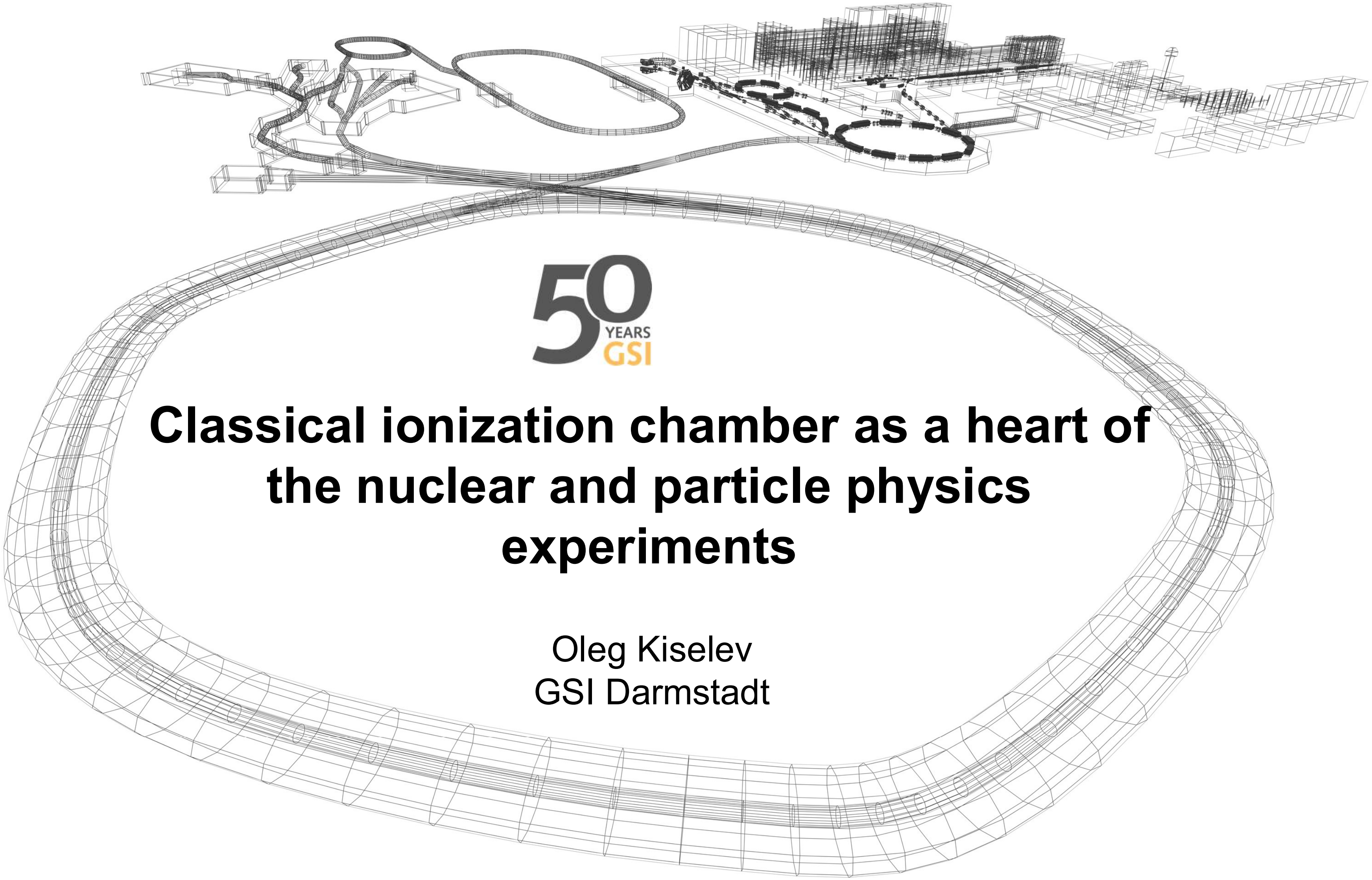
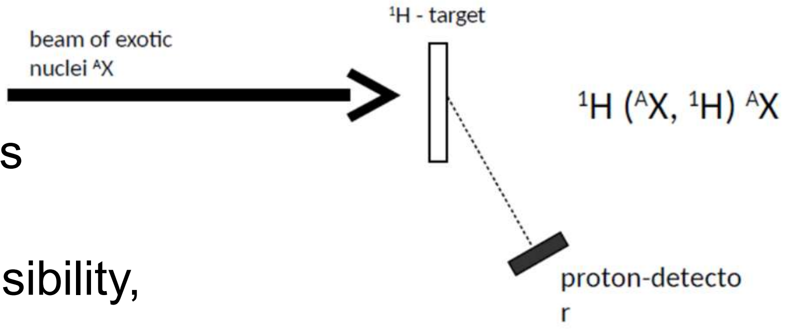


Classical ionization chamber as a heart of the nuclear and particle physics experiments

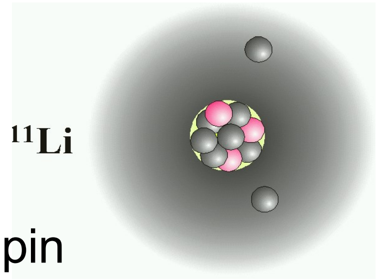
Oleg Kiselev
GSI Darmstadt

Possible reactions studies using active targets

- light ion induced direct reactions: (p,p), (p,p'), (d,p), ...
- to investigate exotic nuclei: inverse kinematics
- important information at low momentum transfer



- <u>of particular interest elastic scattering:</u>
- radial shape of nuclei: skin, halo structures
- special nuclei like: ^{56}Ni, ^{132}Sn
  parameters of the EOS : nuclear compressibility, symmetry energy

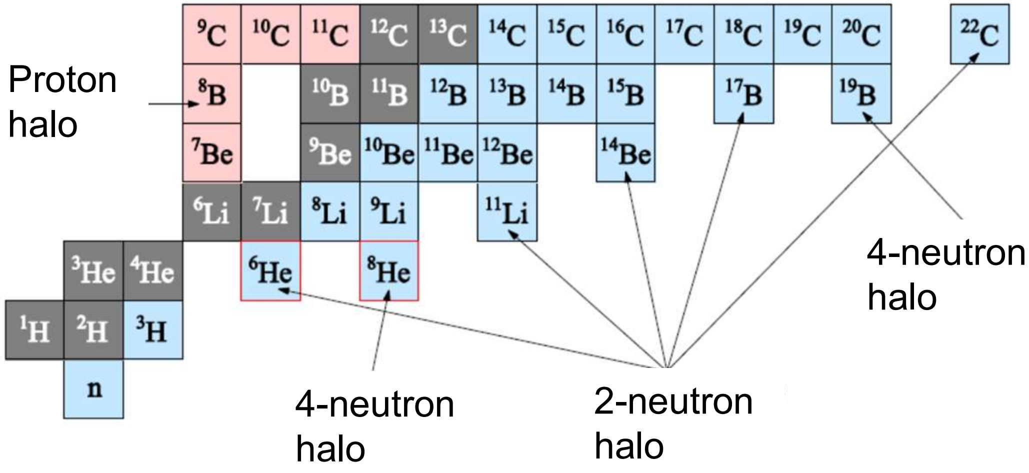


- inelastic reactions like (α, α' γ)
- He-filled target inside the γ-calorimeter

- charge-exchange reactions serve to study spin-isospin excitations. Isobar-analog states (IAS), Gamow-Teller (GT) or spin-dipole resonances, by means of (p,n), (^{3}He,t), or (d,^{2}He)

Proton elastic scattering

- The radial shape and size of nuclei is a basic nuclear property → of high interest for nuclear structure and astrophysics

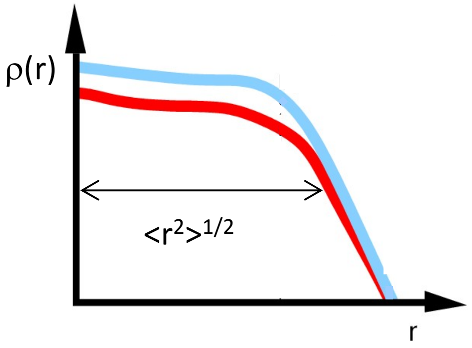


<u>observables:</u> nuclear charge distribution:

$\rho_{ch}(r)$, $\langle r_{ch}^2 \rangle^{1/2}$ via leptonic probes,

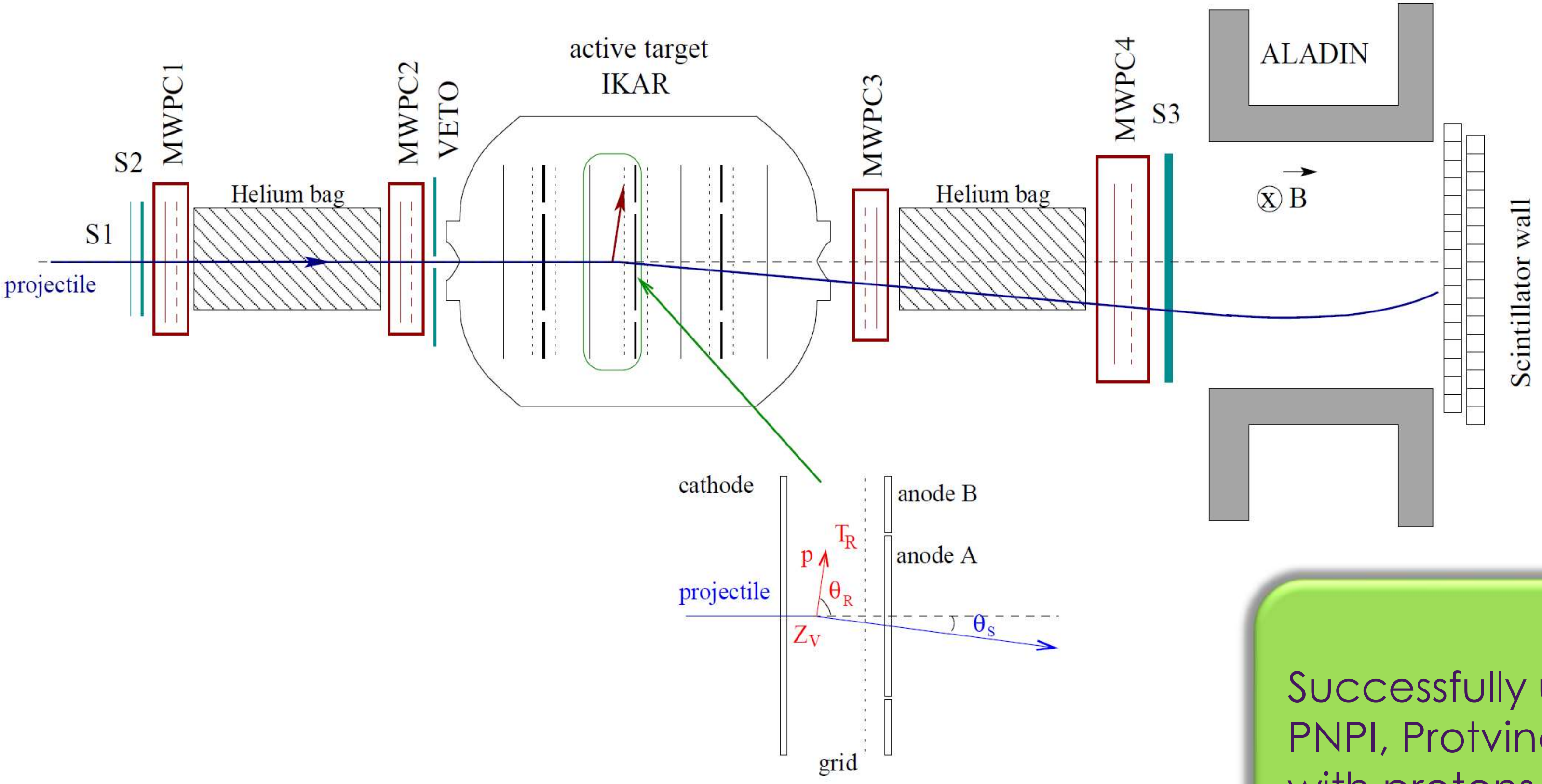
nuclear matter distribution:

