Diamonds for Beam Loss monitoring of LIPAc

ADAMAS – GSI, December 18th 2012

CEA Saclay:

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ADAMAS: Advanced Diamond Assemblies

Overview

IFMIF, LIPAc: a brief introduction

CVD diamonds purpose

Diamonds as µLoM*?

- Cryogenic ability
- counting rates evaluation
- electronics

Summary

*µLoM: micro Losses Monitor

IFMIF

(International Fusion Materials Irradiation Facility)

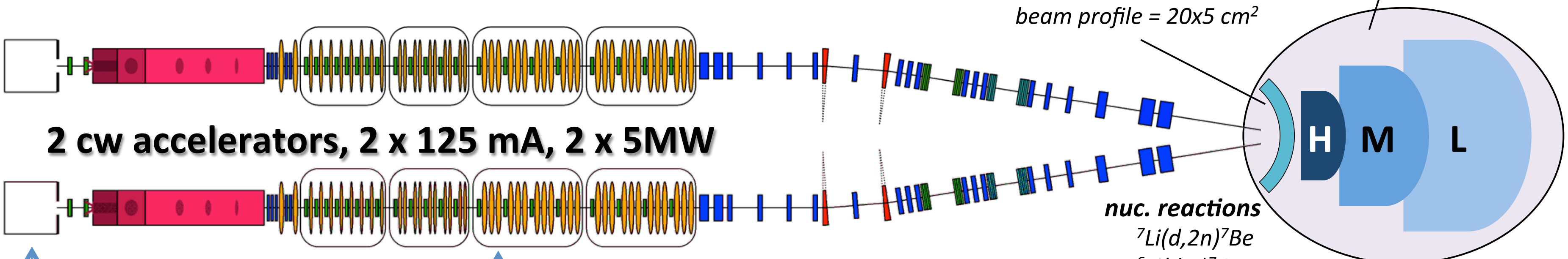
International agreement of the "**Broader Approach**" (Japan + Europe in Feb. 2007)
= IFMIF + IFERC + JT60-SA

IFMIF* : to test materials submitted to very high neutron fluxes for future **Fusion** Reactors.

Very huge neutron source: flux ~ 10^{17} neutrons/s

Lithium Target
25 mm thick, 15 m/s
beam profile = 20x5 cm²

Test Cell



RFQ 5 MeV

deuteron source
140/150 mA, 100 keV

Superconductive Linac 40 MeV
(Half Wave Resonators)

High	> 20 dpa/y	0.5 l
Medium	> 1 dpa/y	6 l
Low	1 dpa/y	> 8 l

LIPAc

(Linear IFMIF Prototype Accelerator)

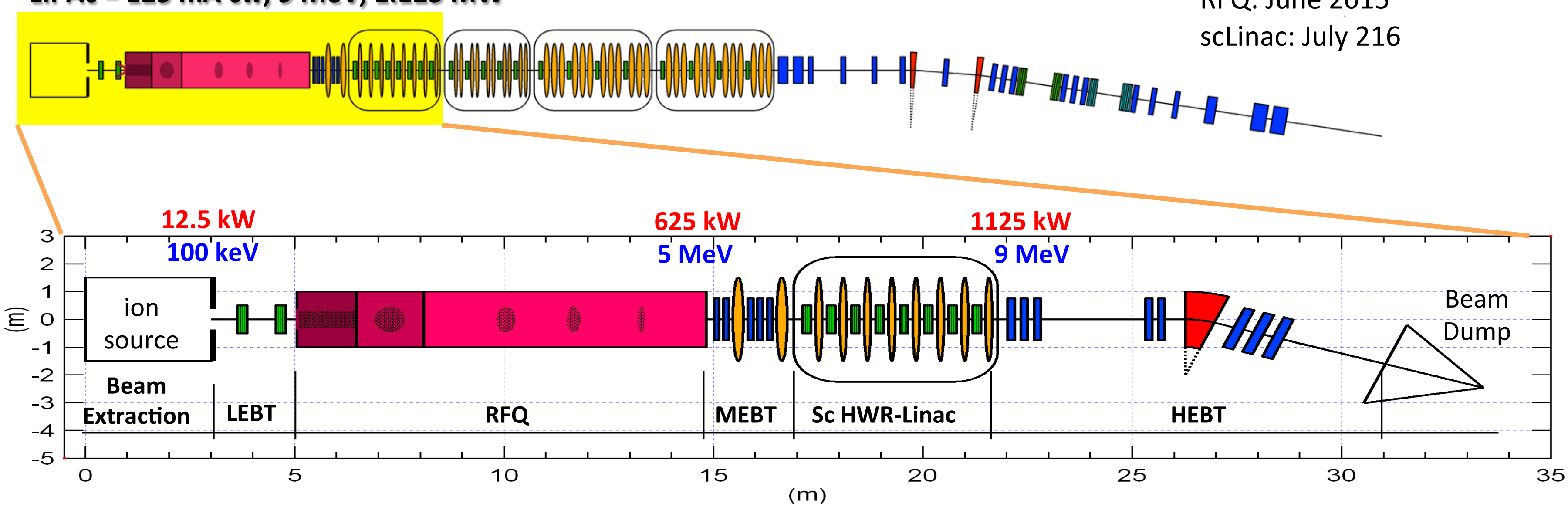
Validation phase:

prototype accelerator → LIPAc (Rokkasho – Japan)

