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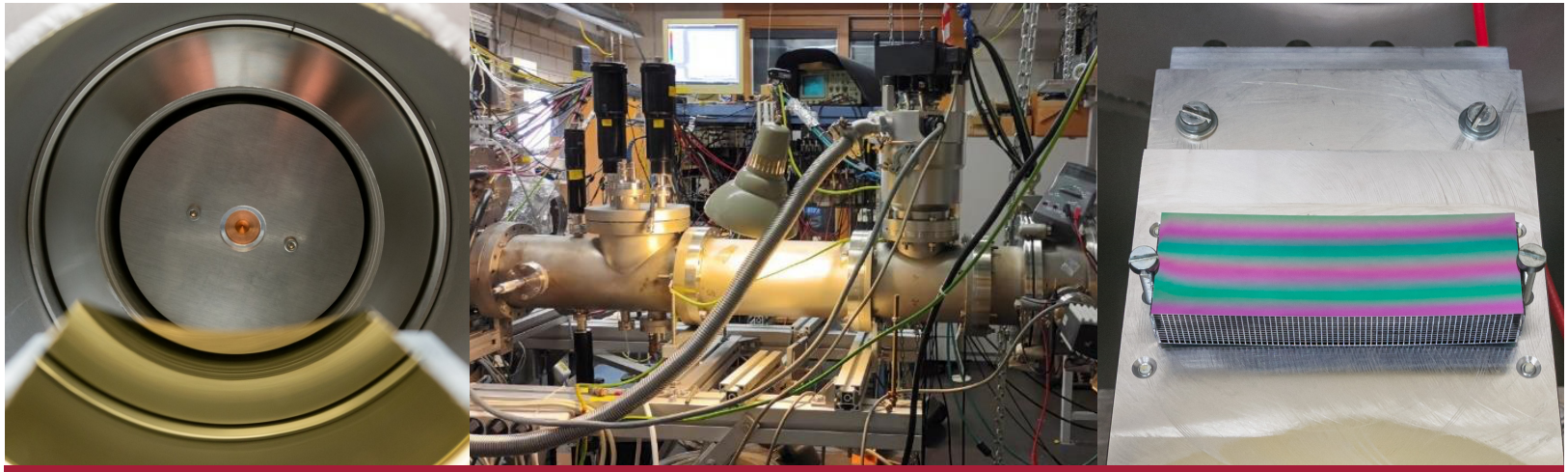


Soft Proton Scattering on X-ray Mirrors

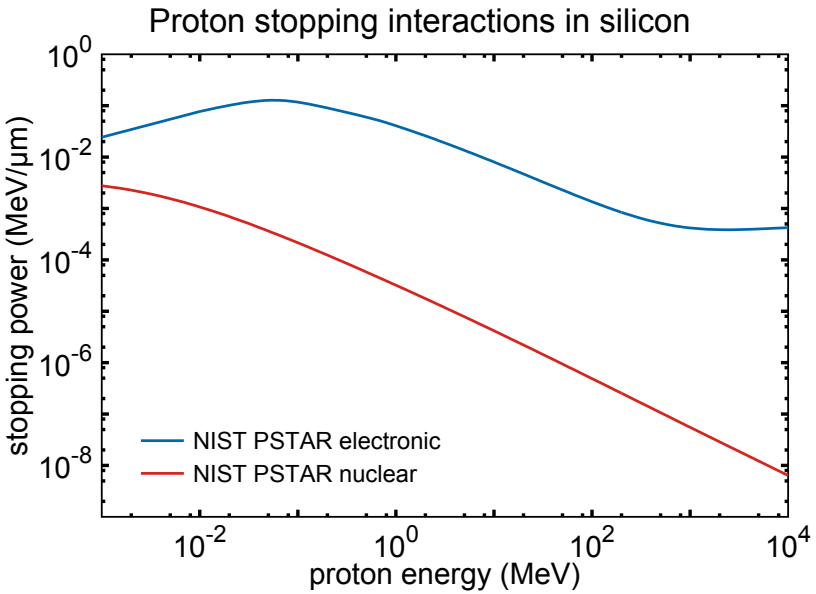
A first look at results from our recent measurements

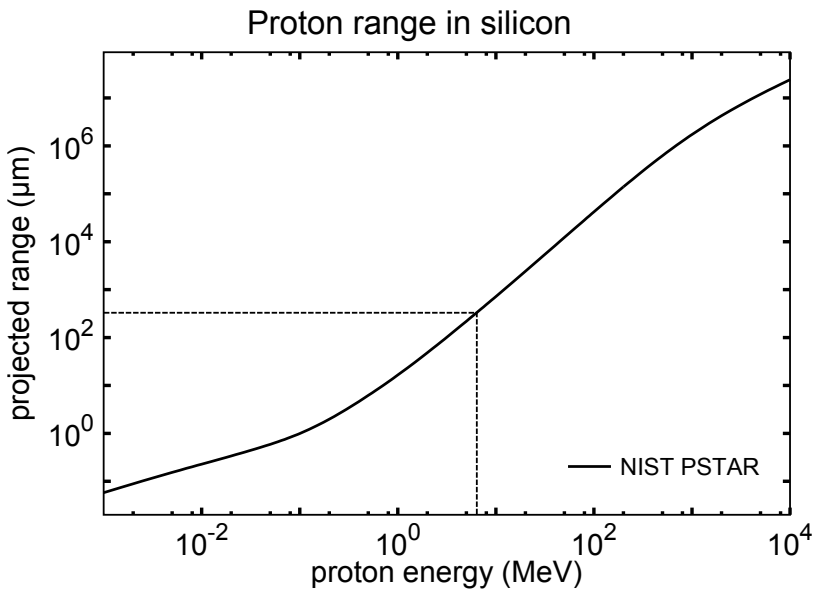
Chris Tenzer, Bastian Hess, Sebastian Diebold, Roberta Amato, Emanuele Perinati, Alejandro Guzman

Interactions of soft protons with detectors

Two types of interactions of charged particles with the detector material:

- Electron scattering => **ionization** (TID)
- Nuclear scattering => **lattice defects and vacancies** (NIEL)

