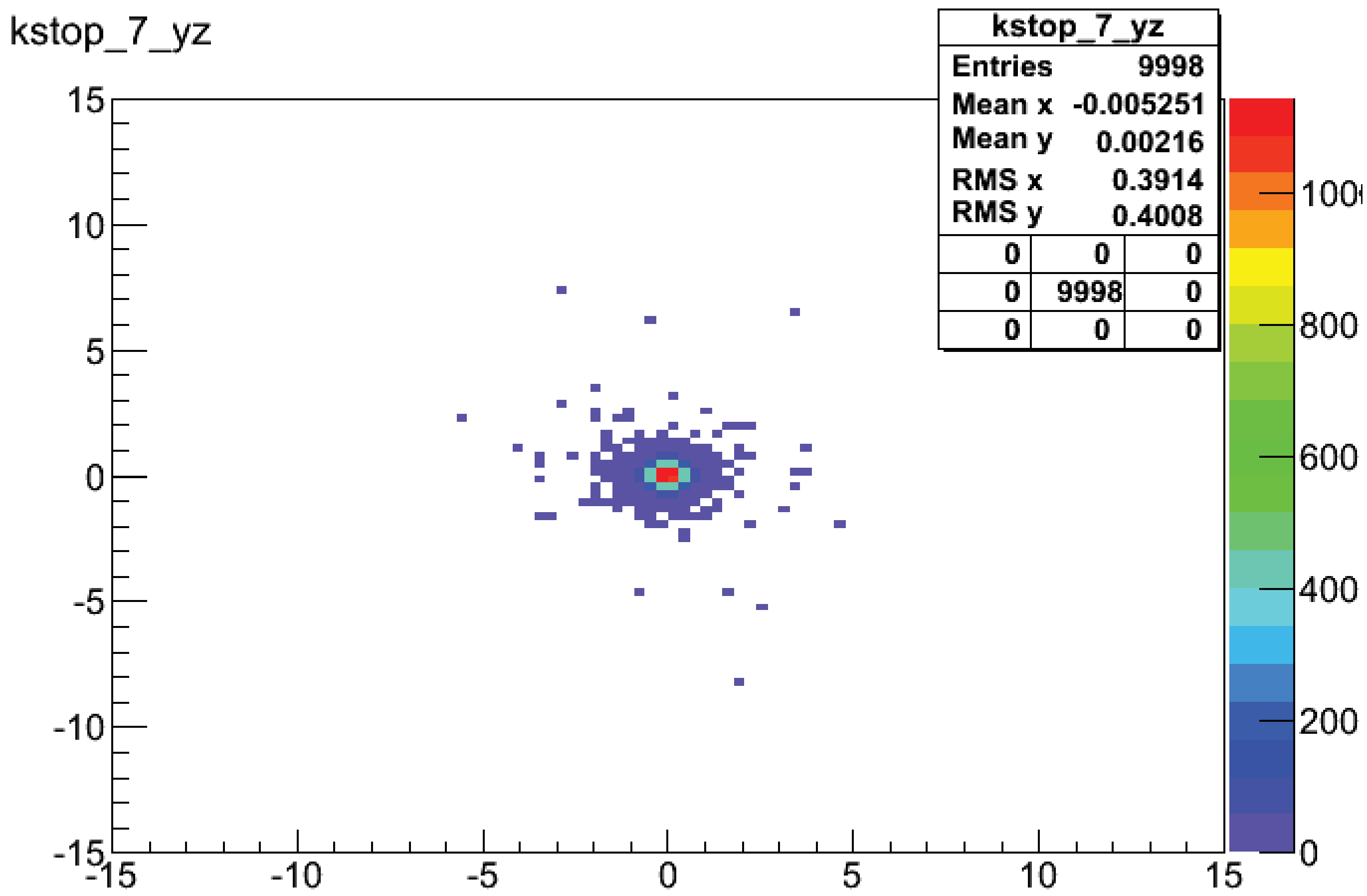
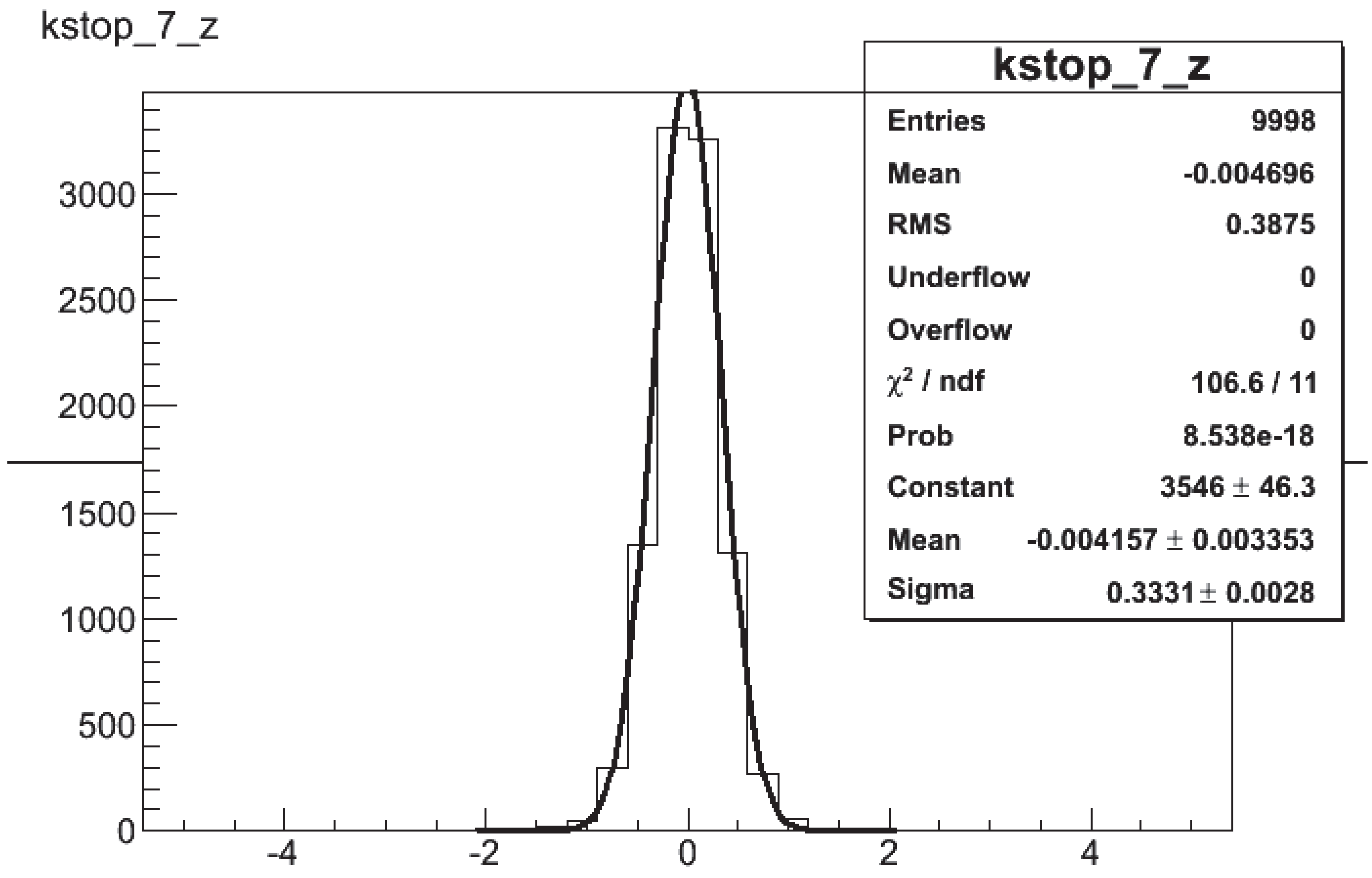
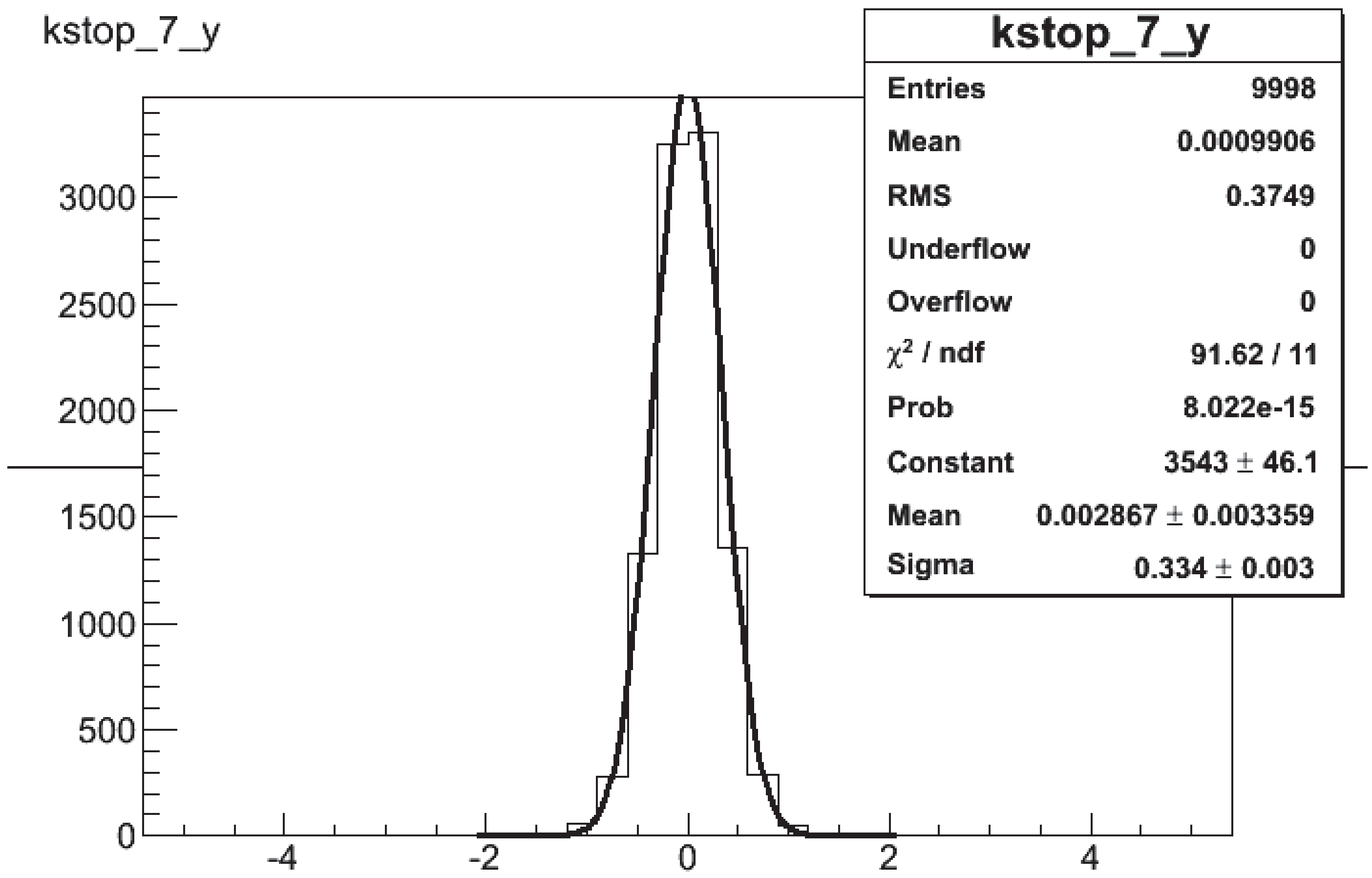
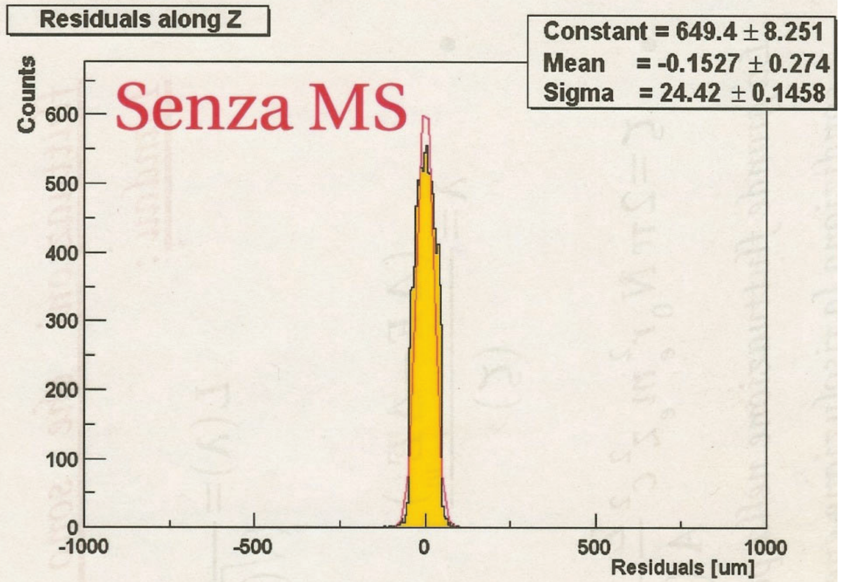
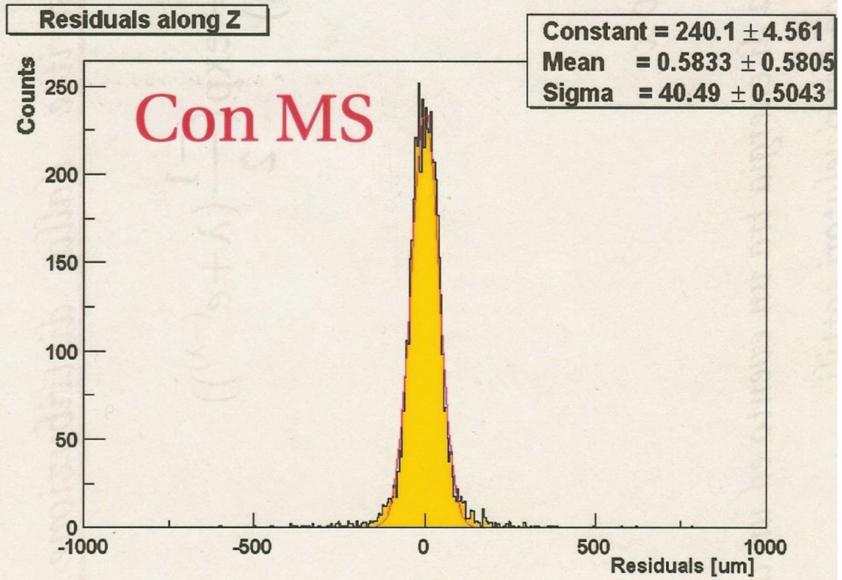
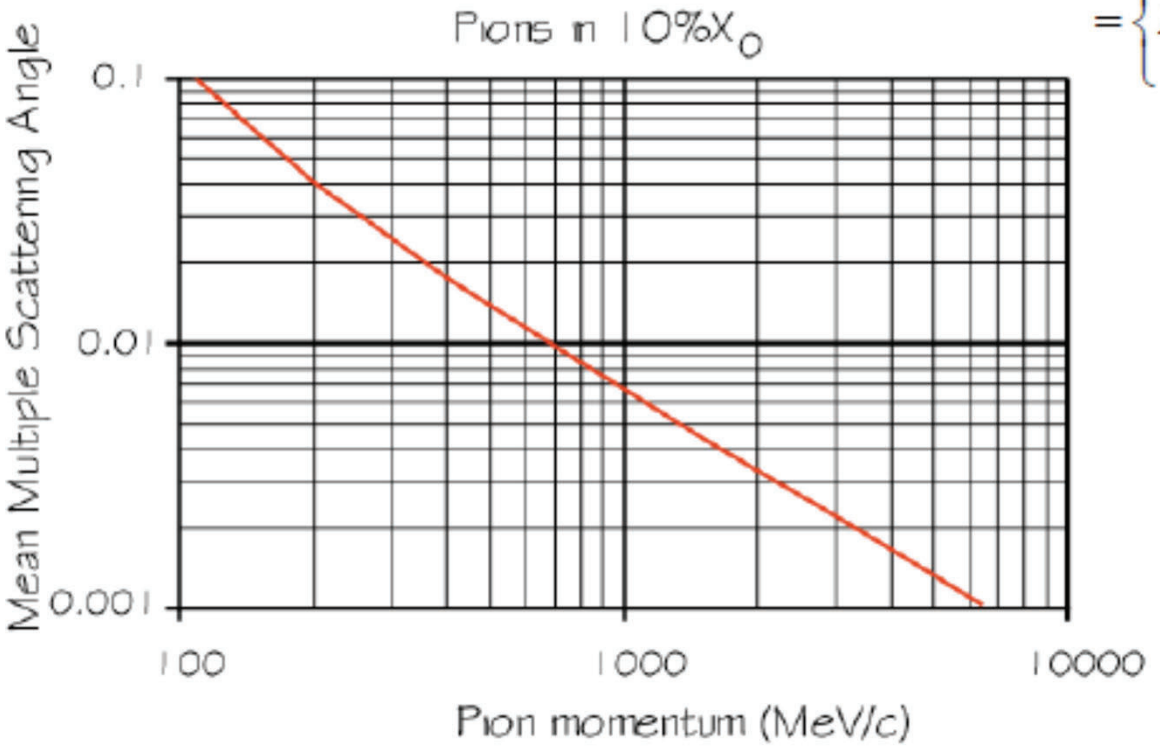

kstop_7_yz
Entries 9998
Mean x -0.005251
Mean y 0.00216
RMS x 0.3914
RMS y 0.4008
0 0 0
0 9998 0
0 0 0


kstop_7_z
kstop_7_z
Entries 9998
Mean -0.004696
RMS 0.3875
Underflow 0
Overflow 0
χ² / ndf 106.6 / 11
Prob 8.538e-18
Constant 3546 ± 46.3
Mean -0.004157 ± 0.003353
Sigma 0.3331 ± 0.0028
3000
2500
2000
1500
1000
500
0
-4
-2
0
2
4


kstop_7_y
kstop_7_y
Entries 9998
Mean 0.0009906
RMS 0.3749
Underflow 0
Overflow 0
χ² / ndf 91.62 / 11
Prob 8.022e-15
Constant 3543 ± 46.1
Mean 0.002867 ± 0.003359
Sigma 0.334 ± 0.003
3000
2500
2000
1500
1000
500
0
-4
-2
0
2
4


Residuals along Z
Constant = 649.4 ± 8.251
Mean = -0.1527 ± 0.274
Sigma = 24.42 ± 0.1458
Senza MS
Counts
600
500
400
300
200
100
0
-1000
-500
0
500
1000
Residuals [um]


Residuals along Z
Constant = 240.1 ± 4.561
Mean = 0.5833 ± 0.5805
Sigma = 40.49 ± 0.5043
Con MS
Counts
250
200
150
100
50
0
-1000
-500
0
500
1000
Residuals [um]


Pions in 10%X0
Mean Multiple Scattering Angle
0.1
0.01
0.001
100
1000
10000
Pion momentum (MeV/c)

$= \{ A$

the number of photons becomes, after angular integration,

$$\frac{dN}{d\lambda} = \frac{2\pi\alpha}{\lambda^2} L \sin^2 \theta_c \tag{5.7}$$

The number of photons emitted in the wavelength interval from λ_1 to λ_2 is then

$$N = 2\pi\alpha L \int_{\lambda_2}^{\lambda_1} \sin^2 \theta_c / \lambda^2 \, d\lambda \tag{5.8}$$

For a counter equipped with a photocathode sensitive in the visible region, $\lambda_1 = 400$ nm and $\lambda_2 = 700$ nm, such that we have

$$\frac{N}{L} = 490 \sin^2 \theta_c \quad \text{photons/cm}$$

If the sensitivity is expanded into the ultraviolet region, the yield of photons can be increased by a factor of two to three. One way of achieving this goal

Fig. 5.6. Cherenkov angle θ_c as a function of the reduced particle velocity $\beta = v/c$ for a series of refractive indices n.