$\rho_{m}(r)$, $\langle r_{m}^2 \rangle^{1/2}$ via hadronic probes



Stable and exotic nuclei

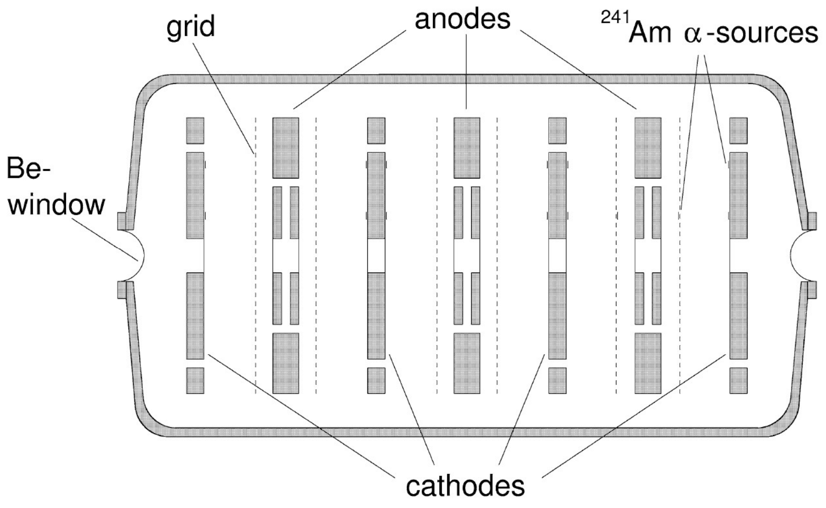
Setup with ionization chamber IKAR

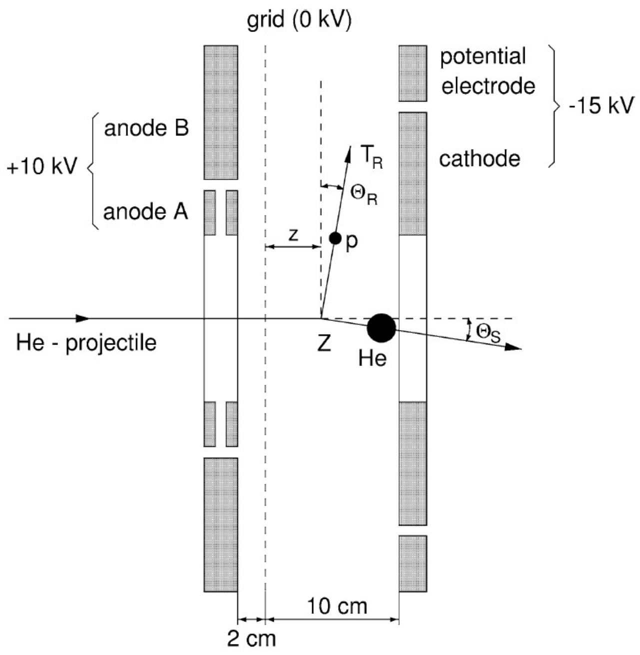


"Classical" ionization chamber, built at PNPI
Pressure up to 10 bar
Diameter of inner anodes – 20 cm, of outer – 40 cm
Normally filled with pure H_2 but D_2, He are also possible
6 independent detection modules in the same gas volume

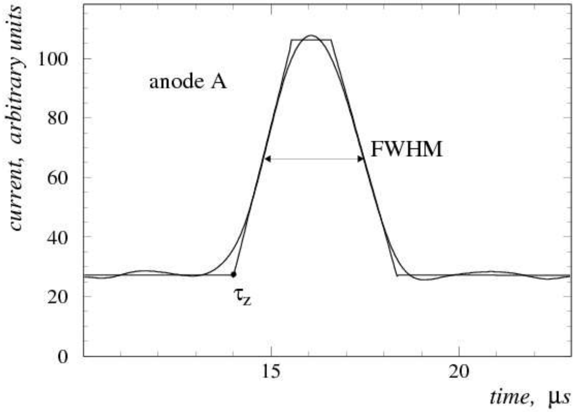
Successfully used at PNPI, Protvino, CERN with protons and at GSI with radioactive ions

Active target IKAR





- Electrodes out of Al, 140 µm
- Be windows, 0.5 mm
- Energy and time of drift measured by FADCs
- Energy resolution – 35-40 keV
- Energy threshold ~100 keV
- Dynamic range for protons – 5.2 MeV



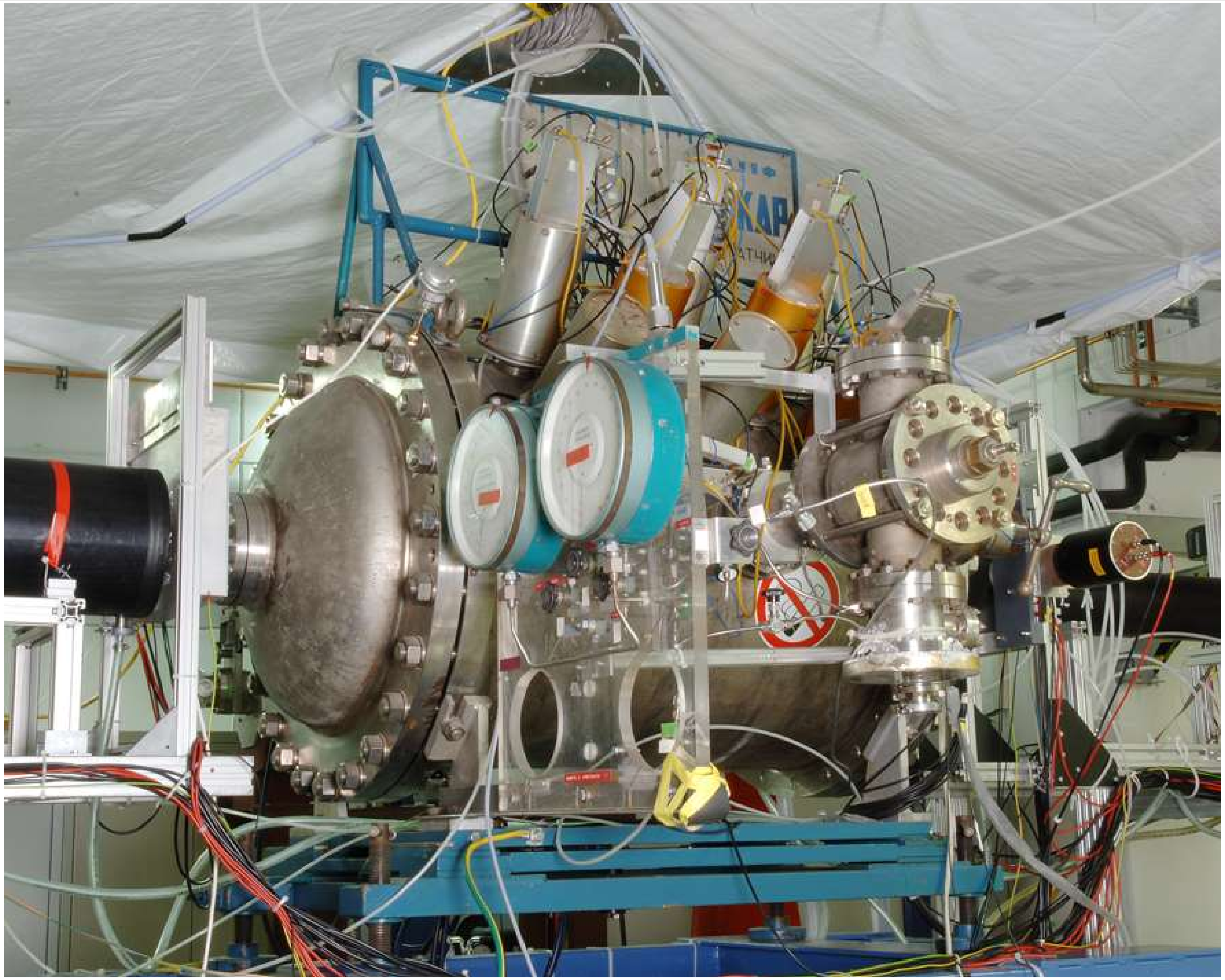
Pulse shape analysis

integral ⇒ recoil energy T_R

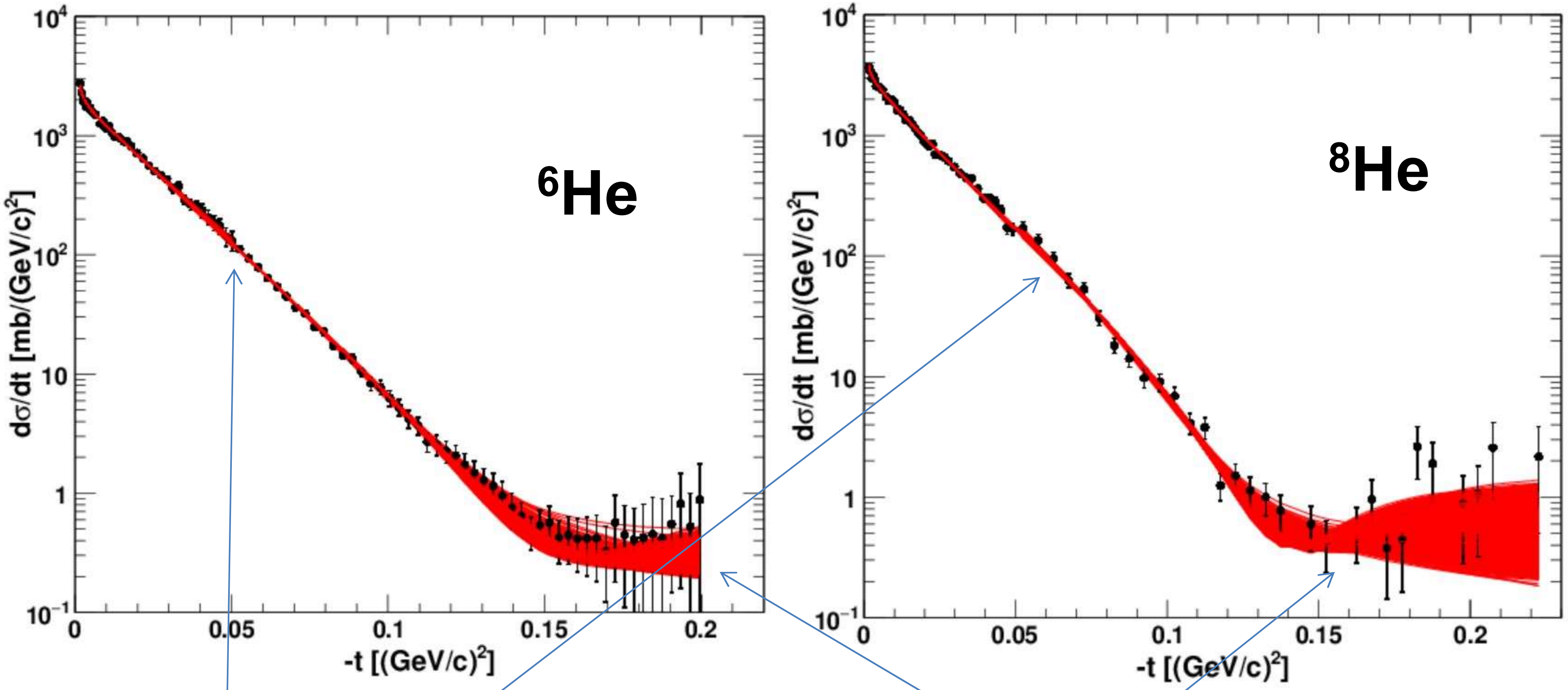
risetime ⇒ recoil angle θ_R ($\Delta\theta_{FWHM} \leq 0.6°$)

