Pulsed, compact, low-background X-ray generator

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Ref: I. Giomataris *et al* JCAP12(2020)043

XDEP Workshop
5-6 february 2024

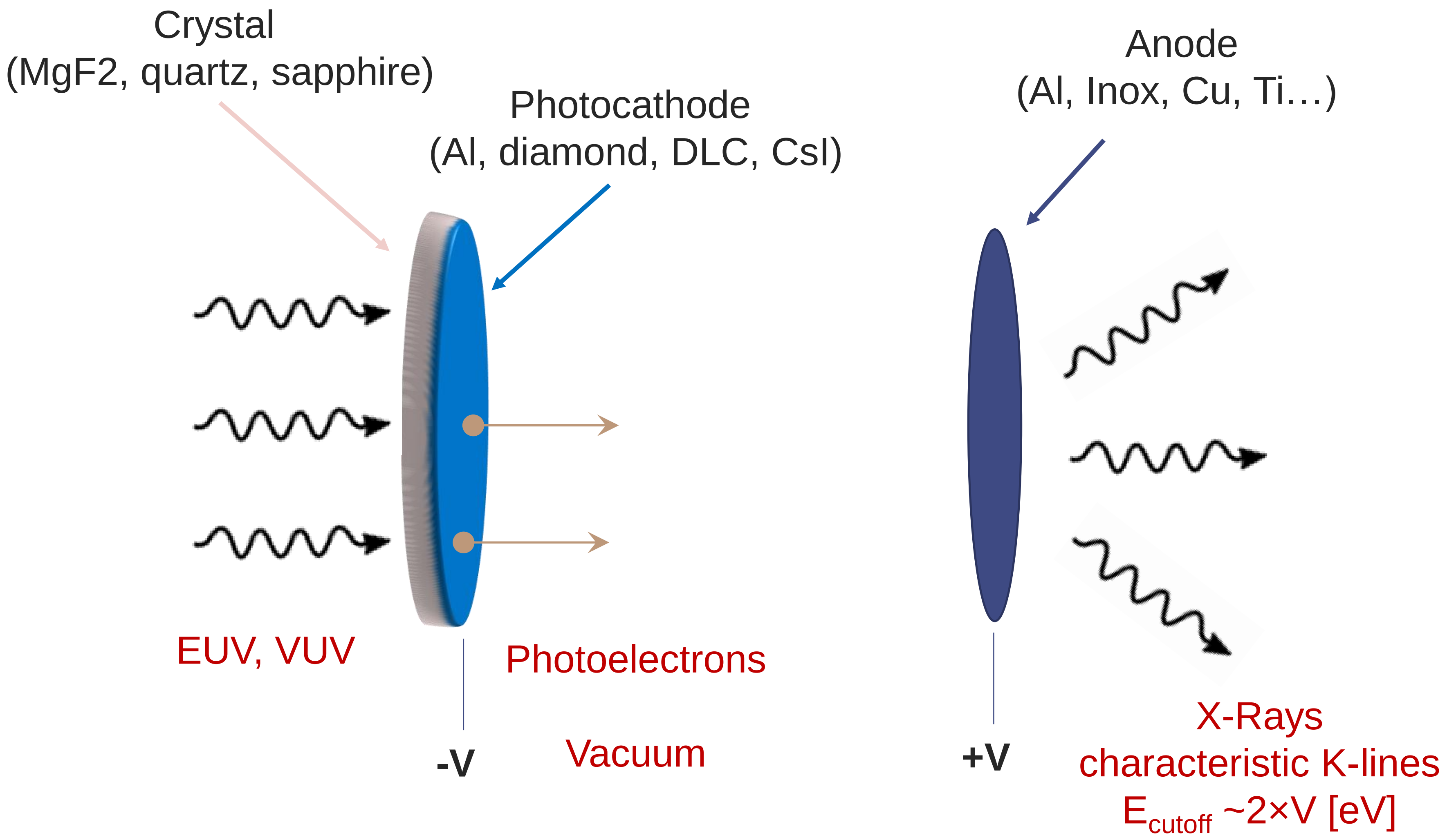
Overview

- Motivation
- Working Principle
- Results (data and MC)
- Implementation for BabyIAXO
- Conclusions

