Active targets for R³B and proton radius measurement at CERN

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Seminar on R³B related detector developments
20.10.2020 (online)

Outline

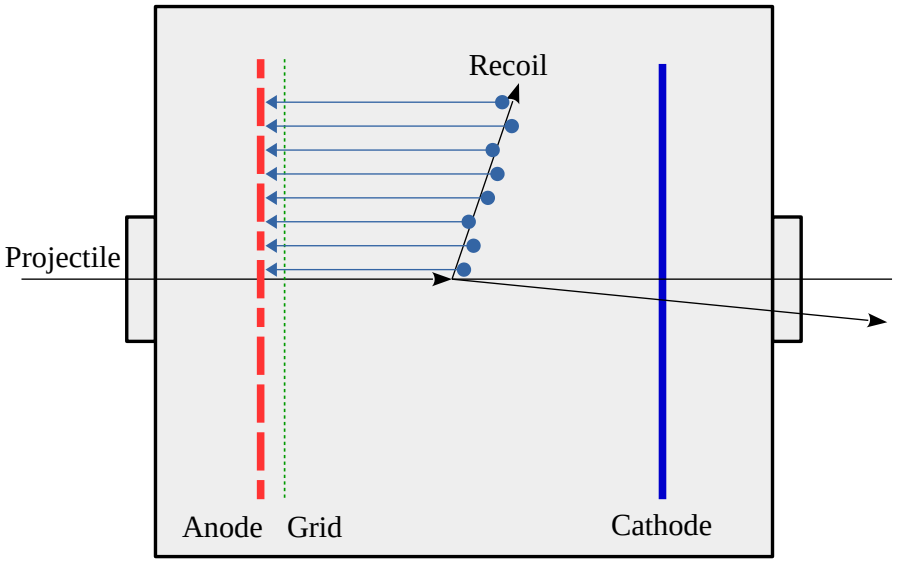
- Experiments at GSI
  - Light nuclei structure studies with IKAR
- Active targets for R³B
  - Prototype test
  - Exotic heavy ions: ACTAF1
  - Inelastic scattering: ACTAF2
- Proton charge radius measurement at CERN (PRM)
  - Motivation
  - Active target for PRM

Active targets

Active target: gas-filled detector in which gas is both the target and detection medium.

Highlights:

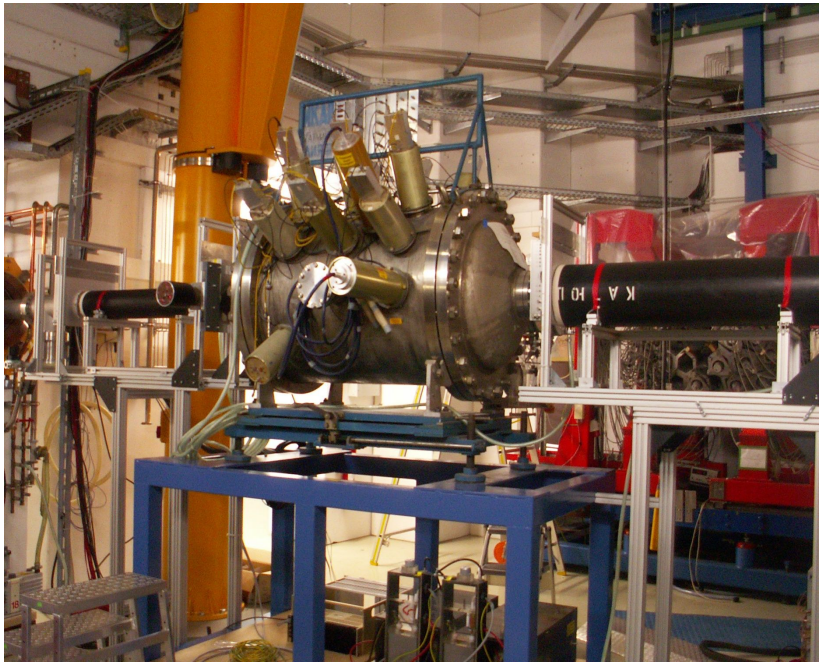
- Study of short-lived nuclei
- Recoil detection (p, α, etc.)
- Low momentum transfer
- Low detection threshold
- High efficiency

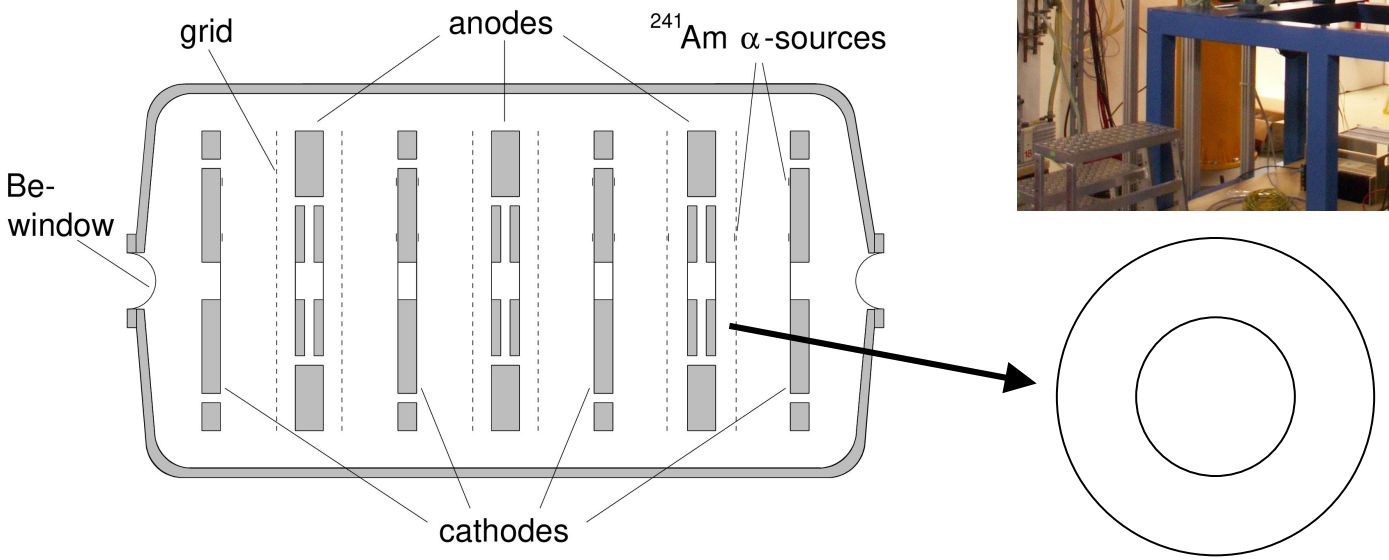


Unique experience of working with active targets at PNPI and GSI

IKAR @GSI

- Material: stainless steel
- Gas: high purity H_2
- Anode diameter: 400 mm
- Pressure: up to 10 bar
- Drift cells: 6×100 mm
- Beryllium windows
- Drift time: ~25 µs



