Highly-integrated light-weight mechanical structures for the **Silicon Tracking System of CBM** at FAIR

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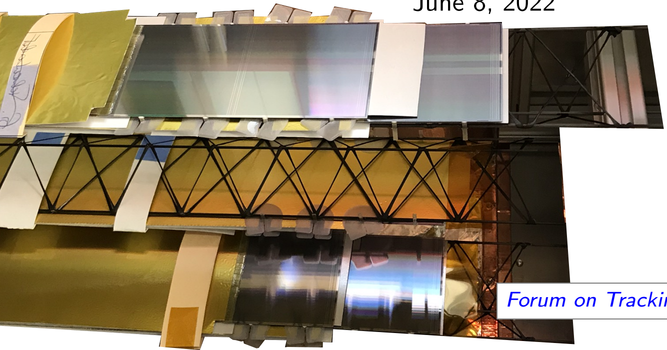
[1] GSI (Darmstadt), [2] INR of NASU (Kyiv) [3] Universität Tübingen

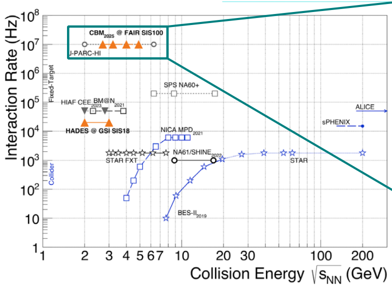
June 8, 2022



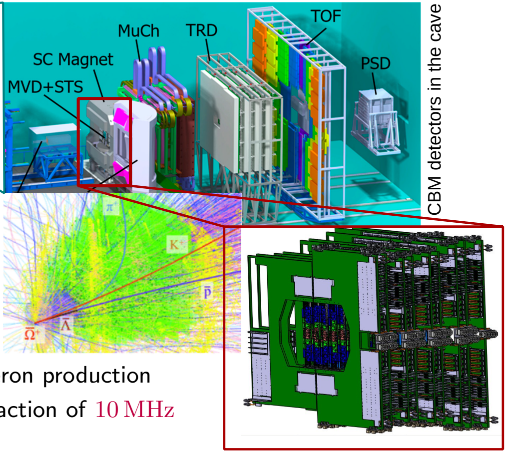
Forum on Tracking Detector Mechanics 2022

Silicon Tracking System of the CBM experiment

core detector for rare probes of compressed nuclear matter in high-rate heavy-ion collisions



N. Herrmann EPJ Web Conf. 259 (2022)

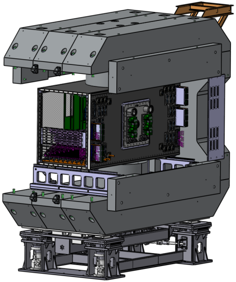


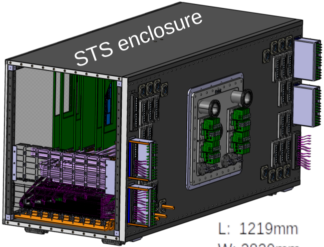
Silicon Tracking System

- CBM aims for multi-strange hyperon production
- Unprecedented beam-target interaction of $10\,\mathrm{MHz}$
- Challenges for tracker:
  - $\lesssim 700$ tracks in aperture /interaction, high granularity
  - low momenta $\rightarrow$ low material budget $(3-8\%\,X_0)$
  - spatial $(<30\,\mu\mathrm{m})$ + timing $(<5\,\mathrm{ns})$ + amplitude $(15\,\mathrm{fC}/5\,\mathrm{bit})$ information collected in free-streaming mode

Design and components of the STS

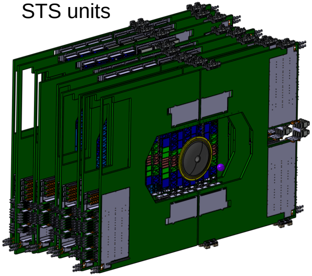
Detector inside the CBM magnet



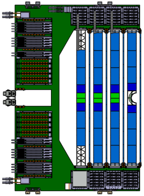


L: 1219mm
W: 2820mm
H: 1425mm

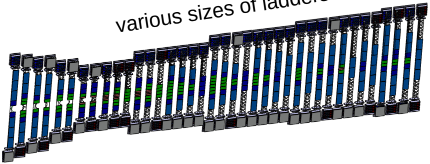
STS units



18 c-frame assemblies



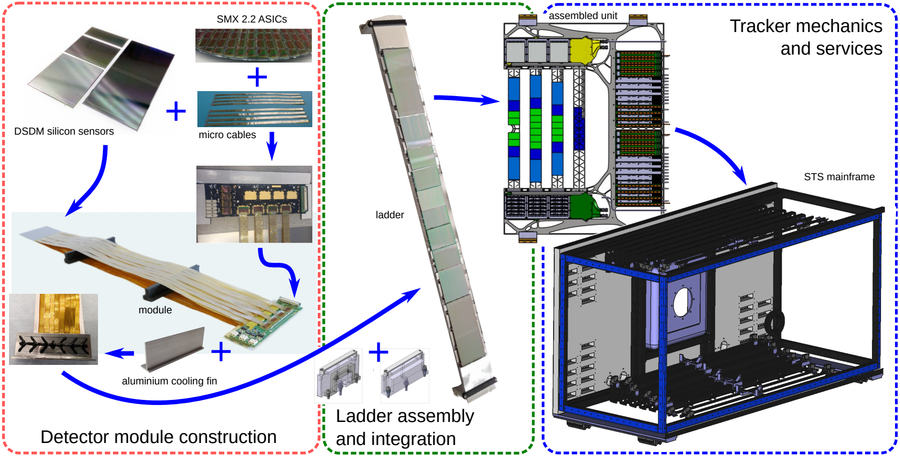
various sizes of ladders



Components:

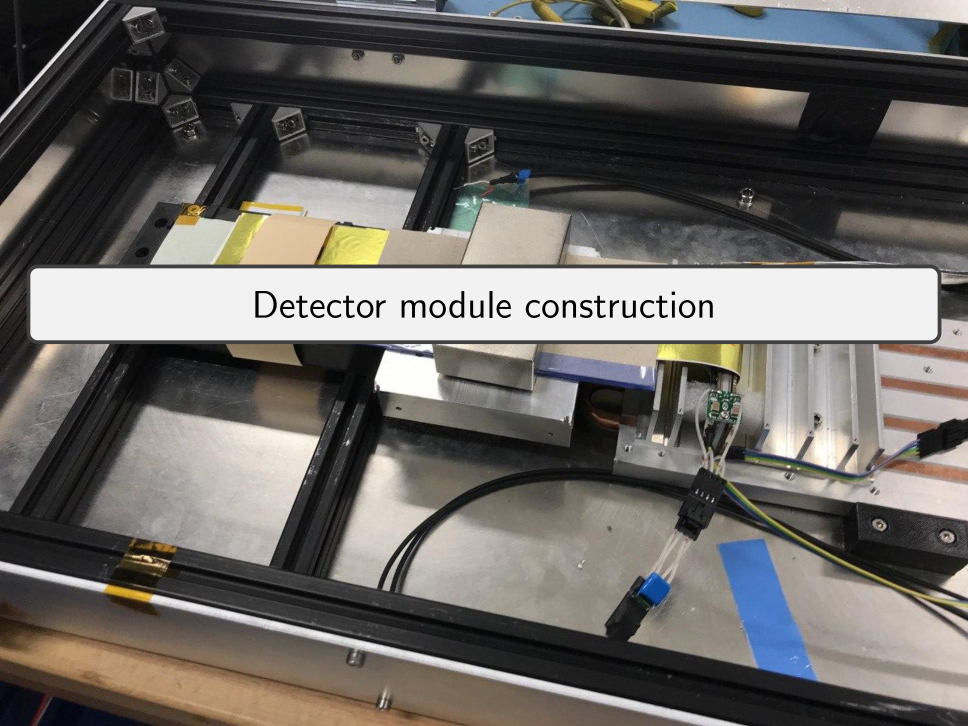
- 8 stations
- 18 half-units
- 106 ladders
- 896 Sensor modules

STS assembly sequence and structure



- 876 modules, 106 ladders, $\gtrsim 14\,000$ r/o ASICs, $\gtrsim 7\,000$ LDOs
- Large number of **unique components**: 199 module variants, 38 ladder types

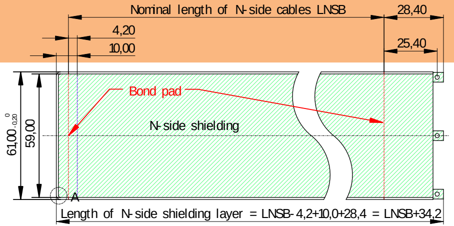
E. Lavrik J.Phys.Conf.Ser. 1390 (2019)



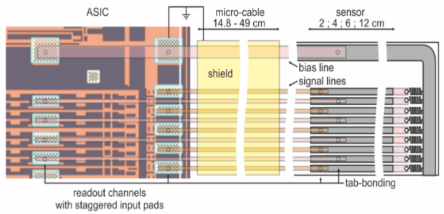
Detector module construction

Ultra-thin r/o micro cables

aluminium analog lines on the polyimid base



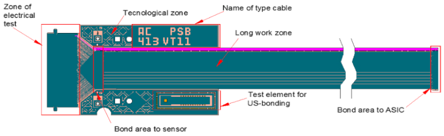
- Front-end electronics connected to double-sided silicon sensors via mictro-cable lines (64 lines/cable)



- Stack of 32 micro cables per module, 8 sub types
- Overall length from 160mm to 495mm

↗ Read-out lines are protected from EMI by aluminium shielding layers

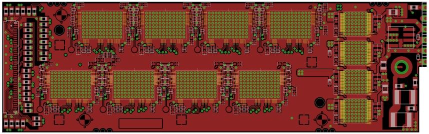
↘ Schematics of a single cable:



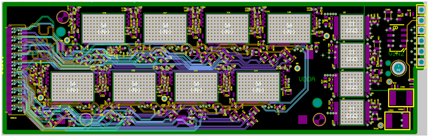
Micro-cable production ongoing at LTU, Kharkiv (60% of $\sim 15\,000$ cables ready at GSI)

Front-end electronics

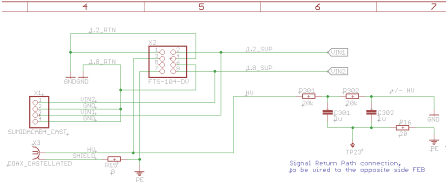
New FEB8-2_B design (PCBs ordered):



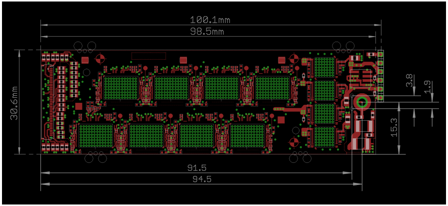
Recent update on FEB8-5_B design:



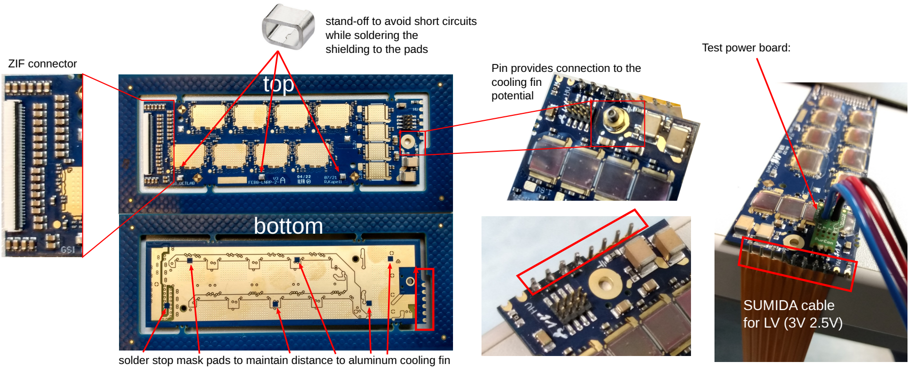
LV/HV circuit updated in new iteration



- PCBs to provide mechanical support, powering, and data links for 8 SMX
- Two flavors for A/B data cable topology
  - multi-layer design with dozens differential lines
  - two FEBs per module (A/B for right-, B/A for left-oriented)
  - up to $8\,\mathrm{W}$ power dissipation
  - withstand HV up to $\pm 250\,\mathrm{V}$
  - $30.6 \times 100.1\,\mathrm{mm}^2$ size



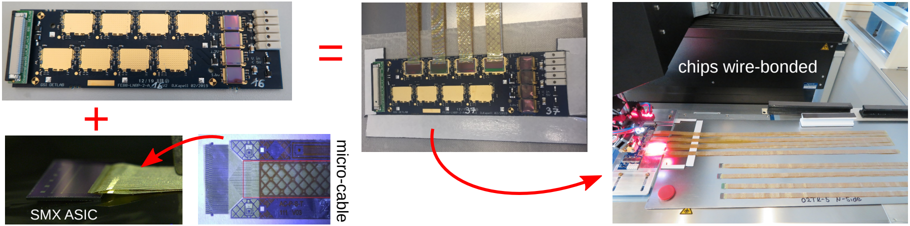
FEB mechanical and electrical features

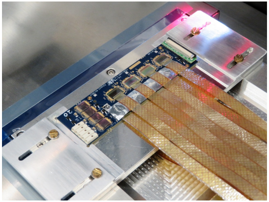


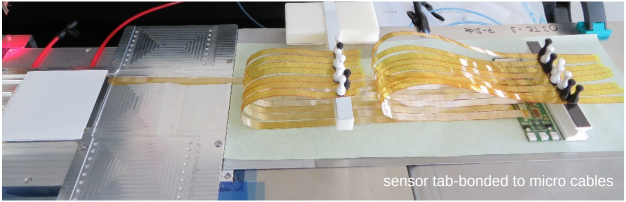
- Data lines + clock: 40 or 100 lines (FEB8_2/FEB8_5)
  - HV decoupling w/ capacitors
  - ZIF connector for data cable
- Analogue lines covered with EM shielding on HV (each layer)
- Ground interfaces through PCB to cooling fin
- Powering:
  - service connector for testing
  - permanent soldering at the edge to the flat LV cable + coax. HV cable

