Cold beta-source tests of SCT modules for ATLAS HL upgrade

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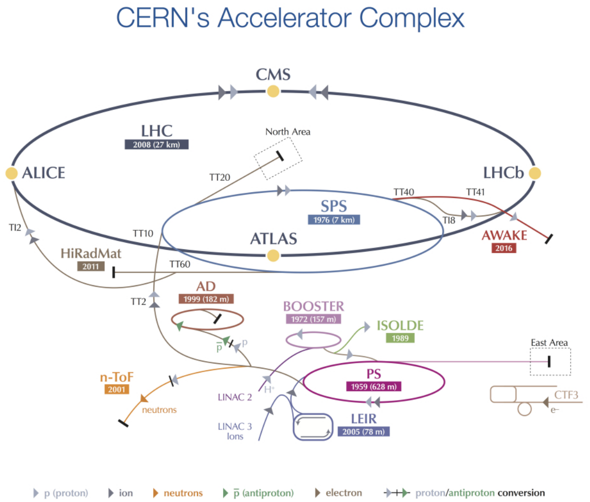
Malá Skála, 13th April 2019

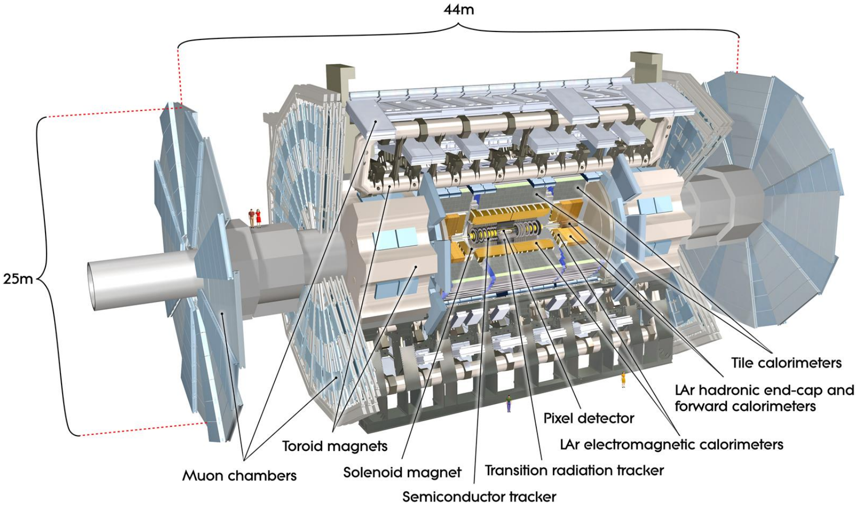
Outline

- Introduction: ATLAS Experiment
- The Need for Upgrade
- Semiconductor Particle Detectors
- ITk SCT Detector Modules
- Cold Beta Source Tests: Setup, DAQ, Analysis & Results

CERN and LHC


CERN's Accelerator Complex
CMS
LHC
2008 (27 km)
North Area
ALICE
LHCb
TT20
TT40
TT41
SPS
1976 (7 km)
TI8
TI2
TT10
ATLAS
AWAKE
2016
HiRadMat
2011
TT60
AD
1999 (182 m)
TT2
BOOSTER
1972 (157 m)
ISOLDE
1989
East Area
n-ToF
2001
PS
1959 (628 m)
CTF3
LINAC 2
neutrons
LINAC 3
Ions
LEIR
2005 (78 m)
p (proton)
ion
neutrons
p̄ (antiproton)
electron
proton/antiproton conversion

ATLAS Experiment



ATLAS Today

- beam crossing @ 40 MHz
- $\sim 10^{11}$ protons per bunch
- $10^{-34}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$ instantaneous luminosity
- collisions per bunch crossing (pile-up) ~ 25
- event recording @ 1 kHz
- $< 500\,\mathrm{fb}^{-1}$ integrated luminosity

The Bright Future

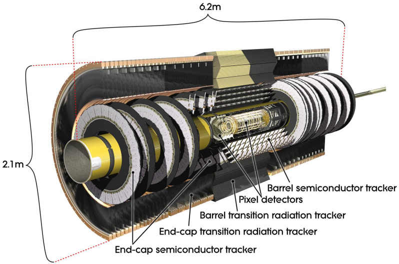
Instantaneous Luminosity will increase by a factor 5–7...

