DE LA RECHERCHE À L'INDUSTRIE

The diagnostics of the PETAL+ project

B. Vauzour, I. Thfoin , A. Duval,

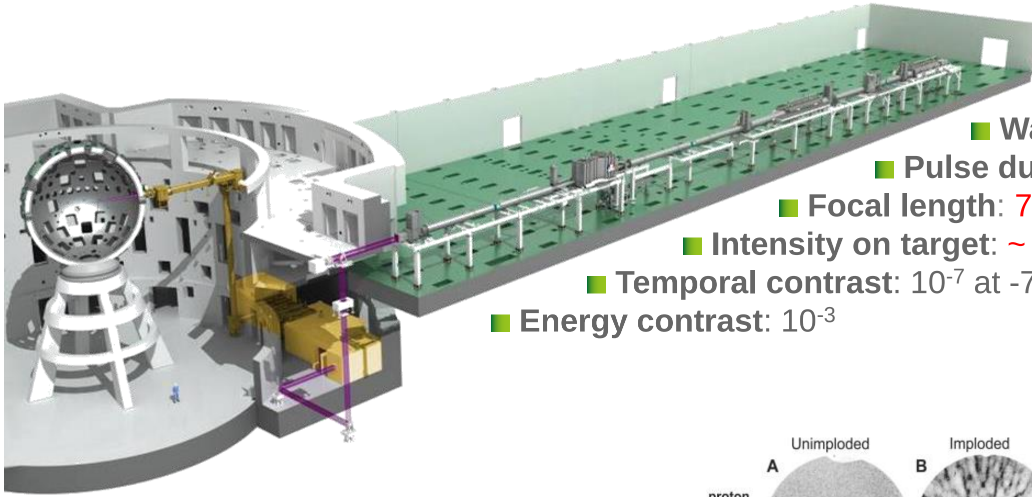
C. Reverdin, B. Rossé, J.-L. Miquel

CEA-NNSA Joint Diagnostic Meeting

June 29-30, 2016

www.cea.fr

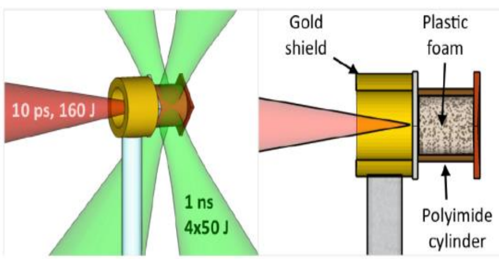
PETAL and the PETAL+ project



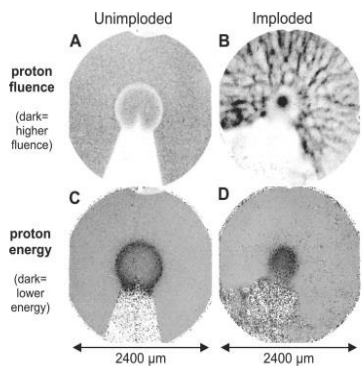
- **Energy**: ~1kJ short term (3,5kJ long term)
- **Wavelength**: 1053 nm (526 nm option)
- **Pulse duration**: from 0.5 to 10 ps
- **Focal length**: 7.8 m (focal spot ~50 µm)
- **Intensity on target**: ~ 10^{20} W/cm²
- **Temporal contrast**: 10^{-7} at -7 ps
- **Energy contrast**: 10^{-3}

A secondary source for:

- X-ray or proton radiography,
- Additional heating of the LMJ target
- Magnetic field characterization,
- Electronic transport experiments,
- …



F. Pérez et al. PPCF, ***51****, 124035 (2009)*

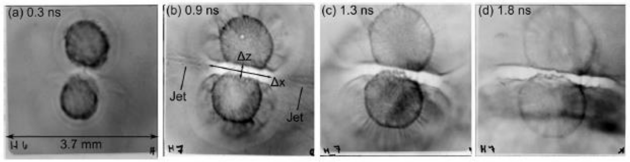


J. R. Rygg et al. Science ***319****,1223-1225 (2008)*

- **PETAL+ project goal: Construction of 3 new diagnostics to characterize the particle source produced by the interaction of PETAL with a target**

D. Batani et al., Phys. Scr, ***T161****, 014016 (2014)*

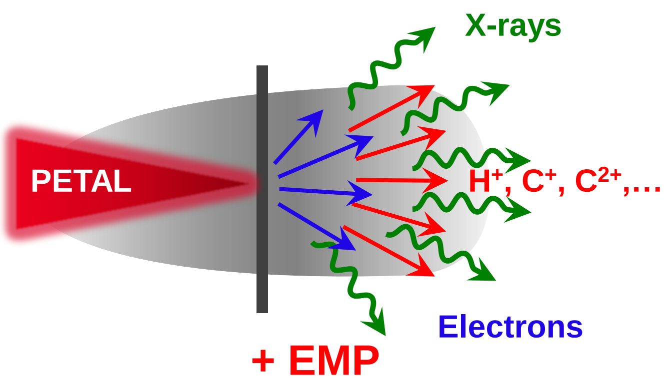
A. Casner et al., HEDP, ***17****, (2014)*

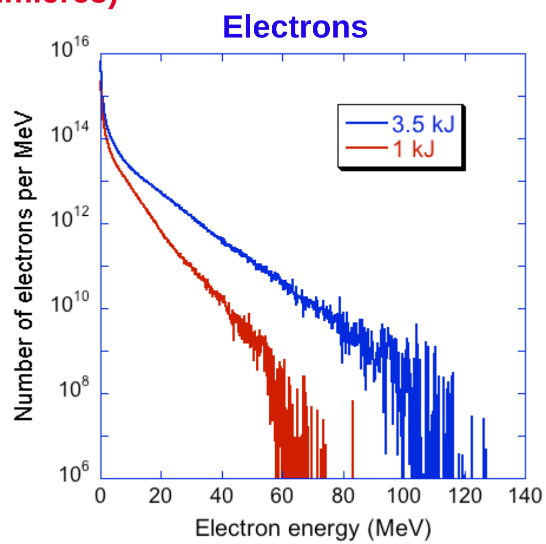


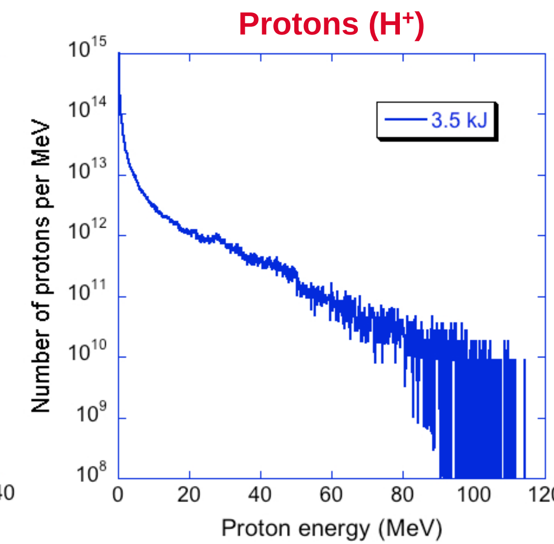
M.J. Rosenberg et al., PRL, ***114****, 205004 (2015)*

Expected particle beams with PETAL

Particle source simulations with PICLS (E. d'Humières)







	X-rays	Electrons	Protons
Spectral range	7 – 100 keV	5 – 150 MeV	0.1 – 150 MeV
Spectral resolution	1/300*	1/20	1/10

*$K\alpha_1$ and $K\alpha_2$ lines must be separated

Passive detectors with a high dynamic range must be used!!!
e.g. Imaging Plates, RCF and CR39 (long term)

DE LA RECHERCHE À L'INDUSTRIE

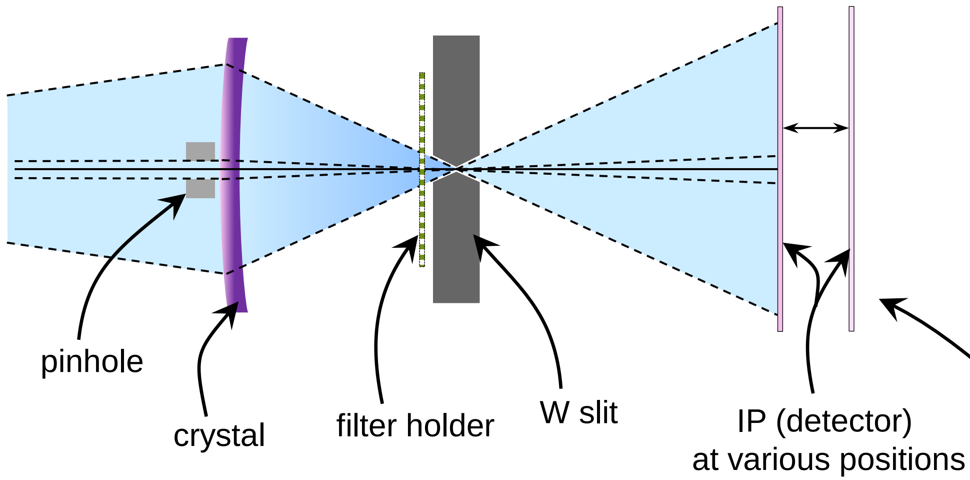
SPECTIX

a X-ray spectrometer

www.cea.fr

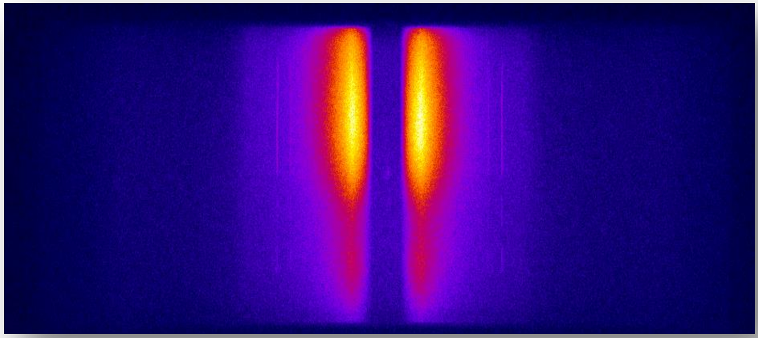
Physical concept of the X-ray spectrometer

