HV-MAPS status update *(17.02.2022)*

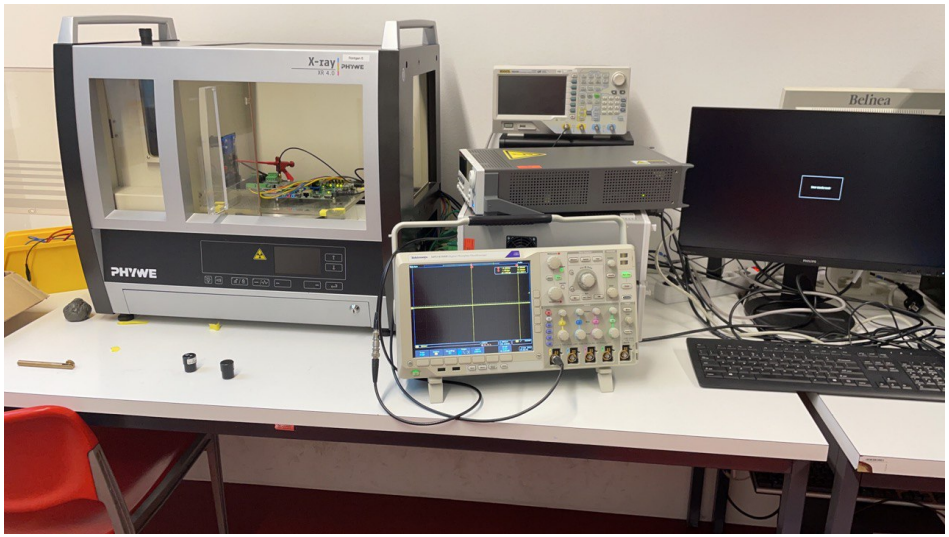
Maja Lecher

17.02.2022

X-Ray tube: Motivation and setup

Idea: Use X-Ray tubes from beginner's lab → Possibility of operating HV-MAPS at high hit rates similar to LHC?

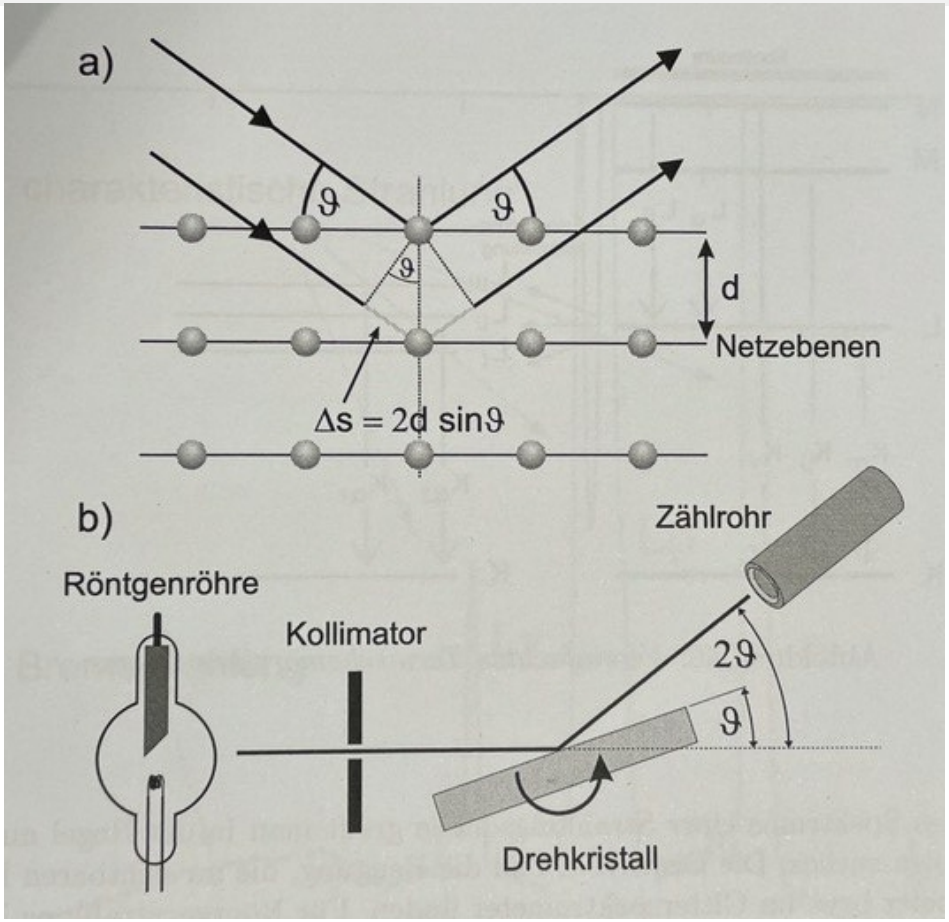
- PHYWE 4.0 X-Ray tube
- Available anodes: W, Mo, Cu
- Available filters: Ni, Zr



