Development of ATLAS Radiation Monitor

Gregor Kramberger, Vladimir Cindro, Igor Mandić, Marko Mikuž, Marko Zavrtanik
Jožef Stefan Institute, Ljubljana

ATLAS radiation monitors

- Instantaneous:
  - Beam Condition Monitor – BCM

    EDMS document: ***ATL-IC-ES-0013***
- Integrating – on-line
  - Total Ionization Dose - TID
  - Non-Ionizing Energy Loss – NIEL
  - Thermal Neutrons

    EDMS document: ***ATL-IC-ES-0017***
- Integrating – off-line
  - TLD, counting on common LHC effort

On-line monitoring

Constraints for on-line monitors:

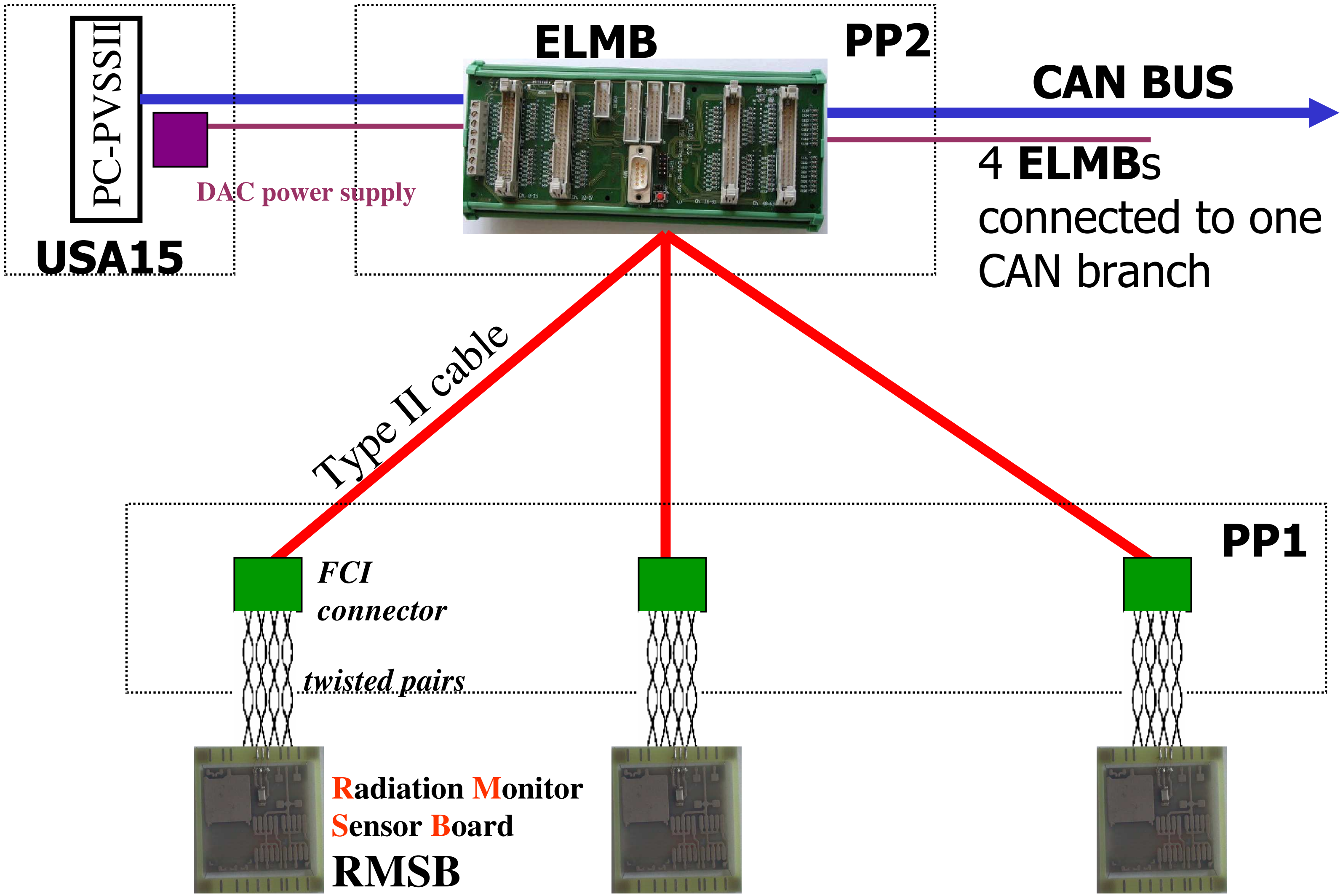
- Use of standard ATLAS DCS components
  - already qualified for use in ATLAS

- Size of the sensor boards
  - dimensions in ATLAS: 8 mm x 4 cm x 4 cm

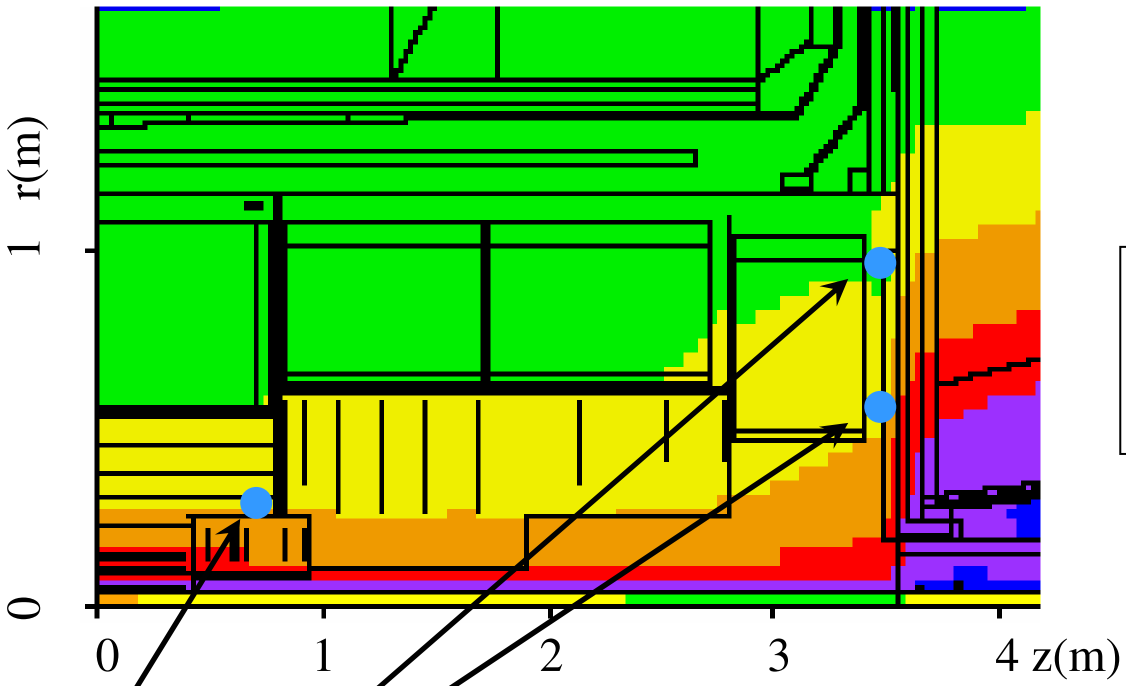
- Cables from user-accessible area *PP2 inside muon system* to *PP1* (allocated few years ago):
  - Type II cable: 12 thin wires 0.22 Ω/m , 4 thick wires 0.033 Ω/m
    ➔ limits the number of sensors per monitoring board

