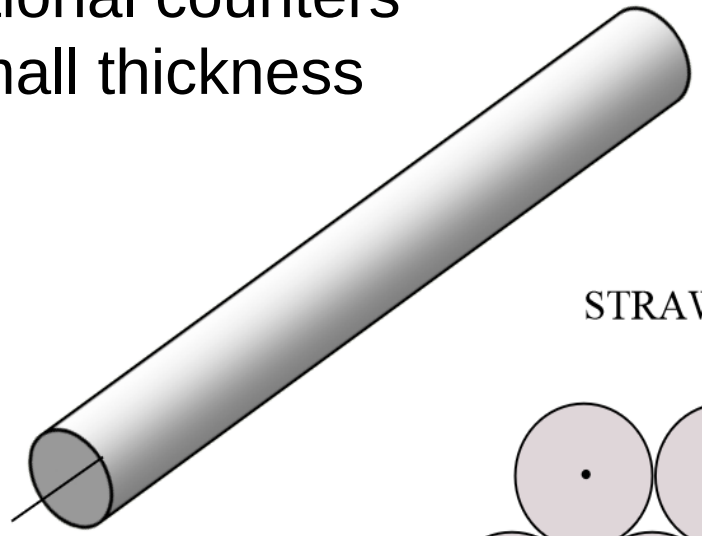
Straw tracker
past, present, future

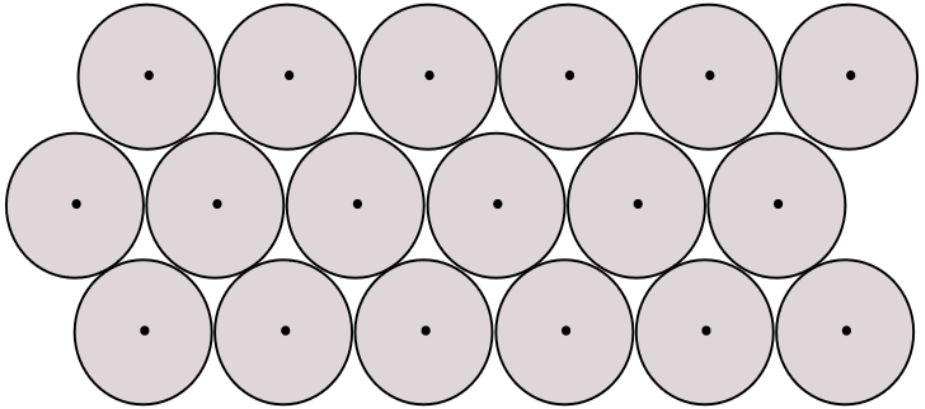
WHAT IS STRAW TRACKERS?

the straw are single proportional counters with small thickness wall.



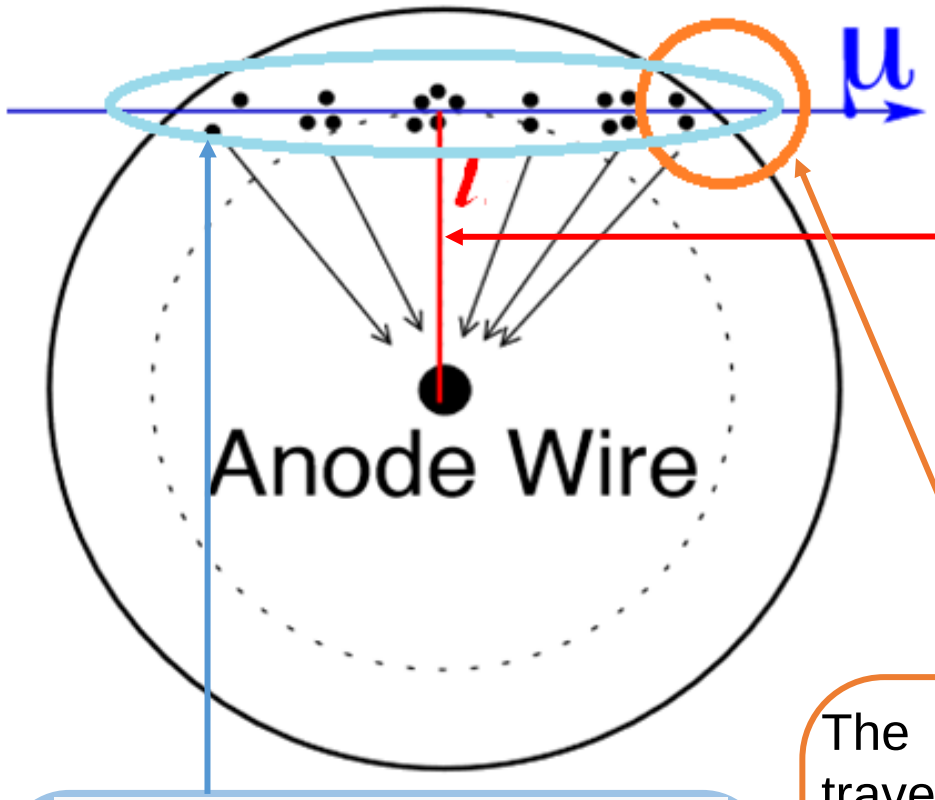
- Sort of proportional drift tube
  - Tracking detector
- Difference
  - Low material budget
  - Smaller in diameter (2-10 mm)
  - Large number of detector elements crossed by particle
  - Can be used also for particle identification (TRT)
  - (tuned to sustain high particle rate)

STRAWS ARRAYS:



From a large number of straw a wall is being built. This is straw tracker.

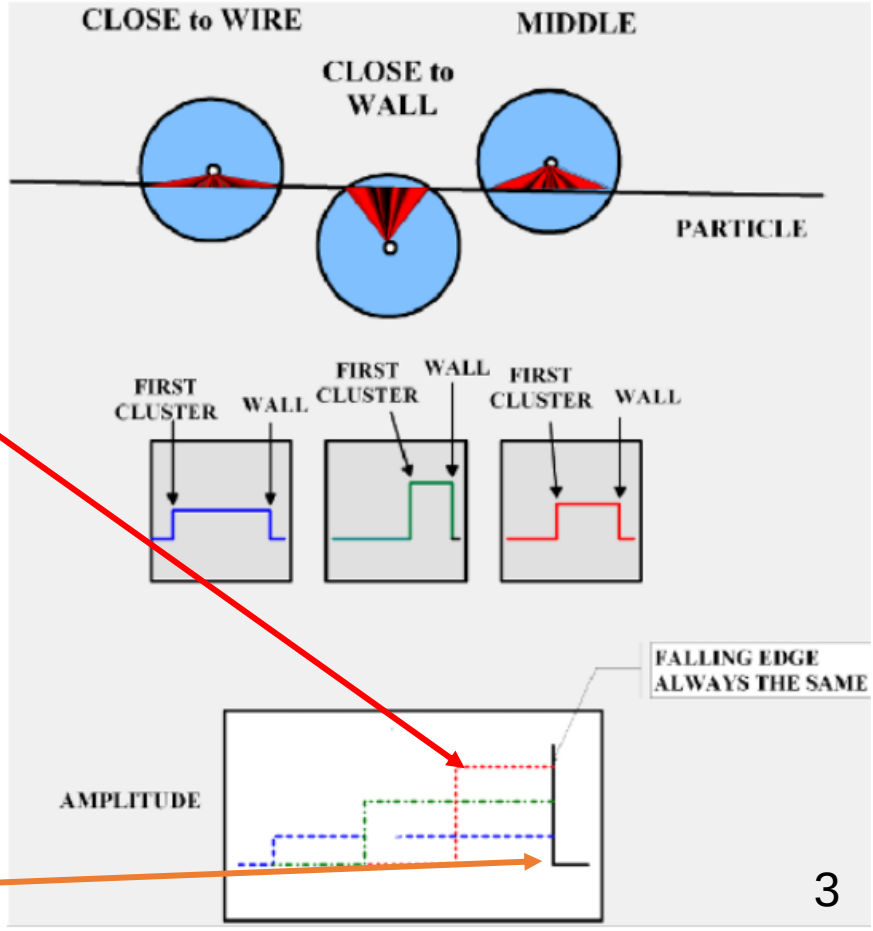
Straw detection principle



An ionizing particle passes at the distance ***l*** from the anode wire and creates primary ionization clusters along its path. The primary electrons drift towards the anode wire where the avalanche amplification occurs. Distance ***l*** is defined by the drift time of the primary electron i.e. by the rising edge of the signal

Straws operate in the proportional mode, so the total charge ***q*** of the iduced signal is proportional to the ionization energy loses dE/dx and may serve PID

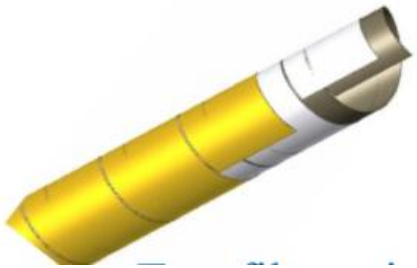
The time when the particle traversed the straw, ***t0***, can be provided by an external detector or defined by the drift time of the last primary electron arriving to the anode, i.e. by the falling edge of the signal

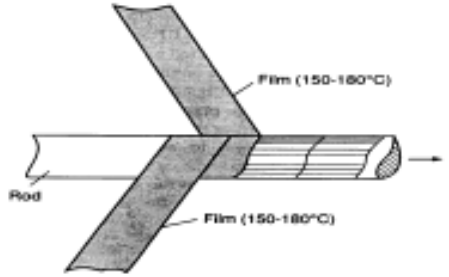


STRAW PRODUCTION

Winding

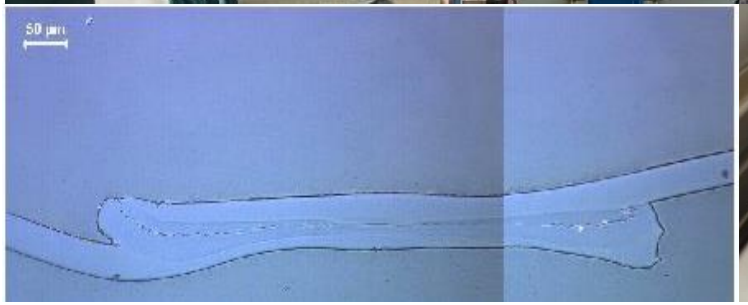
- Production speed: 1 m/min
- Maximal length: 5.5 m
- Diameters: 2,4,6,10,20 mm
- Wall thickness: 15+ um





