A setup for soft proton irradiation of X-ray detectors and mirror shells

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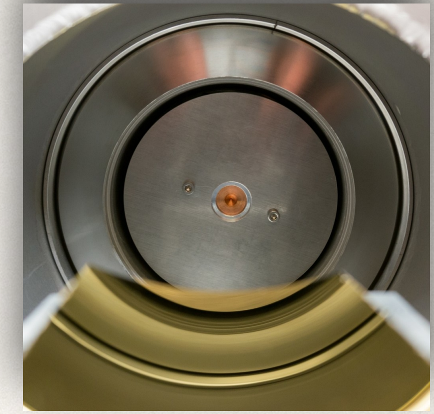
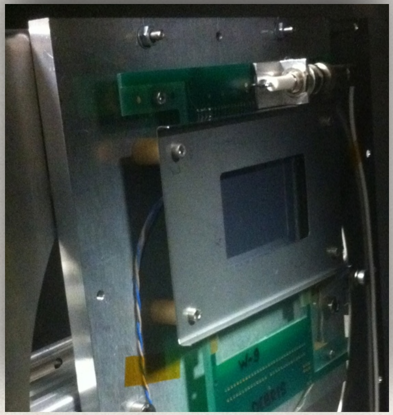
Overview of the talk

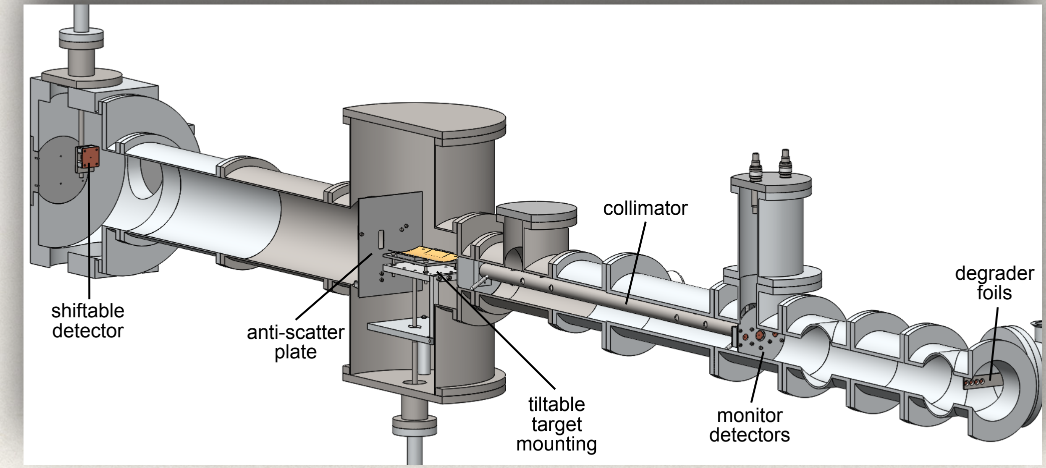
- Soft (E < 1 MeV) proton effects on X-ray detectors
- Reflection of soft protons on X-ray mirrors
- Experimental setup at the accelerator facility
- Examples of measurements performed



eROSITA Mirror Segment



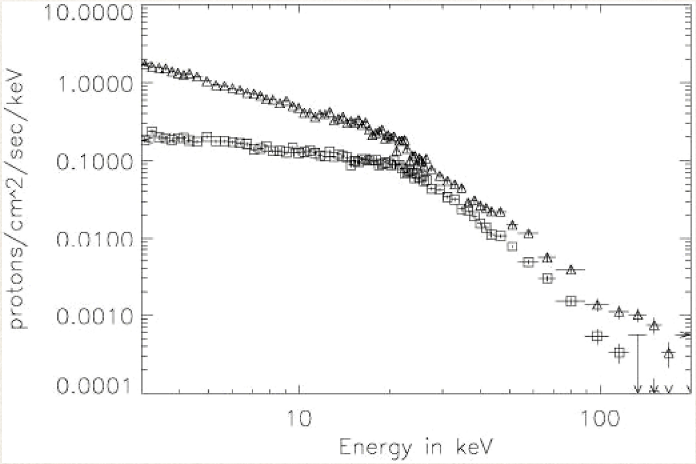
LOFT Detector Prototype in the Chamber



Schematics of the Accelerator Setup

Soft Proton Effects

- Sudden CTI increase of front-illuminated CCDs of the *Chandra ACIS* instrument
  (e.g. Lo et al., 2003)
- Background studies with *EPIC* pn-CCDs of *XMM-Newton*
  (Kendziorra et al., 2000)

