Spectroscopic investigations of irradiated DEPFET sensors

MPI for Physics – MPI Semiconductor Laboratory

Project review

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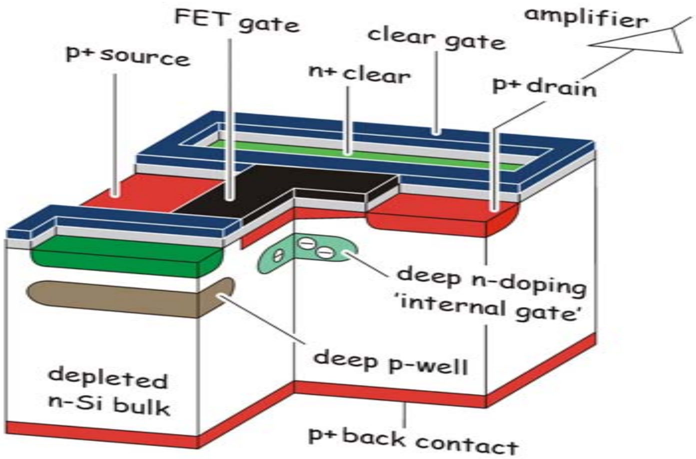
Overview

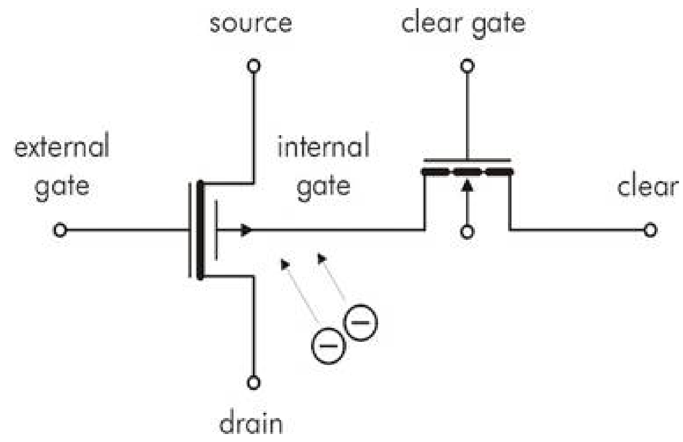
- DEPFET principle
- DEPFET as vertex detector for ILC
- Radiation exposure at ILC
- Spectroscopic investigations of irradiated DEPFET sensors

DEPFET – Depleted Field Effect Transistor

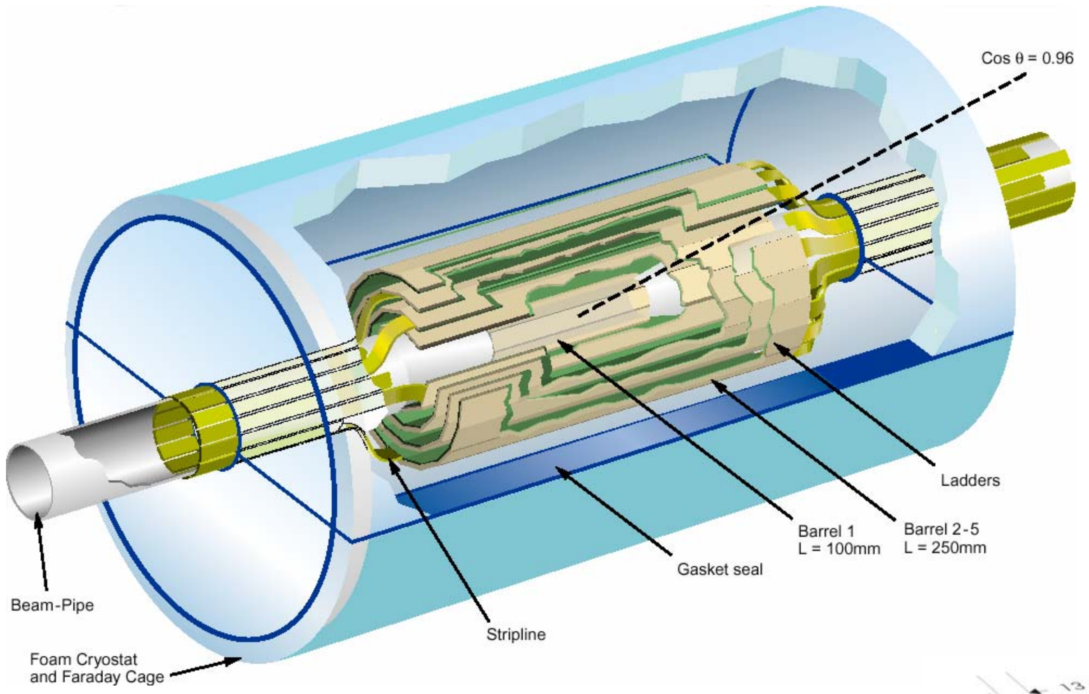
- Combination of **detector grade** silicon with first **p-FET** amplification stage in each pixel
- **Potential minimum for electrons** is created under the channel by means of **sideward depletion** and an additional **n-doping**
- Electrons in the "internal gate" **modulate the transistor current**
- Signal charge is removed via a clear contact

