

# STT Design and Prototype Tests

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

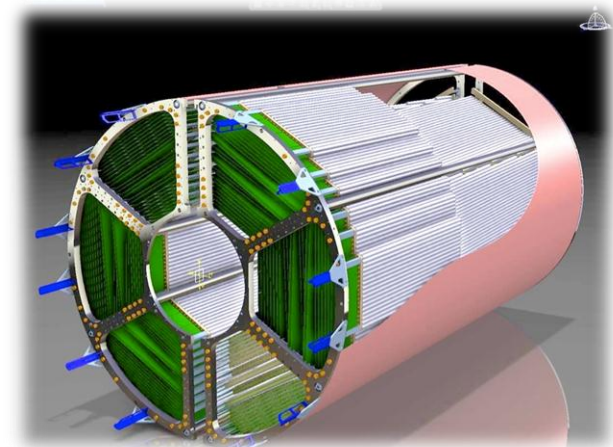
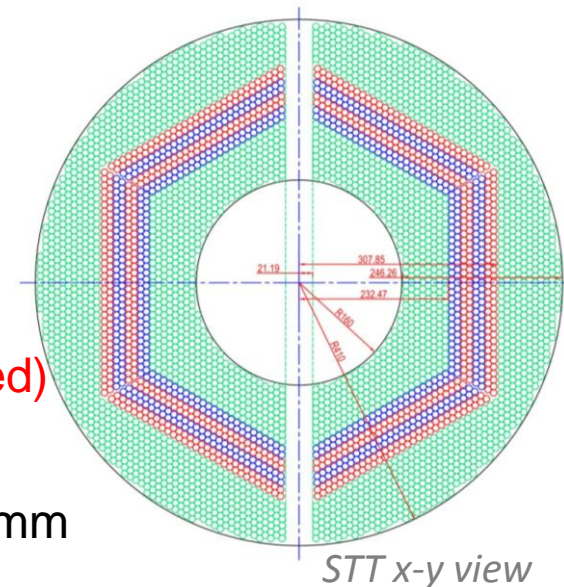
**Review of STT Technical Design Report**

# 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:  $\pm 3^\circ$  skew angle (**blue/red**)
- **STT dimensions**
  - $R_{\text{inner}}/R_{\text{outer}}$ : 150/418 mm, length:  $\sim 1500 + 150$  mm
  - Inner / outer walls ( $\sim 1$  mm Rohacell/CF)
- **$X/X_0 \sim 1.23\%$**  ( $\sim 2/3$  tube wall +  $1/3$  gas)
- **Time / amplitude readout**
  - $\sigma_{r\phi} \sim 150 \mu\text{m}$ ,  $\sigma_z \sim 3.0 \text{ mm}$  (isochrone)
  - $\sigma_E/E < 10\%$  for  $\pi/K/p$  identification
- **$\sigma_p/p \sim 1 - 2\%$**  at  $B=2$  Tesla



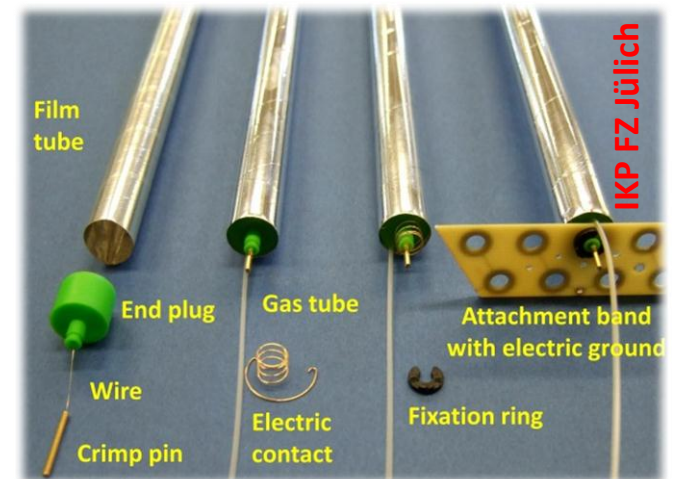
# Straw Tube Materials

Minimised number of materials and material budget (thickness)

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

- **$X/X_0 = 4.4 \times 10^{-4}$  per straw** (2.5g weight)
- **Radiation hard** (p-beam tested)

Straw components



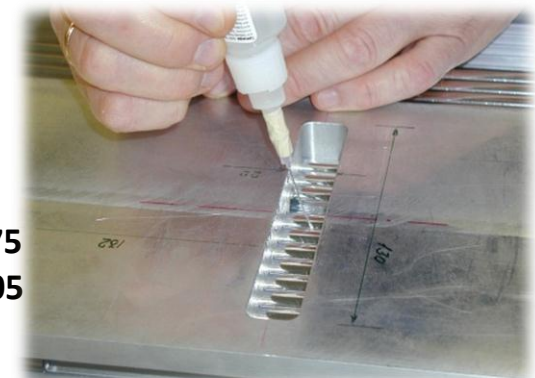
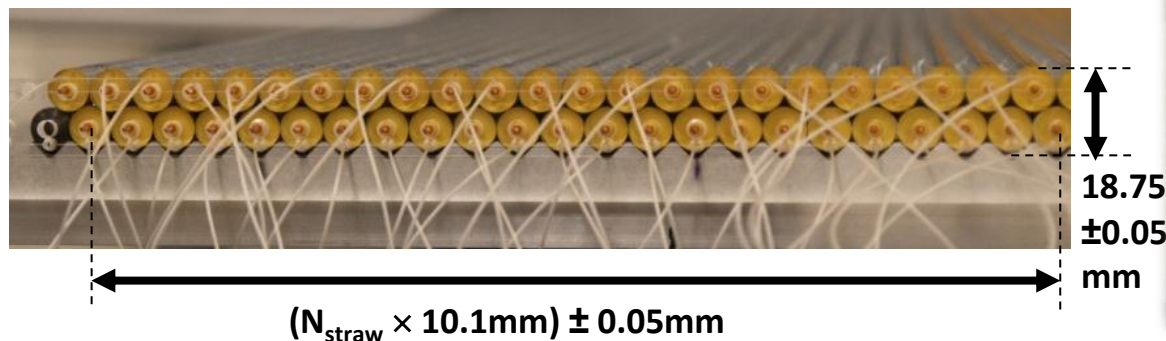
Element	Material	X [mm]	X <sub>0</sub> [cm]	X/X <sub>0</sub>
Film Tube	Mylar, 27 $\mu\text{m}$	0.085	28.7	<b><math>3.0 \times 10^{-4}</math></b>
Coating	Al, 2 $\times$ 0.03 $\mu\text{m}$	$2 \times 10^{-4}$	8.9	$2.2 \times 10^{-6}$
Gas (2bar)	Ar/CO <sub>2</sub> (10%)	7.85	6131	<b><math>1.3 \times 10^{-4}</math></b>
Wire	W/Re, 20 $\mu\text{m}$	$3 \times 10^{-5}$	0.35	$8.6 \times 10^{-6}$
			$\Sigma_{\text{Straw}}$	<b><math>4.4 \times 10^{-4}</math></b>

