STT Design and Prototype Tests

November-15, 2012 | Peter Wintz, IKP - FZ Jülich

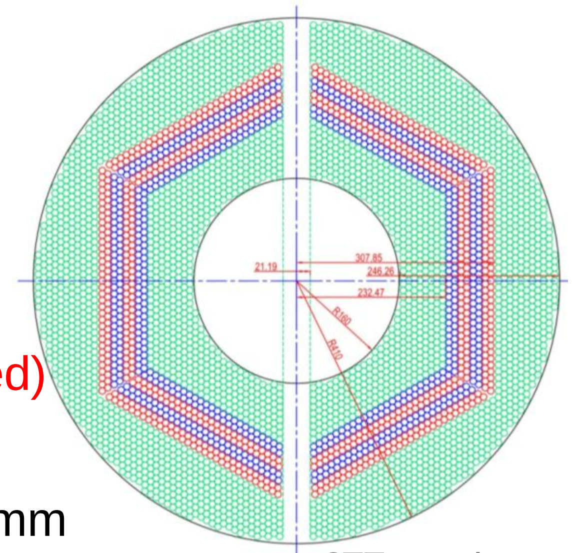
Review of STT Technical Design Report

Outline

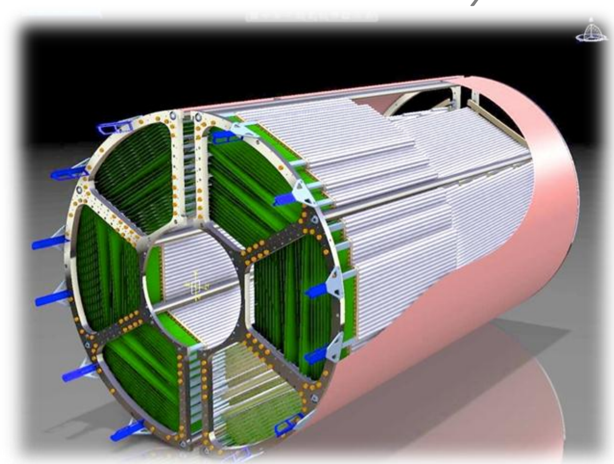
- STT Design overview
  - Mechanical setup
  - Readout system
- Prototype systems
- In-beam tests
  - COSY-STT
  - Aging studies
  - High-rate readout
- Summary

STT Layout

- 4636 straw tubes in 2 separated semi-barrels
- 23-27 planar layers in 6 hexagonal sectors
  - 15-19 axial layers (green) in beam direction
  - 4 stereo double-layers: ±3° skew angle (blue/red)
- STT dimensions
  - R_{inner}/R_{outer}: 150/418 mm, length: ~1500 + 150 mm
  - Inner / outer walls (~ 1mm Rohacell/CF)
- $X/X_0 \sim 1.23\%$ (~ $^2/_3$ tube wall + $^1/_3$ gas)
- Time / amplitude readout
  - $\sigma_{r\varphi} \sim 150\ \mu m$, $\sigma_z \sim 3.0$ mm (isochrone)
  - $\sigma_E/E < 10\%$ for π/K/p identification
- $\sigma_p/p \sim 1 - 2\%$ at B=2 Tesla



STT x-y view

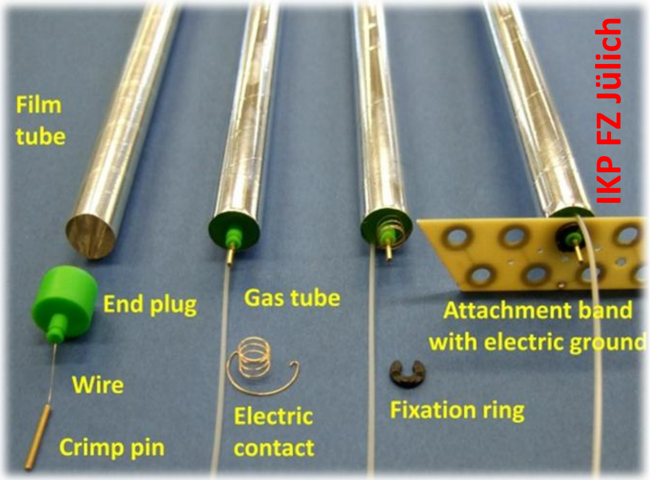

STT 3d-view

Straw Tube Materials

Minimised number of materials and material budget (thickness)

1) Al-mylar film, d=27µm, ∅=10mm, L=1500mm
2) 20µm sense wire (W/Re, gold-plated)
3) End plug (ABS thermo-plastic)
4) Crimp pin (Cu, gold-plated)
5) Gas tube (PVCmed, 150µm wall)
6) Cathode spring (Cu/Be, gold-plated)
7) Attachment strip (GFK), locator ring (POM)

Straw components



- $X/X_0 = 4.4\times10^{-4}$ per straw (2.5g weight)
- Radiation hard (p-beam tested)

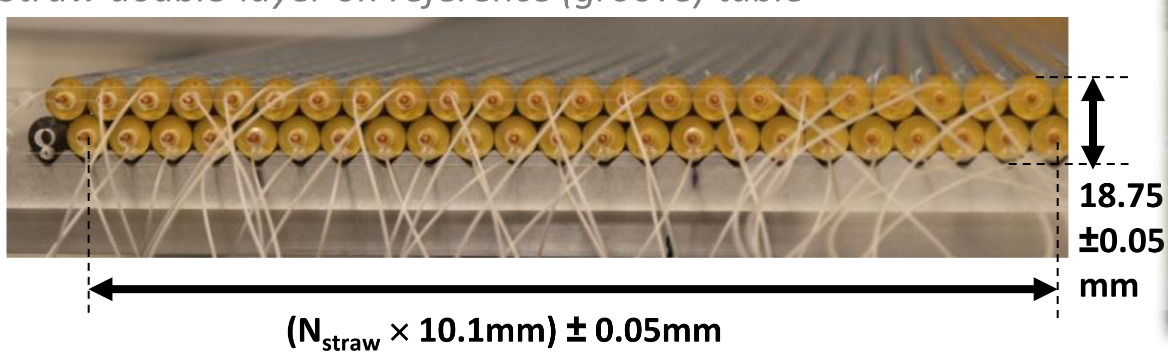
Element	Material	X [mm]	X_0 [cm]	X/X_0
Film Tube	Mylar, 27µm	0.085	28.7	3.0×10^{-4}
Coating	Al, 2× 0.03µm	2×10^{-4}	8.9	2.2×10^{-6}
Gas (2bar)	Ar/CO_2 (10%)	7.85	6131	1.3×10^{-4}
Wire	W/Re, 20µm	3×10^{-5}	0.35	8.6×10^{-6}
			Σ_{Straw}	4.4×10^{-4}

Straw Layer Modules

Novel technique, developed for COSY-STT and modified for PANDA-STT

- Pressurized straws (Δp=1bar) are close-packed (< 20µm gap) in planar layers on a reference groove table and glued together (glue dots)
- Strong rigidity: multi-layer straw module is self-supporting
- No stretching from mechanical frame, no straw reinforcements needed
- Mechanical precision of wire positions: σ < 50 µm (data)
- Lowest weight, precise cylindrical geometry, maximal straw density