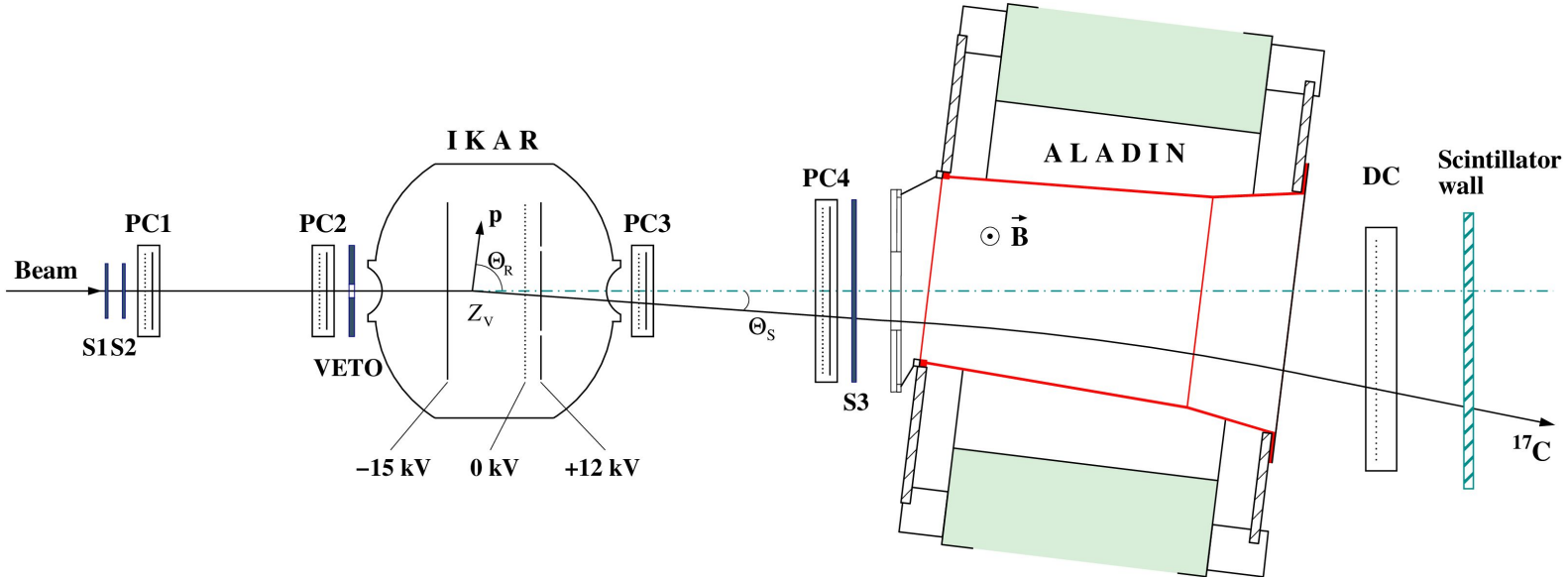


Not suitable
for heavy ions

IKAR @GSI

Method: elastic proton scattering at intermediate energies in inverse kinematics

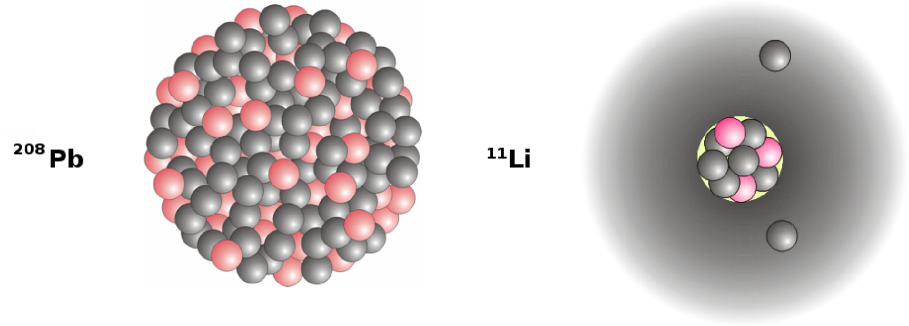
Supporting equipment: scintillators, proportional chambers, magnet, drift chamber



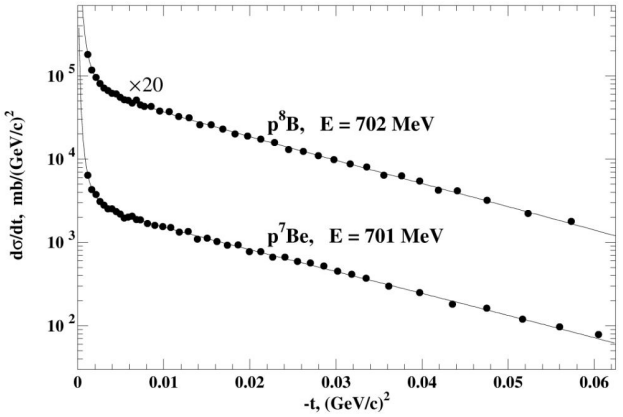
IKAR @GSI

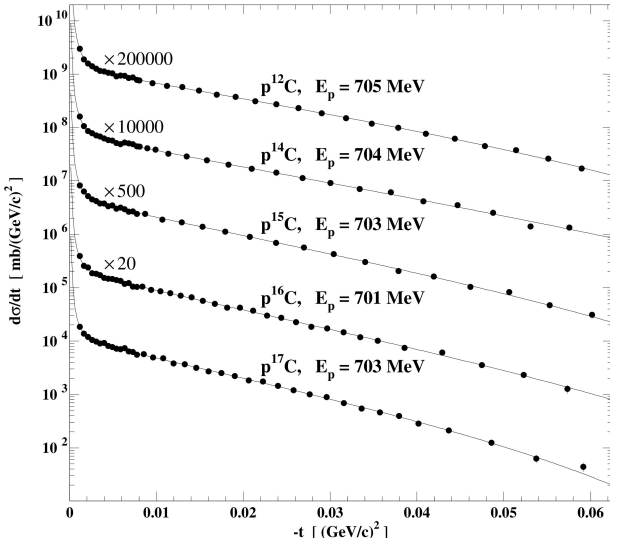
High quality experimental results of high interest for nuclear- and astrophysics:

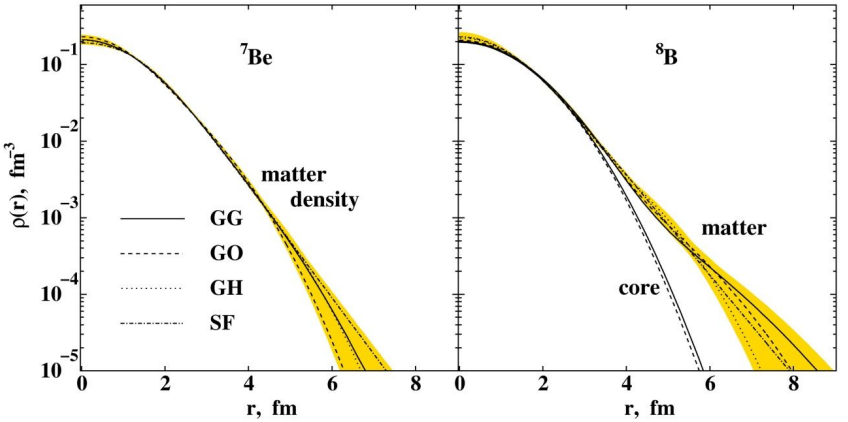
- Measurements of neutron rich nuclei ^{6}He, ^{8}He, ^{8}Li, ^{9}Li, ^{11}Li, ^{12}Be, ^{14}Be and proton rich nuclei ^{7}Be and ^{8}B
- Measurements of the stable nuclei ^{4}He and ^{6}Li
- Measurements of ^{12}C, ^{14}C, ^{15}C, ^{16}C, ^{17}C (latest)
- Elastic cross-sections and matter radii utilizing Glauber theory

