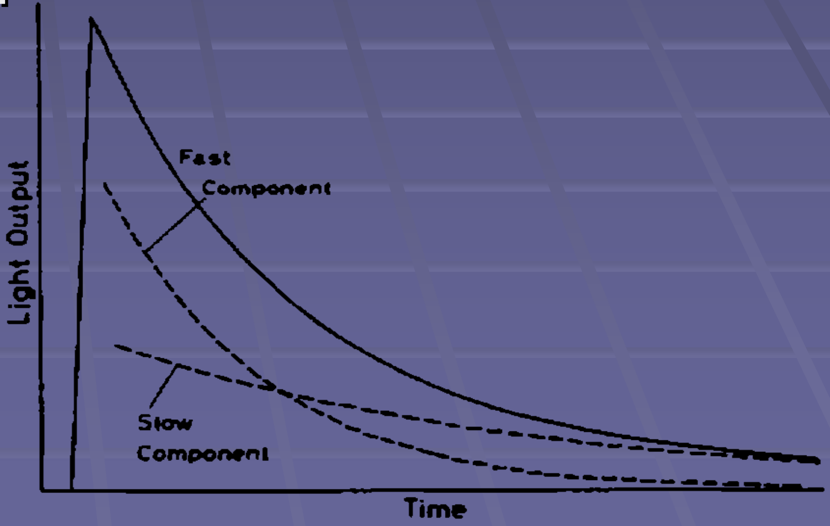
- If reemission 10-8 → fluorescence
- Reemission delayed → excited state is metastable → phosphorescence or afterglow
- Delay time → microsecond → hours

- Property of scintillators → Luminescence
- luminescent materials → exposed certain form of energy → absorb & reemit → in the form of visible light
- Reemission within 10^{-8} s → fluoresence
- 10-8 s is time taken by atomic transitions
- If reemission is delayed , state is meta stable state phosphorescence or afterglow
- Time evolution of reemission process

$$N = A\exp\left(\frac{-t}{\tau_f}\right) + B\exp\left(\frac{-t}{\tau_s}\right)$$



Exponential decay of fluorescent radiation. Rise time is faster than decay time



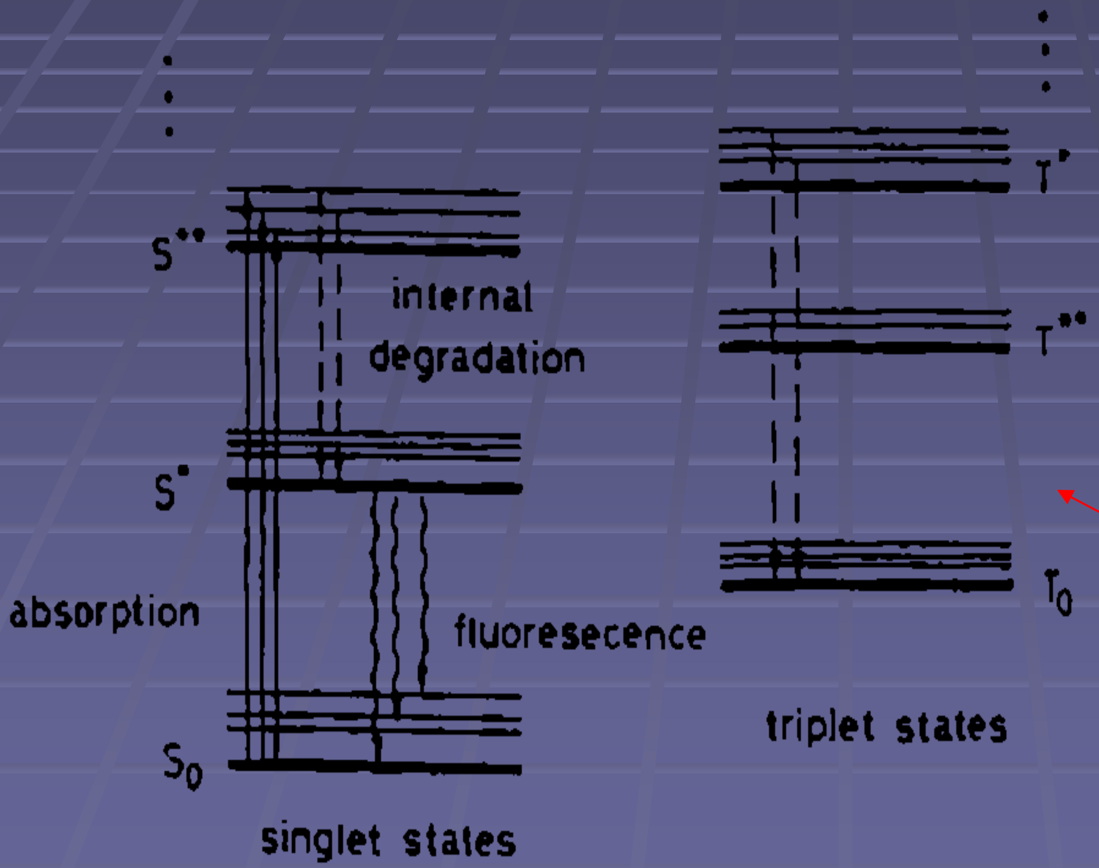
Resolving scintillation light into fast and slow components. Solid line total light decay

