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

HB2016 at Malmö (Sweden)

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# Overview

## IFMIF, LIPAc… quick status & plans

## µLoM for high intensity Linacs

- goal
- Feasibility study
- FEE proposition

## Summary

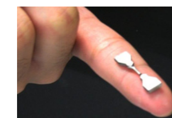
# IFMIF – LIPAc projects in few words

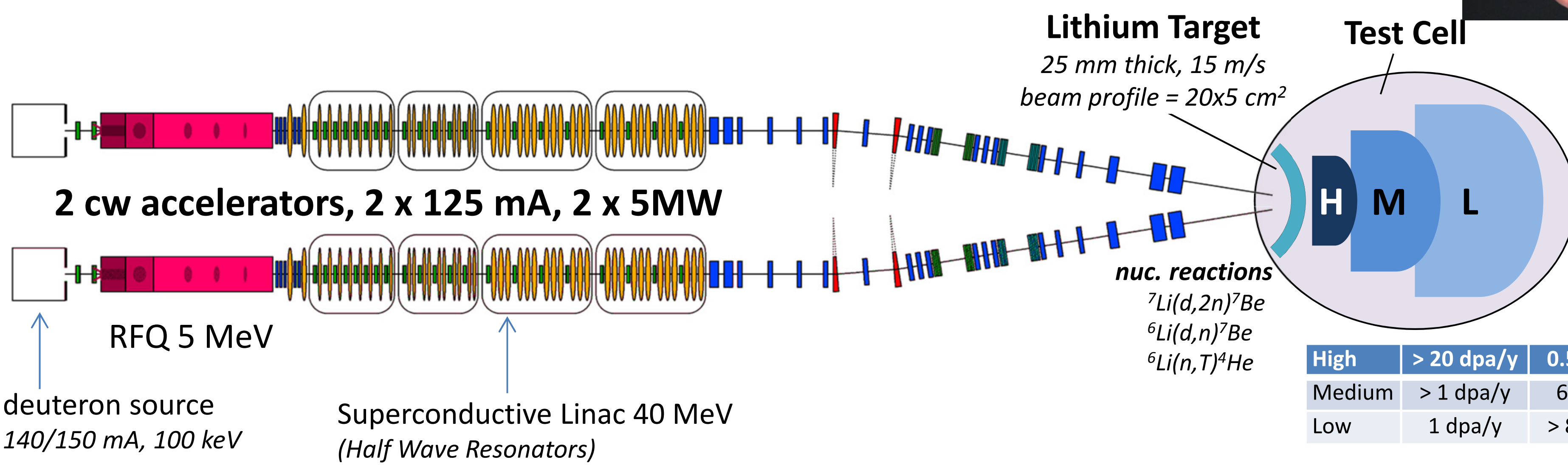
# IFMIF (International Fusion Materials Irradiation Facility)

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/$m^2$/s*






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

# LIPAc (Linear IFMIF Prototype Accelerator)

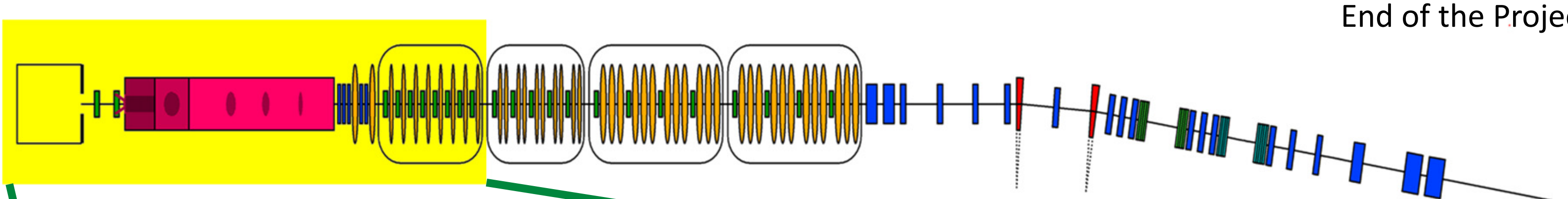
## Validation phase:

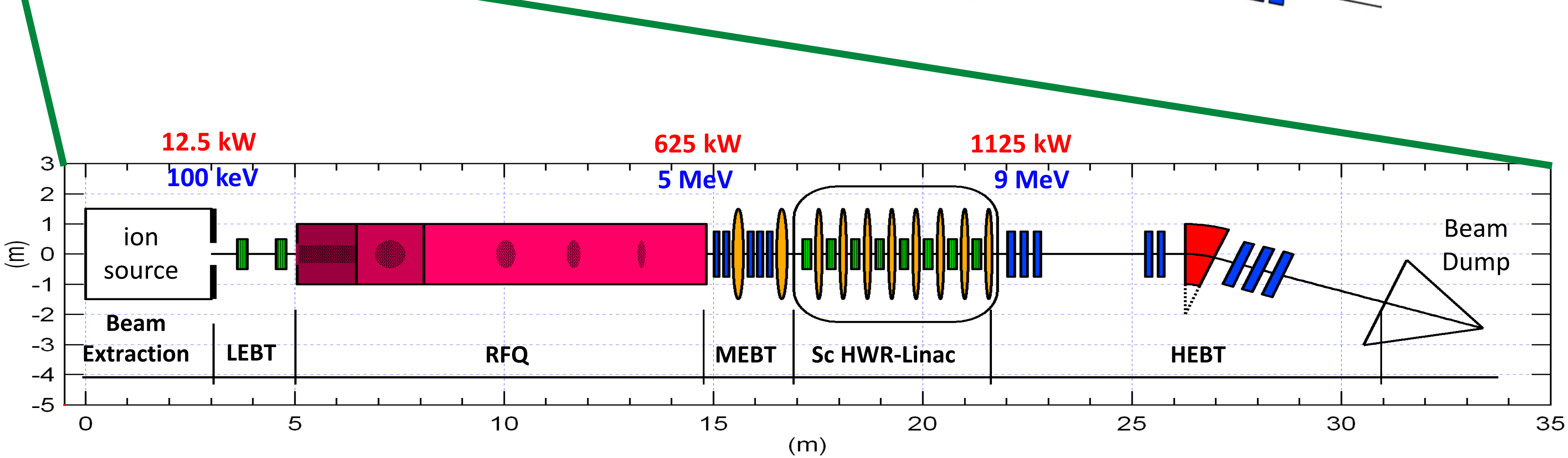
**prototype accelerator** → LIPAc (Rokkasho – Japan)

