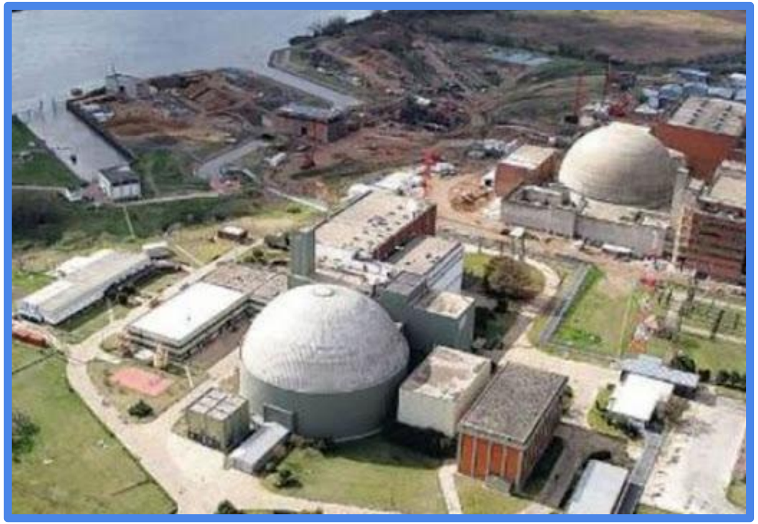
Preliminary results of a Skipper-CCD inside a nuclear power plant

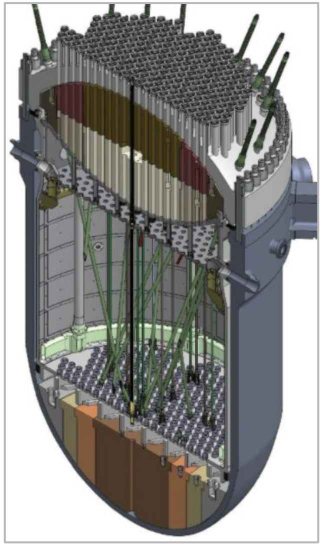


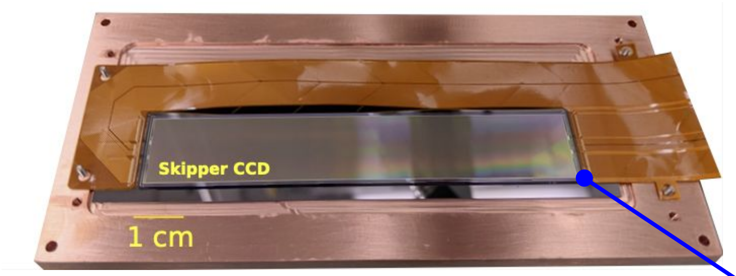
Speaker: Eliana Depaoli

Magnificent CEvNS 2023

Atucha II - Lima, Buenos Aires, Argentina

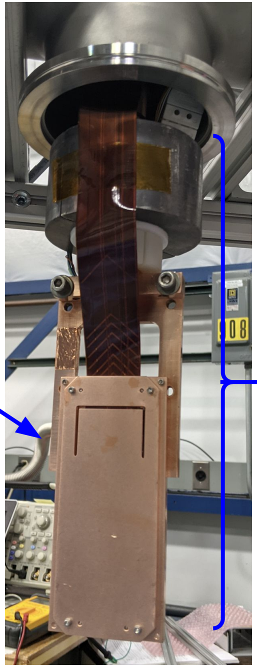
- Commercial facility commissioned on 2014
- Pressurized heavy water reactor (Siemens design)
- 2 GWth
- D_2O moderator & refrigerator
- Fuel: Natural UO_2
- 451 fuel elements, vertically allocated in an hexagonal grid



