Irradiation Pixel CMOS

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Use cases for CMOS pixels in ITK 2024

- **Inner pixel** layers (R=3-6 cm). Use of **FE-RD53 in 65nm** technology with 50x50 um pixel size. Four CMOS 25x25 um **sub-pixels** with thickness <50 um Strong radiation hardness demand up to **1 GRads**
- **Intermediate pixel** layers R=6-25 cm. Use of **FE-RD53** with 50x50 um pixel size. Four CMOS 25x25 um sub-pixels with thickness <50 um interesting, but not mandatory.

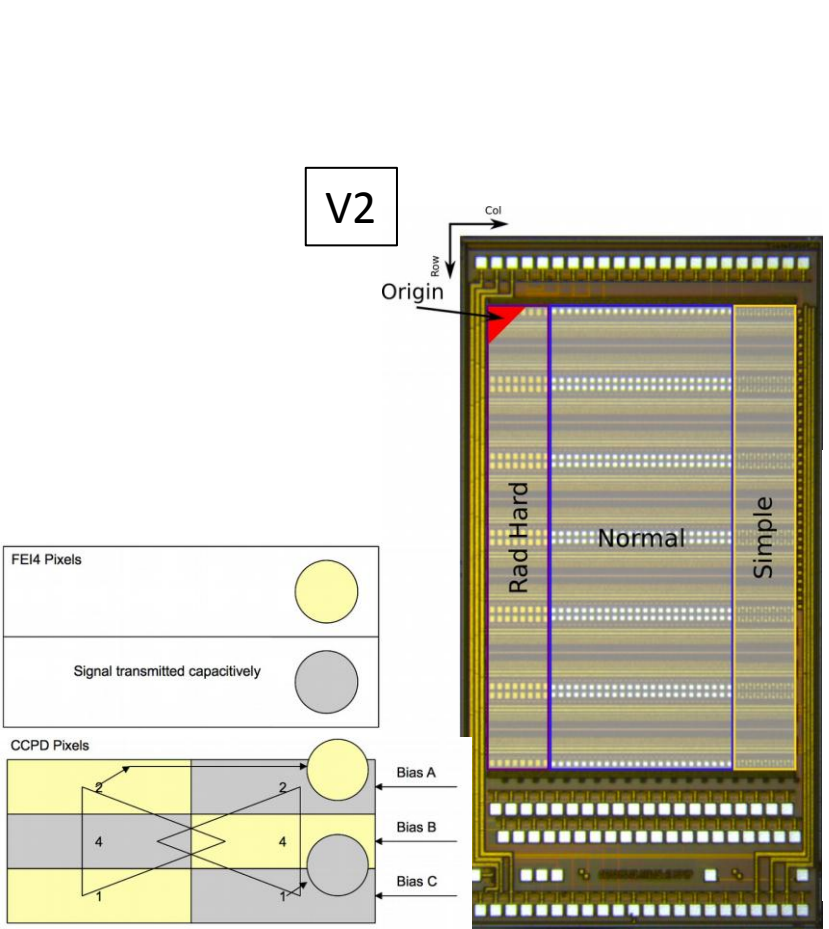
- **Outer pixel layers** R> 25 cm **Use FE-Ix digital tier** with pixel 50x250 um. Low cost bonding (gluing or C4 bumps) mandatory for cost reasons.
- **Outer pixel layers** R>25 cm Use **Full monolithic** CMOS chip with classical column readout

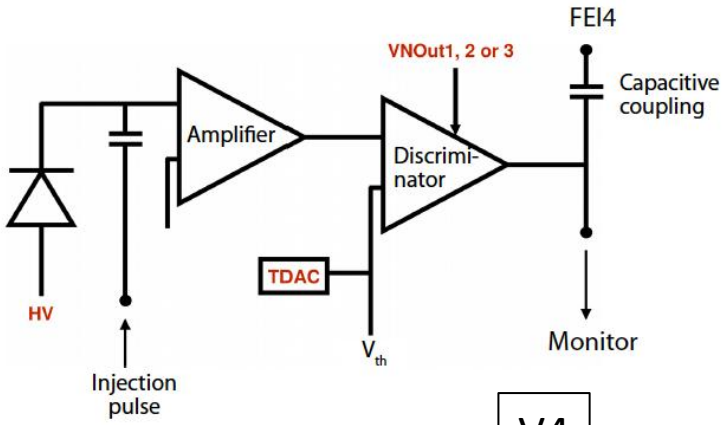
Prototypes submitted (few mm^2)

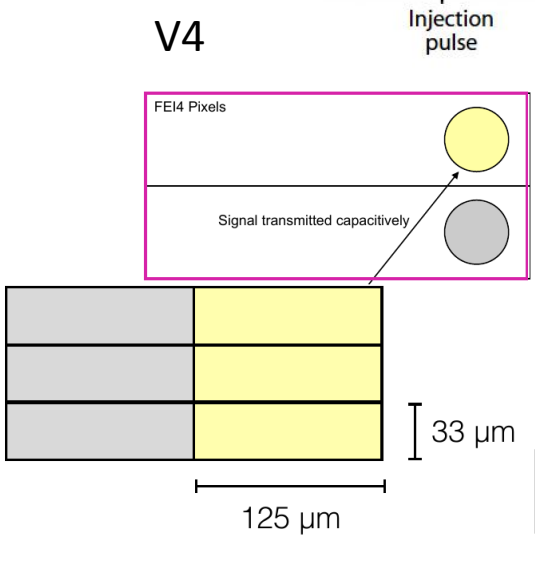
	A	B	C	D	E	F	G	H	I
Node	180nm	350nm	150 nm	180nm SOI	180nm	130nm	150nm	130nm	160nm
Wafer Resistivity	10 ohm	10 ohm 1 khom availab	2 kohm	100 ohm 2k poss.	1-3 k Epi/bulk	3k	2k	10 ohm 3k ???	Select epi
Full CMOS	No	No	Yes	yes	Yes	No	Yes	Yes	Yes
Backside implant	No	No	Yes	No	No	No	Yes	No	No
HEP experience	4 subm Lab Test beam	2 subm Labor Also strips	2 subm Lab No CCPD	Subm Lab	Subm Lab	Subm 6/2014	Subm Receiv 2/2015	Subm Lab	tbd
Groups	Heidelb. Geneva CPPM	Heidel. Geneva	Bonn Prag.	Bonn CERN	Bonn (Strasb)	Bonn	Bonn Heidel. CPPM	CPPM Heidel.	INFN

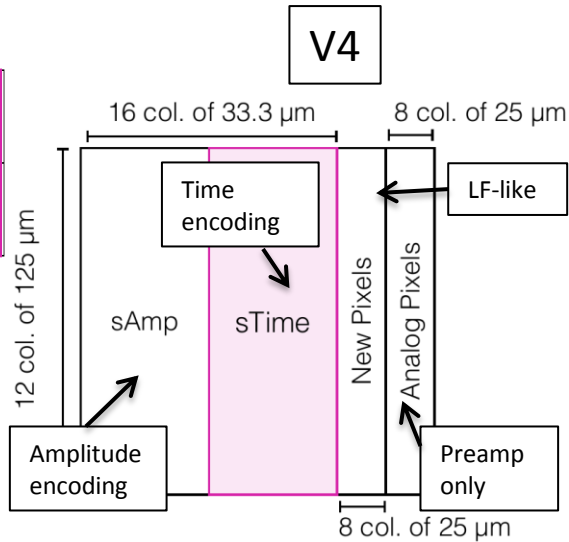
AMS-180nm CCPD prototypes

- Four versions tested standalone and glued on FE-I4. Most advanced results for today from V2 and V4.
- HV with 10 ohm wafer now. Prospect of HR ~100 ohm or 2 kohm in fall 2015 ?
- 3 CMOS sub-pixels 33x125 um readout by one FE-I4 pixel of 50x250 um



