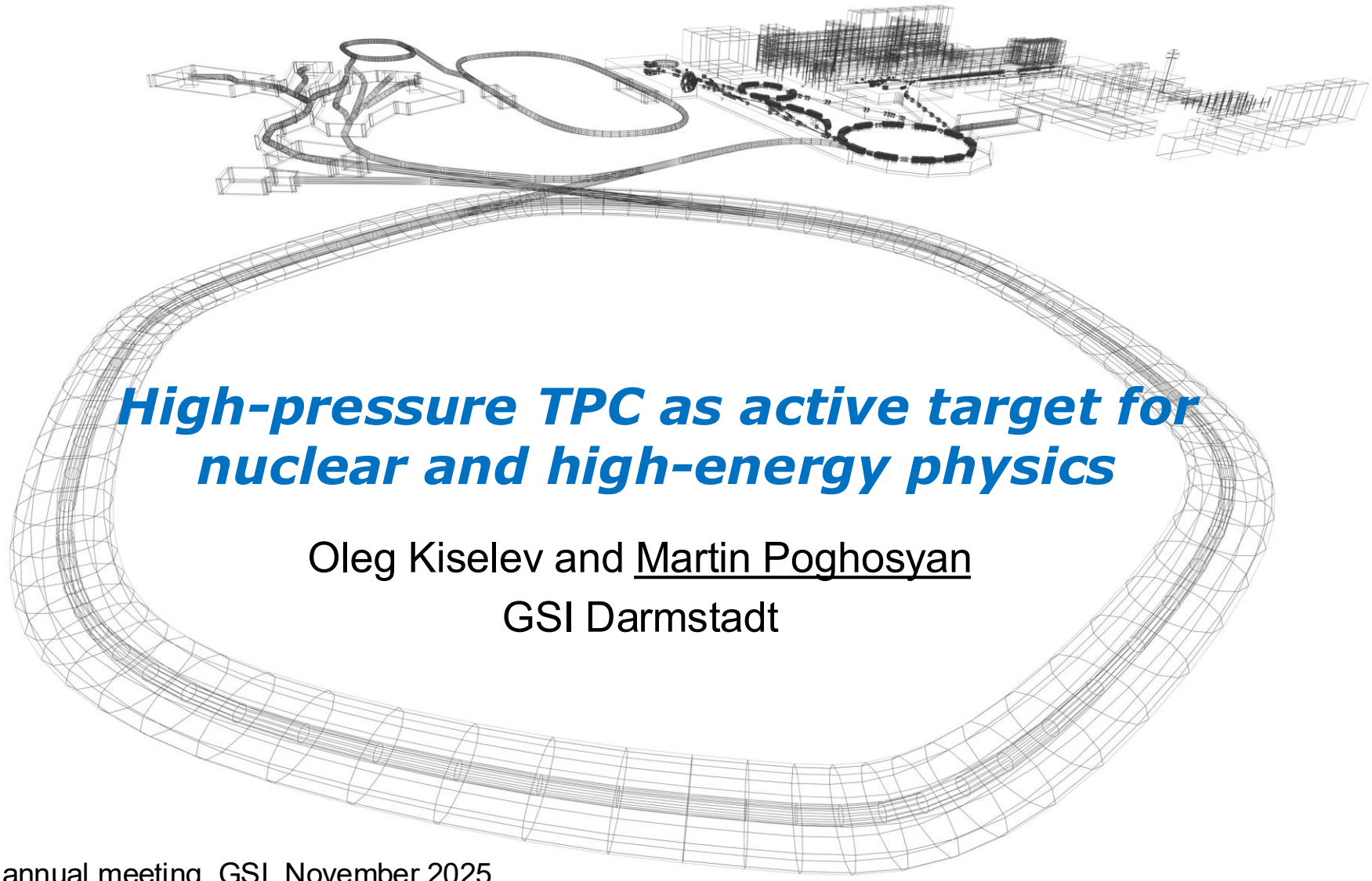


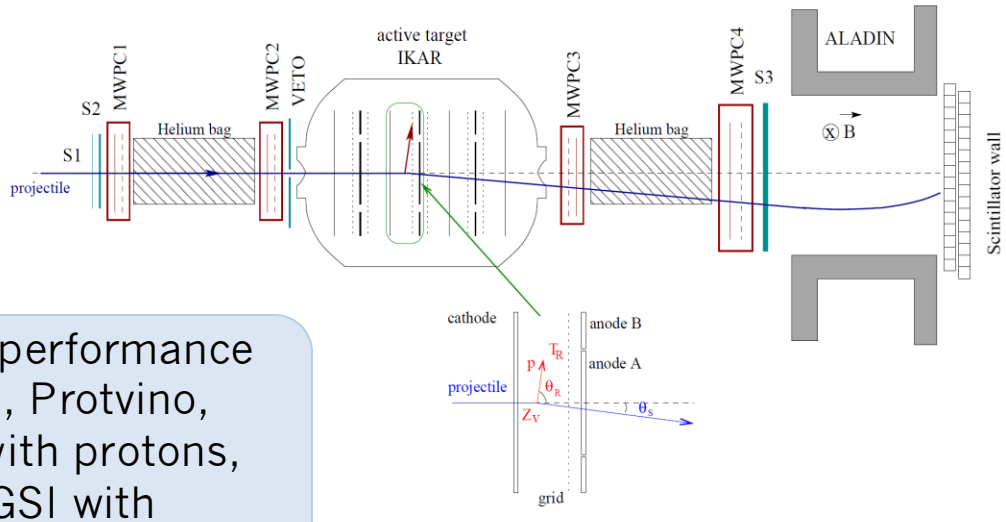
High-pressure TPC as active target for nuclear and high-energy physics

Oleg Kiselev and Martin Poghosyan
GSI Darmstadt

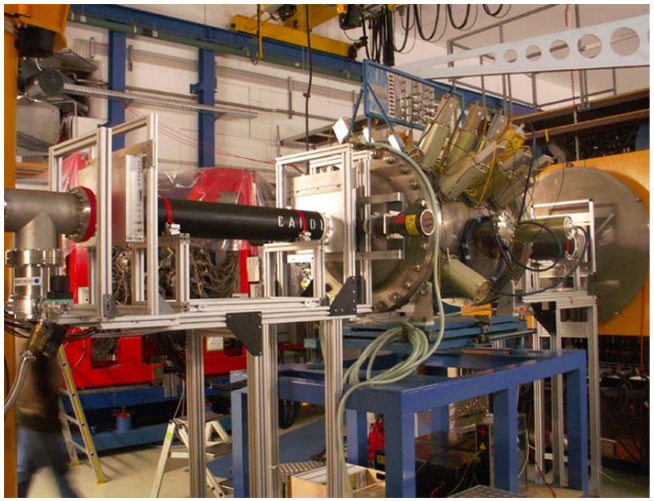
MT annual meeting, GSI, November 2025

Motivation and Previous experience

Why a New TPC?



Proven performance at PNPI, Protvino, CERN with protons, and at GSI with radioactive ions



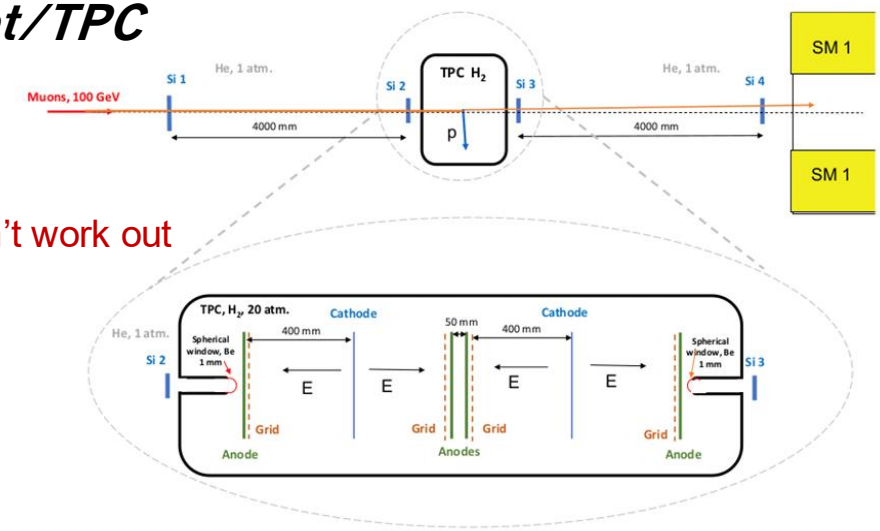
Several successful experiments at GSI with R3B setup

- "Classical" ionization chamber used to measure recoil energy with high precision
- Gas pressure up to 10 bar (H_2 , D_2, He targets)
- 6 independent detection modules in one gas volume
- Limitations: light ions only + low-intensity beams

S.R. Neumaier et al., Nucl. Phys. A 712 (2002) 247
G.D. Alkhazov et al., Nucl. Phys. A 712 (2002) 269
A.V. Dobrovolsky et al., Nucl. Phys. A766 (2006) 1
S. Ilieva et al., Nucl. Phys. A875 (2012) 8
X. Liu et al., Phys. Rev. C 104, 034315 (2021)