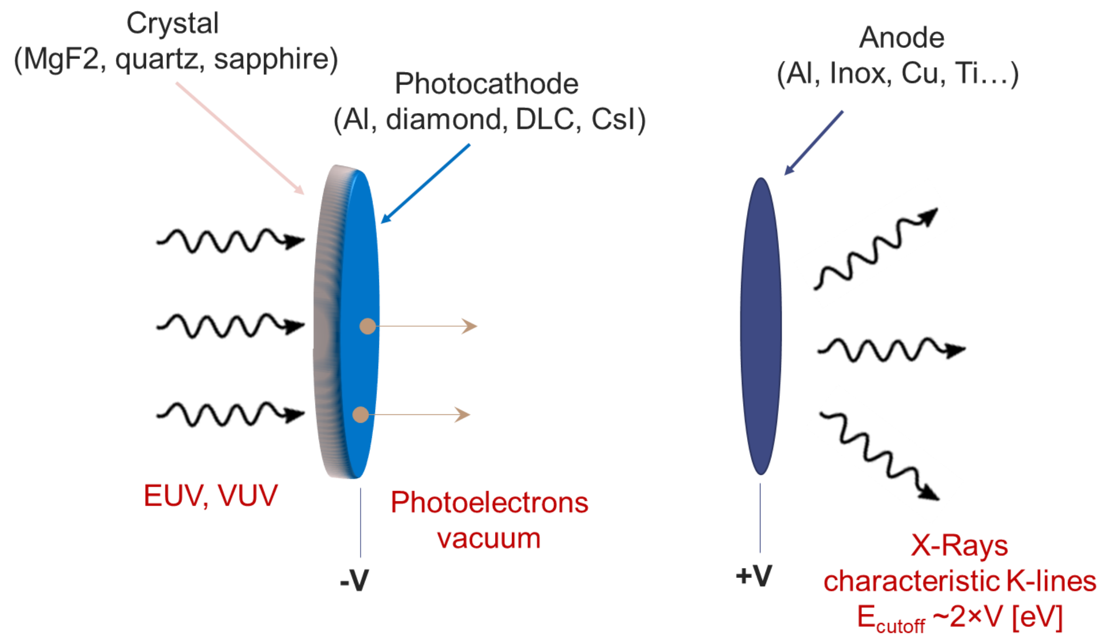
Motivation

- A new type of x-ray generator has been conceived at IRFU (CEA Saclay)
    - Compact, light and radiopure for detector calibration
    - Compatible with vacuum
    - Possibility to tag events and to not affect data taking
- Based on the generation of electrons by a UV pulsed lamp on a metal photocathode and not by the thermionic effect
    - *Gas discharge lamp*
- Applications in rare event searches (Dark matter, axions, etc…)
    - Plan to be implemented in BabyIAXO to calibrate and monitor gain variations
        - It can be also operating during data taking

Working Principle



Working Principle



- Photo-electrons are accelerated to a thin-metallic anode
  - Selection of electrons absorber -- Different X-rays energies
- Radiation is produced by:
  - Characteristic x-rays
  - Bremsstrahlung x-ray photons
- Low material budget
  - For rare event experiments (dark matter, axions)
  - Selection of radio-pure materials “easy”
- No cooling needed. Voltage can be limited to 30 kV
- Low radiation levels expected
  - No radioactive source needed
- Portable and compact size -- Flexible design (few cm for < 8 keV)

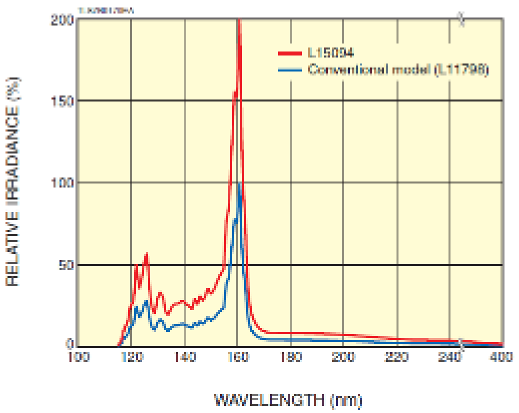
Working Principle: modes

Continuous mode

- Commercial, high power lamp, with continuous emission
- High rate. Long term stability
- Calibration run ≠ data taking
- Low consumption (Typical HV +/- 6 kV, $I_{p.e.}$< 1µA)
- Lamp can be decoupled from the photocathode through a UV vacuum viewport

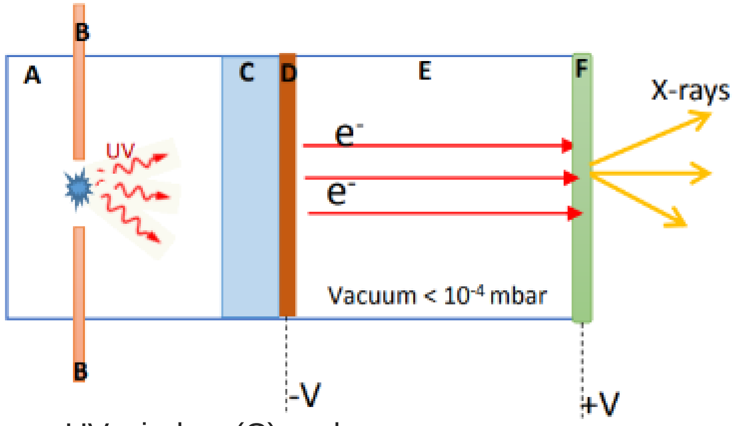
Pulsed Mode

- Lamp with Ar, Xe, Deuterium at <~ 1 bar
- Electrodes causing discharges in the gas
- Dimensions can be optimized to have time tagging of discharges ~1 ns
  - Calibration during data taking
- Very low consumption (~1 mW)
- Low rate



