An InGrid based Low Energy X-ray Detector for the CAST Experiment

RD51 Miniweek - WG2
CERN

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Physikalisches Institut

universitätbonn

Outline

The CERN Axion Solar Telescope

Axions from the sun

- Primakoff effect generates huge axion flux from the Sun
- Axions can reconvert to photons inside large $\vec{B}$ fields
- Energy of solar axions below 15 keV (flux peaks at 3 keV)

Current X-ray Detectors

- Microbulk Micromegas
- X-ray Telescope plus pnCCD (until mid of 2013)
- Prototype SDD

CAST – An axion helioscope

CAST – Data taking

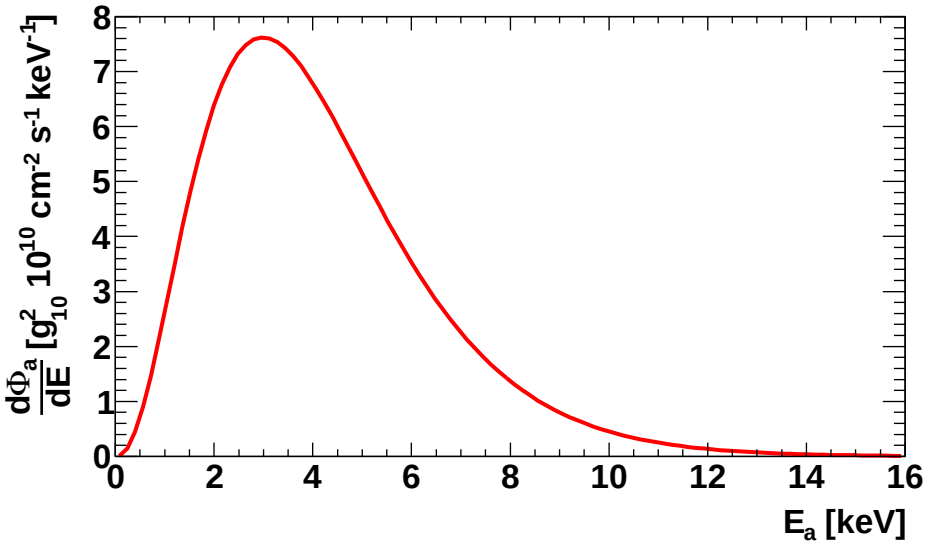
- Magnet can track Sun 2×1.5 h per day
- Otherwise: background data
- Alignment can be checked by Sun- and Moon-filmings

CAST – Future Plans

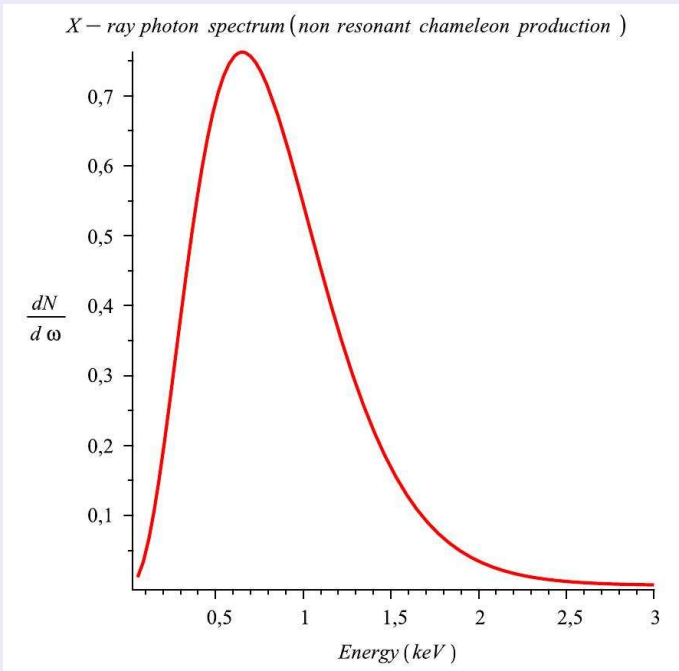
Future Plans

- Increase sensitivity for axion detection
- Additional search for Solar Chameleons (Dark Energy particles)
- Need detectors with threshold below 1 keV

Solar Axions



Solar Chameleons



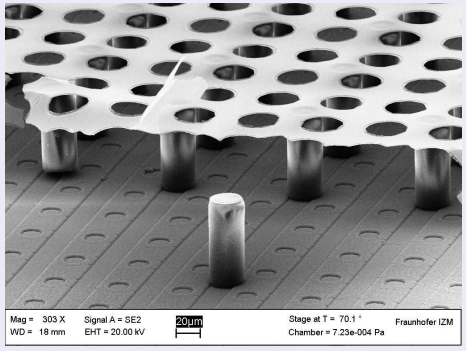
Integrated Micromegas – InGrid

Chefdeville et al - Nucl. Inst. Meth. A 556(2006), p 490

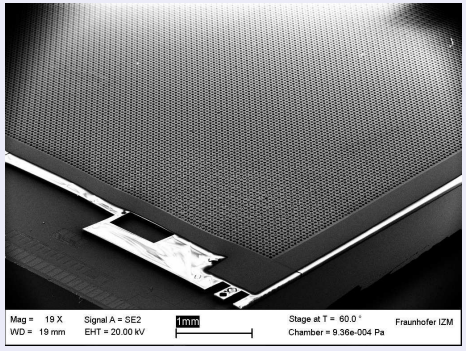
Micromegas on top of Timepix ASIC

- Fabrication by means of photolithographic postprocessing
- Very good alignment of grid and pixels
- Each avalanche is collected on one pixel
- Detection of single electrons possible

InGrid - SEM



Timepix + InGrid



Production of InGrids

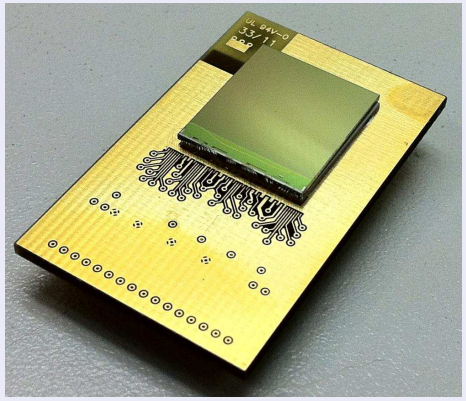
- Single and few chip processing: NIKHEF / Mesa+ (Twente)
- Wafer processing (~ 100 chips at once): in cooperation with IZM Berlin

Timepix ASIC

Facts about the Timepix ASIC

- 256×256 pixels, $55 \times 55\,\mu m^2$ pitch
- $1.4 \times 1.4\,cm^2$ active area
- Charge sensitive amplifier and discriminator in each pixel, $90\,e$ ENC
- Two modes: **Charge** or **Time**

Carrier board



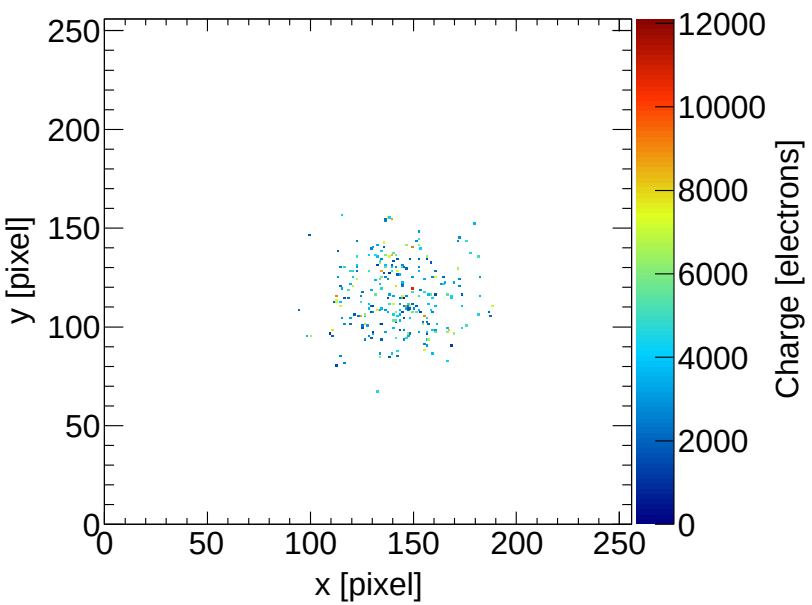
Protection of electronics

- Timepix ASIC is designed for imaging as readout electronics to be bump bonded on a silicon sensor
- Bump bond pads can be used as charge collecting anodes but electronics not designed to survive discharges
- Need resistive protection layer (4 or 8 µm silicon nitride) to spread charge in case of discharge

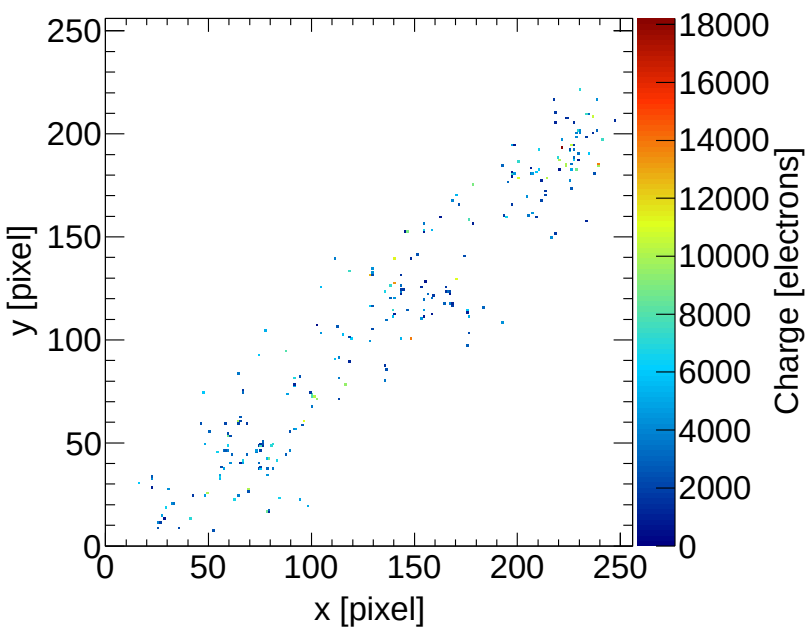
Outstanding Features of an InGrid Based X-ray Detector

- Low energy threshold as single electrons can be observed
- Topological background suppression through event-shape analysis

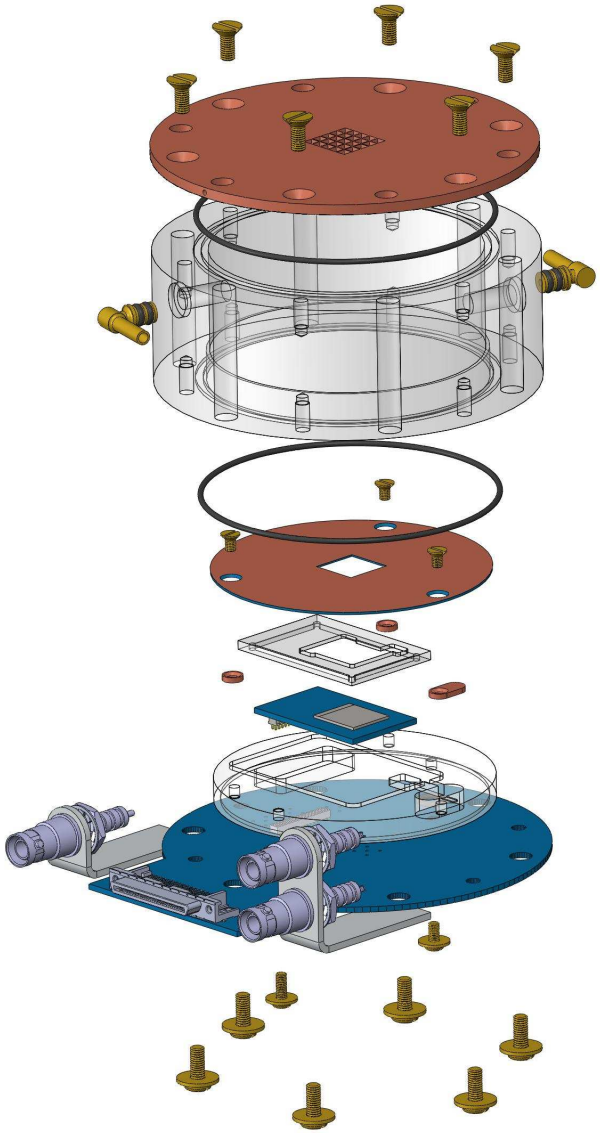
X-ray Event



Background Event

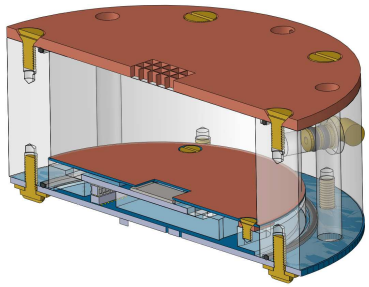


An InGrid based Detector for CAST

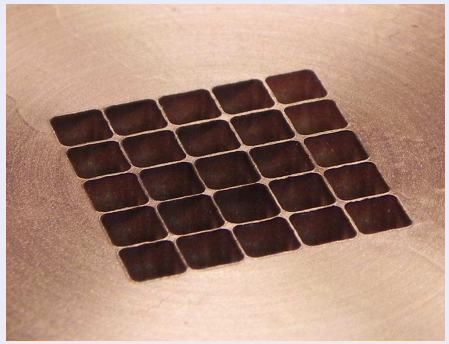


Features

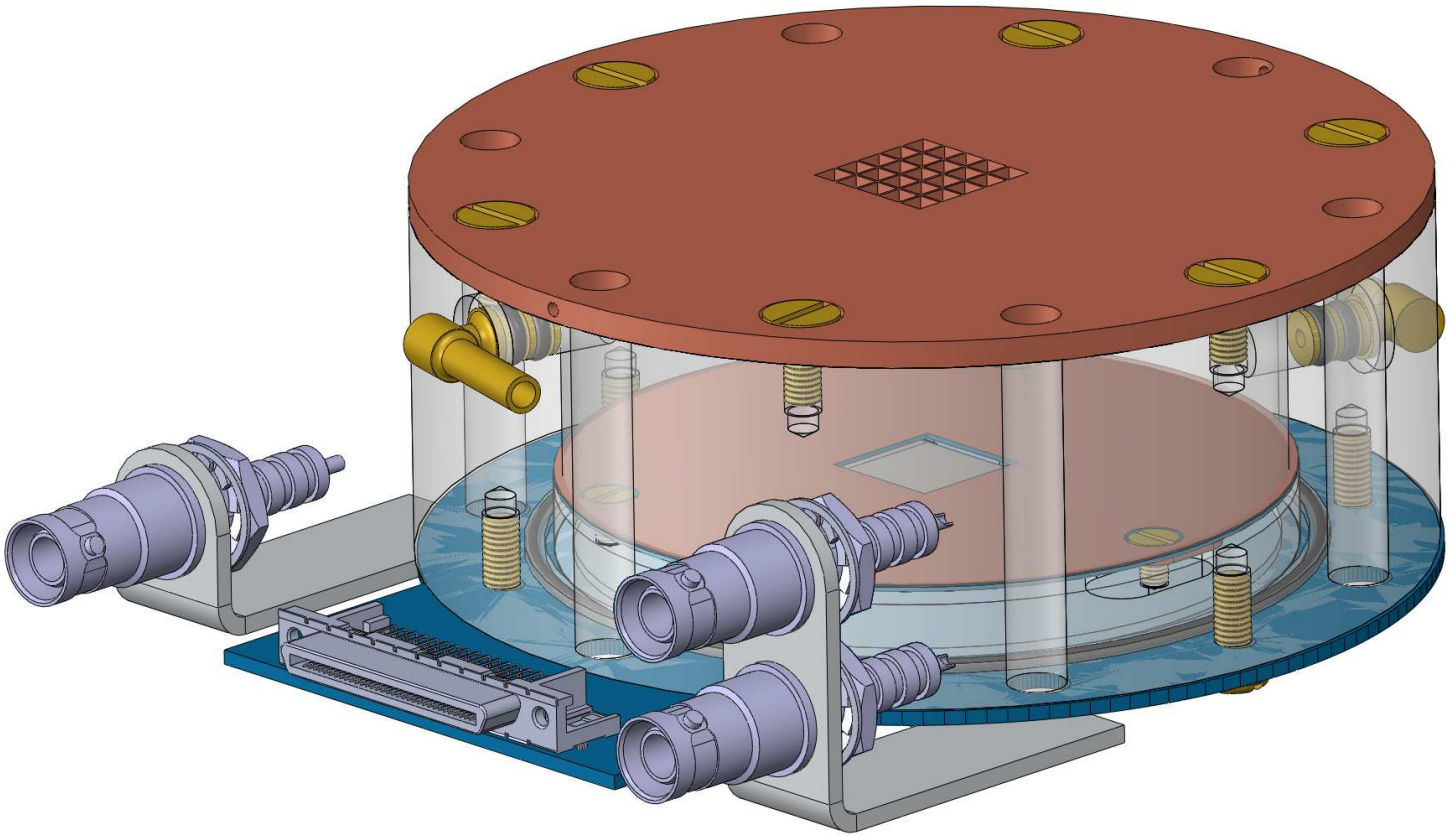
- Modular design based on the 2012 CAST Micromegas
- Body made of plexiglas
- Exchangeable readout module
- Gas: Ar/iC$_4$H$_{10}$ 97.7/2.3
- X-ray Window made of 2 µm Mylar with copper strongback



