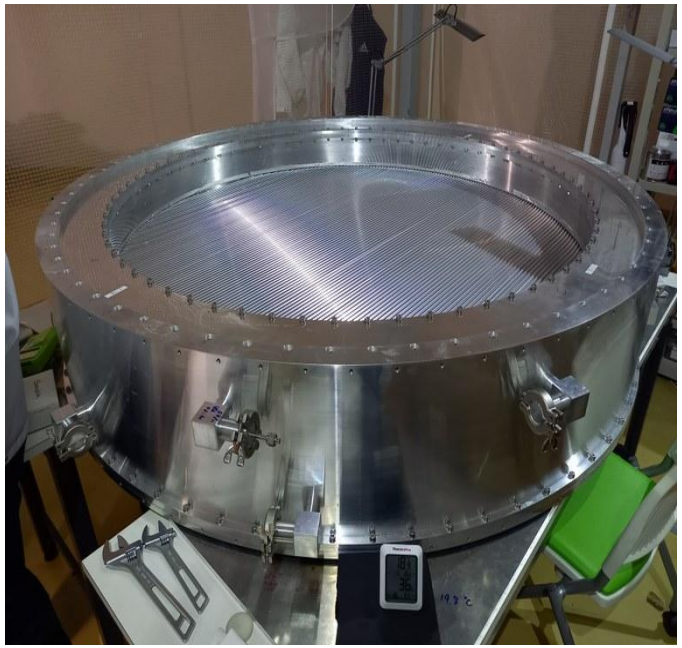
Welding Straw Technology

Temur Enik for the StrawTrackerRD team

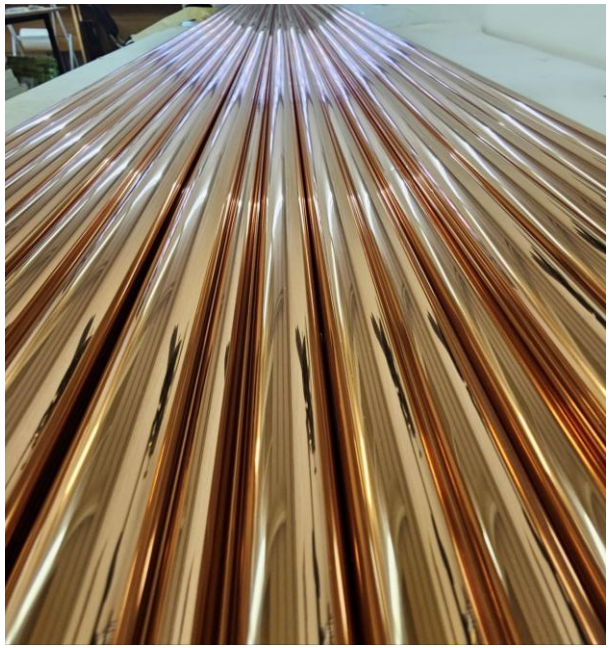
Why a Straw Tracker?

- thin walls - small material budget from 12 um
- it is possible to work in a vacuum
- large area – up to 10 m^2
- 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

NA62

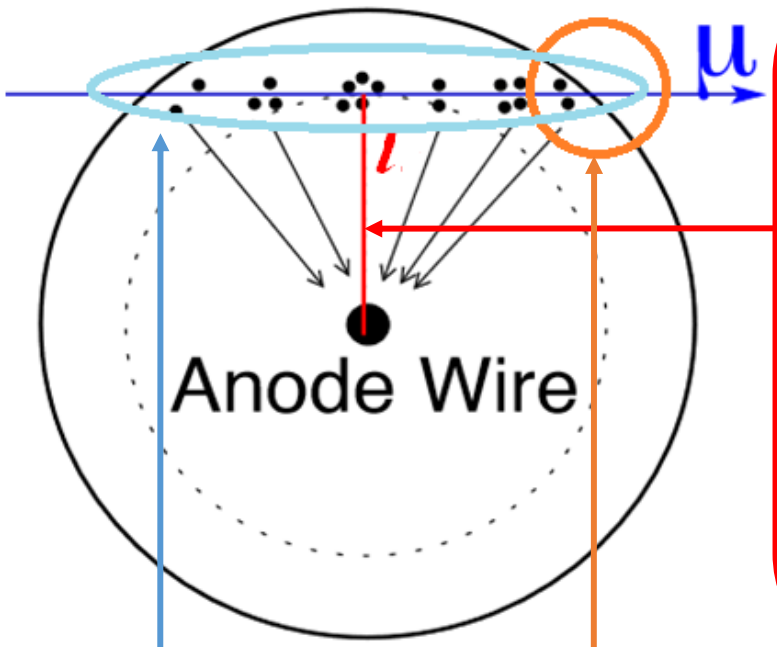


COMET



SHiP

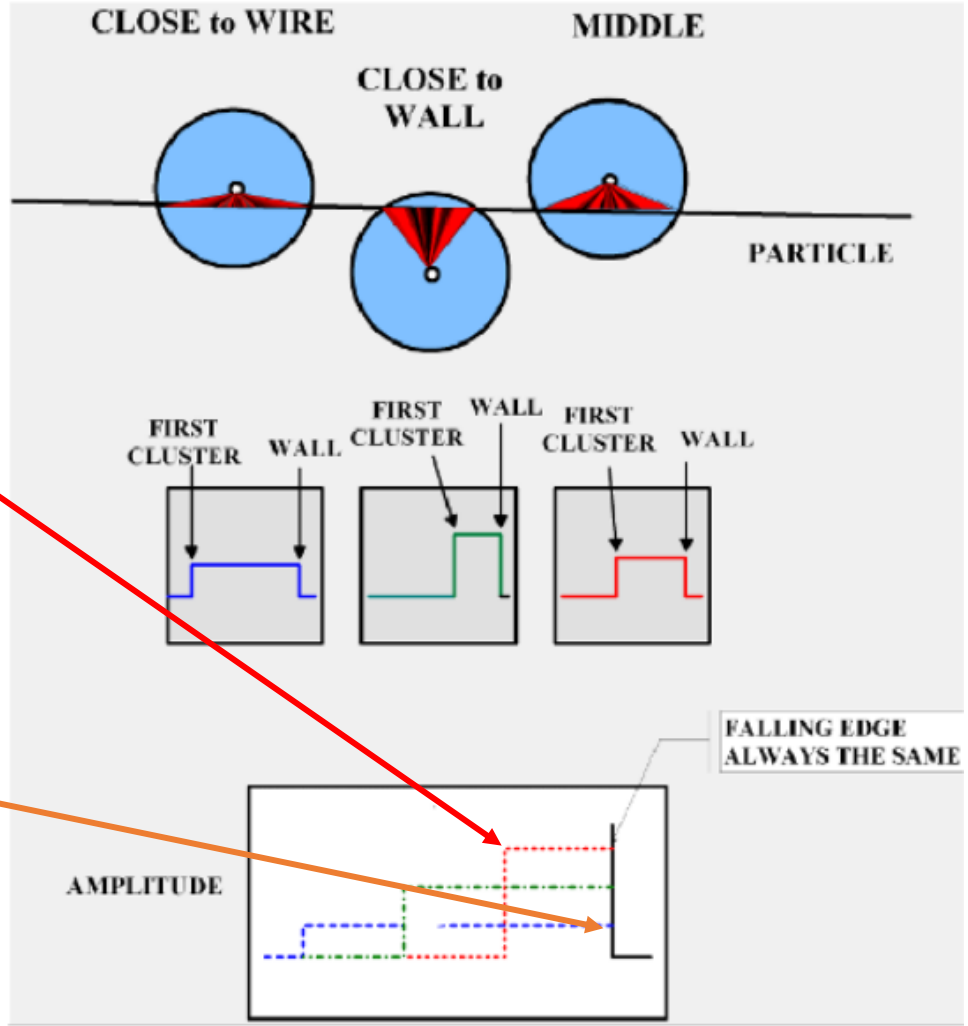
Detection process



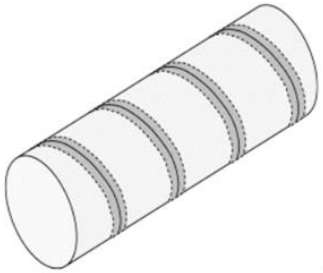
Principle of a straw position measurement. A ionizing particle passes at the distance ***l*** from anode wire, creating ionization clusters along its path. The primary electrons will drift to the anode wire.

Possibility of using the latest electron signal (from straw wall) as a self-trigger

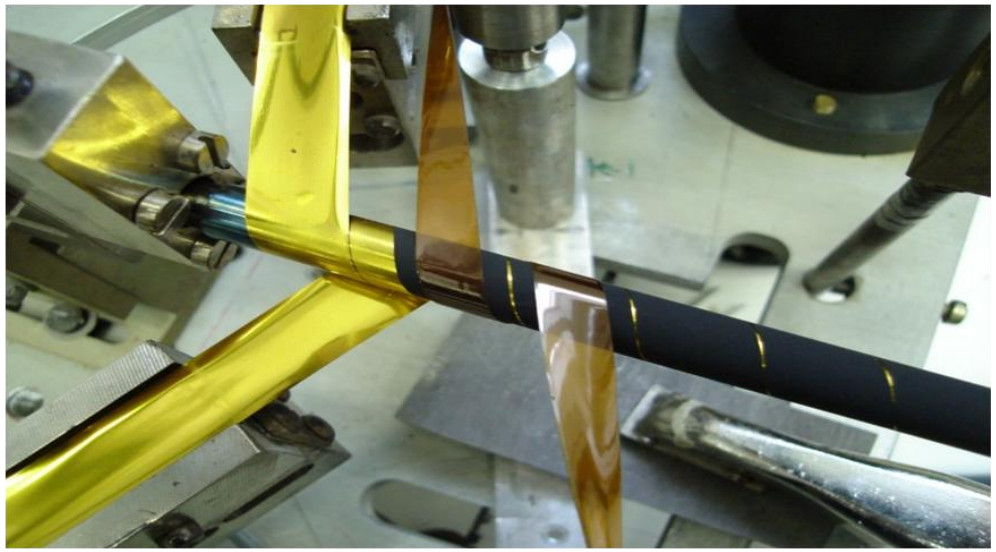
It is necessary to measure the charge in the track to determine the value of dE/dx or dN/dx



STRAW winding

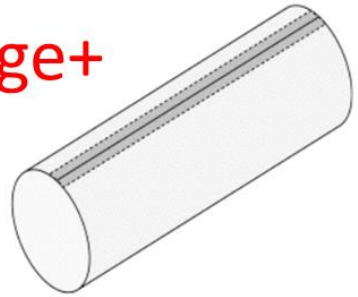


- radiation resistance+
- shape retention+
- diffusion of gases-
- elastic deformation range-
- sensitivity to humidity-

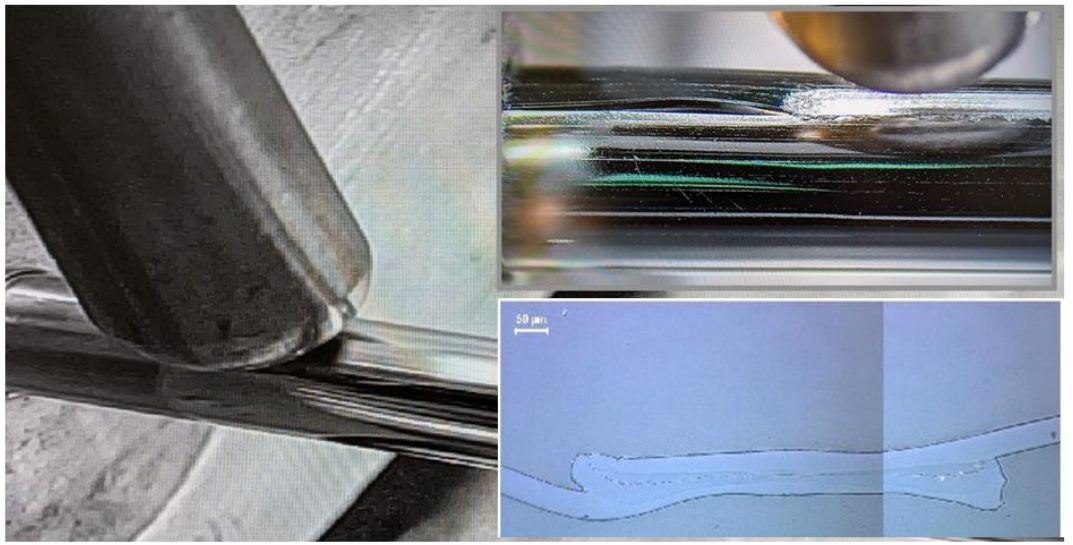


ATLAS, LHCb, COMPASS, COZY-TOF, NA64, Mu2e, PANDA, CBM...