Commissioning at Rokkasho beginning:

Injector: March 2013
RFQ: June 2015
scLinac: July 216

LIPAc = 125 mA cw, 9 MeV, 1.125 MW



LEBT / **MEBT** / **HEBT** = **L**ow / **M**edium / **H**igh **E**nergy **B**eam **T**ransport
RFQ = **R**adio **F**requency **Q**uadruple

Beam tuning challenge

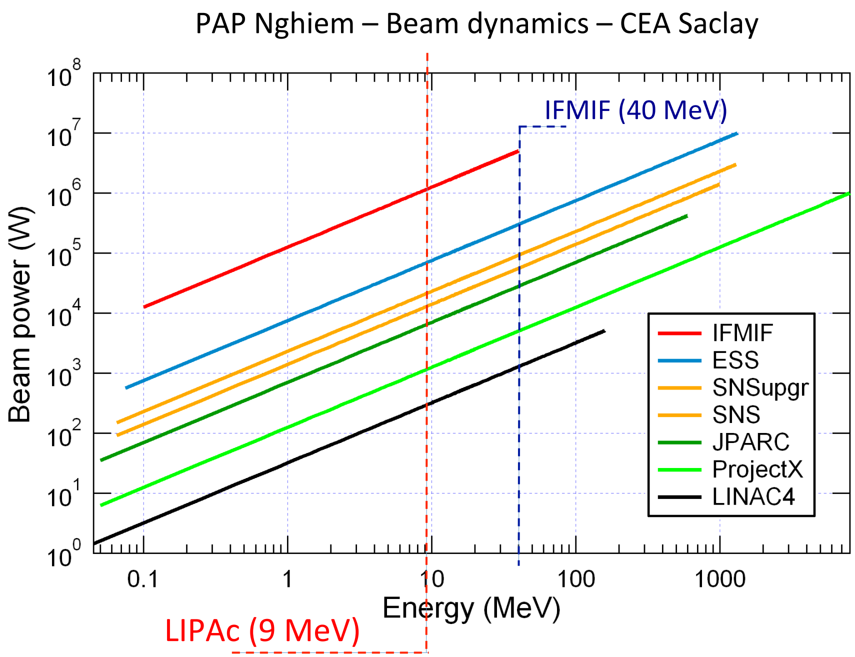
Very challenging machine

- highest beam power
- highest space charge

Space Charge ➞ difficulties for beam tuning (superconductive cavities) ⇒ **original proposition**:

➞ not optimizing the beam core
➞ but, minimizing the beam halo

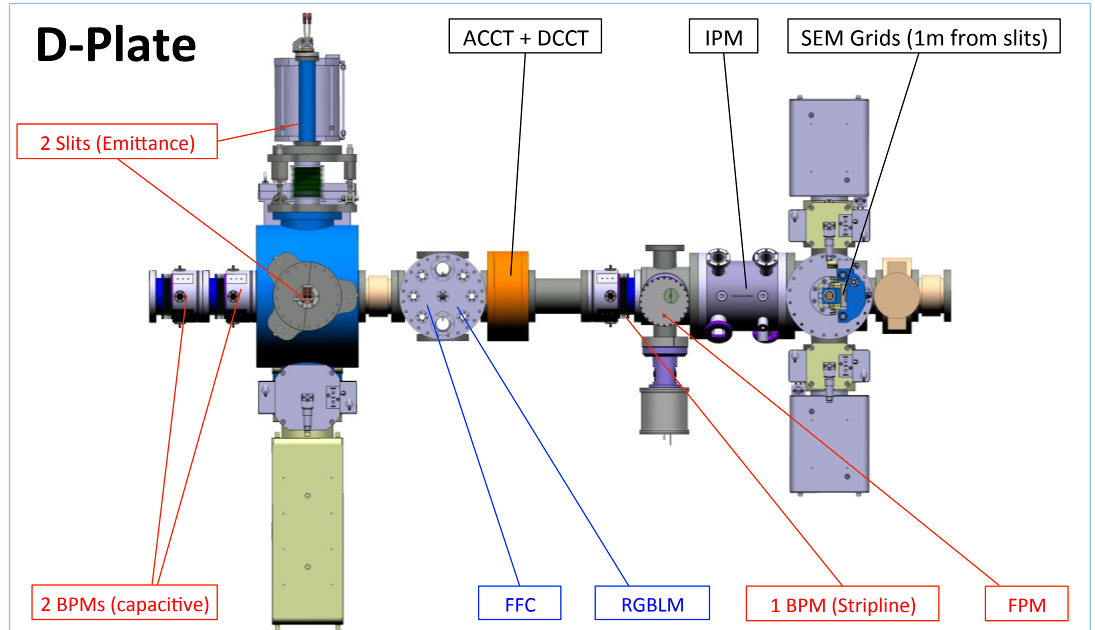
⇒ CVD diamonds for beam halo measurement

