Fully depleted MAPS: Pegasus and MIMOSA 33

For low energy X-ray applications

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Motivation

Goal (success oriented):

- Low energy X-rays (< 10 keV)
- Single photon counting (with > 10^6 ph / 100x100 μm^2)
- Good spatial resolution (few µm)

Chip requirements:

- Depletion depth ~ 50-100 µm
- Low noise (sensitivity to few 100 e^- signal)
- Fast frame rate >> kHz
- Pixel pitch ~ 20 µm

Intermediate step ASIC:

- Counting > 10^3 ph/pixel·s
- Energy range 1 keV – 10 keV
- Noise below 25 e^-
- Pixel size 25 x 25 μm^2
- Chip size ~1 cm^2

How to get depletion??

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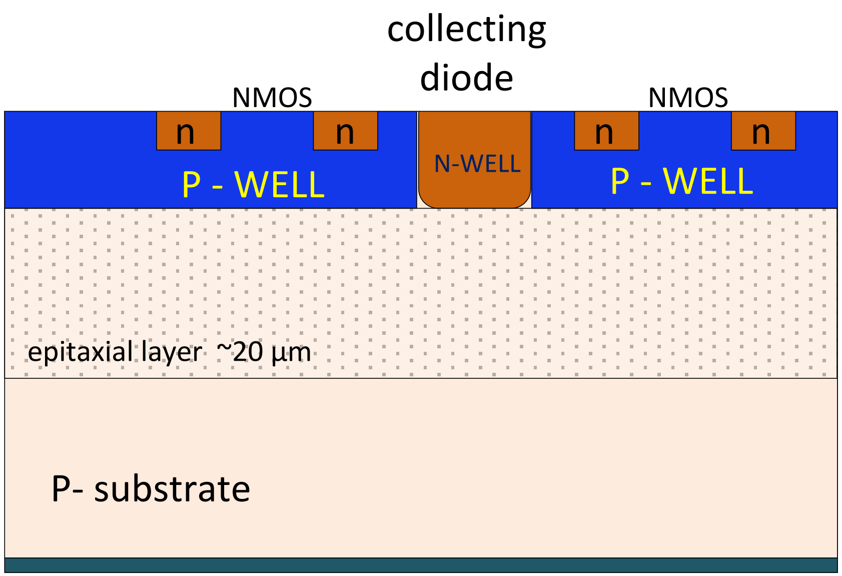
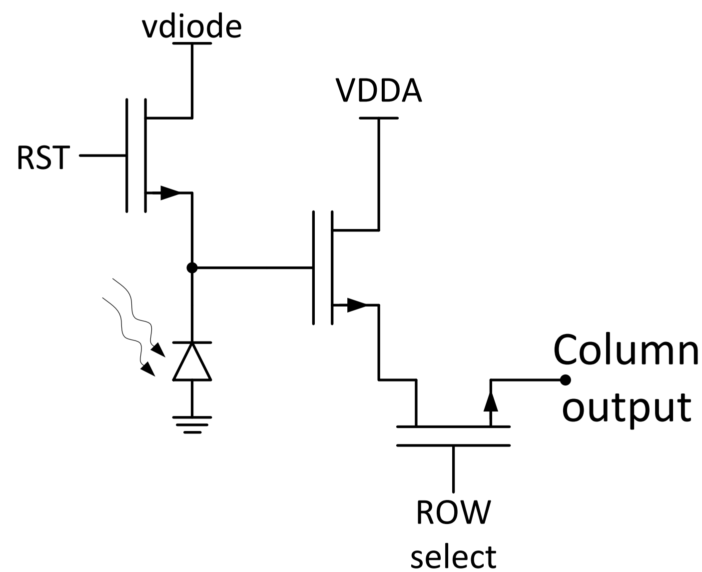
MAPS





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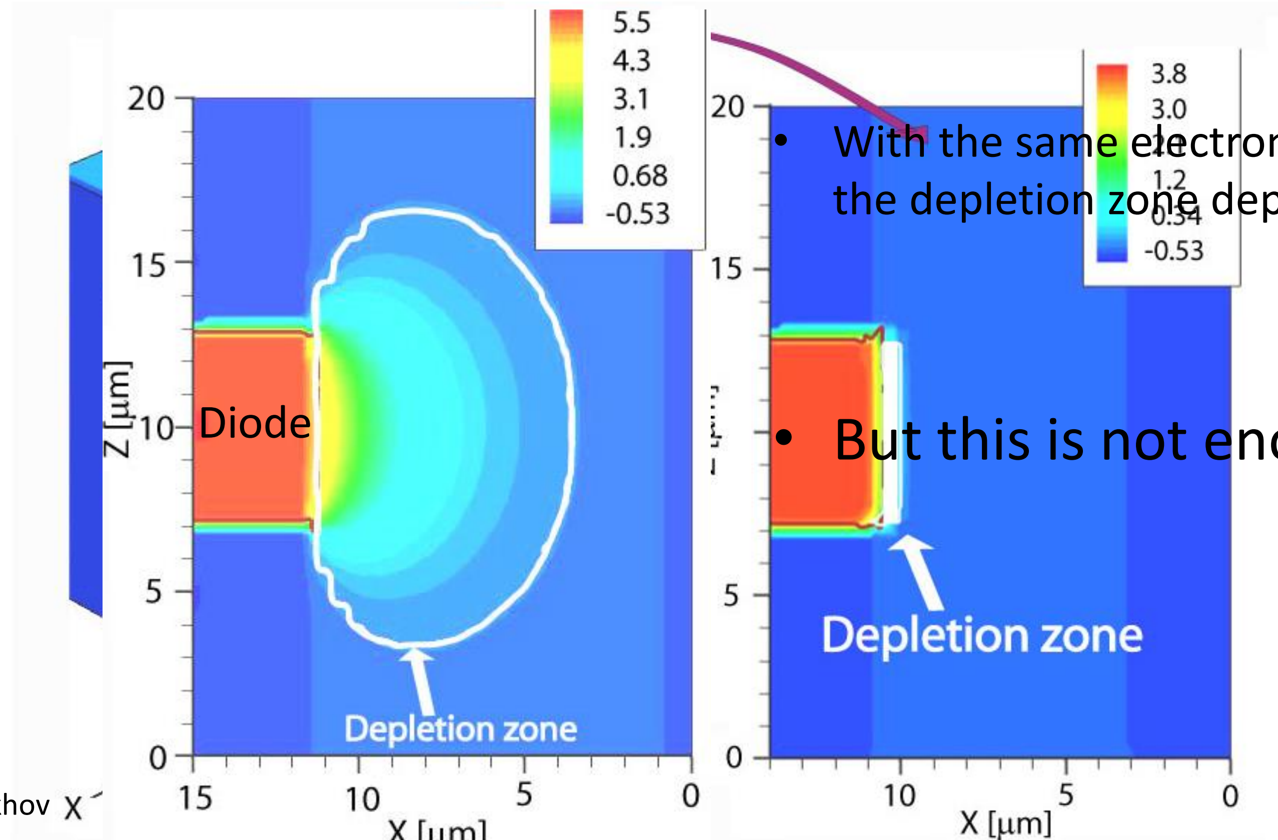
Detection with MAPS