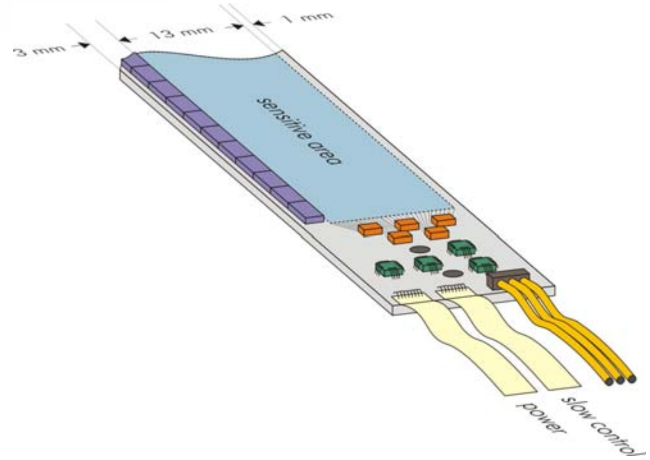


- **Large sensitive volume** due to **fully depleted** bulk
- **Low noise** caused by a small input capacitance and **internal amplification**
- Transistor can be **switched off** by external gate – charge collection is then still active!



DEPFET as vertex detector for ILC



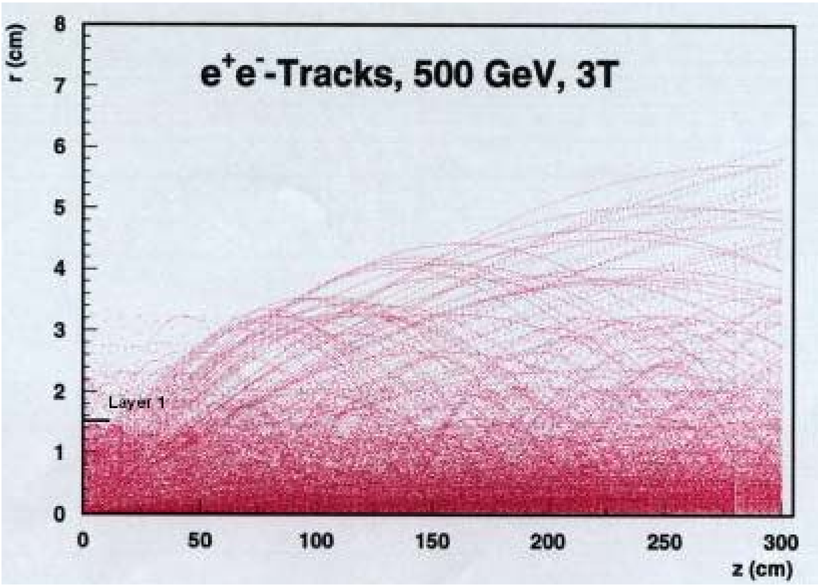


- IP resolution: $\sigma_d \leq 5\mu m \oplus \frac{10\mu m}{p \cdot \sin^{3/2}\vartheta} \, GeV/c$ [Tesla TDR]
  - ➢Good point resolution
  - ➢Small material budget 0.1 %X_0 per layer
- Frame rate ~ 20kHz
- Radiation hardness

Radiation exposure at ILC

- Two main contributions to radiation:
  - Neutrons backscattered from calorimeter
  - e^- - e^+ pairs
    - Predominant source of background hits
    - Cause radiation damage

[C.Büsser, DESY]



•Precision instrument requires high luminosity

- Requires strong focused beams
- Leads to high space charge density

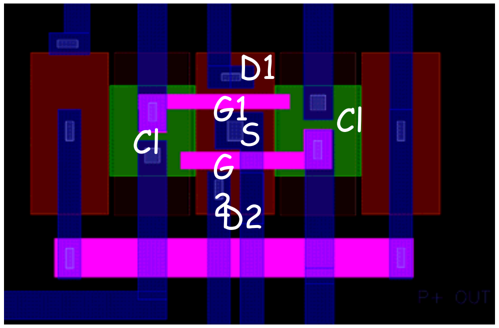
• Beamstrahlungs photons due to e^- - e^+ scattering

•Pair creation of e^- - e^+ pairs

Expected flux:	$1.7 \cdot 10^{12}$ e/cm²/year	@ 10MeV	[LDC DOD]
	10^9 n/cm²/year	@ 1MeV n equiv.	[LDC DOD]
∑ (e^- + n)	**$8.5 \cdot 10^{10}$/cm²/year**	**@ 1MeV n equiv.**	[LDC DOD]

Overview spectroscopy

- Irradiations made by Devis Contarado, Marco Battaglia and Piero Giubilato (LBNL)
- Double pixel structures, 6µm gate length
- Current based readout
- Investigation with respect to:
  - Electric characteristic
  - Leakage
  - Spectroscopic performance



