Istituto Nazionale di Fisica Nucleare

CENTRO RICERCHE ENRICO FERMI

Measurements of the Pauli's Exclusion Principle violation with X-Rays detectors: the VIP group

21 June 2023
Alessio Porcelli

High Precision X-Ray Measurements 2023

Why Fermi-Dirac and Bose-Einstein are distinct?

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WE DON’T KNOW

Beyond Standard Model…

Reasons of Pauli's Exclusion Principle (PEP)

- **Particle nature? Green's general quantum field:** paronic particles
  - Order 1: fermionic/bosonic fields
  - Order>1: parafermionic/parabosonic fileds
  - **Messiah-Greenberg Super-Selection**: no fermion/boson decays into parafermion/paraboson (and vice-versa)
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- **Interactions result? Non-Commutative Quantum Gravity**
  - **θ-Poincaré**: distortion of Lorentz symmetry (visible in a two identical particles system)

$$\left|\alpha,\alpha\right\rangle = \left\langle a^{\dagger},\alpha\right\rangle \left\langle a^{\dagger},\alpha\right\rangle \left|0\right\rangle = \int \frac{d^{d}p_{1}}{2p_{10}} \frac{d^{d}p_{2}}{2p_{20}} e^{-\frac{i}{2}p_{1\mu}\theta^{\mu\nu}p_{2\nu}} \alpha(p_{1})c^{\dagger}(p_{1})\alpha(p_{2})c^{\dagger}(p_{2})$$

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Time

Space distortion

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Space distortion

Magnetic Scenario: $\theta_{0i} = 0$
only space-sector distortions

Electric Scenario: $\theta_{0i} \neq 0$
also space-time mixing

Signature

Anti-/symmetric commutativity with a coefficient β

$$a^\dagger \left|0\right\rangle = \left|1\right\rangle \quad a^\dagger \left|1\right\rangle = \beta \left|2\right\rangle \quad a^\dagger \left|2\right\rangle = 0$$

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$$\delta^2 \propto \frac{1}{\Lambda^2}$$ ← distortion Energy Scale

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How about so far?

- **Ramberg and Snow (1988):** $\beta^2/2 \lesssim 10^{-26}$
- **DAMA (2009):** $\beta^2/2 \lesssim 10^{-47}$
- **Borexino (2011):** $\beta^2/2 \lesssim 10^{-60}$

Models scenarios implications

❑ Democratic scenario

all type of particles have the same degree of violation β

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Models scenarios implications

☒ **Democratic scenario**

all type of particles have the same degree of violation β

☐ **Despotic scenario**

each type of particle has its degree of violation β_i

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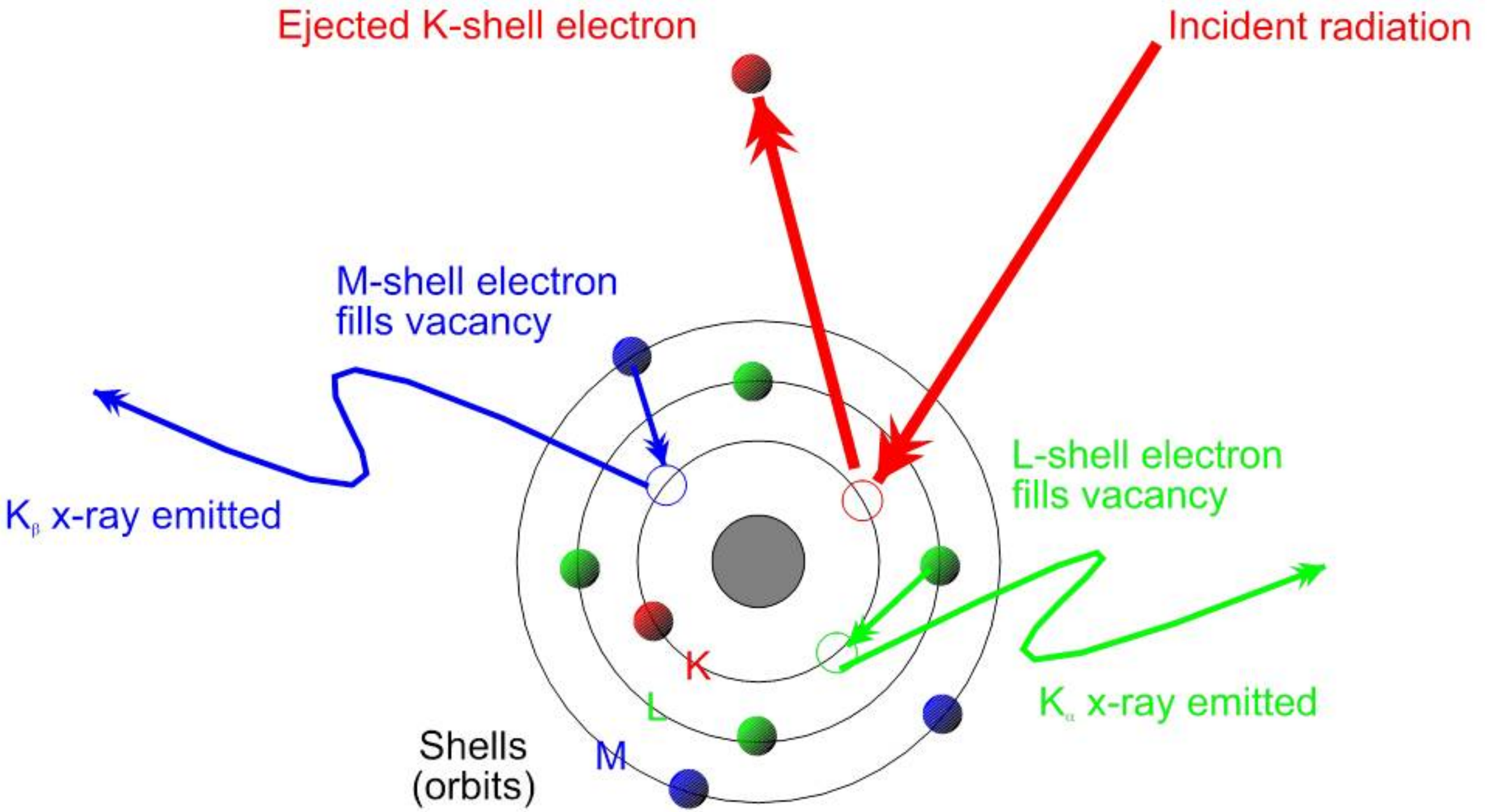
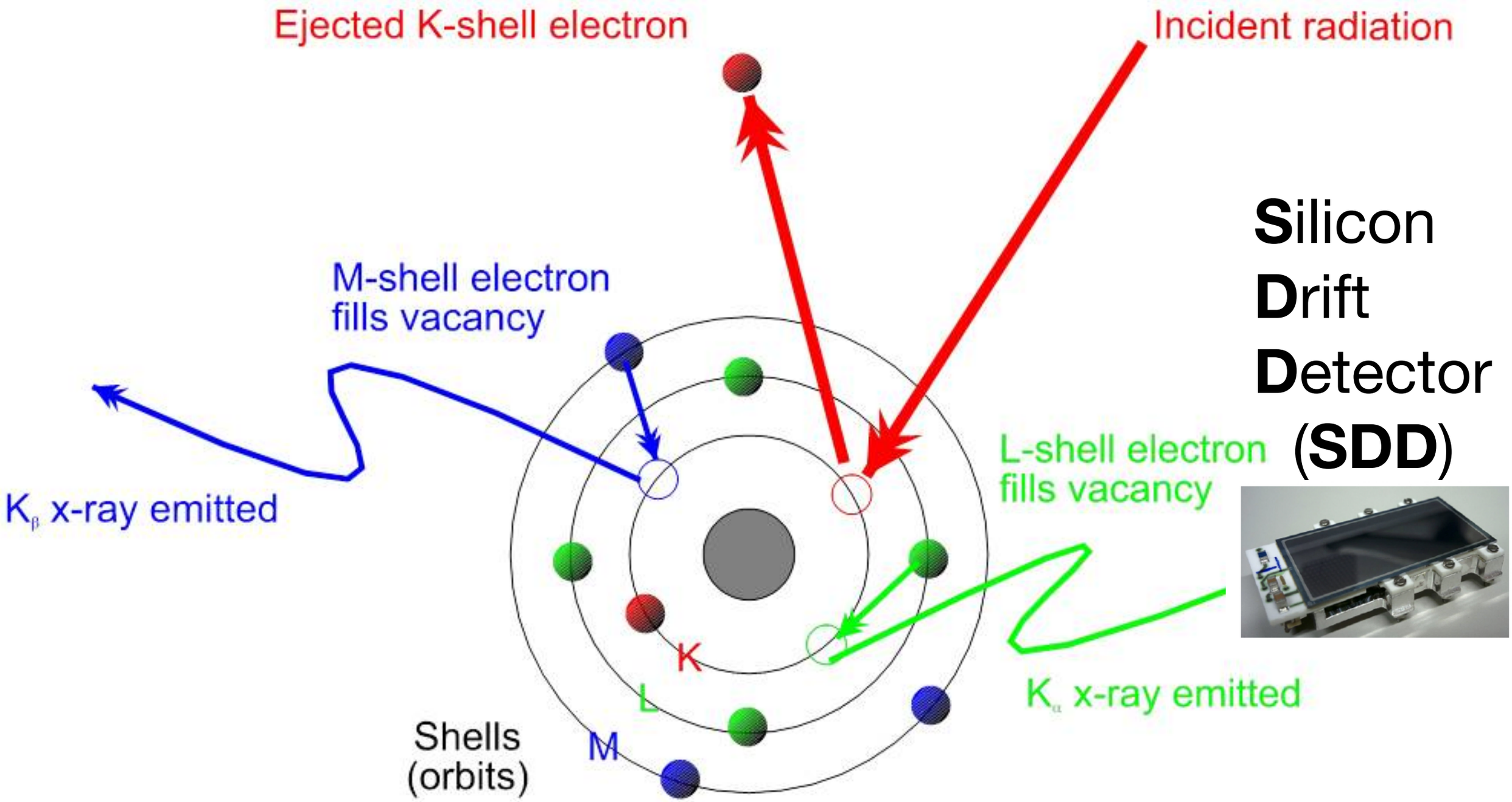
X-Rays

