JÜLICH
FORSCHUNGSZENTRUM

Basics of Particle Detectors

Irakli = ირაკლი
Keshelashvili ≈ ქეშელაშვილი

September 11, 2017

Outline

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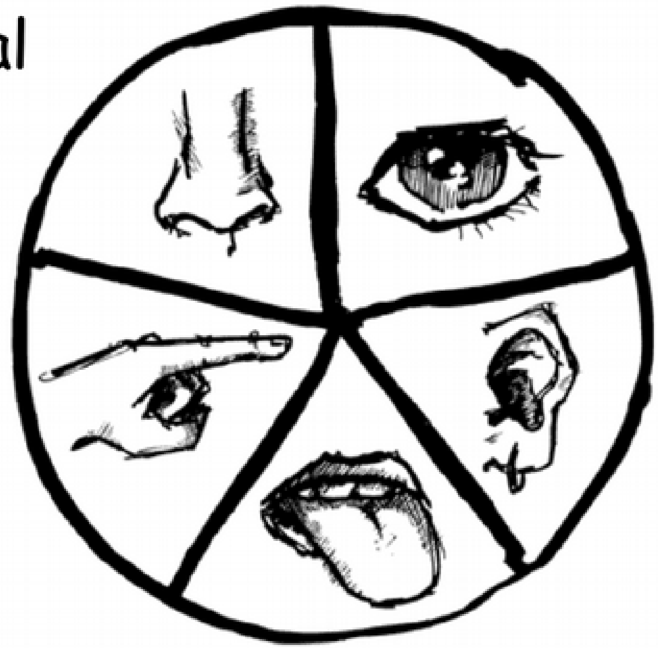
- Introduction
  Why and Where?
- Working Principle
  Direct signal and via optical flash
- Detector Types
  Gaseous, semiconductor, scintillating and Cherenkov
- IKP @ FZJ Activities
  JEDI Polarimeter project
- Summary

Why we need particle detectors?

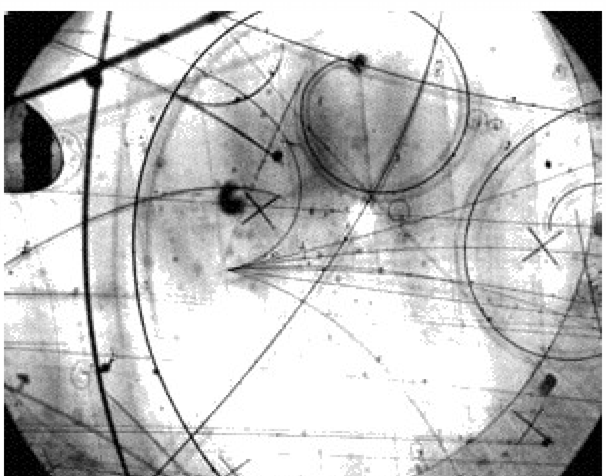
Charged & Neutral

Smaller than the visible photons

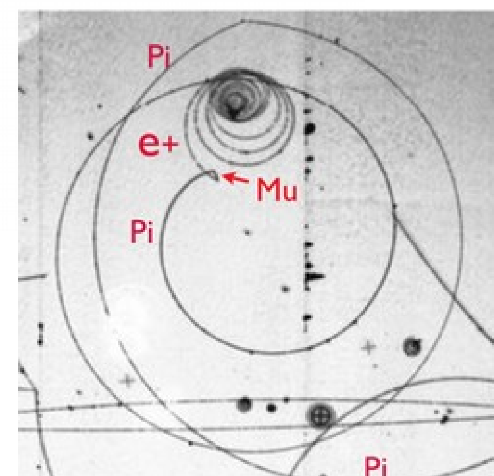


Too Small for the nerves

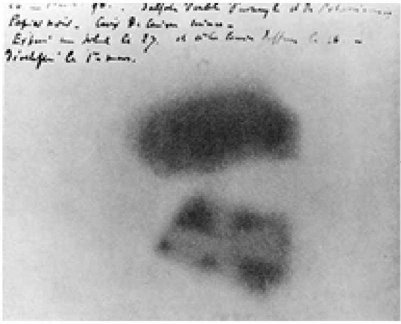
This we always do :)

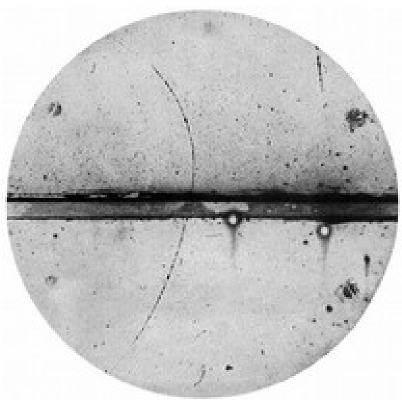


Smaller than molecules



Scientific Method – 6 Steps



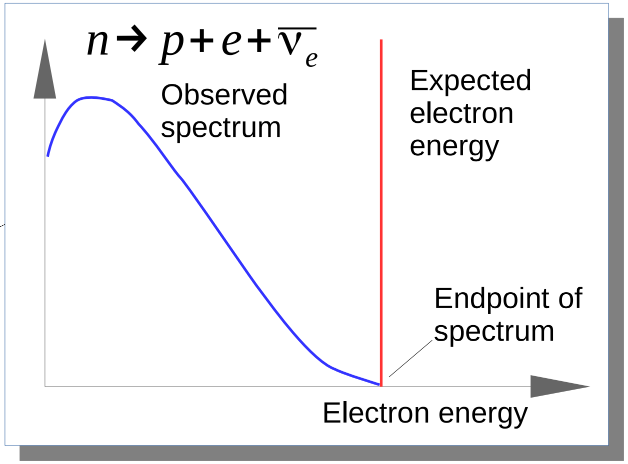


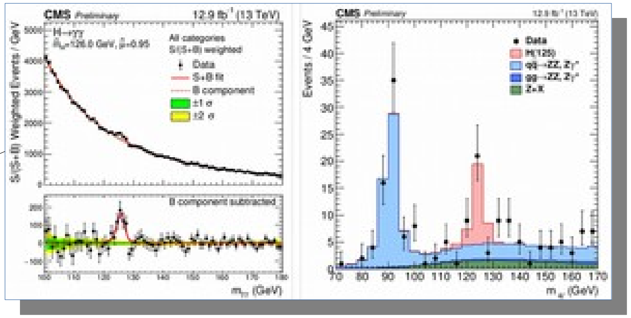
Observation or Unanswered Question

Construct Hypothesis

Test with an Experiment

Analyze Results Draw Conclusion





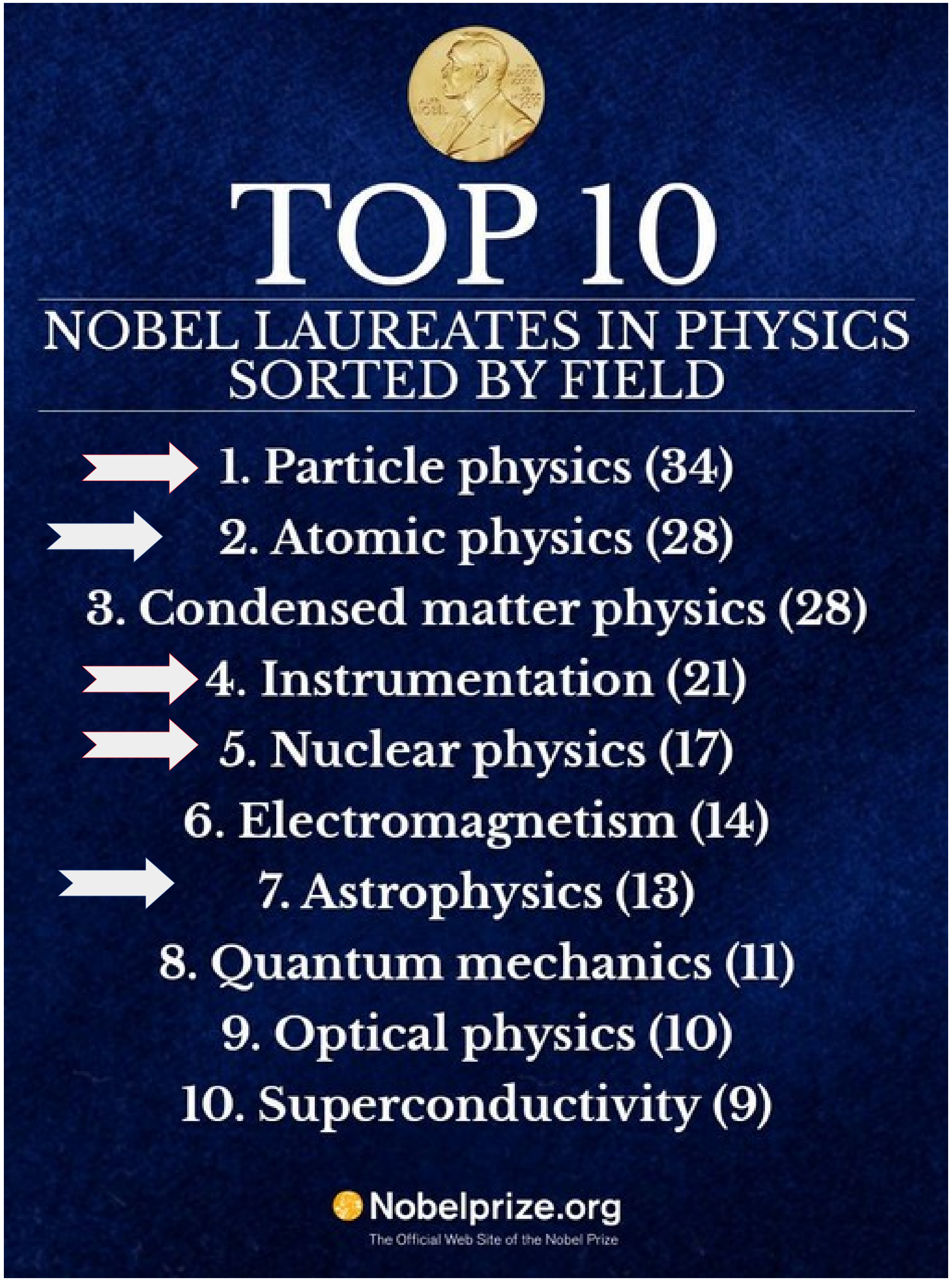
Hypothesis is True !

Hypothesis is False OR Partially True

Report and Publish Results !

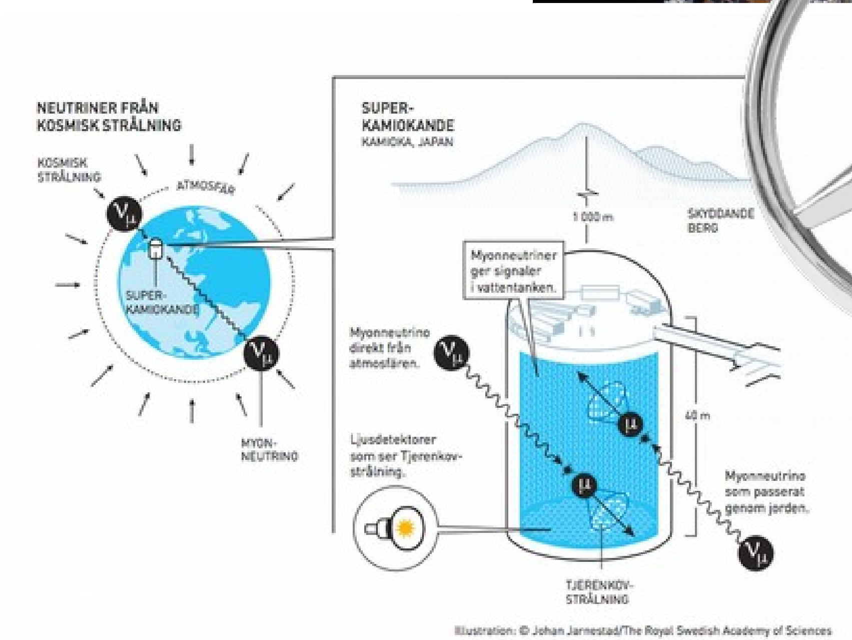
Nobel Laureates by Field

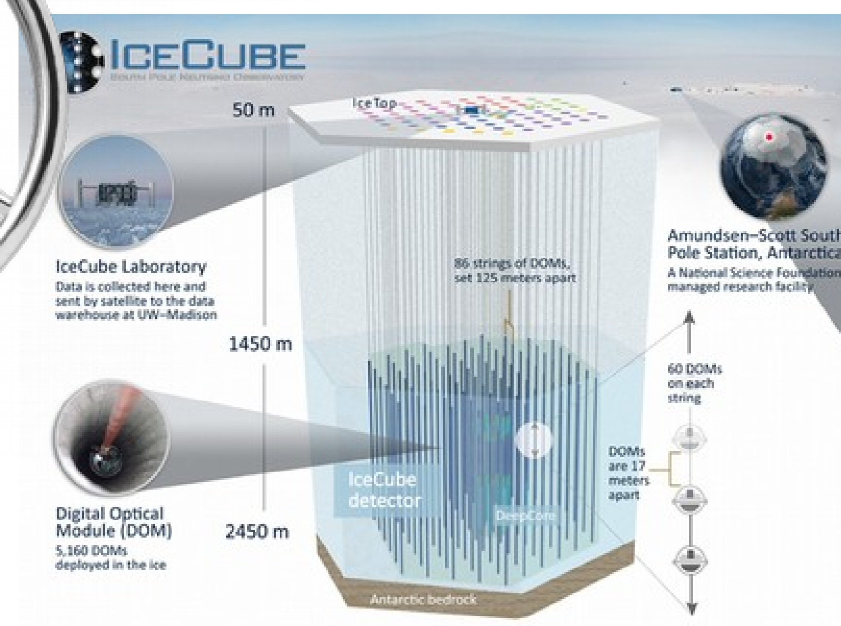
Look how important the scientific instruments are...



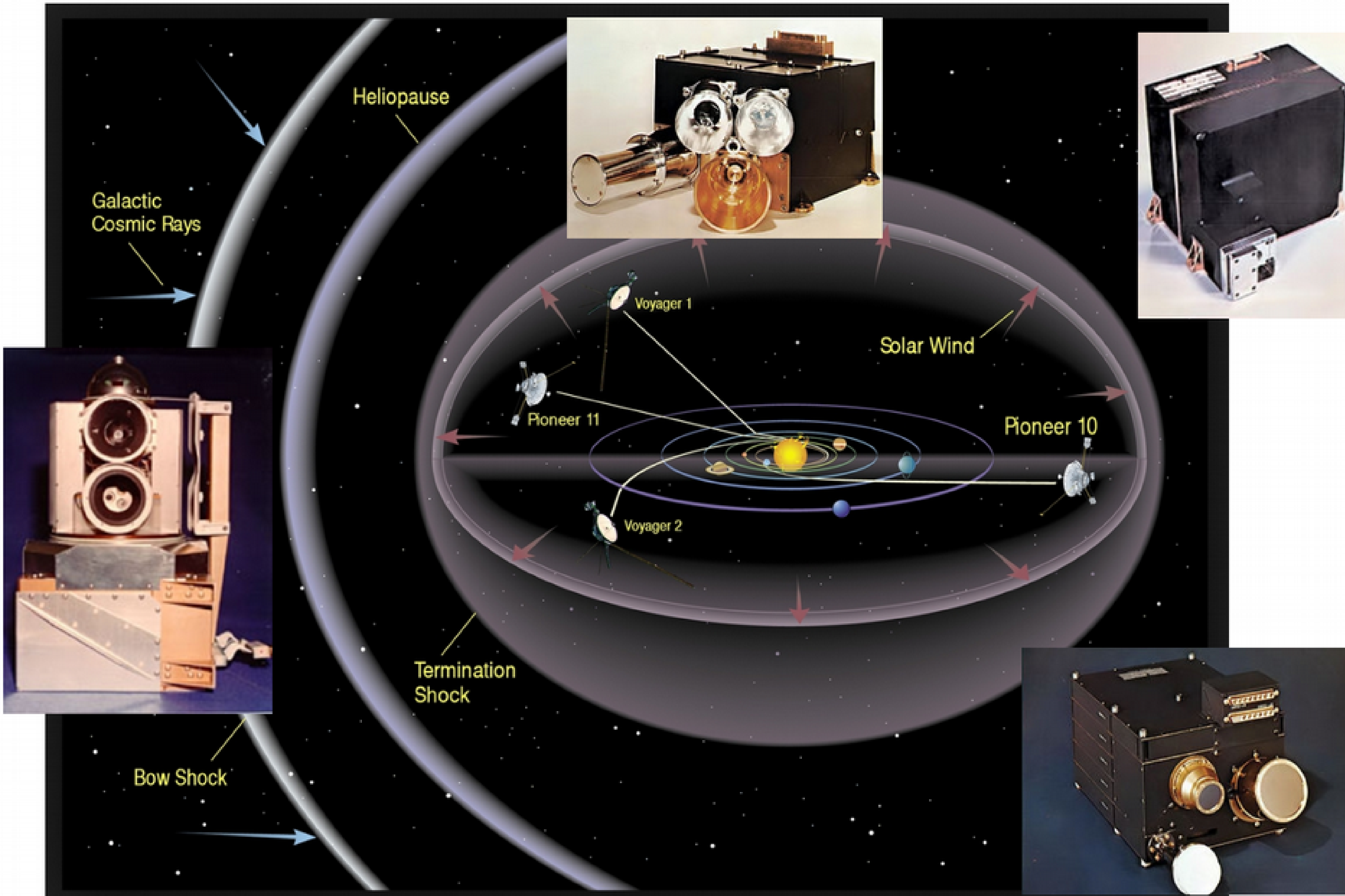
Member of the Helmholtz-Association

Detectors are everywhere





Voyager & Pioneer



RAD on Mars

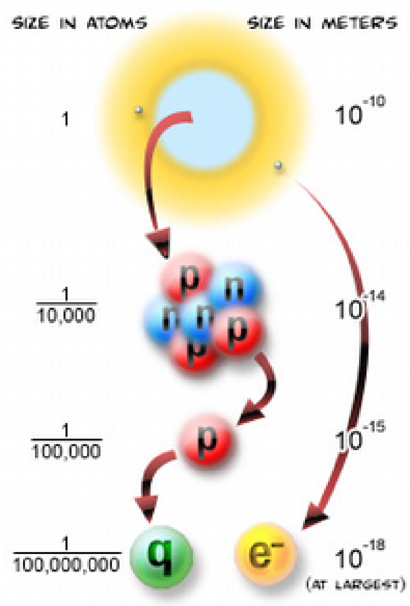
The Radiation Assessment Detector, or RAD

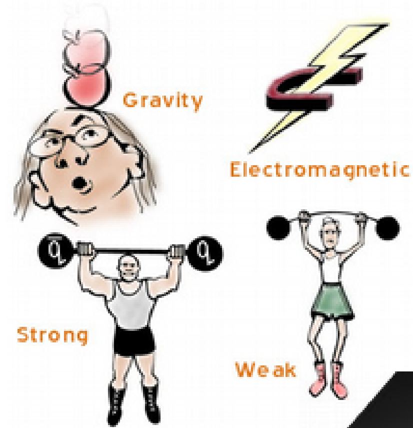
will monitor naturally occurring radiation that can be unhealthful if absorbed by living organisms. It will do so on the surface of Mars, where there has never before been such an instrument, as well as during the trip between Mars and Earth.

