Project of a ton-scale detector for nuclear reactor monitoring

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On behalf of RED collaboration

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At present, there is an intensive work around the world on development of the next generation of relatively compact neutrino detectors for nuclear reactor monitoring:

DANSS, KASKA, iDREAM, Nucifer
The study was started in late 70s by Kurchatov Institute at Rovno NPP.
Similar study - San Onofre NPP
based on IBD (inverse beta-decay on proton): $\tilde{\nu} + p \rightarrow e^{+} + n$

A coherent neutrino-nucleus elastic scattering (CNNES): $\nu + A \rightarrow \nu + A$
was predicted theoretically in 1974: D.Z. Freedman, D.N. Schramm, and D.L. Tubbs. Ann. Rev. Nucl. Part. Sci. 27, 167 (1977)
but has never been observed experimentally because of very low energy transfer

A neutrino interacts via exchange of Z with a nucleus as a whole, coherently up to E_{ν}~ 50 MeV

WHY IT IS ATTRACTIVE? ***$\sigma \sim N^2$***

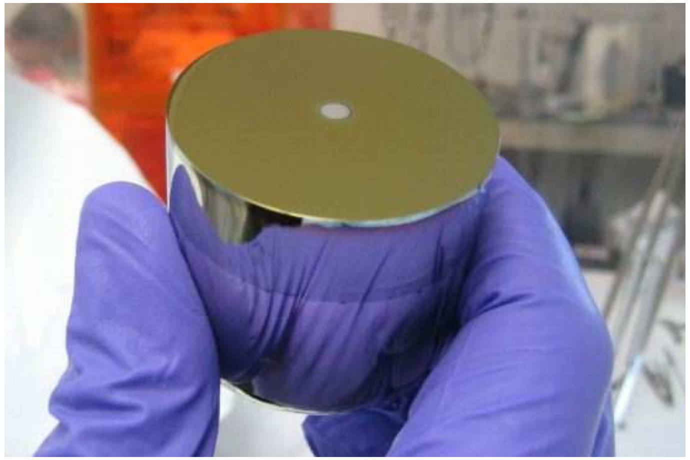
There are several proposals for the 1st observation of this effect (see next slides):

At reactor:
Ge detectors: CoGeNT *(USA)*, **TEXONO** *(Taiwan)*, *JINR Dubna*
Noble gas detectors
Noble liquid detectors: LAr Livermore, LXe ITEP&INR, LXe ZEPLIN-III

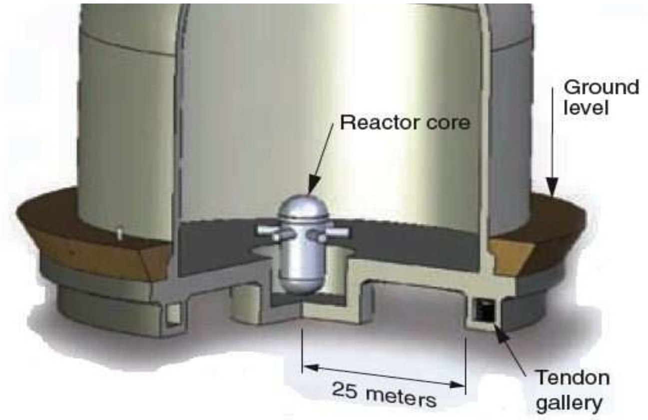
At Spallation Neutron Source: **LXe – RED-100**

Ge detectors: CoGeNT *(USA)*, TEXONO *(Taiwan)*

p-type point contact (PPC) Ge detector:

