INMAPS prototypes characterization & n-irradiated 3T1 analog MAPS test-beam results

S.Bettarini – F.Morsani – A.Paladino – E.Paoloni – G.Rizzo
Universita' di Pisa & INFN

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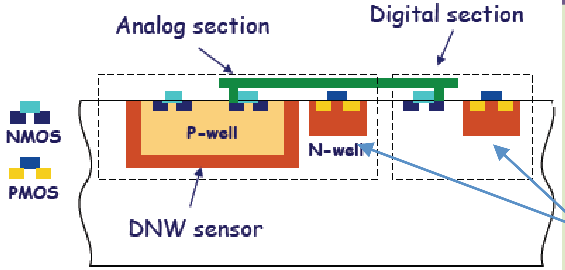
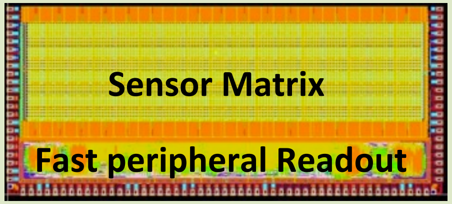
Outline

- INMAPS 32x32 prototype:
  - Digital tests: comparator mis-behavior
  - Analog response to Fe55 and Sr90
- apsel3T1 (n irradiated) analog 3x3 matrices maps. Test-beam results:
  - Efficiency
  - MPV-Landau
- Conclusions

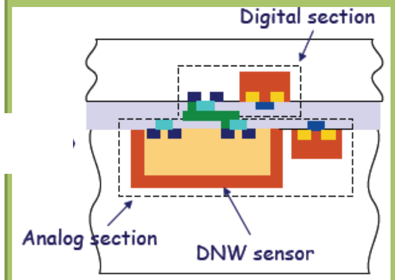
Pixel technologies under study



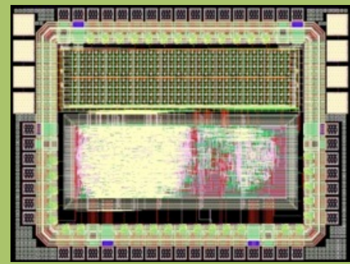
Deep N-well MAPS,
- **In-pixel** front-end electronics (pre, shap, discr).
- **competitive N-well** issue



APSEL4D chip
ST 0.13 um
Beam test **CERN 2008.**
90% efficiency
compatible with deep N-well fill factor

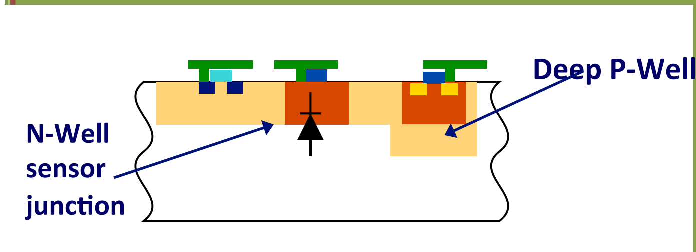


3D MAPS
- **Digital tier: dense pixel digital logic** and peripheral readout
- **In-pixel** analog FE
- **Less competitive N-well issue**

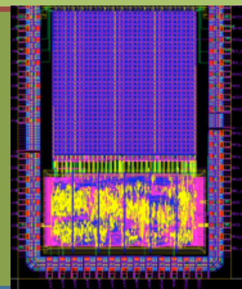


APSEL3D
Tezzaron
Chartered
32x8 matrix

Ongoing tests

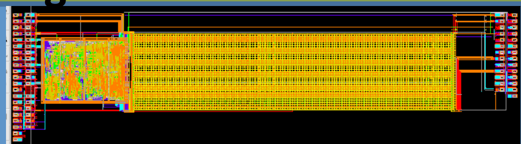


INMAPS technology
- **Deep P-well preventing charge-stealing** by competitive N-wells.
- **High resistivity substrate → more robust against radiation.**

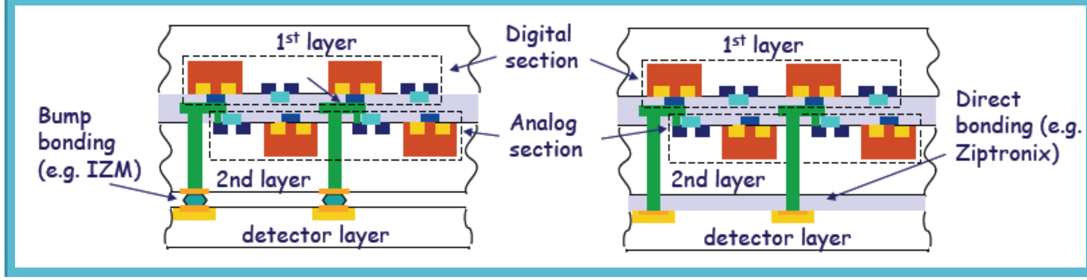


INMAPS 0.18 um
32x32 matrix
submitted July 2011

Hybrid Pixels 50x50 um pitch
- High resistivity, **fully depleted sensor**
- **Fast readout** (analog FE and digital logic at pixel level)



SuperPix0 chip
- **Beam Test** Sept. 2011.
- **Preliminary results presented**



FUTURE… 3D front-end chip
- Dedicated **digital tier**
- **analog tier:** FE electronics.
- **Fully depleted detector** Bump Bonded / Directly Bonded

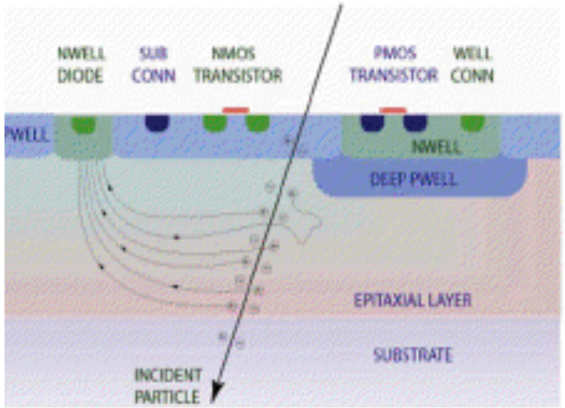
Why INMAPS

Standard MAPS: poor radiation hardness (important displacement damage observed) could be a showstopper.

Deep N-well MAPS: charge collection is affected by the parasitic N-wells. It can be avoided with a buried P-type layer (deep P-well)

Further improvement on charge collection by means of high resistivity epitaxial layer (~1 kOhm cm). Our Hi-Ω chips are expected to be delivered in mid june.

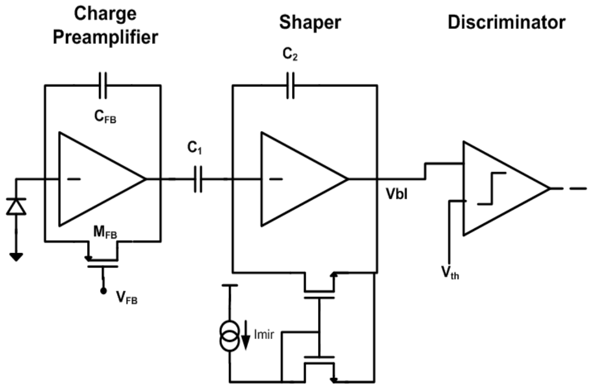
A high-resistivity, fully depleted sensing layer with analog CMOS front-end is the solution we are pursuing.



CMOS sensor in the 180nm INMAPS process with high-Ω epilayer

INMAPS developments for the Layer0

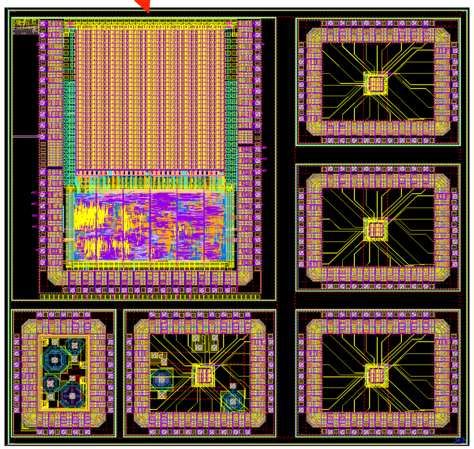
- Small N-well collecting diodes with small input capacitance and low power consumption.
- The forth-well prevents charge stealing by the parasitic N-wells (→ efficiency benefit).
- Implemented the digital architecture as in the latest APSEL chips, to cope with the high bkg rates.



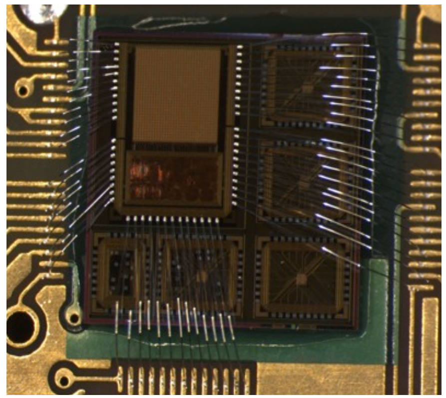
Apsel4well - Post Layout Simulation	
Charge sensitivity	930 mV/fC
t_p @ 800 injected electrons	240 ns
ENC (C_D = 30 fF)	26 e-
Threshold dispersion	23 e-
NLI (@ 2000e-)	1%
Analog Power consumption	18 µW/pixel
Pixel pitch	50 µm

32x32 matrix with sparsified digital readout architecture

3x3 analog matrices with different diodes configurations



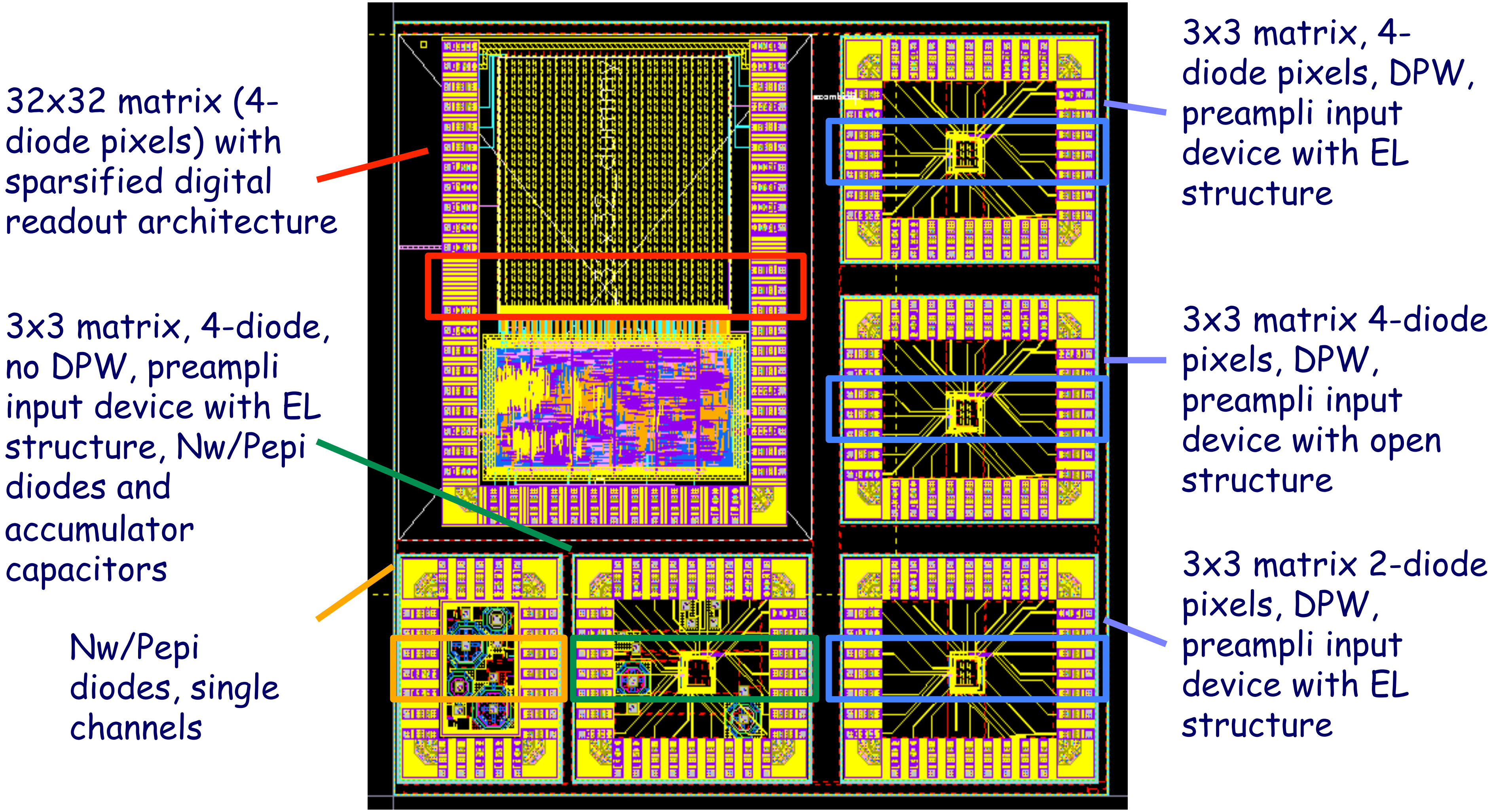
INMAPS Chip (5x5 mm^2)



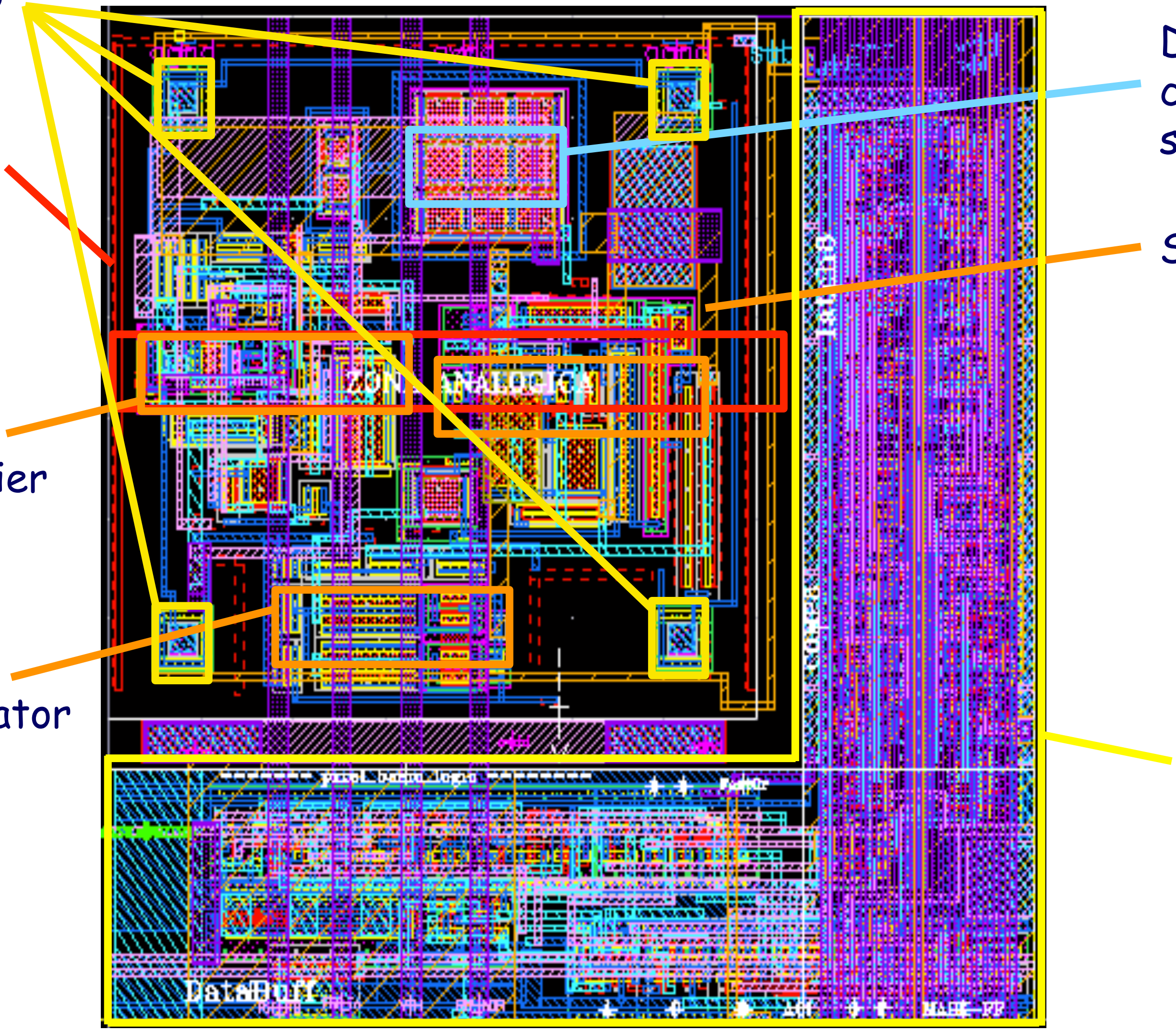
Bonded chips under test

The INMAPS CHIP

In 3x3 matrices all the analog outputs are available and an injection capacitor is connected to the central pixel



