Preliminary results of a Skipper-CCD inside a nuclear power plant

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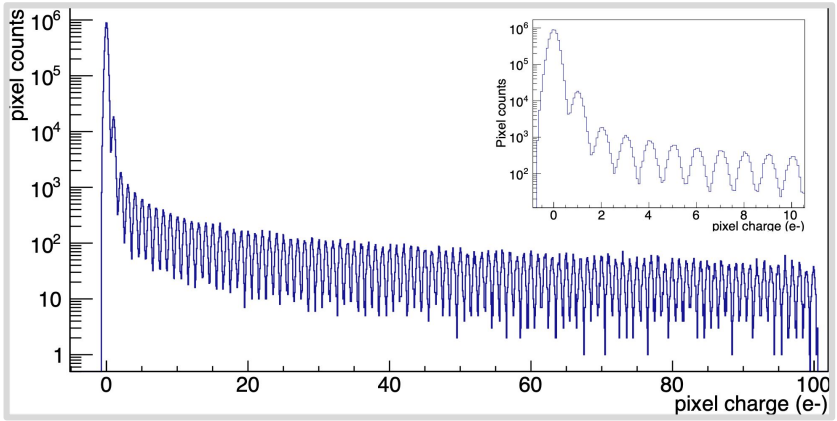
TU Wien / HEPHY

TAUP, Vienna 2023

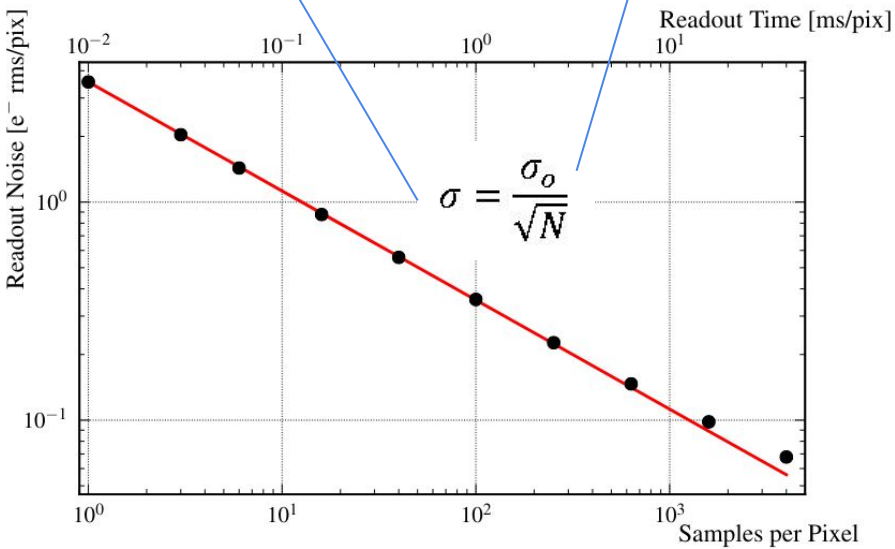
CONNIE upgrade!
Alexis A. Arevalo for CONNIE (29 Aug, 17:00, Hörsaal 21)

