INFN Trieste Group

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Belle II New Collaborators Meeting — Wien, 25-26 April 2013

INFN Trieste group

- Faculty
  - Luciano Bosisio 50%
  - Livio Lanceri 80%
  - Lorenzo Vitale 80%
- Technical staff
  - Pietro Cristaudo

INFN Trieste on-site facilities

- Electronics lab
- Mechanics design and workshop
- Computing and networking support
- More specific silicon detectors lab

our experience

- in BaBar, Alice, SuperB and R&D projects:
  - design and static characterization of double-sided silicon microstrip detectors
  - functional tests of detectors (IR laser, radioactive source and beam tests)
  - construction of a beam telescope
  - read-out by VA and FSSR2 front-end chips

Double-sided sensor testing at INFN-Trieste

1. About 1/2 of BaBar sensors tested
2. All ALICE SSD sensors tested (~2100 including spares) between 2003 and 2006

Sensor testing in Trieste

Hardware:

- Alessi REL55 semi-automatic prober
- *I-V* and *C-V* testing instruments (HP 4156A, Keithley 237, HP4287A) + scanner (Keithley)

Software:

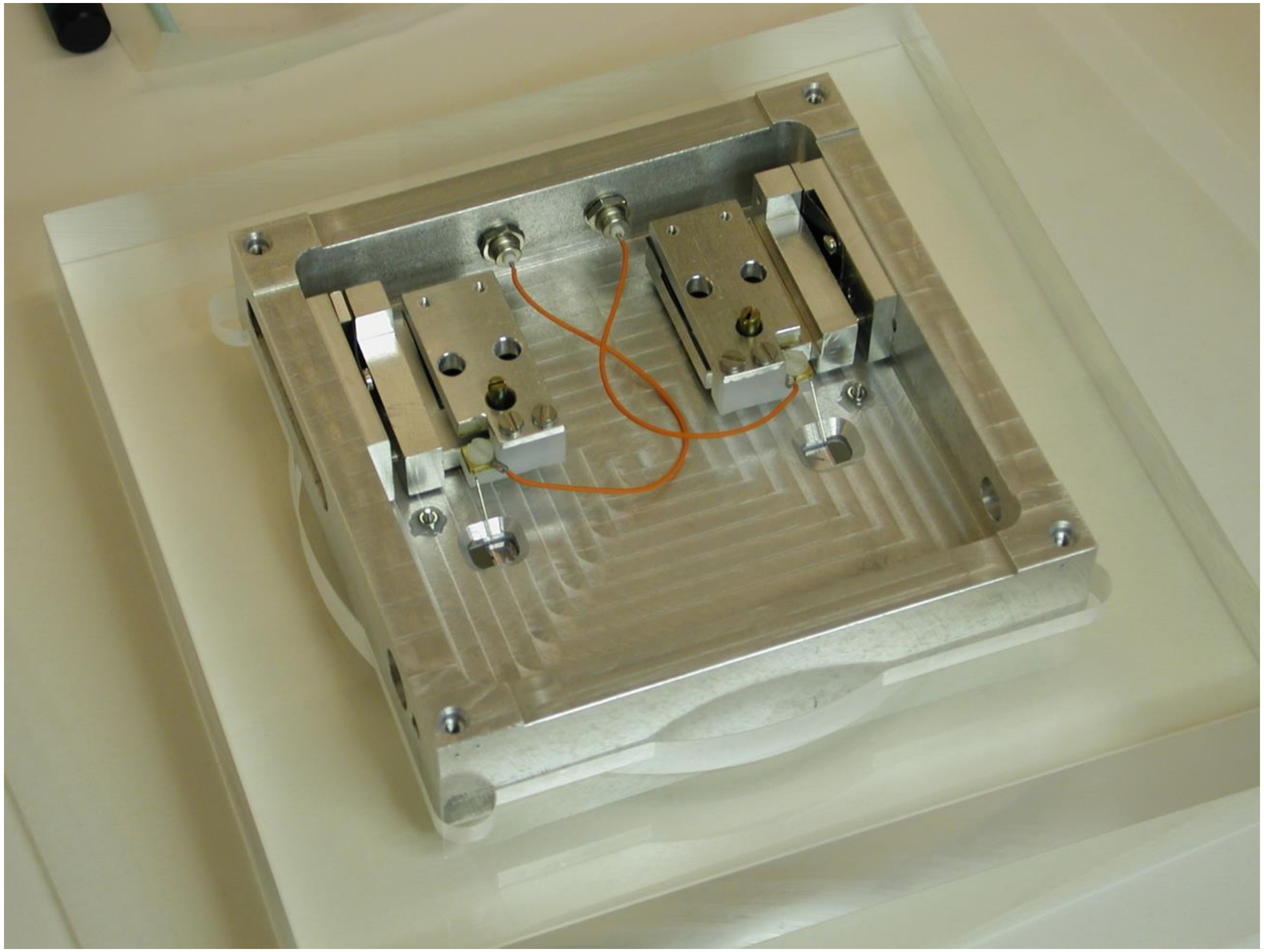
- "M-Shell" set of LabView programs for control, data acquisition and analysis (developed by R.Wheadon, INFN Torino)

Set-up for sensor testing

Sensor held on dedicated support

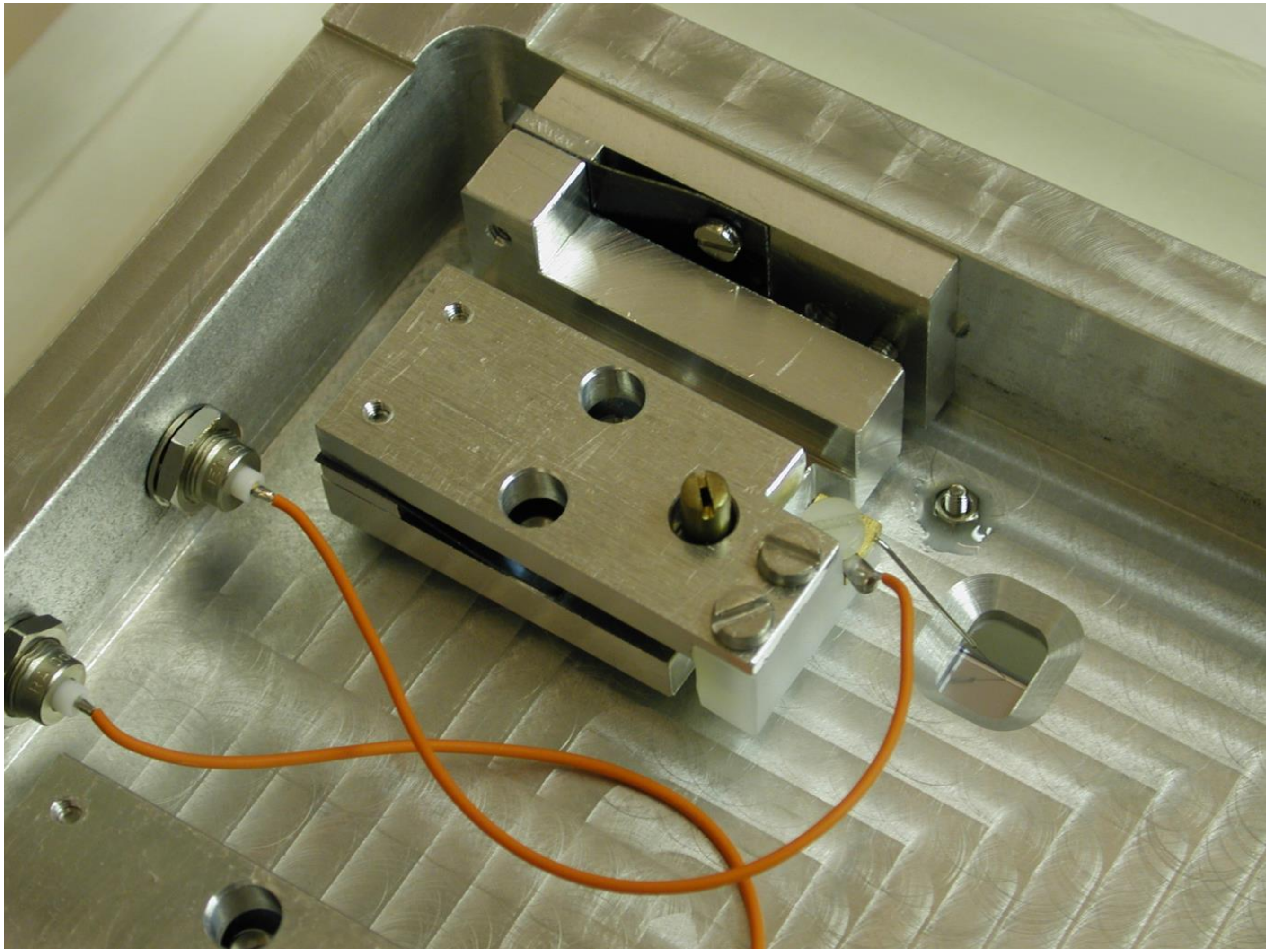
- teflon-clad mounting surface
- plastic clamps (delrin)