Strongback



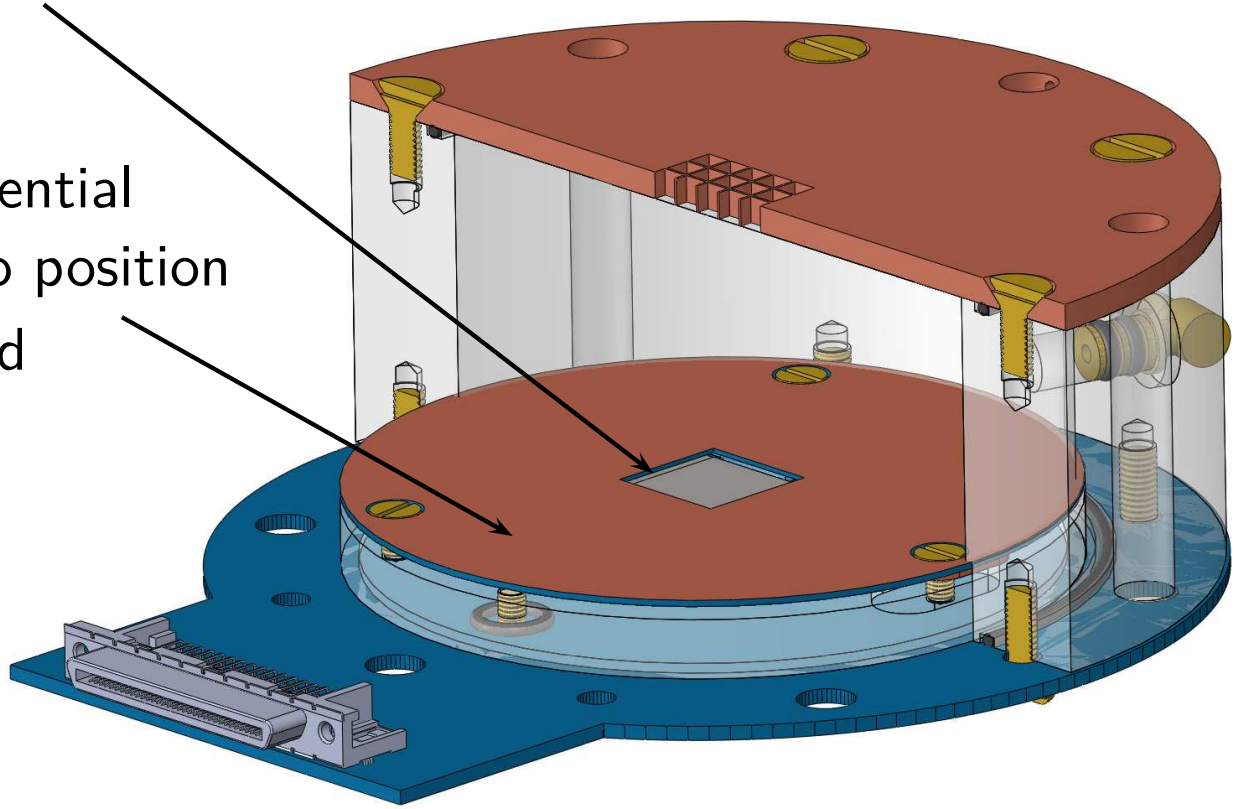
Anode Design - Minimizing Field Distrotions



Anode Design - Minimizing Field Distrotions

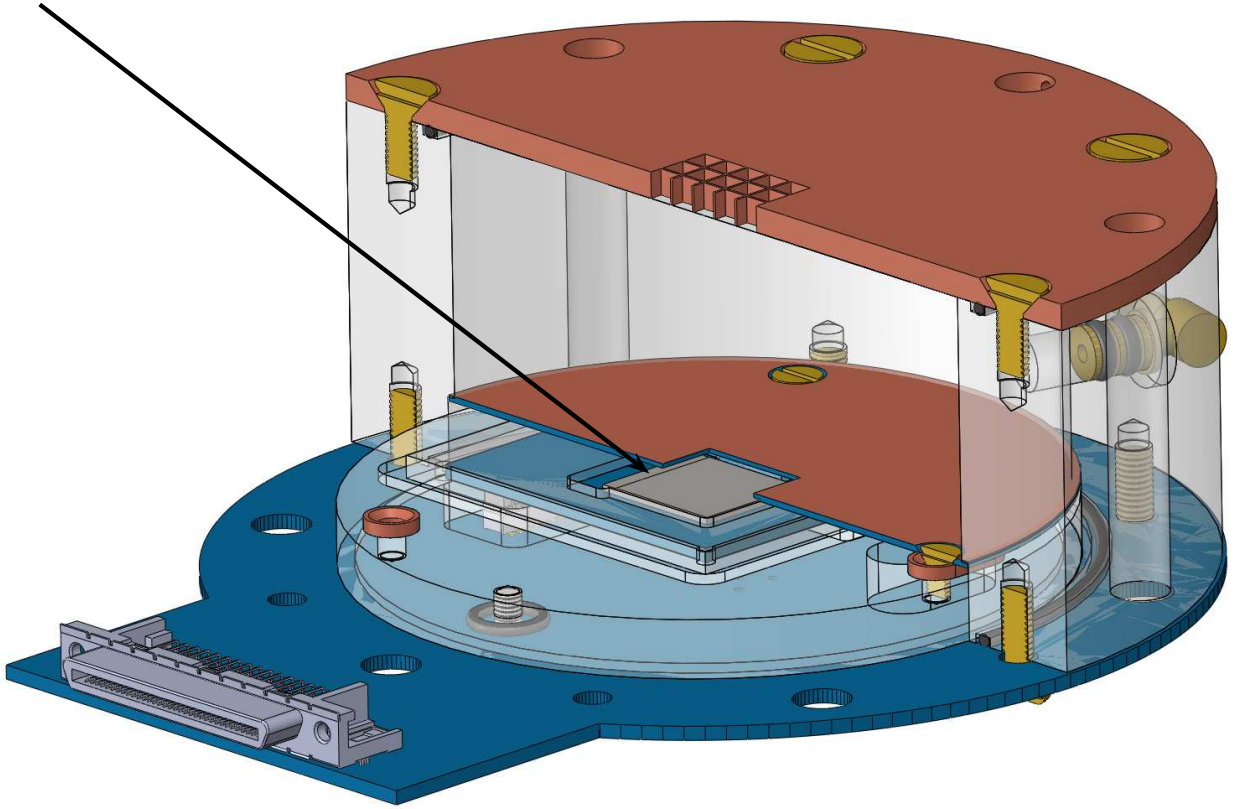
Cutout matched to active area

Anode potential
adjusted to position
in drift field

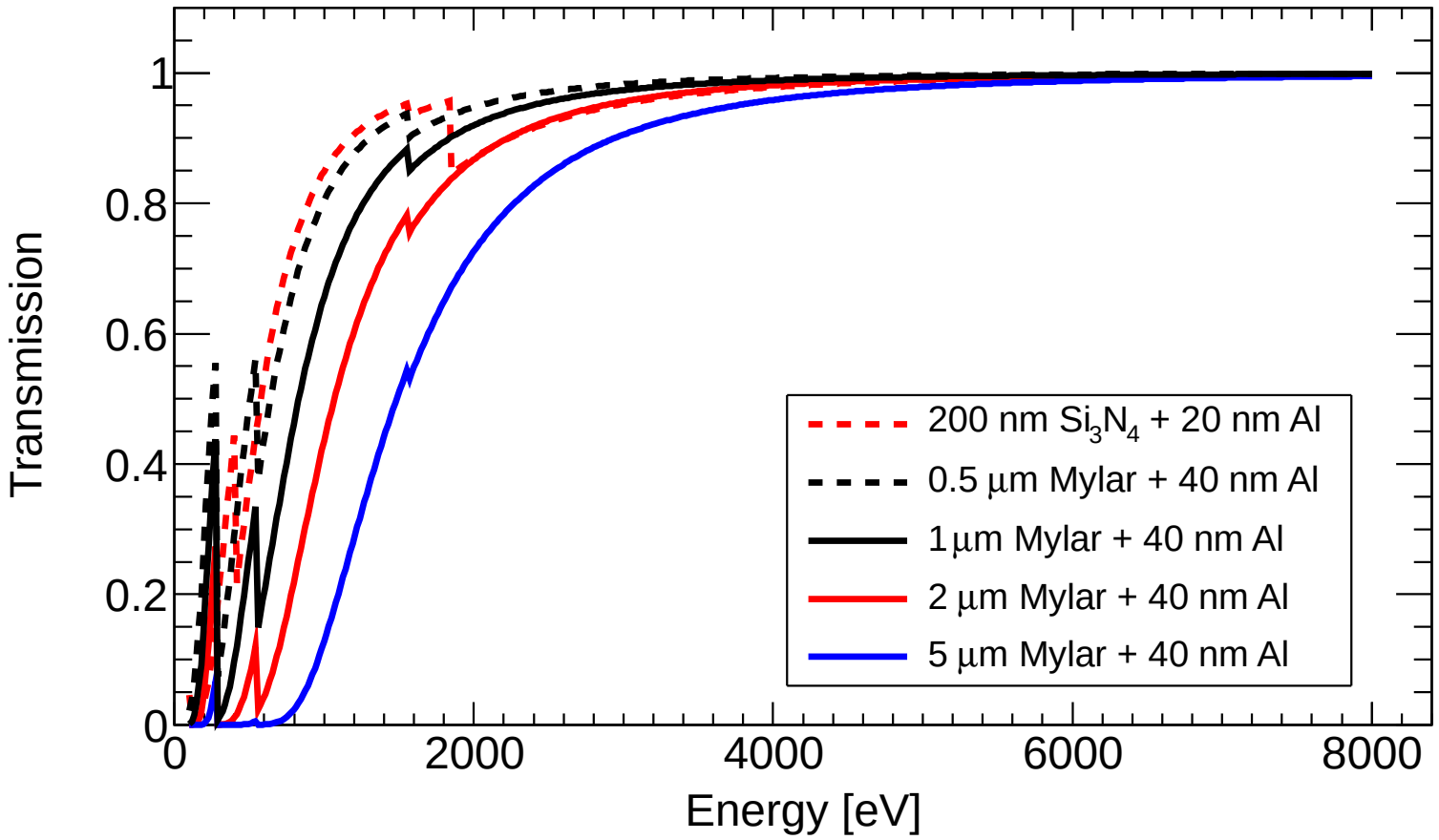


Anode Design - Minimizing Field Distrotions

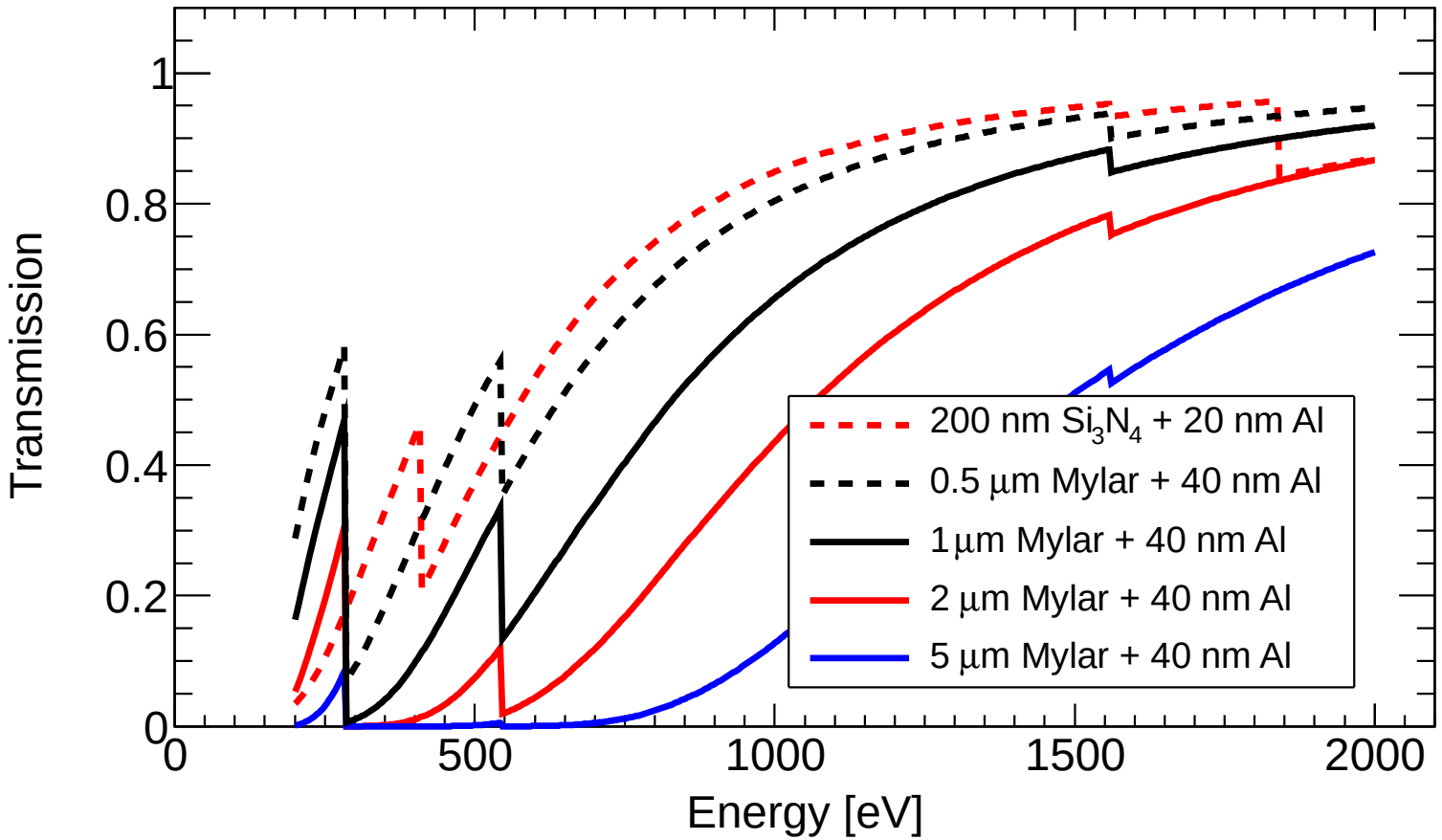
Covering bond pads and wires



X-ray Window Transparency

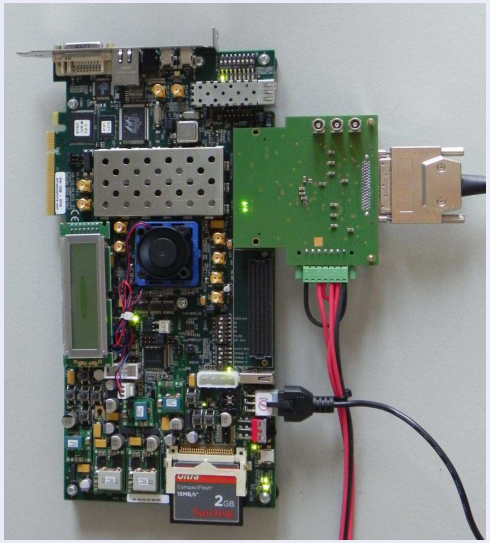


X-ray Window Transparency



Readout System

Virtex6 Readout



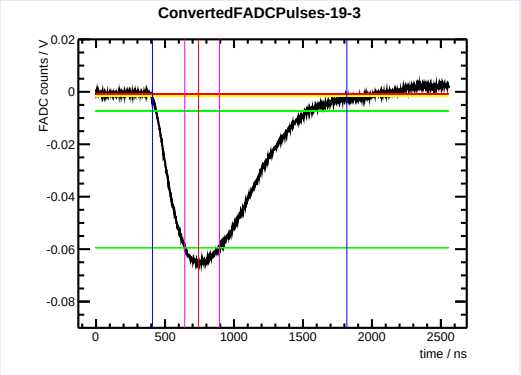
FPGA based readout system

- New readout system for Timepix ASIC has been developed at Bonn
- FPGA based, flexible and customizable
- Full access to firm- and software
- For CAST a system based on a Virtex6 evaluation board is used

