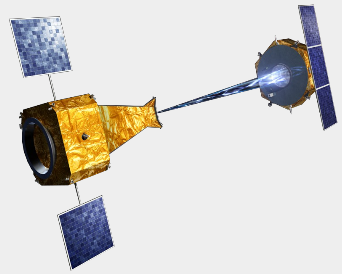
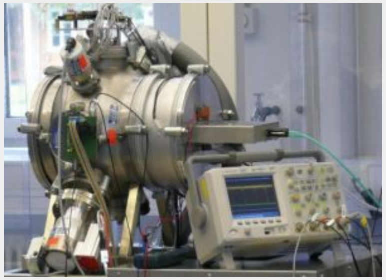
CANDELA, a setup to study a stacked detector configuration and the way to ASTRO-H

14.04.2015, Daniel Maier, P.160

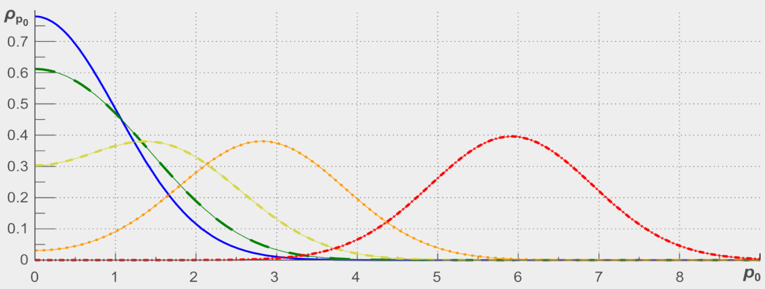
Overview

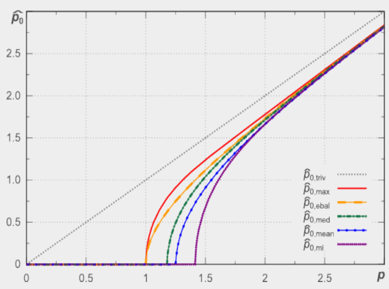
CANDELA setup



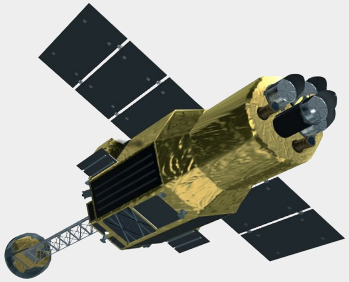


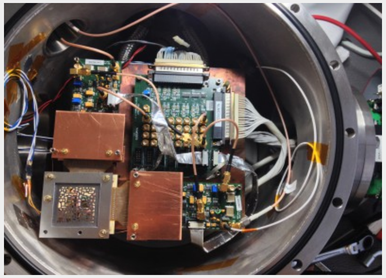
Statistics on polarization measurements

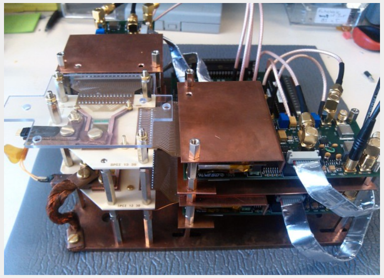




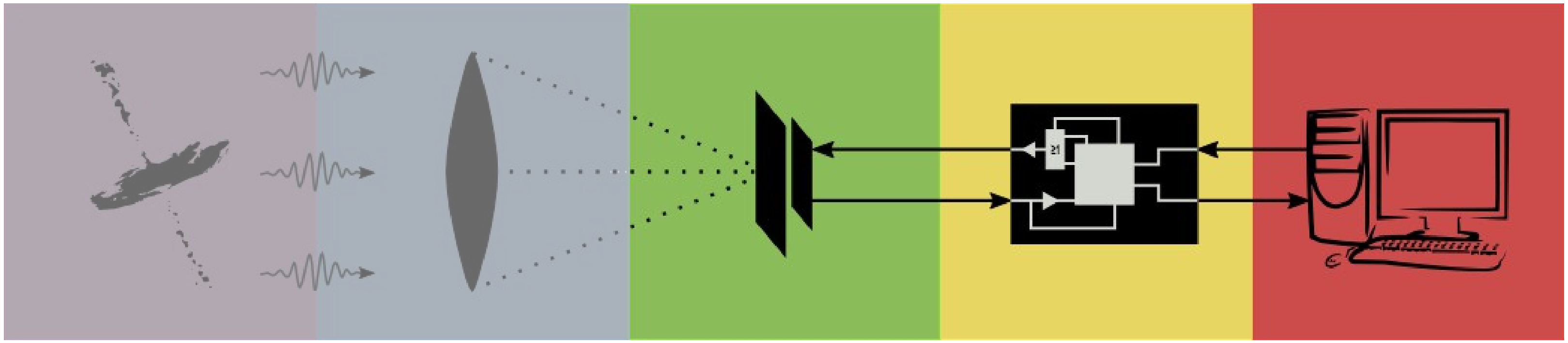
Perspective: ASTRO-H





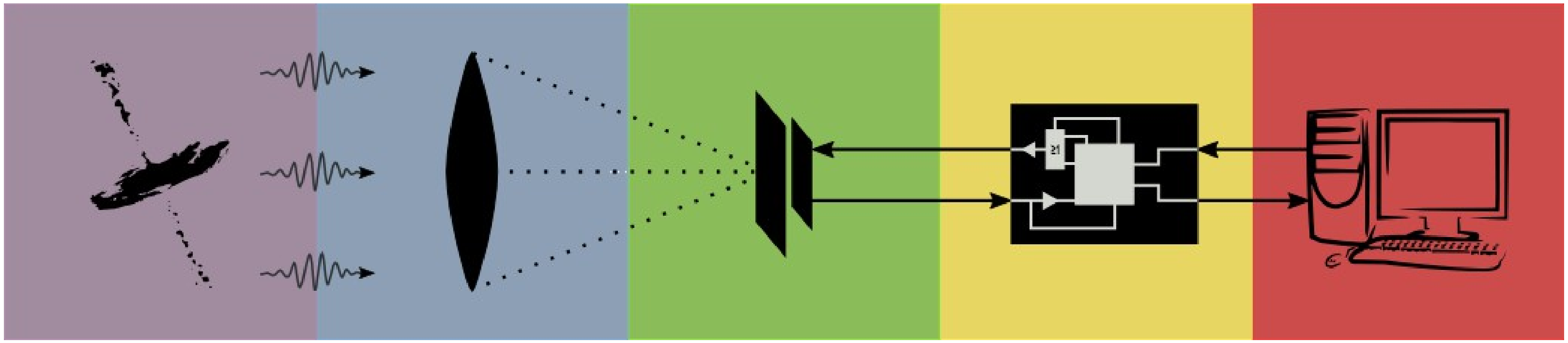


CANDELA setup



sources | optics | detector | onboard electronics | data analysis

CANDELA setup



sources

optics

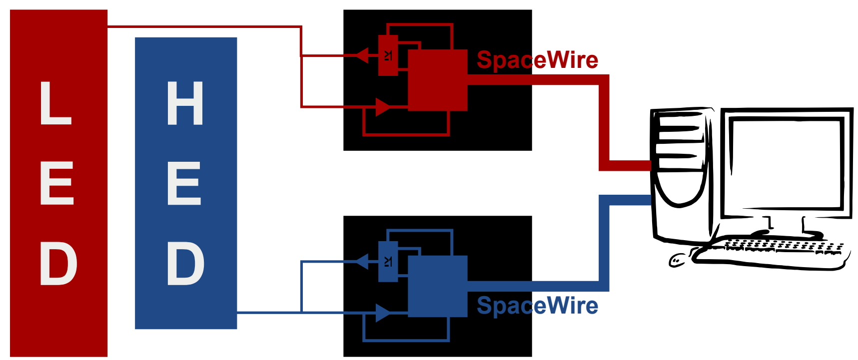
detector

onboard electronics

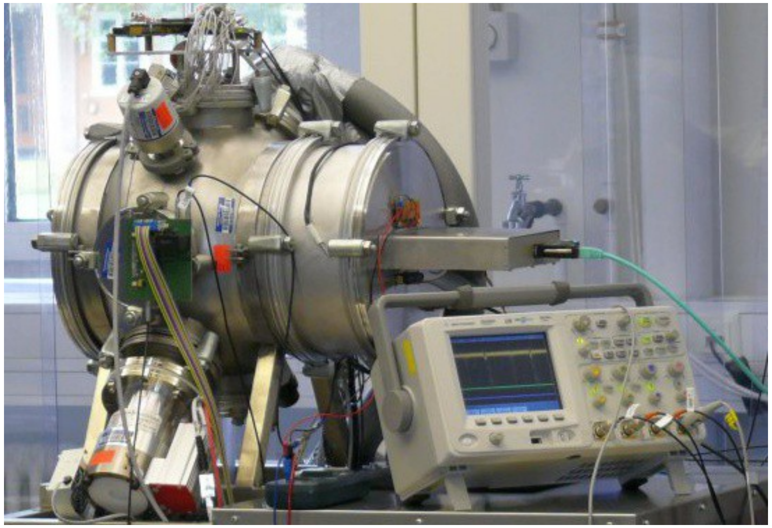
data analysis

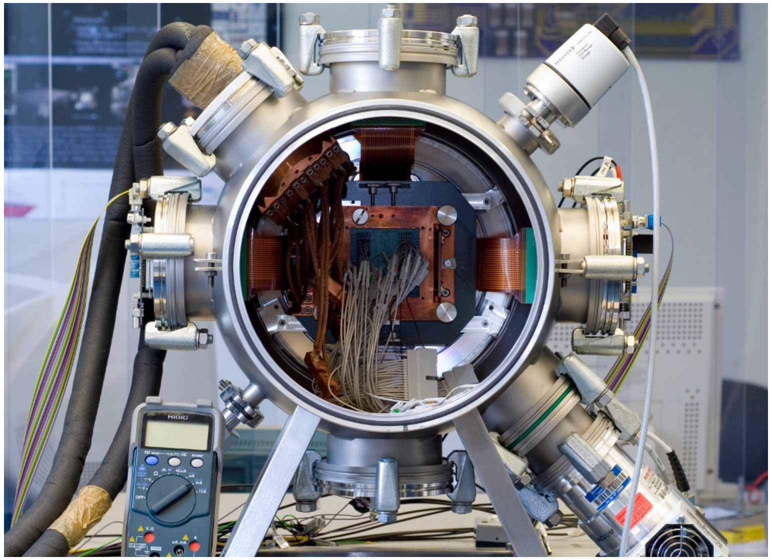
Fe-55

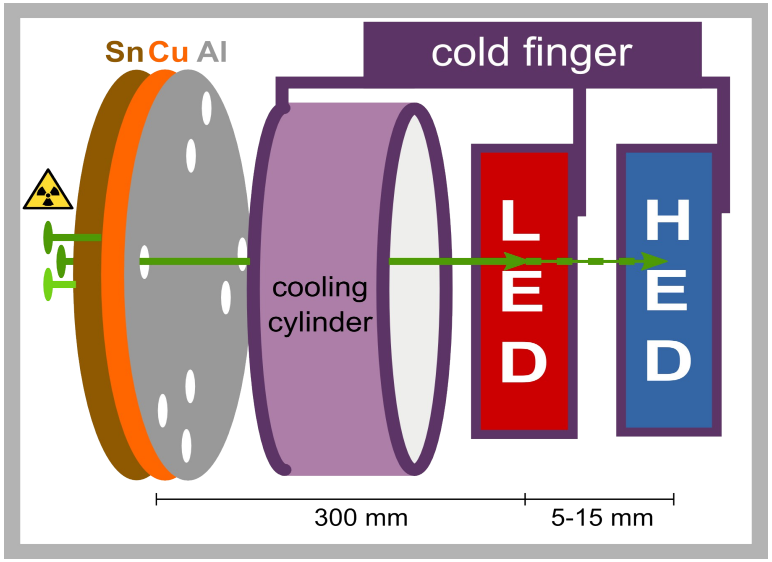
Am-241



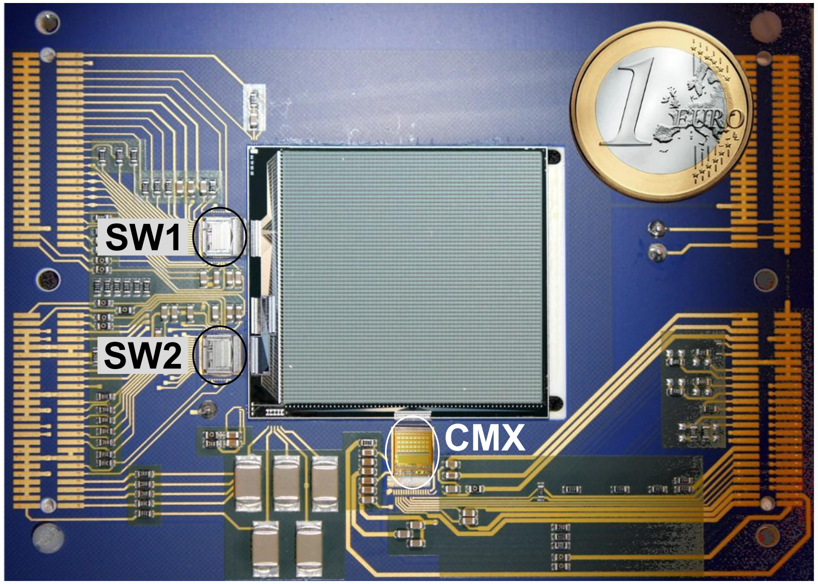
CANDELA setup

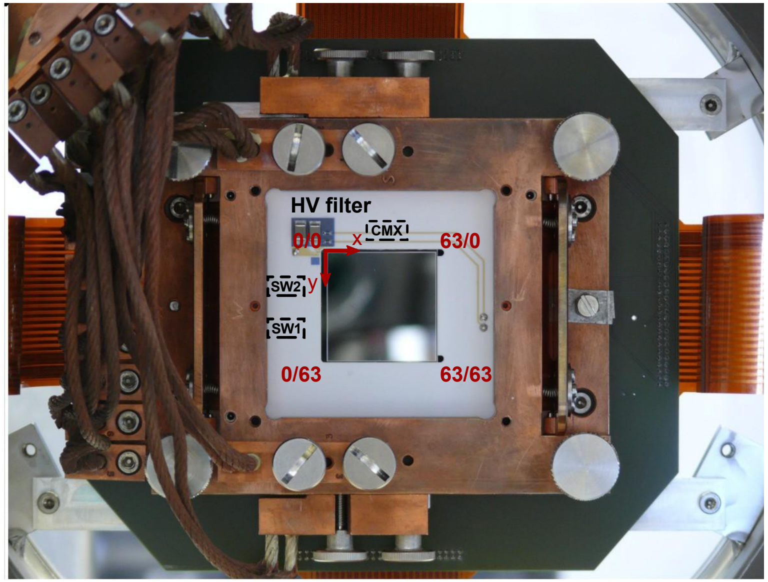






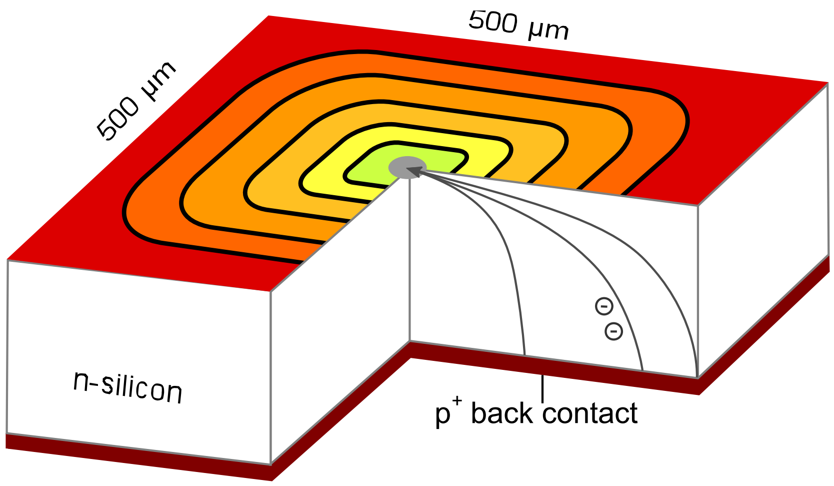
Low energy detector (LED)



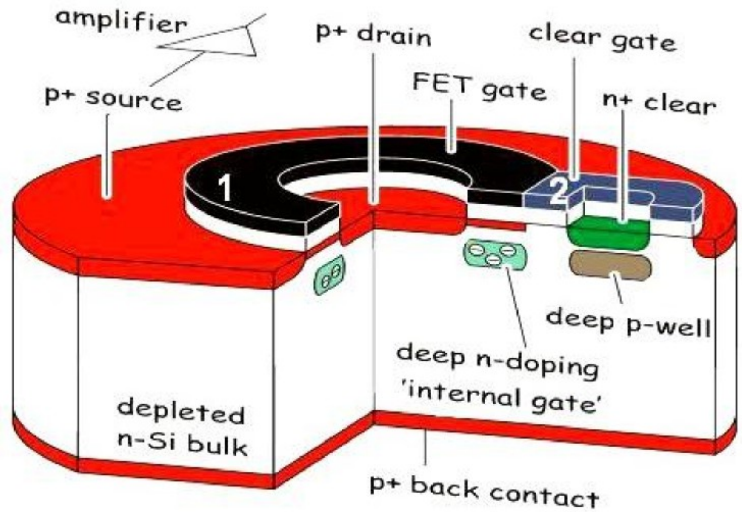


- silicon based (Z = 14)
- active pixel matrix 64 x 64
- Same technology as for ATHENA WFI

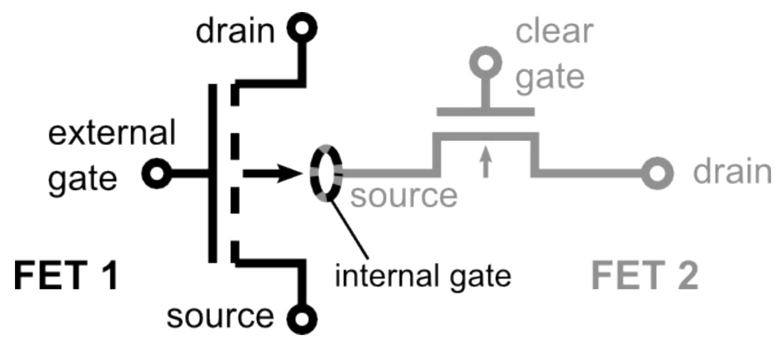
LED pixel structure



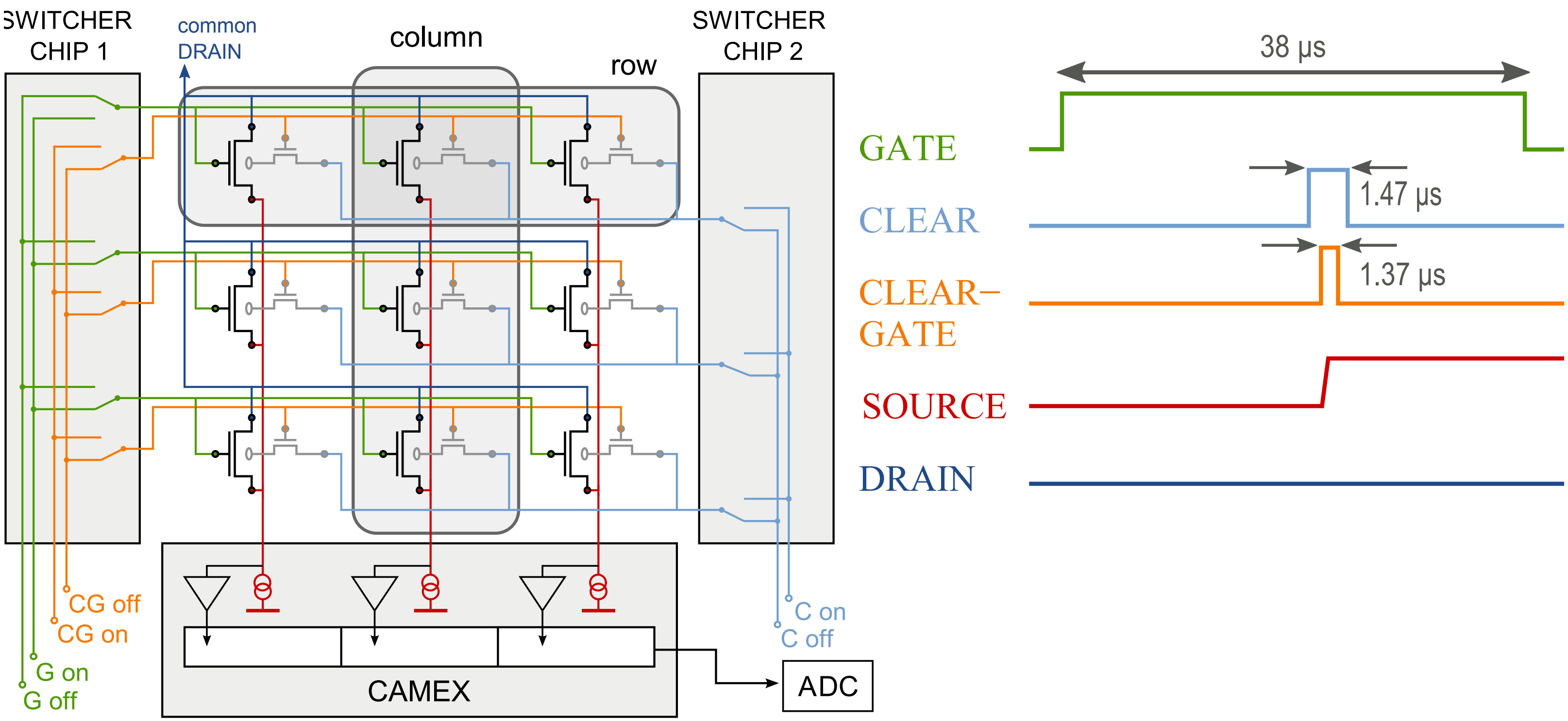
-5 V -10 V -20 V -30 V -40 V -50 V -80 V



- silicon based (Z = 14)
- active pixel matrix 64 x 64
- DePFET pixel:
  - sideward depletion
  - internal gate
  - additional CLEAR FET
- macro pixel

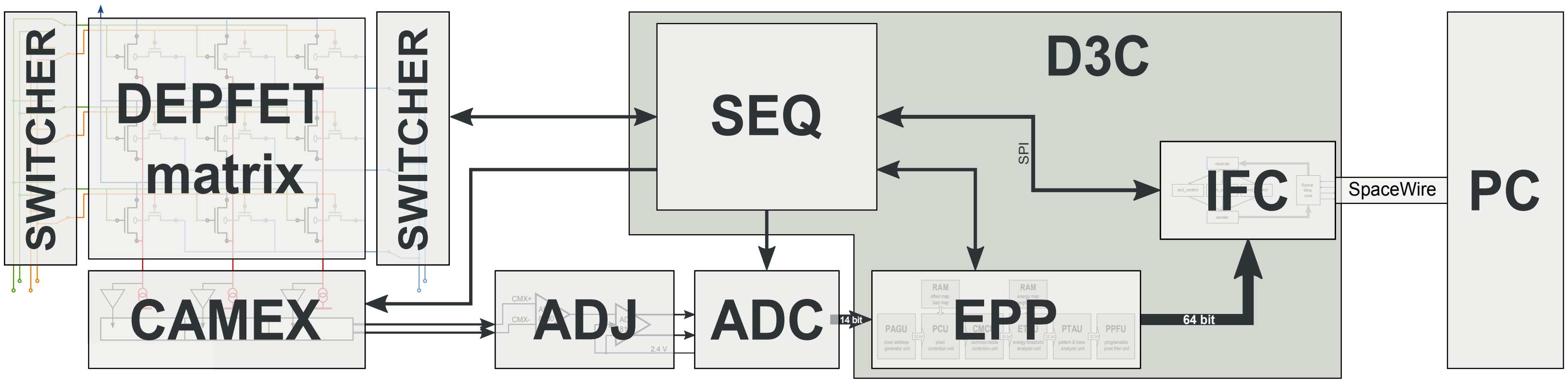


LED matrix structure

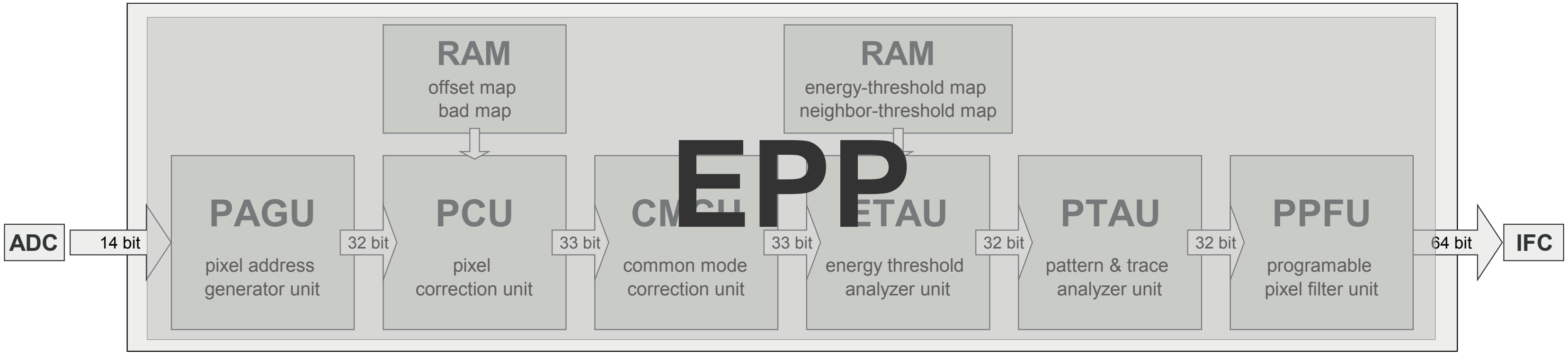


- SWITCHER controller chips
  - switch gate, clear gate, and clear potentials
- CAMEX readout chip (same as for SVOM MXT)
  - signal amplification
  - correlated double sampling
  - multiplexing to ADC

