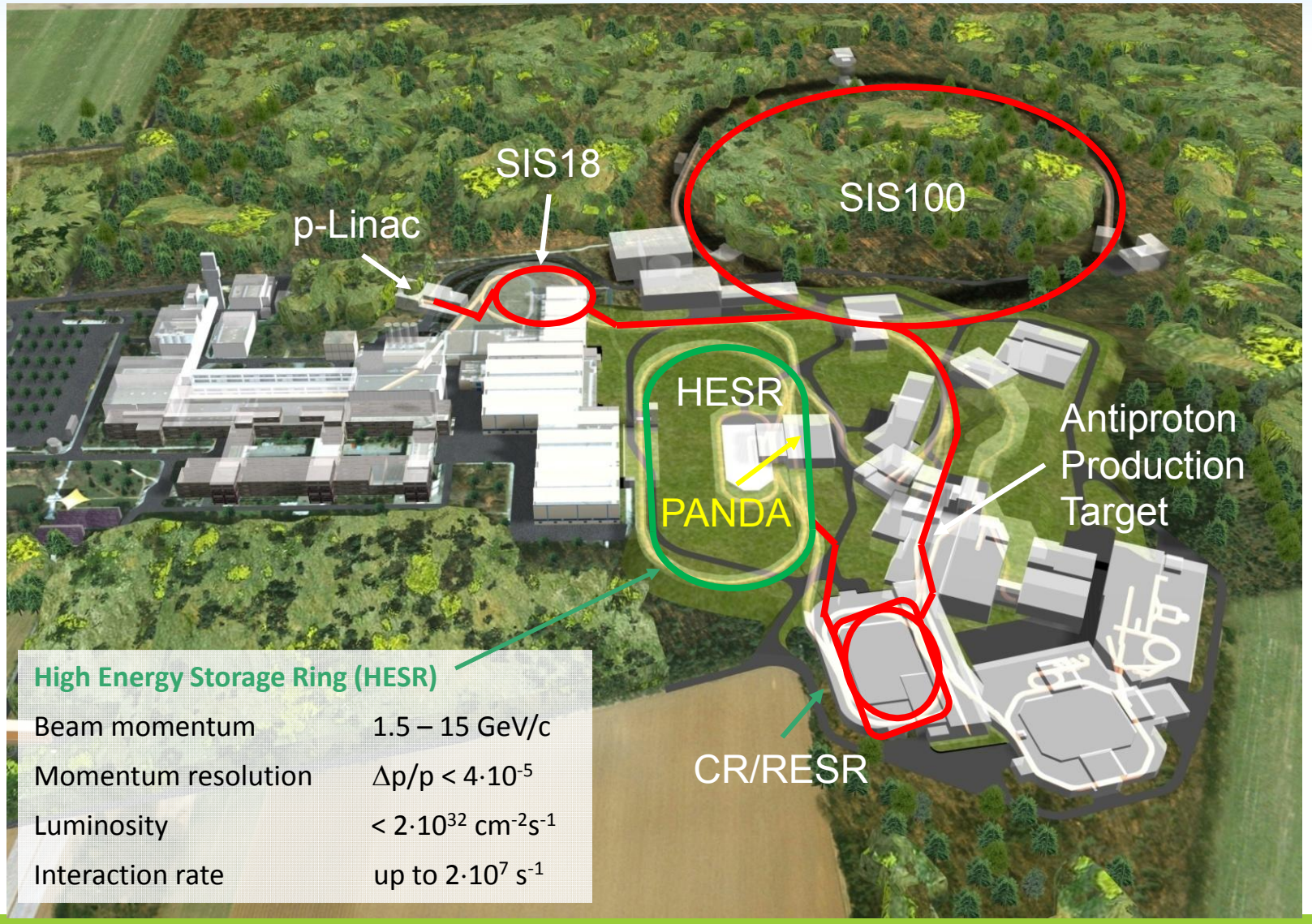
Design of the forward straw tube tracker for the PANDA experiment

JERZY SMYRSKI
JAGIELLONIAN UNIVERSITY, KRAKOW, POLAND

(Facility for Antiproton and Ion Research)



High Energy Storage Ring (HESR)

Beam momentum	1.5 – 15 GeV/c
Momentum resolution	$\Delta p/p < 4 \cdot 10^{-5}$
Luminosity	$< 2 \cdot 10^{32}$ cm^{-2}s^{-1}
Interaction rate	up to $2 \cdot 10^{7}$ s^{-1}

