DEPFET Active Pixel Sensors for the ILC

Test of the Prototype System

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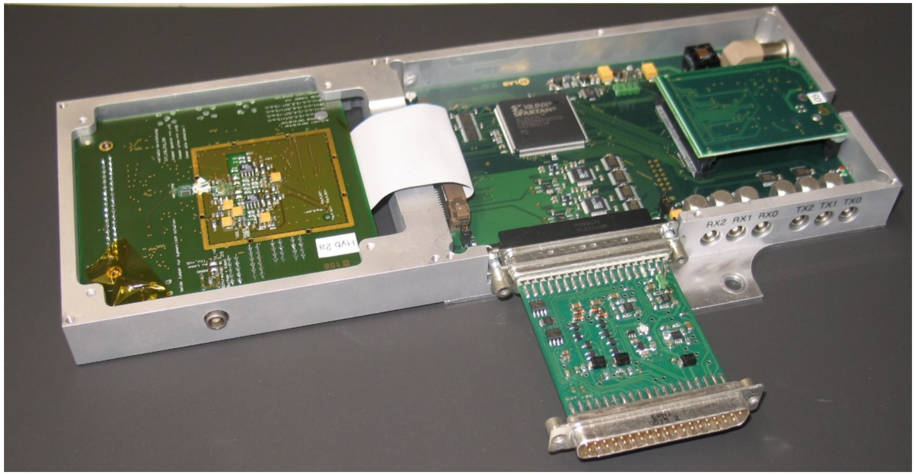
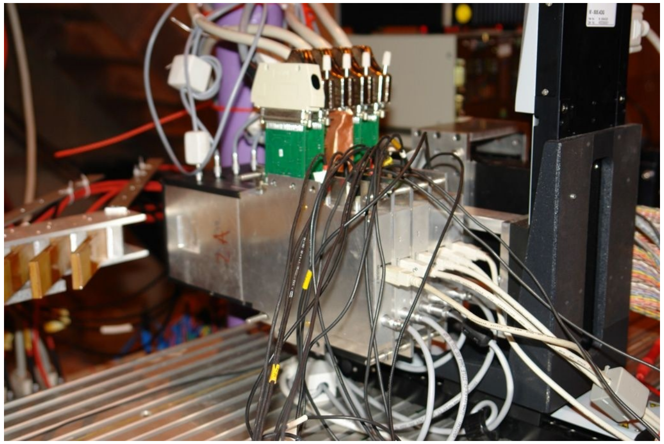


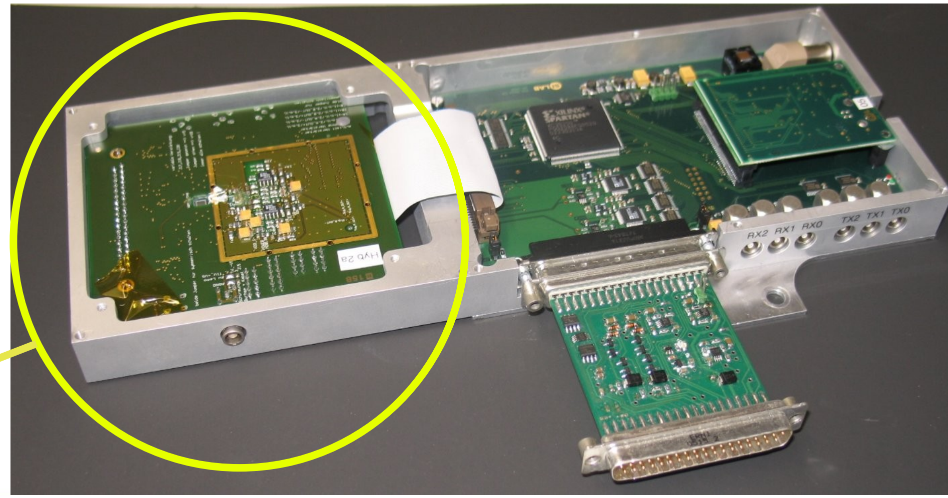


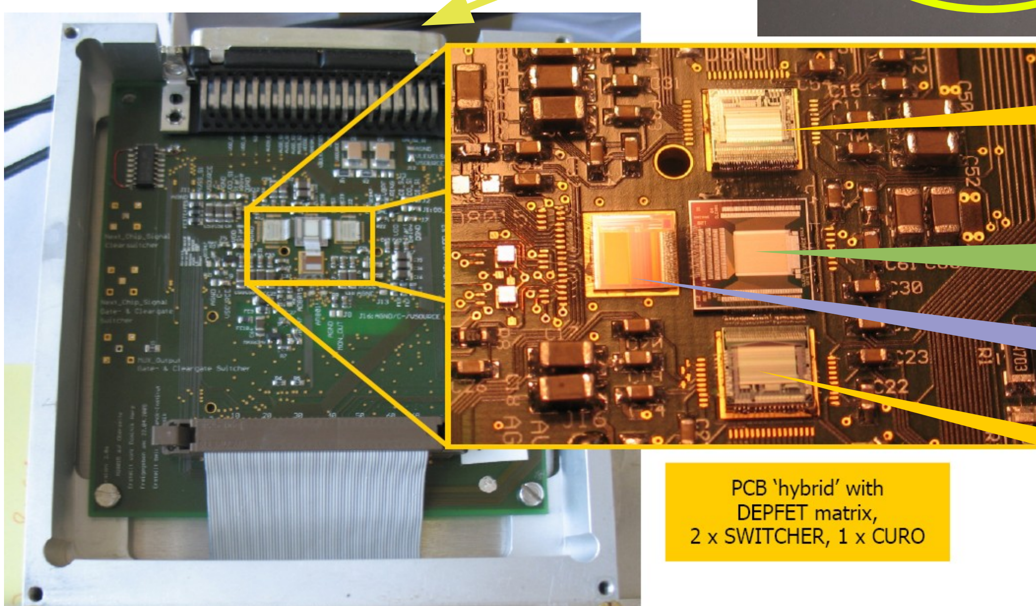
Outline

- ✔ Description of the system
- ✔ Characterization of the system
- ✔ Laser tests
- ✔ Beam test results
  - ➔ DEPFET telescope

Description of the system

- ✔ Hybrid
  - ➔ 64x128 PXD4 matrix
  - ➔ CURO chip
  - ➔ 2 SWITCHER chips
  - ➔ Transimpedance amplifiers
- ✔ S3A Board:
  - ➔ ADCs
  - ➔ FPGA generating DAQ sequences
  - ➔ USB 2.0 link for data transmission

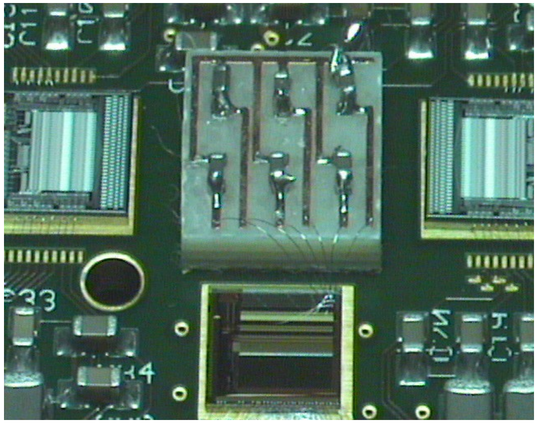


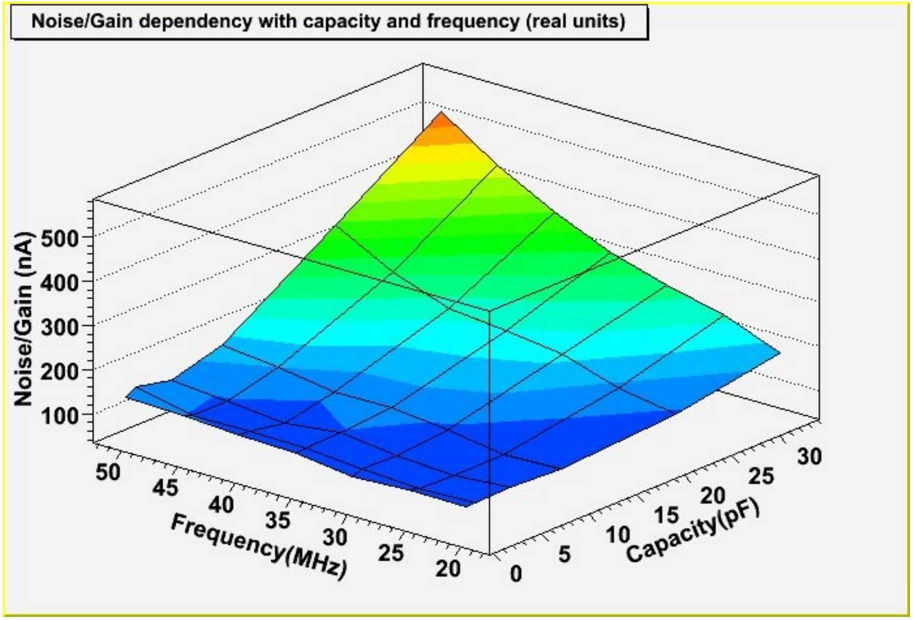


PCB 'hybrid' with DEPFET matrix, 2 x SWITCHER, 1 x CURO

Characterization of the system – CURO

- ✔ Study CURO performance as a function of readout frequency and input capacitance
  - ➔ Use internal calibration circuitry
  - ➔ Scan threshold to obtain the 50% point at each calibration pulse.
- ✔ Array of capacitors at input
  - ➔ 1pF to 33 pF