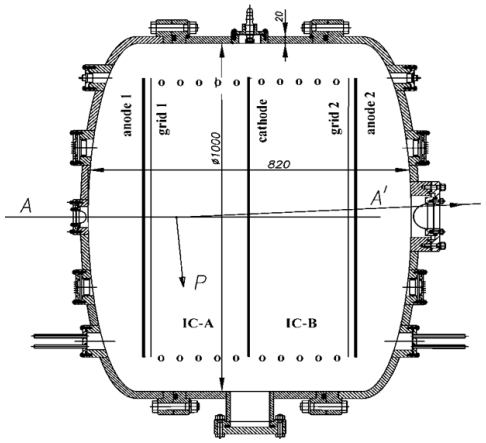
Active Target for FAIR (ACTAF) for the R3B experiment

Towards the New Generation Active Target/TPC



Technical Design Report accepted in 2016

It was considered a Russian in-kind contribution, but it didn't work out



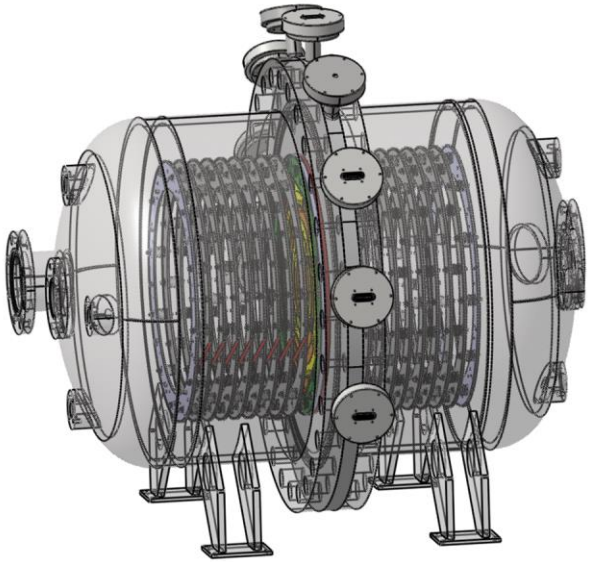
Large diameter and higher pressure – enables higher-energy recoil measurements with high precision

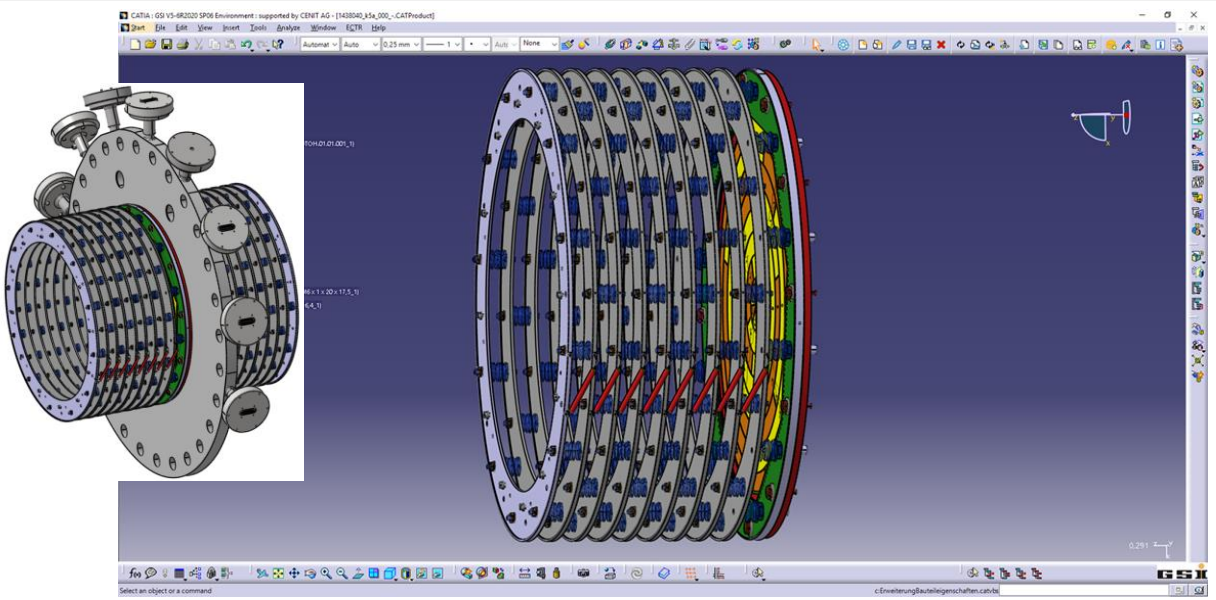
- It turned out a very similar TPC could play a key role for the measurement of the proton radius proposed by the COMPASS at CERN (now AMBER collaboration)

