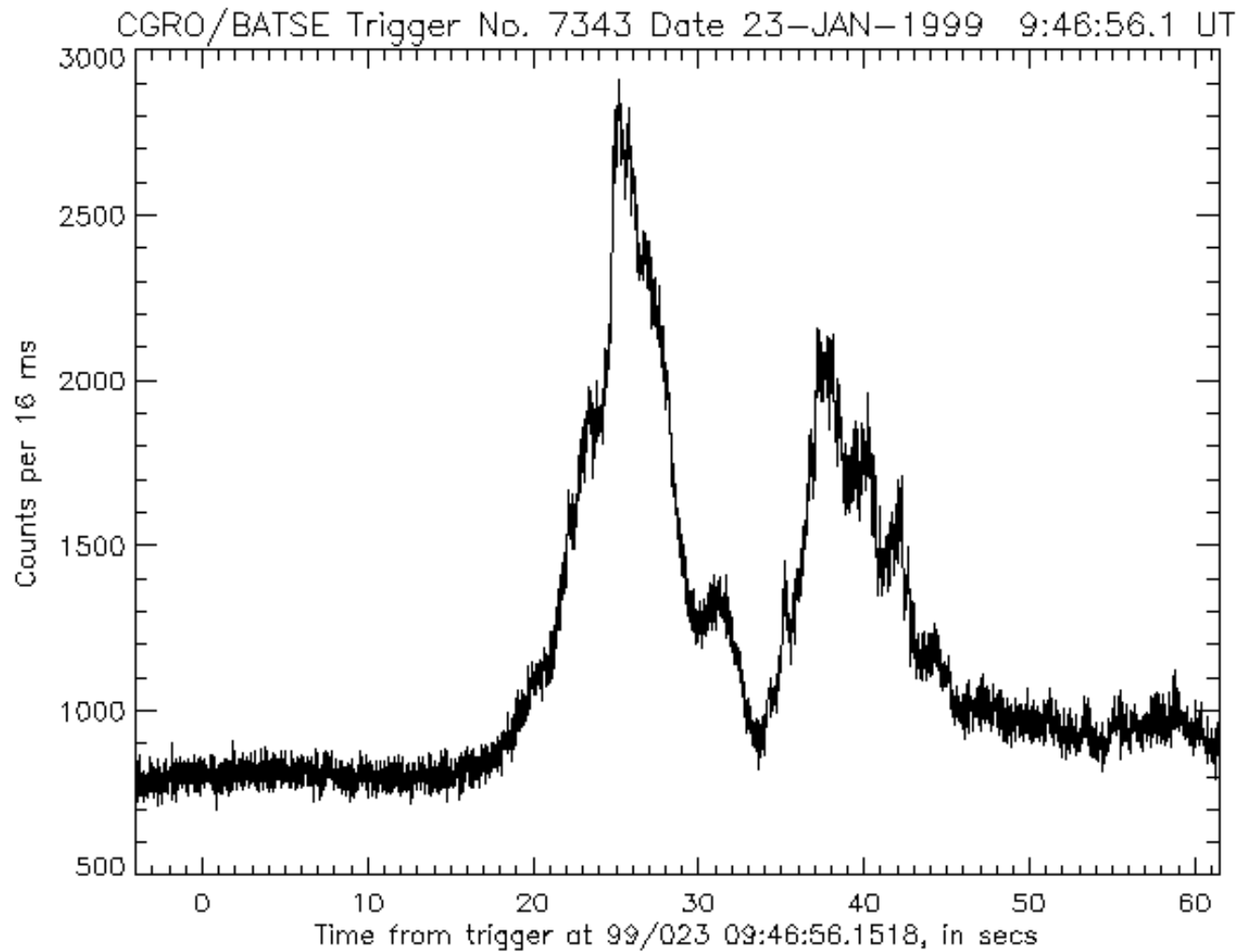


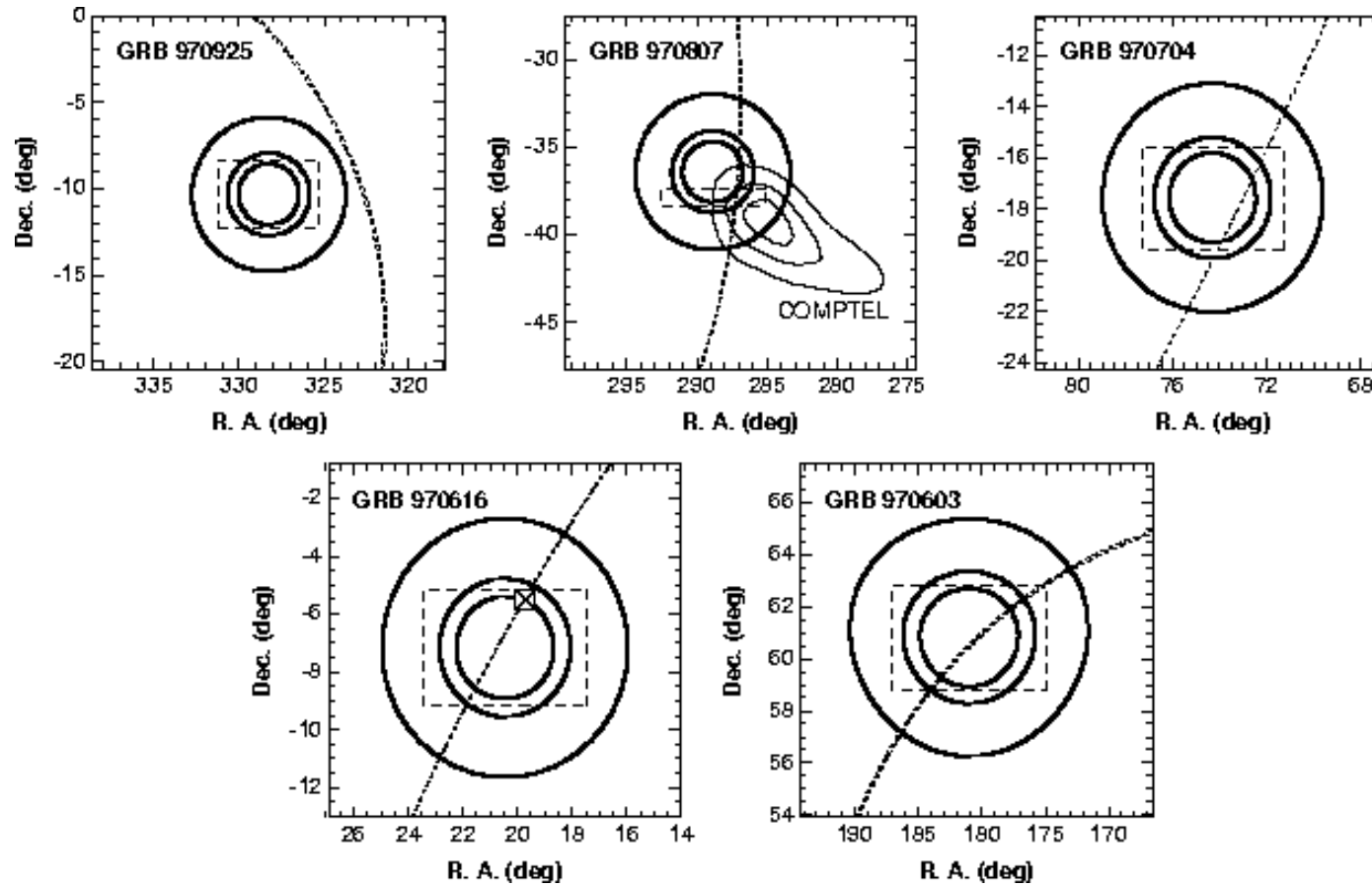
Astrofisica Nucleare e Subnucleare

“GRB” Astrophysics

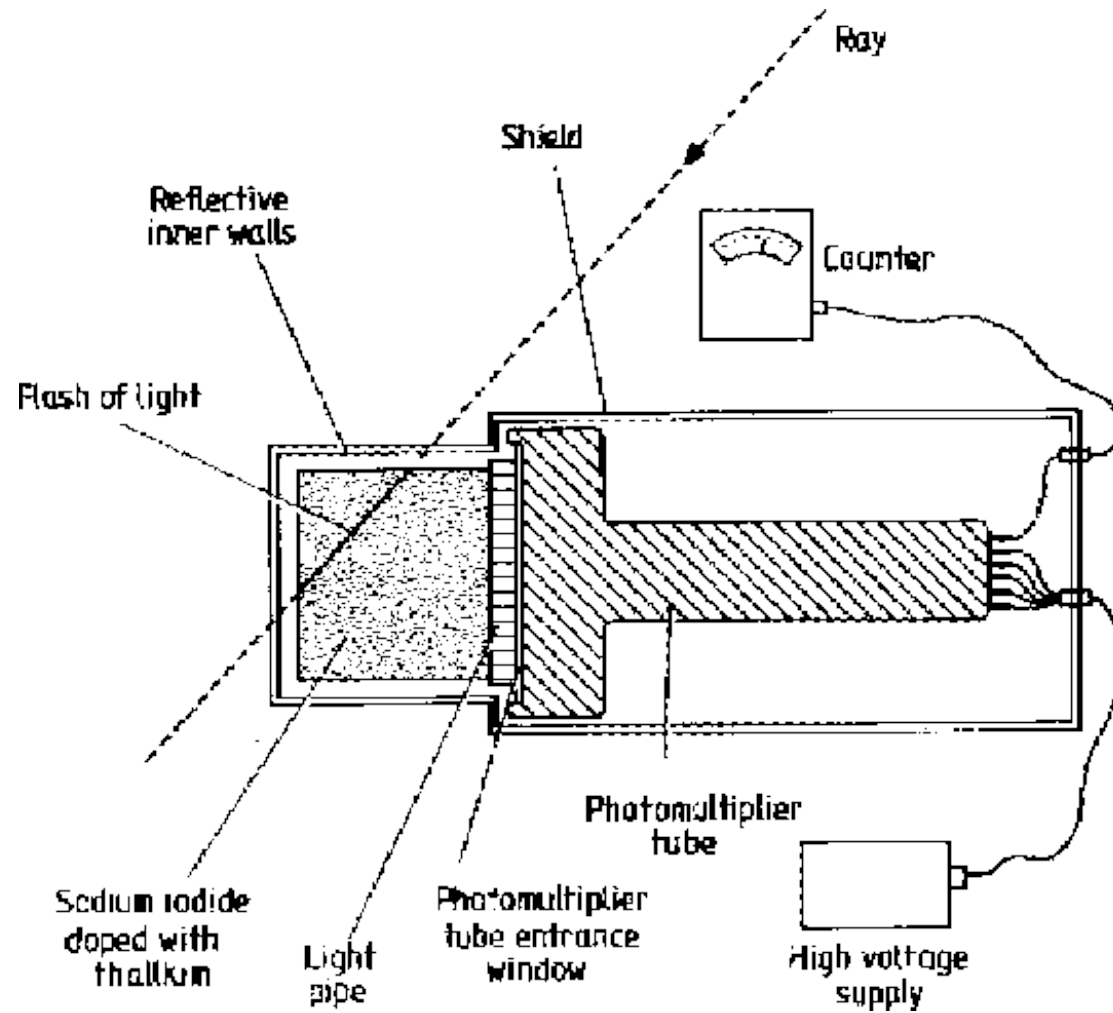
A GRB ...



some GRB locations ...

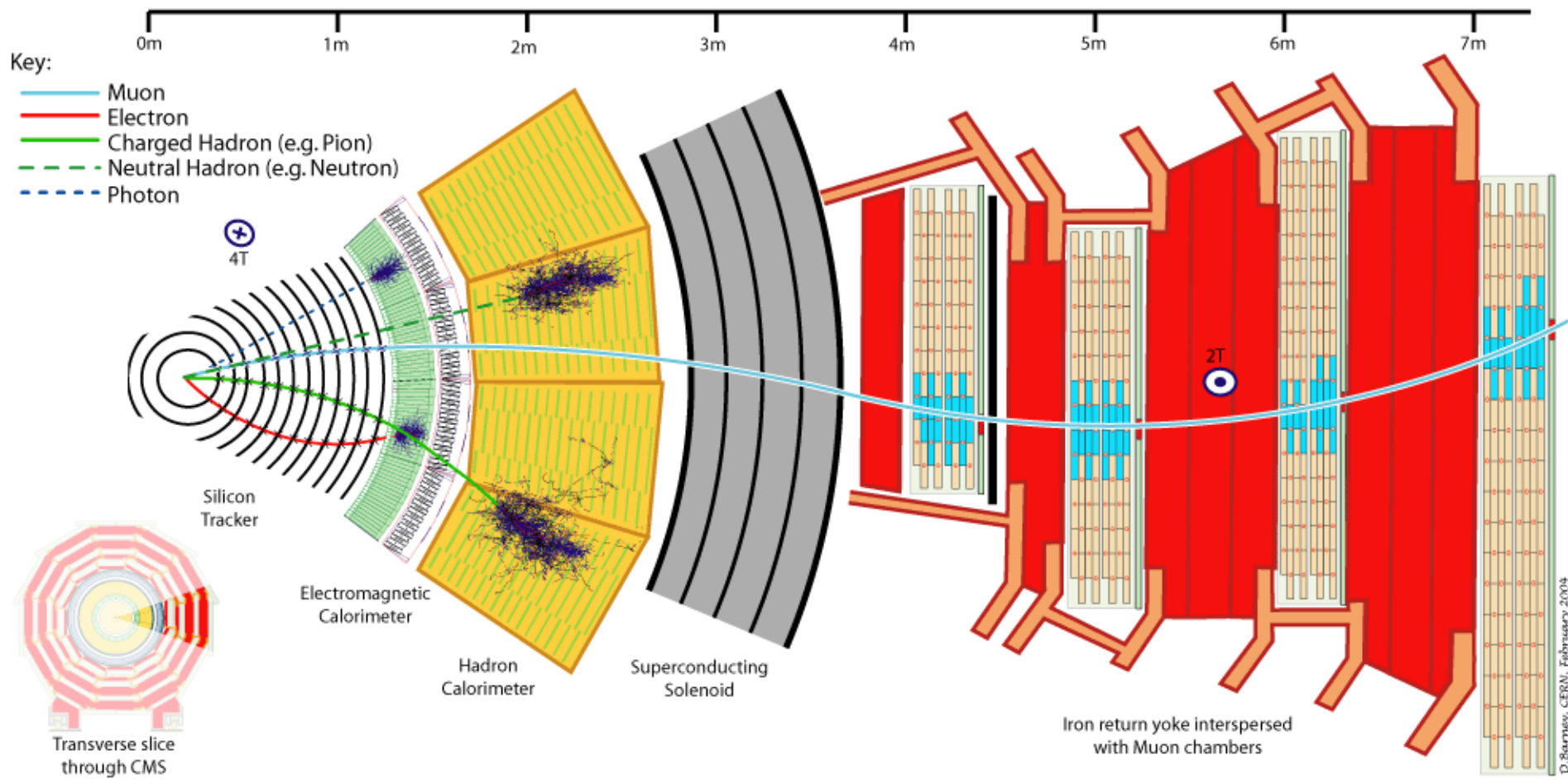


GRB Detectors



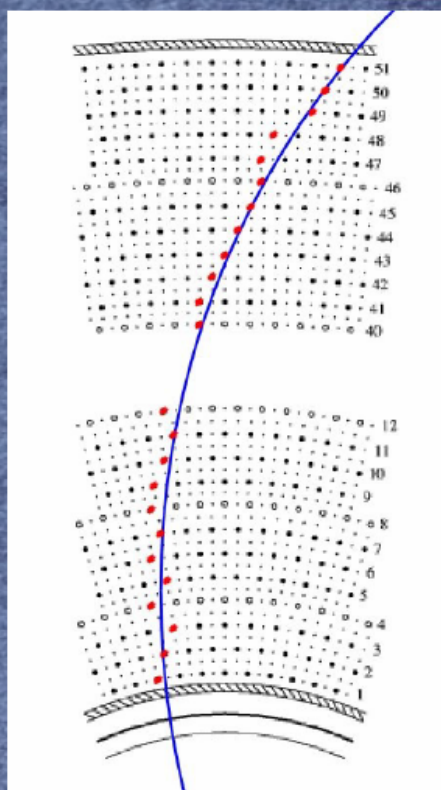
Astrofisica Nucleare e Subnucleare

Interazione Radiazione Materia



Rivelazione delle particelle elementari

Misura del momento e della carica elettrica delle particelle cariche (elettroni, muoni, adroni carichi)

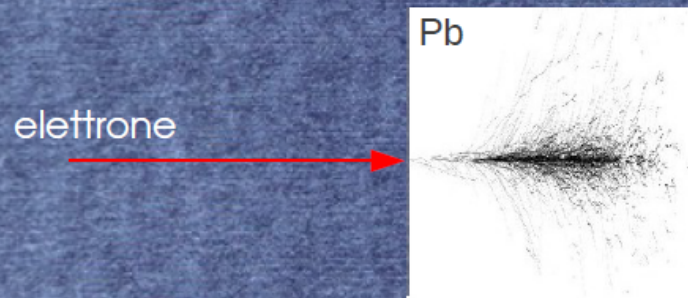


- ◆ Facciamo passare le particelle create nella collisione dentro un campo magnetico uniforme e ne ricostruiamo la traiettoria o "traccia":
- ◆ una serie di rivelatori disposti nello spazio attorno al punto della collisione ("tracciatori") indicano dove la particella carica è passata;
- ◆ cerchiamo l'arco di circonferenza che meglio approssimi i punti misurati e ne determiniamo il raggio;
- ◆ la carica della particella è data dal verso di curvatura della traiettoria, orario o antiorario.

Rivelazione delle particelle elementari

Misura dell'energia delle particelle (elettroni, fotoni, adroni carichi e neutri)

- ◆ Per misurare l'energia degli elettroni, dei fotoni e degli adroni carichi e neutri usiamo i "calorimetri":
 - ◆ le particelle vengono fatte passare attraverso una grossa quantità di materiale molto denso (ferro, tungsteno, piombo ...) dove dissipano tutta la loro energia e si fermano;



- ◆ intervallando il materiale dissipatore con materiale sensibile, l'energia della particella viene convertita in un segnale misurabile che è proporzionale all'energia.
- ◆ A differenza della misura del momento nei tracciatori, la misura dell'energia nei calorimetri rappresenta una "misura distruttiva" della particella.

Particle Detectors

Summer Student Lectures 2010
Werner Riegler, CERN, werner.riegler@cern.ch

- ◆ **History of Instrumentation ↔ History of Particle Physics**
- ◆ **The 'Real' World of Particles**
- ◆ **Interaction of Particles with Matter**
- ◆ **Tracking Detectors, Calorimeters, Particle Identification**
- ◆ **Detector Systems**

Interaction of Particles with Matter

Any device that is to detect a particle must interact with it in some way → almost ...