Start ⇒ vertex point Z_V ($\Delta z_{FWHM} \leq 110$ µm)

IKAR in Cave C



SOG fits of p^{6,8}He elastic scattering data

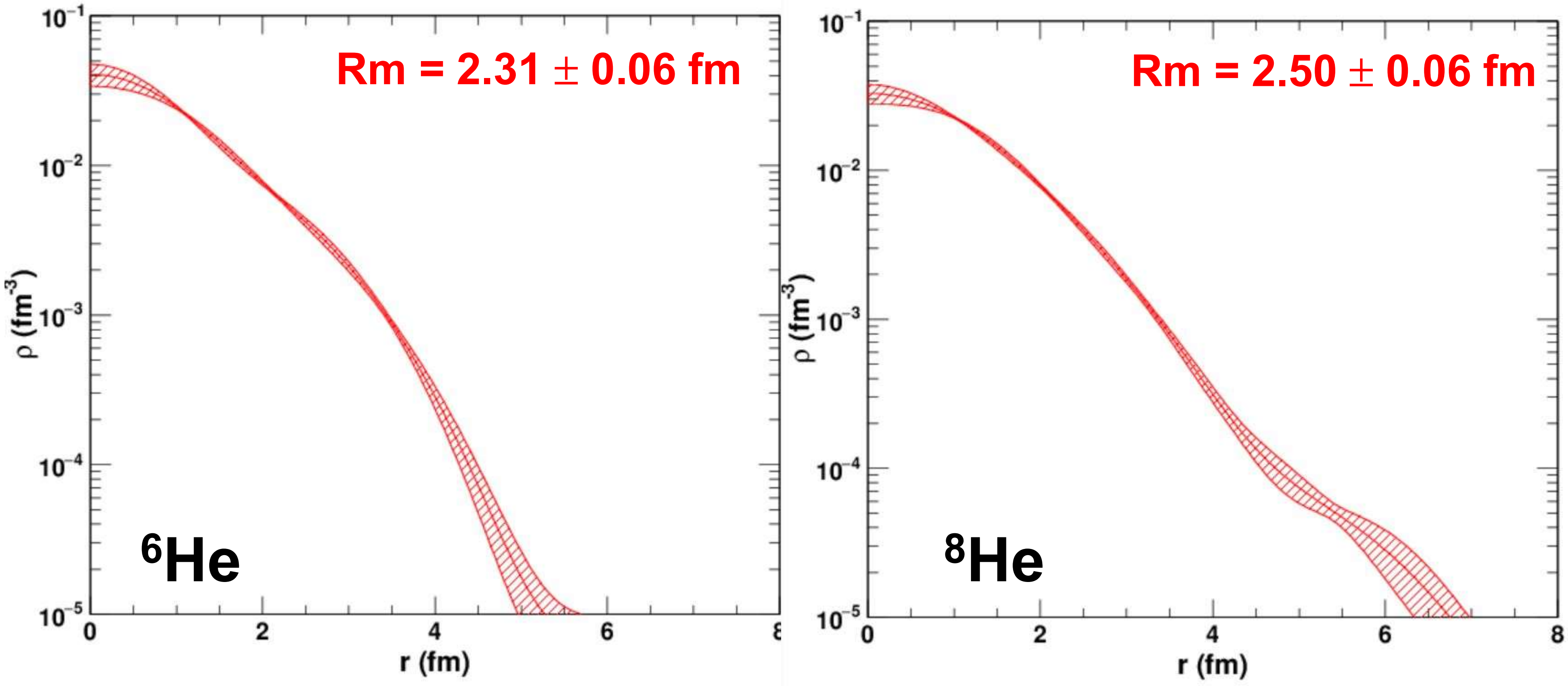


Measurement with the active target

Measurement with the H_2 target

X. Liu, to be published

SOG analysis - matter density distributions of ^{6}He and ^{8}He



2.44 ± 0.07 fm (^{6}He) and 2.50 ± 0.08 fm (^{8}He) from L. Chung et al., Phys. Rev. C 92, 034608 (2015). (full data set)
2.30 ± 0.07 fm (^{6}He) and 2.45 ± 0.07 fm (^{8}He) from G.D. Alkhazov et al., Phys. Rev. Lett. 78, 2313 (1997). (low-t data set)

SOG analysis provides similar Rm within errors

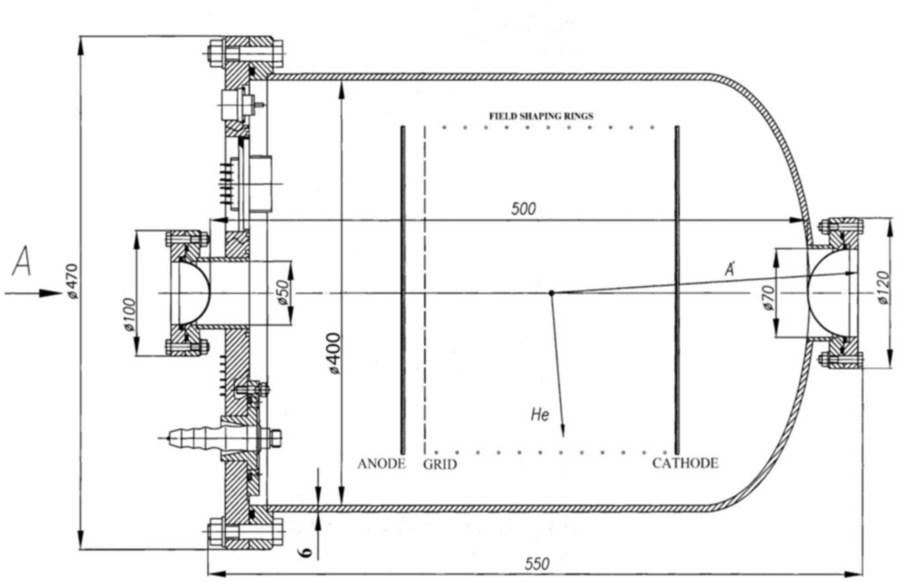
X. Liu, to be published

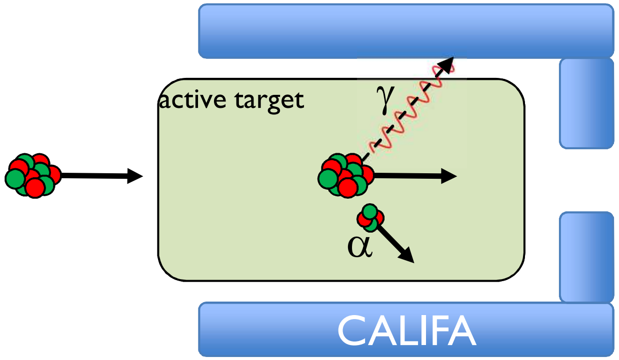
Light exotic isotopes measured with active target IKAR

Изотоп	R_m, fm	R_c, fm	R_h, fm
^{6}He	2.45 (10)	1.88 (12)	3.31 (28)
^{8}He	2.53 (8)	1.55 (15)	3.22 (14)
^{6}Li	2.44 (7)	2.08 (18)	3.04 (45)
^{8}Li	2.50 (6)	--	--
^{9}Li	2.44 (6)	--	--
^{11}Li	3.71 (20)	2.53 (3)	6.85 (58)
^{12}Be	2.71 (6)	2.36 (6)	4.00 (28)
^{14}Be	3.25 (11)	2.54 (11)	4.48 (19)
^{7}Be	2.41 (4)	1.88 (14)	2.94 (11)
^{8}B	2.58 (6)	2.24 (2)	4.24 (25)
^{15}C *)	2.59 (5)	2.41 (2)	4.36 (38)
^{16}C *)	2.72 (6)	2.39 (6)	4.45 (26)
^{17}C *)	2.66 (4)	2.55 (2)	3.99 (48)

Active chamber ACTAF2 inside R3B calorimeter CALIFA

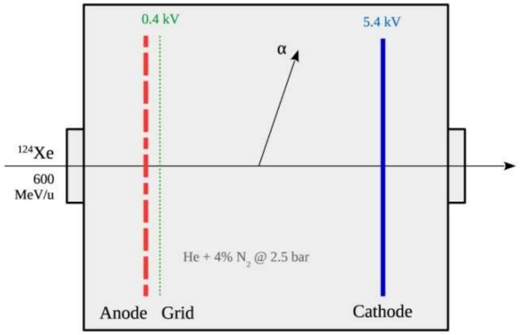
- Investigation of low-lying dipole strength in inelastic α scattering
- Experiments on stable nuclei show significant difference to (γ,γ')
- Extension to unstable nuclei in inverse kinematics
- He gas

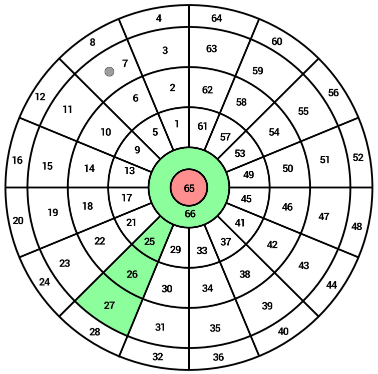


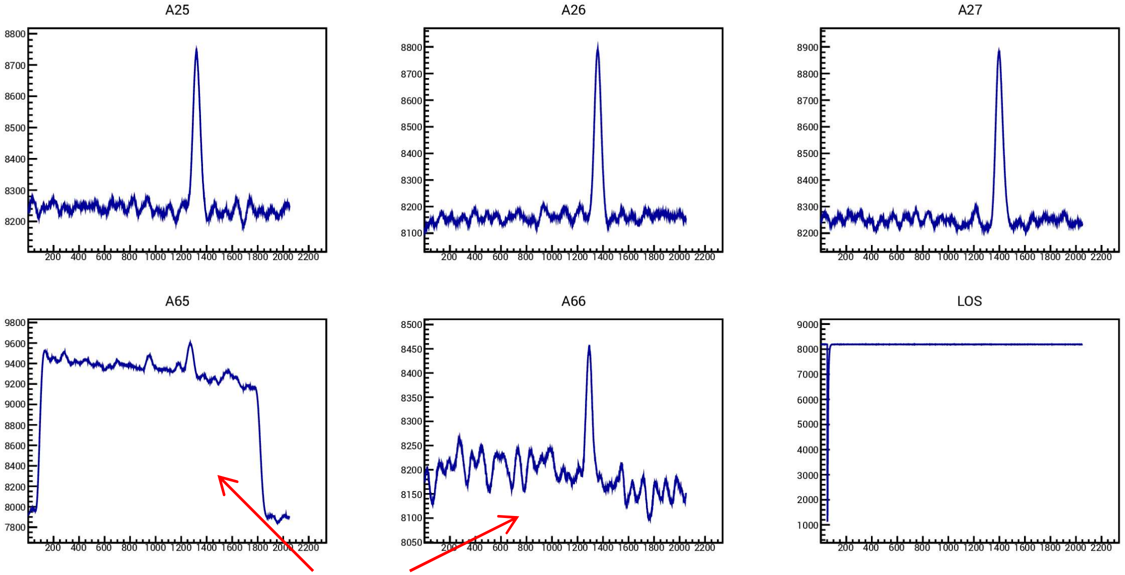


- Coincident determination of excitation and decay energy
- Allows selection of decay channel
- Clean separation of E1 excitation in $(\alpha,\alpha'\gamma)$ experiments

