Towards the optimal performance of Mazinger, a shallow γ-ray spectrometry system of high efficiency and very-low-level background, devoted to $^{210}\mathrm{Pb}$ and U-Th dating for paleoclimatic applications

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Outline

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Introduction

- **What?**: Need of **absolute dating methods** based on precise radionuclide determination.
- **Why?**: Understand **climatic and anthropogenic effects** throughout Earth's history.
- **How?**: Develop and upgrade **Mazinger**[1]. A **very-low-level background** and **high-efficiency γ-ray spectrometry system** used for analyzing oceanic and lacustrine sediments.
- **Who** and **Where?**: Team of **Laboratorio de Radiaciones Ionizantes y Datación** (LRI-D) at the University of Salamanca.
- **Which?**: The upgraded Mazinger was validated through ^{210}**Pb** and ^{137}**Cs dating** of the **SOB22 sediment core** from Sobrado dos Monxes Lagoon (Galicia, Spain).

[1] Rivas-Gómez, R., Romero-Fuentes R., Quintana-Arnés B., Carballeira R., In Press. Towards the optimal performance of Mazinger, a shallow γ-ray spectrometry system of high efficiency and very-low-level background, devoted to 210Pb and U-Th dating for paleoclimatic applications. Applied Radiation and Isotopes 226.

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Mazinger: Spectrometer description

- Two **HPGe BEGe5030** detectors (Canberra) with ULB cryostats.
- Two **anti-Compton rings of NaI(Tl)** surrounding each HPGe detector.
- Two **anti-muon VETO detectors** outside the passive shielding
- **Passive shielding:** Cu (3 mm), old Pb (5 cm), Fe (10 cm, ^{60}Co-free).
- **Underground installation** to minimize cosmic radiation.
- Continuous $\mathbf{N_2}$ **flushing** (5 L/min) to reduce radon presence.
- Acquisition with a **XIA Pixie-4** digital pulse processor.

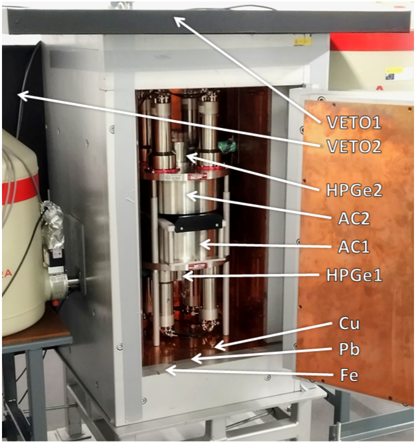

Figure: Picture of Mazinger showing passive and active shielding.

Mazinger: Electronics configuration

Mazinger evolution:

- **M0 configuration**: HPGe detectors + Passive shielding + anti-Compton active shielding + XIA Pixie-4 digital pulse processor.
- **M1 configuration**: M0 + VETO1 active shielding
- **M2 configuration**: M1 + VETO2 + acquisition electronics reconfiguration

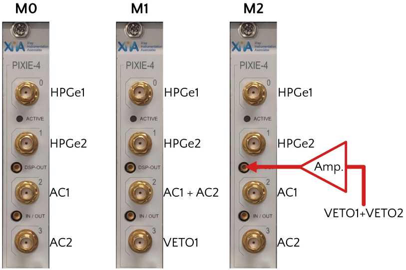

Figure: Schemes of detectors connection to Pixie-4 for each Mazinger's configuration.

Problem: Direct processing of VETO signals through Pixie-4 digitizer inputs caused efficiency loss. **Solution**: Acquisition electronics reconfiguration.

1. VETO signals amplification before entering Pixie-4 (coincidence window).
2. Amplified signals connected to the logical input port of Pixie-4.
3. Acquisition of HPGe and AC detectors is inhibited while the amplified VETO signals are >660 mV.

