A CMOS-based Recoil Proton Telescope for fast neutrons

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IPHC/RaMSeS, Strasbourg (F)

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IRSN/LMDN, Cadarache (F)

- The concept
  - diffusion of fast neutrons
  - the AMANDE facility
- Hardware
  - why large & thin detectors ?
  - the Strasbourg/Cadarache project
- Multiple scattering
  - the (possible) problem
  - EUDET experiment (april 08)

Neutrons: what for ?

- Activation studies, μ-chemistry
- Rad-hardness (materials, electronics)
- Energy (ITER, spallation, nucl. waste manag^{t})
- Neutron imaging (low Z discrimination)
- Hadrontherapy
- Dosimetry
- Physics: baryogen, stars, cold neutrons
- …

CMOS chips as neutron detectors

Detecting Neutrons:

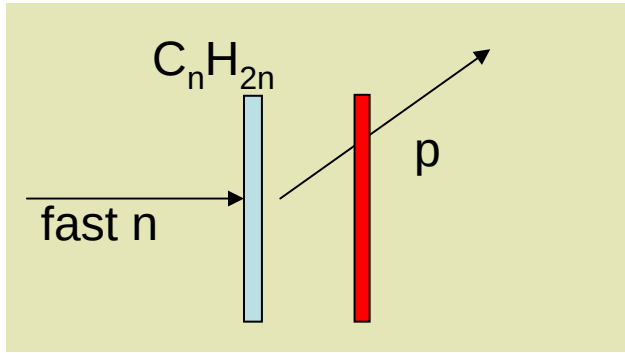
Secondary **charged** partic:

1) d/t + α [1meV-10 keV]

   n+Li/B $\longrightarrow$ α (+d/t)

2) p (fast neutrons ~10 keV-100 MeV

   with σ ~ 1 bn…



Longstanding pb: **n/γ discrim..**

(AmBe source: 0.5 γ / n)

thin* det.~100% γ transpar. !

(**15 μm epi Si*)*

- slow e- < noise
- MeV γ go through..

CMOS **pixels**

(xy resol)

Fast counting:

αRad chip !

~3 10^9 n/cm^2/s

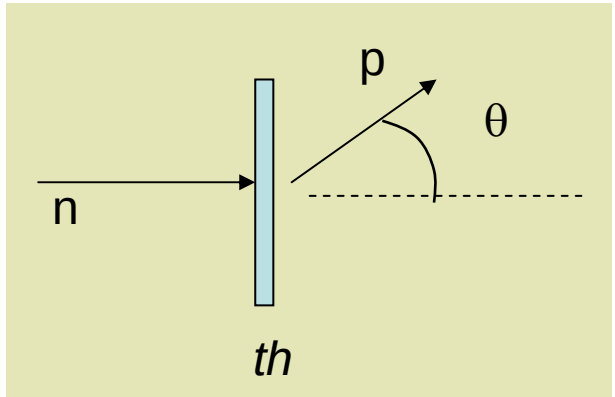
γ-transparent !

Kinematics

1) $\sigma_{elastic} \sim 1$ bn (5 MeV)

Attenuation in C_nH_{2n}: $\mu=\sigma.n_H = 0.12\ cm^{-1}$

$1.2\ 10^{-3}$ p/n in *th*=100 μm



2) $E_p=E_n.\cos^2(\theta)$

$$\sigma(E_n)/E_n = \{(\sigma(E_p)/E_p)^2 + 4.\tan^2(\theta).\sigma_\theta^2\}^{1/2}$$

AMANDE facility, Cadarache(Fr)

LMDN=Lab. Metrology and Dosimetry of Neutrons
(National Institute for Radioprotection IRSN)

ISO certif.

Monoenergetic fields (2 keV-20 MeV)

Metrological quality ⟷ **Reference** facility

High Performance **Detectors** !

Low E: μTPC (^{4}He)
(Grenoble)

5-20 MeV:
CMOS Telescope
Strasbourg

AMANDE : details

Inelastic reactions:

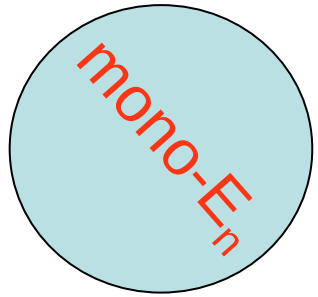
^{45}Sc(p,n): 2 keV, 24 keV

^{7}Li(p,n) : 144, 250, 565 keV

^{3}H(p,n) : 1.2 , 2.5 MeV

^{2}H(d,n) : 2.8 ; 5 MeV

^{3}H(d,n) : 14.8* ; 19 MeV



+ adjustable diffusion angle / target : → E scan

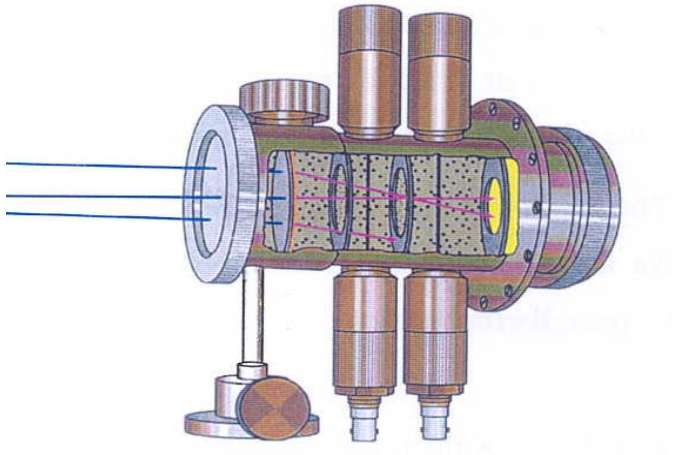
Fluences: measured* ϕ_n @ d=50 cm :

- without apertures: 6500 n/cm^2/s
- with apertures: 1730 n/cm^2/s (+350 γ [0.3;8.46 MeV])

(Compare to IPHC AmBe irradiator : ~20 n/cm^2/s @ 1 m)

The European Reference

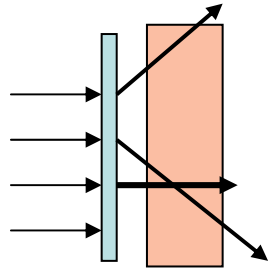
- PTB (*Phys.-Tech. Bundesanstalt*) ,
  Braunschweig (Germany)
- Gaseous cell, « 0 degree », no tracking

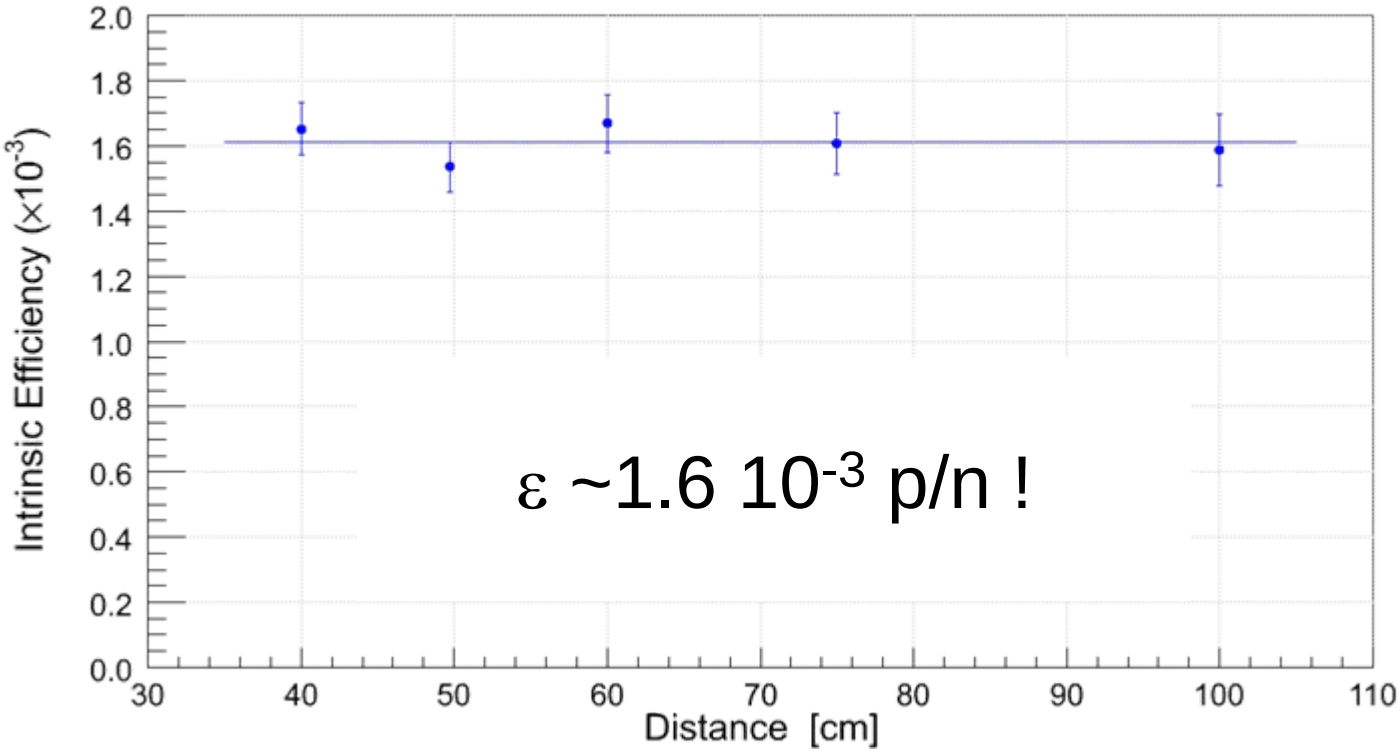


- → ε ~ 10^{-5} p/n (~1% of scatters in [0;5°]…)
- → ε ↗ if all θ detected+ E_p measurement

n-efficiency of CMOS pixels

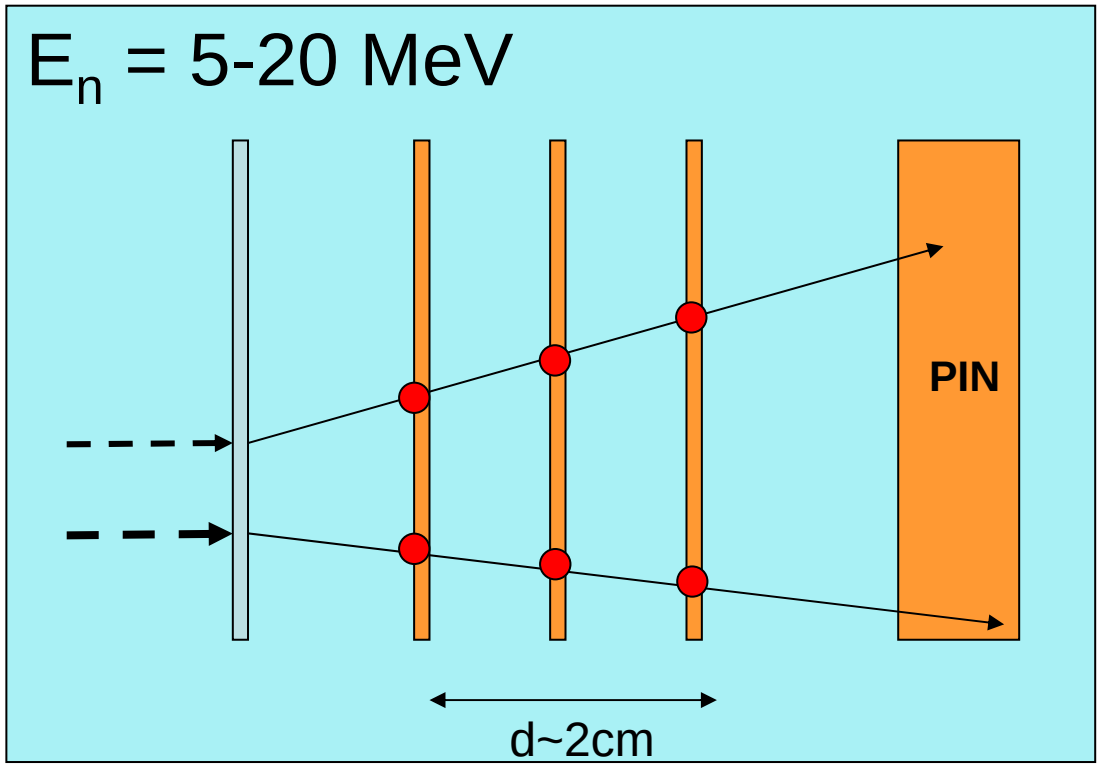
(MimoV in calibrated AmBe)

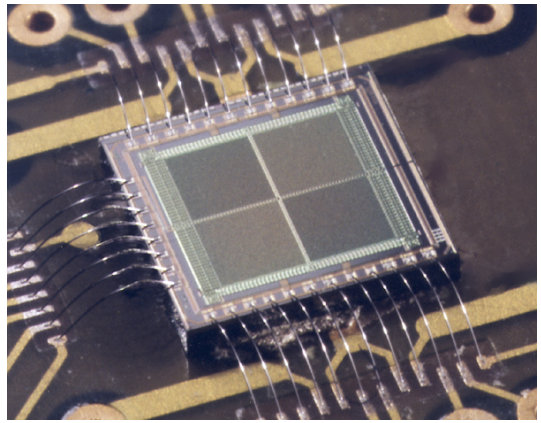




M.Trocmé, D.Husson et al. , Rad.Meas.43(2008)1100

RPT: general outlook





$$\sigma(E_n)/E_n = \{(\sigma(E_p)/E_p)^2 + 4.\tan^2(\theta).\sigma_\theta^2\}^{1/2}$$

Dig.resol. for 30 μm pitch:

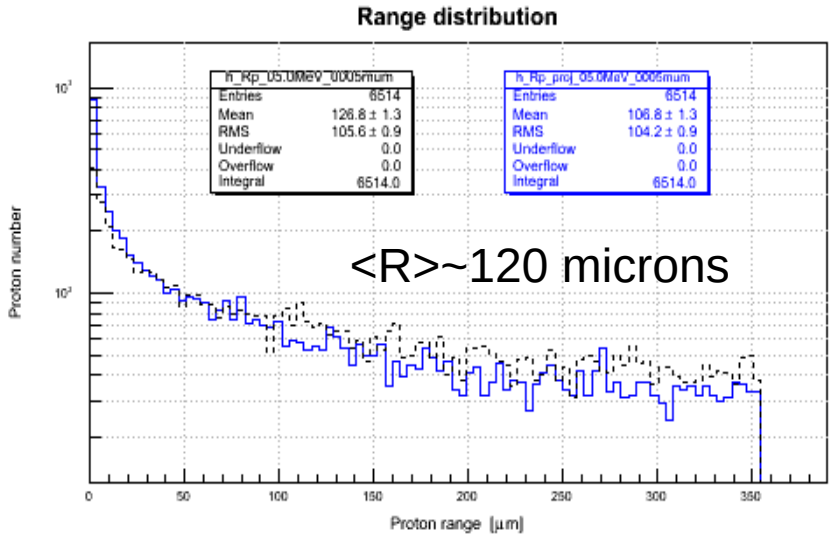
$$\sigma_{xy} < 30\ \mu m/(12)^{1/2}$$

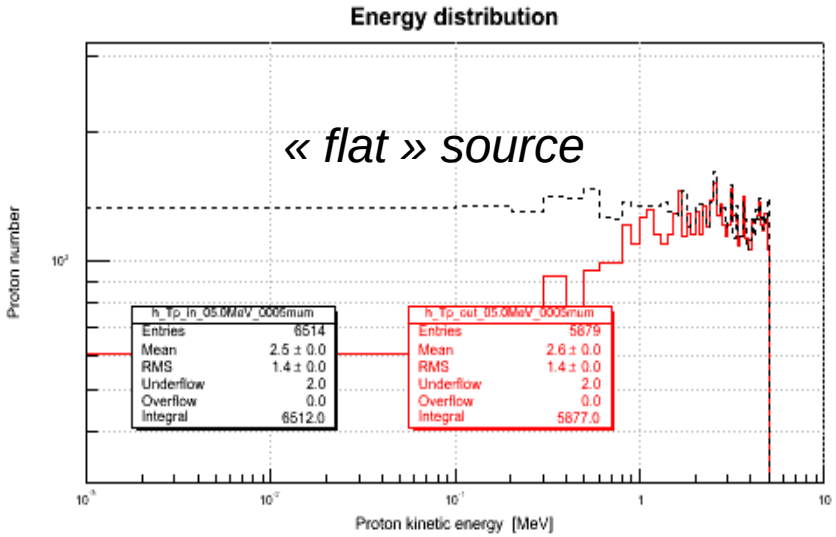
$$\Rightarrow (\sigma_\vartheta)_{elec} < 10^{-3}$$

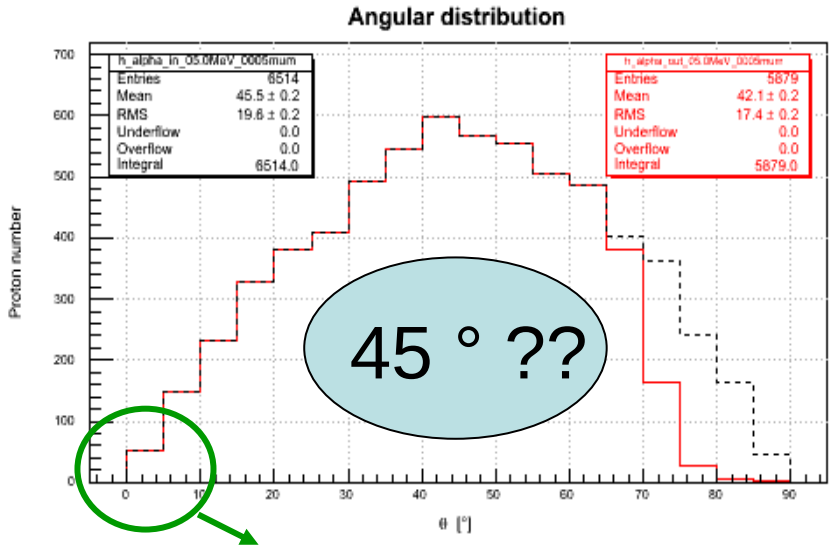
T_n=5e+0 MeV / t_{CH_2}=0005 µm / N_n^0=1e+08

