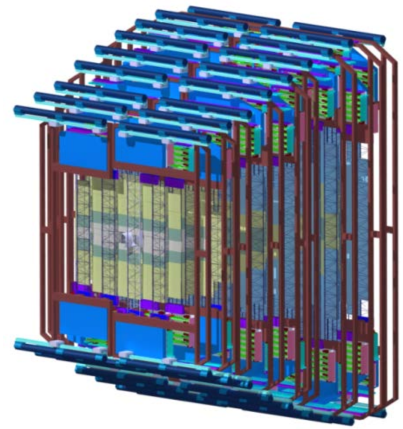
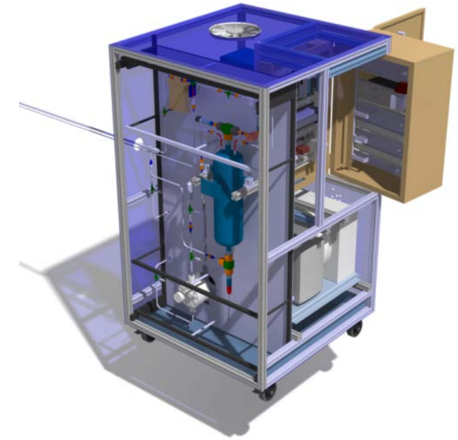
Compressed Baryonic Matter Experiment





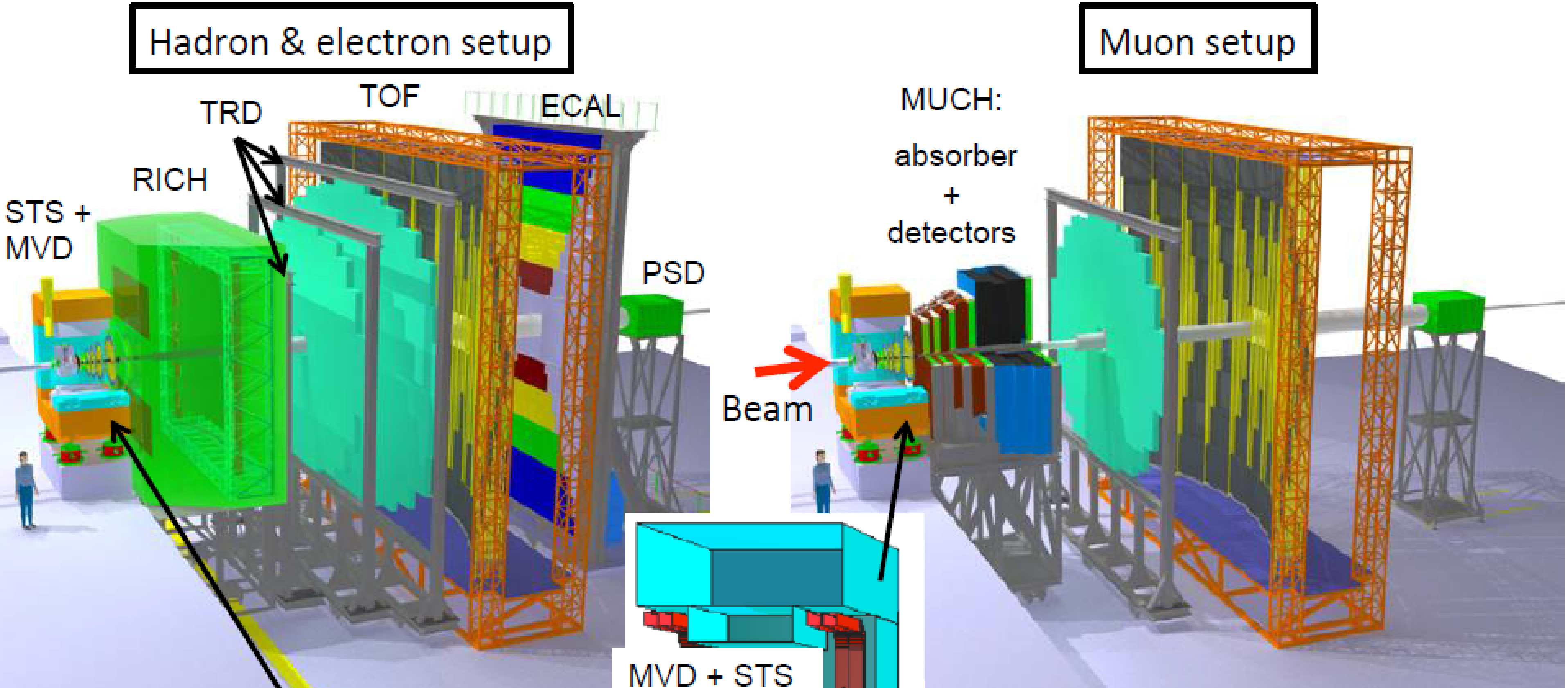
# The Silicon Tracking System of the CBM experiment

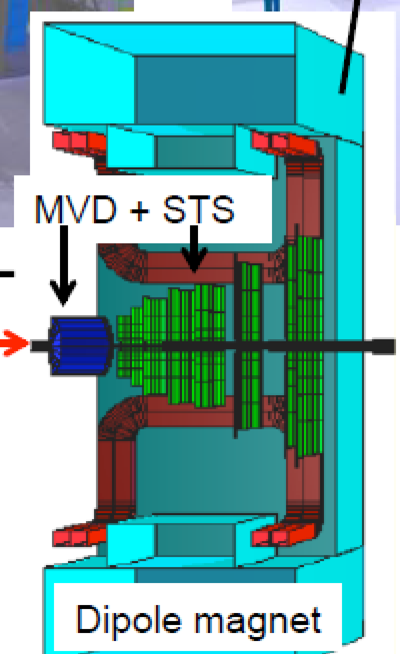
- detector concept
- prototype components
- system integration

Tomas Balog
on behalf of the STS group

4th HIC for FAIR Detector Systems Networking Workshop

# CBM experimental setup

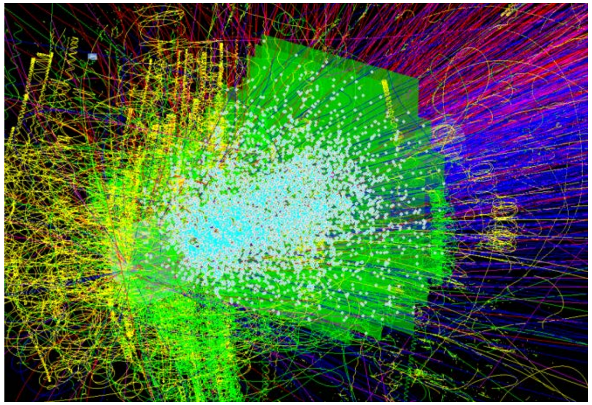



Silicon Tracking System: STS
Micro-Vertex Detector: MVD
Ring Imaging CHerenkov detector: RICH
Transition Radiation Detector: TRD
Time-Of-Flight detector: TOF
Electro-magnetic CALorimeter: ECAL
Projectile Spectator Detector: PSD
MUon CHamber: MUCH

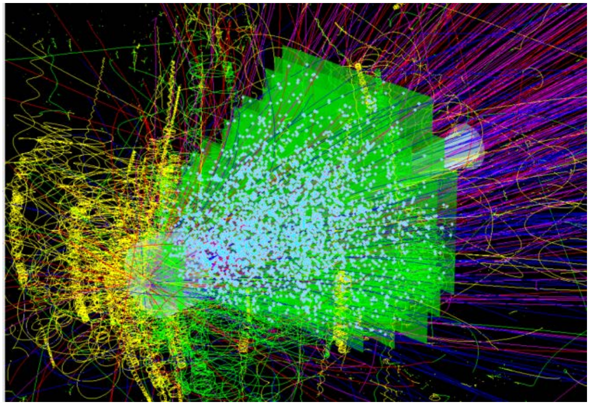
STS: **Tracking**
MVD: **Vertexing**
RICH + TRD: **Electron ID**
TOF: **Hadron ID**
ECAL: **$\gamma$, $\pi^0$, $\eta$ ID**
PSD: **centrality & event plane**
MUCH: **$\mu$ ID**