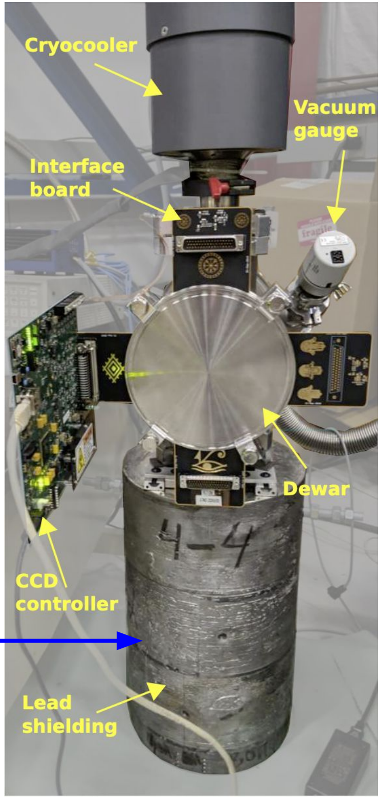


Sensor package:
Skipper CCD + Kapton cable + Copper tray

- Designed by LBNL Microsystems Laboratory and fabricated at Teledyne-DALSA.
- CCDs on high resistivity silicon developed at LBNL
- Low Threshold Acquisition (LTA) controller **arxiv.org:2004.07599**
- 6144 columns by 1024 rows
- Pixels 15 μm x 15 μm
- 675 μm thickness
- 2.5 grams