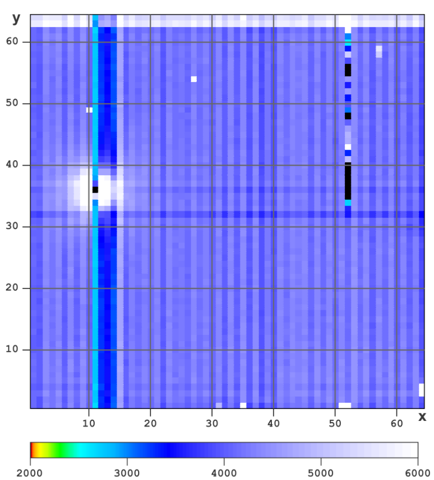
LED electronics



LED electronics: EPP



input:
frame based

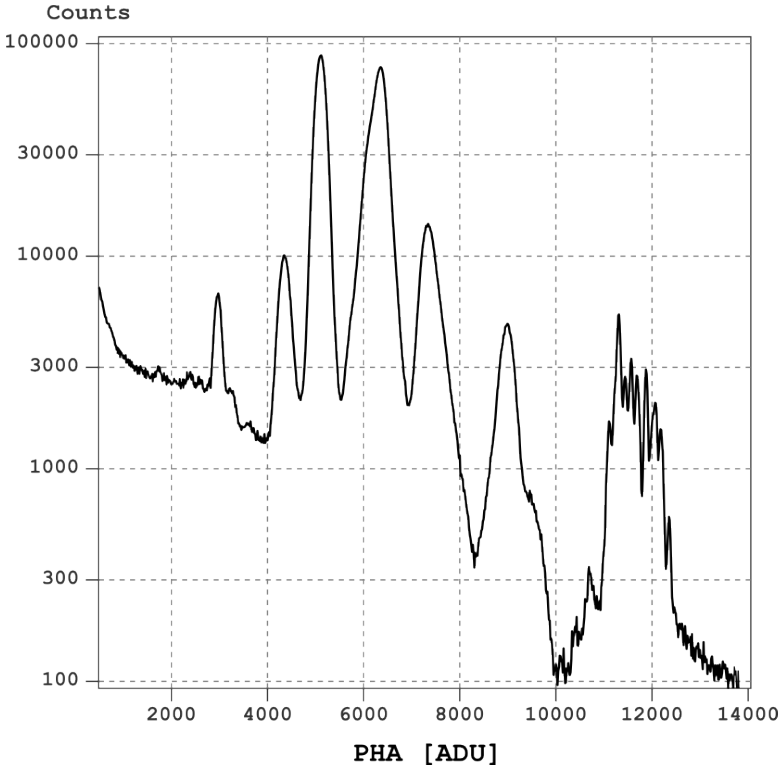


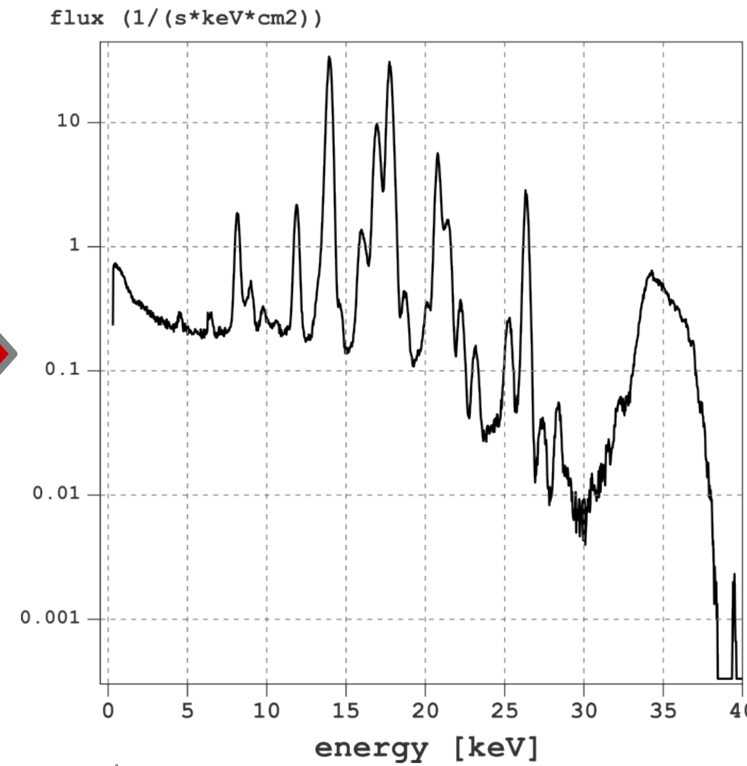
event building

- pixel individual energy tresholds

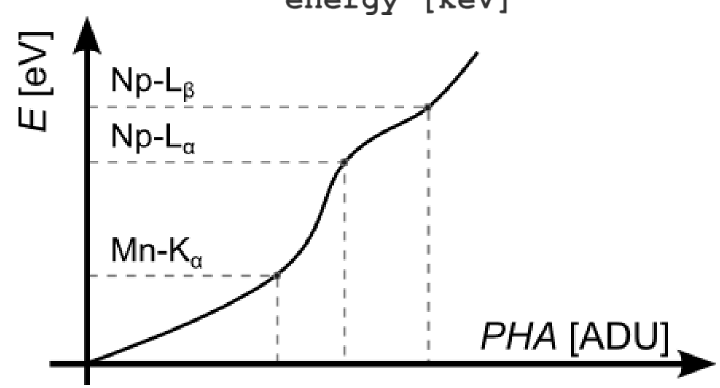
output:
event based
- position
- pulse height
- time

LED energy calibration

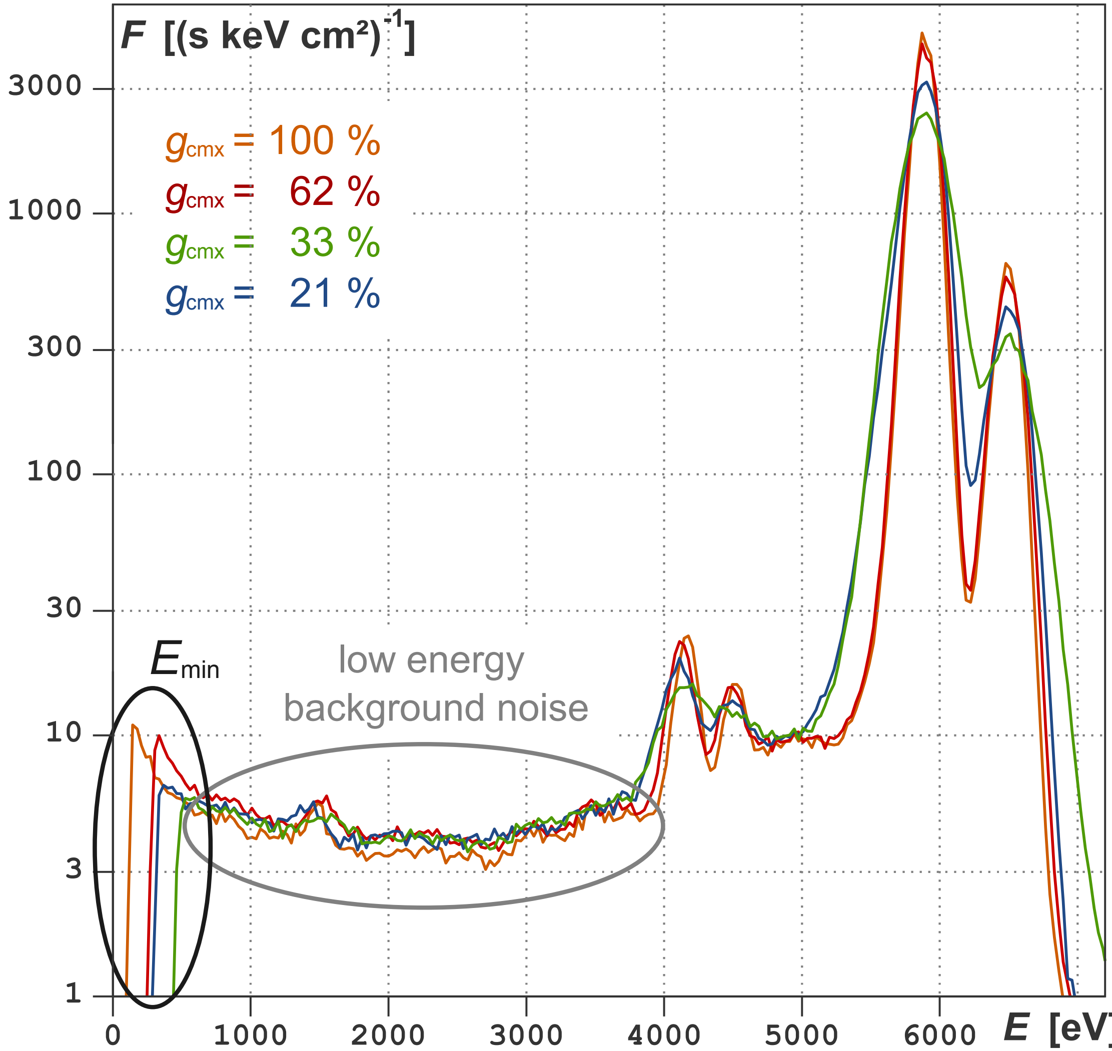




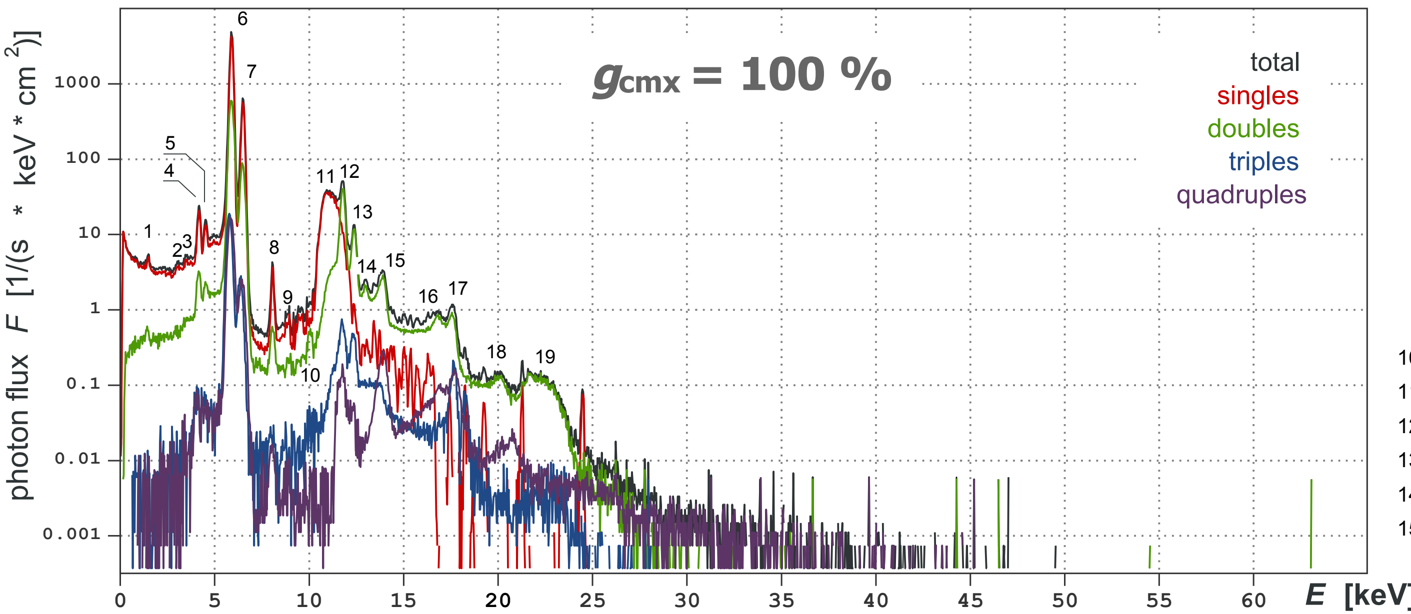
pixel individual calibration
via cubic spline interpolation
→ smooth transition
→ functional description *E*(*PHA*)



LED energy calibration



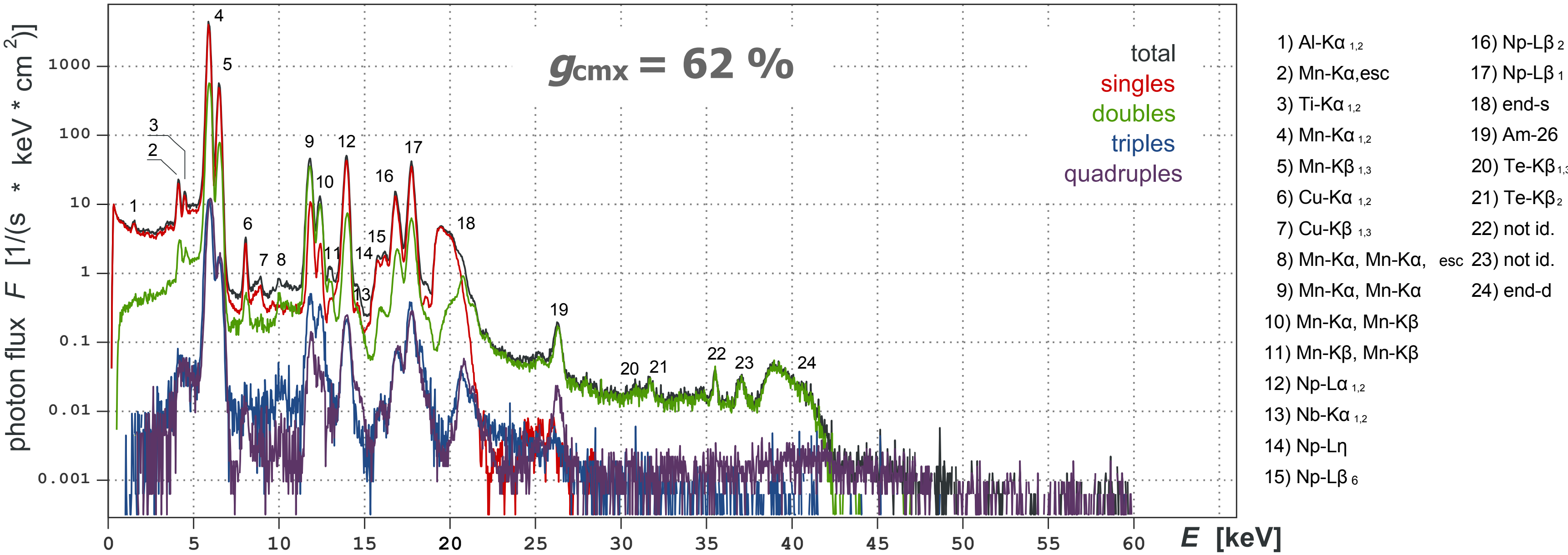
LED spectra



1) Al-Kα 1,2
2) Cd-Lα 1,2
3) Te-Lα 1,2
4) Mn-Kα,esc
5) Ti-Kα 1,2
6) Mn-Kα 1,2
7) Mn-Kβ 1,3
8) Cu-Kα 1,2
9) Cu-Kβ 1,3
10) Mn-Kα, Mn-Kα, esc
11) end-s
12) Mn-Kα, Mn-Kα
13) Mn-Kα, Mn-Kβ
14) Mn-Kβ, Mn-Kβ
15) Np-Lα 1,2
16) Np-Lβ
17) Np-Lβ
18) Np Lγ 1
19) end-d

g_{cmx} [%]	$\bar{o}$ [ADU]	$\bar{n}$ [ADU]	E_{min} [eV]	E_{max} [keV]	ΔE_1 [eV]	ΔE_2 [eV]	ΔE_3 [eV]	E_{off} [eV]	s [%]	d [%]	t [%]	q [%]
100	4409	42	144	10	168	-	-	- 50	79.5	18.3	0.59	0.55
62	3802	32	336	19	198	-	-	+30	80.7	17.3	0.46	0.43
33	3568	23	368	33	267	342	-	+60	83.9	14.5	0.25	0.19
21	3292	20	528	>60	342	344	352	- 50	84.3	14.2	0.18	0.17

LED spectra



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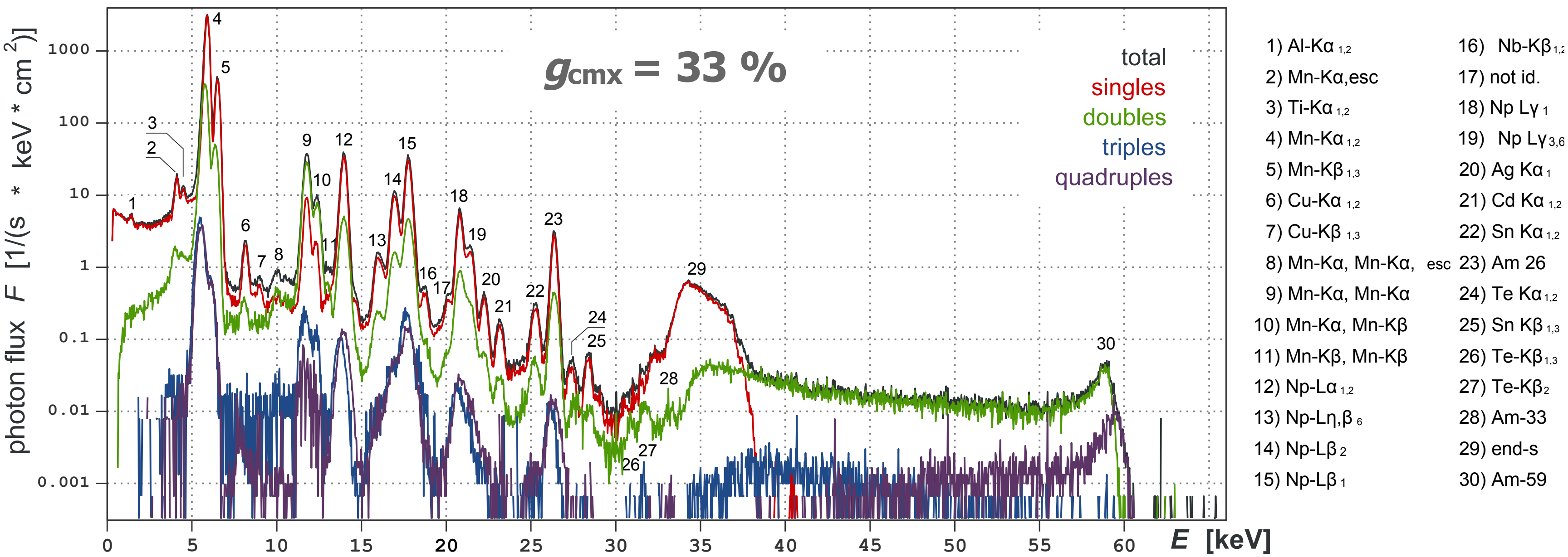

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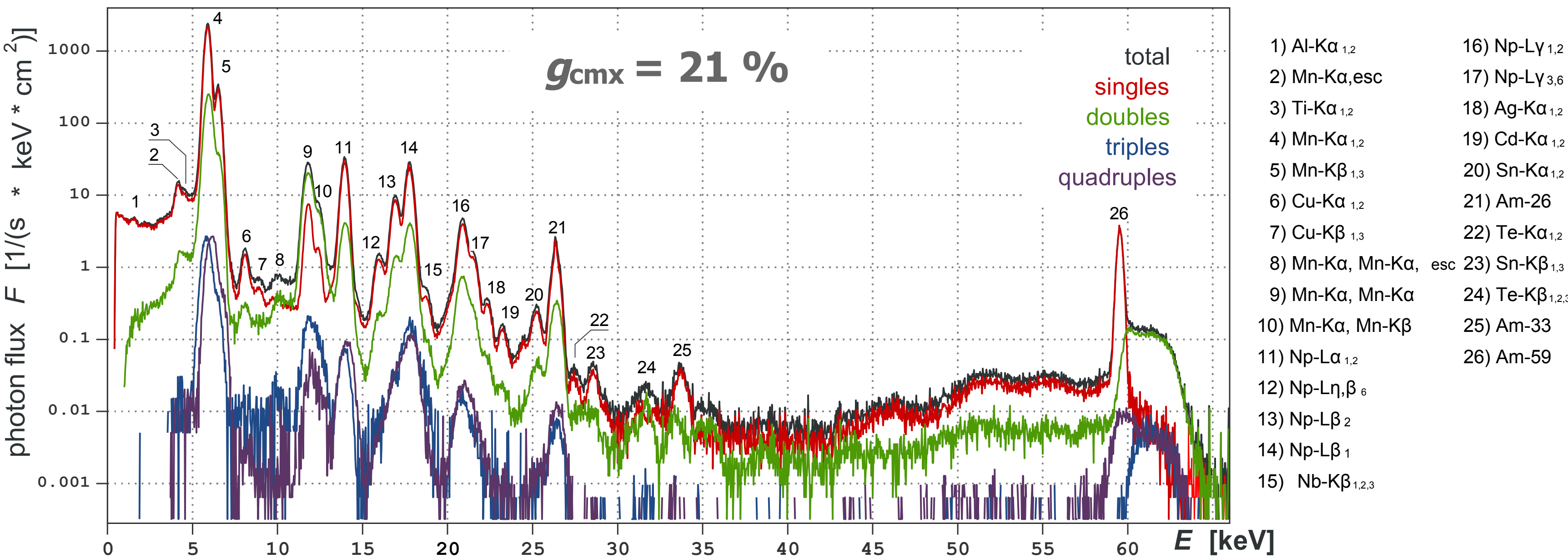