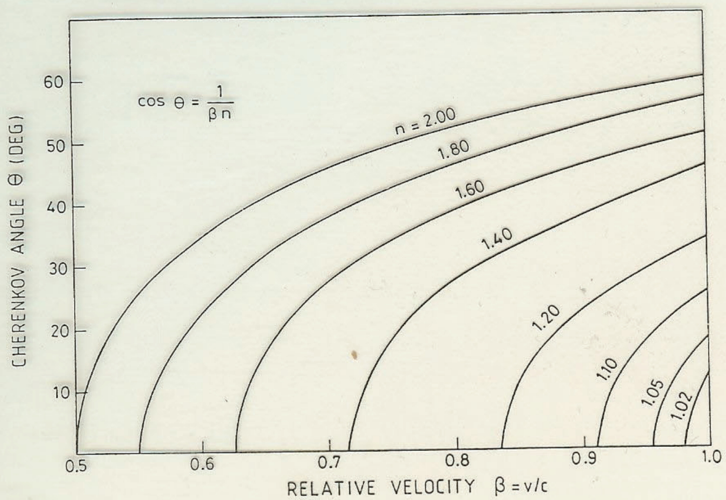


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Table 6.2. *Compilation of Cherenkov radiators [1, 34, 35, 122]. The index of refraction for gases is for 0 °C and 1 atm (STP). Solid sodium is transparent for wavelengths below 2000 Å [447, 448]*

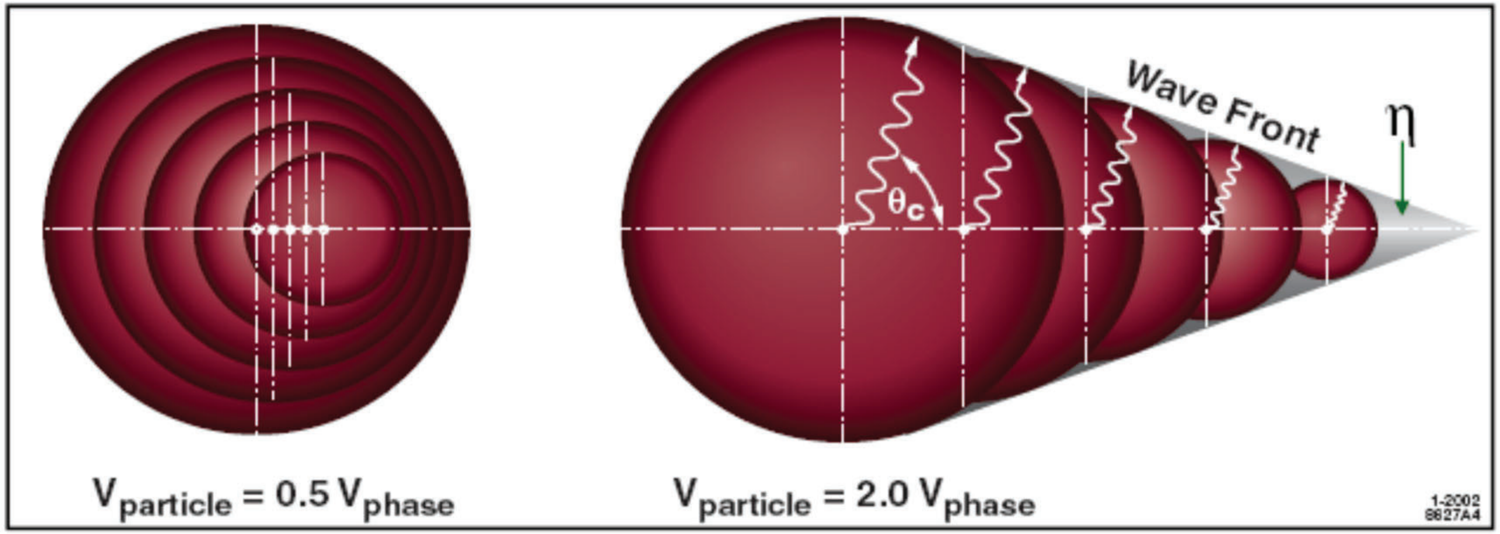
material	$n-1$	β-threshold	γ-threshold
solid sodium	3.22	0.24	1.029
lead sulfite	2.91	0.26	1.034
diamond	1.42	0.41	1.10
zinc sulfide (ZnS(Ag))	1.37	0.42	1.10
silver chloride	1.07	0.48	1.14
flint glass (SFS1)	0.92	0.52	1.17
lead fluoride	0.80	0.55	1.20
Clerici solution	0.69	0.59	1.24
lead glass	0.67	0.60	1.25
thallium formate solution	0.59	0.63	1.29
scintillator	0.58	0.63	1.29
Plexiglas (lucite)	0.48	0.66	1.33
boron silicate glass (Pyrex)	0.47	0.68	1.36
water	0.33	0.75	1.52
silica aerogel	0.025 - 0.075	0.93 - 0.976	4.5 - 2.7
pentane (STP)	$1.7 \cdot 10^{-3}$	0.9983	17.2
CO_2 (STP)	$4.3 \cdot 10^{-4}$	0.9996	34.1
air (STP)	$2.93 \cdot 10^{-4}$	0.9997	41.2
H_2 (STP)	$1.4 \cdot 10^{-4}$	0.99986	59.8
He (STP)	$3.3 \cdot 10^{-5}$	0.99997	123

supposed to be precisely at threshold and does not radiate. Under these circumstances one has:

$$\beta_2 = \frac{1}{n} \qquad (6.26)$$

or

$$\gamma_2 = \frac{1}{\sqrt{1 - \frac{1}{n^2}}} \,. \qquad (6.27)$$



Basic Cherenkov Equations-I

Cherenkov radiation of wavelength λ emitted at polar angle (θ_c), uniformly in azimuthal angle (φ_c), with respect to the particle path,

$$\cos\theta_c = \frac{1}{\beta n(\lambda)}$$

The number of photo-electrons N_{pe} is always "too small".

$$N_{pe} = 370\,L \int \varepsilon \sin^2 \theta_c \, dE = L\, N_0 \sin^2 \theta_c$$

For z=1

Usually N_o ranges between ~ 20 and 100

Depends on velocity and n!

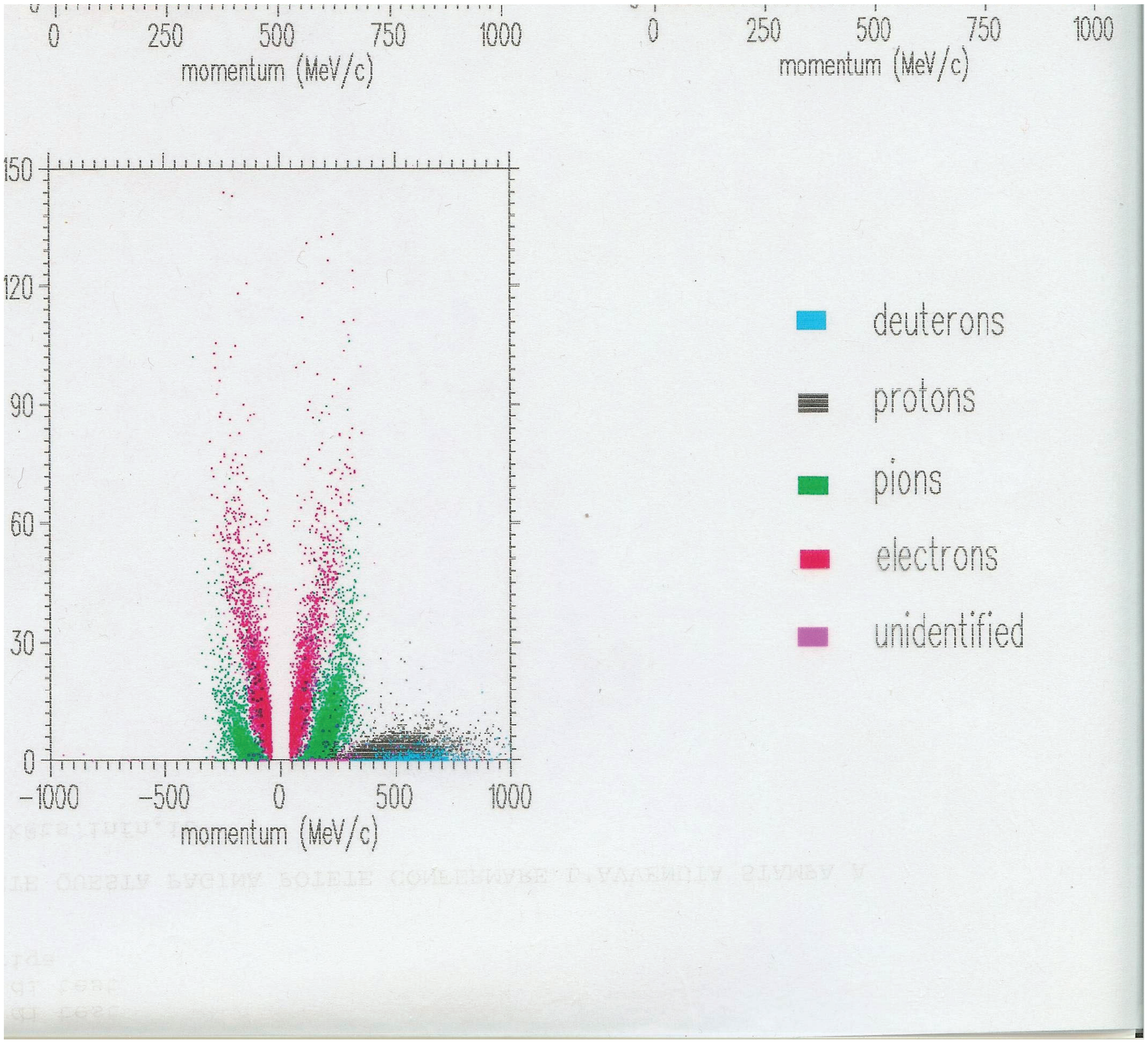
E.g., for No = 50, β = 1;

		n	N_{pe}/cm
Solid	SiO_2	1.47	27
Liquid	H_2O	1.34	22
Gas	C_5F_{12}	1.0017	0.17
Gas	He	0.00004	0.004

Shortcut to Rich07overv.lnk

Shortcut to review.lnk

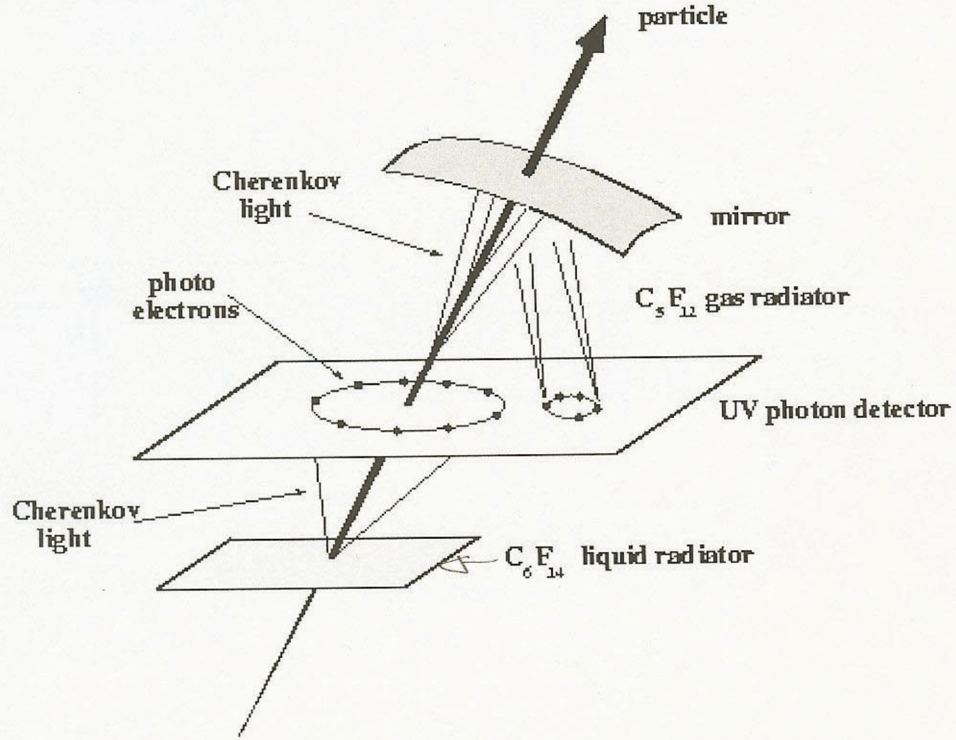
Cherenkov effect +
multiplication (electrons)



particle velocity β. Particles pass through a radiator, the radiated photons may be directly collected by (or are focused by a mirror onto) a position-sensitive photon detector. Respectively, these are called *direct focusing* or *mirror-focused* RICH detectors. For direct focusing radiators have to be kept thin (e.g. a liquid radiator), to avoid broadening the ring or filling it; however, [Fabjan95b] report a use of a similar setup as a threshold counter. The Cherenkov radiation emitted at angle δ is focused onto a ring of radius r at the detector surface, and β can be determined by a measurement of r. For photon detection one uses thin photosensitive (an admixture of e.g. triethylamine to the detector gas) proportional or drift chambers, see [Barrelet91].

A detailed treatment of errors in Cherenkov detectors can be found in [Ypsilantis94]. An outlook for the future use is given in [Treille96].

For the various currently successful ways of building practical RICH detectors, see [Ekelof96] or [Ypsilantis94], and literature given there. An example is the combined RICH with liquid radiator (unfocused) and gas radiator (mirror-focused) of the DELPHI experiment at LEP (see [Abreu96], [Aarnio91]):



A combined tracking cum RICH project, including even identification of particles by energy loss,

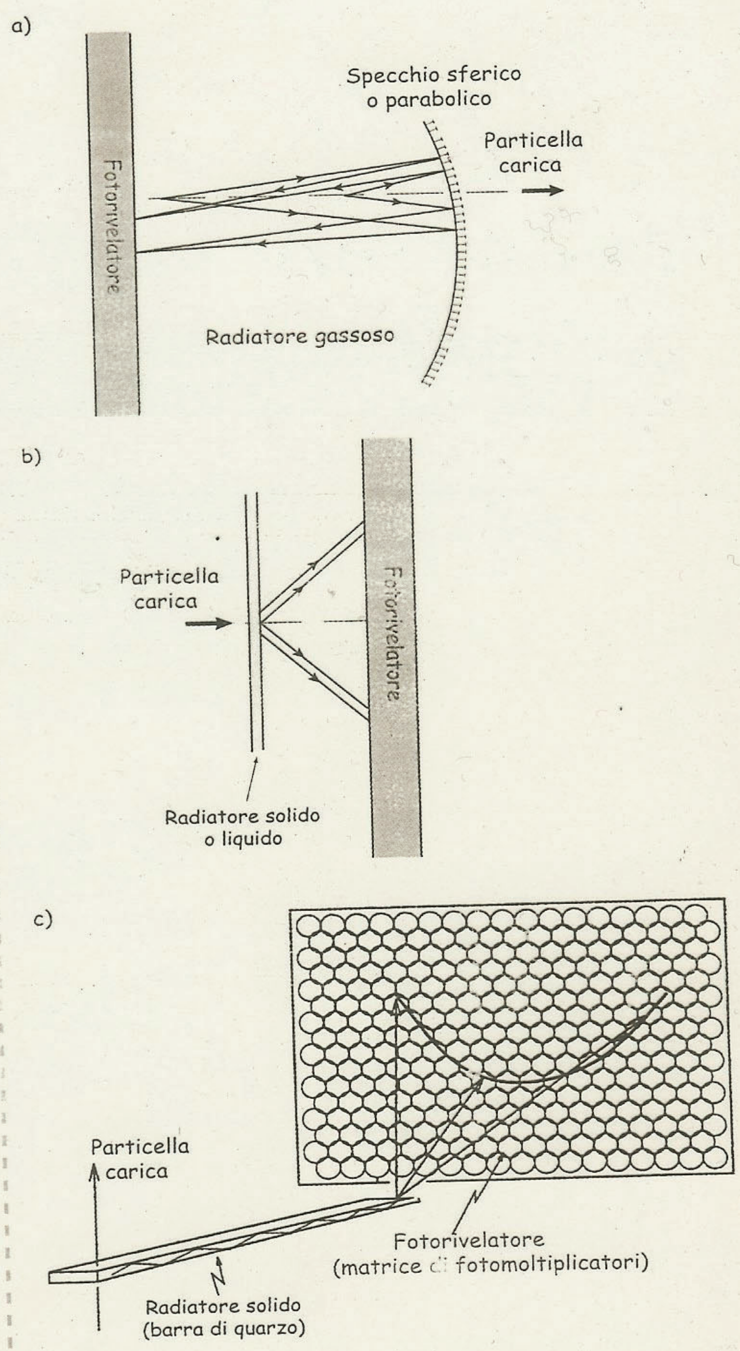


Fig. 2
Principio di funzionamento dei 3 tipi di rivelatori RICH che vengono impiegati in esperimenti di fisica nucleare o subnucleare:

a) RICH con radiatore gassoso e focalizzazione dell'immagine anulare ottenuta con specchi sferici o parabolici;

b) RICH con radiatore solido o liquido "sottile" (nella direzione di attraversamento delle particelle): l'immagine di tipo anulare è dovuta allo spessore ridotto del radiatore ed alla distanza fra questo ed il fotorivelatore;

c) DIRC: la luce intrappolata pe riflessione all'interno di una lunga barra di quarzo, fuoriesce all'estremità conservando l'informazione relativa all'angolo Cerenkov

[2] La tecnica sviluppata per la rivelazione dei neutrini è stata premiata con il premio Nobel per la fisica 2002 (vedi in questo numero *I premi Nobel per la fisica 2002*, a pg. 22).