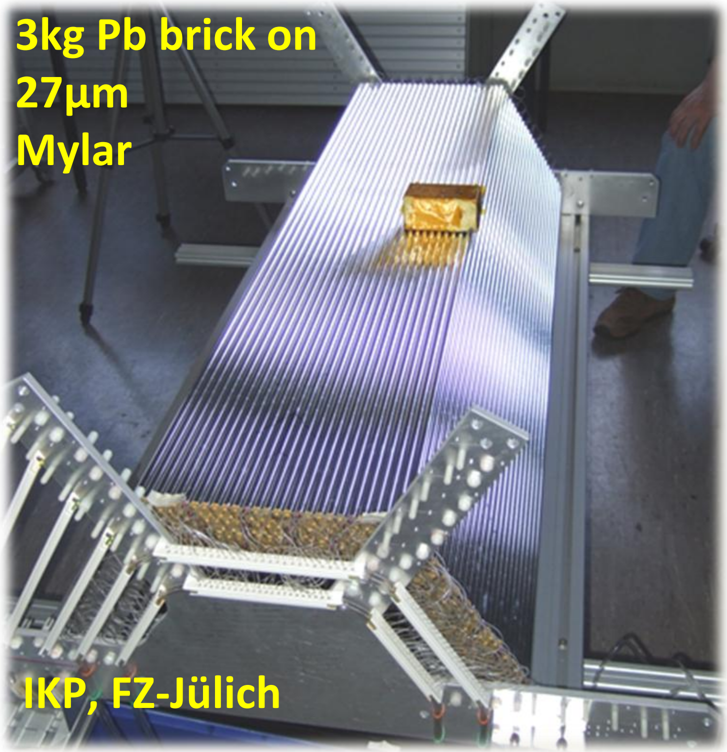
Straw double-layer on reference (groove) table

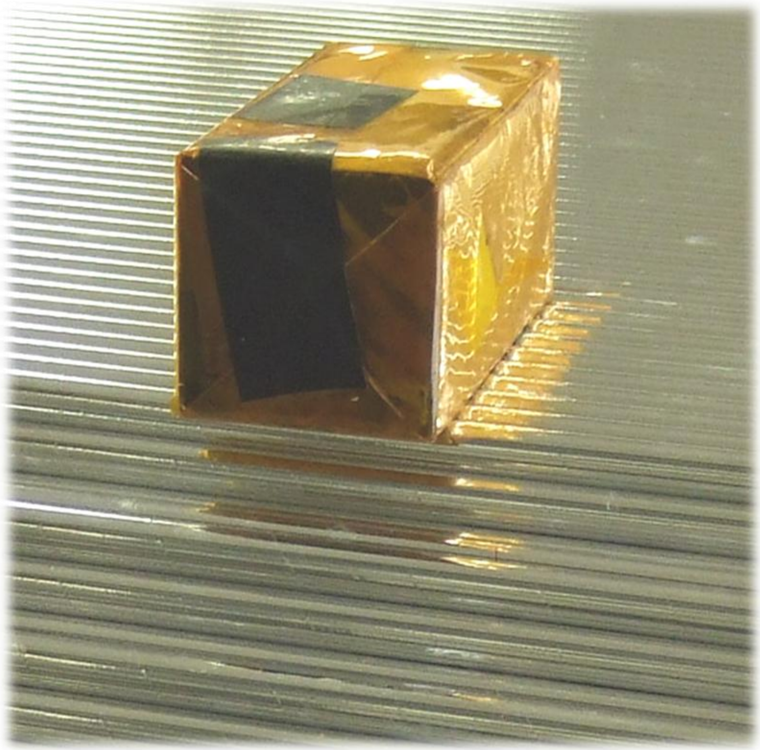


Gluing of straw layer

Self-Supporting Straw Modules

Pressurized, close-packed straw layers show a strong rigidity ..



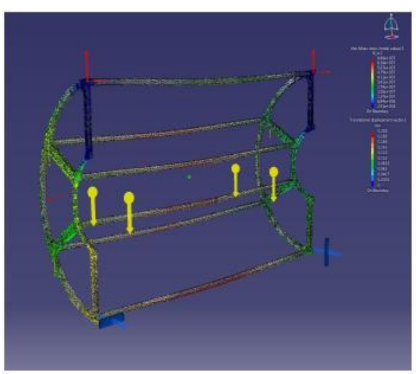


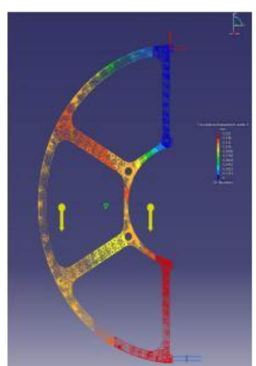
Mechanical Frame

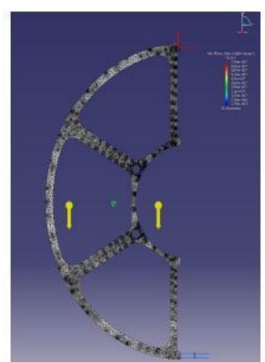
- 2 separate semi-barrels with end flanges, connected by spacer bars
- Precision holes at the flanges to fix straw modules
- FEM analysis: 0.03mm max. deflection
- Mechanical frame weight: 2× 9 kg
- 11.6 kg Straw tubes (4636× 2.5g) with
  - strong wire stretching (230kg equiv.)
  - strong tube stretching (3.6t equiv.)

Semi-barrel components for	**FEM analys**
2 End flanges	60 N
6 Connecting bars (4 needed)	30 N
2300 Straw tubes	60 N
Straw grounding, boards	20 N
Electronics, gas supply	110 N
Total weight	**280 N**