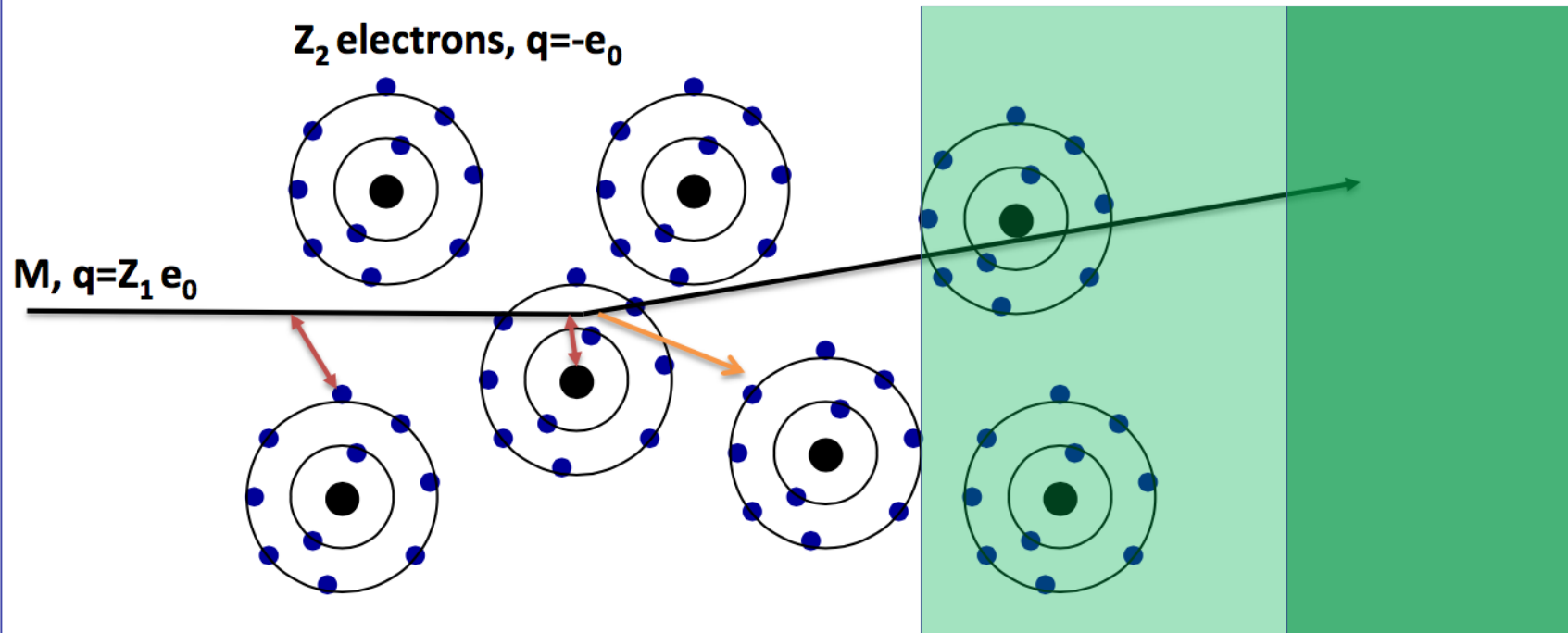
In many experiments neutrinos are measured by missing transverse momentum.

E.g. e^+e^- collider. $P_{\text{tot}}=0$,
If the Σp_i of all collision products is $\neq 0$ → neutrino escaped.



“Did you see it?”
“No nothing.”
“Then it was a neutrino!”

Electromagnetic Interaction of Particles with Matter



Interaction with the atomic electrons. The incoming particle loses energy and the atoms are excited or ionized.

Interaction with the atomic nucleus. The particle is deflected (scattered) causing multiple scattering of the particle in the material. During this scattering a Bremstrahlung photon can be emitted.

In case the particle's velocity is larger than the velocity of light in the medium, the resulting EM shockwave manifests itself as Cherenkov Radiation. When the particle crosses the boundary between two media, there is a probability of the order of 1% to produce and X ray photon, called Transition radiation.

Astrofisica Nucleare e Subnucleare

Ionizzazione

Bethe Bloch Formula

$$\frac{1}{\rho} \frac{dE}{dx} = -4\pi r_e^2 m_e c^2 \frac{Z_1^2}{\beta^2} N_A \frac{Z}{A} \left[\ln \frac{2m_e c^2 \beta^2 \gamma^2 F}{I} - \beta^2 - \frac{\delta(\beta\gamma)}{2} \right]$$

Für $Z > 1$, $I \approx 16Z^{0.9} \text{ eV}$

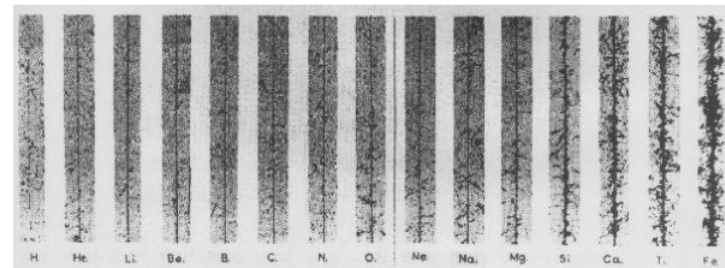
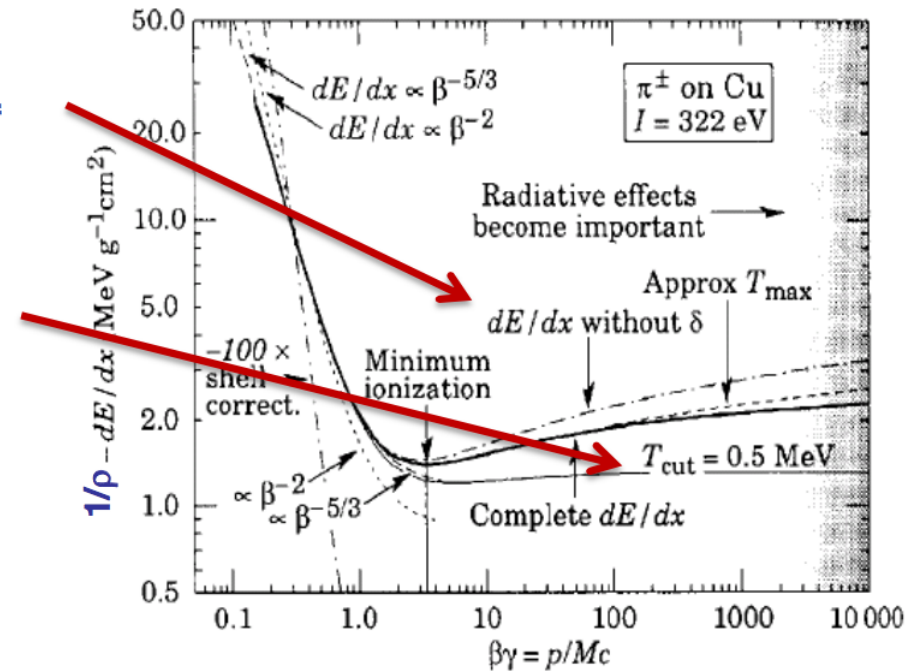
For Large $\beta\gamma$ the medium is being polarized by the strong transverse fields, which reduces the rise of the energy loss \rightarrow density effect

At large Energy Transfers (delta electrons) the liberated electrons can leave the material. In reality, E_{max} must be replaced by E_{cut} and the energy loss reaches a plateau (Fermi plateau).

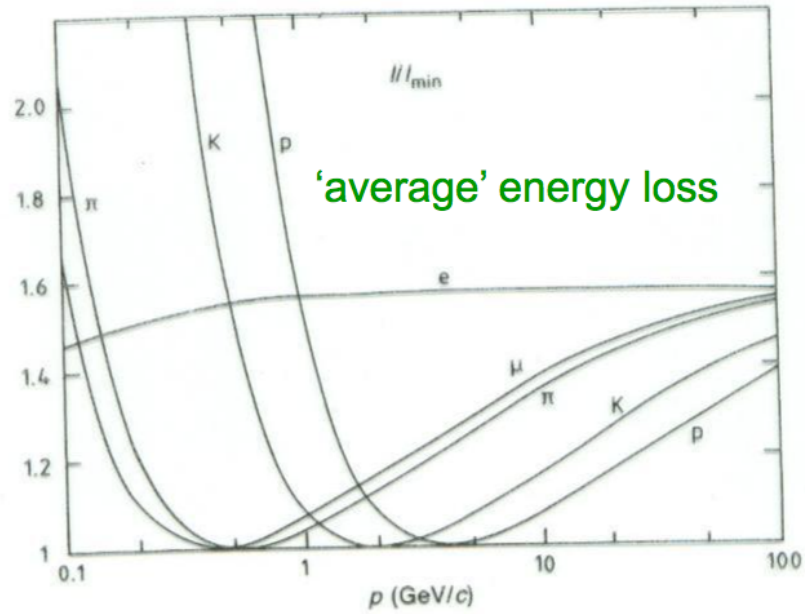
Characteristics of the energy loss as a function of the particle velocity ($\beta\gamma$)

The specific Energy Loss $1/\rho \, dE/dx$

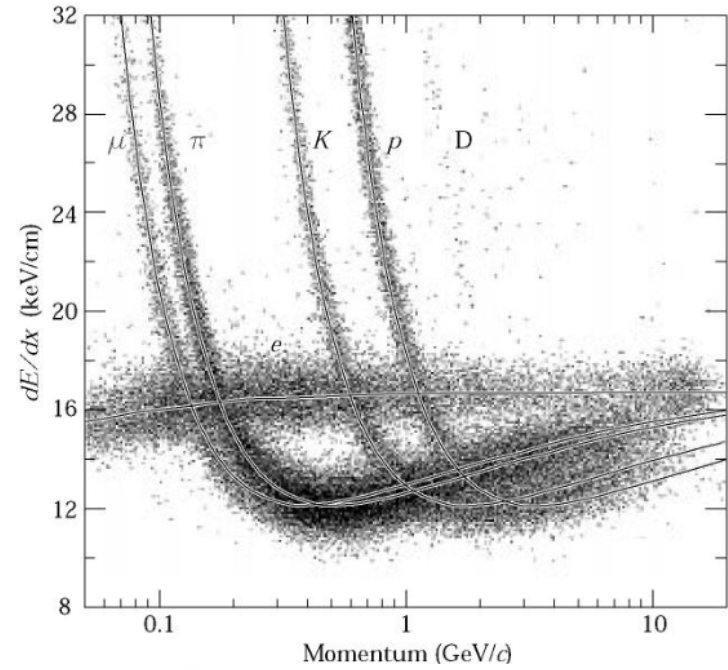
- first decreases as $1/\beta^2$
- increases with $\ln \gamma$ for $\beta = 1$
- is \approx independent of M ($M \gg m_e$)
- is proportional to Z_1^2 of the incoming particle.
- is \approx independent of the material ($Z/A \approx \text{const}$)
- shows a plateau at large $\beta\gamma$ ($\gg 100$)
- $dE/dx \approx 1-2 \times \rho \text{ [g/cm}^3\text{]} \text{ MeV/cm}$



Particle Identification

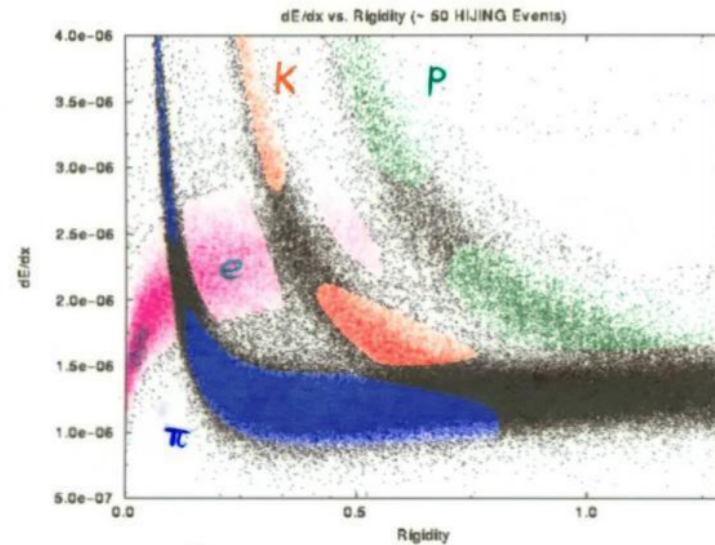


Measured energy loss

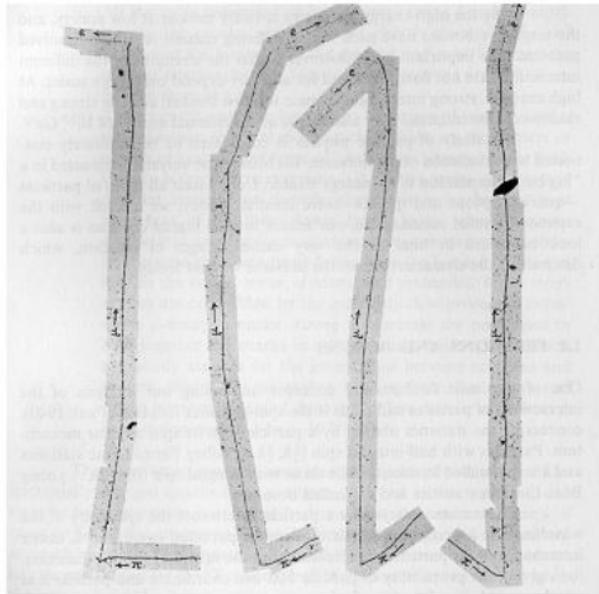


In certain momentum ranges, particles can be identified by measuring the energy loss.

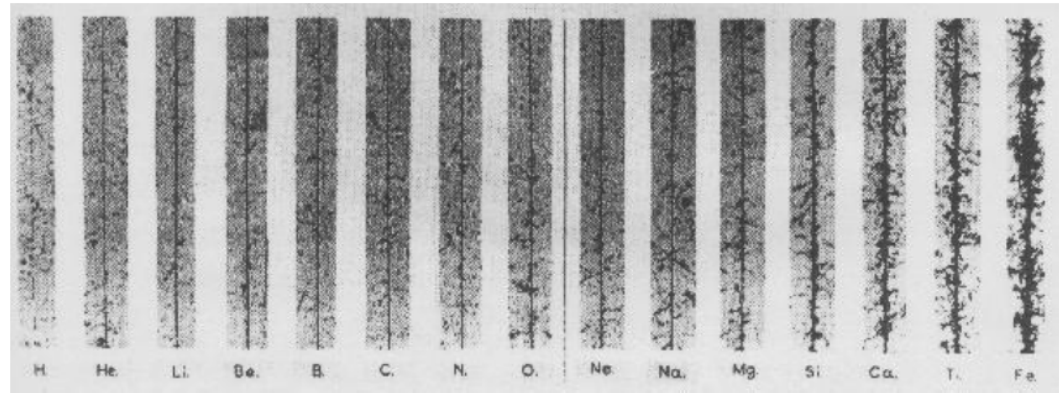
STAR
TPC



Small energy loss
→ Fast Particle

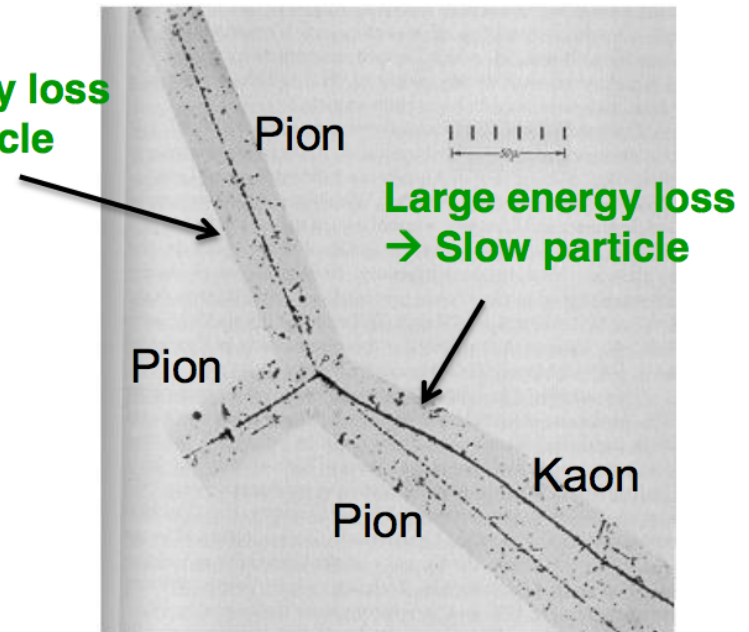


Discovery of muon and pion



Cosmis rays: $dE/dx \propto Z^2$

Small energy loss
→ Fast particle



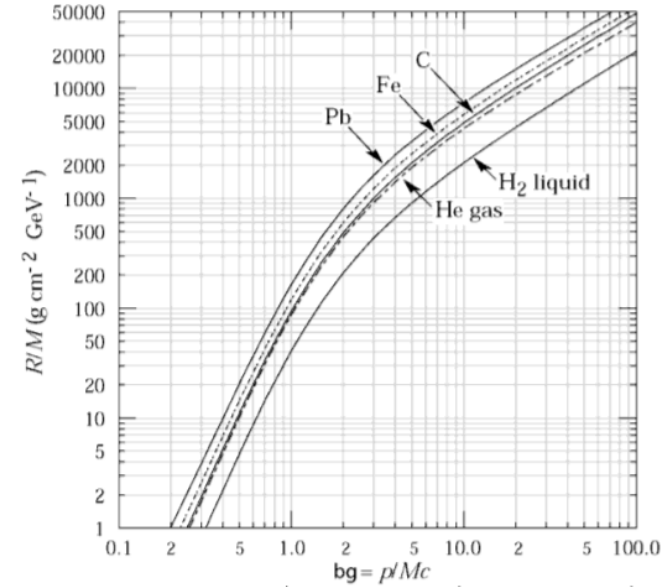
Range of Particles in Matter

Particle of mass M and kinetic Energy E_0 enters matter and loses energy until it comes to rest at distance R .

$$R(E_0) = \int_{E_0}^0 \frac{-1}{dE/dx} dE$$

$$R(\beta_0 \gamma_0) = \frac{Mc^2}{\rho} \frac{1}{Z_1^2} \frac{A}{Z} f(\beta_0 \gamma_0)$$

$$\frac{\rho}{Mc^2} R(\beta_0 \gamma_0) = \frac{1}{Z_1^2} \frac{A}{Z} f(\beta_0 \gamma_0) \quad \approx \text{Independent of the material}$$

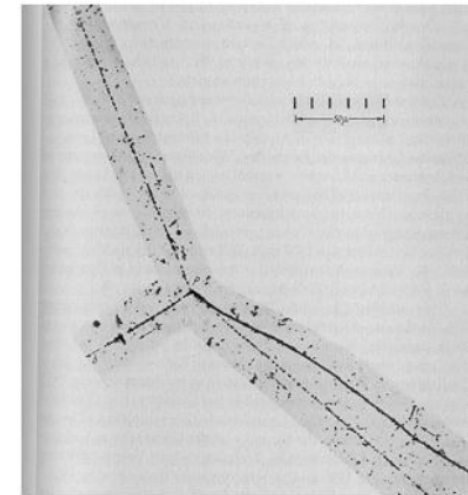
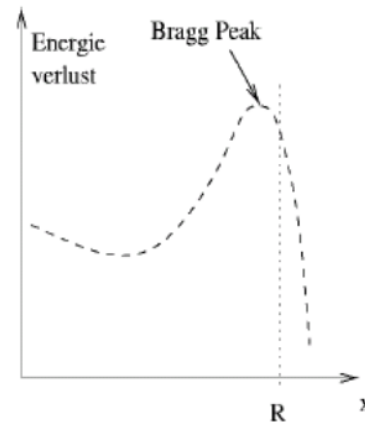


Bragg Peak:

For $\beta\gamma > 3$ the energy loss is \approx constant (Fermi Plateau)

If the energy of the particle falls below $\beta\gamma = 3$ the energy loss rises as $1/\beta^2$

Towards the end of the track the energy loss is largest \rightarrow Cancer Therapy.