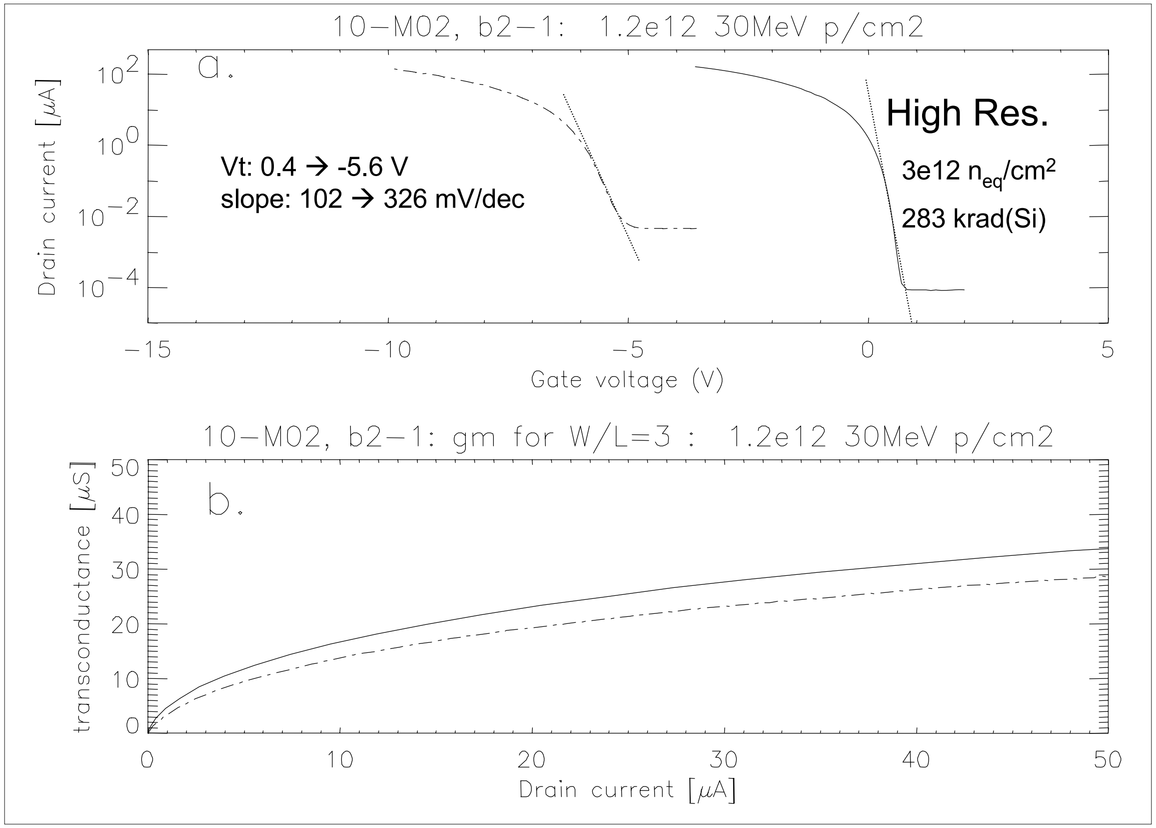
Type	Protons @ 30MeV	Neutrons @ 1-20MeV	Gammas - Co60
Dose	$1.2 * 10^{12}$ p/cm²	$1.6 * 10^{11}$ n/cm²	913kRad
1MeV n equivalent	$3*10^{12}$	$2.4*10^{11}$	
ILC – expectation [LDC DOD]	1MeV n equivalent: $8.5 * 10^{10}$/cm²/year		
ILC operation	35 years	3 years	

Influence of the radiation

- NIEL (Non Ionizing Energy Loss)
  - Damage to bulk
- Ionizing Energy Loss (charged particles)
  - Interface and bulk are damaged

- Macroscopic effects:
  - Thresholdvoltage shift
  - Increase of leakage current – from bulk und interface
  - Increase of 1/f noise
  - Change in effective dopand concentration