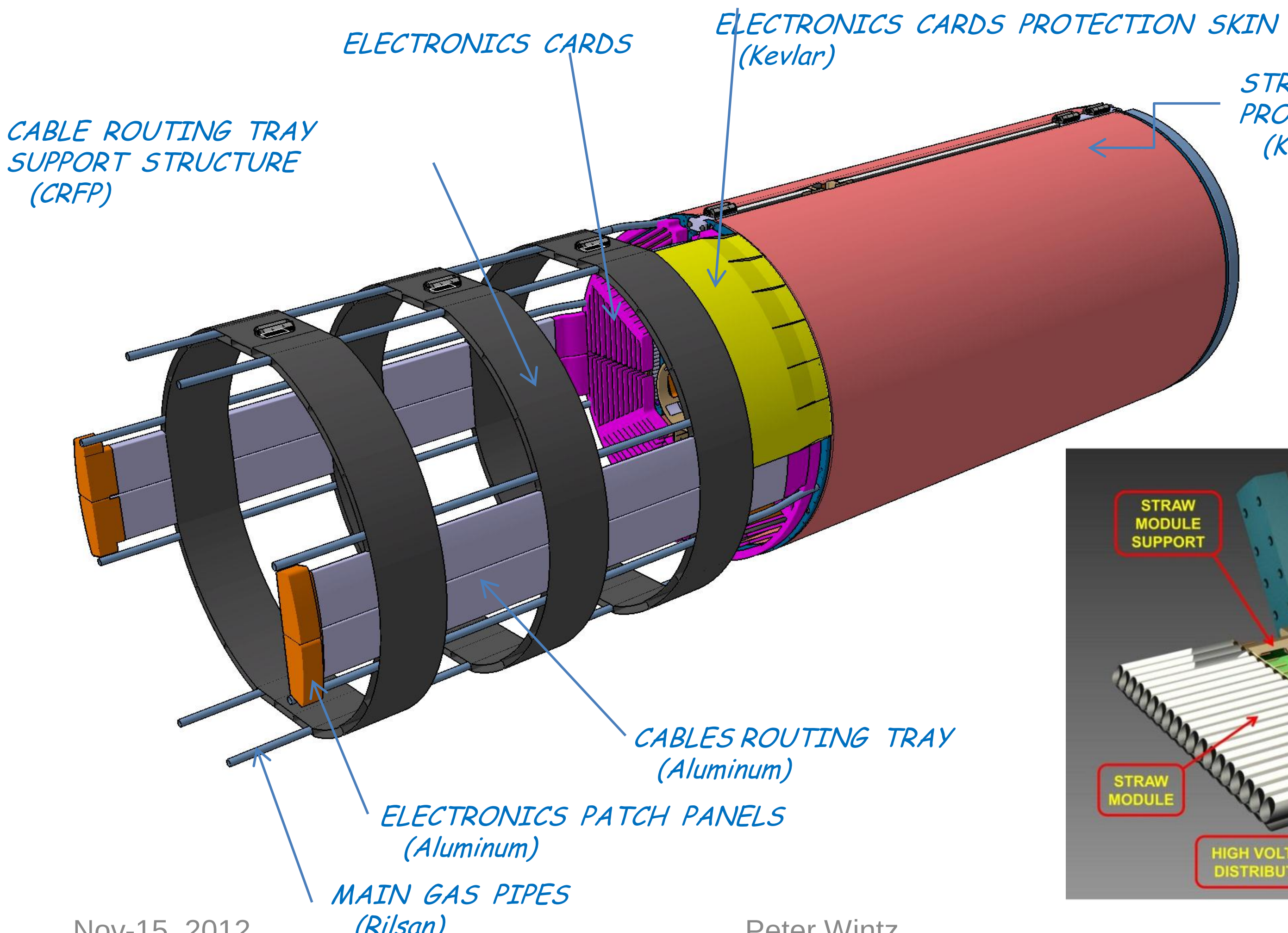
Material	**Aluminum**
Density	2.7 g/cm^3
Youngs modulus	70 GPa
Radiation length (X_0)	9 cm
Thermal expansion	24 ppm/°C



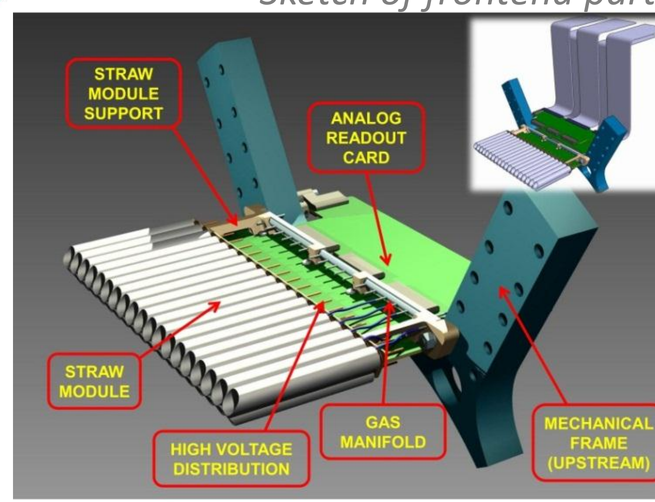




STT Mechanical Layout

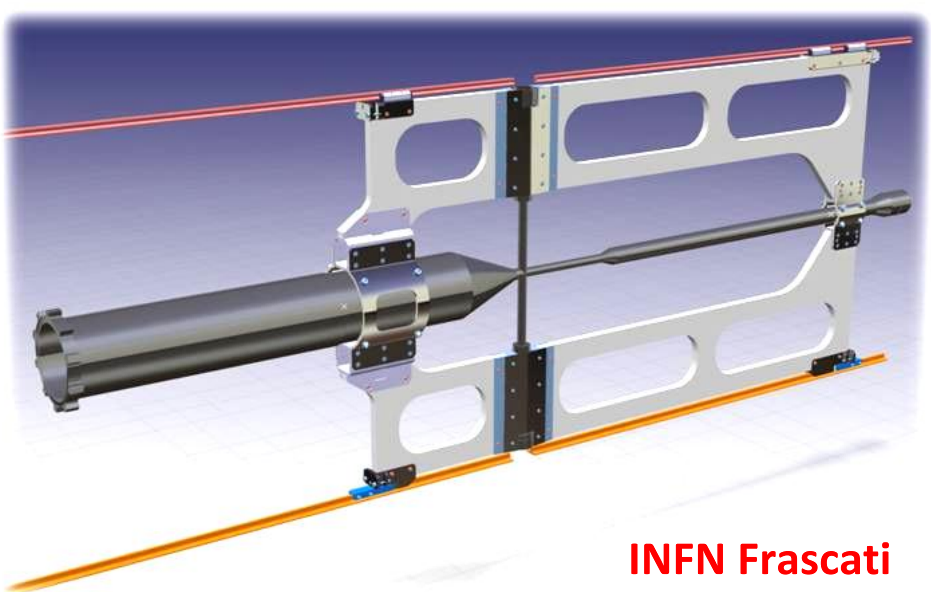


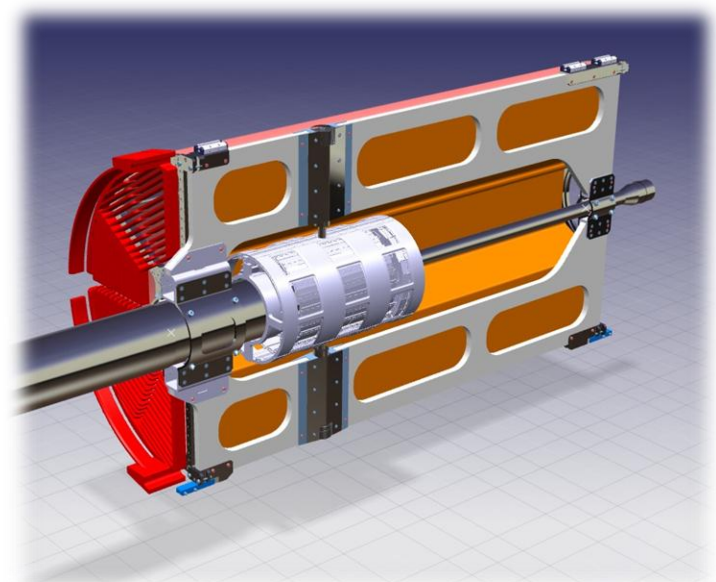
Sketch of frontend part



Central Tracker Mechanical System

- “Central Frame” (CF) to support all central components
  - beam pipe + Micro Vertex Detector + STT semi-barrels
- Rail system for insertion of CF in the PANDA target spectrometer