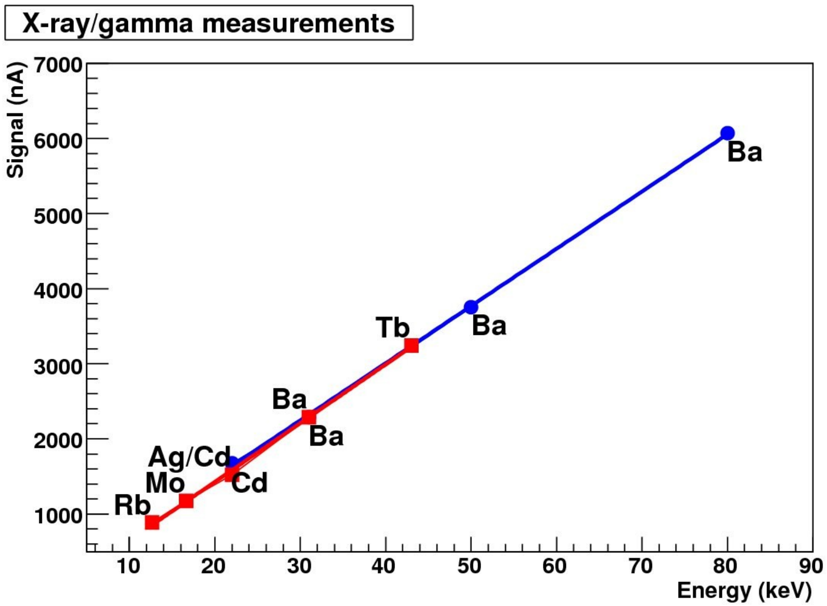




- ✔ For small capacitance, noise is independent of r/o freq.
- ✔ CURO in trouble for high input capacitance and high row r/o freq.
- ✔ For 50µm thick sensors
  - ➔ For 0pF load ⇢ S/N ~ 16
  - ➔ At 40pF load ⇢ S/N ~ 3
- ✔ After CURO *exercise* many problems understood. Next generation should be better.

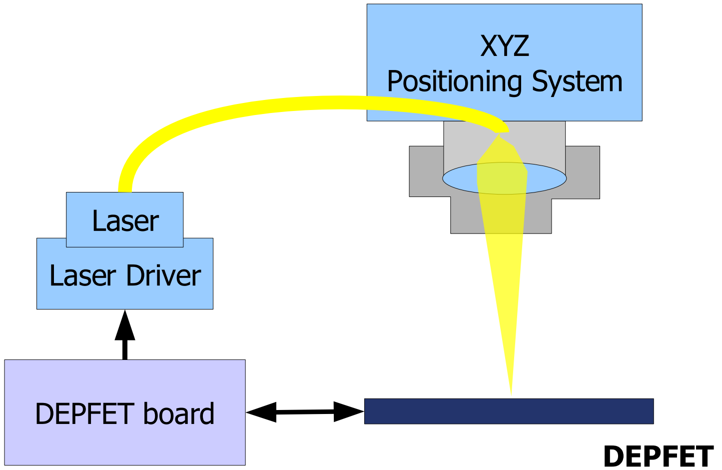
Characterization of the system – PXD4 matrices

- ✔ Measured several X-ray peaks from a number of radioactive sources
- ✔ Linear response from 2000 to 20000 electrons
- ✔ From the slope of the graphs:
  - ➔ g_q = 280 pA/e$^-$
- ✔ g_q value slightly smaller than in single pixel and small arrays tests.
  - ➔ Known and understood problem...
- ✔ Noise is consistent with the one in previous slide: between 320 e$^-$ ENC (this g_q) and 240 e$^-$ ENC (single pixel g_q)
  - ➔ CURO is the main contributor to system noise



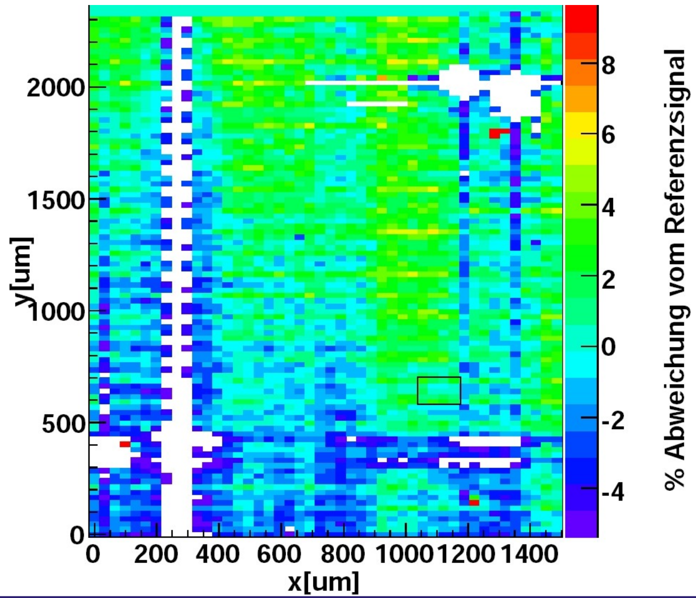
Laser tests

- ✔ Laser setup in several institutes
- ✔ Different wave lengths:
  - ➔ 682nm, 810nm, 1055nm
- ✔ Laser triggered by
  - ➔ Signal generated by DEPFET DAQ sequence
  - ➔ External pulse generator. DEPFET DAQ sequence started by internal trigger



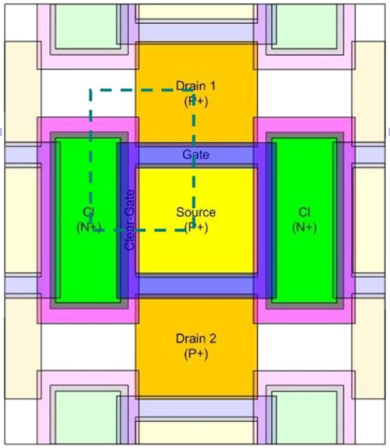
- ✔ Laser focused on matrix backplane
- ✔ Laser spot: 2.5 – 5 μm
- ✔ Laser mounted on a XY-stage with 1μm steps

