

Ultrasonic Welding Technology for the SPD Straw Tracker: From NA62 Experience to Large-Scale Production



Temur Enik for the StrawTrackerRD team

Why Straw Tracker?

- Thin walls — low material budget (from 12 μm)
- Operable in a vacuum and under overpressure over large areas
- Large coverage area (up to 25 m^2)
- Reasonable production cost
- Good spatial resolution (100–200 μm)
- Time-over-Threshold (TOT) measurement capability for noise reduction.
- Ionization charge measurement for particle identification at low momenta
- High radiation tolerance
- High rate capability



Comparison of STRAW Production Methods

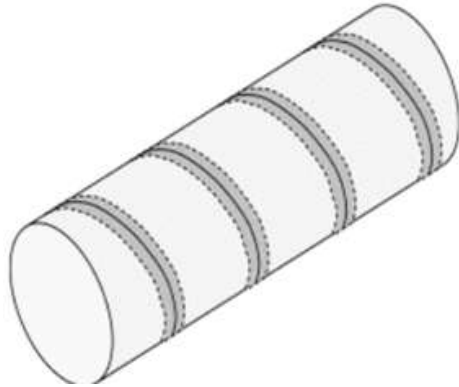
STRAW Winding

Positive Qualities (+):

- Radiation resistance
- Shape retention

Negative Qualities (-):

- Diffusion of gases
- Elastic deformation range
- Sensitivity to humidity



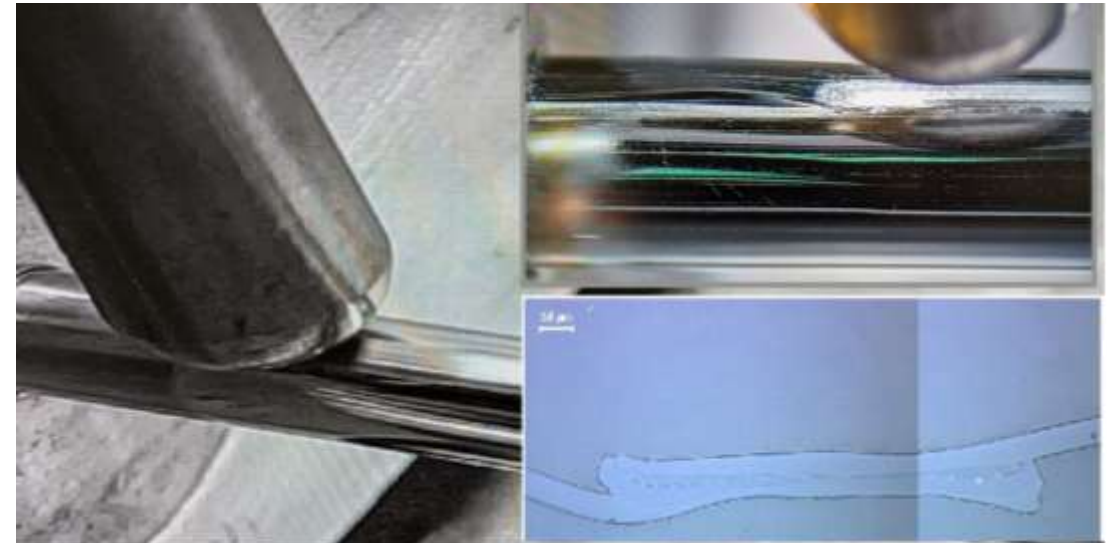
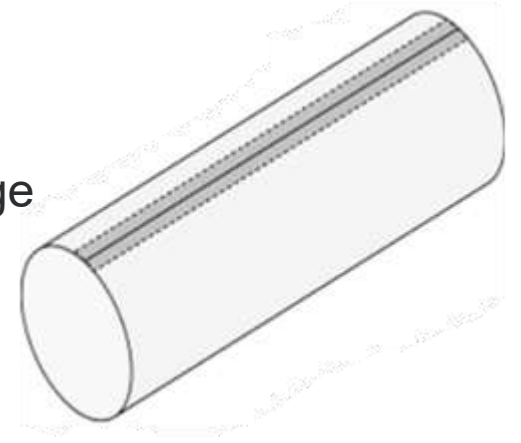
STRAW Welding

Positive Qualities (+):

- Elastic deformation range
- Sensitivity to humidity
- Diffusion of gases

Negative Qualities (-):

- Shape retention under pressure
- Radiation resistance



The straw trackers in the different experiments

Straw winding

- ATLAS
- LHCb
- COMPASS
- Mu2e
- COZY-TOF
- NA64
- PANDA
- CBM
- SVD-2
- Glue-X
- Muon g-2
- OKA
- E871
- NAMAD
- JETSET
- ...



Straw welding

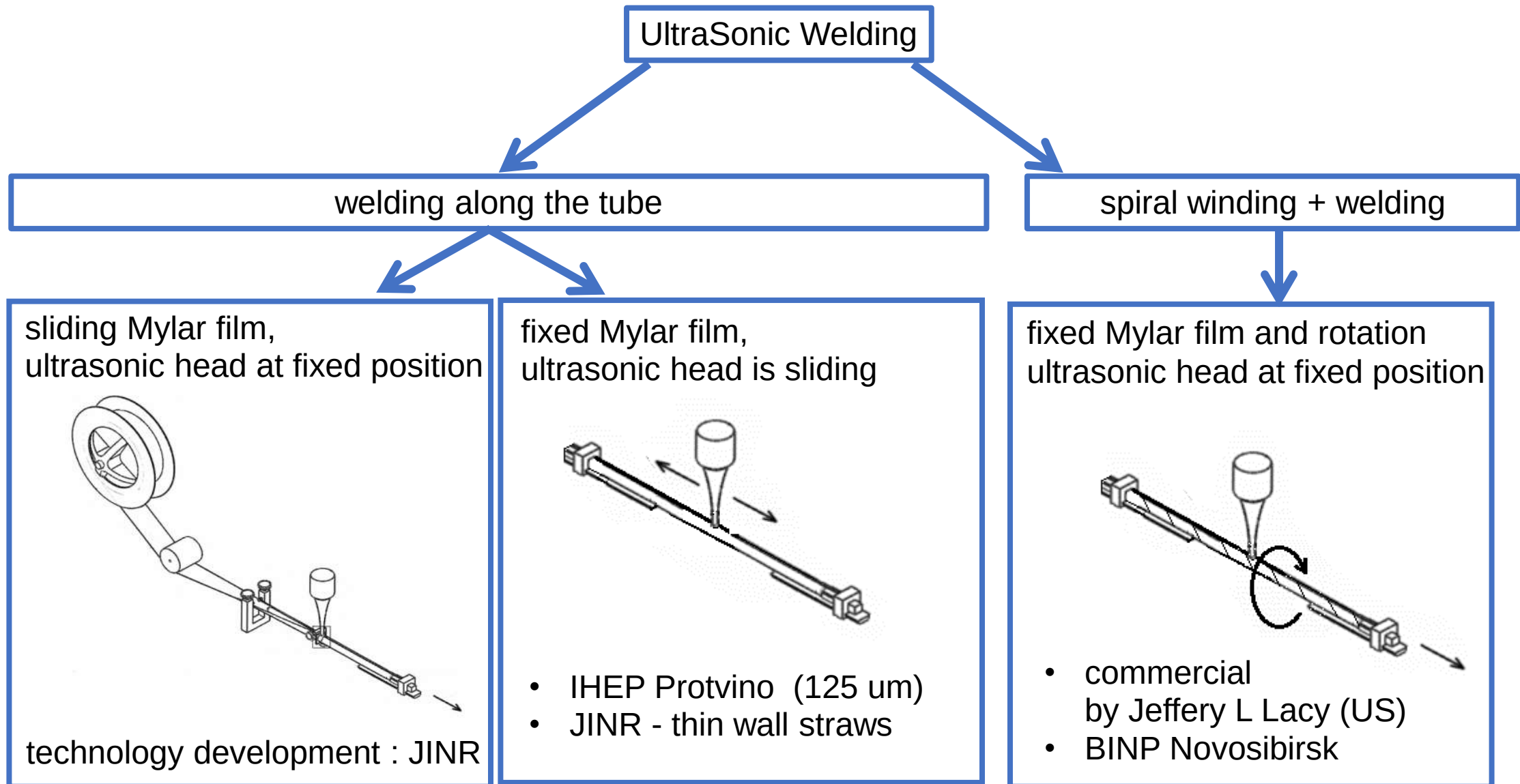
- NA62
- SPD NICA
- KEDR
- COMET
- SHiP
- DUNE
- VES
- HIPTAN
- FCC-ee
- ...



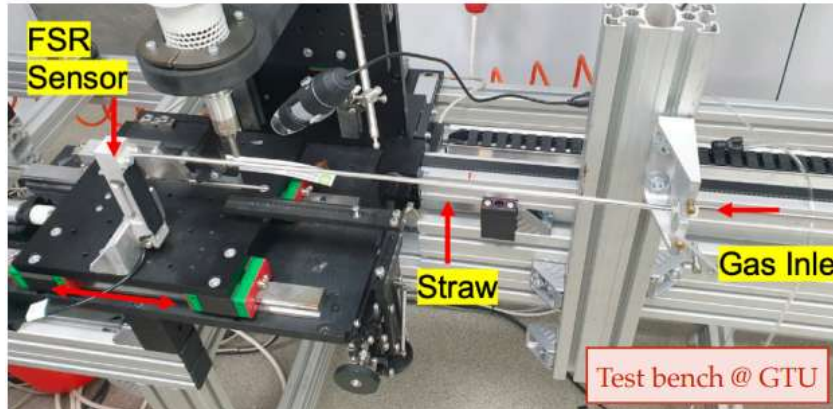
HIPTAN



Different Methods Ultrasonic Welding Technology(USW)



Straw welding-production lines



- JINR (Dubna) – operational for mass production  Joint Institute for Nuclear Research
- GTU (Tbilisi) - operational 
- SEFAR (Swiss industrial company) - operational 
- PNPI (Gatchina) - developing 
- INP (Almaty) - developing mass production lines 
- IHEP (Protvino) - operational for mass production 
- PTI (Houston industrial company)-operational
- BINP (Novosibirsk)-on hold 

