Charge collection studies of silicon microstrips sensors for the CBM Silicon Tracking System

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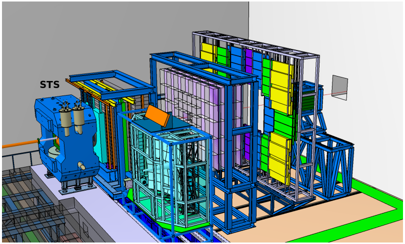
Sitges 2017

1. Introduction
   - Compressed Barionic Matter @FAIR
   - Silicon Tracking System of the CBM experiment
2. Irradiation studies
   - Tests before irradiation
     - Electrical tests
     - Studies of the impact of glue
     - Noise
     - Signal over Noise ratio
   - After irradiation
     - Electrical tests
     - Charge Collection Efficiency
3. Alternative read-out configurations
   - Laboratory tests with a perpendicular track configuration
   - Angular scan with a proton beam
4. Summary

Compressed Barionic Matter Experiment @FAIR Fri, 9-00



- Inside of the dipole magnet:
  - Micro Vertex Detector
  - Silicon Tracking System
- Electron/Muon modes:
  - Ring Imaging Cherenkov Detector
  - Muon Chamber
- Calorimeters:
  - EM – ECAL
  - Hadron – Projectile Spectator
- Time of Flight Wall

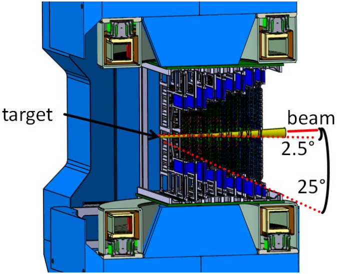
Aim: To study the QCD phase diagram at high net baryon densities and moderate temperatures

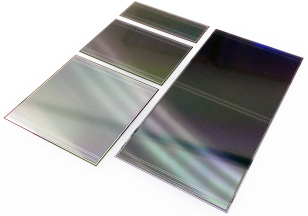
- Au+Au collisions @SIS100
  2 - 11 AGeV,
  10^5-10^7 interactions/s;
- up to 10^3 charged particles per central collision.

physics program @SIS100:

- Strange hadrons
- Lepton pairs
- Collective flow, correlations and fluctuations
- Hypernuclei
- Charm-anticharm quark pairs

The Silicon Tracking System @CBM





Silicon Tracking System:

- 8 tracking stations
- 1220 sensors, 896 modules, 106 ladders
- hit rates up to 20 MHz/cm^2
- low material budget $\sim 1\%$ X_0
- < 25 μm hit spatial resolution
- S/N>10 for the hit reconstruction efficiency $\sim$ 98 %

Double-sided micro-strip Si sensors:

- 285/320 μm thick, 58 μm strip pitch
- sensor sizes 6×2, 6×4, 6×6, 6×12 cm^2
- 7.5° stereo-angle front-back sides
- radiation tolerance: 10^{14} 1 MeV n_{eq}/cm^2

Radiation Challenge

Measuring rare probes with reliable statistics requires high interaction rate (up to 10^7 Au+Au collisions/s) $\sim$ 1000 particles per collision.
(700 π, 160 p, 53 K, 32 Λ, 27 K_s, $\sim$ 1 Θ, 0.022 Ω)

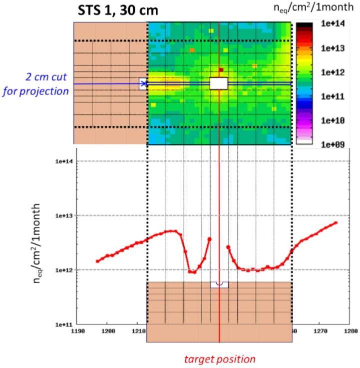


Figure : FLUKA calculation of non-ionizing dose at STS station 1 for 10 AGeV Au+Au collisions at SIS100

For that we need ***Fast, Radiation Tolerant, High-precision Detectors***

Table : Maximum values of ionizing and non-ionizing dose on the STS, after one month with Au+Au collisions.