- Choice of locations limited

Schematic view of the on-line monitor



Position of Radiation Monitoring Sensor Boards (RMSB)



3 boards/octant

(total of 24 in the ID)

r[cm]	z [cm]	Φ_{eq} [10^{14}/m^2]	Φ(E >20 MeV) [10^{14}/cm^2]	TID[10^4 Gy]
20-30	70-80	2.37	2.2	14
40-50	340-350	2.35	1.25	6.7
80-90	340-350	1.06	0.41	1.91
L-Ar, MUONS	t.b.d.	t.b.d.	t.b.d.	t.b.d.

Sensors planned to be used on RMSB

Monitor Total Ionizing Dose (TID):

- RADFET's (threshold voltage increase)
  - High-sensitivity (thick oxide) for LHC startup
  - Low-sensitivity (thin oxide) to cover standard 3+7 scenario

Monitor NIEL:

- EPI PIN-diodes (leakage current increase with NIEL)
  - Rely on $\Delta I/V = \alpha \times \Phi$
  - EPI thin (25 μm) substrate depleted at < 30 V
- PIN diodes under forward bias (resistivity increase with NIEL)
  - OSRAM BPW 34F – high fluence (sensitivity around 10^{13} n/cm^2)
  - High sensitivity diodes – low fluence (sensitivity around 10^{10} n/cm^2)

Monitor thermal neutrons:

- DMILL bipolar transistor from ATMEL (test structures from ABCD3T production wafers)
  - Common emitter current gain degrades with fluence
  - Sensitivity to thermal neutrons ~ 3 x NIEL
  - Provides direct monitoring of damage on ABCD3T input transistor

Temperature control

- all types of sensors are sensitive to temperature
- temperature should be stable to simplify analysis (annealing...)

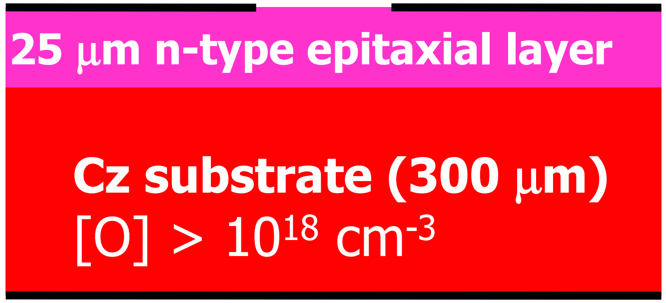
Stabilization achieved by heating sensor boards to few degrees above environment temperature of ~20^{o}C.

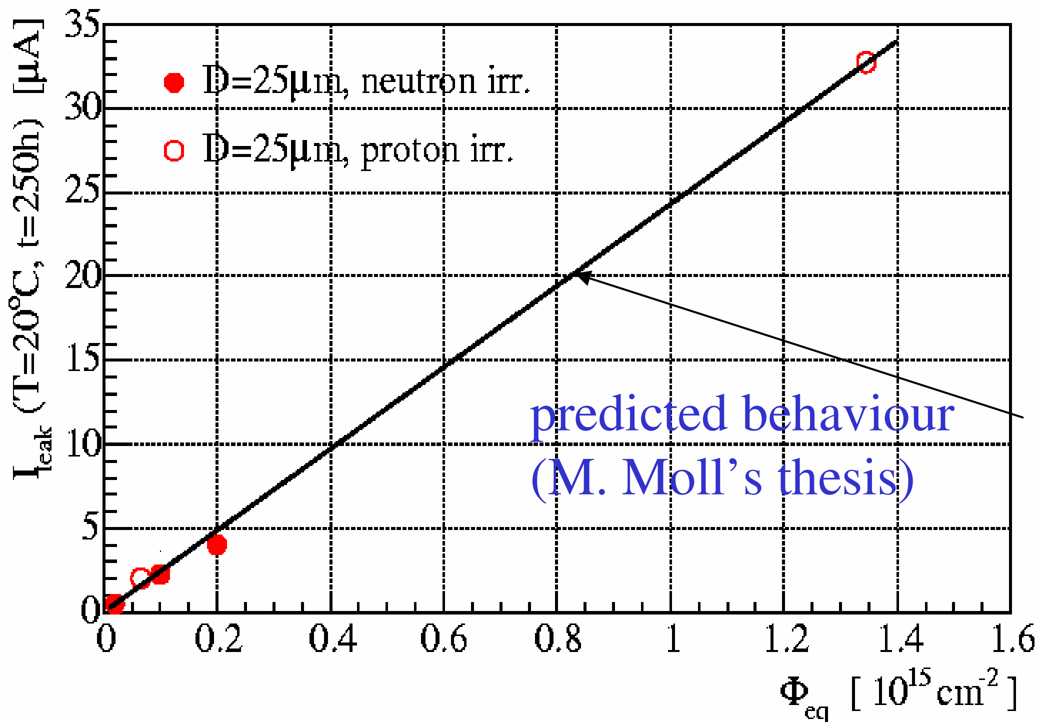
NIEL monitoring – epi-Si diodes

Measurement principle: reverse bias leakage current increase in diode after irradiation $\Delta I/V = \alpha \times \Phi_{eq}$.

