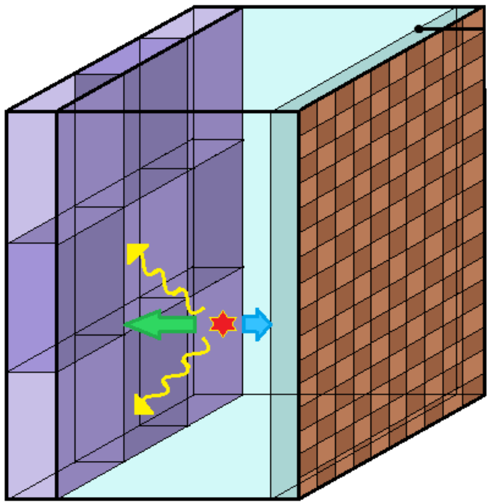
CaLIPSO

Study of Tri Methyl Bismuth ionization parameters

An innovative detector concept

for high-resolution **P**ositron **E**mission **T**omography

using heavy organometallic liquid



Overview

1. Context
    a. Brain imaging
    b. CaLIPSO principle
4. Focus on charge detector : Free ion yield
    a. Current measurement
    b. Monte Carlo simulation
    c. Results
5. Conclusion

Overview

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Brain imaging

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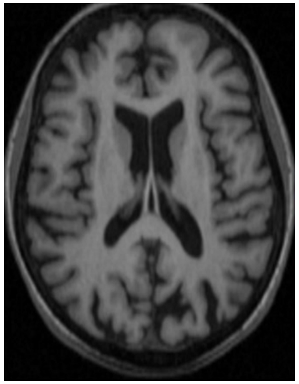
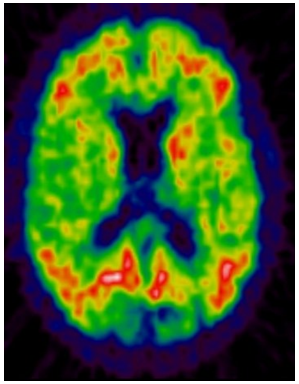
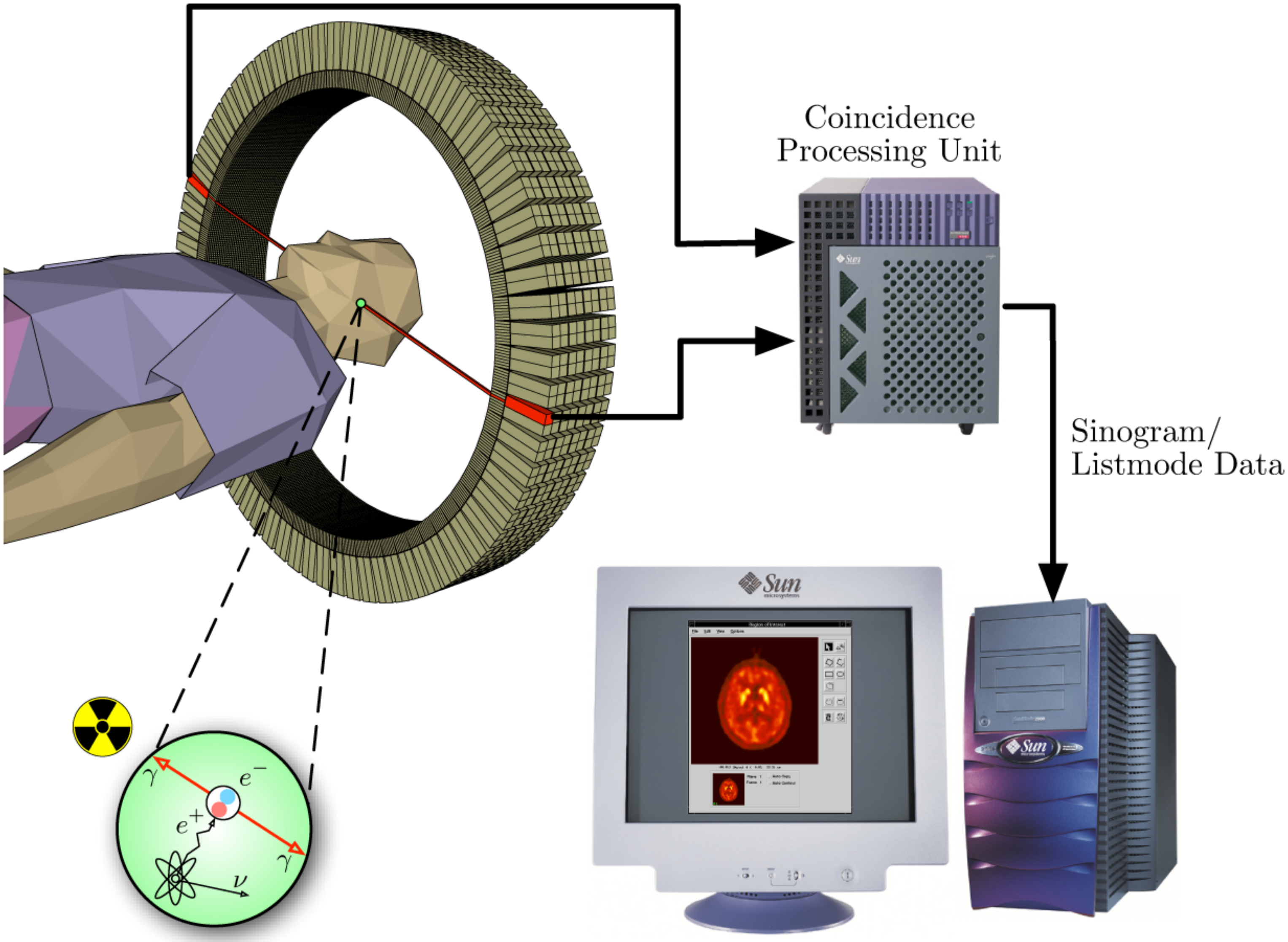
	Magnetic Resonance Imaging	Positron Emission Tomography
Imaging	Structures 	Functions 
Spatial resolution	1 mm^3	$(3\ mm)^3$
Sensitivity	10^{-6} mol	10^{-12} mol
Drawback		Irradiation of patients

Motivation : To quantify activity of brain cells at 1 mm^3

PET-Scan



Coincidence
Processing Unit
Sinogram/
Listmode Data
Annihilation
Image Reconstruction