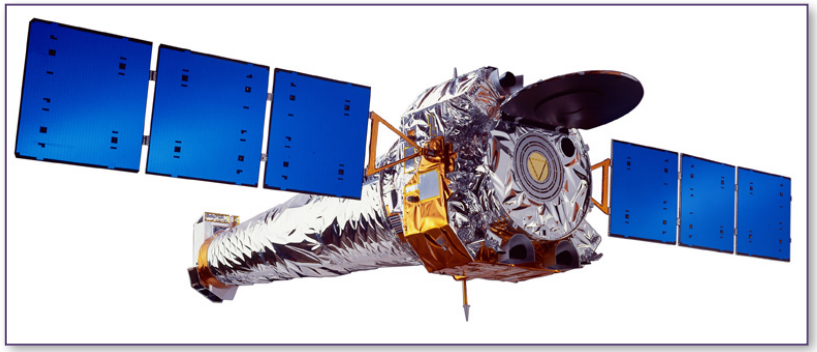




Interactions of soft protons with detectors

Two categories of effects on astronomical observatories:

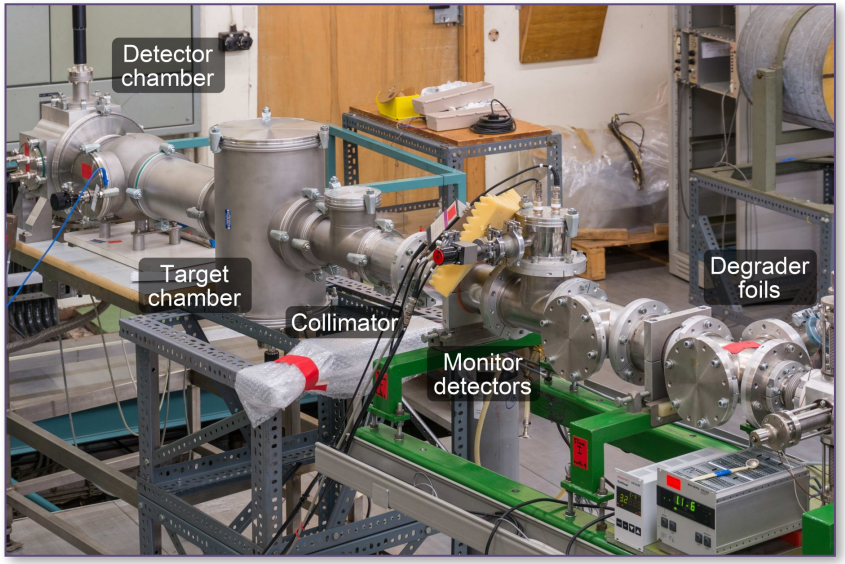
- Degradation of the detector performance
  - Creation of intermediate energy levels => increased leakage current
  - Creation of charge traps => degrading the CTE
- Contributions to background in observations
  - Energy deposition via direct interaction with the detector
  - Triggering of secondary particles in the vicinity of the detector



- **Soft protons are in this respect more harmful than high energy protons.**
- **Severity of effects depend on radiation environment and detector properties.**

Context - Soft Proton Measurements in Tübingen

Accelerator facility



3MV Van de Graaff accelerator at the University of Tübingen, Germany

- Beam energy range: **100 keV - 2.5 MeV**
- Beam current: **200 nA - 40 µA**
- **6 beam lines** (selectable via switching magnet)
- **Several ion types** (p, H^+_2, d, D^+_2, $^4He^+$, $^{12}C^+$, $^{13}C^+$, $^{16}O^+$)

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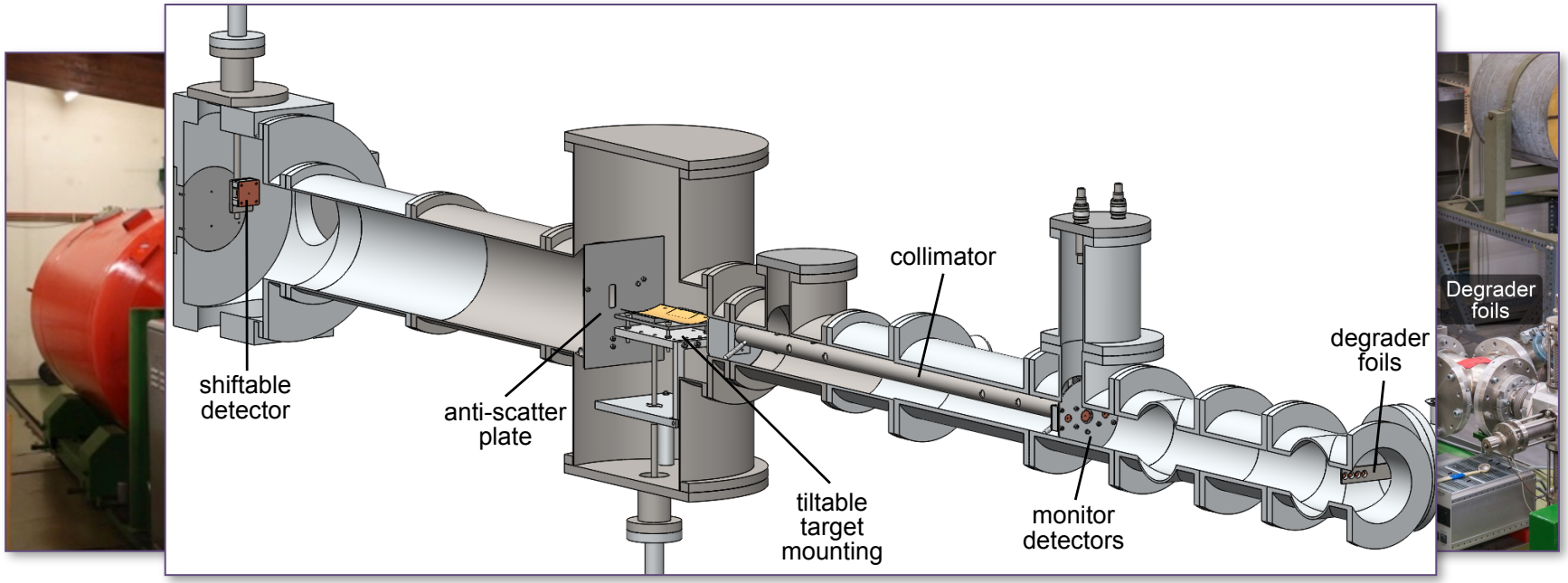

