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# Beam-test of CMOS sensors with 6 GeV electrons at DESY

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on behalf of the DESY/Uni-Hamburg MAPS Group

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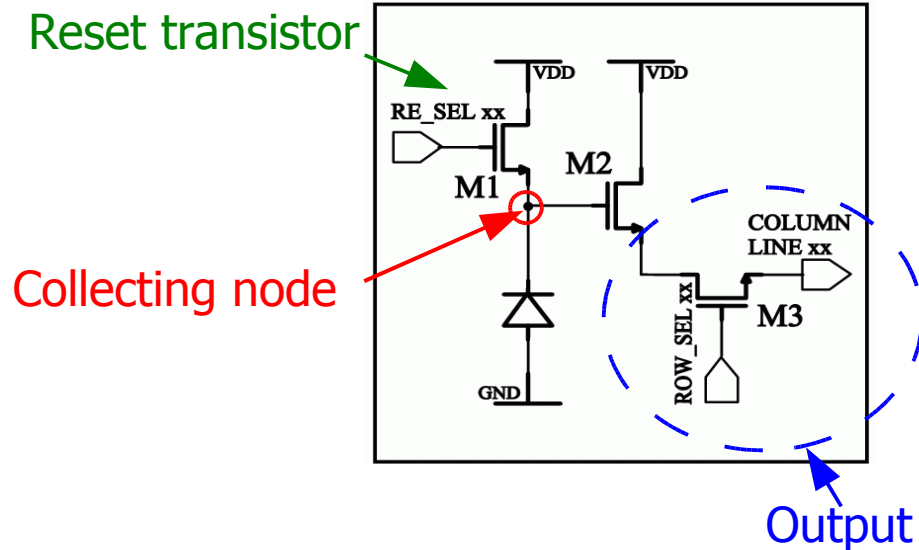
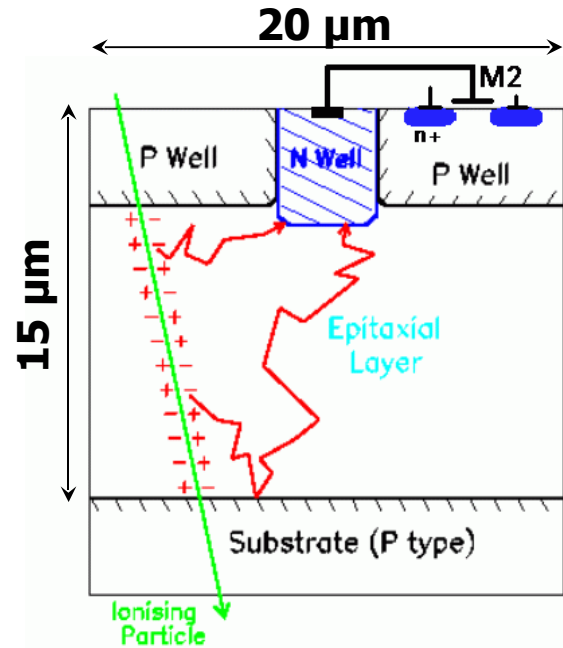
# Outline

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- **Introduction:** CMOS sensors for the VXD at the ILC
- **DESY activities on CMOS sensors** (in collaboration with IReS, Strasbourg)
- **Beam-tests at DESY-II**
- **Experimental results:**
  - Signal and S/N
  - Cluster charge
  - Temperature dependence
- **Irradiation with 10 MeV electrons:** preliminary results
- **Conclusions & Outlook**



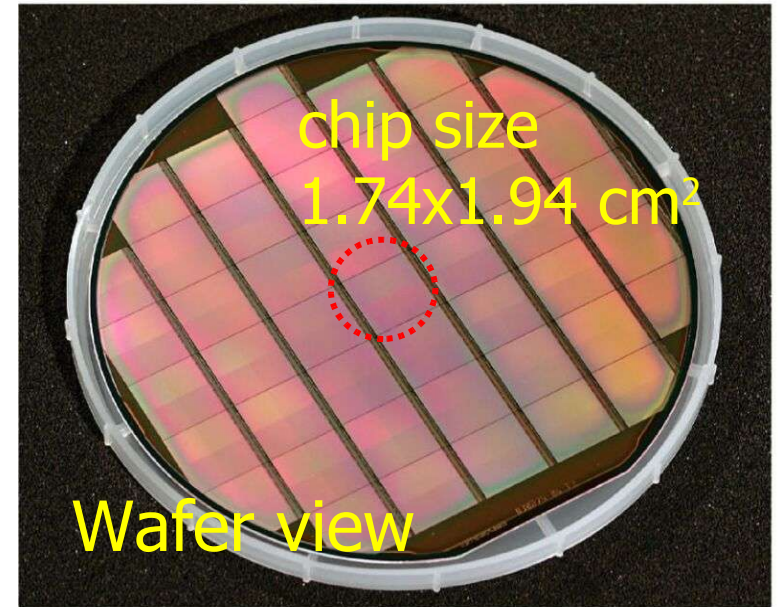
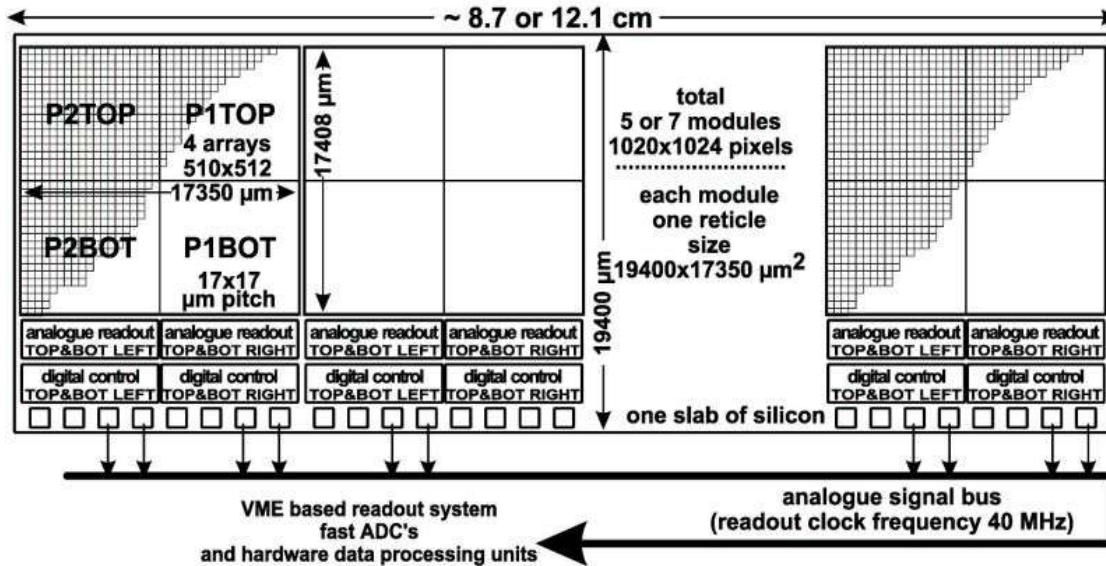
# CMOS sensors for the VXD at the ILC