arXiv:2107.00168v2

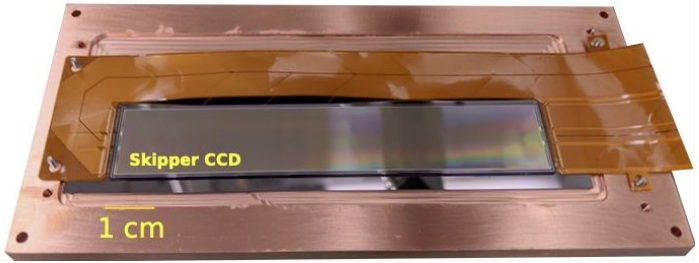


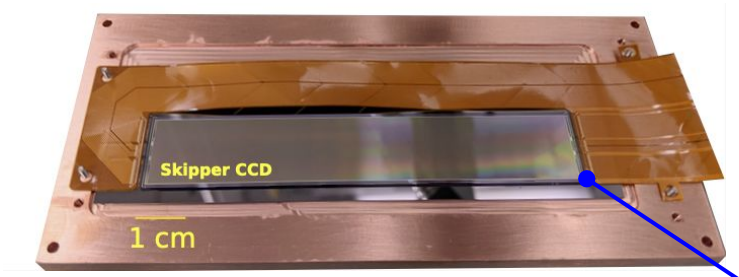
After averaging N samples

Readout noise for a single sample



arXiv:1706.00028

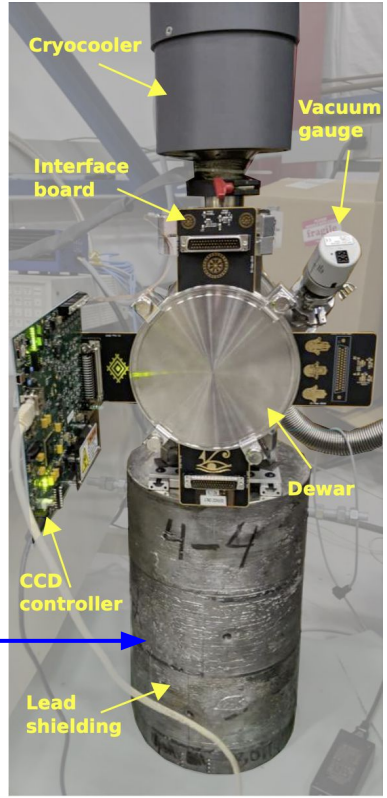




Sensor package:
Skipper CCD + Kapton cable + Copper tray

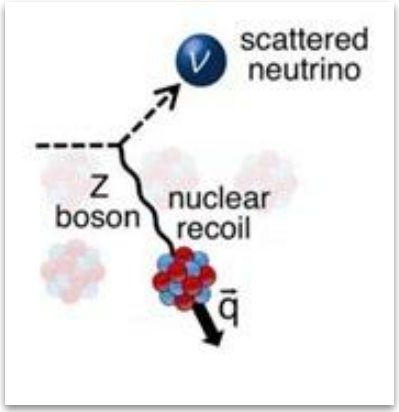
- Designed by LBNL Microsystems Laboratory and fabricated at Teledyne-DALSA.
- SCCDs on high resistivity silicon developed at LBNL
- Low Threshold Acquisition (LTA) controller **arxiv.org:2004.07599**
- Pixel volume: 15 μm x 15 μm x 675 μm
- Total of 6144 columns by 1024 rows
- ~ 2.5 grams each

Sensor stays inside the lead shield

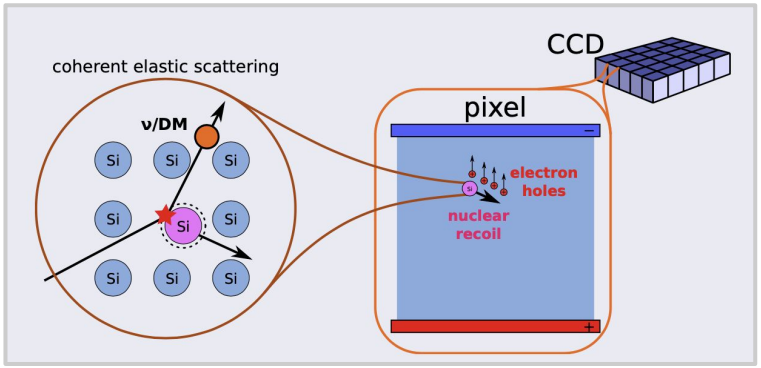


5 cm of lead around the sensor

Scientific cases: CEνNS



$$\frac{d\sigma^{\nu}}{dE_R} \simeq [Q_V^{\mathrm{SM}}]^2 \mathcal{F}^2(E_R) \frac{G_F^2 m_N}{4\pi} \left(1 - \frac{m_N E_R}{2E_\nu^2}\right)$$