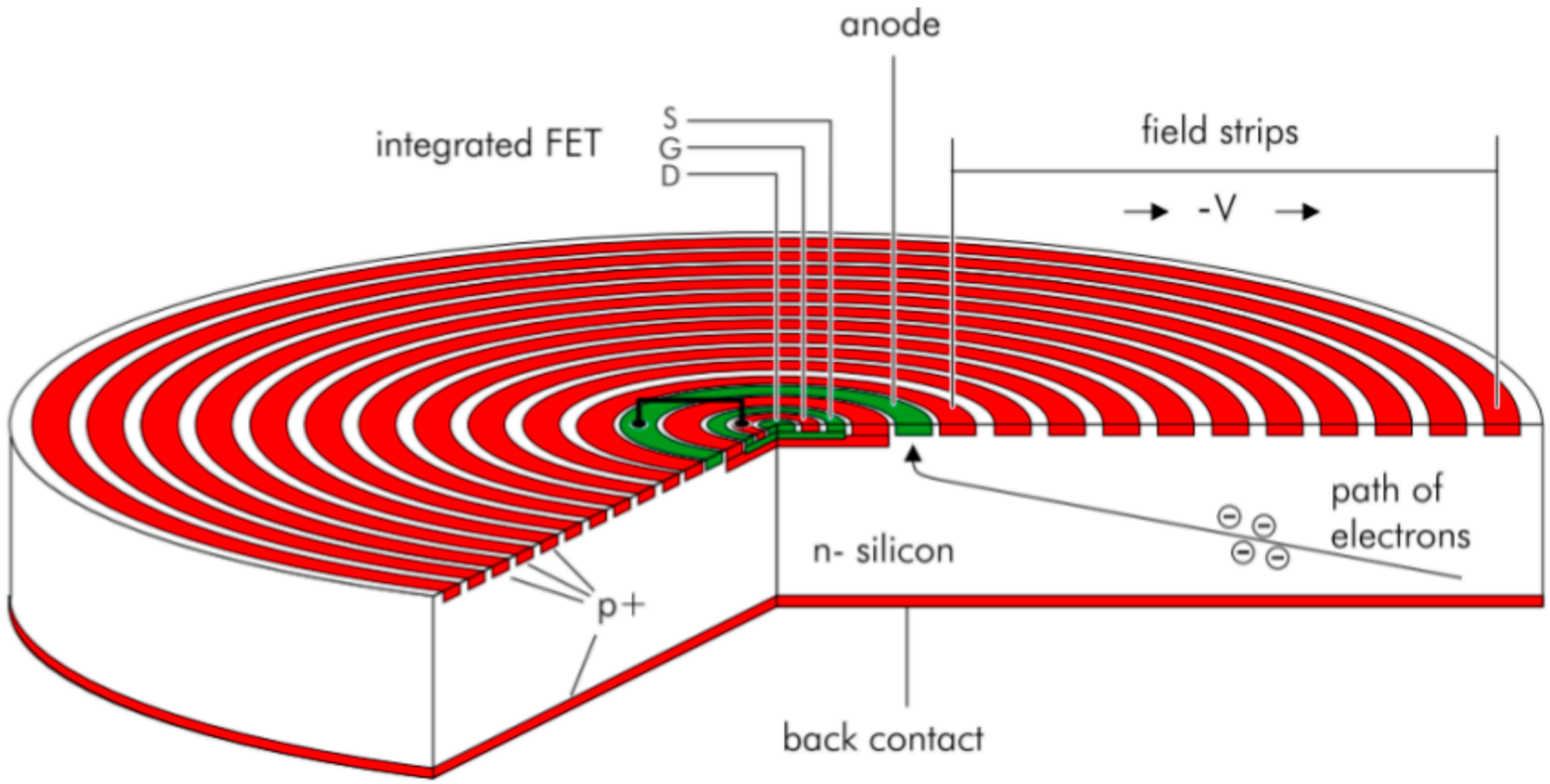

Ejected K-shell electron
Incident radiation
M-shell electron
fills vacancy
L-shell electron
fills vacancy
K_β x-ray emitted
K_α x-ray emitted
K
L
M
Shells
(orbits)

X-Rays



Silicon
Drift
Detector
(**SDD**)

SDDs



- Based on sideward depletion
- Charge particle or photon hits the silicon wafer
  - electron-hole pairs are generated
  - free electrons move to the anode following the lower potential due to the concentric electrodes
- The amount of charge collected by the anode is proportional to the energy of the radiation (X-Rays range)

VIP group

VIolation of **P**auli Exclusion Principle

Open Systems

testing newly injected electrons

- **VIP**
  - **VIP-2**
    - **VIP-3**
  - **GATOR**

Close System

testing spontaneous emissions

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VIP group

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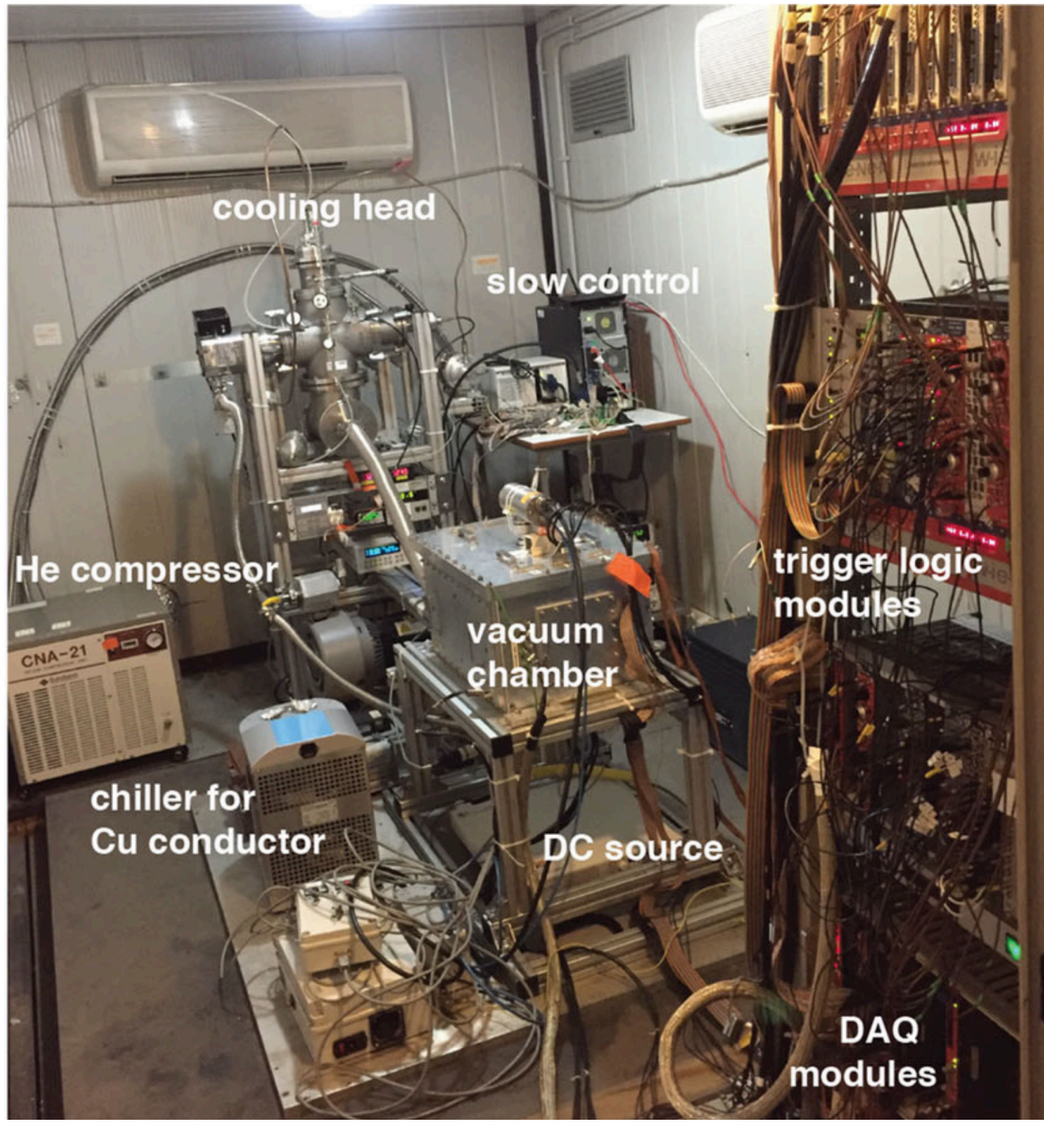
….but also

Wave Function Collapse (CSL, DP)

[see Kristian Piscicchia's talks]

VIP-2



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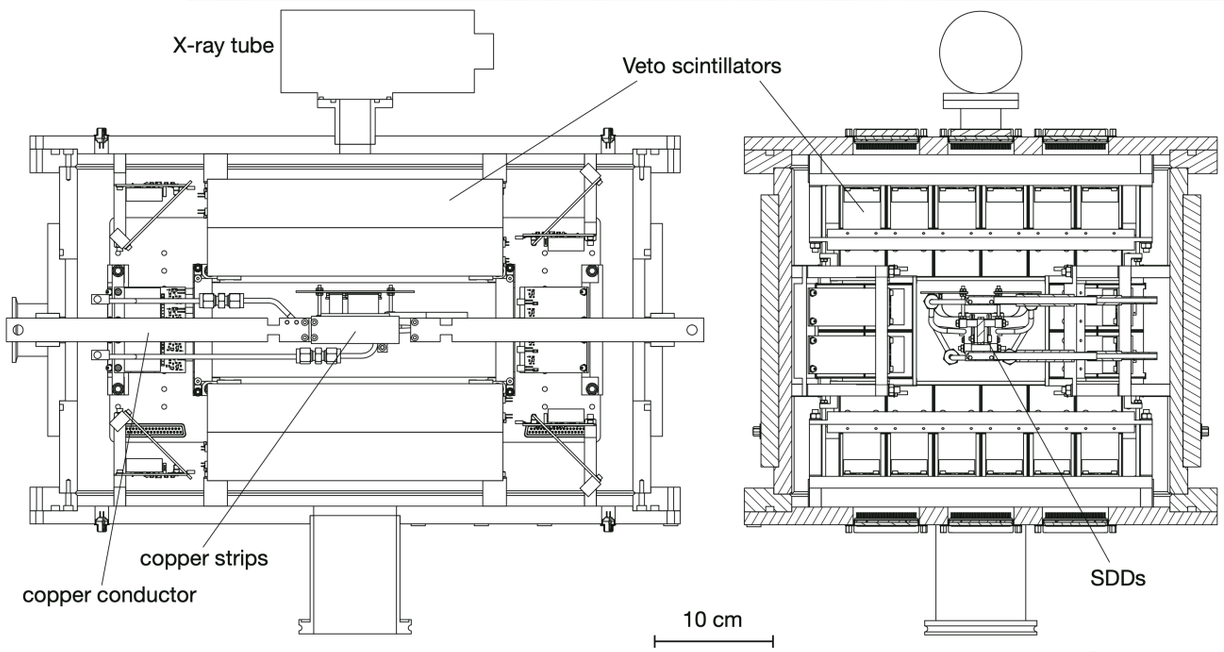