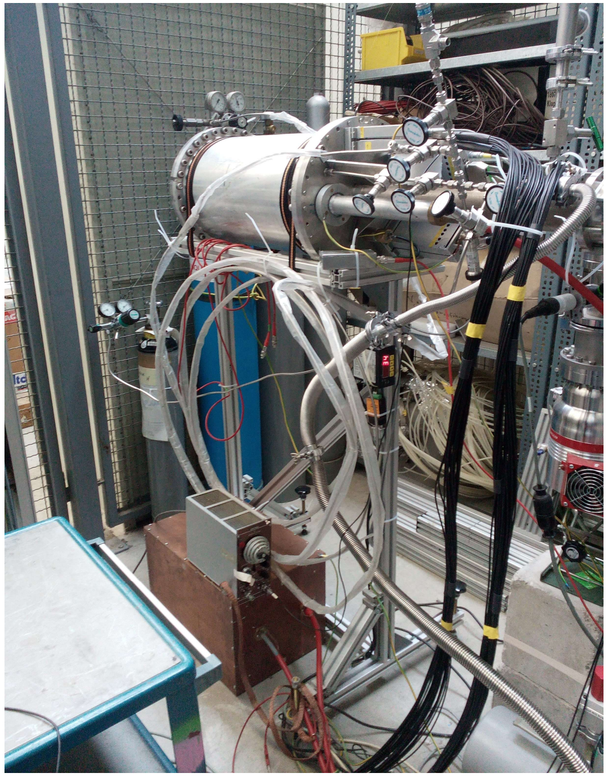
^{124}Xe(α,α') measurement with ACTAF2



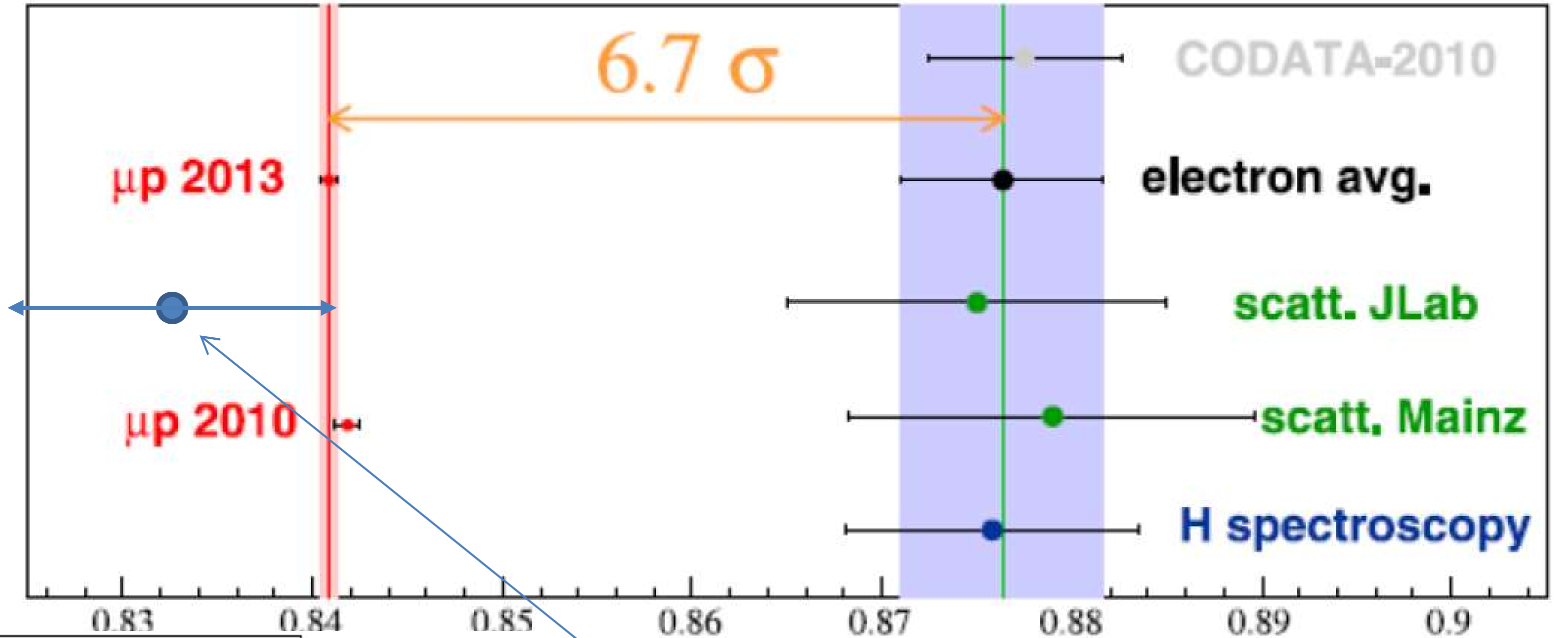




Beam electrodes



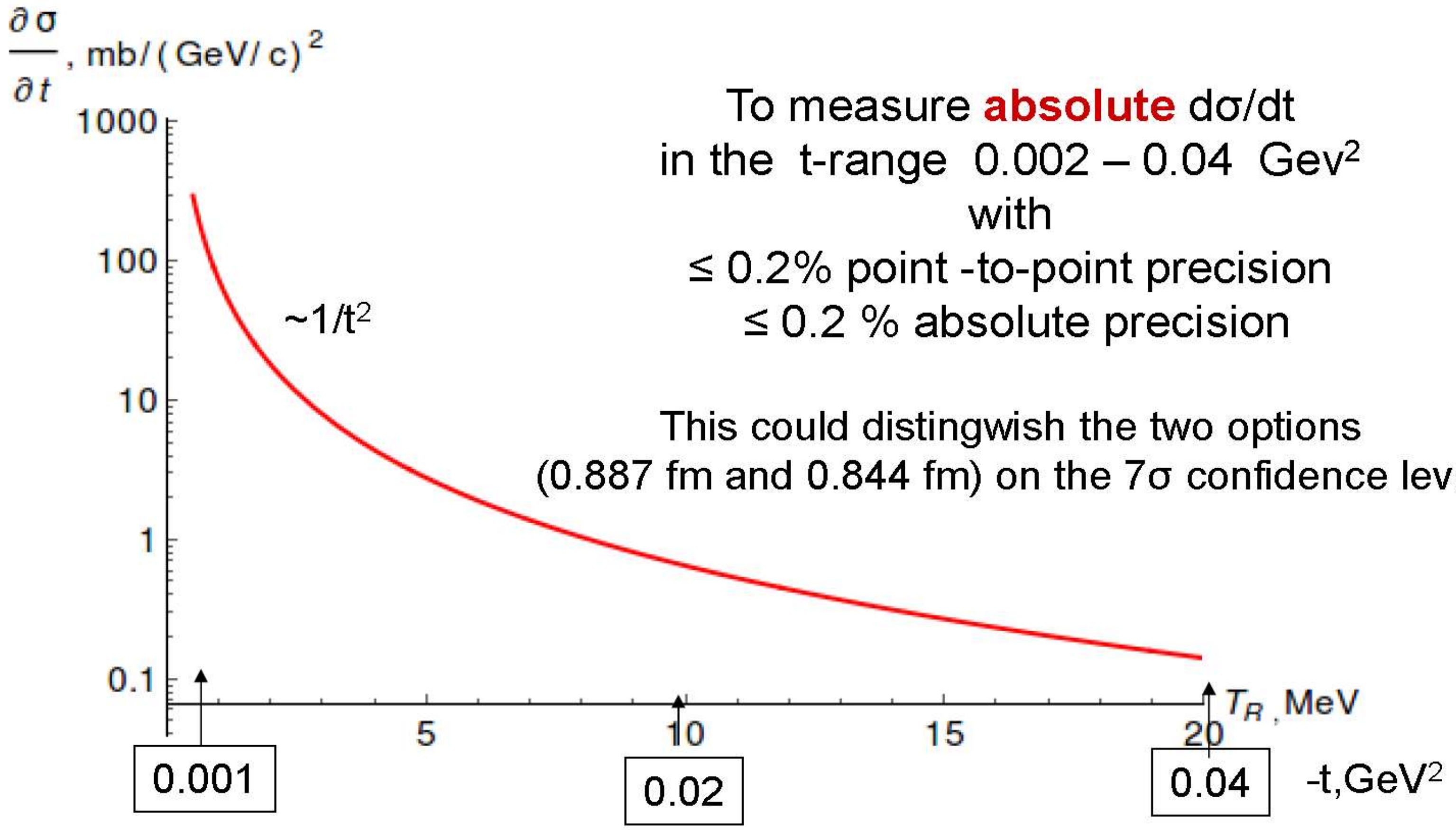
Proton charge radius
status 2016



Rp = 0.877 fm
or
Rp =0.841 fm
???

H spectroscopy (2S – 4P),
A. Beyer et al., Science 358 (2017)

Main goal of the experiment

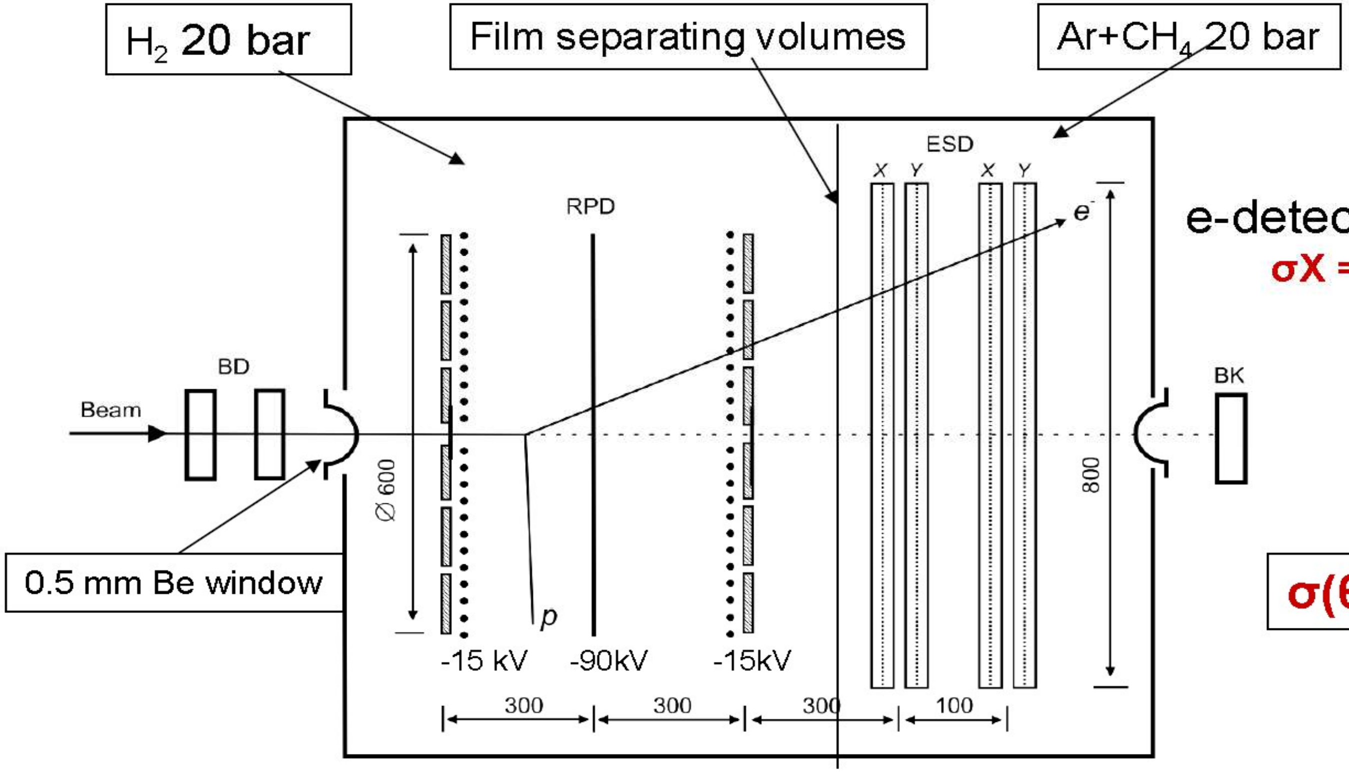


To measure **absolute** dσ/dt
in the t-range 0.002 – 0.04 Gev^2
with
≤ 0.2% point -to-point precision
≤ 0.2 % absolute precision