Sensor stays inside the lead shield



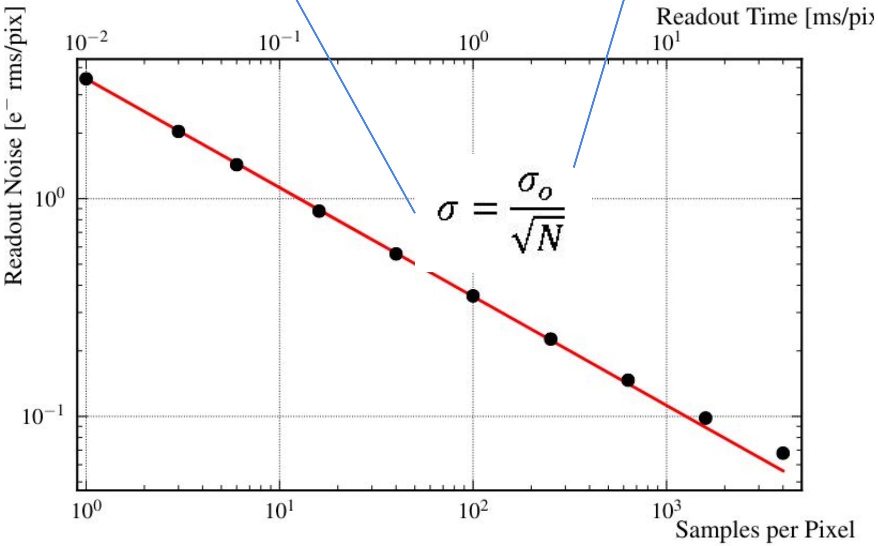
5 cm of lead around the sensor

arXiv:2107.00168v2

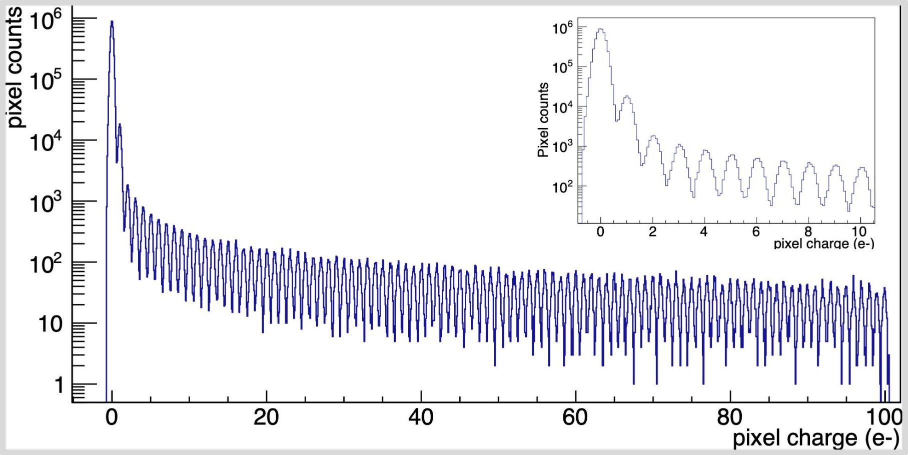
After averaging N samples

Readout noise for a single sample

$$\sigma = \frac{\sigma_o}{\sqrt{N}}$$

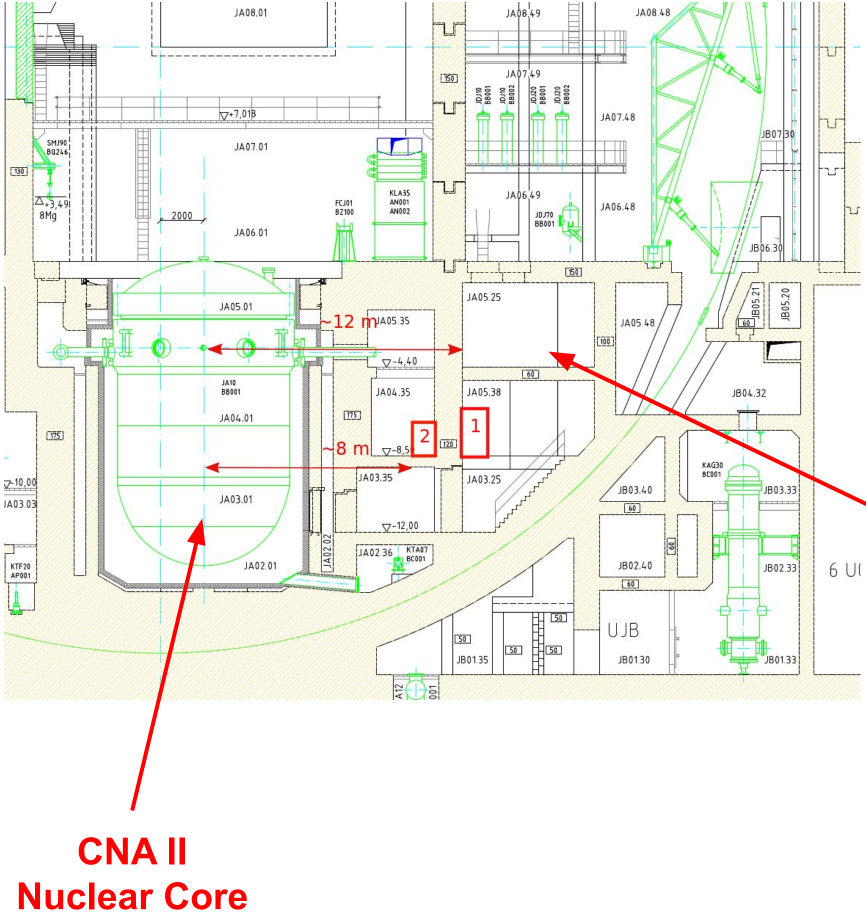


arXiv:1706.00028

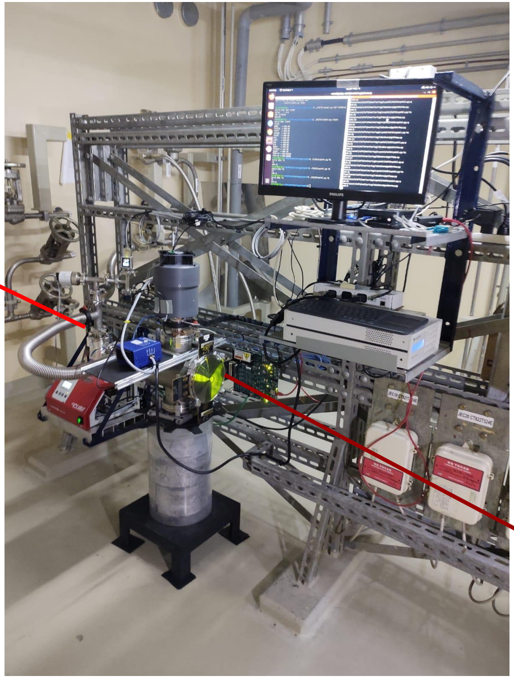


Sub-electron readout noise in a large range