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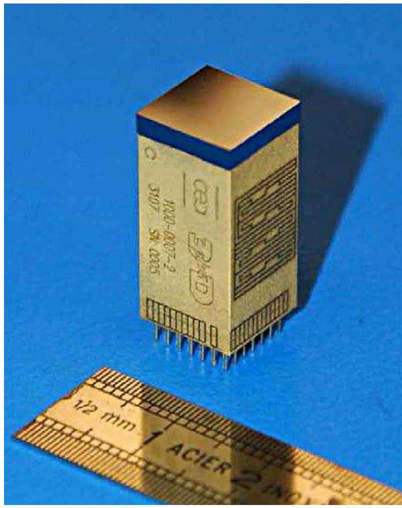
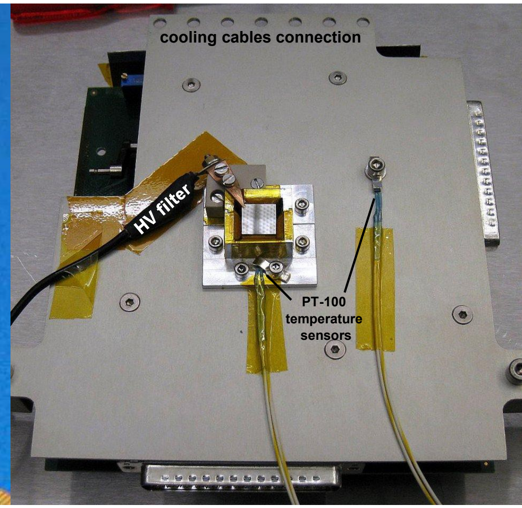
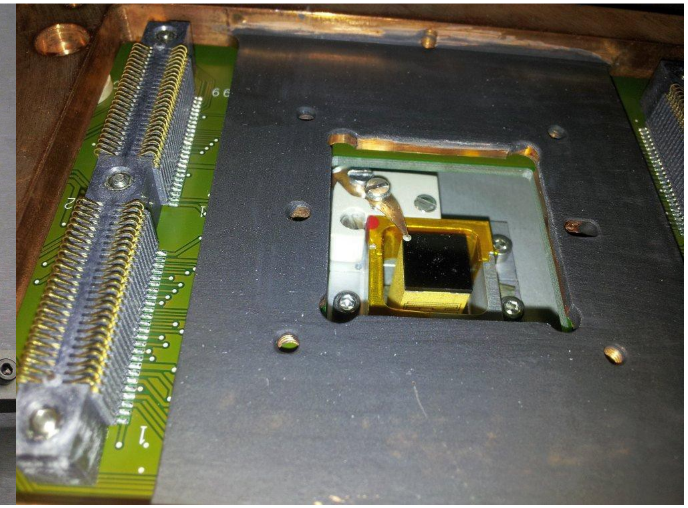
High energy detector (HED)

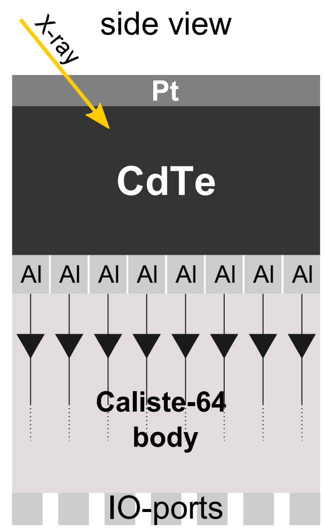


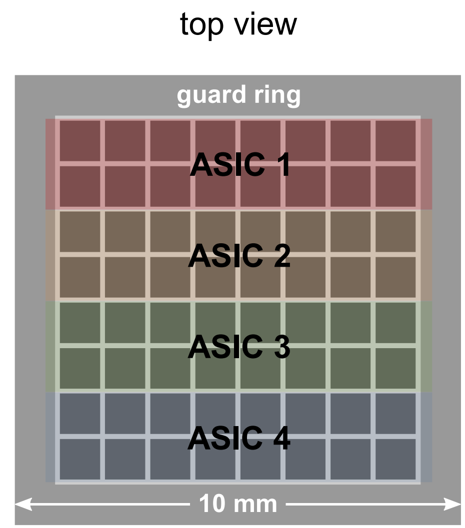




HED:

- CdTe based (Z = 48 & 52)
- 8 x 8 Schottky diodes
- triggered readout mode
- polarization effect





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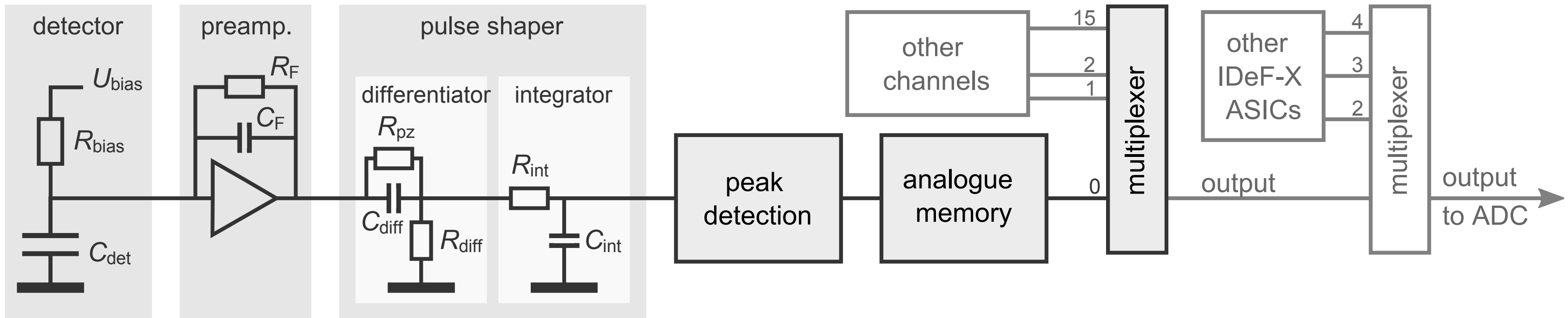
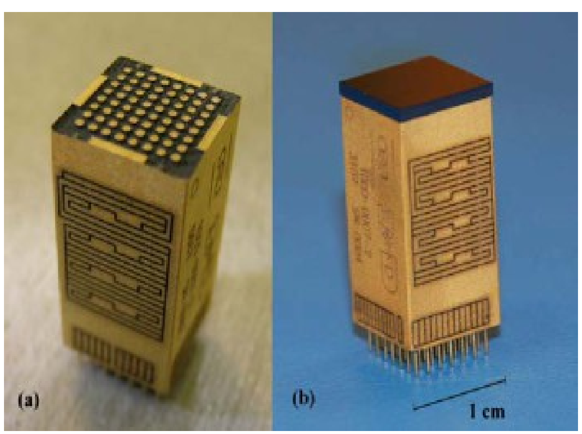
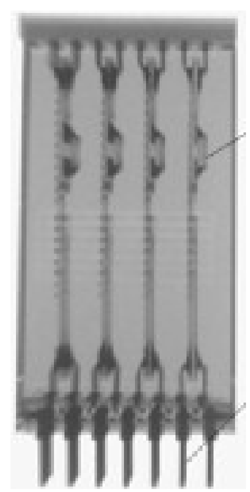
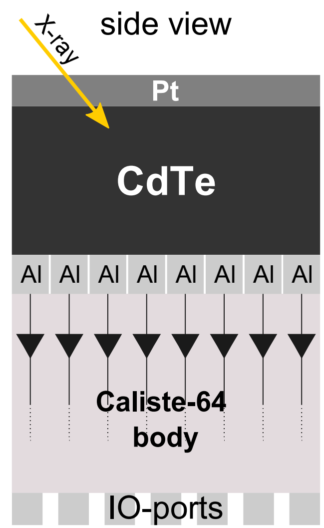
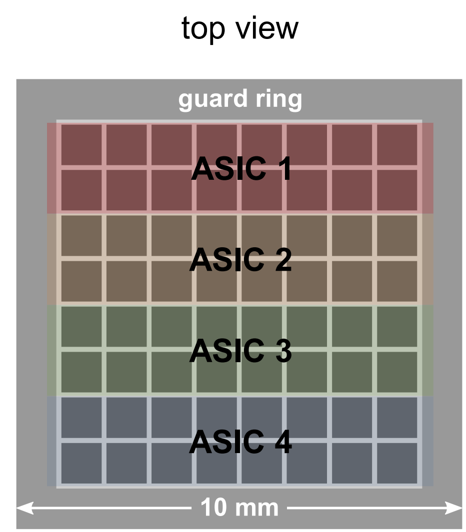






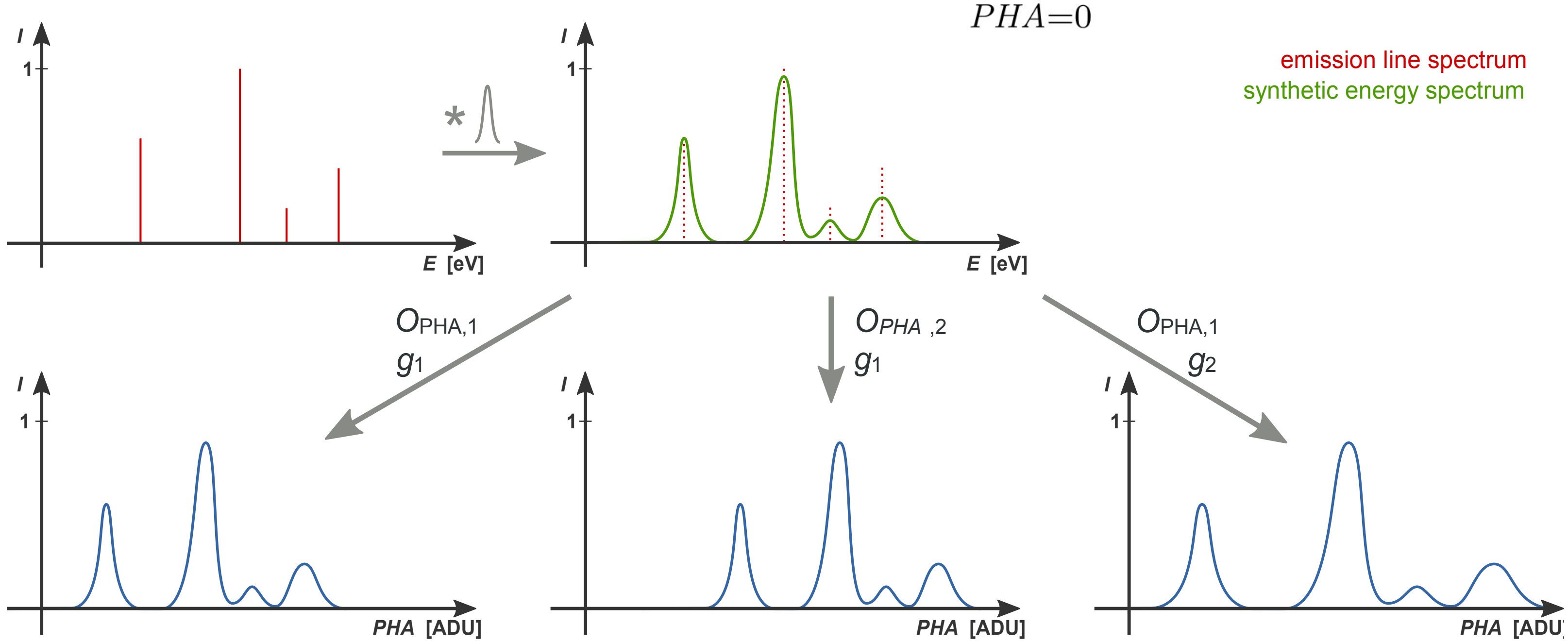




HED: energy calibration

- energy calibration via correlation (ECC)
  - build a synthetic energy spectrum
  - assume a transformation eV ↔ ADU: $E = g*PHA + E_{off}$
  - build several synthetic pulse-height spectra
  - compare the observed with the synthetic spectra via correlation

$$cor = \sum_{PHA=0}^{PHA_{max}} S_{syn}(PHA) \cdot S_{obs}(PHA)$$



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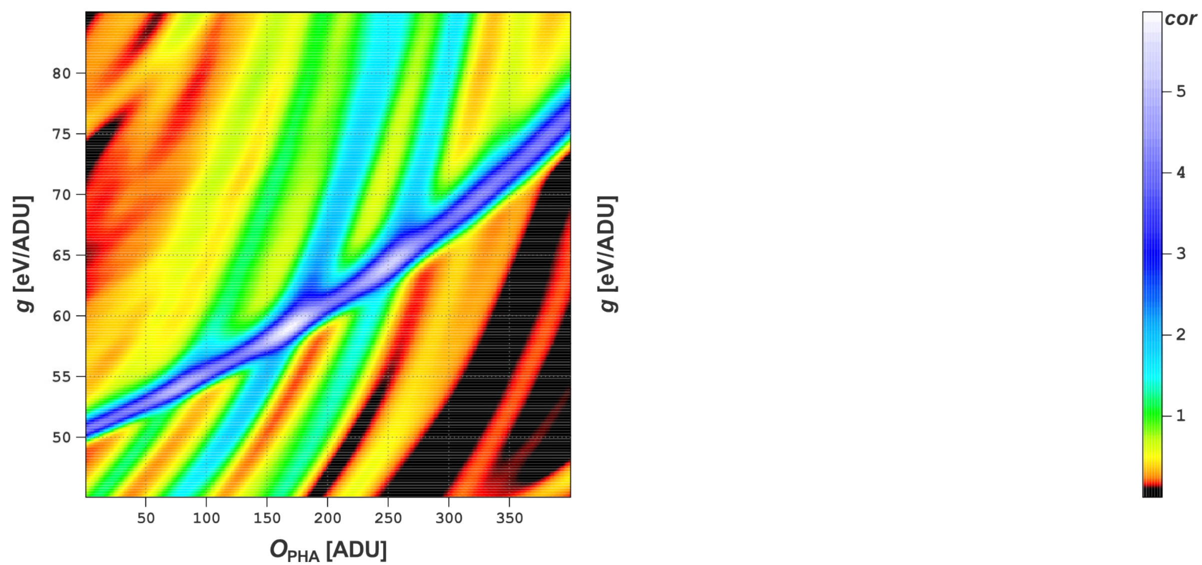

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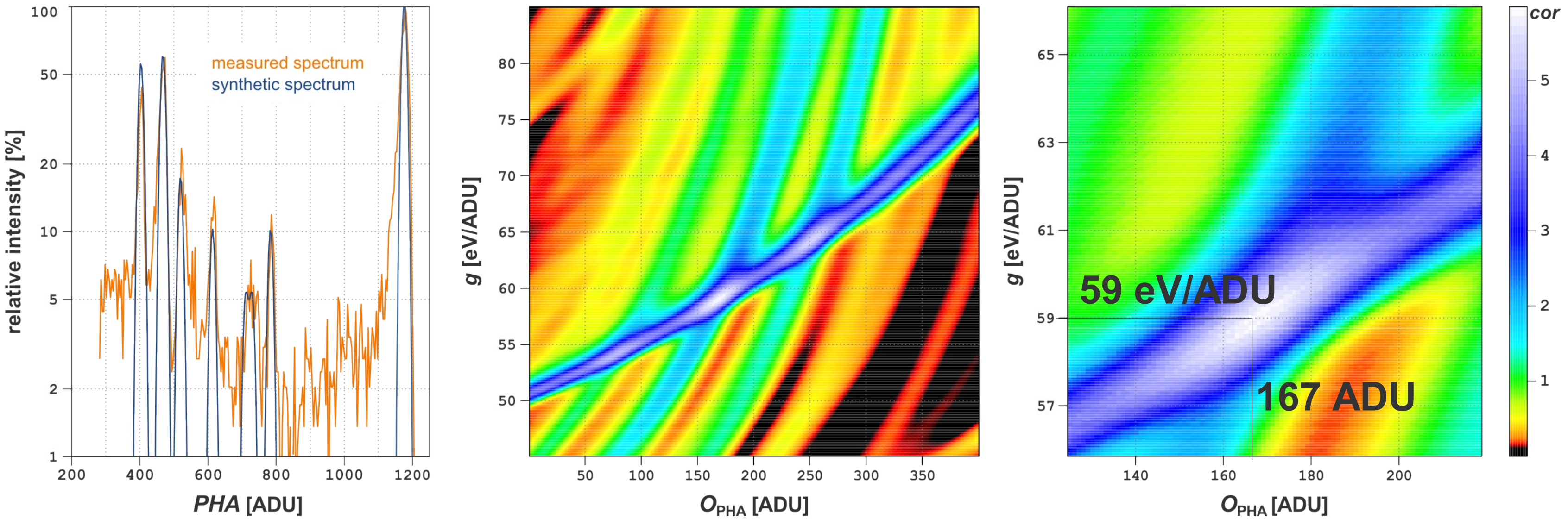
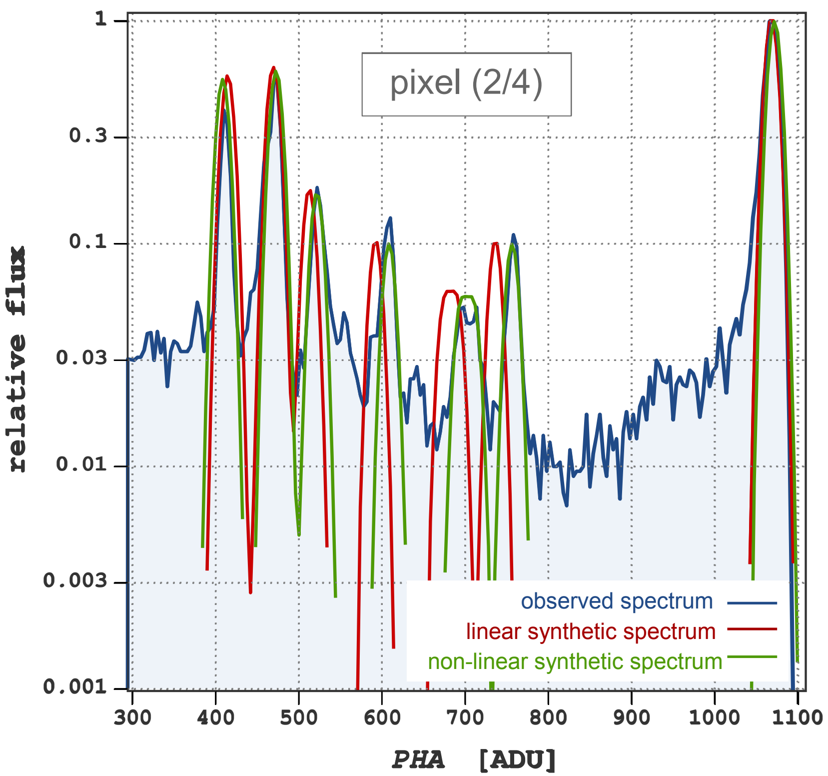
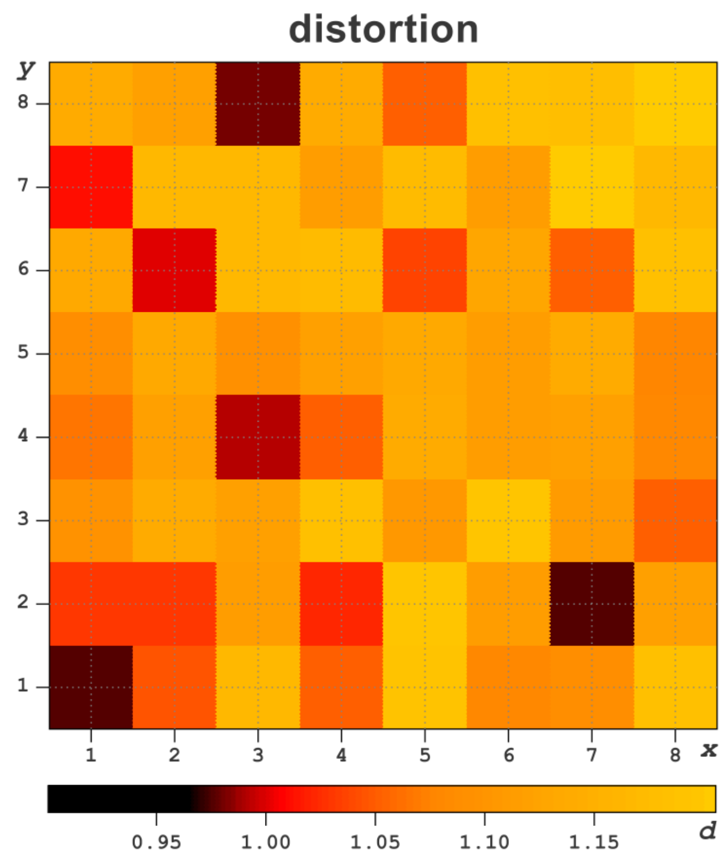


HED: energy calibration

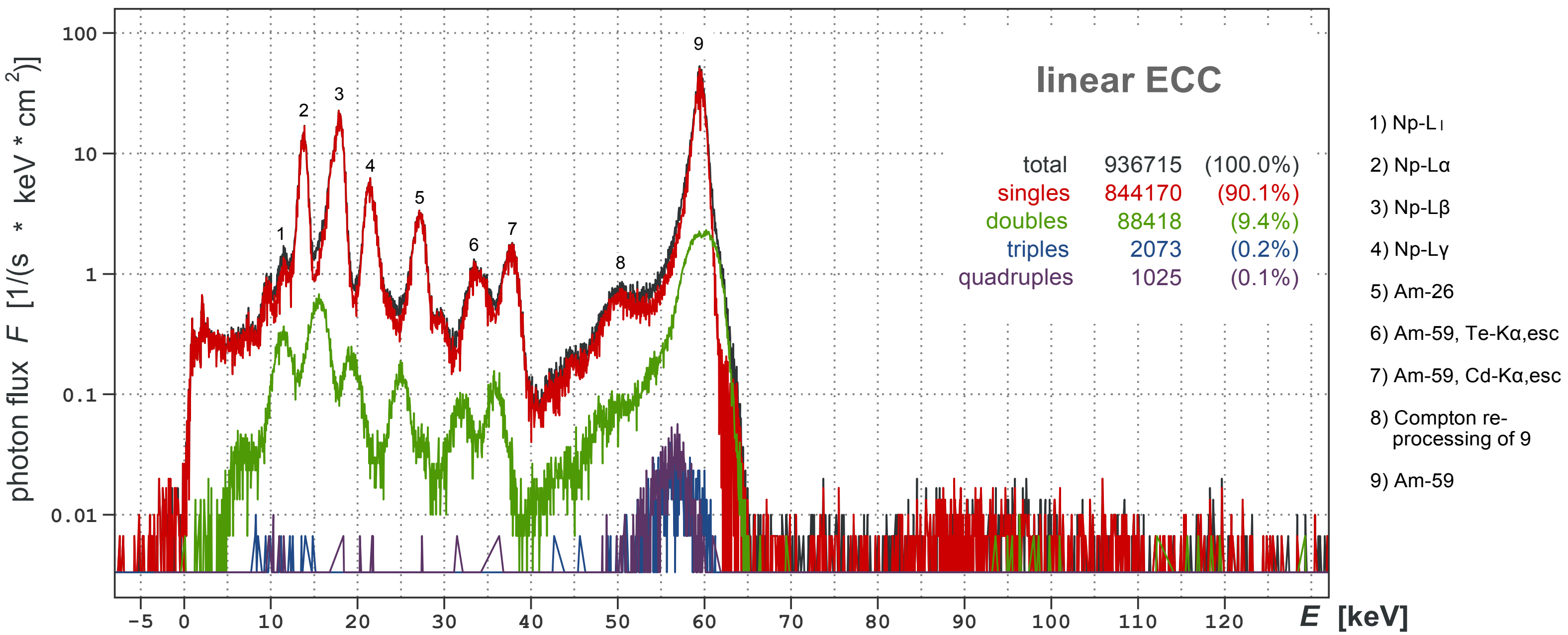
non-linear ECC

$$E = g \cdot (PHA - O_{\mathrm{PHA}})^d$$



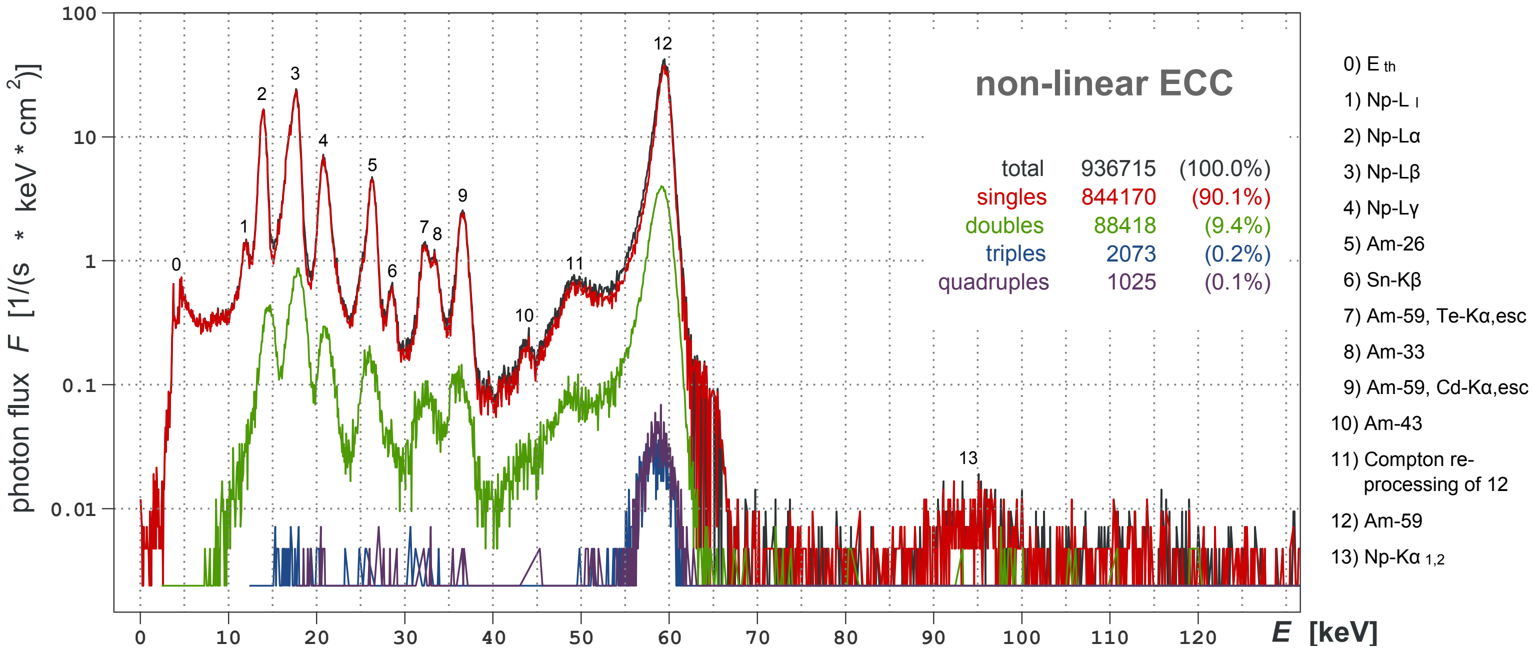


HED spectra



linear ECC
total 936715 (100.0%)
singles 844170 (90.1%)
doubles 88418 (9.4%)
triples 2073 (0.2%)
quadruples 1025 (0.1%)
photon flux F [1/(s * keV * cm 2)]
E [keV]
1) Np-Lₗ
2) Np-Lα
3) Np-Lβ
4) Np-Lγ
5) Am-26
6) Am-59, Te-Kα,esc
7) Am-59, Cd-Kα,esc
8) Compton re-processing of 9
9) Am-59

