Mathematisch-Naturwissenschaftliche Fakultät

C A U

Christian-Albrechts-Universität zu Kiel

Vertiefung in die Extraterrestrische Physik

Cherenkov und Anwendung

Photonen

Bernd Heber

25.11.2007

Interaction of Photons with matter

Interaction of Photons with matter (processes)

Interaction of Photons with matter (D'Alemberts law)

Interaction of Photons with matter (D'Alemberts law)

Photo effect

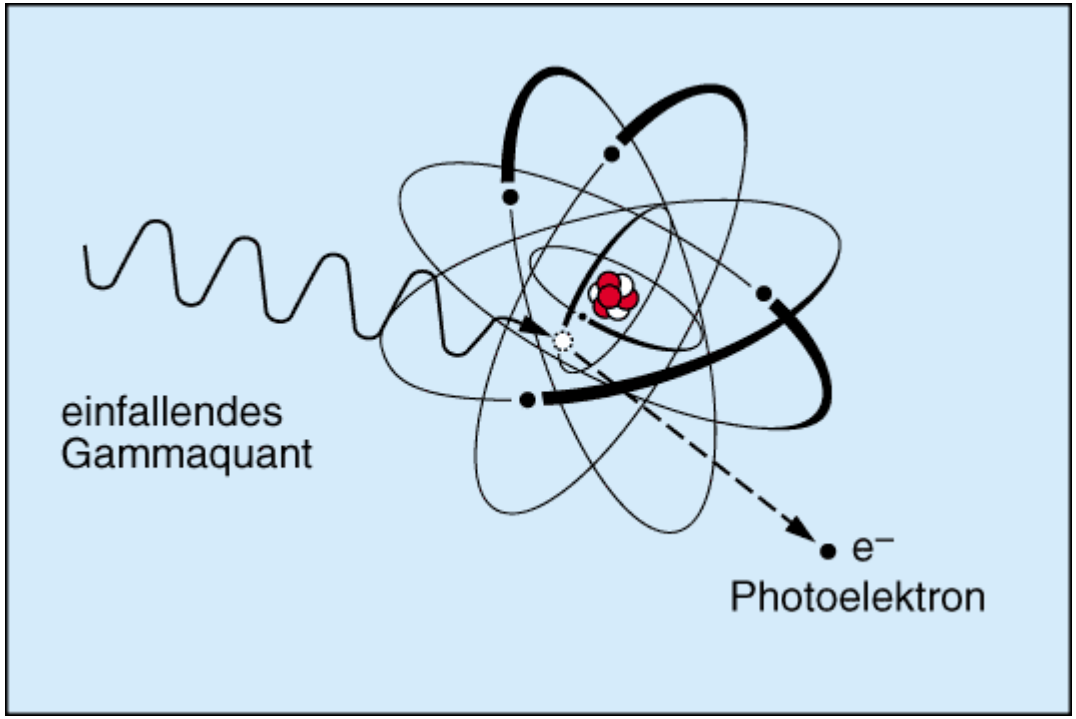


Photo effect (Principals)

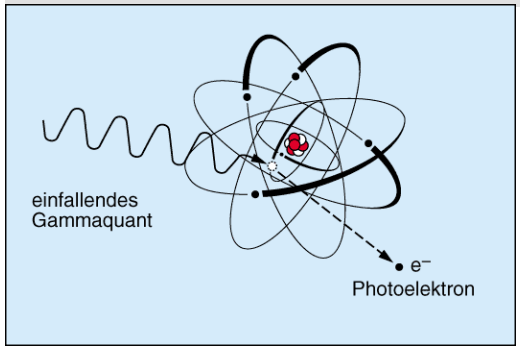


Photo effect (Momentum/energy)

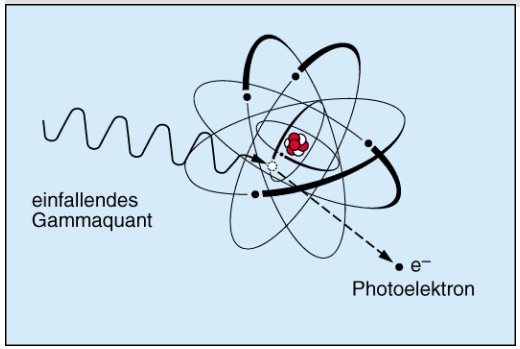
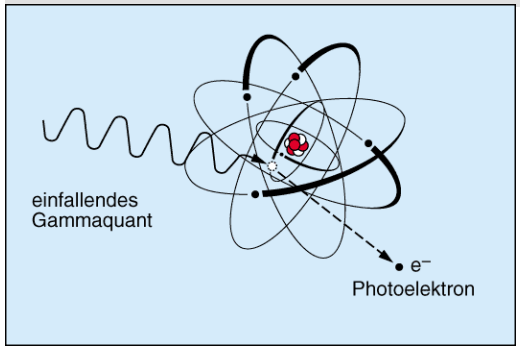


Photo effect (atomic structure)



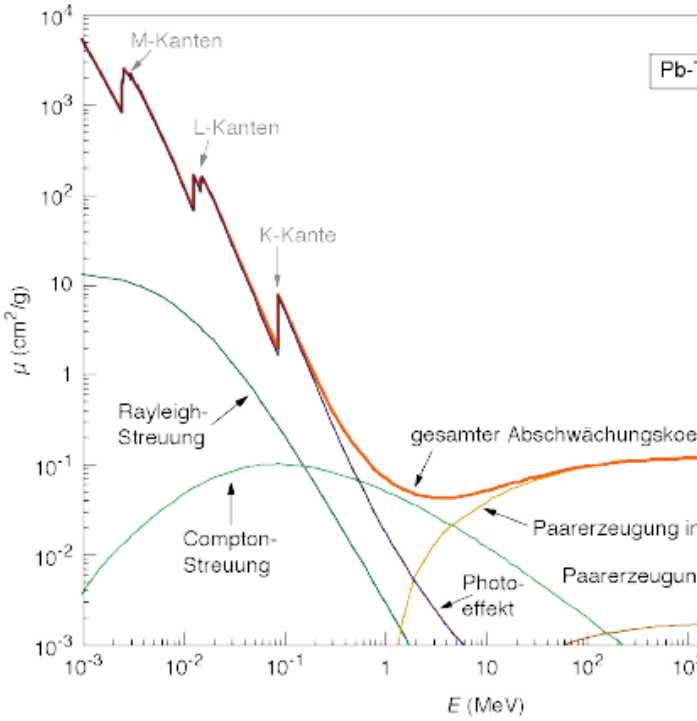
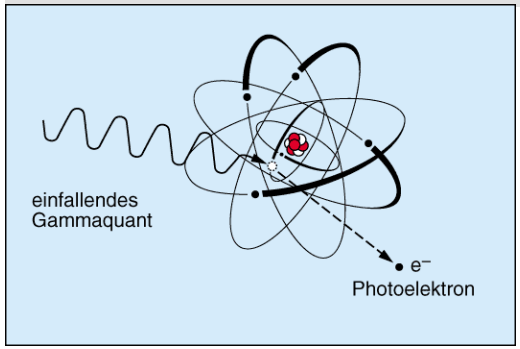


Photo effect (Crossection)



$$\sigma_{photo} = 4\sqrt{2}\,\alpha^4\sigma_0 Z^5\left(\frac{m_e c^2}{E_\gamma}\right)^{7/2} \propto \frac{Z^5}{E_\gamma^{7/2}}$$

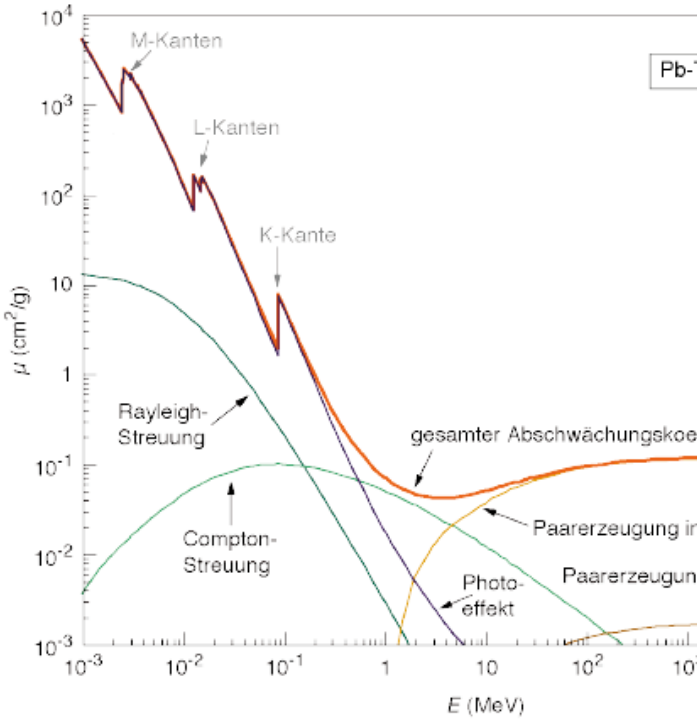
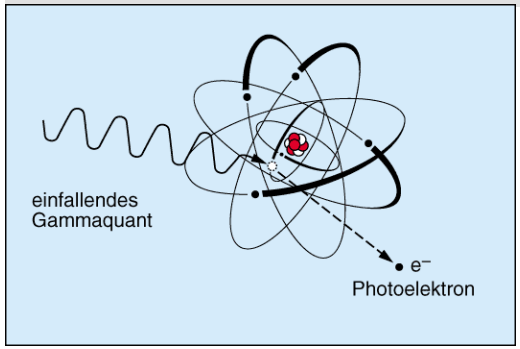
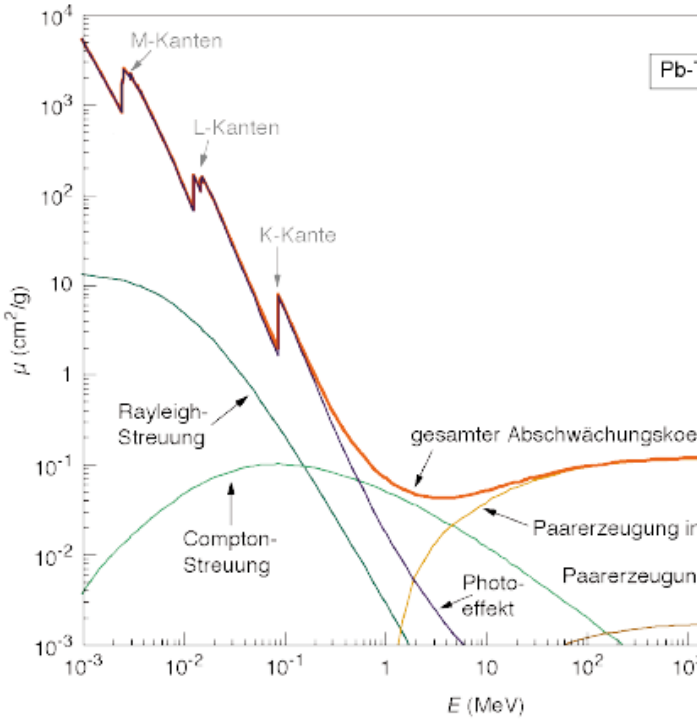


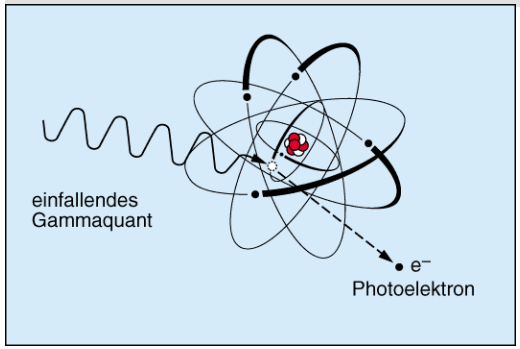
Photo effect (Crossection)



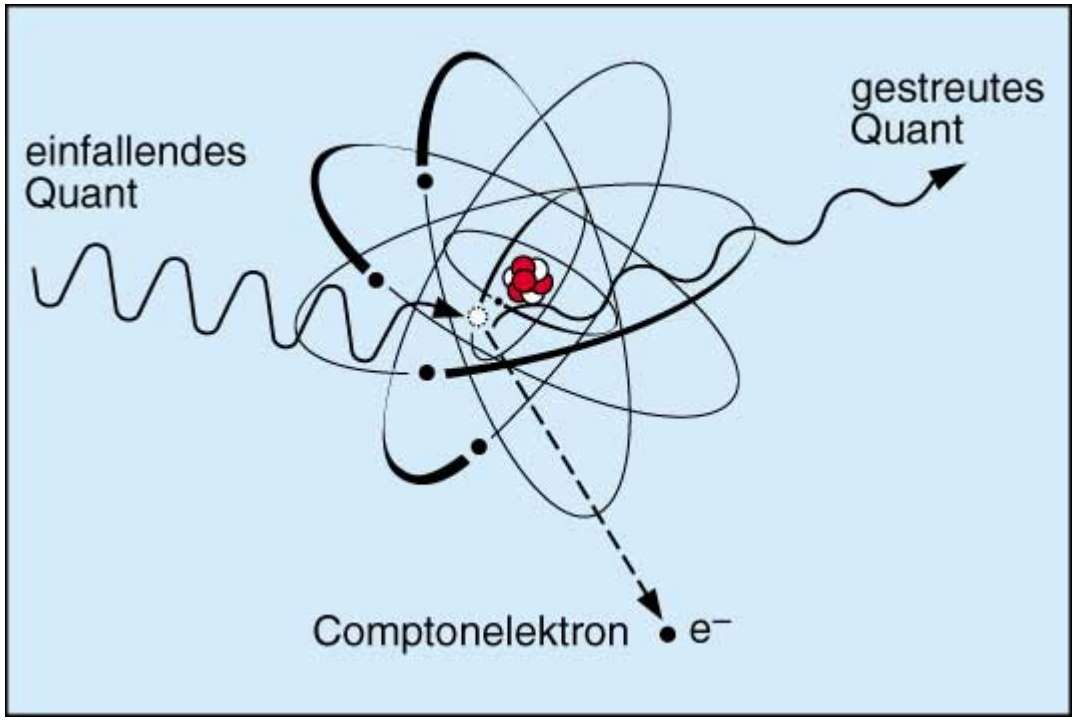


$$\upsilon_{photo} = \frac{3}{2}\alpha^4\upsilon_0 Z^5 \frac{m_e c^2}{E_\gamma} \propto \frac{Z^5}{E_\gamma}$$