Set-up for sensor testing



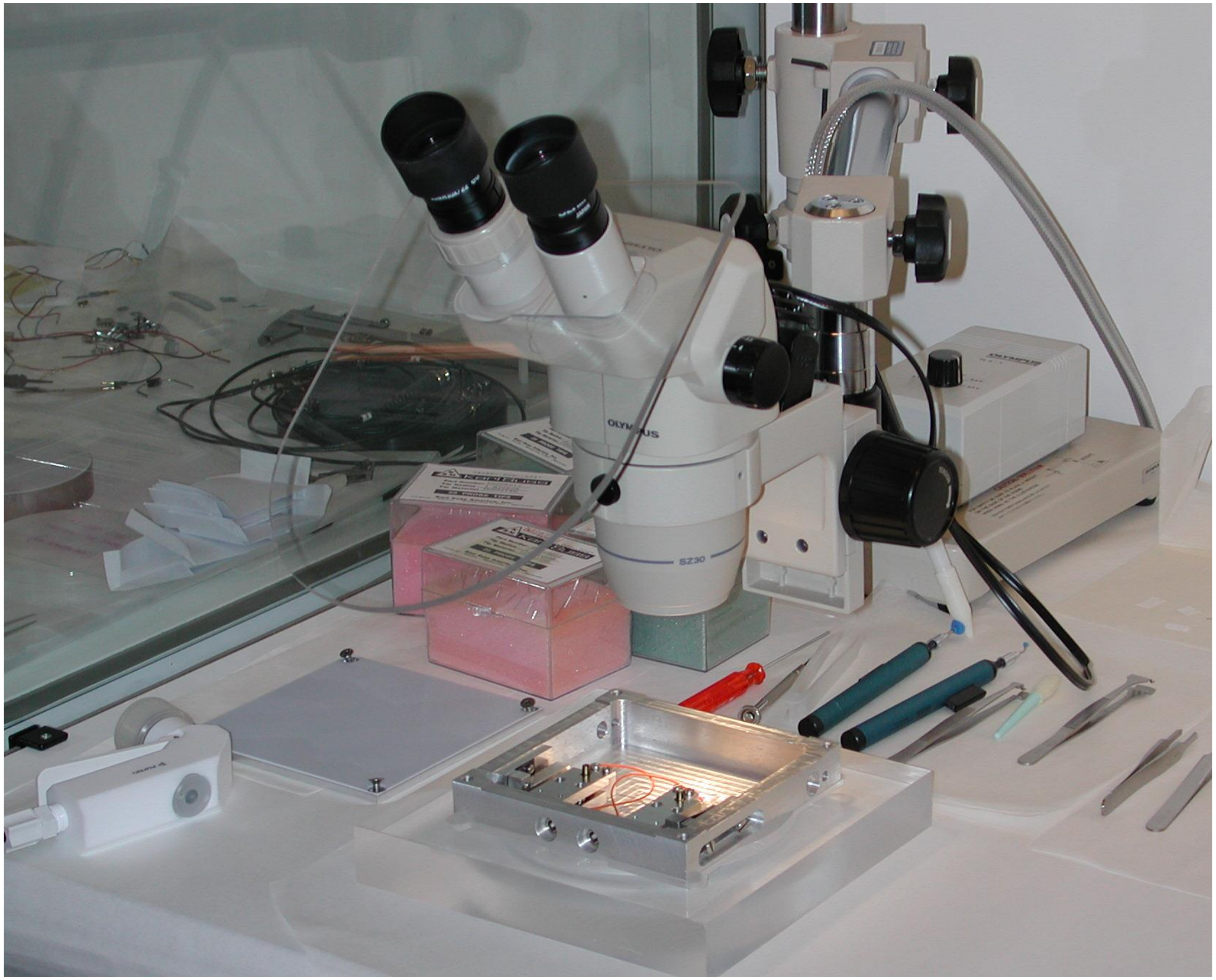
Contacting back-side Guard Ring and Bias Ring by two small manipulators inside the detector support

Set-up for sensor testing



Detail of manipulator with probe needle

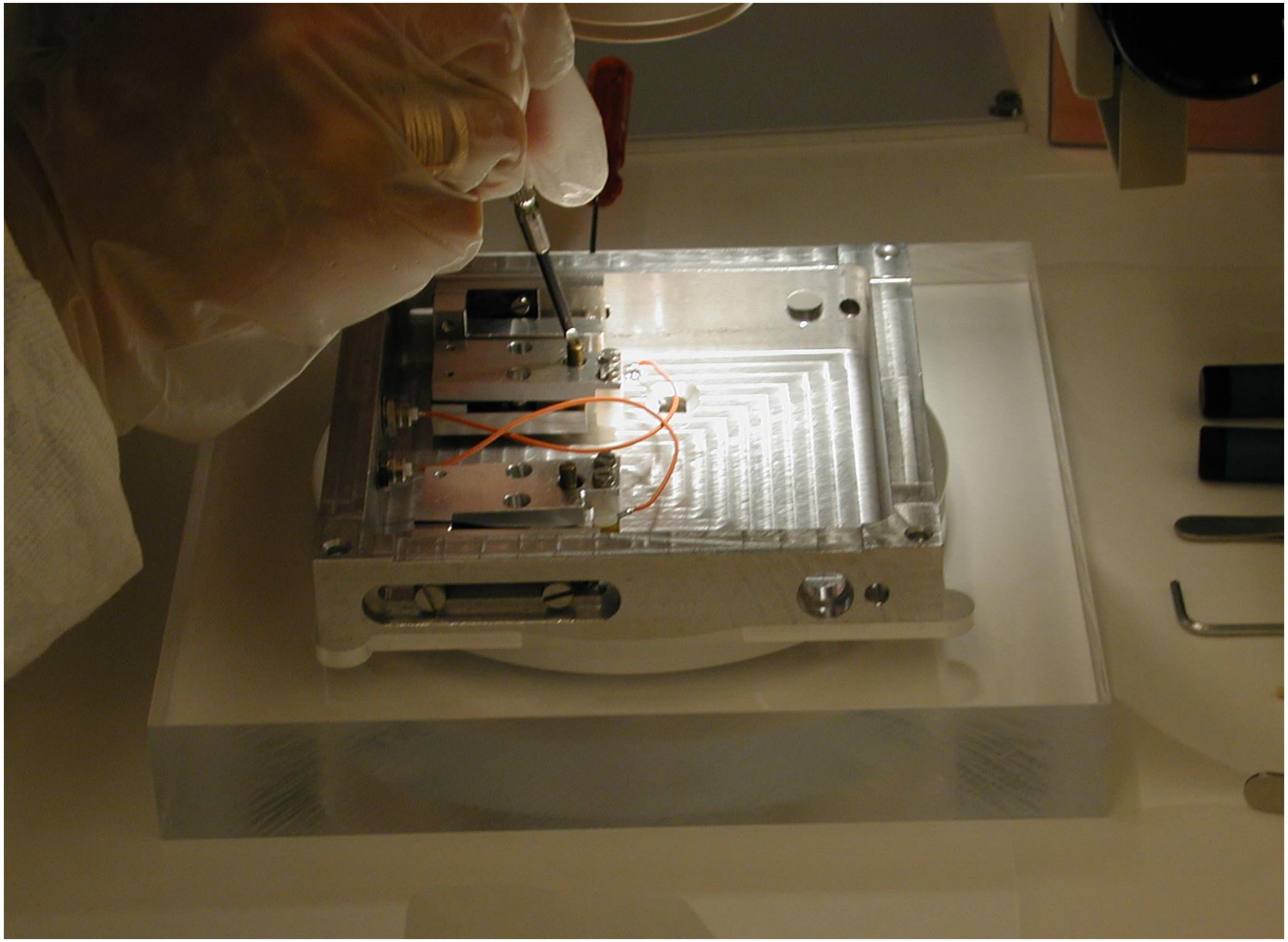
Set-up for sensor testing



Making contact to back-side Guard and Bias Rings:

- probe needles are positioned with the help of a stereo microscope

Set-up for sensor testing



Making contact to back-side Guard and Bias Rings

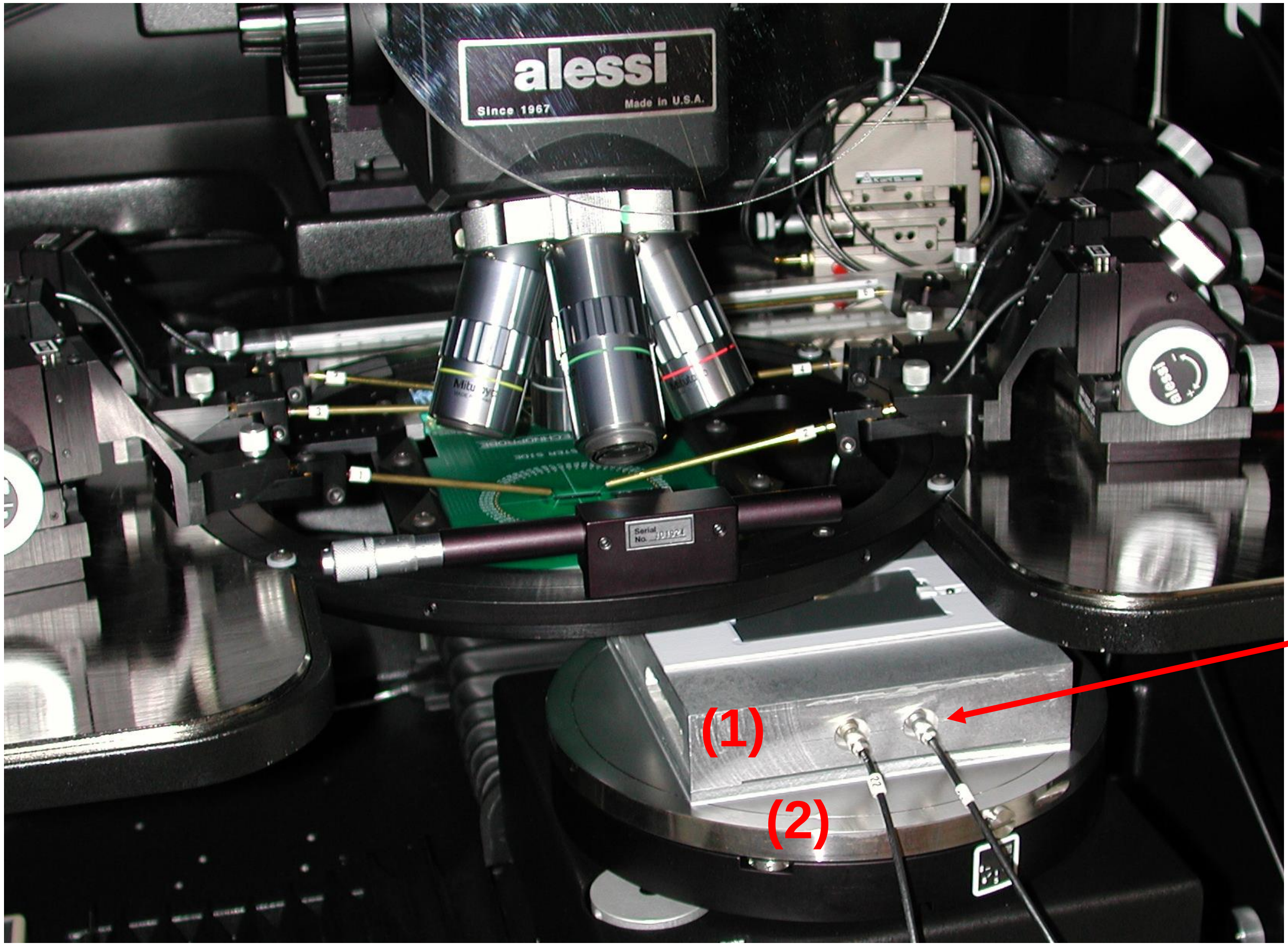
- lowering the probe needles

Set-up for sensor testing

A teflon-clad plate is screwed to the bottom of the support

- allows mounting on standard vacuum chuck of probe station

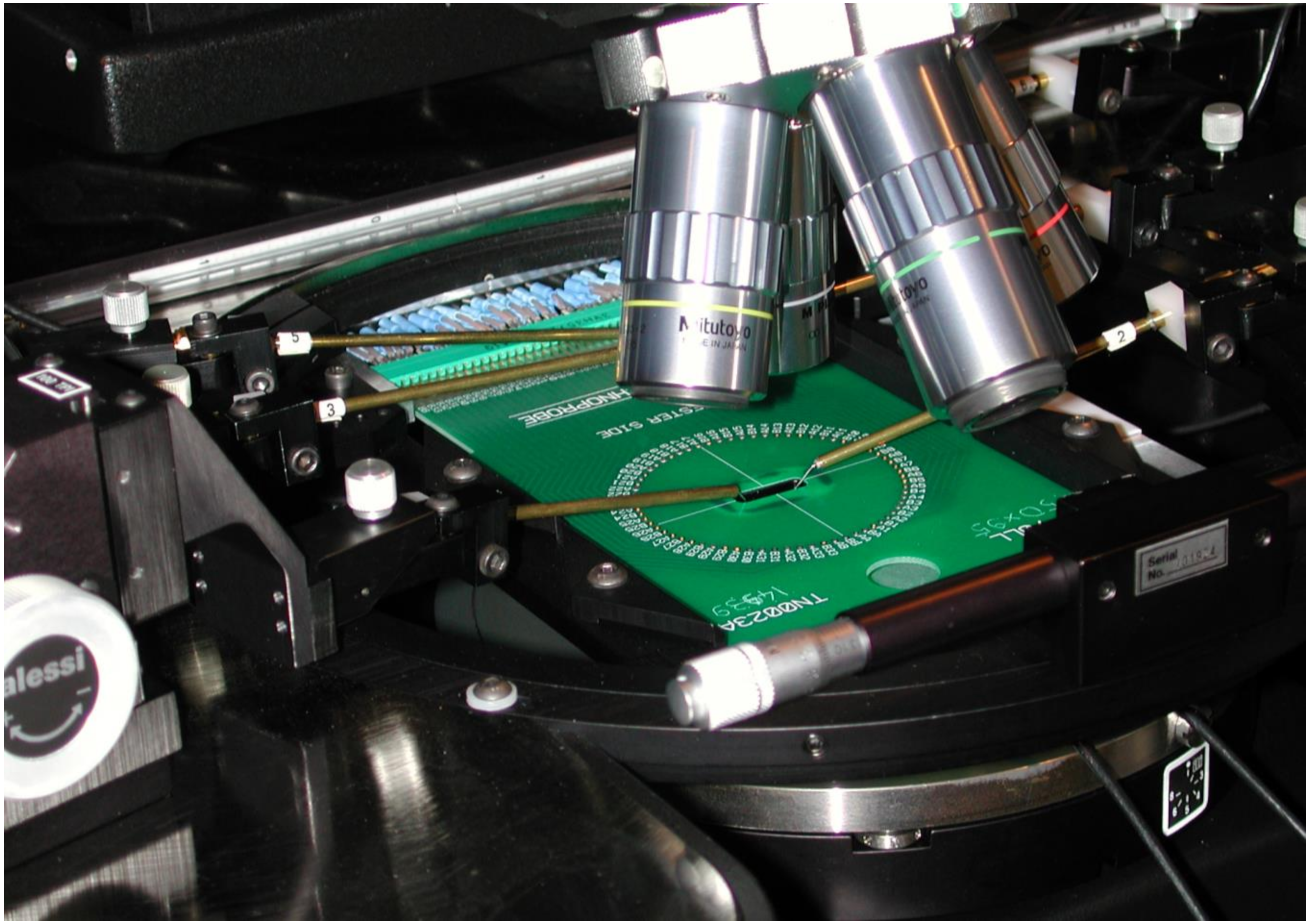
Set-up for sensor testing



The detector support (1) is mounted on the probe station chuck (2)

- held by vacuum
- contacts to backside Bias and Guard Rings available through two coaxial connectors

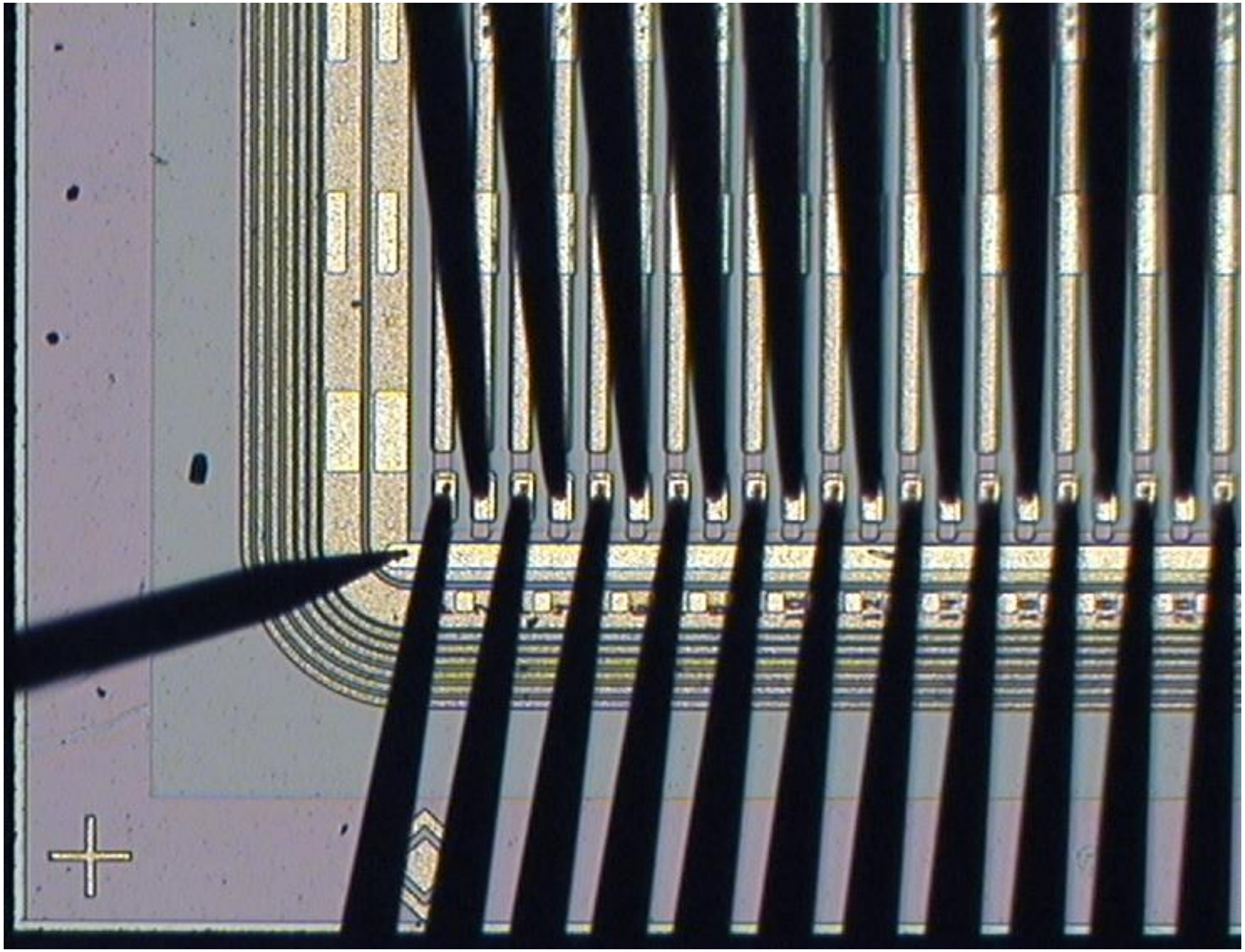
Set-up for sensor testing



Probing the detector top side with:

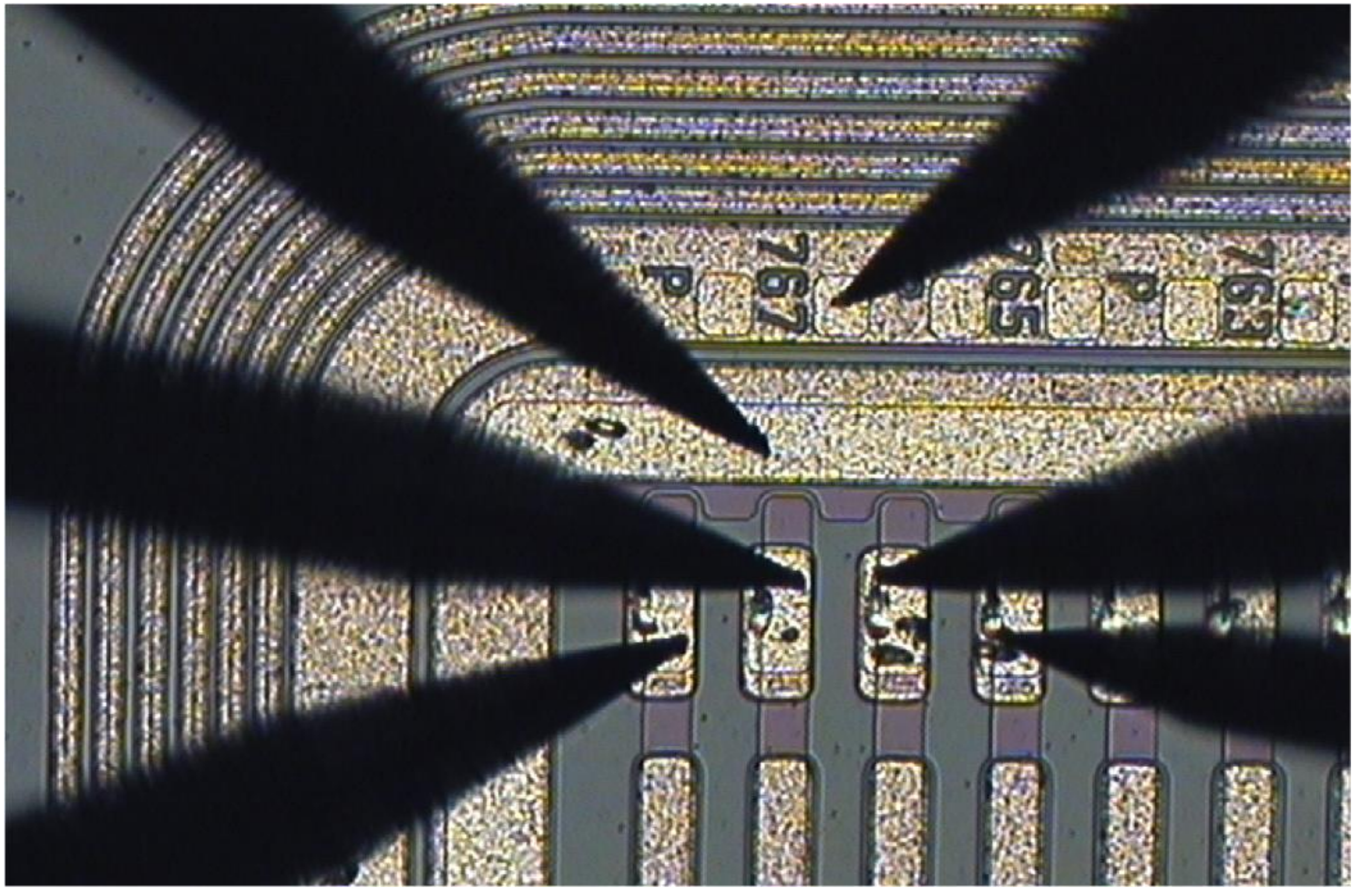
- a probe card to contact 50 strip pads
- two manipulators for Bias Ring and Guard Ring

Set-up for sensor testing



Measuring the 'DC' pads of a detector

Set-up for sensor testing



Contact set-up for a special measurement:

- four needles contact DC pads of four strips
- two needles contact Bias Ring and Guard Ring
- (strip number labels are visible)

Test Sequence (1)

n - side

1) AC strip test on n-side (768 pads).
   20V across capacitors, light on. Measure:
   - Capacitance to bulk (1 kHz)
   - Dissipation factor
   - Leakage current through capacitor

2) I-V Measure (0-100V) on
   - Guard Ring-p, Bias Ring-p
   - Bias Ring-n
   - one n-side Strip (→ insulation voltage)

3) Measure of Punch-Through voltage drop between Bias Ring and two different strips, versus bias voltage.

Test Sequence (2)

4) DC strip test on n-side (768 pads).
40-70V bias (chosen depending on results of 2.)
Measure:

- Leakage current of every strip
- Insulation resistance of every strip at bias voltage: $(\Delta I/\Delta V)^{-1}$, with ΔV = 0.2 V
- Bias Ring and Backside current once every probe card position (16 points)
- Insulation bias voltage for one strip in every probe card position (16 points)

p-side

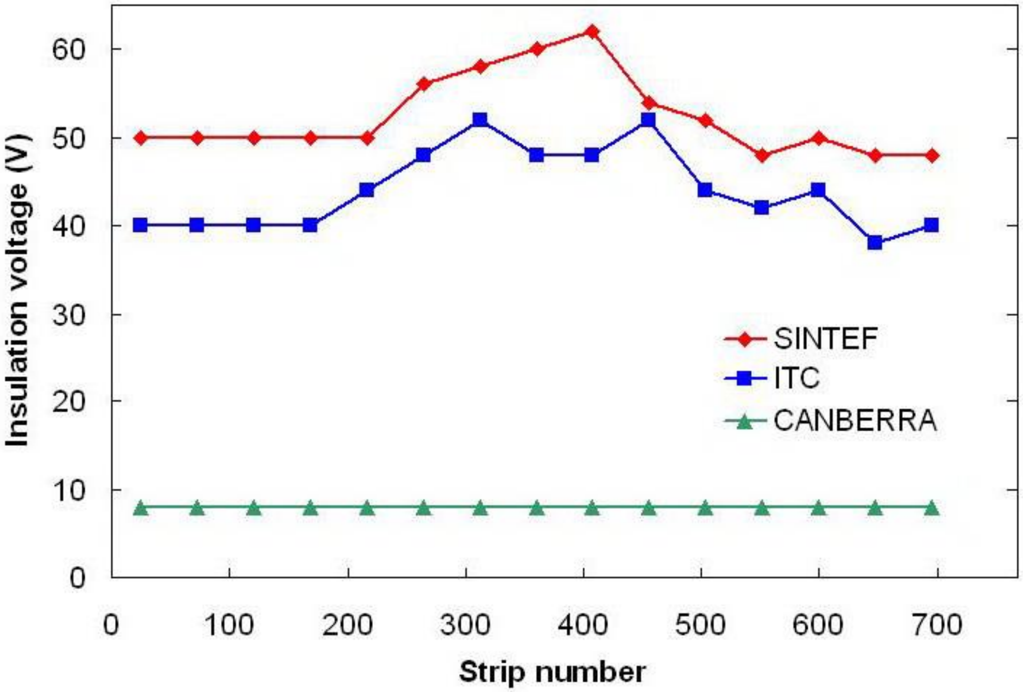
Repeat Measurements 1), 3), 4) on p-side (except no strip insulation voltage is measured during DC scan on p-side)

Total time required: ~ 2 hours/detector

$\Rightarrow$ 4 detectors / day (if no problems arise…)

Doping Variation in the Substrate

- We can profile the depletion voltage across the sensor by measuring the voltage at which *n*-side strips become insulated (routinely done at 15 points on every sensor)
- On FBK and SINTEF sensors there is an increase of 10-20 V from edge to center, reflecting the characteristic doping variations of FZ Si



- Canberra sensors show exceptionally low depletion voltage (⇒ $\rho \approx 30$ kΩ cm) and even more surprising uniformity across the sensor (≈ 70 mm on a 100 mm wafer)
- Exceptional quality of the substrate ⇒ lower electric fields at junction edges ⇒ less susceptible to high currents associated with small defects