- Agreed to construct the detector jointly, use for the proton radius measurement at CERN, and later operate at FAIR

Particle and nuclear physics came together — combining their resources, expertise and efforts on this project

Design Overview





- Two-cell TPC with high anode segmentation within one gas volume
- Pressure up to 20 bar (^{4}He, ^{3}He, H_2, CH_4 gases)
  - vessel tested at 32 bar
- Drift voltage up to 100 kV
  - Electrodes on both sides of middle flange to avoid deformations
  - Field-shaping rings with optimized profile
  - Wire grid separating the anode and drift volume
- No high-outgassing parts inside the gas volume

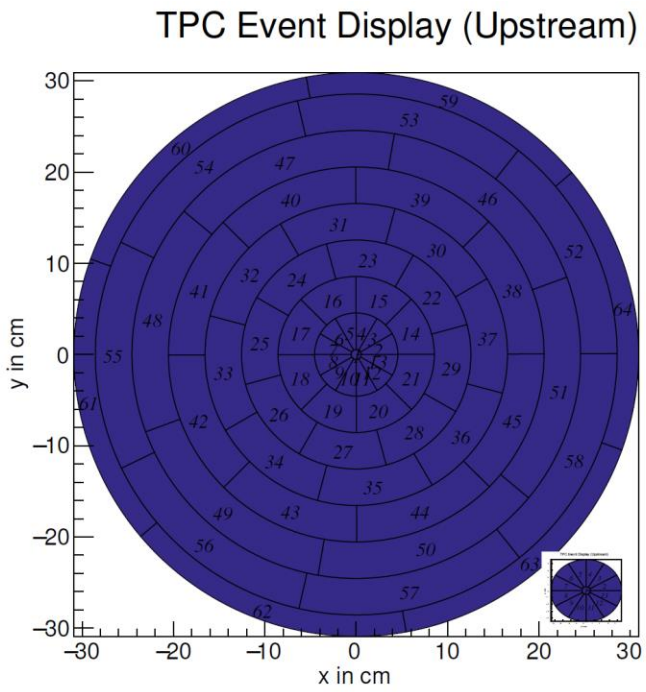
Basically the whole design is done at GSI

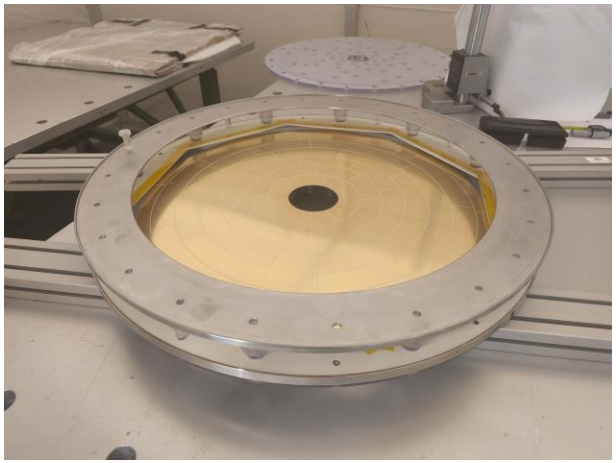
TPC vessel

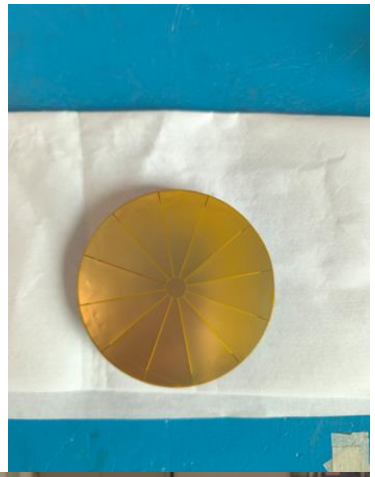
- Assembled at GSI
  - Leak test done
  - Closed with M52 screws (2500 Nm)
  - Electropolished high-quality stainless steel