Physics at PANDA

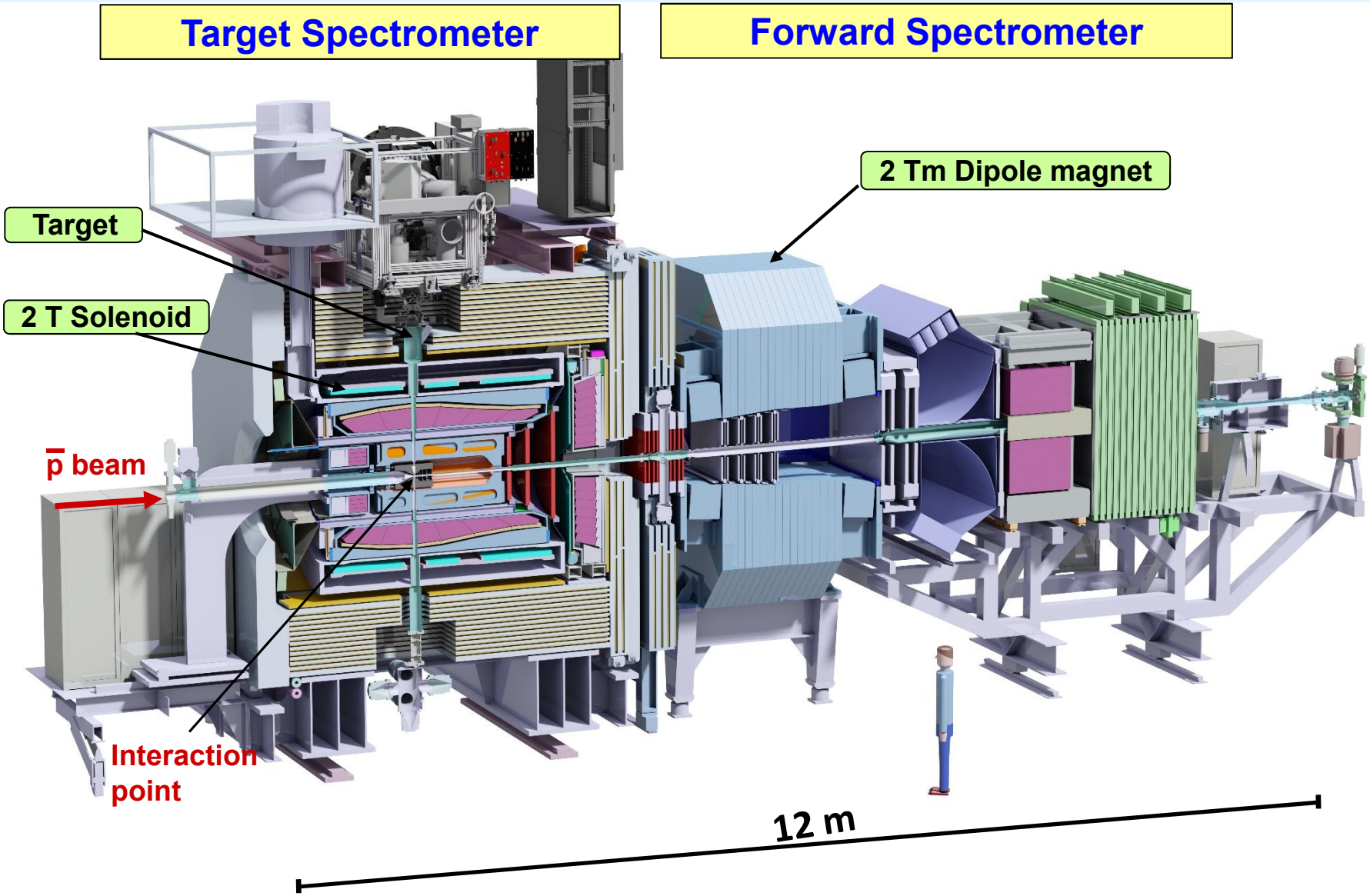
$\bar{p}p$

- **Hadron spectroscopy**
  - Charmonium
  - Exotic states
  - D mesons
  - Strange and charmed baryons
- **Nucleon structure**
  - Timelike form factors
  - Drell-Yan Processes
  - Generalized Parton Distributions

$\bar{p}A$

- **Hadrons in nuclear medium**
  - J/ψ absorption
  - Mass shift of D mesons
- **Double Λ-hypernuclei**

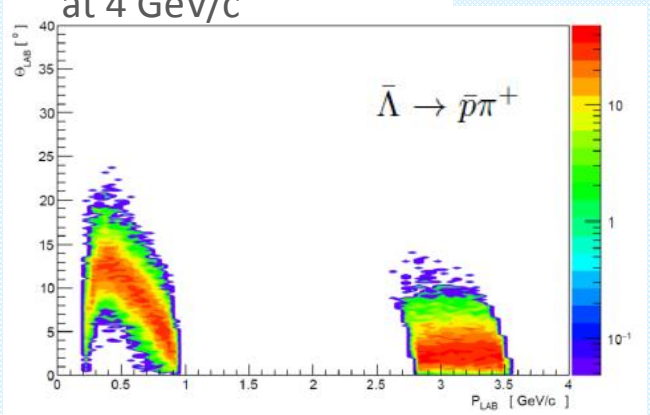
PANDA spectrometers



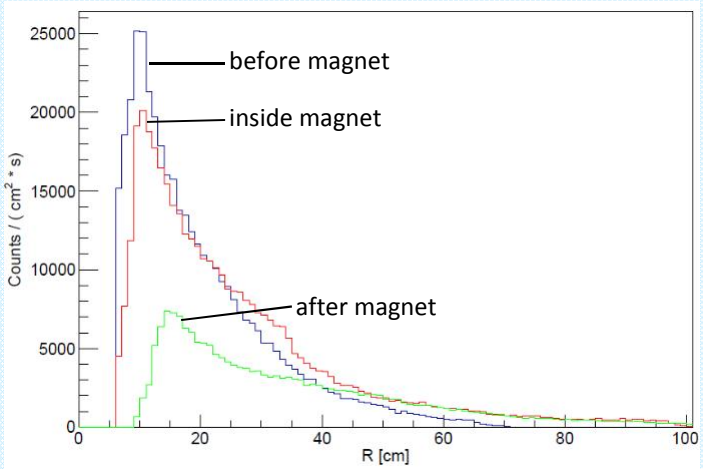
Basic requirements for the FT

- Angular acceptance: ±10° horizontally, ±5° vertically
- Momentum acceptance: down to 0.03 p_{beam}
- Momentum resolution: ~1.5%
- Particle fluxes: up to 25 kHz cm^{-2}
- Total counting rate: up to $5 \cdot 10^7$ tracks/s
- Track multiplicity: <5 (86%) at 15 GeV/c

$\bar{p}p \to \Lambda\bar{\Lambda} \to p\pi^-\bar{p}\pi^+$ at 4 GeV/c

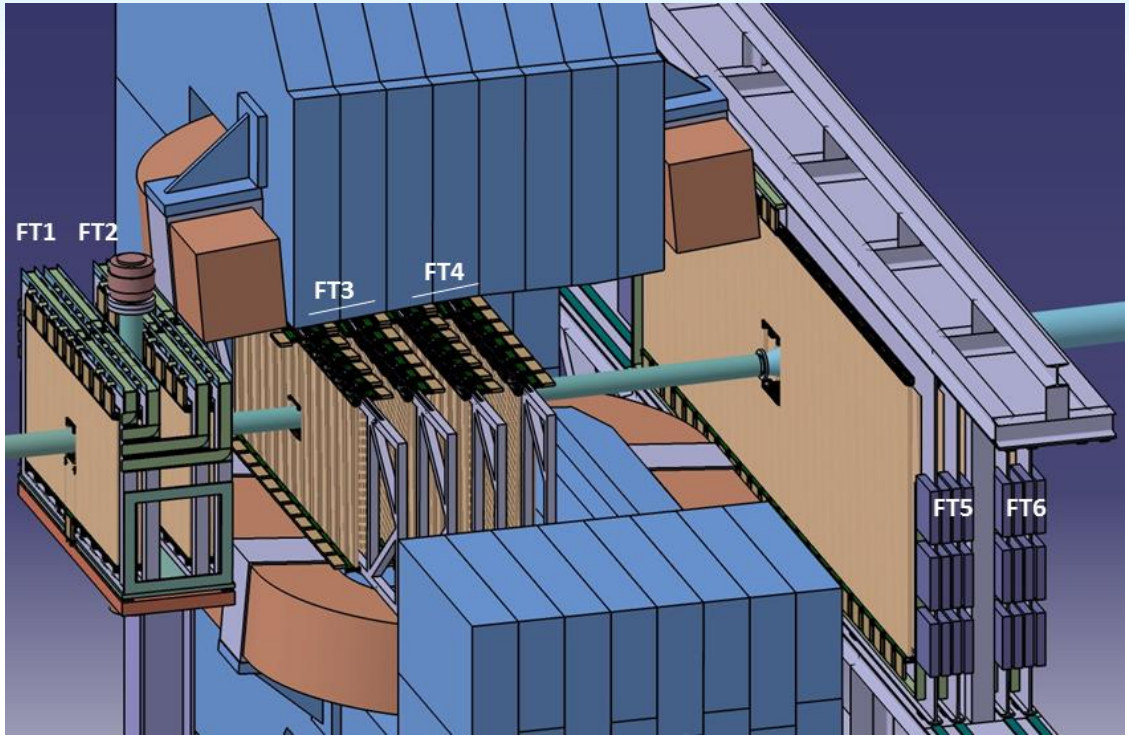


Particle flux vs. distance from beam axis



Background simulations based on the DPM model-pbar-p at 15 GeV/c at the interaction rate $2 \cdot 10^7$ s^{-1}.