Simul thin converter

$$\varepsilon_{out}/\varepsilon_{in} = \frac{N_p^{out}}{N_p^{in}} = 90.3\%$$





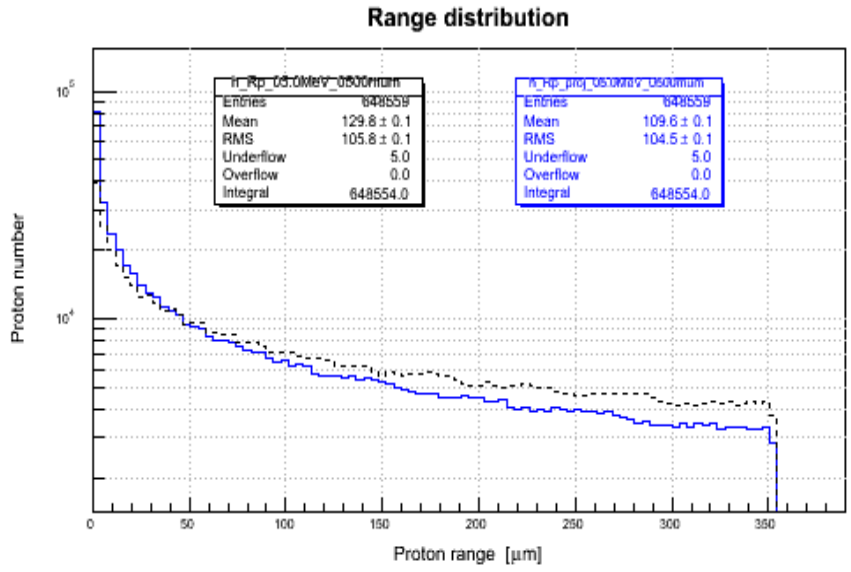


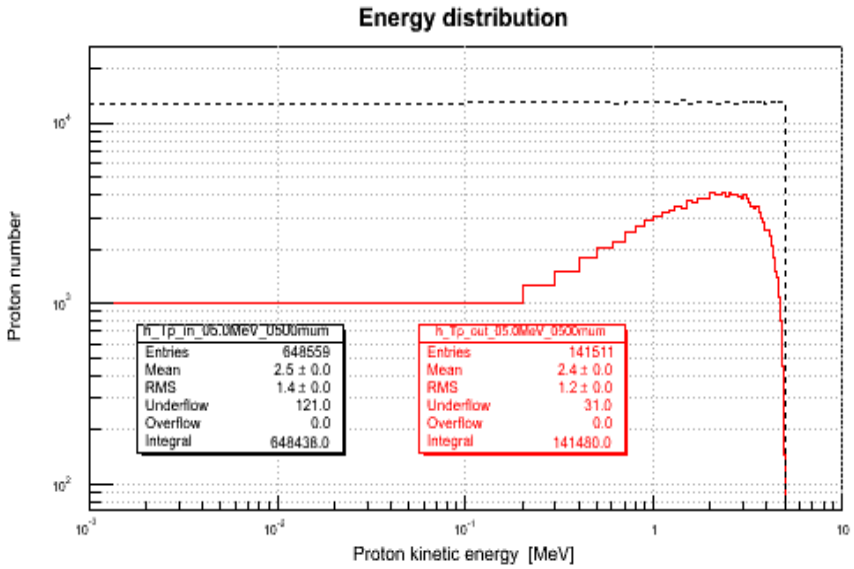
< 1% of protons < 5°…

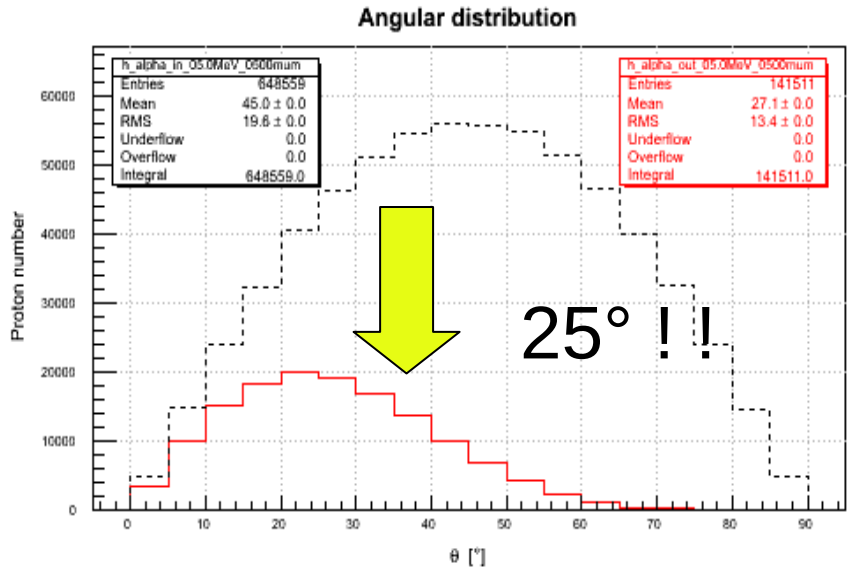
T_n=5e+0 MeV / t_{CH_2}=0500 µm / N_n^0=1e+08

Thick Converter

$$\varepsilon_{out}/\varepsilon_{in} = \frac{N_p^{out}}{N_p^{in}} = 21.8\%$$







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  - EUDET experiment

Why large sensors ?

PTB: 9.9 10^{-6} p/n (« 0° » cell)

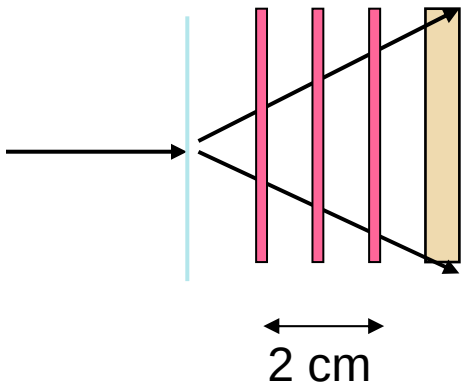
Open the Ω !

$E_n = E_p.\cos^2(\theta)$

tan(30°)=0.57

4.10^{-2}

$$\sigma(E_n)/E_n = \{(\sigma(E_p)/E_p)^2 + 4.\tan^2(\theta).\sigma_\theta^2\}^{1/2}$$

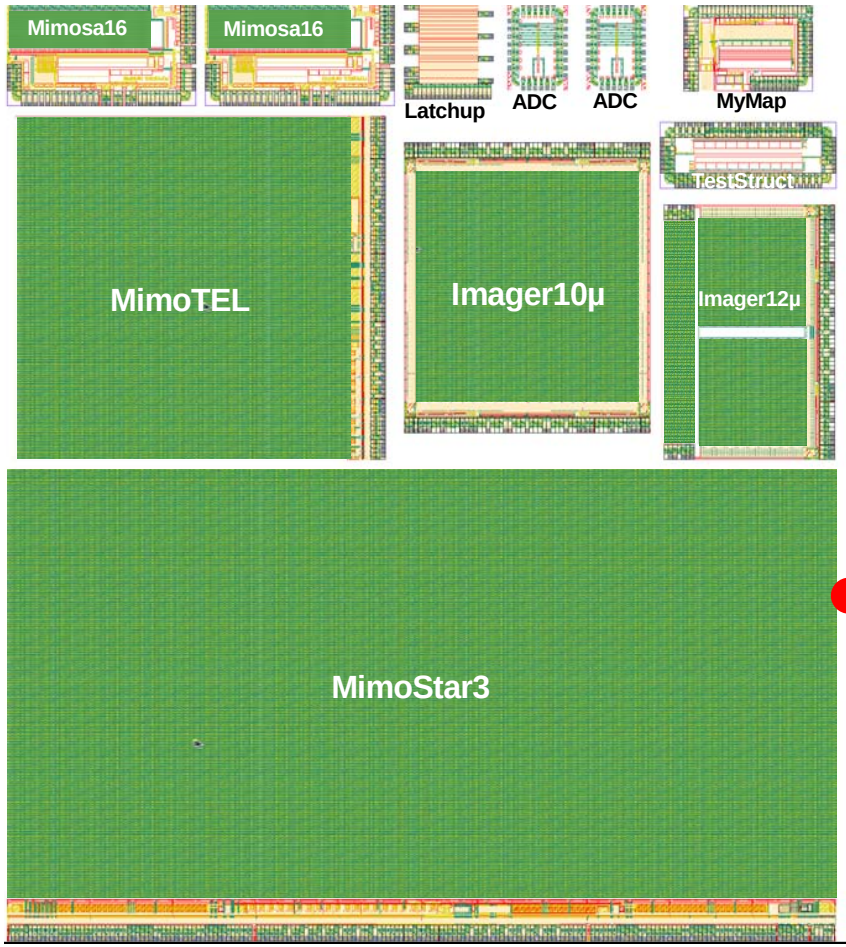


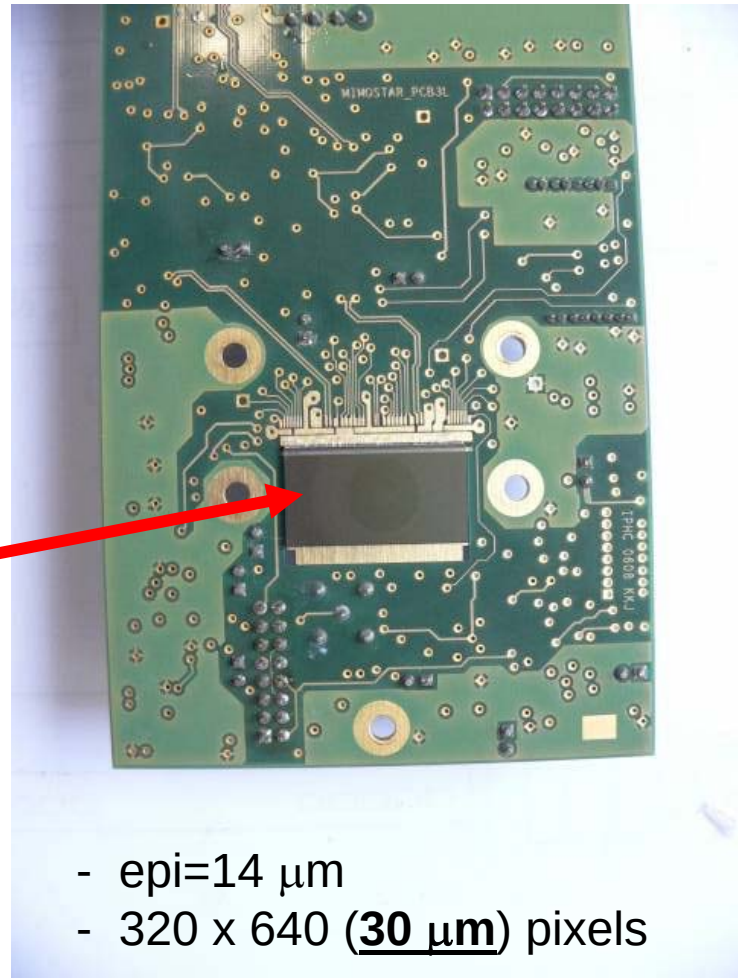
0.1%
diode (3 mm)

High effic
AND
energy < 5%

MIMOSTAR3L: available in Strasbourg!

AMS-035 OPTO 07/2006





- epi=14 µm
- 320 x 640 (**30 µm**) pixels

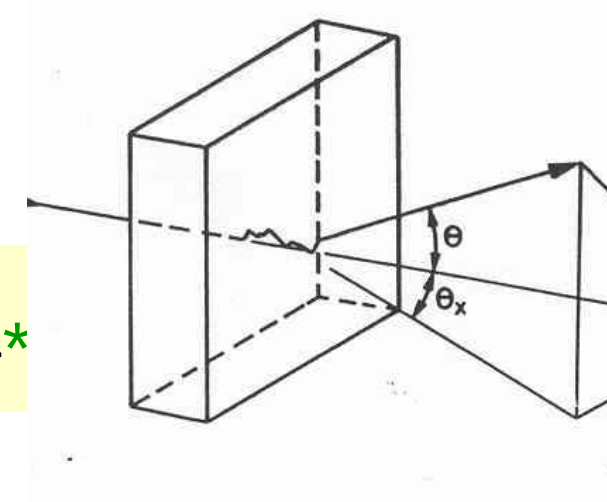
Why thinned CMOS ?

- 100% transparency to MeV photons
- Unmeasured dEdX below 7 %

AND

- Minimize **multiple scattering** !

Coulomb scattering



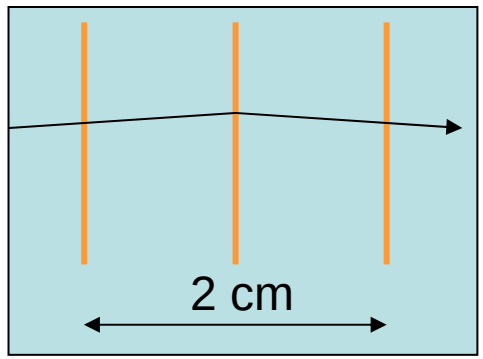
$(\overline{\theta^2})^{1/2} \sim 20\ \text{MeV/c}.(1/p\beta).(z/X_0)^{1/2}.\{\log\}$*

- Silicon: X_0=9.36 cm
- E_c=20 MeV: $p\beta$ = 200*0.2 = 40 MeV/c

*after Highland

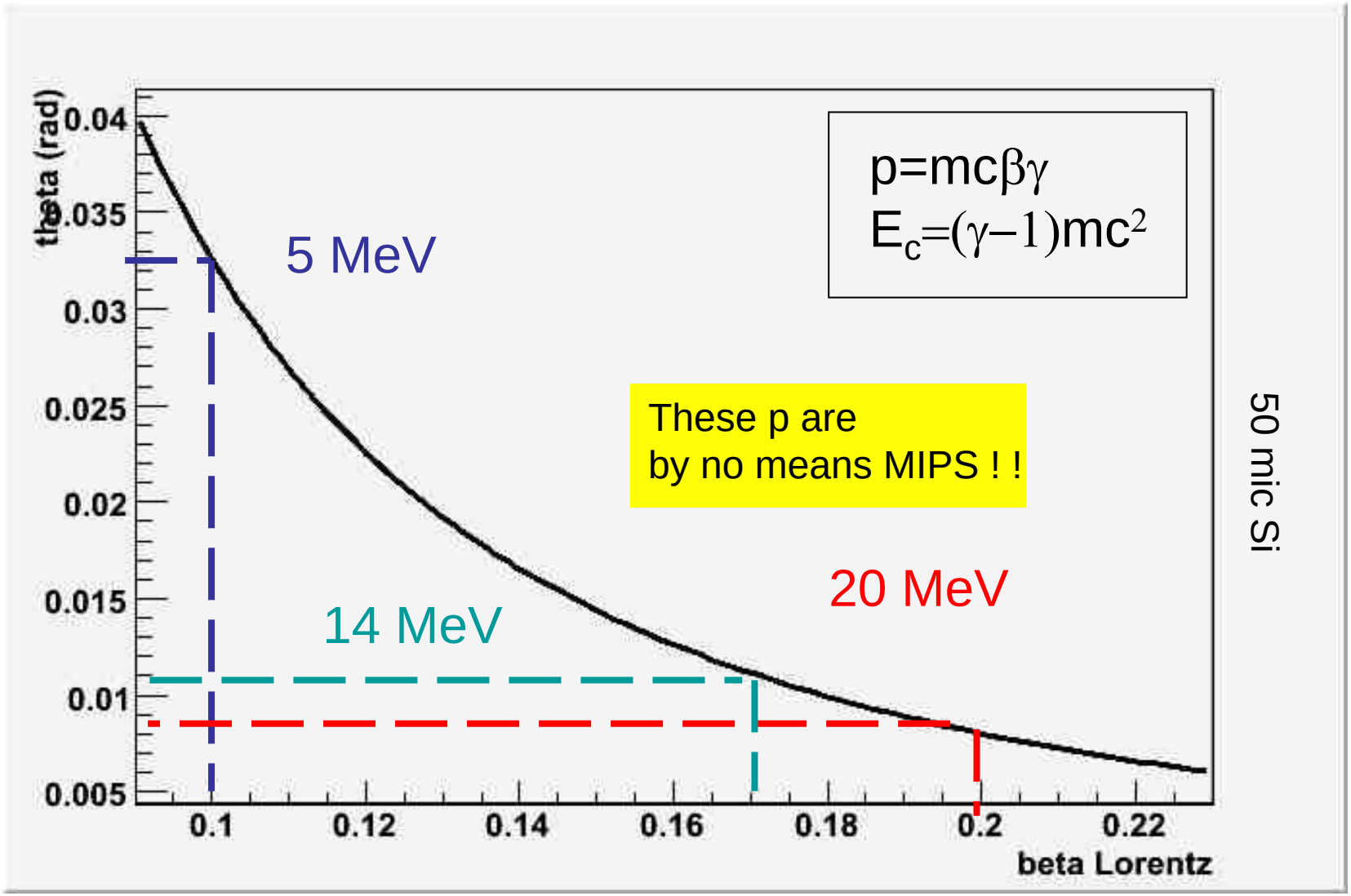
~10 mrad (z_{Si}=50 μm)

proj $\Delta x = r.\Delta\theta \sim$ **100 μm**



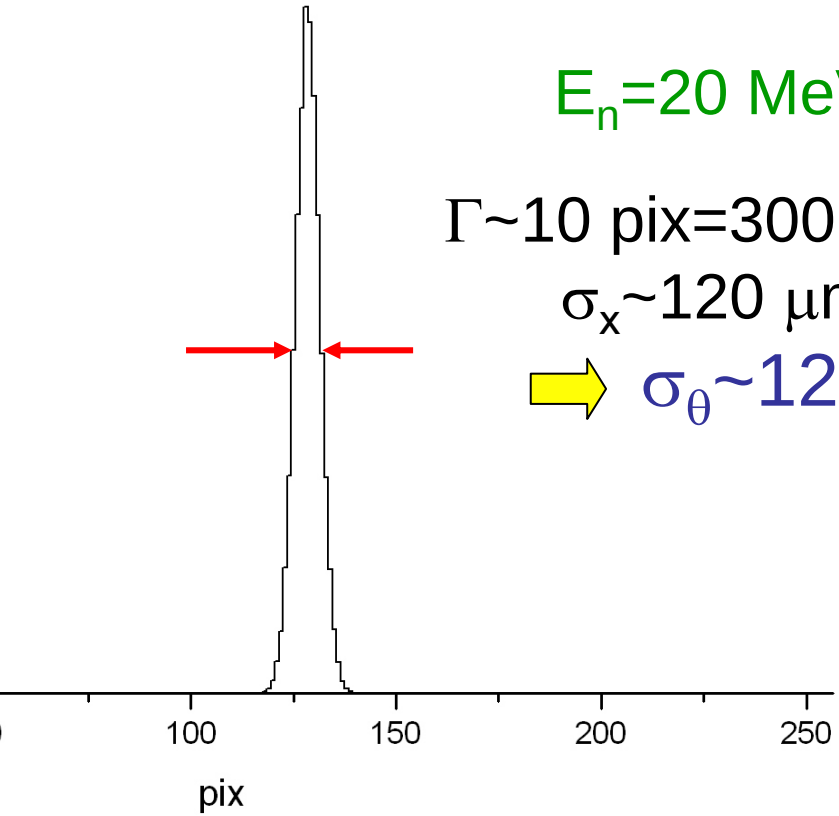
(« large » pixels OK, e.g. 30 μm)