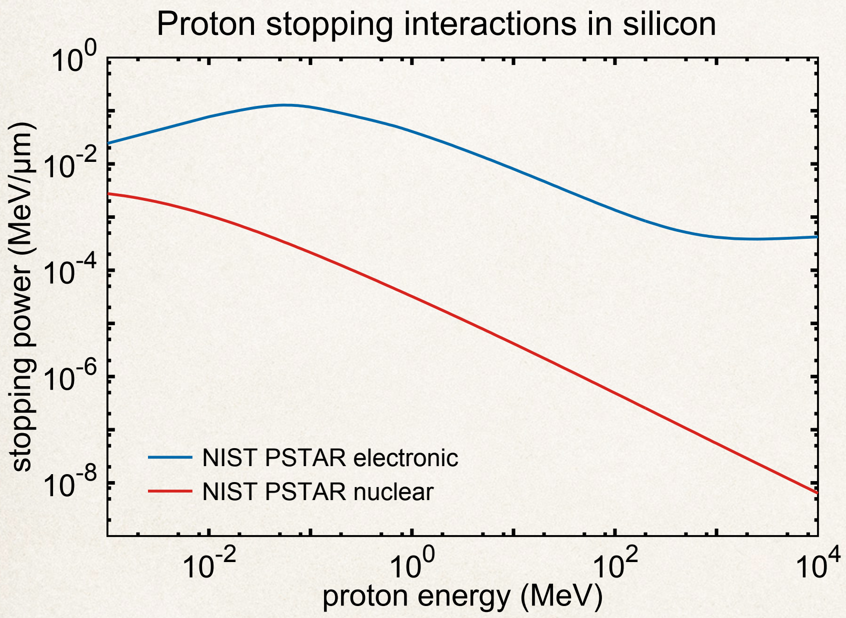


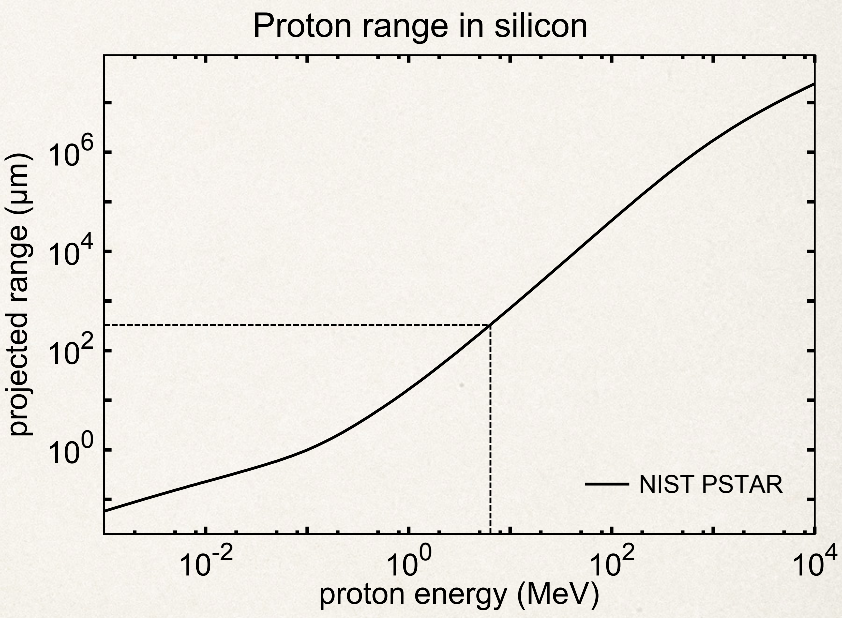
Proton Spectrum measured in orbit with a low gain mode of the pn-camera of XMM-Newton

X-ray Satellites Chandra and XMM-Newton

Detector Interactions

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





Detector Interactions

Degradation of the photon detection performance (sensitive volume, energy resolution, spatial resolution)

- Charge trapped in insulator ⇒ increased voltage for full depletion
- Creation of intermediate levels ⇒ increased leakage current
- Creation of charge traps ⇒ decreased charge collection efficiency

Observational background

- Energy deposition via direct interaction in the detector
- Induction of fluorescent line emission in the vicinity of the detector

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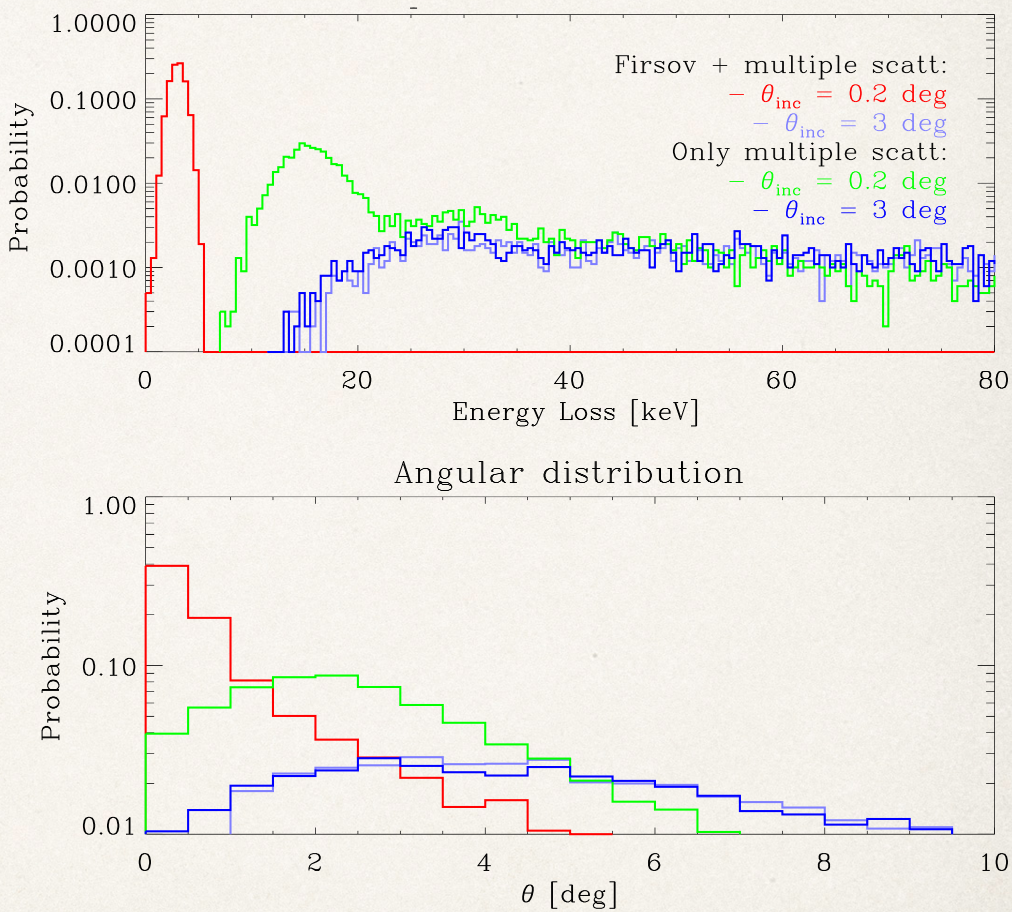
Mirror Interactions