STT Readout

- 4600 straws in STT
  - ~ 10-15 pF straw capacitance, ~ 2 fC sensitivity (threshold ~ 1.2×10^4 e^-)
  - ~ 800 kHz per straw maximum hit rate (only inner layers)
- Drift time readout
  - ~ 200 ns drift time range, Ar/CO_2 (10%), 2 bar, 2 Tesla
  - ~ 1 ns time resolution required
- Specific energy loss measurement (dE/dx) for particle identification
  - (Indirect) amplitude readout needed to measure charge information
  - Required energy resolution $\sigma(E)/E < 10$ % for sufficient π/K/p separation power at low momenta < 800 MeV/c (simulation)
- Readout concept to measure drift time (isochrone) + charge (dE/dx)
  - Hit rates: ~ 800 kHz (max), ~ 400 kHz (avg.)

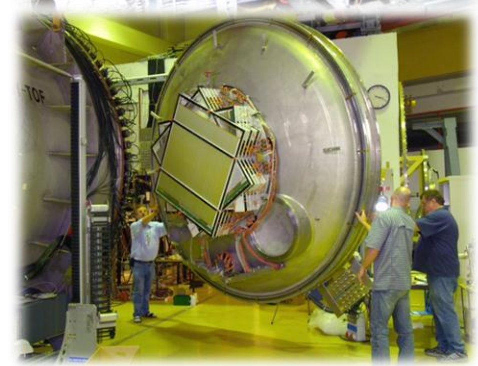
STT Readout Concept

2 concepts under study to measure drift time + charge

- Amplitude measurement by FADC and FPGA readout: $\sum Q$
  - FADC sampling frequency 240 MHz, ~ 4.2ns sampling points
  - Pulse shape analysis realtime by FPGA: LE-Time + $\sum Q$
  - Amplifier-Shaper boards frontend at detector
- Signal height measurement by time-over-threshold (ToT): $Q = f(\text{ToT})$
  - Amplifier-Shaper-Discriminator (ASIC): LE-Time + ToT
  - Time Readout Boards (TRB), TDC in FPGA
  - Option: analog output after 1st amplifier-shaping stage, to ADC
  - ToT method for particle-id (used at ATLAS-TRT, HADES-MDC)
  - New ASIC chip design, optimised for PANDA-STT (AGH Krakov)
- Frontend electronic design: radiation-hard and low power consumption

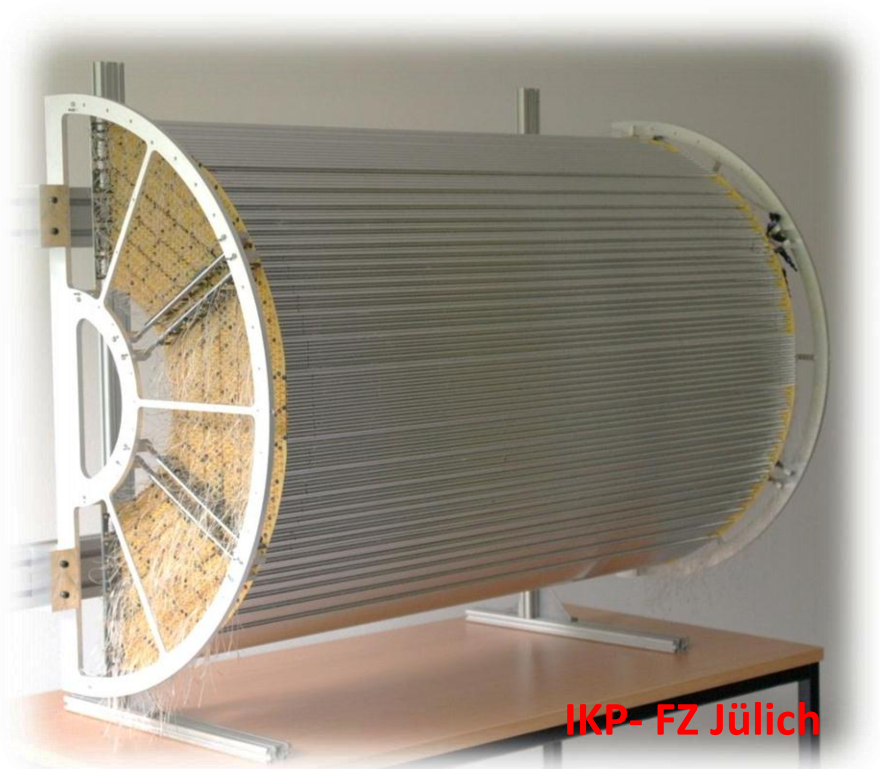
Prototype Productions

- STT semi-barrel (1:1) for developing assembly technique
- Mechanical frame structure (Alu) with rail system
- 3× Small-scale straw setups for readout & in-beam tests
  - 128 Straws in 8 axial layers, 1500mm length, ∅=10mm
  - 400 Straws, 8 axial + 8 stereo layers
  - 32 Straws for aging studies
- STT detector in COSY-TOF experiment
  - “Global“ test system for PANDA-STT
  - Same straw design & materials, close-packed layers
  - Test of mechanical precision and spatial resolution
  - Operated in evacuated time-of-flight barrel (25m^3)
- Straw readout prototypes
  - ASIC (T, ToT) + TRB for time-over-threshold method
  - Preamplifier + FADC for amplitude readout

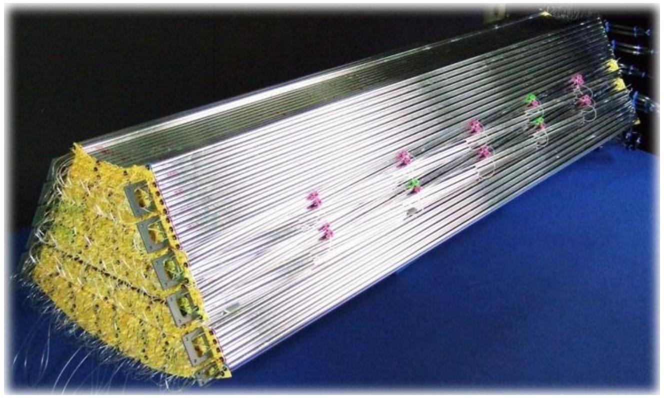


STT Mechanical Prototype

Semi-barrel, length 1.2 m, final radial dimensions, reduced mech. frame



STT prototype, one semi-barrel



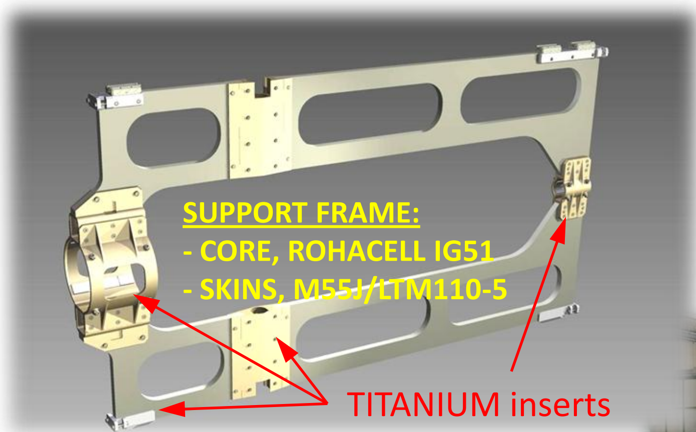
Hexagon sector, mounting brackets to fix modules in mechanical frame