- ✔ 5x5 clusters
- ✔ Pixel-to-pixel variations on Mean signal height are of ~5%

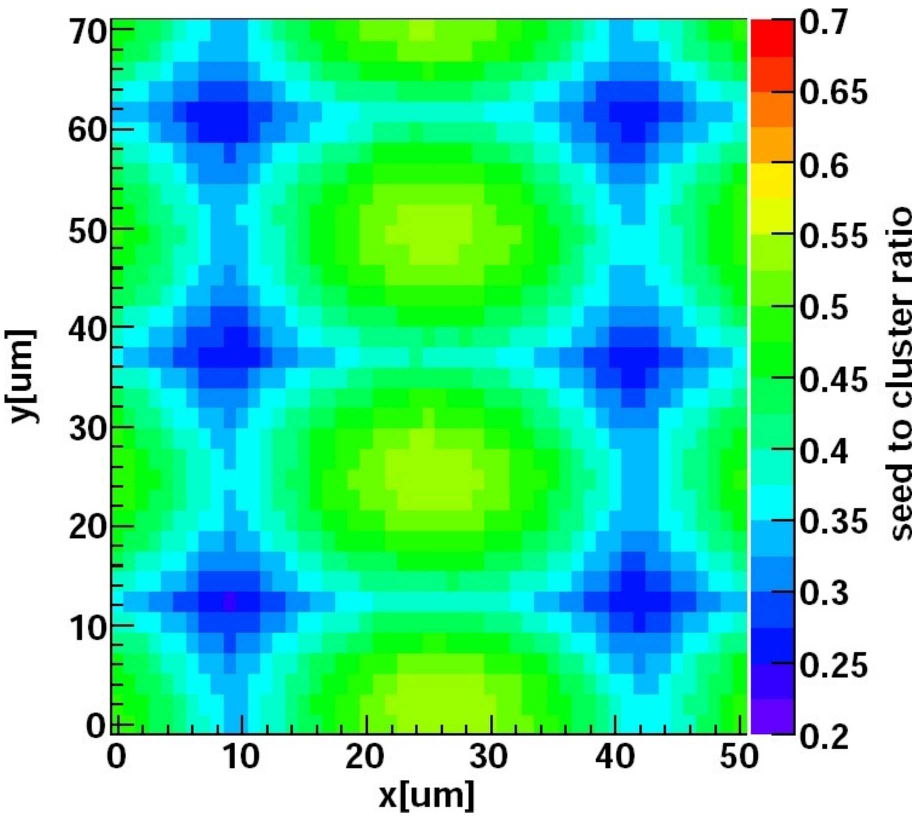


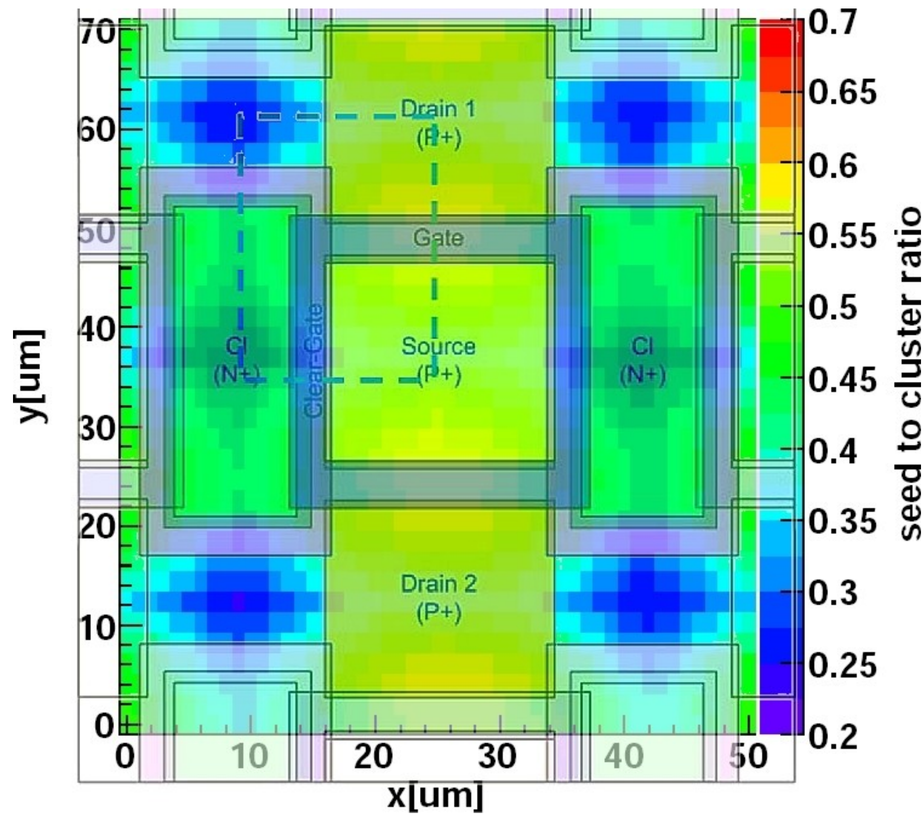
Laser tests

- ✔ Scan with the laser a DEPFET double pixel structure.
- ✔ Figure below shows the seed to cluster signal ratio



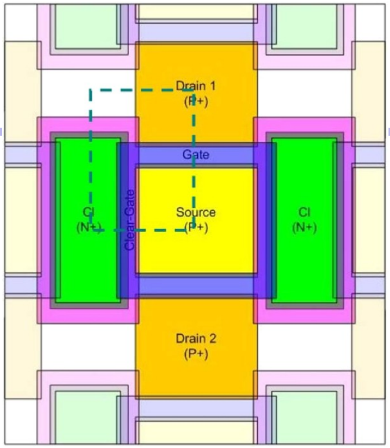
- ✔ Maximum seed fraction happens in the middle of the pixel and decreases in the region between pixels.



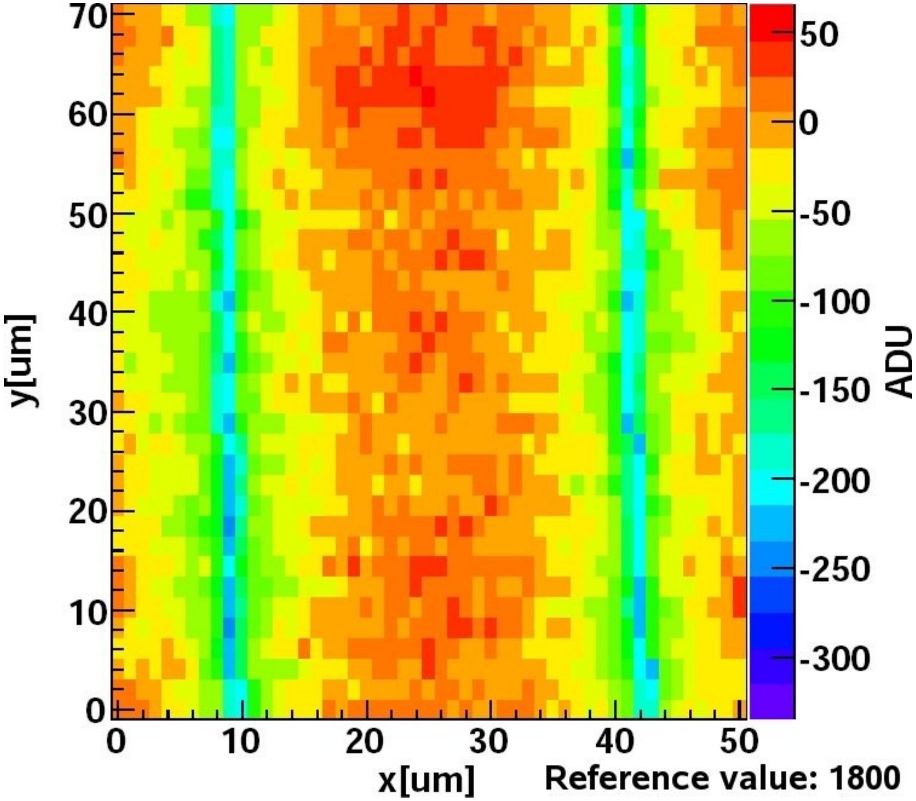


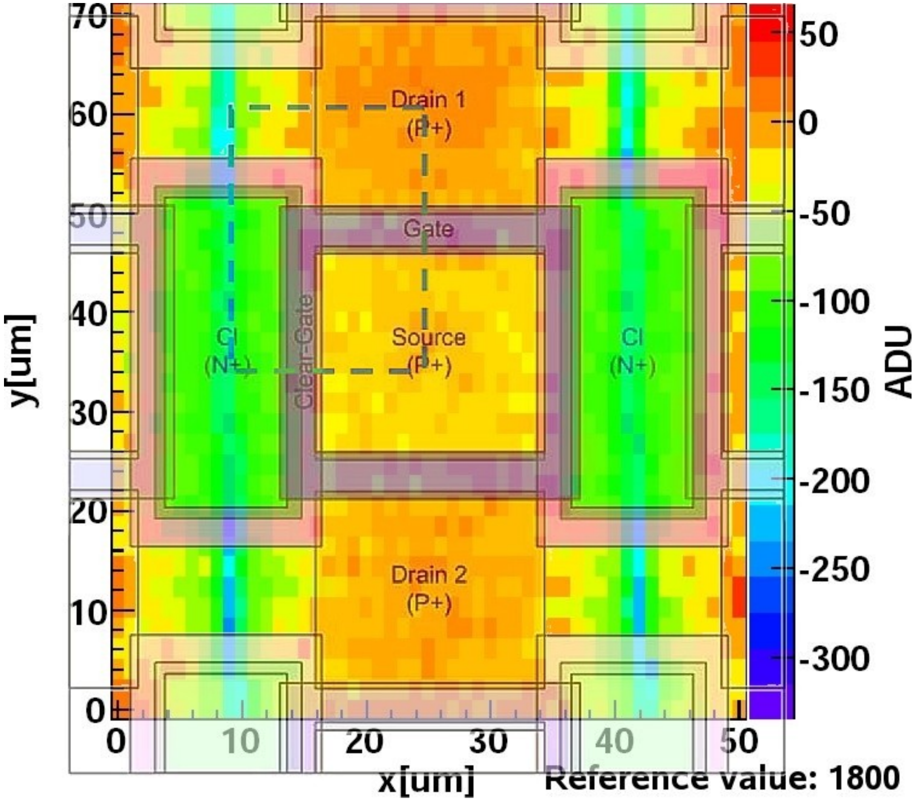
Laser tests

- ✔ Total cluster signal shows charge losses which correspond to the n^+ clear implants
- ✔ Also observed in detailed 3D device simulations.



