CEA - Saclay

R&D on µ-LoM monitors for High intensity Linacs like LIPAc

HB2016 at Malmö (Sweden)

July 7th, 2016

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Overview

IFMIF, LIPAc… quick status & plans

µLoM for high intensity Linacs

- goal
- Feasibility study
- FEE proposition

Summary

IFMIF – LIPAc projects in few words

IFMIF (International Fusion Materials Irradiation Facility)

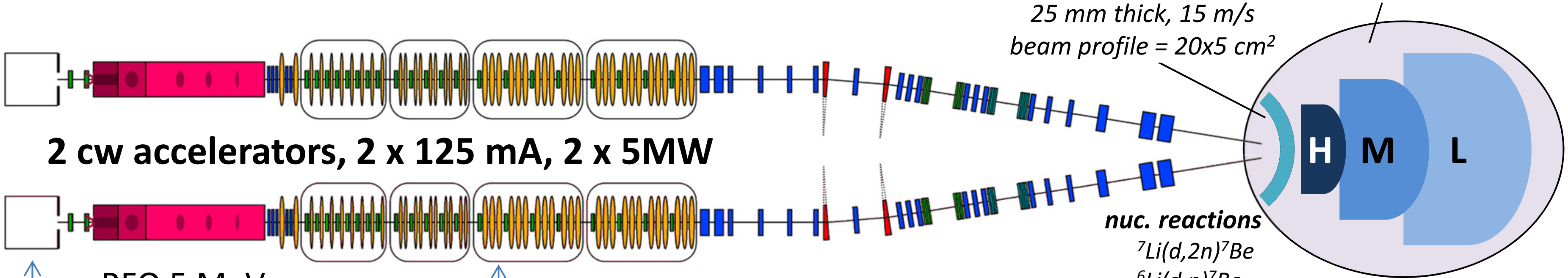
International agreement of the "**Broader Approach**" (Japan + Europe in Feb. 2007)
= IFMIF + IFERC + JT60-SA

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

Very huge neutron source: flux ~ 10^{18} neutrons/m²/s

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

Test Cell



nuc. reactions
$^{7}Li(d,2n)^{7}Be$
$^{6}Li(d,n)^{7}Be$
$^{6}Li(n,T)^{4}He$

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

RFQ 5 MeV

deuteron source
140/150 mA, 100 keV

Superconductive Linac 40 MeV
(Half Wave Resonators)

LIPAc (Linear IFMIF Prototype Accelerator)

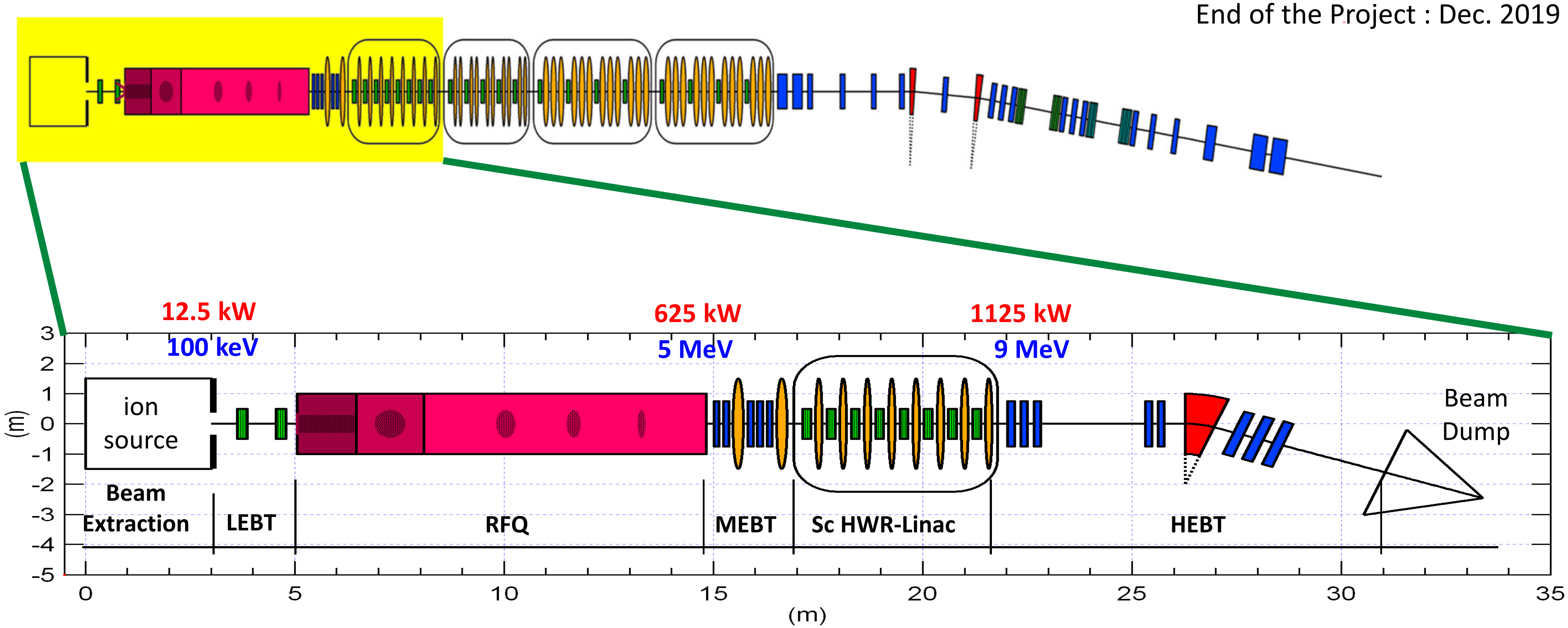
Validation phase:

prototype accelerator → LIPAc (Rokkasho – Japan)

Commissioning at Rokkasho beginning:

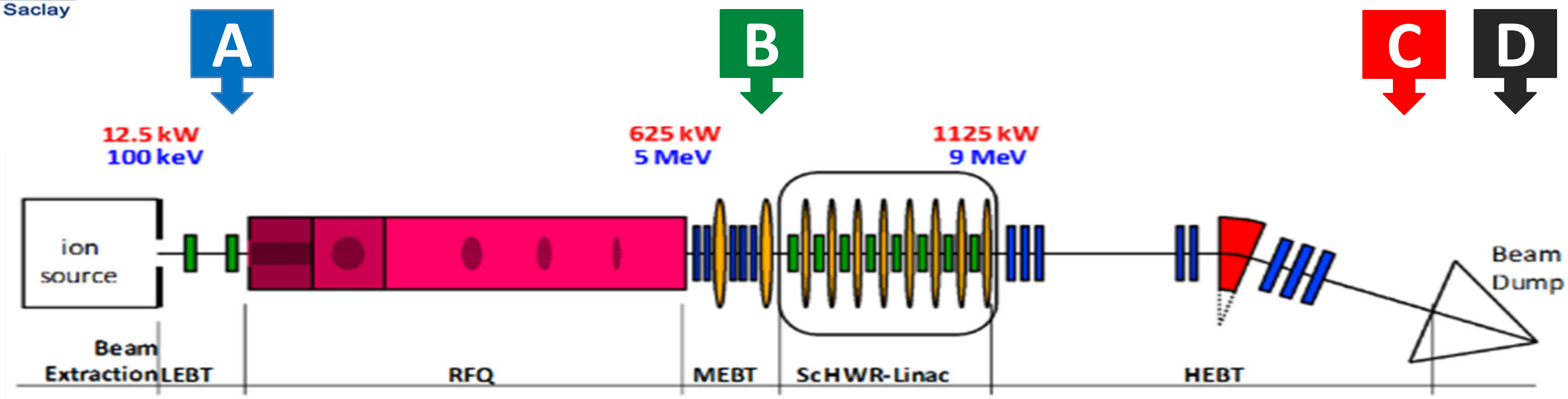
Injector: 2014
RFQ: mid 2017
End of the Project : Dec. 2019

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

LIPAc Status & plans



Phase A: injector Inst.&commissioning

2014 - fall 2016

- H^+ (I_{stop} ≈ 60 mA – 50 keV)
- D^+ (I_{stop} ≈ 120 mA – 100 keV)

→ ε=0.23 π.mm.mrad (10% dc)

Phase B: RFQ Inst.&commissioning (MEBT+DP)

April 2016 - end 2017

- Assembling RFQ module, bead pull…
- Moving RFQ to nominal location
- Commissioning with MEBT+D-Plate → start June 2017
- H^+ & D^+ (low dc)

➢ *Michele Comunian, BH2016, TUPMAY01*

Phase C: SRF + HEBT + LPBD commissioning

Starting ≈ 2018

- SRF cryomodule assembling at Rokkasho (end 2017)
- Installation SRF + HEBT + LPBD
- H^+ & D^+ (low dc)

Phase D: LIPAc

End by December 2019

- Assembling and mounting 1.1 MW HPBD
- H^+ & D^+ beams, up to cw.

