Experimental Verification of the Soft Proton Small Angle Reflection Process on X-Ray Mirror Shells

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Geant4 Space Users' Workshop
Barcelona 04.03.2013

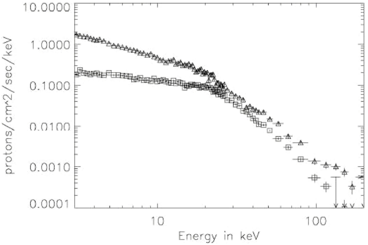
Outline

Chandra Soft Proton Incident

- Sudden CTI increase of front-illuminated CCDs of the *Chandra ACIS* instrument

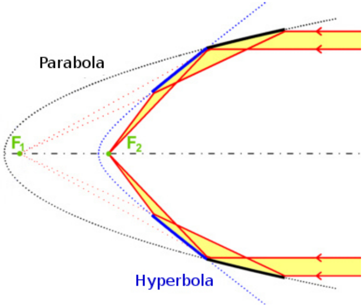
  (e.g. Lo et al., 2003)
- Background studies with *EPIC* pn-CCDs of *XMM-Newton*

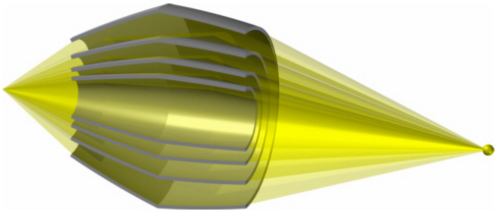
  (Kendziorra et al., 2000)



Focusing X-Ray Optics (Wolter Type I)

- Combination of parabolic and hyperbolic mirrors
- Focusing via two reflections
- Nested mirror shells to enlarge A_{eff}





(www.x-ray-optics.de, modified)

Soft Proton Effects on Solid-State X-Ray Detectors

- Energy range: $\sim$ 10 keV - $<$ 10 MeV
- Stopped inside detector $\Rightarrow$ large energy deposition in small volume (Bragg peak)
- Ionization (TID) and displacement damage (NIEL)
- Degradation of detector performance
  - Ionization in insulating top layers (field oxide and passivation layer) $\Rightarrow$ increased surface leakage current (degr. energy resolution)
  - Displacement damage in detector bulk
    $\Rightarrow$ increased bulk leakage current (degr. energy resolution)
    $\Rightarrow$ creation of charge traps (incr. charge collection inefficiency)

Chronology of Funneling Analysis

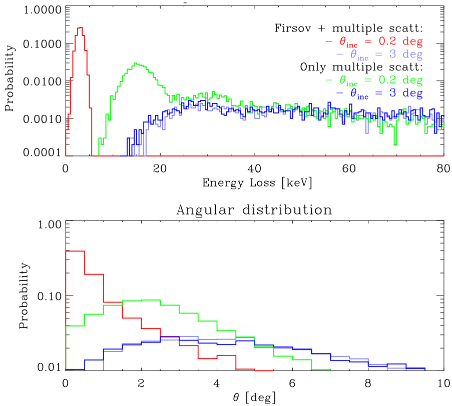
- TRIM simulation (Kolodziejczak, 2000)
- Geant4 simulation (Nartallo, 2001 & 2002)
- Multiple scattering not efficient enough (Dichter et al., 2003)
- Improved Geant4 simulation including Firsov scattering (Lei et al., 2004)
- Different mechanism proposed: Reflection of de Broglie wave (Aschenbach, 2007)

- Results prove proton funneling
- Consistent with laboratory results, but large uncertainty and small coverage of parameter space (Rasmussen et al., 1999)

(Fioretti, 2011)

Firsov Scattering

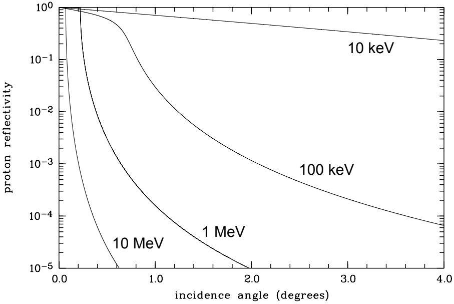
- Protons interact with electron plasma above mirror surface
- Efficient at low incident angles
- Very small energy loss
- Boost to forward angles



