Background Simulations for the IXO Wide Field Imager

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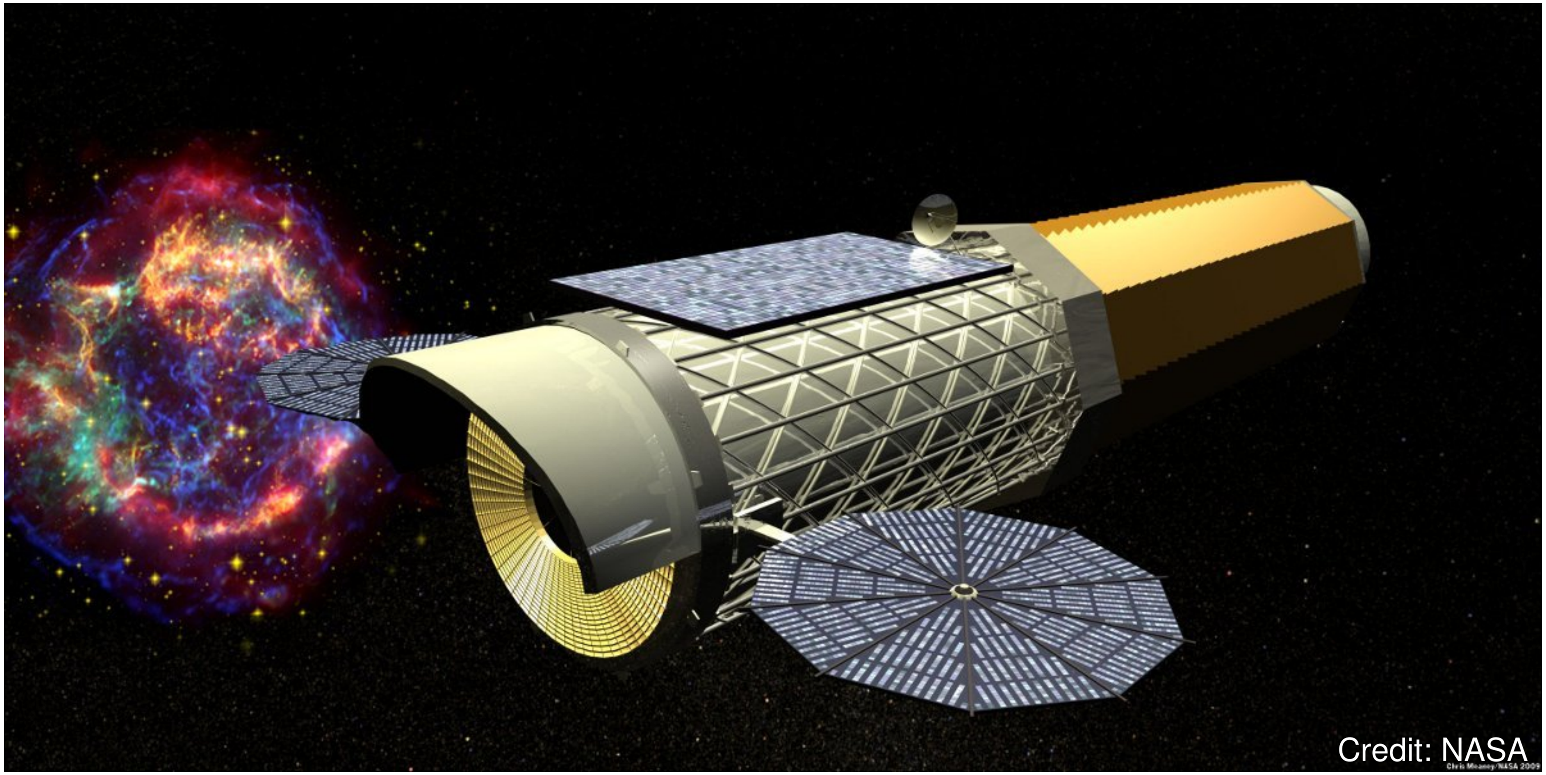


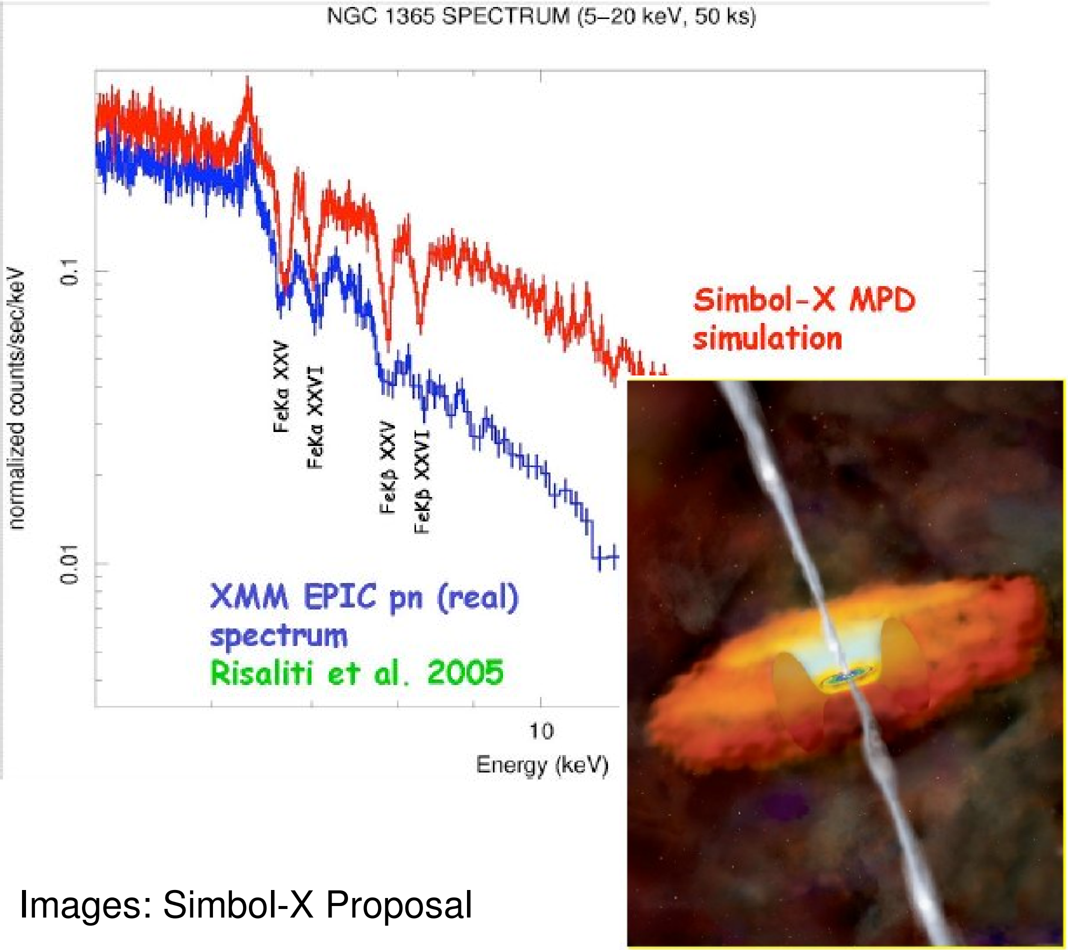
IXO Scientific Goals

Study of AGN, accretion discs and black holes limited by ability to penetrate obscuring dust

Hard X-rays can penetrate this dust

Imaging of extended sources i.e. diffuce X-ray background at high energies requires long focal length