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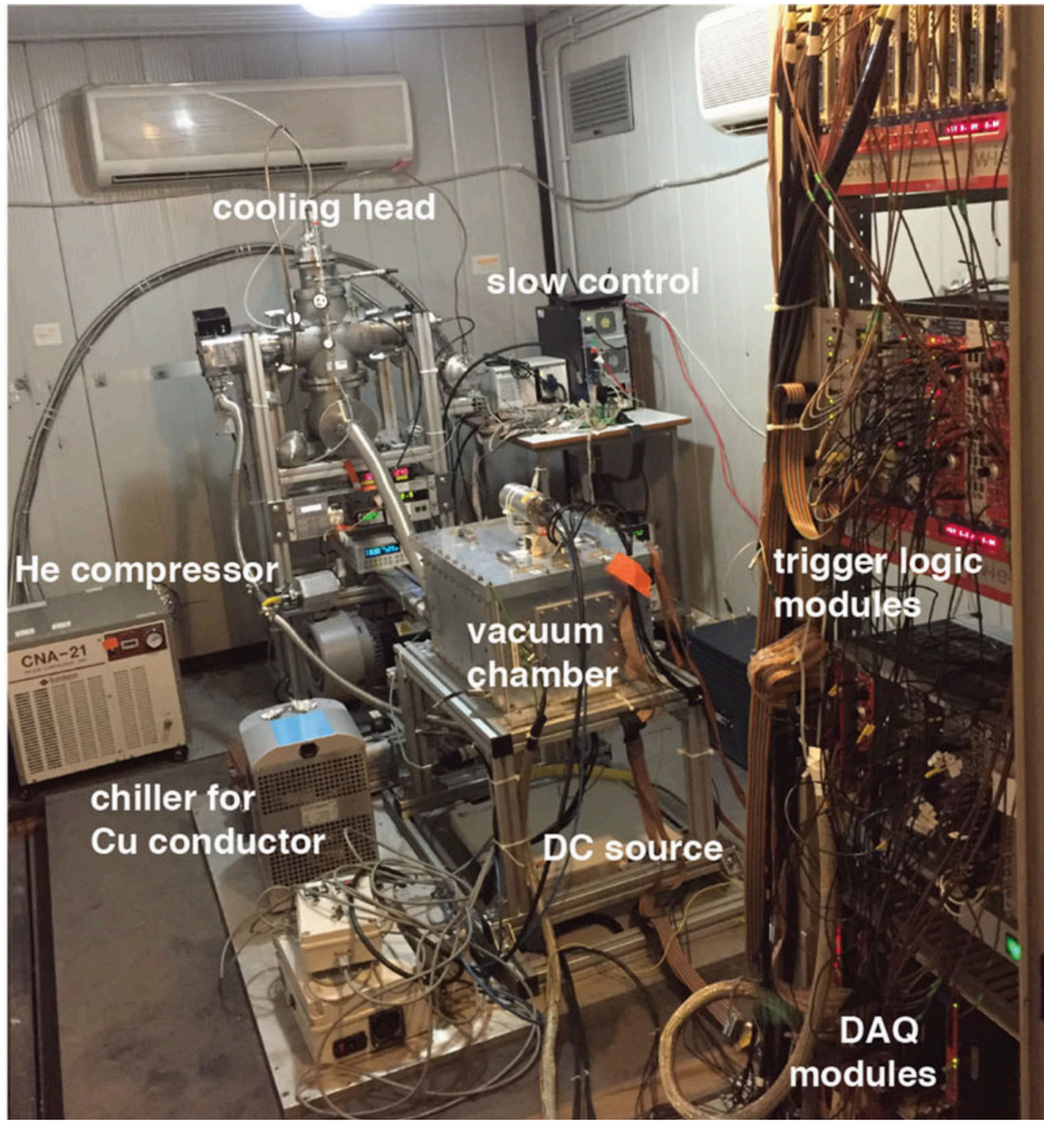
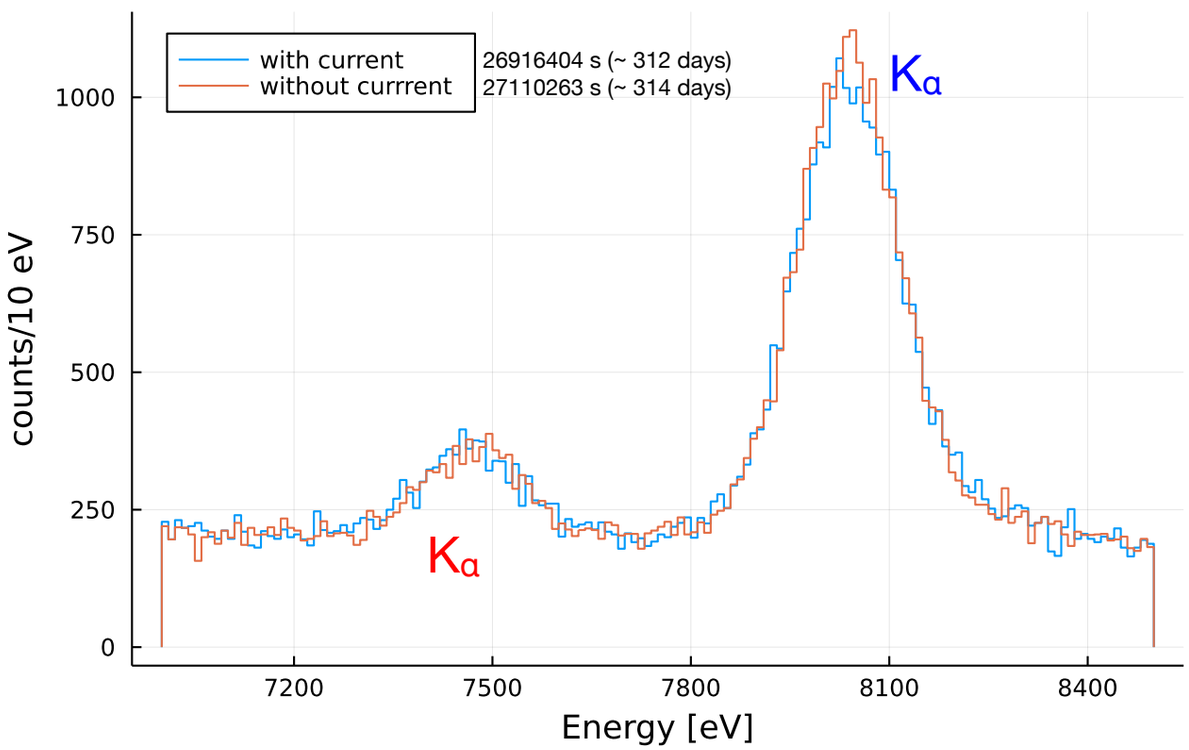
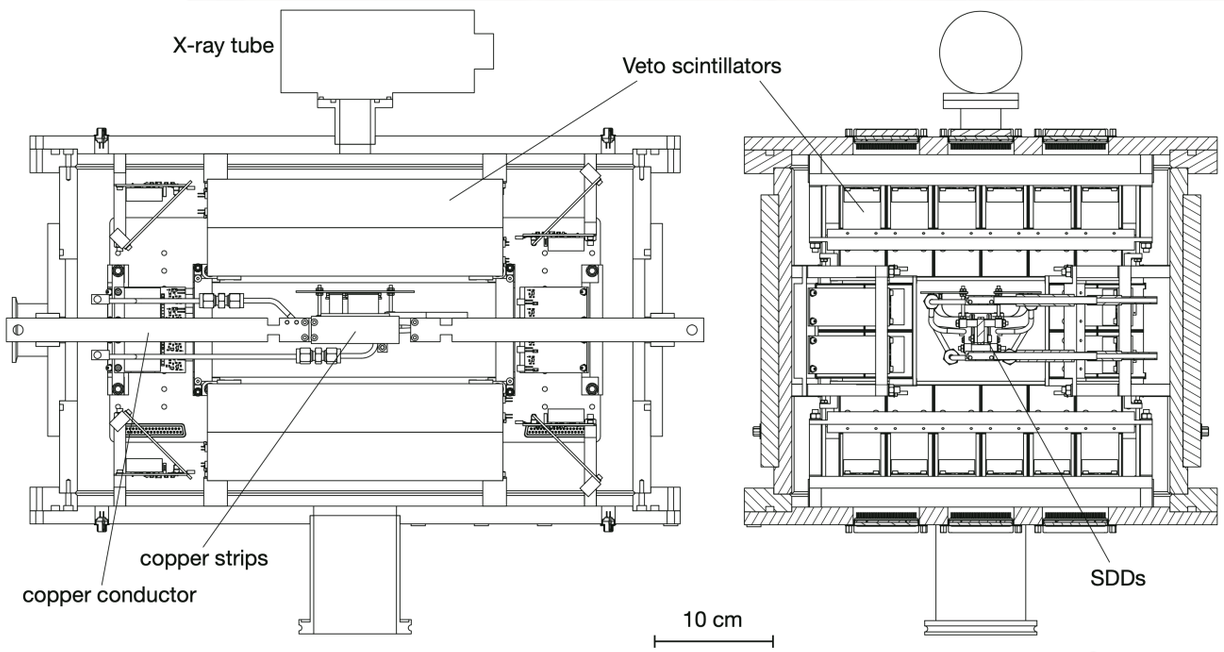
- **Target**: Copper strips
  - **WITHOUT CURRENT** configuration: regime case (stable states: background)
  - **WITH CURRENT** configuration (180 A): dynamic case (PEP violation through electron capture)
- **SDD**: 32 detectors by SDDs, stably kept @ -170^{+1}_{-0} °C even with the current in Cu
- **@LNGS Underground** (beneath Gran Sasso Mountain – IT): ~1400 m of rock shielding







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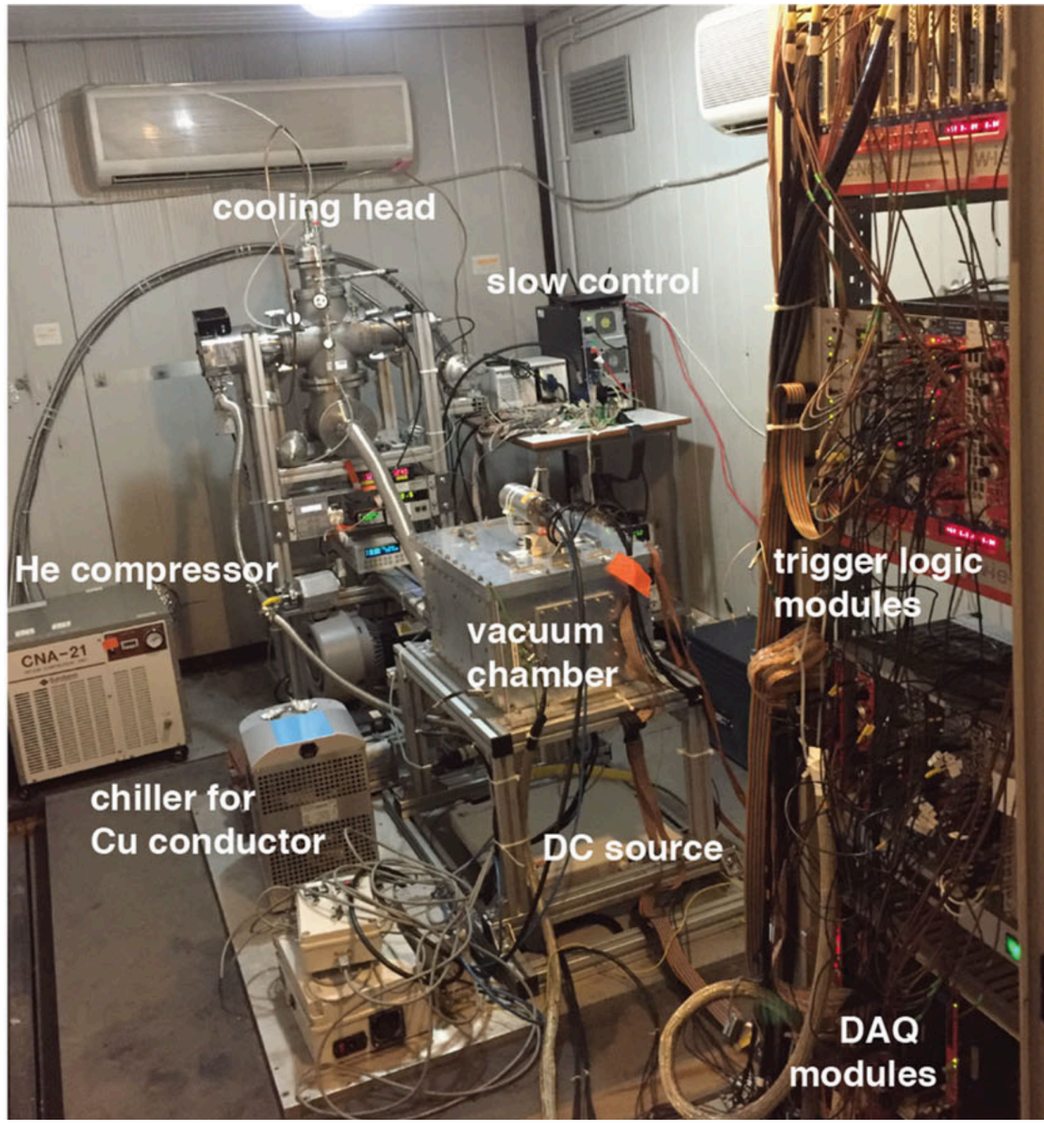