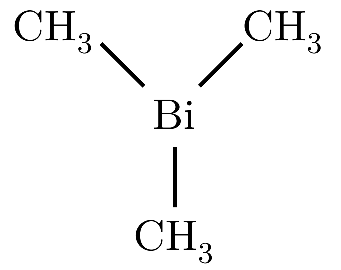
Overview

CaLIPSO detector

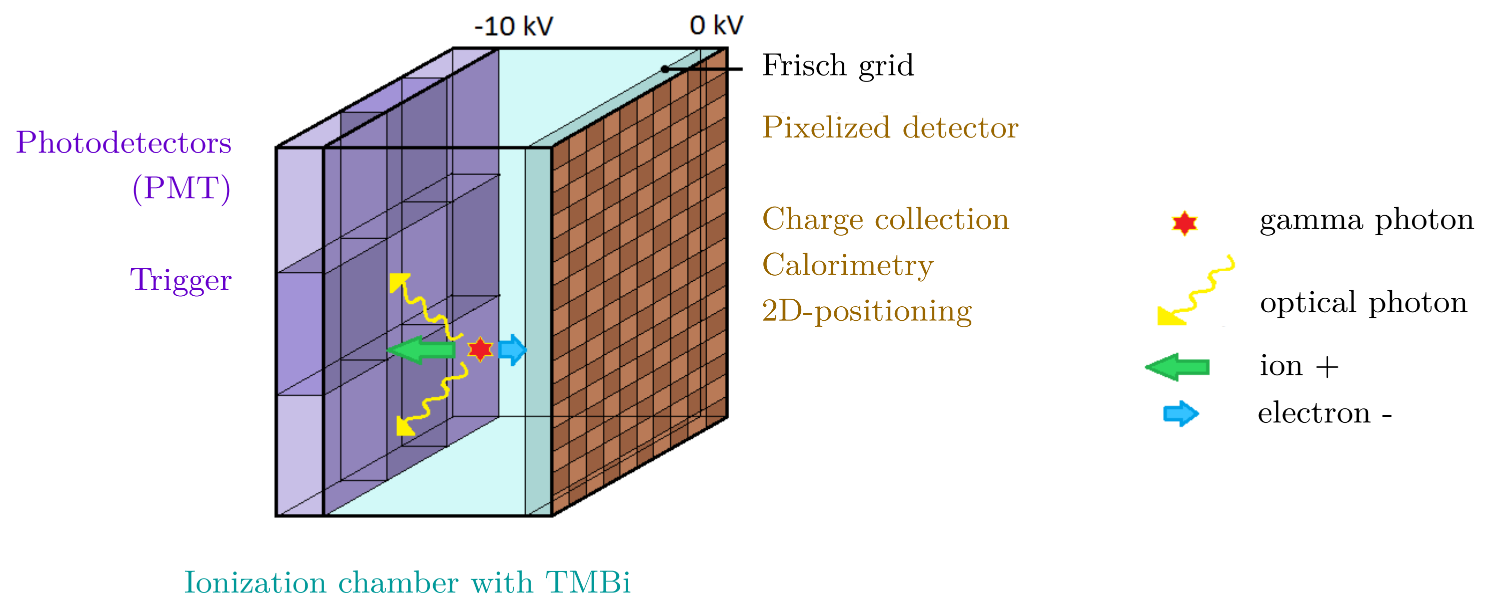
Liquid Tri Methyl Bismuth (TMBi)

→ $Z_{Bi} = 83$: heaviest non radioactive element

→ photoelectric efficiency at 511 keV = **49 %**

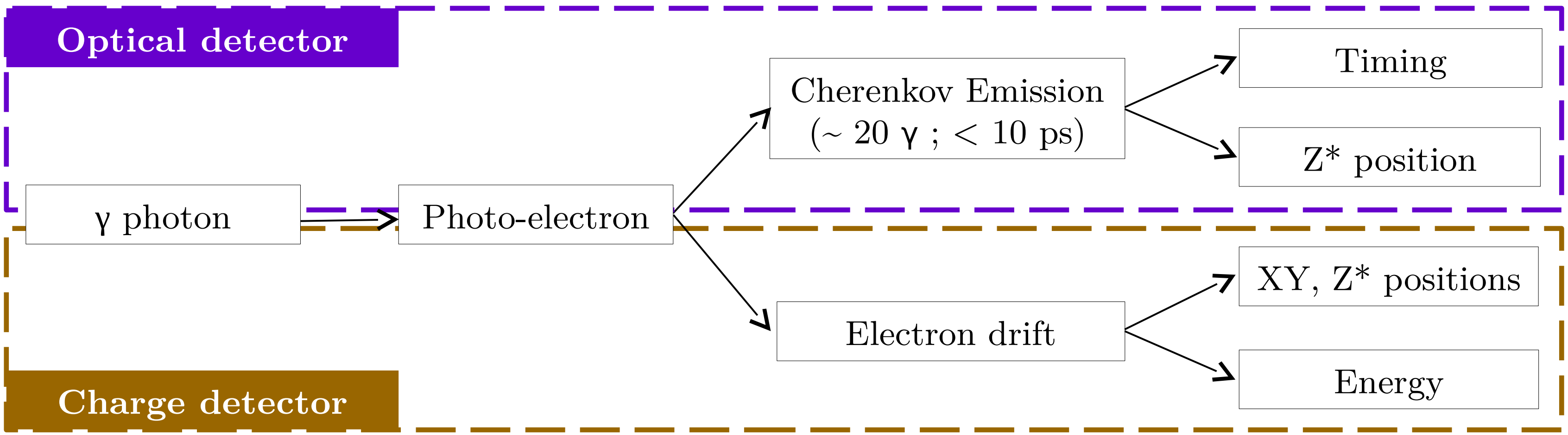


Double detection

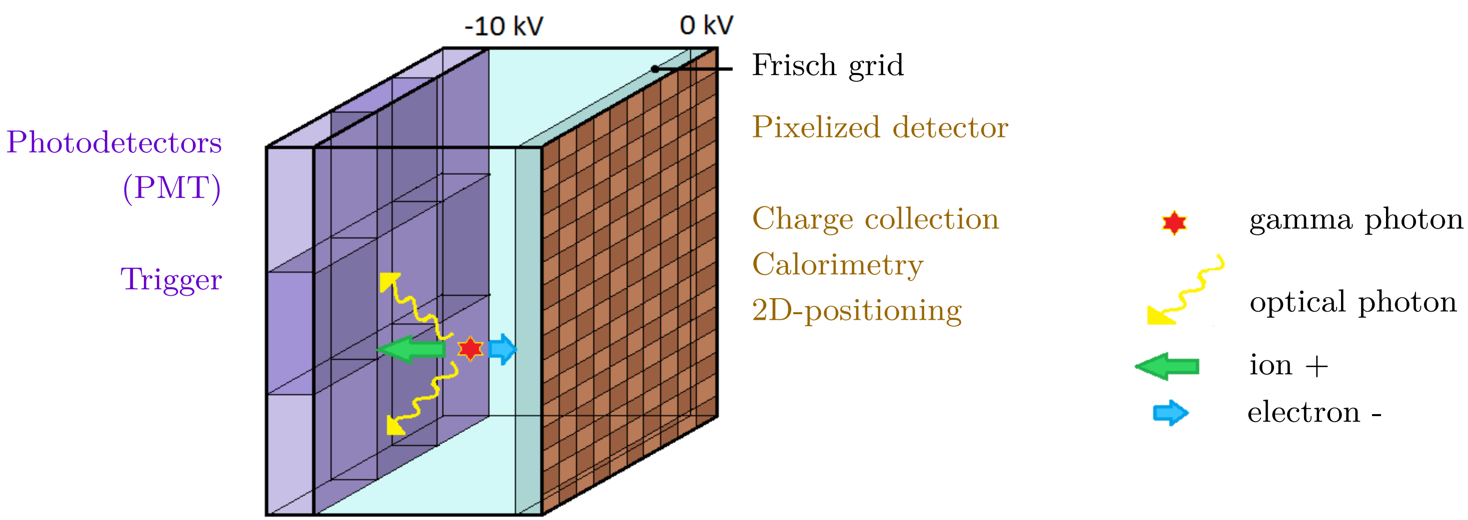


Yvon D, Renault J, Tauzin G, et al. CaLIPSO : A novel detector concept for PET imaging. IEEE Trans Nucl Sci 2014 ; 61(1):60-66