Straw winding-ATLAS, COMPASS

Пешехонов В.Д

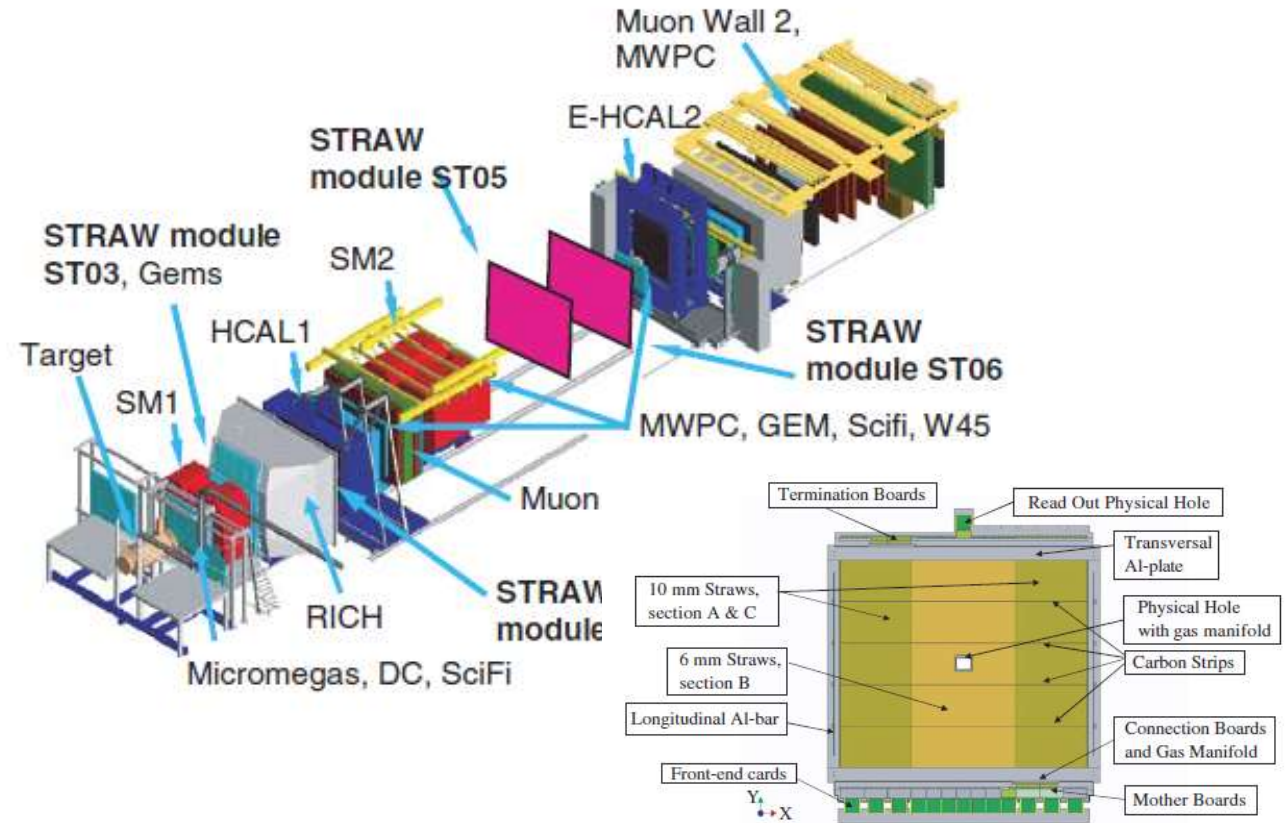
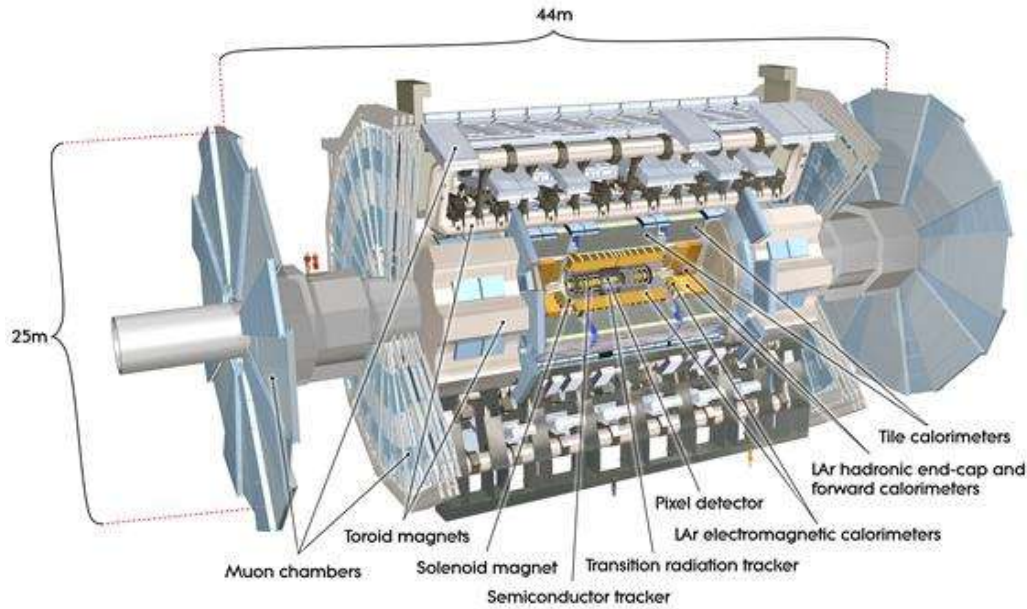


Fig. 2. Schematic view of a chamber (type X).

Endcap modules: 248760 straw
 Module of type A (PNPI) 147456 straw
 Module of type B (LHEP) 98304 straw

12440 straws
 2802x3232(mm x mm) for X
 3254x2427(mm x mm) for Y

Straw welding-NA62



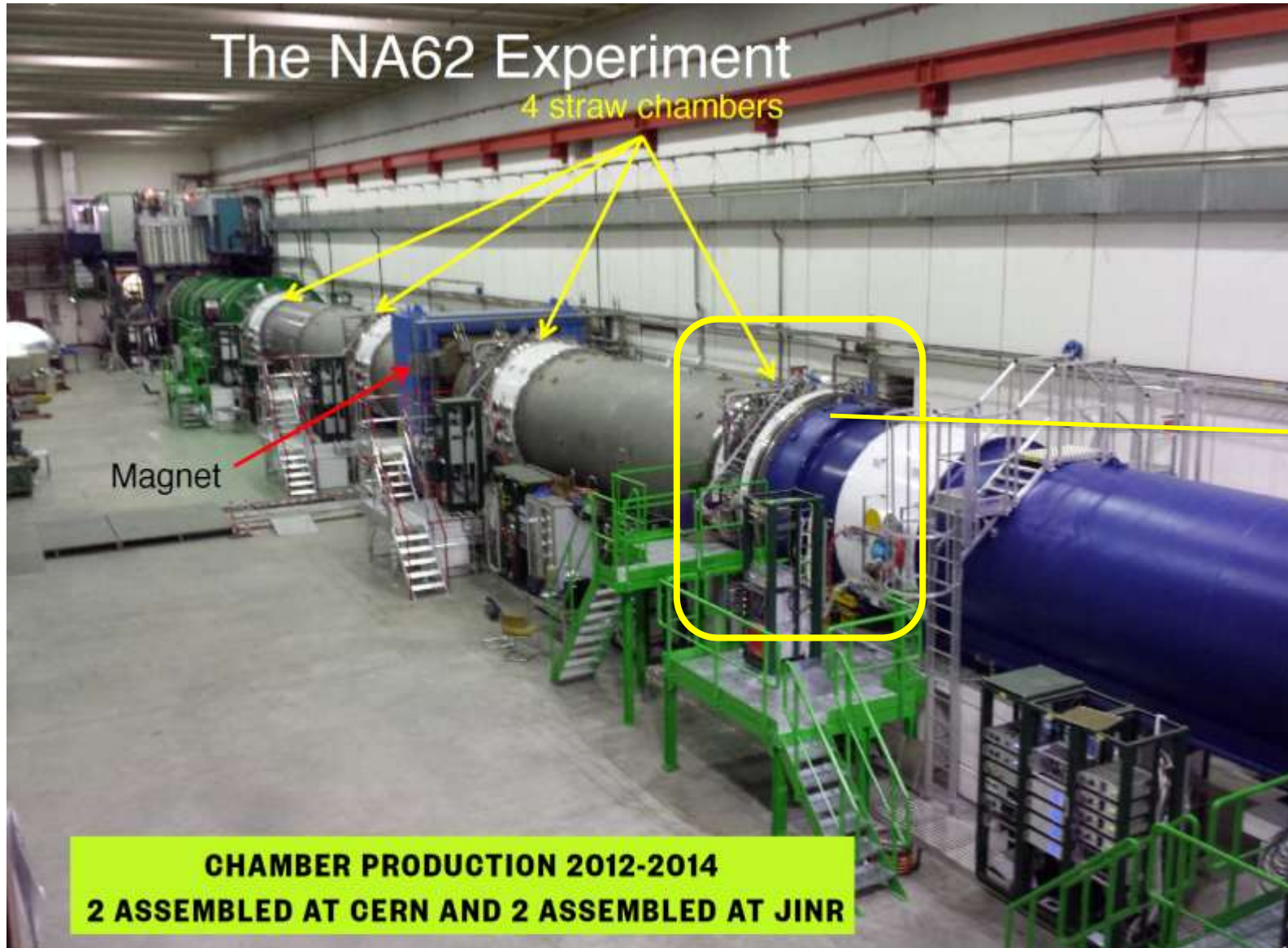
Hans Danielson

Current NA62 straw spectrometer:

- **Straw diameter: 9.8 mm**
 - Material: 36 μm thick PET
 - Plating: 50 nm copper + 20 nm gold
 - Wire: 30 μm tungsten wire
- **Gas: Ar+CO₂ (70:30)**
- **4 chambers, 7168 straws in vacuum**
 - ~30 straw hits per track
- **Total material budget: 1.7% X₀**
 - Dominated by the PET (70%)
- **Single straw timing performance:**
 - Maximum drift time: ~150 ns
 - Leading time resolution: 3-4 ns
 - Trailing time resolution: ~30 ns



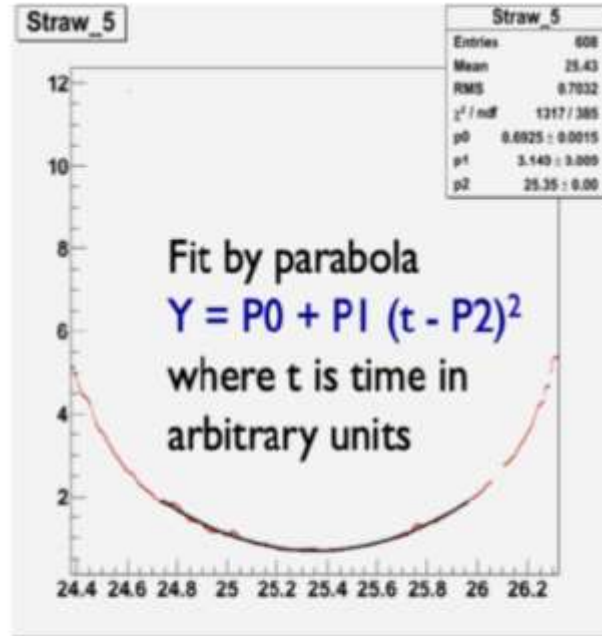
General view of the NA62



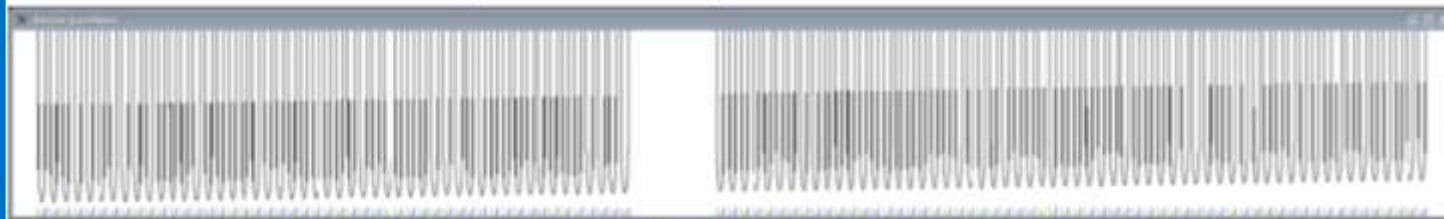
Quality control and Testing during NA62 Straw Tracker Assembly