Forward Tracker - general layout

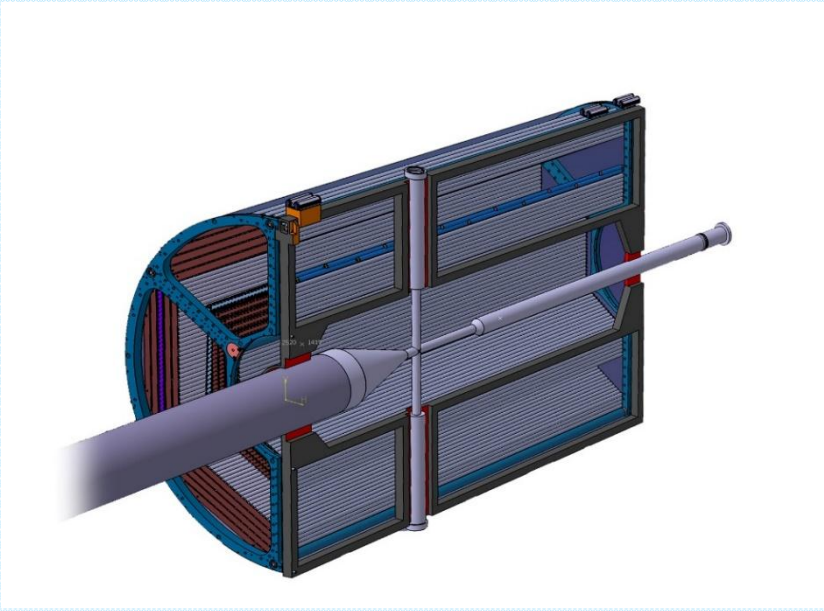


- **3 pairs of tracking stations**: **FT1, FT2** (S ~ 130 x 60 cm^2)
  FT3, FT4 (S ~ 200 x 70 cm^2)
  FT5, FT6 (S ~ 400 x 120 cm^2)
- **One tracking station: 4 double layers of straws oriented at 0°, +5°, -5°, 0°**
- **In total: 6 tracking stations, 6 x 4 = 24 double layers, 12 224 straws**

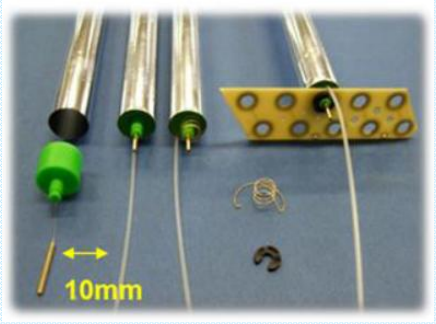
Self supporting straw tubes

- **Self supporting straw tubes developed for the COSY-TOF experiment**
- **Applied also in the PANDA central Straw Tube Tracker**

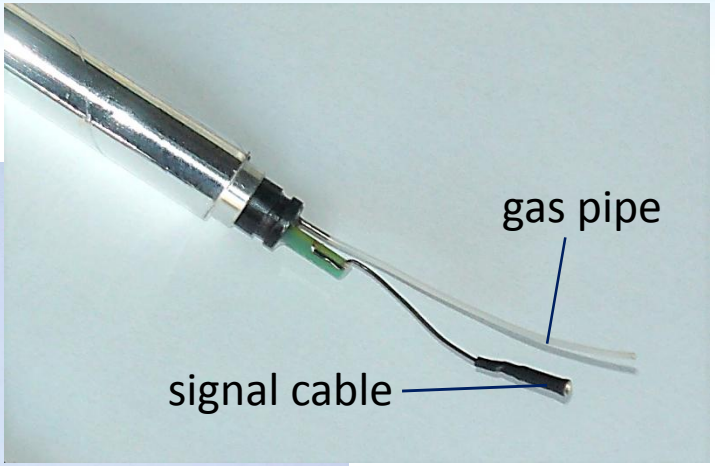
Eur. Phys. J. A49 (2013) 25

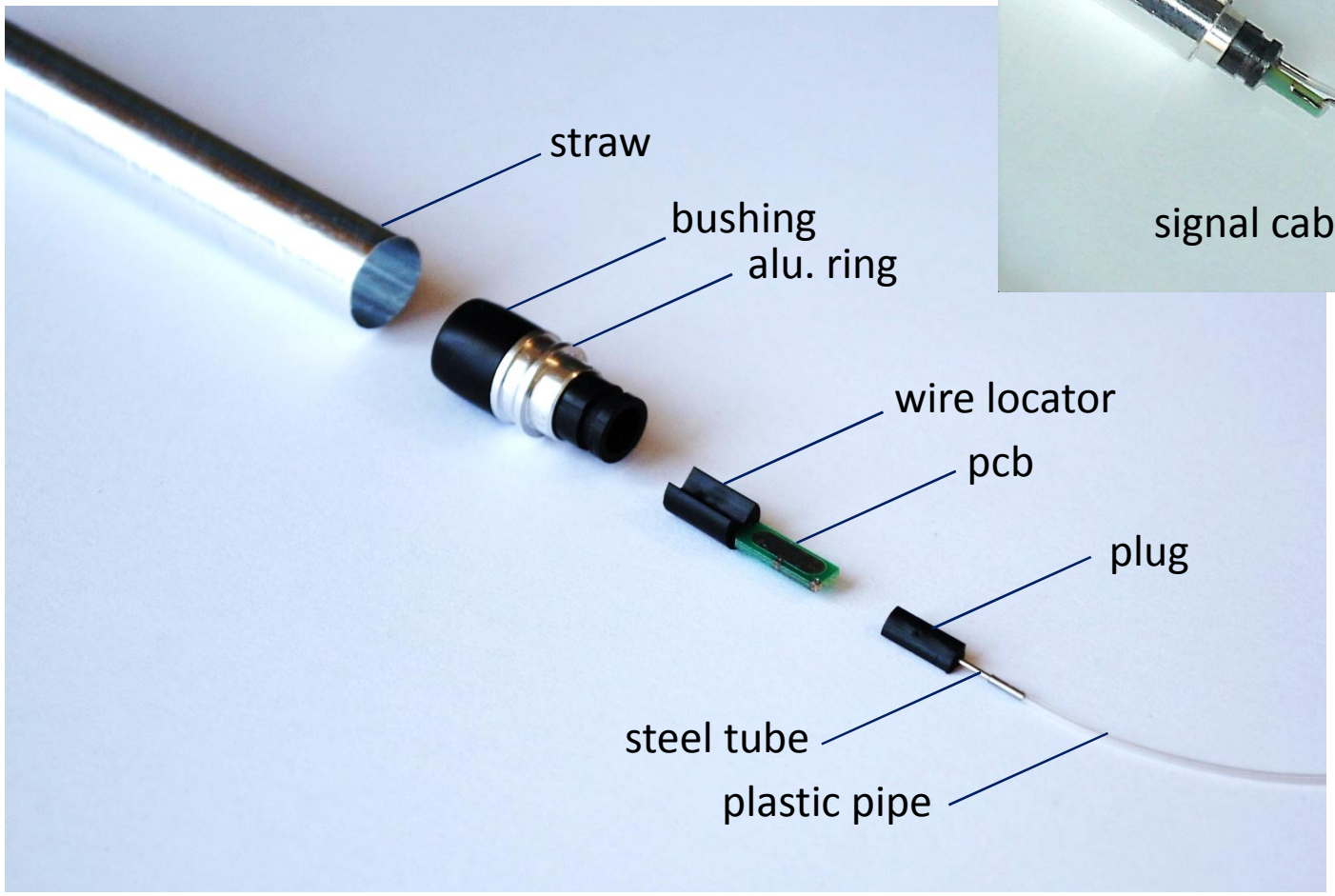


- **Gas overpressure 1 bar:**
  - **mechanical stiffness of straws**
  - **anode wire tension**
  - **the role of detector frames limited to positioning the straws**
- **Straw: ∅10 mm, 27 μm aluminized Mylar**
- **Anode wire: ∅20 μm, Au plated W/Re**
- **Material budget with Ar-CO_2 (90:10) mixture for 24 double layers: $X/X_0 \approx 2\%$**