Geometrical setup



⇒TCS equivalent

Exemple of a raw spectrum obtained with LCS at LULI



A Cauchois-type hard X-ray spectrometer…

- … which is robust and easy to align
- … that covers a wide spectral range
- … with reduced background noise

X-ray dispersion according to the Bragg's law:

$$2d\ \sin\theta = n\lambda$$

The SPECTIX design

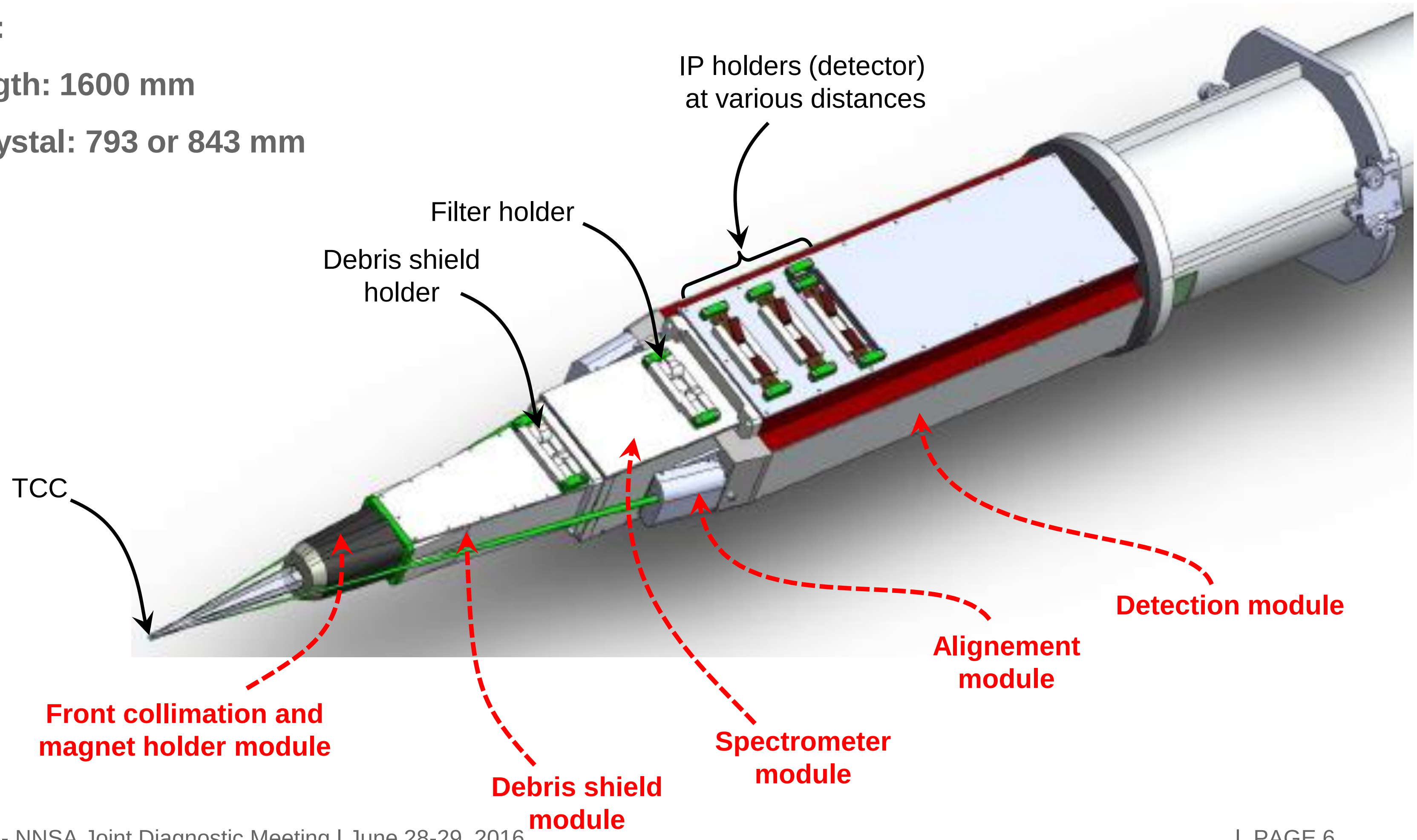
SPECTIX : **S**pectromètre **PE**tal à **C**ristal en **T**ransm**I**ssion **X**

*(**PE**tal **S**pectrometer using a **X**-ray **T**ransm**I**ssion **C**rystal)*

Inserted in the LMJ chamber via a SID

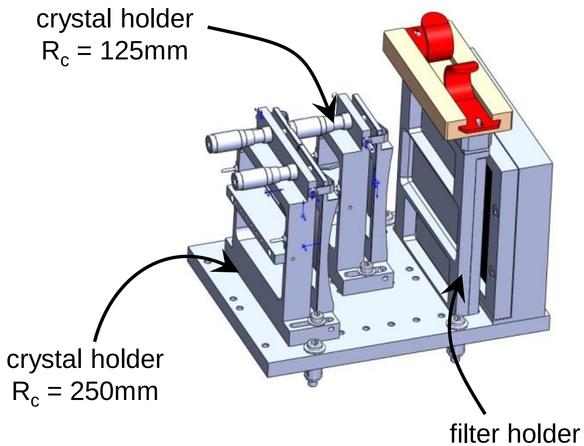
Distances:

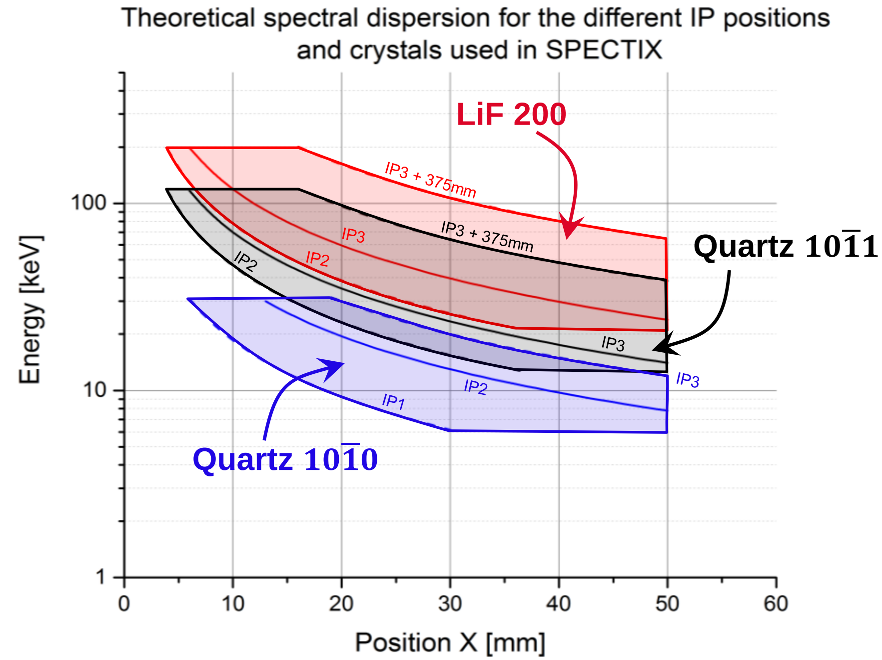
- **Total length: 1600 mm**
- **TCC – crystal: 793 or 843 mm**



Characteristics of the spectrometer module

Spectrometer module





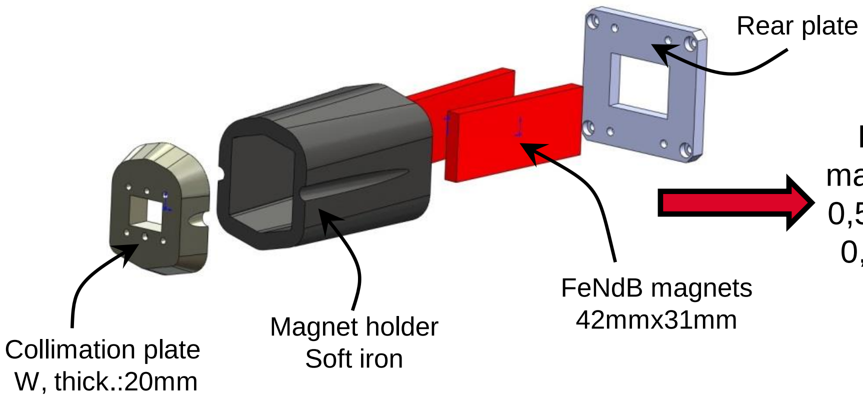
Characteristics of the 3 crystals

Crystal type	2d [Å]	R_c[mm]	Dimensions [mm²]	Target-Crystal distance [mm]	Spectral range [keV]
Quartz (10$\bar{1}$0)	8.512	125	50 x 30	843	6.3 to 31
Quartz (10$\bar{1}$1)	6.687	250	50 x 30	793	14.2 to 117
LiF (200)	4.027	250	50 x 30	793	23.5 to 190

- Enhanced spectral range thanks to a versatile detector positioning and the use of 3 different crystals
- Crystals' reflectivities fully characterized