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Cosa sono

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che picco
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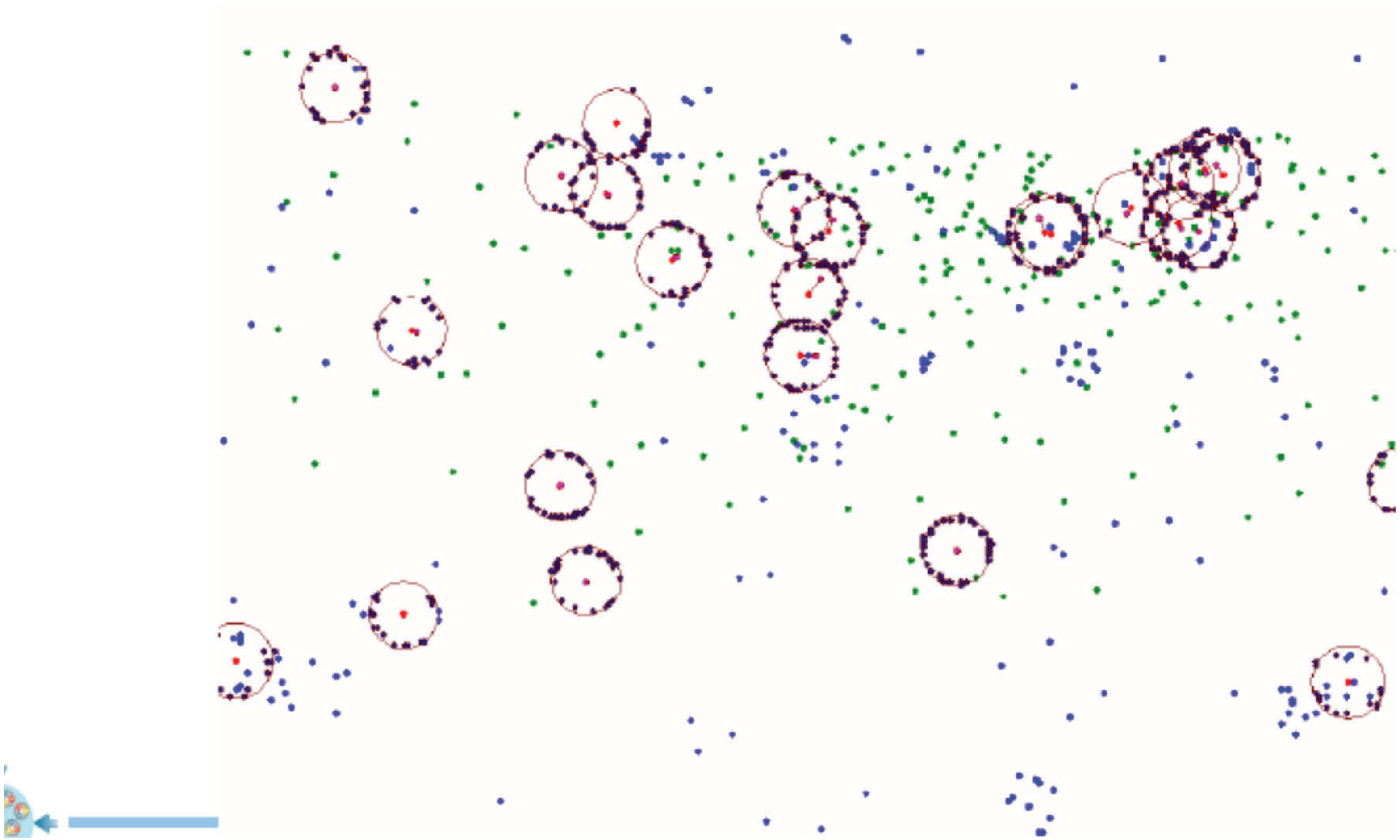
Development of a RICH detector for electron identification in CBM (FAIR/GSI)

UrQMD simulation of central Au+Au collisions, 25 AGeV

event display of inner fraction of RICH detector:



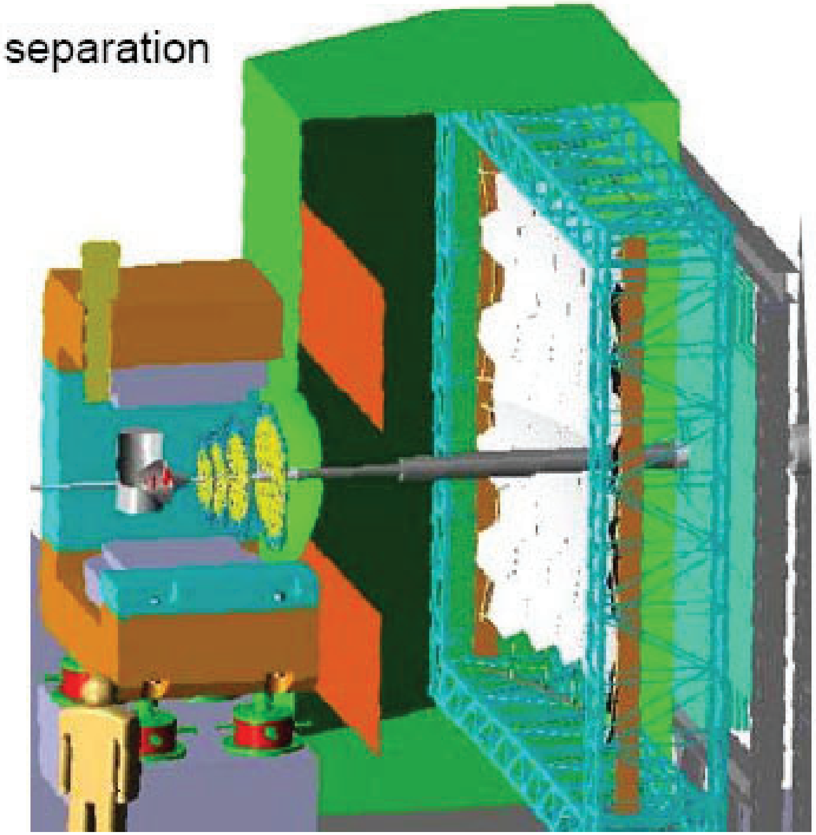
RICH concept (II)

concept

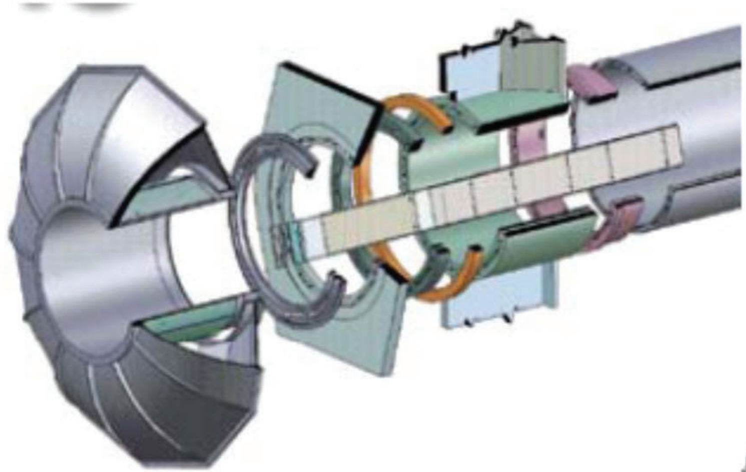
- gaseous RICH detector
- rather high Cherenkov threshold for pions (4.5-6 GeV/c)
  → N_2 radiator (γ_{th}=41, $p_{\pi,th}$=5.6 GeV/c)
- glass mirrors (4-6 mm, R=4.5m) with vertikal separation
  → focus to upper & lower part of CBM
  → photodetector shielded by magnet yoke
- photodetector plane: PMTs
  → MAPMTs
  (e.g. Hamamatsu H8500 with UV windows)
- no further windows

→ Cherenkov photons with $\lambda \geq 200$ nm

→ 2.5 m radiator length (22 hits/ring)

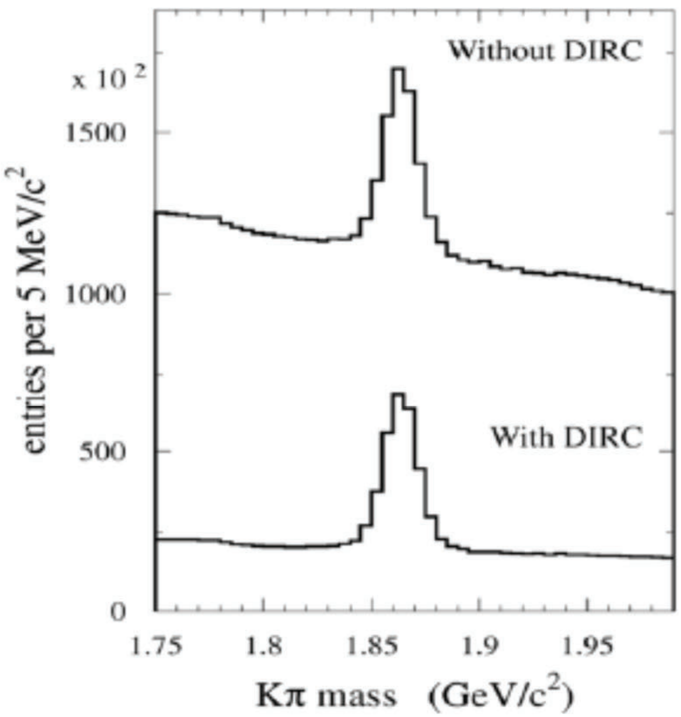


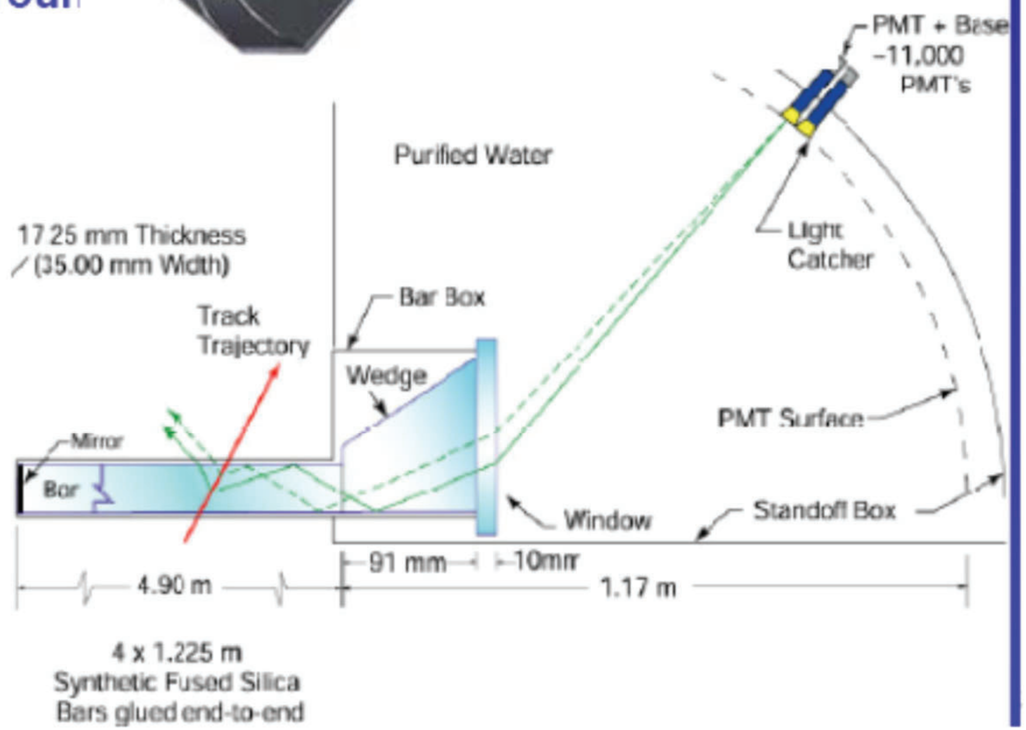
Flavour physics – BABAR DIRC

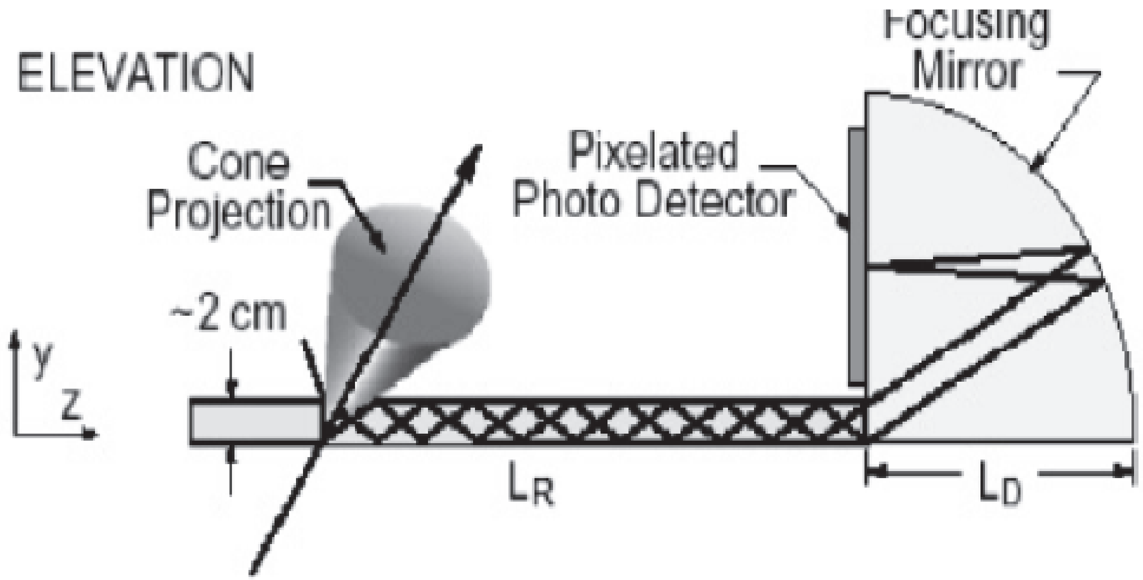


11,000 PMTs: 29mm diameter
π / K separation: 0.5 - 4 GeV/c

N_photons detected > 30 / track
σ_θ < 10 mrad
x 6 reduction in $D^0 \rightarrow K\pi$ backgroun

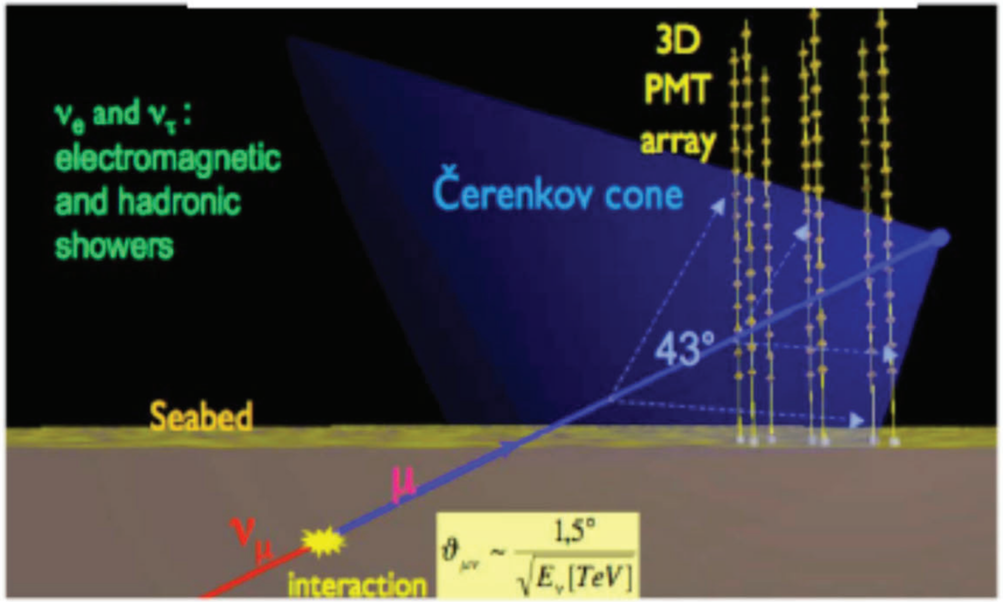


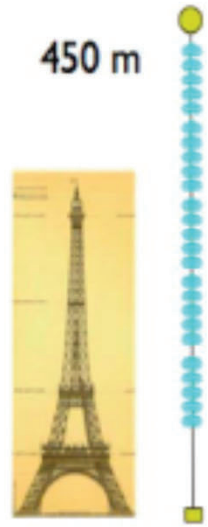



ELEVATION
Focusing Mirror
Pixelated Photo Detector
Cone Projection
~2 cm
y
z
L_R
L_D

Neutrino Astronomy … how ?

Neutrinos can be detected using the visible Cherenkov radiation produced as the high-energy charged lepton (final state of CC interactions) propagates through a transparent medium with superluminal velocity.