INMAPS CELL


Collecting diodes
Analog section
Charge preamplifier
Discriminator
Differentiating capacitor (at the shaper input)
Shaper
Digital section
ZONA ANALOGICA
DataBuff

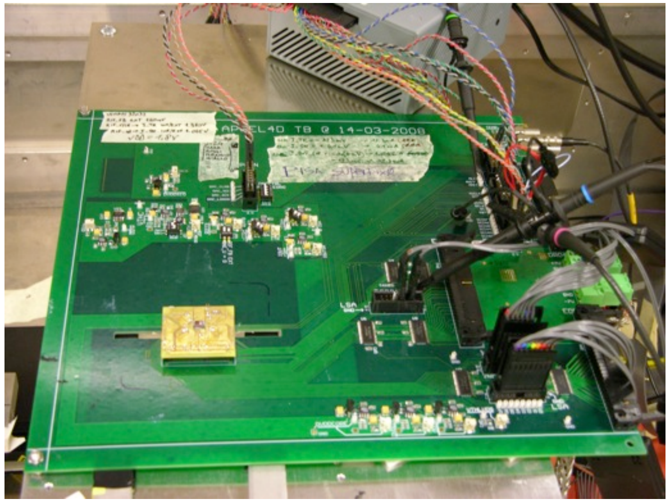
Noise scan calibration

Set-up for INMAPS 32x32:

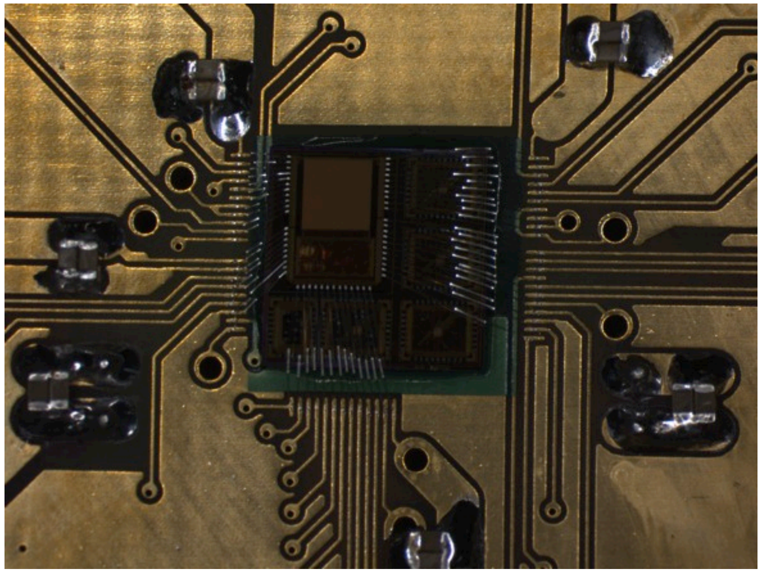
- Modified sequences (directives and operands) for chip initialization according to “user-guide”
- Implemented the noise-scan

- found the (expected) limit on the buffer preventing data output from the 2nd submatrix (problem only during calibration, well dimensioned for data rate > 100 Mhz/cm^2)

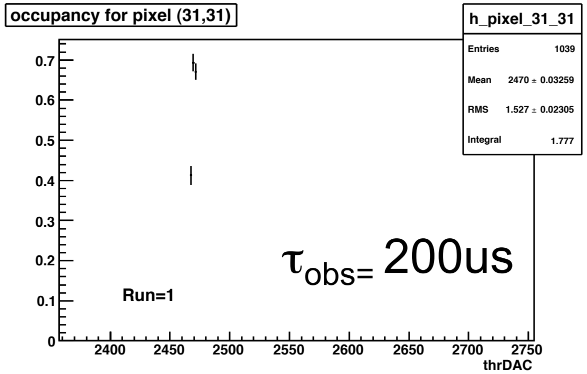
- Calibrations: ¼ chip at a time
- Noise (on the scope): 2.4 mV
- τ_{obs}= 200us → 1ms in different scan configurations

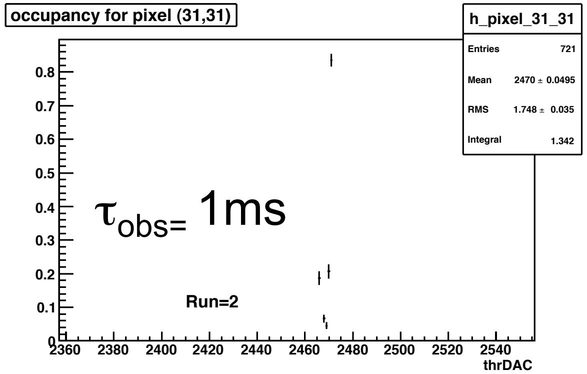


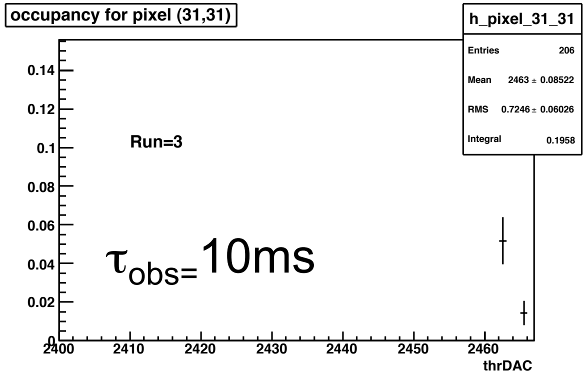
INMAPS chip on carrier mounted on the modified apsel4D board with TLA and scope probes

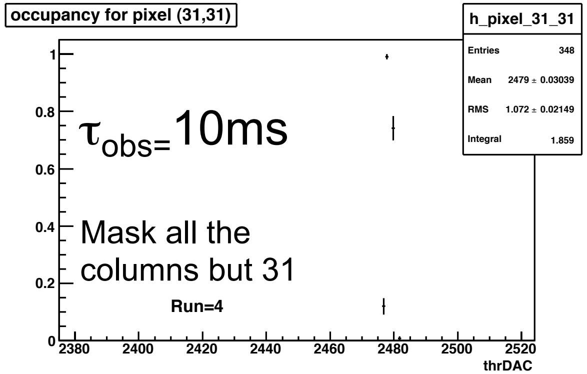


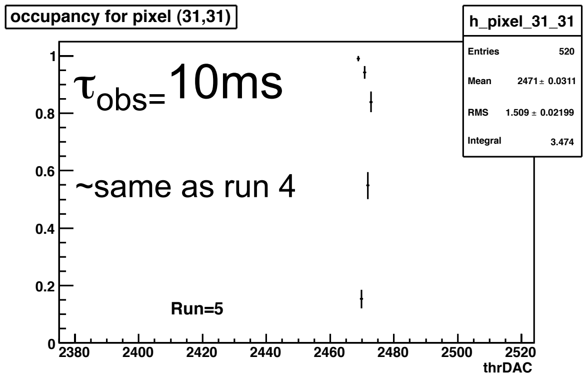
Noise scan calibrations: pixel (31,31)

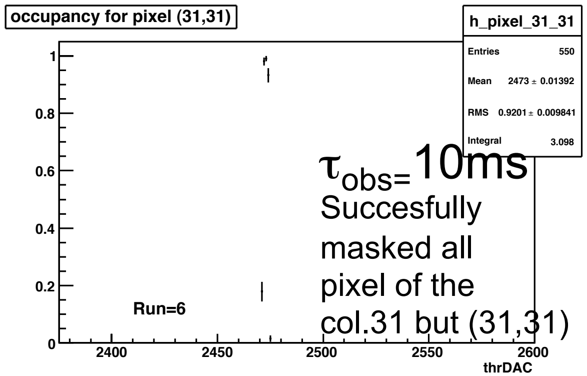












We expected that the S-curves rise/fall in some σ_{noise} (σ_{noise} =2.4 mV /0.3 ~ 7 DAC).

Instead this sharp edge is a hint of something that is causing the pixels suddenly fire, un-correlated with noise. No-change by varing τ_{obs} .

At the beginning WE SUSPECTED: Effects due to INDUCTION ?

Instead …

Tests performed and open issues

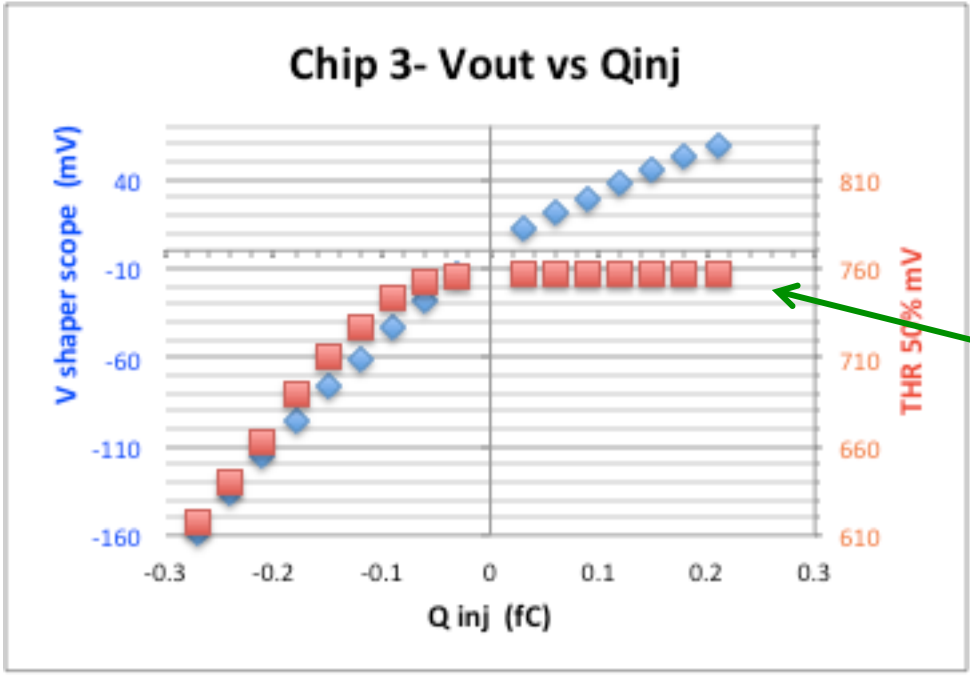
- Noise and gain from analog output measured on several chips:
- On pixel 31,31 in the 32x32 matrix
  - Gain 600-650 mV/fC , Noise ~ 2.5-4 mV → ENC ~ 30 e-
- On pixels from 3x3 analog matrix
  - Gain 800-850 mV/fC (higher than in 32x32) , ENC ~ 30 e-
- Gain with Cinj consistent with Fe55 end point measurements

- In the 32x32 matrix noise from the digital output (noise scans) not consistent with the noise measured on the scope:
  - Fitted values around 1 DAC=0.3 mV too small!
  - Noise scans left-right asimmetric

- Response of the discriminator, studied with injection scans, showed a very strange behavior that has been investigated with simulations.

Injection test on pixel 31,31 (chip3)

- Pixel 31,31 injected with a variable pulse Qinj=- 0.3-0.3 fC (on Cinj=30 fF) and pulse height measured with:
  1. Analog output: V shaper output → oscilloscope
  2. Digital output: threshold injection scan → THR @ 50% Occu



1. Analog output: Good linearity for negative signal (right sign), response to positive pulse less linear (expected)
2. Digital output:
   - For signals smaller than ~ 40mV (scope) the discriminator response doesn't follow the signal and saturate at the "baseline" measured from the noise scans
   - NO positive signals seen (above baseline)

- Different slope in linear region due to buffer gain ~0.9

1MIP~1000e-=0.16 fC

40 mV ~ ½ MIP

•Baseline from noise scan ~ 755 mV very different from the expected one from intercept (~ 820 mV!)

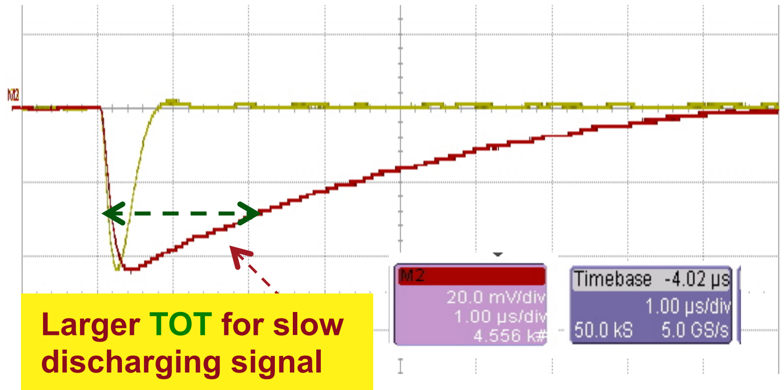
•PROBLEM: how do we estimate the real baseline and threshold dispersion from noise scans?

Issues in the first INMAPS chip design

- Noise and injection scans look strange for small signal.
  - For small signal injected (and seen with the analog output) no hit registered by the discriminator

- This problem is ascribed to a "slow" turn on of the discriminator that prevent signals to be seen if the Time over Threshold (TOT) is too small.

- Fix implemented: increase the discharge time of the analog signal to increase the TOT and allow the "slow" discriminator to fire
  - Not optimal for fast operation!



- In progress (see following talk): investigation on the design to understand the origin of the problem (reproduced by circuit simulations accounting for possible process parameter dispersion) and to implement a more robust design of the discriminator for the next chip.

Revisiting Superpix0: the same effect

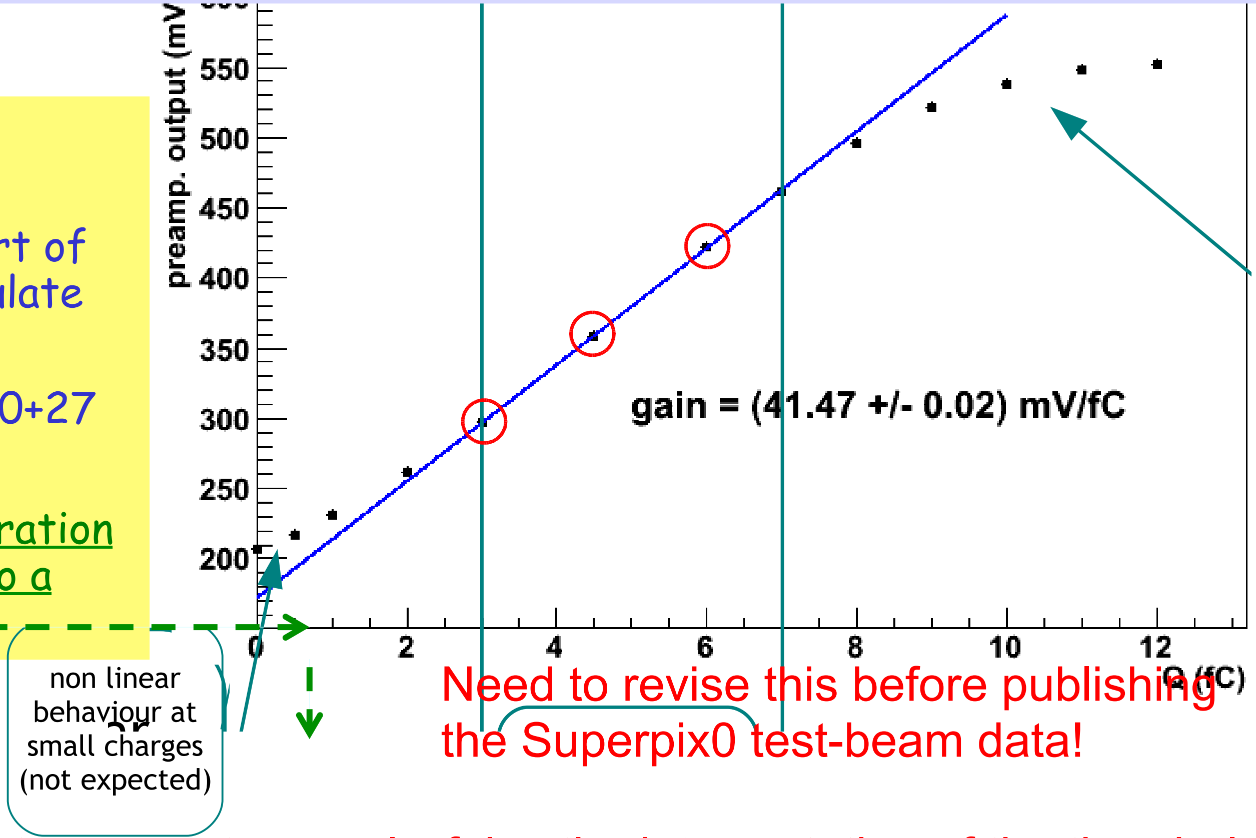
- In Superpix0 the same effect was seen and, the problem started for signal pulse of ~ 40 mV as in INMAPS (Superpix 1MIP=2.6 fC, 200 um Si)
- Since no comparison with analog output was available, we thought that this very low apparent gain was due to the amplifier response

•Mesaured baseline from plot=210 mV

•Using gain from linear part of the plot and baseline calculate THR for ¼ MIP

→ = baseline + 0.65 fC=210+27 mV → 237 mV THR

→ Using instead the calibration plot this corresponds to a THR ~ 1 fC



Need to revise this before publishing the Superpix0 test-beam data!