Readout of the induced on the grid

- Combined readout of chip and FADC
- Possibility of 'triggered' readout
- Use pulse-shape analysis to improve background suppression
- May serve as future detector upgrade

X-ray Pulse



Detector Performance

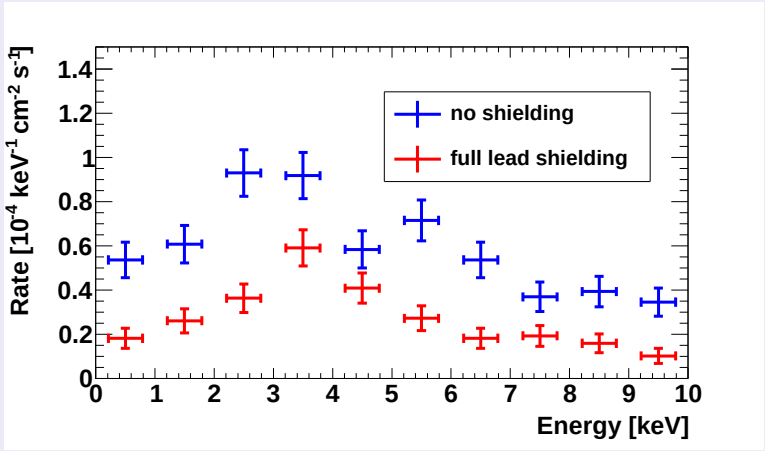
Energy Resolution

- Resolutions down to $\sigma_E/E \approx 3.85\,\%$ at 5.9 keV were observed in Ar/iC$_4$H$_{10}$ 90/10 at optimized settings (Energy determined from pixel counting)
- In Ar/iC$_4$H$_{10}$ 97.7/2.3 resolutions down to $\sigma_E/E \approx 5.33\,\%$ at 5.9 keV are possible

Background Discrimination

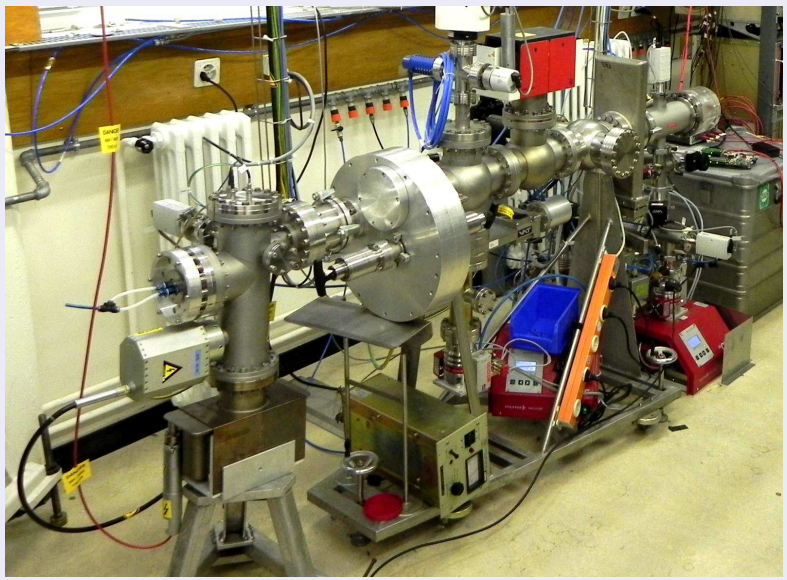
- Background suppression with LHR method
- Decision based on reference data sets

Background Spectrum

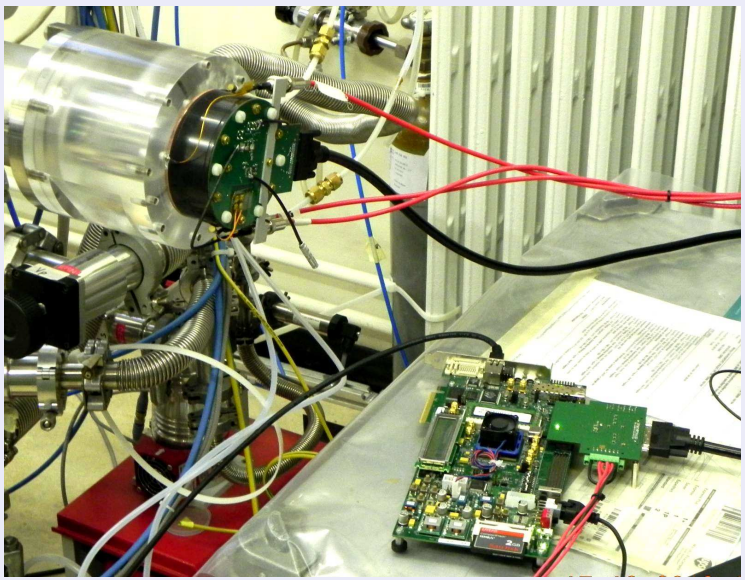


The CAST Detector Lab

X-ray Generator & Beamline



InGrid Detector at CDL



Infrastructure

- X-ray tube with exchangeable targets and filter wheels
- X-ray energies down to few hundred eV
- Vacuum system allowing for differential pumping

Datataking & First Analysis

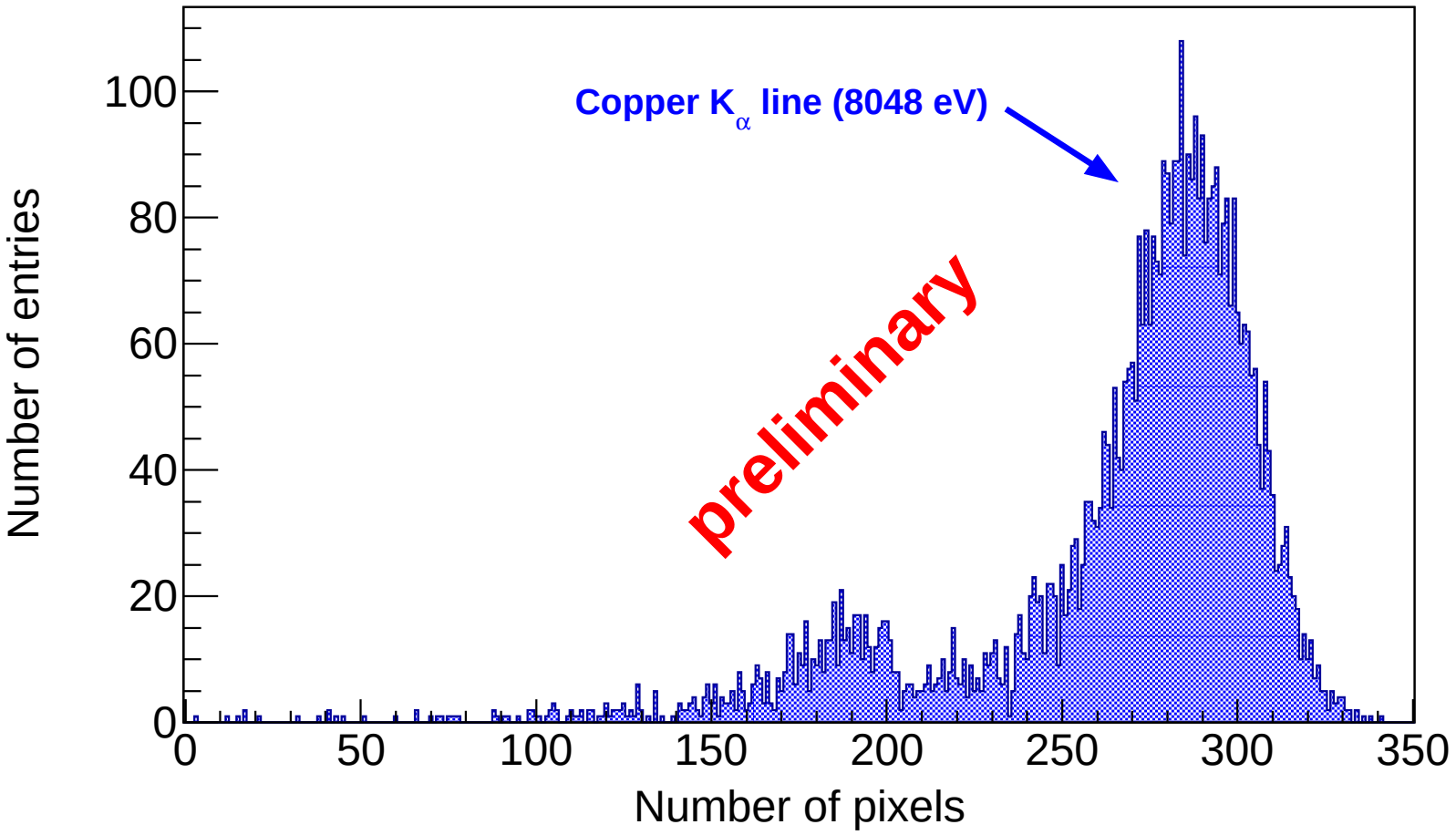
Recording of X-ray Spectra

- Different target and filter combinations to produce X-ray lines between 8 keV and 277 eV
- Length of Timepix frames adjusted to get reasonable low rate of double events

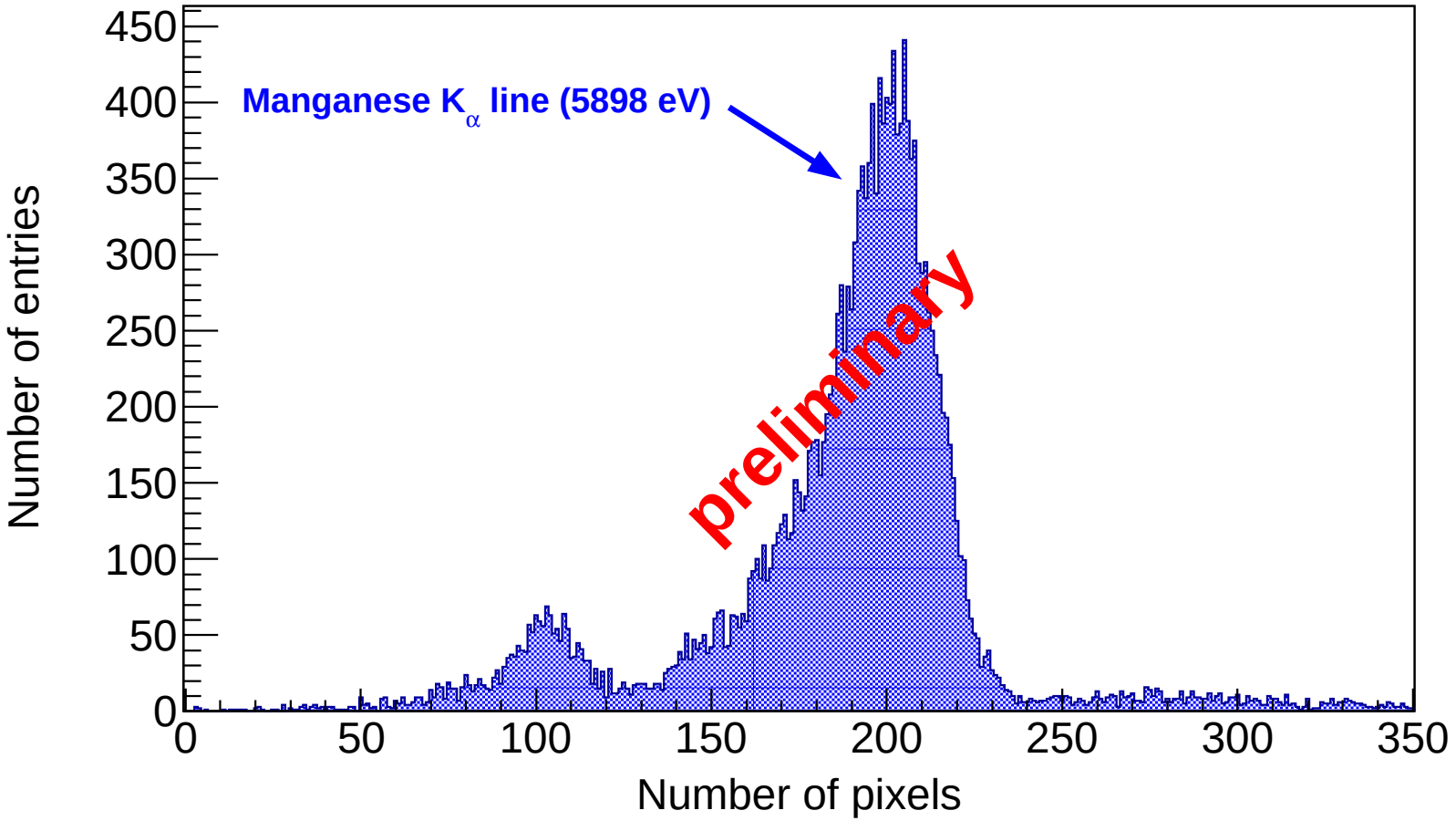
Analysis & Data Selection

- For first analysis all pixels of a frame are considered
- Algorithm determines long and short axis of events
- Selection of fully contained events by cut on center position
- Removal of double events through cuts on geometrical properties (e.g. excentricity, length, rms,...)
- Energy measured by pixel counting or total charge