(Fioretti, 2011)

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 $\Theta_{\text{scatter}} = 2 \cdot \Theta_{\text{inc}}$



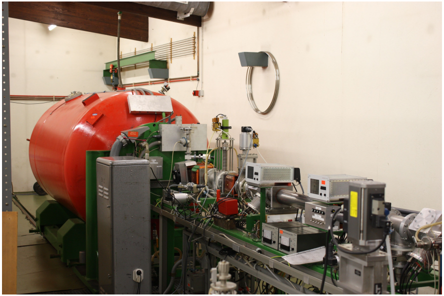
(Aschenbach, 2007)

Setup Specifications for Experimental Verification

- Low energy proton beam ($<$ 100 keV - $\sim$ 1 MeV)
  $\Rightarrow$ **Metal Energy Degrader Foils**
- Small beam diameter (0.1 mm beam diameter under 0.1° grazing incident $\Rightarrow$ elongated 5.7 cm beam spot)
  $\Rightarrow$ **Collimator**
- High accuracy of incident and scattering angle ($\sim$ 0.01°)
  $\Rightarrow$ **Linear manipulators with µm position accuracy, Laser for high precision adjustment**
- Low proton fluxes (maximum detector count rate $\sim 10^5$ Hz)
  $\Rightarrow$ **Pinhole aperture and degrader foils**
- Absolute flux measurement
  $\Rightarrow$ **Flux calibrated monitor detectors for normalization**

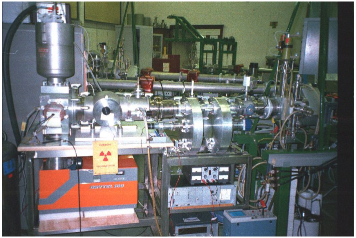
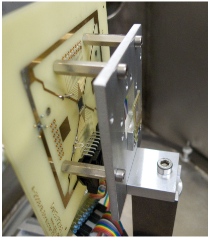
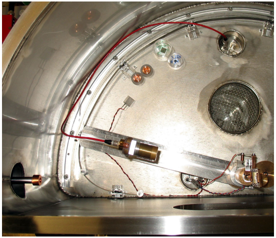
Van-de-Graaff Accelerator Facility

- 3 MV single ended Van-de-Graaff accelerator
- Terminal voltage: 0.7 - 3.7 MV (currently 0.7 - 2.4 MV)
- Beam current: 200 nA - 40 µA continuous current
- Ion types: p, H_2^+, d, D_2^+, $^4He^+$, $^{12}C^+$, $^{13}C^+$, $^{16}O^+$
- 6 beam lines