X-Ray setup

→ **Note**:
Currently restricted to irradiating chip from the back ⇒ $\sim$ 600 μm of Si bulk between beam pipe and depletion zone

Characterization of X-Ray spectra: Overview



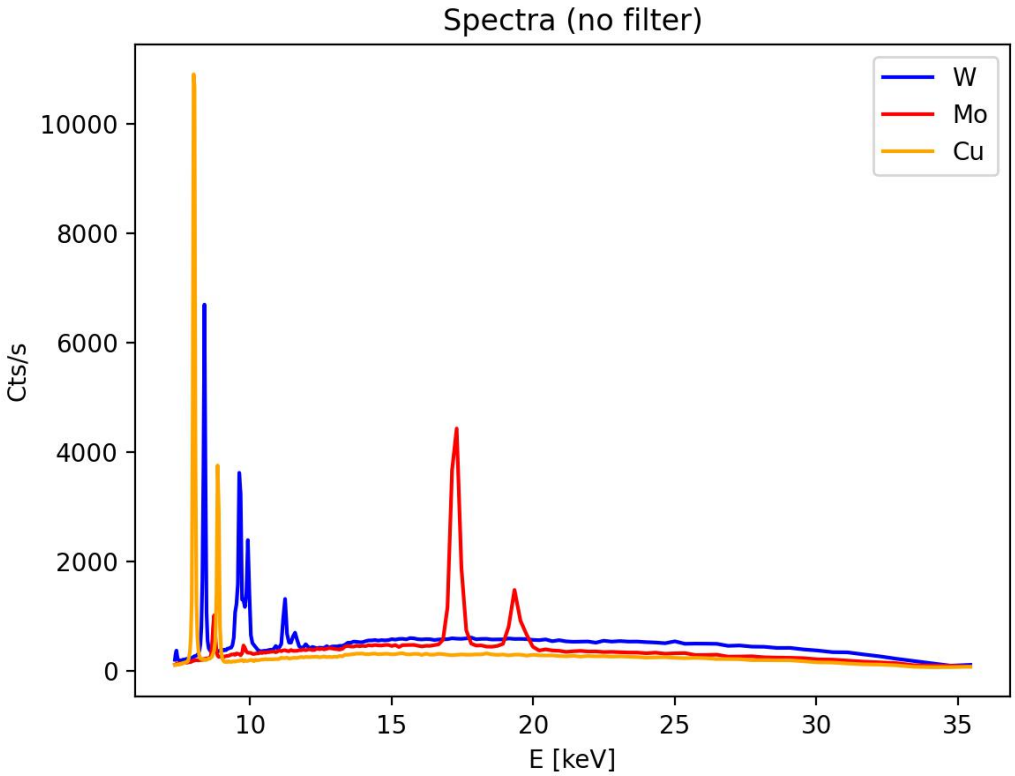
LiF crystal mounted on goniometer
→ Use relationship between wavelength of light and incidence angle of beam on crystal lattice:
Bragg's law → Constructive interference only if
$\Delta s = 2 \cdot d \sin(\theta) = n \cdot \lambda$,
where d = grating const. of crystal

$$\Rightarrow E(\theta) = \frac{hc}{2 \cdot d \cdot \sin(\theta) \cdot q_e}$$

- Detector: Geiger-Müller counter
- E resolution: LiF crystal
- Irradiate through 2 mm collimator