HED spectra



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singles 844170 (90.1%)
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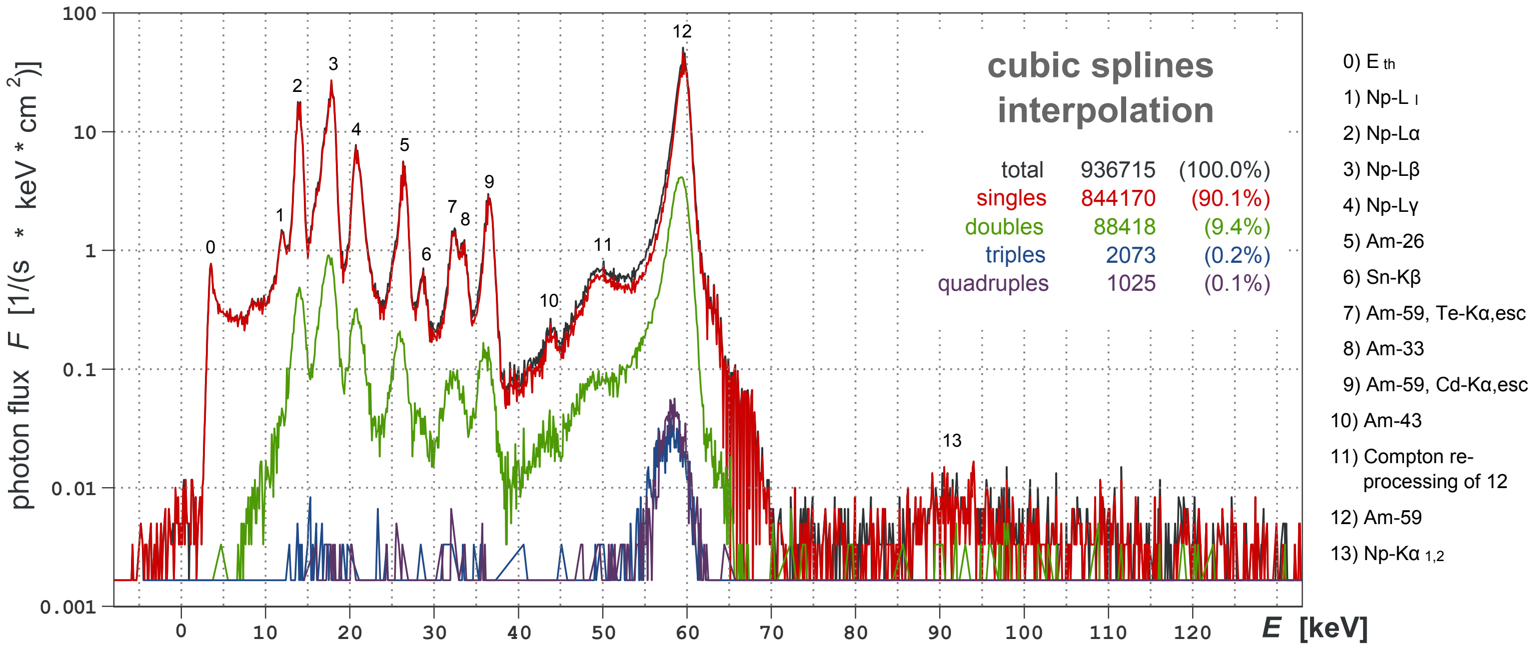
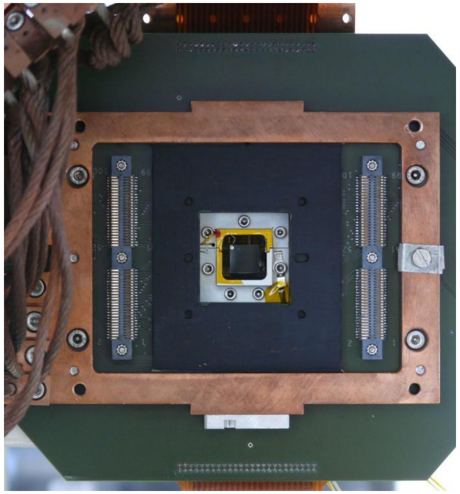
triples 2073 (0.2%)
quadruples 1025 (0.1%)
photon flux F [1/(s * keV * cm 2)]
E [keV]
100
10
1
0.1
0.01
0 10 20 30 40 50 60 70 80 90 100 110 120
0 1 2 3 4 5 6 7 8 9 10 11 12 13
0) E th
1) Np-L l
2) Np-Lα
3) Np-Lβ
4) Np-Lγ
5) Am-26
6) Sn-Kβ
7) Am-59, Te-Kα,esc
8) Am-33
9) Am-59, Cd-Kα,esc
10) Am-43
11) Compton re-processing of 12
12) Am-59
13) Np-Kα 1,2

HED spectra

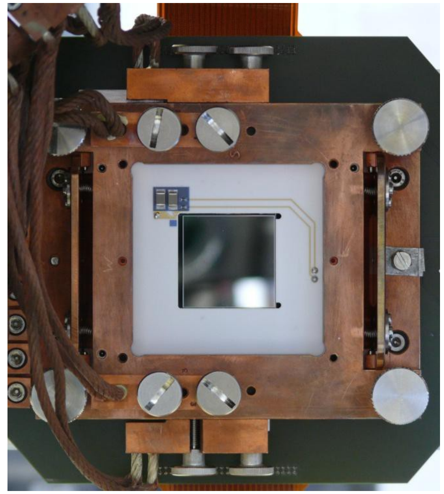


calibration	NNE	$E_{\mathrm{th}}^{\mathrm{obs}}$ [eV]	Δ_{14} [eV]	Δ_{18} [eV]	Δ_{21} [eV]	Δ_{26} [eV]	Δ_{36} [eV]	Δ_{59} [eV]	ΔE_1 [eV]	ΔE_2 [eV]
lin. ECC	256	635	-138	186	652	759	1344	-84	959	1024
nl. ECC	52	3600	66	-73	17	-4	124	-75	935	1023
CSI	102	3054	-40	67	-7	72	69	-9	933	1026

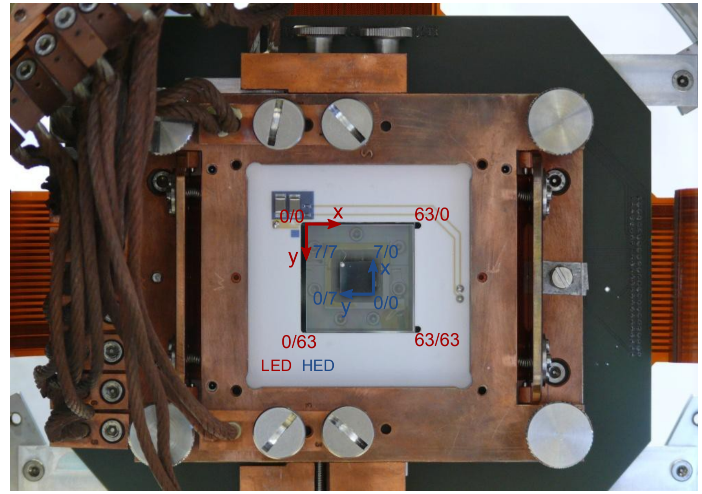
CANDELA: a stacked setup



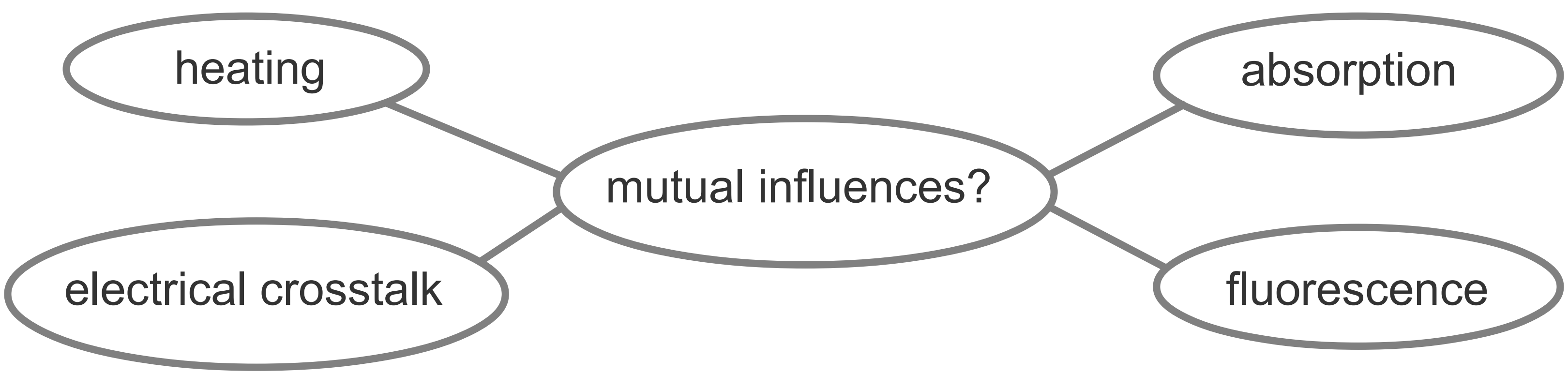
HED



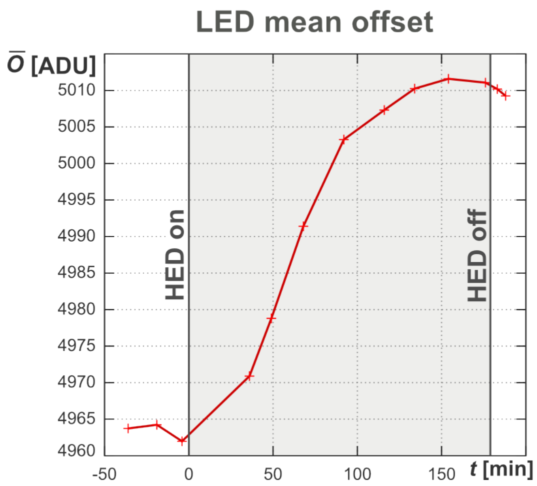
LED

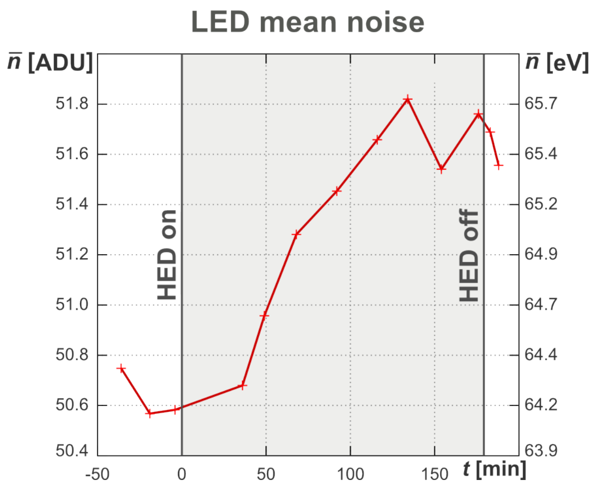


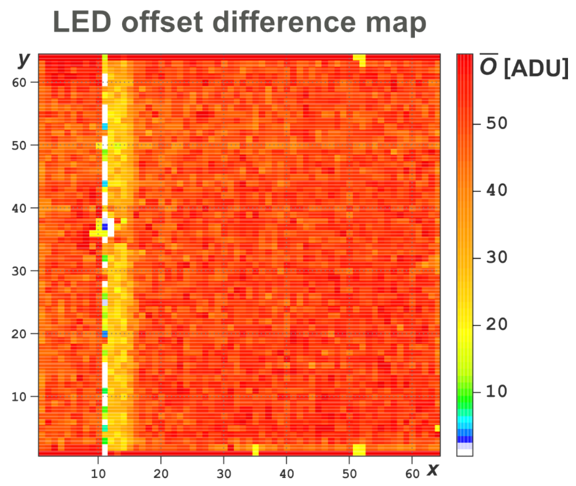
HED + LED



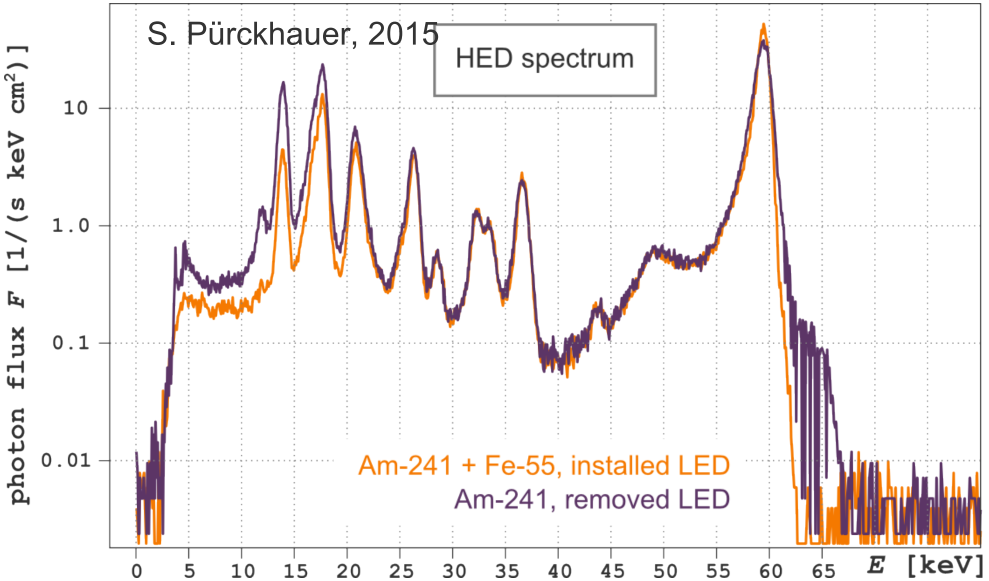
LED-HED mutual influences



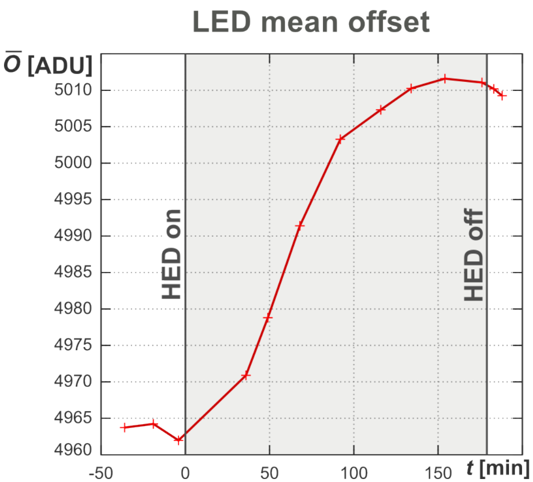


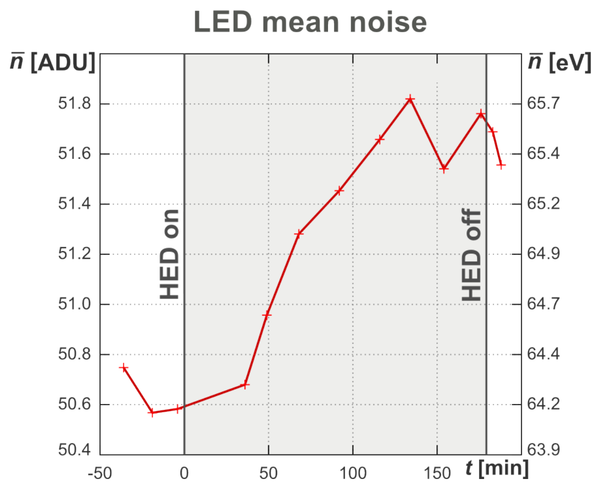


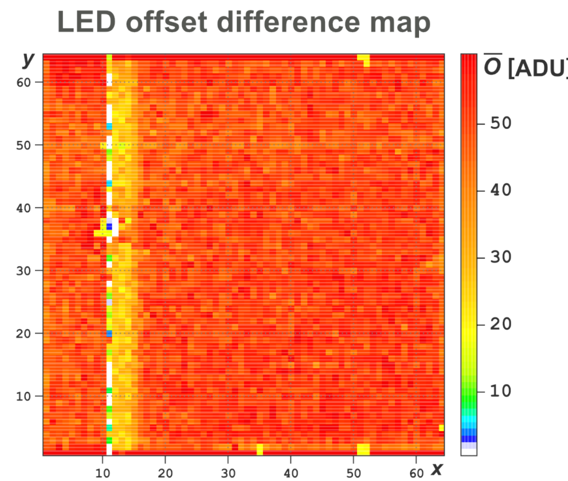
- electrical cross talk
- heating
- absorption
- fluorescence



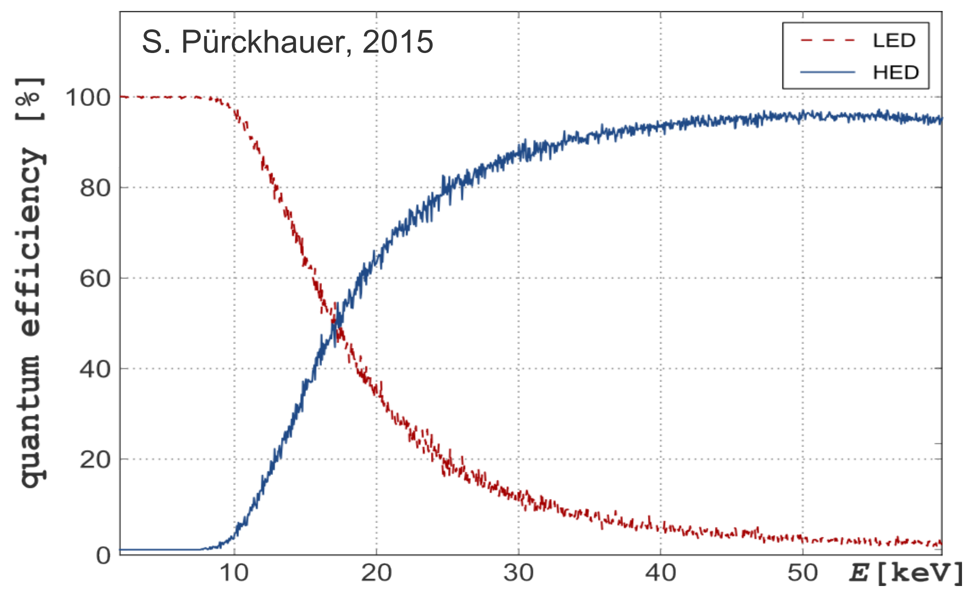
LED-HED mutual influences







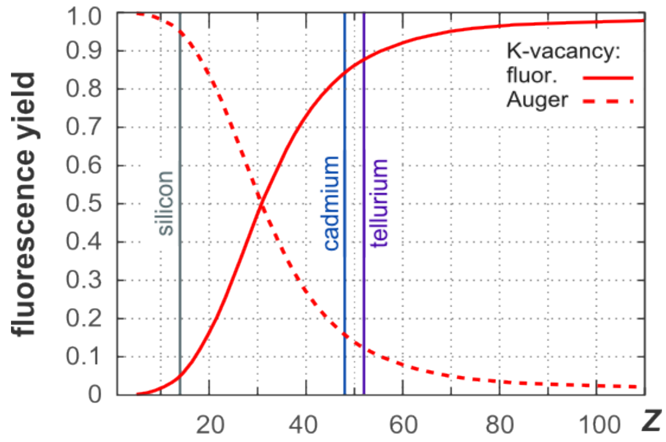
- electrical cross talk
- heating
- absorption
- fluorescence

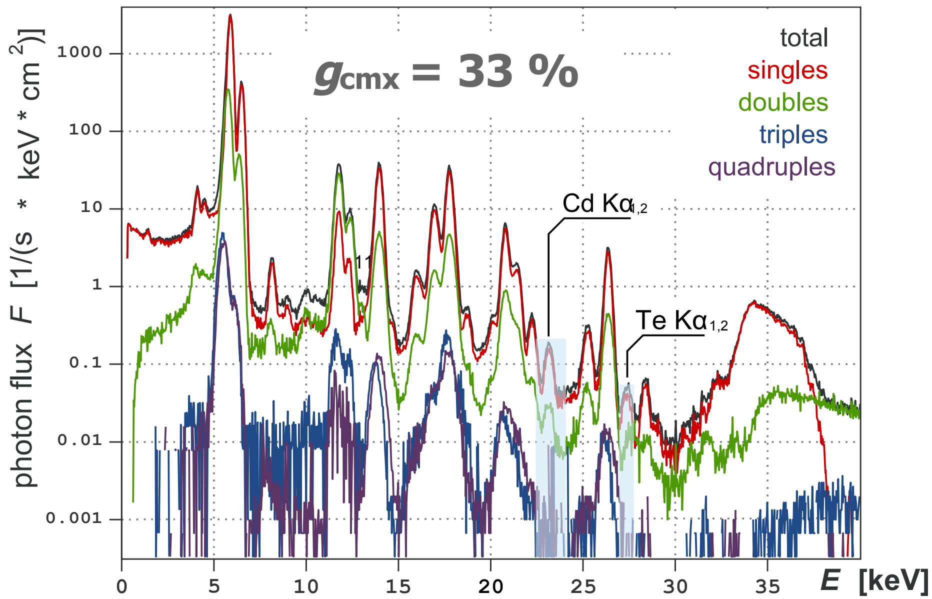


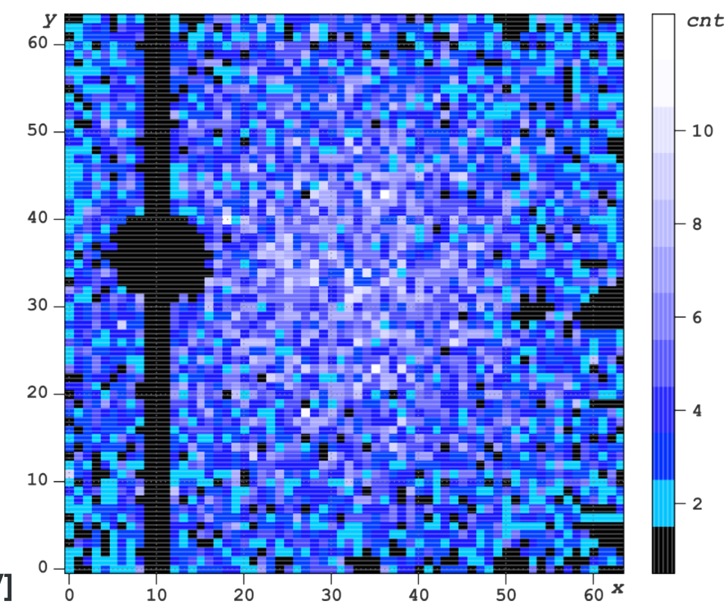
LED-HED mutual influences

fluorescence:

- no Si fluorescence in the HED
  → fluorescence yield
- Cd and Te fluorescence in the LED

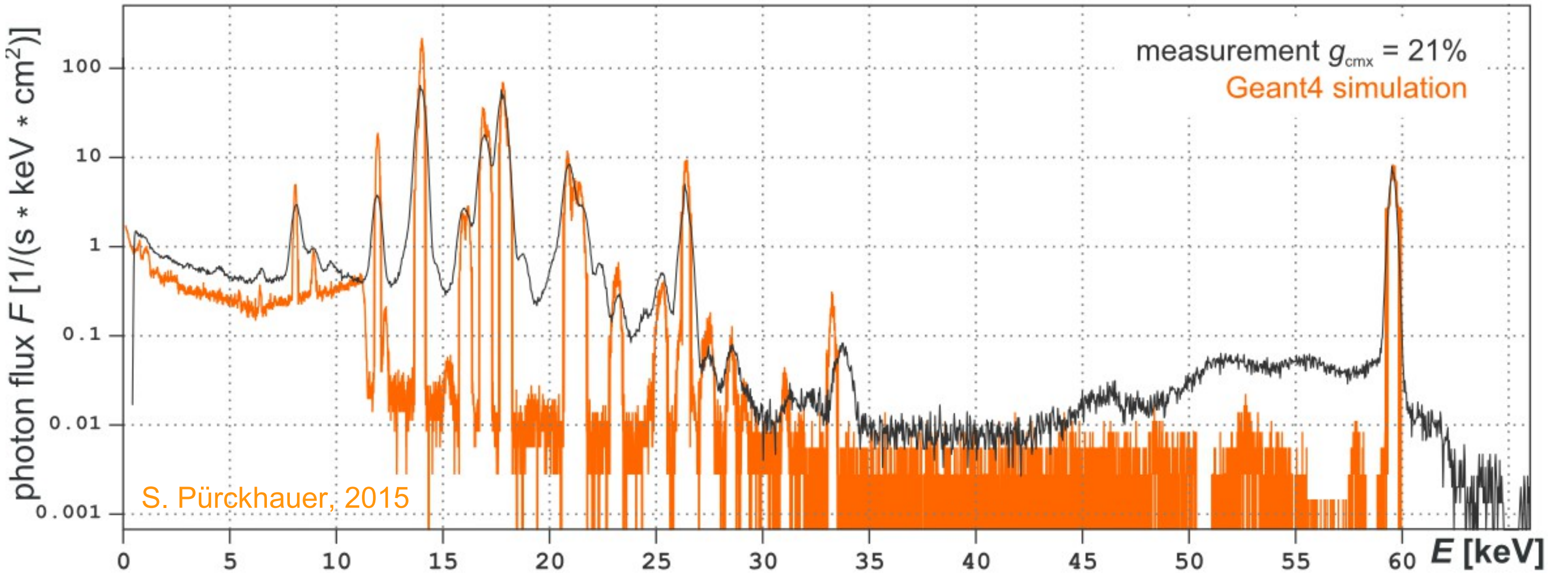






LED-HED (positive) interactions

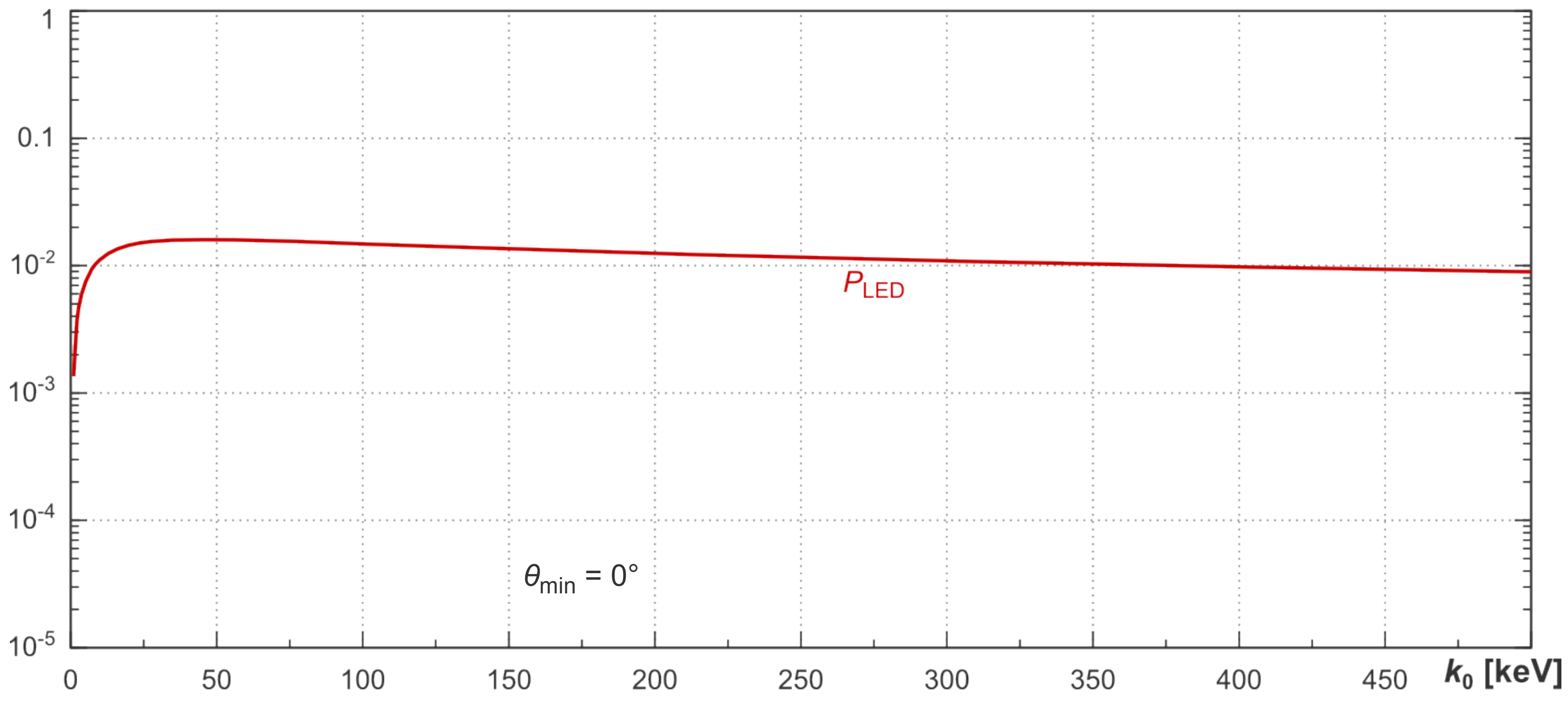
- time coincident events
  - LED fluorescence ↔ HED escape
  - canceling the fluorescence peaks in the LED
  - reducing the escape peaks in the HED by 25.4 %
  - reducing the low energetic background in the LED caused by compton forward scattering
- CANDELA: Δt = 3.0 ms



Compton forward scattering

$$\epsilon(k_0, \theta_{\min}, \theta_{\max}) = P_{\mathrm{LED}}(k_0)$$

Compton scattering in the LED

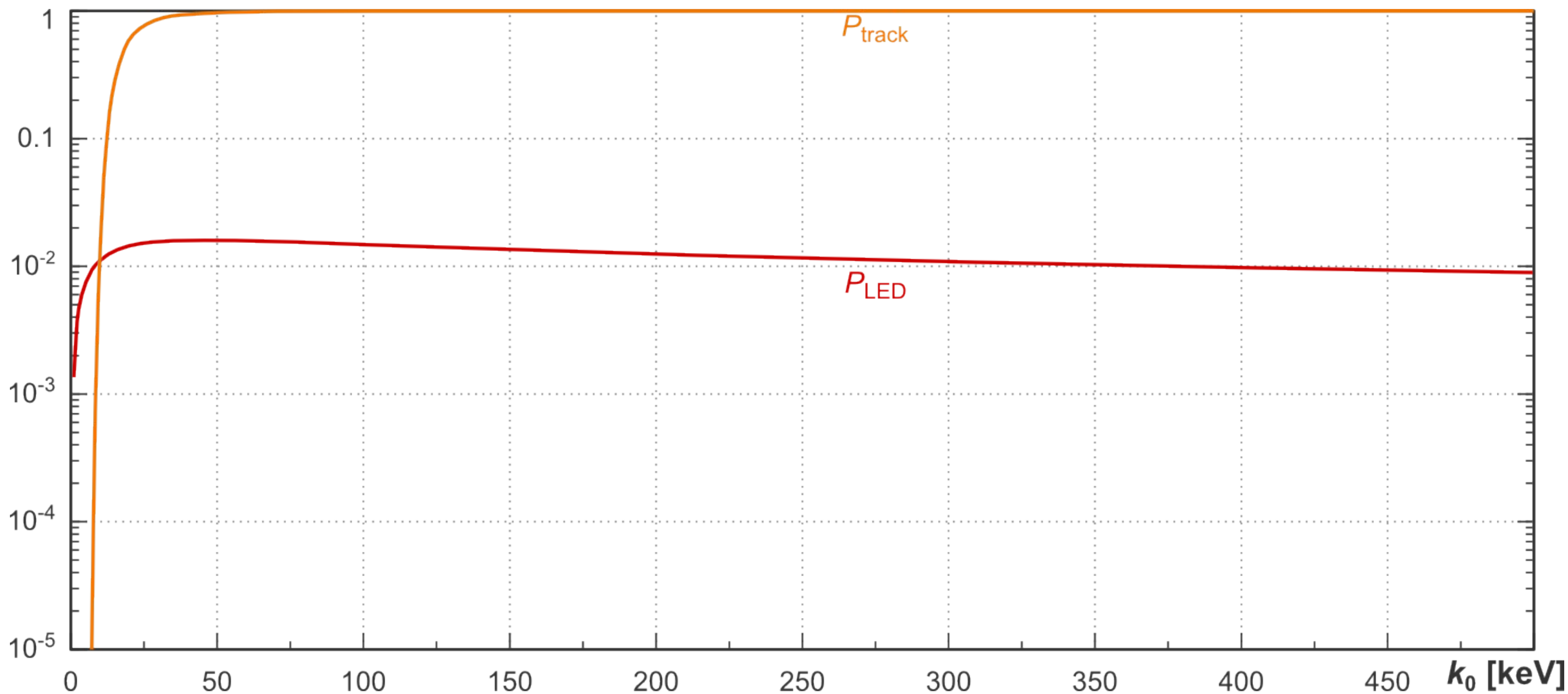


Compton forward scattering

$$\epsilon(k_0, \theta_{\min}, \theta_{\max}) = P_{\mathrm{LED}}(k_0) \cdot P_{\mathrm{track}}(k_0)$$

$P_{\mathrm{LED}}(k_0)$: Compton scattering in the LED

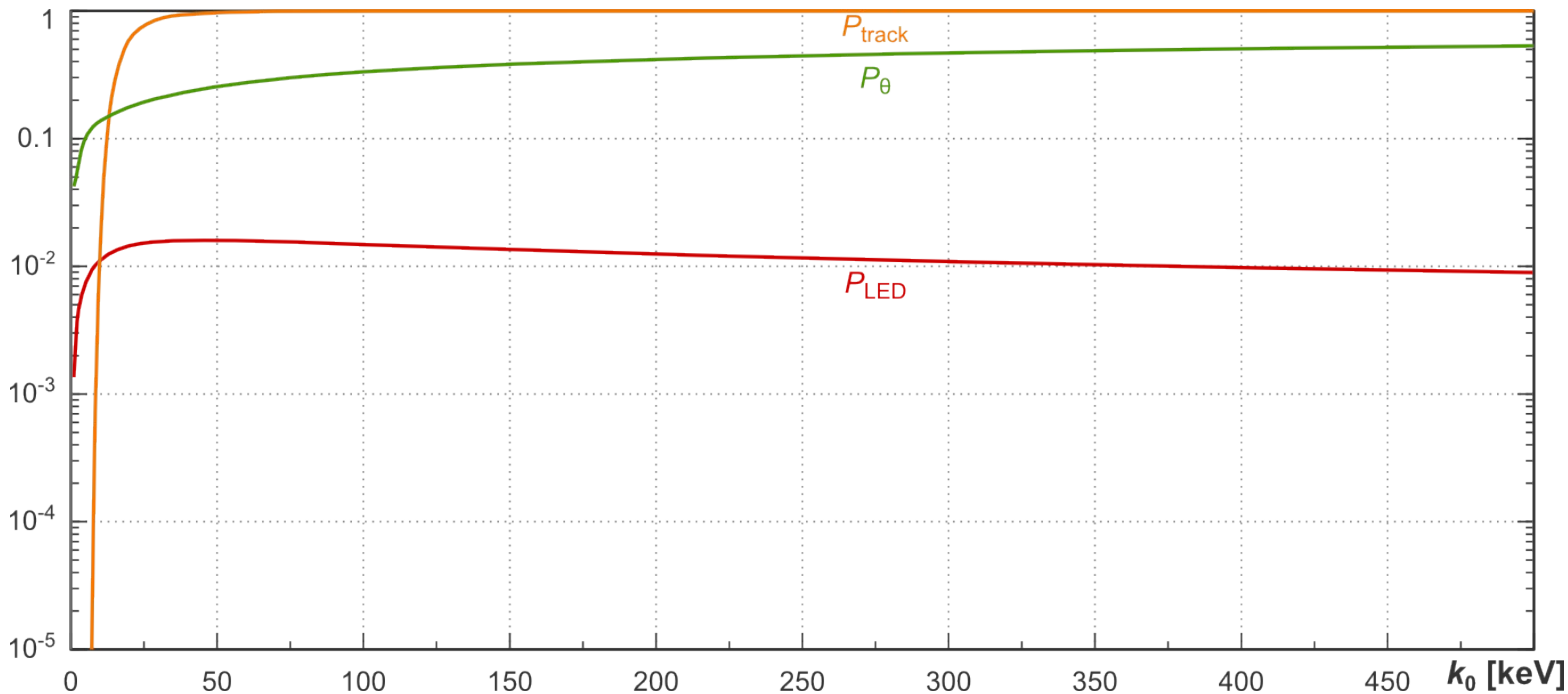
$P_{\mathrm{track}}(k_0)$: sc. photon escapes the LED



Compton forward scattering

$$\epsilon(k_0, \theta_{\min}, \theta_{\max}) = P_{\mathrm{LED}}(k_0) \cdot P_{\mathrm{track}}(k_0) \cdot P_{\theta}(k_0, \theta_{\min}, \theta_{\max})$$

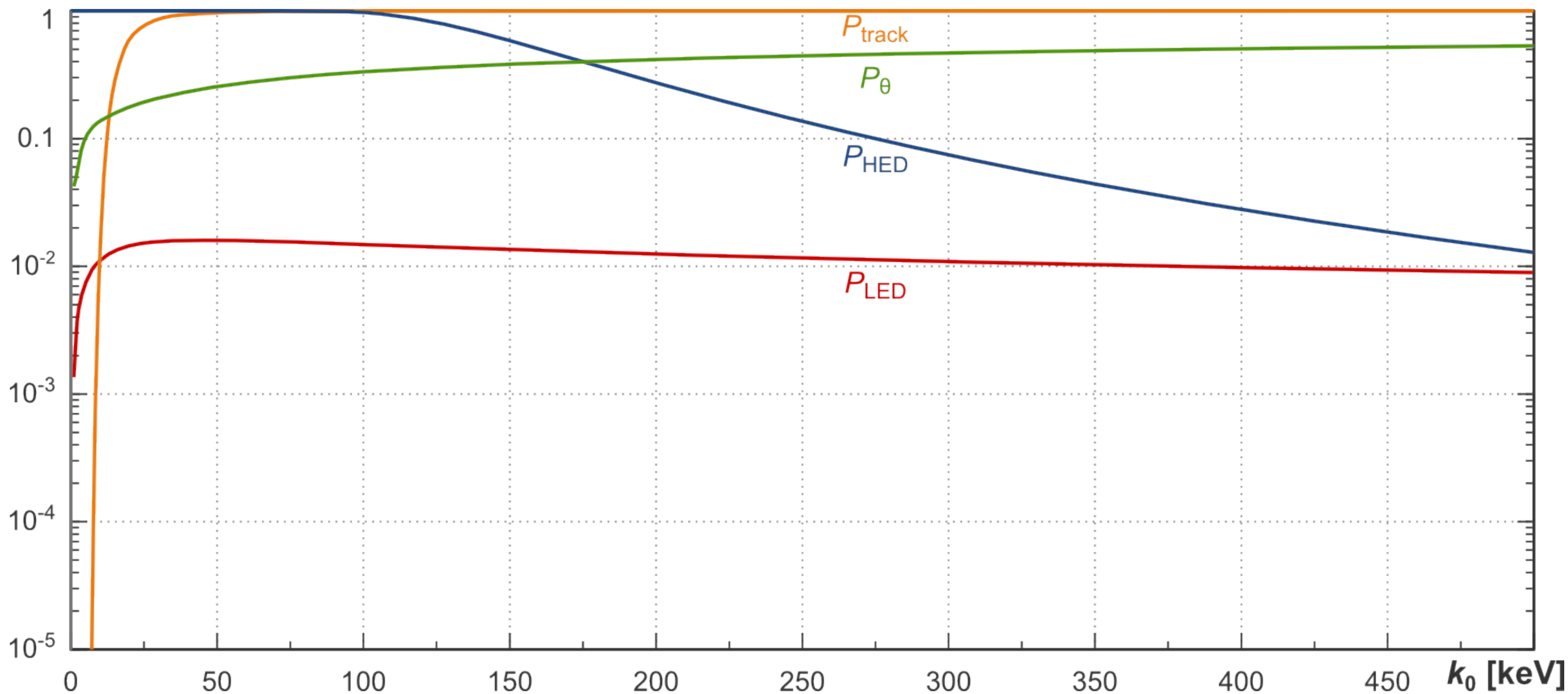
$P_{\mathrm{LED}}(k_0)$	$P_{\mathrm{track}}(k_0)$	$P_{\theta}(k_0, \theta_{\min}, \theta_{\max})$
Compton scattering in the LED	sc. photon escapes the LED	sc. photon is directed to the HED



Compton forward scattering

$$\epsilon(k_0, \theta_{\min}, \theta_{\max}) = P_{\mathrm{LED}}(k_0) \cdot P_{\mathrm{track}}(k_0) \cdot P_{\theta}(k_0, \theta_{\min}, \theta_{\max}) \cdot P_{\mathrm{HED}}(k_0)$$

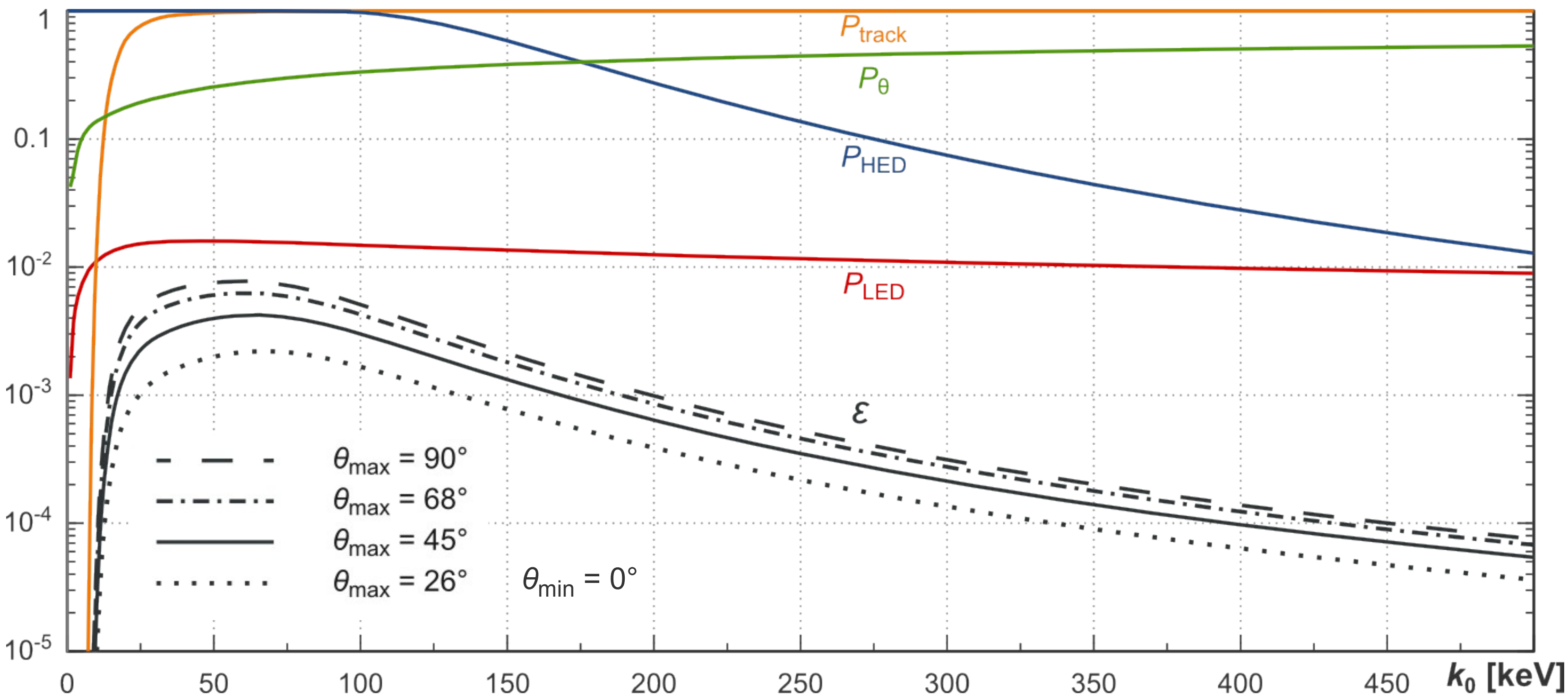
$P_{\mathrm{LED}}(k_0)$	$P_{\mathrm{track}}(k_0)$	$P_{\theta}(k_0, \theta_{\min}, \theta_{\max})$	$P_{\mathrm{HED}}(k_0)$
Compton scattering in the LED	sc. photon escapes the LED	sc. photon is directed to the HED	sc. photon is detected by the HED