Hamamatsu H2D2

Gas discharge VUV lamp



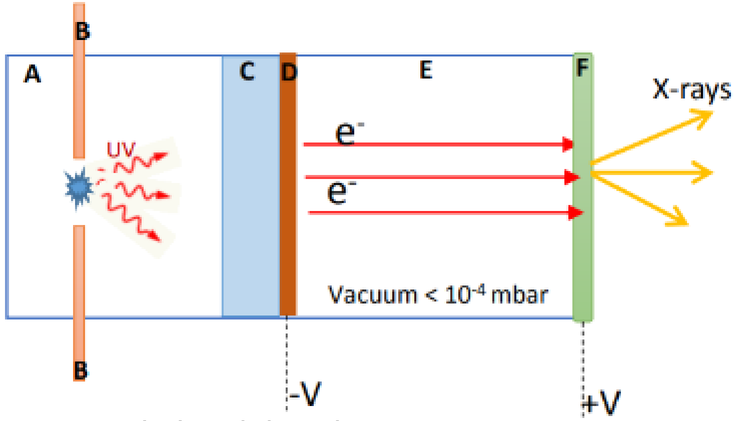
UV window (C) and photocathode (D)

Working Principle: configurations

Semi-transparent mode

- Self-absorption in the anode
  - Thickness to be optimized. Usually ~ µm
    - Fragility problems
- Even at the optimum, the produced rate will be less that the reflective
  - Sometimes enough, don't need to have max rate

Gas discharge VUV lamp



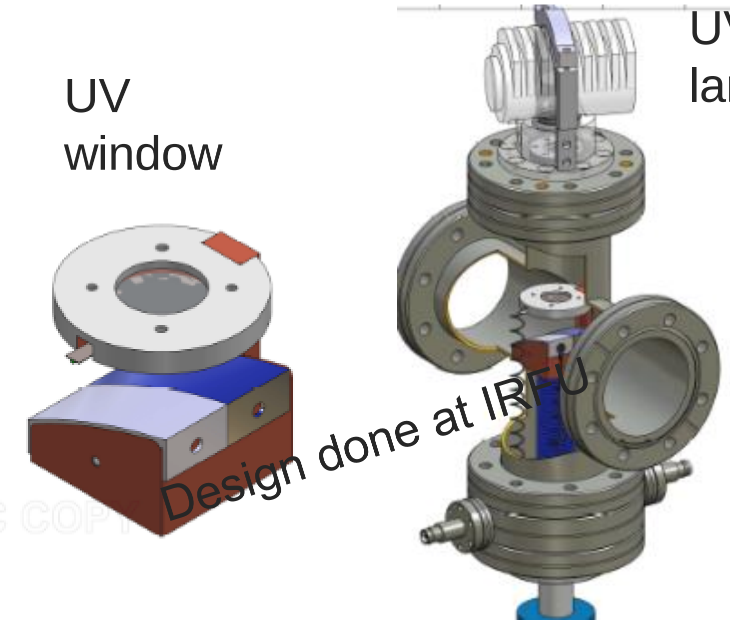
UV window (C) and photocathode (D)

Reflective Mode

- No limitation for the thickness of the anode metal,
  - x-rays are emitted from the same side that the electrons fall.
  - Maximum possible x-ray emission efficiency.

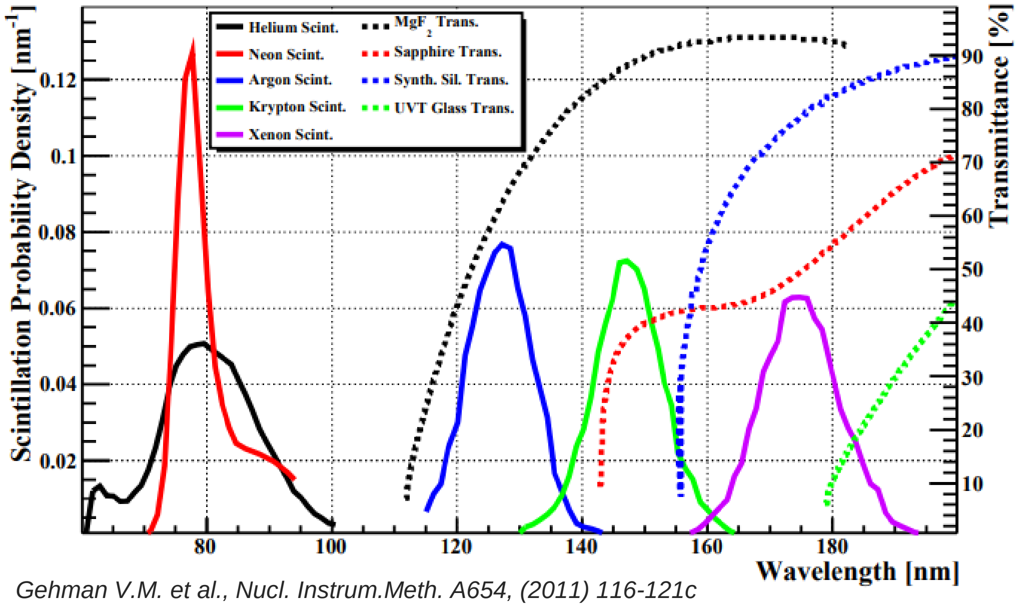
UV window

UV lamp



Optimization

- Lamp
  - Gas : ^{2}H, Ar or Xe safer gases (diff wavelength and timing)
  - UV-window : transmission matched with gas (MgF_2,quartz, sapphire, …)
- Photocathode Q.E.
  - Al, CsI, polycrystalline diamond on quartz, DLC, B_4C
  - Viewport might introduce a higher cut-off
- Lamp power → impact on rate
  - RC circuit controls intensity and repetition rate
- Materials
  - Robust, vaccum compatibles, radiopure
- Smooth parallel plates for HV to reduce size
- Anode
  - Material: Al, **Ti**, **Steel**, Fe, **Cu**, combination…
  - Thickness critical:
    - Spectrum depends on the thickness. In general few mum