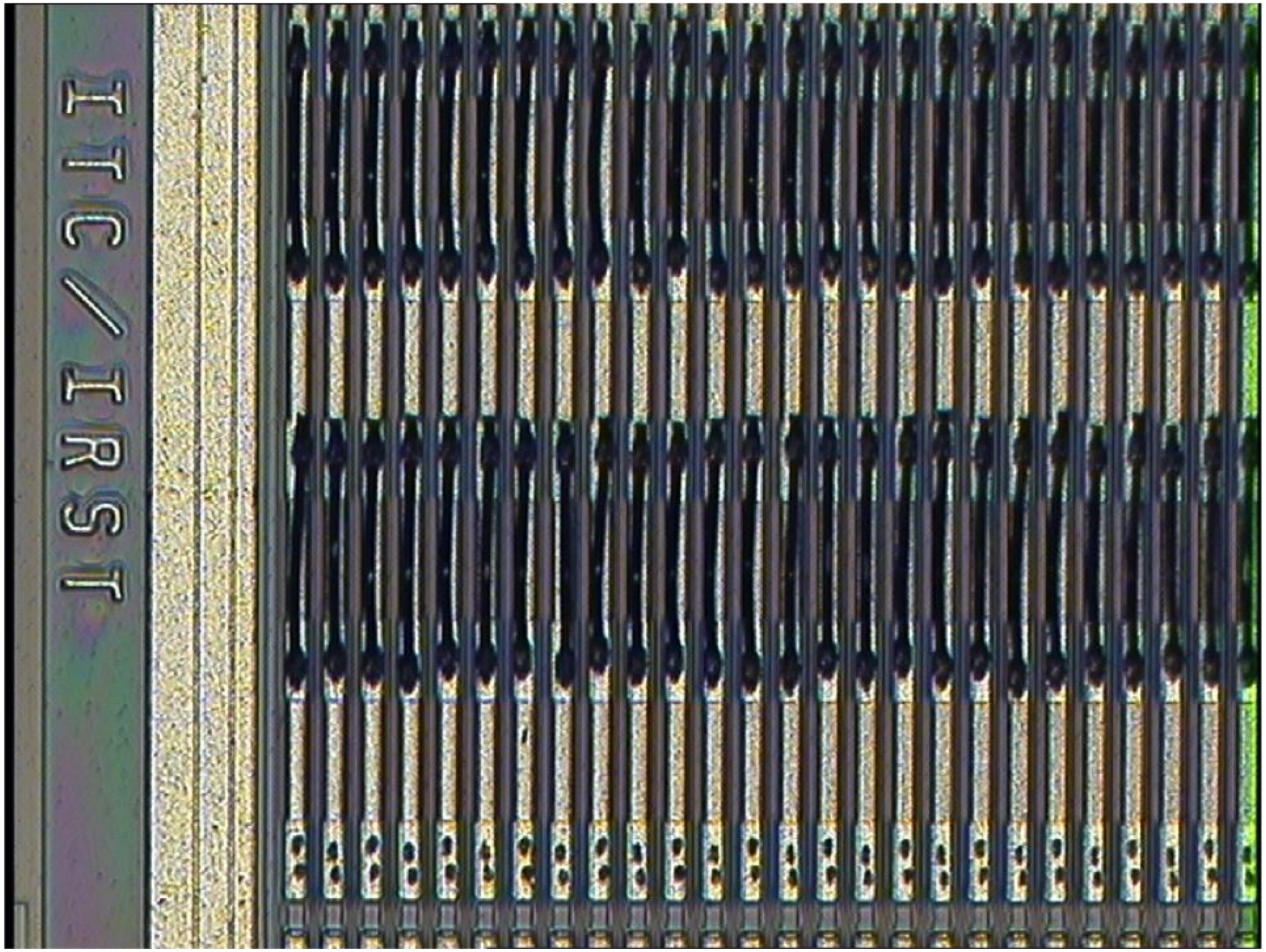
Additional tests

- Measurement of strip capacitance performed on a sampling basis.
- Parametric measurements made on test structures (diodes, gated diodes, MOS capacitors, Van der Pauw structures)
- Stability of leakage current (BR-p and GR-p) for long times (≥ 24 h), under varying humidity conditions (up to 80-90%) performed on a fraction of the sensors.
- Bonding test, to verify the integrity of coupling capacitors after bonding.
  - Performed on the small test detectors (SINTEF), or on dedicated test structures (ITC)
  - Fraction of capacitors damaged by bonding:

    p-side: 15/17408 = 0.09%

    n-side: 8/17408 = 0.05%

Structures for testing defects introduced by bonding



Separate test structures for p - and n - sides (=> single-sided structures):

- 256 short (5mm strips
- 6 AC pads/strip (+ 2 DC pads)
- 4 bonds/strip
- => 1024 bonds

Noise Measurements

References:

- G. Giacomini et al.,
  "Noise Characterization of Double-Sided Silicon Microstrip Detectors with Punch-Through Biasing"
  IEEE Trans. Nucl. Sci. NS-58 (2011) 569-576

- G. Giacomini et al.,
  "Study of frequency-dependent strip admittance in silicon microstrip detectors"
  Nucl. Instr. and Methods A 624 (2010) 344-349

Noise Measurements

Purpose:

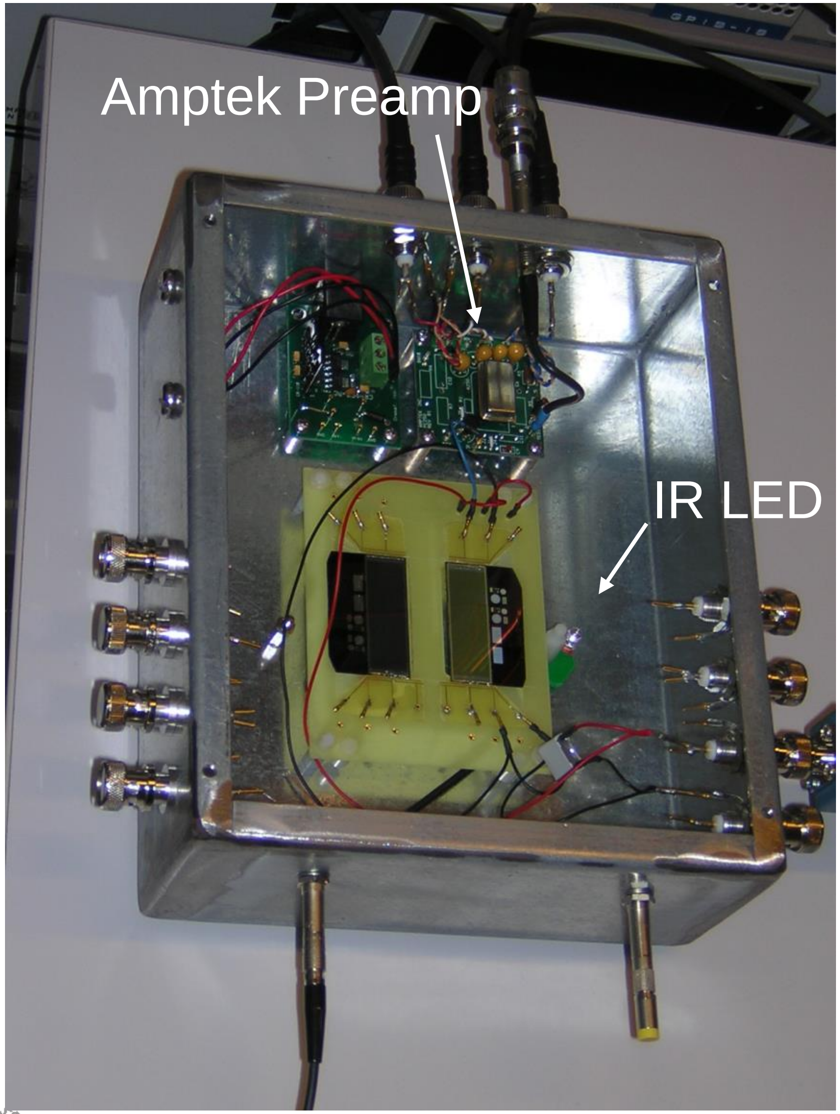
- Investigate the noise contribution of punch-through biasing. Check our understanding of the noise dependence on sensor parameters.
- Compare irradiated with non-irradiated SINTEF sensors, investigating the possible presence of extra noise sources beyond the increased shot noise due to the higher leakage current

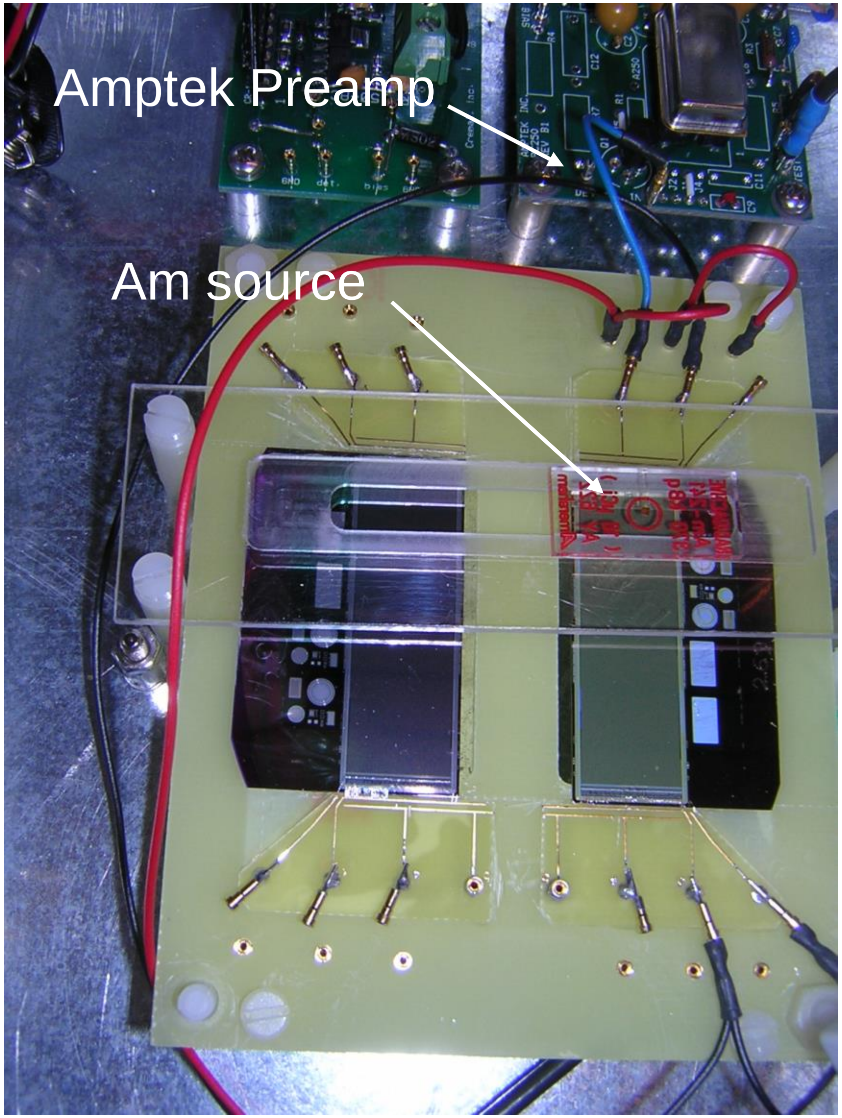
Setup:

- Test sensors glued and bonded to PCB board
  - AC and DC pads of one strip per side bonded to external terminals
  - all other AC strips bonded to a common bus
- Amptek A250 preamplifier with 2SK152 external input JFET
- Amptek PX4 pulse processor with digital filter
- ^{241}Am 60 keV X-ray source for calibration (~2/3 of a m.i.p.)
- IR LED to increase the leakage current by photogeneration
- Single-channel measurement $\Rightarrow$ no C.M. subtraction possible

  $\Rightarrow$ very sensitive to pick-up $\Rightarrow$ good shielding and filtering needed

Noise Measurements: Setup





Noise Measurements

- For both *p*-side and *n*-side strips, the ENC was measured versus
  - *peaking time* of triangular shaper ($/_p = 0.8 - 26\ \mu s$)
  - *leakage current* (in the dark and photogenerated)