CaLIPSO detector




C. Canot



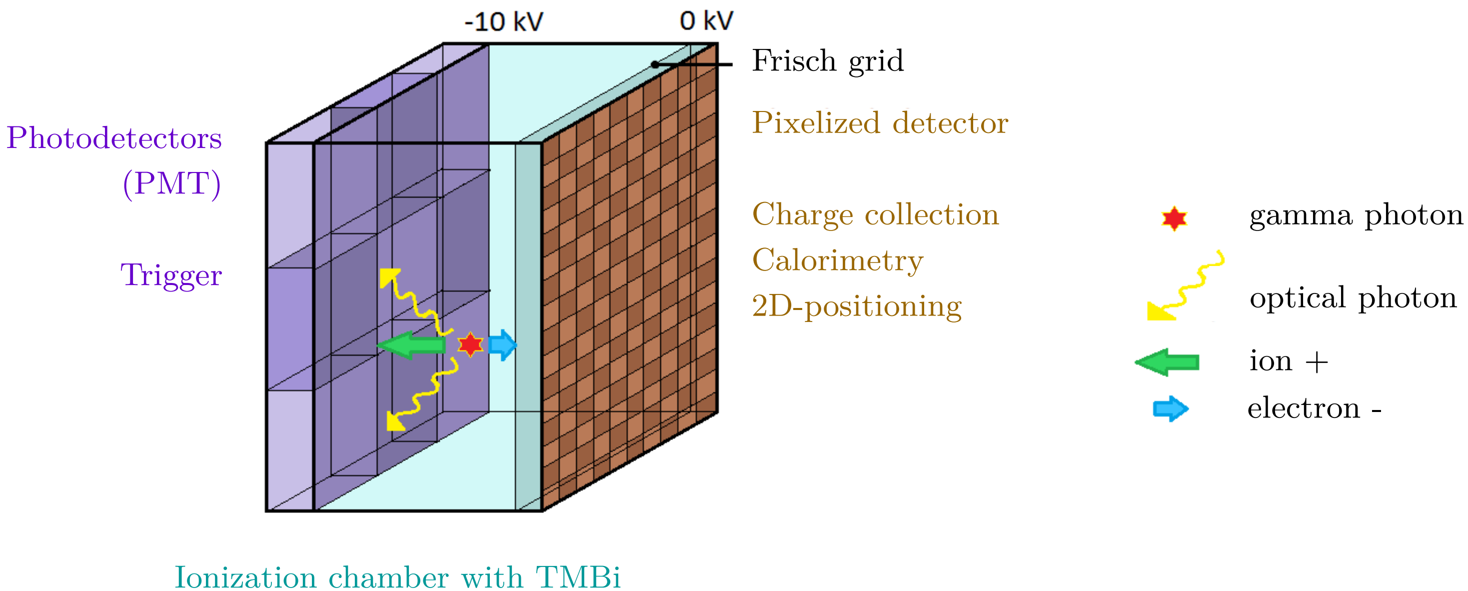
Ionization chamber with TMBi

Yvon D, Renault J, Tauzin G, et al. CaLIPSO : A novel detector concept for PET imaging. IEEE Trans Nucl Sci 2014 ; 61(1):60-66

CaLIPSO detector

Expected performances :

- time resolution ~ 100 ps (FWHM)
- 3D-positioning ~ 1 mm^3
- energy resolution ~ 10 % (FWHM) if G_{fi} = 0,6



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Free ion yield G_{fi}

$$G_{fi}(E) = \underbrace{\frac{I(E)}{e}}_{\substack{\text{number of free electron-ion pairs} \\ \text{escaping initial recombination}}} \cdot \underbrace{\frac{100}{\Delta \epsilon}}_{\substack{\text{created} \\ \text{per 100 eV of absorbed energy}}}$$

with :

I(E)	current induced by the radioactive source (A)
E	applied electric field (V)
e	elementary charge (C)
$\Delta\epsilon$	energy absorbed in the liquid per second (eV/s)

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Onsager model :

Probability of initial recombination (electron with its parent ion) depending on :

→ coulomb attraction,

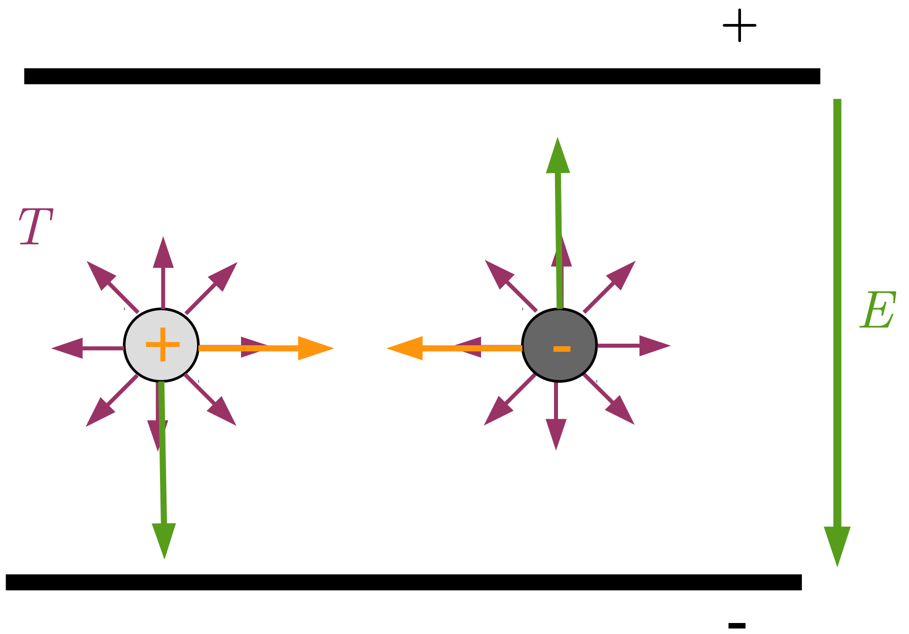
→ thermal motion,

→ and applied electric field.

$$G_{fi}(E) = G_{fi}(0)\,[1+\alpha E]$$

with :

$$\alpha = \frac{e^3}{8\pi\,\epsilon_0\epsilon\,(kT)^2}$$



Onsager L. Initial recombination of ions. Phys Rev, 54 :554–557, 1938

Free ion yield G_{fi}

Our goal :

Measure the free ion yield of TMSi :

- documented in literature,
- in order to validate the measurement.

and of TMBi :

- characterize ionization behaviour of TMBi.

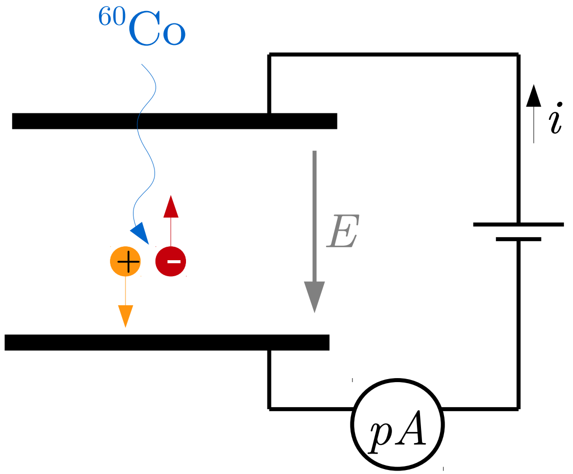
$G_{fi}(0)$	Ref.
0,74	Schmidt, Allen, 1970
0,74	Allen, 1976
0,59	Jungblut et al, 1985
0,60	Gettert, 1988
0,51	Lopes et al, 1988
0,59	Geer et al, 1990
0,65	Holroyd et al, 1991
0,61	Engler et al, 1993
0,63	Mean

Table : some reported values of TMSi free ion yield at zero volt

Overview

Free ion yield G_{fi}

Measurement of the ionization current



Liquid parallel-plate ionization chamber

^{60}Co radioactive source ~ 750 kBq

Two γ emissions per decay : 1,173 MeV and 1,332 MeV

Induced current between electrodes :

→ proportional to the number of electron-ion pairs escaping initial recombination produced by the source per second

Free ion yield G_{fi}

Measurement of the ionization current

→ ionization chamber assembly : standard UHV cleaning, under laminar flow, wearing clean-room equipment