µLoM for high intensity Linacs

Why µloss?

Beam dynamics team

- High intensity beam
  - → reducing losses to 10^{-6} of the beam for maintenance hands-on (1W/m)
  - → " halo matching "

  Note: Unlike classical accelerator → reducing the emittance or so-called "emittance matching "
- beam dynamics team requirements for BLM
  - low sensitivity: $<10^{-6}$
  - Correlation losses/location: close to the beam

→ SRF Linac: implementation of µLoMs inside the cryomodule

- *Nicolas Chauvin, " Beam dynamics Challenges in IFMIF ", HB2016, TUAM2Y01*
- *P.A.P. Nghiem et al., " The IFMIF-EVEDA challenges in beam dynamics and their treatment ", Nucl. Instrum. Meth. Phys. Res. A 654, 63–71.*

µLoMs

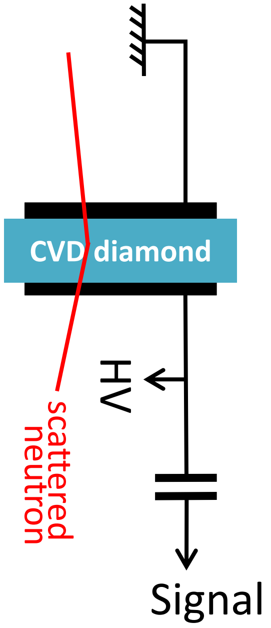
Ideal µLoM

- good sensitivity to beam losses (<10^{-6} of the beam),
- ability to operate at cryogenic temperature (4.5 K),
- radiation hard material since close to beam pipe,
- good counting rates in order to get reasonable statistics at low duty cycle (10^{-3})
- good reliability → cryomodule will not be open for µLoM problems!
- a better response monitor for neutrons wrt γ's (to avoid fake signal coming from cavity emission field)
- reasonable price

Compromise : CVD diamond

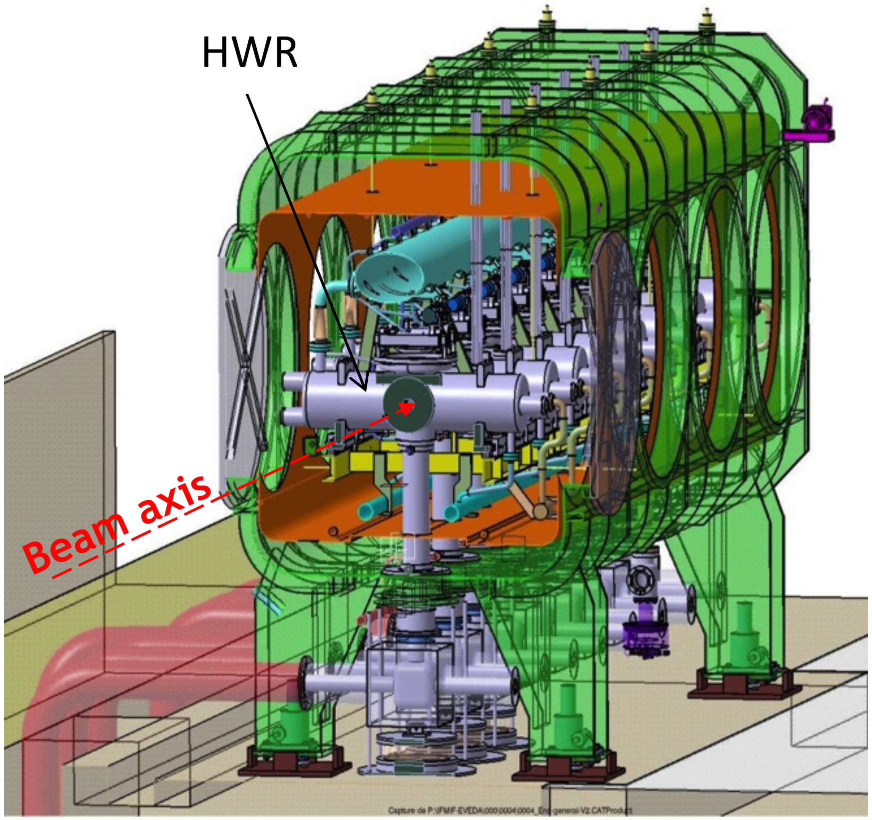
- Fulfill roughly all the previous requirements, but the last. We have even checked the cryogenic behavior at 77 K and 4.5 K.
- Mono crystalline CVD diamond characteristics