# Straw Layer Modules

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

- Pressurized straws ( $\Delta p=1\text{bar}$ ) are close-packed ( $< 20\mu\text{m}$  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:  $\sigma < 50 \mu\text{m}$  (data)
- **Lowest weight, precise cylindrical geometry, maximal straw density**

*Straw double-layer on reference (groove) table*

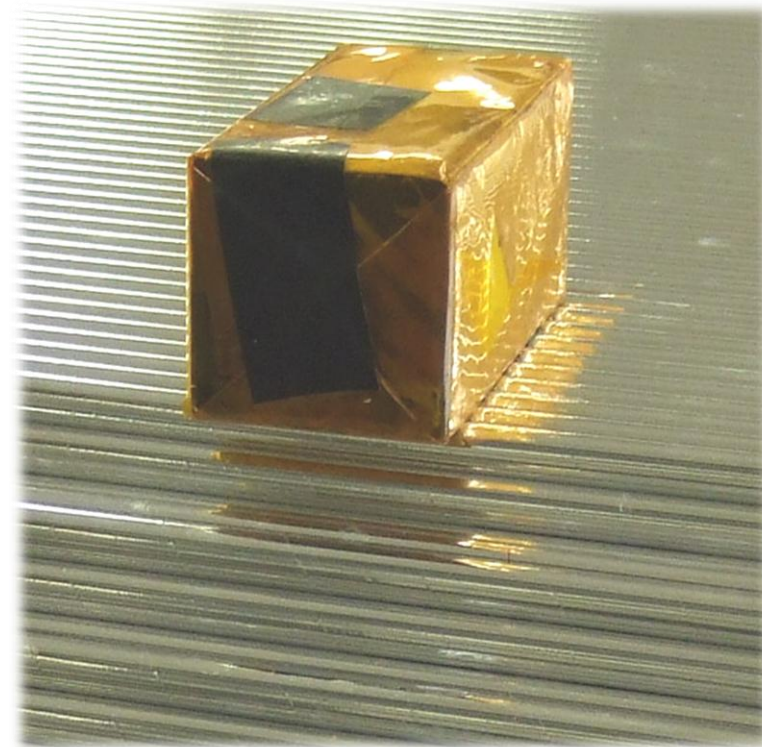
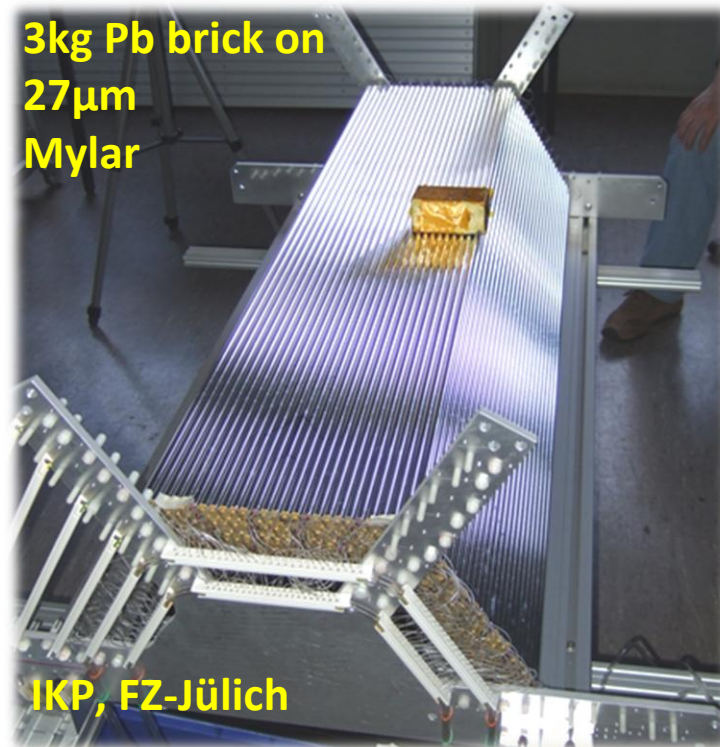


*Gluing of straw layer*  
p. 5



# Self-Supporting Straw Modules

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

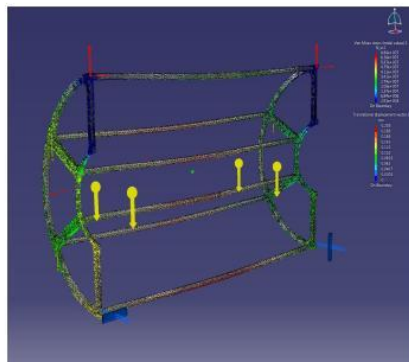


# Mechanical Frame

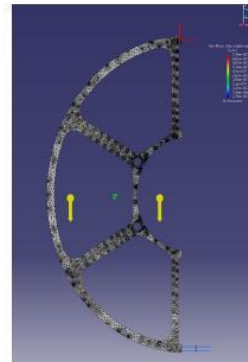
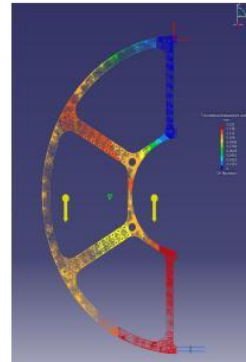
- 2 separate **semi-barrels with end flanges**, connected by spacer bars
- Precision holes at the flanges to fix straw modules
- FEM analysis: **0.03mm max. deflection**
- **Mechanical frame weight: 2× 9 kg**
- **11.6 kg Straw tubes (4636× 2.5g)** with
  - strong wire stretching (230kg equiv.)
  - strong 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
<b>Total weight</b>	<b>280 N</b>

