CARATTERIZZAZIONE DI UN RIVELATORE A DIAMANTE SINTETICO POLICRISTALLINO

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Rivelatori a diamante a disposizione

- Dispositivi planari, 5x5 mm^2, 500 μm di spessore
- elettrodi:
  - una singola pad metallica che copre tutta la superficie di una faccia (5x5 mm^2) e 4 strips sull'altra faccia
    - leggiamo il segnale sul lato del singolo elettrodo

- 1 rivelatore single crystal
  - efficienza ideale
  - prestazioni note
  - utilizzato per calibrazione assoluta
- 2 rivelatori in diamante poly-crystal - da utilizzare per ottenere un segnale di trigger
- 1 rivelatore poly-crystal da testare DUT (Devise Under Test)

GOAL OF THE EXPERIENCE

- 1) Measurement of the CCD of the DUT (poly-crystalline CVD diamond)
- 2) Comparison of the spectrum of a mip with a spectrum of highly ionising charge charged radiation

- Distribution of Q(measured) for mip and non-mip charged particles

- CCD Definition:
  - Charge Collection Distance:
    - CCD = track_length x Q(measured)/Q(generated)
    - track_length = DUT thickness for normally incident ionization radiation
    - Q(generated) = |e| x N(ionizations)
    - Q(measured) = induced signal calibrated in charge

SYNTHETIC DIAMOND (SINGLE CRYSTAL)

Property	Diamond	Silicon
Atomic number	6	14
Density, [g$\cdot$ cm^{-3}]	3.5	2.32
Band gap, [eV]	5.5	1.1
Resistivity, [$\Omega$$\cdot$cm]	$> 10^{12}$	10^5
Breakdown field, [V$\cdot \mu m^{-1}$]	1000 [107]	30 [108]
Electron mobility, [cm$^2 \cdot$ V$^{-1} \cdot$ s^{-1}]	1300∼4500	1500
Hole mobility, [cm$^2 \cdot$ V$^{-1} \cdot$ s^{-1}]	2050∼3800	500
Electron saturation velocity, [μm$\cdot$ns^{-1}]	141	100
Hole saturation velocity, [μm$\cdot$ns^{-1}]	96	100
Dielectric constant	5.6	11.7
Energy per e-h pair, [eV]	13∼16 [111]	3.6
Av.min.ionizing signal per 100 m	3600	8000

Table 6.1: General properties of sCVD diamond compared with silicon in normal conditions

for a mip, average n. of ion pairs
produce in 100 micron

When the particles go through the diamond, the electron-hole pairs are generated due to the ionization processes. If a bias voltage is applied to the electrodes on the surfaces of the diamond, then an electric field is formed in the bulk of diamond. Under the force of this electric field, the electrons and holes start to move and this movement induces the current on the electrodes as described by the Shockley-Ramo theorem. Once the charge-carriers have arrived at the electrodes, the signals are "over" [115].

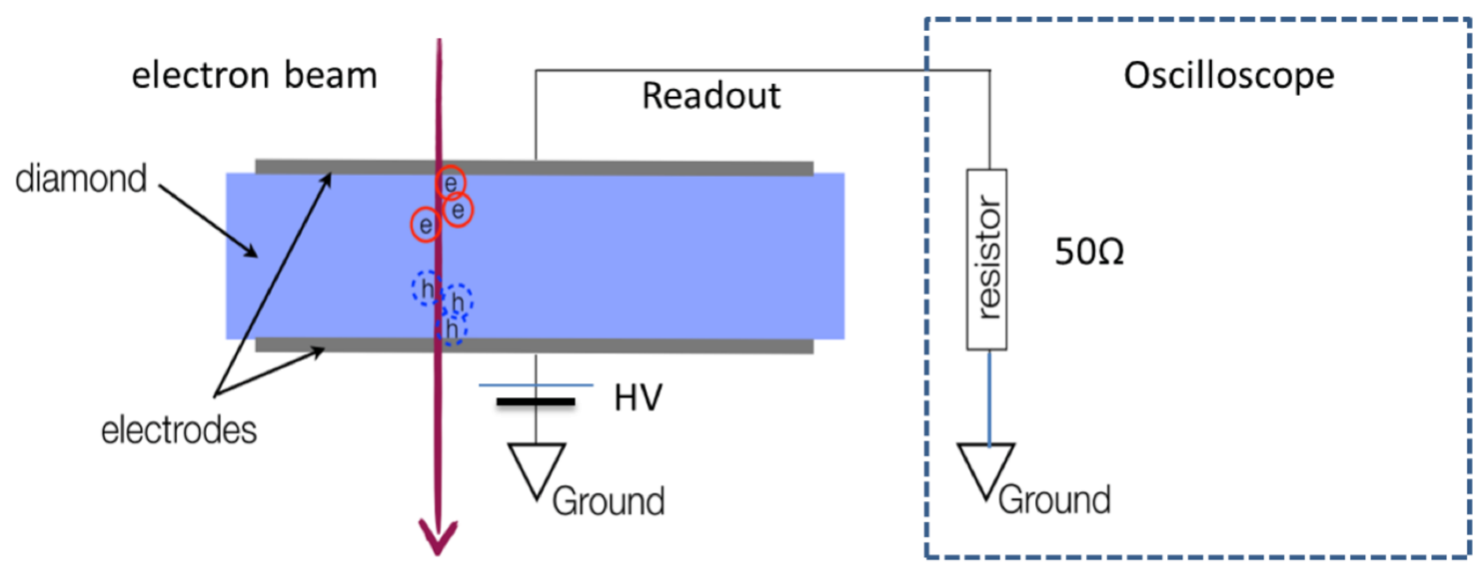


Figure 6.3: Charge generation and collection scheme

The charge collection distance (d_c) is considered as a common figure of merit to characterise the manufacture quality of a diamond, especially for the pCVD diamond, the d_c of which is usually much less than the thickness of the diamond (d). However, for the sCVD diamond, the d_c can sometimes be equal to or even greater than the thickness of the diamond.

As the average minimum-ionizing particle generates about 3600 electron-hole pairs in each 100 μm of diamond, the total charge generated (Q_{gen}) can be calculated as Q_{gen}= 36×d, where d is in μm scale.

If the electrons and holes get trapped or recombined after separating by the distance d_c, then the charge collected by the electrodes (Q_{coll}) can be expressed as:

$$Q_{coll} = Q_{gen} \times \frac{d_c}{d} \tag{6.2}$$

Knowing the charge collected, the charge collection distance can be calculated as:

for a mip, average n. of ion pairs produce in 1 micron

$$d_c = \frac{Q_{coll}}{36\ e^-/\mu m} \tag{6.3}$$

The ratio between the total generated charge and the charge collected by the electrodes is defined as the charge collection efficiency (CCE):

$$CCE = \frac{Q_{coll}}{Q_{gen}} \tag{6.4}$$

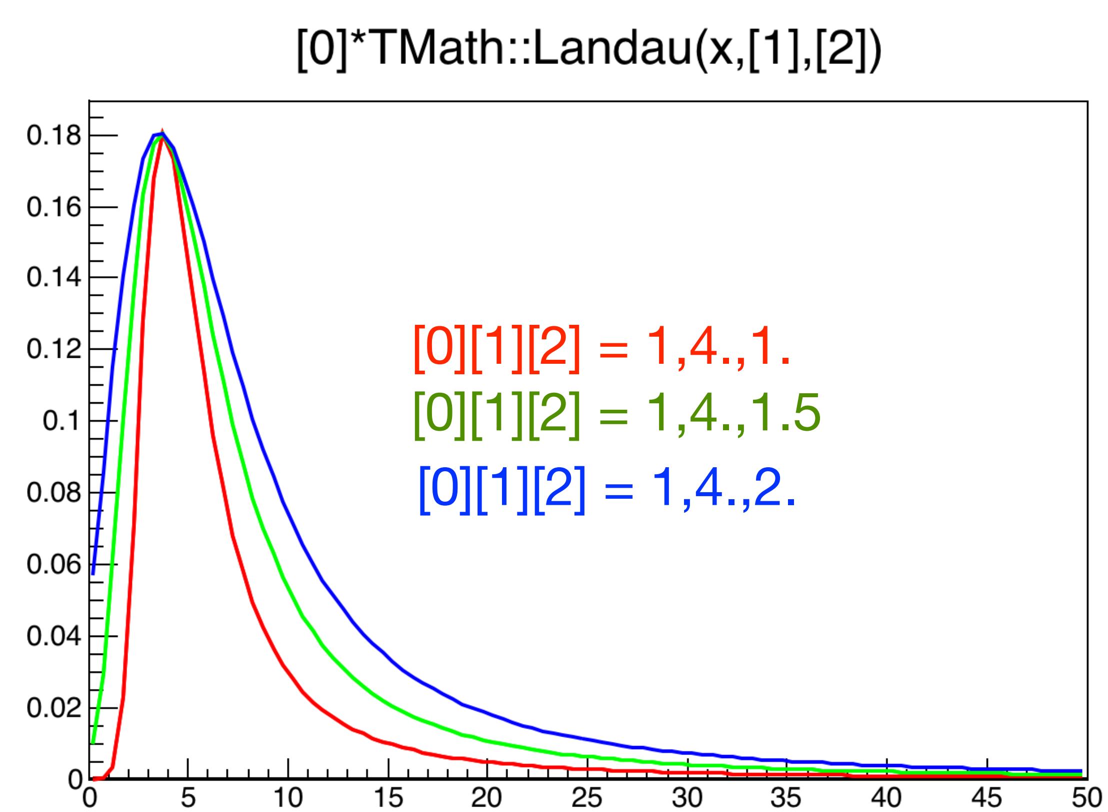
Combining Eq. 6.2 and Eq. 6.4, d_c can then be written as:

$$d_c = d \times CCE \tag{6.5}$$

The CCE has a dependence on the applied bias voltage and it can be measured using the beta sources as described in Section 6.2.1.

HOW CONCEPTUALLY

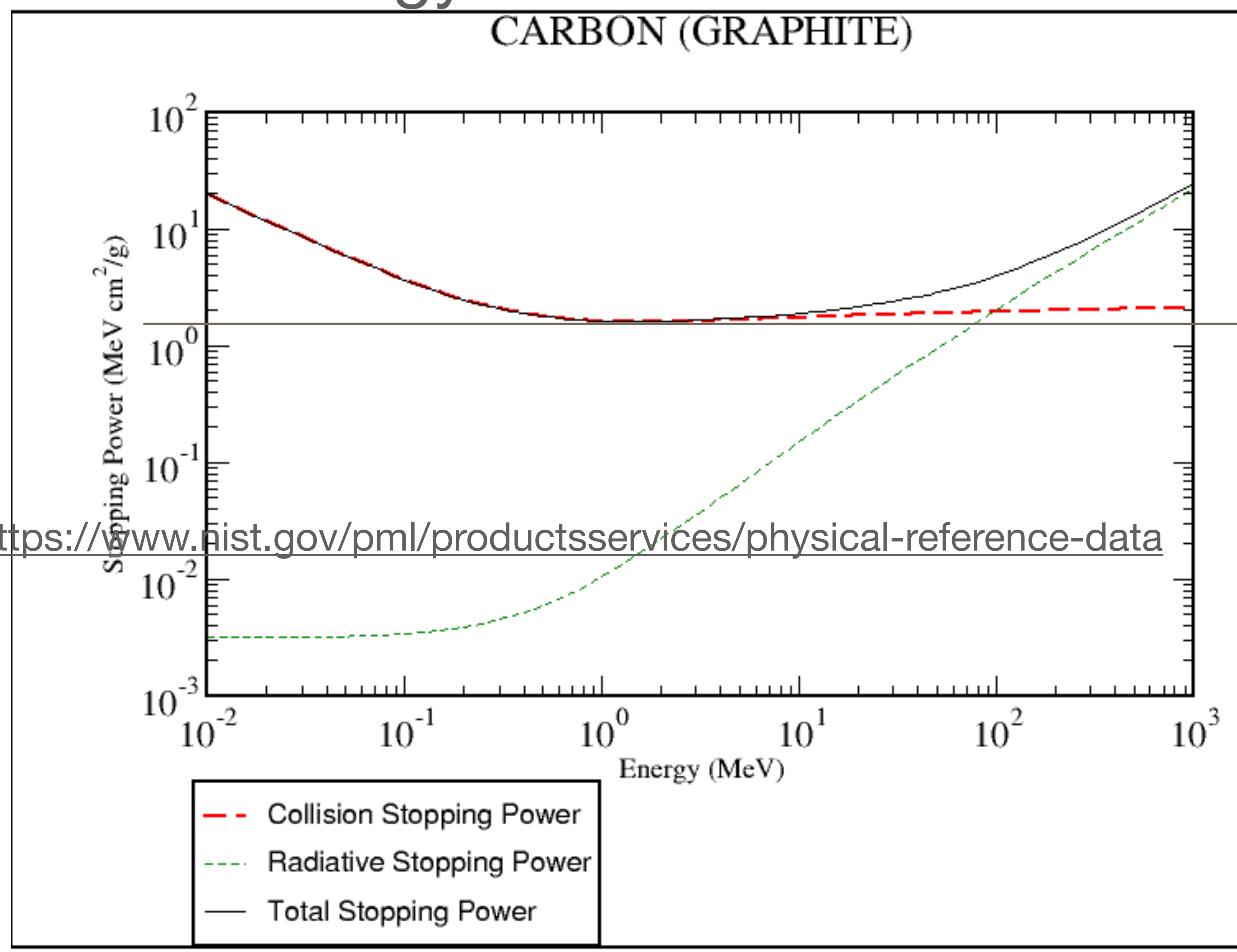
- let's assume to have mono-energetic ionising particles (E > Emip) traversing the ideal diamond normally
- one can estimate, using data from literature, the <ΔE> lost in a 500 μm path in diamond (3600 ionizations/100um)
- the measured E_{loss} will fluctuate with a Landau-Vavilov distribution: m.p.E_{loss} (mpv = [1]) and FWHM (related to the second parameter [2]) will parameterize the shape of the distribution (in TMath::Landau)
- <ΔE> or mpv can be related to the average or mpv of the signal charge integral or signal pulse height distributions (amplifier gain and noise and readout input impedence define how the energy loss and the signal parameter are related)
- the signal parameter distribution can be measured on the DUT with the same readout chain (same calibration) => the known Eloss in the ideal detector, provides the absolute calibration.



HOW TO EMULATE A M.I.P. ?