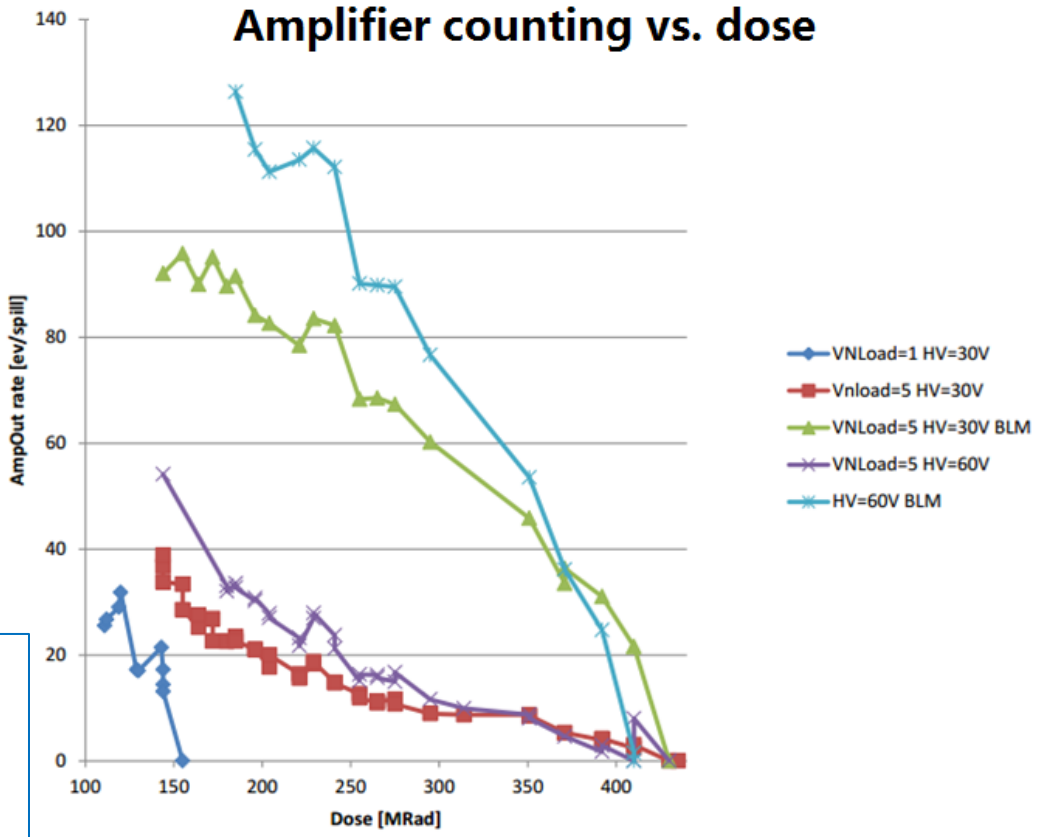






HV2FEI4 series

- V1: first proto, proof of concept, not hard hard

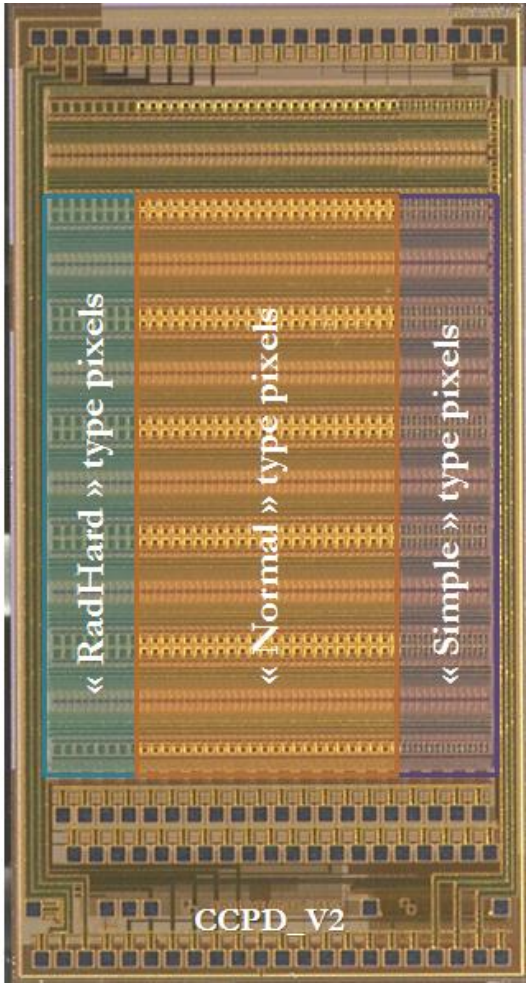


Discriminator is dead at ~0.5 MRads.

Preamplifier is dead at 160 MRads in high gain mode. Whereas it is alive up to 410 MRads in low gain mode.

HV2FEI4 series

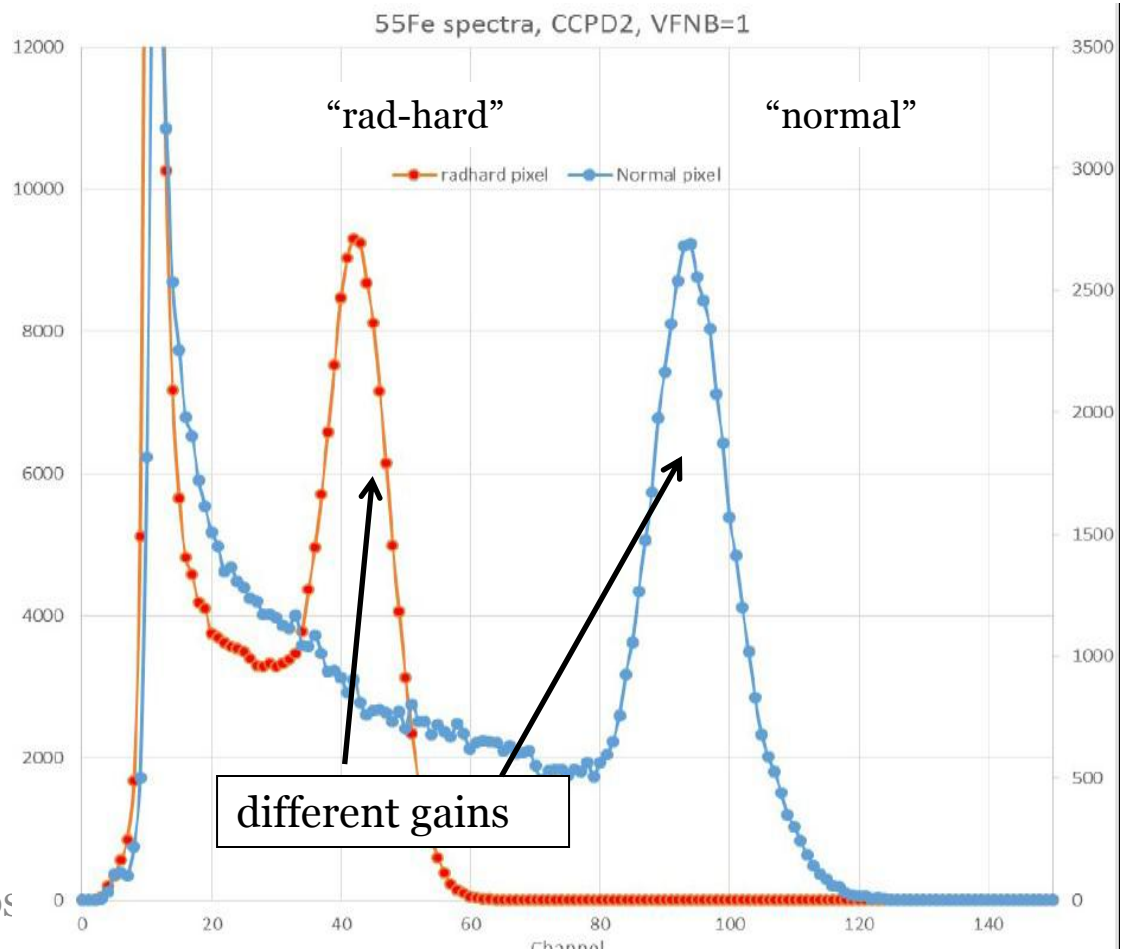
- V2: structures Rad-hard
- AMS 180 nm
- 2.2×4.4 mm^2.
- 60 column×24 rows
- Pixels: 33×125µm^2.
- For actual X-ray irradiation
  - **only standalone way tested**
  - no CCPD coupling to FEI4
  - no strip readout



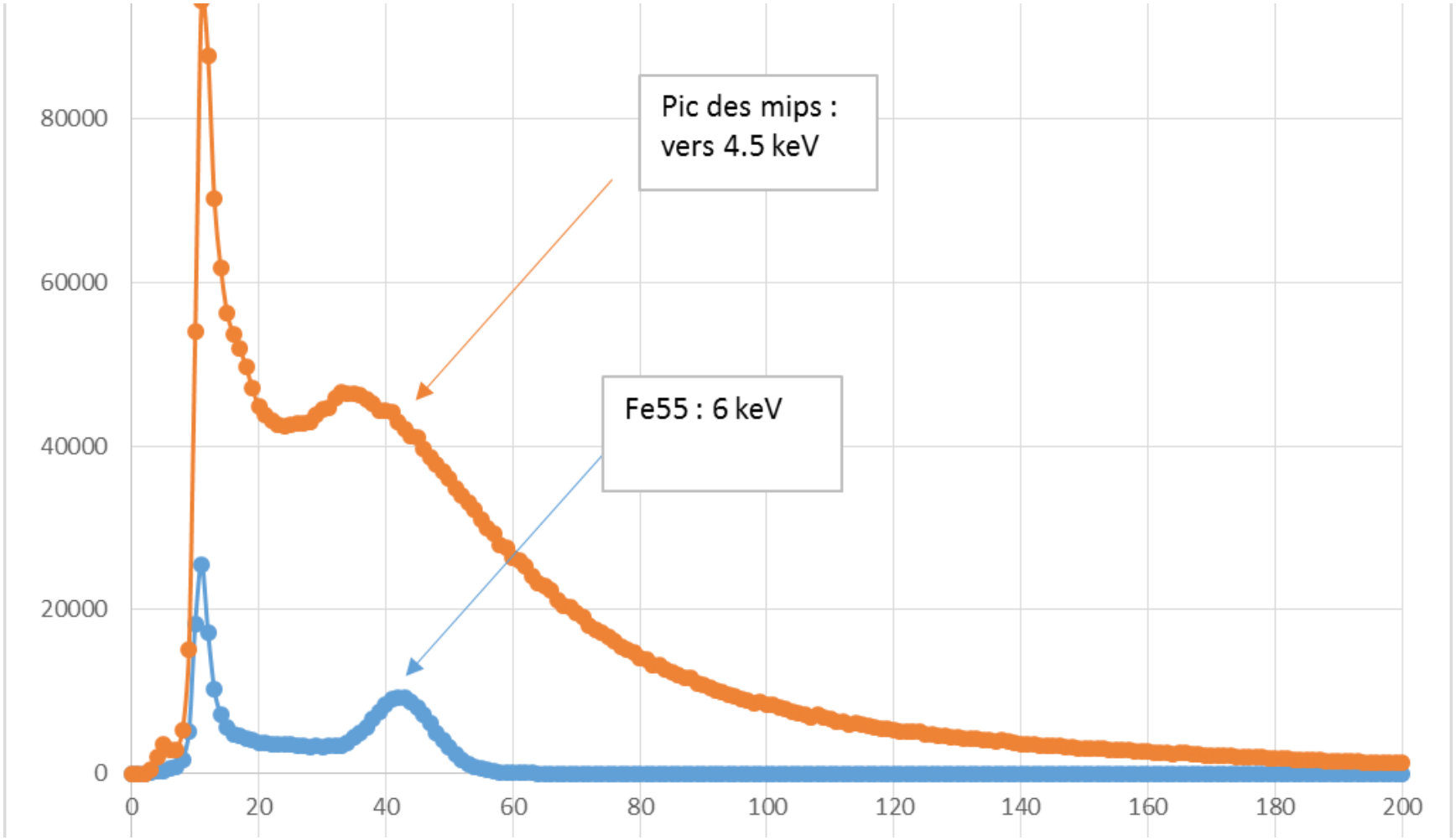
HV2FEI4_V2

- Few pixel flavors with enhanced rad-hardness: guard rings, circular transistors… (different pixel types lead to different gains -expected-).

