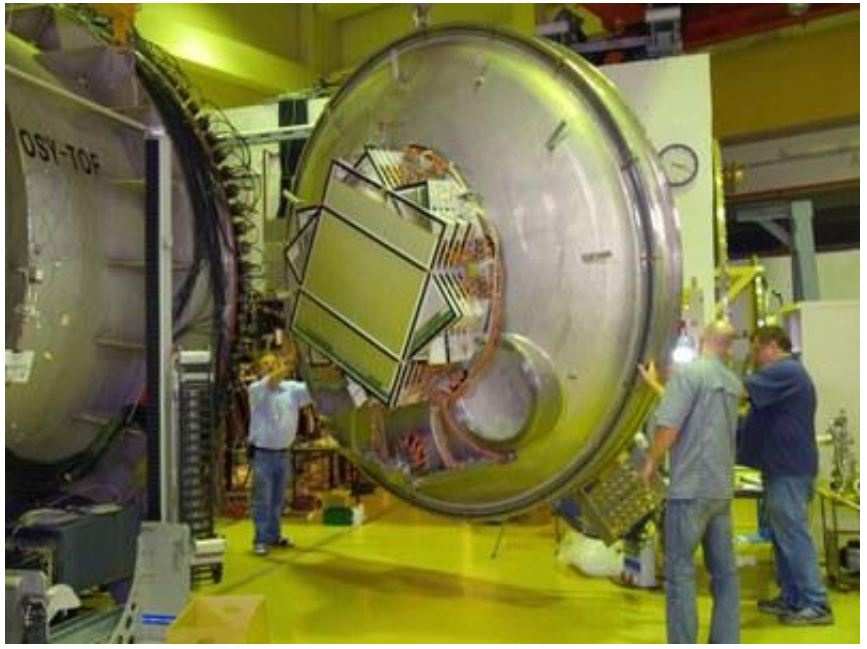
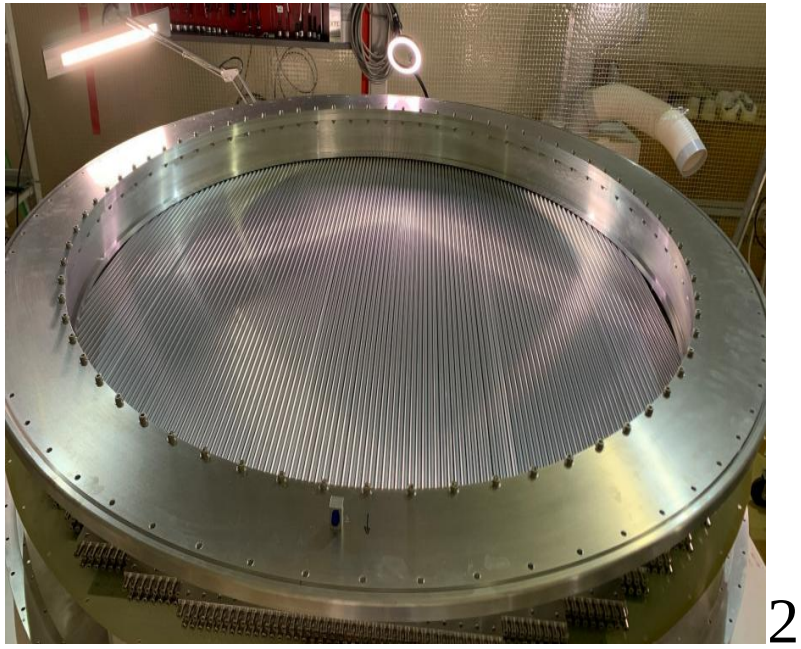
Current Status of Straw Ultrasonic Welding Technology and the SPD Straw Tracker

Temur Enik for the StrawTrackerRD team

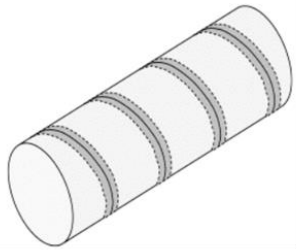
Why is Straw Tracker?

- thin walls - small material budget from 12 um
- it is possible to work in a vacuum
- large area – up to 5 m
- reasonable production cost
- good spatial resolution (100-200 um)
- possibility to use time-over-threshold or ionization charge measurements for noise reduction or particle identification at low momenta
- can work with over pressure over large areas

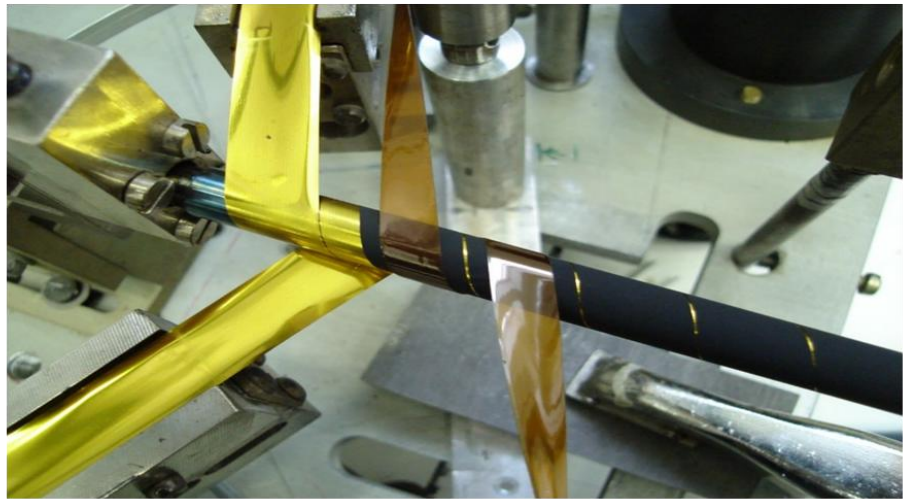




STRAW winding

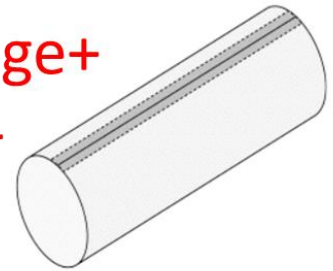


- radiation resistance+
- shape retention+
- diffusion of gases-
- elastic deformation range-
- sensitivity to humidity-

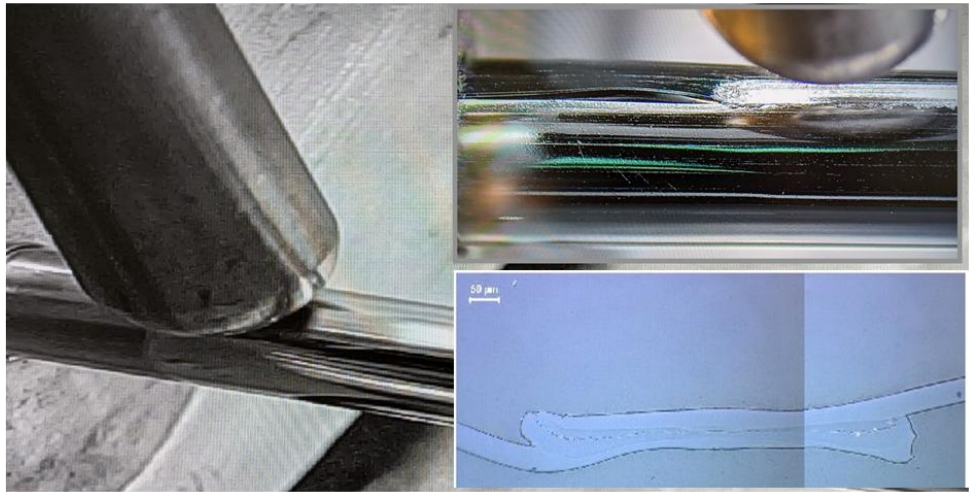


ATLAS, LHCb, COMPASS, COZY-TOF, NA64, Mu2e, PANDA, CBM...

STRAW welding



- elastic deformation range+
- sensitivity to humidity+
- diffusion of gases+
- retains shape under-pressure-
- radiation resistance-



NA62, COMET, SHiP, DUNE, SPD...

The straw trackers in the different experiments

Straw winding

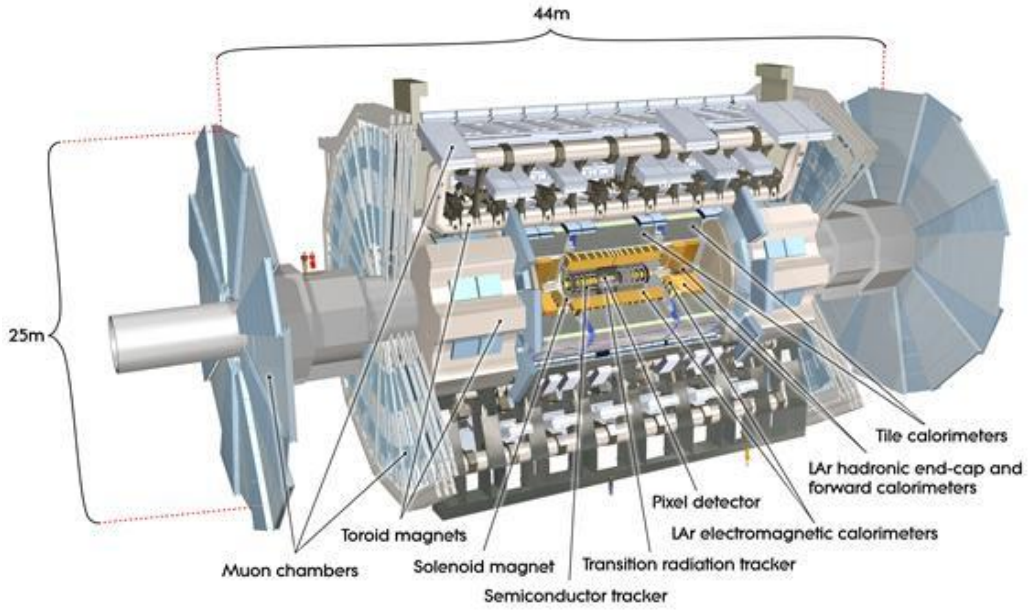
- Mu2e
- ATLAS
- LHCb
- COMPASS
- COZY-TOF
- NA64
- PANDA
- CBM
- SVD-2
- Glue-X
- Muon g-2
- OKA
- …

