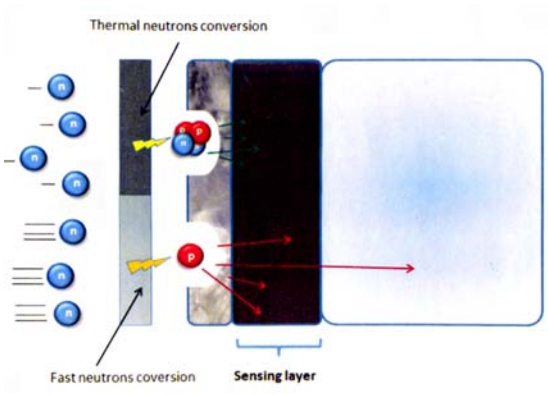
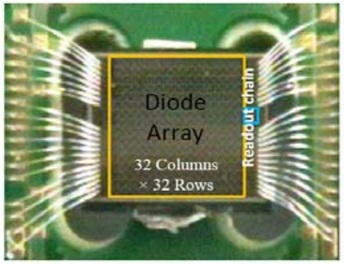
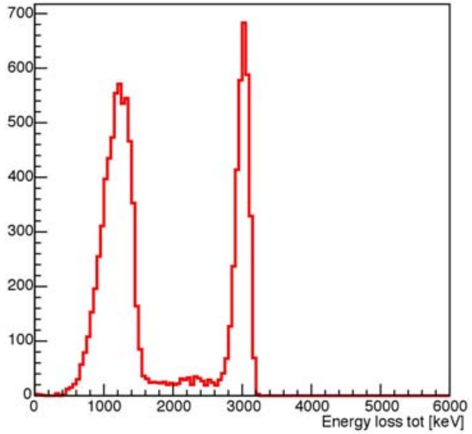
# CMOS in the DeSIs group

**D.Husson (MC HDR)**, N.Arbor (MC), S.Higueret (IR)

*+ M.Vanstalle, A.Allaoua, Y.Zhang, M.Kachel, J.Taforeau, R.Combe…*



# DeSIs team

- **DeSIs** : Dosimetry, Simulation & Instrumentation

- **Activity** :

  Detection of nuclear radiation ($\gamma$, X, neutrons, ...)
  Dose calculation (Geant IV and MCNPX MonteCarlo)
  Cross section calculations (*eV* electrons on single molecules)
  Dosimetry, radioprotection, *in situ* measurements (medical rooms)

- **Collaborations :**

  Research and regulation institutes (IRSN, CEA, AIEA, ANDRA, ...)
  Industry (GE, Aerial, ...)
  Hospitals (CPS Strasbourg, HUS Lyon, HU Mulhouse, CAL Nice)

# Context

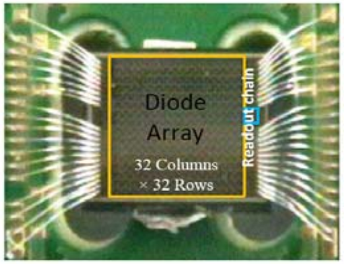
- Growing concern: **out-of-field neutron dose** in radiation therapies (LINAC photons & hadrontherapy).

- Current studies today:
  1) **simulation** (&~**single** off-line measurement for *ambient* dose maps)
  2) mostly *thermal* neutrons + *extrapolation* to *fast neutrons*

- Present requests:
  1) knowledge at the level of patient's ***organs !***
  2) ***on-line*** system to be installed ***inside*** therapy rooms
  3) better knowledge of the *fast* neutrons component

***Simulation***

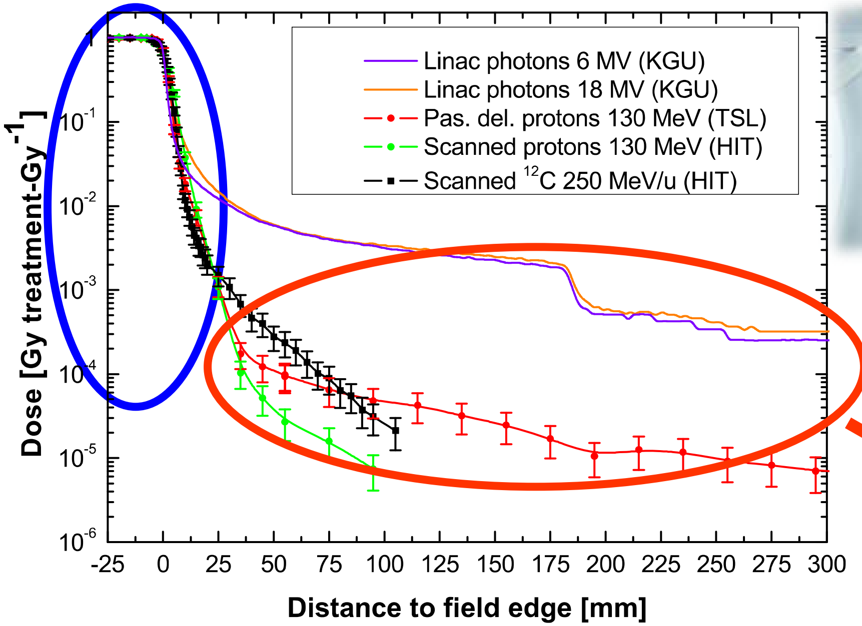
***Instrumentation***




**In-situ, fast (real-time), thermal/fast n, $\gamma$-rejection**

# Dose distribution =f(therapies)

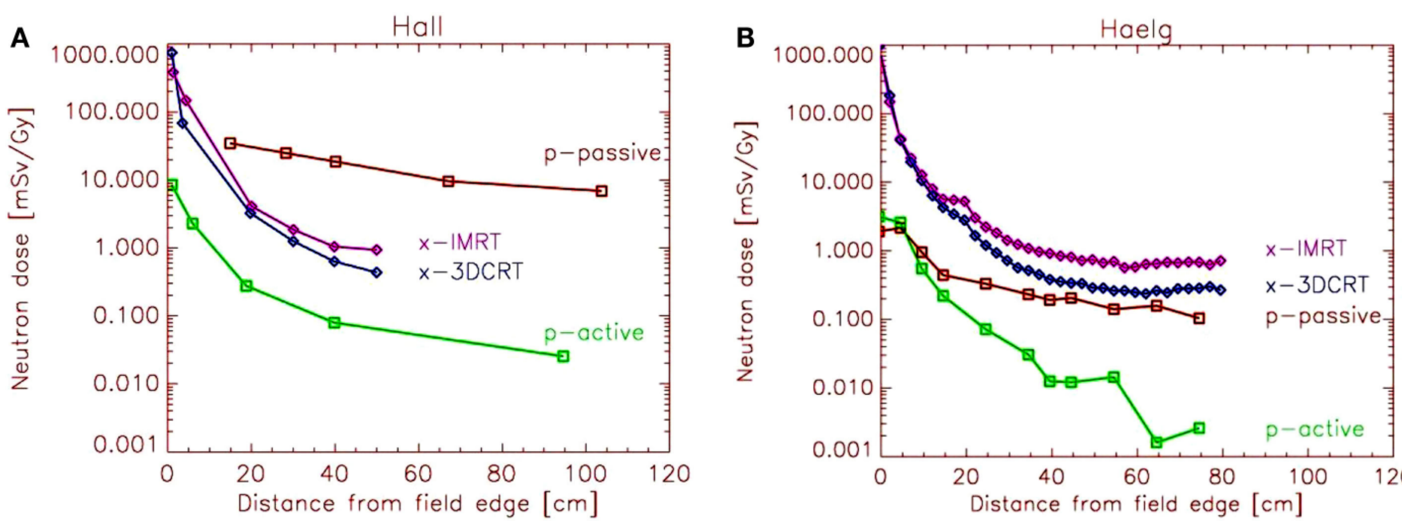
direct




out-of-field

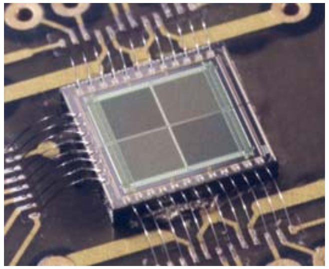
R. Kaderka, Phys. Med. Biol. **57** (2012)

Stray neutrons on patient: **everthing is worse!**



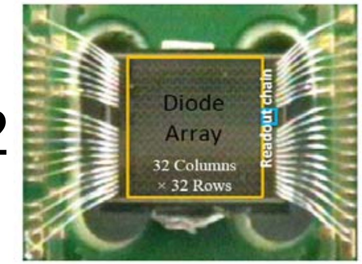

**+considerable *disparities* in published neutron dosimetric data**

# 1) $\alpha$lphaRad project



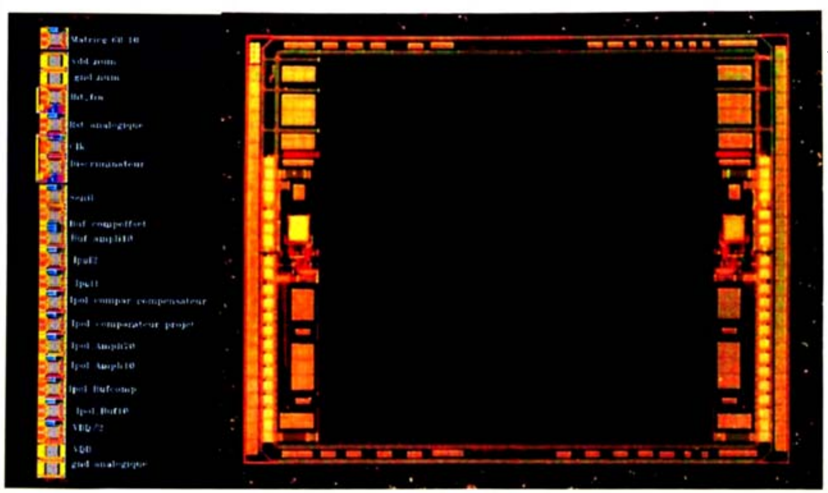
**1999**: MIMOSA I
True pixels (64 x 64)
for MIP tracking

**2009**: AlphaRad 2
(thesis Y.Zhang)

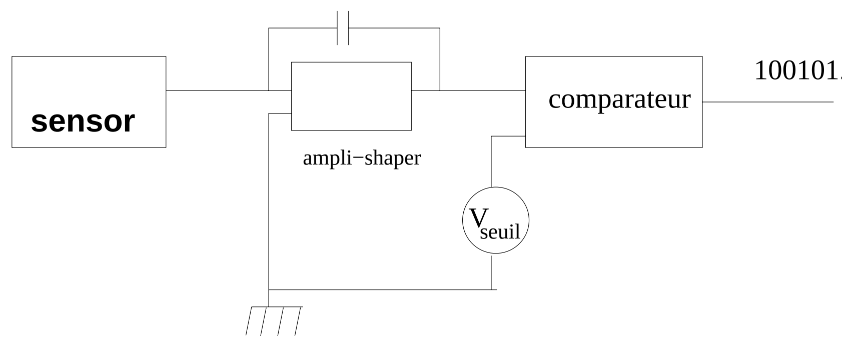



Low noise detection of
1 MeV protons
+ $\alpha$ (backside)

Fast
& thermal n!