STRAW welding



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

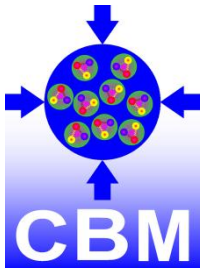


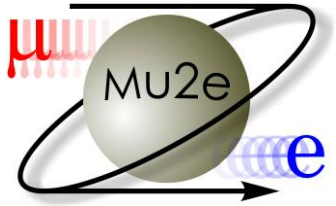
NA62, COMET, SHiP, DUNE, SPD…

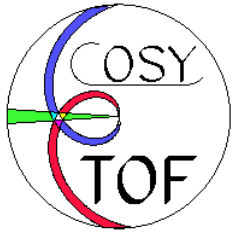
Type of straw trackers used in different experiments

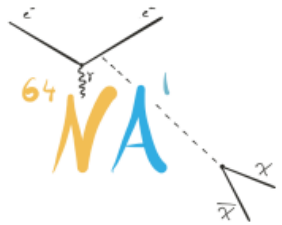
Straw winding

- ATLAS
- LHCb
- PANDA
- CBM
- COMPASS
- Mu2e
- NA64
- SVD-2
- GLUEX
- COZY-TOF
- ..





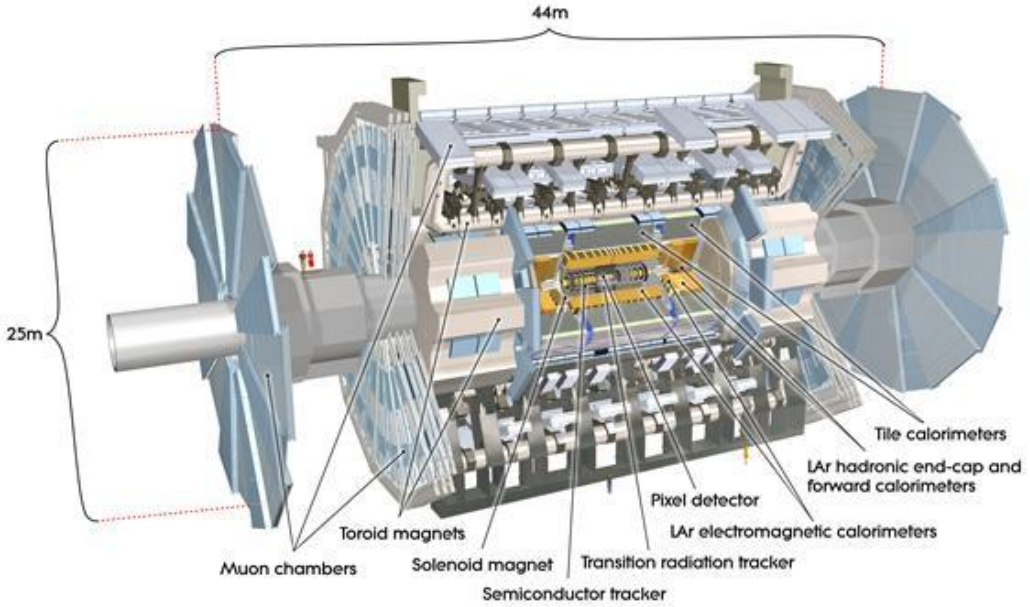


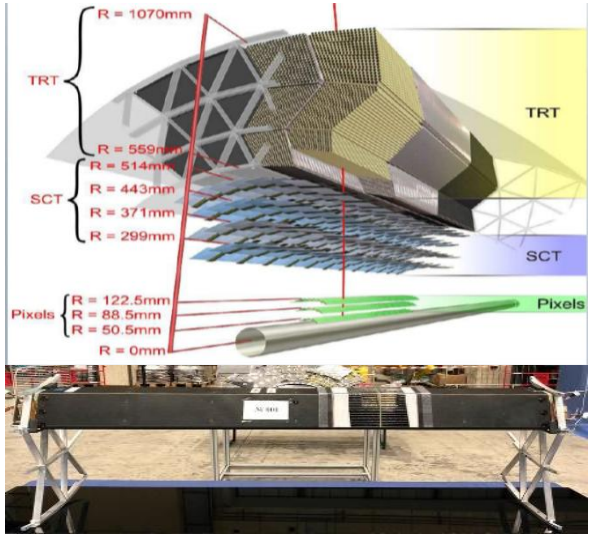


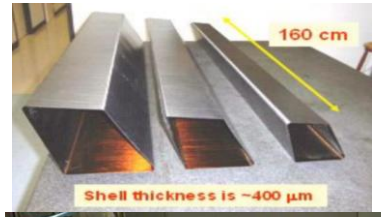
Straw welding

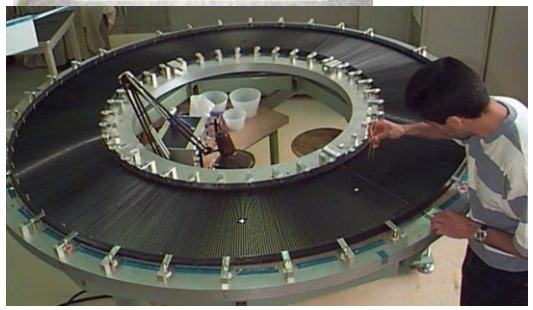
- NA62
- COMET
- SHiP
- DUNE
- ..

ATLAS(CERN,Geneva)





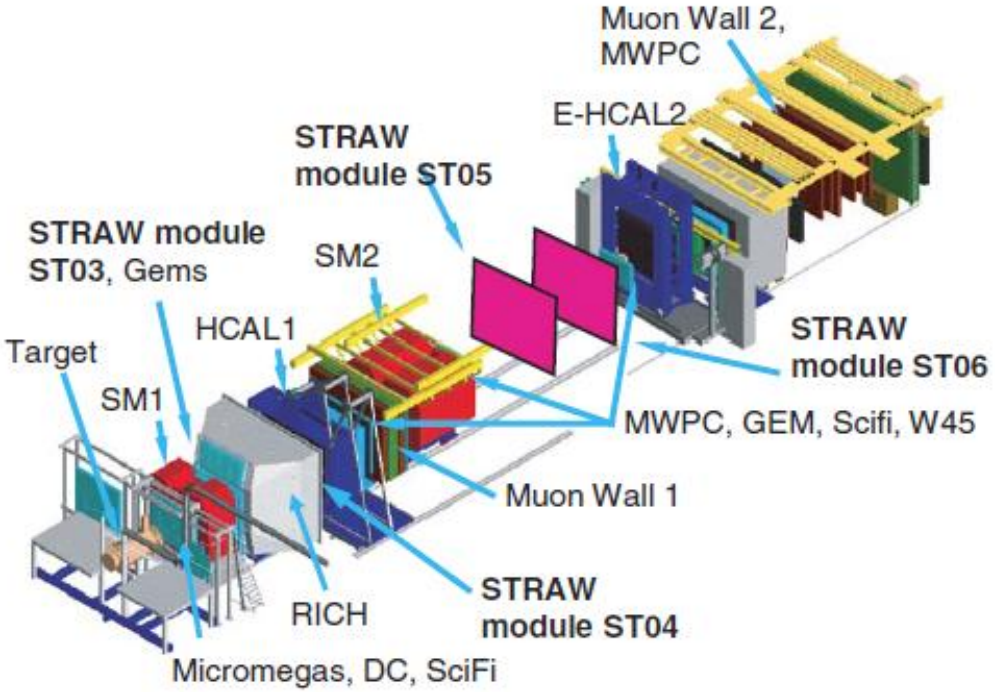




- 350,000 read-out channels
- Volume 12m^3
- Basic detector element: straw tube with 4mm diameter, in the centre a 0.03mm diameter gold-plated tungsten wire
- 50,000 straws in Barrel, each straw 144 cm long. The ends of a straw are read out separately
- 250,000 straws in both endcaps, each straw 39 cm long
- Precision measurement of 170 um
- Provides additional information on the particle type that flew through the detector, i.e. if it is an electron or pion

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

COMPASS(CERN,Geneva)



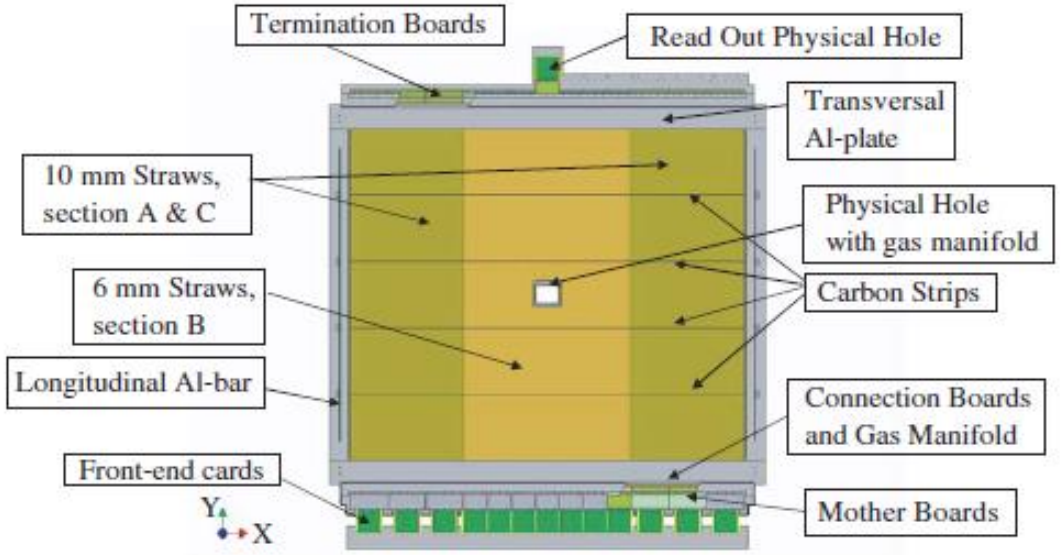
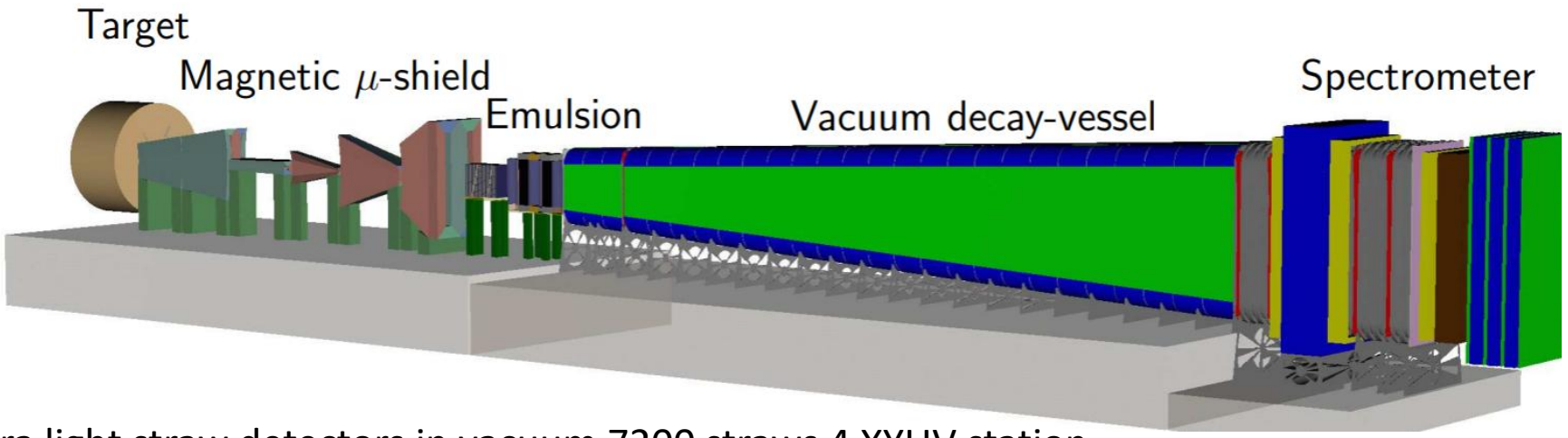


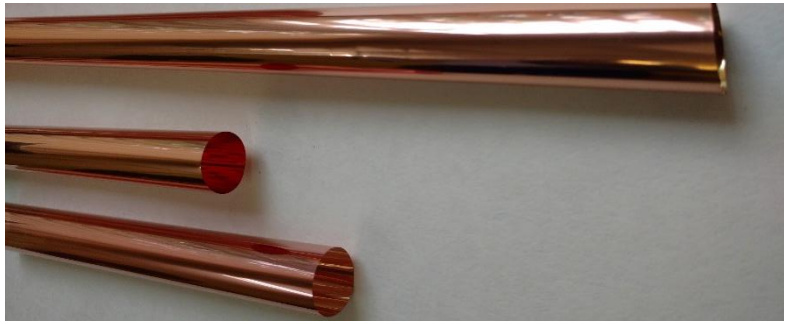
Fig. 2. Schematic view of a chamber (type X).