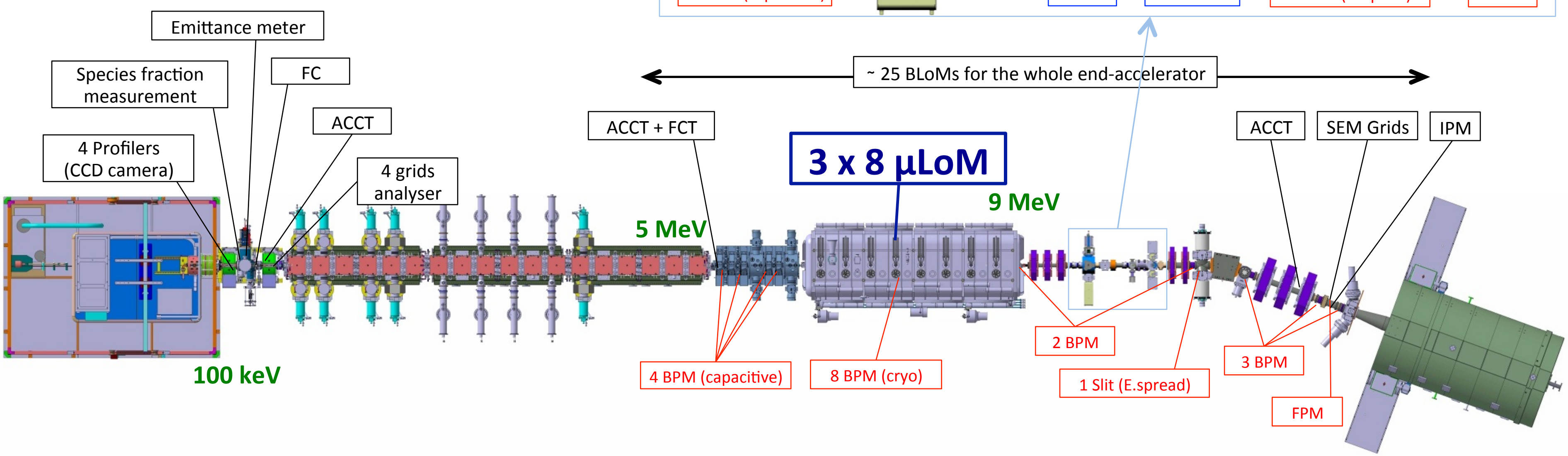


LIPAc

deuteron beam:

E_{max} = 9 MeV
I = 125 mA
P_{max} = 1.125 MW
Duty Cycle: <10^{-4} to cw
RF: 175 MHz (5.7 ns)





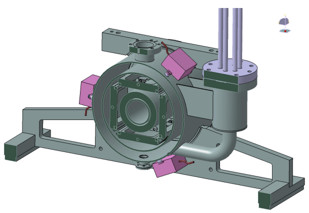
Diamond as µLoM

Ideal micro losses monitor:

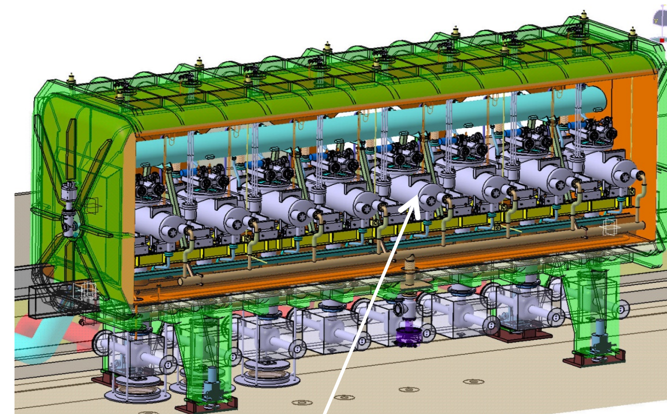
→ sensitive to neutrons, less to X-rays and γ produced by sc cavities
→ reasonable counting rates in ≈ minute (for pulsed beam)
→ ability to work at 4.5K
→ very good reliability (no possibility of dismounting) and radiation hardness
→ **compromise:** single crystalline **CVD diamond** (Chemical Vapor Deposit)

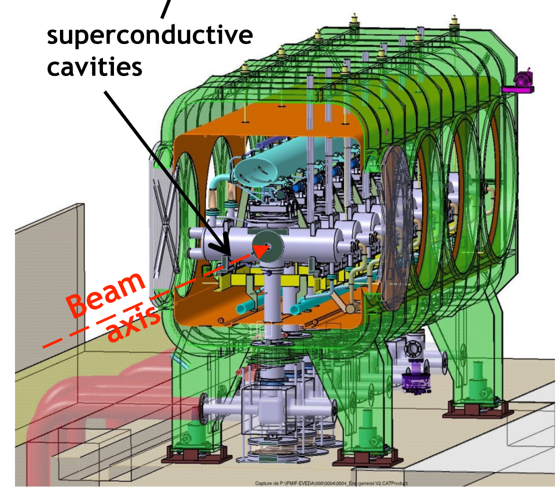
Objective: 3 diamonds/ensemble (8 × [cavity + solenoid + BPM*])