Highland formula: Scattering as f(E_{proton})



Projected proton positions
P1 ➔ P2 @ d=1 cm
(after e_Si_P1=50 μm)

MCNPX simulation

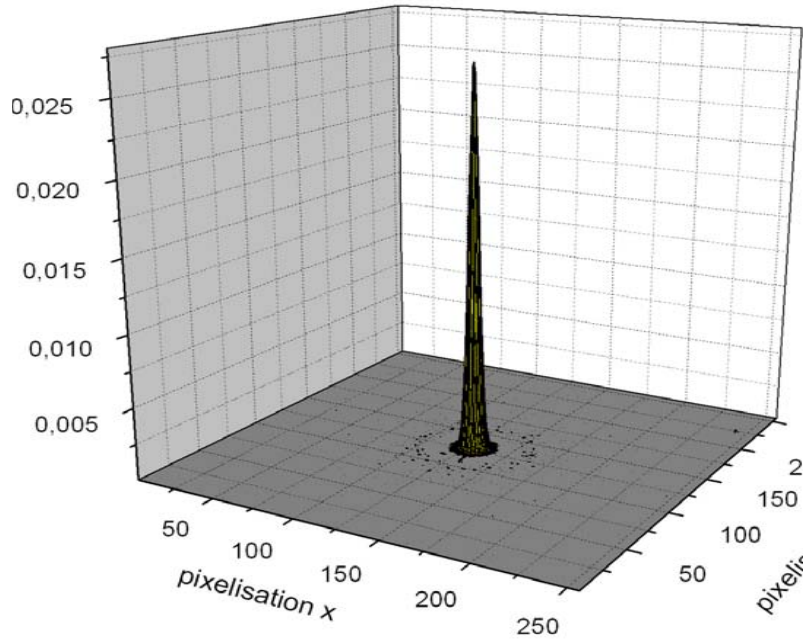


E_n=20 MeV

Γ~10 pix=300 μm

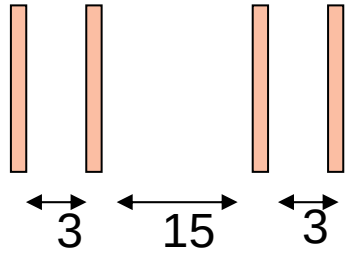
σ_x~120 μm *

⇨ σ_θ~12 mrad



**MCNPX uses Urban algo:*
⟶ *overestimation??*

RPT agenda



- 21/04/08 : EUDET subset

  4 Mimo18: p=10, 250kpix, S=0.5x0.5, e~50μm

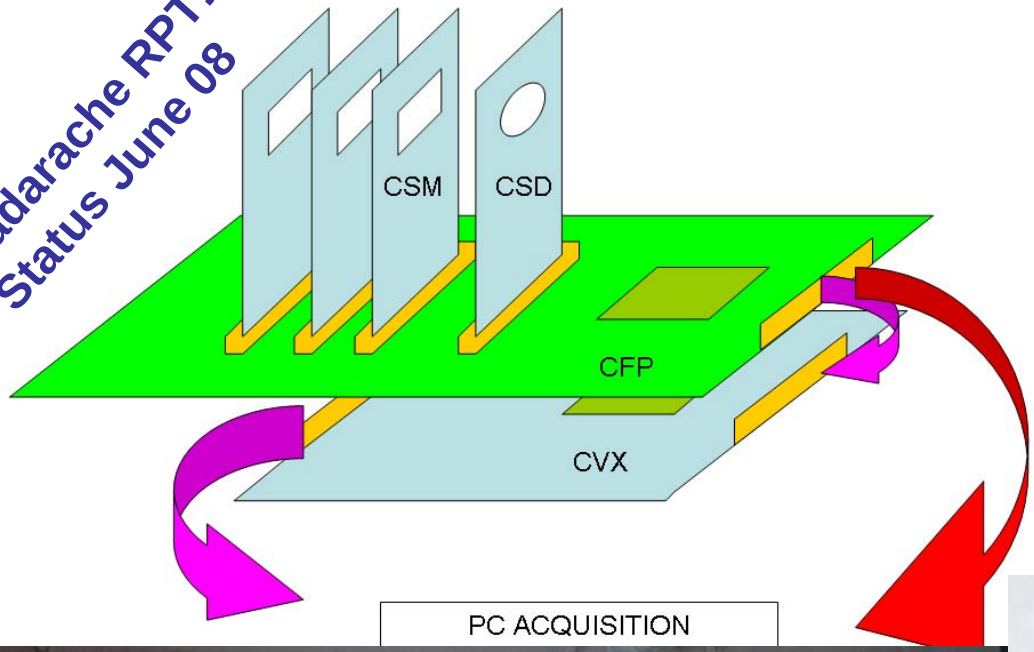
  ⇨ (analysis: track reco, σ_ϑ)

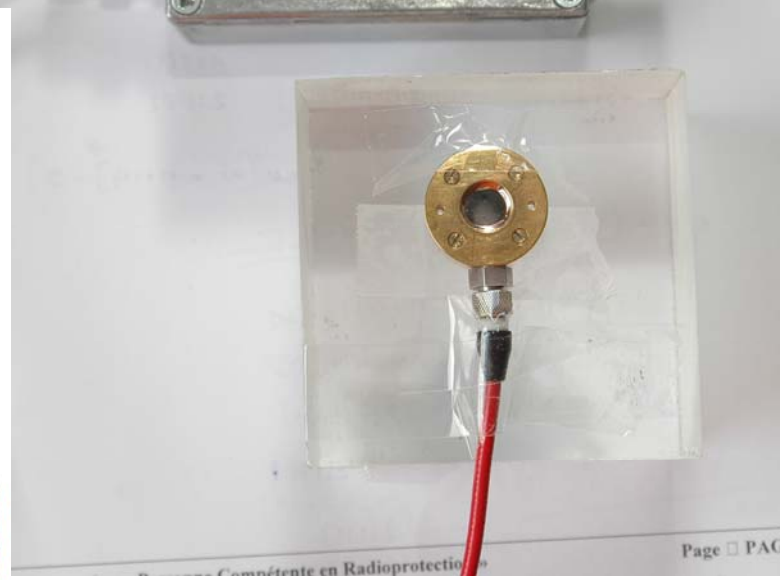
- 02/2009: 3 planes MimoStar3L (p=30 μm; Rad-Tol, S=2x1 cm) + 1 PIN diode (1cm^2, e=3 mm)

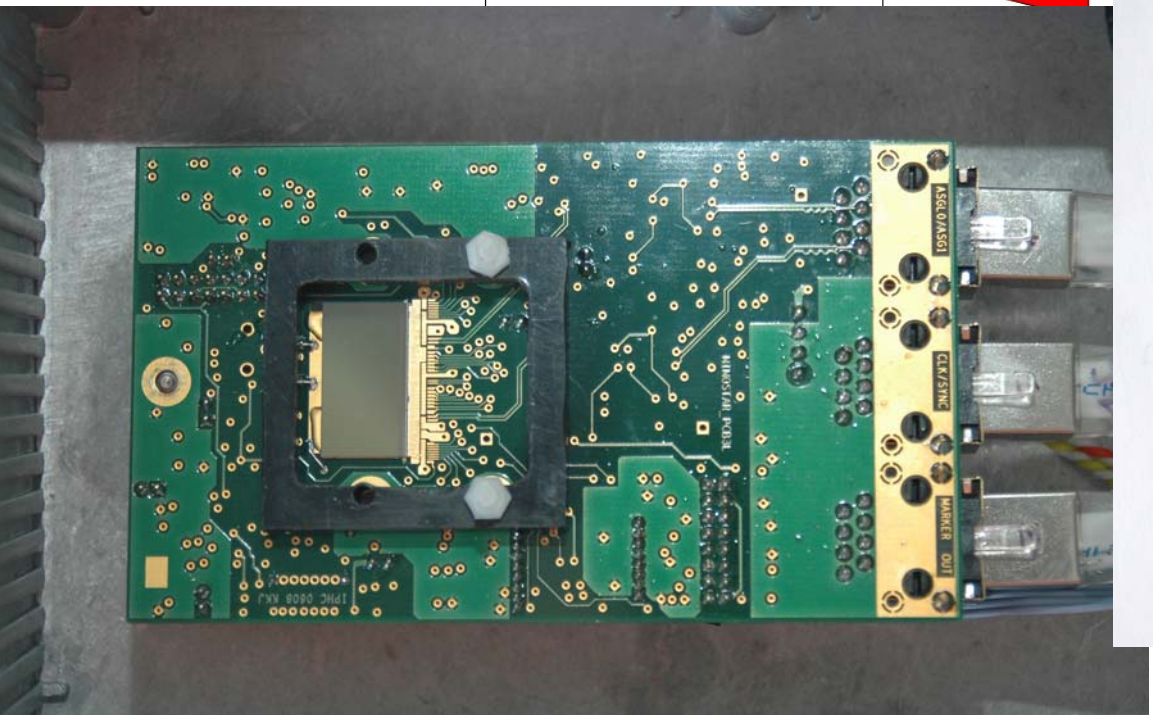
  5 chips avail., 10 PCB (+void),acq board 4 ADC

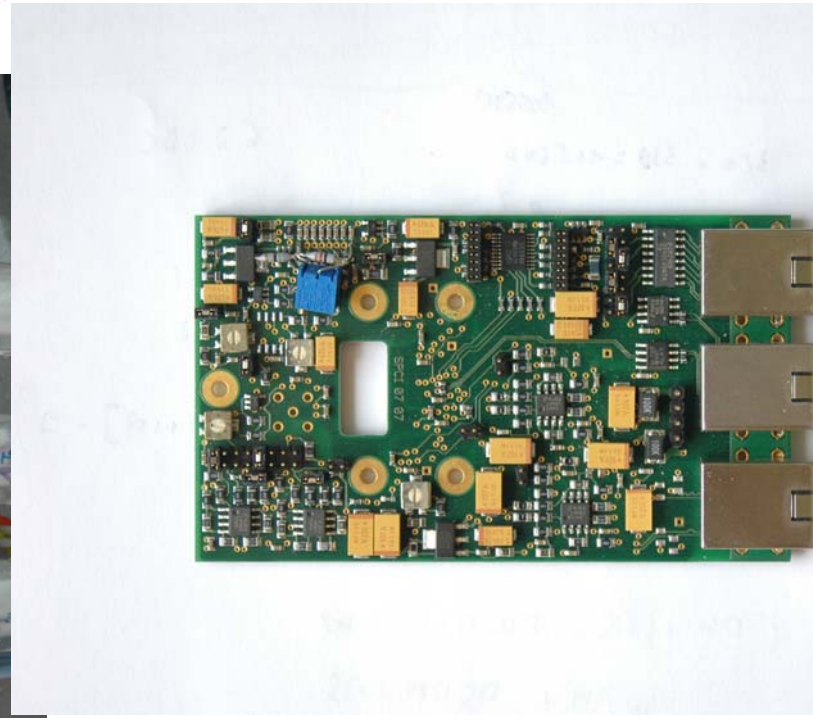
  (already *thinned*, currently glued, mother-card ready)

Cadarache RPT: Status June 08









Electronics & DAQ

- MIMO*3L: simplified CSM; 10-b ADC; measured σ_N~3 ADC
- PIN diode: t_{shap}=300 ns; CSD with SMA connector for HT+V_{thresh} (DAC); 12-b/40 MHz ADC
- Data flow: 320x320=102400 pix (*3); @40MHz: 200 fr/s (ϕ_n=6000n/s; *10^{-3} ***=6 recoil protons/s***)
- Two steps:
  1) PC in close neighbourhood: CFP board;
     fully parallel digital output
  2) remote PC: TCP/IP Gb-Ethernet;
     local data reduct. in CVX board (Xilinx processor)

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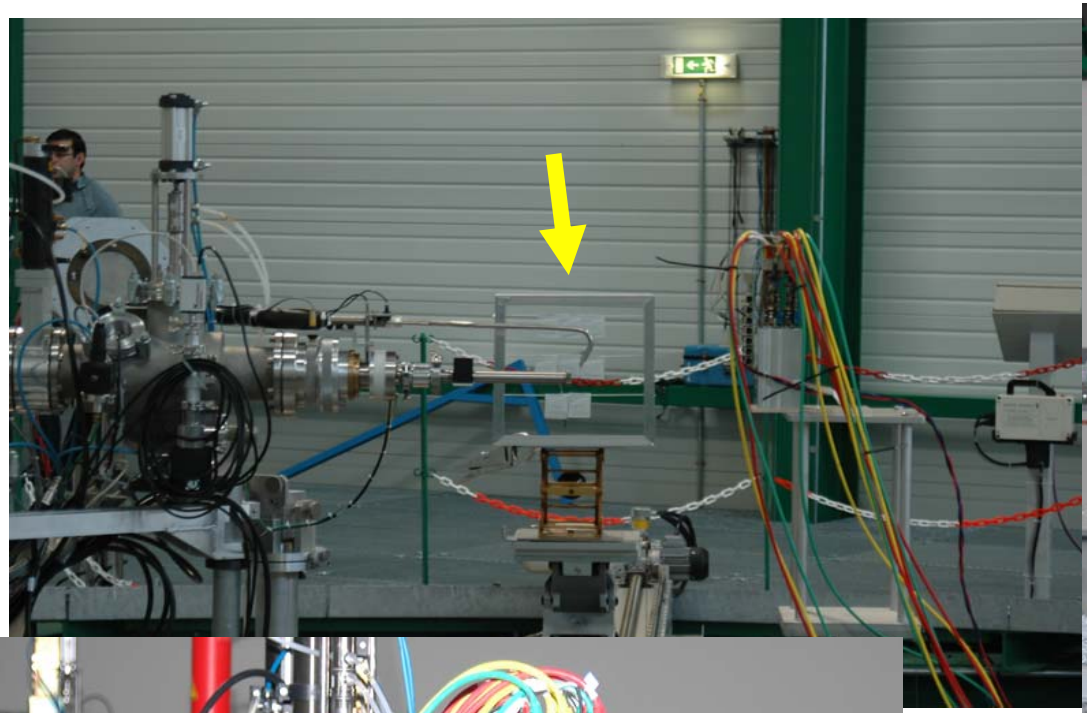
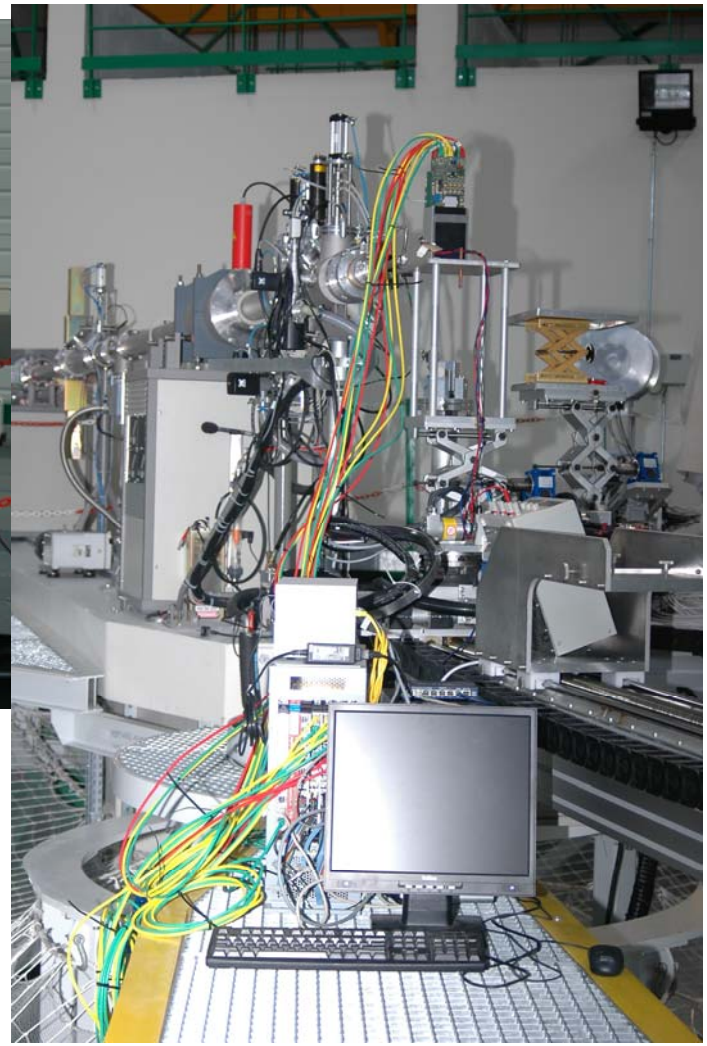
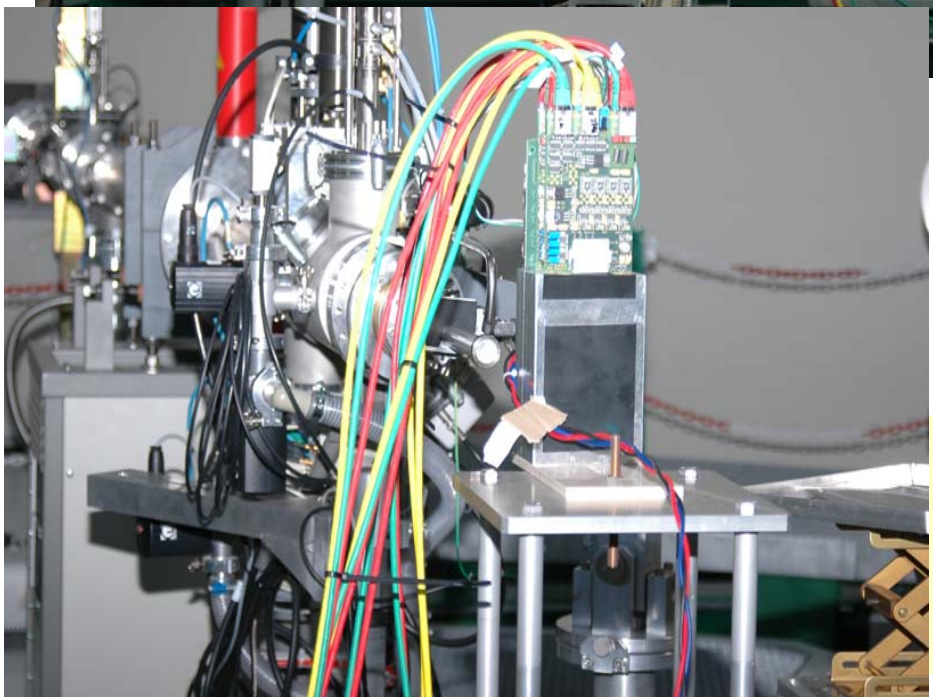
Cadarache, april 2008