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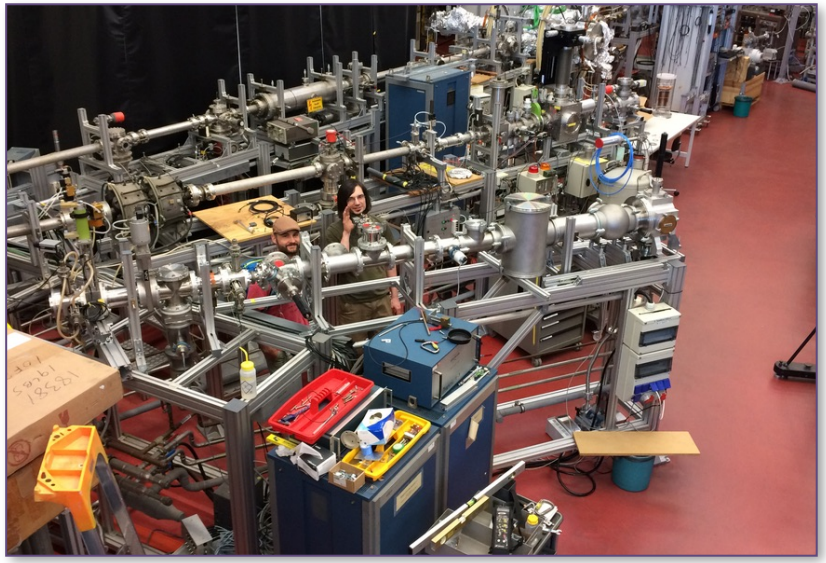
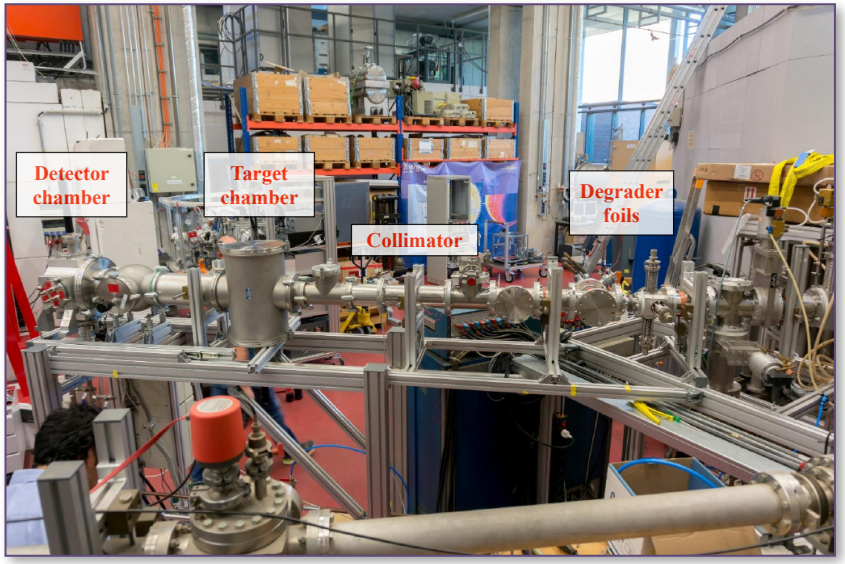
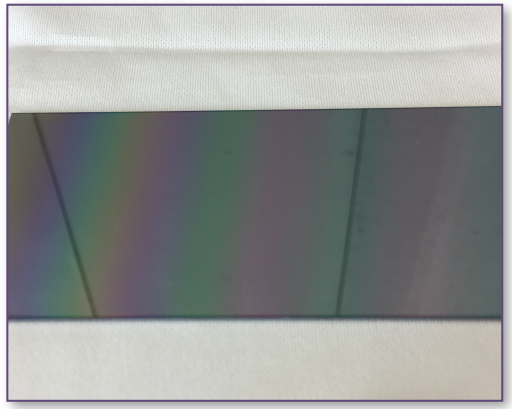




2.5MV Van de Graaff accelerator at the University of Frankfurt, Germany

- Beam energy range: **250 keV - 2.5 MeV**
- Measurements also taken at 3 horizontally-offset angles
- Switch from Ni/Au to Silicon Pore Optics mirrors
- **Several ion types** (p, H^+_2, d, D^+_2, $^4He^+$, $^{12}C^+$, $^{13}C^+$, $^{16}O^+$)



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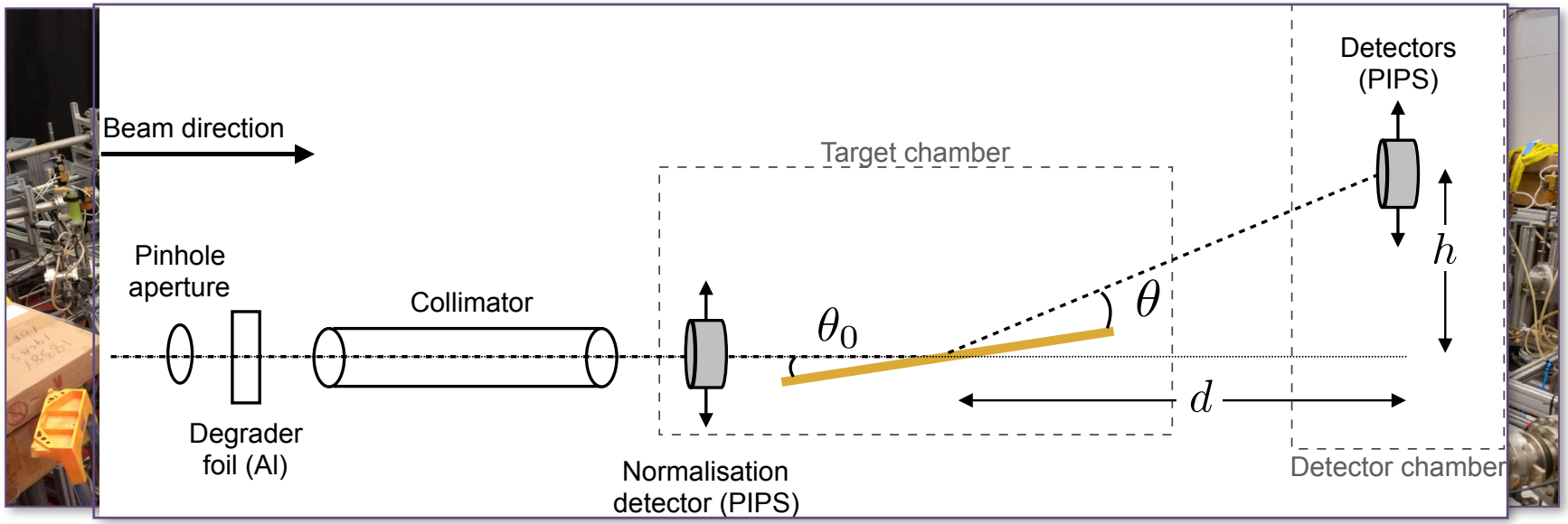