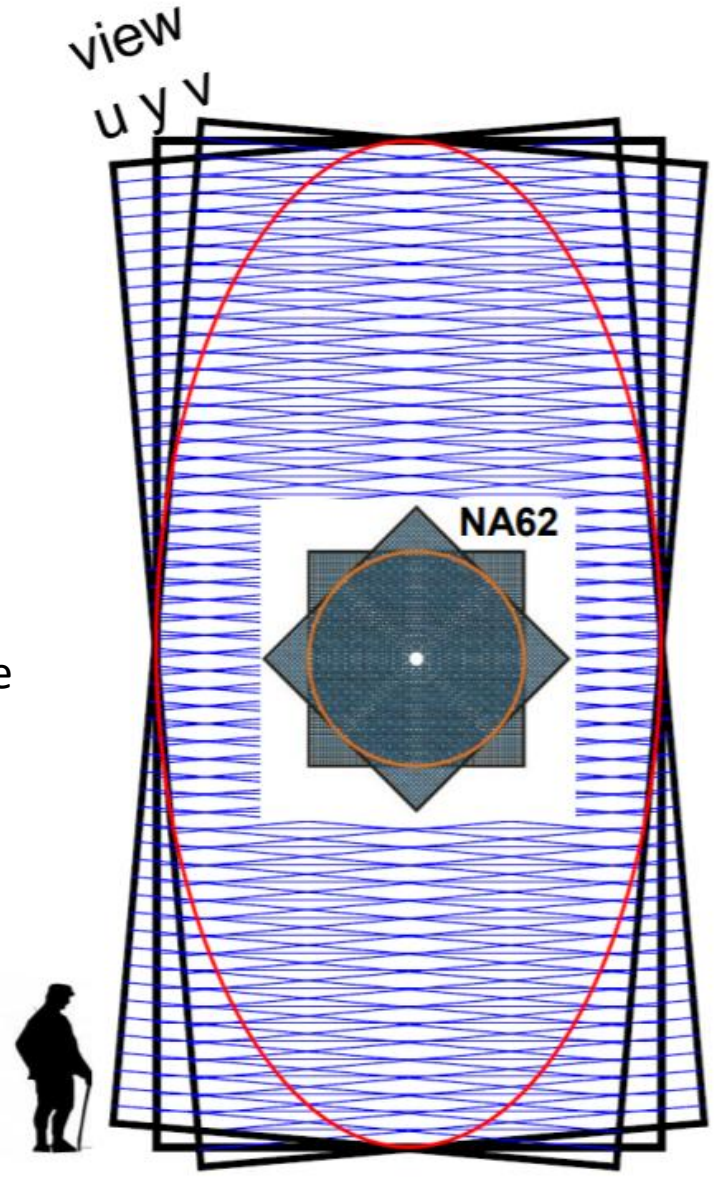
- 12440 read-out channels
- Volume 130m^3
- Sensitive area 2802x3232(mmxmm) for X, 3254x2427(mmxmm) for Y
- Straw tubes of different size (6mm and 10mm diameter) instrumented with 30um diameter gold-plated tungsten wire
- Drift distance resolution: 200 um

SHiP(CERN,Geneva)

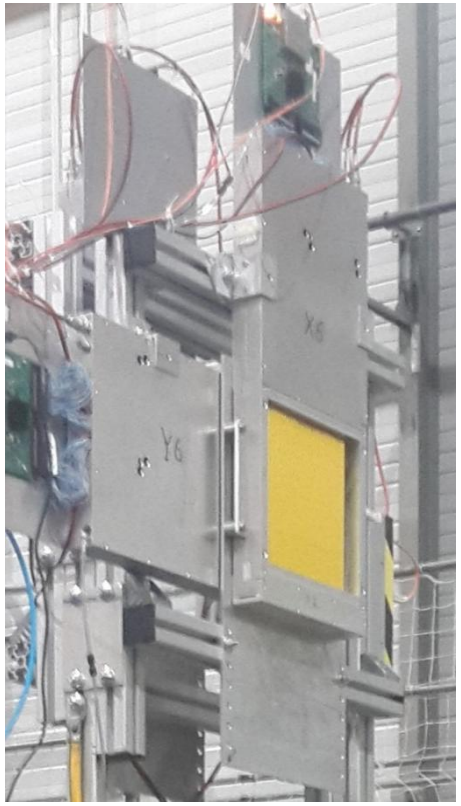


- Ultra light straw detectors in vacuum 7200 straws 4 XYUV station
- Sensitive Area 5x10m^2
- Straw tube with 20mm diameter, in the center a 30mkm diameter gold-plated tungsten wire
- Length of straw 4m
- Drift distance resolution: 160 um





NA64(CERN,Geneva)



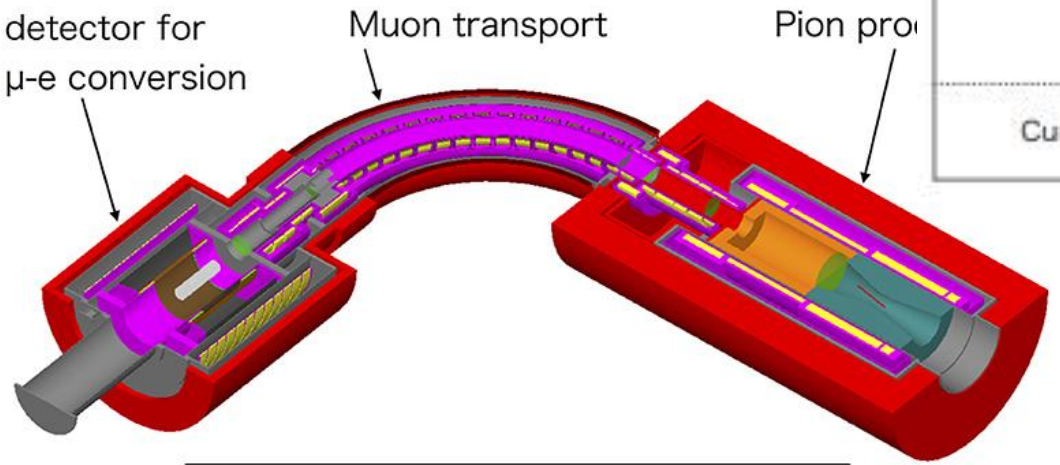
- 768 straws
- 6 XY station
- straw tube with 6mm diameter, in the centre a 30mкm diameter gold-plated tungsten wire
- Length of straw 20 cm
- Drift distance resolution: 200 um

- Planned upgrade: 8 XY station with size 1200x600 mm ~ 4000 channels

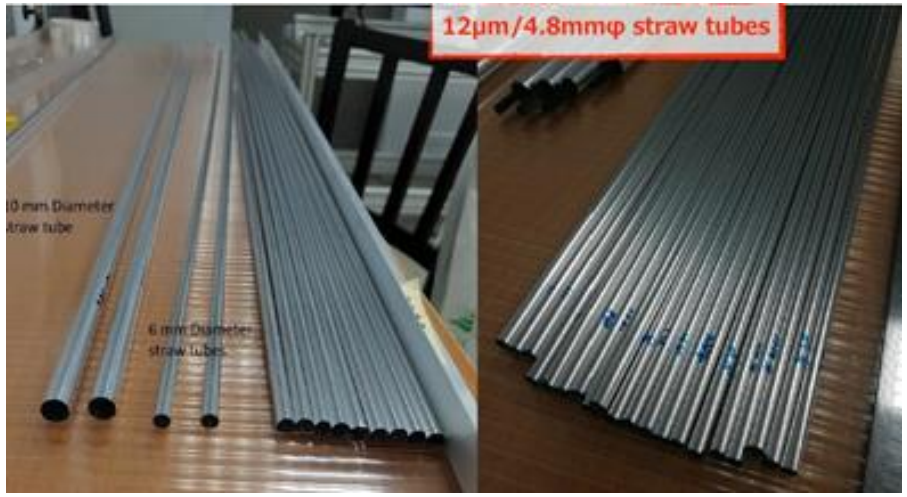
COMET(J-PARC,Tokai)

9.75 mm diameter conducting straws, metalized polyimide film of 20 µm thickness. Anodic wires 25 µm diameter gold plated Tungsten wire. The baseline choice of the gas is Ar/Ethane (50:50).

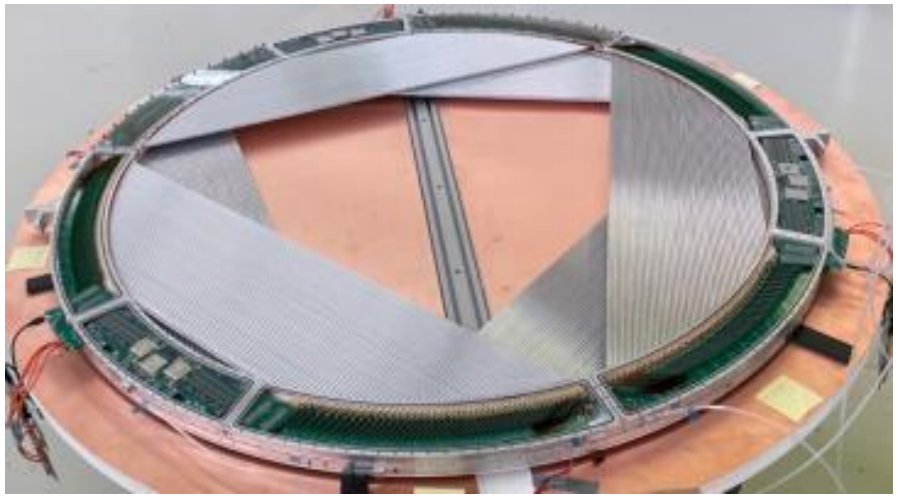
	NA62	COMET Phase-I	New Straw
Straw Wall Thickness	36 µm	20 µm	12 µm
Straw Diameter	9.8 mm	9.8 mm	4.8 mm
Metal Deposition	Cu+Au, 70nm	Al, 70 nm	*Al, 70 nm
Photo			
Current Status	In Operation	Under Construction	Just Developed



COMET Phase-I Layout

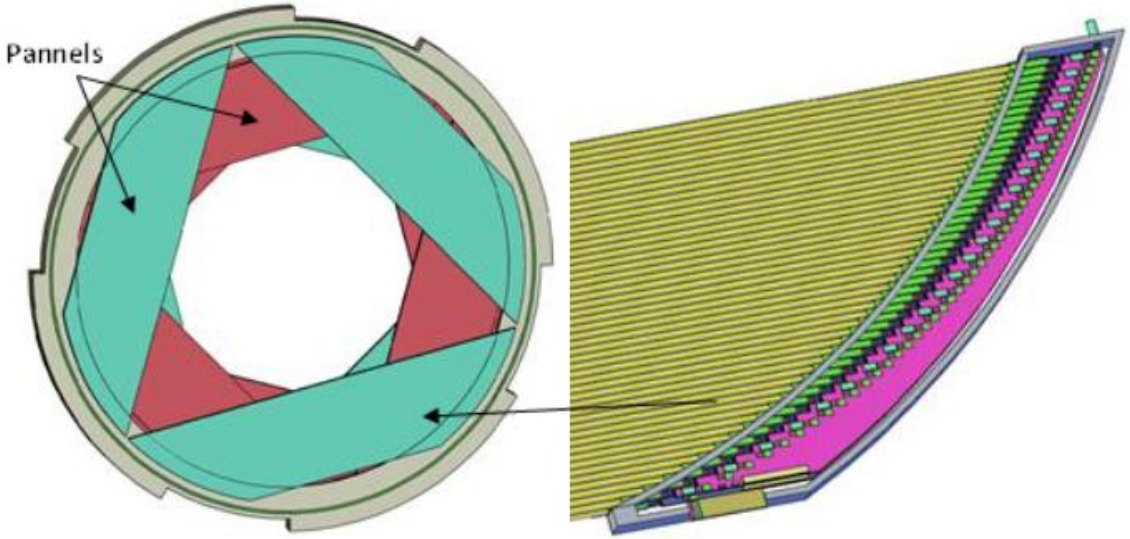


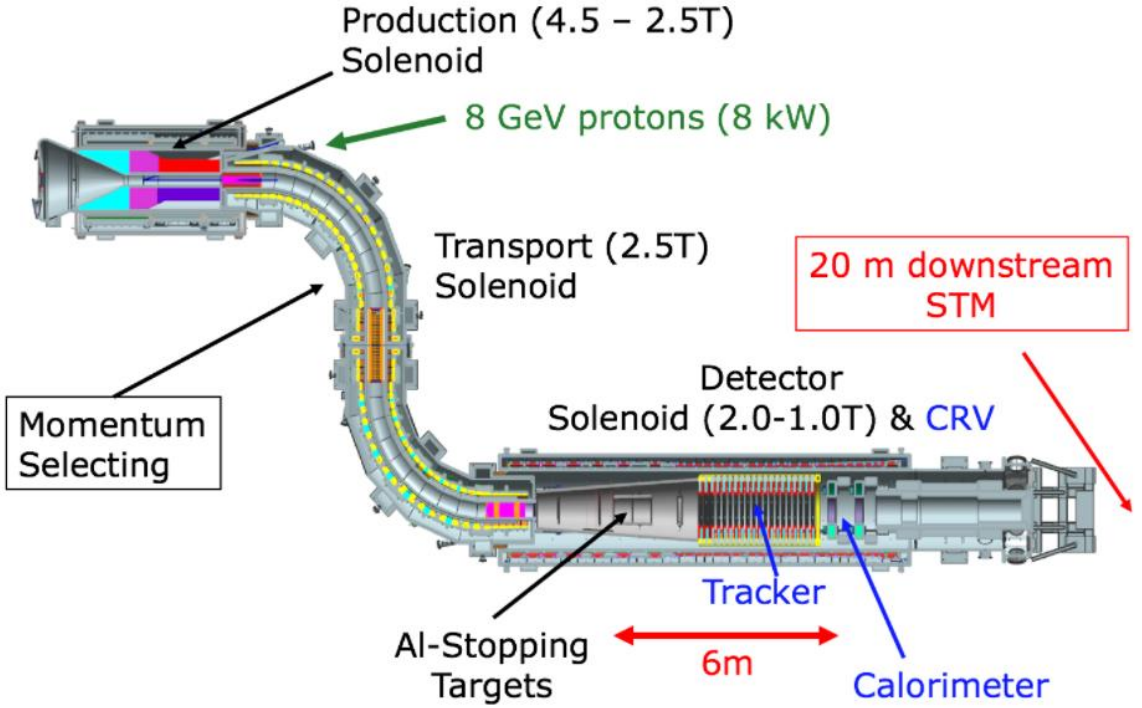
Mu2e (Fermilab, Chicago)



electron trajectory in a 1T magnetic field
Hit rate: > 5MHz/channel, 500 ns after proton bunch hits production target
Operation time: > 10 yrs
20,736 straws 6 µm Mylar + 3 µm adhesive + 6 µm Mylar double helical wrap
High radiation survival (structure & electronics)
Straw diameter: 5 mm
Lengths: 45 to 120 cm Inner wall coating: 500Å Al + 200Å Au, Outer wall coating: 500Å Al

Tracker must be improved → 2030 ….