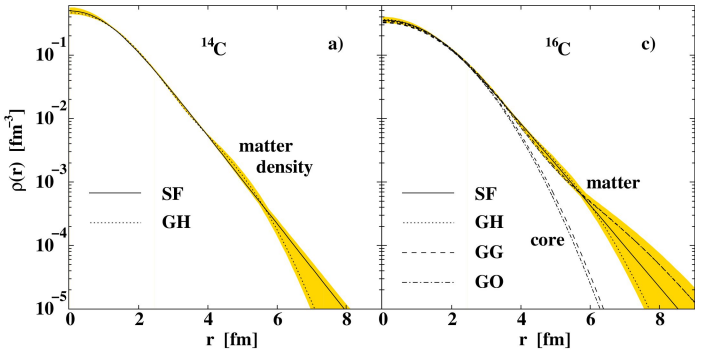


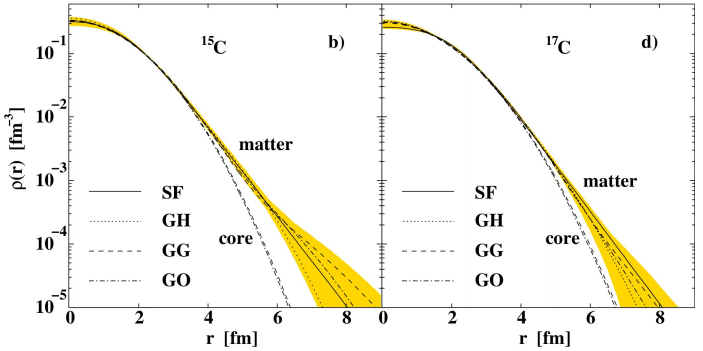
IKAR @GSI







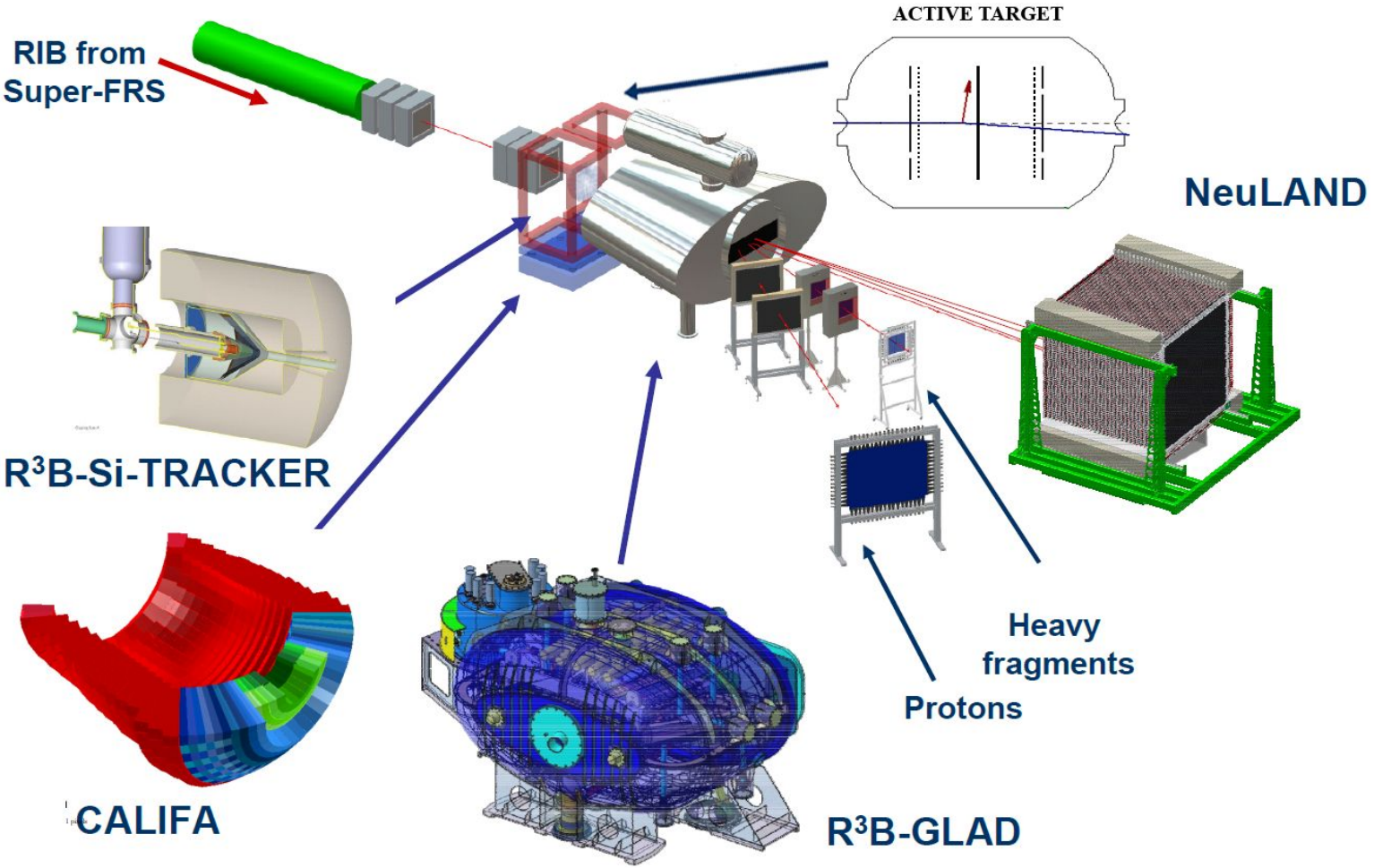




*preliminary

ACTAF @R³B

ACtive **TA**rget for **F**AIR



ACTAF @R³B

- Investigation of elastic scattering of heavier nuclei (e. g. ^{132}Sn) on protons at low momentum transfer in inverse kinematics
- Investigation of inelastic scattering of nuclei in inverse kinematics in coincidence with gamma

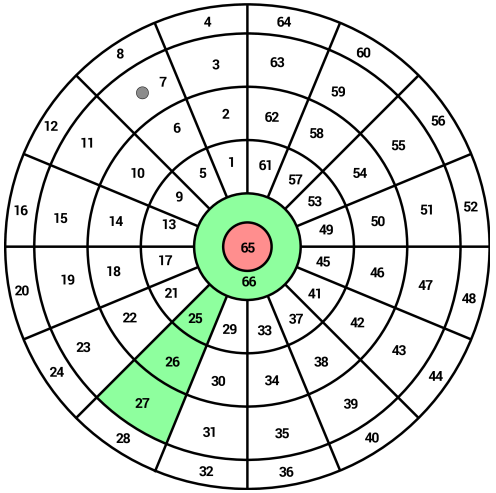
ACTAF @R³B

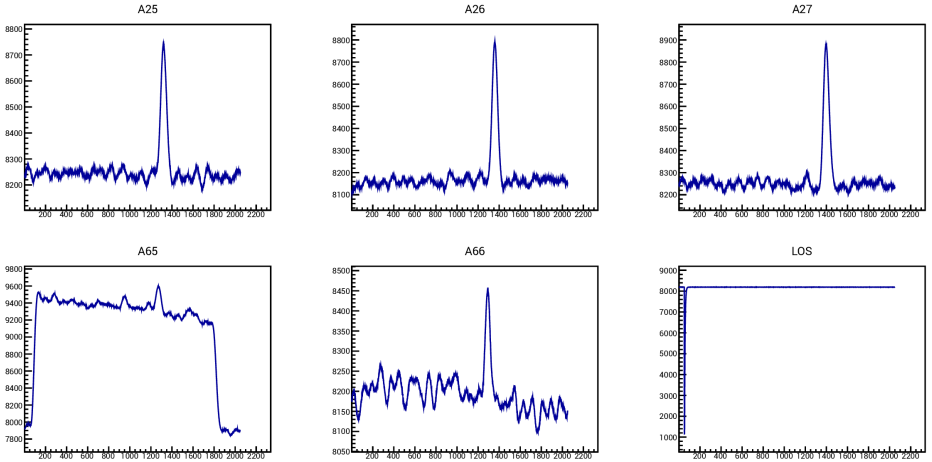
- Gas: H_2, D_2, ^3He, ^4He, CH_4, Ar
- Pressure: 0.5–20 bar
- Registration of all charged particles (p, d, t, ^3He, ^4He) in the active target with the energy of 0.5–50 MeV
- Energy resolution: 20–30 keV rms
- Efficiency of detection (T>0.5 MeV): ~100%
- Z_{vertex} resolution: ~0.5 mm rms
- Recoil angular resolution: ~0.5°
- Wall effects: less than 0.1%