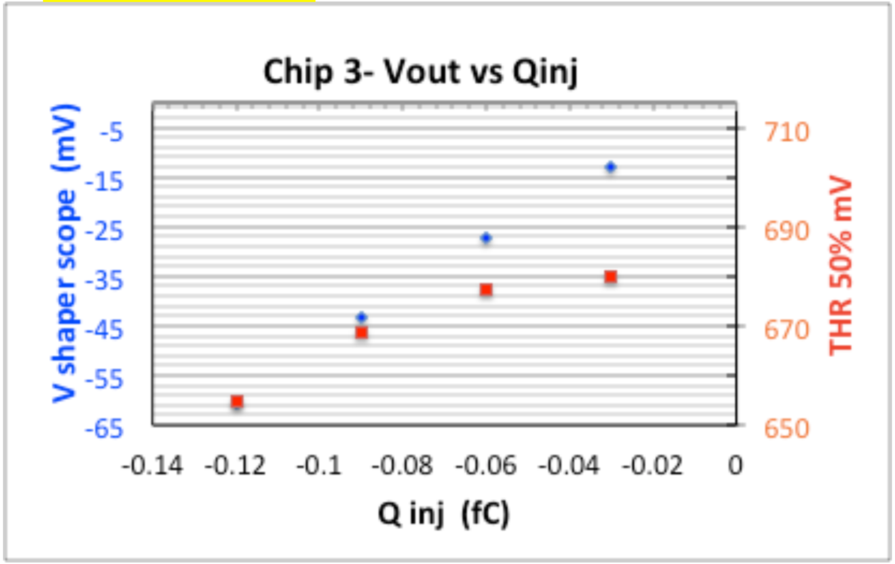
This effect, if not taken into account properly, false the interpretation of the threshold setting on the chip in terms of charge-electrons!

The chip can be operated in order to minimize the discriminator problem

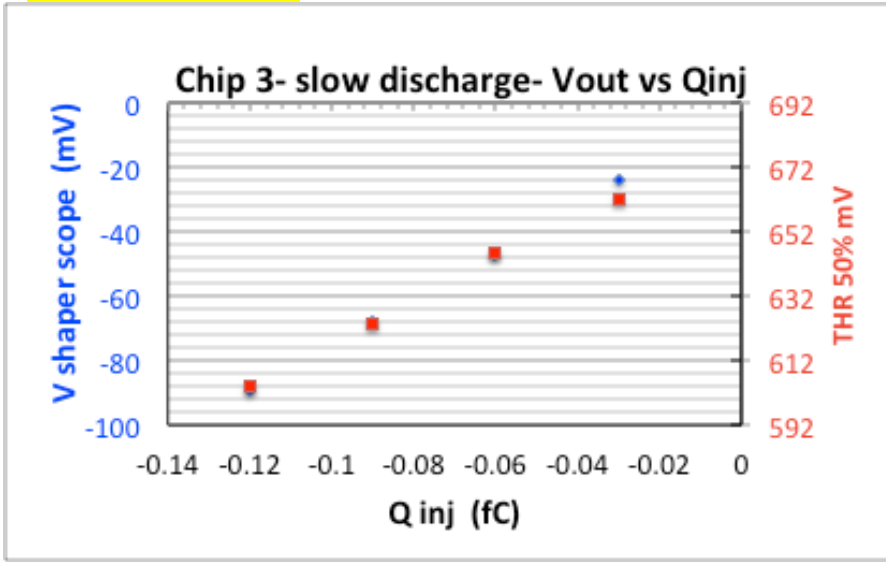
With the slow discharge settings:

- Injection scans now looks better: better agreement of gain measured with analog output and with 50% turn on THR
- For THR close to signal peak TOT is still too small for the slow discriminator to be seen → noise from threshold scan still under-estimated. Simulation is able to quantify this effect.

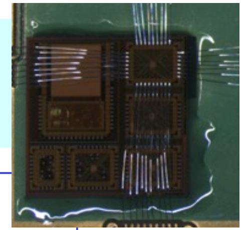
Before the fix

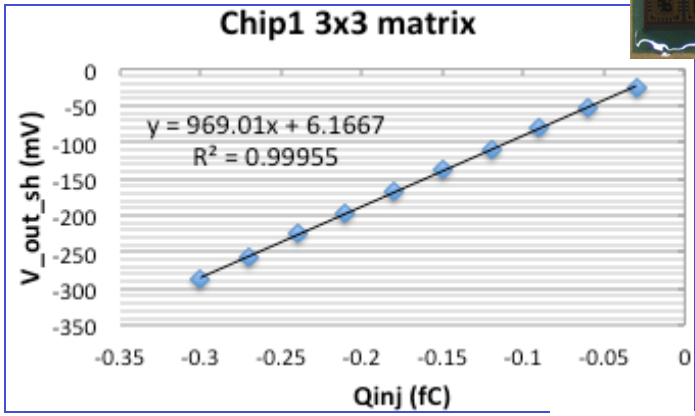


After the fix



INMAPS RESULTS: 3x3 analog matrix

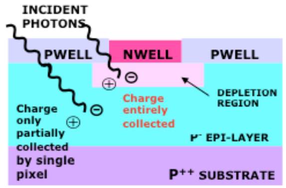




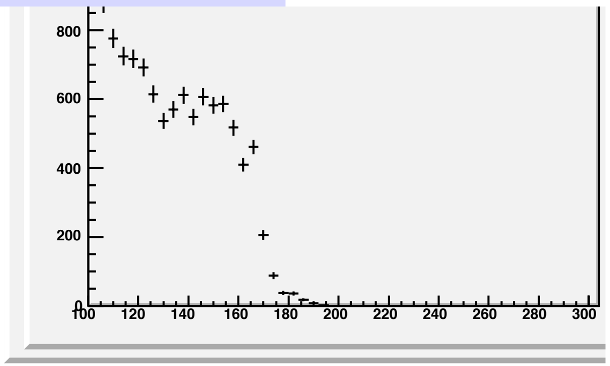
Noise and gain measured in 3x3 analog matrix in good agreement with PLS:

- ENC = 30 e- (~20% dispersion)
- Gain=920 mV/fC (~10% dispersion)

- Response to radioactive source
  - ^{55}Fe γ: 5.9keV foto peak hardly visible due to very small diode area.
    - Charge totally collected for γ interaction in the depleted volume below the diode. Partial collection elsewhere. End point (5.9 keV + 3 σ noise) used for gain evaluation (agreement within 10% with Cinj)
  - ^{90}Sr e- signal cluster: MPV ~ 350 e-, compatible with 5 um epi layer of first chips → chips with 12 um epi layer (standard & high resistivity) available in June.

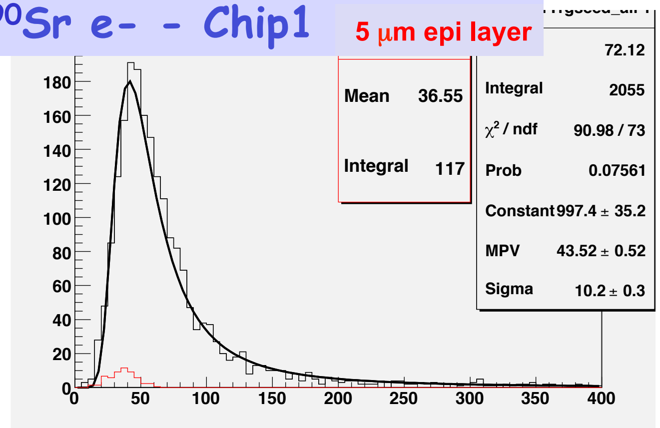


^{55}Fe γ - Chip1



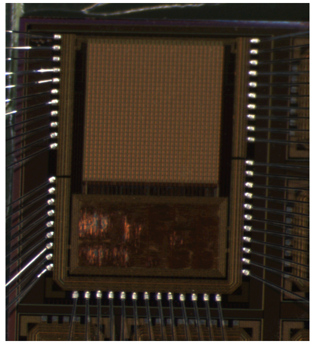
Pixel signal (mV)

^{90}Sr e- - Chip1



Cluster signal (mV)

INMAPS 32x32 digital matrix

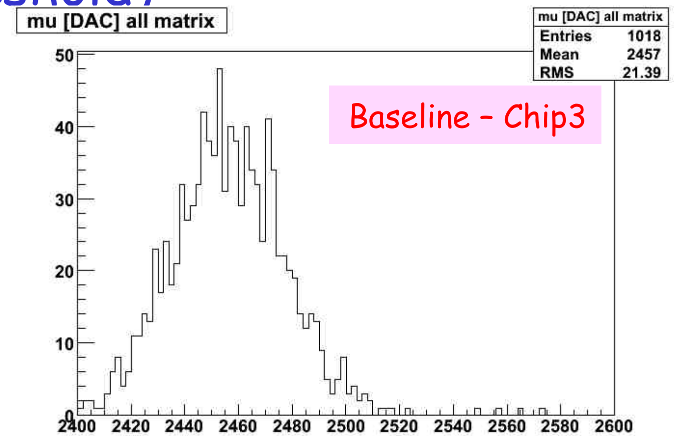


Noise and gain measured in pixels with Cinj and analog output

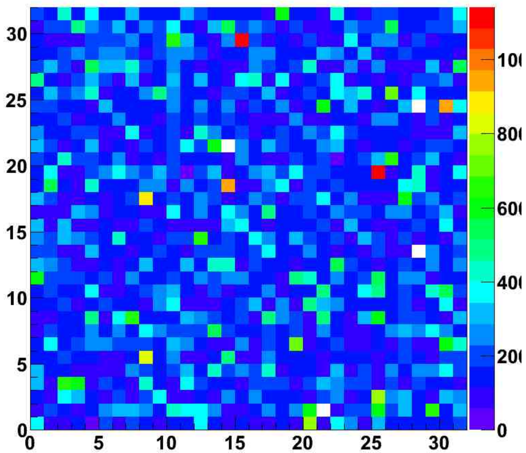
- ENC = 30 e-   gain=680 mV/fC

- Threshold and noise dispersion inside matrix measured with noise scans (occupancy vs discriminator threshold)
  - Threshold dispersion = 7mV (~ 2 x σ_noise)
  - Noise (+gain) dispersion ~ 35-40%
  - Further tests to evaluate gain dispersion with Fe55 end point ongoing.

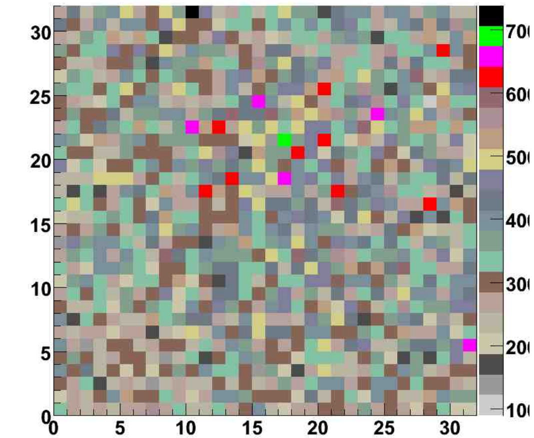
- Few dead pixels: ~ 0.3% (on 3 chips 32x32)



Noise hits – Chip3



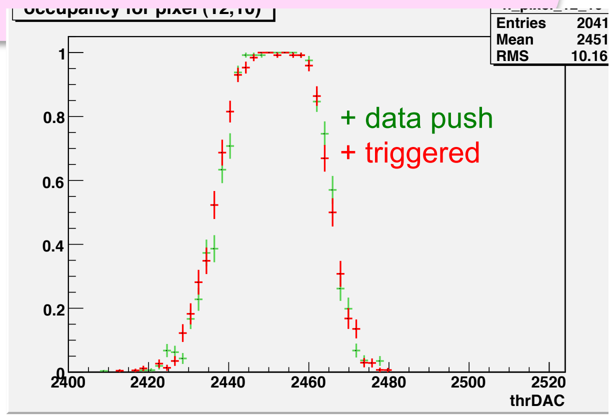
Sr90 hits – Chip1



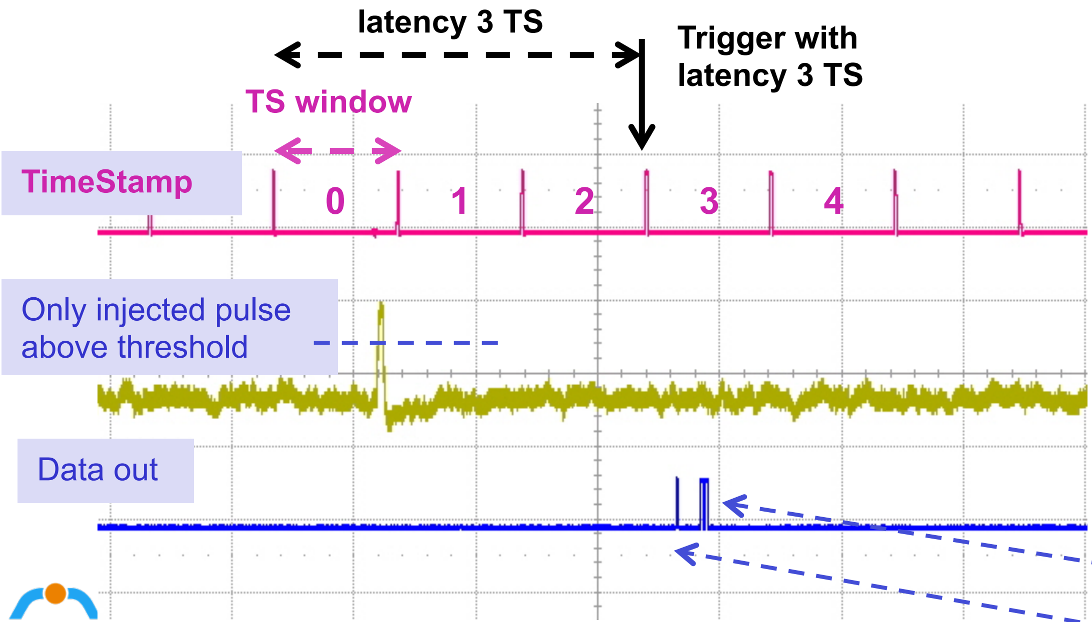
Test of the new readout architecture

- Standard functionality of new readout architecture verified in the two operation modes available on chip: data push (all TS readout) and triggered (only selected TS readout).