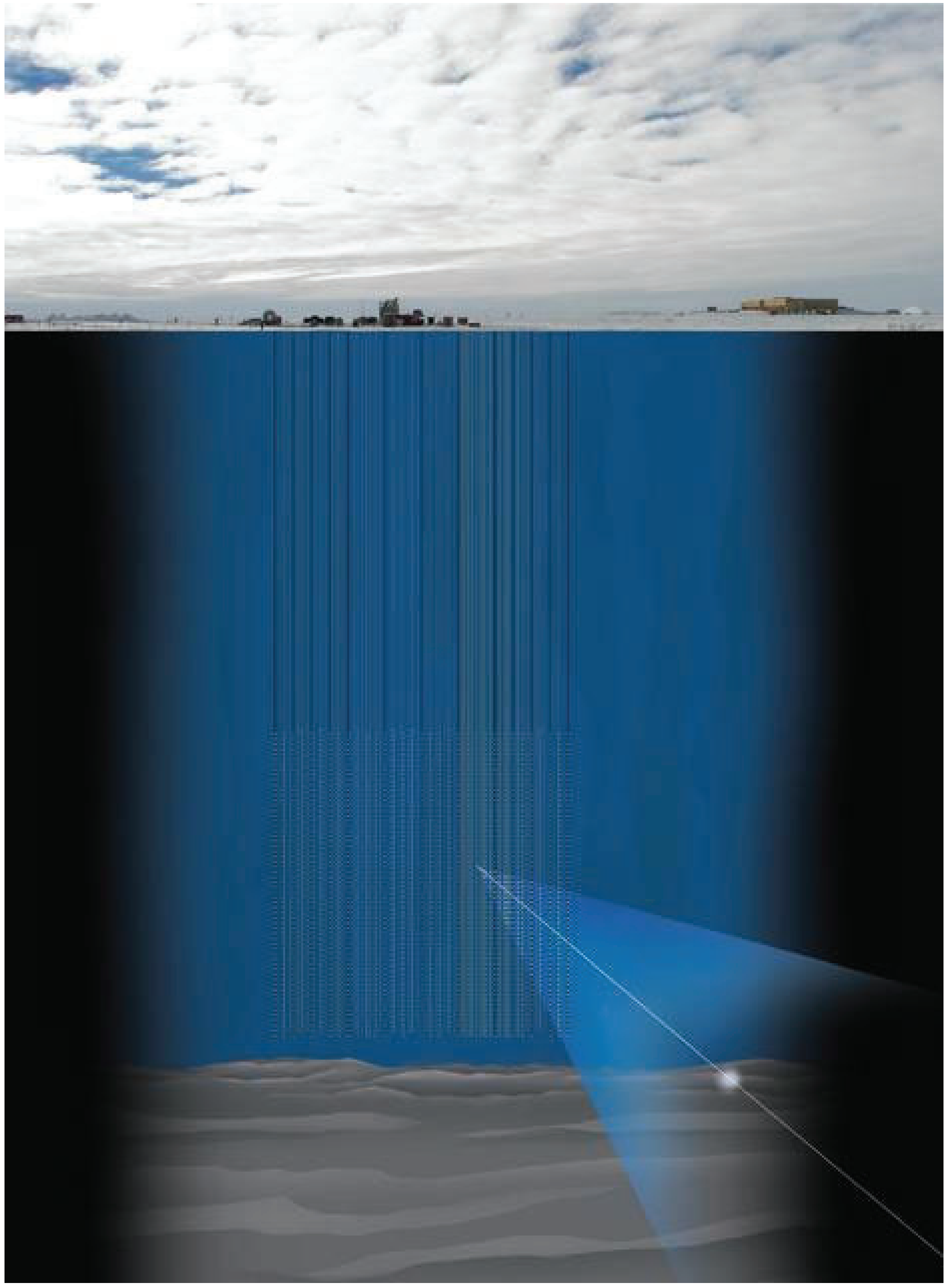




Due to low fluxes expected, cubic-kilometer scale detector are required to perform HE neutrino astronomy (E ~100GeV -10 PeV)→prototype structures currently taking data.

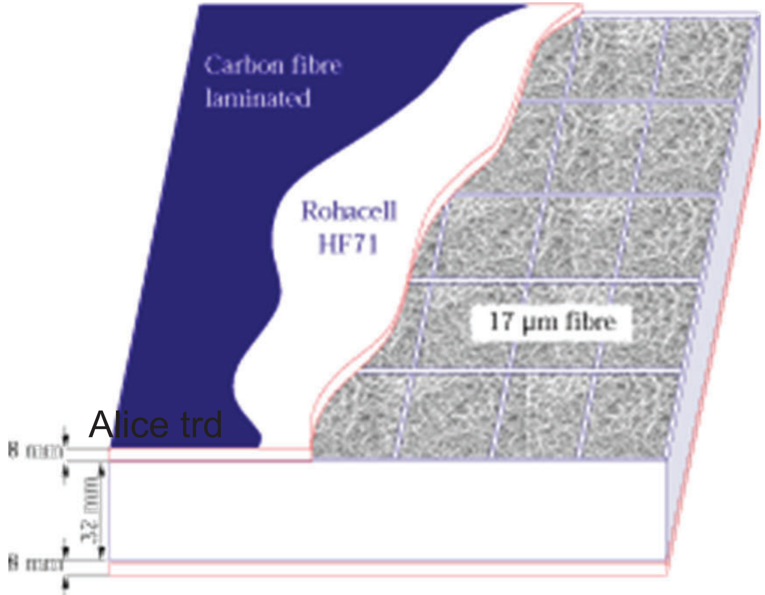
Ice cube
Pictorial event

Selecting events coming from ‘below’
(using the earth as a filter/shield)



Transition radiation detectors: the radiator

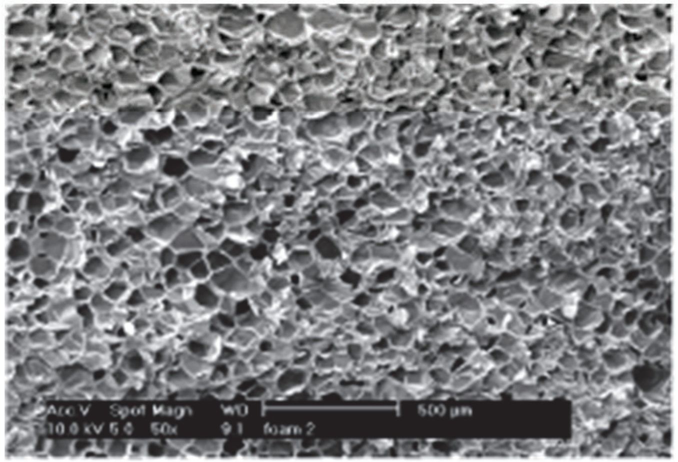
La radiazione di transizione è emessa quando una particella carica attraversa un mezzo con un indice di rifrazione discontinuo, e.g. alla superfice di separazione fra il vuoto ed un dielettrico.

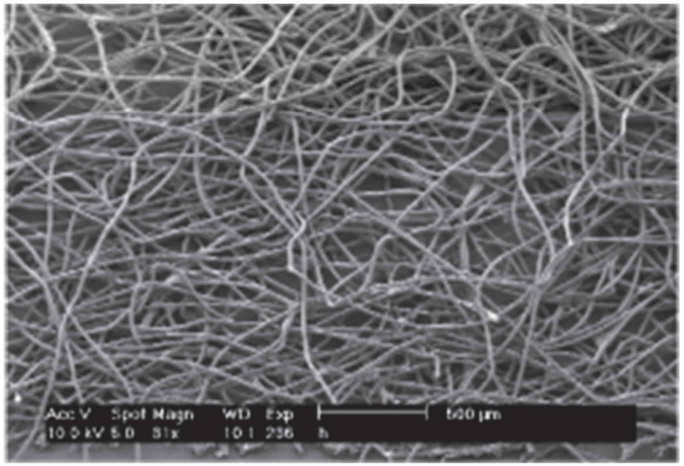


Alice trd

Energia emessa proporzionale a γ

The radiator is optimized to provide the best compromise between transition radiation yield, radiation thickness and mechanical stability. The final radiator consists of polypropylene fibre mats of 3.2 cm total thickness, sandwiched between two Rohacell foam sheets of 0.8 cm thickness each. The foam is reinforced by carbon fibre sheets with a thickness of 0.1 mm laminated onto the outer surface. The measured radiator performance, with a pion rejection factor of 100 at an electron efficiency of 90%, is as required.





Photon interaction with matter

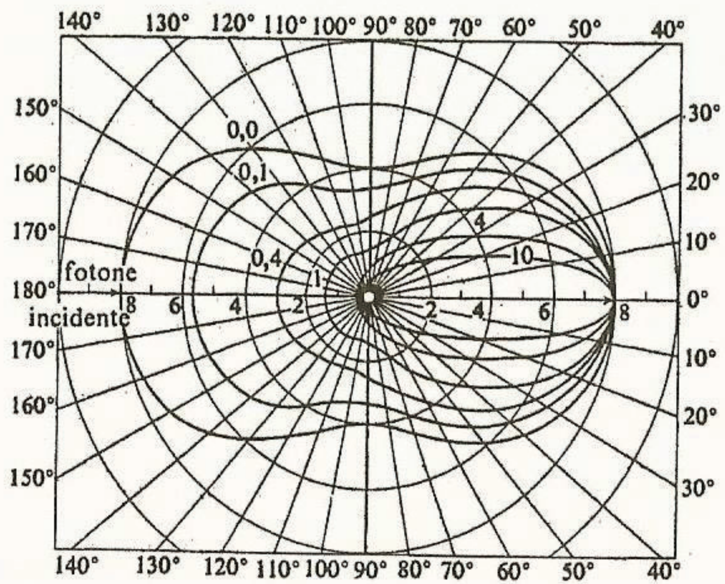


Fig 13.3 distribuzione angolare nell'effetto Compton

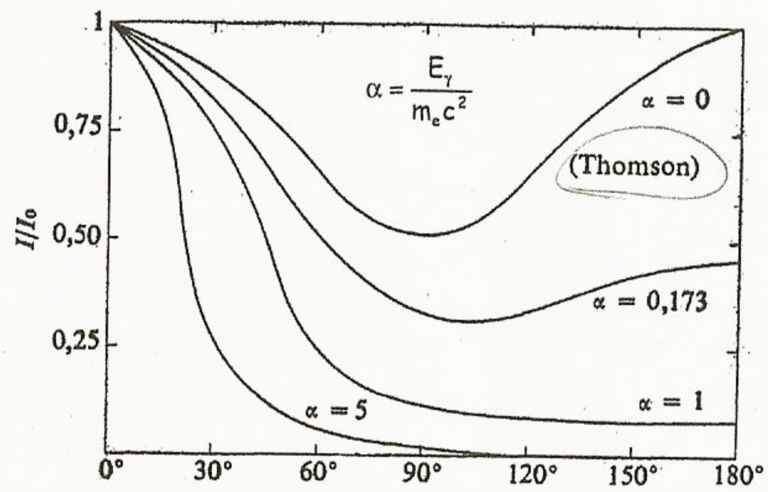
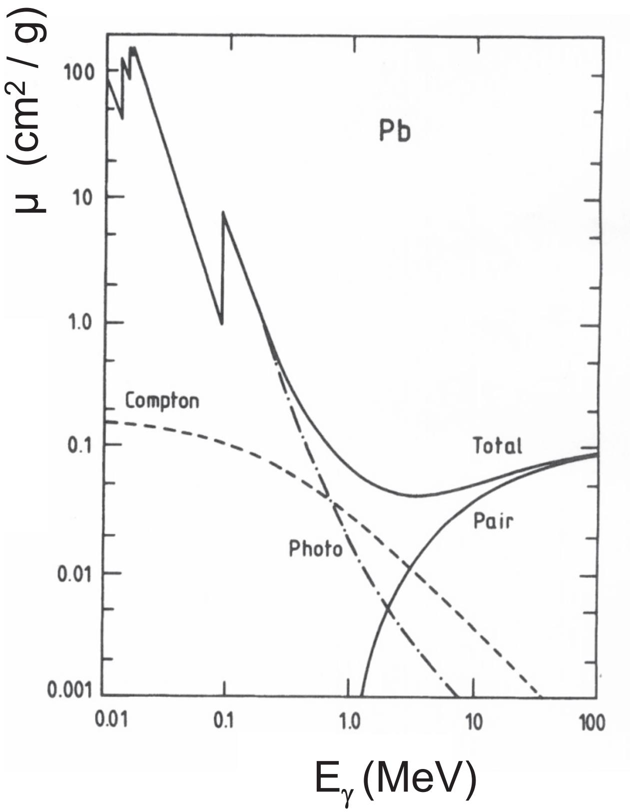
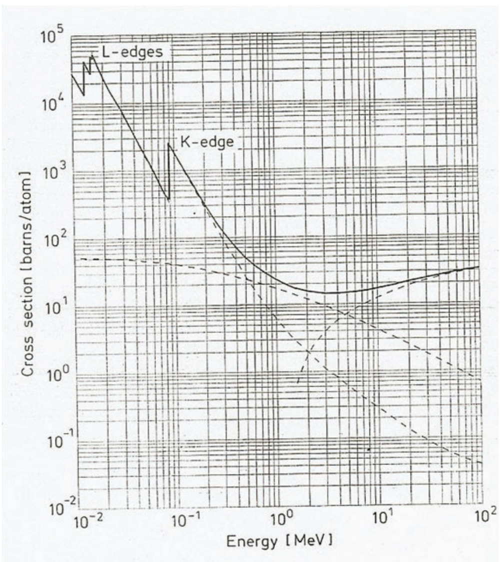
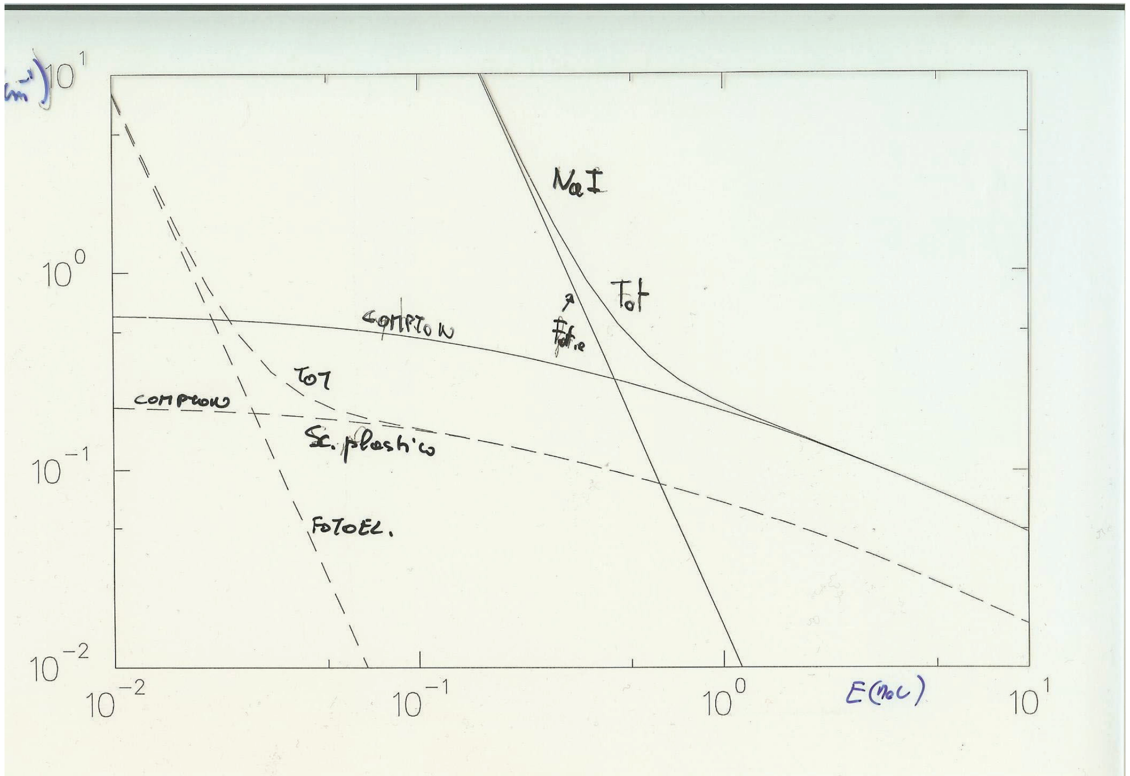


Fig 13.4 sezione d'urto Compton in funzione di energia ed angolo di diffusione


μ (cm² / g)
Pb
Compton
Total
Photo
Pair
Eγ (MeV)


L-edges
K-edge
Cross section [barns/atom]
Energy [MeV]


NaI
Tot
Compton
Compton
Tot
Sc. plastico
Fotoel.
E (MeV)