Astrofisica Nucleare e Subnucleare

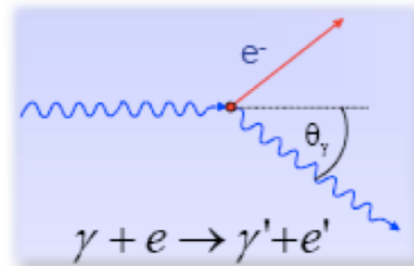
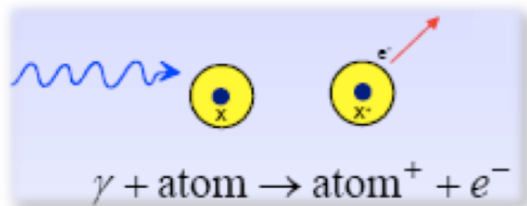
Interazione di Fotoni

Interactions of photons with matter

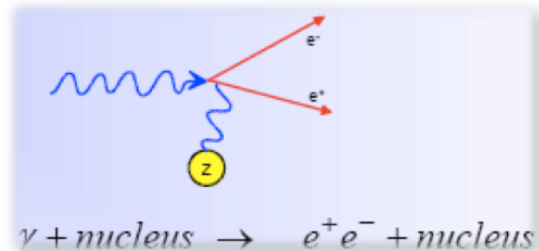
Characteristic for interactions of photons with matter:

A photon is removed from the beam after one single interaction either because of **total absorption** or **scattering**

- 1) Photoelectric Effect 2) Compton Scattering

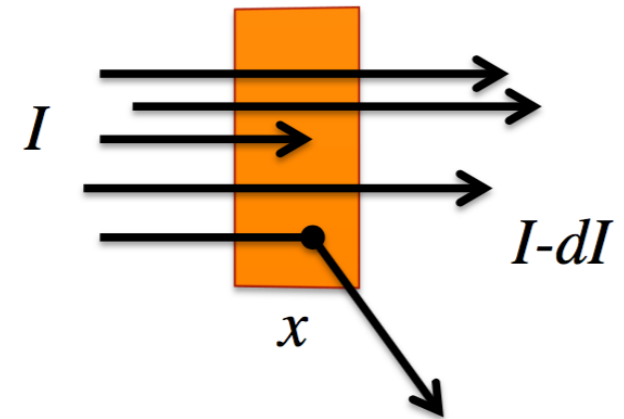


- 3) Pair Production



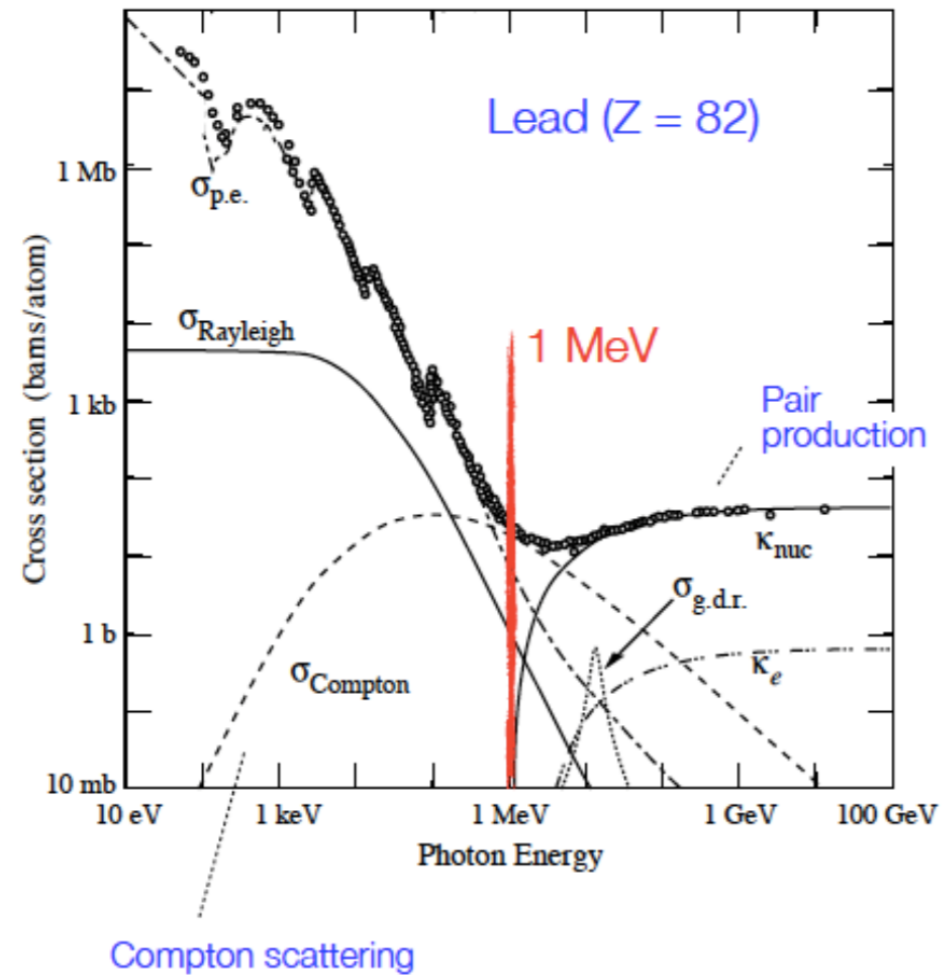
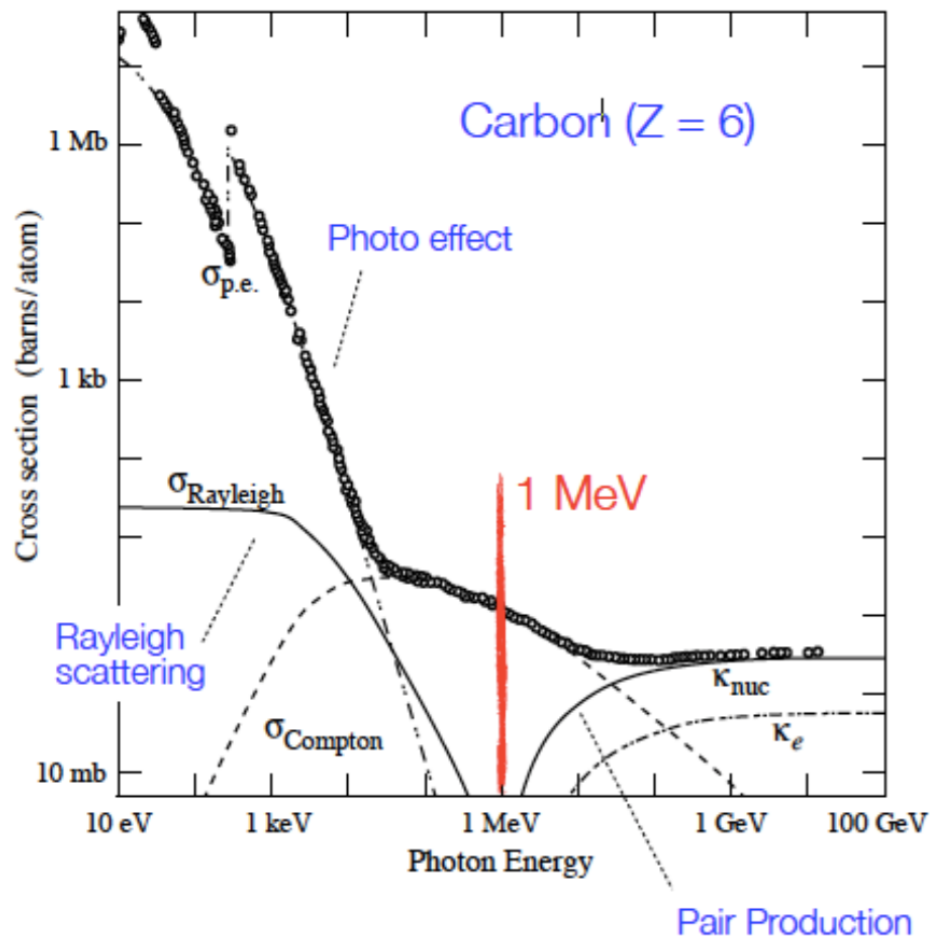
$$I(x) = I_0$$

$$\lambda = 1 / \mu \quad \text{Mean free path}$$



Interactions of photons with matter

Photon Total Cross Sections



Photoelectric effect

From energy conservation:

$$E_e = E_\gamma - E_N = h\nu - I_b$$

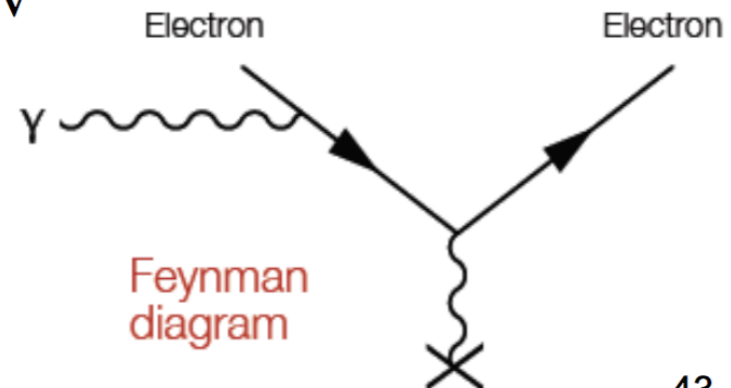
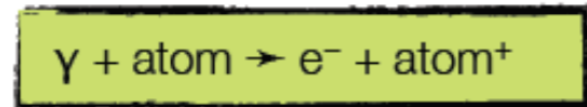
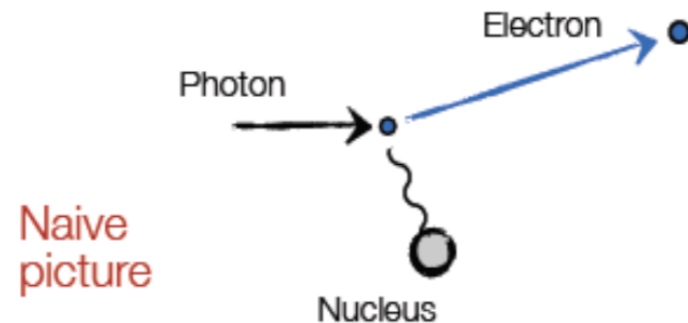
I_b = Nucleus binding energy
introduces strong Z dependence

Cross-section largest for $E_\gamma \approx$ K-shell energy
Strongest E dependence for $I_0 < E_\gamma < m_e c^2$

$$\sigma_{ph} = \alpha \pi a_B^2 Z^5 (I_0 / E_\gamma)^{7/2} \quad \begin{matrix} a_B = 0.53 \text{ \AA} \\ I_0 = 13.6 \text{ eV} \end{matrix}$$

E-dependence softer for $E_\gamma > m_e c^2$

$$\sigma_{ph} = 2\pi r_e^2 \alpha^4 Z^5 (mc)^2 / E_\gamma$$



Compton scattering

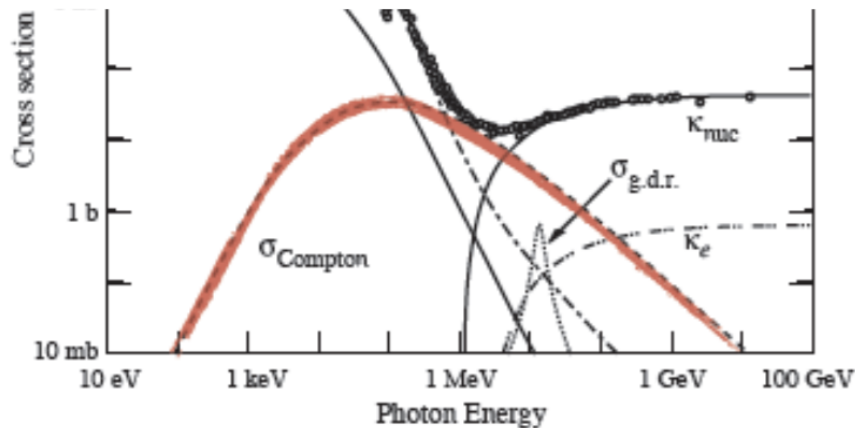
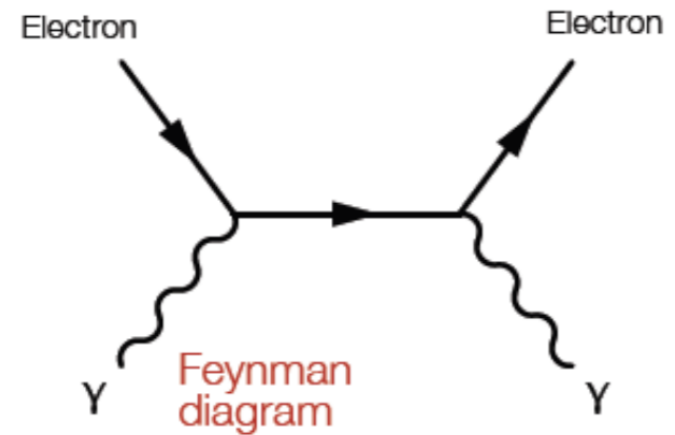
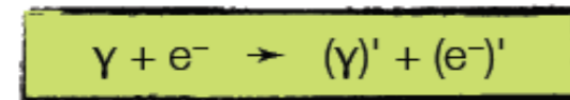
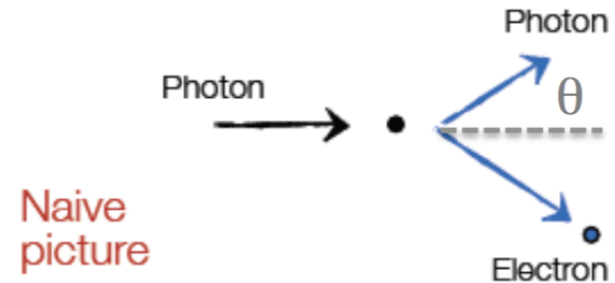
Best known electromagnetic process
(Klein–Nishina formula)

for $E_\lambda \ll m_e c^2$ $\sigma_c \propto \sigma_{Th} (1 - 2\varepsilon)$

Thompson cross-section:
 $\sigma_{Th} = 8\pi/3 r_e^2 = 0.66$ barn

$$\varepsilon = \frac{E_\lambda}{m_e c^2}$$

for $E_\lambda \gg m_e c^2$ $\sigma_c \propto \frac{\ln \varepsilon}{\varepsilon} Z$



Compton scattering

From E and p conservation get the energy of the scattered photon

$$E_{\gamma}' = \frac{E_{\gamma}}{1 + \varepsilon(1 - \cos\theta)} \quad \varepsilon = \frac{E_{\lambda}}{m_e c^2}$$

Kinetic energy of the outgoing electron:

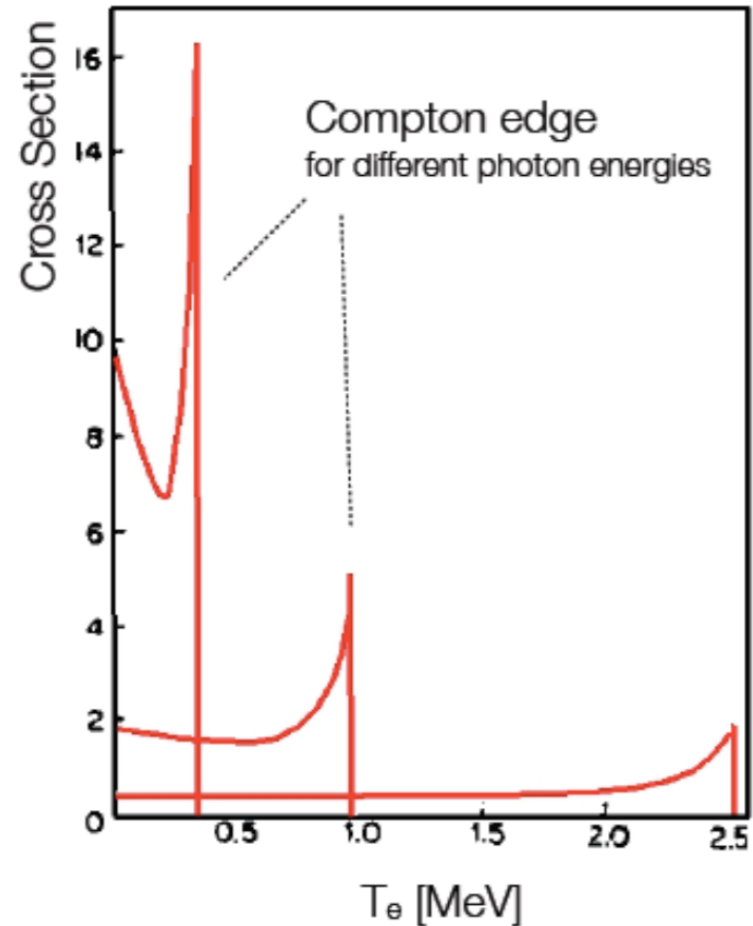
$$T_e = E_{\gamma} - E_{\gamma}' = E_{\gamma} \frac{\varepsilon(1 - \cos\theta)}{1 + \varepsilon(1 - \cos\theta)}$$

Max. electron recoil energy for $\theta = \pi$:

$$T_{\max} = E_{\gamma} \frac{2\varepsilon}{1 + 2\varepsilon}$$

Transfer of complete γ -energy via Compton scattering not possible:

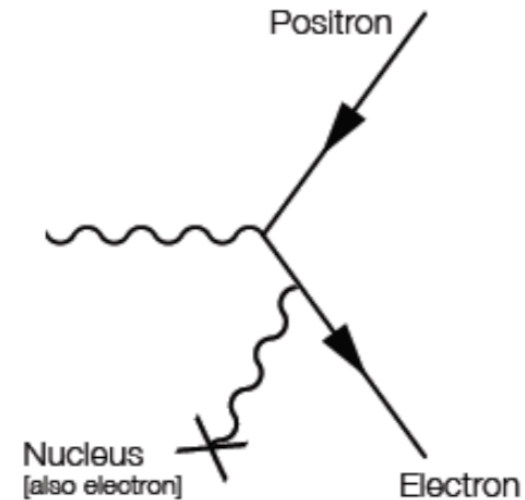
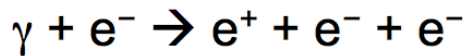
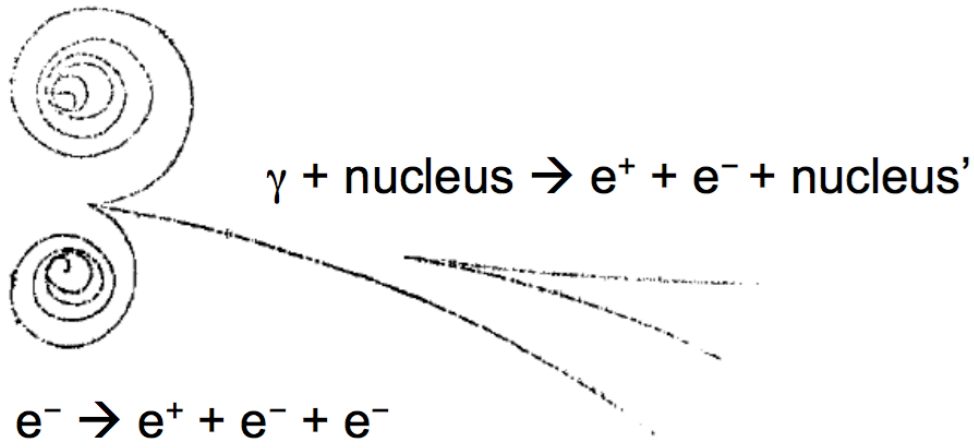
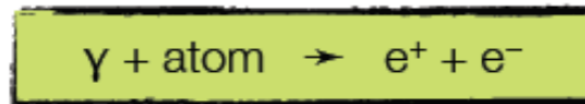
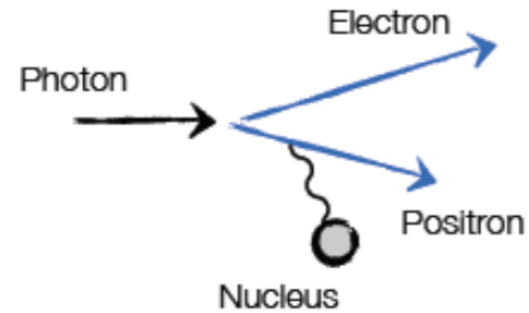
$$\Delta E = E_{\gamma} - T_{\max} = E_{\gamma} \frac{1}{1 + 2\varepsilon}$$