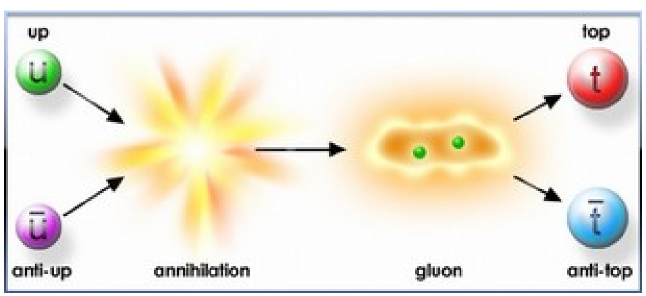
Very First Idea

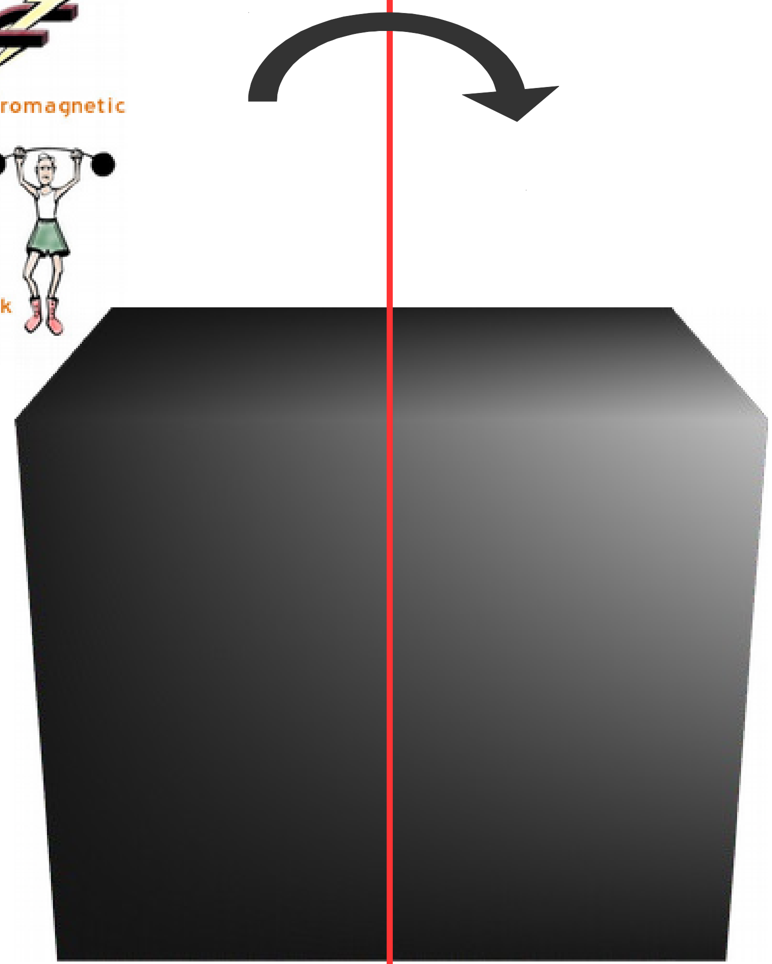
Not human readable world!

Human readable world!









A very important slide

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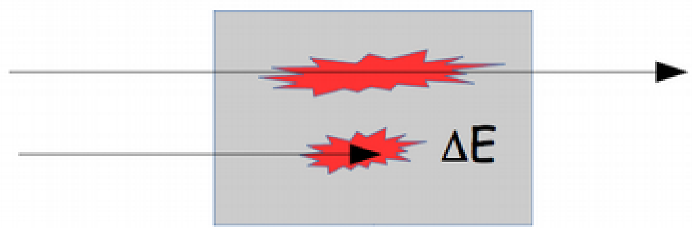
Only the result of an interaction with matter will be observed



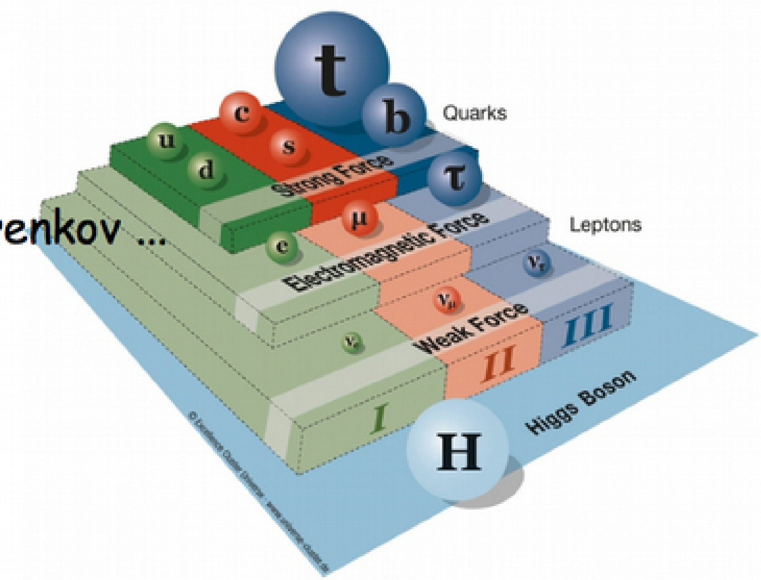
The detection of particles happens

via their ΔE in the material it traverses ...

Charged particles: Ionization, Bremsstrahlung, Cherenkov ...

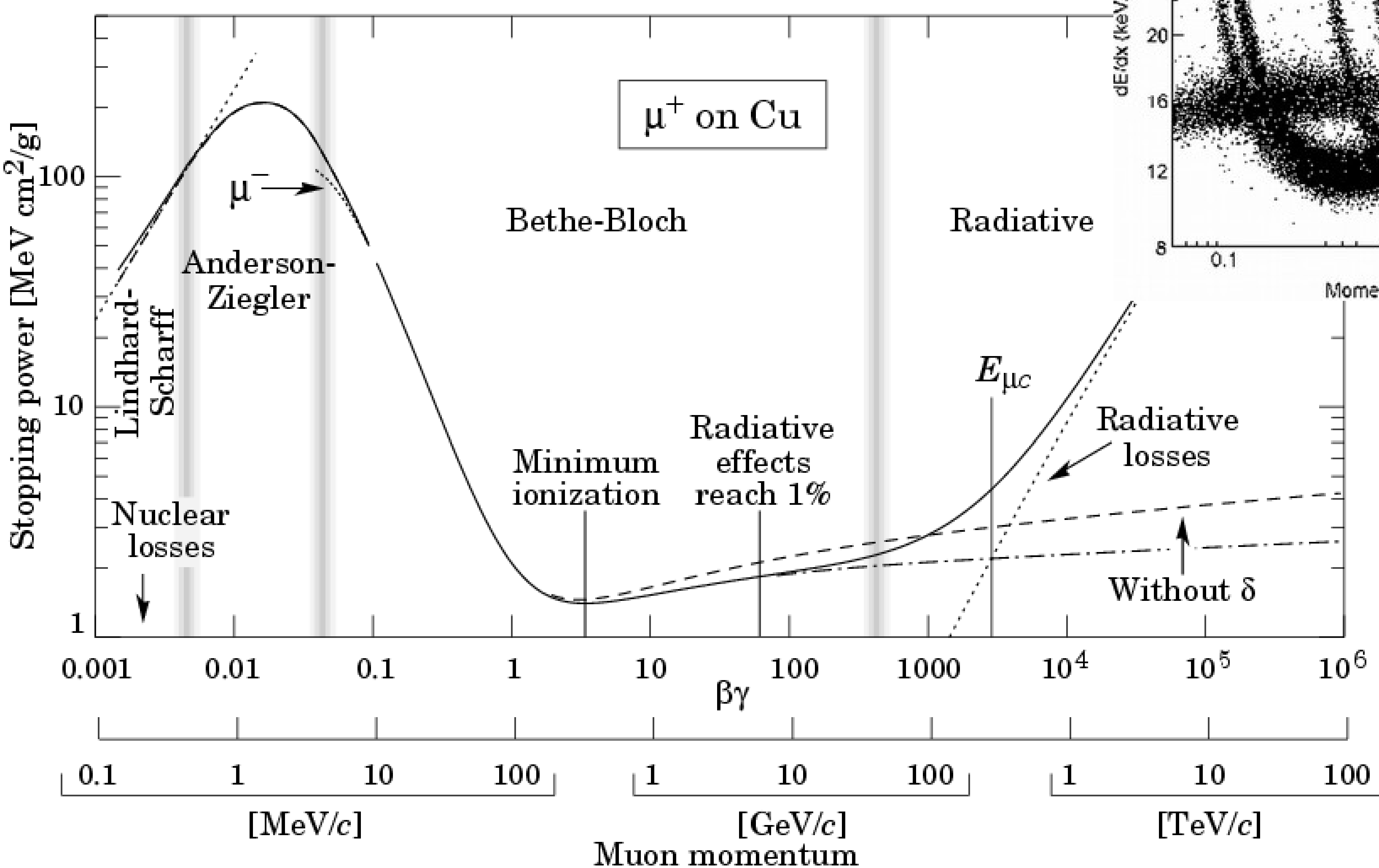
Photons: EM → Photo, Compton, pair production

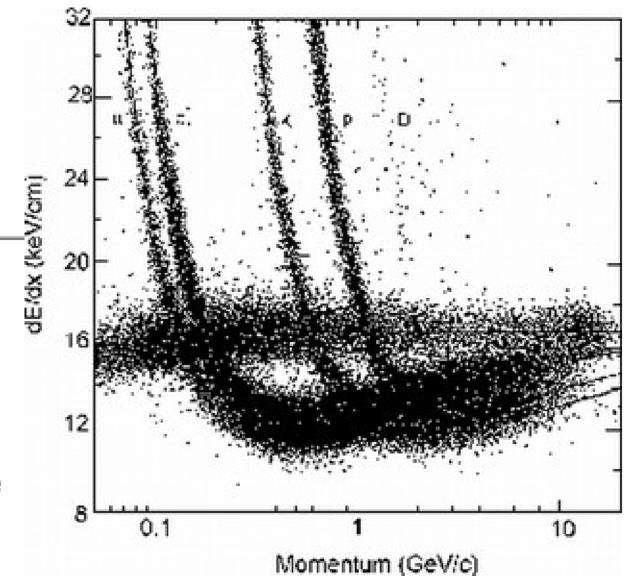
Hadrons: Strong, EM, Weak interactions



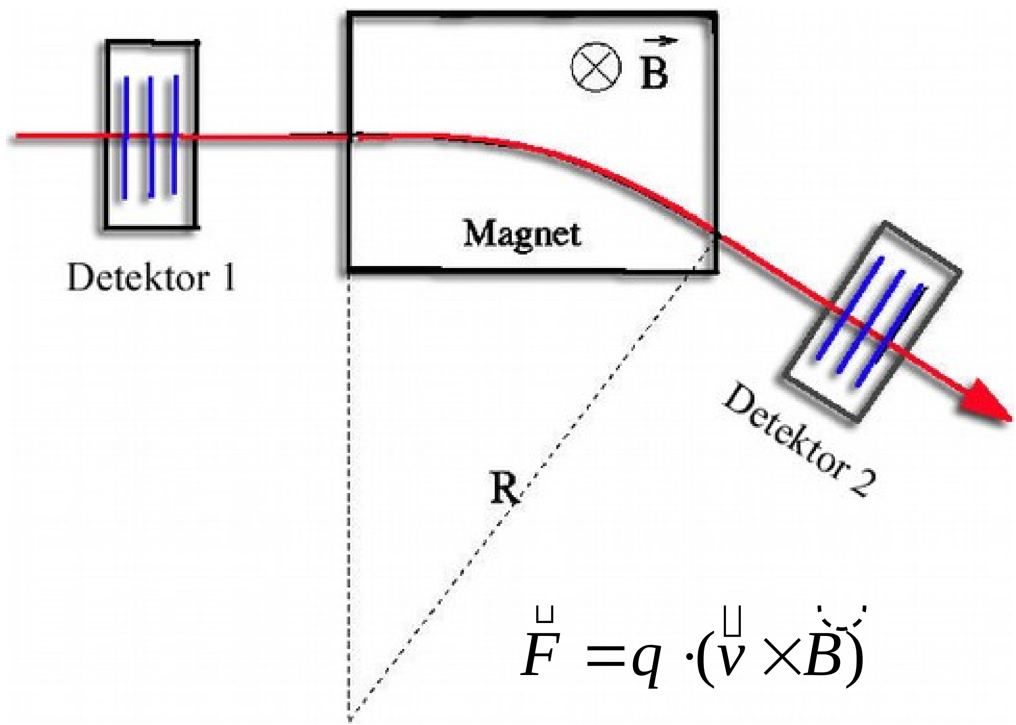
Bethe-Bloch stopping power plot

$$-\frac{dE}{dx} = K \cdot z^2 \cdot \frac{Z}{A} \cdot \frac{1}{\beta^2} \cdot \left[\frac{1}{2}\ln\frac{2m_ec^2\beta^2\gamma^2T_{\max}}{I^2} - \beta^2 - \delta/2\right]$$

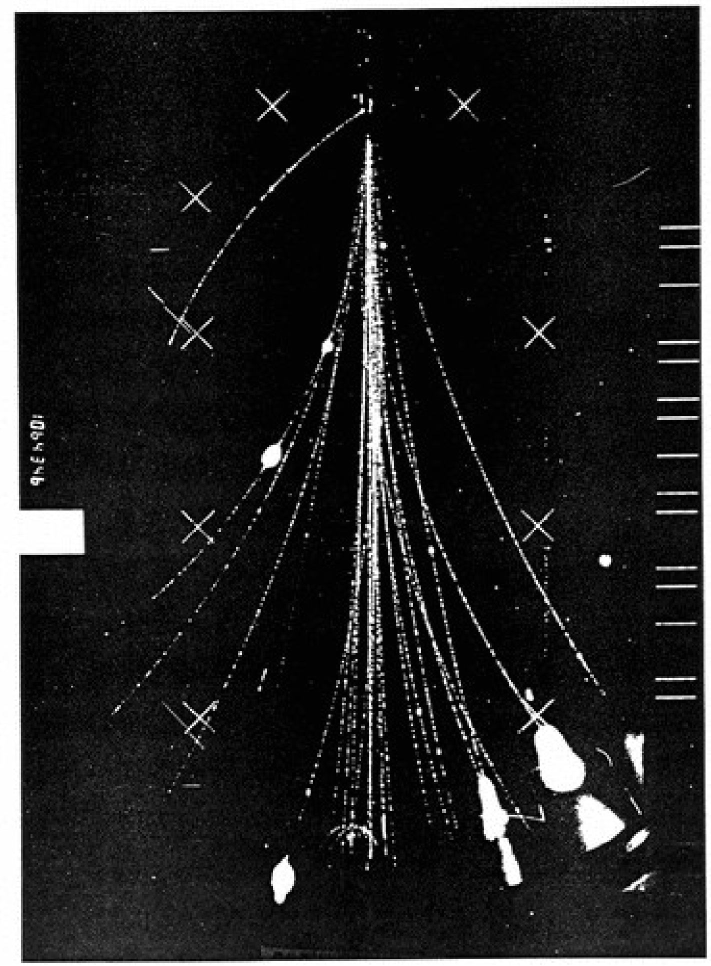




Momentum measurement



$$\vec{F} = q \cdot (\vec{v} \times \vec{B})$$

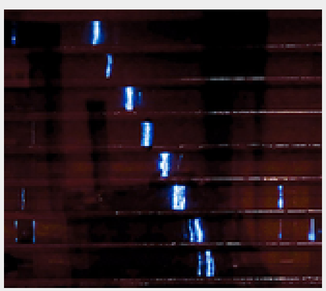


Reordering

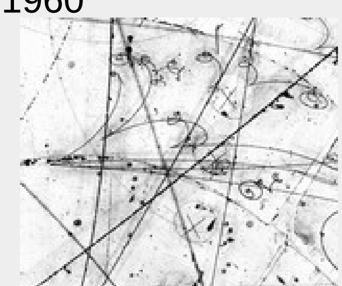
Track visualization

- Cloud/Wilson chamber (supersaturated vapor) 1911; Nobel 1927

- Spark chamber 1930 tracking



- Bubble chamber (superheated liquid) 1952; Nobel 1960



Direct e-charge signal

Gaseous

- Geiger–Müller tube: *1908; radiation*
- Ionization chamber
  flux measurement
- MWPC Multi-wire proportional chamber: *1968, energy, tracking*
- Straw tubes: *energy, tracking*
- Drift chamber: *energy, tracking*
- GEM & micromegas
- TPC Time projection chamber
  3D, energy, traking
- TRD Transition radiation detector
- RPC Resistive plate chamber
  Very precise time measurement

Semiconductor

- Silicon detectors
  vertex reconstruction strip, drift, pixel, ...
- Germanium detectors
  energy measurement
- Diamond detectors
  luminosity detectors
- ? MCP micro-channel plate ?

Photon signal → electric signal

Scintillation

- Organic Plastic
  energy, position, TOF, tracking, fast triggers, dE/E,…
- Liquid: *energy, position, tracking, dE/E, neutron, ...*
- **Inorganic**
  precise energy measurement in very large scale

Cherenkov

- Gaseous, Aerogel
  relativistic particles
- Liquid, solid; *medium energy*
- RICH – ring image Cherenkov
  momentum, charge, direction
- DIRC – Detection of Internally Reflected Chrenkov light