- diameter 1100 mm, length 1600 mm, weight 2200 kg

Anode system



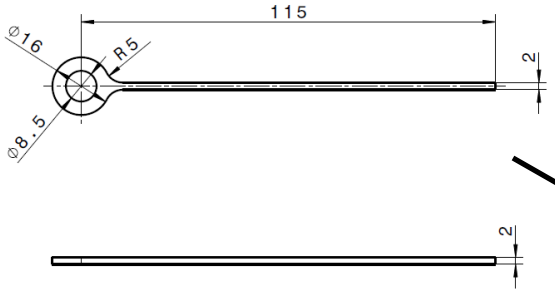


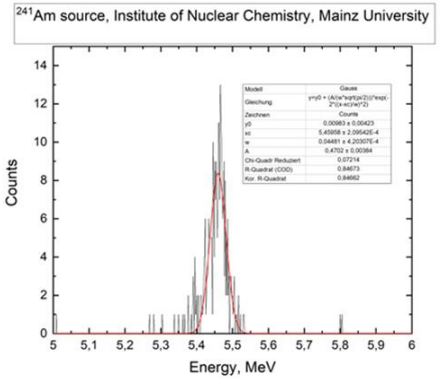


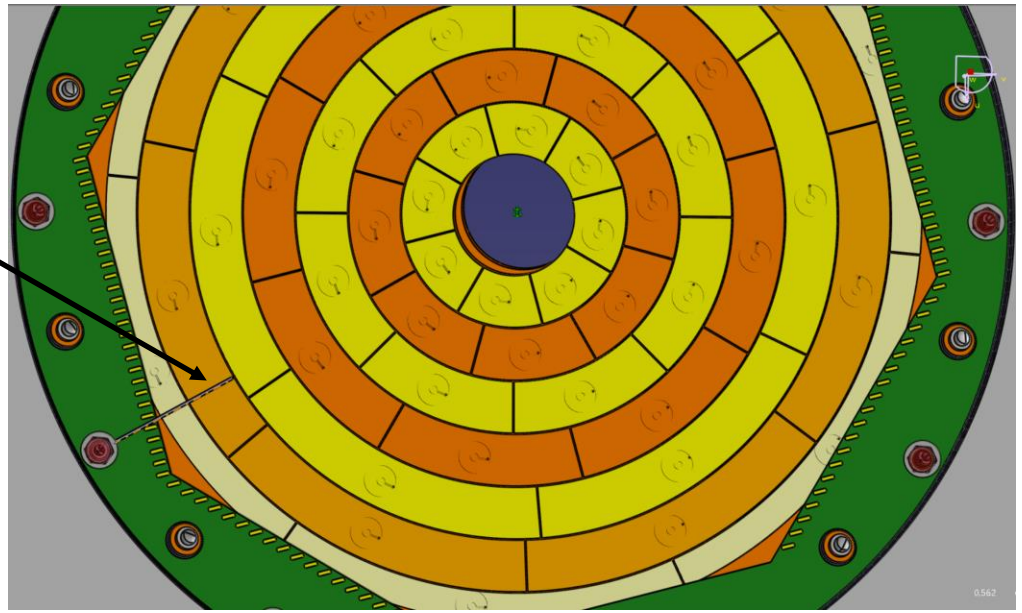
- Fine segmentation → energy + angle (azimuthal/polar) measurement
- PCBs: Rogers RO4053B (low outgassing)
- Central 90 mm area on 50 µm Kapton foil -> reduced scattering
- Each pad individually read out

Designed by GSI detector & experiment electronics labs

Calibration sources



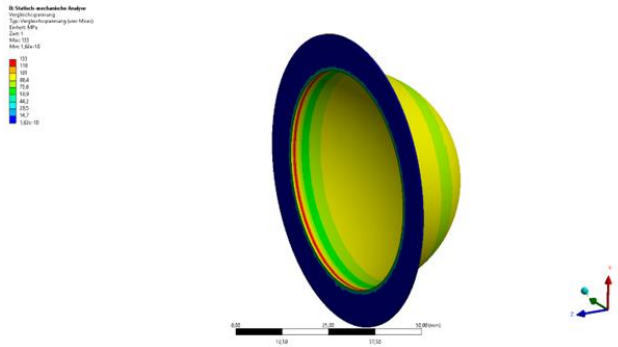




- ^{241}Am open sources (10-15 Bq) positioned in front of same anode pad
- Used to verify gas quality + amplifiers, DAQ, analysis
- Continuous monitoring – sensitivity compatible to gas chromatography

Produced at Institute for Nuclear Chemistry (Mainz)