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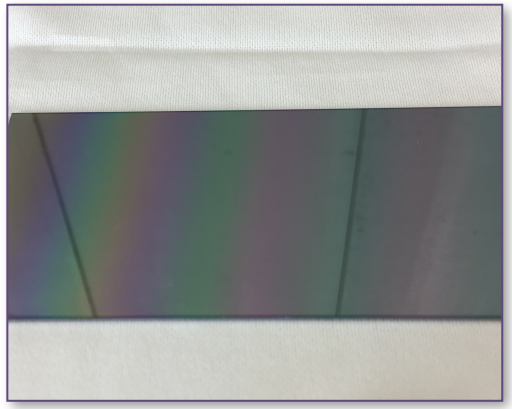

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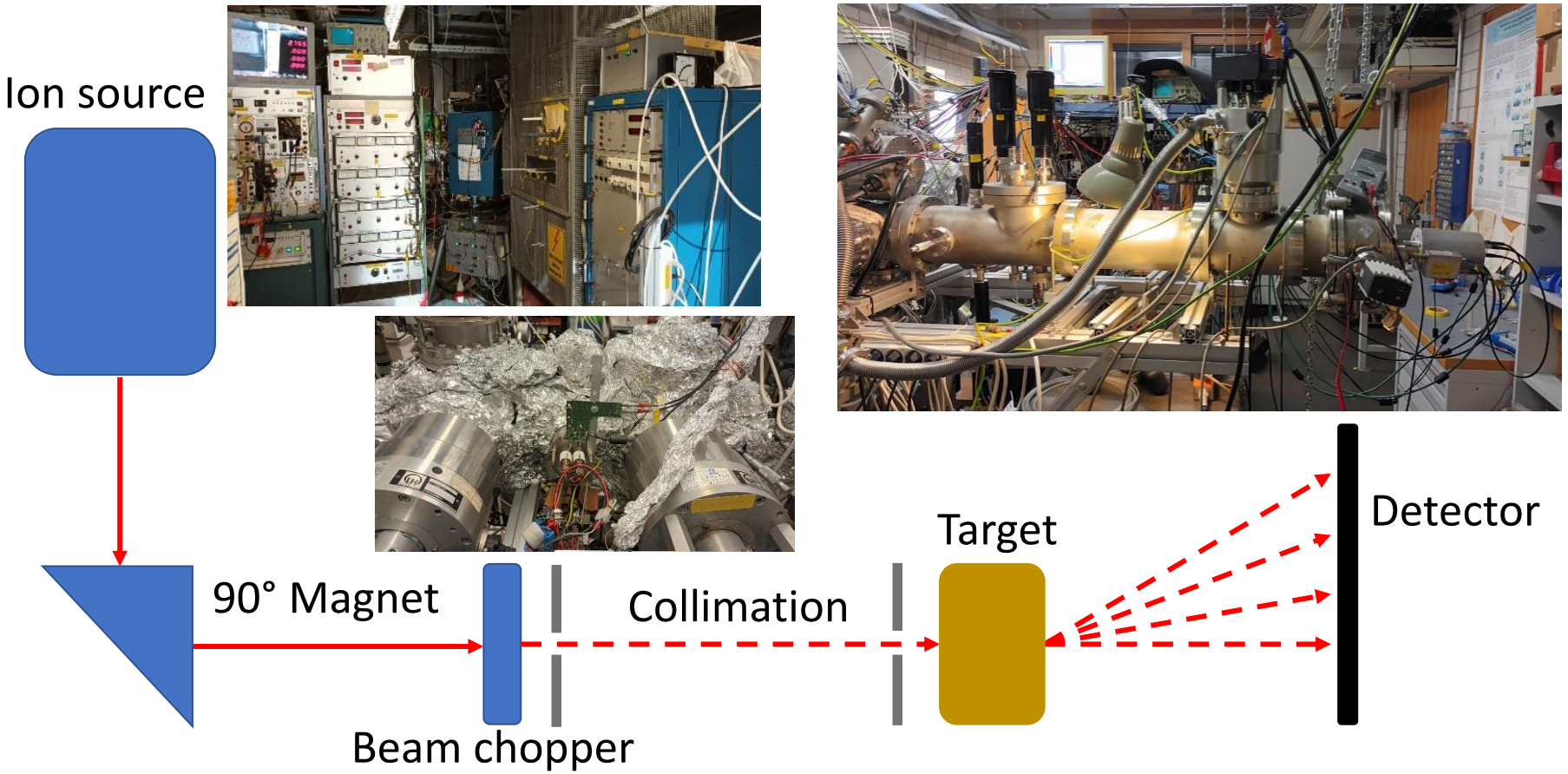
A different approach

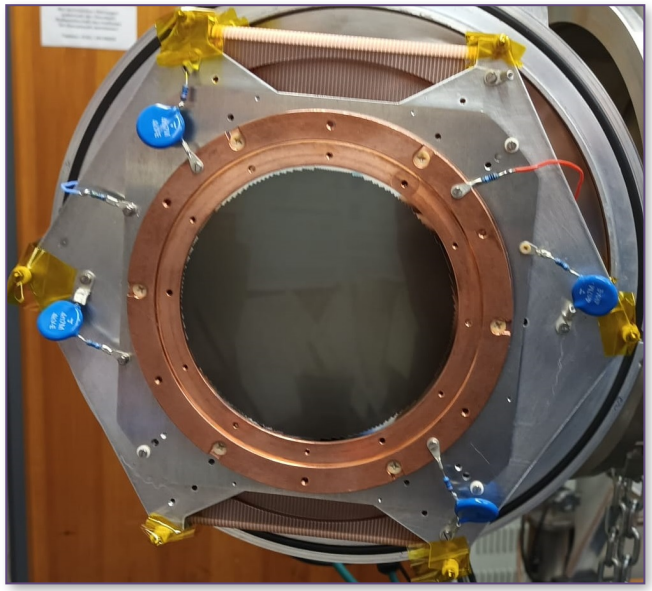
Most recent setup in Frankfurt



Improvements

So what is new?