Firsov Scattering

- Protons interact with electron plasma above mirror surface
- Efficient at low incident angles
- Very small energy loss
- Boost to forward angles

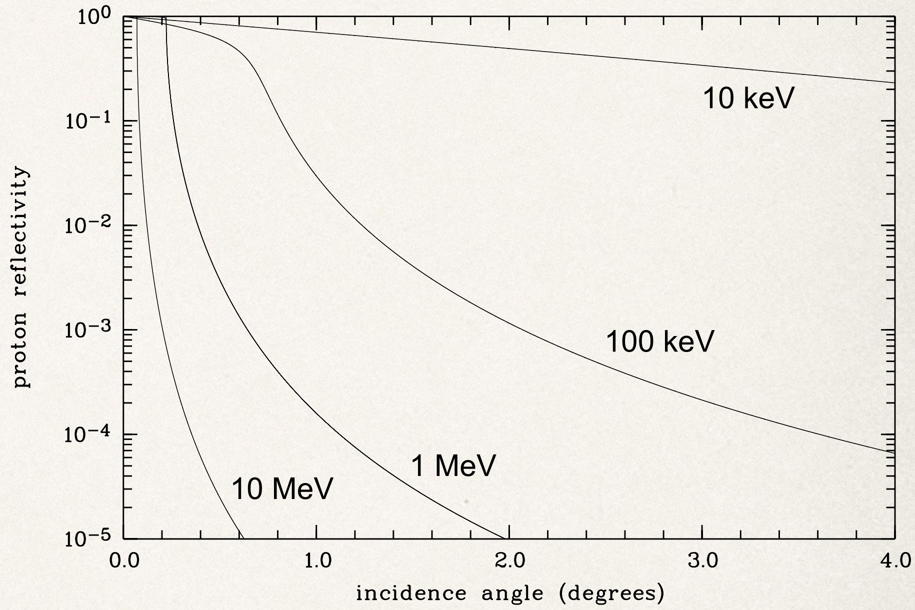


(Fioretti, 2011)

Mirror Interactions

Aschenbach Description

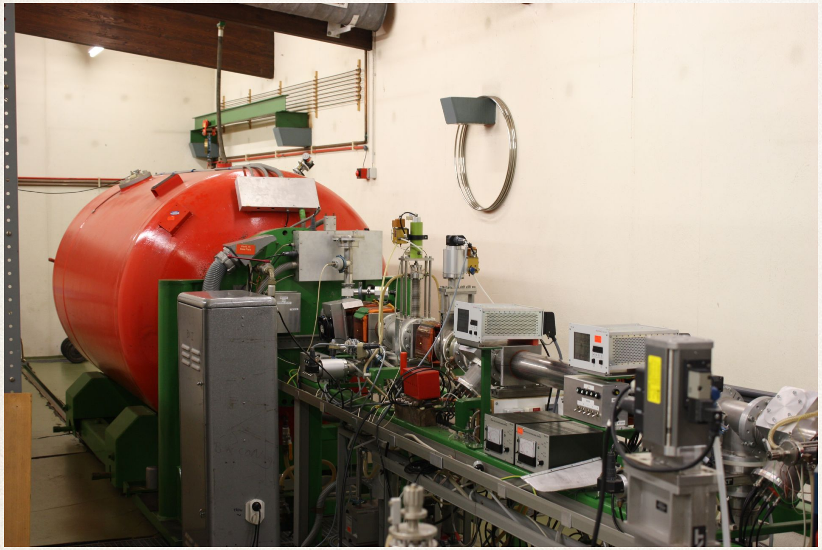
- Describing protons by means of de Broglie wave formalism
- Reflection occures analog to X-ray photons ("Proton Telescope")
- Critical incident angle is energy dependent
- Zero energy loss
- Angular distribution peaks at $\Theta_{\text{scatter}} = 2 \cdot \Theta_{\text{inc}}$



(Aschenbach, 2007)

