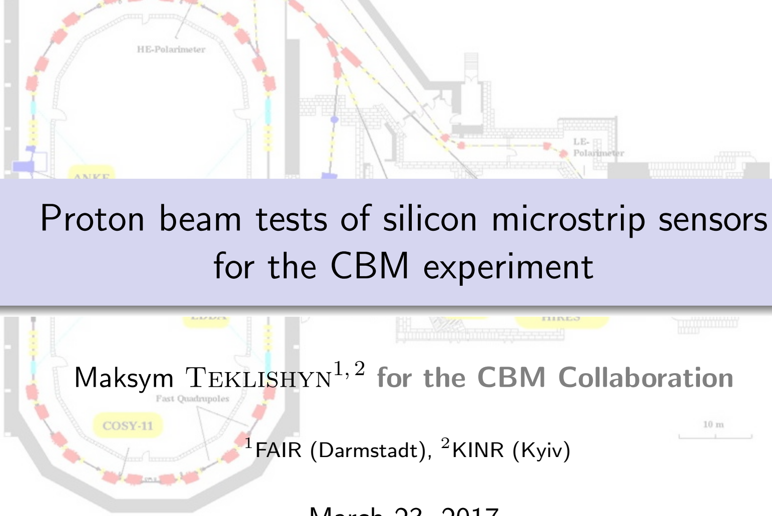

Proton beam tests of silicon microstrip sensors for the CBM experiment

Maksym Teklishyn[1,2] **for the CBM Collaboration**

[1]FAIR (Darmstadt), [2]KINR (Kyiv)

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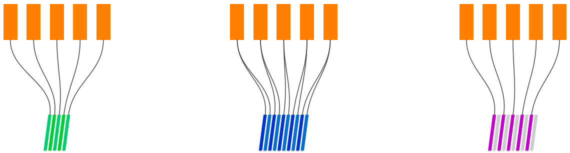
Introduction

- The key quantity : **signal over noise**
  - conservative limit at $S/N \gtrsim 15$
  - charge collection efficiency $\epsilon = Q_{\text{measured}}/Q_{\text{deposited}}$ limits a signal
  - noise is a property of an integrated system
- Influence of the irradiation:
  - bulk damage leads to the traps of the charge carriers, $S \searrow$
  - current increases, shot noise $N \nearrow$
- Non-perpendicular penetration of the sensor $\measuredangle$
  - charge sharing between neighbouring strips, $S_i \searrow$
  - risk of (partial) charge losses due to threshold
  - critical angles:
    - ⋆ $\arctan\left(\frac{300\,\mu\text{m}}{1 \times 58\,\mu\text{m}}\right) \simeq 11^\circ$, $\arctan\left(\frac{300\,\mu\text{m}}{2 \times 58\,\mu\text{m}}\right) \simeq 21^\circ$...
  - nominal acceptance of the STS:
    - ⋆ $2.5^\circ \leq \theta \leq 25.0^\circ$

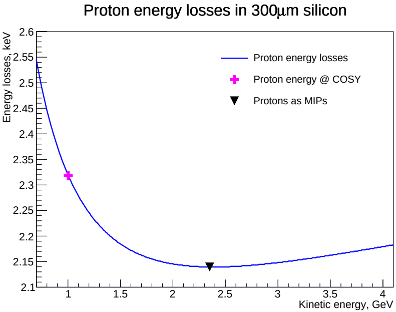
Optional connection schemes

- **Geometrical effects** on the S/N ratio
  - $S/N \propto 1/\sqrt{n_{\text{strips}}}$, where n_{strips} is a cluster size
  - cluster size depending on angle (neglecting cross-talk):
    - $0^\circ \leq \theta \leq 11^\circ$, $n_{\text{strips}} \leq 2$
    - $11^\circ < \theta \leq 21^\circ$, $2 \leq n_{\text{strips}} \leq 3$
    - $\theta \geq 21^\circ$, $n_{\text{strips}} \geq 3$
  - S/N deteriorates by factor of $\sqrt{3}..\sqrt{4}$ for peripheral ladders
- **Geometrical solution**: (effectively) increasing strip width
  - change sensor mask pattern (cost and time consuming)
  - introduce alternative connection schemes to r/o electronics:
    - two strips to one r/o channel, $2 \to 1$
    - every second strip omitted, $2 \to 0$