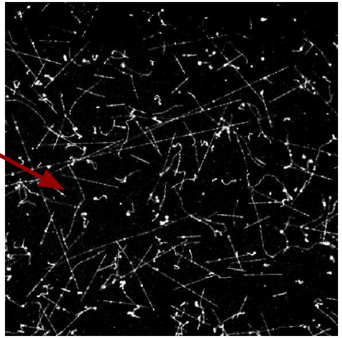
Installation in Atucha II



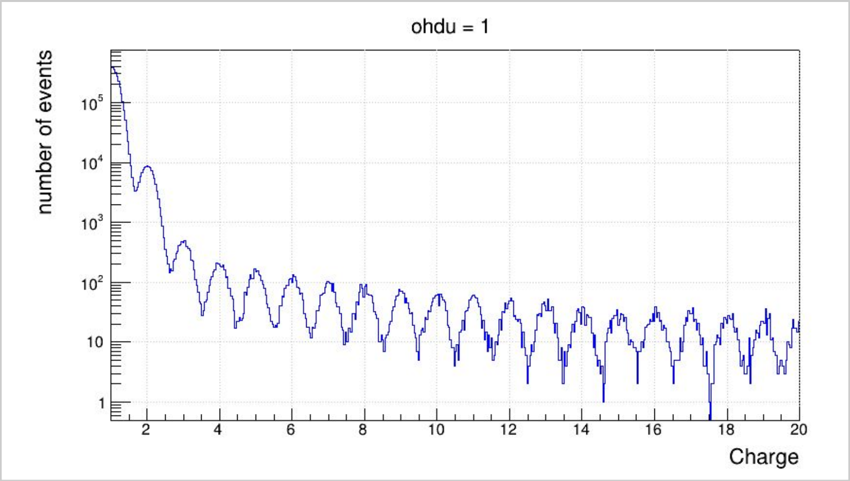
Skipper-CCD inside the nuclear reactor

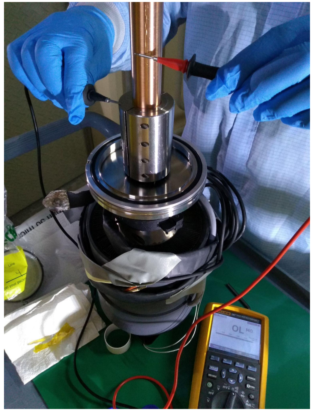


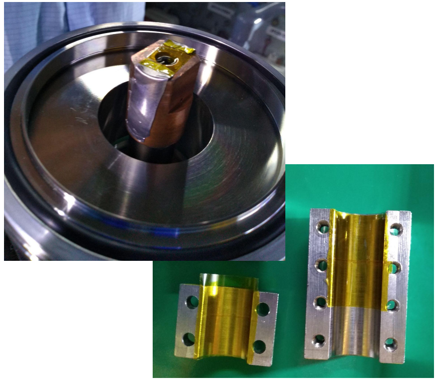
First image

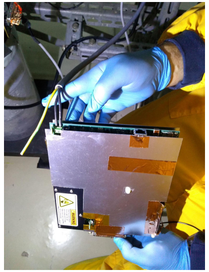


Performance @ Atucha II



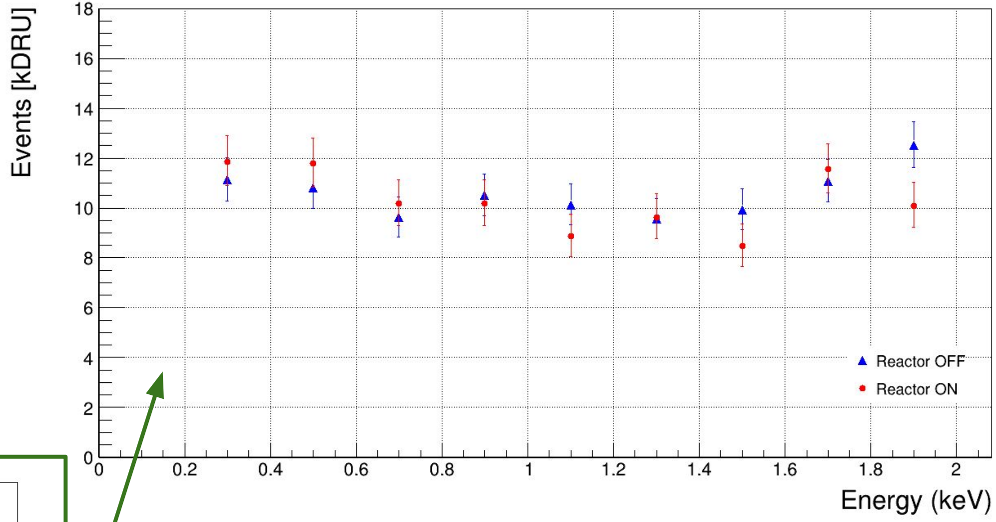


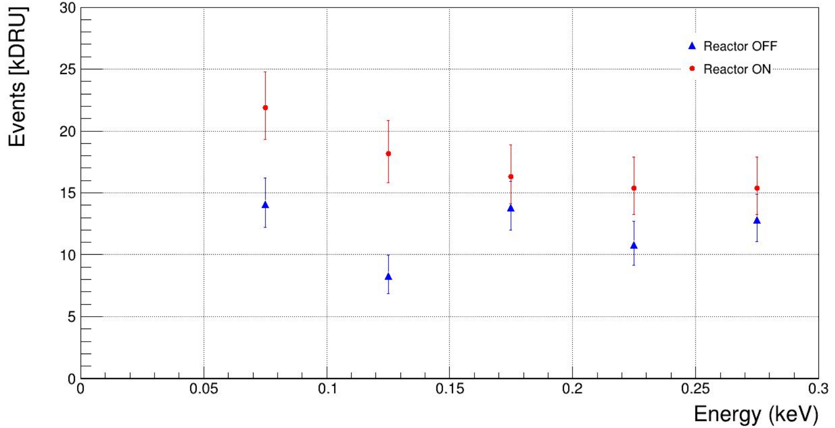