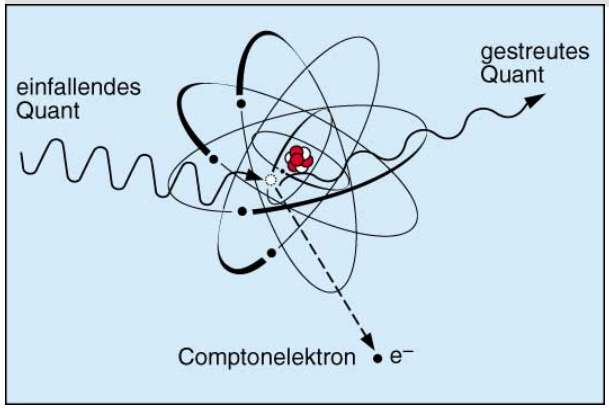
Photo effect (Summary)



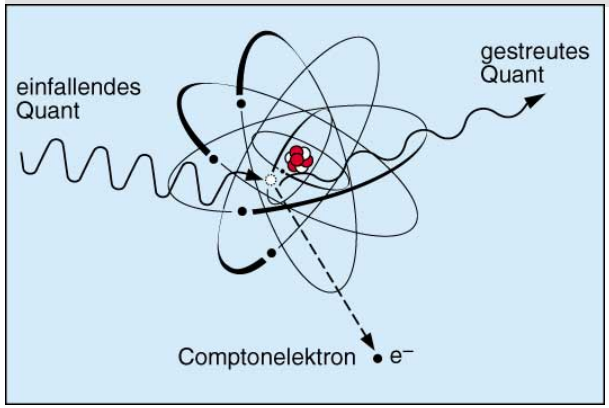
Compton-Effect



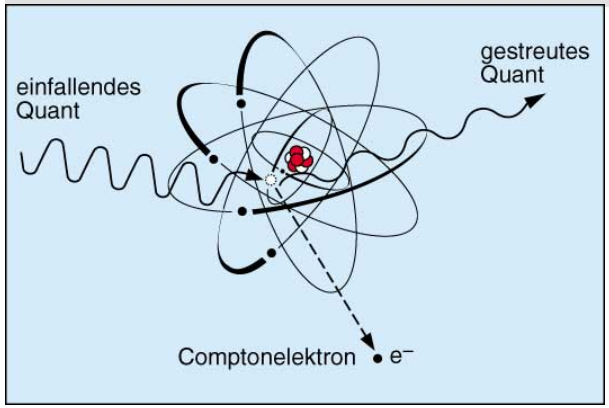
Compton-Effect (Principals)



Compton-Effect (Principals)



Compton-Effect (Process)



Klein – Nishina Formular

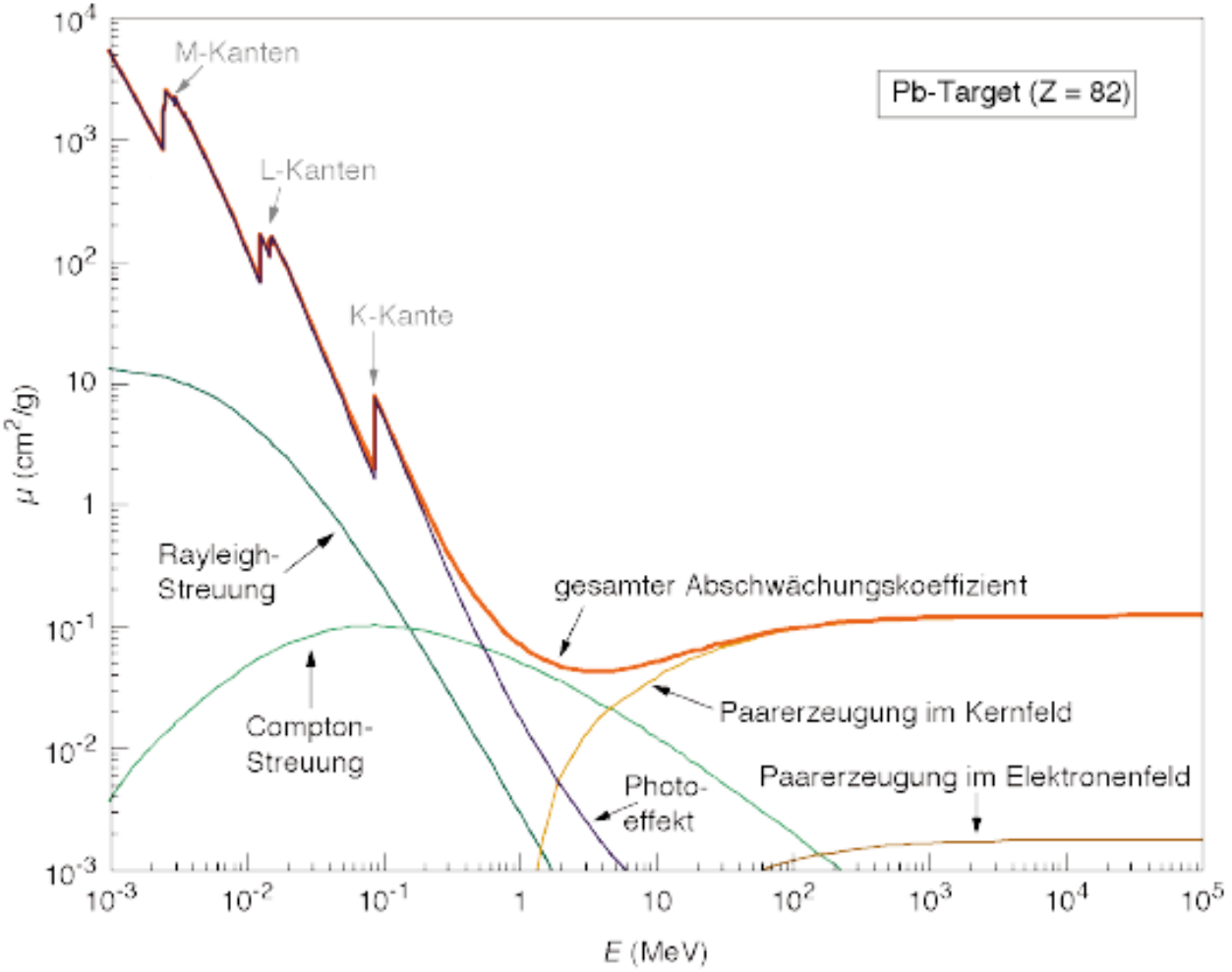
$$\frac{d\sigma_c}{d\Omega} = \frac{r_e^2}{2} \frac{1}{\left[1+\kappa(1-\cos\theta)\right]^2} \left(1+\cos^2\theta + \frac{\kappa^2(1-\cos\theta)^2}{1+\kappa(1-\cos\theta)} \right)$$

$\kappa = E_\gamma / m_e c^2$ … "reduzierte" Photonenergie

Integriert über den gesamten Raumwinkel ergibt sich (*pro Elektron*):

$$\sigma_c = 2\pi r_e \left\{ \frac{1+\kappa}{\kappa^2} \left[\frac{2(1+\kappa)}{1+2\kappa} - \frac{1}{\kappa} \ln(1+2\kappa) \right] + \frac{1}{2\kappa} \ln(1+2\kappa) - \frac{1+3\kappa}{(1+2\kappa)^2} \right\}$$

Crossections

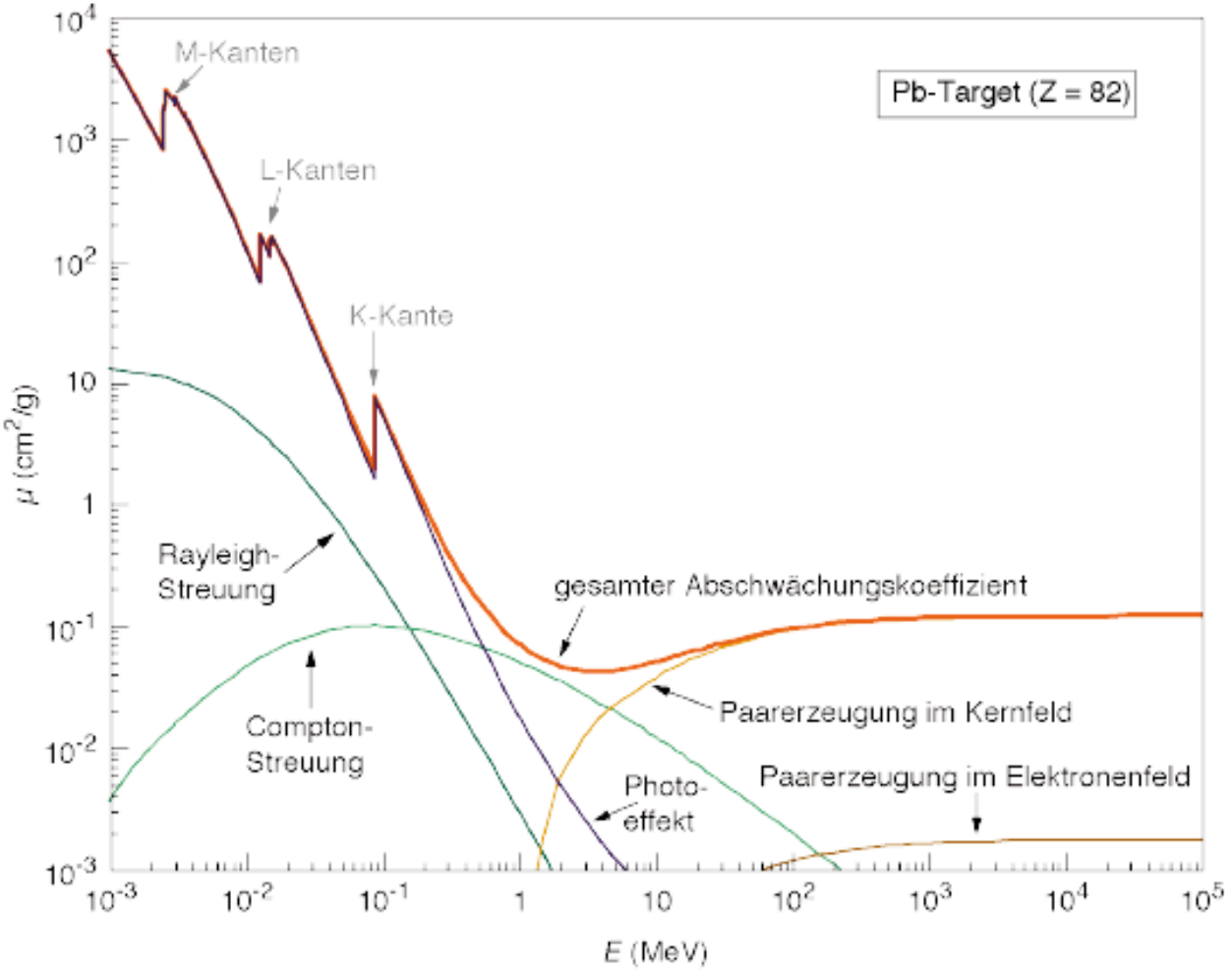


Quelle: http://physics.nist.gov/PhysRefData/
berechnet mittels XCOM
(Photon Cross Sections Database)

Thomson- und Rayleigh-Scattering

Thomson- und Rayleigh-Scattering

Crossections



Quelle: http://physics.nist.gov/PhysRefData/
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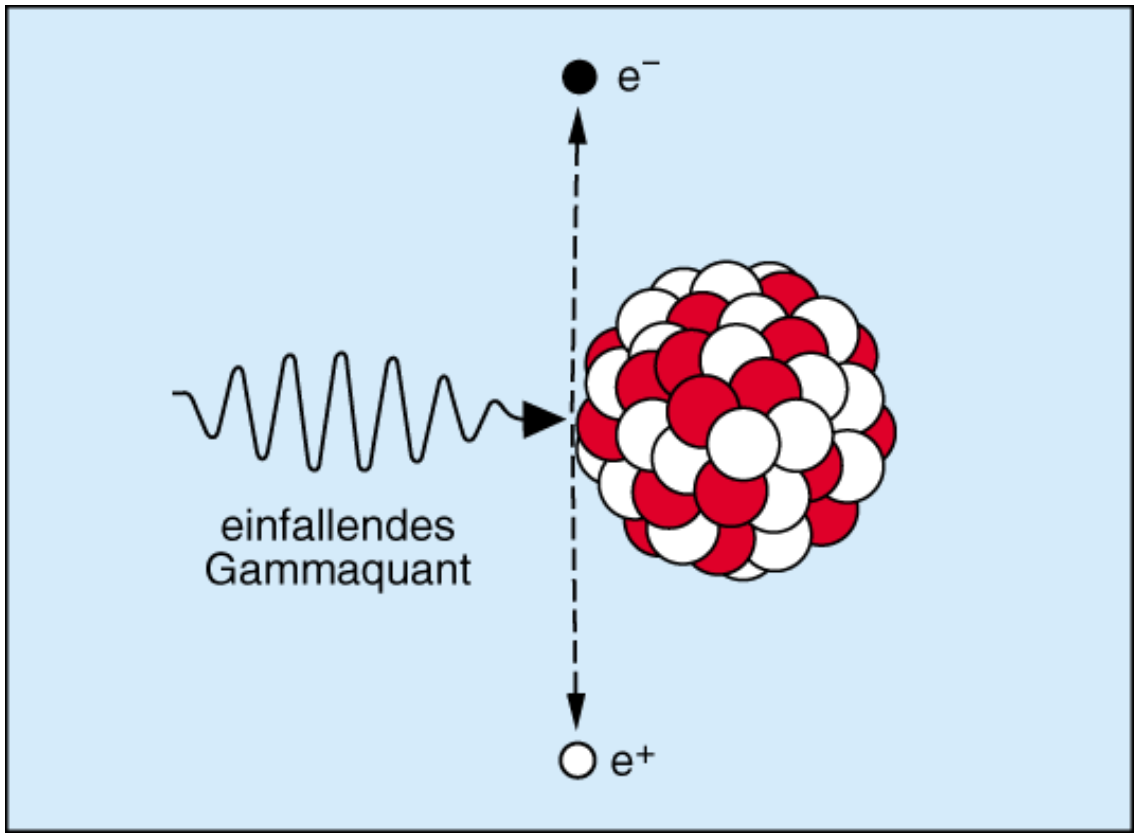
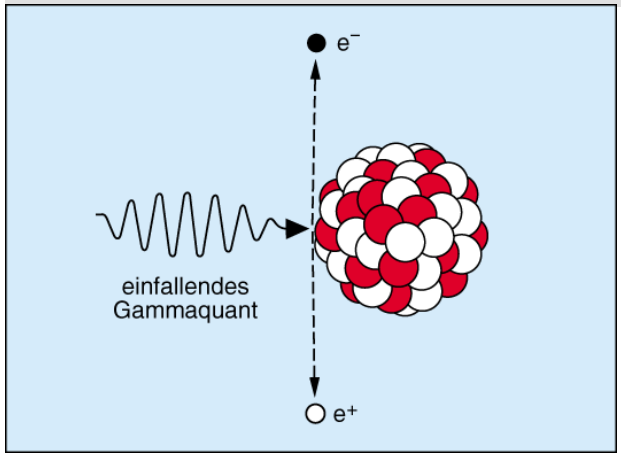
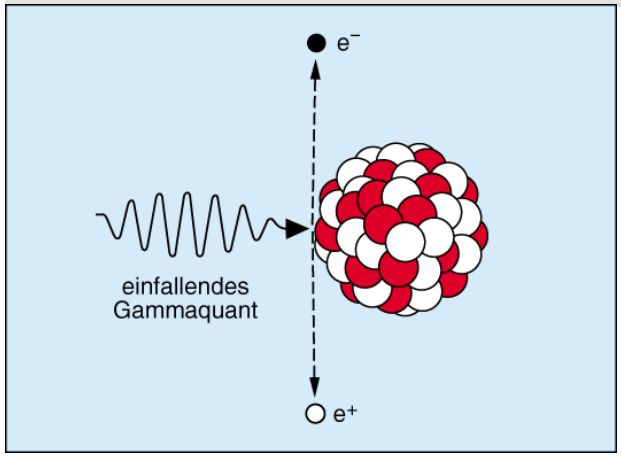
Pairproduction