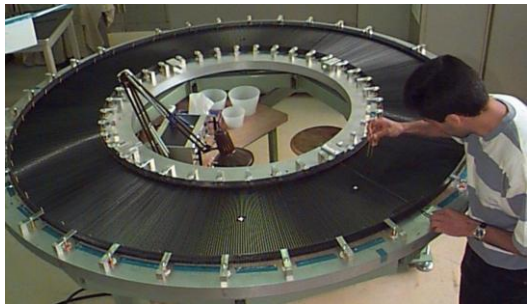
Straw welding

- NA62
- SPD
- KEDR
- COMET
- SHiP
- DUNE
- VES
- HIPTAN
- …

Straw winding-ATLAS, COMPASS

Пешехонов В.Д





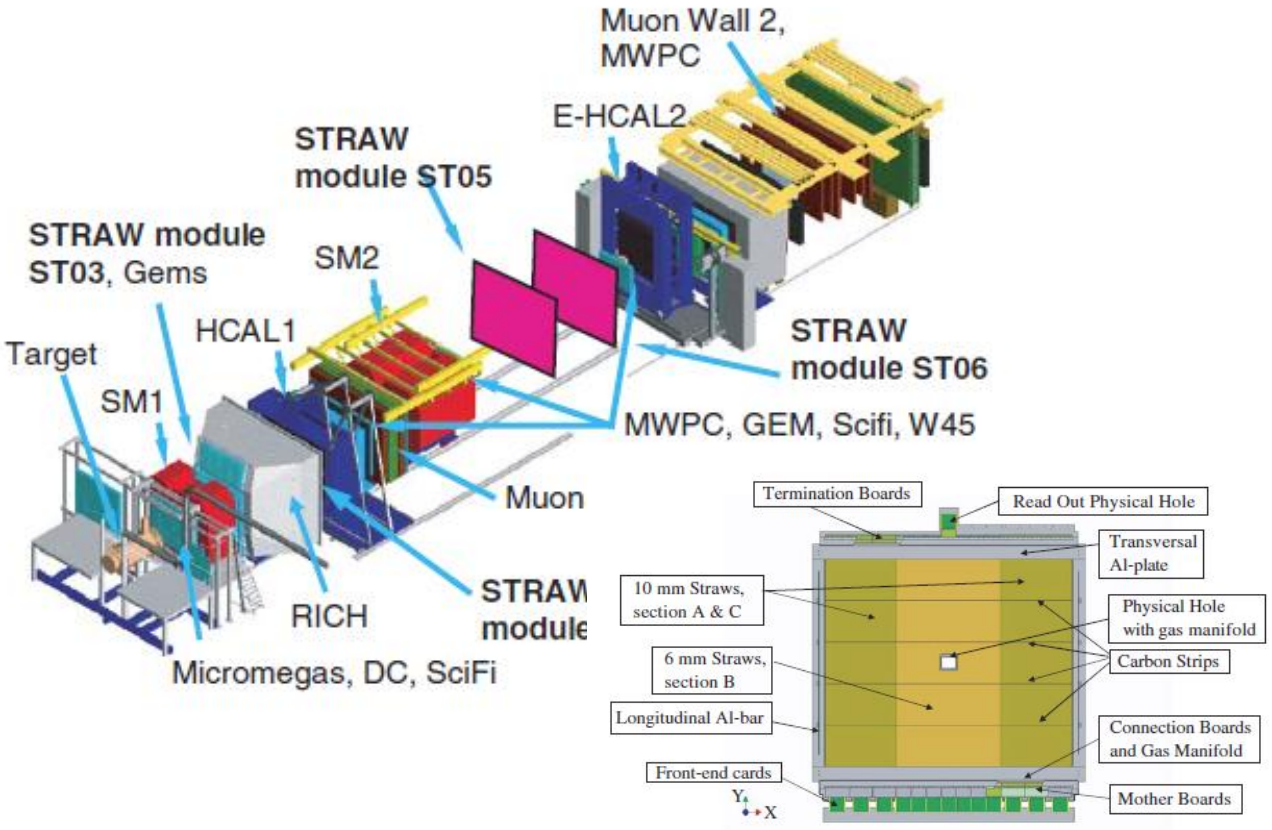


Fig. 2. Schematic view of a chamber (type X).

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

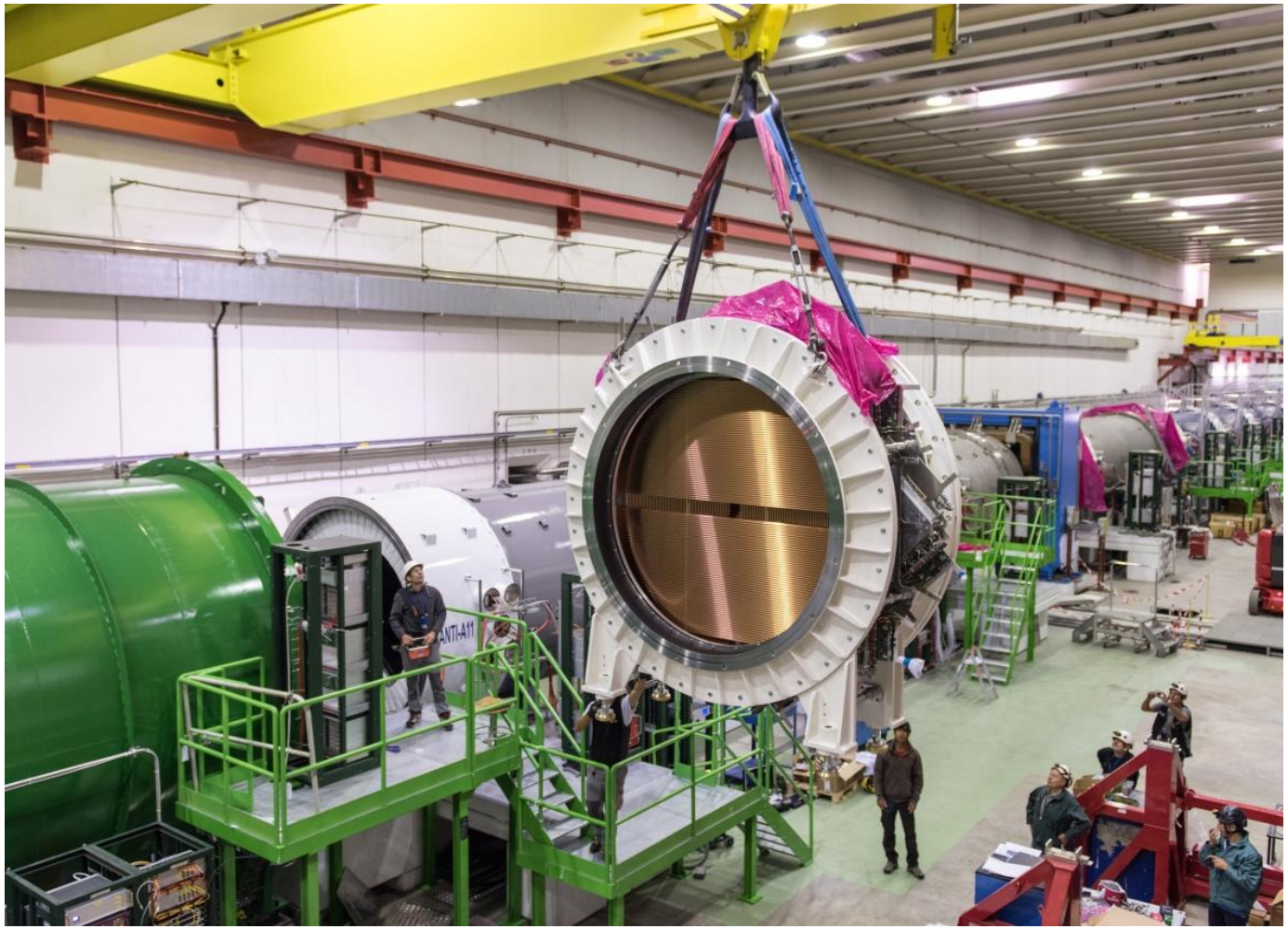
12440 straws
2802x3232(mmxmm) for X
3254x2427(mmxmm) for Y

Straw welding-NA62

Кекелидзе В.Д
Потребеников Ю.К

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+CO_2 (70:30)**
- **4 chambers, 7168 straws in vacuum**
  - ~30 straw hits per track
- **Total material budget: 1.7% X_0**
  - 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



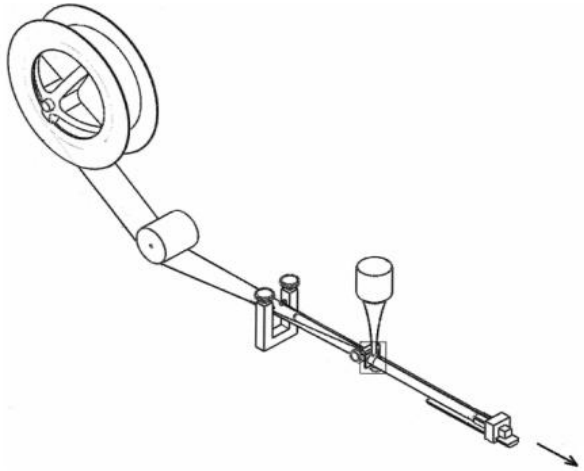
Different Methods Ultrasonic Welding Technology(USW)