p – irradiation - electric characteristic



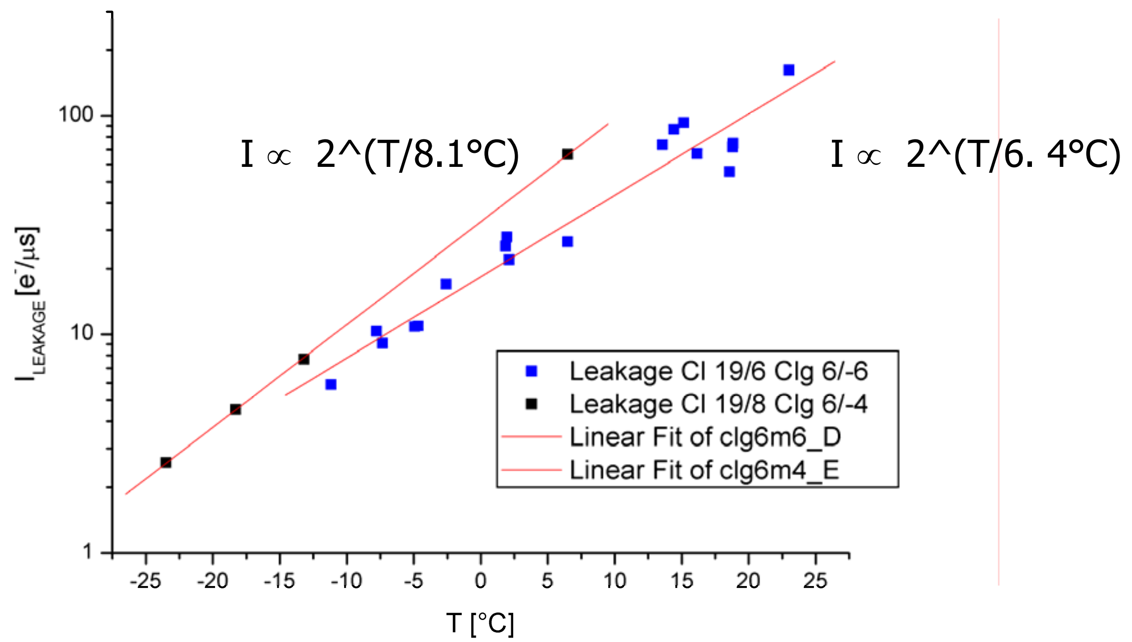
Input characteristic

gm

- Increase of subthreshold slope suggests an increase of 1/f noise
- Gm is noticeably reduced by 15%

p-irradiated - leakage - temperature dependence

Expected increase of leakage by a factor of 2 every 7°C

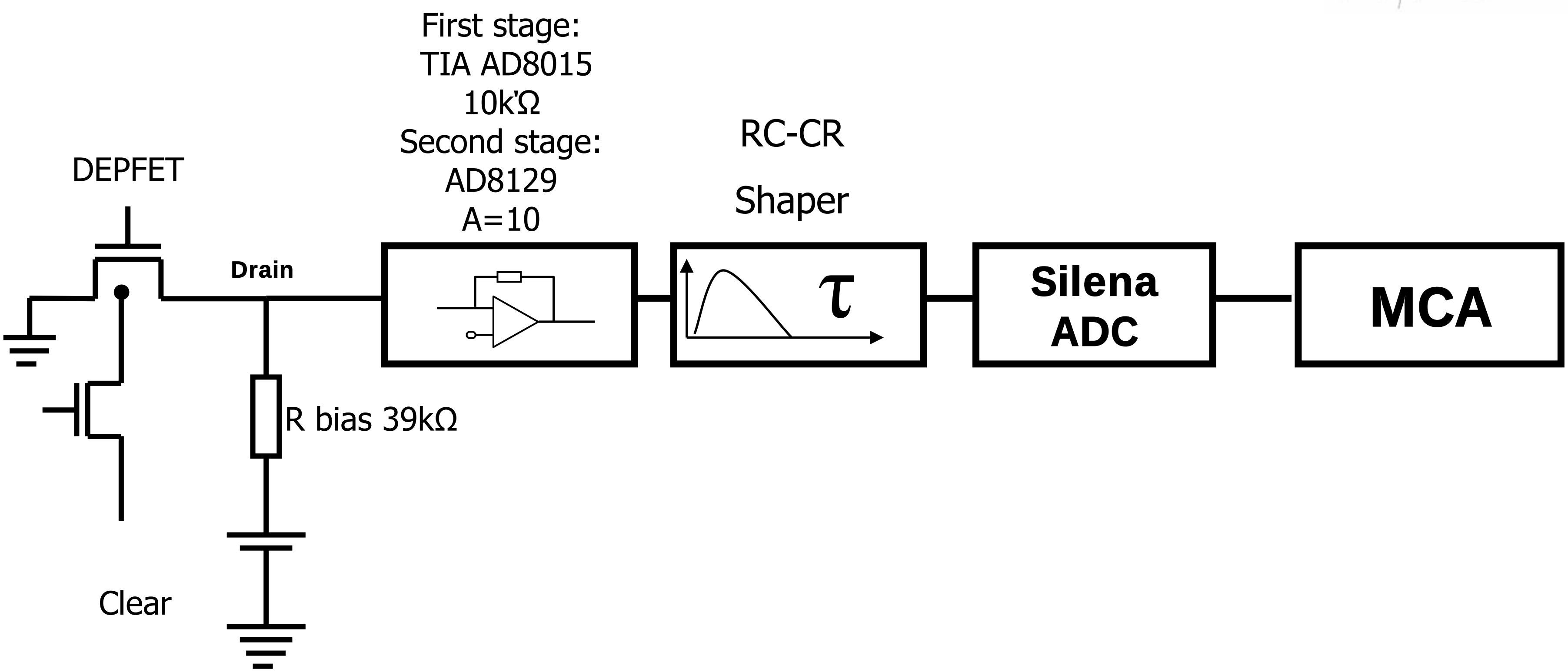


•Dependence on operation voltages shows that there is additional contribution which is not bulk generated