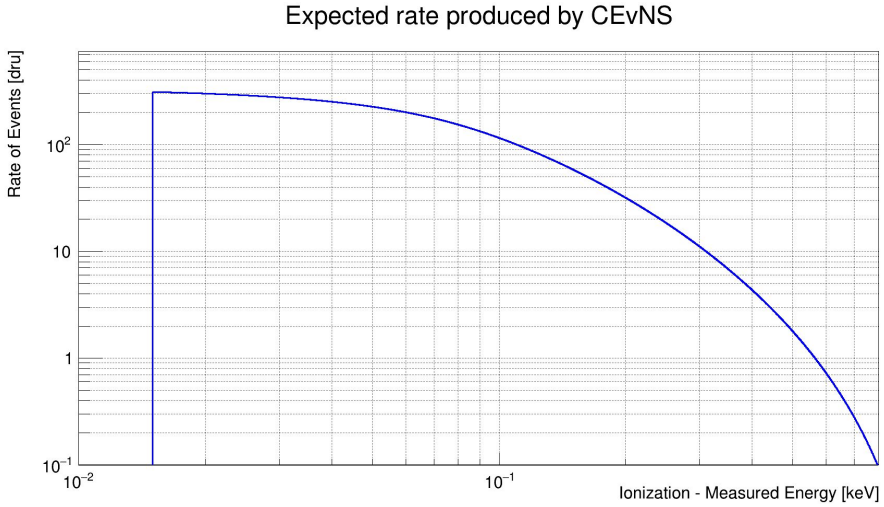
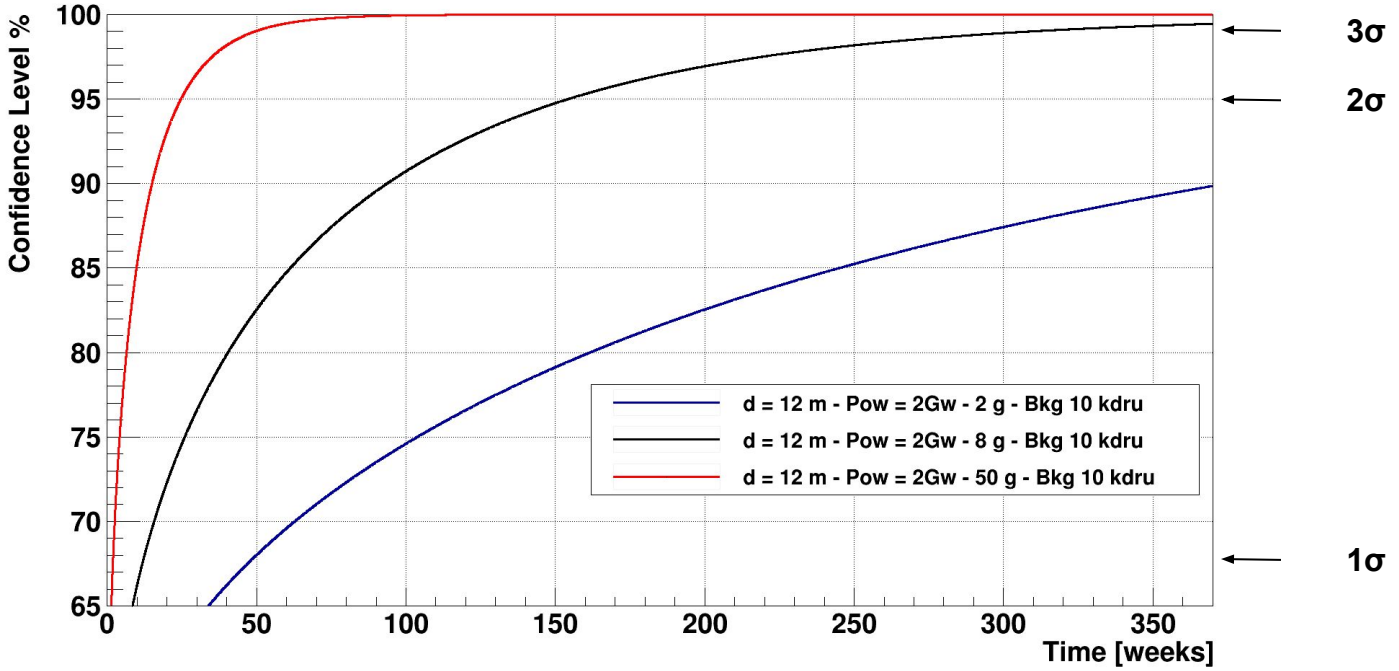


Figure top-left: credits to Akimov et al. (arXiv:1708.01294)

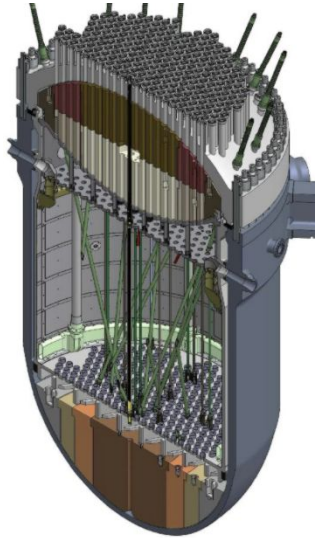
Scientific cases: CEνNS

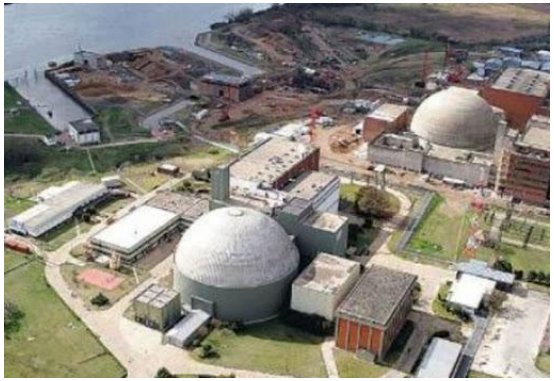
Expected Sensitivity for 2, 8 and 50 grams of Skipper-CCD 12 m away from a 2 GWth power reactor.