- Standard low resistivity epi (few Ω cm)
- High resistivity epi (k Ω cm)

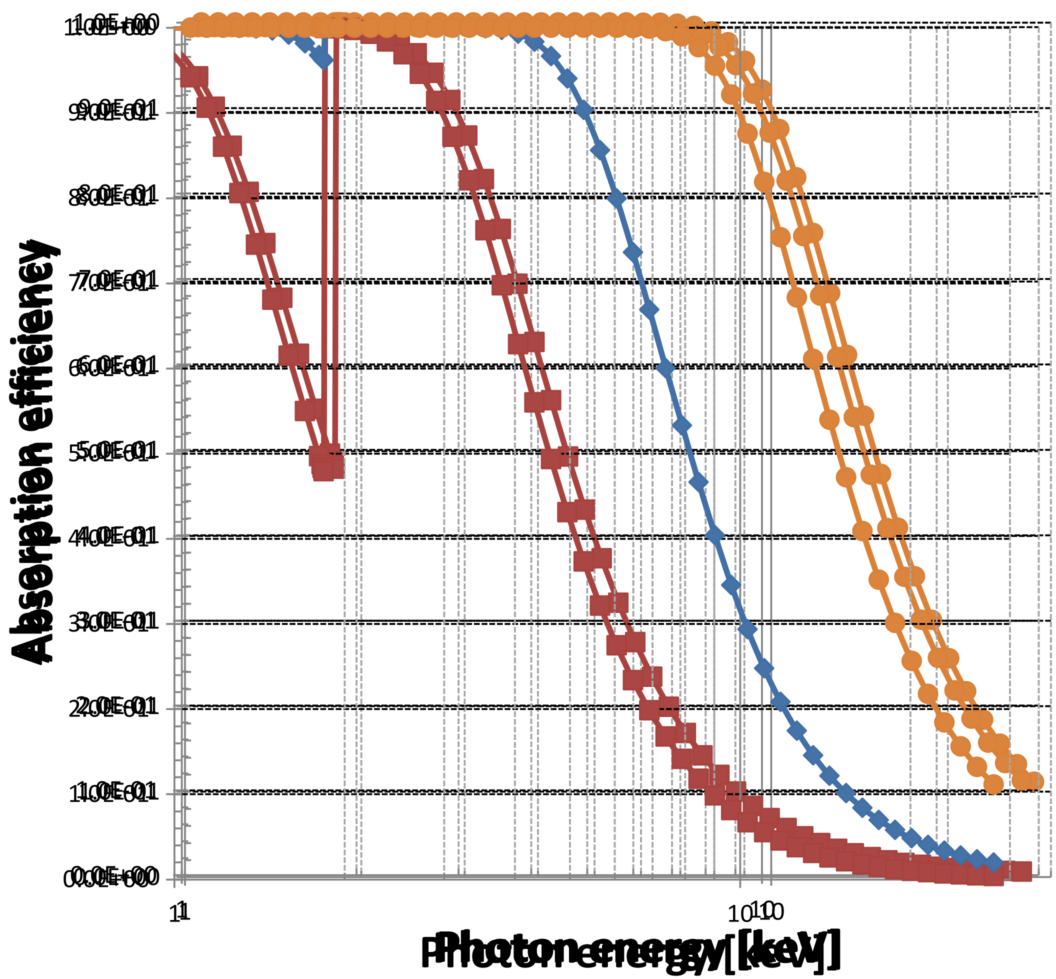


- With the same electronics you gain the depletion zone depth
- But this is not enough!!

Provided by A. Dorokhov

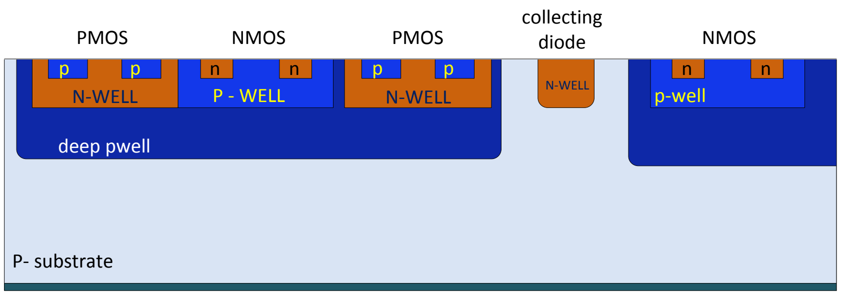
Absorption efficiency of Si

Si - 10 µm Si - 50 µm Si - 300 µm



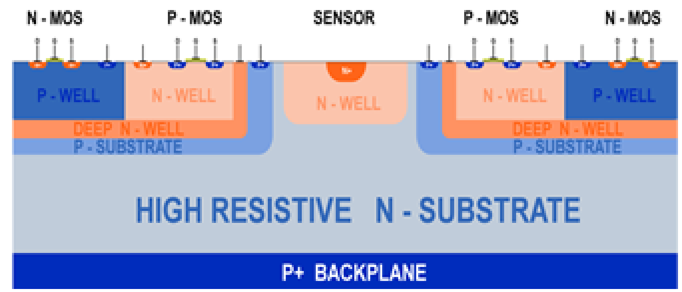
Technology choice

TOWER (0.18 um)



- Quadruple well technology
- P substrate
- Used by CERN

ESPROS (0.15 um)



- Fully depleted 50 µm
- Post processing included
- N substrate (detector grade)
- „Out of the box solution" ?

- Test structures (collecting diodes and amplifiers) were made in both technologies

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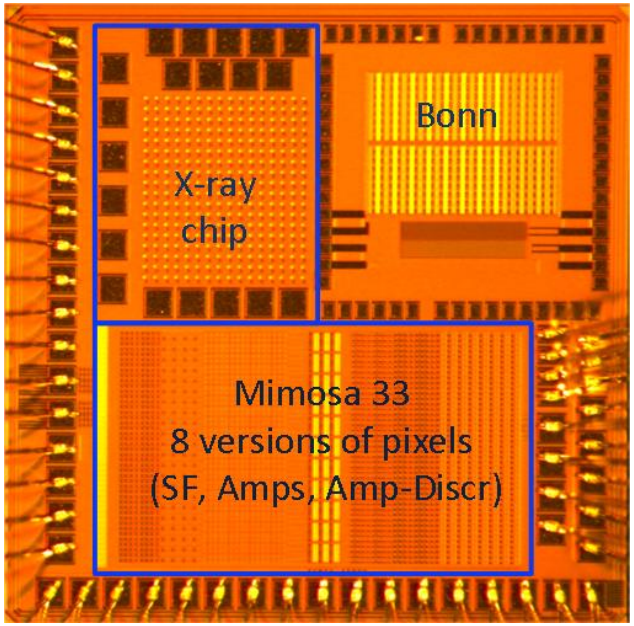
Mimosa 33 submission ESPROS technology