Ultrasonic welding

- Production speed: 1 m/min
- Maximal length: 5.5 m
- Diameters: 5,10,20 mm
- Wall thickness: 15, 20, 36, 50 um



THE STRAW TRACKER IN VARIOUS EXPERIMENTS

Straw winding

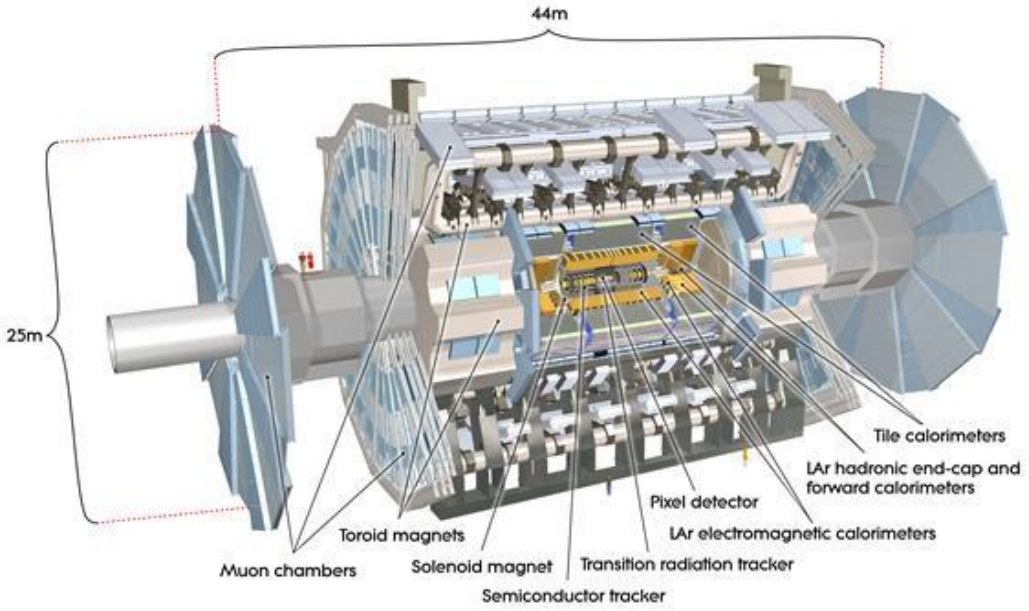
- ATLAS
- LHCb
- PANDA
- CBM
- COMPASS
- Mu2e
- NA64
- SVD-2
- GLUEX
- COZY-TOF
- ..

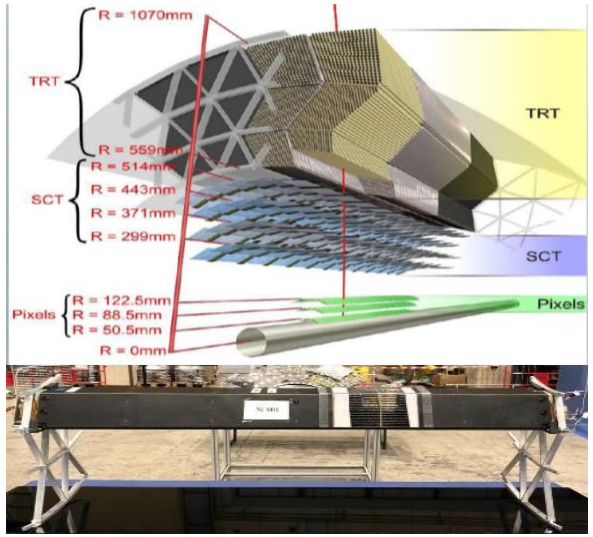
Straw welding

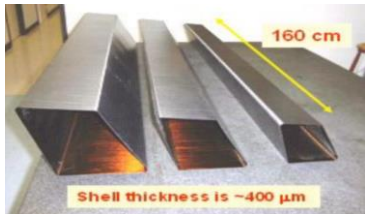
- NA62
- COMET
- SHiP
- DUNE
- SPD NICA
- ,,

red color- straw tracker created with our participation

ATLAS(CERN,Geneva)







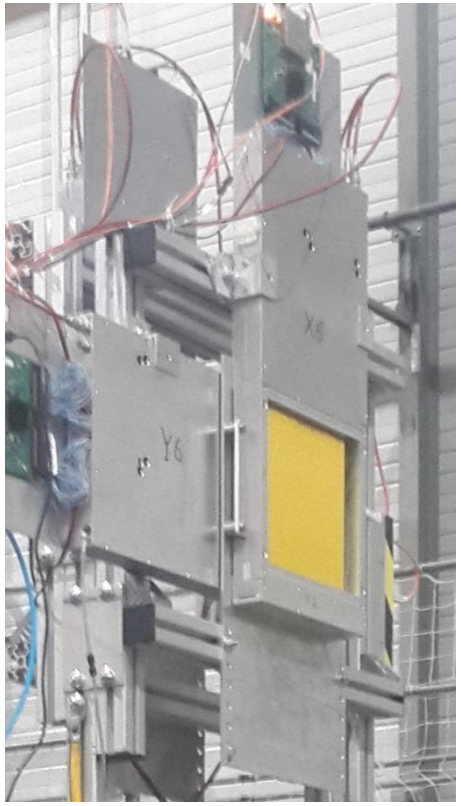
- 350,000 read-out channels
- Volume $12m^3$
- Basic detector element: straw tube with 4mm diameter, in the centre a 0.03mm diameter gold-plated tungsten wire
- 50,000 straws in Barrel, each straw 144 cm long. The ends of a straw are read out separately
- 250,000 straws in both endcaps, each straw 39 cm long
- Precision measurement of 170 mкm
- 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**

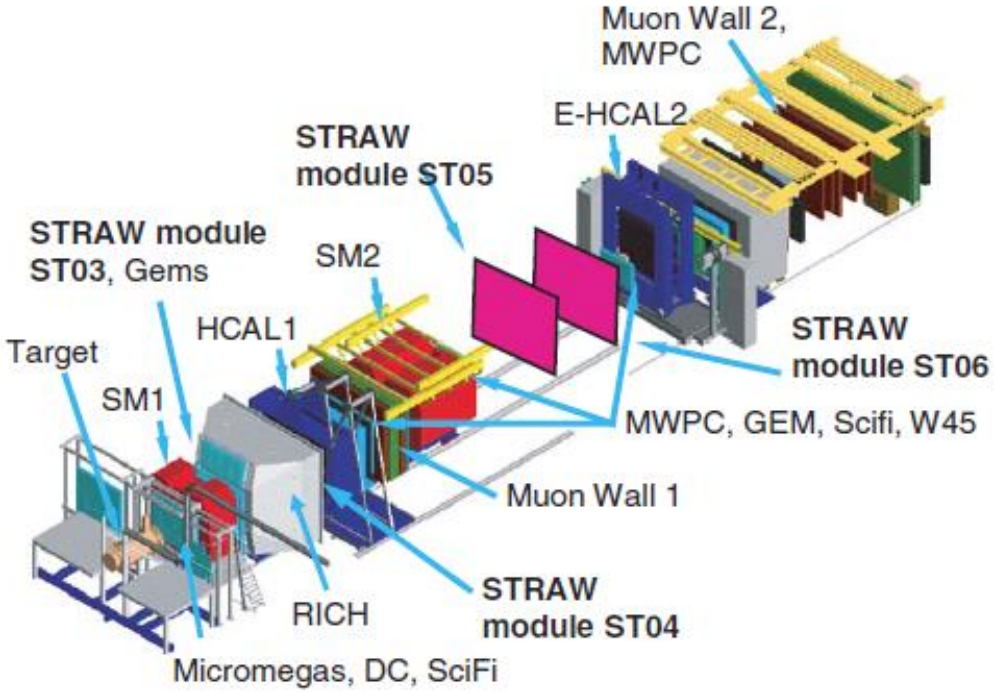
NA64(CERN,Geneva)



- 768 straws
- 6 XY station
- straw tube with 6mm diameter, in the centre a 30mκm diameter gold-plated tungsten wire
- Length straw 20 cm
- Precision measurement of 200 mκm

- Planned 8 XY station with size 1200x600 mm ~ 4000 chann

COMPASS(CERN,Geneva)



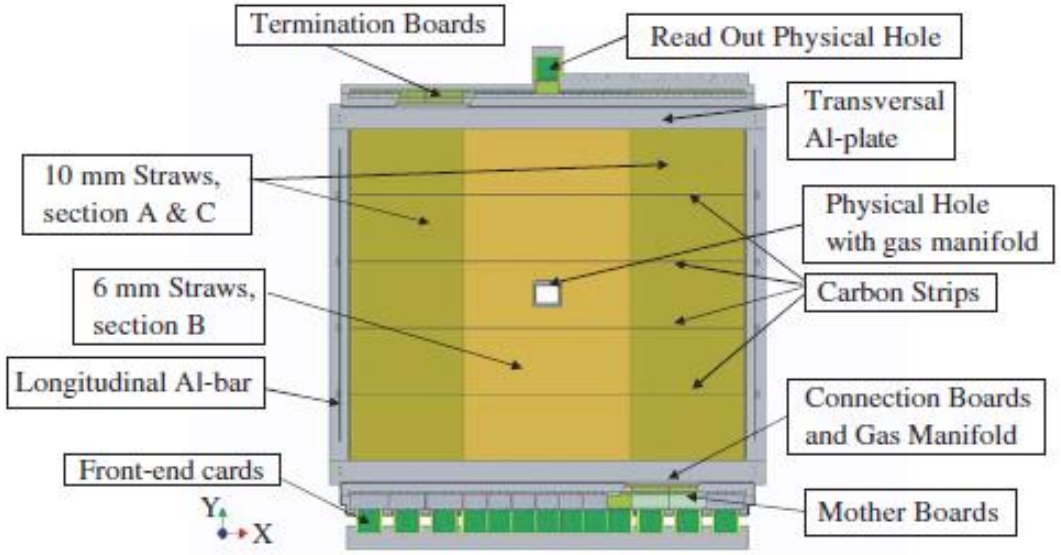


Fig. 2. Schematic view of a chamber (type X).