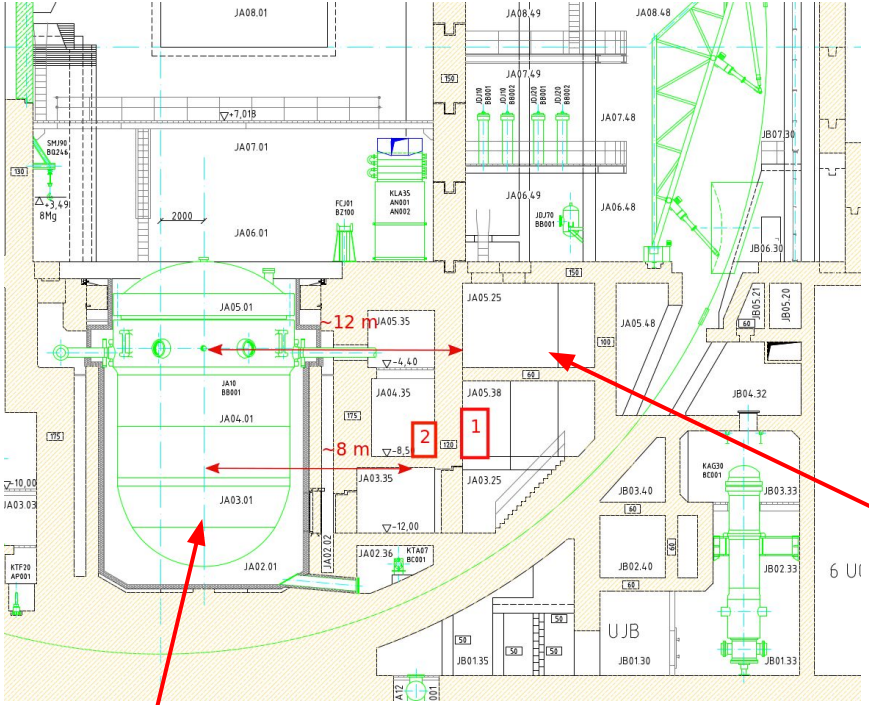
Atucha II - Lima, Buenos Aires, Argentina

- Commercial facility commissioned on 2014
- Pressurized heavy water reactor (Siemens design)
- 2 GWth
- D_2O moderator & refrigerator
- Fuel: natural UO_2
- 451 fuel elements, vertically allocated in an hexagonal grid

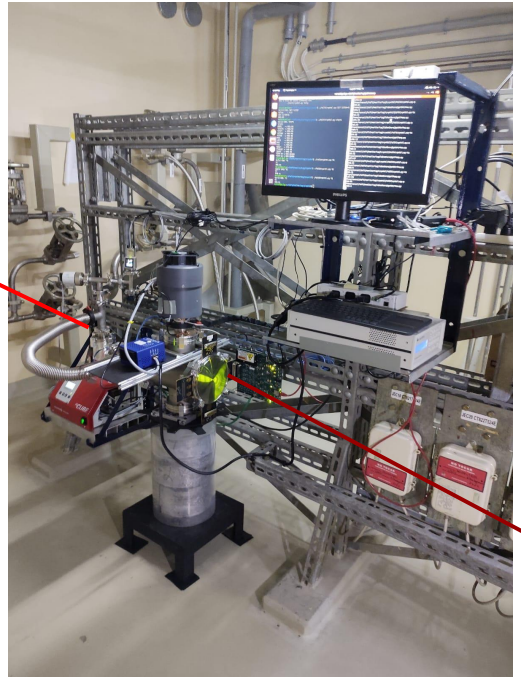




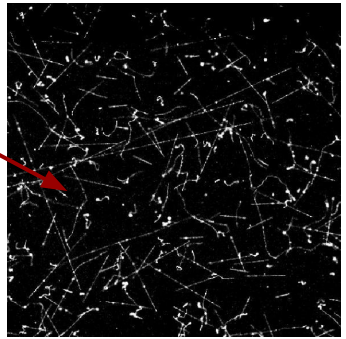
Installation at Atucha II

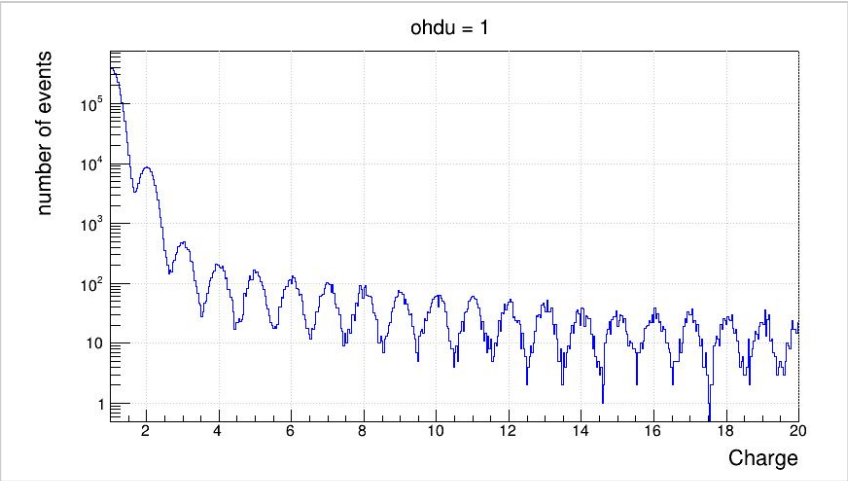


Skipper-CCD 12m from the nuclear core



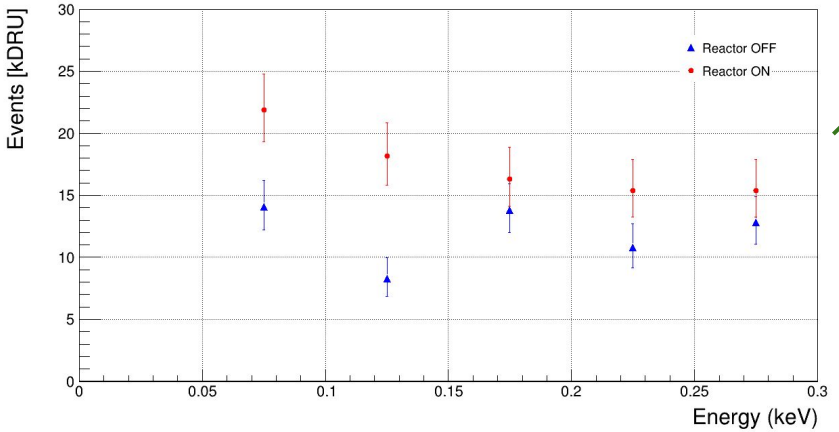
First image!