- Operated at ~ 130 K
- Average readout noise 0.17 electrons

- Horizontal binning: 10 columns
- 300 samples of the charge in each pixel
- Effective mass of 1.158 g





Exposure

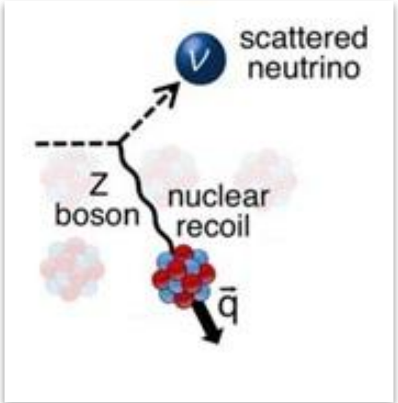
Reactor OFF = 79.6 g days

Reactor ON = 64.9 g days

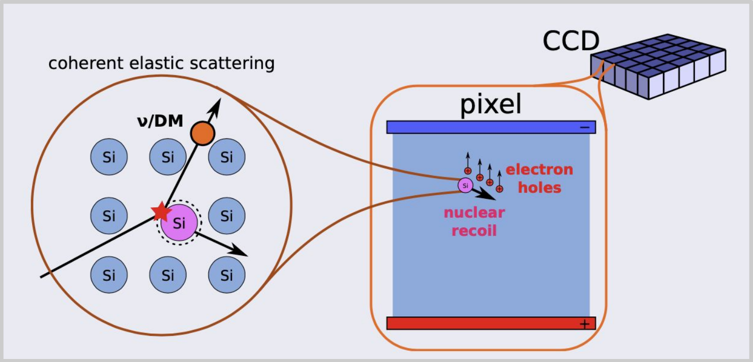
We added 5 cm of polyethylene around the Pb to shield the detector from fast neutrons coming from the reactor

