Status of RED experiment

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Abstract.

We propose a new experiment RED (Russian Emission Detector) to detect neutrino-nucleus neutral current scattering with two-phase noble liquid detector (LXe/LAr; **LXe as a basic option**). For experiment based on nuclear power plant reactor the expected nuclear recoil signal is in the ~1 keV range where responses of liquid Xe and liquid Ar are not known. The expected signals and backgrounds are presented for the high and low assumptions on the nuclear recoil specific ionisation yield in the liquid noble gas and for two detector options: with liquid Xe and liquid Ar. A detector design of RED-100 experiment (100 kg of LXe) is presented.
As a first step, we plan to measure LXe and LAr responses at keV region using quasy-mono energetic neutron beam at the MEPhI research nuclear reactor.

Coherent neutrino scattering

Coherent neutrino scattering is a fundamental process predicted by the Standard Model:

$$\nu + A \rightarrow \nu + A$$

However, it has not been detected yet due to experimental difficulties: the energy deposition is in keV region, and the detection mass must be significant, of an order of several tens of kg or even more.
The differential cross section is given by the formula:

$$\frac{d\sigma}{dE_r} = \frac{G_F^2}{4\pi} Q_w^2 M \left(1 - \frac{ME_r}{2E_\nu^2}\right) F^2(Q^2),$$

where G_F is the Fermi constant, $F(Q^2)$ is the form factor at four-momentum Q and $Q_W = N - (1 - 4\sin^2(\theta_W))Z$ is the weak charge for a nucleus with N neutrons and Z protons, θ_W is the weak mixing angle.

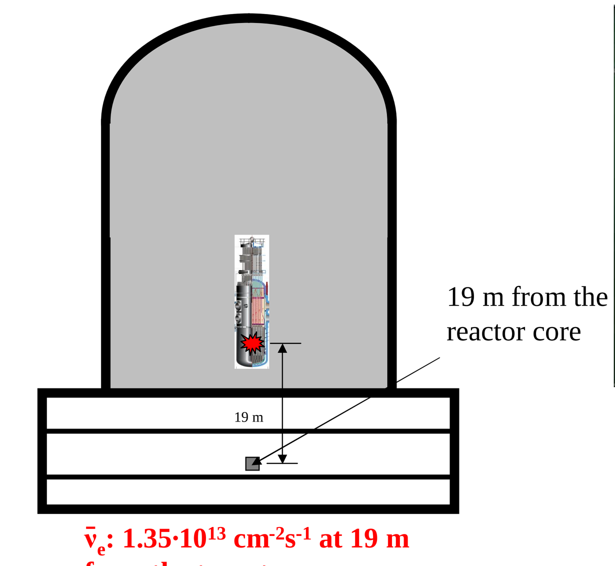
The process plays important role in astrophysics (supernova explosions).

If the cross section is different from the predicted one, it may be an indication of the new physics.

Possible important practical application is nuclear reactor monitoring.

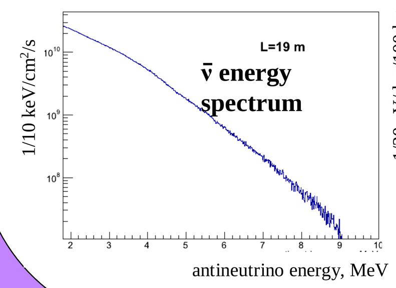
We consider two versions of the experiment

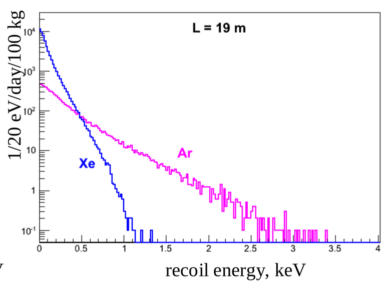
At a nuclear power reactor (Kalininskaya power station, Russian Federeation)