# Tracking nuclear collisions at SIS-300 and at SIS-100



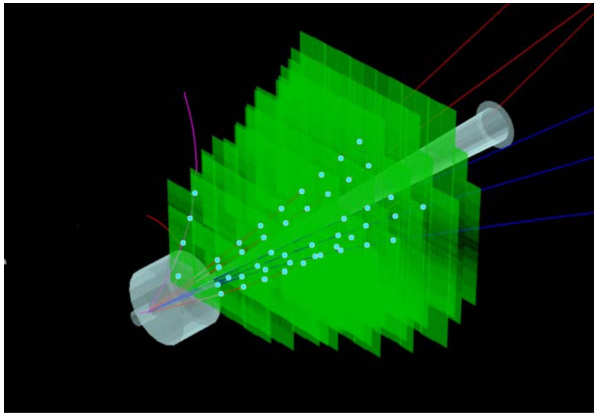
central Au+Au, 25 AGeV

~700 charged particles



central Au+Au, 8 AGeV

~350 charged particles



p+C, 30 GeV

few charged particles

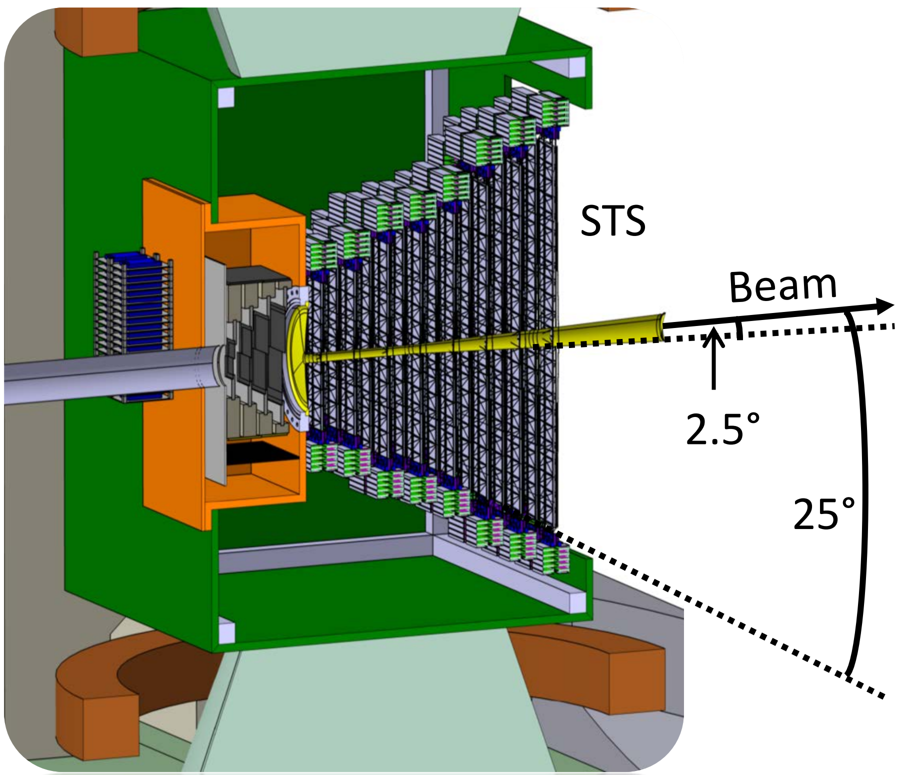
- **CBM: high-rate experiment**
  $10^5$ -$10^7$ interactions/sec
- **hit rates 3-20 MHz/cm²**
  - fast free-streaming readout
  - online event selection
- **radiation hard sensors**

- **low mass** large-area detector
  - high-resolution momentum determination
  - track matching into MVD and RICH/MUCH

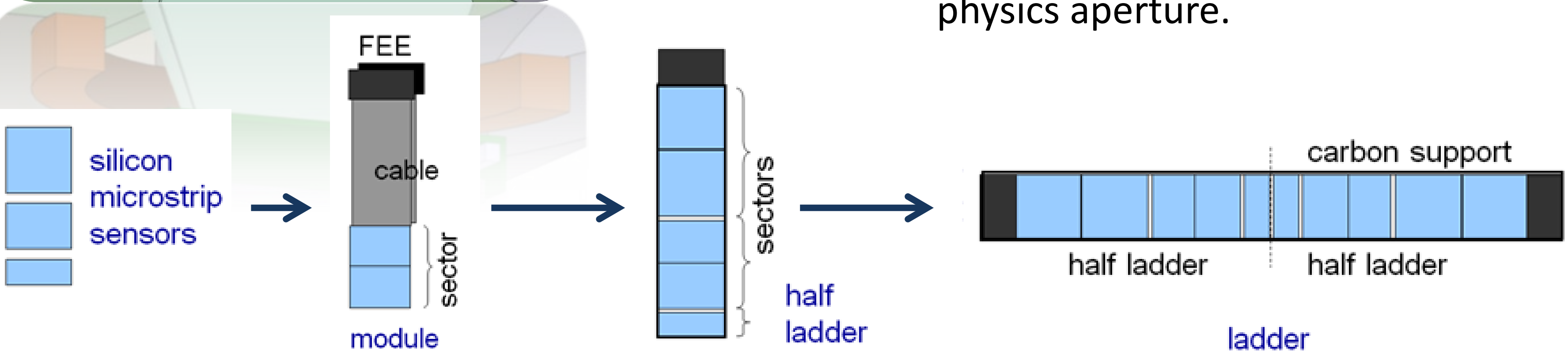
# STS design constraints

- **Coverage:**
  - rapitidies from center-of mass to close to beam
  - *aperture 2.5° < $\Theta$ < 25°*
- **Momentum resolution**
  - δp/p ≅ 1%
  - *field integral 1 Tm, 8 tracking stations*
  - *25 µm single-hit spatial resolution*
  - *material budget per station ~1% $X_0$*
- **No event pile-up**
  - *10 MHz interaction rates*
  - *self-triggering read-out*
  - *signal shaping time < 20 ns*
- **Efficient hit & track reconstruction**
  - close to 100% hit eff.
  - > 95% track eff. for momenta > 1GeV/c
- **Minimum granularity** @ hit rates < 20 MHz/cm$^2$
  - *maximum strip length compatible with hit occupancy and S/N performance*
  - *largest read-out pitch compatible with the required spatial resolution*
- **Radiation hard sensors** compatible with the CBM physics program
  - $1 \times 10^{13}$ $n_{eq}$/cm$^2$ (SIS100)
  - $1 \times 10^{14}$ $n_{eq}$/cm$^2$ (SIS300)
- **Integration, operation, maintenance**
  - compatible with the confined space in the dipole magnet