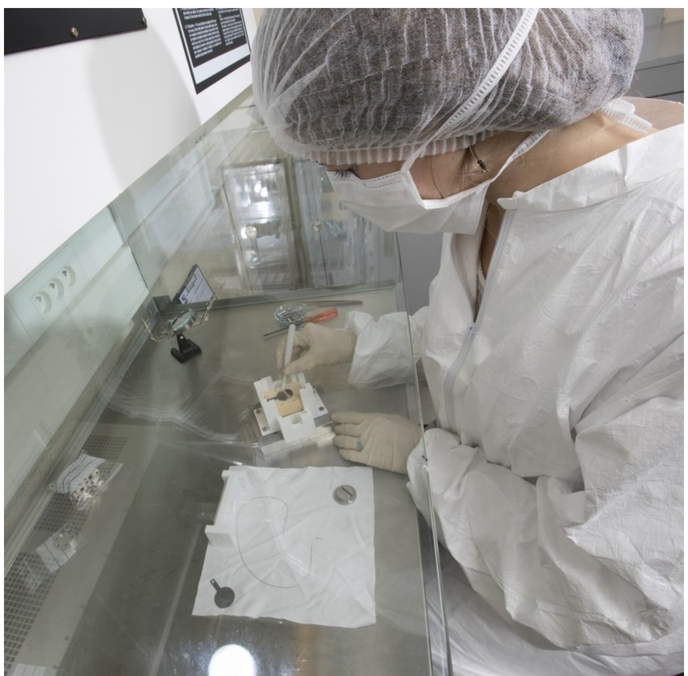


Photo. : Assembly of the ionization chamber

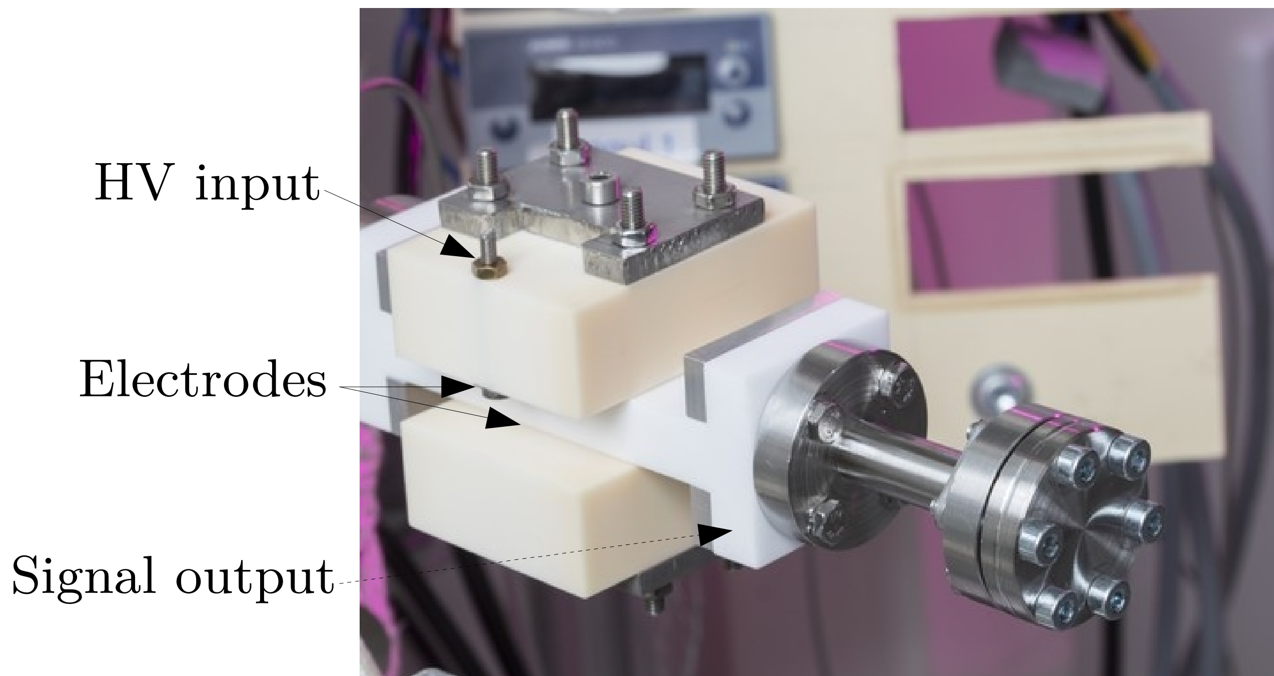


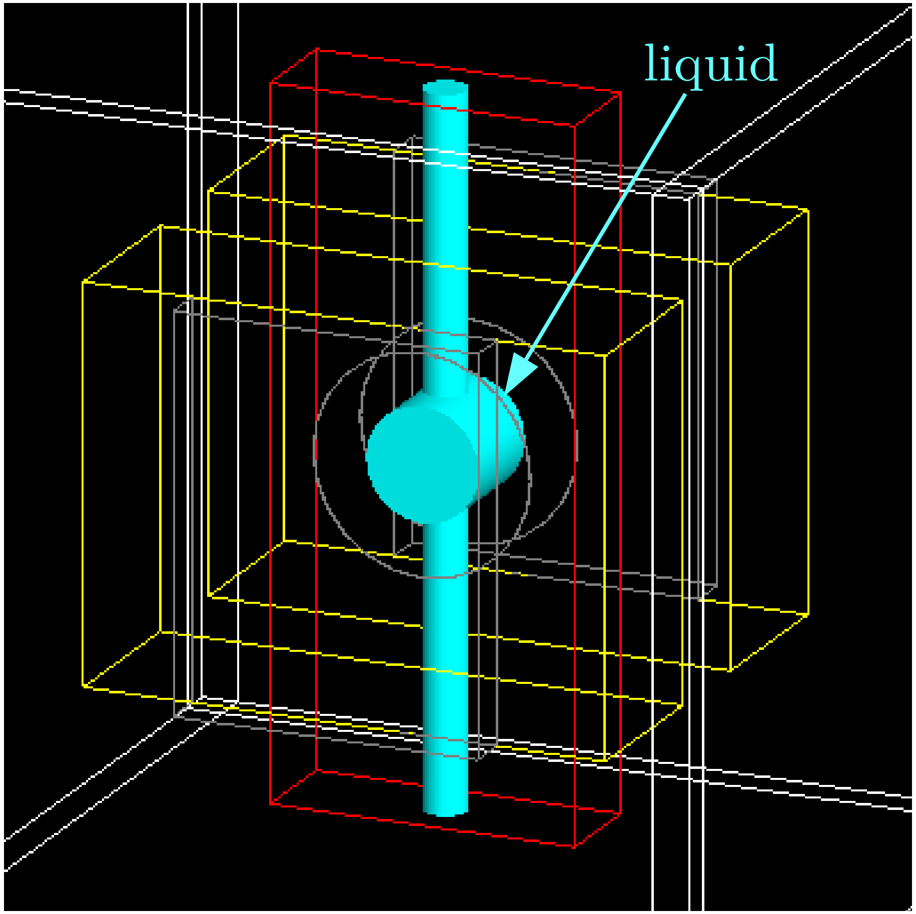
Photo. : Ionization chamber

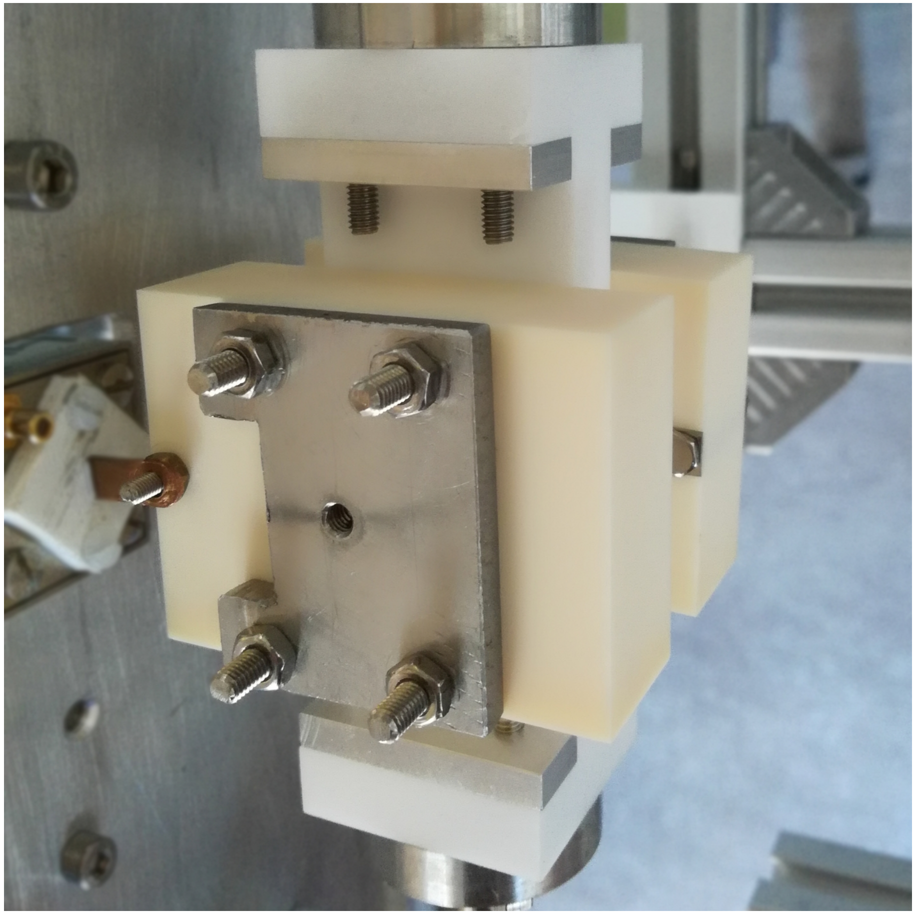
Overview

Monte Carlo simulation

Calculation of energy absorbed

Platform Gate (Geant4)





