Report from STT Working Group

S. Di Falco

INFN Pisa, Italy

R. Petti

University of South Carolina, Columbia SC, USA
IIT Guwahati, India

G. Sirri

INFN Bologna, Italy

SAND meeting
3 December 2024

OUTLINE

Focus on progress since report at 10/2024 SAND meeting:

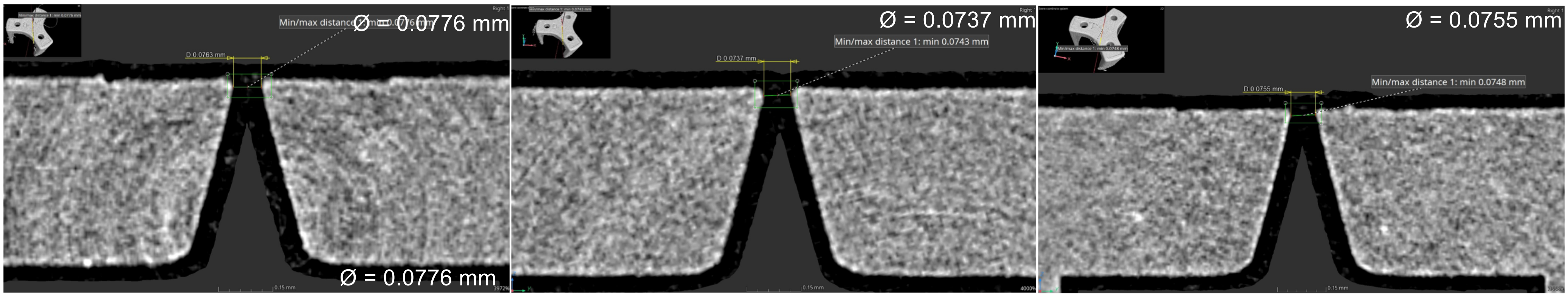
- *Tests of wire spacers at CERN;*
- *Tests of crimping pins;*
- *Testbeam exposures at SPS and PS at CERN;*
- *Analysis of testbeam data;*
- *Mechanical analysis and assembly of full-scale STT modules;*
- *Thermal analysis of STT super-module with VMM3a readout;*
- *Initial STT configuration and operating conditions;*
- *Performance of initial STT configuration.*

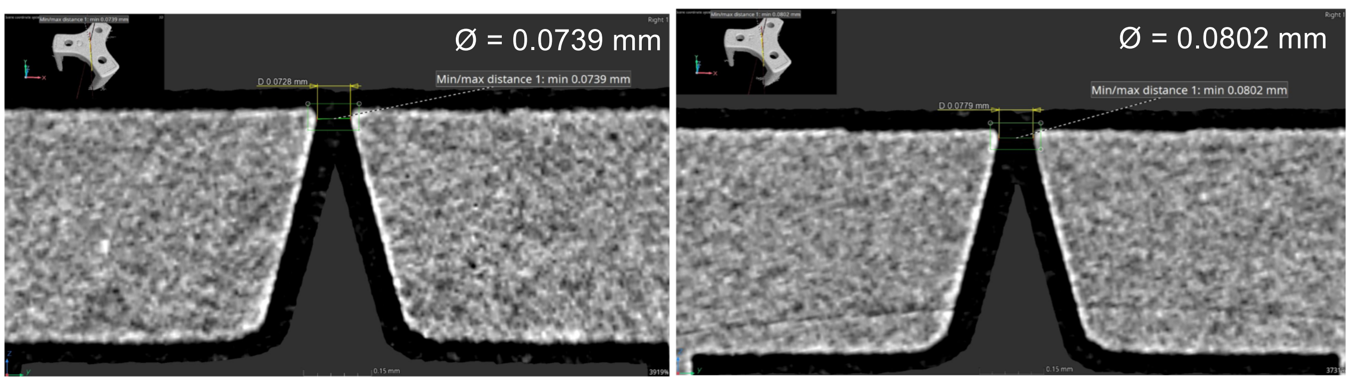
Material presented during WG meetings (Thursdays, 8:00am Central Time / US) available on Indico:
`https://indico.fnal.gov/category/1402/`

TESTS OF SPACER SAMPLES AT CERN

K. Buchanan (CERN)

Internal minimum diameter



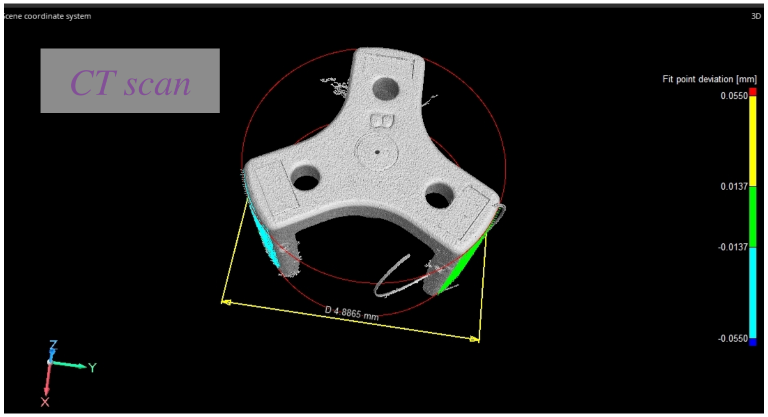


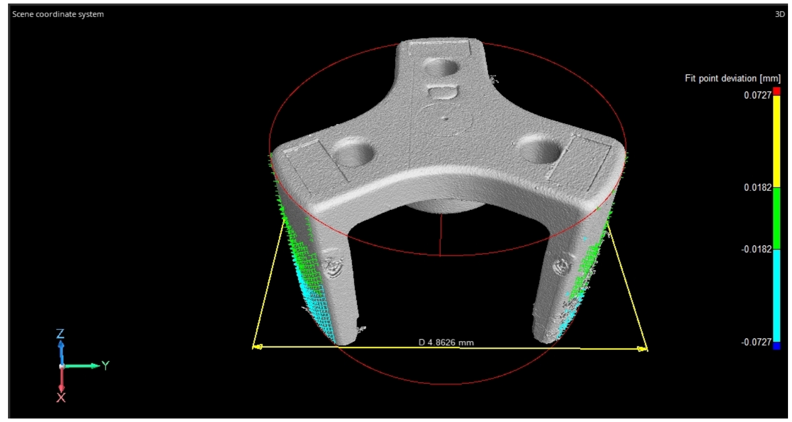
Average diameter (mm) = 0.7618 ± 0.0028
Maximum diameter (mm) = 0.0802
Minimum diameter (mm) = 0.0737

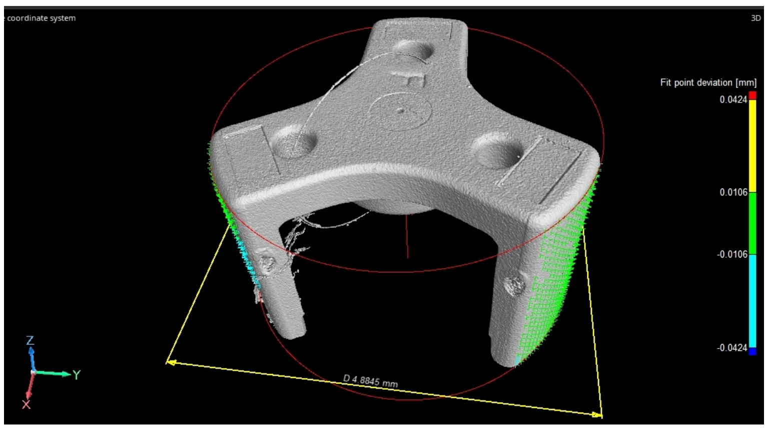
Acceptable to the standard set of < 0.08 mm

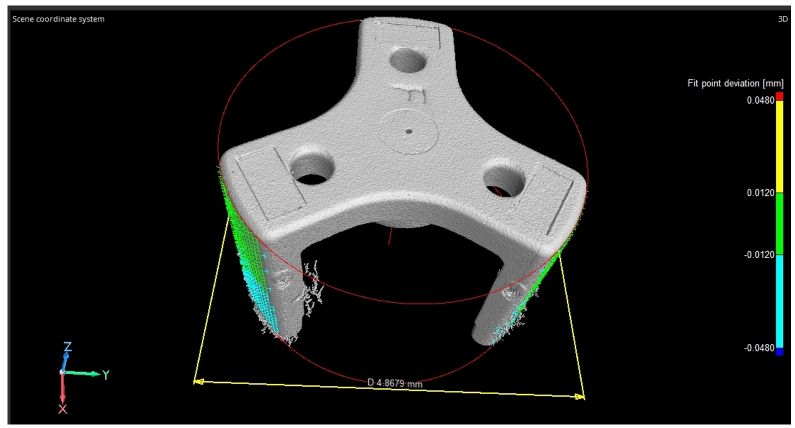
Final samples of STT spacer produced by injection molding tested at CERN

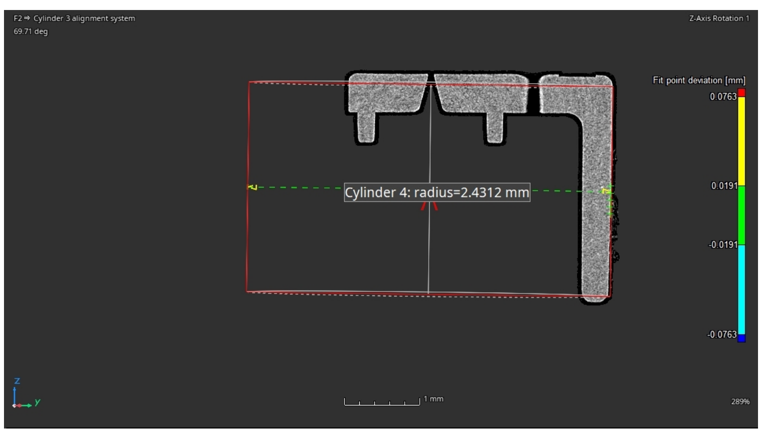
External maximal diameter

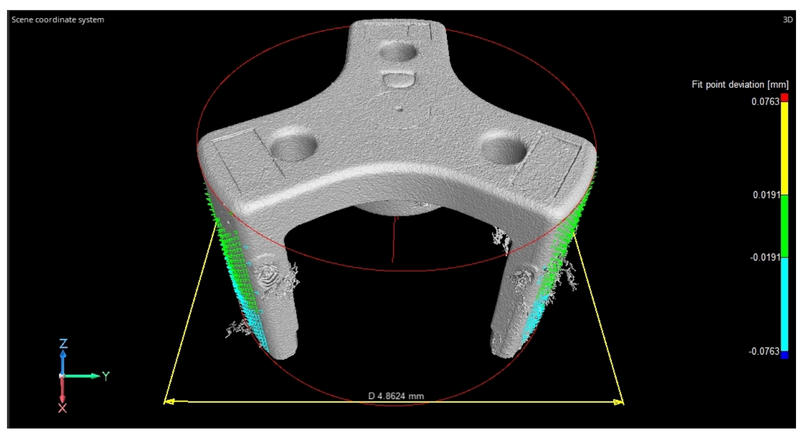








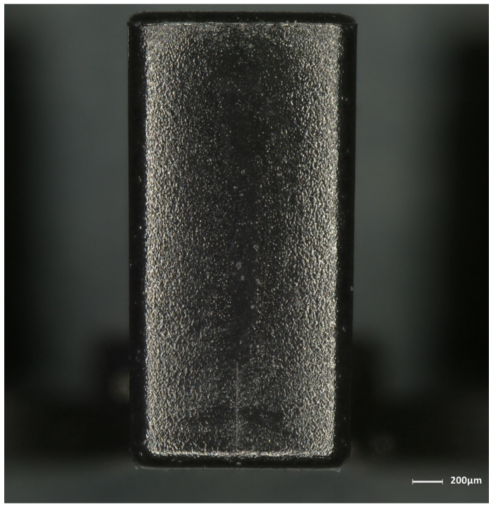


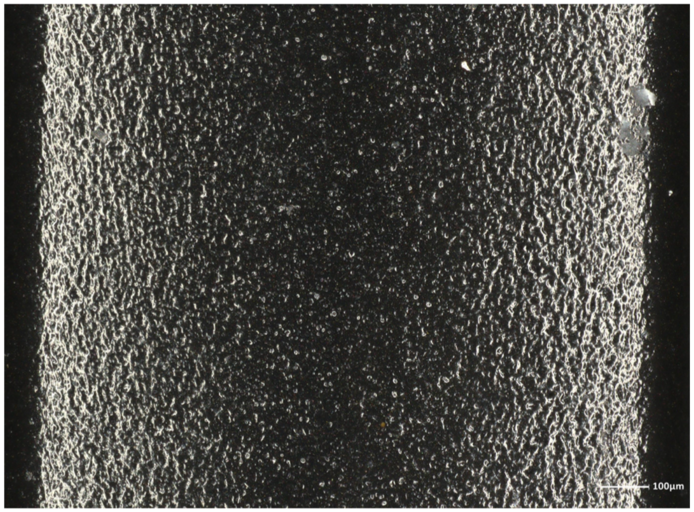


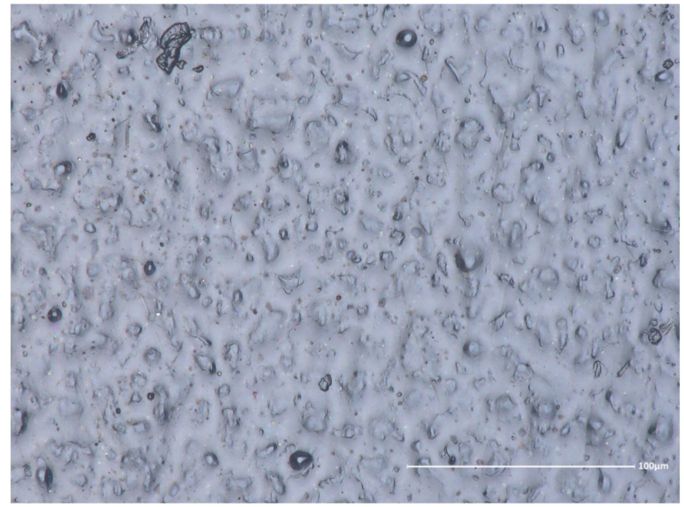
Acceptance criteria:
External diameter
(**nominal 4.88+0.0-0.03 mm**)

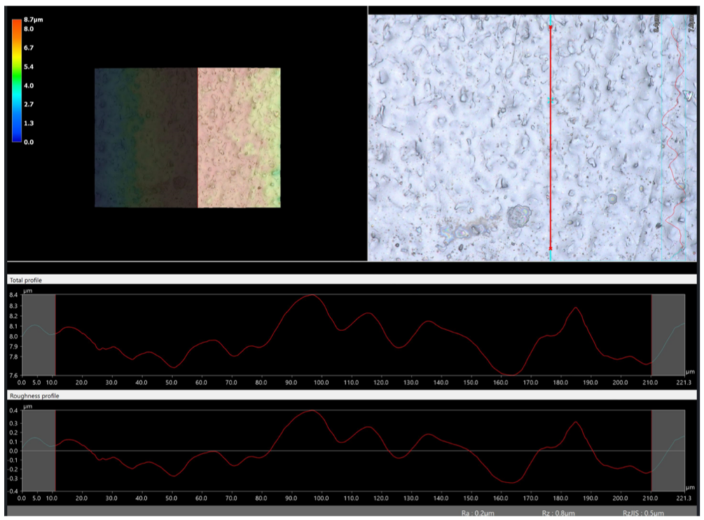
Average diameter
= 4.873 ± 0.012 mm
therefore acceptable