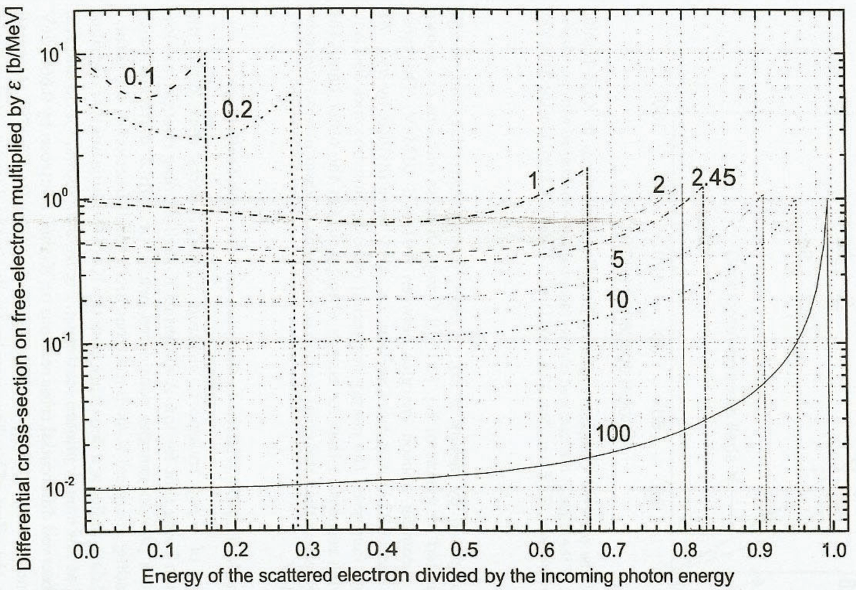
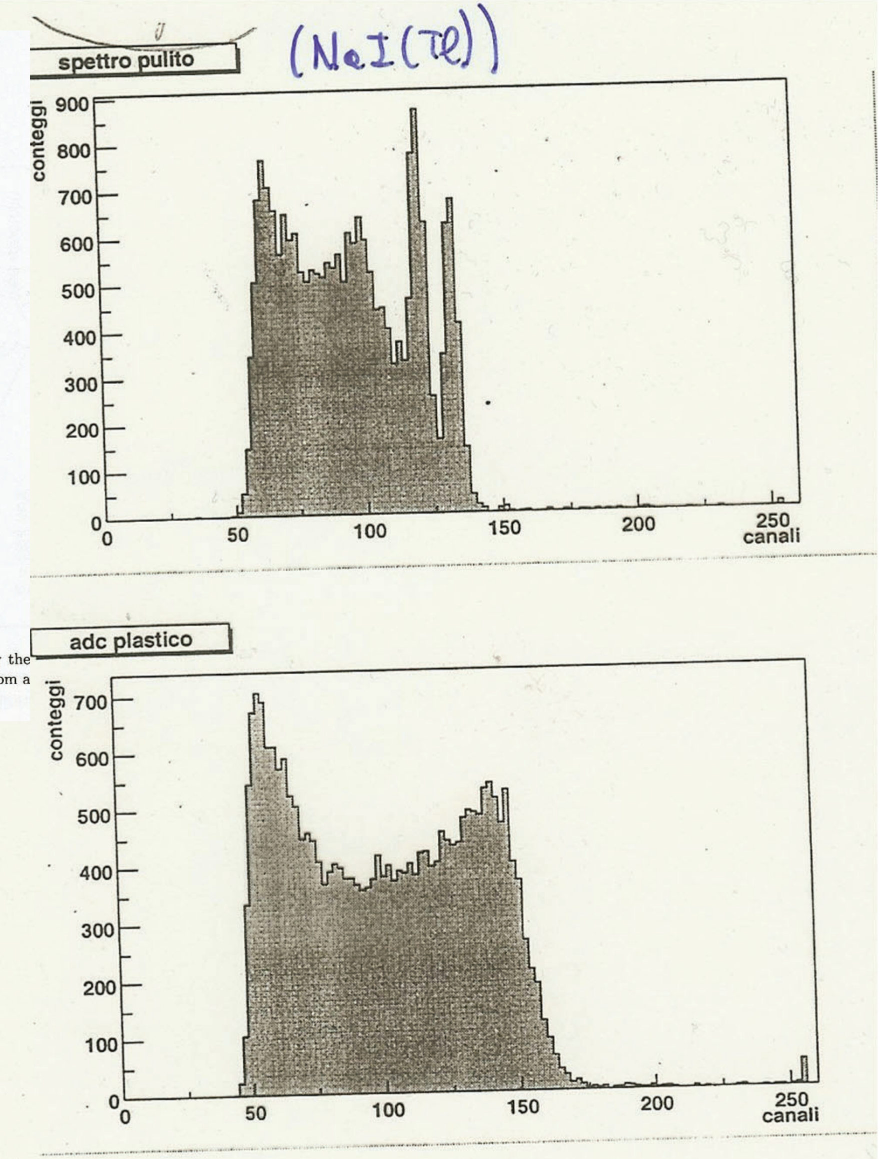


Fig. 2.55 Compton differential cross-sections on a free electron [Eq. (2.185)] multiplied by $\mathcal{E}$ as a function of the kinetic energy divided by the incoming photon energy [η_e, see Eq. (2.184)]. The curves are for $\mathcal{E} = 0.1, 0.2, 1, 2, 2.45$ (i.e., it corresponds to the average energy of photons from a ^{60}Co source), 5.10 and 100.



Photon Energy, 5.11 keV	Photon Energy, 5.11 MeV
$\alpha = \frac{5.11\ \text{keV}}{0.511\ \text{MeV}} = 0.010$	$\alpha = \frac{5.11\ \text{MeV}}{0.511\ \text{MeV}} = 10$
$E_{e(max)} = 5.11\ \text{keV} * \left(2 * \frac{0.01}{1.02}\right)$	$E_{e(max)} = 5.11\ \text{MeV} * \left(2 * \frac{10}{21}\right)$
$= 0.10\ \text{keV}$	$= 4.87\ \text{MeV}$
$h\nu'\ (\text{min}) = 5.11\ \text{keV} * \frac{1}{1.02}$	$h\nu'\ (\text{min}) = 5.11\ \text{MeV} * \frac{1}{21}$
$= 5.01\ \text{keV}$	$= 0.24\ \text{MeV}$
Energy transferred: 2%	Energy transferred: 95%

Figure by MIT OCW.

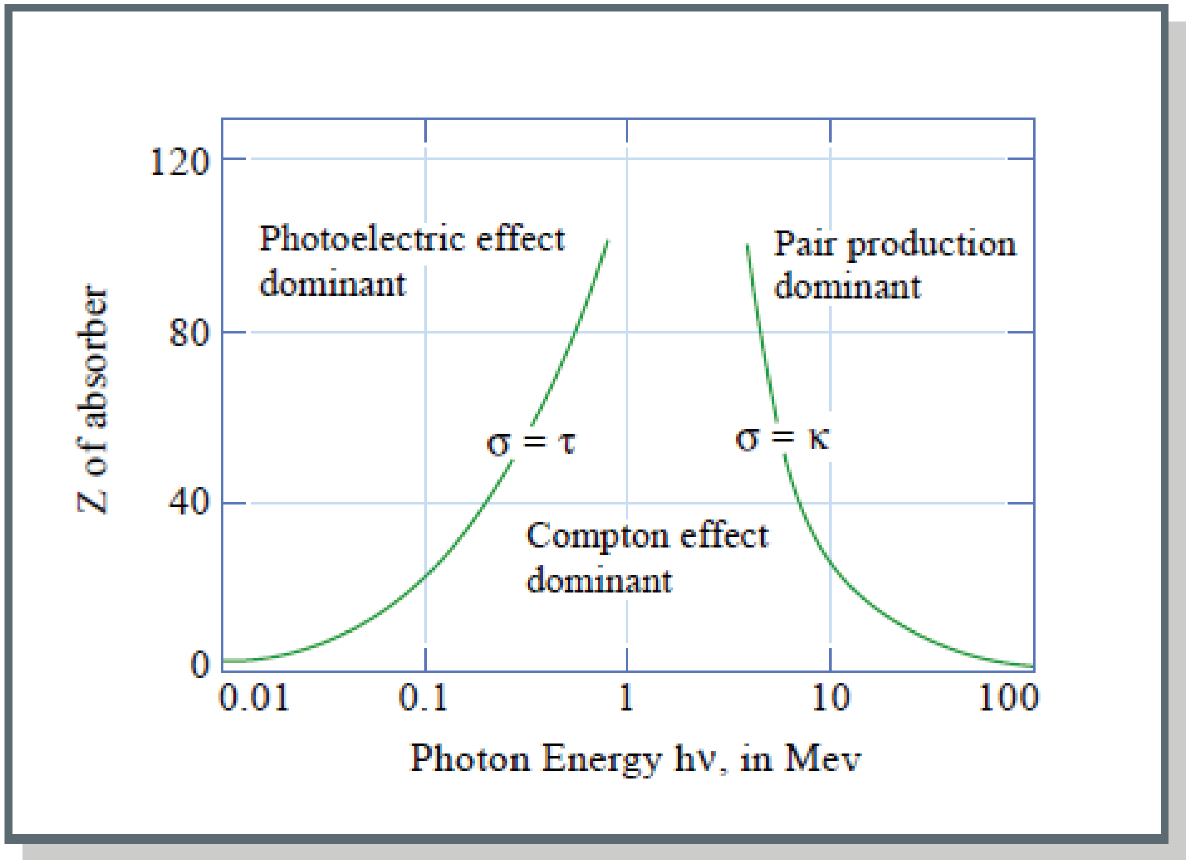
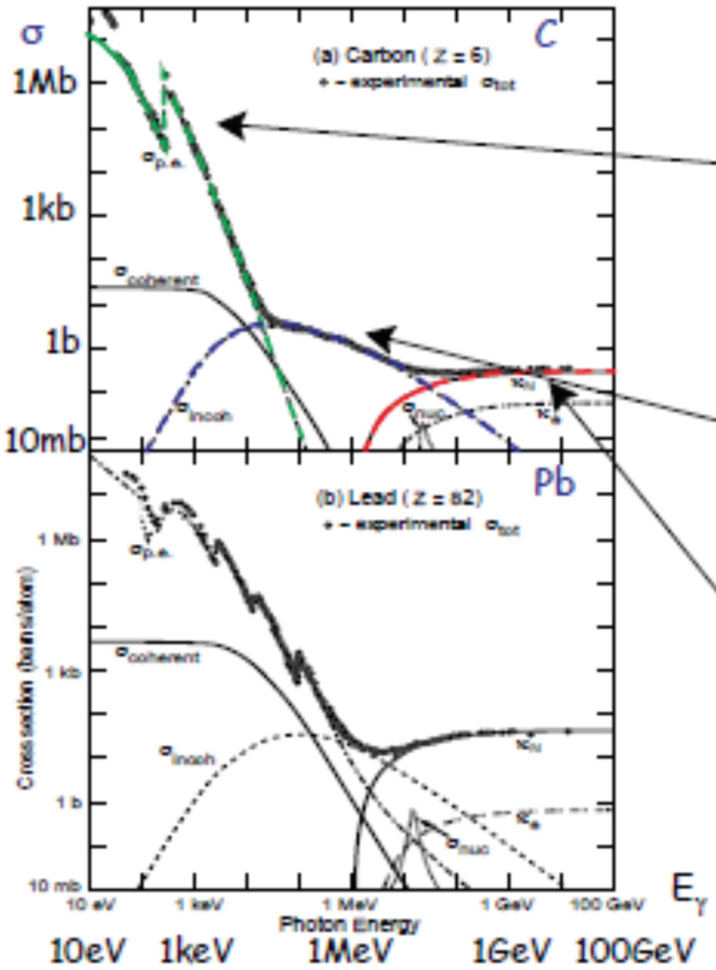


Figure by MIT OCW.

Interaction of Photons with Matter



Three effects are important:

- Photoeffect: $\gamma + \text{atom} \rightarrow e^- + \text{atom}^+$

  $$\sigma_{Ph} \propto \frac{Z^5}{E^{3.5}}$$

- Comptoneffect: $\gamma + \text{atom} \rightarrow \gamma + e^- + \text{atom}^+$

  $$\sigma_{Compton} \propto \frac{\ln E}{E} \cdot Z$$

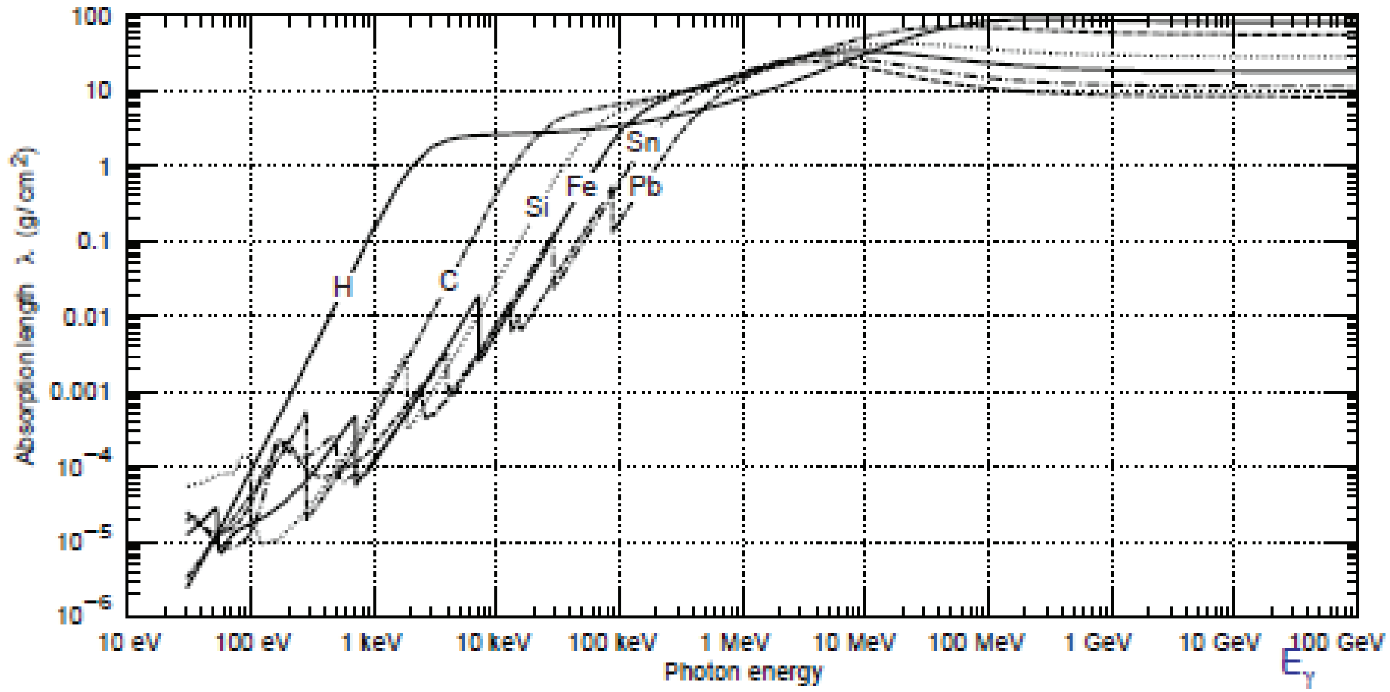
- Pairproduction: $\gamma + \text{nucl.} \rightarrow e^+ + e^- + \text{nucl.}$

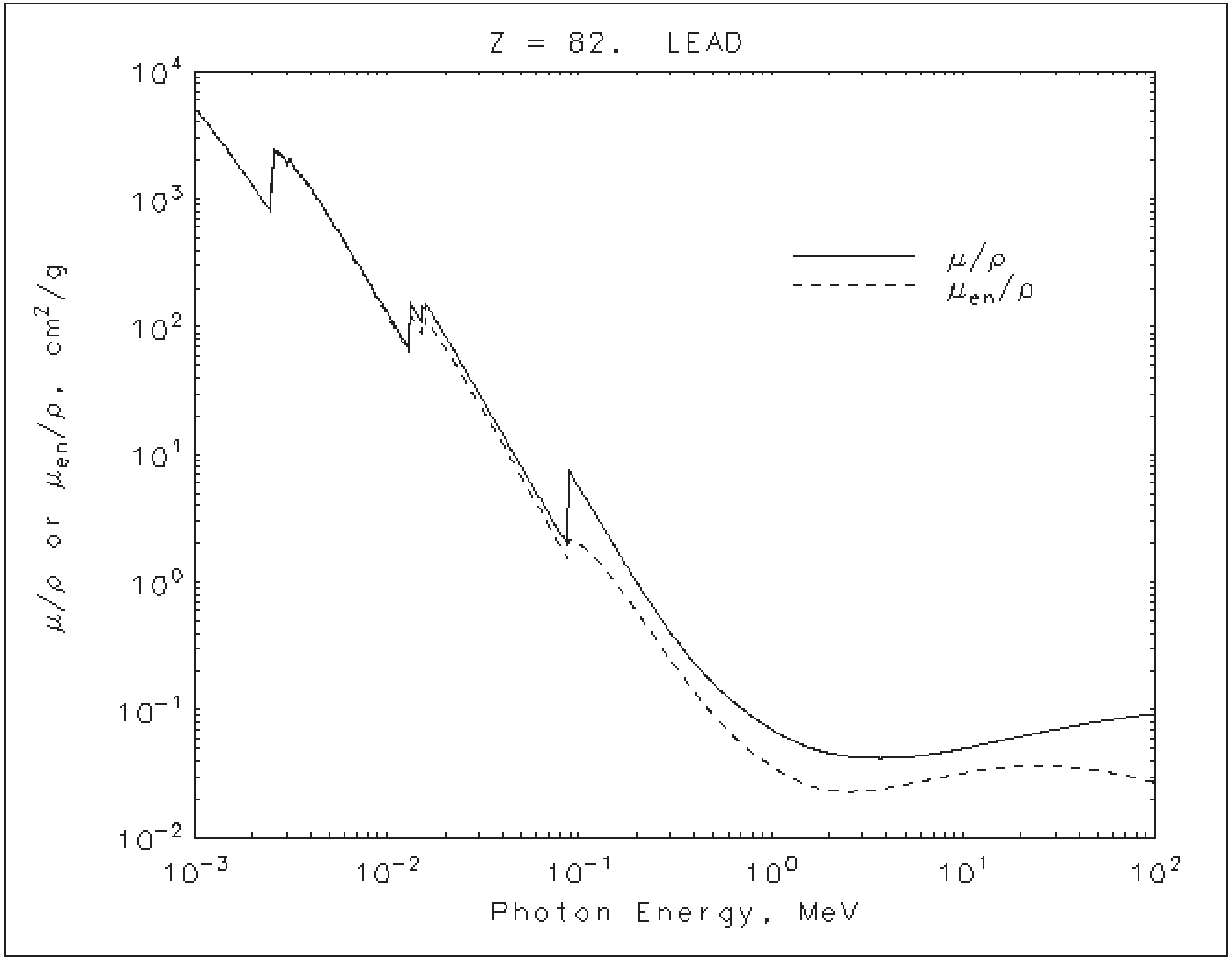
  $$\sigma_{Pair} \propto Z^2 \quad \text{für} \quad E_\gamma \gg 2m_e c^2$$