→ improve reliability
→ better transverse localization



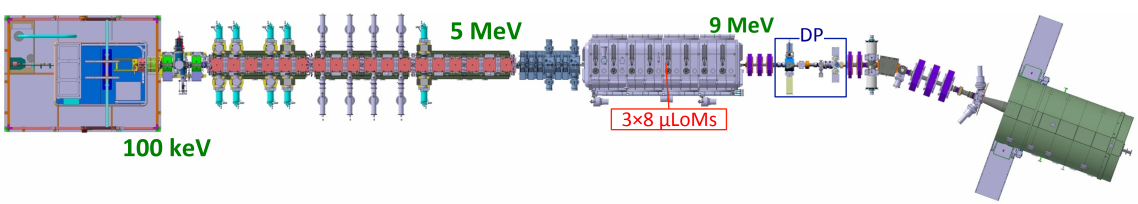
*BPM: Beam Position Monitor





Feasibility study:

→ cryogenic temperatures
→ simulation for 1W/m losses
→ electronics



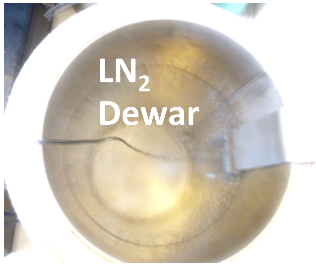
Cryogenic temperature ability?

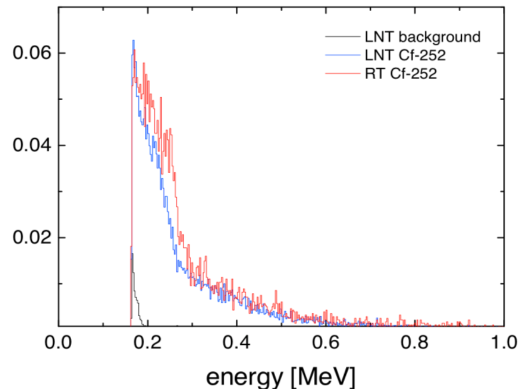
2010 : nothing was found in literature about diamond at cryogenic temperature

- **Test at 77 K (LN_2) ➞ Saclay, December 2010**

  ^{252}Cf: "neutrons" and γ
  mono CVD: 4×4×0.5 mm^3

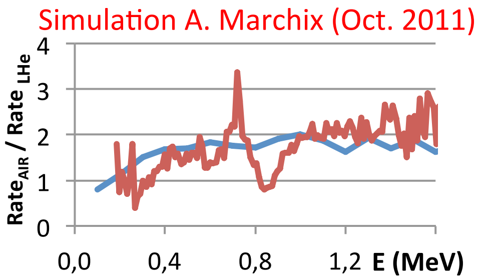
  ⇒ good agreement with simulation

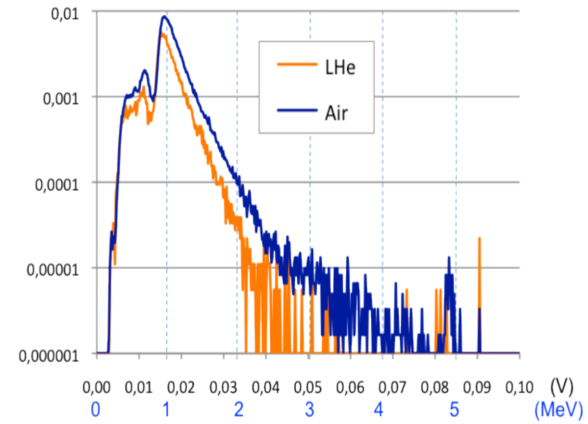




- **Test at 4.5 K (LHe) ➞ Saclay, May 2011**

  ^{252}Cf: "neutrons" and γ





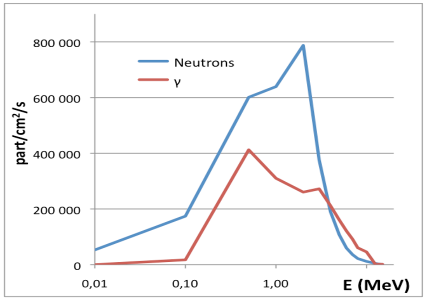
⇒ good agreement with simulation

Results show diamond ability to work at cryogenic temperature

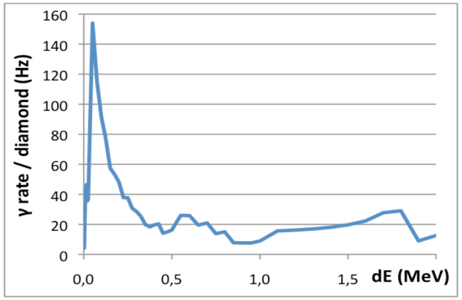
Feasibility study: counting rates

Rate versus the electronic threshold (keV) for neutron & γ (*calculated for 1W/m beam energy losses*)