- 12440 read-out channels
- Volume 130m^2
- Sensitive area 2802x3232(mmxmm) for X, 3254x2427(mmxmm) for Y
- Basic detector 2 element: straw tube with 6mm and 10mm diameter, in the centre a 30mkm diameter gold-plated tungsten wire
- Precision measurement of 200 мкм

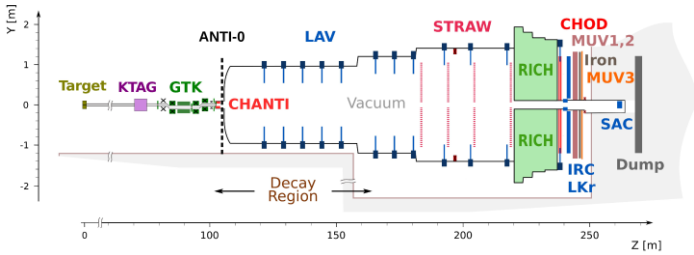
NA62(CERN,Geneva)

Current NA62 straw spectrometer:

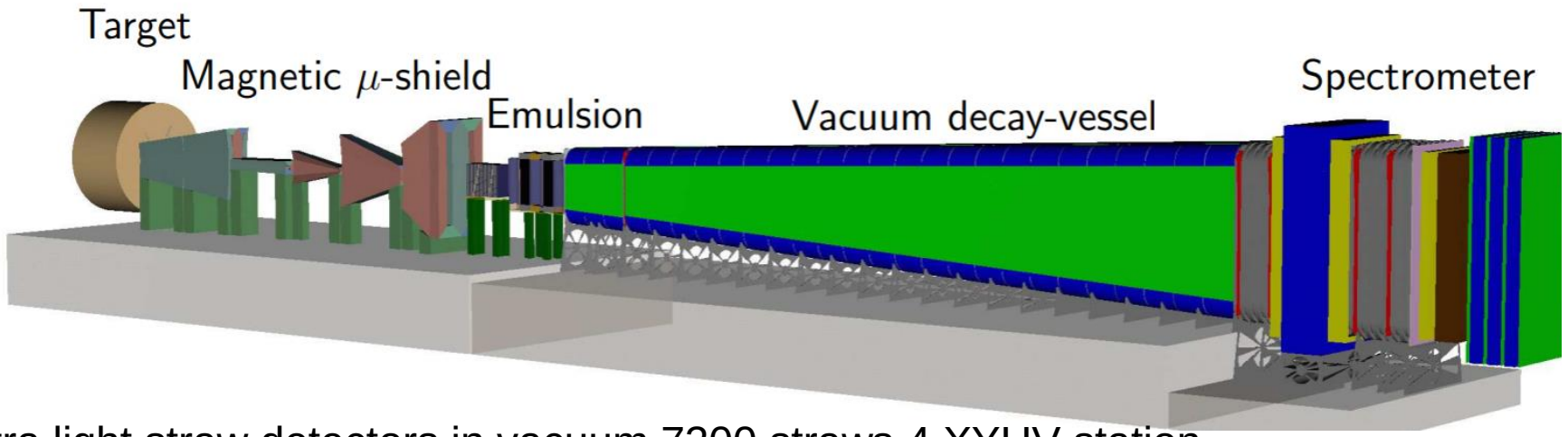
- **Straw diameter: 9.8 mm**
  - Material: 36 μm thick PET
  - Plating: 50 nm copper + 20 nm gold
  - Wire: 30 μm tungsten wire
- **Gas: Ar+CO_2 (70:30)**
- **4 chambers, 7168 straws in vacuum**
  - ~30 straw hits per track
- **Total material budget: 1.7% X_0**
  - Dominated by the PET (70%)
- **Single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

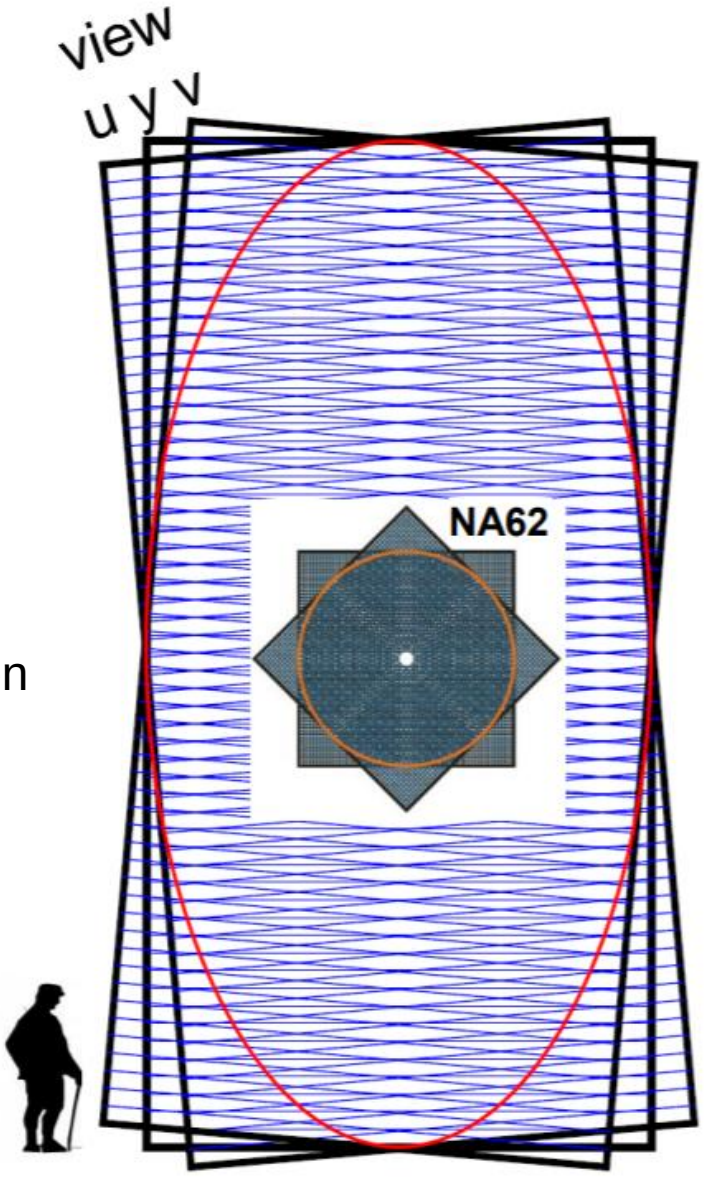
New straw detector, main features:

- Smaller straw diameter: 4.8 mm
  - Maximum drift time reduced to ~80 ns
  - Trailing time resolution improved to ~6 ns
- Keeping the 4 chambers layout, ~21000 straws
  - Number of hits per track increased to ~40
- Thinner straw material: 19 or 12 μm thick PET
- Lower total material budget: 1.0 – 1.5% X_0
  - Depending on the PET thickness option
  - Still dominated by the straw wall (60 – 70%)

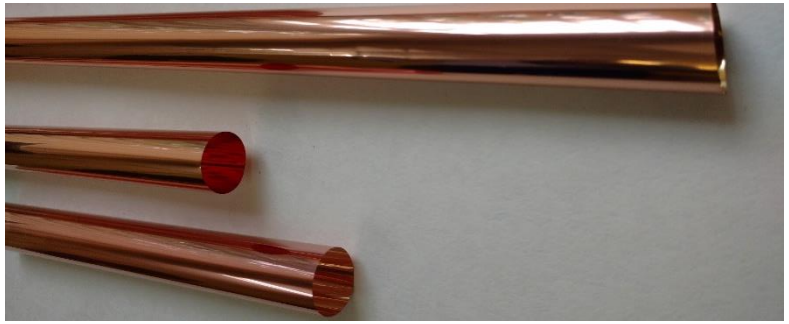


SHiP(CERN,Geneva)





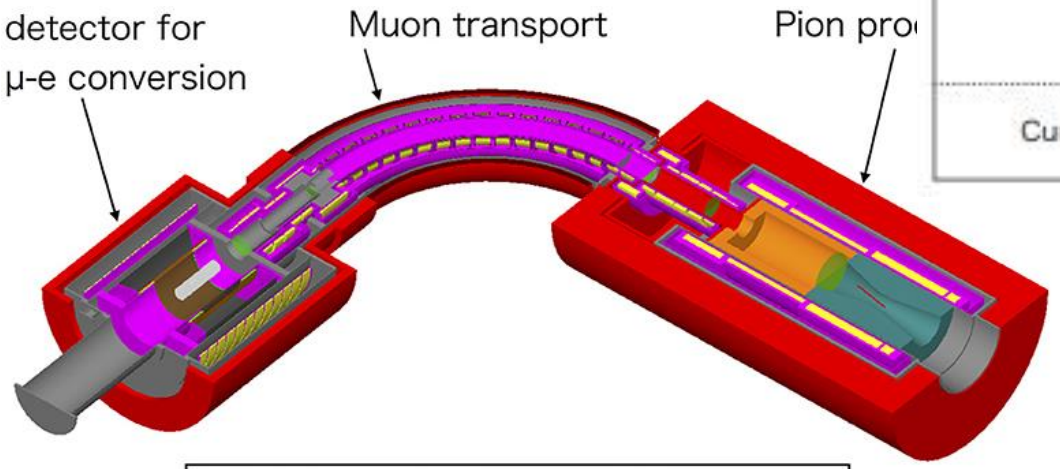
- Ultra light straw detectors in vacuum 7200 straws 4 XYUV station
- Sensitive Area 5x10m
- Straw tube with 20mm diameter, in the center a 30mkm diameter gold-plated tungsten wire
- Length straw 5m
- Precision measurement of 160 mkm