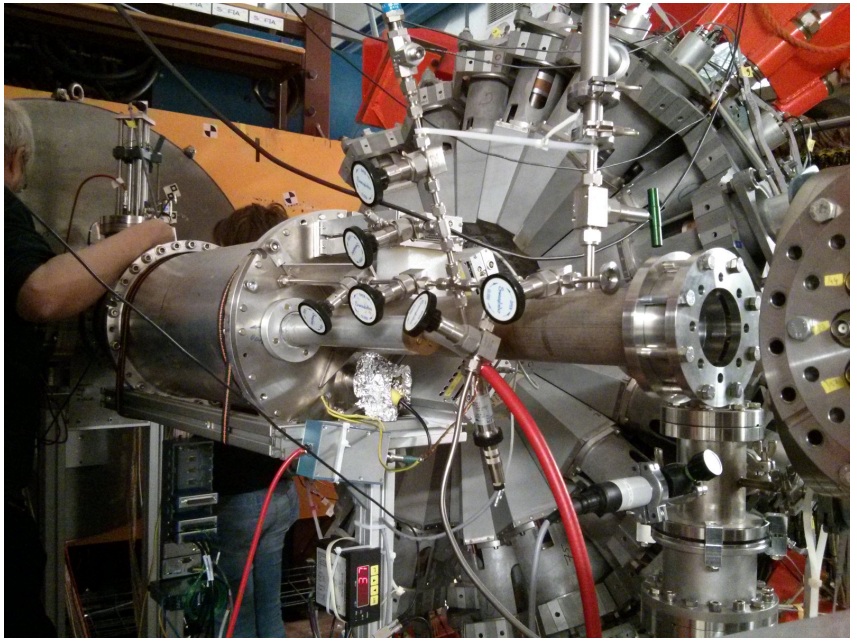
Prototype test @GSI

- ^{124}Xe, 600 MeV/u beam

Segmented anode

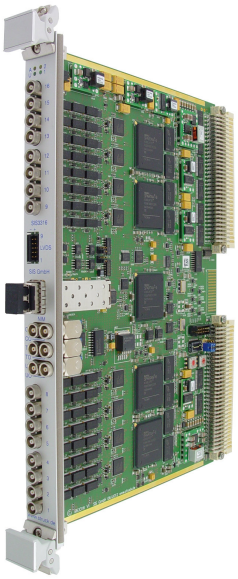






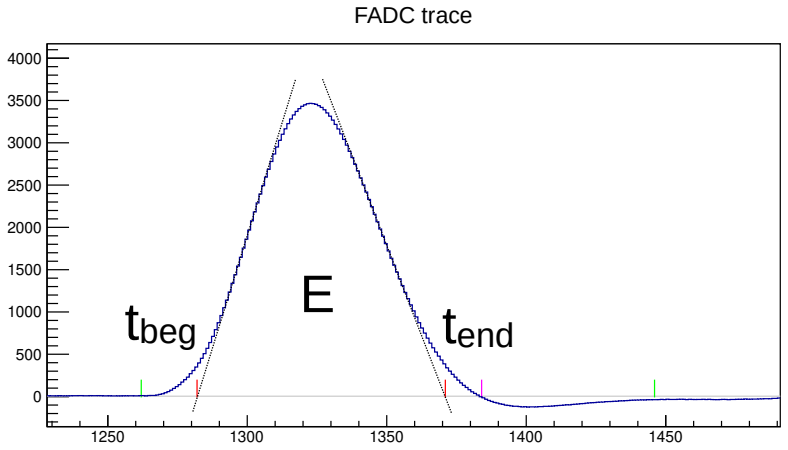
Can work with heavy beams!

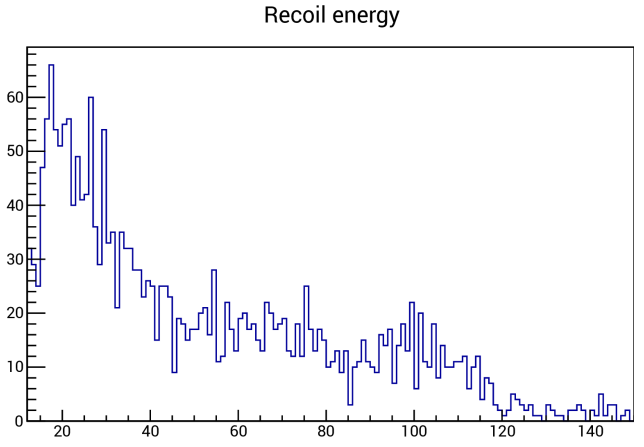
Data acquisition and analysis



SIS3316 VME digitizers (FADCs)

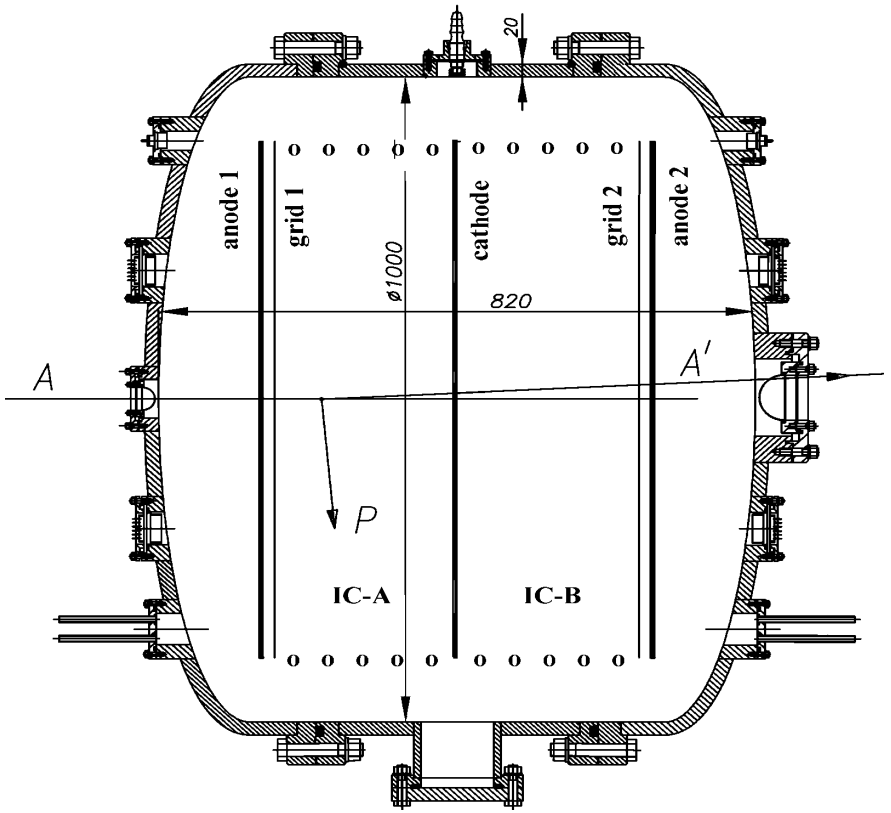
- 16 channels per module
- 25 MHz (40 ns bin), up to 250 MHz
- 14 bit, 5 V (2 V) range
- Int./ext. trigger
- MAW energy/threshold