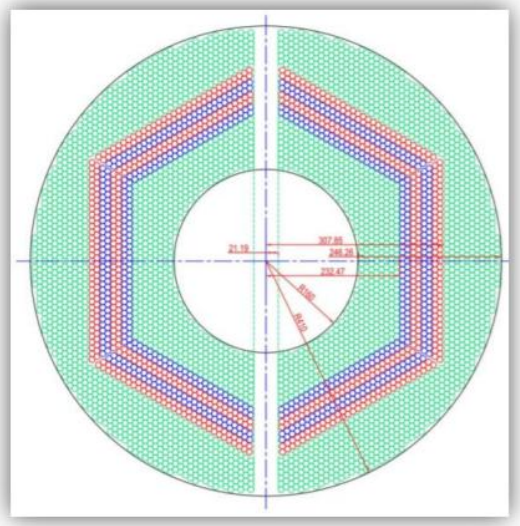


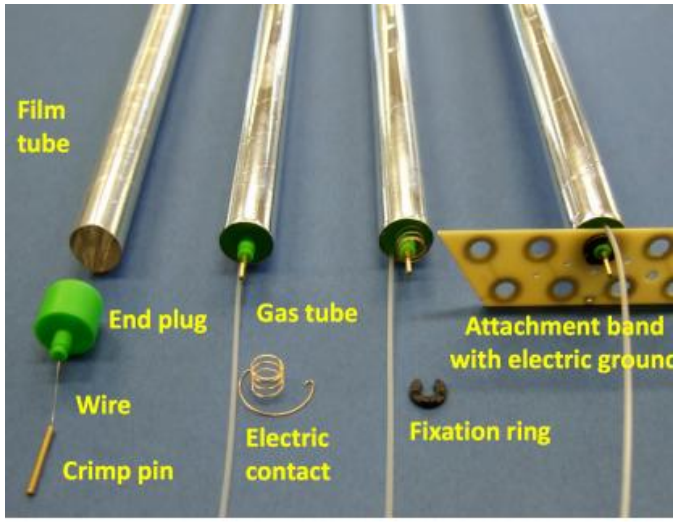


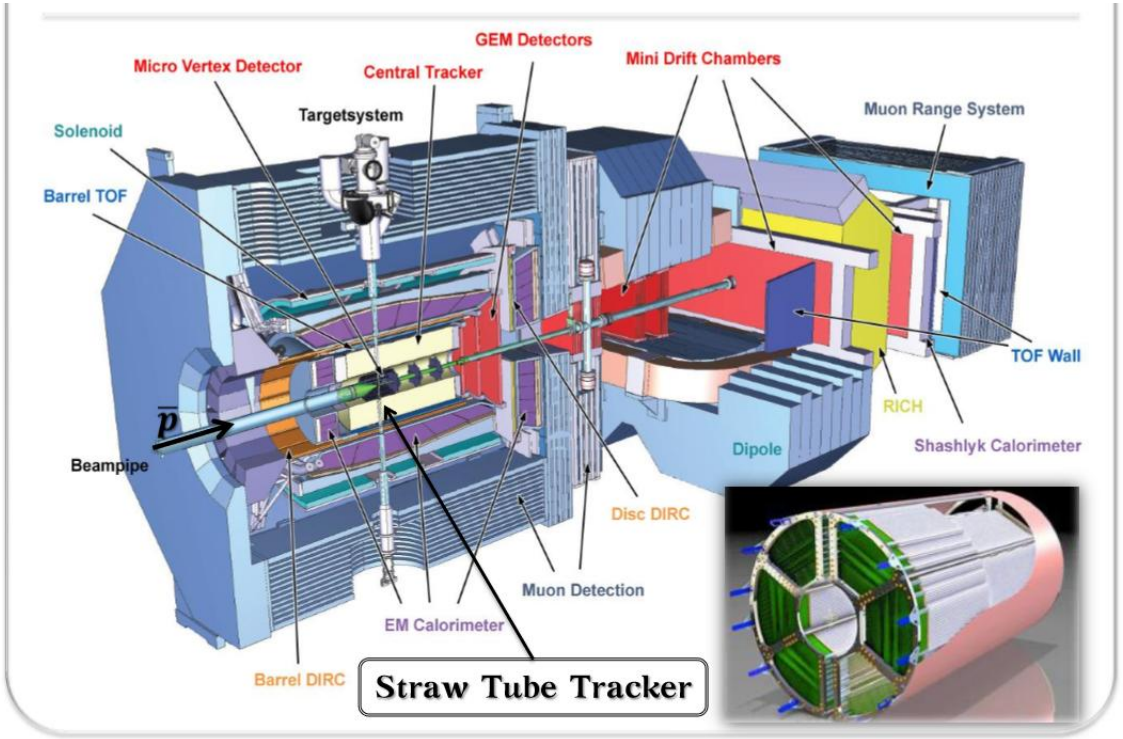
PANDA(FAIR,Darmstadt)

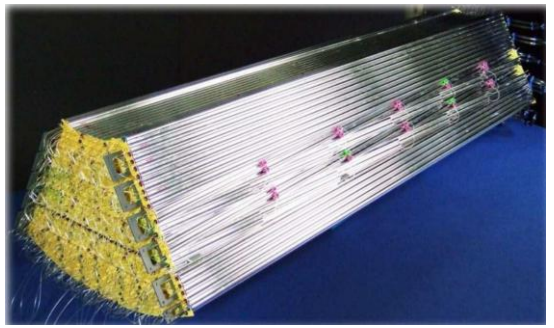
STT LAYOUT

- 4636 straw tubes in 2 semi-barrels around beam/target pipe
- 23-27 planar layers in 6 hexagonal sectors
  - 15–19 axial layers (green) parallel to the detector axis
  - 8 stereo layers (± 2.89°) for 3D reconstruction (blue/red)
- Length: 1500mm + 150mm (RO upstream)
- R_{in}/R_{out}: 150 / 418 mm
- Angular acceptance: near 4π
- High momentum resolution: δ_p/p ~ 1-2% at B = 2 Tesla
- High spatial resolution: $\sigma_{r\varphi}$ ~ 150 (100) μm, σ_z ~ 3.0 (2.0) mm (single hit)

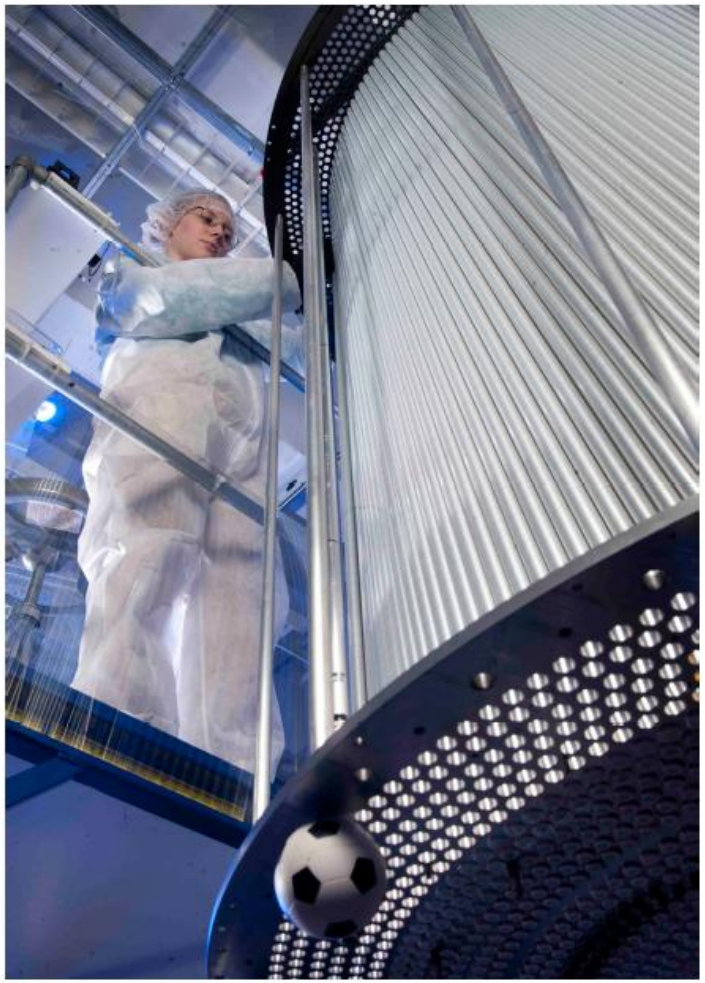








GLUEX(JLab,Virginia)