End-plugs for FT straws

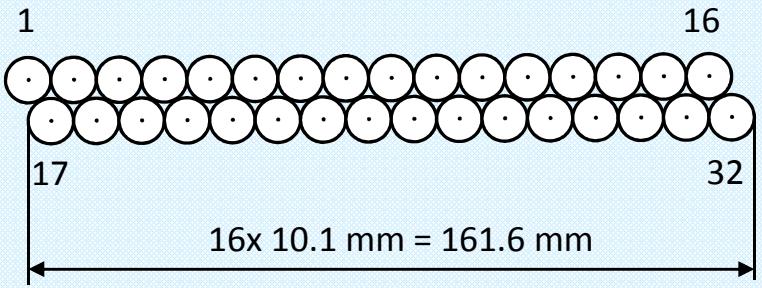




Straw tube modules

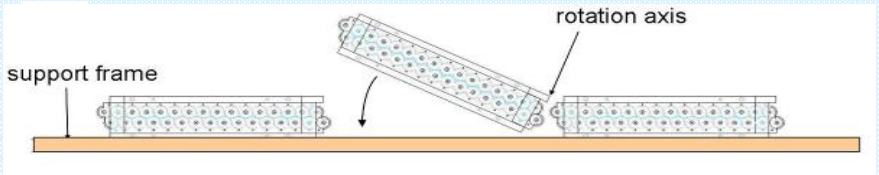
- Module: double layer of 32 straws.
- It has its own gas supply, HV supply and front-end cards.
- Module can be mounted and dismounted from support frame without necessity to remove the neighboring modules.
- Modular construction allows for fast repair and/or replacement of broken modules.

Module: 2 x 16 = 32 straws

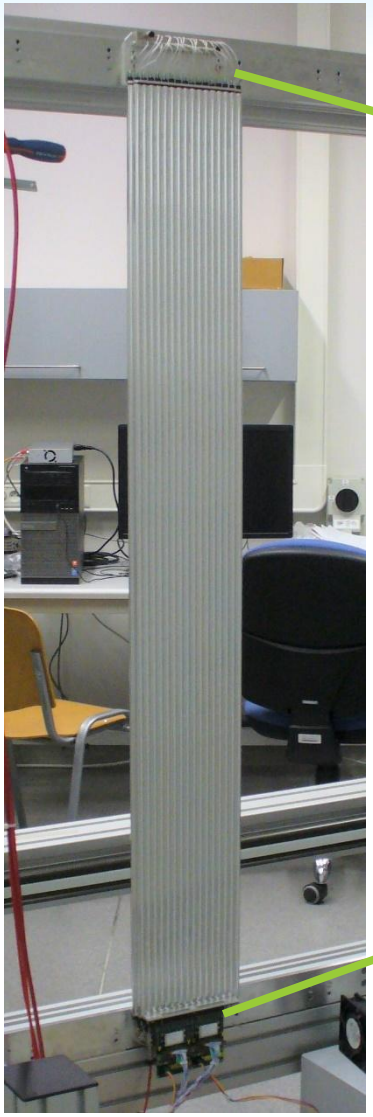


Gluing together pressurized straws on reference jig

Assembly of modules on suport frame



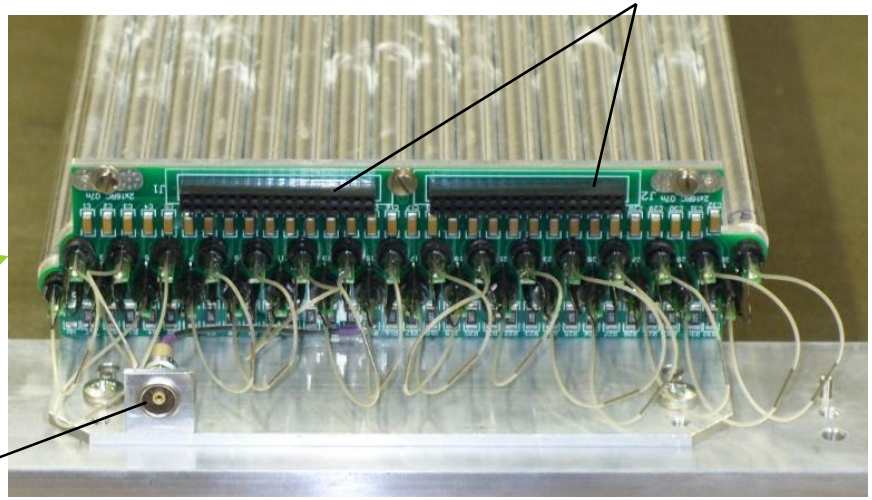
Straw tube module (125 cm long straw tubes for FT5)