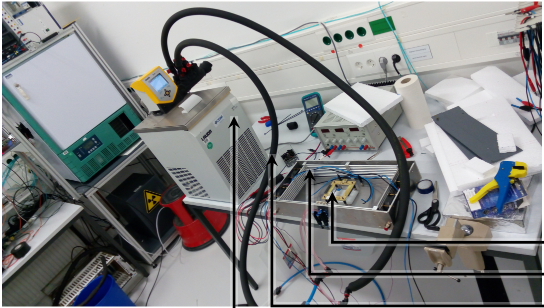
Motivation for the beam tests

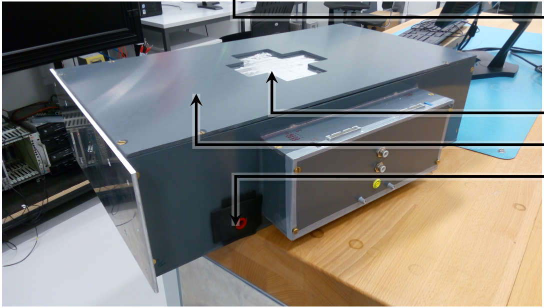
- Relativistic protons **(close to the real experiment conditions)**
  monochromatic: predictable $\Delta E/\Delta x$
  low momentum spread: good for angular studies
- **COSY** proton synchrotron in Jülich, Germany [R. Maier, NIM Volume 390, Issues 1–2, 1 May 1997, Pages 1–8, ISSN 0168-9002]
  kinetic energy $E_k = 1\,\mathrm{GeV} \pm 1‰$ in August 2016
  polar angle $\phi \ll 0.5^\circ$ (limited by station positioning precision)
- Studies of the charge collection efficiency
  - $$\frac{\Delta E(1.7\,\mathrm{GeV}/c)}{\Delta E_{\mathrm{MIP}}} = 1.08(4)$$
- Limited scattering in the material
- High statistics



Custom made cooling station

- Sensors will be cooled in STS:
  - current decreases
  - shot noise ↘
- Cooling station was required





sensor holder

coil made of aluminum tubes

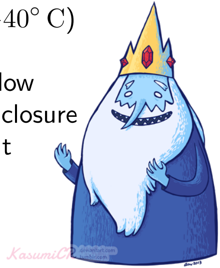
insulated pipes

Lauda chiller ($T_{\text{bath}} > -40^{\circ}$ C)