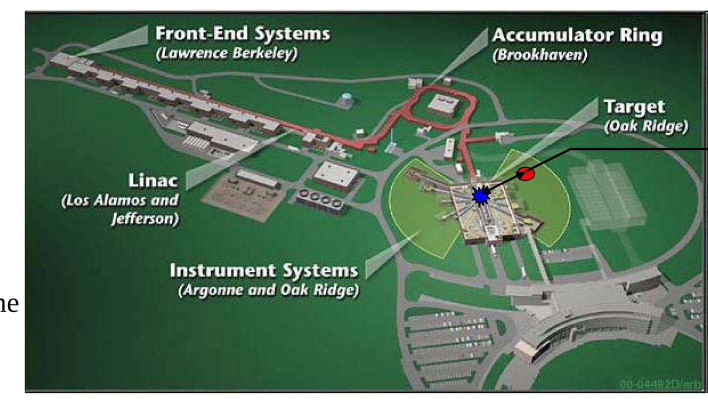
19 m from the reactor core

$\bar{\nu}_e$: 1.35·10^{13} cm^{-2}s^{-1} at 19 m from the target

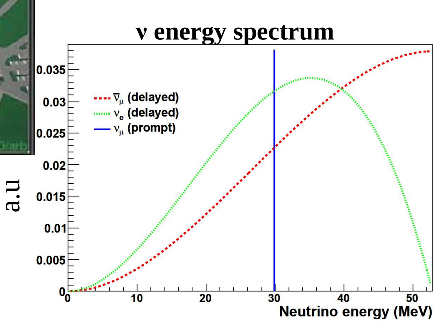




At spallation neutron source (SNS, Oak Ridge National Laboratory, USA)

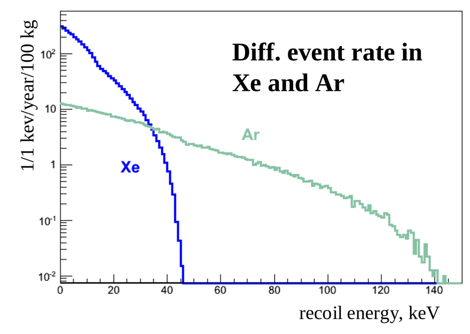


~ 40 m from the target; ~ 10 m underground



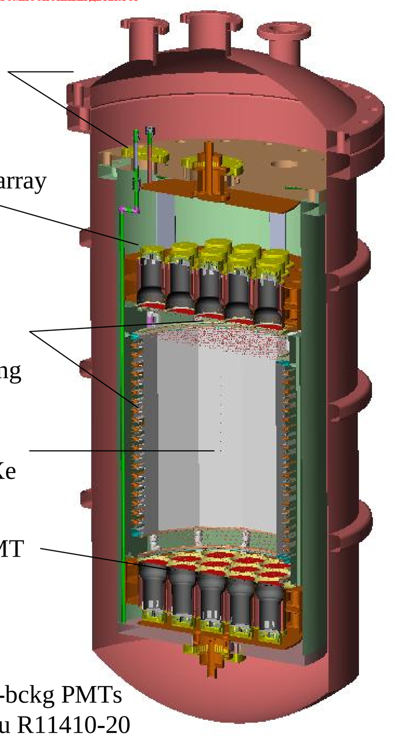
Proton beam energy – 0.9 - 1.3 GeV
Intensity - 9.6 x 10^{15} protons/sec
Pulse duration – 700 ns
Repetition rate – 60 Hz
Liquid Mercury target

1.9·10^{22} year^{-1} neutrinos each of three flavor (ν_e, ν_μ, $\bar{\nu}_\mu$): 5·10^6 cm^{-2}s^{-1} at 40 m from the target



Detector RED-100 (~100 kg of LXe in FV, ~250kg total)

Russian Emission Detector



RED-100 is a two-phase noble gas emission detector. A two-phase emission detector is TPC with a condensed noble gas as a detection medium and a readout via electroluminescence (EL) in a gas phase.

We consider LXe (**200 kg, basic option**) and LAr (**100 kg**) options, **~100** and **~50 kg in FV**, correspondently.

The sensitive volume will have **~ 45 cm** in diam. and **~ 45** cm in height, will be defined by the top and bottom optically transparent mesh electrodes and thin field-shaping rings.

Drift field is **0.5 ÷ 1 kV/cm**. Extraction field, and the field in EL region is **~ 7 ÷ 10 kV/cm** (in the gas phase).

PMTs are Hamamatsu R11410-10 (low-background): U/Th <0.4 /<0.3 mBq/PMT, ^{40}K - 8.3 mBq/PMT, ^{60}Co - 2 mBq/PMT.

Depth of the EL region – **1 cm**. The expected ***number of photoelectrons per one electron*** extracted to the gas phase in this region is **~ 80**.