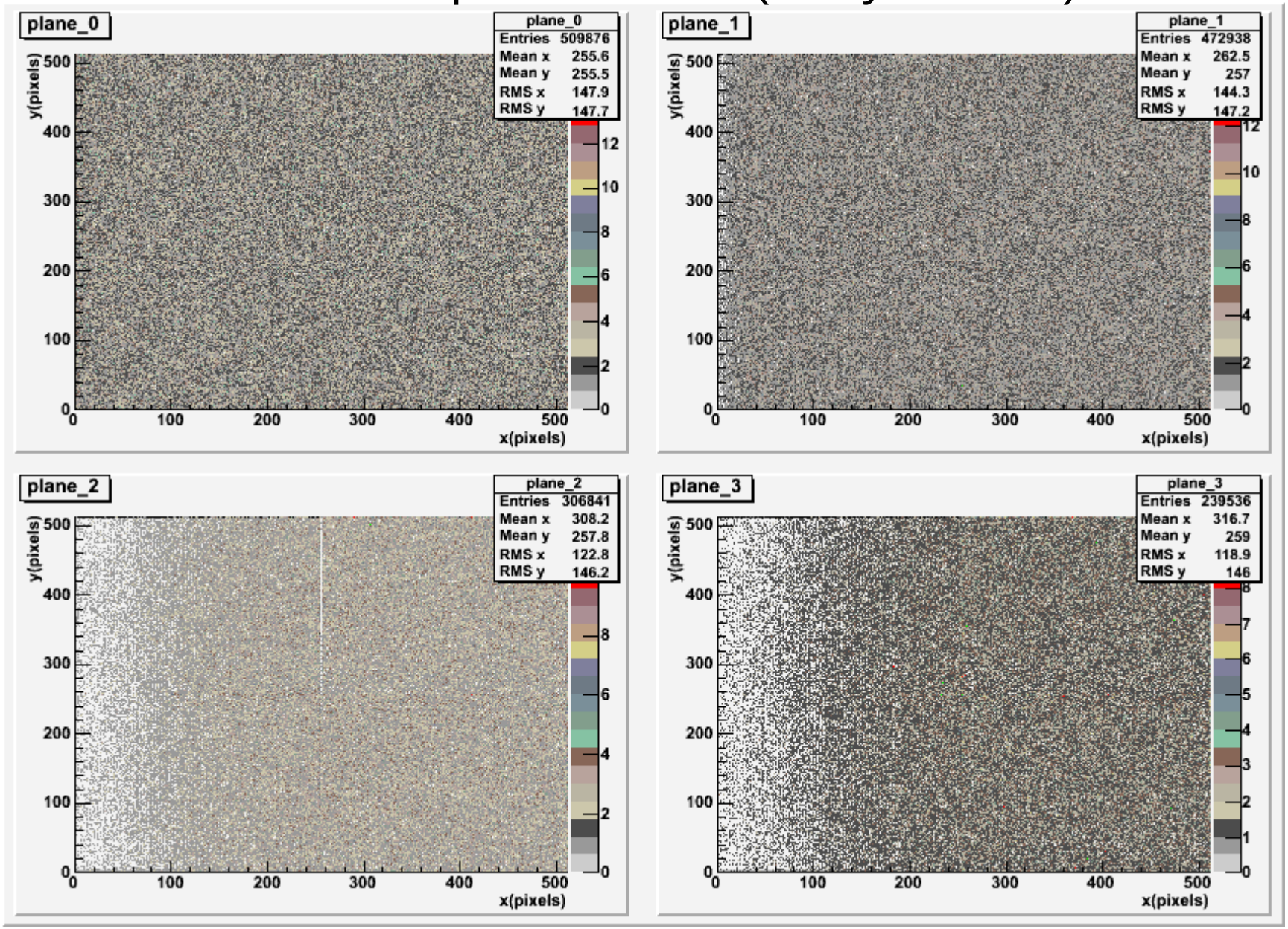




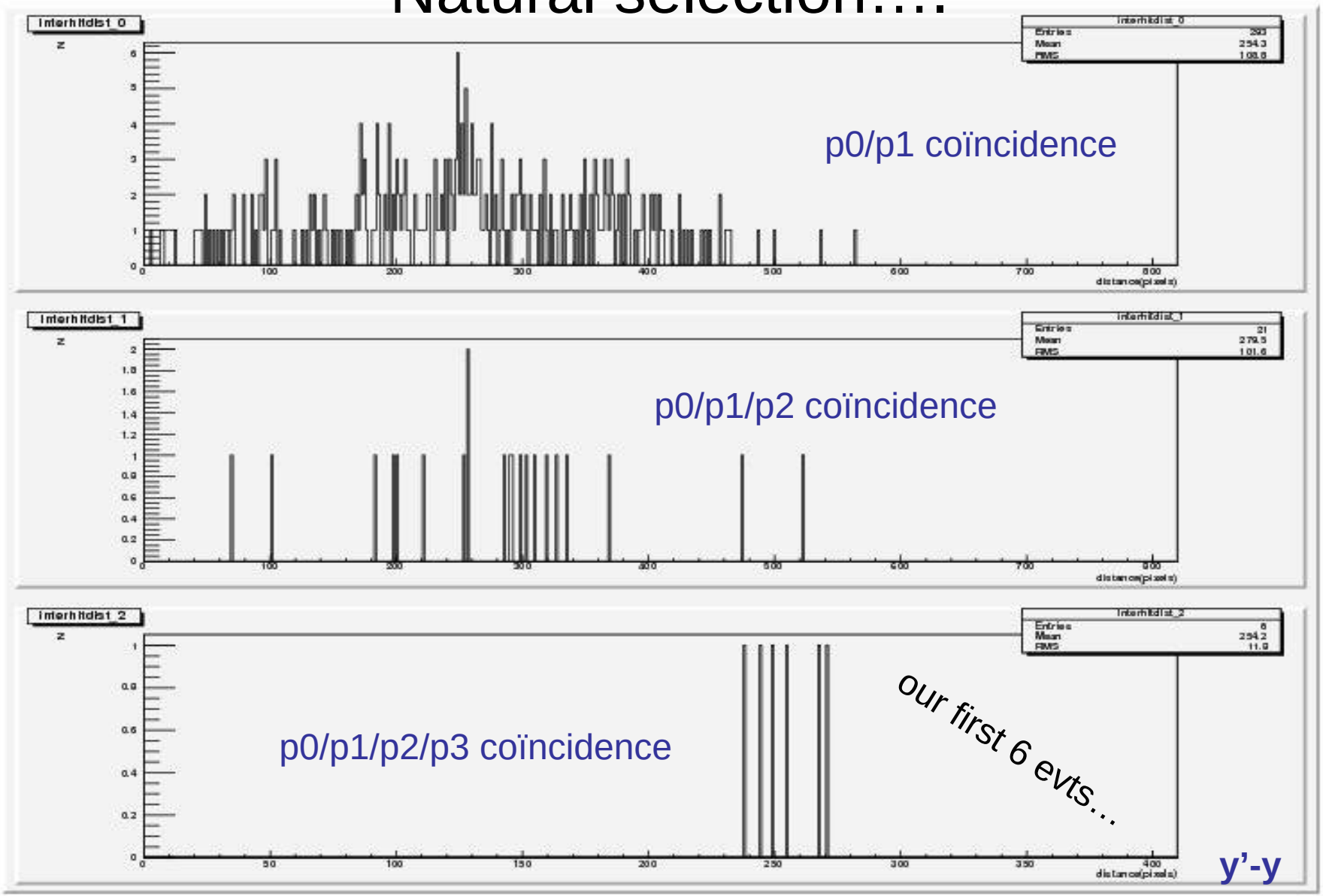


DH,SH,MiT+MT,MV,EB (RaMSeS)
WD,E.Corrin,D.Haas **(EUDET)**
A.Allaoua,L.Lebreton (LMDN)

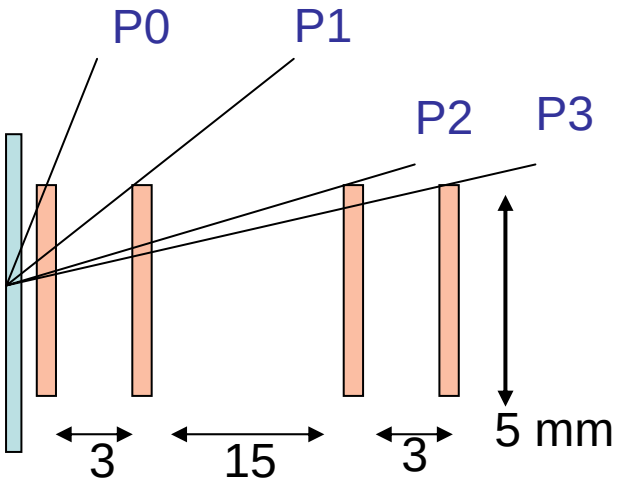
Cumulated proton events (1 day 19 MeV)

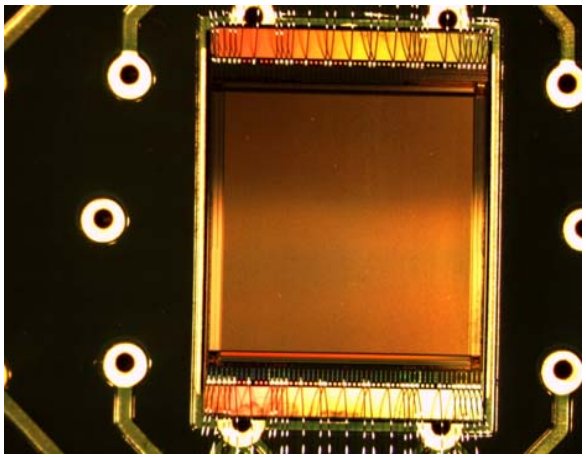


Natural selection….



Acceptance angles

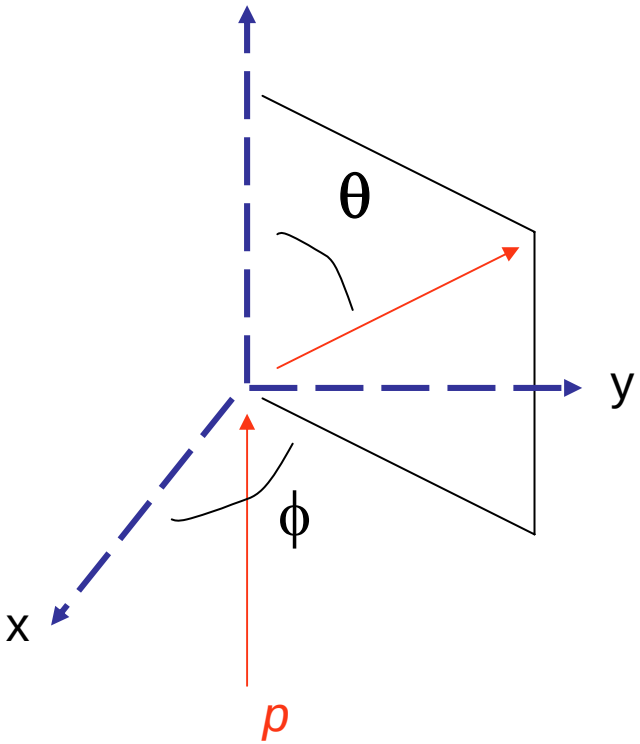




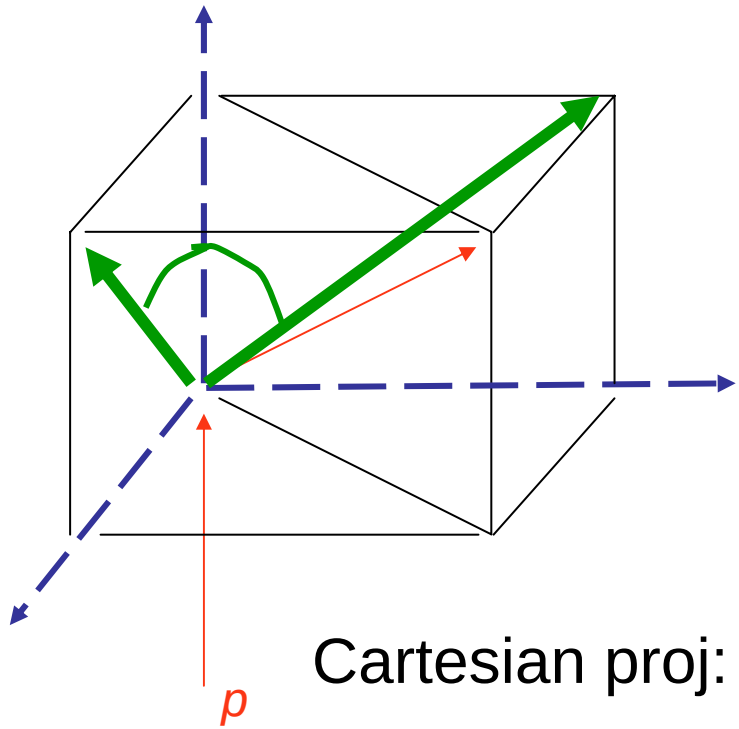
Geometry Ω_{p+1}/Ω_p:	Detected protons N_{p+1}/N_p:
0/0: 100%	0/0: 100%
1/0: 28.1 %	1/0: 21.97 %
2/1: 2.06 %	2/1: 2.95 %
3/2: 1.56 %	3/2: 0.84 %

(14.4 MeV)

Scattering angles (in any plane)