Type of Dose	Non-Ionising, n_{eq}/cm^2	Ionising, Gy
SIS 100, 10 AGeV	2.1×10^{13}	11.9×10^{3}

Impact of radiation on Si sensors

Before irradiation

- Average energy per pair creation: E_{e-h}=3.6 eV, charge MPV (300 μm of Si) $\sim$ 22ke$^-$
- Noise
  depends on a sensor:
  - nA leakage current $\rightarrow$ negligible contribution
  - capacitive load

  and r/o electronics:
  - for final STS-XYTER $\sim$1000e$^-$

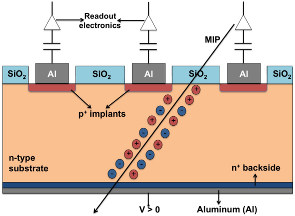
After irradiation

- Signal
  - degradation of the charge collection efficiency
  - higher depletion voltage required
- Noise
  - leakage current increases (by orders of magnitude): $\Delta I/V = \alpha \times \Phi_{eq}, A/cm^3$

$\Rightarrow$ Deterioration of the S/N ratio

Actions to compensate impact of irradiation:

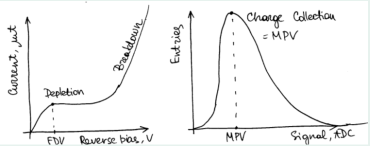
- Increase bias voltage (up to 300 V … 500 V)
- Decrease leakage current by cooling
- Beneficial annealing



Procedure

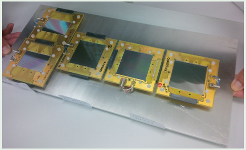
Preparation and measurement before irradiation

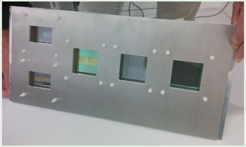
- Electrical characteristics: current-voltage (IV) and capacitance-voltage (CV) dependence
- Measurements of charge the collection efficiency



Shipment, irradiation

Sensors installed in a pure Al frame → irradiated.
Cooled during storage → delivered to GSI.

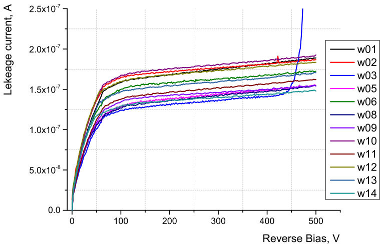




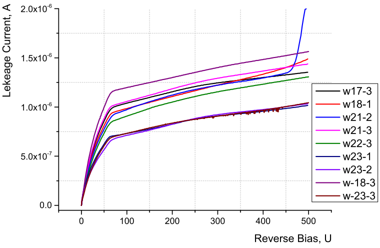
Measuring after irradiation

repeat the same measurements

CiS and Hamamatsu sensors 6×2 cm^2



Hamamatsu



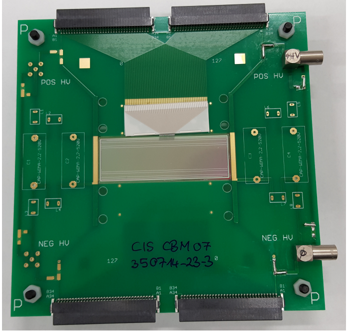
CiS

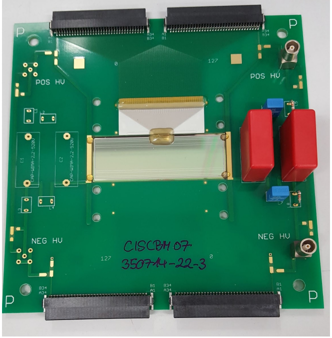
* 12 sensors were selected and wire-bonded to the PCB frames.

Tests of the impact of glue

2 sensors 6×2 cm^2 were selected to check their performance after protecting bonds from mechanical damage.
Possible changes:

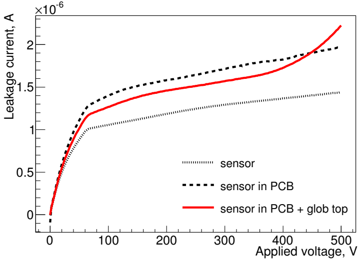
- leakage current;
- earlier breakdown;
- affection of the noise.