Module assembly

- STS detector modules are produced in the assembly centres in GSI and KIT
  - tools and procedures are shared between centres
  - highly integrated objects: extensive testing at each step

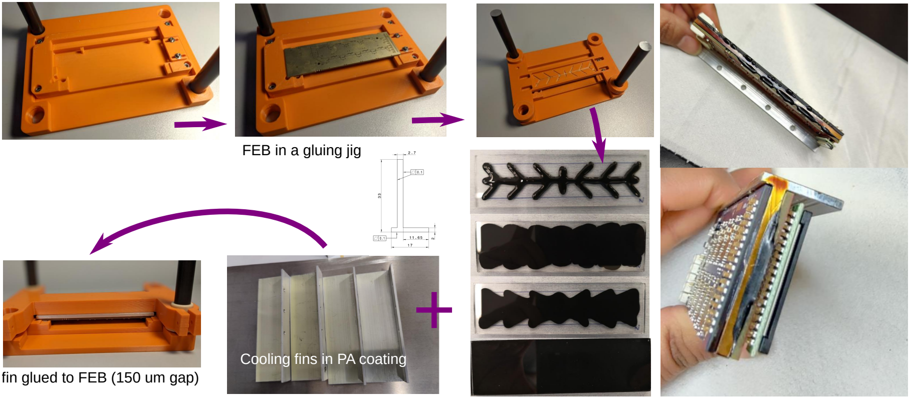






- Pre-series production in spring 2022 to validate the sequence

Gluing of the thermal interface

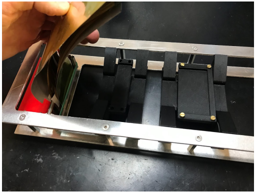
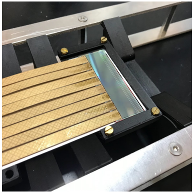


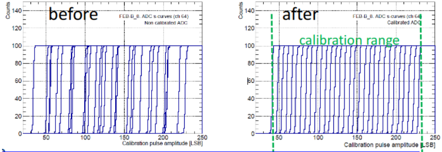
- After module assembly, 2.7mm thick aluminum cooling fin is glued in between
- Low viscosity glue, $150\,\mu m$ thick
  - thermal interface
  - insulation for $\pm 250\,V$

Details in poster of Shaifali Mehta

Module functionality tests: reception, calibration, burn-in

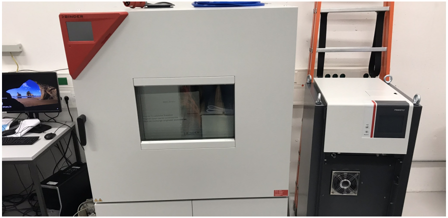
- Module installed into the carrier structure with interfaces for testing:

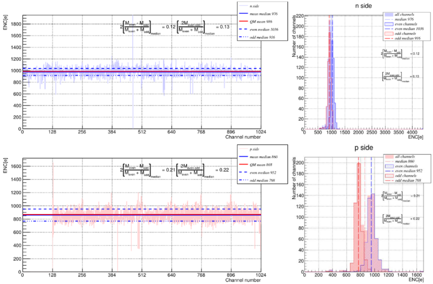


A. Rodriguez Rodriguez PhD Frankfurt U. (2020)

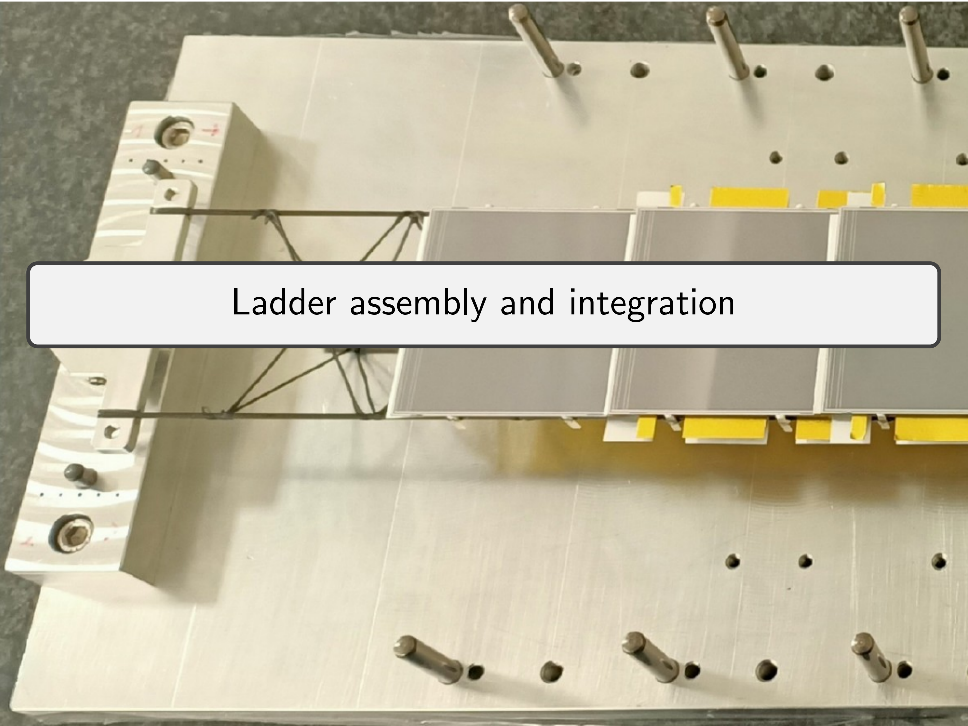
- Module burn-in: performance test under thermal stress:
  - cycles from $+25^{\circ}$C to -40°C



- Module beseline width measured



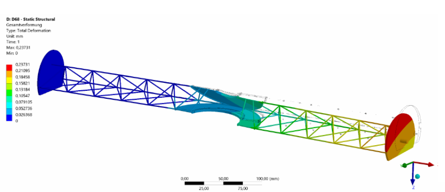
See poster of Marcel Bajdel about temp./humidity sensors