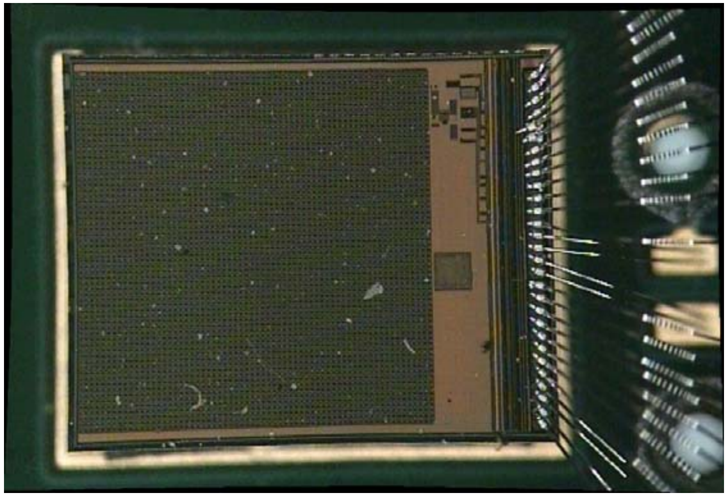


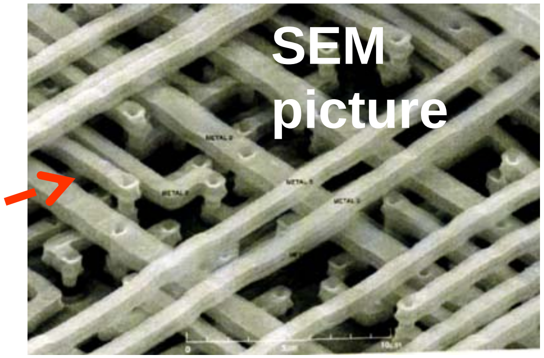
**2006**: AlphaRad 1
« 0-pixel » chip (**ONE single** analog output)




***CMOS technol.(14 $\mu$m): naturally $\gamma$-free***

# 2013: αlphaRad3

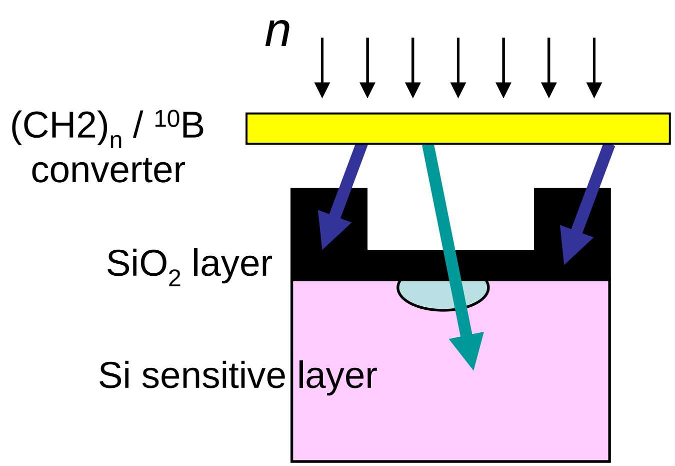


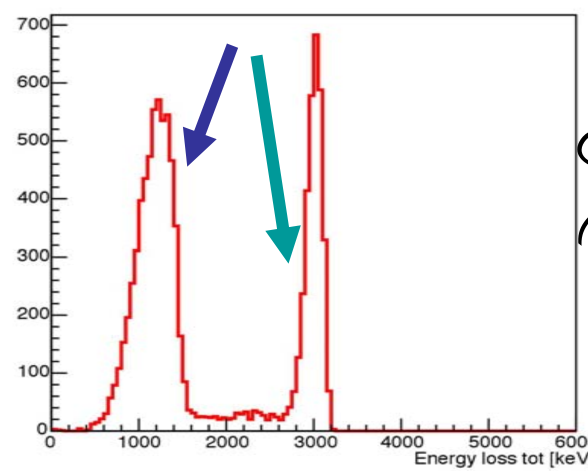



<u>Problem:</u> top layer 8 μm $SiO_2$+Al lines

1.4 MeV α ***stopped*** ! (no thermal *n*)

<u>Solution</u>: XFAB 0.35 μm techno provides **openings** in oxyde layer

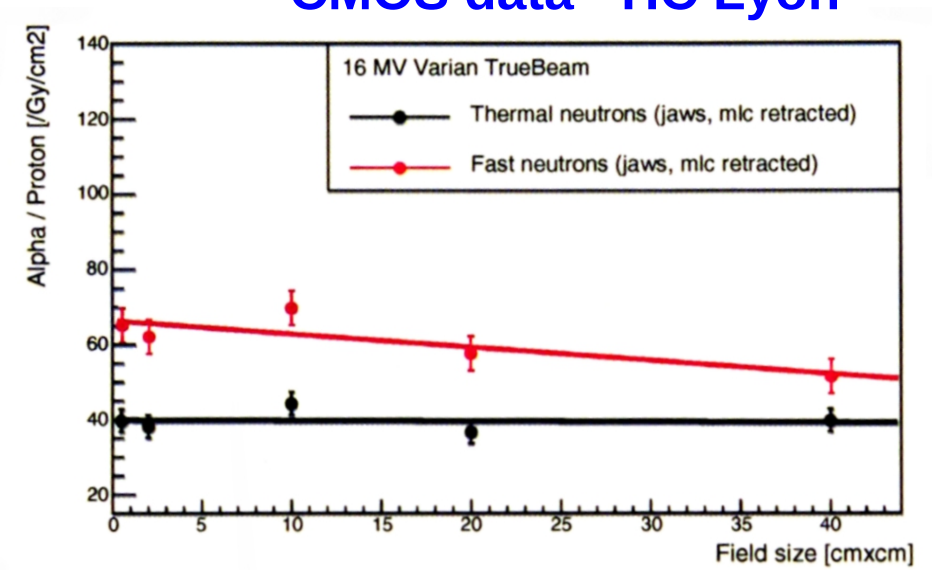


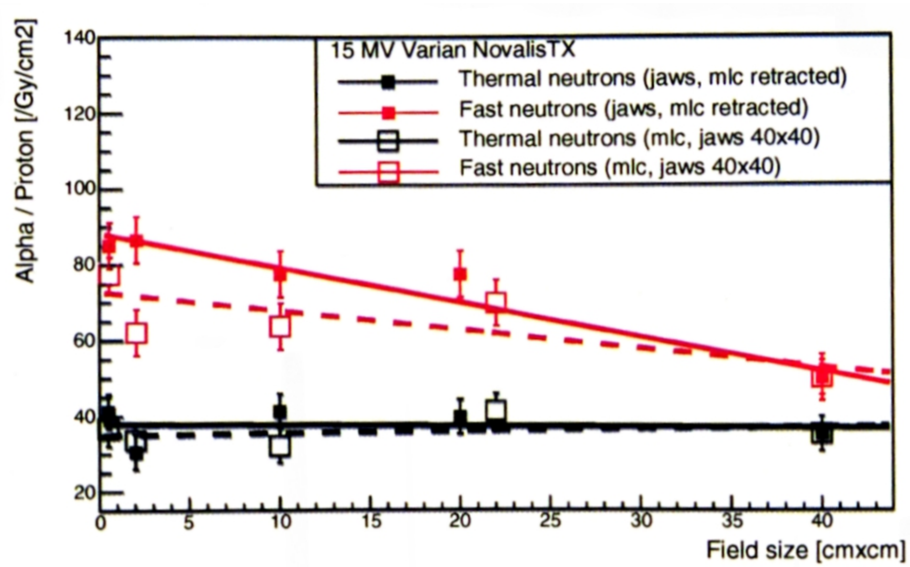

GEANT IV simu (5 MeV α)

# aRad3 in radiotherapy: machine effect

**CMOS data - HC Lyon**

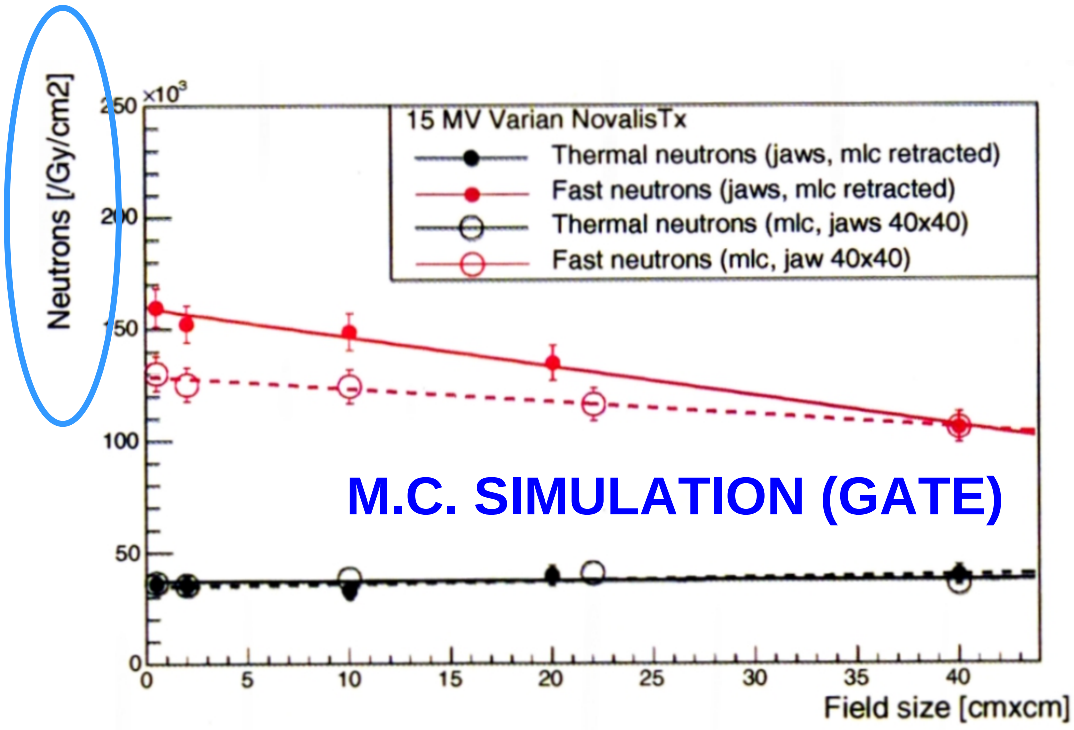



**CMOS data - CPS Strasbourg**

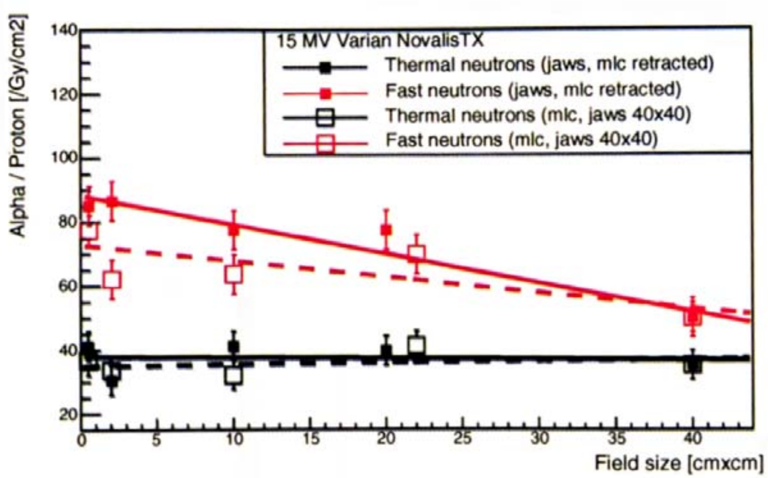



Fast neutrons: evidence for machine-settings effects!