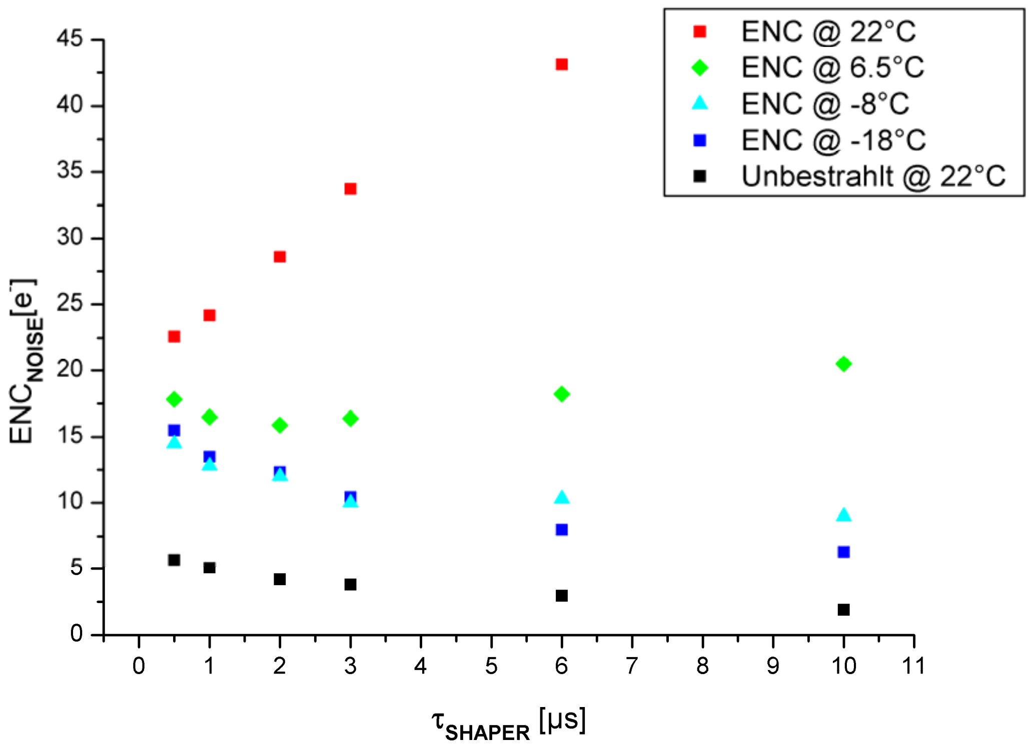
•Thick detector - bulk generated current will decrease with thickness

•At 0°C around 20e/µs! -> L=50µs -> 31e contribution to ENC

Spectroscopic setup



p irradiation – spectroscopic performance



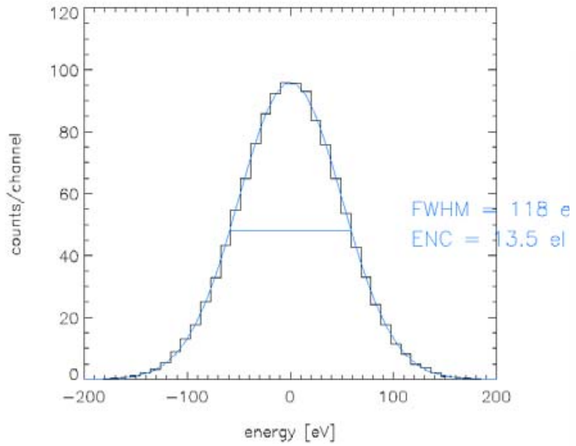
$$ENC = \sqrt{C_1 \frac{1}{\tau} + C_2 + C_3 I_{leak} \tau}$$