    Note: *Equivalent Gaussian shaping time* $\approx \frac{1}{2}\ /_p$

- Several variants explored, including:
  - strip biasing by a high value external resistor vs. punch-through biasing
  - injecting current through the DC pad vs. photogeneration by an IR LED
  - taking the signal from the DC pad

Noise Contribution of Punch-Through Biasing

- Punch-through current = carriers emitted over a potential barrier ⇒ affected by Poisson fluctuations ⇒ shot noise contribution
- If fluctuations in I_{PT} and in I_{Leak} are uncorrelated, the two shot noise contributions add in quadrature
- We then expect, for triangular shaping with peaking time τ :

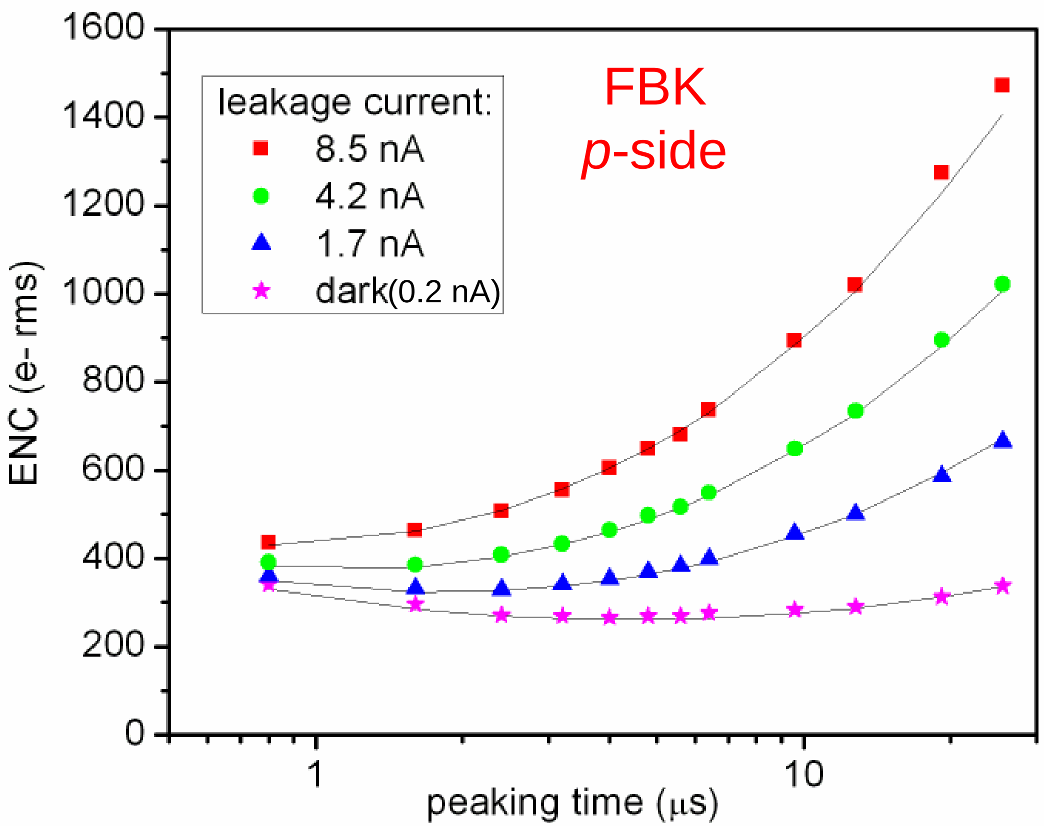
$$q^2 ENC^2 = \frac{\tau}{3}\left(2qI_L + 2qI_{PT} + \frac{4kT}{R_f}\right) + \frac{C^2}{\tau} 4kT \left(\frac{2}{3g_m} + R_S\right) + C^2 A_f \qquad (1)$$

where:

- C = total capacitance at amplifier input
- R_S = sum of the series resistances
- R_f = feedback resistance of amplifier
- g_m = transconductance of the input JFET
- A_f = series flicker ($1/f$) noise coefficient

In normal situations $I_{PT} = I_L$ and we get a leakage current contribution $\tau/3(4qI_L)$ to the (squared) noise, instead of just $\tau/3(2qI_L)$

FBK sensor *p*-side
Noise vs. peaking time and leakage current



Continuous lines: calculated from Eq.(1)

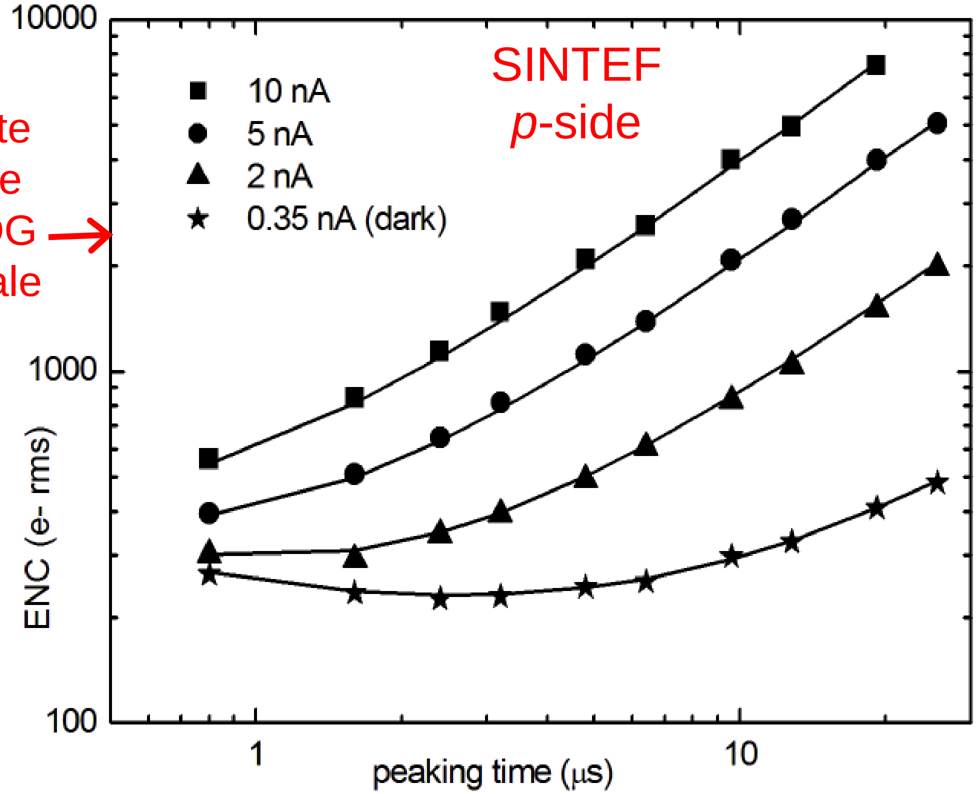
- Leakage current varied by photogeneration
- The measured noise agrees well with the prediction of Eq.(1), with:
  - g_m, R_f, C_{det} determined by direct static measurements
  - C_{input}, R_S, A_f evaluated from noise measurements with open amplifier input

⇓

- The noise contribution of punch-through is as expected

Excess Noise on *p*-side of SINTEF Sensor

Note the LOG scale



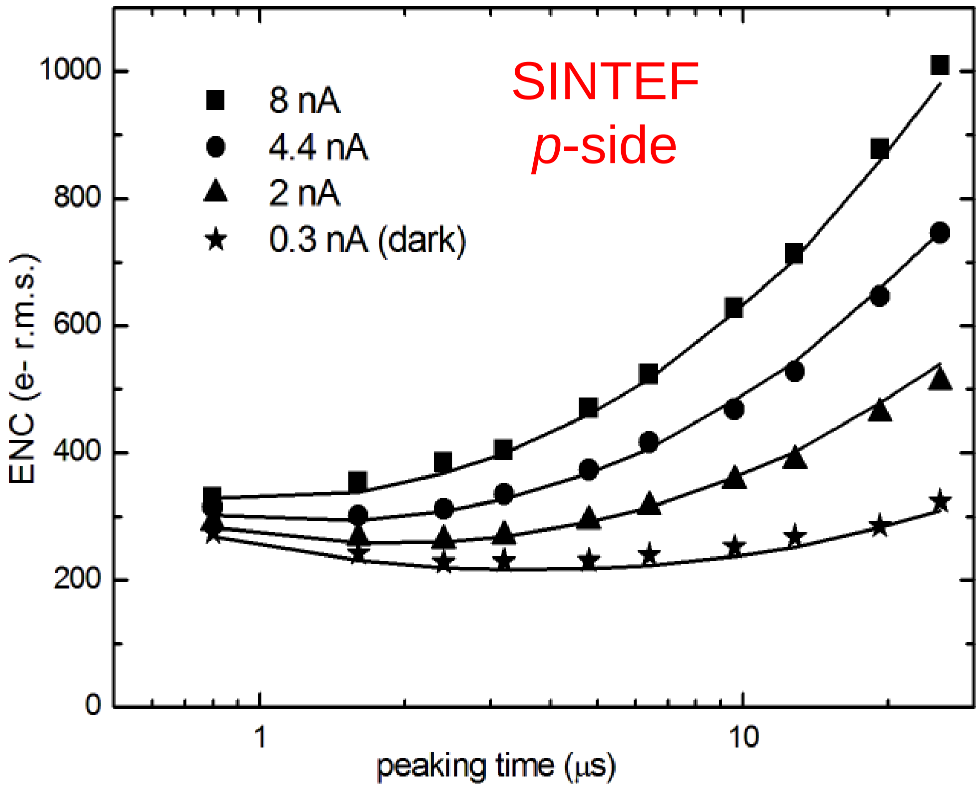
Continuous lines: calculated from Eq.(1) with the extra noise term (2), where the value of A is defined by fitting the data

- Photogenerated current
- At high τ and/or I_L values, noise is
  - much higher than expected
  - directly proportional to both τ and I_L