Samples (ITME grown epi-Si, CiS process)

- 25 μm epi-Si , $\rho_{initial}$=50 Ωcm, V_{fd}=25 V, 5x5 mm^2
- V_{fd} always less that 28 V (limited by DAC)



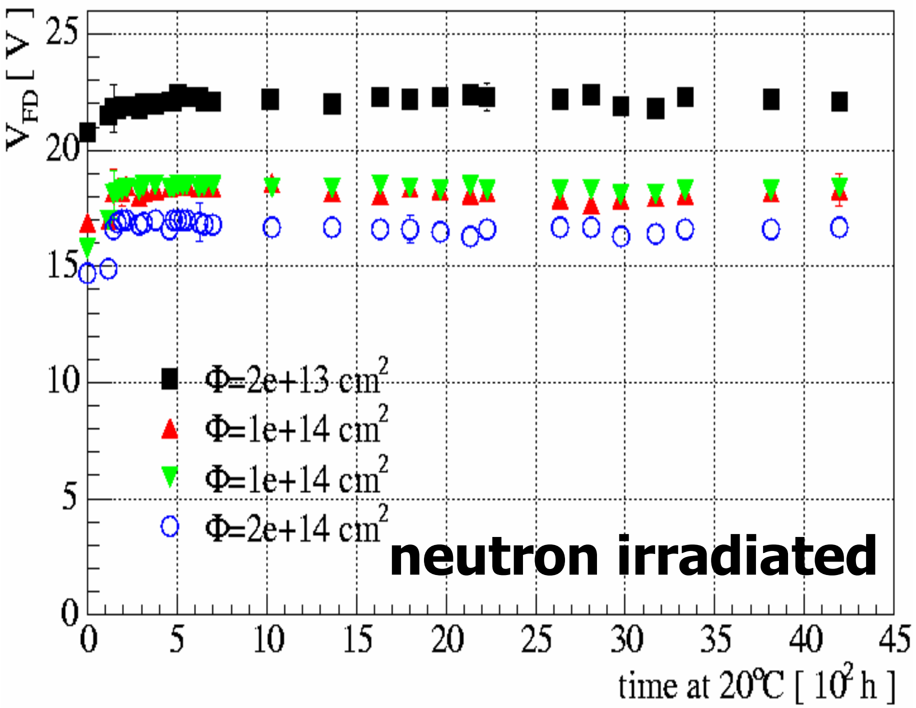


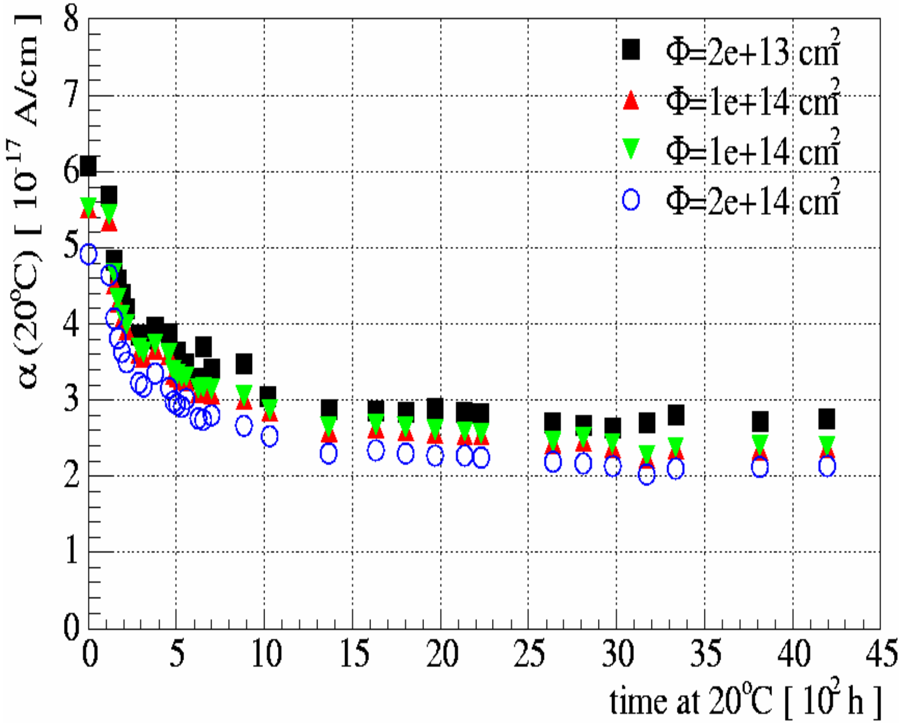
- irradiated with neutrons at JSI reactor in Ljubljana
- Irradiated with 23 GeV protons at CERN PS

Measured leakage currents are in accordance with expectations

Operational (V_{fd} < 28 V) even at 10^{15}cm^{-2} !