- 2D HEXanode delay-line MCP detector
  - 8 cm detector diameter
  - Measure full 2D scattering distribution in one run
  - Follow single proton, create individual detector events
  - ~100 ps time resolution
  - ~0.05 mm spatial resolution
- Energy determined by Time of Flight measurement
  - Energy resolution < 1 keV
- Softer Protons!
  - Energies from 20 keV to 50 keV

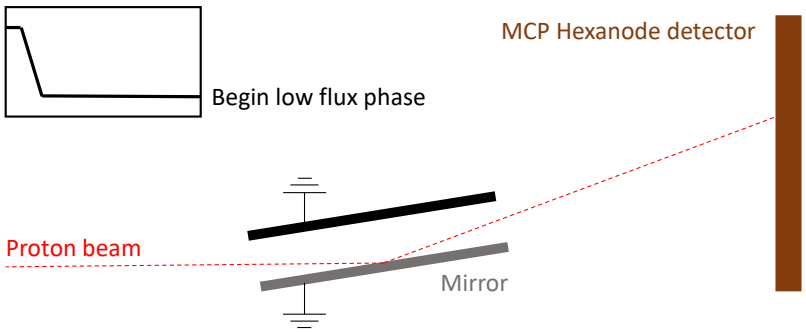


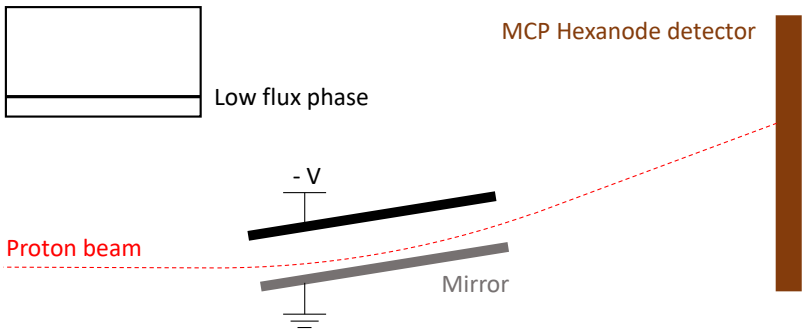
MCP detector (RoentDek) at the setup

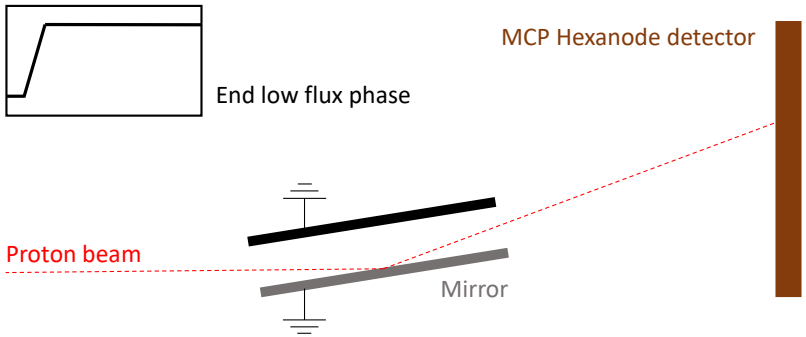
Improvements

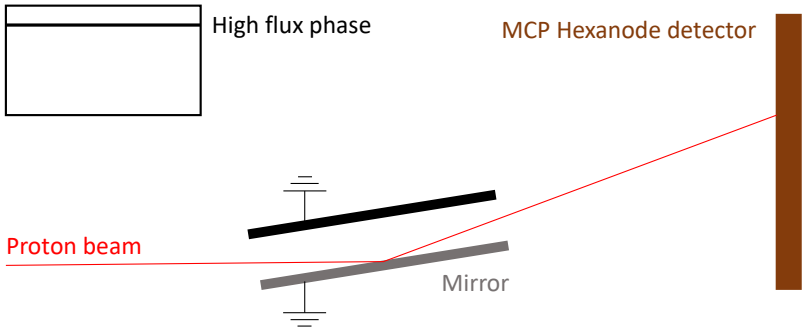
What else is new?

- Beam Chopper reduces beam intensity to single protons
- Capacitor plates move beam vertically and horizontally

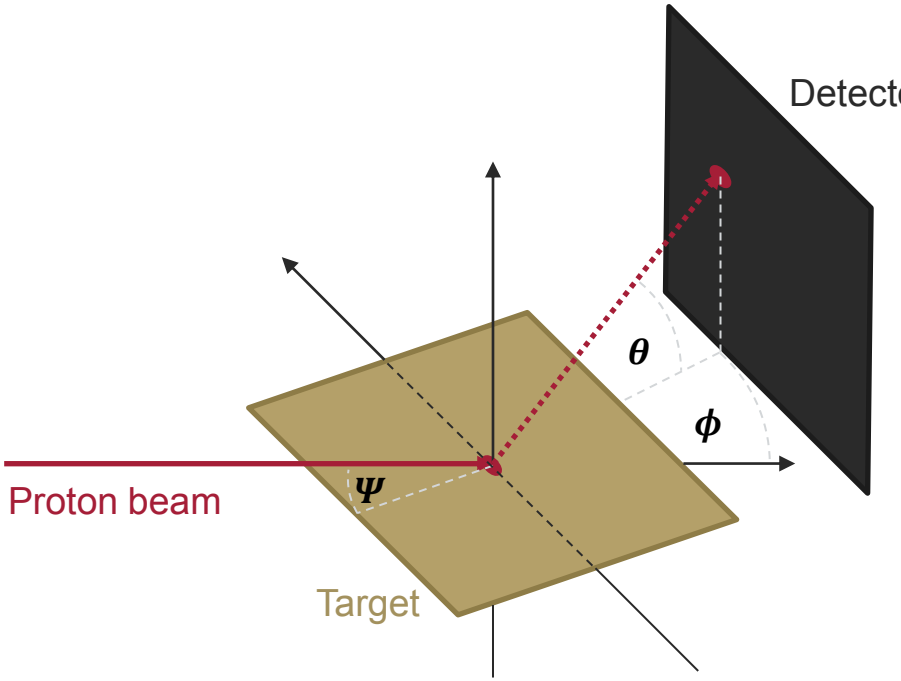








Terminology



- Ψ: Grazing angle between proton beam and target plane
- θ: Scattering angle, vertical angle between incident beam and scattered beam
- ϕ: Azimuth angle, horizontal angle between incident beam and scattered beam