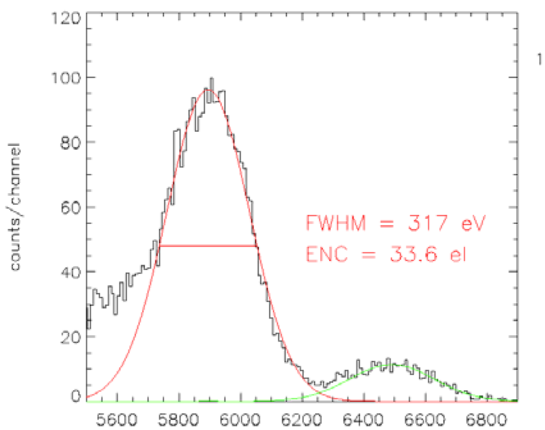
Therm. noise

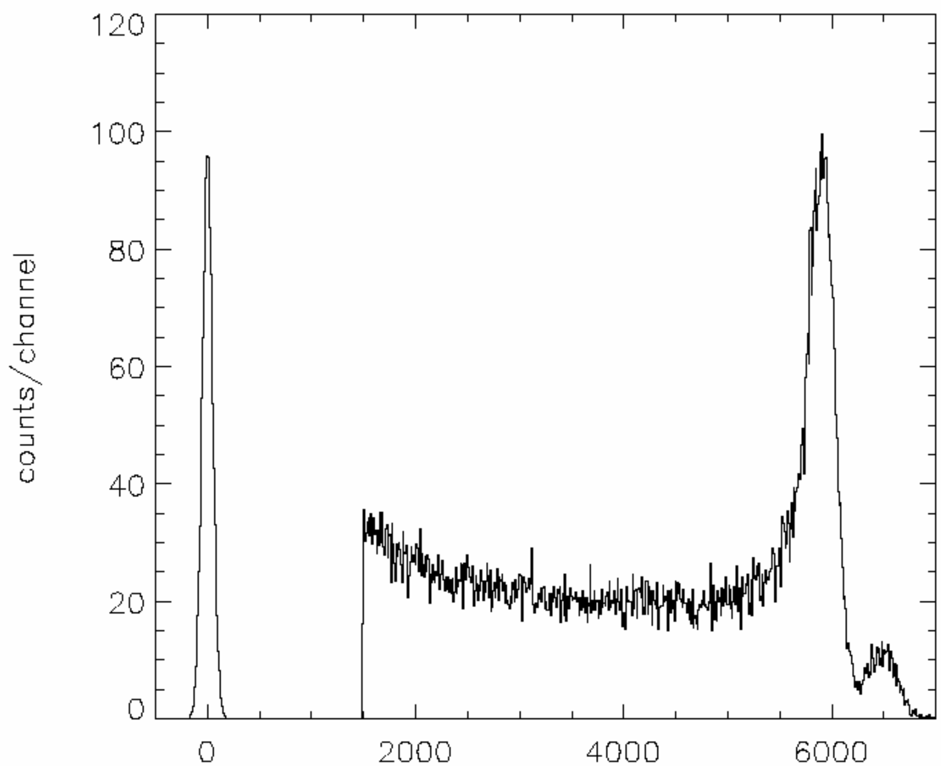
1/f

I_L

p irradiation- Fe55 spectrum





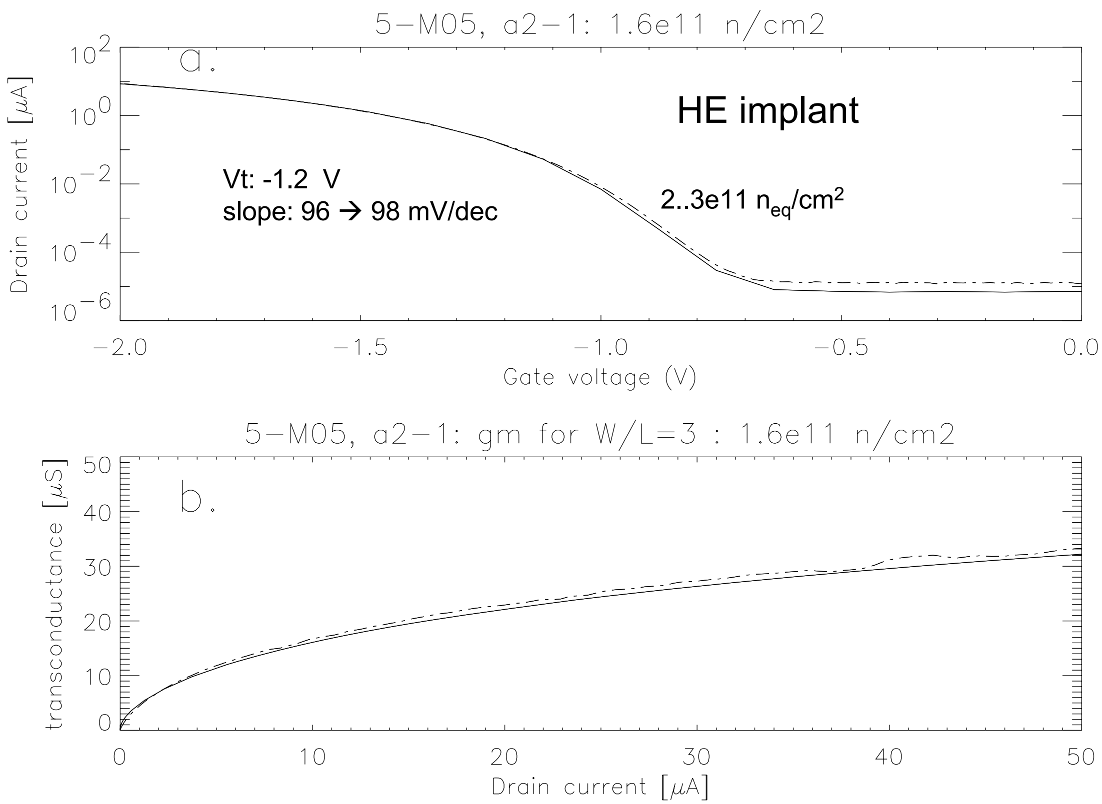


- Separated Kα Kβ Peak!

