Using an InGrid-Detector to search for solar chameleons with CAST

Klaus Desch (for C. Krieger, Y. Bilevych, J. Kaminski, M. Lupberger)
University of Bonn
on behalf of the CAST collaboration

11th Patras Workshop on Axions, WIMPs and WISPs
Zaragoza, 23/06/2015

universitätbonn

CAST

CAST: a versatile WISP infrastructure

- strong dipole magnet (LHC prototype, B=9T, 9m)
- sun tracking (2x 1.5/day)
- XRTs (MPE Abrixas telescope, LLNL Xray telescope (new))
- variety of low detectors (existing & planned)

Micromegas, CCD, SDD, InGrid	→ Axions, Chameleons (β_γ)
Force sensor (KWISP)	→ Chameleons (β_m)
Microwave cavities (CAPP, RADES)	→ relic axions

transformation of CAST from a „pure“ Axion helioscope into
a low-cost(!) exploratory facility for axion-like particle searches

CAST as versatile ALPS infrastructure

CAST at this meeting:

Micromegas	solar axions (Wed 17:35h, Garcia-Pascual)
InGrid	solar chameleons β_γ (KD, this talk)
KWISP	solar chameleons β_m (Thu 18:40h, Cantatore)
CAST-CAPP	relic axions cavity (Fri 10:00h, Miceli)

Chameleons

From `dreamatico.com` (a website about dream interpretation):

"Dreaming about chameleon talks of your capacity to change and be adaptive to the uncertain and even the unpredictable things in your life, and this is the interpretation especially if the chameleon that you dream of is in a healthy and green environment."

Chameleons

poor experimentalist´s understanding:

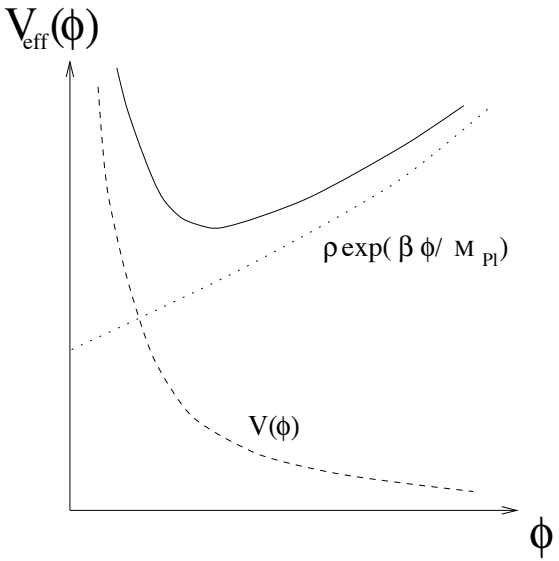
- microscopic explanation of Dark Energy (DE) is a top-priority mystery of fundamental physics
- explanations of DE by scalar fields (e.g. quintessence) are attractive
- typical complication: these scalar fields lead to 5th forces at observable distances
- chameleon: a way to avoid large 5th force effect → „chameleon shielding“

[Khoury, Weltman PRL93(2004)171104, PRD69(2004)044026]

→ the chameleon acquires a mass proportional to the ambient matter density

$$V_{eff}(\phi) \equiv V(\phi) + \rho e^{\beta\phi/M_{Pl}}$$

ambient matter density



Solar chameleon phenomenology

Chameleons may be created deep in the sun through inverse Primakoff effect similar to axions [Brax, Zioutas Phys.Rev.D82:043007,2010]
[Brax, Lindner, Zioutas, Phys.Rev. D85 (2012) 043014]

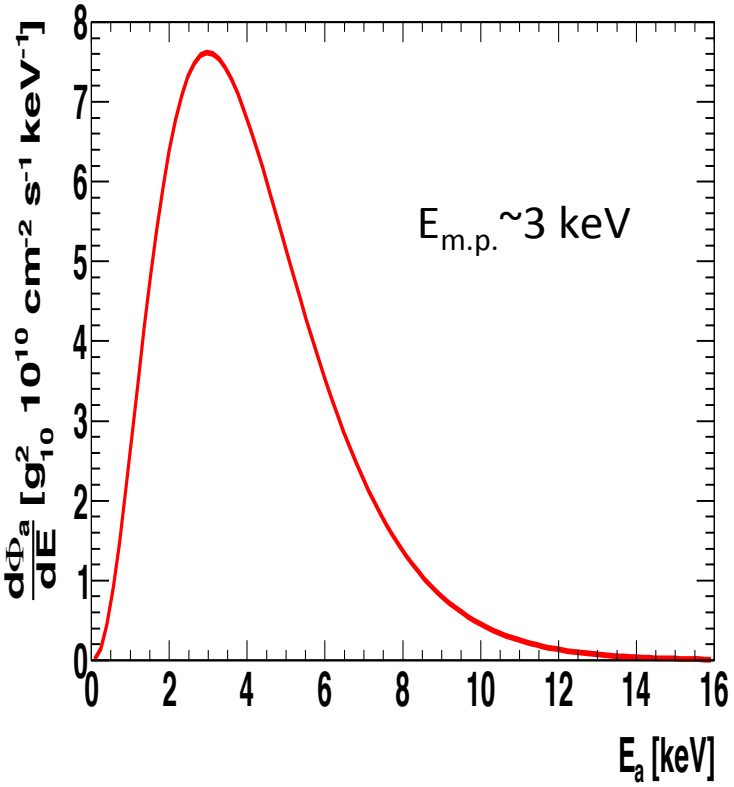
However, they do not stem from the core of the sun (unlike Axions)

→ need to be produced further outside
→ need strong magnetic fields nevertheless
→ production in solar tachocline (R ~0.7 $R_{\odot}$, B~50 T)

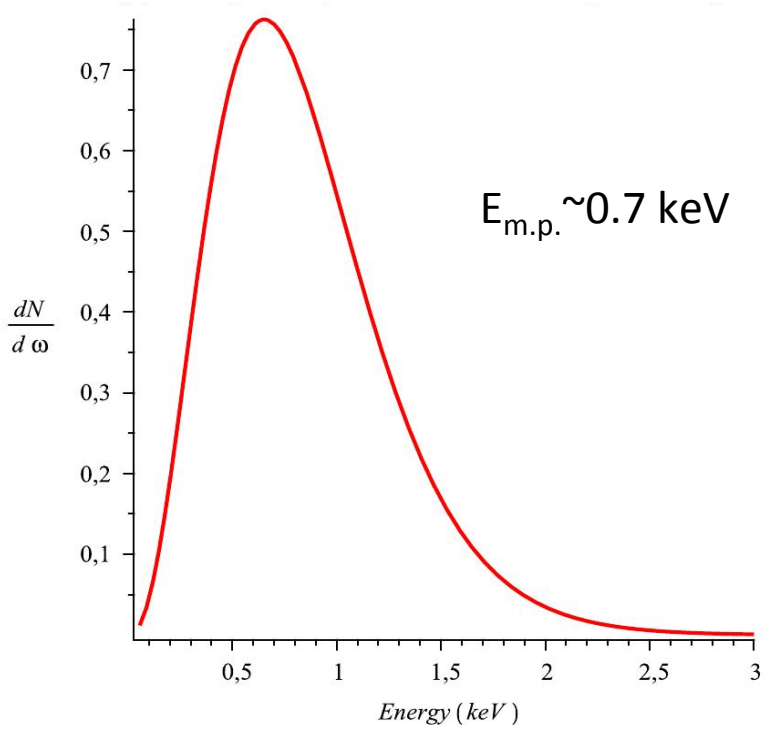
→ thermal energy of escaping chameleons smaller than for axions →

Solar chameleon phenomenology

axions

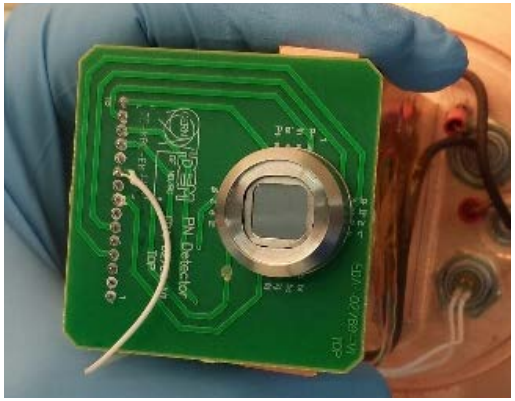


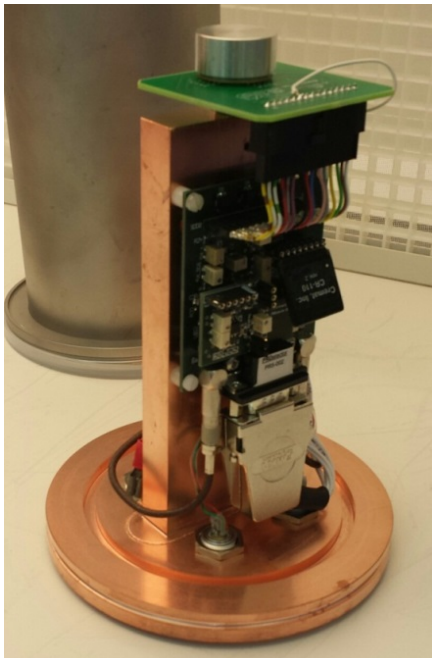
chameleons



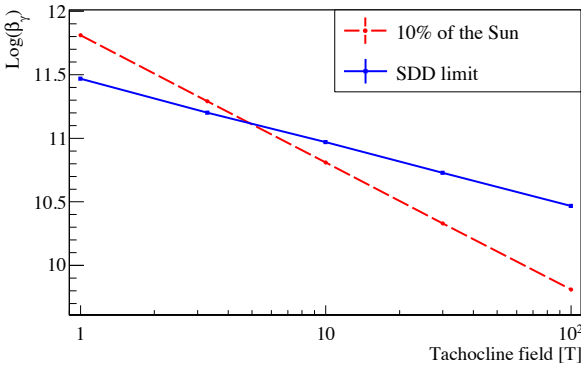
→ need X-ray detector sensitive to sub-keV photons

First chameleon search with CAST: SDD





Silicon Drift Dectector (SDD) operated in 2013
directly operated in vacuum (no window)
QE > 70% for E > 400 eV



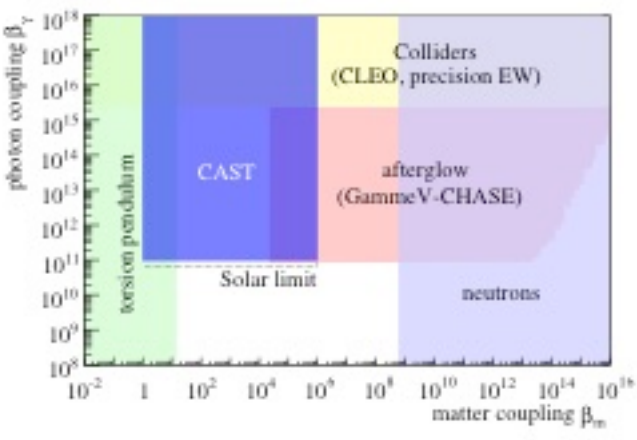


Figure 11: The CAST limit on β_γ for different values of magnetic fi
tachocline.