- Leak testing at different stages
 - Aluminum frames and straws are leak tested before installation
 - Specifications: 1mbar x cm³/min/straw (mainly diffusion of CO₂)
- Straw straightness measurement
- Straw tension verification
 - An infrared emitter/receiver measures natural frequency to calculate straws tension
 - A straw is replaced if the tension is below 70% of its nominal tension (1.5kg)
- High Voltage (HV) testing
 - A first HV test is carried out once the webs are installed and a second HV test after the wires are inserted
- Wire tension measurement
 - A mechanical test of the wire tension is used by applying a fixed force (F) on the crimp tube

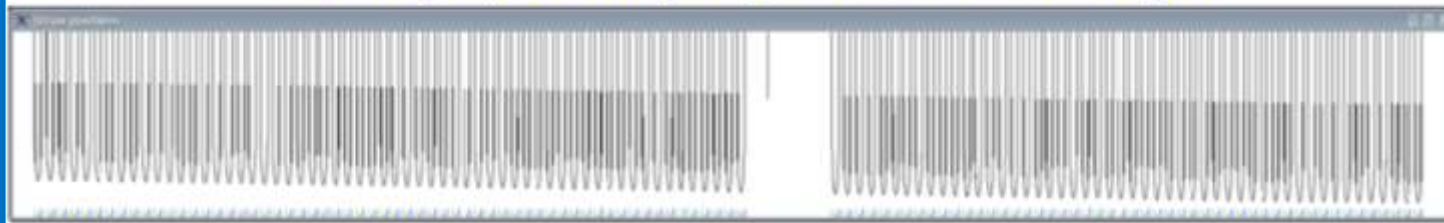
Measurement of the straw straightness, tension, positioning



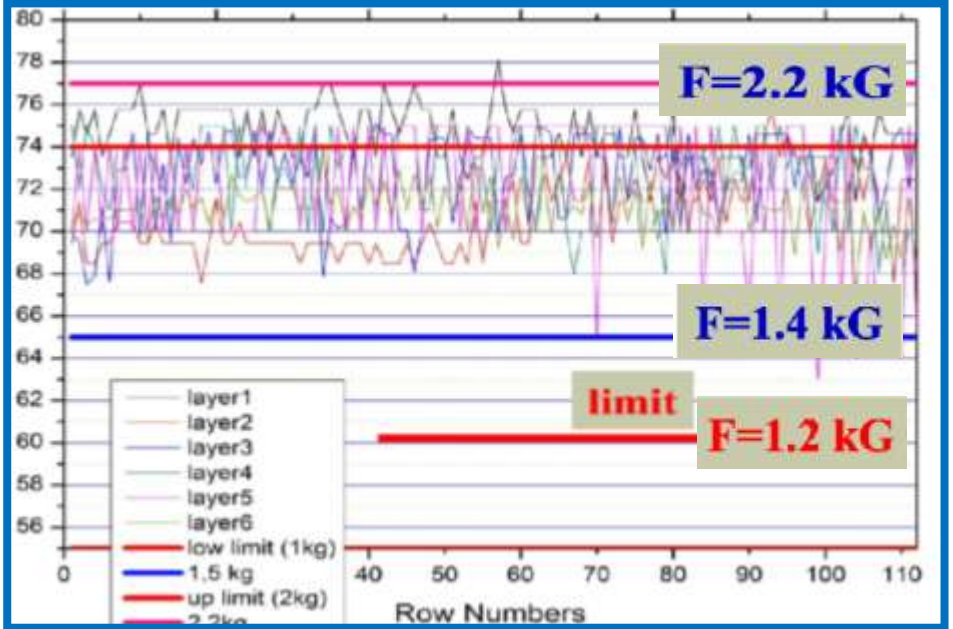
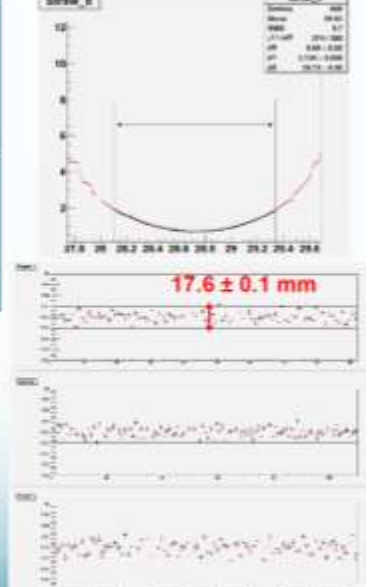
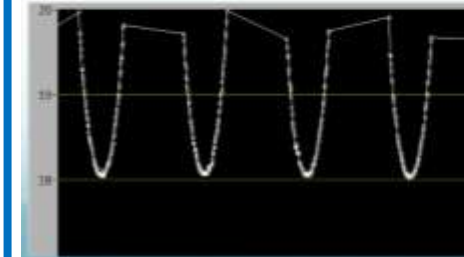
First layer, central part, movement to the left



First layer, central part, movement to the right

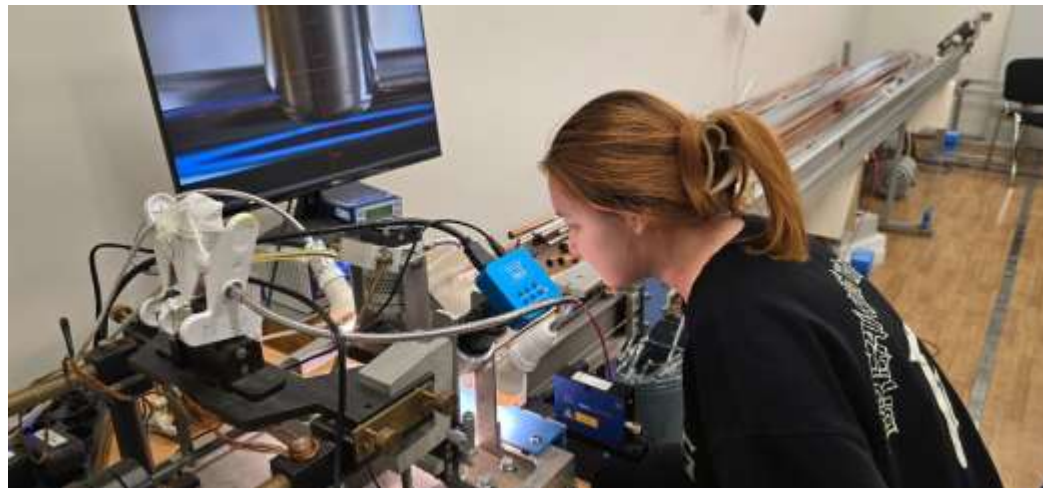
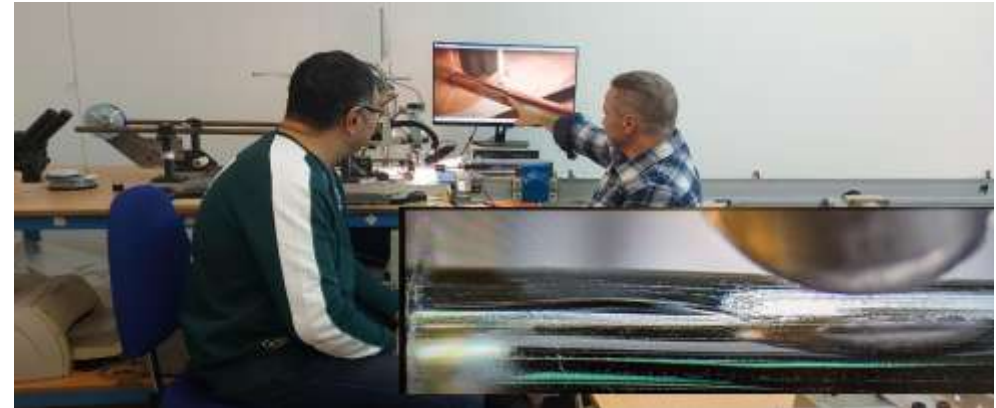
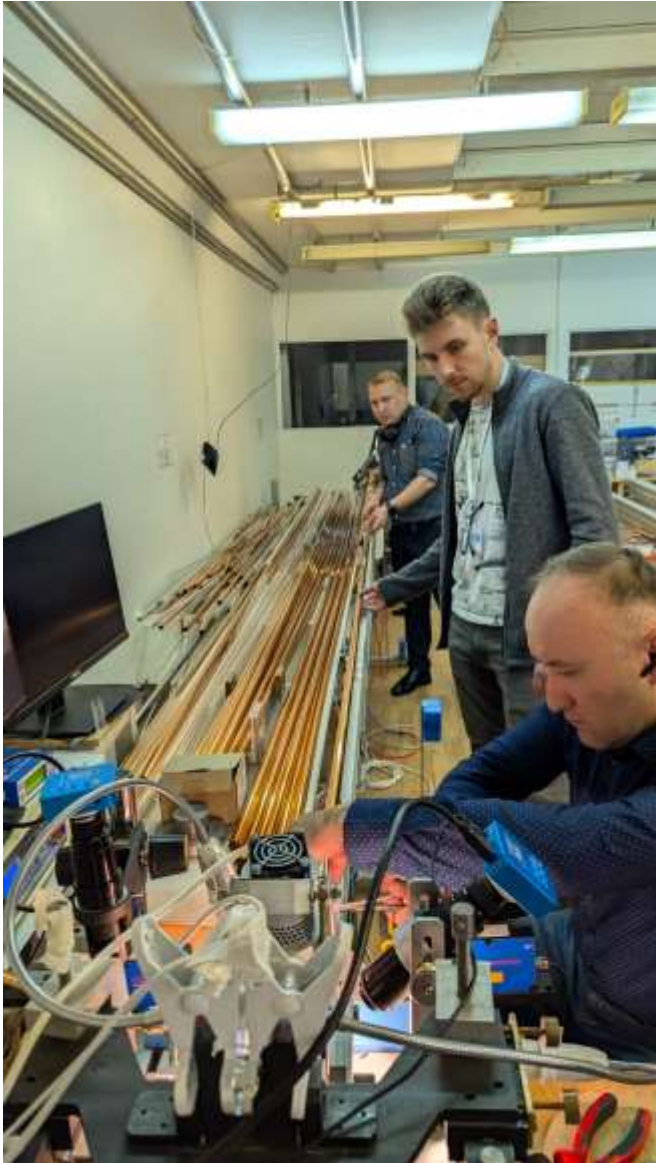