Photon Absorption Length λ

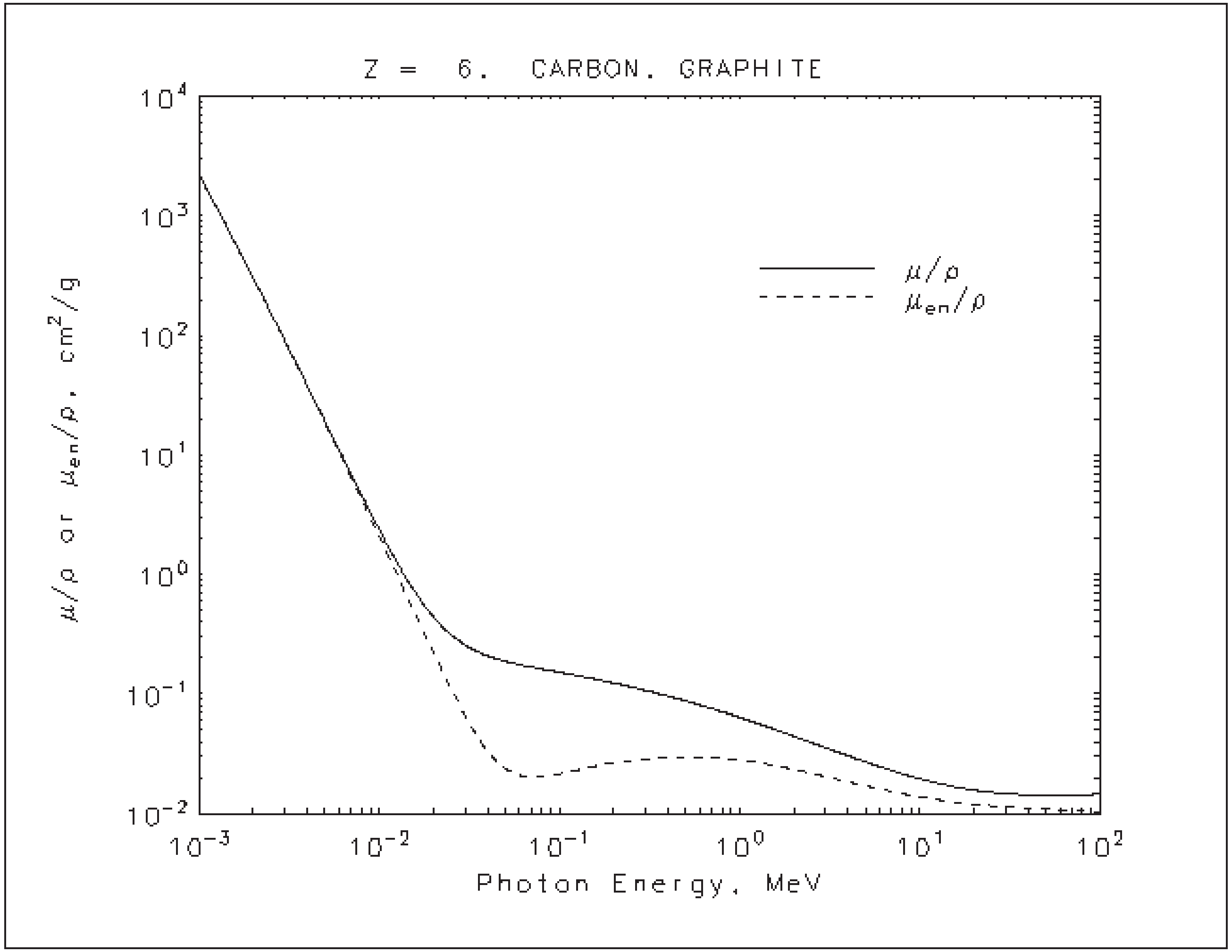
Definition of mass absorption coefficient: $\lambda = \frac{1}{(\mu/\rho)}$ [g cm^{-2}]

$\sigma_{Ph} \propto \frac{Z^5}{E^{3.5}}$ $\sigma_{Compton} \propto \frac{\ln E}{E} \cdot Z$ $\sigma_{Pair} \propto Z^2$





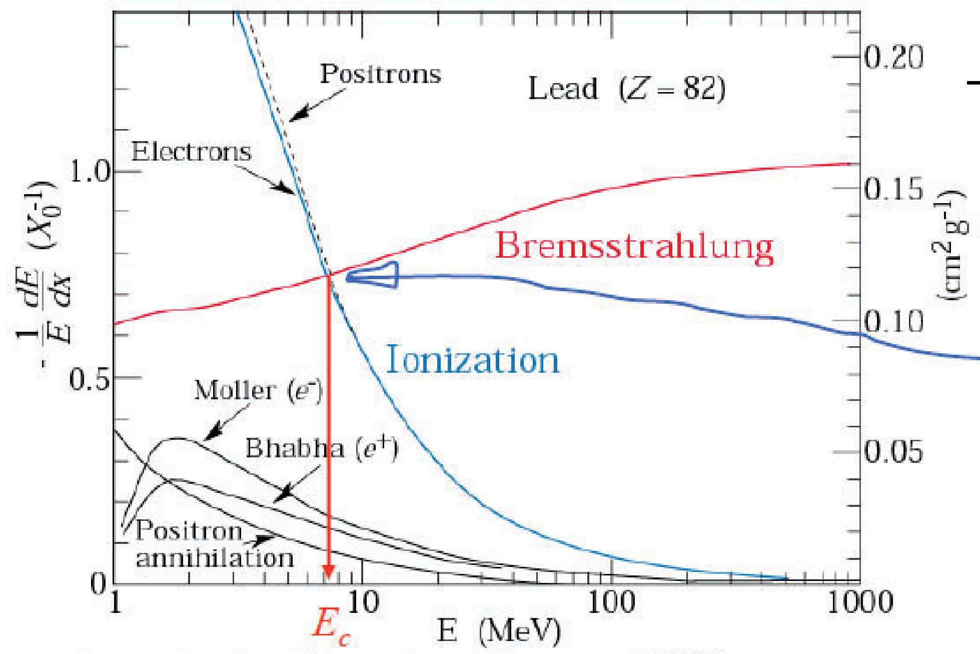
<u>Photon linear absorption coefficent</u>



Photon linear attenuation coefficent

Pair production

Critical Energy



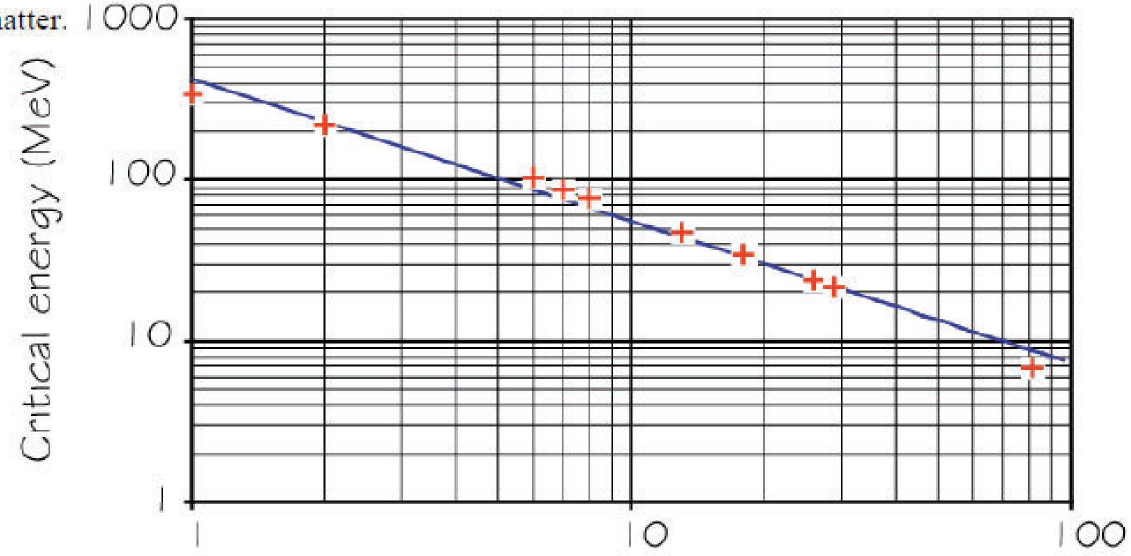
Electron (positron) interaction with matter.

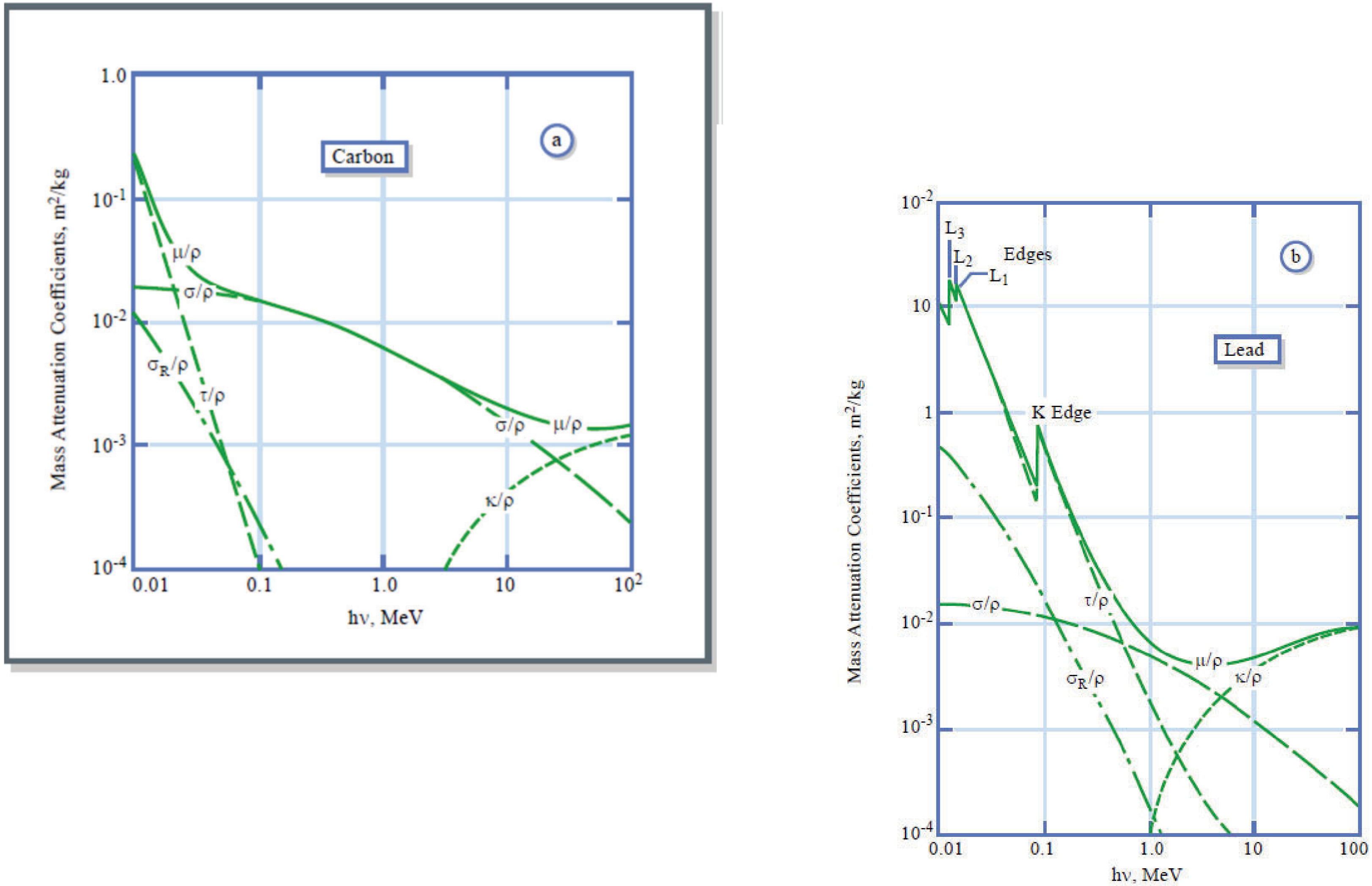
Critical energy

E_c

Ionization = Bremsstrahlung

$$E_c \propto Z^{-0.9}$$





Mass attenuation coefficients for carbon (a) and lead (b). τ/ρ indicates the contribution of the photoelectric effect, σ/ρ is that of the Compton effect, κ/ρ that of pair production, and σ_R/ρ that of Rayleigh (coherent) scattering. μ/ρ is their sum, which is closely approximated in Pb by the τ/ρ curve below $h\nu = 0.1$ MeV.

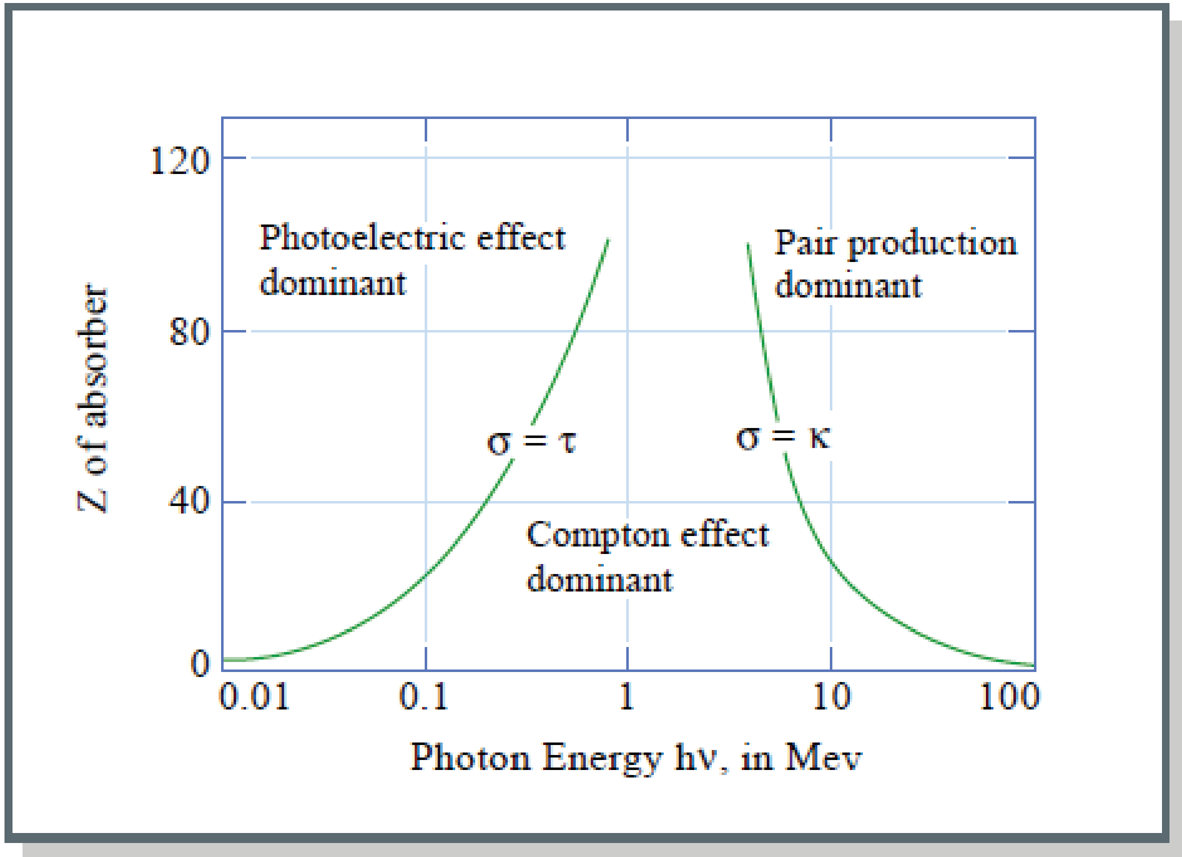


Figure by MIT OCW.

Table 2.3. Radiation lengths for various absorbers

Material	[gm/cm^2]	[cm]
Air	36.20	30050
H_2O	36.08	36.1
NaI	9.49	2.59
Polystyrene	43.80	42.9
Pb	6.37	0.56
Cu	12.86	1.43
Al	24.01	8.9
Fe	13.84	1.76
BGO	7.98	1.12
BaF_2	9.91	2.05
Scint.	43.8	42.4

Table 2.2. Critical energies of some materials

Material	Critical energy [MeV]
Pb	9.51
Al	51.0
Fe	27.4
Cu	24.8
Air (STP)	102
Lucite	100
Polystyrene	109
NaI	17.4
Anthracene	105
H_2O	92