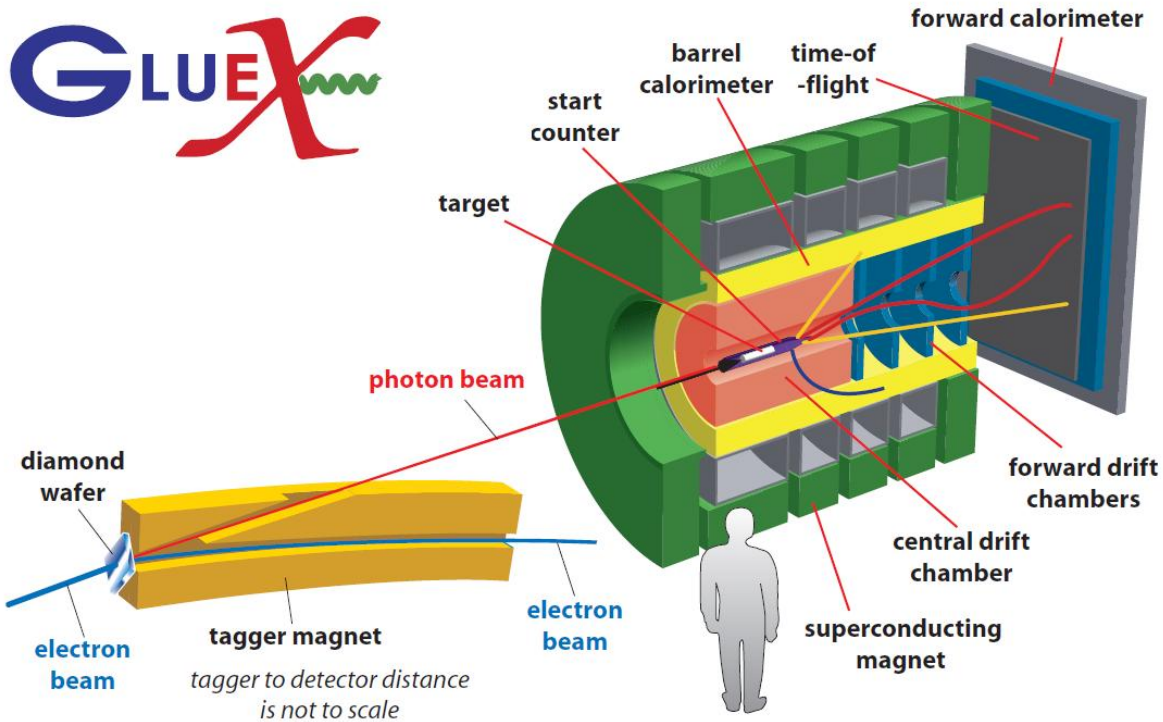
Straw tube chamber

1.5m long x 1.2m diameter

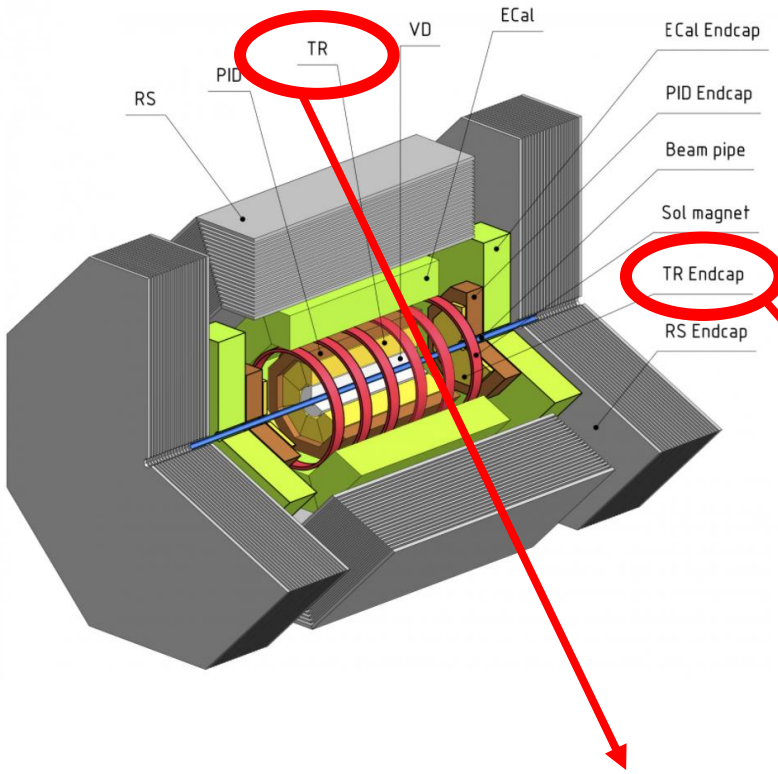
3522 straws, 1.6cm diameter

28 layers, 12 straight, 16 stereo

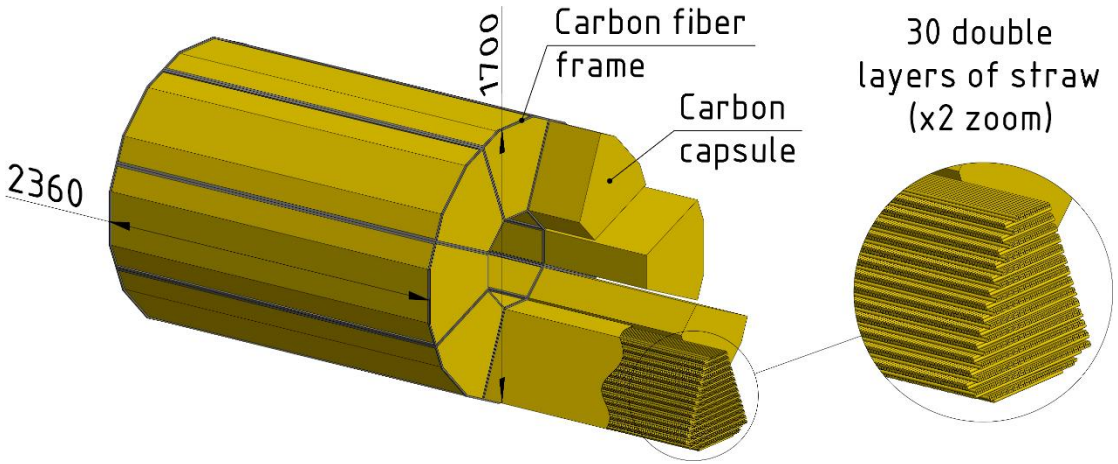
Example of cylindrical chamber with stereo angle

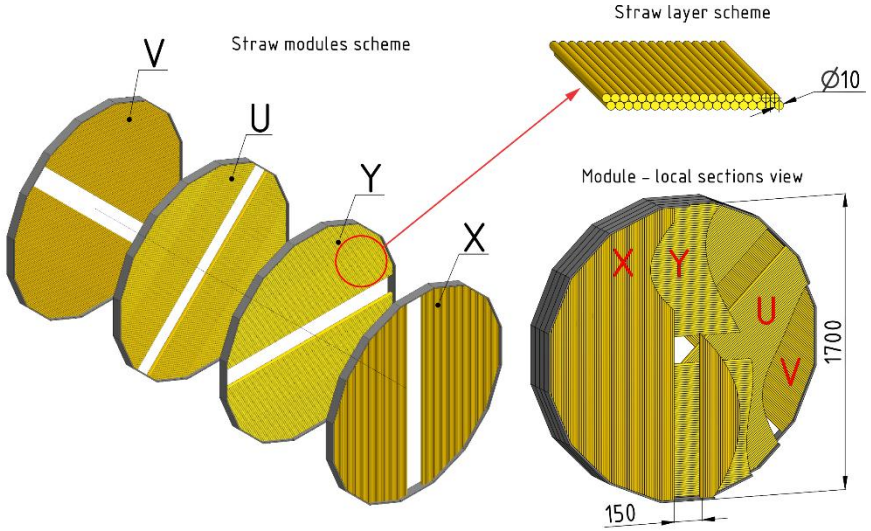


SPD NICA(JINR,Dubna)



- Main tracker system of SPD
- Straw diameter 10mm thickness 36mkm PET
- Spatial resolution of 150mkm
- Barrel is made of 8 modules with up to 30 double-layers, with the ZUV orientation
- Endcaps are made of 12 double-layers with the XYUV orientation
- Vast experience in straw production in JINR for several experiment: COMPASS, NA-62, NA-64, SVD-2; prototypes for: CREAM, SHiP, COMET, DUNE.

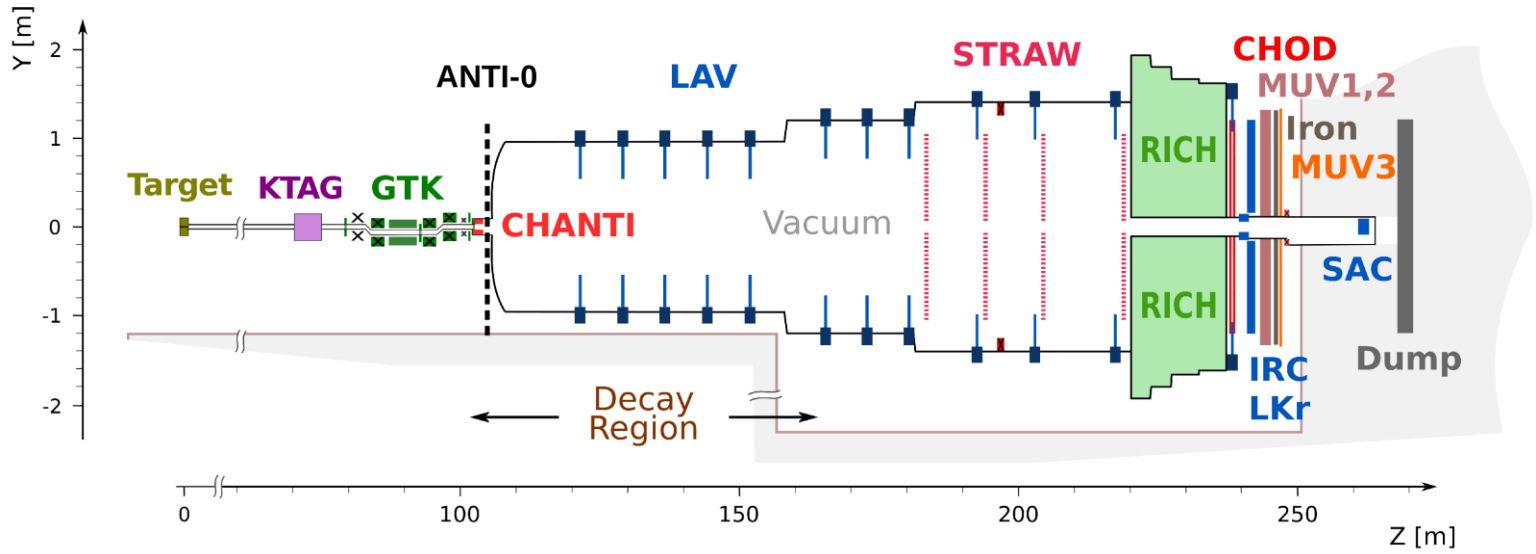


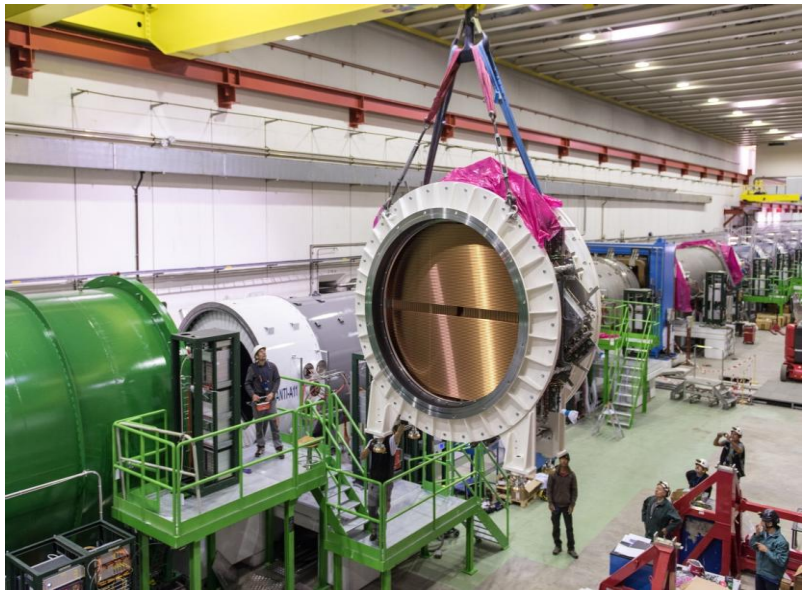


NA62(CERN,Geneva)

NA62 straw spectrometer:

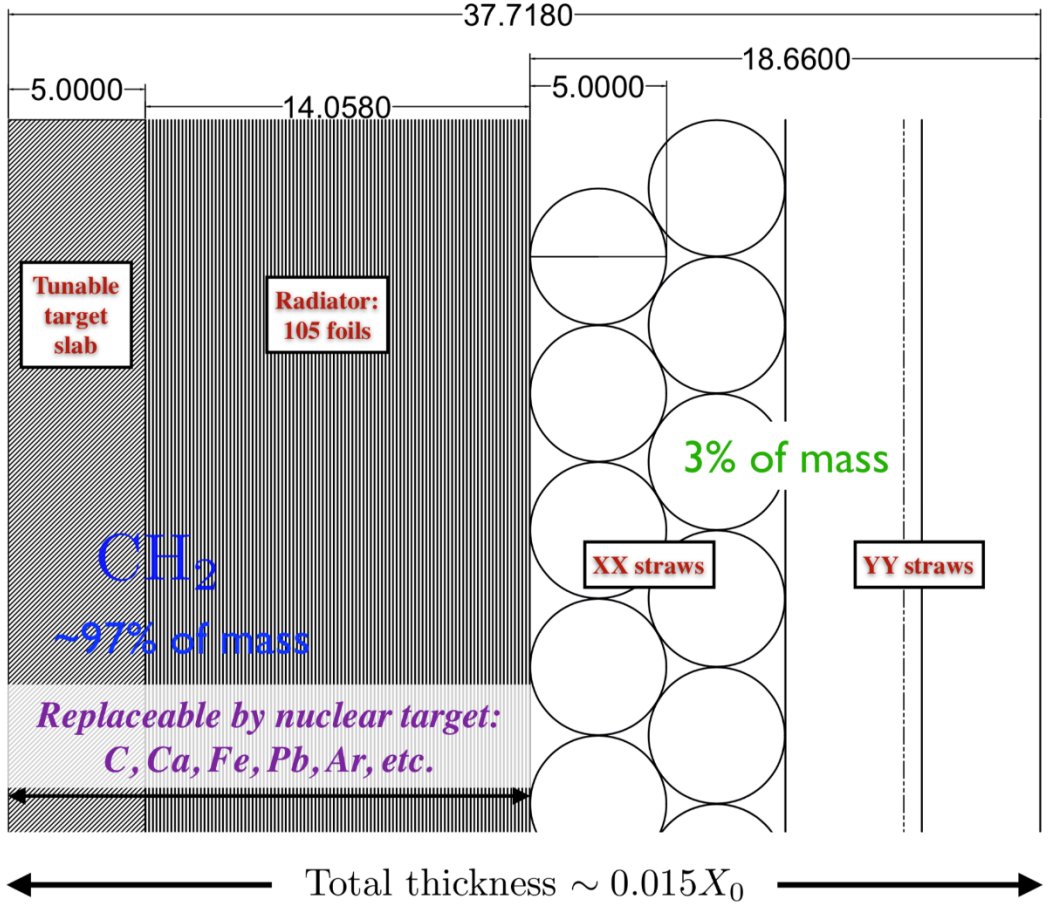
- **Straw diameter: 9.8 mm**
  - Material: 36 μm thick PET
  - Plating: 50 nm copper + 20 nm gold
  - Wire: 30 μm tungsten wire
- **Gas: Ar+CO_2 (70:30)**
- **4 chambers, 7168 straws in vacuum**
  - ~30 straw hits per track
- **Total material budget: 1.7% X_0**
  - Dominated by the PET (70%)
- **Single straw timing performance:**
  - Maximum drift time: ~150 ns
  - Leading time resolution: 3-4 ns
  - Trailing time resolution: ~30 ns