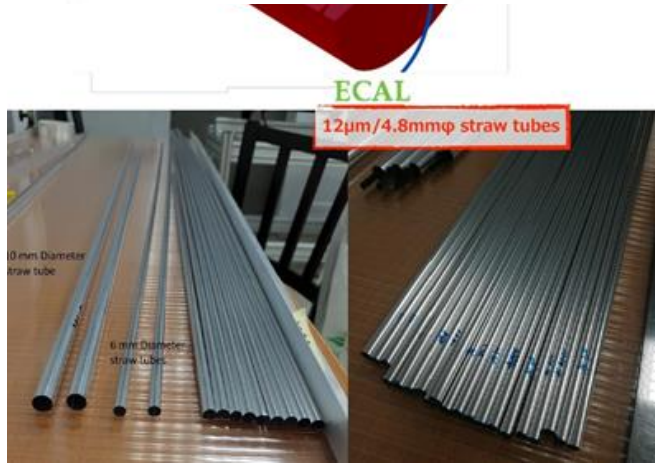
COMET(J-PARC,Tokai)

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

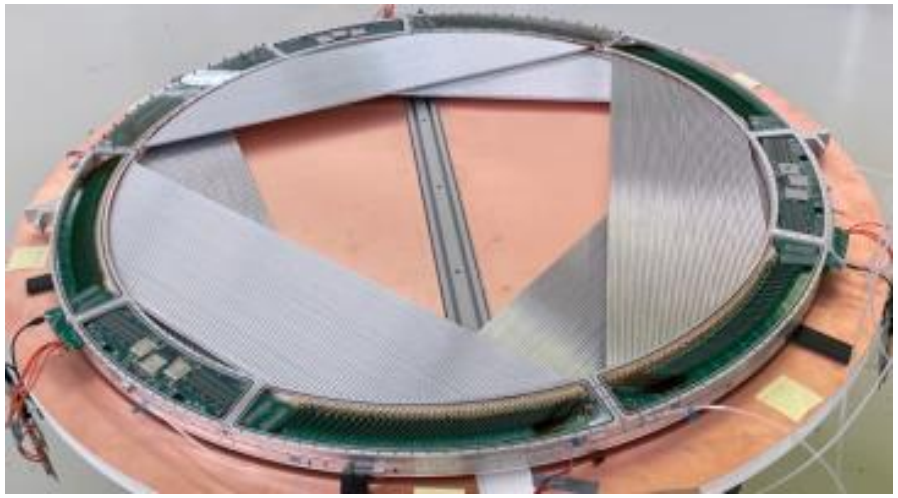


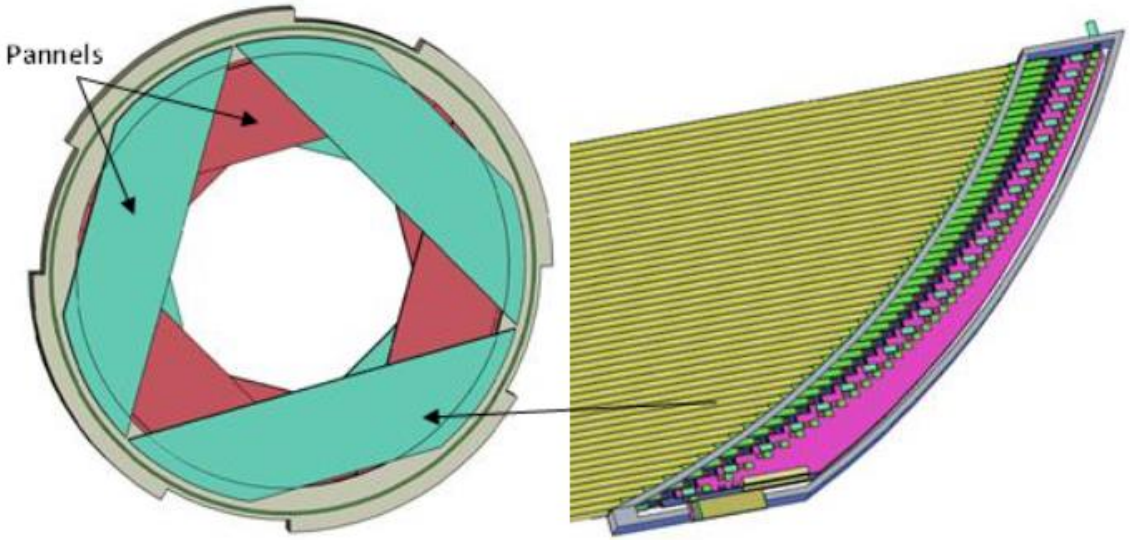
COMET Phase-I Layout

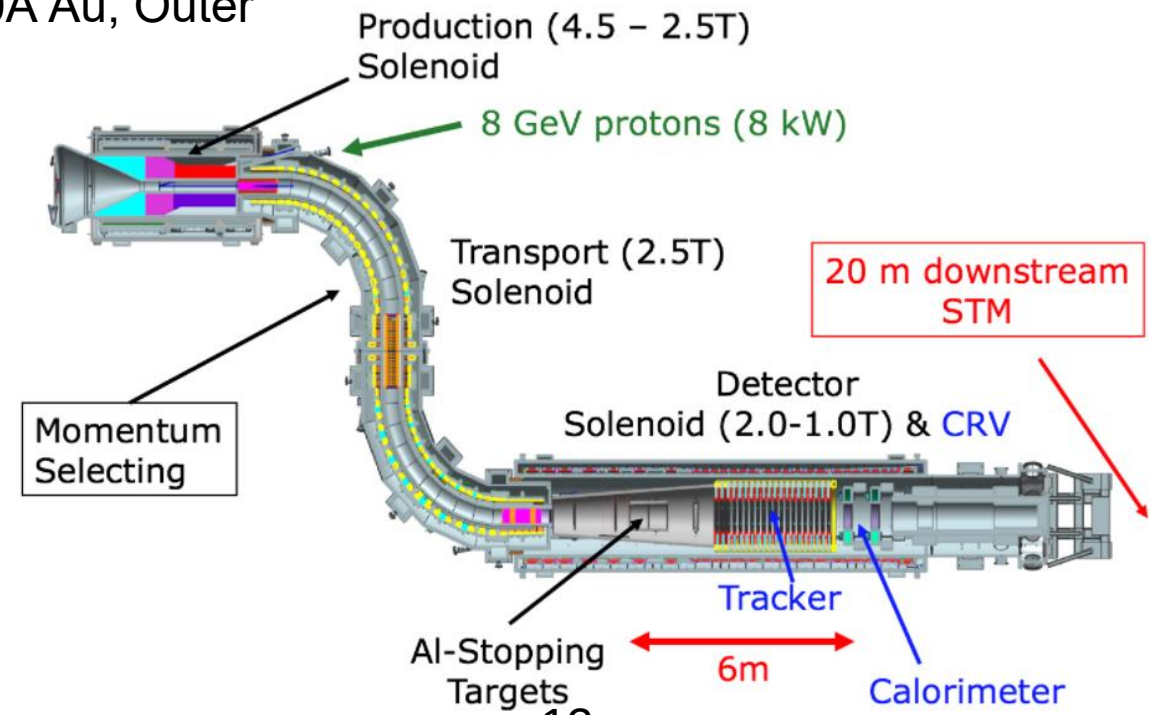


Mu2e (Fermilab, Chicago)

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) 5 mm diameter
Lengths: 45 to 120 cm Inner wall coating: 500Å Al + 200Å Au, Outer wall coating: 500Å Al
Tracker must be improved → ~2028 – 2030