Annealing studies performed at 20°C

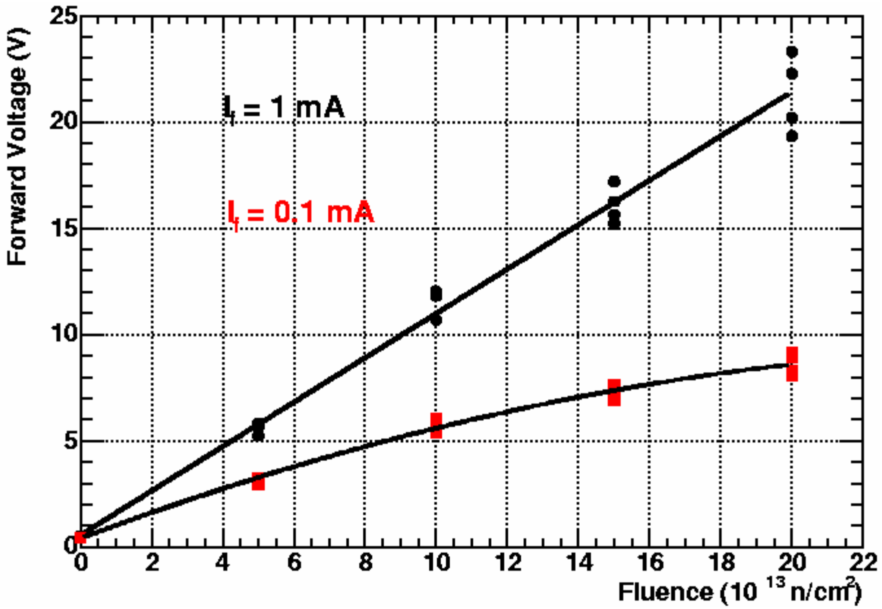


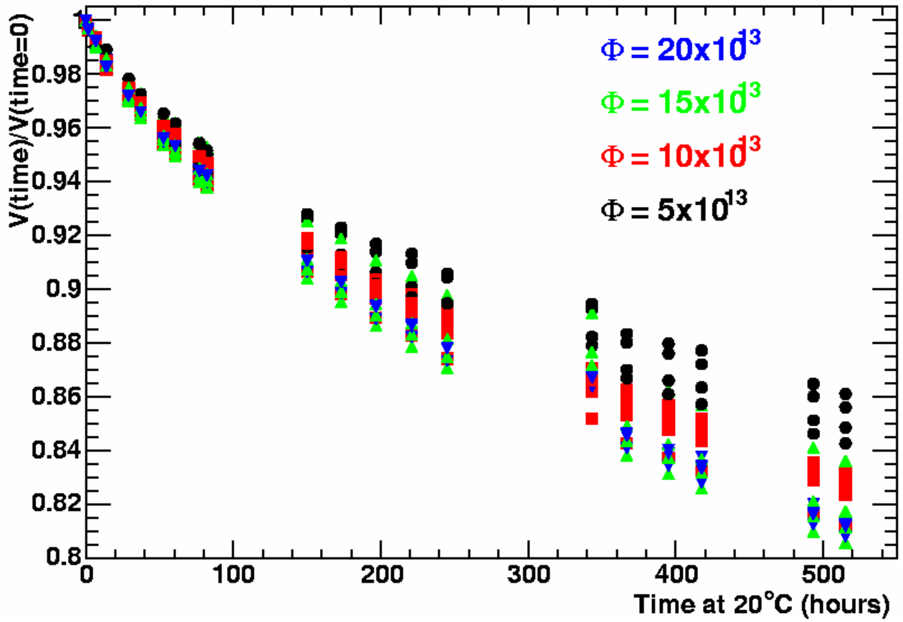


epi-Si can be sensitive also during low luminosity running!

NIEL monitoring – OSRAM PIN (BPW 34F)

Measurement of forward bias resistance of irradiated PIN diodes

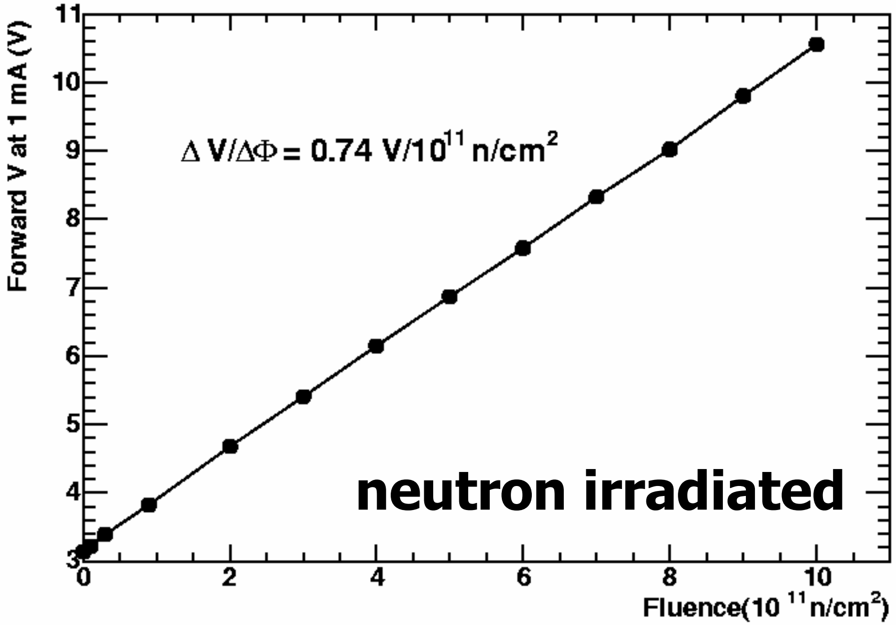


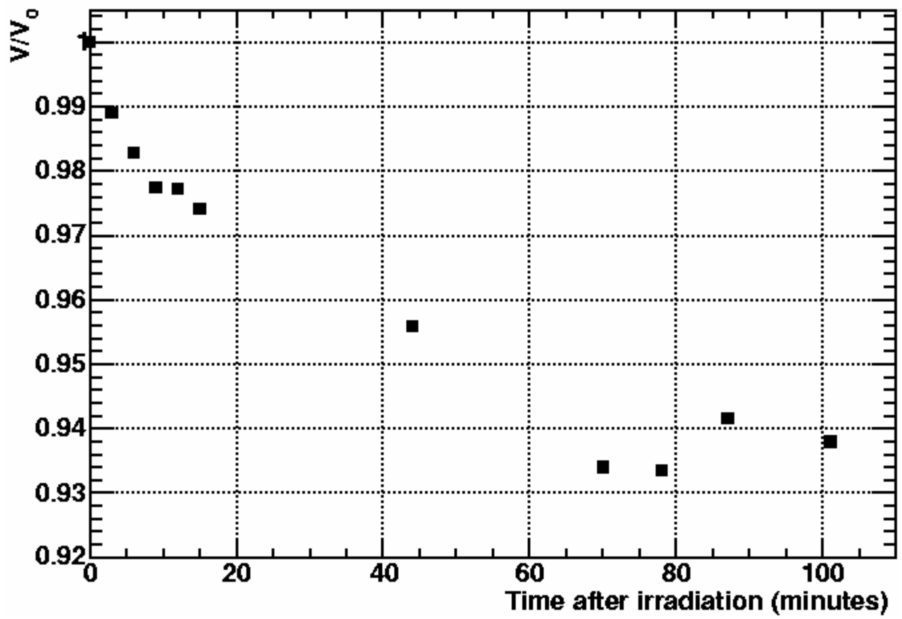


Several samples irradiated with neutrons at JSI reactor in Ljubljana:

- Better linearity with fluence at higher current
- Annealing does play a significant role