# Neutrons in radiotherapy: simu/data

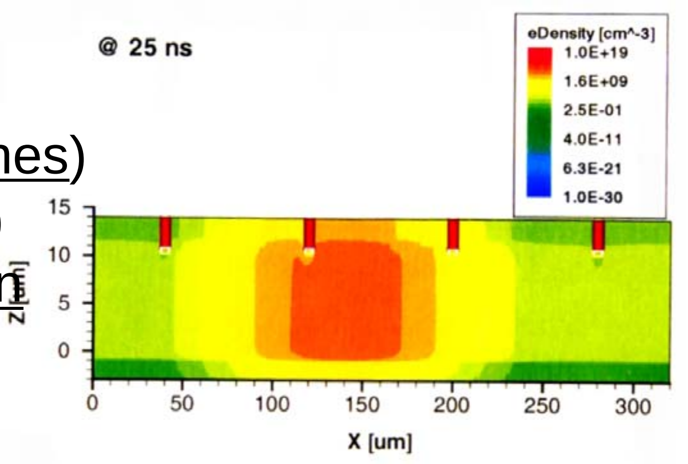



**CMOS data**

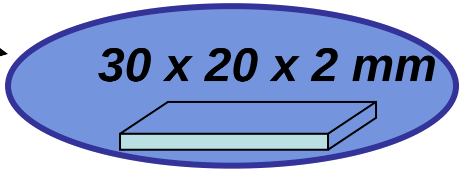



*Fast* neutrons: machine effects well reproduced by MC simulation

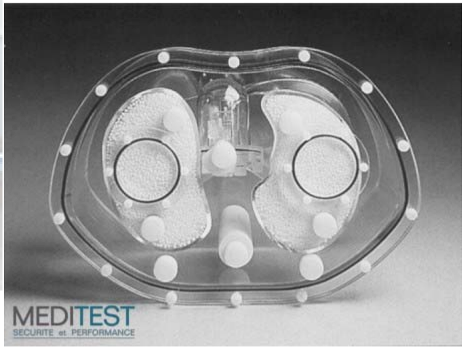
# αlphaRad4 (jun 2017)

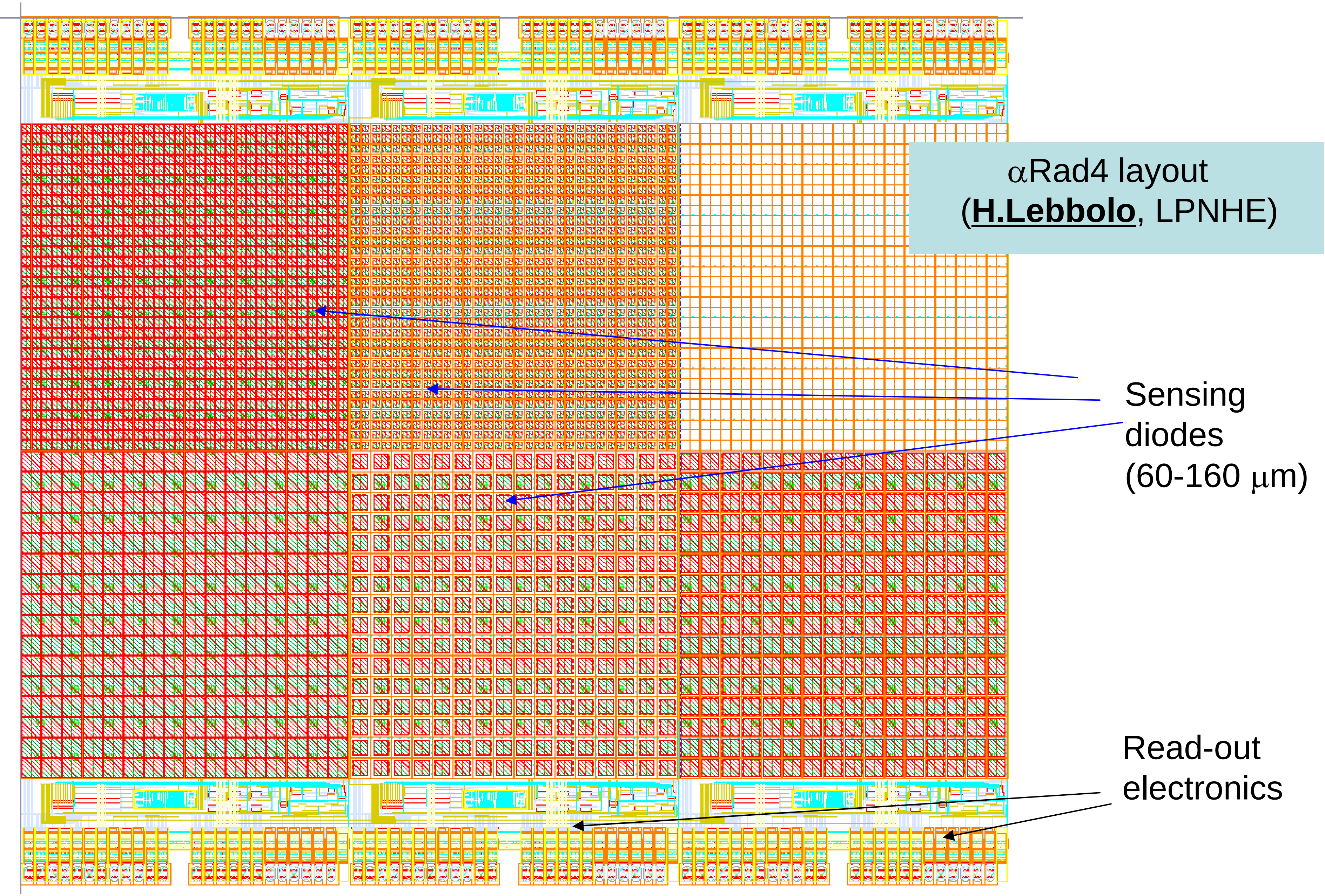



- XFAB 0.35 (low noise; mixed analog/digit.; trenches)
- ISE TCAD simu (**A.Dorokhov**) ⇨ larger diodes (**60-160 μm**) for better charge collection
- Multiple diode segmentation (structure optimiz.)
- Wider openings: ⇨ alphas efficiency > 50%
- Multiple programmable thresholds (discriminating power)
- Digital counter included on-chip
- **Ultra-small PCB board** (2 x 3 cm):



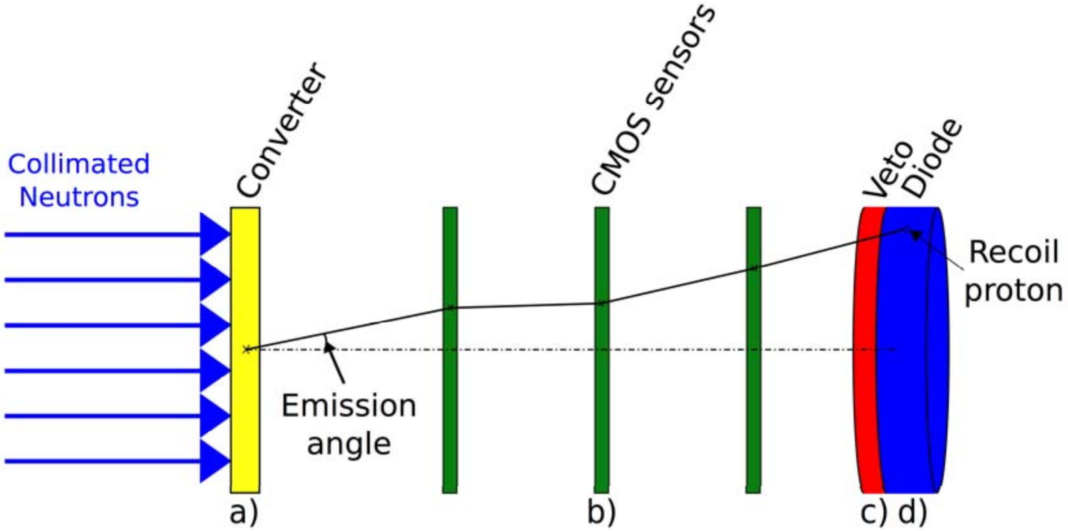

⇨ to be inserted INSIDE anthropomorphic phantoms (access to **doses at organs** !)




αRad4 layout
(**H.Lebbolo**, LPNHE)
Sensing
diodes
(60-160 μm)
Read-out
electronics

# 2) Recoil Proton Telescope

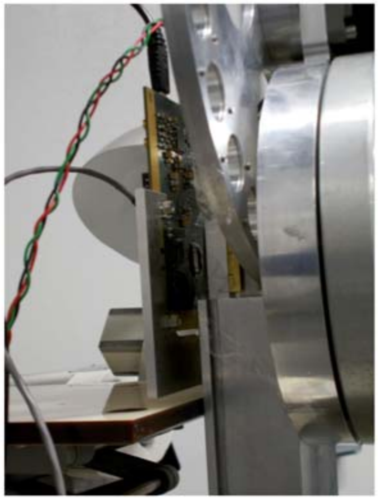
-Aim: real-time, **fast neutrons** spectroscopy (metrologic level $\Phi$+$E_n$)
-Grant: 300 kEUR from LNE and LMDN team at Cadarache (IRSN)
-Technology: CMOS pixels (p-tracking) + residual p energy measurement
-Final prototype for the AMANDE neutron source: summer 2019
-Future: developments for hadrontherapy at DeSIs