Material	Aluminum
Density	2.7 g/cm <sup>3</sup>
Youngs modulus	70 GPa
Radiation length (X <sub>0</sub> )	9 cm
Thermal expansion	24 ppm/°C



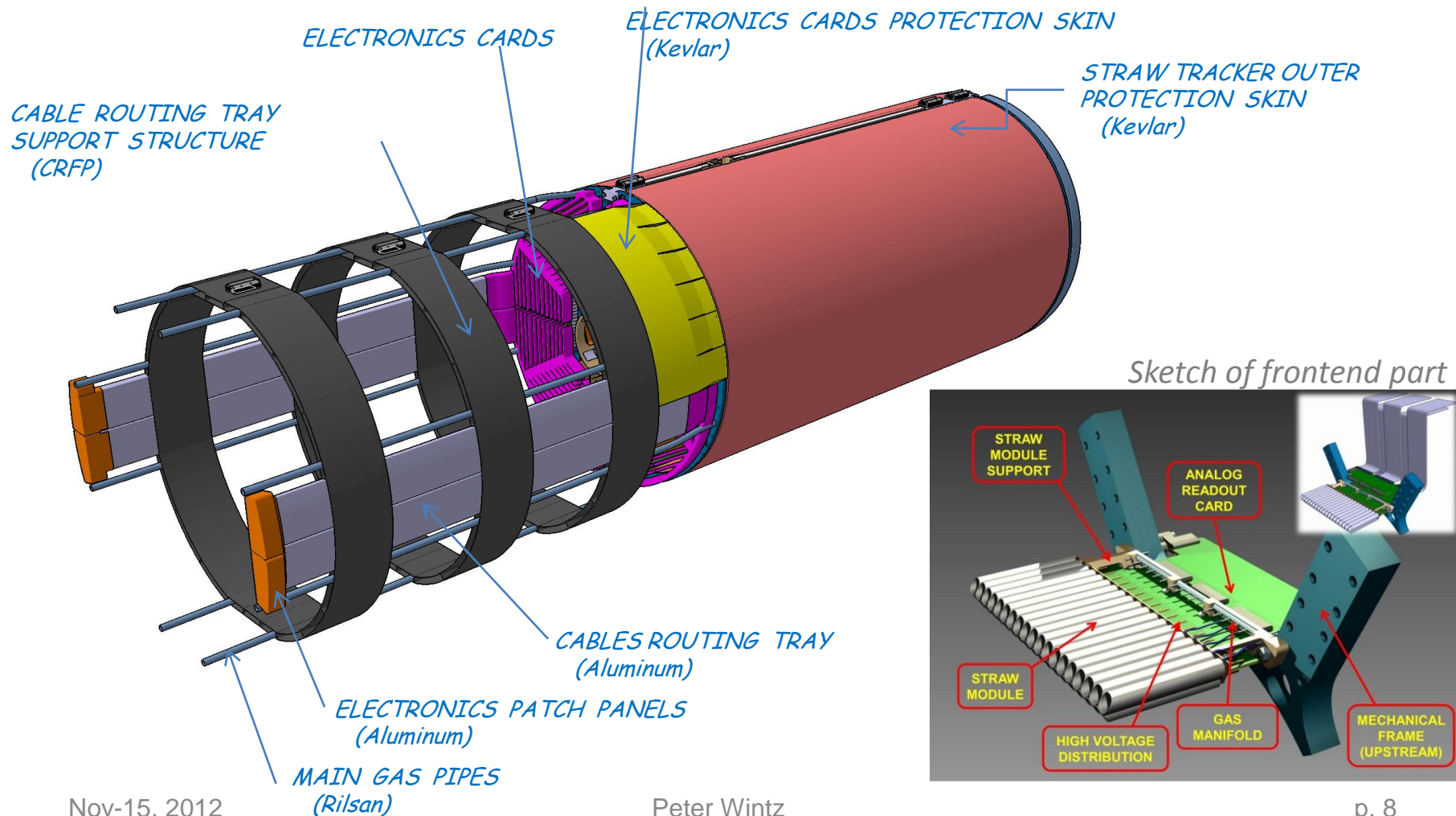
Nov-15, 2012



Peter Wintz



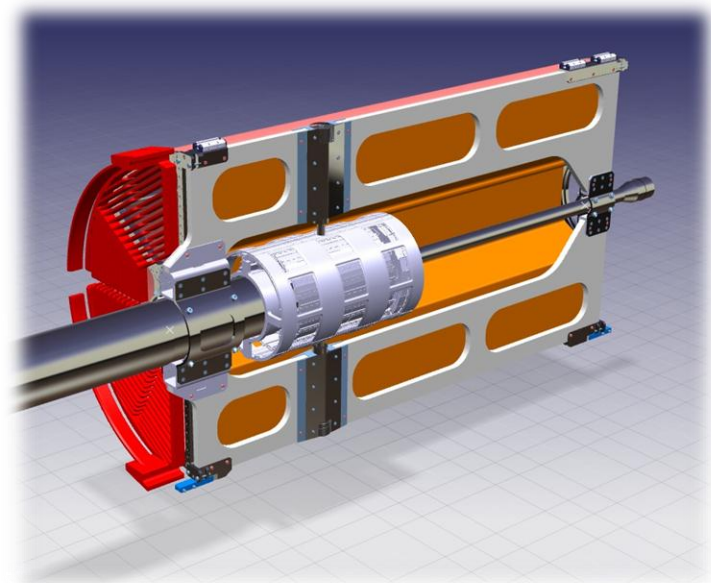
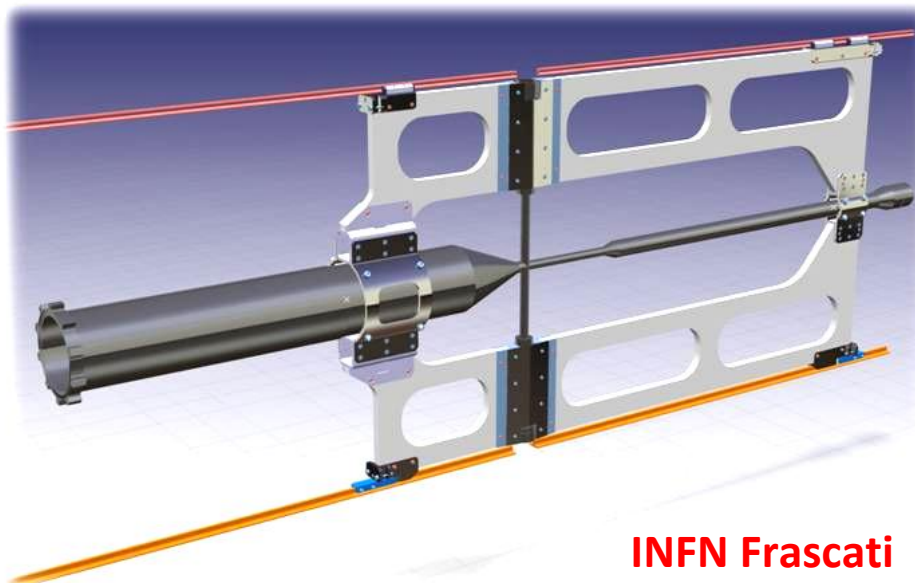
# STT Mechanical Layout