NIEL monitoring – high-sensitive PIN





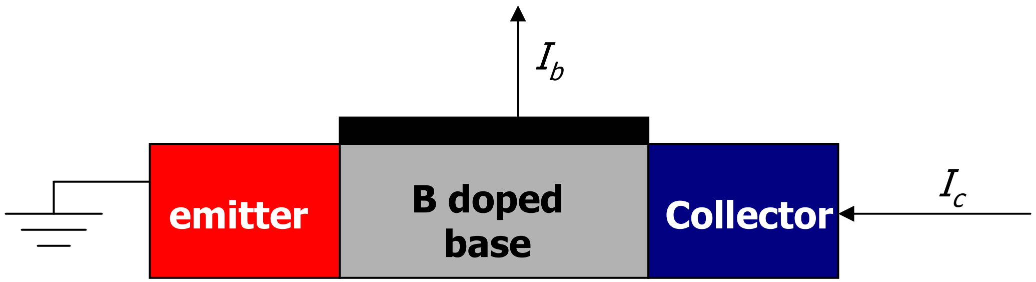
Irradiation of single diode in steps

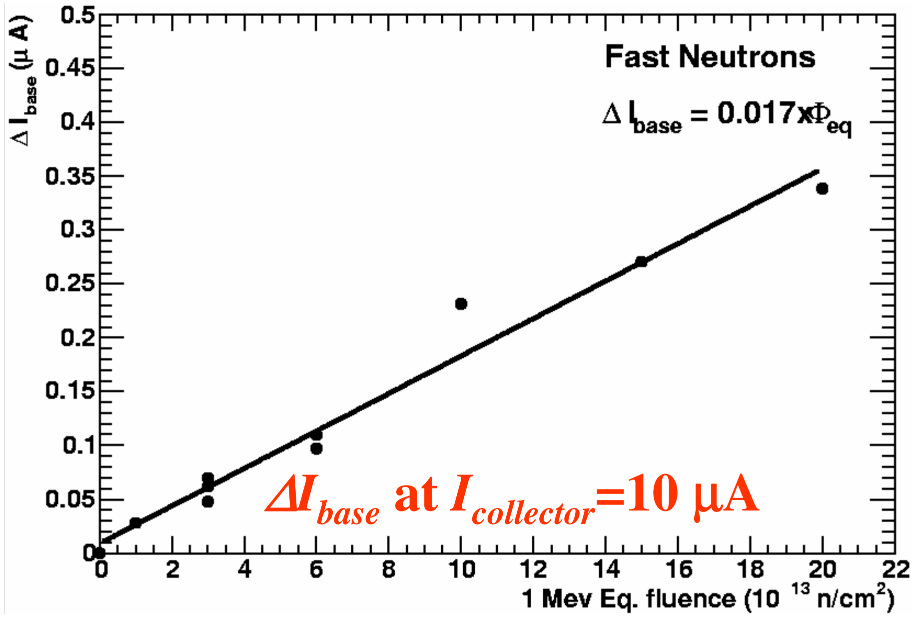
- One minute between two fluence points
- Excellent sensitivity for low fluences
- Annealing could be important – studies in progress