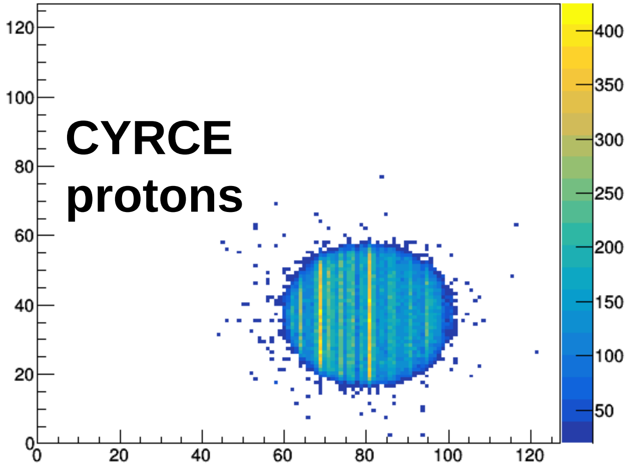


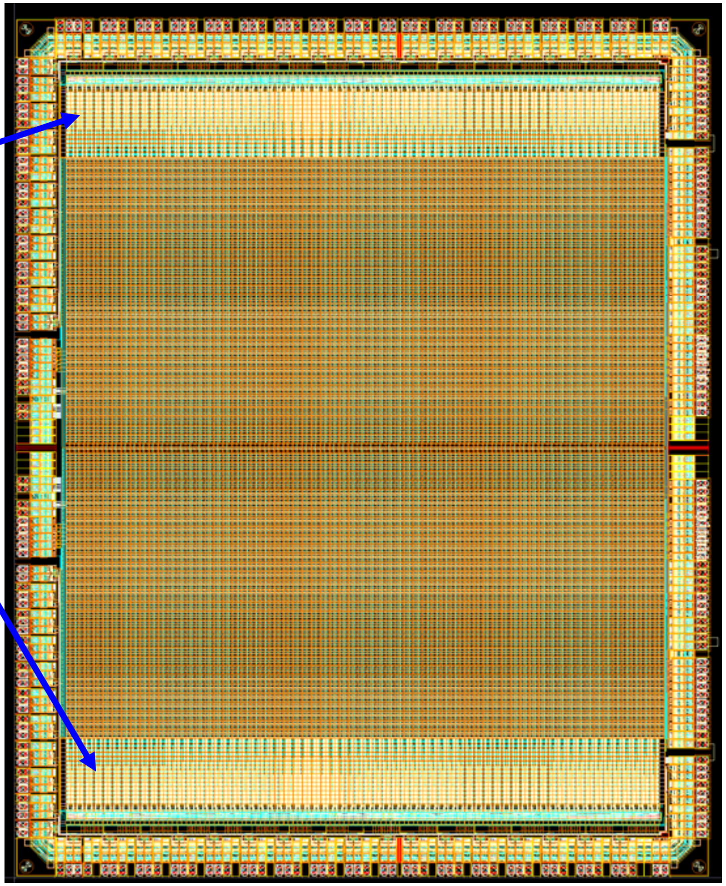

$$E_n=E_p/\cos^2\theta$$

# The FastPixN chip

- 128x128 pixels  6.4x6.4 mm
- 50 $\mu$m pitch
- protons 4-24 MeV
- column-ADC readout (4 bits)
-12 $\mu$s / frame
- XFAB 0.35 technology

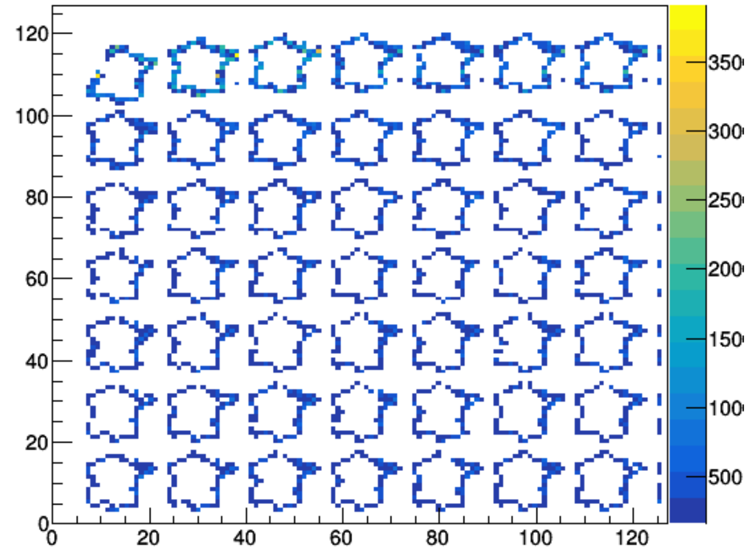




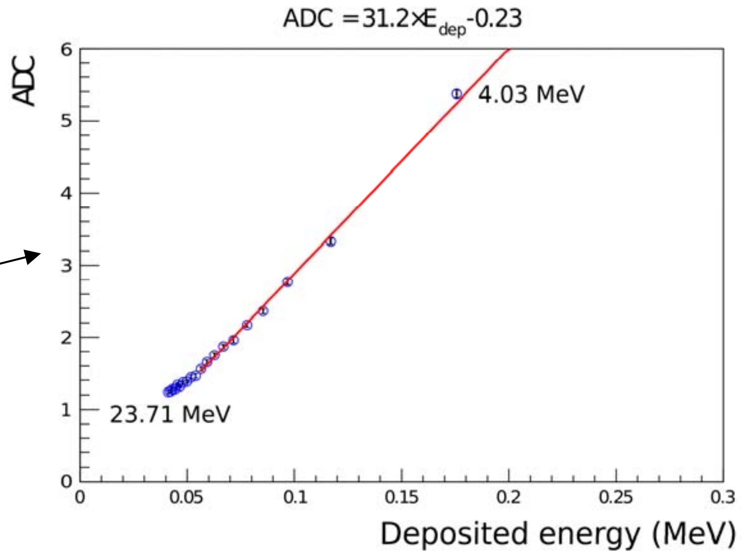
Capteur FastPixN

# Microscale testing at AIFIRA (CENBG Bordeaux)



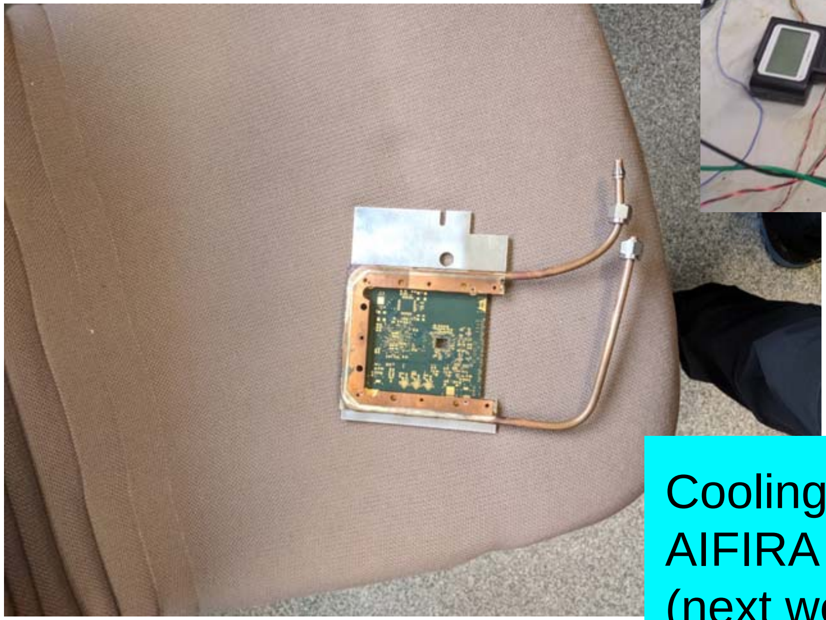

- -2 MeV alphas
- -1 & 3.3 MeV protons

Uniformity +
charge sharing +
charge calibr.



The 3 final PCBs

Our test lab

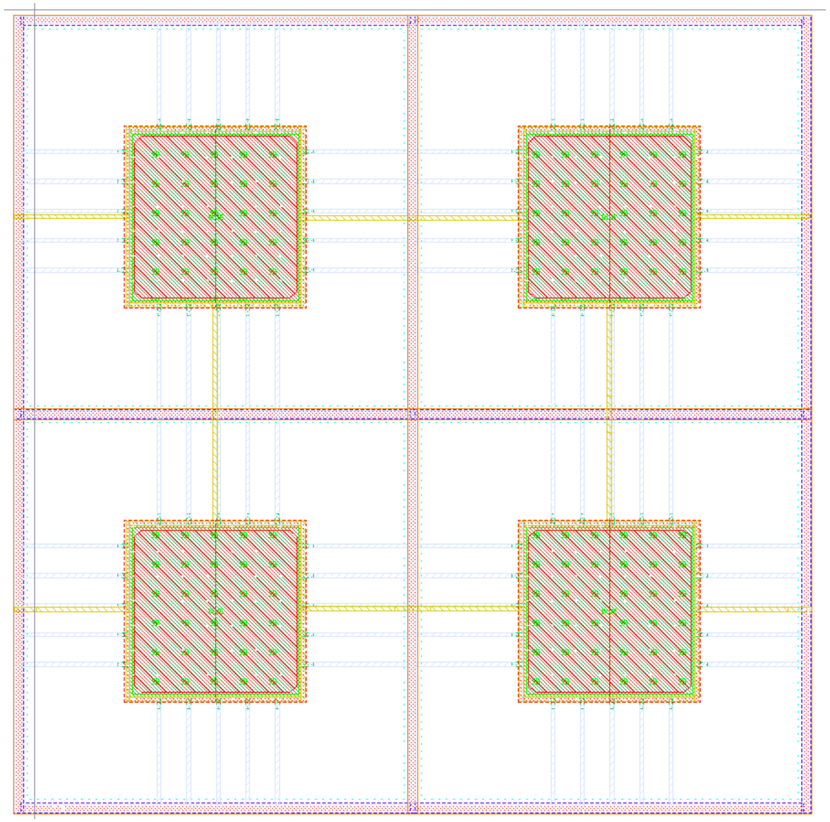


Cooling system for the AIFIRA vacuum chamber (next week experiments)