Pair production

Minimum energy required for this process
 $2 m_e c^2 + \text{Energy transferred to the nucleus}$

$$E_\gamma \geq 2m_e c^2 + \frac{2m_e c^2}{m_{Nucleus}}$$



Pair production

for $E_\lambda \gg m_e c^2$ $\sigma_{\text{pair}} = 4\alpha r_e^2 Z^2 \left(\frac{7}{9} \ln \frac{183}{Z^{1/3}} - \frac{1}{54} \right)$ [cm²/atom]

Using as for Bremsstrahlung the radiation length

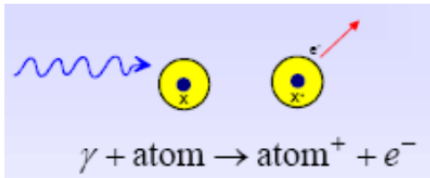
$$X_0 = \frac{A}{4\alpha N_A Z^2 r_e^2 \ln \frac{183}{Z^{1/3}}}$$

$$\sigma_{\text{pair}} = \frac{7}{9} \frac{N_A}{A} \cdot \frac{1}{X_0}$$

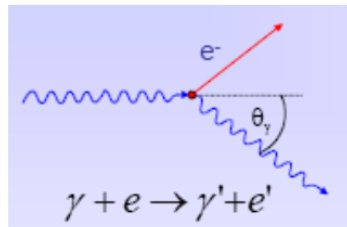
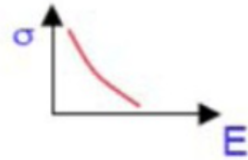
| | ρ [g/cm ³] | X_0 [cm] |
|----------------------|-----------------------------|-----------------|
| H ₂ [fl.] | 0.071 | 865 |
| C | 2.27 | 18.8 |
| Fe | 7.87 | 1.76 |
| Pb | 11.35 | 0.56 |
| Luft | $1.2 \cdot 10^{-3}$ | $30 \cdot 10^3$ |

Electromagnetic interactions

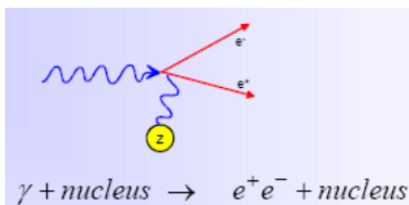
Gammas



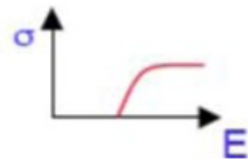
- Photoelectric effect



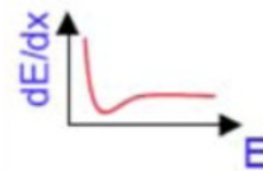
- Compton effect



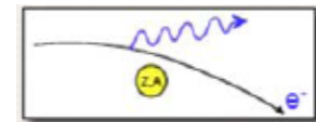
- Pair production



- Ionisation



- Bremsstrahlung



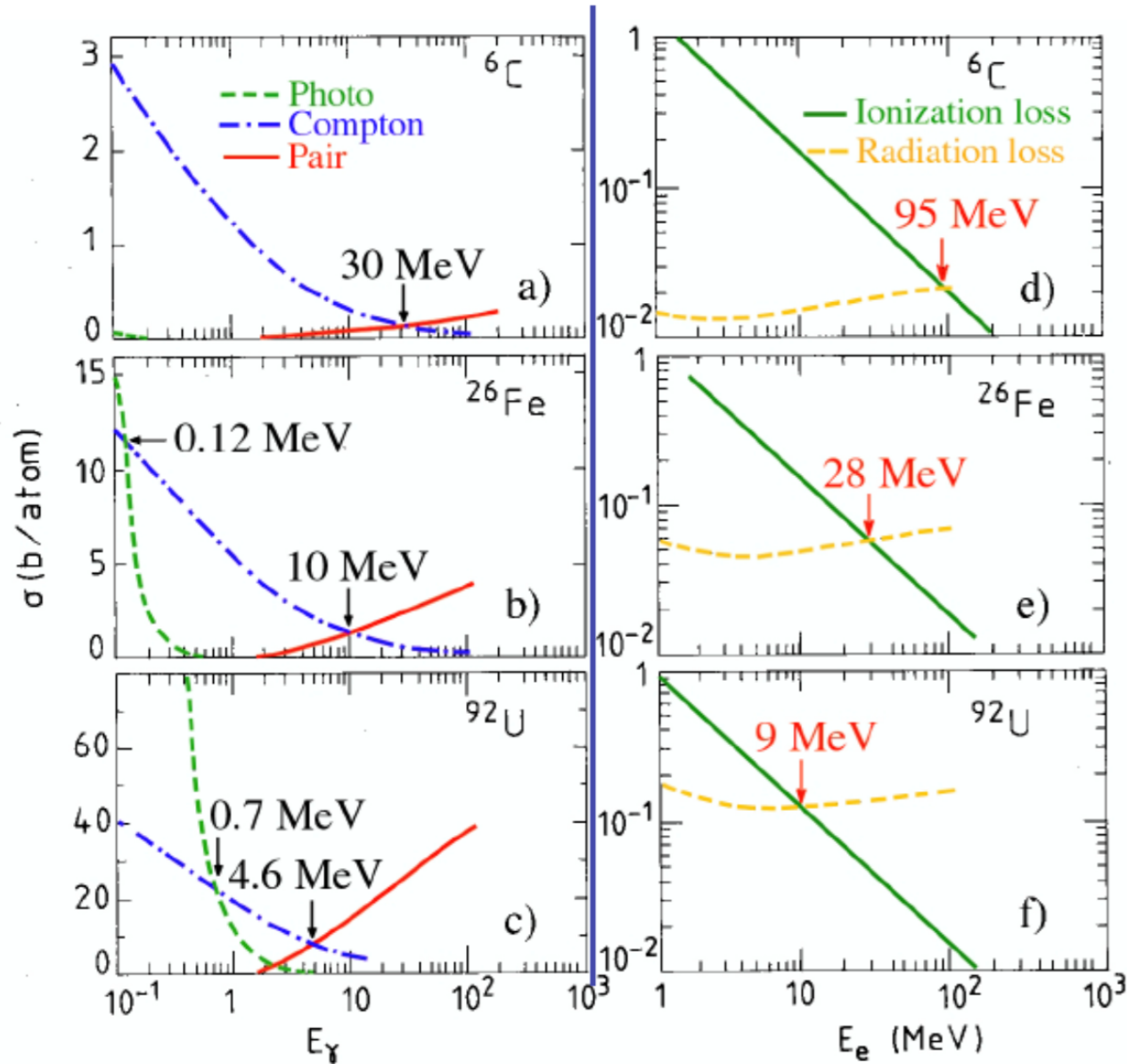
Electrons

Material dependence

Increasing Z



Gamma



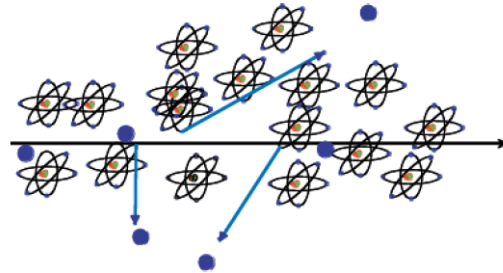
Electron

Astrofisica Nucleare e Subnucleare

Scintillation Detectors

Creation of the Signal

Charged particles traversing matter leave excited atoms, electron-ion pairs (gases) or electrons-hole pairs (solids) behind.

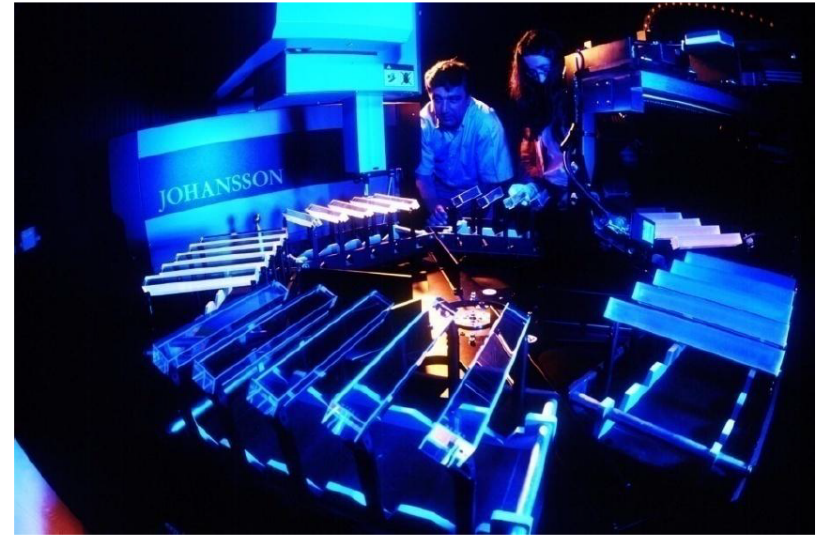


Excitation:

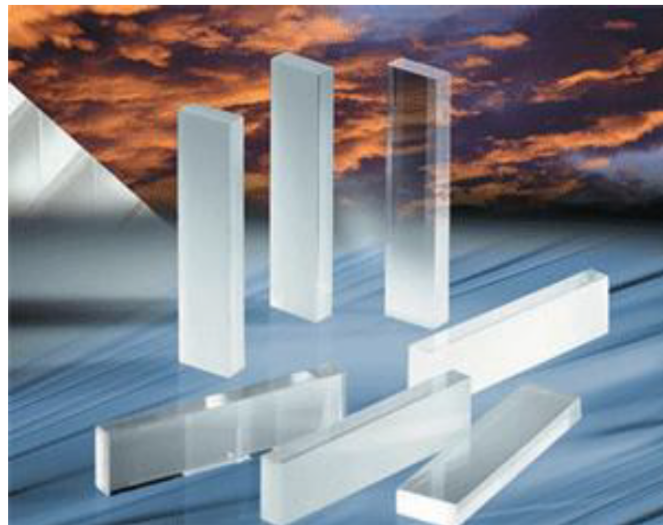
The photons emitted by the excited atoms in transparent materials can be detected with photon detectors like photomultipliers or semiconductor photon detectors.

Ionization:

By applying an electric field in the detector volume, the ionization electrons and ions are moving, which induces signals on metal electrodes. These signals are then read out by appropriate readout electronics.



Detectors based on registration of excited Atoms → Scintillators

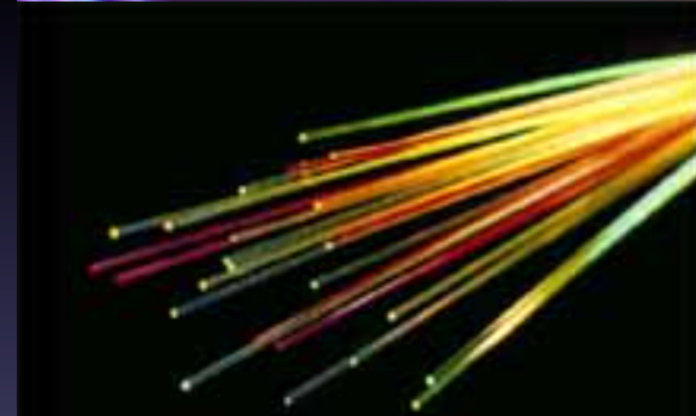


Scintillators

- dE/dx converted into light and then it is detected via photo-sensor (photomultipliers, SiPM,....)
- Main features
 - Sensitivity to energy
 - Fast time response
 - Pulse shape discrimination
- Requirements:
 - High efficiency for conversion of exciting energy to fluorescent radiation
 - Transparency to its fluorescent radiation to allow transmission of light
 - Emission of light in a spectral range detectable for photo-sensors
 - Short decay time to allow fast response

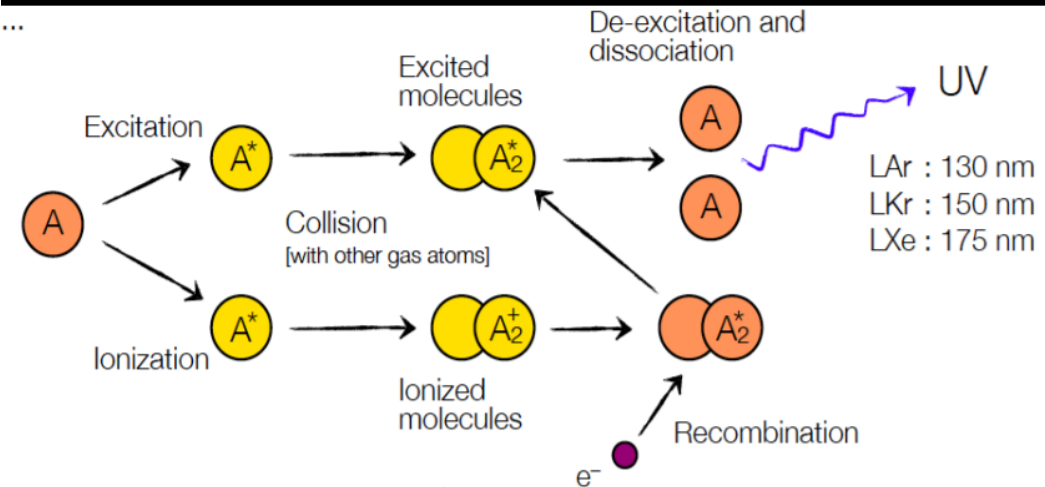


Plastic Scintillator BC412

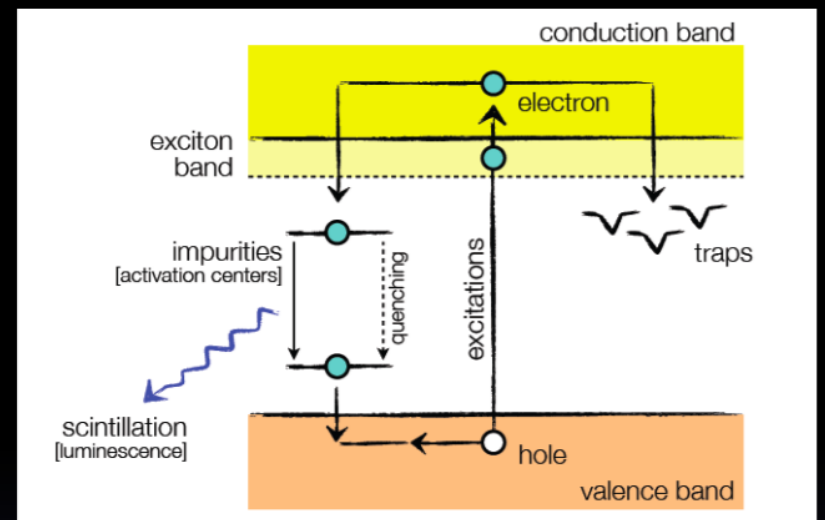
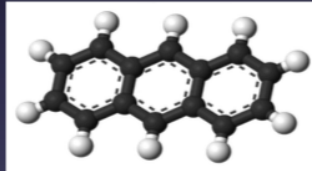


Scintillators

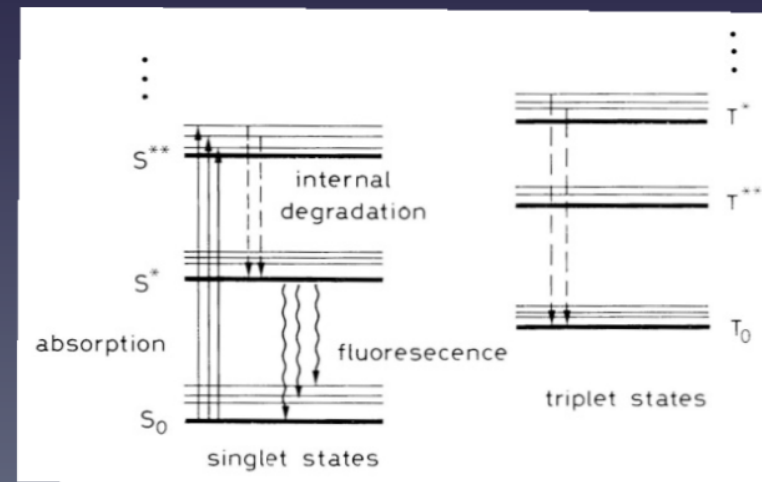
- Inorganic (Sodium iodide (NaI), Cesium iodide (CsI),...)