- One step back:
  - how to select a sample of ionizing particles releasing (in average) always the same amount of energy ?
  - no need of monoenergetic particles, a mip is enough
    - for E > E_{mip} average Eloss is very stable
- muons from cosmic rays ?
  - too low rate
  - a not too well defined sample (E distribution)

Energy loss of electrons in C

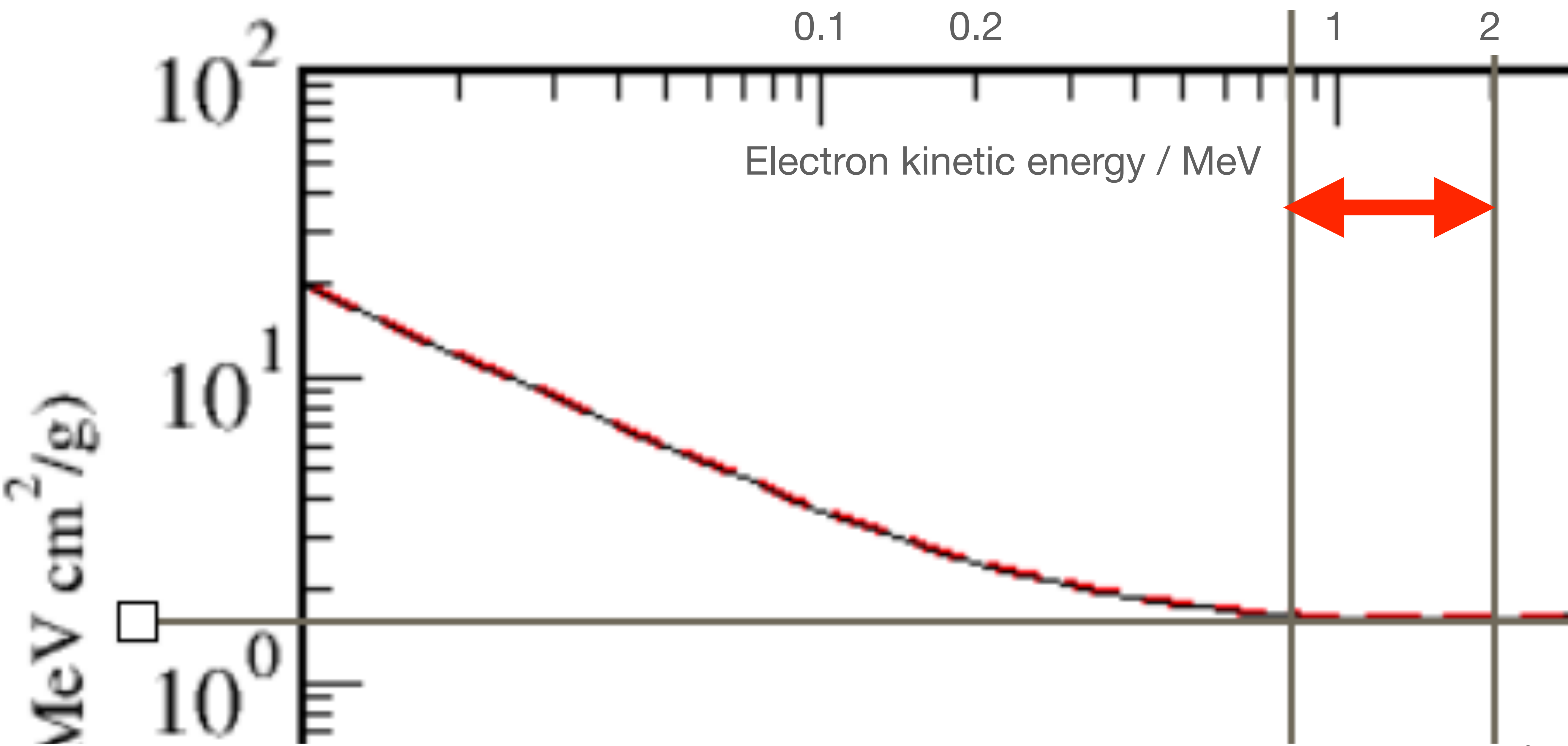


https://www.nist.gov/pml/productsservices/physical-reference-data

- E(kinetic) > 800KeV => e- is a m.i.p. in Carbon/Diamond/Graphyte

Electron energy loss in Carbon

- zoom on the region 800 KeV - 2 MeV
  - no appreciable variation of the mean E_{Loss}

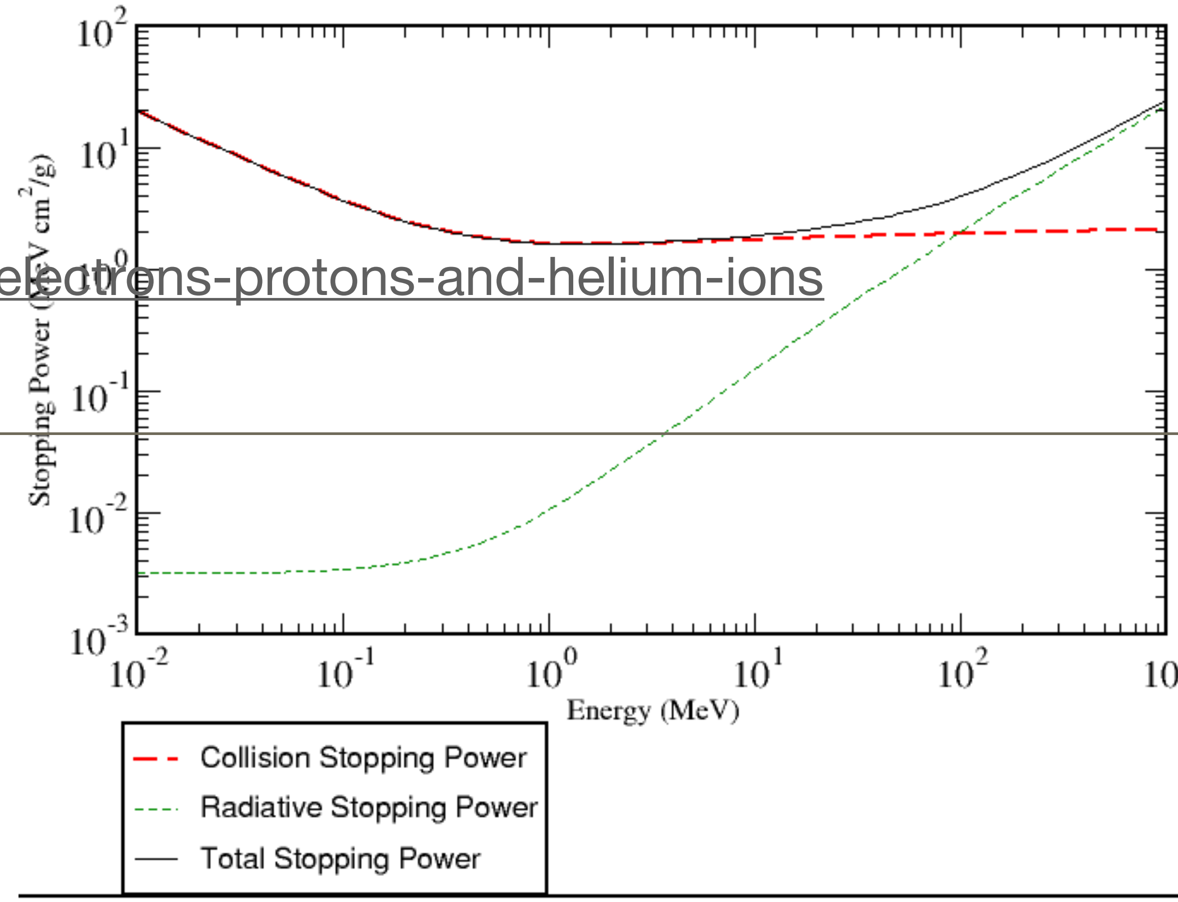


How to emulate a m.i.p. ?

https://www.nist.gov/pml/productsservices/physical-reference-data
- radiation/dosimetry data

https://www.nist.gov/pml/stopping-power-range-tables-electrons-protons-and-helium-ions

Energy loss of electrons in C



Contents:

1. Introduction
2. ESTAR: Stopping Powers and Ranges for Electrons
3. PSTAR and ASTAR: for Protons and Helium Ions (alpha particles)
4. References
5. Appendix: Significance of Calculated Quantities

Access the Data:

1. Electrons
2. Protons
3. Helium Ions

- E(kinetic) > 800KeV => e- is a m.i.p. in Carbon/Diamond/Graphyte

NIST
National Institute of Standards and Technology
Physical Meas. Laboratory

estar stopping-power and range tables for electrons

The ESTAR program calculates stopping power, density effect parameters, range, and radiation yield tables for electrons in various materials. Select a material and enter the desired energies or use the default energies. Energies are specified in MeV, and must be in the range from 0.001 MeV to 10000 MeV.

Help   Text version   Material composition data

Select a common material:

6: Carbon, Amorphous (density2.0g/cm3)

or enter a unique material

- ◉ **Graph stopping power:**
  - ☑ Total Stopping Power
  - ☐ Collision Stopping Power
  - ☐ Radiative Stopping Power
- ○ **Graph density effect parameter**
- ○ **Graph CSDA range**
- ○ **Graph radiation yield**
- ○ **No graph**

Additional Energies (optional):

Use energies from a file*

Choose File no file selected

or

Use energies entered below (one per line)

☑ Include default energies

Note: Only stopping powers and the density effect parameter will be calculated if additional energies are used.

Submit Reset

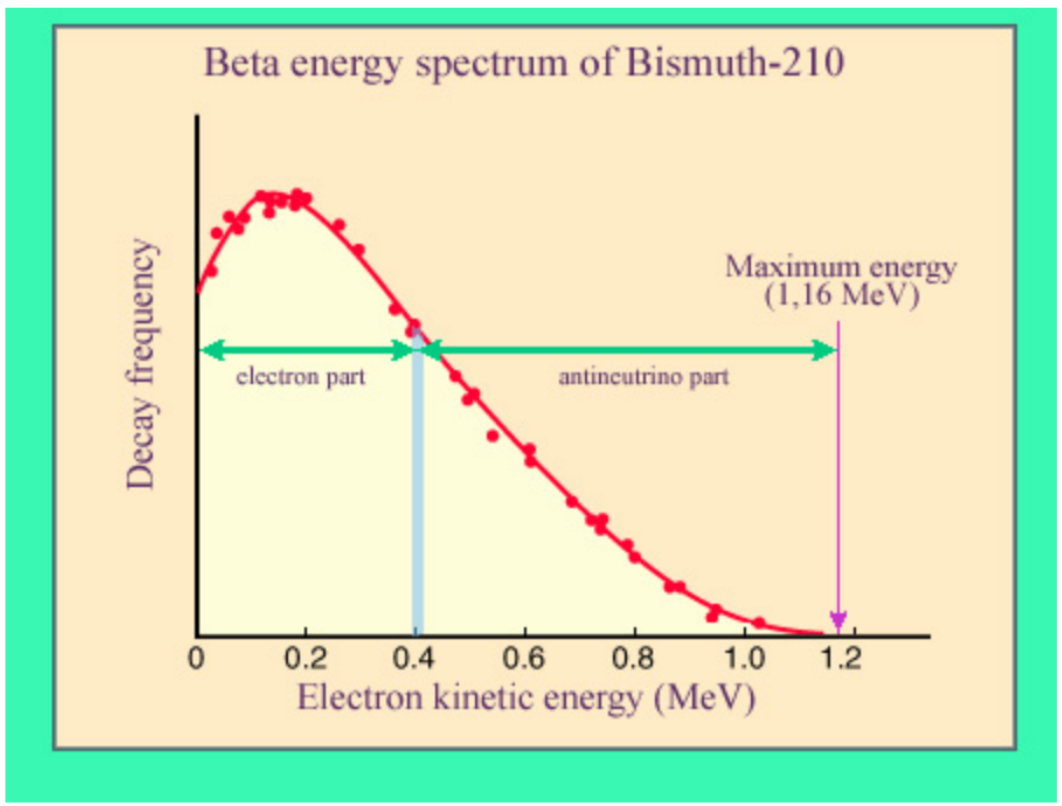
ELECTRON SOURCES: RADIOACTIVE SOURCE

- ^{90}Sr is a product of nuclear fission. It is present in significant amount in spent nuclear fuel and in radioactive waste from nuclear reactors and in nuclear fallout from nuclear tests. For thermal neutron fission as in today's nuclear power plants, the fission product yield from U-235 is 5.7%, from U-233 6.6%, but from Pu-239 only 2.0%.
- ^{90}Sr undergoes β– decay with a half-life of 28.79 years and a decay energy of 0.546 MeV distributed to an electron, an anti-neutrino, and the yttrium isotope ^{90}Y, which in turn undergoes β– decay with half-life of 64 hours and decay energy 2.28 MeV distributed to an electron, an anti-neutrino, and ^{90}Zr (zirconium), which is stable. *Note that ^{90}Sr/Y is almost a pure beta particle source; the gamma photon emission from the decay of ^{90}Y is so infrequent that it can normally be ignored.*

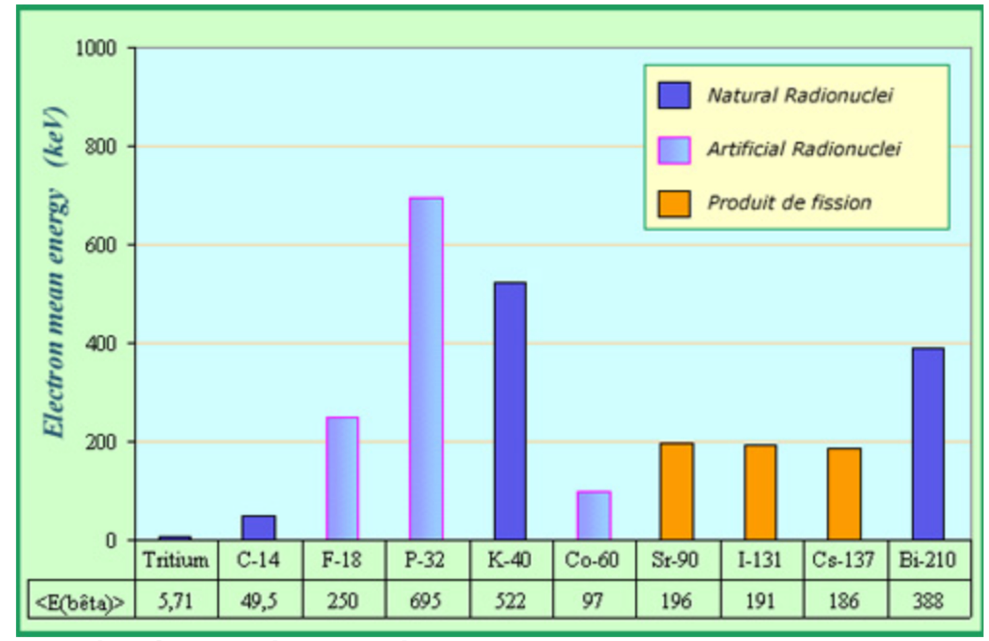
Strontium-90	Full table
General	
Name, symbol	Strontium-90, ^{90}Sr
Neutrons	52
Protons	38
Nuclide data	
Natural abundance	syn
Half-life	28.79 years
Decay products	^{90}Y
Decay mode	**Decay energy**
Beta decay	0.546 MeV

SPECTRUM OF ELECTRONS FROM BETA DECAYS

- max $E_{electron}$ given by the Q value of the decay
- neutrino E is Q-$E_{electron}$



Beta spectrum : a sharing of energy:
In a beta decay like that of a bismuth-210 nucleus, the decay energy is shared between the nucleus, an electron and an antineutrino. As the nucleus, is much more massive than the two others (its mass is 320 000 times the mass of the electron) it takes away a negligible amount of kinetic energy. The energy is therefore shared between the electron and the antineutrino. The antineutrino escaping detection, one observe only the beta electron with a variable energy. The figure display the characteristic energy repartition of beta electrons – the beta spectrum – of the bismuth-decay
©IN2P3



Examples of average beta energies
Since the energy of beta electrons emitted by a radionucleide. is not unique, one compares generally radionucleides by their average beta energies. These energies vary considerably : for instance, the average energy of beta emitted by tritium is a hundred times lower than that of phosphorus-32.beta. The average energies are below 1 MeV, much lower than those of alpha particles (usually above 4 MeV).
©IN2P3

The prevalence of low energy beta electrons is beneficial for radiological protection, because low energy electrons are easier to stop. In radiological protection, one is more interested in the average energy of electrons than by their maximum energy. This average energy varies within wide proportions, ranging from 5.69 keV in the case of tritium to 695 keV in the case of phosphorus-32 a powerful beta emitter.

Compared to alpha particles, the energies of beta electrons are much lower, below 1 MeV in most of the cases while the energies of alpha particles are always above 4000 keV (4 MeV). The lifetimes (half-lives) are much shorter, with the exception of potassium-40.