1. Threshold scans similar in both operation modes

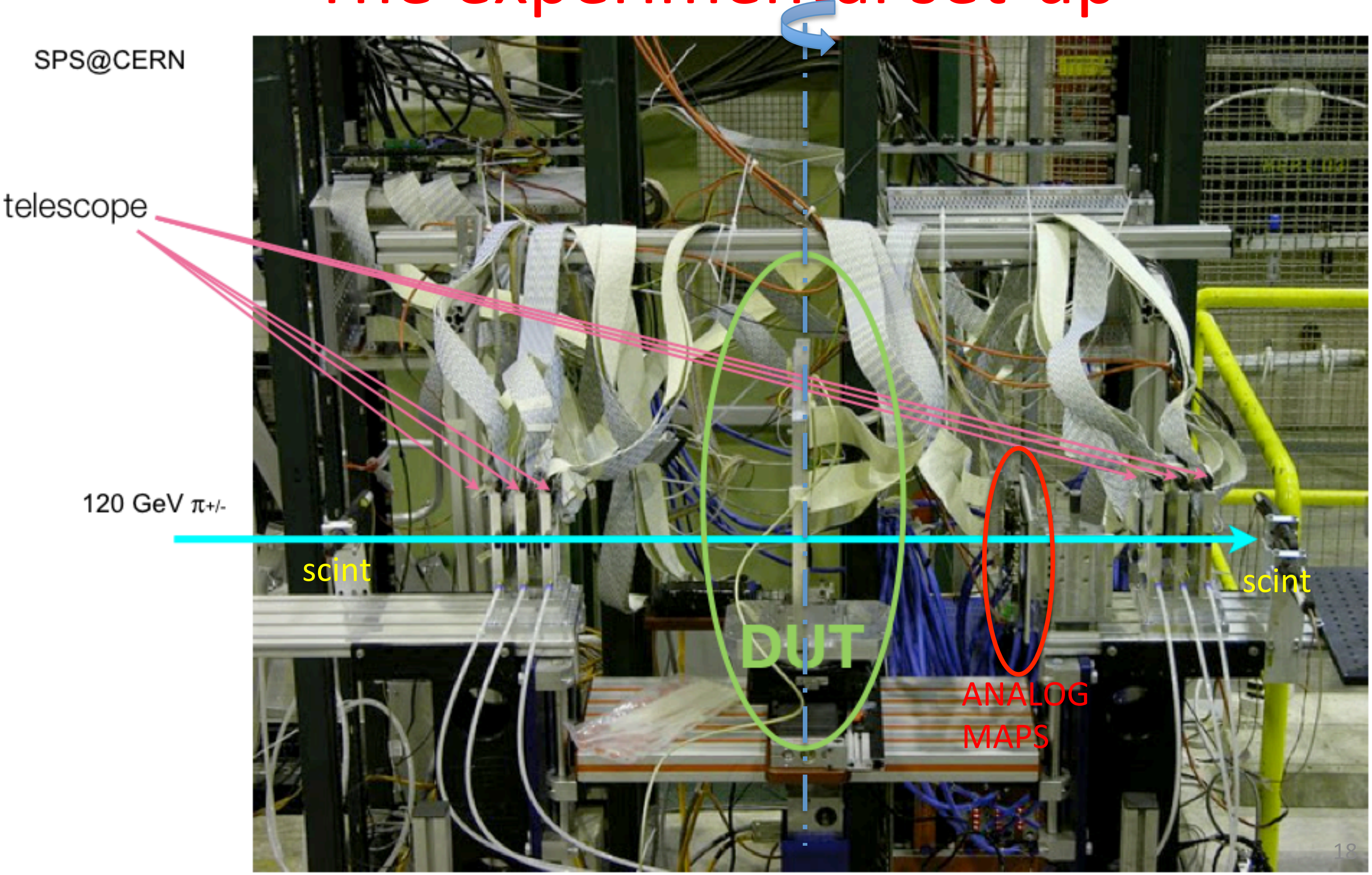


2. Triggered mode also verified with specific test retrieving data injected at selected TS.



1. Pulse injection @ TS = 0
   - → high threshold
   - → no noise hits above threshold
2. Trigger arrives @ TS =2 with trigger latency setting = 3 TS
   - → triggered event TS = 0
3. Data out stream info:
   - TS =0:1 fired pixel in submatrix1
   - TS =0: 0 pixels in submatrix0

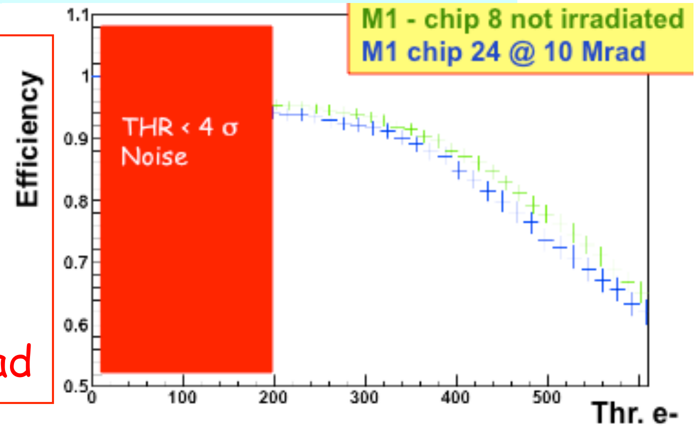
Test-beam 2011
The experimental set-up



Apsel3T1 MAPS Radiation hardness

Irradiations with γ from ^{60}Co up to 10 Mrad

- beam test results for MAPS (3x3 matrix) with analog output (pre/post irrad)
  - Qcluster ~1040 e- for M1 (930 e- for M2)
  - S/N~15-20 depending on the electrode geometry
- modest reduction in collected charge and efficiency
  ENC increased by ~35% in chip irradiated up to 10 Mrad



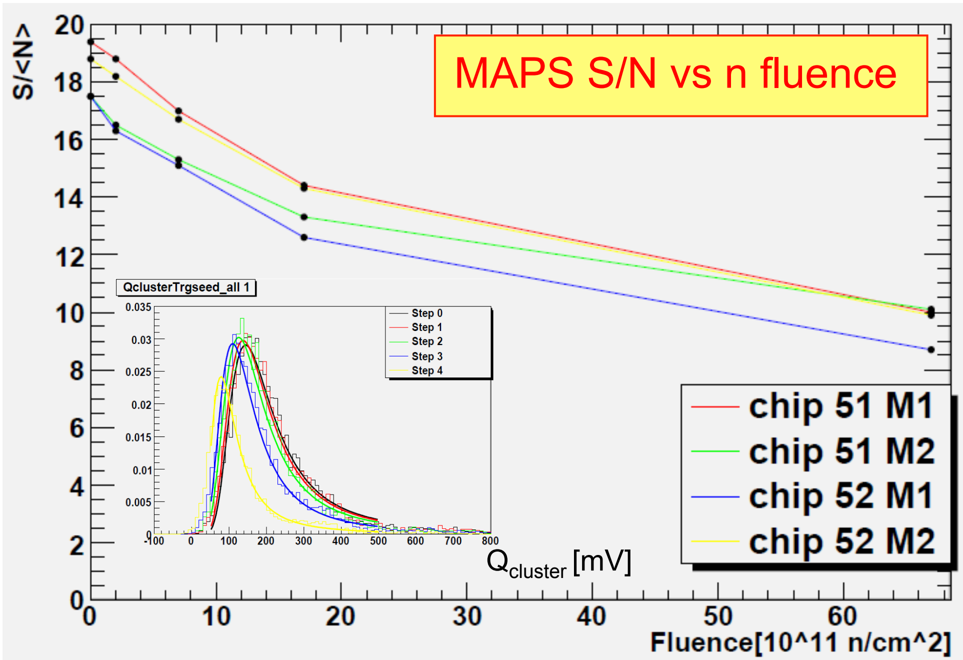
Irradiation with neutron up to ~ $7\times10^{12} n/cm^2$

- Expected fluence in Layer0 ~ $5\times10^{12} n/cm^2/yr$ (no safety included)

Lab. Results (with a β source):

- Noise and gain not affected by neutron
- Signal degradation studied with β Sr^{90} source at each step:
- S/N → 10 in last step → limitation for application in Layer0
- Expect higher resistance with MAPS on high resistivity epitaxial layer

Chip 52 put on beam

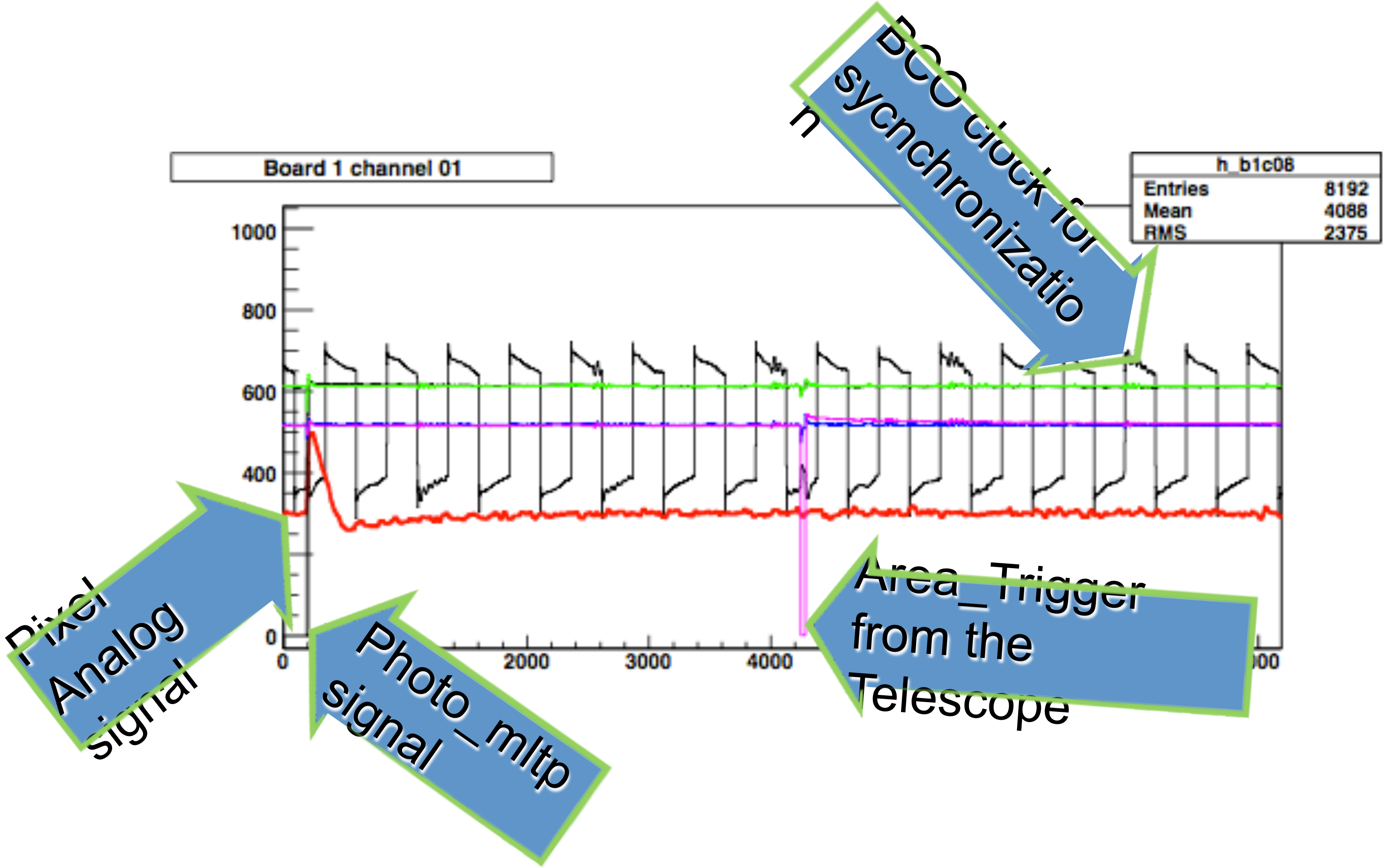


3T1 Analog MAPS on beam

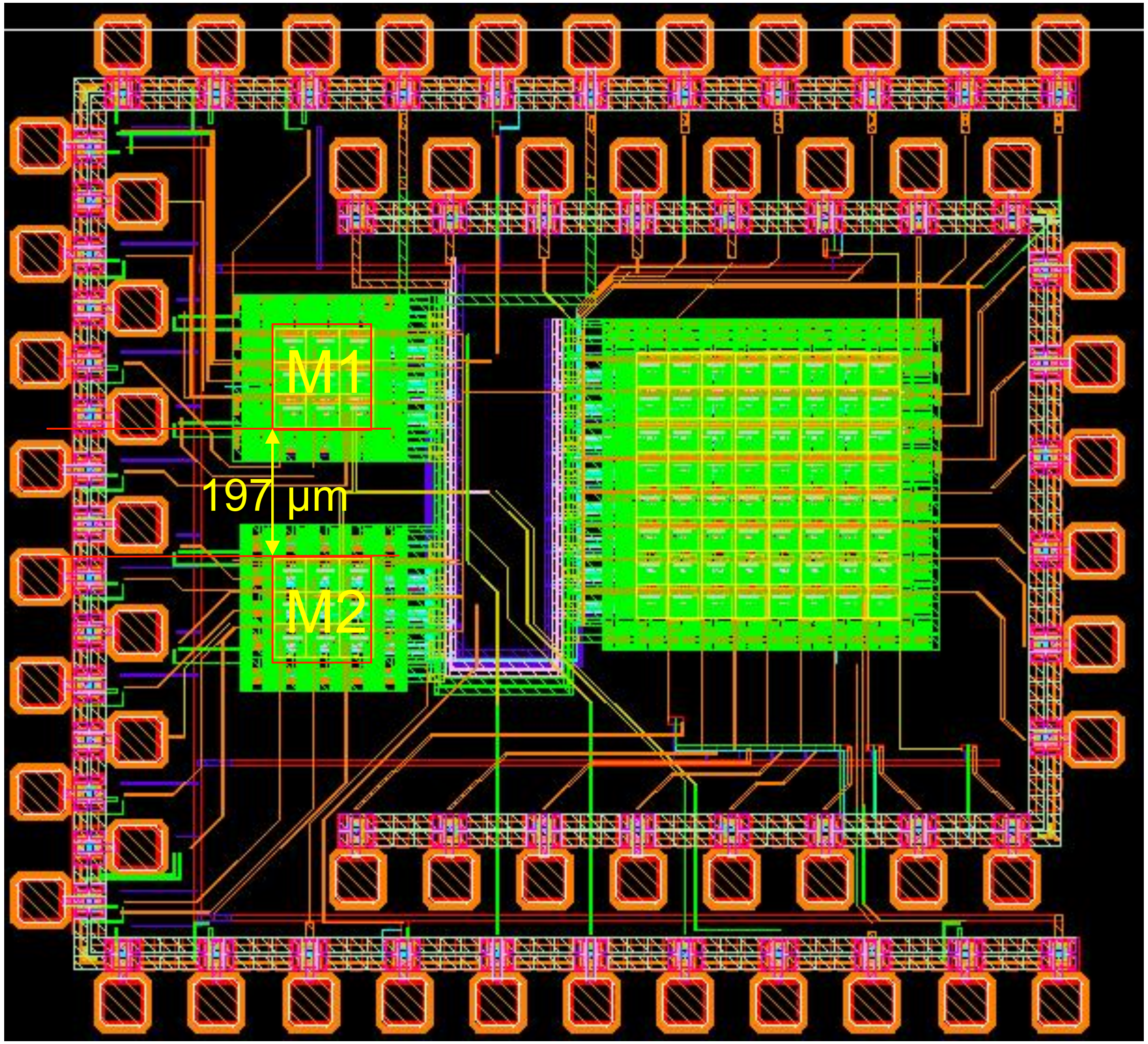
- Alignment: the runs must be reconstructed with the correct align. constant, otherwise a fake inefficiency may arise
- By cutting on the PH of pixels → defined the center of the matrix area with tracks extrapolated at the MAPS plane.