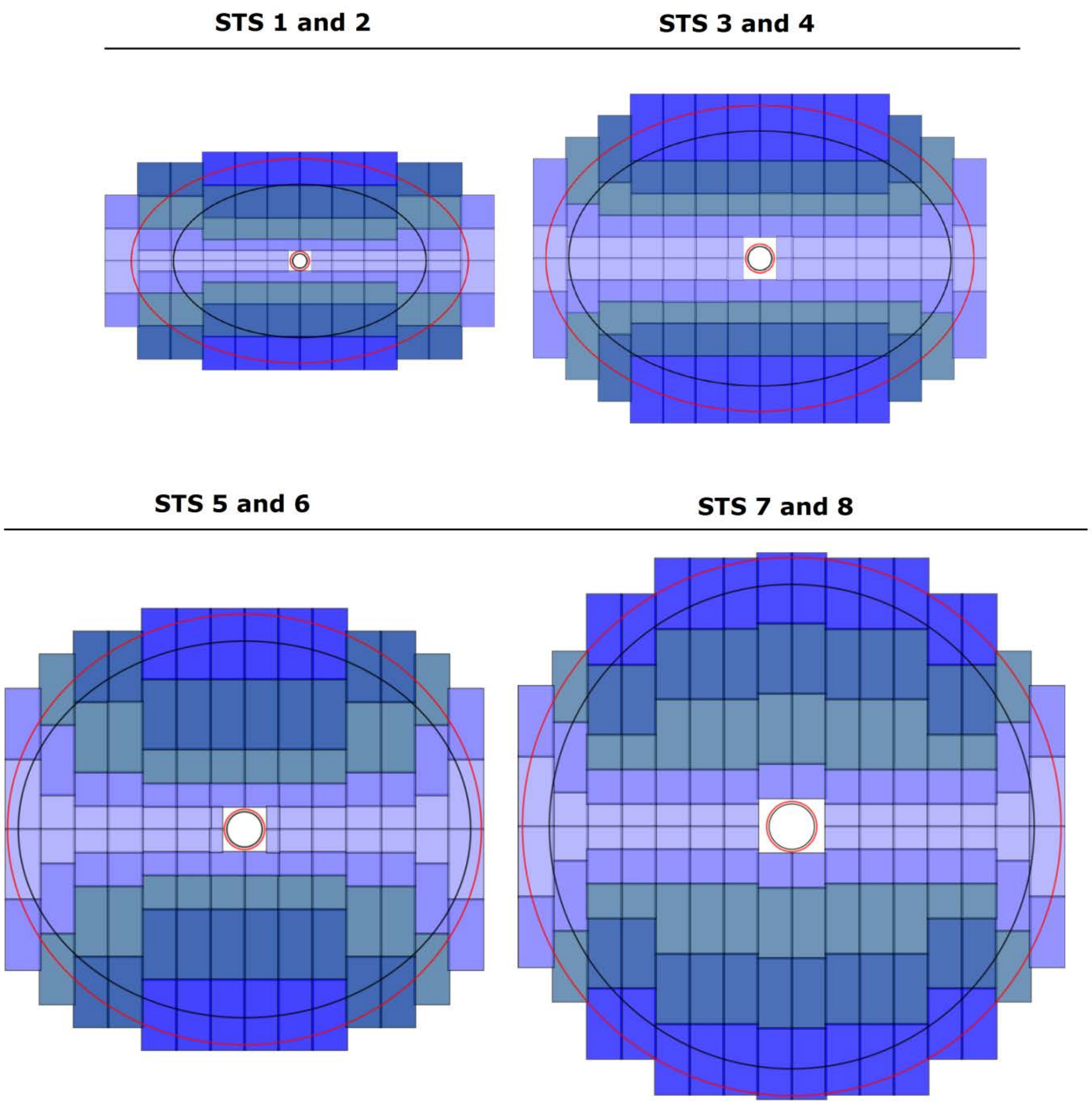
# STS concept




- Aperture: 2.5° < Θ < 25° (some stations up to 38°).
- 8 tracking stations between 0.3 m and 1 m downstream the target.
- Built from double-sided silicon micro-strip sensors in 3 sizes, arranged in modules on a small number of different detector ladders.
- Readout electronics outside of the physics aperture.



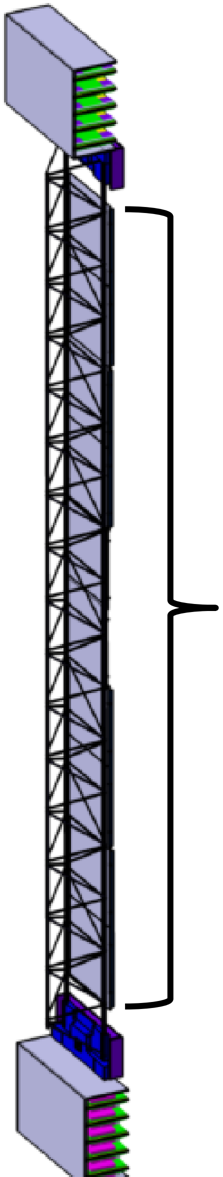
# STS layout

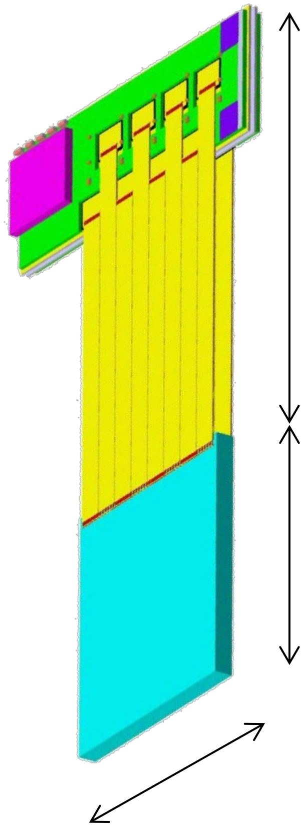



- Stations arranged in 4 duplets
- Minimizing amount of modules
- Strips lengths – 2 cm, 4 cm, 6 cm and in case of daisy chained sensors 12 cm
- Granularity according to the hit densities
- Components breakdown:
  - ✓ 106 ladders (17 types)
  - ✓ 896 modules
  - ✓ 1220 sensors
  - ✓ 14144 chips
  - ✓ 1.8 Mio channels

# STS module

module := building block of ladders
smallest assembled functional unit





front-end electronics board

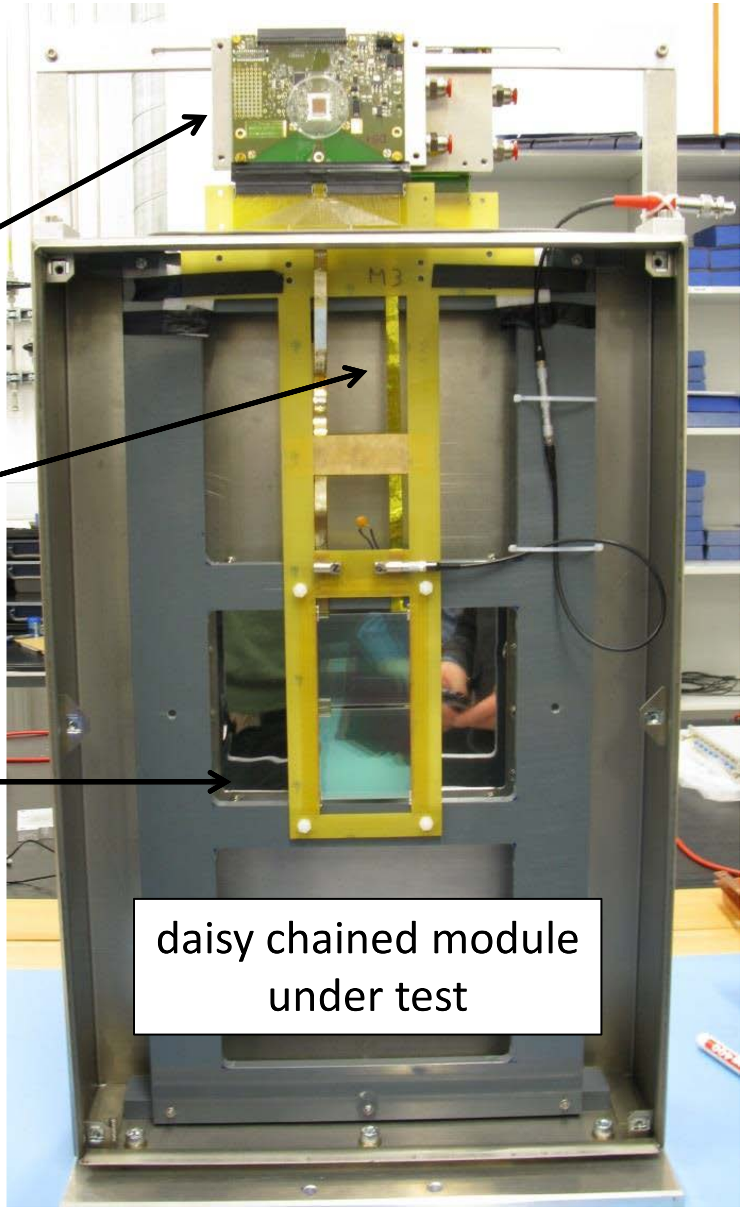
read-out cables

10 – 50 cm

sensor

2, 4, 6, (12) cm

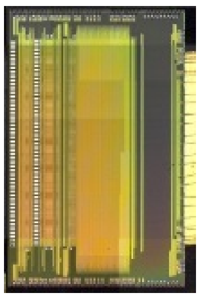
6 cm

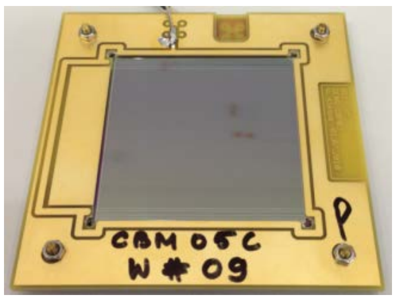


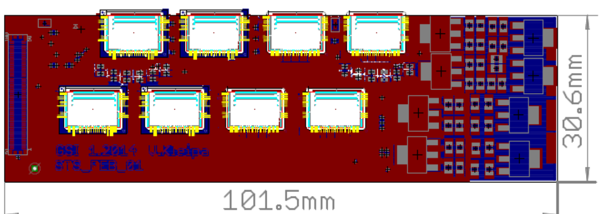
# STS module integration

- High-density silicon detector module
- Procedures for module assembly + integration
- Exploration of technologies for mass-production