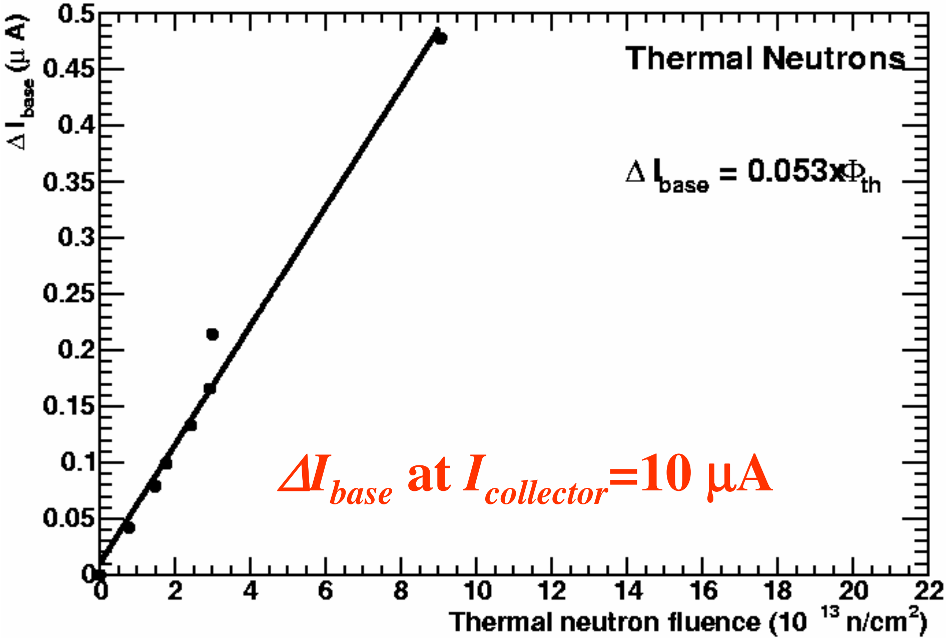
DMILL structures

Measurement of ΔI_b at fixed I_c

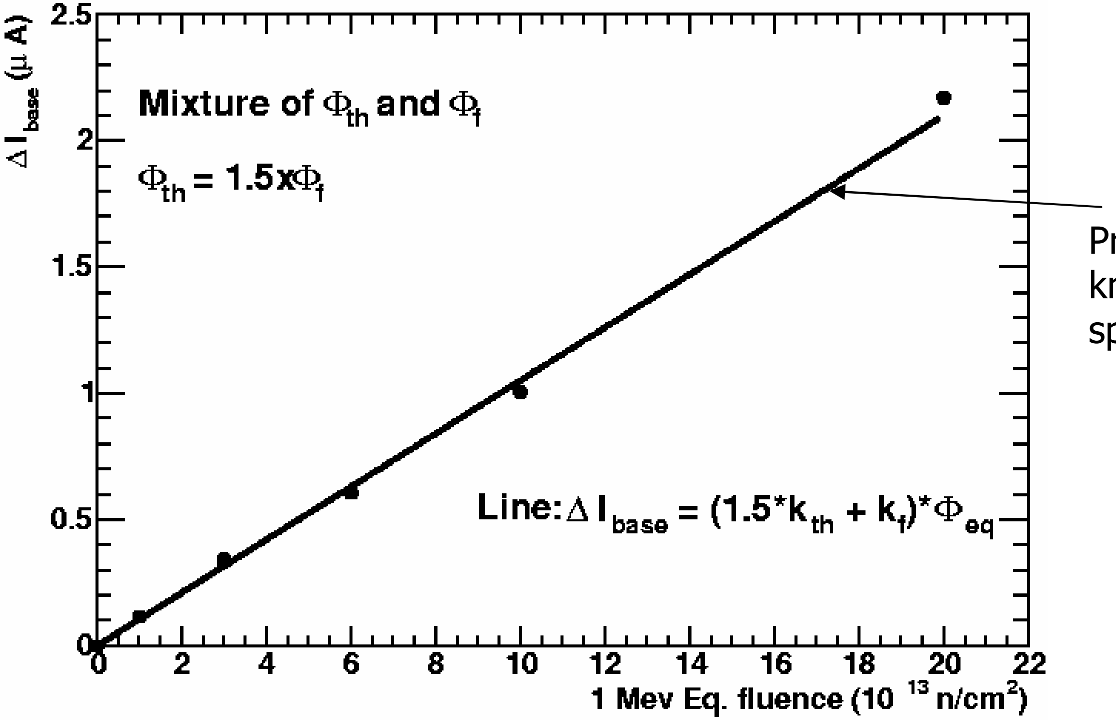
- $n_{thermal} + {}^{10}B \to {}^{7}Li + {}^{4}He + \gamma$
- Fragments cause significant bulk damage (decrease of carrier lifetime)
- Increase of base current at fixed collector current (current gain $\beta = I_c/I_b$ degradation)







Same transistor as input transistor of ABCD3T readout chip



$$\Delta I_{base} = k_{th} \cdot \Phi_{th} + k_{eq} \cdot \Phi_{eq}$$

ΔI_{base}: measured; k_{th}: known calibration; k_{eq}: known calibration; Φ_{eq}: measured

more details: *I. Mandić et al., IEEE TNS NS-51 (2004) 1752.*

Read-out

ELMB + DAC boards:

- ELMB available, 64 ADC channels
- DAC boards will be produced next year (prototypes were tested), 4 boards (16 channels each) per ELMB

Fully compatible with ATLAS DCS (CAN bus communication)

Compliant with radiation tolerance requirements

3-4 "RM sensor boards" per ELMB:

(each sensor board will be connected with 16 wires)

- epi-Si diode (3 wires)
- 1 or 2 PIN for high fluence (1 or 2 wires)
- 2 or 1 PIN for low fluence (2 or 1 wires)
- 1 or 2 RADFETs high doses (1 or 2 wires)
- 2 or 1 RADFETs low doses (2 or 1 wires)
- 2 DMILL transistor structures (4 wires)
- Pt1000 or NTC (1 wire)
- GND (1 wire)
- Heater (1 wire)

Each sensor board needs:

- 13 ADC channels
- 12-16 DAC channels (depends on heater)

DACs: with external power supply of 30 V
•current output: 0-1 mA maximum voltage drop 28 V (sensors)
0-10 mA maximum voltage drop 10 V (heaters)
•voltage output: current drop over the resistor

ADCs: 64 (12 bit)
•conversion rate from 2-100 Hz
•different dynamic ranges can be selected
•use of attenuators, Pt1000 readouts etc. with resistor/capacitor network plugs

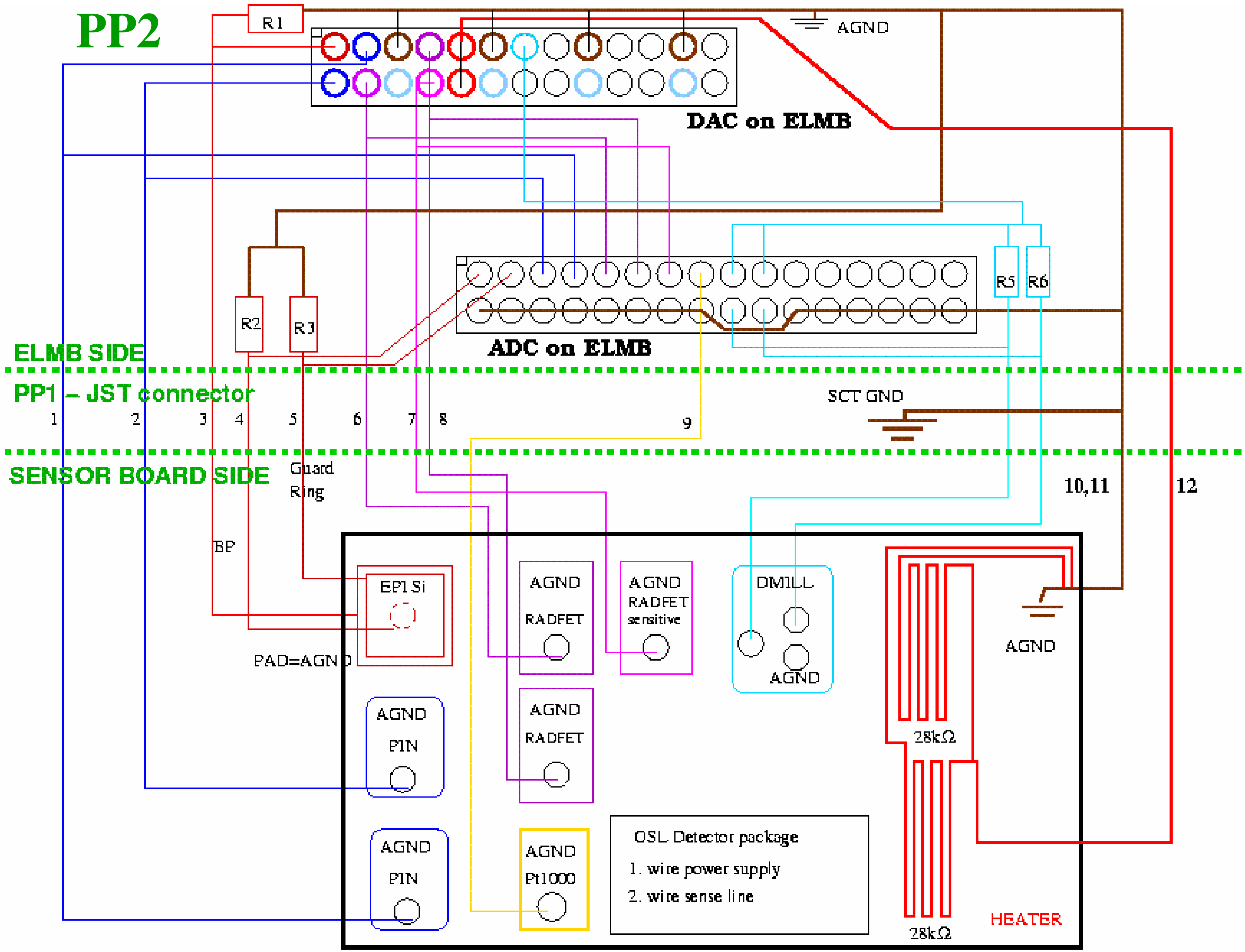
<u>Readout principles</u>

RADFET,PIN: current enforced (DAC)-voltage measured (ADC)