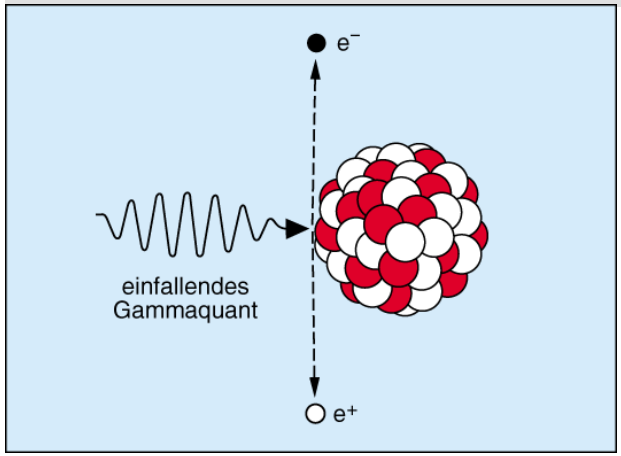
Pairproduction



Pairproduction

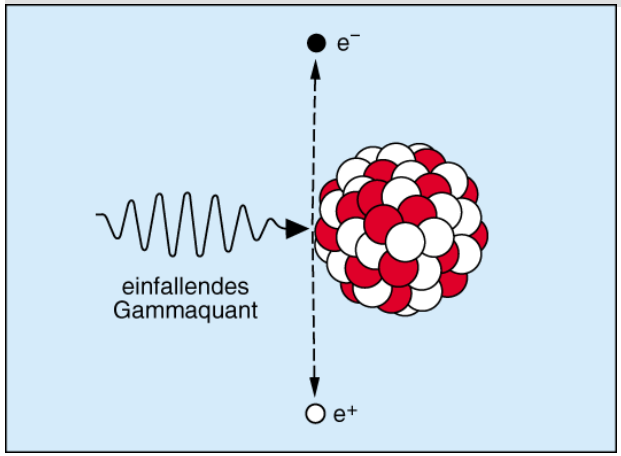


Pairproduction



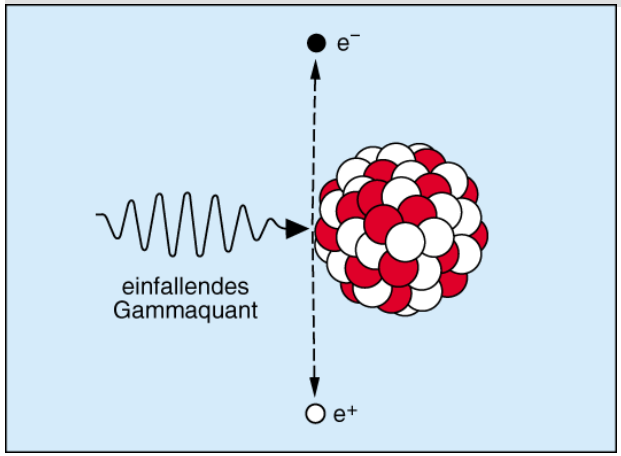
$$\sigma_{\text{pair,nucl}} = 4\alpha r_e^2 Z^2 \left[\frac{7}{9}\ln\left(\frac{2E_\gamma}{m_e c^2}\right) - \frac{109}{54}\right] \qquad \text{für} \qquad 1 << \frac{E_\gamma}{m_e c^2} < \frac{1}{\alpha Z^{1/3}}$$

Pairproduction



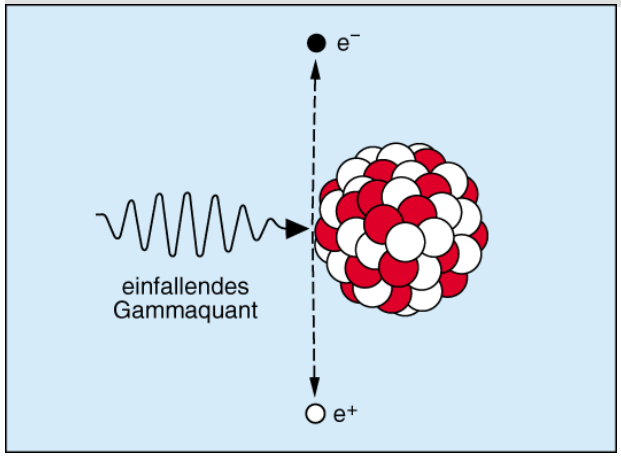
$$\sigma_{\text{pair,nucl}} = 4\alpha\, r_e^2 Z^2 \left[\frac{7}{9}\ln\left(\frac{183}{Z^{1/3}}\right) - \frac{1}{54}\right] \qquad \text{für} \qquad \frac{E_\gamma}{m_e c^2} > \frac{1}{\alpha Z^{1/3}}$$

Pairproduction



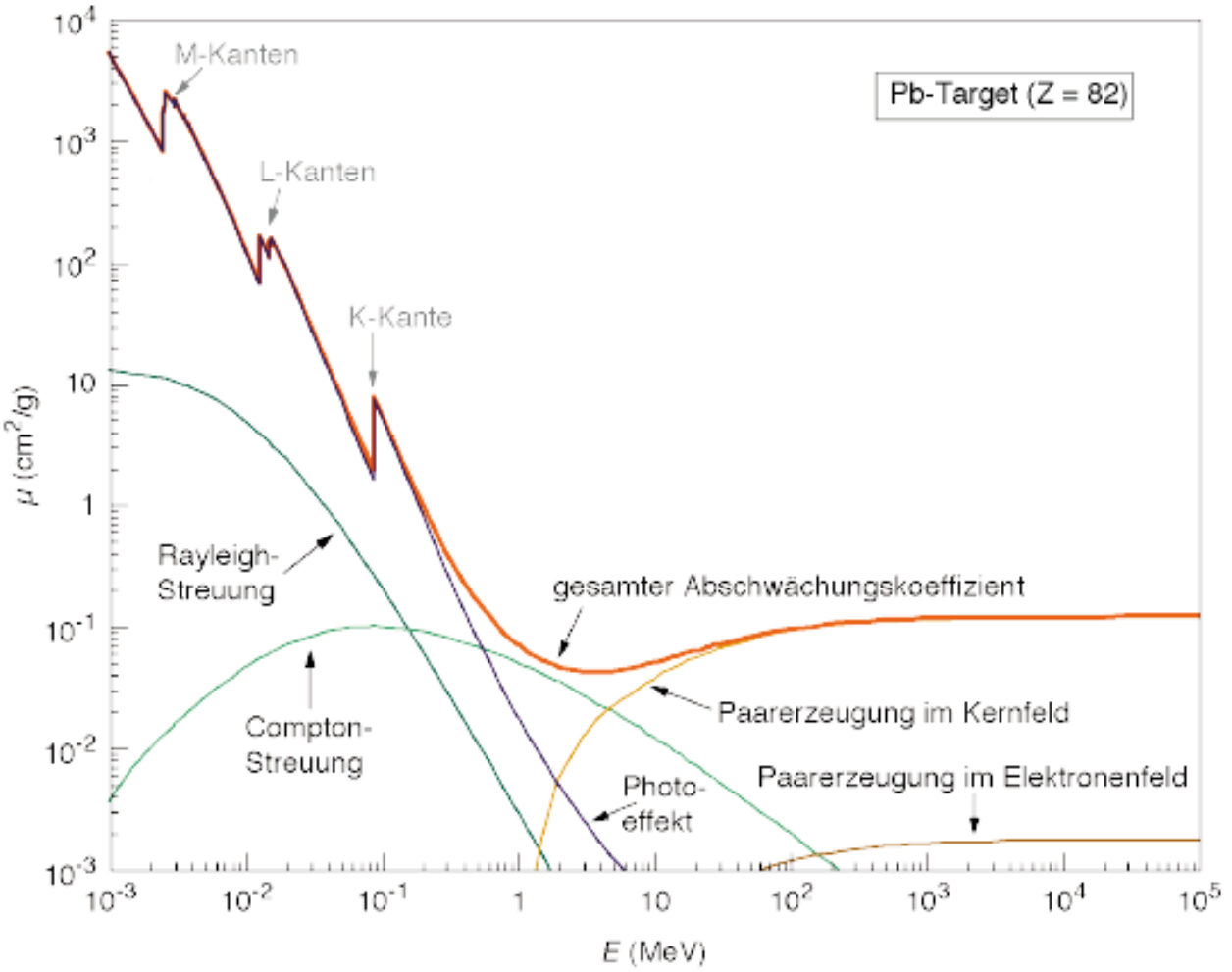
$$\lambda_{pair} = \frac{A}{N_A \rho} \frac{1}{\sigma_{pair,atom}}$$

Pairproduction



$$\lambda_{pair} = \frac{9}{7} X_0$$

Crossection: Summary



Quelle: http://physics.nist.gov/PhysRefData/
berechnet mittels XCOM
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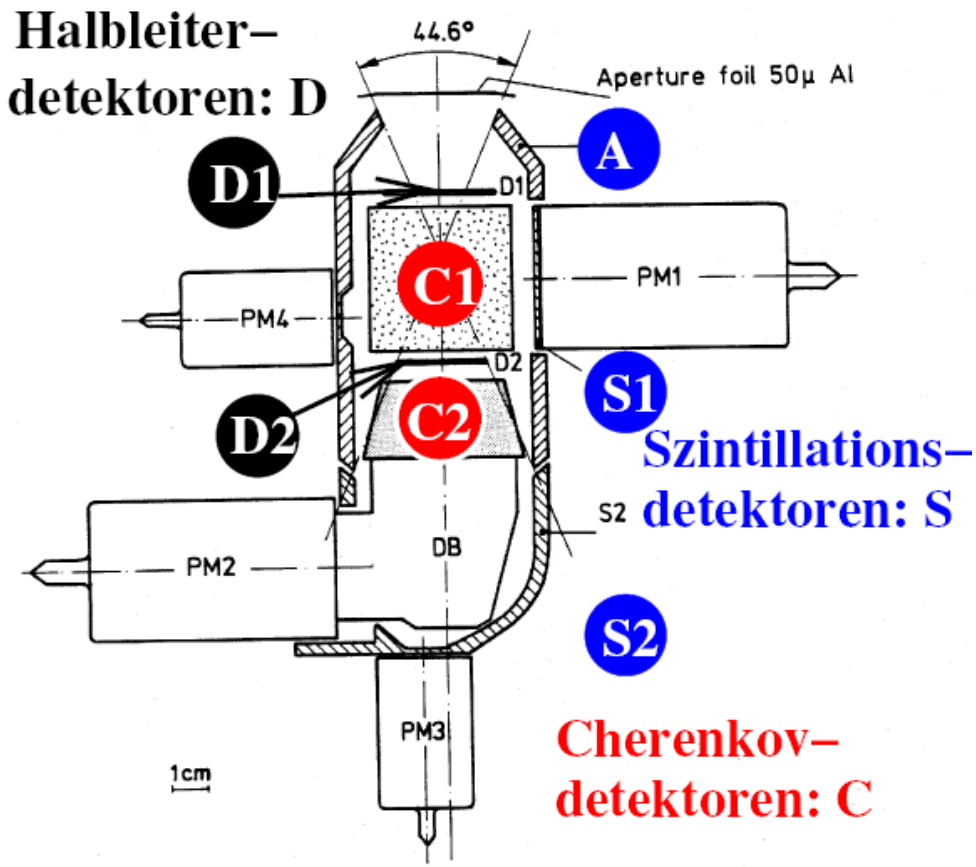
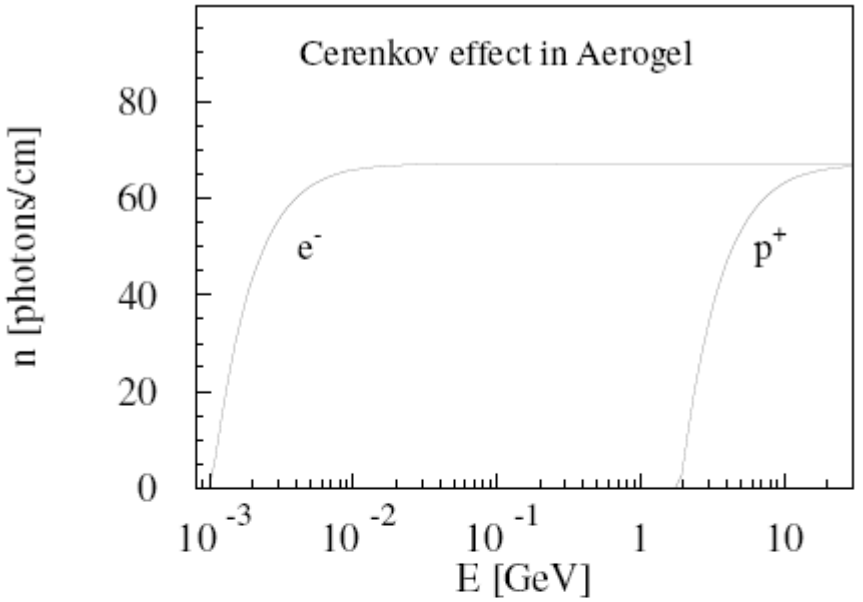
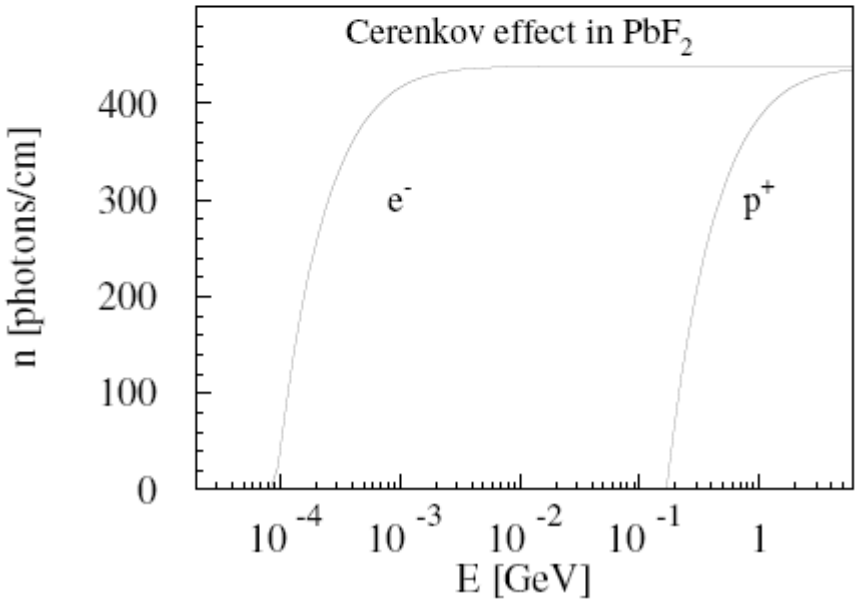
Application: The Kiel Electron Telescope aboard Ulysses