^{55}Fe spectra, unirradiated

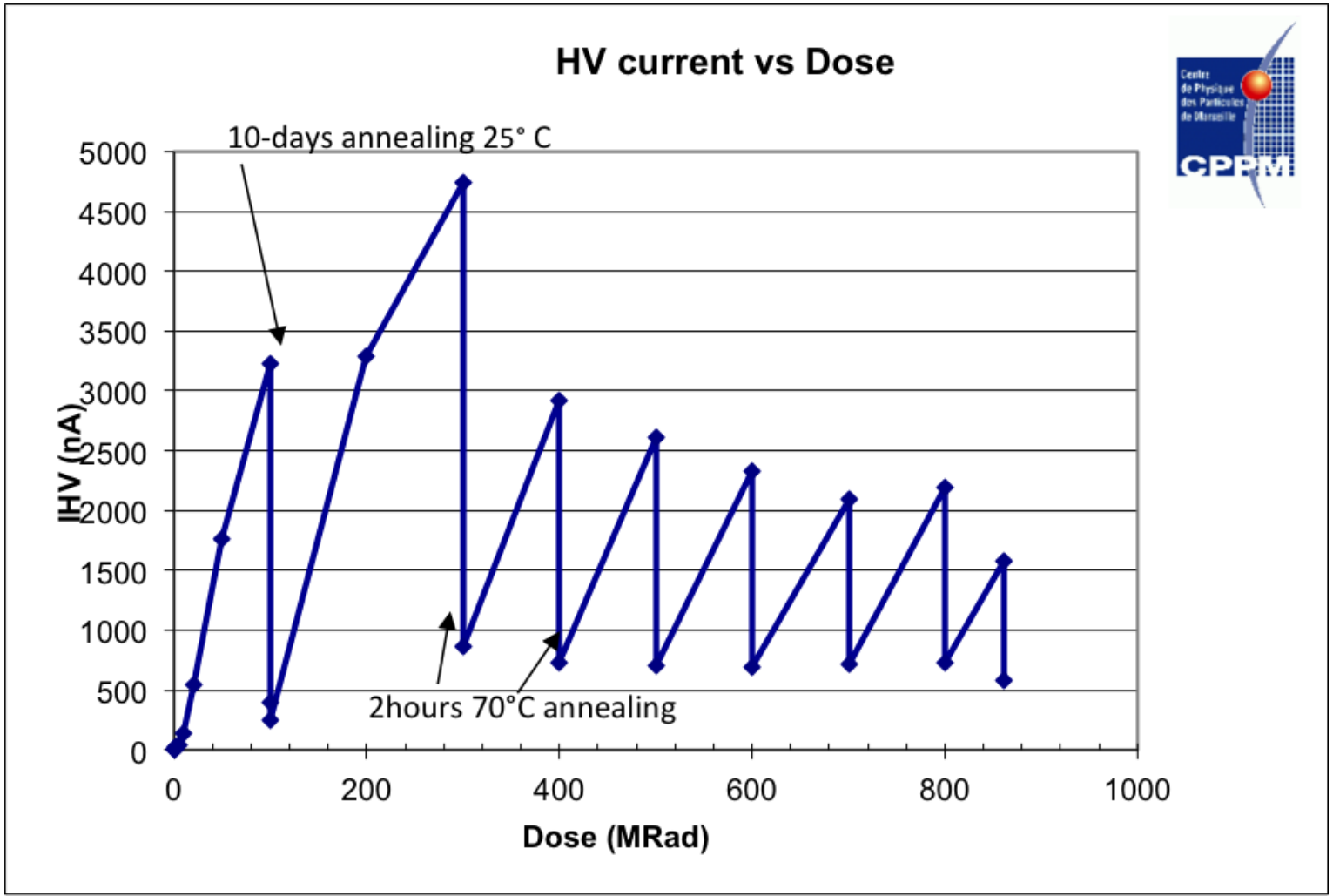


Sr-90 at HV=30V



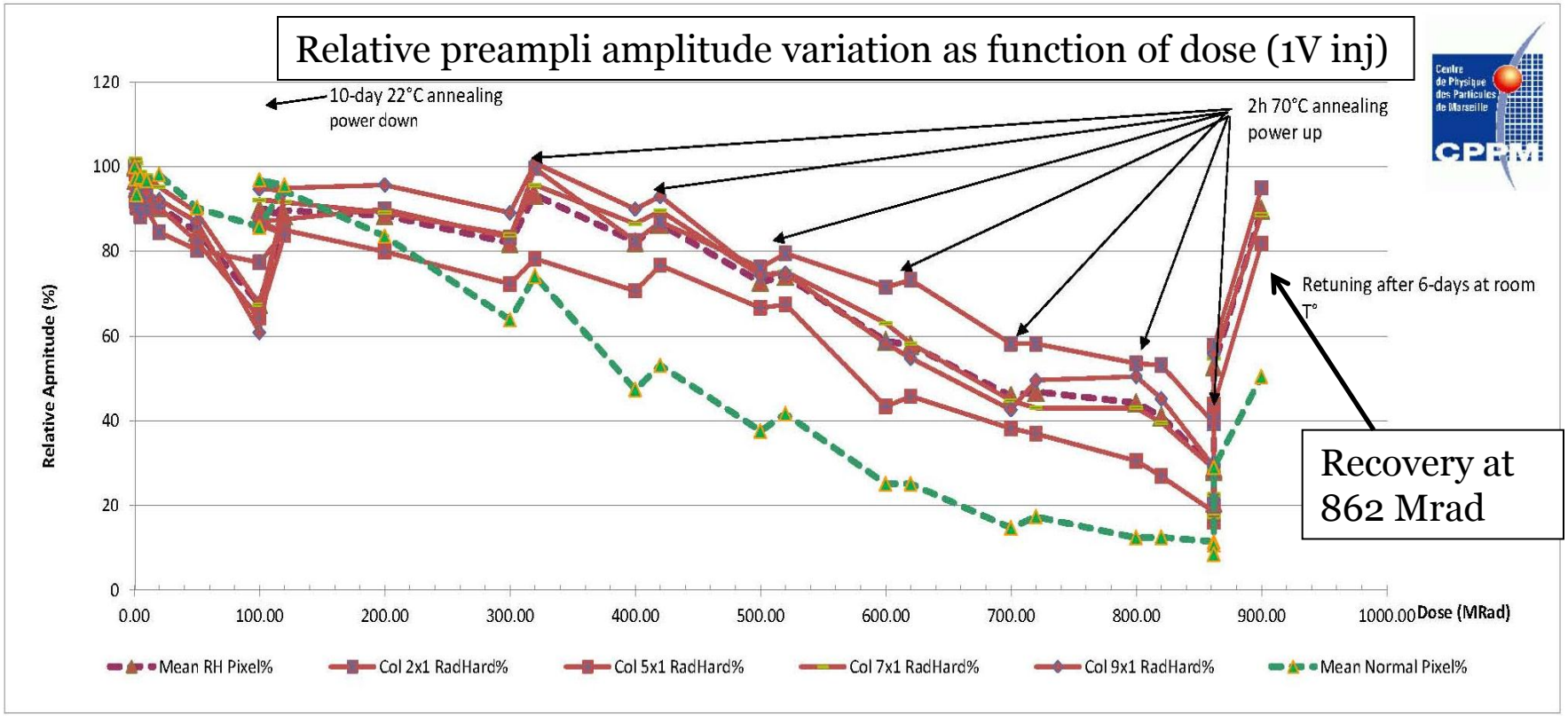
HV curent vs Dose

- After each 100 Mrad apply 2 hours of 70° C annealing
- After 5 days room temp annealing the current I=590 nA
- After 6 days and one row selection I=465 nA



HV2FEI4 V2

- After 862 MRad Xray (annealing of 2h at 70° C each 100MRad), after parameter retuning, amplifier gain loss recovered to 90% of initial value