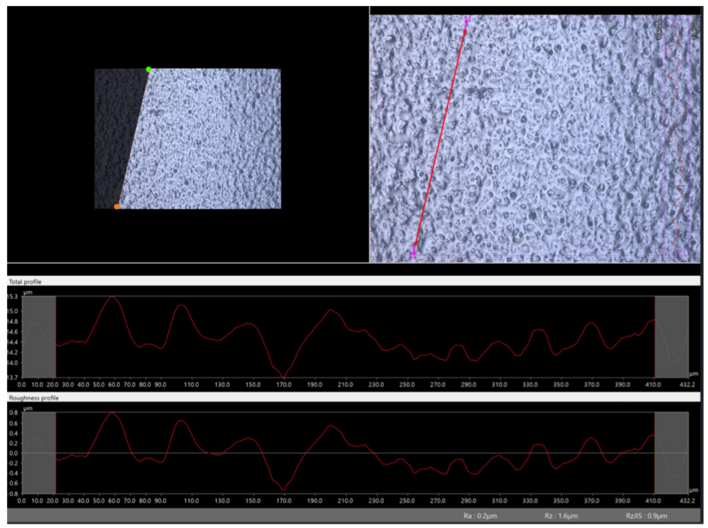
Roughness measurement











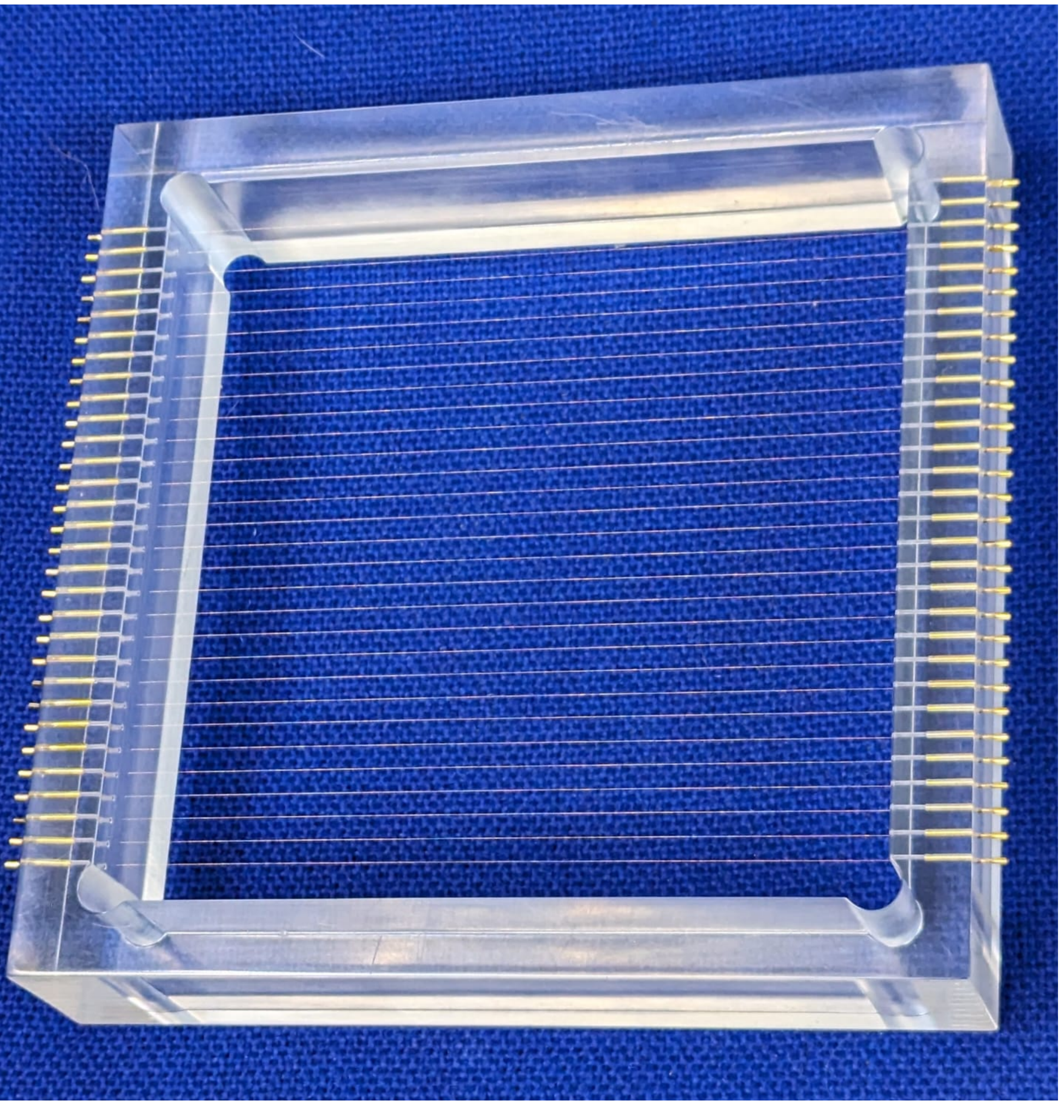
Roughness measured across the samples was averaged at Ra 0.25 µm therefore acceptable

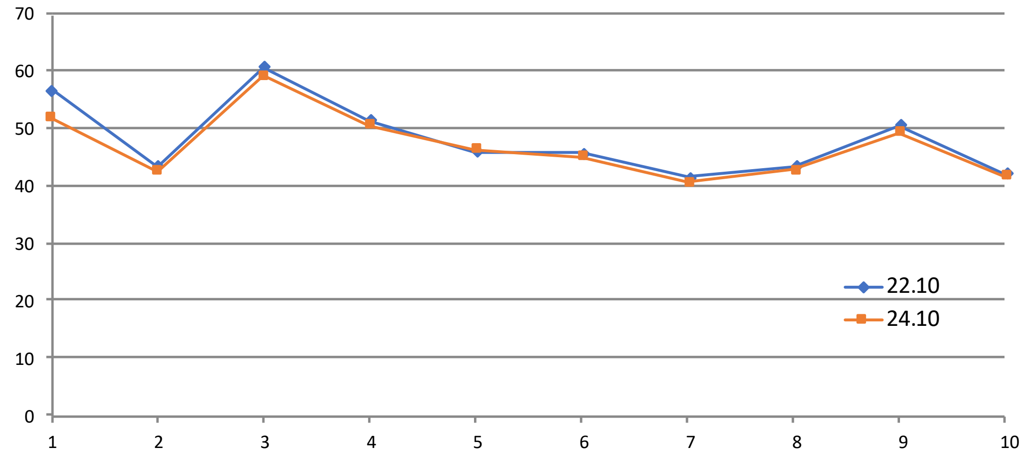
Expected value from the data sheet **0.25 µm, therefore acceptable**

TESTS OF CRIMPING PINS

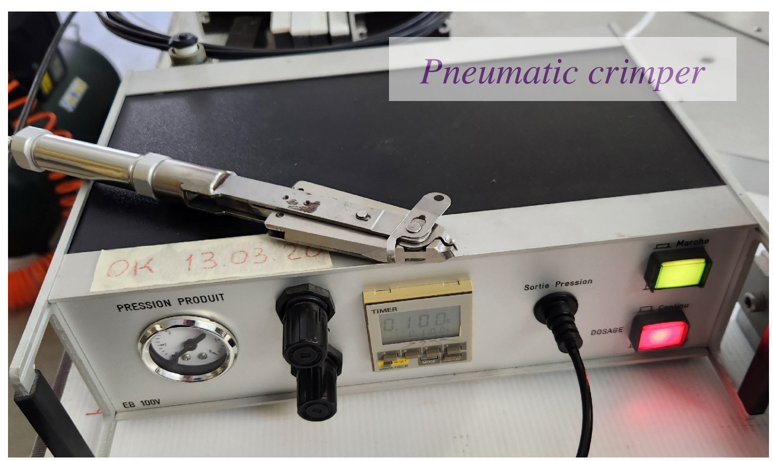
S. Romakhov (INP)

- ✦ *Setup for testing crimping pins based on machined plexiglass frame;*
- ✦ *Use 20 μm wire from LUMA and pneumatic crimping tool developed by ATLAS TRT for mass production;*
- ✦ *Better reproducibility and long term stability obtained with pneumatic crimping tool compared to manual one.*





Softness (thermal annealing) of base copper material main requirement for good and stable crimping results



SPS AND PS TESTBEAM EXPOSURES

K. Kuznetsova (UF)

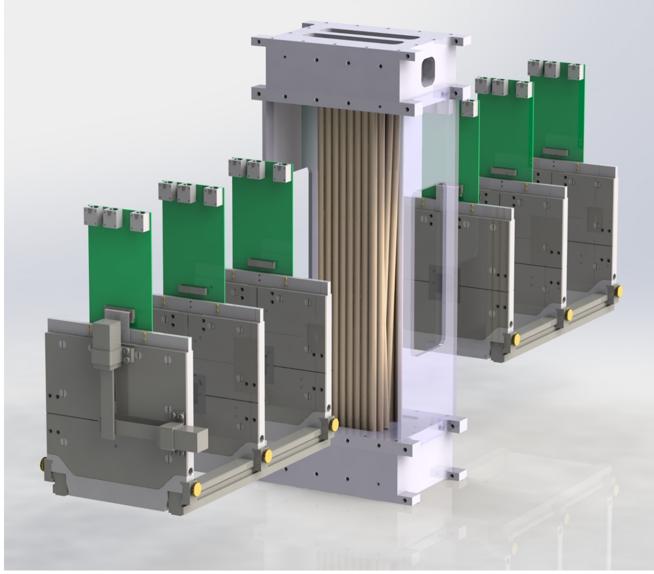
✦ *Testbeam exposure in H4 SPS at CERN (18 Sep. - 02 Oct. 2024)*:

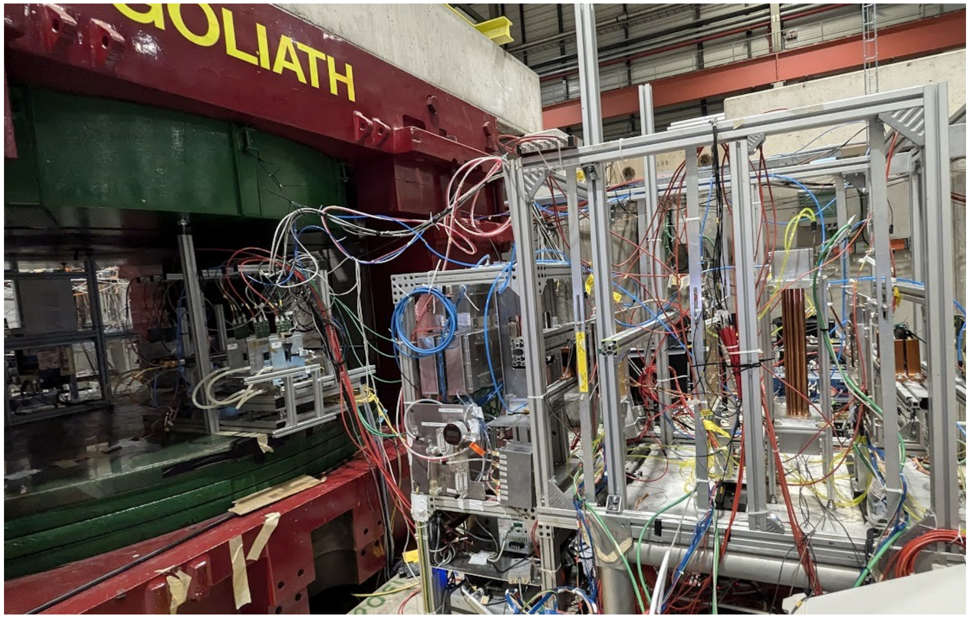
- *Straw tracker prototype with same geometry and straws as STT (5mm diameter, 20 μm wire);*
- *4 MicroMega external trackers (3X + 1Y) with pitch 250 μm;*
- *Coincidence of 2 scintillators for time reference;*
- *New high precision (∼6 μm) AZALEA silicon tracker (6 planes with 18.4 μm pitch).*

✦ *Runs with and without B field with two different readouts: VMM3a (Mu2e board) and ASD (ATLAS)*

$\Longrightarrow$ *Time & charge measurements vs. internal gas pressure, thresholds, and B*

Testbeam setup at H4 in Sep. 2024



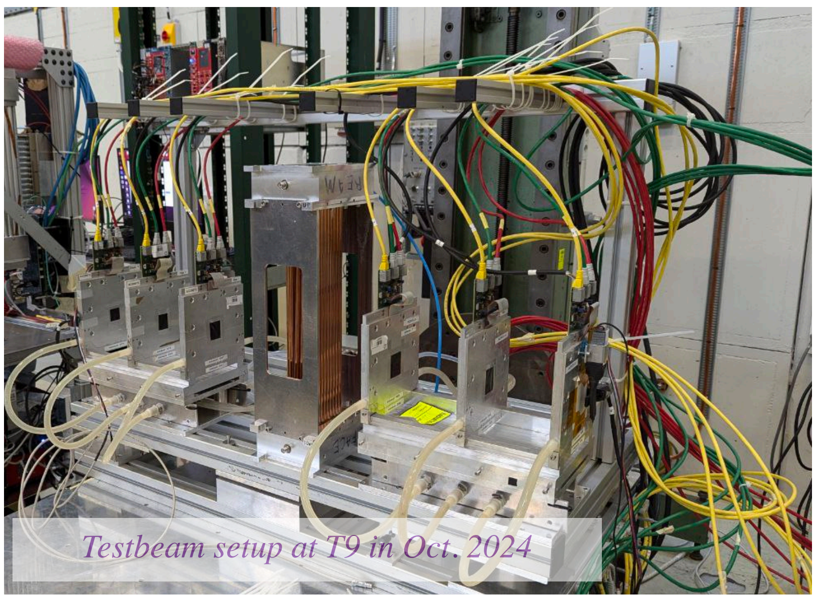


✦ *Testbeam exposure in T9 PS at CERN (2 Oct. - 9 Oct. 2024)*:

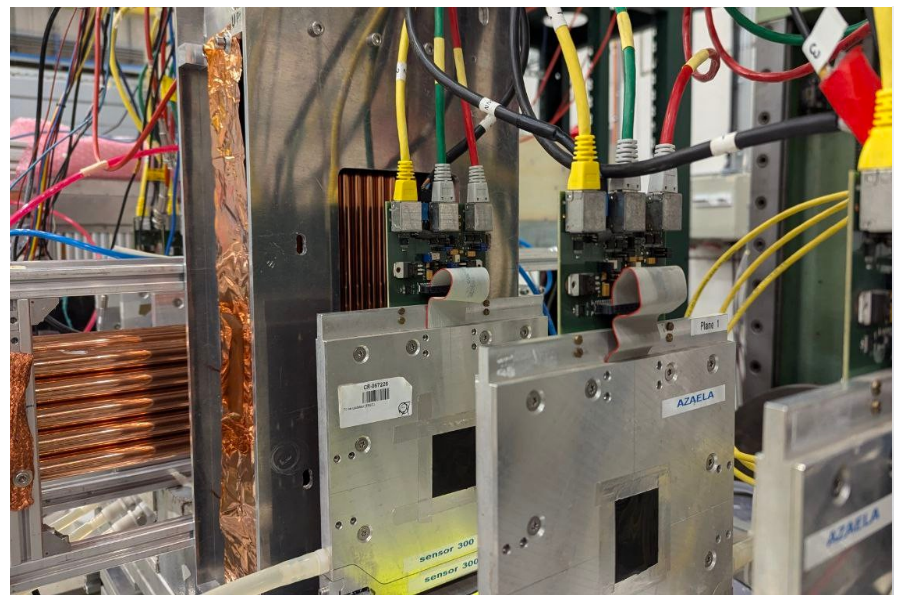
- *Straw tracker prototype with same geometry and straws as STT (5mm diameter, 20 μm wire);*
- *Coincidence of 2 scintillators for time reference;*
- *New high precision (∼6 μm) AZALEA silicon tracker (6 planes with 18.4 μm pitch).*

✦ *High (5 and 15 GeV) and low (≤ 2 GeV) energy runs with VMM3a, ASD, and custom readout*