Scattering efficiency:

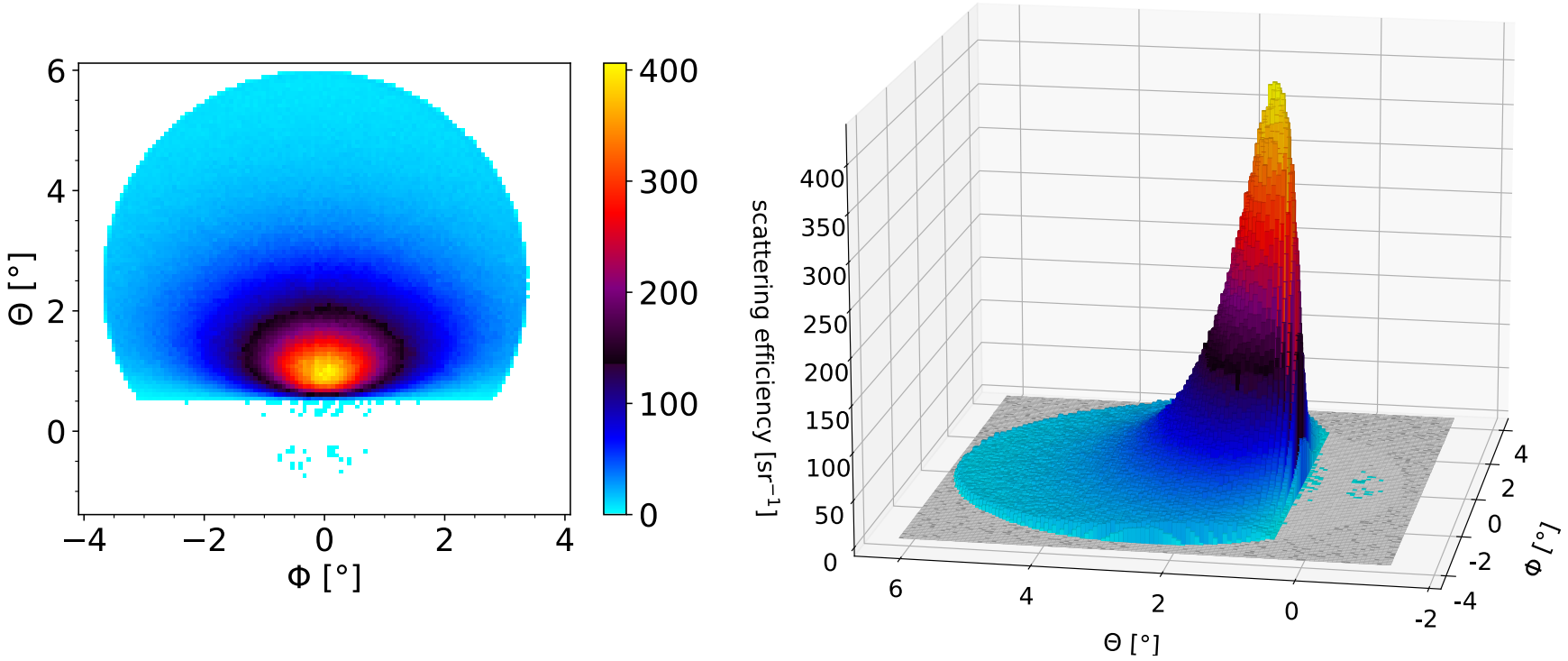
$$\eta(\Psi,\theta,\phi) = \frac{N_{scattered}(\Psi,\theta,\phi)}{N_{beam}\, d\Omega}$$

- Normalisation phases: incoming beam flux on mirror is determined
- Binned detector events: normalised to solid angle of bin

Energy loss:

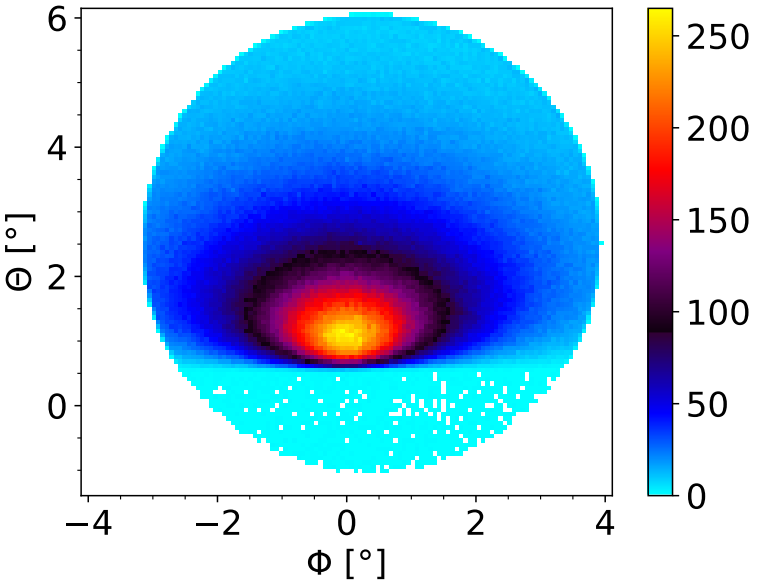
- Time of Flight measurement of time delay between direct and scattered protons is used to determine the energy loss.

Results - Scattering Efficiency Examples

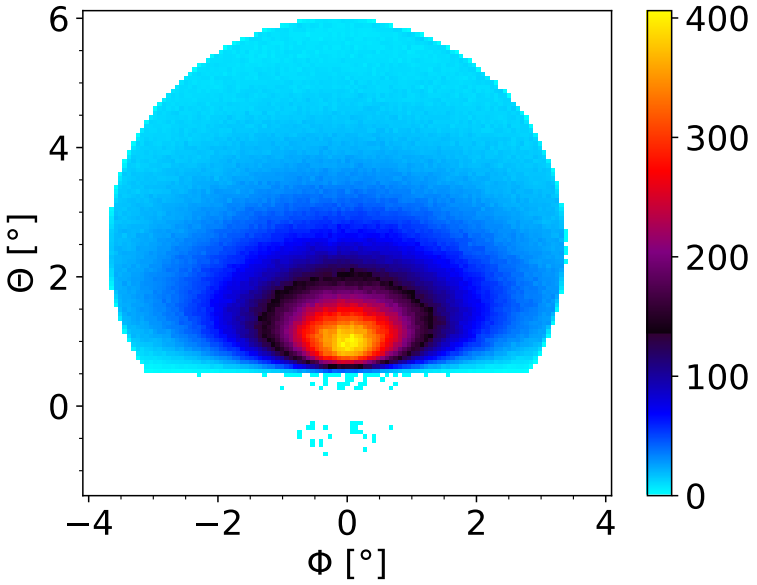


2D and 3D representation of the scattering efficiency at E_0 = 35 keV and Ψ = 0.5°. The cut at Θ=Ψ corresponds to the mirror edge stopping any particles below this scattering angle.