# 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 ~  $1.2 \times 10^4$  e<sup>-</sup>)
  - ~ 800 kHz per straw maximum hit rate (only inner layers)
- **Drift time readout**
  - ~ 200 ns drift time range, Ar/CO<sub>2</sub> (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  $\pi/K/p$  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.)**

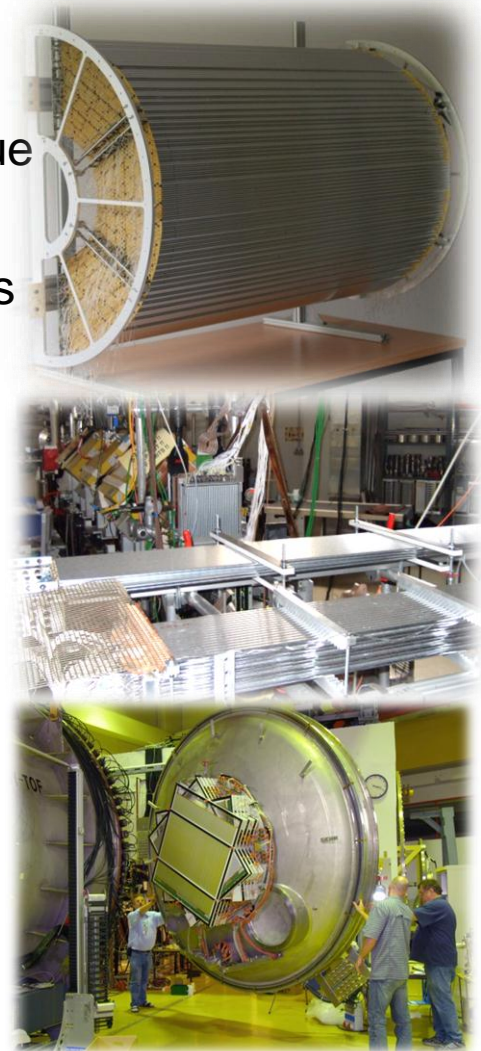
# STT Readout Concept

2 concepts under study to measure drift time + charge

- **Amplitude measurement** by FADC and FPGA readout:  $\Sigma Q$ 
  - FADC sampling frequency 240 MHz,  $\sim 4.2\text{ns}$  sampling points
  - Pulse shape analysis realtime by FPGA: **LE-Time +  $\Sigma Q$**
  - 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,  $\varnothing=10\text{mm}$
  - 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<sup>3</sup>)
- **Straw readout prototypes**
  - ASIC (T, ToT) + TRB for time-over-threshold method
  - Preamplifier + FADC for amplitude readout



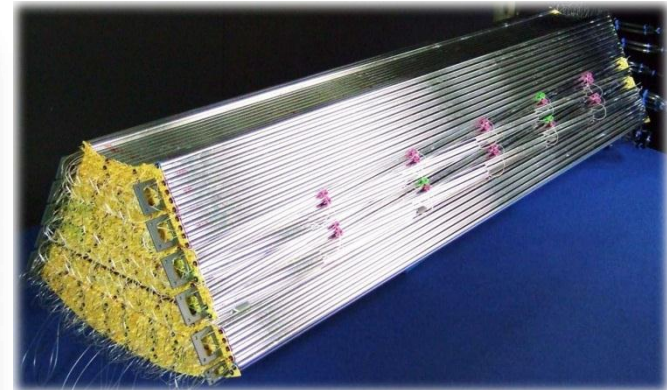


# STT Mechanical Prototype

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



*STT prototype, one semi-barrel*



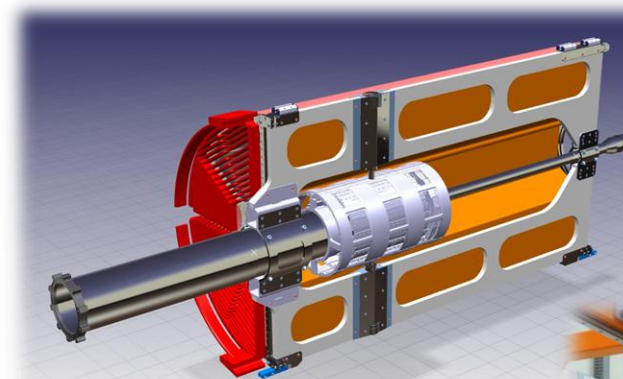
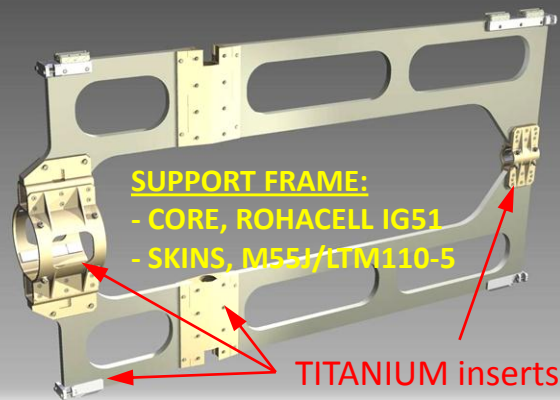
*Hexagon sector, mounting brackets to fix modules in mechanical frame*