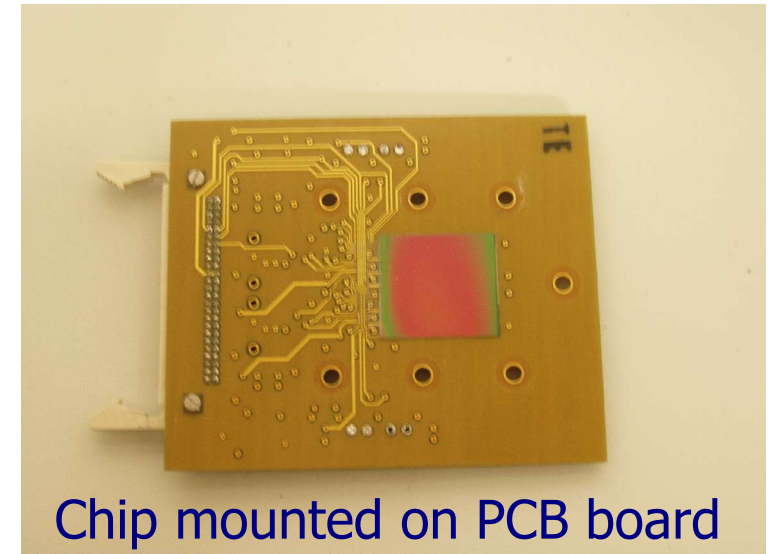
- ...also known as **Monolithic Active Pixel Sensors (MAPS)**
- **CMOS process with epitaxial layer** (large scale availability)
- Pixel pitch  $\sim 20 \mu\text{m}$ . **Position resolution** proved down to  $\sim 1.5 \mu\text{m}$
- Charge collection by **thermal diffusion** (collection times  $< 100 \text{ nsec}$ )
- **Integration of read-out electronics** on the same sensor substrate
- **Thinning** possible down to epilayer (low material budget)

# MIMOSA V: real-size sensor

**MIMOSA**=**M**inimum **I**onising particle **MOS** **A**ctive pixel sensor



- Developed by IReS/Lepsi (Strasbourg)
- real-size prototype: 3.5  $\text{cm}^2$ , 1M pixels
- 2003 batch; improved fabrication process
- AMS 0.6  $\mu\text{m}$  CMOS with 14  $\mu\text{m}$  epilayer
- pixel pitch 17x17  $\mu\text{m}^2$
- 4 independent matrices of 512x512 pixels
- serial analogue readout @ 10 MHz
- back-thinned down to 120  $\mu\text{m}$