Remaining background noise removal using the magnet module

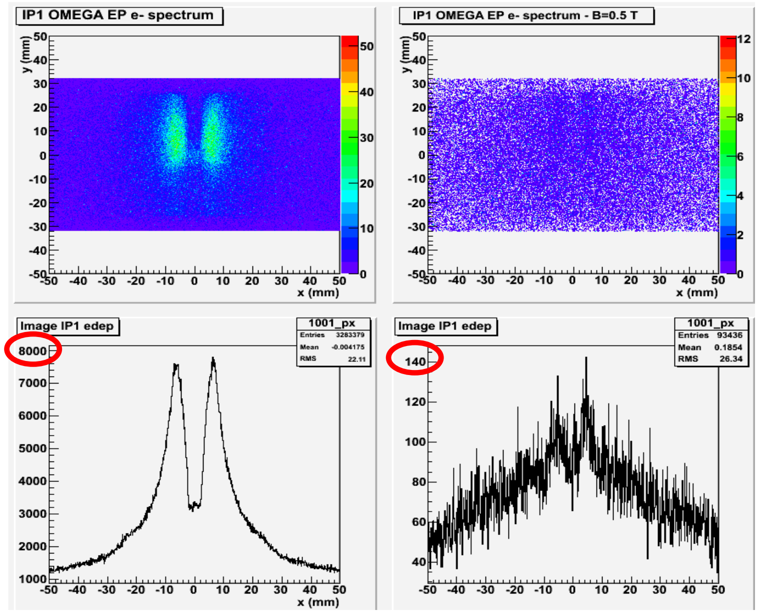
The magnet geometry



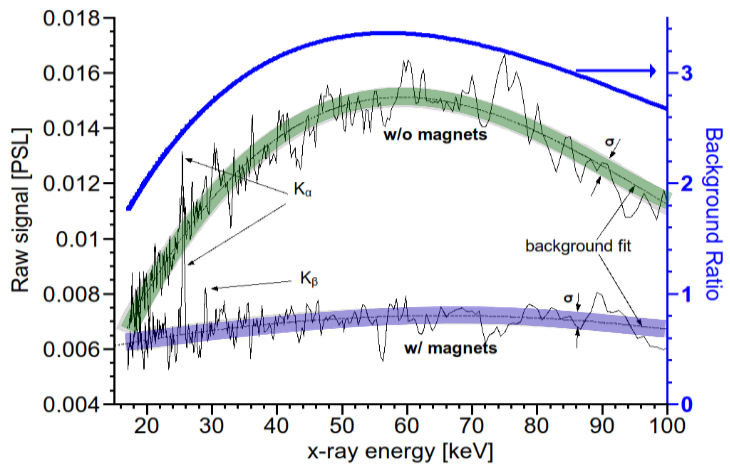
Resulting magnetic field 0,5T (front) to 0,25T (rear)

3D modeling of the noise removal using Geant4 simulations

Without magnet **With magnet**



Experimental validation at LULI2000



I. Thfoin et al., Rev. Sci. Inst., ***85****, 11D615 (2014)*

- Geant4 simulations well reproduce the remaining background noise often observed experimentally
- This background noise is produced by the incoming charged particles that pass through the slit (especially electrons)
- Results (Simulations + experiment) show that the use of a magnet in front of the spectrometer allows to considerably reduce this noise

The SPECTIX performances

	REQUIRED	SPECTIX
Spectral range	7 – 100 keV	7 – 190 keV
Spectral resolution	1/300*	1/300 – 1/50
Dynamic range	10^{10} – 10^{13} ph/sr (over the whole spectral range)	Not fulfilled for E>100keV (>10^{11} ph/sr)

*$K\alpha_1$ and $K\alpha_2$ lines must be separated

Available in 2017 for experiments

DE LA RECHERCHE À L'INDUSTRIE

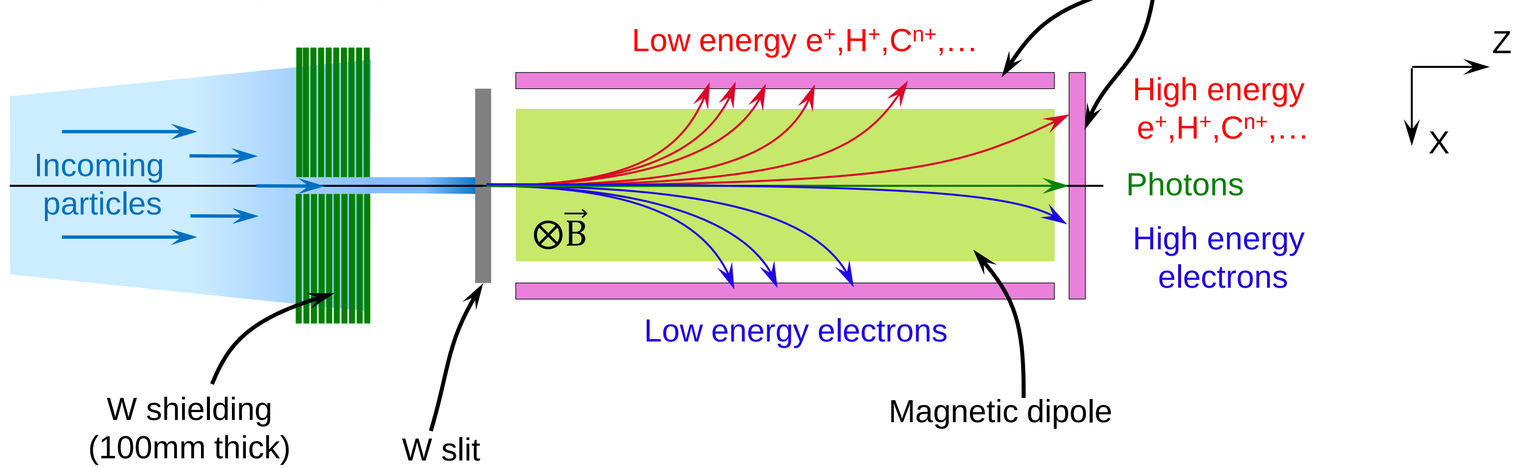
SESAME

the electron spectrometer

www.cea.fr

Physical concept of the SESAME spectrometer

Lorentz force: $\overrightarrow{F_L} = \mathrm{q}(\vec{v} \times \vec{B})$



Dispersion equation

- Energy dispersion along the X-axis due to $\vec{B}$

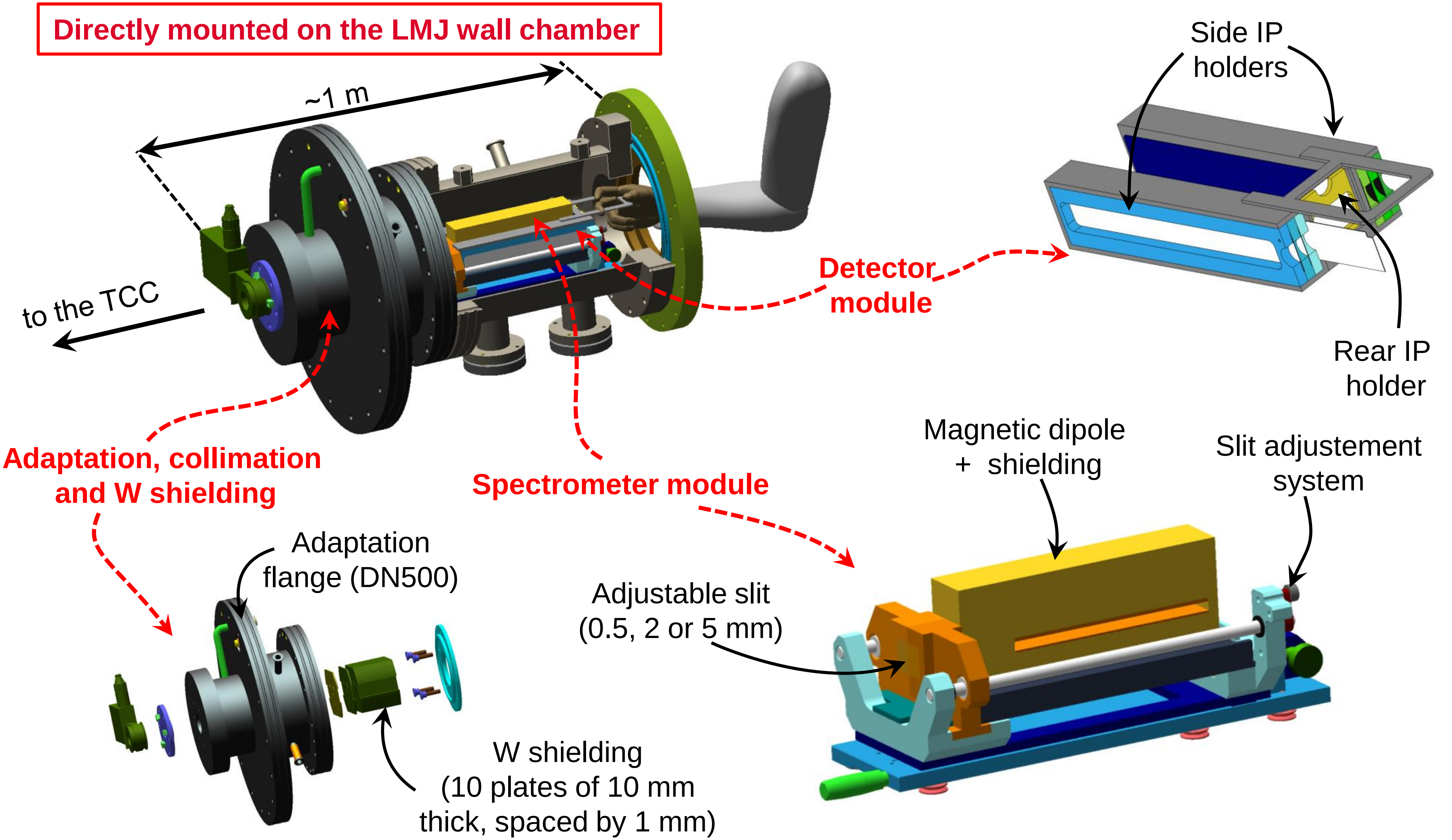
$$E_{kin} = \frac{q^2 e^2 L_m^2\, B^2 \left(D_m + \frac{L_m}{2}\right)^2}{2mX^2}$$

L_m: Magnets length
D_m: Drift distance between magnets and detector
m : Particle mass