*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



**INFN Frascati**



# 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  $\sigma(E) \sim 8 \pm 1\%$  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)

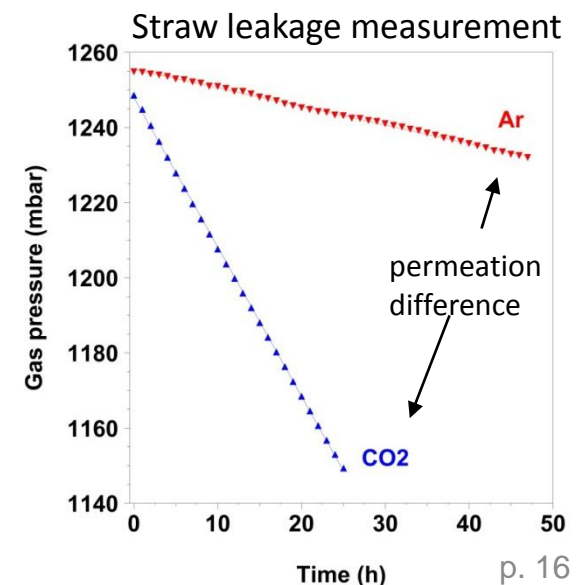
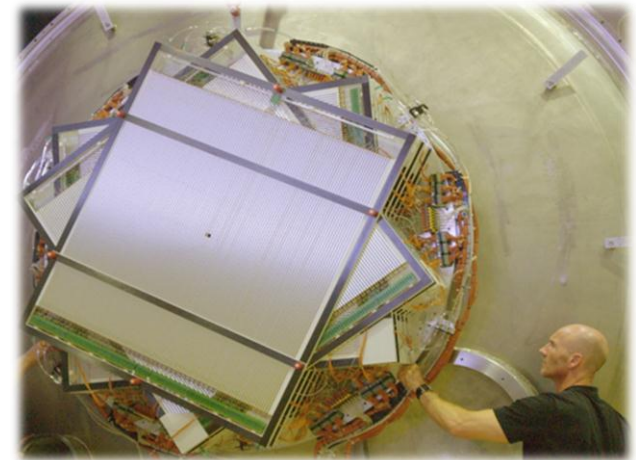
# Testsystem COSY-STT

## 2704 straw tubes

- Al-mylar:  $d=32\mu\text{m}$ ,  $\varnothing=10\text{mm}$ ,  $L=1050\text{mm}$
- 13 planar double-layers, skewed by  $i \times 60^\circ$
- Embedded in CF-rohacell sandwich frames
- Ar/CO<sub>2</sub> (20%) at  $p=1.2\text{bar}$
- Time readout (isochrones)

## Operated in vacuum since 4 years now

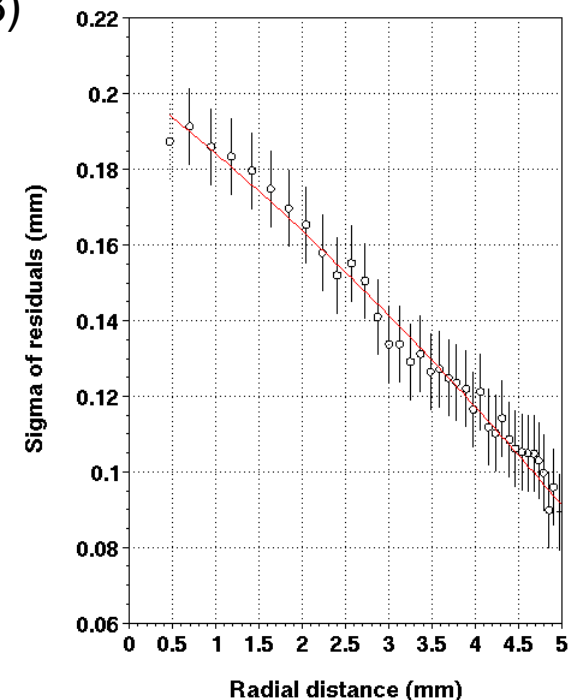
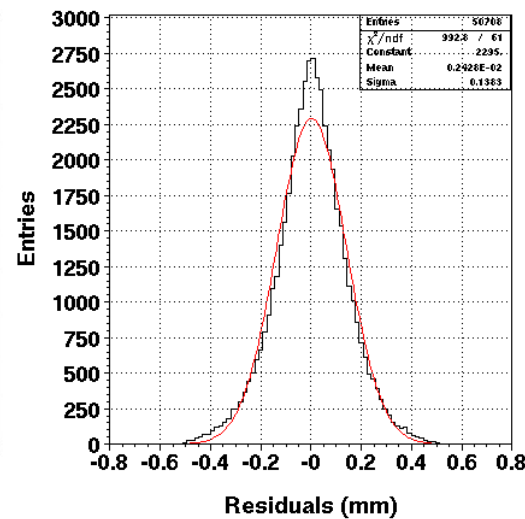
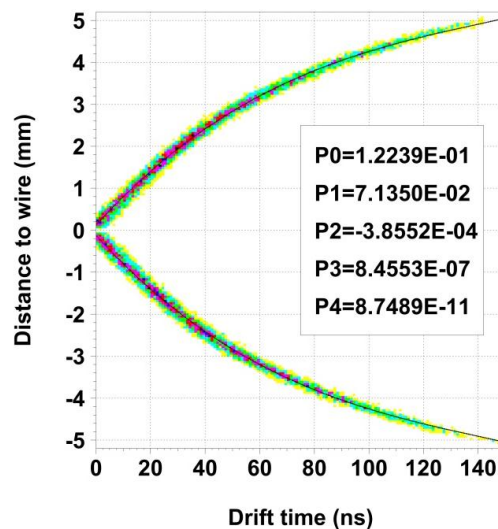
- Gas leakage stays on permeation level
- No real leakage (no dissolving glue, brittle materials,...)
- Strong confidence in all straw materials and assembly techniques for PANDA-STT