- A good scintillator depends → on following
- High efficiency for conversion → exciting energy to fluoresent radiation
- Transparency to its fluorescent radiation → so as to allow → transmission of light
- Emission of spectral range → consistent with spectral response of PMT
- A short decay constant, τ

Organic scintillators

- The organic scintillators → hydrocarbon compunds → condensed benzene rings
- Rapid decay time → few ns
- Scintillation → transitions made → free valence electrons
- Delocalized electrons → not associated to particular atoms in molecule
- Occupy π-molecular orbitals
- Spin singlet
- Spin triplet

- Fine structure constant, → excited vibrational mode of molecule
- Energy spacing between electron levels → is few eV
- Energy spacing between vibrational levels is few tenths of eV



Energy level diagram of an organic scintillator molecule

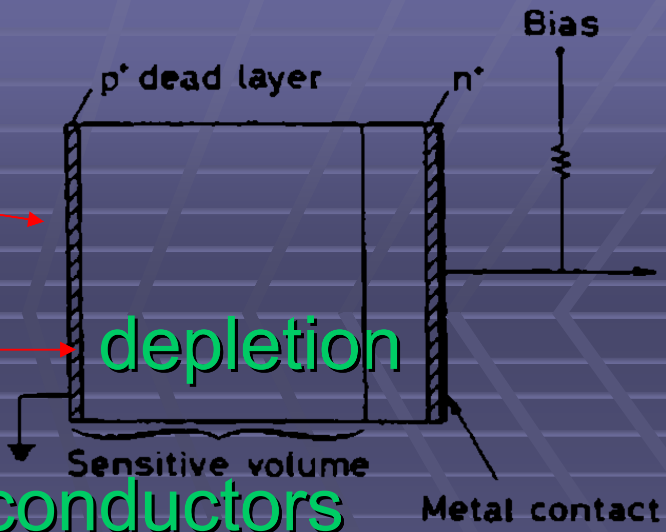
- Radiation ionizes both electron and vibrational level
- Singlet excitations generally decay immediately to S* i.e 10 ps
- Internal degradation
- From S* to S^0, probability of radioactive decay from vibrational state to ground state in few nano second time
- This process is called flourescence
- The same mechanism occur for triplet excited state

Inorganic crystals

- Alkali halides
- Scintillation mechanism is characteristic of electronic band structure
- When a particle enters, two process can occur
- Excite electron from valence to conduction band, creating a free electron and a free hole
- Create exciton
- 2-3 orders of magnitude slow compared to organic scintillators
- Greater stopping power because of high Z
- Highest light output
- Suitable for gamma rays anf high energy electrons and positrons