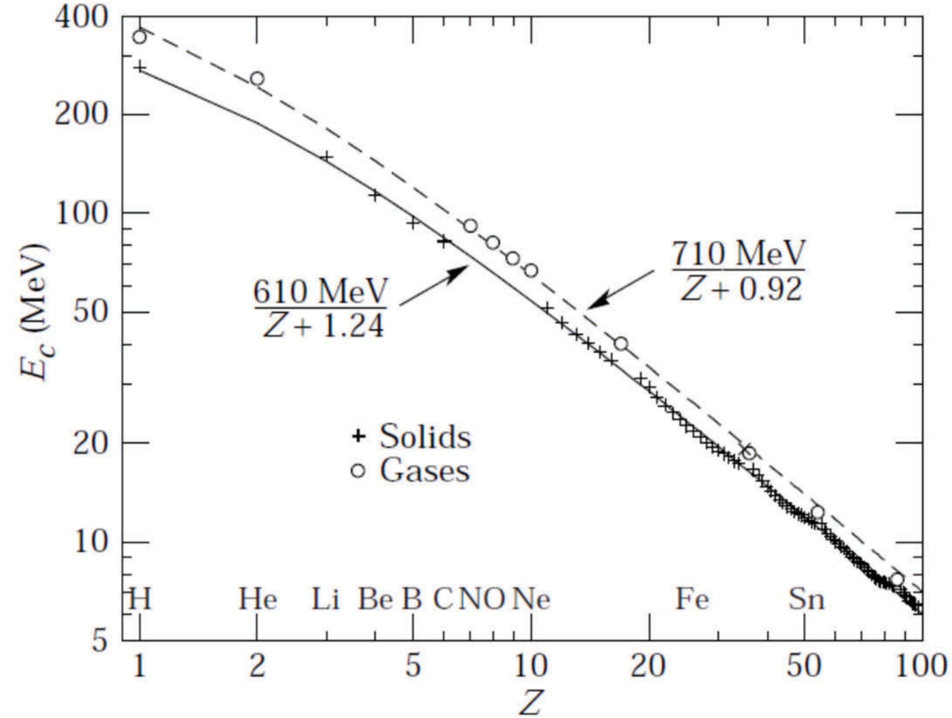
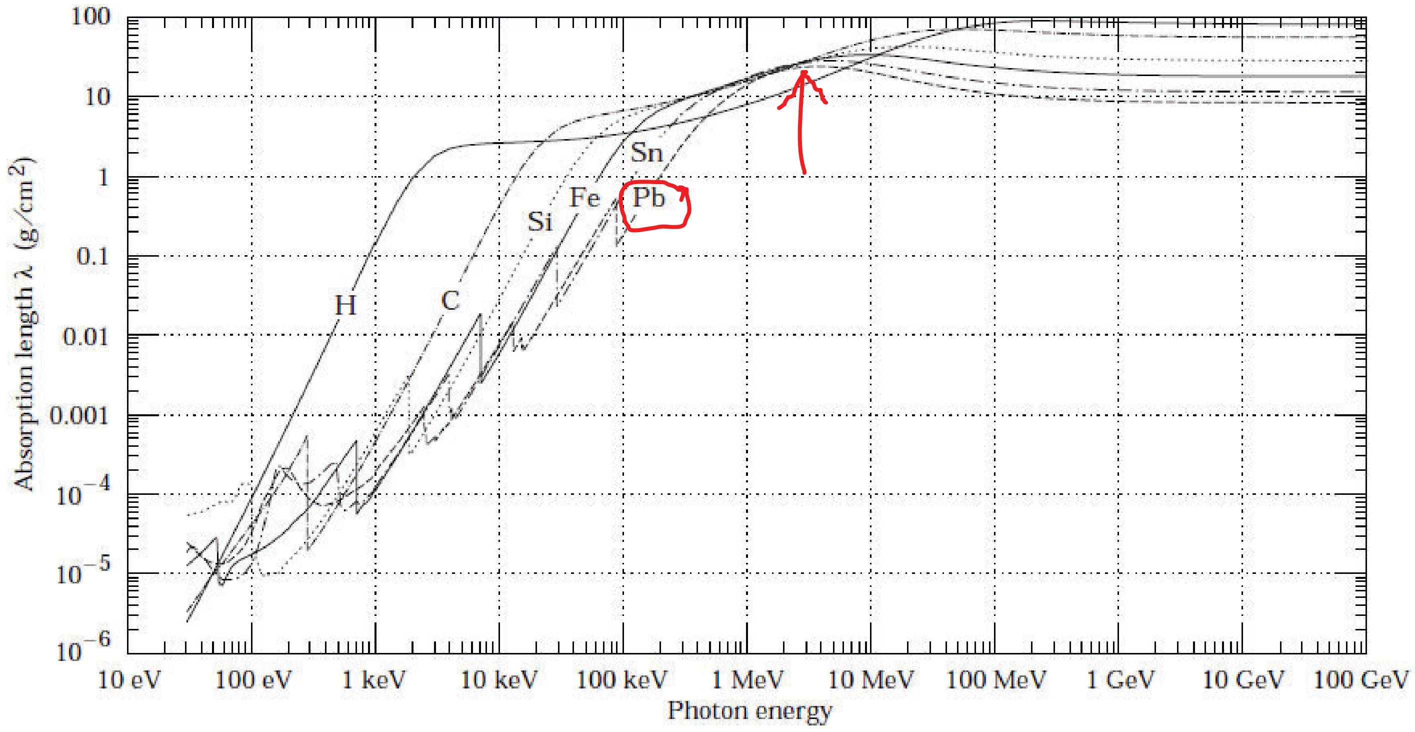
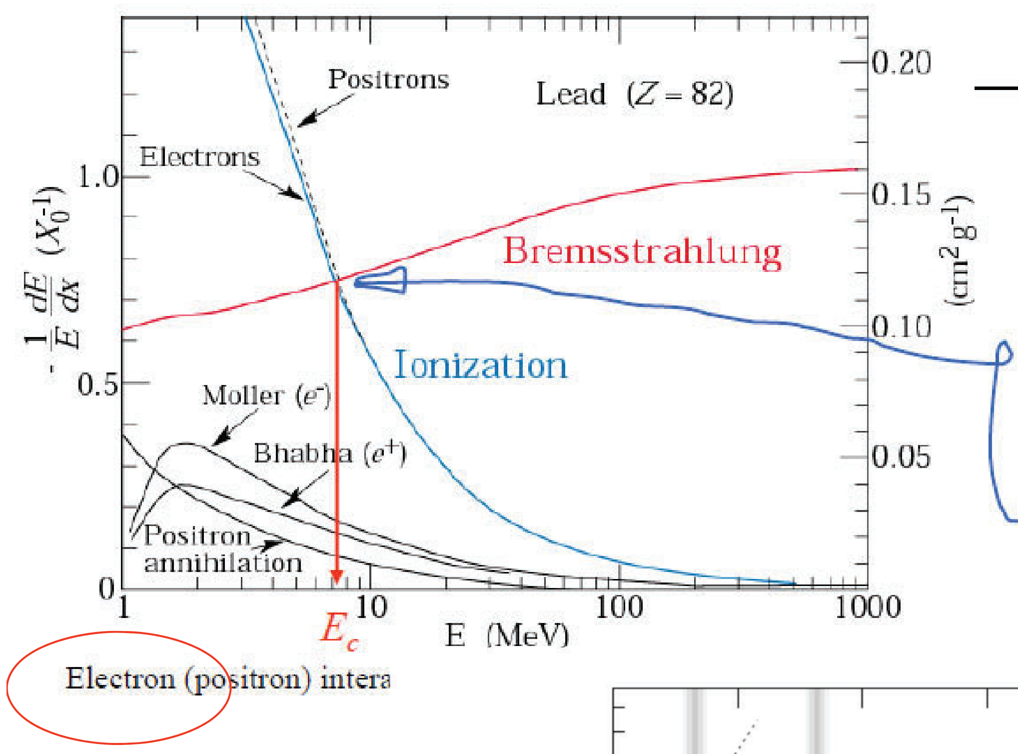


Figure 27.13: Electron critical energy for the chemical elements, using Rossi's definition [2]. The fits shown are for solids and liquids (solid line) and gases (dashed line). The rms deviation is 2.2% for the solids and 4.0% for the gases. (Computed with code supplied by A. Fassó.)



Absorption length λ (g/cm²)
100
10
1
0.1
0.01
0.001
10⁻⁴
10⁻⁵
10⁻⁶
H
C
Si
Fe
Sn
Pb
10 eV
100 eV
1 keV
10 keV
100 keV
1 MeV
10 MeV
100 MeV
1 GeV
10 GeV
100 GeV
Photon energy

Critical Energy

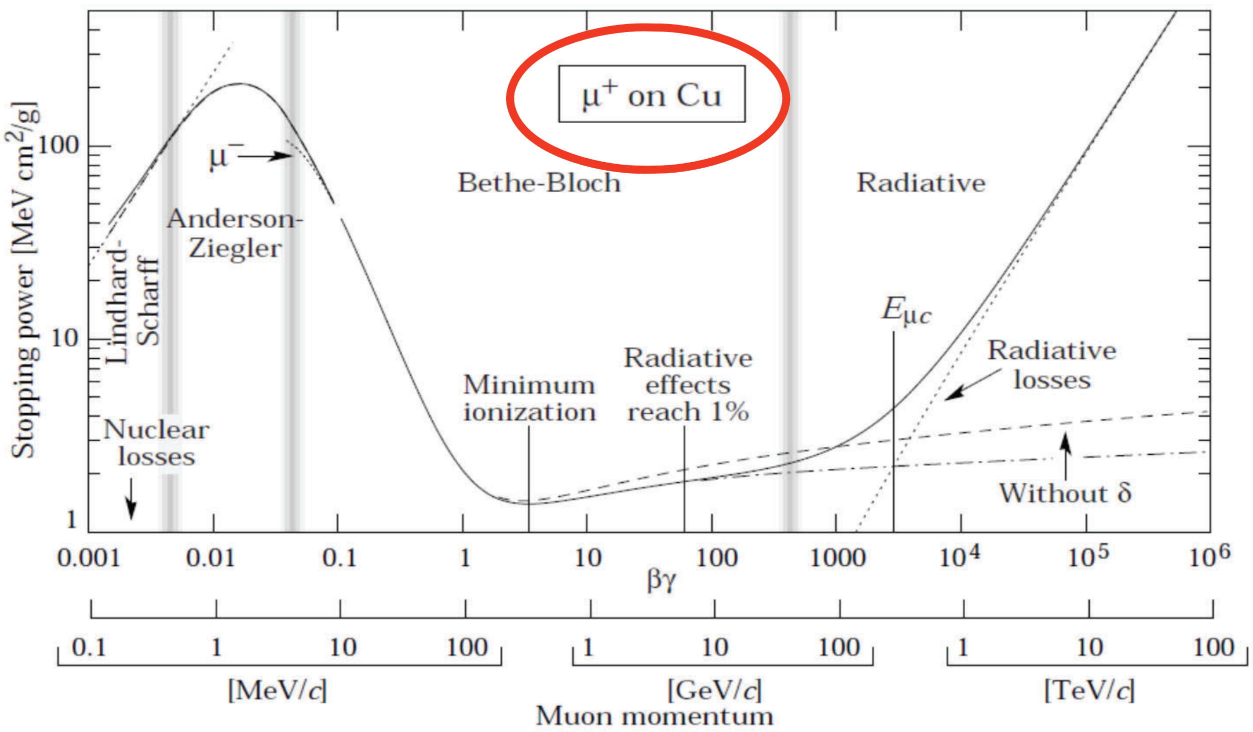


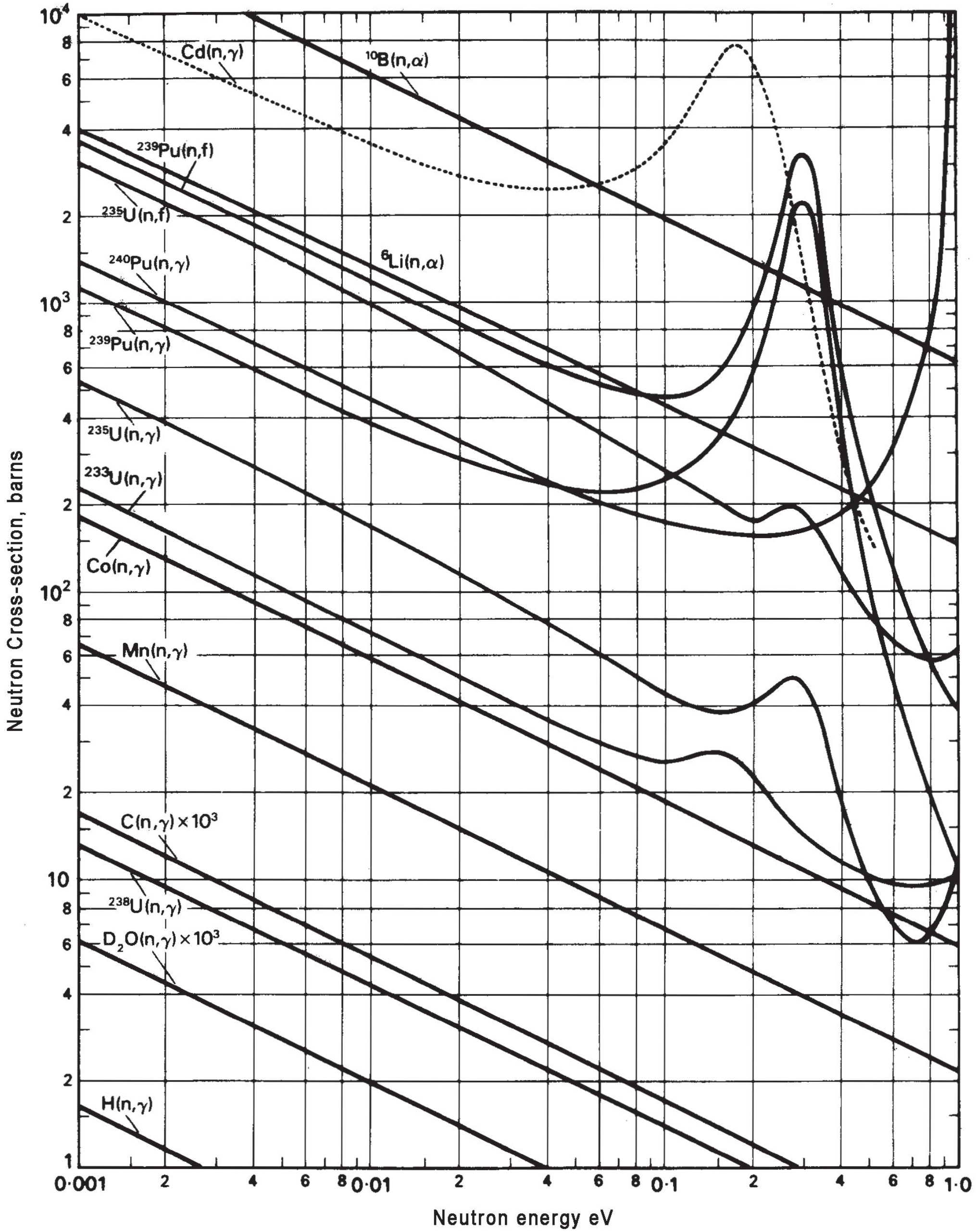
Critical energy

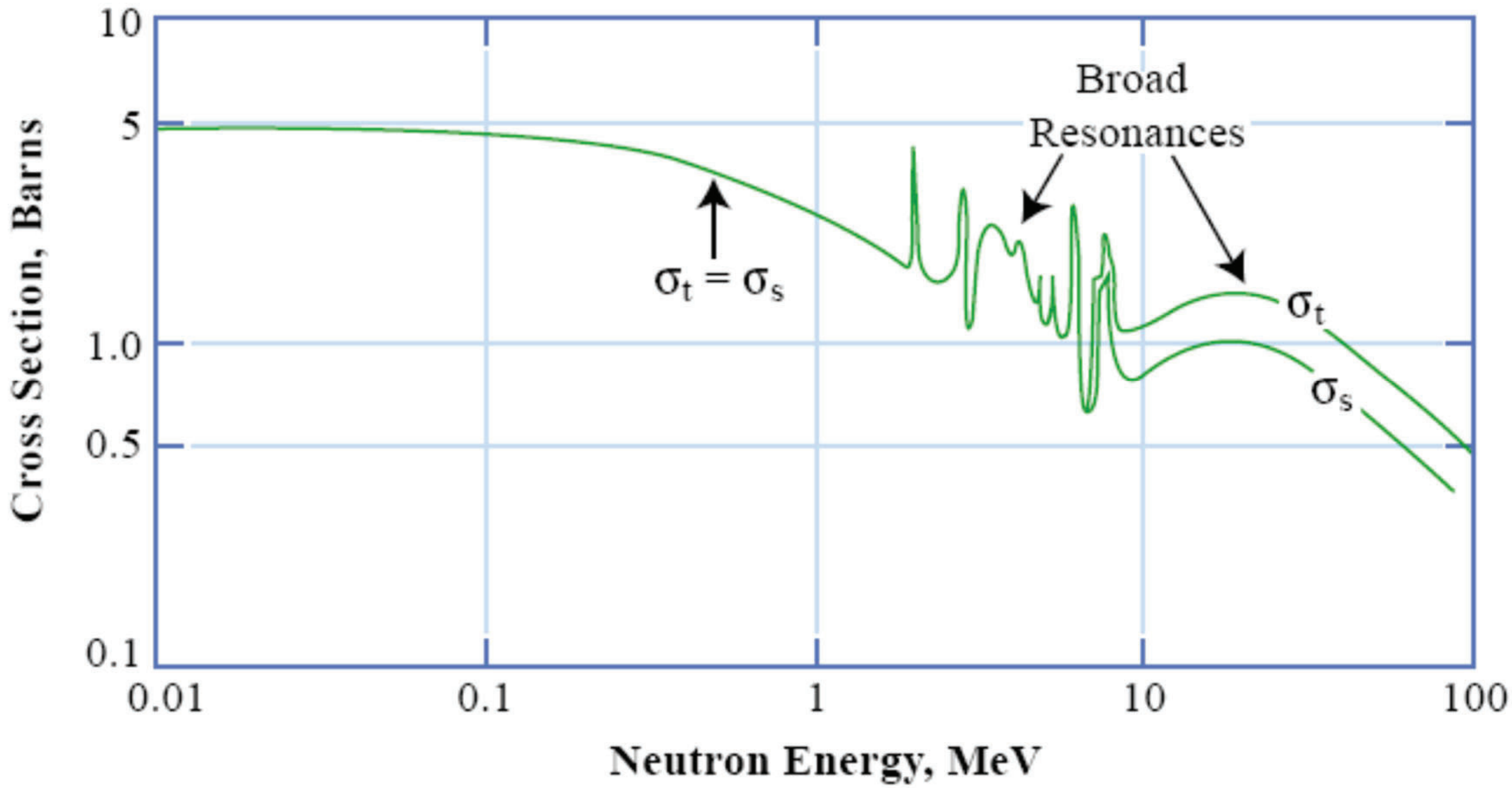
E_c

Ionization = Bremsstrahlung

$$E_c \propto Z^{-1}$$



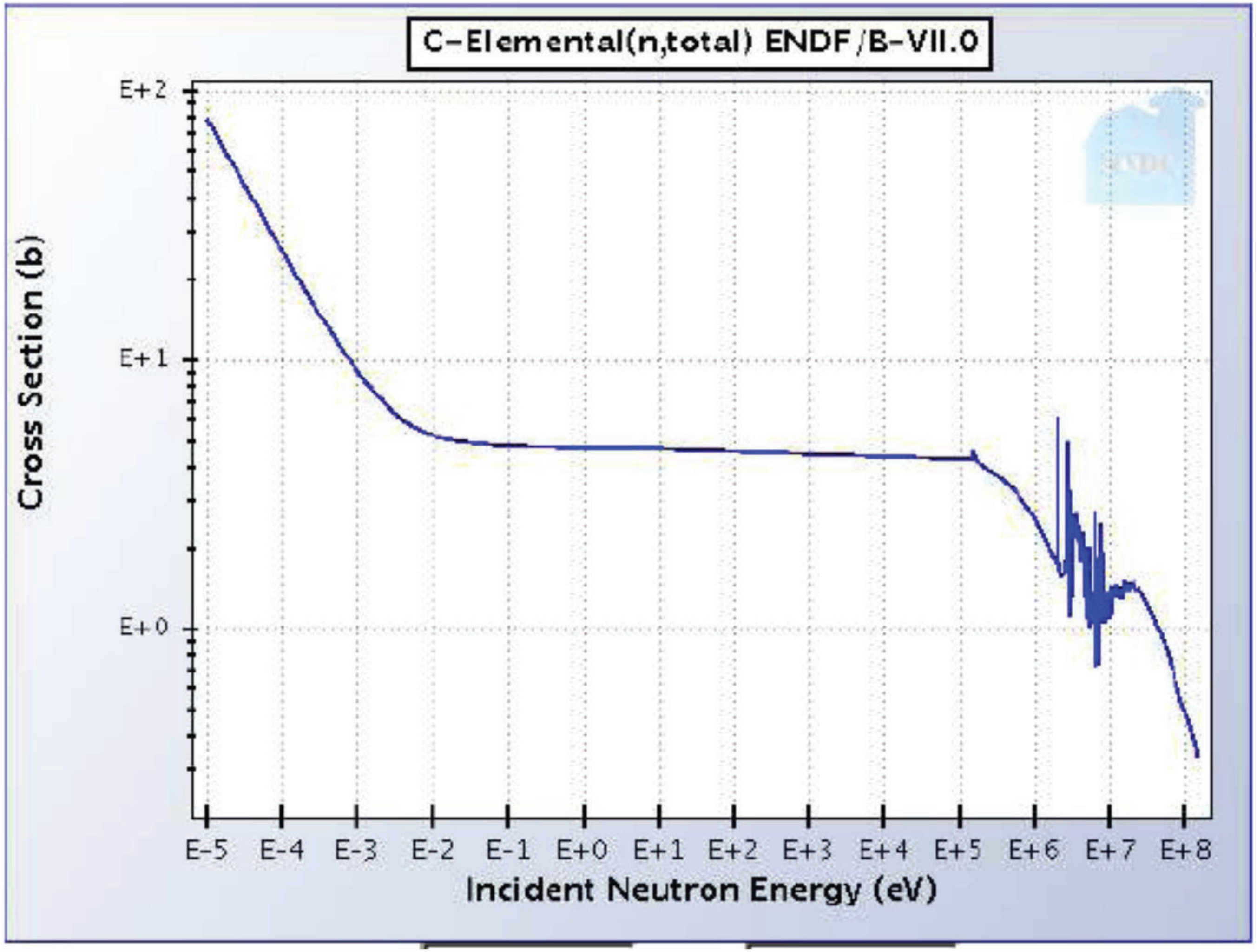

Neutron Cross-section, barns
Neutron energy eV
Cd(n,γ)
10B(n,α)
239Pu(n,f)
235U(n,f)
6Li(n,α)
240Pu(n,γ)
239Pu(n,γ)
235U(n,γ)
233U(n,γ)
Co(n,γ)
Mn(n,γ)
C(n,γ)×10³
238U(n,γ)
D2O(n,γ)×10³
H(n,γ)