Characterization of X-Ray spectra: Overview

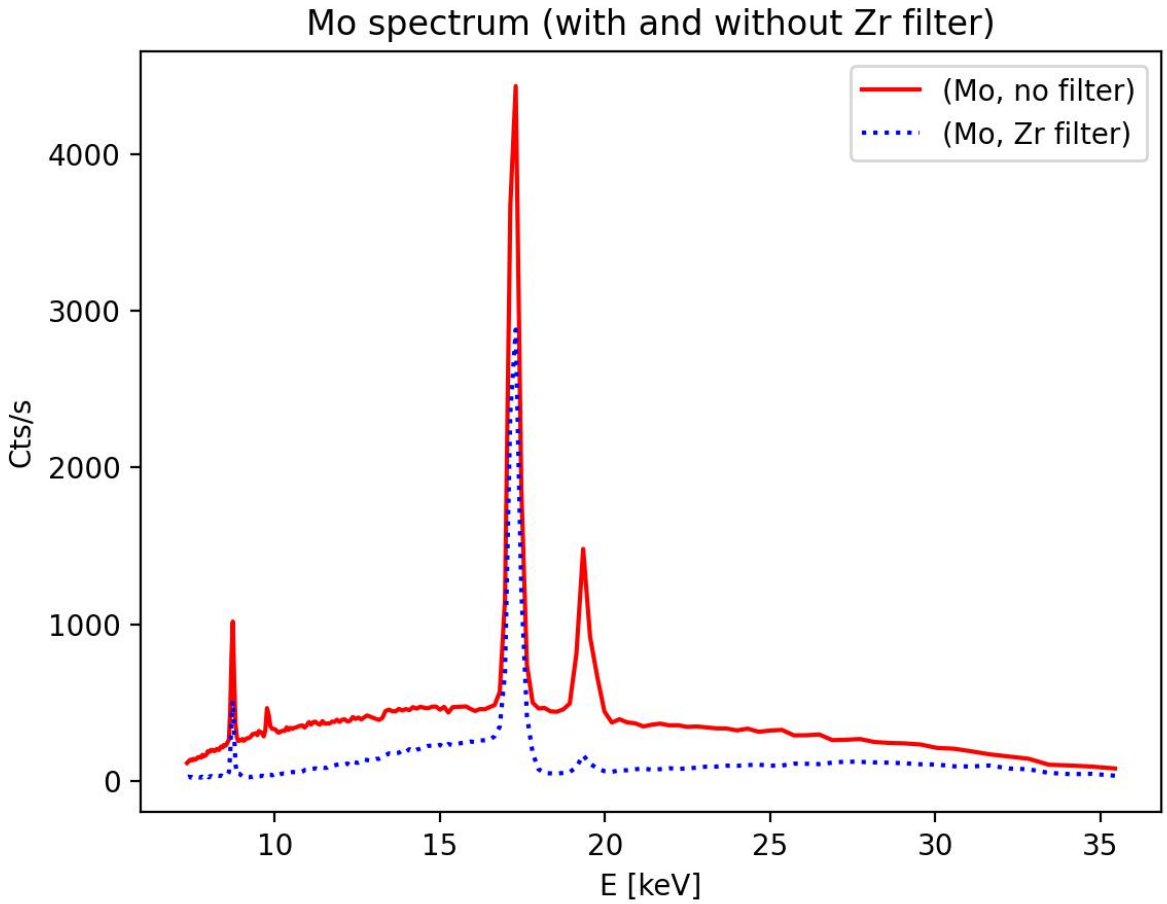
Raw spectra of different anodes:



- Brems spectrum + Characteristic anode lines
- Ideal for our purposes: single sharp line
  $\hookrightarrow$ filtering

- Detector: Geiger-Müller counter
- E resolution: LiF crystal
- Irradiate through 2 mm collimator

Characterization of X-Ray spectra: Beam absorption



- Intermediate layers of material have an impact on spectra → Can use this to our advantage (filtering out unwanted peaks)
- Has implications for spectra expected for our chip!