A beta decay often comes with the emission of a gamma-ray due to the desexcitation of the nucleus. This emission decreases the energy to be shared between the electron and the antineutrino. For instance, the available energy in the caesium-137 beta decay is 1176 keV, but in 95 % of the cases it is accompanied by the emission of a characteristic 662 kev gamma in which case the available energy is only 514 keV. The observed spectrum beta becomes the sum, in the proportions of 5% and 95%, of the two spectra corresponding to the modes without or with gamma.

ELECTRONS FROM A ^{90}SR SOURCE

- The decay energy Q is the mass difference dm between the parent and the daughter atom and particles

- beta- decay:
  - n -> p e- anti-ν_e
    - Q = 939.565 - 938.272 - 0.511 = 0.782 MeV
  - ^{90}Sr -> ^{90}Y e- anti-ν_e
    - Q=546 MeV -> the maximum energy of electrons from a ^{90}Sr decay is 0.546 MeV smaller than E_{mip};
    - the <E> of e- is 196 KeV
  - ^{90}Y -> ^{90}Zr e- anti-ν_e
    - Q = 2.28 MeV
    - the <E> of e- is 1 MeV

Main isotopes of yttrium

iso	NA	half-life	DM	DE (MeV)	DP
^{87}Y	syn	3.4 d	ε	–	^{87}Sr
			γ	0.48, 0.38D	–
^{88}Y	syn	106.6 d	ε	–	^{88}Sr
			γ	1.83, 0.89	–
^{89}Y	100%	is stable with 50 neutrons			
^{90}Y	syn *Z=39, N=51*	2.7 d	β−	2.28	^{90}Zr
			γ	2.18	–
^{91}Y	syn	58.5 d	β−	1.54	^{91}Zr
			γ	1.20	–

Standard atomic weight (A_r) 88.905 84(2)[1]

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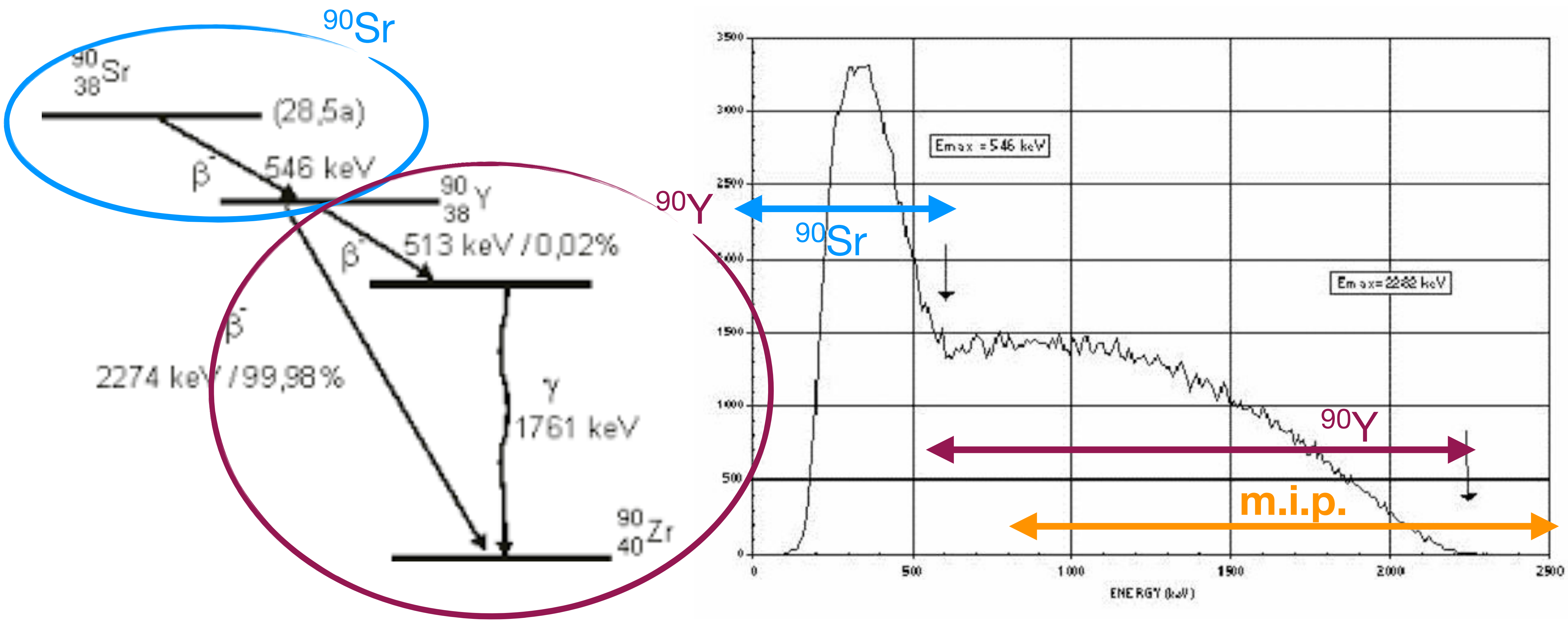
Zirconium stable Z=40, N=50

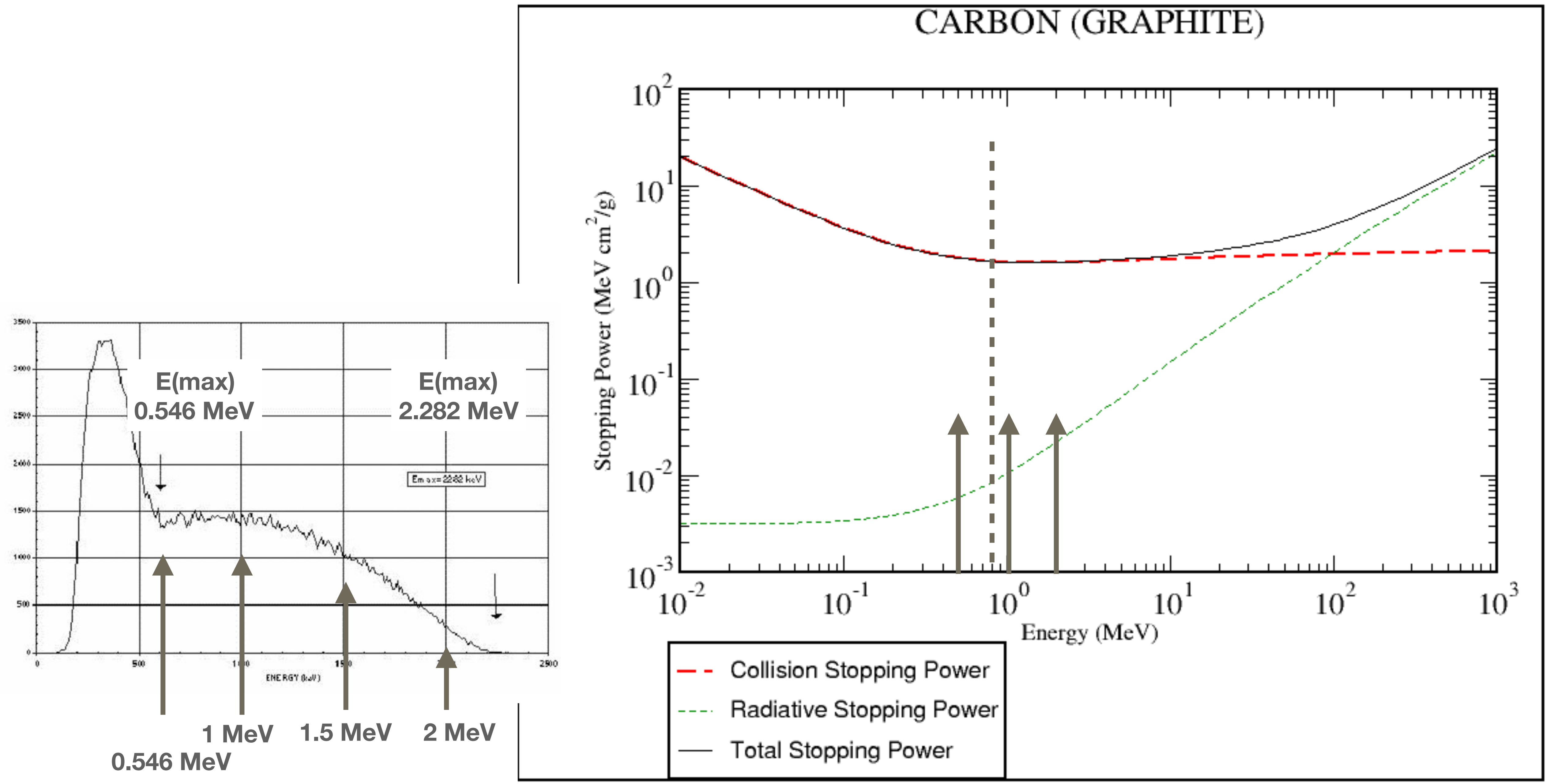
Zirc

ELECTRON SPECTRUM IN ^{90}SR



- after cutting electrons with energies < 0.8 MeV in the e- spectrum of a ^{90}Sr source, we are left with a m.i.p. sample

ELECTRON SPECTRUM IN ^{90}SR



- E(kinetic) > 800KeV => e- is a m.i.p. in Carbon/Diamond/Graphyte

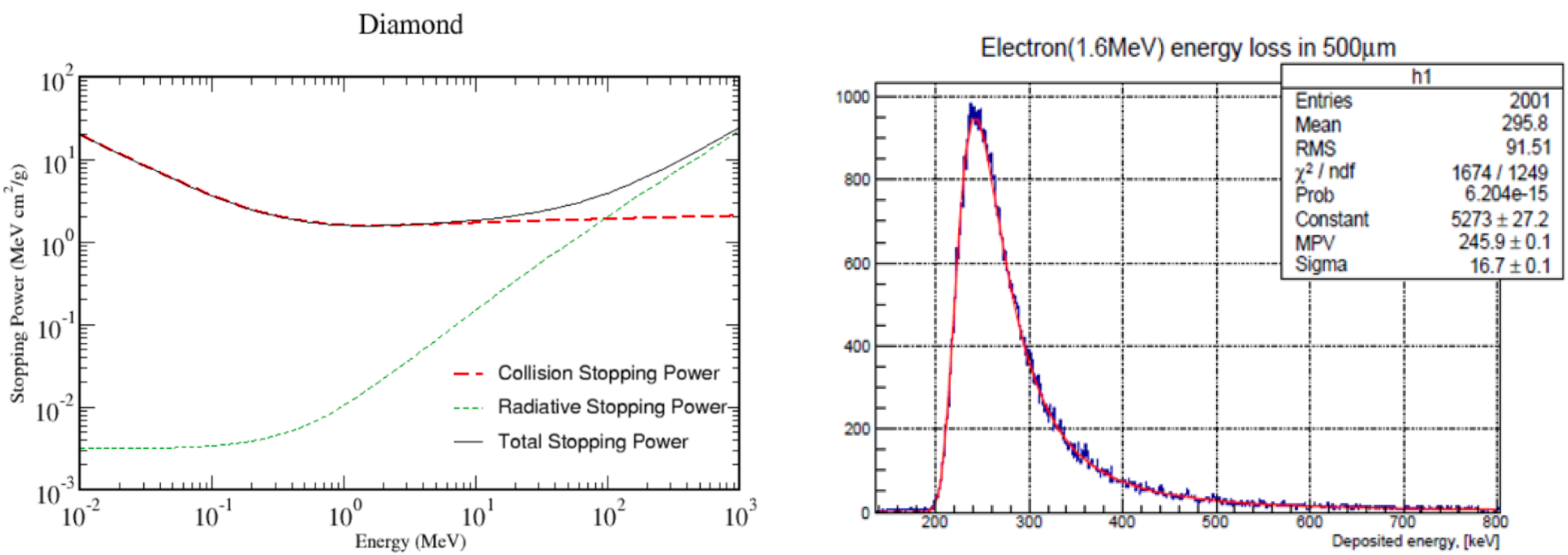
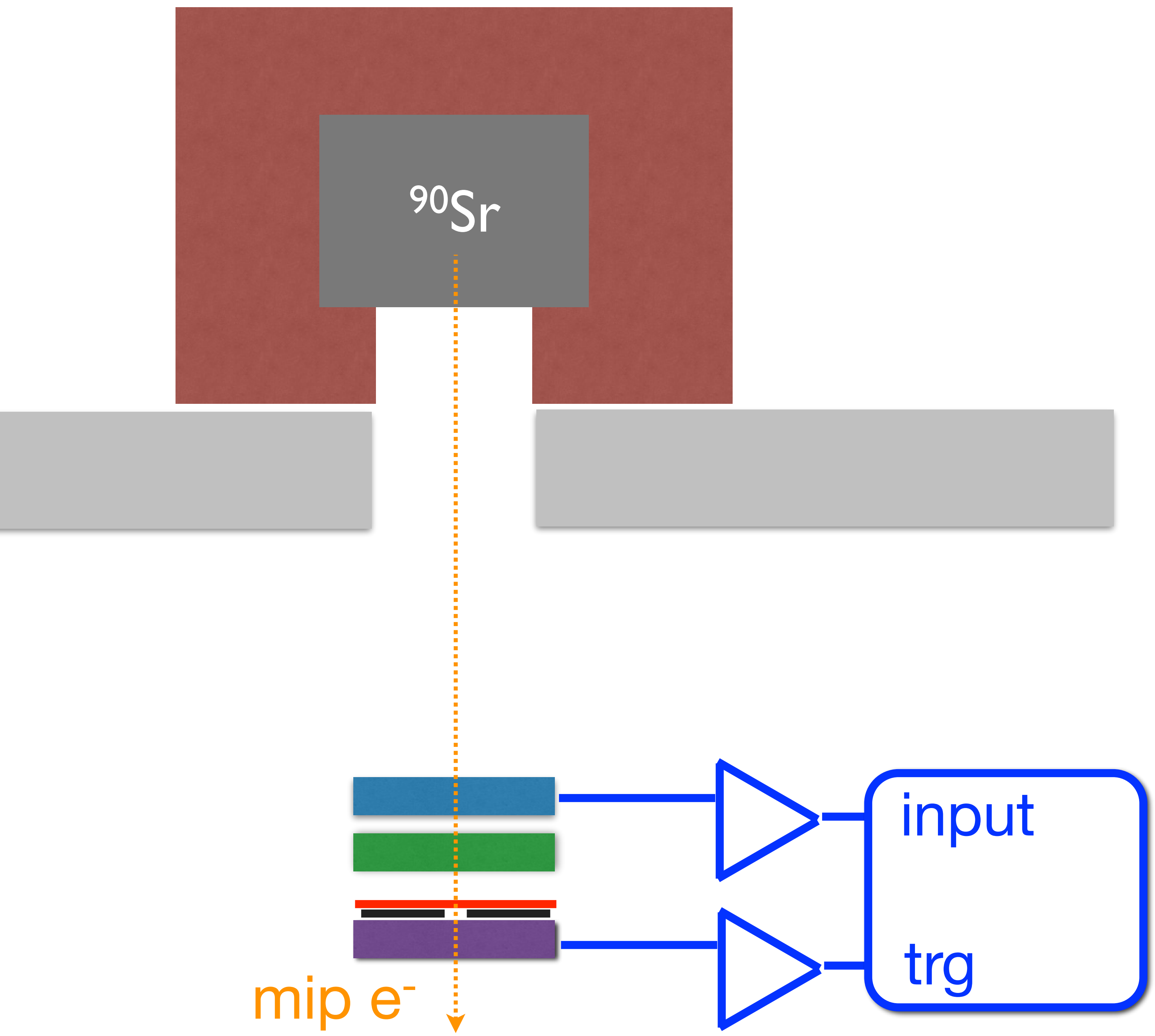