Accelerator in Tübingen

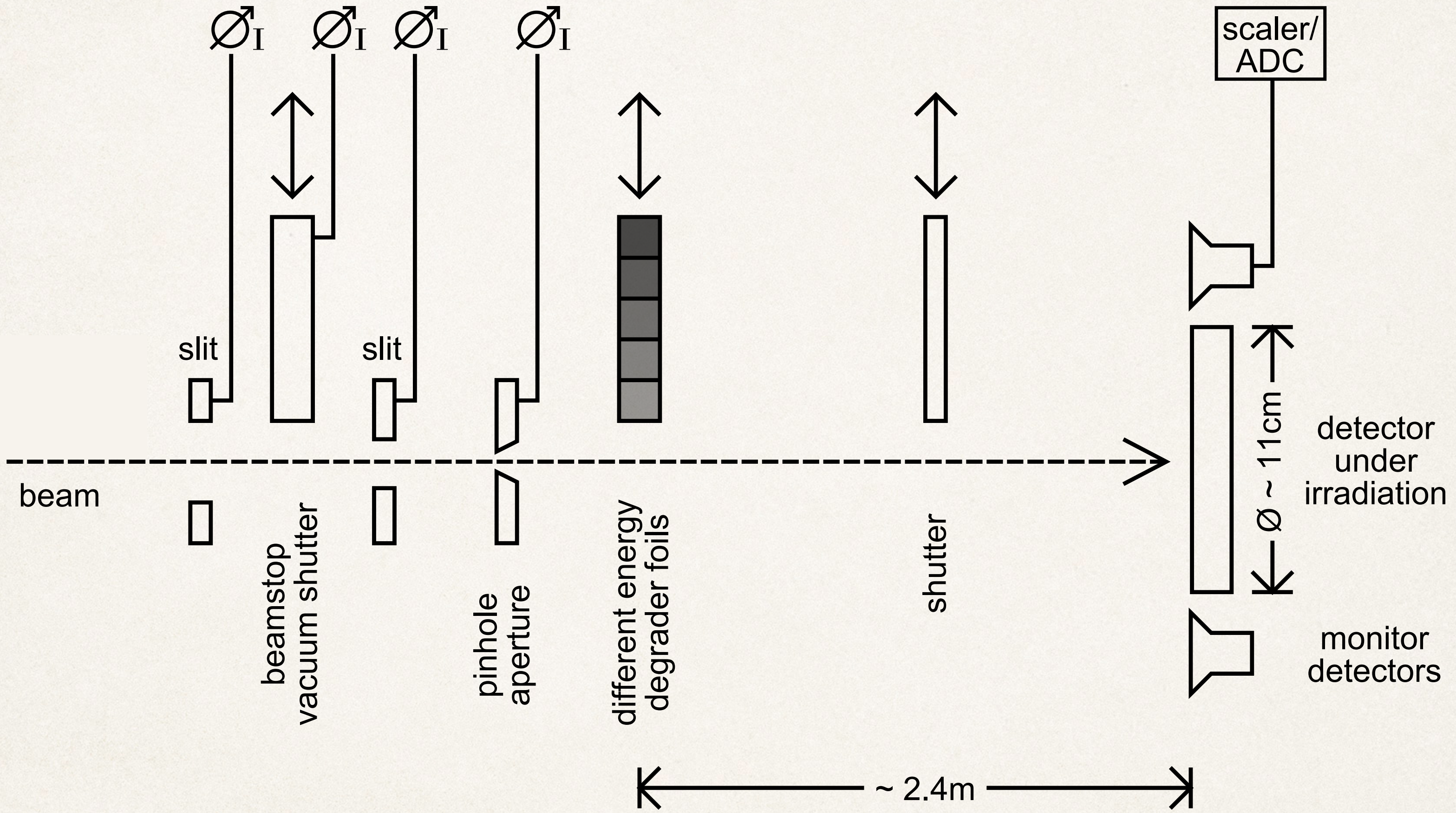
- 3 MV Van de Graaff accelerator
- Current terminal voltage range: 0.7 – 2.0 MV
- Beam current: 10 nA – 10 µA continuous current
- Ion types: p, H_2^+, d, D_2^+, $^4He^+$, $^{12}C^+$, $^{13}C^+$, $^{16}O^+$
- 6 beam lines



Accelerator at the Rosenau in Tübingen

Three of the Six Beamlines

Detector Irradiation



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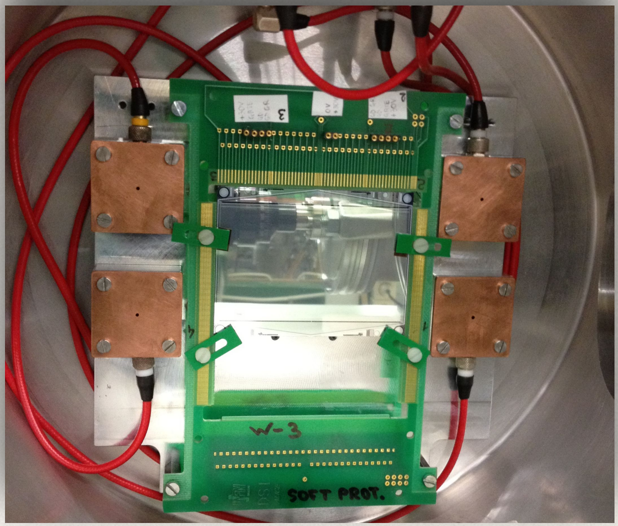
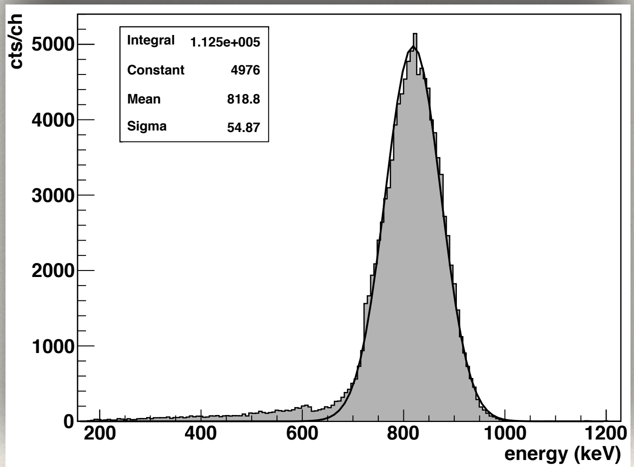
Detector Irradiation