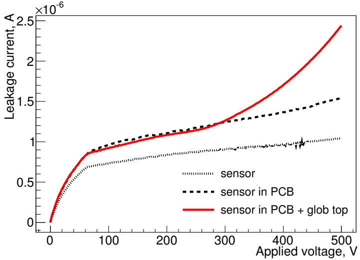


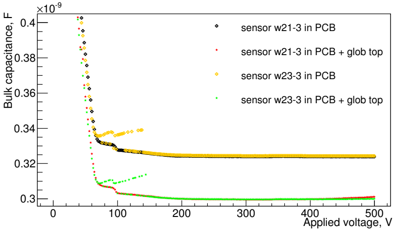
Glue Tests: IV, CV

cbm06c2w21-3



cbm06c2w23-3

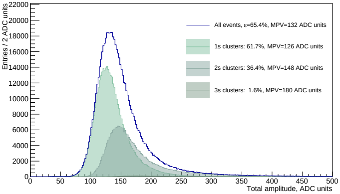




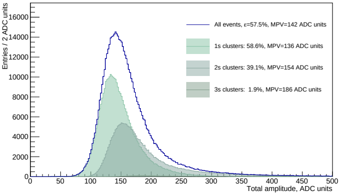
- Two sensors studied before irradiation.
- The IV curve changes after the glue was applied.
- The CV curve:
  - same shape
  - capacitance of both sensors increased by 0.026 nF.

Protection of the wire-bonds with glue: Signal

before applying glue

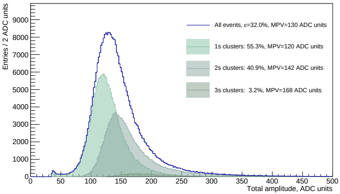


p-side

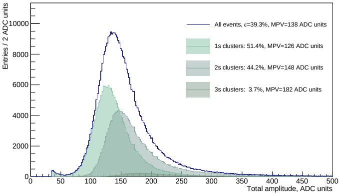


n-side

after applying glue



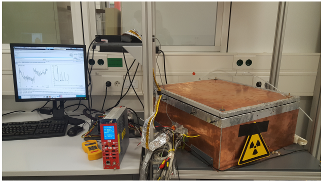
p-side

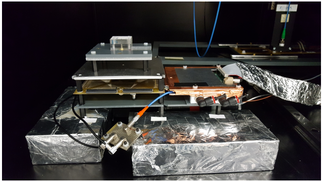


n-side

Set-up @STS lab

side view



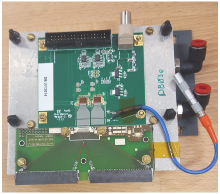


top view

β source: ^{90}Sr (^{90}Y decay E_{max}=2.28 MeV)
Trigger and Mips selector: Scintillator (2.5 cm thick) + PM.

Thermal enclosure:

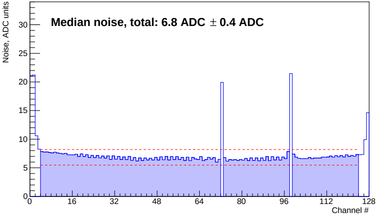
- cycle from +23°C till -11°C and back ∼ 2 h;
- cooling liquid: Glycole + H_2O;
- 2 radiators; 6 fans.

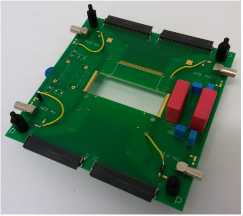


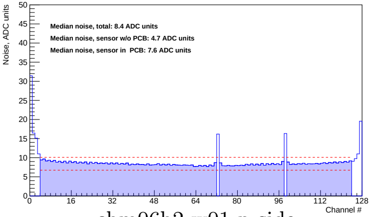
Noise pattern of the 2×6 cm^2 sensors

Noise = Sensor ⊕ Pitch adapter ⊕ PCB(printed circuit board) ⊕ Daughter board ⊕ ...