Figure 6.2: Left: the mean energy loss of an electron in diamond; Right: Landau distribution simulated using Geant4

- https://groups.lal.in2p3.fr/atf2/files/2015/05/Chapter6_v3.pdf

SETUP: MEASUREMENT MODE



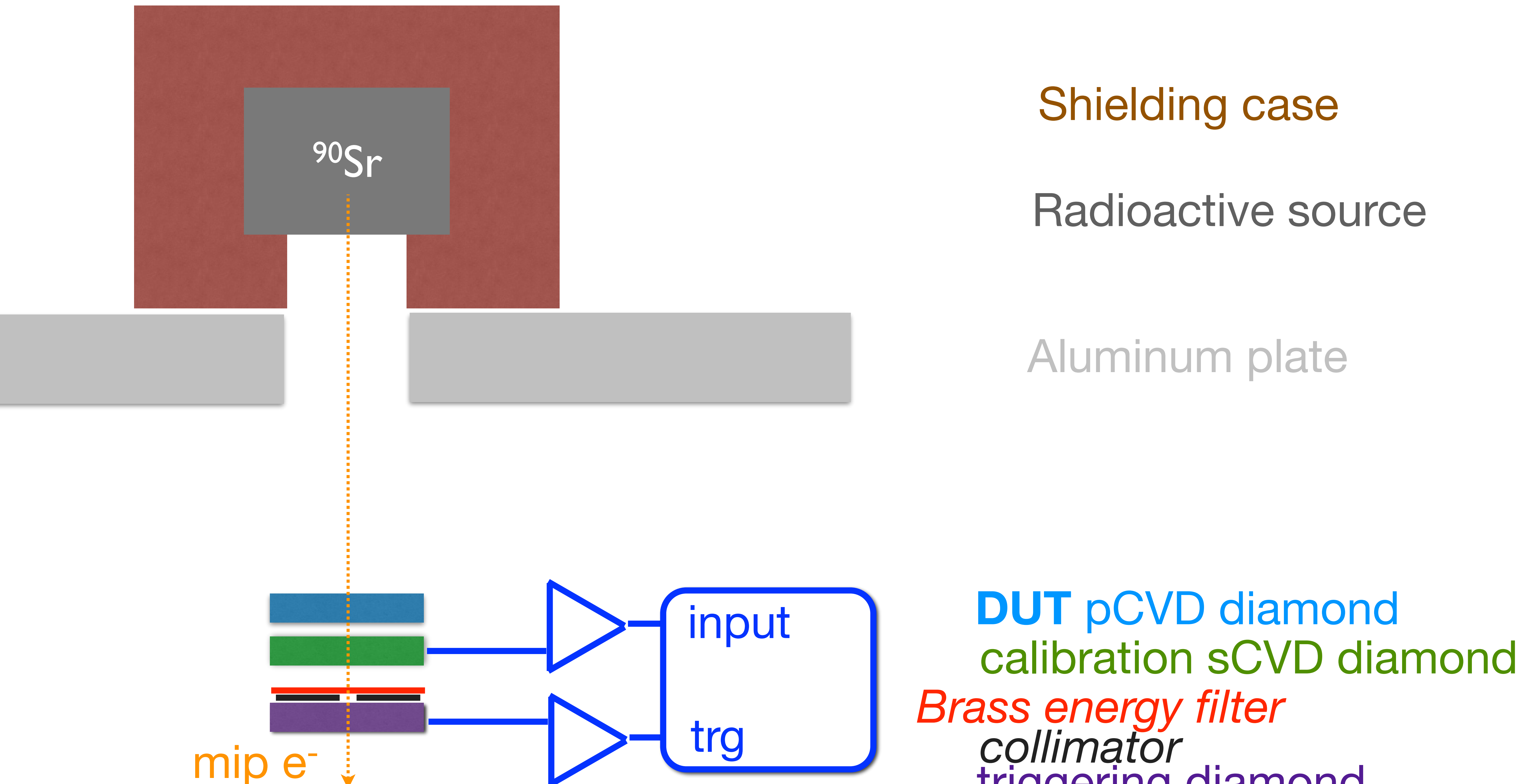
Shielding case

Radioactive source

Aluminum plate

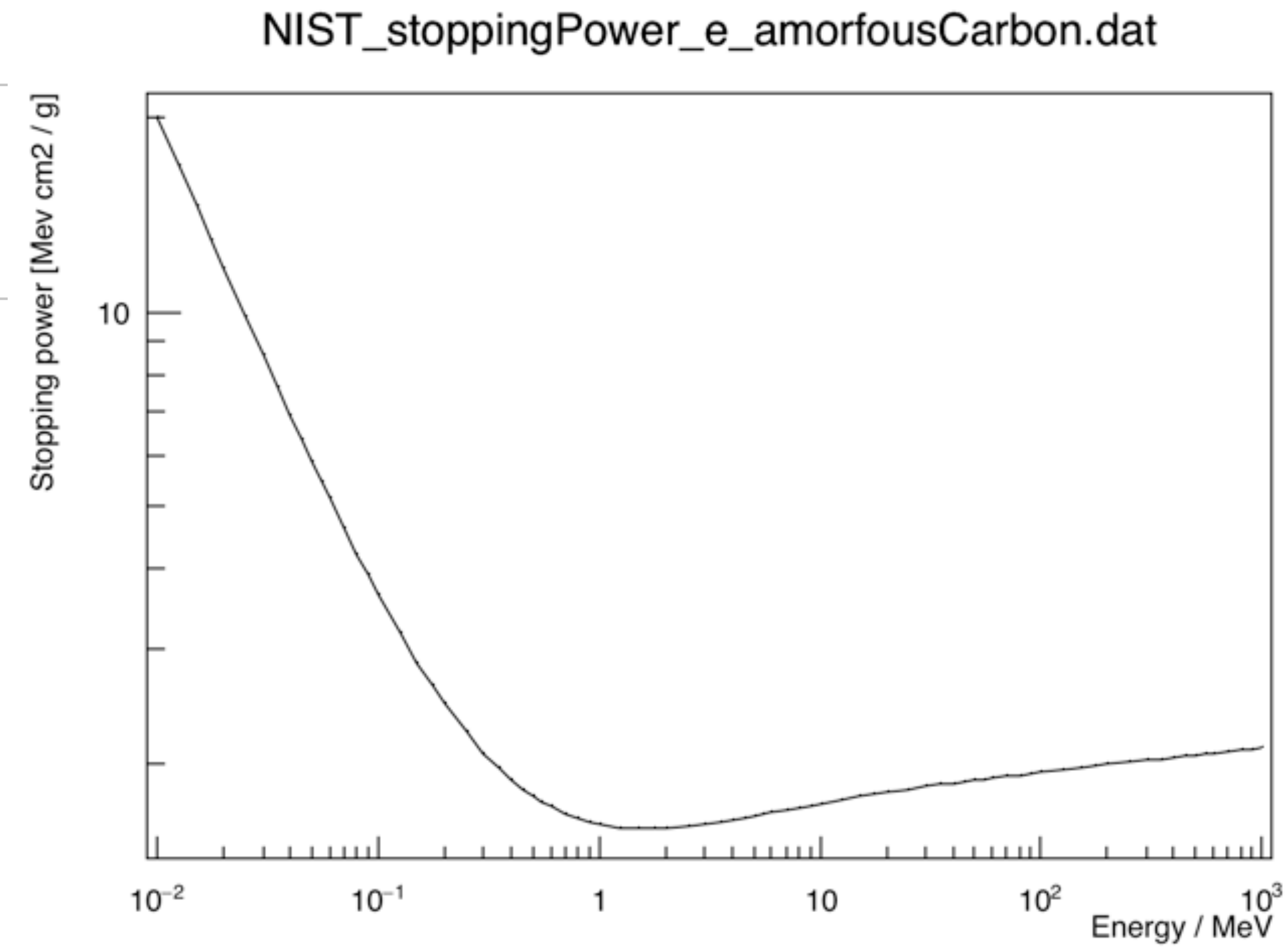
DUT pCVD diamond
calibration sCVD diamond
energy filter
collimator
triggering diamond

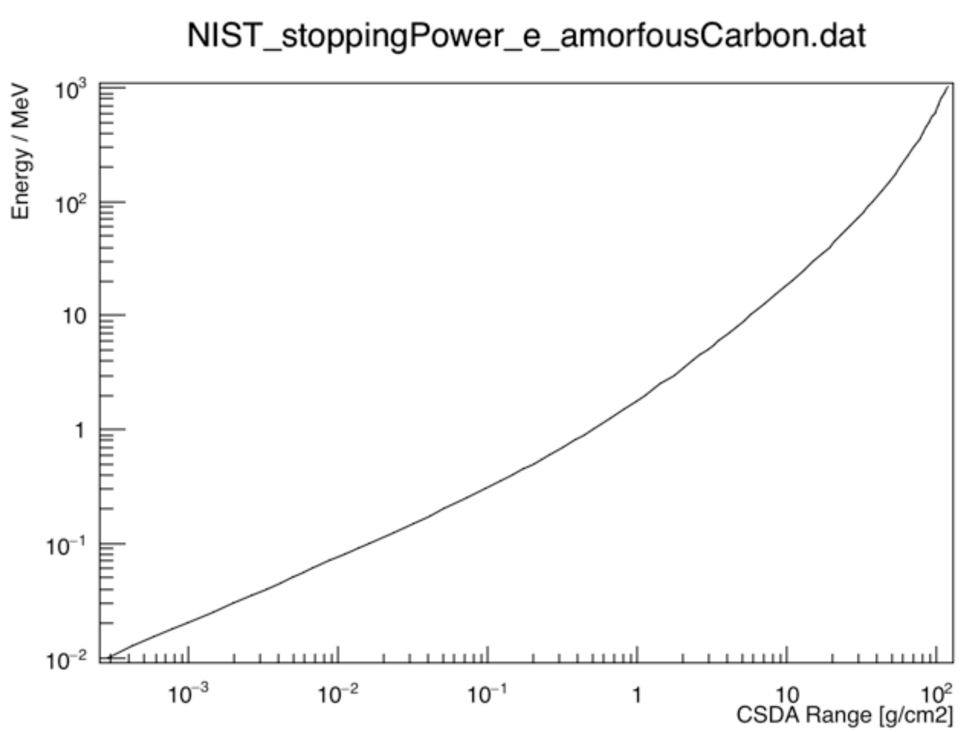
SETUP: CALIBRATION MODE

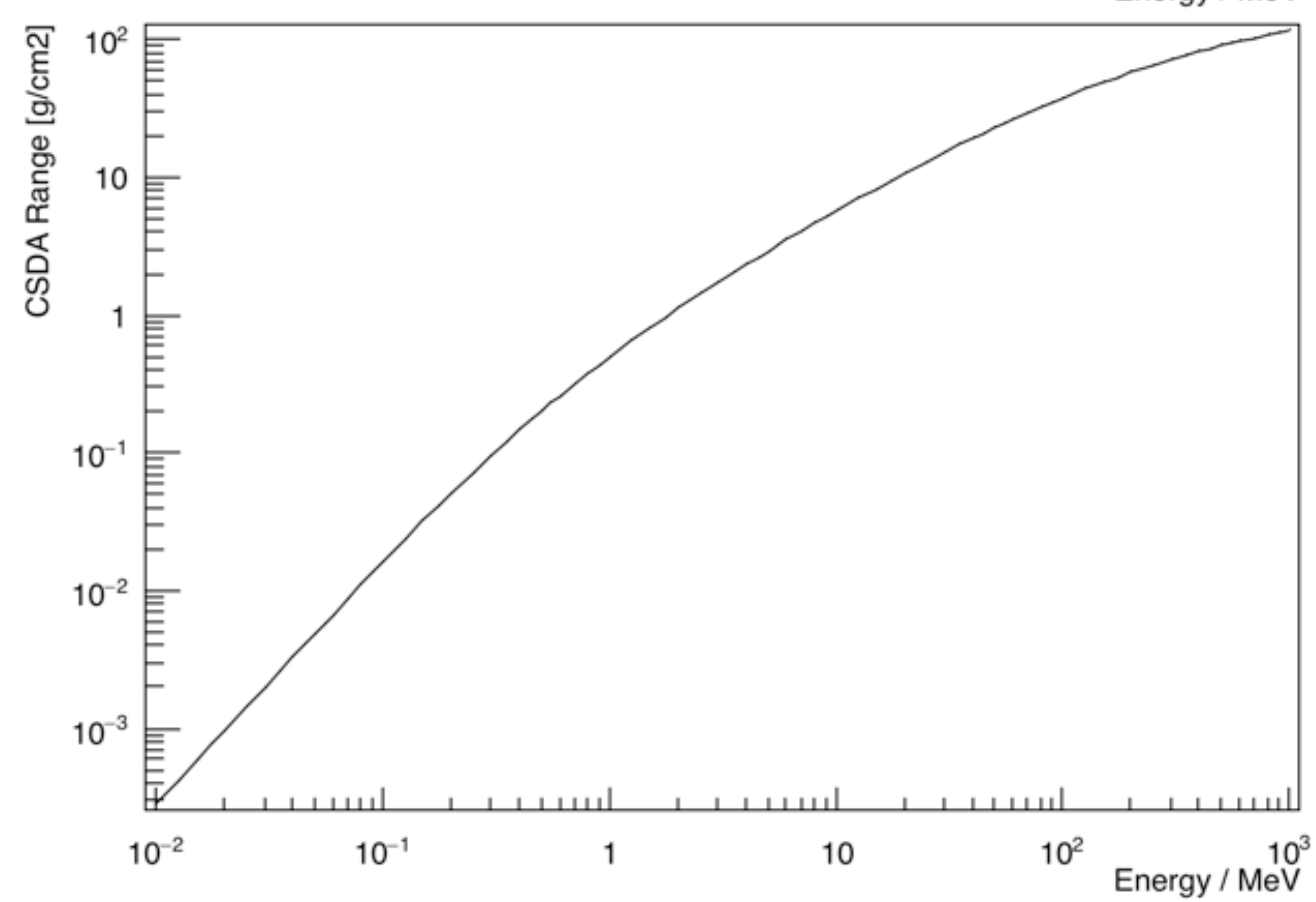


DIAMOND

- from ESTAR db







BRASS

- Brass (60% Cu 40% Zn);
- density = 8.5 g/cm3;
- http://physics.nist.gov/PhysRefData/St

Fill out the following form to define your unique material, or return to the **common material form**.