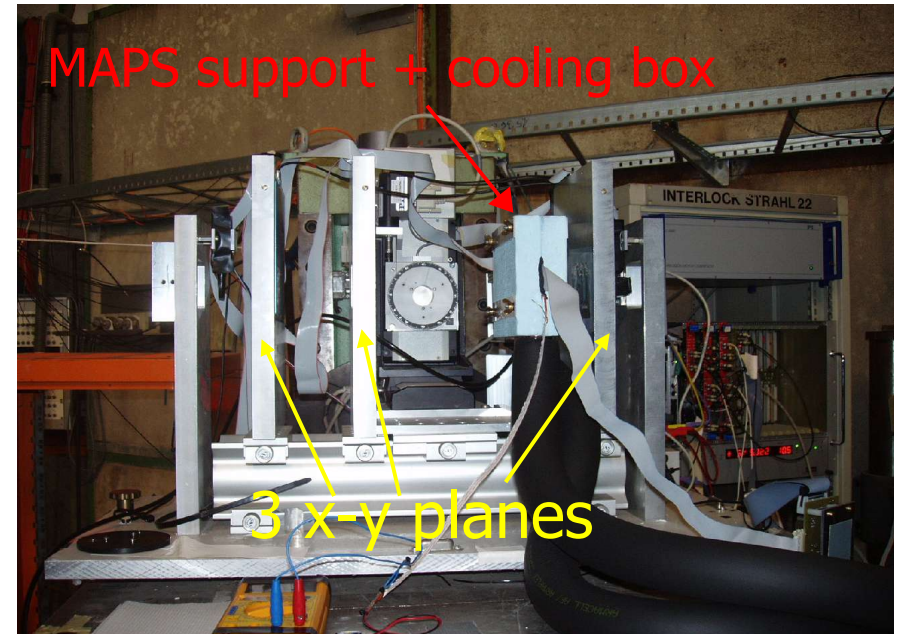
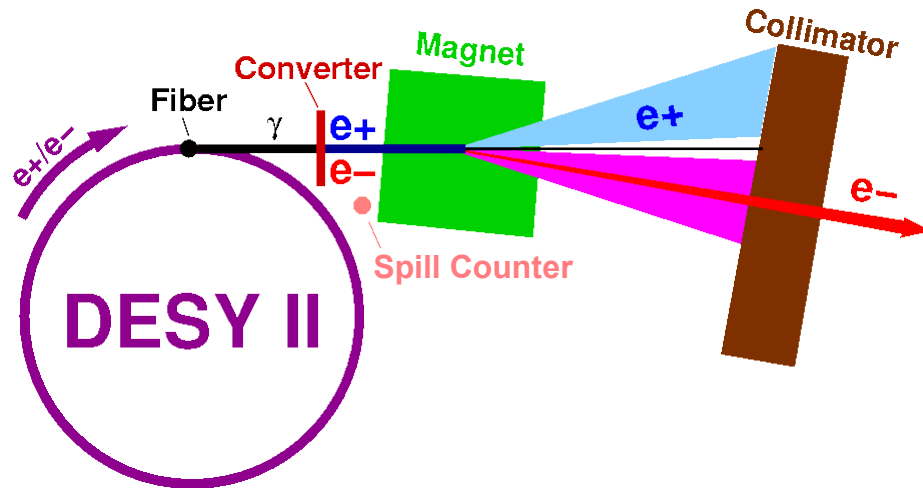
# DESY activities on CMOS sensors

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- Chip tests: beam-tests, radioactive sources
- Radiation studies
- Device simulations
- Power consumption and cooling studies: simulation and tests
- Mechanical layout
- Physics simulations: optimization of VXD design



# Beam-tests at DESY II

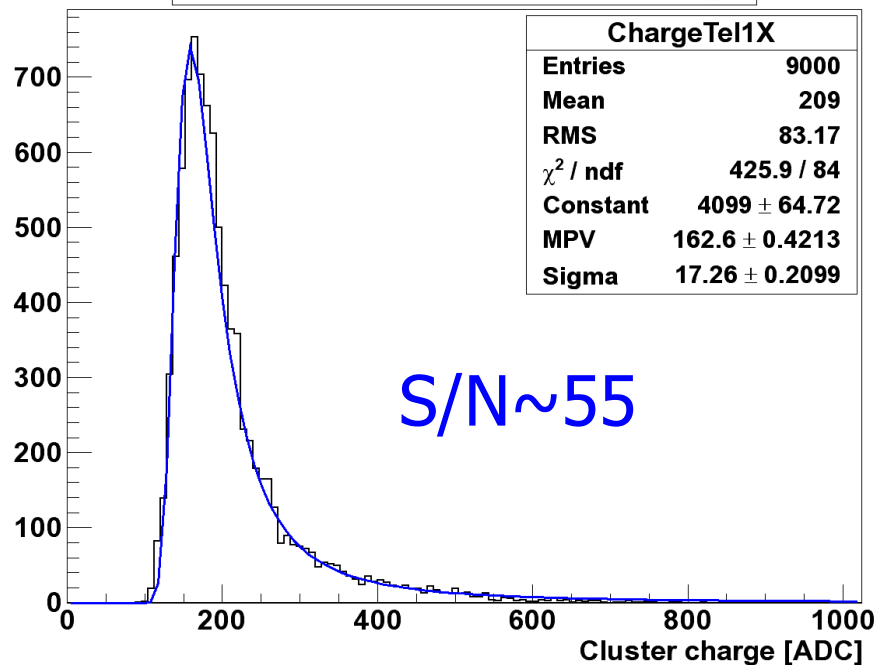


- Electrons up to 6 GeV
- 3 x-y planes silicon reference telescope
- Event rate  $\sim$ Hz (MAPS + reference telescope)
- VME telescope readout + dedicated ADC board for MAPS
- Cooling to  $-15^{\circ}\text{C}$
- Dec '04 – Jan '05 run: 400000 events