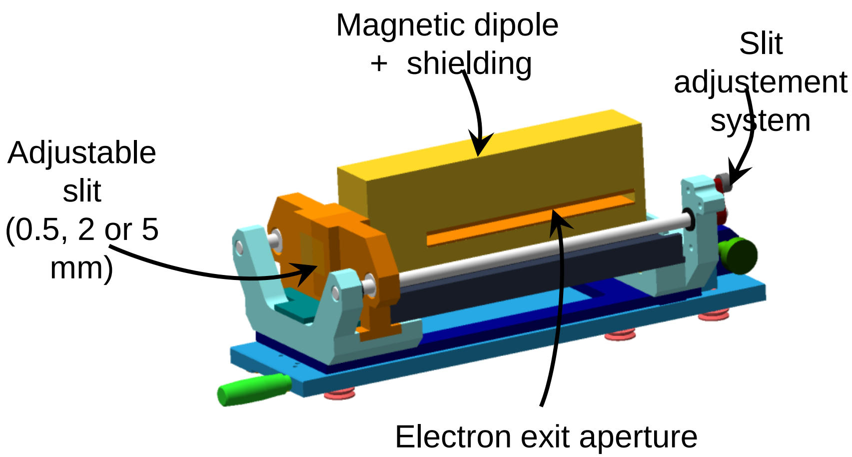
The SESAME design

SESAME: **S**pectromètre **E**lectron**S** **A**ngulaire **M**oyennes **E**nergies

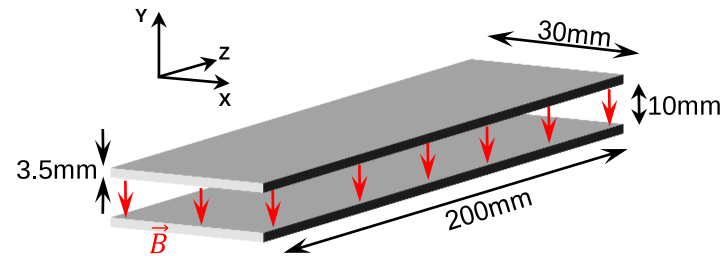
Directly mounted on the LMJ wall chamber



Characteristics of the spectrometer module



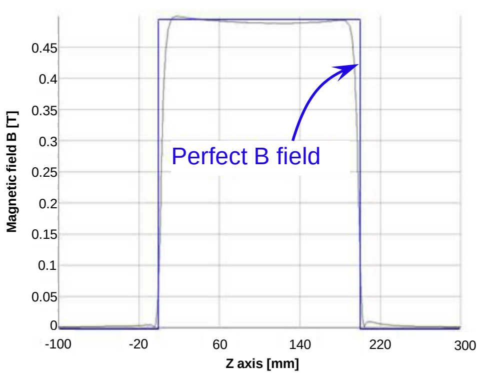
Magnetic dipole characteristics



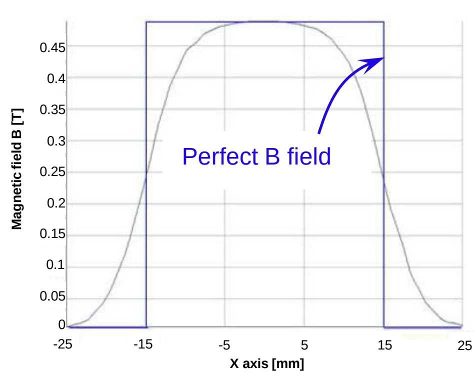
B field [T]	0,5
Magnet material	NdFeB (N45)
Magnet holder material	Soft iron

B field modelling with OPERA 3D

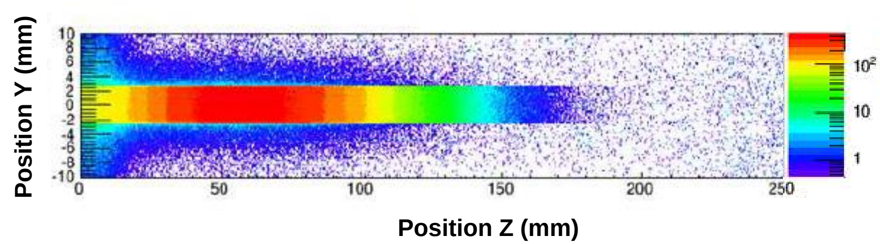
Along the Z axis



Along the X axis



Geant4 simulation of a typical electron trace obtained with SESAME (side IP)



The SESAME performances

	REQUIRED	SESAME
Spectral range	5 – 150 MeV	5 – 150 MeV
Spectral resolution	1/20 (5%)	1/100 (1%) – 1/16 (6%)
Dynamic range	10^8 – 10^{15} e^-/MeV/sr (over the whole spectral range)	3.10^9 – 5.10^{15} e^-/MeV/sr

Available in 2017 for experiments

DE LA RECHERCHE À L'INDUSTRIE

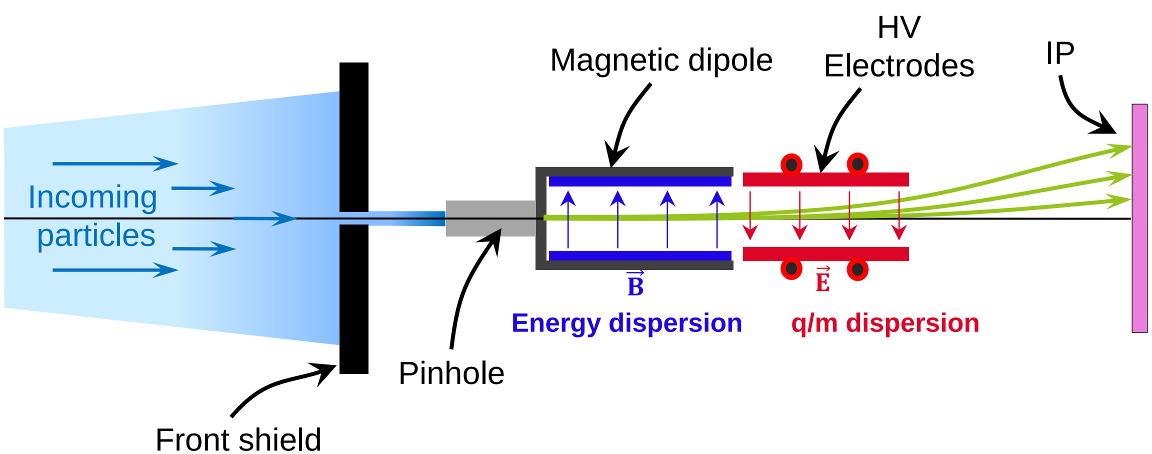
SEPAGE

the proton and electron spectrometer

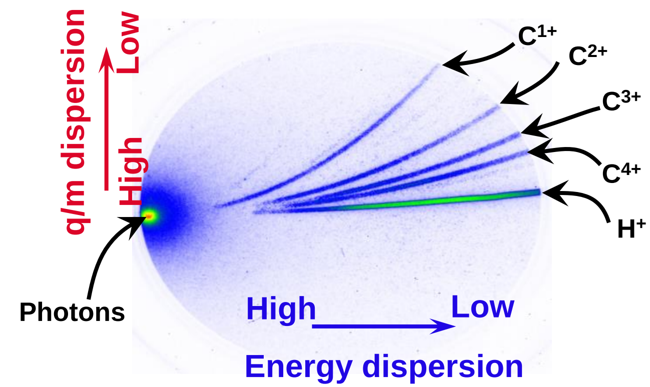
www.cea.fr

Physical concept of the Thomson Parabola (TP)

Lorentz force: $\overrightarrow{F_L} = q(\vec{E} + \vec{v} \times \vec{B})$



Example of TP raw spectra



Due to the Lorentz force:

- Energy dispersion along the X-axis due to $\vec{B}$
- q/m dispersion along the Y-axis due to $\vec{E}$

$$Y = \frac{A\, m\, L_e\, E\, \left(D_e + \frac{L_e}{2}\right)}{q e L_m^2\, B^2 \left(D_m + \frac{L_m}{2}\right)} X^2$$

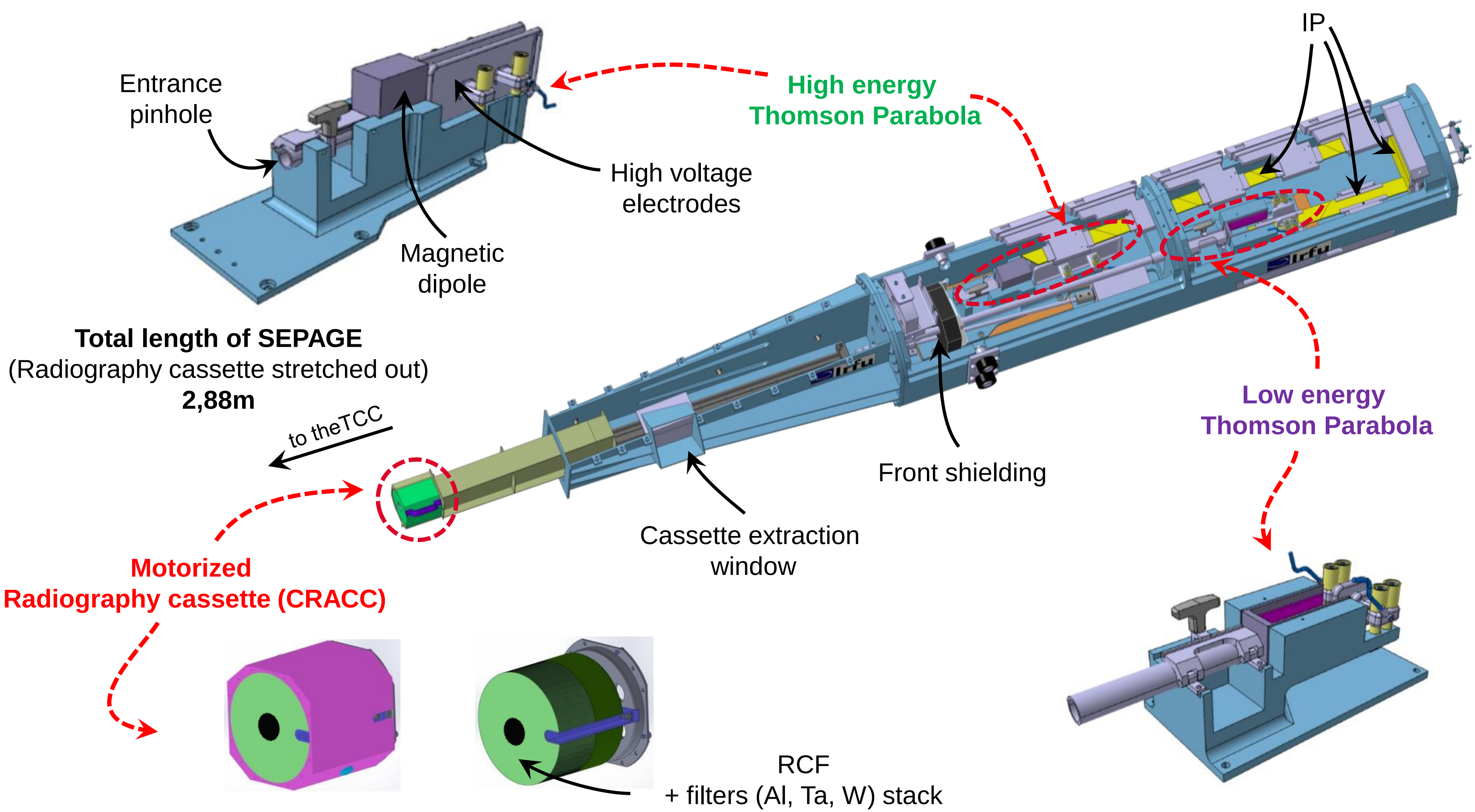
L_e: Electrodes length
L_m: Magnets length
D_e: Drift distance between electrodes and detector
D_m: Drift distance between magnets and detector
m : Particle mass
A : Atomic weight