Low background for faint and/or extended sources



Images: Simbol-X Proposal

The IXO Spacecraft

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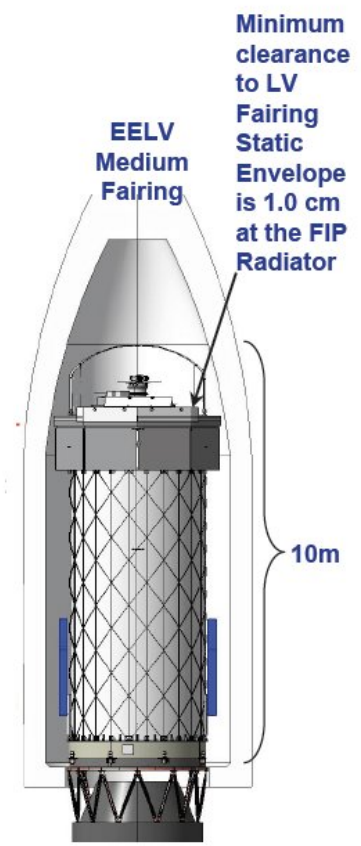
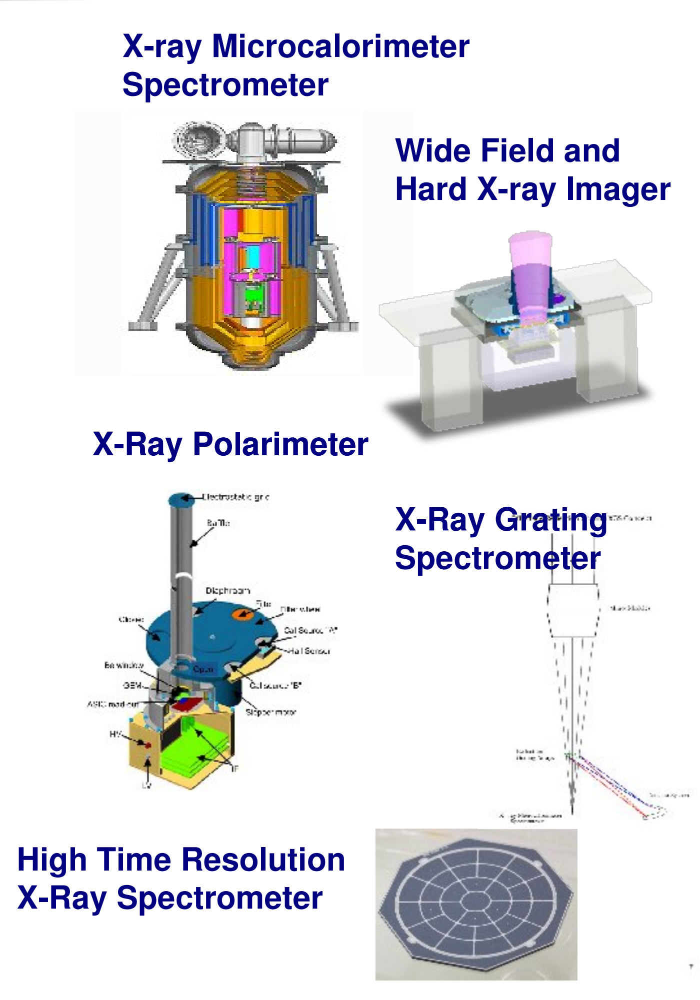
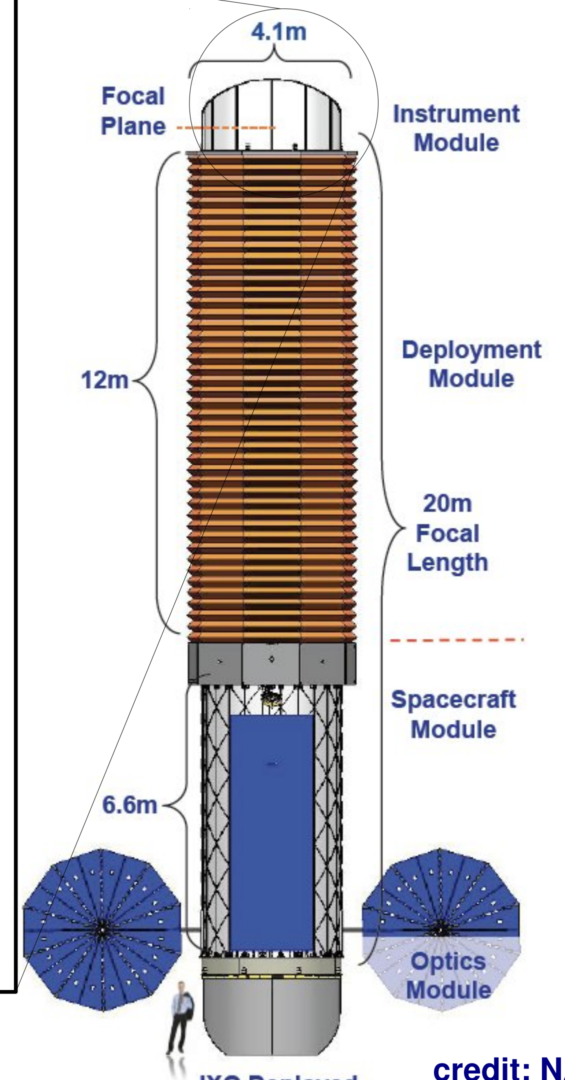


IXO in Launch Configuration





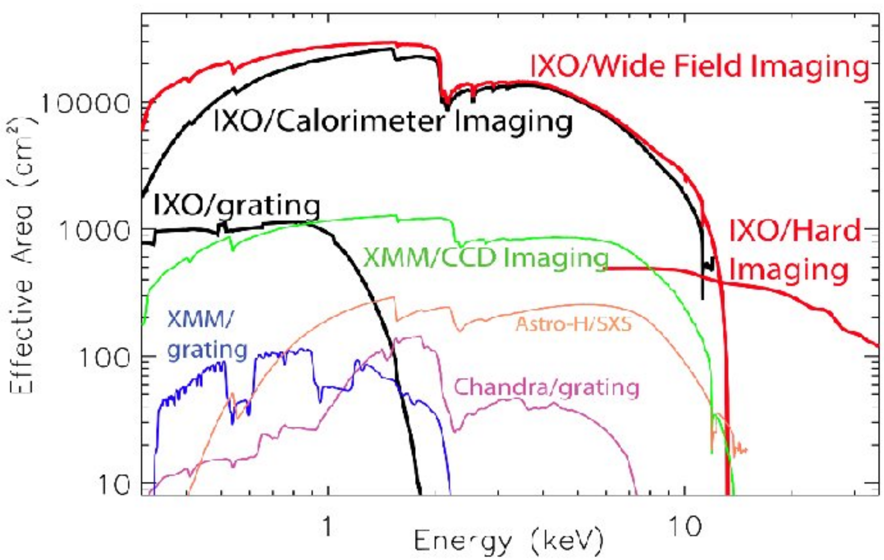
IXO Deployed

credit: NASA

IXO & WFI Specifications

IXO Optics

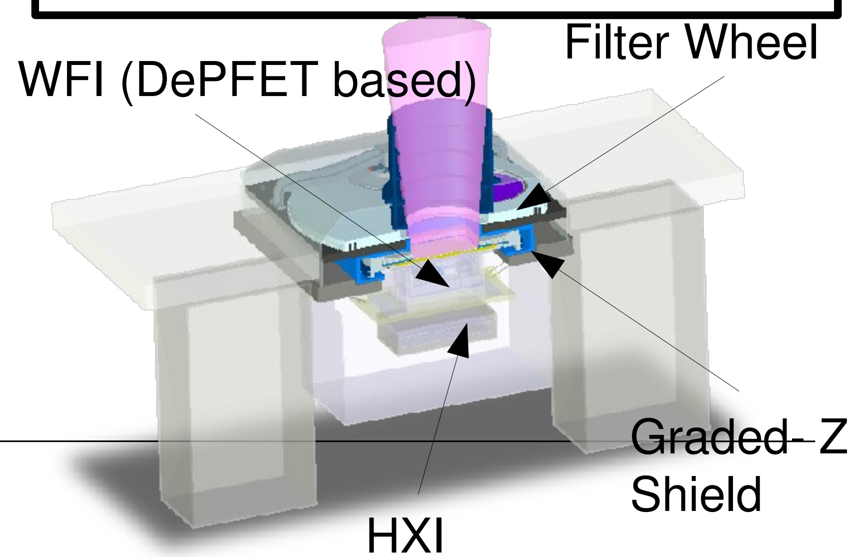
- Optic system offers 10x the effective area of XMM below 7 keV
- Effective area comparable to XMM up to 40 keV