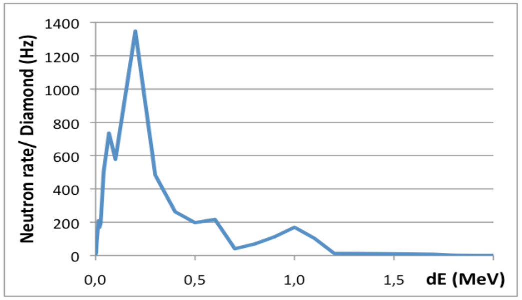
Incident neutron & γ spectra



ΔE **γ** spectrum in diamond



ΔE **neutron** spectrum in diamond

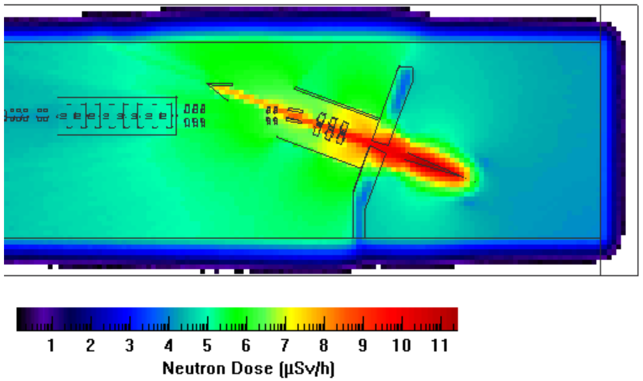


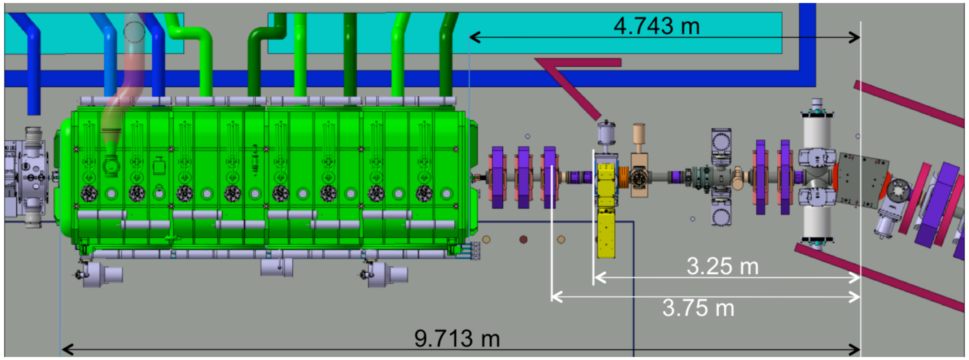
Simulation MCNPX, A. Marchix (Oct. 2011)

Threshold	γ+n	
	Continuous beam	pulsed beam: 1 ms/s
keV	*kHz*	*counts/mn*
100	4.3	258
200	2.7	162
300	2.1	126

diamond:
- $4 \times 4 \times 0.5$ mm^2
- $3 \times 3 \times 0.5$ mm^2 (active size)

Vault background → negligible versus 1 W/m loss contribution





Experimental counting rates validation

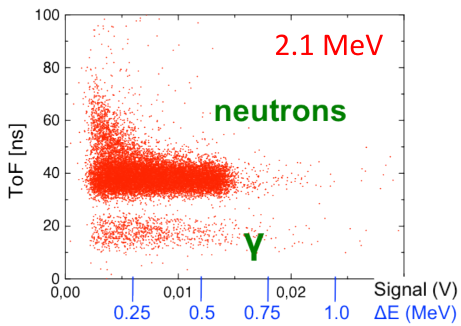
Neutron tests made with a Van de Graaff (CEA Bruyères-le-Châtel):

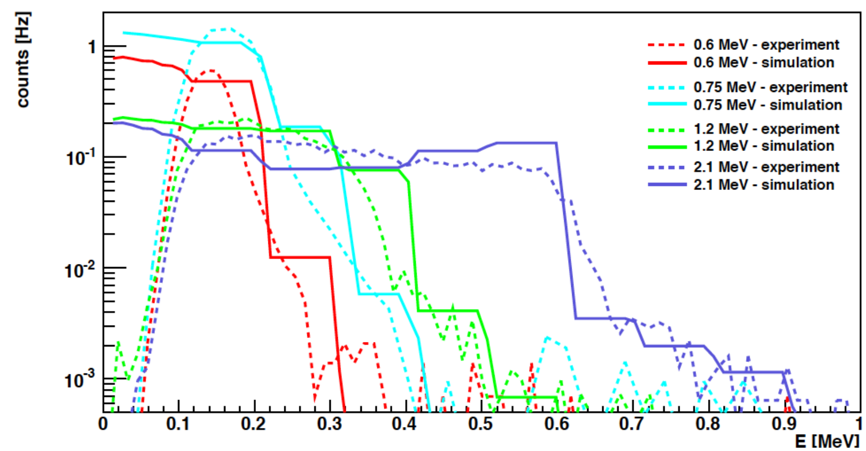
E_n = 0.2, 0.6, 0.75, 1.2, 2.1, 3.65, 6, 16 MeV