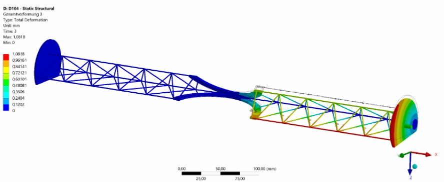


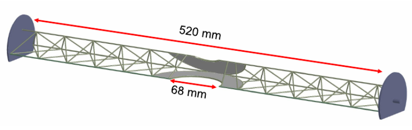
Ladder assembly and integration

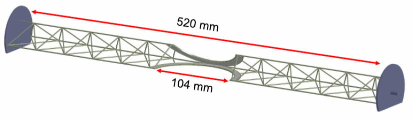
Central ladder shape

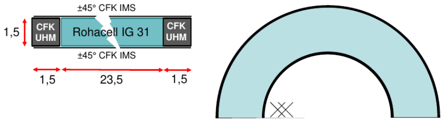
- CF ligjt-wight (but sufficiently stiff) ladder structures to hold on sensors
- Central ladders w/ cut-out for beam pipe (various designs considered):

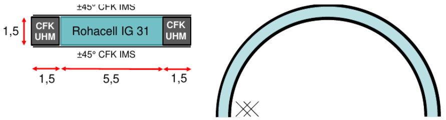






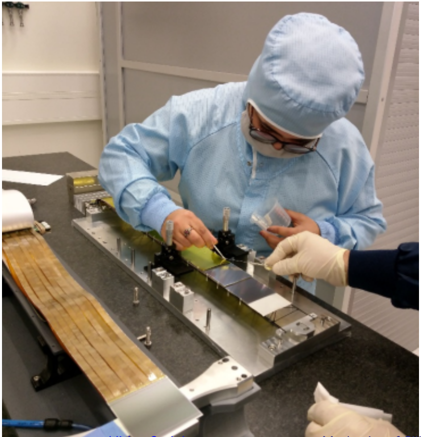


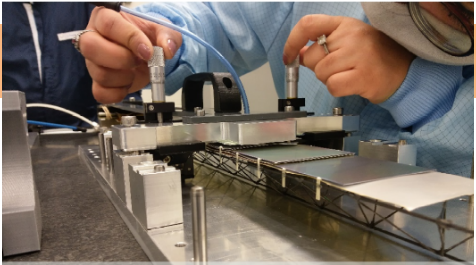




Ladder assembly sequence

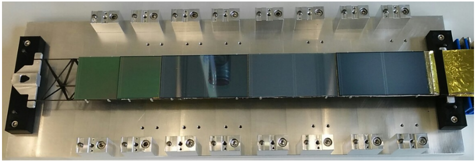
- From 8 to 10 detector modules installed on the light-weight carbon structures: ladders
- Sensors precisely positioned ($\lesssim 30\,\mu\mathrm{m}$) with jigs



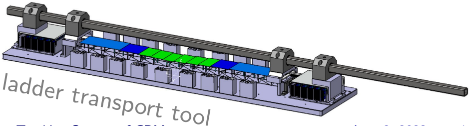


Positioning the Sensorholder, here: mSTS

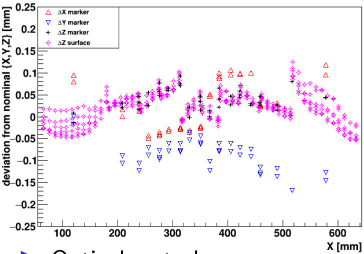
- Assembled ladders undergo metrology survey and functionality tests



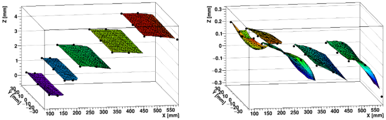
- After tests ladder is installed on c-frame



Optical metrology and functionality tests of the ladders

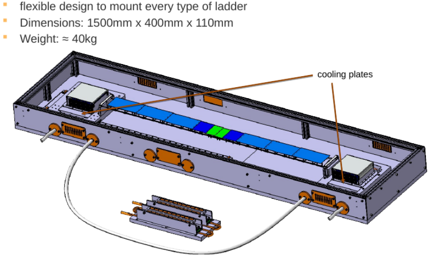


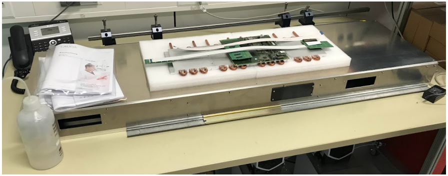
- Optical metrology:
  - dedicated table with camera
  - $\mathcal{O}(10\,\mu\mathrm{m})$ measured precision
  - multi-point probing



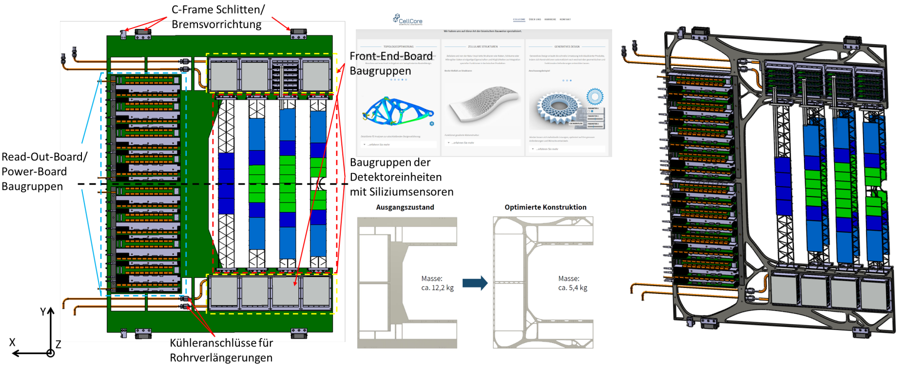
- Actual position of the sensors stored in data base

- Performance check with the assembled ladder:
  - DAQ communication test
  - HV (spark) test





Optimisation of the c-frame structure

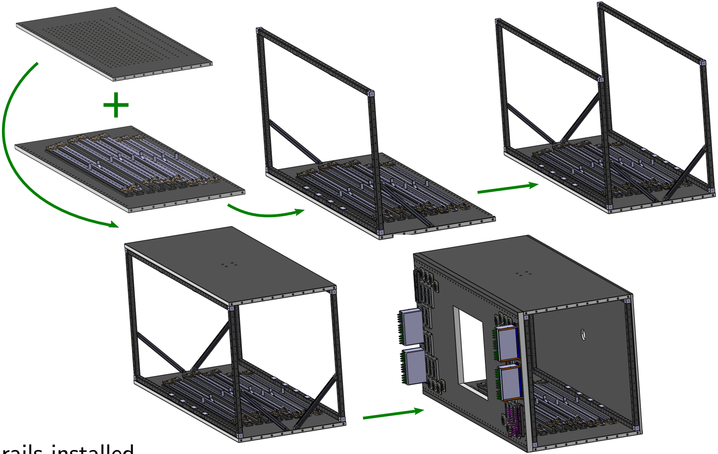


C-Frame design workflow:

- Starts with the rough definition of the component positioning and description
- Iterations CellCore:
  - use case and loads definition for the Unit
  - optimization study with FE → mass reduction and stiffness increase
- Redrawing of the FE Result → compatibility with manufacturing

Tracker mechanics and services

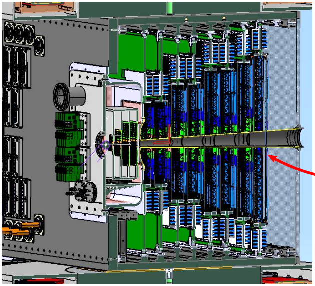
Mainframe assembling sequence

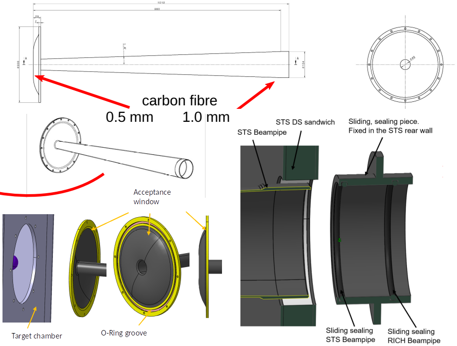


- Alu. rails installed
- Verticals then horizontal CF beams mounted on bottom plate
- Top plate and front/back walls attached (CF + AIREX sandwich of 30 mm)

Beam pipe

- Beam pipe full-size prototype will be produced this year
- FEM simulation: critical part is transition from membrane to cone

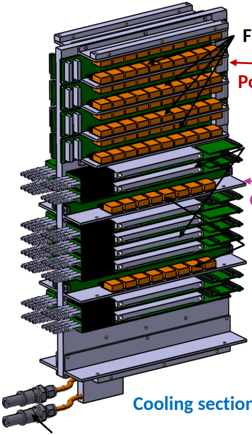


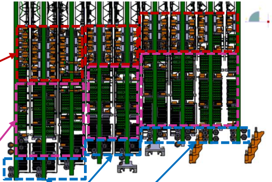


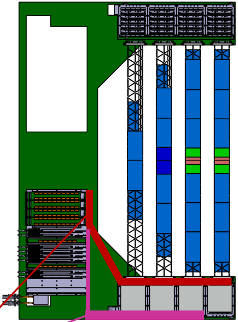
- Window and conical pipe:
  - separate target/MVD vacuum and non-interacting beam from STS aperture
- Carbon fiber material: 0.5 mm (window)
  1.0 mm (1.8° cone)
- Window attached to target vacuum chamber
- Zero-force interface at back wall towards downstream section

Powering and electrical r/o lines

ROB Stack overview:





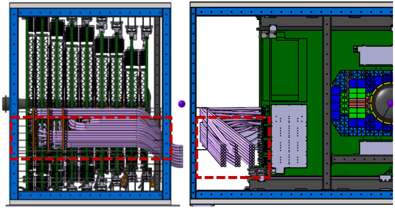


Topology of ROB POB Stacks is driven by the concept of cable routing from the Ladders and corresponding FEB boxes to the stack.

- Geometrical separation of the Read out and Power cables on the C-Frame
- Assembly/cabling sequence of the Ladders/C-Frame

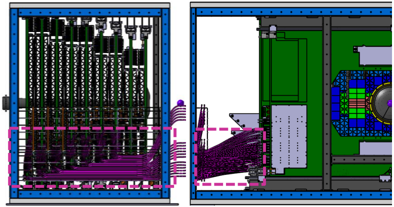
Topology of the STS services

Power section



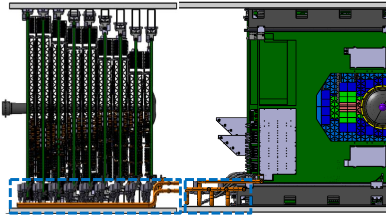
- One round bundle per POB approximation – 16,5mm
- POB to feed through routing

Optics section



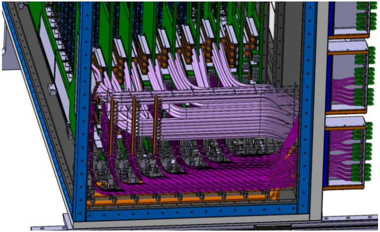
- Individual optic lines from ROB to fan out
- Bundles to feed through and MPO-MPO panel

Cooling section

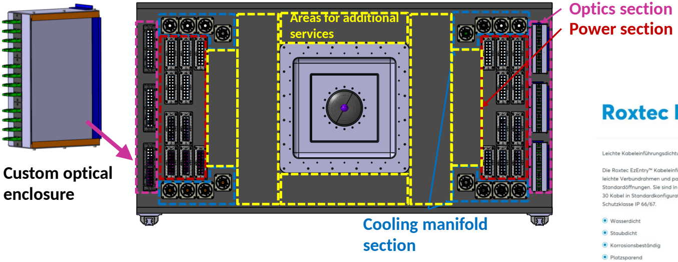


- 1“ manifold with 1/4“ pipes towards C-Frames
- 1/4“ swagelok steel flex hoses

All sections



STS front wall and services



Power and optical feed throughs:

Roxtec EzEntry™

Leichte Kabeleinführungsdichtungen mit Verbundrahmen.

Die Roxtec EzEntry™ Kabeleinführungsdichtungen haben leichte Verbundrahmen und passen direkt in Standardöffnungen. Sie sind in 6 Größen erhältlich für 4 bis 30 Kabel in Standardkonfigurationen und bieten Schutzklasse IP 66/67.

- Wasserdicht
- Staubdicht
- Korrosionsbeständig
- Platzsparend
- Nimmt vorkonfektionierte Kabel auf

Cooling feed throughs:

Roxtec-Dichtung RS

Die Roxtec RS Abdichtung ist ein runder Stopfen, bestehend aus zwei Hälften und einem Kern, dessen Innendurchmesser durch das Entfernen der Pellen anpassbar ist. Die Kompression ist in die Dichtung integriert. Ermöglicht die Installation um ein vorhandenes Kabel oder Rohr.