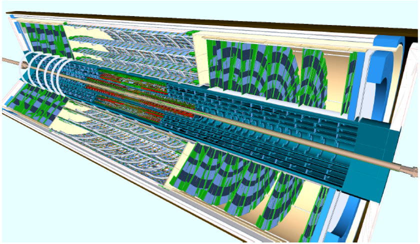
- Pile-up will increase from current to $>$140.
- $\sim 3000\,\mathrm{fb}^{-1}$ Integrated luminosity during HL phase

$\Longrightarrow$ Readout electronics will have to be faster - HL trigger record rate 10 kHz

$\Longrightarrow$ An order-of-magnitude harsher radiation environment

ID vs. ITk

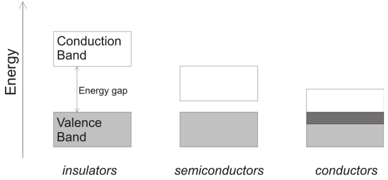


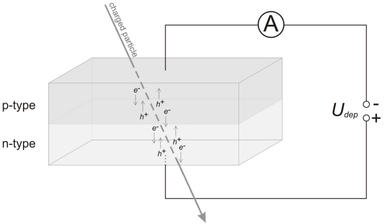


ID (left) & ITk (right)

Semiconductor Detectors - Principles

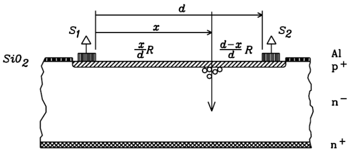
- We need to get rid of free charge carriers - pure semiconductor $\times$ p–n junction.



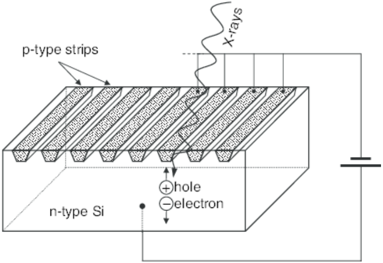


Tracking Semiconductor Detectors

Position sensitivity can be implemented in two ways...