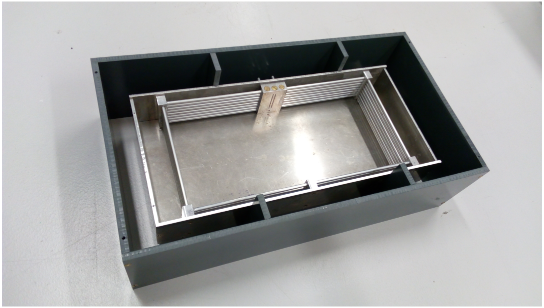
beam window

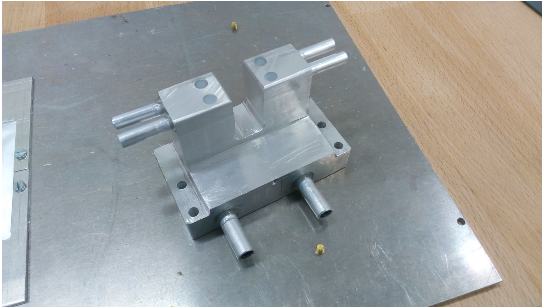
thermal enclosure

glycol input

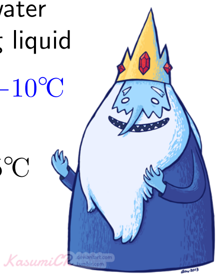


Cooling station design & performance



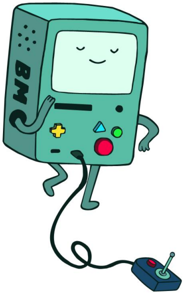


- Cooling station was made:
  - plastic outer box
  - aluminum inner box
  - $40\,\mathrm{mm}$ of plastic foam in between
  - coil of 8 parallel aluminum tubes of $\varnothing 6\,\mathrm{mm}$
- 1:1 ethylene glycol with distilled water as cooling liquid
- $23℃ \to -10℃$ $\simeq 90\,\mathrm{min}$
- $\Delta T < 0.5℃$

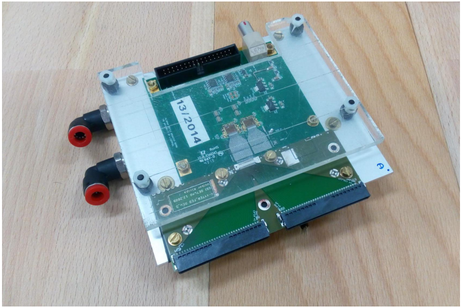


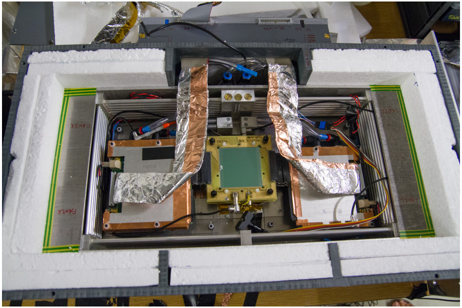
Read-out electronics

- `nXYTER` based read-out chain in use by the STS teams during R&D phase
  - ASIC was being upgraded to `nXYTER v2` (temperature stability)
  - chain not available at that time
- Alibava systems was used
  - based on the *Beetle* chip
  - 2×128 r/o channels, DC coupling
  - $40\,\mathrm{MHz}$ analogue rate
  - 128 per chip analogue memory stack
  - $\gtrsim 4\,\mu\mathrm{s}$ digitisation rate
  - components:
    - ★ Daughter Board (front-end)
    - ★ Mother Board (FPGA based controlling PCB)
    - ★ communication with PC via USB
  - $\leq 1\,\mathrm{kHz}$ data storage to PC



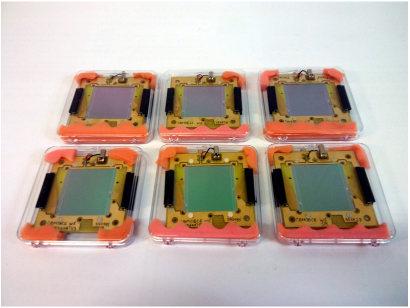
Customised Daughter Board

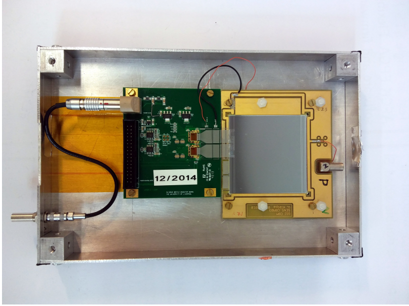




- One *Beetle* chip is involved
- Wire-bonded to the cut-off of the nXYTER FEB
  - 128 ch./2 ERNI connectors
- Aluminium support plate, cooling block attached
- Input lines on the ground potential:
  - only on sensor side r/o
- However, two sensors were planned to be tested per one thermal cycle
- DBs and flat cables were shielded
  - sensor strips act like antennas
- Shielding and aluminium box at the ground potential