Gas manifold

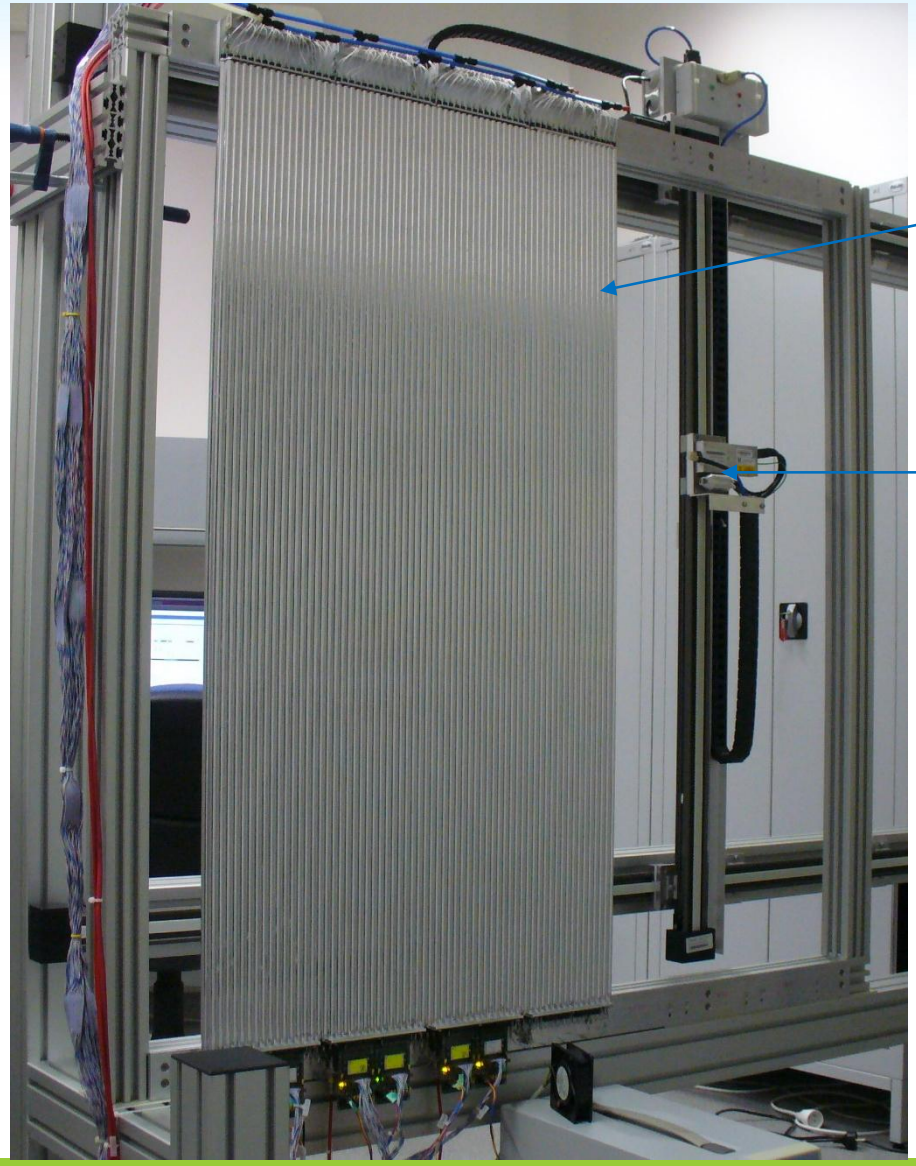
Gas inlet

Plugs for FE boards



HV plug

Double layer

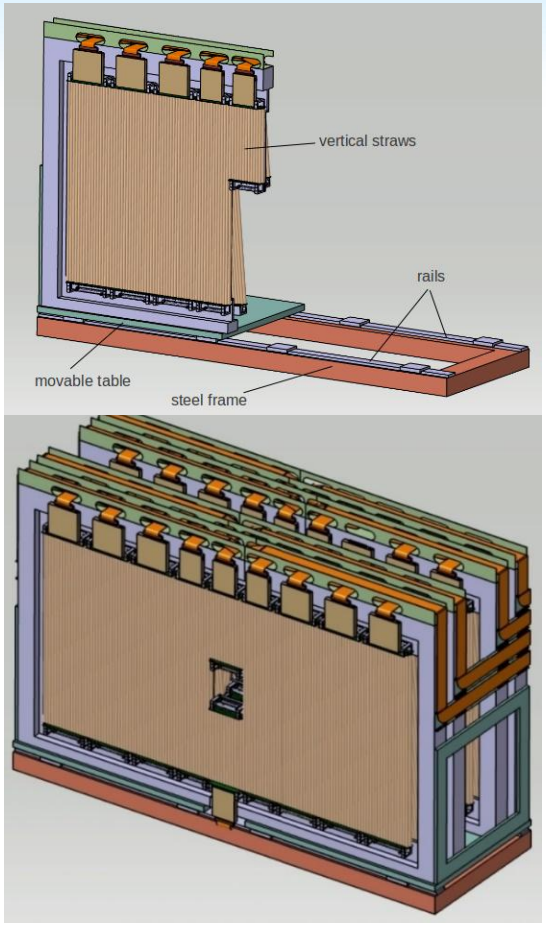


Double layer: modules closely arranged (without gaps) next to each other

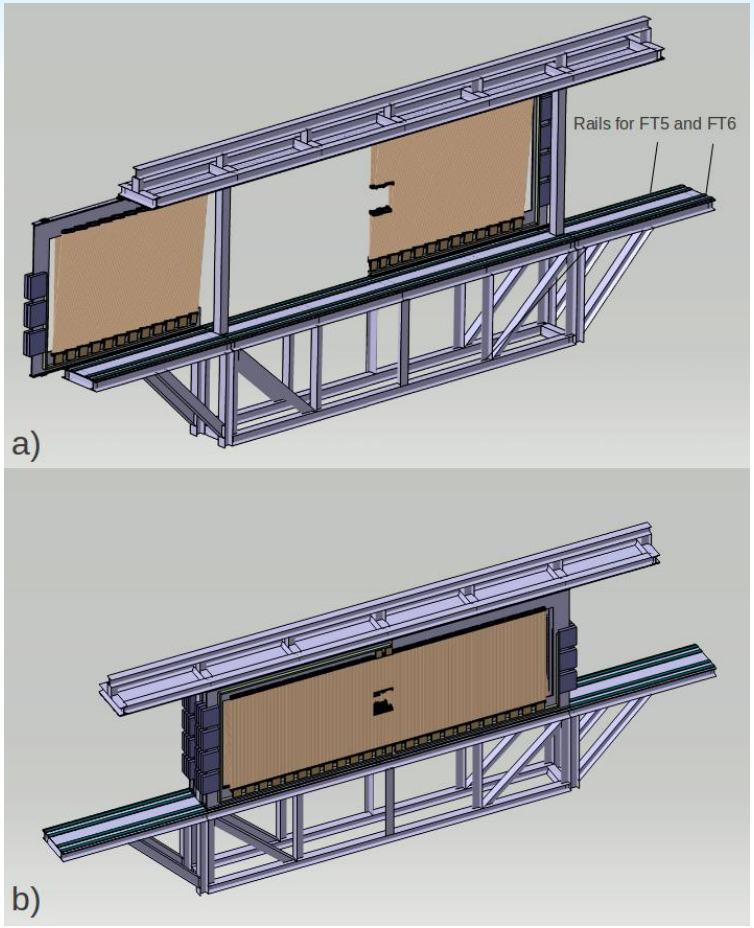
X-ray scanner for measuring positions of straws and wires in a double layer