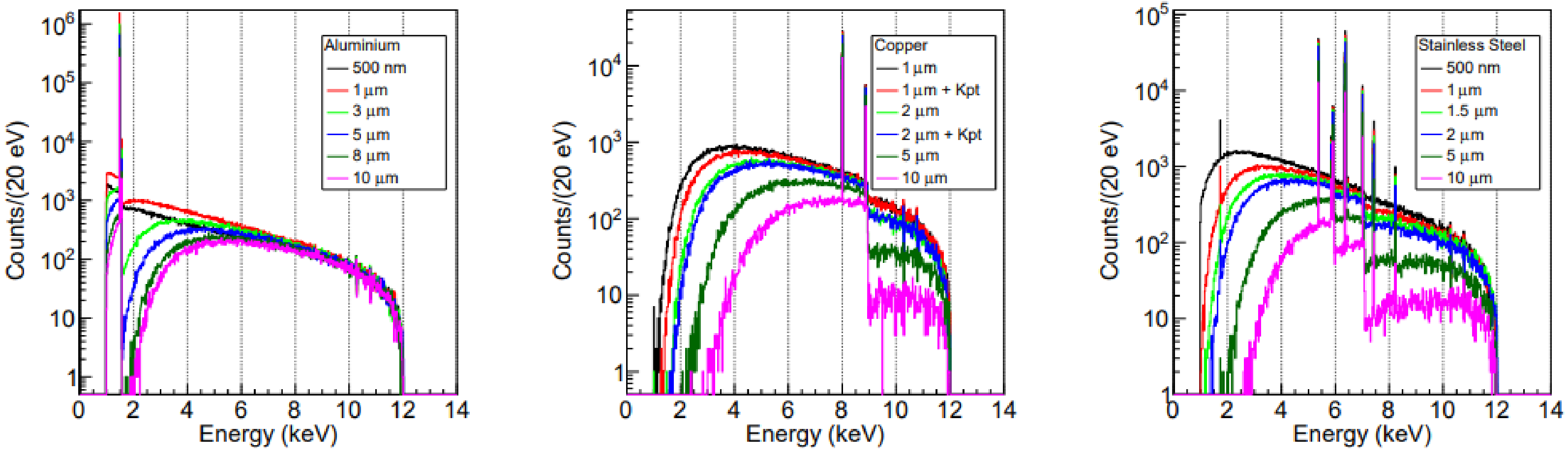
Gehman V.M. et al., Nucl. Instrum.Meth. A654, (2011) 116-121c

Material	Characteristic x-rays (eV)		
	Kα1	Kα2	Kβ
Al	1486.3	1486.7	1557.5
Cr	5414.7	5405.5	5946.7
Ti	4510.8	4504.9	4931.8
Cu	8027.8	8047.8	8905.3

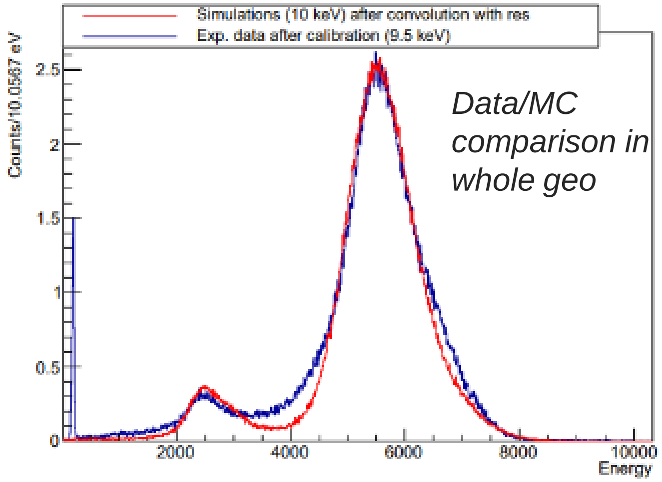
From “X-Ray Data Booklet” LBNL

Optimization

- MonteCarlo simulations using GEANT4
- Minimal geometry to obtain x-ray spectrum
- Different materials and thickness



Energy spectrum from electrons energy of 12 keV at impacting at target with different thickness