- Organic crystals
 - Aromatic hydrocarbon compounds with benzene rings such as Anthracene (C₁₄H₁₀), etc
- Plastic scintillators
 - Organic scintillators suspended in the aromatic polymer (easy to mold and machine)
- Liquid scintillators



- Noble gases (Liquid Argon, Liquid Xenon...)
- Molecule structure generates energy levels with transition $\lambda=360-500$ nm



Detectors based on Registration of excited Atoms → Scintillators

Organic ('Plastic') Scintillators

Low Light Yield

Fast: 1-3ns

| Type | Light ^a output | λ_{max} ^b (nm) | Attenuation ^c length (cm) | Risetime (ns) | Decay ^d time (ns) | Pulse FWHM (ns) |
|---------|------------------------------|--------------------------------------|--|------------------|------------------------------------|-----------------------|
| NE 102A | 58-70 | 423 | 250 | 0.9 | 2.2-2.5 | 2.7-3.2 |
| NE 104 | 68 | 406 | 120 | 0.6-0.7 | 1.7-2.0 | 2.2-2.5 |
| NE 104B | 59 | 406 | 120 | 1 | 3.0 | 3 |
| NE 110 | 60 | 434 | 400 | 1.0 | 2.9-3.3 | 4.2 |
| NE 111 | 40-55 | 375 | 8 | 0.13-0.4 | 1.3-1.7 | 1.2-1.6 |
| NE 114 | 42-50 | 434 | 350-400 | ~1.0 | 4.0 | 5.3 |
| Pilot B | 60-68 | 408 | 125 | 0.7 | 1.6-1.9 | 2.4-2.7 |
| Pilot F | 64 | 425 | 300 | 0.9 | 2.1 | 3.0-3.3 |
| Pilot U | 58-67 | 391 | 100-140 | 0.5 | 1.4-1.5 | 1.2-1.9 |
| BC 404 | 68 | 408 | — | 0.7 | 1.8 | 2.2 |
| BC 408 | 64 | 425 | — | 0.9 | 2.1 | ~2.5 |
| BC 420 | 64 | 391 | — | 0.5 | 1.5 | 1.3 |
| ND 100 | 60 | 434 | 400 | — | 3.3 | 3.3 |
| ND 120 | 65 | 423 | 250 | — | 2.4 | 2.7 |
| ND 160 | 68 | 408 | 125 | — | 1.8 | 2.7 |

LHC bunchcrossing 25ns

Inorganic (Crystal) Scintillators

Large Light Yield

Slow: few 100ns

| | Relative light output | λ_{max} emission (nm) | Decay time (ns) | Density (g/cm ³) |
|---|-----------------------------|-------------------------------------|-----------------------|---------------------------------|
| <i>Inorganic crystals</i> | | | | |
| Nal(Tl) | 230 | 415 | 230 | 3.67 |
| CsI(Tl) | 250 | 560 | 900 | 4.51 |
| Bi ₄ Ge ₃ O ₁₂ (BGO) | 23-86 | 480 | 300 | 7.13 |
| <i>Organic crystals</i> | | | | |
| Anthracene | 100 | 448 | 22 | 1.25 |
| Trans-stilbene | 75 | 384 | 4.5 | 1.16 |
| Naphthalene | 32 | 330-348 | 76-96 | 1.03 |
| <i>p,p'</i> -Quarterphenyl | 94 | 437 | 7.5 | 1.20 |
| <i>Primary activators</i> | | | | |
| 2,5-Diphenyl-oxazole (PPO) | 75 | 360-416 | 5 ^a | |
| 2-Phenyl-5-(4-biphenyl)- 1,3,4-oxadiazole (PBD) | 96 | 360-5 | | |
| 4,4'-Bis(2-butyloctyloxy)- <i>p</i> - quaterphenyl (BIBUQ) | 60 | 365,393 | 1.30 ^a | |

LEP bunchcrossing 25μs

Scintillators

Inorganic Scintillators – Properties

| Scintillator material | Density [g/cm ³] | Refractive Index | Wavelength [nm] for max. emission | Decay time constant [μs] | Photons/MeV |
|---|------------------------------|------------------|-----------------------------------|--------------------------|------------------|
| NaI | 3.7 | 1.78 | 303 | 0.06 | $8 \cdot 10^4$ |
| NaI(Tl) | 3.7 | 1.85 | 410 | 0.25 | $4 \cdot 10^4$ |
| CsI(Tl) | 4.5 | 1.80 | 565 | 1.0 | $1.1 \cdot 10^4$ |
| Bi ₄ Ge ₃ O ₁₂ | 7.1 | 2.15 | 480 | 0.30 | $2.8 \cdot 10^3$ |
| CsF | 4.1 | 1.48 | 390 | 0.003 | $2 \cdot 10^3$ |
| LSO | 7.4 | 1.82 | 420 | 0.04 | $1.4 \cdot 10^4$ |
| PbWO ₄ | 8.3 | 1.82 | 420 | 0.006 | $2 \cdot 10^2$ |
| LHe | 0.1 | 1.02 | 390 | 0.01/1.6 | $2 \cdot 10^2$ |
| LAr | 1.4 | 1.29* | 150 | 0.005/0.86 | $4 \cdot 10^4$ |
| LXe | 3.1 | 1.60* | 150 | 0.003/0.02 | $4 \cdot 10^4$ |

* at 170 nm

Scintillators

Organic Scintillators – Properties

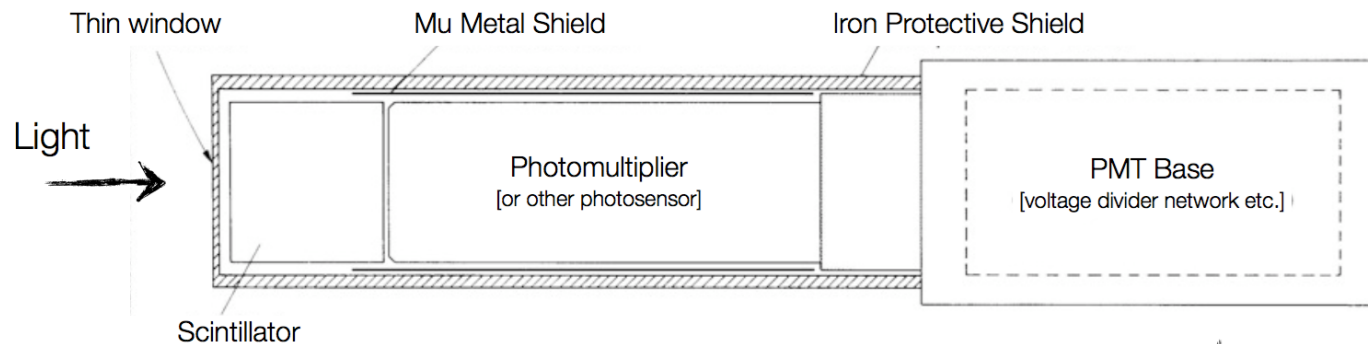
| Scintillator material | Density [g/cm ³] | Refractive Index | Wavelength [nm] for max. emission | Decay time constant [ns] | Photons/MeV |
|-----------------------|------------------------------|------------------|-----------------------------------|--------------------------|------------------|
| Naphtalene | 1.15 | 1.58 | 348 | 11 | $4 \cdot 10^3$ |
| Antracene | 1.25 | 1.59 | 448 | 30 | $4 \cdot 10^4$ |
| p-Terphenyl | 1.23 | 1.65 | 391 | 6-12 | $1.2 \cdot 10^4$ |
| NE102* | 1.03 | 1.58 | 425 | 2.5 | $2.5 \cdot 10^4$ |
| NE104* | 1.03 | 1.58 | 405 | 1.8 | $2.4 \cdot 10^4$ |
| NE110* | 1.03 | 1.58 | 437 | 3.3 | $2.4 \cdot 10^4$ |
| NE111* | 1.03 | 1.58 | 370 | 1.7 | $2.3 \cdot 10^4$ |
| BC400** | 1.03 | 1.58 | 423 | 2.4 | $2.5 \cdot 10^2$ |
| BC428** | 1.03 | 1.58 | 480 | 12.5 | $2.2 \cdot 10^4$ |
| BC443** | 1.05 | 1.58 | 425 | 2.2 | $2.4 \cdot 10^4$ |

* Nuclear Enterprises, U.K.

** Bicron Corporation, USA

Scintillators

Scintillators – Basic Counter Setup

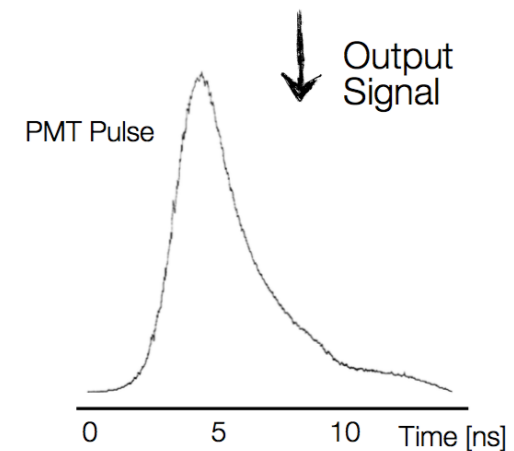


Scintillator Types:

Photosensors

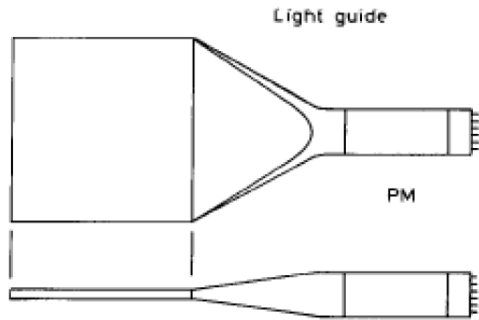
- Photomultipliers
- Micro-Channel Plates
- Hybrid Photo Diodes
- Visible Light Photon Counter
- Silicon Photo Multipliers

- Organic Scintillators
- Inorganic Crystals
- Gases

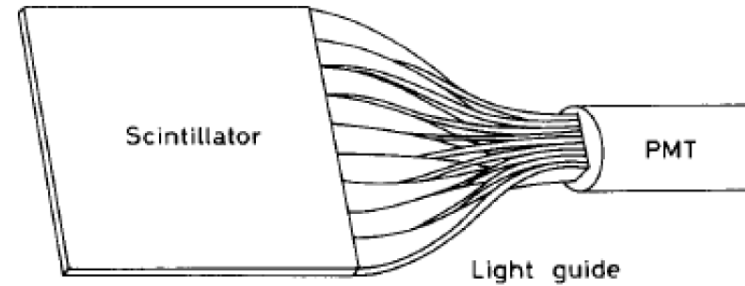


Typical Geometries:

- Light guides: transfer by total internal reflection (+outer reflector)

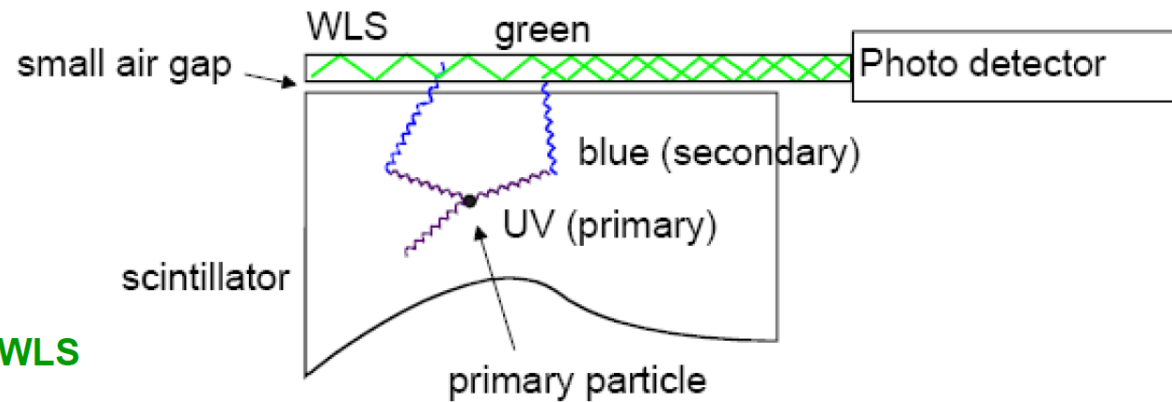


“fish tail”



adiabatic

- wavelength shifter (WLS) bars



UV light enters the WLS material
Light is transformed into longer wavelength

→ Total internal reflection inside the WLS material

→ ‘transport’ of the light to the photo detector

The frequent use of Scintillators is due to:

Well established and cheap techniques to register Photons → Photomultipliers
and the fast response time → 1 to 100ns

Schematic of a Photomultiplier:

- Typical Gains (as a function of the applied voltage): 10^8 to 10^{10}
- Typical efficiency for photon detection:
 - < 20%
- For very good PMs: registration of single photons possible.
- Example: 10 primary Elektronen, Gain 10^7 → 10^8 electrons in the end in $T \approx 10$ ns. $I=Q/T = 10^8 \cdot 1.603 \cdot 10^{-19} / 10 \cdot 10^{-9} = 1.6$ mA.
- Across a 50Ω Resistor → $U=R \cdot I = 80$ mV.

Semitransparent photocathode

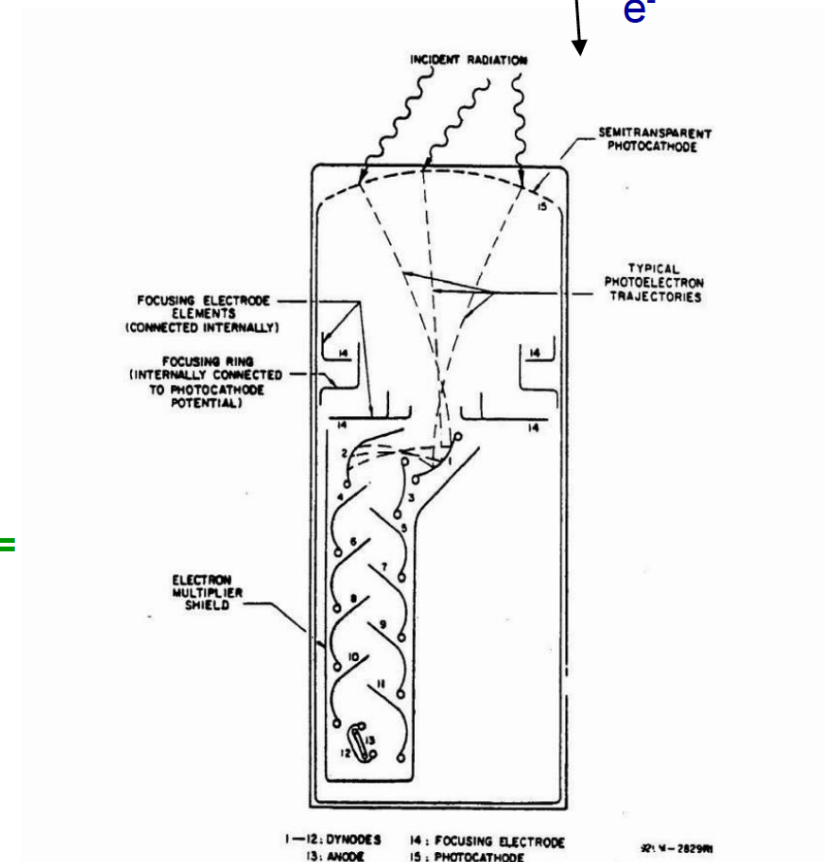


Photo-detectors

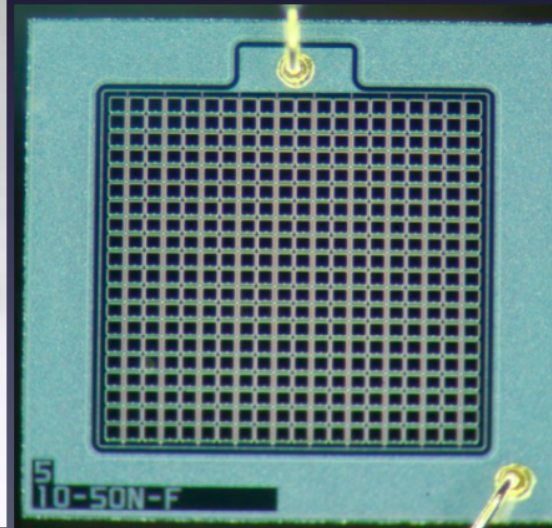
- Convert light into an electronic signal by using the photo-electric effect to convert photons into photo-electrons (p.e.)
- Requirement :
 - High Photon Detection Efficiency (PDE) or
 - Quantum Efficiency; $Q.E. = N_{p.e.}/N_{photons}$