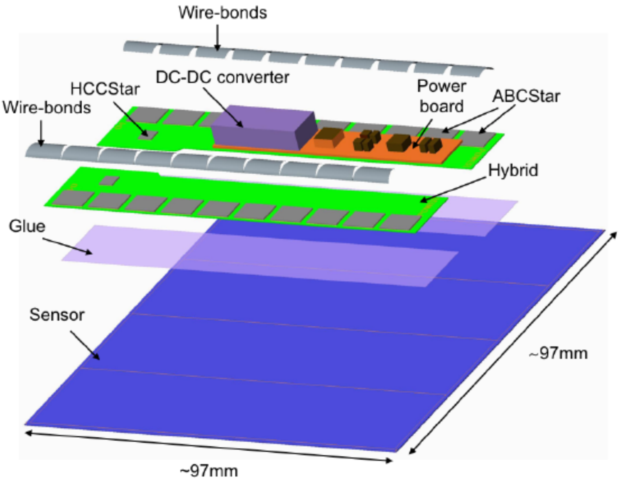


Resistive charge division
Full amplitude readout

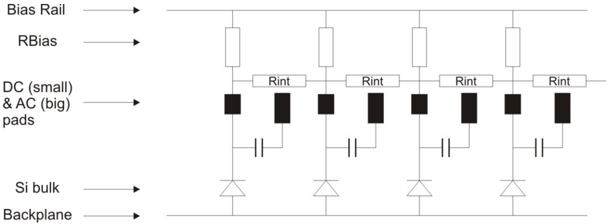


Fine division of one of the electrodes
Binary readout possible

Module Design



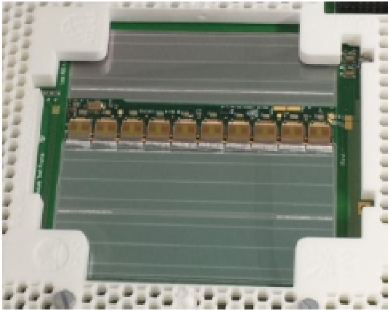
Sensors

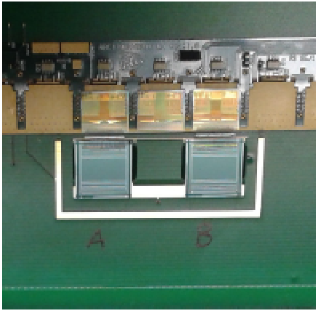


Characteristics	Non-irradiated sensor	Irradiated sensor
Leakage current	$\sim 10^{-9}$ A	$\sim 10^{-7}$–10^{-4} A
Interstrip resistance	$\sim 10^{10}$–10^{11} Ω/cm	$\sim 10^{9}$–10^{7} Ω/cm
Interstrip capacitance	$\sim 10^{-12}$ F/cm	$\sim 10^{-12}$ F/cm
Coupling capacitance	$\sim 10^{-11}$ F/cm	$\sim 10^{-11}$ F/cm
Bias resistance	$\sim 10^{6}$ Ω	$\sim 10^{6}$ Ω

Electronics

- ABC130 - Atlas Binary Chip, 256 channels, pre-set threshold, buffer...
- HCC - Hybrid Control Chip
- FEAST - DC-DC convertor



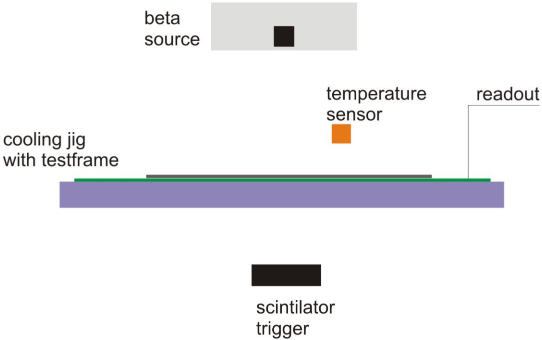


Cold Testing – Motivation

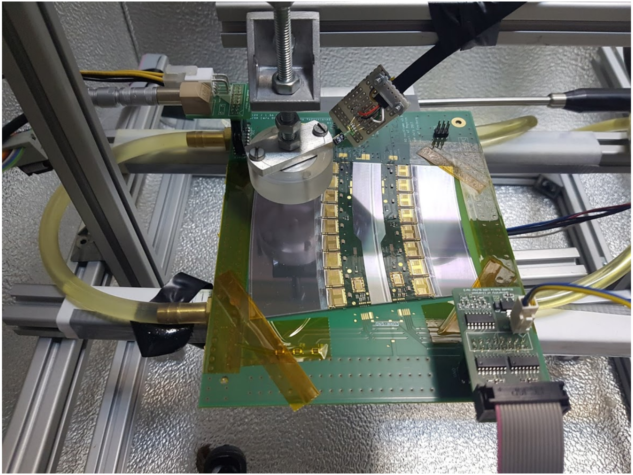
- During operation, ITk will be cooled down to $\sim$ -30 °C
- Leakage current drops to the order of tens of nA

… do the modules work as expected?