Cloud / Wilson chamber

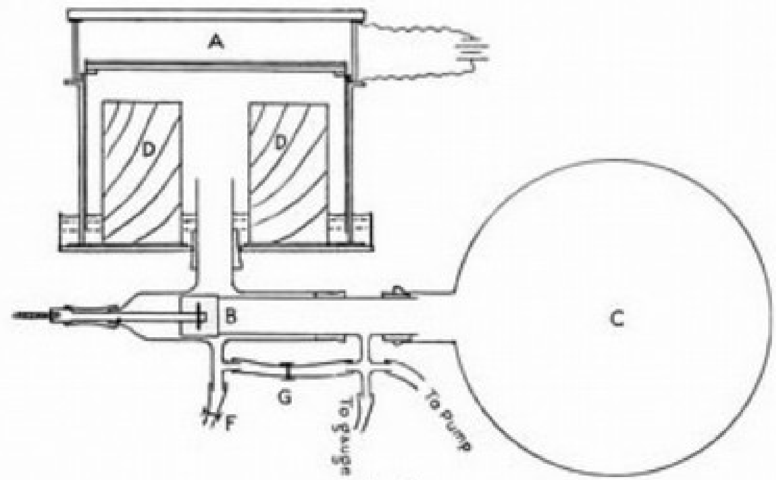
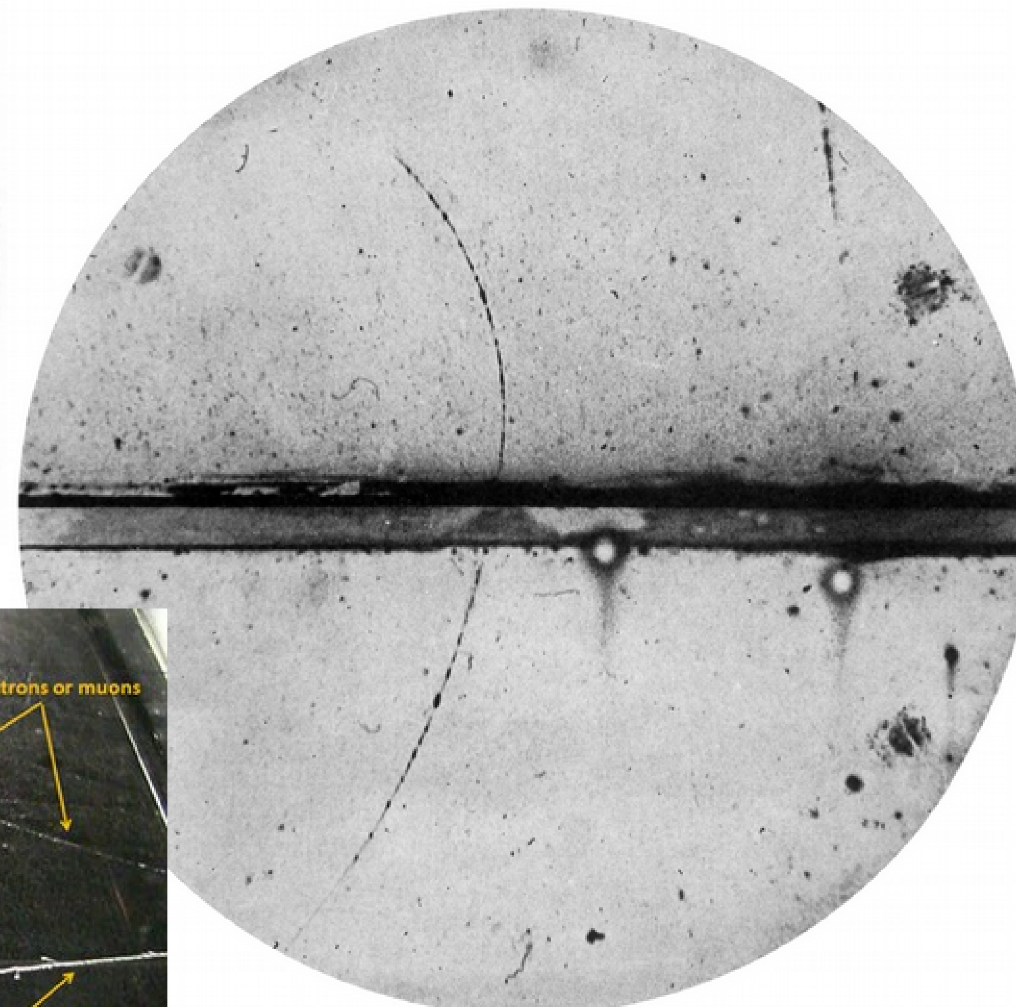
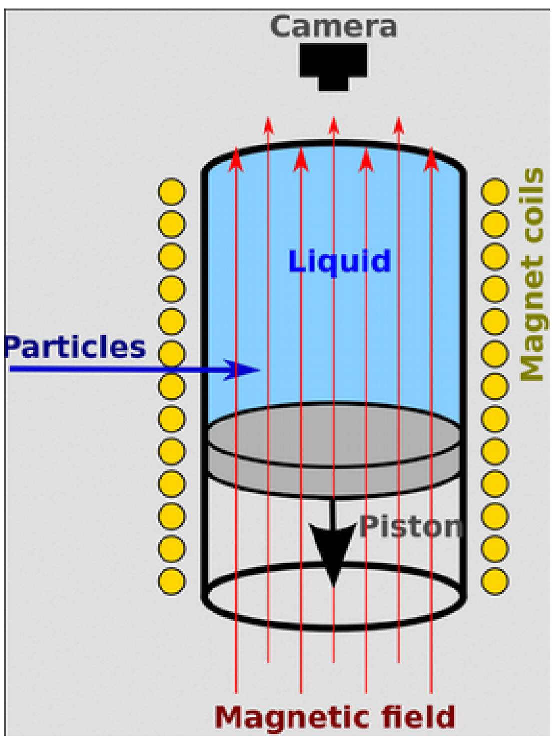


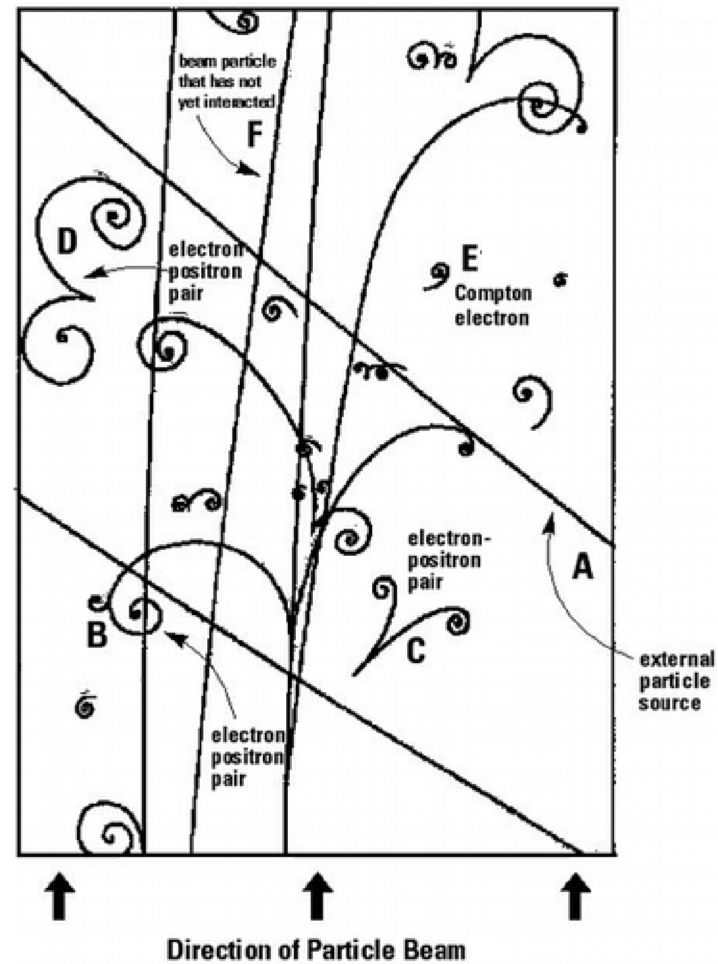
Fig. 1.

A diagram of Wilson's apparatus. The cylindrical cloud chamber ('A') is 16.5cm across by 3.4cm deep.

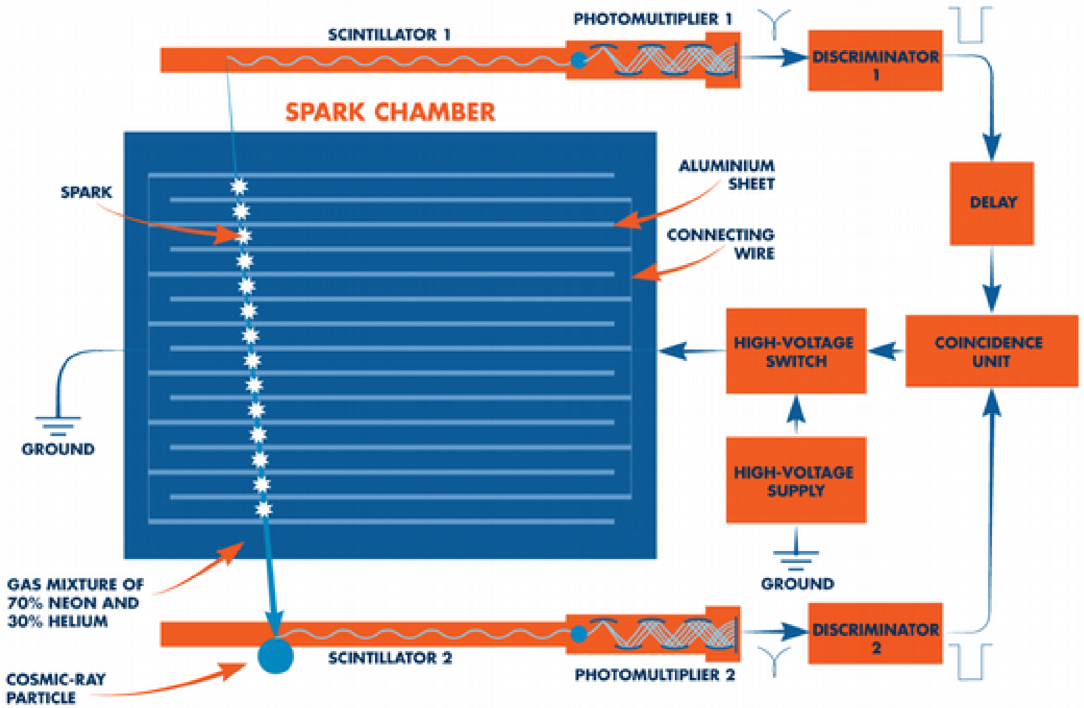


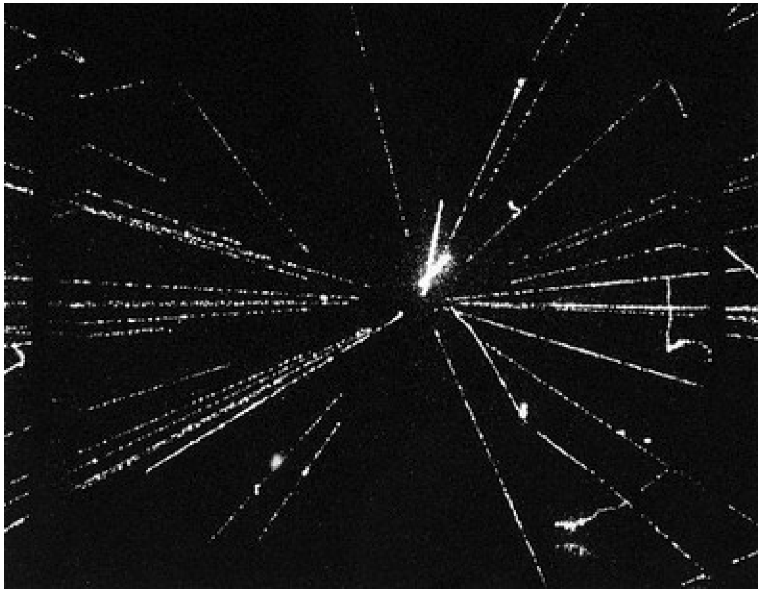
A bubble chamber is a vessel filled with a superheated transparent liquid (most often liquid hydrogen) used to detect electrically charged particles moving through it. It was invented in 1952 by Donald A. Glaser, for which he was awarded the 1960 Nobel Prize in Physics.