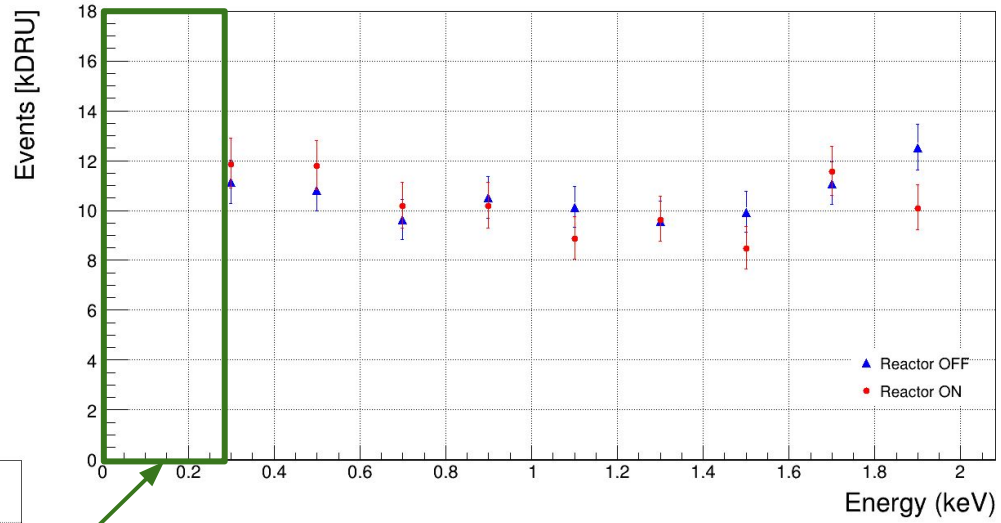




- Operated at ~ 130 K
- Average readout noise 0.17 electrons

- Horizontal binning: 10 columns
- 300 samples of the charge on each pixel
- Effective mass of 1.16 g (50%)





Exposure

Reactor OFF = 79.6 g days

Reactor ON = 64.9 g days

Production: mCP flux emitted from a nuclear reactor

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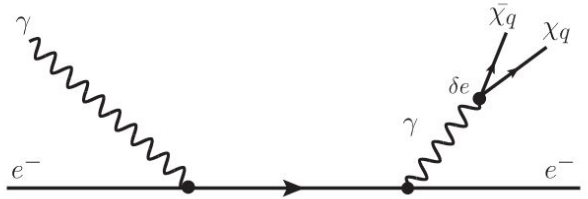
$$\frac{d\phi_{\chi_q}}{dE_{\chi_q}} = \frac{2}{4\pi R^2} \int \frac{1}{\sigma_{\text{tot}}} \frac{d\sigma}{dE_{\chi_q}} \frac{dN_\gamma}{dE_\gamma} dE_\gamma$$

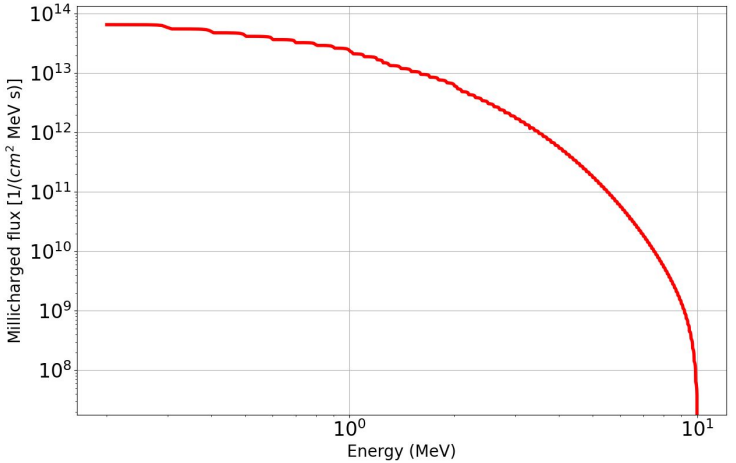
Distance to the center of the core (12 m)

Cross section

Gamma ray emission flux from the nuclear core



The production of χ_q-$\bar{\chi}_q$ via Compton-like mechanism based on the kinetic mixing of dark photon with the SM photon.