**Commissioning at Rokkasho beginning:**

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

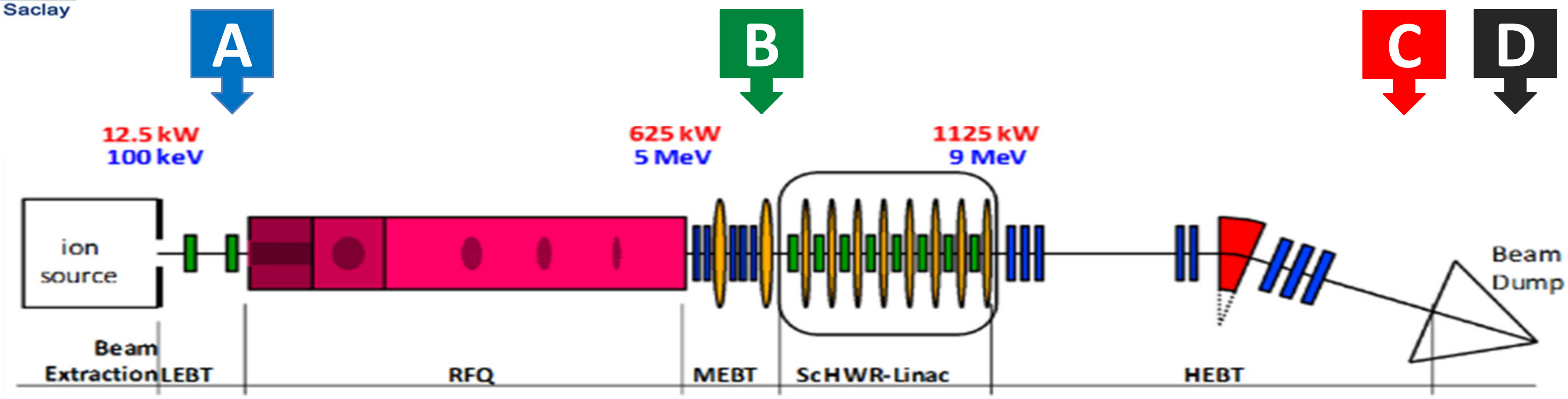
**LIPAc = 125 mA cw, 9 MeV, 1.125 MW**






**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

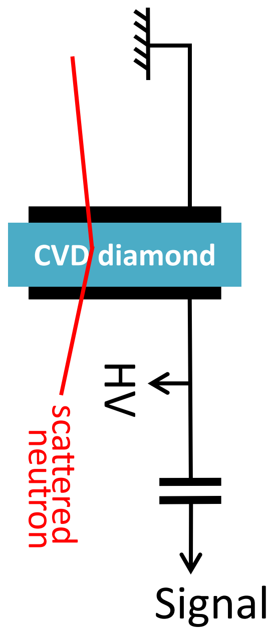
## Ideal µLoM

- 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

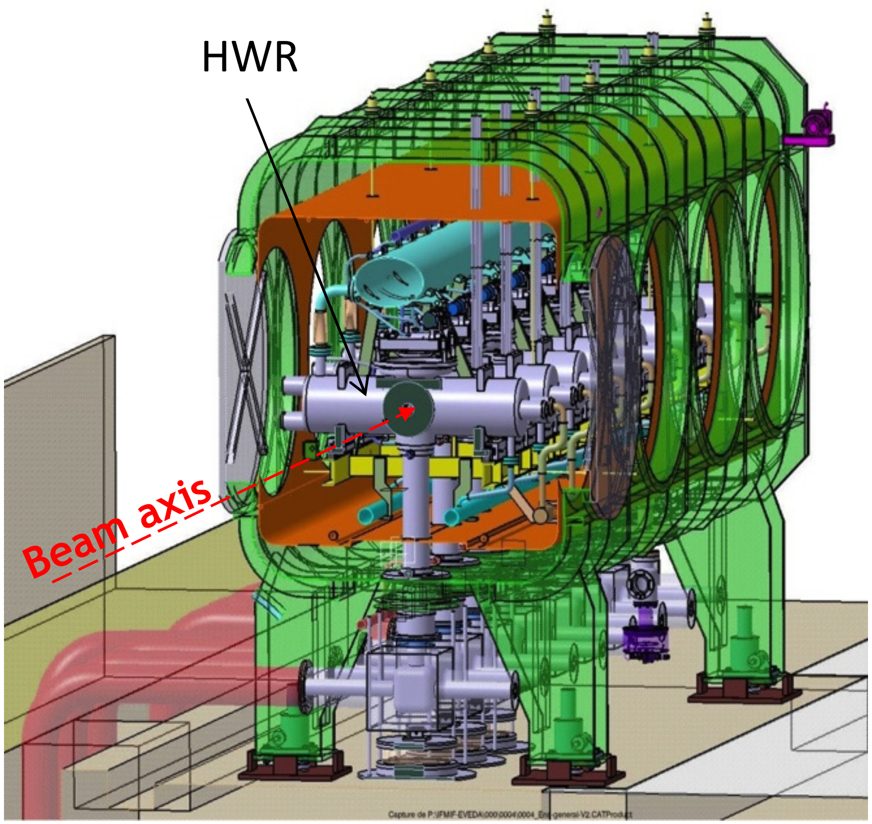
- Fulfill roughly all the previous requirements, but the last. We have even checked the cryogenic behavior at 77 K and 4.5 K.
- Mono crystalline CVD diamond characteristics