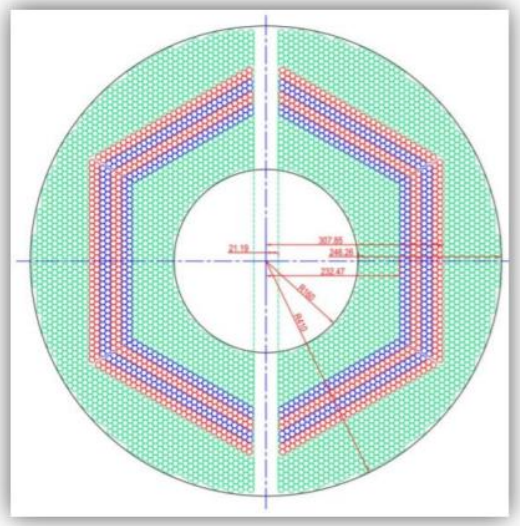


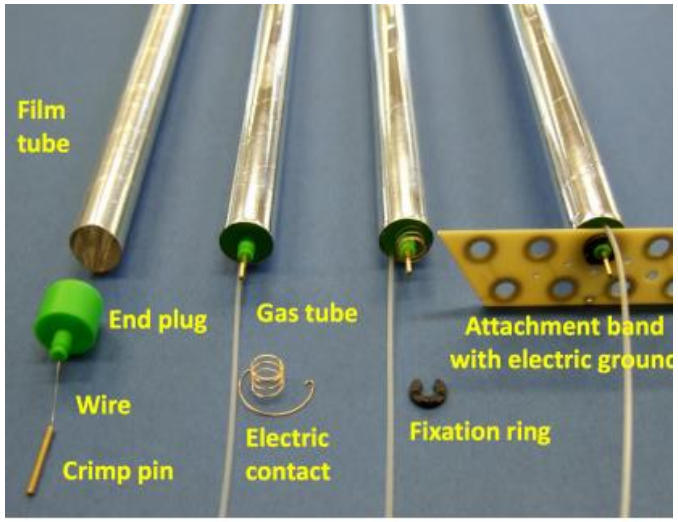


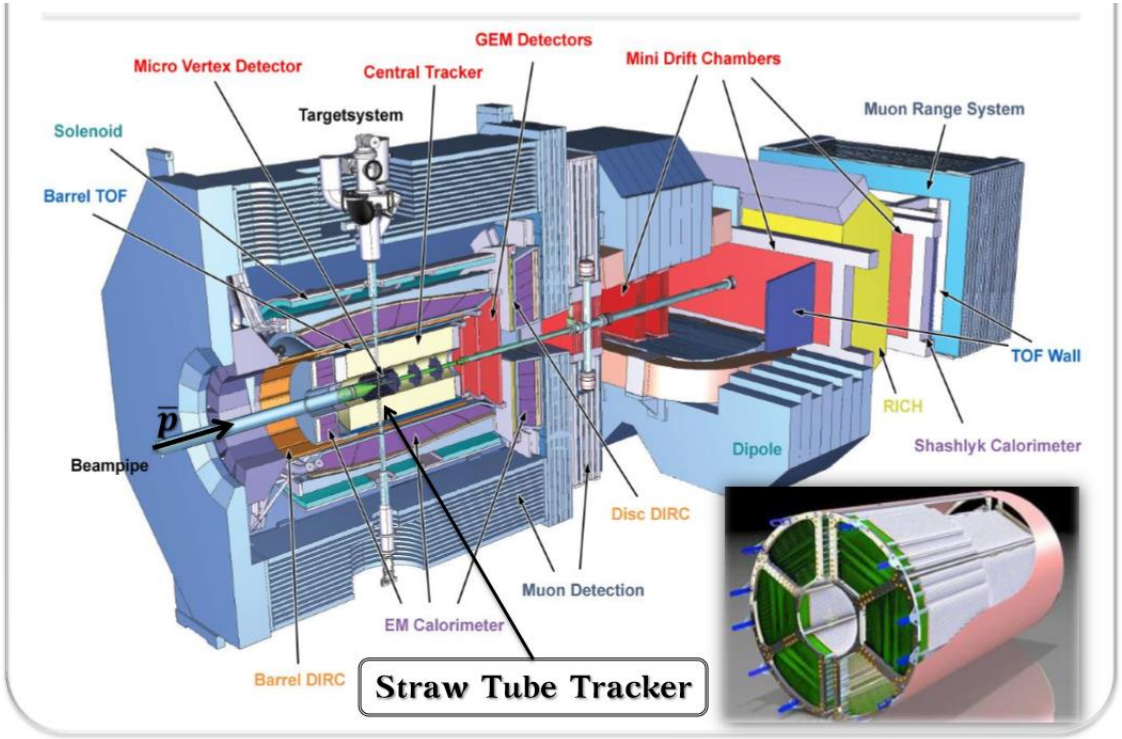
PANDA(FAIR,Darmstadt)

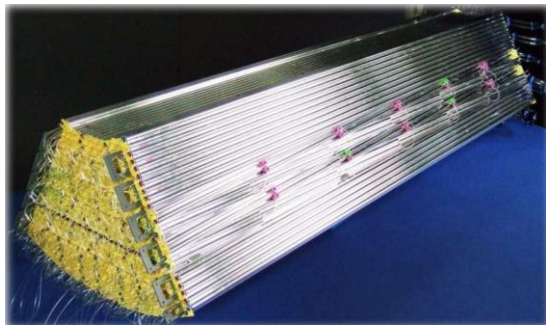
STT LAYOUT

- 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)

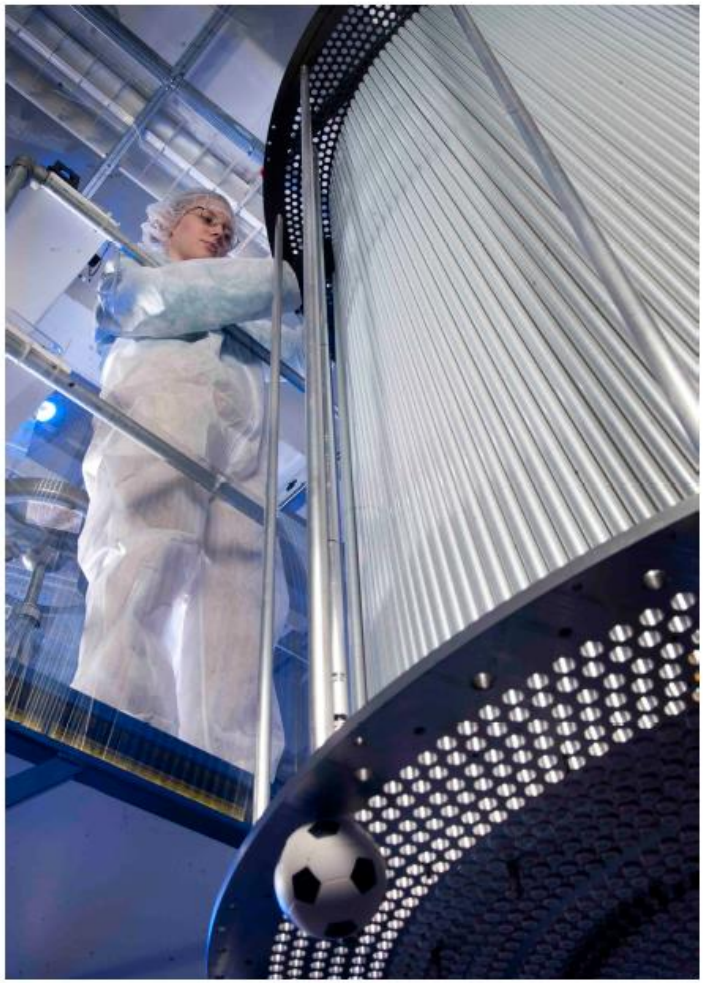








GLUEX(JLab,Virginia)