Results - Scattering Efficiency Examples



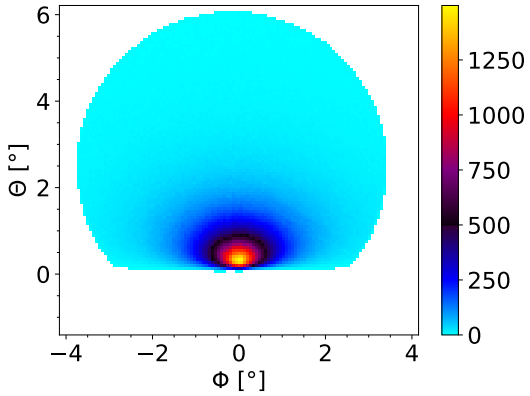
E_0 = 20 keV, Ψ = 0.5°



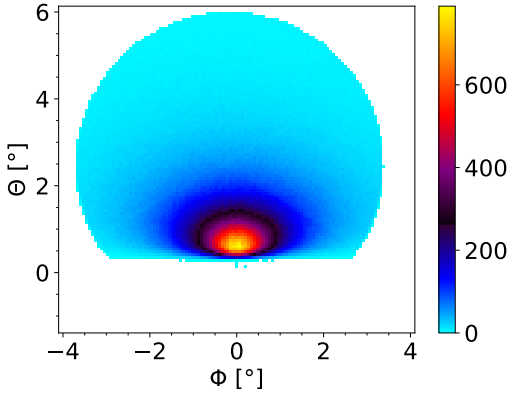
E_0 = 35 keV, Ψ = 0.5°

Increasing the beam energy results in a more narrow distribution on the detector.

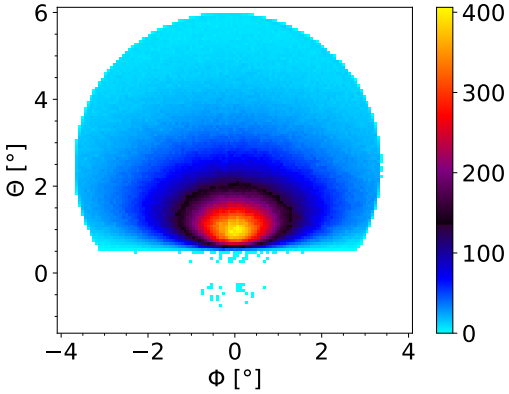
Results - Scattering Efficiency Examples



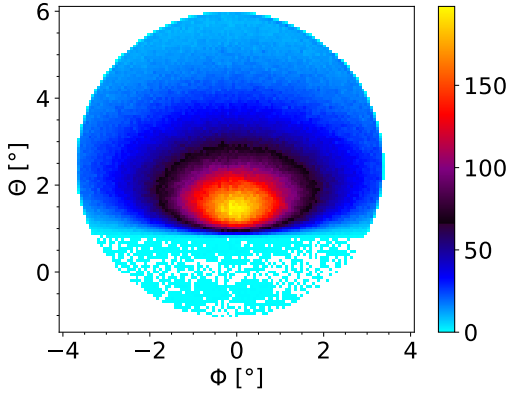
Ψ = 0.1°



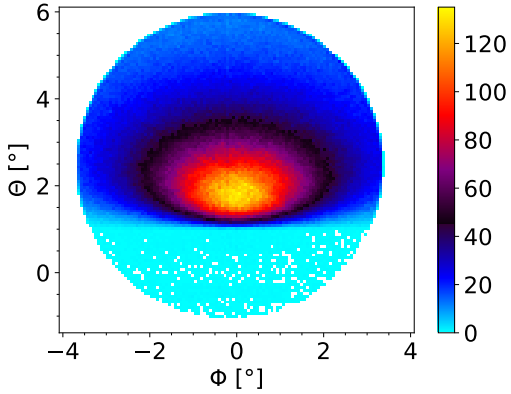
Ψ = 0.3°



Ψ = 0.5°



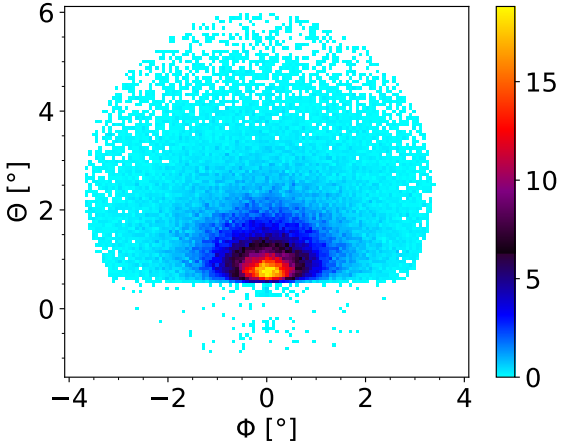
Ψ = 0.8°



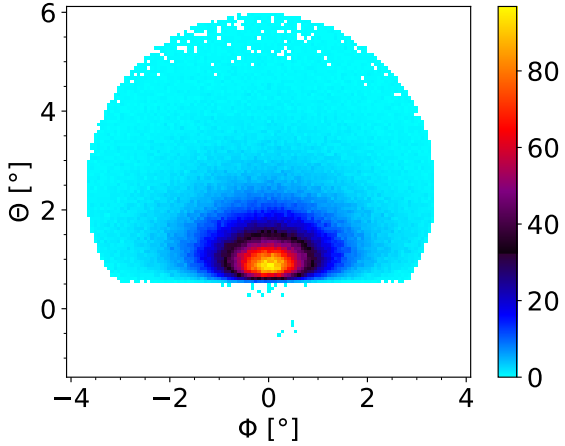
Ψ = 1°

Different incidence angles for E_0 = 35 keV. The maximum moves with Θ = 2 * Ψ.