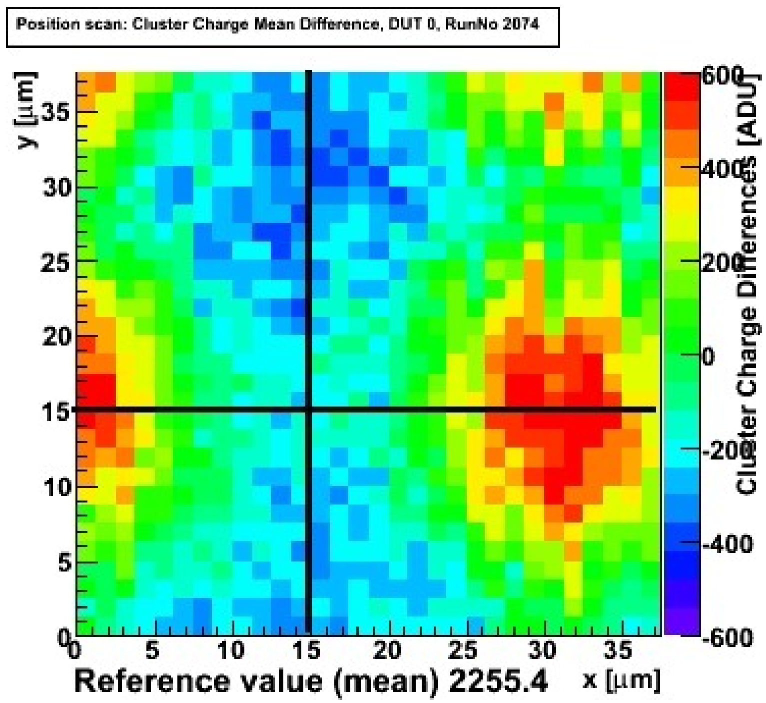
- ✔ This explains why we observe a g_q value which is smaller than the one measured with single pixels



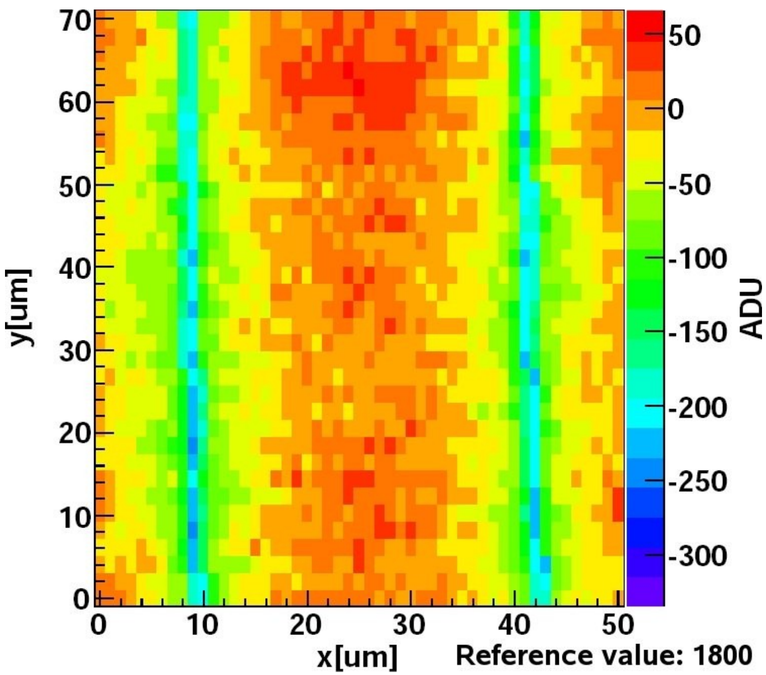


Laser tests

- ✔ Measurements show that charge losses are bigger in matrices without the HE implant
- ✔ This has also been confirmed by the 3D device simulations.
  - ➔ We believe that the new matrix design with a better clear region will solve these problems.



Matrix w/o HE implant



Matrix with HE implant

Laser tests

- ✔ Helped considerably to understand charge collection in the double pixel structure
- ✔ Charge losses in the clear region explain the discrepancy in g_q measurements between single pixels and matrices
- ✔ This effect has been understood and reproduced with 3D device simulations
- ✔ New PXD5 matrices have a much more improved clear region in order to overcome this problem.

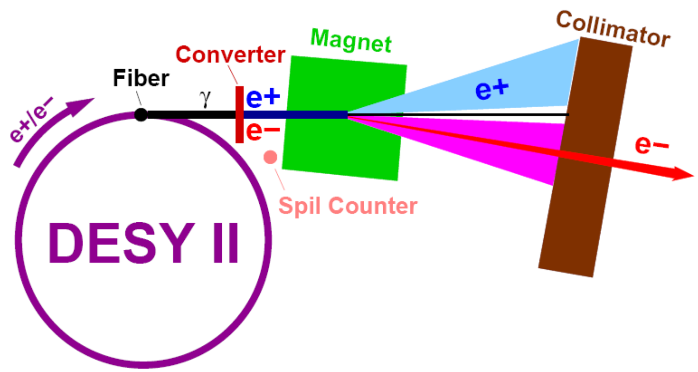
Beam test

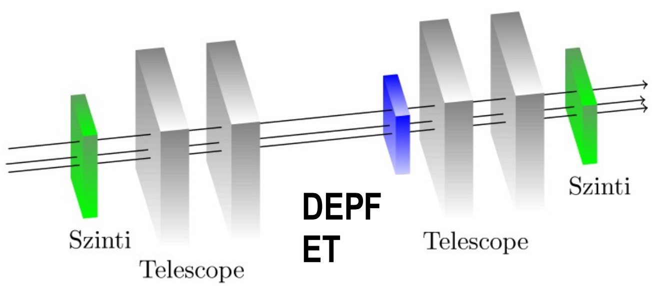
- ✔ Beam tests made in the period 2004-2006
  - ➔ At DESY synchrotron (6 GeV/c electrons)
  - ➔ At CERN (SPS) with ~180 GeV/c pions
- ✔ Sensors are
  - ➔ 450 µm thick
  - ➔ Pixel size: 36x22 µm
- ✔ Analogue readout: read all pixels in rolling shutter mode
- ✔ Speed
  - ➔ 0.5 kHz continuous frame rate
    - ➘ Dominated by USB transf.

Stage	Time	
Clear pulse duration	60 ns	
Sampling 1 row (sample-clear-sa	320 ns	This would give 3MHz row rate
One double row	14.8 µs	Non zero sup. r/o
One Frame	947.2 µs	

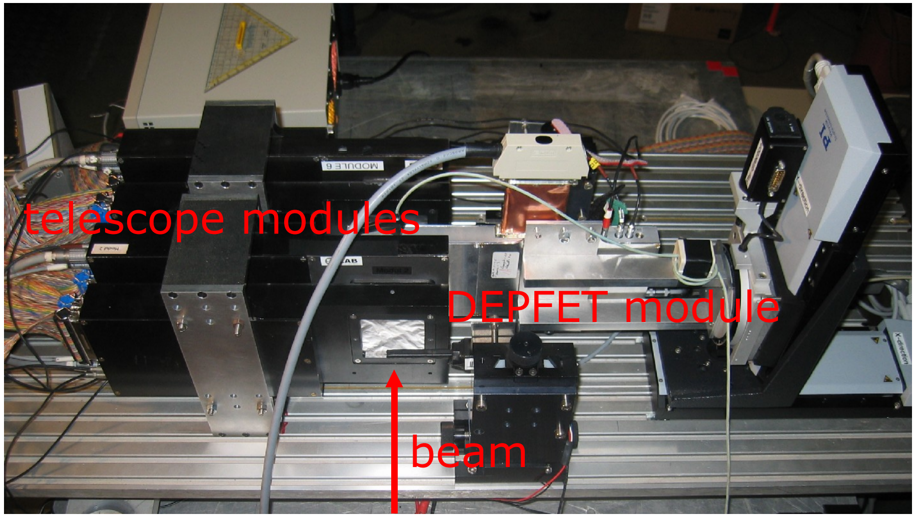
- ✔ In the recent CERN testbeam a **DEPFET telescope of 5 DEPFET planes has been operated**

Beam test - DESY





- ✔ Bonn ATLAS Telescope system
  - ➔ 4planes of double sided silicon strip sensors with 50 µm pitch
  - ➔ Resolution ~5 µm
  - ➔ 4.5 kHz r/o rate
- ✔ Trigger provided by coincidence of 2 scintillators
- ✔ DEPFET mounted on XYφ stage