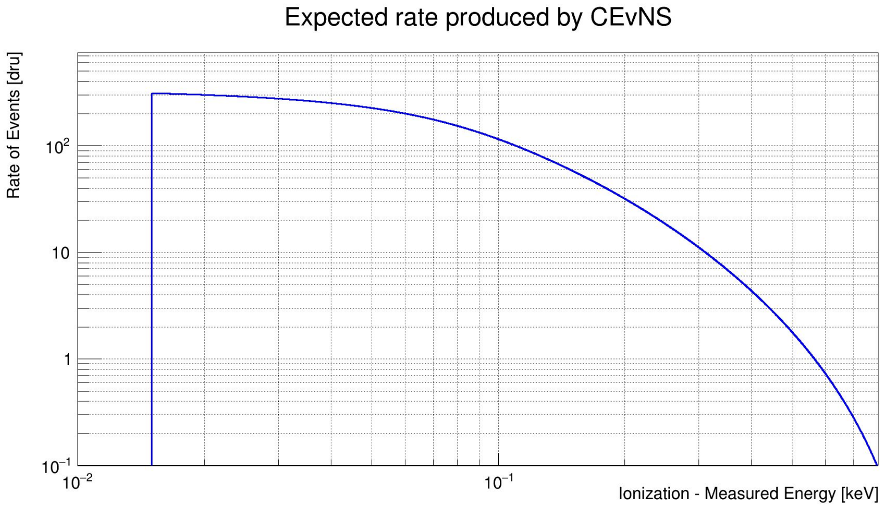
~ 25 kg of mass

Physics goals and preliminary results

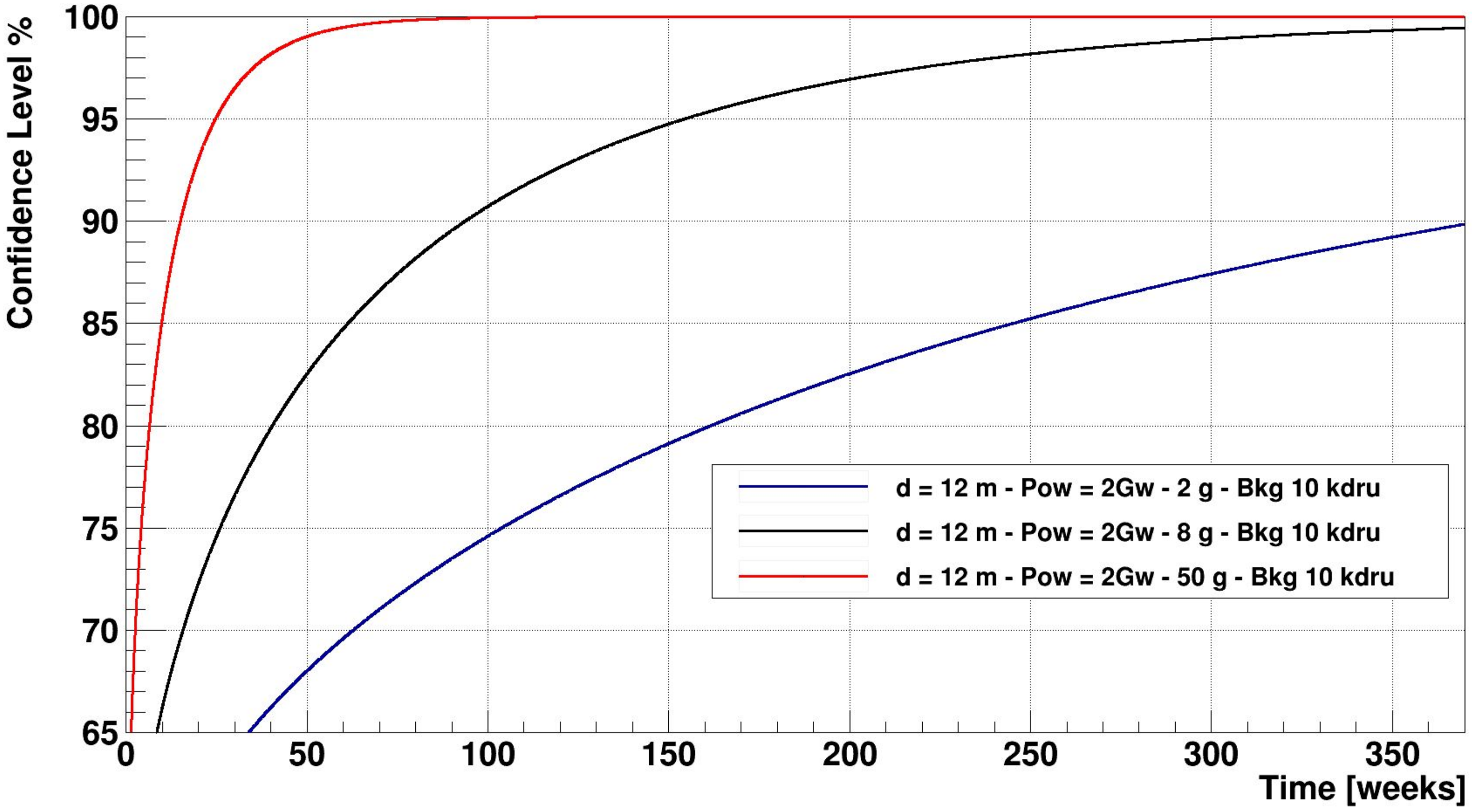


$$\frac{d\sigma^{\nu}}{dE_R} \simeq [\mathcal{Q}_V^{\rm SM}]^2 \mathcal{F}^2(E_R) \frac{G_F^2 m_N}{4\pi}\left(1 - \frac{m_N E_R}{2E_\nu^2}\right)$$





Expected sensitivity for CEvNS



Production: mCP flux emitted from a nuclear reactor

PHYSICAL REVIEW D 99, 032009 (2019)