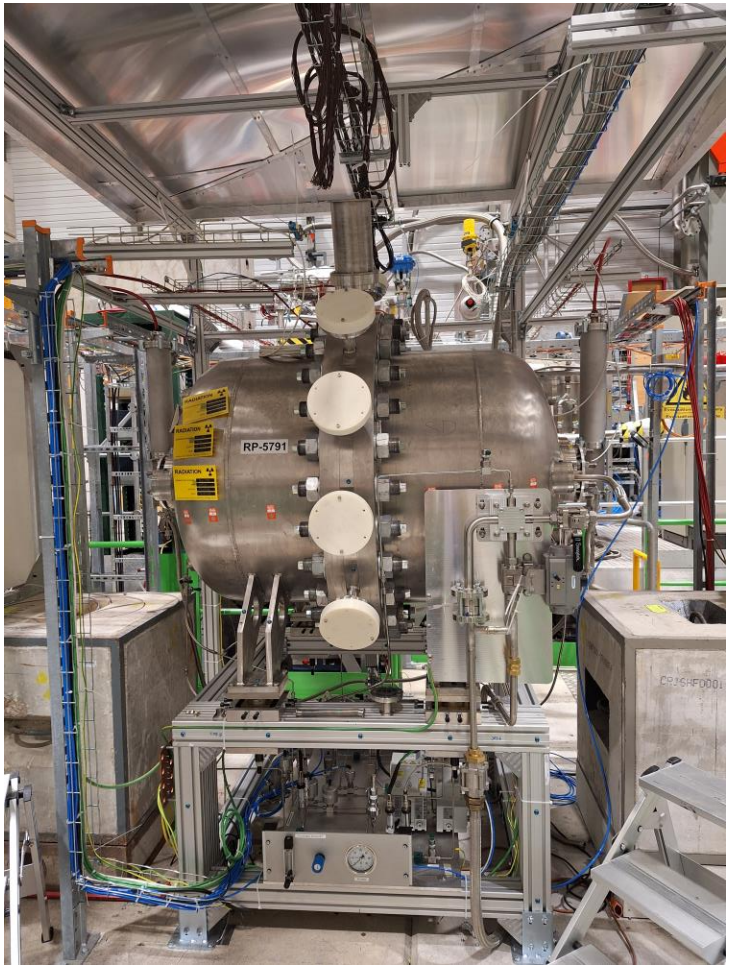
New Carbon-Fiber Beam Windows



- Replaces earlier Be design
- 1 mm thick carbon-fiber windows tested up to 100 bar
- Deformations confirmed via ANSYS calculations
- Applicable to future projects

Designed and produced at GSI

Advanced gas system

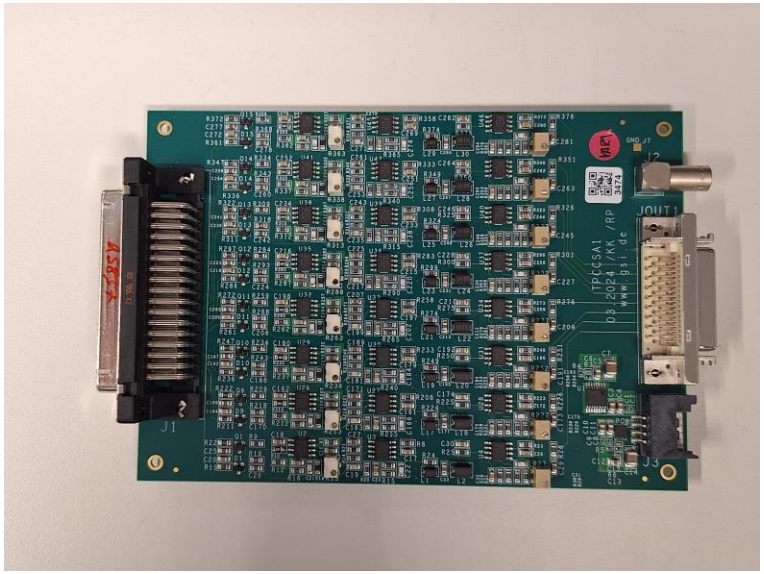


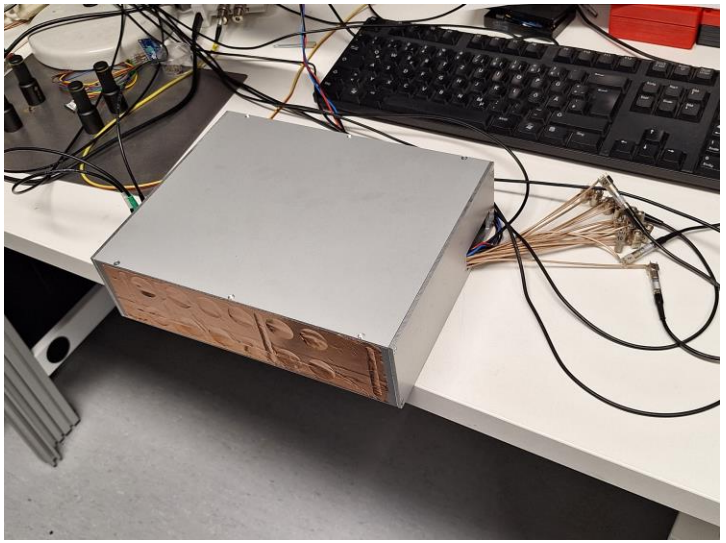
- Operation with H_2 and other gases up to 20 bar
- Pressure and flow stabilization
- Precise pressure & temperature control (10^{-5} precision)
- O_2/H_2O sensors with ppm-level sensitivity