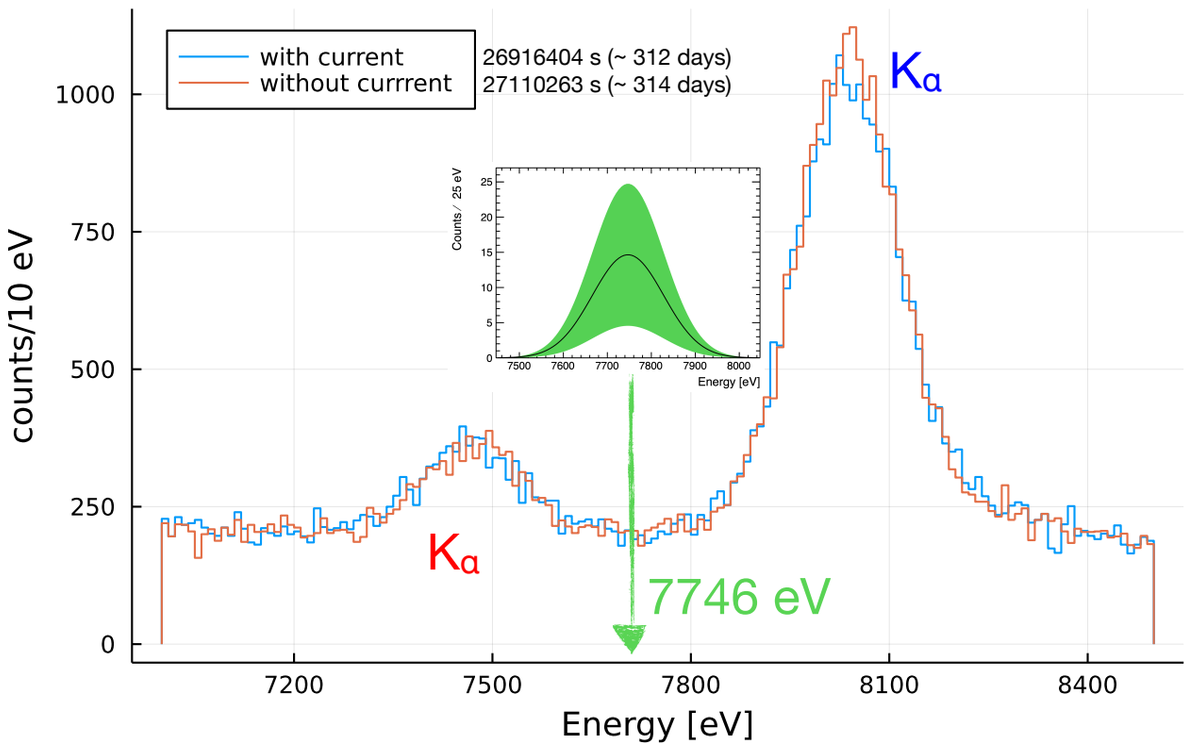

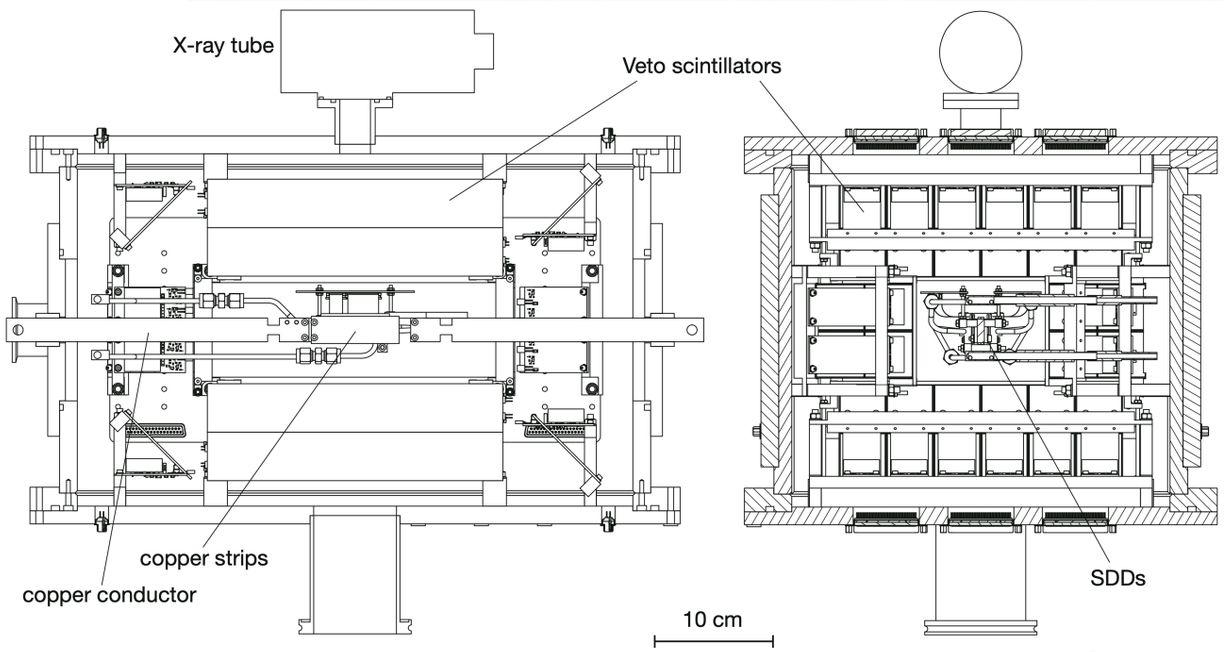

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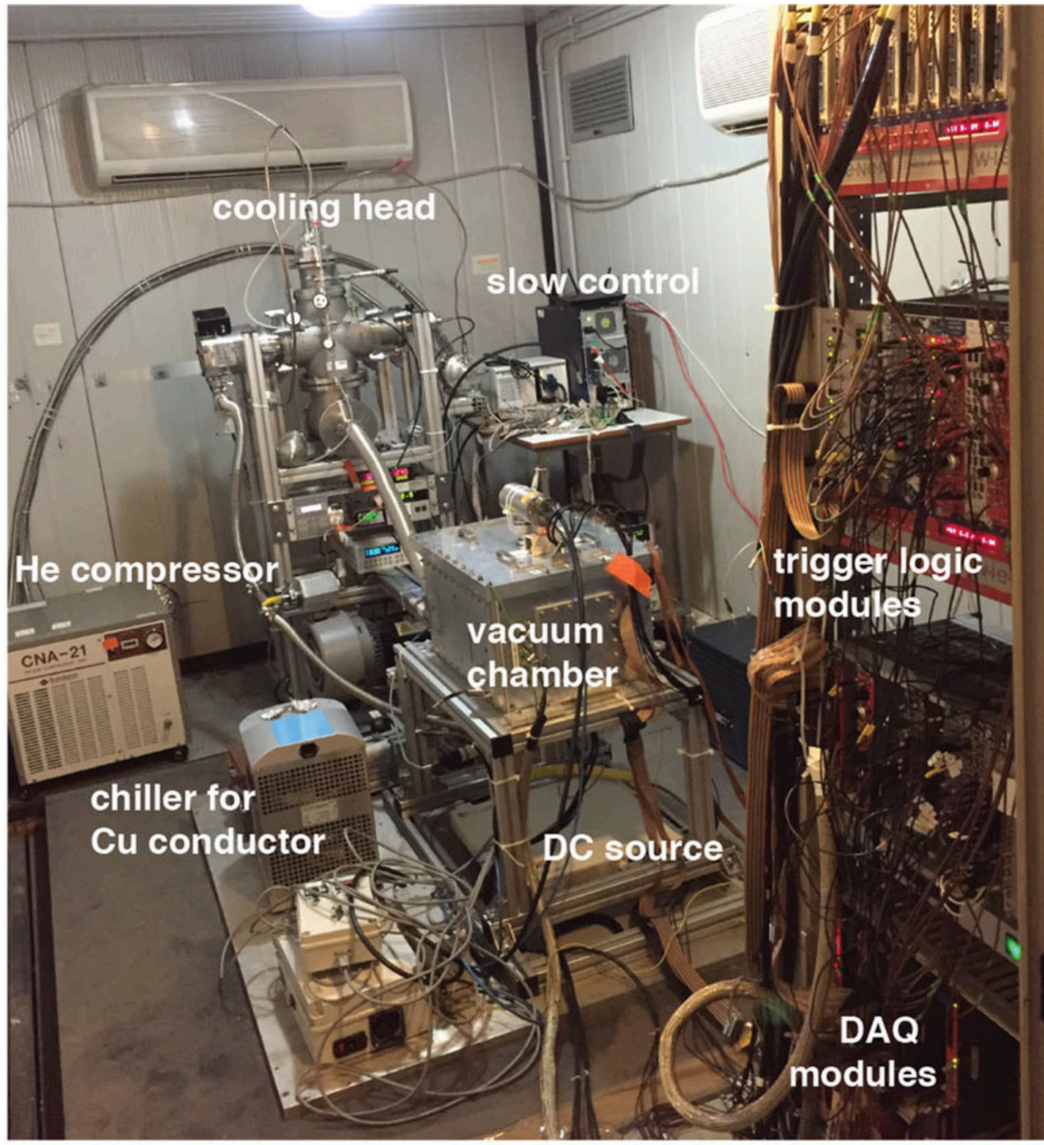
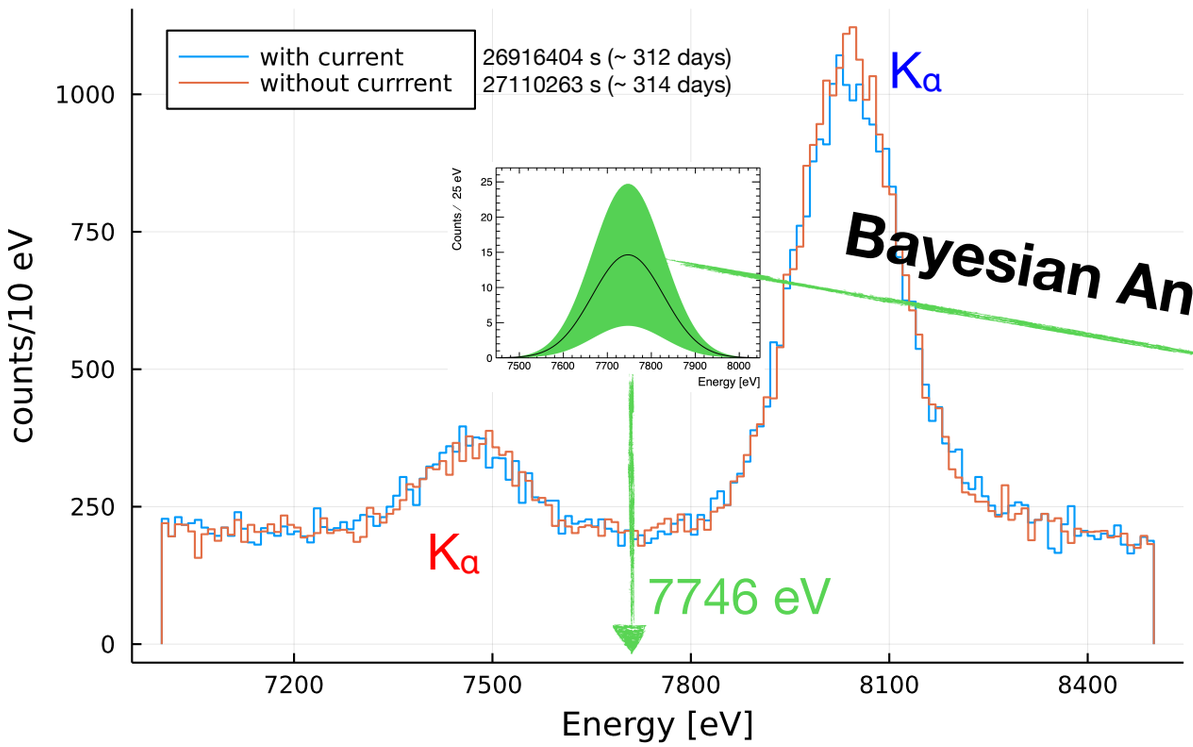
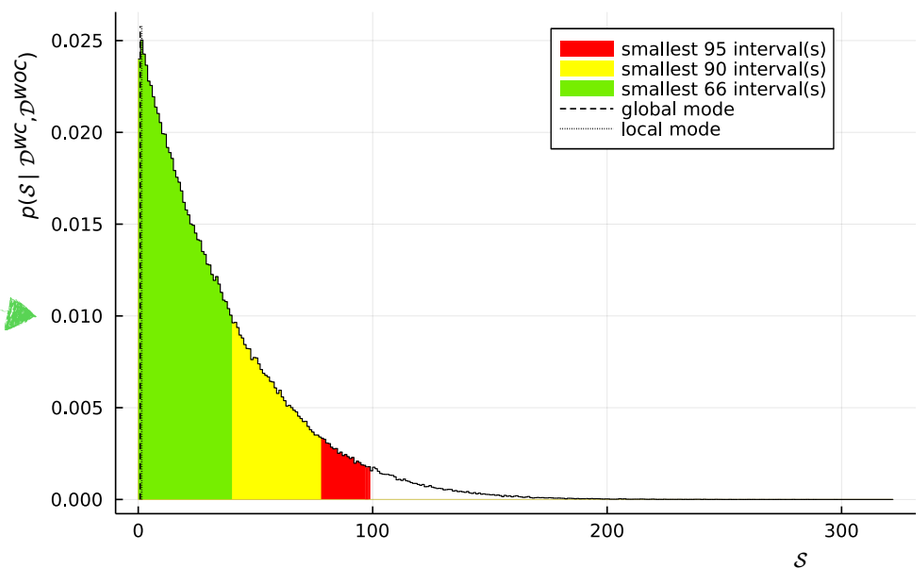