EPI: current (DAC) converted to voltage (resistor) –
voltage drop on resistor due to leakage current measured (ADC)

DMILL: collector current enforced (DAC) –
voltage drop on resistor due to base current measured (ADC)

HEATER: 3-5 DAC channels (200 mW/ch.) connected together


PP2
R1
AGND
DAC on ELMB
R2
R3
R5
R6
ADC on ELMB
ELMB SIDE
PP1 – JST connector
1
2
3
4
5
6
7
8
9
SCT GND
SENSOR BOARD SIDE
Guard
Ring
10,11
12
BP
EP1 Si
PAD=AGND
AGND
RADFET
AGND
RADFET
sensitive
DMILL
AGND
AGND
AGND
PIN
AGND
RADFET
28kΩ
AGND
PIN
AGND
Pt1000
OSL Detector package
1. wire power supply
2. wire sense line
HEATER
28kΩ

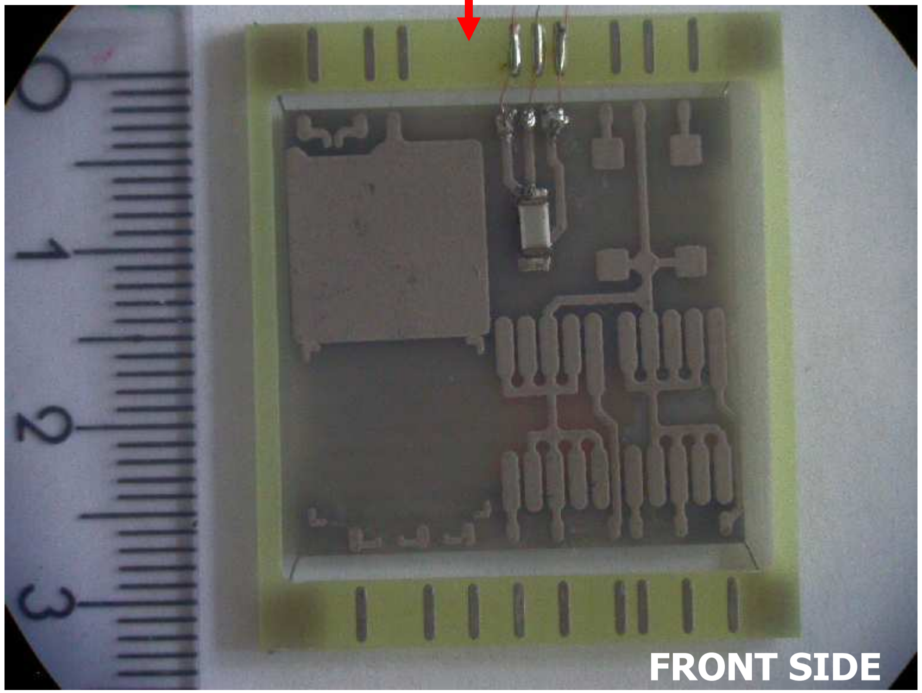
Sensor board

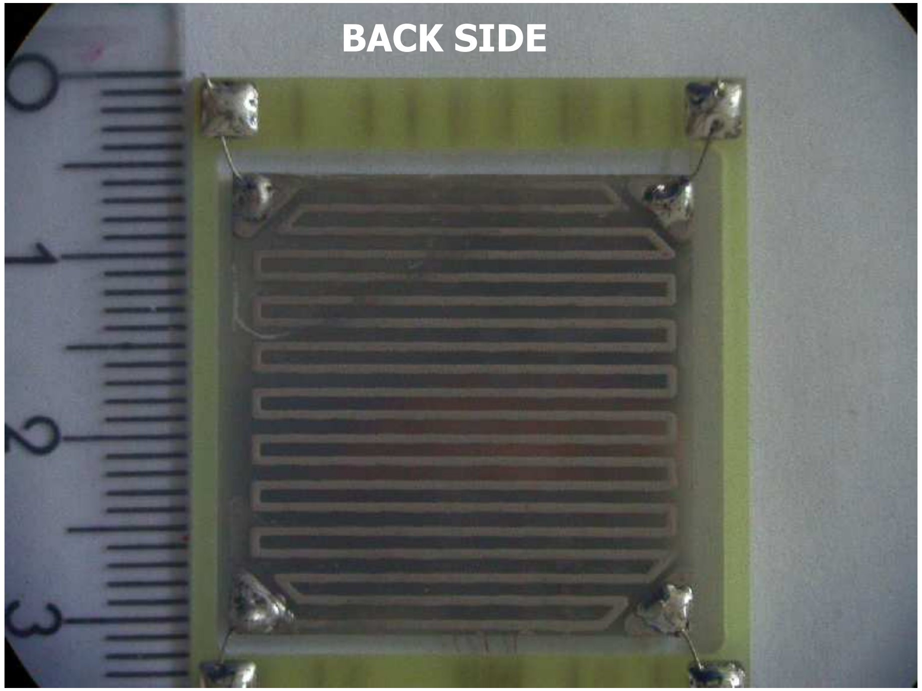
Sensor boards will be made on square inch AlN ceramics:

- 600 μm thick
- bondable (Au) and solderable contacts (Pd-Ag)
- good heat conductance (140-177 W/m K)
- high resistivity (10^{10} Ωcm)

Board will be connected through PCB frame (mechanical support and thermal isolation)