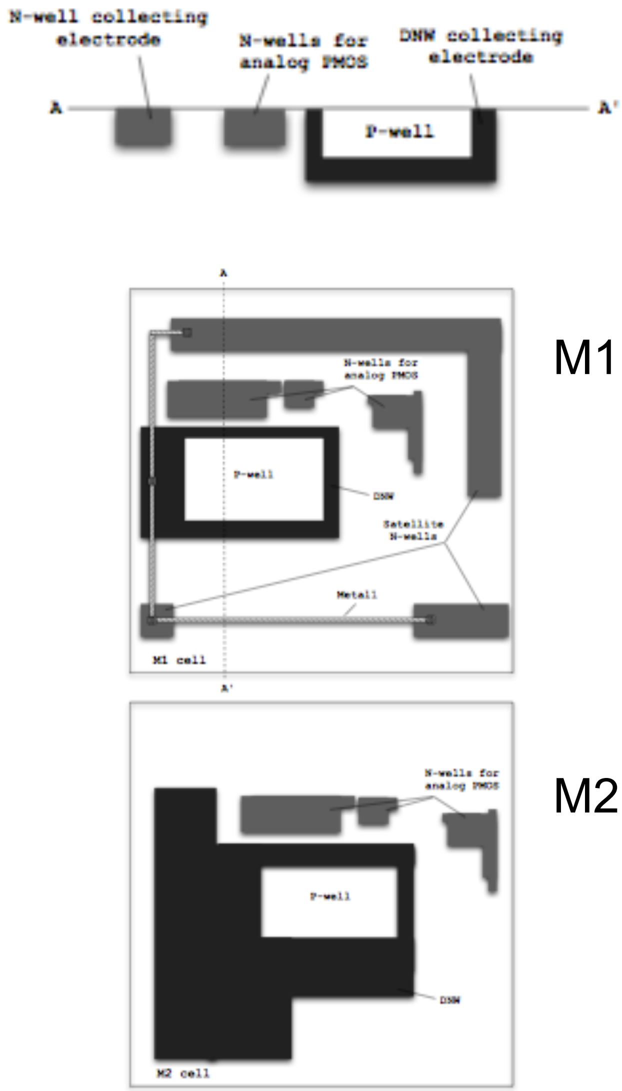
  Then we select a window of +- 1pitch around the center.
- Analized the 2 matrices (apsel3T1) neutron-irradiated/not-irr
- Peaking time 400 ns (ph independent)→ Cluster charge obtained summing up the PH of the 9 matrix pixels @ τ_{peak}
- Important info to extract:
  - Efficiency (parasitic n-well at work)
  - Landau MPV on MIP → effect of bulk damage by radiation on the collected charge

MEG - EDRO syncronization

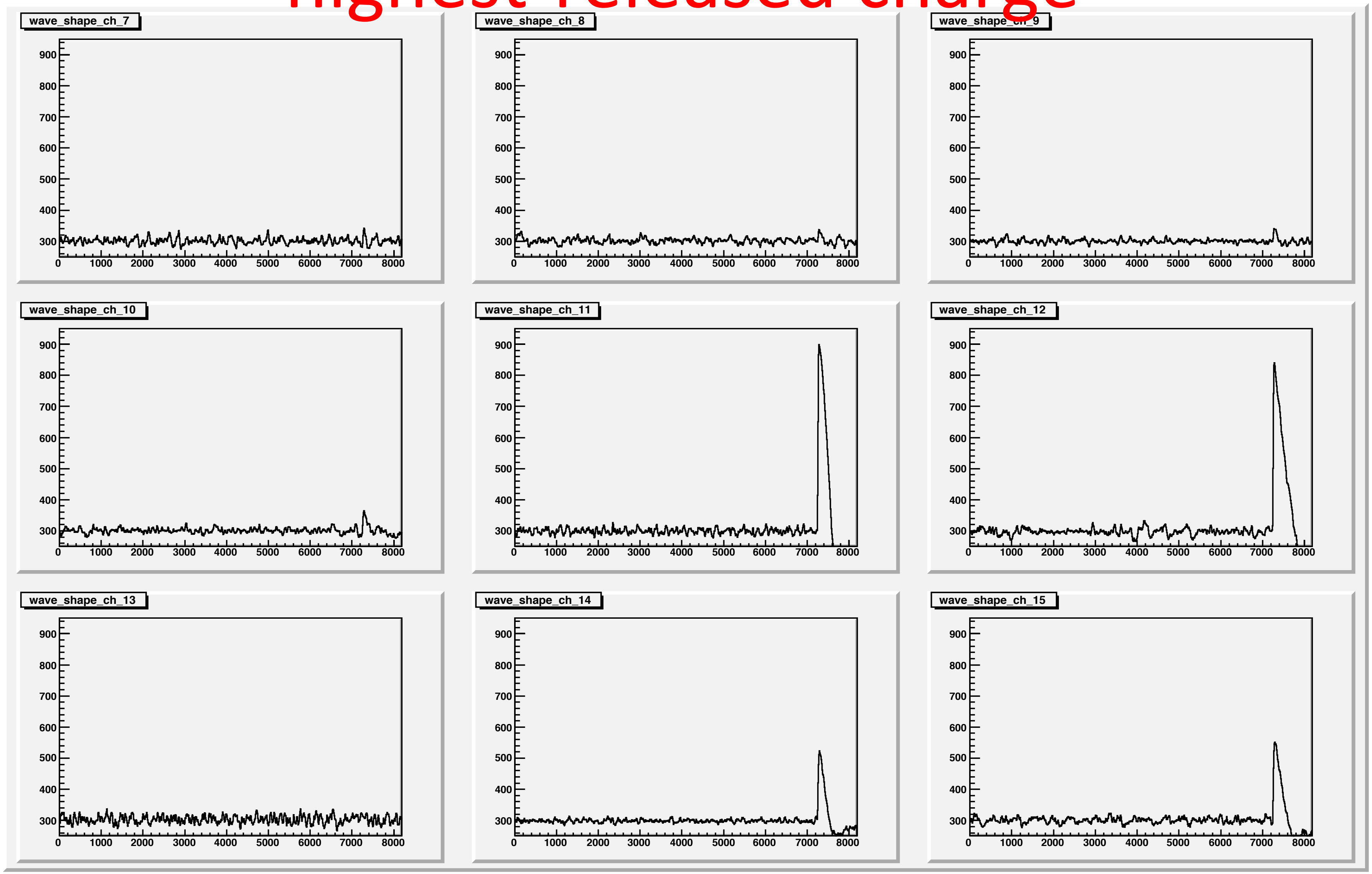


Chip Layout & M1/2 electrode geometry

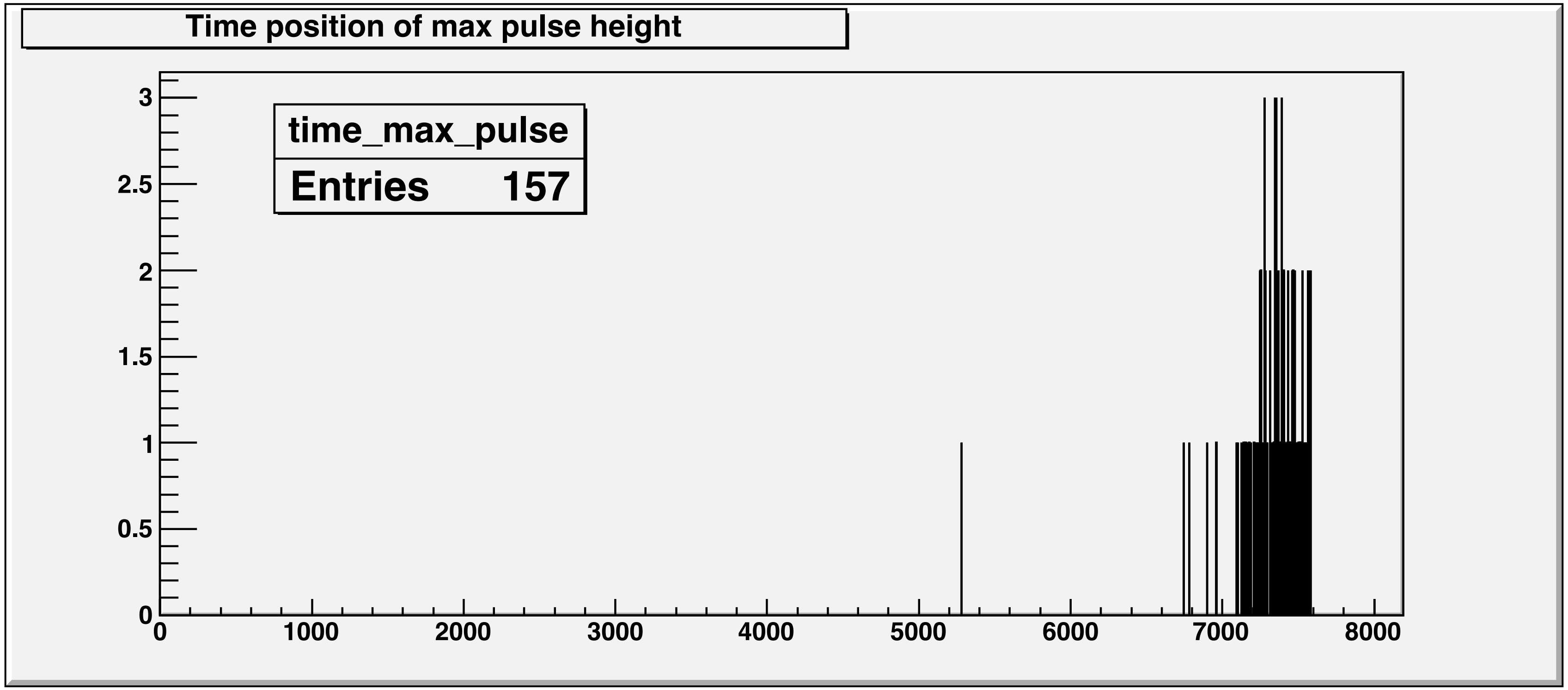




Waveforms of the event with the highest-released charge



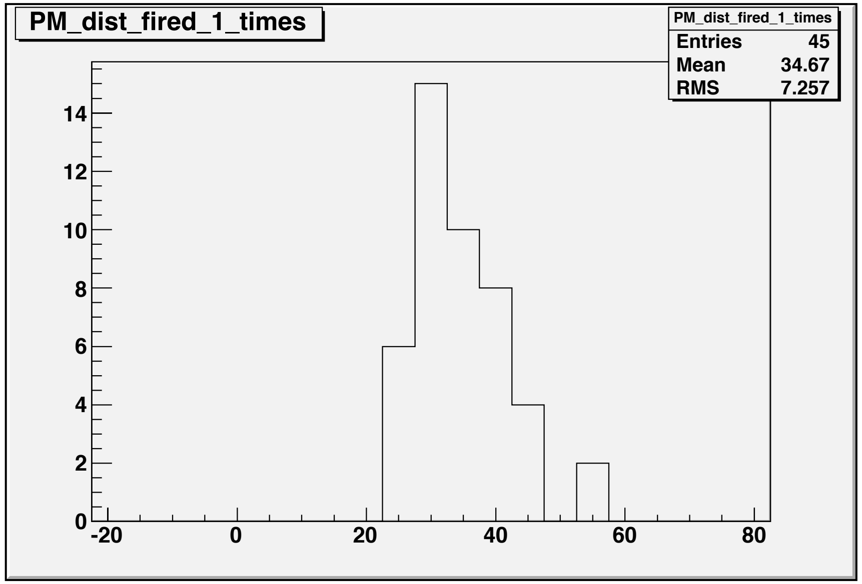
Checks (I)



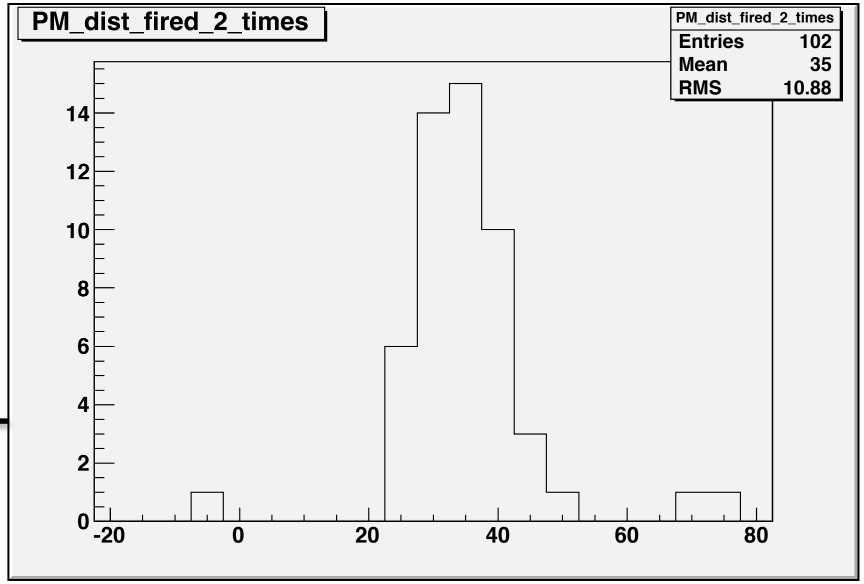
Working on events with large signal, maximum pulse height is found between sample 6500 and sample 7600. A window between 6000 and 8000 is chosen to found the maximum.

Checks (II)

Apsel3T1 shaping time is 400ns, the time interval between the maximum pulse height and the signal from photomultiplier is ~350 ns.



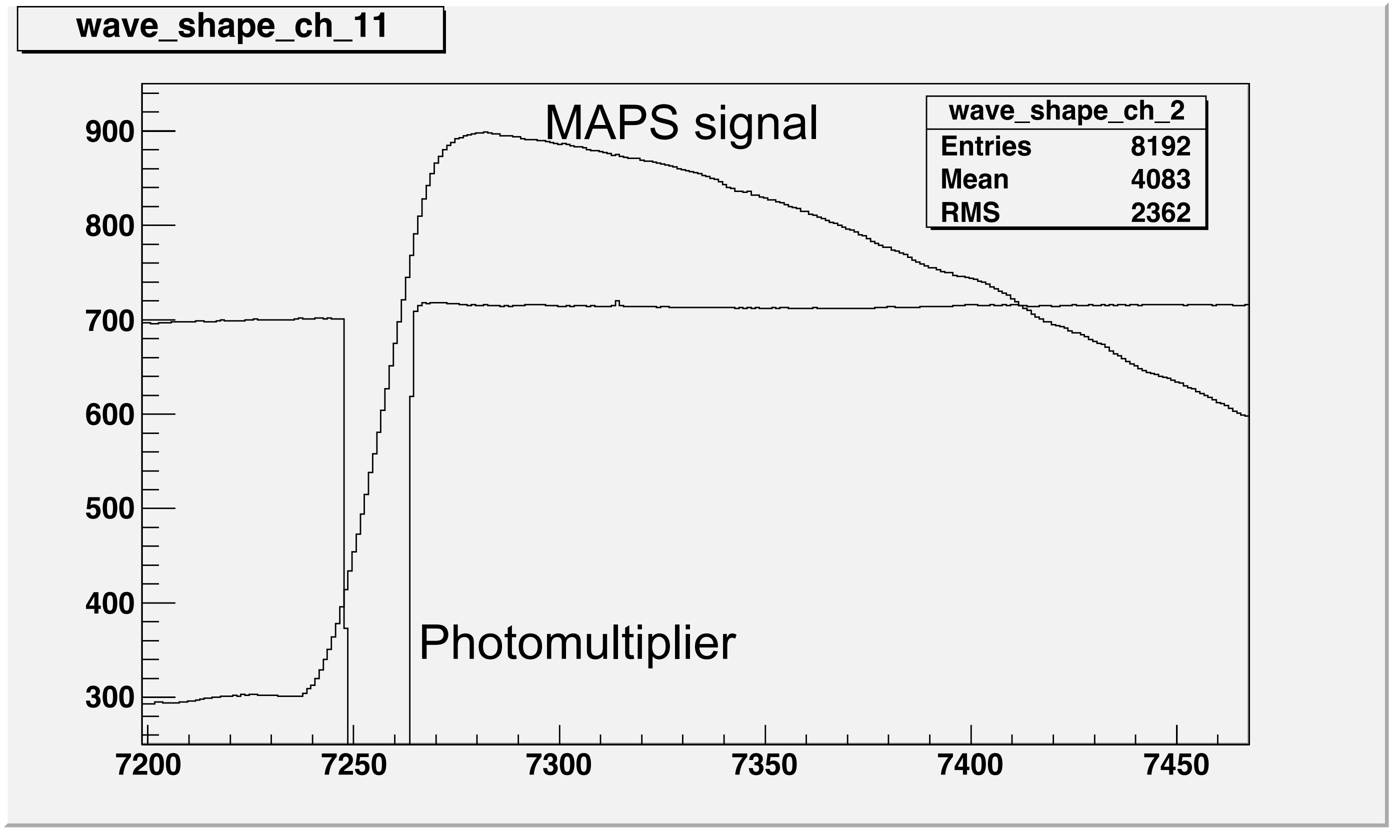
When the photomultiplier fires more than once, one shot is in the right window, the others are spread randomly outside that.