Characterization of X-Ray spectra: Approach

Irradiate depletion layer through chip substrate ⇒ Photons need to traverse bulk Si & convert inside depletion zone for detection

→ Expect modified spectra

↪ **What happens to photons in depletion layer?**



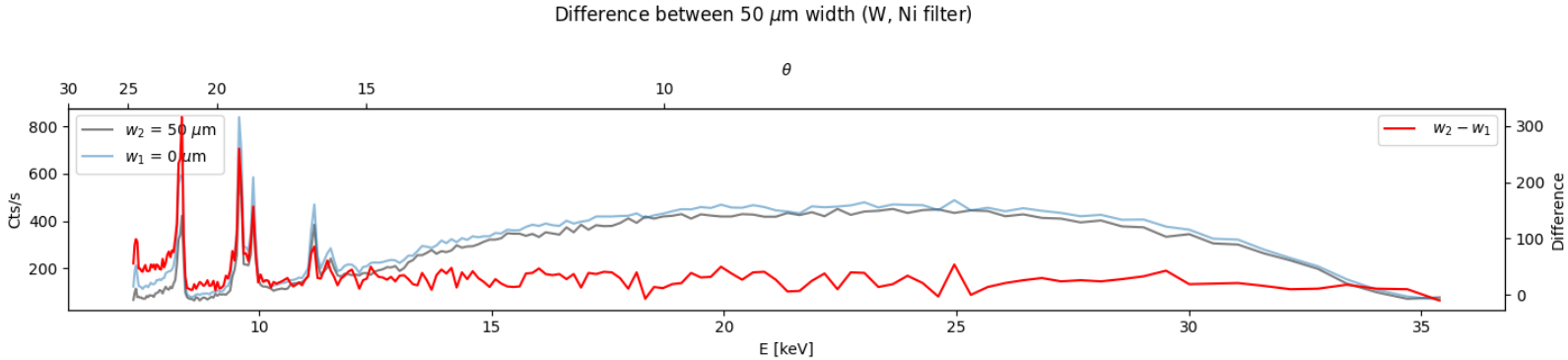
Si filter

→ **Approach**:

- Filter X-ray beam through layers of discarded Si chips placed between beam pipe & Geiger-Müller counter
- Compute difference between spectra through different bulk layers
- Note: Approximate location of depletion volume:
  - 600 and 650 μ m (irradiation through back)
  - 100 and 150 μ m (irradiation from front)

Characterization of X-Ray spectra: Filtered through Si

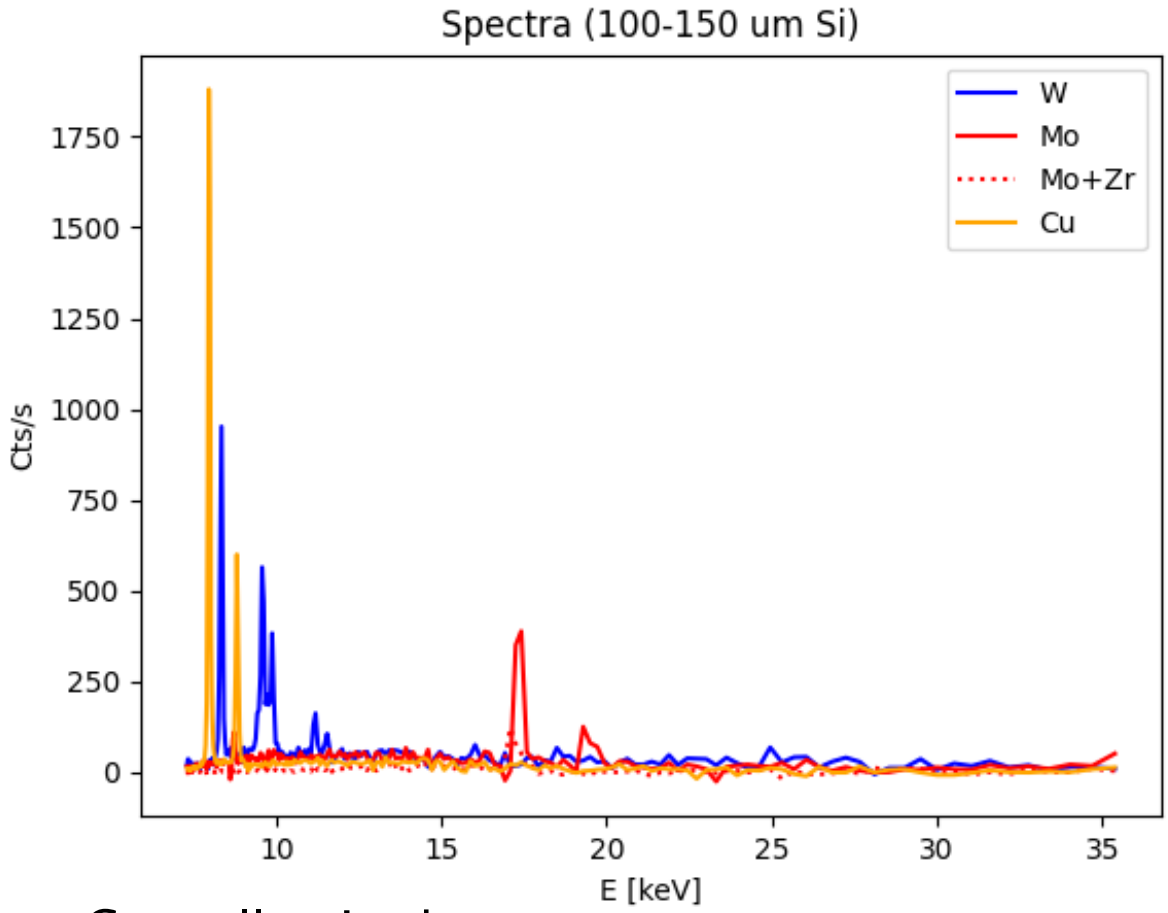
Example:



- Blue, gray: Spectra taken through 0 and 50 μm of Si bulk, respectively
  $\hookrightarrow$ Overall count reduced
- Red: Difference between spectra = spectrum expected in a depleted zone of 50 μm (for direct irradiation without intermediate bulk)
  $\hookrightarrow$ Here: Strong reduction of Brems spectrum

Characterization of X-Ray spectra: Filtered through Si

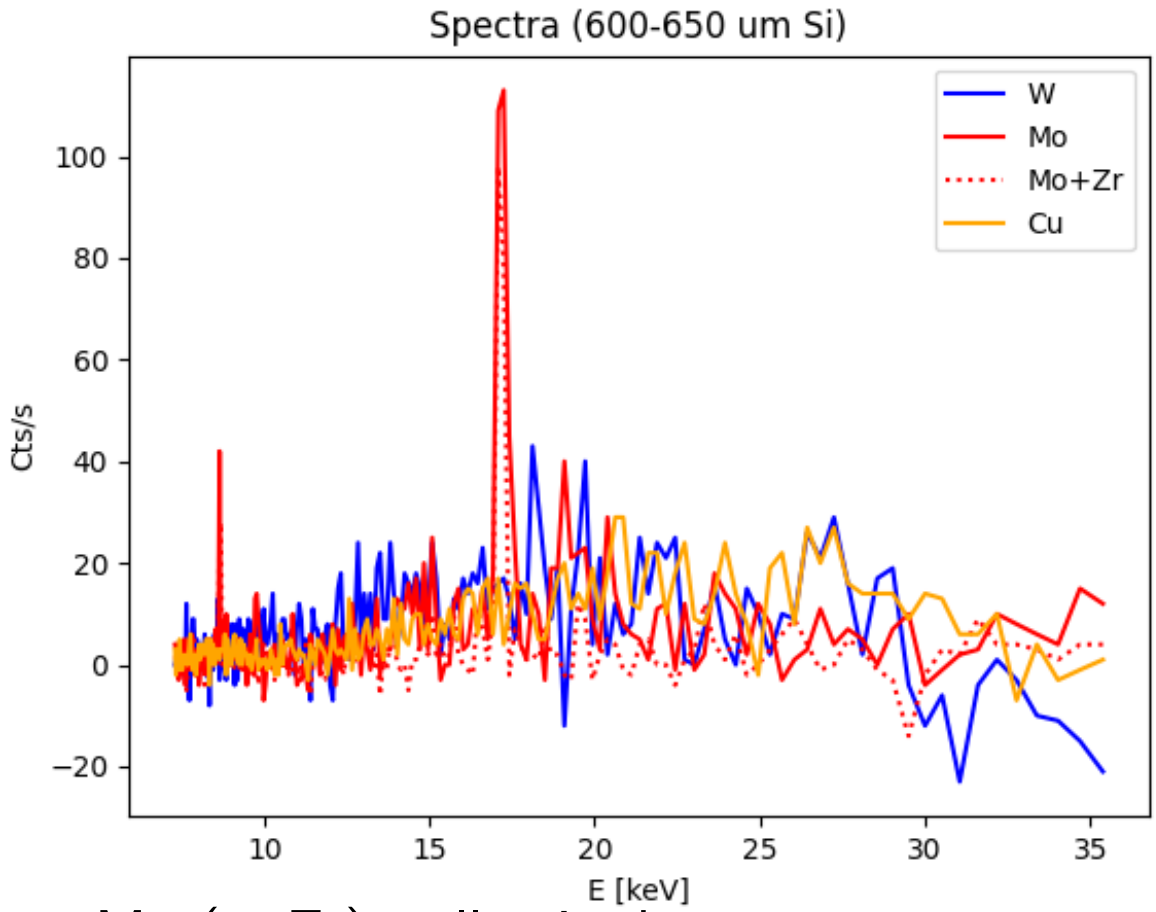
100 - 150 μm :