Set of sensors for the beam tests



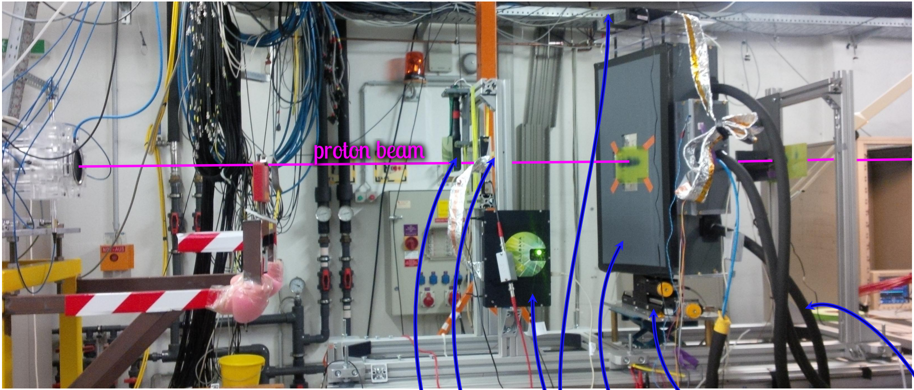


- 6 sensors in the PCB frame (64 channels r/o)
  - 2 double-metal, 4 single-metal

  pro: exchangeable, access to two sides

  cont: higher noise, $1/4$ of Alibava channels can be used
- 1 hard-bonded sensor, p-side (256 channels r/o)
- Connection schemes:
  - direct connection
  - $2 \to 1$ and $2 \to 0$ interconnectors
  - hard-bonded:
    - 8 groups of connections
    - $1 \to 1$, $2 \to 1$ and $2 \to 0$

Beam setup



- Two sensors exposed in one run:
  - cold station (35℃..-15℃), $x \leftrightarrow$ and ϕ ↻, sensor exchangeable
  - warm fixed station, hard-bonded sensor
- Triggering with two plastic scintillators

Collected data

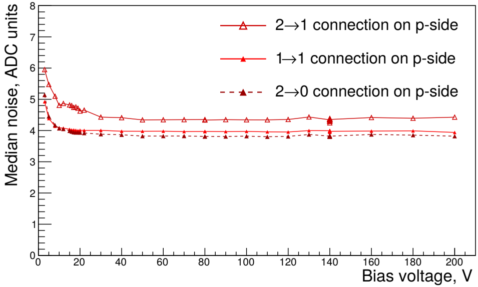
- Latency scans for the signal time profile studies (technical runs)
- Voltage scan of the hard-bonded sensor ($0..200\,\mathrm{V}$)
- Temperature scan of the DM sensor
- Angular scans ($-30^\circ..30^\circ$):
  - double-metal sensors, p ans n sides (at $T = -10℃$)
    - direct connection
    - $2 \to 1$ and $2 \to 0$ interconnectors
  - "matryoshka" setup for the hard-bonded sensor (at $T = +10℃$):
    - open aluminium case inside cold station

- > 200 runs, including technical ones, > 70 Gb of data to be analysed

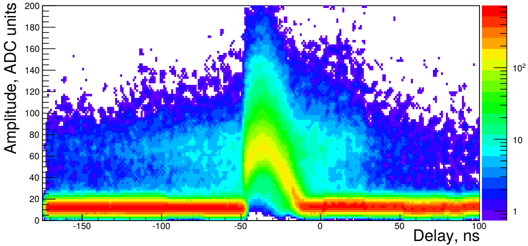
First steps in analysis

bias and latency scans

- Bias scan of the hard-bonded sensor (median noise)
  - consistent with the nominal deletion voltage of $70\,\mathrm{V}$
  - capacitance dependence for different interconnections



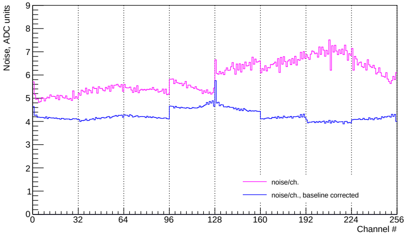
- Latency scan was performed to deduce the time profile of the signal
  - important for time-selection in the further analysis
  - further runs were performed with latency $130 \times 25\,\mathrm{ns}$