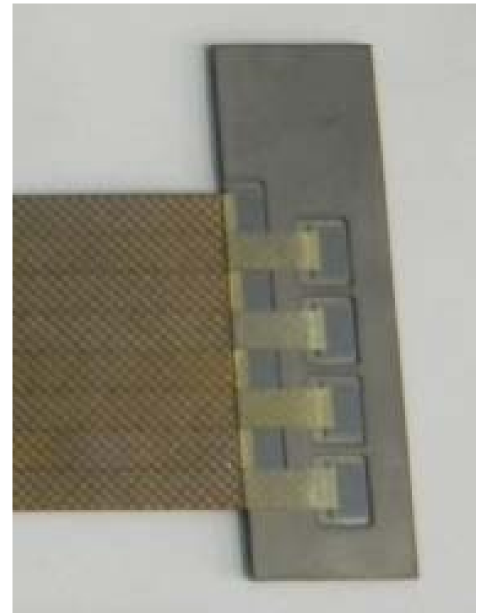
components:
ASICs, sensors, FEB, read-out cables

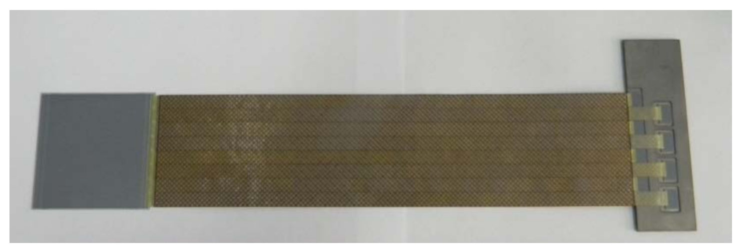


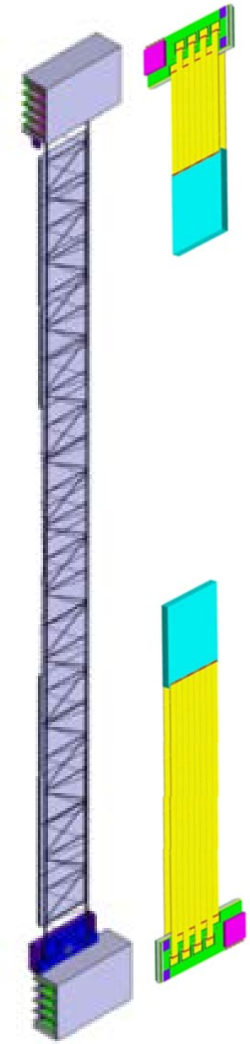



module
assembly
study



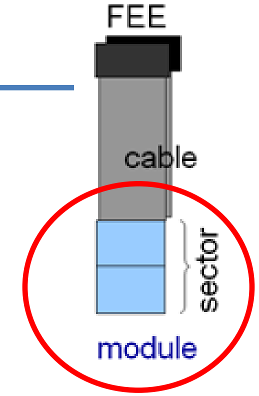




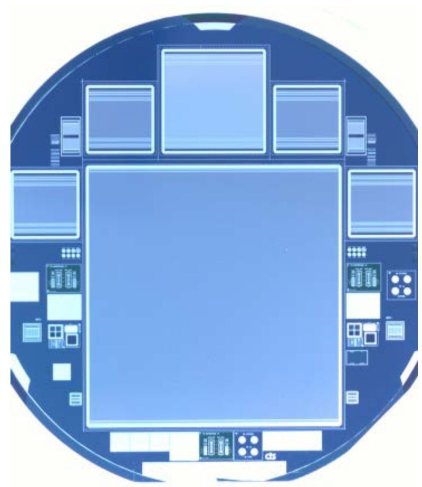
EU-FP7 HadronPhysics3 – *Work Package ULISINT*

http://www.hadronphysics3.eu/

# Micro-strip silicon sensors

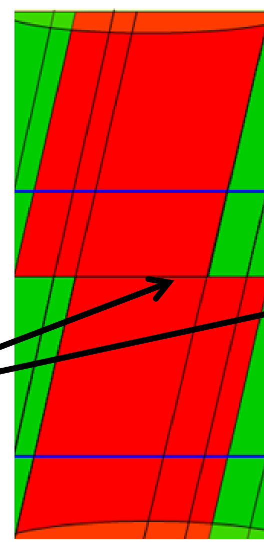


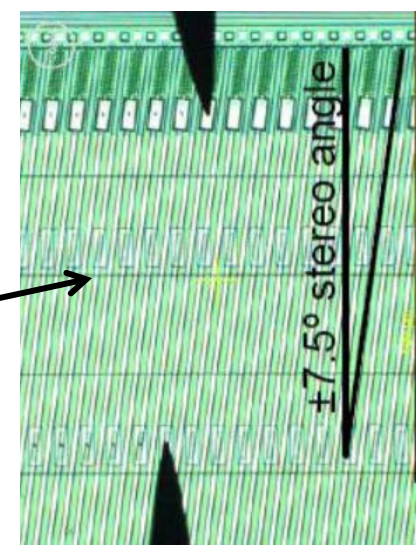

- double-sided, p-n-n structure
- width: 6.2 cm
- 1024 strips at 58 $\mu$m pitch
- three types, strip lengths: 2, 4, 6 cm, 12 cm
- stereo angle front-back-sides 7.5°
- integrated AC-coupled read-out
- double metal interconnects on p-side, or replacement with an external micro cable
- operation voltage up to few hundred volts
- radiation hardness up to $1 \times 10^{14}$ $n_{eq}/cm^2$



Strips reaching the border are continued on the other side

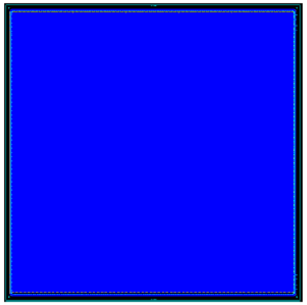
$\Rightarrow$ Needs double metal layer or external cable



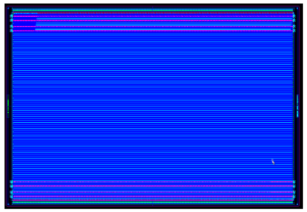


# Prototypes of STS micro-strip silicon sensors

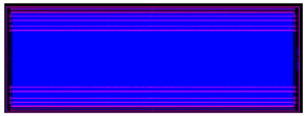
| Prototype | Year | Vendor | Processing | Size [cm$^2$] | Description |
|---|---|---|---|---|---|
| CBM01 | 2007 | CiS | double-sided | 5.5 × 5.5 | ±7.5 deg |
| CBM03 | 2010 | CiS | double-sided | 6.2 × 6.2 | ±7.5 deg |
| CBM03’ | 2011 | CiS | Single/CBM03 | 6.2 × 6.2 | test for CBM05 |
| CBM05 | 2013 | CiS | double-sided | 6.2 × 6.2 | 7.5/0 deg, full-size |
| CBM05H4 | 2013 | Hamamatsu | double-sided | 6.2 × 4.2 | 7.5/0 deg, full-size |
| CBM05H2 | 2013 | Hamamatsu | single-sided | 6.2 × 2.2 | 7.5/0 deg, full-size |
| CBM06 | 2014 | Hamamatsu, CiS | double-sided | 6.2 × 6.2 | 7.5/0 deg, full-size |