Application: The Kiel Electro





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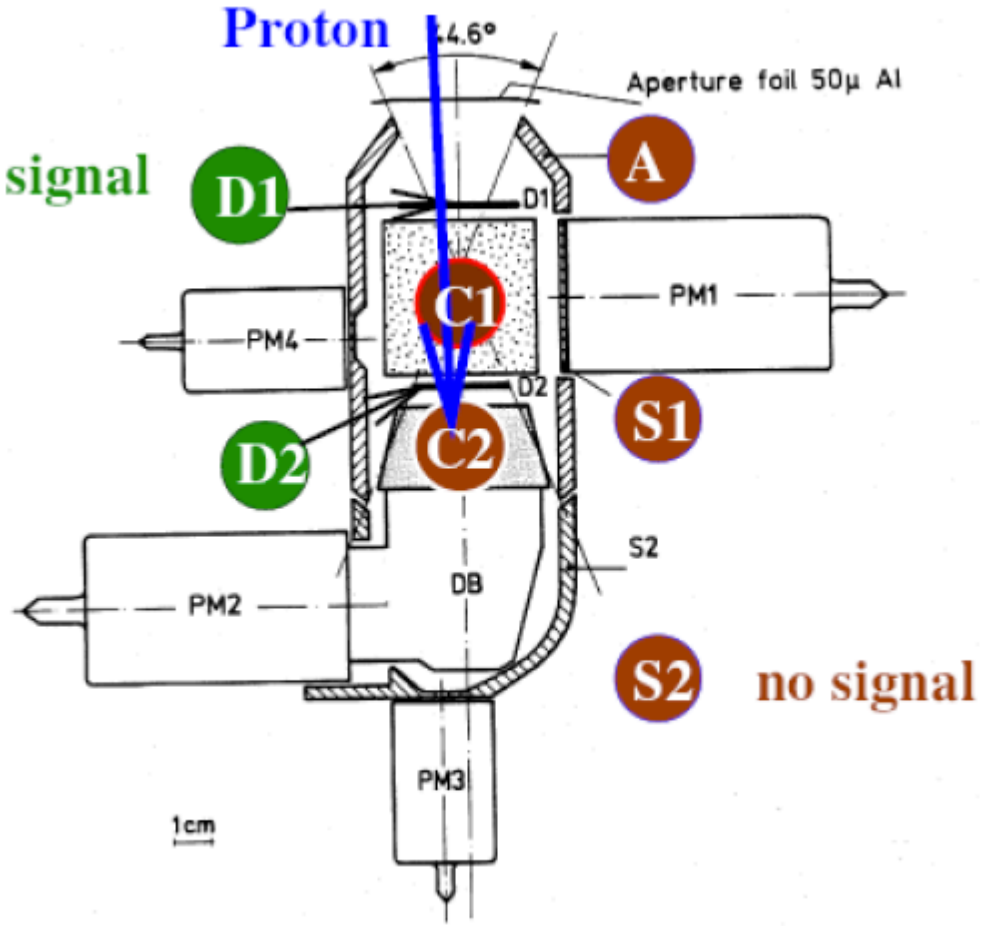

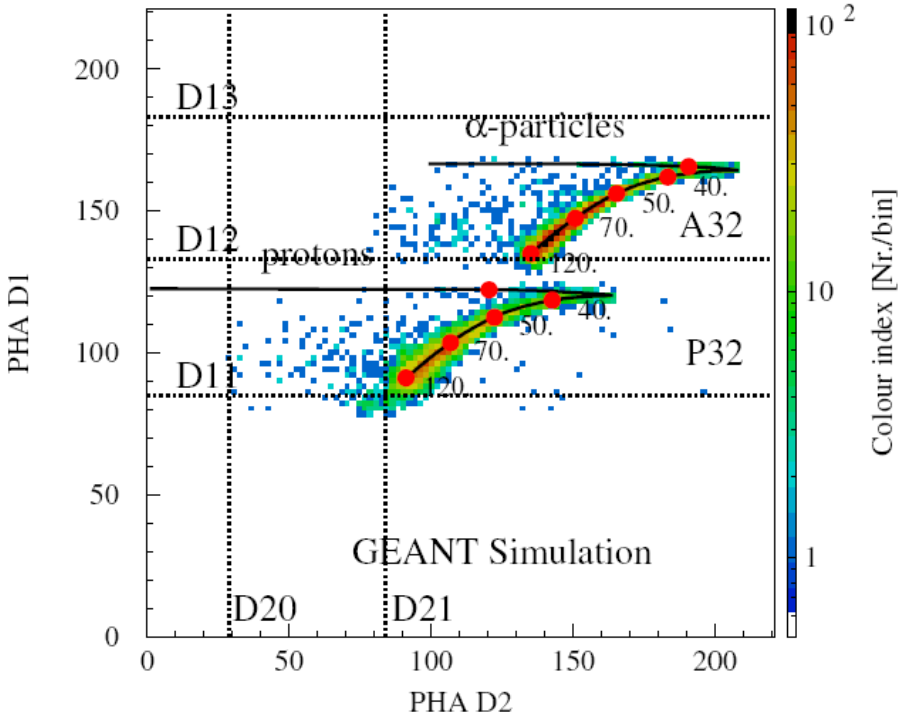

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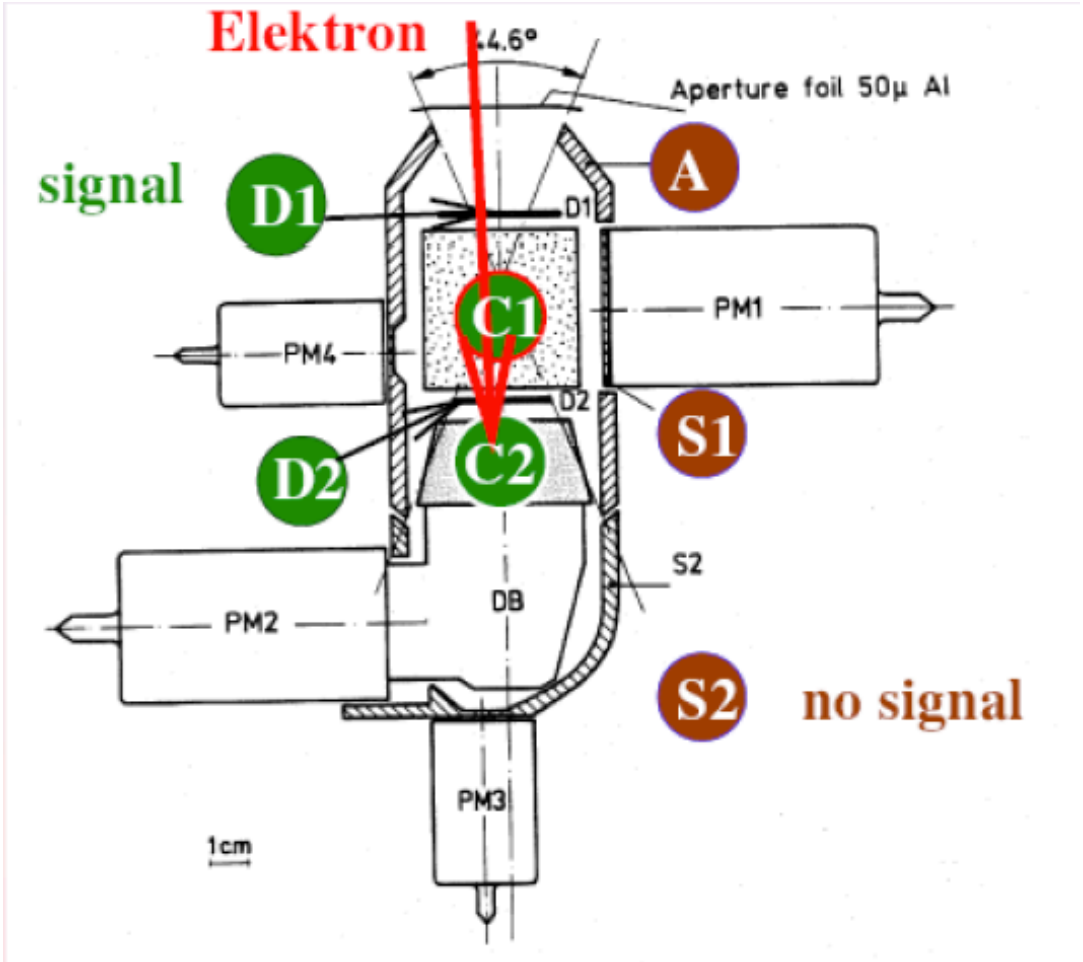

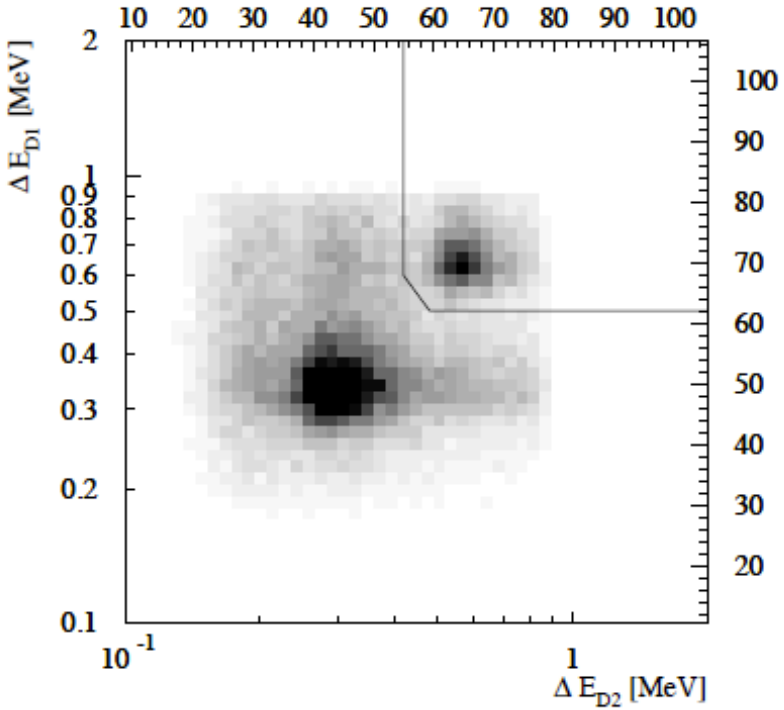

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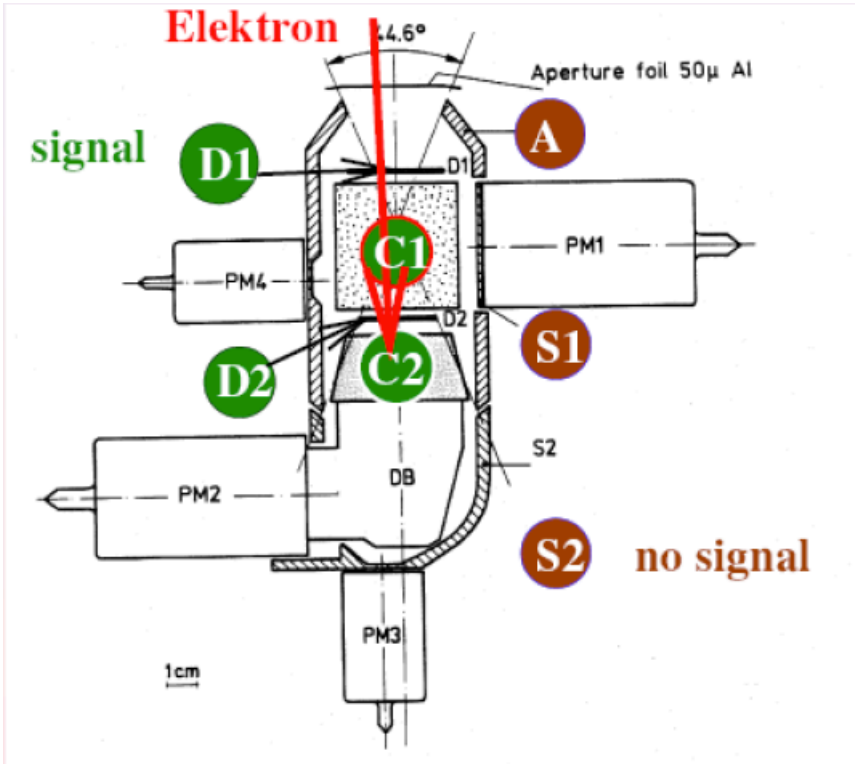