Solid state detectors

- Ionizing radiation → creates electron-ion pair which are then collected by E.F
- Average energy required → an ele-ion pair 10 times → smaller → than → gas ionization
- Amount of ionization produced → for given energy → an order of magnitude → greater resulting → energy resolution
- Because of greater density → greater → $-dE/dx$
- Compact in size → fast response time
- Basic properties of semiconductors
- Doped semiconductors



Basic layout of junction detector

- The np semiconductor junction → depletion depth
- Detector characteristics of semiconductors
- In order to collect ionization → electrodes must be fitted → two sides of junction
- For semi-conductor → ohmic contant cannot in general, be formed by directly depositing metal onto semi-con material
- Contact between many metals and → semiconductors → results in creation of rectifying → reslting depletion zone extended

- To prevent this formation → heavily doped layers of n+ and p+ is used → between → semiconductor and metal leads
- High dopant concentrations → depletion depth essentially zero
- Then this forms desired → ohmic contact
- For signal isolation purposes → the bias voltage to the detector is supplied through → a series resistor rather than → directly.
- To collect the charge signal from → the detector, a preamplifier of the → charge-sensitive type → is generally used.

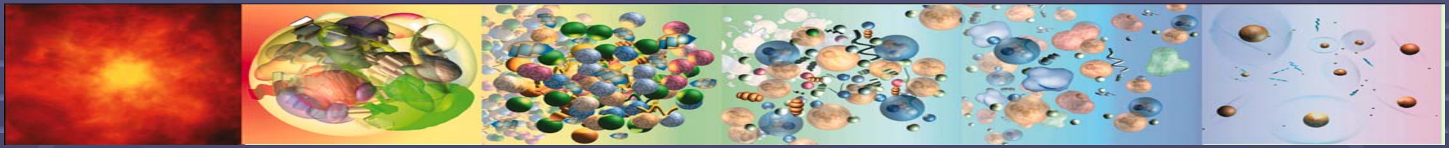
- Because of the low-level of the signal, → this preamplifier → must have → low-noise characteristics.
- Signal processing → after the preamplifier also → requires pulse shaping → in order to obtain the → best signal-to-noise
- **Detector characteristics of semiconductors**
- Average energy per Electron-Hole pair
- Linearity
- Fano Factor and energy resolution
- Leakage current
- Sensitivity and intrinsic efficiency
- Pulse shape. Rise time