Size	$4 \times 4 \times 0.5$ mm^3
Density	3.52 g/cm^3
Resistivity	10^{13} - 10^{16} Ω.m
ε_r	~ 5.7
e/hole pair production	~ 13.2 eV
Band-gap	5.5 eV
Radiation hardness	~ 500 Mrad for 24 GeV proton



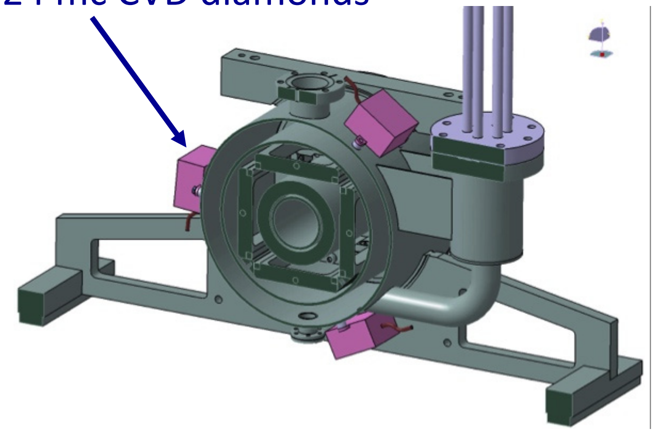
where, how…

- Inside the cryostat of the SRF Linac → 4.5 K
- Diamond boxes (Faraday cages)
- Feedthroughs are foreseen on the cryogenic tank for cabling CVD diamonds.



8 identical sets

- 1 HWR cavity
- 1 BPM
- 1 solenoid



Note: 3 diamonds per Solenoid→ transverse localization + reliability

Feasibility study

Counting rates - Hypothesis

Feasibility study: Simulation *(A. Marchix, Saclay, Sept. 2010)*:

- Loss: **1 W/m** with MCNPX 2.5.0

  D^+ + Fe → neutron (or γ) + X

  Part of the SRF Linac materials taken into account

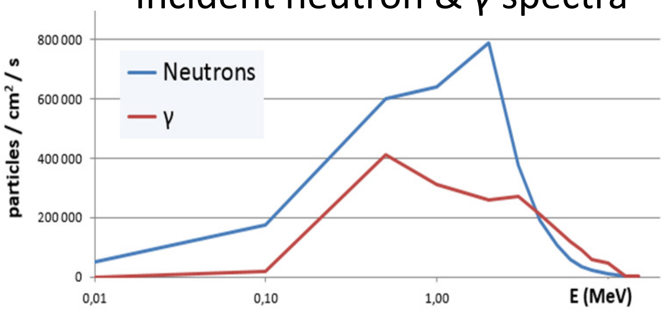
incident particles	targets	escaping particles
d (beam)	Stainless steel (Fe / Cr / Ni)	n, γ
neutron, γ	Ti, Nb, Cu, Stainless steel (Fe / Cr / Ni)	n, γ

- 2 background (BG) sources identified

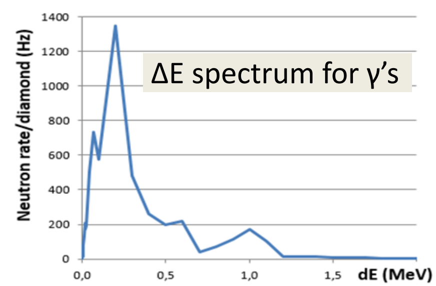
Counting rates

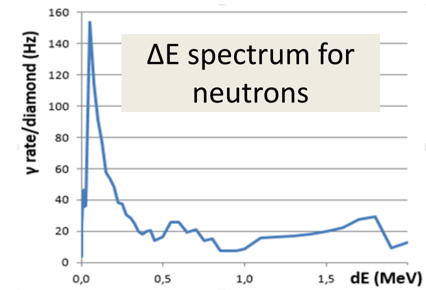
Rate for 1W/m losses (active diamond surface = 9 mm²)

Incident neutron & γ spectra



Energy loss ΔE in CVD diamond





Rate versus the electronic threshold (keV) for 1W/m

Threshold (keV)	**70**	**100**	**200**	**300**	**400**	**500**
Neutron (kHz)	3.7	3.2	1.8	1.3	1.1	0.9
γ (kHz)	1.2	1.1	0.9	0.8	0.7	0.6