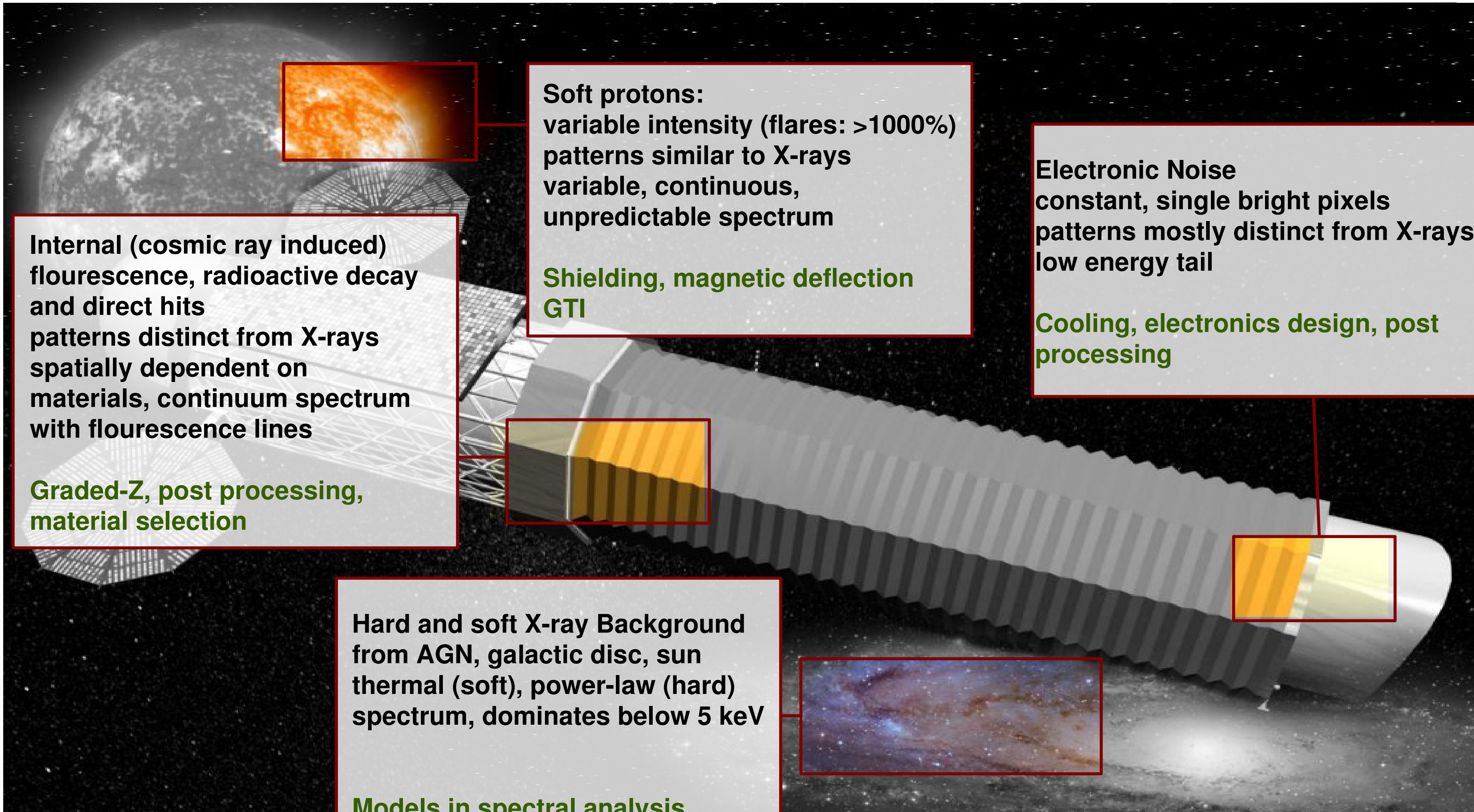
credit: A. Parmar

Wide Field Imager (and HXI)

Energy ranges	0.1 – 15 keV
	5 – 40 keV
Resolution	1024 x 1024 px
	5 “
Pixel size	100µm x 100µm
Focal plane area	10.24 cm x 10.24 cm



IXO Radiation Environment



Soft protons:
variable intensity (flares: >1000%)
patterns similar to X-rays
variable, continuous,
unpredictable spectrum

Shielding, magnetic deflection
GTI

Electronic Noise
constant, single bright pixels
patterns mostly distinct from X-rays
low energy tail

Cooling, electronics design, post processing

Internal (cosmic ray induced)
flourescence, radioactive decay and direct hits
patterns distinct from X-rays
spatially dependent on materials, continuum spectrum with flourescence lines

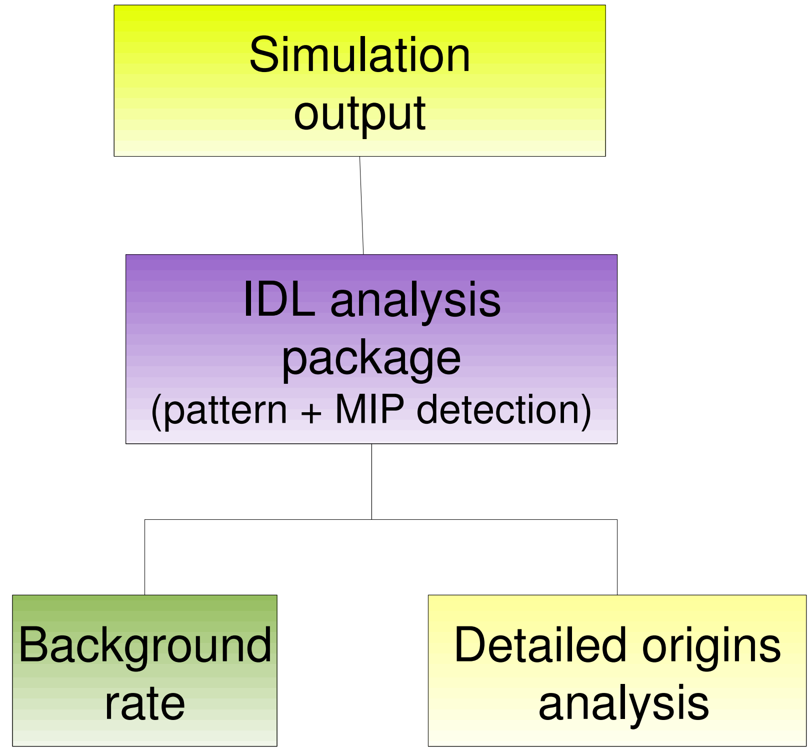
Graded-Z, post processing, material selection

Hard and soft X-ray Background
from AGN, galactic disc, sun
thermal (soft), power-law (hard)
spectrum, dominates below 5 keV