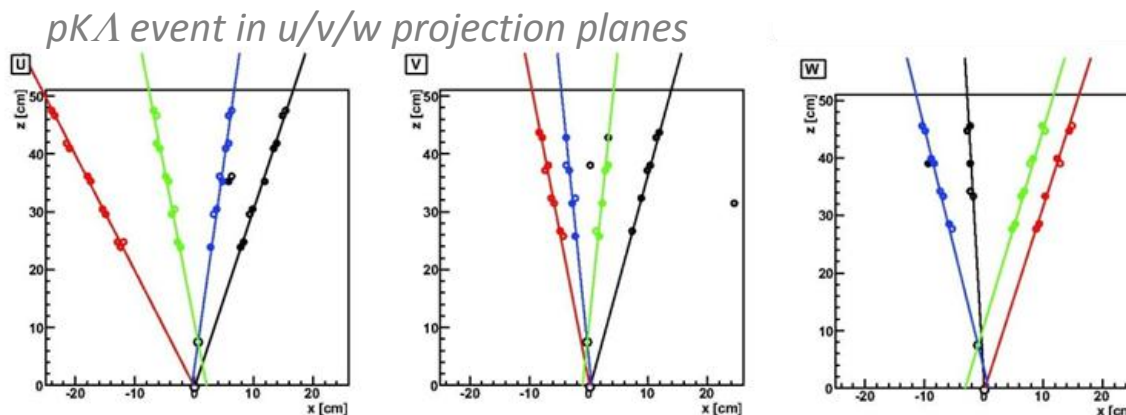
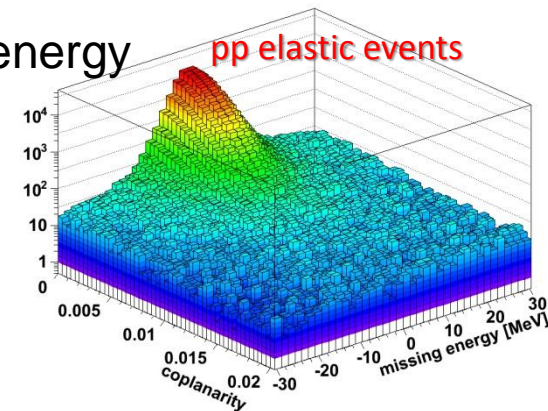
# COSY-STT Spatial Resolution

- Isochrone radius – drift time calibration  $r(t)$  by integration of drift time spectr.
- Global parametrisation (2700 straws) by 4<sup>th</sup> order polynomial (Fig.1)
- Track reconstruction by  $\chi^2$ - fit to isochrones
- **Spatial resolution** by residual distribution (Fig.2, 3)
  - $\sigma_{r\phi} = 138\mu\text{m}$ ,  $\sigma_{r\phi}(r) \sim 190 - 90 \mu\text{m}$
  - Ar/CO<sub>2</sub> (20%) at 1.25 bar pressure



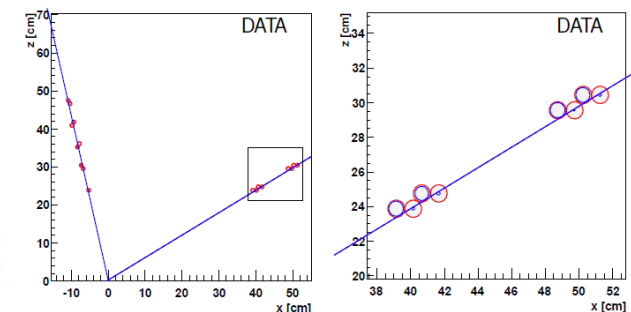
# COSY-STT Tracking Results

- Physics: hyperon production, (pol.) p-beam on  $\text{IH}_2$ -target,  $p_b \sim 3\text{GeV}/c$
- Reconstructed  $pp \rightarrow pp$  elastic scattering events
  - resolutions:  $\sigma \sim 110\mu\text{m}$  vertex, 4.5 MeV missing energy
- Example of reconstructed  $pp \rightarrow pK\Lambda$  event with delayed decay  $\Lambda \rightarrow p\pi^-$  (black circle)



( $\rightarrow$  Ph.D. thesis of M. Roeder)

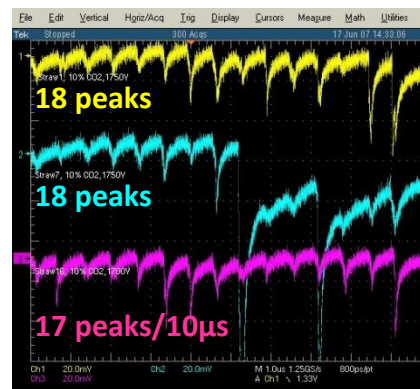
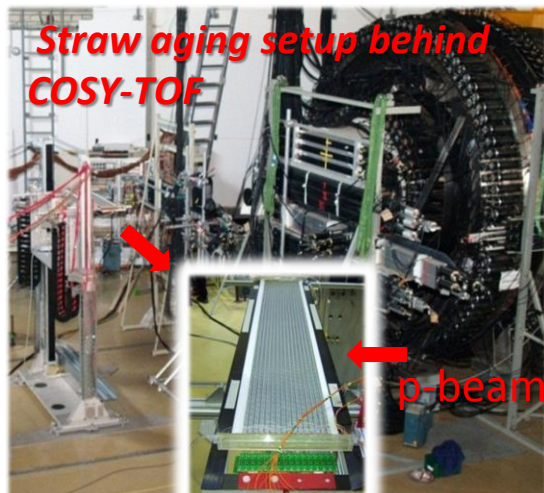
*Trackfit to isochrones, pp-event*



# 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**,  $\sim 2.3 \times 10^6 \text{ s}^{-1} \text{ cm}^{-2}$  (by SciFiber Hodo)
  - Straw rate:  $\sim 2 \times 10^6 \text{ s}^{-1}$  per 1-2 cm wire ( $\sim 140 \times$  **PANDA-straw rates**)
- **Measurement of gas gain (loss)** by signal amplitude height from  $^{55}\text{Fe}$ -source



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

Straw no	Gas mixture @ 1.65 bar	$I_{\max}$ ( $\mu\text{A}$ )	$\Sigma Q$ (C/cm) in 199h	Aging $\Delta G/G_0$
1 – 8	Ar/ $\text{CO}_2$ (10%)	1.4	0.72	<b>0..3%</b>
9 – 16		1.1	0.58	<b>0..7%</b>
17 – 20	Ar/ $\text{CO}_2$ (30%)	2.3	<b>1.23</b>	no
21 – 24		1.5	0.79	no
25 – 32	Ar/ $\text{C}_2\text{H}_6$ (10%)	1.7	0.87	no