Goal: diamond response (energy deposit…), counting rates…

but, at room temperature

neutron/γ discrimination ➞ time of flight





Conclusion

Threshold is ≈ 100 keV, but short cable

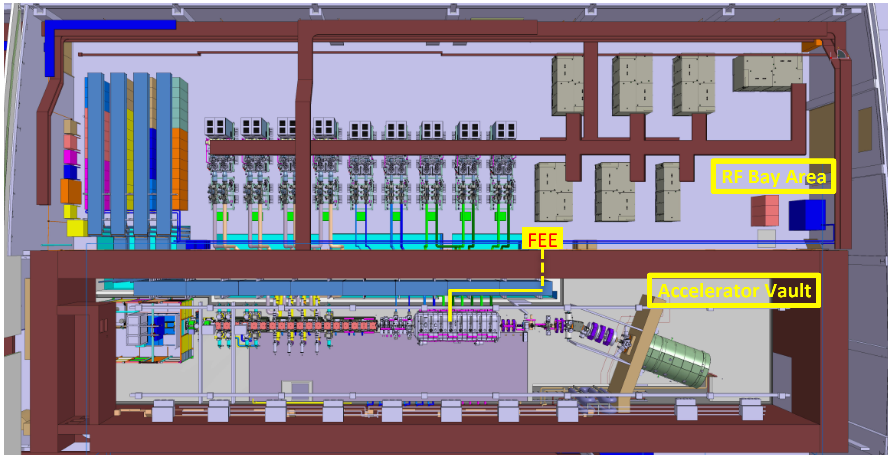
Simulation fits quite well data

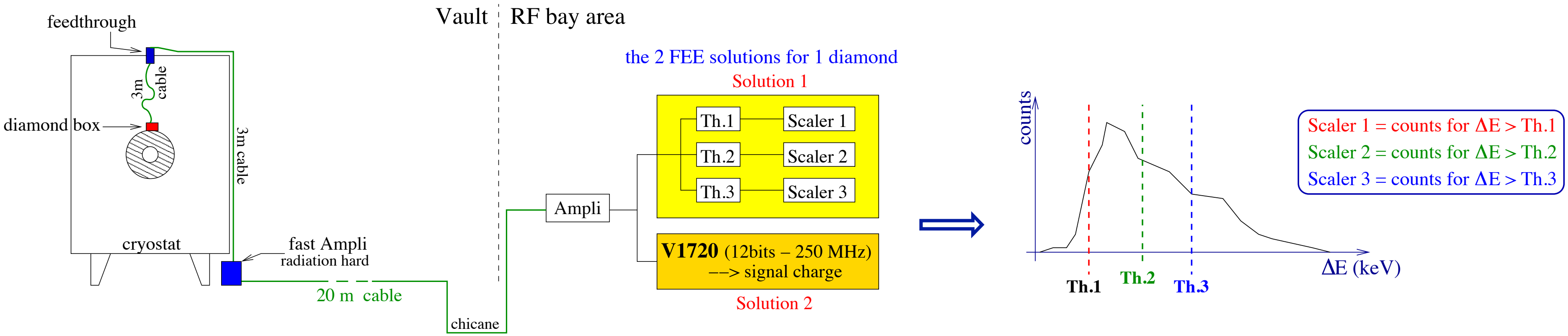
⇒ more confidence in previous counting rates.

Front-End Electronics (FEE)

FEE located in 2 places

- Diamond + cable ~ 6 m length
- Fast amplifier in the accelerator vault
  - → BW ~ 1 GHz
  - → Gain > 40 dB
- Cable ~ 20 m length
- FEE in the RF bay area
  - → amplifier
  - → 2 solutions
    - counting rates for 3 thresholds
    - signal integration to reconstruct the energy deposited in diamond (CAEN 1720 ➞ tbt beginning 2013)