The detector will be placed in a passive borated polyethylene and lead shield + active muon veto.

The detector is under construction. Cryostat will be manufactured at the fall of 2012 - beginning of 2013.

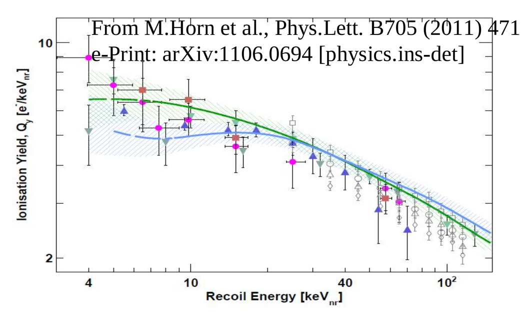
The significant background is spontaneous emission of single electrons (SE) from the surface with a rate of several tens Hz. We consider two values of the count rate of such events:

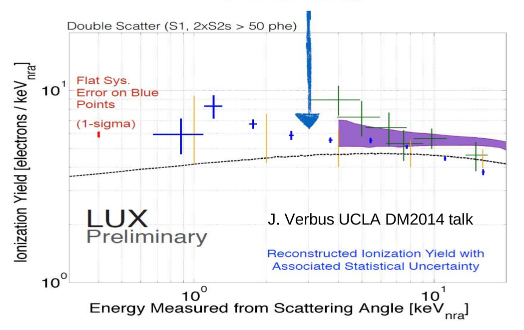
1. **~ 10 Hz as in E. Santos et al., JHEP 1112 (2011) 115; e-Print: arXiv:1110.3056 [physics.ins-det].**
2. **~ 100 Hz**

The events of ν-N scattering must be selected starting from the number of ionisation electrons (N_e) more than two, where the SE background is negligible.
XY mapping will allow one to reduce the background of accidental coincidences of spontaneous SE by a factor of 10.

Expected recoil spectra

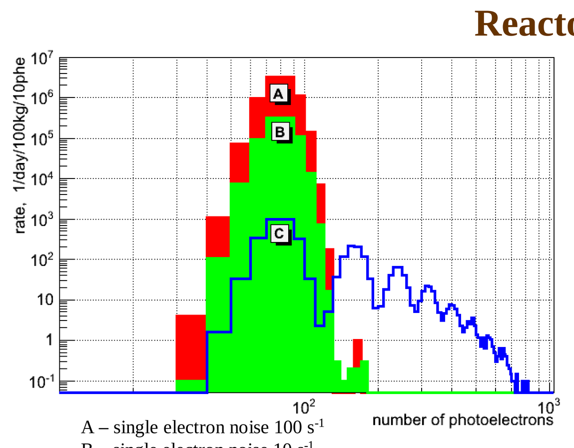
Experimental data on ionisation yield for NR are available for ≥4 keV for LXe. There are no experimental data for LAr



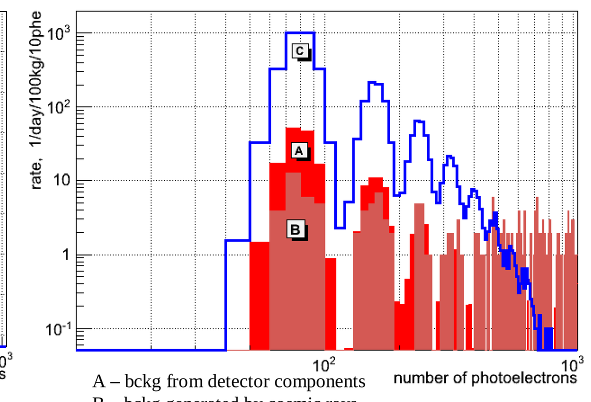


For our simulations we used a fit of the existing data with 12.5·$E^{-0.34}$ (E in keV$_{nr}$) for E > 4 keV and for E < 4 keV a smooth function going to "0"