- A laser device measures the distance to the straws and the positions of the straw centres are calculated
- A decoder measures the x-position in each straw layer (top, center and bottom position)
- The nominal distance between two adjacent straws is 17.6 mm

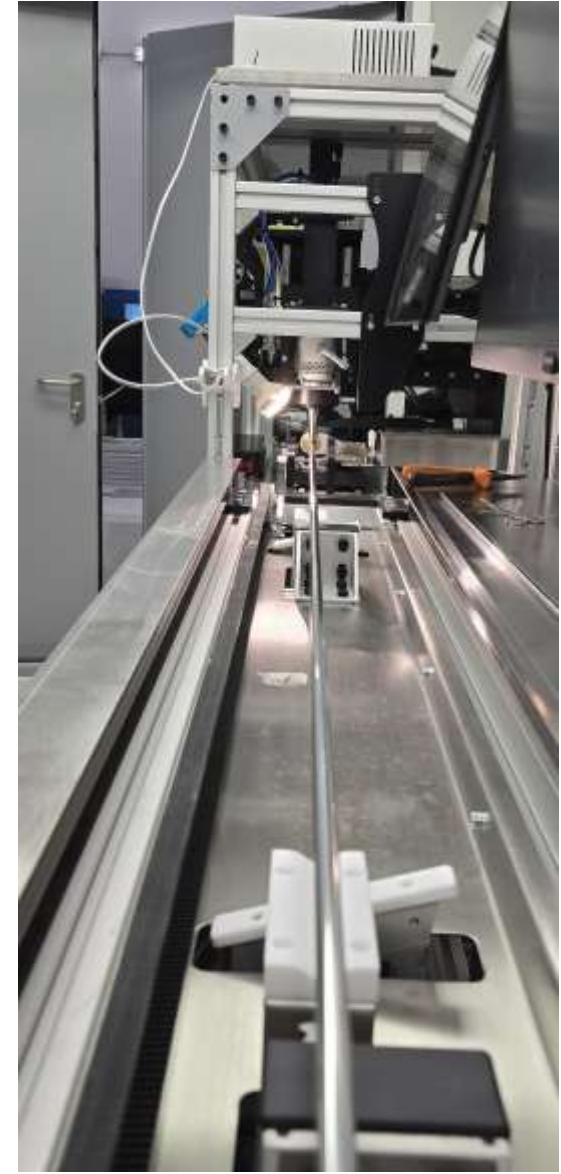


“Old” Straw production line at JINR

- added a new microscope with better resolution for visualization
- improved the seam positioning system
- production line speed 1 m per minute
- active work is underway in the field of R&D with colleagues from the INP



New Straw production line and assembling place JINR

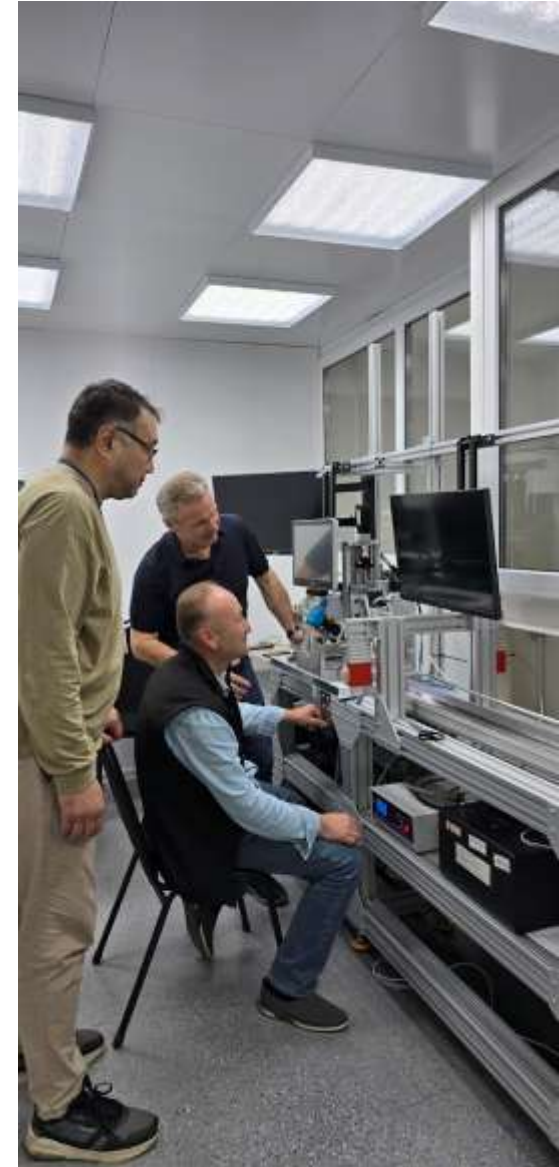


- Area ~200 sq.m., clean room~100 sq.m, machine shop and assembling hall~50 sq.m and 8,5 m high
- Production line length~12m
- Fine-tuning work began successfully and the first 12 meter straw was welded
- The possibility of integrating AI into the production and quality control process is provided

Straw production line and assembling place at INP(Almaty)



- The line was manufactured and successfully tested at JINR
- INP(Almaty) engineers and physicists took an active part in the development and testing
- The line is disassembled and shipped to Almaty.
- Commissioning work is planned to be carried out in June
- Production is scheduled to start at the end of June



Advancing the USW technology : production quality control

During production:



visual control of seam quality



visual control of the position of the ultrasonic head

Post-production:



express stress test at the beginning and at the end of the seam



overpressure tests guarantee good long-term operation stability

Overpressure tests:

Short-term test: several minutes - NA62: 3 atm, DUNE: 5 atm
Long-term test: ~month - NA62: 1 atm, DUNE: 3 atm

Continuous measurement of outer straw diameter during production

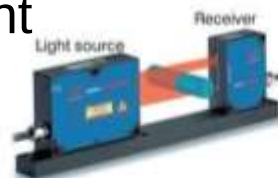


Fig. 5 Sensor unit SU

A measurement system consists of:



Fig. 6 Controller CU

- laser
- receiver
- controller

Measurement of the inner straw diameter (both straw ends) with tools;



Quality control of welds at CERN- Cross sectional

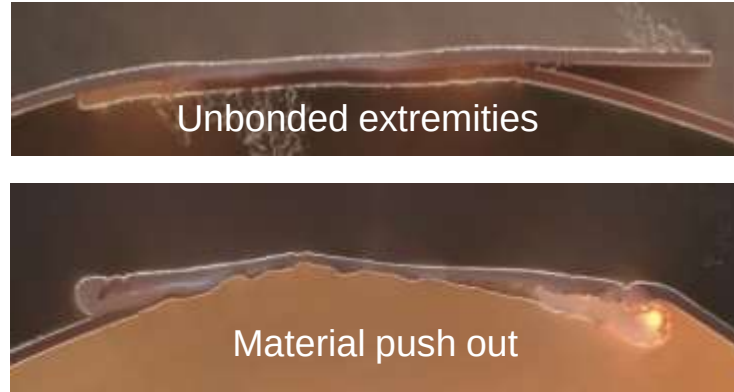
This step tells us most about the weld and its soundness prior to mechanical testing.

Strong



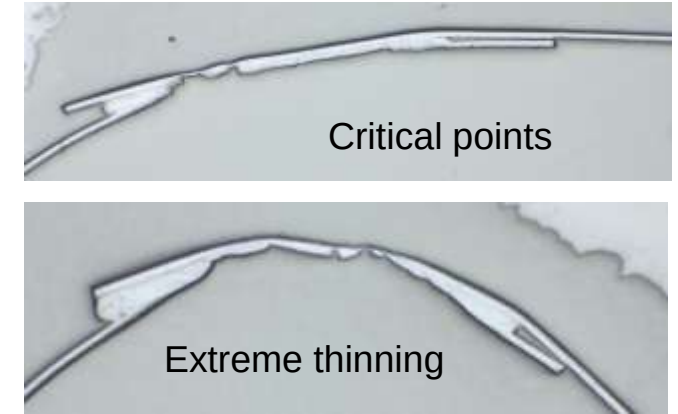
A good weld interface showing a strong “double thickness” maintaining the mechanical strength of the part, with extremities bonded and no thinning or critical points.

Uncertain



Unbonded extremities cause a risk due to the reduction in the length of bonded interface so need to be limited. Moreover, risk due to the presence of a stress concentrator. Material push out risks the reduction of “double layer” required for optimal mechanical strength.

Bad

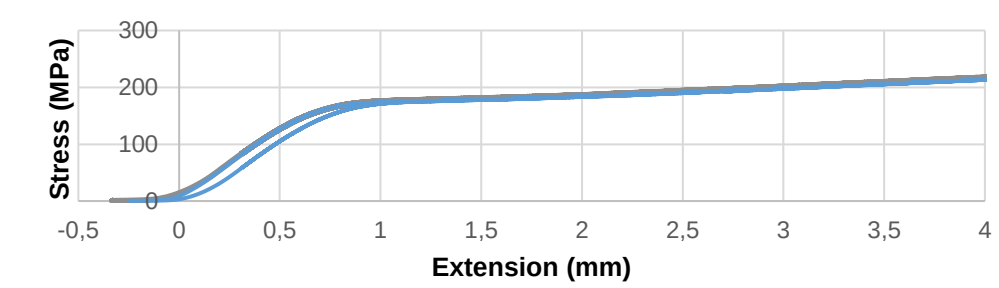


Any areas showing critical points or extreme thinning are catastrophic to the mechanical ability of the straws. These issues severely limit the durability of the weld and therefore the straw.