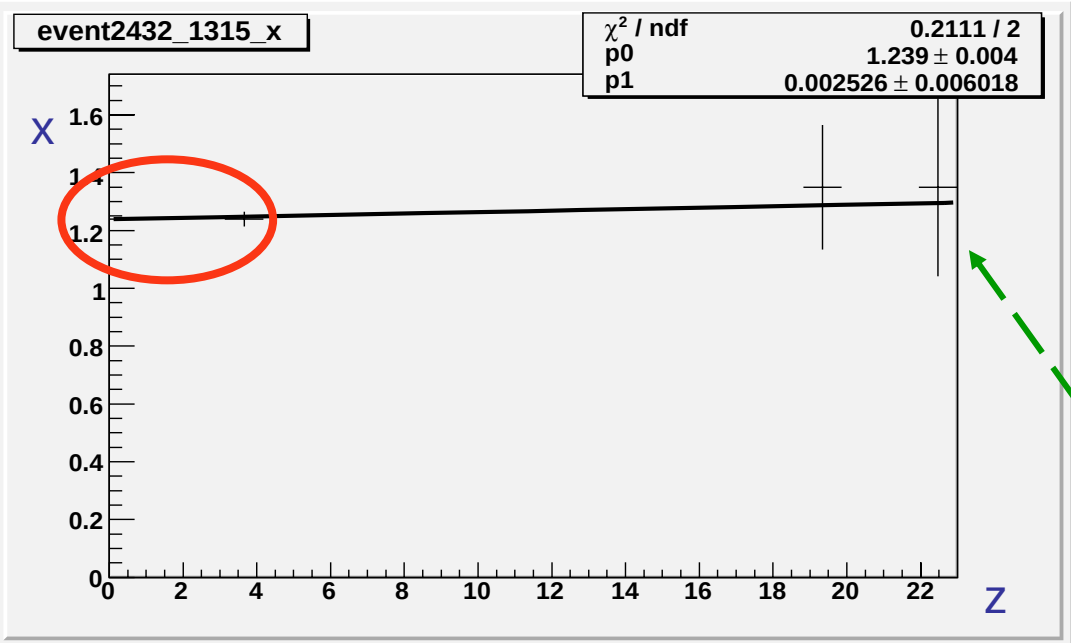


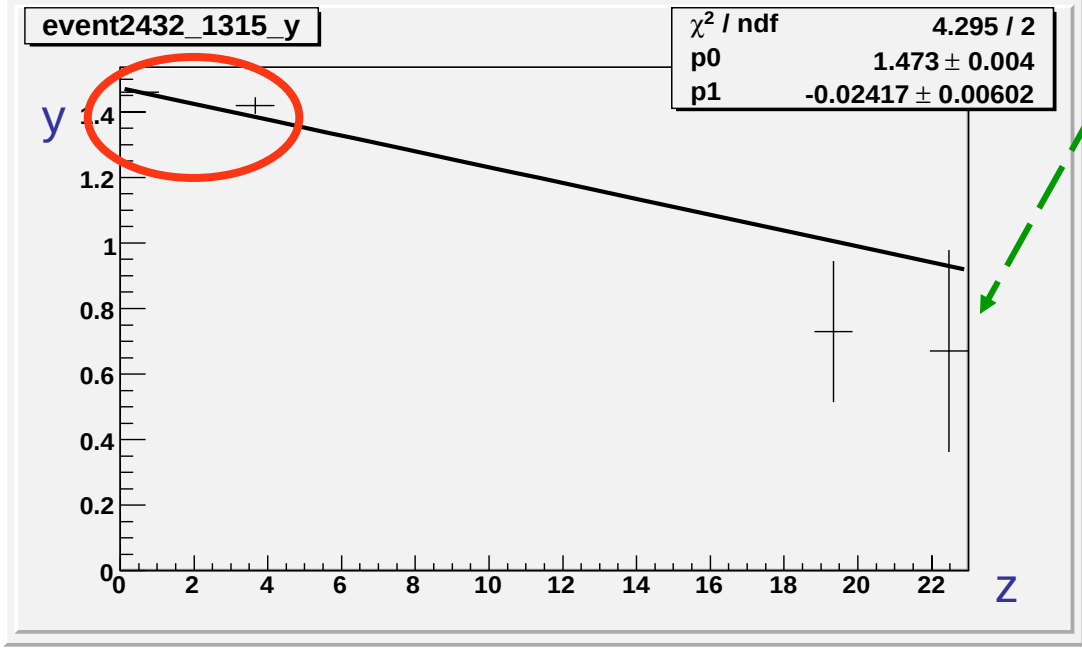
Spherical



Cartesian proj: θ_x , θ_y

(should be independant…)





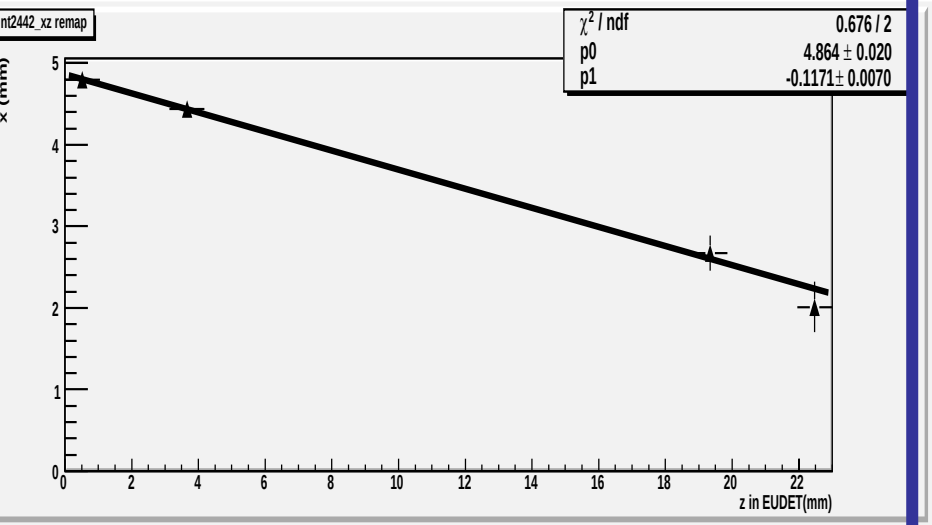
Reconstructed proton track

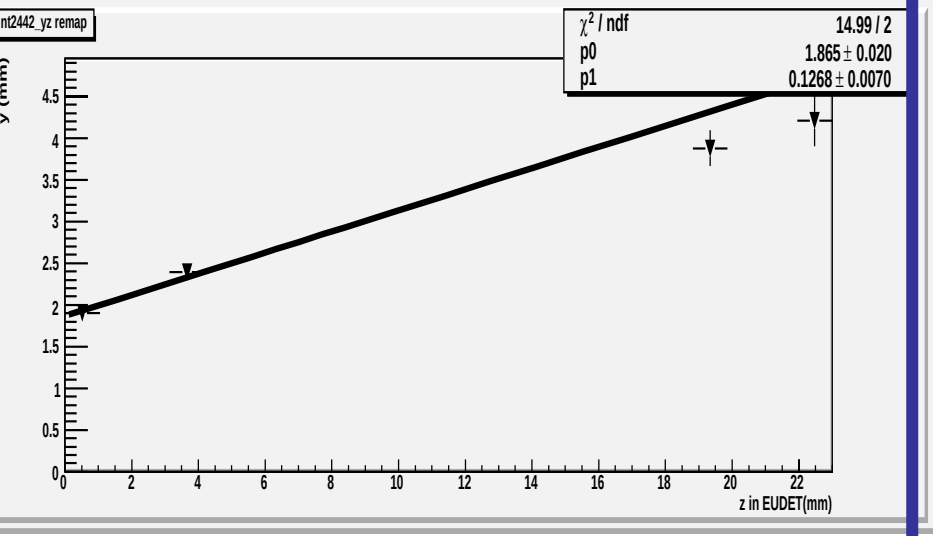
4 P requested (to remove backgr.events)

Step 1) χ^2 search:
error bars include scattering
$(\sigma x_2)^2=(\sigma x_1)^2+(z.\sigma_{scatt}(E))^2$

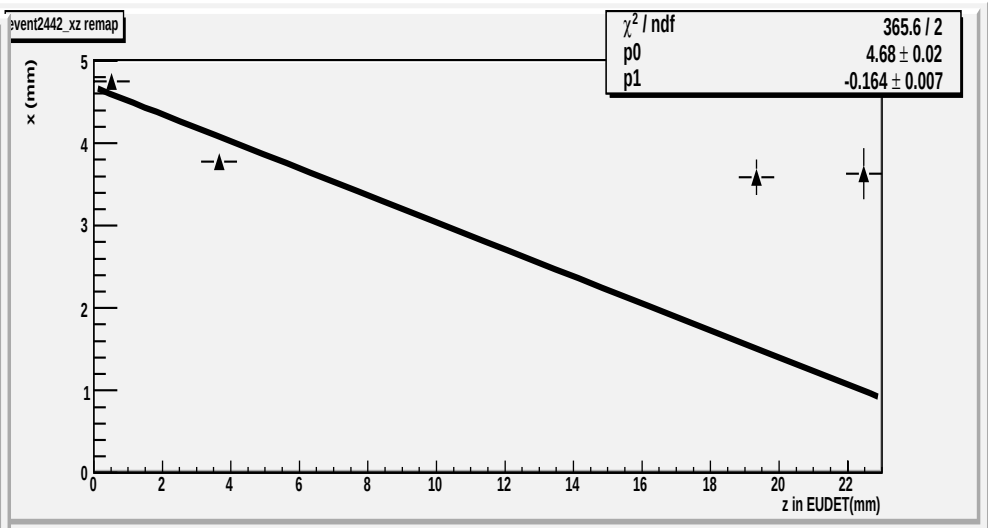
Step 2) best *initial* angle:
only p0+p1 and $\sigma_{xy}=\sigma_{CMOS}$

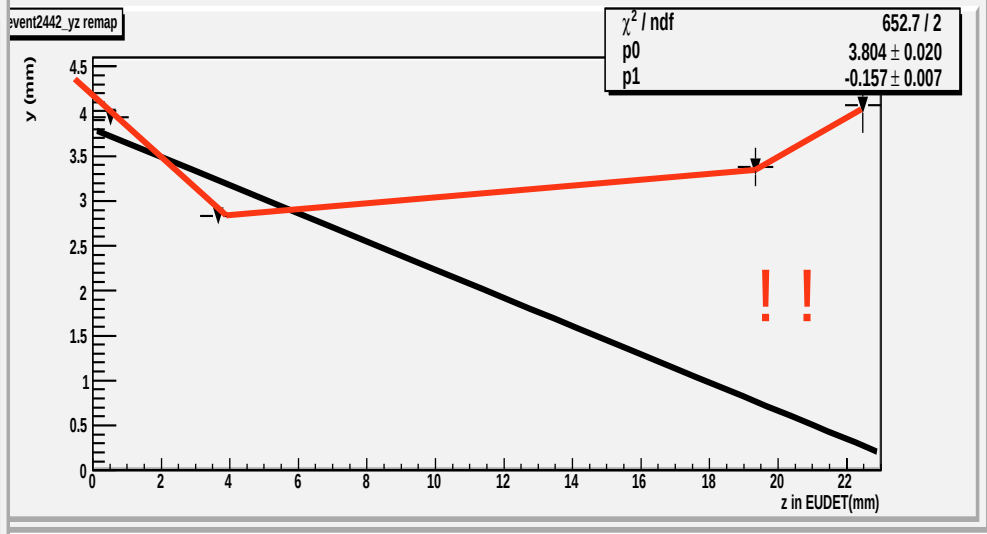
Life can be nice…

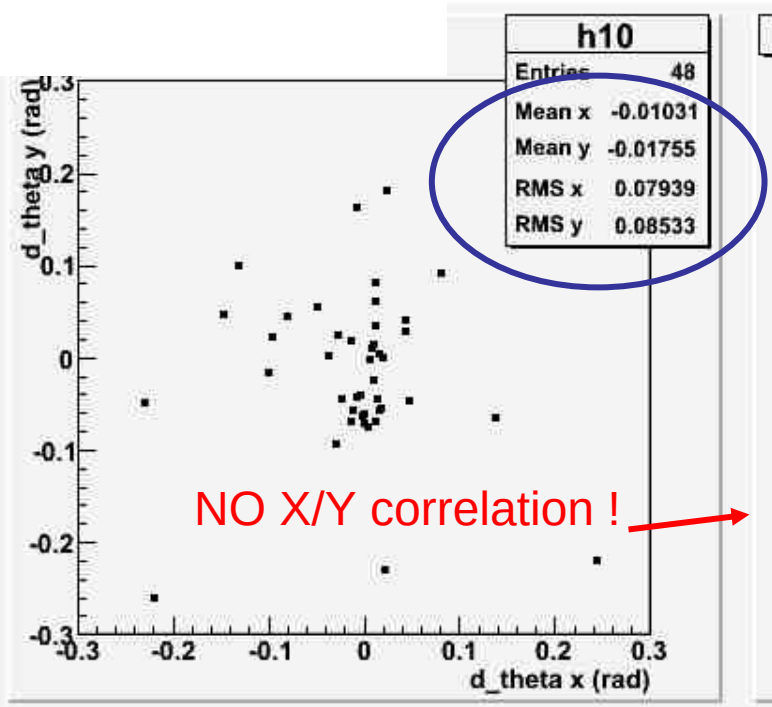




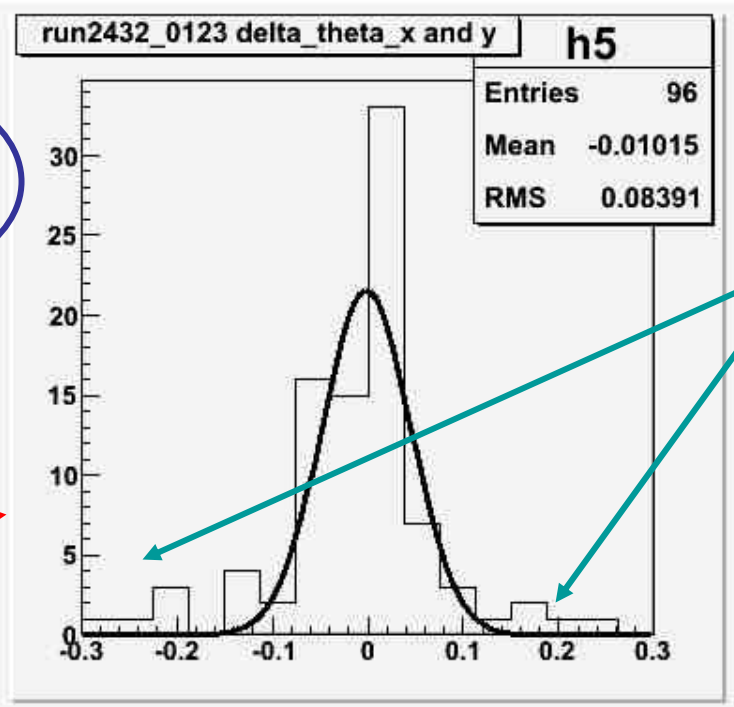
…or complicated…



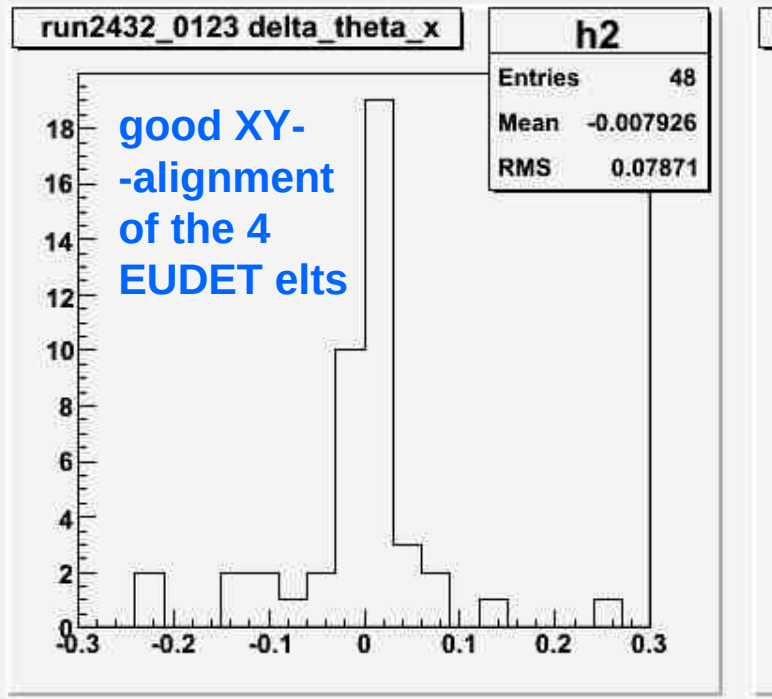




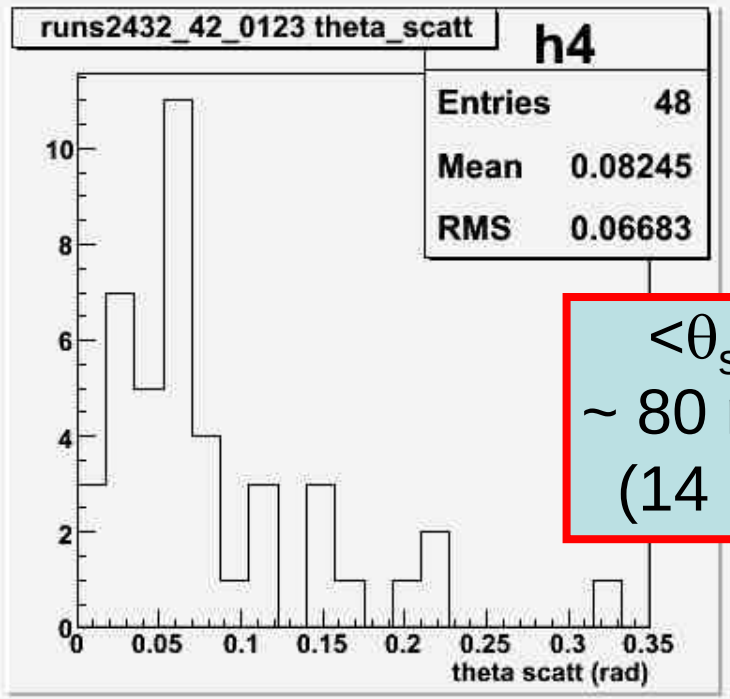
NO X/Y correlation !