UltraSonic Welding

welding along the tube

spiral winding + welding

sliding Mylar film,
ultrasinic head at fixed position



technology development : JINR

fixed Mylar film,
ultrasinic head is sliding

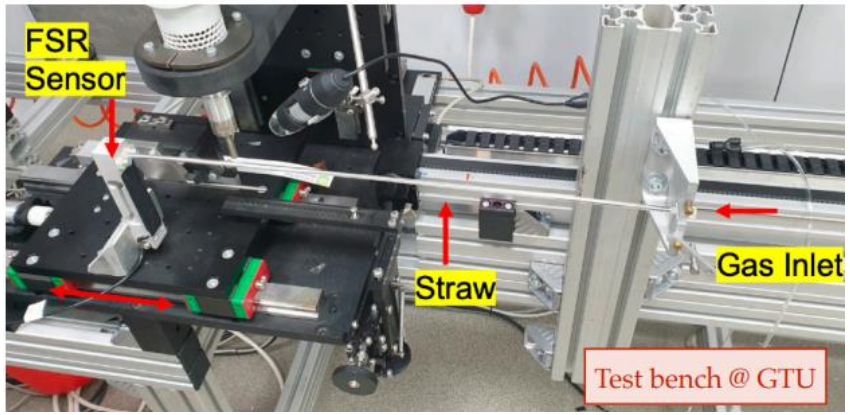
- IHEP Protvino (125 um)
  more details: by Rinat Fakhrutdinov
- JINR - thin wall straws

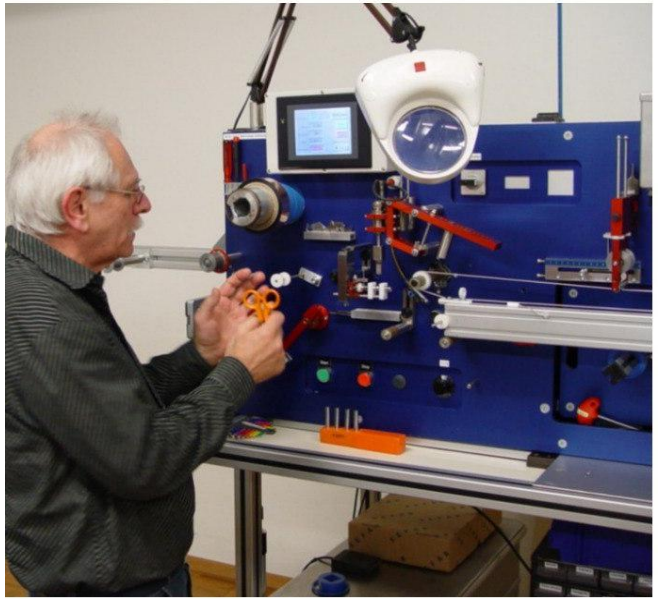
development :

- commercial
  by Jeffery L Lacy (US)

- BINP Novosibirsk
  more details: the link

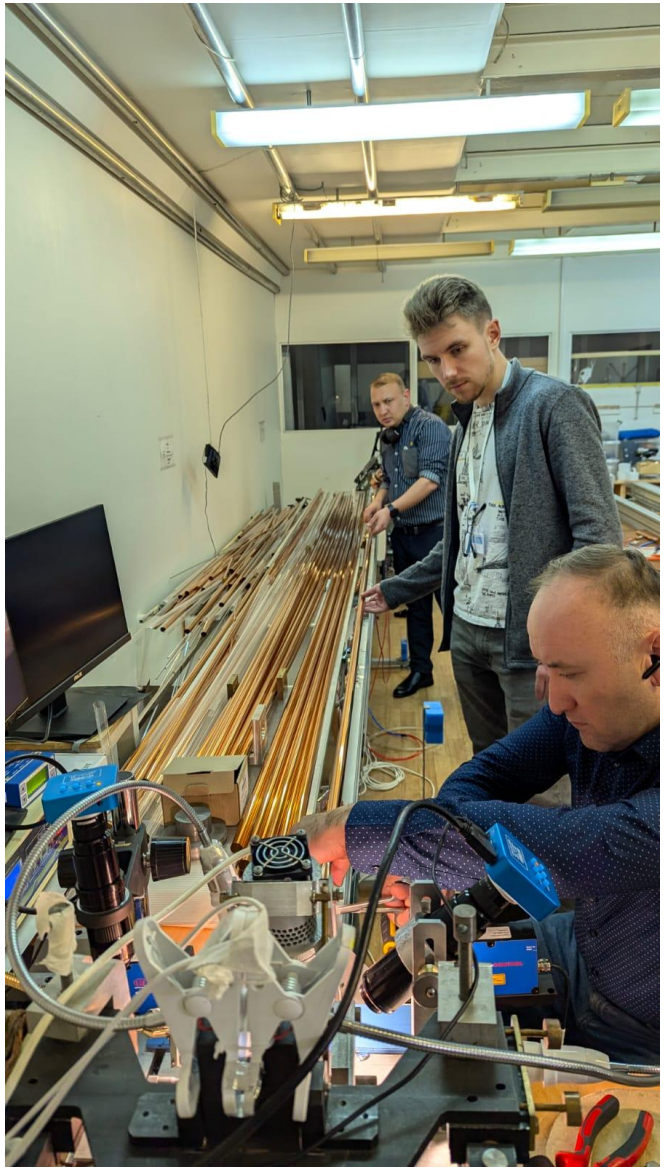
Straw welding-production lines



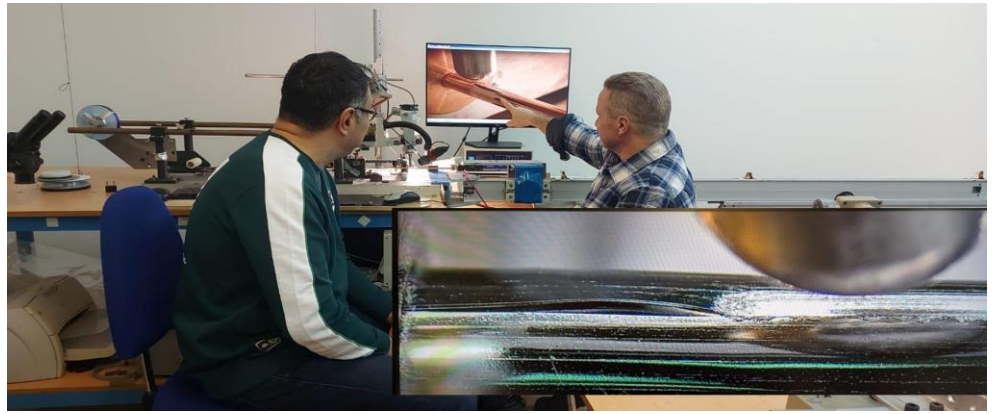


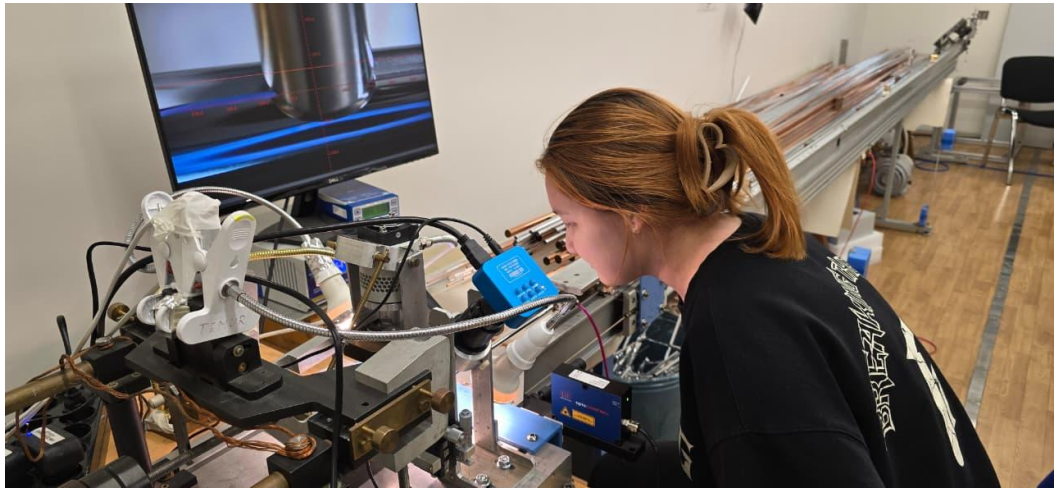
- JINR (Dubna) – operational for mass production
- GTU (Tbilisi) - operational
- SEFAR (Swiss industrial company) - operational
- PNPI (Gatchina) - developing
- INP (Almaty) - developing mass production lines
- IHEP (Protvino) - operational for mass production
- PTI (Houston industrial company)-operational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

“Old” Straw production line at JINR

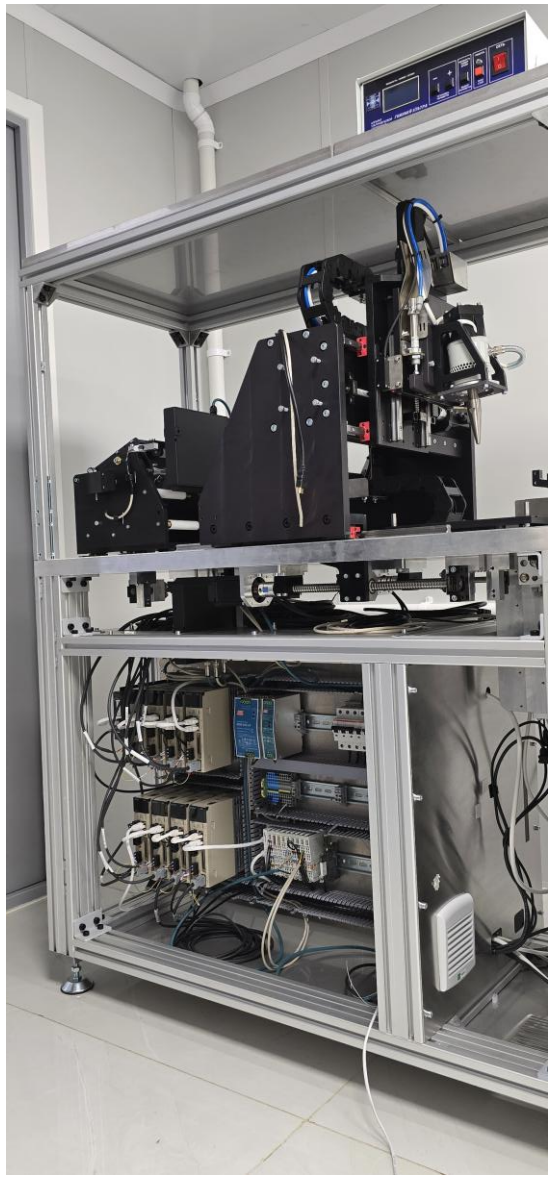


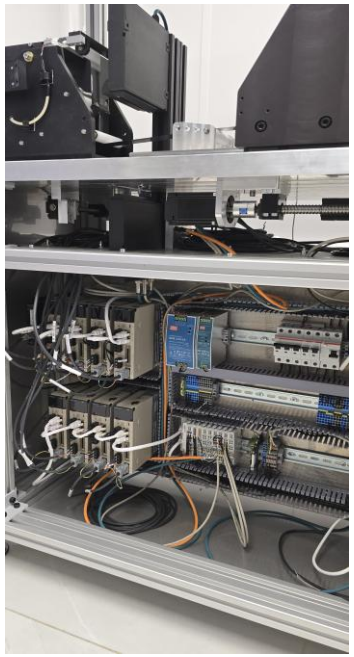
- added a new microscope with better resolution for visualization
- improved the seam positioning system
- production line speed 1 m per minute
- active work is underway in the field of R&D with colleagues from the INP