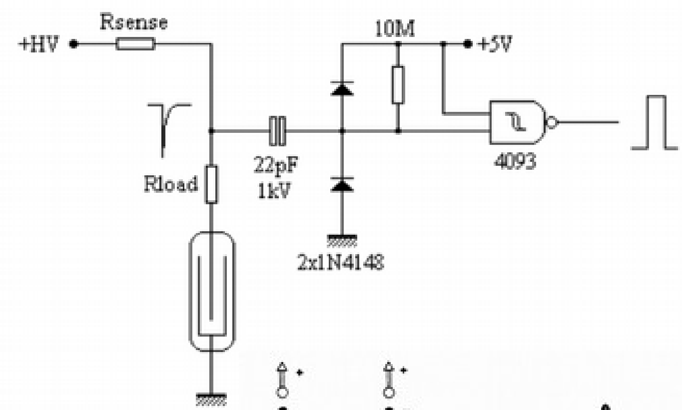


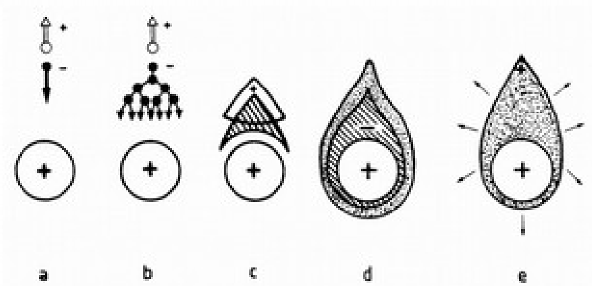
Spark chamber

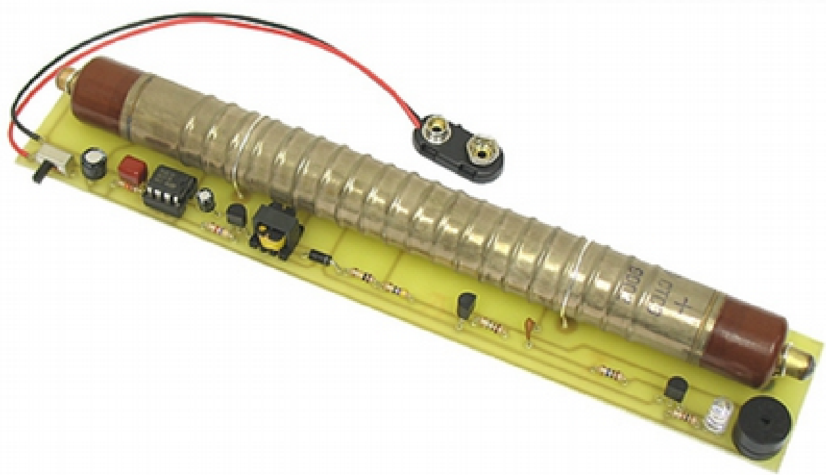


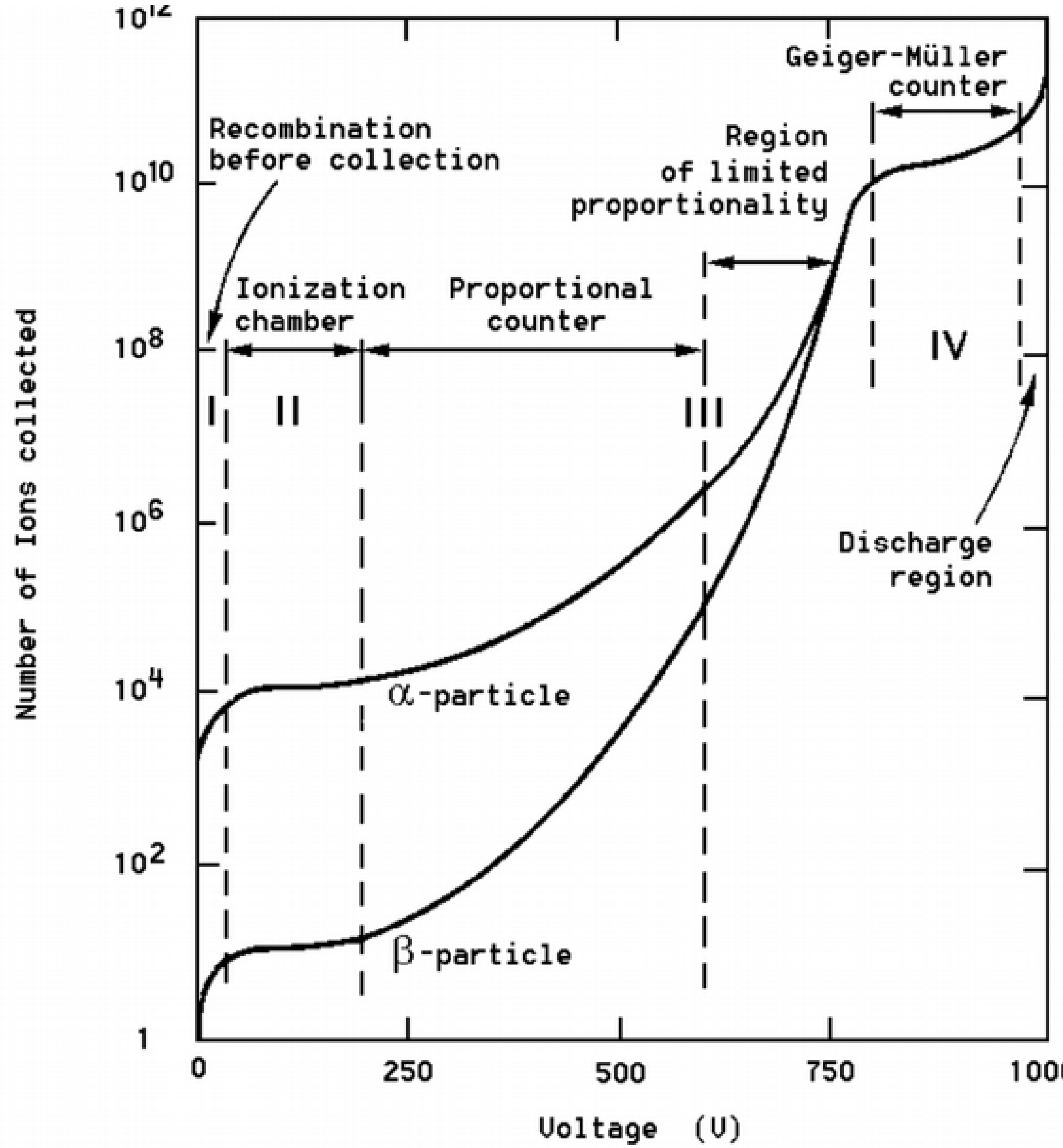


Gaseous detectors

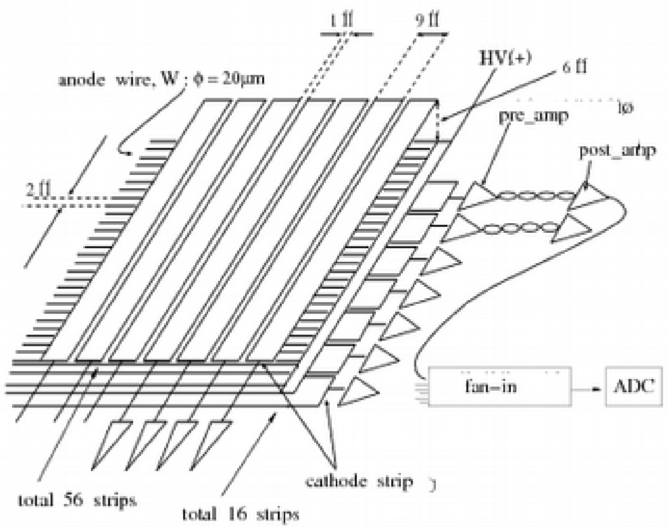


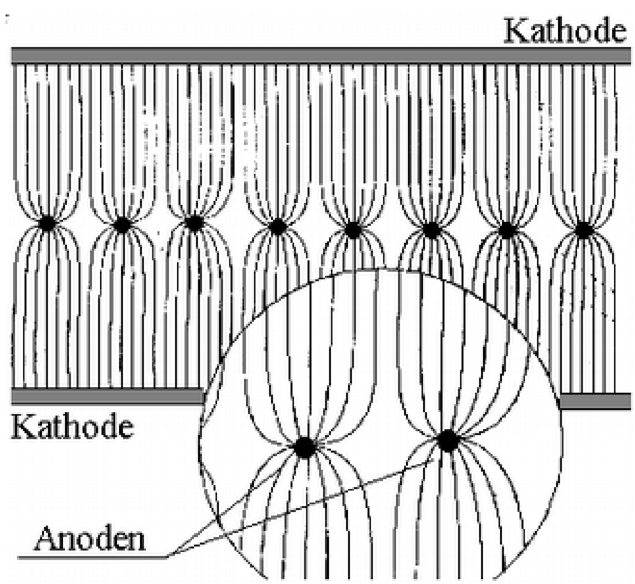


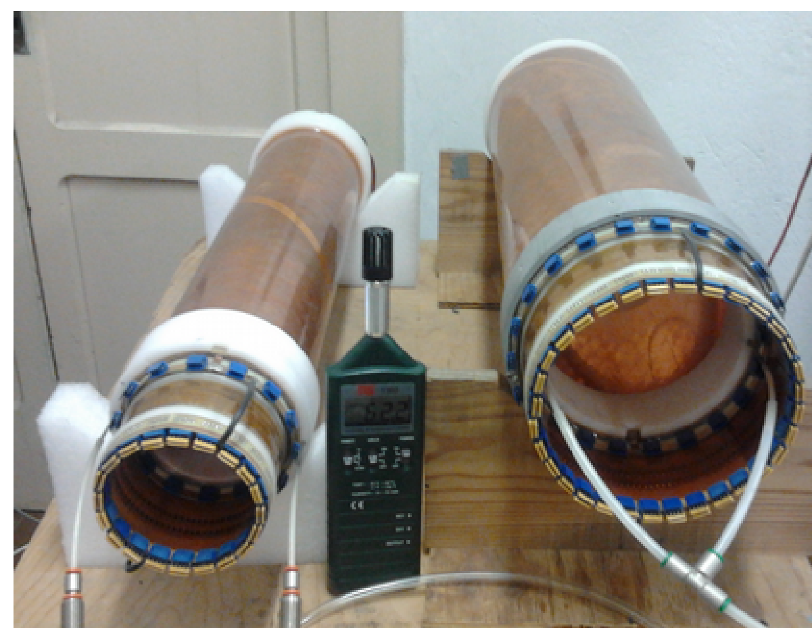




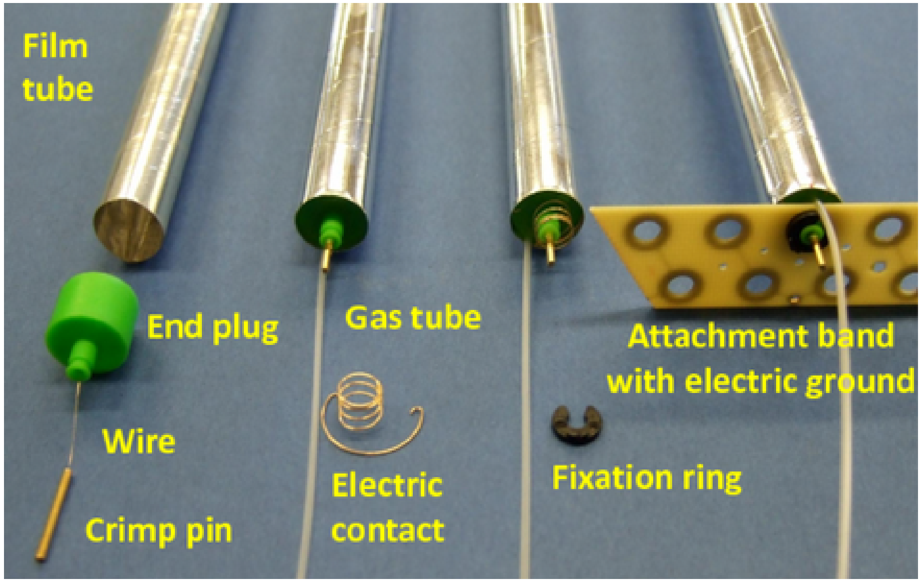
MWPC – multi wire proportional chamber



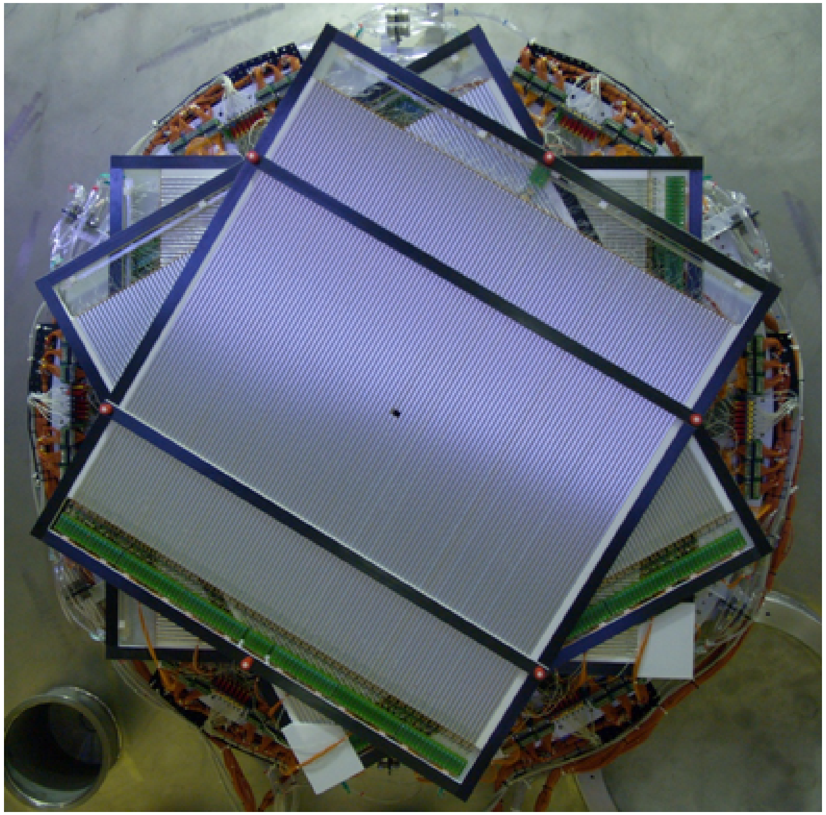


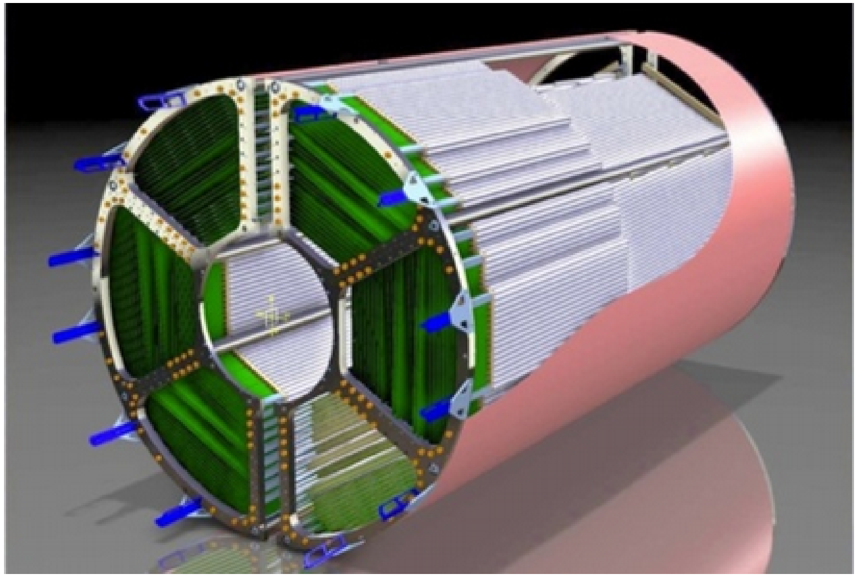


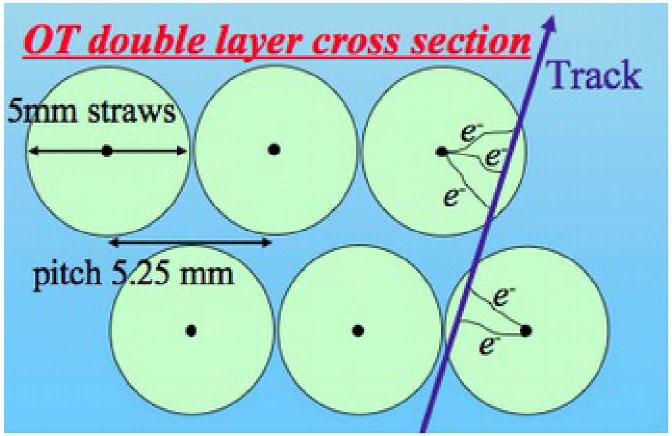
Straw tubes



Film tube
End plug
Wire
Crimp pin
Gas tube
Electric contact
Attachment band with electric ground
Fixation ring

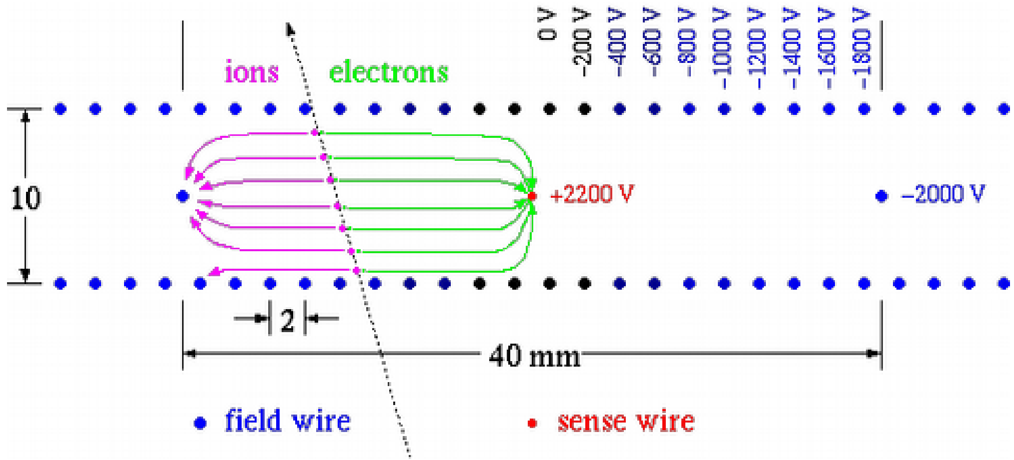


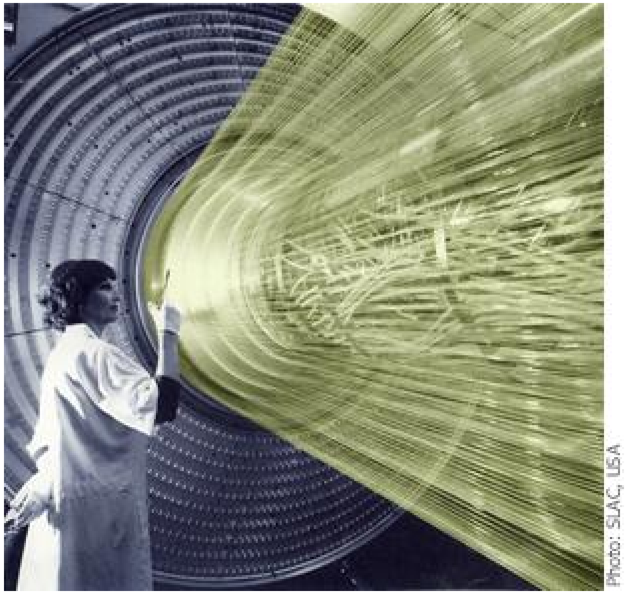


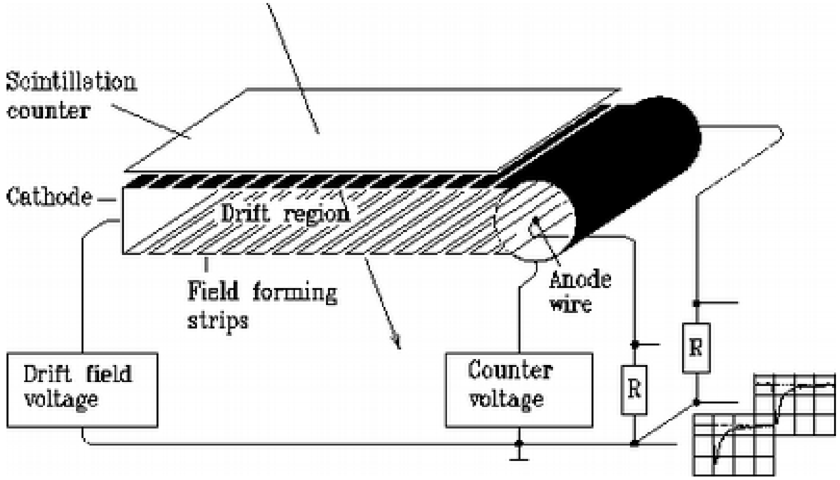


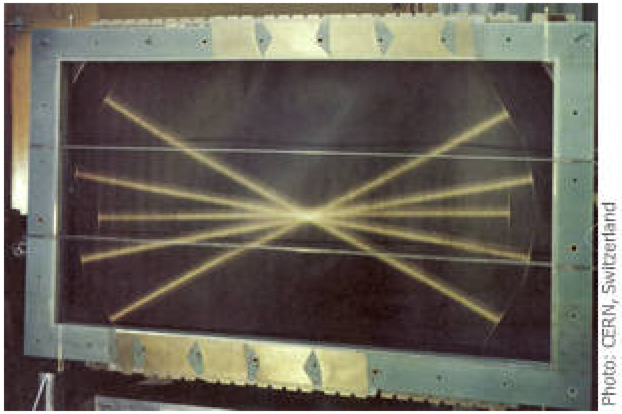
OT double layer cross section
Track
5mm straws
e⁻
e⁻
e⁻
pitch 5.25 mm
e⁻
e⁻