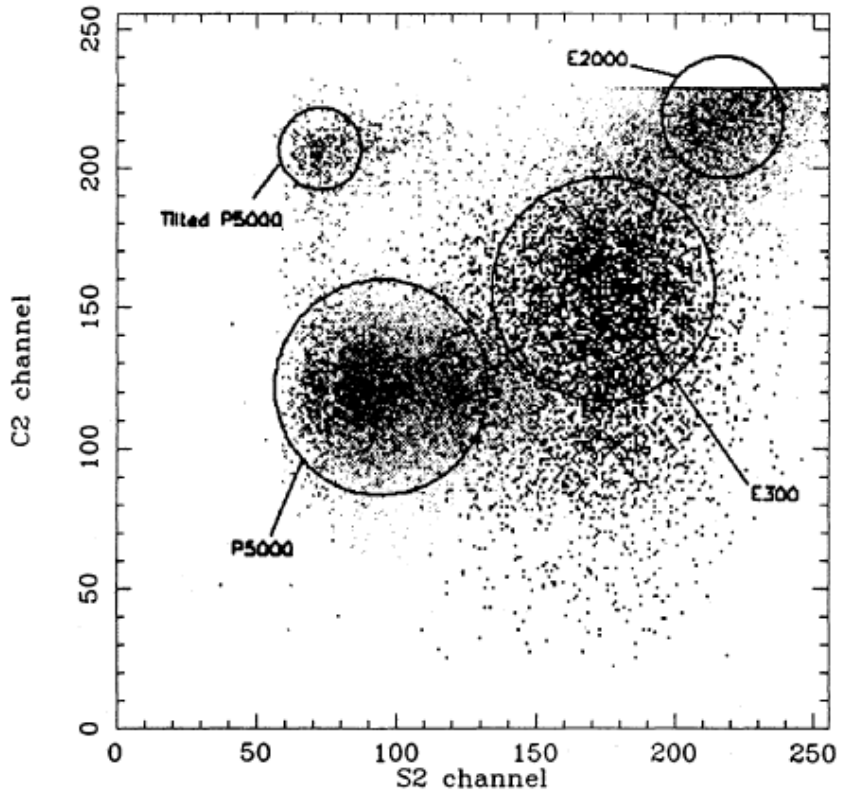

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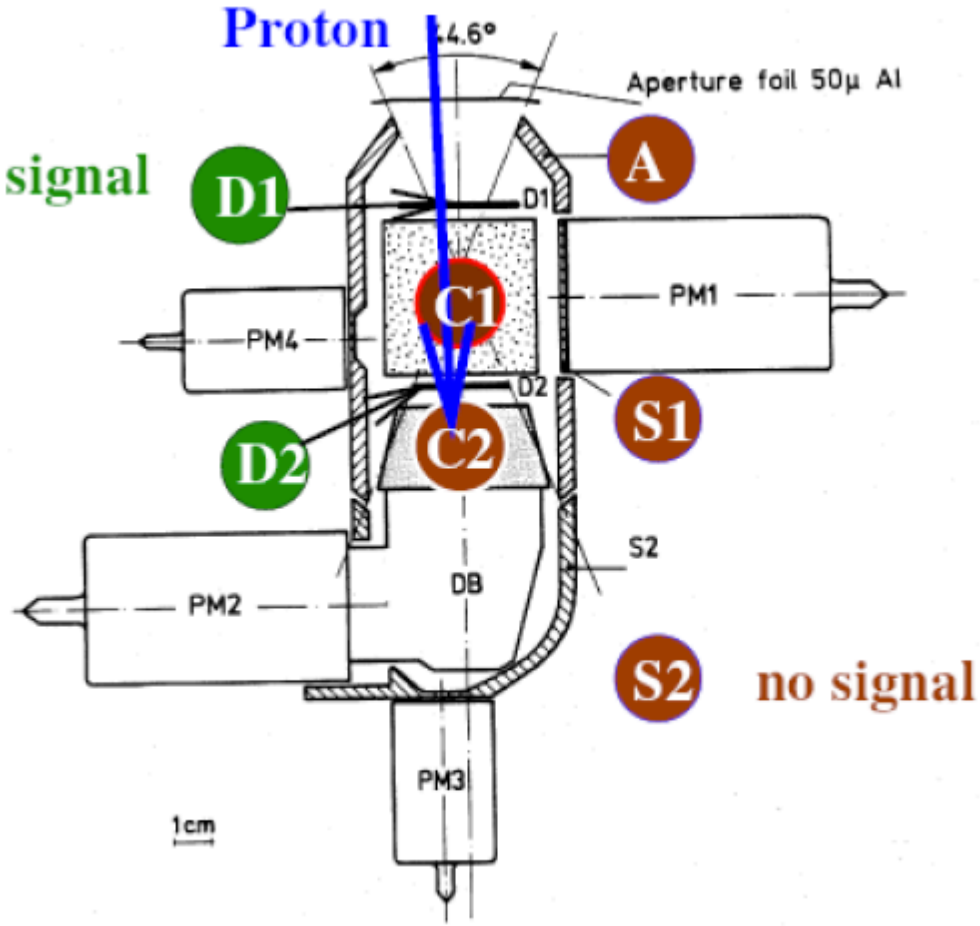
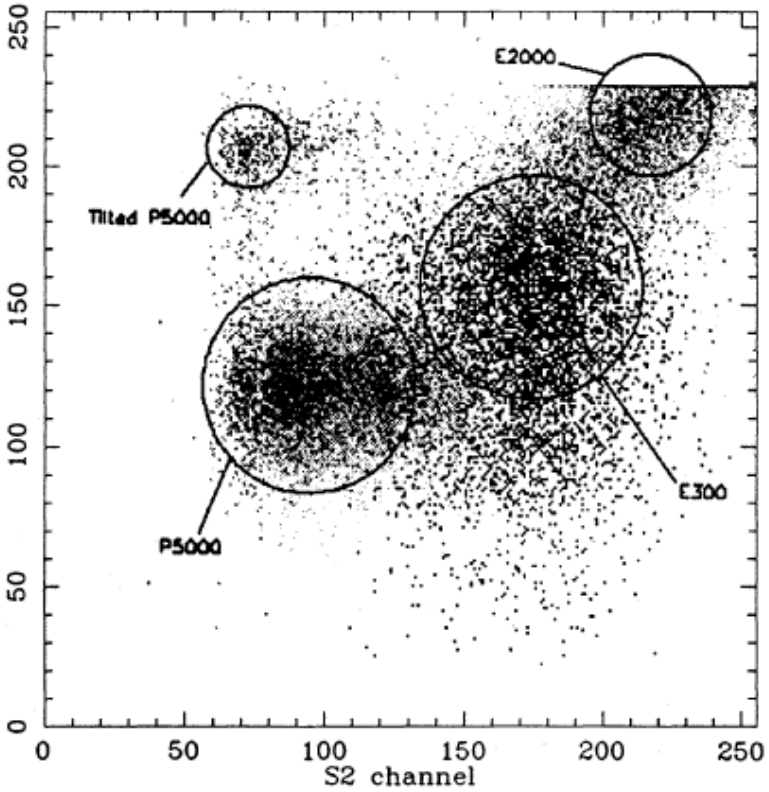




Hadronic Interactions (Shower Generation)

Hadronic Interactions (Shower Generation)

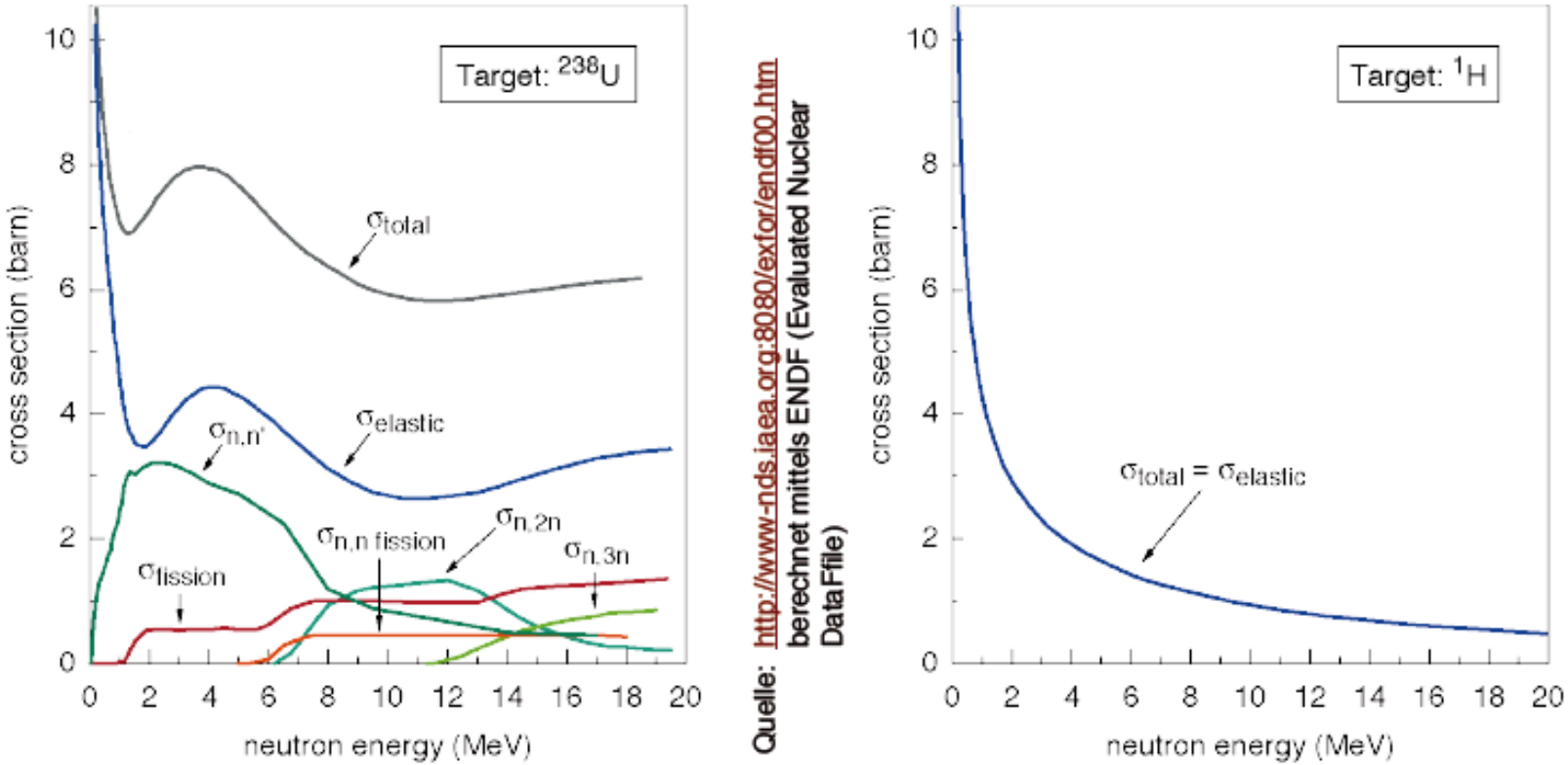
Hadronic Interactions (Shower Generation)

Hadronic Interactions (Shower Generation)

Hadronic Interactions (Shower Generation)

Cross Sections for hadronic Processes

Hadronische Wirkungsquerschnitte für hochenergetische Neutronen in Uran bzw. in Wasserstoff. (Für Uran sind nicht alle möglichen Teilreaktionen dargestellt.)



Quelle: http://www-nds.iaea.org:8080/exfor/endf00.htm berechnet mittels ENDF (Evaluated Nuclear DataFile)

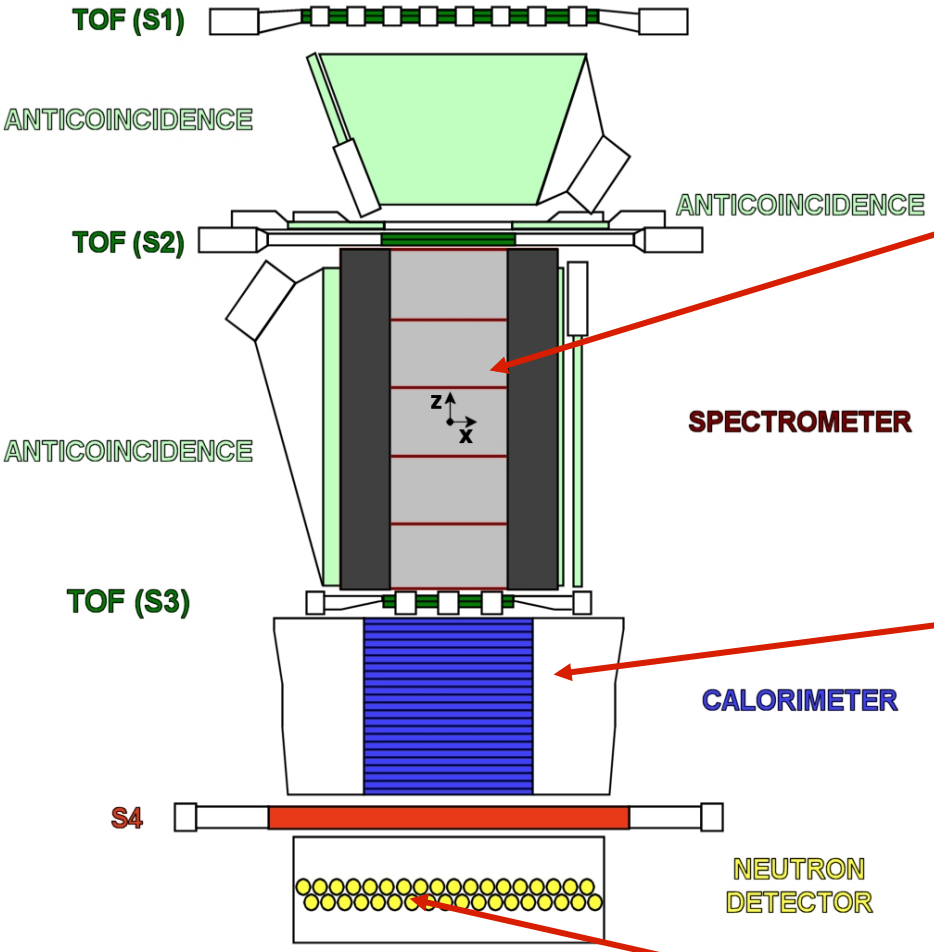
Examples

Wirkungsquerschnitte und Absorptionslängen für hochenergetische Neutronen (≈ 100 GeV) in diversen Materialien:

Material	σ_{tot} (barn)	$\sigma_{inelastic}$ (barn)	$\lambda_t \rho$ (g/cm^2)	$\lambda_a \rho$ (g/cm^2)	λ_t (cm)
H_2	0.0387	0.033	43.3	50.8	516.7
C	0.331	0.231	60.2	86.3	26.6
Al	0.634	0.421	70.6	106.4	26.1
Fe	1.120	0.703	82.8	131.9	10.5
Cu	1.232	0.782	85.6	134.9	9.6
Pb	2.960	1.77	116.2	194	10.2
Luft (STP)			62.0	90.0	51.5
H_2O			60.1	83.6	60.1
Polystyrol			58.5	81.9	56.7

siehe z.B.: – C. Grupen, *Teilchendetektoren*, BI-Wissenschaftsverlag, 1993

Application: The PAMELA apparatus



Spatial Resolution
- ≅ 2.8 μm bending view
- ≅ 13.1 μm non-bending view

MDR from test beam data ≅ 1 TV

Calorimeter Performances:
- $\bar{p}/e^+$ selection eff. ~ 90%
- p rejection factor ~ 10^5
- e^- rejection factor > 10^4