STT for DUNE

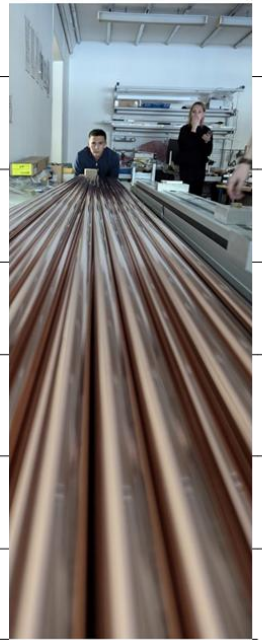
- Thin (1-2% X_0) passive target(s) separated from active tracker of negligible mass (STT)
- Many target layers dispersed within tracker by keeping low average density ρ~0.18 g/cm^3
- Replaceable targets of high chemical purity give ~97% of total STT mass (straws ~3%)
- "Solid" hydrogen target from subtraction between CH_2 (polypropylene) and C (graphite)

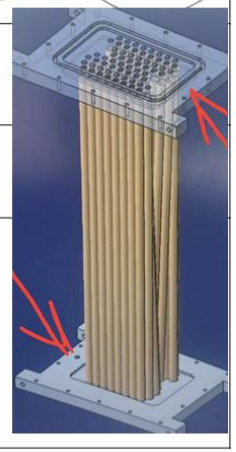


- Straw outer diameter: 5 mm
- Wall thickness: 20 μm or lower
- Double film metallization: 70 nm (inner) + 70 nm (outer)
- Wire: W/Re 20 μm diameter
- 4 straw layer XXYY glued assembly
- Operated at internal overpressure of about 1 bar (2 bar absolute)
- Thin modules with light C-composite frames
- Compact low-power frontend readout integrated into frames

Ultra Sonic Welding (USW) Straw Trackers for future experiments

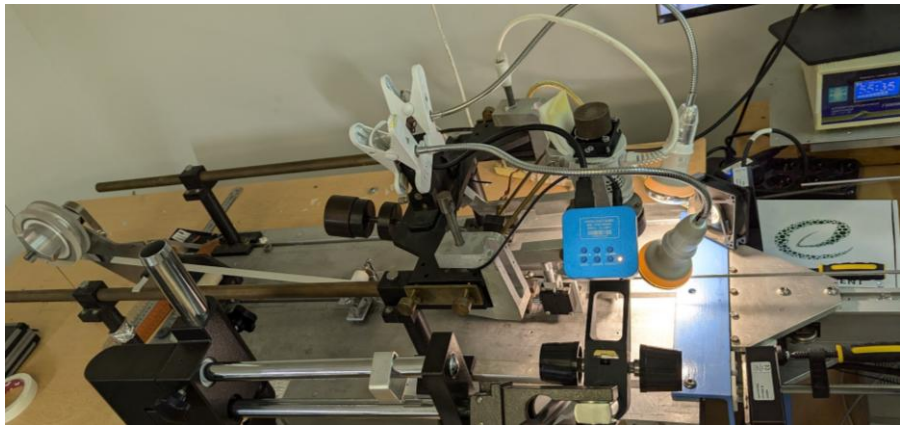
	SHiP @ SPS [2]	DUNE (SAND) [3]	SPD @ NICA [4]
Diameter [mm]	20	5	10
Length [m]	4	up to 4	2.4
Film thickness [um]	36	20	36
Metalization [nm]	50(Cu)+20(Au)	70(Al) double-side	70(Al)
Operation pressure	1 atm	2 atm	1 atm
N of straws	~20 000	~250 000	~30 000
Occupancy [kHz]	10-100	<1	15-150
Readout (under development)	time + time-over-threshold, rising edge shape (optional)	time + charge (PI	time + charge (PID)

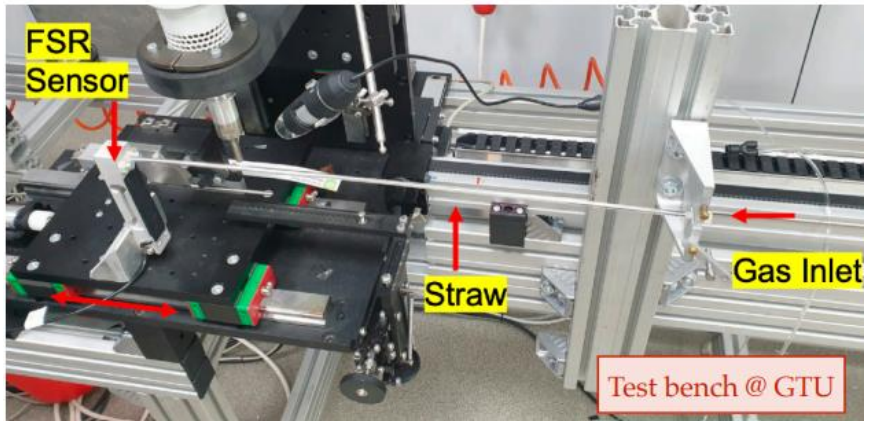


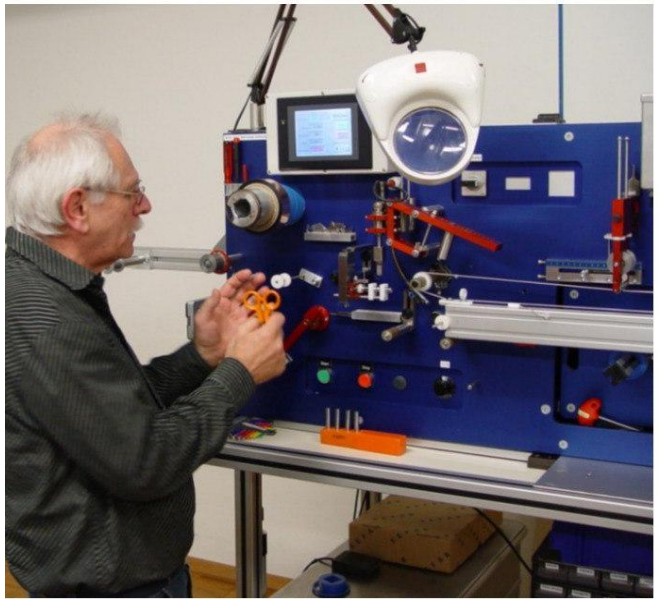


The possibility of using this Straw tracker is also considered for FCCee

Straw welding-production lines







- JINR (Dubna) – operational for mass production
  - up to 5.5 m straw length with speed of 2 m/min
- GTU (Tbilisi) - operational
- SEFAR (Swiss industrial company) - operational
- PNPI (Gatchina) - developing
- INP (Almaty) – developing mass production lines

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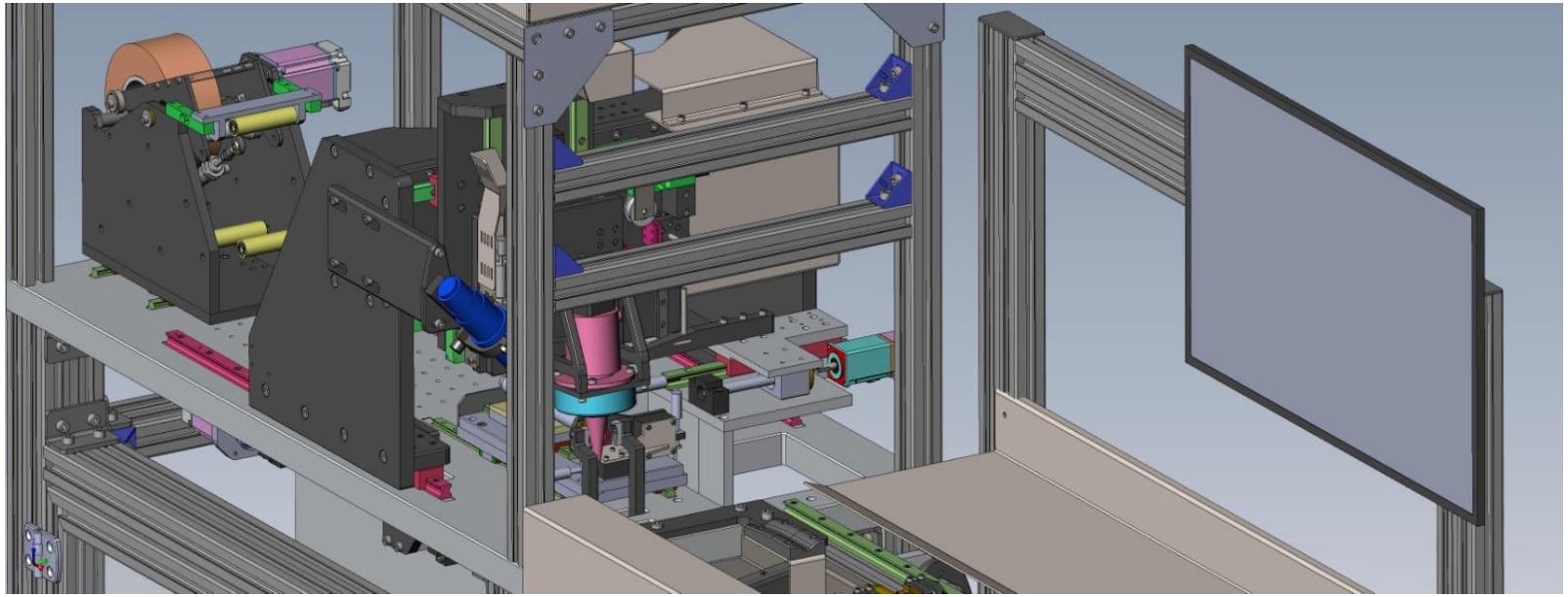
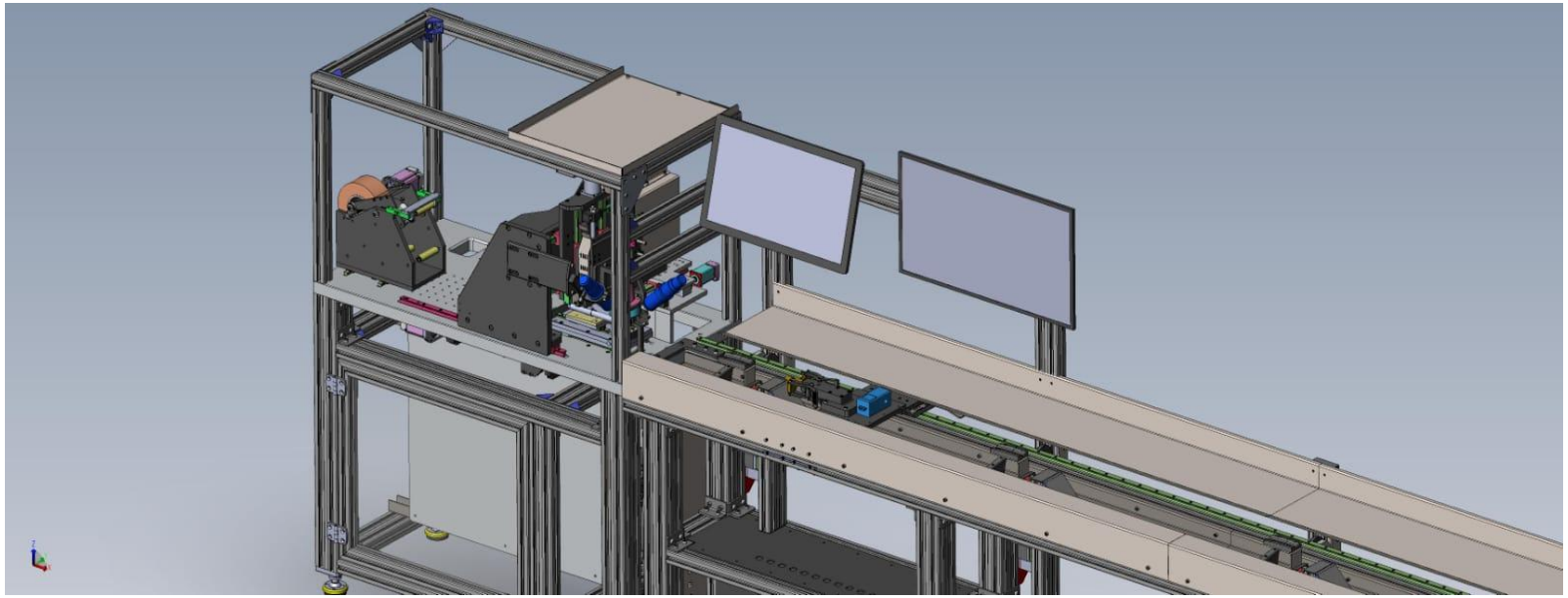
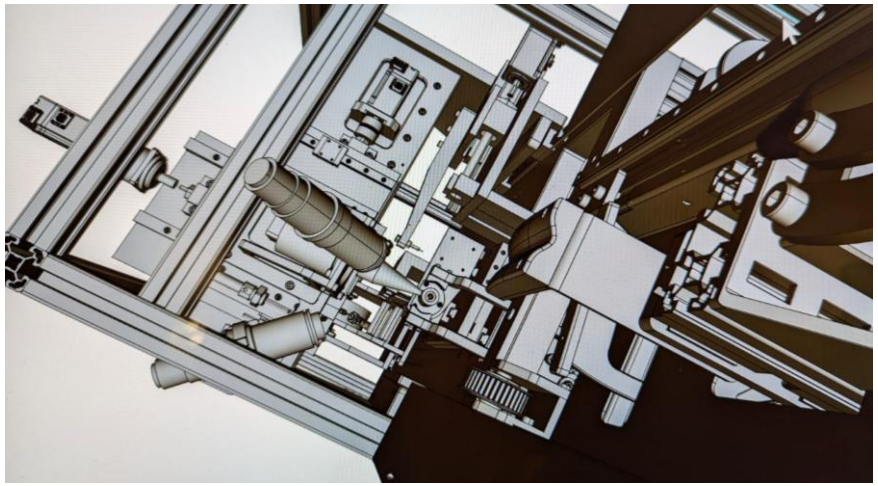
inp