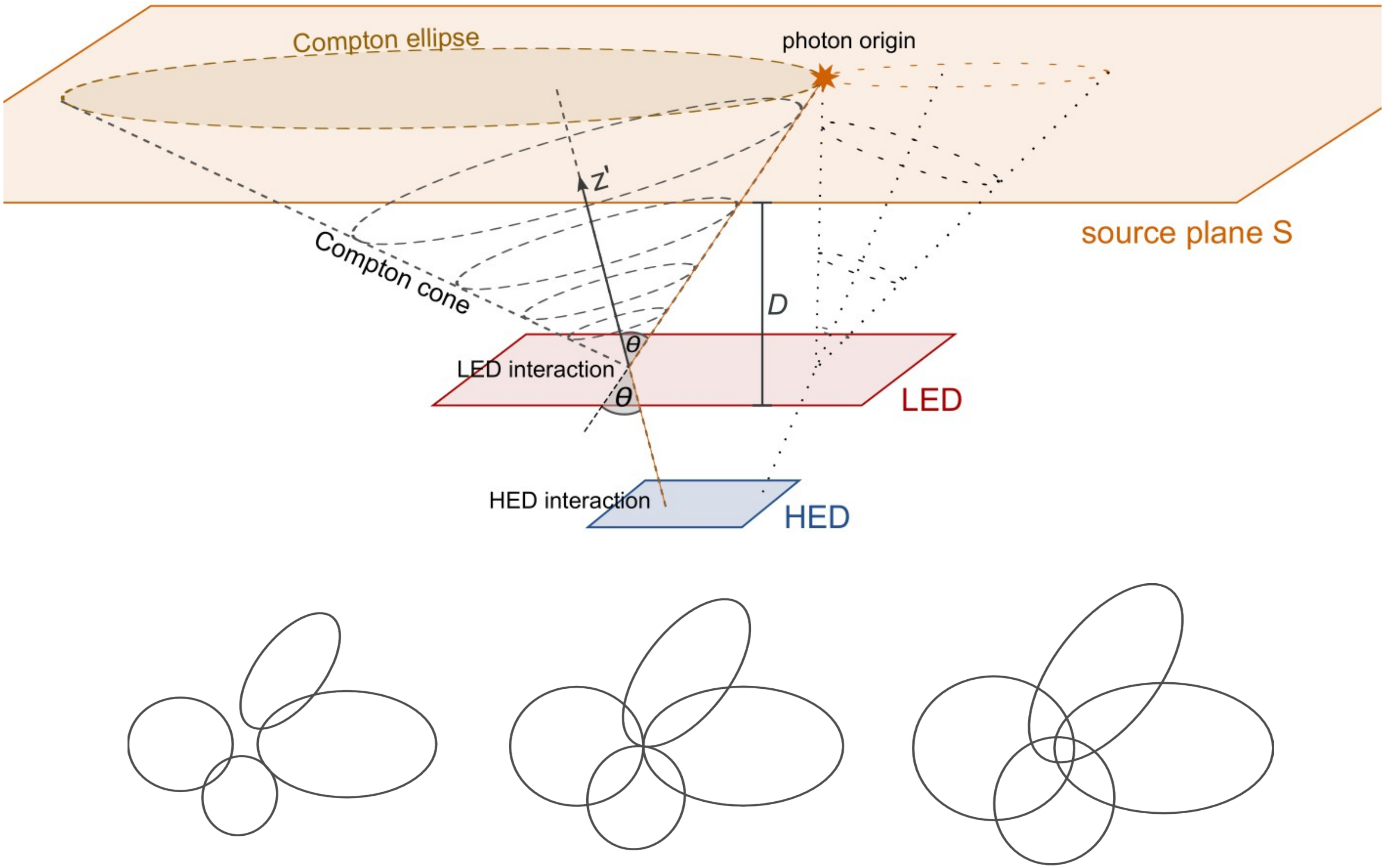
Compton forward scattering

$$\epsilon(k_0, \theta_{\min}, \theta_{\max}) = P_{\mathrm{LED}}(k_0) \cdot P_{\mathrm{track}}(k_0) \cdot P_{\theta}(k_0, \theta_{\min}, \theta_{\max}) \cdot P_{\mathrm{HED}}(k_0)$$

$P_{\mathrm{LED}}(k_0)$	$P_{\mathrm{track}}(k_0)$	$P_{\theta}(k_0, \theta_{\min}, \theta_{\max})$	$P_{\mathrm{HED}}(k_0)$
Compton scattering in the LED	sc. photon escapes the LED	sc. photon is directed to the HED	sc. photon is detected by the HED

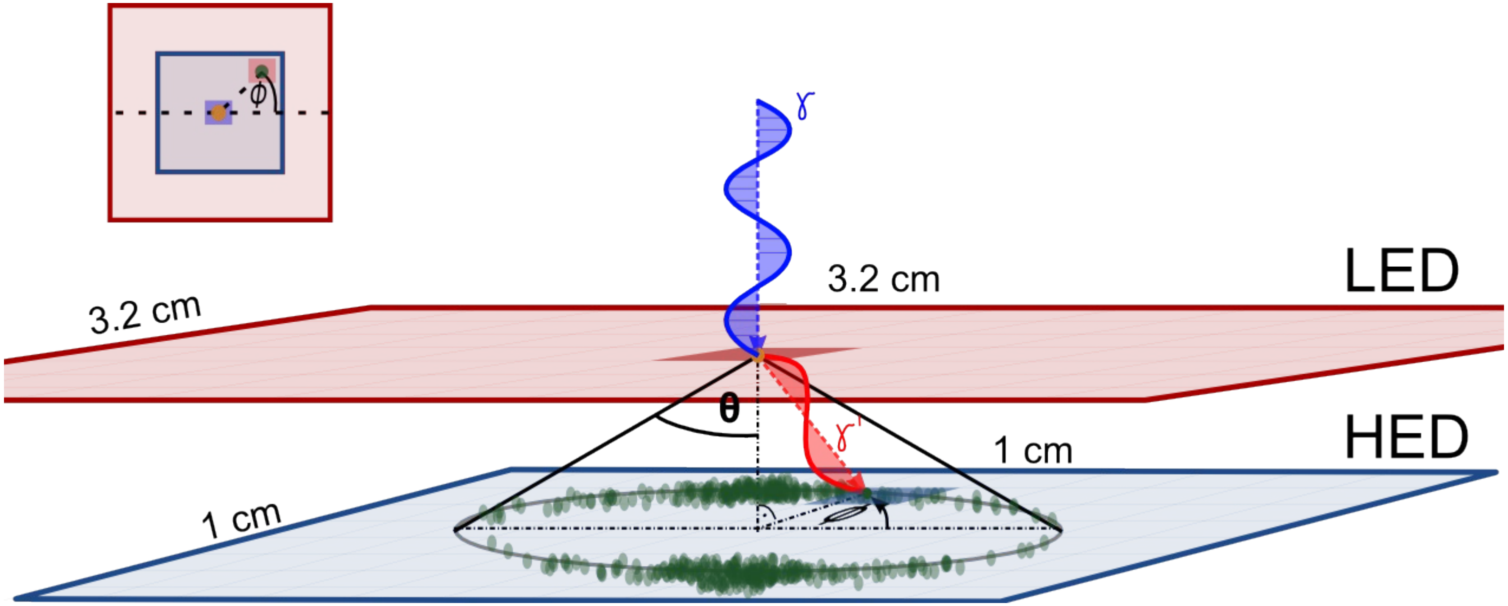


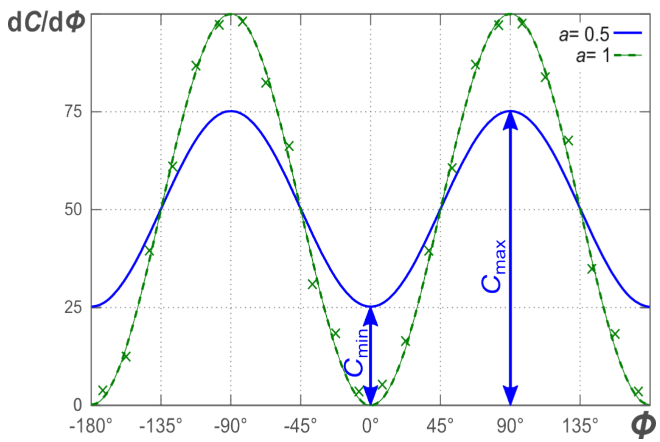
Compton camera

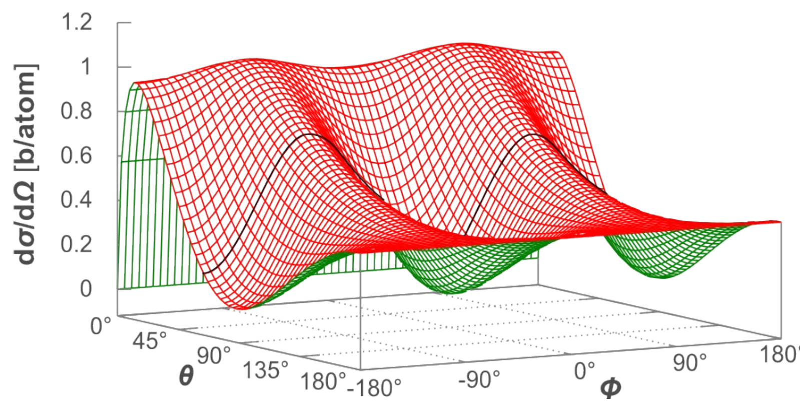


$D < D_0$ $D = D_0$ $D > D_0$

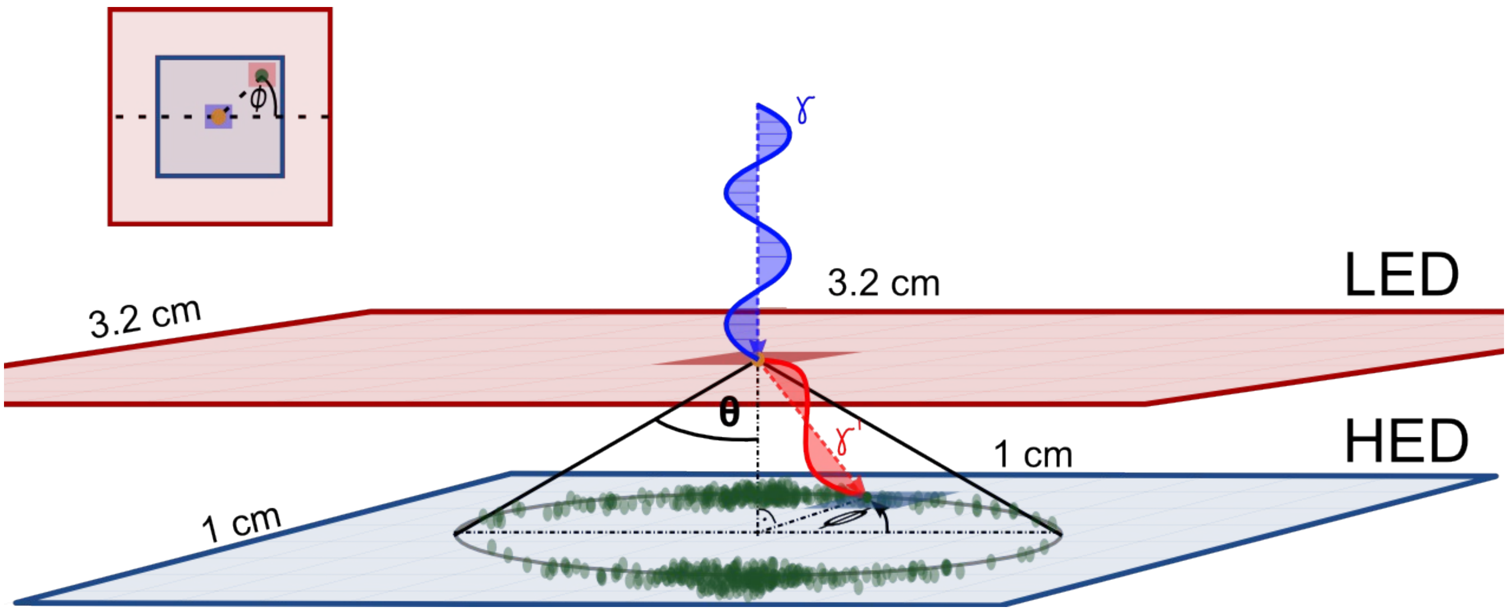
Compton polarimeter







Compton polarimeter



configuration	$\theta_{\max}$	$\theta_{\min}^{\mathrm{opt}}$	$\mu_{\max}$ [%]	$\overline{\mu}$ [%]	P_θ [%]	$\overline{\mu}\sqrt{P_\theta}$	sensitivity gain
current	26.6°	15.2°	11.13	6.98	14.11	2.62	1.0
A	45.0°	25.7°	33.07	20.61	22.88	9.86	3.8
B	68.2°	38.9°	72.66	47.61	29.79	25.99	9.9
optimum	90.0°	51.3°	90.08	73.16	33.92	42.61	16.3

Statistics & polarimetry

degree of polarization $P = \sqrt{q^2 + u^2}$

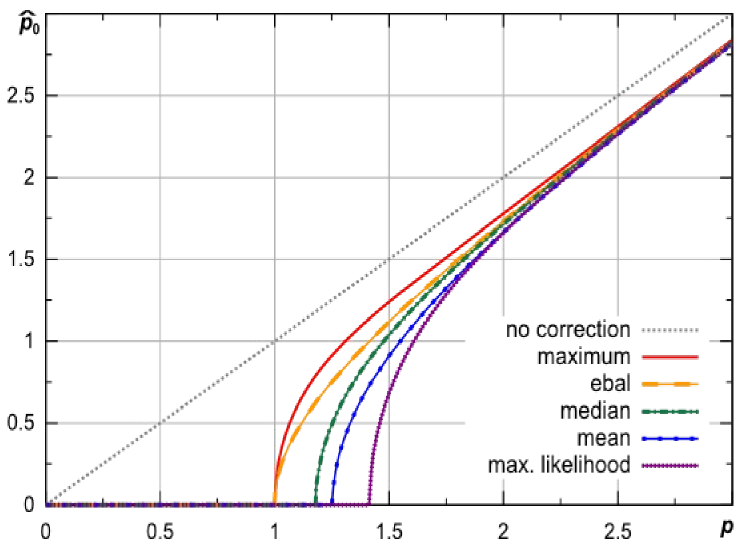
angle of polarization $\Psi = 0.5 \arctan(u/q)$

instrument

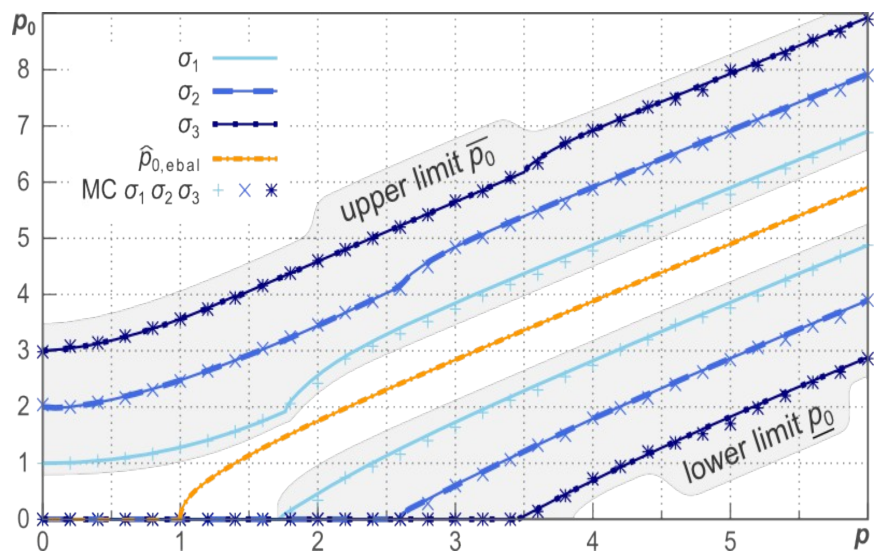
$$p = P \cdot \mu \cdot \frac{1}{\sigma_c}$$

source observation

point estimations



interval estimations



Statistics & polarimetry

degree of polarization $P = \sqrt{q^2 + u^2}$

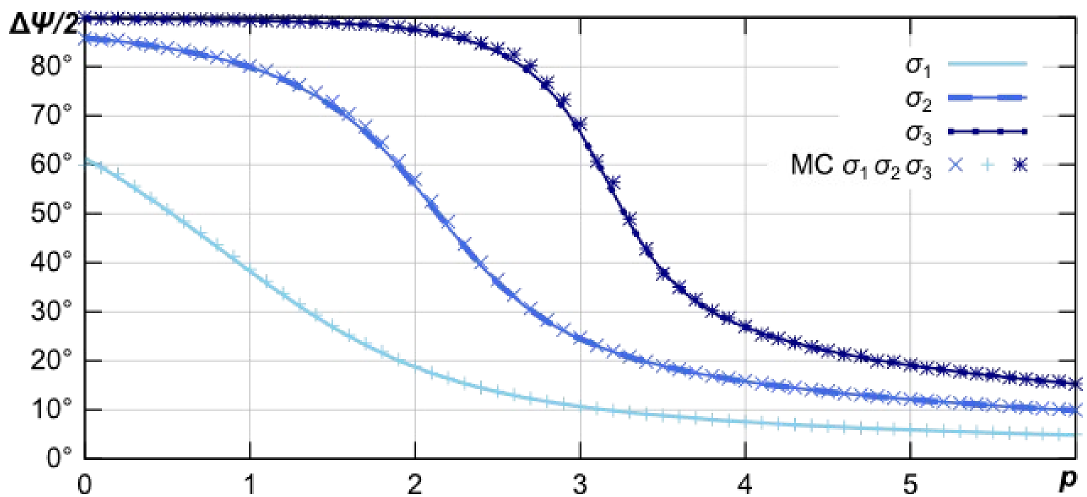
angle of polarization $\Psi = 0.5 \arctan(u/q)$

instrument

$$p = P \cdot \mu \cdot \frac{1}{\sigma_c}$$

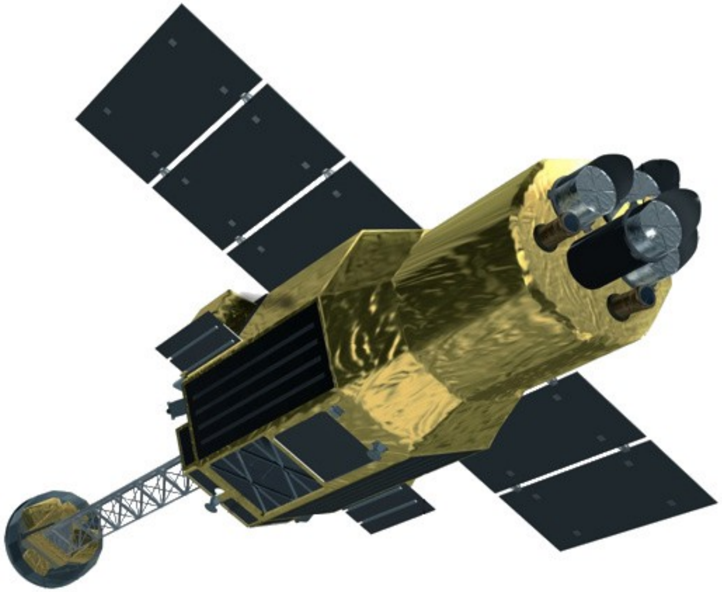
source observation

interval estimations



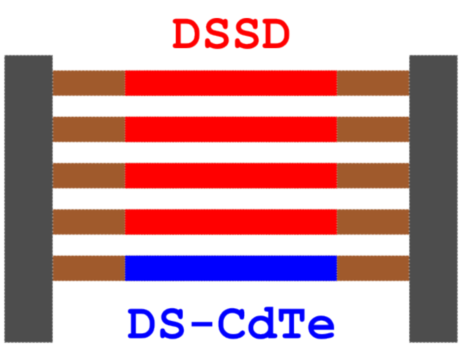
Maier et al. 2014: Point and interval estimations for the degree and the angle of polarization. A Bayesian approach.

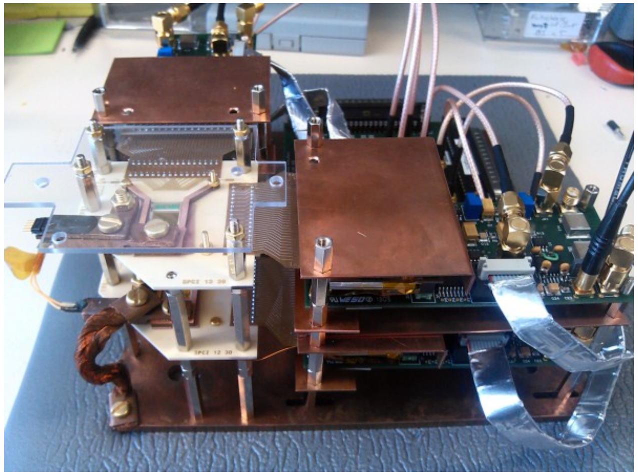
Perspective: ASTRO-H



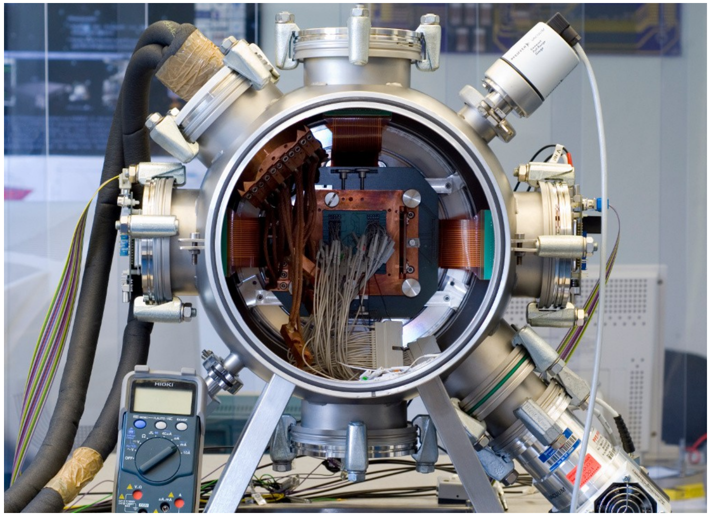
- soft X-ray imager SXI
- soft X-ray spectrometer SXS
- **hard X-ray imager HXI**
- soft gamma ray detector SGD

- supported by ESA & CNES
- launch 2016
- 550 km LEO
- m = 2.4 t
- L = 14 m



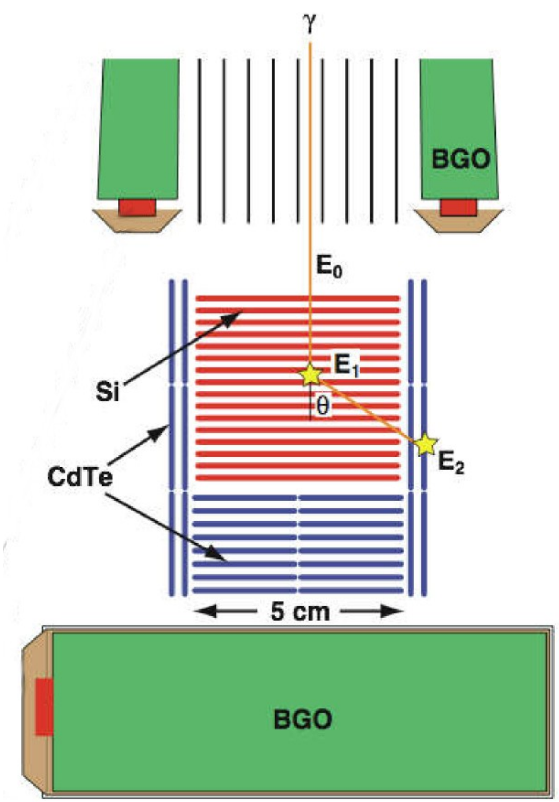


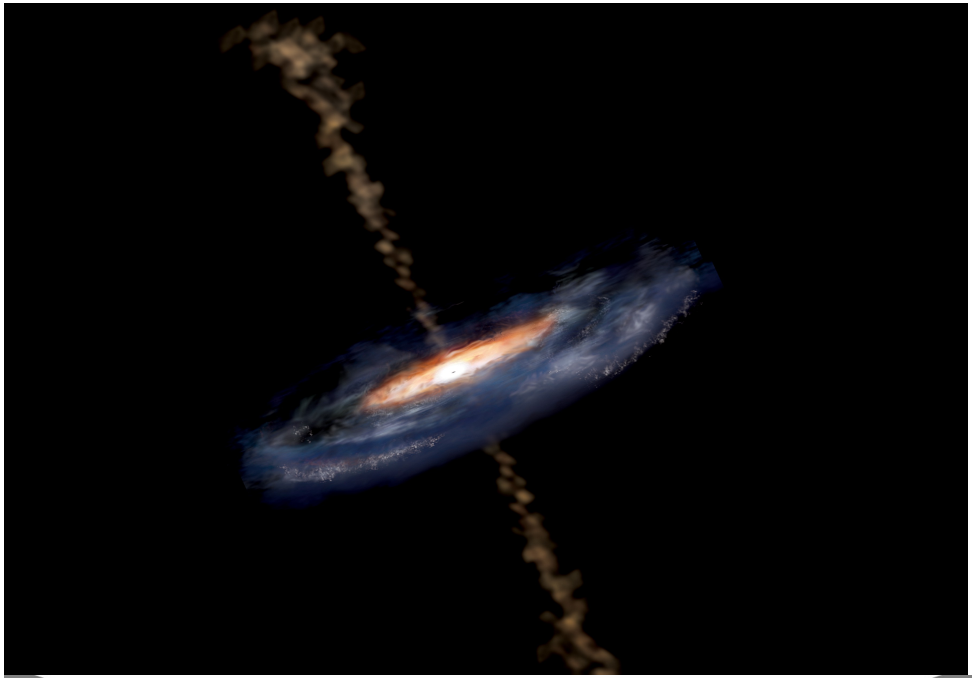
Comparison

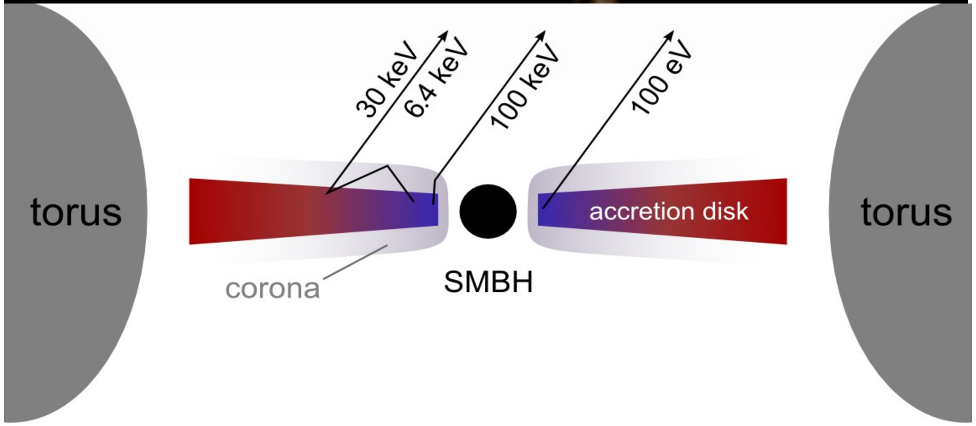
CANDELA setup	ASTRO-H setup
	
• Si + CdTe • pixelized detectors • timing: 3 ms	• CdTe + CdTe • strip detectors • timing: ~ 1 µs • to do (hardware): - adding the 2nd detector - test long term operation

To do: (Science) HXI & SGD

- proposals
- AGN & CXB
- polarization







Thank you.