Probably the most advanced and sophisticated gas system of any GSI detector

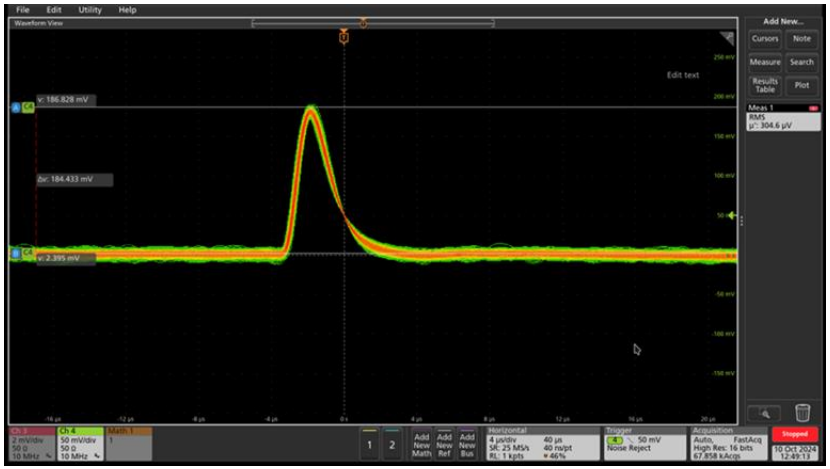
Designed and built by CERN gas group – ATEX-compliant PLC control

Low-noise Charge Amplifiers





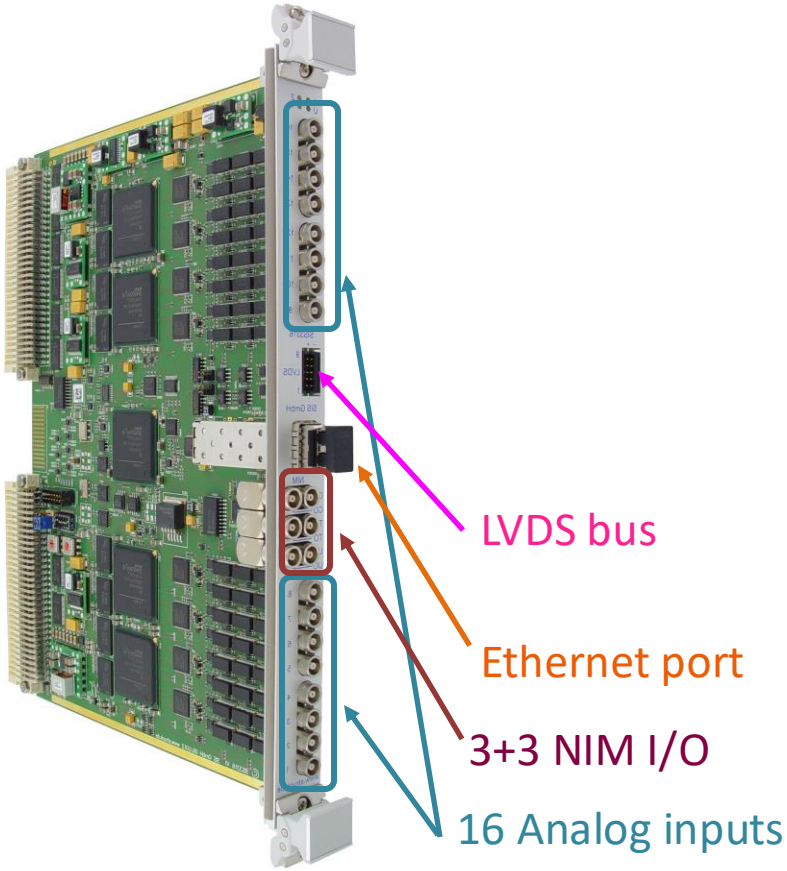
- No gas amplification – primary ionization signal only
- Charge-sensitive amplifier / shaper (16 ch per PCB)
- 128 channels in total -> 14-bit digitalization