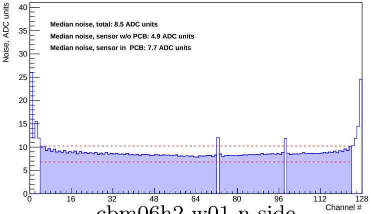
$$Noise_{sensor} = \sqrt{Noise^2_{DB+PCB+sensor} - Noise^2_{DB+PCB}}$$







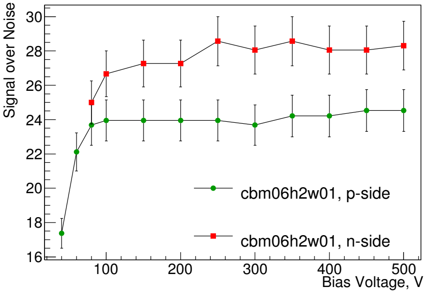
cbm06h2 w01 p-side



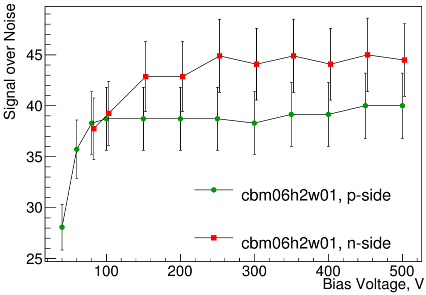
cbm06h2 w01 n-side

Voltage scan of the cbm06h2 w01 sensor

Assume,
$Noise_{sensor-in-PCB}$



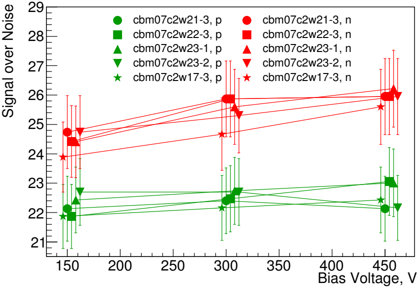
Assume,
$Noise_{sensor-w/o-PCB}$



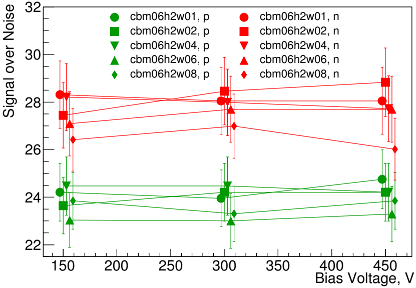
For better illustration points of n-side were shifted to +3V

S/N for measured CiS and Hamamatsu sensors

CiS



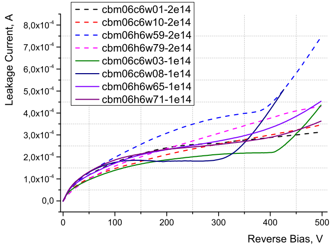
Hamamatsu



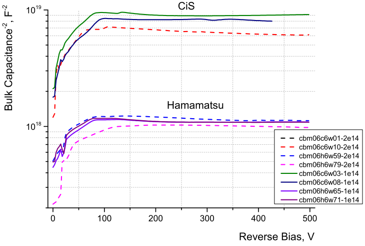
* Each sensor was measured for p- and n-side at three different voltages: 150 V, 300 V, 450 V – to compare values after irradiation at the same point;
* S/N for p- and n-side is the same within the error bars.

Electrical tests of 6×6 cm^{2}sensors: IV, CV

Leakage current dependence on the applied bias voltage.



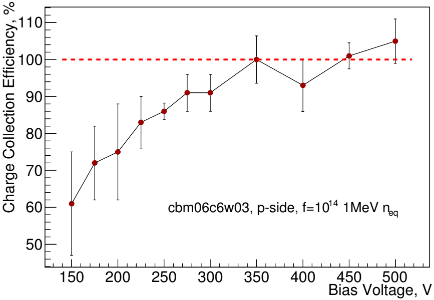
Bulk capacitance as a function of reversed bias

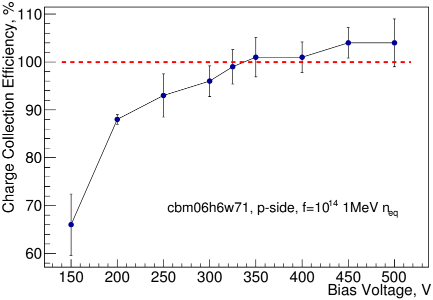


After irradiation:

- Leakage current increases by a factor 500 (10^{14} n$_{eq}/cm^2$) or 1000 (2×10^{14} n$_{eq}/cm^2$).
- Sensors are constantly cooled:
  - to suppress current during data taking;
  - to avoid annealing during storage.