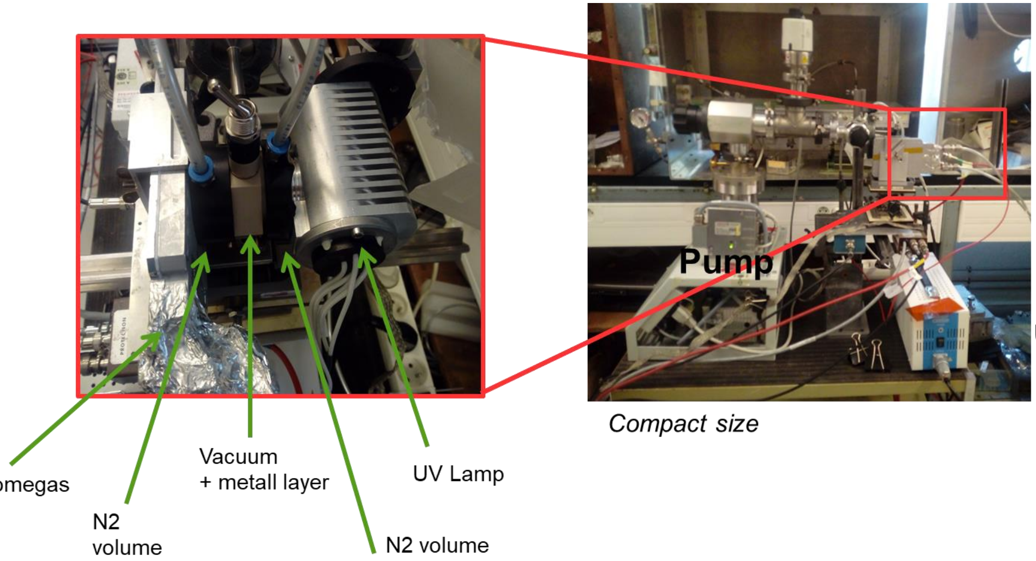


- X-ray lines emerge from the Bremsstrahlung spectrum
  - Down to self-absorption and up to 12 keV (e- energy)
- ↑↑ X-ray efficiency for a thickness close to the range of electrons in the material
- Thicker converter → larger separation between characteristics X-rays and bremsstrahlung
  - Higher probability to absorb low energy X-rays

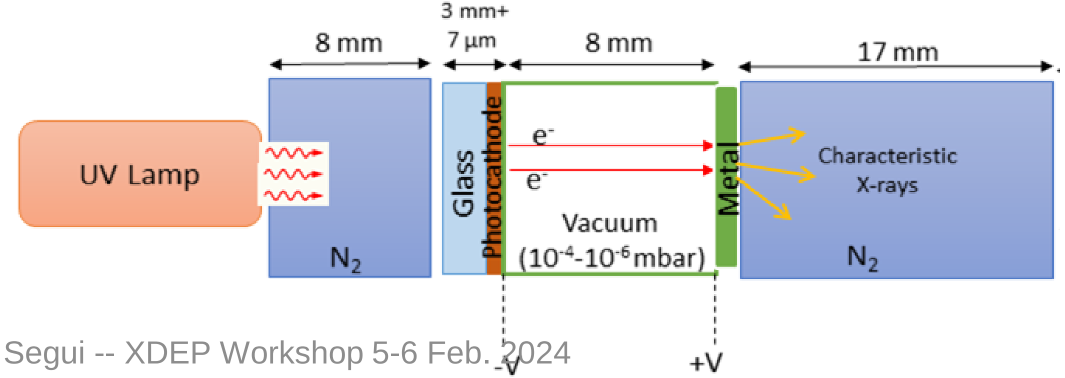
Experimental Results

- First: a test bench using a **continous** off-the-shelf **UV lamp**
- Different electrons absorbers tested

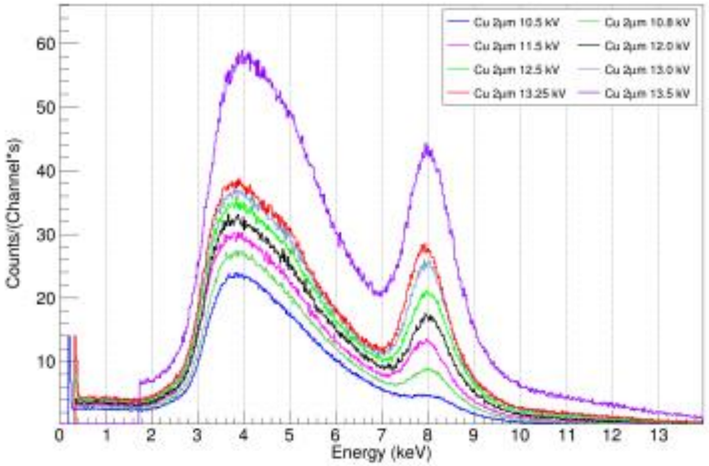
Hamamatsu L2D2
(type L10904)



Compact size



2 µm Cu (on 12 µm Kapton)



Voltages (e^- energy (keV))	Total Rate (Hz)	Rate in the 8.0 keV peak (Hz)
10.5	4567 ± 67.6	305.9 ± 17.5
10.8	5449 ± 73.8	504.7 ± 22.5
11.5	6351 ± 79.7	732.2 ± 27.1
12.0	7161 ± 84.6	932.5 ± 30.5
12.5	8160 ± 90.3	1162 ± 34.1
13.0	8889 ± 94.3	1395 ± 37.3
13.25	9360 ± 96.7	1521 ± 39.0
13.5	14540 ± 120.6	2406 ± 49.0