$\Rightarrow$ Thin chips: Cu well-suited

Characterization of X-Ray spectra: Filtered through Si

600 - 650 μm :



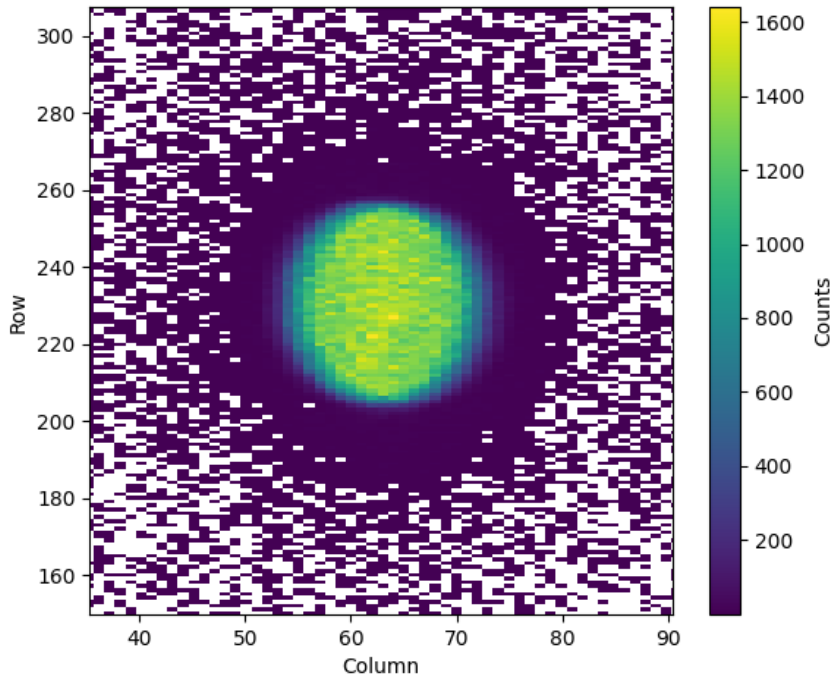
$\Rightarrow$ Thick chips: Mo (+ Zr) well-suited

Rate measurements: Setup

General setup:

- X-Ray voltage: 35 kV
- Anode current: 0.01 - 0.1 mA
- 2mm collimator
- Anode: W, Mo

Hitmap of beam spot:



- Mo anode
- I = 0.01 mA
- Beam spot: Area $\sim$ 10 mm^2

Rate measurements: As fct of anode current

Question: Expected photon rate?