Low duty cycle:

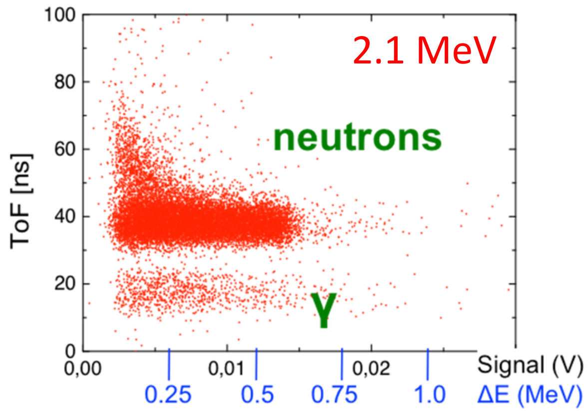
- During commissioning, small pulse (10^{-3} duty cycle):
  - 200 keV threshold ⇒ 162 counts/mn
  - 300 keV threshold ⇒ 126 counts/mn
  - but for 1W/m, during commissioning we may expect higher losses!

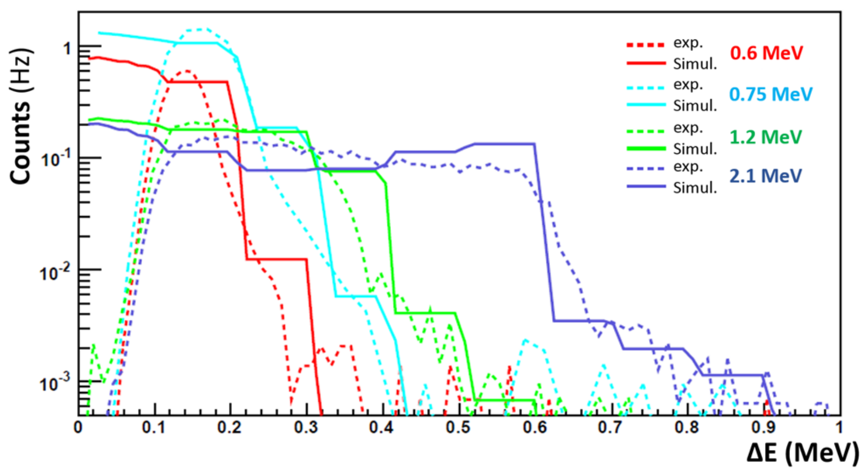
Experimental counting rate validation

Neutron tests made with a Van de Graaff (CEA Bruyères-le-Châtel – July 2011):

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





Summary

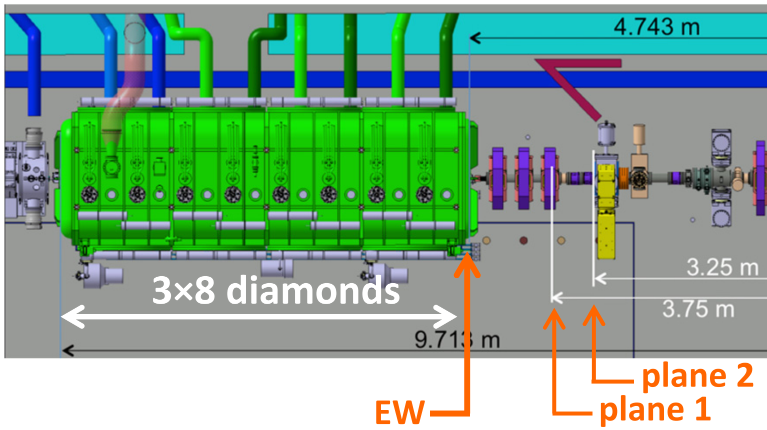
Threshold was ~ 100 keV, but with short cable

Simulation fits quite well data

⇒ more confidence in previous counting rates.