Bayesian Analysis



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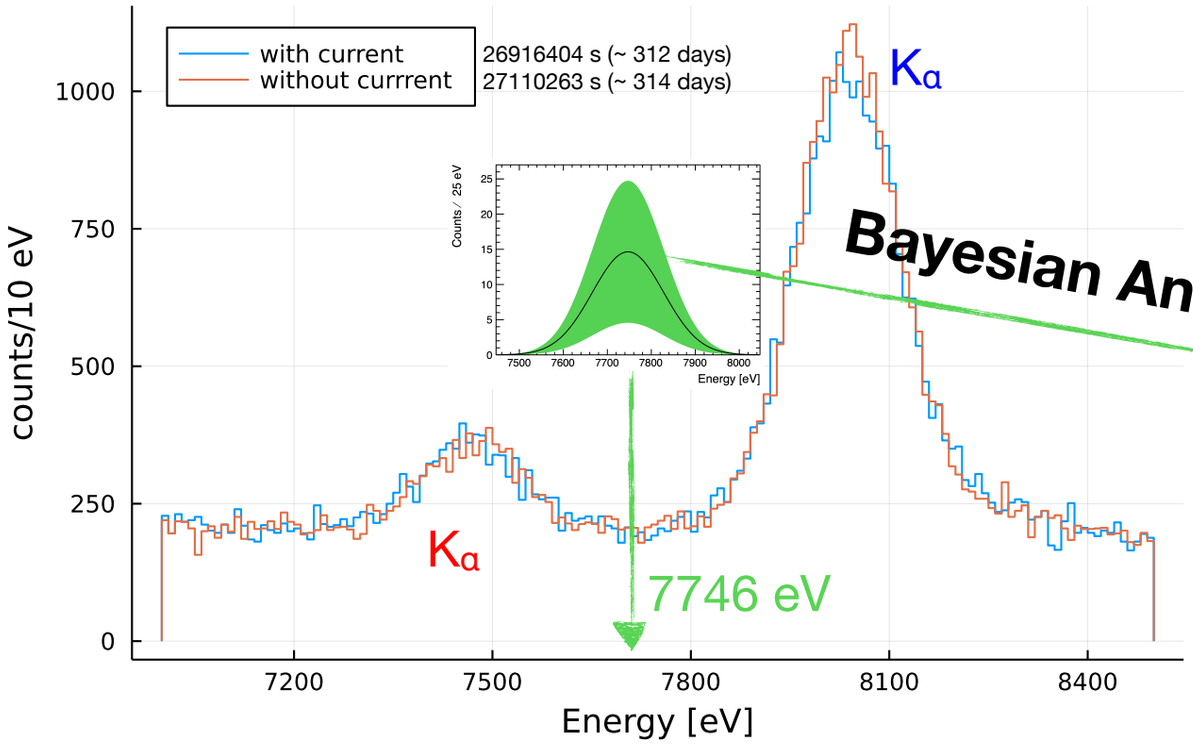

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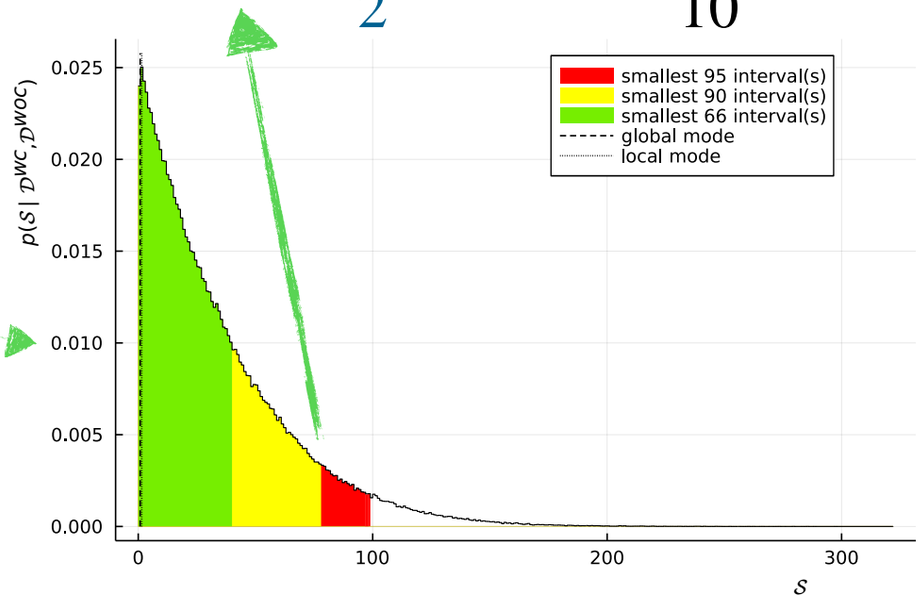
$$\mathcal{S} \simeq \frac{\beta^2}{2} \cdot N_{\text{new}} \cdot \frac{N_{\text{int}}}{10} \cdot 7.25 \times 10^{-2}$$



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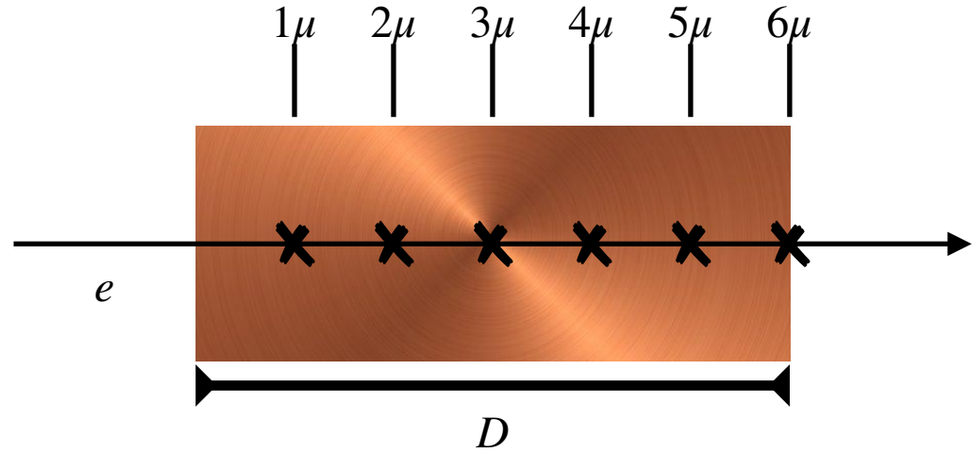
Linear Scattering
based on copper resistance