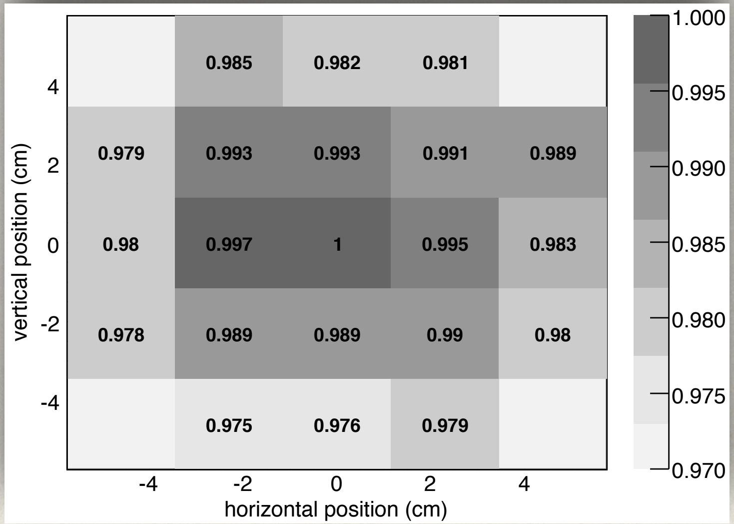
- Originally designed for LOFT detector irradiation
- Allows homogeneous distribution over large detectors (11 cm diameter)
- Fluences of 0.5x, 1x, 5x and 10x mission lifetime were applied at different energies
- leakage current was measured at different temperatures and annealing was monitored in the following months



LOFT Detector Prototype



Input Spectrum Measured at the Detector Location



Homogeneity of the Irradiation

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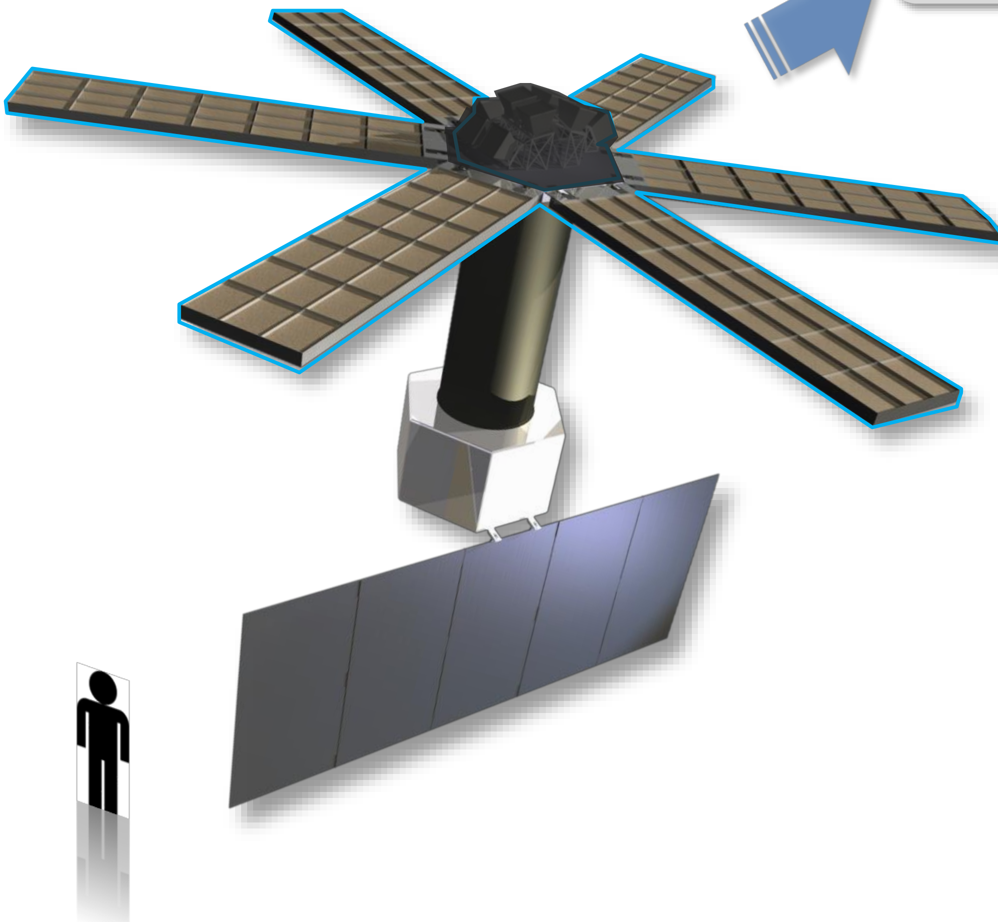
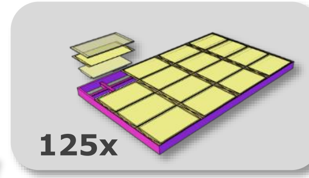
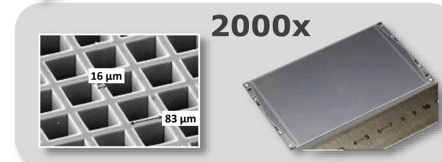
Detector Irradiation