Vault radiation background

Radiation background using old simulations from UNED (Madrid 2008)



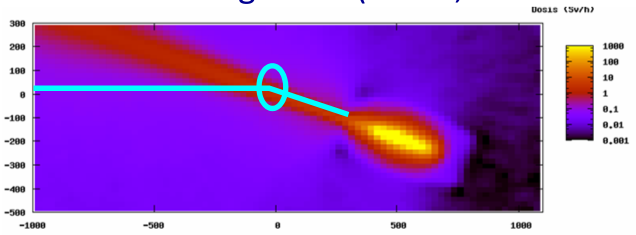
No data at the SRF Linac, 1 m downstream

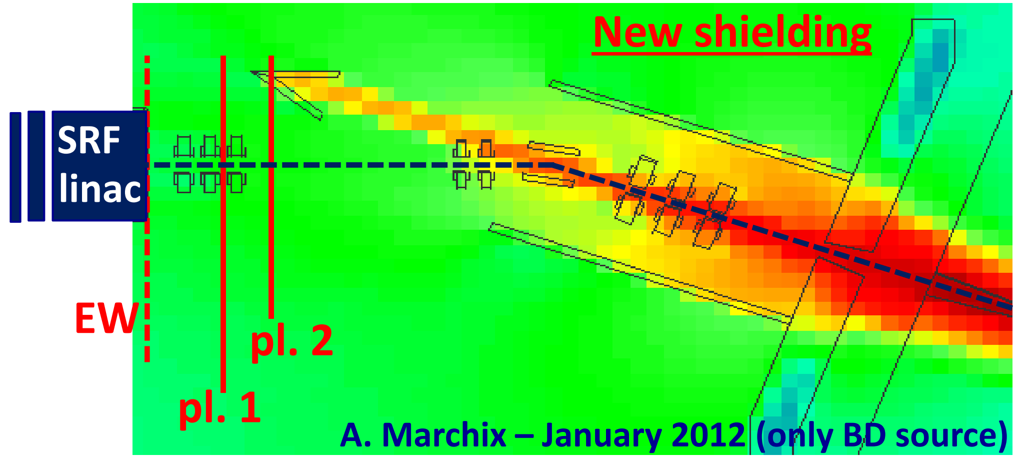
Threshold (keV)	Neutron rates (kHz)		γ rates (kHz)		γ+n (kHz)	1 W/m
plan number	**1**	**2**	**1**	**2**	**1**	
100	0.9	1.9	0.13	0.26	**1.0**	**4.3**
200	0.5	1.2	0.10	0.21	**0.6**	**2.7**
300	0.4	0.9	0.08	0.17	**0.5**	**2.1**

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

Vault radiation background (2)

Radiation background (UNED, Madrid 2008)





	Vault Background					
Threshold (keV)	Neutron rates (kHz)		γ rates (kHz)		γ+n (kHz)	1 W/m
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300	0.4	0.9	0.08	0.17	**0.5**	**2.1**

Remark:

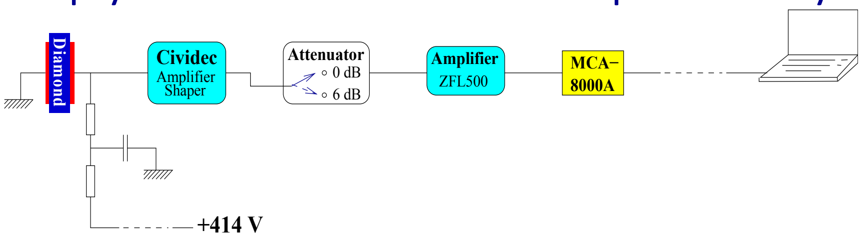
- plan2 / plan1 ≈ 2.1 ⇒ plane 1 >> background rate inside the SRF Linac
  ⇒ EW < "plane 1"/4 ≈ 5% (linear extrapolation)
- Background should be stable while beam losses >> 1 W/m, particularly during commissioning!

Preliminary conclusion: counting rates seems to be reasonable.

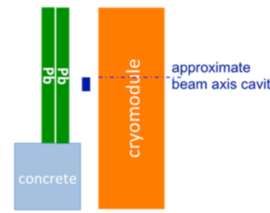
Cavity emissions: X and γ

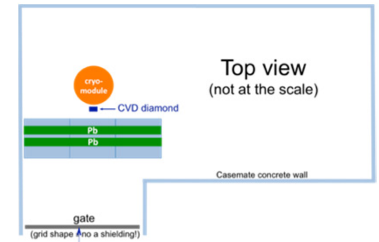
done at CEA Saclay on a Spiral2 cavity – Feb. 2013

- daq system and test stand with Spiral2 cavity in a cryostat.