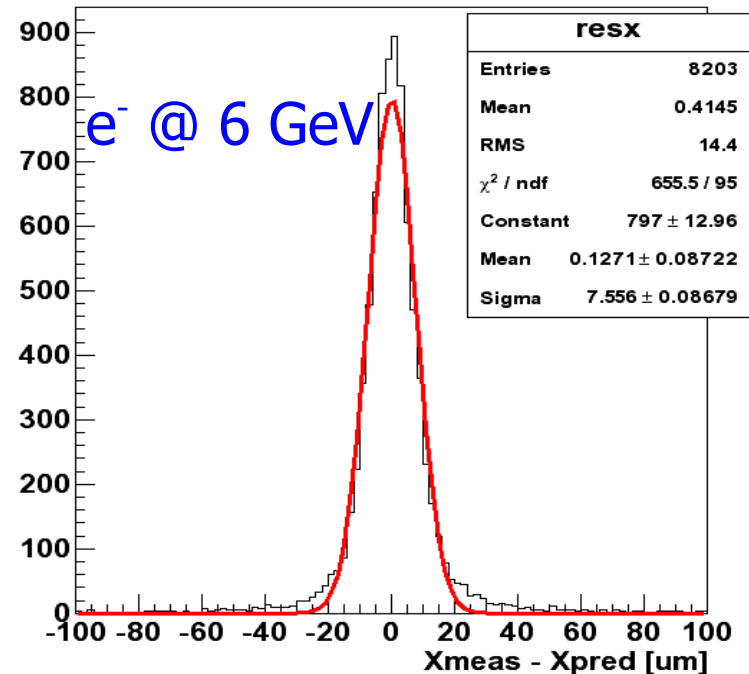


# The silicon reference telescope

Telescope I-X, cluster charge



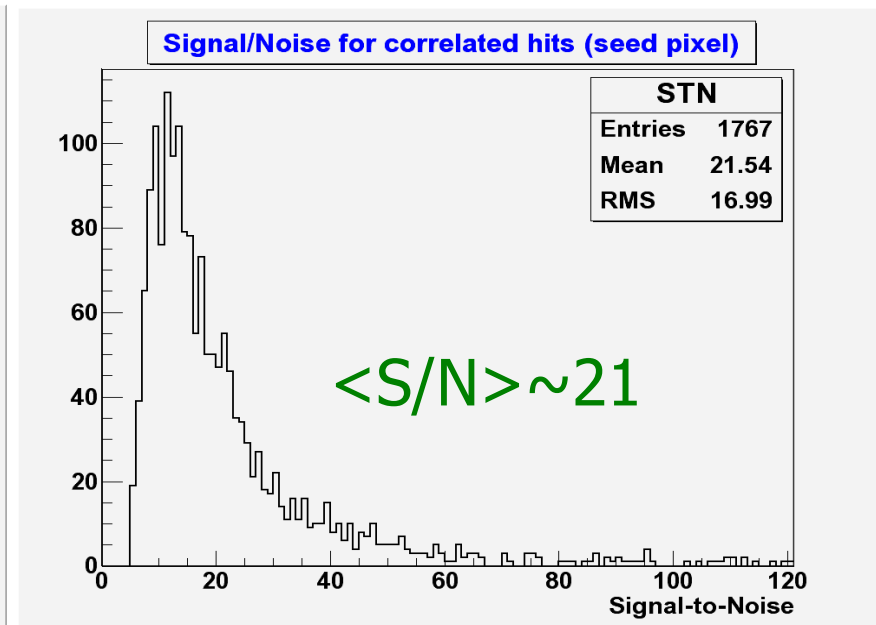
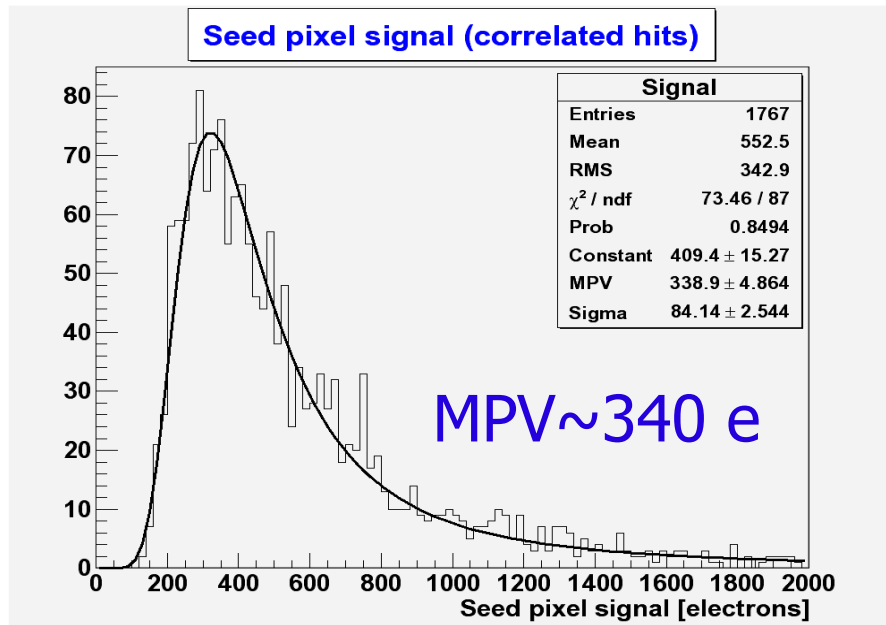
Residual distribution after track fitting