Results of gas gain measurements

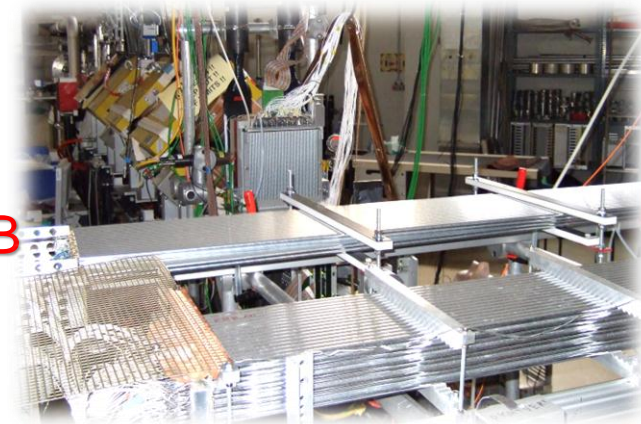
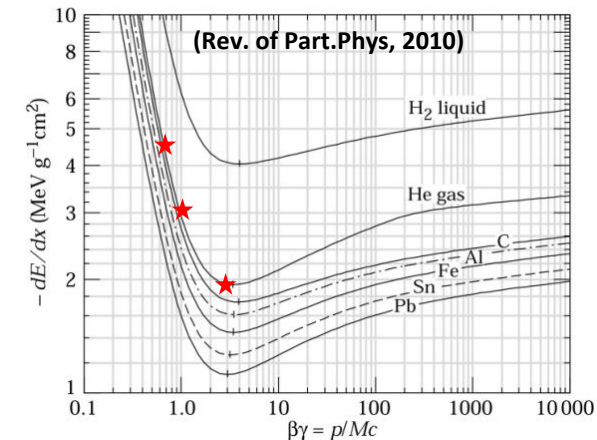
# Aging Results And Strategy

- Results:
  - No loss seen for Ar/CO<sub>2</sub> (30%) and Ar/Ethane (10%)
  - Small gas gain drop (<7%) seen for Ar/CO<sub>2</sub> (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<sub>2</sub> preferred gas mixture**: highly tolerant to highest irradiation
  - Charge loads for STT@PANDA: ~ 0.2 C/cm/year (~1 C/cm at  $z \sim 2 \pm 1$  cm)
  - **No aging expected with Ar/CO<sub>2</sub> 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  $z = 2 \pm 1$  cm (0.3% of STT)** after 2 years
  - Technique developed to replace single faulty straws in modules, saves cost / time



# In-Beam Readout Tests

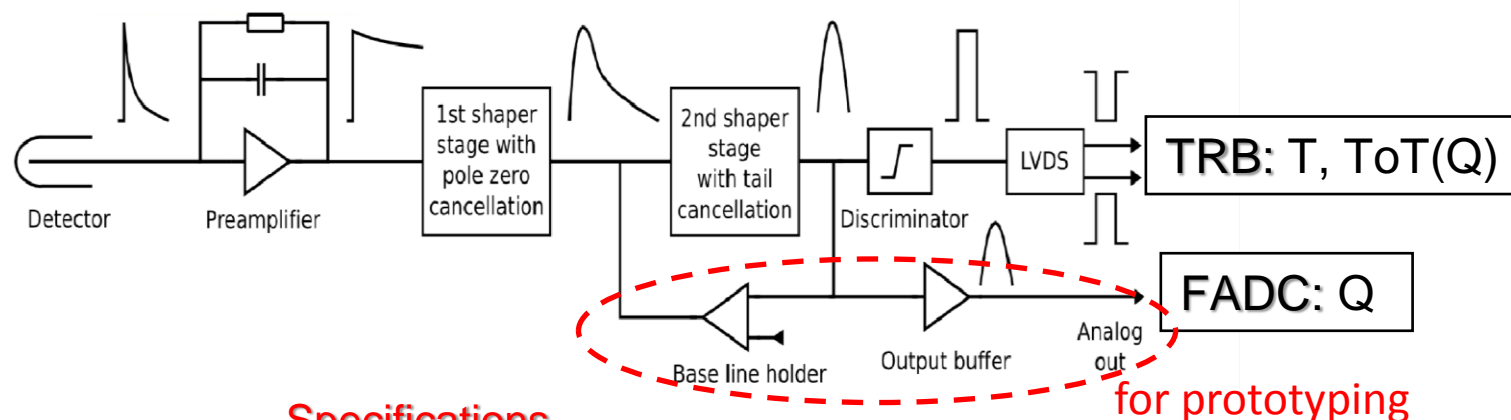
- **Proton beam with different momenta**
  - Range 0.6 - 3 GeV/c
- **2 straw setups with different readout systems**
  - Ar/CO<sub>2</sub> (10%) at p=2bar
  - Orientations of setups to beam varied
- **Readout with current amplifier + FADC**
  - FPGA (time, ampl.) + raw mode readout
  - Sampling rate 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*