Tracking stations before and after the magnet

FT1, FT2

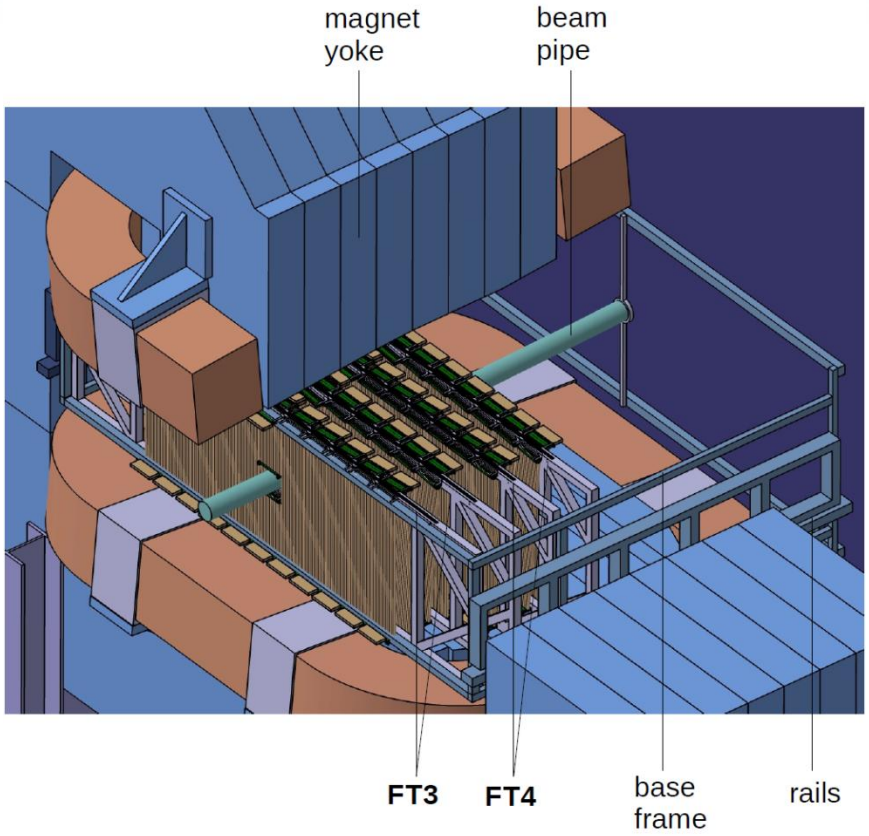


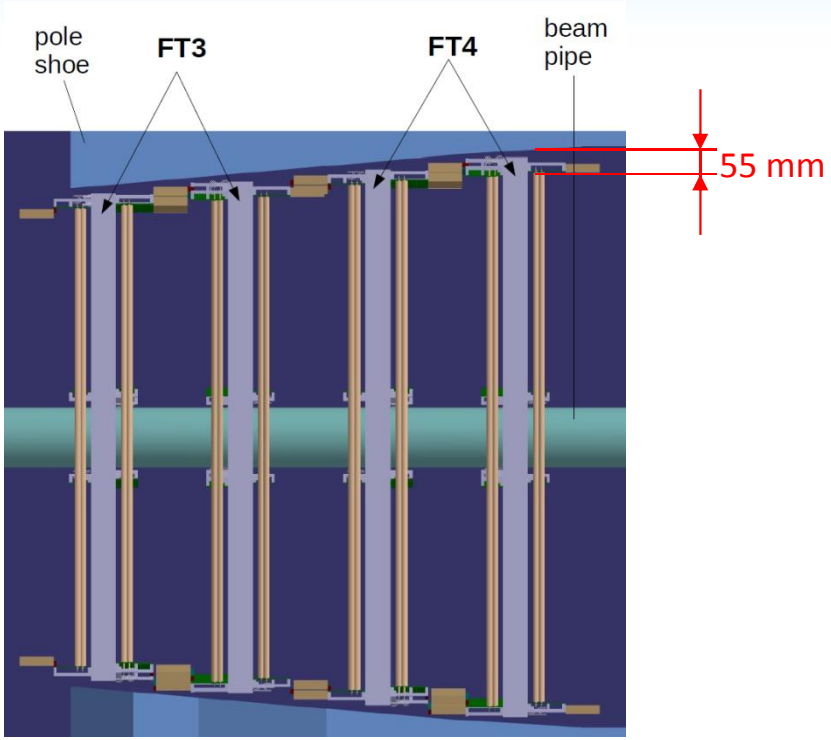
FT5, FT6



- **Two straw tube double layers are mounted on one rectangular support frame.**
- **For easy installation on the beam line, rectangular frames are split in pairs of movable C-shaped half-frames.**

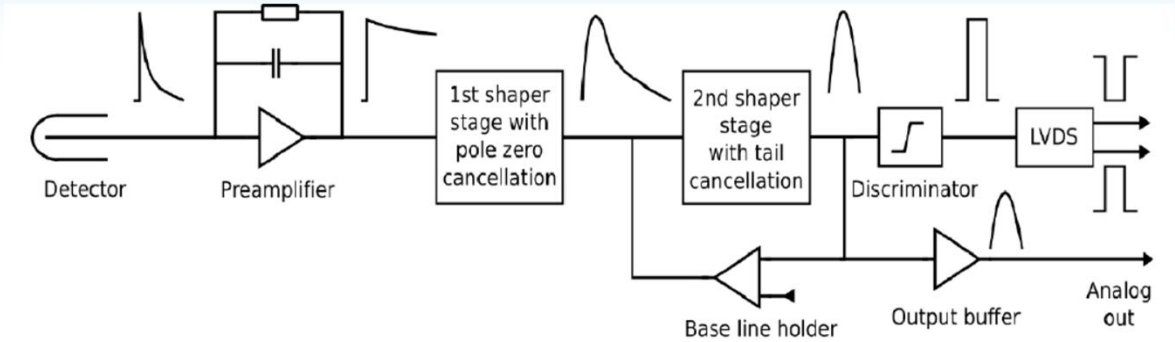
Tracking stations inside the magnet gap





- **Rectangular frames with modules are mounted on a base frame which is slide inside the dipole magnet gap.**
- **Space for support frames is limited to 55 mm in vertical direction.**

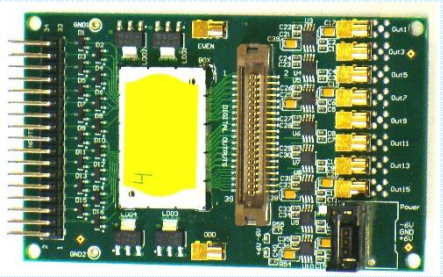
PASTTREC ASIC



- AMS 0.35 μm CMOS
- 8 channels
- T_{peak}: ~17, ~23, ~39, ~64 ns, gain: 0.67, 1, 2, 4 mV/fC
- Ion tail cancellation and baseline stabilization
- Leading edge discriminator for time and TOT measurements
- LVDS output and buffered analog output
- Configurable gain, peaking time, tail cancelation, common discriminator threshold and individual baselines
- Can be used for broad range of gas detectors operated at high counting rates and with different gas mixtures and gains

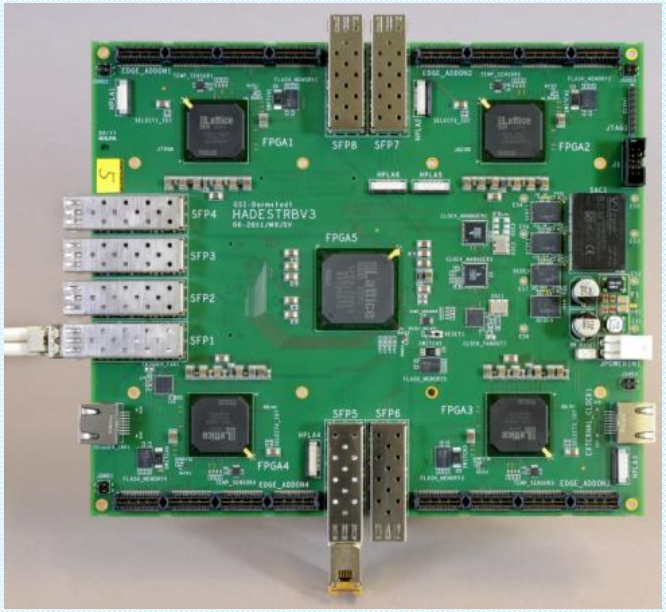
D. Przyborowski et al., JINST 11, P08009 (2016)

Front-end card
16 ch. (2 ASICs)



Trigger Readout Board (TRB v3)

- 4 TDC in FPGA (Lattice ECP3M), 48 TDC channels per FPGA + 1 central FPGA for control
- time of the rising and falling edges of LVDS pulses registered with resolution up to 8 ps (RMS)
- max. data rate is limited by the size of the internal buffers and the bandwidth of data transmission (130 MB/s) to about 56 kHz/ch. (rate of pulses supplied to all 192 TDC channels)
- integrable with the PANDA readout synchronization system SODAnet