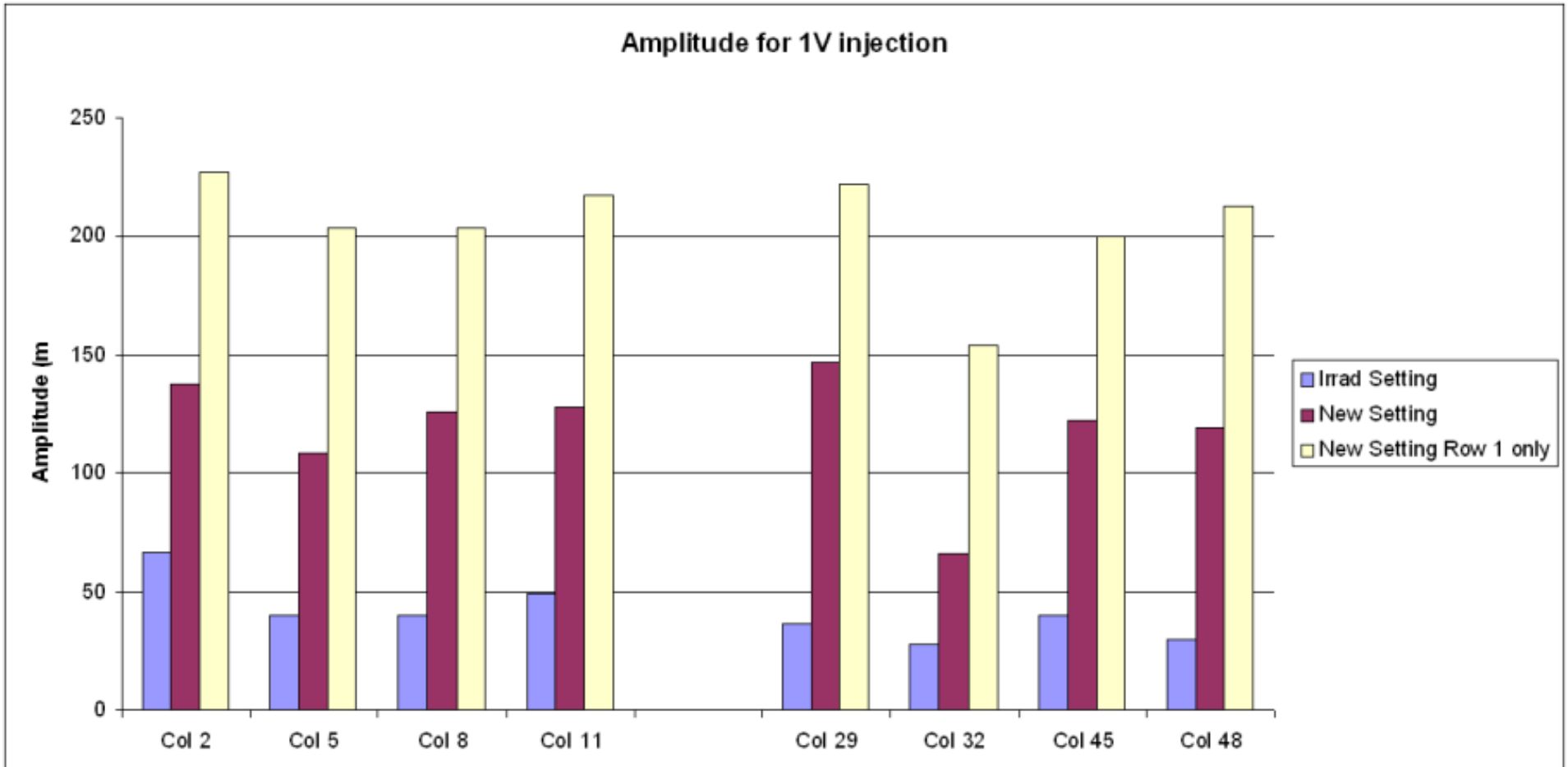


New settings after irradiation

- BLR = 1 (instead of 20) reduce threshold, Disc signal length increased from ~ 1us to ~1.3 us
- VNLoad = 60 (instead of 5) increase Ampli output by factor 2-3 (only linear transistor …)
- VNComp = 5 (instead of 20) increase the Disc signal length
- VNBuff = 0 (instead of 30) reduce consomption Vdda
- Gate = 2.0 V (Instead of 2.2V) shape Discr output
- Enable one row (row=1) increase Ampli signal by 1.5-2.0 , disconnect not used pixels, reduce Issa

After 862 MRAd and Enable row 1 only

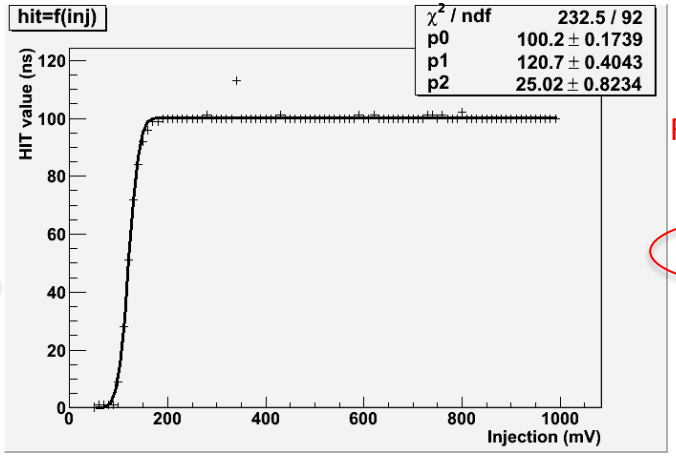
- Ampli scope 1V injection all 8 pixels



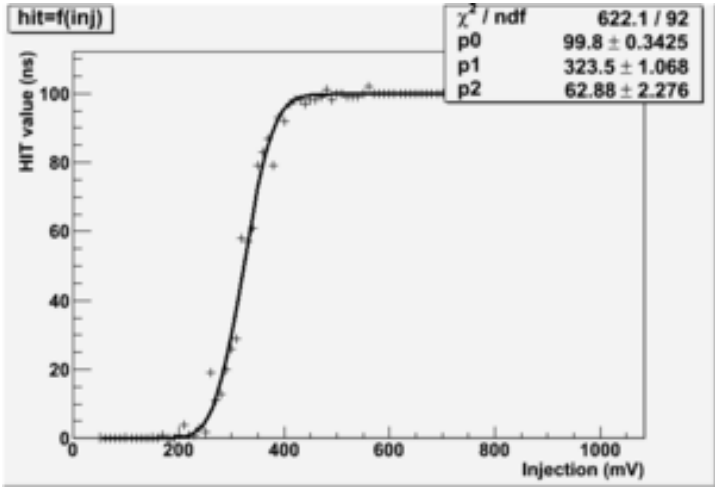
V2 Threshold measurement with S-curve

- Produce S-curve by vary the injection pulse from zero to 1 V. 50% point on S-curve defines the threshold point.

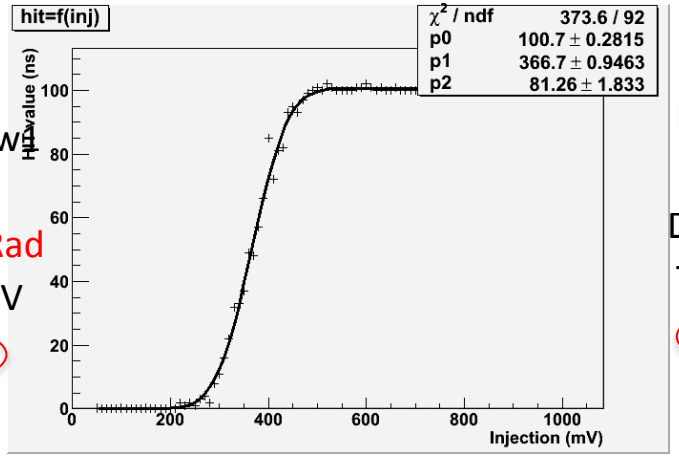
Pixel col30xrow1
Normal.
Dose= 0.5 Mrad
Thresh= 121 mV
Noise = 25 mv



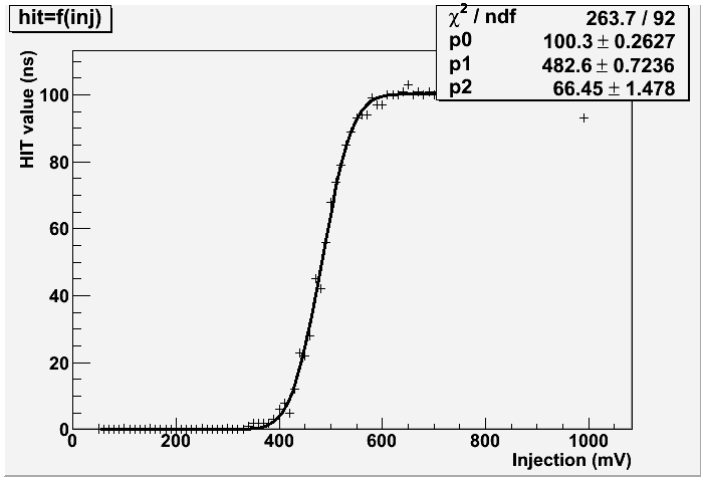
Pixel col2xrow1
Radhard
Dose= 0.5 Mrad
Thresh= 324 mV
Noise = 63 mv