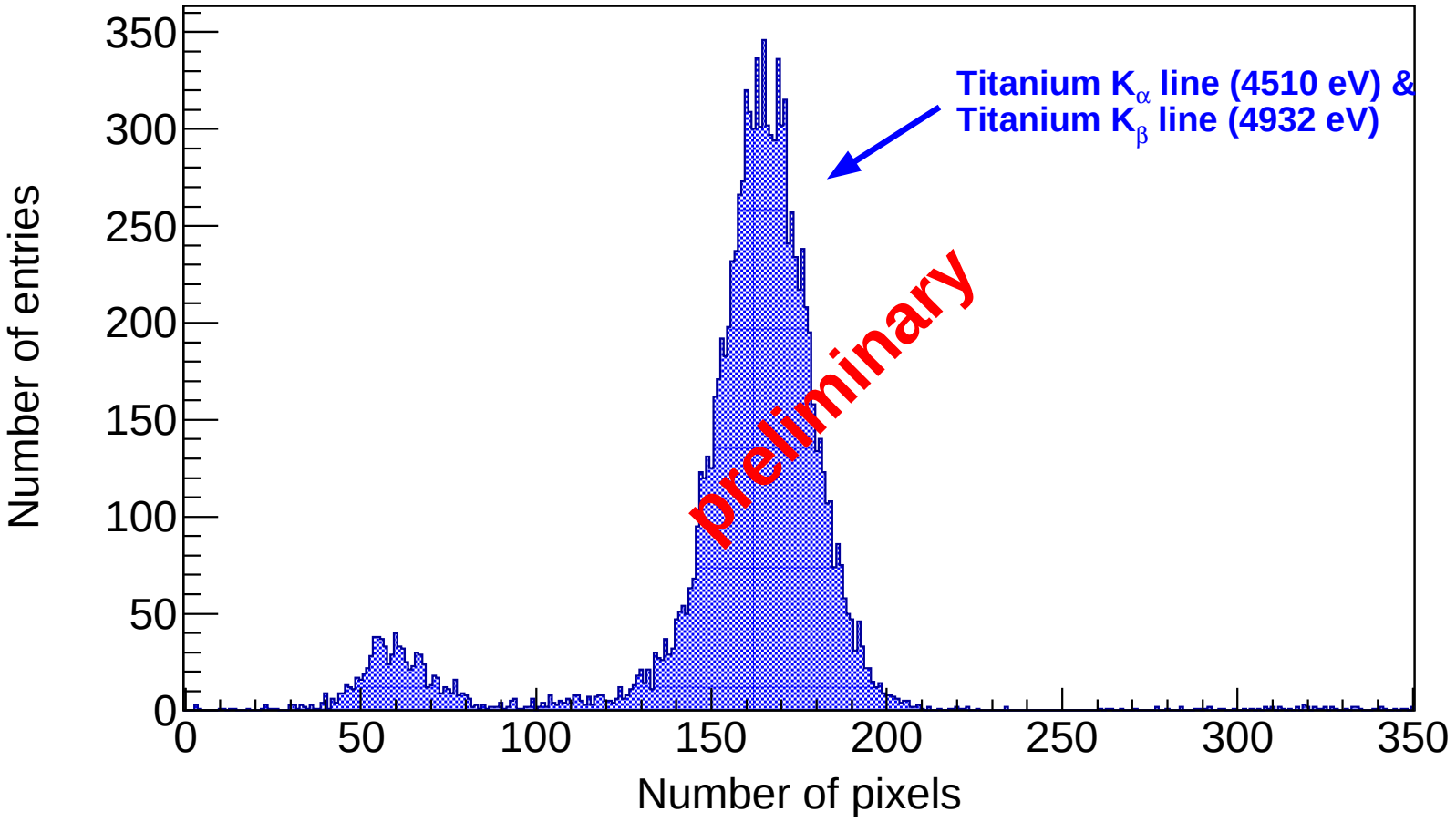
X-ray Spectra



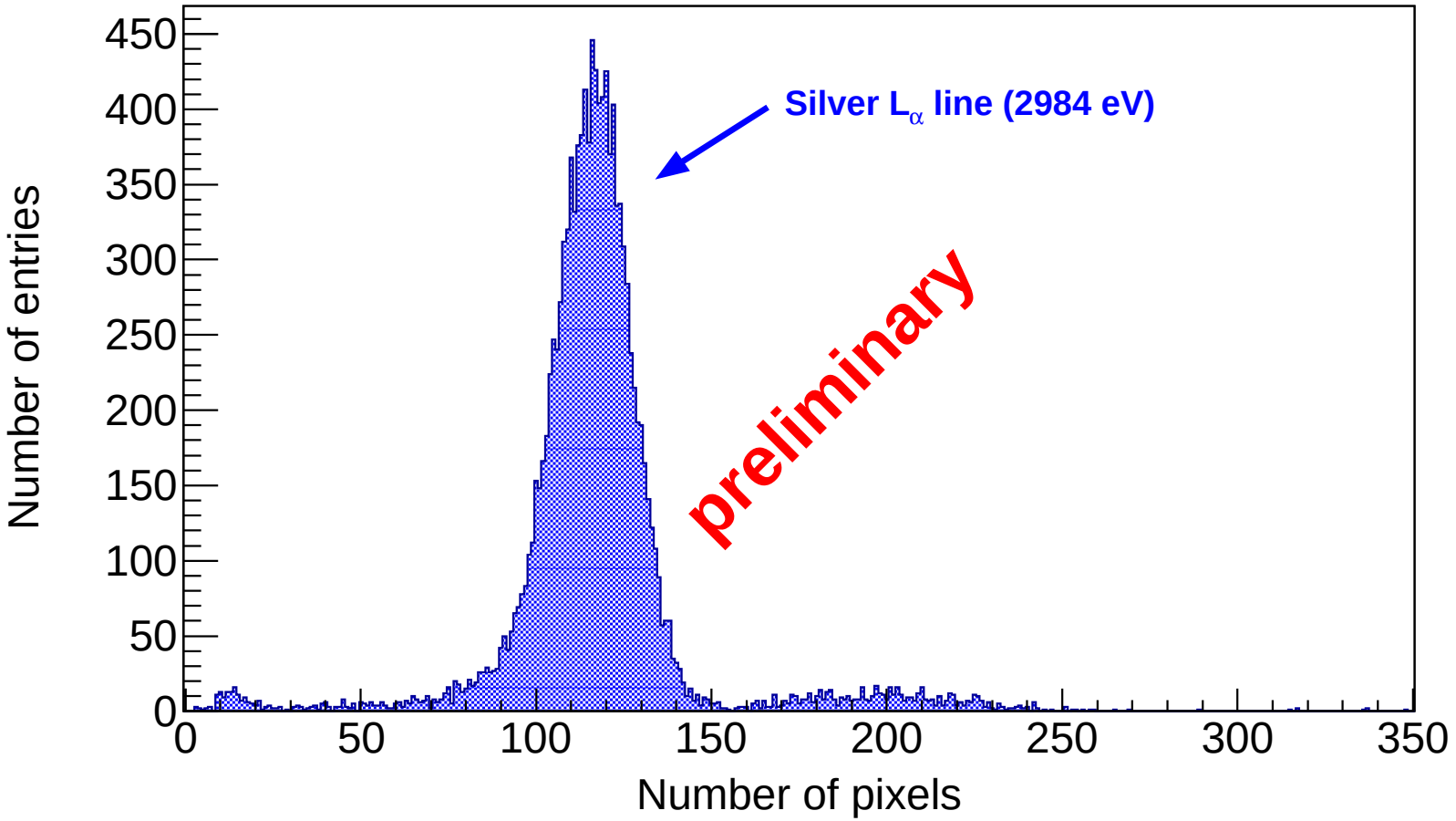
X-ray Spectra



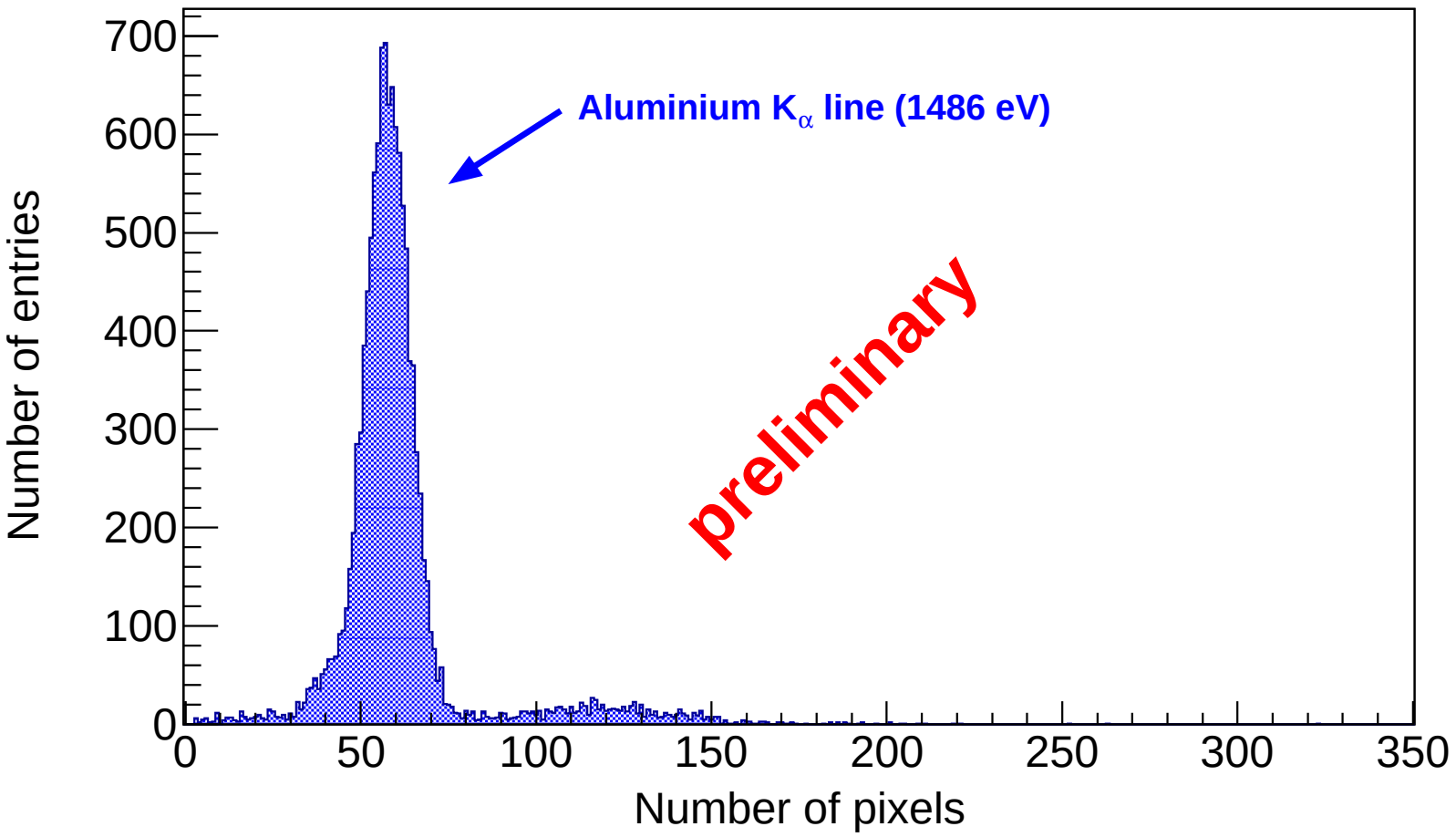
X-ray Spectra



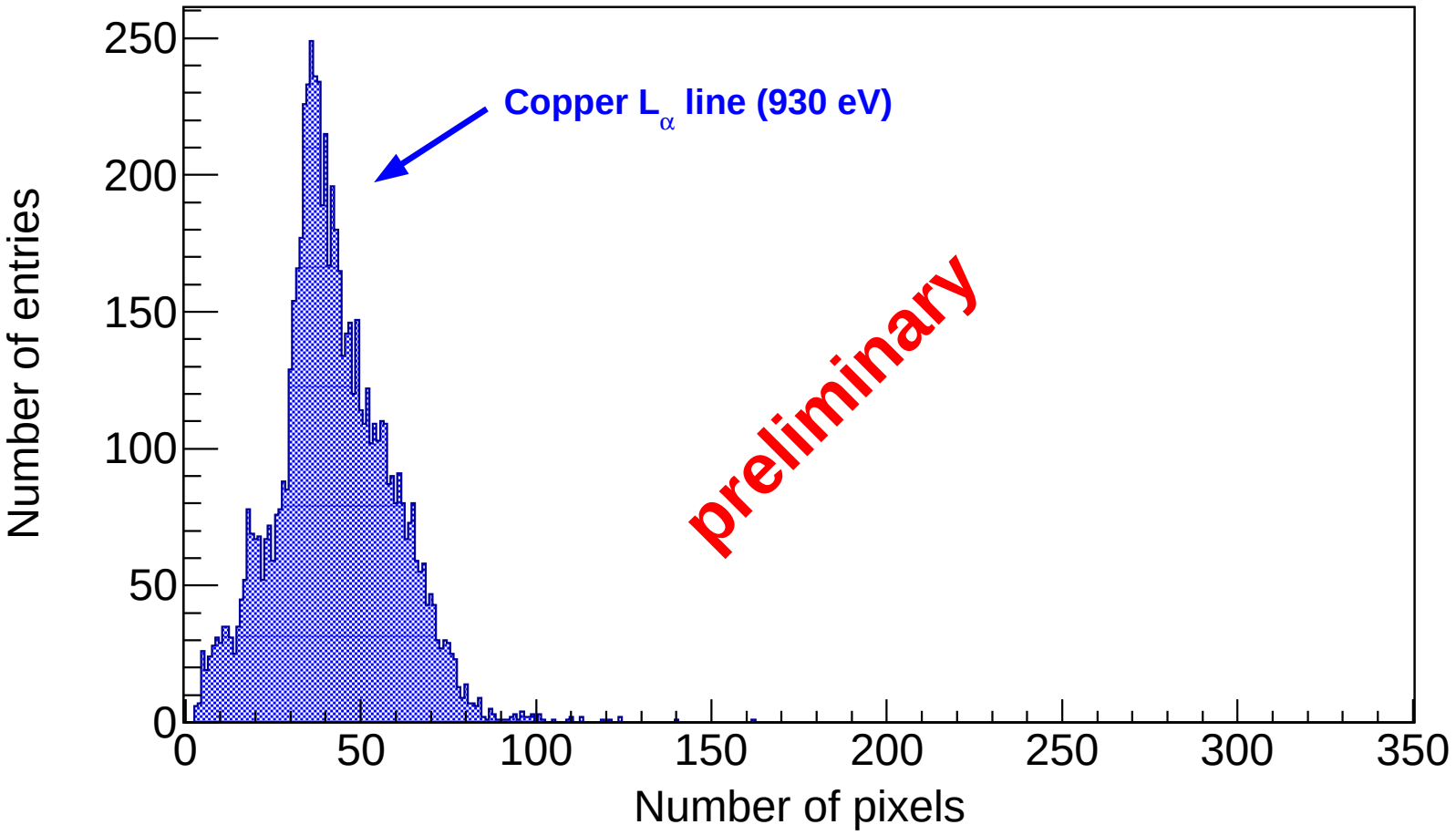
X-ray Spectra



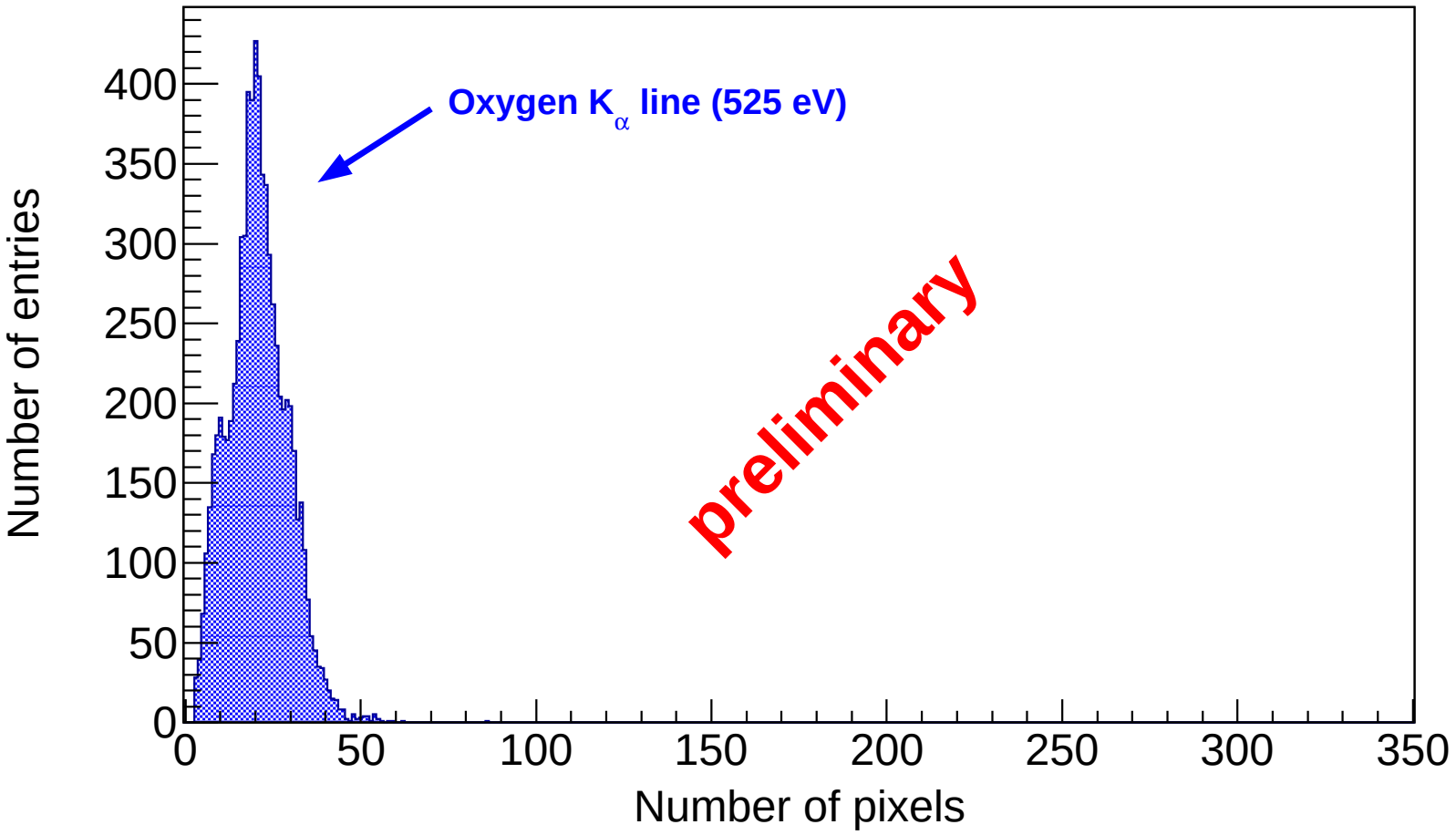
X-ray Spectra



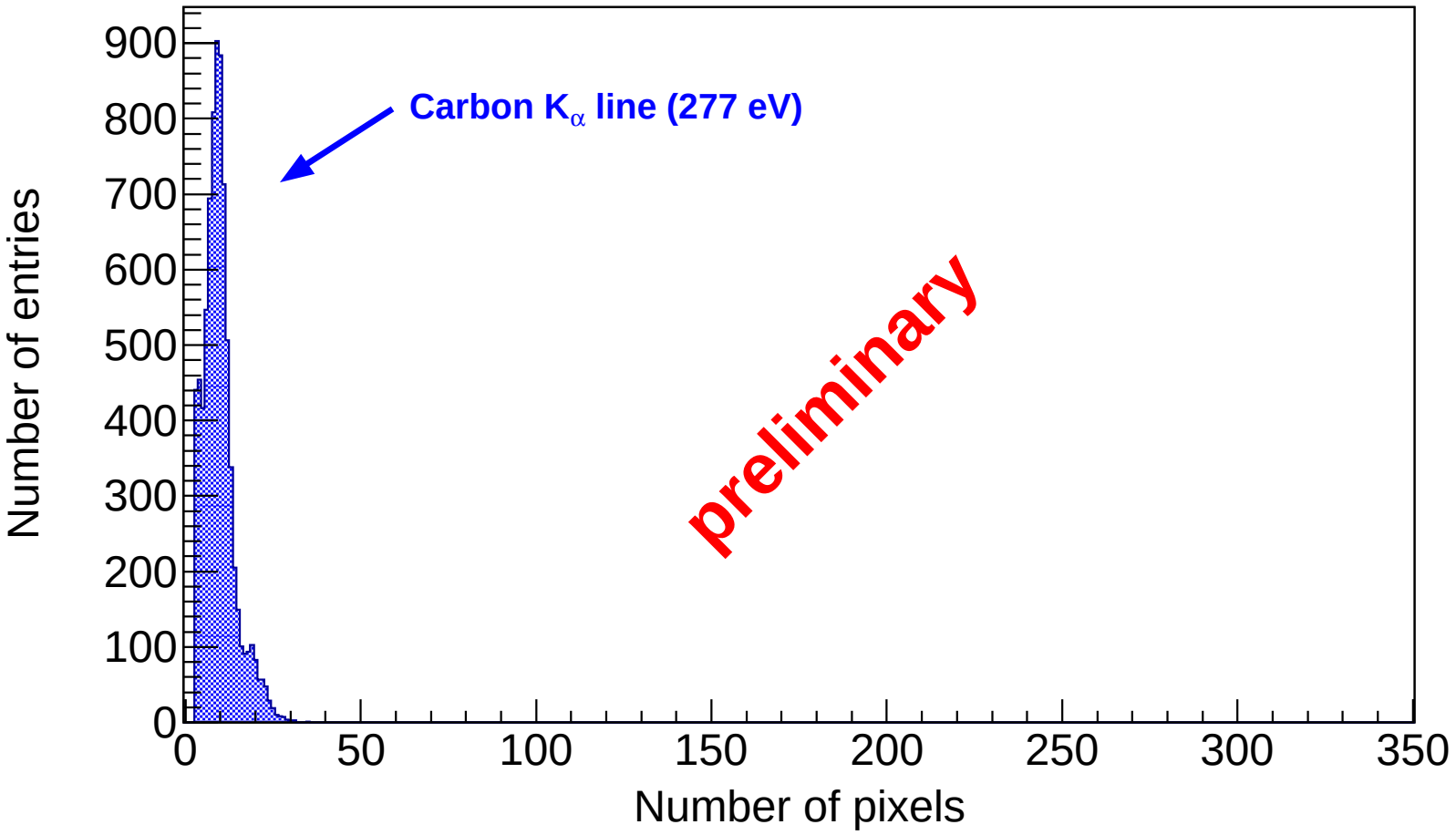
X-ray Spectra



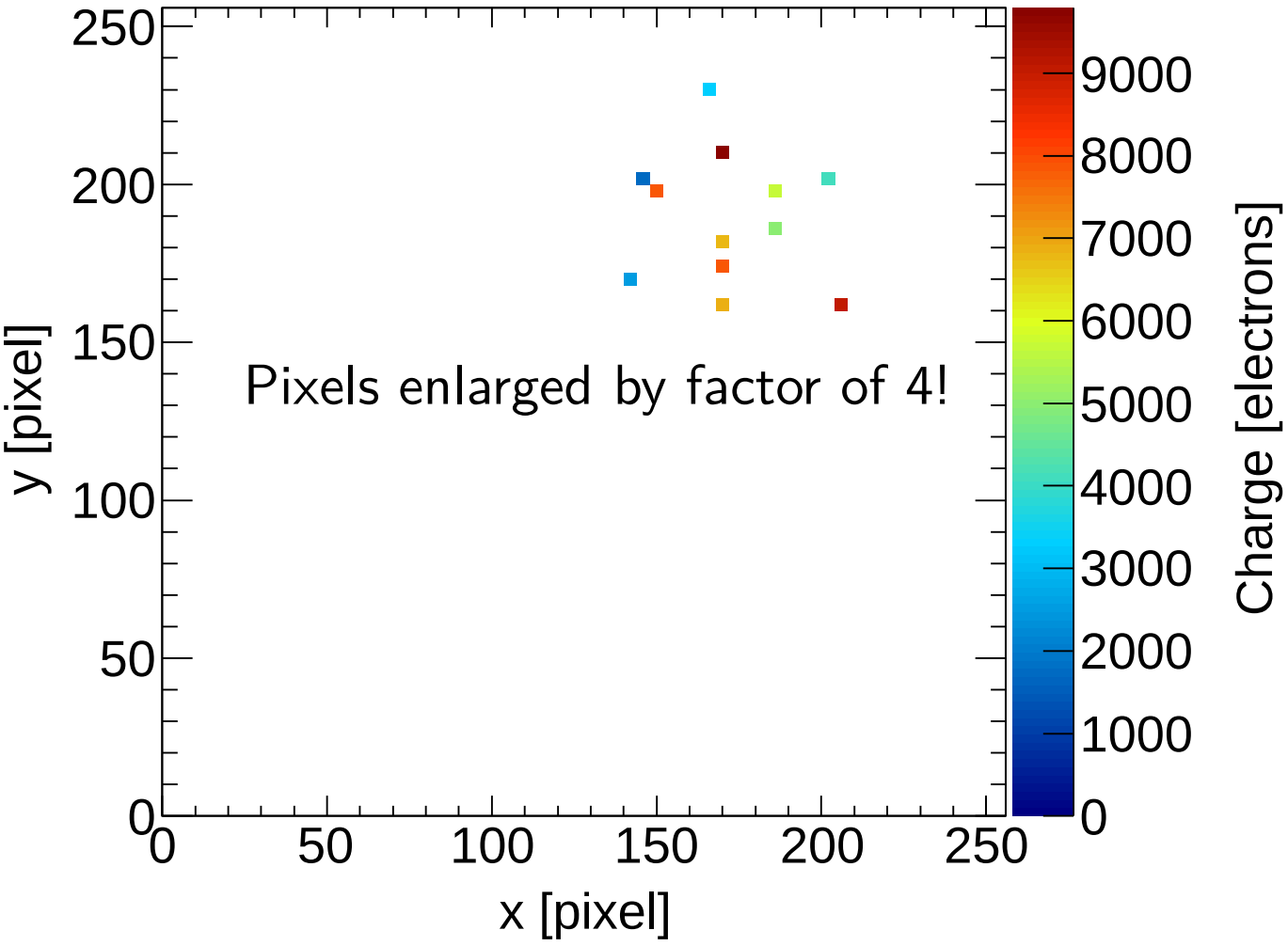
X-ray Spectra