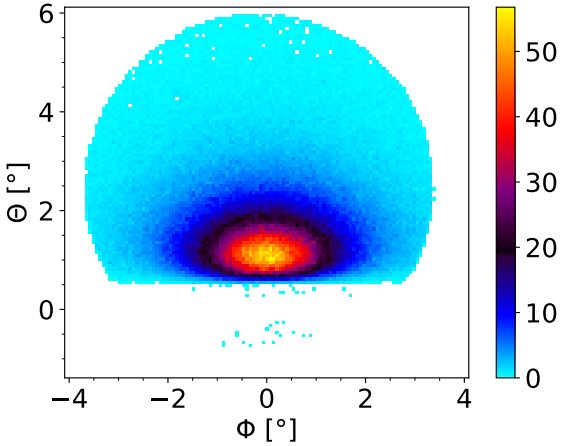
Results - Energy Loss Example



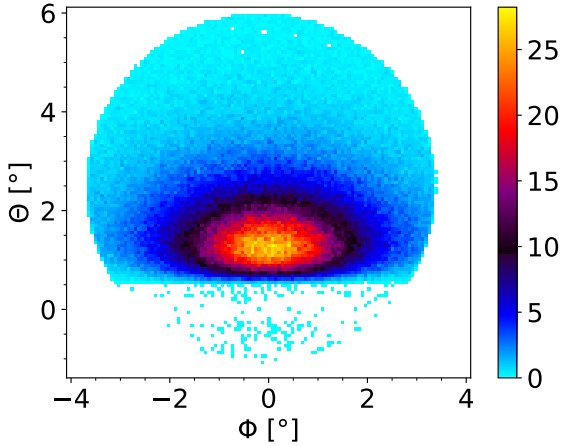
$E/E_0 = 1.0$



$E/E_0 = 0.96$



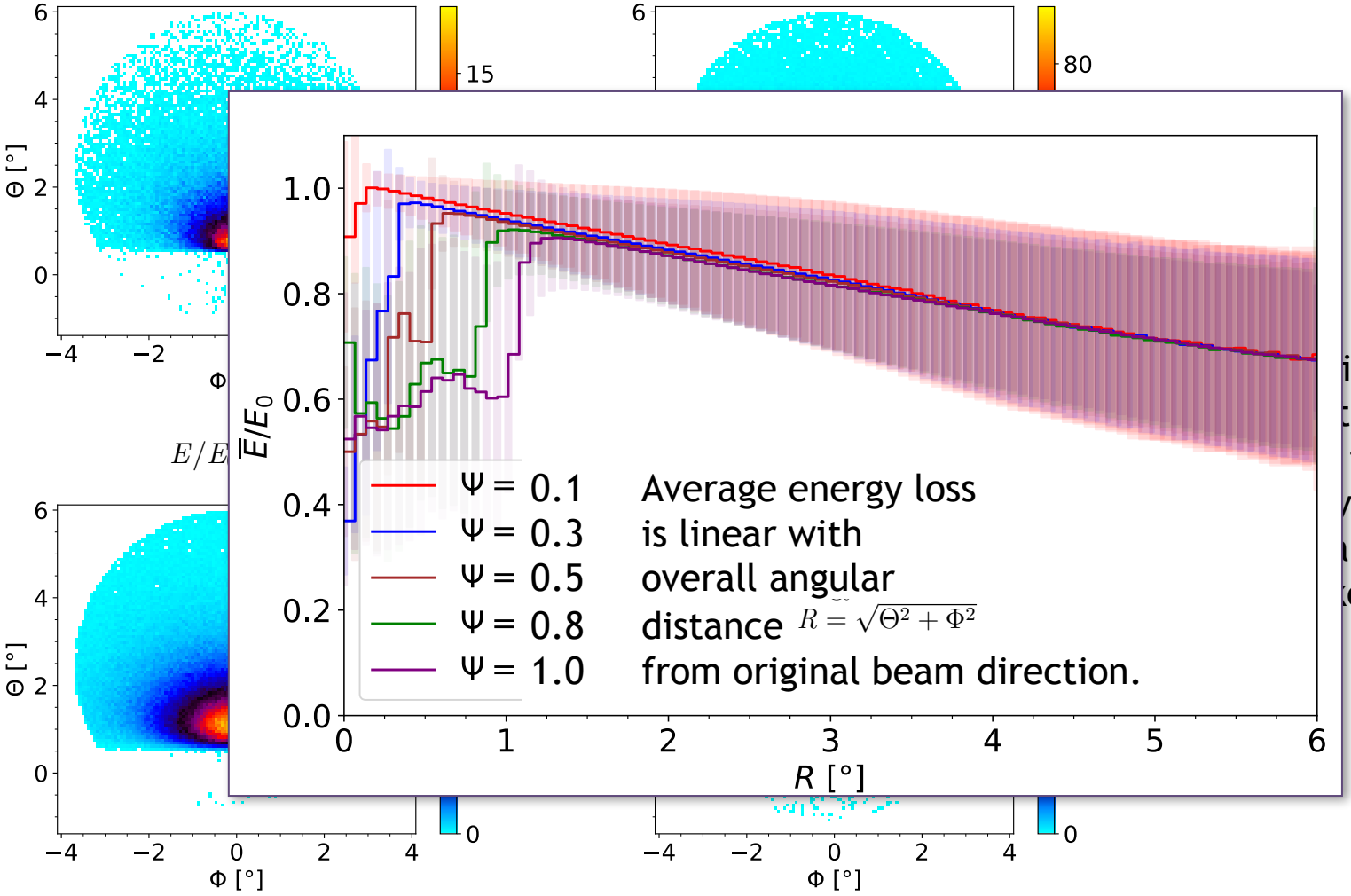
$E/E_0 = 0.92$



$E/E_0 = 0.88$

Angular distribution of protons that suffered the respective energy loss (+- a few %) at E_0 = 35 keV

Results - Energy Loss Example



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few %) at
eV

Summary

- Our new setup in Frankfurt opened up a lot of possibilities to measure the parameters of soft proton reflection in great detail.
- We have only just begun to explore the data from our first series of measurements.
- Measurement results are in good agreement with our previous 1D measurements
- Energy loss can be clearly observed. It depends linearly on the scattering distance/angle away from the beam.
- Data indicate that a noticeable amount of proton neutralisation seems to happen during the reflection at these low energies. => under investigation
- A model of our measured data will be made available in a Geant4 useable format to enable the simulations of the process in MonteCarlo simulations.