$\hookrightarrow$ Expectation for LHCb: 50 MHz/chip in hottest region ($=$ 125 kHz/mm^2)
Considerations for rate calculation:

Basic idea:

- Count number of photons within a well-defined window of time
- Data collection: each hit raises hit flag, after which hits are collected for 200 ns and labeled with the same time stamp
  $\Rightarrow$ data for each timestamp bin intrinsically contains at least one hit
  $\rightarrow$ First hit in each time bin serves as trigger and is not counted (else: would introduce selection bias & lead to overestimation of rate)

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Cluster corrections:

- Some hits registered in same/adjacent pixels ("cluster")
  ↪ Assumption: events triggered by single photon
  ⇒ Photon rate: need to correct for clusters

Rate measurements: As fct of anode current

Question: Expected photon rate?

↪ Expectation for LHCb: 50 MHz/chip in hottest region (= 125 kHz/mm^2)

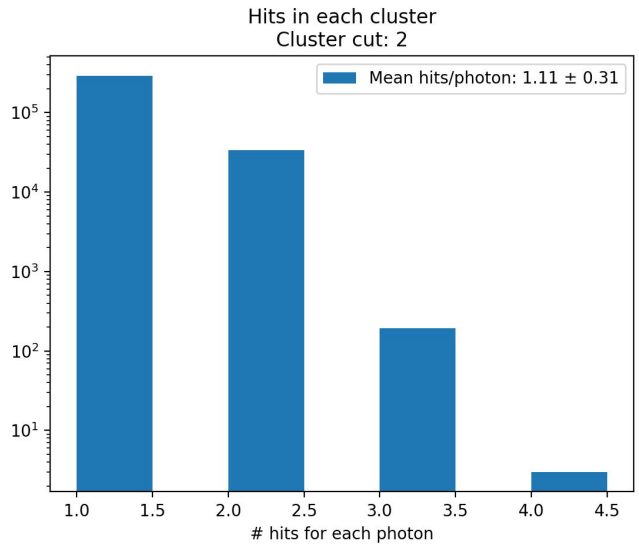
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Cluster corrections:

Typical distribution:



Rate measurements: As fct of anode current

Question: Expected photon rate?

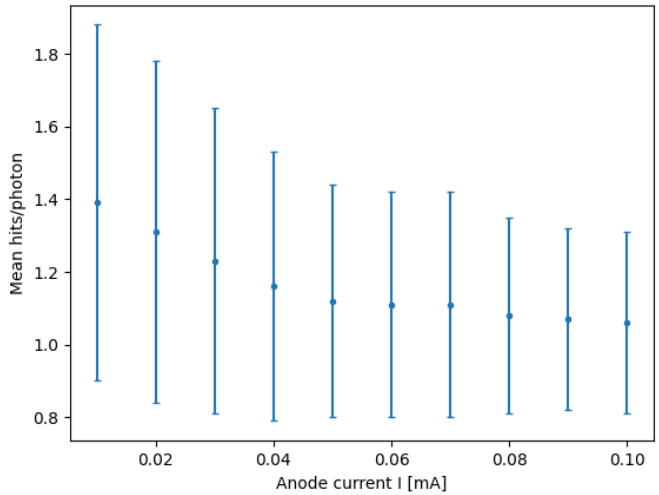
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Cluster corrections:

Mean # hits for each photon as fct of anode current:



Rate measurements: As fct of anode current

Question: Expected photon rate?

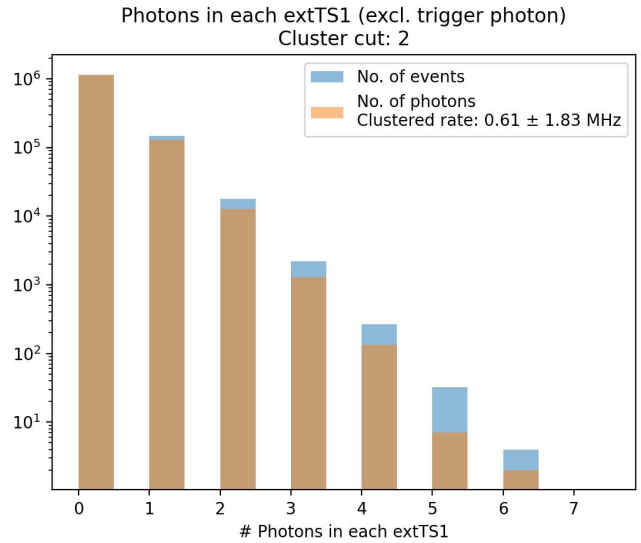
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Cluster corrections:

Distribution of no. of events/photons found in each time bin of 200 ns:



Rate measurements: As fct of anode current

Question: Expected photon rate?