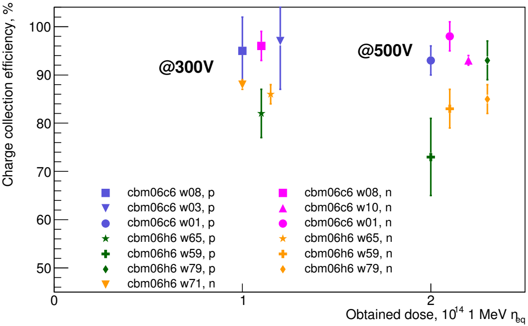
Charge collection after irradiation





By increasing of depletion voltage it is possible to restore 100 % of the charge collection efficiency.

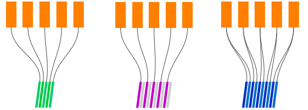
Charge collection after irradiation

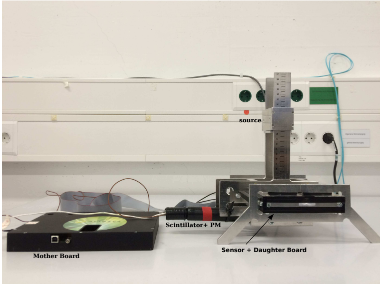


- 100 % = collected charge of non-irradiated sensor;
- bias voltage:
  300 V (for $10^{14} n_{eq}$)
  or 500 V (for $2 \times 10^{14} n_{eq}$)
- after irradiation CCE drops down by 10% - 20 %

Charge collection studies with different read-out configurations

- Tracks are non-perpendicular in the outer part of STS → larger clusters → risk of the signal losses
- To get signal higher → to read not every strip, but from two or every second strip
- First approach: only perpendicular tracks

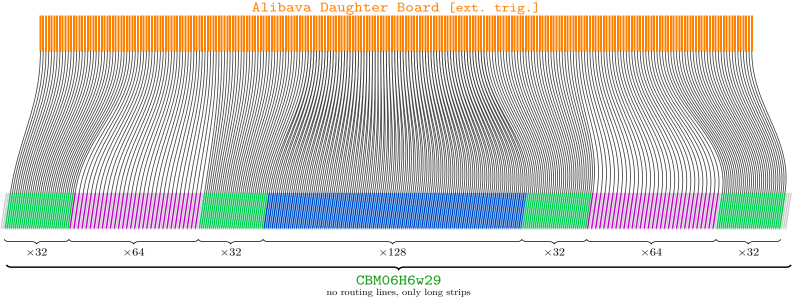




Charge collection studies with different read-out configurations

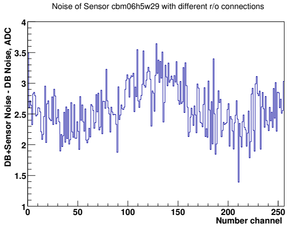
Different configurations of connection in the outer aperture of STS detector were tested:

- each strip corresponds to one r/o channel
- every second strip is read-out
- two strips connected to one r/o channel

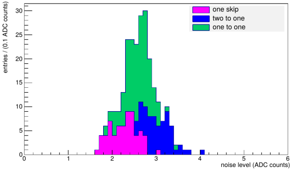


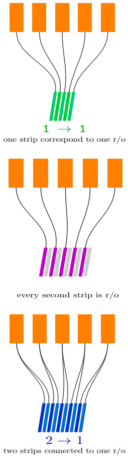
Advantage:
* possible S/N improvement

Noise



Edge & noisy channels were removed from analysis



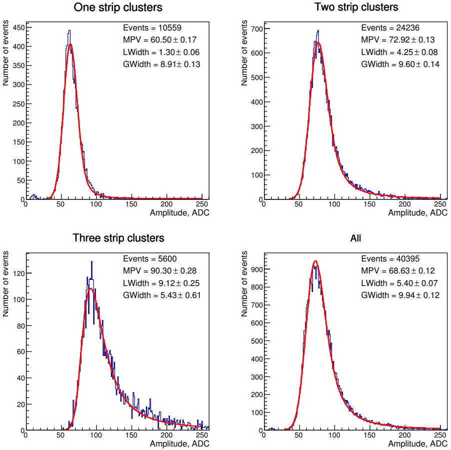


I case
2.58±0.02 ADC

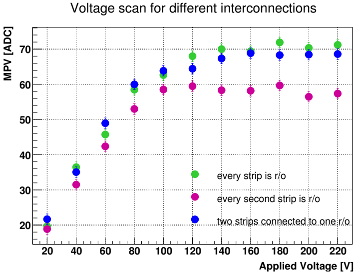
II case
2.27±0.04 ADC

III case
3.05±0.05 ADC

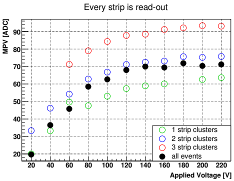
Charge collection studies with different read-out configurations