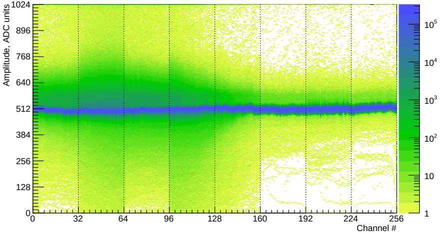
First steps in analysis

baseline and common mode correction

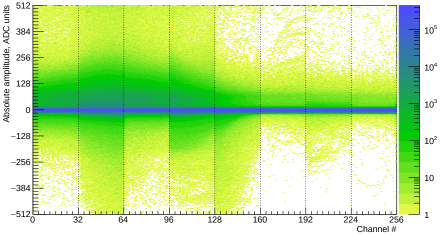
- Raw data were converter from binaries to ROOT files
- Median value from all events served as zero estimation
- Median value over all channels for each event was then subtracted (common mode correction)
- FWHM of each was used as **noise estimation:**



Raw data before correction



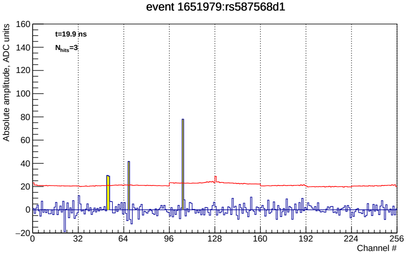
Common mode corrected, baseline subtracted

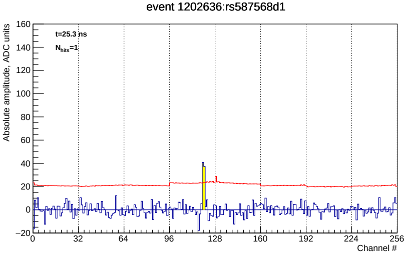


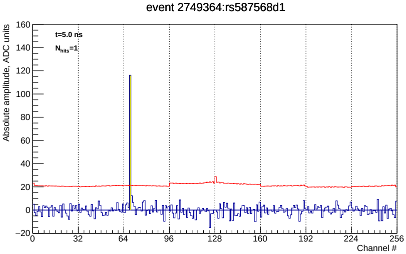
`rs587568d1_allcn_cbm06c6w29sm_+140V_phi+00deg_2047MB` run used for the illustration

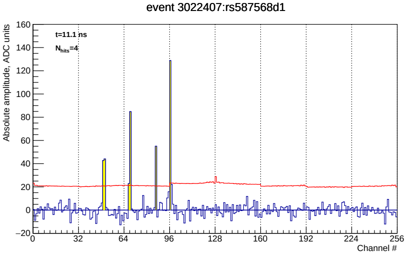
Examples of the events

- Multiple hit events for $\simeq 1/2$ triggers: careful selection is required





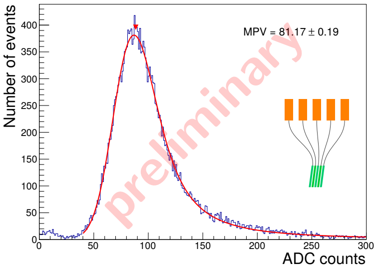


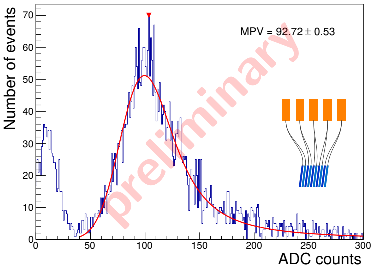


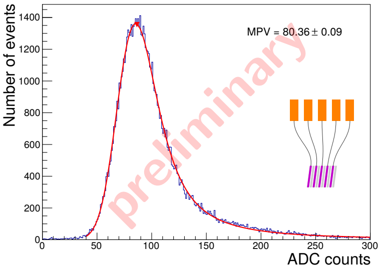
`rs587568d1_allcn_cbm06c6w29sm_+140V_phi+00deg_2047MB` run used for the illustration