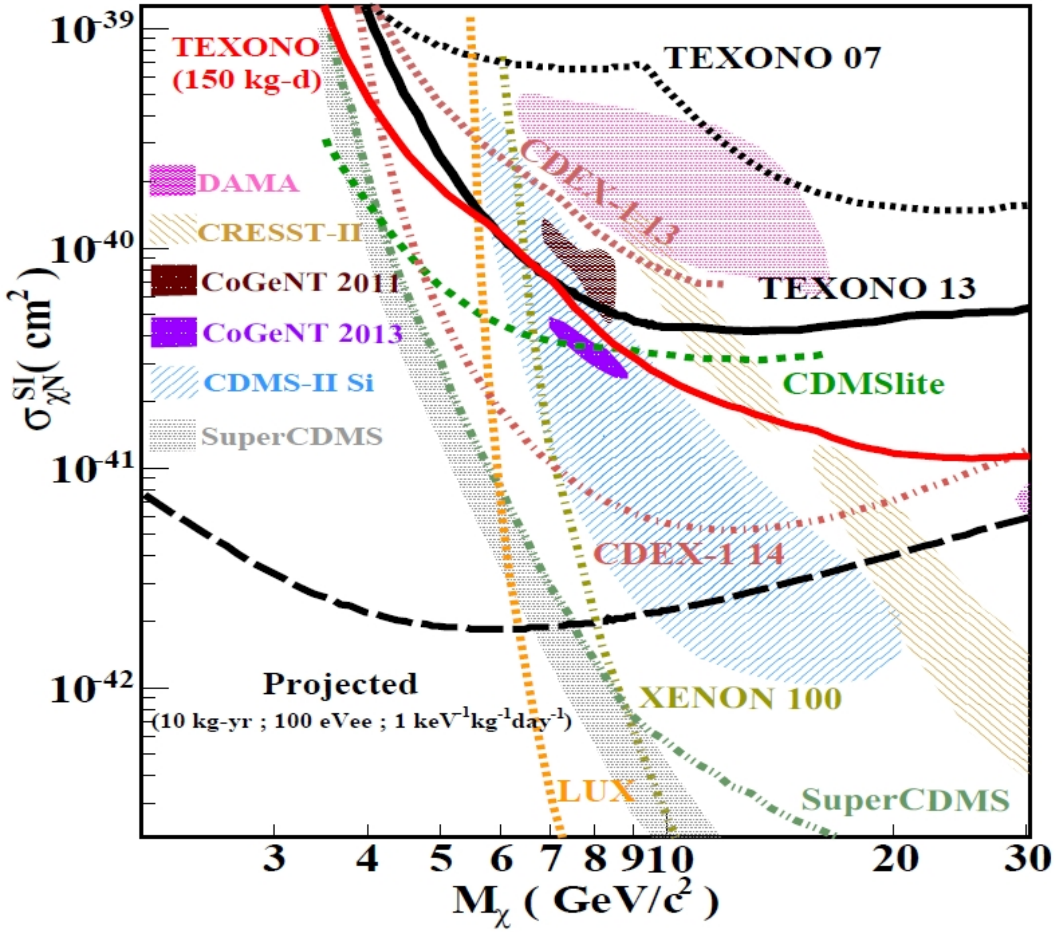


CoGeNT - San Onofre Nuclear Power Reactor, USA



Can operate with a very low threshold (below 1 keV)!

Both detectors were used in DM search experiments:

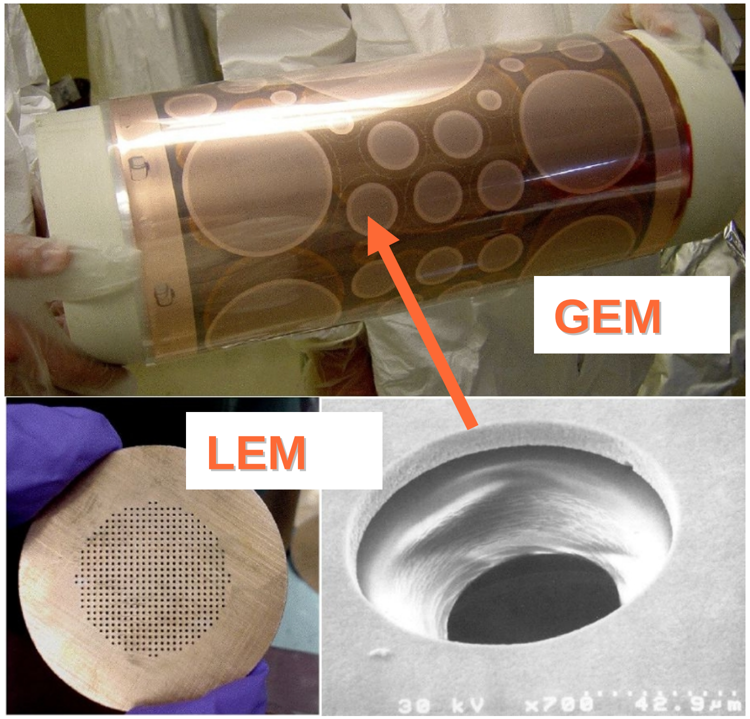


Attempts to build gas detectors

Array of cylindrical gas proportional counters.

A. V. Kopylov et al., Advances in High Energy Physics V. 2014 (2014), Article ID 147046

Gas detectors with micro pattern amplification structures



P. S. Barbeau et al., IEEE Trans. on Nucl. Sci., V. 50 (2003), no. 5, 1285

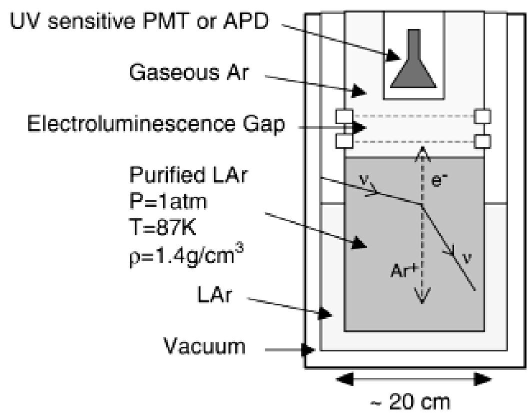
Such detectors have very low energy thresholds.

However, it is difficult to obtain the mass higher than several kg

Proposals to use two-phase detector for CEνNS experiments

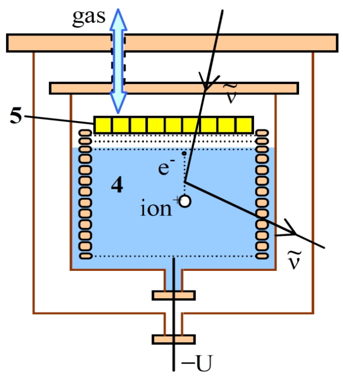
Proposal of Lawrence Livermore National Lab. with a two-phase LAr:

C. Hagmann, A. Bernstein, IEEE Trans. Nucl. Sci. 51 (2004) 2151 [nucl-ex/0411004].



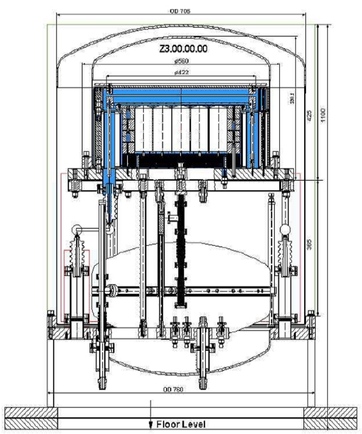
Proposal of ITEP&INR LXe:

D. Akimov, A. Bondar, A. Burenkov, and A. Buzulutskov, JINST 4 (2009) P06010 [arXiv:0903.4821]



Proposal of ZEPLIN-III Collaboration LXe:

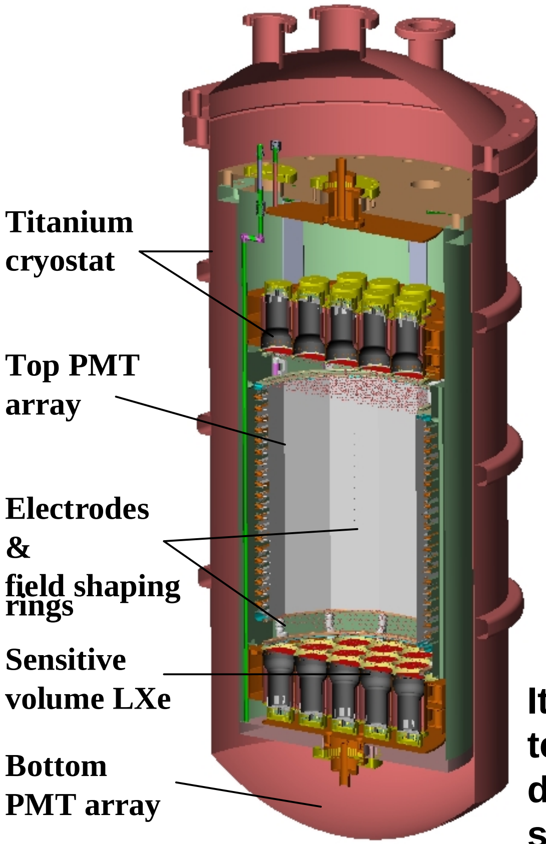
E. Santos, B. Edwards, V. Chepel et al., JHEP 1112 (2011) 115 [arXiv:1110.3056].



Р Э Д

РОССИЙСКИЙ ЭМИССИОННЫЙ ДЕТЕКТОР

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



RED-100 is a two-phase noble gas emission detector. Contains ~250 kg of LXe, ~100 kg in FV.

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

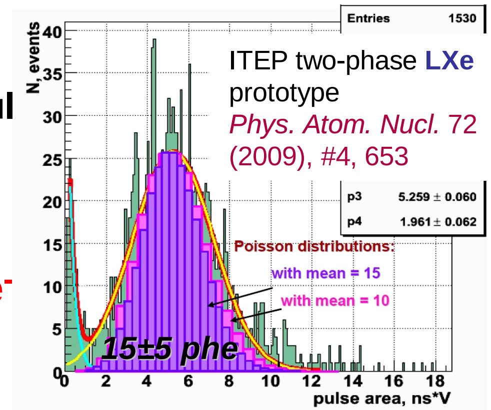
PMTs are Hamamatsu R11410-20 (low-background); 38 in total (2 x 19)

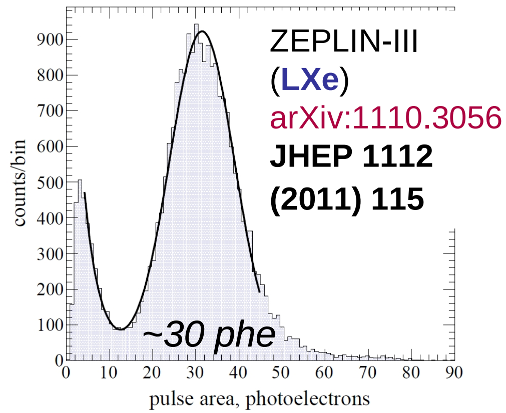
Drift field is **~ 0.5 ÷ 1 kV/cm**;

Field in EL region is **~ 7 ÷ 10 kV/cm** (in the gas phase).