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Mazinger performance: FWHM

E (keV)	FWHM (keV)		
	HPGe1	HPGe2	Mazinger-M2
59.5409(1)	0.434	0.499	0.473
88.034(1)	0.493	0.554	0.528
122.06065(12)	0.549	0.604	0.580
136.47356(29)	0.561	0.622	0.597
165.8575(11)	0.610	0.676	0.654
391.698(3)	0.906	0.923	0.924
661.657(3)	1.107	1.145	1.147
834.848(3)	1.252	1.275	1.277
898.042(11)	1.334	1.368	1.352
1115.539(2)	1.413	1.444	1.452
1173.228(3)	1.444	1.479	1.488
1332.492(4)	1.544	1.575	1.586

Table: FWHM with M2 configuration.

Mazinger performance: Background

- BEGe5030: 0.86745(88) $\mathrm{s^{-1}kg^{-1}}$
- M0: 0.60668(36) $\mathrm{s^{-1}kg^{-1}}$
- M1: 0.36228(22) $\mathrm{s^{-1}kg^{-1}}$
- M2: 0.22027(23) $\mathrm{s^{-1}kg^{-1}}$

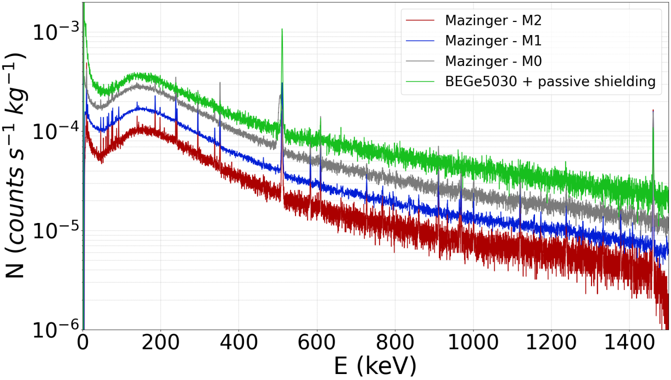

Figure: Comparison of background spectra between our BEGe5030 with a passive shielding and Mazinger's configurations

Mazinger performance: Efficiency

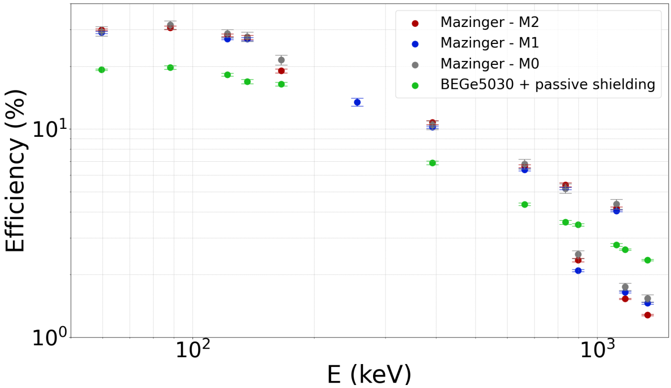

Figure: Comparison of detection efficiency between our BEGe5030 and Mazinger's configurations (without True Coincidence Summing Corrections)

Mazinger performance: Figure Of Merit

$$FOM = \frac{\varepsilon^2}{4 \cdot \text{Background}}$$

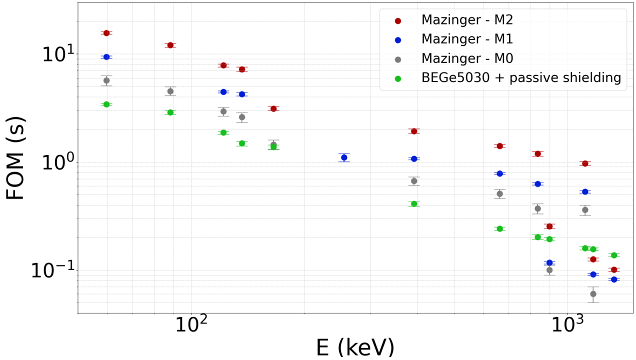

Figure: Comparison of Figure Of Merit between our BEGe5030 and Mazinger's configurations