$\Downarrow$

- There is an excess noise term
  $$q^2 ENC^2 = A t^2 I_{PT}^2 \qquad (2)$$
  added in quadrature
  (A = dimensionless constant)
- Spectral power density of this current noise is $\propto 1/f$: '*parallel flicker noise*'

SINTEF sensor *p*-side
Noise when the P-T current is suppressed



- Photogenerated current
- Strip polarized through an external resistor (470 MΩ) connected to the DC pad

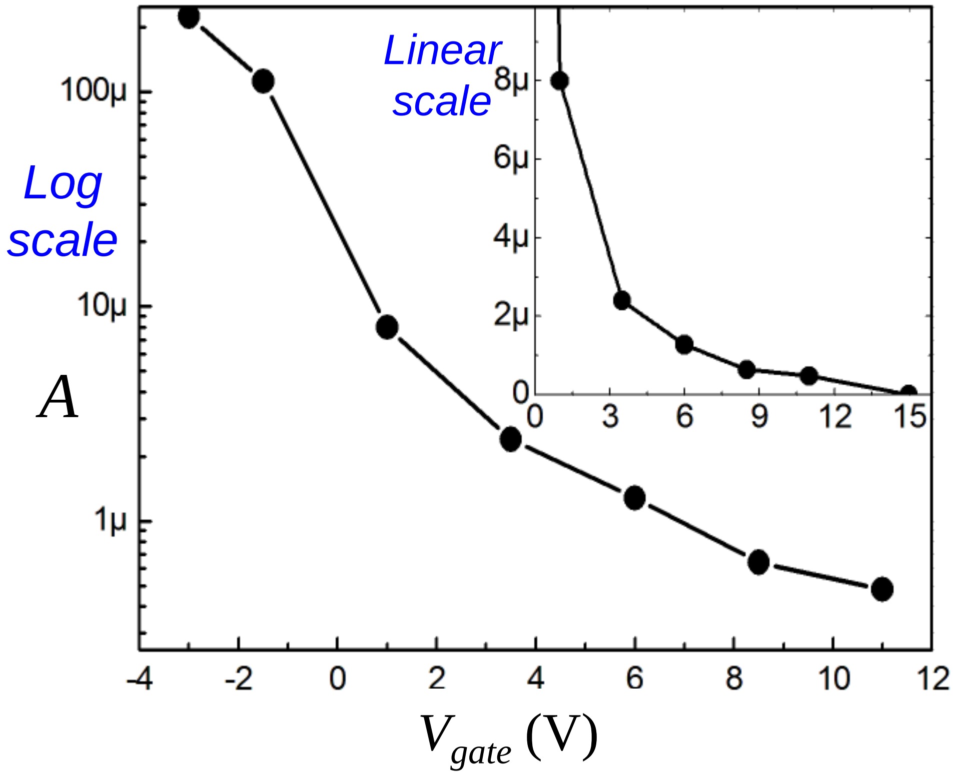
⇒ NO Punch-Through current

⇒ NO extra noise term

- Confirms that the extra noise is due to the punch-through current

Continuous lines: calculated from Eq.(1)
with the added thermal noise of the bias resistor: $q^2 ENC^2 = \frac{t}{3}\left(\frac{4kT}{R_{bias}}\right)$

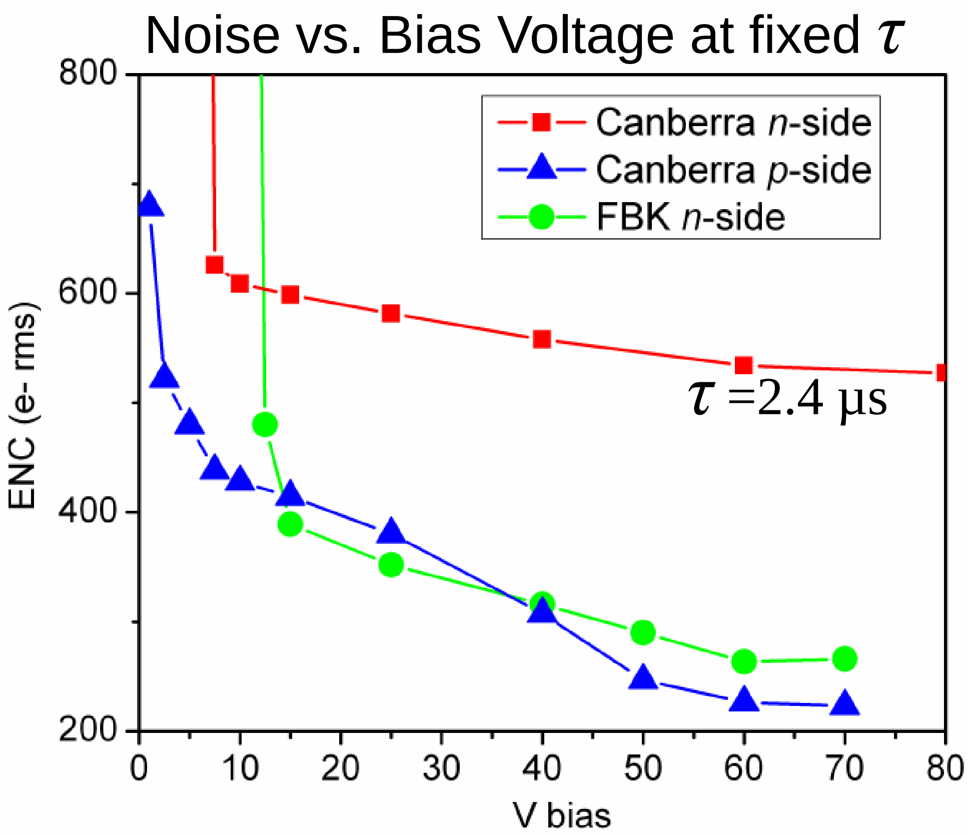
SINTEF sensor *p*-side
Effect of gate over the Punch-Through region



- SINTEF sensors have a (floating) metal gate above the P-T region
- Noise was measured versus voltage applied to gate
- Excess noise (Eq.(2)) extracted and dimensionless constant A plotted vs. gate voltage
- Positive V_{gate} suppresses the excess noise, negative V_{gate} enhances it

- Interpretation: Due to the low oxide fixed charge of Sintef sensors, the P-T hole current runs close to surface, where it is affected by $1/f$ noise due to interface traps (as is the channel current in a MOSFET).
- Positive V_{gate} pushes the P-T hole current away from the surface, suppressing the excess noise.

Further Excess Noise Contribution



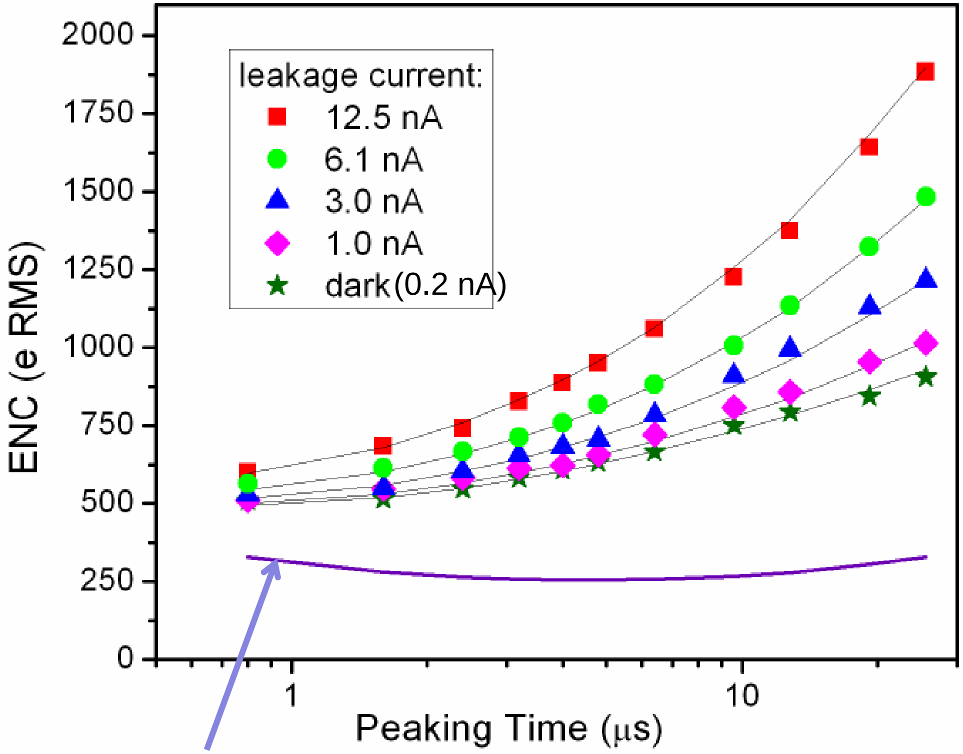
(Continuous lines here simply join the data points)