Drift chamber

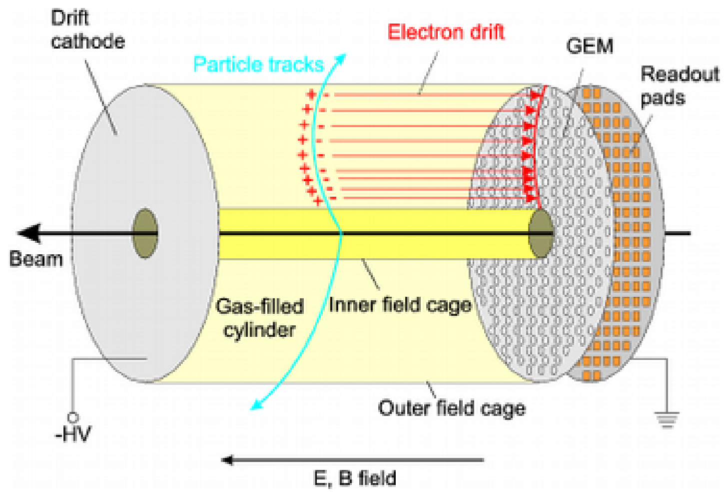


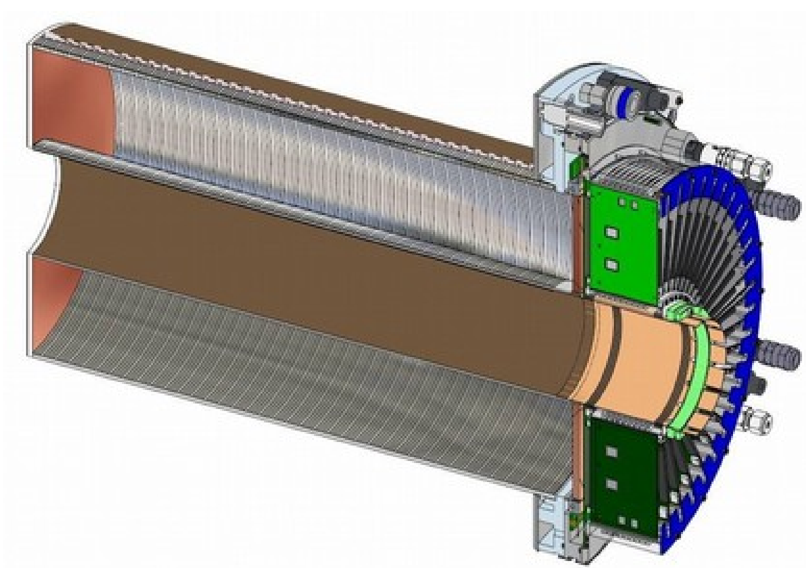


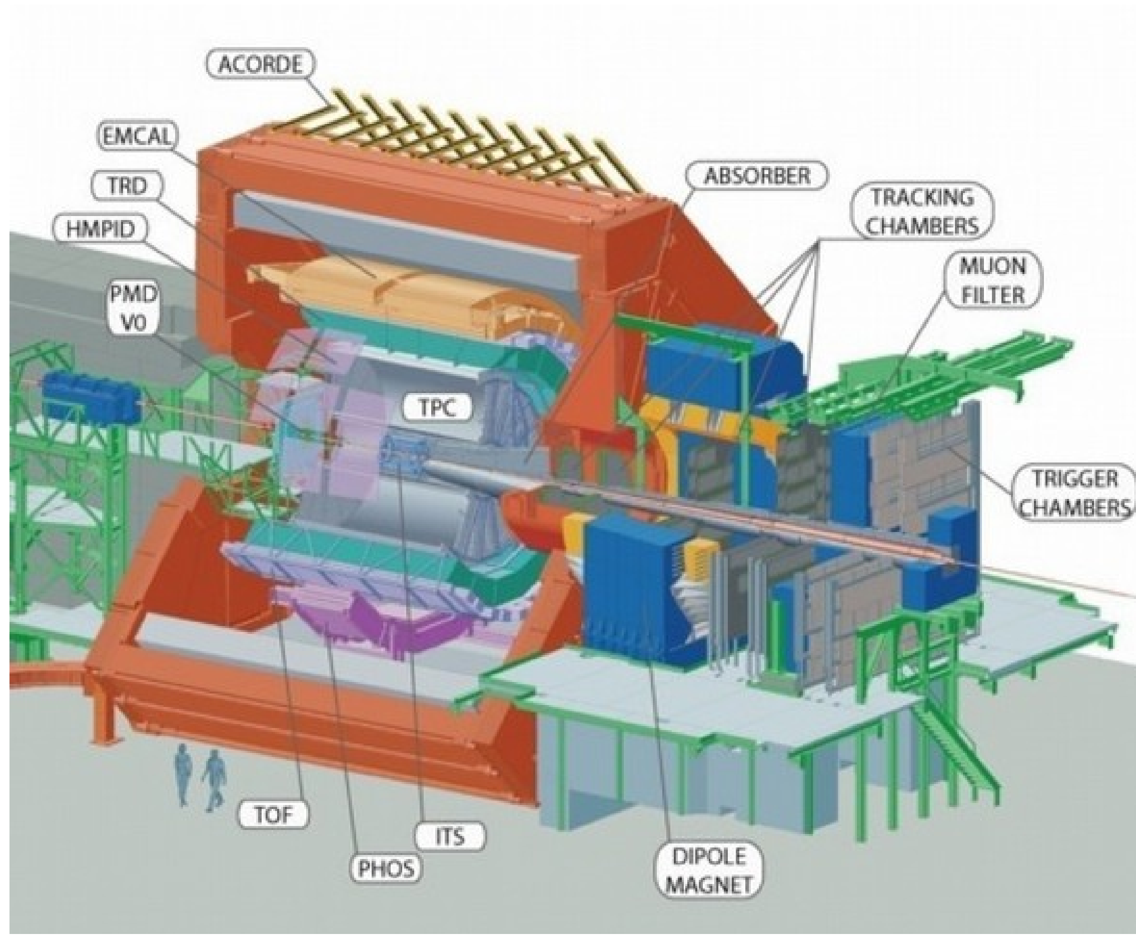




TPC time projection chamber

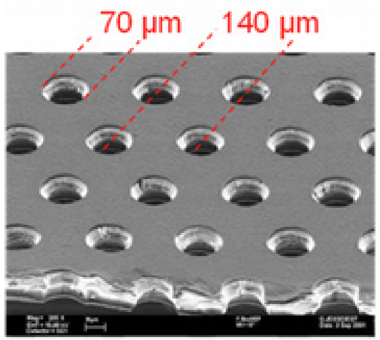


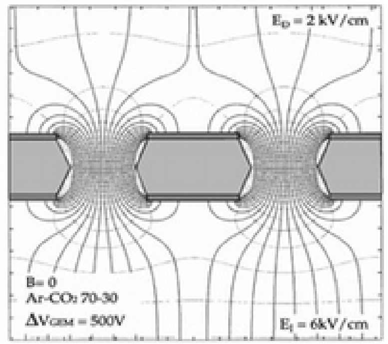


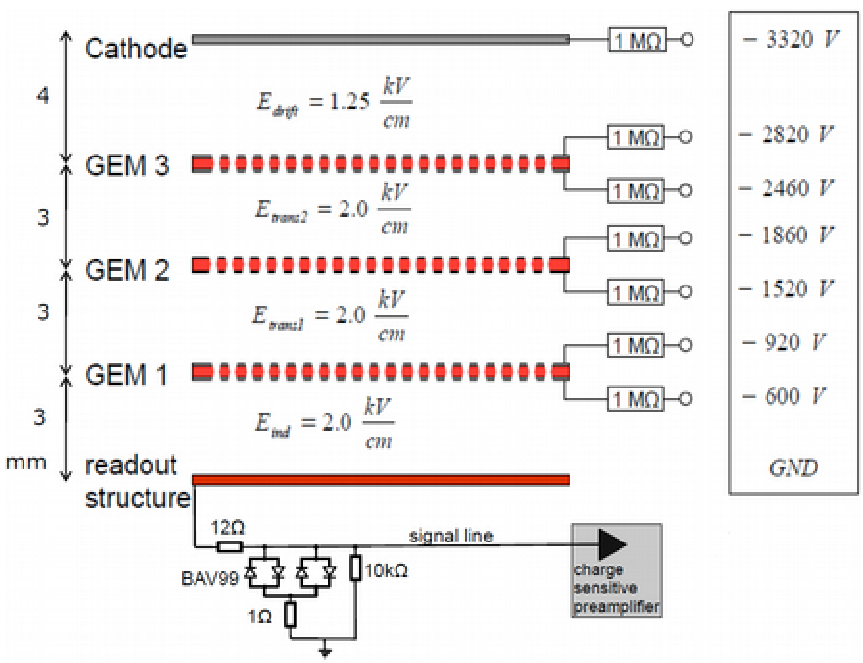


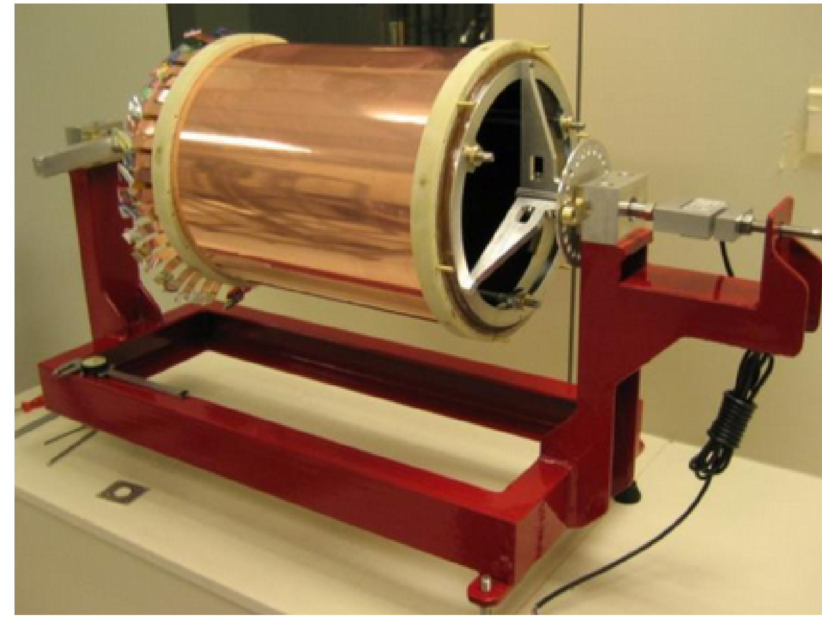
Member of the Helmholtz-Association

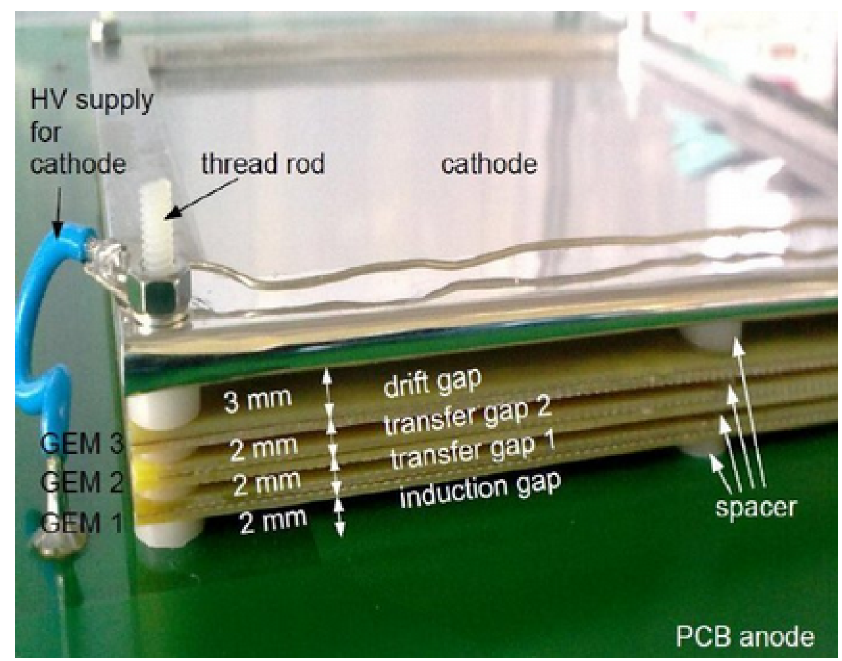
GEM – gas electron multiplier



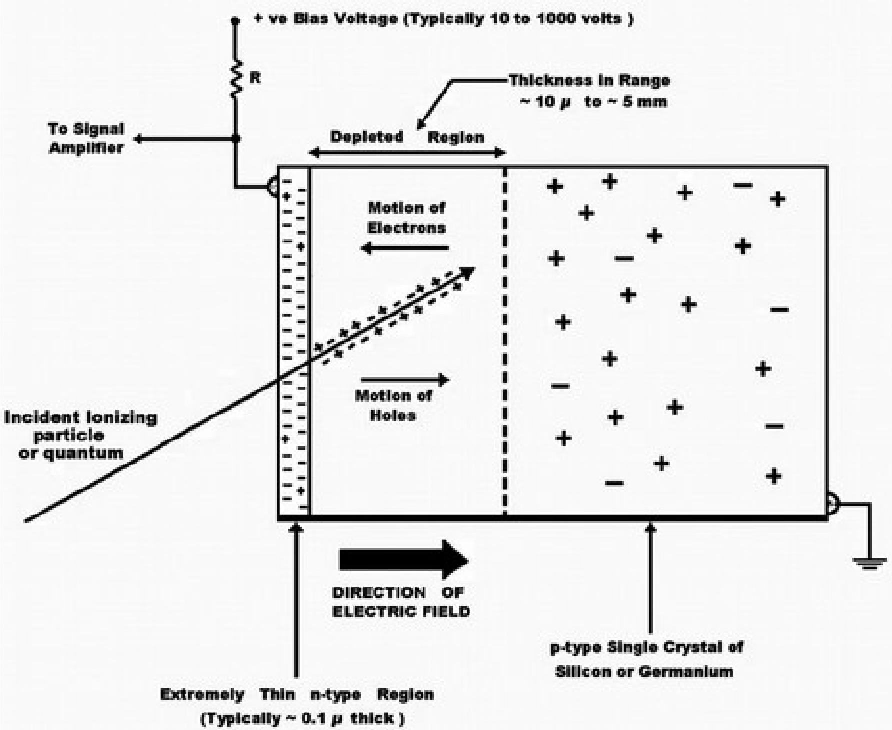


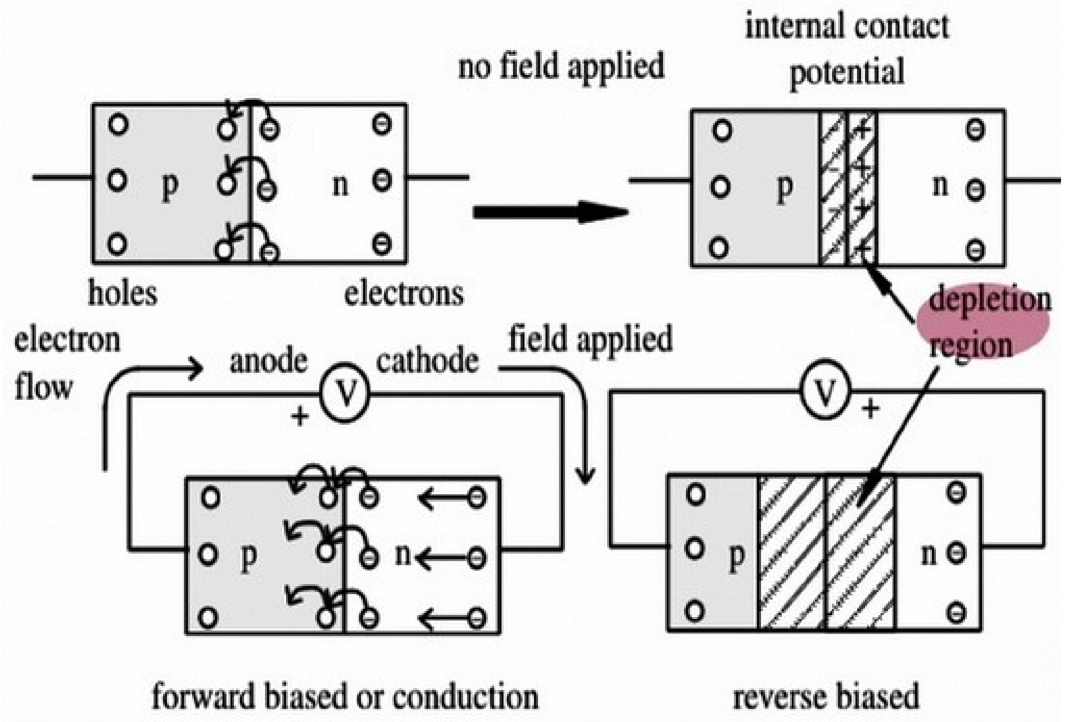


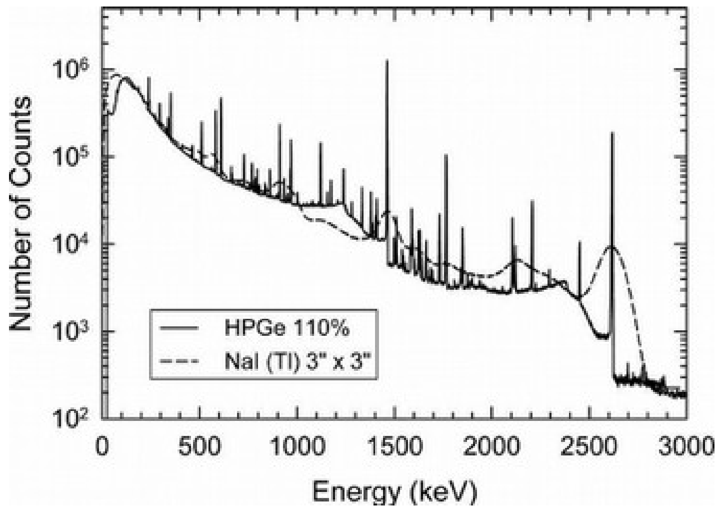


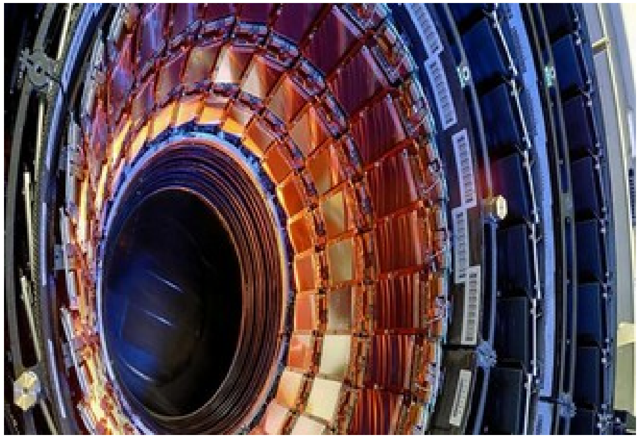


Semiconductor detectors



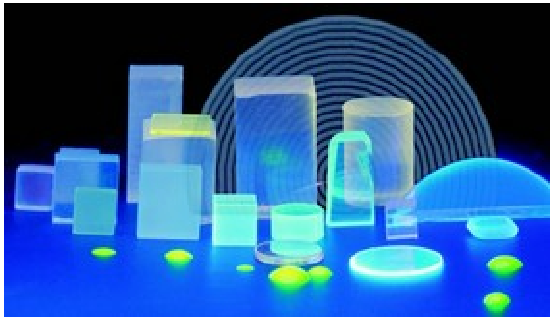


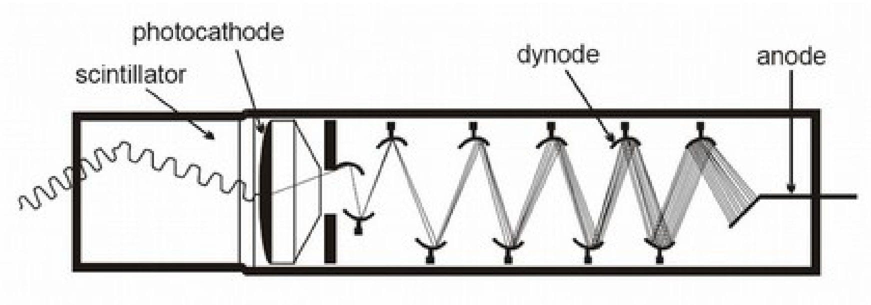


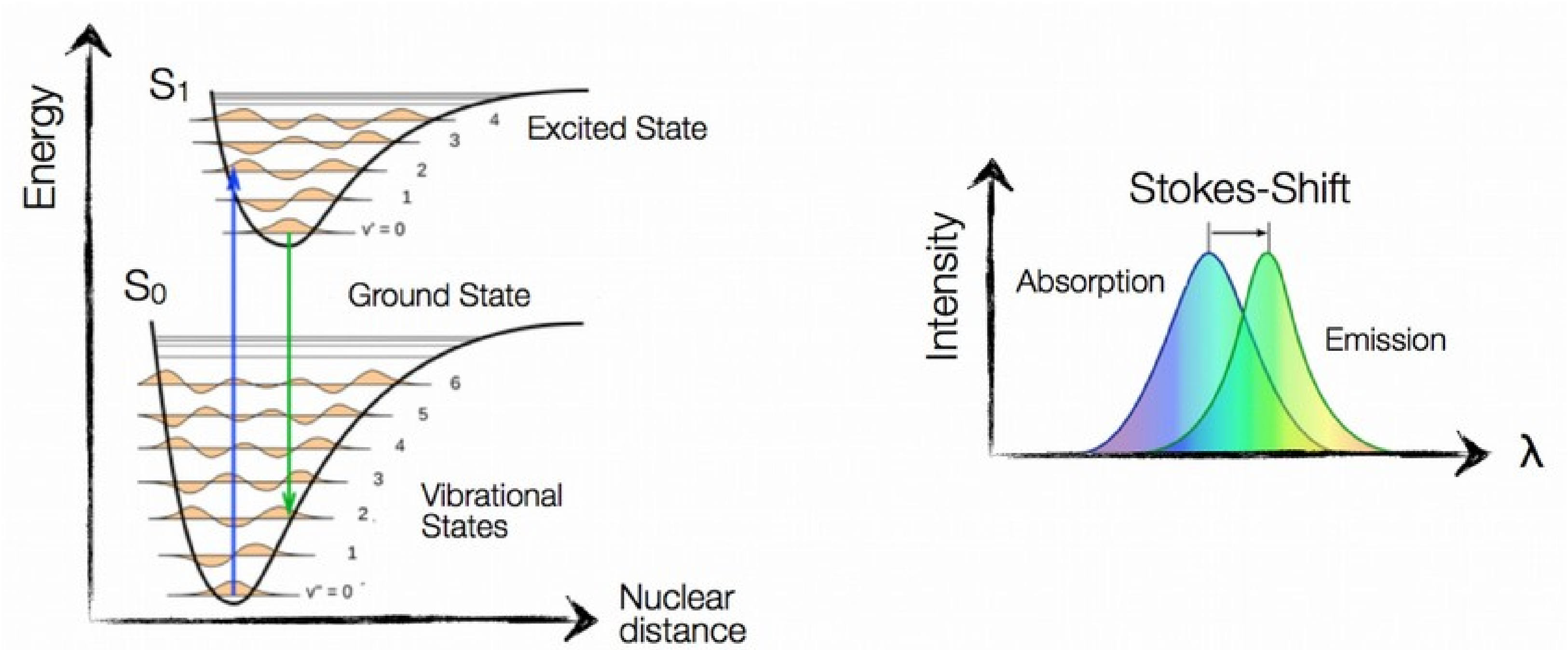


Scintillation

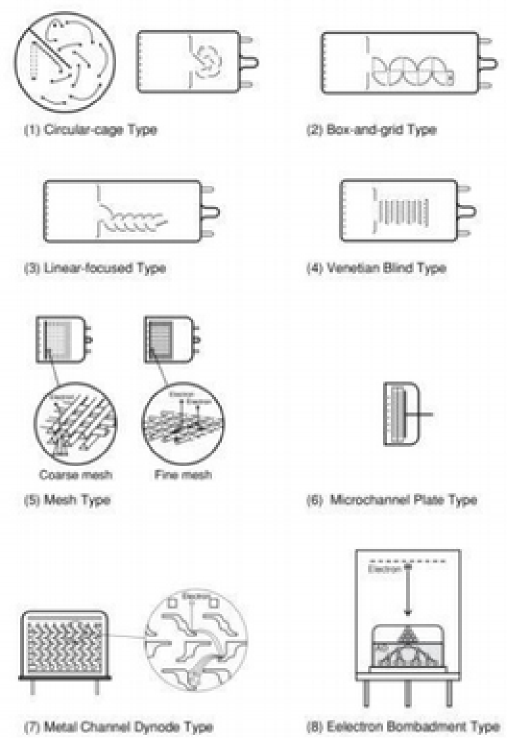
The light emission is governed by the electronic transitions in the molecule. The electronic levels have a typical energy spacing of ~4 eV. The vibrational levels of the molecule (dE ~ 0.2 eV) also play a role. Electrons in high levels typically deexcite to the lowest excited state without emission of radiation.