Checks (III)

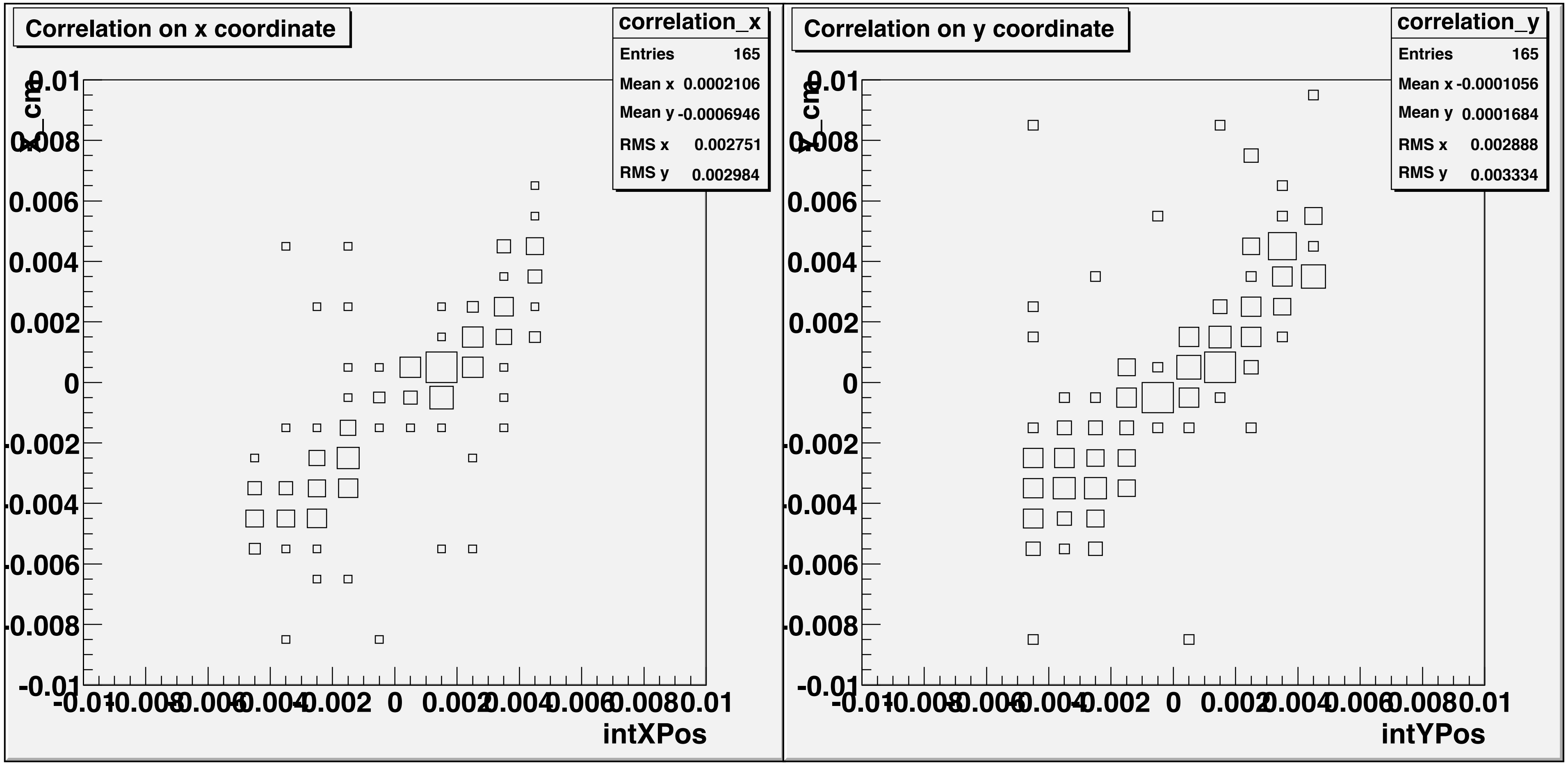
PM time offset.

The PH maximum is 350 ns after the photomultiplier fires.

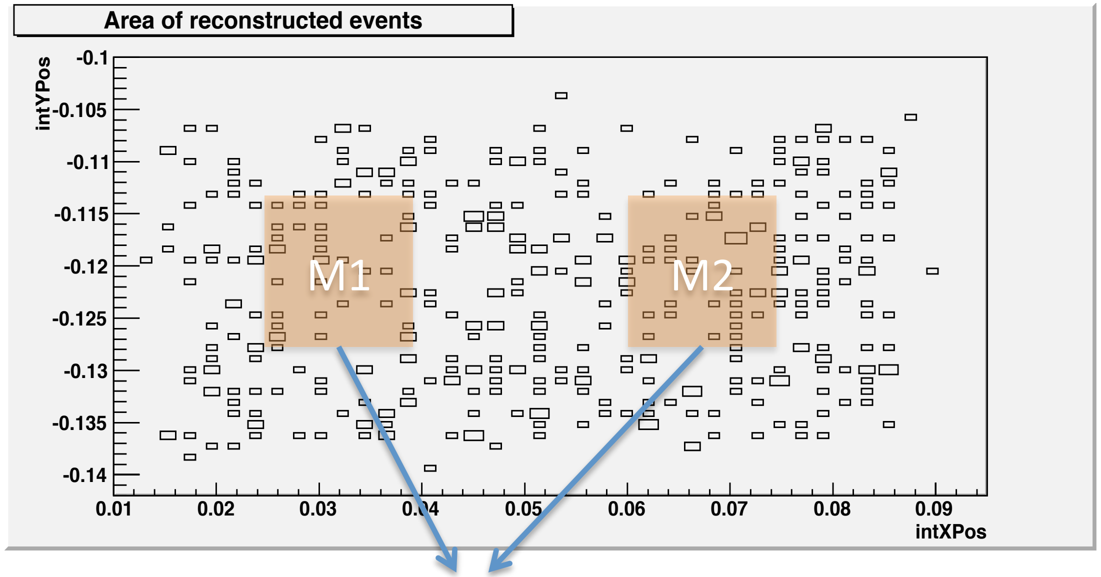


Checks (IV)

The correlation between the center of mass in the local matrix coordinate and the intercepts of the track fitted with the telescope hits (wrt the center of the matrix).

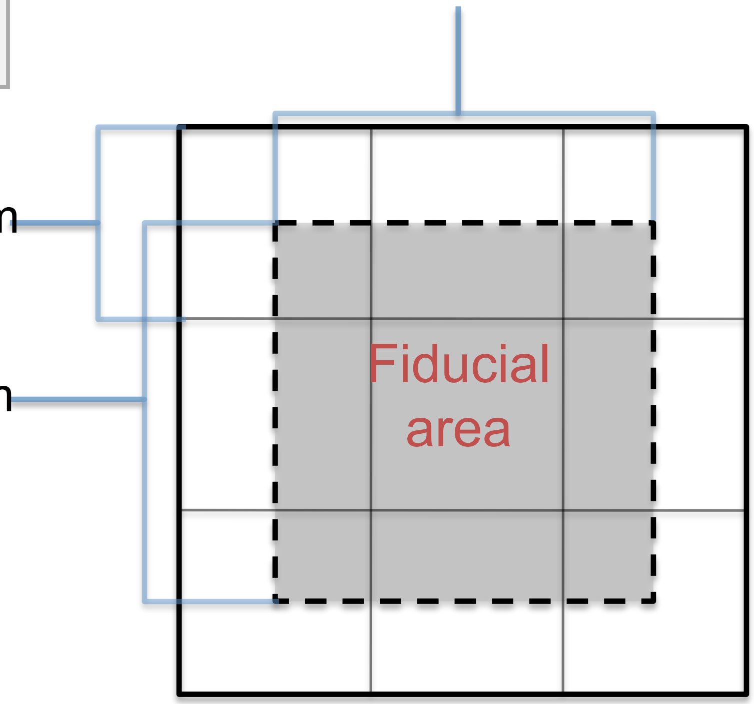


Fiducial region



Position of the two matrices

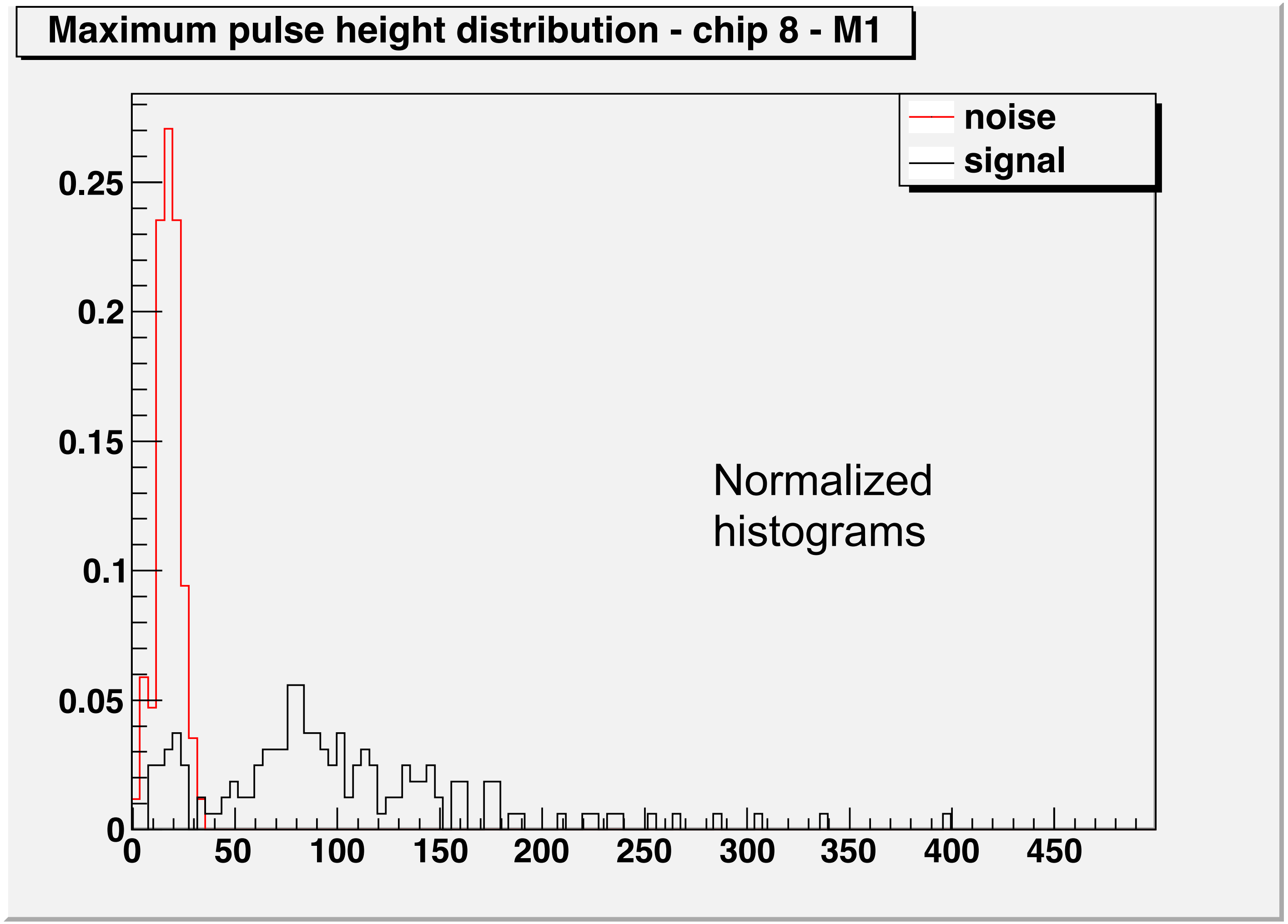
The "shadow" of the two matrices is found looking at the intercepts of the (telescope) tracks with the MAPS layer.



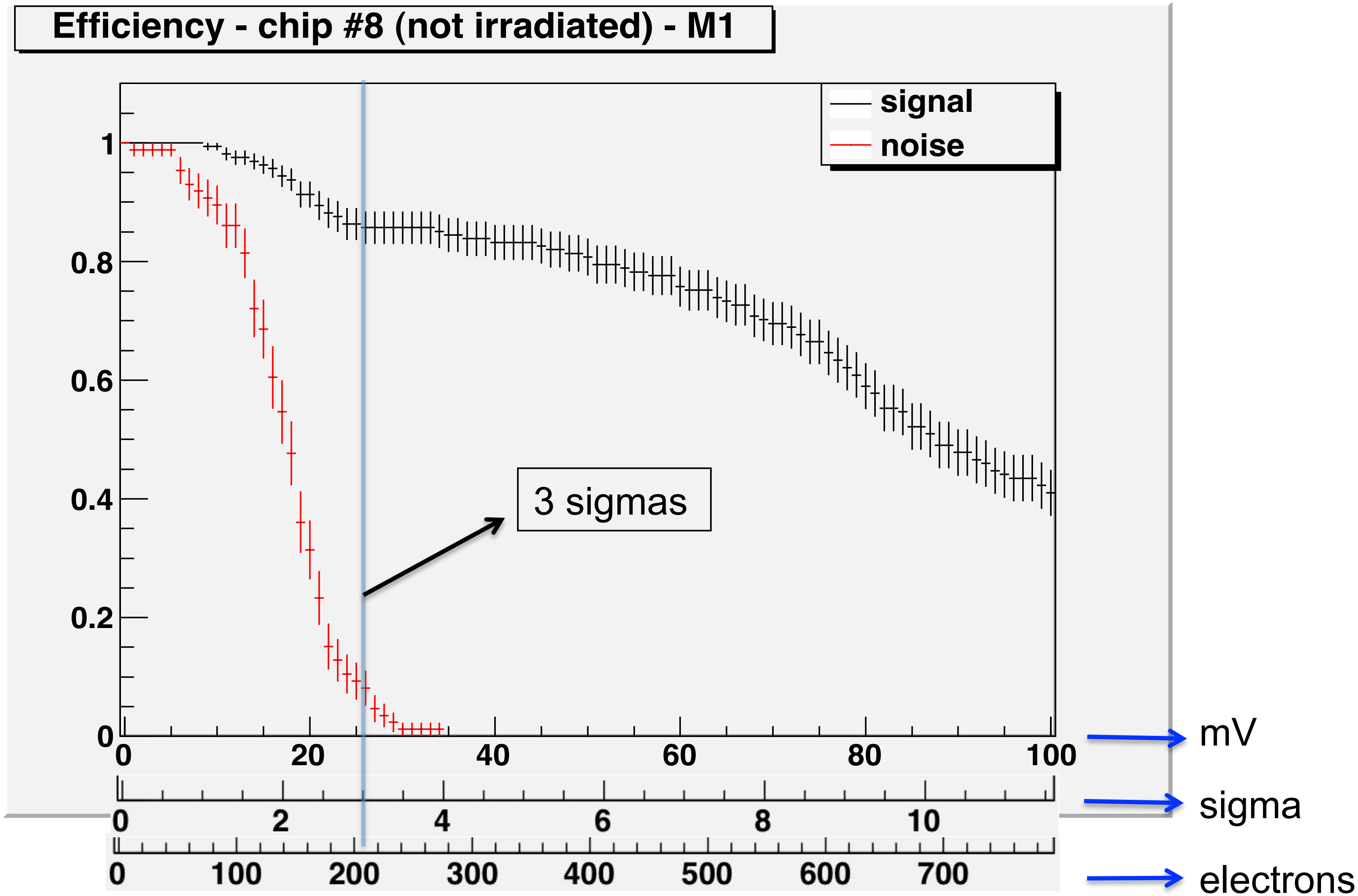
The center of each matrix is found with a cut on the MAPS pulse height.
Then a smaller 100 x 100 μm^2 region around the center of each matrix is used as fiducial region (for efficiency & Landau).

Maximum pulse height

The maximum pulse height is evaluated finding the maximum value of pulse height between the nine pixels 350 ns after the photomultiplier.