LOFT (Large Observatory for X-ray Timing) currently in the ESA M4 selection process







EFFECTIVE AREA	4 m^2 @ 2 keV 10 m^2 @ 8 keV 1 m^2 @ 30 keV
ENERGY RANGE	2-30 keV (30-80 keV ext.)
ENERGY RESOLUTION FWHM	200 eV @ 6 keV
COLLIMATED FOV	1 deg FWHM
ABSOLUTE TIME ACCURACY	1 µs

Input Spectrum Measured at the Detector Location

Homogeneity of the Irradiation

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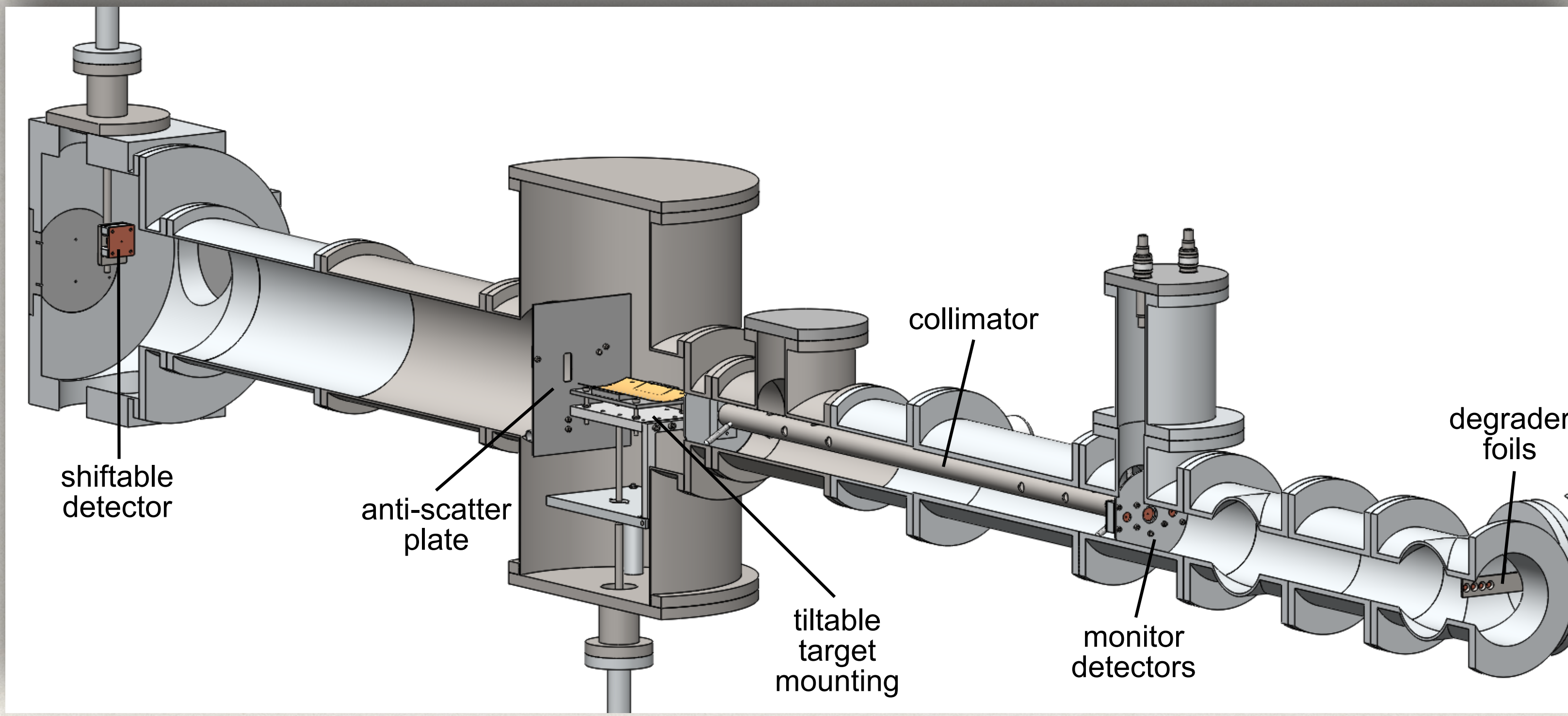
Mirror Scattering