$\Longrightarrow$ *Time & charge measurements for particle identification (e, π, μ, p) and tracking*

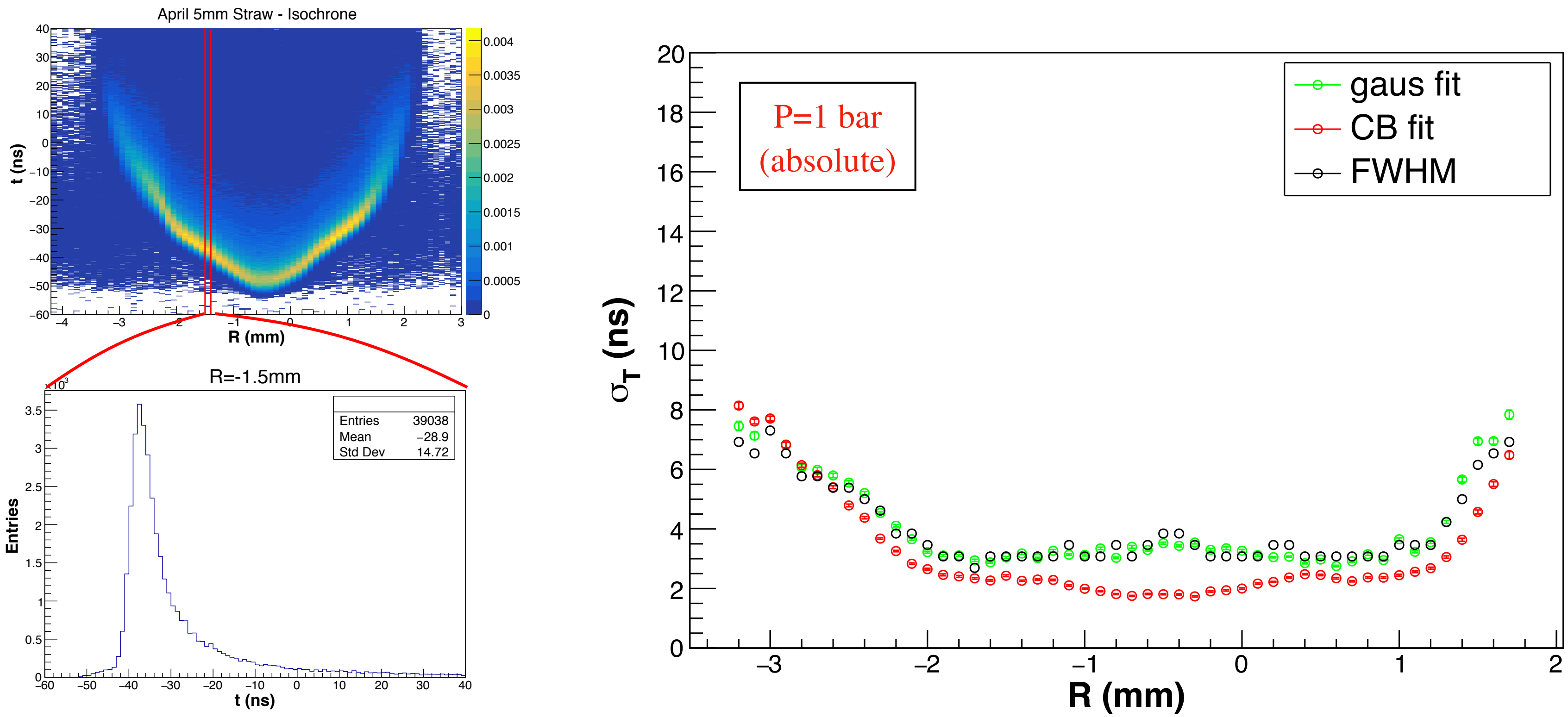


Testbeam setup at T9 in Oct. 2024



ANALYSIS OF TESTBEAM DATA

S. Pincha (IIT Guwahati)

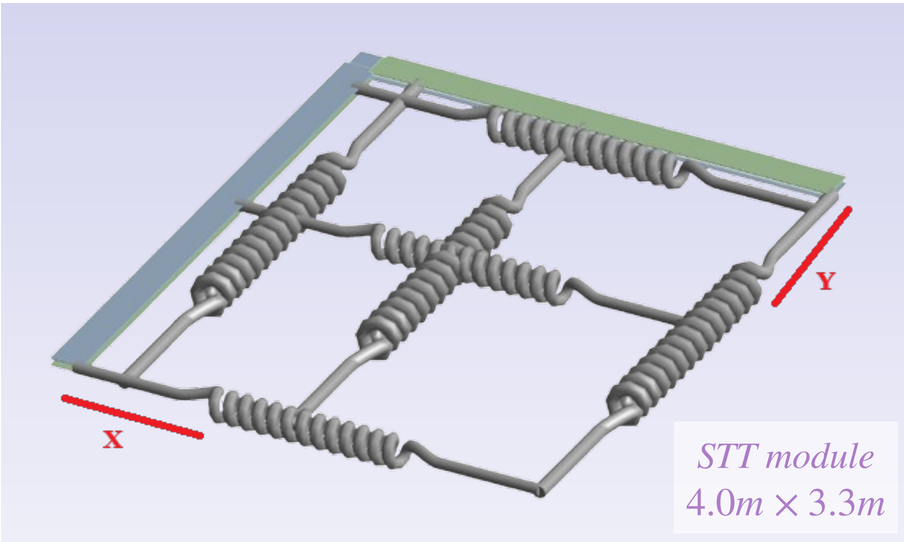


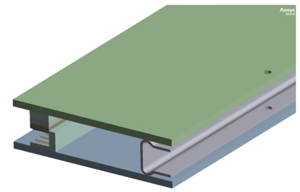
- ✦ *Tiger readout with 60 ns peaking time and 12 mV/fC gain (signal saturation);*
- ✦ *Preliminary single hit resolution ~200 μm, ongoing analysis to understand noise and uniformity*

$\Longrightarrow$ *Upper limit on hit resolution with non-optimal readout already satisfies STT requirement*

MECHANICAL ANALYSIS OF FULL-SCALE MODULES

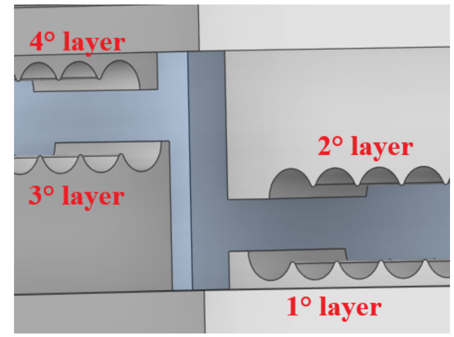
S. Mameli (INFN Pisa)





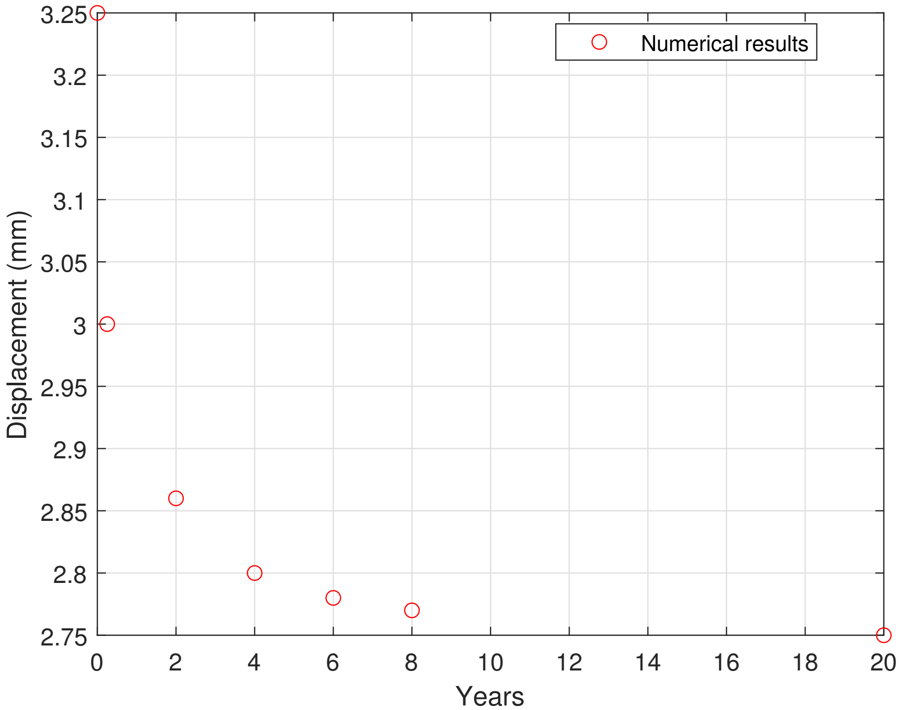
Layer	Deformation (mm)	Limit (mm)
1°	2.75	3.69
2°	2.75	3.69
3°	3.25	3.09
4°	3.25	3.09

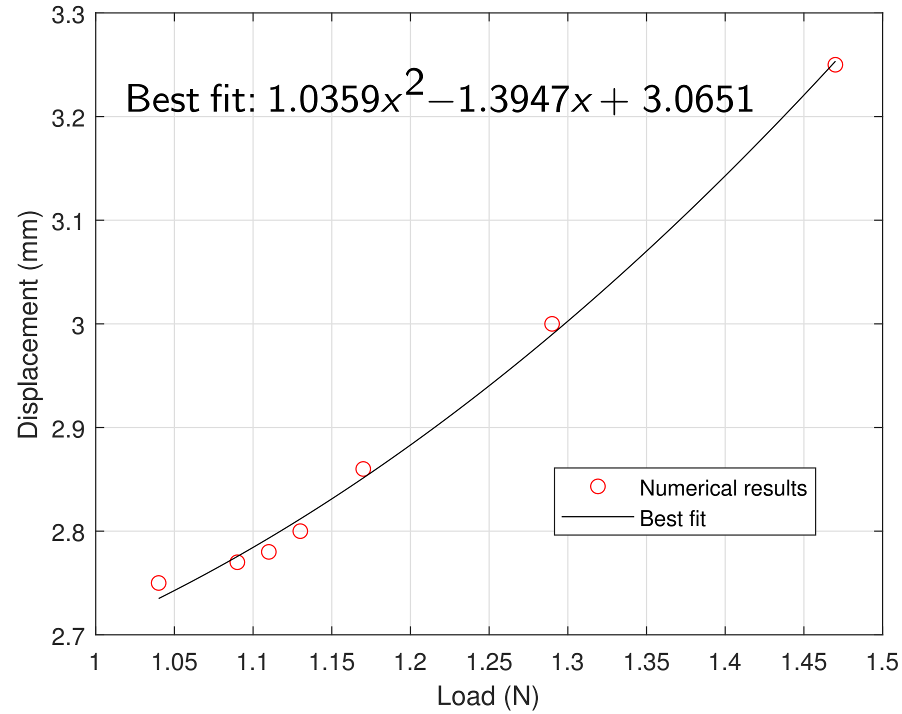
Total deformations are the sum at both straw ends.
Long straws are 1° and 2° layer. Short straws are 3° and 4° layer



- *Assembly procedure from mechanical analysis of full-scale module 4m×3.3m;*
- *Spring (rope) behavior of straws & wires: straw assembly pressure of 2.5 bar relative gives pre-tension load;*
- *Assembly pressure tuned to achieve force cancellation on frame in operating condition of 1 bar relative.*

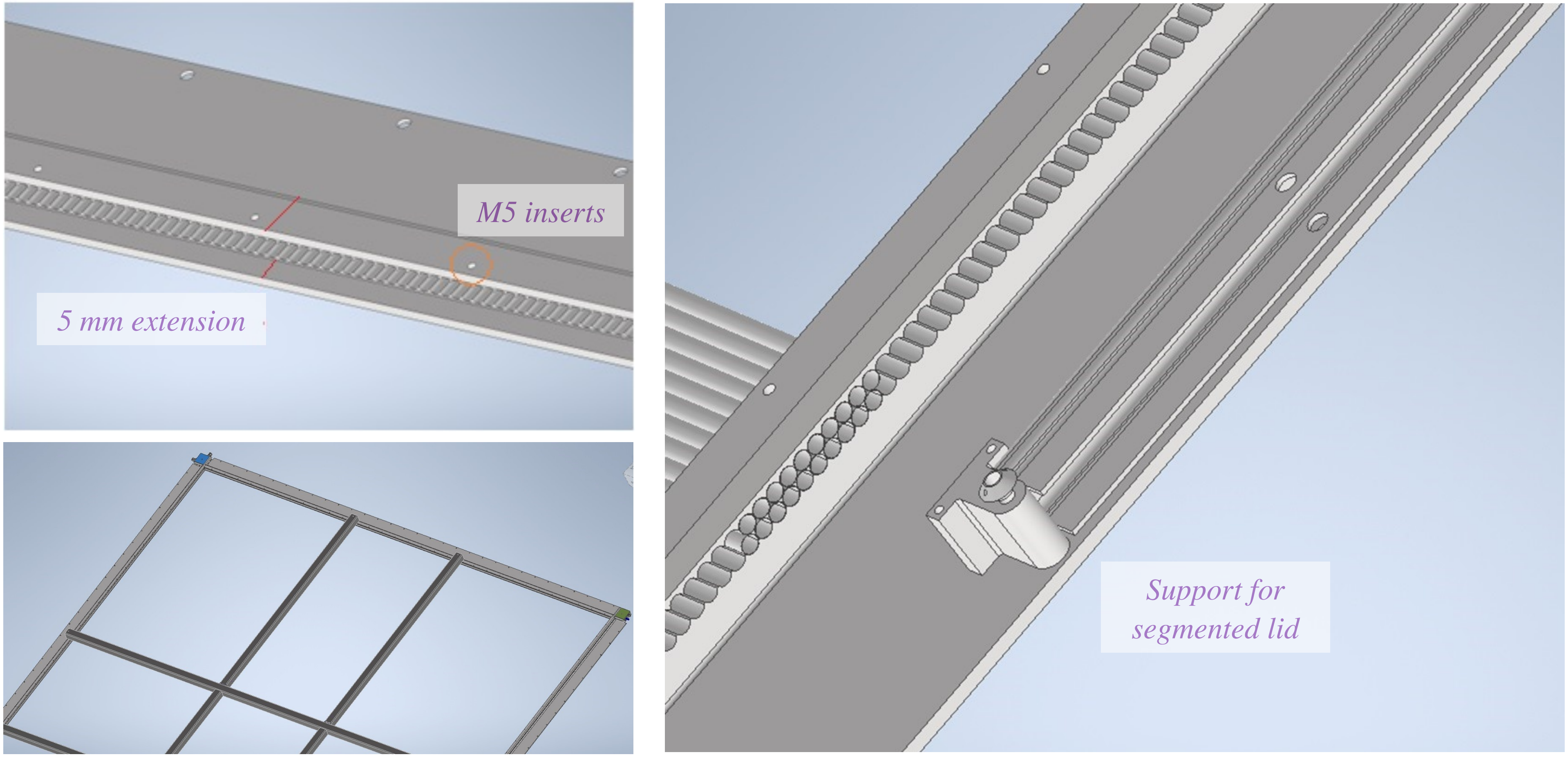
$\Longrightarrow$ *The C-fiber frame does not present risks regarding mechanical strength*





- *Study the effect of the straw relaxation, temperature, and humidity over a period of 20 years of data taking;*
- *Use the creep rate of straws measured at Duke University (Seog) to model straw relaxation vs. time;*
- *Mechanical analysis of full-scale modules vs. time assuming straws stored for 100 days before assembly.*