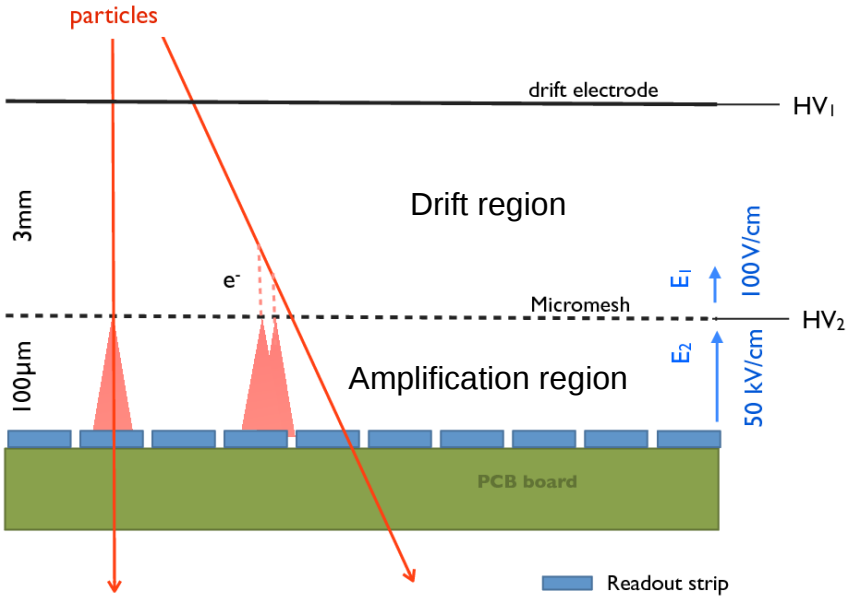
[CAST collab., arXiv:1503.04561]

room for improvement:

- not operated behind XRT (limited acceptance)
- no position sensitivity (background supression)
- only 15.2h of solar tracking (1 week)

→ InGrid detector

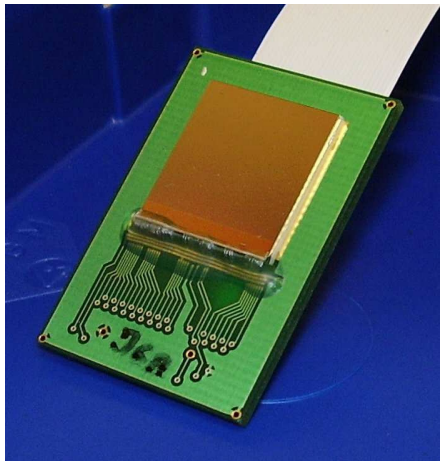
InGrids



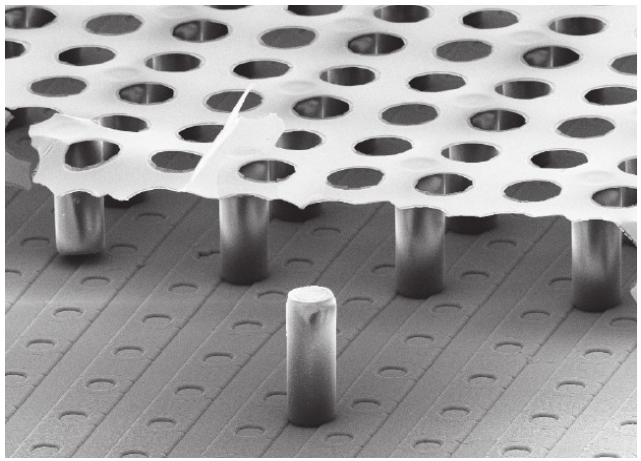
Micromegas mounted on a pixel chip via photolithographic post-processing

pioneered by U Twente&NIKHEF&CEA
J. Schmitz, M. Chefdeville et al.

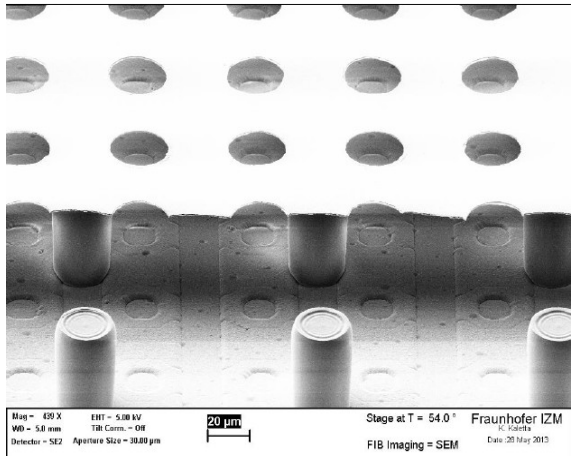
Pixel chip: Timepix
256x256 pixels (55x55 µm^2) ~ 2 cm^2
Typical threshold: 500 e$^-$



Timepix



InGrid



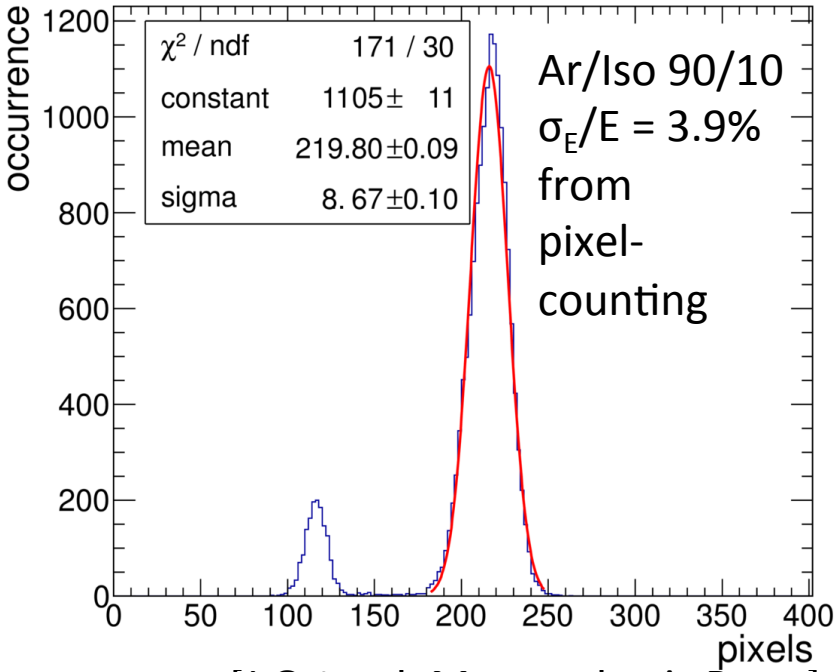
InGrids as X-Ray detectors

- almost 100% single-electron efficiency
- diffusion in drift region → 1 primary electron per pixel →
  - → electron-counting to measure energy
  - → no gain fluctuations
  - → optimal topological suppression of charged background
  - → alternative energy measure: total charge in all pixels

Optimization for E-resolution:

Ar/iC_4H_{10}	U_{grid} / V	Gain	E_{grid}/E_{drift}	R
90/10	380	6346.1 ± 5.1	368	3.85% ± 0.06%
95/5	335	6069.8 ± 3.4	134	4.38% ± 0.05%
96/4	320	6122.0 ± 3.3	163	4.76% ± 0.06%
97/3	300	3735.5 ± 2.3	257	4.60% ± 0.05%
97.7/2.3	280	2381.5 ± 1.4	96	5.33% ± 0.04%
98/2	290	3493.8 ± 2.1	133	5.40% ± 0.06%
99/1	275	2053.7 ± 1.5	169	9.02% ± 0.10%

@5.9 keV

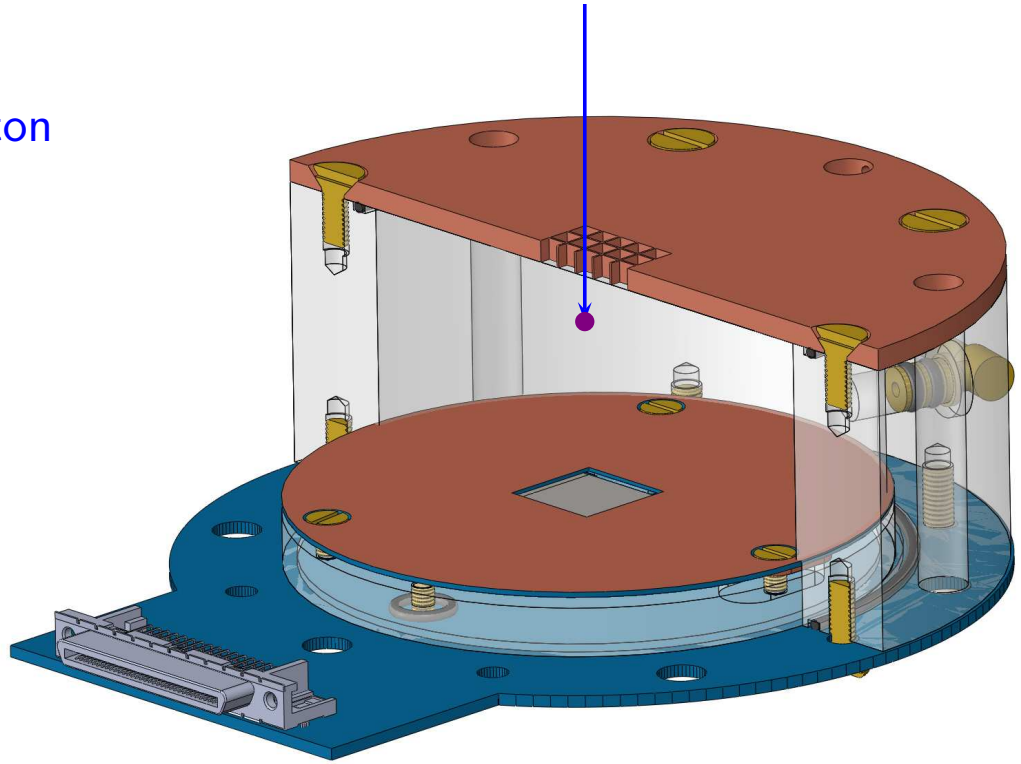


[J.Ottnad, Master thesis Bonn]