GF ~20.5 cm²sr
Mass: 470 kg
Size: 120x40x45 cm³
Power Budget: 360 W

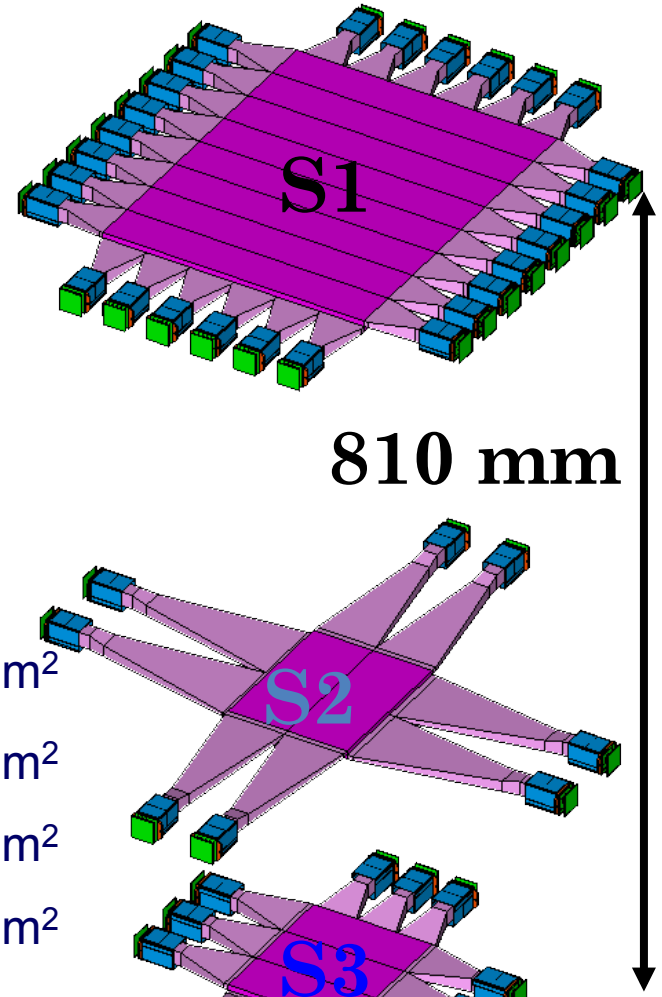
ND p/e separation capabilities >10 above 10 GeV/c, increasing with energy

Time of Flight / Scintillator

- 6 x-y layers arranged on 3 planes;
- 48 channels.
- Albedo rejection dE/dx
- Part ident. Up to 1 GeV with 150ps resolution
- Nuclear identification up to Oxygen

3 double-layer scintillator paddles

- Timing resolution:
  - σ(paddle) ≈ 110 ps
  - σ(ToF) ≈ 330 ps (MIPs)



DIMENSIONS

S11	8	330 x 51 mm^2	7 mm	357 mm^2
S12	6	408 x 55 mm^2	7 mm	385 mm^2
S21	2	180 x 75 mm^2	5 mm	375 mm^2
S22	2	150 x 90 mm^2	5 mm	450 mm^2
S31	3	150 x 60 mm^2	7 mm	420 mm^2
S32	3	180 x 50 mm^2	7 mm	350 mm^2

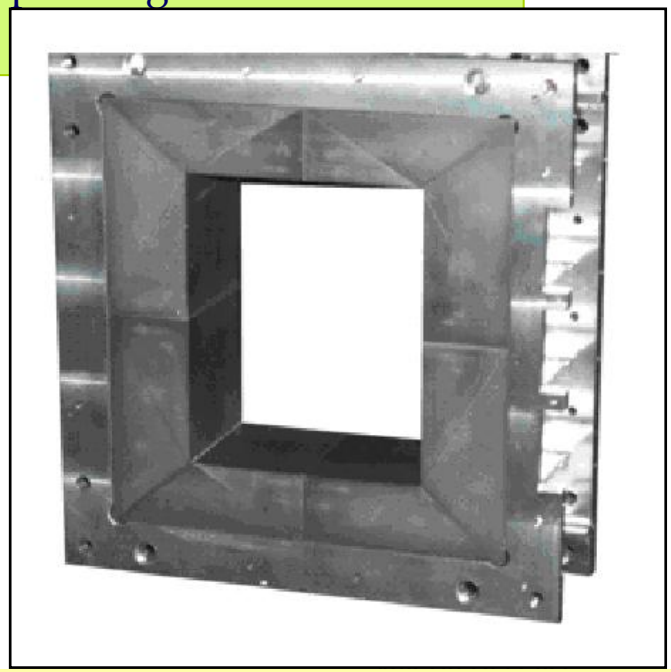
Adapted from W. Menn

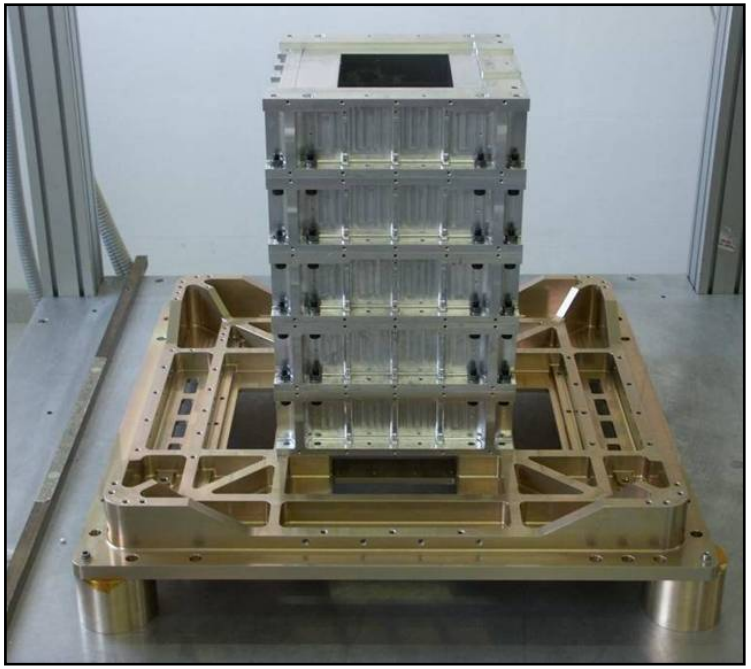
The permanent magnet

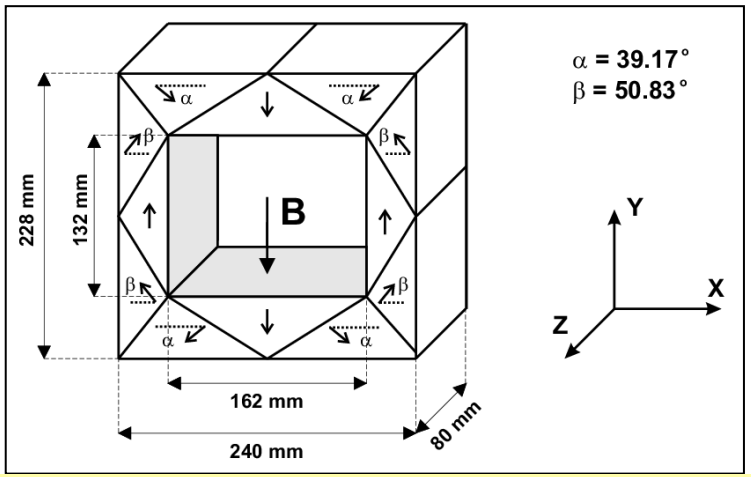
- 5 magnetic modules
- Permanent magnet (Nd-Fe-B alloy) assembled in an aluminum mechanics
- Magnetic cavity sizes (132 x 162) mm^2 x 445 mm
- Field inside the cavity 0.48 T at the center
- Average field along the central axis of the magnetic cavity : **0.43 T**

Geometric Factor: **20.5 cm^2sr**

- Black IR absorbing painting
- Magnetic shields







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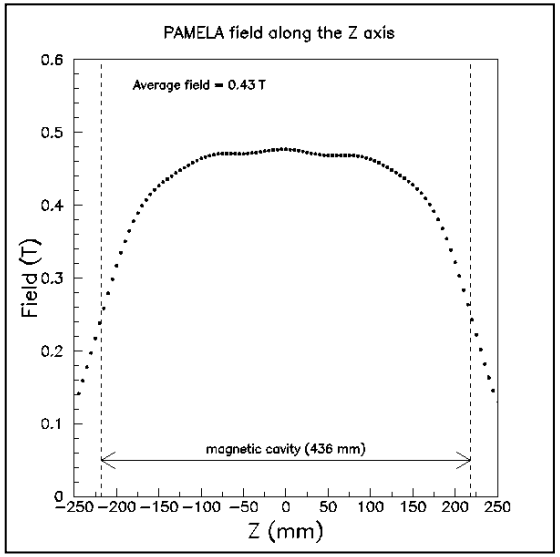
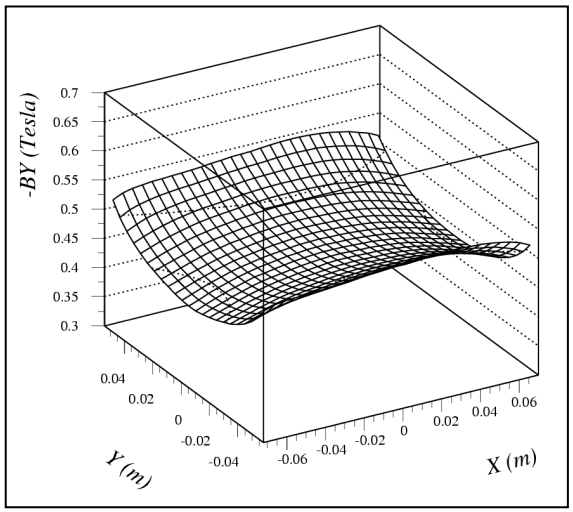


MAGNETIC FIELD MEASUREMENTS

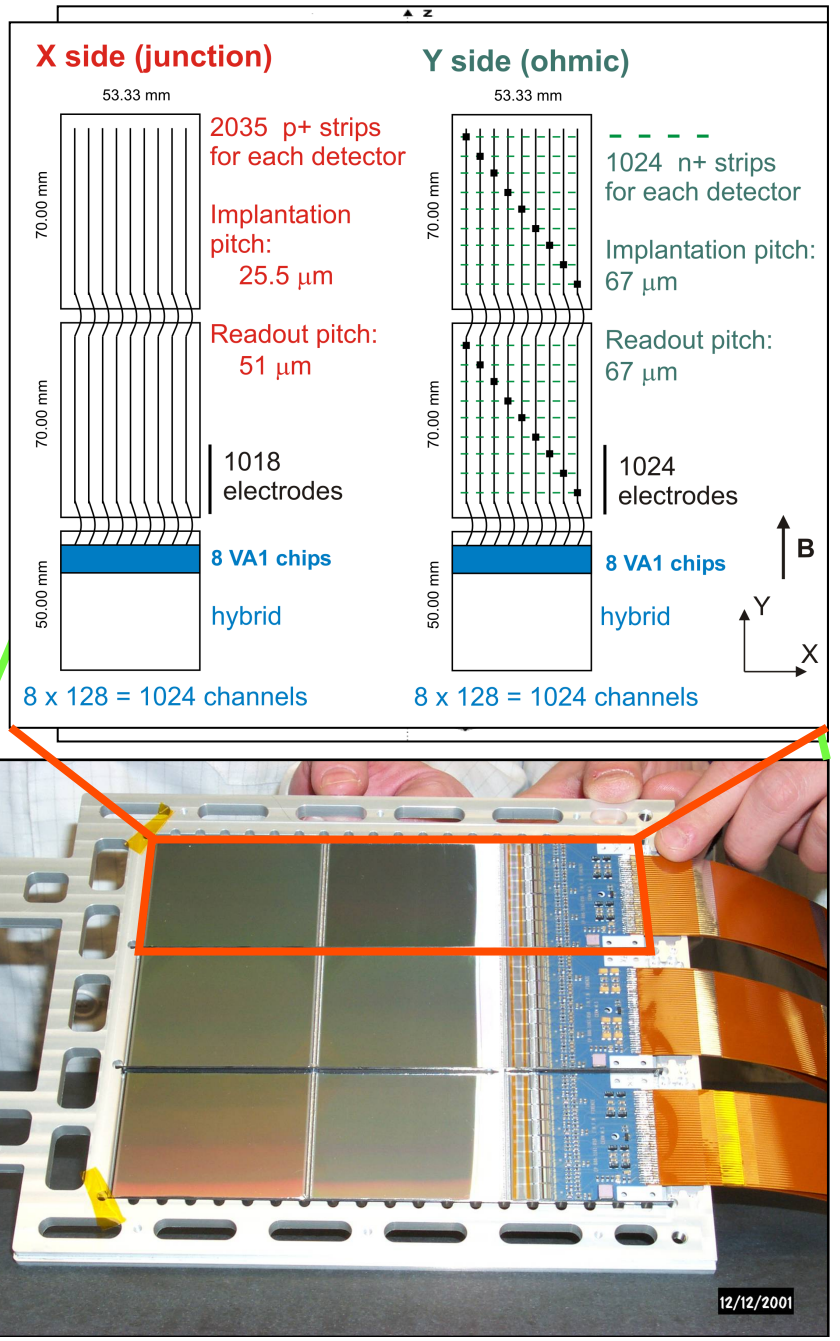
- Gaussmeter (F.W. Bell) equipped with 3-axis probe mounted on a motorized positioning device (0.1mm precision)
- Measurement of the three components in 67367 points 5mm apart from each other
- Field inside the cavity 0.48 T at the center
- Average field along the central axis of the magnetic cavity : **0.43 T**
- Good uniformity
- Measurement of external magnetic field – magnetic momentum < 90 Am^2



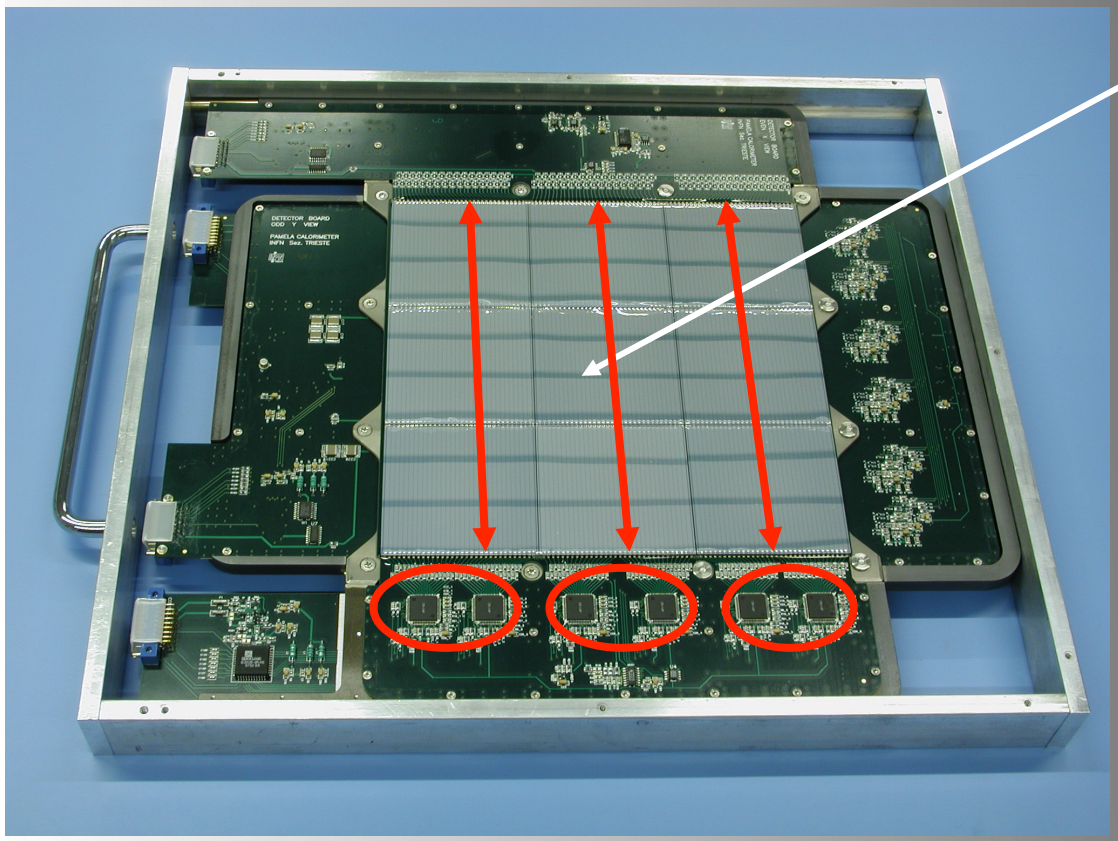
The tracking system

6 detector planes composed by 3 "ladders"