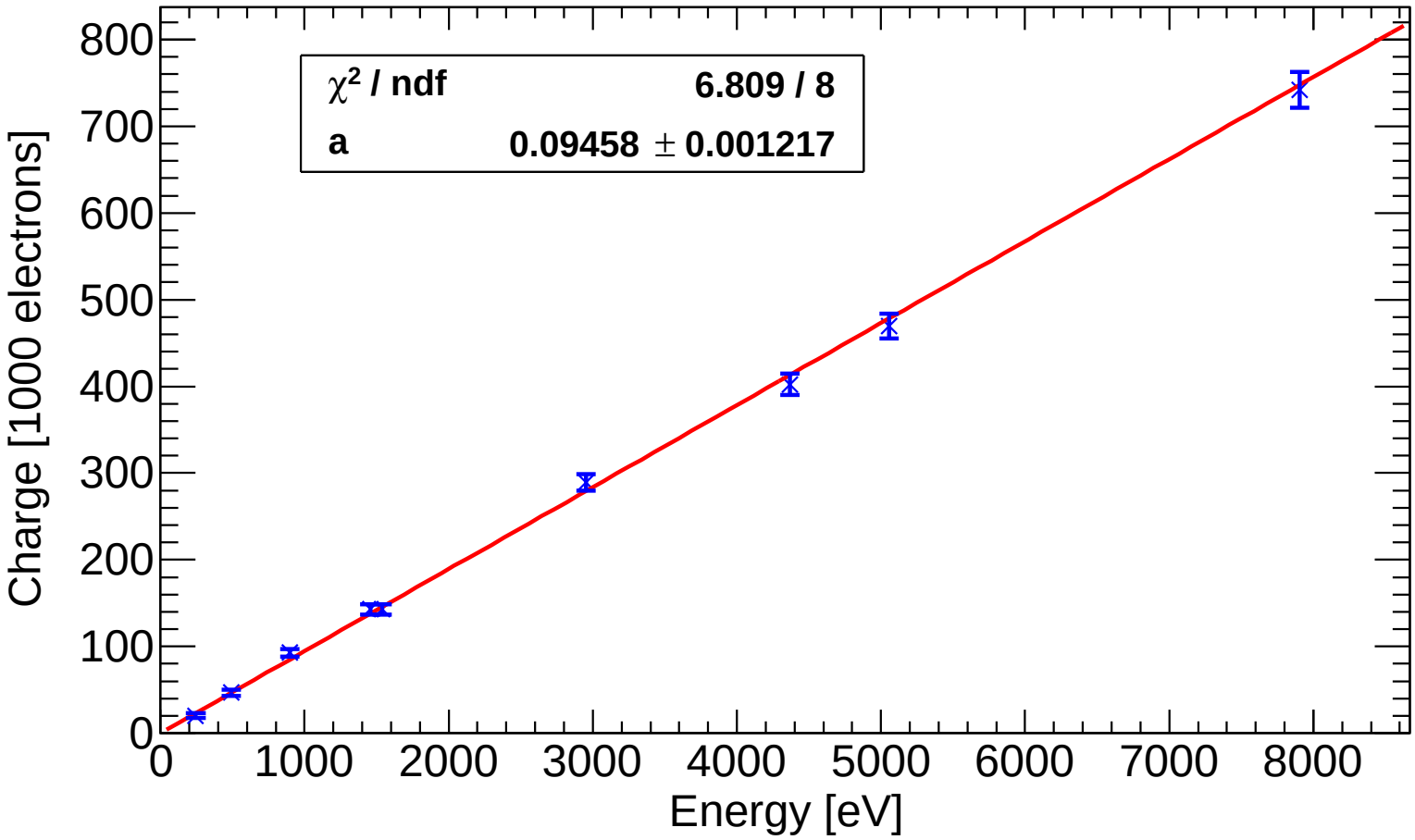
X-ray Spectra



Sample Carbon K_α event

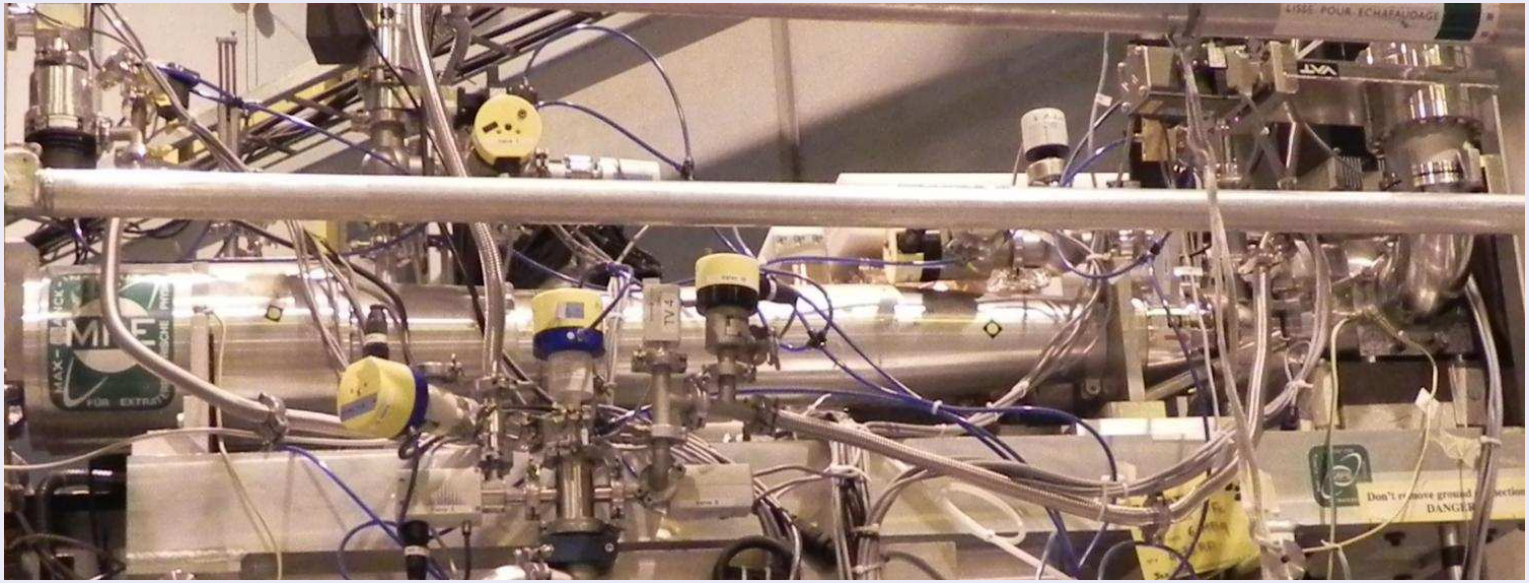


Energy Calibration



Replacing the pnCCD at the XRT

X-ray Telescope & pnCCD

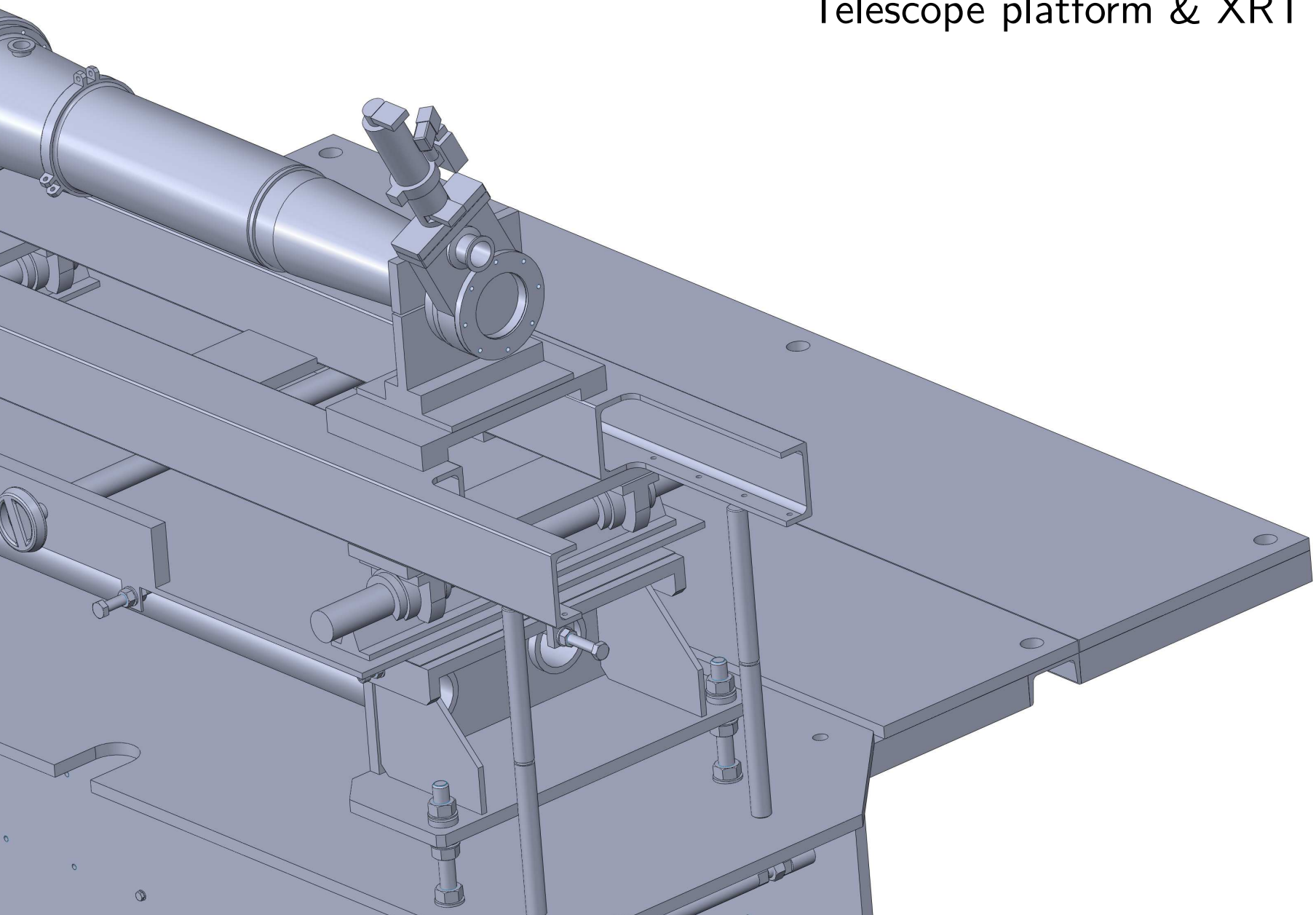


Interfacing the InGrid Detector with the XRT

- Very limited space: $\sim 300\,\text{mm}$ from gate valve to focal plane
- Need space for lead shielding and ^{55}Fe source manipulator