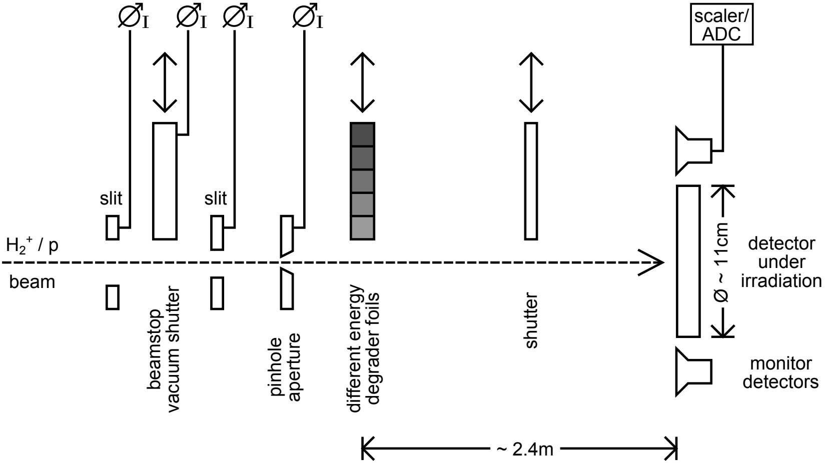


Recent Applications

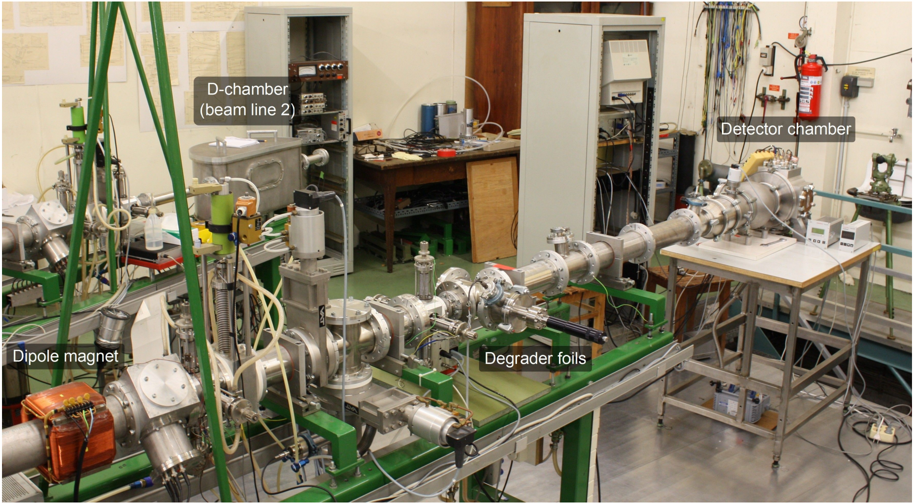
- Soft proton radiation hardness tests of *XMM-Newton* CCDs and silicon drift detector prototypes for *LOFT* (details follow)
- Low energy proton (75 - 1440 keV) response measurement of silicon strip detector for *EXL@FAIR*
- Thin film material analysis (RBS)
- Under construction: D_2 gas target for neutron radiation hardness tests of silicon detectors for *CBM@FAIR* and *ALICE@LHC*

Soft Proton Irradiation Setup (1)

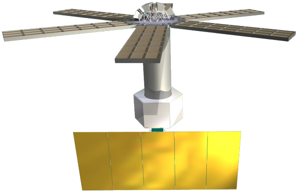


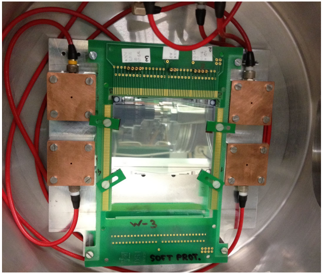
Soft Proton Irradiation Setup (2)



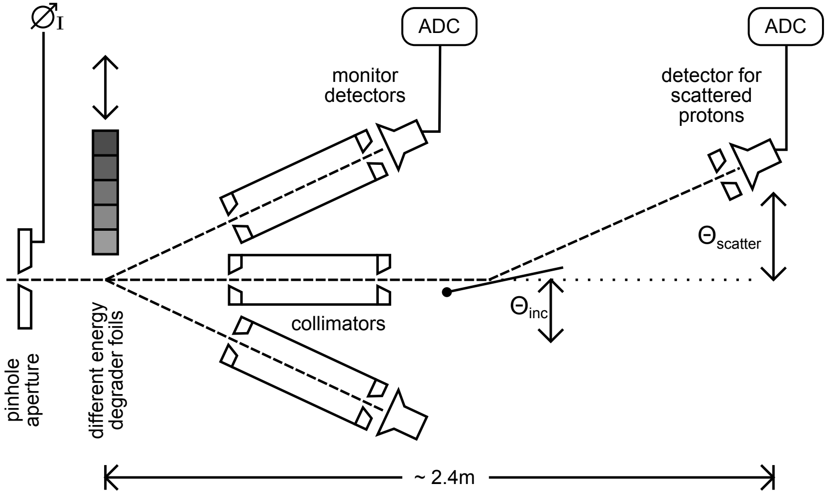
Soft Proton Irradiation of *LOFT* SDD protoypes