Detection: mCP flux emitted from a nuclear reactor

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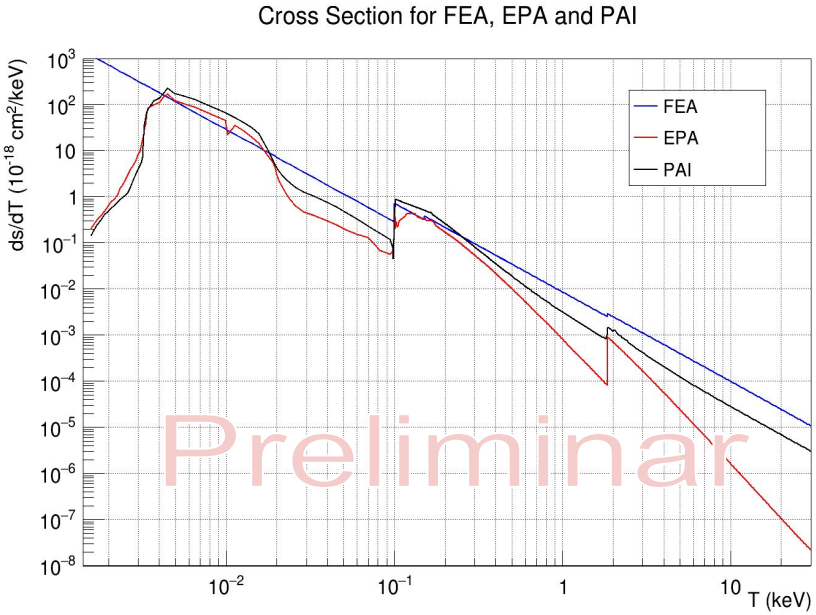

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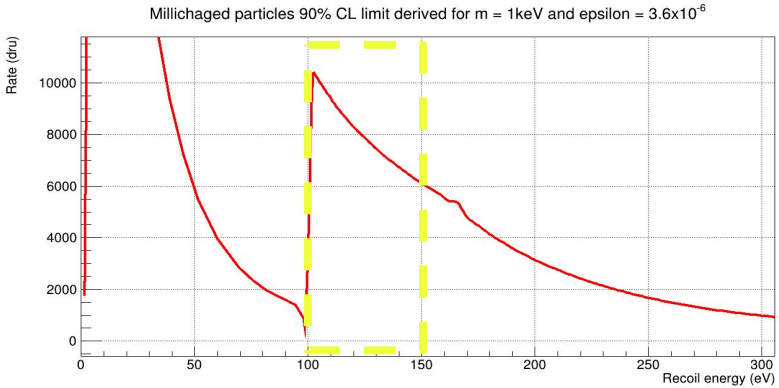
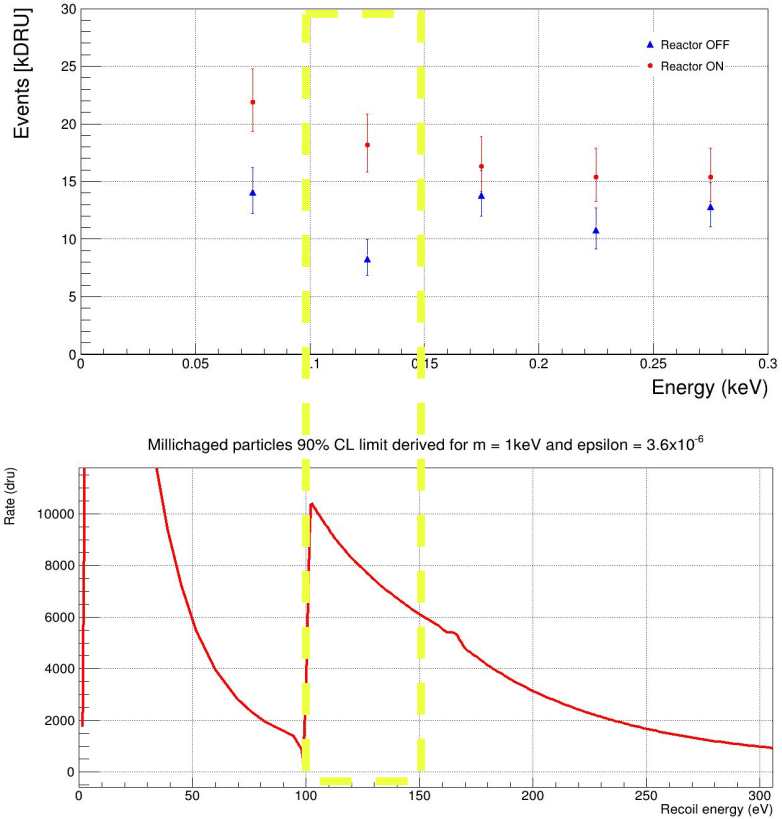


See arXiv:2305.04964 for cross-section calculation details

Preliminary experimental exclusion limit on mCP

We need to improve the shielding so that the reactor is not visible at low energies.