$$\frac{\beta^2}{2} \lesssim 10^{-31}$$

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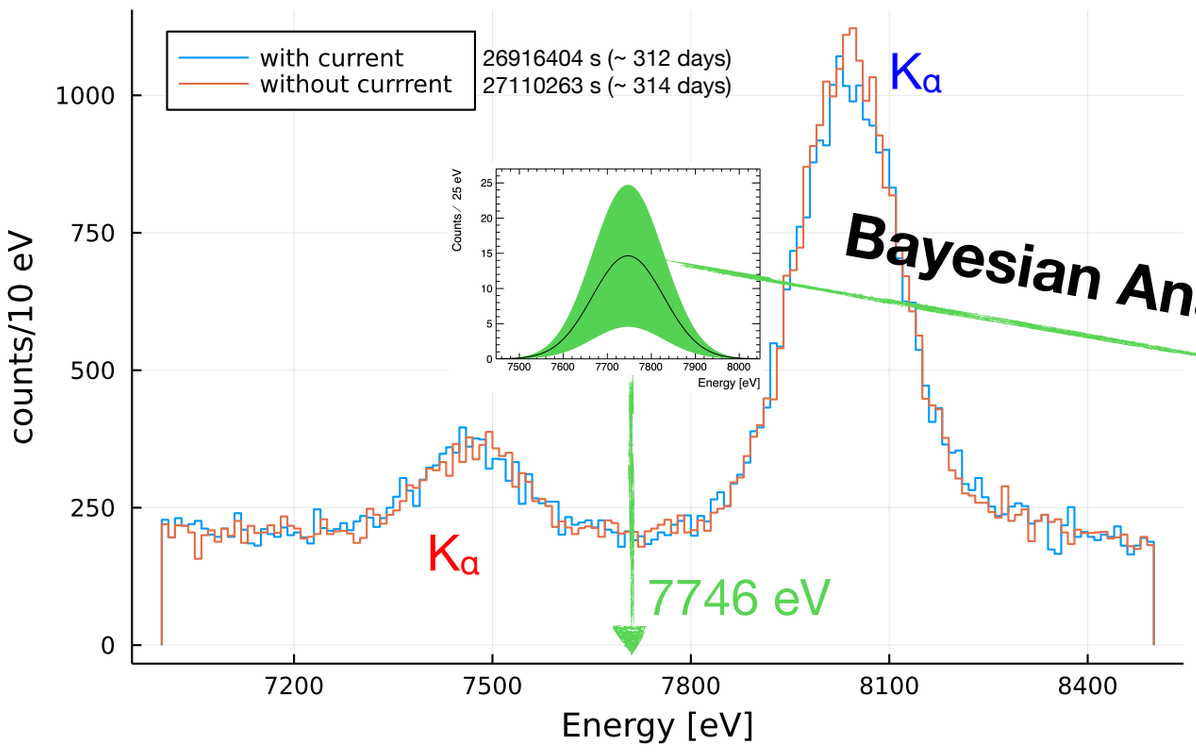
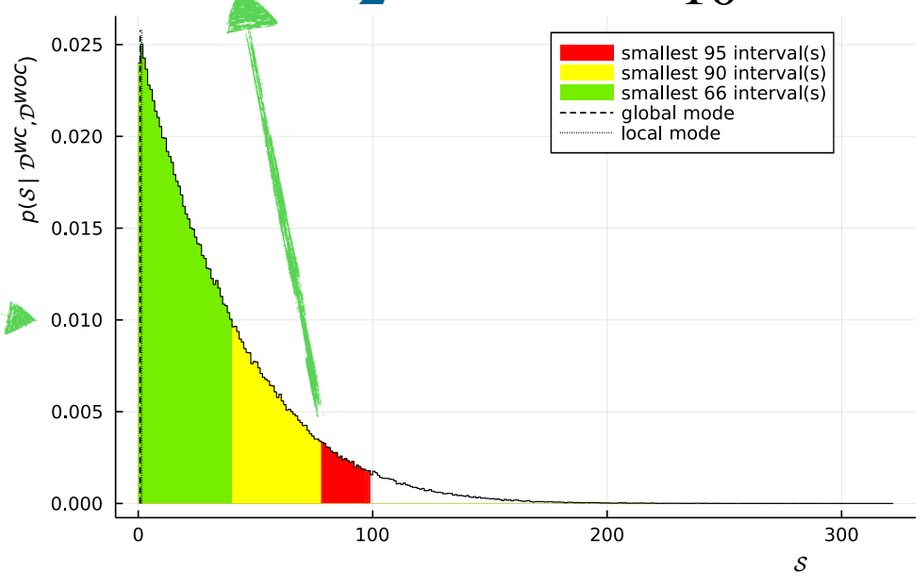


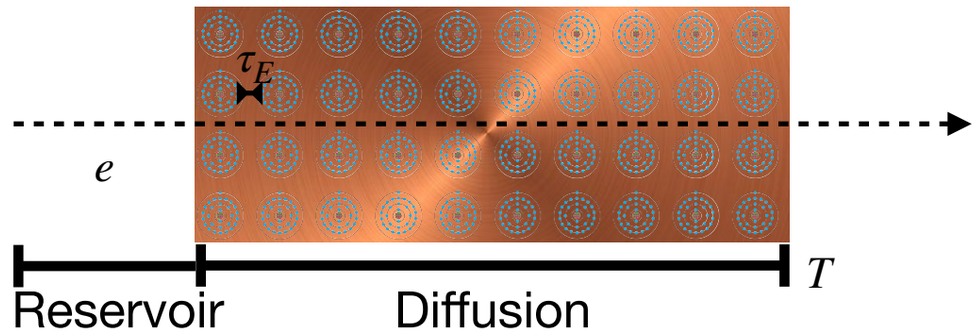
Bayesian Analysis



VIP-2

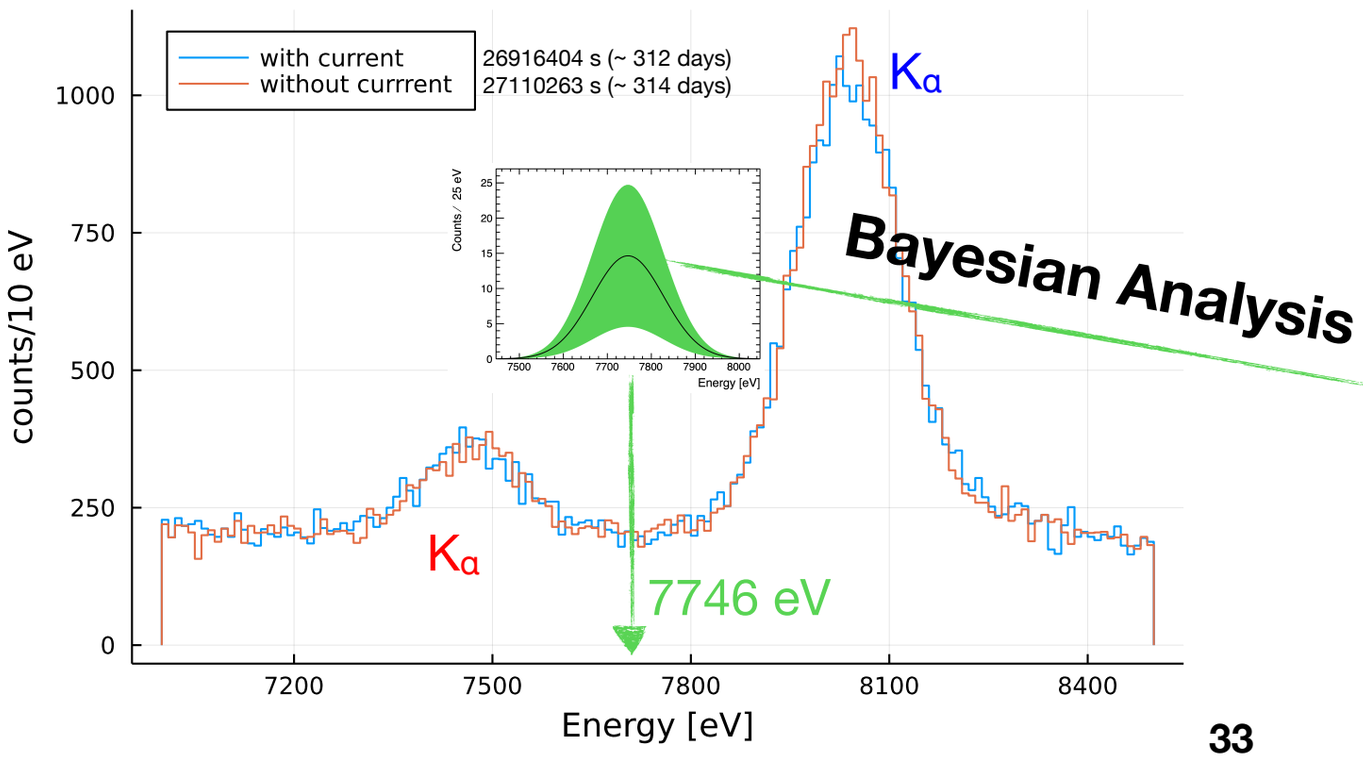
- **Target**: Copper strips
  - **WITHOUT CURRENT** configuration: regime case (stable states: background)
  - **WITH CURRENT** configuration (180 A): dynamic case (PEP violation through electron capture)
- **SDD**: 32 detectors by SDDs, stably kept @ -170^{+1}_{-0} °C even with the current in Cu
- **@LNGS Underground** (beneath Gran Sasso Mountain – IT): ~1400 m of rock shielding

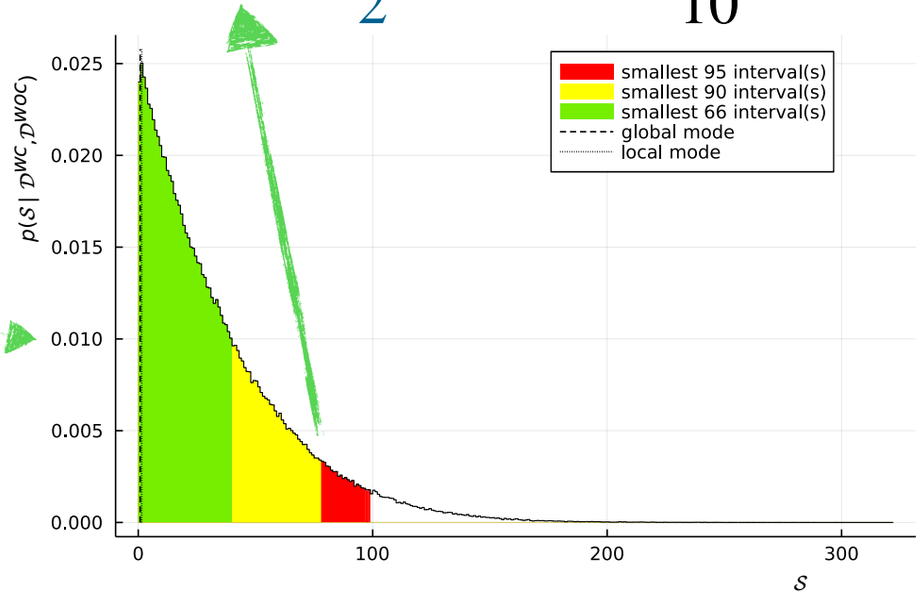
Linear Scattering
based on electrons
Diffusion-Transport theory