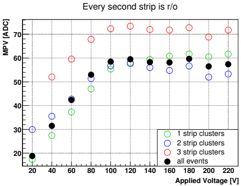


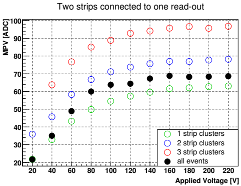
- Cluster charge spectrum was fitted by the Landau-Gaussian convolution
- MPV interpreted as collected charge



Voltage scan for different read-out configurations







Assume, our noise is uniform: $S/N_{\mathrm{cluster}} = S/(\sqrt{m} \times N)$,
S – signal [ADC], N – noise [ADC], m – cluster size

Table : Signal over noise for perpendicular tracks

Cluster size:	Connection scheme:		
	One to one	One omitted	Two to one
One strip	60.09/2.58 ∼ **23.3**	60.8/2.27 ∼ **26.8**	62.18/3.05 ∼ **20.4**
Two strips	73.42/3.65 ∼ **20.1**	56.01/3.21 ∼ **17.5**	76.93/4.31 ∼ **17.8**
Three strips	91.2/4.47 ∼ **20.4**	71.79/3.93 ∼ **18.3**	96.64/5.28 ∼ **18.3**

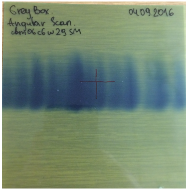
Set-up at COSY

Main components:

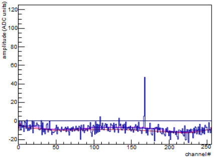
- Cold box on movable platform and r/o + exchangable sensors;
- Warm box with sensor bonded to r/o;
- *Trigger:* two scintillators (perpendicular to each other) in coincidence scheme.
- *Read out:* front-end ASIC and DAQ - Alibava system (Beethle chip): – 2 × 128 r/o channels;

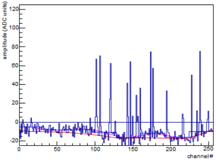
What to measure:

- Charge collection;
- Signal dependence on beam incidence angle;
- Cross talk.

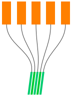
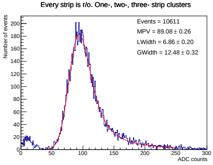
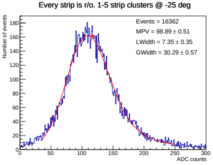
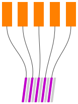
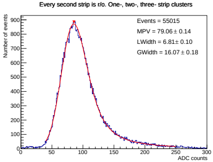
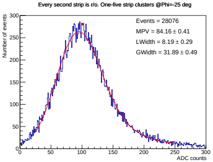
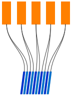
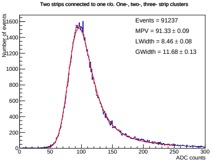
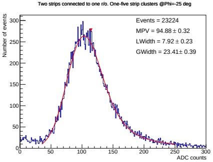


angular scan from -25° to +25°





Charge collection at different beam angles

Type of connection	$\Phi = 0°$		$\Phi = 25°$	
 $1 \rightarrow 1$ one strip correspond to one r/o		~ 20		~ 17
 every second strip is r/o		~ 20		~ 17
 $2 \rightarrow 1$ two strips connected to one r/o		~ 17		~ 14

Summary:

* STS will provide track reconstruction and momentum determination for charged particles @CBM experiment.
* Signal-over-Noise for non-irradiated sensors is ~ 40 for p- and n-side.
* The prototype sensors from two vendors show a reduction of charge collection by 10% to 20% after irradiation to twice the maximum neutron fluence expected in the CBM experiment.
* S/N for final unit (sensor + cable + read-out) to be studied.