Reactor

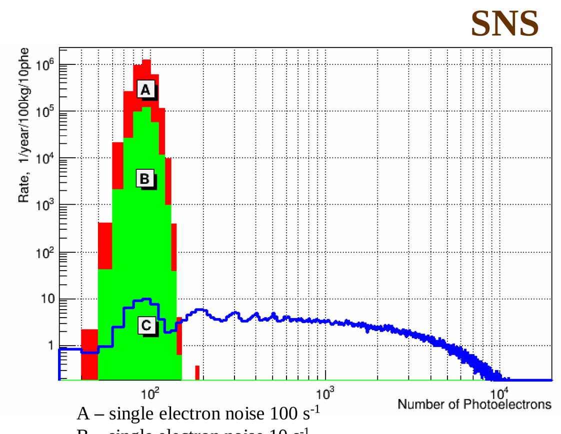


A – single electron noise 100 s^{-1}
B – single electron noise 10 s^{-1}
C – neutrino nucleus elastic coherent scattering



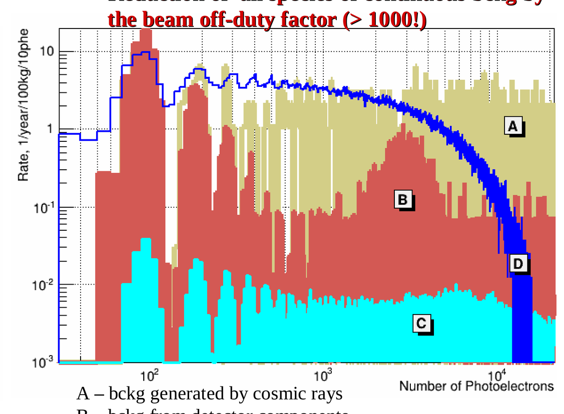
A – bckg from detector components
B – bckg generated by cosmic rays
C – neutrino nucleus elastic coherent scattering

SNS



A – single electron noise 100 s^{-1}
B – single electron noise 10 s^{-1}
C – neutrino nucleus elastic coherent scattering

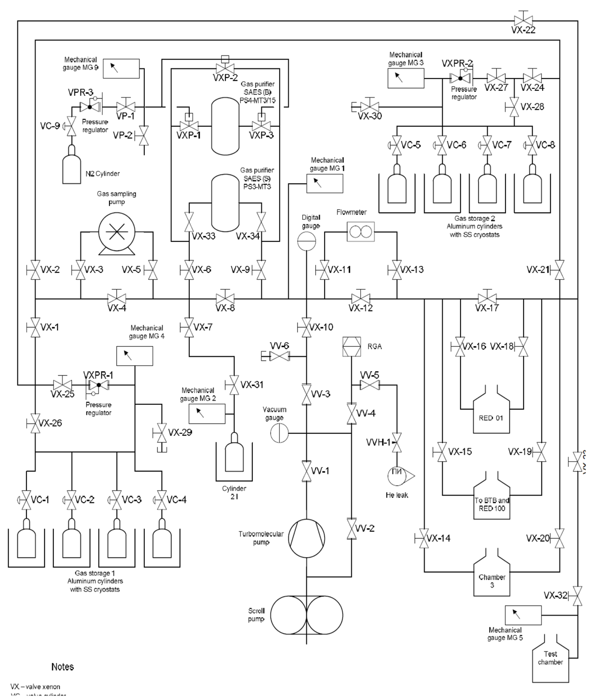
Reduction of all species of continuous bckg by the beam off-duty factor (> 1000!)



A – bckg generated by cosmic rays
B – bckg from detector components
C – neutron bckg from SNS
D – neutrino nucleus elastic coherent scattering

Gas system of RED-100 is completely assembled

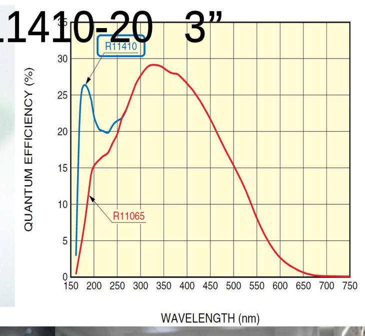
250 kg of Xe delivered to the gas system (depleted from ^{136}Xe ^{136}Xe => EXO-200)
Xe is from the same batch that was used in ZEPLIN-III
40-y old => 85Kr concentration is reduced by a factor 16 rel. to initial level
According to ZIII underground measurements this Xe is equivalent to the present-day Xe with 150 ppt of Kr