The CAST InGrid Detector

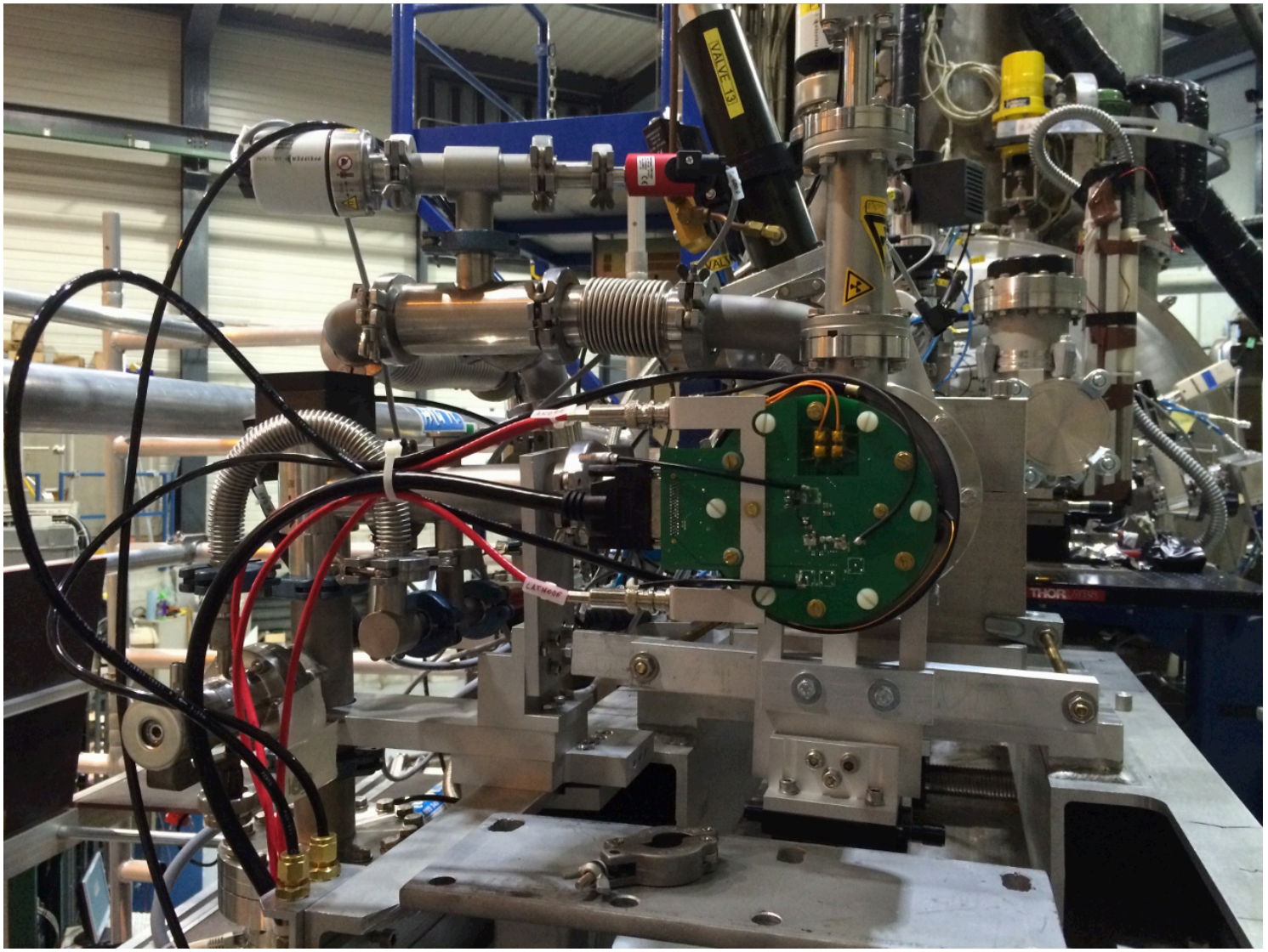
X-ray photon

Gas atom

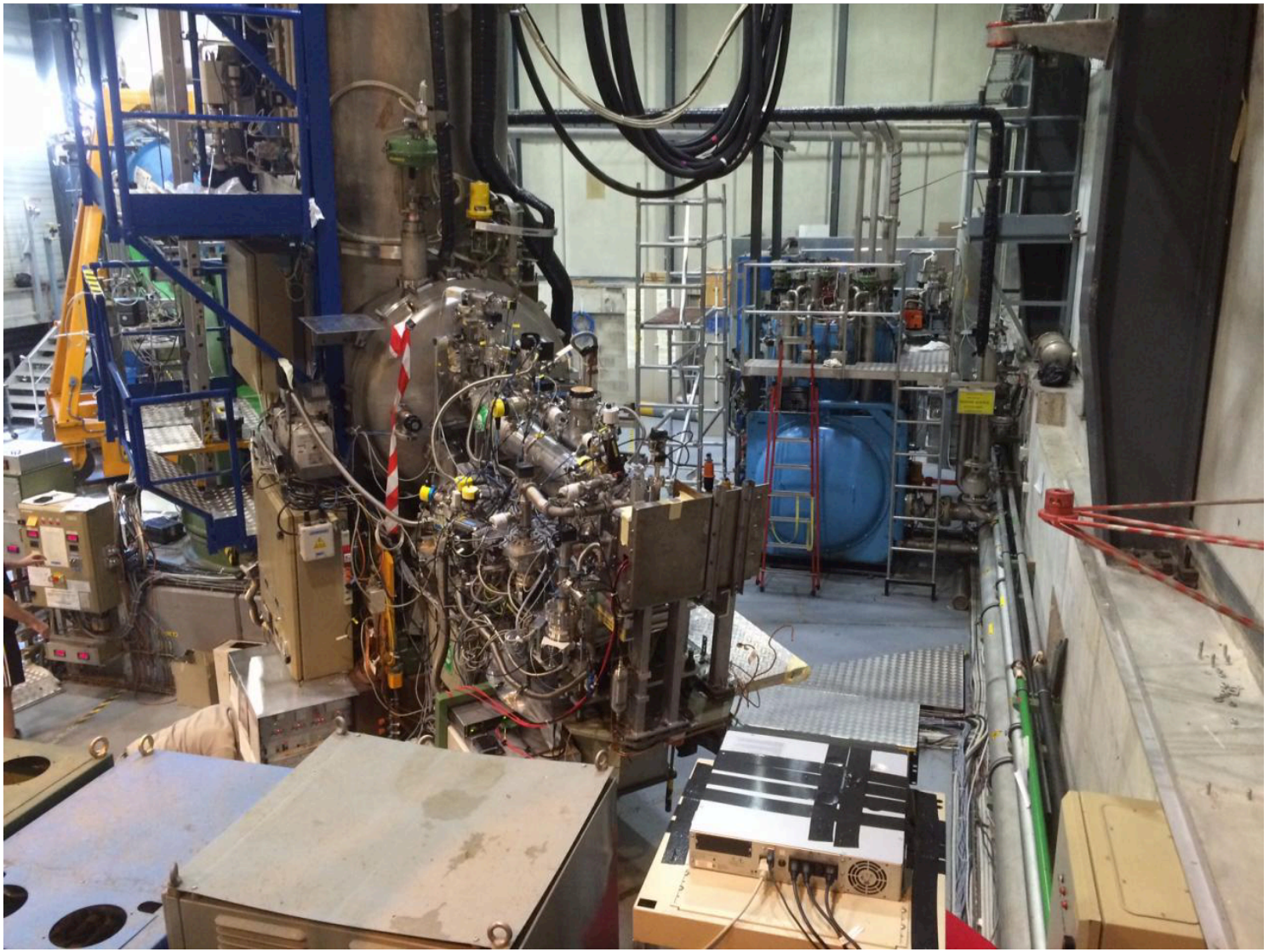


Setup in CAST

Setup in CAST



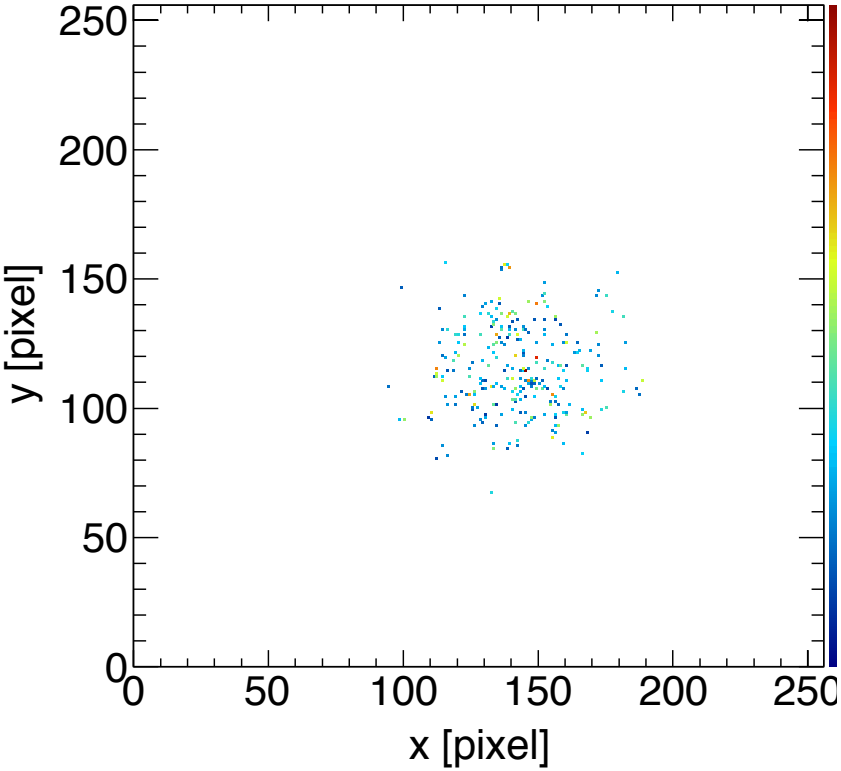
Setup in CAST



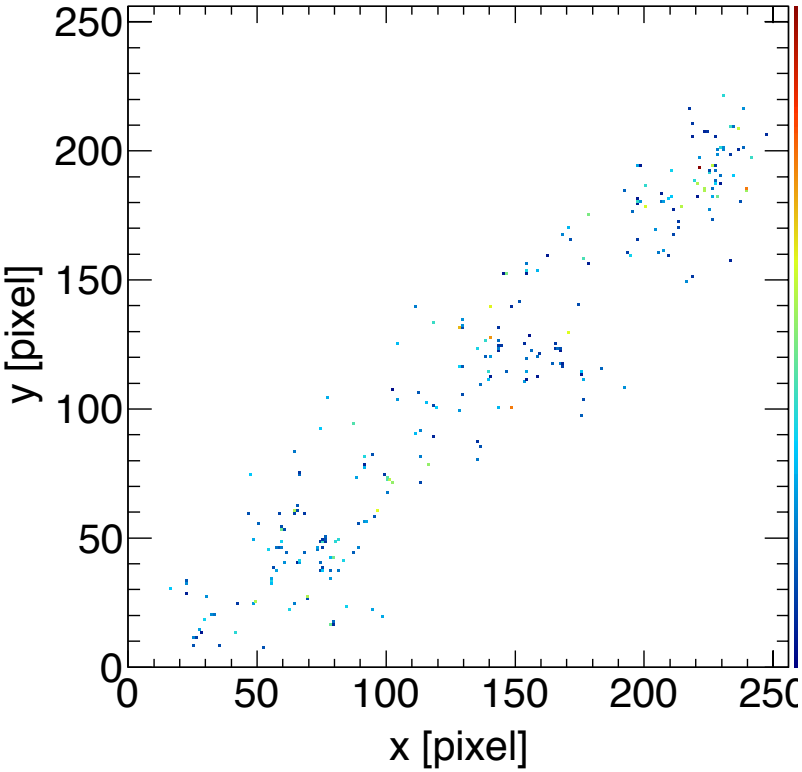
Topological Background Rejection

Distinguish between signal (left) and background (right) using the shape of the pixel hit pattern