CBM05

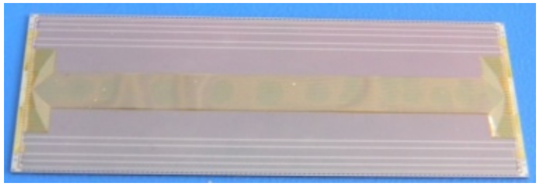


CBM05H4



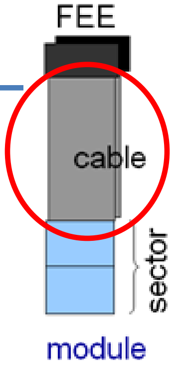
CBM05H2

under study: replacement for integrated 2nd metal layer

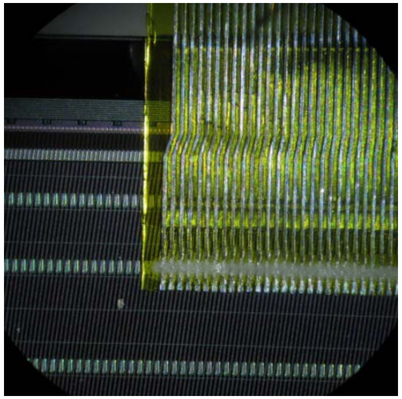


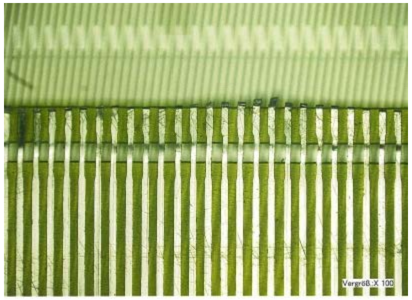
external on-sensor cable

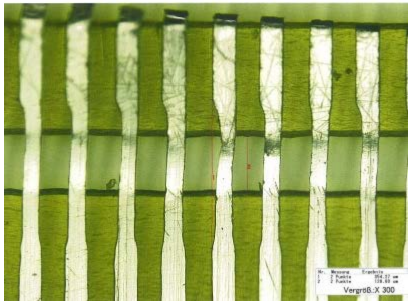
# STS low-mass micro-cables

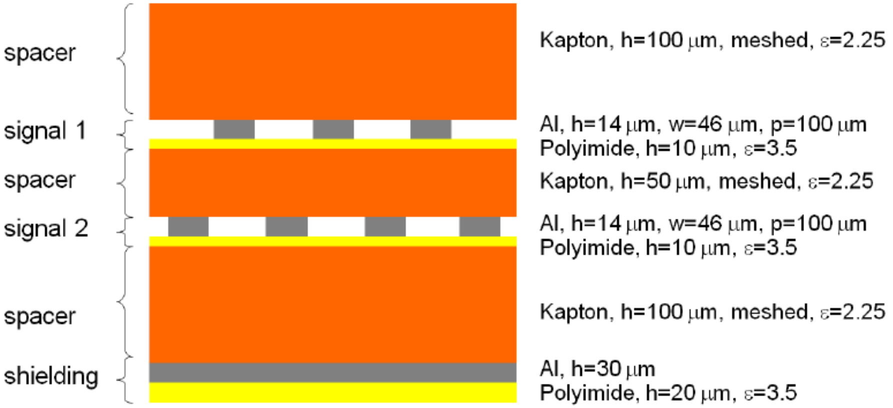


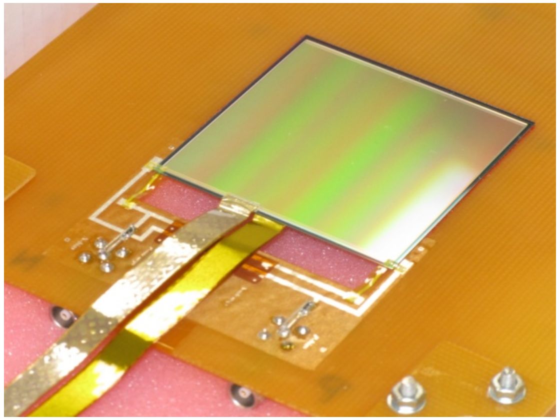

- Cable
  - radiation length: 0.1% Xo
  - two signal layers
  - strip pitch 116 µm
  - thickness 24 µm
  - additional spacer to reduce the capacitance
  - tap bonded to sensor
  - 1024 channels to connect
  - in prototypes 128 channels on each side are connected



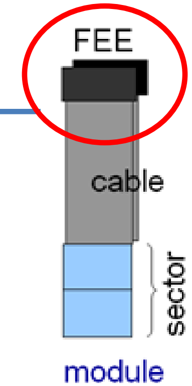




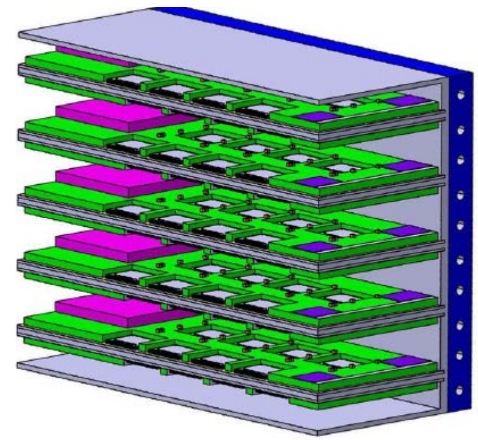


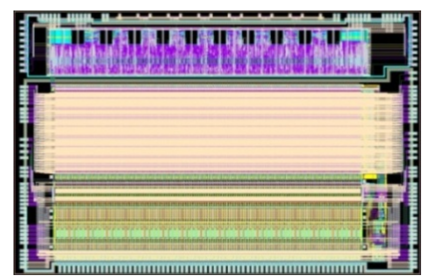
# Read-out chip STS-XYTER

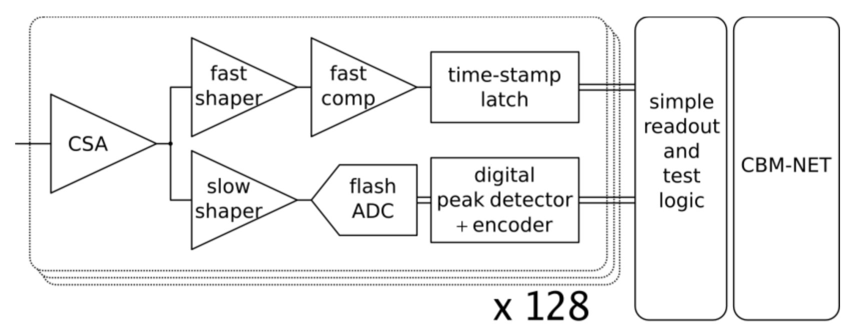



- full-size prototype dedicated to signal detection from the double-sided micro-strip sensors in the CBM environment
- fast ⇔ low noise ⇔ low power dissipation
- new w.r.t. n-XYTER architecture:
  - *effective two-level discriminator scheme*
- design V1.0 @ AGH Kraków
- *UMC 180 nm CMOS*



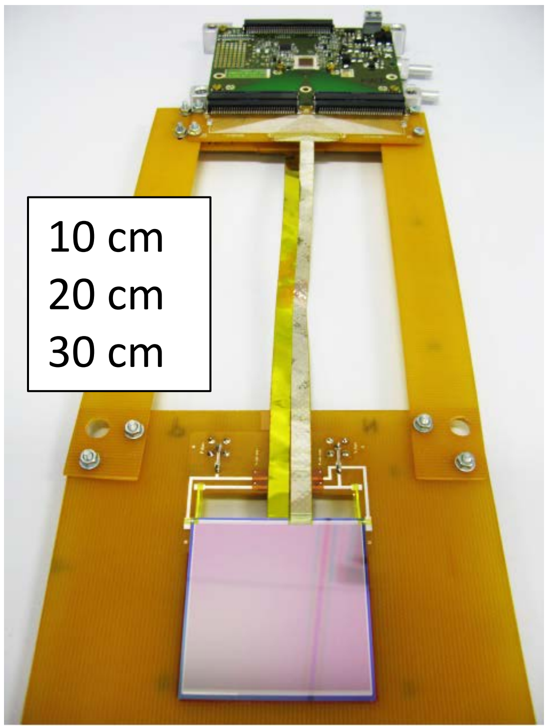
| Channels, pitch | 128 + 2 test |
|---|---|
| Channel pitch | 58 |
| Input signal polarity | + and - |
| Input current | 10 nA |
| Noise at 30 pF load | 900 $e^-$ |
| ADC range | 16 fC, 5 bit |
| Clock | 250 MHz |
| Power dissipation | 4 mW/channel (analog) |
| Timestamp resolution | < 10 ns |
| output interface | 4 × 500 Mbit/s LVDS |