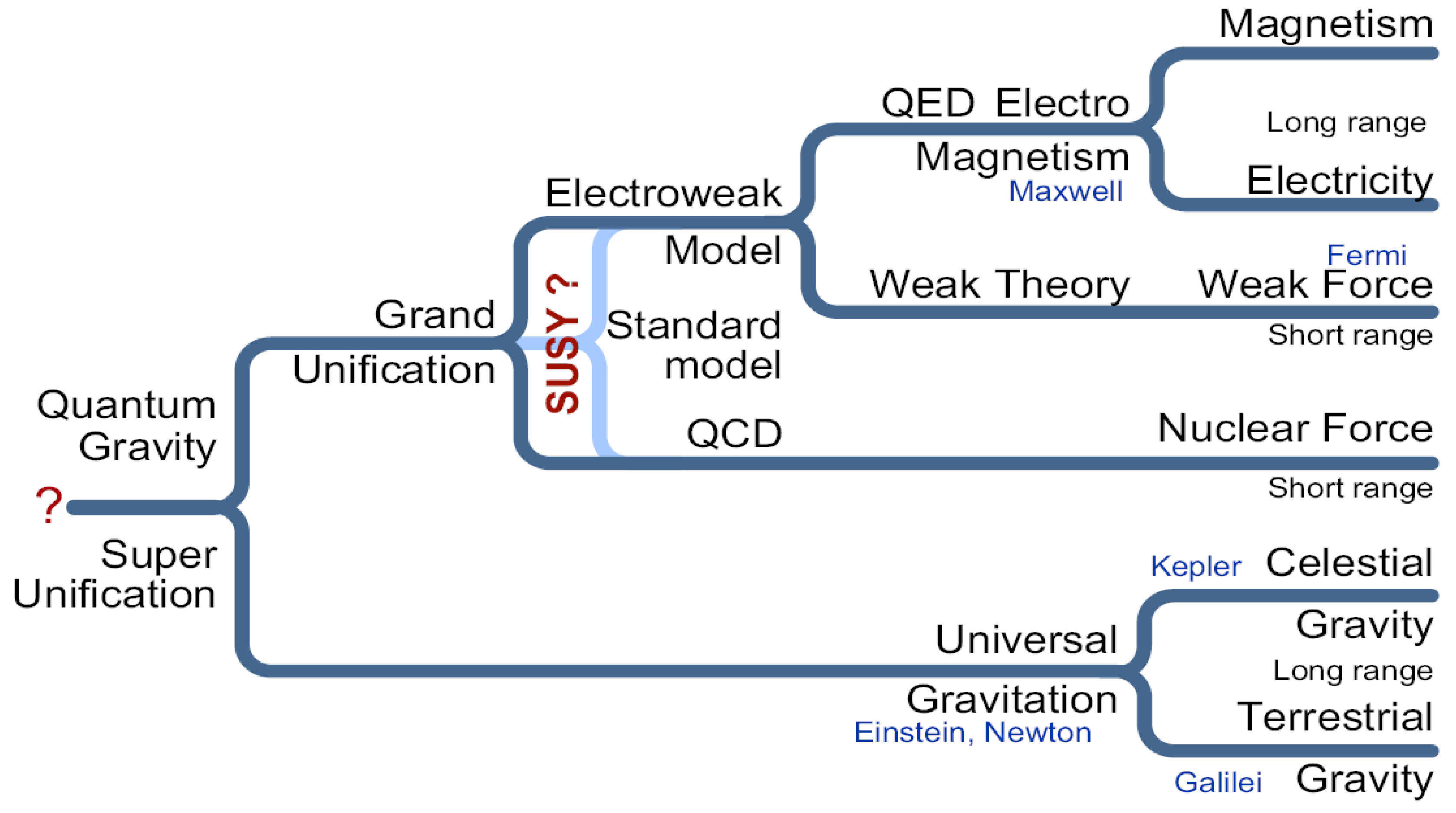
Conclusions

- Interaction of particles in material
- Common features of detectors
- Gaseous detectors
- Scintillator detectors
- Solid state detectors
- Introduction to LHC

Thanks

10^{-43} sec 10^{-32} sec 10^{-10} sec 10^{-4} sec 100 sec 300000 years





?

Quantum
Gravity

Super
Unification

Grand
Unification

SUSY ?