Models in spectral analysis

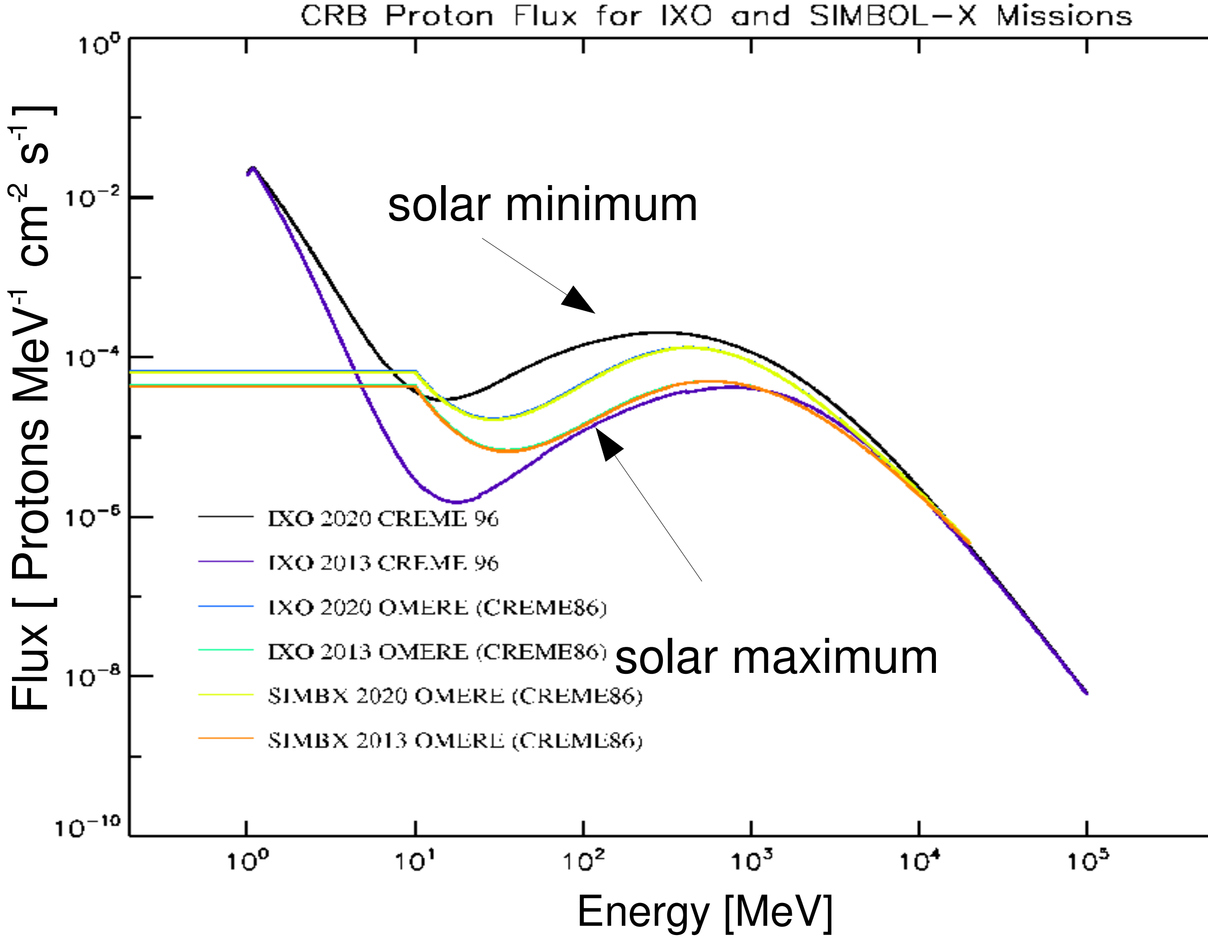
Geant4 Simulation Overview

- Geant4 version: 4.9.1 & 4.9.2 (with patches, 64 bit)
- Physics: Low-Energy EM, user physics list for hadronics (binary cascade)
- Geometry: hand-coded, CGS, pixelized detector (in tracking and readout geometry)
- Source: GPS, user defined spectral input, spherical, isotropic
- Output: FITS compatible events list, detailed output of processes and particle origin separatly possible.



IXO Radiation Enviroment
The Simulation Input

- CREME 96
- Valid up to Mars orbit – so it should be valid at L2
- Simulations at solar minimum
- Mean flux: 2.31 protons/cm²/s
- Neglect He and heavier elements (<2% of total flux)



WFI Geometrical Design and Simulation Implementation

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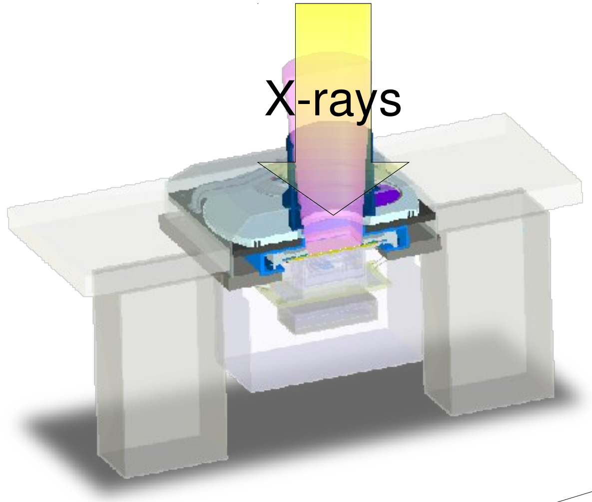
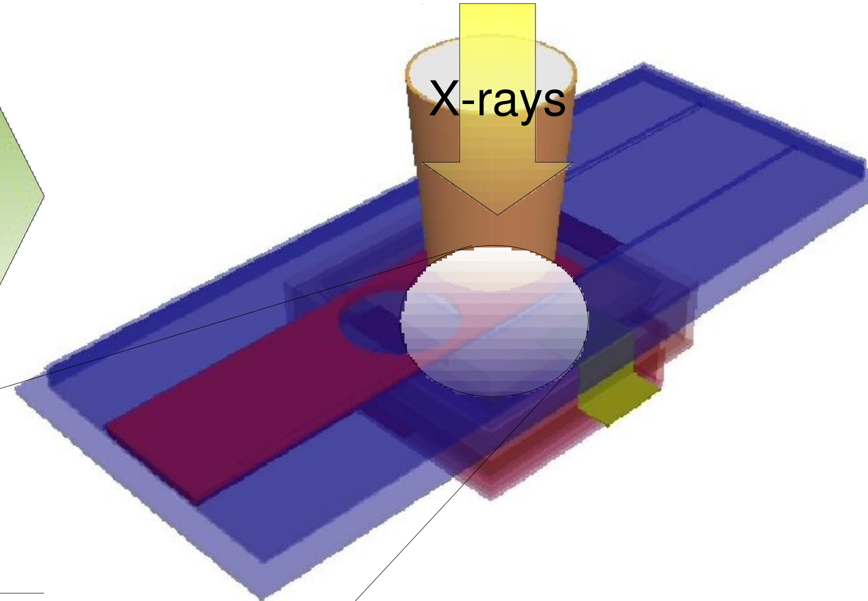
Mechanical Design Model

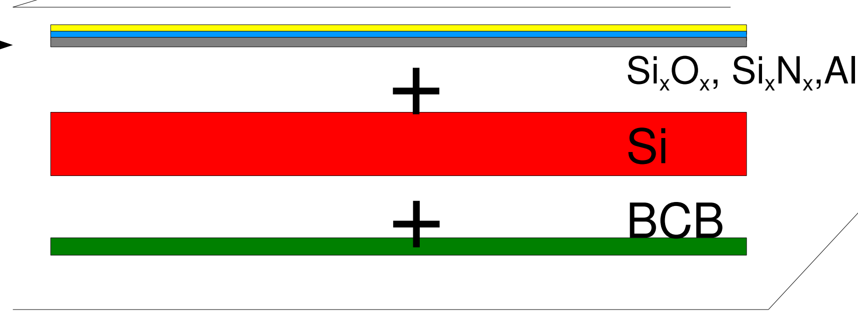


Approx. by primitives

GEANT4 Representation (C++)



Thin layers (~10nm)



Wafer-proximity in greater detail

WFI Geometrical Design

Influence of Fixed and Movable Instrument Platforms

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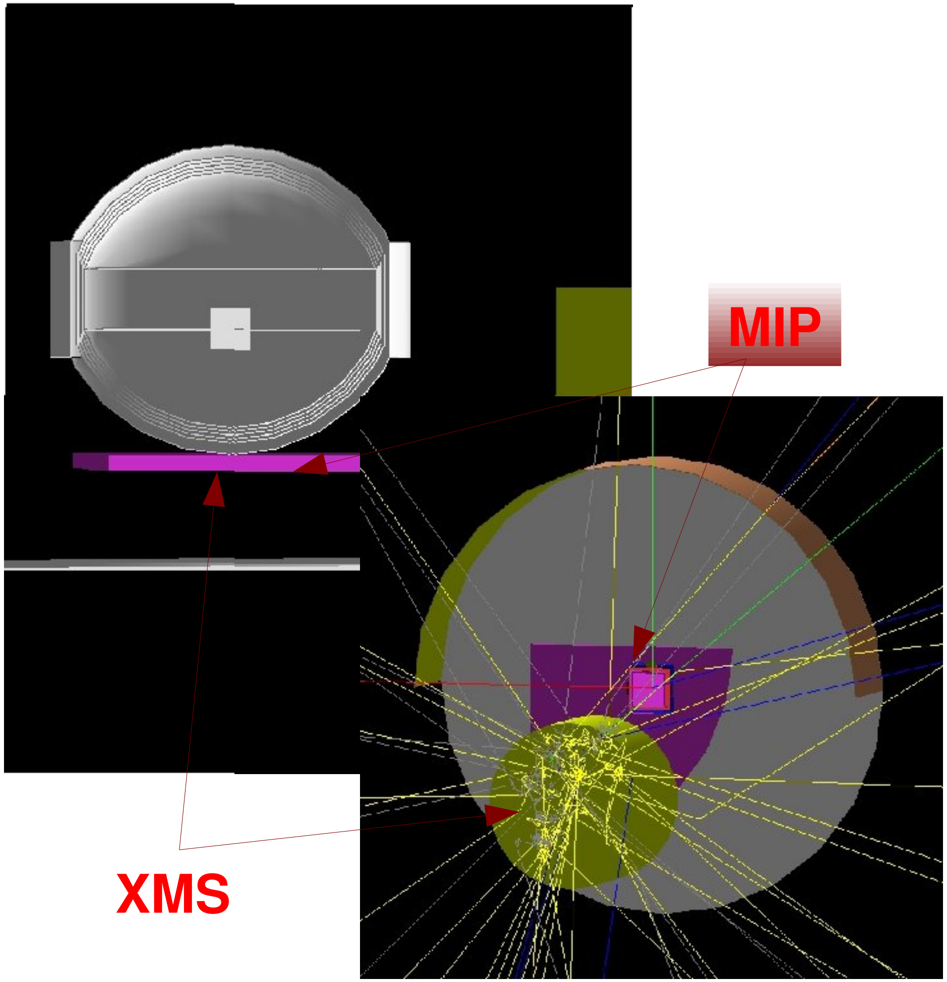
- Possibility to add XMS, MIP and FIP mass dummys
- This prolongs the simulation time since more volume has to be irradiated by source → longer runs for same statistics on detector
- Change in count rate is negligable :
  - with satellite structs: 21.0±2.7
  - w/o sattellite structs: 18.9±0.3