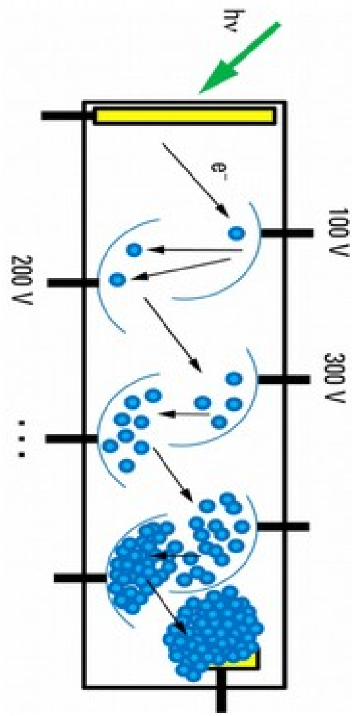




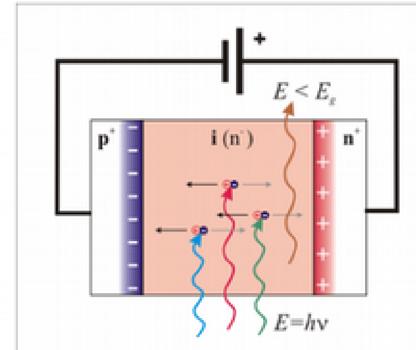


Photosensors

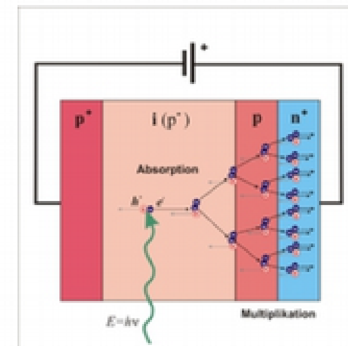


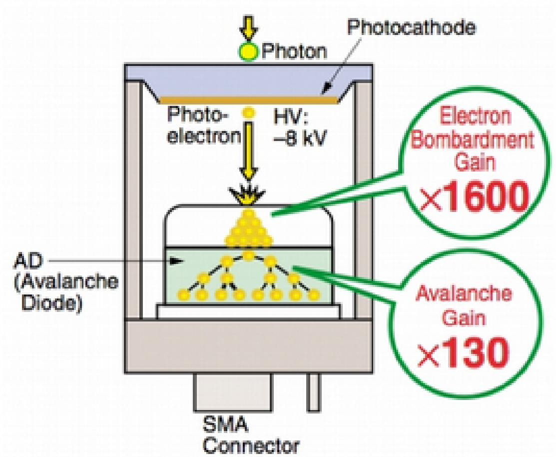


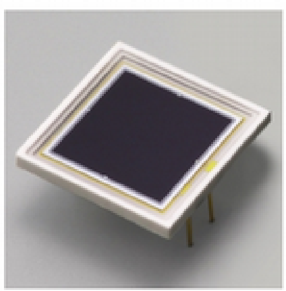
PIN



APD

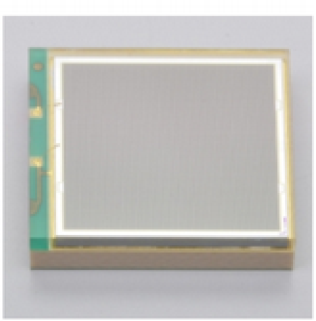






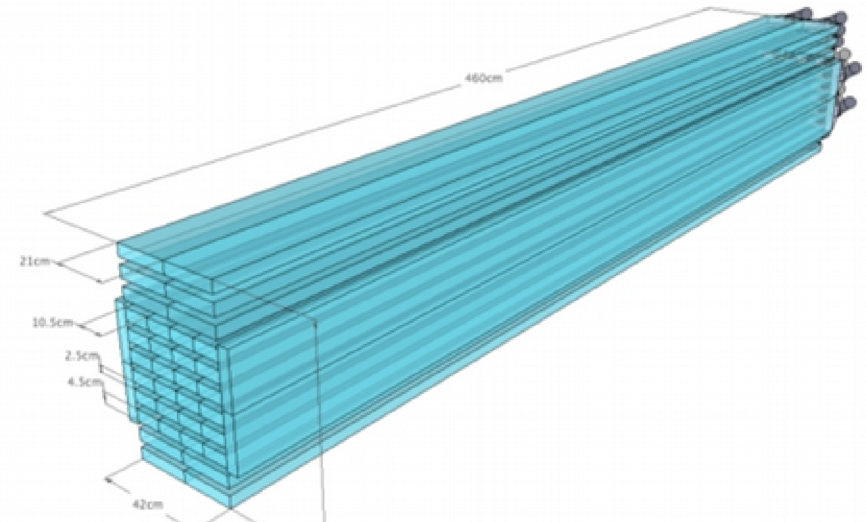
PIN/APD

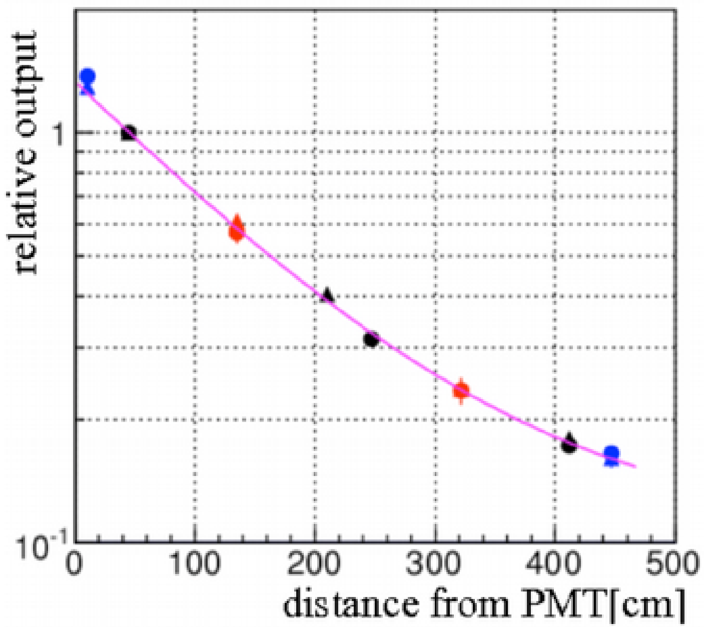
SiPM

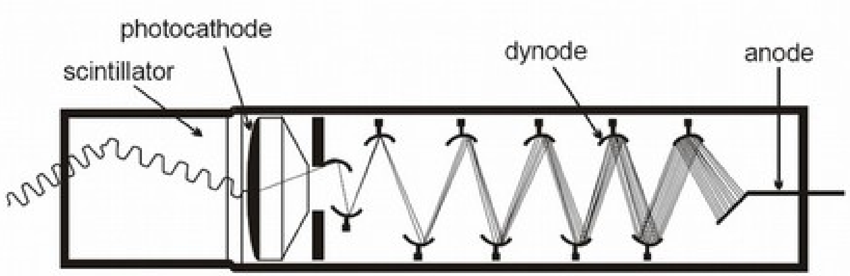


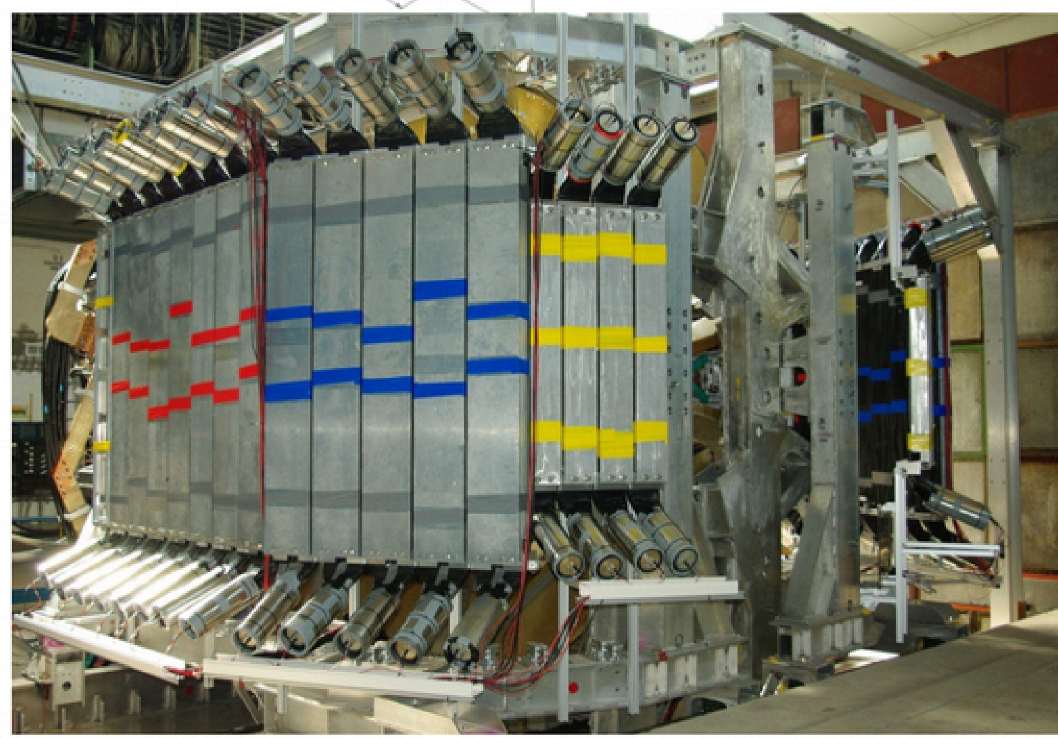
TOF – time of flight wall

$$Y = Y_0 \cdot e^{\frac{-l}{\lambda}}$$

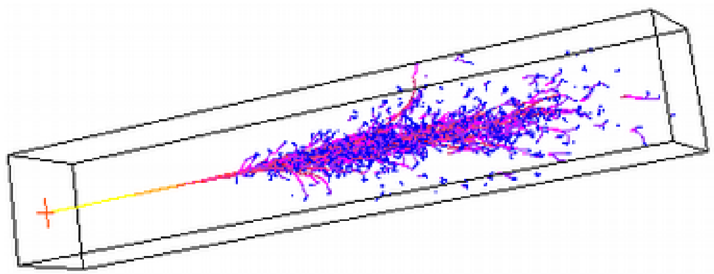


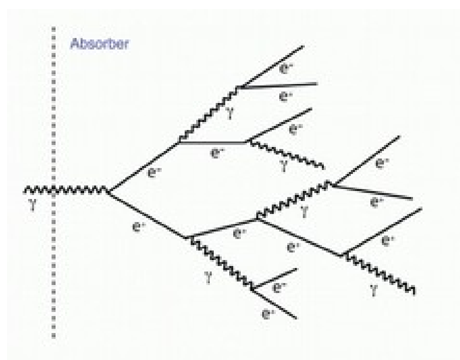


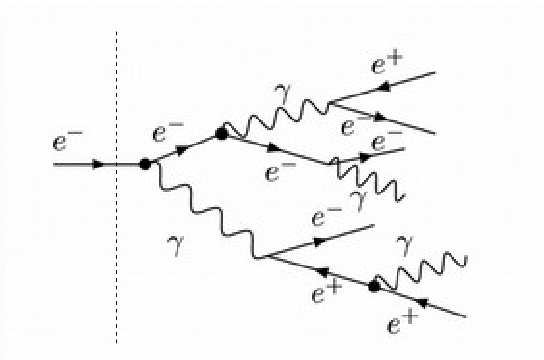


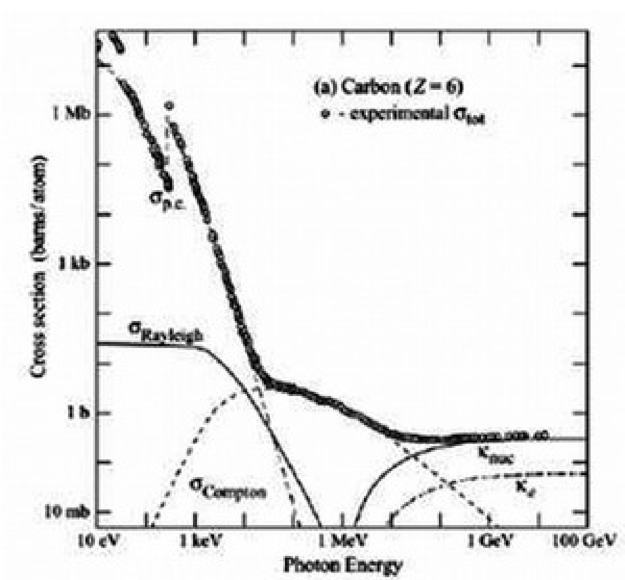


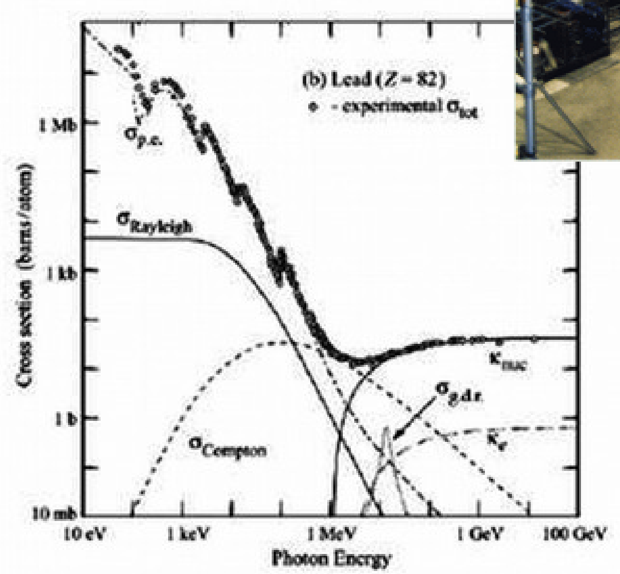
EMC Electromagnetic calorimeters

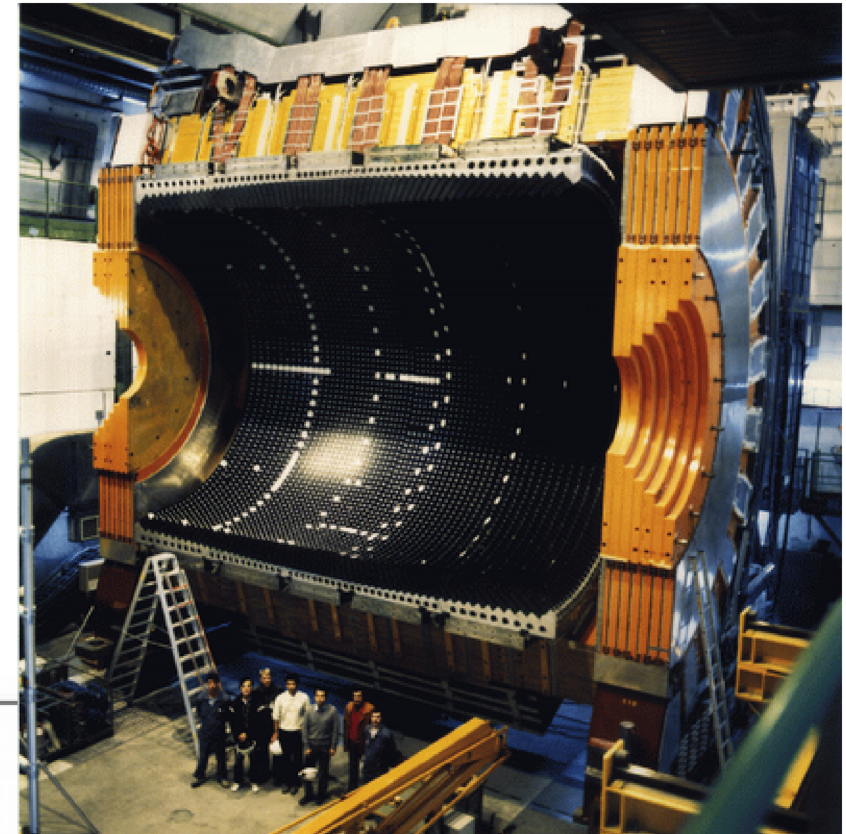




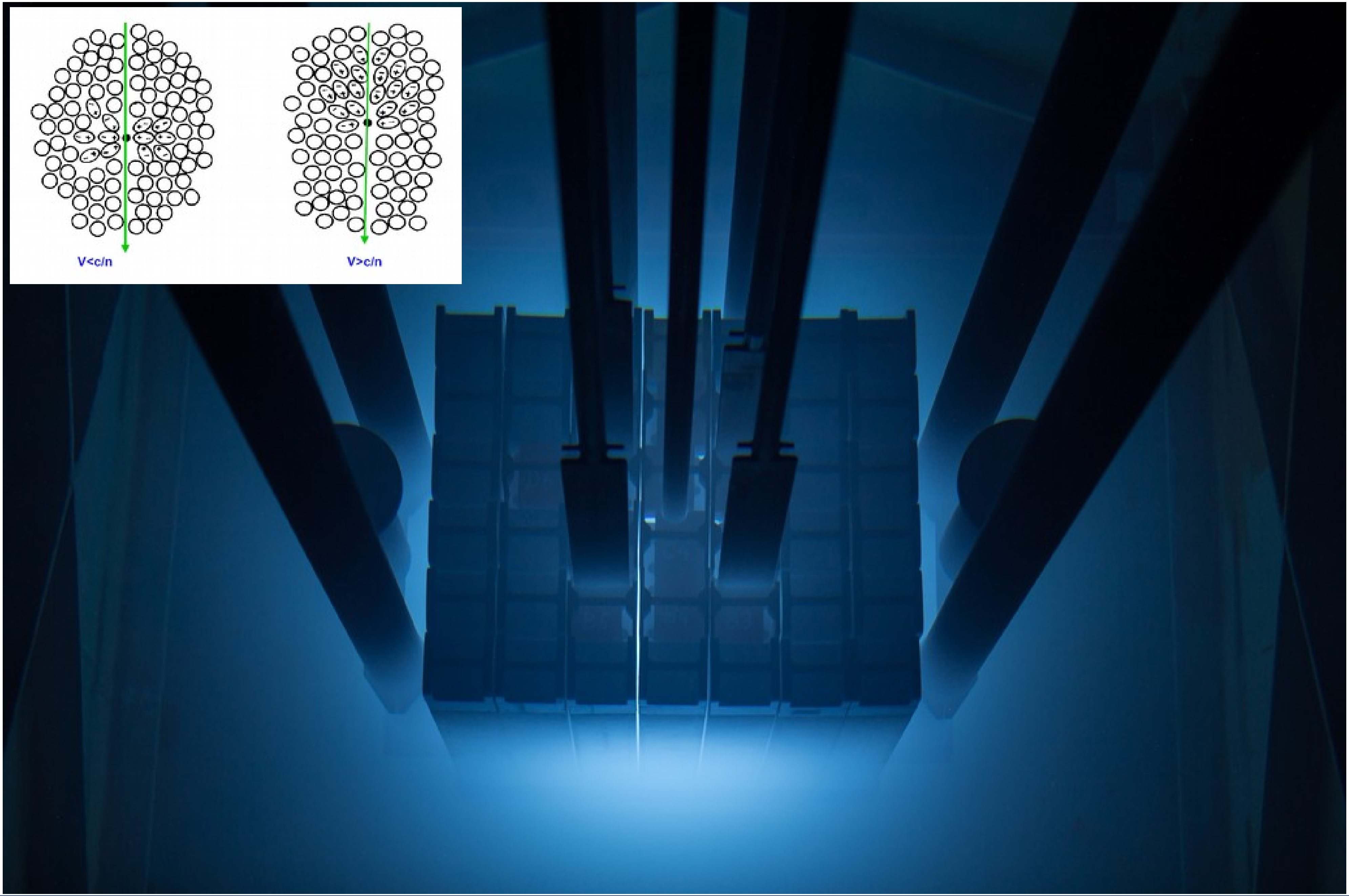








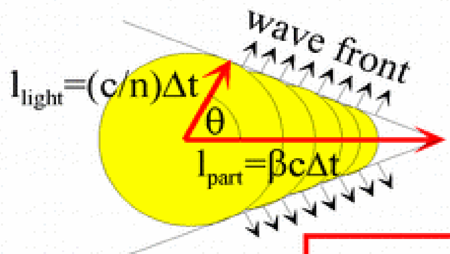
Uni Basel 2kW nuclear reactor

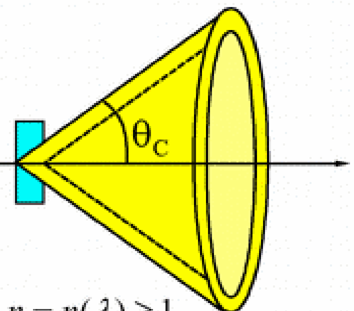


Cherenkov effect

Cherenkov radiation is emitted when a charged particle passes a dielectric medium with velocity

$$\beta \geq \beta_{thr} = \frac{1}{n} \quad n: \text{refractive index}$$



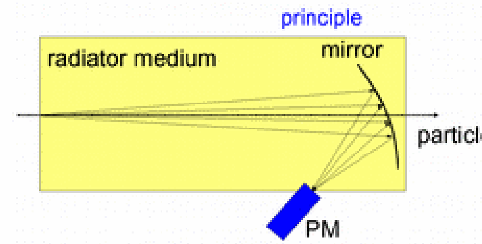


$$\cos\theta_C = \frac{1}{n\beta} \quad \text{with} \quad n = n(\lambda) \geq 1$$

$$\beta_{thr} = \frac{1}{n} \rightarrow \theta_C \approx 0 \qquad \text{threshold}$$