↪ Expectation for LHCb: 50 MHz/chip in hottest region (= 125 kHz/mm^2)

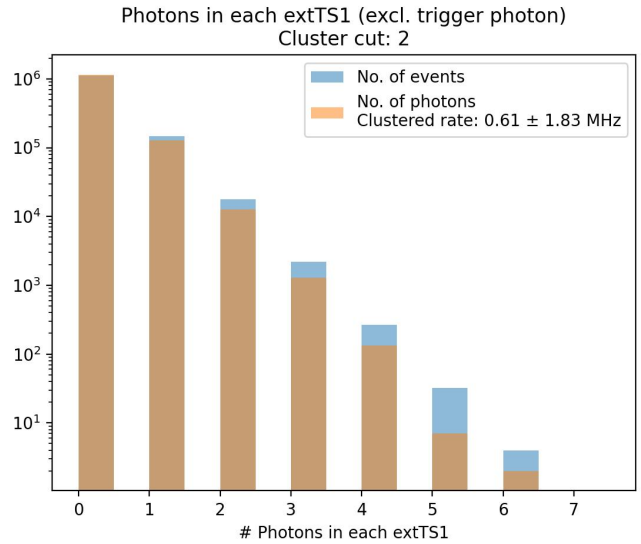
Considerations for rate calculation: $\text{Rate} = \frac{\text{hits w same TS - hits belonging to cluster -1}}{\text{200 ns}}$

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Cluster corrections:

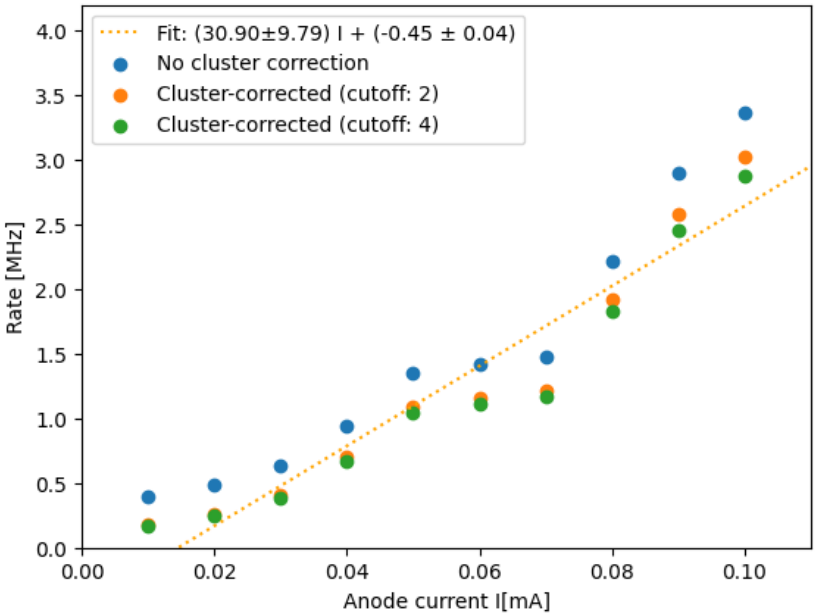
Distribution of no. of events/photons found in each time bin of 200 ns:



Rate measurements: As fct of anode current

Result:

- Measure rates at increasing anode currents between 0.01 and 0.1 mA
- Readout-limited: bring down rate using 700 μm Si
- Rate $= \frac{\text{hits w same TS - hits belonging to cluster -1}}{\text{200 ns}}$



$\hookrightarrow$ Rate: $\mathcal{O}$ (MHz)

Uncertainties:

- Crosstalk?
- Effect of correction depends on cutoff value

Conclusion:

- Anode current: can reach up to 1 mA (factor 10 higher than current limit)
- Artificially lowered rate using additional Si bulk

$\Rightarrow$ Should be able to reach LHCb rates

Rate measurements: As fct of anode current

Future of rate measurements:

- Use external trigger
- Record hits directly on FPGA s.t. rate not limited by readout speed