  x 10^{-4} cts/cm²/s/keV
- Therefore most simulations w/o satellite structures



Pattern Detection as a Background Reduction Measure

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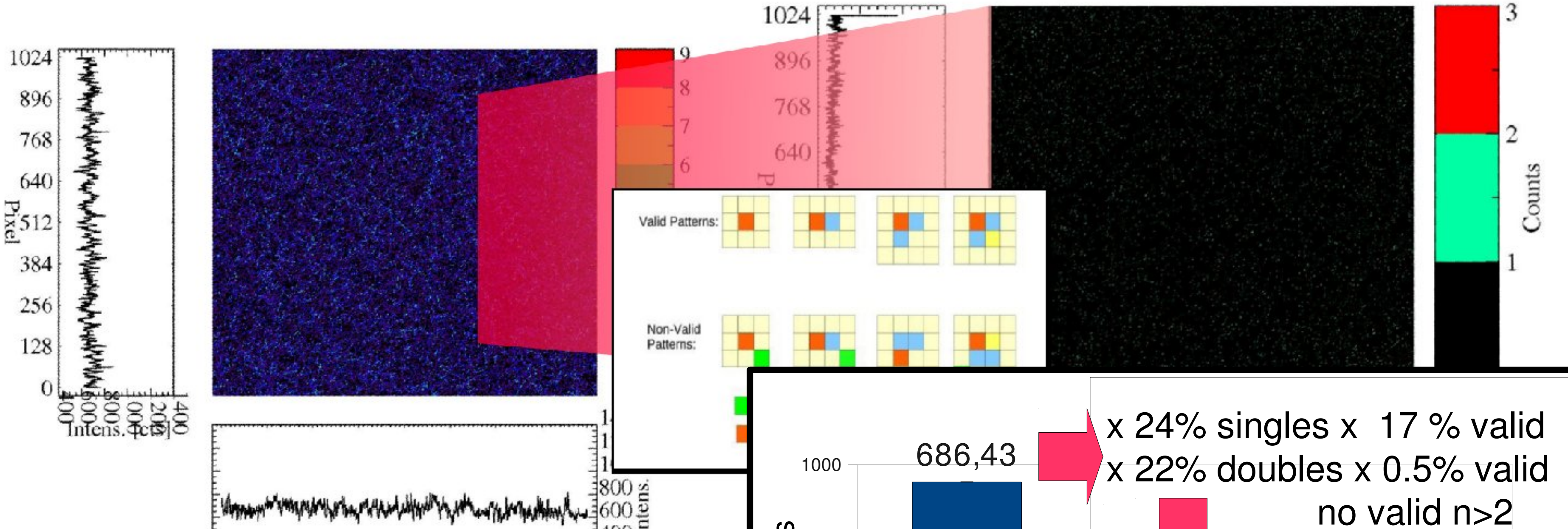

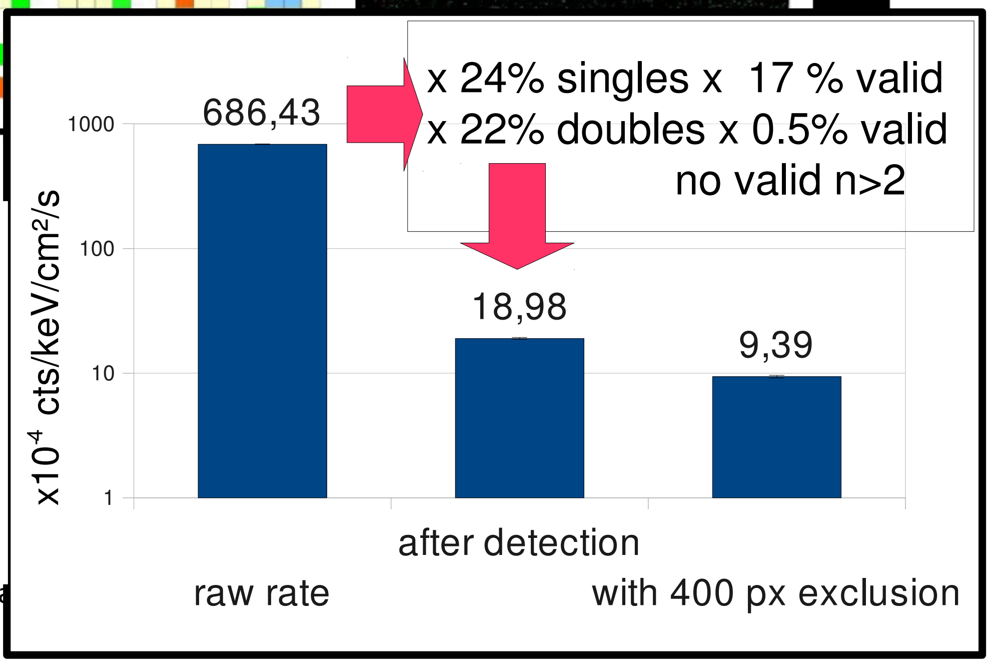

- Pattern detection for invalid patterns caused by non-gamma particles (similar to XMM Newton)
- MIP detection
- Significant reduction of background rate
- BUT: in wafer charge distribution not modelled yet

WFI Background Spectrum - Before Pattern and MIP Detection

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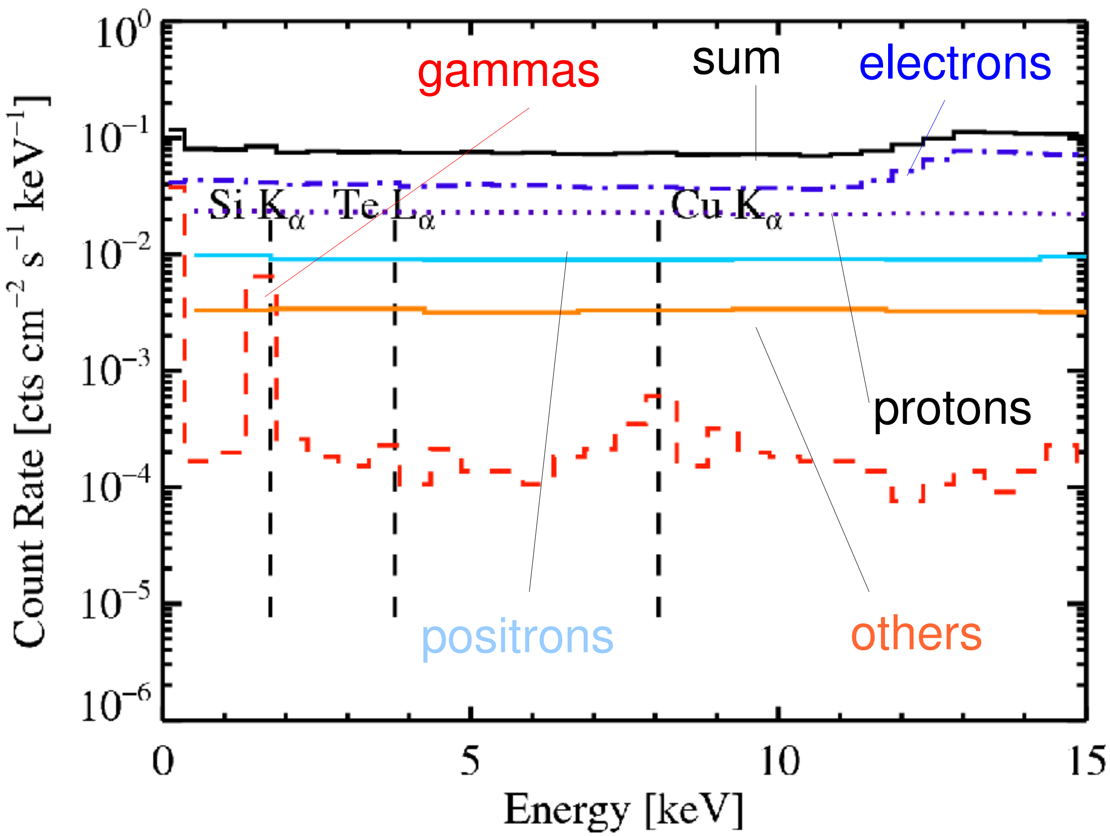
- No line emission except Si – supressed by graded-Z shield
- Electrons main component
- Protons second strongest component
- Flat spectrum