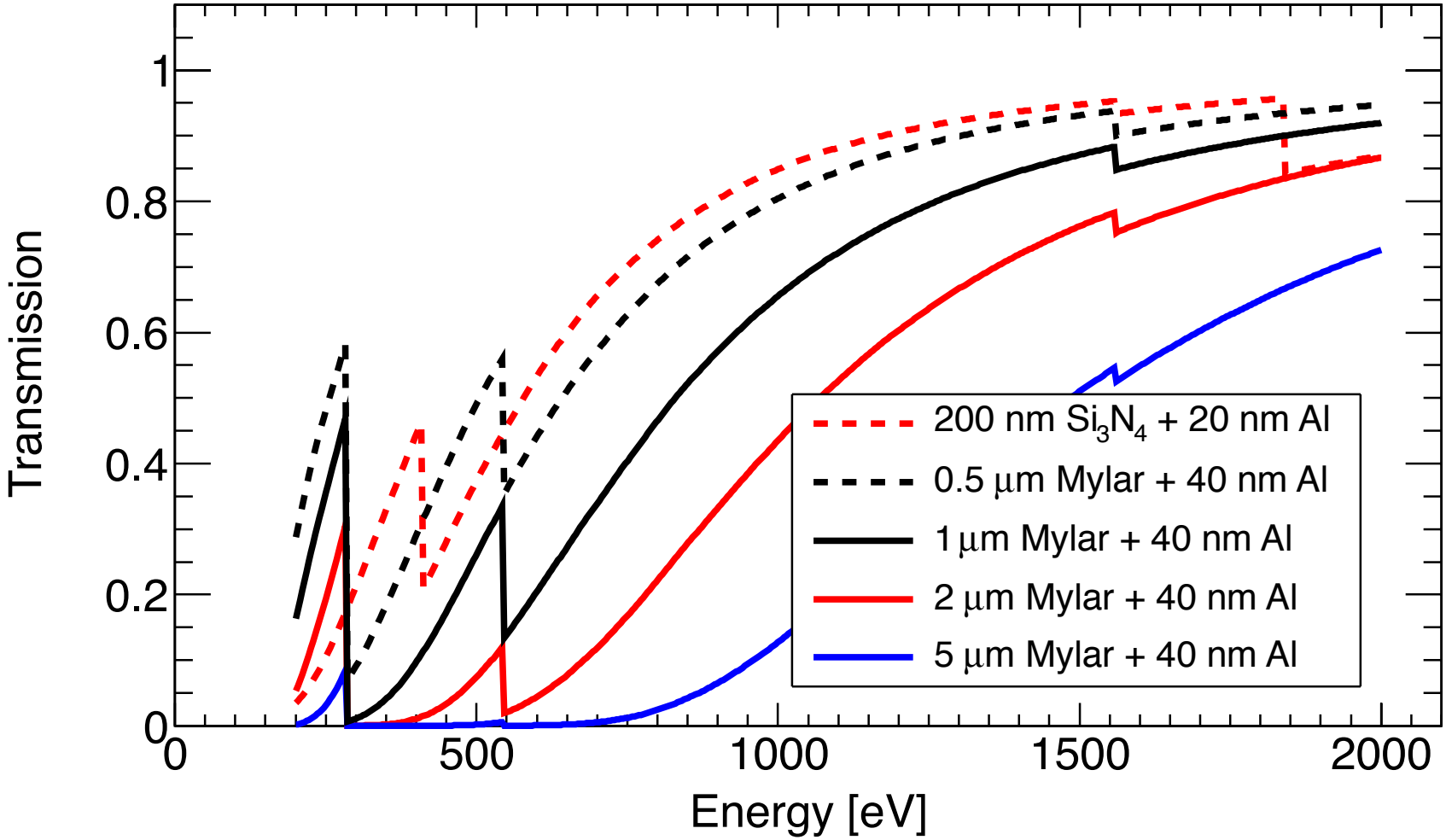
X-Ray (E=5.9 keV)



Cosmic track

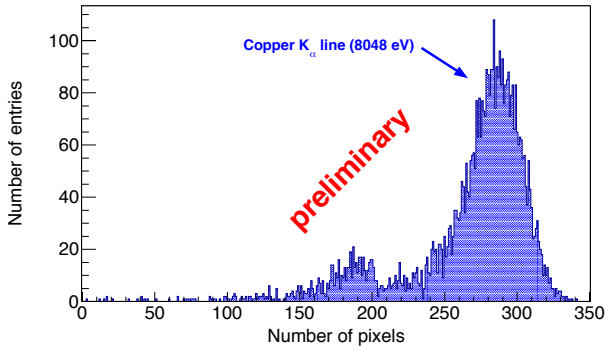


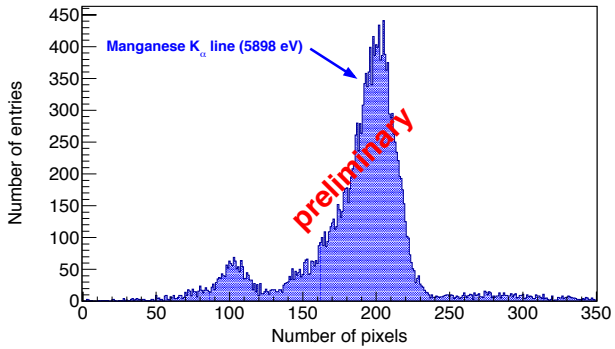
X-Ray Window

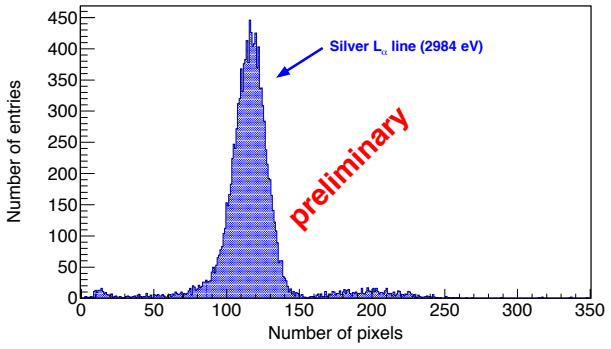


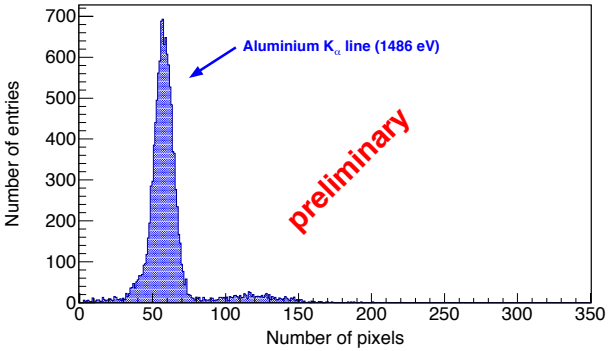
Currently: 2 μm Mylar (aluminized) + Cu strong-back (copied from CAST MMs)