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



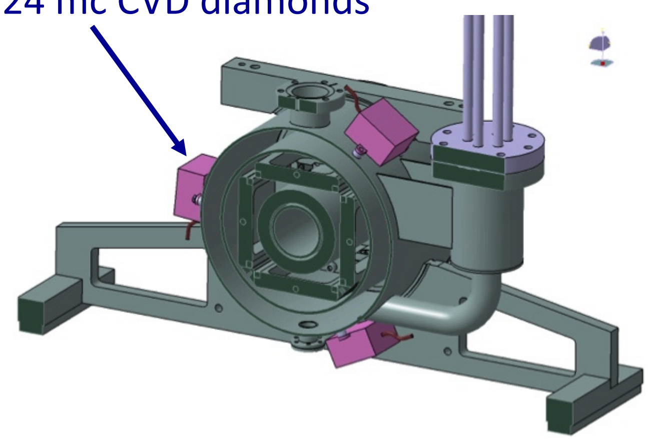
# where, how…

- 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

  $D^+ + Fe \rightarrow$ neutron (or γ) + X

  Part of the SRF Linac materials taken into account

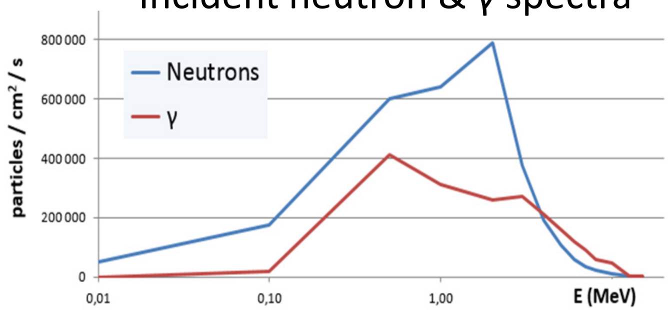
| incident particles | targets | escaping particles |
|---|---|---|
| d (beam) | Stainless steel (Fe / Cr / Ni) | n, γ |
| neutron, γ | Ti, Nb, Cu,<br>Stainless steel (Fe / Cr / Ni) | n, γ |

- 2 background (BG) sources identified

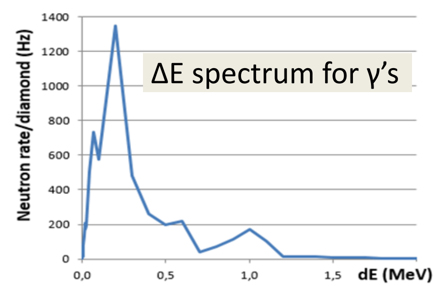
# Counting rates

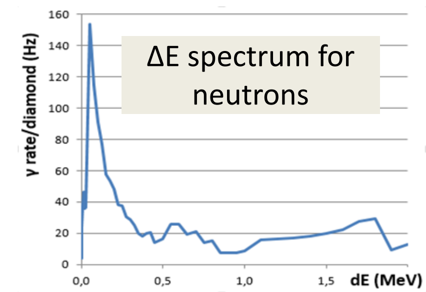
## Rate for 1W/m losses (active diamond surface = 9 mm$^2$)

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:

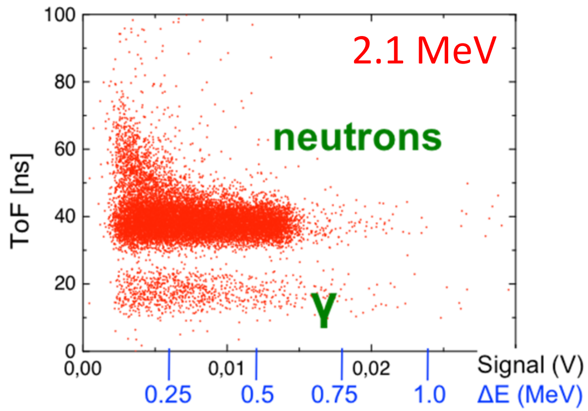
- During commissioning, small pulse ($10^{-3}$ duty cycle):
    - 200 keV threshold ⇒ 162 counts/mn
    - 300 keV threshold ⇒ 126 counts/mn
    - but for 1W/m, during commissioning we may expect higher losses!