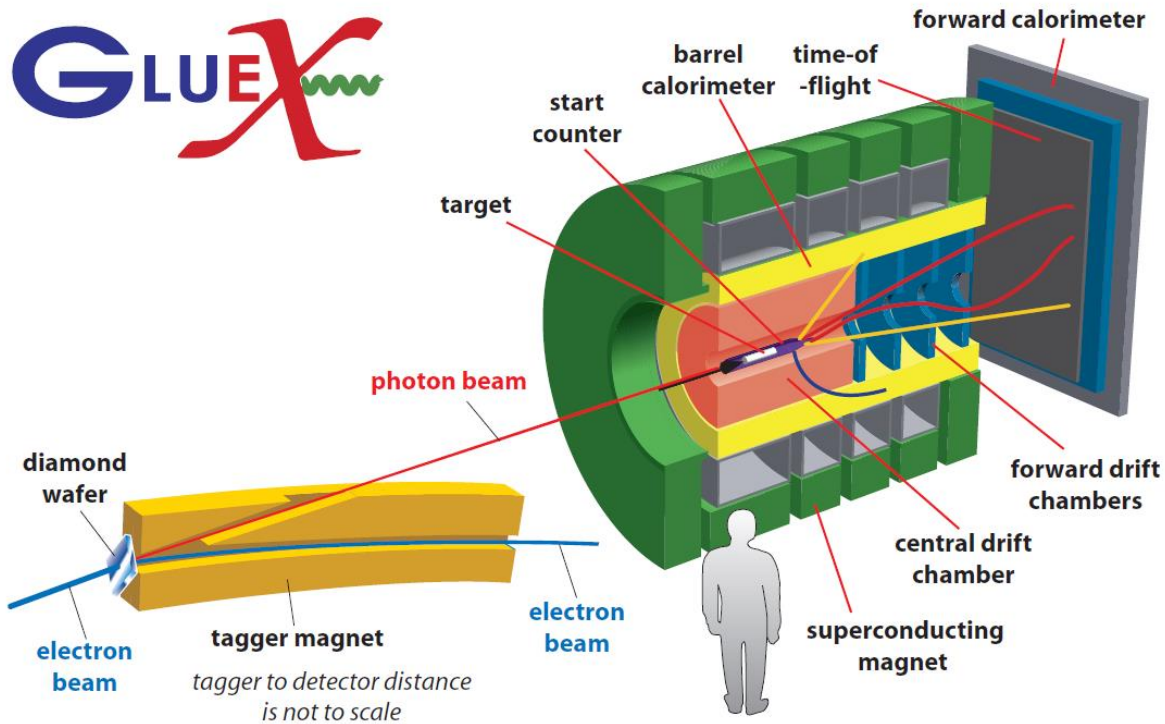


Straw tube chamber

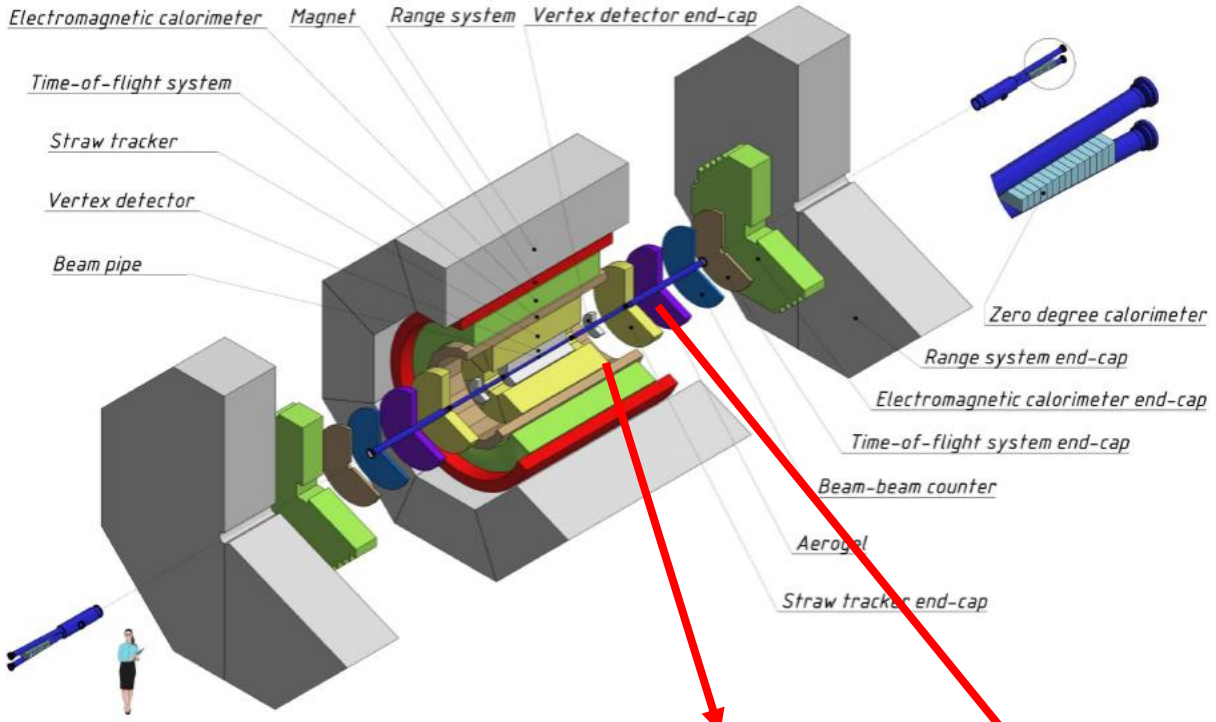
1.5m long x 1.2m diameter

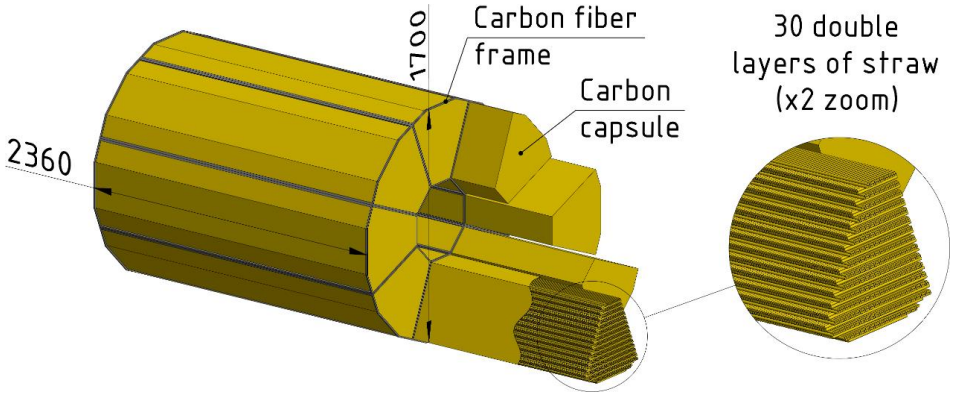
3522 straws, 1.6cm diameter

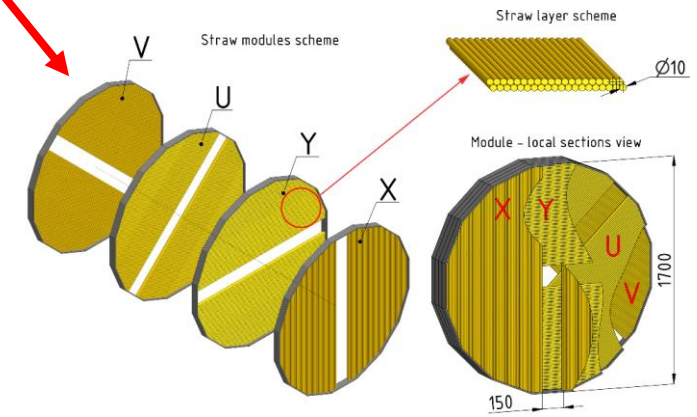
28 layers, 12 straight, 16 stereo



Spin Physics Detector(JINR,Dubna)

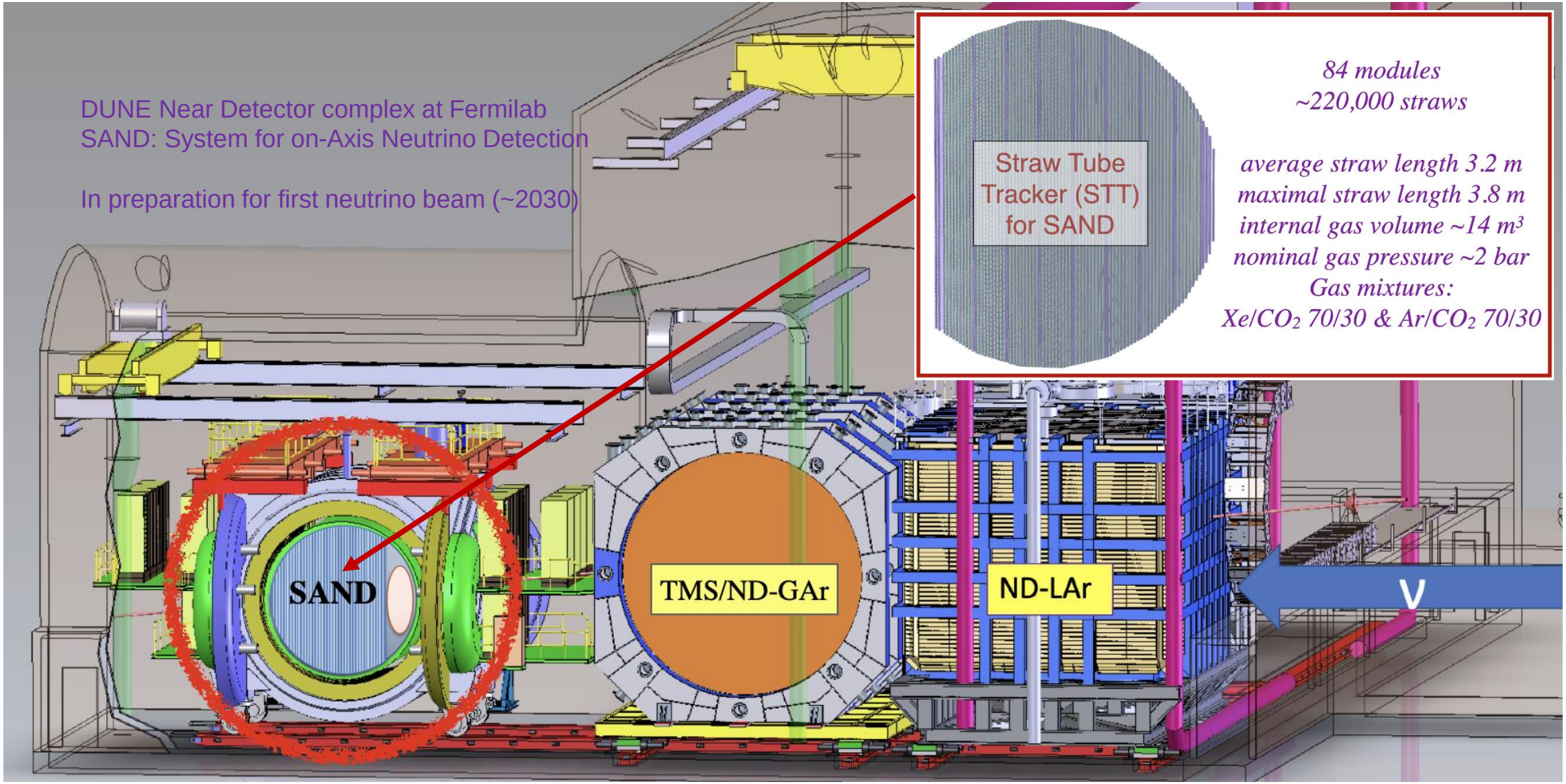






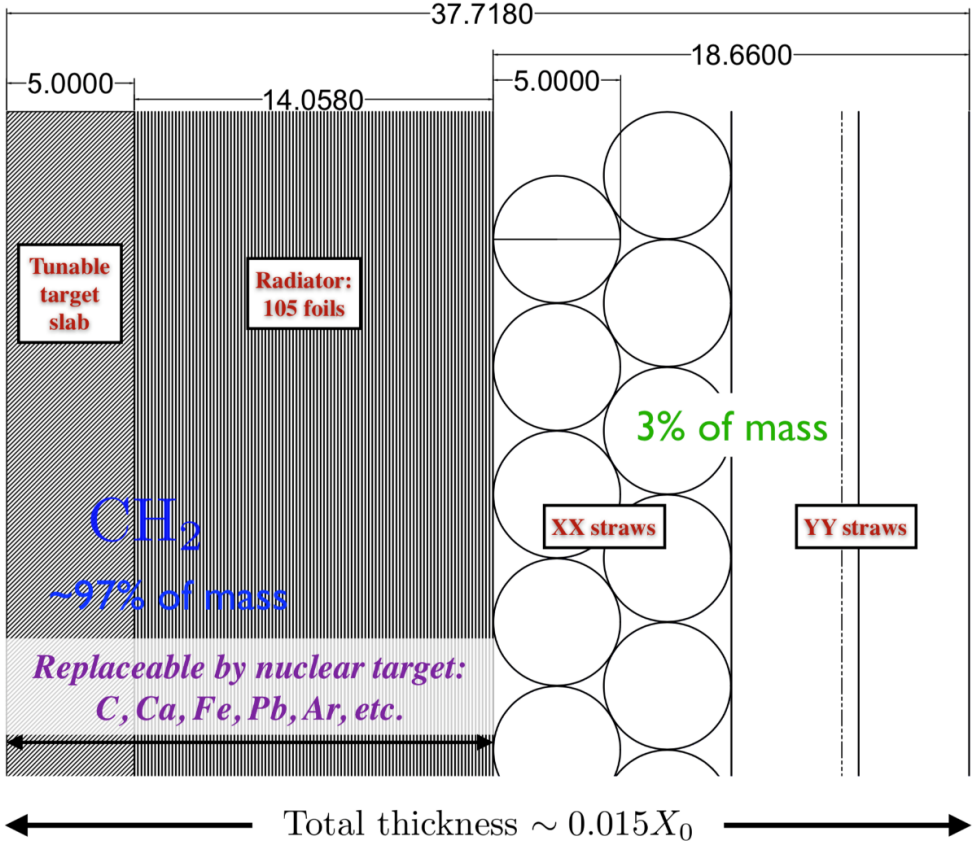
- Straw Tracker - the main tracking system of SPD
- Straw diameter: 10mm thickness 36um PET
- Expected spatial resolution of 150um
- Barrel is made of 8 modules with up to 30 double-layers, with the ZUV orientation (0^0,$+3^0$,-3^0)
- Endcaps are made of 12 double-layers with the XYUV orientation(0^0,90^0,$+45^0$,-45^0)