Pixel col30xrow1
Normal
Dose= 862 MRad
Thresh=367 mV
Noise = 81 mv



Pixel col2xrow1
Radhard
Dose= 862 MRad
Thresh=482 mV
Noise = 66 mv

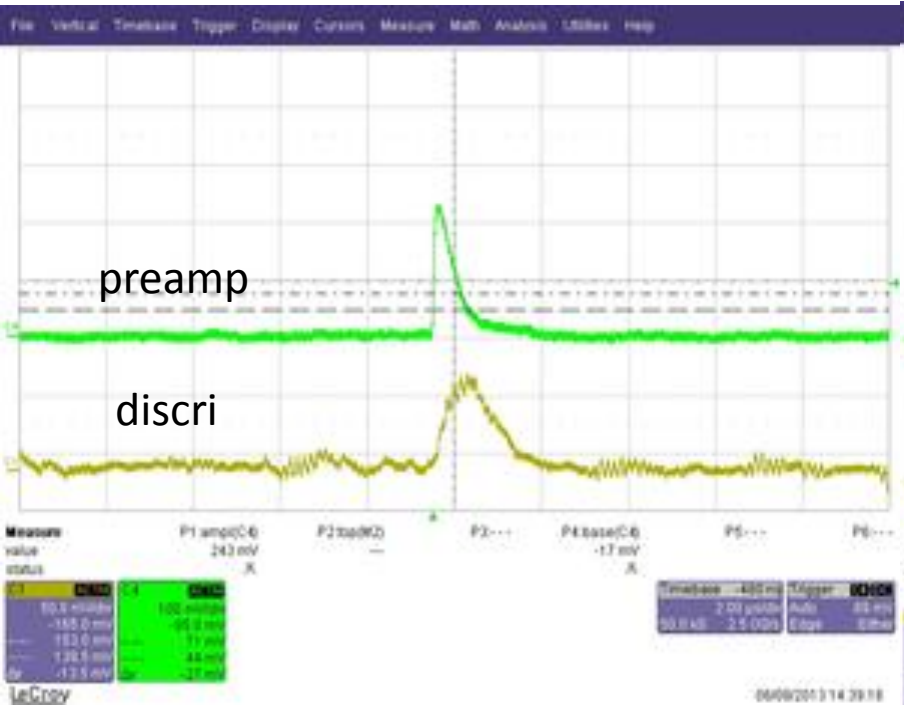


A.Rozanov AUW CMOS session 4.11.13

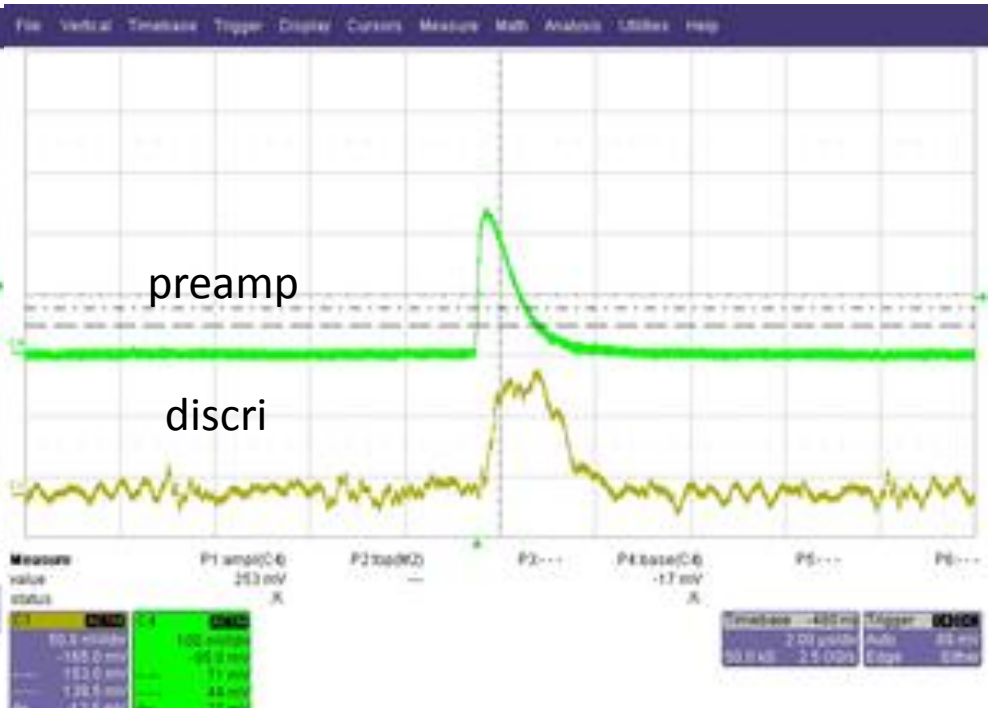
Injection 1V signal after 862 MRad

- Both RadHard and Normal pixels works

RadHard pixel col2 row 1



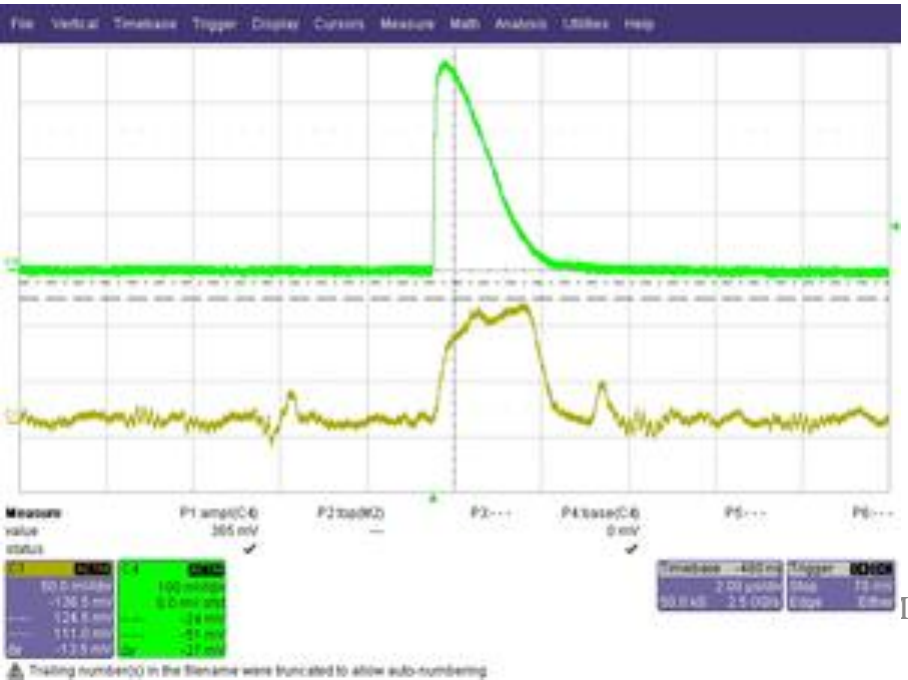
Normal pixel col29 row 1



Normal pixel after 862 MRad

- pix 29x1 Sr90 signals seen, Fe55 only weak Amp

Sr90 signal

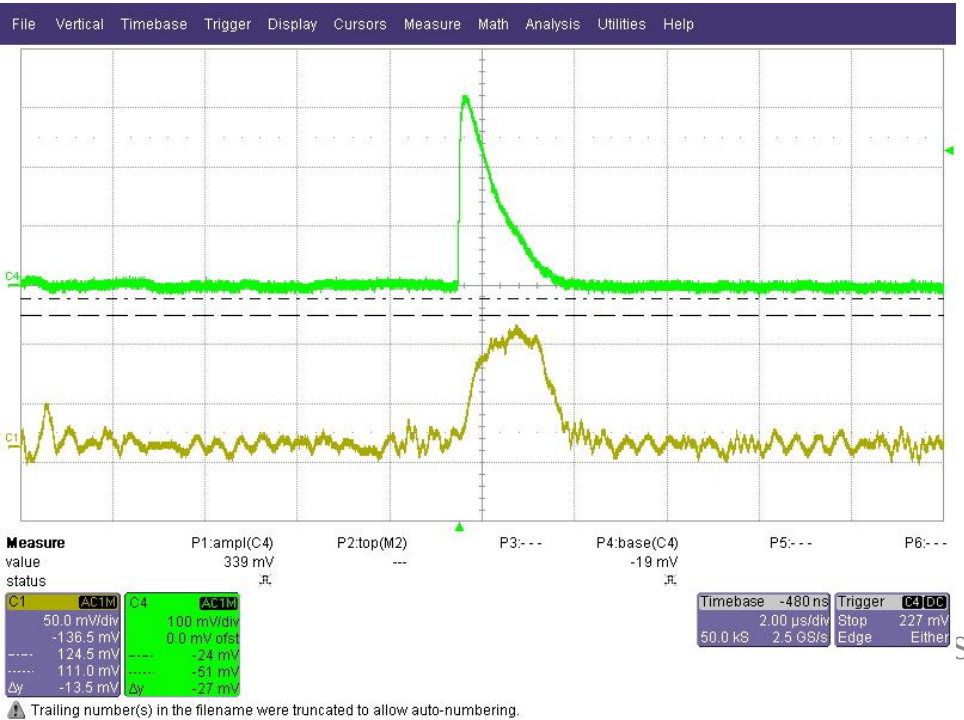


Fe55 signal

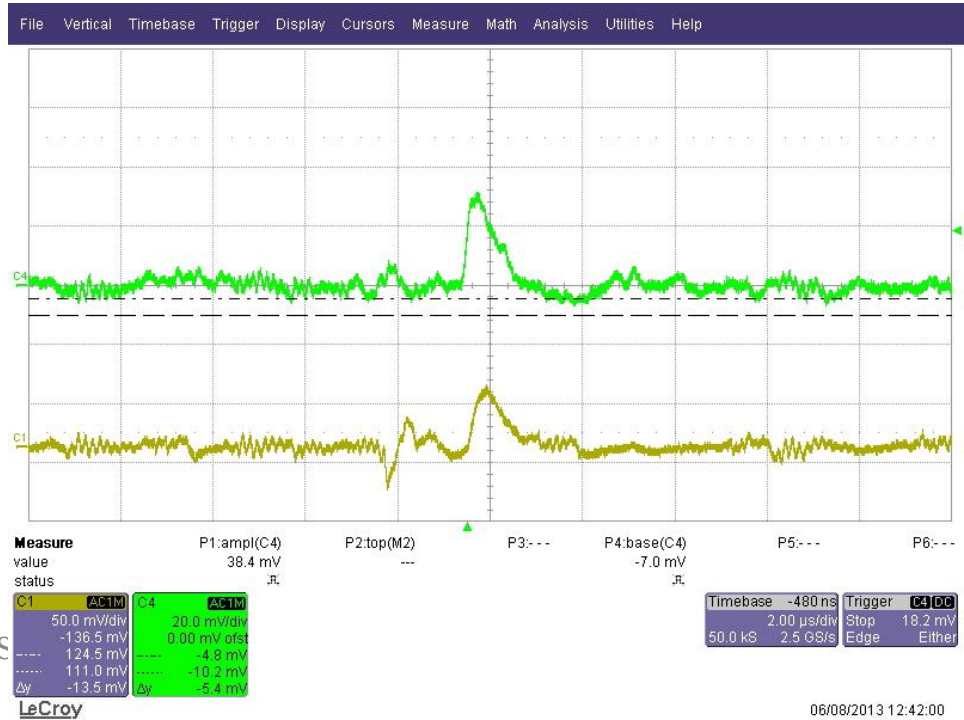
RadHard pixels after 862 MRads.