Fast amplifiers

^{60}Co source tests

Diamond + cable ~ 6 m length

Fast amplifier in the accelerator vault

→ BW ~ 2 GHz

→ Gain > 40 dB

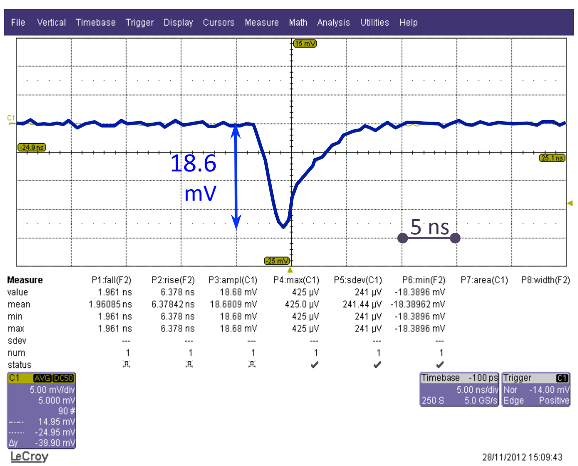
Fast amplifier in the accelerator vault

→ amplifier

→ 2 solutions

- counting rates for 3 thresholds
- signal integration to reconstruct the energy deposited in diamond (CAEN 1720 ➞ tbt beginning 2013)

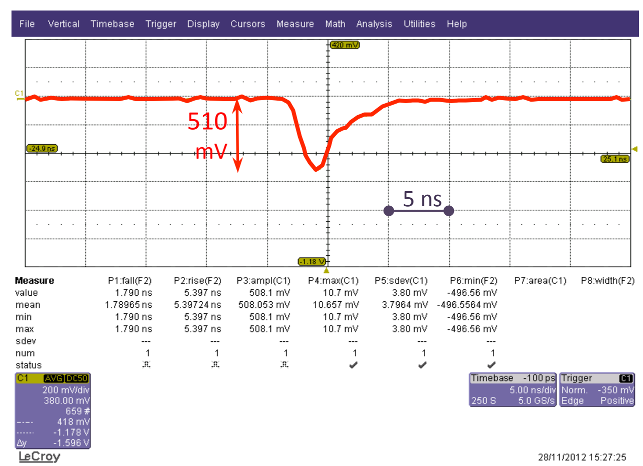
➞ ^{60}Co Cividec (noise = -10 mV)



Cividec 40dB ("Vault") + Ampli (ZFL500)

➞ elec. noise ≈ -300 mV

➞ ^{60}Co (threshold = 350 mV)



Summary & Perspectives

CVD diamonds look promising for LIPAc beam monitoring, tuning

- good neutron and γ sensitivity
- cryogenic temperatures
- quite good radiation hardness
- reasonable counting rates

but,

- expensive (diamonds & electronics)
- diamond behavior in superconductive cavity vicinity (X-rays)?
    - → test foreseen in January 2013 at Saclay on superconductive cavity of Spiral2

Next year

Energy deposit calibration in diamond

FFE design completion by may 2013 (amplifiers + daq)

Faraday boxes for diamond implementation in the cryostat (Rf shielding, noise)

Thank you very much to

CEA Saclay:

DSM/Irfu: P. Abbon, J. Egberts, J.F. Denis, A. Marchix

DRT/List: M. Pomorski

the organizers,

and, for your attention.

Backups

Diamond signal

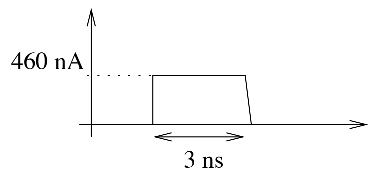
ρ=3.52 g/cm^3
Resistivity~10^{13} and 10^{16} Ω.cm
ε_r ~ 5.7
HV ~ 1 V/µm
Pair e/hole ~ 13.2 eV
E_{gap} = 5.4 eV

Q=10^{-6} x 2.5 10^{-9} = 2.5 fC

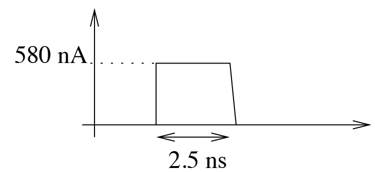
Pair production for MIP:
- PDB (MIP)→
  - dE=1.7 MeV/(g/cm^2)
- 0.5mm thickness
  - → ΔE=300 keV
  - → 22000 e$^-$/h pairs
  - → 44 e$^-$/h pairs per µm
  - Rk: find 33!

Events occuring in the center of the diamond

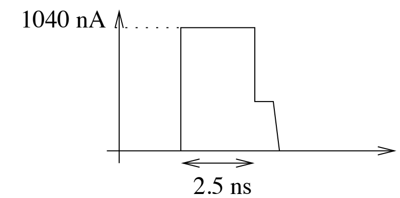
electron signal
(rise time = few ps & fall time = 200ps)



hole signal
(rise time = few ps & fall time = 200ps)

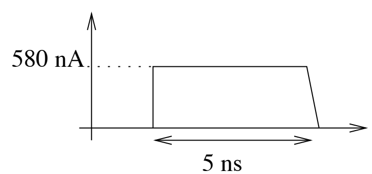


electron + hole signal



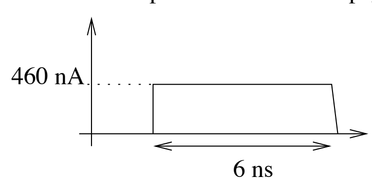
Events occuring close to the positive electrode (electron signal is negligible)

hole signal
(rise time = few ps & fall time = 200ps)



Events occuring close to the negative electrode (hole signal is negligible)