Mechanical testing- Results

Machine type	Old machine	Old machine	Old machine	Old machine	Old machine	Old machine	Old machine	New Machine
Year	2014	2023	2025/2026	2018	2025	2025	2026	2026
Material supplier	Fraunhofer	Fraunhofer	Fraunhofer	Fraunhofer	Fraunhofer	Fraunhofer	Unknown	India
Thickness (mm)	0.036	0.019	0.019	0.036	0.036	0.019	0.036	0.036
Metallized	Cu & Au	Cu & Au	Cu & Au	Cu & Au	Cu & Au	Al double	Al single side	Al -Single
Projects	Na 62	R&D HIKE	R&D HIKE	SHiP	SHiP	DUNE	FCCe + R&D	R & D
Weld institute	JINR	JINR	JINR	JINR	JINR	JINR	JINR	JINR
Diameter (mm)	10	5	5	20	20	5	10	10
Stress at break (MPa)	103.5 ± 0.9	101.6 ± 20.8	69.32 ± 0.22	79.14 ± 3.39	69.80 ± 9.07	72.09 ± 12.89	66.9 ± 10.97	62.71 ± 5.60
Force at break per unit length (N/mm)	3.6 ± 0.14	2.05 ± 1.11	2.63 ± 0.22	5.70 ± 0.24	10.05 ± 1.31	2.75 ± 0.49	4.82 ± 0.79	4.52 ± 0.4

20 mm Stress vs Extension curves



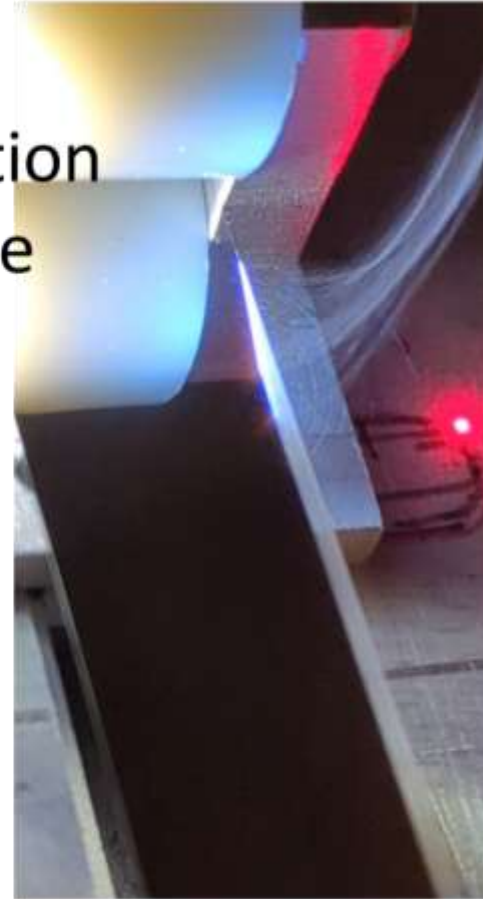
Katie Elizabeth Buchanan

Advancing the USW technology : production from double-side Al-metalized film



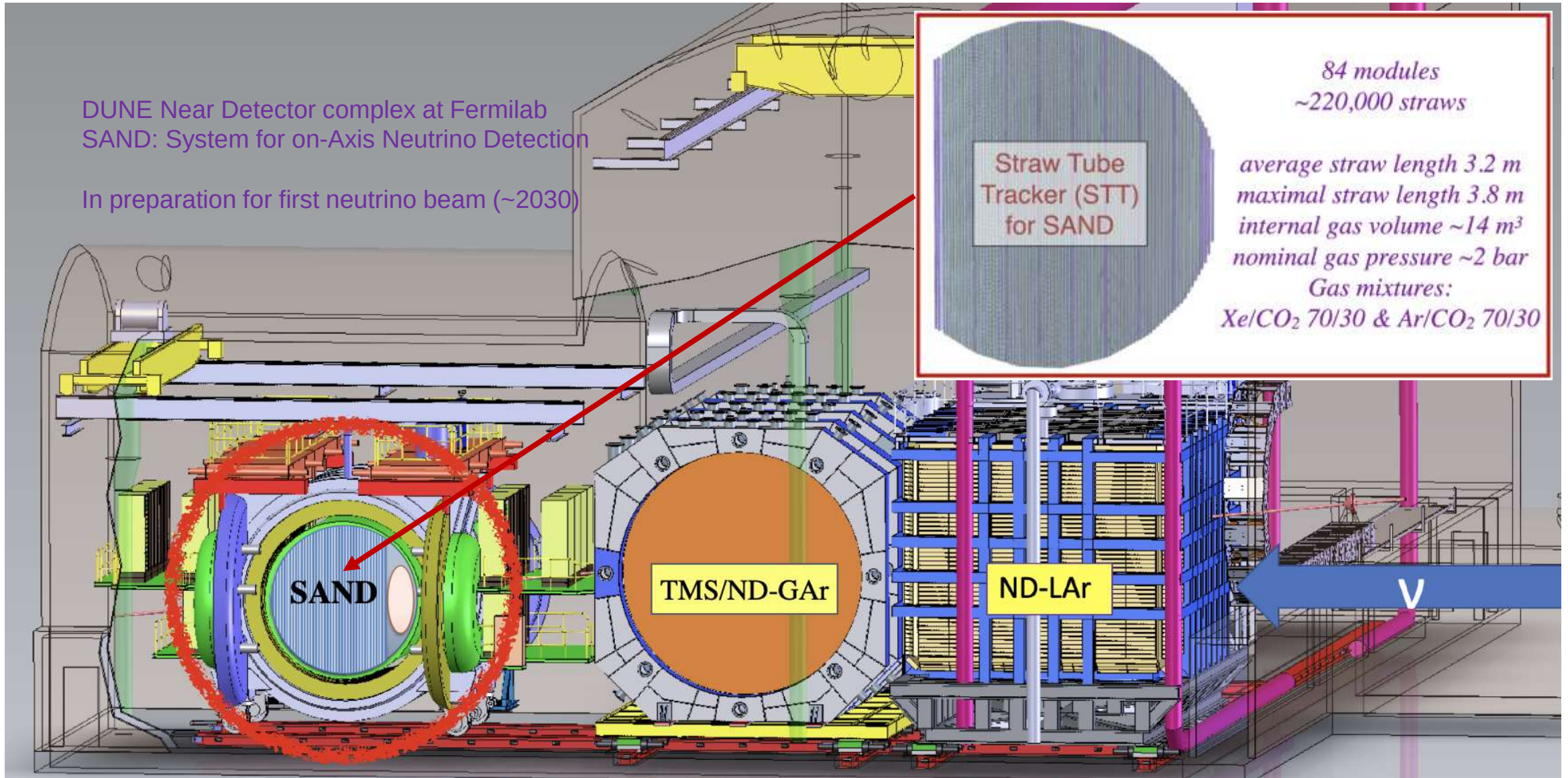
the process of destruction of the ultrasonic head under the influence of aluminum oxide

the process of removing metallization from the edge of the tape using a laser during welding



Removing the metallization made it possible to achieve the required quality

Deep Underground Neutrino Experiment(DUNE)



DUNE Straw Tube Tracker (STT)

Item description	Requirement	Comment
Average radiation length X_0	≥ 2.8 m	Comparable to total thickness of FV
Average density ρ	≤ 0.17 g/cm ³	From minimal radiation length
Maximal fiducial mass m_{FV}	$\lesssim 4.5$ t	From FV of 26.7 m ³ and average density
Thickness of individual targets	$\sim 0.015X_0$	For $> 95\%$ acceptance of p from H
Thickness of individual modules	< 4 cm	From FV length and target thickness
Momentum resolution	$< 5\%$	From MS with $B = 0.6$ T & $L = 1$ m
Single hit resolution	< 200 μm at 1 bar	Value at 2 bar scaled by $1/\sqrt{2}$
Momentum scale uncertainty	$\Delta p/p < 0.2\%$	Relative flux and E_ν scale
Particle identification (PID)	TR, dE/dx charge	$\nu_e, \bar{\nu}_e$ CC (TR) and $p/\pi/K$ (dE/dx)
Readout dynamic range	$\sim 10^3$	Charge measurement for PID ($p, e^\pm$)
Straw geometry	XXYY	L-R ambiguities, X-Y symmetry
Straw diameter	5 mm	Module thickness & large angle tracks
Straw wall thickness	< 20 μm	Vertex location for single tracks $< 0.5\%$
Tracking fiducial mass	$< 5\%$ of m_{FV}	Small compared with target mass
Operating gas pressure	2 bar absolute	Mechanical design & performance
Wire centering	< 100 μm	Guaranteed by self-centering design
Assembly tolerances	~ 100 μm	Not critical with wire self-centering
Ar leak rate per module	$< 4 \times 10^{-4}$ liter/min	Operation with Xe/CO ₂ at 2 bar
Maximal power dissipation	< 15 mW/channel	Total dissipation of integrated readout
Nominal gas flow rate	5 nliter/min/module	Self-cooling design

SPD TDR: Natural Sci. Rev. 1 1, 2024 (arXiv:2404.08317)

- Polarized and unpolarized phenomena at **low energies** ($3.4 \text{ GeV} < \sqrt{s}_{pp} < 9.4 \text{ GeV}$) and **reduced luminosity**
- p-p, d-d, and ion collisions (up to Ca)
- Simplified detector set-up
- Up to 2 years of data taking

Range System

muon identification and
coarse hadron calorimetry

BBC

local polarimetry
luminosity monitoring

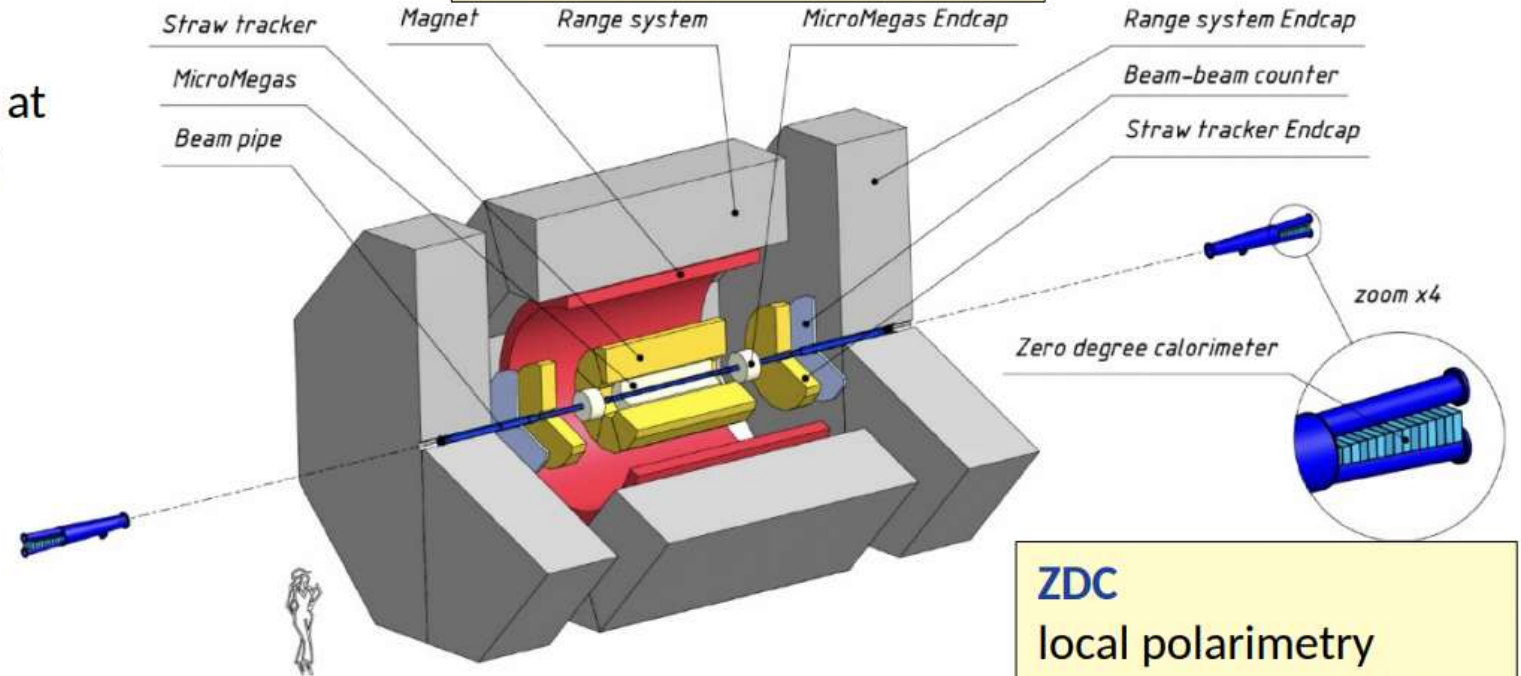
Straw tracker:

- $\sigma \sim 150 \mu\text{m}$
- $\sigma(dE/dx) = 8.5\%$

Micromegas central tracker:

$\sigma \sim 150 \mu\text{m}$

Magnetic field up to **1.2 T**



ZDC

local polarimetry
luminosity monitoring

SPD TDR: Natural Sci. Rev. 1 1, 2024 (arXiv:2404.08317)

Electromagnetic calorimeter:

$$\sigma E/E = 5\%/\sqrt{E} \oplus 1\%$$

Time of flight system:

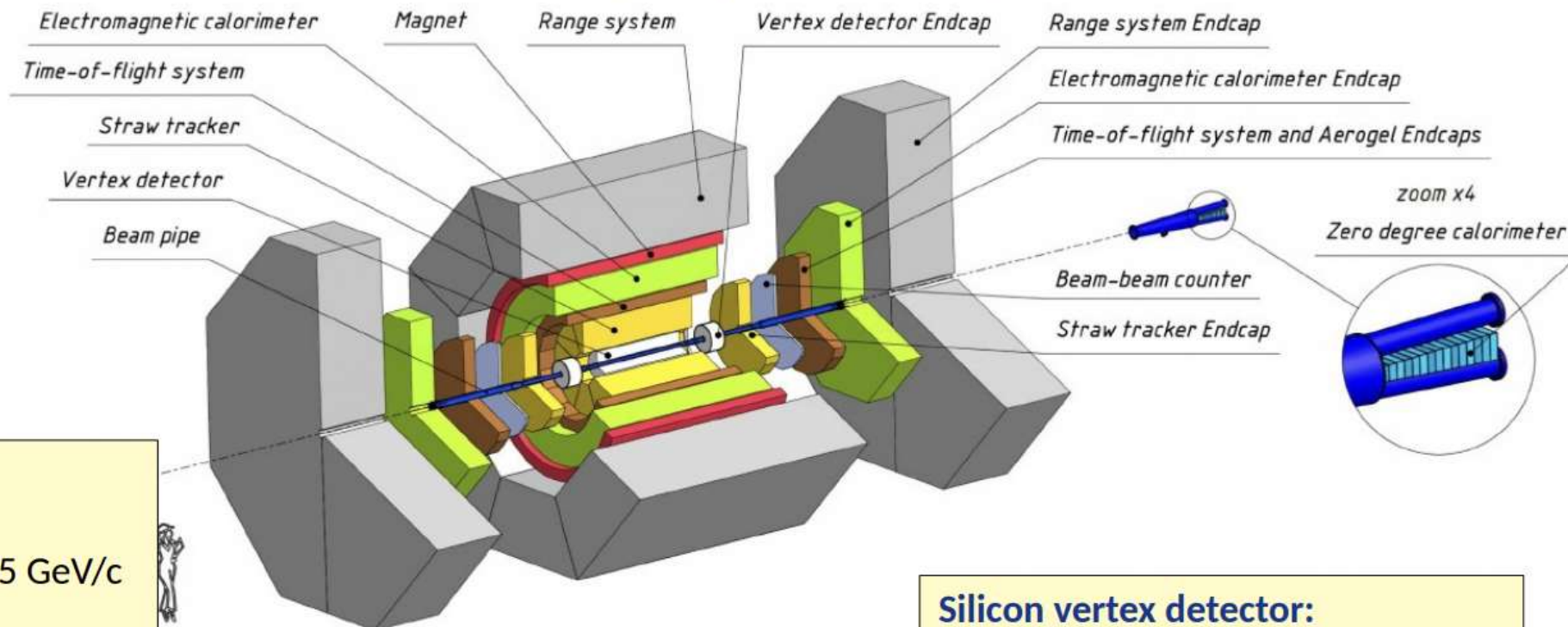
$$\sigma = 50 \text{ ps}$$

3σ π/K separation for $p < 1.5 \text{ GeV}/c$

FARICH in endcaps for pion/kaon separation for particle momentum up to **5.5 GeV/c**

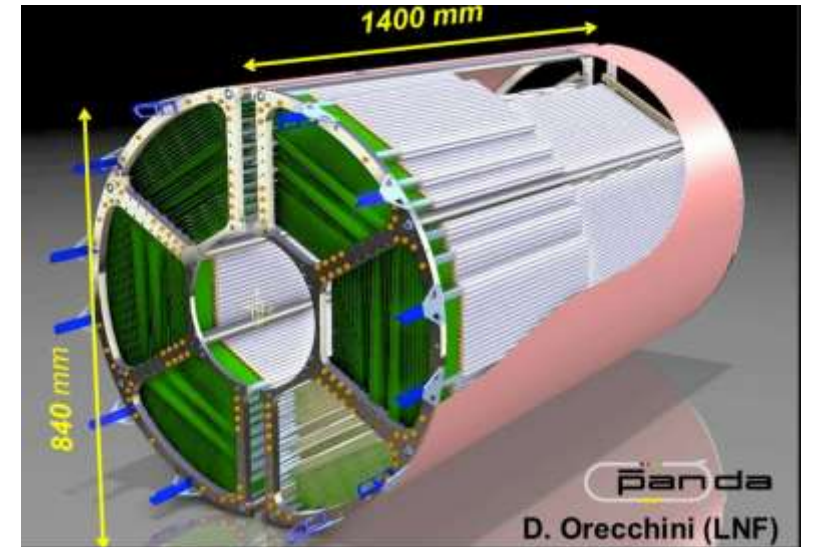
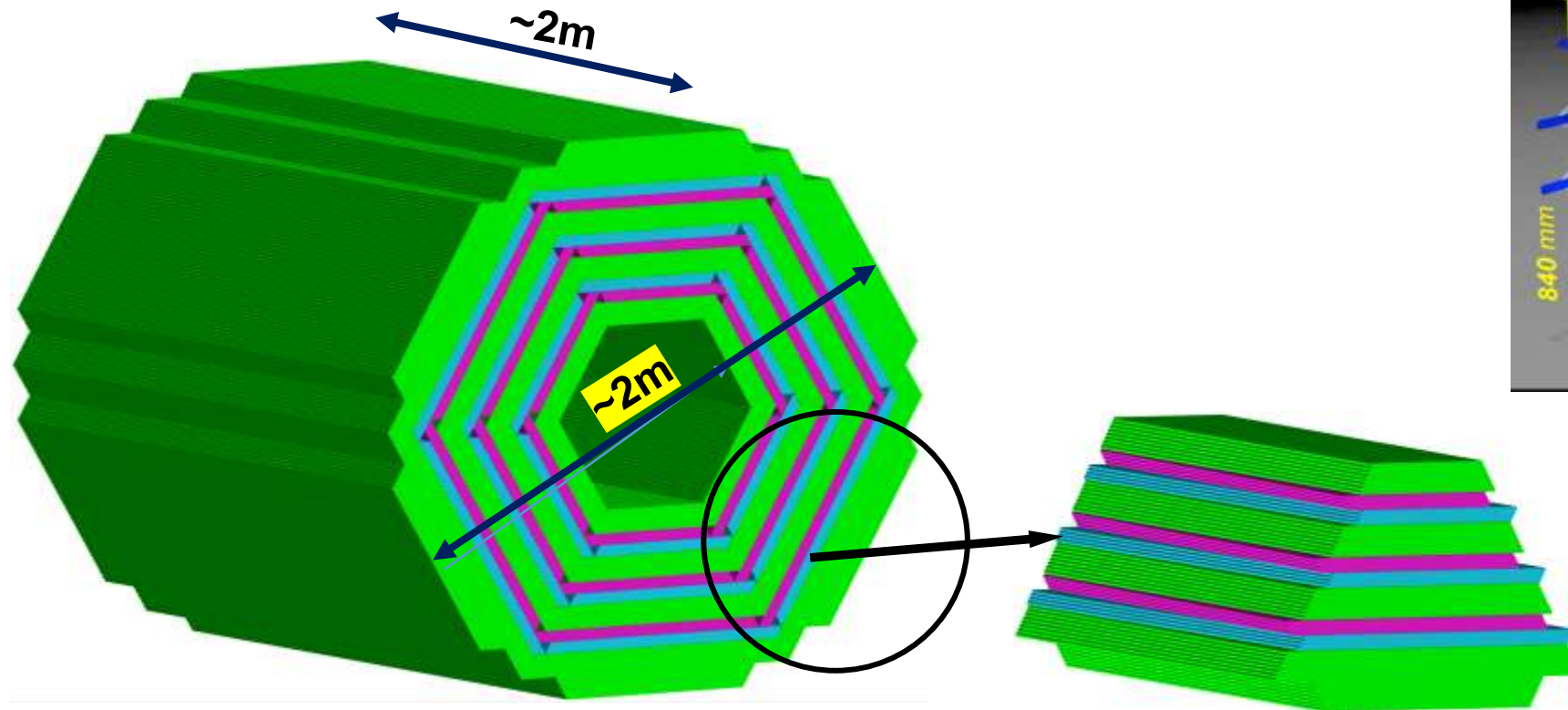
Silicon vertex detector:

- MAPS (4 layers): $\sigma = 10 \text{ } \mu\text{m}$
- DSSD (3 layers): $\sigma_{\phi} = 27.4 \text{ } \mu\text{m}$,
 $\sigma_z = 81.3 \text{ } \mu\text{m}$