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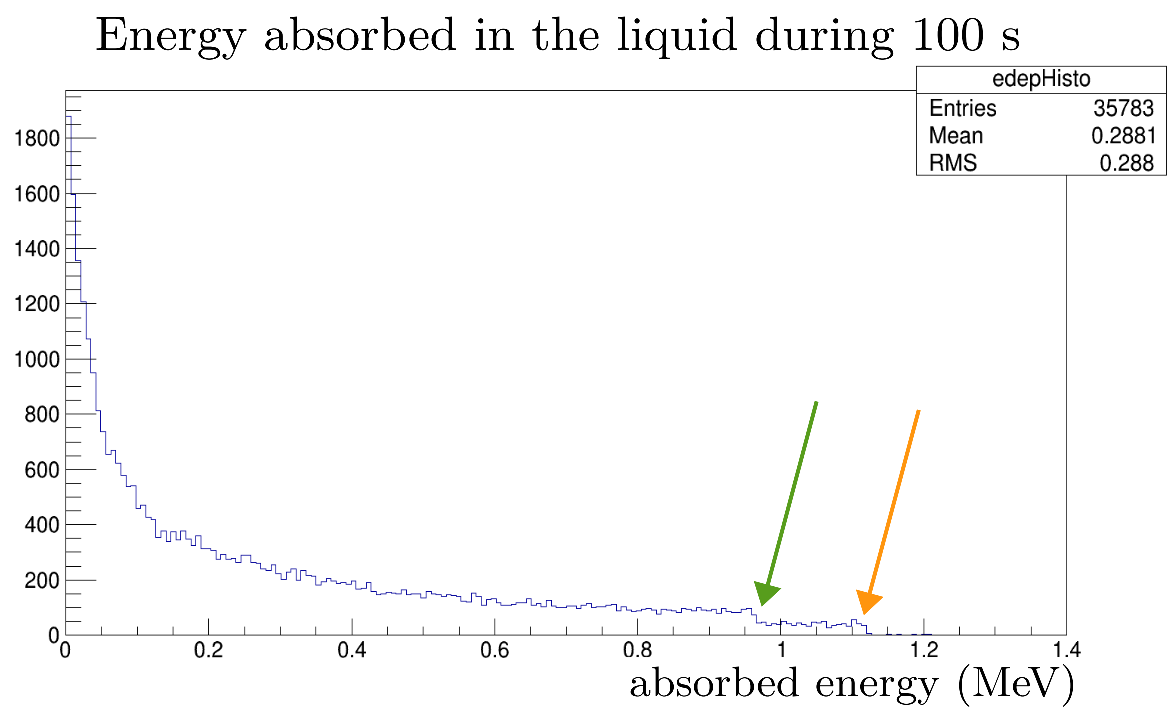
Calculation of energy absorbed in TMSi



→ two Compton edges at 0,96 MeV and 1,12 MeV

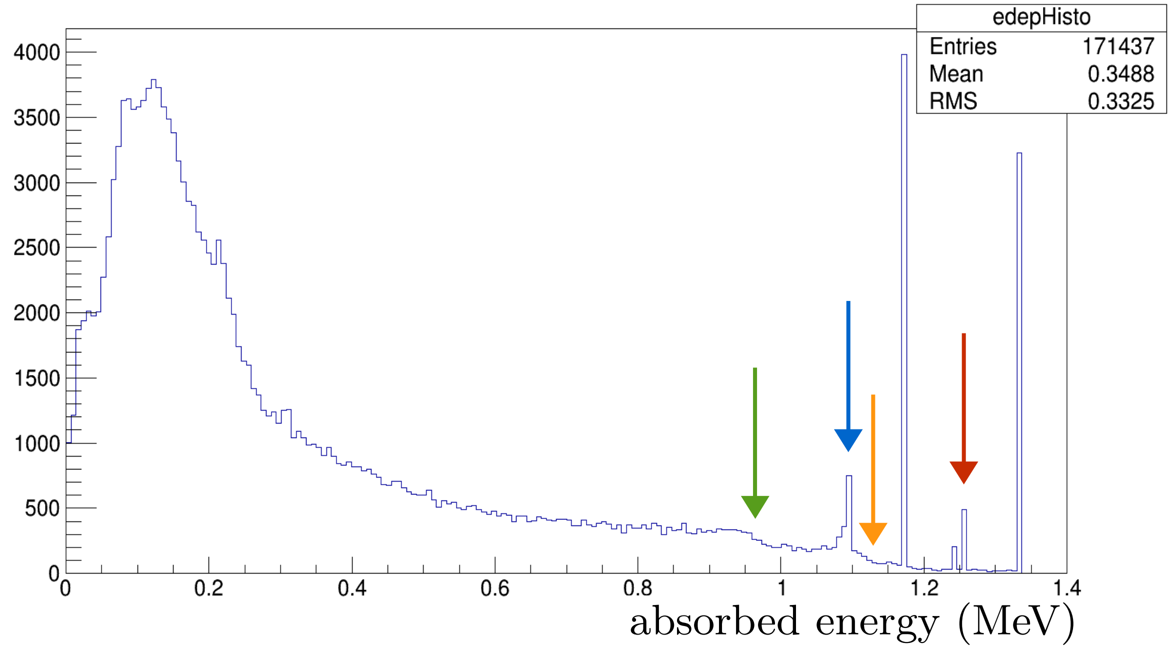
→ significant part of energy absorbed < 100 keV

→ energy absorbed in TMSi per second : $\Delta\epsilon = 1{,}03 \,.\, 10^8$ eV/s

Monte Carlo simulation

Calculation of energy absorbed in TMBi

Energy absorbed in the liquid during 100 s



→ two Compton edges at 0,96 MeV and 1,12 MeV

→ two photo-peaks at 1,10 MeV and 1,26 MeV

→ energy absorbed in TMBi per second : $\Delta\epsilon = 5{,}98 \,.\, 10^8$ eV/s

Overview

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Free ion yield of TMSi

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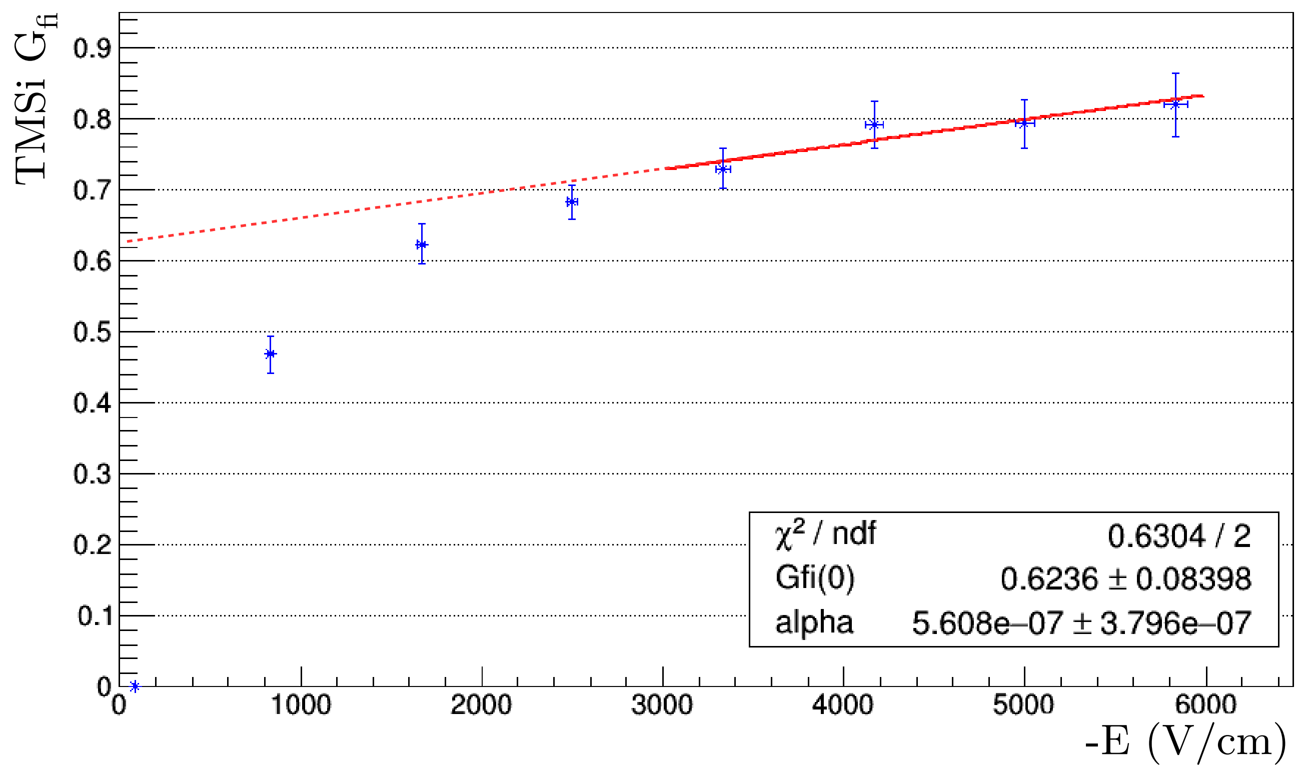
Onsager equation :