Help Text version

Material Name:

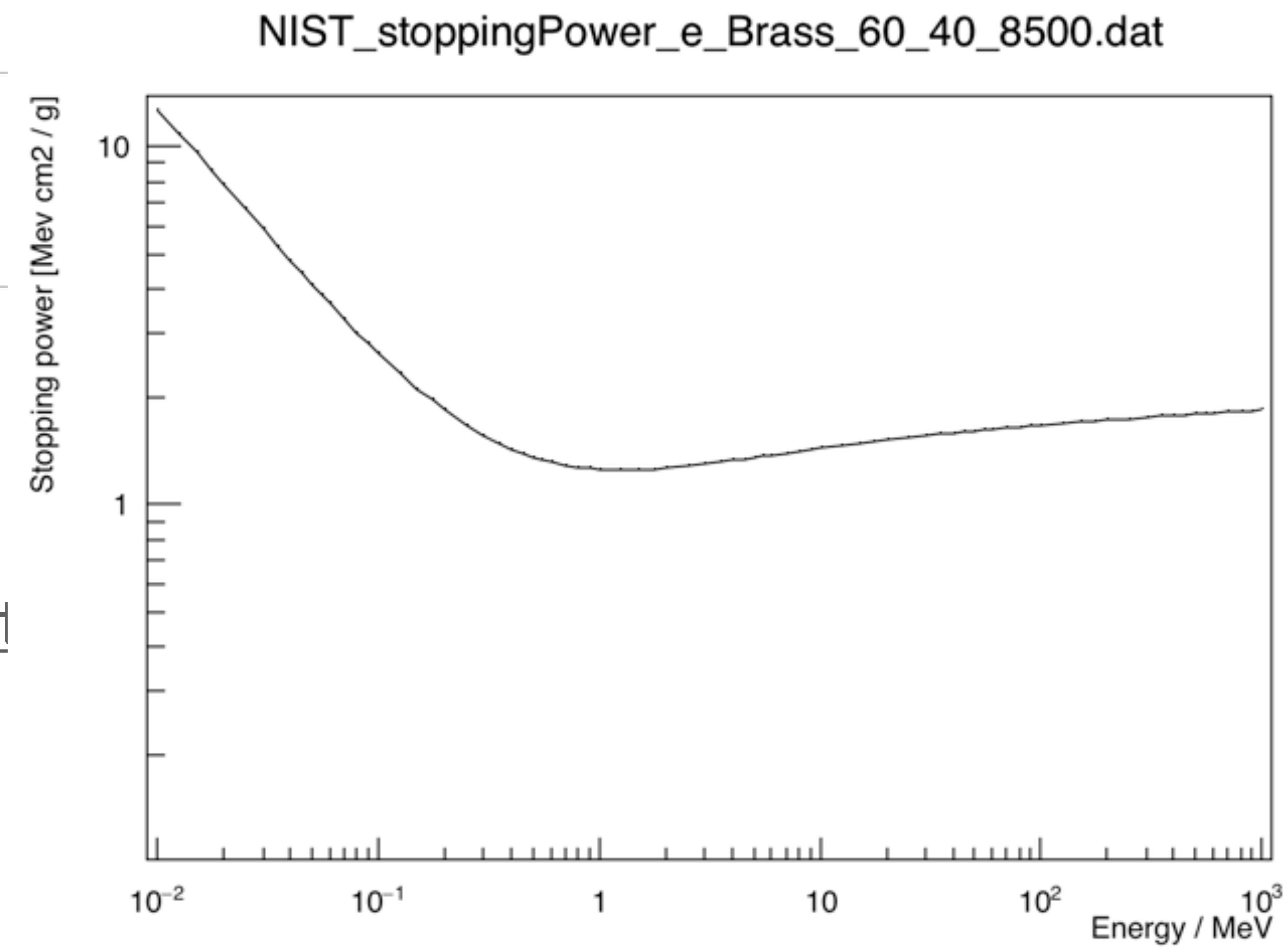
Density: (g/cm^3)

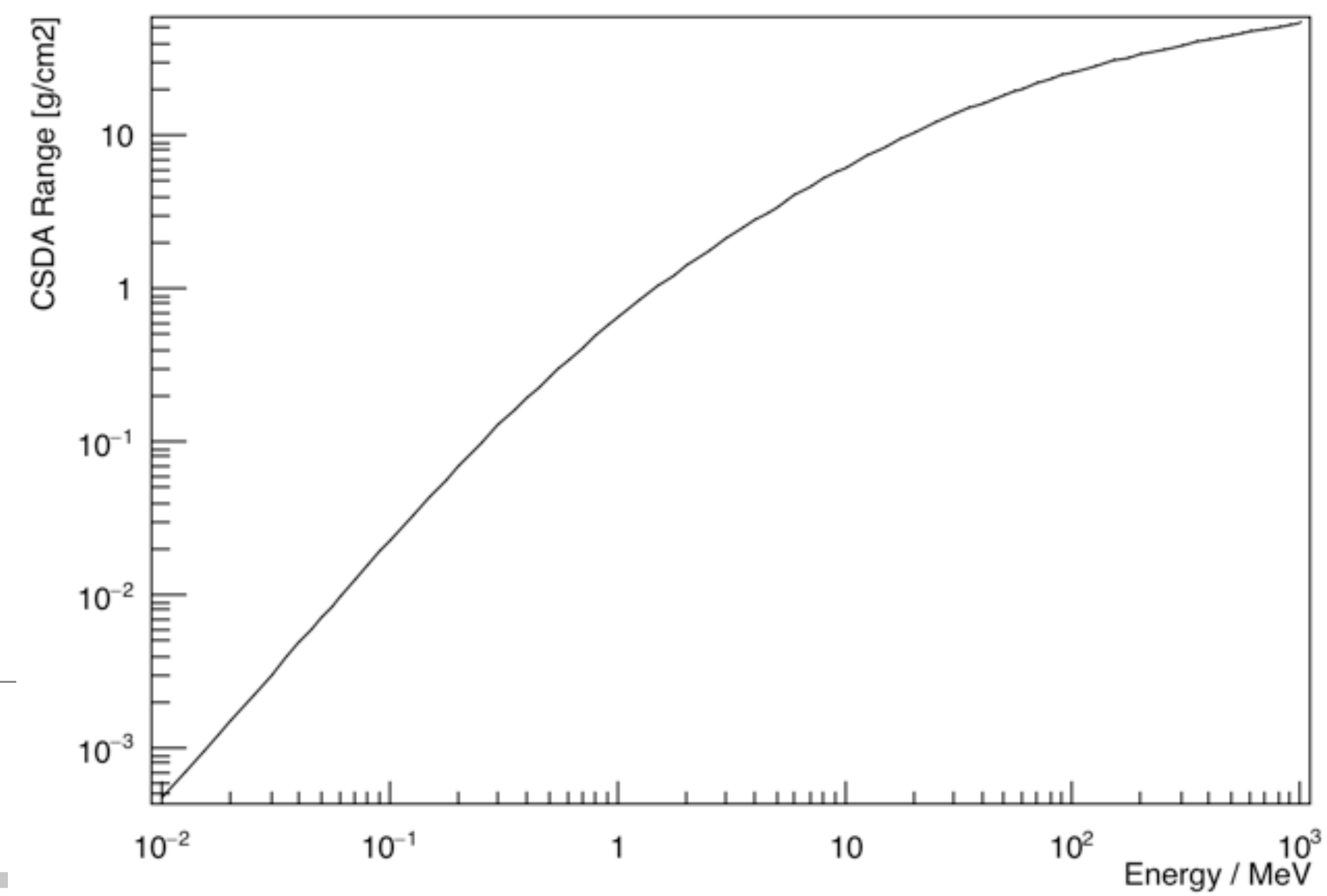
Enter the formulae and relative weights separated by a space for each item.
One compound or element per line. For example, salt water with 10 % (by weight) salt:

```
H2O 0.9
NaCl 0.1
```

Note: Weights not summing to 1 will be normalized.

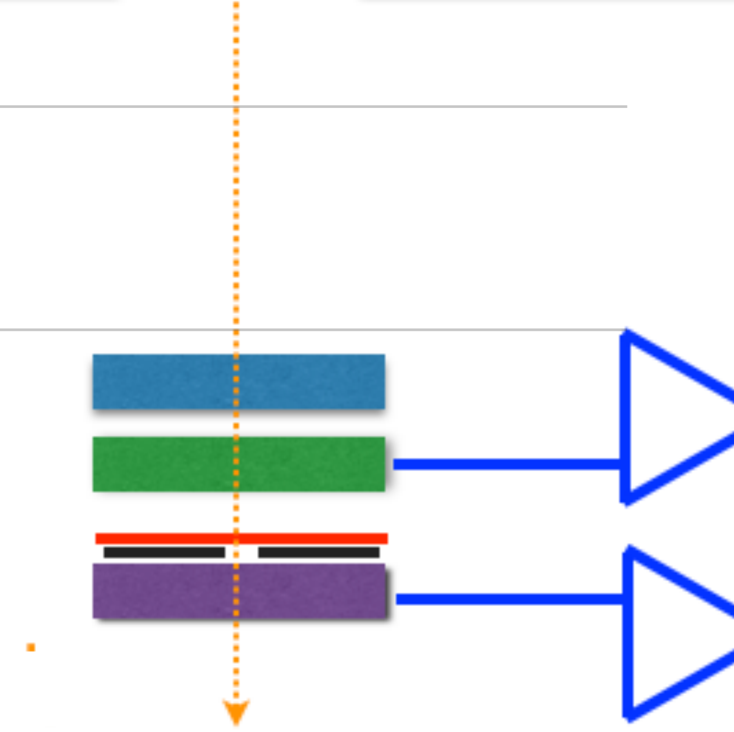
Submit Reset

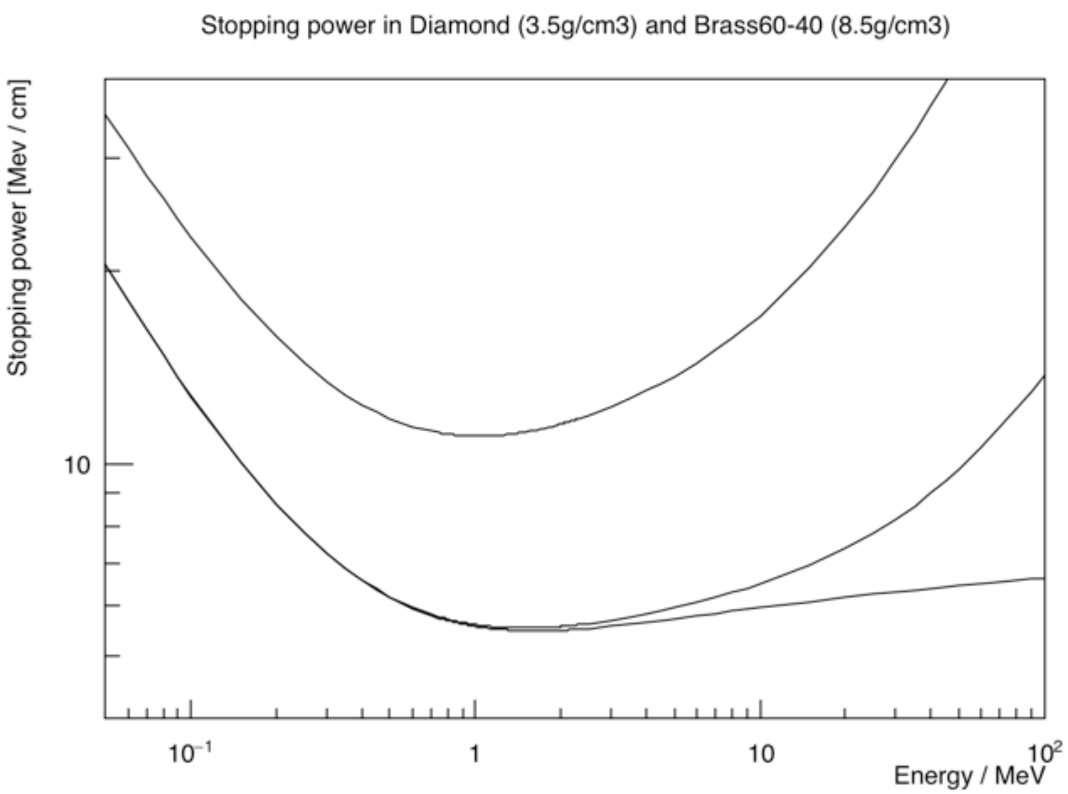




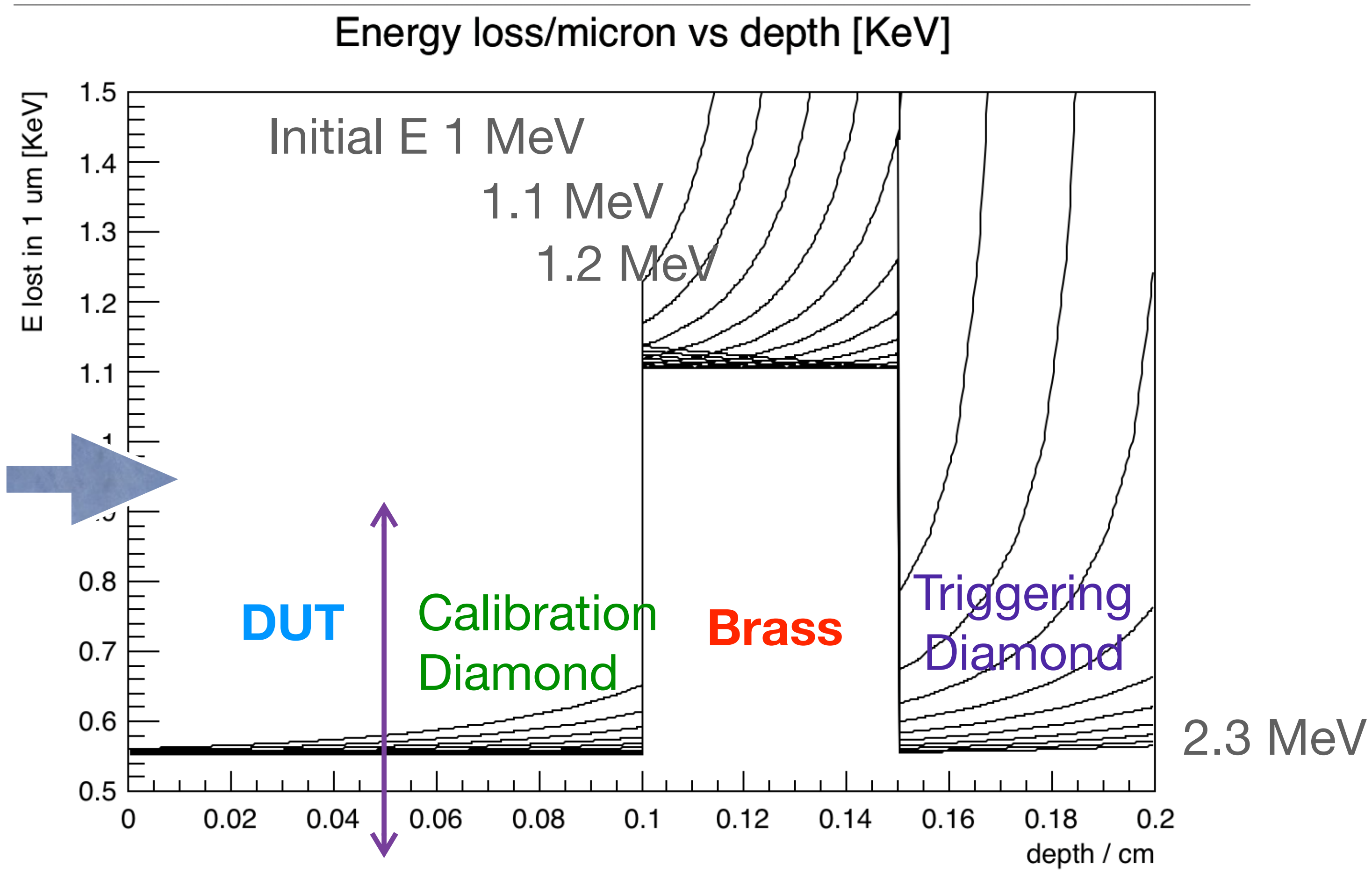
Cal. Diamond & DUT with Brass 0.05cm

Diamond
Density:
3.5 (g/cm³)
Mean Excitation Energy:
81.0 (eV)
Atomic Constituents:
C
1.