- Sr90 and Fe55 signals seen !!!
- Enable row 1 only, pix col2xrow1

Sr90 signal



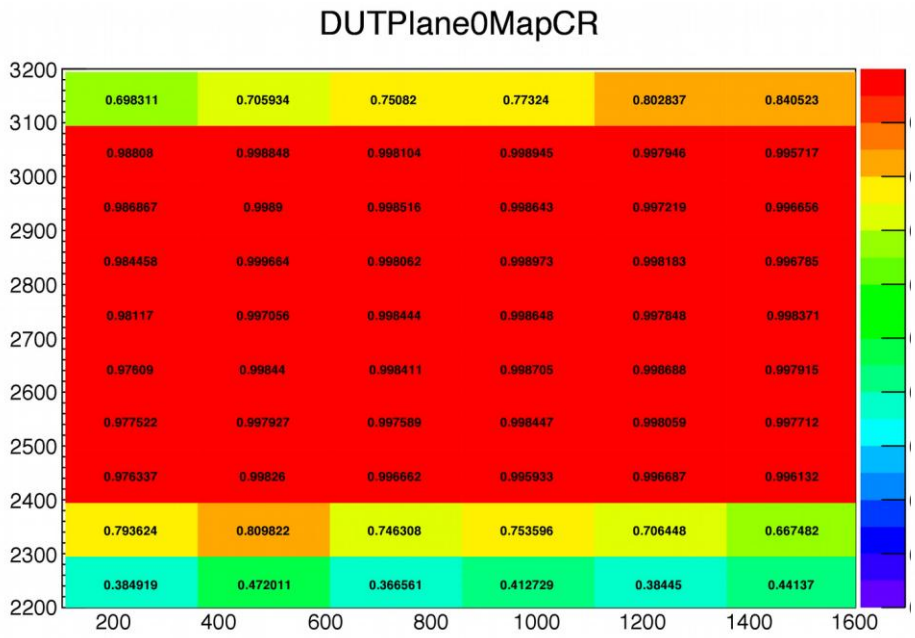
Fe55 signal

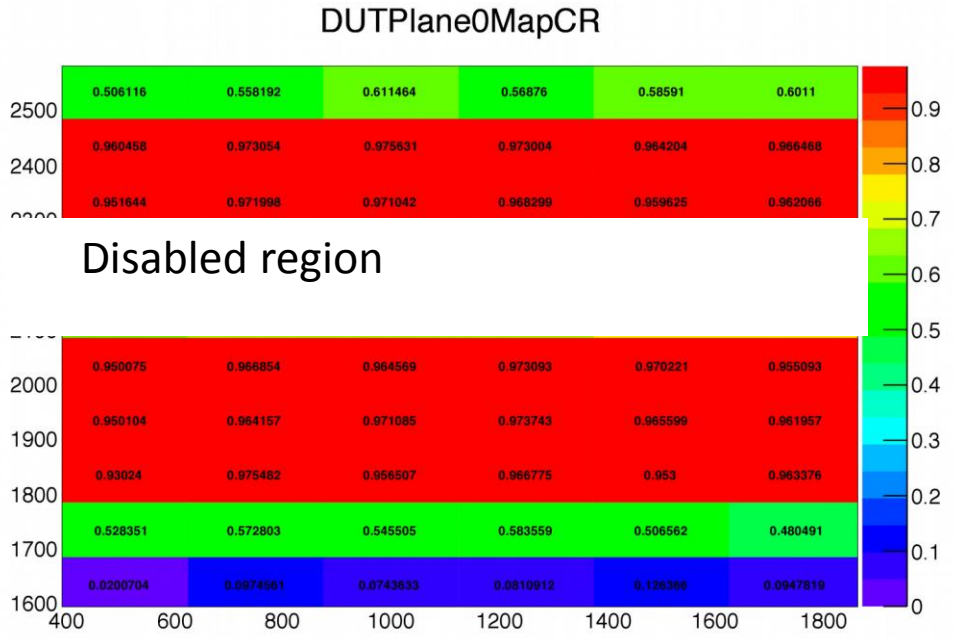


Test beam efficiency CCPD-V4

- Non-irradiated
- HV=-12V
- Vth=0.84V
- Efficiency=99.7%

- Neutron irradiated 10^{15} $n_{eq}cm^{-2}$
- HV=-30V
- Vth=0.84V
- Efficiency=96.2%



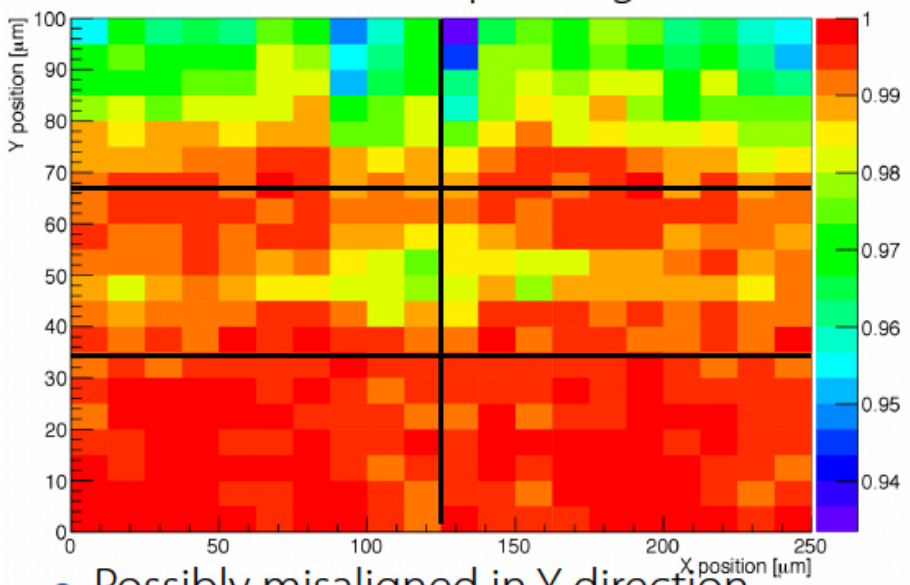


In pixel efficiency CCPD-V4

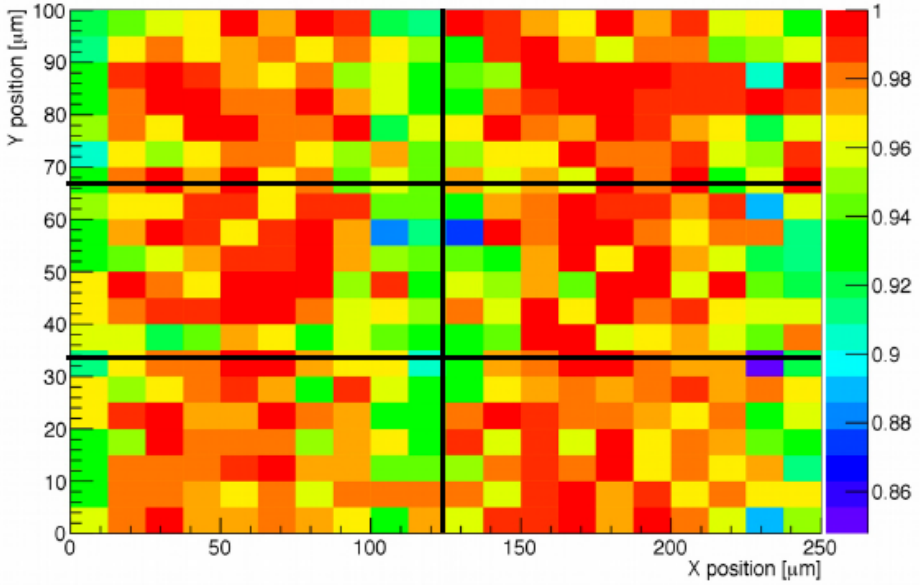
- Non-irradiated
- HV=-12V
- Vth=0.84V
- Efficiency=99.7%
- Efficiency close to specification

- Neutron irradiated 10^{15} $n_{eq}cm^{-2}$
- HV=-30V
- Vth=0.84V
- Efficiency=96.2%
- Inter-pixel regions to be optimized to increase efficiency