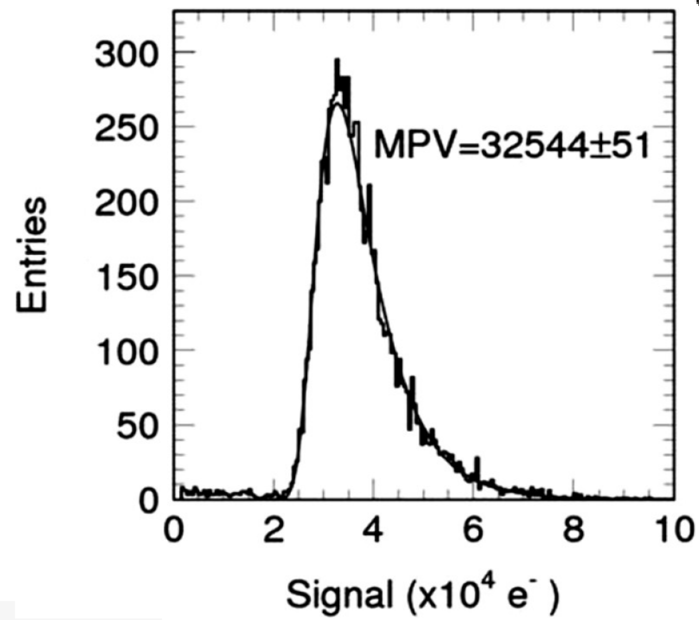


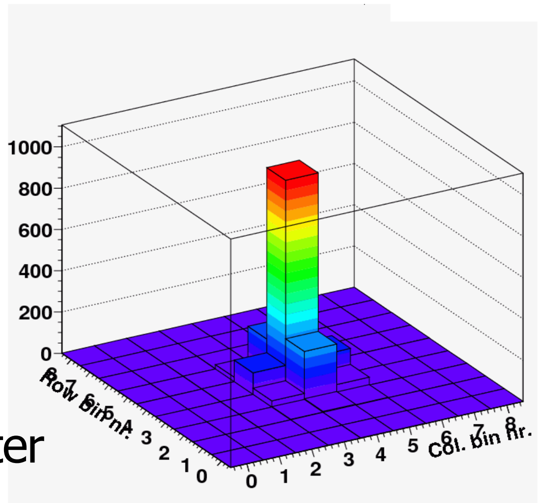
Test beam – cluster charge

- Clusters are found requiring
  - Seed with signal > 5σ
  - Add neighbors with > 2σ in NxN
- Signal is mostly confined in 3x3 clusters

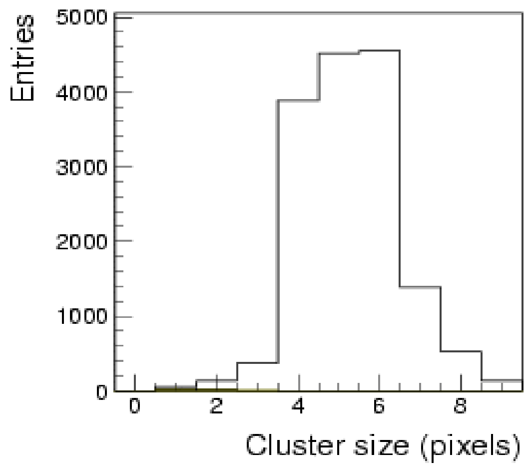
Size	Signal (ADC)
3x3	1835
5x5	1854
7x7	1873

- Noise is determined from pedestals, after common mode subtraction: 16.5 ADC
- S/N ~ 110