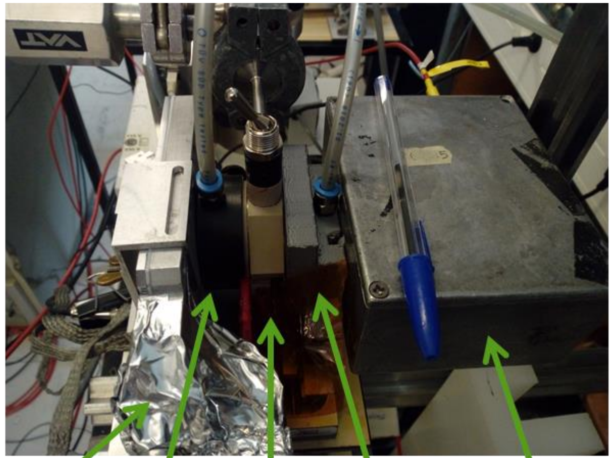
Vaccum 1.6 x 10^{-4} mbar
Th in rate in 0.5 keV

Experimental Results

Pulsed Lamp – proof of principle

Very initial reuslts for proof of concept

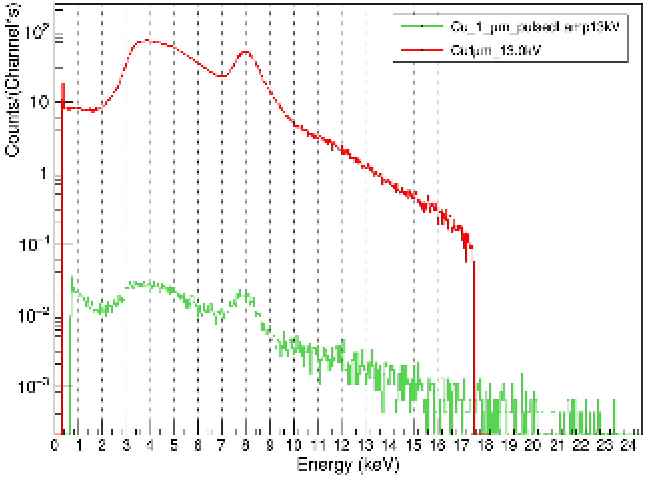
- Same setup but replacing the continus lamp by a Deuterium pulse one
- Sapphire window
- Discharge every second
- Not high initial photon rate



Micromegas

Vacuum
+ metal layer

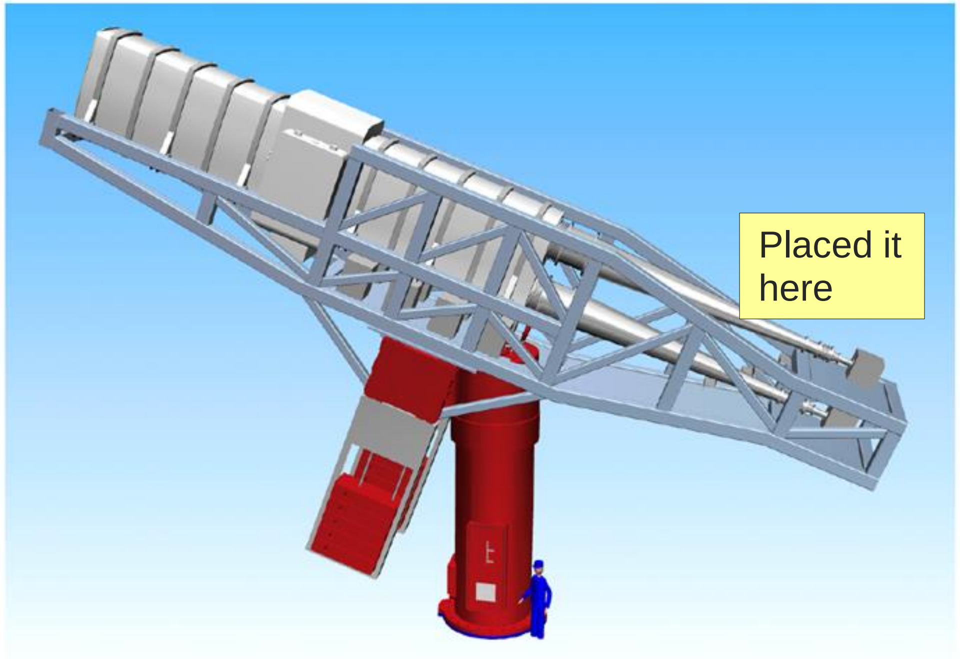
UV Pulsed Lamp



Data with the MCA (no trigger from lamp)