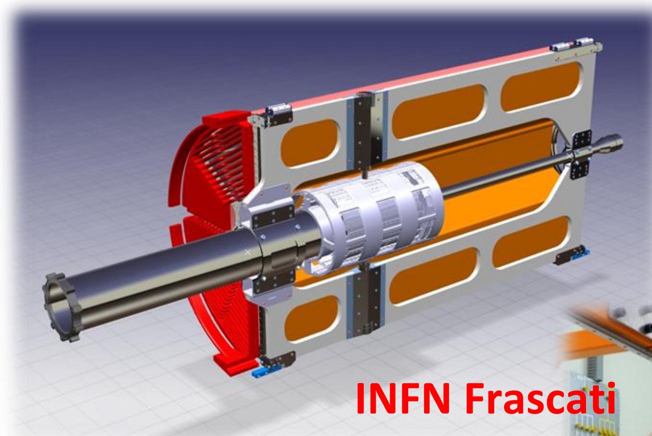
A STT sector consists of 6 straw modules:

2 inner axial + 2 stereo + 2 outer axial

Central Frame Prototype

- Central Frame to support beam pipe + MVD + STT
- STT support frame prototype
- Rail system for insertion





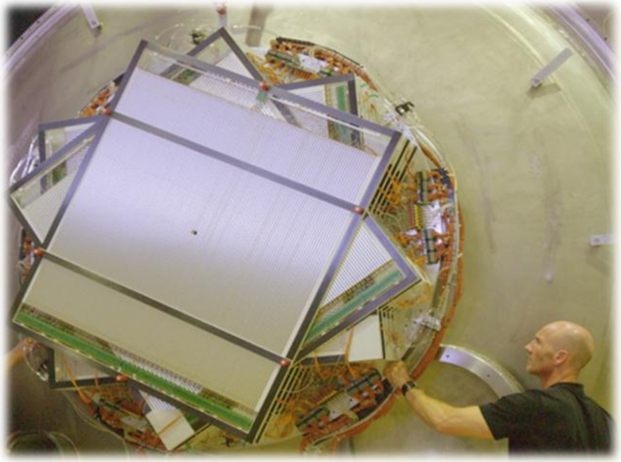
Prototype In-Beam Tests

- STT detector in COSY-TOF experiment at external COSY beam line
- Aging tests with straw prototype and p-beam at COSY
  - Gas mixture and straw materials, radiation hardness
- Readout tests with straw prototype systems in proton beam
  - Energy resolution of $\sigma(E) \sim 8\pm1\%$ measured with amplitude readout
  - Setup of new ASIC readout for ToT done, optimisation of parameters
- High-rate readout tests ongoing (1-2 MHz per straw)
  - Different beam momenta, range 0.6 – 3 GeV/c
  - At least 2 beam times per year foreseen (COSY p/d-beam, FAIR weeks)

Testsystem COSY-STT

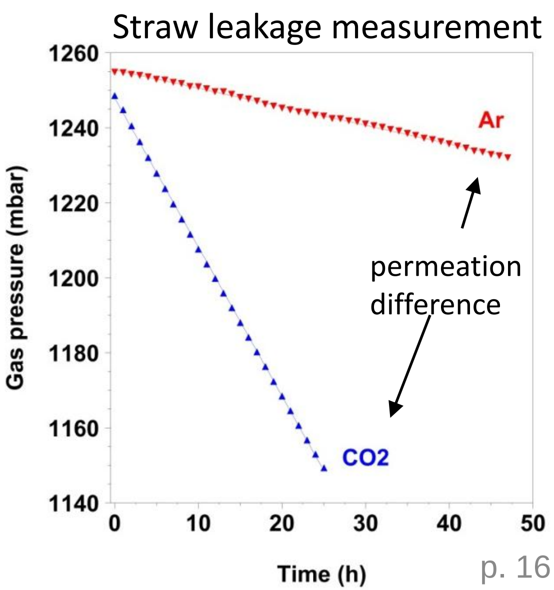
2704 straw tubes

- Al-mylar: d=32µm, ∅=10mm, L=1050mm
- 13 planar double-layers, skewed by i×60°
- Embedded in CF-rohacell sandwich frames
- Ar/CO_2 (20%) at p=1.2bar
- Time readout (isochrones)



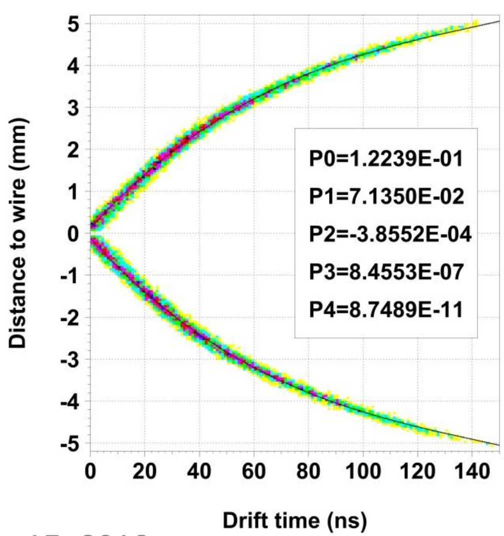
Operated in vacuum since 4 years now

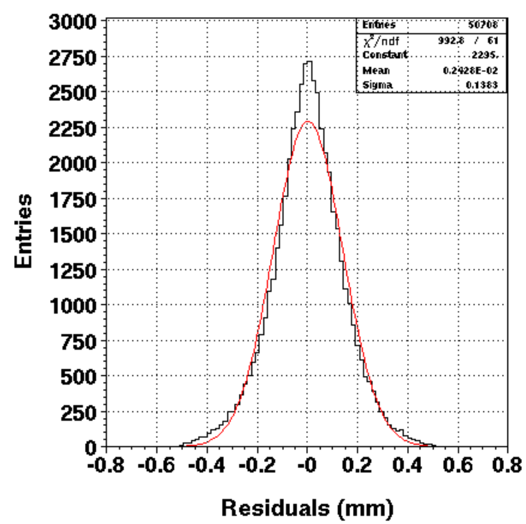
- Gas leakage stays on permeation level
- No real leakage (no dissolving glue, brittle materials,..)
- Strong confidence in all straw materials and assembly techniques for PANDA-STT