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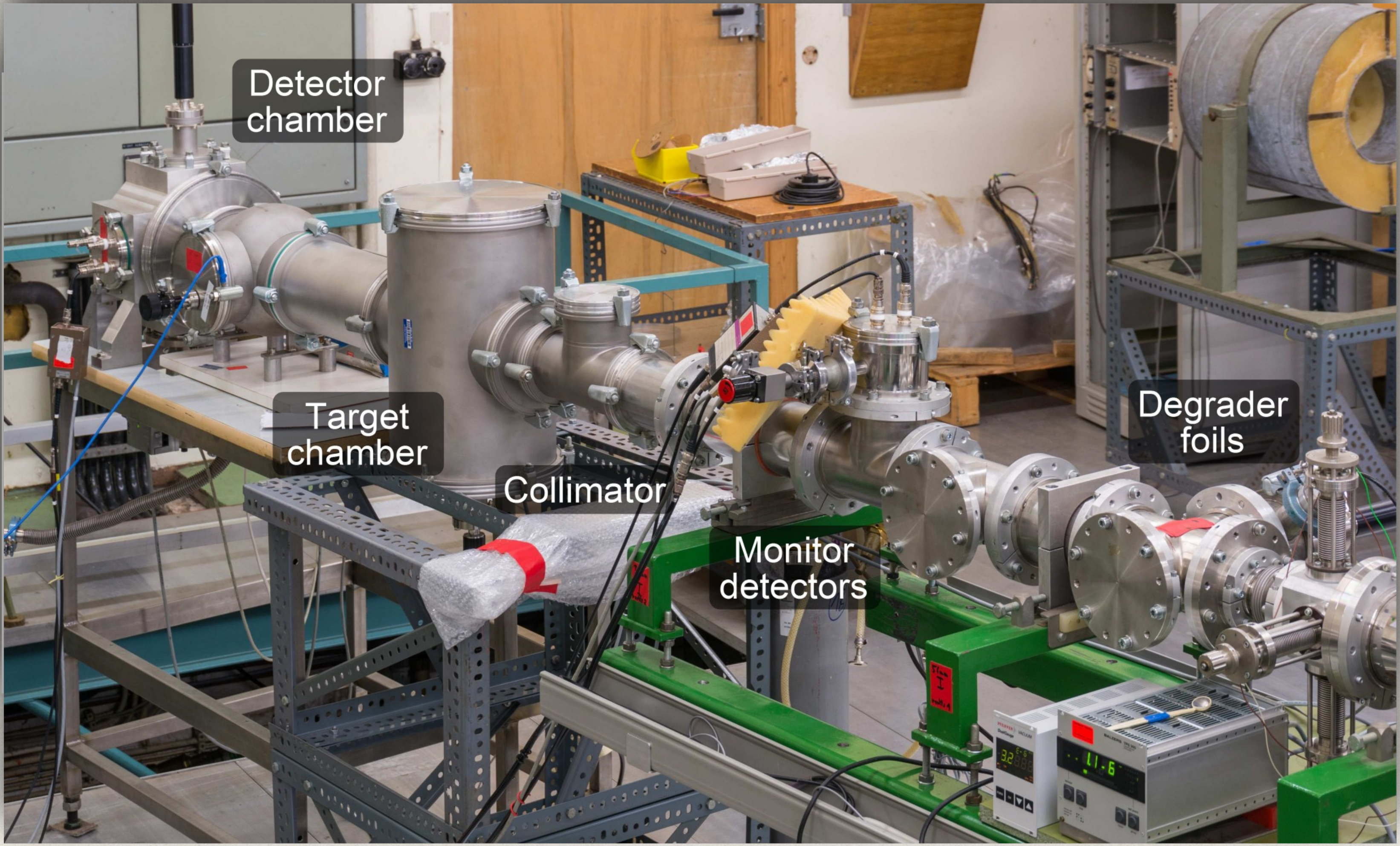