NON-gaussian tails…



good XY--alignment of the 4 EUDET elts



$\langle\theta_{scatt}\rangle$ ~ 80 mrad (14 MeV)

Conclusions

1) $\Delta\Omega+\varepsilon+\sigma_\theta$: OK (14 MeV): Proof Of Principle!
2) Found 15 events @ 5 MeV ! (R~250 μm..)
3) Inelastic events: pb @ 19 MeV…
4) Strasbourg RPT:
   - hardware + assembly underway
   - 3 M*3L(d=6+6mm)+thick PIN (tests LMDN : *05/09)*
   - *PHD Thesis: A.Allaoua, Sept.2009*

EUDET

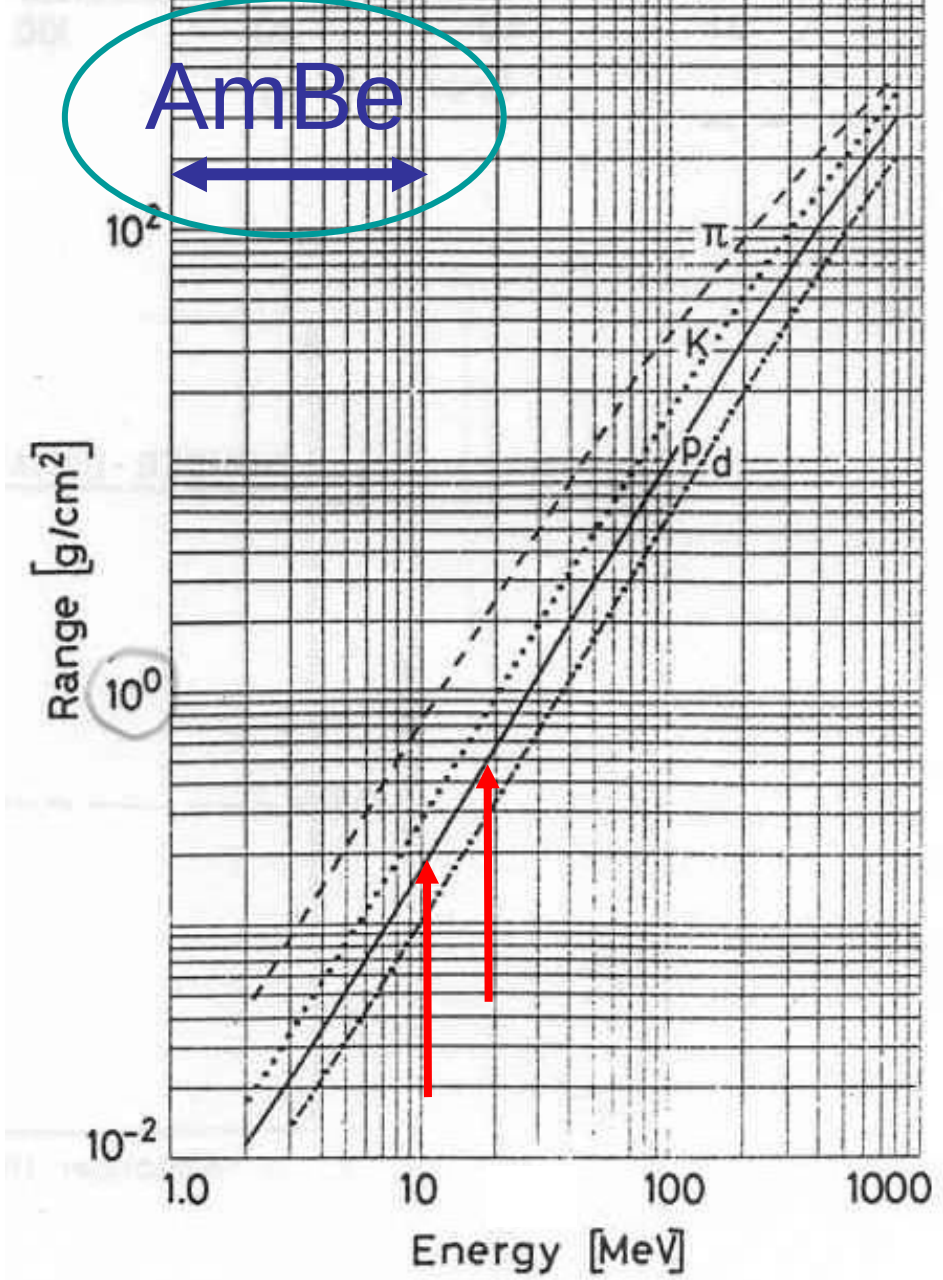
Ackowledgments to Woj, Emlyn, Daniel@EUDET
Vincent@Cadar , Mathieu, Christine@Strasbourg !

…more…

Range of PROTONS

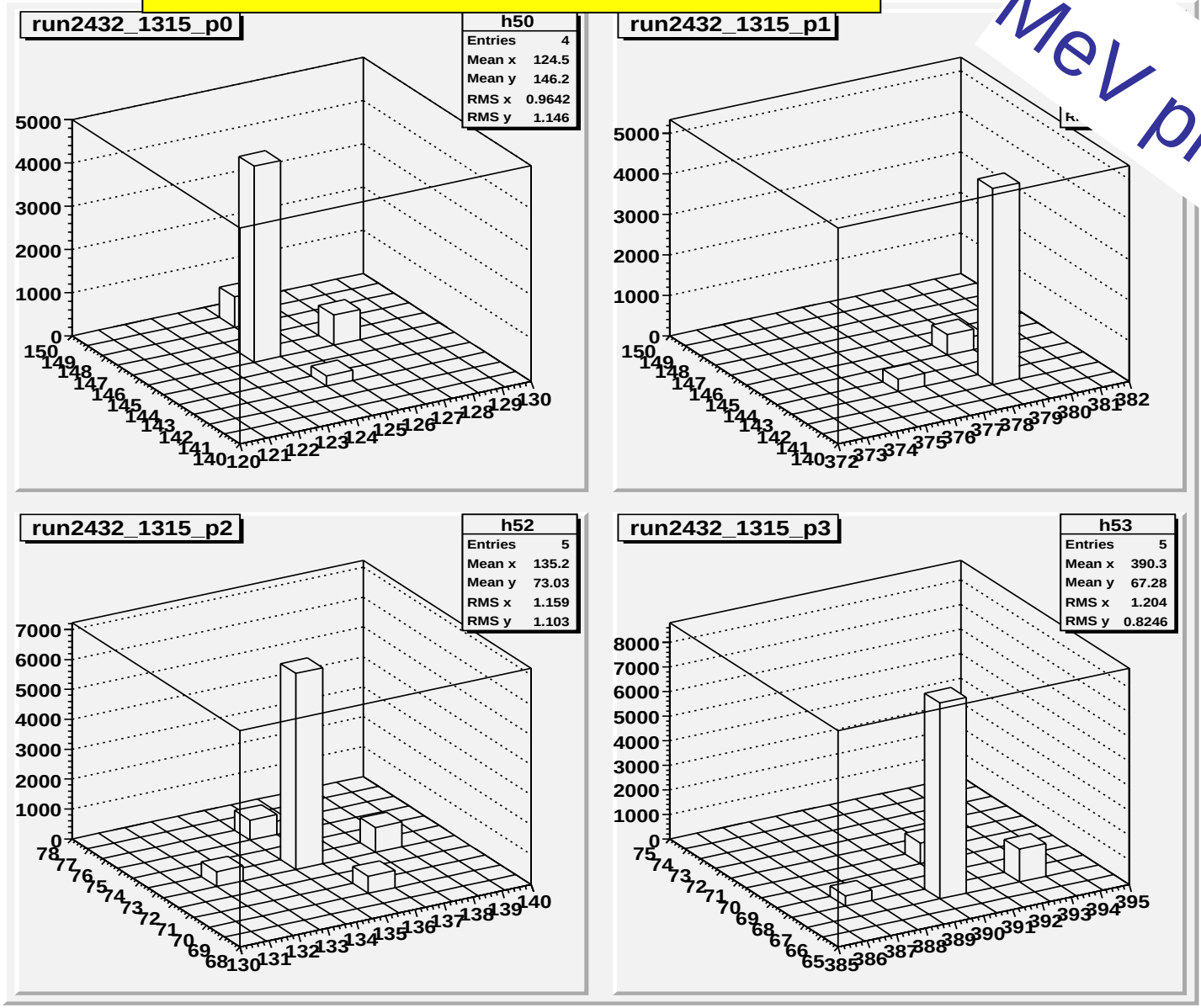
$E_p = E_n * \cos^2(30°) = 3/4\ E_n$

	C_nH_{2n}	Si	
3.75 MeV	200	100	μm
10 MeV	2	1000	
20 MeV	6	3000	

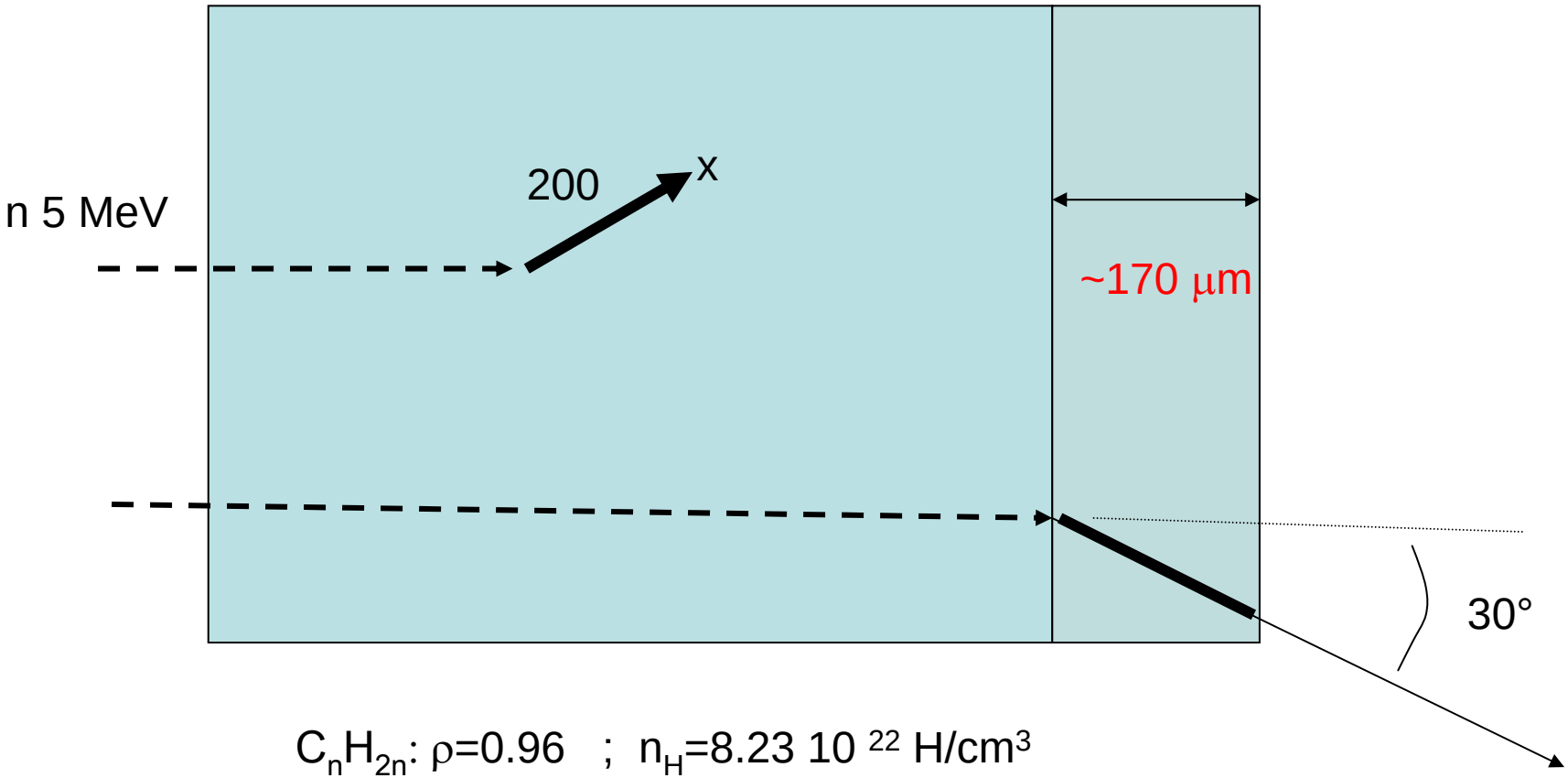


Looking for clusters..

14 MeV protons !



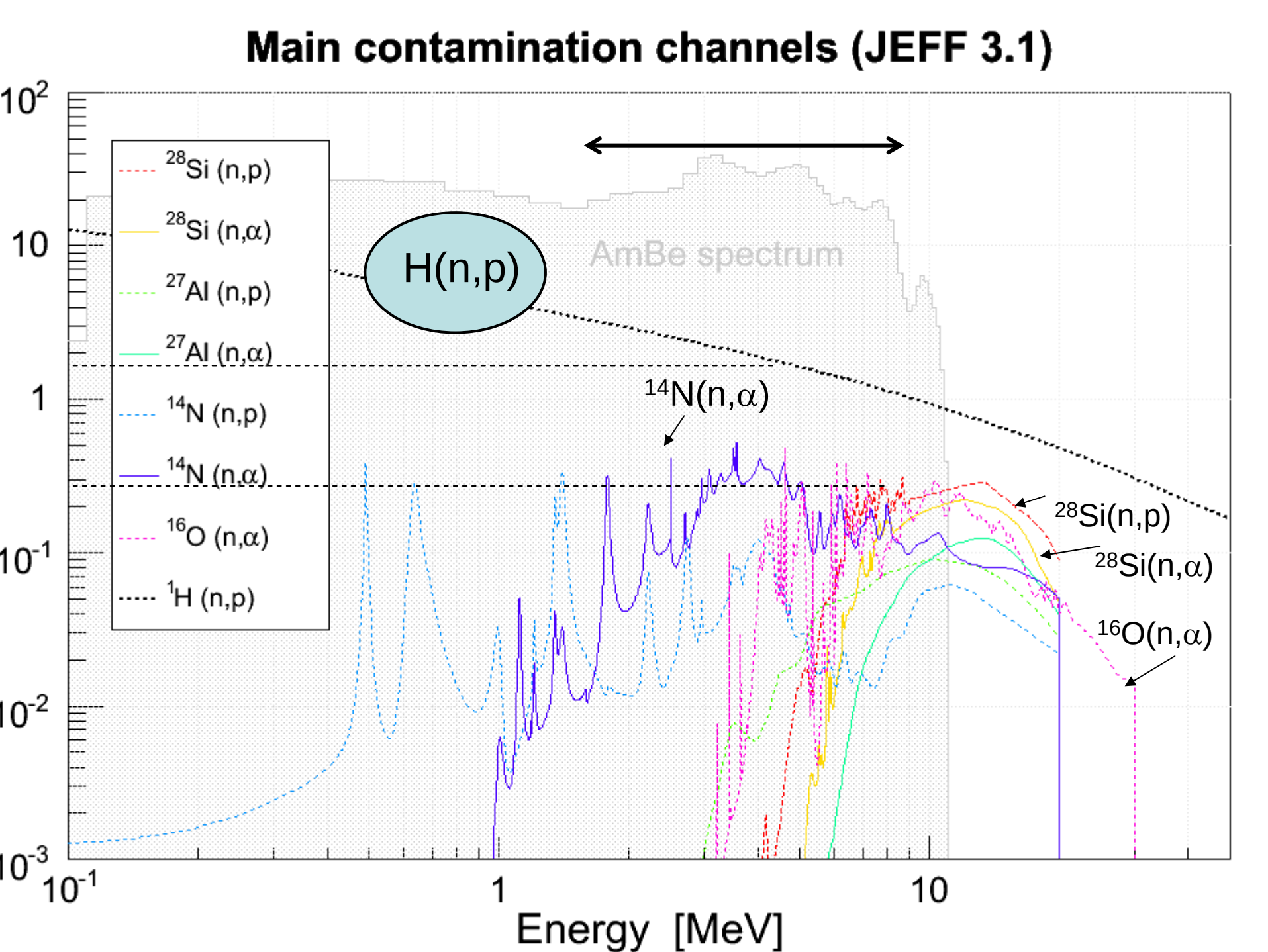
Effective convertor thickness



C_nH_{2n}: ρ=0.96 ; n_H=8.23 10 ^{22} H/cm^3

p+H → n+p: σ (5 MeV)=1.5 bn

→ $\mu=\sigma.n_H$= 0.12 cm^{-1} = 1.2 10^{-3} / 100 μm


Main contamination channels (JEFF 3.1)
^{28}Si (n,p)
^{28}Si (n,α)
^{27}Al (n,p)
^{27}Al (n,α)
^{14}N (n,p)
^{14}N (n,α)
^{16}O (n,α)
^{1}H (n,p)
H(n,p)
AmBe spectrum
^{14}N(n,α)
^{28}Si(n,p)
^{28}Si(n,α)
^{16}O(n,α)
10^{2}
10
1
10^{-1}
10^{-2}
10^{-3}
10^{-1}
1
10
Energy [MeV]