- Large Observatory For x-ray Timing
- One of five M3 candidates in ESA's Cosmic Vision program
- Two instruments:
  - Large Area Detector (LAD): collimated, large $A_{\text{eff}} \approx 10\,\text{m}^2$ @ 8 keV
  - Wide Field Monitor (WFM): coded mask, large FOV
- Same detector: modified version of the ALICE ITS Silicon Drift Detector (SDD)
- Two soft proton irradiation campaigns in 2012 with different SDD protoypes

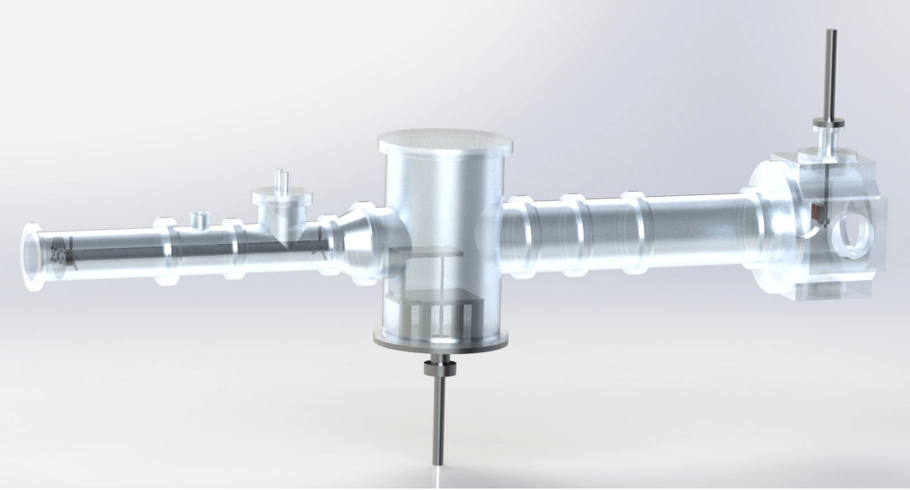




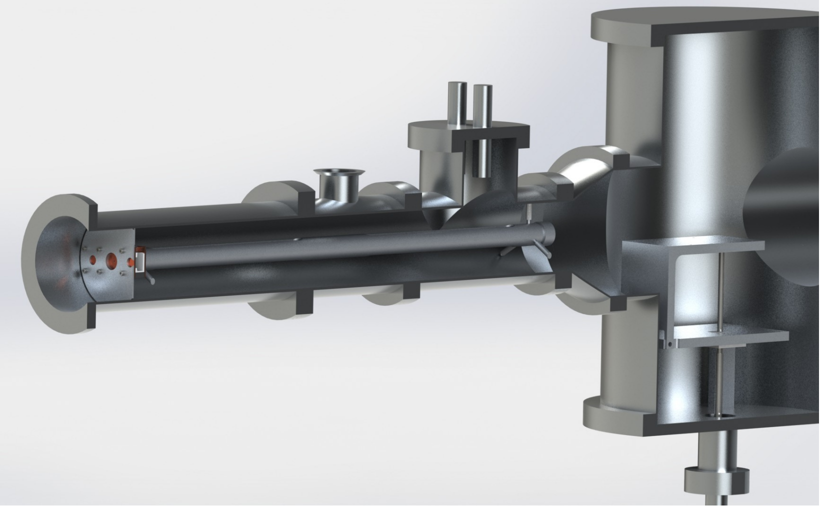
Schematic of the Scattering Setup (Preliminary)



CAD Model of the Scattering Setup (Preliminary) (1)



CAD Model of the Scattering Setup (Preliminary) (2)



Status

- Soft protons can be funneled through focusing X-ray optics
- Severe degradation of detector performance possible
- Different physical processes for funneling proposed
- Up to now, no clear experimental verification

Outlook

- Small angle proton scattering setup in Tübingen reaches end of planning phase
- Construction will start in April 2013
- First measurements expected in Summer 2013
- Goal: Sufficient energy and angular resolution to constrain underlying physical process
  $\Rightarrow$ Enhanced precision of soft proton background and detector damage studies for future X-ray observatories