- Mechanical assembly
  - no material above/below the plane (1 plane = 0.3% X_0)
  - carbon fibers stiffeners glued laterally to the ladders
- ladder : - 2 microstrip silicon sensors
  - 1 "hybrid" with front-end electronics
- silicon sensors (Hamamatsu):
  - 300 mm, Double Sided - x & y view
  - Double Metal - No Kapton Fanout
  - AC Coupled - No external chips
- FE electronics: VA1 chip
  - Low noise charge preamplifier -
  - Operating point set for optimal compromise:
    - total FE dissipation: 37 W on 36864 channels
    - Dynamic range up to 10 MIP
- DAQ: 12 DSPs
  - data compression (>95%)
  - on-line calibration (PED,SIG,BAD)

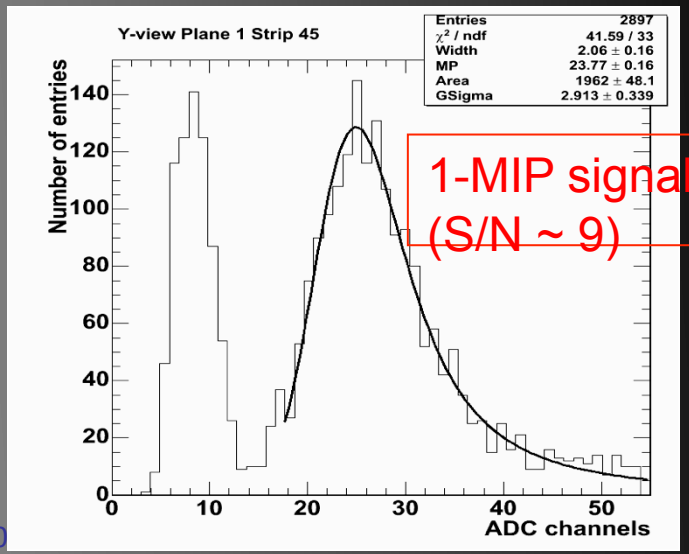


Imaging Calorimeter



44 Si detector views (22X and 22Y)

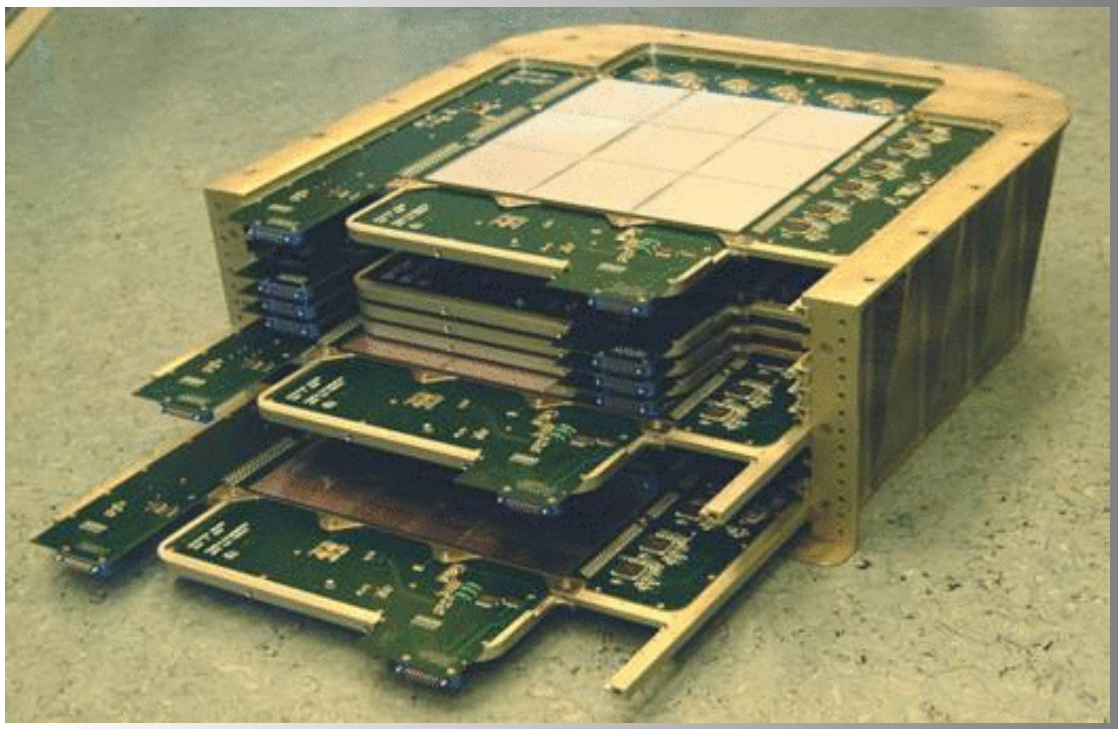
- 8x8 cm^2 detectors arranged in a 3x3 matrix
- 32 strips/detector, 2.4 mm pitch
- Strips of detectors in the same row (column) are bonded together (ladder) ⇒ 24 cm long strips
- Each ladder (32 channels) is read out by 2 CR1.4P front-end chips ⇒ 6 front-end chips/view
- In total:
  - 396 silicon detectors
  - 264 CR1.4P chips
  - 4224 channels



1-MIP signal distribution (S/N ~ 9)

From V. Bonvicini

Imaging Calorimeter



- **Main tasks:**
- lepton/hadron discrimination
- $e^{+/-}$ energy measurement

- **Characteristics:**
- 22 W plates (2.6 mm / 0.74 X_0)
- 44 Si layers (X-Y), 380 μm thick
- Total depth: 16.3 X_0 / 0.6 λ_I
- 4224 channels
- Self-triggering mode option (> 300 GeV; GF~600 cm^2 sr)
- Mass: 110 kg
- Power Consumption: 48 W

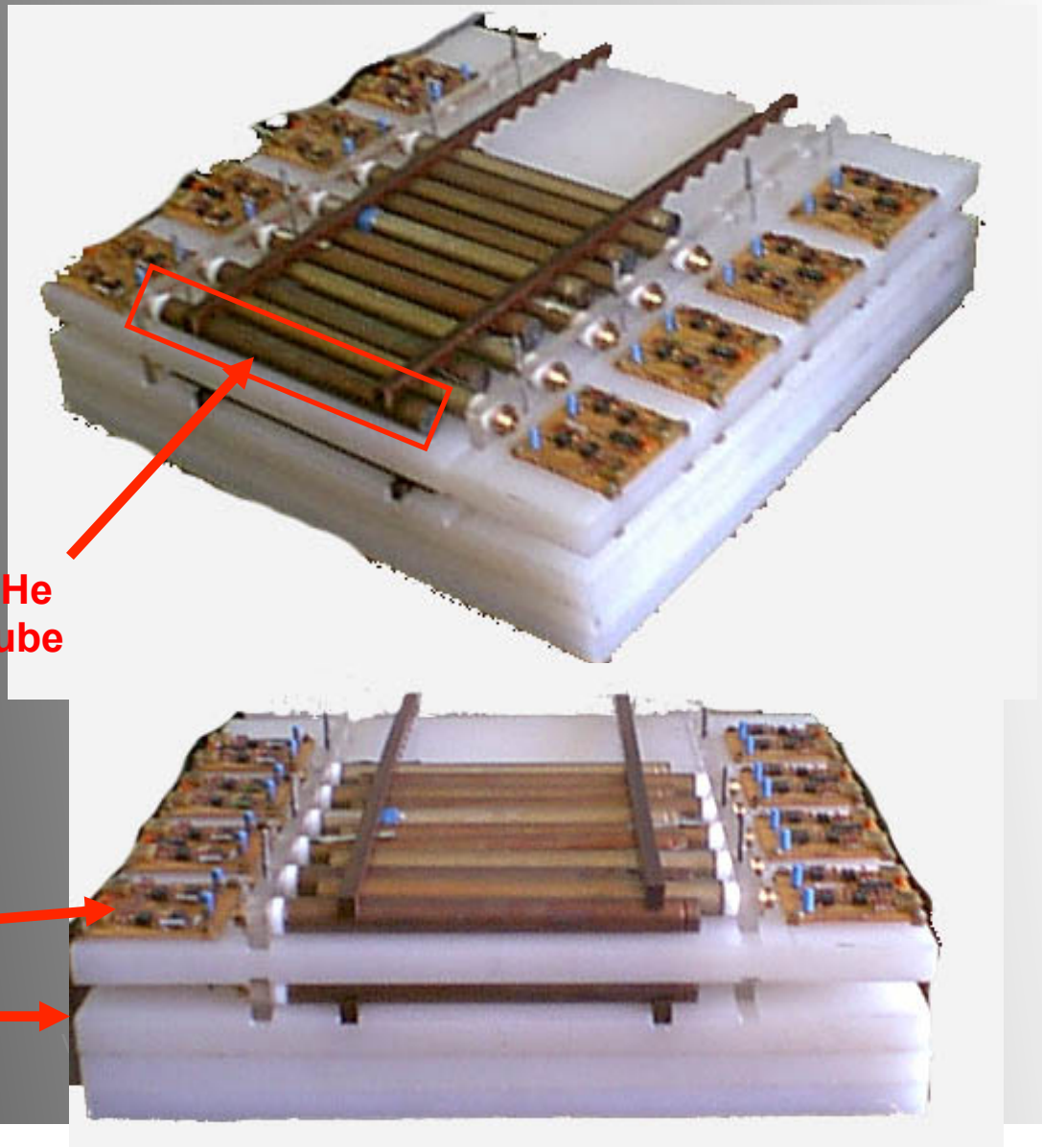
- **Design performance:**
- $\bar{p}$,e^+ selection efficiency ~ 90%
- p rejection factor ~ 10^5
- e rejection factor > 10^4
- Energy resolution ~ 5% @ 200 GeV

Adapted from V. Bonvicini

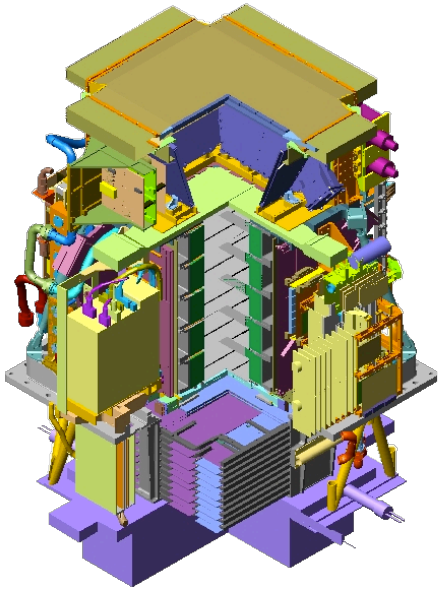
Neutron Detector

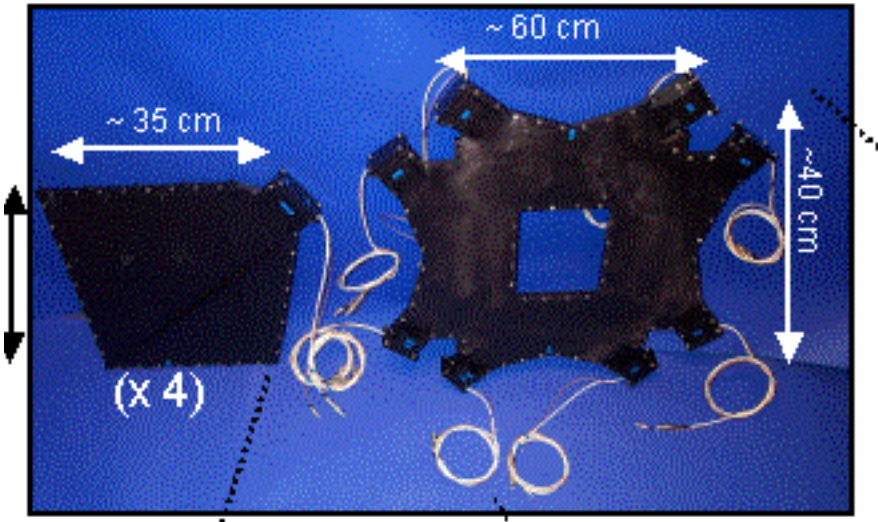
Lebedev Physical Institute Academy of Science, Russia

- 36 ^{3}He containers (2 planes)
- 9.5 cm polyethilene moderator enveloped in thin cadmium layer.
- 60x55x15 cm^{3}, 30 kg, 10 W
- **(10% eff for E<1MeV n)**
- Triggered counts
- Background counting

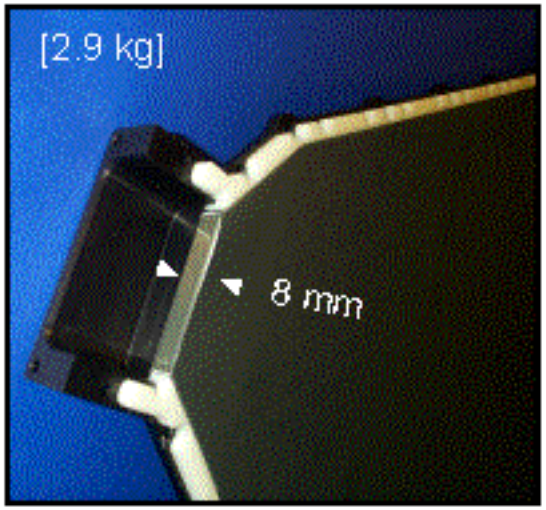


The Anticoincidence Systems



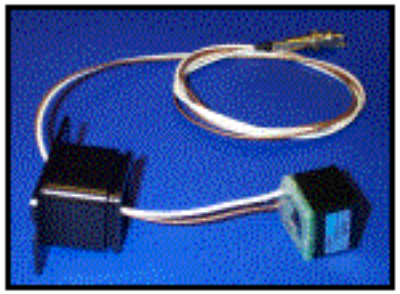


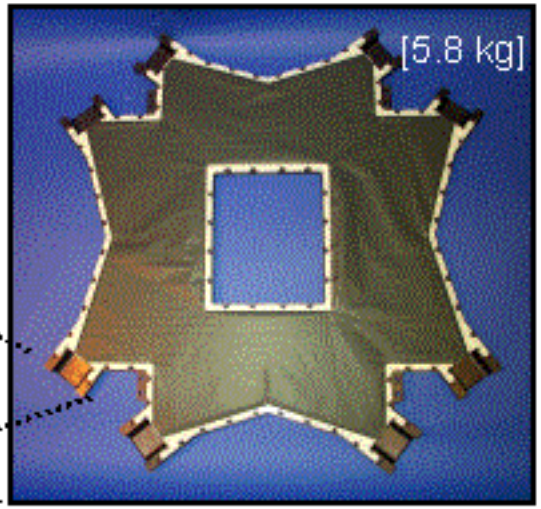
Anticoincidences are mounted on the sides, top and interscintillator area. They are used to reject false triggers coming from the satellite