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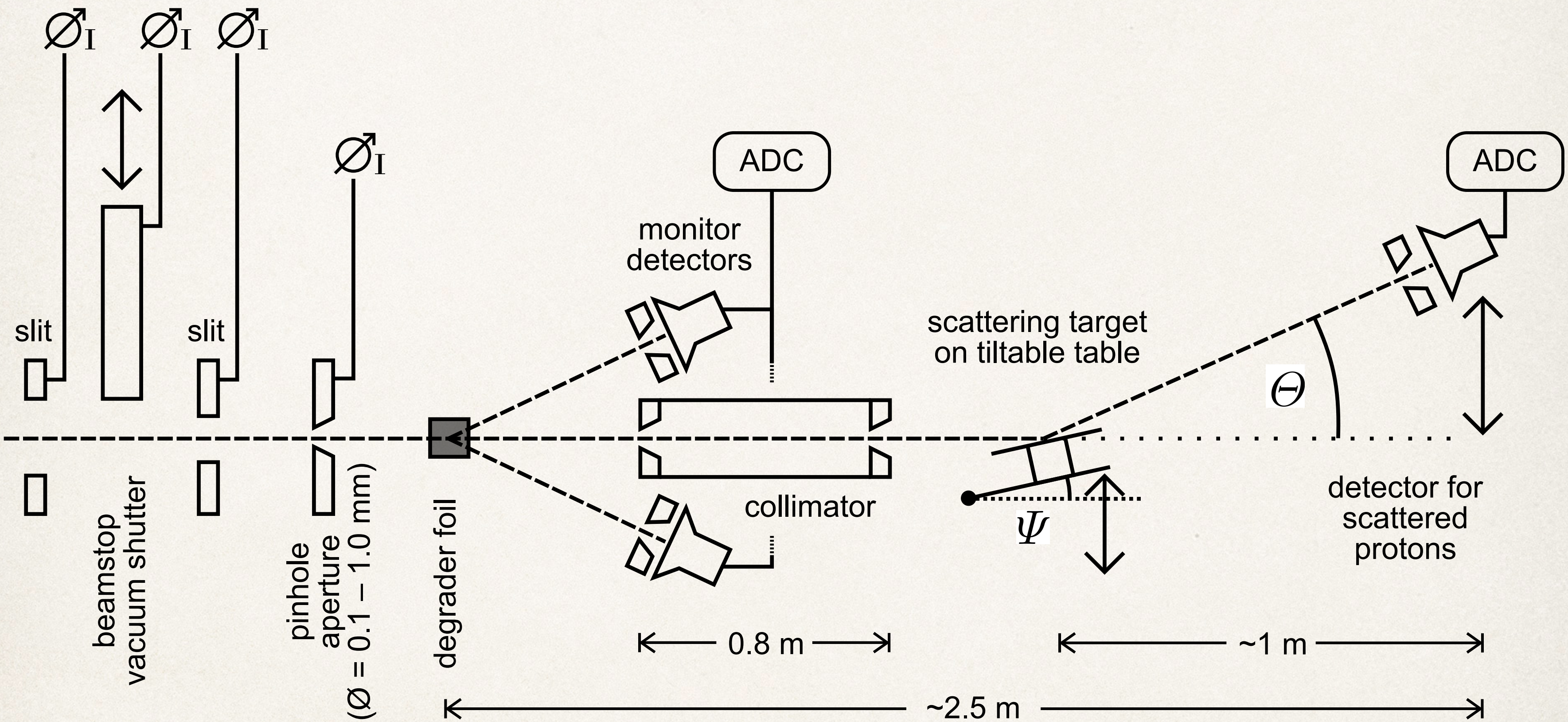
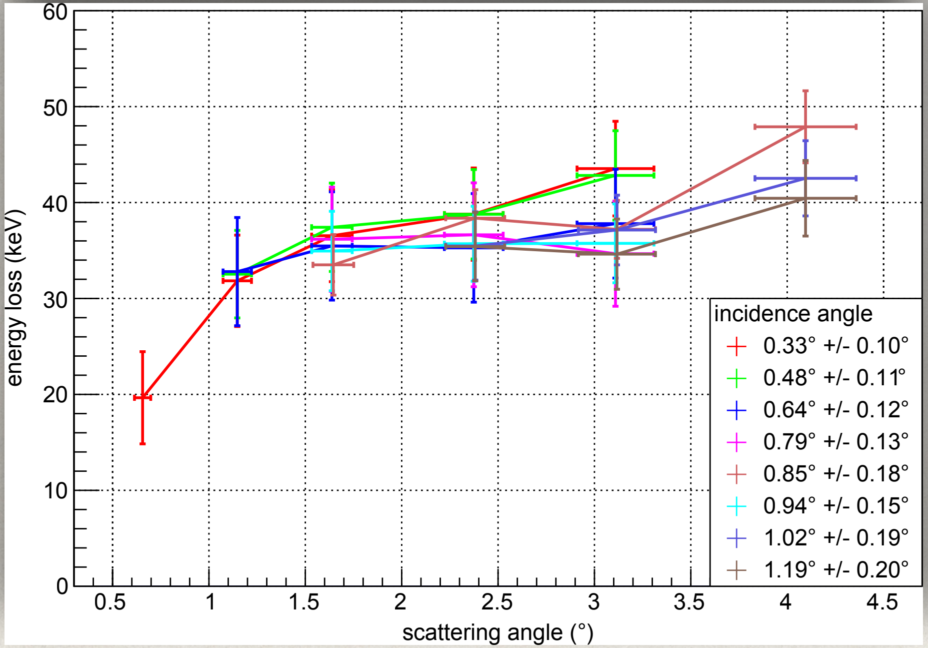
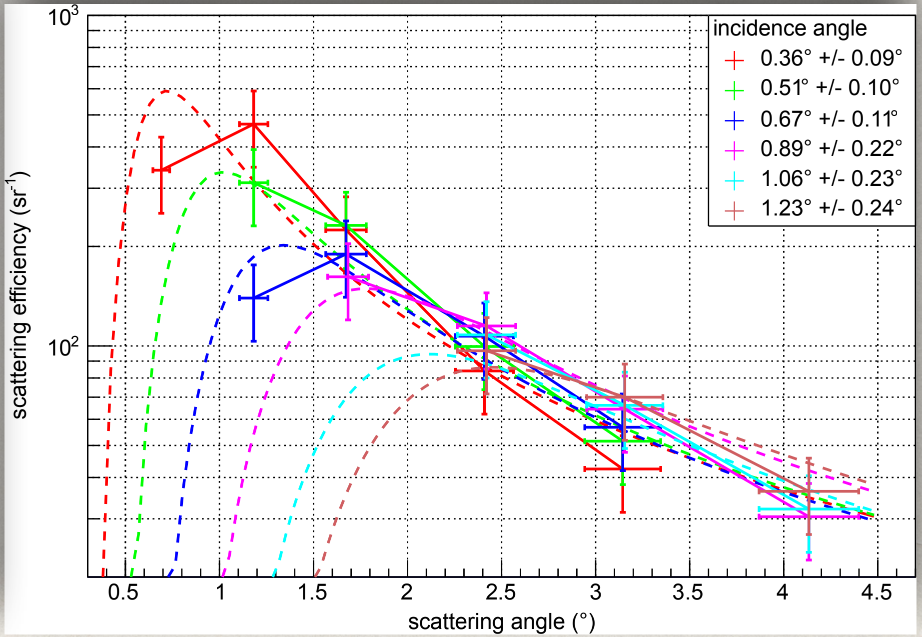


Mirror Scattering

- scan the target area with a movable SSB detector
- record the scattering efficiency for different incidence angles and energies
- accumulate spectra and determine the average energy loss



Energy Loss at 500 keV



Scattering Efficiency at 250 keV

Summary

- we are currently updating the setup to improve on the resolution of the energy measurement and the angular distribution
- we are preparing measurements with multi-layer coated mirrors and are open for other interested groups to test their mirrors (or detectors)
- the results obtained so far for eROSITA are published and will now be compared with recent Geant4 simulations and a raytracing code developed in a collaboration with INAF Palermo

Summary

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Thank you!