DUNE (Fermilab, USA)



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

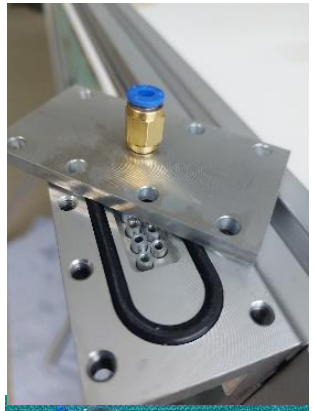
5m long straws for STT prototyping produced at JINR

Material tests and prototyping

Component and assembly tests

- Foil tests, wire test
- Crimping: anode pins, crimpers
- Straw end-plugs
- Adhesives and sealing






First prototypes:

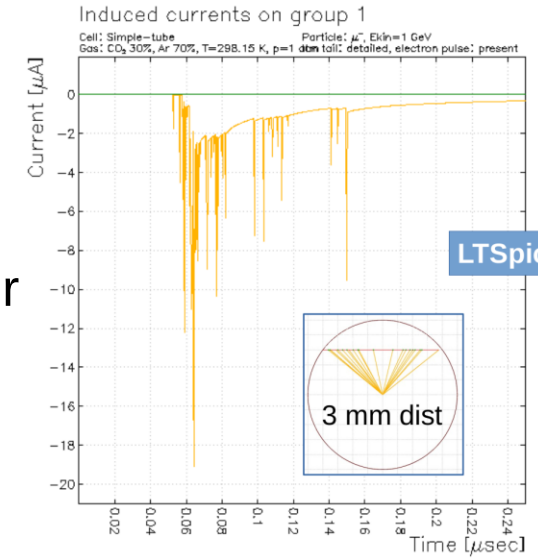
- General R&D – straws of different metallization and diameter 5 (Dune, Hike), 10 (SPD, NA62) and 20 (SHiP) mm => 110 straws
- ZUV (~110 straws) - ongoing




Straw response simulation – validation with experimental data

SPD straw - bare GARFIELD

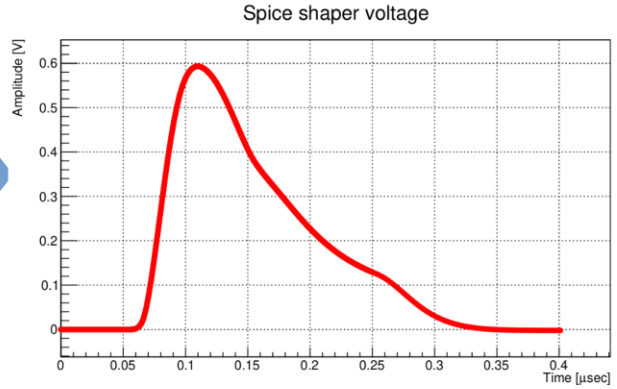
SPD straw geometry/gas are the same as of the NA62 Straw Tracker



GARFIELD output interfaced to LTSpice (read-out emulation)

We assume VMM3a-based readout

LTSpice

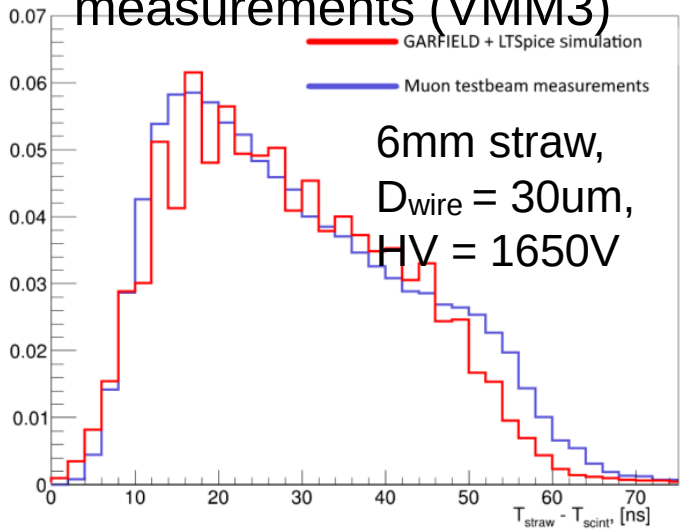


*We are grateful to **RD51 collaboration** for sharing the electronic circuit*

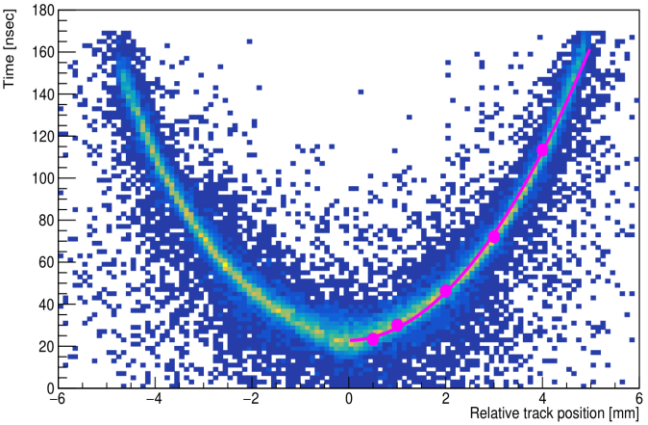
9

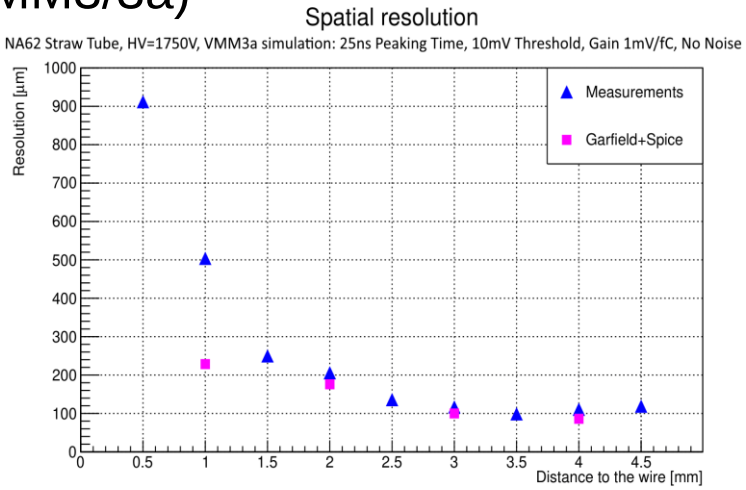
Validation:

GARFIELD/LTSpice (VMM3/3a) vs test beam measurements (VMM3)



Validation: NA62 measurements (CARIOCA) vs GARFIELD/LTSpice (VMM3/3a)