- On Canberra *n*-side the noise decreases slowly with bias above total depletion (~ 8 V), but is ~ 2 X higher than expected
- Canberra *p*-side and FBK *n*-side (total depletion ~ 15 V) show an excess noise between depletion and ~ 60 V.
- The dependence of this noise on peaking time has been found to be rather odd: $q^2 ENC^2 = K\sqrt{t}$

  where $K \approx 10^{-30}$ C^2 Hz$^{1/2}$, independent of the current

Noise due to Resistive Layers at the Interface

Canberra *n*-side 80 V bias



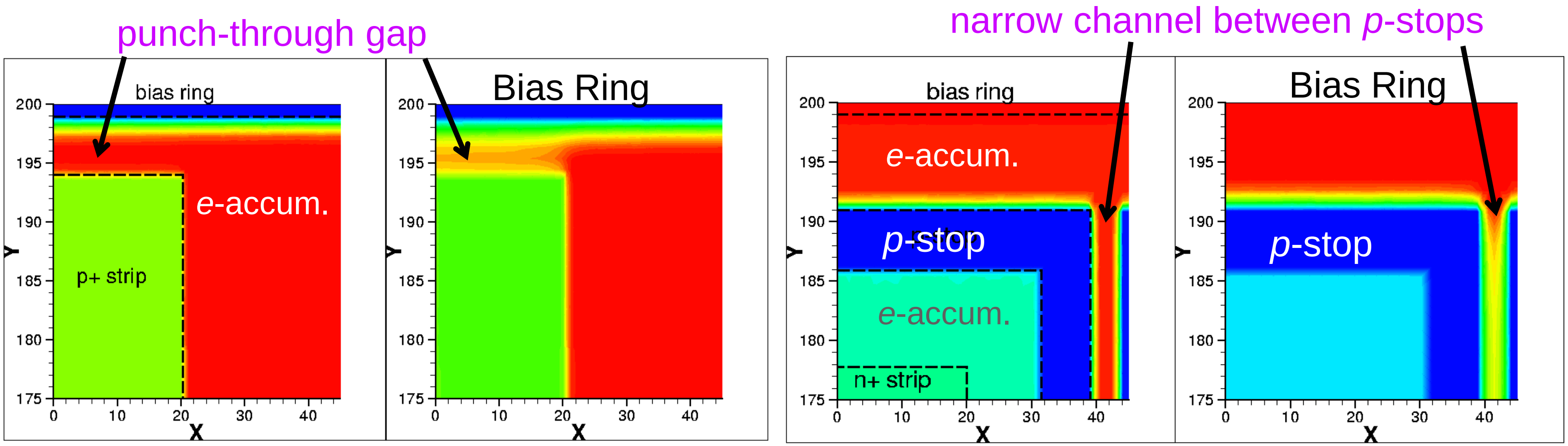
0.2 nA , calculated from the model, without excess noise

⇒ The excess noise is dominant over other noise sources

- Comparison with measurements of strip capacitance and dissipation factor vs. frequency and bias voltage suggest that this noise term may be due to continuous resistive layers at the interface, extending over the whole sensor:
  - electron accumulation layer on *p*-sides and on FBK *n*-side
  - *p*-spray on Canberra *n*-side
- But it's not just thermal noise capacitively coupled to the strip (different τ dependence)

Noise due to Resistive Layers at the Interface

- The suppression of this noise at high bias voltage could be related to the interruption of the electron accumulation layer
  - in the punch-through gap on *p*-side
  - in the region between *p*-stops close to strip ends on *n*-side
- 3-D numerical simulation of electrostatic potential at the interface, (floor view of a small region at strip end)



Lower V_{bias} *Continuous*

Higher V_{bias} *Interrupted*

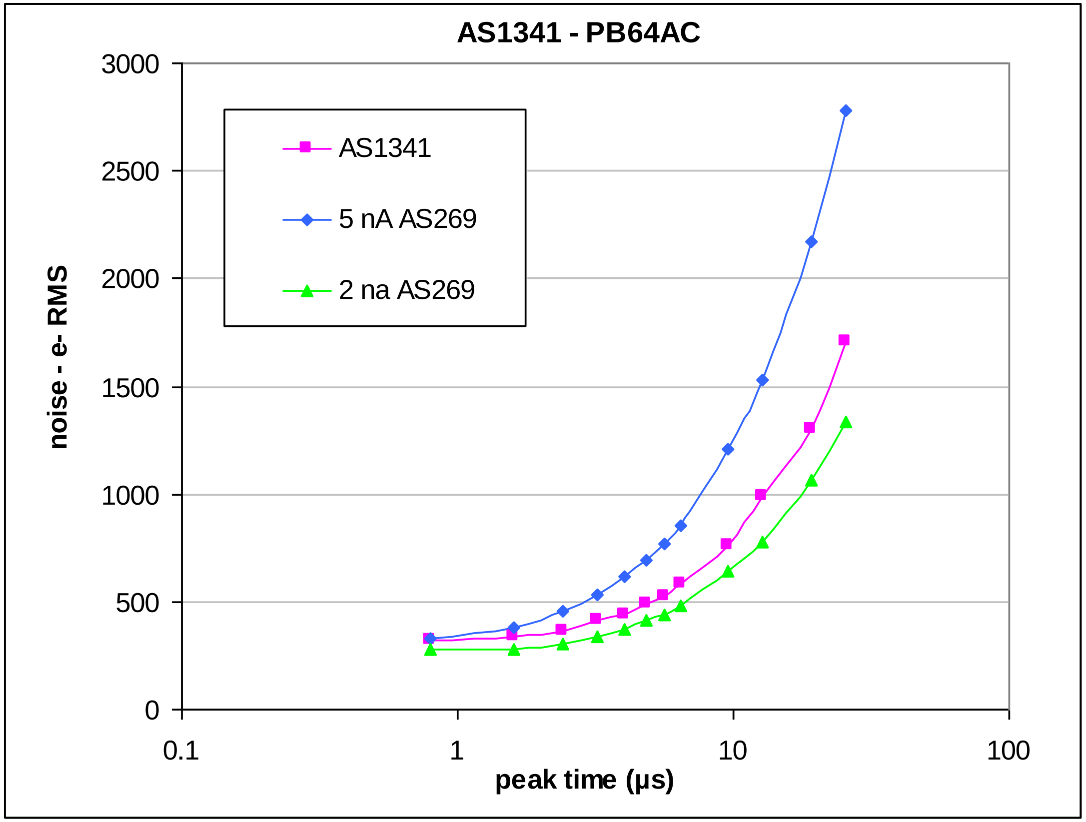
Lower V_{bias} *Continuous*

Higher V_{bias} *Interrupted*

<---------- Canberra *p*-side ----------->   <--------------- FBK *n*-side ------------->

X-ray Irradiated Sintef Sensor: *p*-side strips

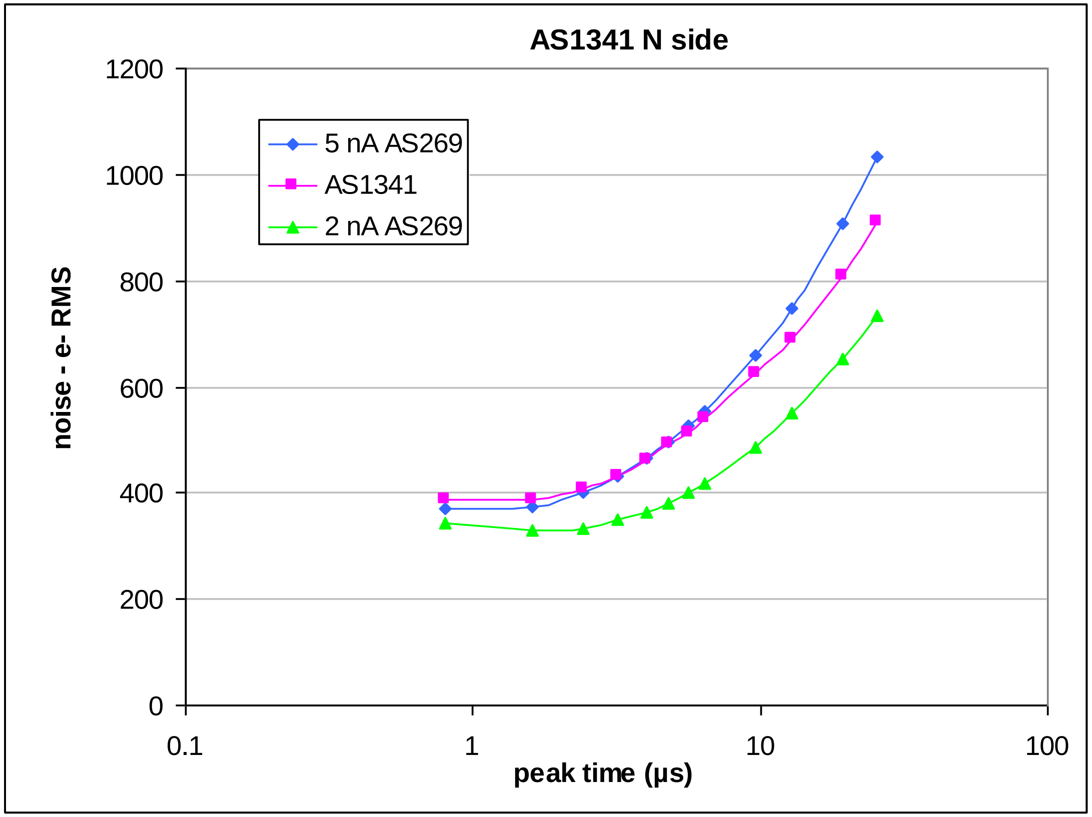
Comparison between irradiated (AS1341) and non-irradiated (AS269) sensors, for comparable values of leakage current



- Noise of irradiated sensor is compatible with its higher leakage current (given the observed contribution of punch-through current)
- No further contribution to noise was found
- ENC < 400 e r.m.s. at shaping times of 1-2 µs

X-ray Irradiated Sintef Sensor: *n*-side strips

Comparison between irradiated (AS1341) and non-irradiated (AS269) sensors, for comparable values of leakage current



- Noise of irradiated sensor is roughly compatible with its higher leakage current (a few nA)
- ENC is still < 400 r.m.s. at shaping times of 1-2 µs

Summary of Noise Measurements

- Punch-through biasing contributes by adding in quadrature a further shot noise contribution, i.e. doubling the shot noise contribution to ENC^2

  ↓

  Carrier injection by punch-through from strip to BR undergoes Poisson fluctuations, and these fluctuations are uncorrelated to the fluctuations in carrier generation and collection by the strip.

- On SINTEF sensors, the punch-through mechanism on *p*-side contributes extra noise, directly proportional to punch-through current and to shaping time. This 'parallel flicker noise' is attributed to the current flowing very close to the interface, where it is affected by interface traps.

- The X-ray irradiation does not appear to add additional noise beyond what expected given the increased current.

- At 2 μs shaping time the noise is well acceptable in all cases (ENC < 500 e).