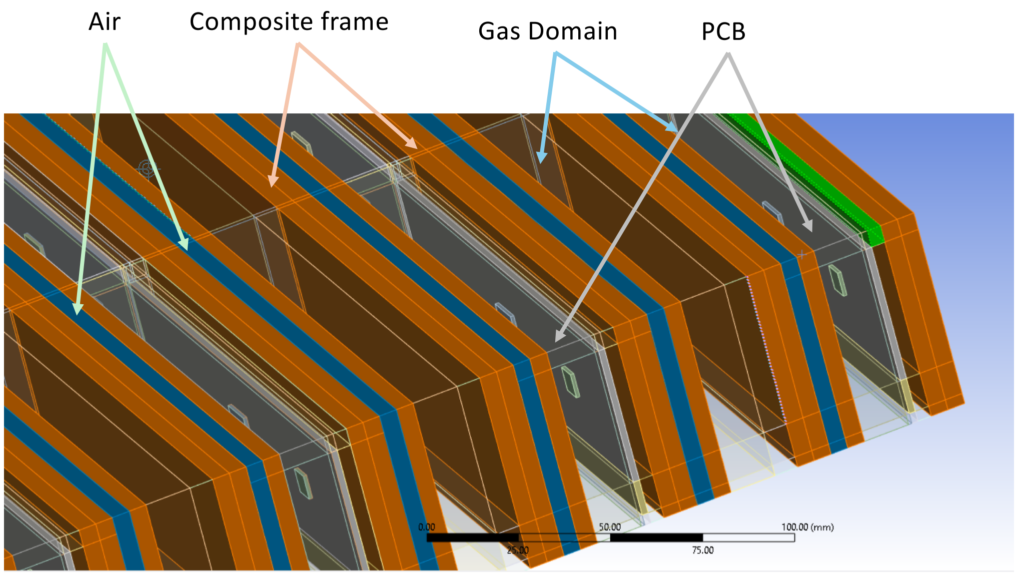
$\Longrightarrow$ *Compensation of straw relaxation by natural spring from internal overpressure*

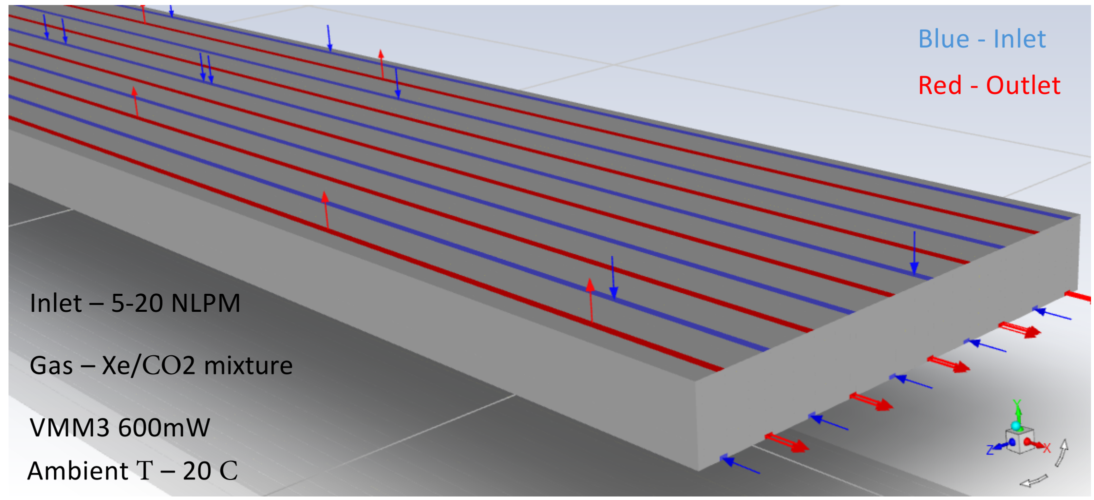


Final drawings of the full-scale 4m $\times$ 3.3m STT module (prototype in production)

THERMAL ANALYSIS OF SUPER-MODULE

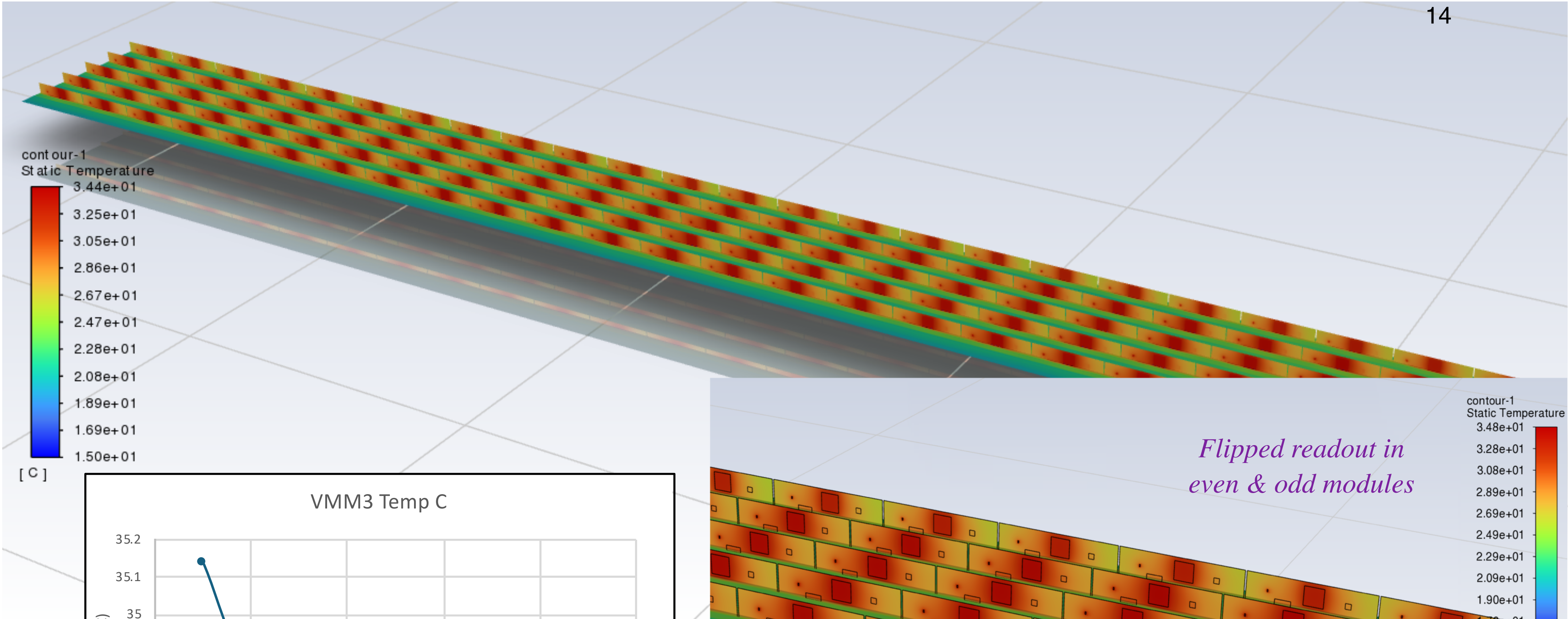
O. Kemularia (GTU)

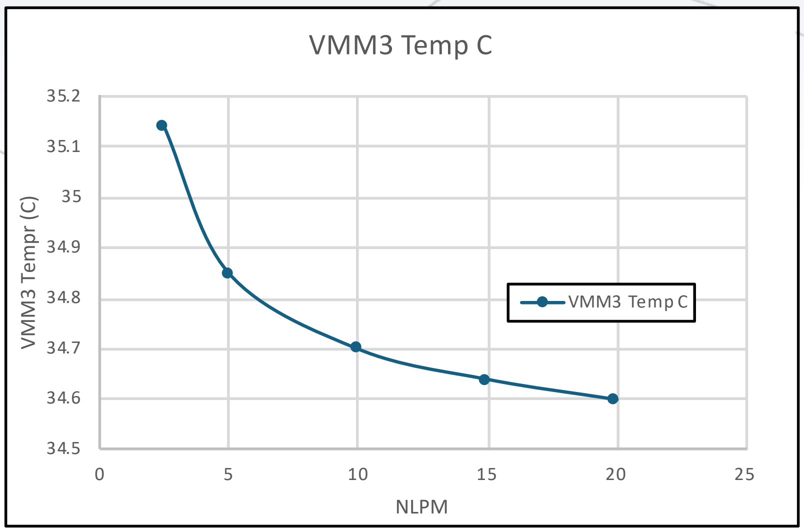


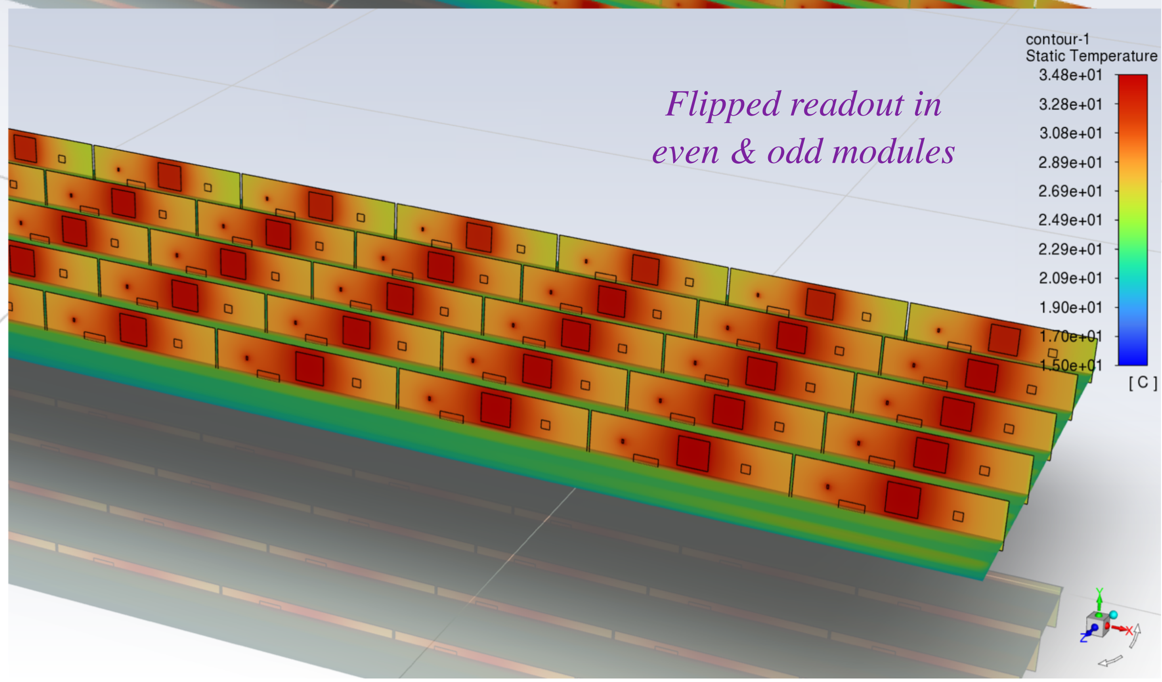


- *Thermal analysis of full-scale super-module assembly: 10 STT modules with 24×5 FE boards;*
- *Self-cooling design with expected total power dissipation about 0.80 W per board (VMM3a 0.60 W)*

$\Longrightarrow$ *Study cooling performance with initial VMM3a readout and realistic geometry*







Flipped readout in even & odd modules

Maximal temperatures on VMM3a chip well below 40^{0}C allow extended board lifetime

STT CONFIGURATION FOR INITIAL DATA TAKING

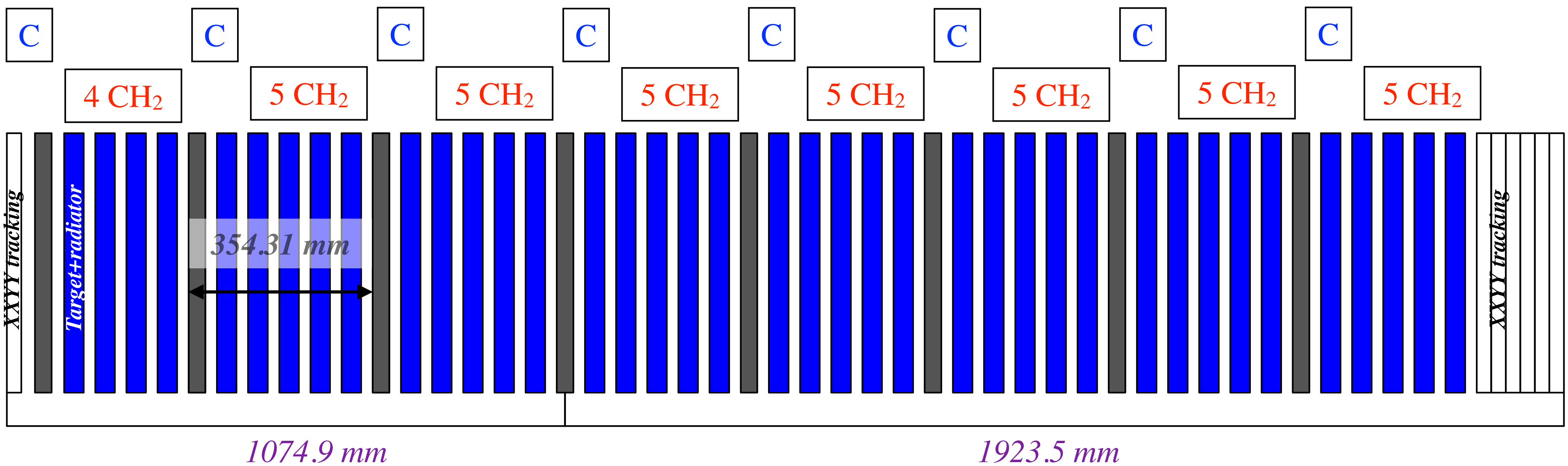
- ✦ *Use STT configuration with 54 modules as default for the initial SAND data taking*
  $\Longrightarrow$ *Simulation studies indicate that initial STT is consistent with SAND physics goals*

- ✦ *Backup readout with VMM3a* in direct output mode *with "external" ADC* (upgradeable)
  $\Longrightarrow$ *Readily available & tested with STT prototypes*

- ✦ *Reduction of project risks with initial STT without compromising physics potential*
  $\Longrightarrow$ *Keeping same construction schedule as before provides substantial contingency*

- ✦ *Define STT upgrade path after initial data taking with minimal detector modifications*
  $\Longrightarrow$ *Addition of the 32 missing modules and replacement of integrated readout*

INITIAL STT CONFIGURATION



Initial STT configuration with backup integrated VMM3a readout:
39 CH_2 modules with target+radiator (37.718 mm)
8 C (graphite) modules (32 mm)
7 tracking module XXYY (28 mm)
Total 54 modules, 8+1 super-modules

Item description	Initial STT	Complete STT
Number of straws	136,192	219,334
Total straw length (km)	430	700
Straw outer diameter (mm)	5	5
Average straw length (m)	3.16	3.19
Maximal straw length (m)	3.75	3.75
Total straw film area (m^2)	6,751	10,990
Total straw internal volume (m^3)	8	14
Total detector length (mm)	2,998	2,998
Average density (g/cm^3)	0.11	0.17
Average radiation length X_0 (m)	4.3	2.8
Fiducial (20 cm) C mass (t)	0.544	0.544
Fiducial (20 cm) CH_2 mass (t)	2.334	3.863
Total number of modules	54	86
Number of modules with CH_2 target & radiator	39	48
Number of modules with CH_2 target only	0	23
Number of modules with graphite target	8	8
Number of tracking modules (no target)	7	7
Number of straw planes	232	344
Number of modules per super-module	6	10
Number of super-modules	8+1	8+1
Number of FE boards	2,128	3,427
Modularity of FE boards (channels)	64	64
ASIC in FE boards	VMM3a	Custom
Number of HV channels	108	172
Number of LV channels	126	190
Number of DAQ/DTS interface boards	18	18
Number of LV distribution boards	18	18