Electroweak

Model

Standard
model

QCD

QED Electro
Magnetism
Maxwell

Weak Theory

Magnetism

Long range

Electricity

Fermi
Weak Force

Short range

Nuclear Force

Short range

Universal
Gravitation
Einstein, Newton

Kepler Celestial
Gravity

Long range

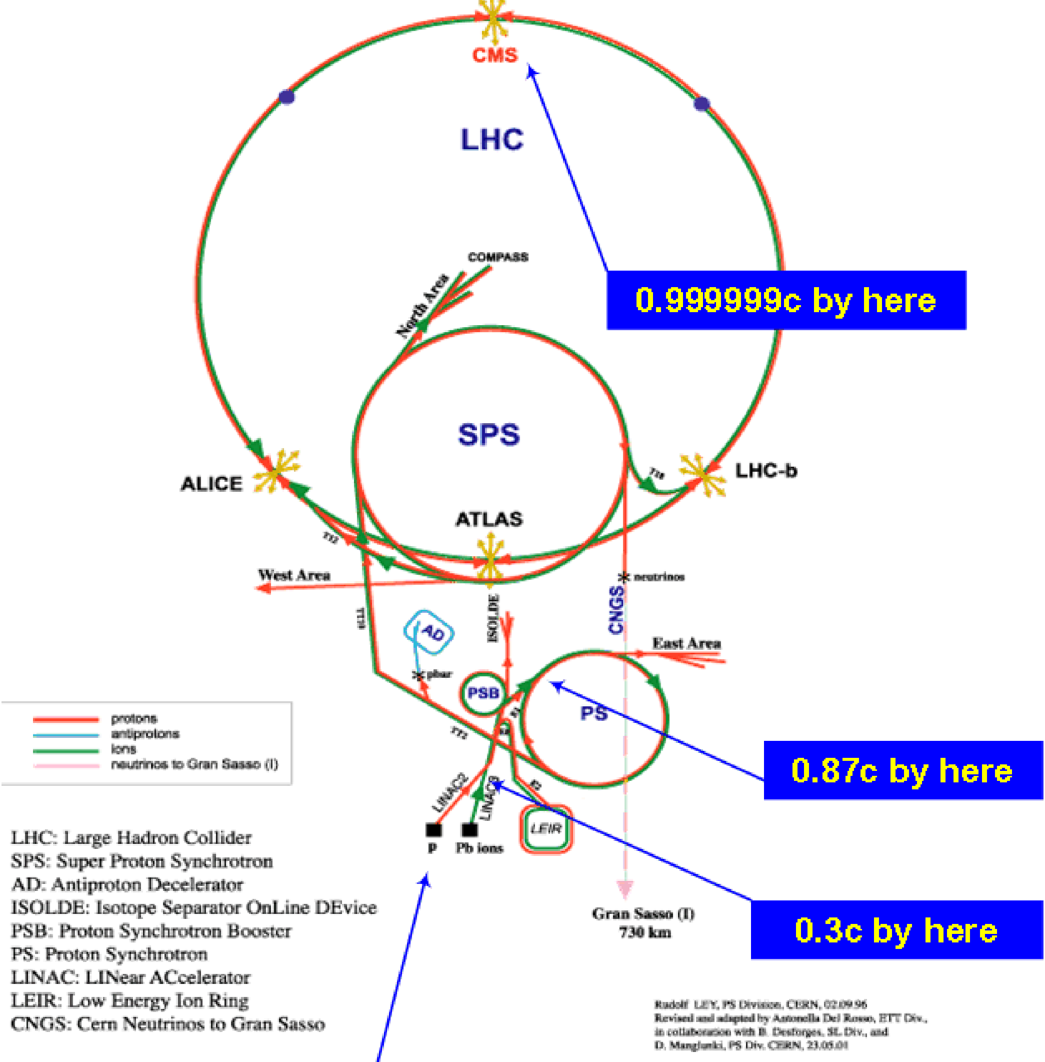
Terrestrial
Galilei Gravity

Introduction to LHC

- Proton-proton collider
- proton beam energy is 7 TeV
- center of mass energy = 14 TeV
- 1232 dipole magnets are used, each has length 14.3 m
- Number of bunches 2808
- Number of particles in one bunch 1.15 X 10^{11}
- Luminosity ~ 10^{34} cm^{-2} sec^{-1}
- Four interaction points
- Four detectors

CERN Accelerators

(not to scale)



LHC: Large Hadron Collider
SPS: Super Proton Synchrotron
AD: Antiproton Decelerator
ISOLDE: Isotope Separator OnLine DEvice
PSB: Proton Synchrotron Booster
PS: Proton Synchrotron
LINAC: LINear ACcelerator
LEIR: Low Energy Ion Ring
CNGS: Cern Neutrinos to Gran Sasso