This could distingwish the two options
(0.887 fm and 0.844 fm) on the 7σ confidence level

$-t = 2MT_R$

Combined active target and electron tracker



e-detection coordinates

$\sigma X = \sigma Y = 30\mu m$

$\boxed{\sigma(\theta_S) \leq 5 \cdot 10^{-4}}$

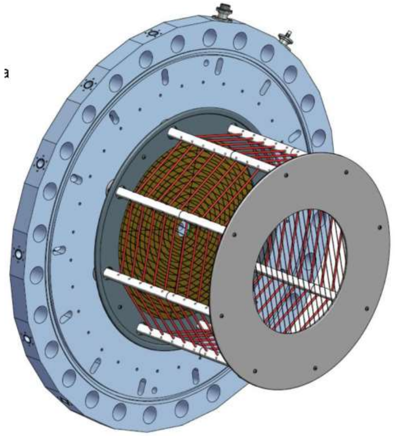
Scattering point coordinates

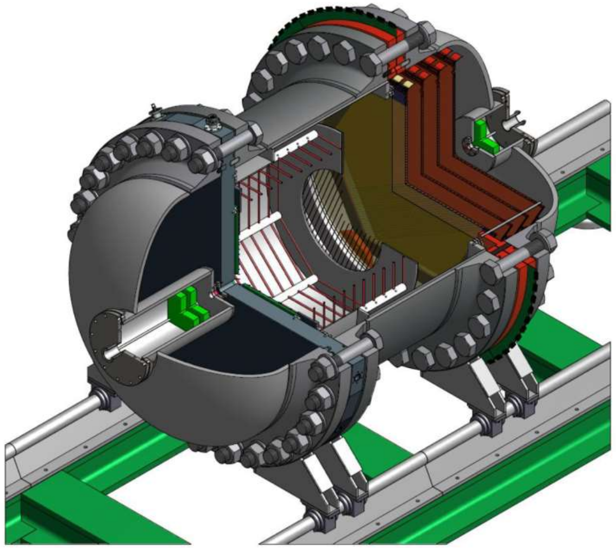
$\sigma X = \sigma Y = 30\mu m$ (determined by beam telescope)
$\sigma Z = 150\ \mu m$ (determined by TPC)