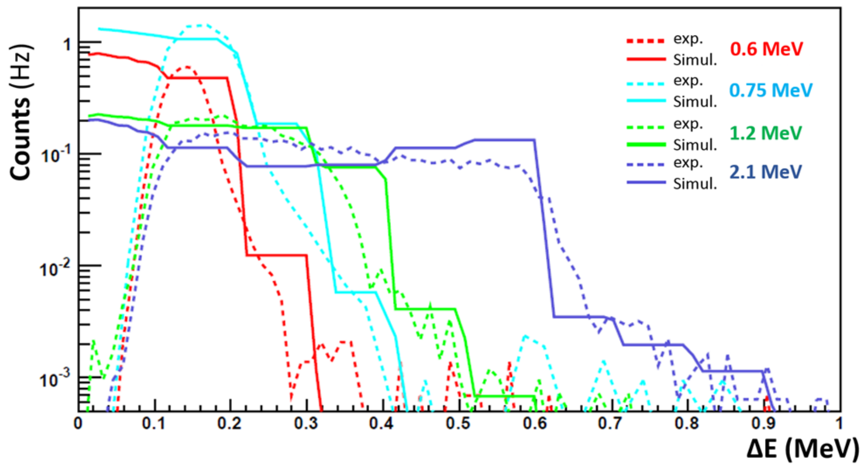
# Experimental counting rate validation

**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

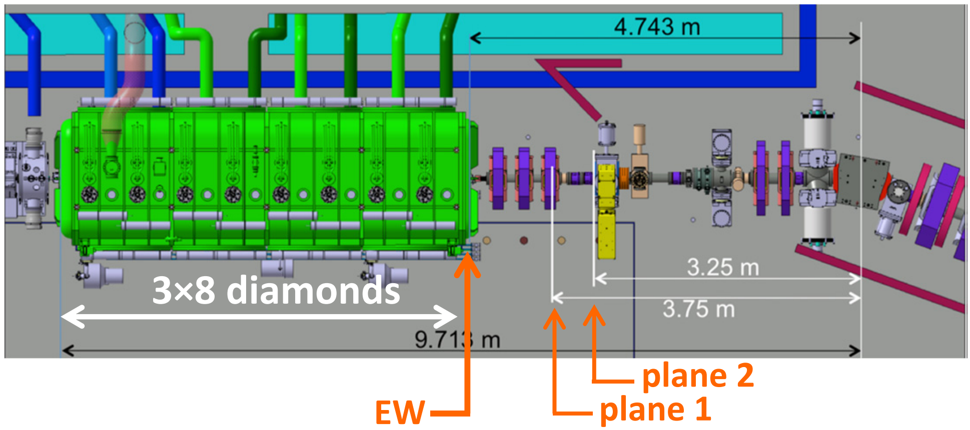
Threshold was ~ 100 keV, but with short cable

Simulation fits quite well data

⇒ more confidence in previous counting rates.