SOB22 sediment core analysis and dating: ^{210}Pb dating

$$^{210}Pb_{ex} = ^{210}Pb - ^{210}Pb_{sup} \equiv ^{210}Pb - ^{226}Ra$$

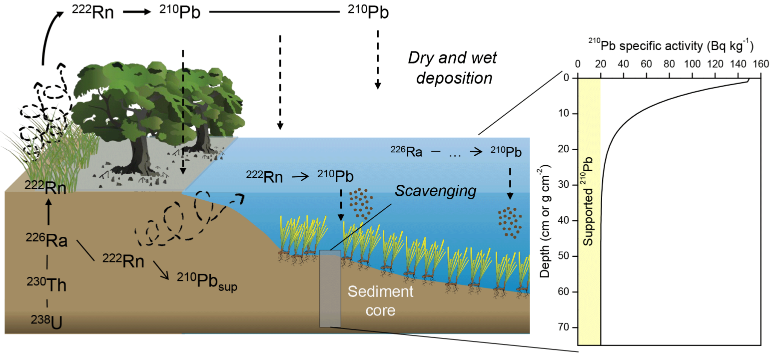

Figure: ^{210}Pb natural cycle. (https://doi.org/10.5194/bg-15-6791-2018).

SOB22 sediment core analysis and dating: CRS model

Model assumptions:

- Constant $^{210}Pb_{ex}$ flux
- Variating sedimentation rates

$$t_{CRS}(i) = \frac{1}{\lambda_{Pb_{210}}} \ln\left(\frac{I_{0\to\infty}}{I_{i\to\infty}}\right) \quad \text{(yr)}$$

$$I_{i\to\infty} = \sum_{k=i}^{\infty} \Delta I_k \quad (\mathrm{Bq/m^2})$$

$$\Delta I_k = a_k(^{210}Pb_{ex}) \cdot \frac{\Delta m_k}{S} \quad (\mathrm{Bq/m^2})$$

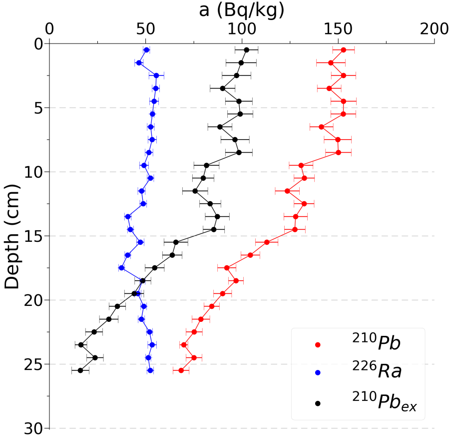

Figure: Depth profiles of ^{210}Pb, ^{226}Ra and $^{210}Pb_{ex}$ activities.

SOB22 sediment core analysis and dating: age model

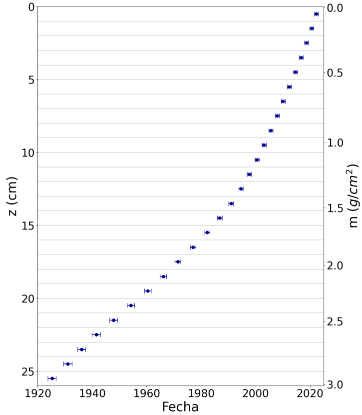

Figure: Age model obtained applying CRS model to data

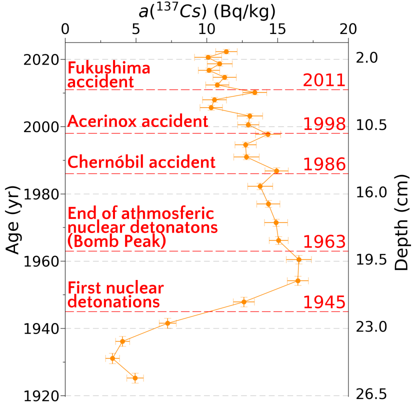

Figure: Depth profiles of ^{137}Cs activity and nuclear events.

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Conclusion

- The Mazinger γ-ray spectrometer, equipped with two HPGe detectors and both passive and active shielding, is described following its recent upgrade.
- The reconfigured acquisition electronics improved measurement quality.
- The new active shielding reduced the continuum background by a factor of four compared to a single detector.
- The FOM increased by a factor of five, especially when source geometries adapted to Mazinger were used.
- The determination of $^{210}\mathrm{Pb}$, $^{226}\mathrm{Ra}$, and $^{137}\mathrm{Cs}$ in recent sediments demonstrates Mazinger's suitability for high-precision chronological and paleoclimate studies.

Thank you!

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