Experimental Setup



Experimental Setup



Cooling cycle

Water is bad, ice is even worse

- The sensor has to be kept over the dew point temperature at all times
- Control with jig thermometer, one temperature & RH sensor above the test frame and another near the wall of the freezer
- Dew point automatically calculated every few seconds

$$\gamma = \frac{RH}{100} + \frac{bT}{c+T}, \quad T_{dp} = \frac{c\gamma}{b-\gamma}$$

where $b = 18.678$ and $c = 257.14\,^{\circ}\mathrm{C}$

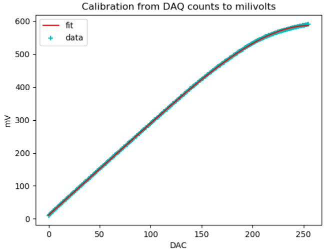
DAQ - Readout Calibration

Charge collected by strips in different units:

- **DAC** - **D**ata **A**cquisition **C**ounts - internal units of the DAq electronics expressing signal strength
- **mV** - Calibration from DAC to mV dependent of FE electronics settings
- **fC** - Actual ammount of charge deposited by particle, calibration from mV to fC dependent of ("almost") instantaneous conditions

DAQ - Readout Calibration

- Calibration from DAC to mV
- Strobe Delay – synchronization of electronics
- Three Point Gain - Calibration from mV to fC



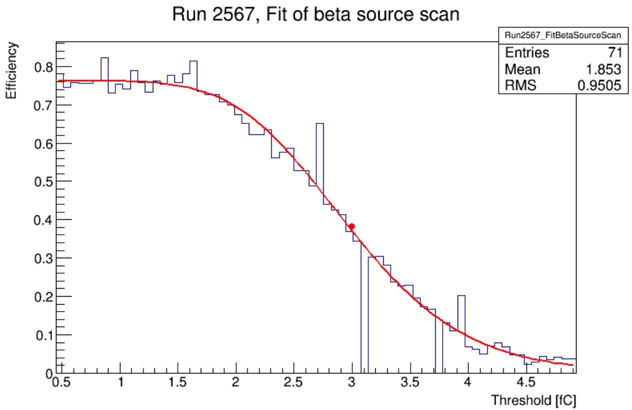
Threshold Scan

Threshold = value of collected charge in one channel below which the electronics reads out zero.

- The signal originating in detector has Gauss-convoluted Landau distribution.
- By raising the value of threshold, we make the detector accept only more energetic hits.
- Measured value is Efficiency - hits registered by detector / hits registered by trigger
- Output from threshold scan is the value of threshold corresponding to 50 % of the maximal efficiency.

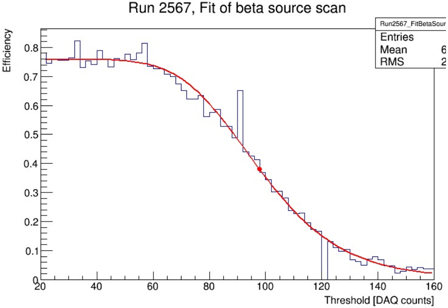
Threshold Scan

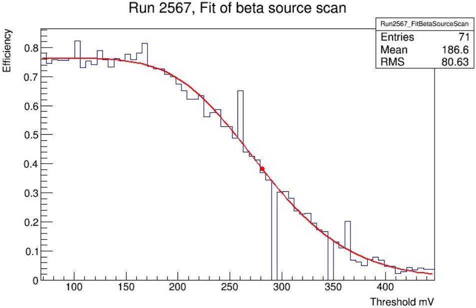
By scanning through threshold values, we obtain cummulative Gauss-Landau distribution, which can be fitted with S-curve (Skewed Complementary Error Function).



Threshold Scan

In which units should we fit the data?