$$G_{fi}(E) = G_{fi}(0)\,[1+\alpha E] \qquad \textit{with:} \qquad \alpha = \frac{e^3}{8\pi\,\epsilon_0\,\epsilon\,(kT)^2} = 5{,}6.10^{-7}\ m/V$$

$$G_{fi}(0) = 0{,}62 \pm 0{,}09$$

$$\alpha = (6 \pm 4).10^{-7}\ m/V$$



Free ion yield of TMBi

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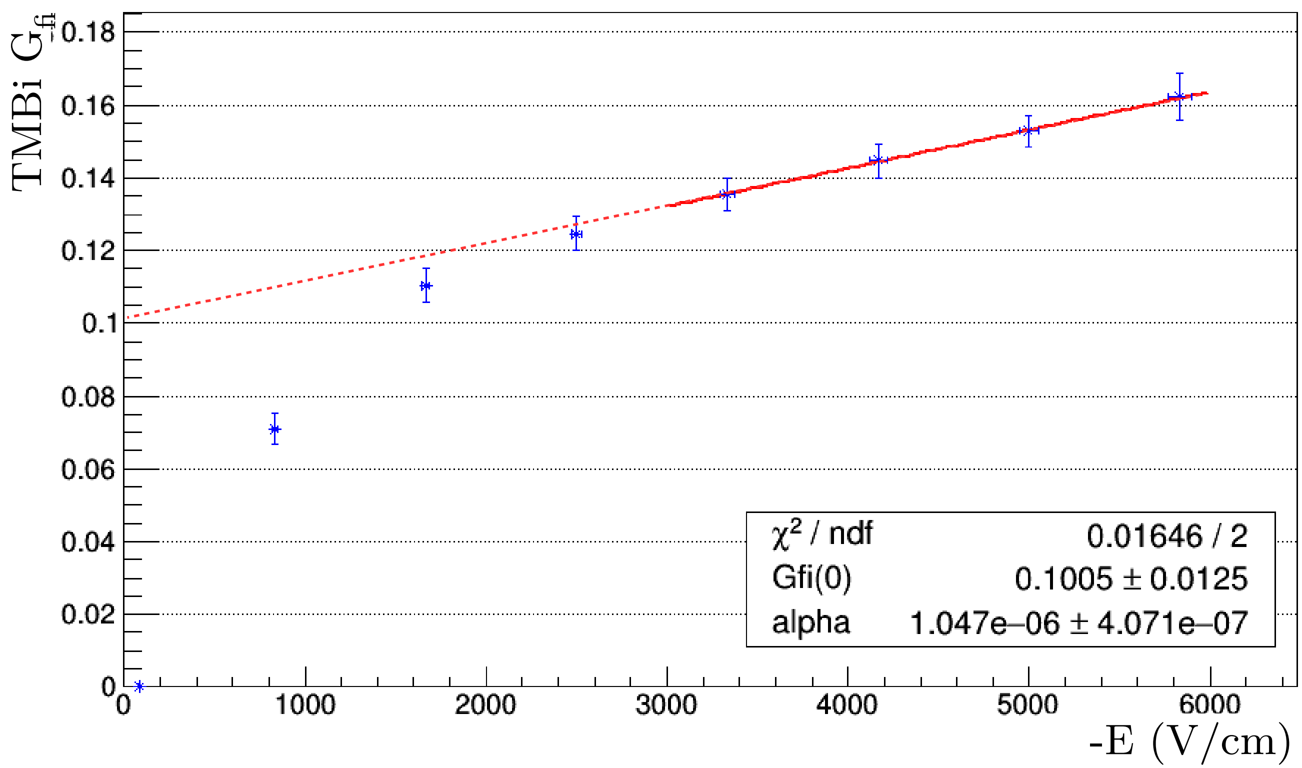
Onsager equation :

$$G_{fi}(E) = G_{fi}(0)\,[1+\alpha E] \qquad with: \qquad \alpha = \frac{e^3}{8\pi\,\epsilon_0\,\epsilon\,(kT)^2}$$

$$G_{fi}(0) = 0{,}10 \pm 0{,}01$$

$$\alpha = (1{,}0 \pm 0{,}4).10^{-6}\ m/V$$



Overview

Conclusion

Measurement of free ion yield :

- TMSi :

  Good agreement with literature and with Onsager model.

- TMBi :

  Needs to be understood...

  - free electrons trapped by electronegative impurities ?

  - signal reduced by electronic affinity of TMBi ?

Conclusion

Next goals (in process) :

→ To develop a new detection chamber, with :

a guard ring,

and a Frisch grid.

→ To quantify the charge induced by a single photon.

- measurement of electron lifetime in liquid : assess the purity level of liquids,
- measurement of energy spectrum of interactions in the liquids.

Thank you !

Photo. : CaLIPSO team

Any question ?