10
5
1.0
0.5
0.1
Cross Section, Barns
0.01
0.1
1
10
100
Neutron Energy, MeV
Broad
Resonances
σt = σs
σt
σs

National Nuclear Data Center

NNDC Databases:



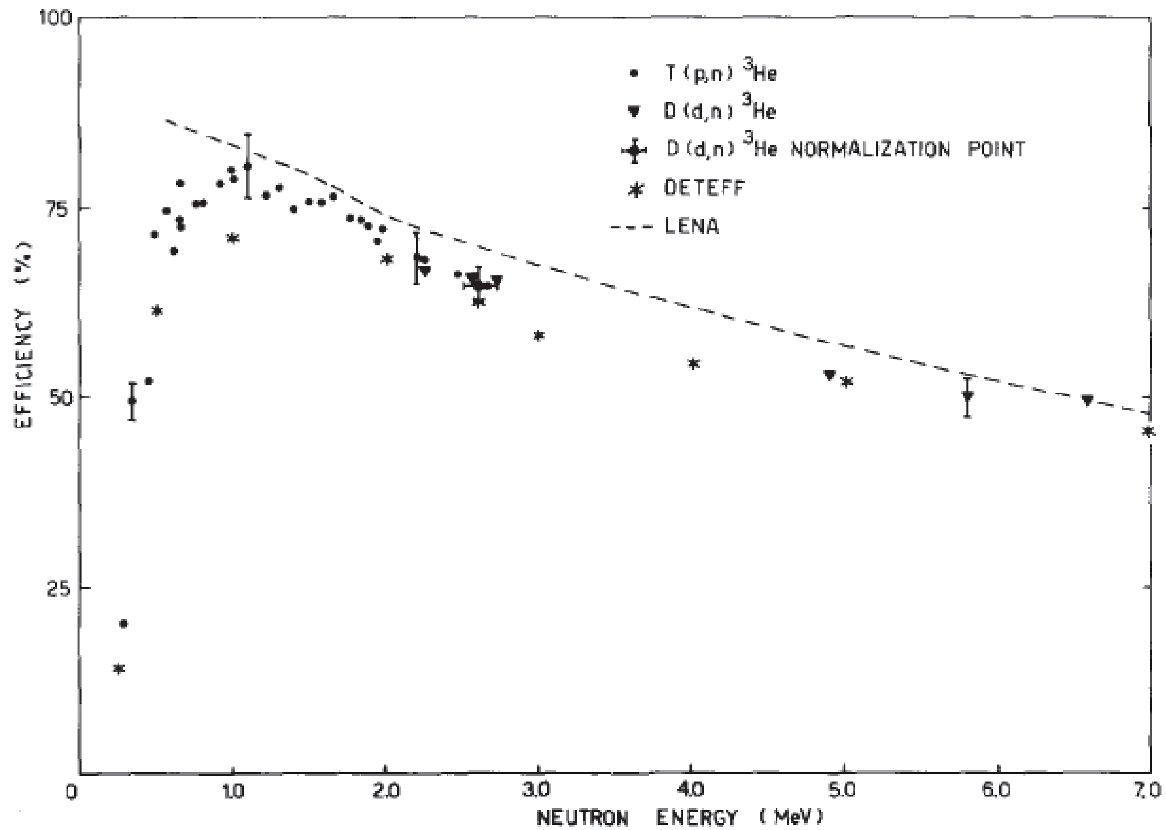


Fig. 1. Experimental neutron detection efficiency of the 10.0 cm × 10.0 cm NE104 scintillator. DETEFF and LENA refer to the Monte Carlo calculations of refs. 7, 8.

MAIN

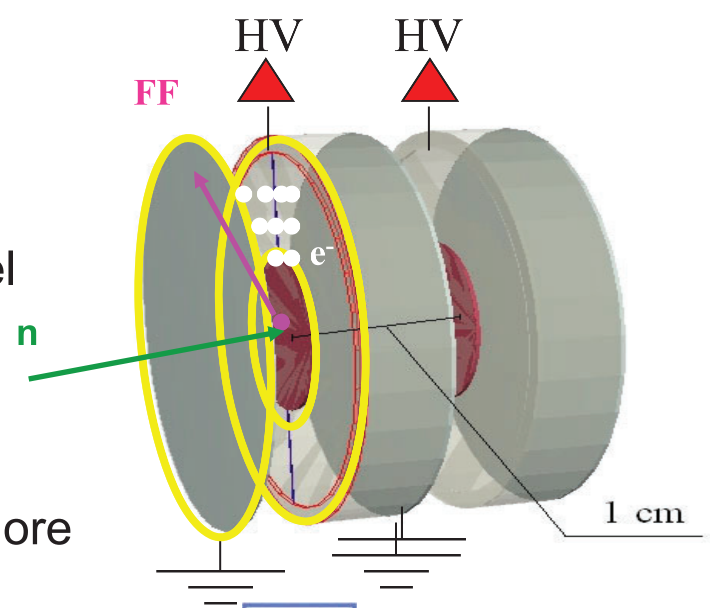
Principio di funzionamento

- La camera a ionizzazione è composta da uno stack di celle che si ripetono modularmente
- ogni cella è composta da 3 elettrodi

  - finestra di Al messa a terra

  - supporto di Al, connesso a High Voltage (il target è "dipinto" su entrambi i lati del supporto)

  - finestra di Al messa a terra
- quando un *n* colpisce il target, può causare fissione. Il *FF* è emesso nel gas e lo ionizza. Si formano coppie *elettrone-ione* e gli *elettroni* driftano verso l'elettrodo a potenziale maggiore



Pulse shape analysis

- La perdita specifica di energia (-dE/dx) di particelle cariche in un mezzo è descritta dalla formula di Bethe:

carica (e) e rest mass (m) dell' elettrone

densità atomica (N), numero atomico (Z) e potenziale di ionizzazione (I) del mezzo

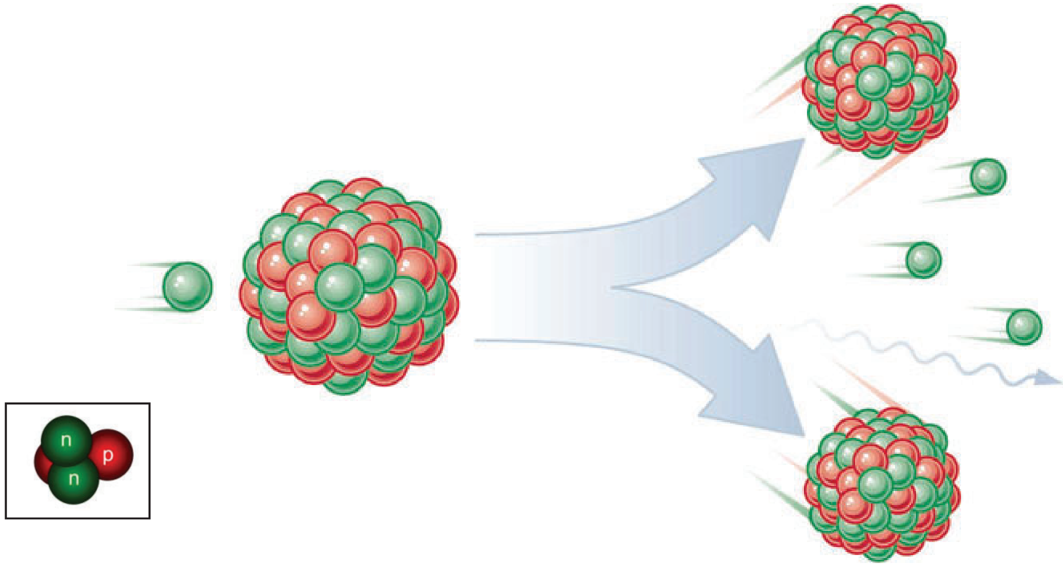
$$-\frac{dE}{dx} = \frac{4\pi e^4 z^2}{m_0 v^2} N Z \left[ln \frac{2 m_0 v^2}{I} - ln\left(1 - \frac{v^2}{c^2}\right) - \frac{v^2}{c^2} \right]$$

carica (ze) e velocità (v) della particella che provoca ionizzazione

- I termini elevati al quadrato incidono maggiormente
- A parità di cammino particelle con numero atomico maggiore (z) perdono più energia nel mezzo.

Il metodo del rapporto

- La corrente di particelle uscenti è determinata contando il numero di FFs



$$R_b = \sigma I_a N$$

- R_b = emission rate → Determinato contando i FFs
- N = nuclei/area → Noto se nota la geometria del campione
- I_a =neutron "beam" intensity ? → Ratio method

Estrazione $\sigma_{(n,f)}(E_n)$

- Come visto prima

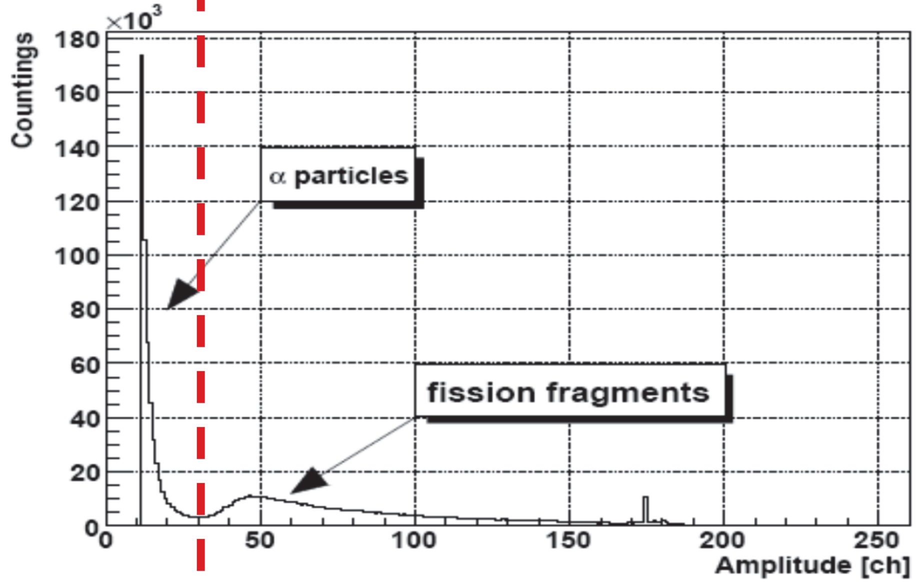
  i FFs possono venire

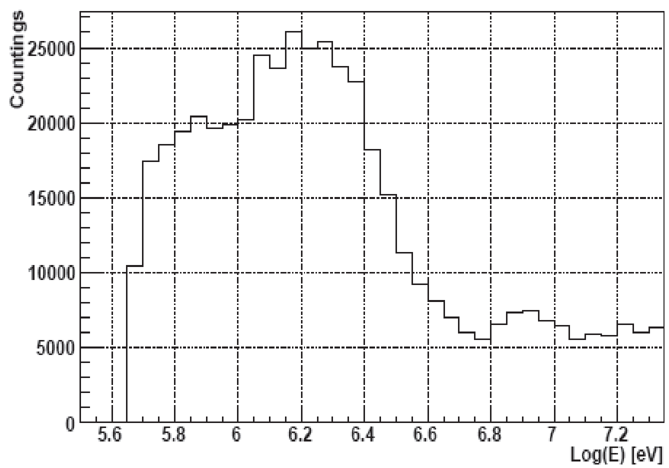
  isolati in base all'analisi

  della forma dell'impulso

  del segnale indotto dalla

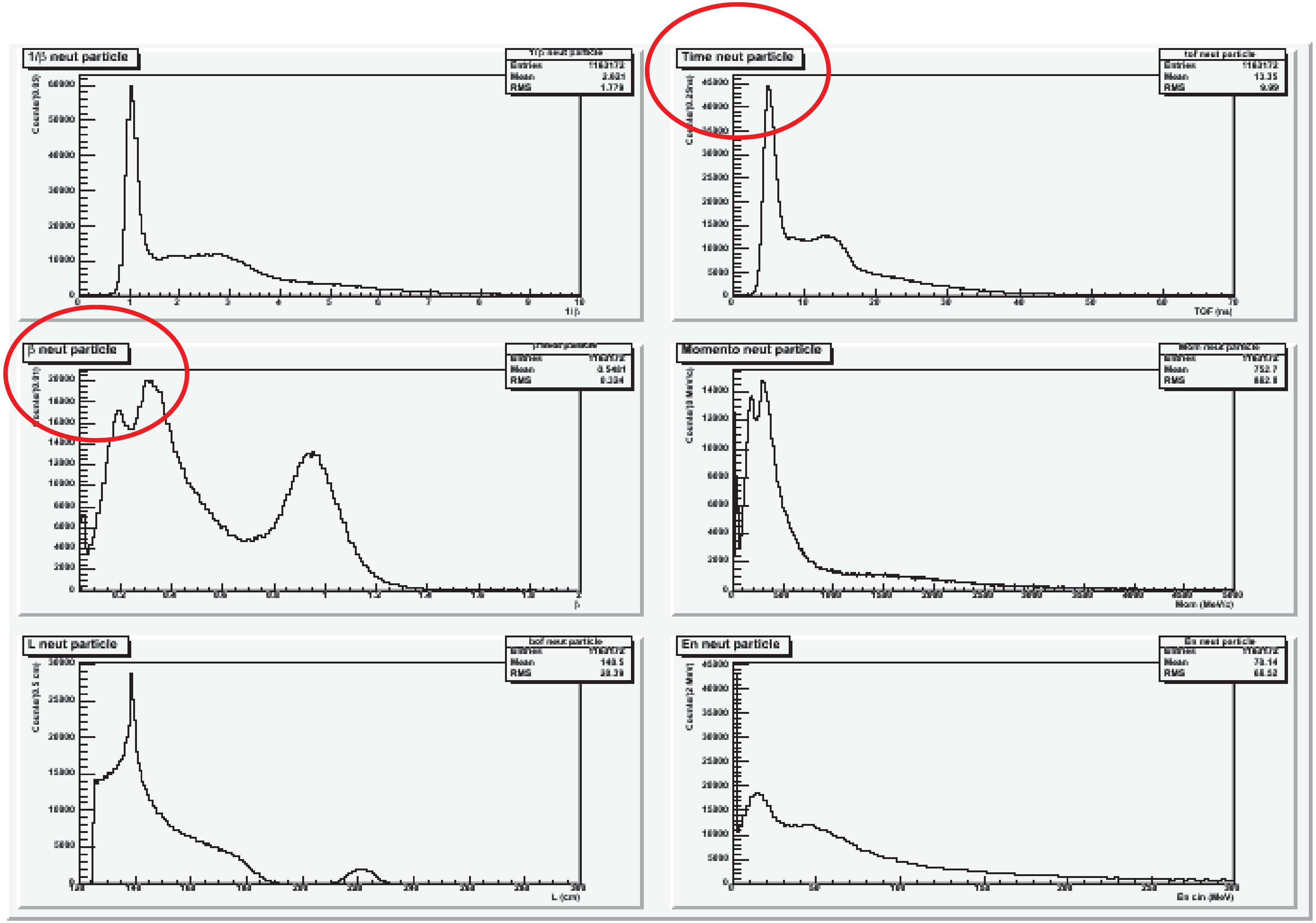
  fissione





- Si riempie l'istogramma del # di FFs rivelati in corrispondenza di ogni E_n

$$\sigma_{xxx(n,f)} = \sigma_{235_{ENDF}(n,f)} \cdot \frac{Y_{xxx}}{Y_{235}} \cdot \frac{m_{235}}{m_{xxx}} \cdot \frac{A_{xxx}}{A_{235}}$$


1/β neut particle
Time neut particle
TOF (ns)
β neut particle
Momento neut particle
Mom (MeV/c)
L neut particle
L (cm)
En neut particle
En cin (MeV)