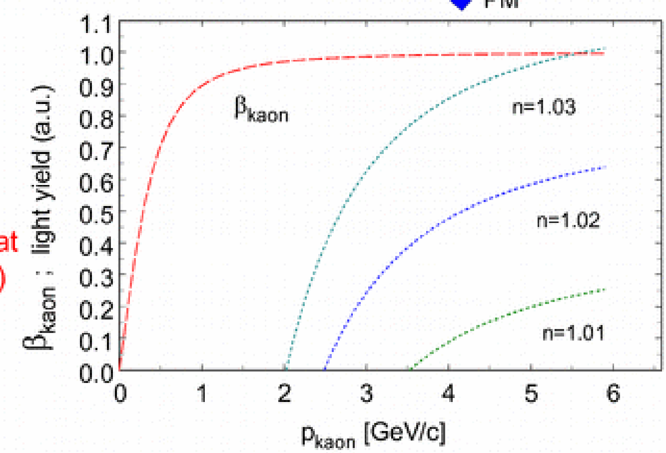
$$\theta_{max} = \arccos\frac{1}{n} \qquad \text{'saturated' angle } (\beta=1)$$

$$N \approx 1 - \frac{1}{n^2\beta^2} = 1 - \frac{1}{n^2}\cdot\left(1 + m^2/p^2\right)$$

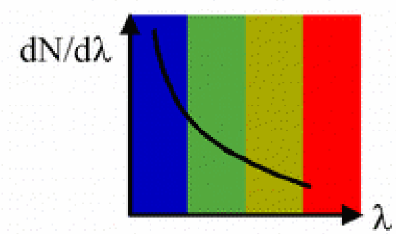


Example: study of an Aerogel threshold detector for the BELLE experiment at KEK (Japan)

Goal: π/K separation

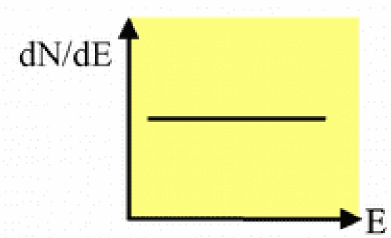


Number of emitted photons per unit length and unit wavelength interval

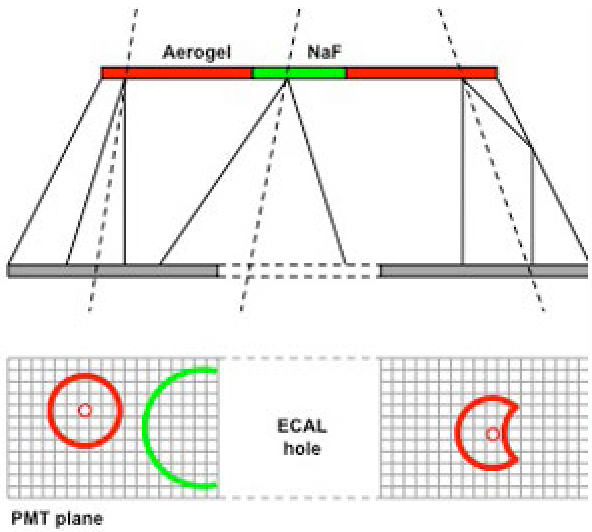


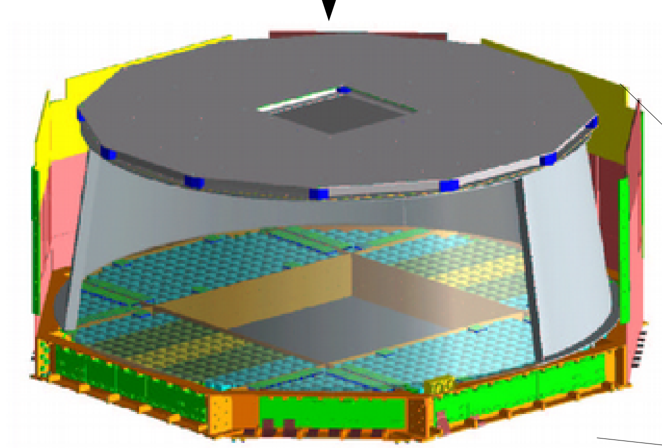
$$\frac{d^2N}{dx\,d\lambda} = \frac{2\pi z^2\alpha}{\lambda^2}\left(1 - \frac{1}{\beta^2 n^2}\right) = \frac{2\pi z^2\alpha}{\lambda^2}\sin^2\theta_C$$

$$\frac{d^2N}{dx\,d\lambda} \propto \frac{1}{\lambda^2} \quad \text{with} \quad \lambda = \frac{c}{\nu} = \frac{hc}{E} \qquad \frac{d^2N}{dx\,dE} = const.$$

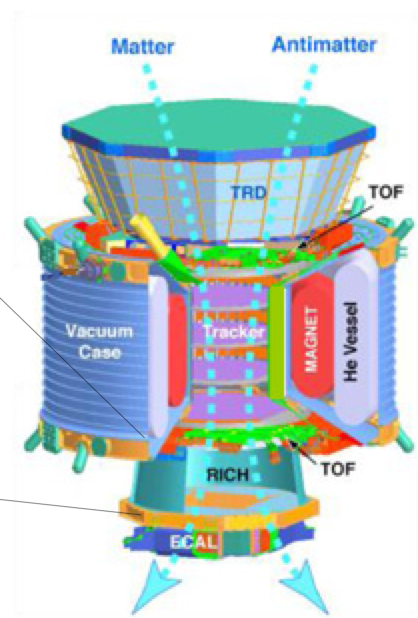


AMS-2 alpha magnetic spectrometer

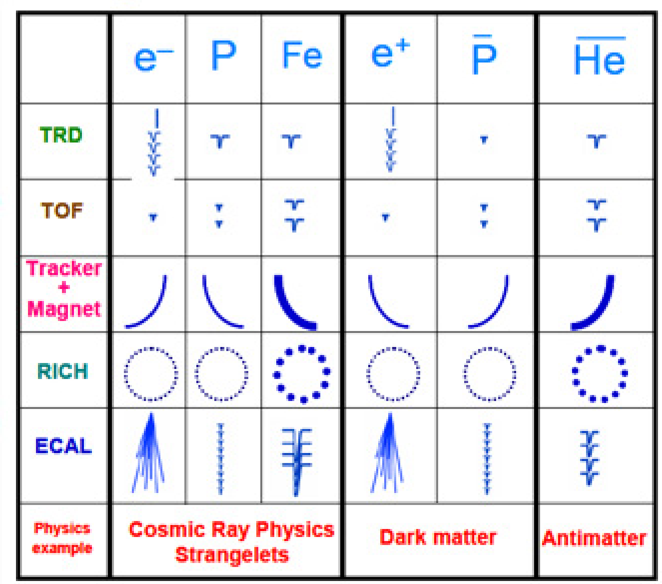




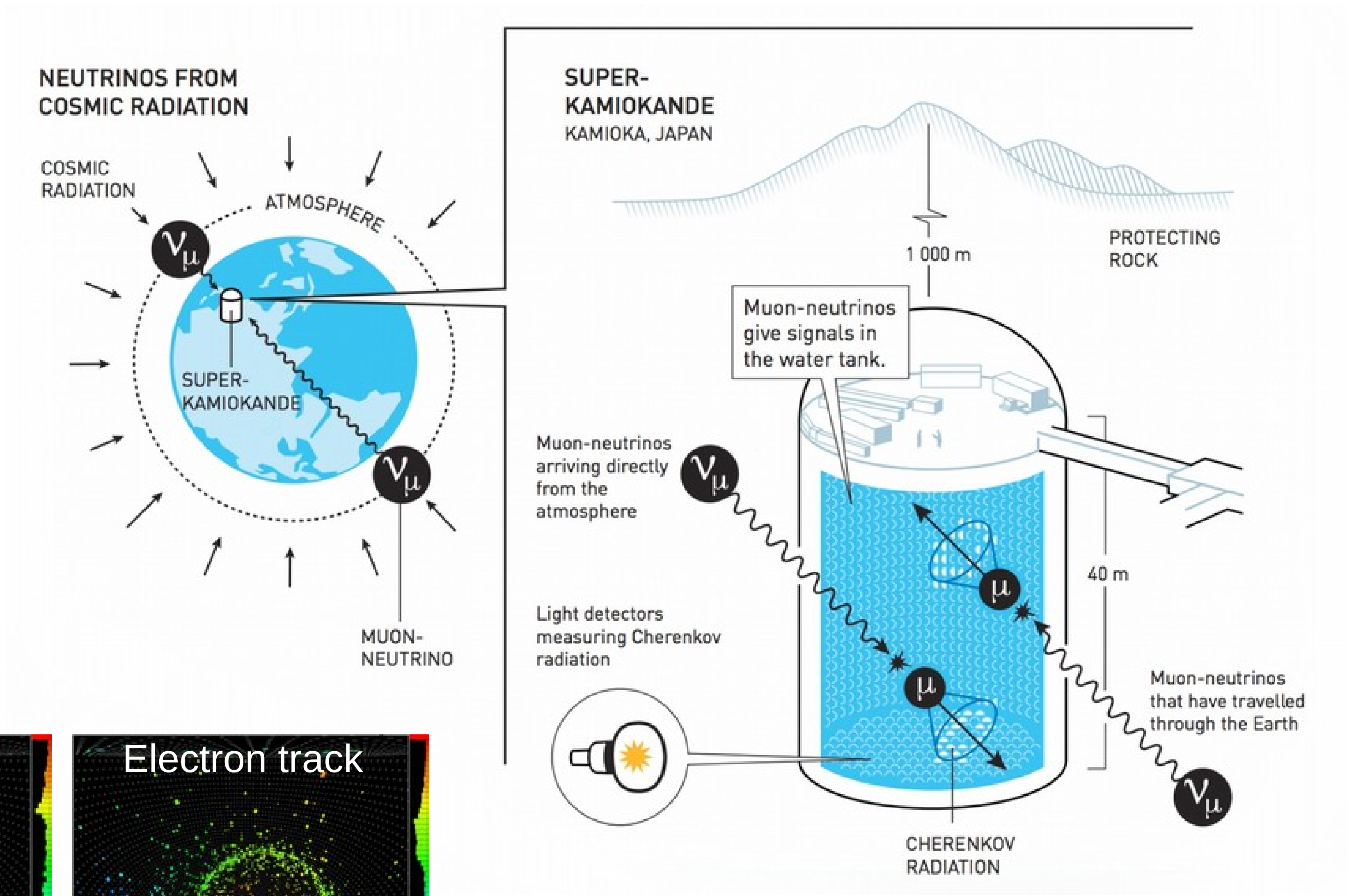
AMS: A TeV Magnetic Spectrometer in Space

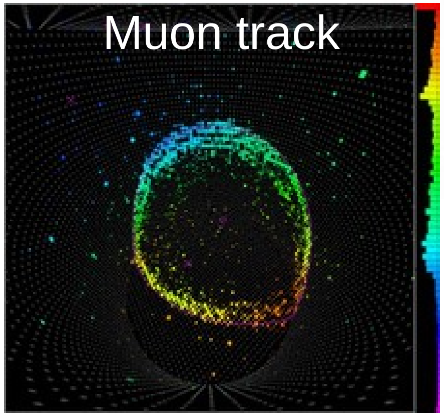


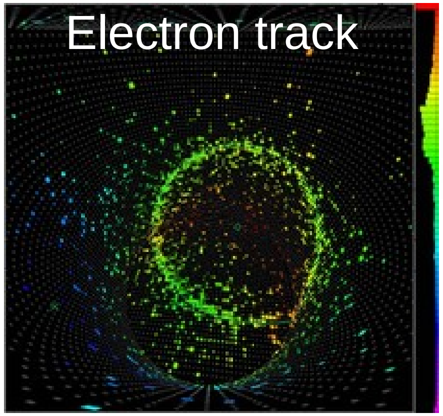
Data Signature of Various Particles in Each Detector