- Differential pumping necessary to ensure good vacuum in XRT

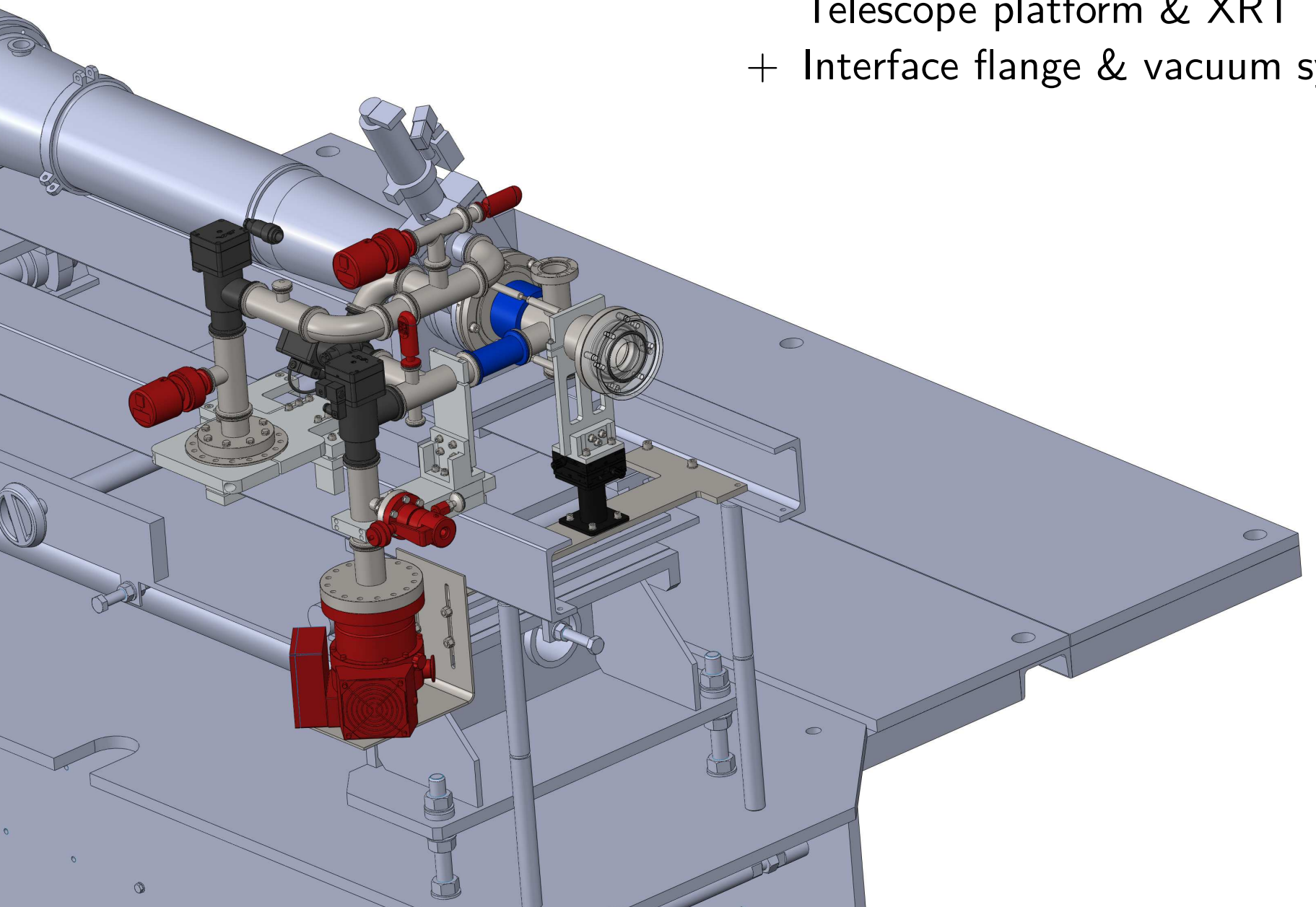
CAD Integration

Telescope platform & XRT

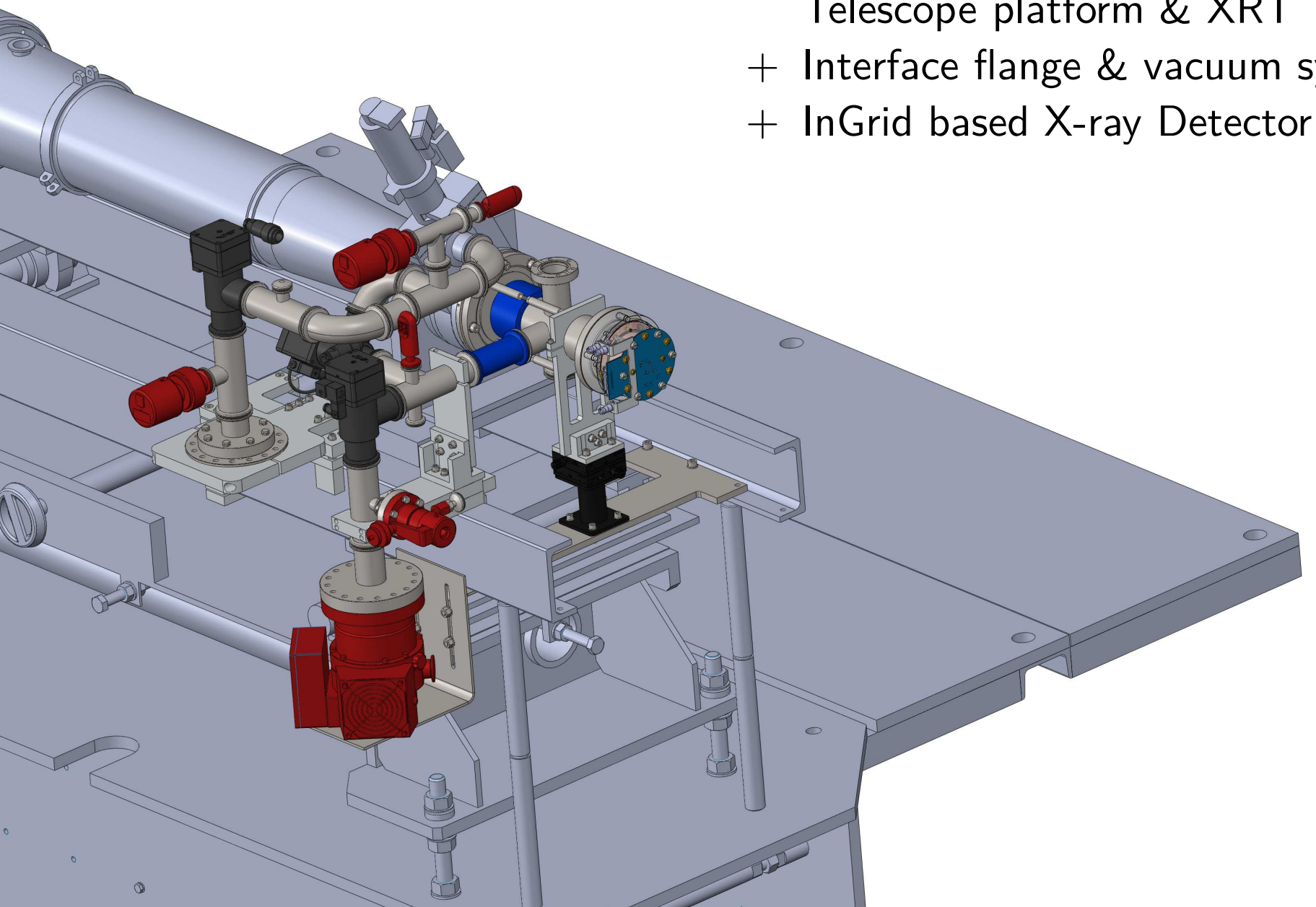


CAD Integration

Telescope platform & XRT
\+ Interface flange & vacuum system

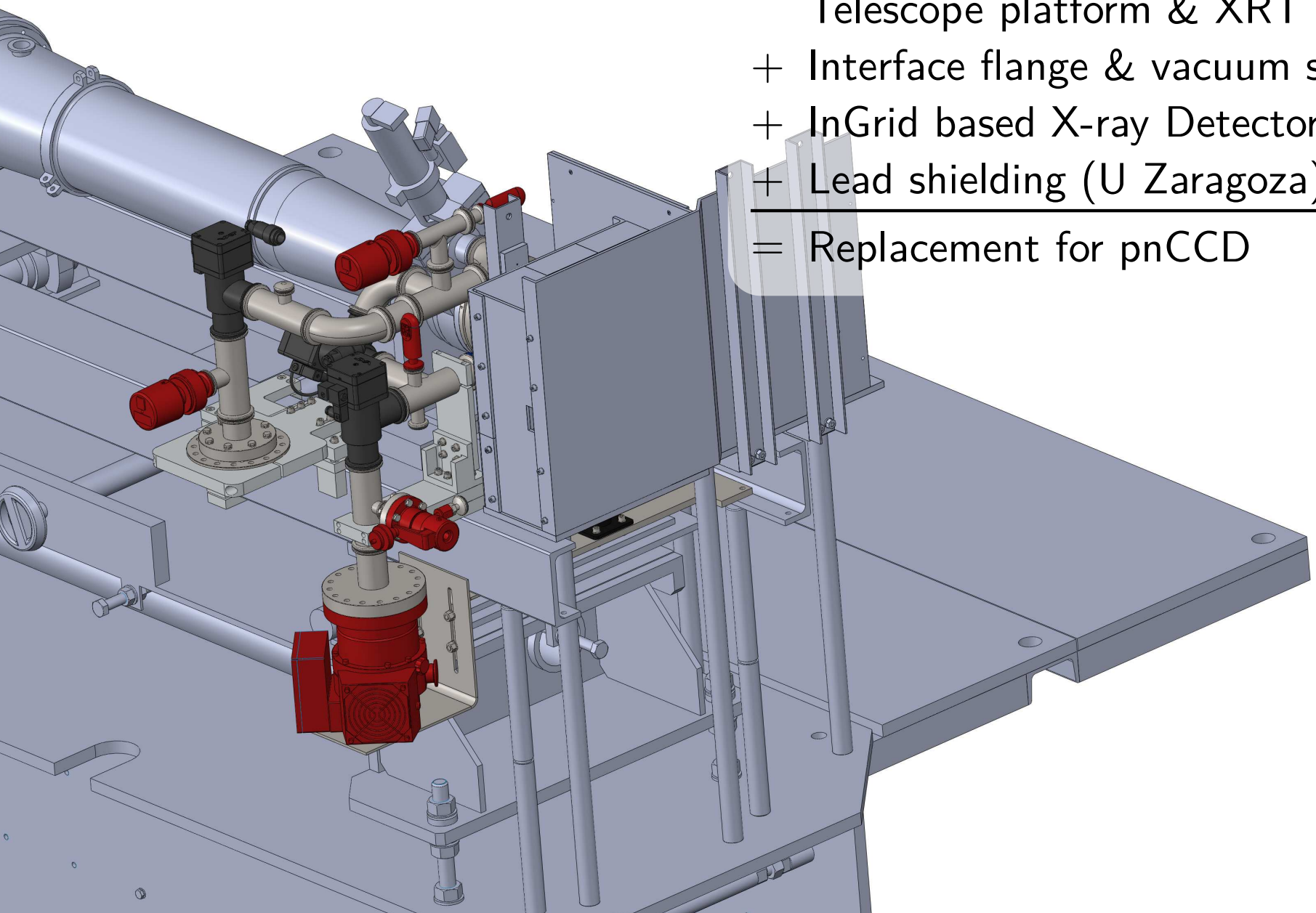


CAD Integration



Telescope platform & XRT
+ Interface flange & vacuum system
+ InGrid based X-ray Detector