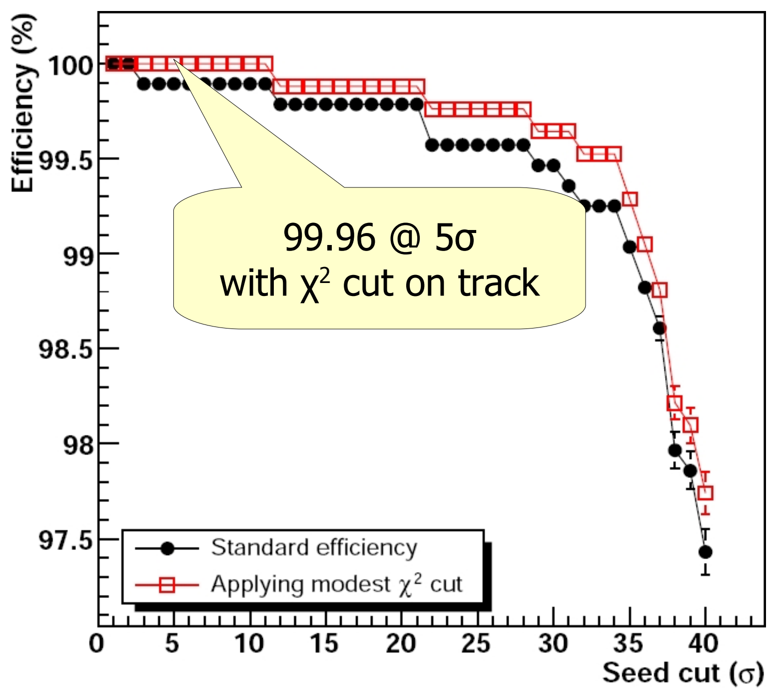
Averaged cluster

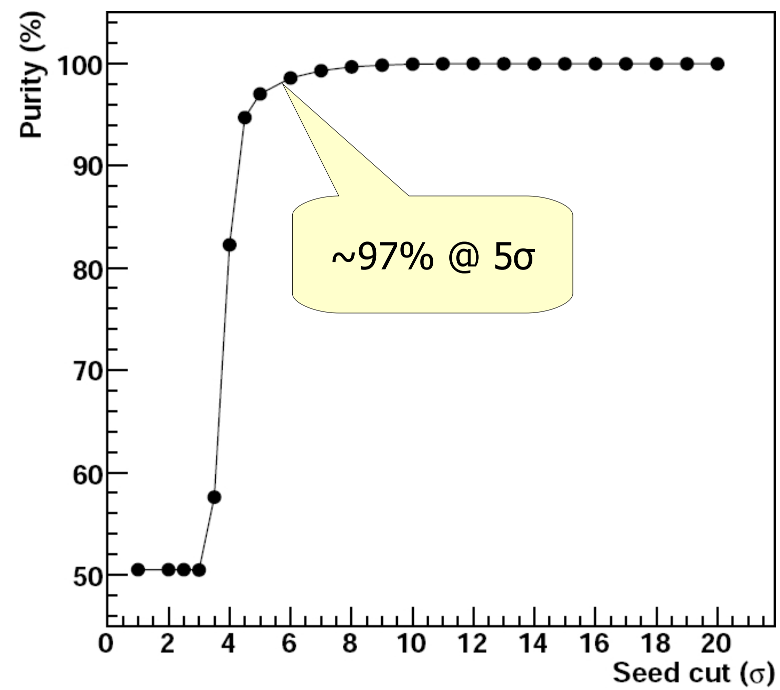


Test beam – Efficiency and purity

$$Efficiency = \frac{Number\ of\ clusters}{Number\ of\ good\ tracks}$$

$$Purity = \frac{Number\ of\ clusters \in track}{Number\ of\ all\ clusters}$$

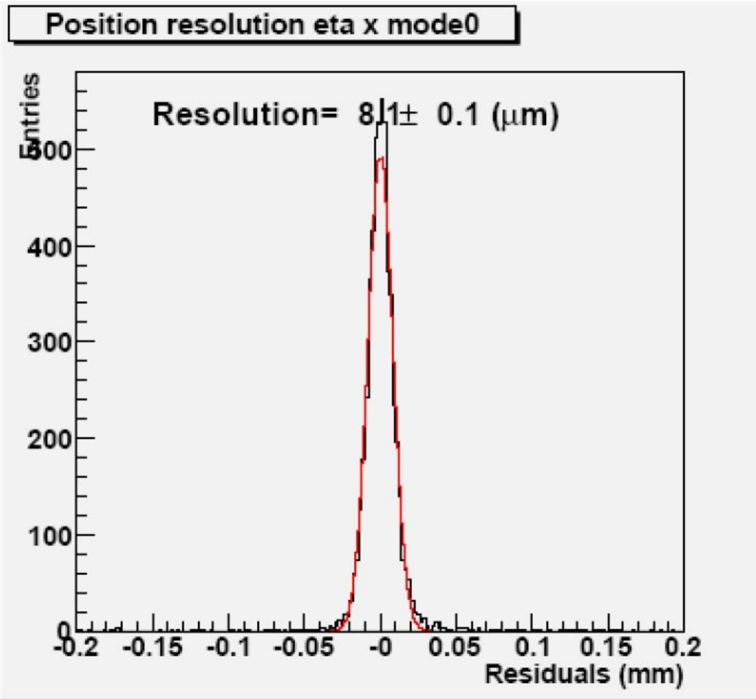




Cluster accepted if within ±2 pixels around predicted position

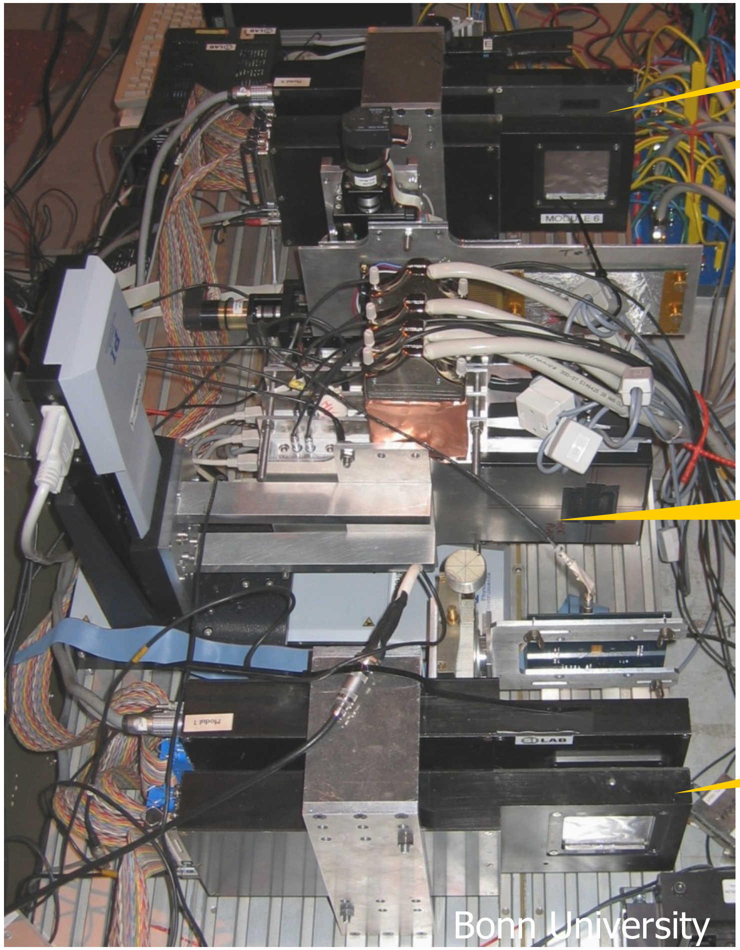
Test beam – Position resolution (DESY)

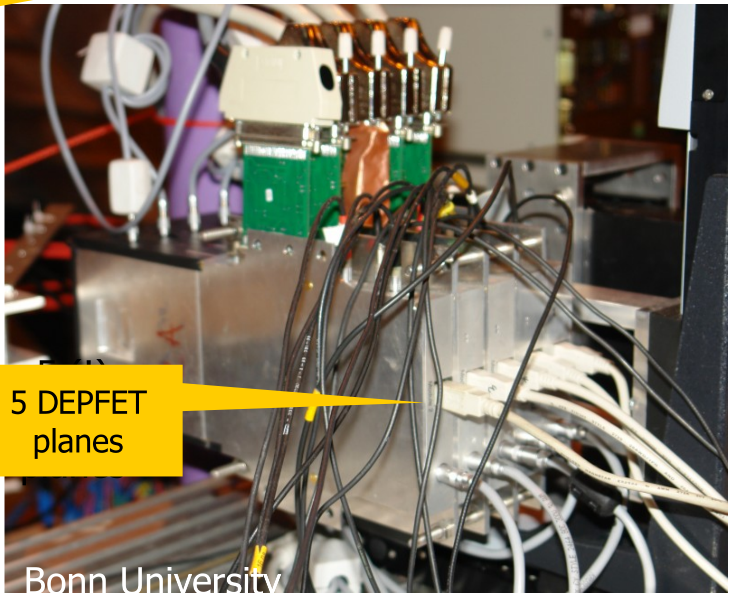
- ✔ Hit positions had a residual of
  - ➔ 8 μm in X
  - ➔ 7 μm in Y
- ✔ Predicted position had a limited resolution due to multiple scattering and telescope performance (~5 μm)
  - ➔ Geant4 studies yielded ~7 μm
  - ➔ Bigger than the intrinsic pixel resolution
- ✔ After correcting for that
  - ➔ 4.2 μm in X
  - ➔ 1.5 μm in Y
- ✔ We wanted to avoid the multiple scattering and, also, have a telescope providing a position resolution smaller than the intrinsic pixel resolution....



Test beam – DEPFET telescope

- ✔ DEPFET telescope
  - ➔ 5 DEPFET modules 25 mm apart
- ✔ Tested at CERN SPS with ~180 GeV/c pions





2 strip planes

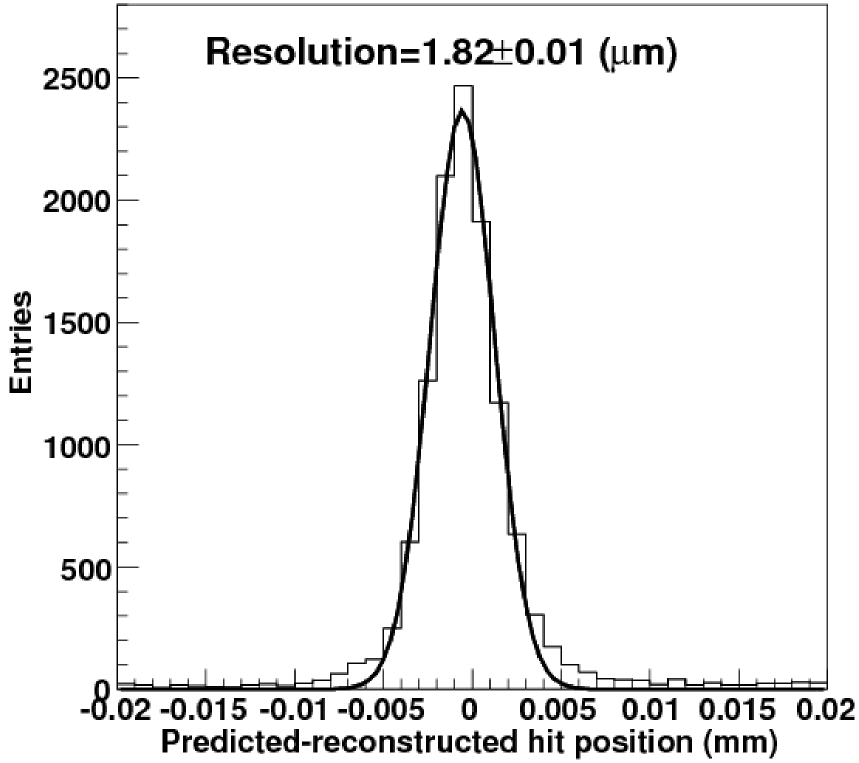
5 DEPFET planes

2 strip planes

Test beam – DEPFET telescope

- ✔ Analysis like with DESY data
- ✔ Much better position resolution since multiple scattering is smaller

DEPFET ID	σ_X (μm)	σ_Y (μm)
1	12.62	5.45
2	7.15	3.81
3	3.78	2.17
4	5.36	1.82
5	6.50	3.68



- ✔ Numbers include track extrapolation error
- ✔ If we estimate with Geant4 this extrapolation error get for the Y coordinate

	DEPFET id (res. μm)		
	2	3	4
Measured resolution	3.71	2.28	1.89
Track extrapol error	2.49	1.46	1.41
Intrinsic resolution	2.75	1.75	1.25

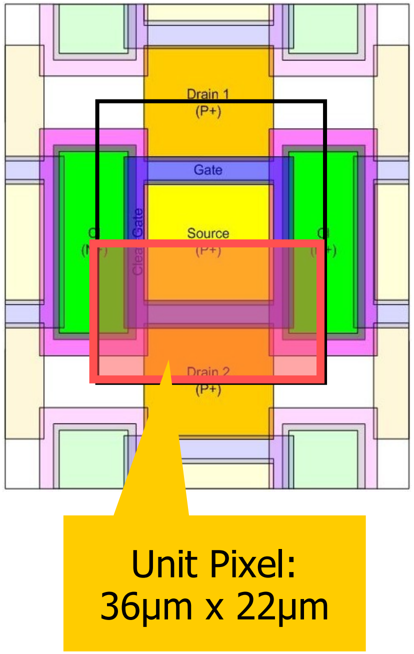
Summary

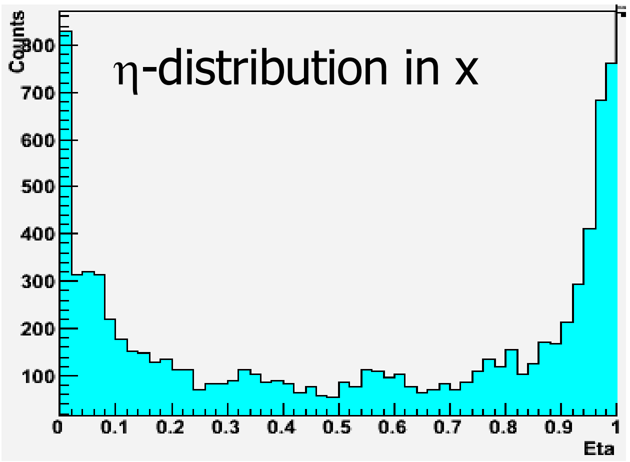
- ✔ Our system has allowed us to test many aspects of the DEPFETs and their readout
  - ➔ The CURO has been a good battle horse to exercise the system
    - ➘ Unable to perform at high capacitive loads
      - ✘ Has helped in pointing to the main problems of a drain mode readout
  - ➔ Laser and X-ray setup
    - ➘ Charge losses have been understood and
    - ➘ we are confident we have the tools to control this and tune/contrast the 3D device simulation
  - ➔ The system has been operated with test beams at DESY and at CERN
    - ➘ S/N ~ 110 for 450 μm
    - ➘ The system noise is understood and prospects for an ILC module are good
    - ➘ Position resolution is also good given the size of the pixels
  - ➔ We have built and operated a 5 DEPFET planes telescope