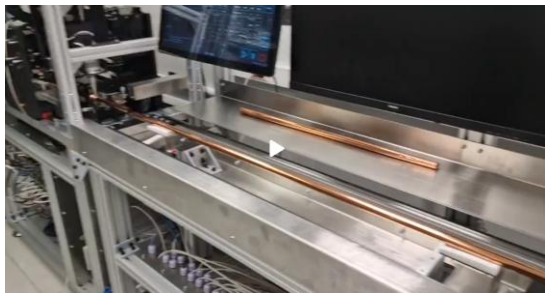


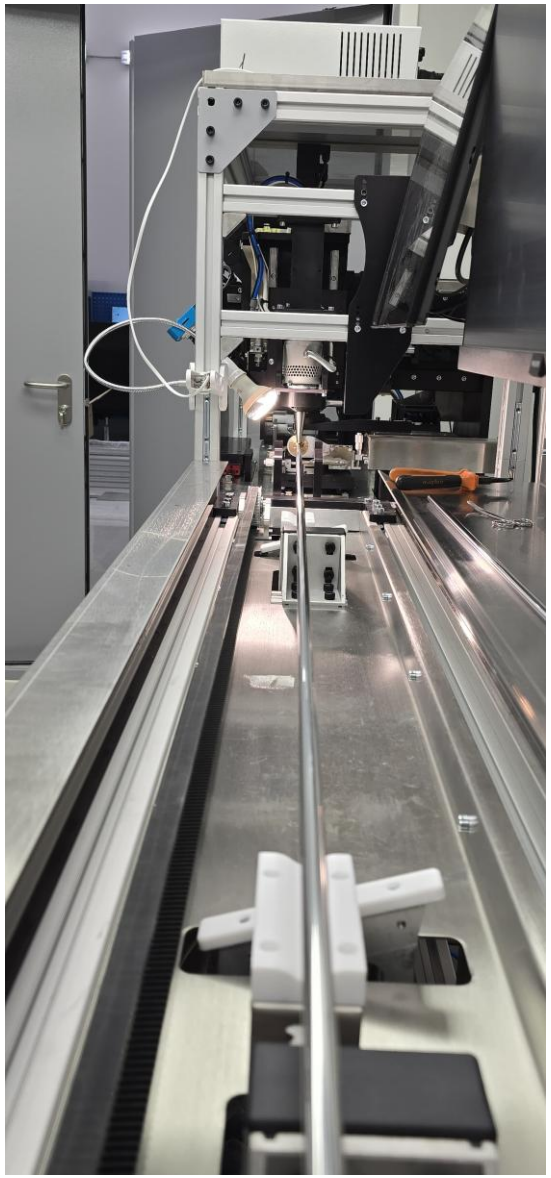


New Straw production line and assembling place JINR



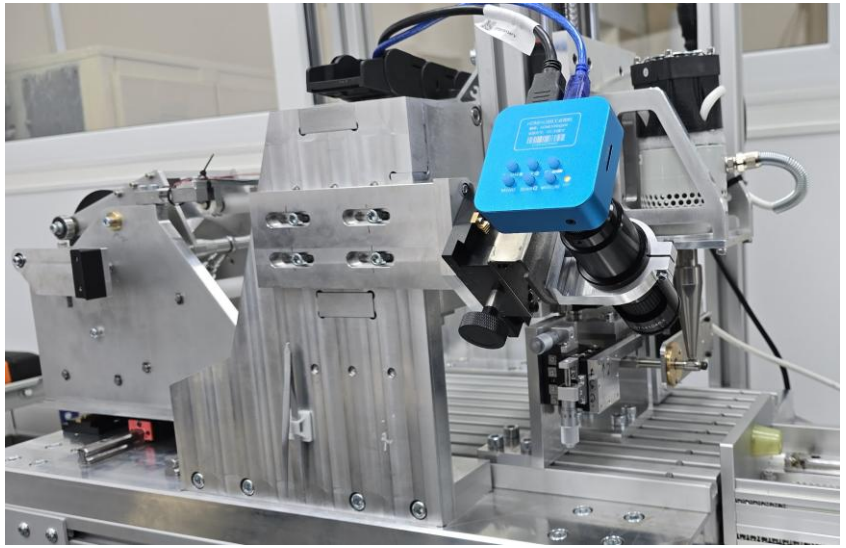




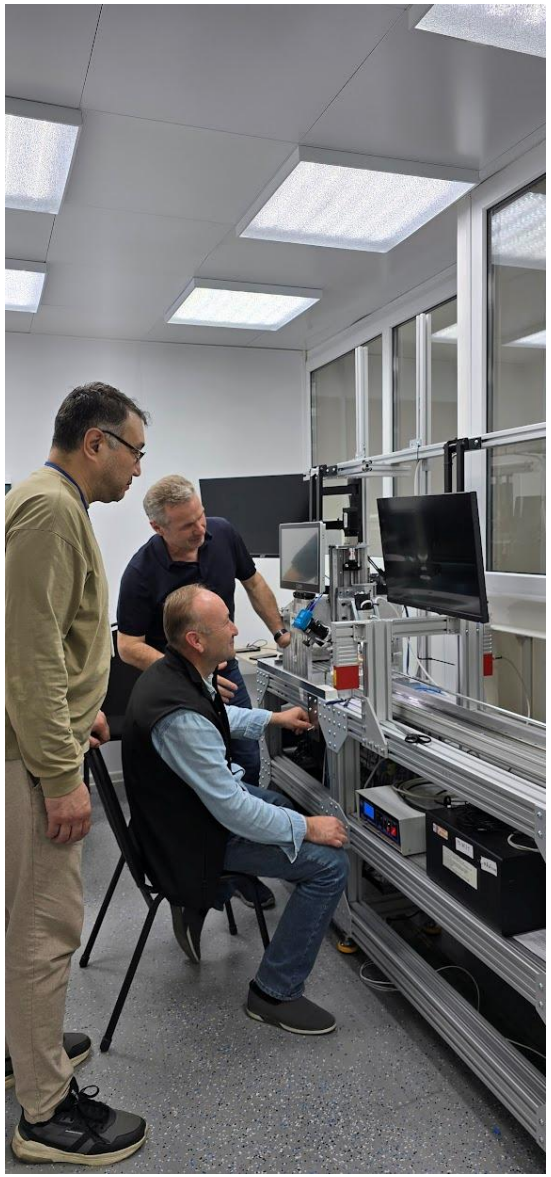


- Area ~200 sq.m., clean room~100 sq.m, machine shop and assembling hall~50 sq.m and 8,5 m high
- Production line length~12m
- Fine-tuning work began successfully and the first 12 meter straw was welded
- The possibility of integrating AI into the production and quality control process is provided

Straw production line and assembling place at INP(Almaty)

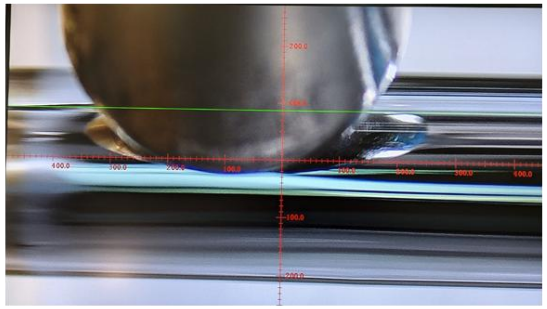


- The line was manufactured and successfully tested at JINR
- INP(Almaty) engineers and physicists took an active part in the developt and testing
- The line is disassembled and shiped to Almaty.
- Commissioning work is planned to be carried out in June
- Production is scheduled to start at the end of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



Advancing the USW technology : production quality control

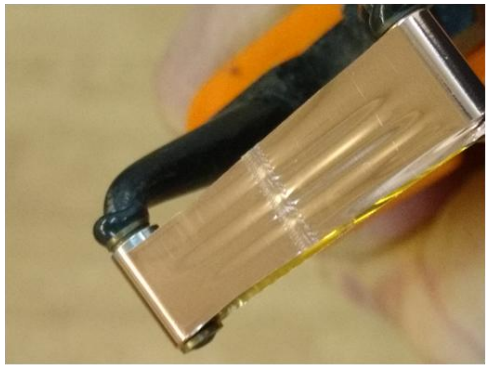
During production:



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

Fig. 6 Controller CU

A measurement system consists of:
- laser
- receiver
- controller

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

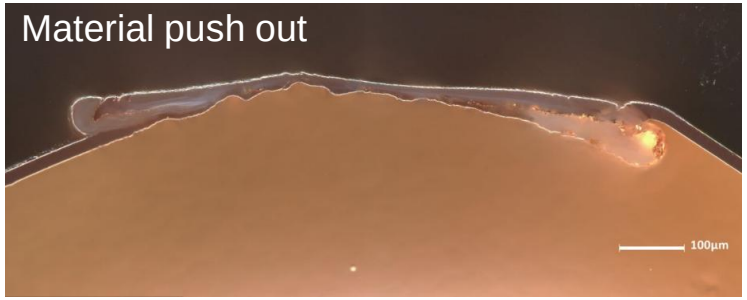
Quality control of welds at CERN- Cross sectional

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

Strong

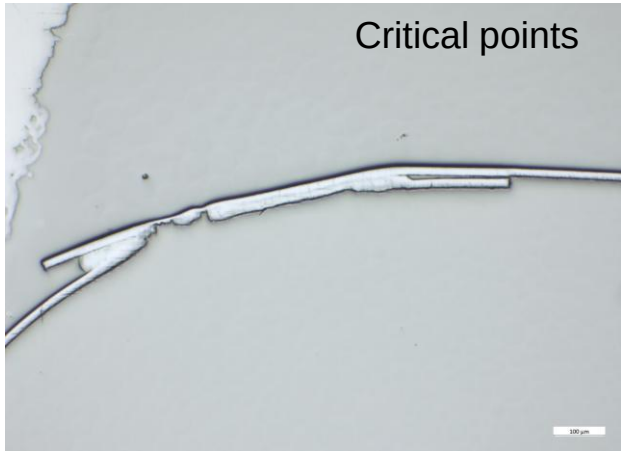
A good weld interface showing a strong “double thickness” maintaining the mechanical strength of the part, with extremities bonded and no thinning or critical points.