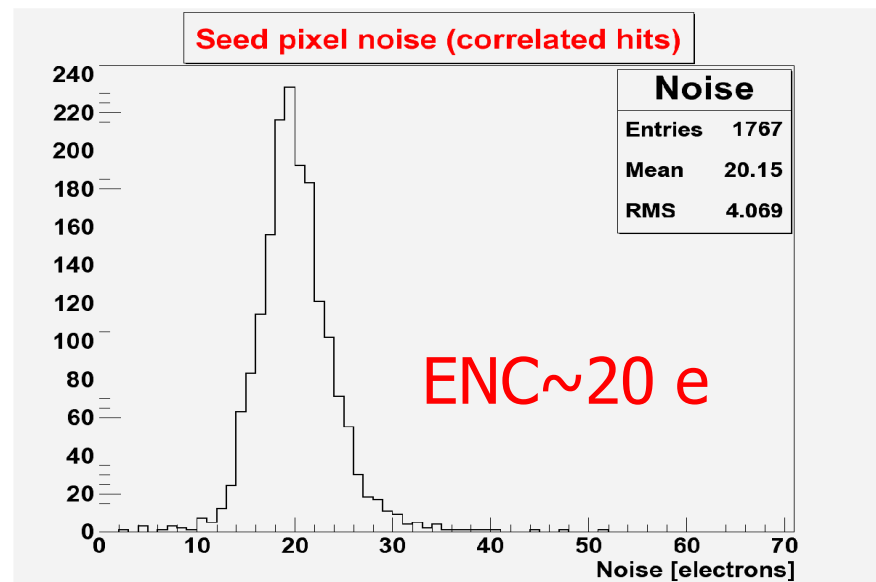
- Single-sided silicon microstrip detectors, 50  $\mu\text{m}$  readout pitch
- Detection efficiency >99%, S/N ~ 45-85
- Intrinsic resolution ~ 3  $\mu\text{m}$ , but in real life... multiple scattering!
- In this work: track fitting with ~ 6  $\mu\text{m}$  precision



# Experimental results: signal & S/N

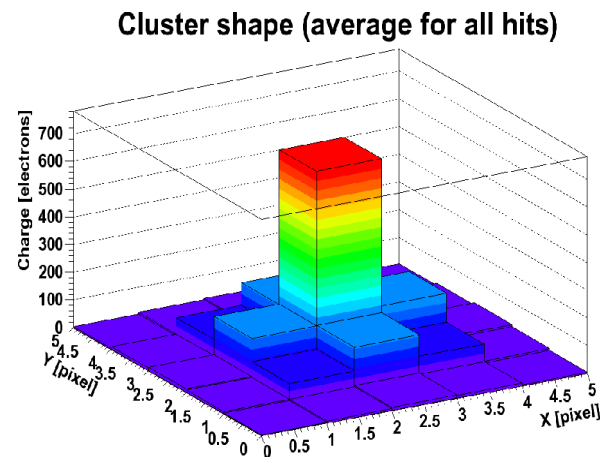
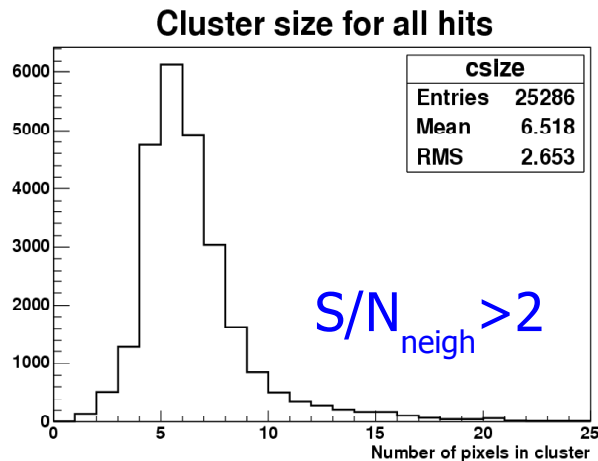
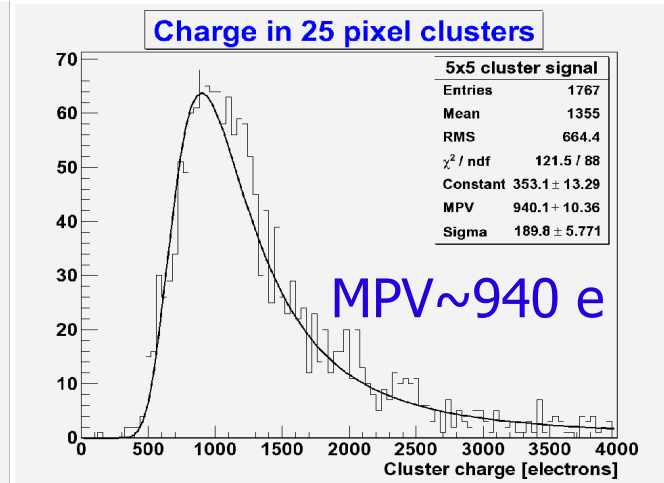
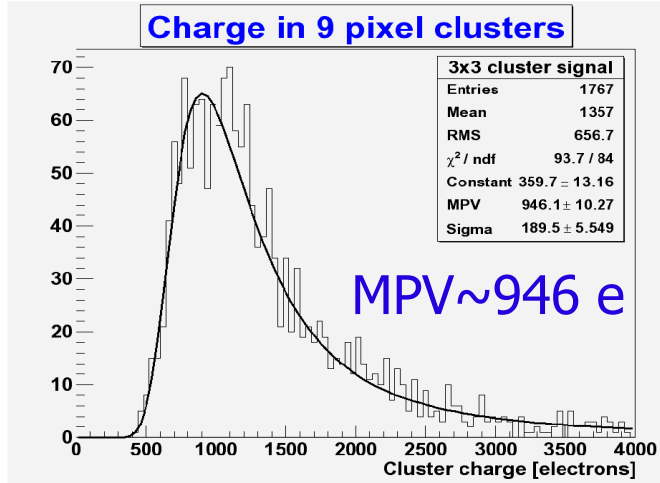