- Inefficiencies in inter-pixel regions

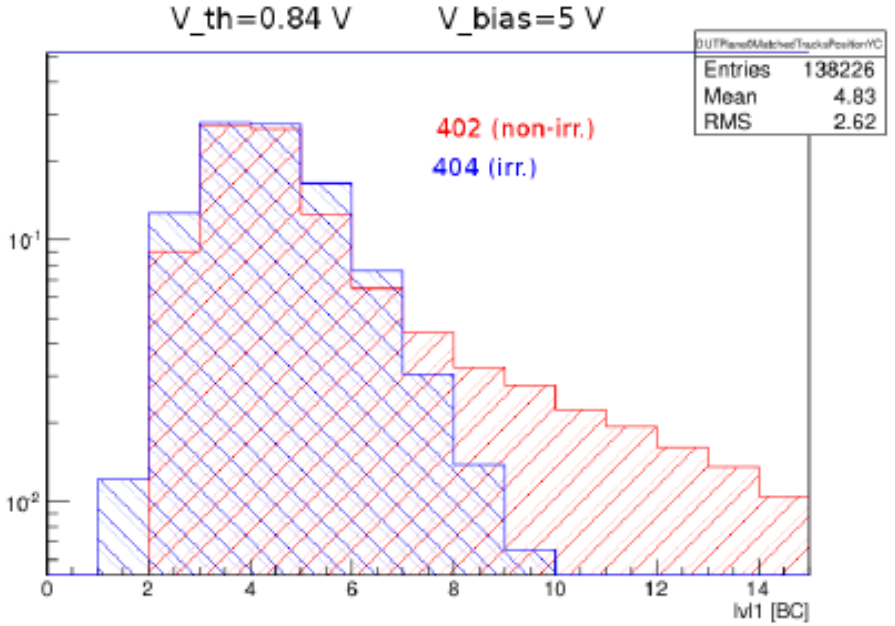


- Possibly misaligned in Y direction

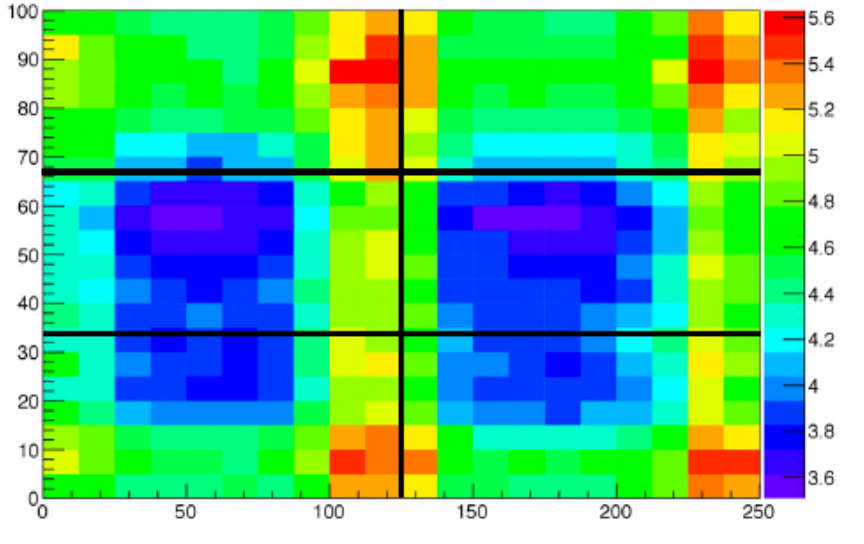


In-Pixel Timing

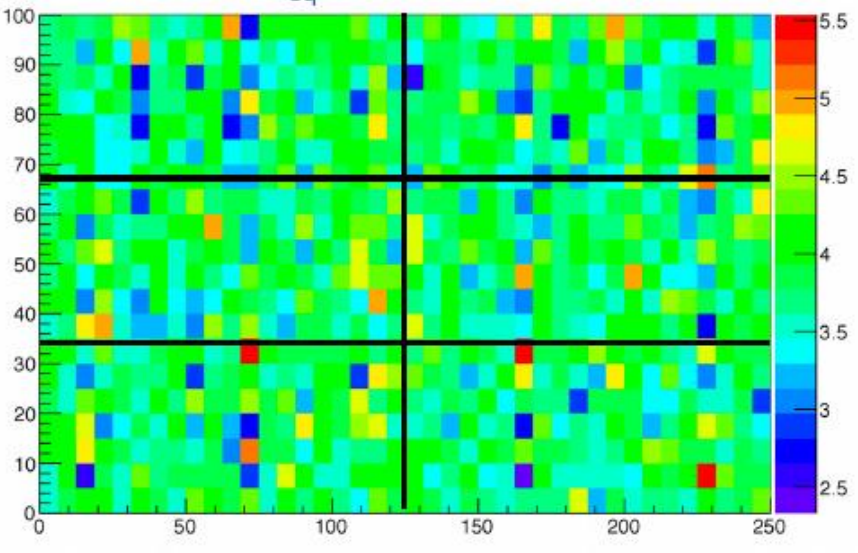
- Spatial dependence of timing disappears after irradiation due to the killing of diffusion
- Time width of 5 BC is still far from specification. In future: smaller thresholds, HR increase of signal and time slewing corrections



402 (unirradiated, -12V)



404 ($1x10^{15}n_{eq}cm^{-2}$, -30V)



IAP

BCID distributions AMS 180 nm

- sample CCPD-V4 sn404, bias 30V, 10^{15} neq/cm^2

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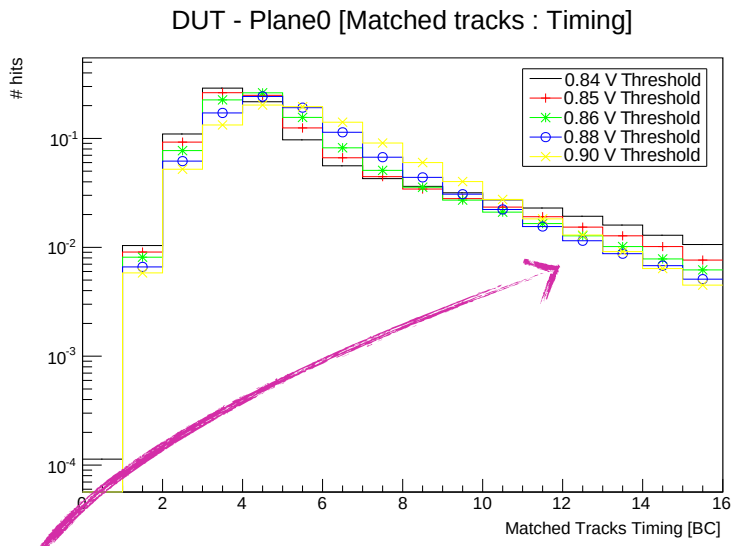
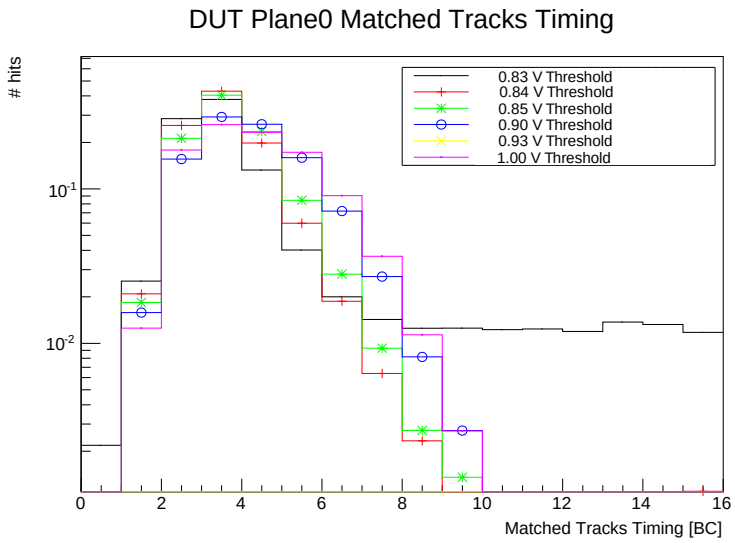
v4 Timing vs Threshold.

402, unIrradiated
Th 0.84 V



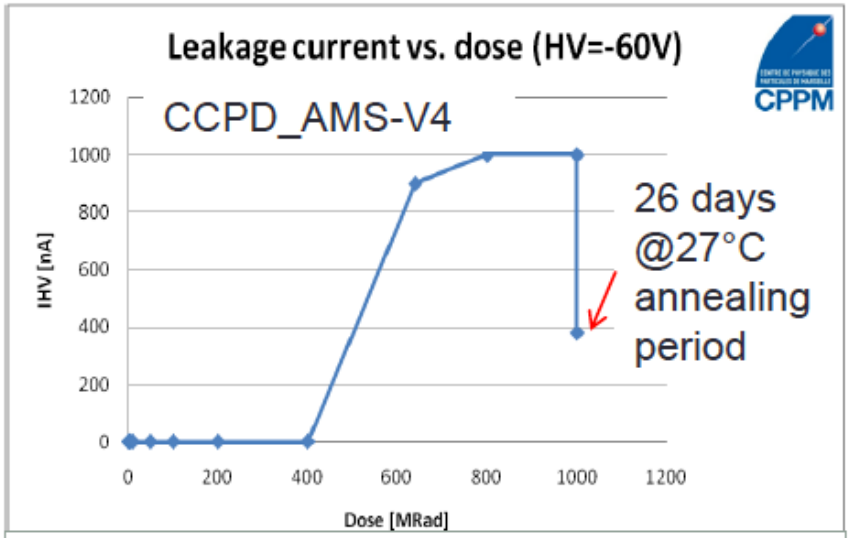
404, 10^{15} n_{eq}/cm^2, Bias 30 V



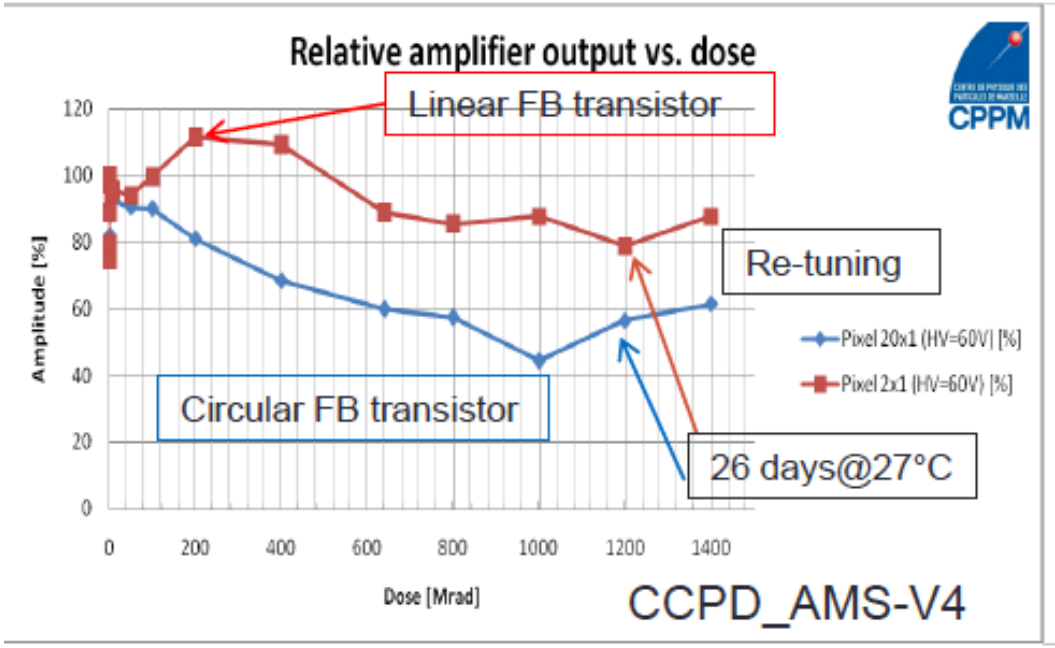
Low threshold show smaller tails, indication of a time-walk effect.
High threshold reduces the diffusion contribution (low Amplitude).