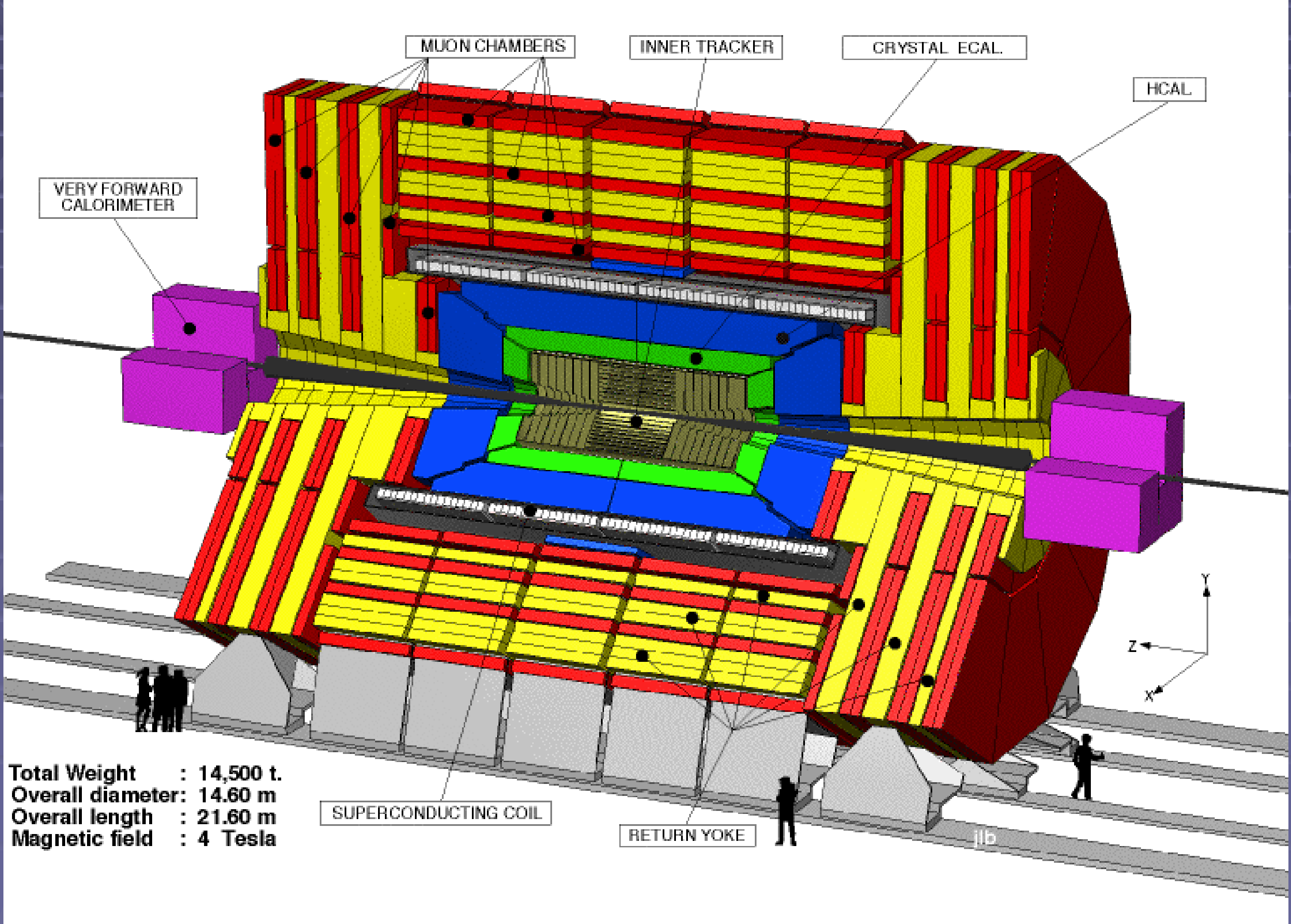
Rudolf LEY, PS Division, CERN, 02.09.96
Revised and adapted by Antonella Del Rosso, ETT Div.,
in collaboration with B. Desforges, SL Div., and
D. Manglunki, PS Div. CERN, 23.05.01

0.999999c by here

0.87c by here

0.3c by here

Start the protons out here



Total Weight : 14,500 t.
Overall diameter: 14.60 m
Overall length : 21.60 m
Magnetic field : 4 Tesla