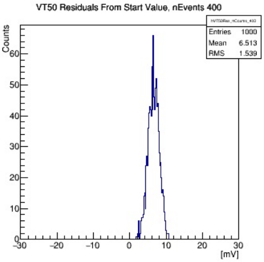


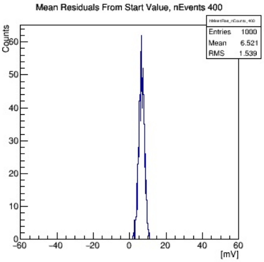
Uncertainity

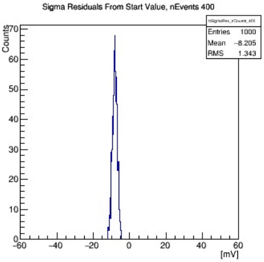
Uncertainity of the 50 % efficiency threshold were determined by resampling:

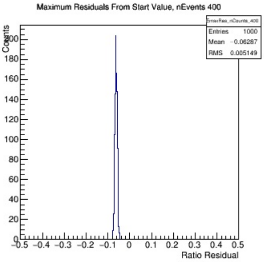
1. Sub - selection of the measured data is made
2. Sub - selection is fitted with S-curve and find 50 % efficiency point
3. Repeat 1500 times

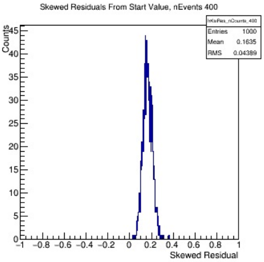
Uncertainity





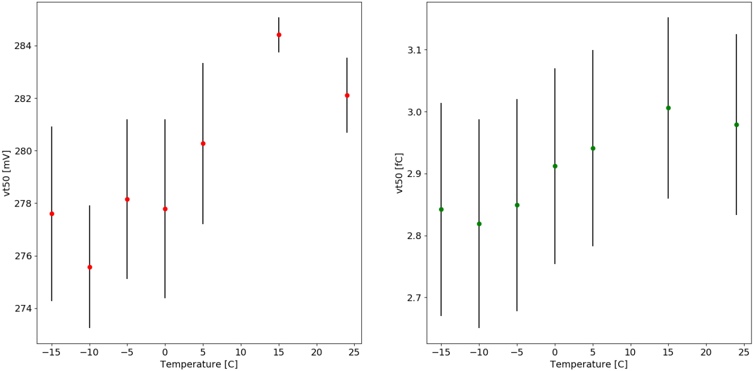






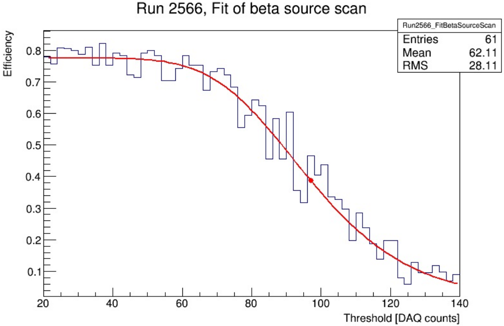
Results

50 % efficiency threshold, chip #6



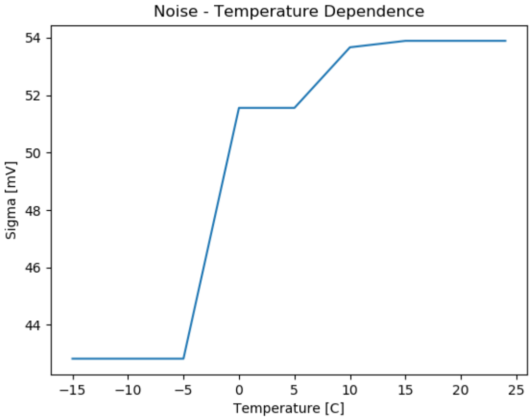
Problems

Some of the scans terminated sooner than at the desired threshold:



Fitting was done with unphysical S-curve. We would like to fit with cumulative Gauss convoluted Landau to extract physical parameters.

Results (Preliminary)



Conclusion

- Ability of IPNP to perform low-temperature β-source tests was demonstrated
- Tests of R0 module prototype were performed, showing slight decreasing trend of 50 % efficiency threshold with decreasing temperature
- Equivalence of fitting the data in various units was tested
- Safe cooling cycle was established

Thank you for your attention!

References

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