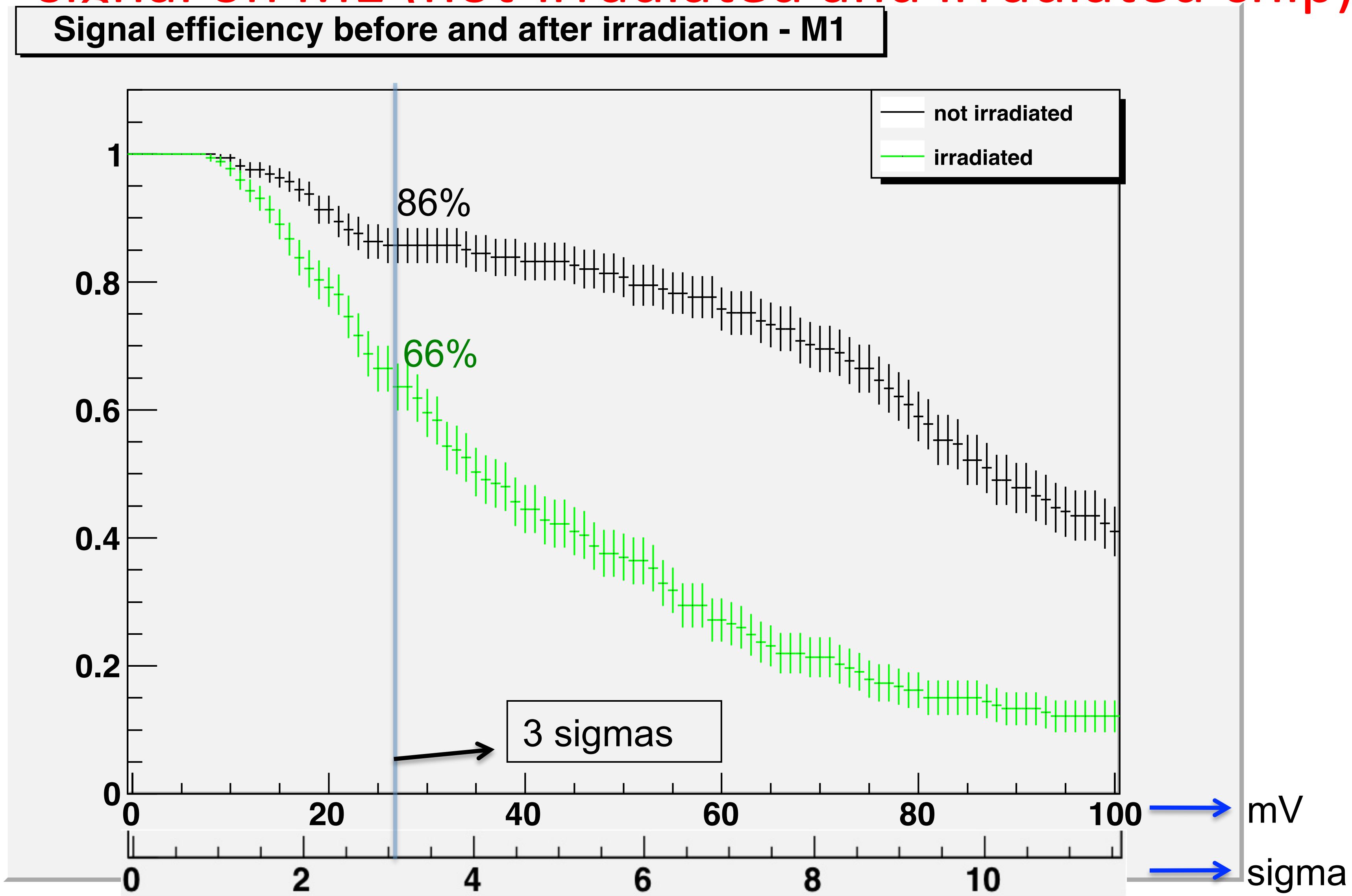


Efficiency (I)
signal and noise (i.e. off time)



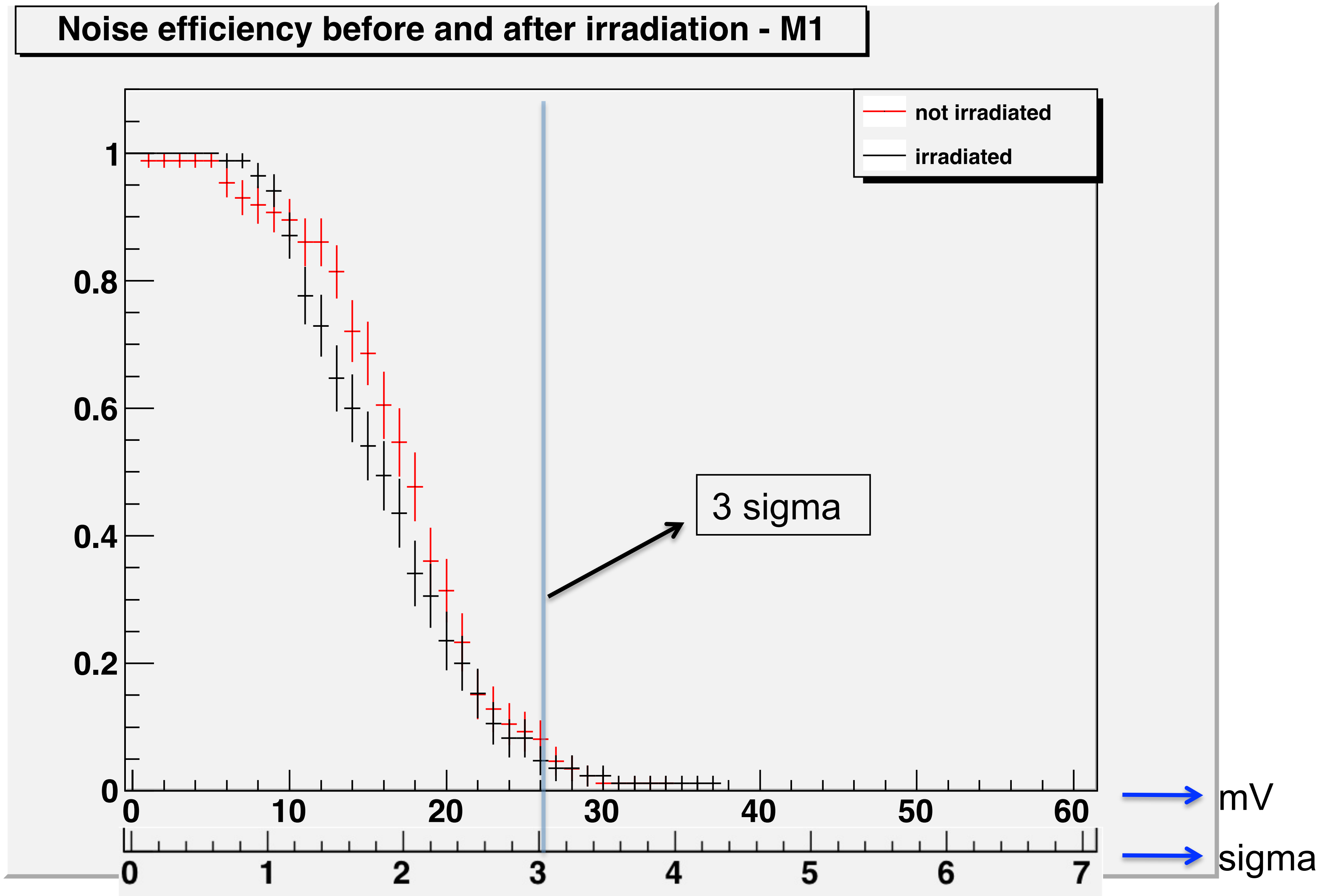
Efficiency (II)

signal on M1 (not-irradiated and irradiated chip)



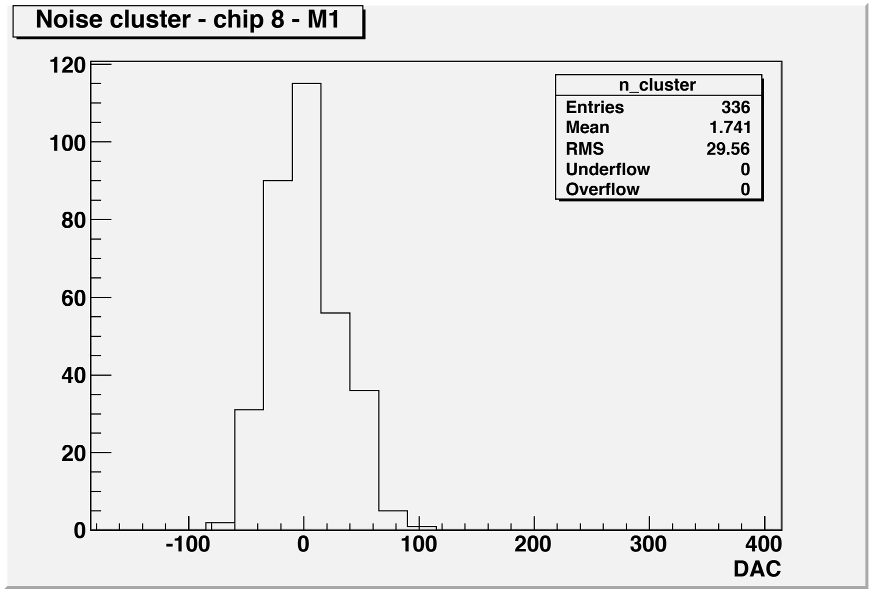
Efficiency (III)

noise (events off time wrt PM)

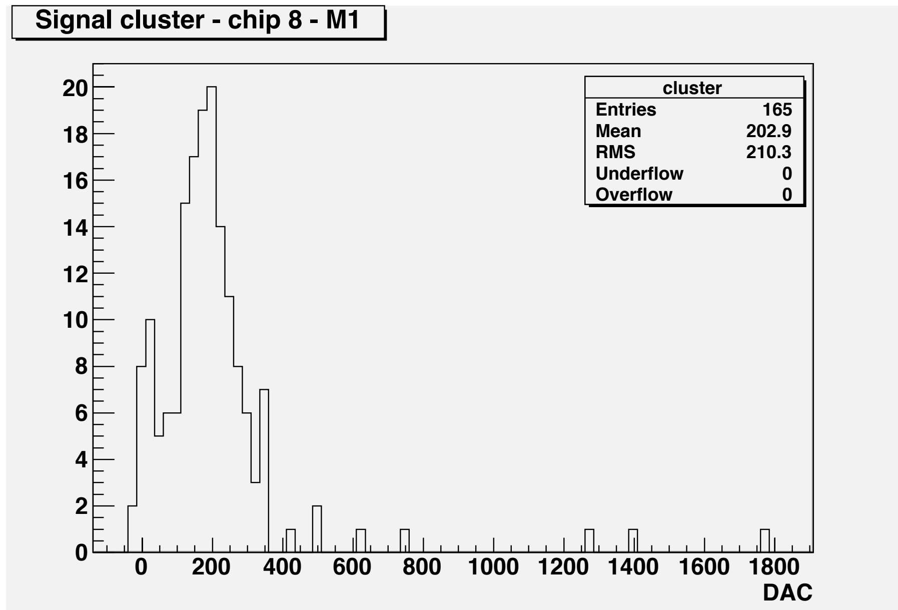


Landau (I)

The cluster of signal contains also events where the matrix is inefficient.

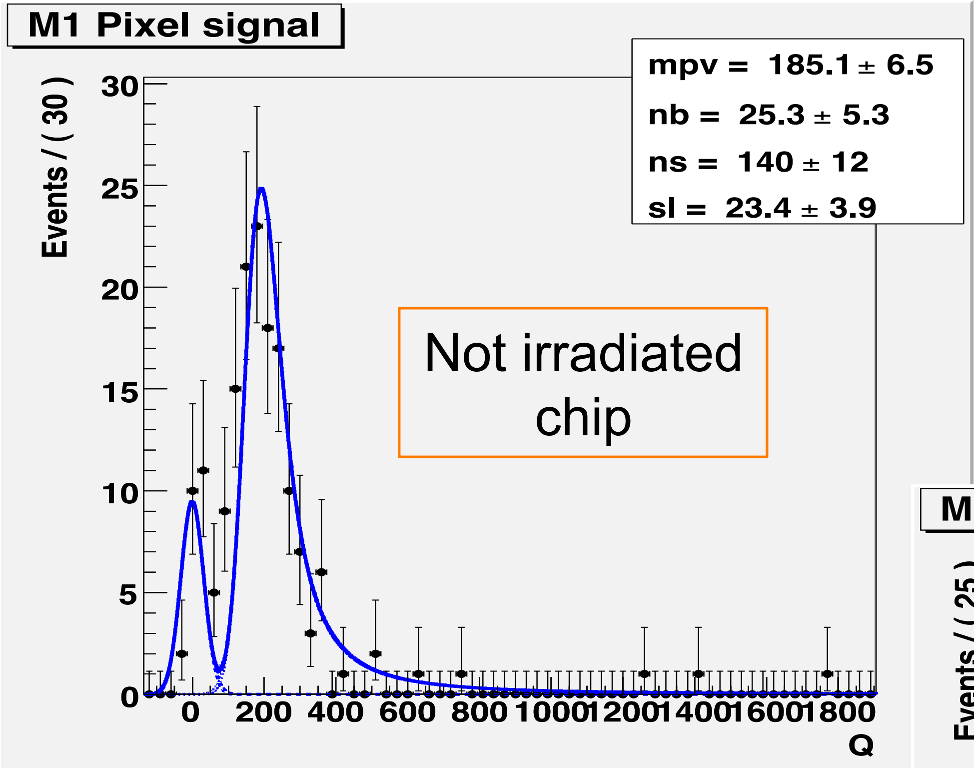


- Noise (off time): the cluster charge is fitted with a Gaussian →the mean and sigma are determined and fixed.



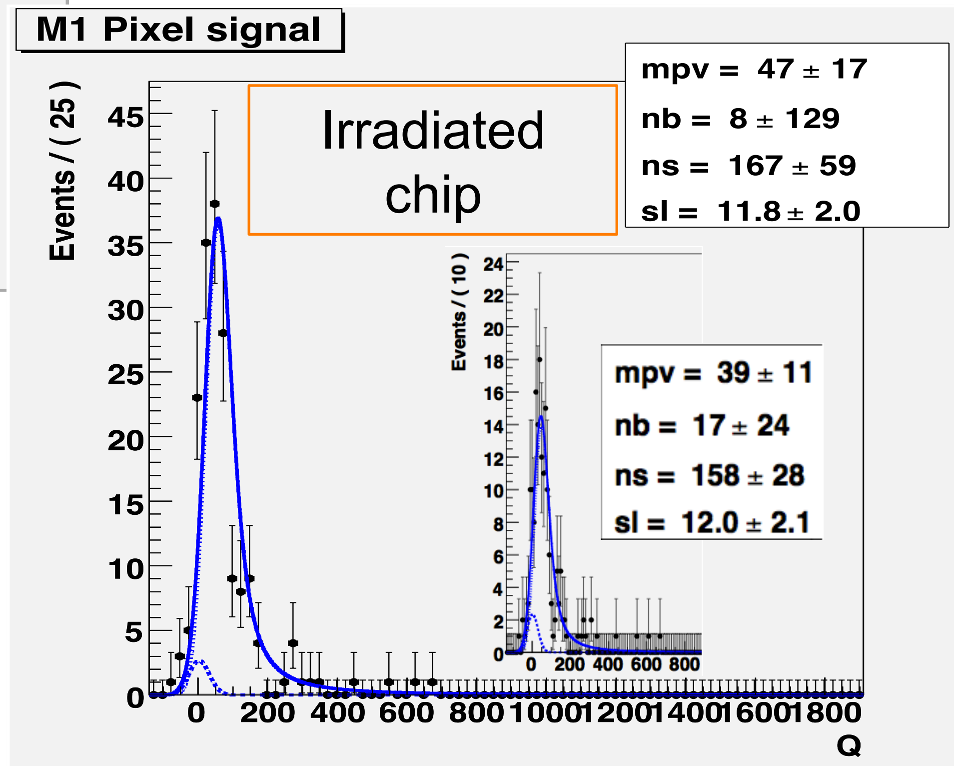
- The cluster charge is fitted with a Landau convoluted with the Gaussian (with parameters previously obtained) and the Gaussian for the bkg.