Design and layout done at GSI

SIS3316 Digitiser

High-precision Flash-ADC
Two models: 250 MHz / 14-bit and 125 MHz / 16-bit



TPC case (current implementation)

9 modules total

- 8 for detector signals
- 1 for AMBER TimeTag

Readout and Configuration via Ethernet

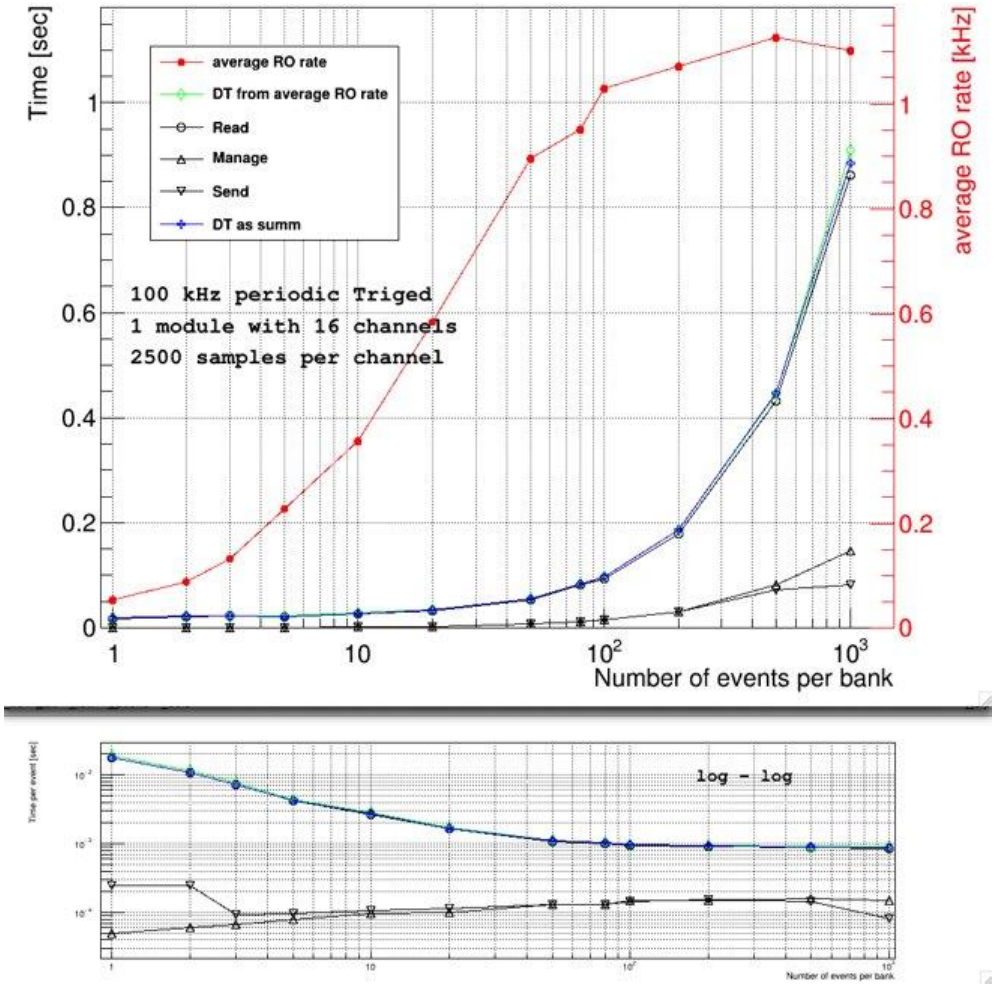
- 1GBit/s speed per module
- DRASI based readout
- VME crate used for power and trigger unit

Synchronisation

- Clocks and internal Time-Stamps via LVDS bus
- Busy signal
  - Raised per event during processing
  - When both banks (buffers) full
- UserCounters stored

DAQ Software developed at GSI

Average readout rate – qualitative picture



2 banks with 128 MB per channel each

Instantaneous readout rate can be quite high:

e.g. ~25 khz for 2500 samples/ch

Average readout rate limited by the data transfer time

Optimisation knobs:

- samples/channel
- events/bank
- trigger rate
- packets/request

Optimise transfer during spill-off

Summary

Major GSI contributions in designing/producing

- Vessel & anode plane
- Amplifier + Shaper
- Carbon-fiber beam window
- Calibration sources
- DAQ Software
- Analysis Software (R3Broot)
- Assembly and commissioning

Current status:

Detector commissioning/testing at CERN with AMBER Collaboration