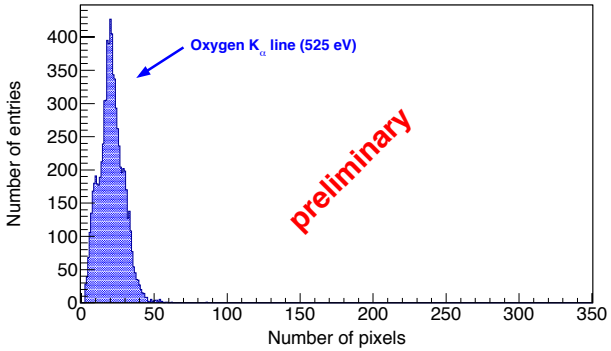
X-ray calibration at CAST detector lab

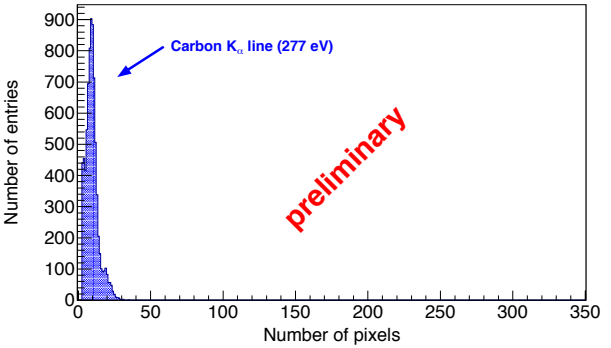


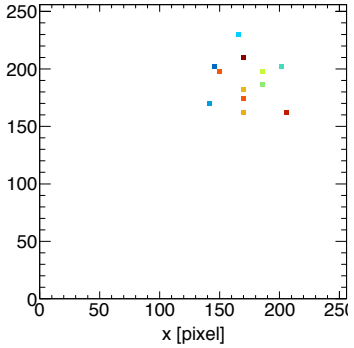












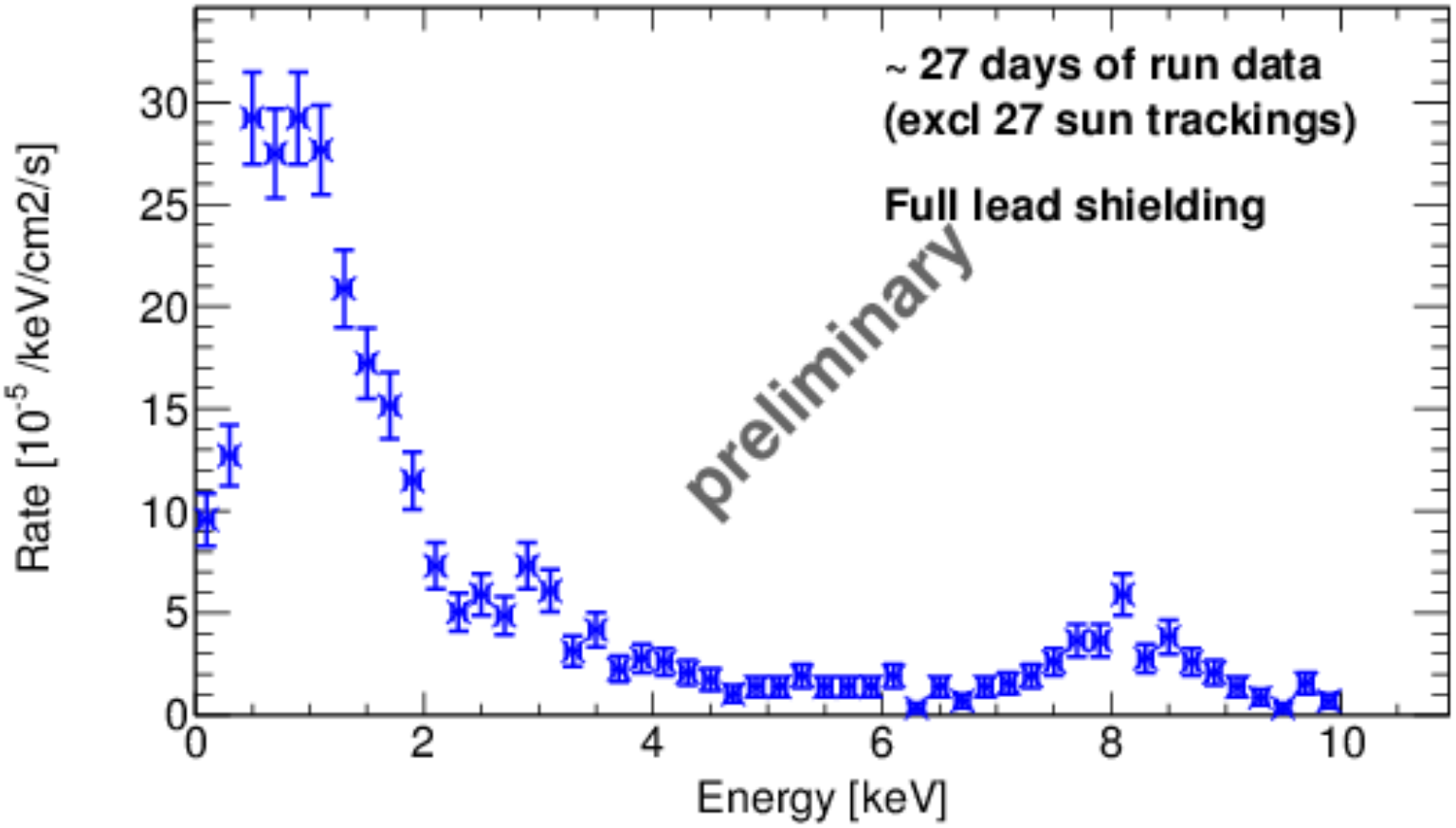
First data taking 2014

- Successful running in CAST in Oct/Nov 2014
- Detector operated without intermission for 27 days
- 2 379 029 frames of 0.98 s each have been recorded
- 27 sun trackings (data still blinded)

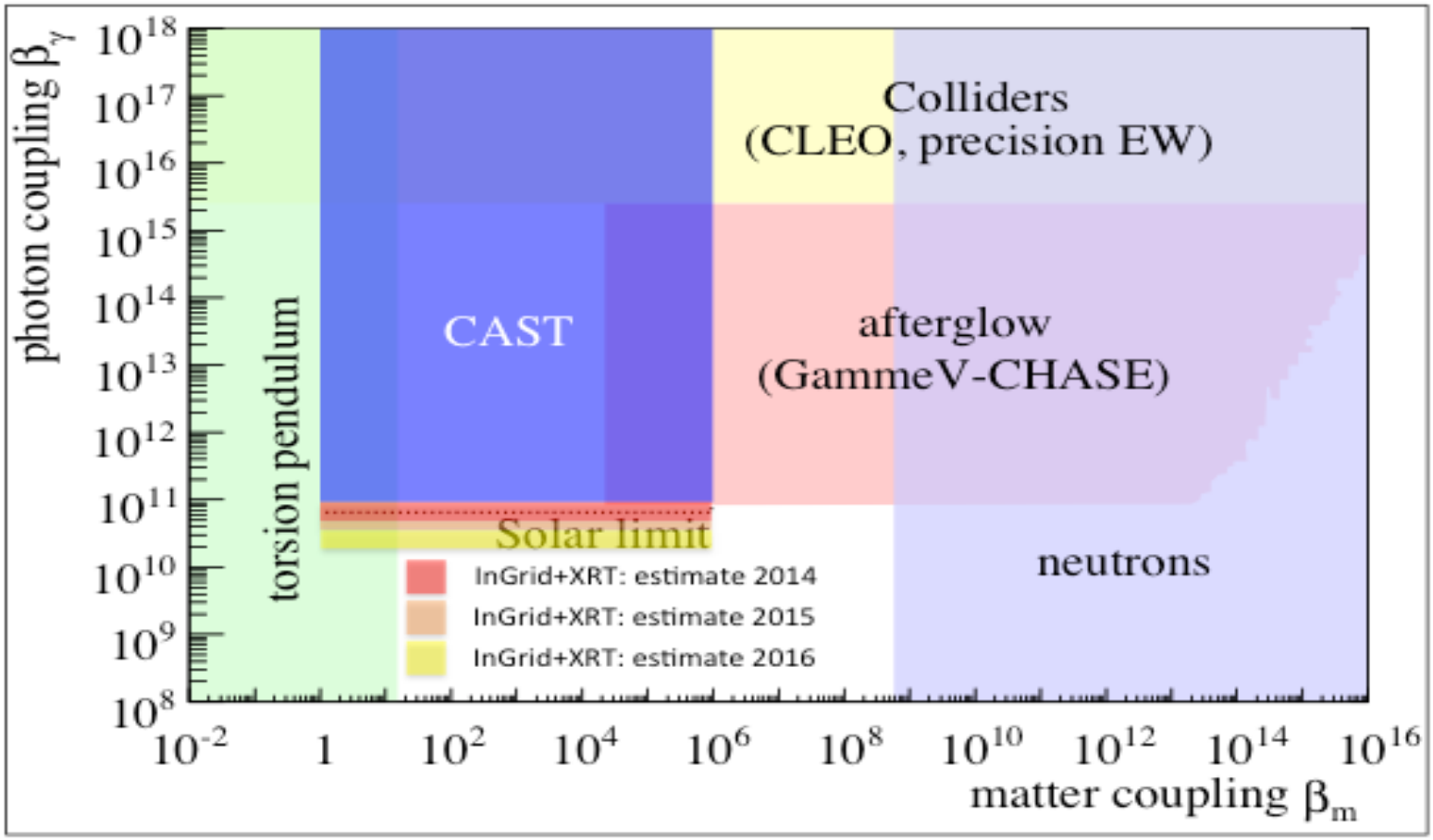
- analysis of data is ongoing
- preliminary background spectrum based on full data set (tuned for ~90% software efficiency)

- using simple 3-variable likelihood with real X-rays as reference

Background spectrum: 27 days



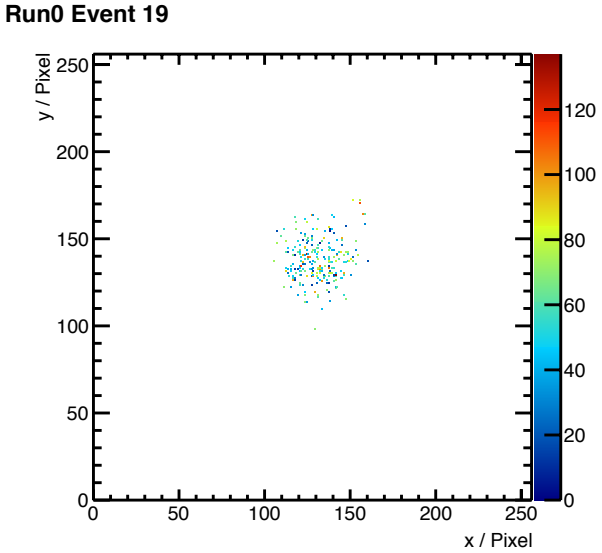
Expected sensitivity estimate

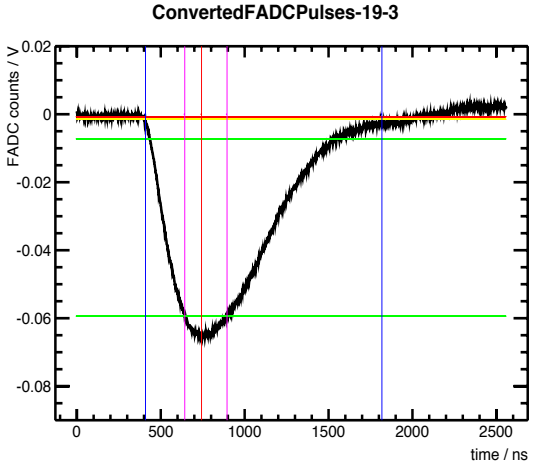


expect a discovery or a world-best limit on new physics (chameleons) using Timepix + InGrid...