Landau (II): results on M1



Pdf = nb * Gauss +
ns * Landau(mpv,sl) x Gauss

Fit parameters:
nb # of bkg events
ns # of sgn events
mpv Landau
sl sigma (=Γ/4) of the Landau curve

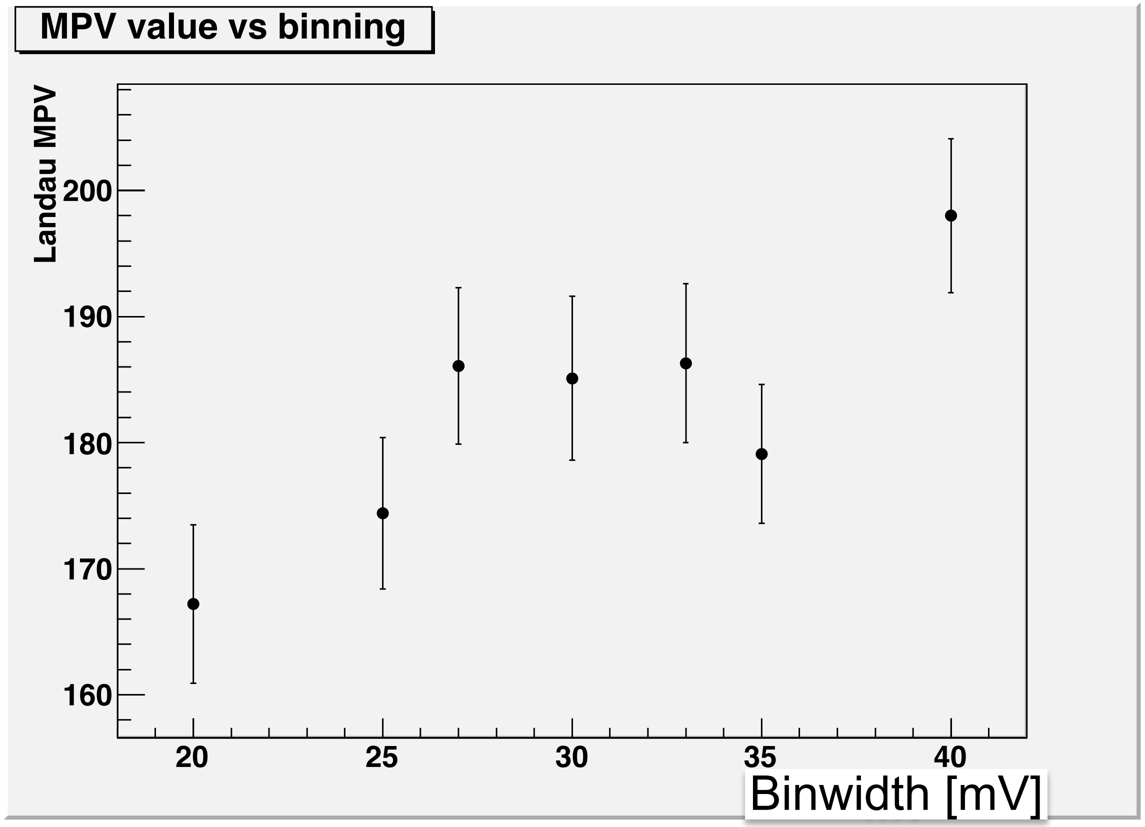


Low statistics and small signal charge:
In the irradiated chip the fit is not able to distinguish the sgn from noise.
With smaller bin: see the inset.

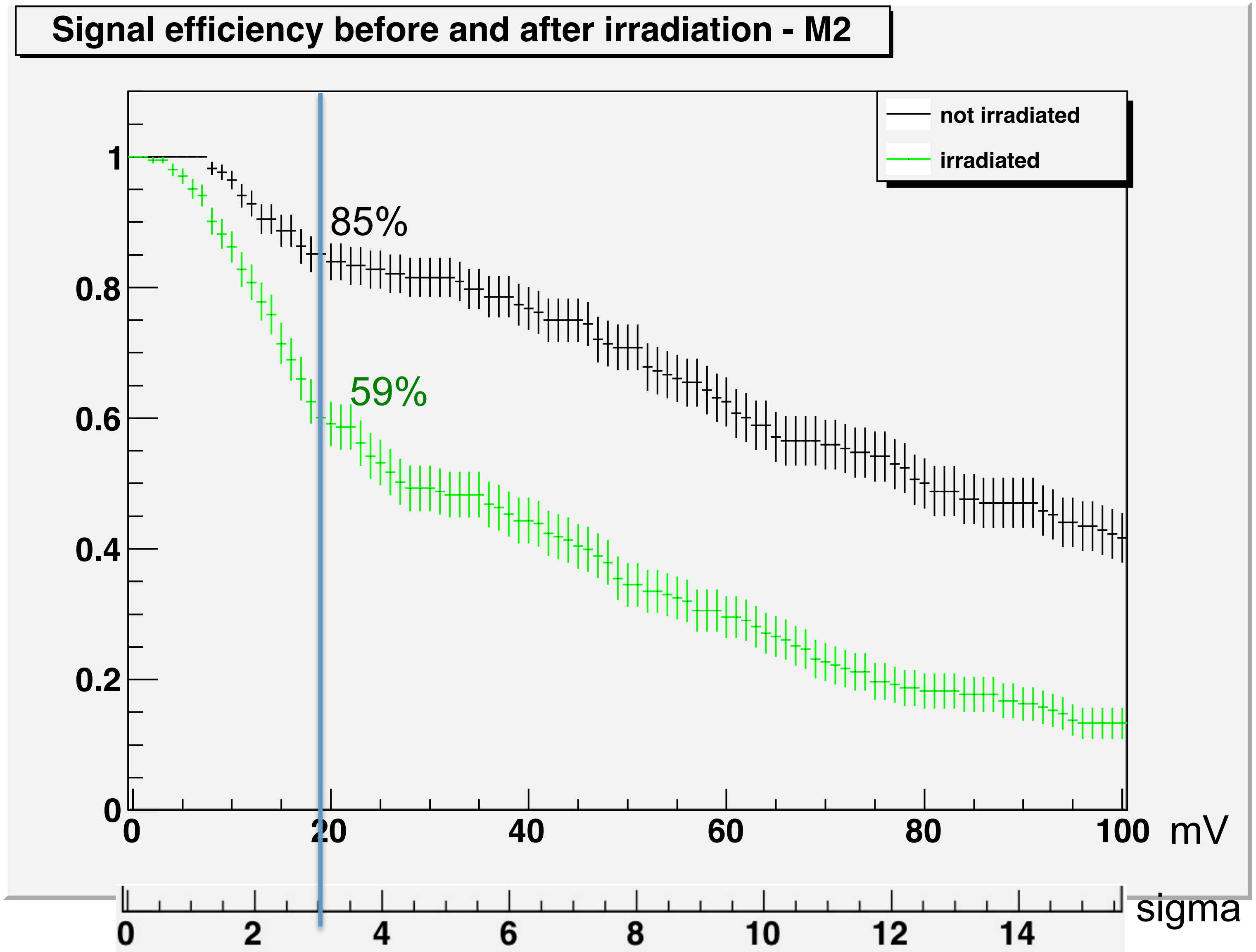
An un-binned max likelyhood FIT required

Landau (III) vs binwidth

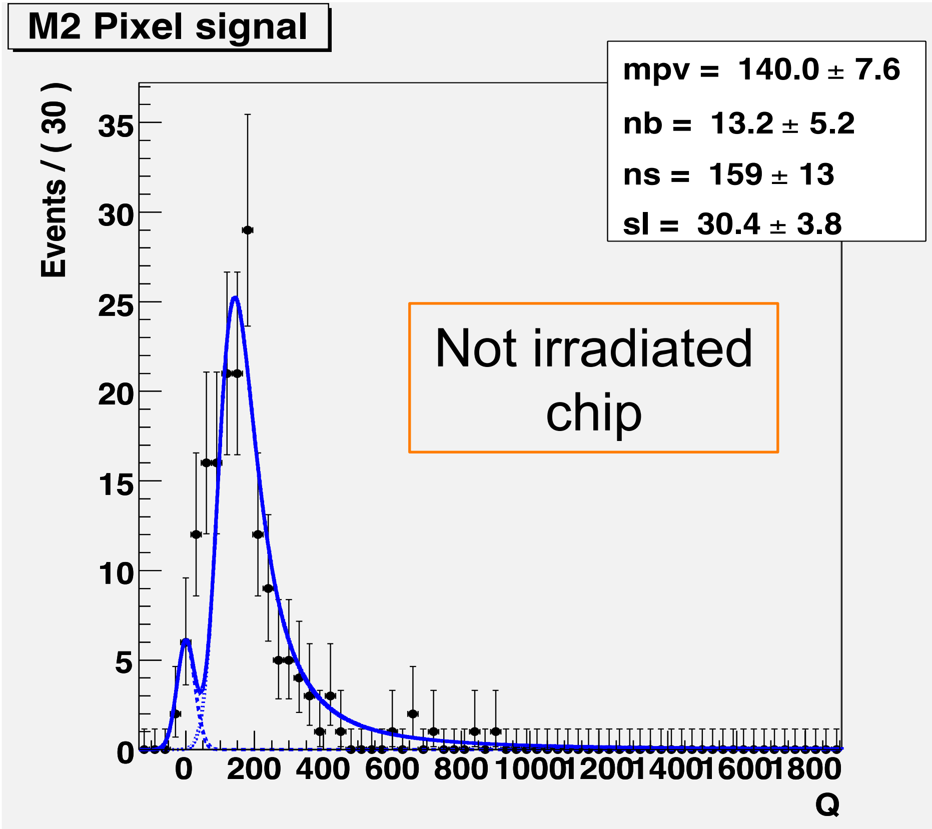
The charge cluster is evaluated in mV.
The fit of this histogram could depend on binning used to fill the histogram itself. MPV was fitted for different binnings:



Efficiency (IV) for M2
(not-irradiated and irradiated chip)

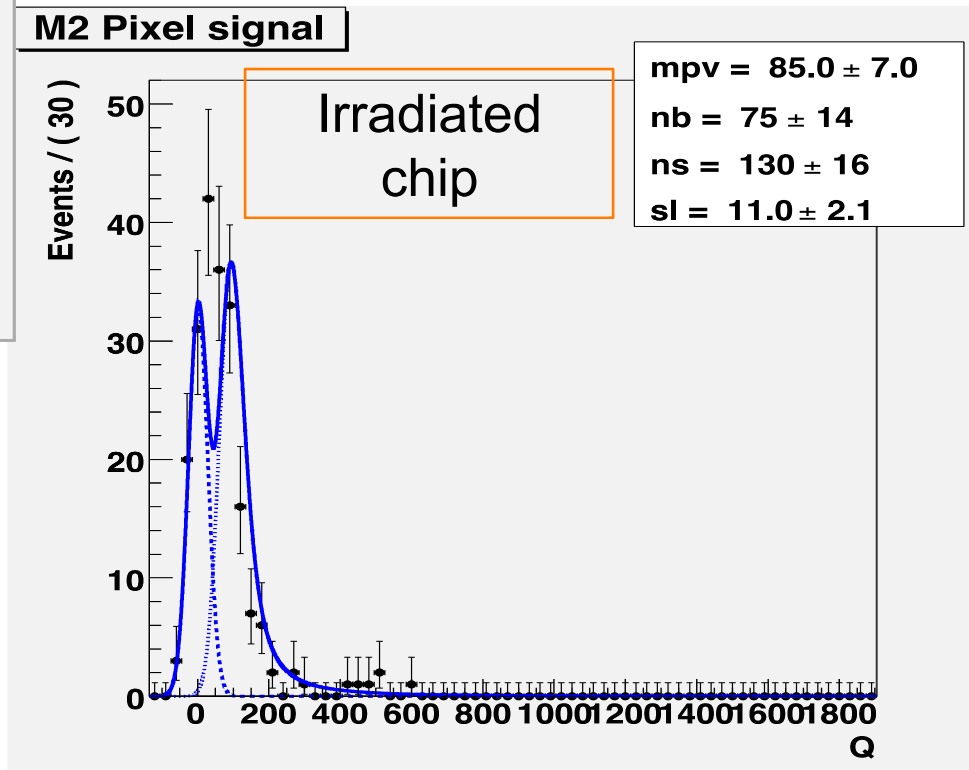


Landau (IV): results on M2



Pdf = nb * Gauss +
ns * Landau(mpv,sl) x Gauss

Fit parameters:
nb # of bkg events
ns # of sgn events
mpv Landau
sl sigma (=Γ/4) of the Landau curve



Low statistics and small signal charge:
For irradiated M2 the fit succesfully distinguishes the sgn from noise.

Results

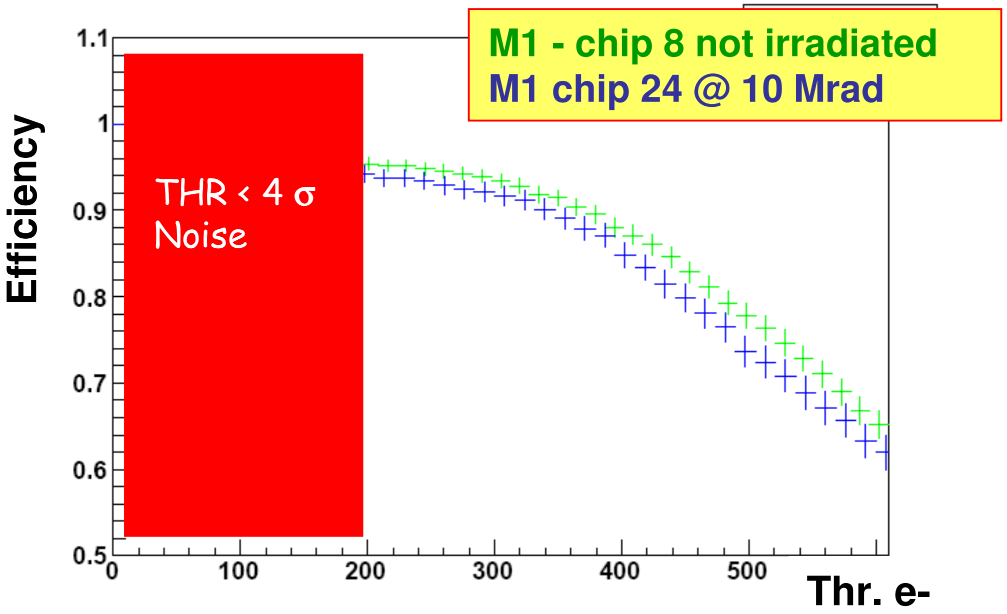
	chip 8 M1	chip 8 M2	chip 52 irr M1	chip 52 irr M2
RMS noise[mV]	8.11	6.06	8.64	6.68
Gain[mV/fC] from Fe55	791.4	771.9	821.0	780.2
Fe55 peak (1640e-) [mV]	208	203	215	205
Landau [mV]	185	140	47	85
Landau[e-]	1462	1134	358	681

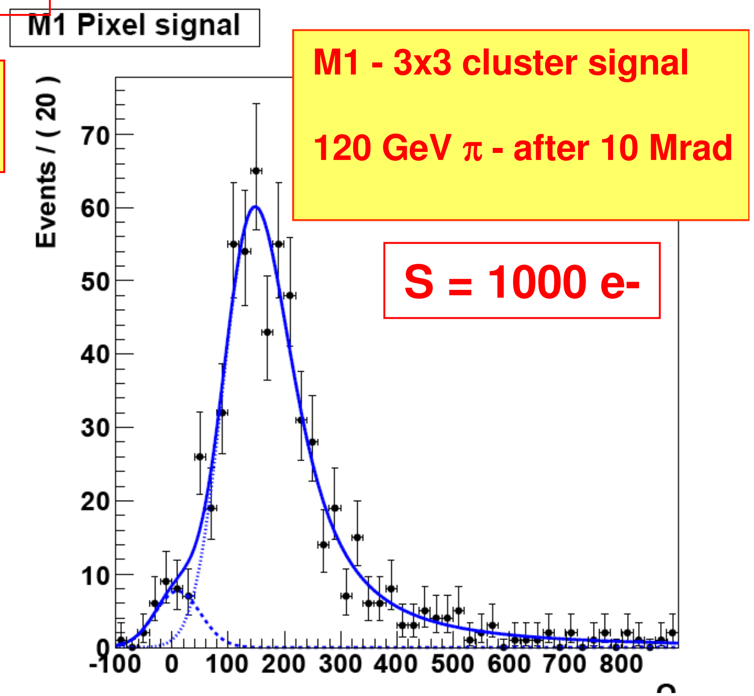
Comparison vs apsel3T1 (TB 2009)

Tesbeam with γ irradiated MAPS - 2009

Results for MAPS (3x3 matrix) with analog output (pre/post irrad. 10 Mrad ^{60}Co γ)

- Qcluster ~1000 e- for M1 (930 e- for M2)
- S/N~15-20 depending on the electrode geometry
- Efficiency~90% for both M1,2 in agreement with the measurements on digital MAPS
- Modest reduction in collected charge and efficiency in chip irradiated up to 10 Mrad
  - ENC increased by ~35% (after annealing)





Conclusions

- Tests on the INMAPS 32x32 matrix have spotted a mis-behaviour of the comparator.

  The analog section is properly working (ENC~30 e-) and the basic digital functionalities are insured.

- Test beam preliminary results on irradiated apsel3T1 (DNW) chip 3x3 matrix confirmed the high bulk damage previuosly seen by Lab. tests (β from a Sr90 source and i.r. Laser).

  Efficiency and charge collection heavely affected

- Test-beam analisys to be completed with the last analog structure: apsel 65 nm