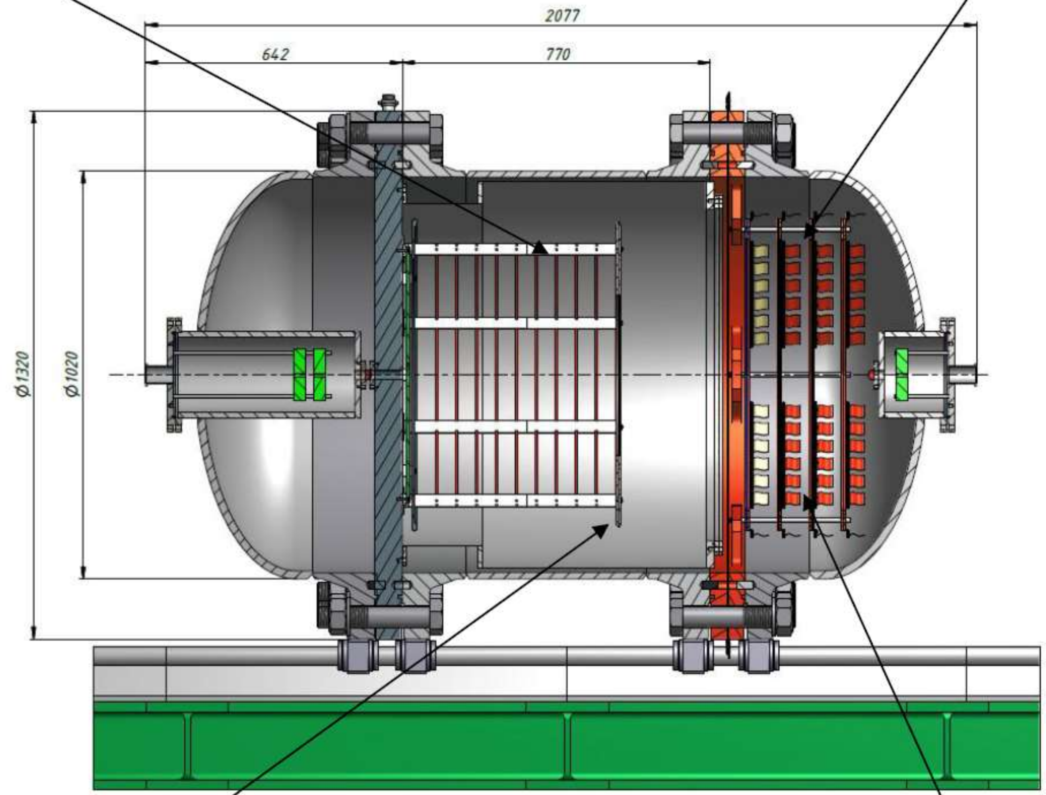
Detector design

H_2 @ 20 bar
Purity 10^{-8}

Ar + CH_4 @ 20 bar



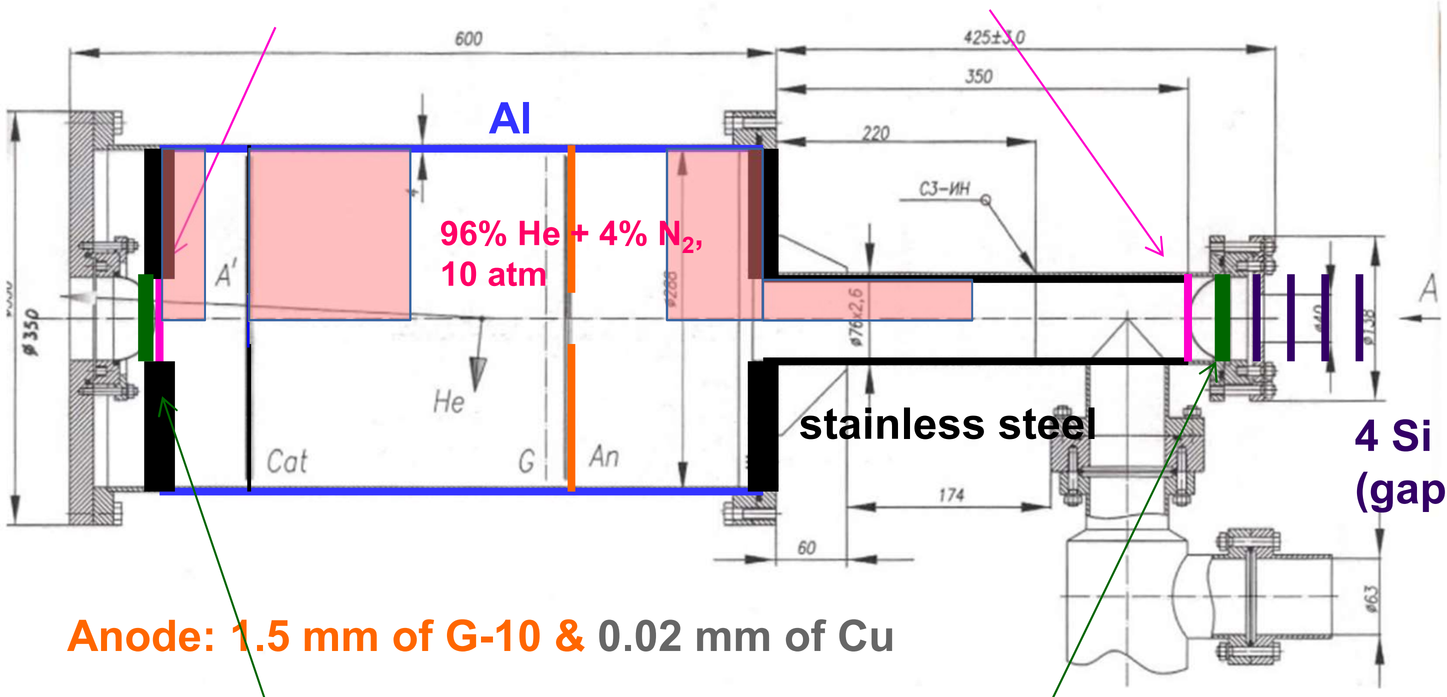




100 кV

10 kV

R3B ACTAF2 prototype – beam test at MAMI



Be windows of 0.5 mm thickness

Al

96% He + 4% N_2,
10 atm

T(e) = 720 MeV

stainless steel

4 Si Detectors 0.05 mm
(gaps of 50 mm)

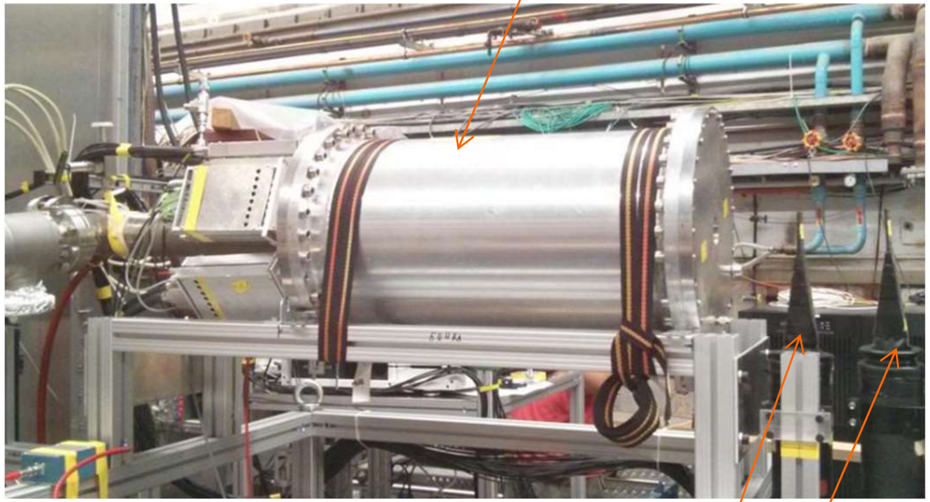
Anode: 1.5 mm of G-10 & 0.02 mm of Cu

Cathode: 1 mm of steel & 0.02 mm of Al

z

Scintillators (C_9H_{10}), 2 mm

Experimental conditions at MAMI

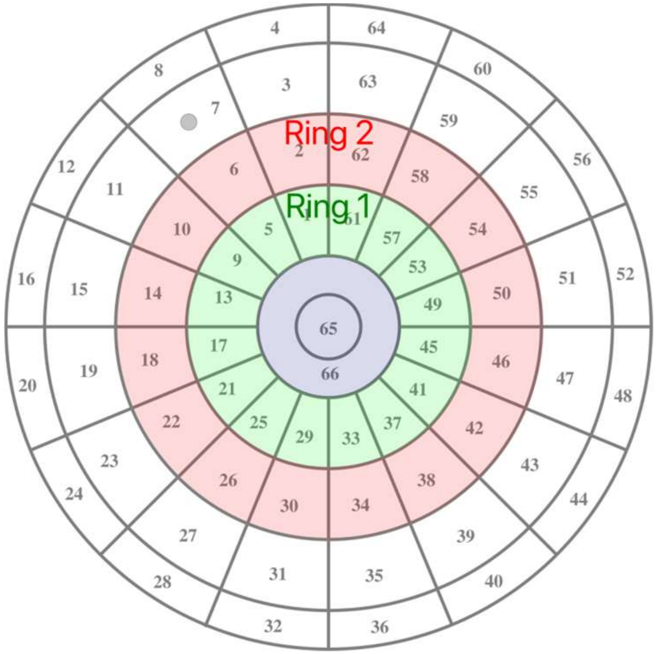


ACTAF2 prototype

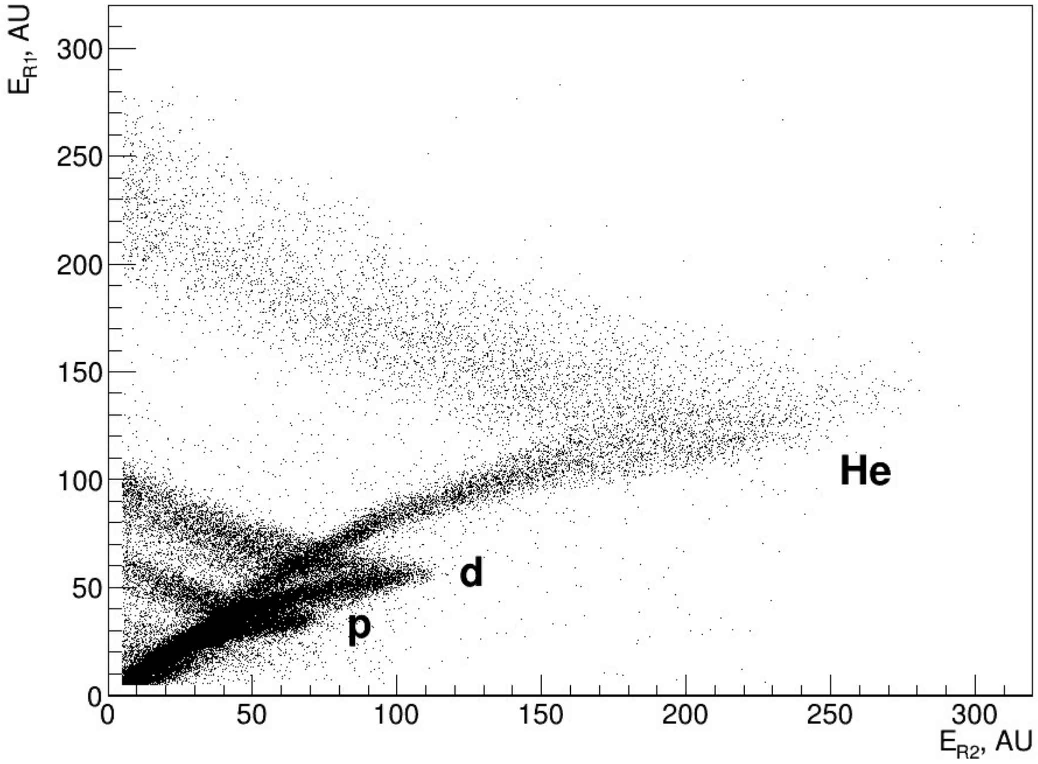
Scintillation counters

	Test run	Main experiment
Gas	**$He+4\%N_2$**	**clean H_2**
Pressure	**10/5 bar**	**20/4 bar**
Intensity	**1.6×10^6**	**2×10^6**

E-p scattering, energy correlations



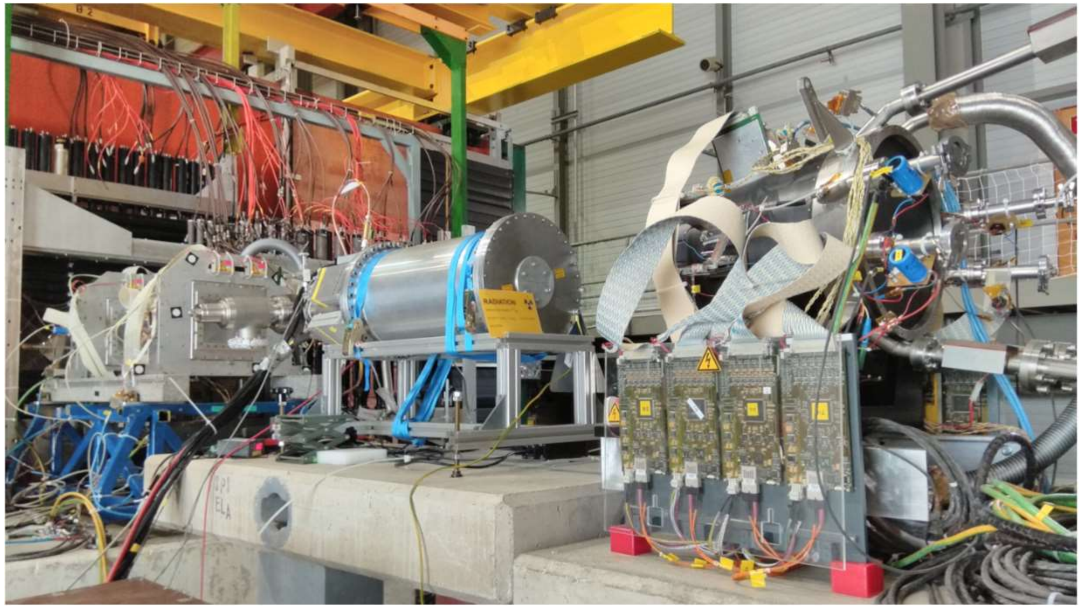
Energies on anode rings 1 and 2

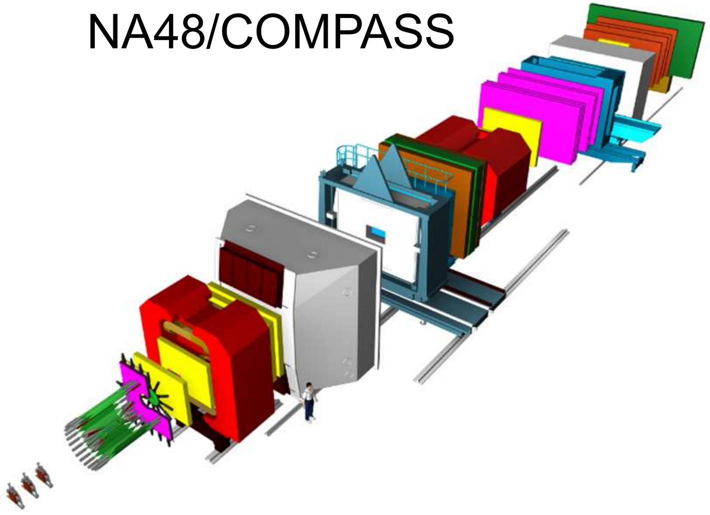


1 AU = 22 keV

Energies correspond to those calculated by SRIM

Proton radius measurement via μ-p scattering





NA48/COMPASS

Test run May 2018

Si microstrip detectors for tracking

Rate – up to 2 MHz

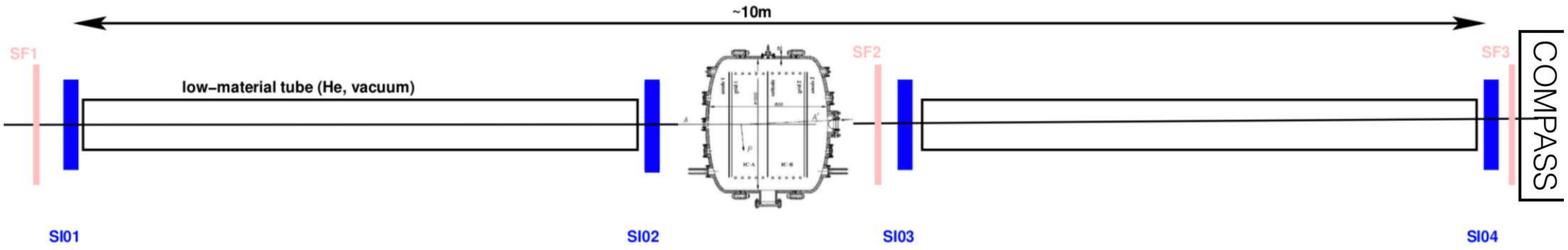
E_μ = 190 GeV

Wide beam (RMS ≈ 20 cm)

Duty cycle: ~20% (spill — 5 c)

Smaller (as for electron) QCD radiative corrections

Main experiment at CERN

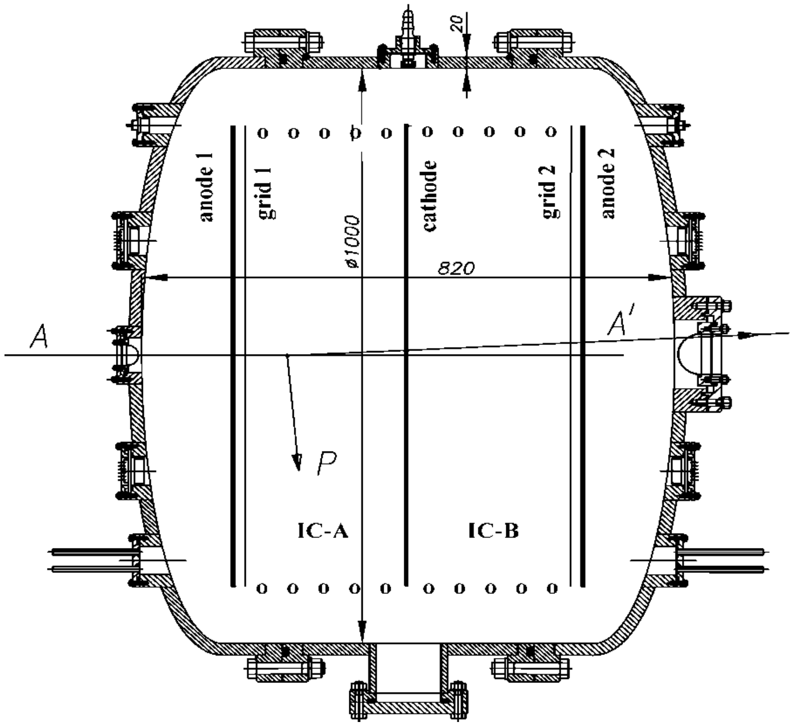


- Beam size: $\sigma \approx 8$ mm
- Energy: 100 GeV
- Scattering angles (μ) 0.3–2 mrad ($Q^2 = 0.001–0.04$ GeV^2/c^2)
- Base: 5 м — scattering 1.5 – 10 mm
- Si detectors $\Delta x < 10$ μm ($\Delta\theta < 2$ μrad at 5 m)

- New fast electronics fro the Si detectors
- Scattering trigger («kink trigger» — SciFi detector)

- **New active target: diameter — 800 мм, 20 bar H_2**
- Beam intensity: $2 \cdot 10^6$ μ/s — 1 year running time (2022 г.)