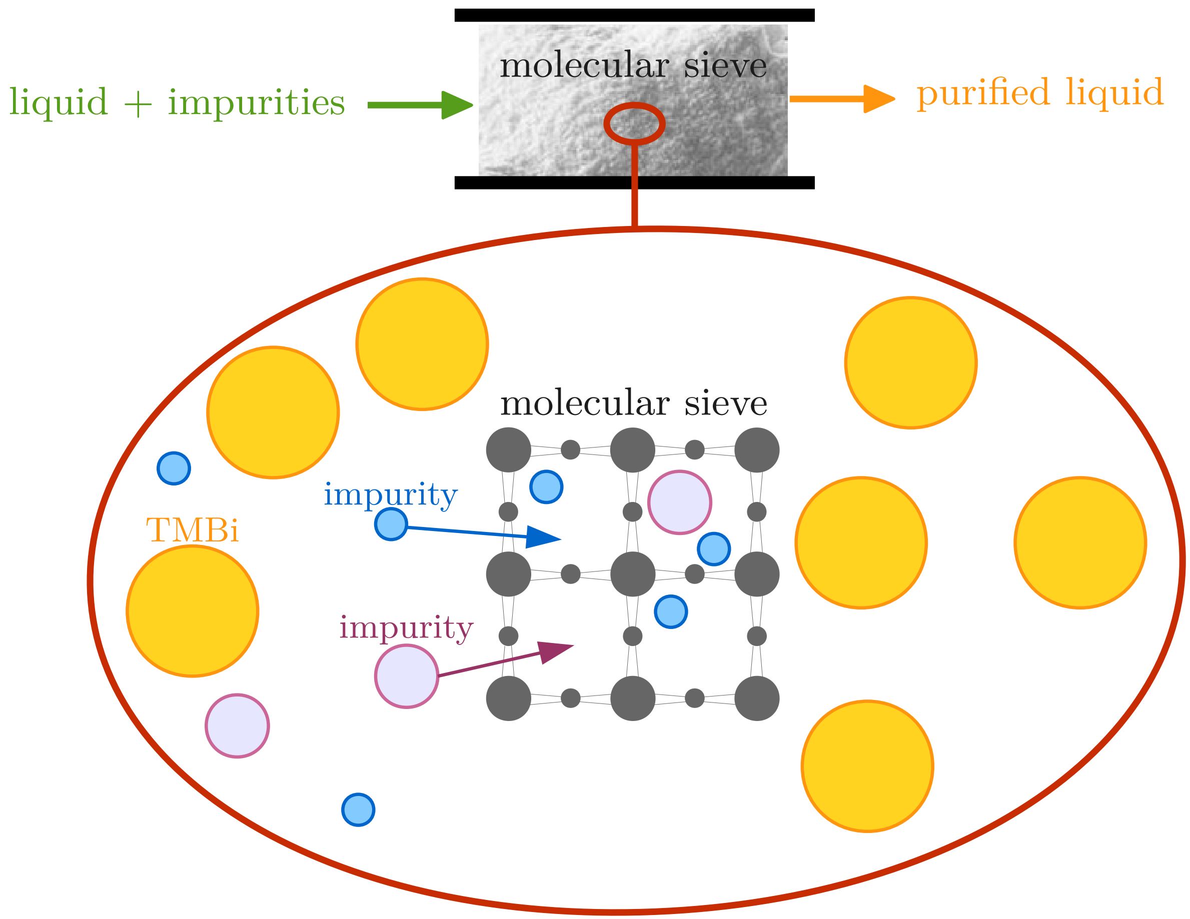
PET-Scan technology

	Scintillation crystal (LSO)	Semi conductor (CdTe)	CaLIPSO expected (TMBi)
Photoelectric attenuation coefficient at 511 keV	0,26 cm^{-1}	0,09 cm^{-1}	0,16 cm^{-1}
Energy resolution at 511 keV	~ 15 %	~ 2 %	~ 10 %
Time resolution	~ 300 ps (up to 100 ps)	~ 10 000 ps	~ 100 ps
Interaction positioning	None	3D	3D

Purification

Removing residual electronegative impurities by **adsorption on zeolites**

- Polar molecules adsorbed in preference
- Periodic micro-porous : molecular sieve



Purification

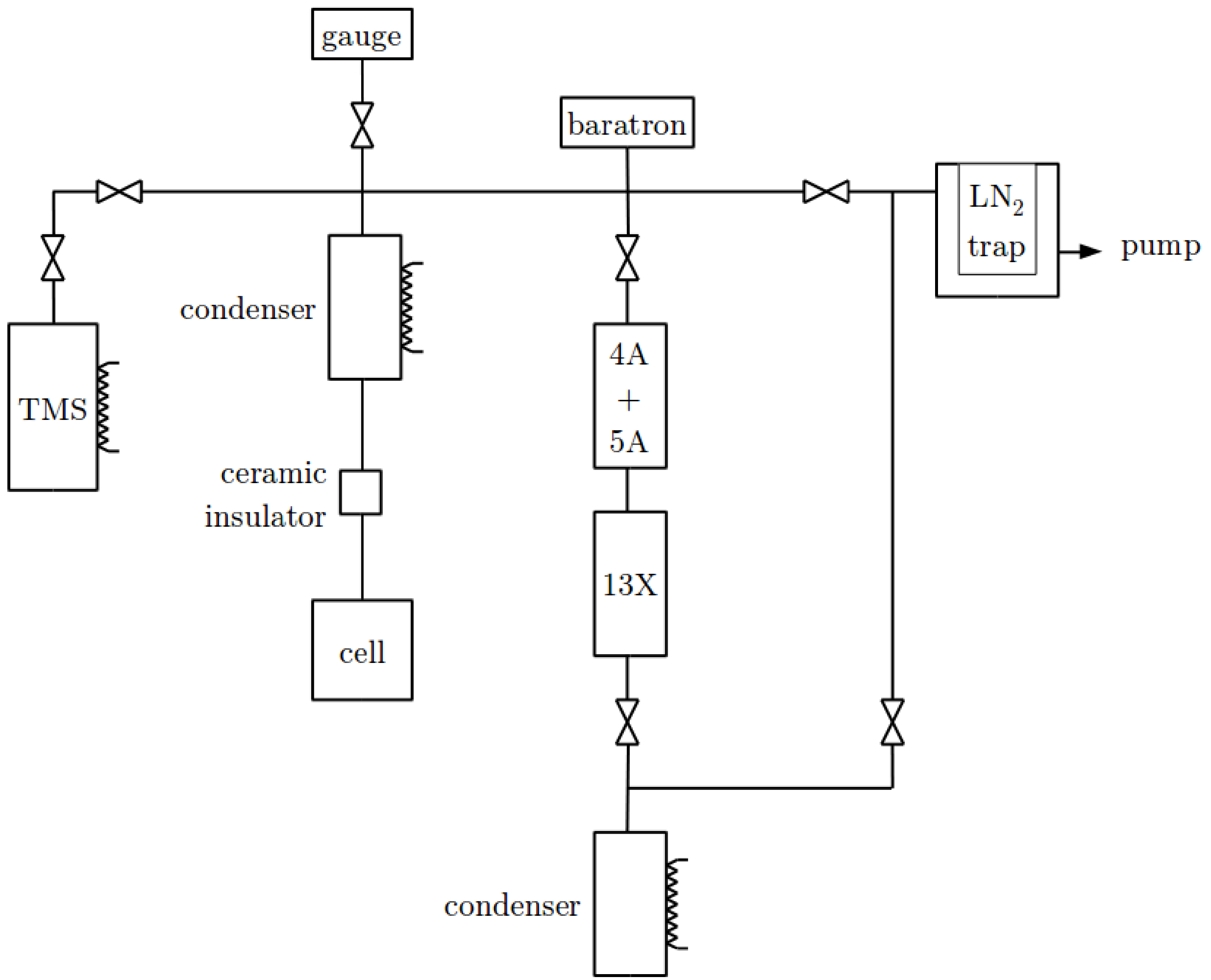
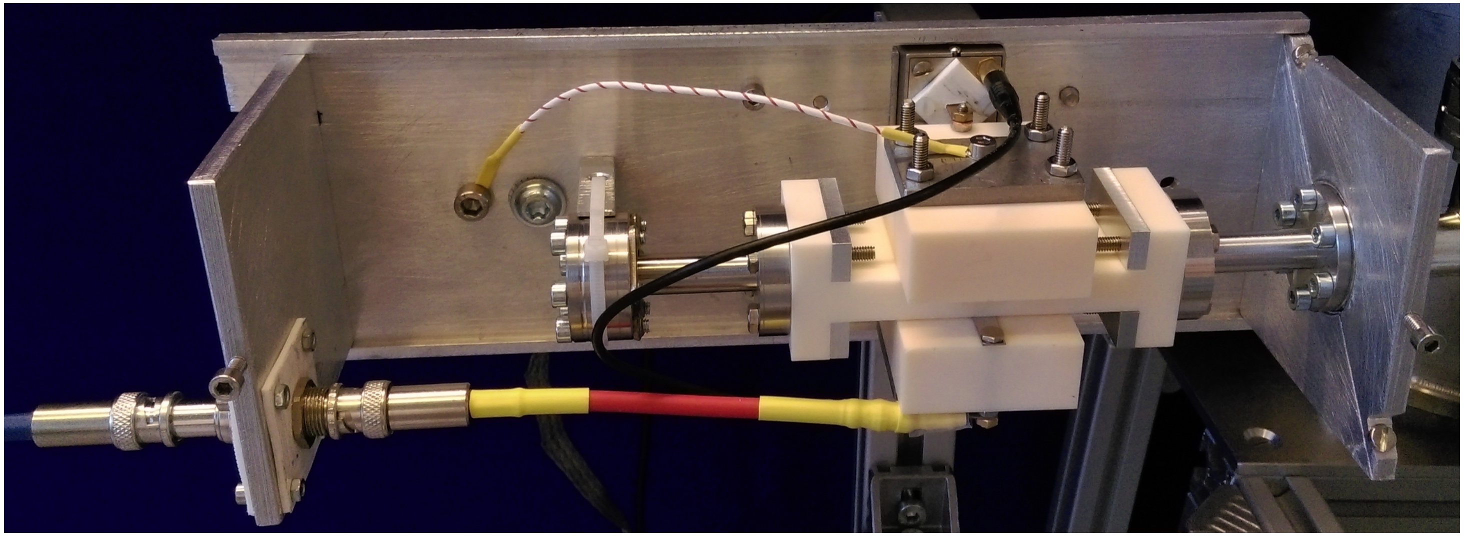
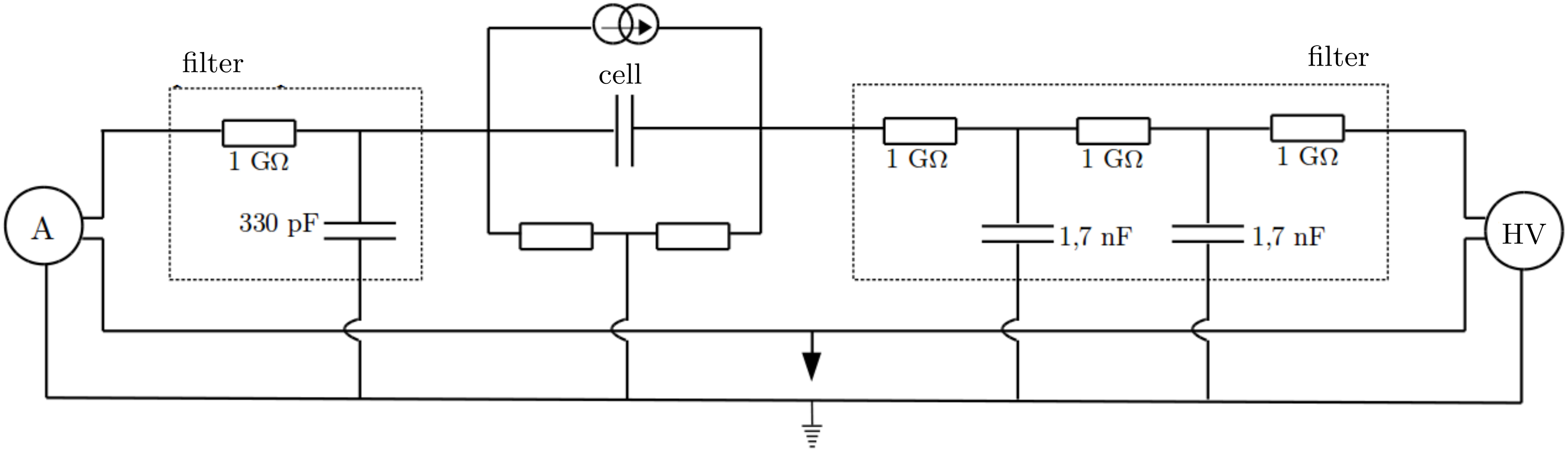