- Study different biasing approches

  - Bias the diode from bottom

  - Bias from the top – DC coupling



- Study the charge collection with different pixel pitch
- Prototype of a simple X-ray counter

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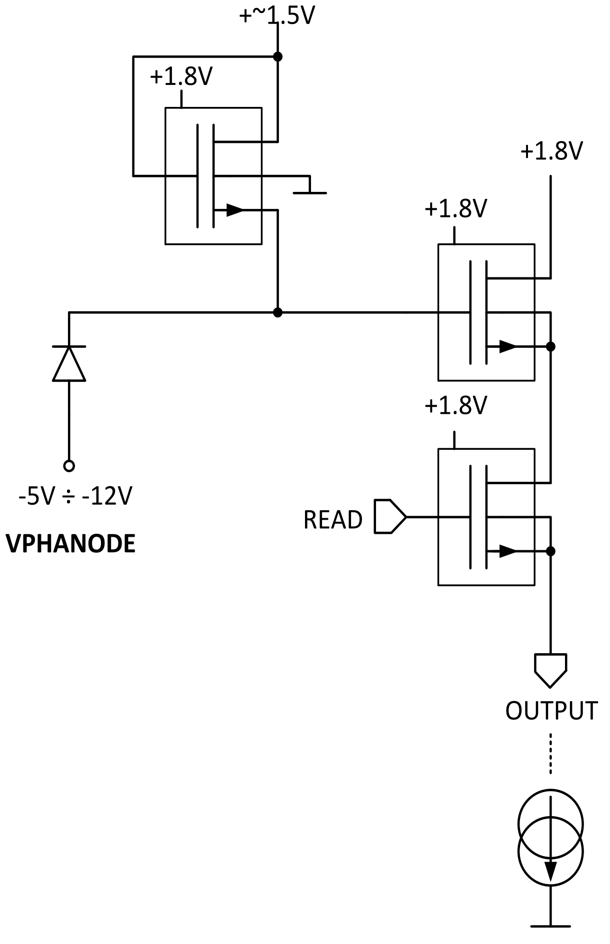
M33: Standard SF pixel



- Isolated NMOS transistors (but used with std voltage)
- Diode biased from the anode side with negative voltage
- SF bias - self biased solution

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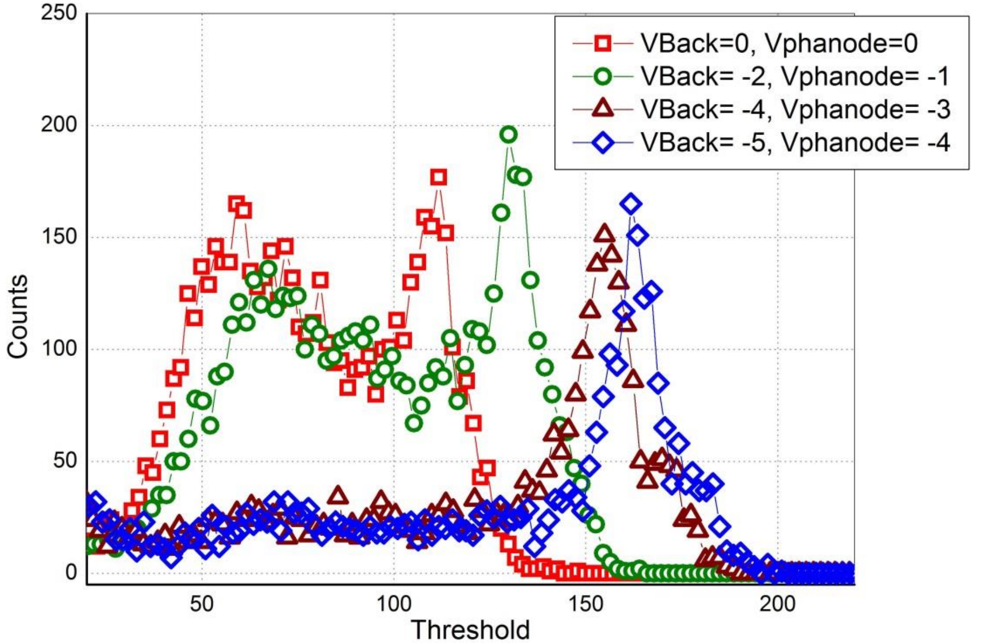
M33: Standard SF mesurements

Fe55 measurements with different biasing(Vback, Vphanode)

Seed pixel



- Increasing the Vphanode improves the charge collection
- High noise ~ 50 e^- rms ?

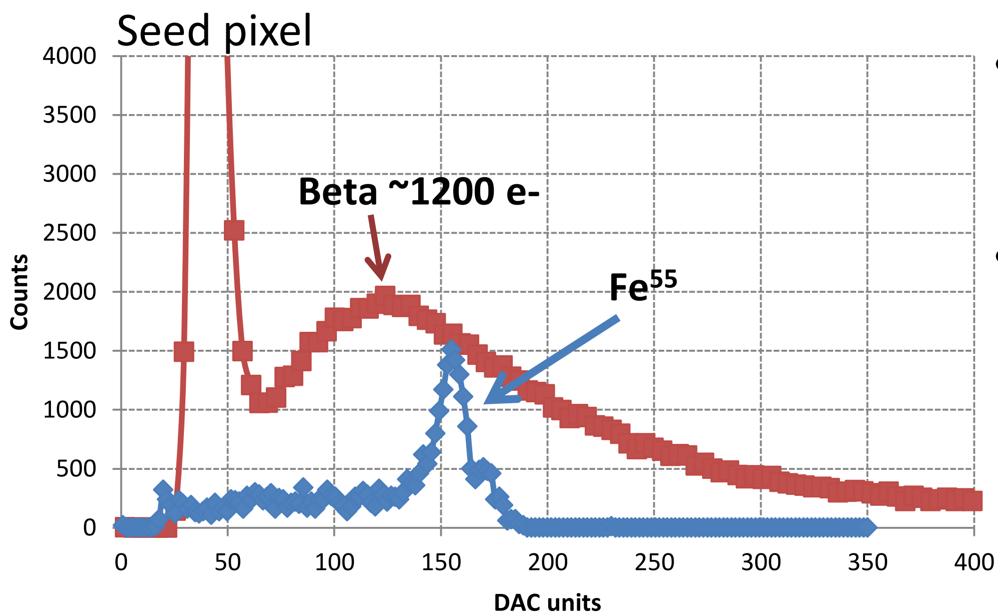
Low gain because of the large capacitance at the input node ??