# Vault radiation background

Radiation background using old simulations from UNED (Madrid 2008)



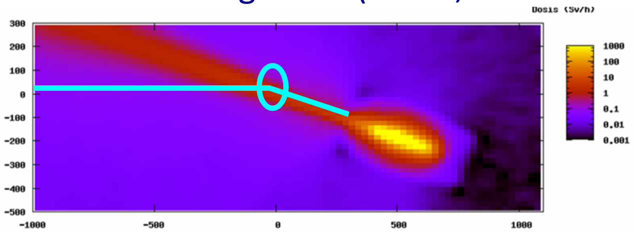

No data at the SRF Linac, 1 m downstream

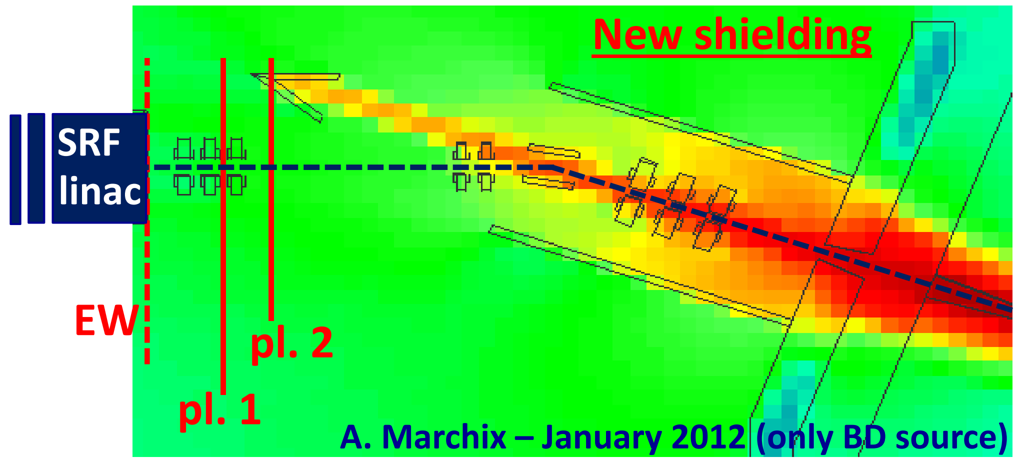
| Threshold (keV) | Neutron rates (kHz) | | γ rates (kHz) | | γ+n (kHz) | 1 W/m |
|---|---|---|---|---|---|---|
| **plan number** | **1** | **2** | **1** | **2** | **1** | |
| **100** | 0.9 | 1.9 | 0.13 | 0.26 | **1.0** | **4.3** |
| **200** | 0.5 | 1.2 | 0.10 | 0.21 | **0.6** | **2.7** |
| **300** |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

Remark:

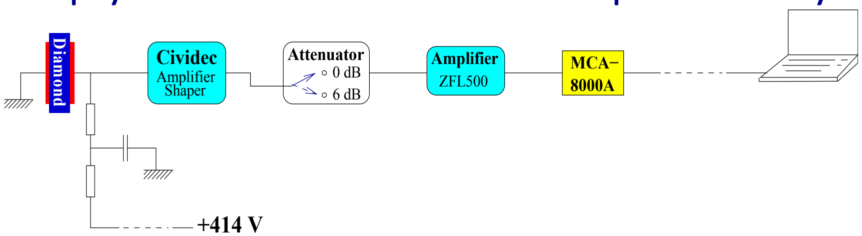
- plan2 / plan1 ≈ 2.1 ⇒ plane 1 >> background rate inside the SRF Linac
  ⇒ EW < “plane 1”/4 ≈ 5% (linear extrapolation)
- Background should be stable while beam losses >> 1 W/m, particularly during commissioning!

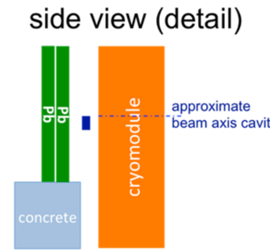
**Preliminary conclusion:** counting rates seems to be reasonable.