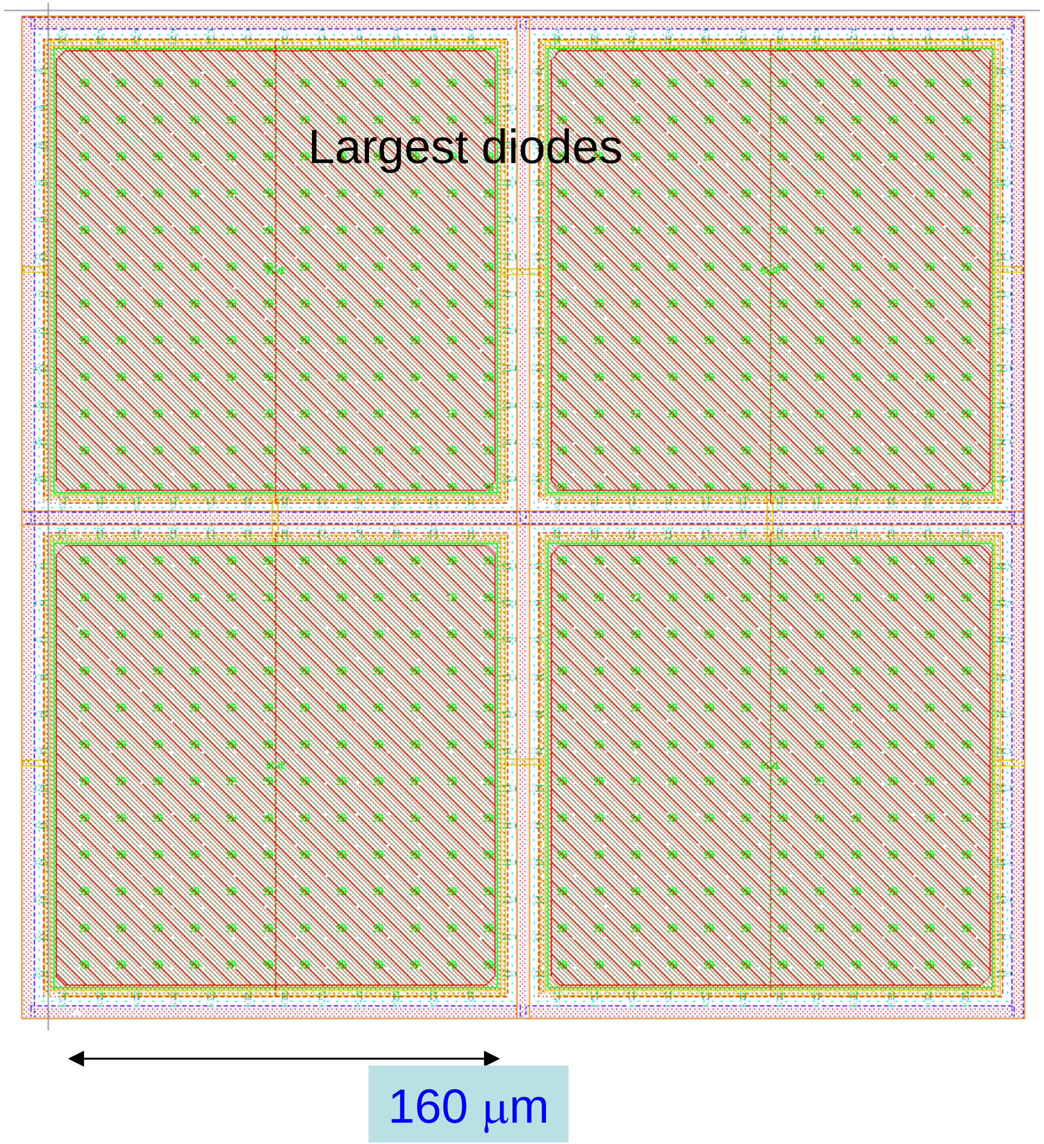
# Funding & designers

| Chip | date | designer | $ |
|---|---|---|---|
| $\alpha$Rad1 | 2005 | A.Bozier (UdS) | CMP/LEPSI |
| $\alpha$Rad2 | 2012 | Y.Zhang (U.Beijing) | RAMSES |
| $\alpha$Rad3 | 2013 | M.Kachel (postDoc) | DeSIs |
| $\alpha$Rad4 | 2017 | H.Lebbolo (LPNHE) | DeSIs |
| FastPixN | 2013 | M.Kachel (postDoc) | IRSN |

# Spares



Smallest diodes



# Our strategy

**Simulation (Gate/Geant IV)**

***On-line* monitoring during treatment**

thermal ***and*** **fast** neutrons

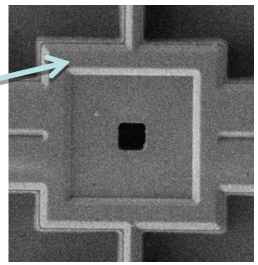
- Detector must be:
  - useful in medical rooms = easy operation,***small***
  - operational = fast+efficient
  - discriminating $\gamma$ & { ***fast*** / *thermal* } neutrons.

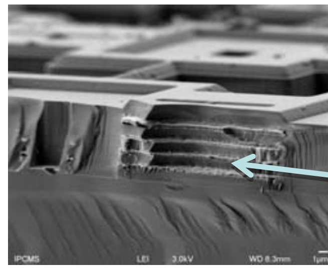
- Poorly useful: Bonner sph.(big!) resp.passive SSNTD
  ⟷ Off-line treatment ! (deconvolution resp.chemical processing)

# Micro-scale characterization (AlphaRad 3)

- CMOS sub-structure ($SiO_2$ edge, metal layer) impact **low energy particles** detection
- Micro-beam scanning using alpha/proton AIFIRA facility

$SiO_2$ edge



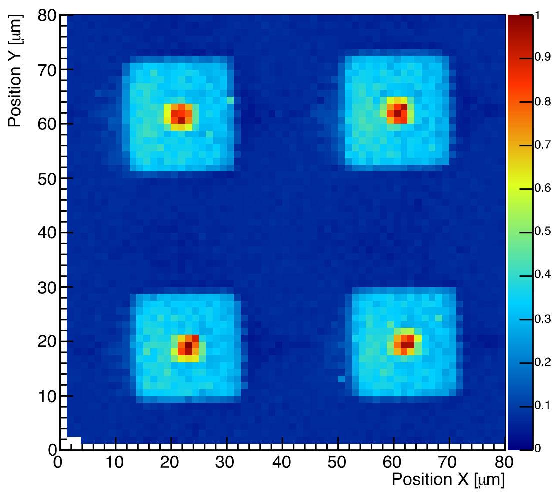


metal layers

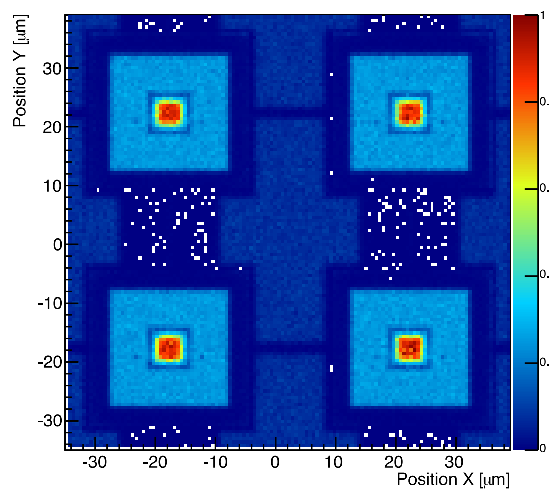
AIFIRA – CENBG (Bordeaux)

## Geant4 simulation :

Deposited energy 700 keV protons




AIFIRA data




Geant4

Full Geant4 simulation

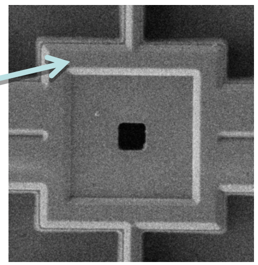
⇔

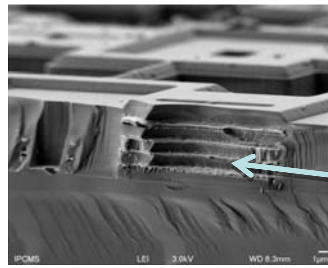
amplitude spectrum analysis

# Micro-scale characterization (AlphaRad 3)

- CMOS sub-structure ($SiO_2$ edge, metal layers) impact low energy particles detection
- Micro-beam scanning using alpha/proton AIFIRA facility

$SiO_2$ edge

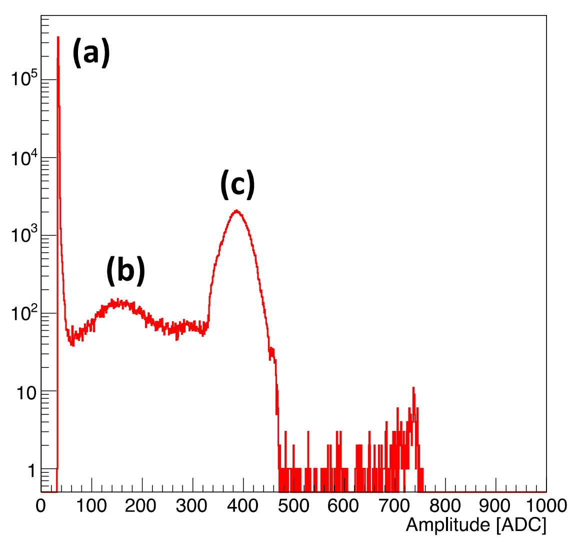


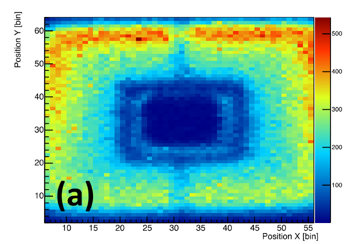


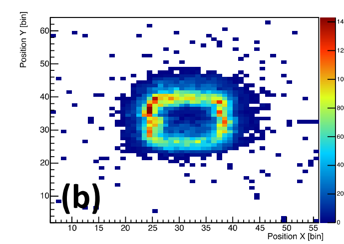
metal layers

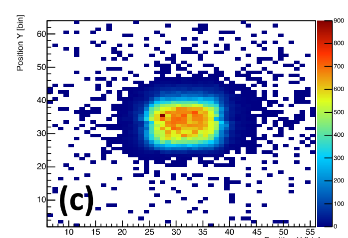
AIFIRA – CENBG (Bordeaux)

2.2 MeV alpha $\mu$ -scan :



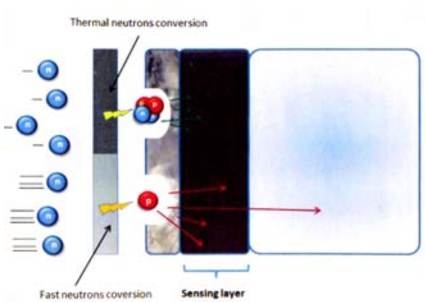
# 2) Out-of-field neutrons in radiotherapy

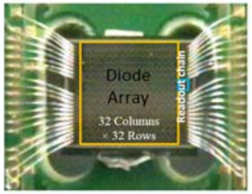
- Exp. on 2 Varian LINACs 16 MV TrueBeam™ (HCL)

  & 15 MV NovalisTx™ (CPS)
- Fast & thermal neutron production during treatment (IMRT):

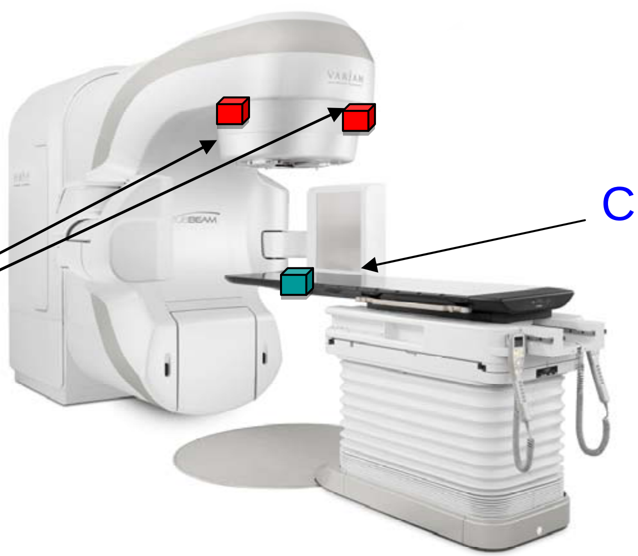
  on-line variation as a function of field size (jaws/120 leaf MLC)
- Cross-check with CR39 (isocenter+CMOS pos.)