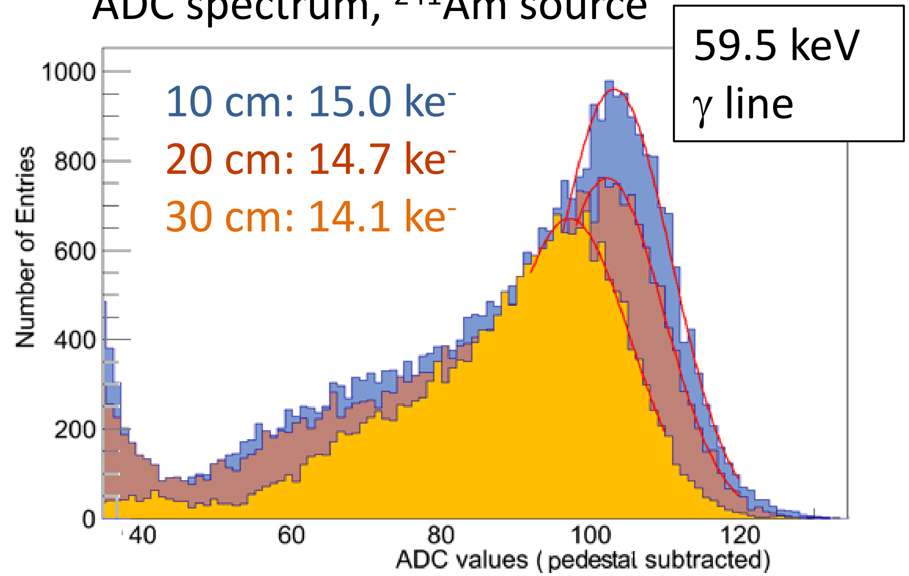
# Module prototype tests

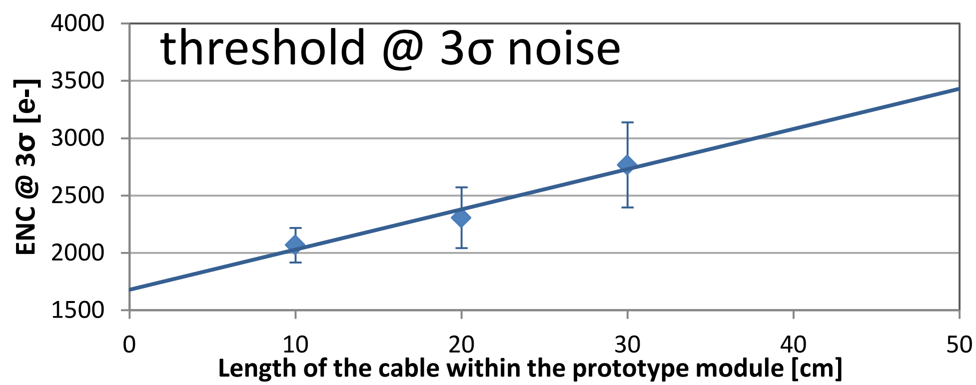
- First module prototype with CBM01 sensor and first batch of the low-mass micro-cables and n-XYTER FEB




S/N for MIP > 20

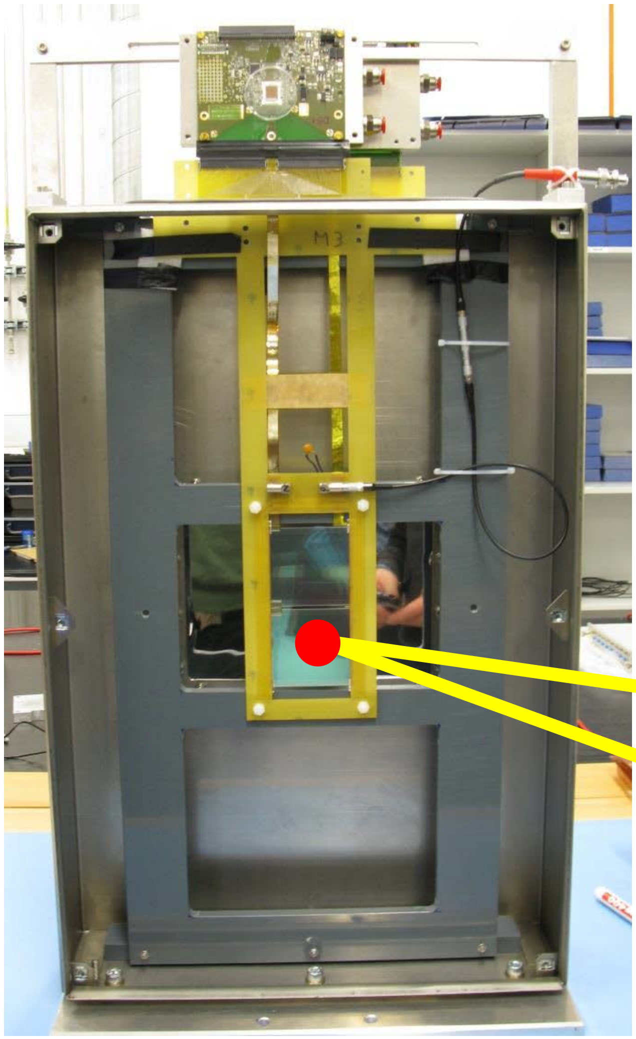
ADC spectrum, $^{241}$Am source

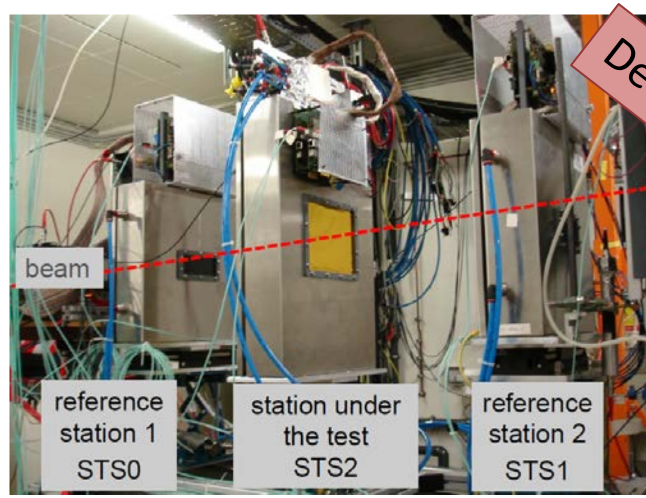


# Module prototype tests

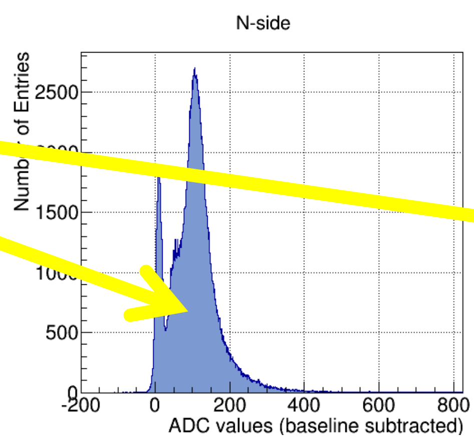
- Second module prototype with CBM05 sensor and second batch of the low-mass micro-cables and n-XYTER FEB