High γ-transparency of a 10 μm Si layer

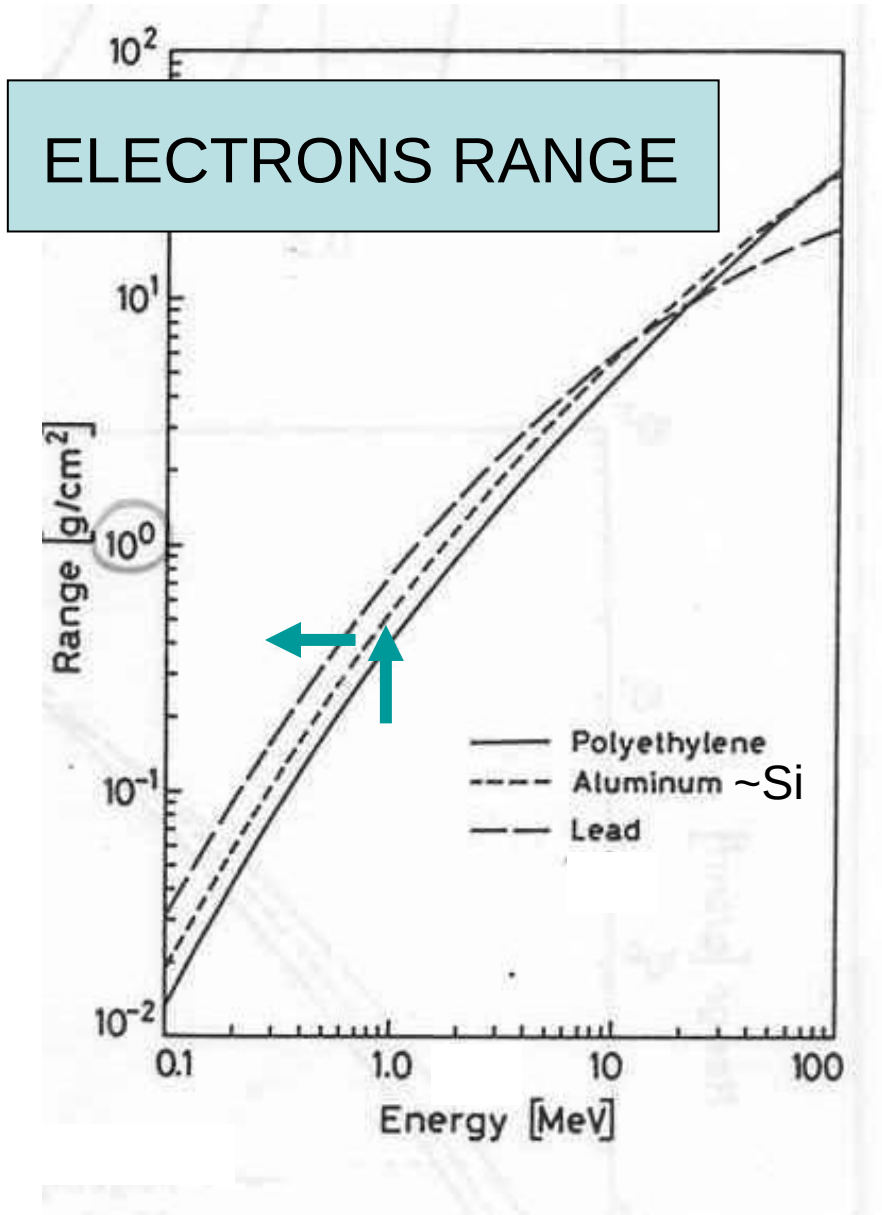
- neutron 14 MeV
  → ***proton ~10 MeV:***

  dEdX= **30** keV / 10 μm Si

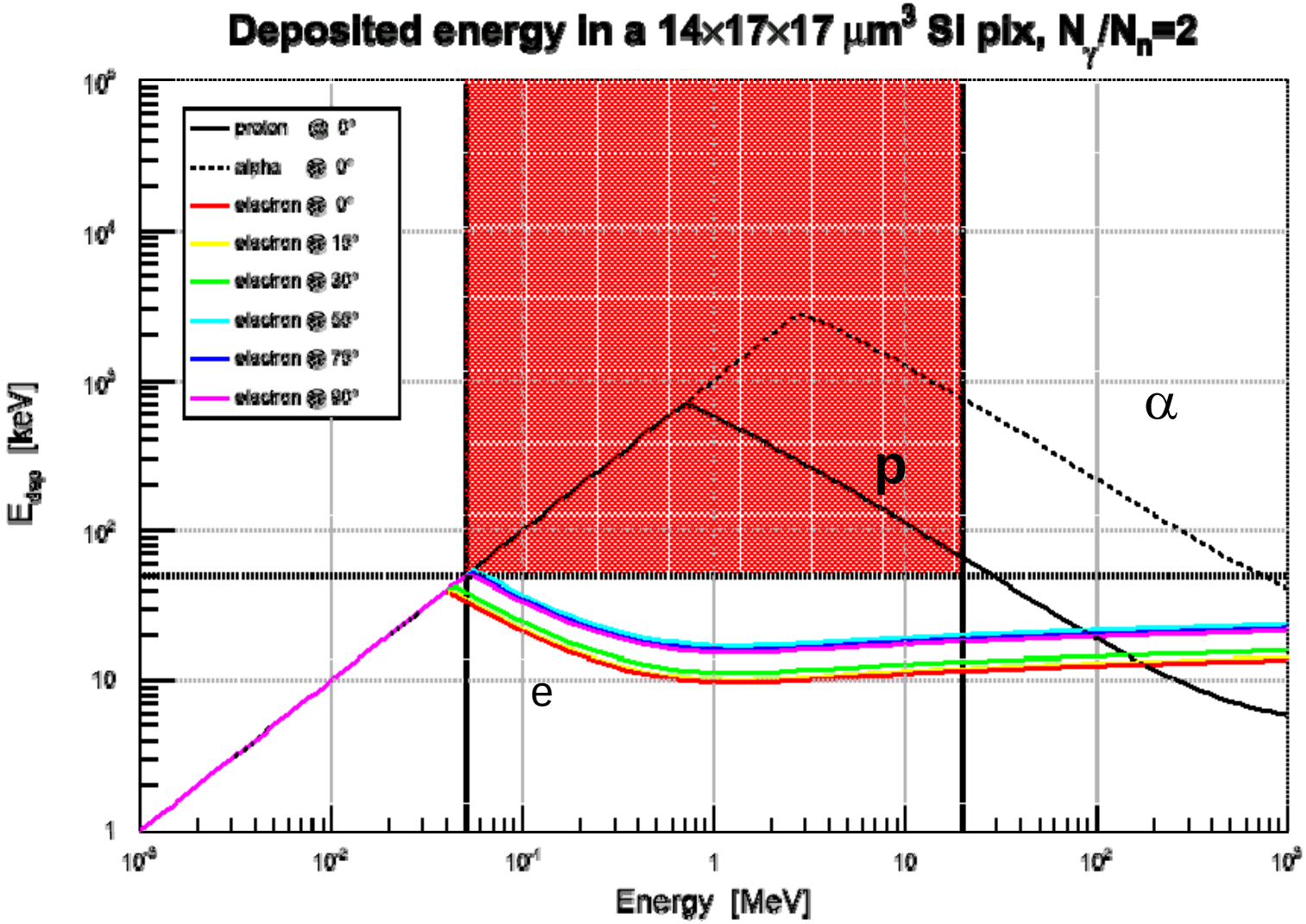
- γ MeV → e ~ 1MeV
  = MIP

  dEdX = **2.4** keV / 10 μm Si
  L_{abs}(Si) = 4 mm

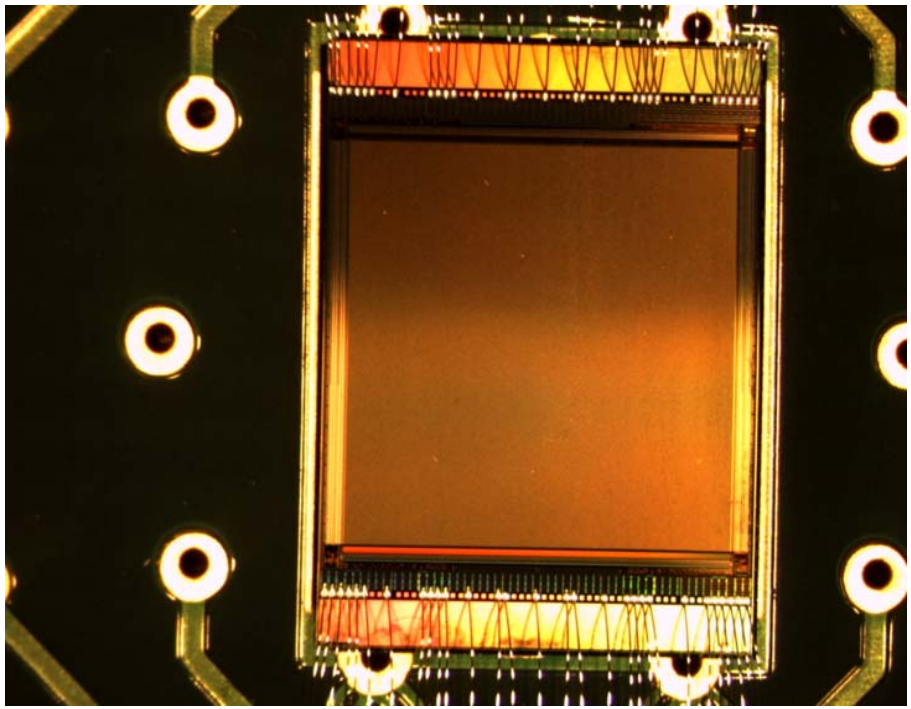
→ S/N > 10

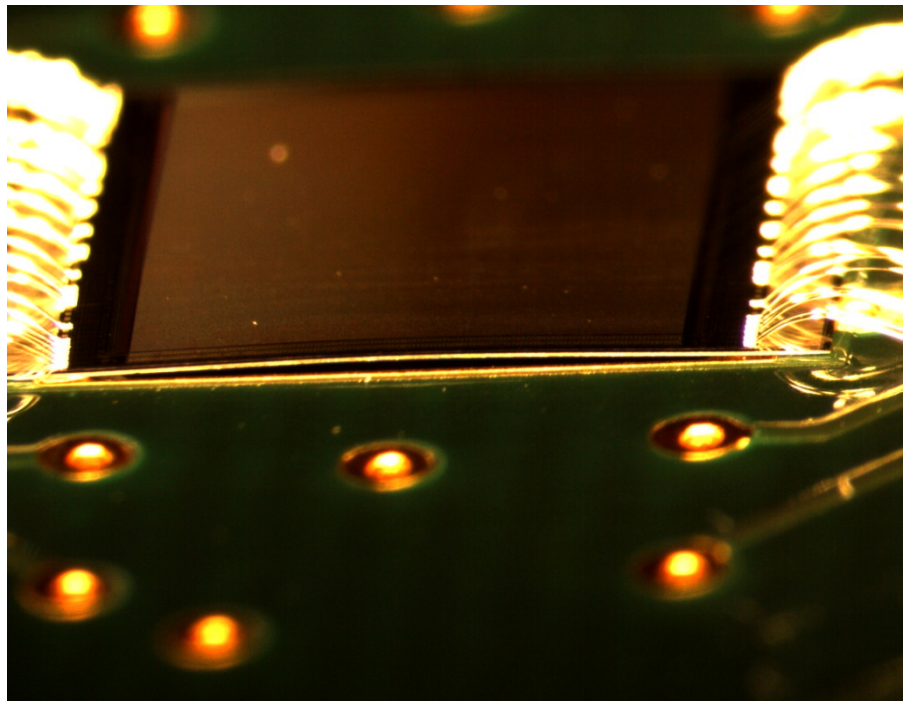


Gamma-transp

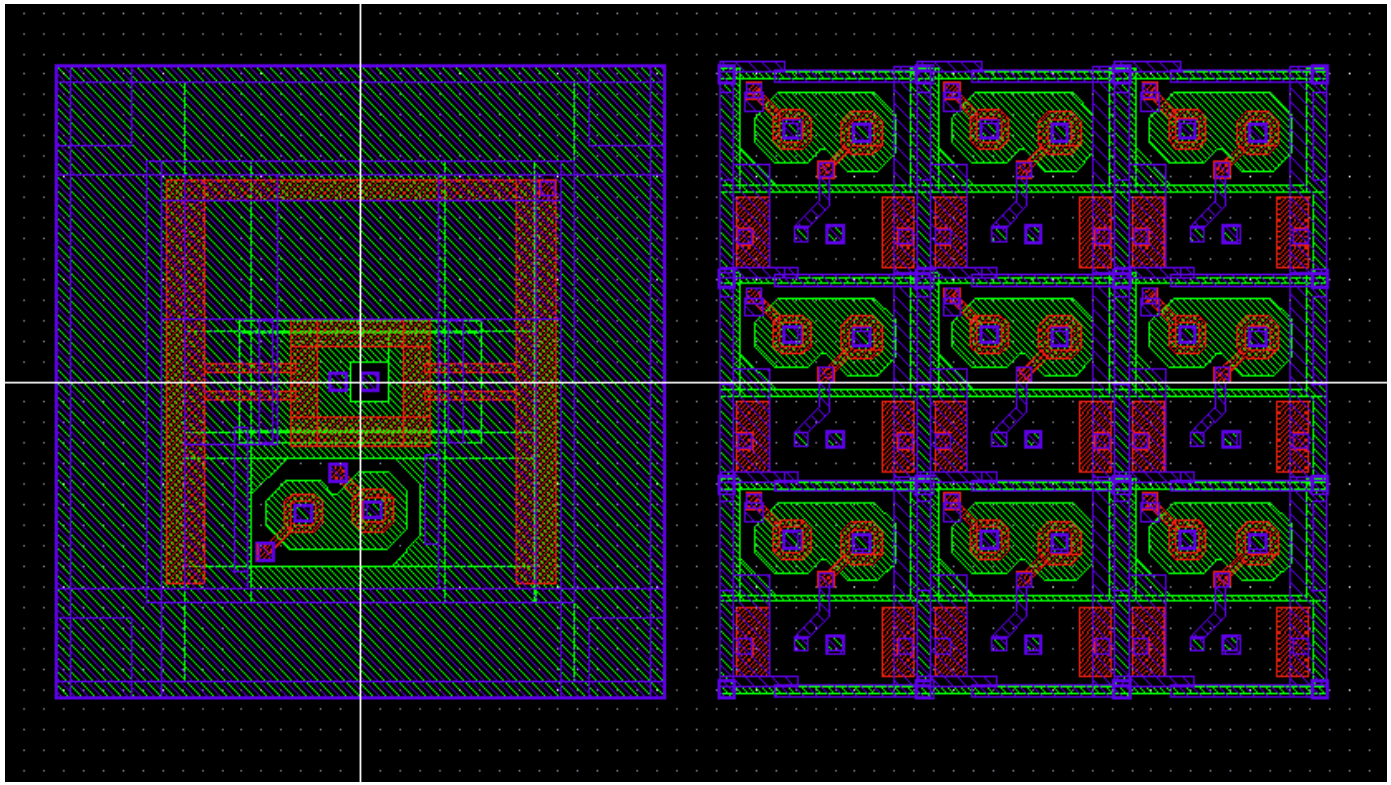


PCB-bonding of Mimosa18 (10 μm pixels)





Layout



MimoSTAR3 pixel

Mimosa18 3x3 pixel cluster
(same area as M*3 single pixel)

The DOSIPIX-N

$E_{neutrons}$ = meV-MeV

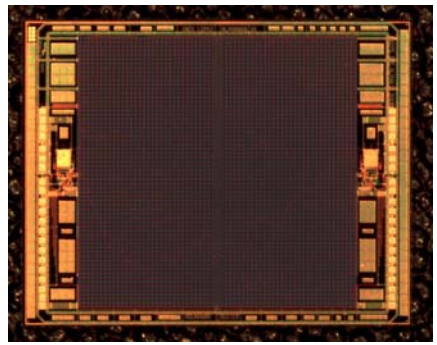
- Dosimétrie actuelle: passive ! (PN3)

- Opérationnelle? <u>aucun</u> système électronique de référence

➡ Transparence γ: → CMOS >> tout autre système
+ Intégration 100% (**15 μm epi*)

- Outils: MiV puis αRad 2
  + MCNPX,GEANT IV

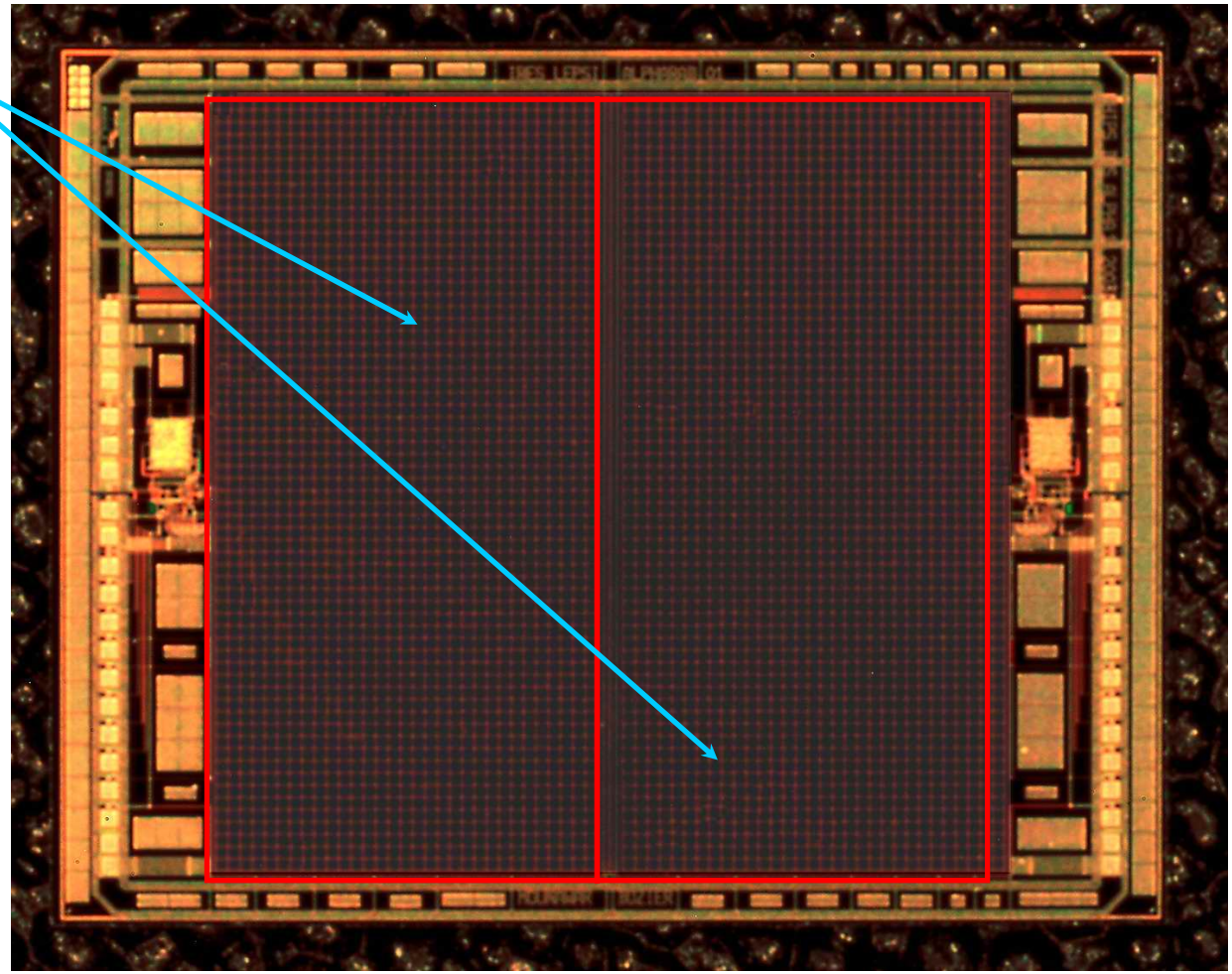
- Thèses: **<u>M.Trocmé</u>**, Zhang Ying