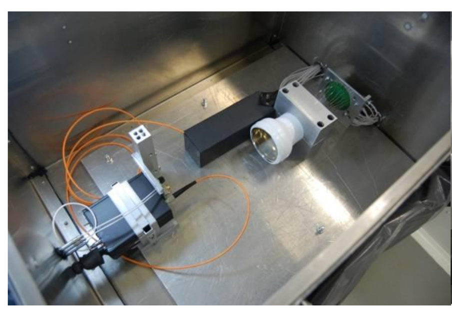


Electron lifetime measurements have started

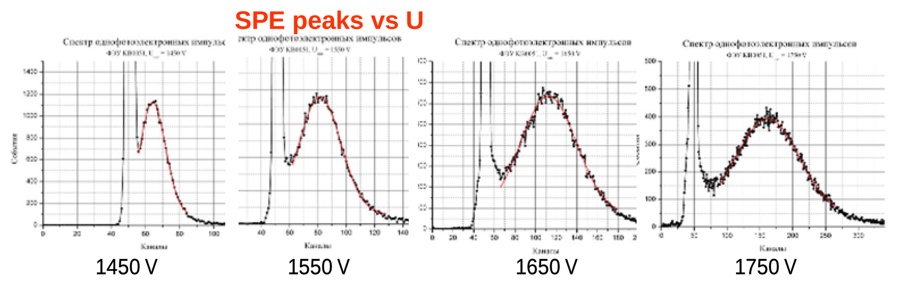
PMT characterization

Hamamatsu R11410-20 3"

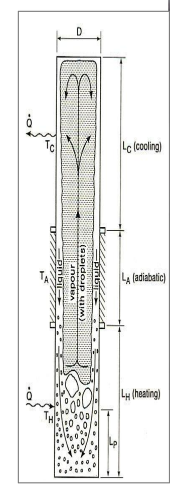




SPE peaks vs U

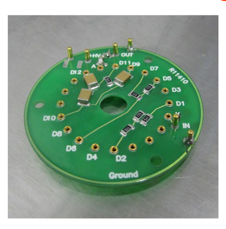


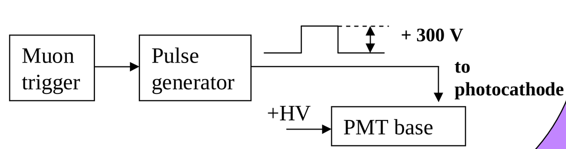
Thermosyphon assembling



To be connected to detector

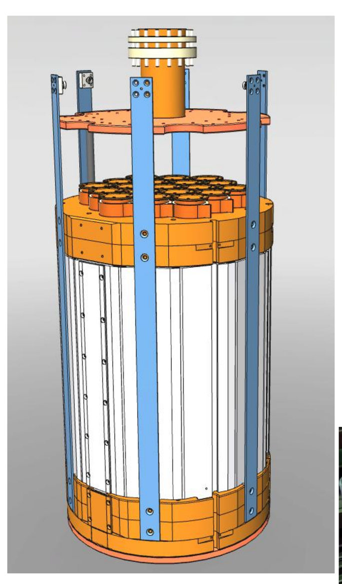
Active PMT base (divider), to prevent photocathode aging from huge electroluminescent pulses from muons.