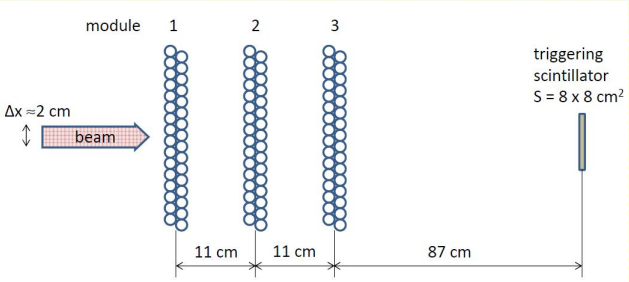


M. Traxler et al., JINST 6, C12004 (2011)

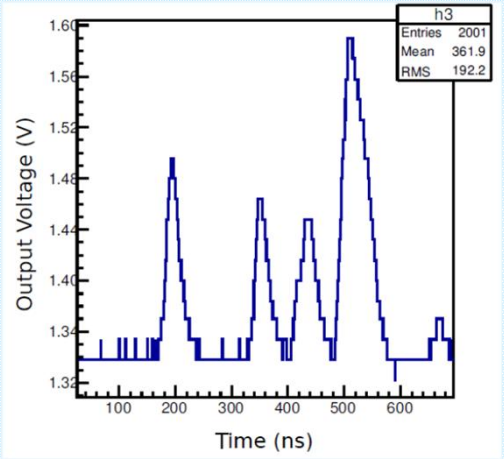
Results of tests with the COSY proton beam

Beam momenta: 0.55 ÷ 3.0 GeV/c
Beam intensity: 50 kHz ÷ a few MHz

Gas mixture: Ar:CO_2 (90:10) at 2 bar,
High voltage: +1800 V (gas gain ~ $5 \cdot 10^4$)

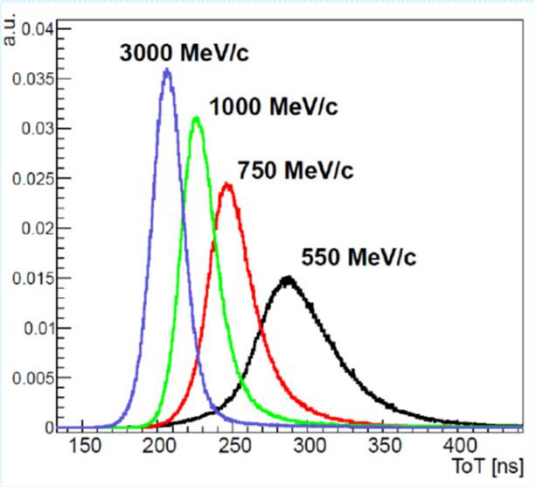


Front-end response
at counting rate of about 10 Mc/s



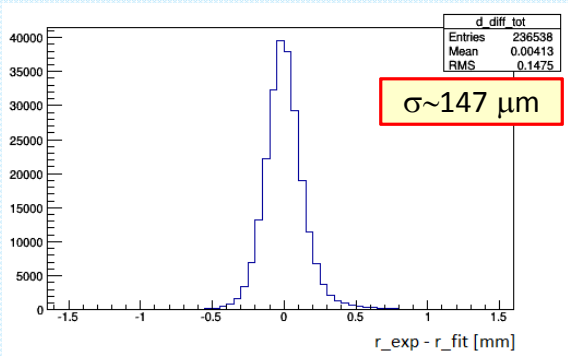
Baseline stable at very high rates

TOT truncated mean 20%



TOT measurement applicable for PID

Residuals from reconstruction of 0.6 GeV/c proton tracks at rates of a few times 100 kHz/straw



Track reconstruction at high rates demonstrated

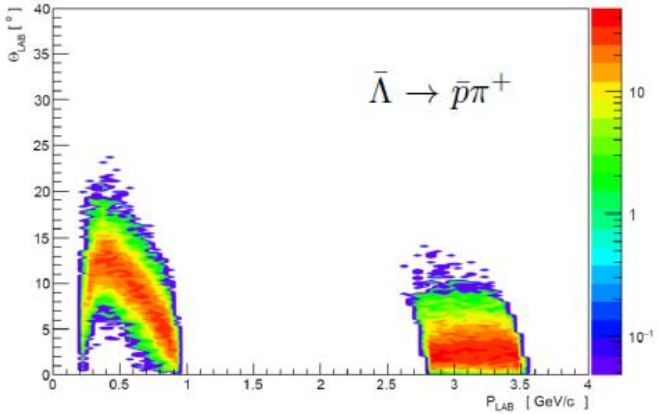
Summary

- **The Forward Tracker is designed for momentum analysis of charged particles in the dipole magnet of the PANDA Forward Spectrometer**
- **Six tracking stations comprise 6 x 4 = 24 double layers of straw detectors**
- **Applied self-supporting straw tubes allow to reach a low material budget (X/X_0 = 2% for the whole FT) and use compact support frames**
- **Modular construction is used for easy repairs**
- **C-shaped half frames allow for easy installation on the beam line**
- **Readout electronics is based on configurable PASTTREC chips and TRB-v3 boards for time and time-over-threshold measurement**
- **Technical Design Report for the Forward Tracker will be submitted for review in June 2017. We are ready to start the production of straws after its approval.**

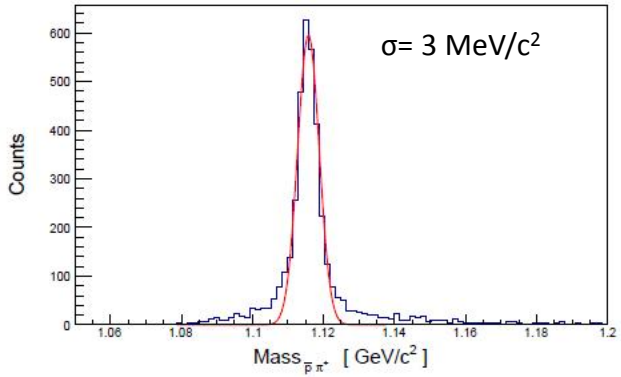
Benchmark channels for the FT

$$\bar{p}p \to \Lambda\bar{\Lambda} \to p\pi^-\bar{p}\pi^+$$

at 4 GeV/c

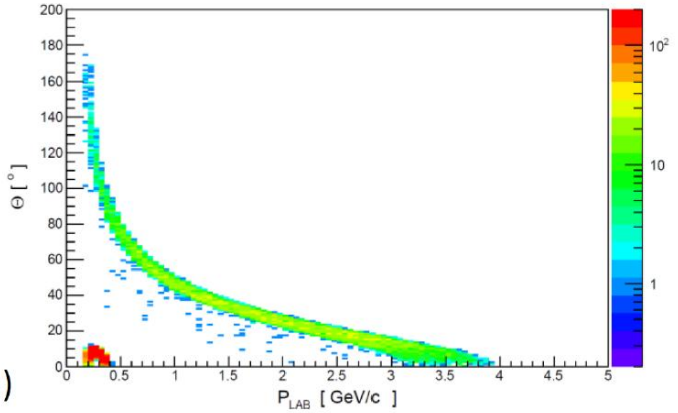


Reconstructed $\bar{\Lambda}$ mass

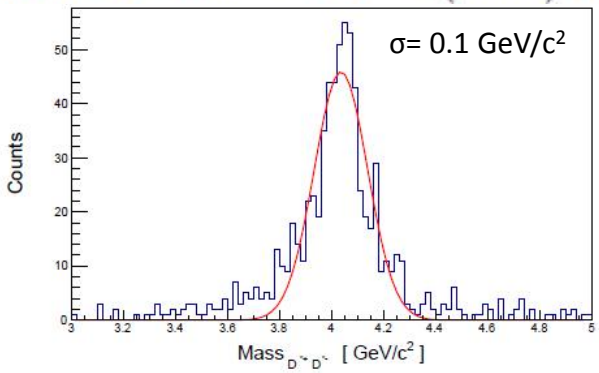


$$\bar{p}p \to \Psi(4040) \to D^{*+}D^{*-} \to$$
$$D_0\pi^+\bar{D}_0\pi^- \to K^+K^-\pi^+\pi^-\pi^+\pi^-$$

a)