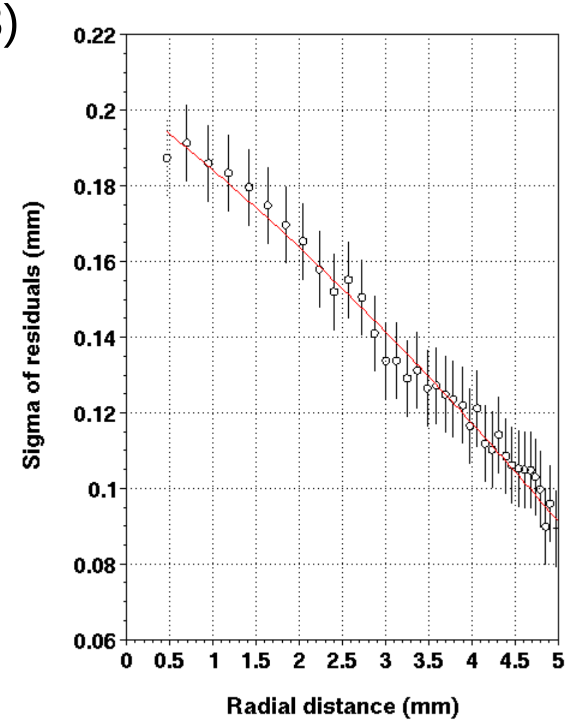


COSY-STT Spatial Resolution

- Isochrone radius – drift time calibration r(t) by integration of drift time spectr.
- Global parametrisation (2700 straws) by 4th order polynomial (Fig.1)
- Track reconstruction by χ^2- fit to isochrones
- Spatial resolution by residual distribution (Fig.2, 3)
  - $\sigma_{r\Phi}$ = 138µm, $\sigma_{r\Phi}(r)$ ~ 190 – 90 µm
  - Ar/CO2 (20%) at 1.25 bar pressure



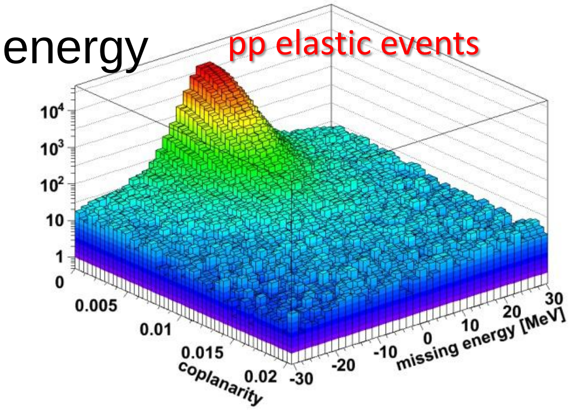




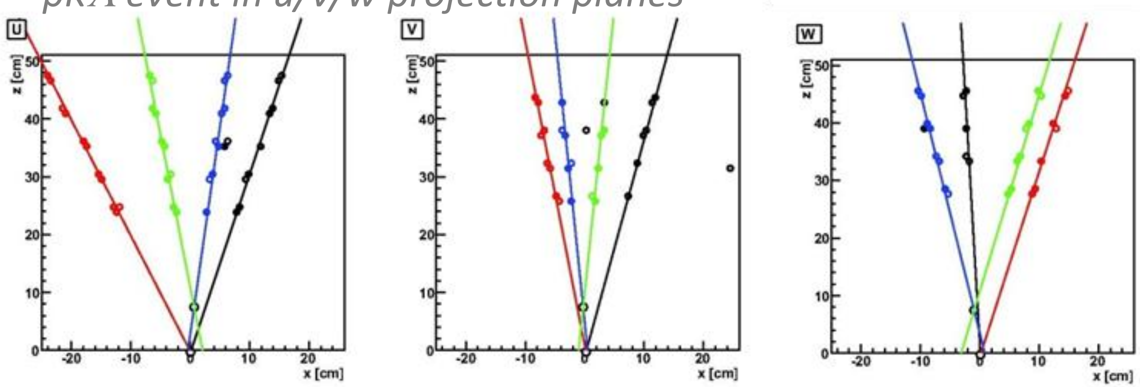
COSY-STT Tracking Results

- Physics: hyperon production, (pol.) p-beam on lH_2-target, p_b~3GeV/c
- Reconstructed pp $\rightarrow$ pp elastic scattering events
  - resolutions: σ ~ 110µm vertex, 4.5 MeV missing energy
- Example of reconstructed pp $\rightarrow$ pKΛ event

  with delayed decay $\Lambda \rightarrow p\pi^-$ (black circle)

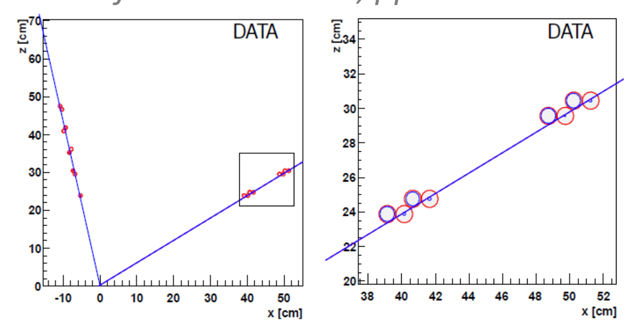


pKΛ event in u/v/w projection planes



(→ Ph.D. thesis of M. Roeder)

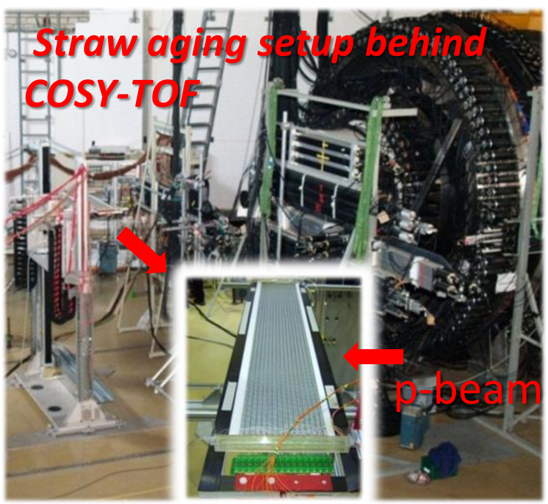
Trackfit to isochrones, pp-event

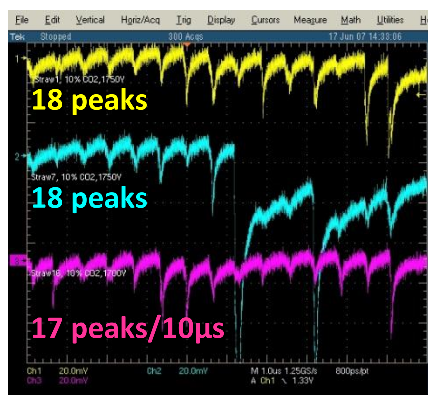


Aging Studies

Parasitic test setup behind COSY-TOF spectrometer

- 32 straws, L=1m, 3 diff. gas mixtures, HV current monitored per 2 straws
- p-beam, 3 GeV/c, 10 days, ~ $2.3\times10^6\ s^{-1}cm^{-2}$ (by SciFiber Hodo)
  - Straw rate: ~ $2\times10^6\ s^{-1}$ per 1-2 cm wire (~ 140× PANDA-straw rates)
- Measurement of gas gain (loss) by signal amplitude height from ^{55}Fe-source