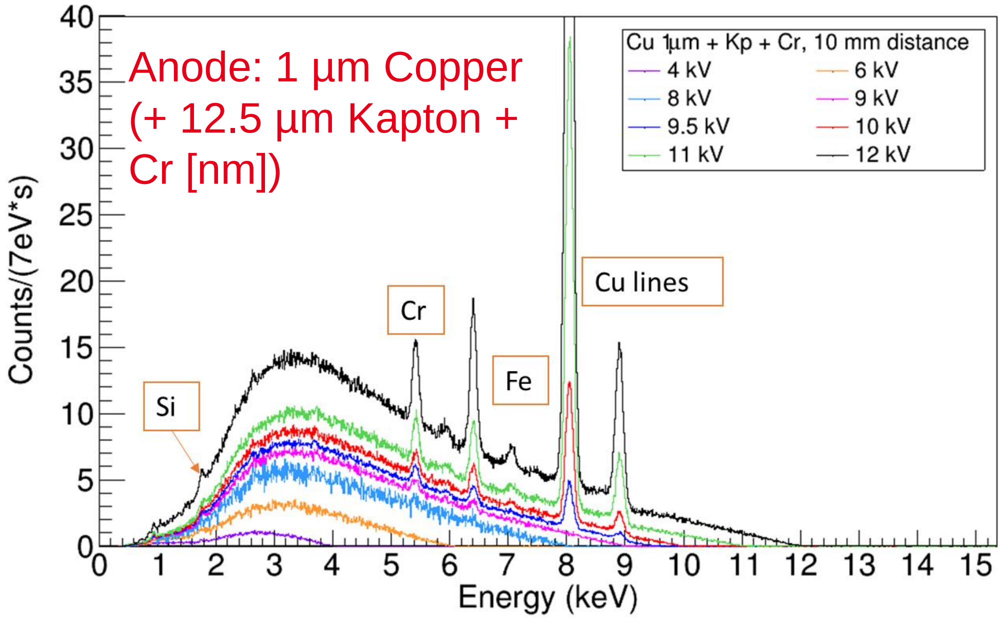
Possible Implementation in BabyIAXO

- To be placed between telescope and Micromegas
- Off the focal line
- Calibration, gain study during parking periods OR
- Continuos calibration

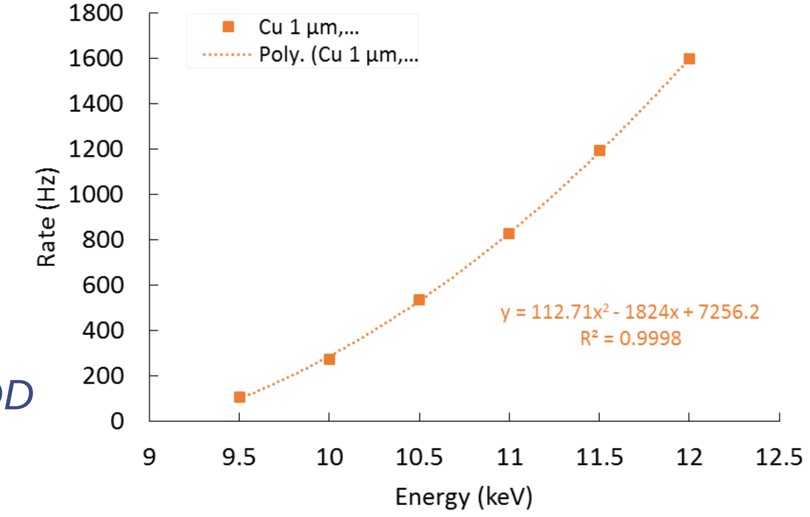


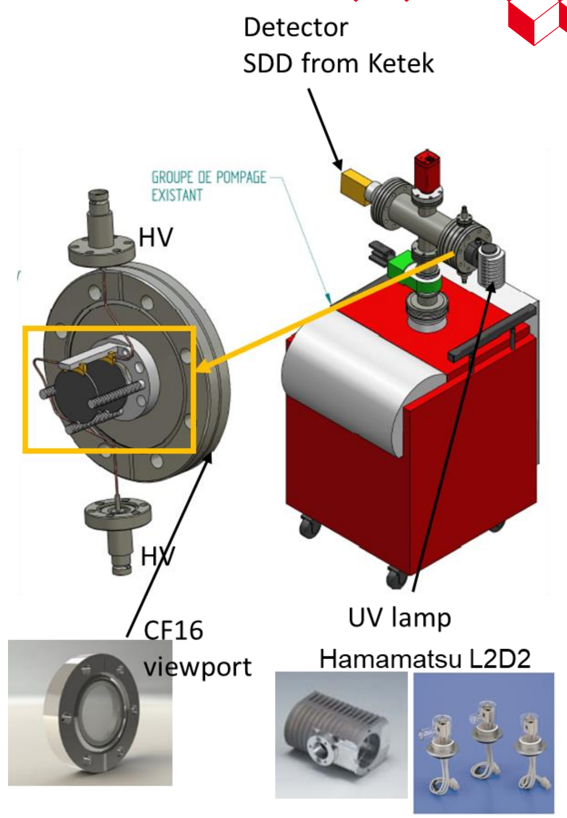
Possible Implementation in BabyIAXO

- Setup at IRFU (data in 2020 with SDD, now with a Micromegas installed)
- The photocathode crystal and the anode are placed entirely inside the magnet Vacuum
- HV: standard SHV feedthrough, V_{max} < 9 kV