■ Photomultipliers

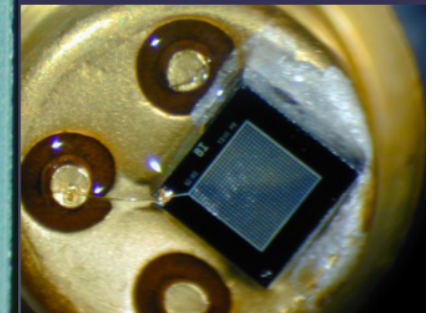


■ SiPM

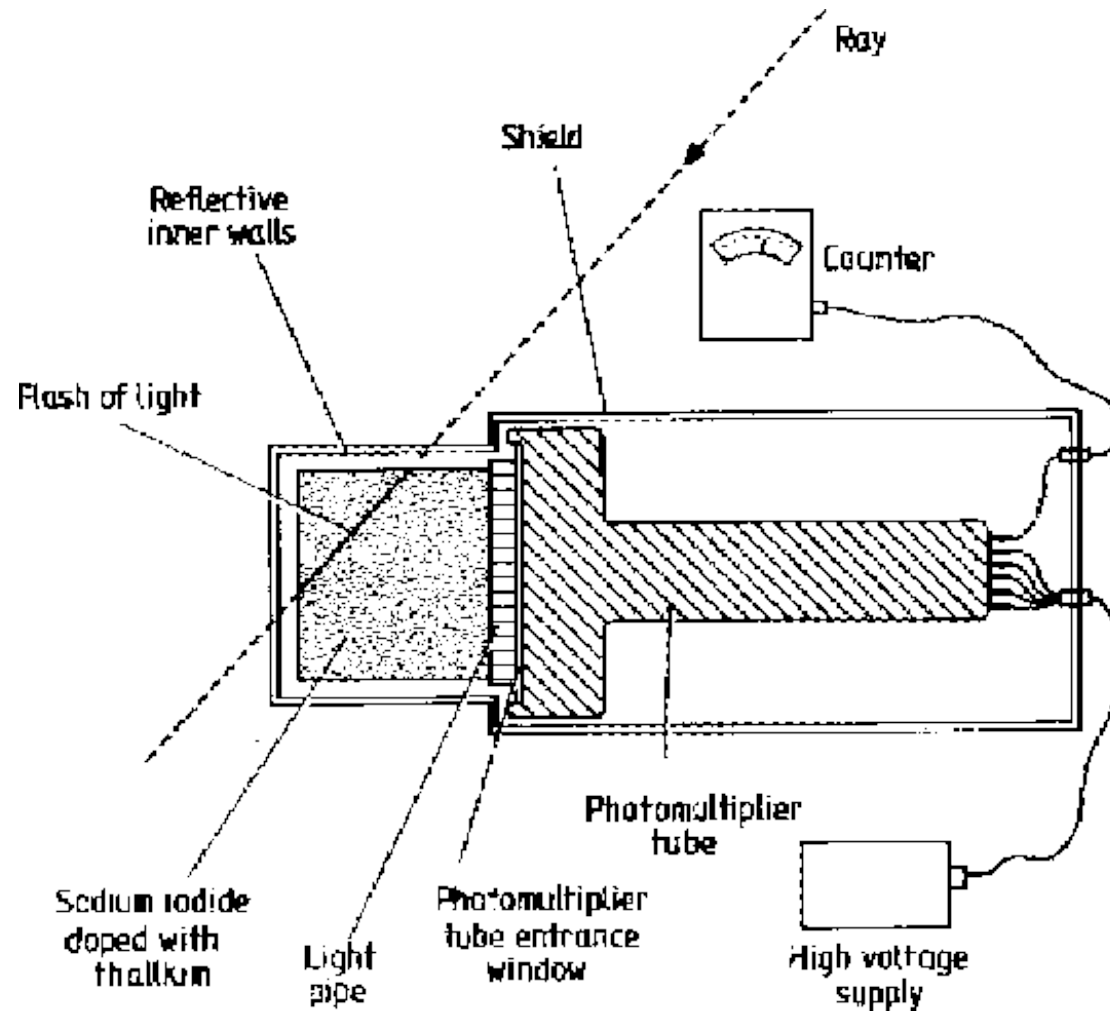
Hamamatsu MPPC



One of the first
SiPM
Pulsar, Moscow



Scintillator Detectors



Risposta del rivelatore - 1

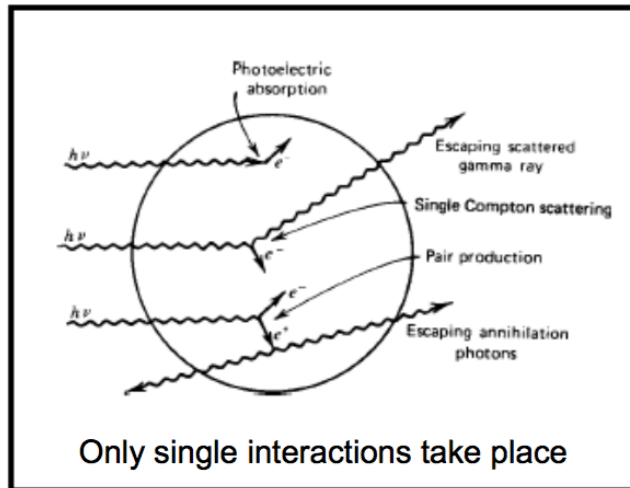


Figure 9: "Small" detector

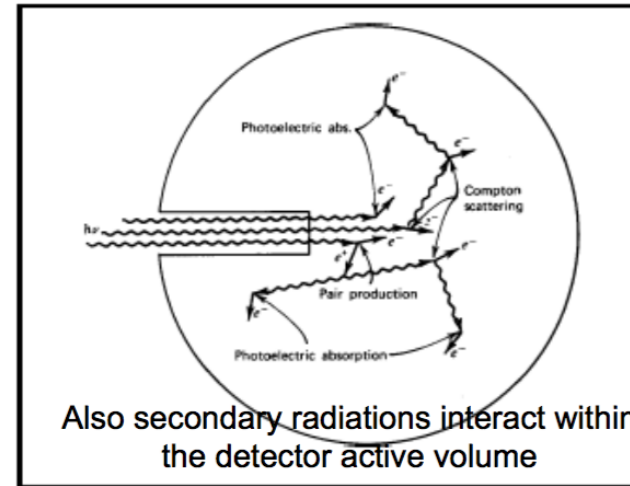


Figure 10: "Large" detector

most of the "secondary products" remain in the detector

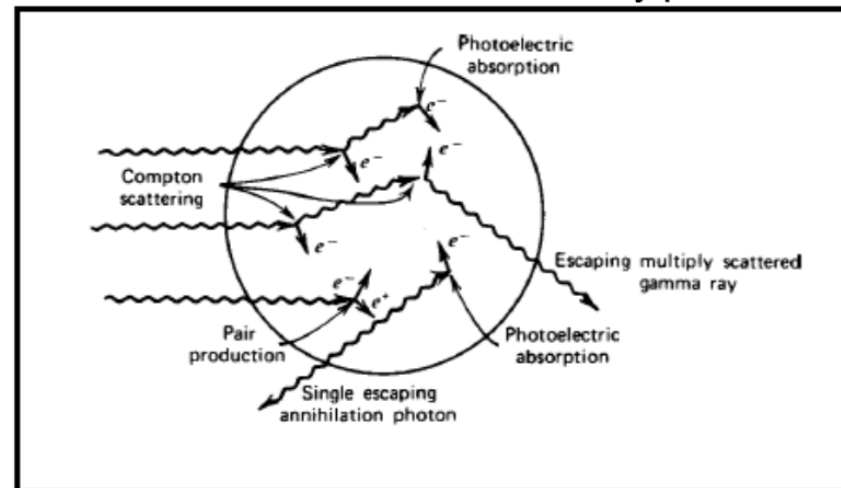


Figure 11: Intermediately sized detector

Risposta del rivelatore - 2

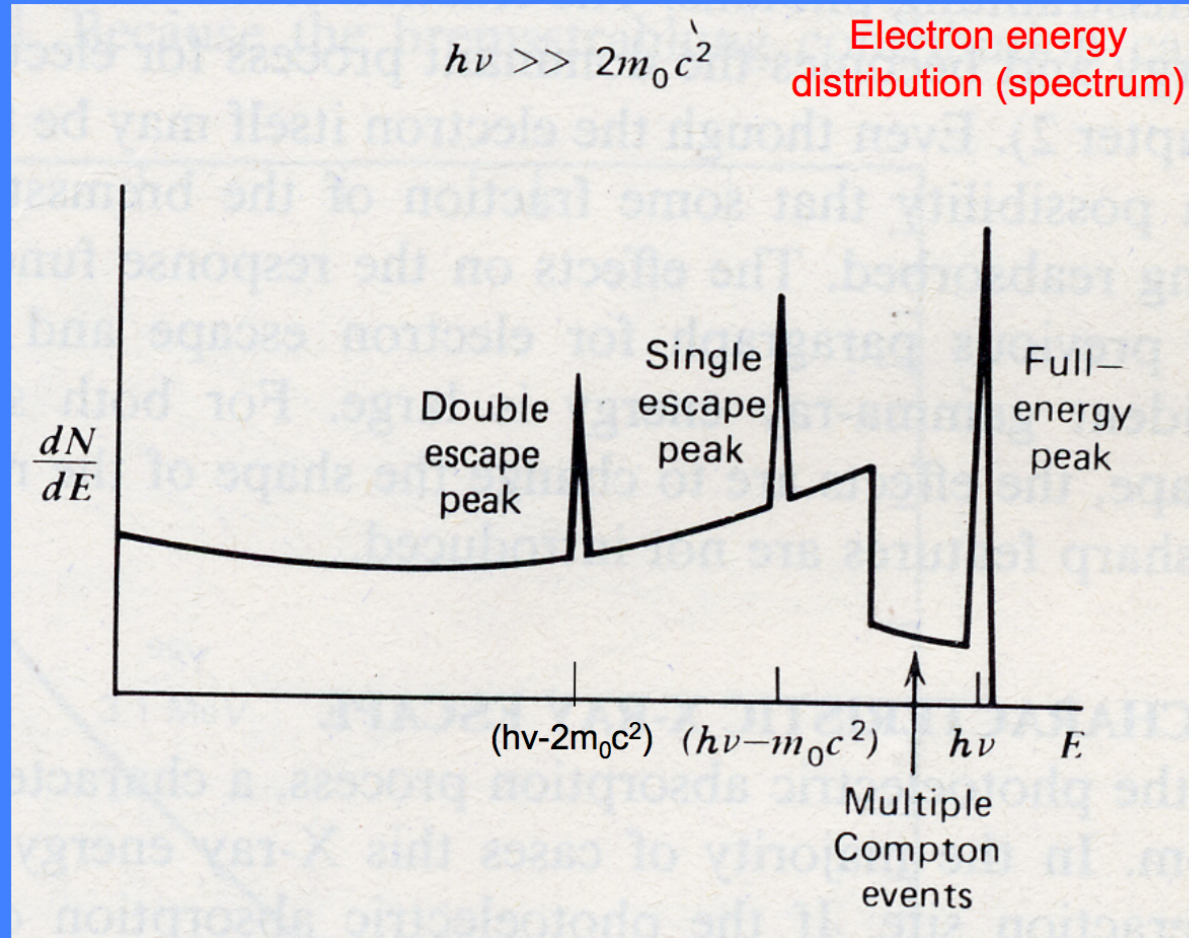


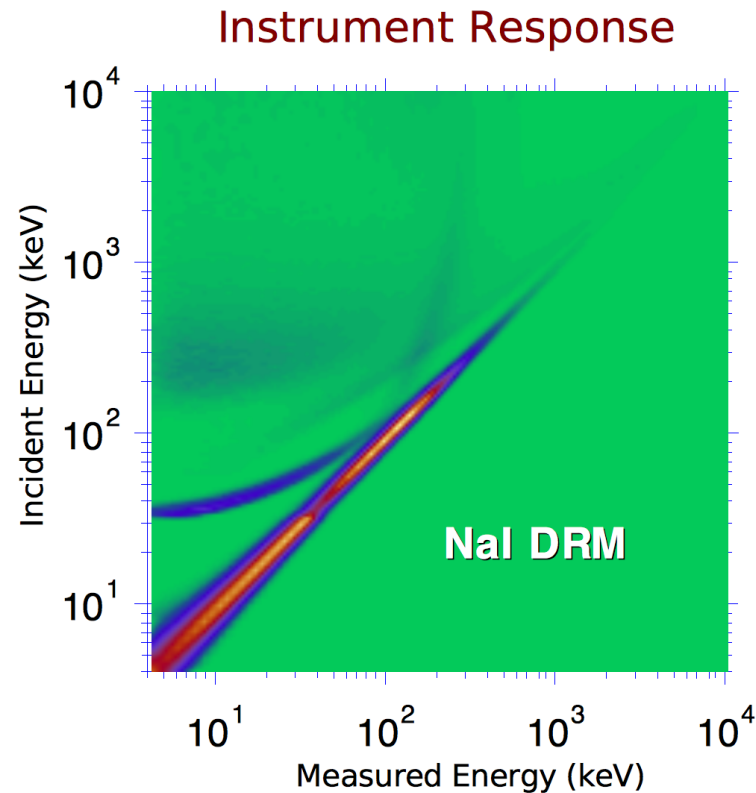
Photo-peak (full-energy peak): all photoelectric events remain in the detector and produce an energy deposit at the energy of the incoming photon

Single-escape peak: one annihilation photon leaves the detector without further interaction

Double-escape peak: both annihilation photons leave the detector (escape)

Case of intermediate-size detector (Knoll)

Detector Response Matrix

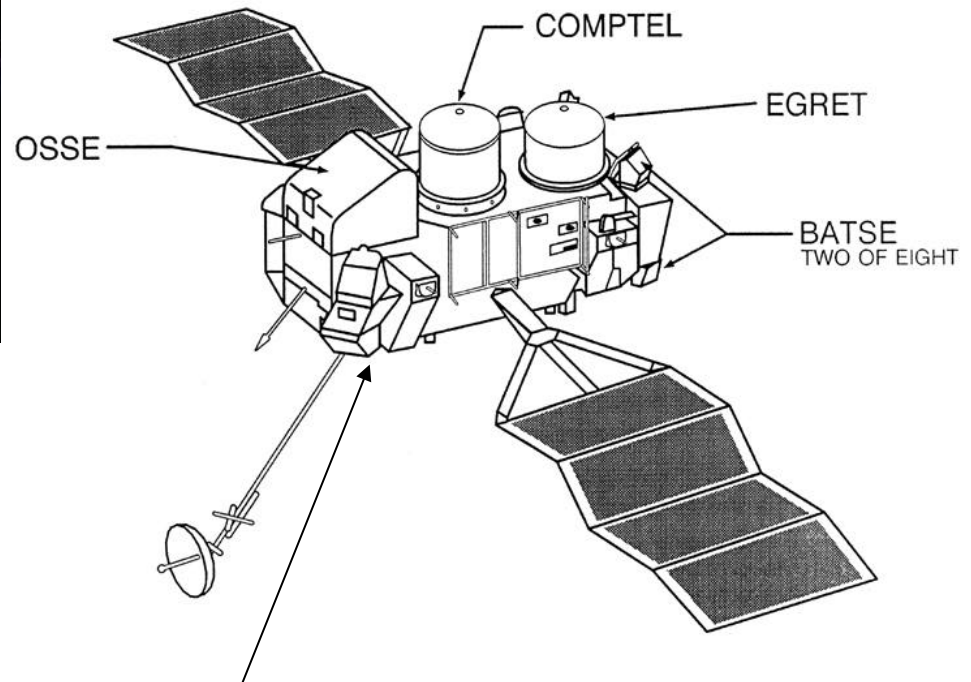


The response of a detector, which signal depends of the energy of an incoming photon, distributes the photon of a certain energy over many pulse height channels according to the gain and energy resolution of the detector. Usually this resolution function is relative complicated and depends on the photon energy. Since the energy acceptance and resolution of a given detector is determined by its design it is convenient to table this function while the photon energy serves as a parameter. This procedure leads directly to a form of a matrix and gives the whole data set the name *detector response matrix*.

CGRO-BATSE (1991-2000)



COMPTON OBSERVATORY INSTRUMENTS



The Instruments on CGRO Cover Six Orders of Magnitude in Photon Energy

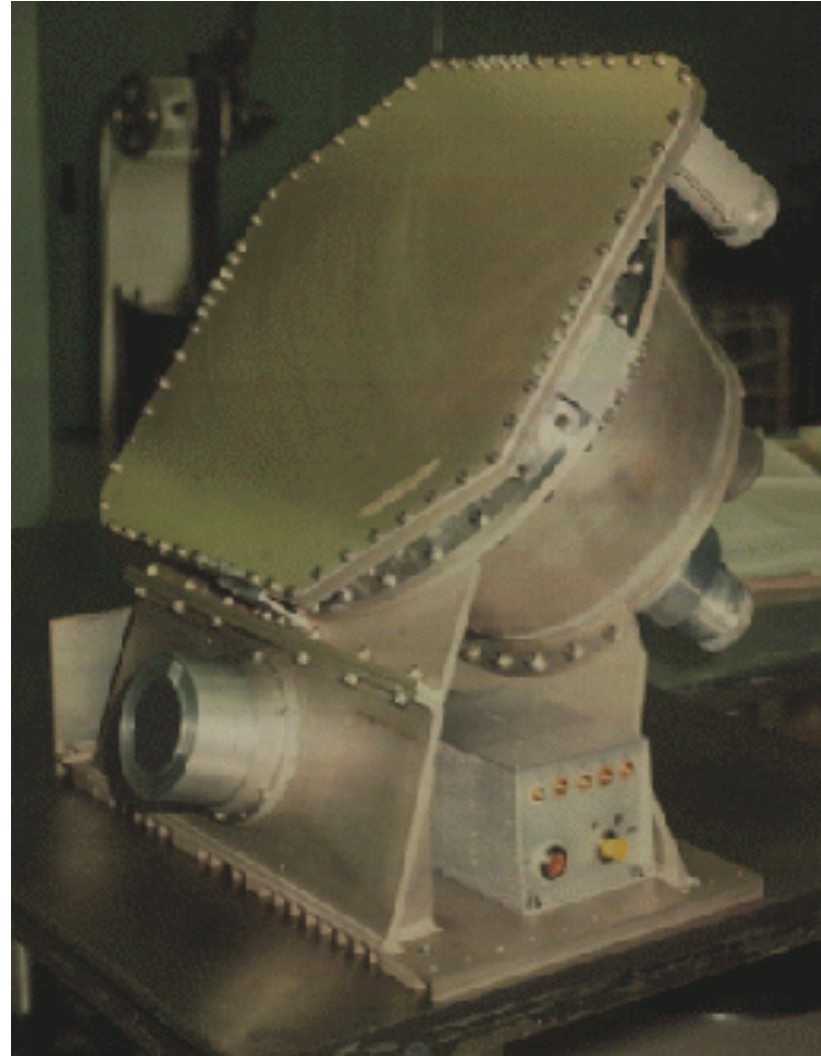


10 keV 100 keV 1 MeV 10 MeV 100 MeV 1 GeV 10 GeV 100 GeV

CGRO/BATSE (20 keV ÷ 10 MeV)