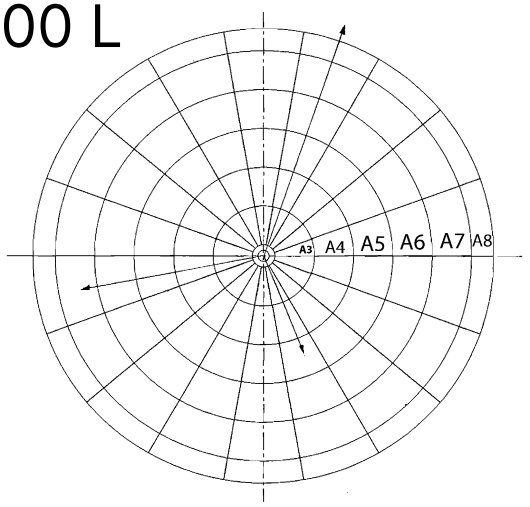


ACTAF1

ACTAF1: large chamber to be placed upstream of GLAD magnet

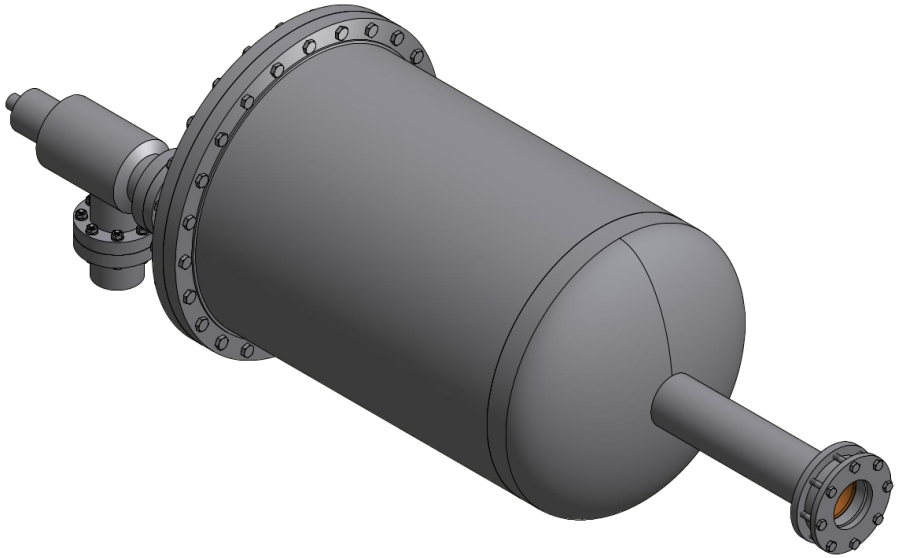


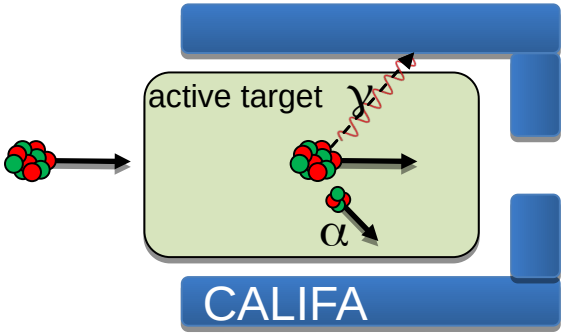
- Material: stainless steel
- Pressure: up to 20 bar
- Anode diameter: 800 mm
- Drift cells: 2×220 mm
- Beryllium windows
- HV: 80 kV
- Volume: ~600 L

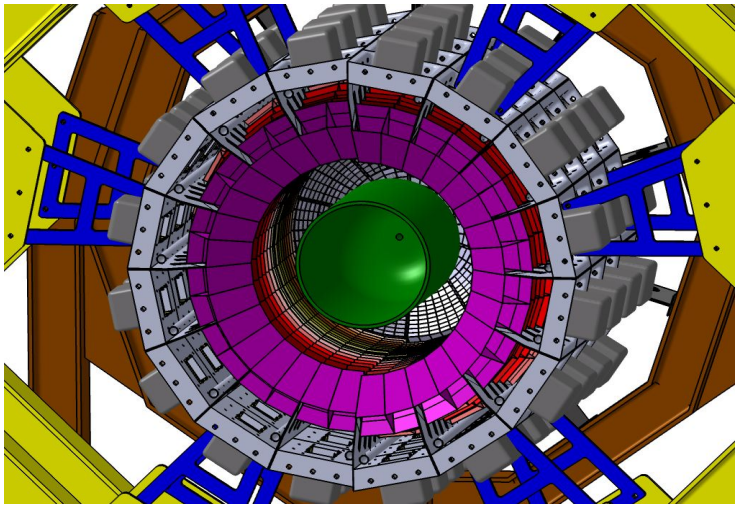


ACTAF2

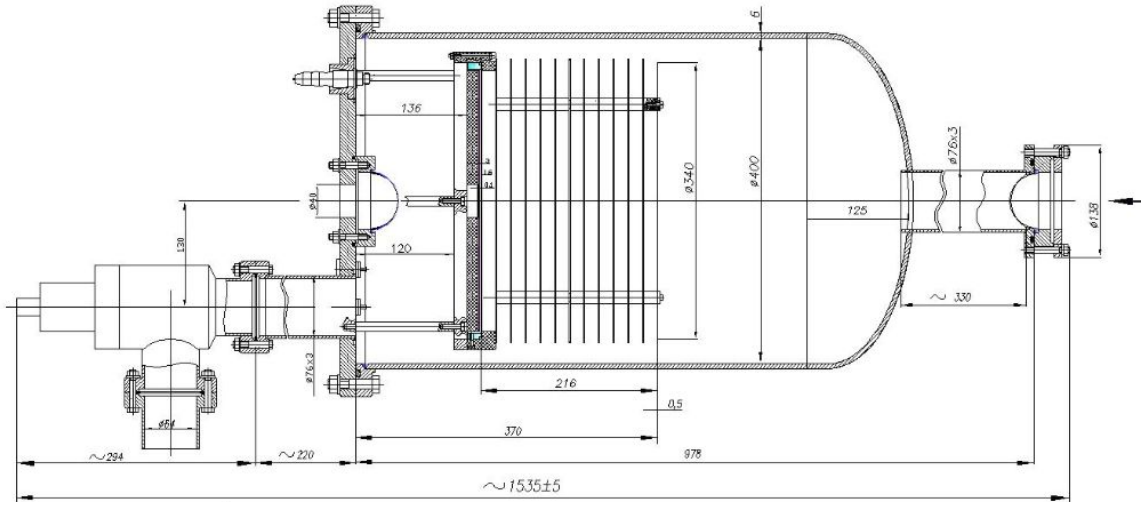
ACTAF2: small chamber to be located inside CALIFA gamma spectrometer