Large ionisation chamber



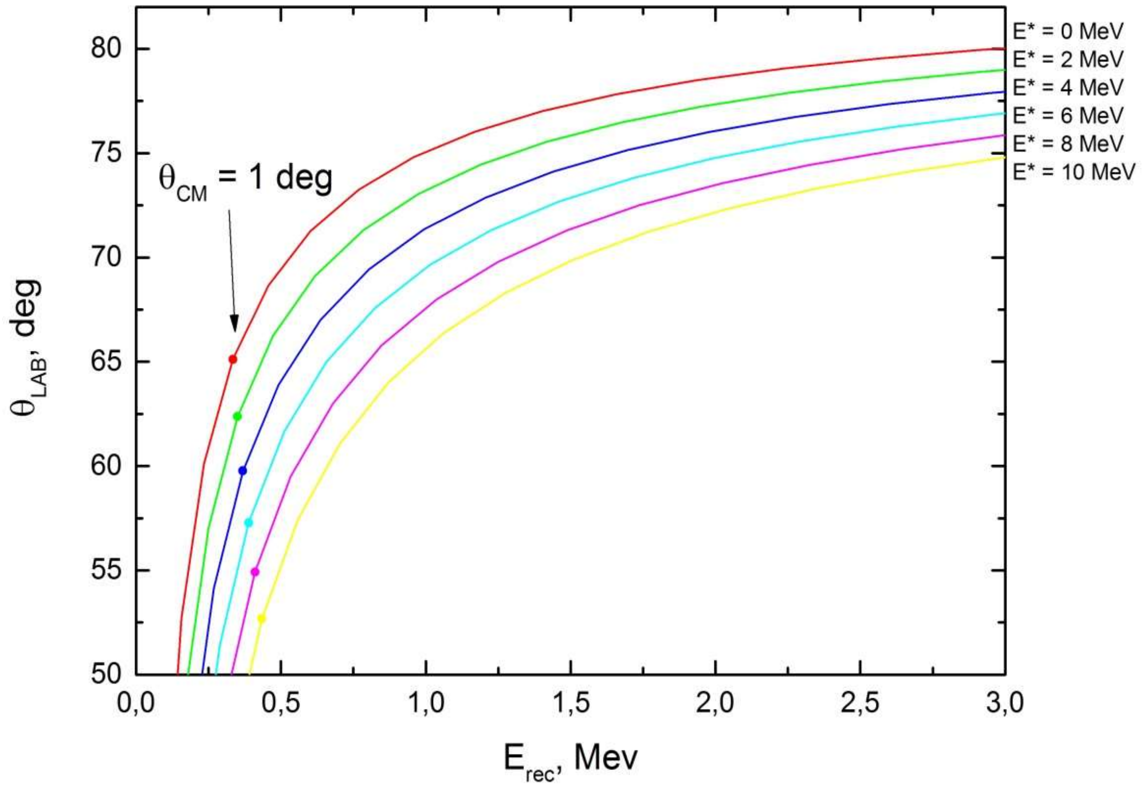
- ➢ 820 mm long
- ➢ Inner diameter 1000 mm
- ➢ Total volume 600 liters
- ➢ Weight is 2000 kg
- ➢ Internal surfaces electrically polished
- ➢ Gas pressure up to 20 bar, tested up to 25 bar
- ➢ Spherical Be windows for the beam
- ➢ HV up to 80 kV

- Proton-ion elastic scattering
- μ-p elastic scattering for proton radius measurement
- Charge-exchange reactions

Charge-exchange reactions

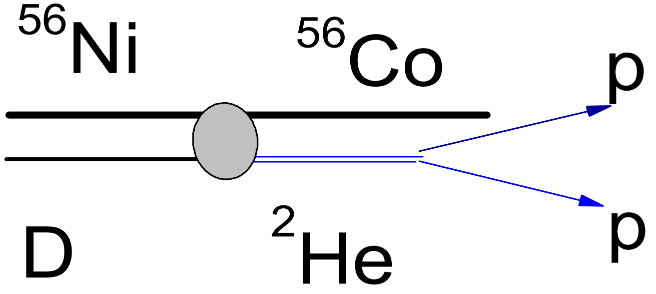
- Reactions like (^{3}He,t) or (d,^{2}He) at 200-400 MeV/u
- Isovector spin-flip part of the nucleon-nucleon interaction is strongest at these energies
- Gamow-Teller transition study (nucleosynthesis in non-massive stars), spin-isospin transitions (nuclear processes in a supernova), Isobaric Analogue Resonance States (IAS) for stuning of single particle properties of neutron-rich nuclei.
- Triggering on the residual beam-like nuclei in forward direction
- Identification of the residuals using magnetic analysis
- Substantial background suppression (of competing reaction channels) can be achieved

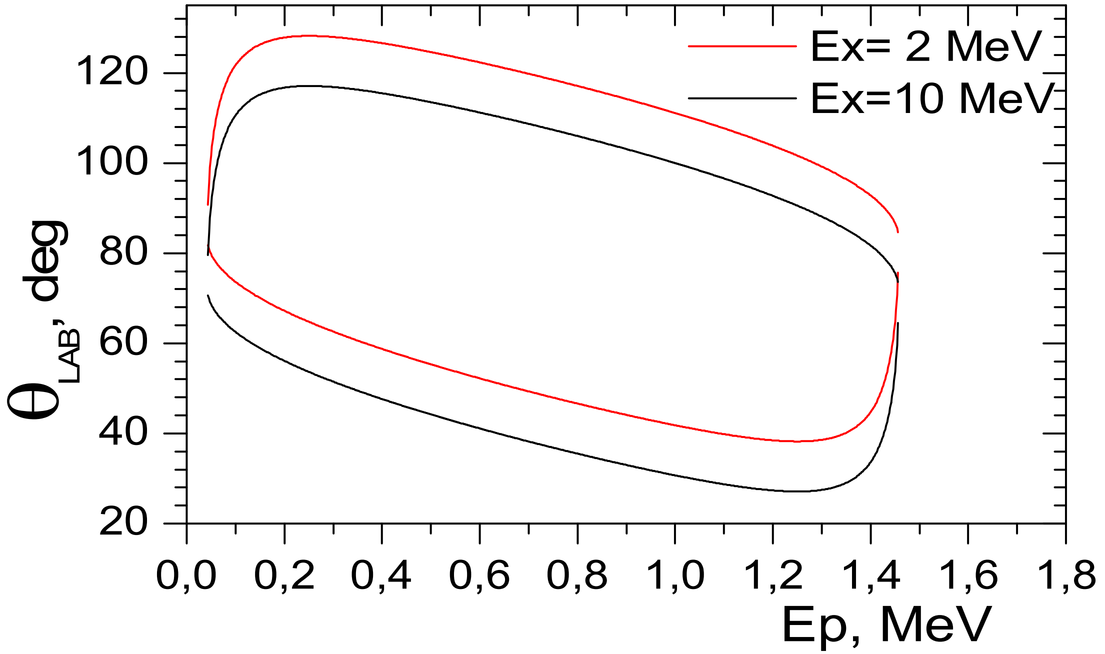
^{56}Ni(^{3}He,t) @ 300 MeV/u



- Very low recoil energy
- Noise and energy threshold need to be extremely low
- 3He - regeneration

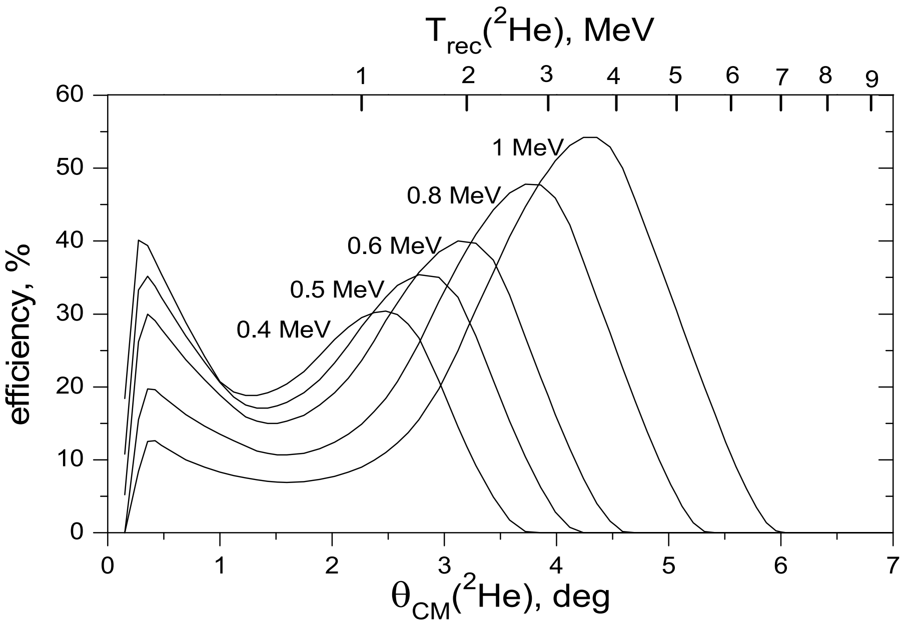
D,2p reaction





- ^{56}Ni (d, 2p)^{56}Co - excitation of GT states
- Formation of ^{2}He in a virtual state, followed by the decay to two protons
- Setup needs to be able detecting two protons – (relative) high segmentation
- D – needs to be recovered

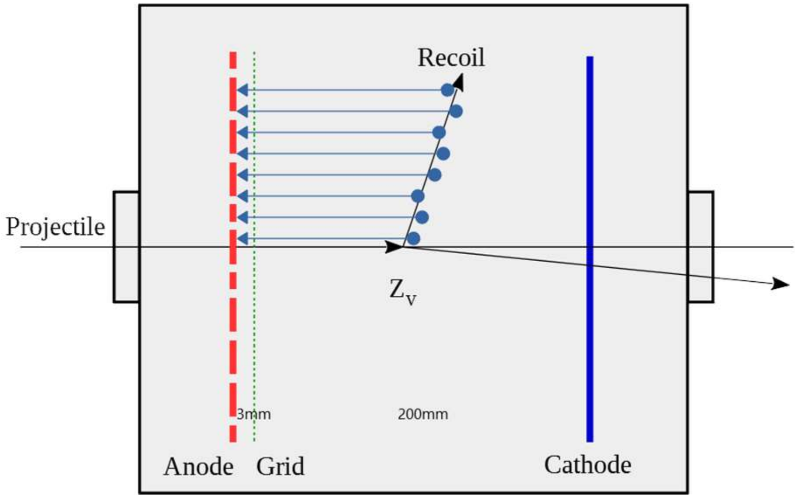
Efficiency, count rate in case of charge-exchange reactions