Project new production line in JINR and INP

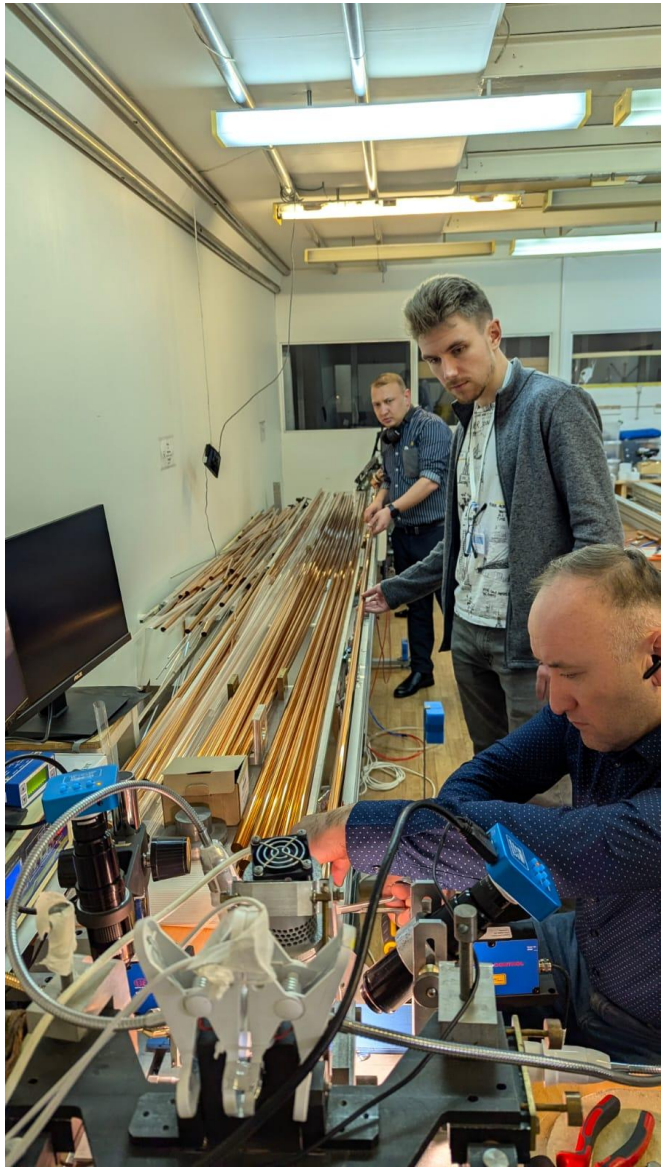




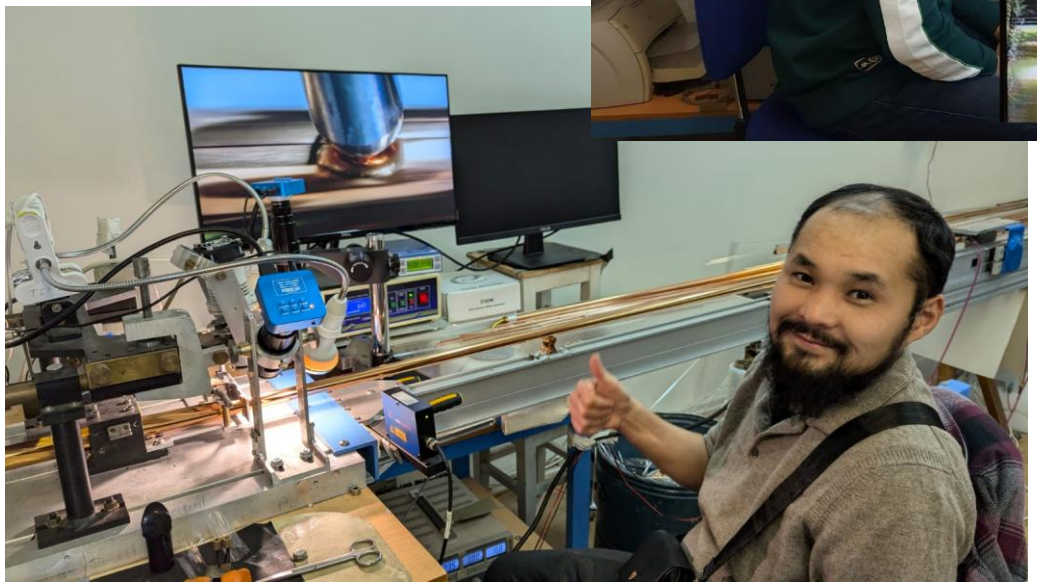
- Commissioning JINR- May 2025
- Lengh-12m
- Start of construction of production line at INP of May 2025
- Commissioning INP– July 2025
- Production speed is about 2 m/min
- The production line will be integrated with many automated control systems
- It is planned to use artificial intelligence to determine the quality of the seam

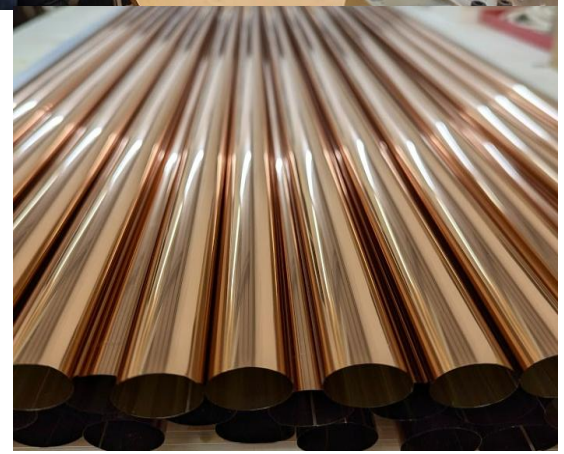


INP Personel traning at JINR Straw Production Site



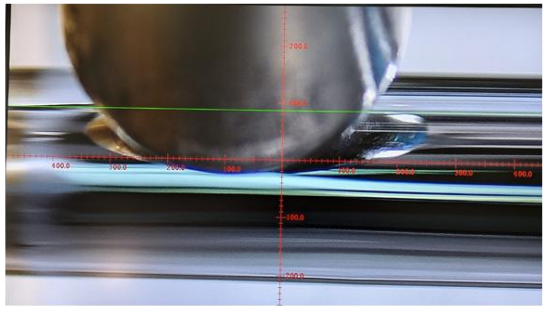
- added a new microscope with better resolution for visualization
- improved the seam positioning system
- production line speed ~3 km/month
- active work is underway in the field of R&D with colleagues from the INP
- installed a laser





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

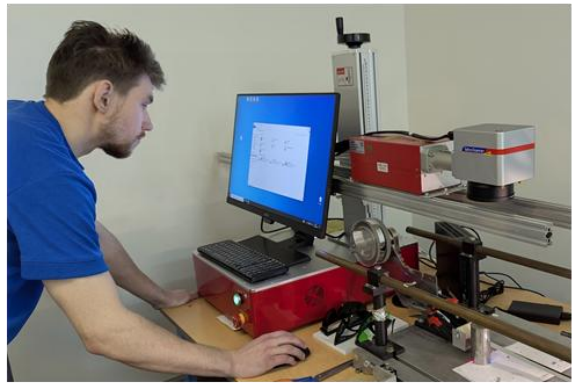
A measurement system consists of:
- laser
- receiver
- controller

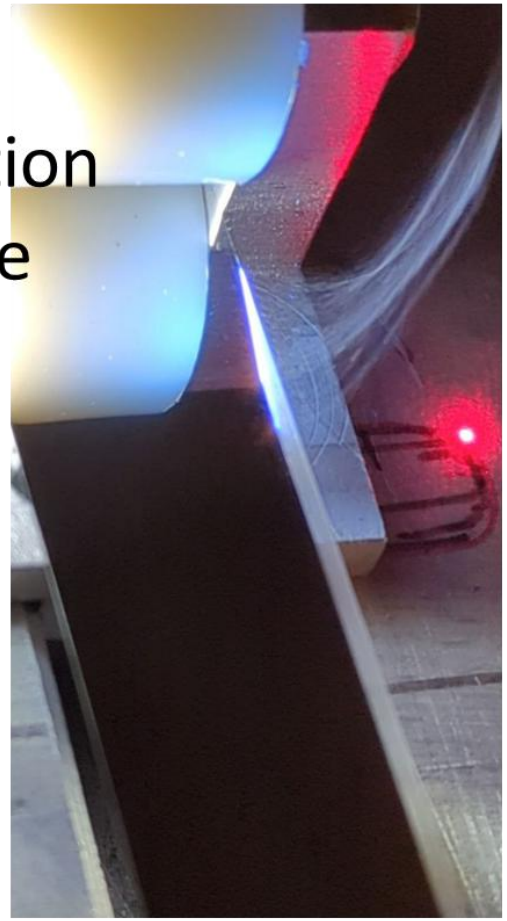
Measurement of the inner straw diameter (both straw ends) with tools;

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

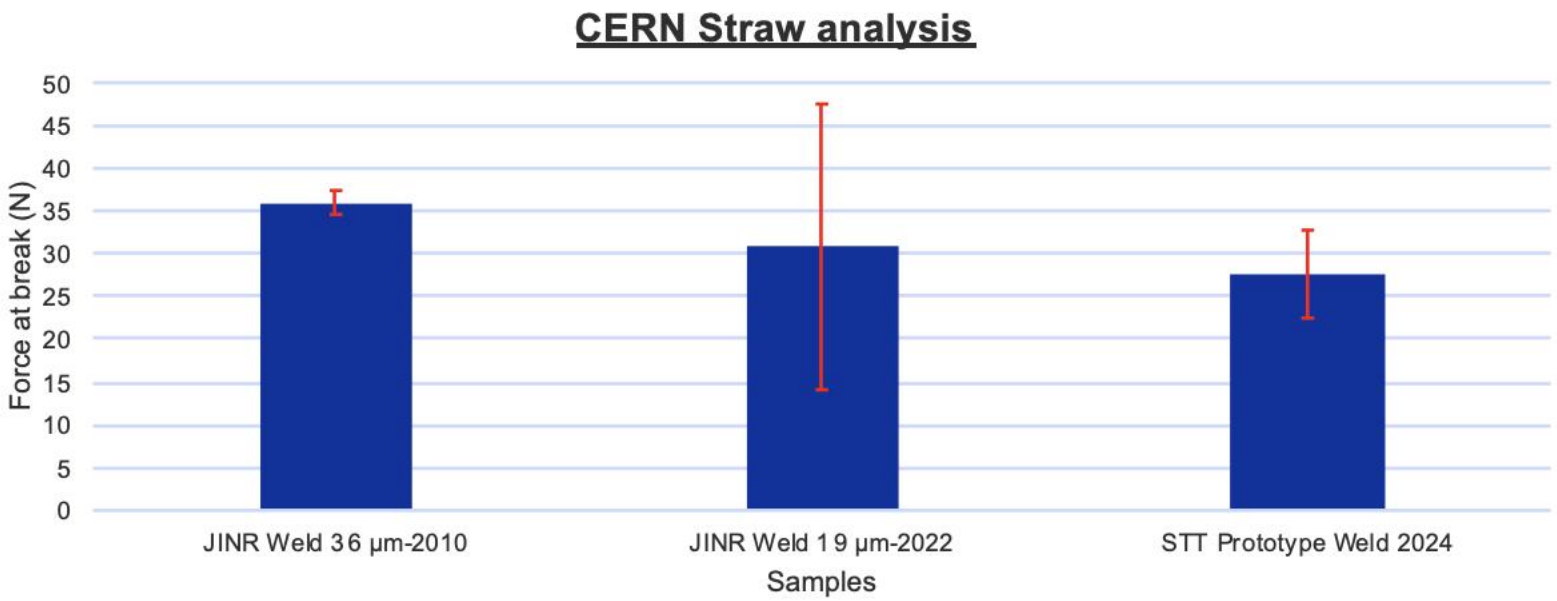


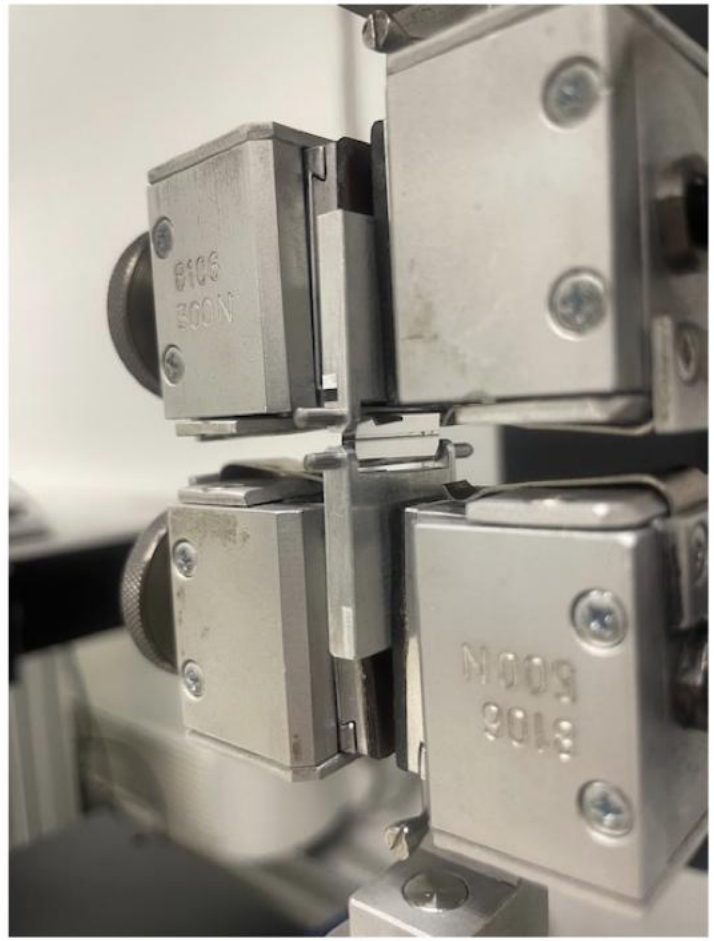


Removing the metallization made it possible to achieve the required quality

Test of mechanical strength of the welding for DUNE STT straws at CERN

	JINR 2010 (36µm)	JINR 2022 (19µm)	DUNE 2024 (19µm)
Stress at break σ_t (MPa)	103.5 ± 0.9	102.2 ± 20.8	95.99 ± 19.64
Force at break (N)	36.0 ± 1.4	31.0 ± 16.7	27.62 ± 5.14
Force at break per unit length (N/mm)	2.40	2.06	1.82 ± 0.37