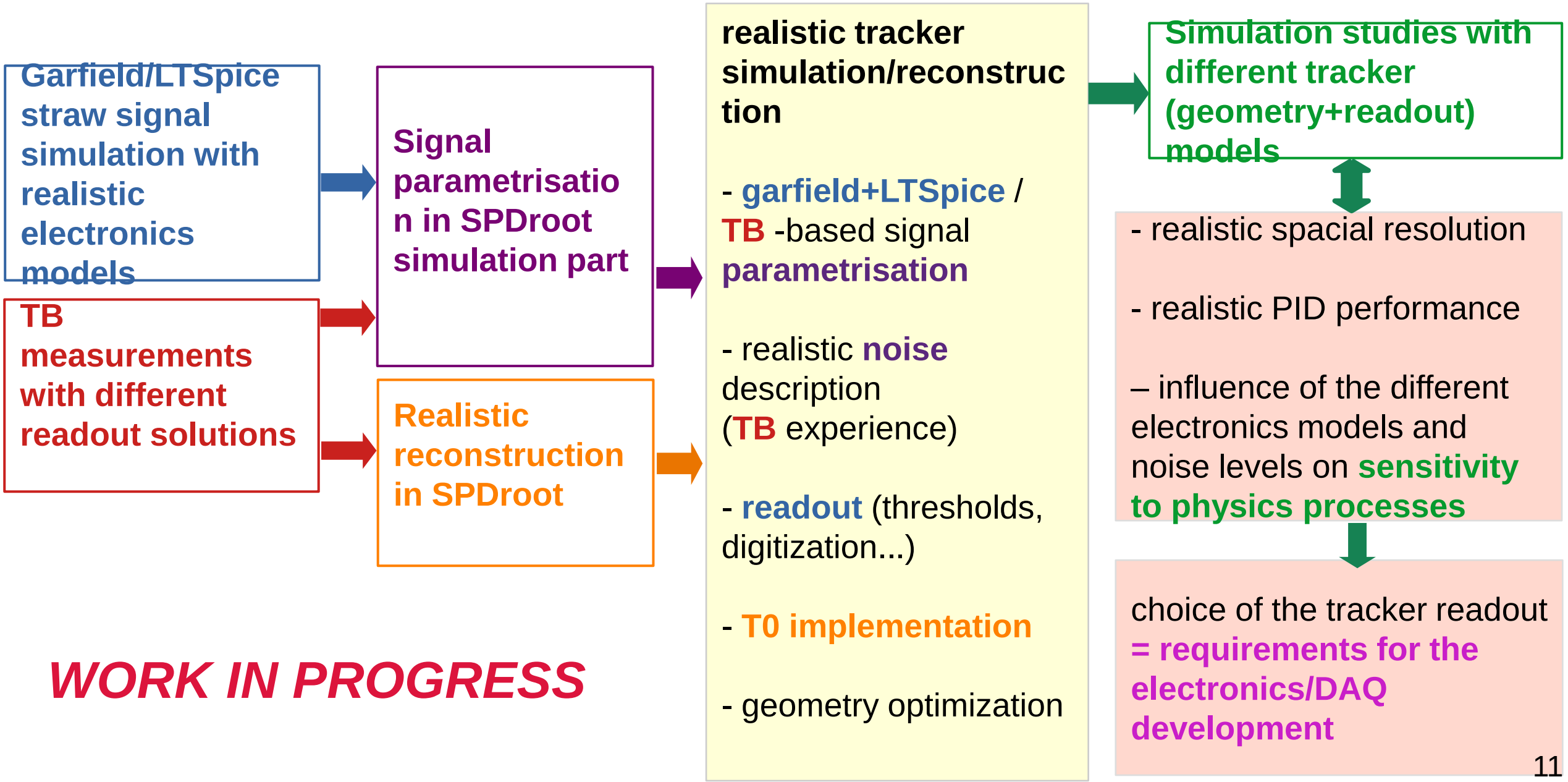




GARFIELD/LTSpice simulation validated with the test beam measurements allows to

- Predict performance of any new straw readout under development
- Provide input for the developing realistic simulation of the SPD Straw Tracker

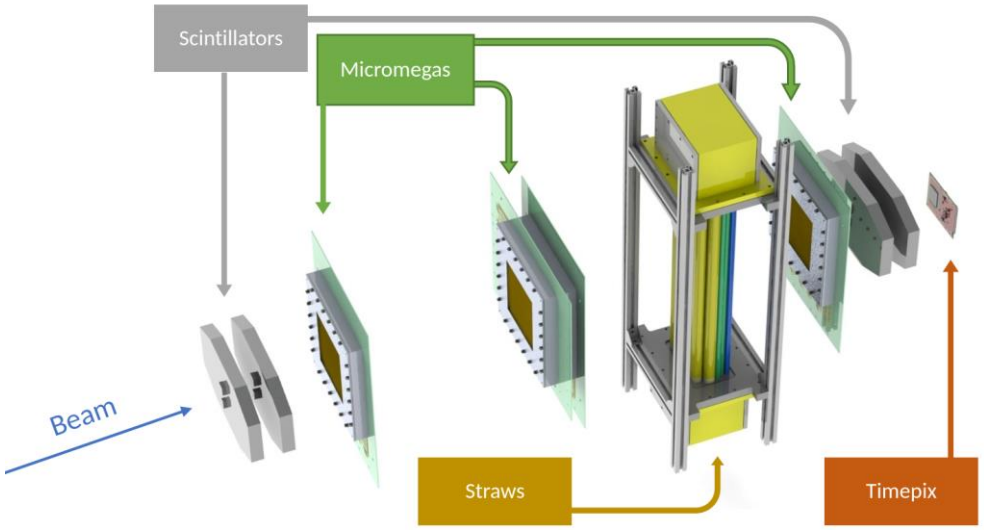
Realistic simulation of the Straw Tracker



WORK IN PROGRESS

Test beam activity within the general Straw Tracker R&D

Ongoing from year 2021



Current configuration:
Reference tracking:

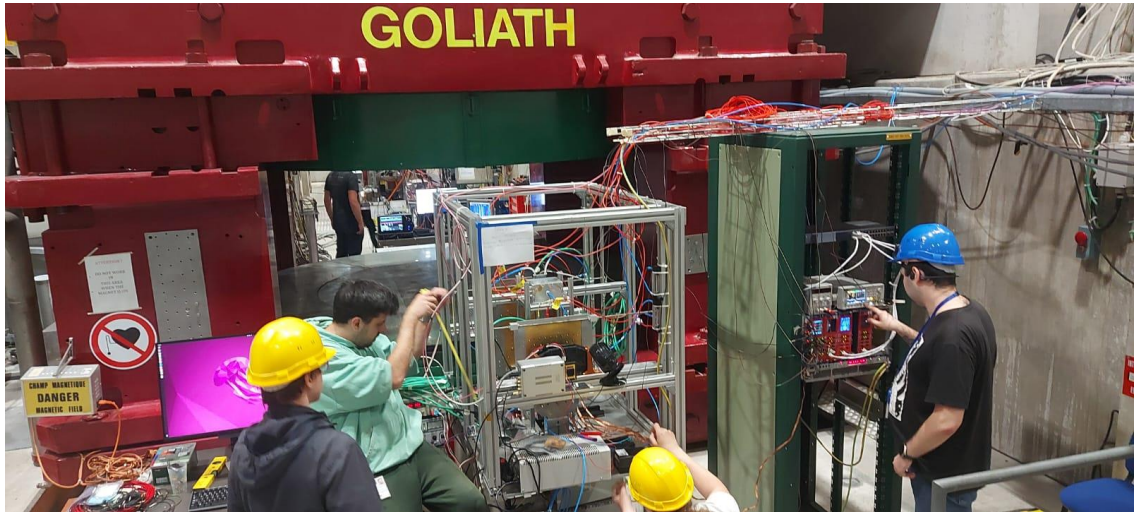
- MicroMegas (250 um) + Tiger readout (Torino University)

- Timepix4 – 50um x 50um

Goals:

- explore the existing readout possibilities (ASICs)
- if no solution exists,
  define the requirements for new ASIC development
- test the combined straw tracker prototype

ASICs tested:

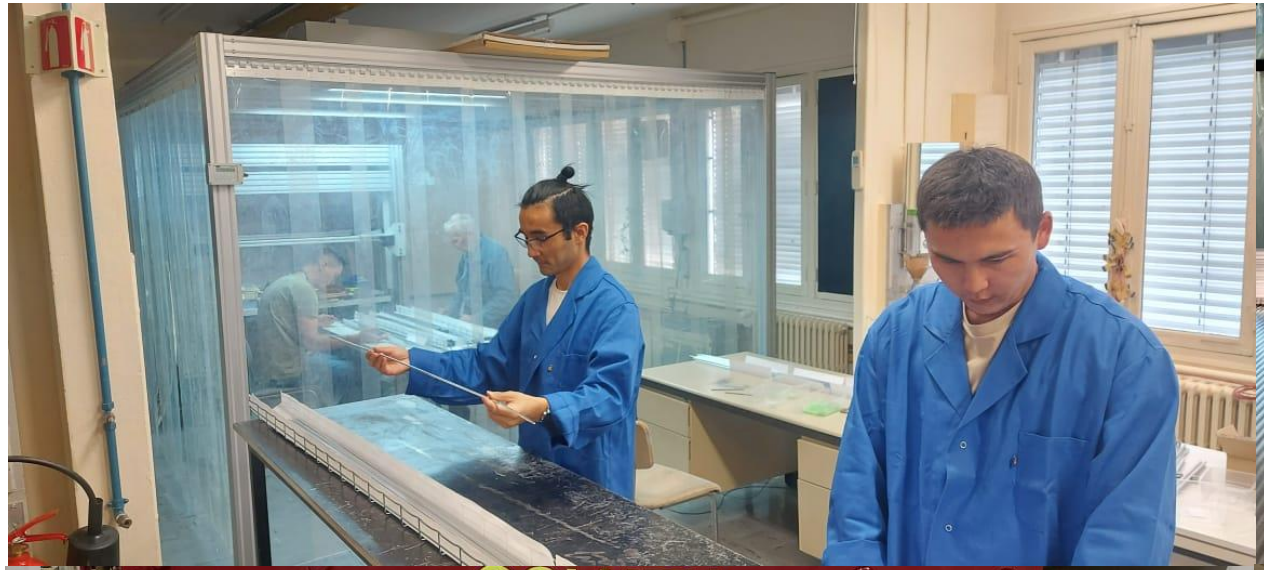


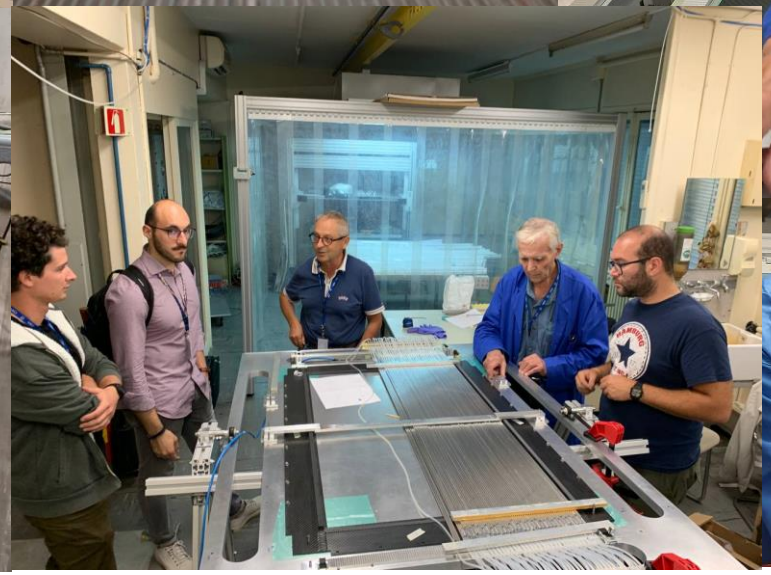
- **VMM3a** in Time-at-Threshold mode (discarded after testing, see Proceedings to PM2021, NIM.A 1047 (2023) 167864)

-**Tiger** (talk by V.Bautin at TIPP2023)

- **VMM3**

Finding the best assembly solutions





Thanks for your attention