- 6 GeV electrons, cooling to  $-10^\circ\text{C}$
- MPV for seed pixel signal  $\sim 340$  e
- ENC  $\sim 20$  electrons
- Average Signal-to-Noise  $\sim 21$





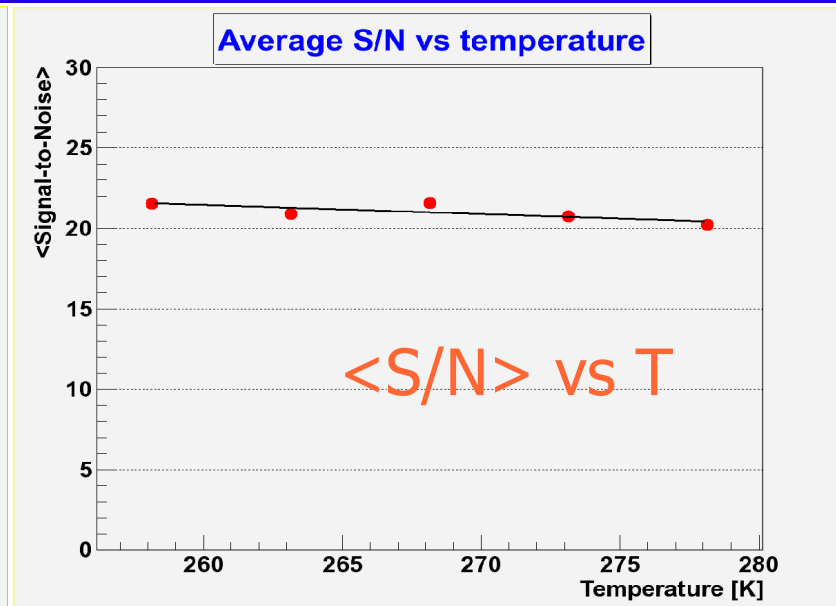
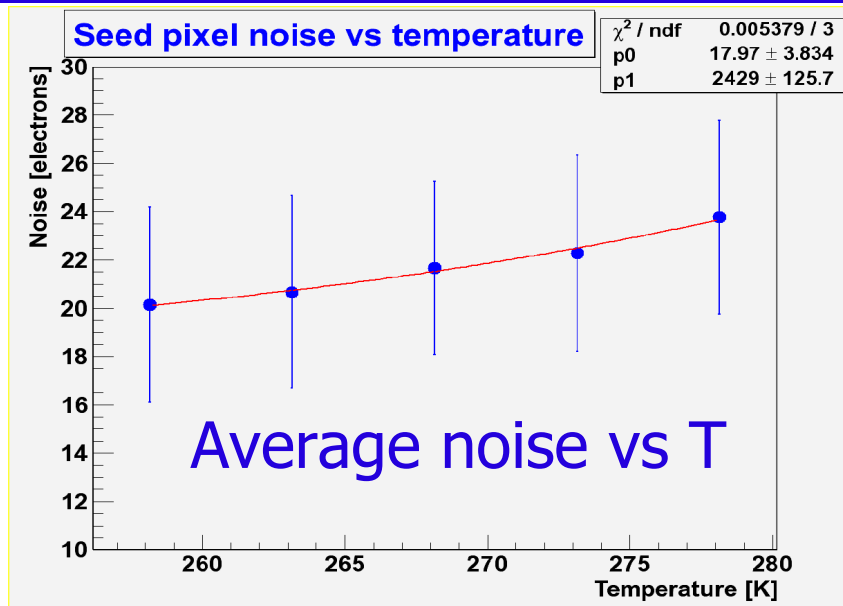
# Experimental results: cluster charge



- Average cluster size  $\sim 6$  (cut of  $S/N > 2$  for neighbors)
- Most of the charge collected within 9 pixel (then fluctuations)
- Charge sharing is symmetric!



# Signal-to-Noise: temperature dependence



(bars= RMS of pixel distribution)