Uncertain

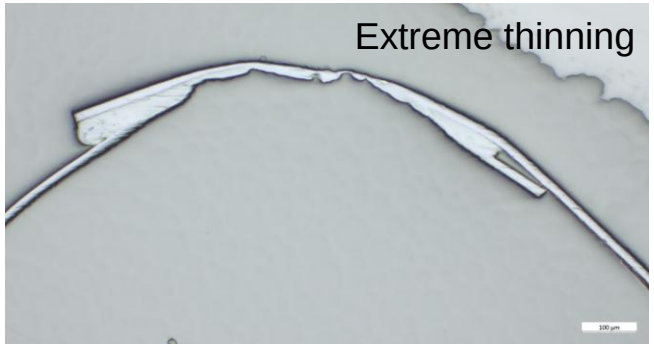


Unbonded extremities cause a risk due to the reduction in the length off bonded interface so need to be limited. Moreover, risk due to the presence of a stress concentrator.
Material push out risks the reduction of “double layer” required for optimal mechanical strength.

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.

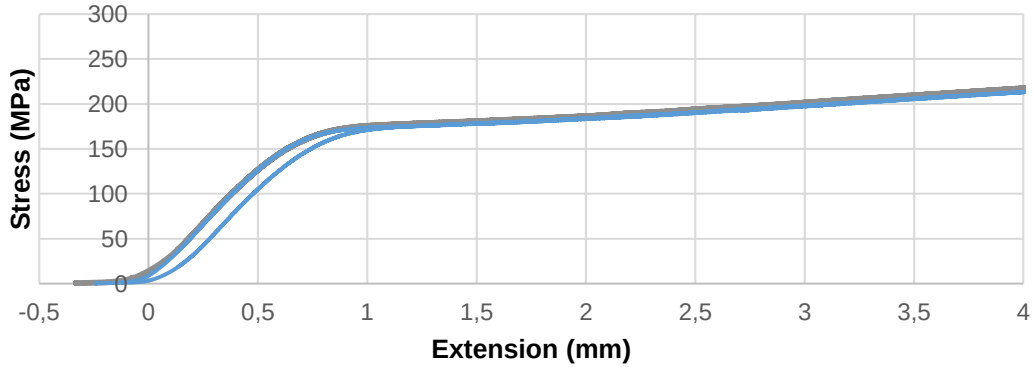


Mechanical testing- Results

	NA 62 2010	NA 62 NEW 2022-2023	DUNE 2024	DUNE 2025	R & D	SHiP 2025	NA 62 NEW 2022-2023	NA 62 Future 2025
Weld Company	JINR	JINR	JINR	JINR	JINR	JINR	SEFAR	SEFAR
Samples					10	15		24
Metallization	Cu & Au	Cu & Au	Al single layer	Al double layer	Al single layer	Cu & Au	Cu & Au	Cu & Au
Thickness of film (μm)	36	19	19	19	36	36	19	19
Diameter (mm)	10	5	5	5	10	20	5	5
Stress at break (MPa)	103.5 ± 0.9	101.6 ± 20.8	95.99 ± 19.64	72.09 ± 12.89	232.5 ± 15.3	256.50 ± 23.52	95.5 ± 6.60	6.37 ± 3.05
Force at break per unit length (N/mm)	3.6 ± 0.14	2.05 ± 1.11	1.82 ± 0.37	2.75 ± 0.49	9.30 ± 0.61	10.26 ± 0.94	1.81 ± 0.13	0.97 ± 0.03
Elastic modulus (GPa)	-			51.79 ± 4.87				

Due to samples changing thickness, results are not yet normalised

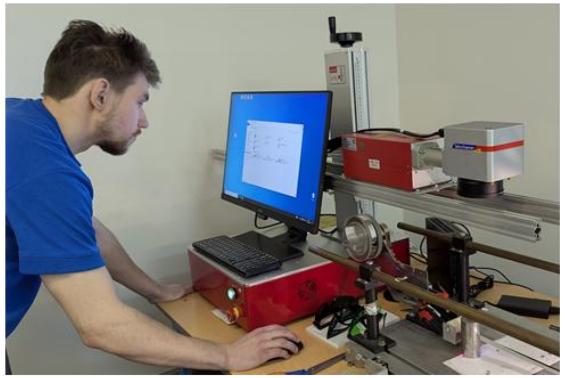
20 mm Stress vs Extension curves

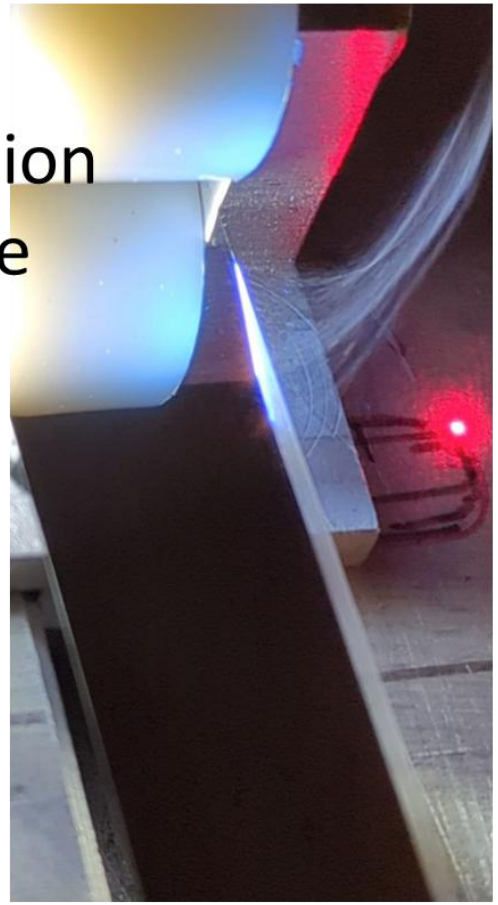


Advancing the USW technology : production from double-side Al-metalized film

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

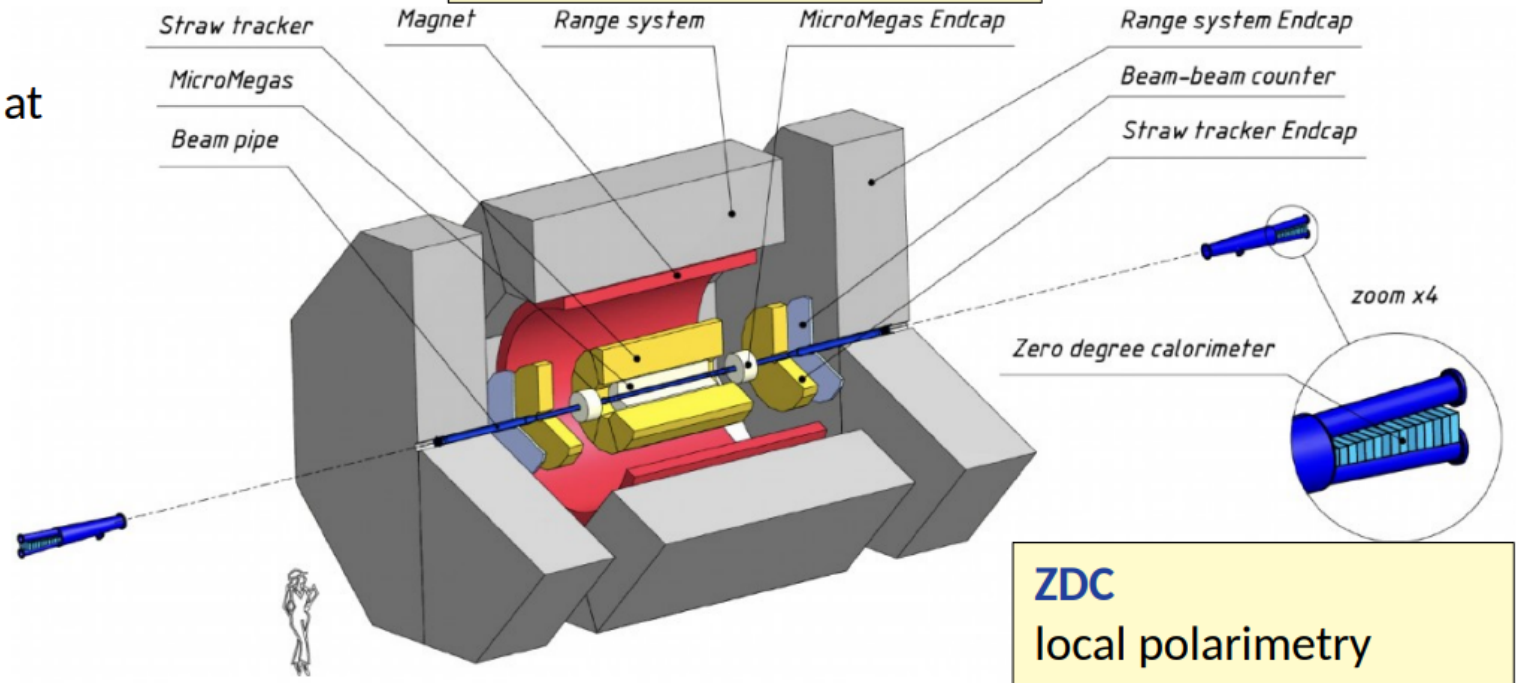
SPD initial stage

Denisenko Igor

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

- Polarized and unpolarized phenomena at **low energies** (3.4 GeV < $\sqrt{s_{pp}}$ < 9.4 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