Summary of key numbers for the initial and complete STT configurations

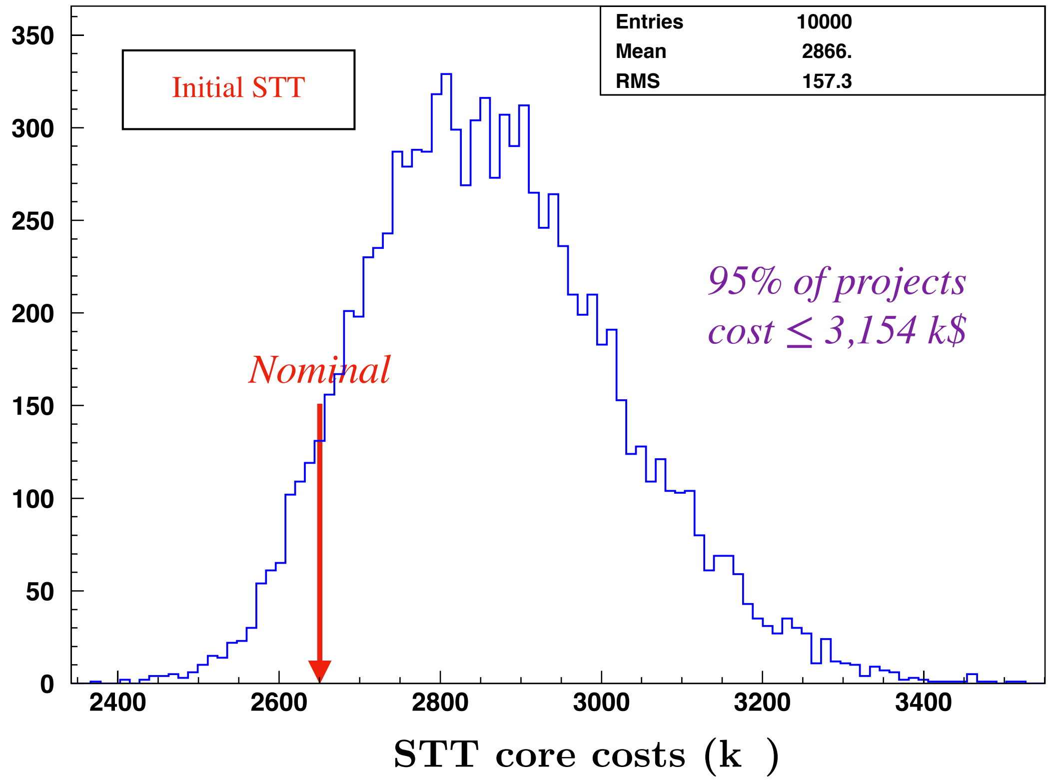
CORE COSTS FOR THE INITIAL STT

ITEM		COST	SUPPLIER/SOURCE	QUOTE	DELIVERY TIME	VALIDATED
Procure mylar film (19 μm, double 70 nm Al)	$	147,189	Fraunhofer FEP, Germany	Mar-24	3 months	✓
Procure endplugs (PC transparent)	$	7,992	CLM Co. LTD, China	Apr-24	45 days	✓
Procure wire spacers (PC black)	$	20,459	GJT Co. LTD, China	Apr-24	45 days	✓
Procure crimping pins (1.2 mm gold plated)	$	13,375	SZLE Co. LTD, China	Feb-24	4 weeks	✓
Procure anode wire (W/Re 20 μm)	$	201,369	Luma metall AB, Sweden	Feb-24	14 weeks	✓
Procure C-fiber frames	$	581,073	DSNM Co. LTD, China	Jul-24	5 months	
Procure Al corner blocks	$	1,296	PIM Co. LTD, China	Jun-24	2 weeks	✓
Procure gas and electrical connectors	$	5,337	CERN store, Switzerland	Jun-24	4 weeks	✓
Procure STT tools	$	340,000	JINR/GTU facilities			
Procure miscellaneous items & consummables	$	125,000	STT prototypes			
Procure gas system (Xe/CO_2 + Ar/CO_2 + cooling)	$	525,000	CERN DT, Switzerland	Jul-24	6 months	✓
Procure BOPP radiator film (18 μm, 3.3 m)	$	4,050	HMNM Co. LTD, China	May-24	8 weeks	✓
Procure CH_2 targets (HDPE tiles)	$	10,058	HJM Co. LTD, China	Jun-24	8 weeks	
Procure graphite targets (isostatic IFS-H7 tiles)	$	15,066	CFCC Co. LTD, China	Mar-24	8 weeks	✓
Procure C-fiber frames for targets/radiators (T700)	$	47,504	HRC Co. LTD, China	Jun-24	1 month	✓
Procure rods+nuts for super-module assembly	$	3,237	PIM Co. LTD, China	Jul-24	3 weeks	✓
Procure VMM3a ASIC chips (existing masks)	$	195,000	Globalfoundries, USA	Jun-24	8 months	✓
Procure VMM3a ASIC packaging	$	109,000	Muse semiconductor, USA	Jun-24	5 months	✓
Procure integrated readout boards (MCU, ADC, SSR)	$	92,298	PCBWay, China	Jul-24	7 weeks	✓
Procure flexible Kapton PCBs (PCIe connector)	$	20,065	PCBWay, China	Jun-24	36 days	✓
Procure HV components	$	38,012	CAEN, Italy	Jun-24	3 months	✓
Procure LV components	$	63,271	CAEN, Italy	Jun-24	4 months	✓
Procure cables & connectors	$	23,223	CERN store, Switzerland	Jul-24	4 months	✓
Procure LV distribution boards	$	18,000	ATLAS NSW			
Procure DAQ/DTS interface boards	$	45,000	DUNE DAQ group			
TOTAL	**$**	**2,651,875**				

Average cost per module: $49,109

Average cost per channel: $19

STT COST CONTINGENCY

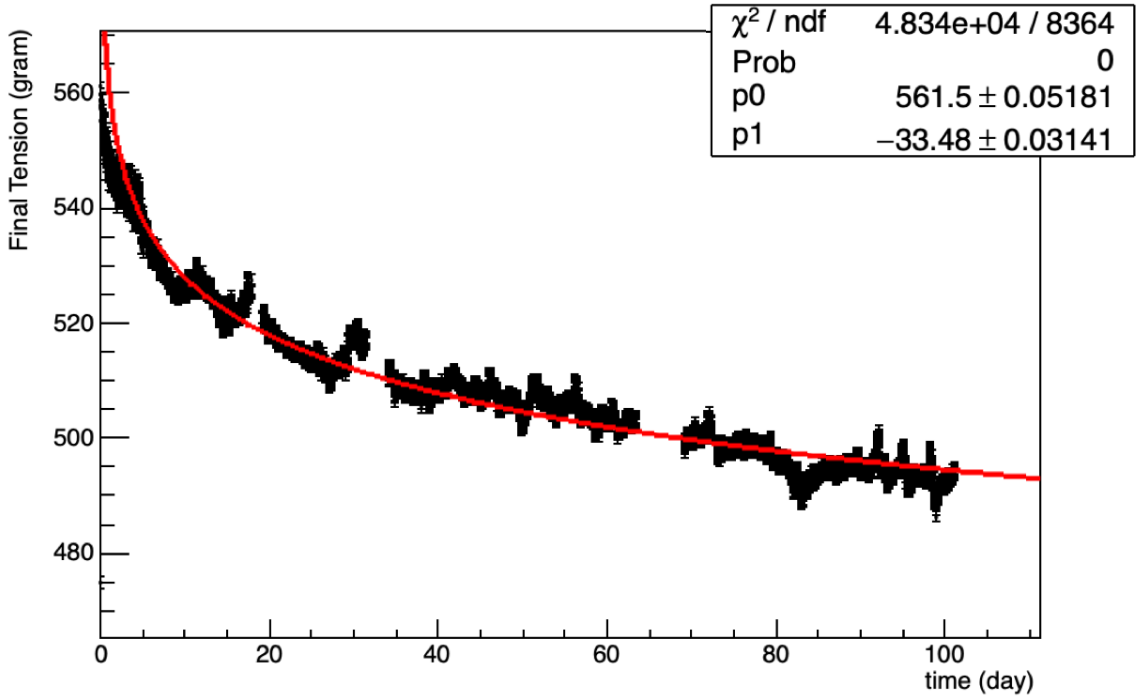


MC simulation of 10,000 projects with cost variations based on STT risk register
Define cost contingency covering 95% of simulated projects

CORE COSTS FOR THE STT UPGRADE

ITEM	COST	SUPPLIER/SOURCE	QUOTE	DELIVERY TIME	VALIDATED
Procure mylar film (19 µm, double 70 nm Al)	$ 92,421	Fraunhofer FEP, Germany	Mar-24	3 months	✓
Procure endplugs (PC transparent)	$ 5,658	CLM Co. LTD, China	Apr-24	45 days	✓
Procure wire spacers (PC black)	$ 16,405	GJT Co. LTD, China	Apr-24	45 days	✓
Procure crimping pins (1.2 mm gold plated)	$ 8,165	SZLE Co. LTD, China	Feb-24	4 weeks	✓
Procure anode wire (W/Re 20 µm)	$ 126,441	Luma metall AB, Sweden	Feb-24	14 weeks	✓
Procure C-fiber frames	$ 321,664	DSNM Co. LTD, China	Jul-24	5 months	
Procure Al corner blocks	$ 768	PIM Co. LTD, China	Jun-24	2 weeks	✓
Procure gas and electrical connectors	$ 3,162	CERN store, Switzerland	Jun-24	4 weeks	✓
Procure CH_2 targets (HDPE tiles)	$ 10,942	HJM Co. LTD, China	Jun-24	8 weeks	
Procure C-fiber frames for targets/radiators (T700)	$ 30,360	HRC Co. LTD, China	Jun-24	1 month	✓
Procure rods+nuts for super-module assembly	$ 2,065	PIM Co. LTD, China	Jul-24	3 weeks	✓
Custom ASIC design (64 channels, 180 nm)	$ 600,000	DG Circuits, USA	May-24	12 months	✓
Procure ASIC prototypes (MPW+packaging)	$ 41,000	Muse semiconductor, USA	May-24	10 weeks	✓
Procure ASIC production mask	$ 105,000	Muse semiconductor, USA	May-24	4 weeks	✓
Procure ASIC chips (6 wafer pilot)	$ 9,000	Muse semiconductor, USA	May-24	6 weeks	✓
Procure ASIC packaging	$ 30,000	Muse semiconductor, USA	May-24	2 weeks	✓
Procure integrated readout boards (MCU, ADC, SSR)	$ 148,639	PCBWay, China	Jul-24	7 weeks	✓
Procure HV components	$ 14,263	CAEN, Italy	Jun-24	3 months	✓
Procure LV components	$ 23,327	CAEN, Italy	Jun-24	4 months	✓
Procure cables & connectors	$ 13,762	CERN store, Switzerland	Jul-24	4 months	✓
TOTAL	**$ 1,603,044**		**Average cost per module:**	**$50,095**	
(Without ASIC design and mask: $ 725,750)			**Average cost per channel:**	**$19**	($9)

OPERATING CONDITIONS: CREEP RATE

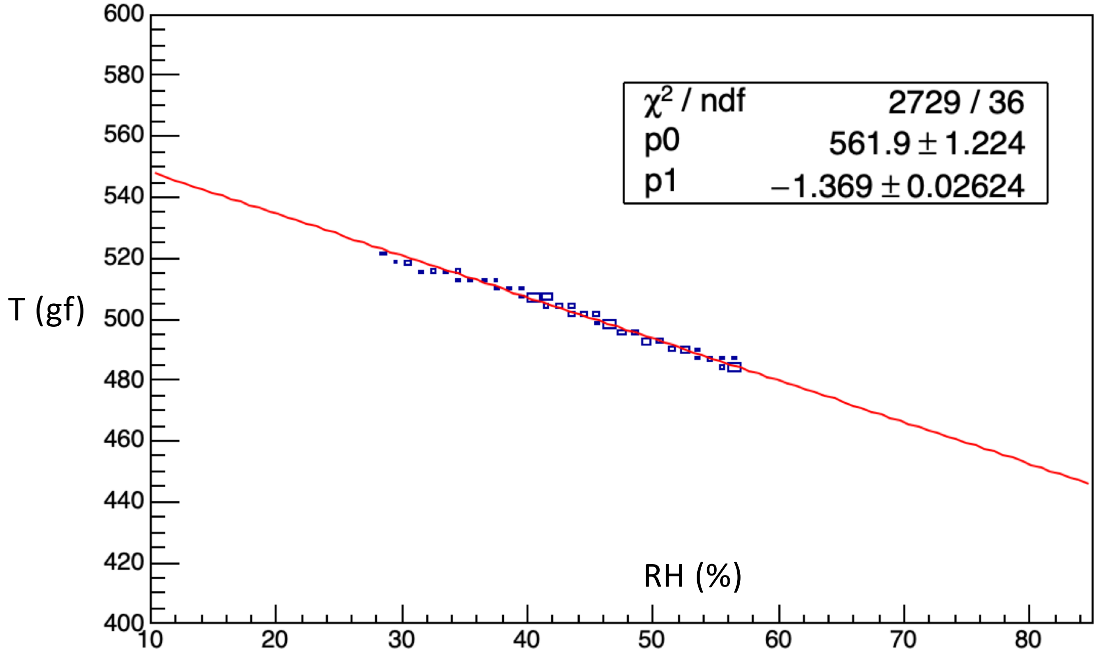


- *Creep rate of straws from the CERN prototype (produced by GTU) measured at Duke University (Seog);*
- *Fit logarithmic function $p_0 + p_1 \log_{10}(t)$ with t in days: normalized slope $p_1 = 0.06$*
- *Expected maximal variation in straw elongation for 3.75m straws after 20 years at operating 2 bar:*

$$\left[1 - \frac{1 - 0.06\log_{10}(7300)}{1 - 0.06\log_{10}(100)}\right] 2.8\ mm = 0.36\ mm$$

$\Longrightarrow$ *Operating conditions should correspond to variations in straw elongation $\lesssim 0.36\ mm$*

OPERATING CONDITIONS: RELATIVE HUMIDITY



- *Humidity dependence of straws from the CERN prototype measured at Duke University (Seog);*
- *Linear fit with respect to relative humidity gives a humidity coefficient* $0.8 \times 10^{-6}\ cm/cm/\%\,RH$
- *Expected maximal variation in straw elongation for 3.75m straws and a variation of 50% RH:*

$$0.8 \times 10^{-5} mm/cm/\%\,RH \times 375\ cm \times 50\,\%\,RH = 0.15\ mm$$

$\Longrightarrow$ *Variations of straw length due to relative humidity well below expected creep rate*

OPERATING CONDITIONS: TEMPERATURE

- *Temperature dependence of straws from CTE coefficient of base Mylar film:*

$$17 \times 10^{-3}\, mm/m/{}^0C \times 3.75\, m = 0.064\, mm/{}^0C$$

$\Longrightarrow$ *Control temperature to $\pm 5^0 C$ to keep variations below 20y creep rate $\lesssim 0.36$ mm*

- *Straw elongations from both temperature and humidity were found (Mu2e) to be reversible once temperature and humdity return to nominal*