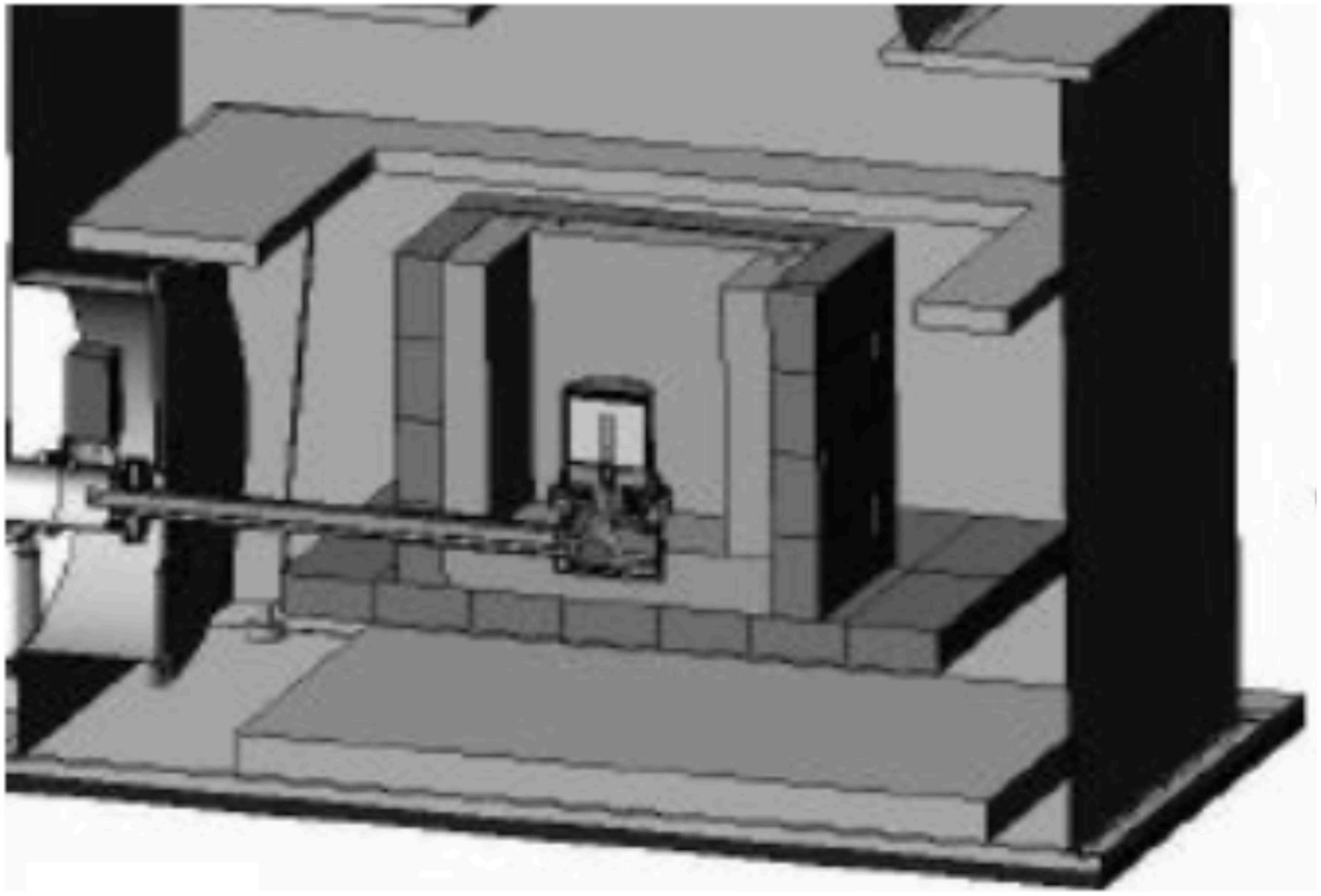
$$\frac{\beta^2}{2} \lesssim 10^{-43}$$

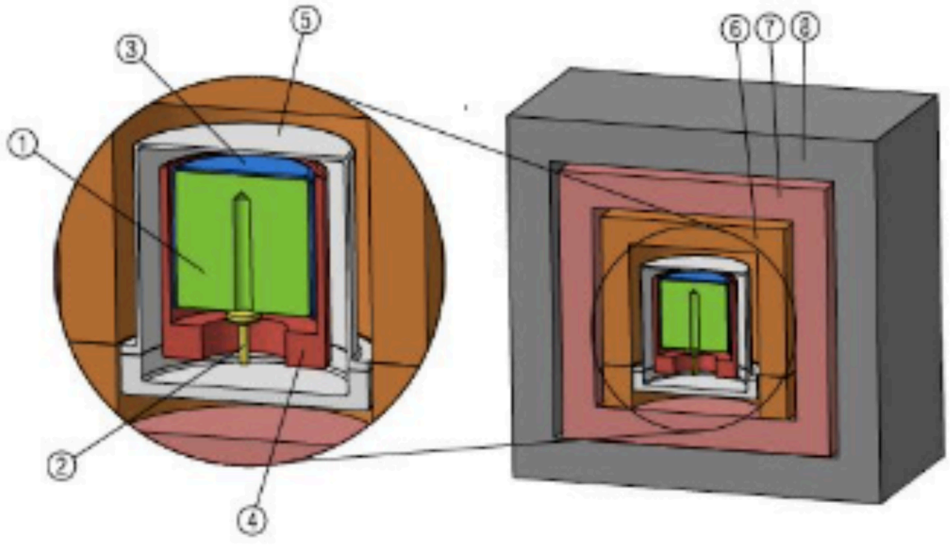
$$\mathcal{S} \simeq \frac{\beta^2}{2} \cdot N_{\text{new}} \cdot \frac{N_{\text{int}}}{10} \cdot 7.25 \times 10^{-2}$$