70 Mio. primaries, with realistic wafer, WFI only



Flux by Particle Species

Particle species	Flux (10^{-4} cts/cm²/s/keV)
e-	452.68±1.52
p	228.04±1.08
e+	91.04±0.68
γ	12.2±0.25

WFI Background Spectrum - After Pattern and MIP Detection

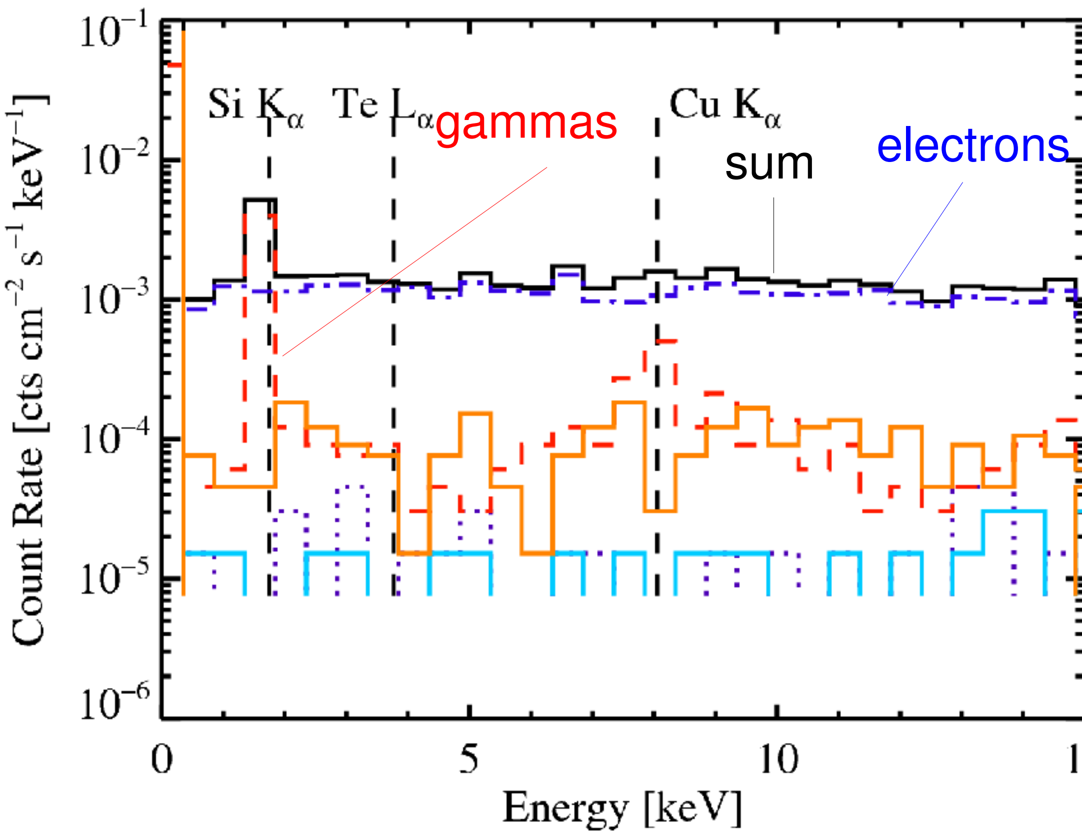
- **Events produced by protons are suppressed by pattern recognition**

- **Electron component one order of mag. stronger than others outside Si-line → primary optimization goal**

Flux by Particle Species

Particle species	Flux (10^{-4} cts/cm²/s/keV)
e-	11.21±0.17
p	0.12±0.02
e+	0.09±0.2
γ	7.54±0.15

70 Mio. primaries, with realistic wafer, WFI only



Angular Distribution of Secondary Electron Component

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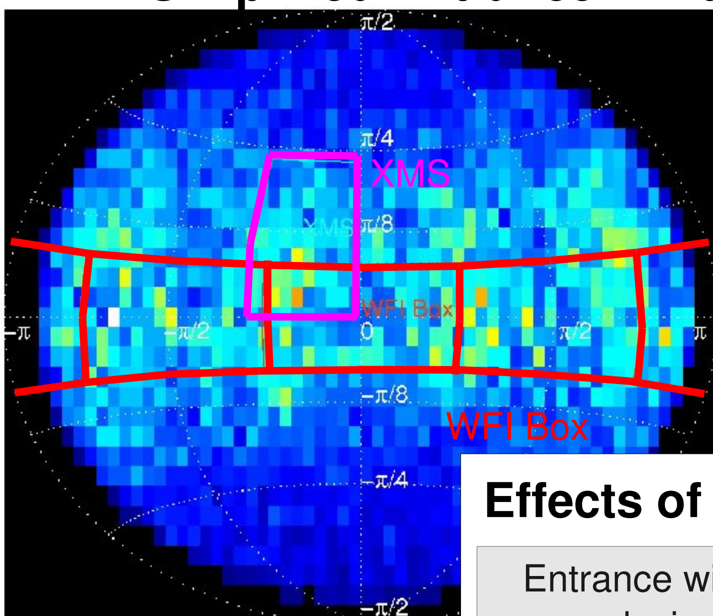
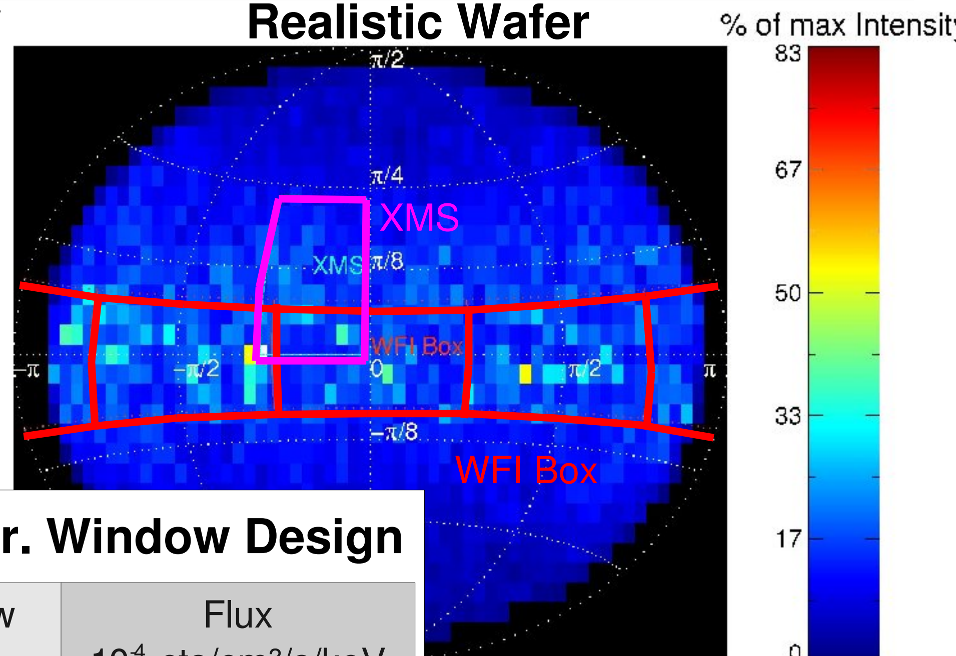
- Dominating electron component mainly incident at small angles
- Additional Al-layer on Si-wafer could help → switch from simplified entrance window representation to more realistic one
- Significant reduction