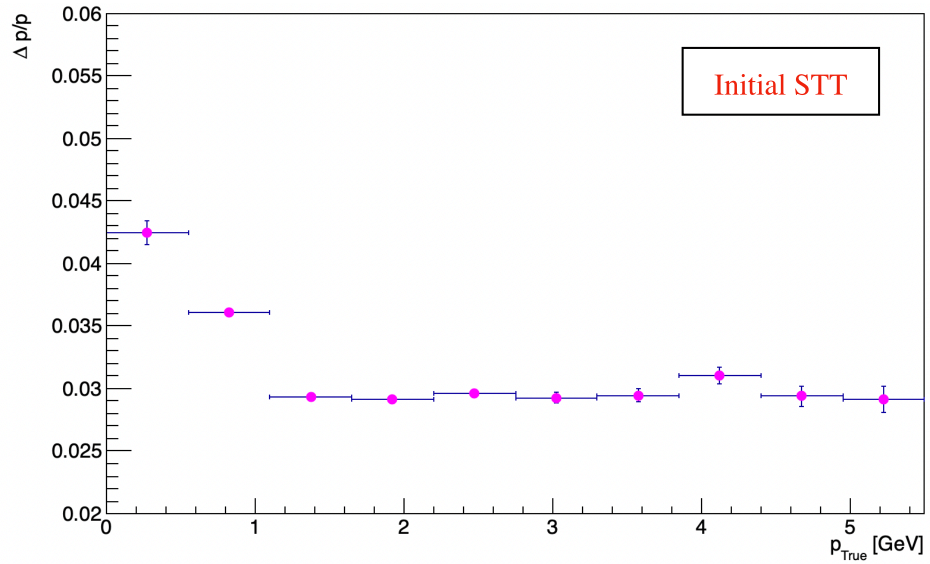
- *Internal overpressure (straws operated at 2 bar absolute) provides natural spring mechanism compensating automatically for variations of straw elongation within elastic limit*

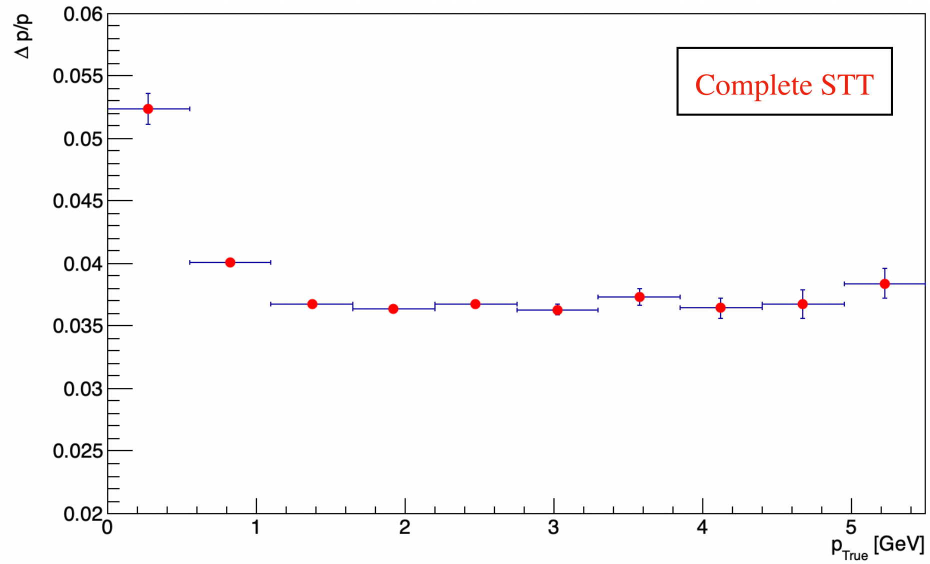
- *Thermal analysis of super-modules indicates that a variaton of the ambient temperature within $5^0 C$ still compatible with maximal chip temperatures $\sim 40^0 C$*

PERFORMANCE OF INITIAL STT

N. Talukdar (USC)

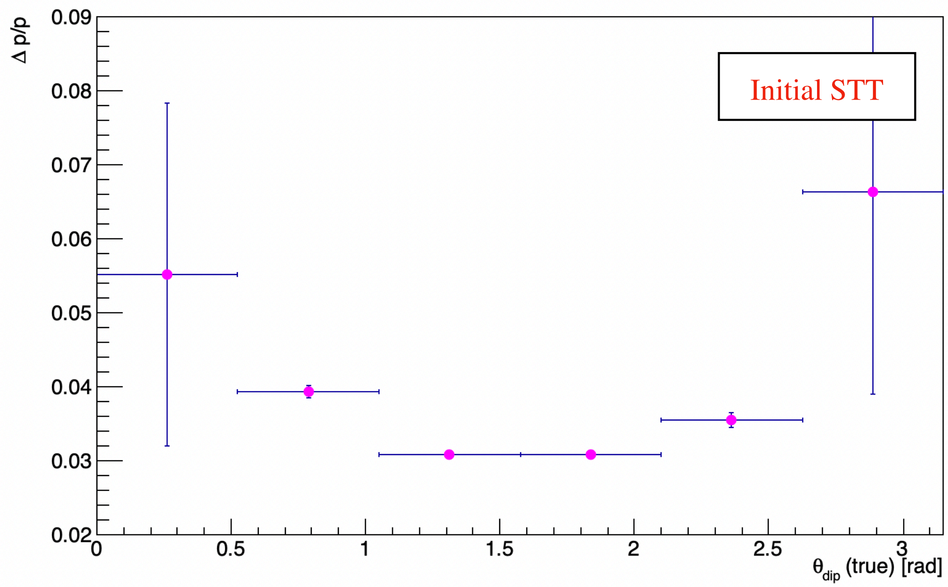
- *Full track reconstruction based on Kalman filter using drift circles implemented*;
- *Minimal cuts applied*: *true vertex in FV (20cm) & ≥ 4 hits in the YZ bending plane*.

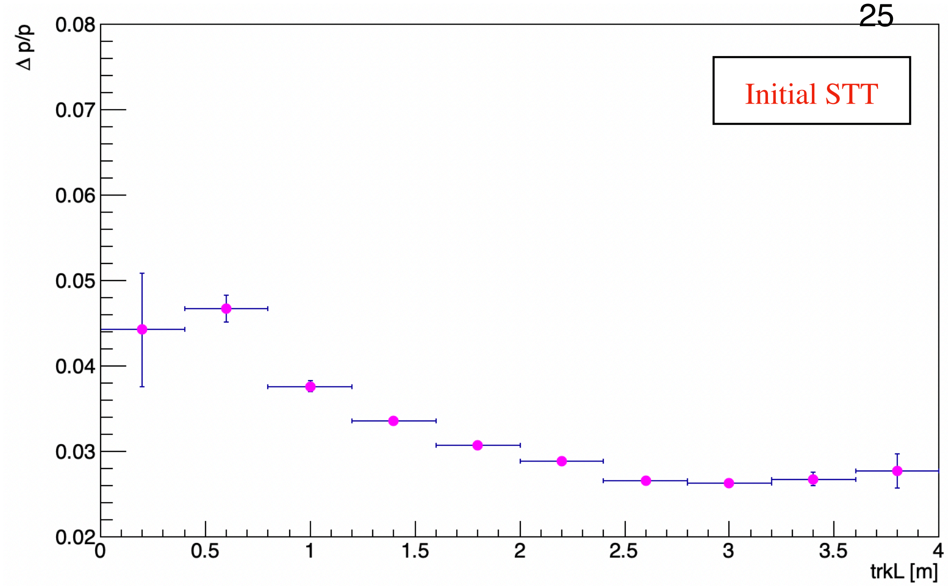


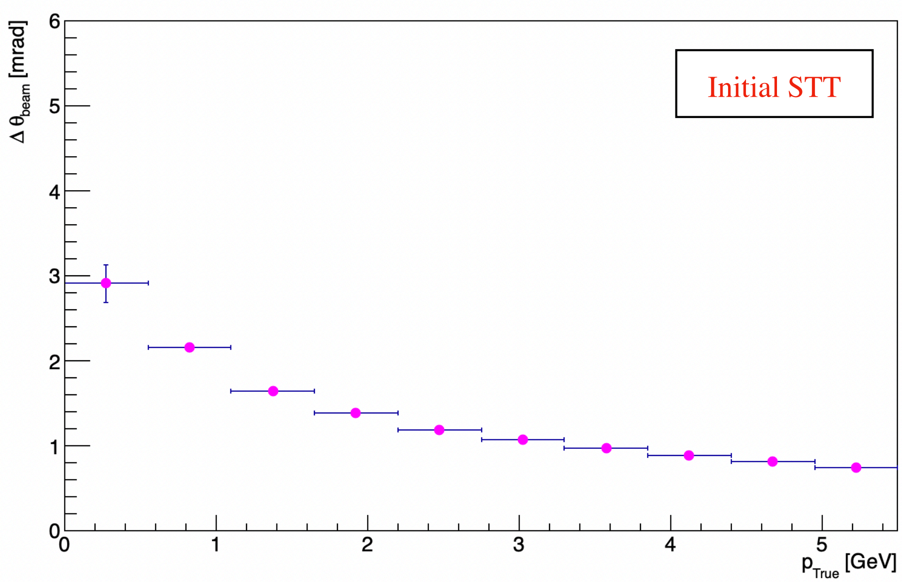


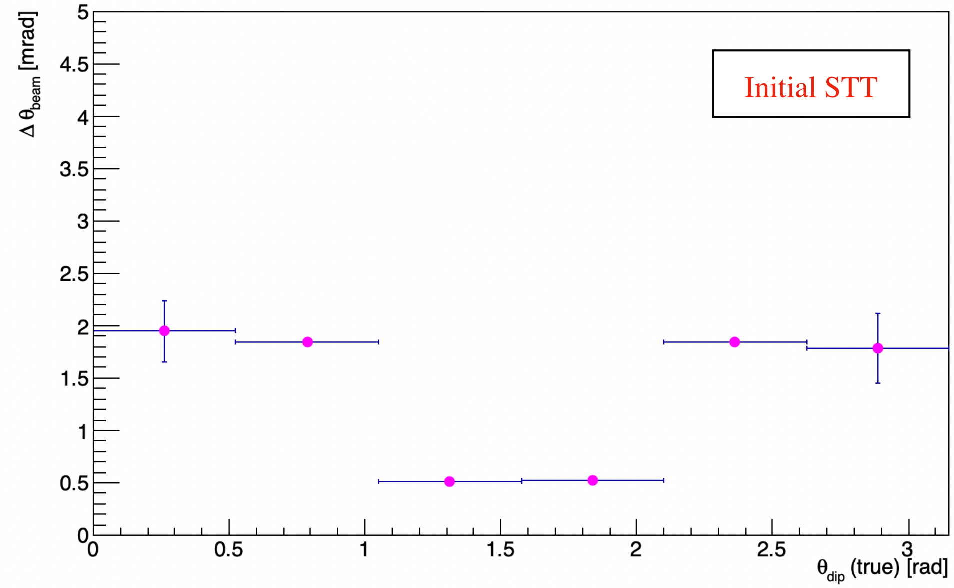
μ from inclusive ν_μ CC FHC

	Acceptance	Reconstructed	Reconstruction efficiency
Initial STT	99.4%	99.1%	99.7%
Complete STT	98.8%	98.2%	99.1%









Initial STT has improved momentum and angular resolution

Backup slides

CORE COSTS AND RISK REGISTER

✦ *Comprehensive list of components based on STT prototypes & advanced design stage:*

- *Quotes from multiple vendors obtained for each item;*
- *Selection of main supplier (+ backup one) for each item;*
- *Qualification of components with sample tests & prototypes.*

$\Longrightarrow$ *Realistic estimate of STT core costs*

✦ *Pre-production procurements from selected vendors for Pisa & full-scale STT prototypes*

✦ *Identified 22 STT risks including threats, opportunities, and uncertainties:*

- *Technical, management, and external risks following Fermilab Risk Breakdown Structure (RBS);*
- *Defined mitigations and responses for each STT risk;*
- *Initial implementation into standard format of Fermilab risk register with corresponding metadata.*

$\Longrightarrow$ *Preliminary evaluation of probability and project impact for each STT risk*

Risk ID (placeholder)	Risk title	Risk area (RBS)	Prob.	Impact	Rank	Mitigations and Responses
RT-131-ND.05-501	Delay in custom ASIC development for STT	Management Risk / Planning	10%	Low	Low	Complete backup readout based on existing VMM3a available, which satisfies the main STT requirements. The ASIC development is not on critical path, since the backup readout can be used for STT construction/testing and for initial data taking. The modular design of the readout boards with PCIe connector allows easy replacements/upgrades.
RT-131-ND.05-502	Delay of the full-scale STT prototype	Management Risk / Planning	35%	Moderate	Medium	Schedule contingency allowed up to the end of 2025, with final engineering proceeding partially in parallel with the preparation of the production sites. Early procurement and test of main components required for full-scale prototypes already started in 2024.
RT-131-ND.05-503	Delay in module assembly during the STT construction	Management Risk / Planning	20%	Moderate	Medium	The STT design makes each individual module functionally independent, allowing the operation of the detector with less modules. A backup STT configuration with 54 modules instead of 86 is foreseen, which fulfills the main physics scopes and can be used at the beginning of the data taking while staging the remaining modules.
RT-131-ND.05-504	Inconsistent quality across the STT production sites	Technical Risk / Quality	20%	Low	Low	Strict QA/QC procedures and acceptance criteria will be required across all production sites. A production manager will coordinate the production and QA/QC at sites, including verifications by inspections. Common purchases of the detector components required for assembly and a joint training of the assembly personnel are foreseen. In addition, the backup STT configuration can be produced at a single assembly site equipped with 2-3 assembly tables.
RT-131-ND.05-505	Difficulties in procurement of C-fiber frames for STT	External Risk / Vendors	35%	Low	Low	Verification of quality of prototype C-fiber frames. Qualification of different vendors during prototyping activities and selection of backup vendors.
RT-131-ND.05-506	Difficulties in the procurement of W/Re wire for STT	External Risk / Vendors	20%	Low	Low	Qualification of different vendors during prototyping activities and selection of backup vendors. Quality tests of wire samples from all selected vendors at CERN.
RT-131-ND.05-507	Problems encountered during tests of custom ASIC prototypes	External Risk / Industry	20%	Low	Low	Development of custom ASIC for STT based upon sub-circuits and functions largely inherited from the well-established NRL and VMM3a chips, which have been extensively tested with STT prototypes. Direct involvement of the designer of NRL and VMM3a chips in the development of the custom ASIC for STT.
RT-131-ND.05-508	Problems with the tooling for the assembly of STT modules	External Risk / Facilities	20%	Moderate	Medium	Construction and test of STT full-scale prototype ("module 0") will be used to validate the tooling and identify potential issues. Initial tooling from the existing ones developed for the COMPASS straw tracker with modules of similar size and geometry as in STT.
RO-131-ND.05-509	Use of boats and standard drums for the film production	External Risk / Vendors	20%	Low	Low	The selected vendor proposed a feasibility study to evaluate if the PET film with double side coating of 70 nm Al can be produced with boat evaporation and a standard cooling drum without film damages or wrinkles.
RO-131-ND.05-510	Reuse of some components from the gas system of the ATLAS TRT for	External Risk / Vendors	35%	Low	Low	The CERN gas group provided a list of components from ATLAS TRT which could be reused for STT after inspection of the TRT gas system in operation. The reuse of the components for STT has been already agreed with the management of the ATLAS TRT. The refurbishing of the relevant ATLAS TRT components is being studied.
RU-131-ND.05-511	Price variations from market changes	External Risk / Market	20%	Low	Low	For most items obtained quotes from multiple vendors and monitor costs over time. The contracts for the purchase of the main components are expected to be signed by 2026.