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

It is a very powerful technique for detection of very small ionisation; **down to single e⁻**





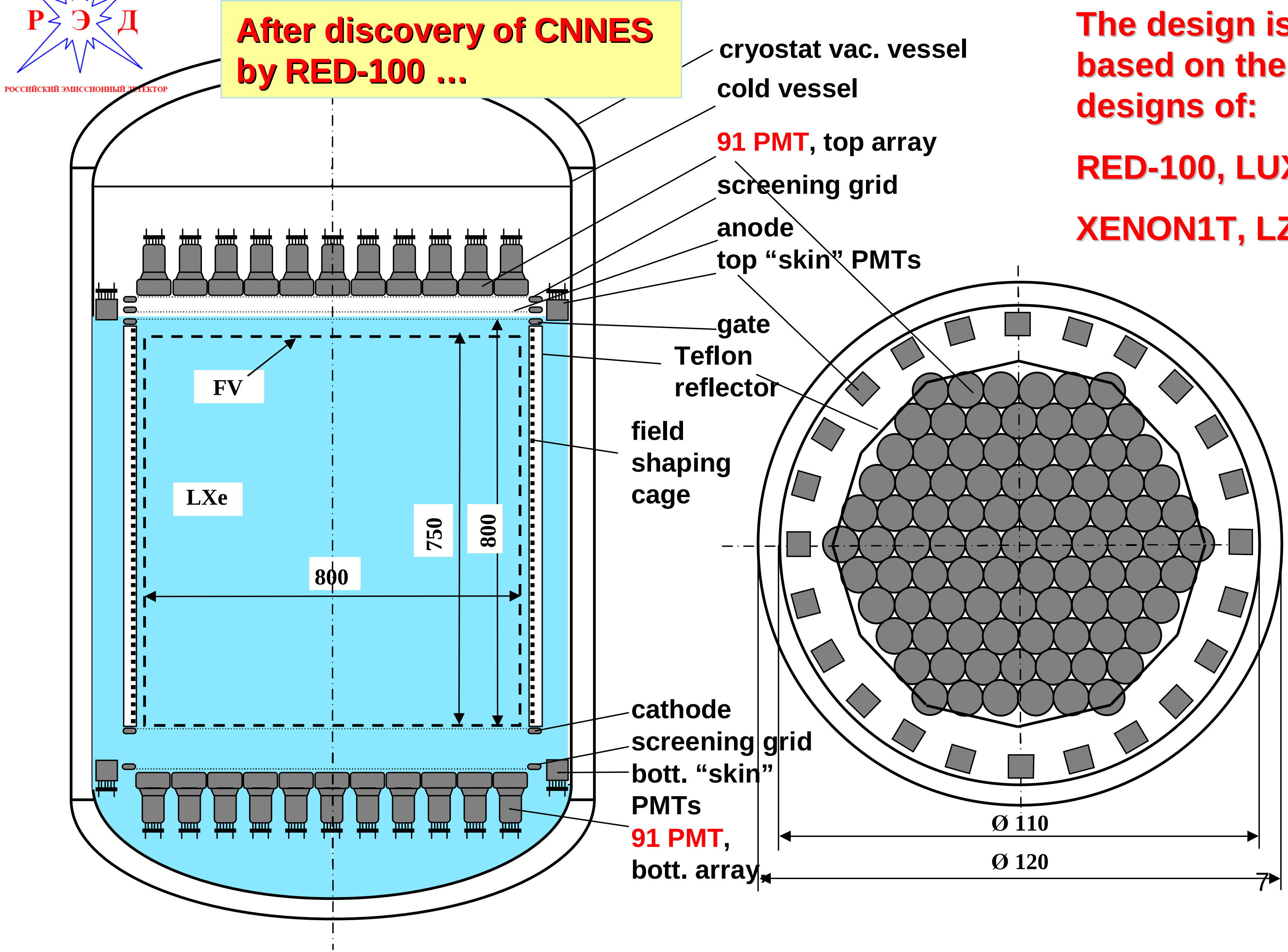
RED-1000 schematic design (~1000 kg of LXe in FV)