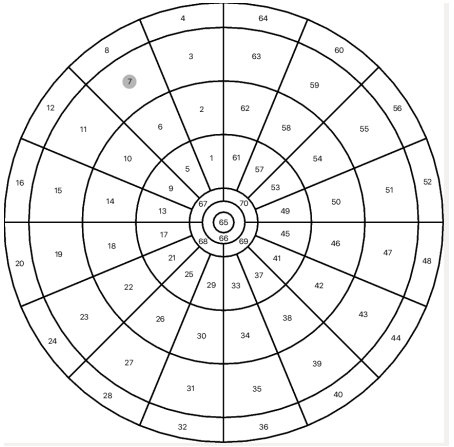




ACTAF2

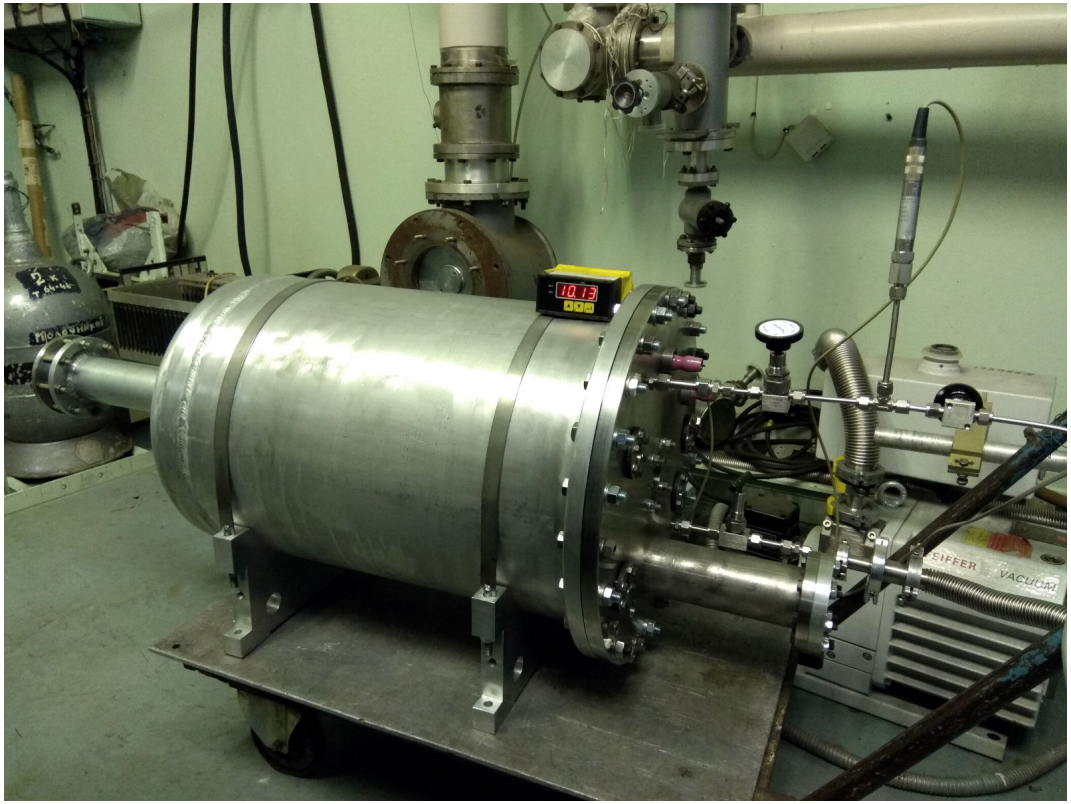


- Material: aluminum
- Pressure: up to 10 bar
- Anode diameter: 340 mm
- Drift cells: 1×216 mm
- Beryllium windows
- HV: 40 kV

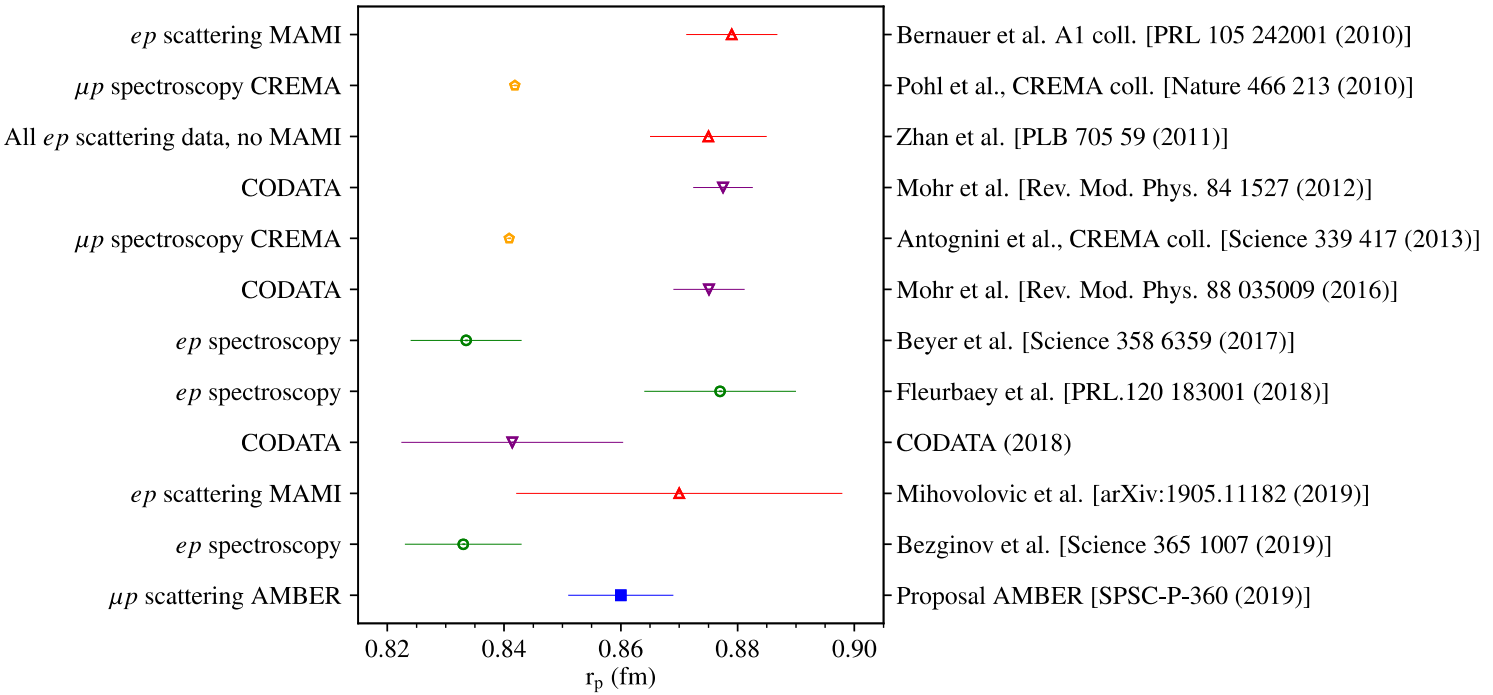


ACTAF2

- Pressure vessel produced and tested at PNPI
- Electronics is in production



Proton radius puzzle



High significance for nuclear & particle physics, including IKAR & ACTAF experiments