- Expansionsmontage in der Einbauöffnung
- Für ein einzelnes Kabel oder Rohr
- Optionale Mantelrohre erhältlich

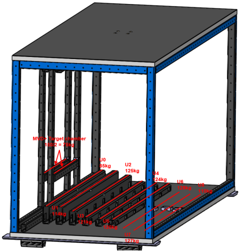
RS 75 AISI316

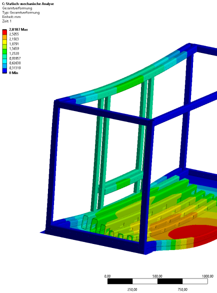
The front wall of the STS enclosure hosts inlets for detector services:

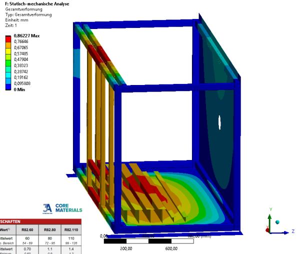
- Suitable feed-through for
  - optical fibres
  - HV/LV power cables
  - cooling pipes
- Additional custom enclosure for optical connections on the front wall
- Areas reserved for additional services still available

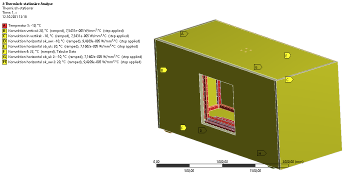
Mechanical deformation for the mainframe

FEA simulations



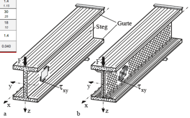






AIREX — CORE MATERIALS

MECHANISCHE EIGENSCHAFTEN						
Typische Daten für AIREX® R82		Einheit (metrisch)	Wert[1]	R82.60	R82.80	R82.110
Dichte	ISO 845	kg/m³	Mittelwert Typ. Bereich	60 54 - 69	80 72 - 95	110 99 - 126
Druckfestigkeit senkrecht	ISO 844	N/mm²	Mittelwert Minimum	0.70 0.60	1.1 0.9	1.4 1.2
Druckmodul senkrecht	DIN 53421	N/mm²	Mittelwert Minimum	46 40	62 56	83 60
Zugfestigkeit in Plattenebene	ISO 527 1-2	N/mm²	Mittelwert Minimum	1.7 1.2	2.0 1.7	2.2 1.9
Zugmodul in Plattenebene	ISO 527 1-2	N/mm²	Mittelwert Minimum	45 35	54 50	64 54
Schubfestigkeit	ISO 1922	N/mm²	Mittelwert Minimum	0.80 0.65	1.1 0.9	1.4 1.15
Schubmodul	ASTM C393	N/mm²	Mittelwert Minimum	18 15	23 20	30 25
Schubbruchdehnung	ISO 1922	%	Mittelwert Minimum	25 15	23 15	18 10
Schlagzähigkeit	DIN 53453	kJ/m²	Mittelwert	1.0	1.3	1.4
Wärmeleitfähigkeit bei Raumtemperatur	ISO 8301	W/m.K	Mittelwert	0.036	0.037	0.040

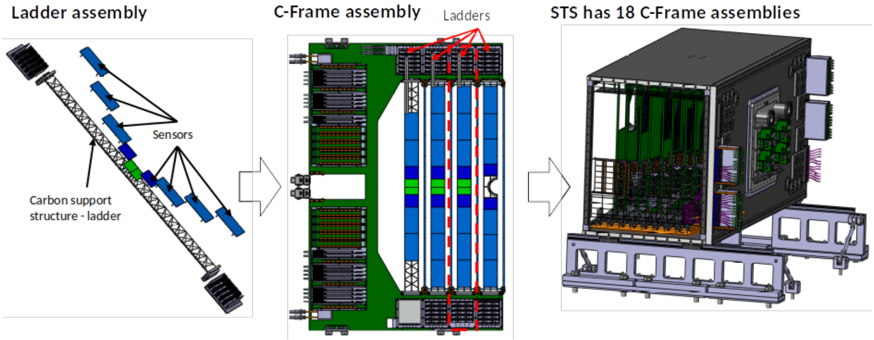


- CF profiles + CF sandwiches
- Max. baseplate deformation $\sim 0.9\,\mathrm{mm}$

- 5 mm Woven Epoxy Carbon (395GPa)
- Airex R82.110 foam 0.04 W/mK

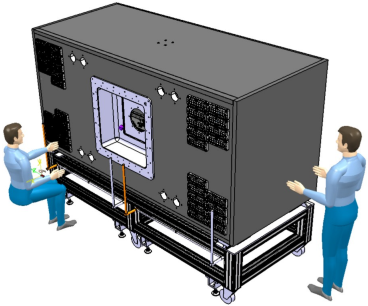
Mechanical precision

- Knowledge of the mechanical behavior of the system is essential
  - number of free parameters of the sensors: 850×5 (3 coordinates + 2 angles)
  - par. matrix reduced by constraints (down to 18×3 w/ ladder/unit metr.)
  - known and predictable deformation of the structural elements

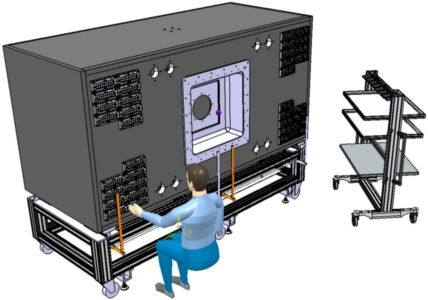


- Track-based alignment cannot be avoided
  - external "coarse tuning" information
  - from metrology during assembly + validated simulations

Assembling and transportation table



ergonomic height



workplace system for tools and

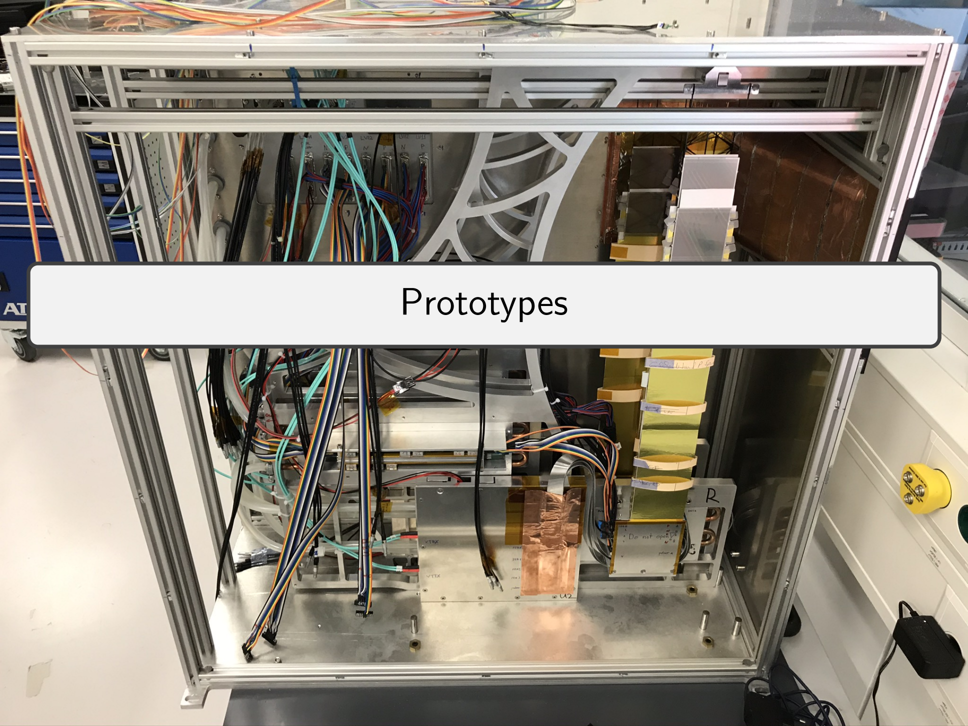
Substructure holds the weight of 2t, movable with 2 persons