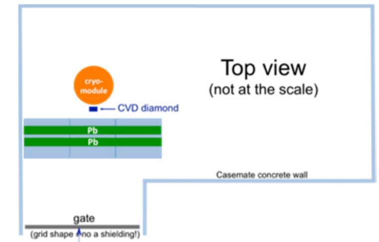
# Cavity emissions: X and γ

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

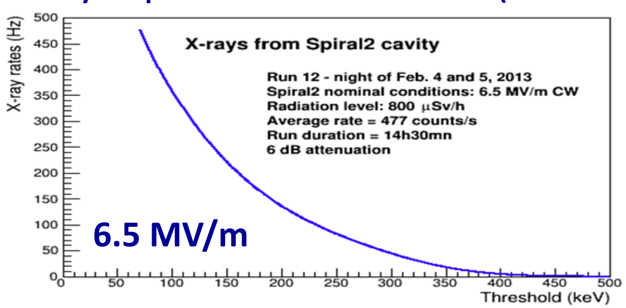
- daq system and test stand with Spiral2 cavity in a cryostat.

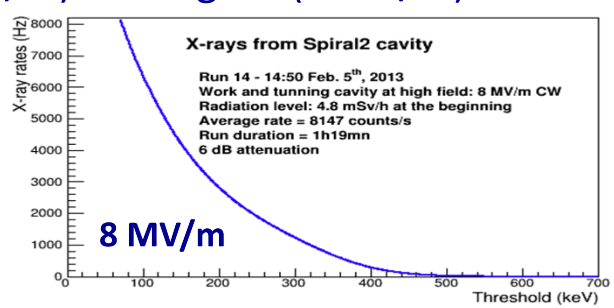



- X-rays spectra for nominal (6.5 MV/m) and higher (8 MV/m) accelerating electric field conditions




- 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% |

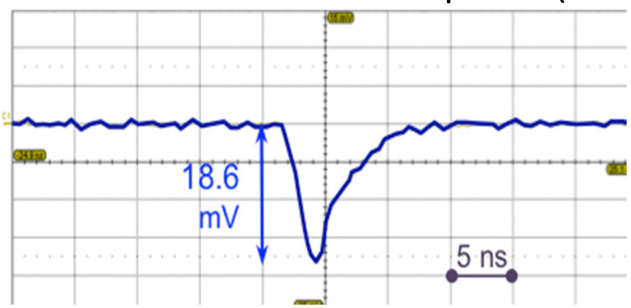
→ In normal conditions, <X, $\gamma_{cavity}$> = 5% at 100 keV, and 2% at 200 keV wrt "1 W/m"

# Front-End Electronics (FEE)

CEA - Saclay

## 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

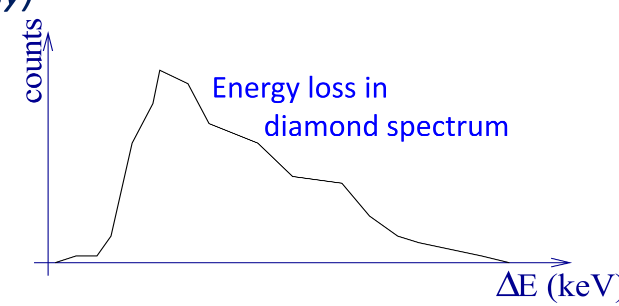
- signal sampling (charge ΔE) → VT1720 Caen (250MHz, 12 bits, 8 channels)
- diamond shaping amplifier (Cx-L Cividec - FWHM pulse width: 180ns)
- **Cable 75Ω** *(attenuation length is lower for a given frequency)*

Source test (courtesy E. Griesmayer)