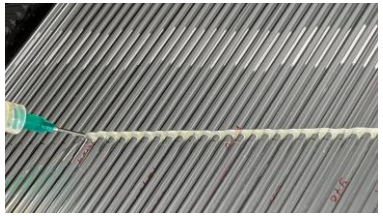
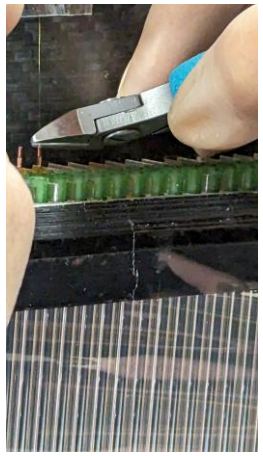


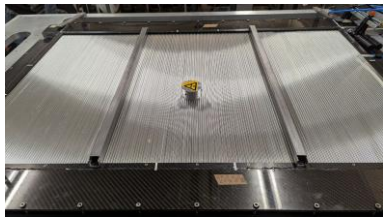
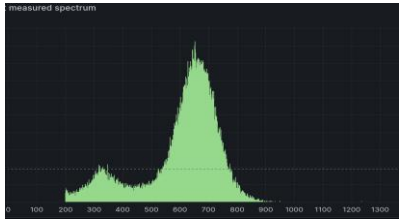


Test of mechanical strength of the welding for STT straws at CERN

Prototyping

The first prototype((1200x800mm) was built at CERN in late 2023

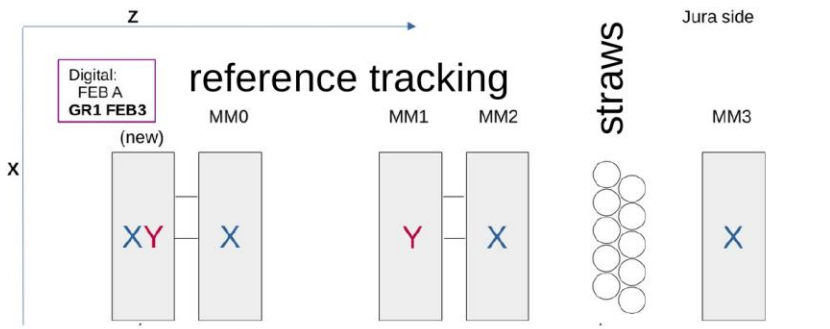




The second prototype((1200x800mm) is currently under construction in Pisa



The SPS setup



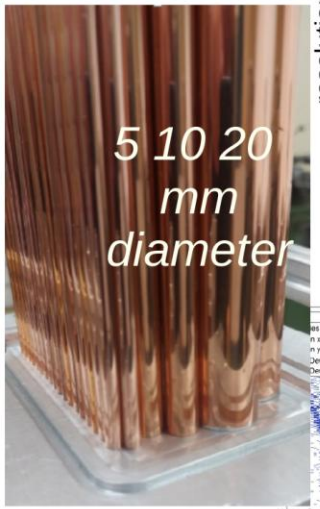
Reference tracking:

- MM detectors (250 um, 400 um) + Tiger readout (Torino University)

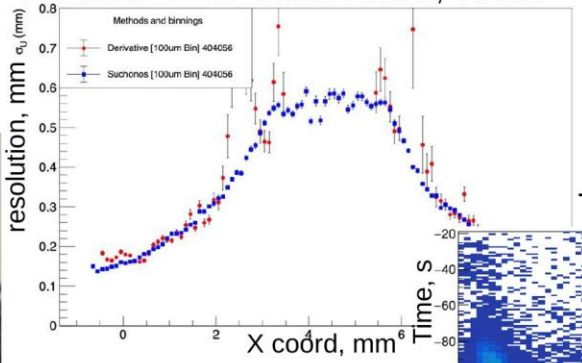
Under test: a **combined straw tracker prototype +** two types of readout: **Tiger and VMM3**

Goals:

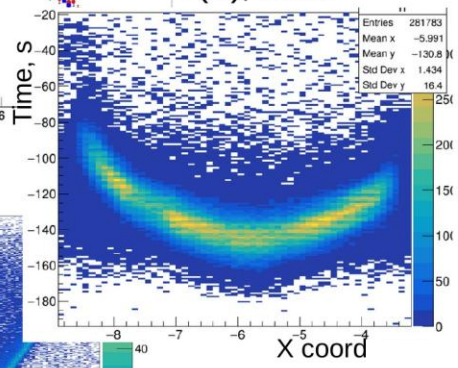
- evaluation of the realistic noise prediction and thresholds settings for the developing ASICs (Dune, DRD1-WP3)
- evaluation requirements for SHiP STT readout
- evaluation of TimeOverThreshold mode capability for straw readout with Tiger ASIC (to be continued at H8)
- evaluation of the charge measurement requirements for future PID optio (to be continued at PS T9)



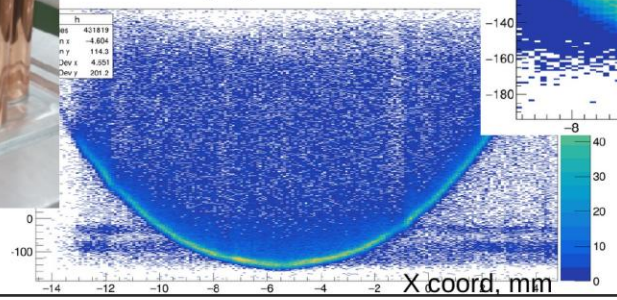
Coordinate resolution: **10mm**, VMM3



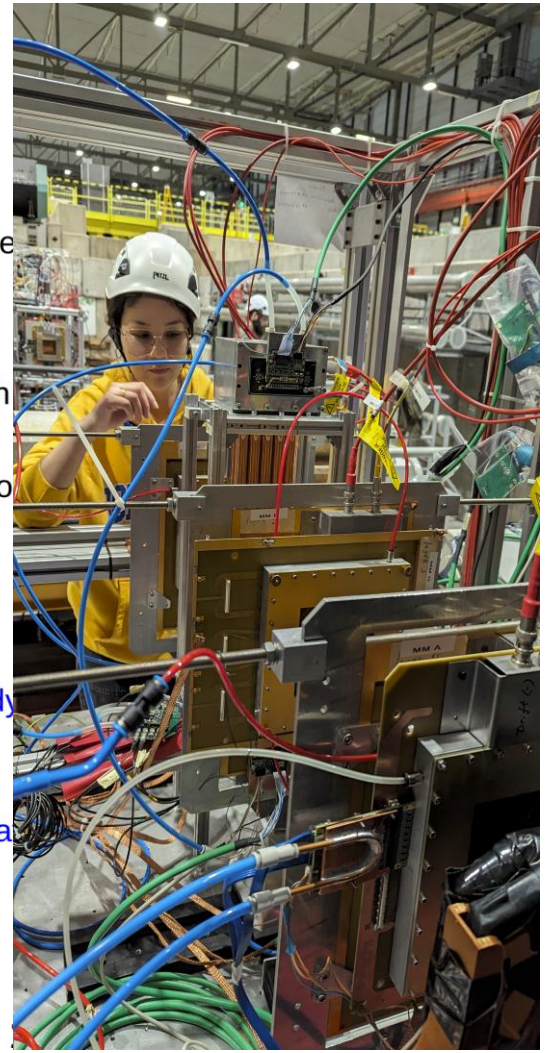
T(R), **5mm**



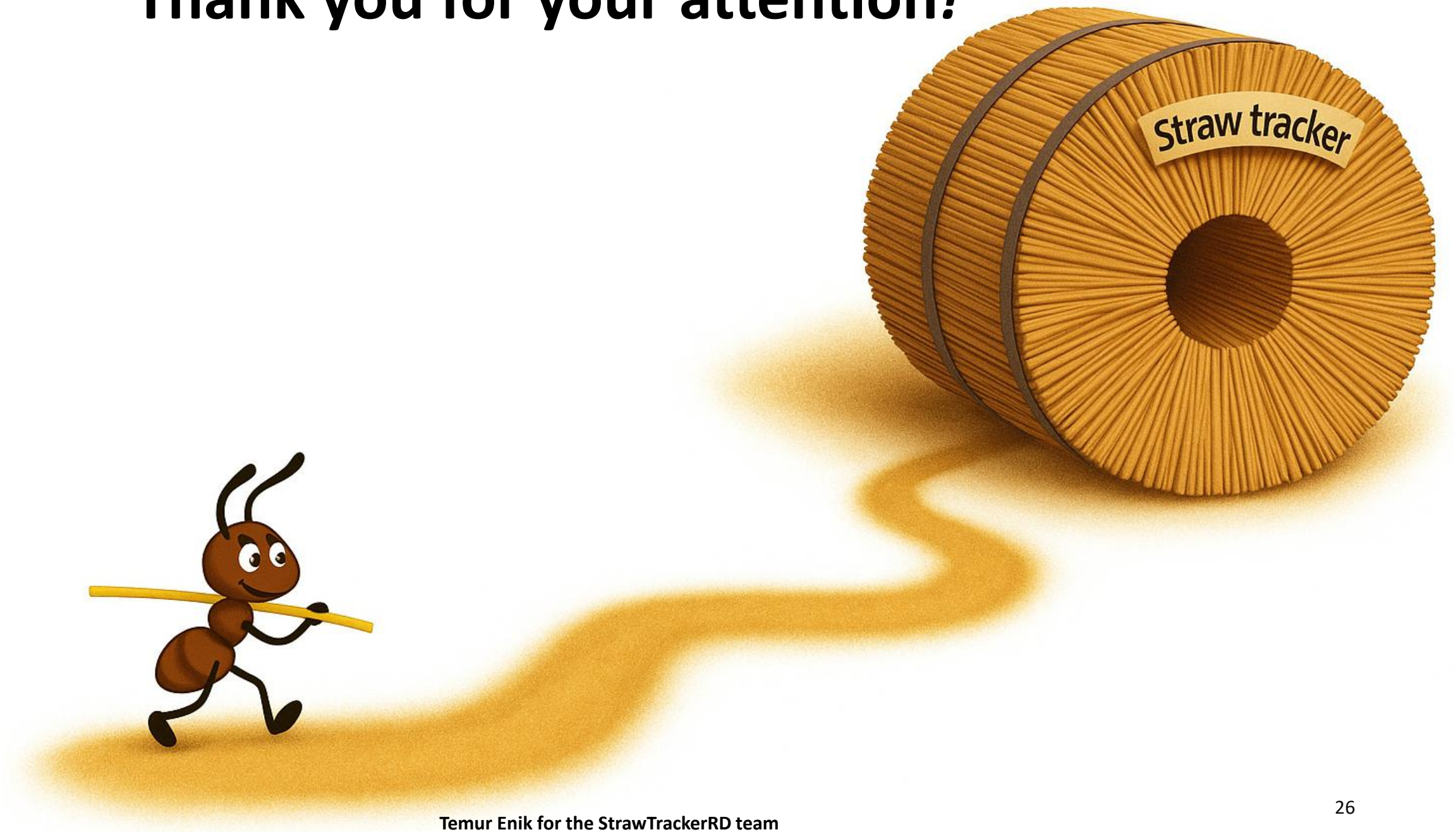
T(R), **20mm**



- ✔ Improved reference tracking resolution
- ✔ TIGER readout for high charge/high rate under study
- ✔ Upgraded TIGER FEB and cooling design
- ✔ Efficient data taking at H4, studies to be continued a
- ✔ Offline analysis started
- ✔ Very grateful to **RD51/DRD1** for support and infrastructure and to XMAS for great beam!



Thank you for your attention*!*



Temur Enik for the StrawTrackerRD team