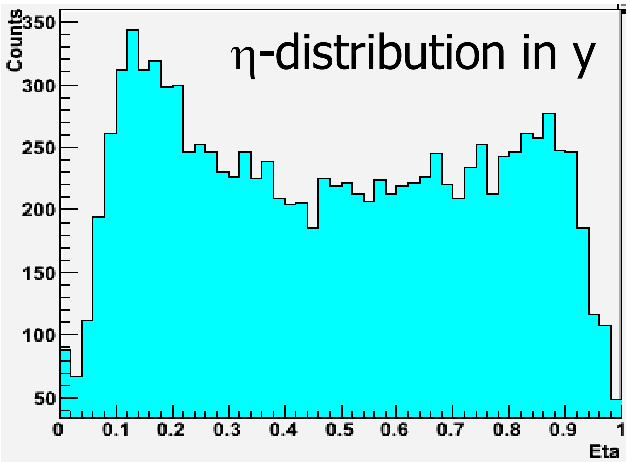
Backup Slides

Test beam – Charge sharing

- ✔ Eta distribution gives information about charge sharing
- ✔ In the "double pixel" configuration, charge sharing is higher in Y
  - ➔ We expect better resolution in Y for these devices

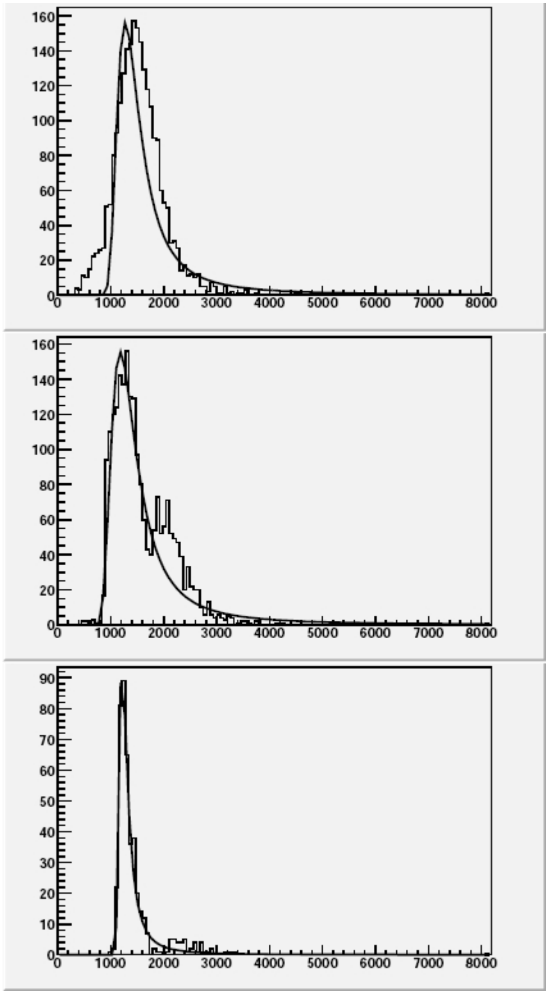






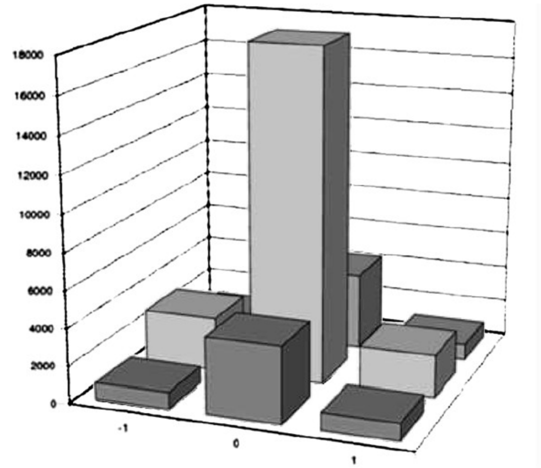
Test beam – zero suppression

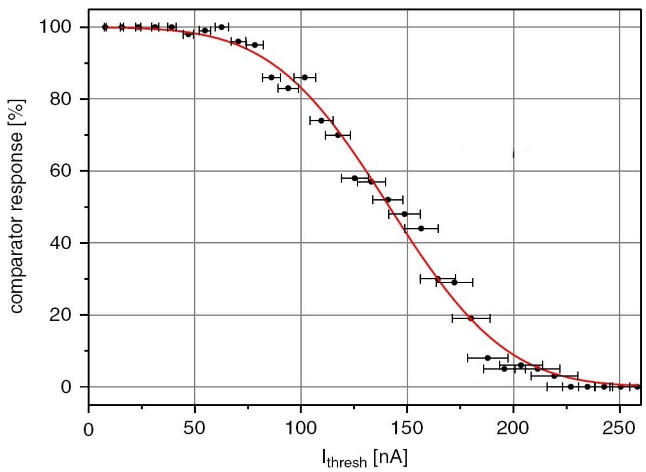
- ✔ Zero suppression exercised in the test beam
  - ➔ Top: low threshold
    Noise is taken as cluster seed and many pixels are added as neighbors
  - ➔ Middle: medium threshold
    Tails at both ends disappear
  - ➔ Bottom: high threshold
    Neighbors are not included and the distribution is narrower