The SEPAGE design

SEPAGE : **S**pectromètre **E**lectrons **P**rotons **A** **G**randes **E**nergies

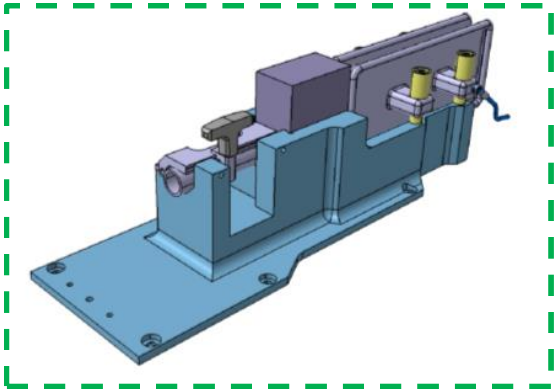
(High Energy Electrons and Protons Spectrometer)

Inserted in the LMJ chamber via a SID

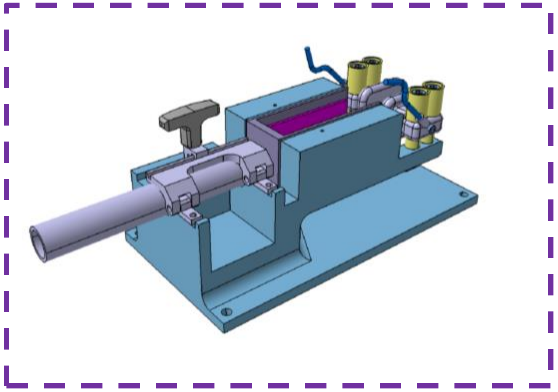


Characteristics of the two Thomson Parabola

High energy TP



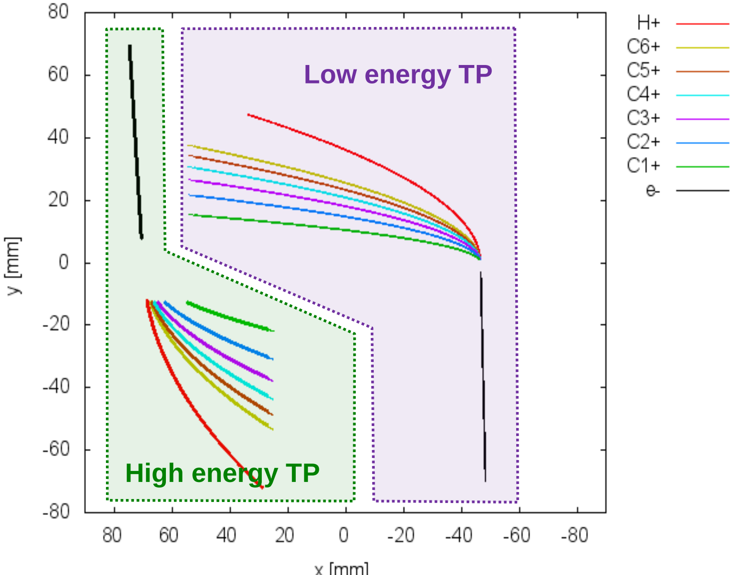
Low energy TP



Characteristics of the two TP

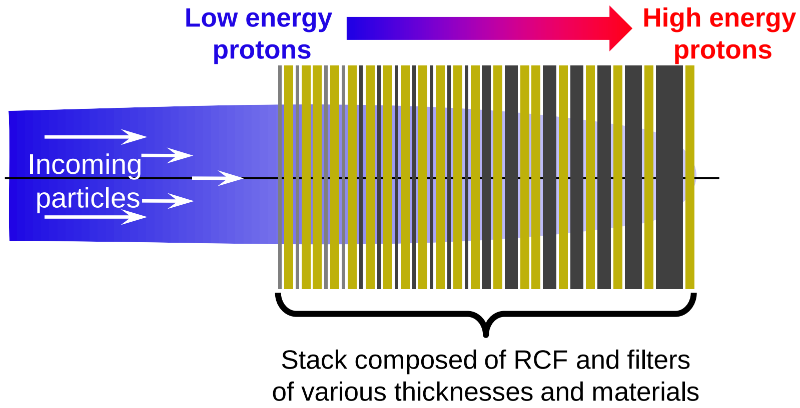
TP	High energy	Low energy
B field [T]	0.5	0.05
Magnet dimensions [mm^3]	6x52x100	3x40x104
E field [kV/mm]	5	2.6
Electrode dimensions [mm^3]	2x100x240	2x30x40
Pinhole dimensions	500 µm x 40 mm	200 µm x 4 mm
Proton range [MeV]	**10 – 200**	**0.1 – 20**
Electron range [MeV]	**8 – 150**	**0.1 – 20**
Dynamic [MeV^{-1}sr^{-1}]	$10^8 – 10^{14}$	$10^8 – 10^{16}$
Field of view	~10 mm (4,2mrad)	~2,3 mm (1,25mrad)

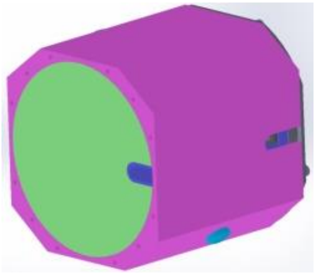
Raw TP spectra expected with SEPAGE (Rear IP)