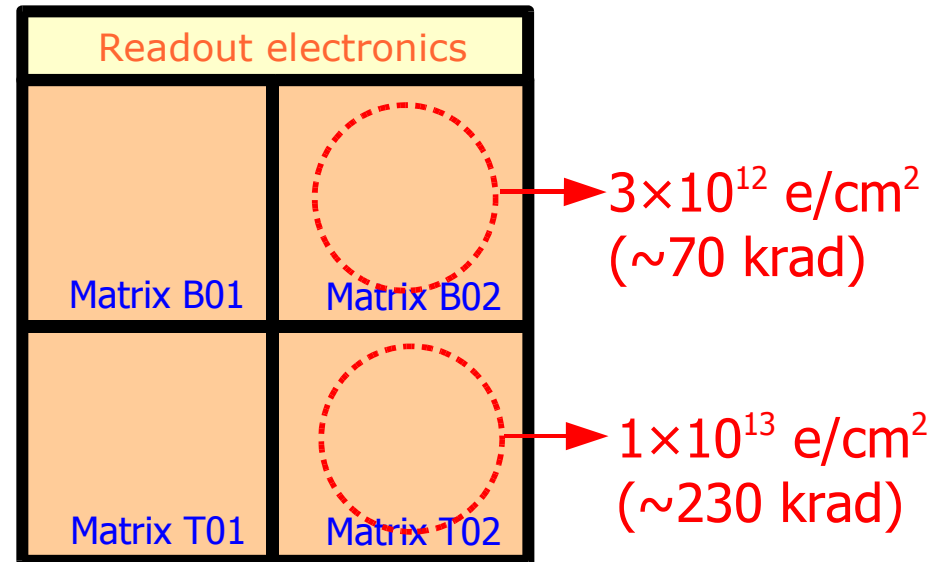
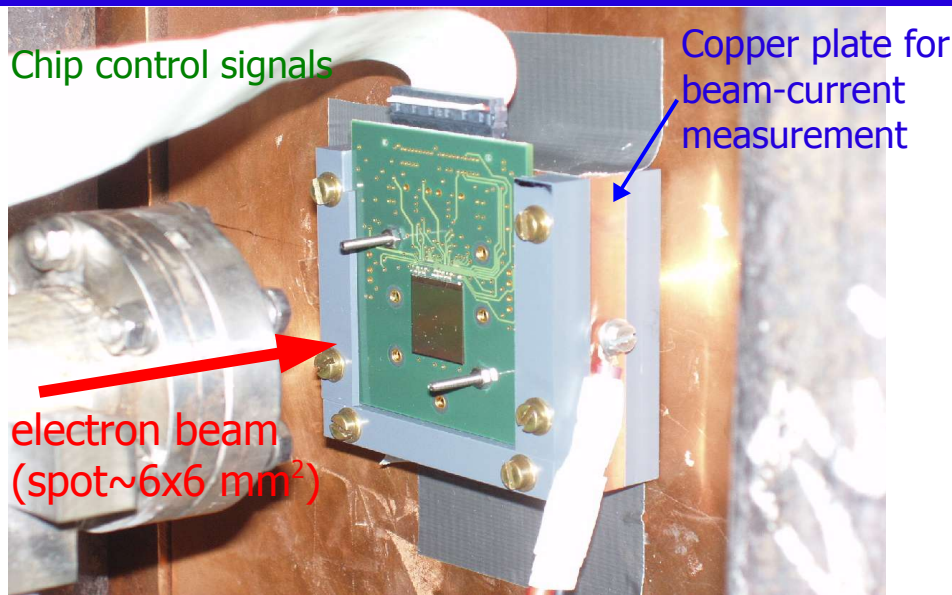
$$\text{noise} = c_0 + c_1 \sqrt{T^2 \exp\left(-\frac{E_g}{2k_B T}\right)}$$

Leakage current term

$$\text{Noise} \propto (I_{\text{leak}})^{1/2}$$

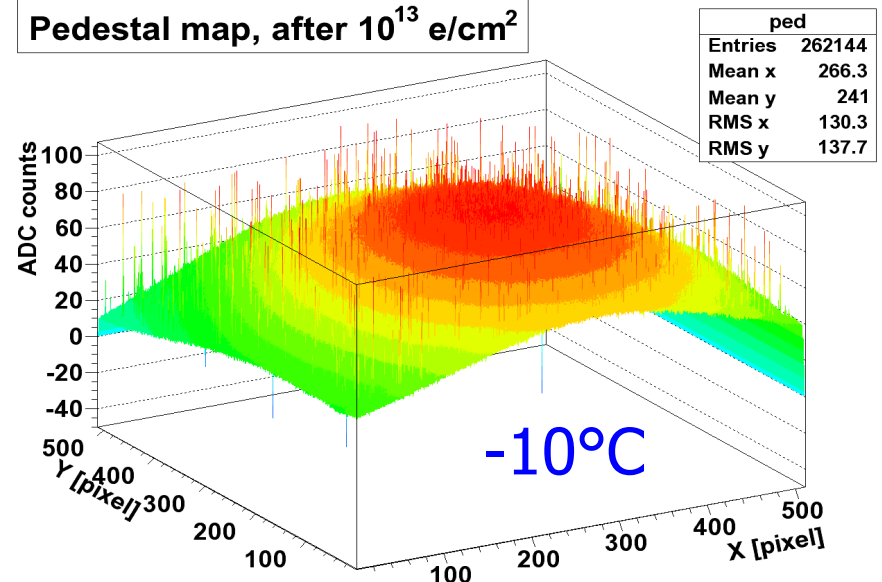
- Measurements performed from  $-15^\circ\text{C}$  to  $+5^\circ\text{C}$
- Cooling is needed to keep noise level low w.r.t. room T
- Slight dependence of S/N between  $-15^\circ\text{C}$  and  $+5^\circ\text{C}$