Magnetic field up to **1.2 T**



Range System
muon identification and coarse hadron calorimetry

ZDC
local polarimetry
luminosity monitoring

BBC
local polarimetry
luminosity monitoring

Straw tracker:
- **σ ~ 150 μm**
- **σ(dE/dx) = 8.5%**

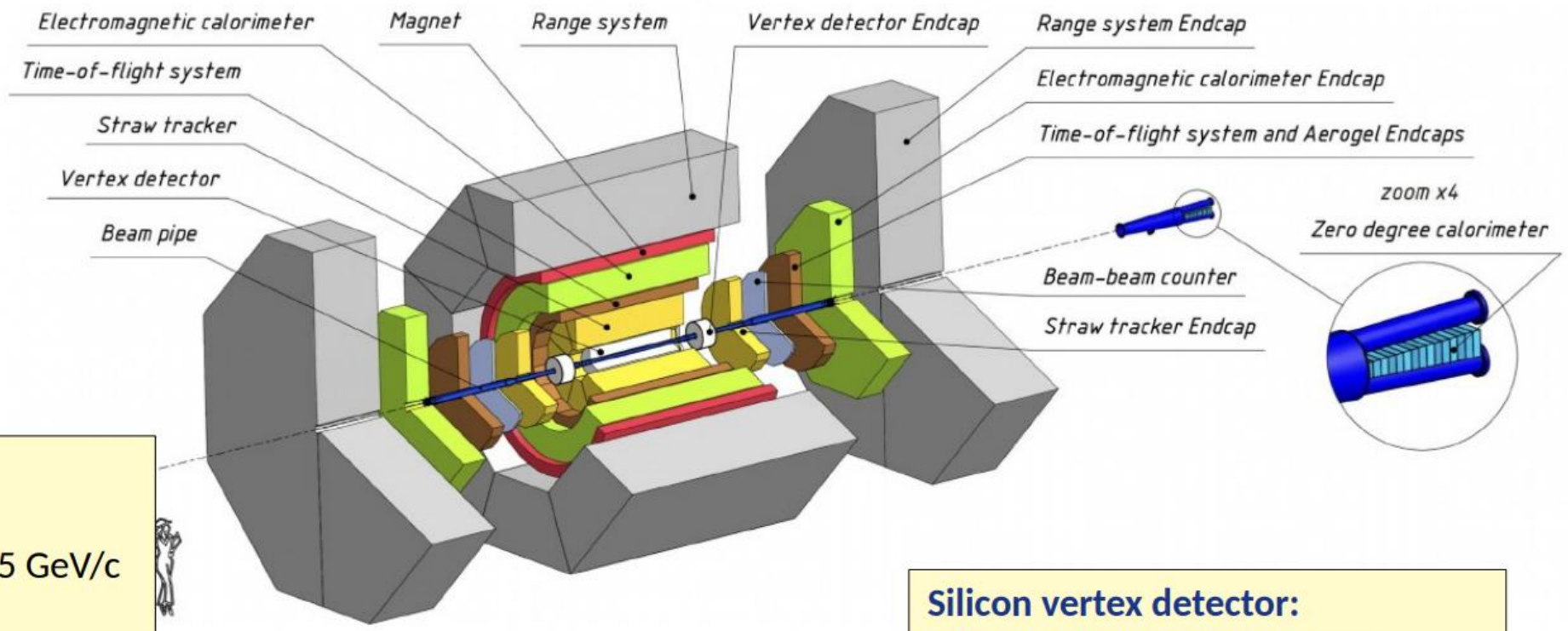
Micromegas central tracker:
σ ~ 150 μm

SPD final layout

Denisenko Igor

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

Electromagnetic calorimeter:
σE/E = 5%/√E ⊕ 1%



Time of flight system:
σ = 50 ps
3σ π/K separation for p < 1.5 GeV/c

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

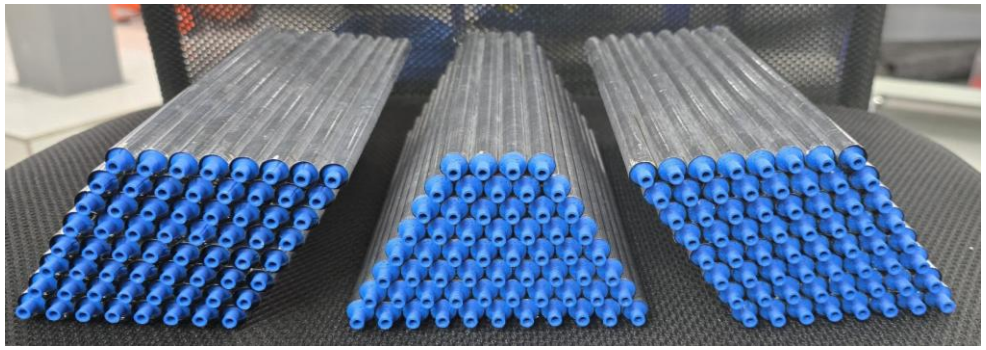
Silicon vertex detector:
- MAPS (4 layers): **σ = 10 μm**
- DSSD (3 layers): σ_φ **= 27.4 μm,** σ_z **= 81.3 μm**

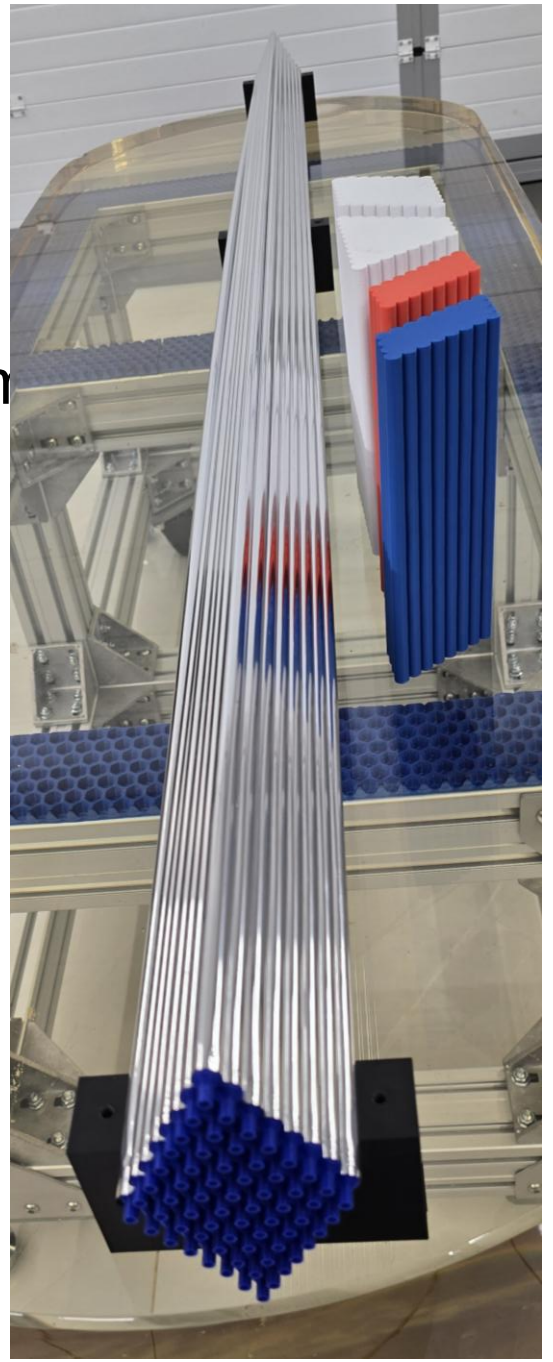
Geometry Concept

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 m
- Outer diameter 1751 mm
- Inner diameter 544 mm