VIP-Lead



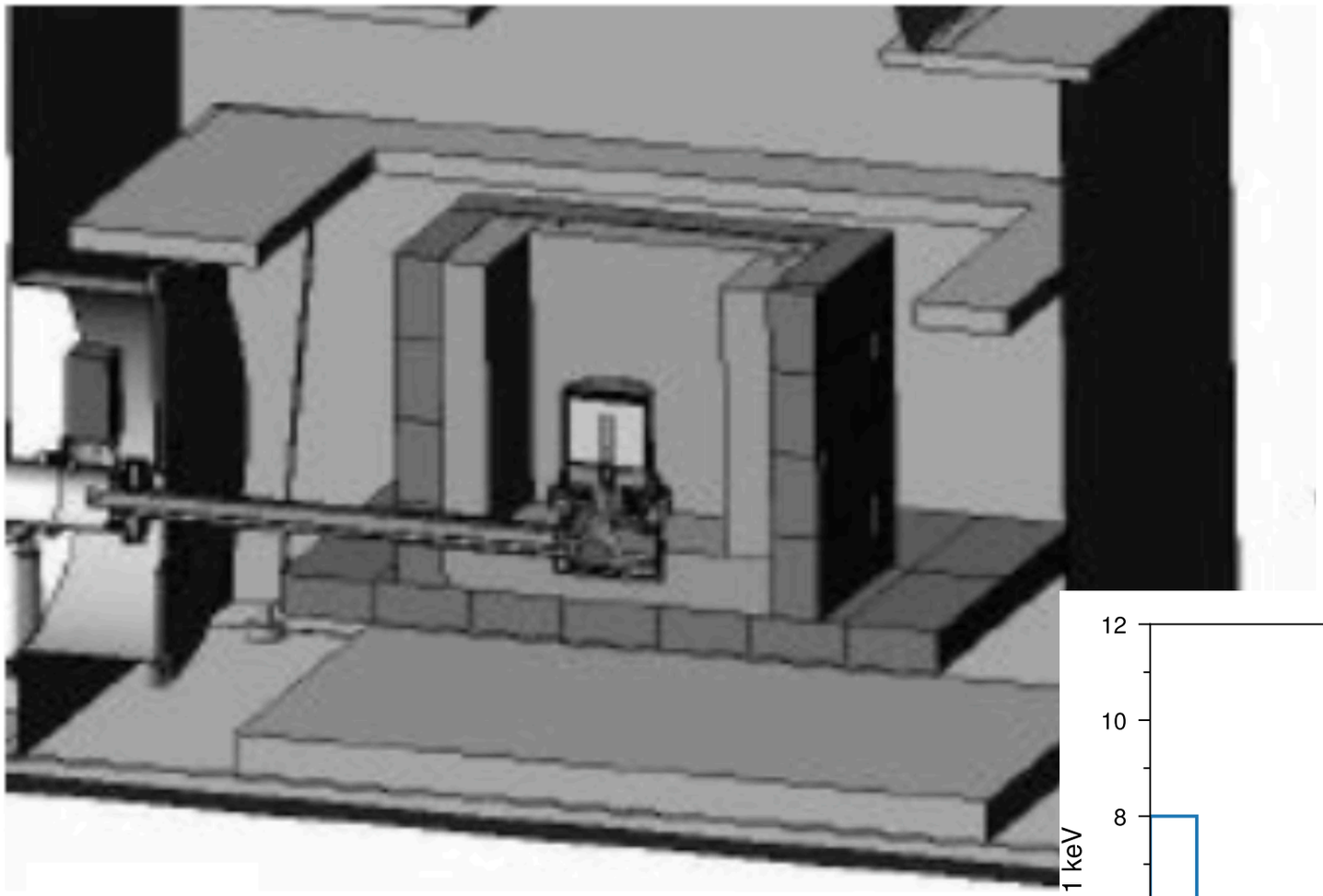


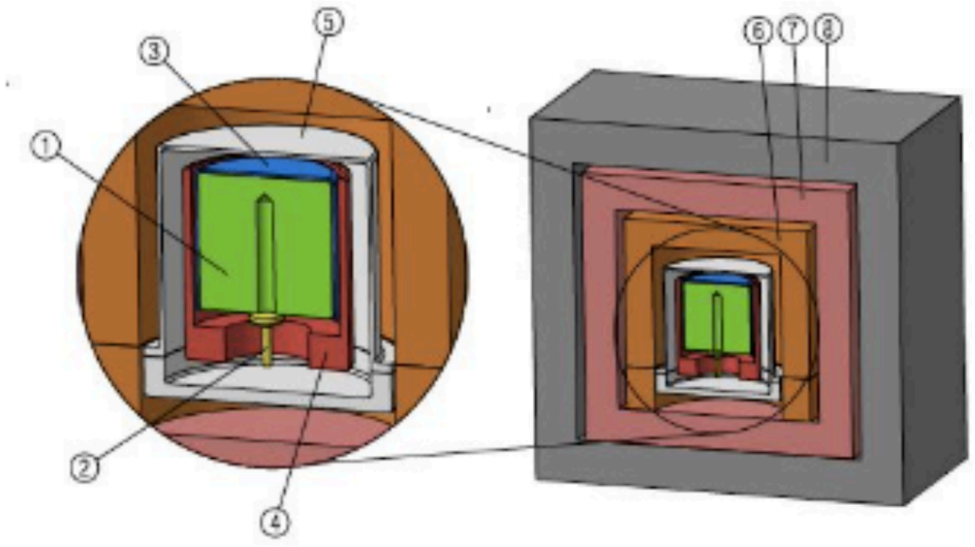
Close System

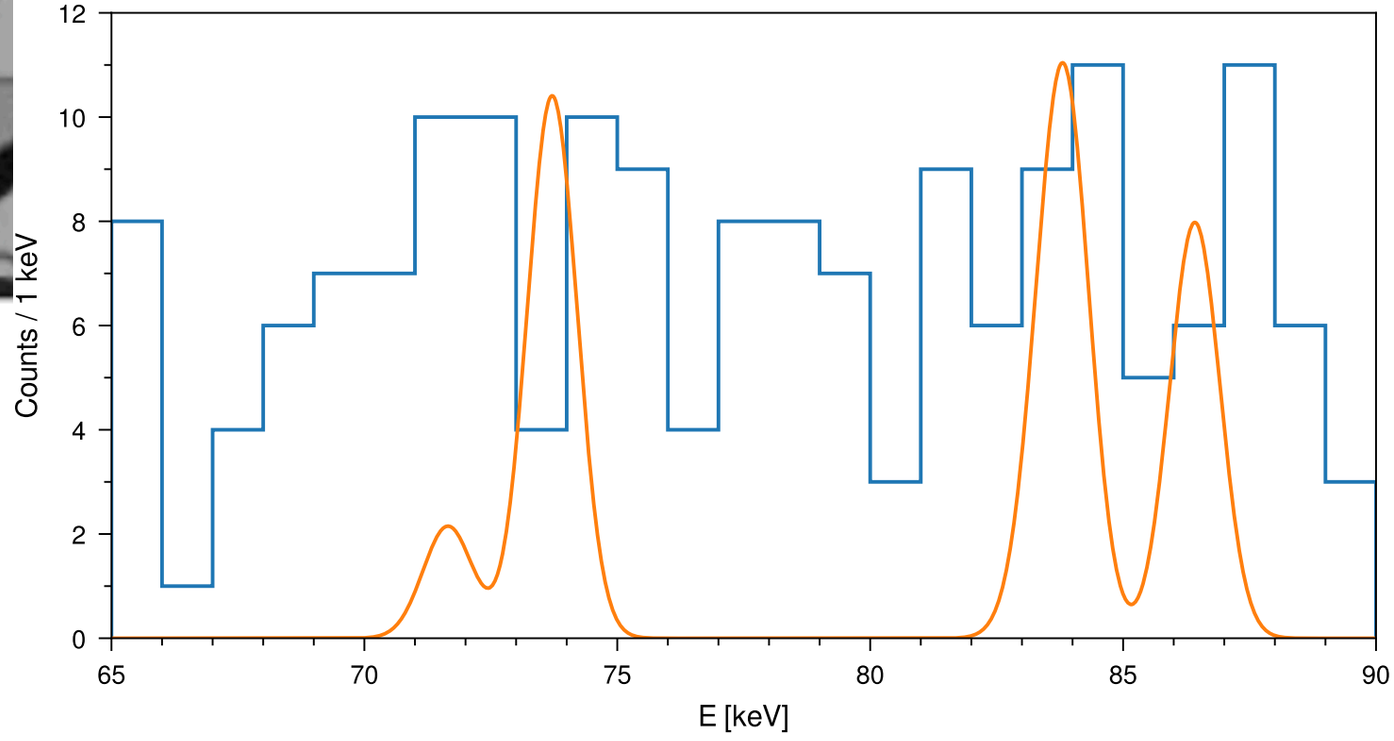
testing spontaneous emissions

VIP-Lead *NCQG* **BEGe**

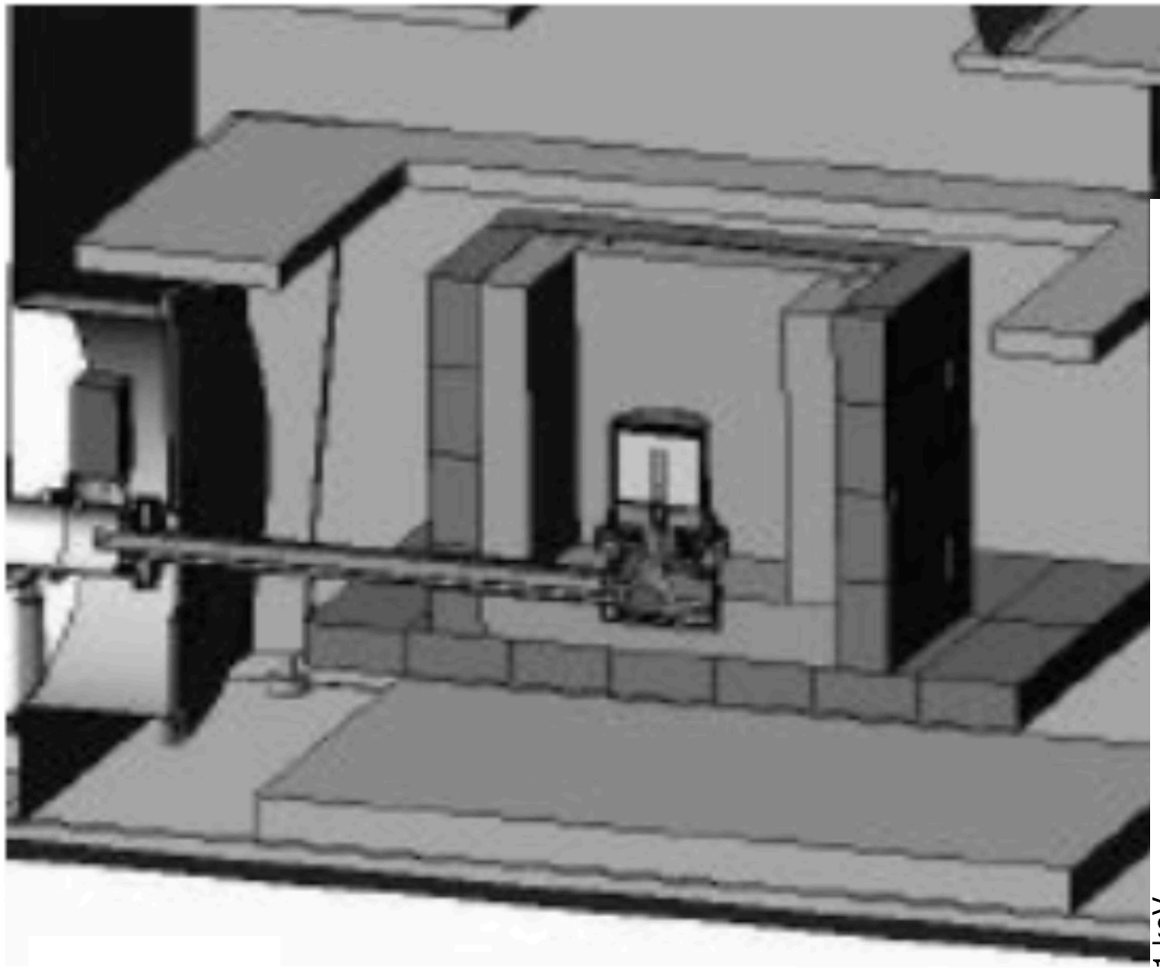
VIP-Lead

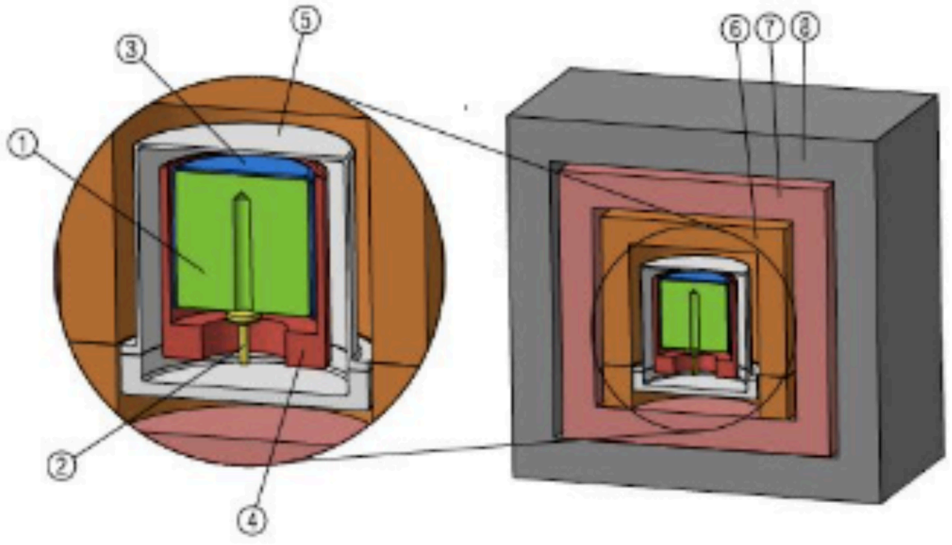






VIP-Lead

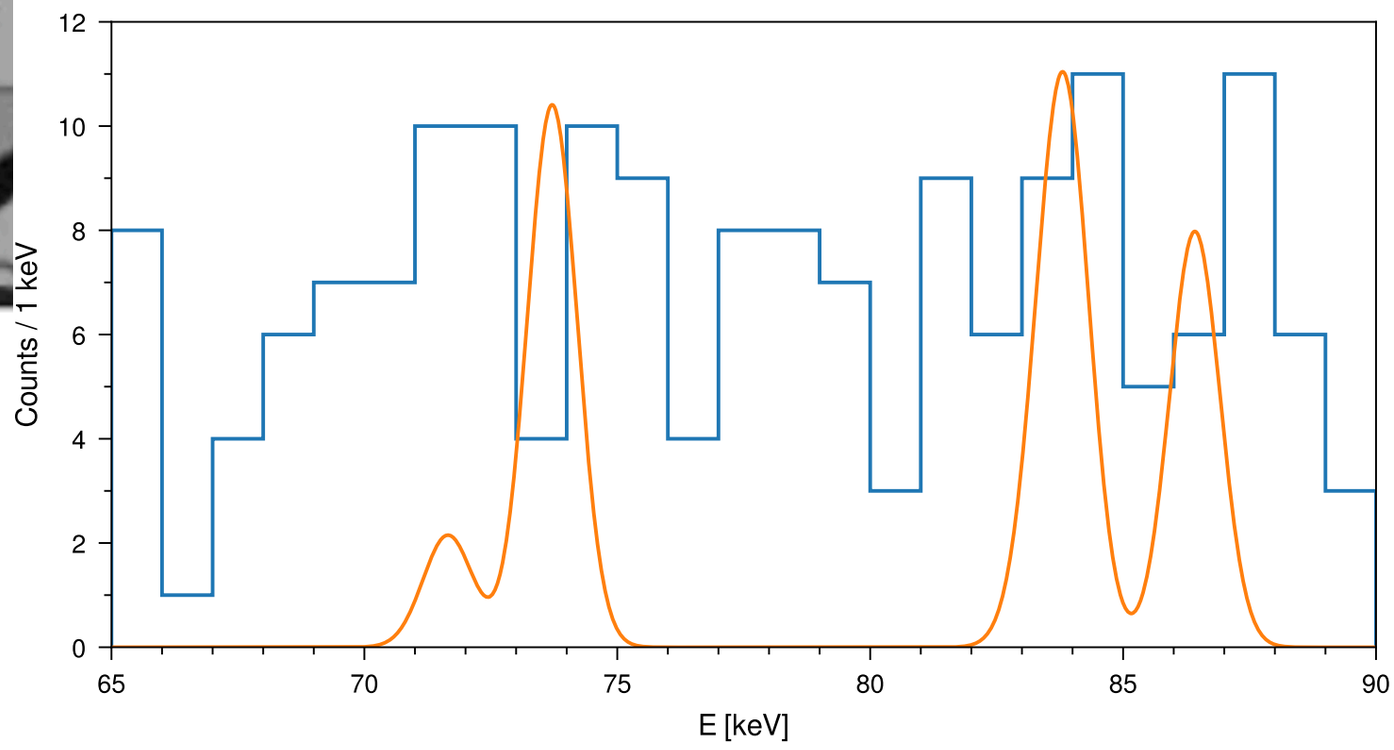




@ 90% CL

θ_{0i}	$\bar{S}$	**lower limit on Λ (Planck scales)**
$\theta_{0i} = 0$	13.2990	$6.9 \cdot 10^{-2}$
$\theta_{0i} \neq 0$	18.1515	$2.6 \cdot 10^{2}$

[Phys. Rev. Lett. **129** (2022), 131301]



[under revision for Universe]

Outlook

Beyond Standard Models can be tested with X-Rays through the Pauli's Exclusion Principle Violation (PEPV)

Open system:

- VIP (past), **VIP-2 (current)**, and VIP-3 and GATOR (future)
  - **Rigorous Data Analysis** (Bayesian inference)
  - Need for better **Electron-atoms interaction modeling (N_{int})**

Close system:

- BEGE, **VIP-Lead**
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  - **Exclusion of the Electric Scenario** and strong **constraint over the Magnetic Scenario**

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THANK YOU