`StoppingPowerIntegrateIdEdx.C`



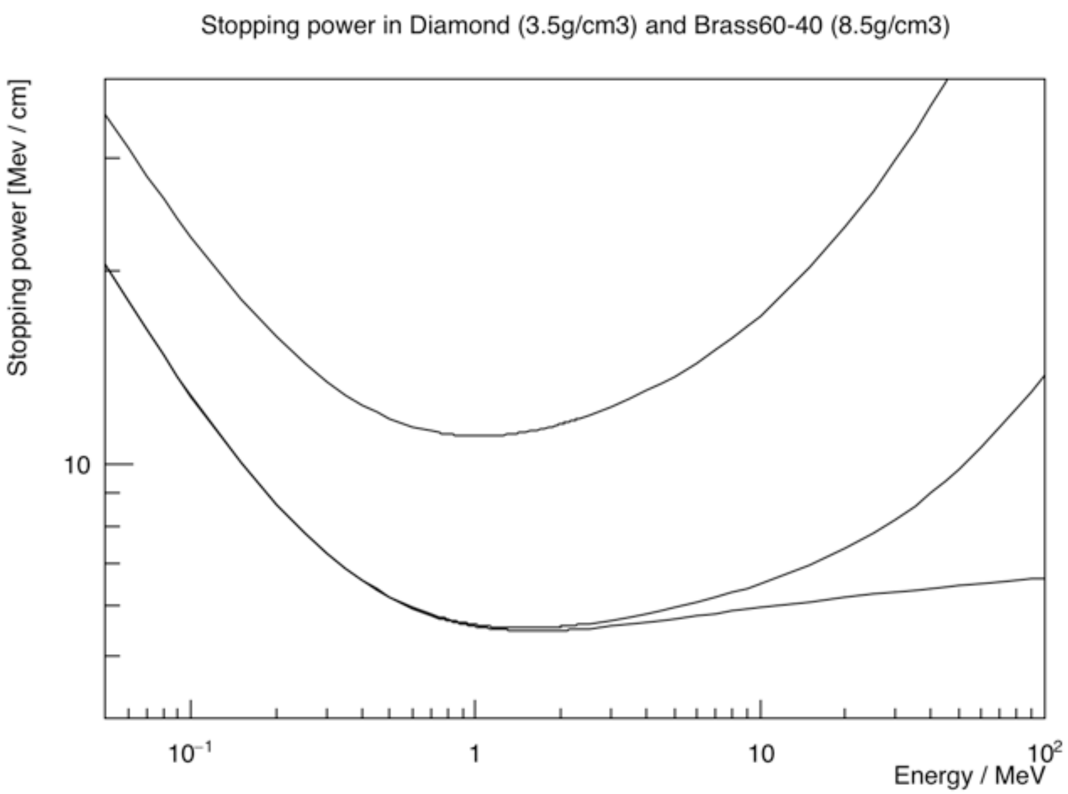
Estart 2.3 MeV … very good m.i.p.

Elost in DUT 0.27925 MeV
in Calib Diamond 0.277849 MeV
in Brass 0.560274 MeV Brass thickness = 0.05 cm
in Triggering Diamond 0.278285 MeV

elecron survives the materials of the setup; **final energy = 0.90 MeV**

1MeV e are absorbed in brass, no trigger

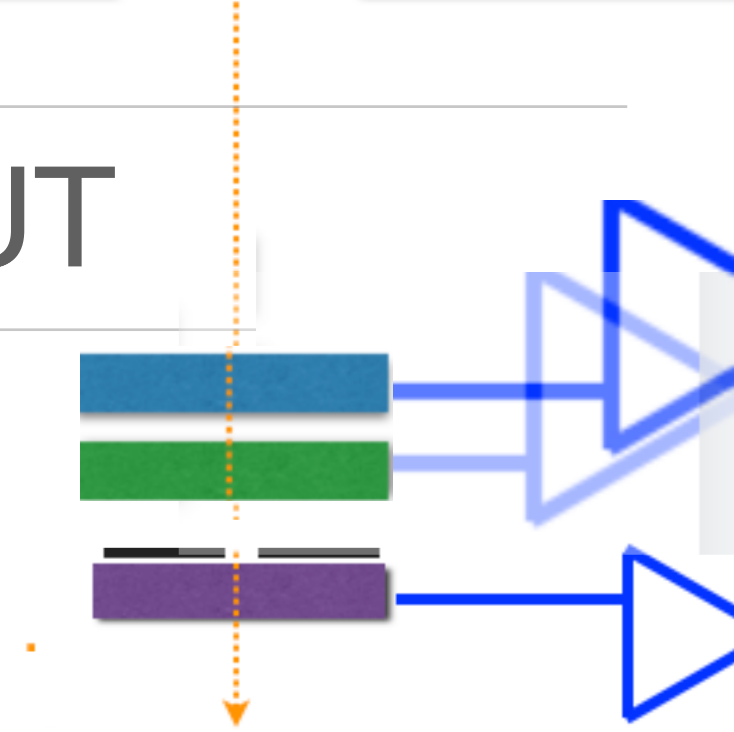
No Brass, Cal. Diamond & DUT

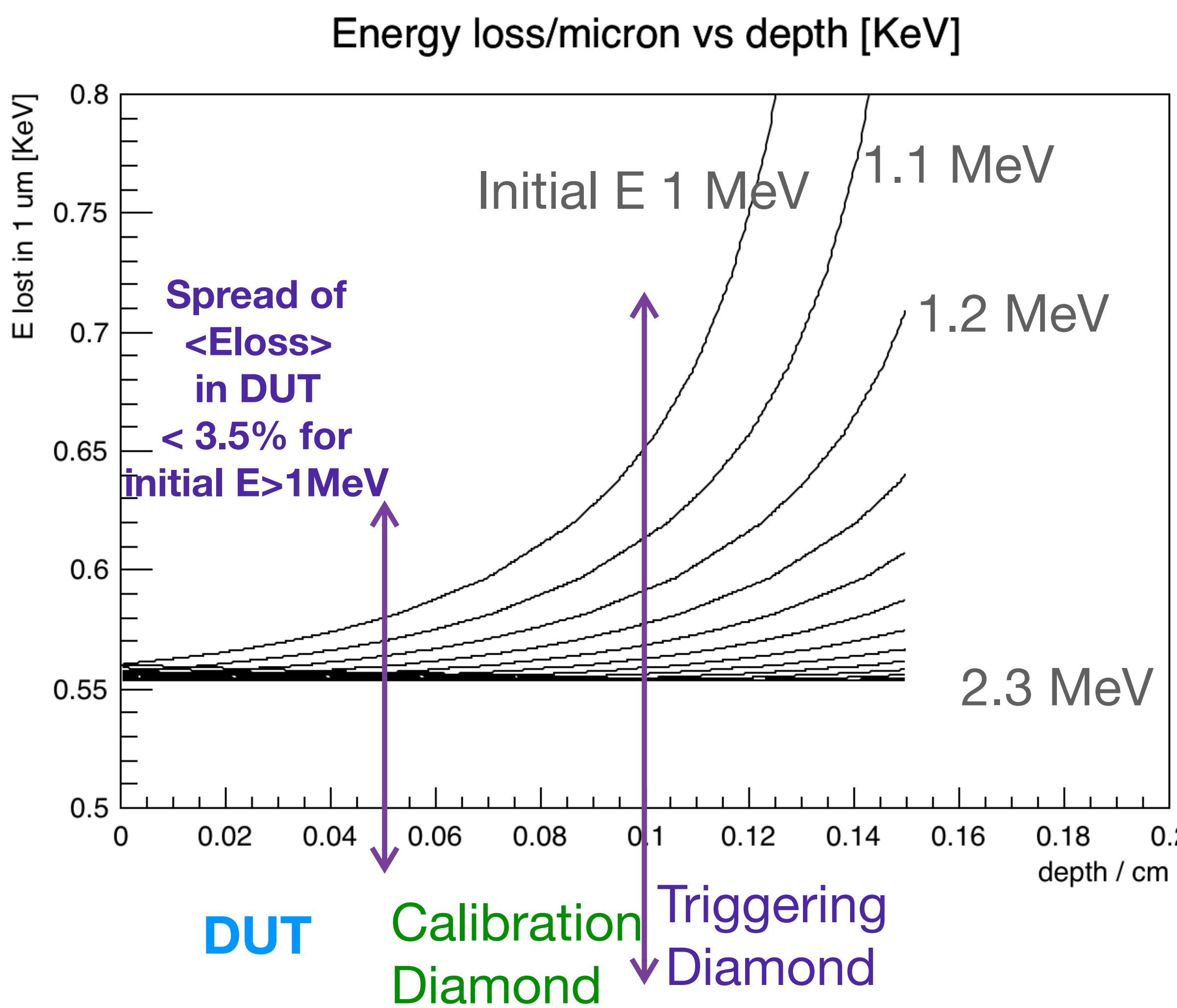


Estart 1 MeV
Elost in DUT 0.27925 MeV
in Calib Diamond 0.277849 MeV
in Brass 0. MeV Brass thickness = 0 cm
in Triggering Diamond 0.459445 MeV
Effective track length in triggering Diamond = 0.044 cm

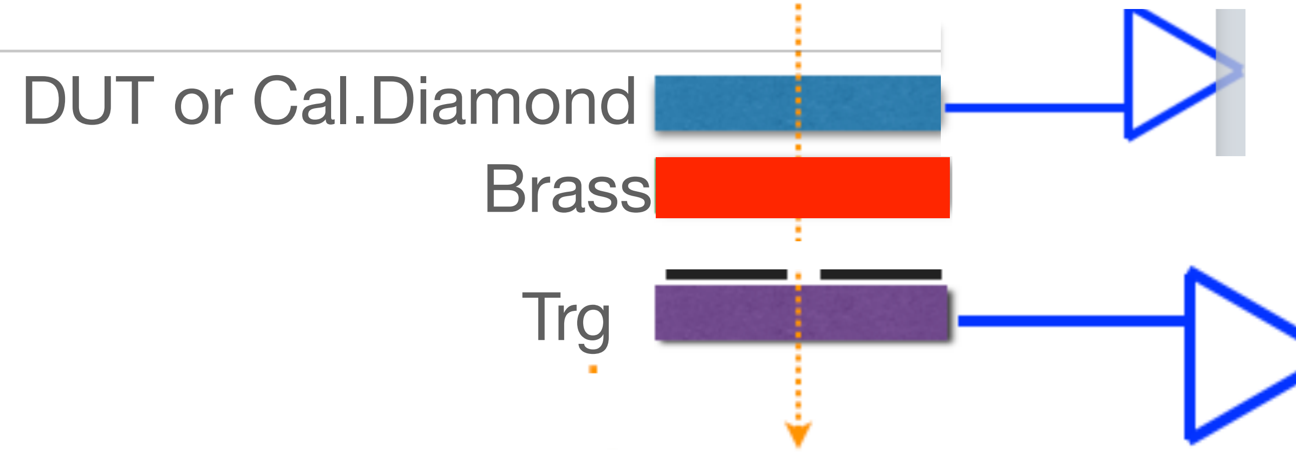
Estart	1 MeV
Estart - ElostinDUT	0.721 MeV
Estart - ElostinDUT - ElostinCD	**0.443 MeV**

Estart 2.3 MeV
Elost in DUT 0.27925 MeV
in Calib Diamond 0 MeV
in Brass 0.277849 MeV Brass thickness = 0 cm
in Triggering Diamond 0.275586 MeV
Energy after triggering Diamond = 1.46732 MeV