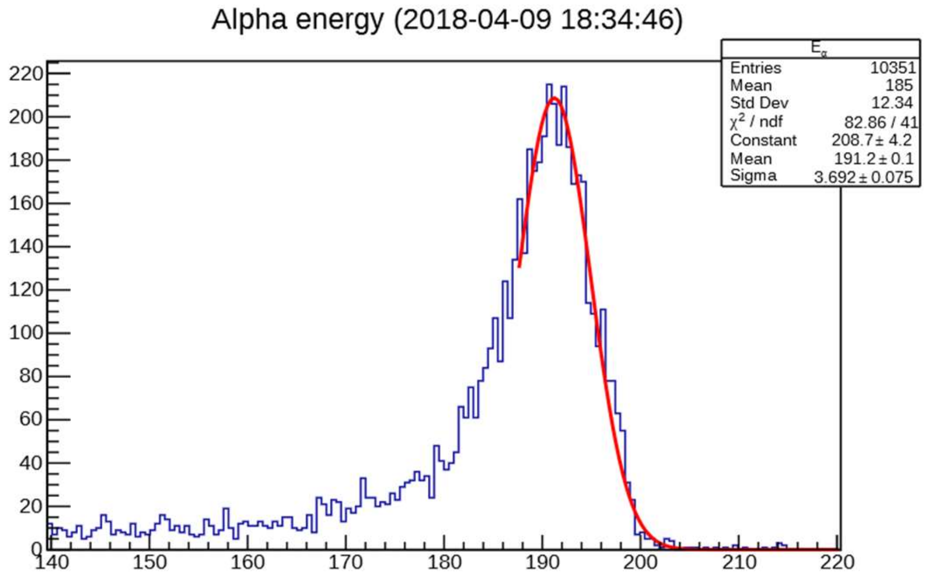


$^{56}Ni(d, ^2He)^{56}Co$ @ 300 MeV/u

- Detection efficiency for the two protons vs the kinetic energy of the ^2He
- Protons selected within θ_{LAB}> 45 deg
- Thresholds for the proton detection indicated above the corresponding curves
- Drop of the efficiency at higher energies is due to the size of the active target
- Rate at 10^{-5} ions/s – few hundreds in the GT peak per day
- Nevertheless, in case of short-lived nuclei the use of an active target for such kind of measurements has practically no alternative

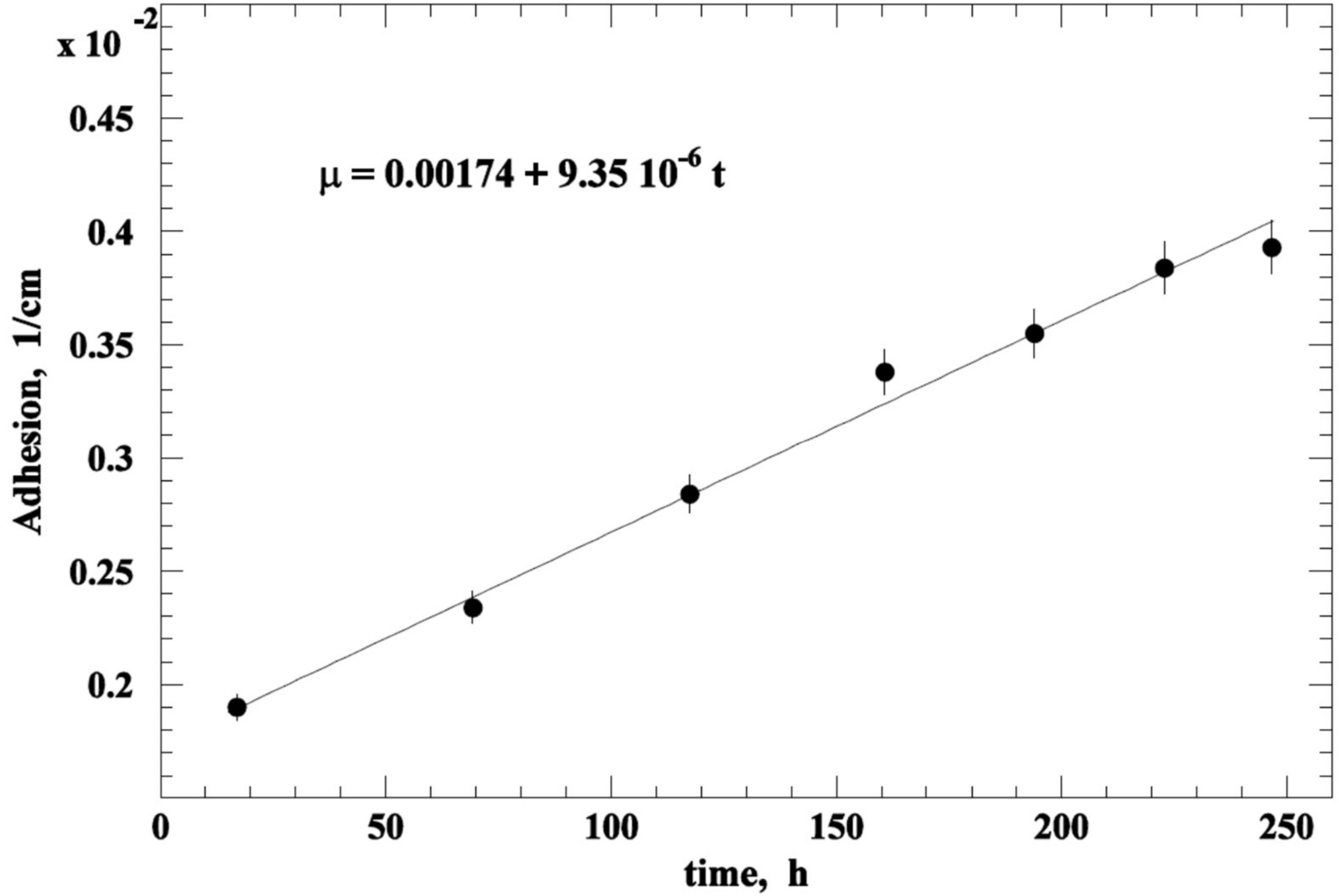
Gas quality check during each experiment





- α-spectrum measured several times per day
- Shift of the maximum ~1%/day (~1 ppm O_2)
- Refilling – once per week

Attachment in H_2 gas



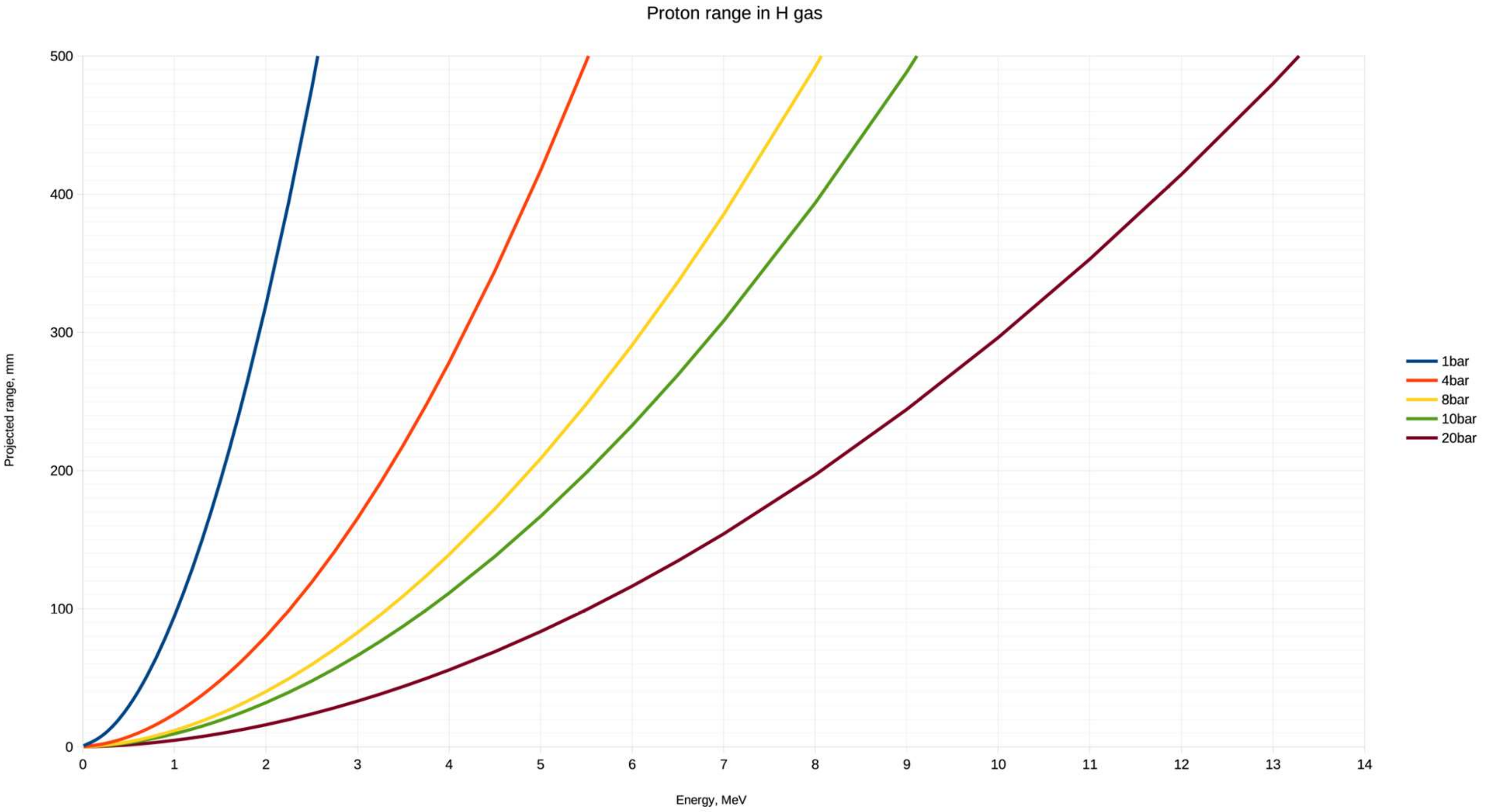
- Measured with IKAR chamber
- No gas purification or circulation

Gas system un procedures

- Combined high-vacuum/gas-supply systems
- UHV-grade stainless steel construction
- Dielectrics (PCBs, holdings) made of ceramic
- Except of two large Viton O-rings, all other sealings are metallic
- Oil-free forevacuum pumps, high quality turbopumps
- Full-metallic VAT valves with 70-100 mm apertures
- The whole system is bakable up to 130°
- Before each run the pressure vessel is pumped out while being baked to 120–130°
- Heating/cleaning procedure made until vacuum 10^{-7} mbar or better is reached

Summary

- Application of ionization chamber (without gas amplification) as an active target for the elastic proton scattering at the intermediate energies is very powerful method to study the nuclear matter distribution of stable and exotic nuclei
- Many light exotic nuclei like ^{6,8}He, ^{11}Li, ^{8}B, ^{12,14}Be, ^{15,16,17}C and very many stable nuclei (from p to Pb) are measured
- New active targets will allow measurement with the heavy beams like ^{132}Sn, elastic, inelastic scattering and charge-exchange reactions
- Similar techniques can be used for e-p and μ-p experiments aiming the measurement of the proton radius with high precision
- Outgassing and attachment kept very low using UHV-rated materials and technics
- Using gases like 3He or D is planned but requires modifications of the gas system


Proton range in H gas
Projected range, mm
500
400
300
200
100
0
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
Energy, MeV
1bar
4bar
8bar
10bar
20bar