  (maximal photon fluence)



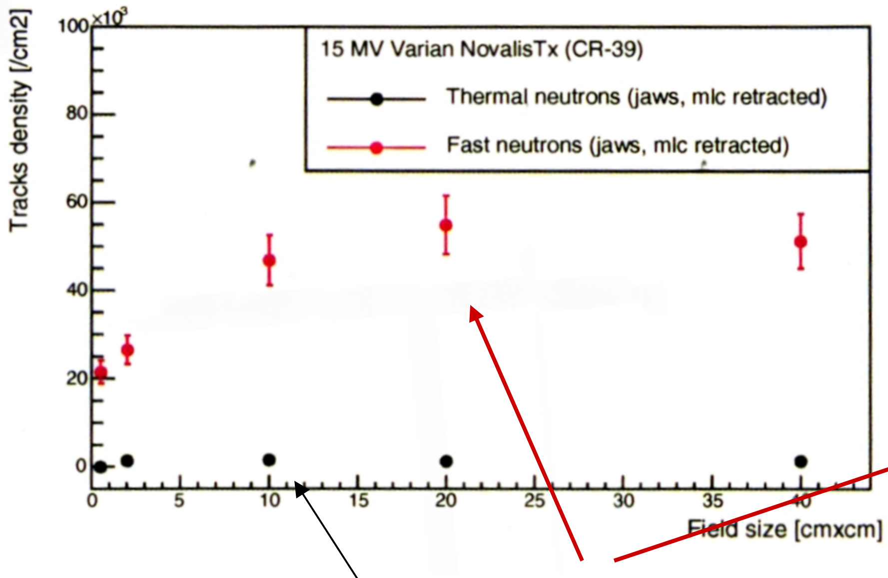

CMOS sensors



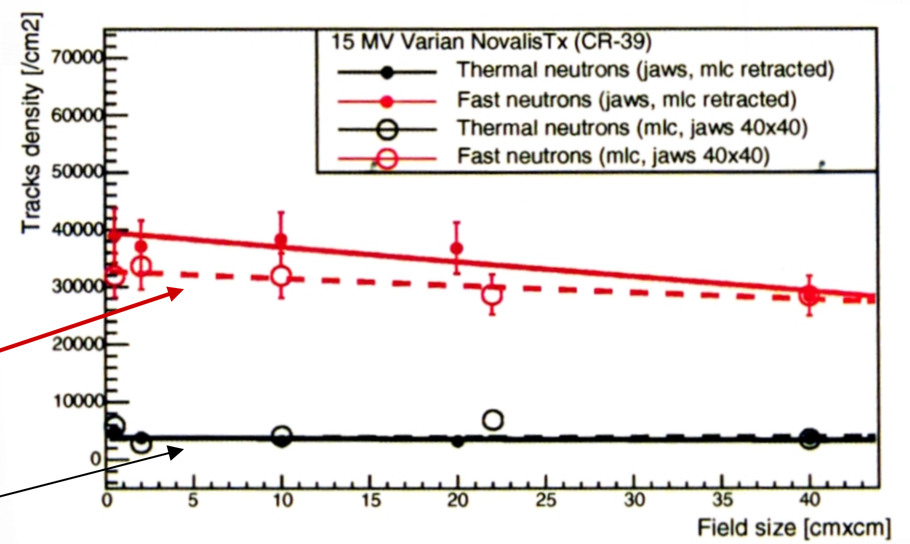
CR39

# 2’) Neutrons in radiotherapy: CR39 results

Isocenter




60 cm away from isocenter



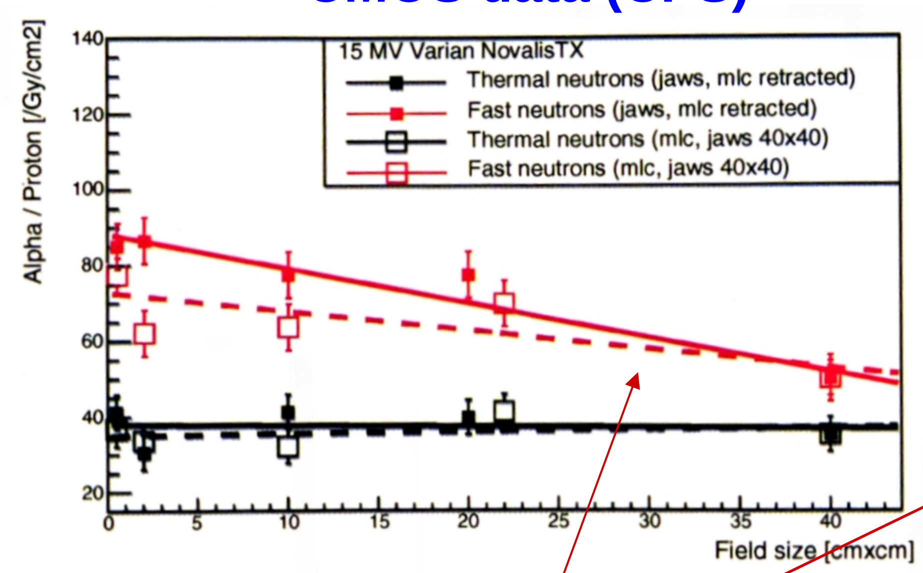

fast

thermal neutrons:
no detectable effect of field size

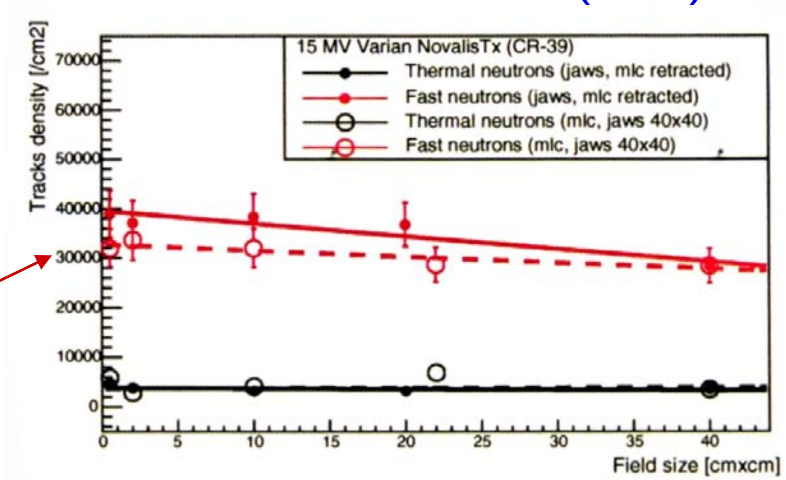
@isocenter=direct fast *n* produced at the top of machine’s head
@60 cm: fast *n* prod/diffused by jaws

# 2'') Neutrons in radiotherapy: CR39 / αRad3

**CMOS data (CPS)**




SSNTD (CPS)



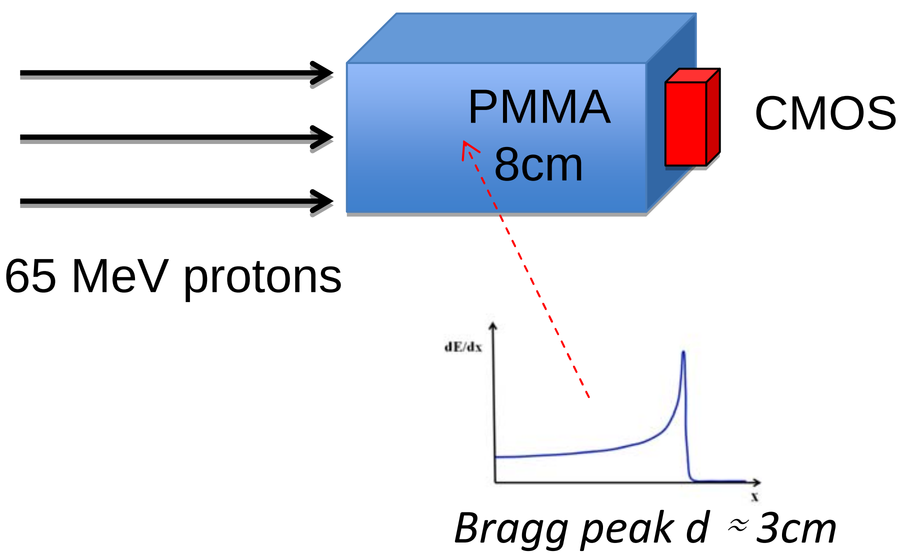

Fast neutrons: clear effect of machine configuration

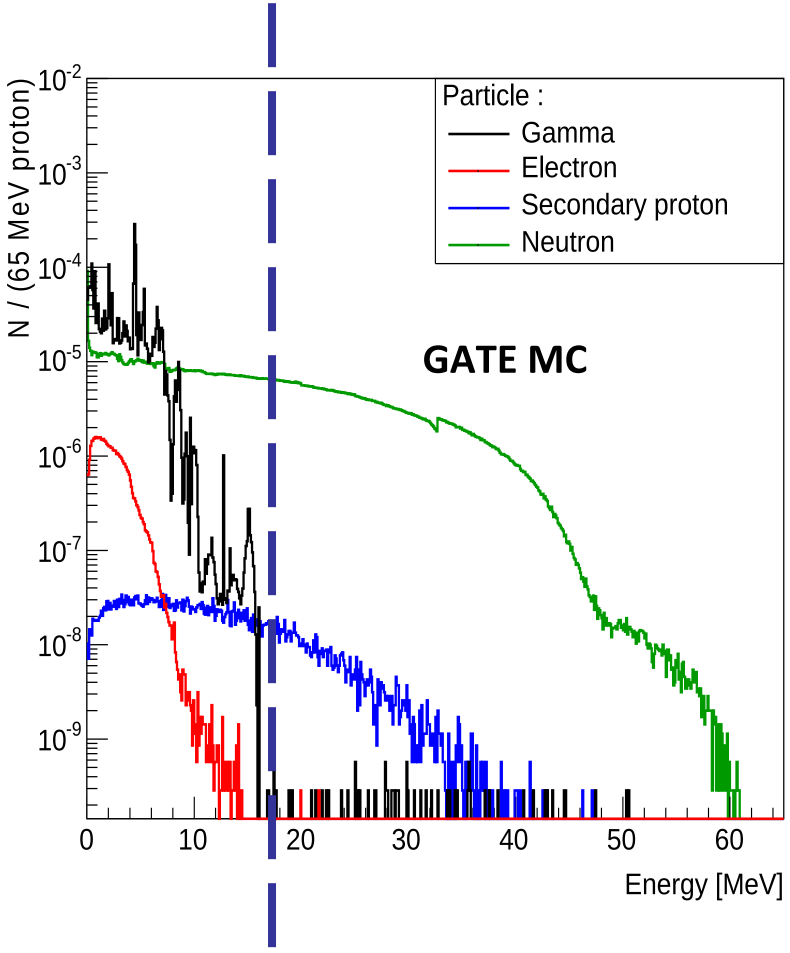
$\gamma \rightarrow n$ reactions in these parts of the machine (jaws/MLC)