$$C = \frac{Q}{V} = \frac{2792 \cdot 10^{-19}}{9.68\ mV} = \underline{27.92\ fF}$$

where the extracted capacitance at the gate of input transistor ~ 1-2fF

M33: Standard SF mesurements (I) depletion depth

- Mimosa 33 was tested with Sr beta source

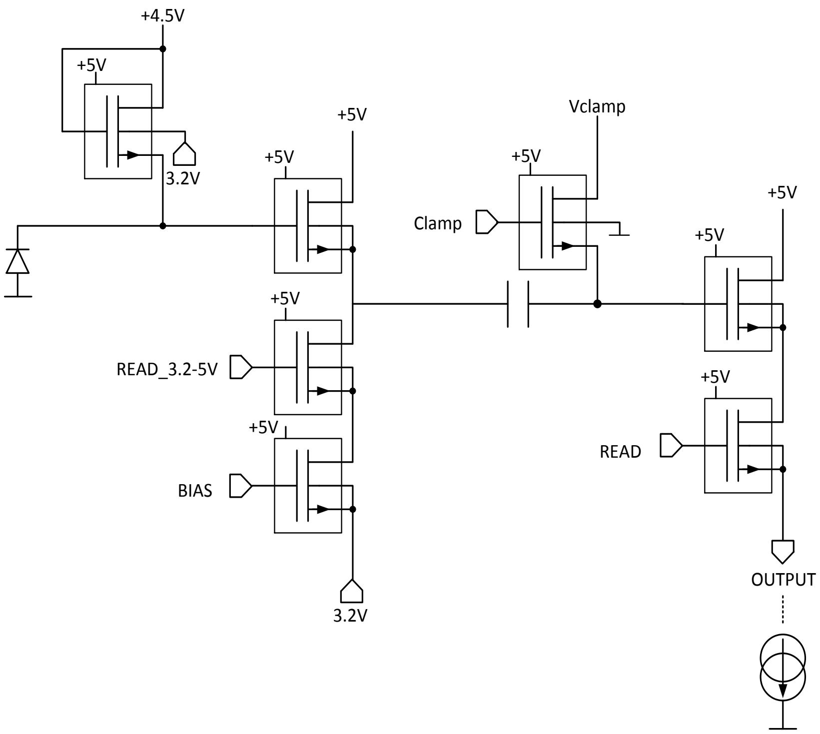


- Beta particle leave ~80 e^- / µm of detector
- 1200 e^- -> 15um of depleted substrate ??

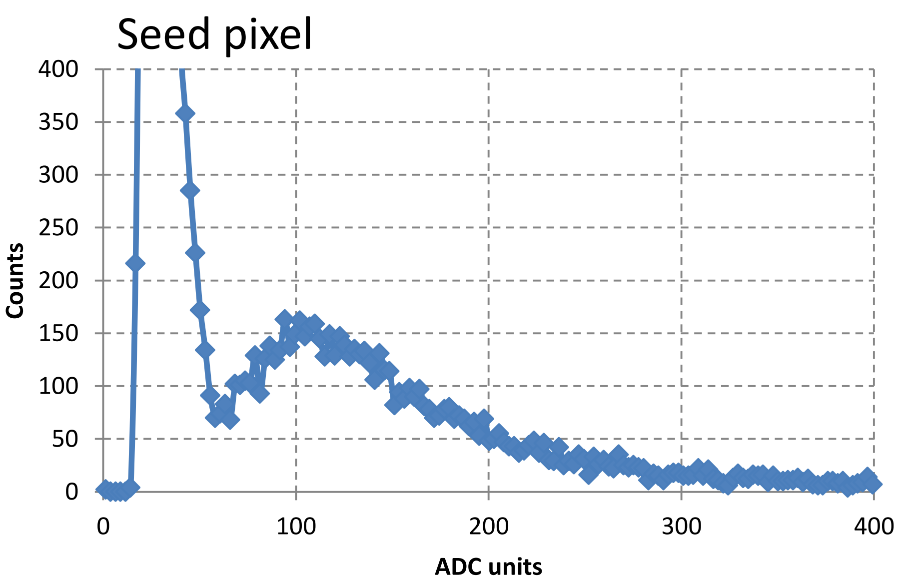
- It looks like there is **<u>only 15µm</u>** of depleted detector (out of 50)

Apart from that – good charge collection -> most of the charge is collected by the single pixel

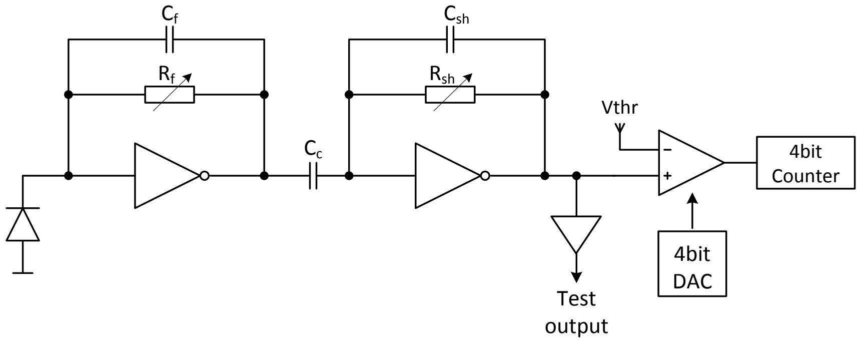
M33: bias the diode from the top



- First stage of the pixel can be supplied from higher voltages (i.e. 3.2 V – 5.0 V)
- ~4V at the diode
- With vback=-3V (or even 0V) response from beta particles is similar to the previous case

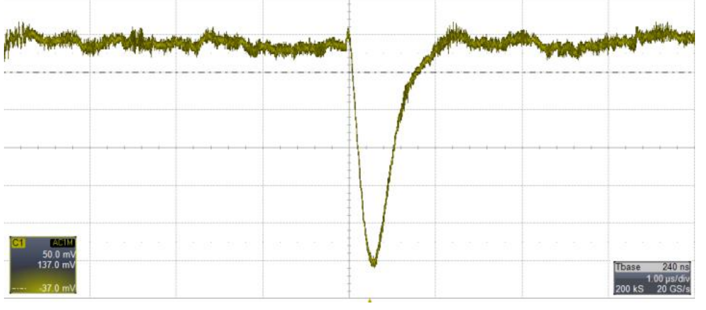


M33: X-ray counter

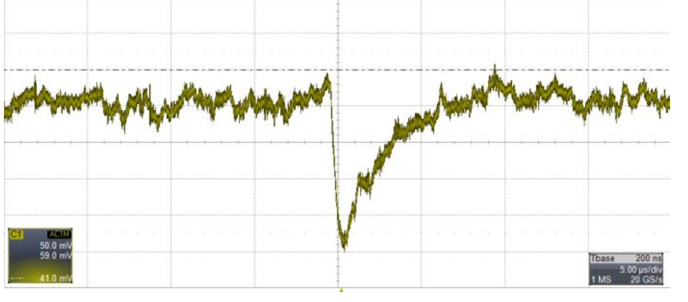


- Developed as a proof of concept
- 16 x 18 pixels – 50 um pitch
- In pixel:

CSA, shaper, comparator , 4bit counter and 4bit DC correction



SR^{90} beta source



Fe^{55} X-ray source

- Chip is responsive
- Due to the low gain problem the chip was not tested extensively

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M33: problem & second submission