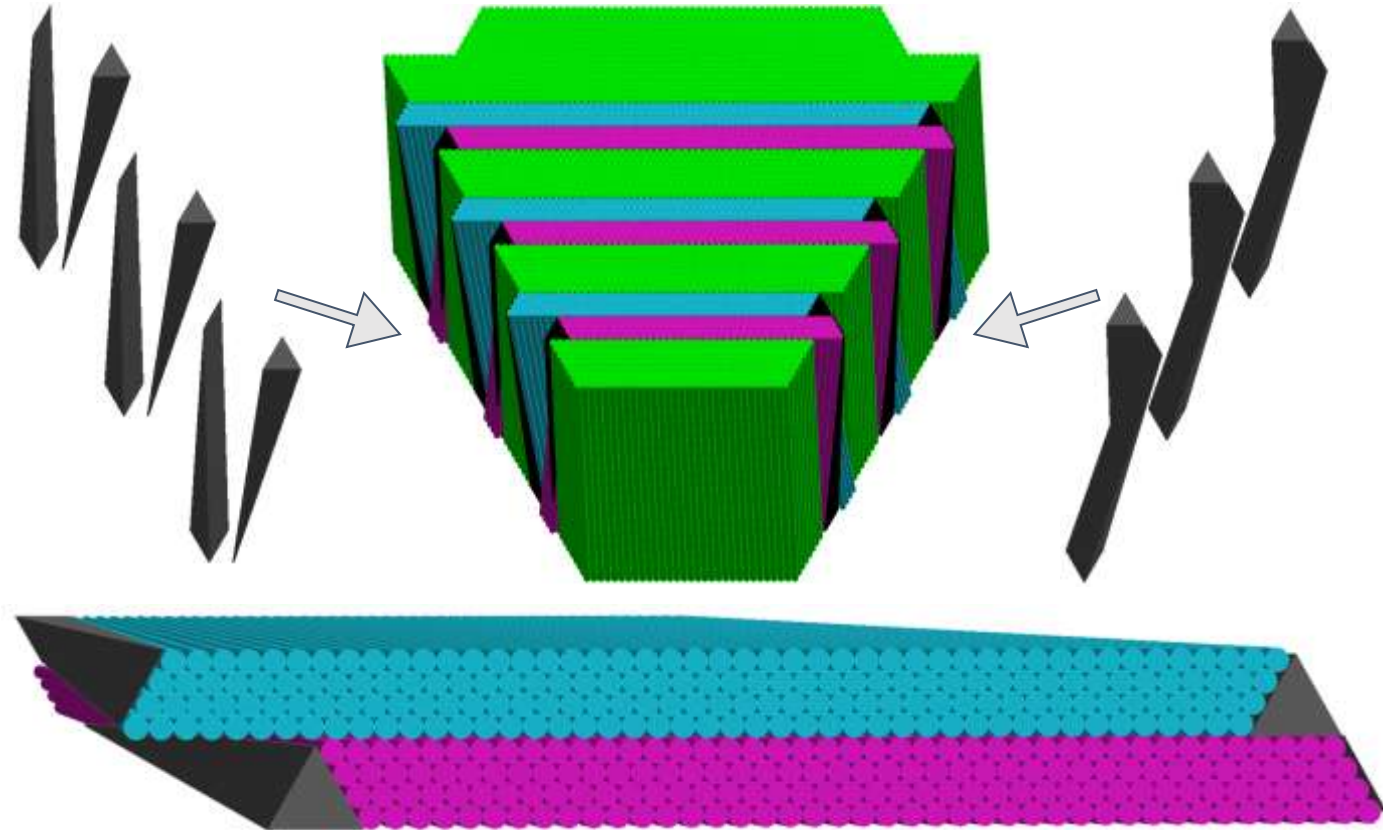
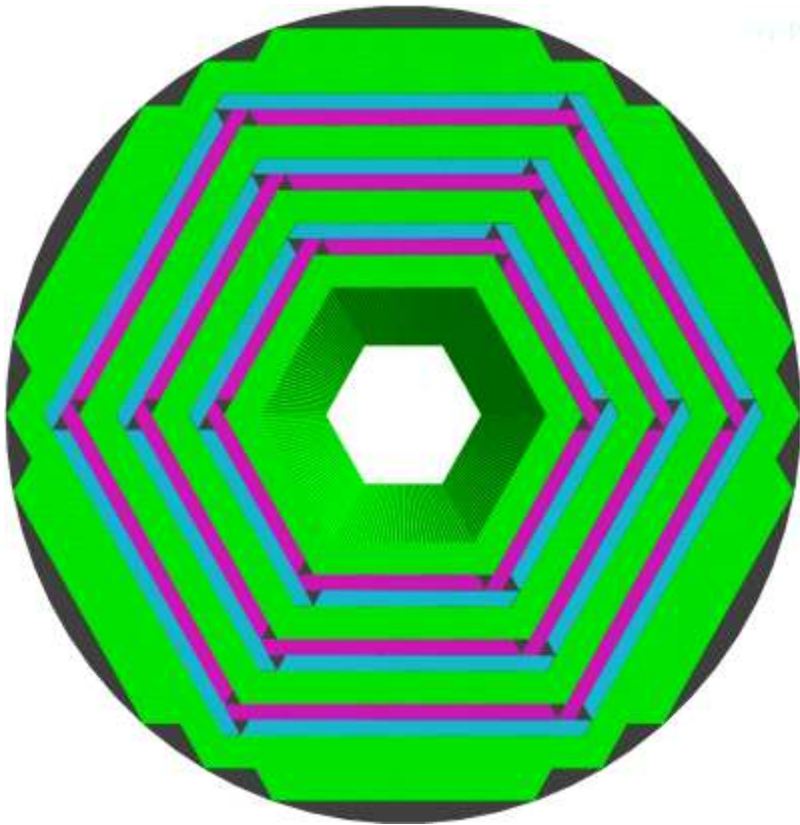
Barrel of Straw Tracker

- ST barrel consists of **6 identical modules** (sextants)
- One sextant contains 3860 tubes in total, which are arranged in layers with orientation **Z**, **+1.24°**, **-1.24°**
- Total number of tubes is $3860 \times 6 \text{ modules} = \mathbf{23\ 160 \text{ tubes}}$
- One straw is made of PET foil ultrasonic welded longitudinally thus forming a tube with $\varnothing = 10 \text{ mm}$



Inserts

- 6 identical sextants: 3 types of UV-layers, angle = 1.24°
- 36 identical inserts on each side, symmetrically placed
- Empty space partially replaced by tubes - 864 additional UV tubes in the full barrel

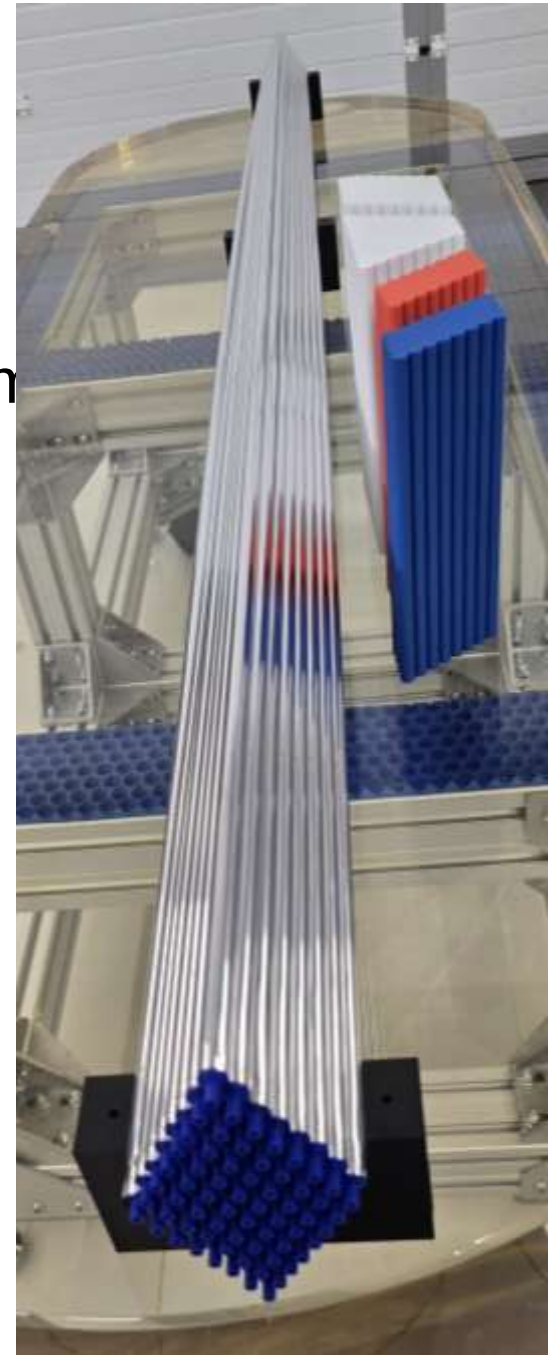
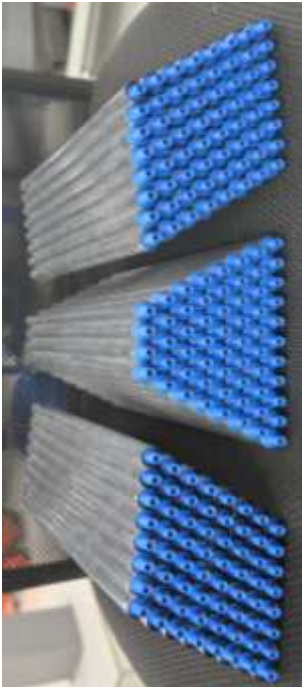