τ=1μs T=-18°C

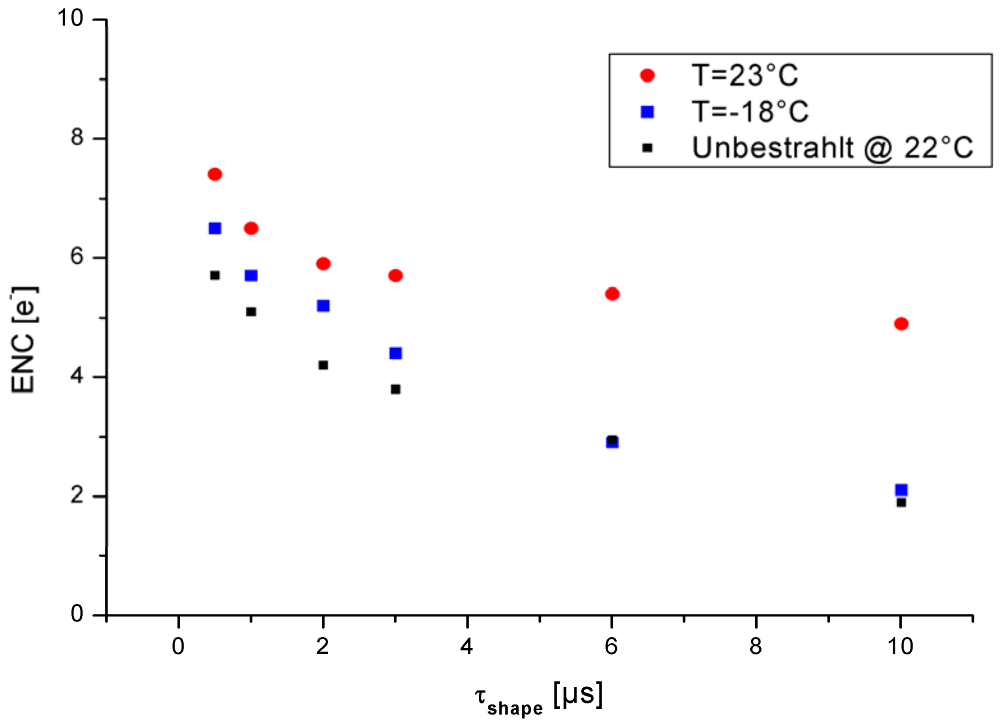
ENC_{noi} = 13.5e^{-}

n irradiation - electric characteristic



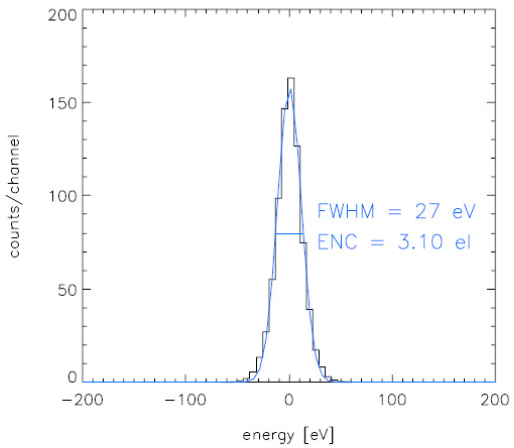
- No thresholdvoltage shift
- No visible increase of sub threshold slope

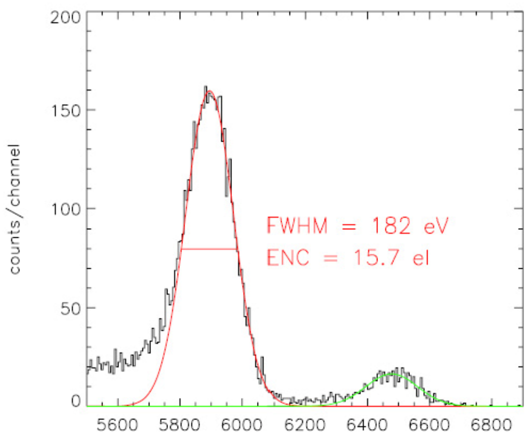
n irradiation – spectroscopic performance

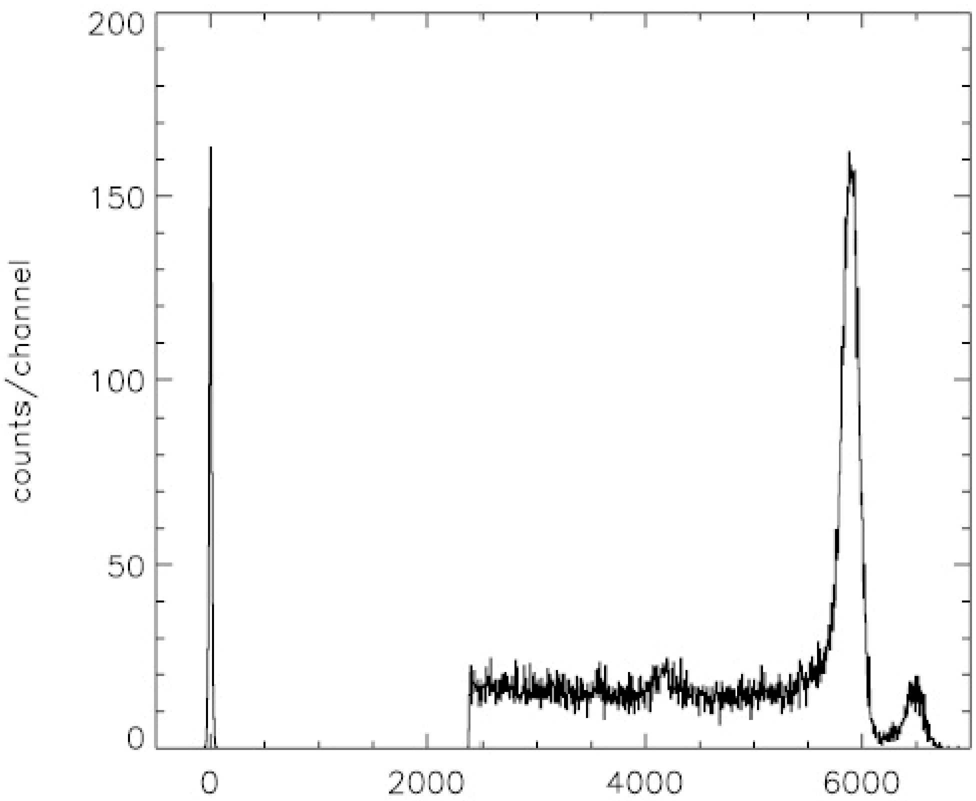


- Leakage current around **8.9e/µs @ 23°C**
- At low temperatures only slight deviations from unirradiated detector observed

n irradiation – Fe55 spectrum







τ=6μs T=6°C

ENC_{noi} =3.1e$^-$

Conclusion

mpi halbleiterlabor

• n-irradiated structure shows at low temperatures a performance similar to unirradiated structures