Photo. : TMSi purification bench at Irfu

Current measurement

Measurement of the ionization current

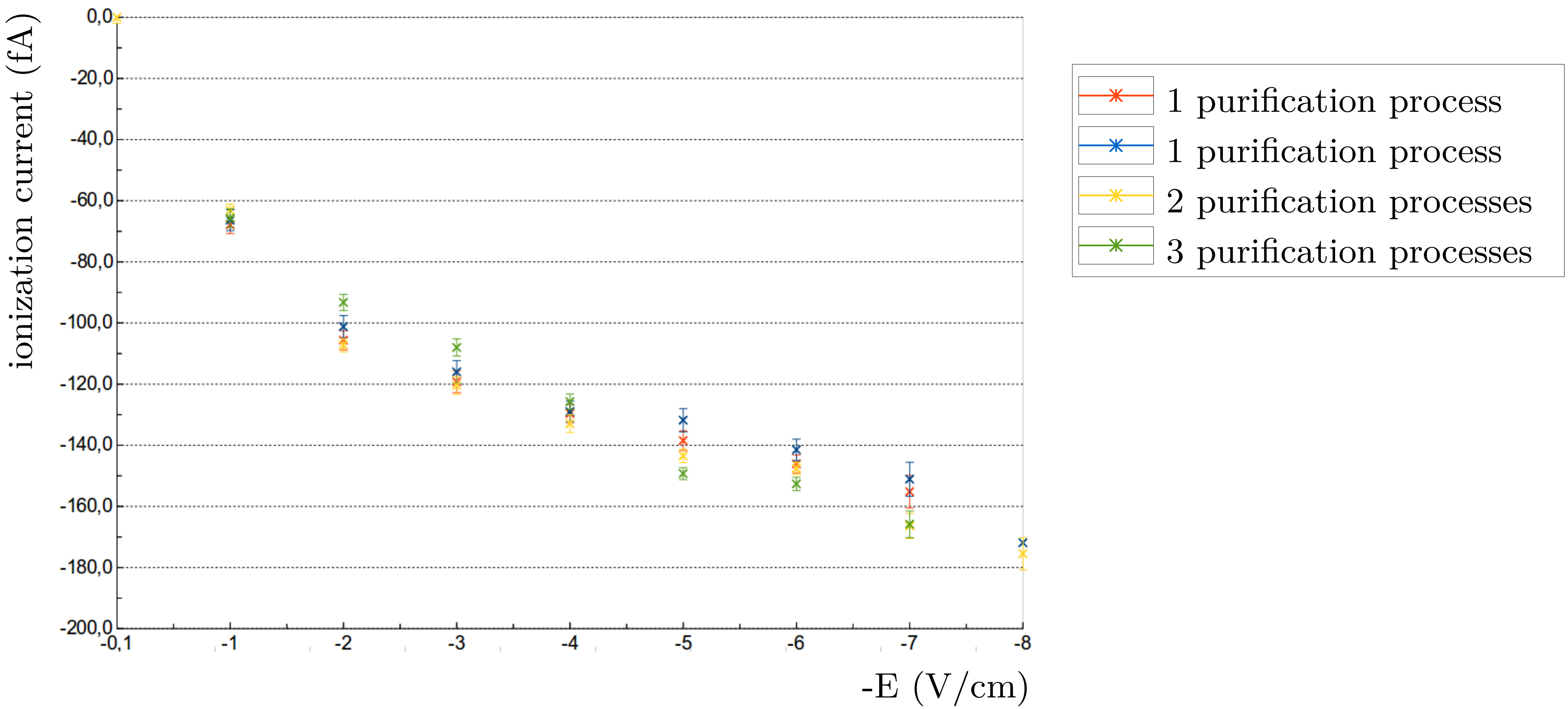




Current measurement

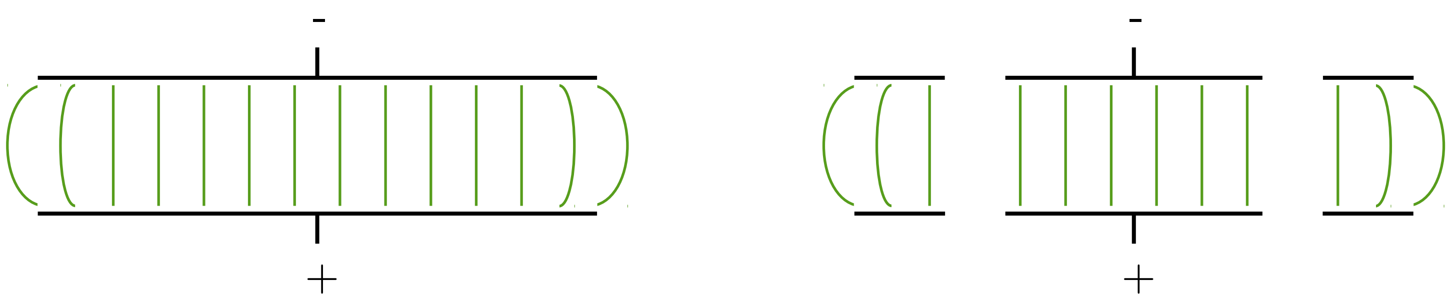
Measurement of the ionization current in TMBi

Repeatable and reproducible measurement



Electron lifetime measurement

- Guard ring : sacrifice a part of the plate surface to ensure that the electric field lines remain parallel throughout the active volume.



- Frisch grid : another electrode kept at an intermediate potential between cathode and anode, to remove the interaction position dependency, from the induced signal on the anode.