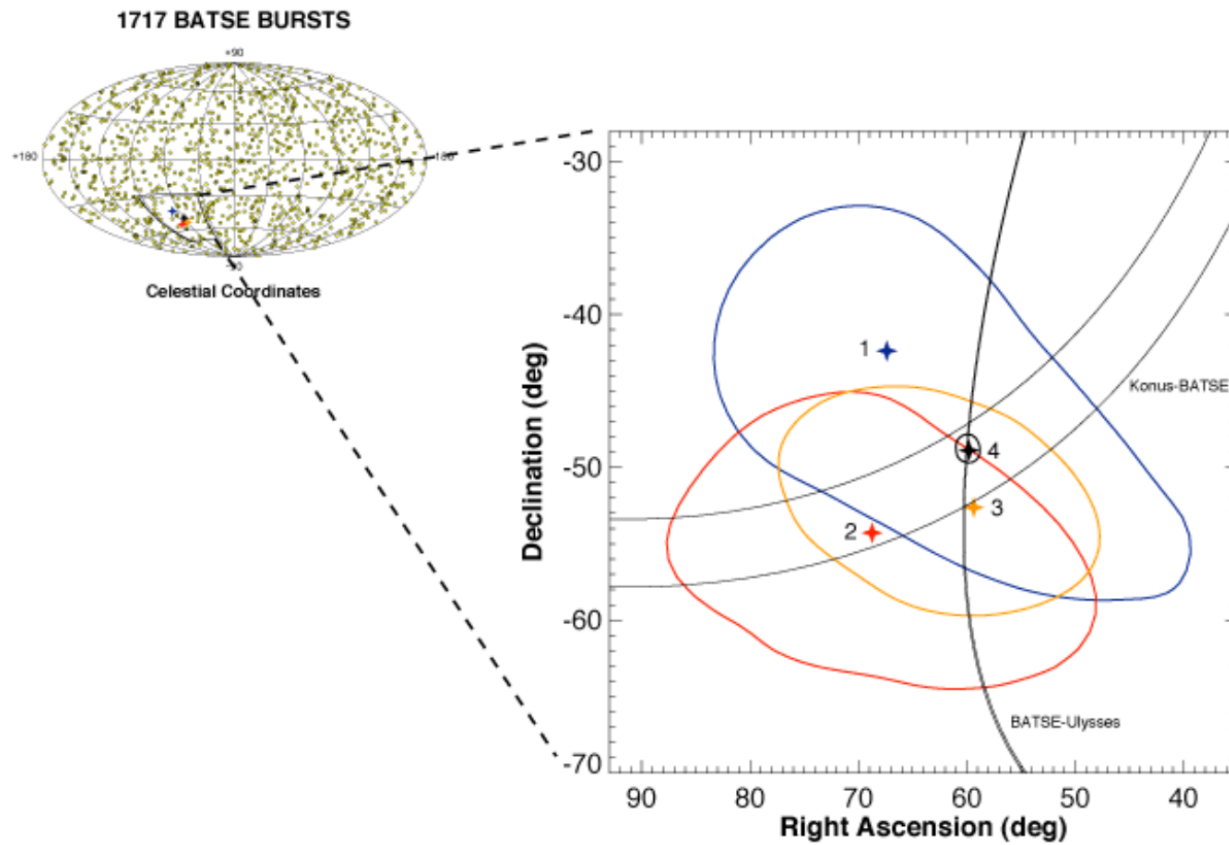
The BATSE instrument

- NaI scintillators
- 20 keV – 2 MeV
- FoV 4π



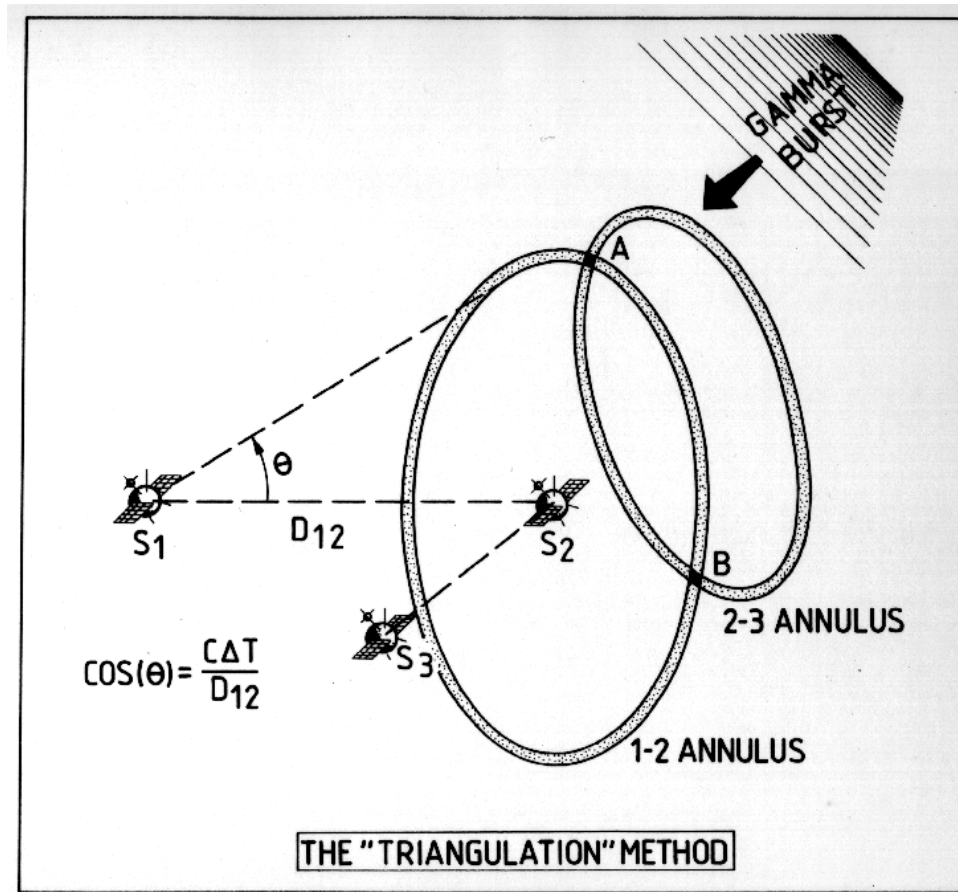
GRB localisation

BATSE GAMMA-RAY BURST CLUSTER



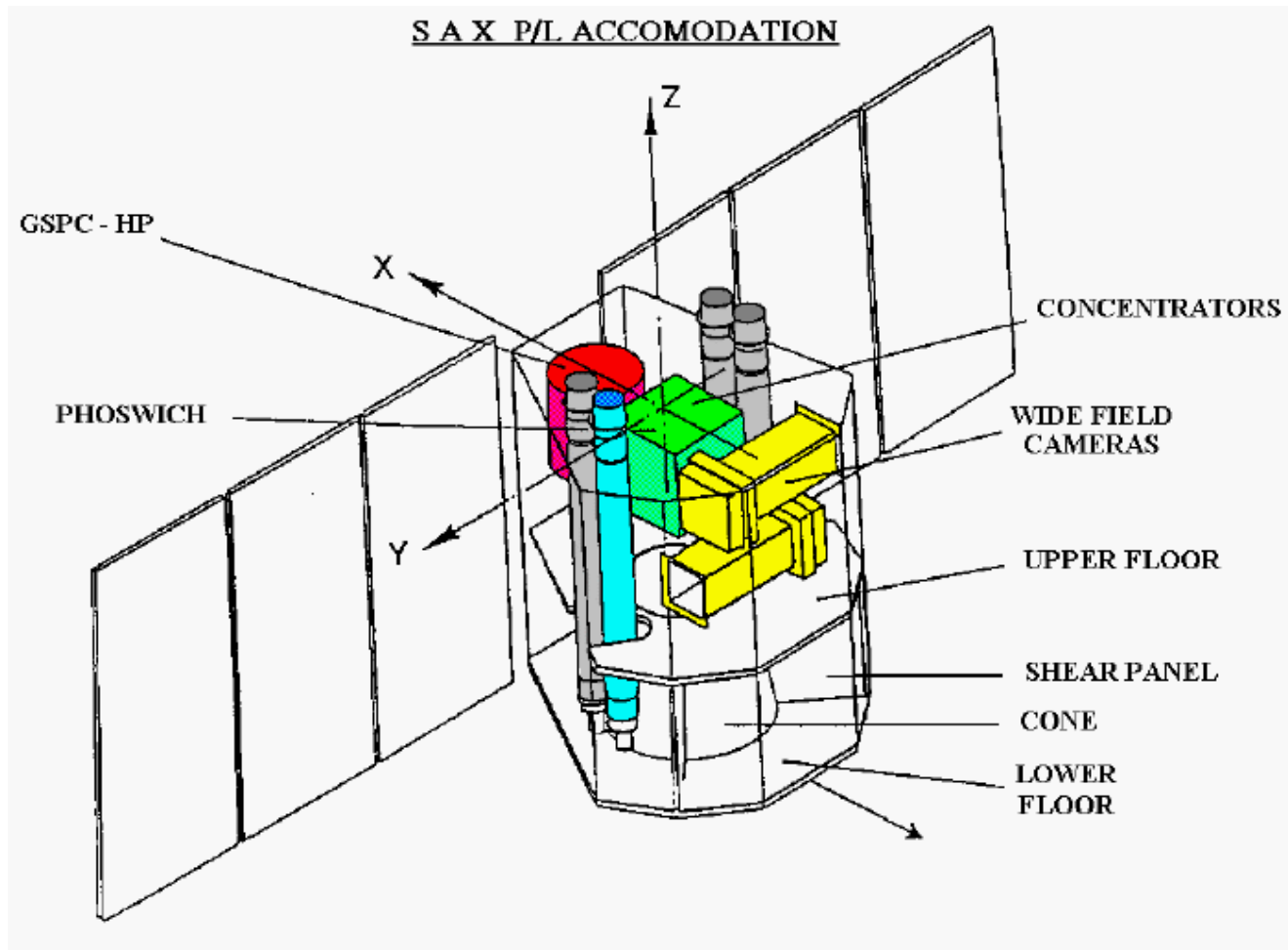
GRB History

- Interplanetary Network (IPN)

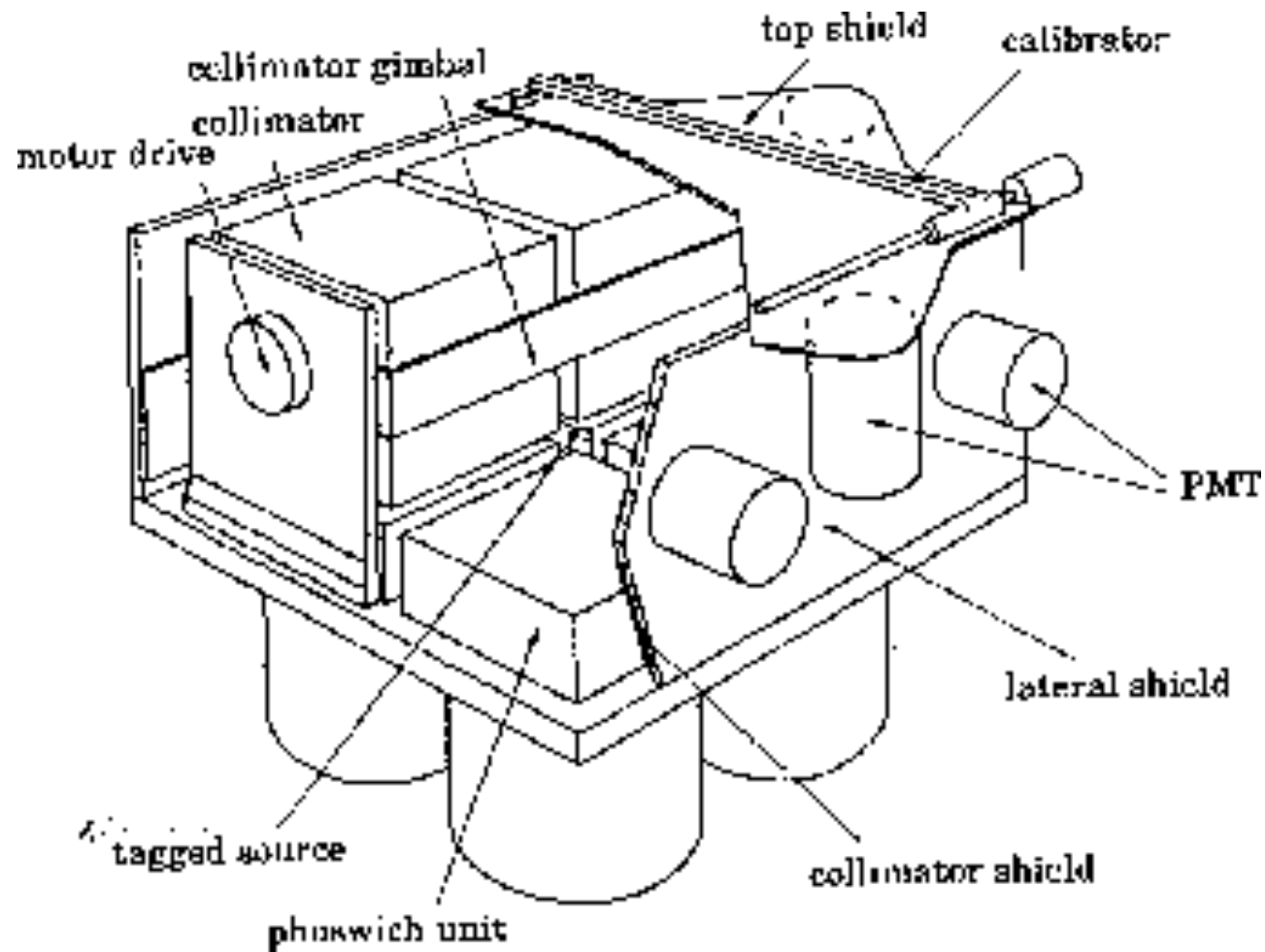


<http://www.ssl.berkeley.edu/ipn3/>

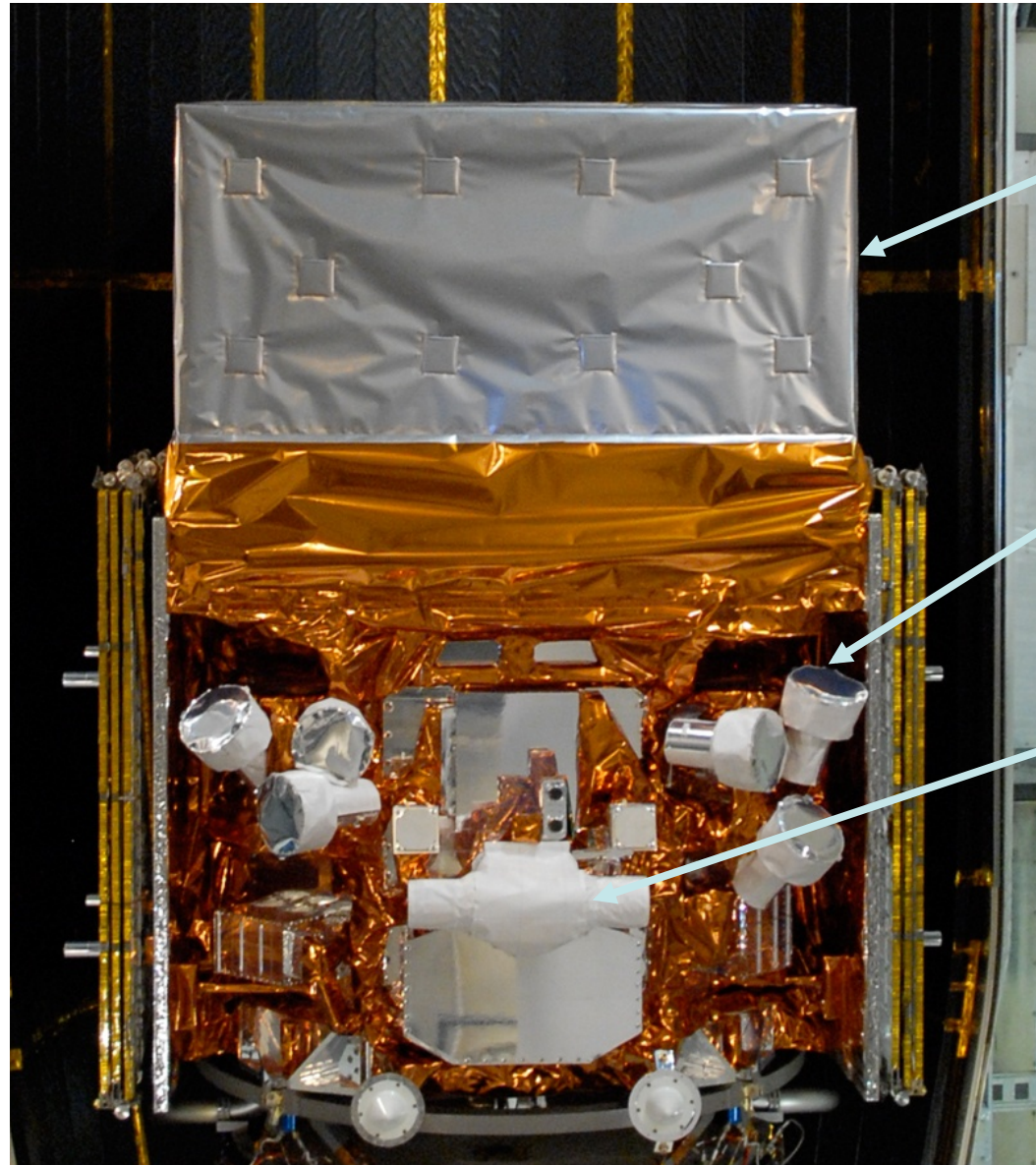
BeppoSAX (1995 - 2002)



BeppoSAX (1995 - 2002)



Fermi/GBM detector (2008 -- ..)



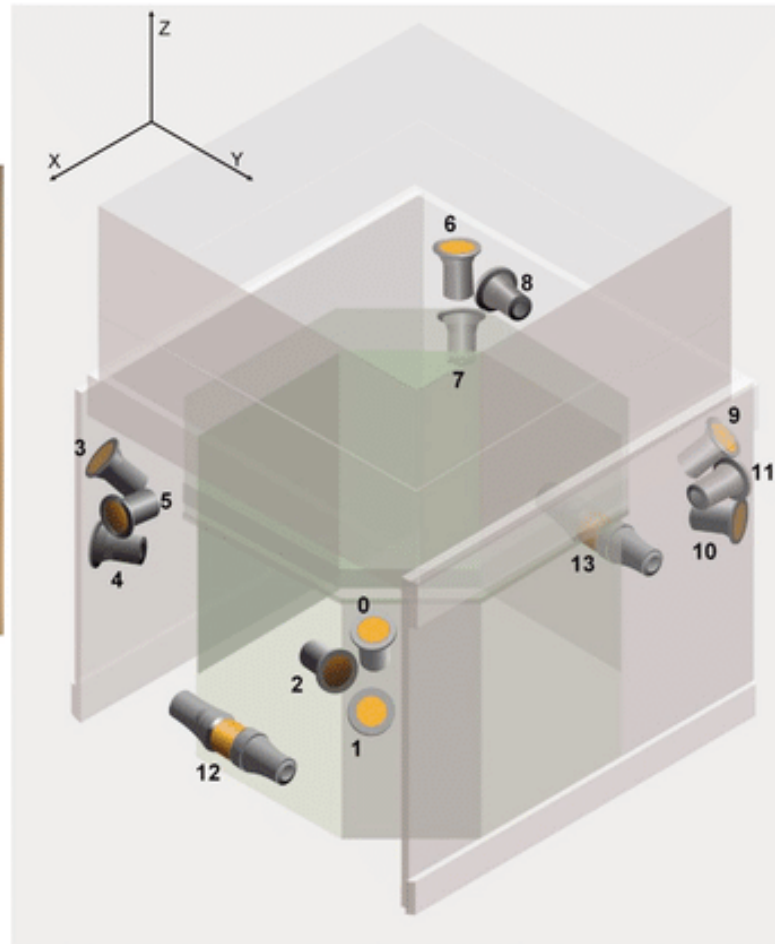
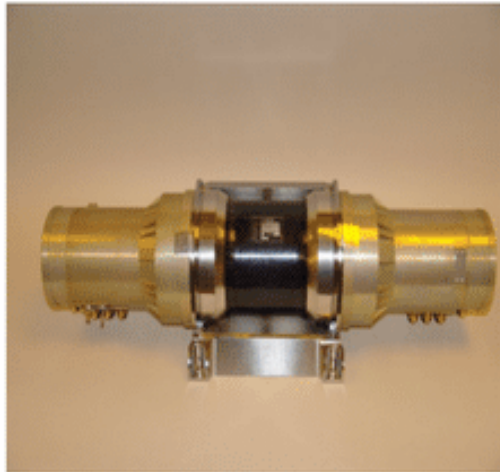
LAT

GBM
NaI
Detector

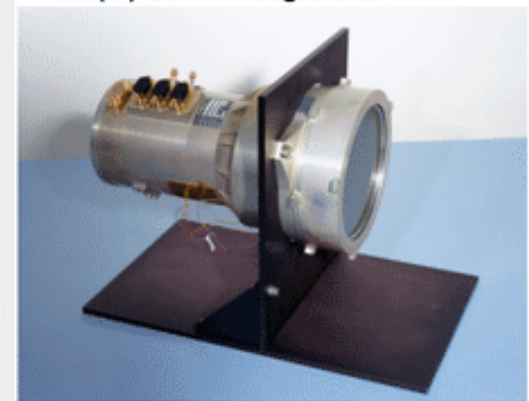
GBM
BGO
Detector

Fermi/GBM detector (2008 -- ..)