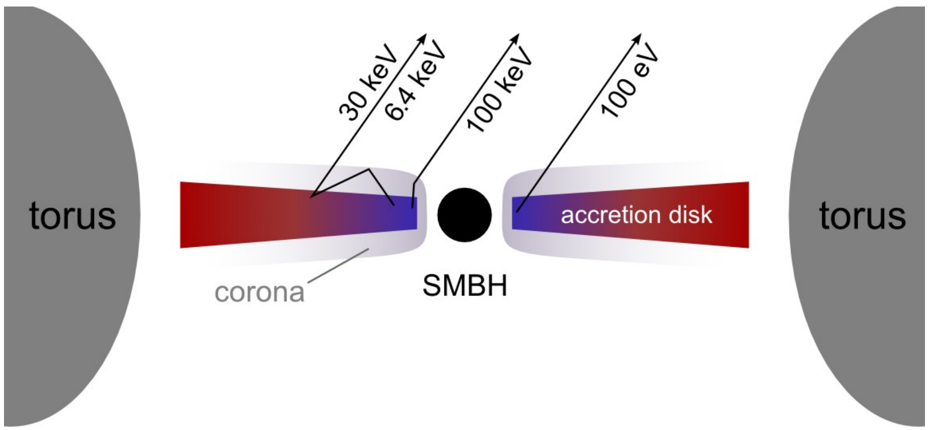
Contact:

Daniel Maier
room: P.160

daniel.maier@cea.fr

Astrophysical X-ray sources

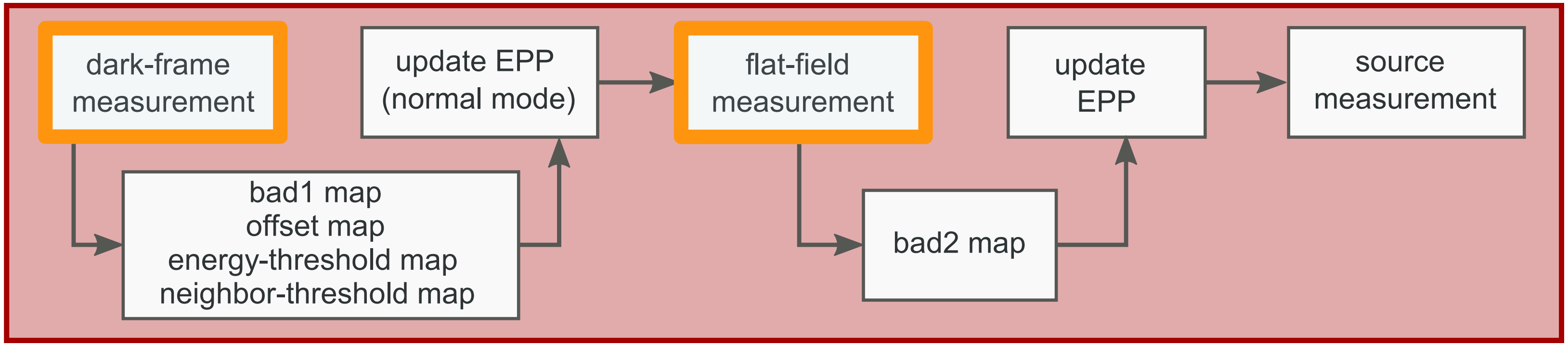
- active galactic nuclei (AGN)
  - X-ray sources:
    - soft X-ray emission of the disc
    - inv. Compton scattering in the corona
    - fluorescence emission of the disc ~6.4 keV
    - Compton reflection hump ~30 keV



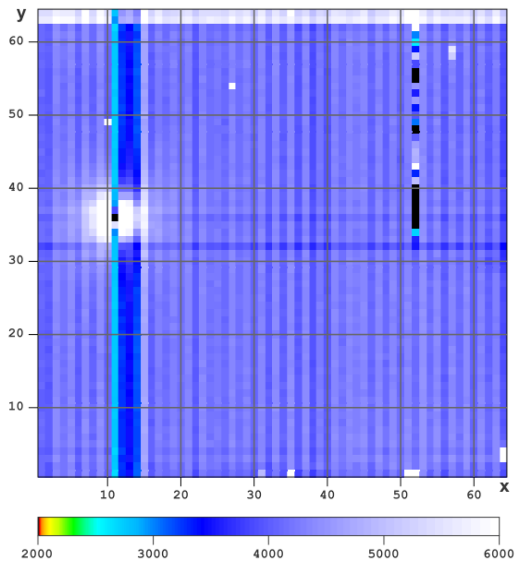
  - fields of research
    - accretion on SMBH
    - galaxy evolution
    - feedback on the interstellar & intracluster medium

Centaurus A, Chandra observation
NASA/CXC/CfA/R. Kraft et al.

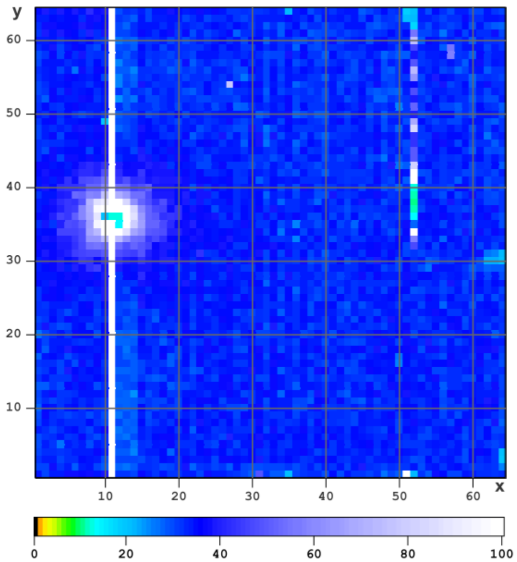
LED configuration



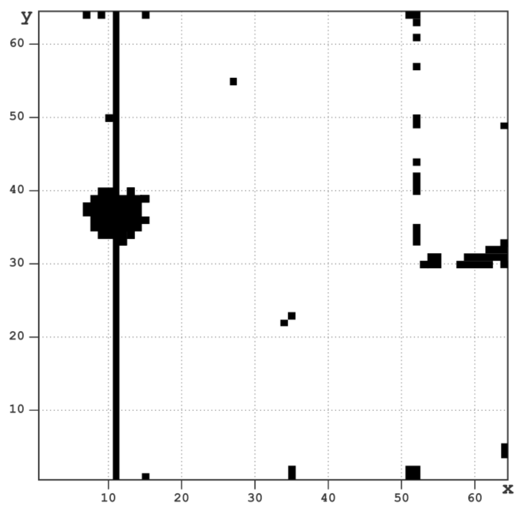
offset map



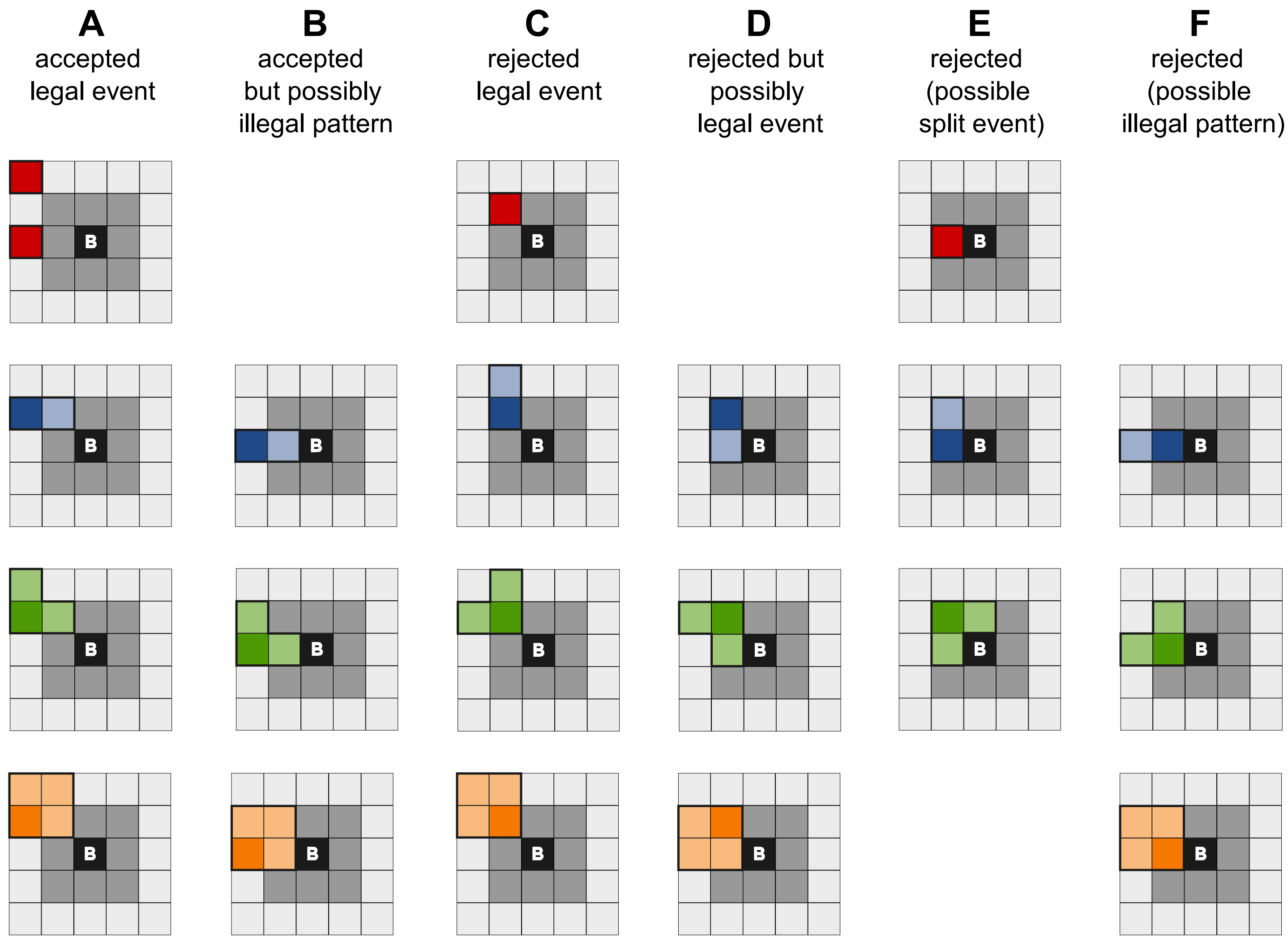
noise map



bad map

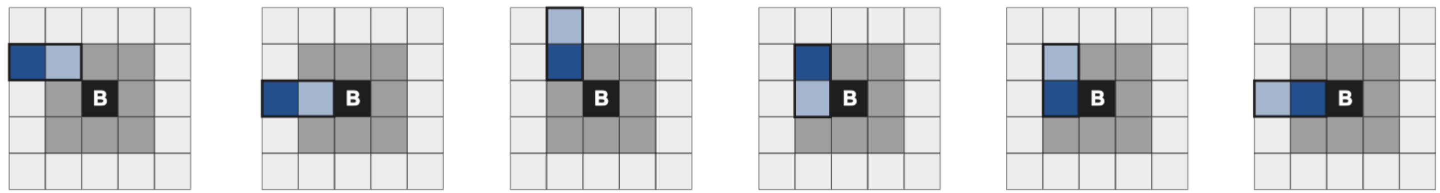


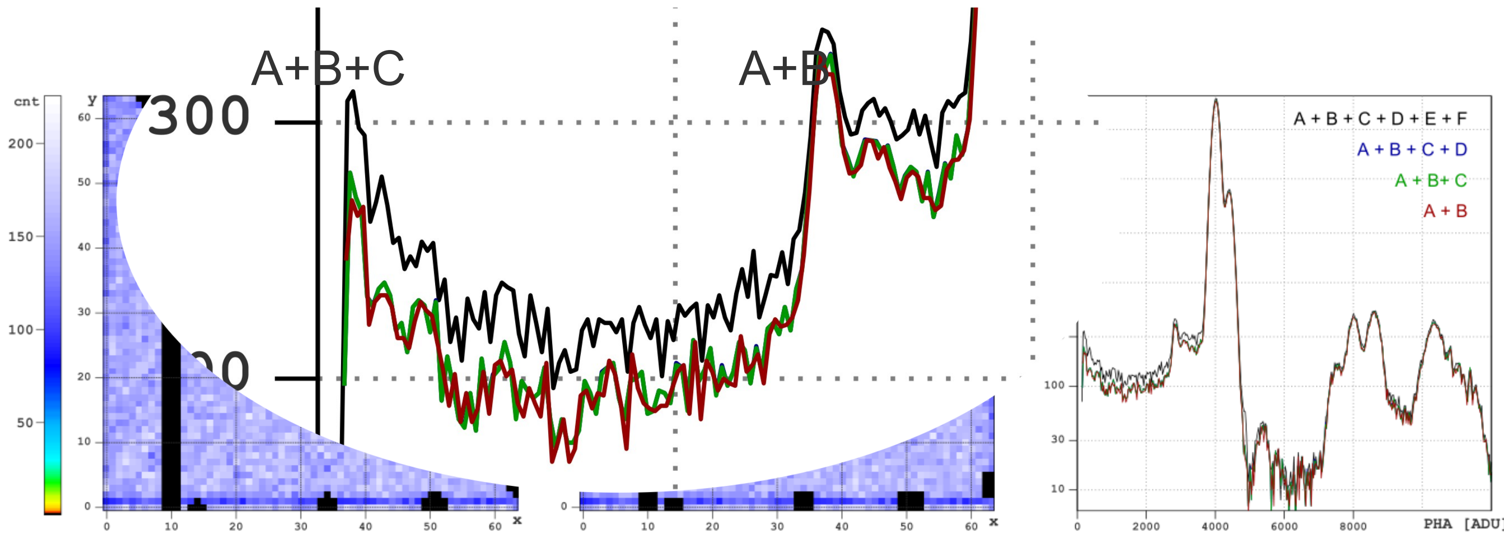
LED analysis: bad pixel



LED data analysis: bad pixel

A	**B**	C	**D**	E	F
accepted legal event	**accepted but possibly illegal pattern**	rejected legal event	**rejected but possibly legal event**	rejected (possible split event)	rejected (possible illegal pattern)





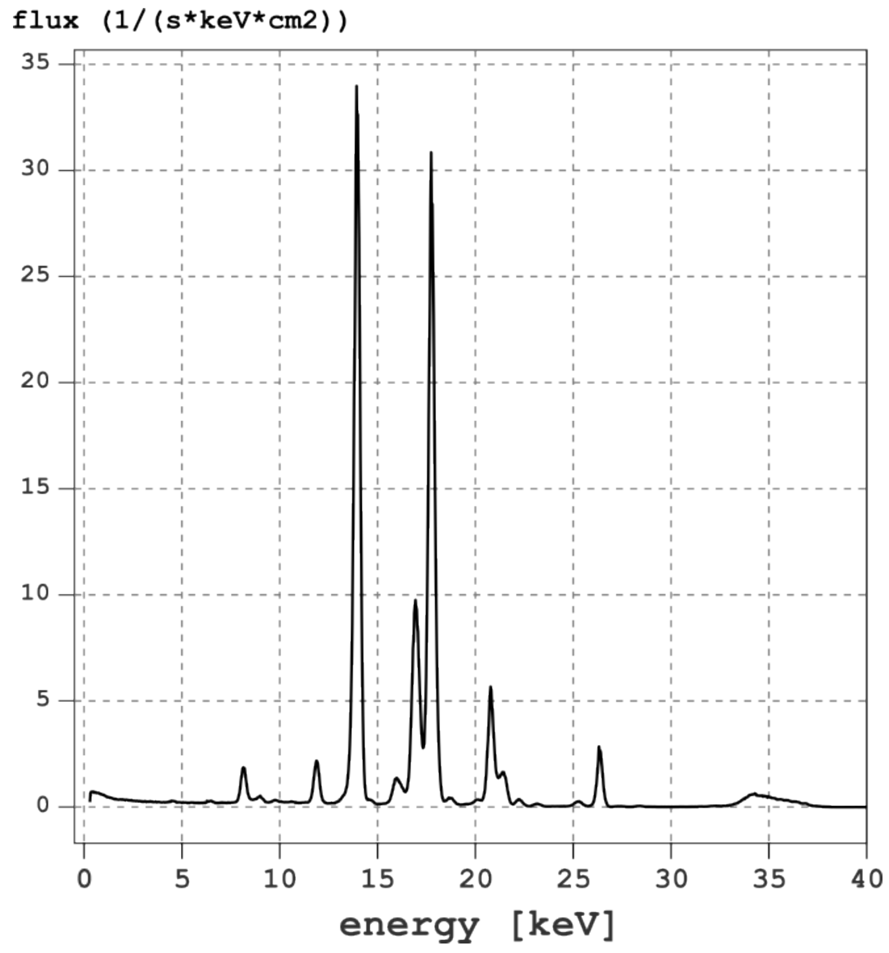
	A to F	A to D	A + B + C	A + C	A + B	A
abs. cnt.	580197	544128	543082	541589	533465	531995
rel. cnt. [%]	100	93.8	93.6	93.3	91.9	91.7

LED spectra

		Al-$K_{\alpha\,1,2}$	Cd-$L_{\alpha\,1,2}$	Sn-$L_{\alpha\,1,2}$	Te-$L_{\alpha\,1,2}$	Mn-$K_{\alpha,\,esc}$	Ti-$K_{\alpha\,1,2}$	Ti-$K_{\beta\,1,3}$
E_0	[eV]	1487	3133	3443	3768	4155	4509	4932
E	[eV]	1493	3085	3475	3732	4186	4519	4955
ΔE	[eV]	+6	-48	+32	-36	+31	+10	+23

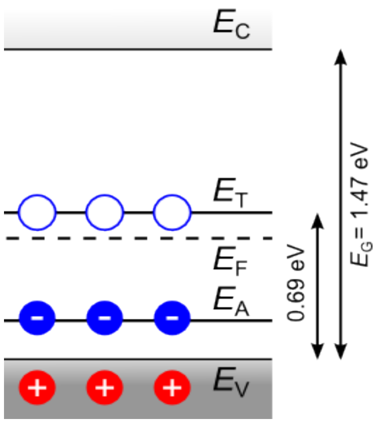
		Cu-$K_{\alpha\,1,2}$	$2 \cdot$ Mn-$K_{\alpha\,1,2}$	Np-$L_{\eta\,\beta 6}$	Np-$L_{\beta\,2}$	Nb-$K_{\beta\,1,2,3}$
E_0	[eV]	8041	11790	15996	16840	18656
E	[eV]	8086	11799	15970	16927	18702
ΔE	[eV]	+45	+9	-26	+87	+46
ΔE_{cal}	[eV]	1551	0	1754	910	906
		Cd-$K_{\alpha\,1,2}$	Sn-$K_{\alpha\,1,2}$	Te-$K_{\alpha\,1,2}$	Sn-$K_{\beta\,1,3}$	Am-33
E_0	[eV]	23108	25193	27377	28471	33196
E	[eV]	23216	25252	27447	28548	33594
ΔE	[eV]	+108	+59	+70	+77	+398
ΔE_{cal}	[eV]	2324	1152	1032	2126	6851

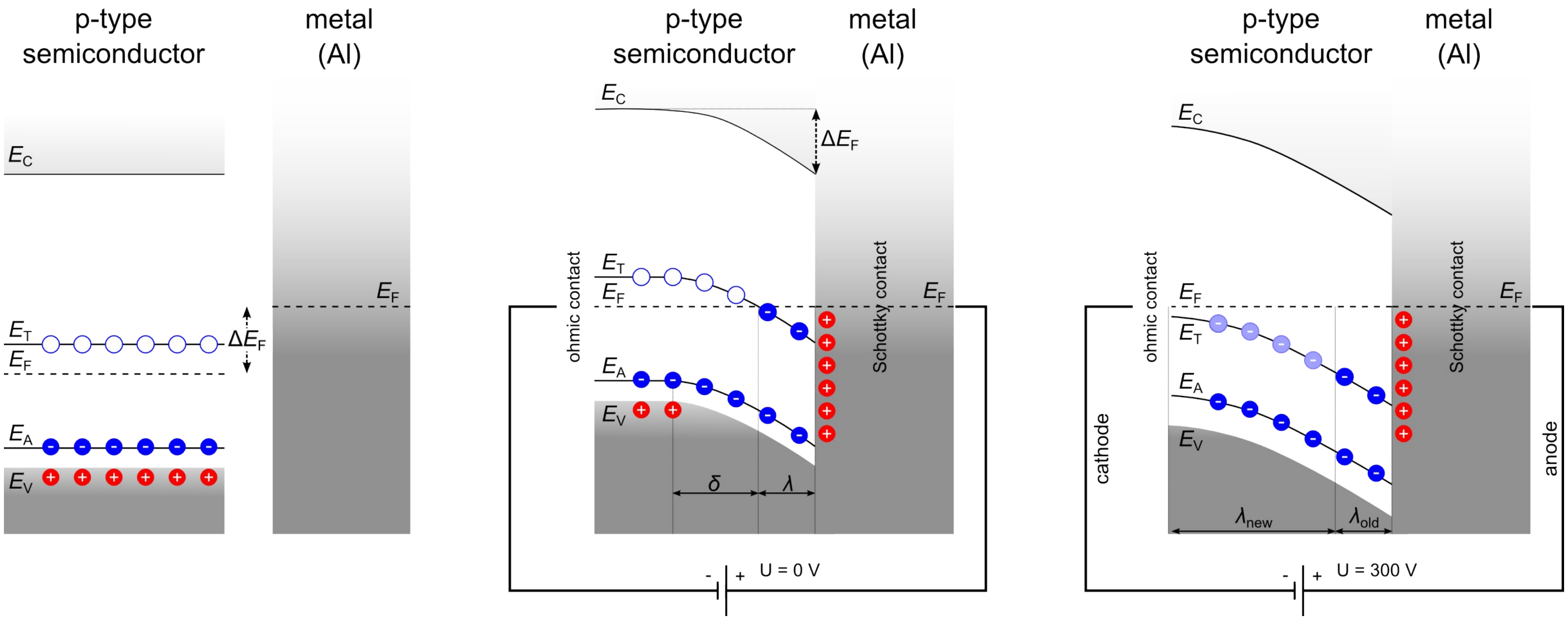
LED Am spectrum



HED: polarization effect

- CdTe: many mid-gap levels
- band bending due to Schottky contact
- increased n_{ion} → rearrangement of the electric field inside the crystal





HED: polarization effect

- spectroscopic effect
  - reduced charge collection efficiency
  - reduced quantum efficiency