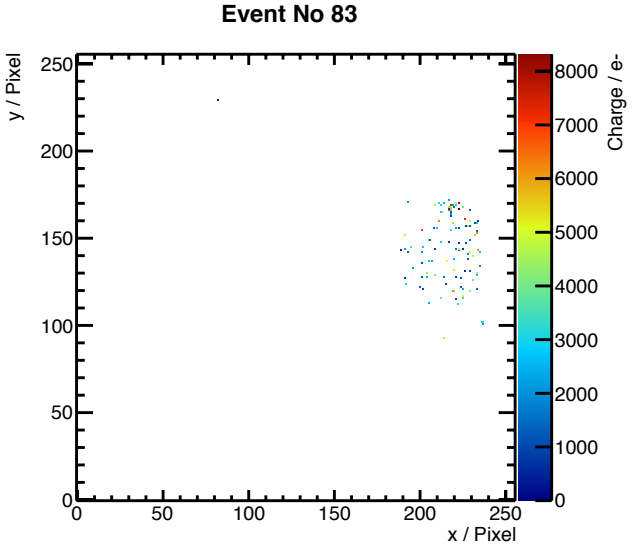
Outlook: Grid signal readout

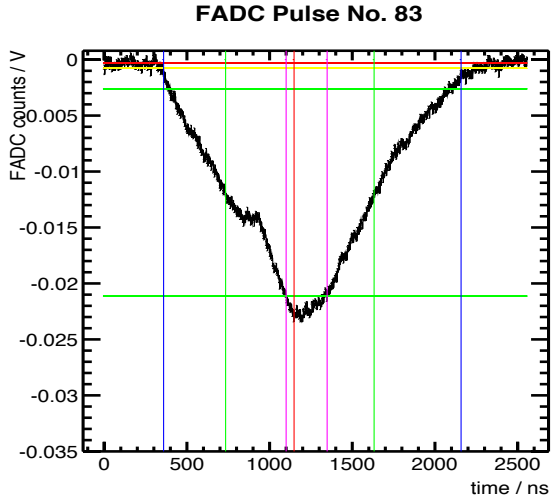
5.9 keV photon:





Perpendicular cosmic track:





Timepix signal

Induced pulse on the grid

Outlook: TimePix-3

Timepix-3 chip available
not equipped with InGrid

- fully data-driven readout
- 640 MHz timing clock
- simultaneous readout of charge (TOT) and time per pixel (TIME)

→full 3D reconstruction of charge cloud possible

→improved background rejection for ⊥ cosmics

Summary & Conclusion

- CAST setup is being used to broaded its physics scope (solar axions, solar chameleons, relic axions)
- Successful data taking with InGrid as low-energy X-Ray detector in 2014
- data analysis ongoing, sun trackings still blinded sensitivity should outperform SDD
- CAST run 2015 with InGrid „imminent“
- several ideas for further improvement towards (in 2015 & 2016)
- R&D towards IAXO

The group in Bonn

Christoph Krieger

Jochen Kaminski

Yevgen Bilevych

Michael Lupberger

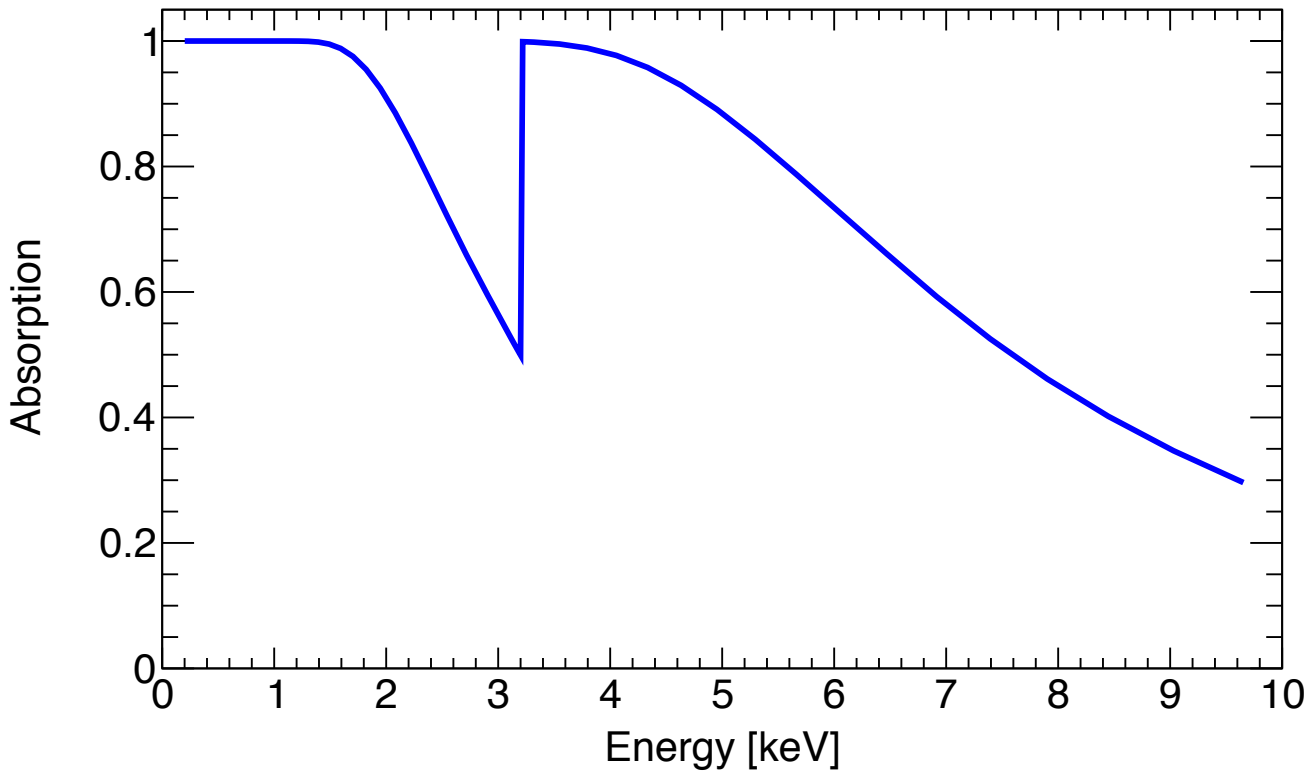
Many thanks to the great CAST collaboration for all their support and for accepting us as „late comers“

CAST

CERN Axion Solar Telescope

Backup

Photon absorption in 3cm Ar

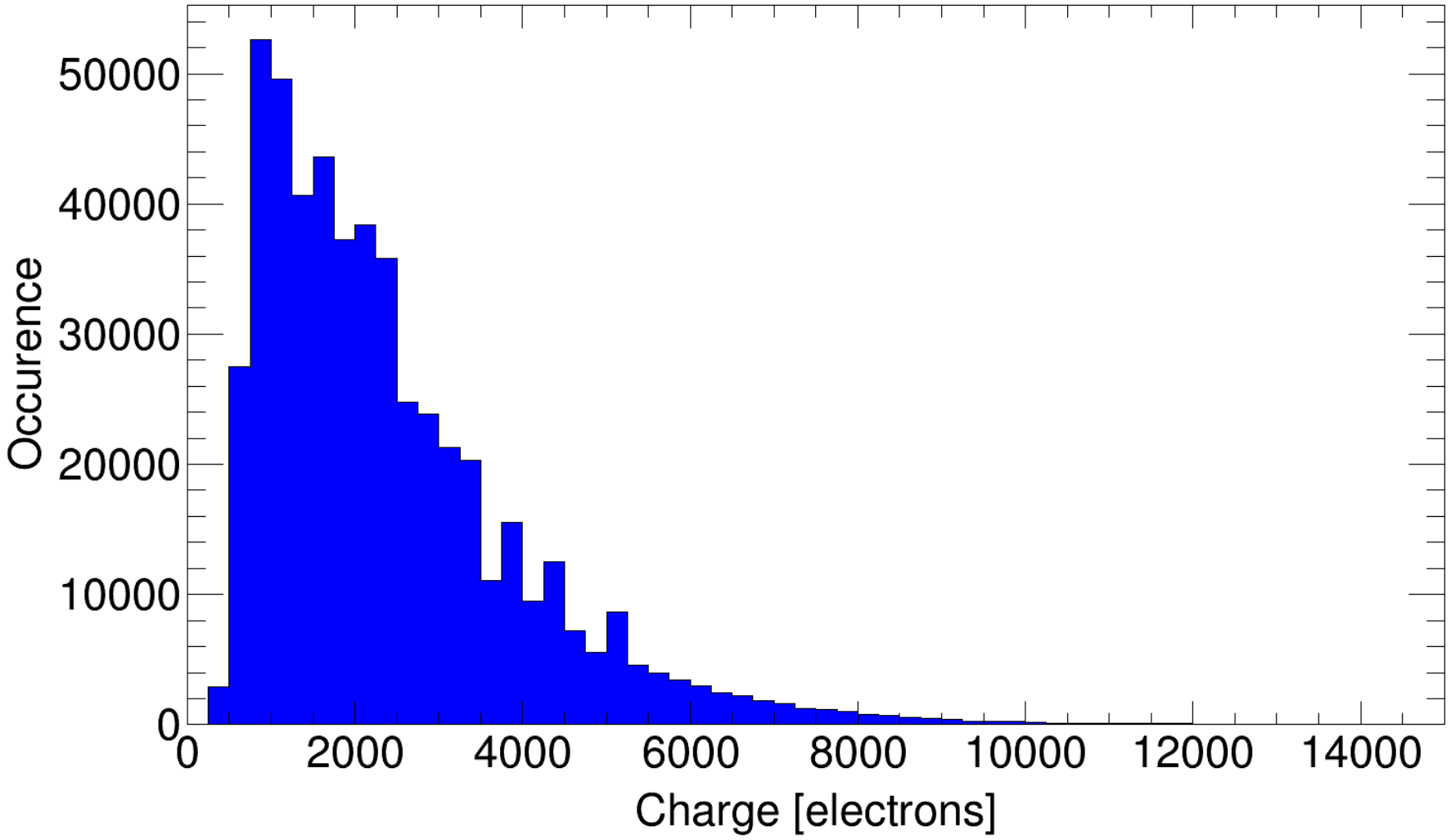


Backup

Detector operational parameters:

U_{grid} = 295 V
E_{drift} = 500 V/cm
l_{drift} = 3 cm
Gas Ar/Isobutane 97.7/2.3
gas gain ~ 2400
threshold: 1000 e^-
$\sigma_E/E \approx 6\%$ @ 5.9 keV

Backup

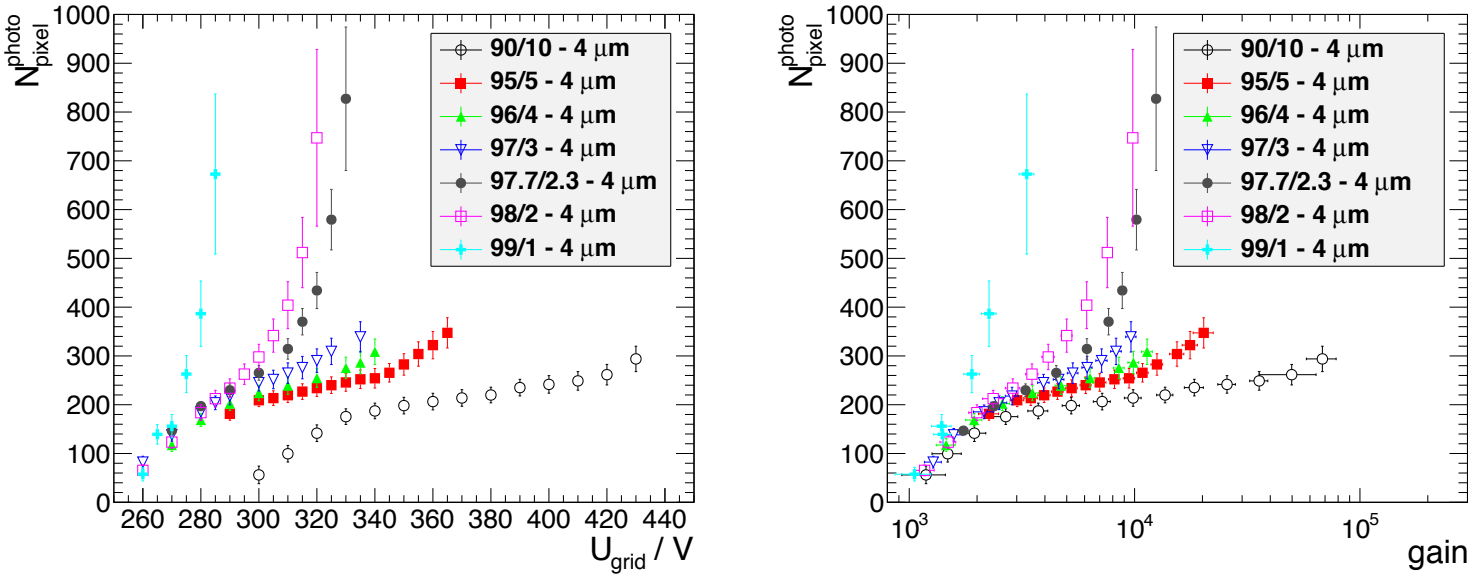

Occurence
50000
40000
30000
20000
10000
0
0
2000
4000
6000
8000
10000
12000
14000
Charge [electrons]

Backup

Energy bins for likelihood

low [keV]	high [keV]	line
0	0.4	C K-alpha
0.4	0.7	O K-alpha
0.7	1.2	Cu L-alpha
1.2	2.1	Al K-alpha
2.1	3.2	Ag L-alpha
3.2	4.9	Ti K-alpha
4.9	6.9	Mn K-alpha
6.9		Cu K-alpha

Backup

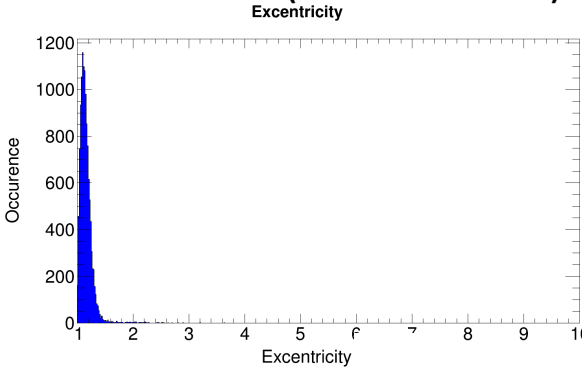


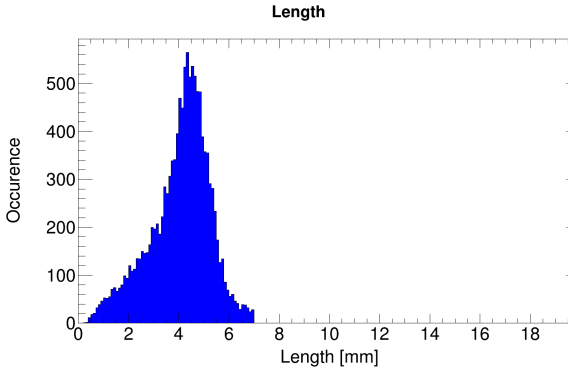
(a) (b)

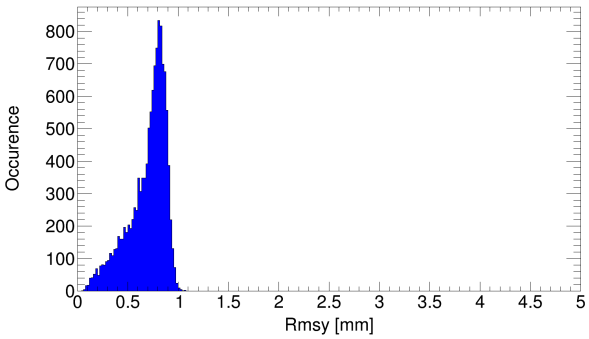
Figure 9.2: Dependence of the number of pixels over threshold in the photo peak on the grid voltage U_{grid} (a) and the gas gain (b) for different Ar/iC_4H_{10} mixtures. All error bars are inflated by a factor of 100.

Backup

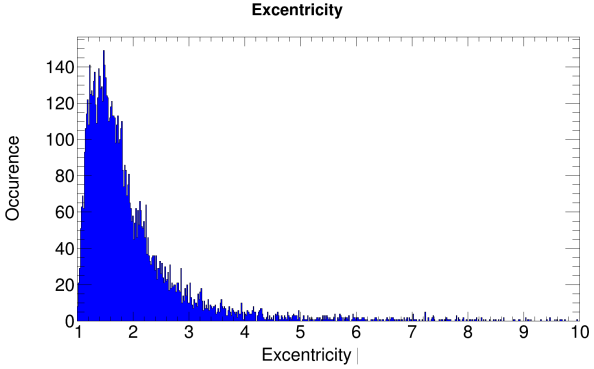
reference (2.1 – 3.2 keV)

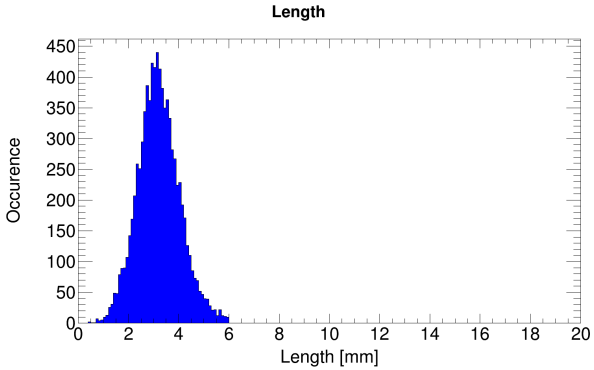


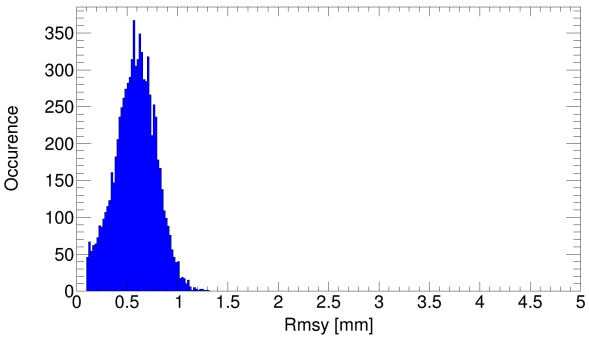




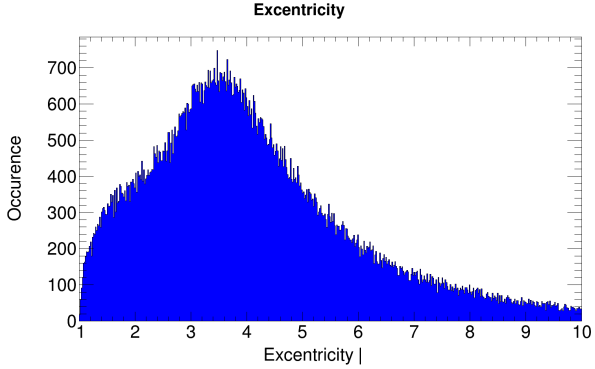
reference (<0.4 keV)