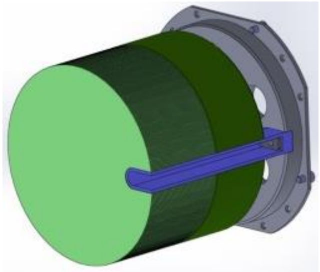


The radiography cassette

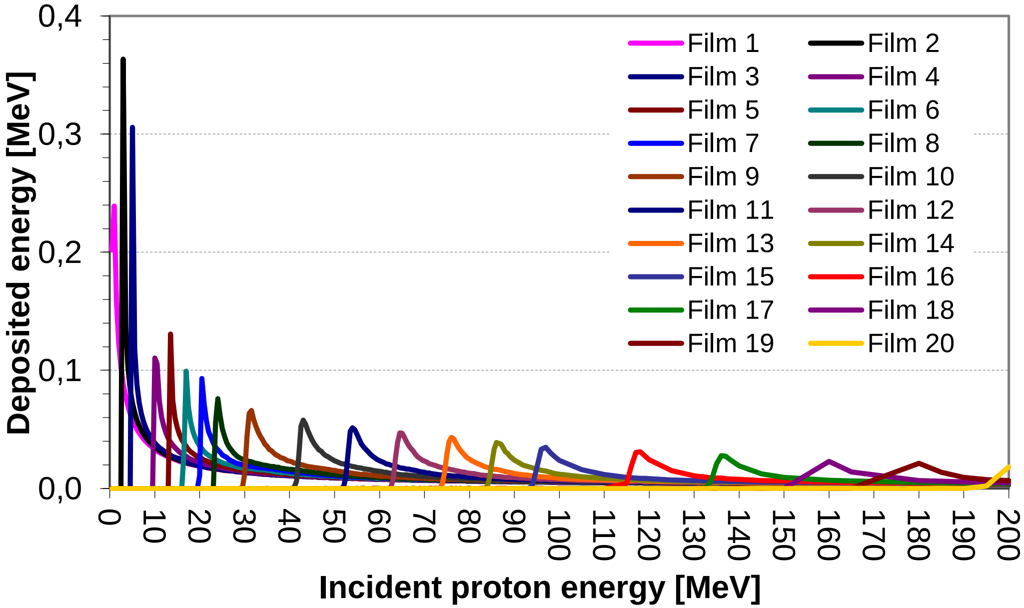
Radiography cassette setup







Geant4 simulations of dose deposition inside a stack of 20 RCF



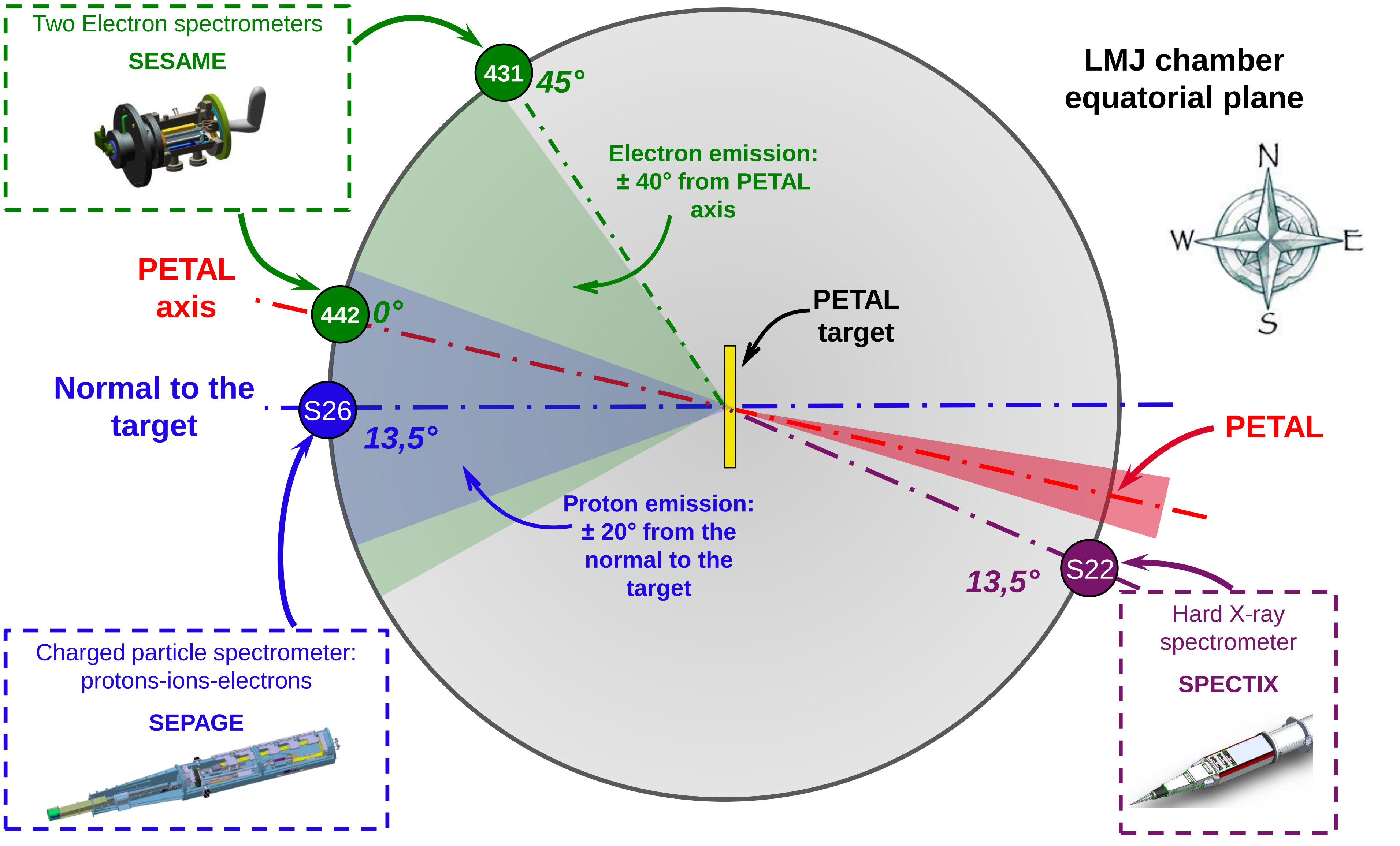
- Proton range: 3 – 200 MeV
- Film diameter: 95 mm
- Adjustable distance to TCC (min 100 mm)
- Various type of RCF to cover the whole dynamic range
- Stack design adaptable to experiments

The SEPAGE performances

	REQUIRED	SEPAGE
Spectral range	0.1 – 200 MeV	0.1 – 200 MeV
Spectral resolution	1/10	1/10
Dynamic range	$10^6 – 10^{15}$ p^+/MeV/sr (over the whole spectral range)	**Low energy TP** $10^8 – 10^{16}$ p^+/MeV/sr **High energy TP** $10^6 – 10^{14}$ p^+/MeV/sr

Radiography cassette (CRACC) available in 2017 for experiments
Spectrometer (TP) available in 2018

Overview of the PETAL+ diagnostics



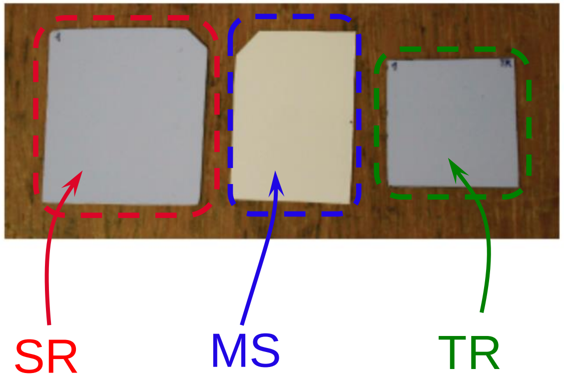
DE LA RECHERCHE À L'INDUSTRIE

Calibration of the detectors

www.cea.fr

Absolute X-ray calibration of the Imaging Plate

3 different types of IP

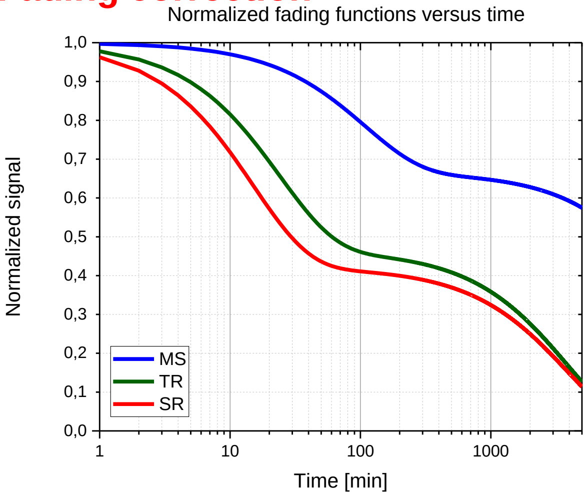


X-ray source ^{55}Fe + fit

$$f(t) = A_1 e^{-t/B_1} + A_2 e^{-t/B_2}$$

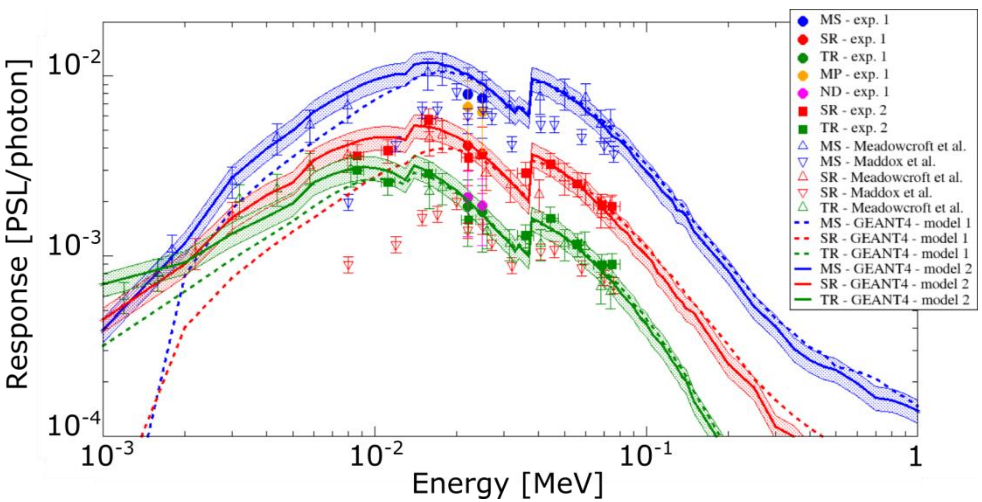
Exp + Geant4 simulations

Fading correction



G. Boutoux et al. Rev. Sci. Inst. ***86****, 113304 (2015)*

IP response as a function of the X-ray energy



G. Boutoux et al. Rev. Sci. Inst. ***85****, 043108 (2016)*

- Absolute calibration of the 3 different IP for X-rays in the **1-100keV** range
- Good agreement between Geant4 simulations and experimental results
- The present model allows to extend the calibration up to MeV energies
- **Absolute calibration for protons and electrons have also been realized**

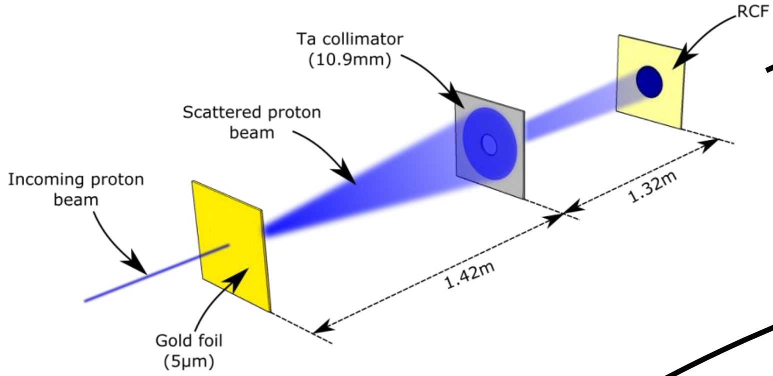
⇒ *G. Boutoux et al. Rev. Sci. Inst.* ***86****, 113304 (2015) (Electrons)*

⇒ *N. Rabhi et al. Rev. Sci. Inst. To be published (2016) (Electrons)*

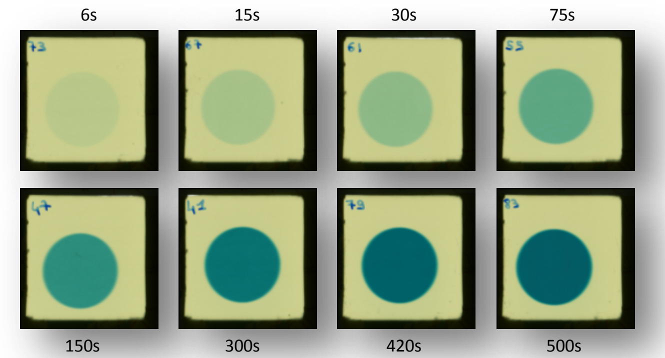
⇒ *T. Bonnet et al. Rev. Sci. Inst.* ***84****, 013508 (2013) (Protons)*