Invariant mass of the $\Psi(4040)$ meson

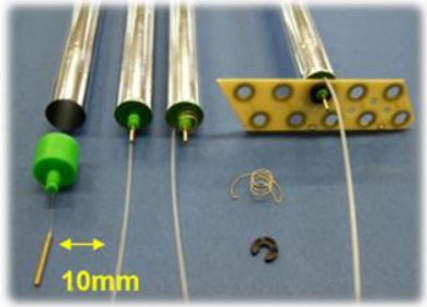


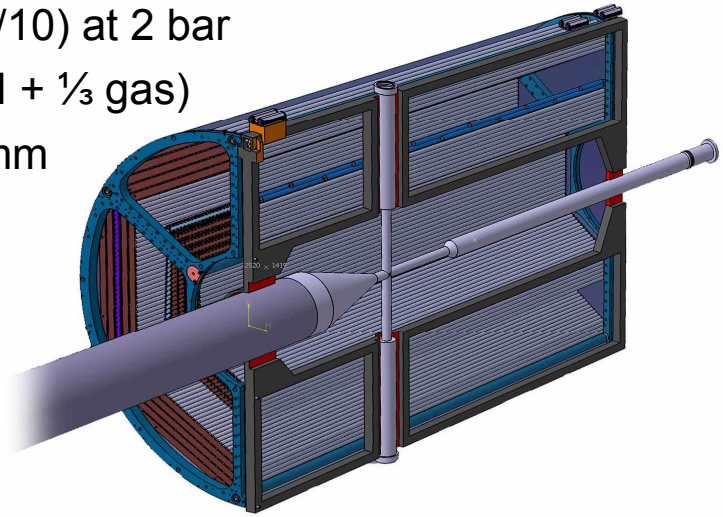
Central Straw Tube tracker

- Two half-cylinders
  - R_{in} /R_{out}: 150 / 418 mm
  - Length: 1500 mm + 150 mm (readout)
- 4636 pressure stabilized straw tubes
- 23-27 planar layers in 6 hexagonal sectors
  - 15-19 axial layers
  - 4 stereo double-layers
  - ±2.89º skew angle
- Gas mixture: Ar/CO_2 (90/10) at 2 bar
- X/X_0 ~ 1.2% (⅔ tube wall + ⅓ gas)
- $\sigma_{r\varphi}$ ~ 150 □m, □$_z$ ~ 1.0 mm
- σ_p ~ 1.2% (B=2 Tesla)

Self supporting straw tubes (overpressure 1 bar) developed for the COSY-TOF experiment

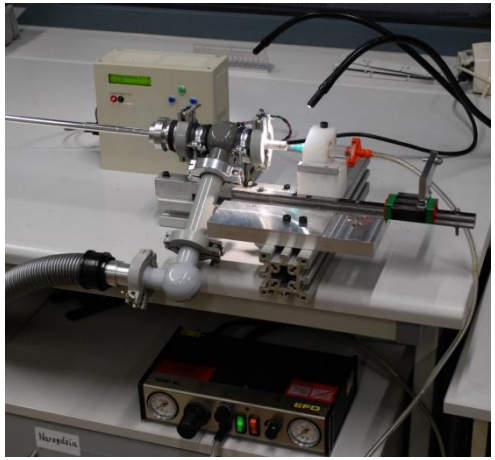
- Straw diameter: 10mm
- Material: Mylar, 30μm;
- Anode wire: W/Re, 20μm



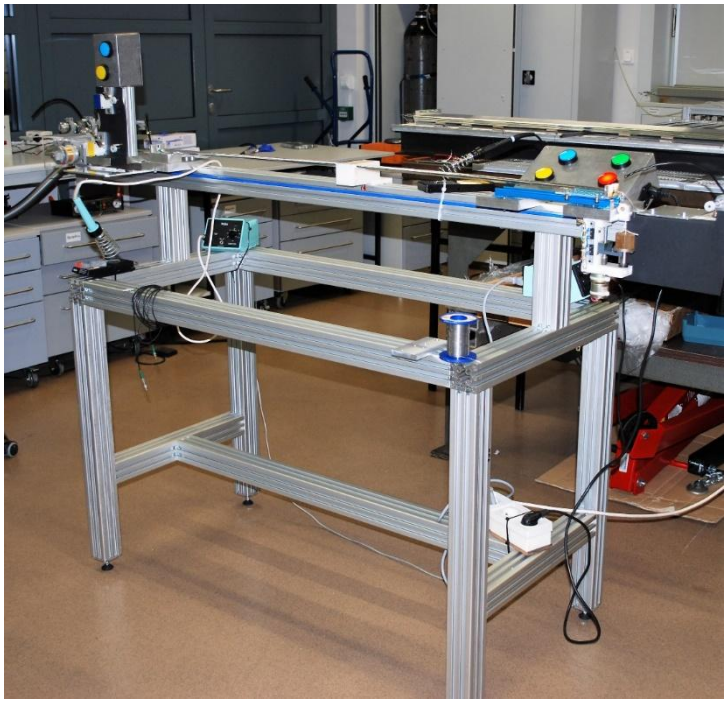


Assembly procedure of straws

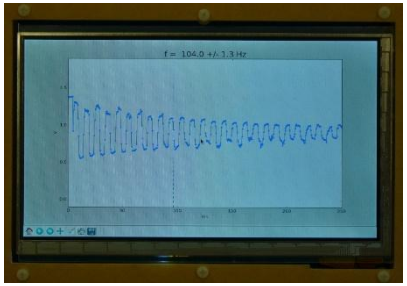
1. Gluing end plugs in straws:
two component adhesive (UHU Endfest 300) for plastic plugs, conductive epoxy (MG-Chemicals 8330S) for aluminum rings



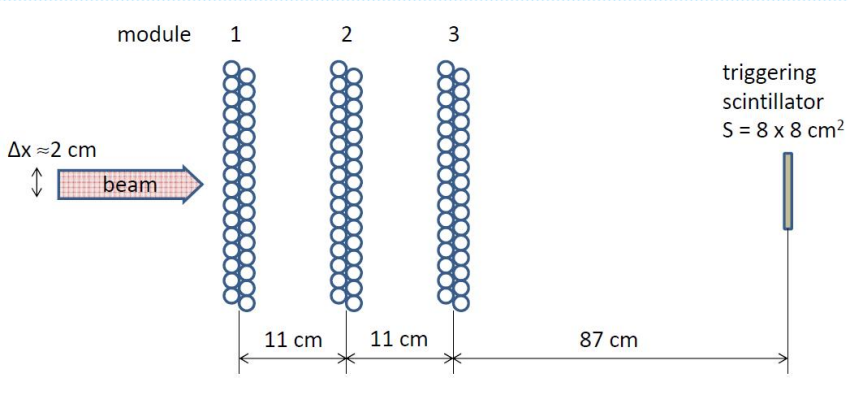
2. Tensioning straw with a weight imitating the gas pressure
3. Pulling wire through straw and tensioning it (50 g)
4. Inserting wire locators
5. Soldering wire
6. Inserting plugs with gas pipes and sealing them with adhesive



7. Quality control: gas tightness and mechanical tension of wire



Tests with the COSY proton beam



- External proton beam from COSY
- Momenta: 0.5 ÷ 3.0 GeV/c
- Beam intensity: 50 kHz ÷ a few MHz

Three FT1 modules