Landau⊗Gaussian spectra

- Very first look on the charge collection efficiency (analysis of Ie. Momot)
  - cbm06c6w29 sensor
  - no event classification yet
  - “1 plus 2 neighbours” cluster hypothesis, $3 < \tau < 7$ (ns)
  - plots look promising
- Evidence of $S \to 1.1S$ for $2 \to 1$, no big change for $2 \to 0$







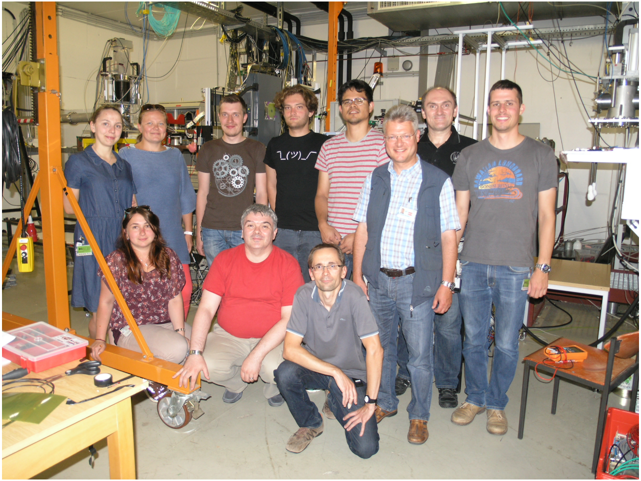
Conclusions

CBM STS beam test at COSY with custom-made read-out system (Alibava based on the *Beetle* chip)

- Sensor performance was studied in controlled conditions
- Clean (or relatively clean) samples of data were acquired, > 200 runs performed in 6 days:
  - ☑ latency scan
  - ☑ voltage scans
  - ☑ studies of charge collection efficiency for p and n-sides
  - ☑ single metal and double metal sensors
  - ☑ (connection schemes)$\times$(penetration angles) matrix filled
  - ☑ viel Spaß in Jülich
- Data analysis is ongoing (much fun is foreseen)
  - ☑ offline noise suppression
  - ☐ ...

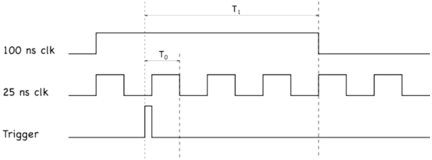
Participated in beam tests: Olga Bertini, Johann Heuser, Anton Lymanets, Hanna Malygina, Ievgeniia Momot, Maksym Teklishyn

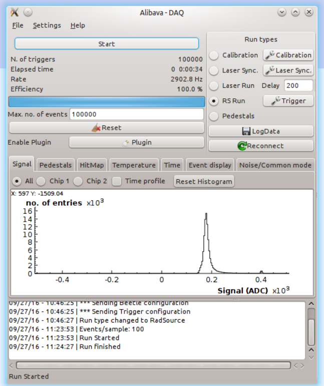
Helped with preparation: Mladen Kis, Adrian Rodrigez[2], Carmen Simons, Daniel Soyk, Christian Sturm, Oleg Vasylyev — many thanks!



Data acquisition procedure

1. 2 *Beetles* make "snapshot" of 256 channels every 25 ns
2. Analogue data are stored in 160 rows ($\times[2 \cdot 128]$ columns)
3. If trigger comes:
   - one of the rows (def. $\#128$) goes to pipeline
   - amplitudes are digitised sequentially
   - TDC output stored





- Data is stored to the PC
- Binary files are transformed to `ROOT` files (custom soft)
- Structure of the `ROOT` file:
  - tree: clock, time, temperature, amplitude[256]
  - histograms: pedestals, noise

Baseline profiles