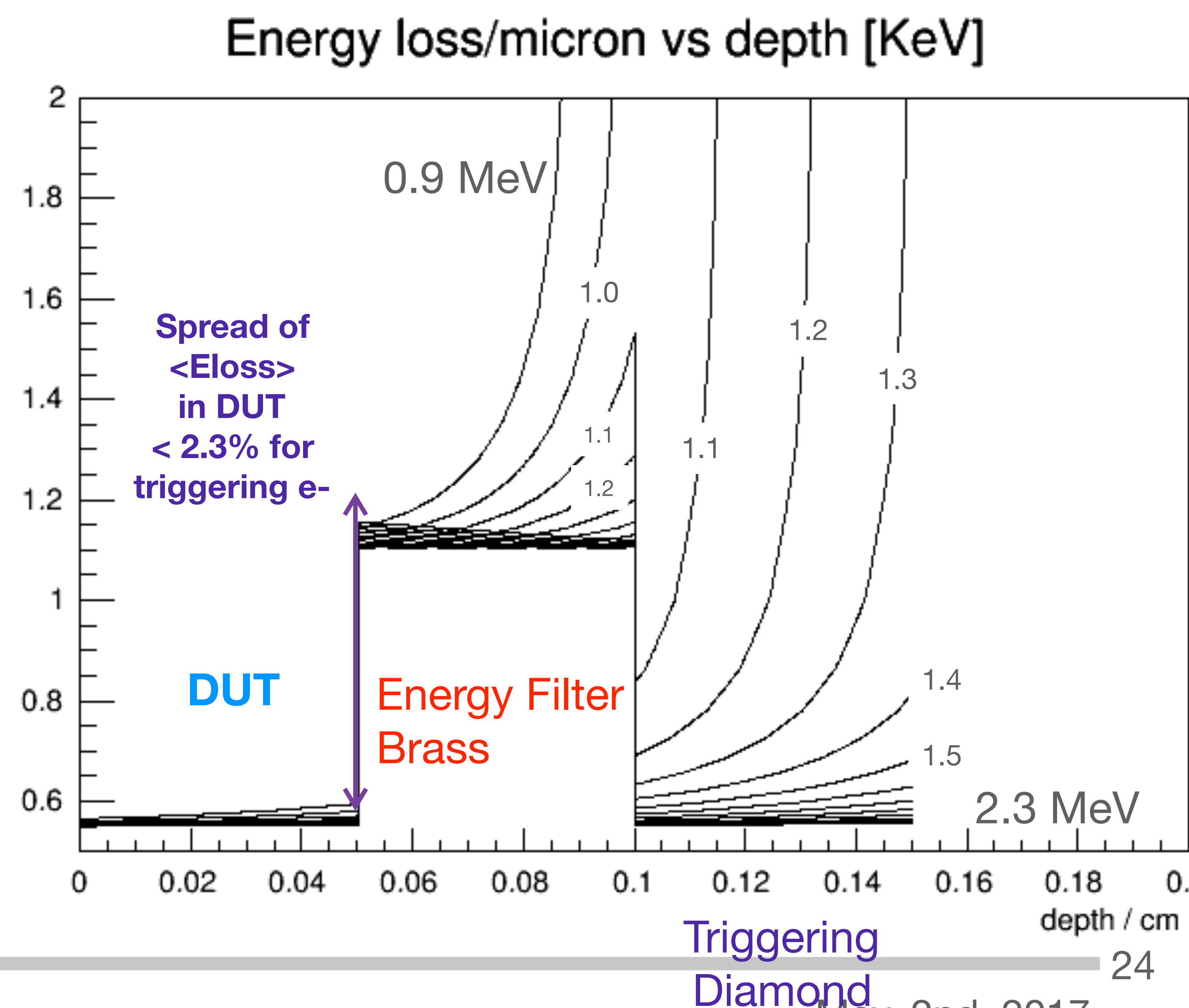




No Brass, Cal. Diamond & DUT

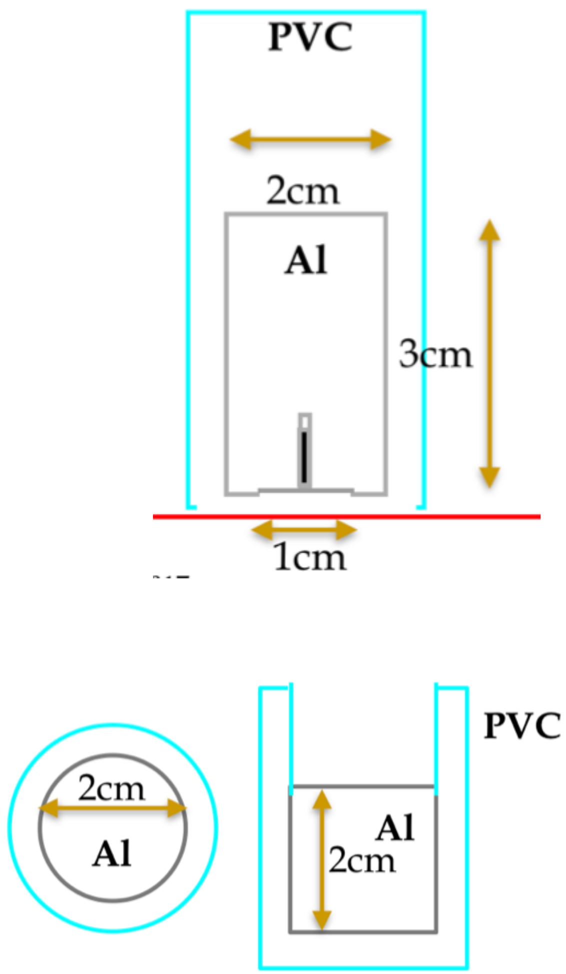


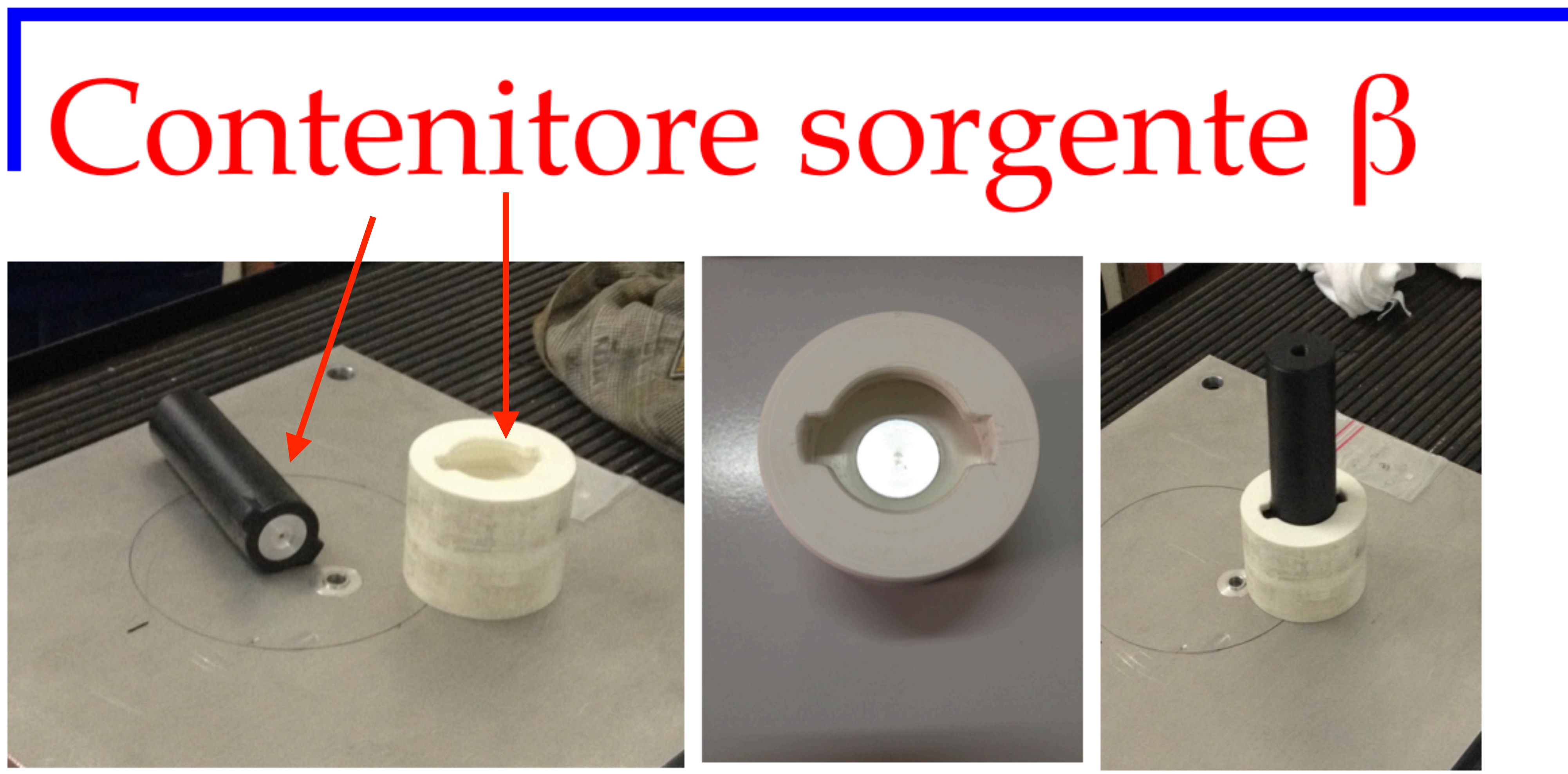
Initial Energy MeV	E lost in DUT	E lost in Brass	E lost in Trg Diamond	Dept in Trg Diamond	Eloss spread in DUT
MeV	KeV			μm	%
2.3	280	568	277	500	0.56
2	278	560	280	500	0.44
1.5	278	555	310	500	0.24
1.3	279	565	421	500	0.93
1.2	280	577	359	335	1.5
1.1	282	603	235	165	2.3
1	285	718	-	-	3.5
0.9	289	all	-	-	5.3
0.8	296	all	-	-	8.2



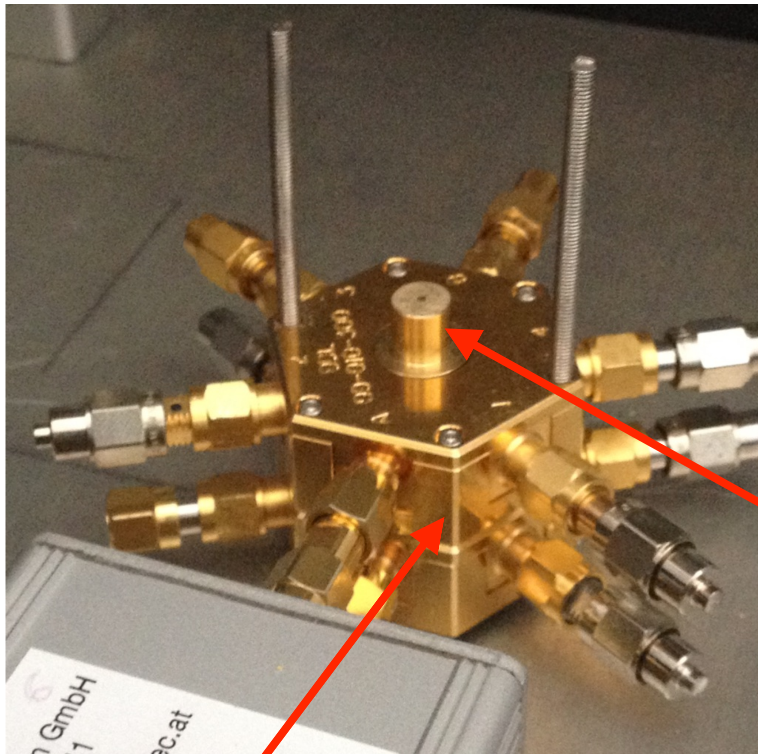
IL SETUP IN LABORATORIO

- **Sorgente**: codice prodotto: SIFB10088
  - 90 Sr VZ-2931-001 attività 3,7 MBq
  - ago del diametro di 2mm protetto in un contenitore che lo scherma e ne consente la movimentazione

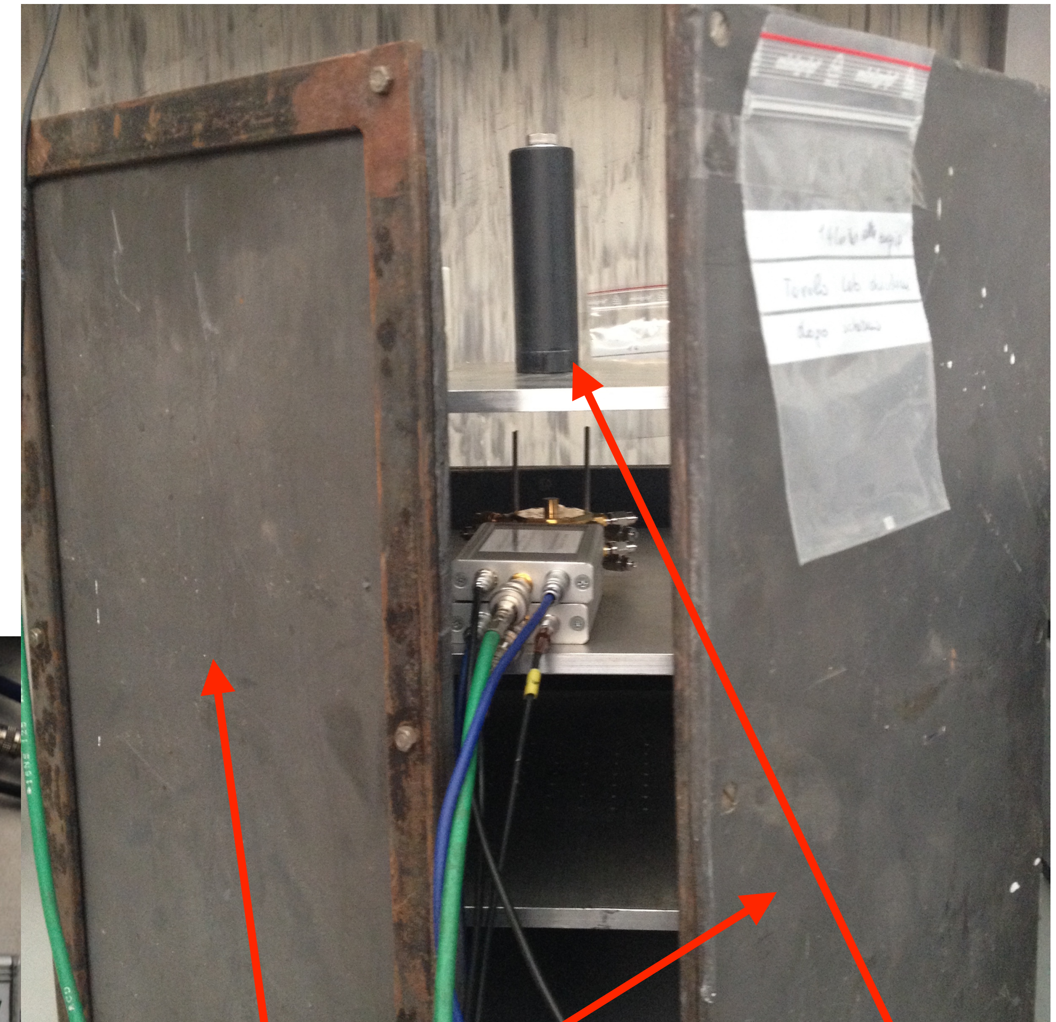




Setup sperimentale – Misura con sorgente β



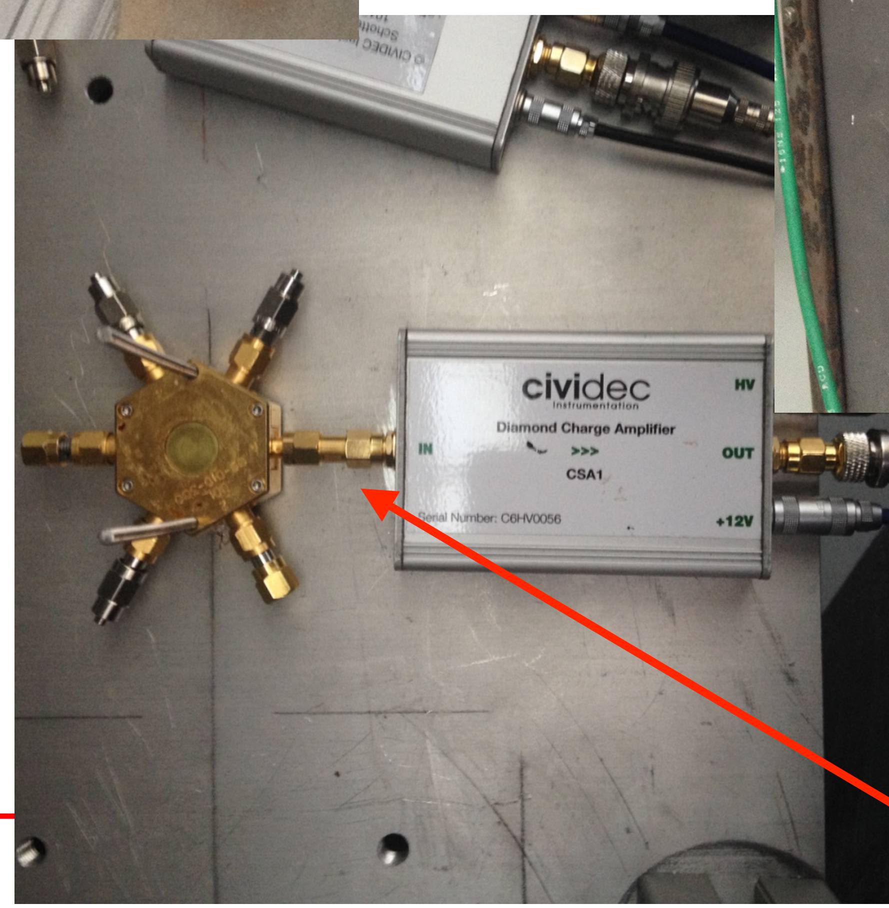
collimatore in ottone (1cm)