Simplified Entrance Window



Realistic Wafer



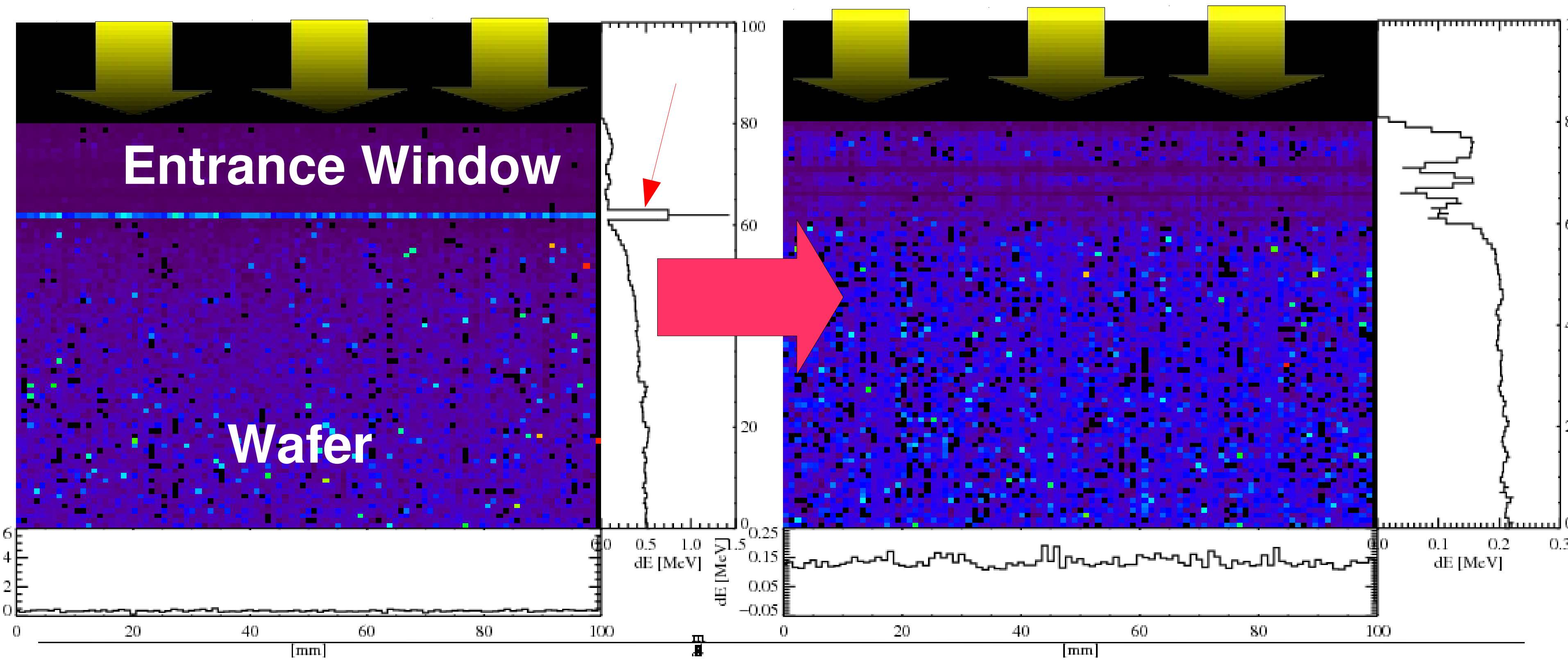
Effects of Entr. Window Design

Entrance window design	Flux 10^{-4} cts/cm²/s/keV
simplified	22.99±0.31
realistic	18.98±0.34

Realistic Wafer Representation

Problems encountered

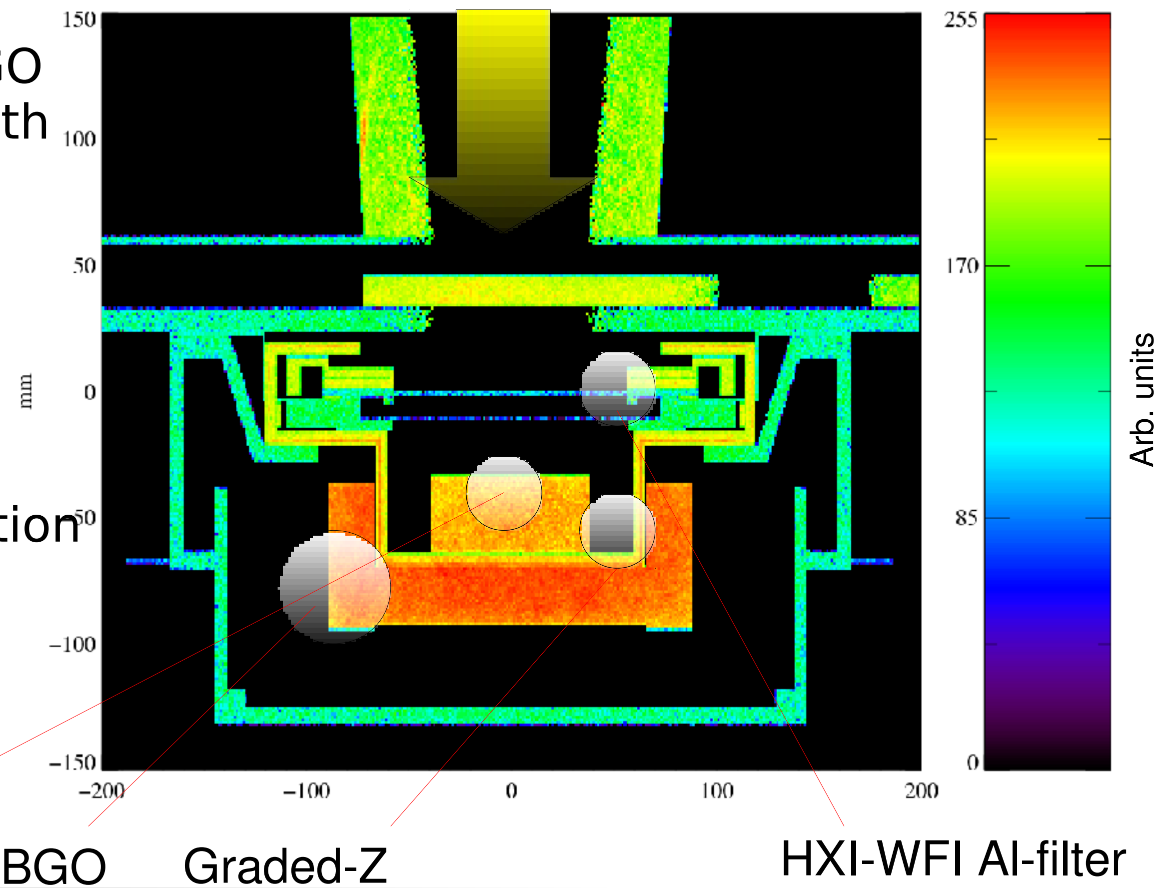
- Energy deposit at SiO – Si boundry shows unrealistically sharp peak
- By default no secondary production in Si below approx. 10nm or 990 eV particles
- Need to manually tell Geant to process these particles.
- Problem of scales (macroscopic vs. microscopic) known → intensive work within nano5 R&D