CCPD V4 X-ray irradiation

- Stand alone CCPD V4 irradiated up to 1000 MRads in X-rays
- Increase of leakage current only after 400 MRads
- After 26 days room temperature annealing drop to 380 nA, no need for high temperature annealing as for V2
- Amplifier with linear FB transistor stable (+-15%) up to 1 Grad, but noisy after 100 MRads

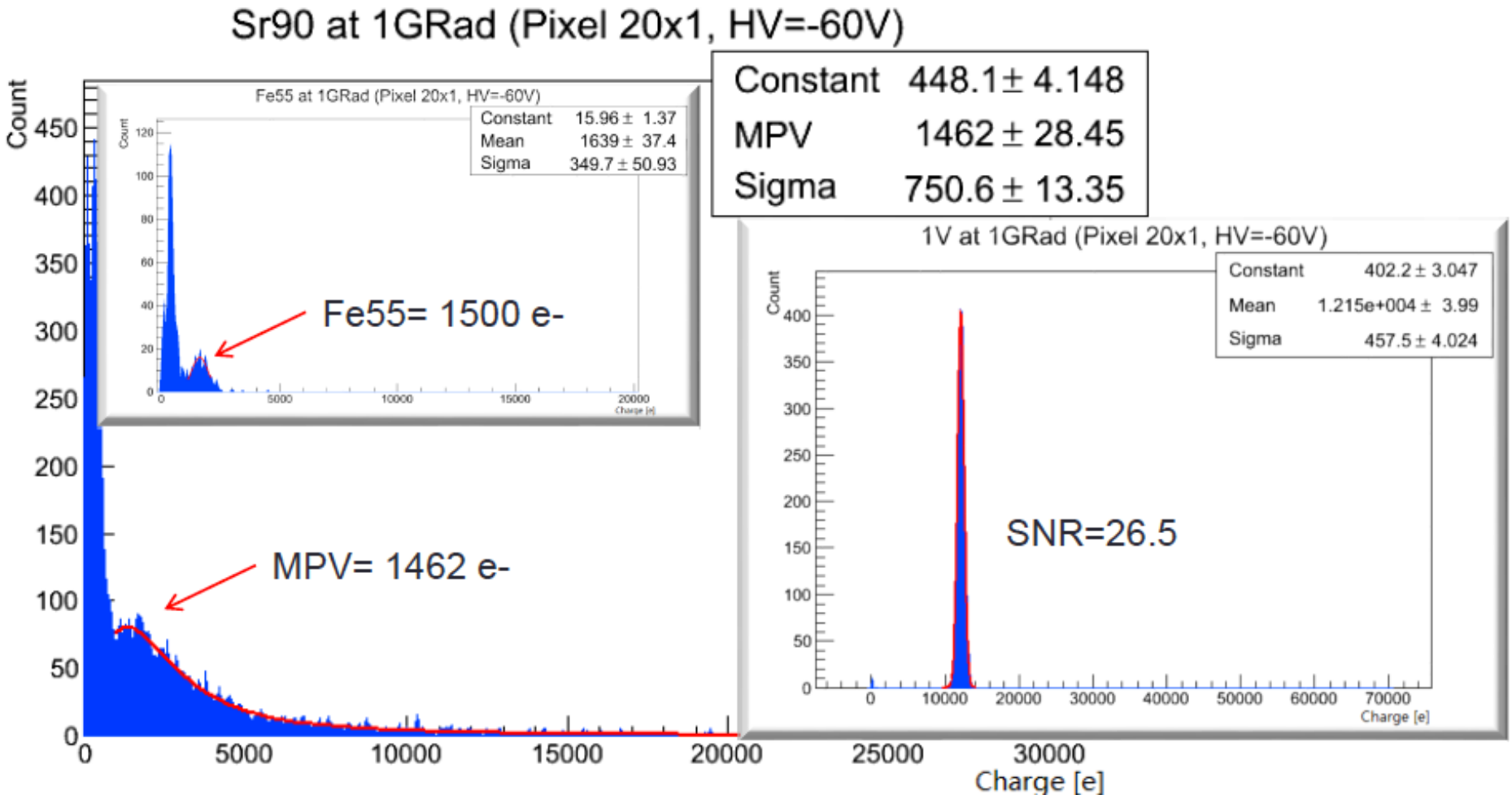


After 26 days @27°C (annealing period), the leakage current reduces from 1000nA to 380nA.



CCPD V4 after 1 Grad in X-rays

- Pixels with circular feedback transistors keep low noise up to 1 Grad, but more variation of gain



Conclusions

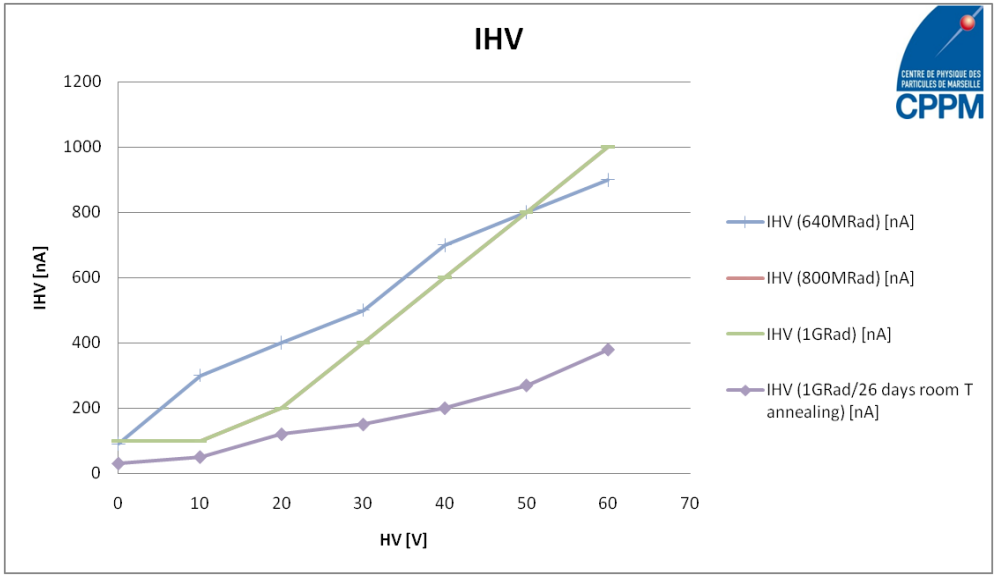
- CMOS pixel prototypes produced in 8 different technologies.
- First CCPD V1 prototype were radiation soft.
- HV2FEiI4_V2 is alive after 862MRads in X-ray irradiation. Need retuning after irradiation.

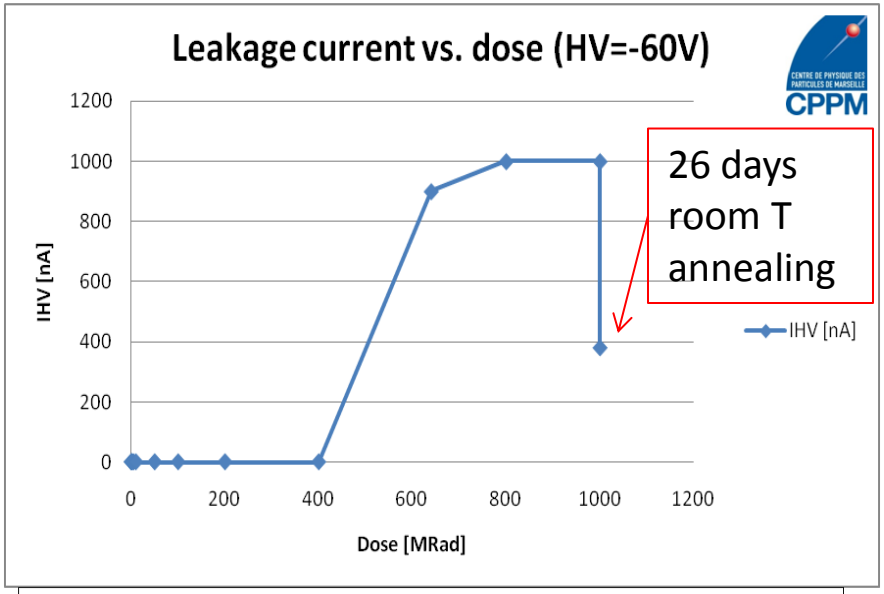
- Most advanced CCPD test beam results in AMS 180 nm technologies results 99.7% efficiency and 5 BC timing spread. Timing to be improved (lower thresholds, higher signals with HR, time slewing corrections)
- With CCPD-V4, reached 1 Grad in X-ray and few Mrads in 24 GeV proton beam. Fe55 signal is observed after 1 grad.

- V4 : Proton irradiation to be continued next week.
- CCPD-LF proton irradiation to be started next week.

Backup

CCPD V4 Leakage current vs. dose





After 26 days room T annealing, the leakage current reduces from 1000nA to 380nA.

At 800MRads,
V2: IHV = 1.53nA/pixel (2h 70deg annealing at each stop)
V4: IHV = 1.54nA/pixel (no 70deg annealing)