# ASIC Prototype For ToT-Measurement

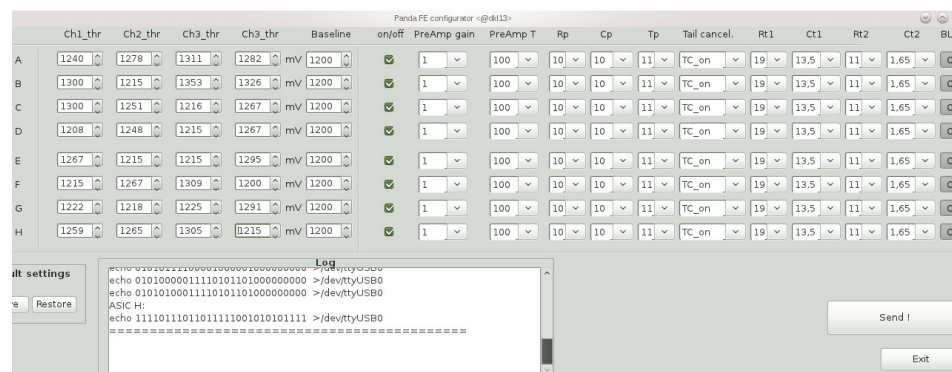
M. Idzik, D. Przyborowski, AGH - Kraków



## Specifications

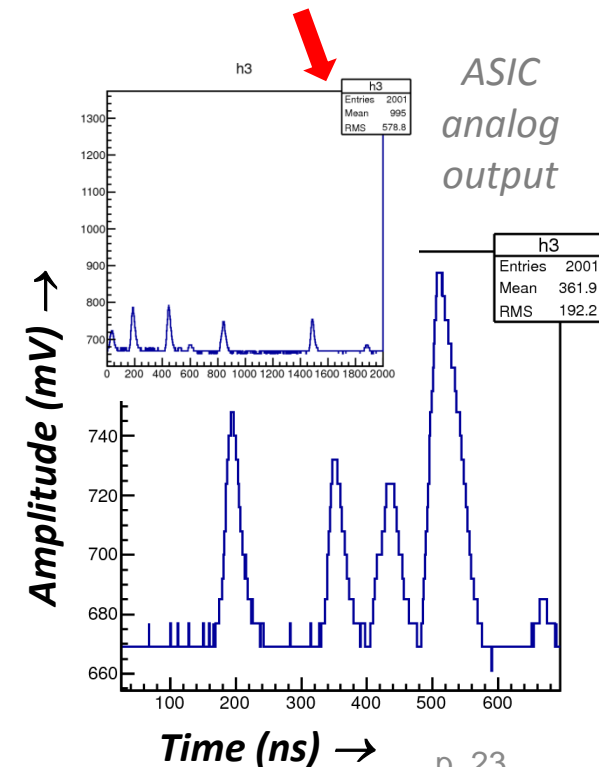
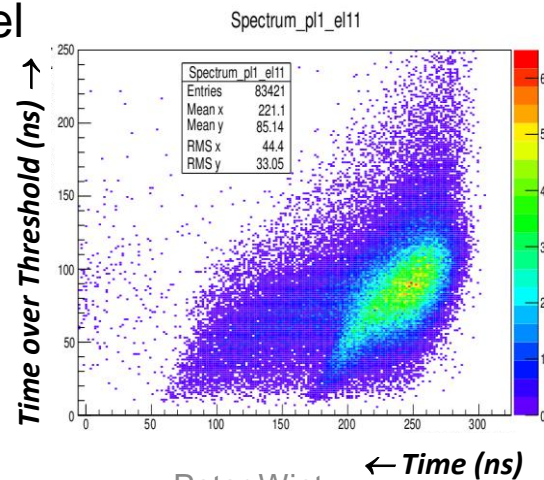
Technology:	AMS CMOS 0.35μm
Input resistance	~120 Ω
Gain	3-20 mV/fC
Peaking time	15-40 ns
Timing resolution	1-2 ns
Input range	0-200 fC
ENC noise	< 0.4 fC
Digital output	LVDS
Power	30 mW/ch

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



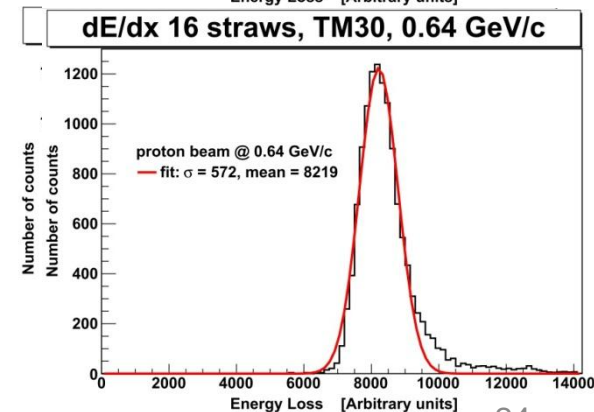
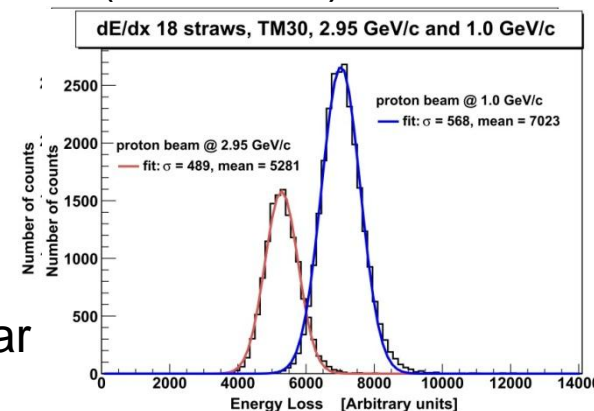
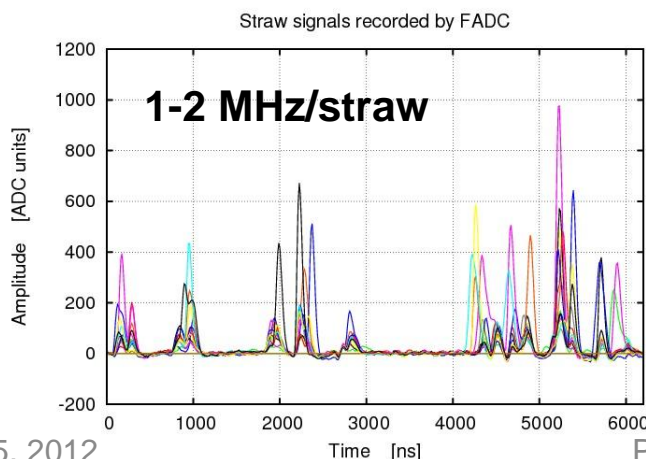
# ToT-Prototype Results

- In 2012: 1<sup>st</sup> 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:  $2 \times 10^4$  and  $2 \times 10^6 \text{ s}^{-1} \text{ cm}^{-2}$
- 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,  $\sim 100$  kHz/cm
- **PANDA-STT: 25 straw layers**
  - $\sigma_{dE/E} \sim 7.0\%$  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 ( $\sim 2\times$  per year)
  - Steady access to beam time at COSY (FAIR weeks)
  - (Main) laboratories: AGH/JU/IFJ - Cracow