# 3) Signal distribution in Protontherapy

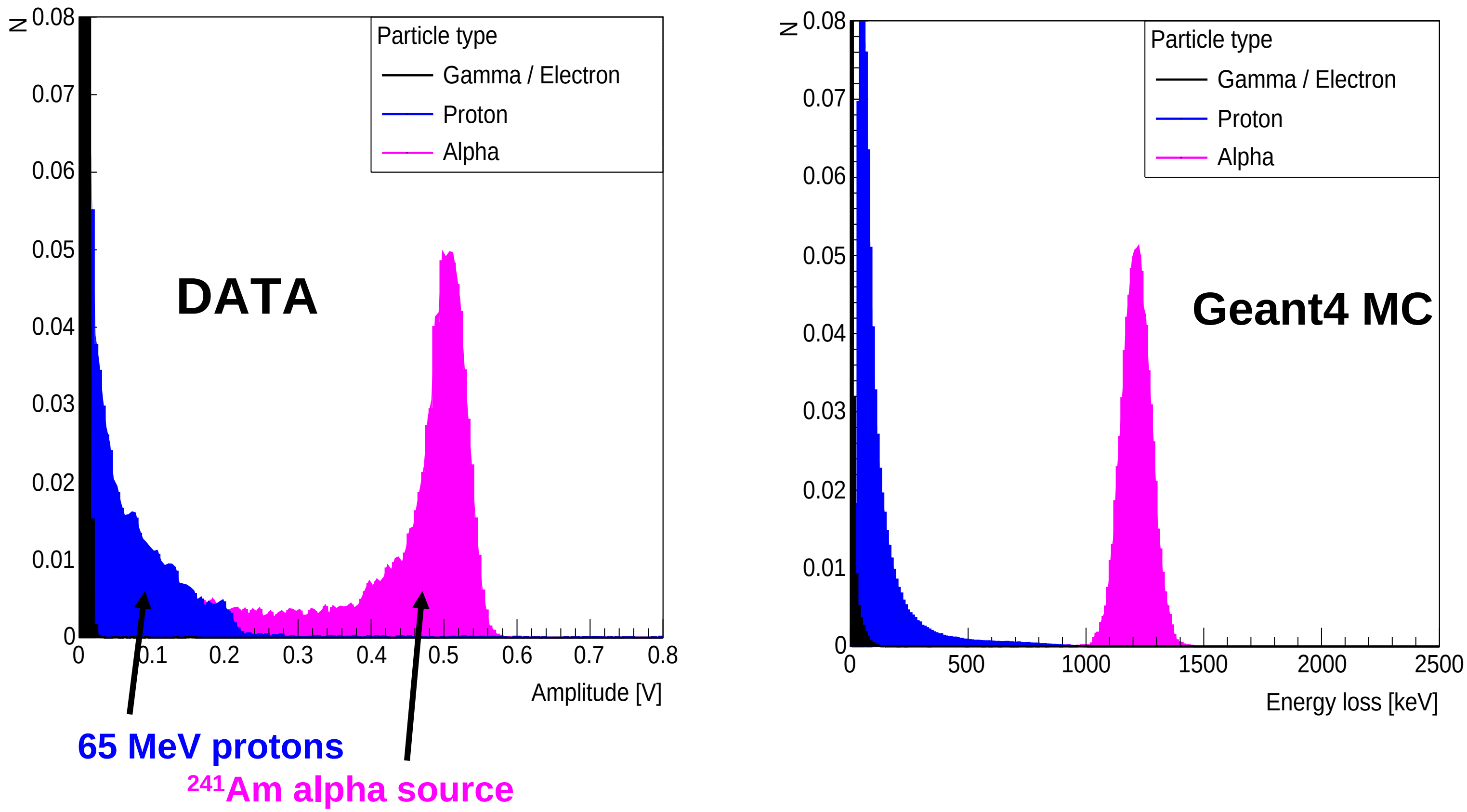
**65 MeV protons**

(CAL – Nice (France))



# Clear separation fast / thermal n

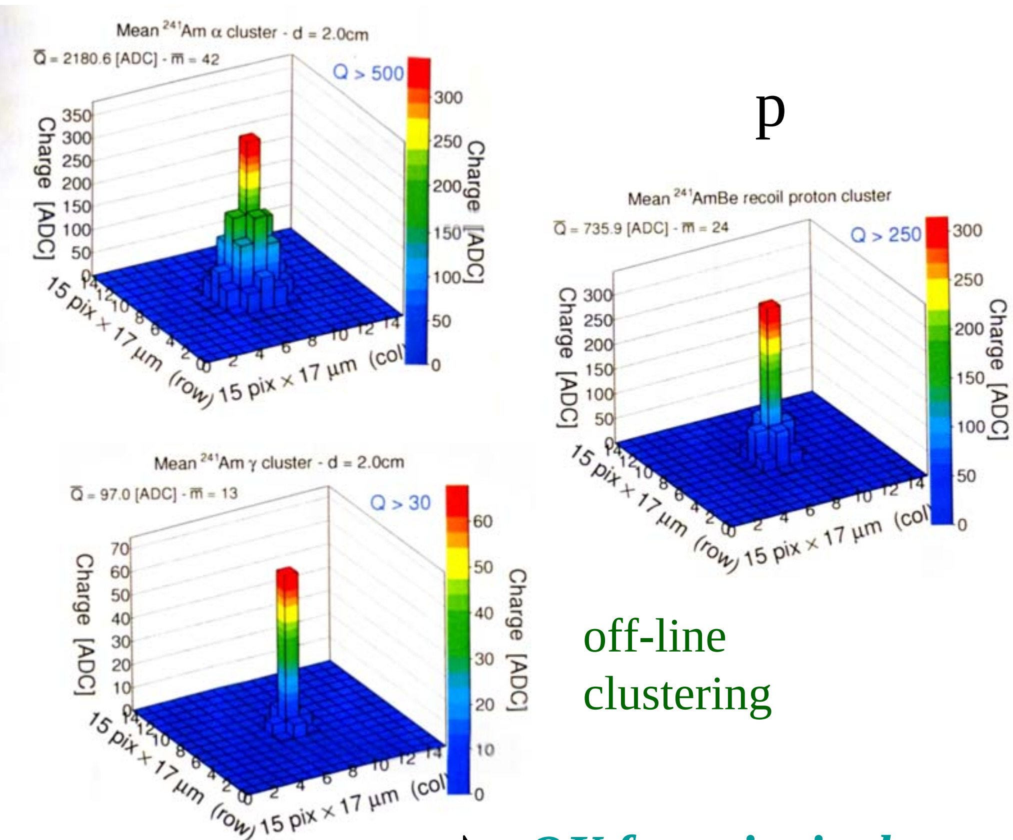



$\Rightarrow$ High purity selection with CMOS sensor trhrough amplitude threshold

# N-Dosimetry with CMOS pixels

a) True pixels: MIMOSA V

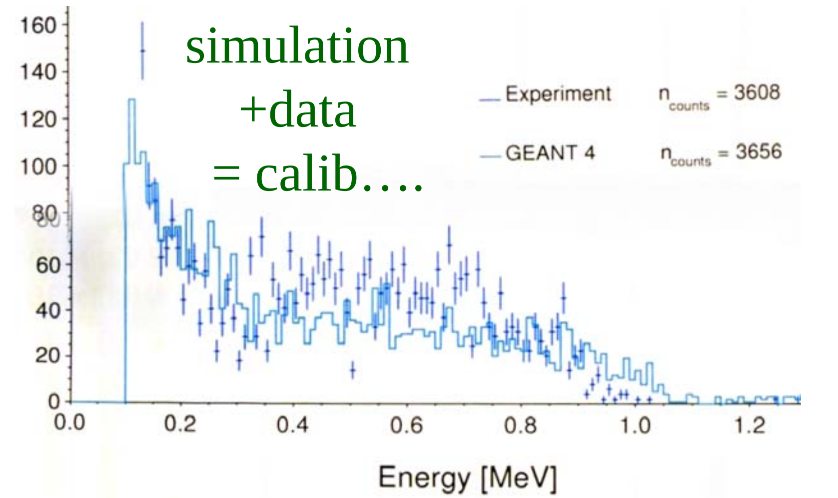
(M.Vanstalle, UdS Thesis 2012)

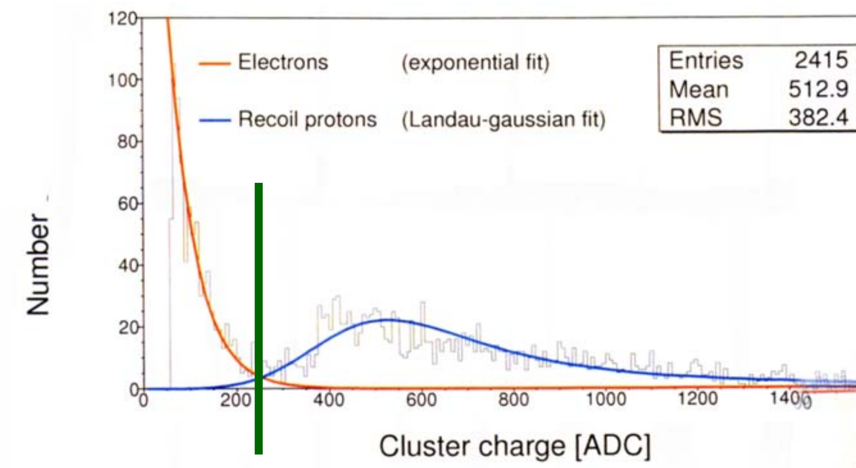



p

γ

off-line
clustering



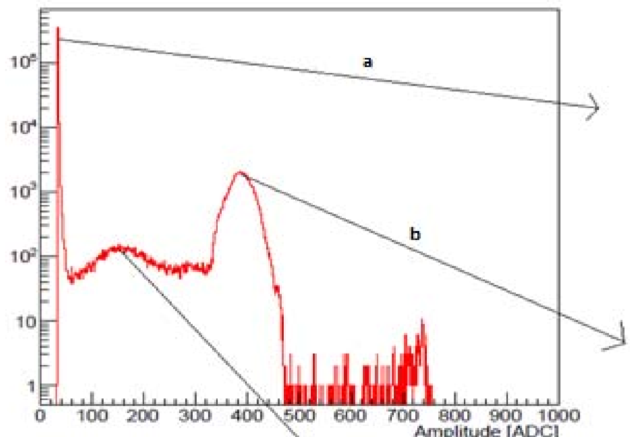

***OK for principal…***

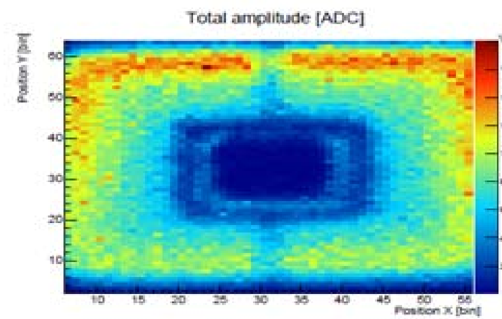
First results in source: efficiency very poor !