Risk ID (placeholder)	Risk title	Risk area (RBS)	Prob.	Impact	Rank	Mitigations and Responses
RU-131-ND.05-512	Foreign exchange rate fluctuations	External Risk / Market	20%	Low	Low	STT core costs based on quotes from a mixture of currencies from selected vendors in different countries. The procurement of most components should occur by 2026, thus reducing long-term uncertainty in exchange rate fluctuations.
RT-131-ND.05-513	Delay in the availability/ approval of funding / resources	Management Risk / Funding and Resources	35%	Moderate	Medium	Value engineering resulted in a reduction of core costs for the minimal backup STT configuration. Multiple funding proposals for STT have been submitted to funding agencies by participating institutions, exceeding the estimated core costs. A firm support by the DUNE management is required.
RT-131-ND.05-514	Damage of STT modules during shipping to Fermilab	Management Risk / Logistics	5%	Low	Low	The STT modules will be shipped as super-module units via water/ground transportation. We will take advantage of the shipping experience of similar COMPASS modules from JINR to CERN. We will engage an engineering/shipping firm from an early stage of the production process.
RT-40ND-ND.05-515	Gas leakage in a STT module	Technical Risk / Reliability and Performance	1%	Low	Low	Each STT half-module (XX or YY straw double layer) is fed by independent parallel gas input/output lines, with an individual valve and pressure sensor for each module. Depending on the type of leak detected the affected half-module can be either moved from the Xe/CO_2 to the Ar/CO_2 distribution, or disconnected altogether from the gas distribution, without stopping the STT data taking. The STT design allows to fix leakages during one of the beam-off periods.
RT-40ND-ND.05-516	Failure of STT gas system including pump	Technical Risk / Reliability and Performance	1%	Low	Low	A second backup pump is included into the STT gas system allowing a quick switch without major losses of data taking while the faulty pump is being repaired.
RT-40ND-ND.05-517	Leakage/breakage of STT straws	Technical Risk / Reliability and Performance	<0.01%	Low	Low	Strict QA/QC protocols and acceptance criteria will be used during the straw production, similar to the ones implemented for the NA62 straw tracker, in which no straw breakage was observed over many years of operation. The quality of the straw welding has been validated with dedicated tests at CERN.
RT-40ND-ND.05-518	Failure of a STT integrated readout board	Technical Risk / Reliability and Performance	1%	Low	Low	The STT readout boards are connected in parallel with a robust BUS interface so that the failure of a readout board does not affect the remaining ones. The failure of a readout board implies the temporary loss of only 64 straws, corresponding to 0.03% of the detector, and does not require to stop the data taking. The affected board can be safely replaced during one of the beam-off periods.
RT-40ND-ND.05-519	High voltage short circuit/failure	Technical Risk / Reliability and Performance	1%	Low	Low	Each STT readout board is equipped with a Solid State Relay (SSR) allowing to remotely disconnect HV in case an overcurrent is detected. The effect of a HV short circuit/failure is a temporary loss of 64 straws, corresponding to 0.03% of the detector, and does not require to stop the data taking.
RT-40ND-ND.05-520	Low voltage short circuit/failure	Technical Risk / Reliability and Performance	1%	Low	Low	Each STT readout board is equipped with surge protections and LV fuses confining the effect of a LV short circuit within the individual board. The effect of a LV short circuit/failure is a temporary loss of 64 straws, corresponding to 0.03% of the detector, and does not require to stop the data taking.
RT-40ND-ND.05-521	Broken wire in a STT straw	Technical Risk / Reliability and Performance	<0.1%	Low	Low	The breakage of a wire in a STT straw requires to temporarily disconnect the corresponding readout board via the SSR, taking offline 64 straws. The broken wire is self-contained within the straw and will not be removed, the affected channel will be permanently disconnected by removing the HV resistor on the board during one of the beam-off periods.
RT-40ND-ND.05-522	Aging of STT straws	Technical Risk / Reliability and Performance	<0.5%/ year	Moderate	Low	The use of ultrasonic welding with double Al metallization protects the straws. The main aging effect expected is a relaxation of the tension on the straw walls over time, given that STT operates at room temperature with negligible irradiation. We will store all straws for 100 days at a pressure of 3 bar to allow a stabilization of the film before module assembly. The residual relaxation expected is 11% during 20 years, which does not have significant effects on the detector performance. Impact of humidity on the straws is reversible and can be corrected by monitoring temp. and humidity.

STRAW PRODUCTION & MODULE ASSEMBLY

- *Fabrication of STT includes two main functional blocks:*
  - *Production and test of straws with the ultrasonic welding technology;*
  - *Assembly and test of complete STT modules from components (straws, frame, wires, etc.).*

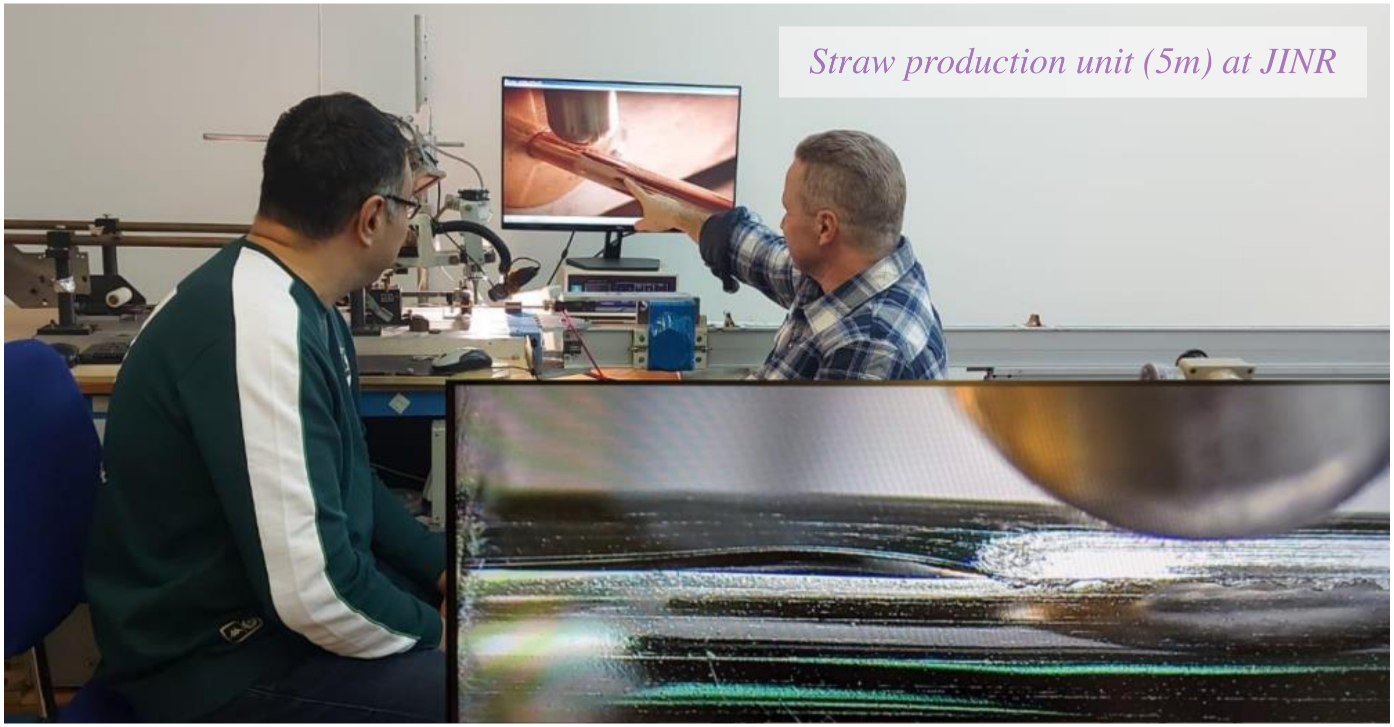
  $\Longrightarrow$ *Fuctionally independent could operate from same or different sites*

- *Basic Straw Production (SP) unit:*
  - *Straw production line 5m long equipped with ultrasonic welding (UL) technology;*
  - *Automatization of welding process and SP line as in existing lines at GTU & JINR;*
  - *Required personpower including quality tests (in parallel to SP):*
    4 people for single line (regardless of length), 6 people for double line;
  - *Expected average production rate: 50 straws/day.*

  $\Longrightarrow$ *Minimal number of SP units required: 3 (available at GTU+JINR)*

- *Basic Module Assembly (MA) unit:*
  - *Mounting table and tooling required to assemble full scale (4m) STT modules;*
  - *Need ceiling >5m to allow modules in vertical position for stycast gluing and wiring;*
  - *Required personpower including quality tests (in parallel to MA): 7 people;*
  - *Expected average production time: $\sim$ 2.5 months / module.*

  $\Longrightarrow$ *Minimal number of MA units required: 2-3 (single production site)*

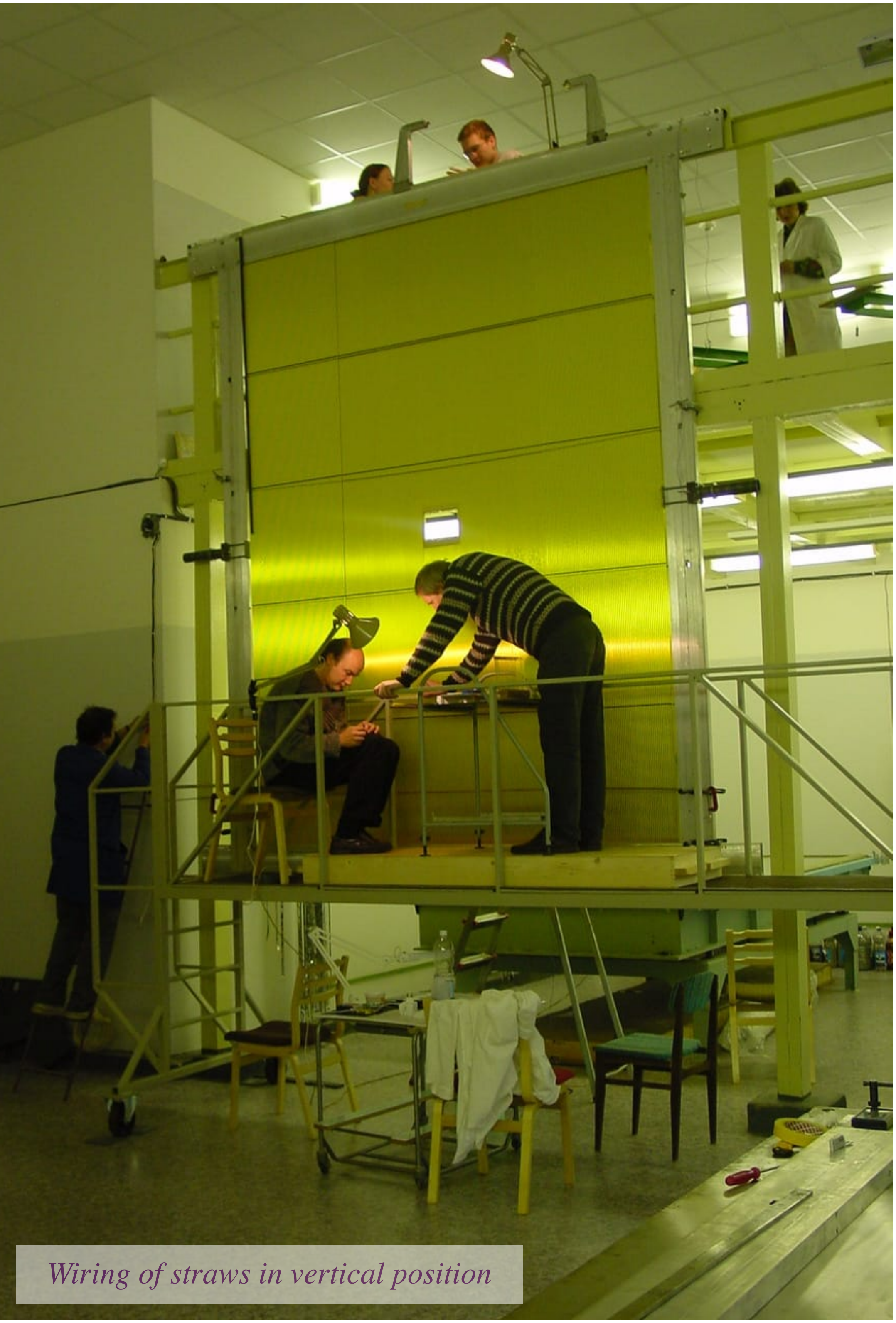


Straw production unit (5m) at JINR

Double SP unit 5m long at GTU

5m STT straws with Fraunhofer film at JINR

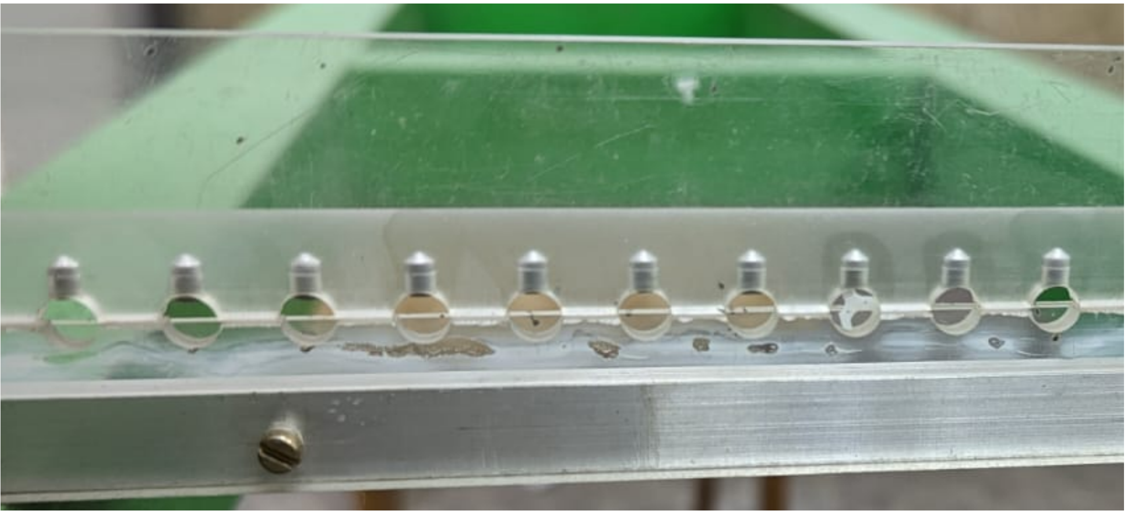
MA tooling for the assembly of 4m modules developed for the COMPASS straw tracker