Absolute calibration of the RCF

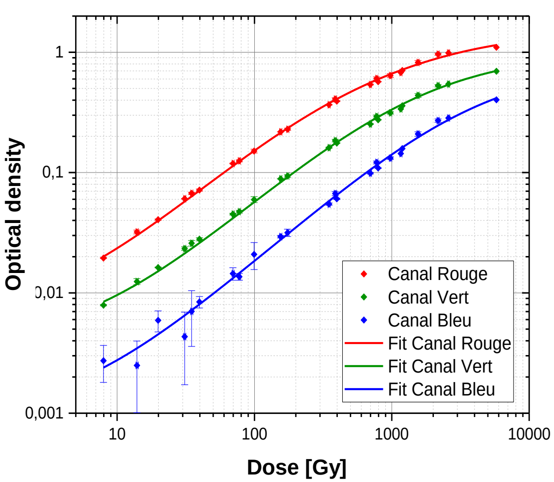
Experimental setup on the 4MV accelerator (CEA/DIF Van de Graaff)



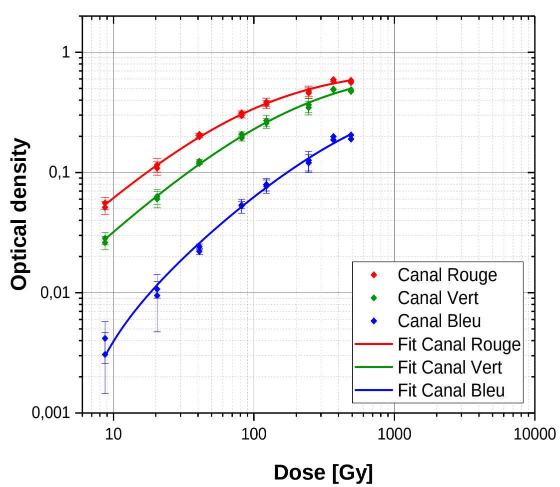
RCF response to protons versus exposure time



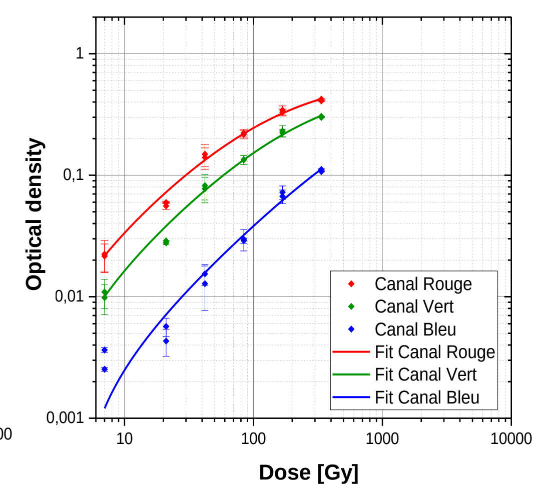
HD-V2



EBT-3



EBT-XD



Summary

- The PETAL+ project $\Rightarrow$ construction of 3 new diagnostics to detect and characterize the particle produced by PETAL
  - An X-ray spectrometer: **SPECTIX**
  - An Electrons spectrometer: **SESAME**
  - An Electrons/Protons/Ions spectrometer: **SEPAGE** + Radiography cassette (**CRACC**)

- **SPECTIX**, **SESAME** and **CRACC** are under construction and will be available in **2017**
- **SEPAGE** will be available in **2018**
- Absolute calibration of the new RCF generation (HD-V2, EBT3, EBT-XD and MD-V3) is in progress

Collaborators

CEA-DAM-DIF : A. Duval, C. Reverdin, B. Rossé, I. Thfoin, L. Lecherbourg, B. Vauzour, A. Casner, R. Maroni, J.-L. Miquel

CEA-DAM-CESTA : F. Granet, S. Noailles

CEA-DSM-IRFU : J.C. Toussaint, B. Gastineau, D. Leboeuf, A. Chancé, J.C. Guillard, F. Harrault,, X. Leboeuf, D. Loiseau, A. Lotode, C. Pès

LULI : S. Bastiani-Ceccotti, E. Brambrink J. Fuchs, M. Koenig, J.R. Marquès

LKB : C. Szabo

CEA-DSM-IRAMIS : T. Ceccotti, S. Dobosz-Dufrénoy

CELIA : D. Batani, G. Boutoux, J.E. Ducret, S. Hulin, E. D'Humières, K. Jakubowska, N. Rabhi

CENBG : L. Sérani

Thank you!!!

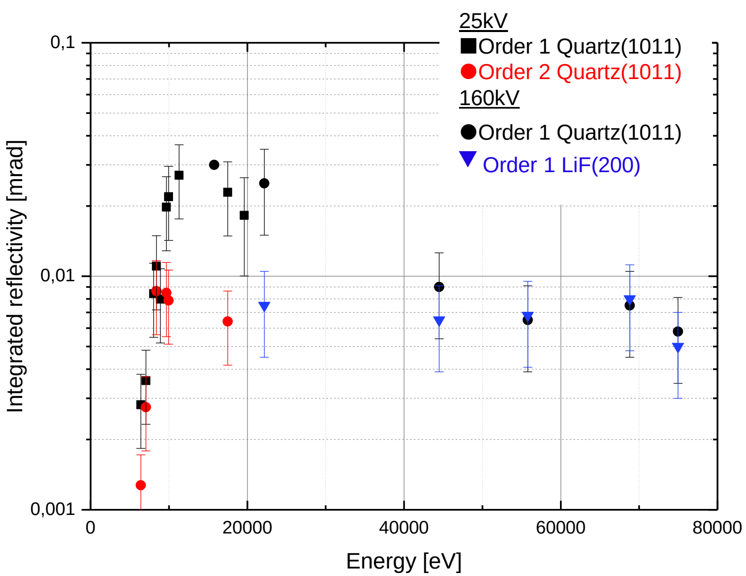
Commissariat à l'énergie atomique et aux énergies alternatives
Centre de Saclay | 91191 Gif-sur-Yvette Cedex
T. +33 (0)1 69 26 40 00 | F. +33 (0)1 XX XX XX XX

DIF
DCRE
SCEP

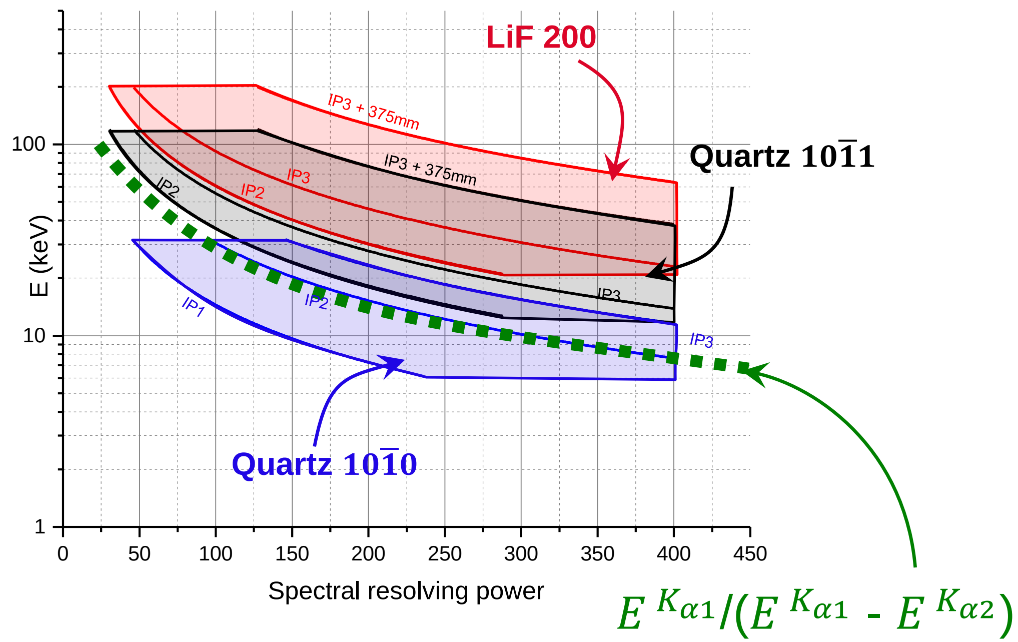
DE LA RECHERCHE À L'INDUSTRIE

Crystal reflectivities and spectrometer resolution

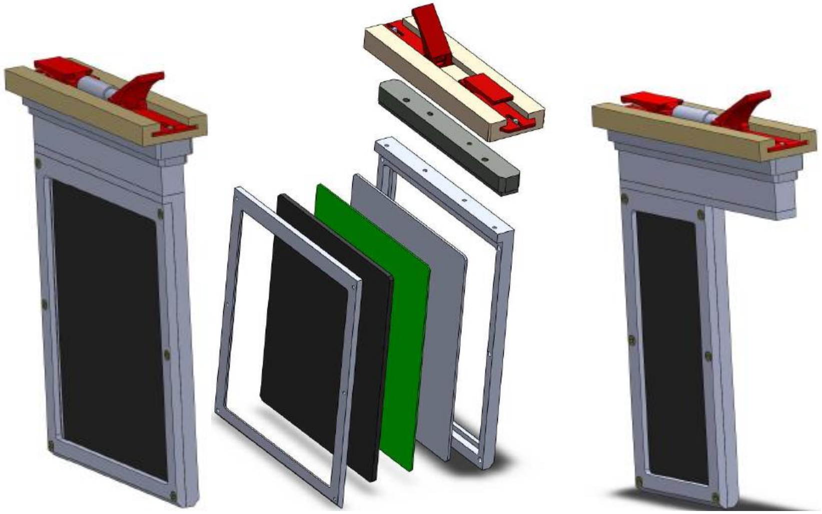
Integrated reflectivities

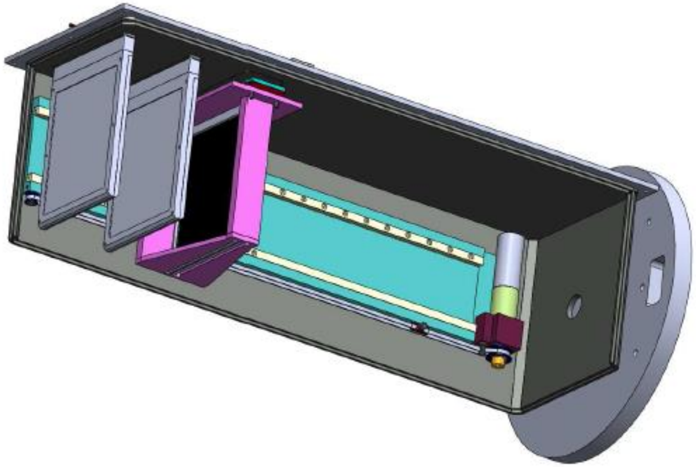


Spectrometer resolving power (with IP SR)