After discovery of CNNES by RED-100 …

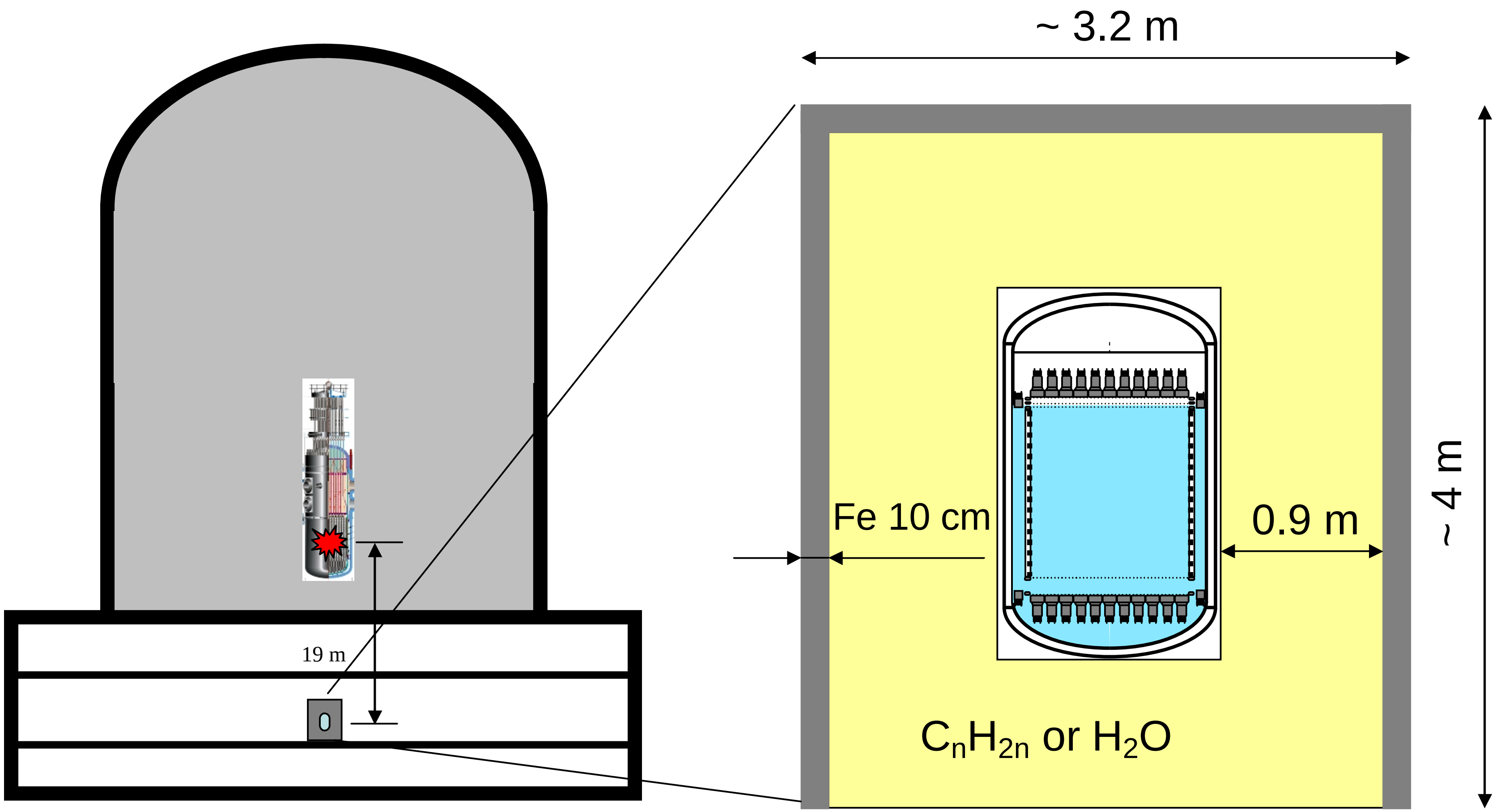
The design is based on the designs of:

RED-100, LUX

XENON1T, LZ



Layout of RED-1000 at W W E R - 1000 reactor (KNNP)



At this location:

$\tilde{n}$ flux = $1.35 \cdot 10^{13}$ $cm^{-2}s^{-1}$

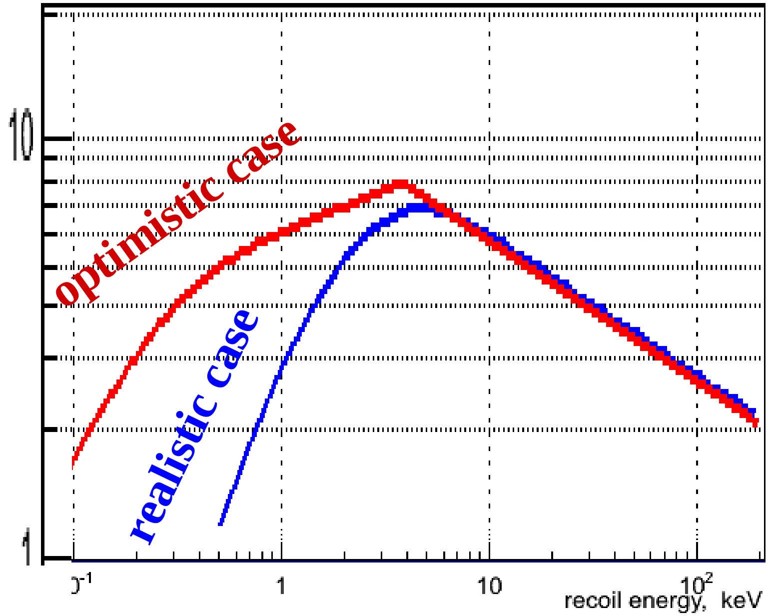
μ flux is reduced by factor ~5

RED-1000 basic characteristics

Ionisation yield for sub-keV nuclear recoil

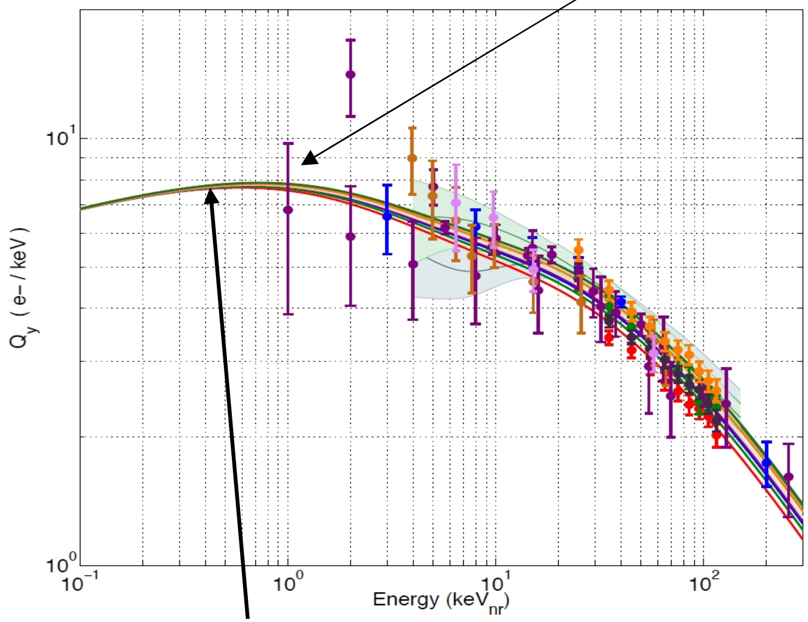
3 y ago!

No experim. data below 1 keV$_{nr}$



Now!