Geometry Concept

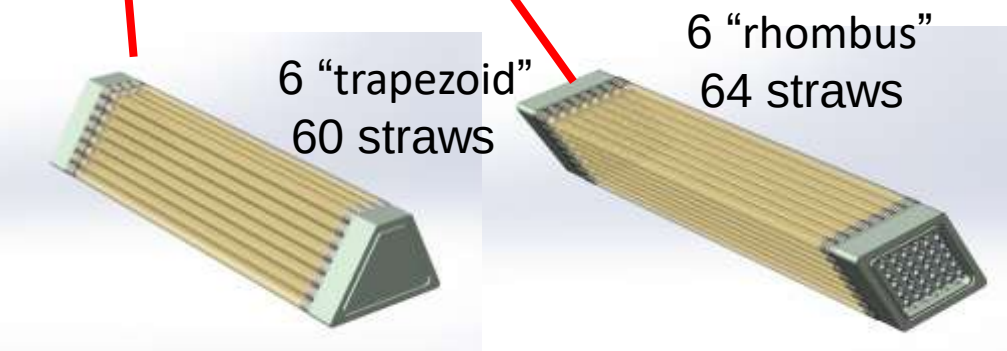
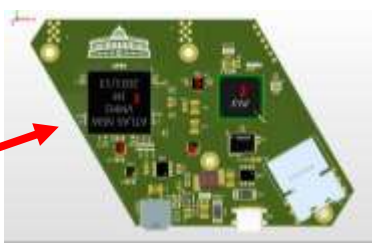
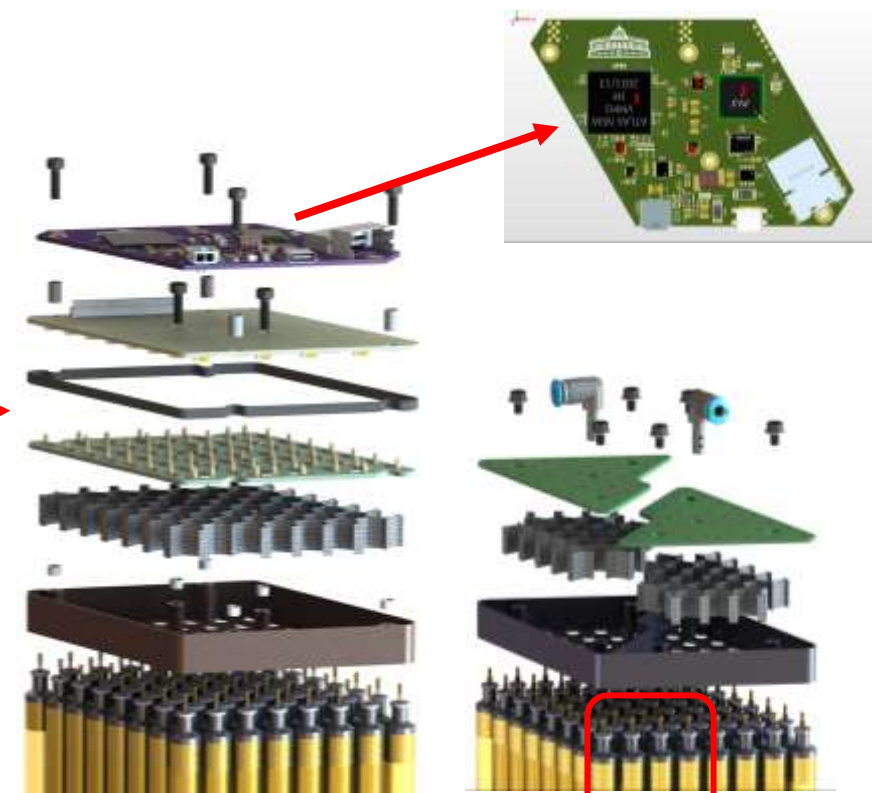
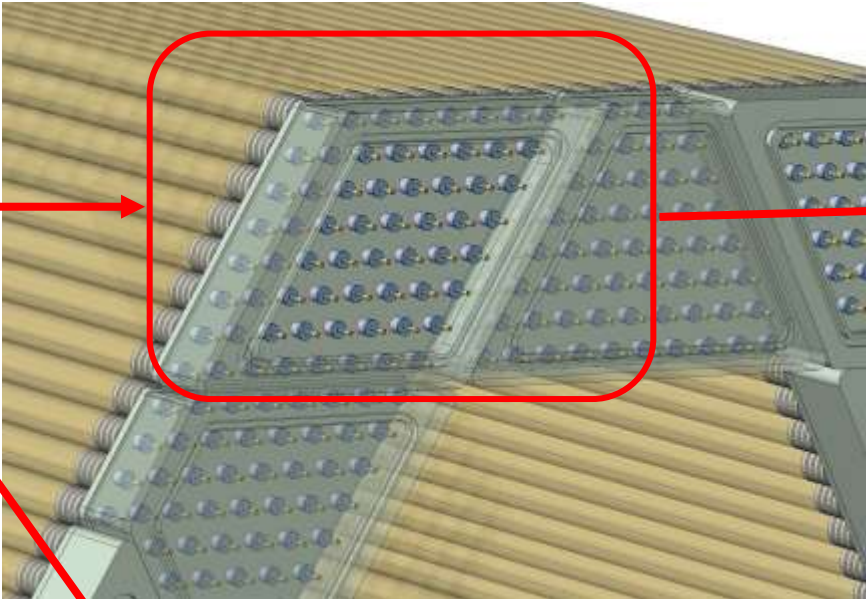
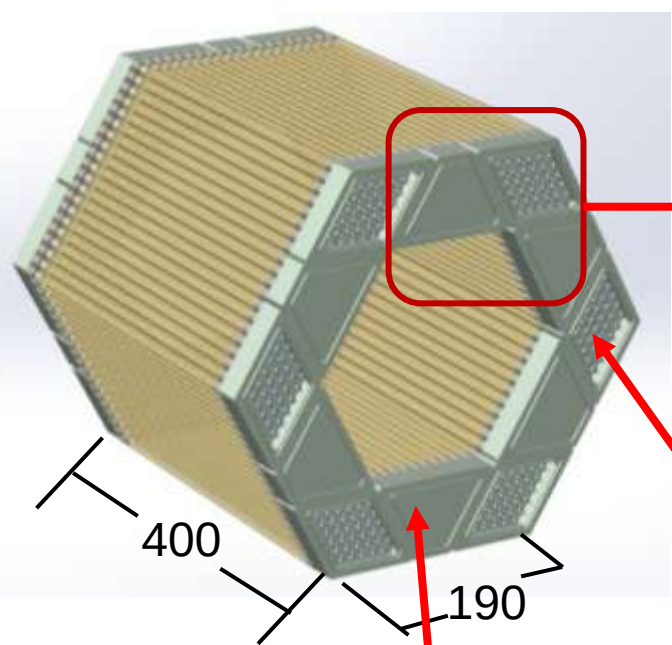
Current version:

- the innermost layers with 31/33 straws
- the sensitive barrel length 1966 mm
- The total barrel length (incl the gas manifolds and readout) 2186 mm
- Outer diameter 1751 mm
- Inner diameter 544 mm

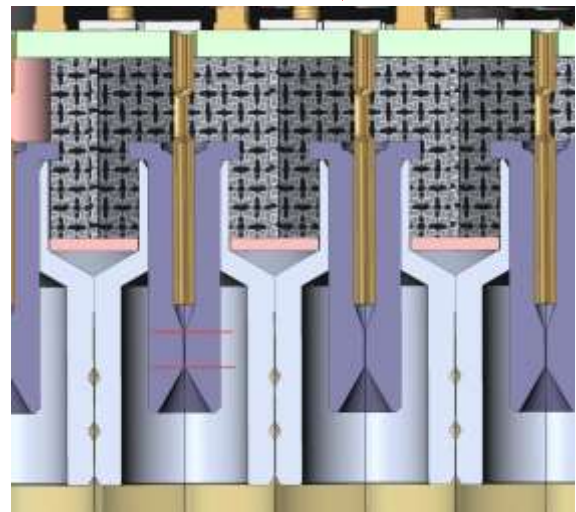
Modularity for 64 and 60 channels



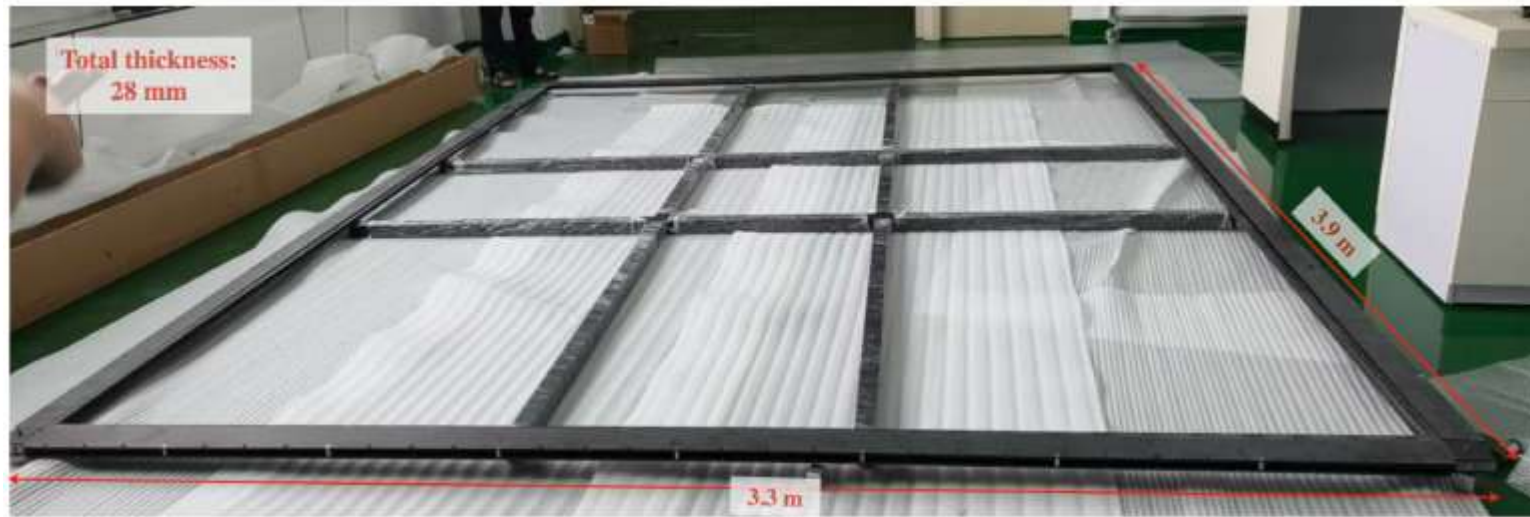
Prototyping



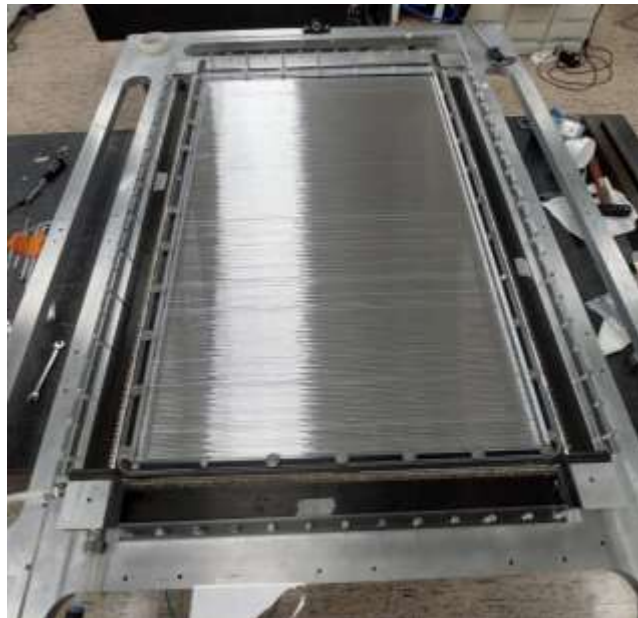
Numbers of straws-724 pcs
Length-400mm



Carbon Frame

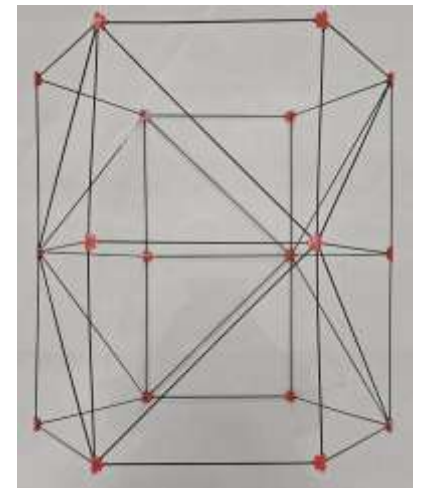


DUNE Frame 3.9x3.3m



**Prototype DUNE Frame
1.2x0.8m**

**Prototype SPD Straw
Tracker Frame 0.4m**



Thank you for your attention