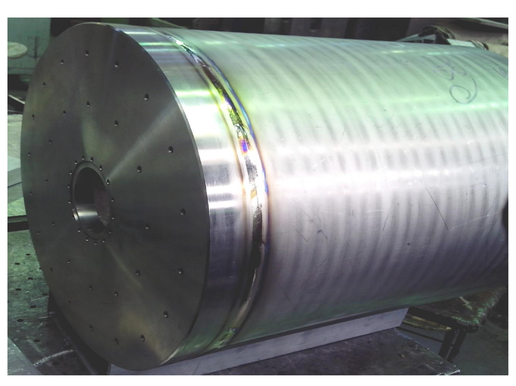


Detector & Cryostat

The inner structure is ready for cleaning and assembling



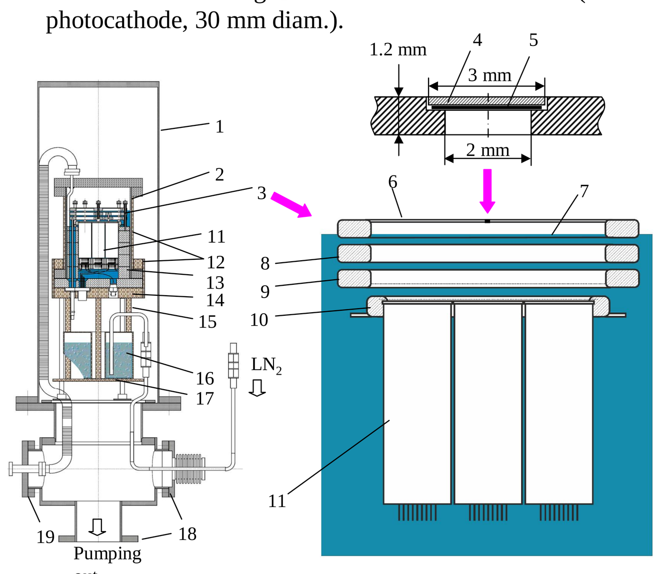
Titanium cryostat manufacturing is ongoing



Detector prototype (RED-1)

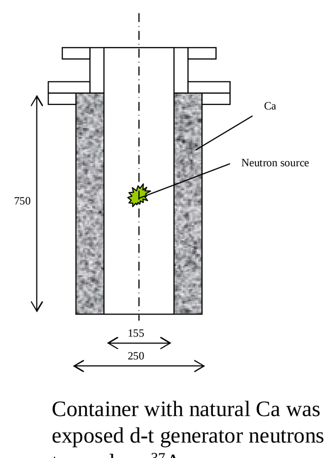
At the moment, the prototype is deployed at a 24-keV neutron beam ready to start measurements of the LXe to sub-keV nuclear recoils. Waiting MEPhI research nuclear reactor ON.
A detector was built a decade ago as a full-functional prototype of the ZEPLIN-III dark matter detector. The depth of the LXe between the cathode and the surface of LXe is **22 mm**, the diameter of the target is **105 mm**, the electroluminescence gap (between the surface of the LXe and the anode) is **5 mm**.

The UV-sensitive MgF$_2$-windowed PMTs FEU-181 (not low-background) by MELS production are used to detect the Xe 175-nm emission (QE 15%, multialkali photocathode, 30 mm diam.).



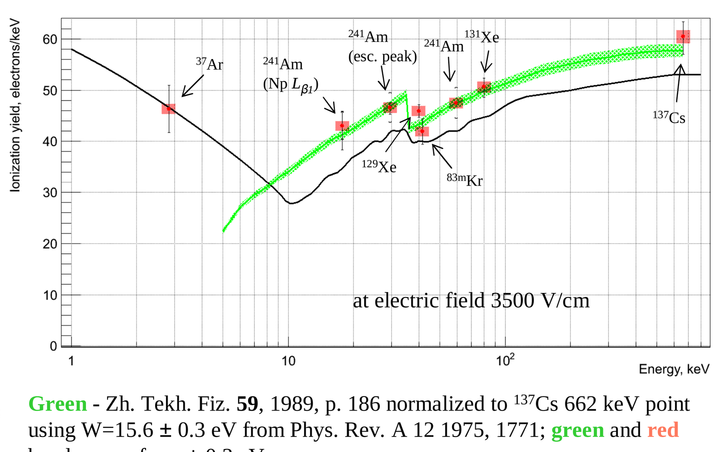
1 – warm vessel; 2 – cold vessel; 3 – electrode system; 4 – ^{241}Am source; 5 – stainless steel foil (200 μm); 6 – anode; 7 – LXe surface; 8 – field shaping ring; 9 – wired cathode (0.1 mm diam., 1 mm pitch); 10 – wired grid (0.1 mm diam., 1 mm pitch); 11 – PMTs; 12 – copper jacket; 13 – stainless steel LXe displacers; 14 – copper base plate; 15 – thermo conducting copper fingers; 16 – container filled with liquid nitrogen; 17 – copper base plate; 18 – vacuum ports.

First measurement of LXe ionization response to electron recoils below 100 keV



Container with natural Ca was exposed d-t generator neutrons to produce ^{37}Ar. Dimensions are in mm.

^{37}Ar
2,82 keV
0,27 keV
(10:1)



Green - Zh. Tekh. Fiz. **59**, 1989, p. 186 normalized to ^{137}Cs 662 keV point using W=15.6 ± 0.3 eV from Phys. Rev. A 12 1975, 1771; **green** and **red** bands come from ± 0.3 eV.

Black – NEST (Noble Element Simulation Technique); http://nest.physics.ucdavis.edu/site/

NEST gives the right prediction of ionization yield at low energies (below ~10 keV)