- The reason for the low gain/high noise was the wrong sensing element placed by the foundry
- Corrected version of chip was resubmitted and is expected in November 2014.
- Foreseen tests
  - Study the charge collection with different pixel pitch (25 um, 50um)
  - Custom made sensing elements inserted
  - Pixel designs modified, with AC coupled diode

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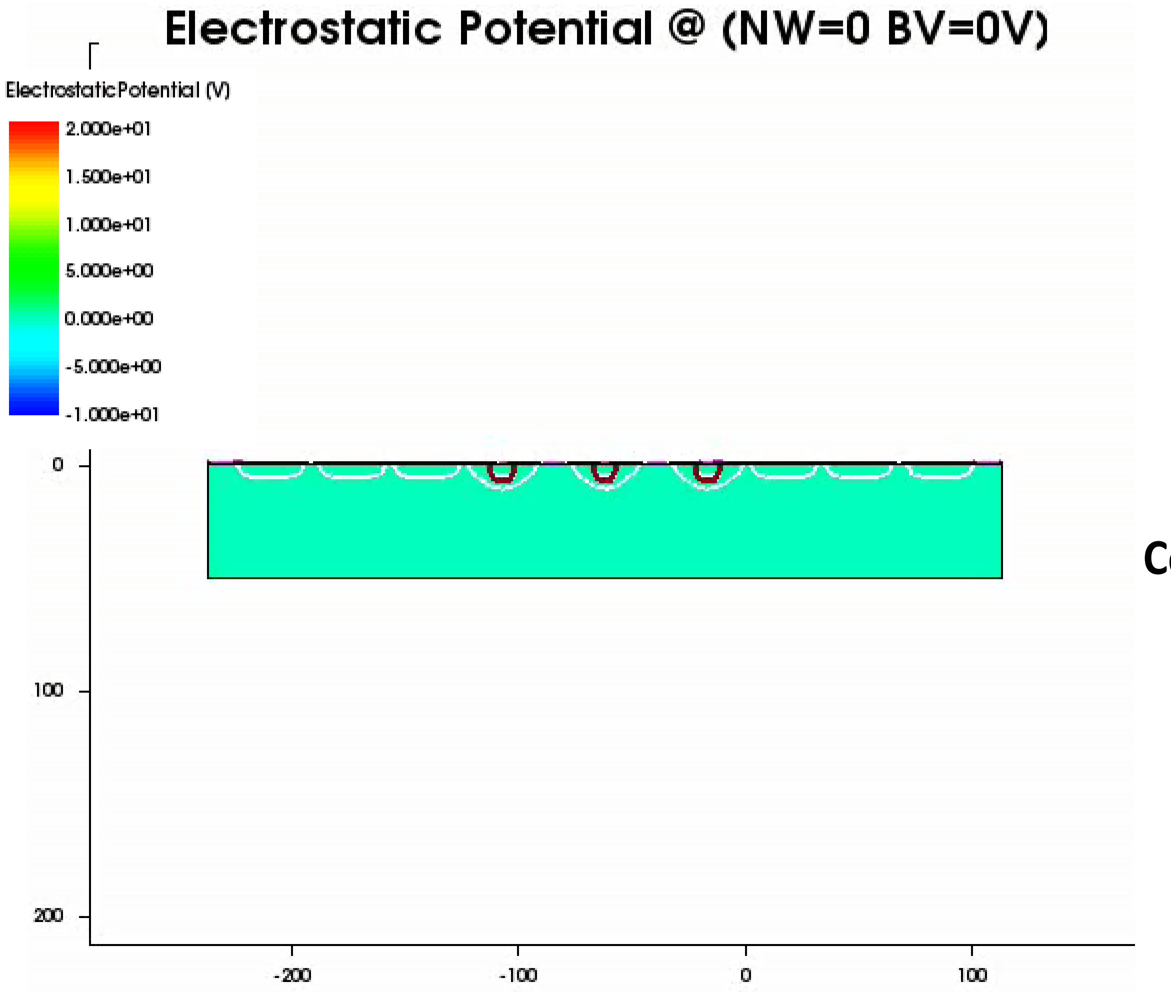
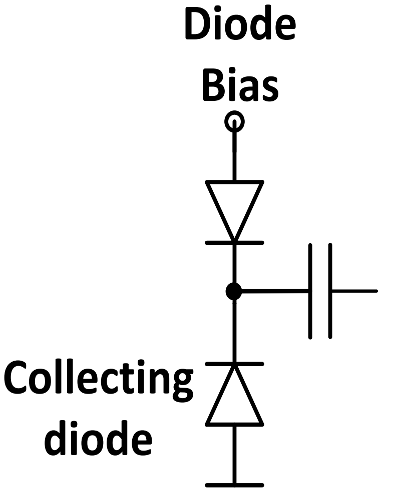
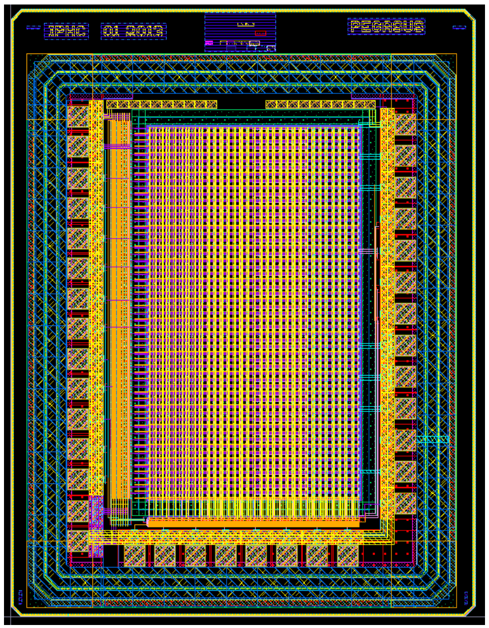
Use standard CMOS technology