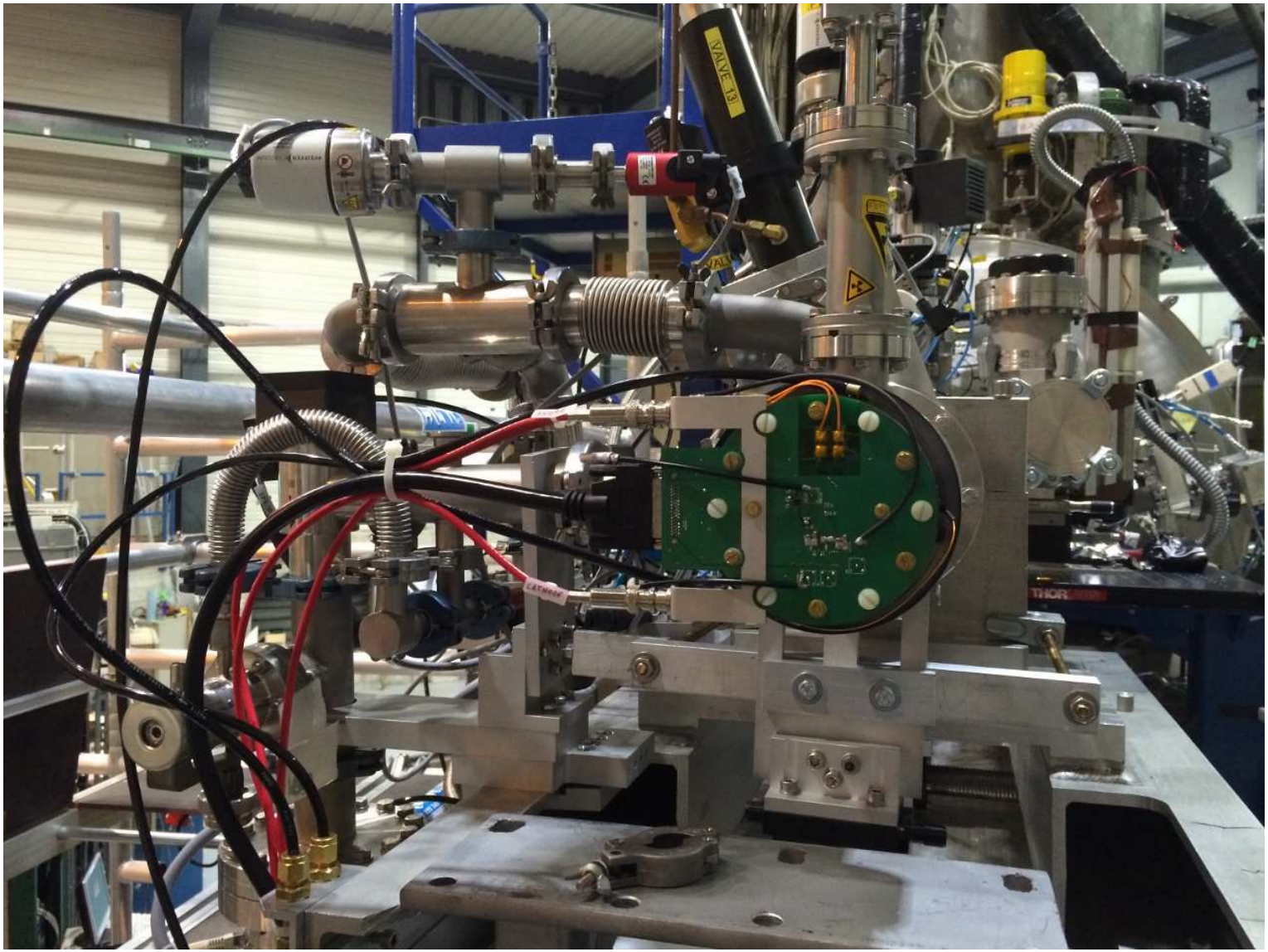
CAD Integration



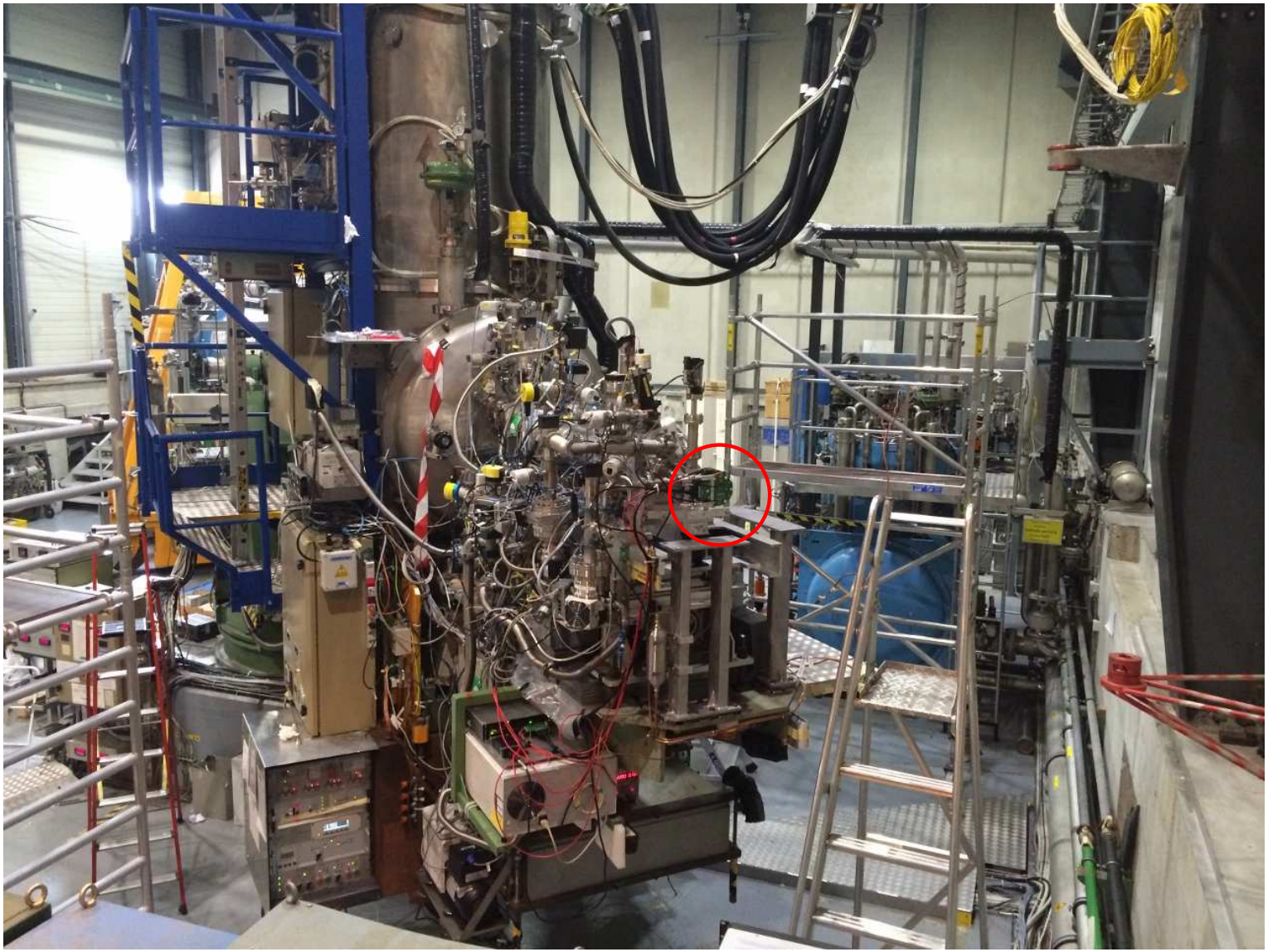
Telescope platform & XRT
+ Interface flange & vacuum system
+ InGrid based X-ray Detector
+ Lead shielding (U Zaragoza)

= Replacement for pnCCD

Vacuum System and InGrid Detector @ CAST



Vacuum System and InGrid Detector @ CAST



Conclusion & Outlook

Conclusion

- InGrid based X-ray Detector provides promising candidate for Chameleon search at CAST
- Tests in the CAST Detector Lab demonstrated the performance of the detector
- Detection of carbon K_α line at 277 eV is possible
- InGrid based detector has been installed along with the necesary infrastructure at the CAST experiment

Outlook

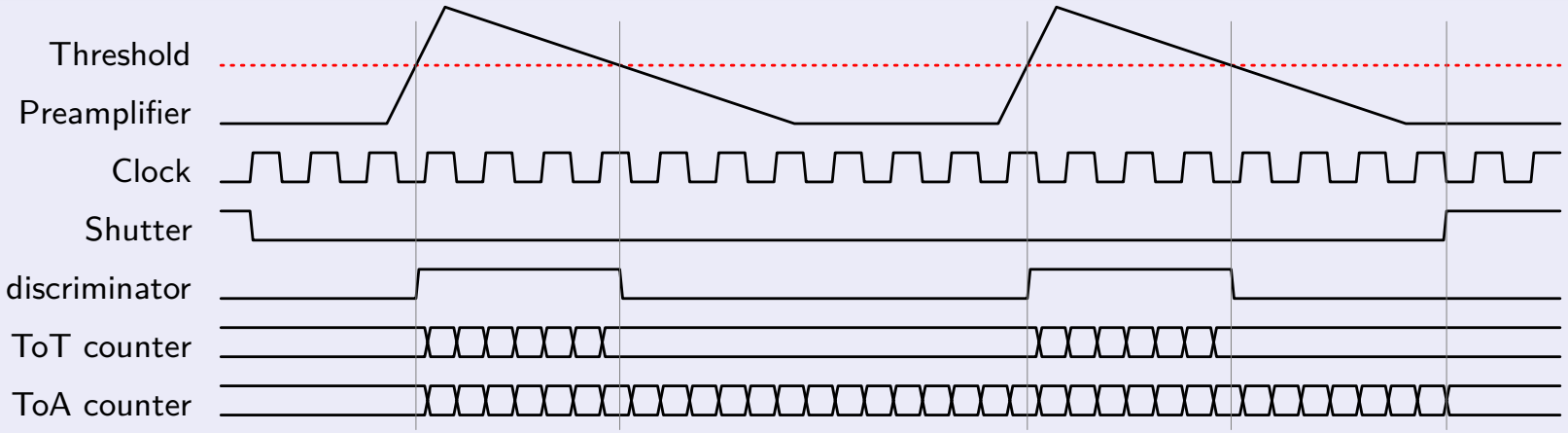
- Search for axions & chameleons with InGrid based detector during CAST run 2014 (starts soon!)
- Work on final implementation of grid signal in readout scheme and optimize setup
- Improve analysis and background rejection

Thanks for your attention!

Backup Slides

Timepix ASIC – More Details

Timing Diagram

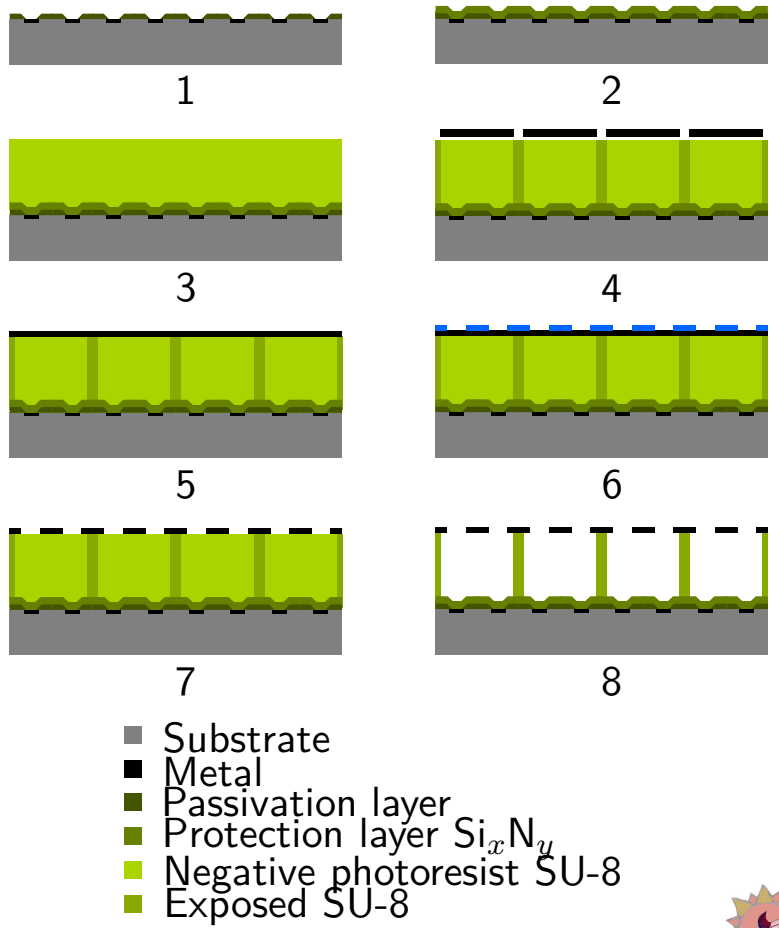


Timepix 3

- Has been submitted 2013 – First chips are available
- Ability to recognize multihits and to measure Charge and Time simultaneously
- Allows for data driven readout

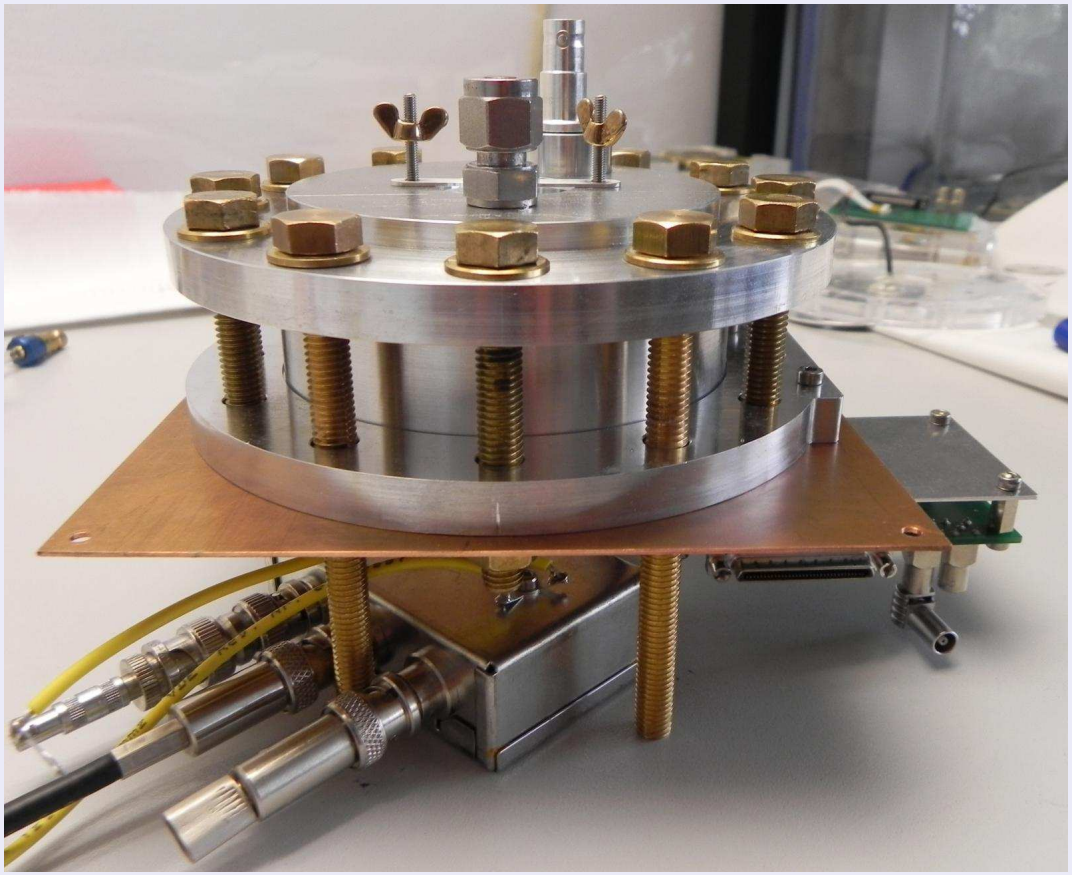
How to build an InGrid on top of a Timepix?