# Irradiation with 10 MeV electrons

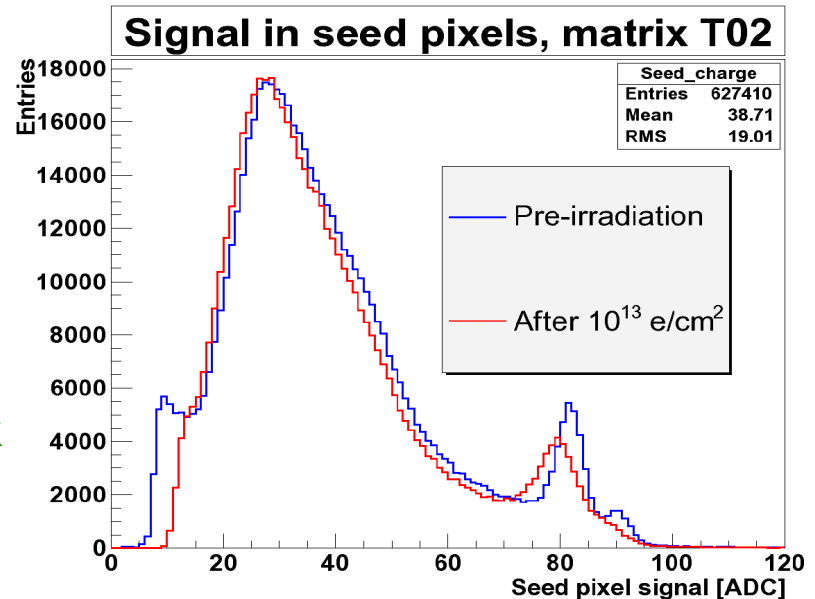
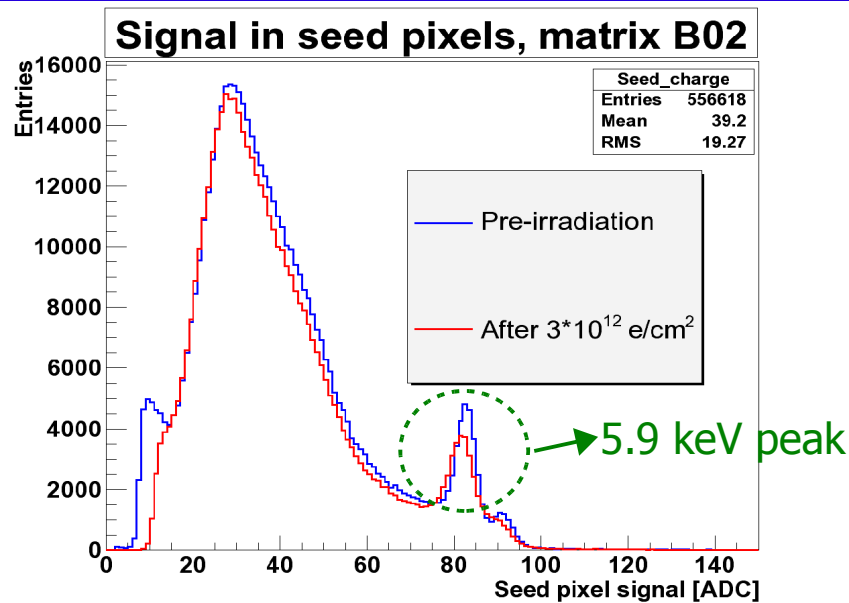


- Performed at the **S-DALINAC** of **Darmstadt Technical University** (Germany)
- **9.4 MeV electrons** (tunable), current  $\sim 1 \text{ nA}$
- Irradiation under bias & clock
- **2 different fluences** ( $\sim$ background in **1<sup>st</sup> VXD layer**) on 2 different matrices

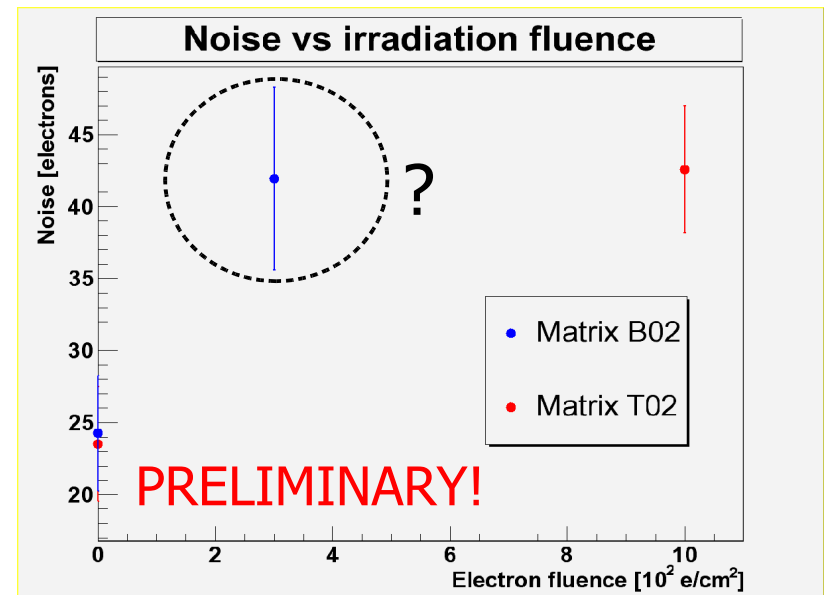
Pedestal map, after  $10^{13} \text{ e/cm}^2$



# Preliminary results from $^{55}\text{Fe}$ calibration



- Measurements performed at  $-10^\circ\text{C}$
- Pedestal levels strongly and non-uniformly shifted after irradiation (but correlated with dose)
- Loss in performance observed from calibration characteristics
- Further studies under way!



# Conclusions & Outlook

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## Beam-test of CMOS sensors with 6 GeV electrons at DESY

- Results for signal, S/N and noise consistent with known values (from Strasbourg tests)
- No significant temperature effect observed between -15°C and +5°C
- Efficiency still under study

## Irradiation with 10 MeV electrons

- Irradiation at doses comparable with expectations for first VXD layer background
- Preliminary results from  $^{55}\text{Fe}$  calibration show loss in performance after  $3 \times 10^{12}$  e/cm<sup>2</sup>: further investigations under way

## Next steps

- Efficiency check: priority!
- Improve telescope performance/alignment: eventual position resolution studies from energy scans
- Beam-test of irradiated chip