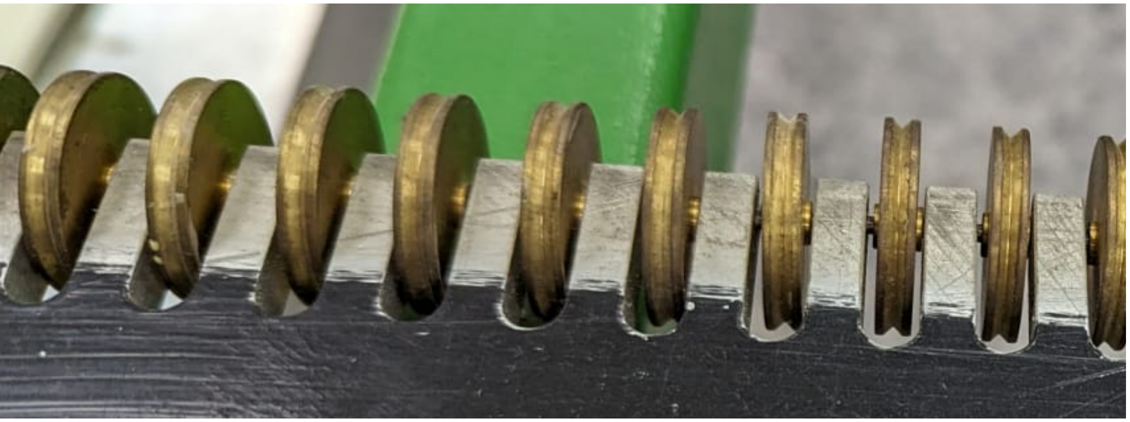


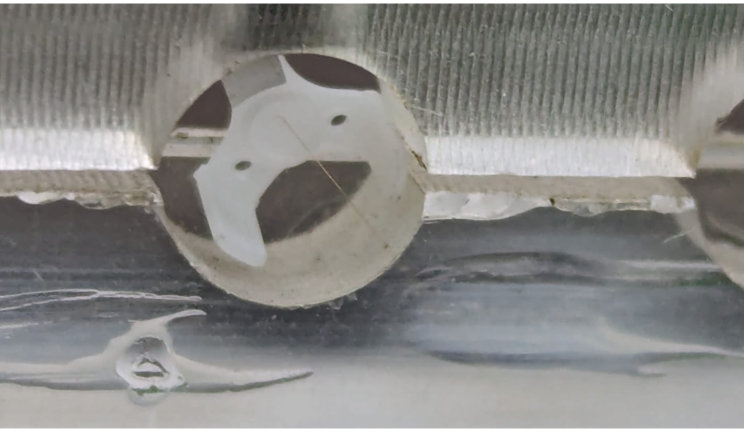
Wiring of straws in vertical position

Glue dispenser and robotic arm for automatic gluing

Assembly table for 4m modules

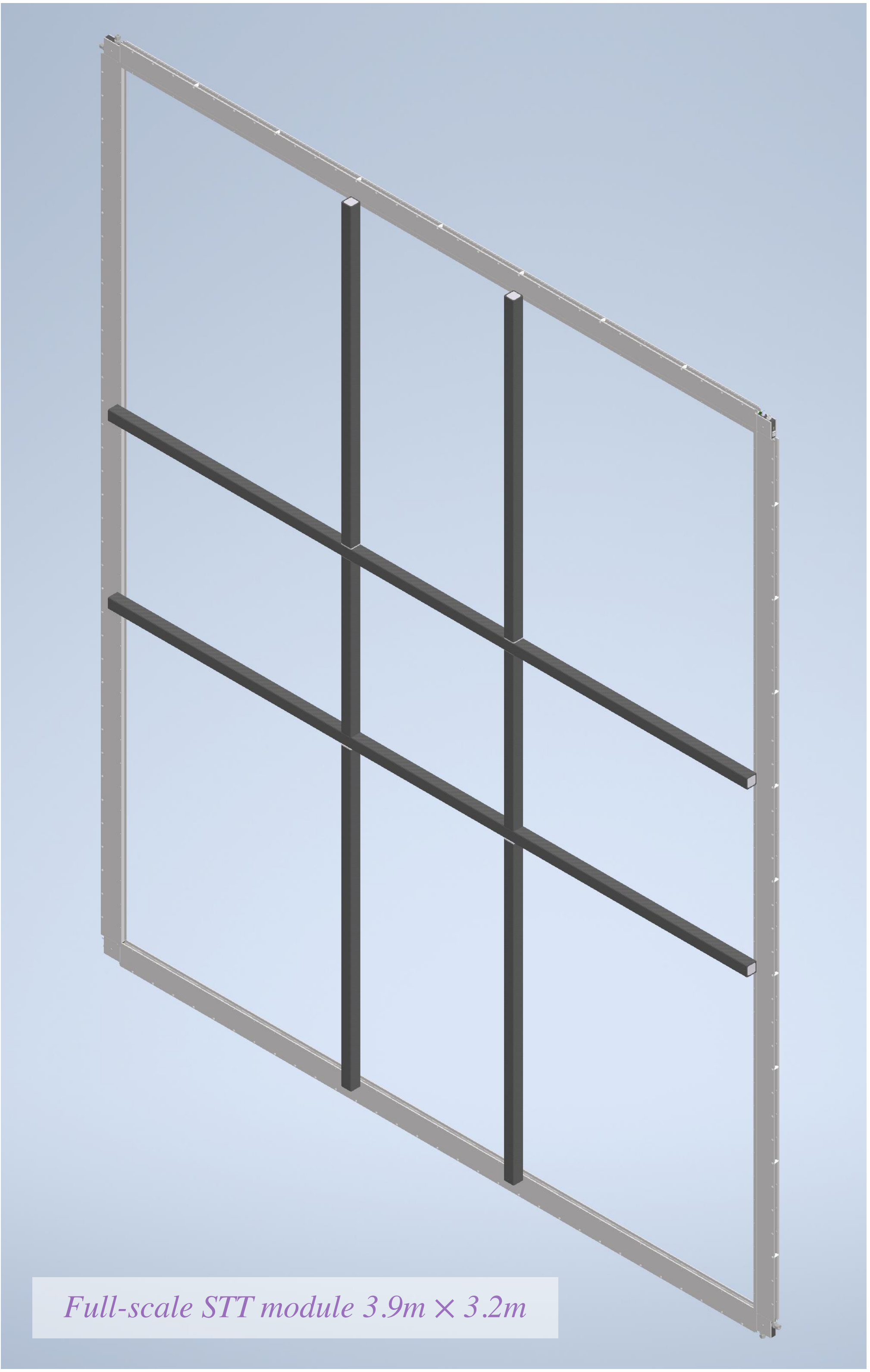


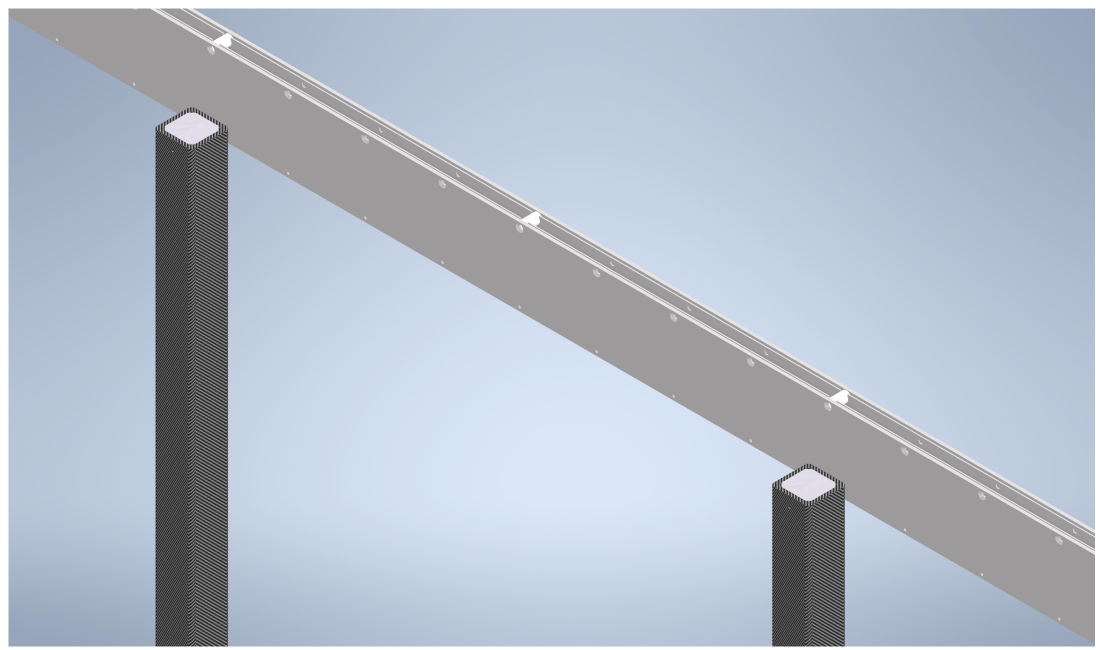




MA tooling developed for COMPASS to glue spacers on 4m long wires before insertion into straws

MA tooling for external support of full-scale STT frames during the wiring and assembly process based on cross-bracing with C-fiber square tubes





Country	STT Institutions	Contributions	Planned Contributions
Italy	INFN Pisa, Bologna	Management Design and engineering Procurement of film, prototype frames, assembly tooling Testbeam exposures Construction of prototypes Simulations and reconstruction Analysis and physics studies	Setup at least 1 MA unit Assembly of STT modules ASIC and readout
Georgia	GTU	Design and engineering Tests of straw properties Construction of 2.5 SP units Product of straws for prototypes Construction of prototypes	Setup 1 MA unit Production of straws Assembly of STT modules
India	IIT Guwahati IIT Kanpur NISER Panjab	Procurement of components Tests of straw properties Readout and testbeam exposures Simulation and reconstruction Analysis and physics studies	Construction of 1 SP unit Setup 2 MA units Production of straws Assembly of STT modules Readout electronics
Kazakhstan	INP, Almaty (+ JINR)	Design and engineering Readout and testbeam exposures Tests of straw properties Construction of 1 (+ 3) SP units Construction of prototypes Simulations and analysis	Construction of 3 SP units Setup 2 MA units Production of straws Assembly of STT modules Readout electronics
USA	Duke University USC	Management Design and engineering Procurement of straw components, targets/radiator, VMM3a, readout, full-scale frame prototype Readout and testbeam exposures Tests of straw properties Simulations and reconstruction Analysis and physics studies	Construction of 1 SP unit Setup 1 MA unit Readout electronics

CORE COSTS FOR THE COMPLETE STT

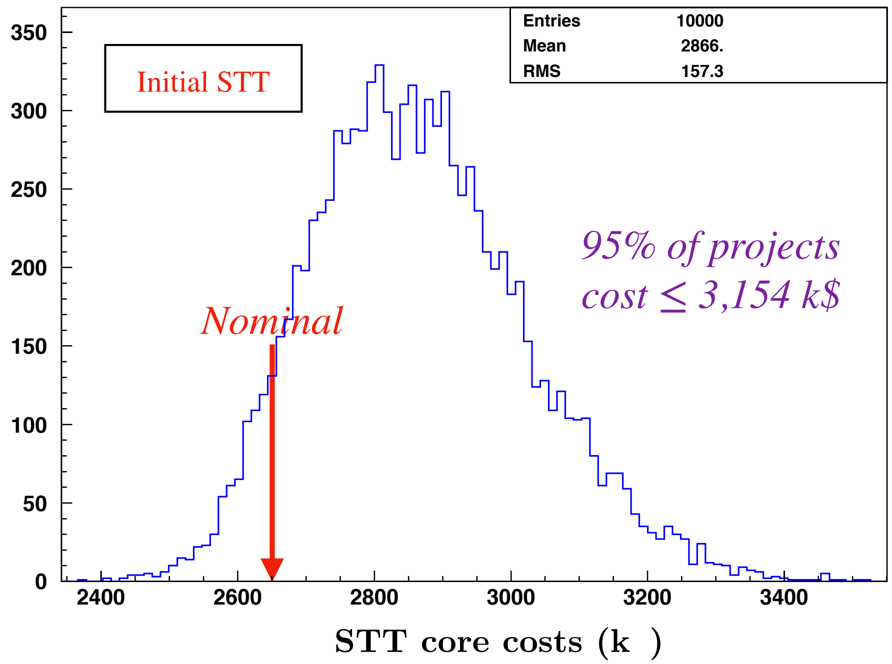
ITEM	COST	SUPPLIER/SOURCE	QUOTE	DELIVERY TIME	VALIDATED
Procure mylar film (19 μm, double 70 nm Al)	$ 239,610	Fraunhofer FEP, Germany	Mar-24	3 months	✓
Procure endplugs (PC transparent)	$ 11,651	CLM Co. LTD, China	Apr-24	45 days	✓
Procure wire spacers (PC black)	$ 32,748	GJT Co. LTD, China	Apr-24	45 days	✓
Procure crimping pins (1.2 mm gold plated)	$ 21,540	SZLE Co. LTD, China	Feb-24	4 weeks	✓
Procure anode wire (W/Re 20 μm)	$ 327,810	Luma metall AB, Sweden	Feb-24	14 weeks	✓
Procure C-fiber frames	$ 902,737	DSNM Co. LTD, China	Jul-24	5 months	
Procure Al corner blocks	$ 2,064	PIM Co. LTD, China	Jun-24	2 weeks	✓
Procure gas and electrical connectors	$ 8,499	CERN store, Switzerland	Jun-24	4 weeks	✓
Procure STT tools	$ 340,000	JINR/GTU facilities			
Procure miscellaneous items & consummables	$ 125,000	STT prototypes			
Procure gas system (Xe/CO_2 + Ar/CO_2 + cooling)	$ 525,000	CERN DT, Switzerland	Jul-24	6 months	✓
Procure BOPP radiator film (18 μm, 3.3 m)	$ 4,050	HMNM Co. LTD, China	May-24	8 weeks	✓
Procure CH_2 targets (HDPE tiles)	$ 18,791	HJM Co. LTD, China	Jun-24	8 weeks	
Procure graphite targets (isostatic IFS-H7 tiles)	$ 15,066	CFCC Co. LTD, China	Mar-24	8 weeks	✓
Procure C-fiber frames for targets/radiators (T700)	$ 70,136	HRC Co. LTD, China	Jun-24	1 month	✓
Procure rods+nuts for super-module assembly	$ 4,942	PIM Co. LTD, China	Jul-24	3 weeks	✓
Custom ASIC design (64 channels, 180 nm)	$ 600,000	DG Circuits, USA	May-24	12 months	✓
Procure ASIC prototypes (MPW+packaging)	$ 41,000	Muse semiconductor, USA	May-24	10 weeks	✓
Procure ASIC production mask	$ 105,000	Muse semiconductor, USA	May-24	4 weeks	✓
Procure ASIC chips (6 wafer pilot)	$ 9,000	Muse semiconductor, USA	May-24	6 weeks	✓
Procure ASIC packaging	$ 30,000	Muse semiconductor, USA	May-24	2 weeks	✓
Procure integrated readout boards (MCU, ADC, SSR)	$ 148,643	PCBWay, China	Jul-24	7 weeks	✓
Procure flexible Kapton PCBs (PCIe connector)	$ 32,314	PCBWay, China	Jun-24	36 days	✓
Procure HV components	$ 50,492	CAEN, Italy	Jun-24	3 months	✓
Procure LV components	$ 81,699	CAEN, Italy	Jun-24	4 months	✓
Procure cables & connectors	$ 36,985	CERN store, Switzerland	Jul-24	4 months	✓
Procure LV distribution boards	$ 18,000	ATLAS NSW			
Procure DAQ/DTS interface boards	$ 45,000	DUNE DAQ group			
TOTAL	**$ 3,847,779**				

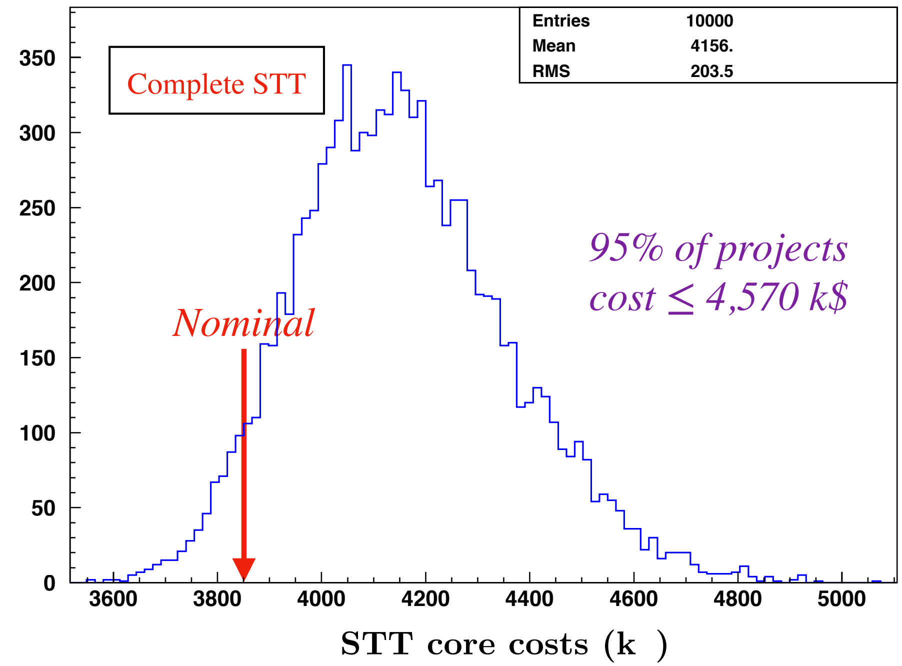
(Without ASIC design and mask: $ 3,107,779)

Average cost per module: $44,742

Average cost per channel: $18 ($14)

STT COST CONTINGENCY





MC simulation of 10,000 projects with cost variations based on STT risk register
Define cost contingency covering 95% of simulated projects