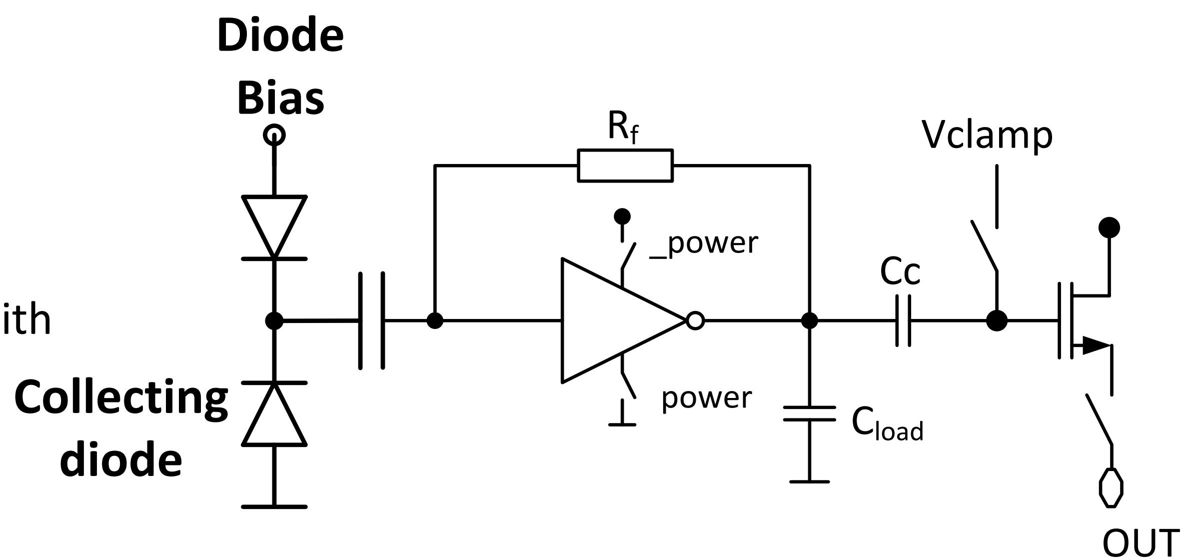
Courtesy of T. Hemperek
Bonn University

Pegasus



- 180nm CMOS (Tower)
- Various types of epi in submission
- 25 x 25µm^2 pixels
- Matrix - 56x32 with 4 versions of pixels
  - Two source followers
  - Two amplifiers

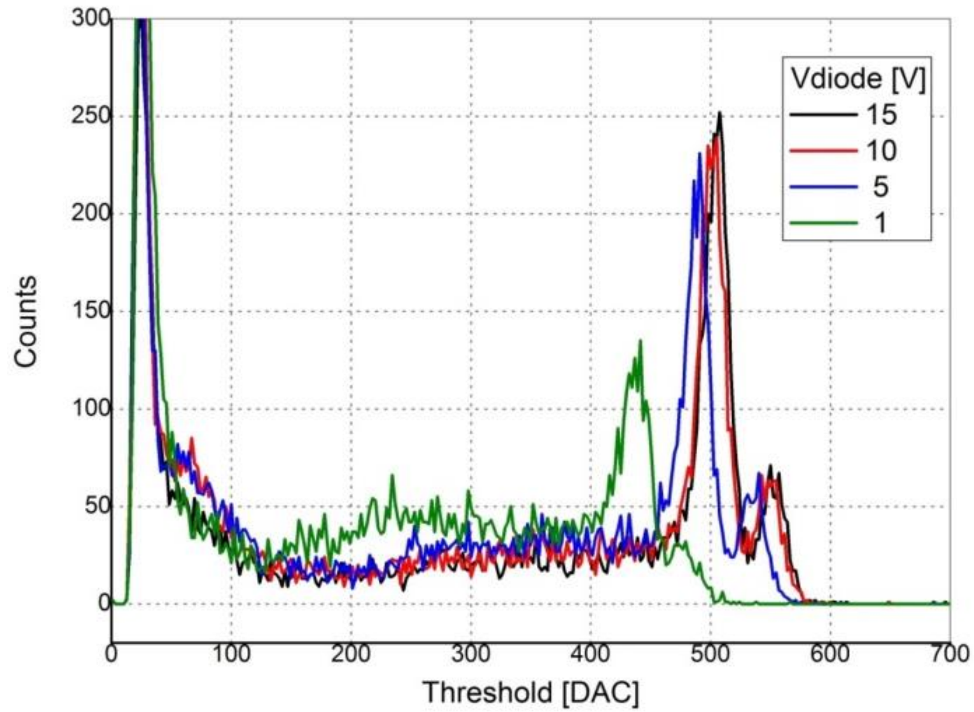
Amplifier
- Input diode AC coupled with amplifier
- Based on inverter
- No bias needed



Pegasus – measurements results

- Tests performed on the chips with a 18 µm thick epitaxial layer

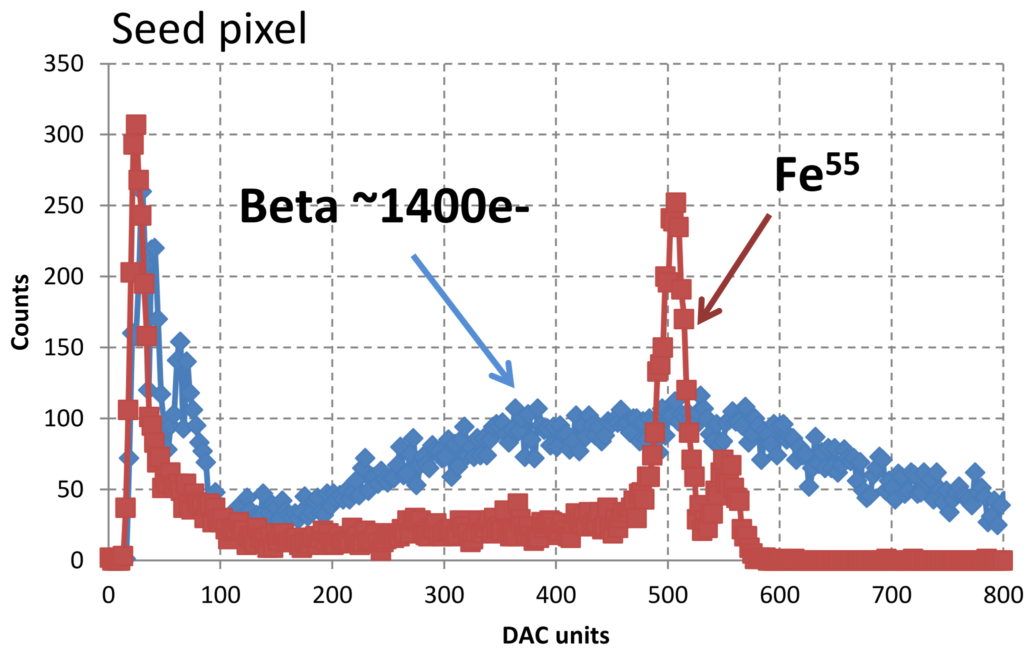
Fe^{55} spectrum with different diode voltage (seed pixel)



ENC ~25 e^-

Pegasus
depletion depth estimation

- Pegasus chip (in-pixel amplifier)