schermo

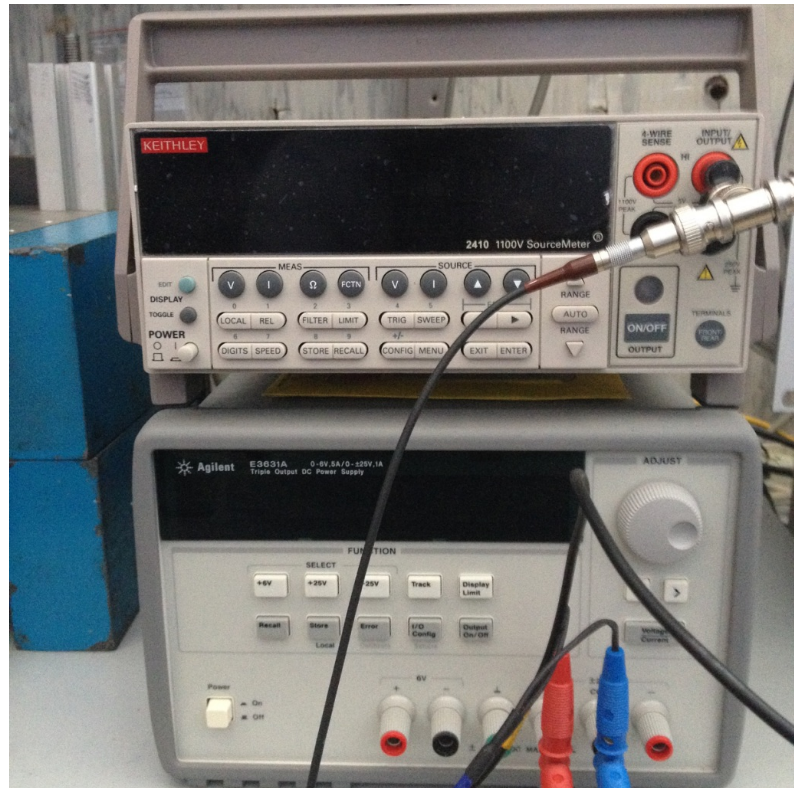
alloggiamento della sorgente

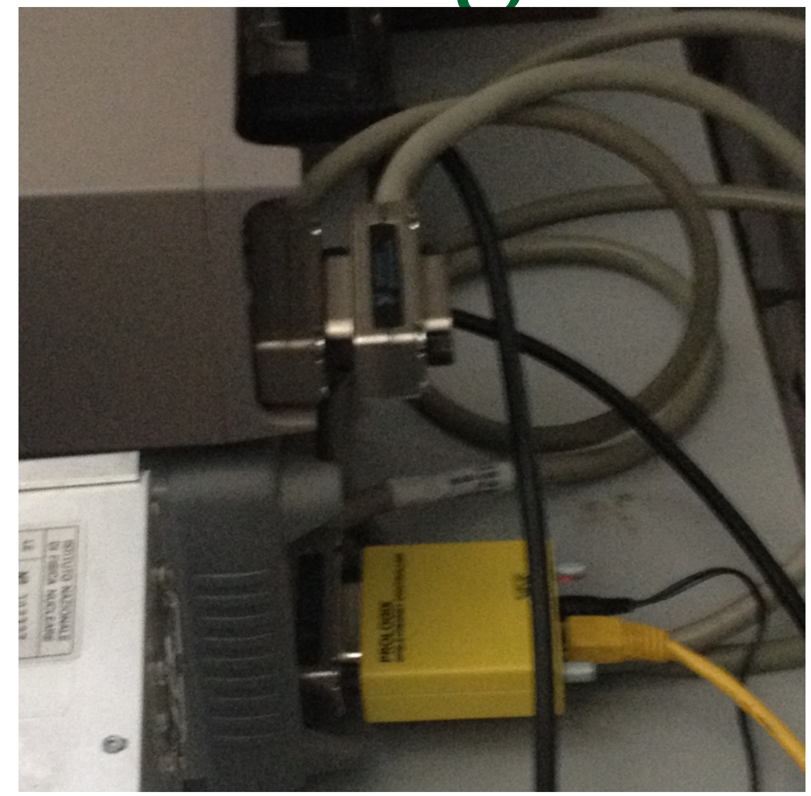
2 case esagonali in ottone sovrapposti che contengono ciascuno i rivelatori a diamante e garantiscono la connessione elettrica attraverso i 6 connettori - uno per l'alimentazione di alta tensione e, gli altri per estrarre i segnali sulle 4 strip (+2 guard rings)



connessione diretta con un amplificatore di carica Cividec

Strumentazione – Misura con sorgente β



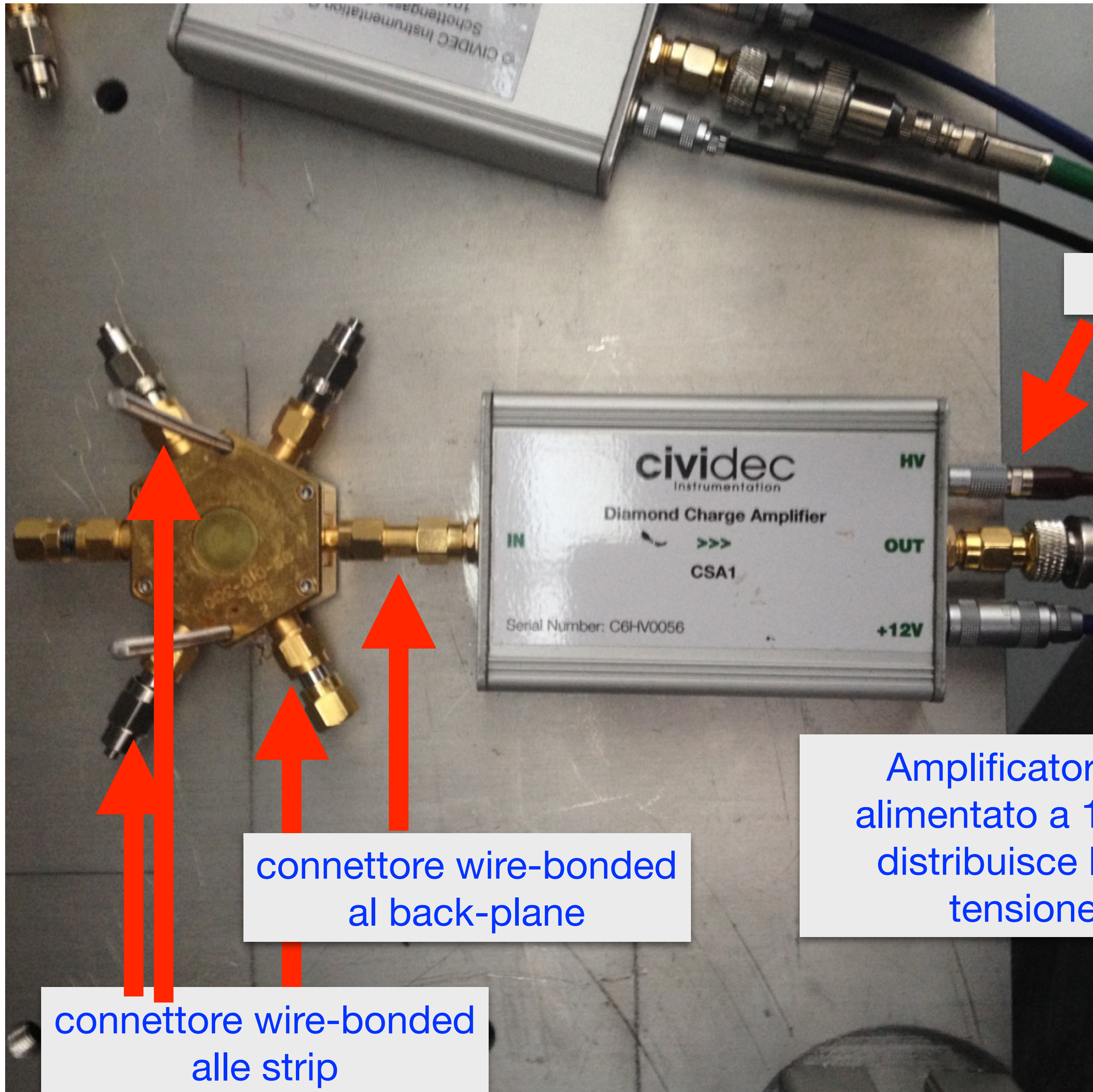


Oscilloscopio ad ampia banda passante (500MHz) per l'acquisizione delle forme d'onda dei segnali dal diamante

Alimentatore di alta tensione per applicare il campo elettrico nel diamante

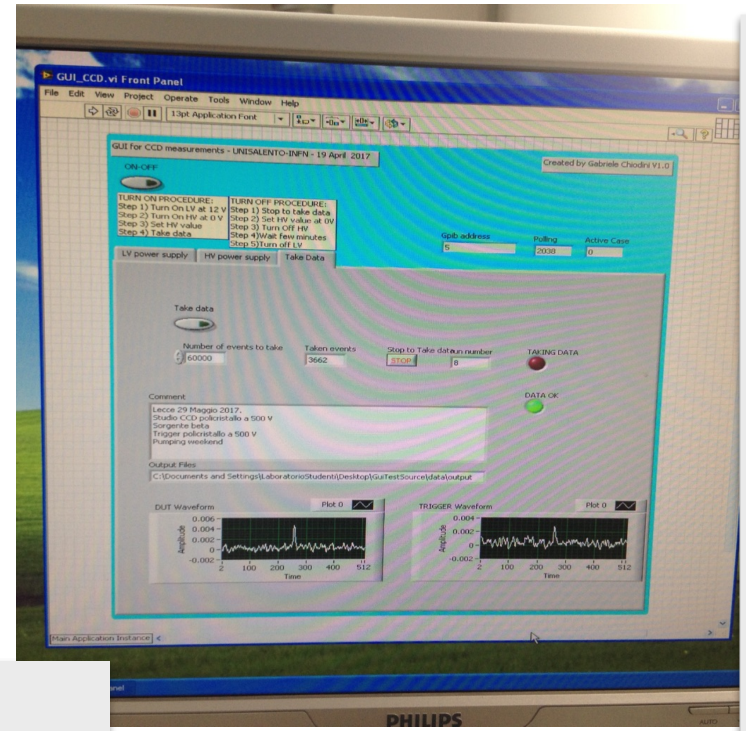
Generatore di bassa tensione per alimentare gli amplificatori

Cavo GPIB per la comunicazione del programma di DAQ con gli strumenti (alimentazioni e controlli)


civi dec
Instrumentation
Diamond Charge Amplifier
IN
>>>
CSA1
Serial Number: C6HV0056
HV
OUT
+12V
HV input
segnale in output, inviato all'oscilloscopio
LV
Amplificatore e' alimentato a 12 V e distribuisce l'alta tensione
connettore wire-bonded al back-plane
connettore wire-bonded alle strip

Data acquisition e Detector control system

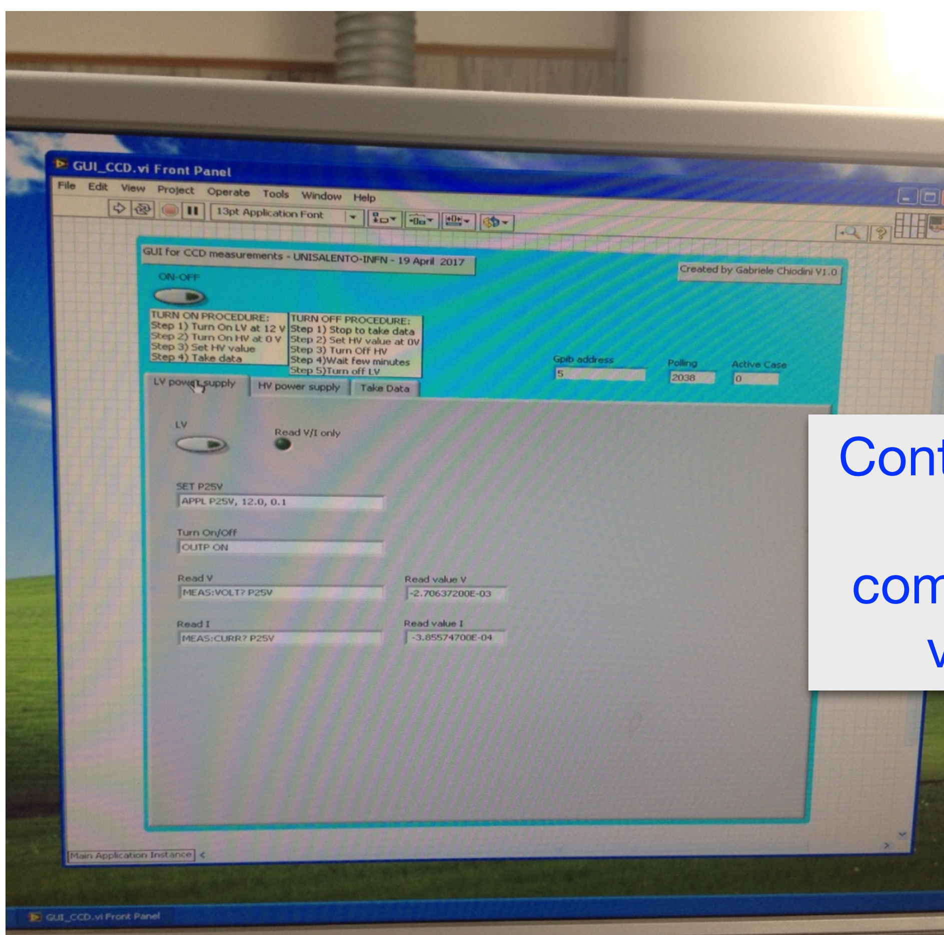
PC di gestione del DAQ



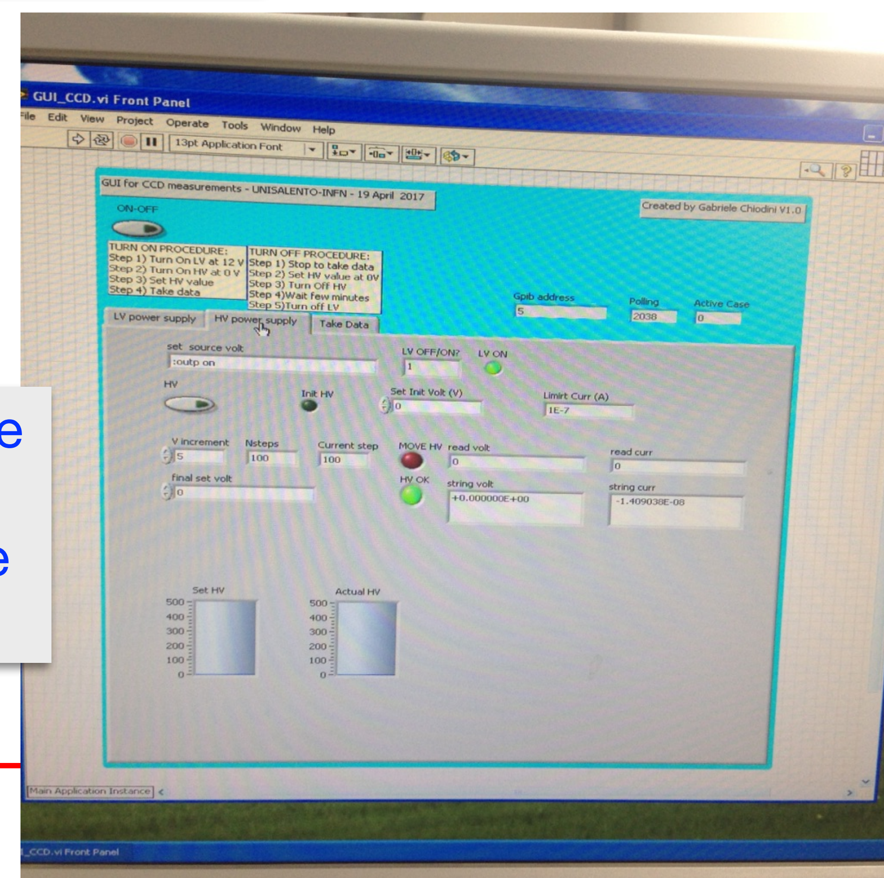
GUI del programma di DAQ, comunicazione via GPIB con l'oscilloscopio.

Il DAQ legge la forma d'onda del segnale in ingresso ad ogni trigger dell'oscilloscopio (proveniente dal segnale sul sensore di trigger)

LabView



Controlli di HV e LV, comunicazione via GPIB



DATI E SW

- http://www.dmf.unisalento.it/~spagnolo/LabFNSN/macro/

  - **analizewaveforms.C** - processa le forme d'onda del segnale e produce una ntupla in cui sono salvati per ogni evento l'integrale del segnale in una finestra temporale definita, l'integrale del background (della baseline)

  - **SpectrumFitSC.C**
  - **SpectrumFitPoly.C**
    - fit dello spettro dell'integrale del segnale in una finestra fissata con una Landau convoluta con una gaussiana (risoluzioni di elettronica e misura)

- **analizewaveforms.C** - processa le forme d'onda del segnale e produce una ntupla in cui sono salvati per ogni evento l'integrale del segnale in una finestra temporale definita, l'integrale del background (della baseline)
  - 512 parole (campionamenti per forma d'onda) - unita' Volt - scansione temporale dipende dal setting dell'oscilloscopio (scala orizzontale)
    - setting oscilloscopio 1Jun2017 20ns/div (scala orizzontale) - scansione temporale 2ns / bin
    - scale verticale: 2mV/div => le tensioni nel files sono scritte in Volt sempre
-