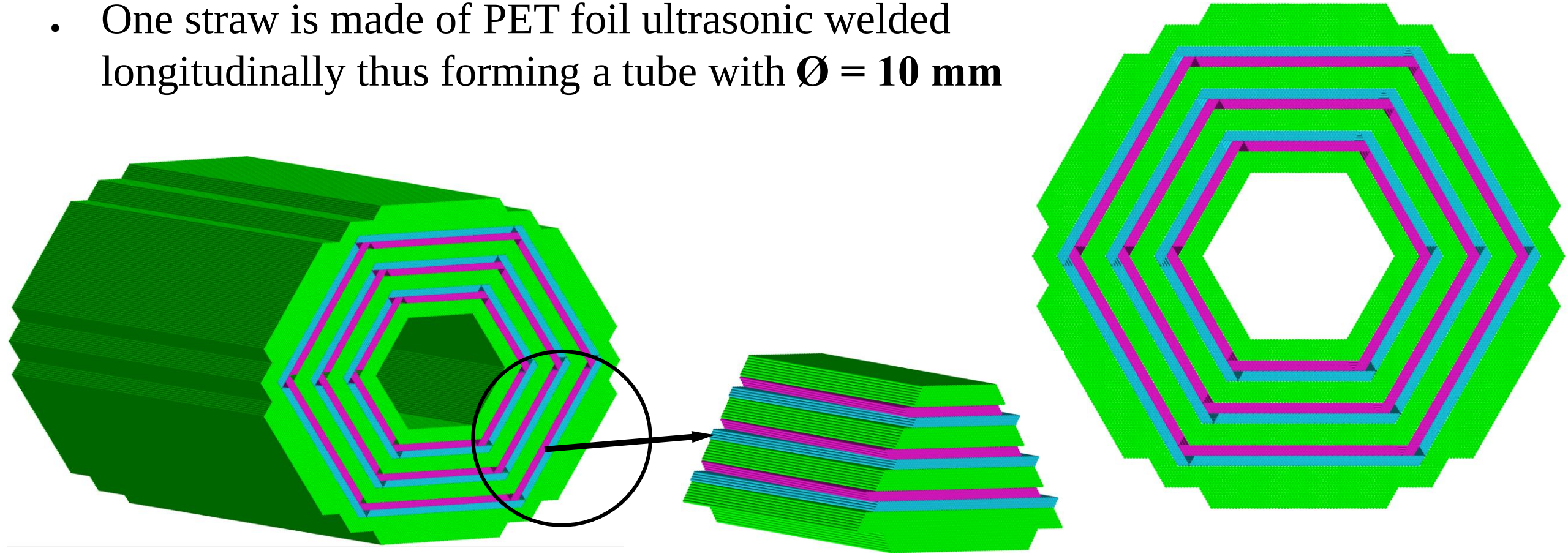
Modularity for 64 and 60 channels





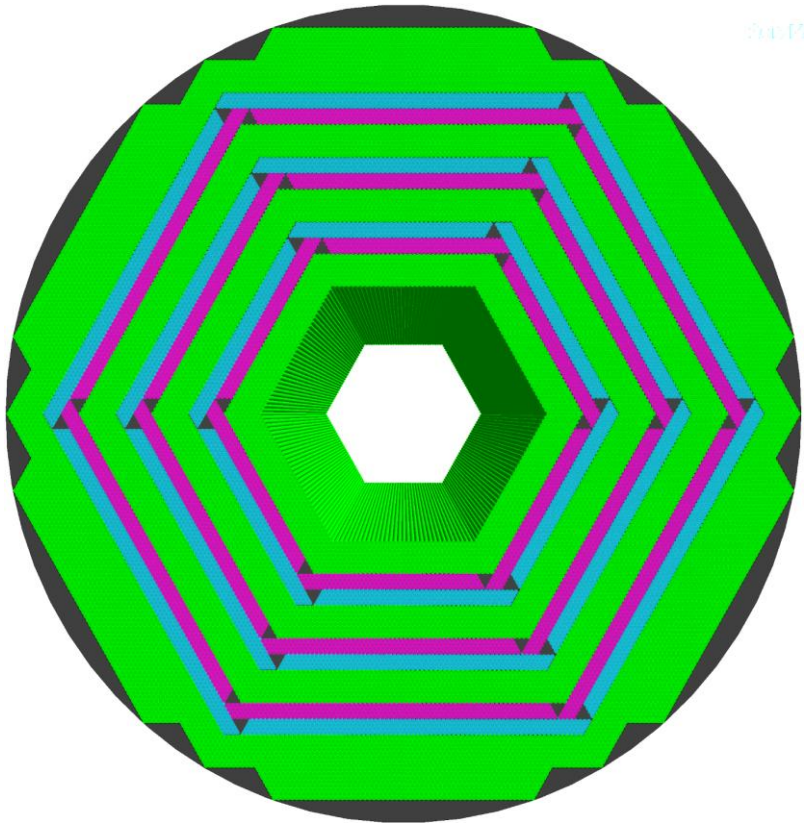
Barrel of Straw Tracker (new version)

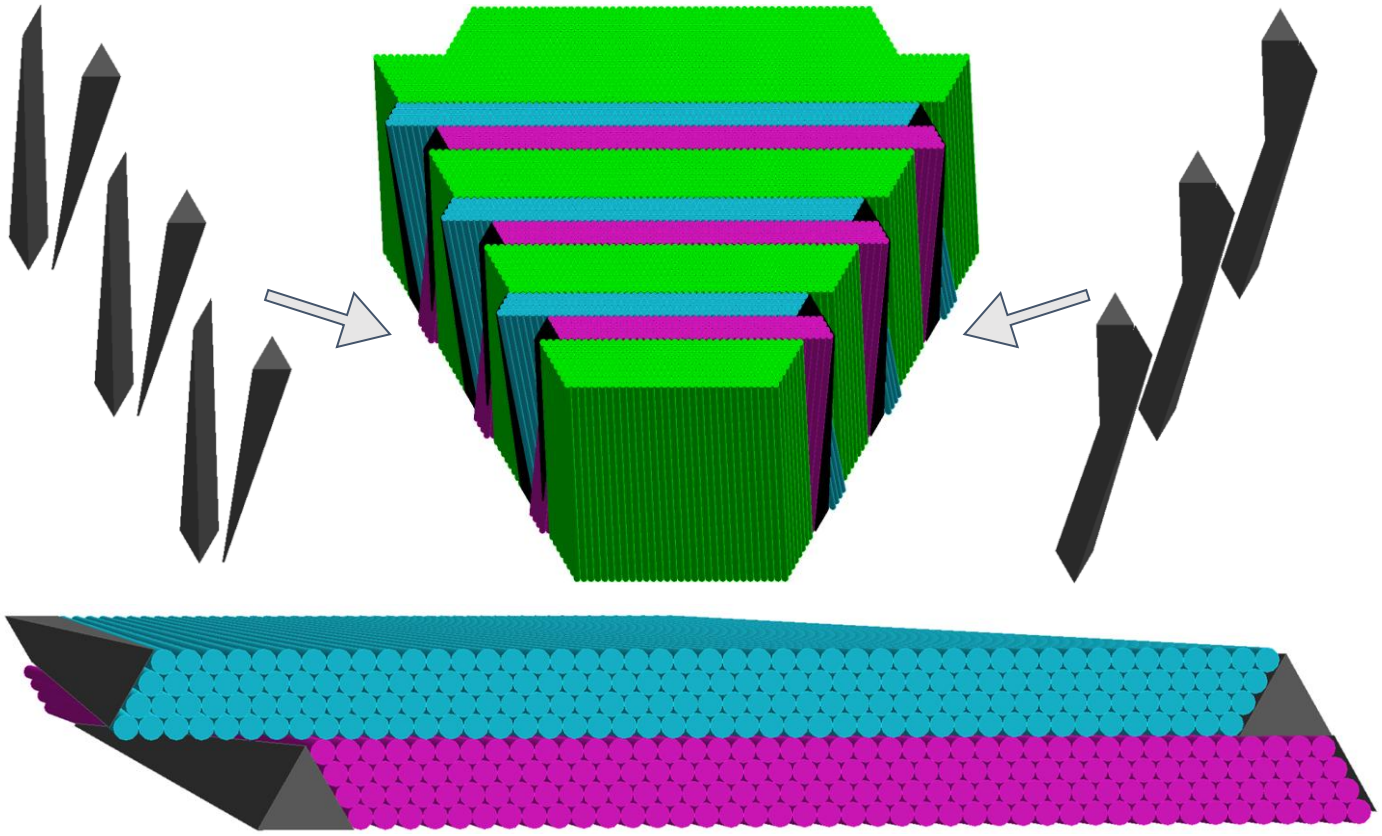
- ST barrel consists of **6 identical modules** (sextants)
- One sextant contains 3860 tubes in total, which are arranged in layers with orientation **Z, +1.24° , -1.24°**
- Total number of tubes is 3860 x 6 modules = **23 160 tubes**
- One straw is made of PET foil ultrasonic welded longitudinally thus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



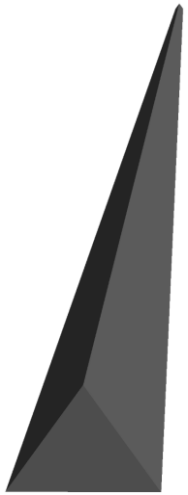
Inserts

- 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

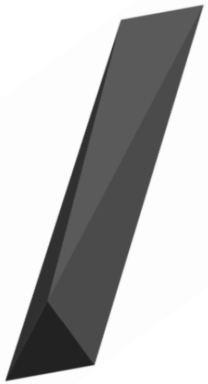




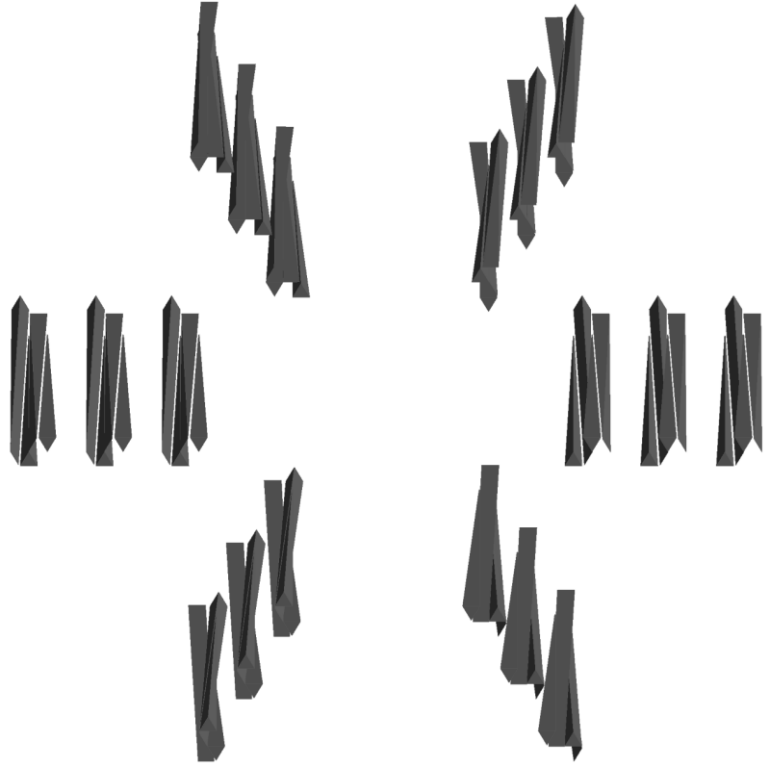
Inserts and cover

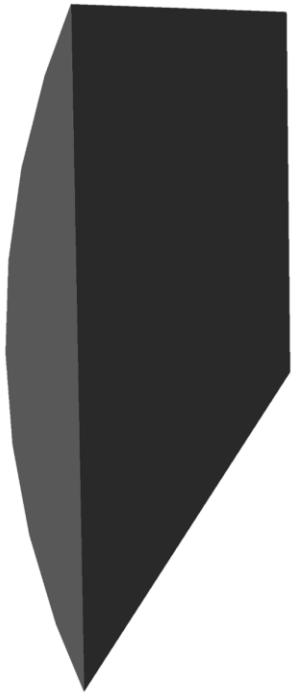


x 36 (Side Z+)