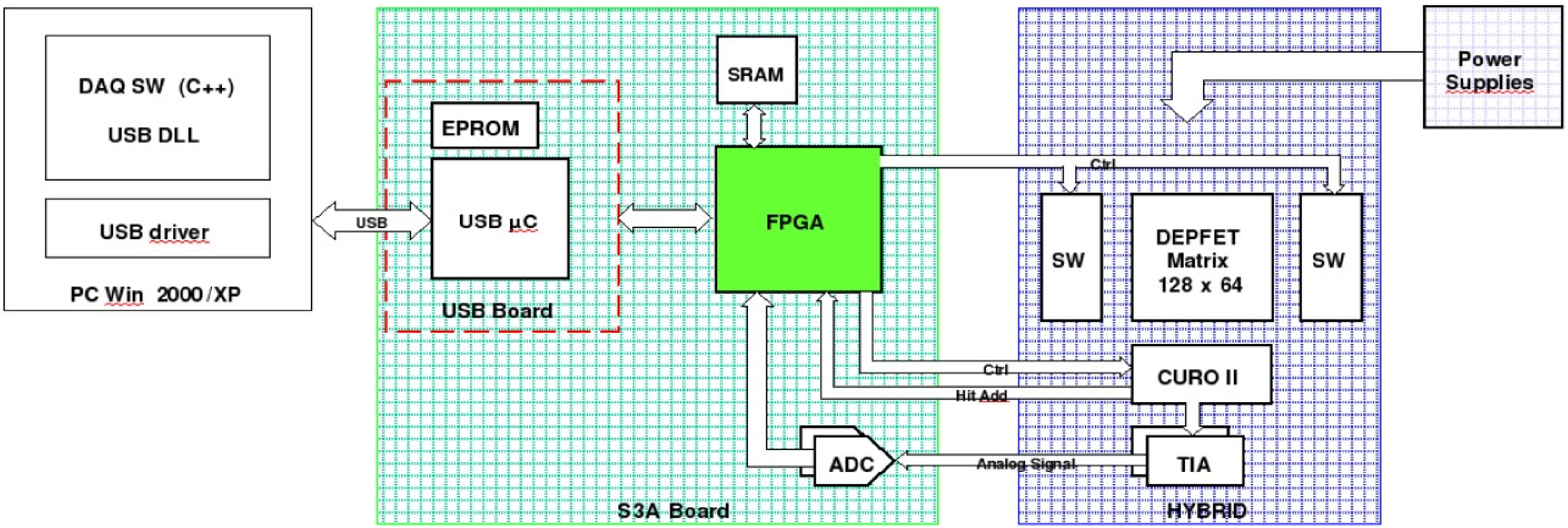


Conventions for Data Analysis

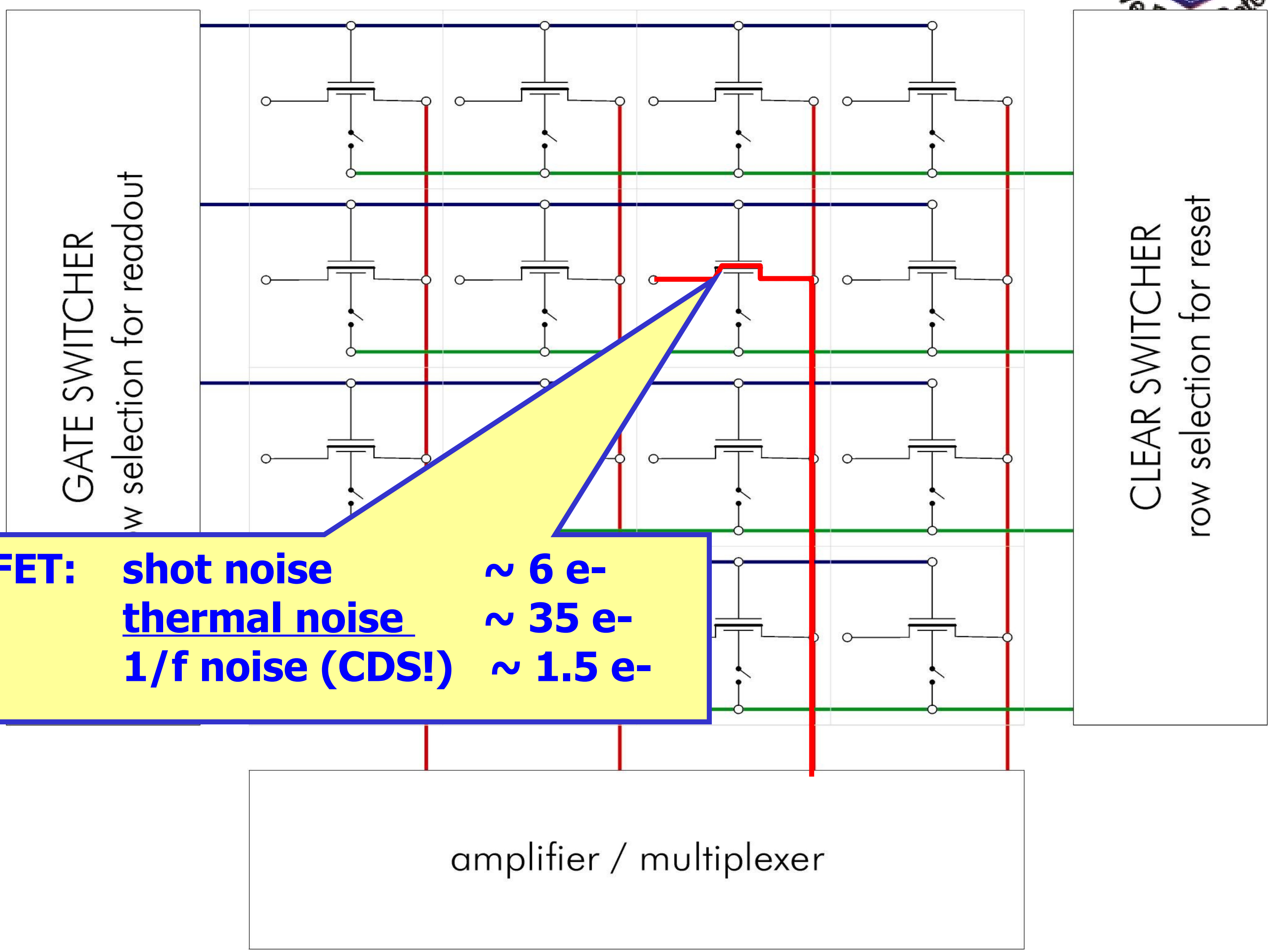
- ✔ Cluster definition
- ✔ S-curve






DAQ SW (C++)
USB DLL
USB driver
PC Win 2000 /XP
USB
EPROM
USB µC
USB Board
SRAM
FPGA
S3A Board
ADC
Ctrl
Hit Add
Analog Signal
Power Supplies
Ctrl
SW
DEPFET Matrix 128 x 64
SW
CURO II
TIA
HYBRID

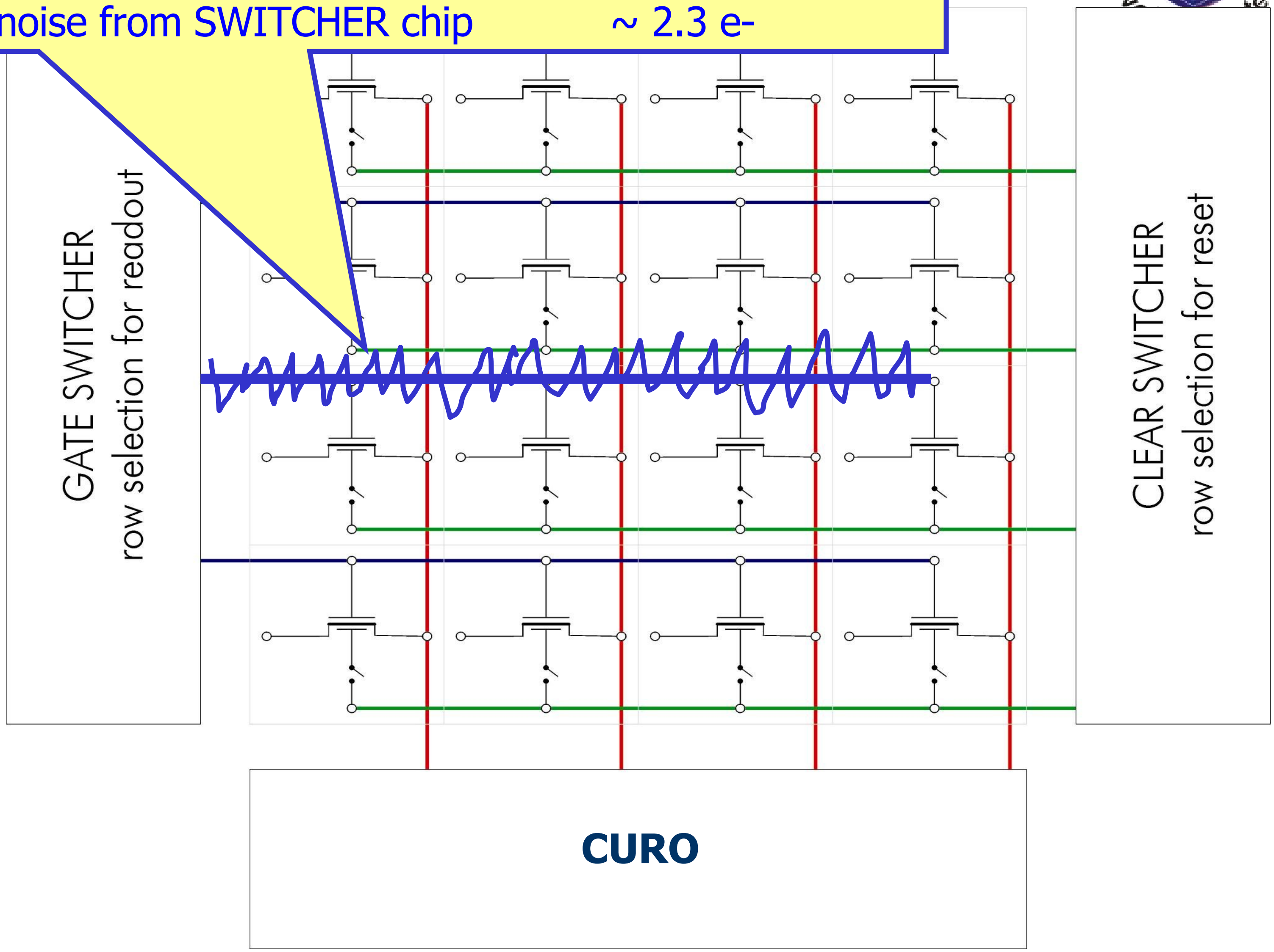
System Noise



from DEPFET: sensor — **shot noise** ~ 6 e-
thermal noise ~ 35 e-
1/f noise (CDS!) ~ 1.5 e-

System noise

kT/C - noise from SWITCHER chip ~ 2.3 e-



System noise