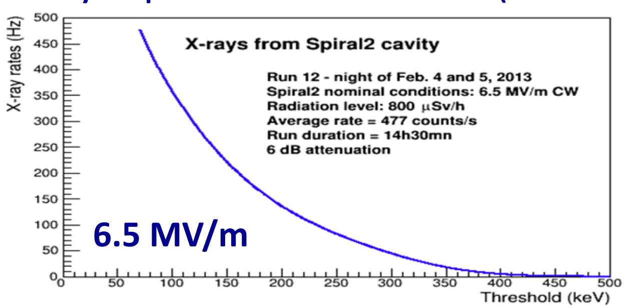


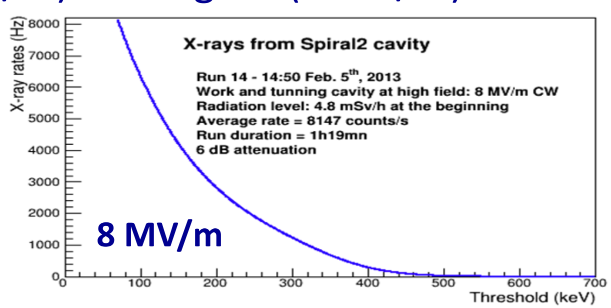
side view (detail)





- X-rays spectra for nominal (6.5 MV/m) and higher (8 MV/m) accelerating electric field conditions





- X-rays contribution to 1 W/m signal with "Spiral2" scheme

Run	"1 W/m"	12	13	14	15	17
$Th_{100\ keV}$ (Hz)	*4400*	357	254	6340	121	80
		8%	6%	145%	3%	2%
$Th_{200\ keV}$ (Hz)	*2700*	135	98	2813	46	29
		5%	2%	64%	1%	1%

→ In normal conditions, <X, γ_{cavity}> = 5% at 100 keV, and 2% at 200 keV wrt "1 W/m"

Front-End Electronics (FEE)

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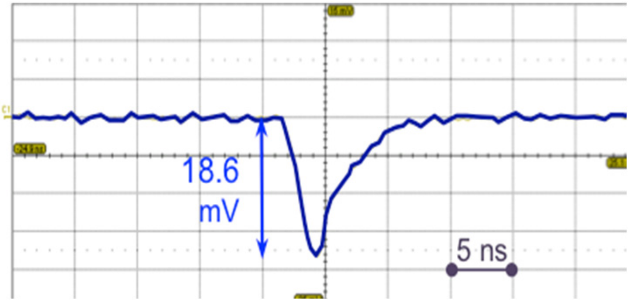
Signal test

- ^{60}Co source signal on CVD diamond
- γ simulated response gives around 0.9 - 1 MeV energy deposit
- cable length ≈ 3m
- broadband Cividec amplifier (BW>1GHz – 40dB) and radiation tolerant (1 MGy).



Proposed FEE for energy loss in CVD diamonds

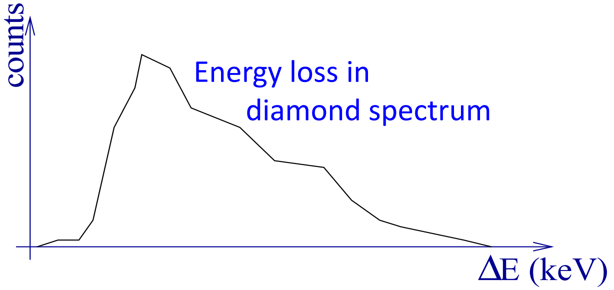
- signal sampling (charge ΔE) → VT1720 Caen (250MHz, 12 bits, 8 channels)
- diamond shaping amplifier (Cx-L Cividec - FWHM pulse width: 180ns)
- **Cable 75Ω** *(attenuation length is lower for a given frequency)*

Source test (courtesy E. Griesmayer)