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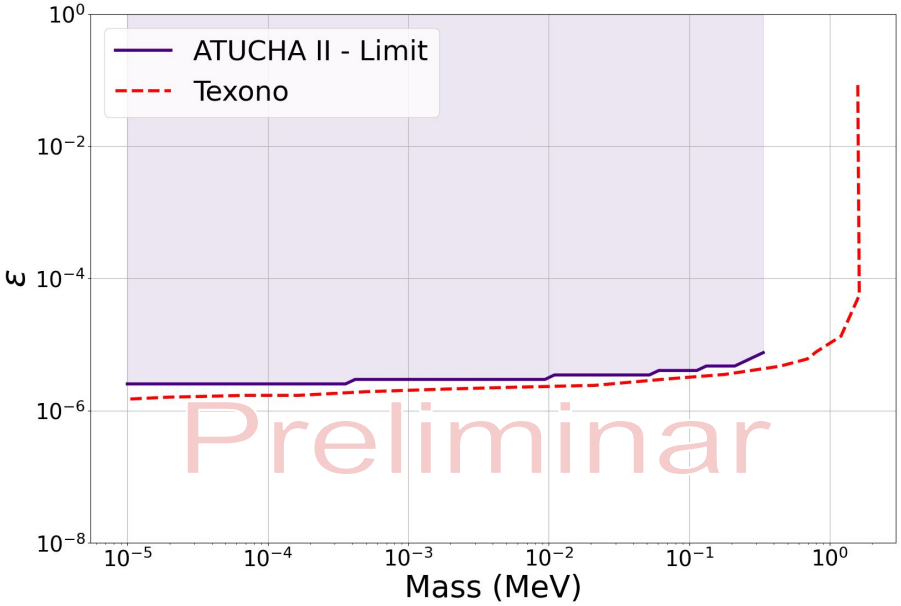
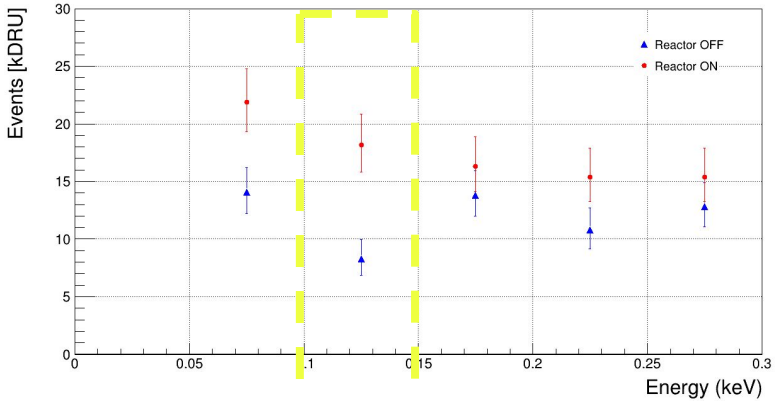
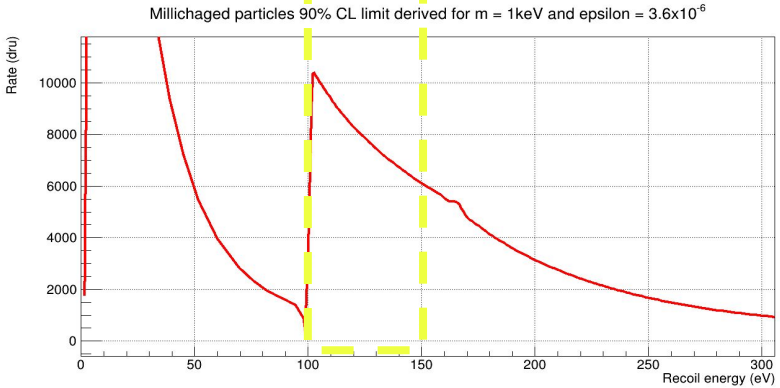
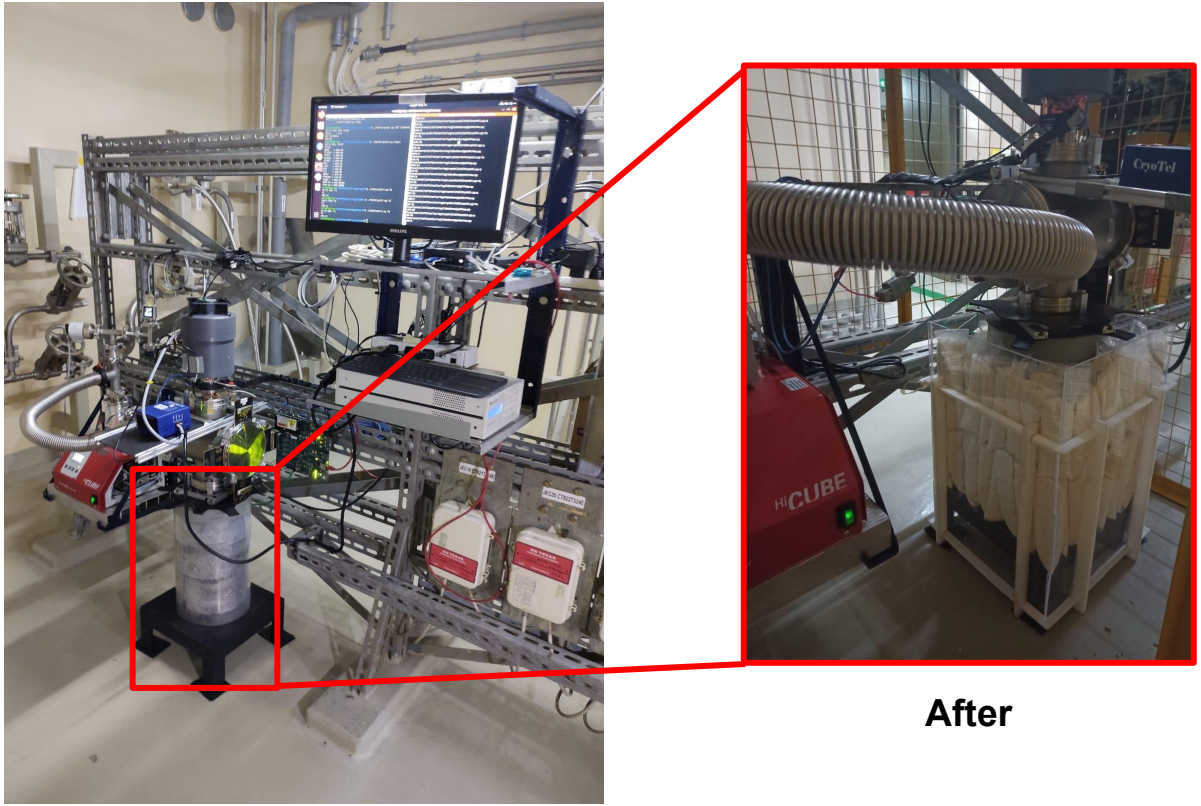