Origin pb ? new techno XFAB 0.35, openings SiO2 ?

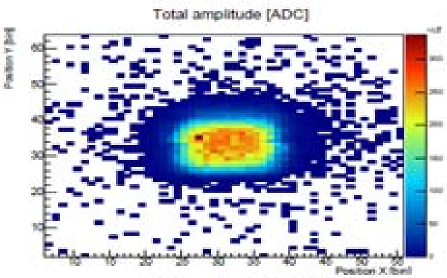
Solution: scan AIFIRA ! α + protons [0.7 – 3] MeV

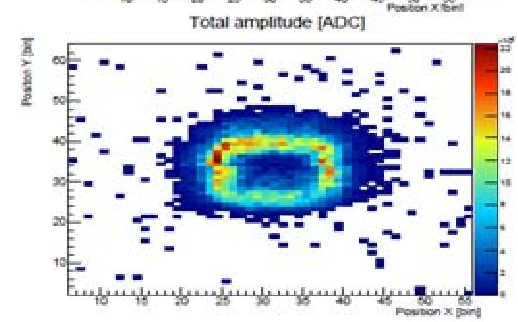
α 2.2 MeV (mai 2015)



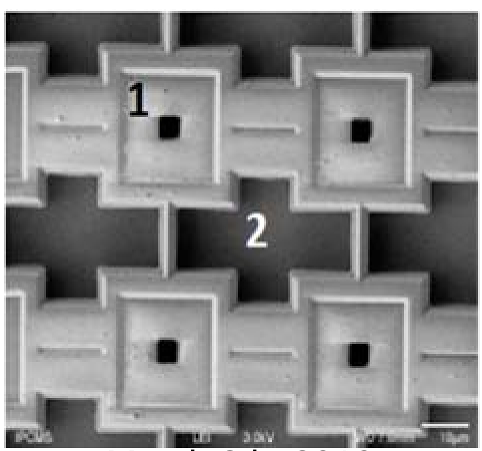




15 µm

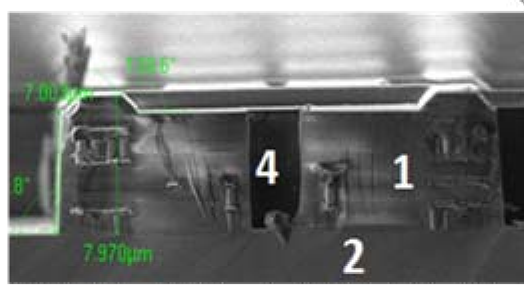



40 µ

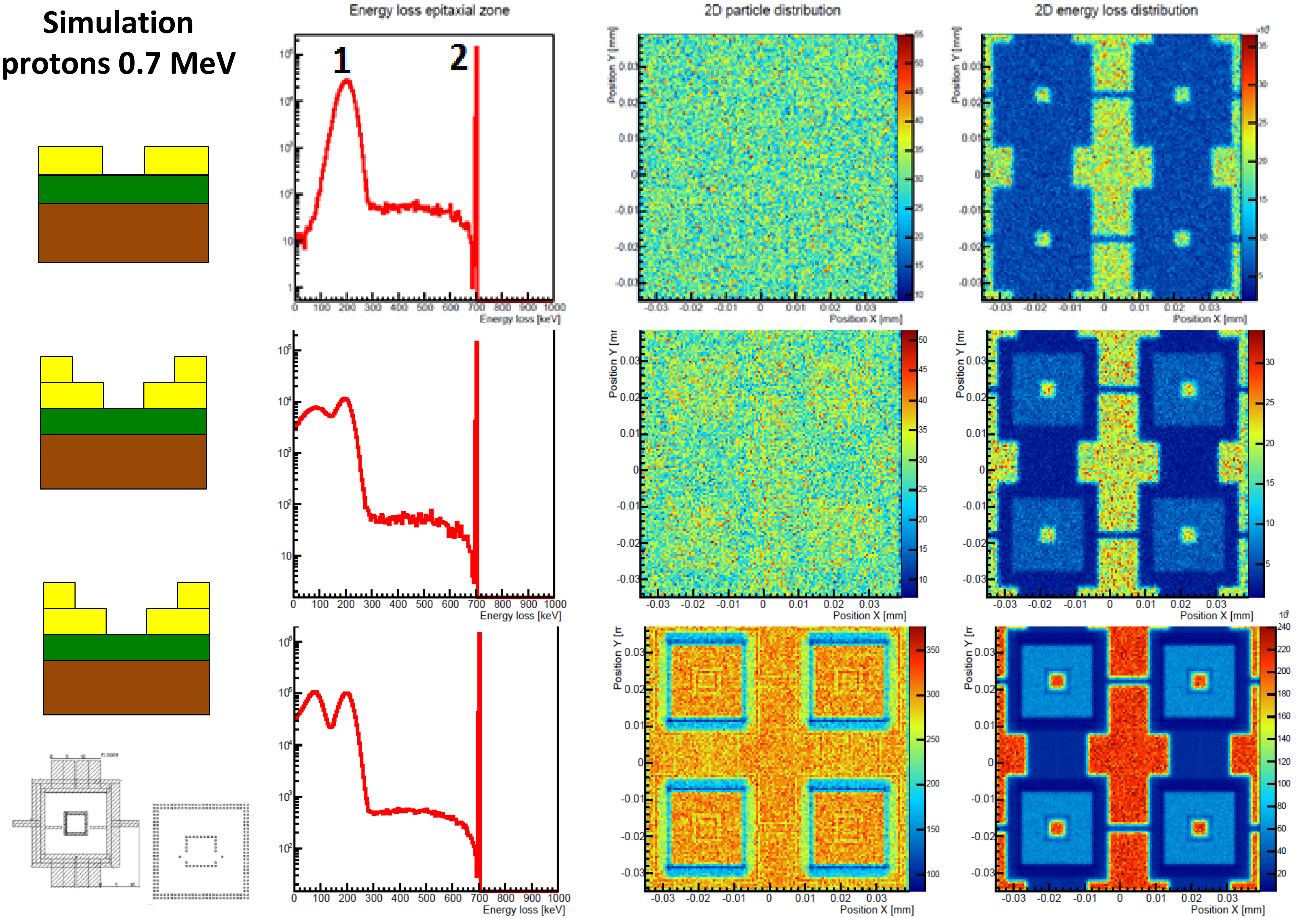



SEM



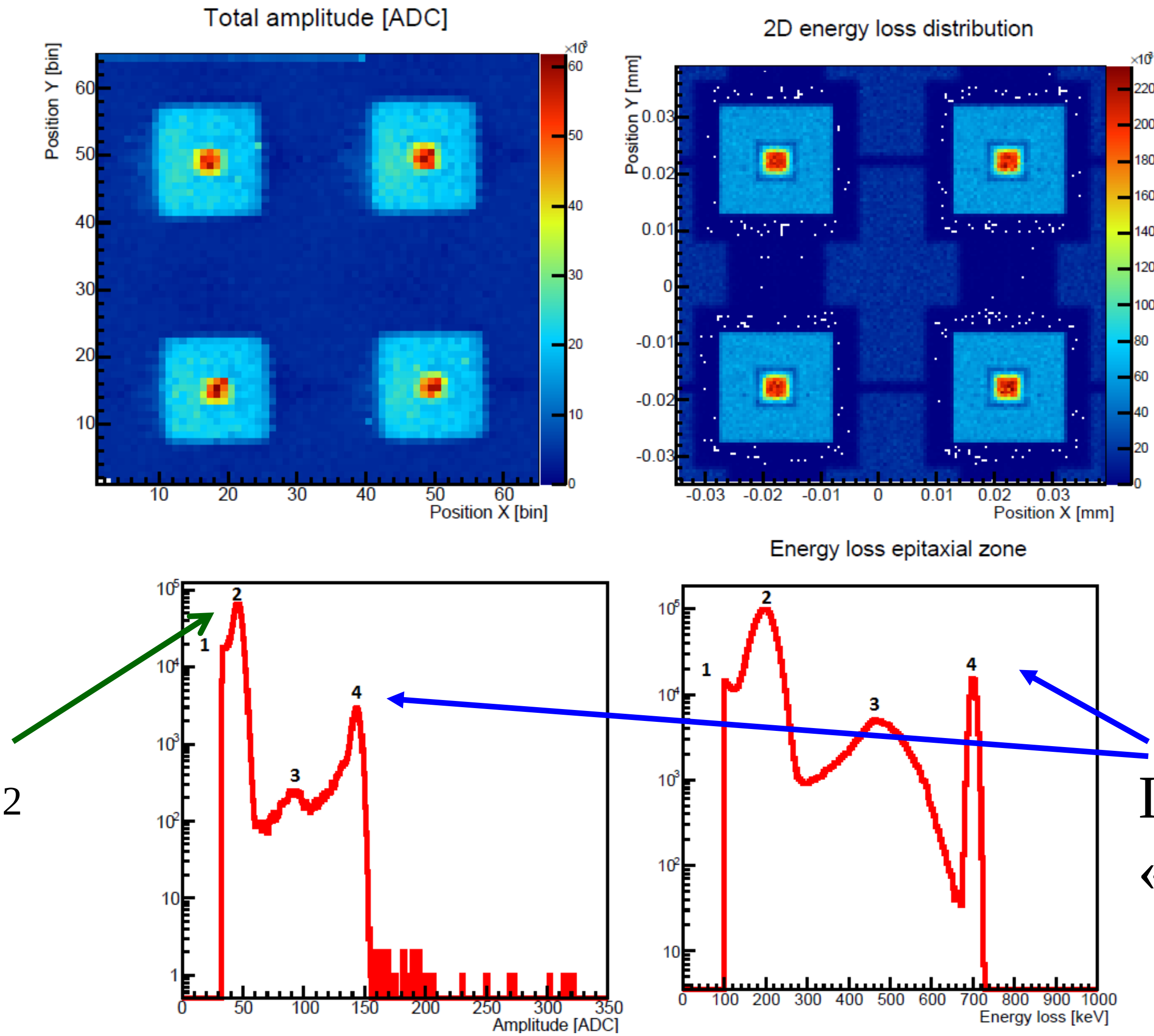

8 µ

# Simulation protons 0.7 MeV



**0.7 MeV protons**

*Data*
*AIFIRA*




*Simulations*
*Geant IV*

Effect $SiO_2$
+ metallic
structures

Impacts
« in trench »

- Al parasistic effets reproducibles by simulation
- Design <u>next chip</u> AlphaRad4 done: FAB ON THE WAY …

# MC spectrum for a 15 MV machine (isoc)