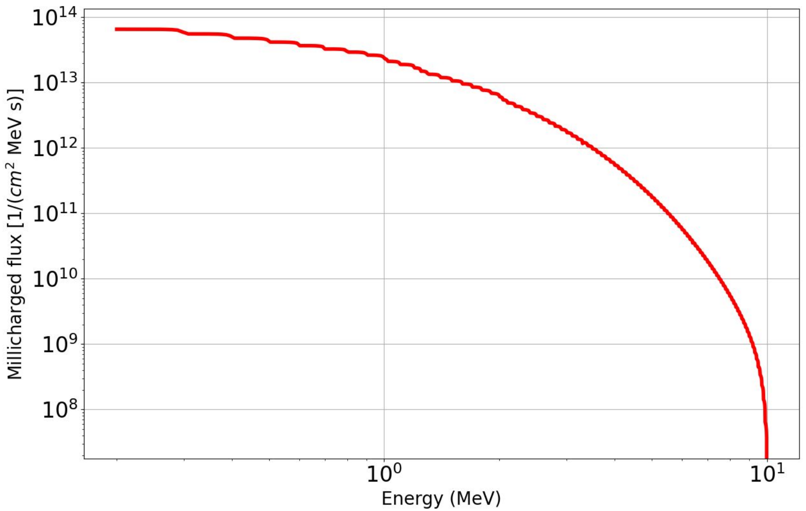
$$\frac{d\phi_{\chi_q}}{dE_{\chi_q}} = \frac{2}{4\pi R^2}\int \frac{1}{\sigma_{\text{tot}}}\frac{d\sigma}{dE_{\chi_q}}\frac{dN_\gamma}{dE_\gamma}dE_\gamma$$

Distance to the center of the core (12 m)

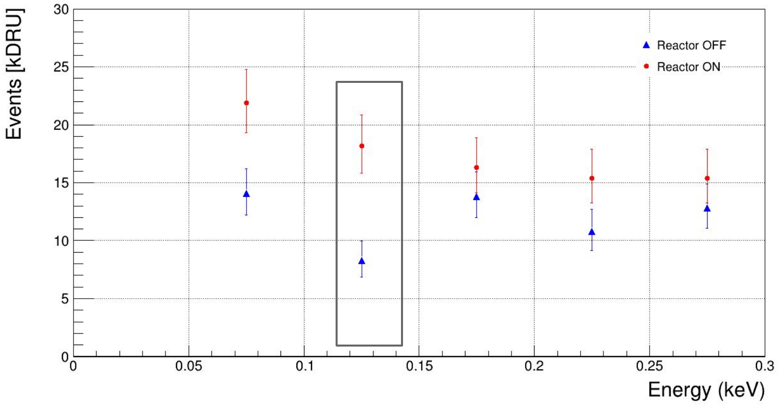
Cross section

Gamma ray emission flux from the nuclear core

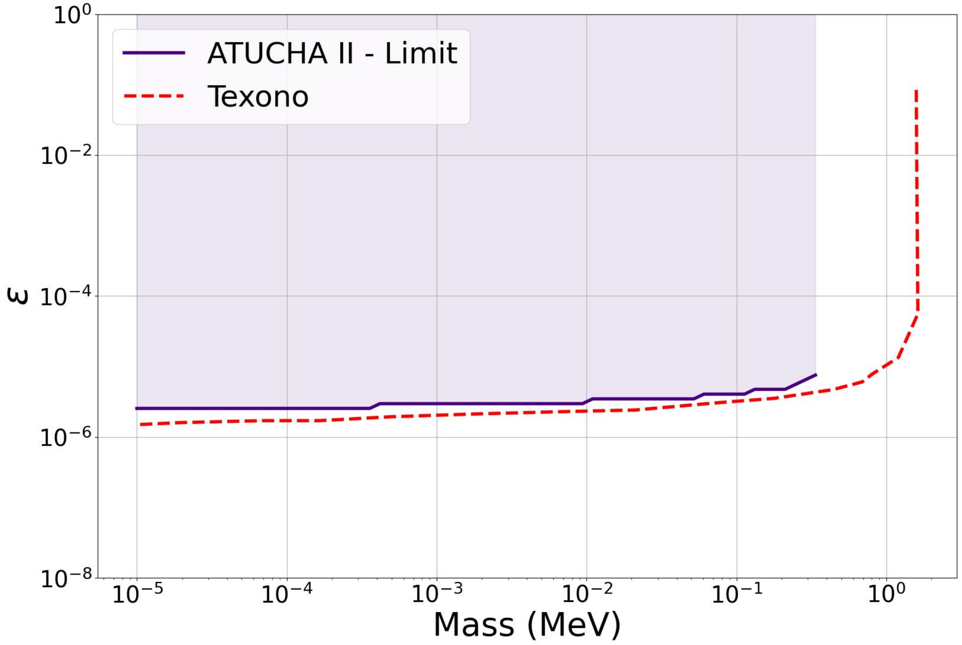
FIG. 1. The production of χ_q-$\bar{\chi}_q$ via Compton-like mechanism based on the kinetic mixing of dark photon with the SM photon.