250 keV → 3 fC

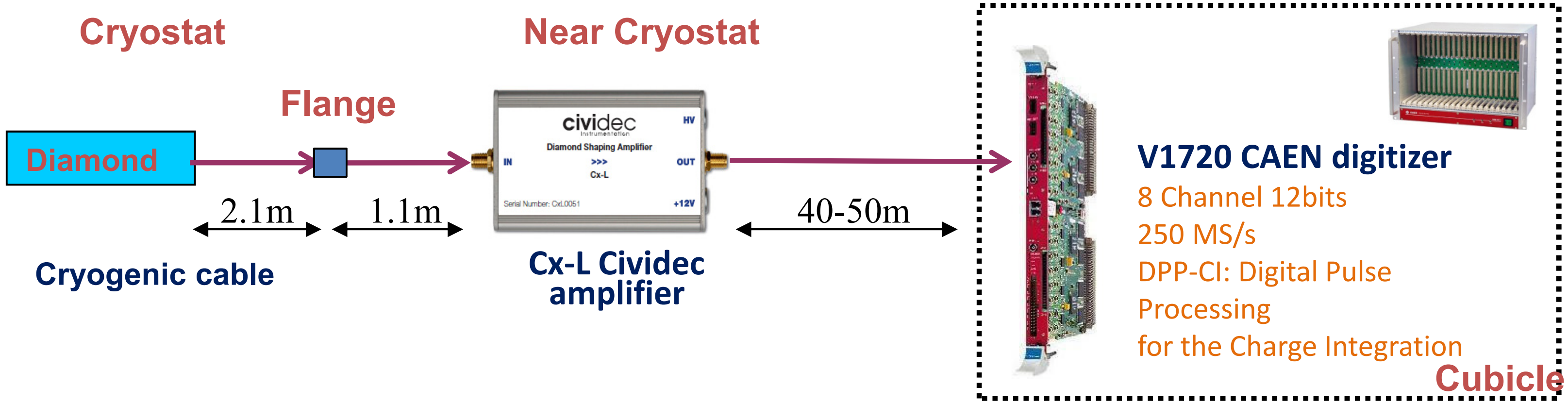
4m cable (**75 Ω)** length

Signal/noise = 5

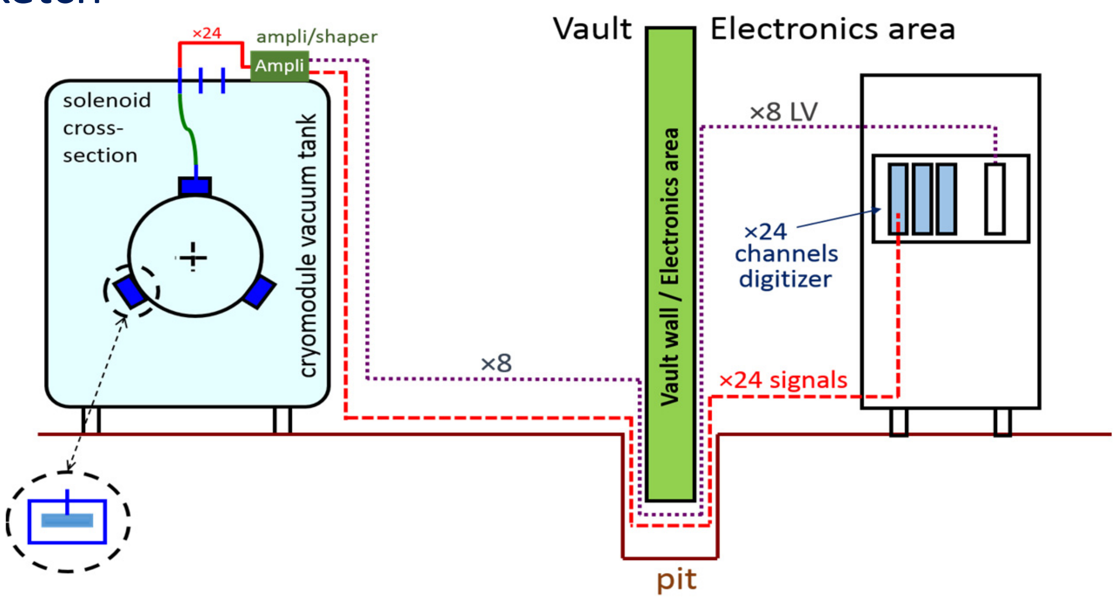


# FEE (2)

## Diamond electronic chain for LIPAc




## LIPAc sketch



CEA - Saclay

# 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***