250 keV → 3 fC

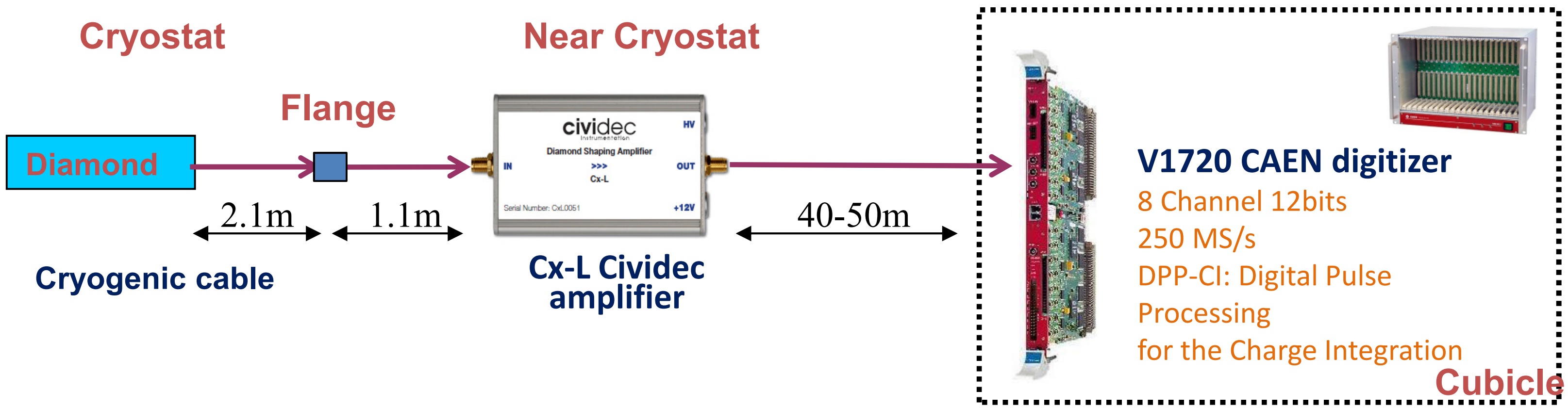
4m cable (**75 Ω)** length

Signal/noise = 5

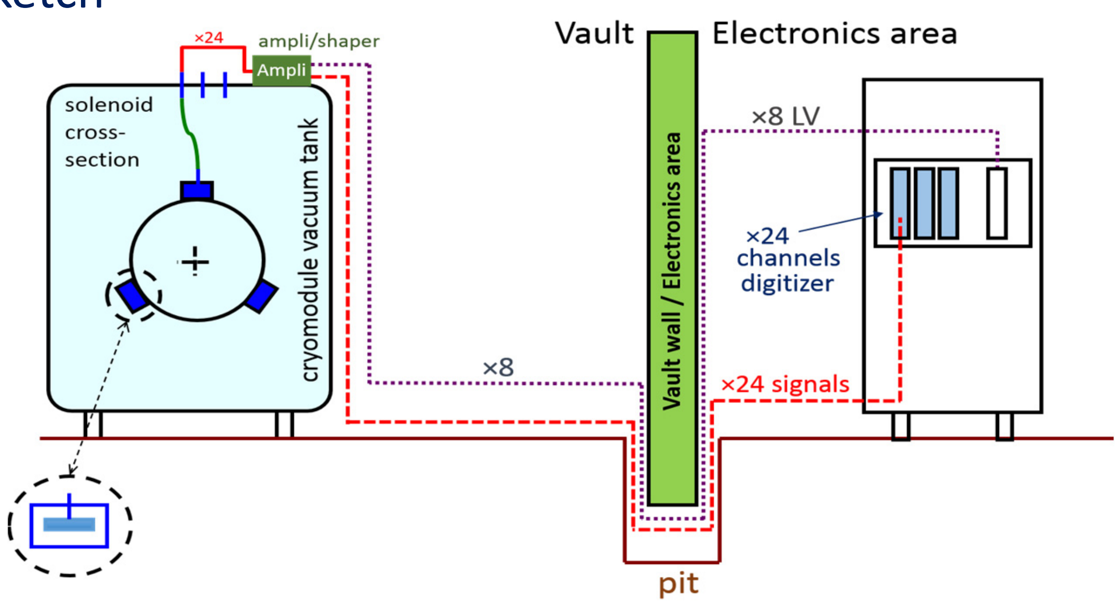


FEE (2)

Diamond electronic chain for LIPAc



LIPAc sketch



Summary

LIPAc…

- Commissioning has already begun, and is almost finish for the injector
- Assembling of the RFQ is in good progress. Beam commissioning should start in June 2017

µLoM for high intensity Linacs

- µLoM are requested by Beam Dyn. for beam tuning while keeping losses below 1W/m (hands-on maintenance)
- CVD diamonds should be good candidates for this purpose
  - Propriety: radiation tolerant, cryogenic…
  - Counting rate estimates:
    - 1W/m → look reasonable and were checked experimentally
    - BG (vault + cavity emission) < 1W/m
  - Cautions: electron cavity emission (care about high E_{field})
  - FEE was tested and proposed

Thanks a lot for your attention

and thanks to my Saclay's colleagues

P. Abbon, A. Marchix, M. Pomorski