[Bicron BC-448M]

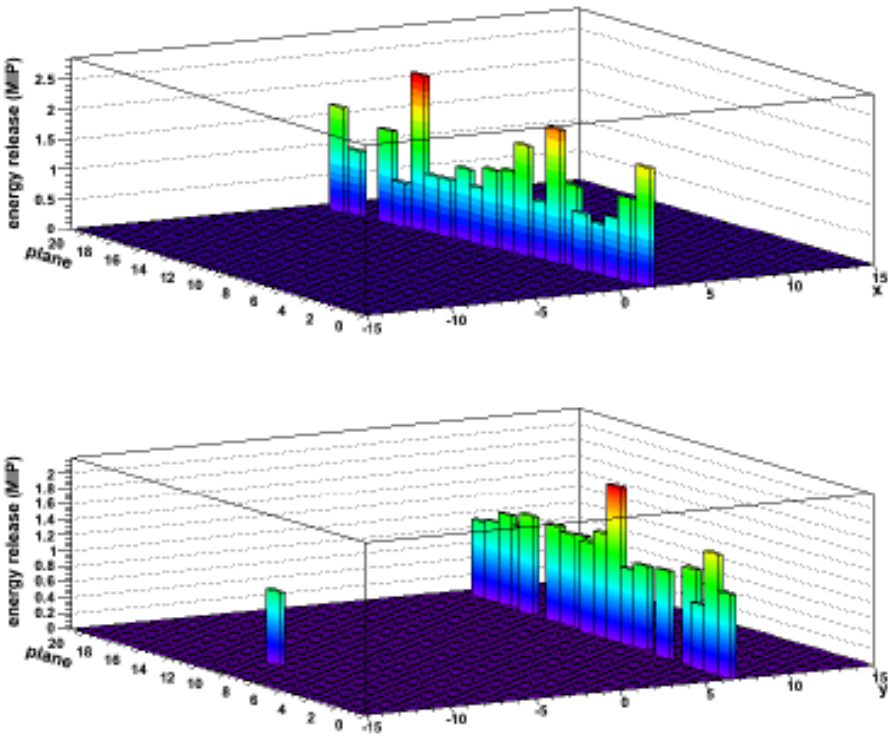
[Hamamatsu R5900U]

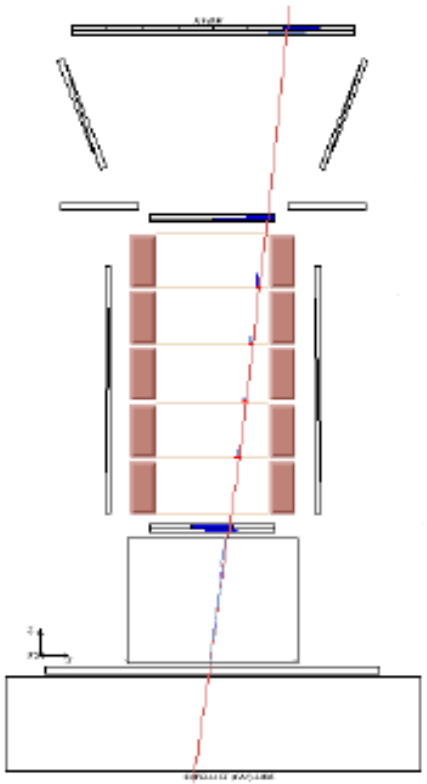




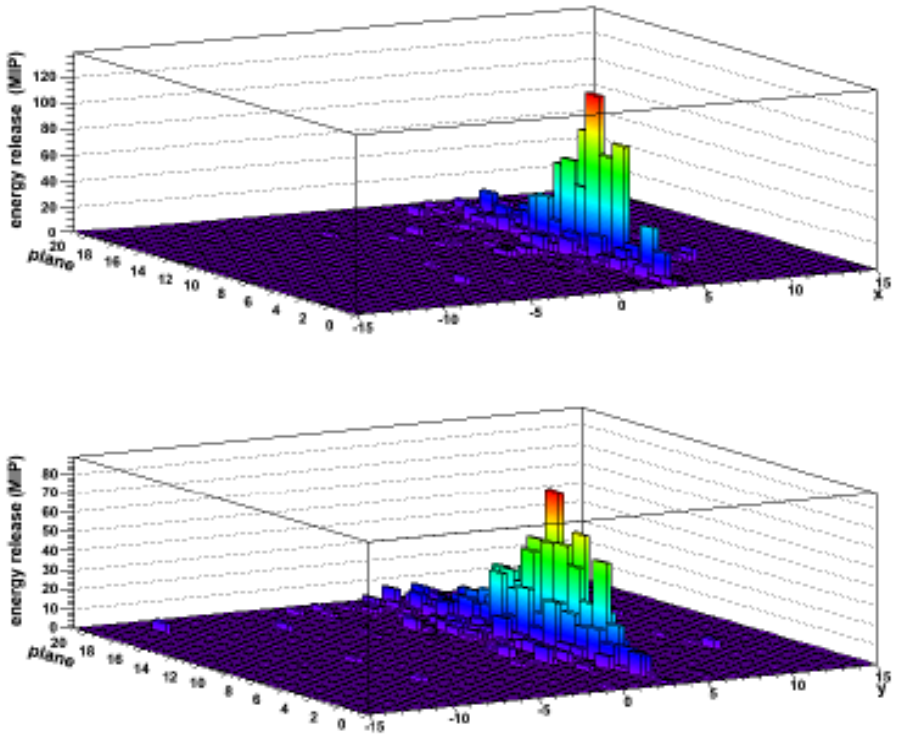
[3M Tedlar / Tyvek]

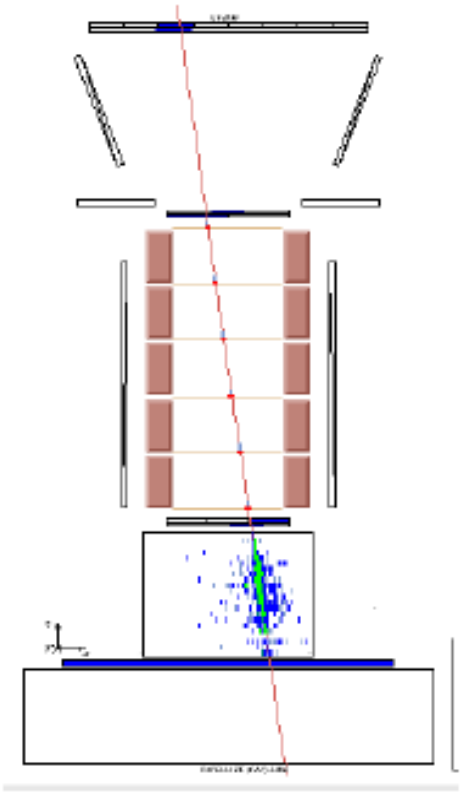
Non interacting proton in the calorimeter



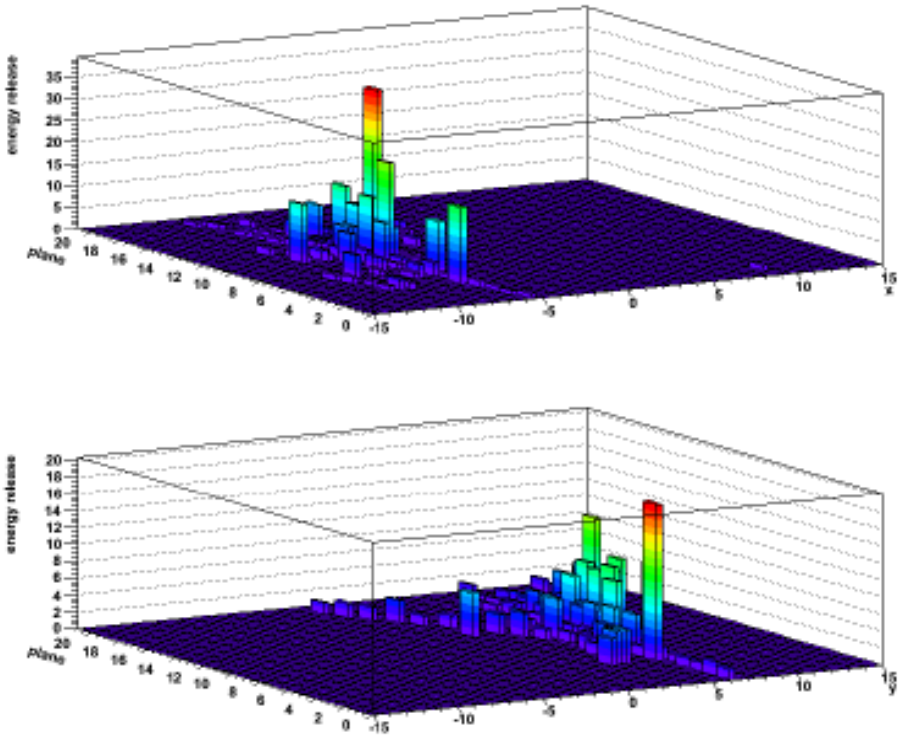


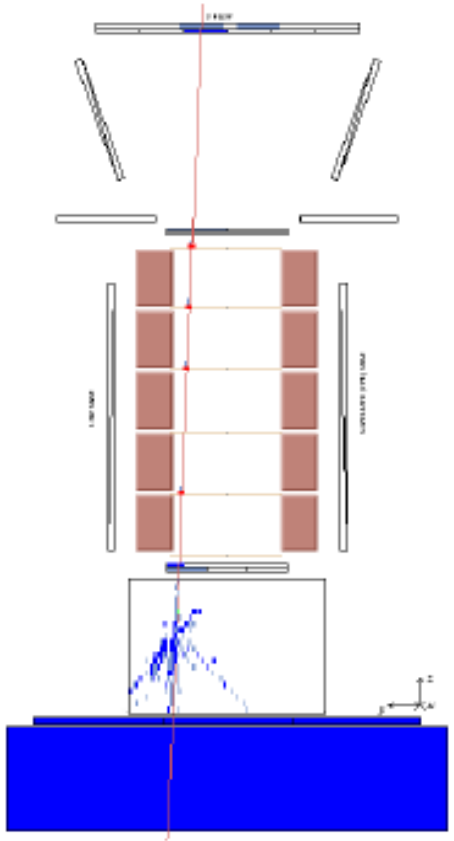
Positron in the calorimeter



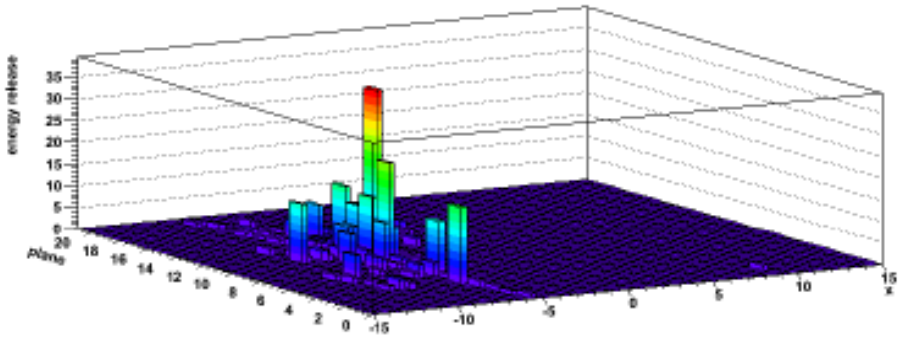


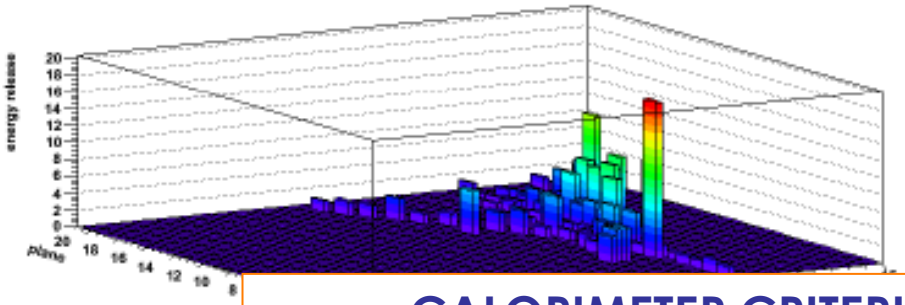
Interacting proton in the calorimeter

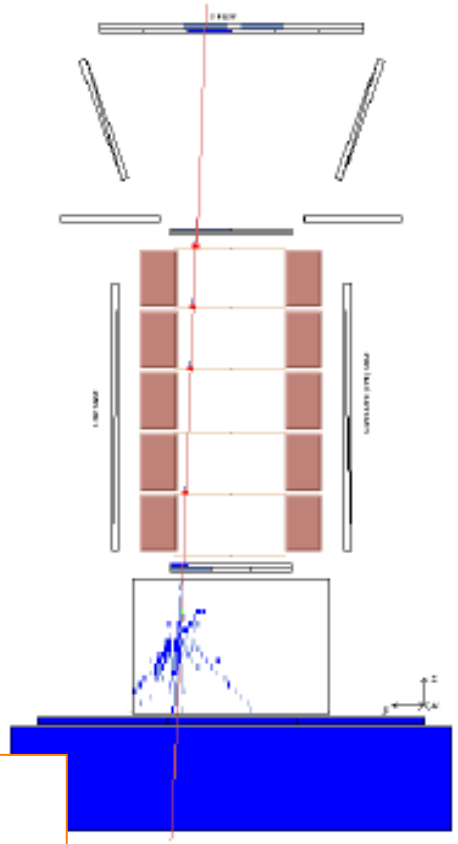




Interacting proton in the calorimeter







CALORIMETER CRITERIA

- Longitudinal profile
- Lateral profile
- Topological development
- Shower starting point