0 < t [s] < 1000

1000 < t [s] < 2000

2000 < t [s] < 3000

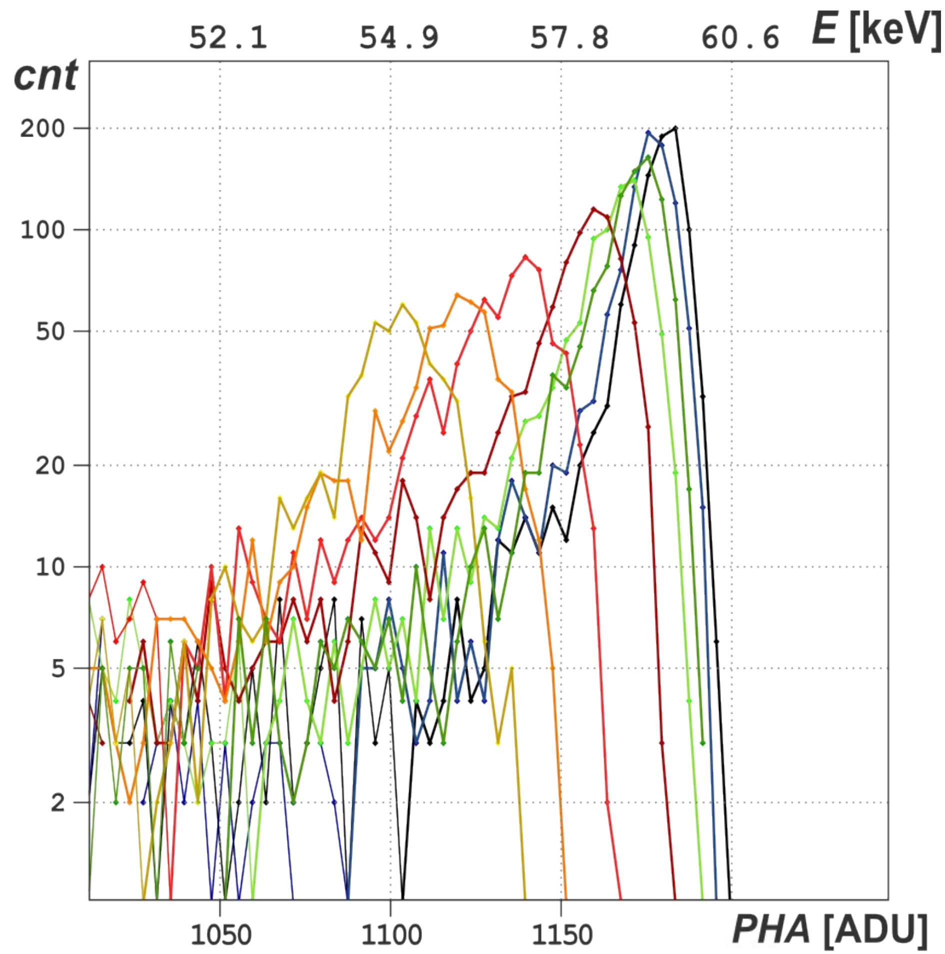
3000 < t [s] < 4000

4000 < t [s] < 5000

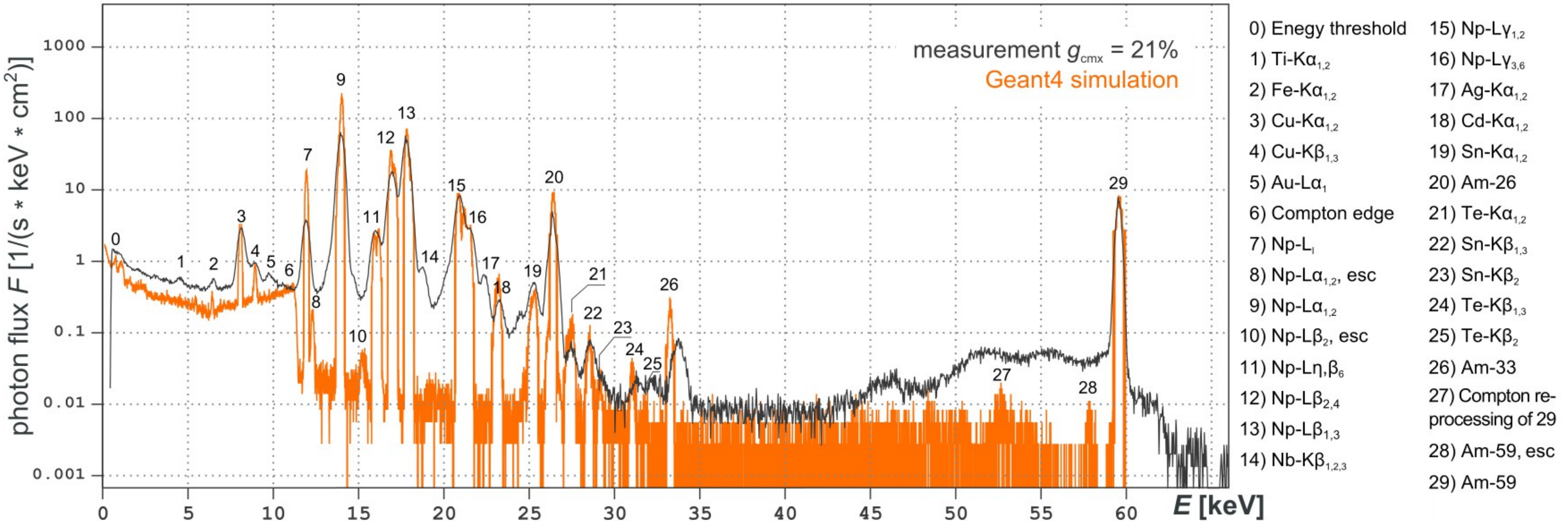
5000 < t [s] < 6000

6000 < t [s] < 7000

7000 < t [s] < 8000

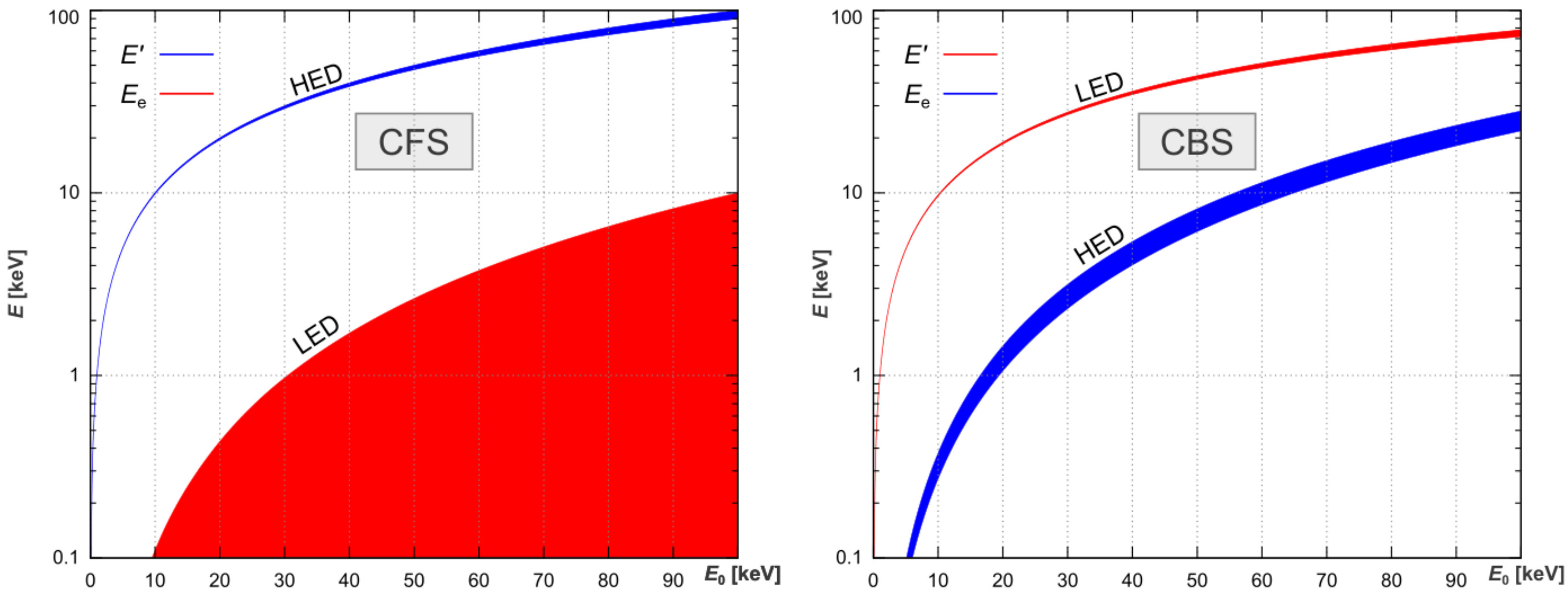


LED: Geant4 simulation



credit: S. Pürckhauer, 2015

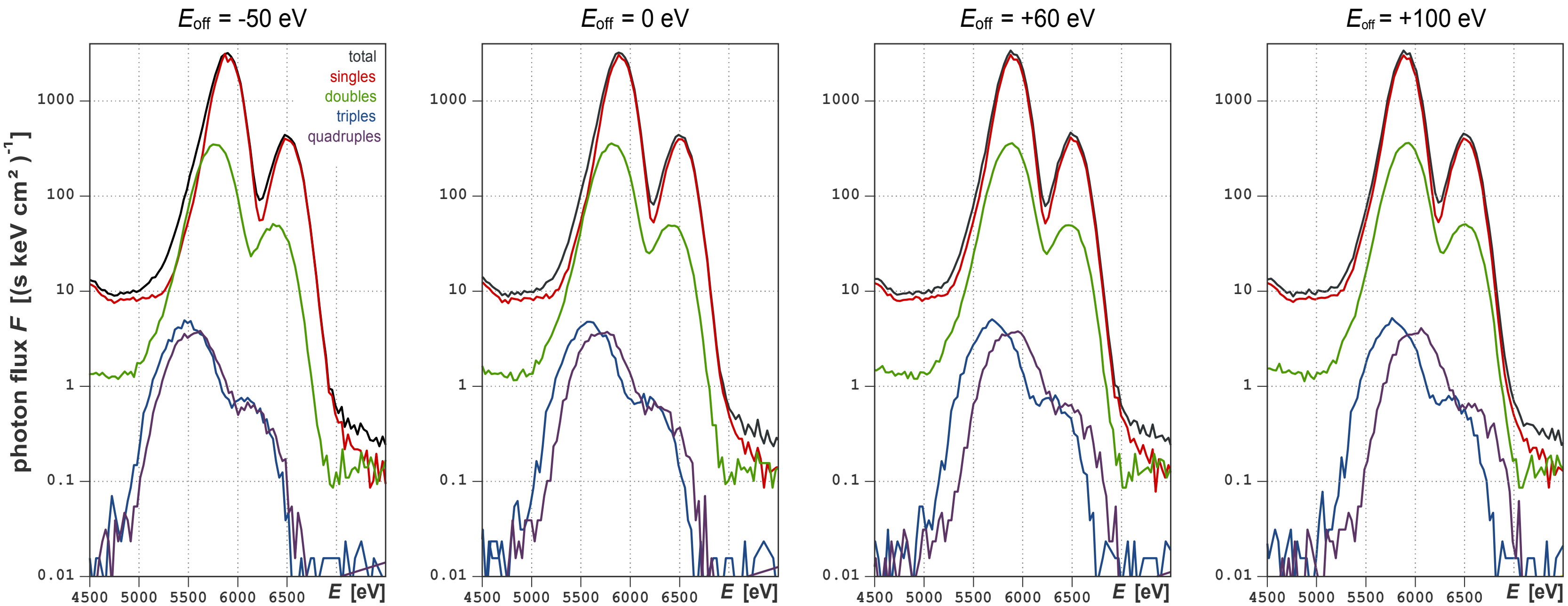
CANDELA: Compton kinematics



$$E' = \frac{E_0}{1 + \frac{E_0}{511\,\mathrm{keV}}\left(1 - \cos\left(\theta\right)\right)}$$

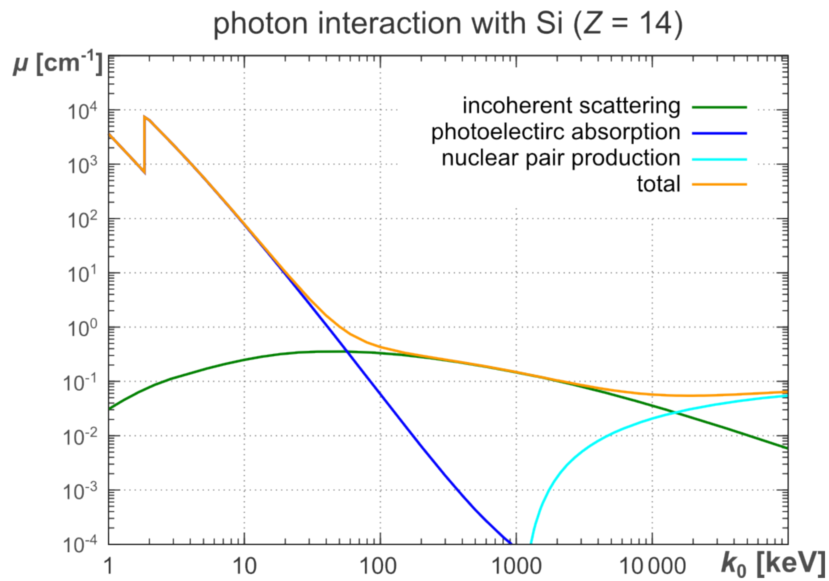
$$E_\mathrm{e} = E_0 - E'$$

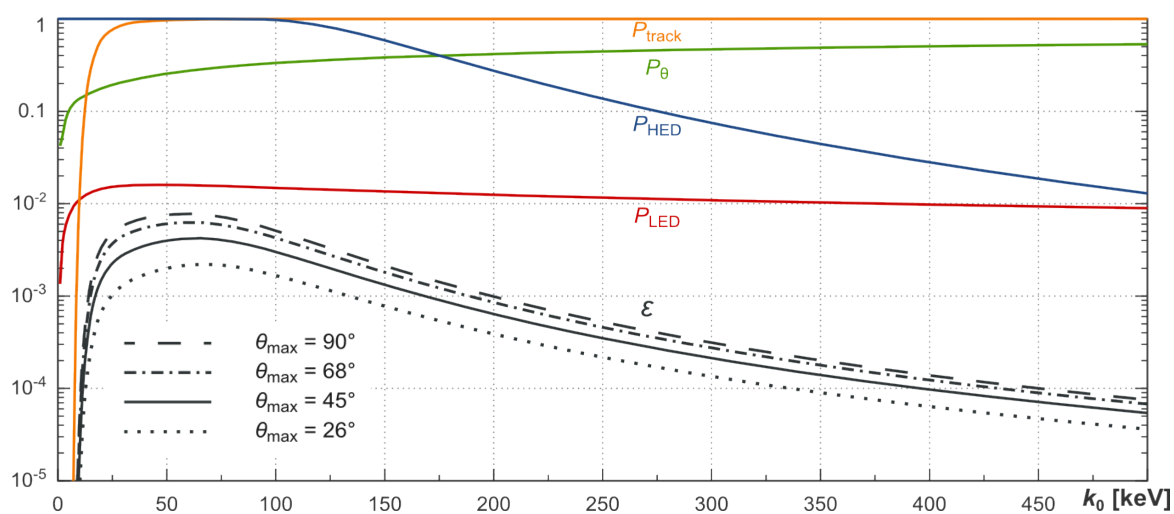
LED energy calibration



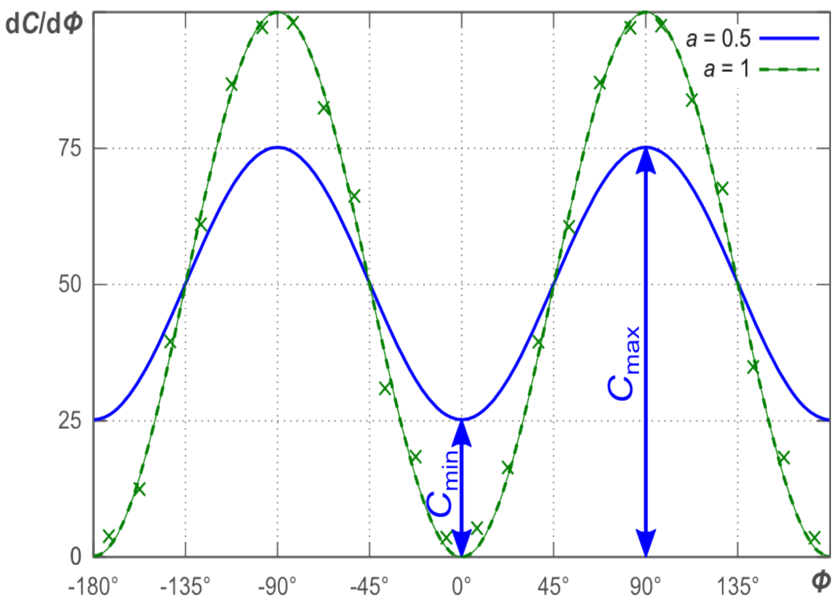
Compton forward scattering

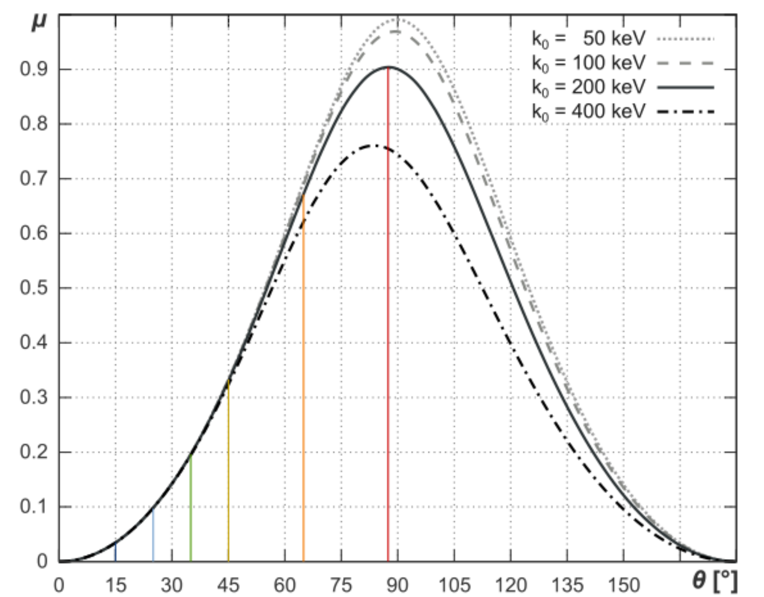
- photoelectric absorption
  ↔ detection of time coincident events
- Compton electron must be detected by the LED
  → CAMEX gain





Compton polarimeter





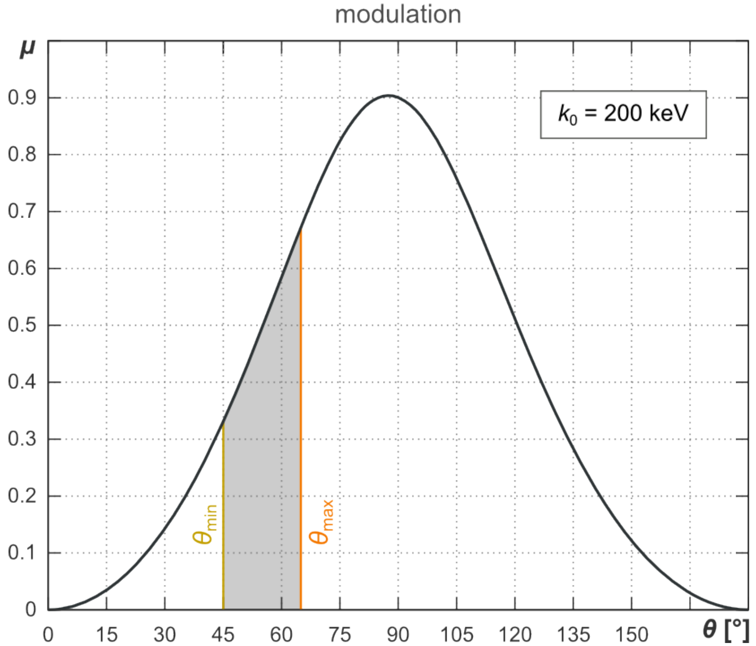
modulation factor:

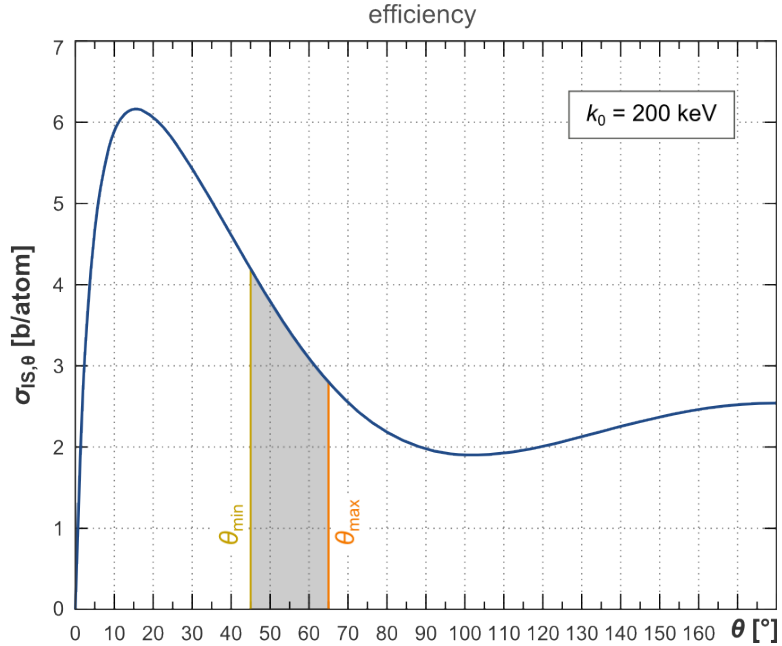
$$\mu = \frac{C_{max} - C_{min}}{C_{max} + C_{min}}$$

$$\overline{\mu}(k_0) = \frac{1}{\theta_{\max} - \theta_{\min}} \cdot \int_{\theta_{\min}}^{\theta_{\max}} \mu(k_0, \theta)\, \mathrm{d}\theta$$

$$\mu(k_0, \theta) = \frac{\frac{\mathrm{d}\sigma_{\mathrm{IS}}}{\mathrm{d}\Omega}(k_0, \theta, \phi = 90^\circ) - \frac{\mathrm{d}\sigma_{\mathrm{IS}}}{\mathrm{d}\Omega}(k_0, \theta, \phi = 0^\circ)}{\frac{\mathrm{d}\sigma_{\mathrm{IS}}}{\mathrm{d}\Omega}(k_0, \theta, \phi = 90^\circ) + \frac{\mathrm{d}\sigma_{\mathrm{IS}}}{\mathrm{d}\Omega}(k_0, \theta, \phi = 0^\circ)} = \frac{\sin^2(\theta)}{\frac{k}{k_0} + \frac{k_0}{k} - \sin^2(\theta)}$$

Compton polarimeter





$$\theta_{\mathrm{min}}^{\mathrm{opt}}(\mathrm{deg}) \approx 0.57 \cdot \theta_{\mathrm{max}}(\mathrm{deg})$$

(Muleri & Campana, 2012)

configuration	θ_{max}	$\theta_{\mathrm{min}}^{\mathrm{opt}}$	μ_{max} [%]	$\overline{\mu}$ [%]	P_θ [%]	$\overline{\mu}\sqrt{P_\theta}$	sensitivity gain
current	26.6°	15.2°	11.13	6.98	14.11	2.62	1.0
A	45.0°	25.7°	33.07	20.61	22.88	9.86	3.8
B	68.2°	38.9°	72.66	47.61	29.79	25.99	9.9
optimum	90.0°	51.3°	90.08	73.16	33.92	42.61	16.3

Summary and outlook

- LED 64x64
  - energy range: 150 eV – 15keV
  - ΔE = 168 eV @ 6 keV
  - ΔE = 352 eV @ 60 keV
  - systematic error < 100 eV for 6 keV < E < 28 keV
  - Δt = 2.44 ms → window mode

- HED 8x8
  - energy range: 3 – 150 keV
  - ΔE = 1 keV @ 60 keV
  - systematic error < 100 eV for 14 keV < E < 60 keV
  - Δt < 7 μs

- broad band energy range: 150 eV < E < 150 keV
- status: time coincident events can be measured
  - next: Compton camera
    - test the 3d source positioning
    - study the imaging accuracy → interval estimations?
  - next, next: Compton polarimeter
    - validate the predicted modulation factor
    - check the predicted point and interval estimations