Size:
- H: ergonomic height ($\sim 70 - 75\,\mathrm{cm}$)
- W: not larger than the STSBox to allow manoeuvres in the lab

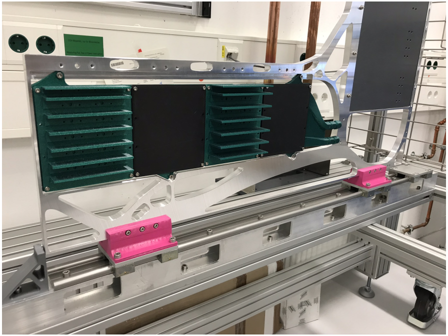
- Extendable thread bolts in the bottom table frame could fix table position
- Place for cable storage

★ First ready prototype in the STS lab@GSI

Prototypes

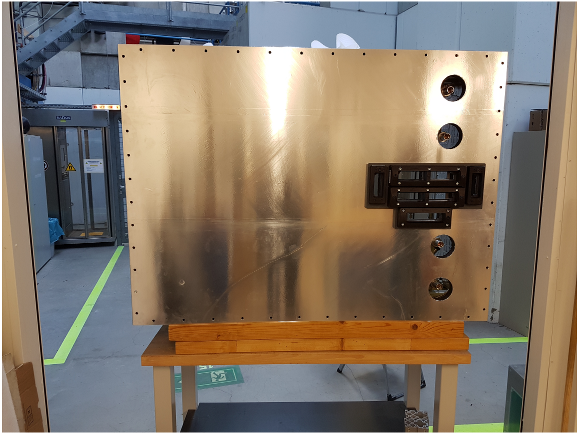


Mechanical mock-up of the detector



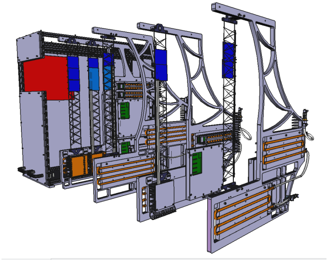
- Real life mechanical behaviour
  - cabling and wiring
  - micro cables, detectors
- Test bench for the assembling
  - evaluation of the accessibility
  - exercise metrology

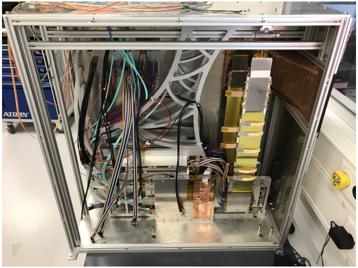
Thermal demonstrator

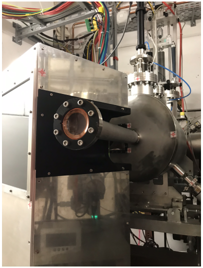


- Close-to-final prototype to check thermal behavior of the system
- Playground for mechanical studies:
  - CF sandwich panels but aluminium frame
  - aluminium c-frames + CF ladders + pipes + dummy components (heat loads, structural components...)

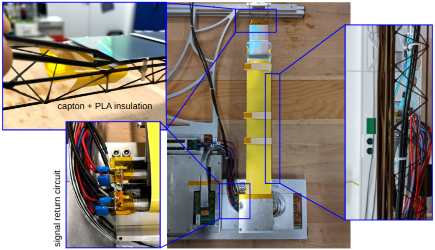
mSTS: functional full-scale detector prototype





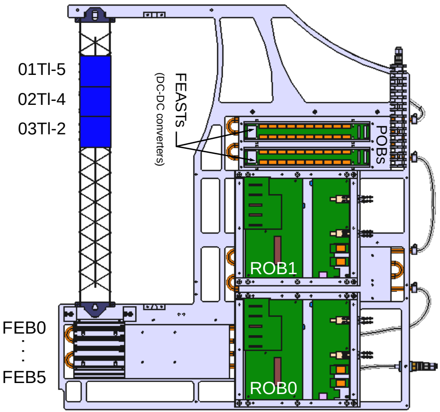


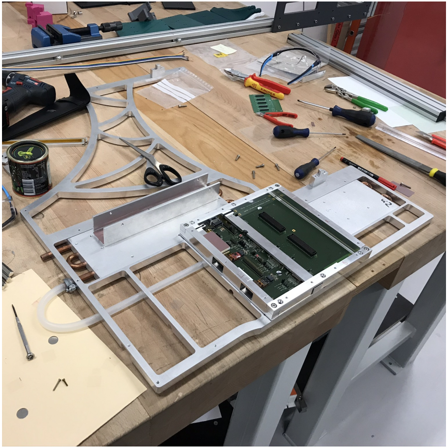
- Two tracking stations (layers) $12 \times 12\,\mathrm{cm}^2$ and $18 \times 18\,\mathrm{cm}^2$ arranged by 4 units
- Ultimate test of the detector performance **in the fully integrated system**
- Close-to-final running conditions
- Commissioning of the **assembling and testing procedures** to be used
- Hit/track reconstruction performance with the **heavy ion beam at SIS18**



mSTS construction

c-frame mechanical assembly

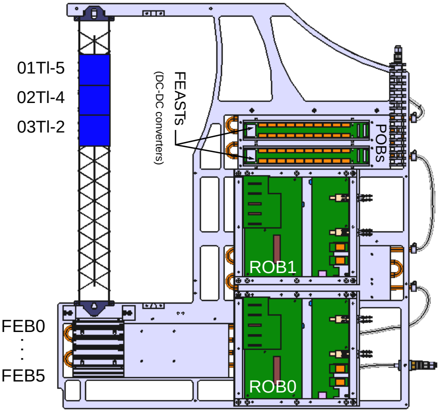


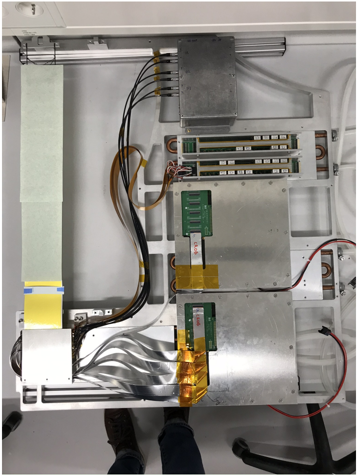


- All mech. components + services integrated on c-frame before ladder installation