1400 e^- -> substrate with 18µm epi

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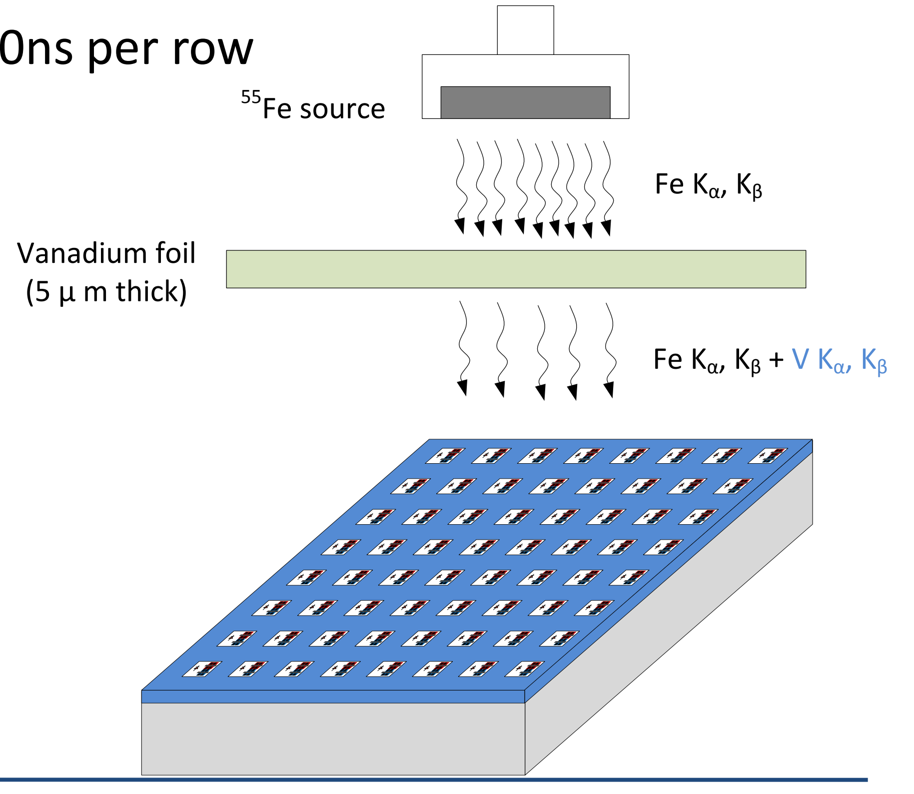
Pegasus 2

- Similar to Pegasus 1 (also 4 versions of pixels)
- Problems with high frame rate in first submission
  pixels optimized
    - Rolling shutter readout -> 150ns per row

- Tests just started



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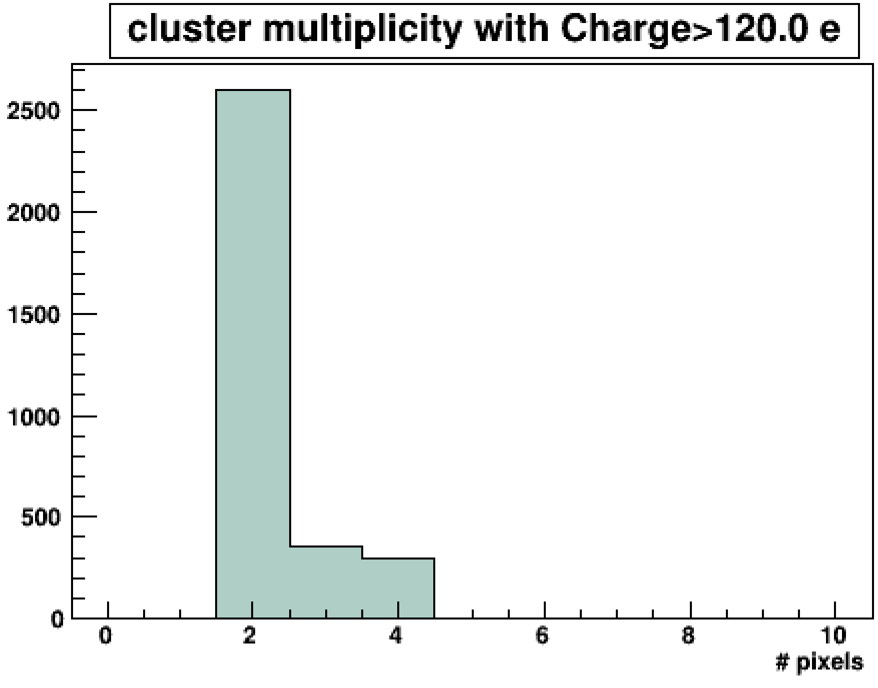
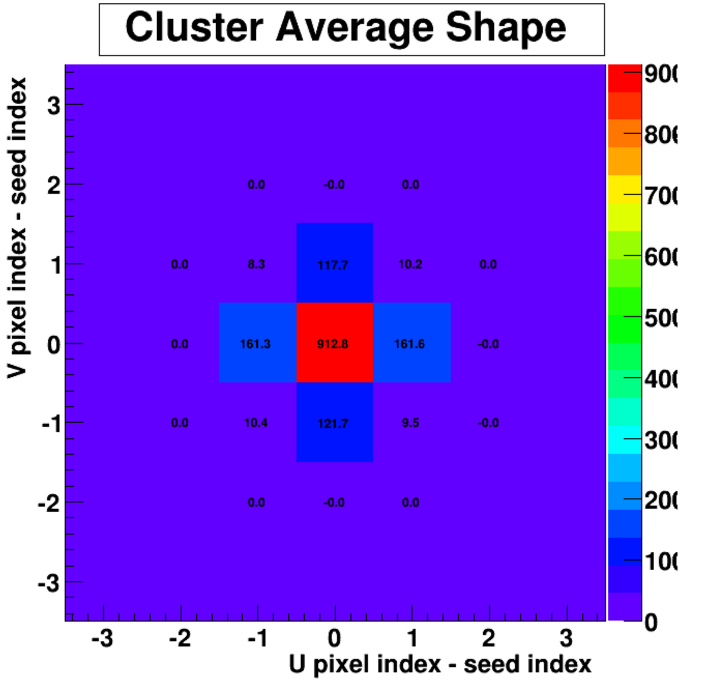
Pegasus 2
Cluster shape