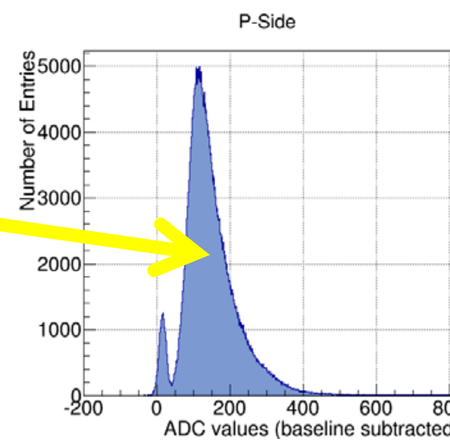





Detailed analysis in progress

COSY @ Jülich

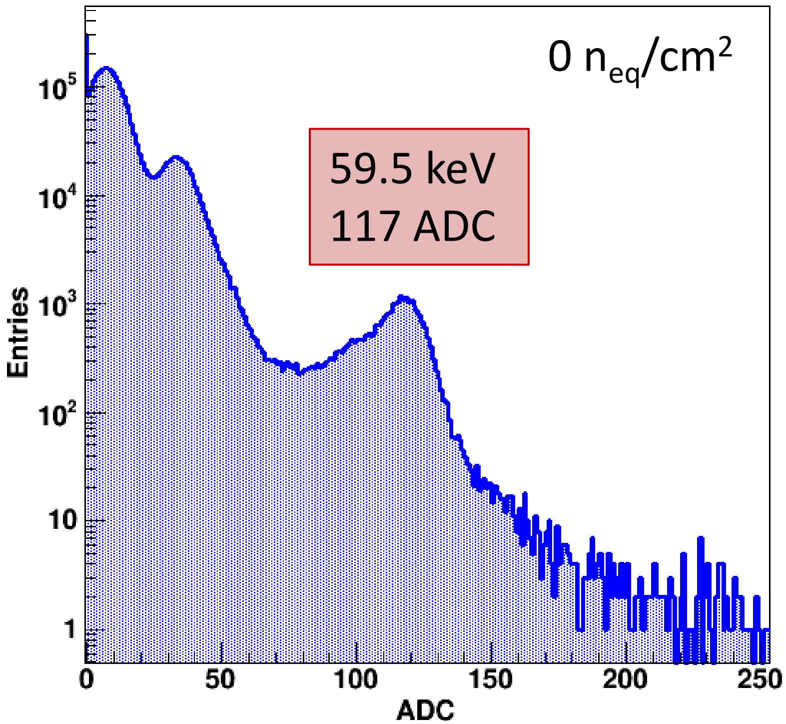


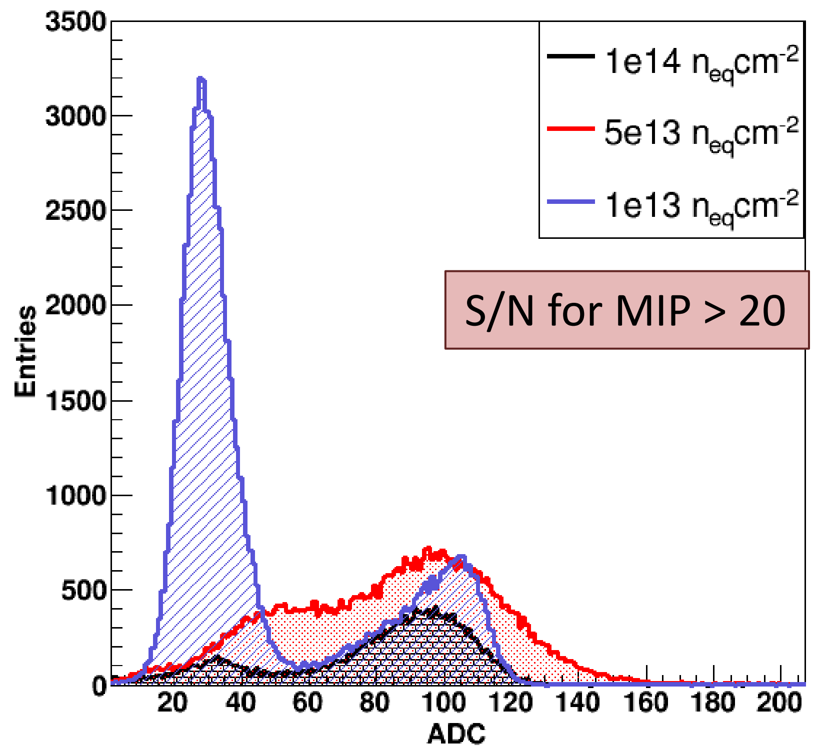



# Source tests of the latest silicon sensor prototype CBM05

- ADC spectrum, $^{241}Am$ gamma source
- expected signal at 117 ADC - 16.5 ke-

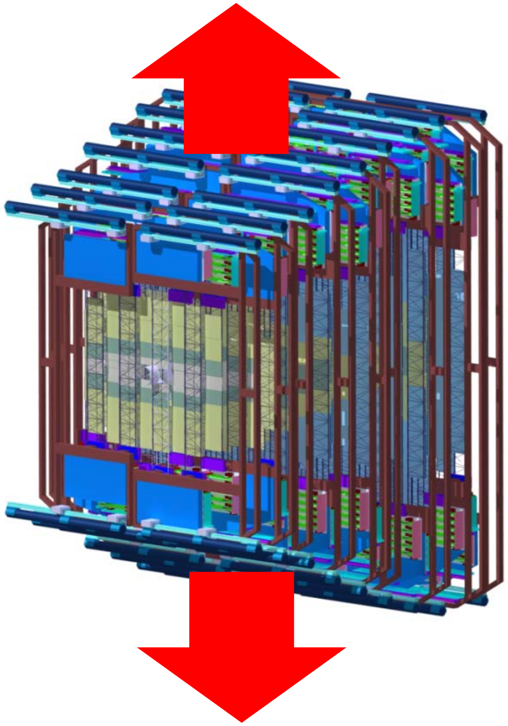
| Fluence | ADC (peak) | Efficiency |
|---|---|---|
| $0\ n_{eq}/cm^2$ | 117 | 100 % |
| $1 \times 10^{13}\ n_{eq}/cm^2$ | 104 | 89 % |
| $5 \times 10^{13}\ n_{eq}/cm^2$ | 98 | 84 % |
| $1 \times 10^{14}\ n_{eq}/cm^2$ | 97 | 83 % |



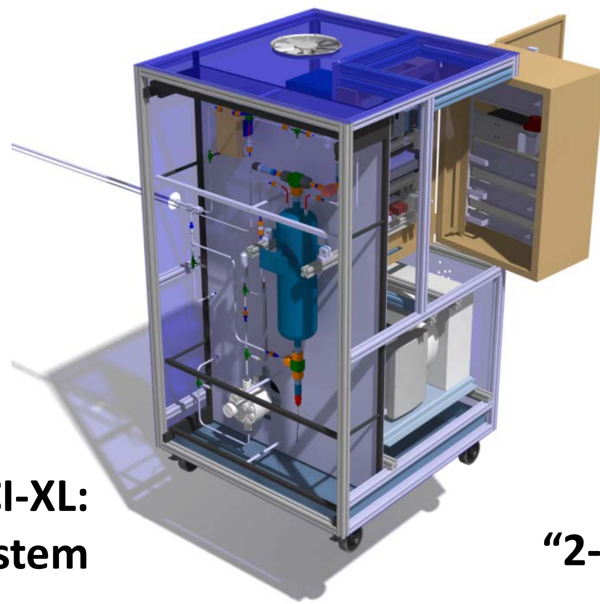
# Cooling

20 kW

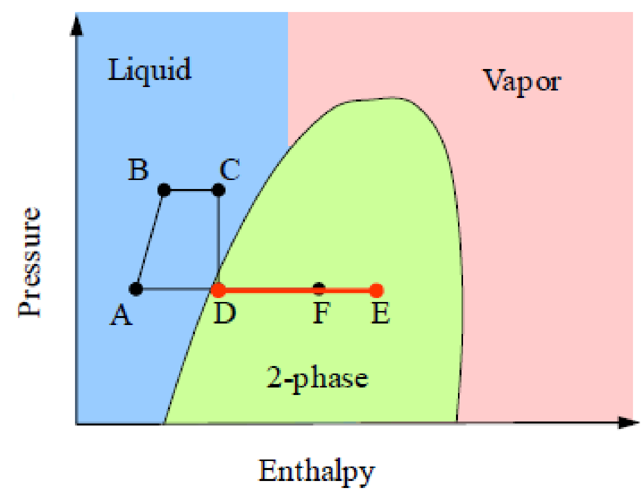


20 kW

- STS read-out electronics dissipates ca. 40 kW
- cooling with bi-phase CO2:
  - high efficiency at small spatial requirement
- standard for tracker upgrades at LHC
- cooperation of GSI with CERN: TRACI-XL