BGO detector unit



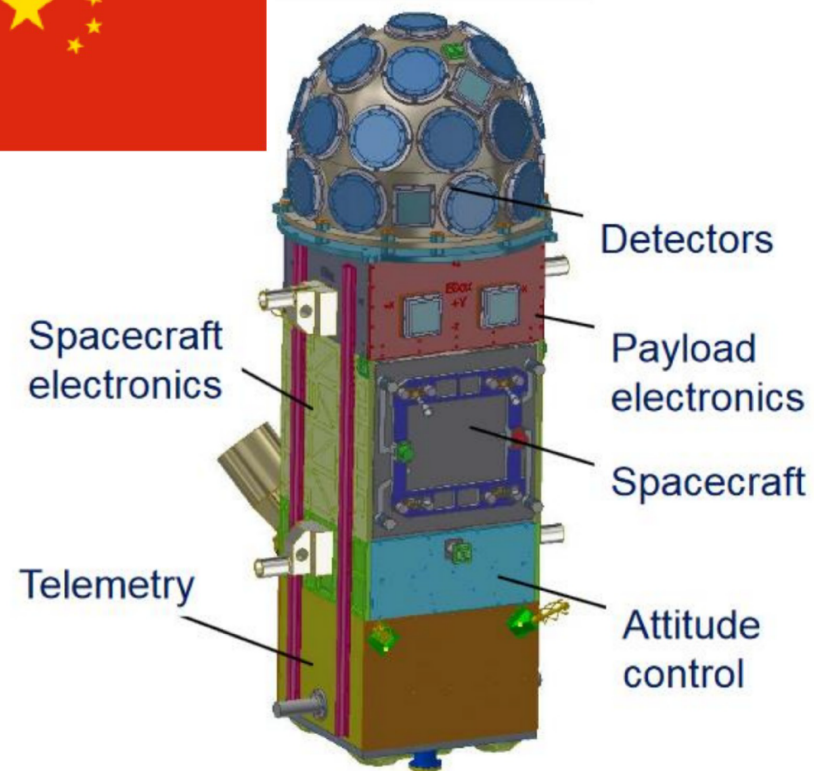
Nal(Tl)-detector flight unit



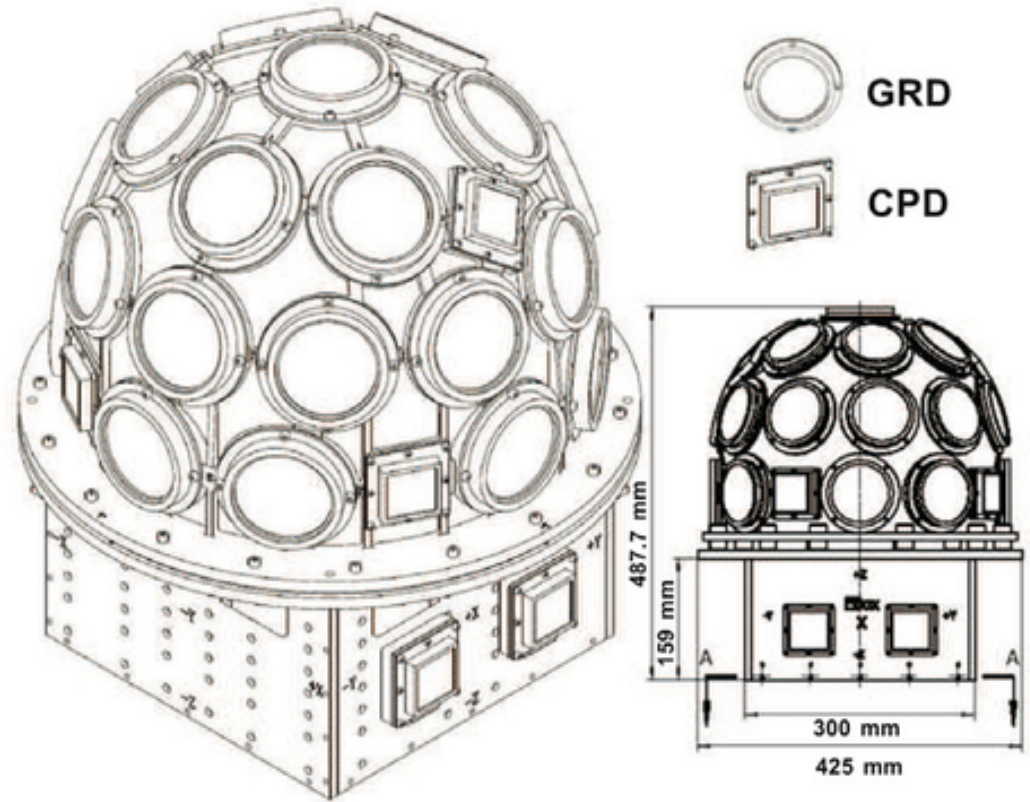
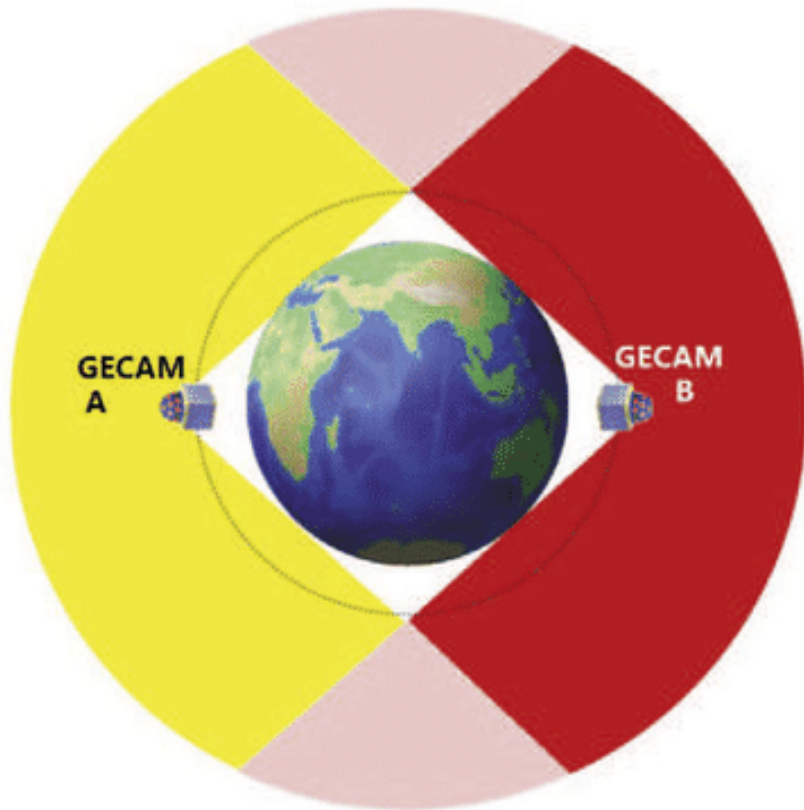
GECAM

GCAM

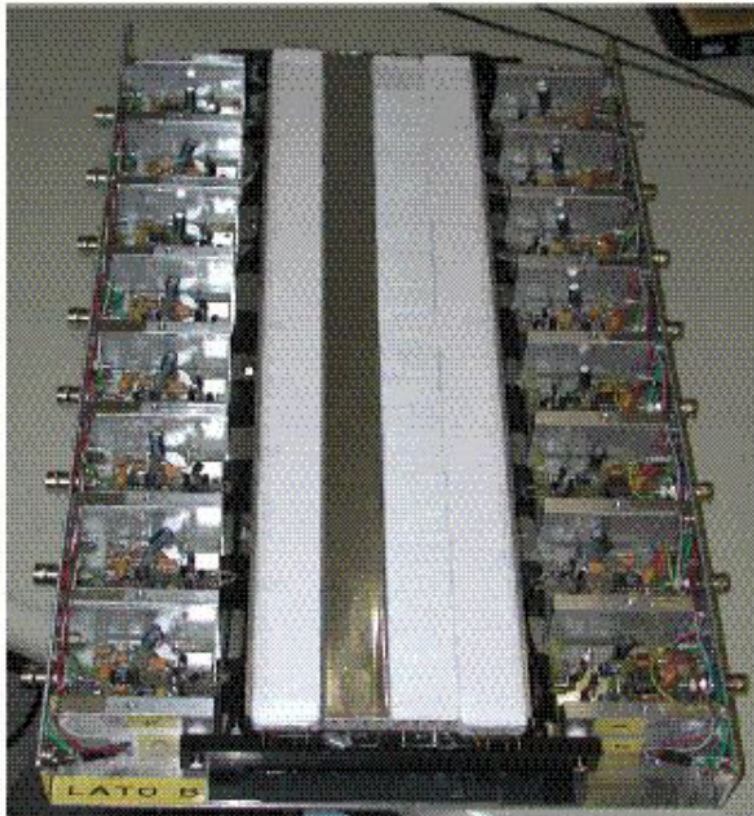
Chinese mission
Launch 2021
2 satellites
100% sky coverage.
Very similar to GBM.
Positioning by triangulation
(need 3 participants)
Some directionality.
Cannot do the work to alert CTA all
by itself.



GECAM



AGILE MCAL



MINI-CALORIMETER

DETECTOR

- 30 CsI bars wrapped with tight diffusion material organized in 2 orthogonal trays
- bar dimension: $40 \times 2.3 \times 1.5 \text{ cm}^3$
 - total radiation length: $1.5X_0$ (in axis)

FRONTEND ELECTRONICS

- 1 photodiode on each side of the bar
- optically coupled

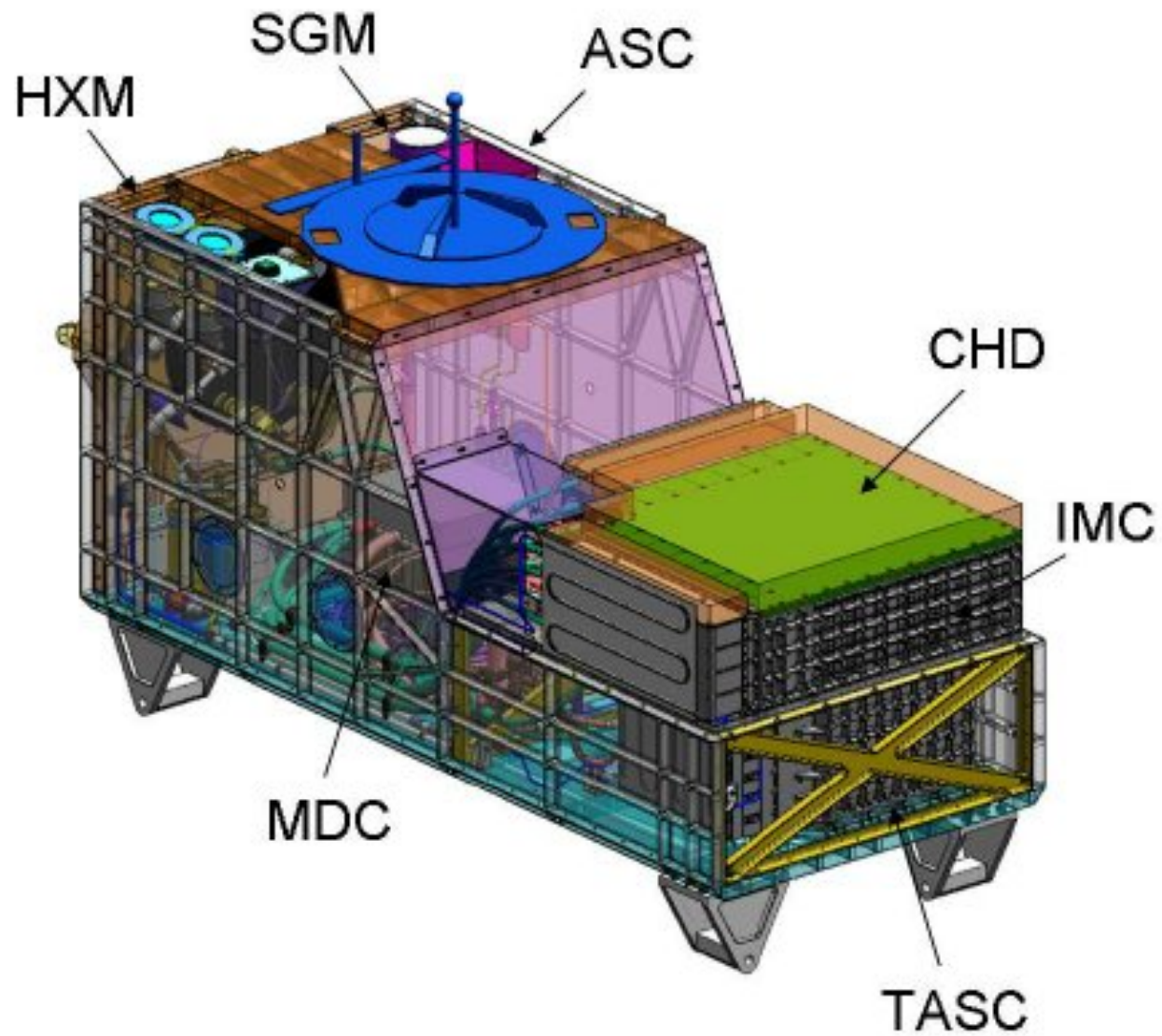
GOAL

- measure energy deposit of the photon conversion pair (GRID mode)
- detect GRBs and transients in the range 0.25-250MeV (BURST mode)

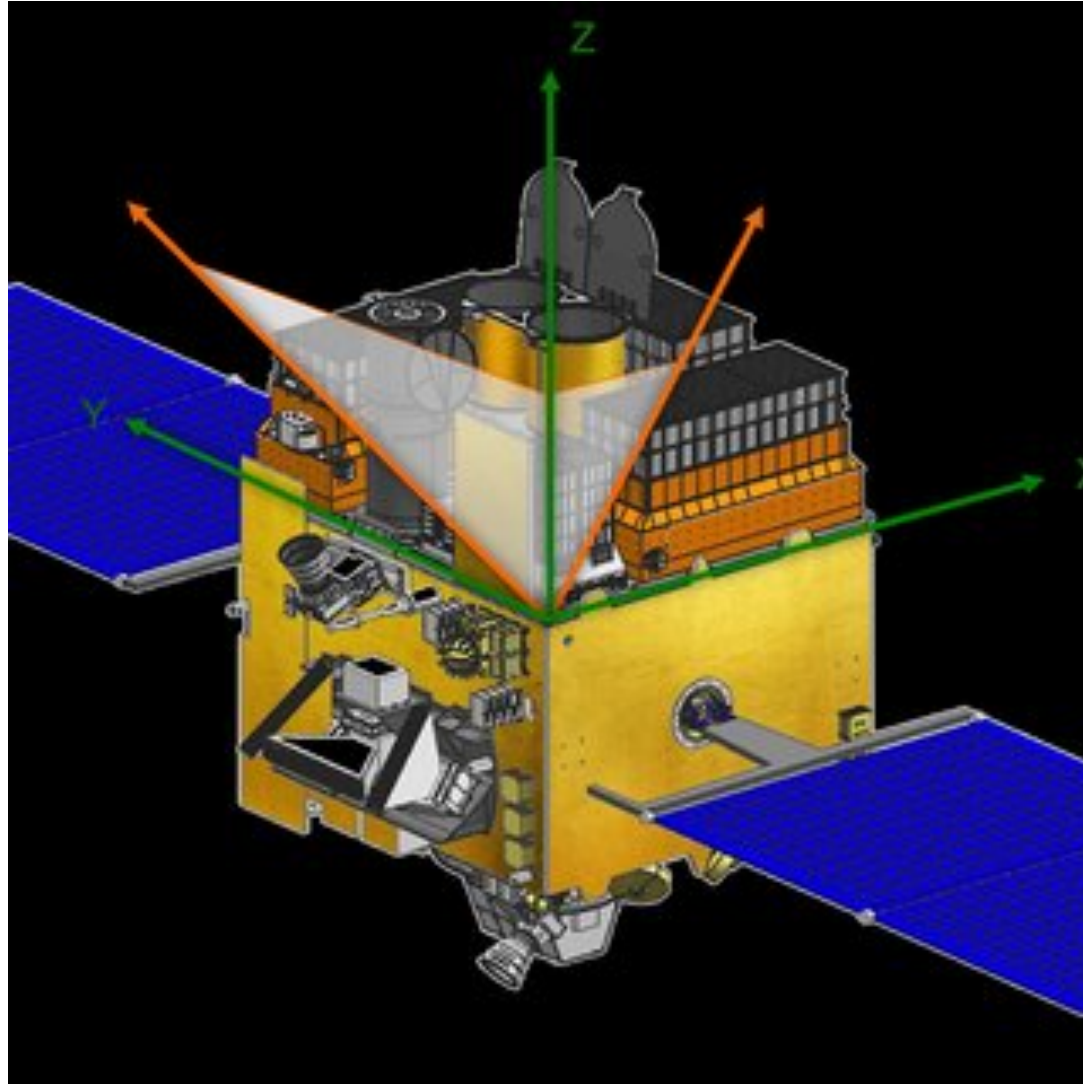
SCIENTIFIC FEATURES

- energy resolution: 22-24%(FWHM) @ 1MeV
0.7% @ 100MeV
- spatial resolution: 15mm @ 1MeV
2mm @ 100MeV
- timing resolution: $2 \mu\text{s}$ (BURST mode)

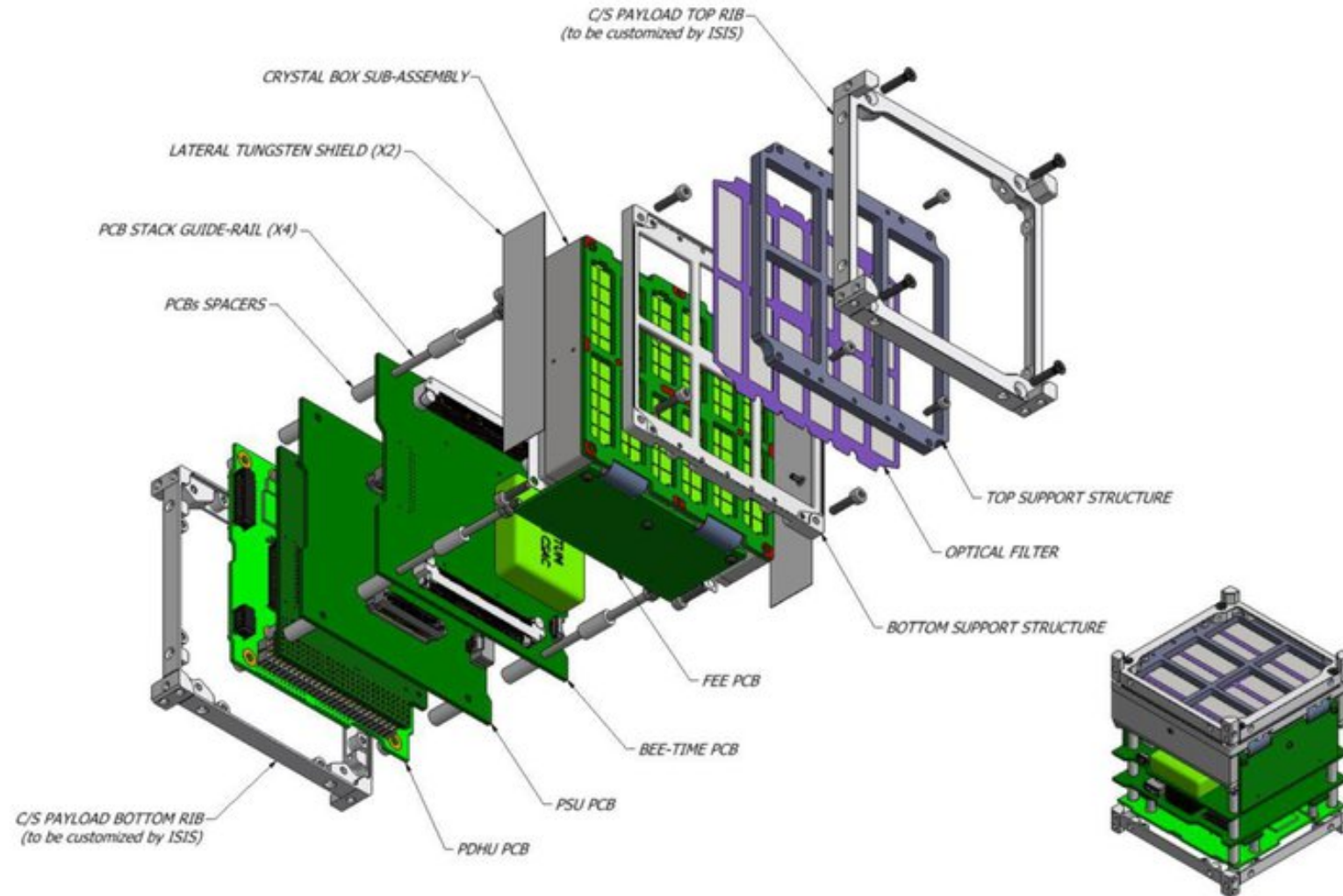
CALET



AstroSAT



HERMES



Exercise #1

- Find the web sites of BATSE
- Find the web site (if any) of BeppoSAX
- Find the web site of Fermi/GBM
- Find the web site of AGILE/MCAL GRB catalog
- Find the web site of CALET GRBM
- Find the web site of AstroSAT CZTI GRB