mSTS construction

c-frame mechanical assembly

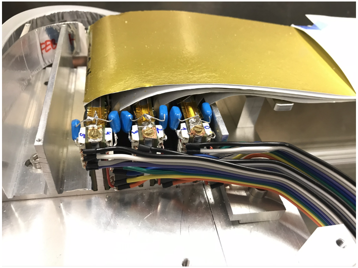


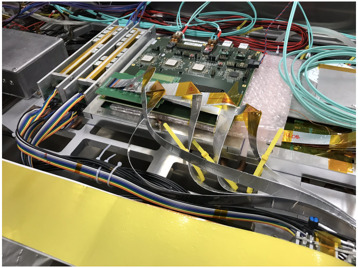


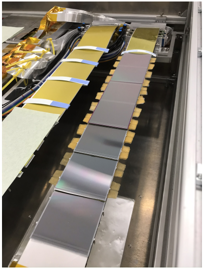
- All mech. components + services integrated on c-frame before ladder installation
- Back-end electronics (CROBs) and power electronics (POBs w/ FEASTs) installed after mechanics (cooling blocks, support elements...)

mSTS construction

ladder integration and services



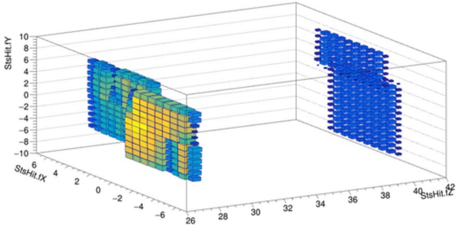


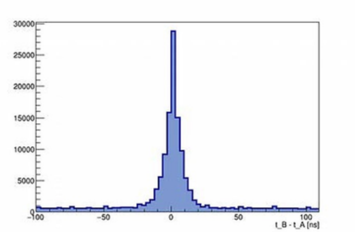


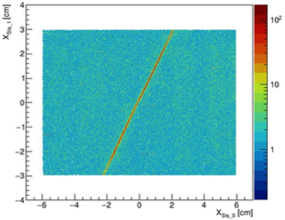
mSTS: functional full-scale detector prototype

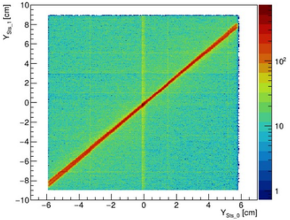
tests with ion beam at GSI

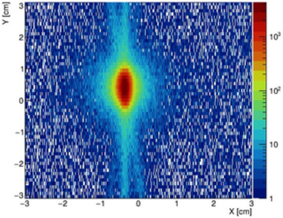
- mCBM was operated in beam campaigns in 2020 and 2021
- mSTS demonstrated tracking with 2/2 detector layers mostly operational



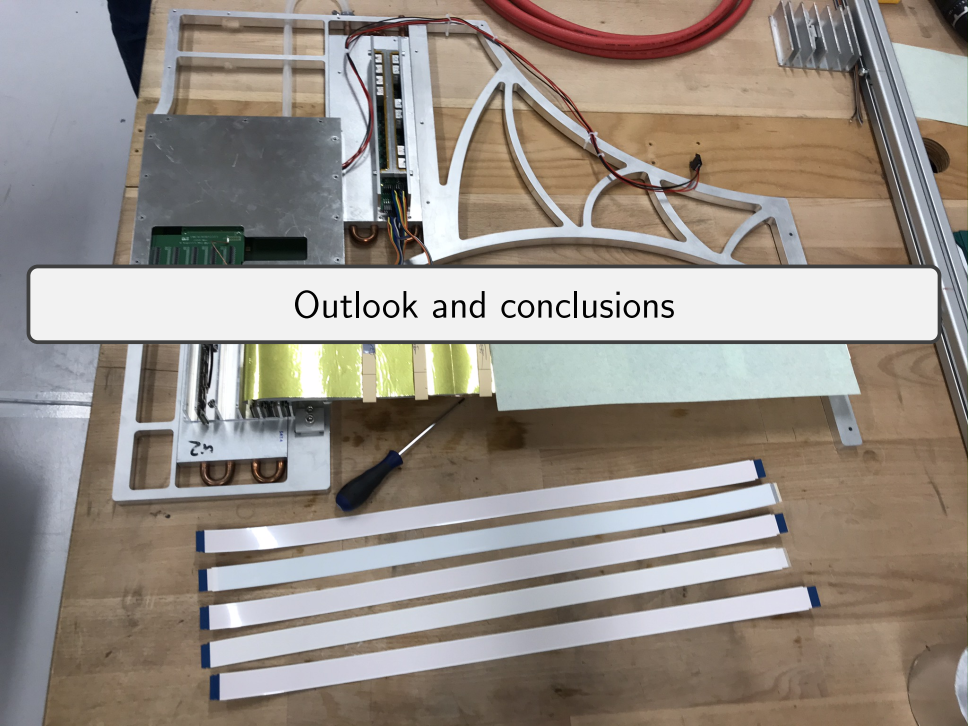






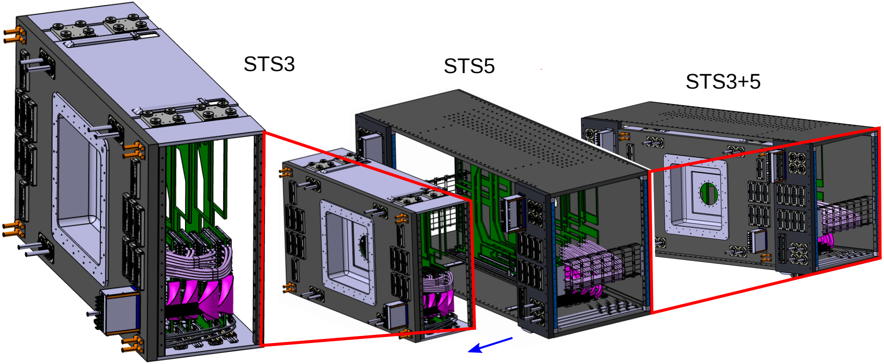


Outlook and conclusions



Outlook: possible modularity of STS

- **Very preliminary study:** modular two-part STS design
  - additional space reqs. completed in X, Y, Z follows
  - service separation concept between movable and stationary STS Units almost done
  - movable inner frame conceptually done
- Better upgradability potential
- Adjustable geometry to accommodate acceptance for different energies



Status of work in progress

- The mechanical design of the STS detector is close to its conclusion
- Concept is well developed
- Key features are established
- Module design frozen
  - new pre-serial production with last FEB iteration
  - gluing/powering to be checked
- Ladder assembling procedure tried out and established
- Ladder integration questions to be addressed:
  - attachment of the data cables/power cables, installation sequence...
- Simulations + prototypes to validate critical issues of design and assembling