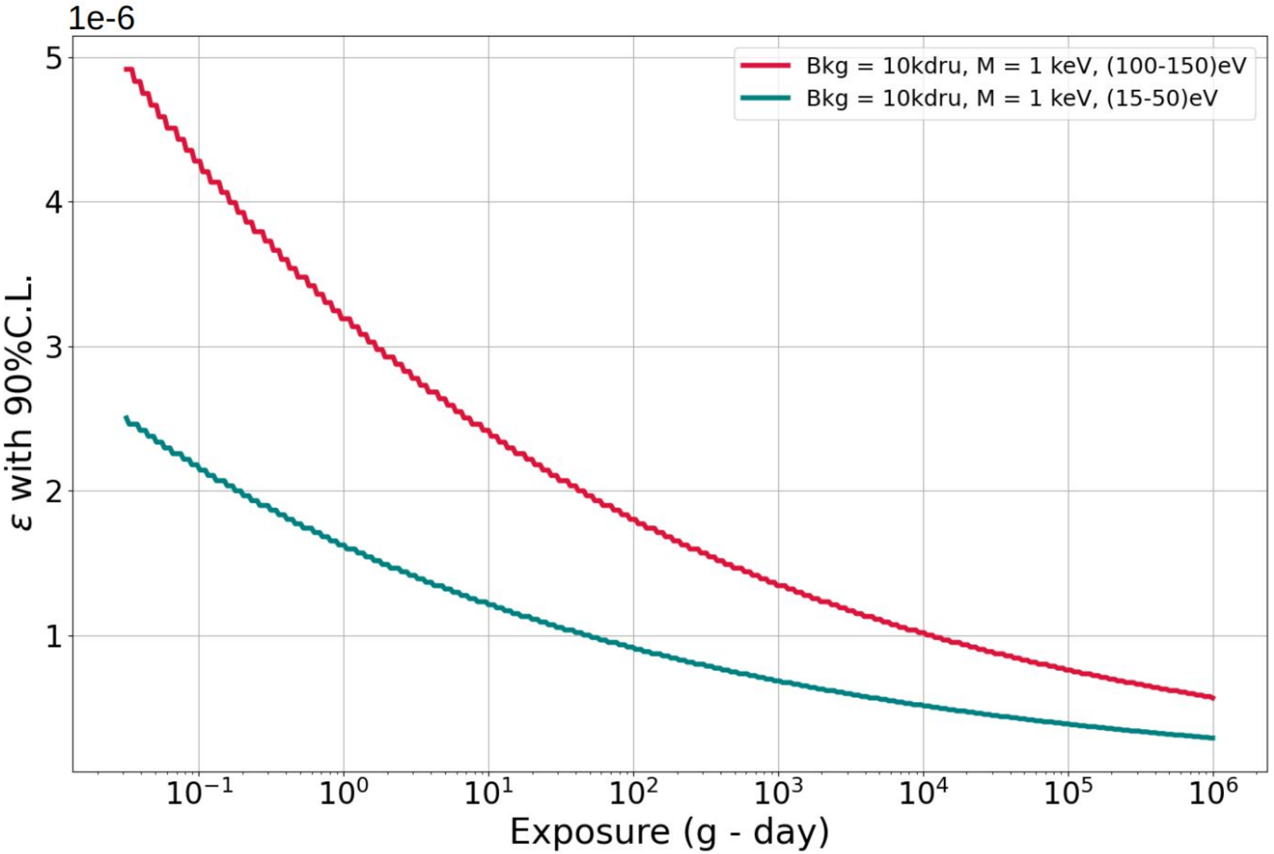
Preliminary experimental exclusion limit on mCP



Preliminar exclusion limit on mCP using a fraction of the collected data between 100 eV & 150 eV



Forecast for exclusion limit on millicharge particles



Conclusions

- ★ First Skipper-CCD installation inside a commercial nuclear power plant.
- ★ 2.5 grams of CCD running at 12 m of a 2 GWth reactor.
- ★ System has similar performance to the one achieved at Fermilab before shipping.
- ★ Performance was improved by reducing sources of noise.
- ★ We are now collecting data with new neutron shielding.
- ★ We preliminary set a very competitive limit for millicharge.