Optimization Possibilities

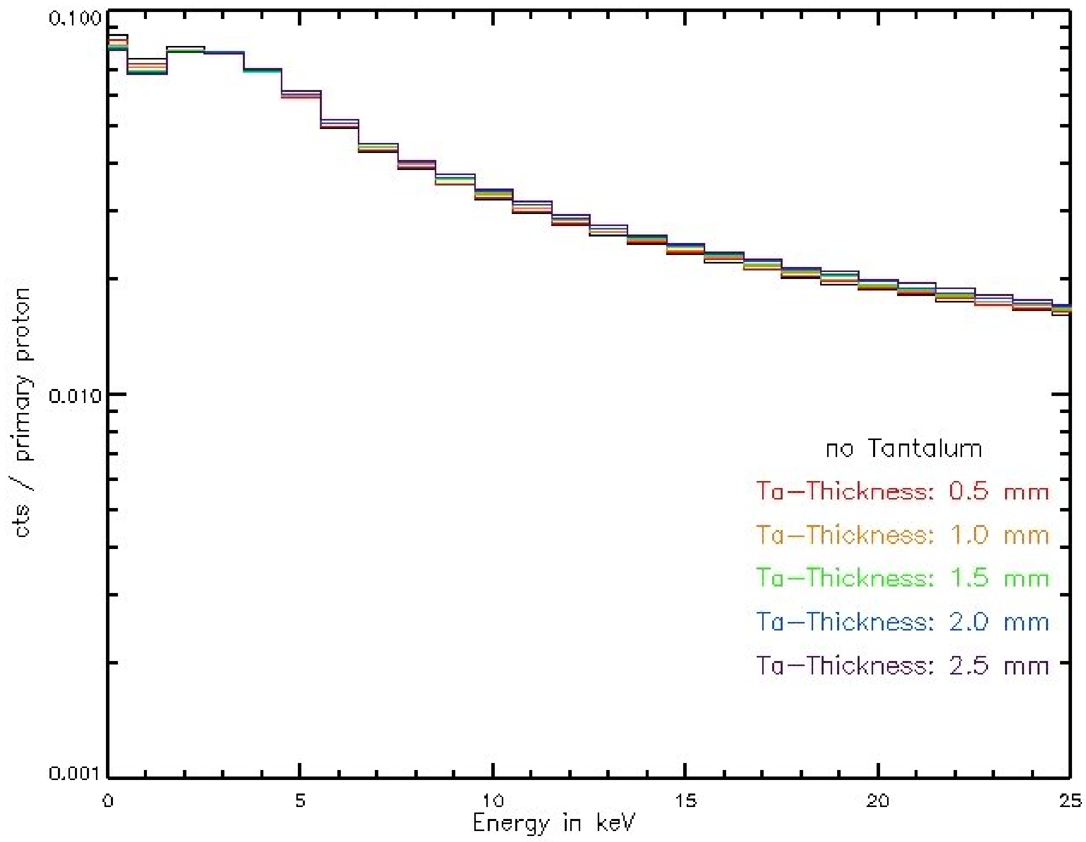
- HXI, BGO and graded-Z are important contributers
- Optimization of HXI and BGO needs to be coordinated with HXI group
- Simplified simulation of shielding layers shows that changes in high-Z layer configuration do not significantly change secondary electron production (see next slide)

Secondary e- Production



Influence of Graded-Z Composition on e- Production

Secondary e- Production with Varying Ta-Thickness



- Changes in high-Z layer thicknesses have marginal influence on secondary electron production

- Electrons instead produced in next lower layers

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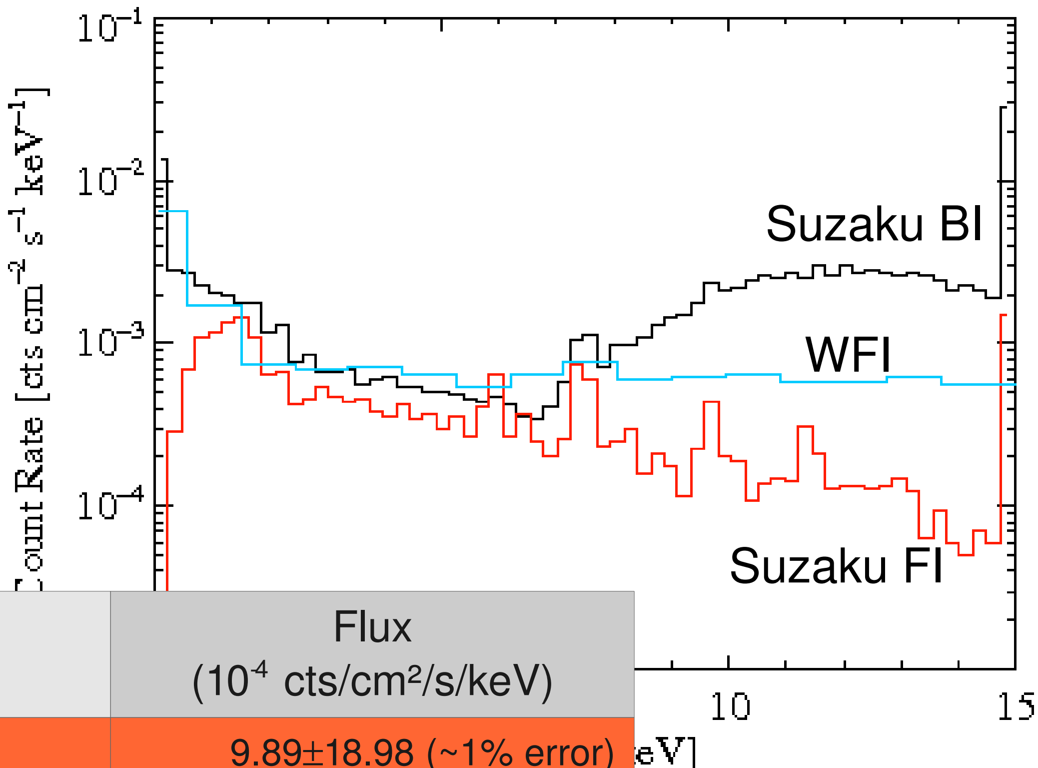
Comparison to Suzaku



	Flux (10^{-4} cts/cm²/s/keV)
IXO	9.89±18.98 (~1% error)
Suzaku BI	30.25-80.25 (err. unknown)
Suzaku FI	13.75-27.50 (err. unknown)

- IXO: simulation
  Suzaku: measured blank sky files
- Similar pattern and MIP detection algorithms
- Similar detector specs: 1024x1024 px, 0.4-12 keV energy range
- IXO data is near solar minimum while Suzaku data was taken during intermediate cycle

Summary

- All major costituents of the background were identified.
- Secondary electrons domitate background by one order of magnitude outside Si-K_α line.
- Currently implemented, non mass optimized graded-Z shield supresses all emission lines except Si (emitted from wafer bulk).
- Graded-Z shielding is currently being optimized for mass and minimum electron production.
- Main contributers of the different constituents indentified within the geometry. For secondary electrons: HXI and BGO and graded-Z shield.
- Pattern and MIP detection algorithms significantly reduce the background by 90%, by reliantly identifying events due to protons and positrons.
- Realistic representation of the entrance window is needed, since this has non-negliable influence on the dominating secondary electron component.

Summary

- Geant4 has problems simulating microscopic and macroscopic geometry within one simulation.
  Special care has to be taken when using layers thinner then default minimum secondary production threshold because artifacts may appear.
  This problem is known and is intensively being worked on within the nano5 R&D effort.
- **Current estimate of the WFI background lies between 9.89 and 18.98 x 10^{-4} cts/s/cm²/keV depending on post-processing and entrance window implementation.**
  This is partly below the measured background of the Suzaku XIS detector even under more severe background conditions (solar minimum vs. intermediate cycle)

Outlook

- Optimisation of the graded-Z shield is currently ongoing. The goal is to optimize for mass and reduce the secondary electron production while retaining the good emission line supression capabilities.
- Realistic inplementation of charge collection and charge cloud distribution in wafer needs to be added → event splitting
- Prototype of WFI could be used for benchmarking simulation

- Include simulation of background due to radioactive decays of satellite materials (either intrinsic or through on orbit activation)
- Validation of radioactive decay physics and inclusion of long term activation as part of nano5 project

Ongoing activities

Mauro Augelli, Marcia Begalli, Steffen Hauf,
Mincheol Han, Chan Hyeong Kim, Markus Kuster,
Maria Grazia Pia, Lina Quintieri, Paolo Saracco,
Hee Seo, Georg Weidenspointner, Andreas Zoglauer

- **Epistemic uncertainties in Monte Carlo simulation**

  - Paper in IEEE TNS, October 2010 issue (26 pages original text)
  - Test case study: proton Bragg peak simulation
- **Low energy electrons** — Paper being finalized

  - 2 new models of ionization cross sections + experimental validation
  - Relevant to radiation effects, microdosimetry etc.
  - Validation of EEDL (basis of Geant4 "low energy" ionization)
- **X-ray physics** — Paper being finalized

  - Survey of Geant4, EGS, MCNP, Penelope etc. atomic parameters
  - Validation w.r.t. experimental data
- **Physics data libraries** — Paper in preparation

  - Design and performance improvements
  - New compilations (PIXE, X-ray physics, electron cross sections etc.)

and more…

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