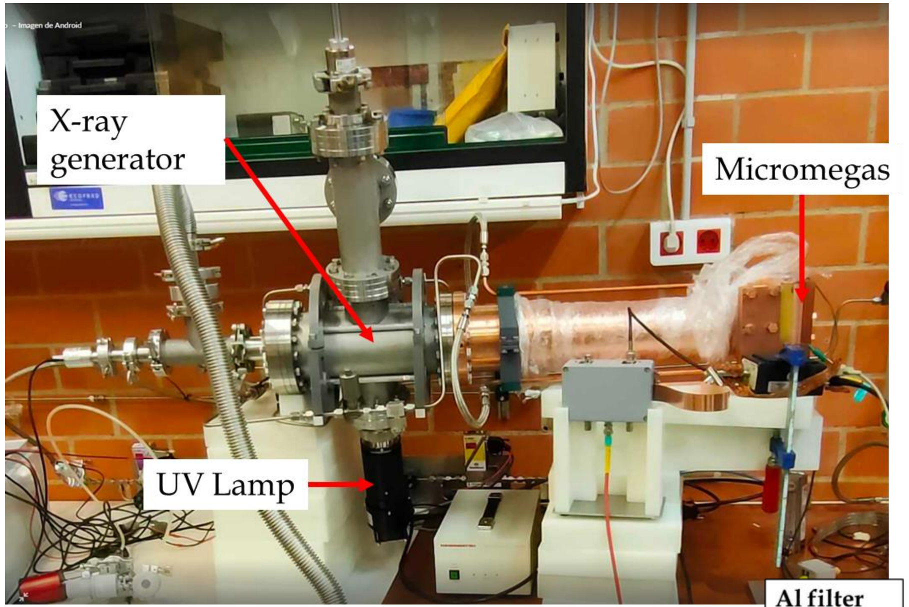
Data with SDD

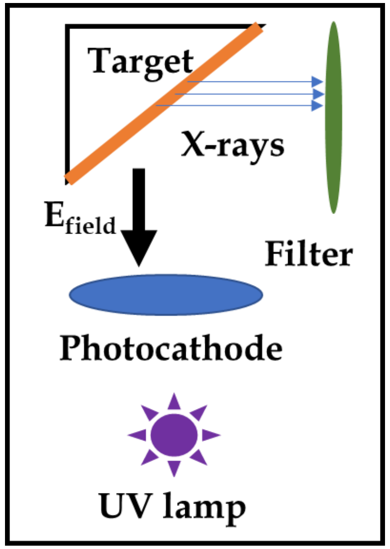


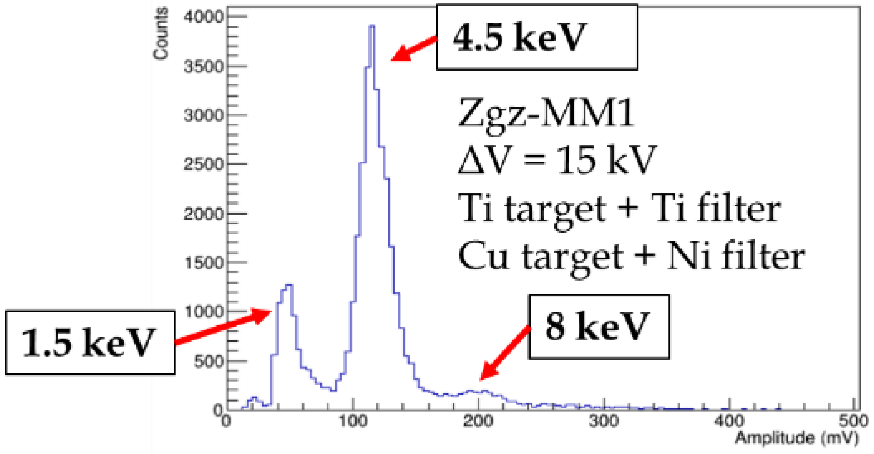


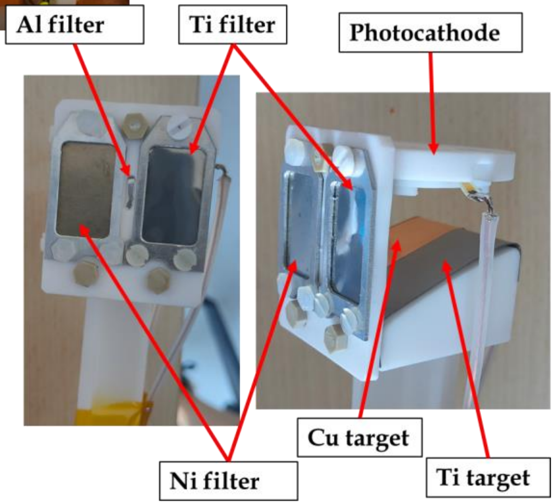
Possible Implementation in BabyIAXO

- Implemented in IAXO-D1 (at Zaragoza group)
- **Reflective mode** + Two targets at same time









- Filters to reduce Bremsstrahlung
- Lamp very high rate → discharges
- On-going work towards stability and optimization

Conclusions

- New xray generator based on the generation of electrons by a UV pulsed lamp on a metal photocathode and not by the thermionic effect
- X-ray energies can be chosen changing the target. Efficiency determined by thickness
- Compact, light, radiopure, low consumption
- Low radiation expected. No cooling needed. V can be kept <30 kV. Easier to implement
- To calibrate rare event experiments. Tagging of events possible, can be used during data taking
- Posible implementation in babyIAXO under study. Setups at IRFU and Zaragoza

Thank you!

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