1. Starting with bare Timepix
2. Deposition of protection layer (4 or 8 µm Si_xN_y)
3. Deposition of negative photoresist SU-8 (50 µm)
4. Exposure of SU-8
5. Sputtering aluminium (1 µm)
6. Putting mask on aluminium layer (photoresist)
7. Structuring aluminum layer by etching the holes
8. Development of SU-8, cleaning of interistitials



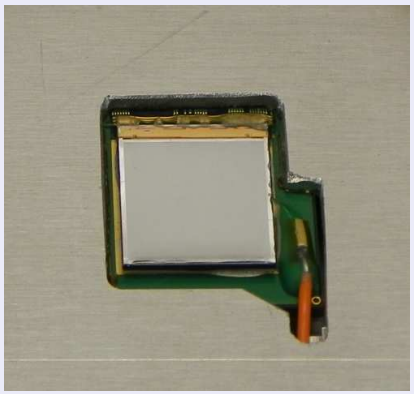
Prototype Detector

X-ray detector



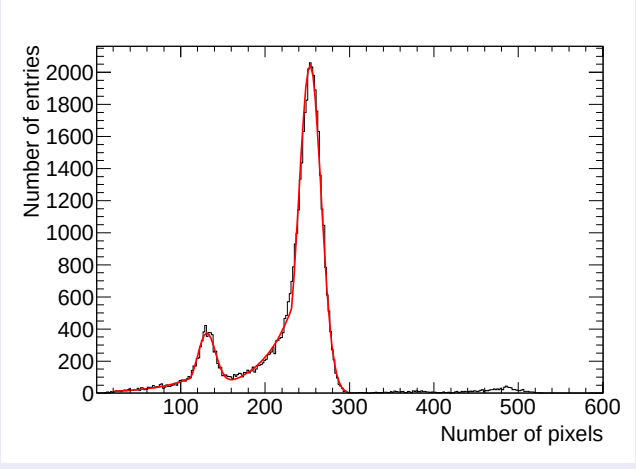
Cathode

Anode

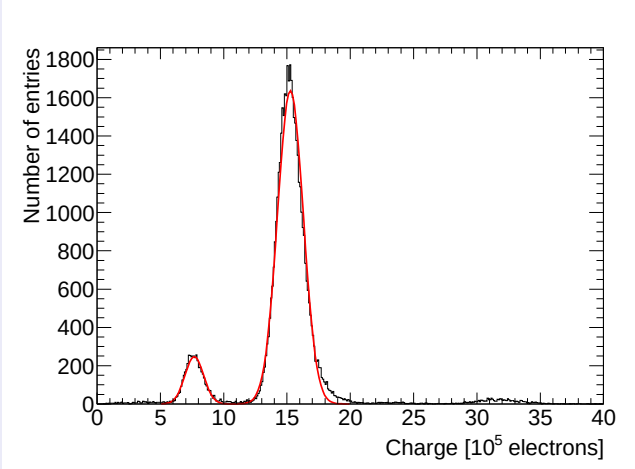


Detector Performance – Tests with ^{55}Fe

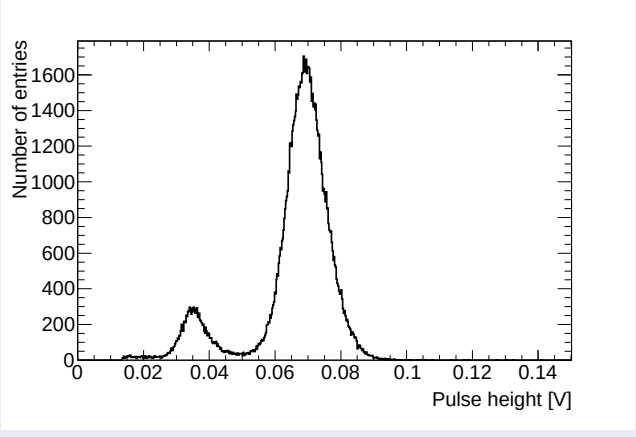
Spectrum - Pixels



Spectrum - Charge



Spectrum - Grid

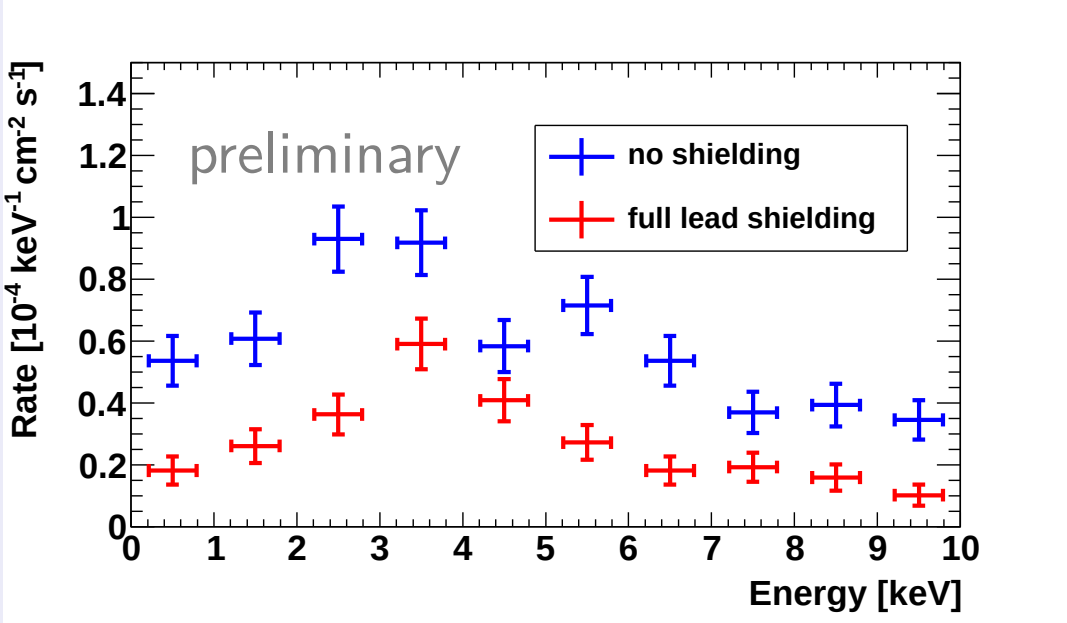


Energy resolution

- Ar/iC$_4$H$_{10}$ 95/5
- Cr foil to suppress 6.1 keV
- Pixels: $\sigma_N/N \approx 5.2\,\%$
- Charge: $\sigma_Q/Q \approx 6.7\,\%$
- Grid: $\sigma_U/U \approx 8\,\%$

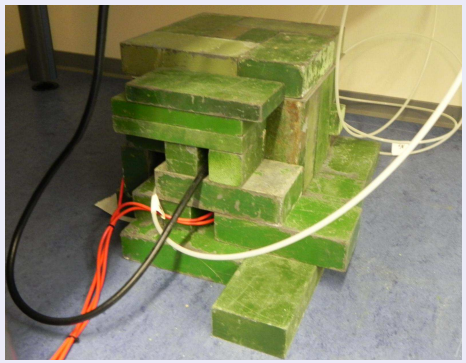
Background Rates

After Likelihood-Ratio based discrimination

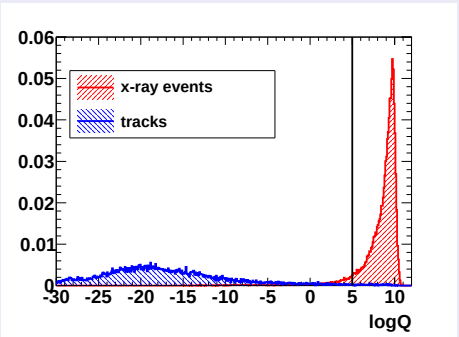


- Reduction should be possible by improvement of algorithm

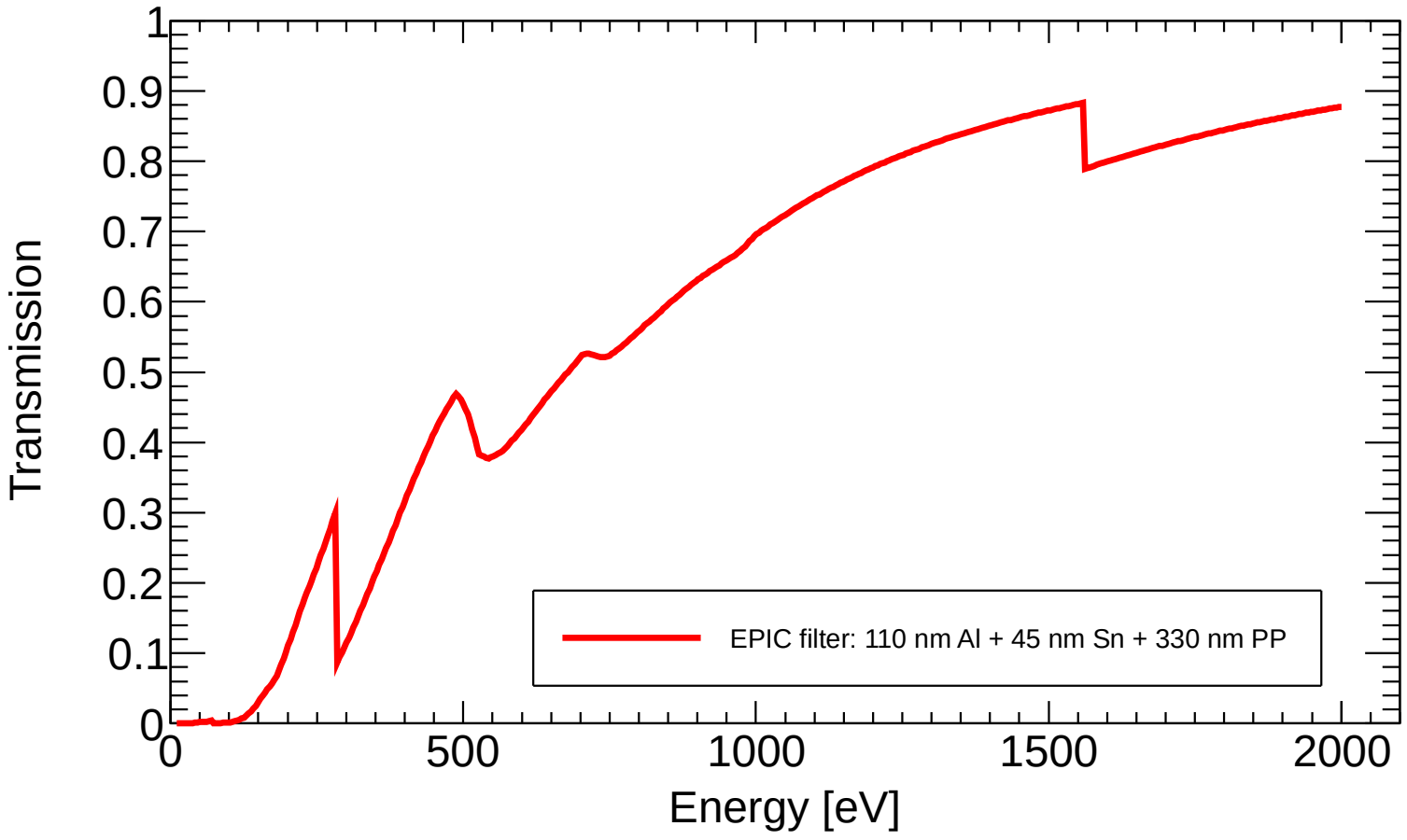
Lead shielding



Likelihood-Ratio

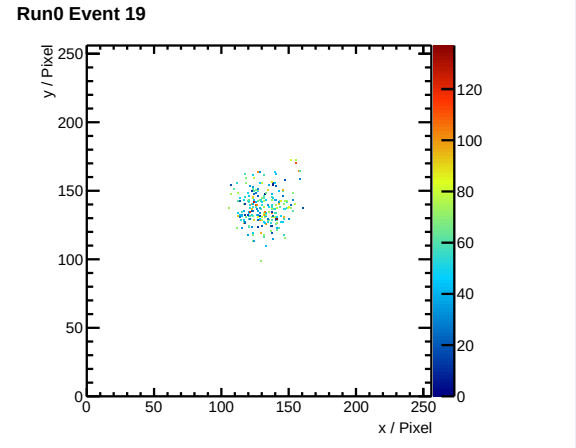


European Photon Imaging Camera

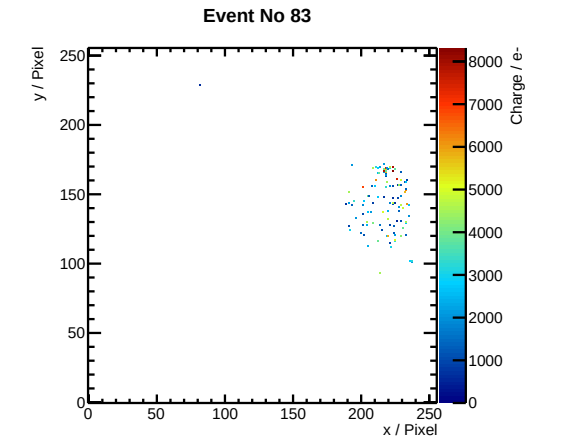


Sample Events: X-ray and Cosmic Muon

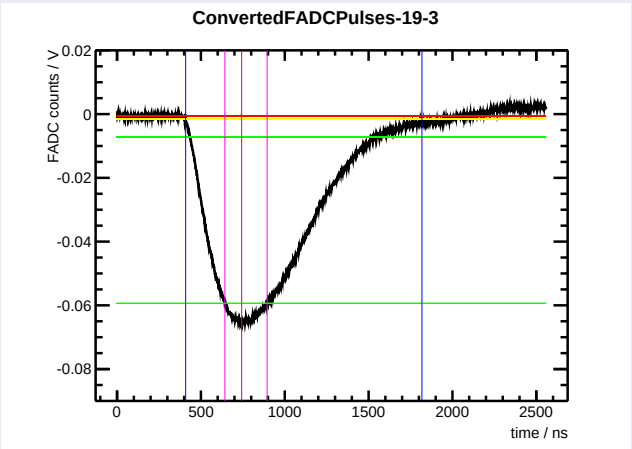
X-ray Chip Data



Cosmic Chip Data



X-ray Pulse



Cosmic Pulse