**TRACI-XL:**
**1 kW test cooling system**

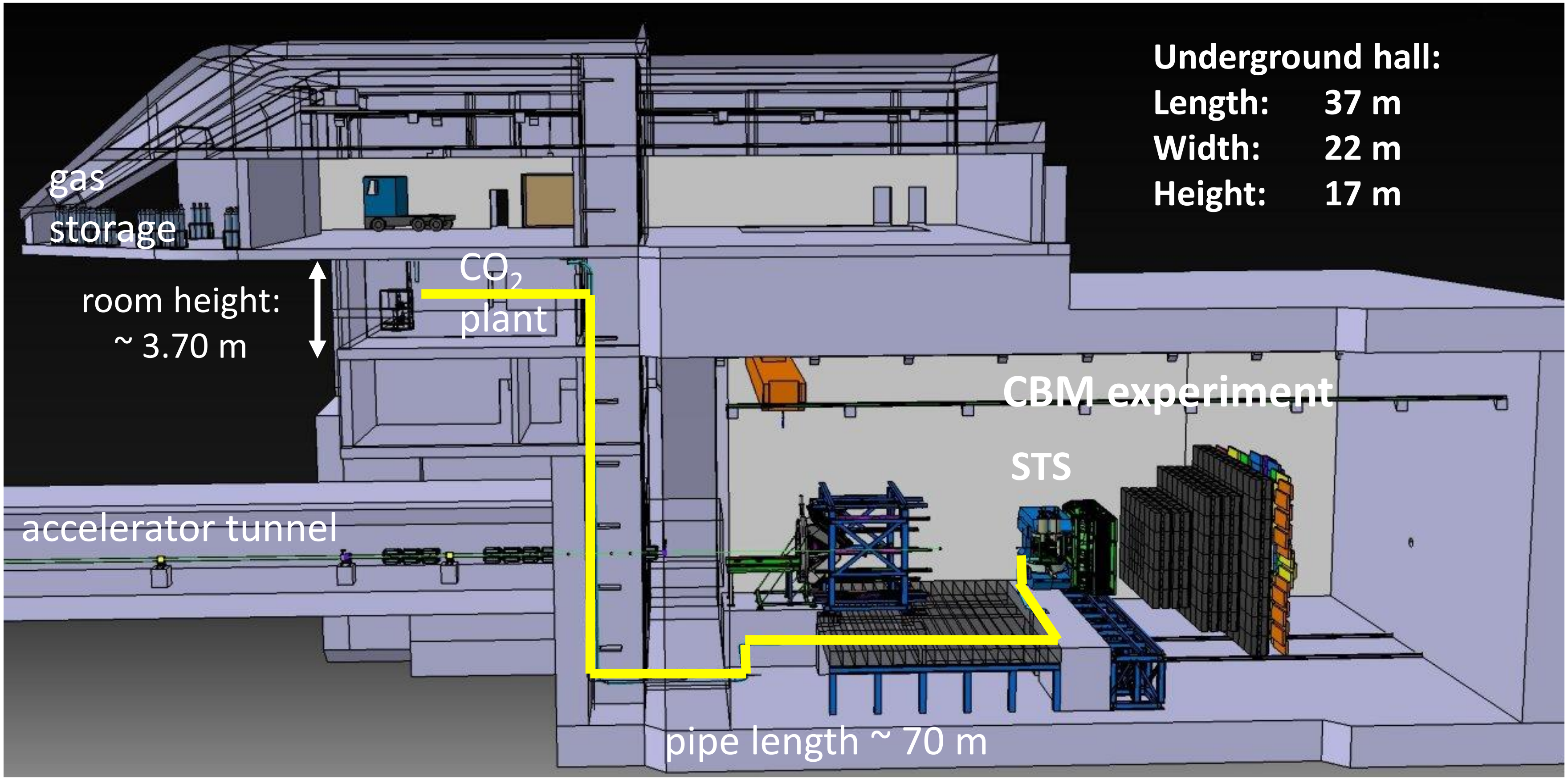



**"2-phase accumulator controlled loop"**

EU-FP7 CRISP– *Work Package $CO_2$ cooling*

http://www.crisp-fp7.eu/

# Cooling infrastructure inside CBM building

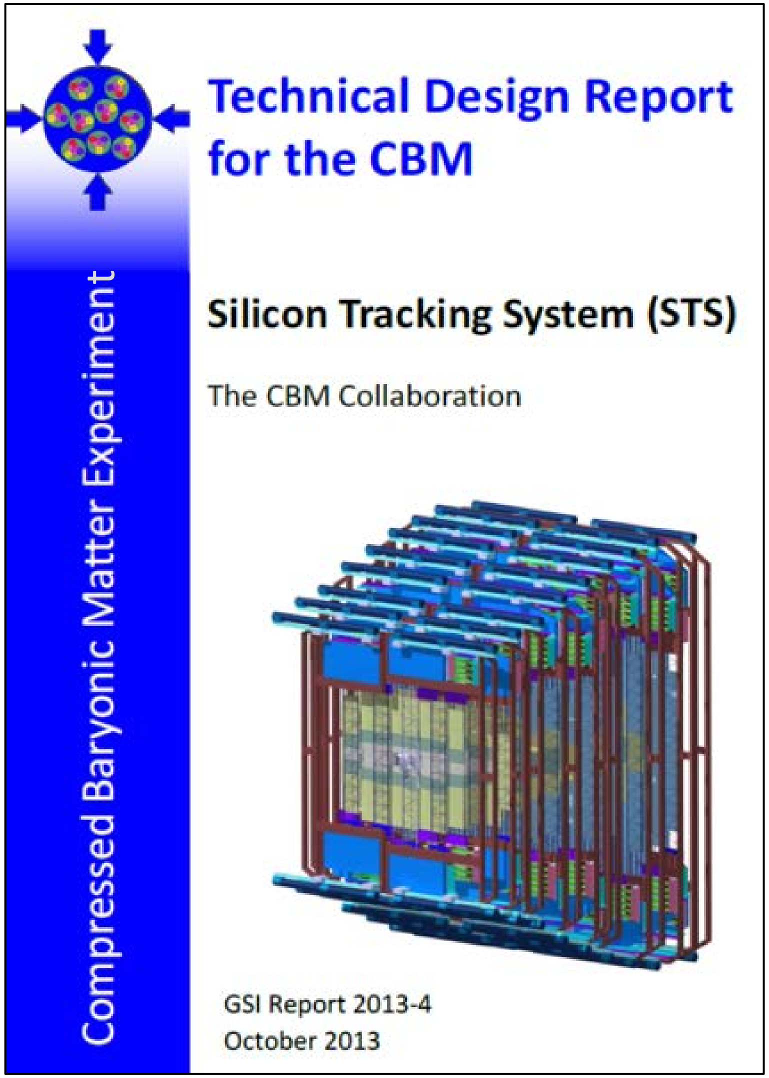


# STS Technical Design Report

Approved by FAIR in Summer 2013

**Content:**

- CBM experiment
- Silicon Tracking System
  - *constraints*
  - *concept*
  - *layout*
- Physics performance
- Radiation environment
- Development of components
  - *micro-strip sensors*
  - *read-out cables*
  - *front-end electronics*
  - *module, ladders*
- Prototypes
- System integration, maintenance
- Project structure



# Timeline for the STS

I 2014: R&D, prototyping and engineering design

II 2014 – 2017: Production phase
*- Pre-production (2014 - 7/2015)*
*- Production Readiness Review mid 2015*
*- Series production (2015 - 2017)*

III 2018: Installation, commissioning w/o beam, ...

# Thank you!