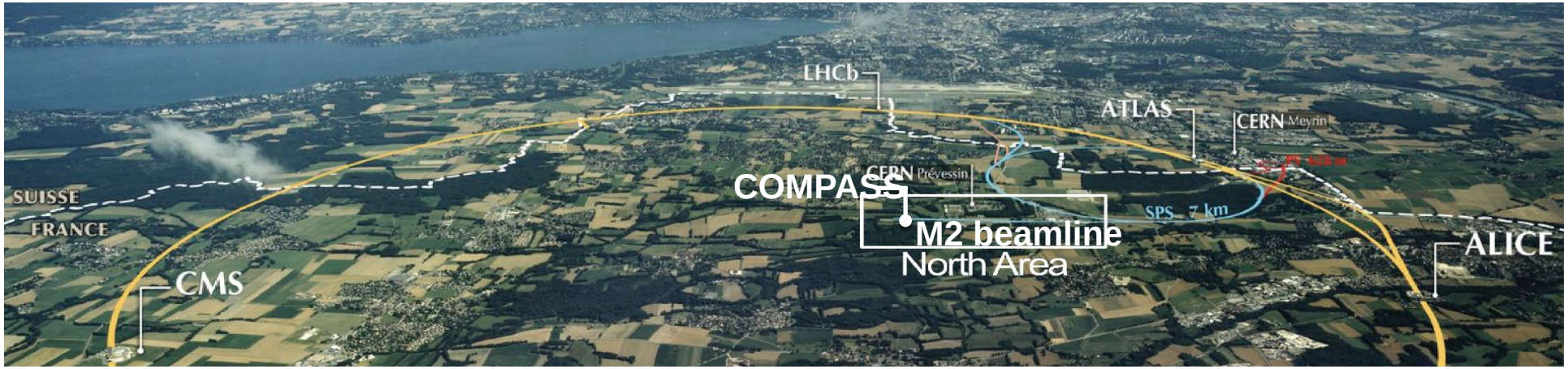
A. Vorobyev (PNPI) + A2 proposal: elastic ep scattering at MAMI

Followup proposal with COMPASS: elastic μp scattering at CERN

Proton charge radius @CERN

Unique M2 beamline at the CERN SPS provides a high-intensity muon beam up to 200 GeV/c with a flux up to 10^7 μ/s

Measurement can be performed at the site
of the current COMPASS experiment



Proton charge radius @CERN

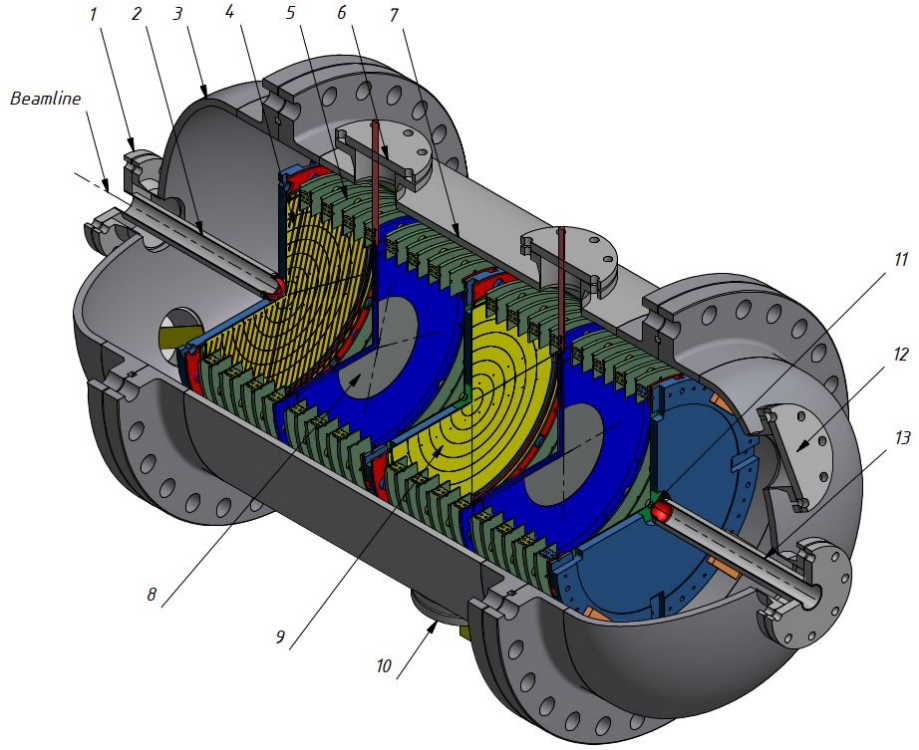
Elastic μp-scattering at Q^2 = 0.001–0.04 GeV^2/c^2

Highlights:

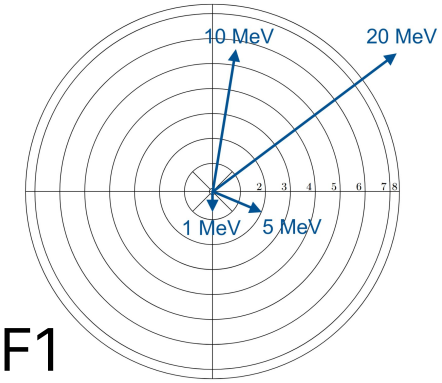
- Low momentum transfer
- High extracted proton radius precision: below 1%

- Beam: ~100 GeV, 2×10^6 μ/s
- Active target gas: H_2 @4 & 20 bar
- Recoil energy: 0.5–20 MeV
- Beam detectors: fibers (timing, trigger), silicons (projectile tracking)
- COMPASS spectrometer (muon momentum and background)
- Pilot run scheduled for 2021 with modified IKAR
- IKAR modifications suitable for experiments with heavy beams
- Main experiment scheduled for 2022

Active target for PRM



- Material: stainless steel
- Pressure: up to 20 bar
- Anode diameter: 600 mm
- Drift cells: 4×400 mm
- Beryllium windows
- HV: 100 kV



Design very similar to ACTAF1

- Vacuum parts, HV system, electronics and DAQ used for IKAR and prepared for ACTAF1/ACTAF2 can be an in-kind contribution (on a temporary basis) of GSI to the experiment
- After the run in 2022 - 2023 the setup (fully commissioned and tested) will be free for other experiments/applications

Summary

- Active target is a powerful tool for nuclear structure studies in both stable and exotic nuclei
- A series of experiments on light nuclei were performed at GSI with IKAR detector
- New active targets for R³B will allow measurement with the heavy beams, elastic and inelastic scattering
- High precision proton radius measurements at MAMI and CERN utilize similar techniques
- ACTAF program benefits from experience on new active target developments

Thank you!

Prototype test @CERN