The detector holders

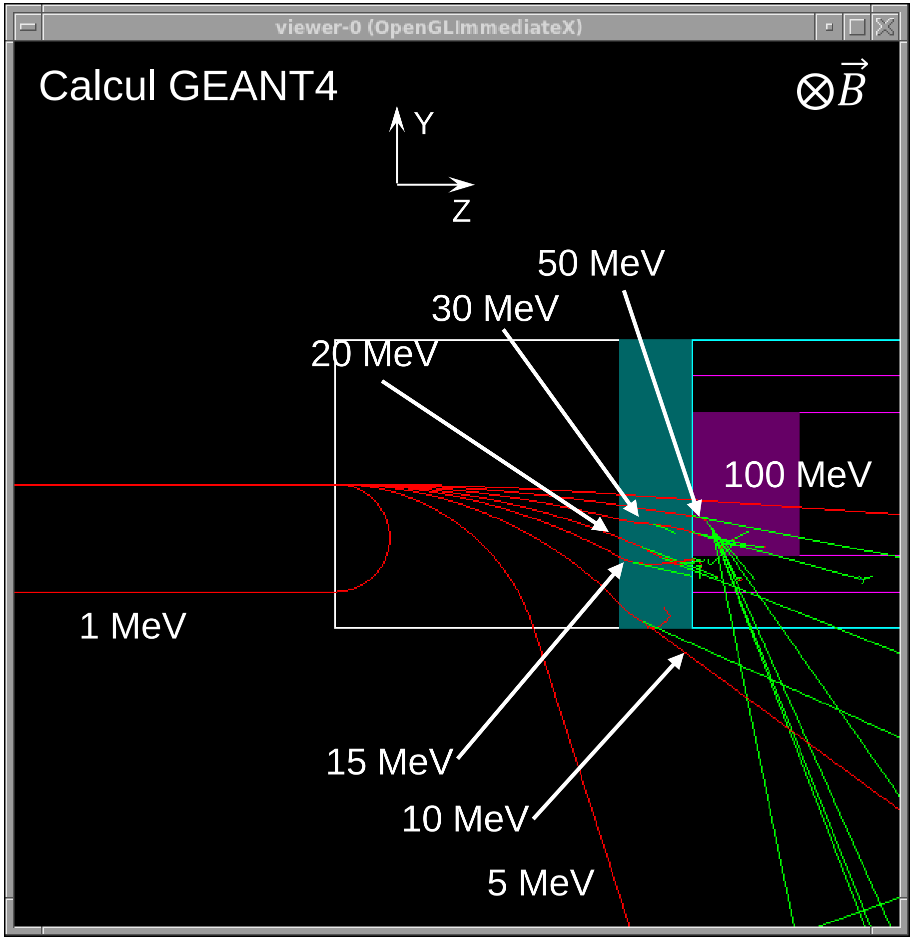


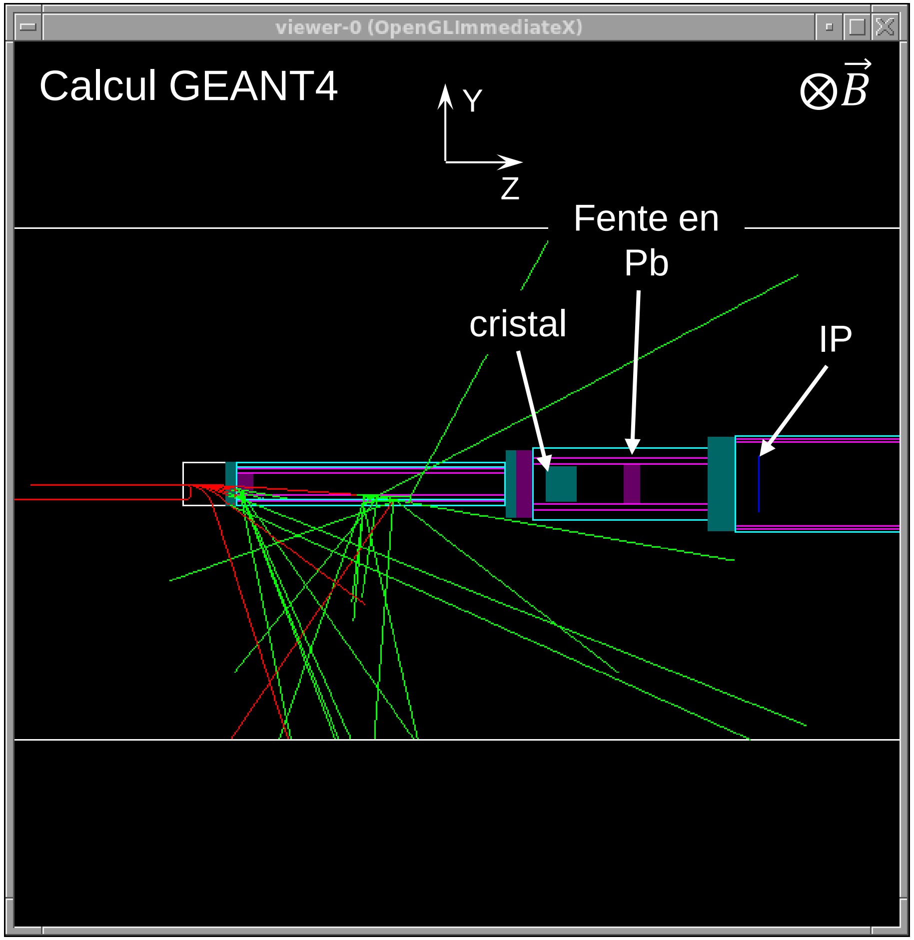


Geant4 simulations of electron deviation in the presence of the front magnet

Magnetic field: 0,5 T parallel to the X-axis (horizontal), length: 50 mm.

All the electrons with E<100 MeV are deviated before the crystal.

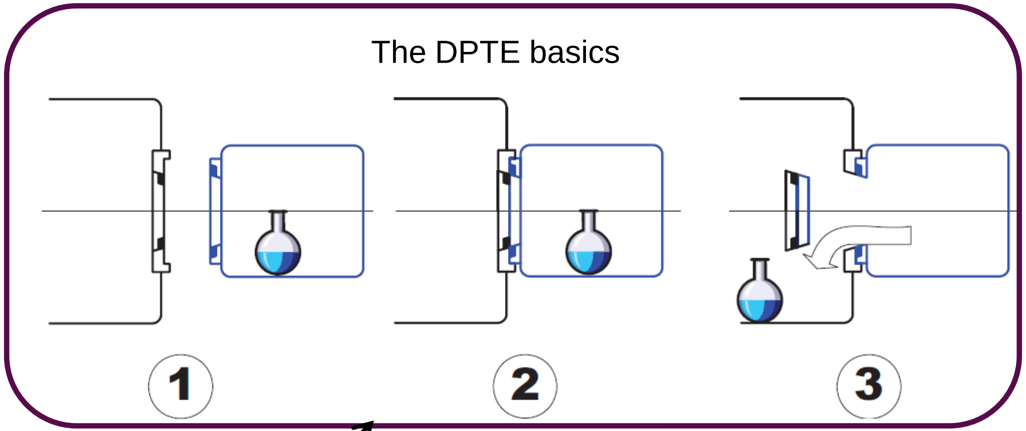




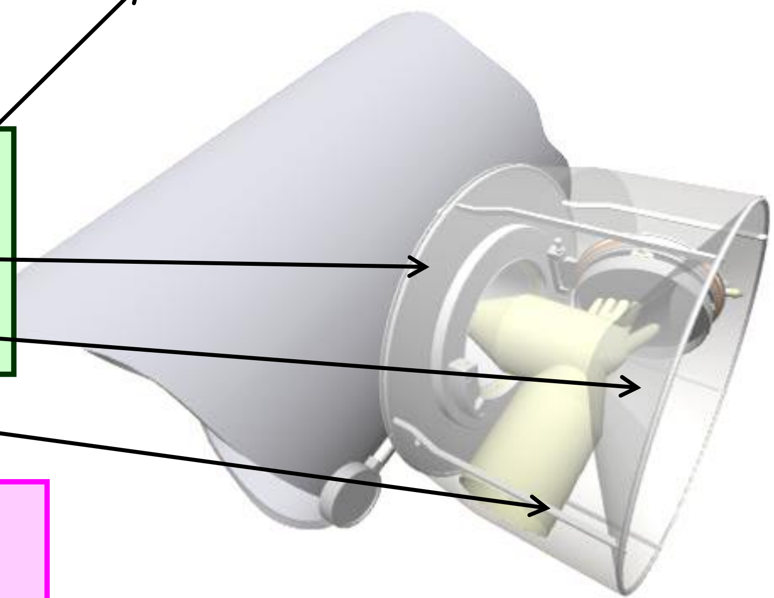
How to get back detectors which are under confinement?

Needs: get back/replace films between two shots.

Constrains :
- maintain the continuity of the confinement
- vacuum limit of the LMJ chamber
- being able to see what we are doing
- resist to the nuclear ventilation system
- adapted to the arm length



Solution:
- Use of the DPTE (Vacuum proof double doors transfer system)
- The solid part is vacuum compatible
- Flexible transparent film
- Deformable structure



Prototype is under construction (CESTA/DLP) and will be implemented on the front window of the SID+ for SPECTIX and SEPAGE, and at the rear of SESAME