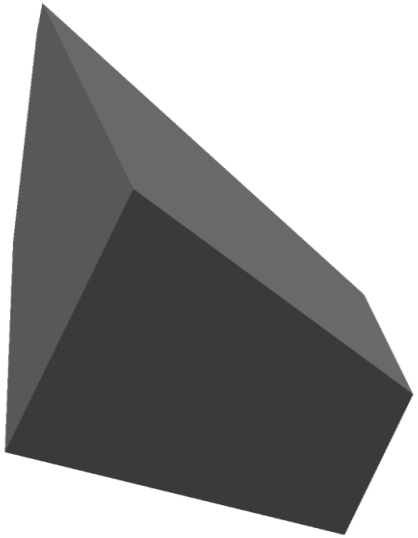


x 36 (Side Z-)

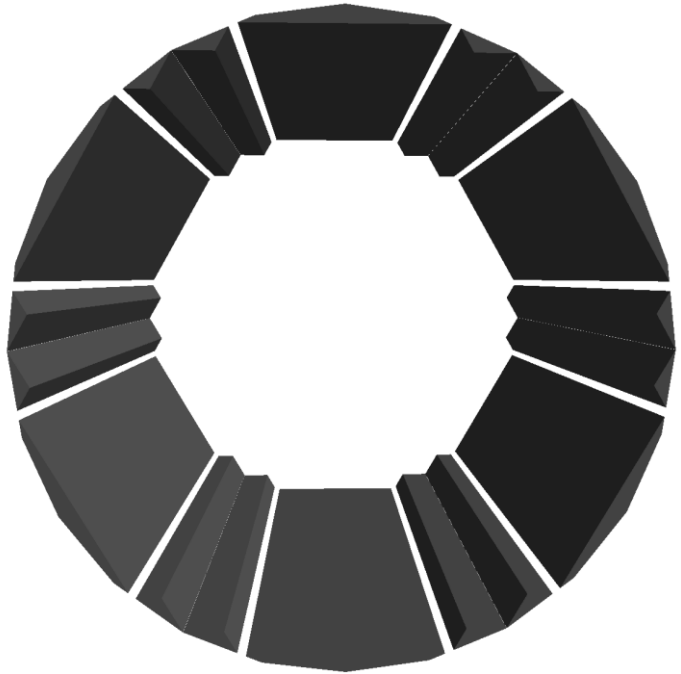




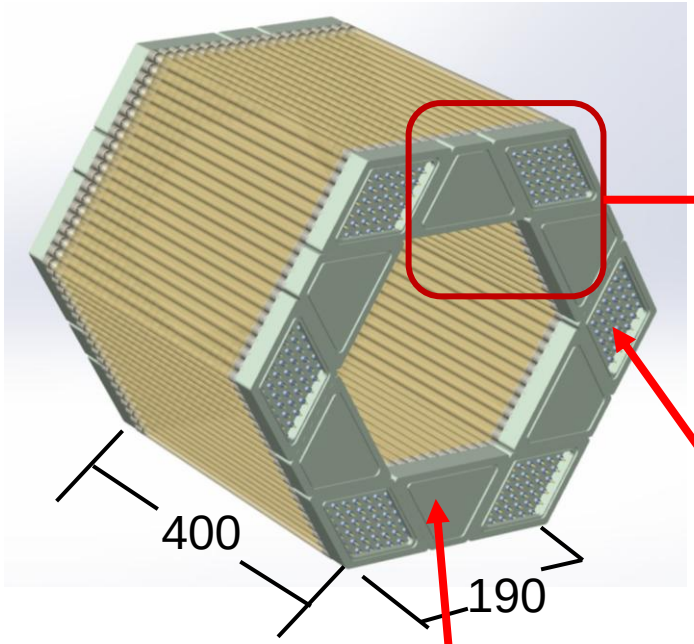
x 6 Cover-sector

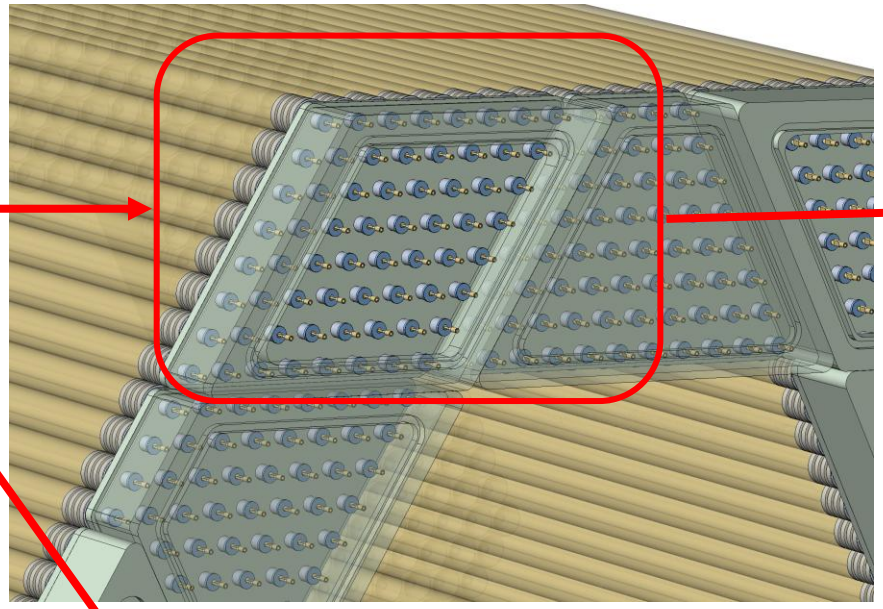


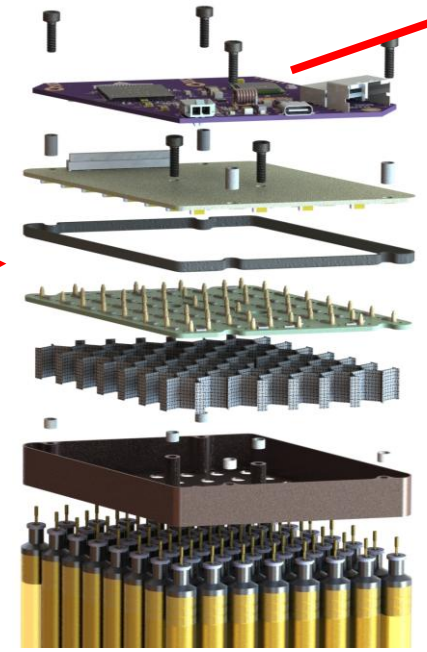
x 12 Cover-triangle

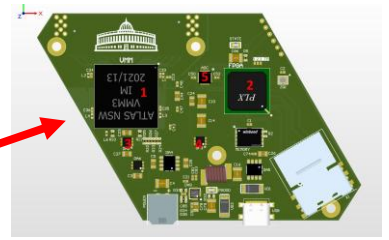


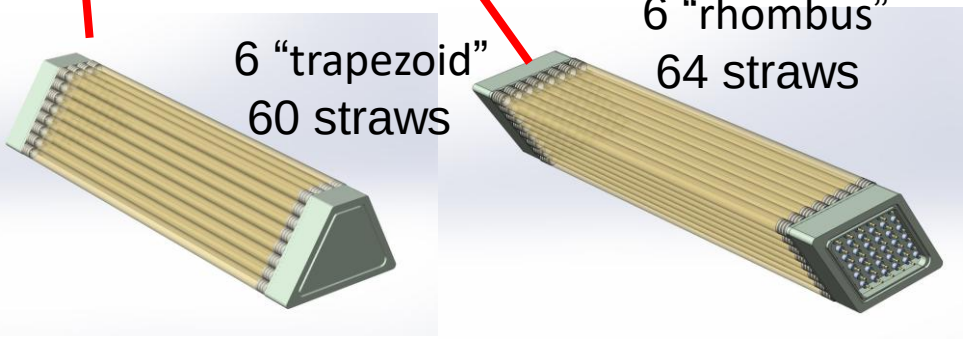
Prototyping



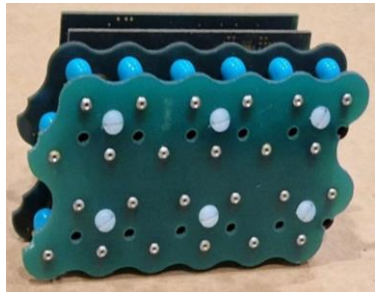




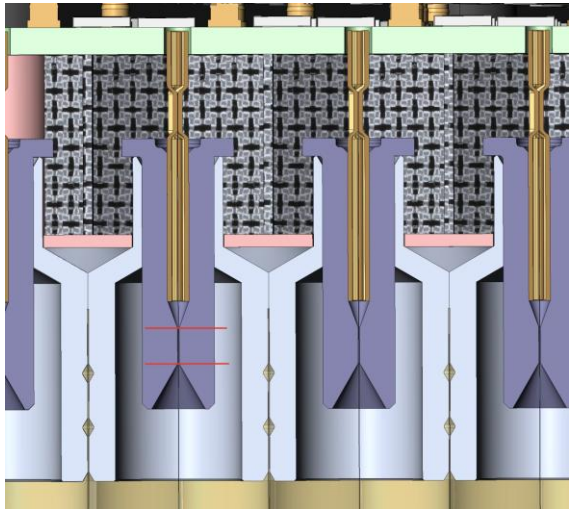




Numbers of straws-724 pcs
Length-400mm



Layot of electronic
ATLAS sMDT



Thank you for your attention