LUX data



We considered
"optimistic" and "realistic" scenarios

NEST – Noble Element Simulation Technique

Interaction cross-section: energy averaged <σ> ≈ $7 \cdot 10^{-41}$ cm^2

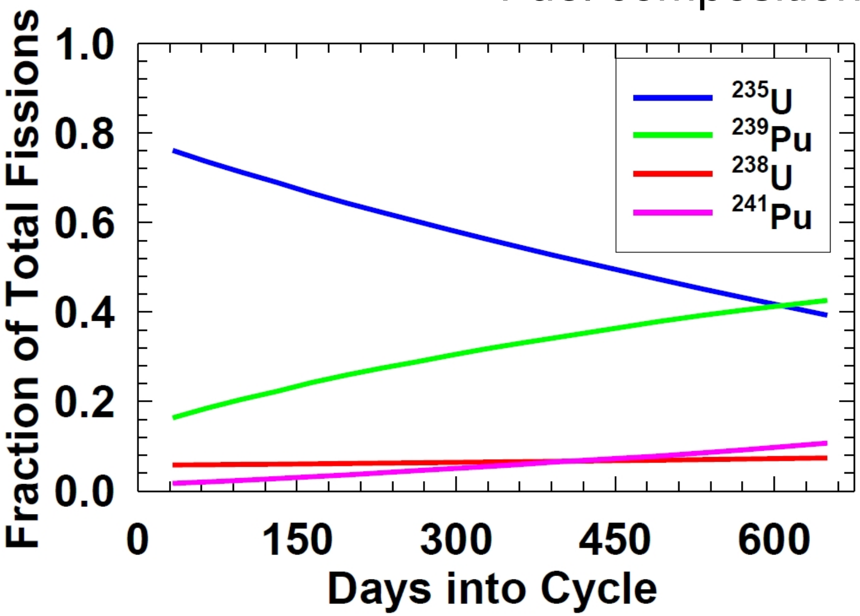
With these yield and <σ> è count rate ≈ 30000 event day^{-1} t^{-1} (bckg is by > 10 less)

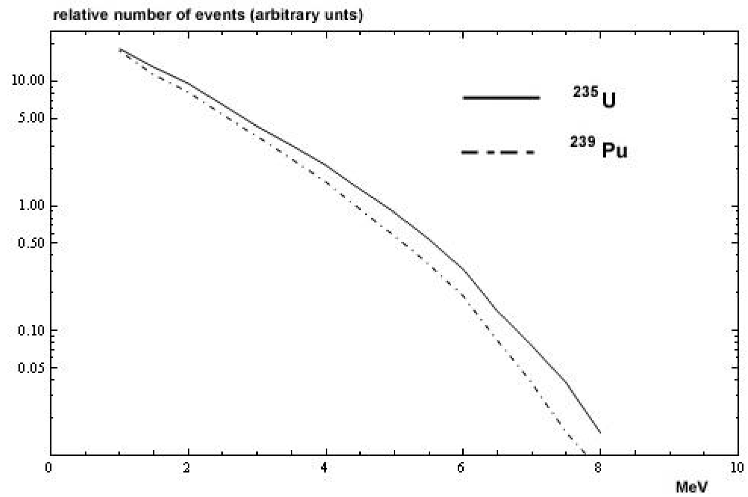
for events with $N_e \geq 2$ 8% detection efficiency

(total number of interactions = 384000 day^{-1} t^{-1})

What can we do with this detector?

- Thermal power monitoring in real time
- Fuel composition monitoring





$\tilde{n}$ energy spectra for ^{235}U and ^{239}Pu

This results in ~12% count rate reduction over the course of a 600 day cycle

or ~ 0.2% /10 days

The number 30000 events /day

is enough for DAILY monitoring of power with statistical accuracy

~ 0.6%

=> 300000 evens/10day

statistical accuracy ~ 0.2%

Detector CAN see variation of the $\tilde{n}$ flux due to fuel burn-up

SUMMARY

- **Coherent neutrino-nucleus elastic scattering is very attractive for reactor monitoring due to its “huge” cross-section**
- **After discovery of this process by RED-100, we propose scaling up of this technique to a ton-mass detector**
- **Statistical accuracy of neutrino flux measurements (for 10-day intervals) will be of the same magnitude as the variation of the neutrino flux due to fuel burn-up**