Prototype



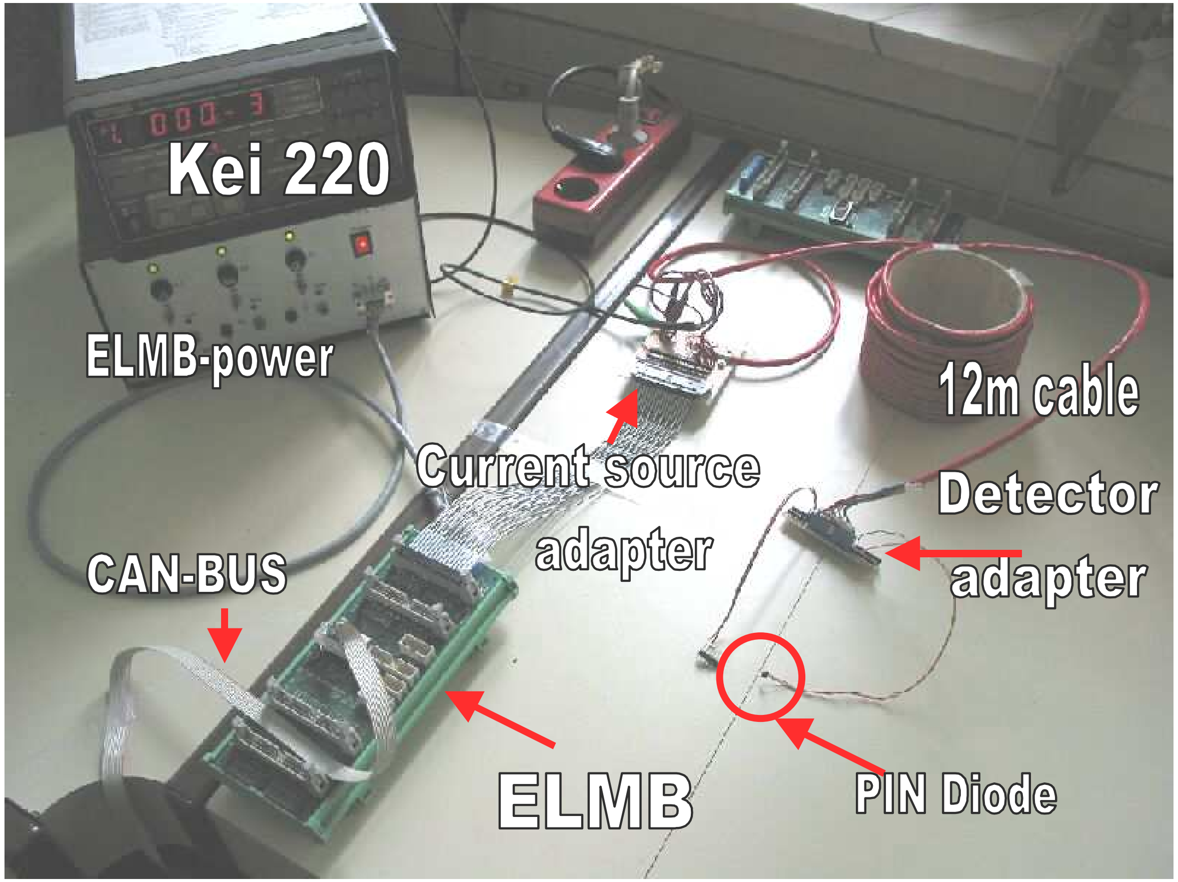


First test - readout

ELMB readout:

- 12 m Type II cables
- No DAC's available yet – use Keithley current source
- Read-out over CAN-bus

➔ successful readout of all types of sensors demonstrated

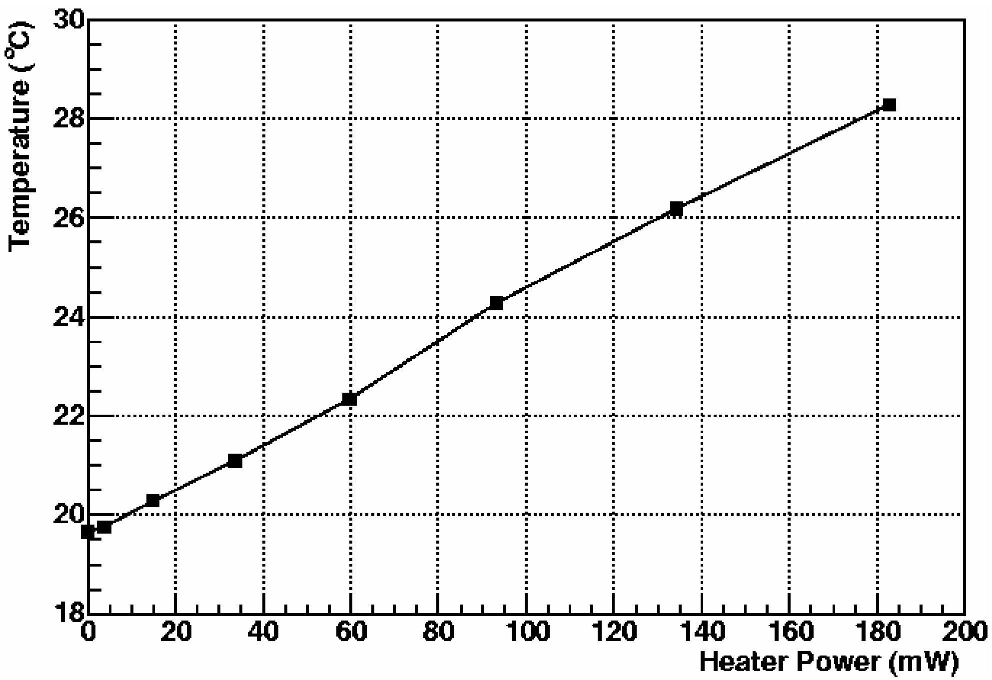


Heater test

First tests:

•At least 3 DAC channels 200 mW each planned for heater

→enough power for stabilization of temperature of RMSB



Future plans

SENSOR studies:

•PIN BPW 34F – continue annealing at 20^{o}C and start it also at 30^{o}C to get data for Arrhenius relation interpolation
•DMILL – already irradiated with n and p (CERN PS) , annealing studies will follow
•EPI – annealing studies (n,p irradiated samples) to verify the predicted behavior (M. Molls thesis)

RM board development:

•population of the prototype boards with sensors
•development of housing (PEEK plastics – radiation hard up to 1 GRad)
•studies of realistic thermal properties of the sensor

DAC:

•first series will be commissioned soon

READ-OUT:

•PVSSII software development (has already started)