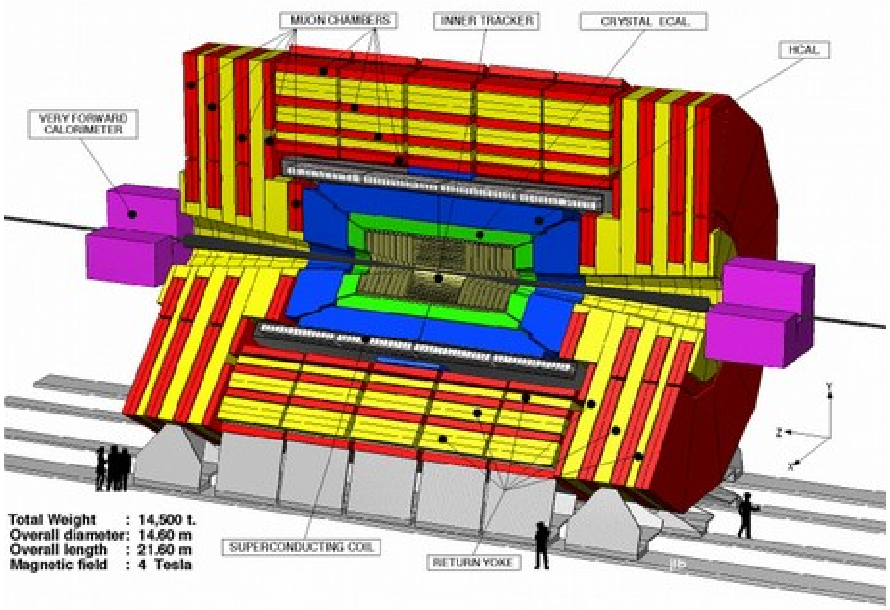
Super-Kamiokande neutrino detector

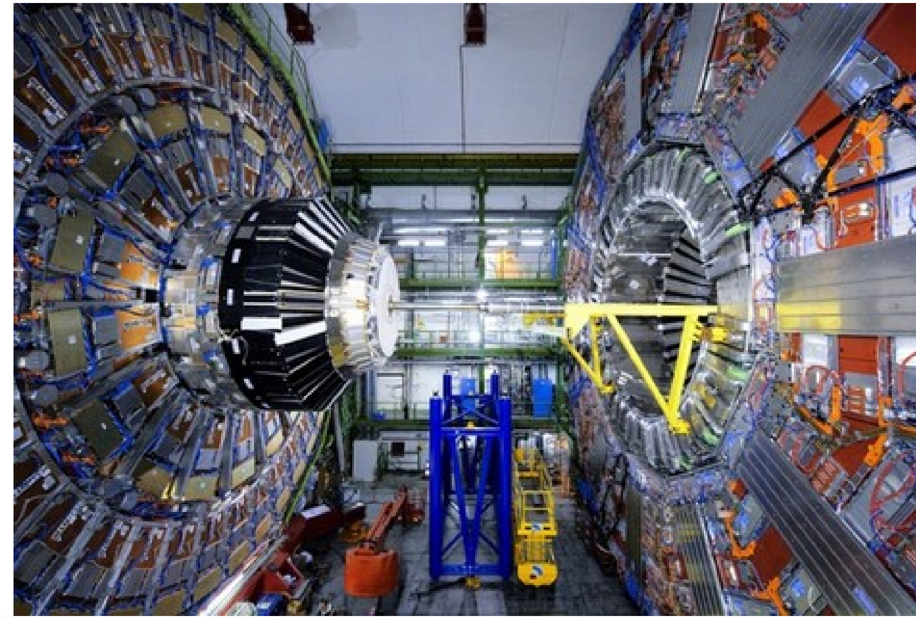


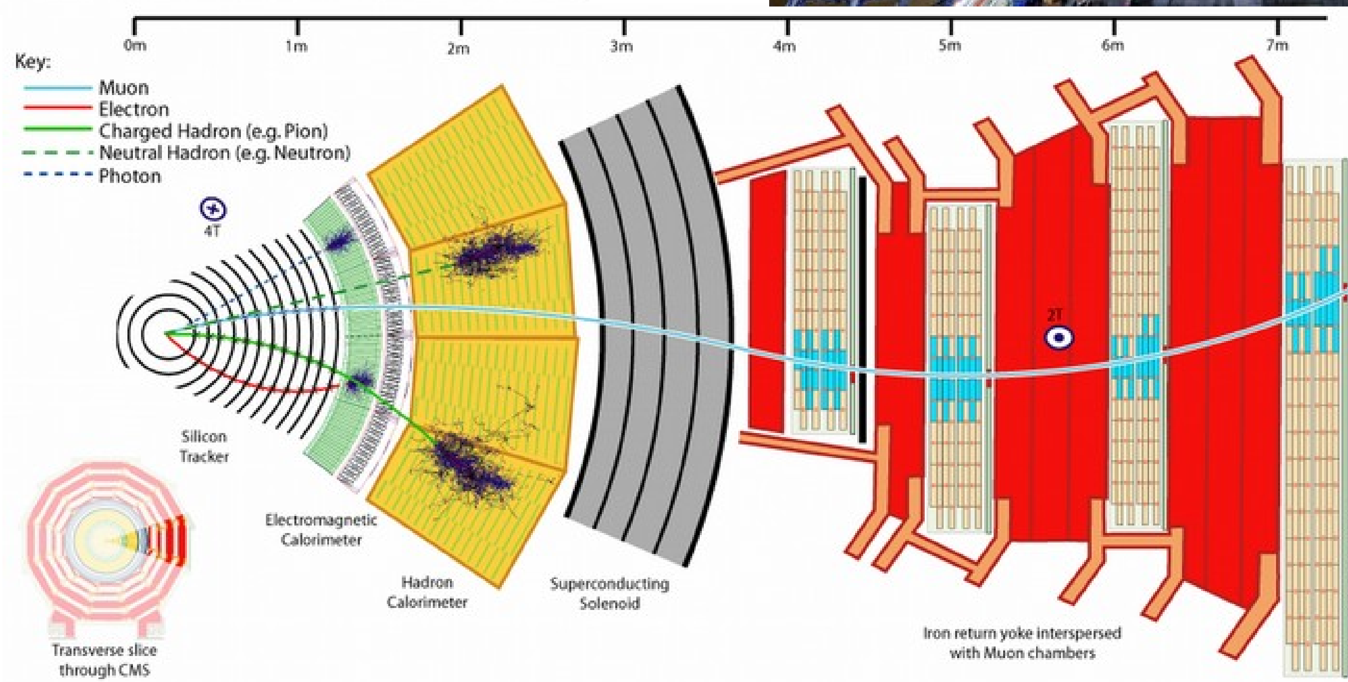




CMS detector at LHC, CERN



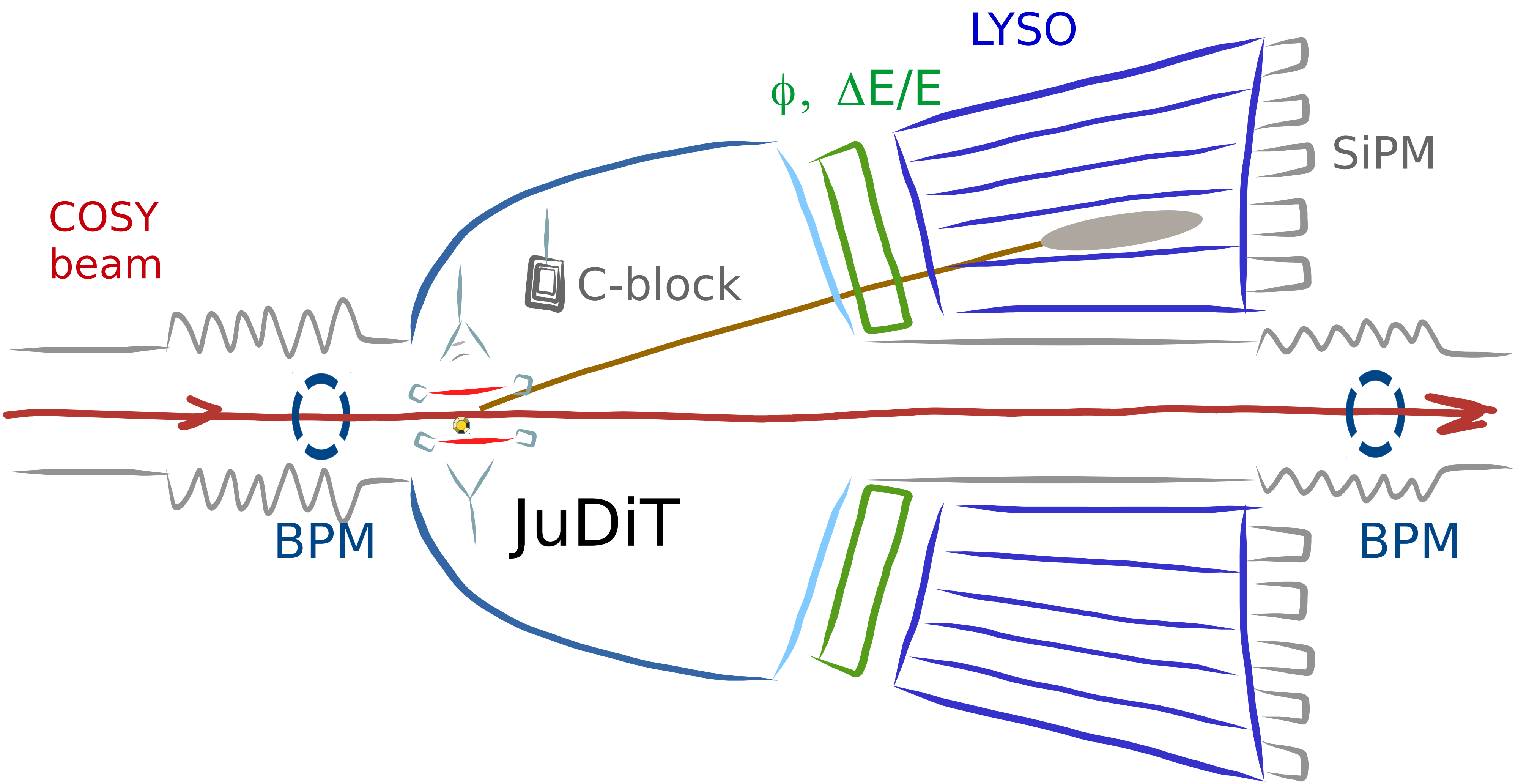




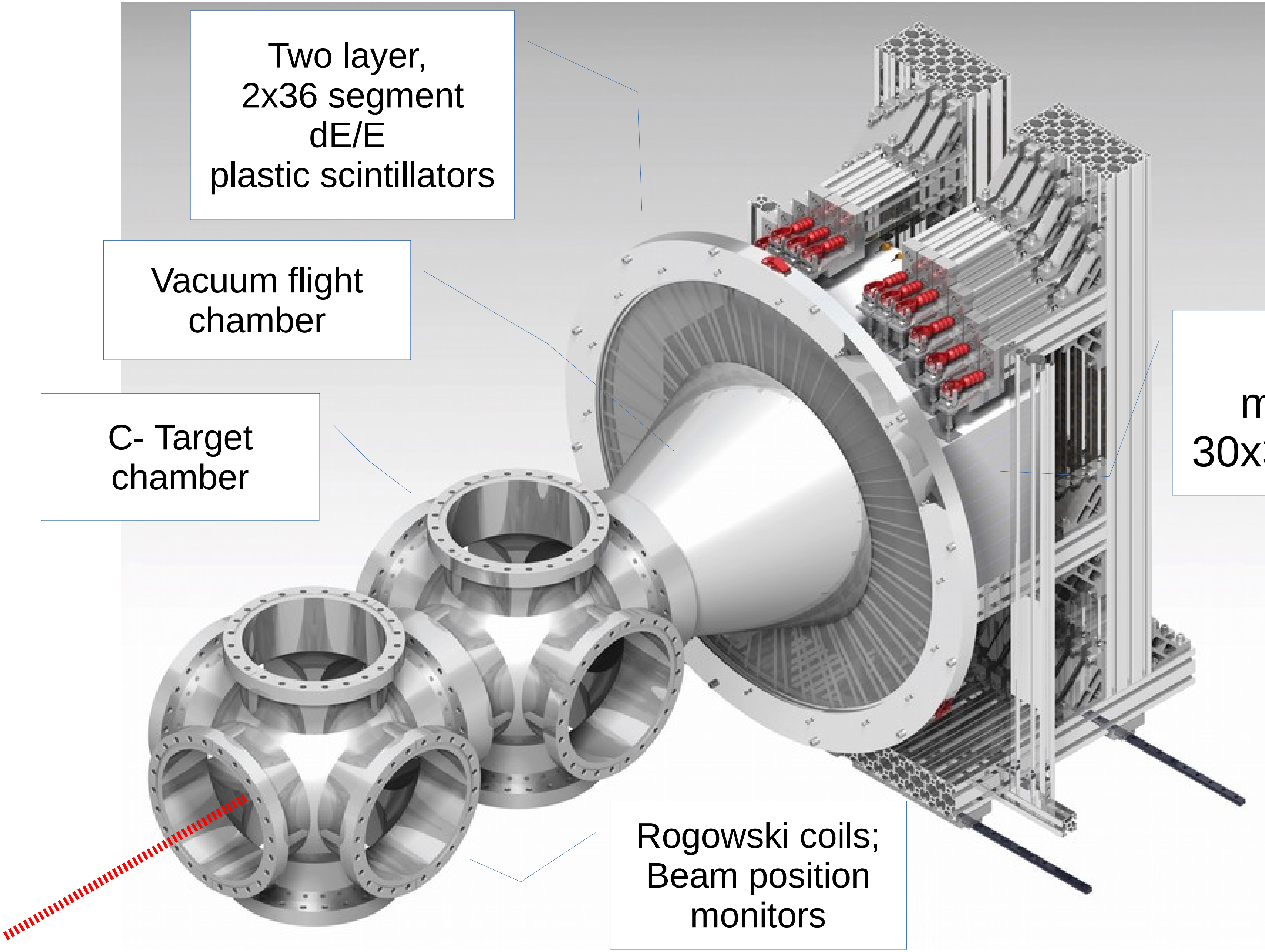
Member of the Helmholtz-Association

JEDI Polarimeter

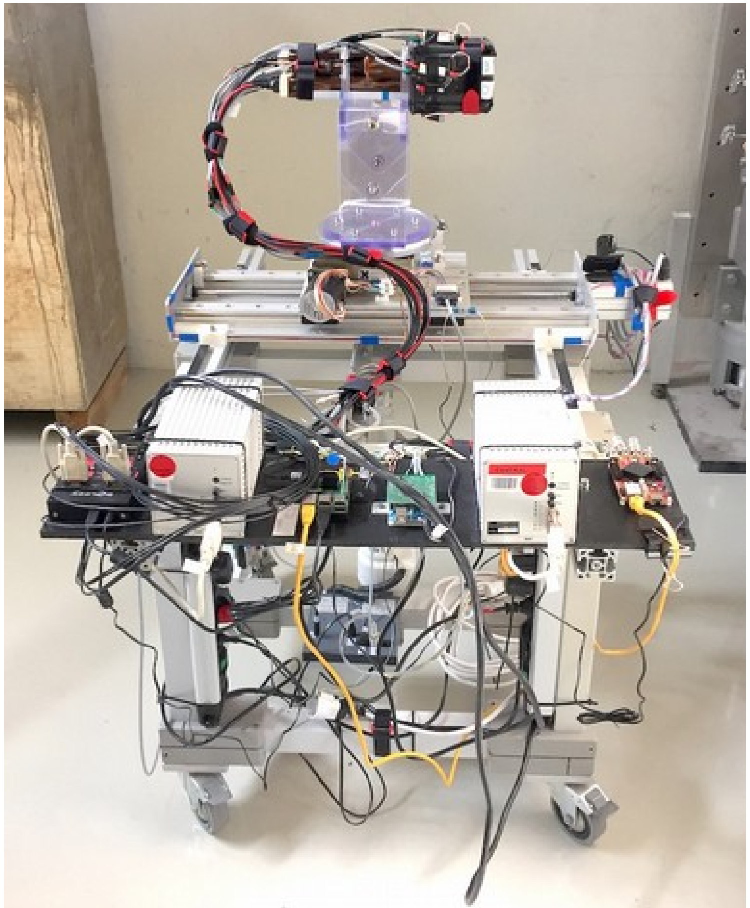
JÜLICH FORSCHUNGSZENTRUM

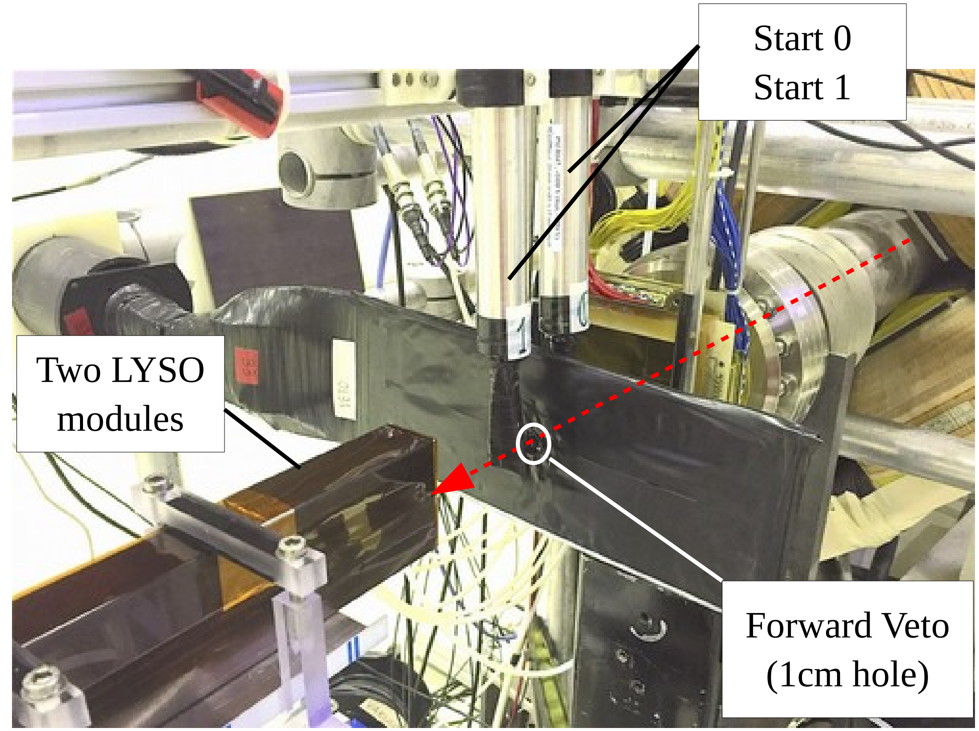


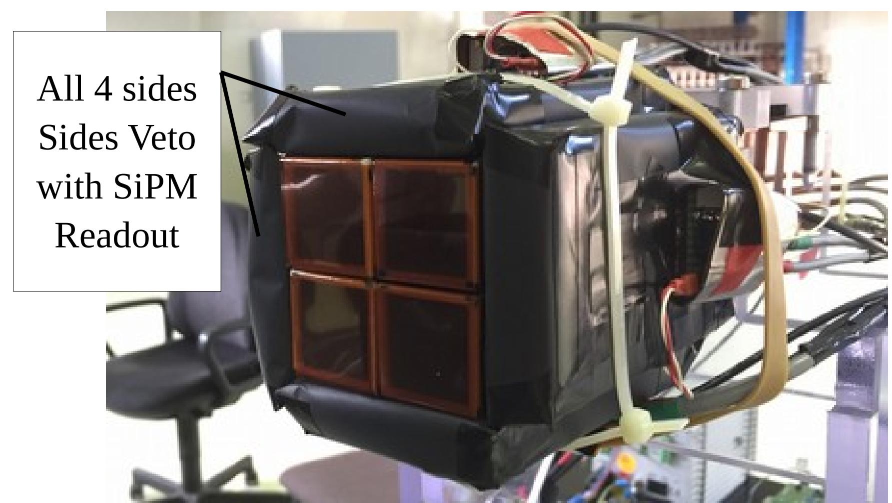
JEDI Polarimeter - JePo



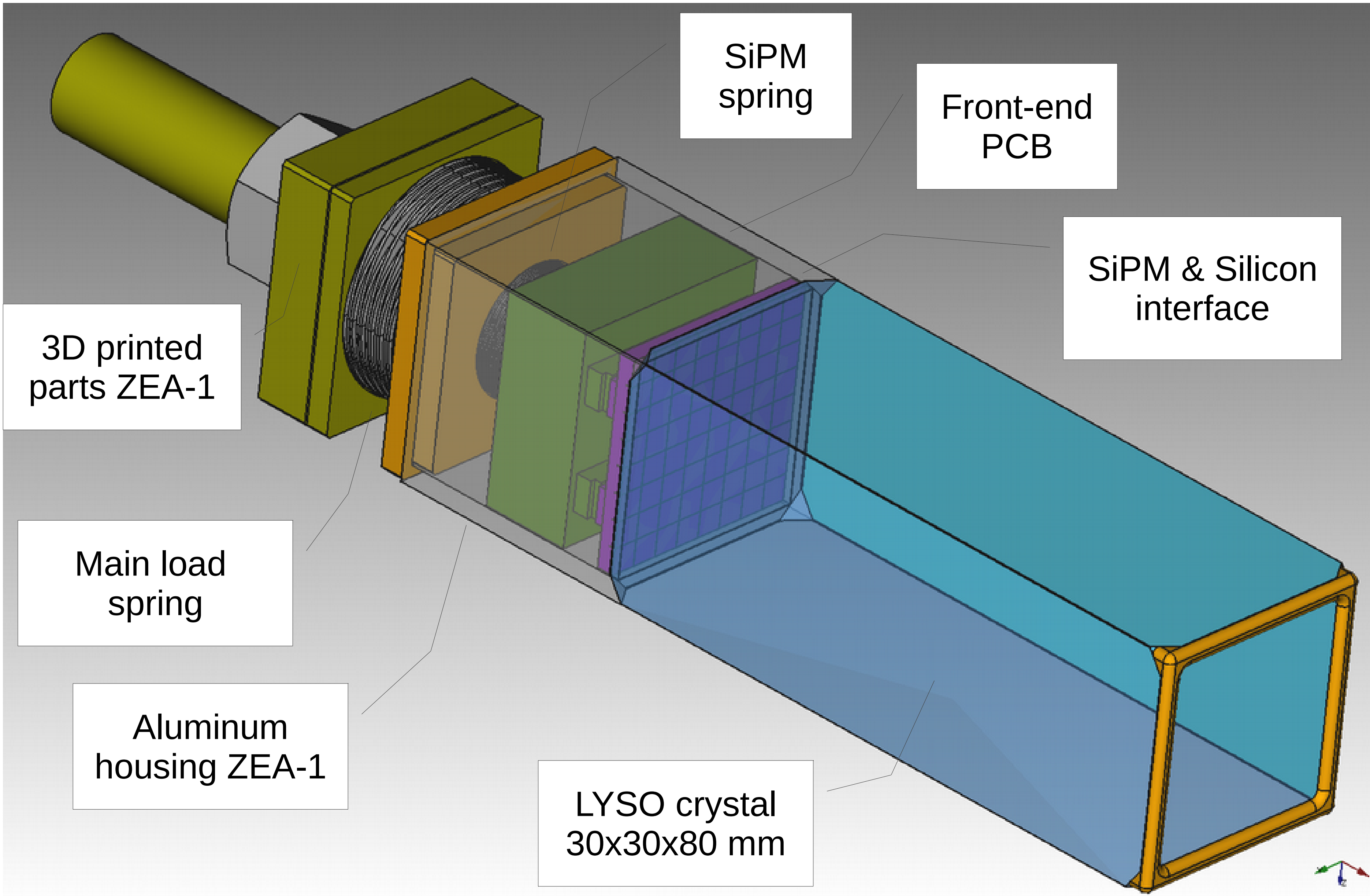
First test of LYSO modules



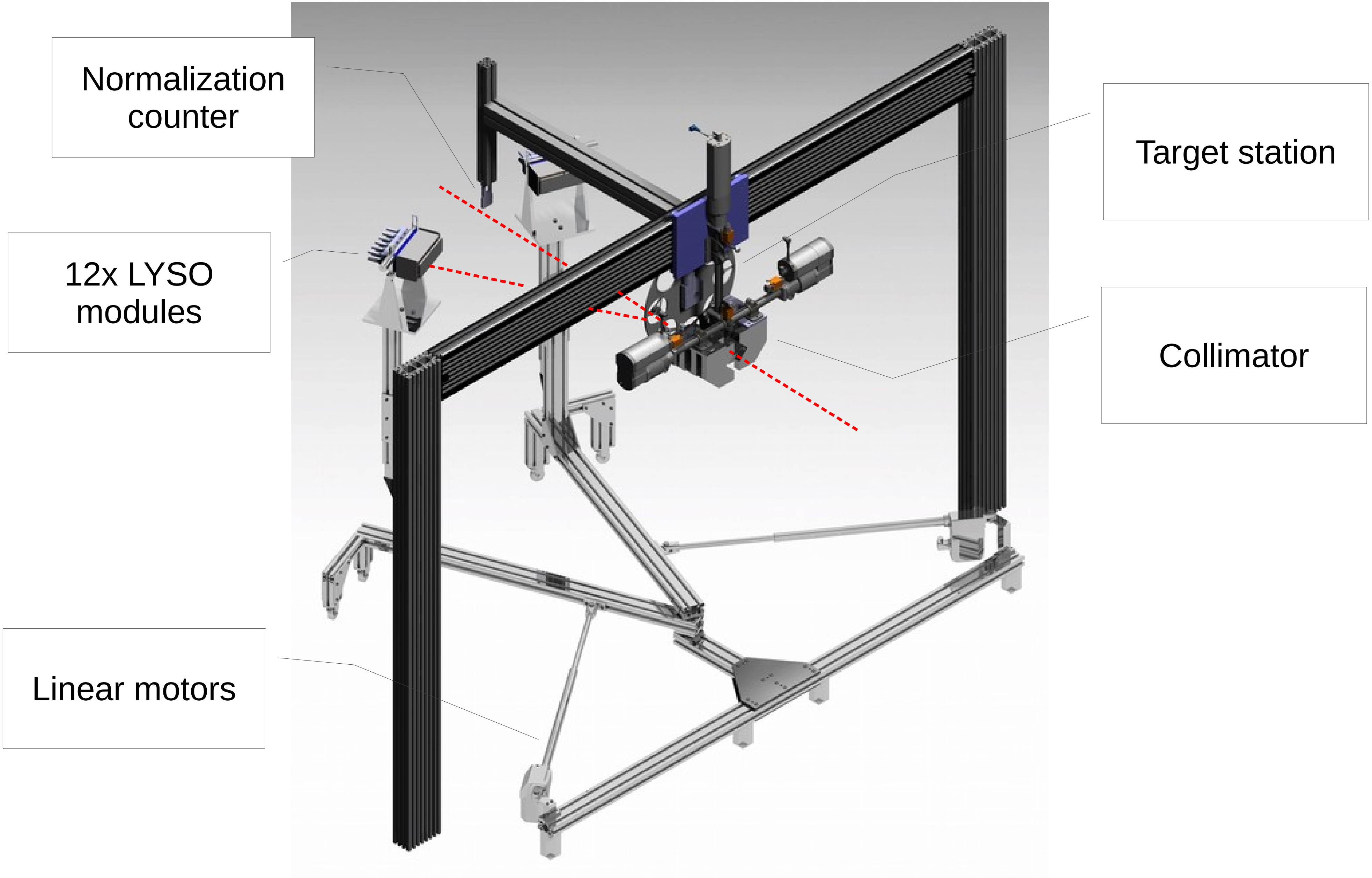




LYSO Module Mk2



Next beam time



Parts for the new setup