<u>αRad</u>
5x5mm^2, 1.2 E6 α/cm^2/s

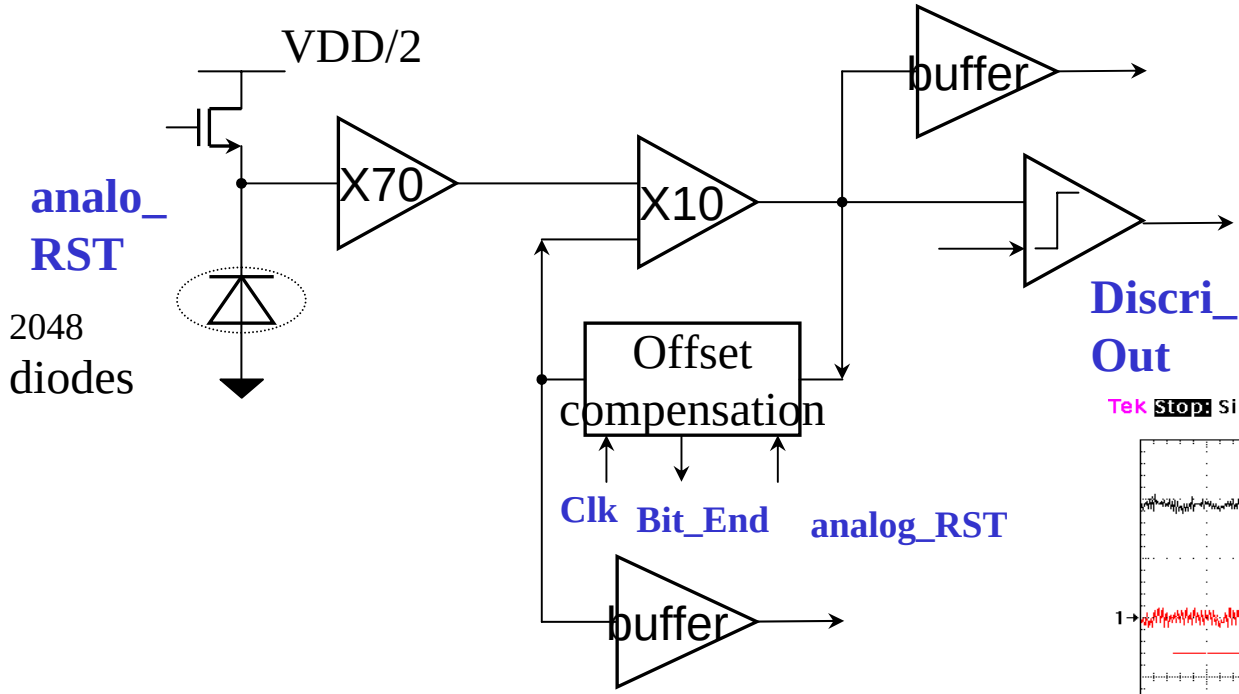
The AlphaRad chip (IPHC, 2003)

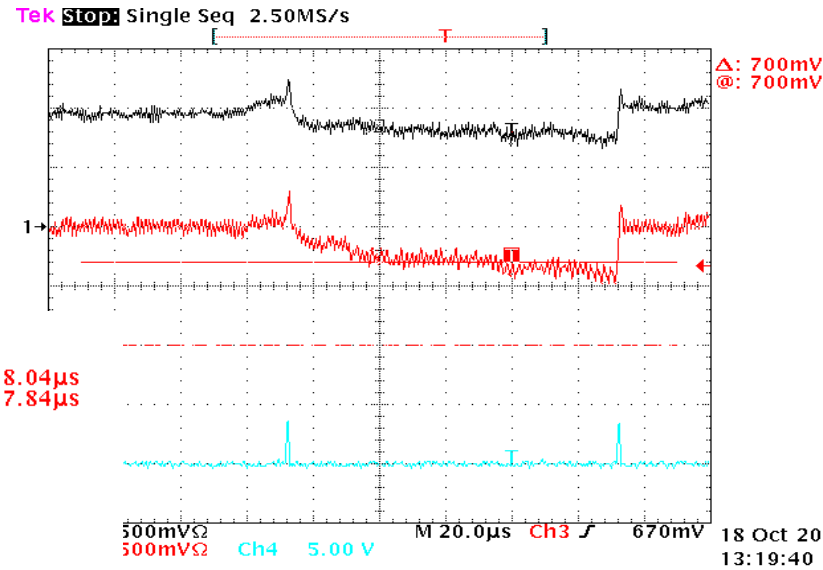
-Syst-on-Chip
-Techno. AMS 0.6 µm (***epi***)
-2 x 2.5 x 5 mm
-Détection α, p, d (⟹ **n**)
-Digital out (discr.)
-$f_{utilisation}$ = 3-300 kHz
-Cons: ~10 mA

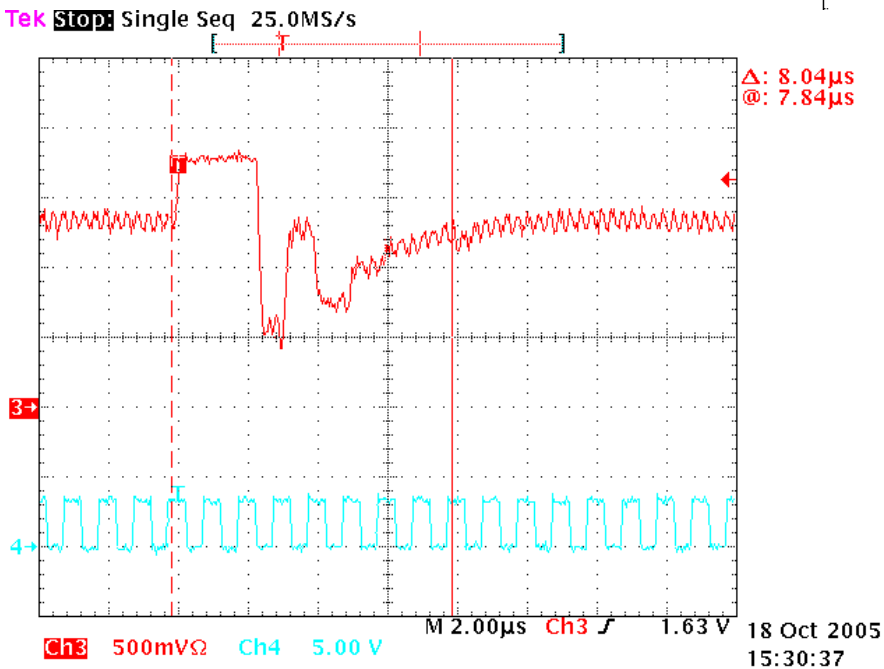


Physics Simul.:
Q_α=4.10^5-10^6 e/h
d_{dd}= 80 µm t_{coll} =100 ns

CAO:
C_{tot}=17pF+33pF ; I_{leak}=5 pA
W (Rst_TR) ~15µm....

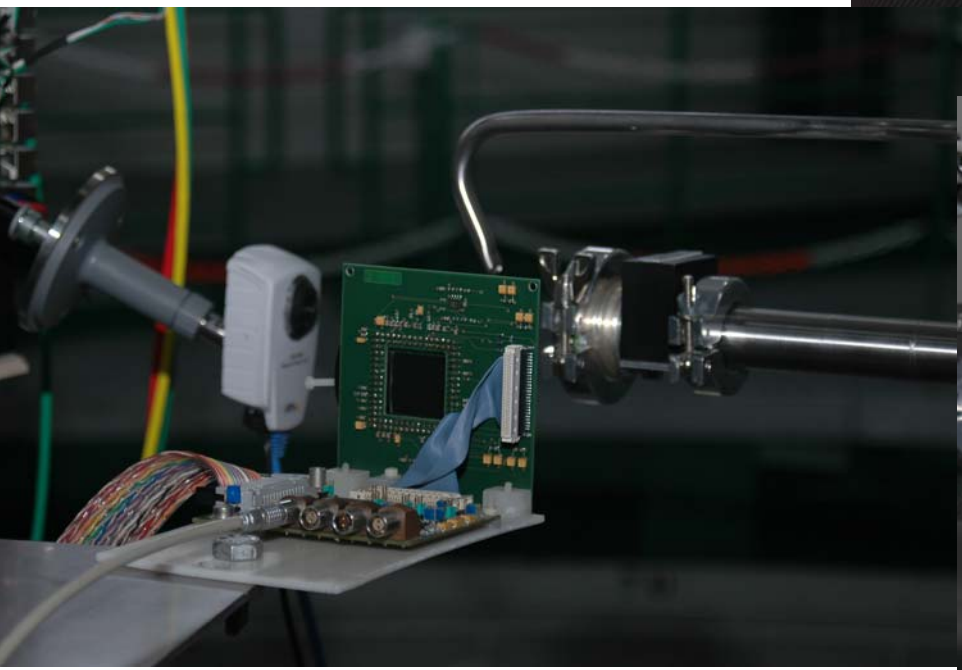

VDD/2
analo_
RST
2048
diodes
X70
X10
buffer
Discri_
Out
Offset
compensation
Clk
Bit_End
analog_RST
buffer


Tek Stop: Single Seq 2.50MS/s
Δ: 700mV
@: 700mV
500mVΩ
M 20.0µs Ch3 ƒ 670mV
500mVΩ Ch4 5.00 V
18 Oct 20
13:19:40

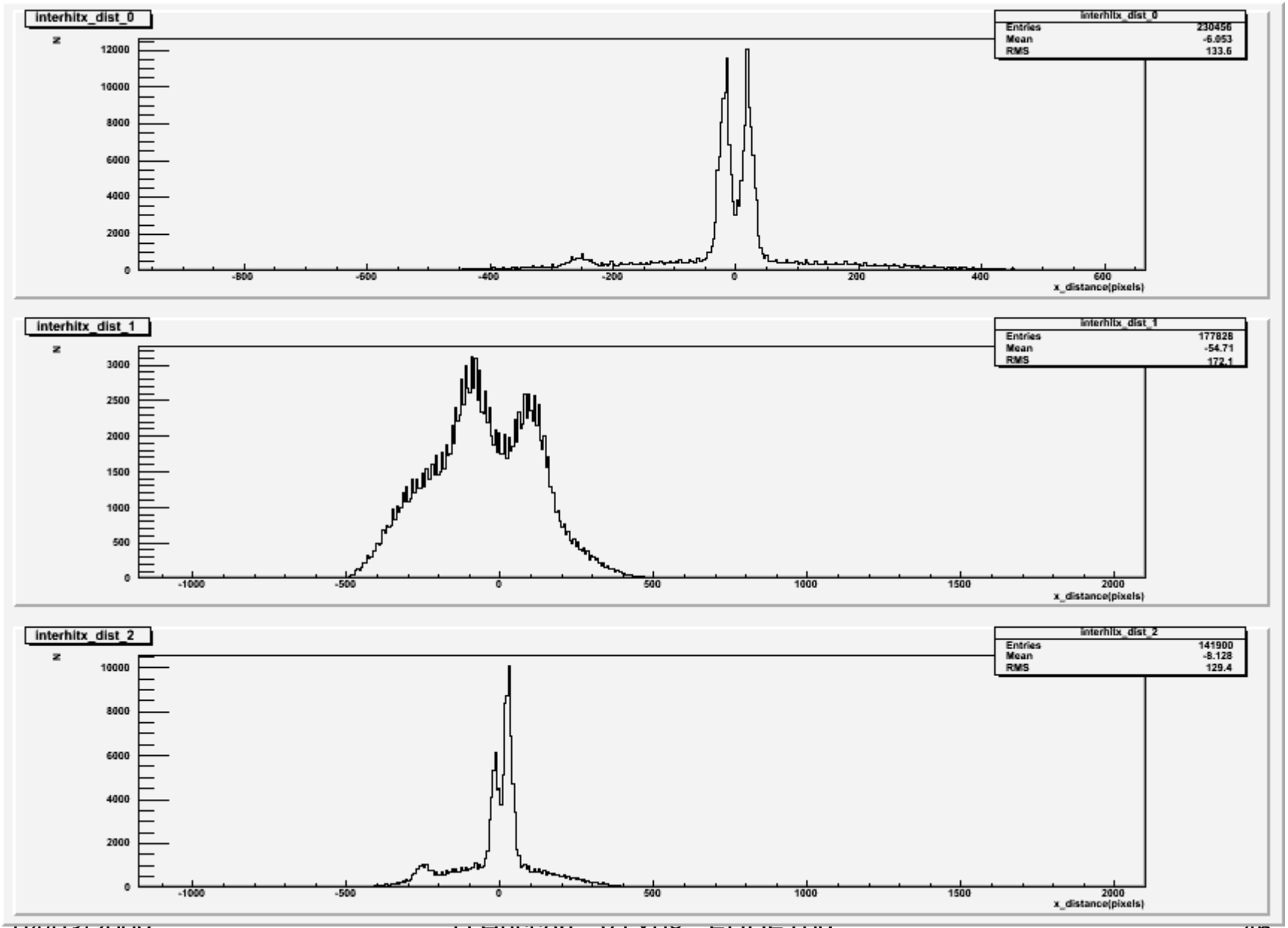

Tek Stop: Single Seq 25.0MS/s
Δ: 8.04µs
@: 7.84µs
M 2.00µs Ch3 ƒ 1.63 V
Ch3 500mVΩ Ch4 5.00 V
18 Oct 2005
15:30:37

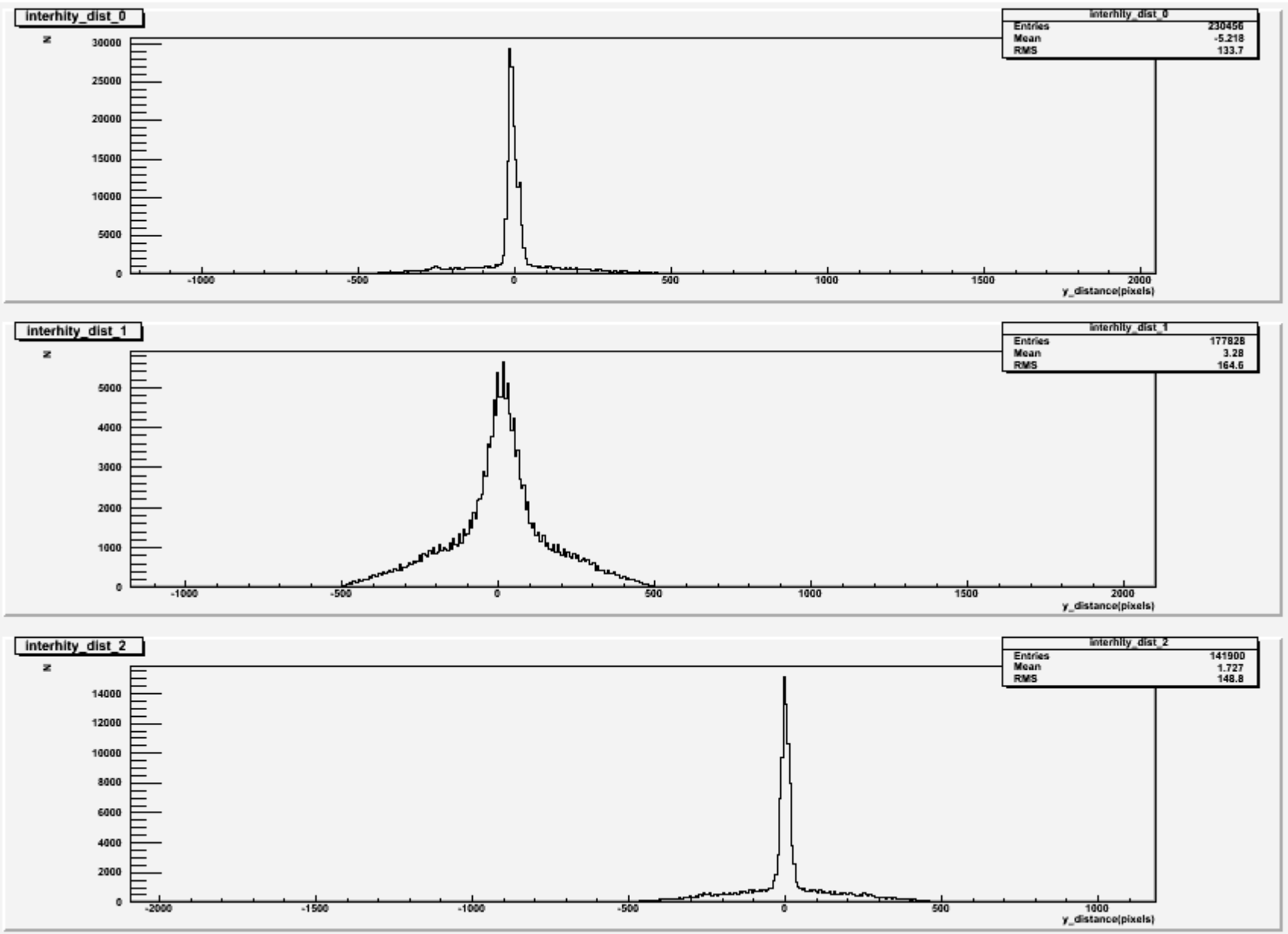
Cadarache, april 2008

^{252}Cf
$+D_2O$



Run 2450: 19 MeV




interhity_dist_0
interhity_dist_0
Entries 230456
Mean -5.218
RMS 133.7
y_distance(pixels)
interhity_dist_1
interhity_dist_1
Entries 177828
Mean 3.28
RMS 164.6
y_distance(pixels)
interhity_dist_2
interhity_dist_2
Entries 141900
Mean 1.727
RMS 148.8
y_distance(pixels)