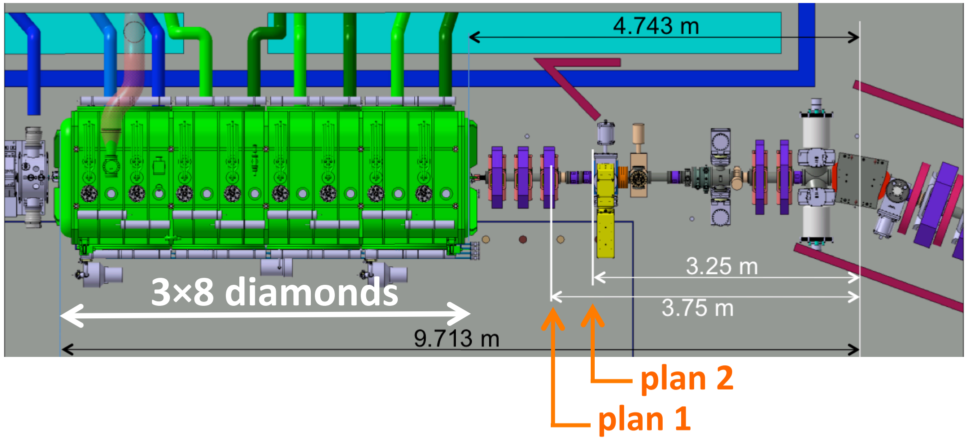
electron signal
(rise time = few ps & fall time = 200ps)



Note: other events are close to these extreme cases. For 1 interaction, we assume 18000 e/h pairs.

Radiation background counting rates

Radiation background using old simulations from UNED (Madrid 2008)



No data at the SRF Linac,
1 m downstream

Threshold (keV)	Neutron rates (kHz)		γ rates (kHz)		γ+n (kHz)	1 W/m
plan number	1	2	1	2	1	
100	0.9	1.9	0.13	0.26	**1.0**	**4.3**
200	0.5	1.2	0.10	0.21	**0.6**	**2.7**
300	0.4	0.9	0.08	0.17	**0.5**	**2.1**

Rate versus the electronic threshold (keV) for neutron & γ background compared to 1W/m

Remark:

- plan2 / plan 1 ≈ 2 ⇒ plan 1 > background rate inside the SRF Linac
- Background should be stable while beam losses >> 1 W/m, particularly during commissioning!

Preliminary conclusion: counting rates seems to be reasonable.

^{252}Cf source & neutron cross sections

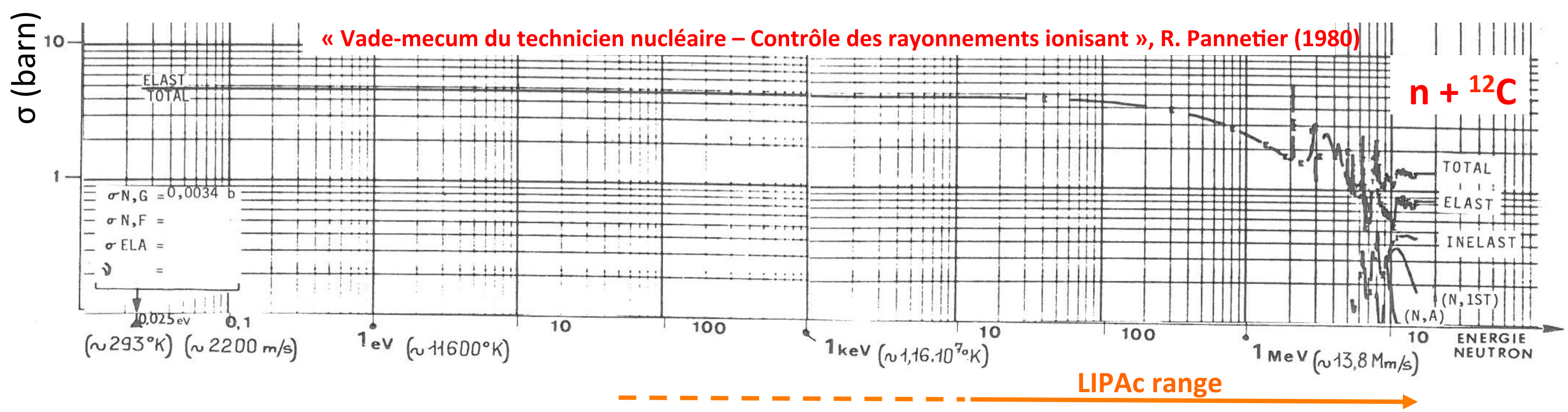
^{252}Cf source

decays

- 96.9% → α (giving ^{248}Cm with 340 kyear of ½ life - $<E_n>\approx 1.42$ MeV with 3.7 n/fission)
- 3.1 % → spontaneous fission

½ life : 2.645 years

Old radioactive source implies less fission processes → more γ will be produce from other processes



Simulation with ^{60}Co source

^{60}Cf source simulated response