  • No significant increase in 1/f and thermal noise

  • Only bulk damage observed

• p-irradiated structure shows even at low temperature an increased noise

  • 1/f increased as one would expect from subthreshold slope

  • Decreased gm lead to an increase of white noise

•**BUT: both structures show nevertheless a good spectral resolution!**

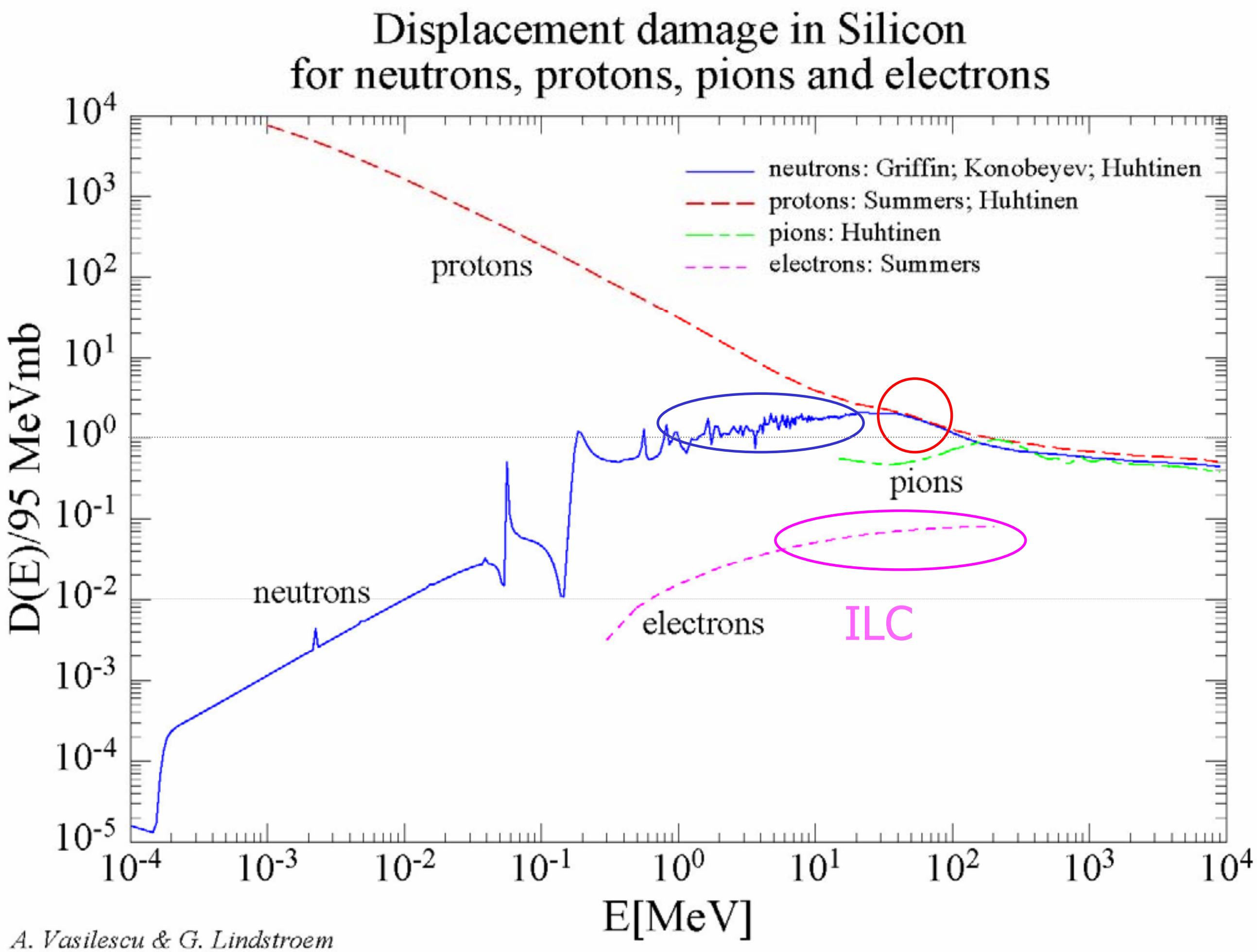
• Precise measurement of the spectral noise density will be done soon

• **The DEPFET double pixel structure could be considered as radiation hard with respect to the ILC requirements**

•Irradiations of matrices will complete the picture

- Backup….

Backup…



Displacement damage in Silicon
for neutrons, protons, pions and electrons
neutrons: Griffin; Konobeyev; Huhtinen
protons: Summers; Huhtinen
pions: Huhtinen
electrons: Summers
protons
neutrons
pions
electrons
ILC
D(E)/95 MeVmb
E[MeV]
A. Vasilescu & G. Lindstroem