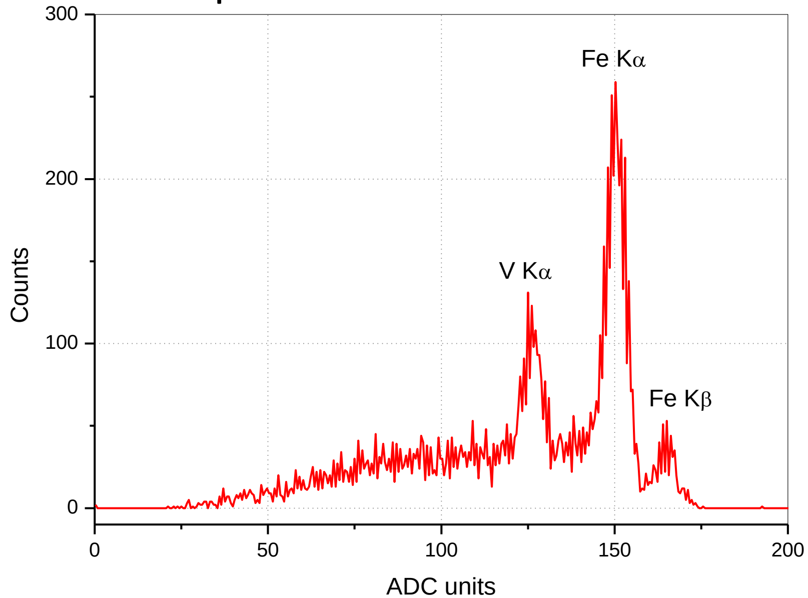


Pegasus 2 preliminary measurements

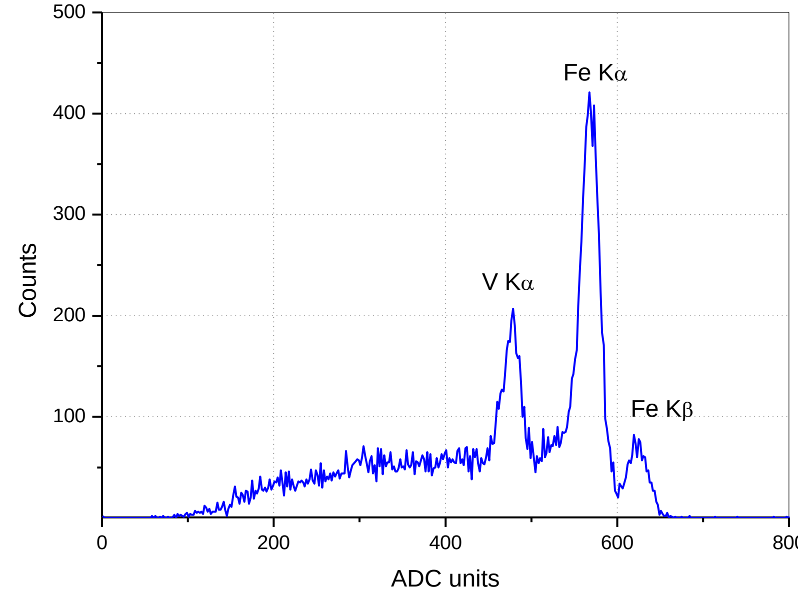
Source follower:
Gain 17 uV/e- => C_{in} = 9.38 fF
ENC 17 e- (base)
28 e- (Fe peak)

Amplifier:
Gain 70 uV/e-
ENC 16 e- (base)
30e- (Fe peak)

Seed pixel



Seed pixel



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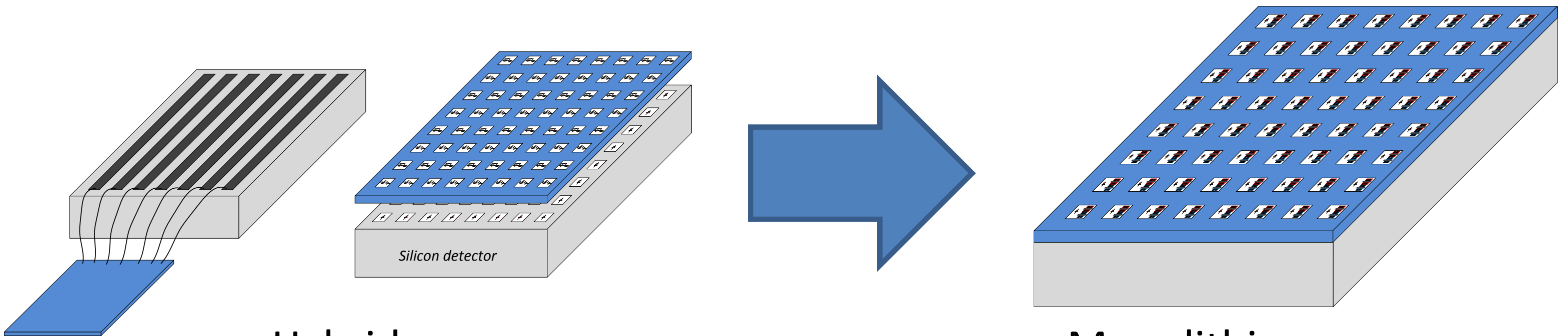
Conclusions

- With those „new" technologies MAPS looks promising for **wide variety** of low energy X-ray applications
- Both approaches are promising
  - Charge collection – TOWER – full depletion of epi - most of the events in 1-2 pixels
  - Small noise – 100 eV resolution at 6 keV
  - Frame rate – to achieve the high frame rate goal -> 3D approach like professionals do
- Study of the charge collection and depletion capabilities will be performed
  - Charge collection with different pixel pitch (4µ, 25µ, 50µ)
  - Response linearity with energy
  - Sensitivity to 1 keV photons
  - Depletion uniformity– Sr source, Edge TCT studies
  - Neutron irradiated samples

Thank you for your attention

Motivation



Hybrids

Monolithic sensor

Advantages :

- Different materials of detectors
- Thick detectors for higher energies available
- Radiation hardness

Disadvantages:

- Pixel pitch
- Hard to set the threshold low
- Costs: Detectors, Bonding

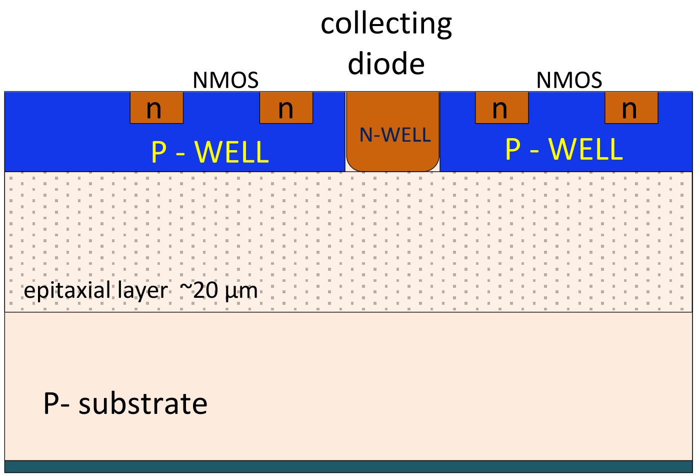
Advantages :

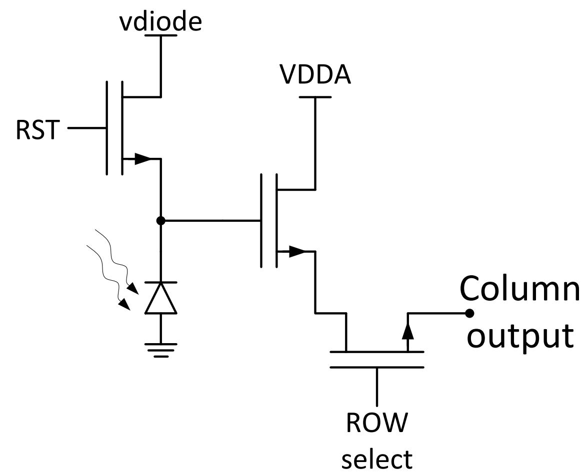
- Smaller pixels
- Standard CMOS technology (**$**)
- No bump bonding needed
- Noise lower than in hybrid det. Due to small capacitance at the input

Disadvantages:

- Low energy X-rays only (< 20 keV)
- Radiation tolerance smaller than in hybrids

MAPS





<u>Standard MAPS</u>

- Introduced at the end of the XXth century for digital cameras
- Only NMOS transistors in pixels (PMOS would take part in charge collection)
- Charge collection mainly through diffusion (low efficiency, no depletion)
- Thin sensitive area – limited in Xray applications, but work with indirect detection
- Used in various charge particle detection applications