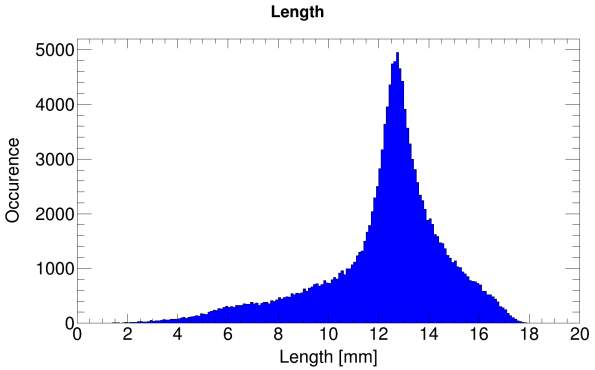


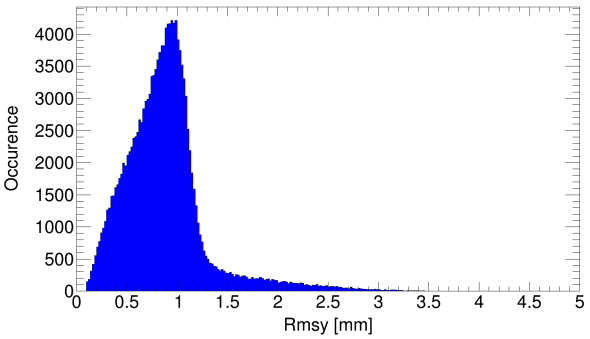




background

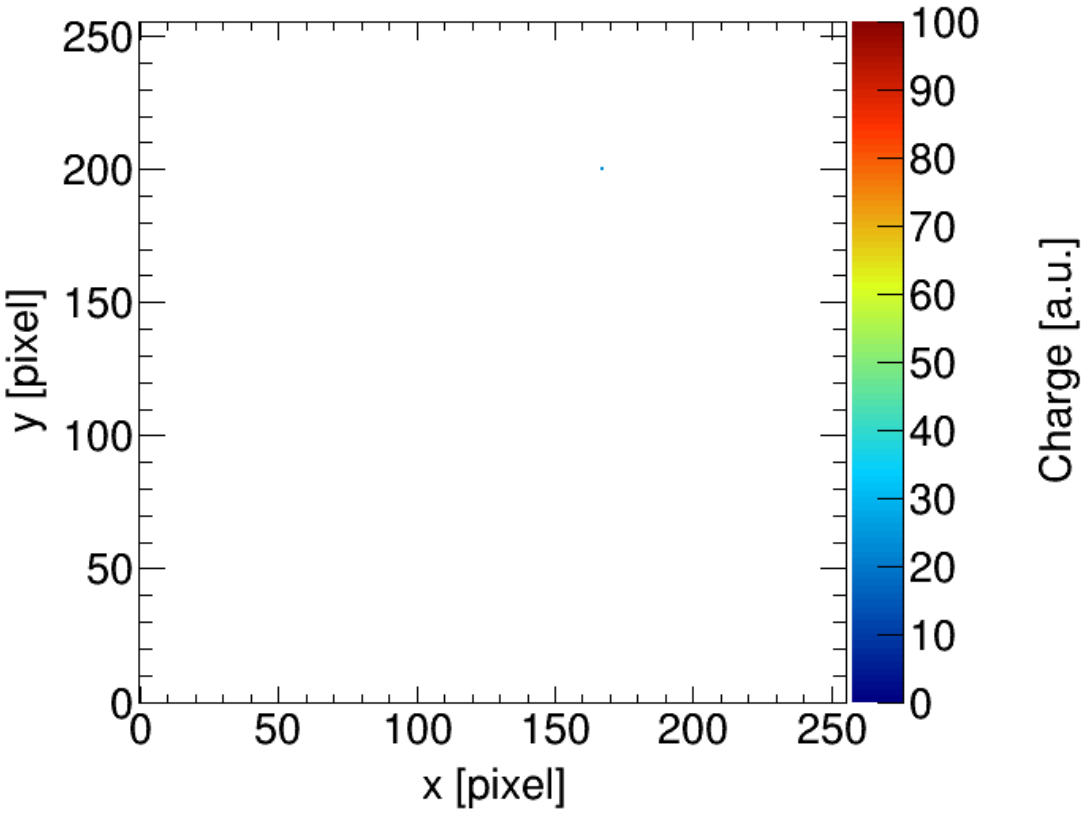






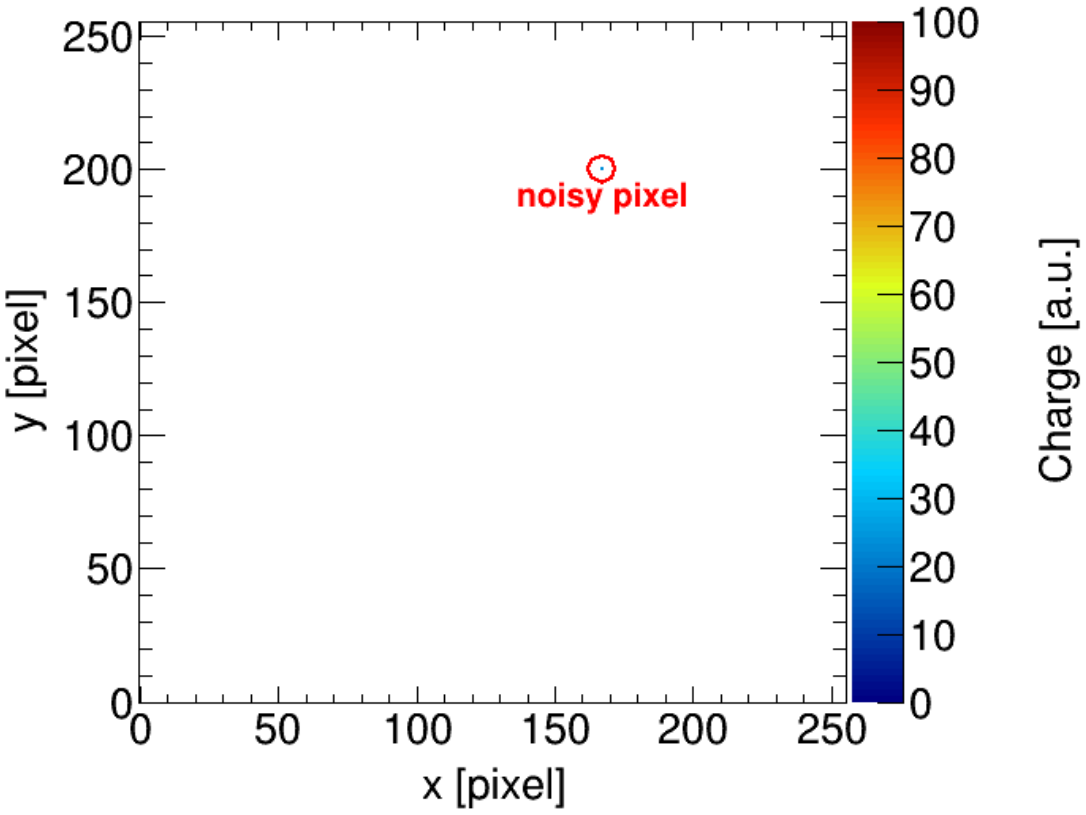
Noise? No

Out of 2379029 frames (0.98s) 1988773 frames look like this:



Noise? No

Out of 2379029 frames (0.98s) 1988773 frames look like this:

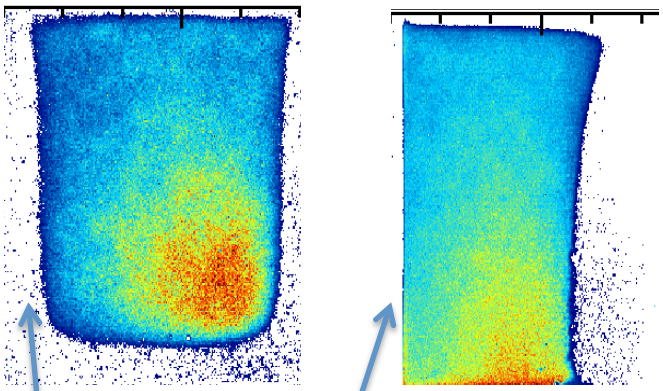


suitable for rare event searches...

Outlook: Larger Areas

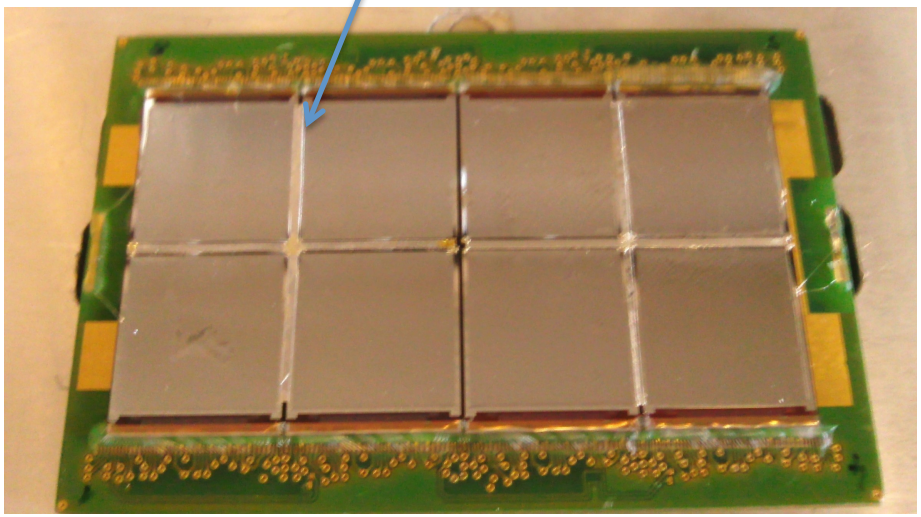
8-chip InGrid boards existing (Octopuce/Saclay, Octoboard/Bonn)
Challenge (for X-ray detector):

- dead areas between chips
- field distortions



no Al strip with Al strip

(only left edge can be compared)



promising but better procedure needed...