3 Straw signals on scope, time structure by COSY-beam extraction

Straw no	Gas mixture @ 1.65 bar	I_{max} (µA)	ΣQ (C/cm) in 199h	Aging $\Delta G/G_0$
1 – 8	Ar/CO_2 (10%)	1.4	0.72	0..3%
9 – 16		1.1	0.58	0..7%
17 – 20	Ar/CO_2 (30%)	2.3	1.23	no
21 – 24		1.5	0.79	no
25 – 32	Ar/C_2H_6 (10%)	1.7	0.87	no

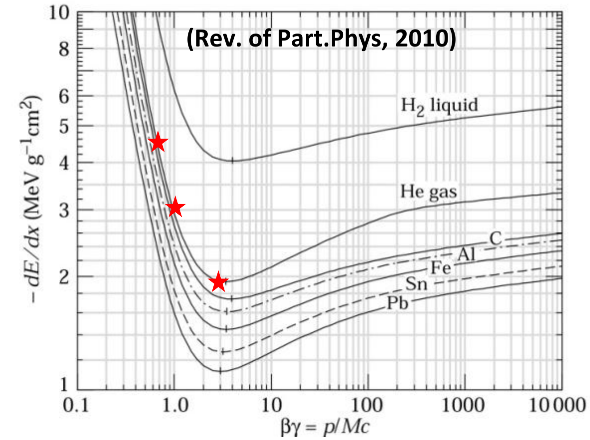
Results of gas gain measurements

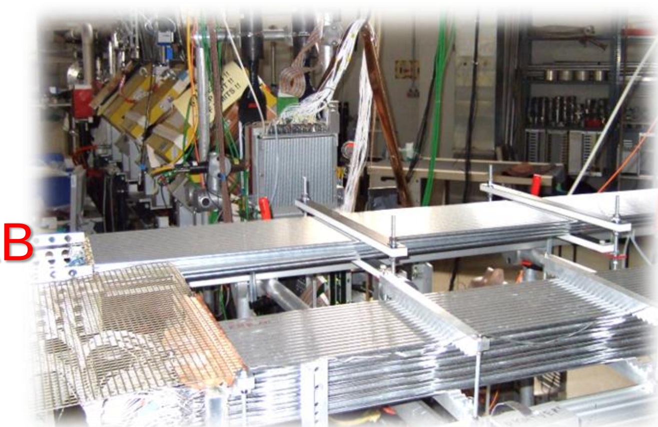
Aging Results And Strategy

- Results:
  - No loss seen for Ar/CO_2 (30%) and Ar/Ethane (10%)
  - Small gas gain drop (<7%) seen for Ar/CO_2 (10%) in some straws
  - Localized, correlated with beam intensity
  - Charge load was ~ 0.6 - 1.2 C/cm, equiv. to ~ 5 years PANDA-STT
- Strategy:
  - Ar/CO_2 preferred gas mixture: highly tolerant to highest irradiation
  - Charge loads for STT@PANDA: ~ 0.2 C/cm/year (~1 C/cm at z~2±1cm)
  - No aging expected with Ar/CO_2 at mod. gas gains for 99.7% of STT during >5 years of PANDA operation at full luminosity
  - Slight aging caused by low energy protons from elastic scattering may start around z=2±1cm (0.3% of STT) after 2 years
  - Technique developed to replace single faulty straws in modules, saves cost / time

In-Beam Readout Tests

- Proton beam with different momenta
  - Range 0.6 - 3 GeV/c
- 2 straw setups with different readout systems
  - Ar/CO_2 (10%) at p=2bar
  - Orientations of setups to beam varied
- Readout with current amplifier + FADC
  - FPGA (time, ampl.) + raw mode readout
  - Sampling rate 240MHz (~4.17ns)
- Readout with Ampl-Shap-Discr (ASIC)+TRB
  - First tests with beam
  - Tuning of ASIC parameters