However, we already have competitive limits!



Before

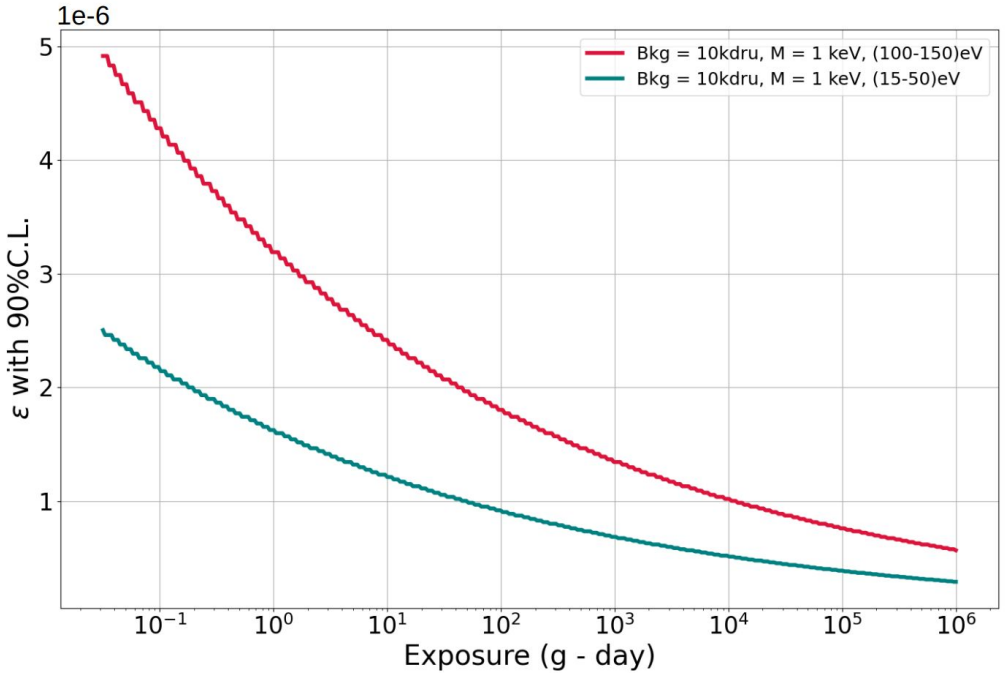
After

We added 5 cm of polyethylene around the Pb to shield the detector from fast neutrons coming from the reactor

~ 25 kg of mass

Forecast for exclusion limit on millicharge particles

Impact on exclusion limit when using Skipper-CCD's 15-50 eV interval instead of 100-150 eV



- ★ **First Skipper-CCD** installation inside a commercial **nuclear power plant**.
- ★ 2.5 grams of CCD running at **12 m** of a **2 GWth** reactor.
- ★ Performance was optimized by **reducing sources of electronic noise**.
- ★ Although no yet competitive for **CEvNS**, we have preliminarily set a competitive limit for **millicharge**.
- ★ Ongoing efforts with **CONNIE** for a **combined millicharge exclusion limit**.
- ★ We are now collecting data with **new neutron shielding**, new interesting data soon!