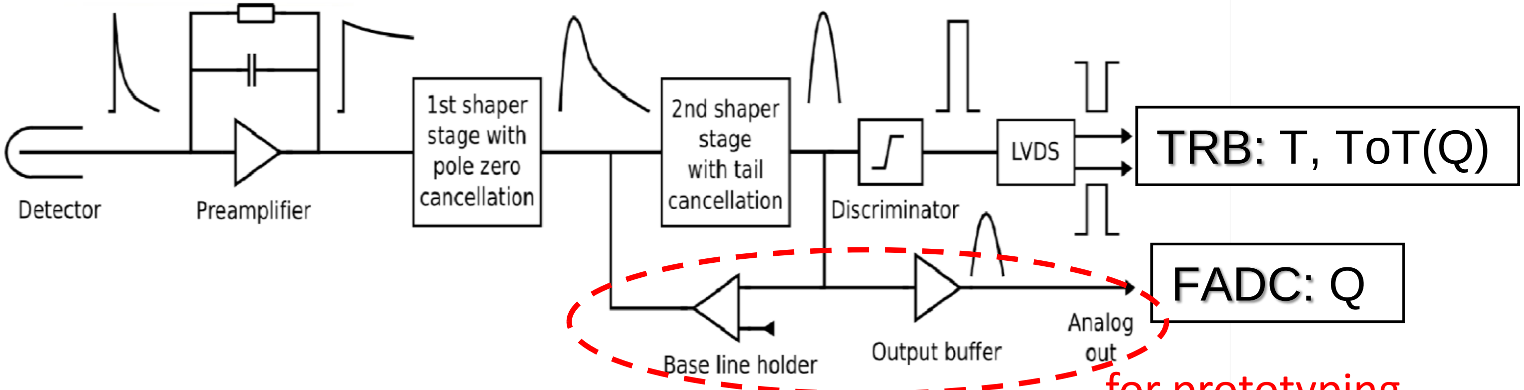


2 straw setups, proton beam coming from the back

Mitglied der Helmholtz-Gemeinschaft

ASIC Prototype For ToT-Measurement

M. Idzik, D. Przyborowski , AGH - Kraków

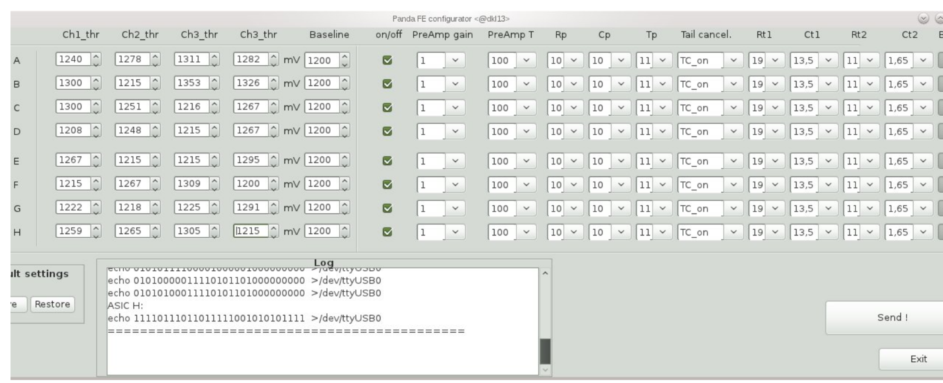


for prototyping

Specifications

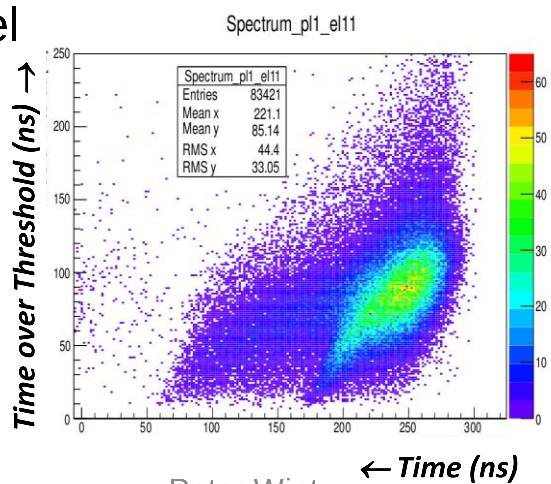
Technology:	AMS CMOS 0.35µm
Input resistance	~120 Ω
Gain	3-20 mV/fC
Peaking time	15-40 ns
Timing resolution	1-2 ns
Input range	0-200 fC
ENC noise	< 0.4 fC
Digital output	LVDS
Power	30 mW/ch

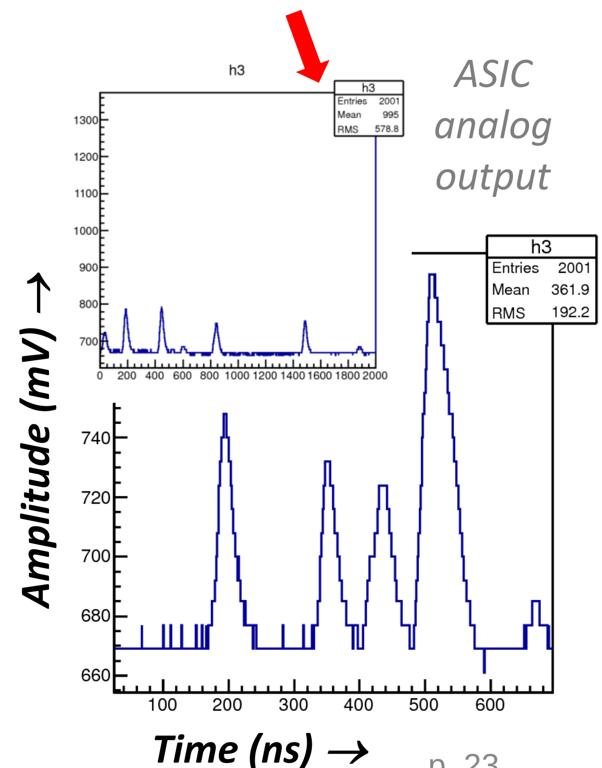
Software control of ASIC parameters: gain, t-peak, BLH, tail-ca ..



ToT-Prototype Results

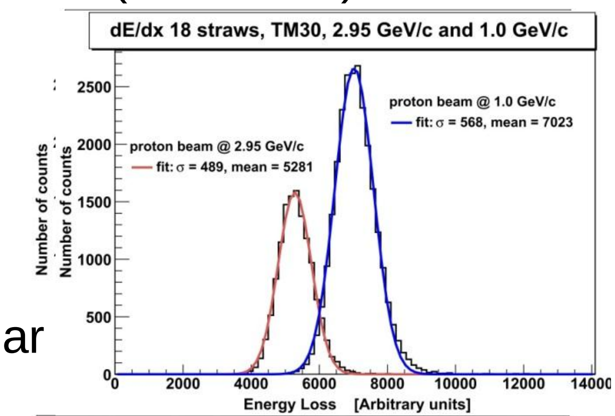
- In 2012: 1st ASIC prototype, readout boards + DAQ successfully running
- Task: optimisation of ASIC parameters (software control!)
  - Verify signal shape, ion tail cancellation, baseline stability (~ 1MHz here)
  - Variable amplifier gain and peaking time
  - Additional analog output (FADC, on scope)
- P-beam momentums: 0.9 + 2 GeV/c
- Beam intensities: 2×10^4 and 2×10^6 s^{-1} cm^{-2}
- Both readouts in parallel
  - FADC + ToT-ASIC

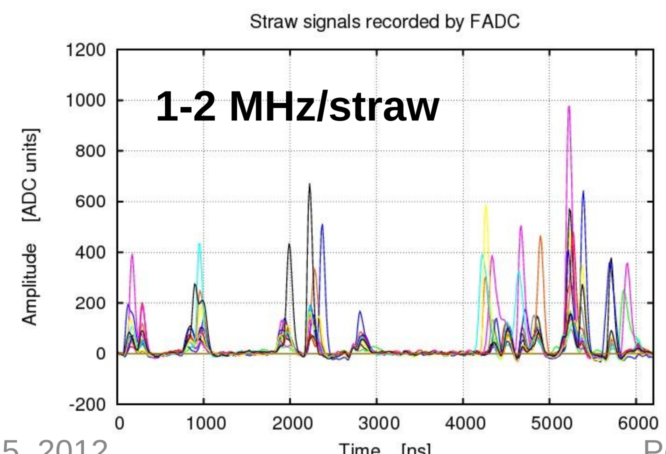


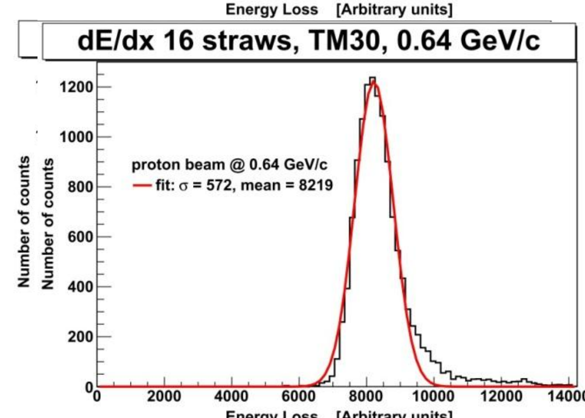


First Results of Energy-Loss Measurements

- FADC-readout, dE/dx resolutions (30% truncation)
  - $\sigma_{dE/E}$ = 9.3% (2.9 GeV/c), 8.1% (1.0 GeV/c), 7.0% (0.6 GeV/c)
  - Up to 19 straw hits per track
  - Lower beam intensity so far, ~ 100 kHz/cm
- PANDA-STT: 25 straw layers
  - $\sigma_{dE/E}$ ~ 7.0 % feasible
- Dedicated high-rate beam tests started this year







Summary

- Mechanical STT construction is clear
  - Materials, designs, tools and assembly techniques verified
  - 2 (main) laboratories: INFN Frascati and FZ-Jülich
- Readout systems needs (1-2) more iterations
  - High-rate beam tests ongoing (~ 2$\times$ per year)
  - Steady access to beam time at COSY (FAIR weeks)
  - (Main) laboratories: AGH/JU/IFJ - Cracow