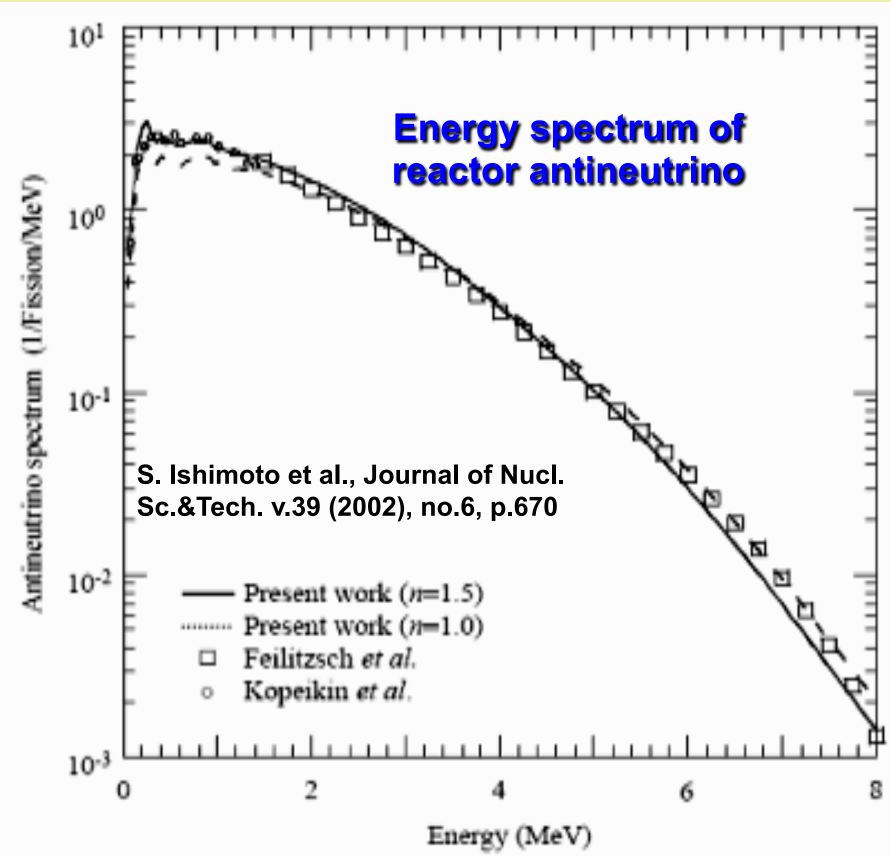
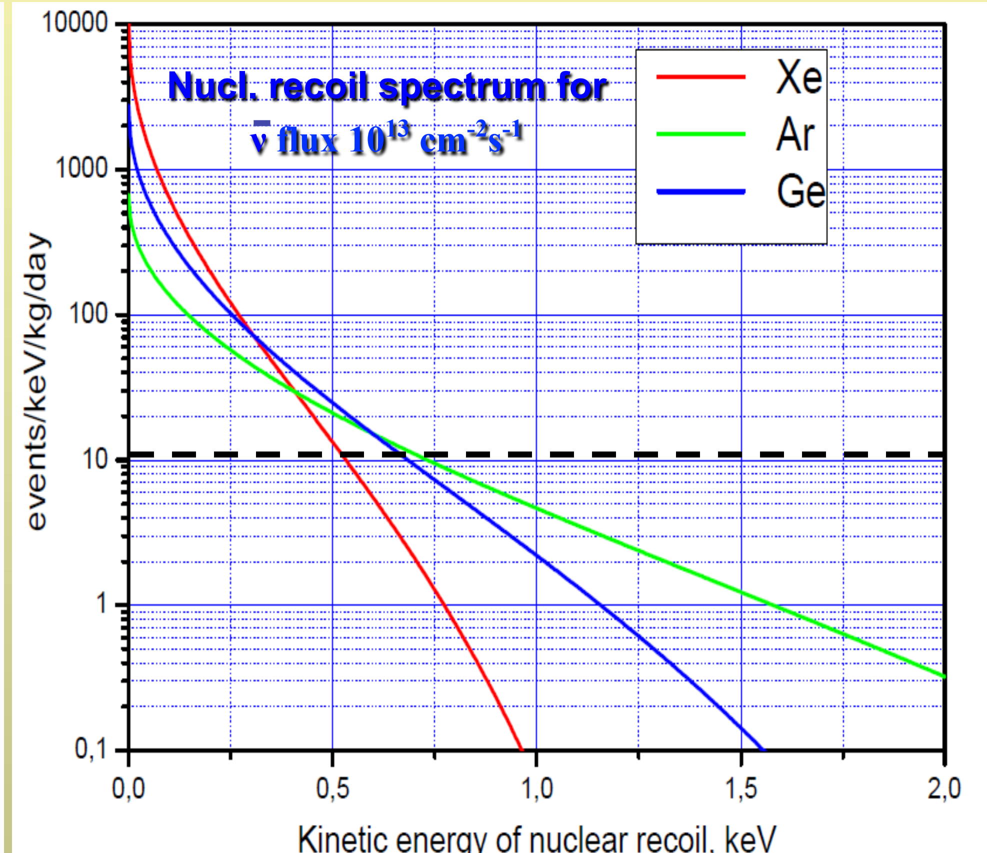
Detection of Small Ionization Signals in a Two-Phase LXe Detector: Successes and Obstacles

D.Akimov
ITEP&MEPhI, Moscow

1-st obstacle: single electron noise (SE)

For CS experiment, a detector must have extremely low energy threshold

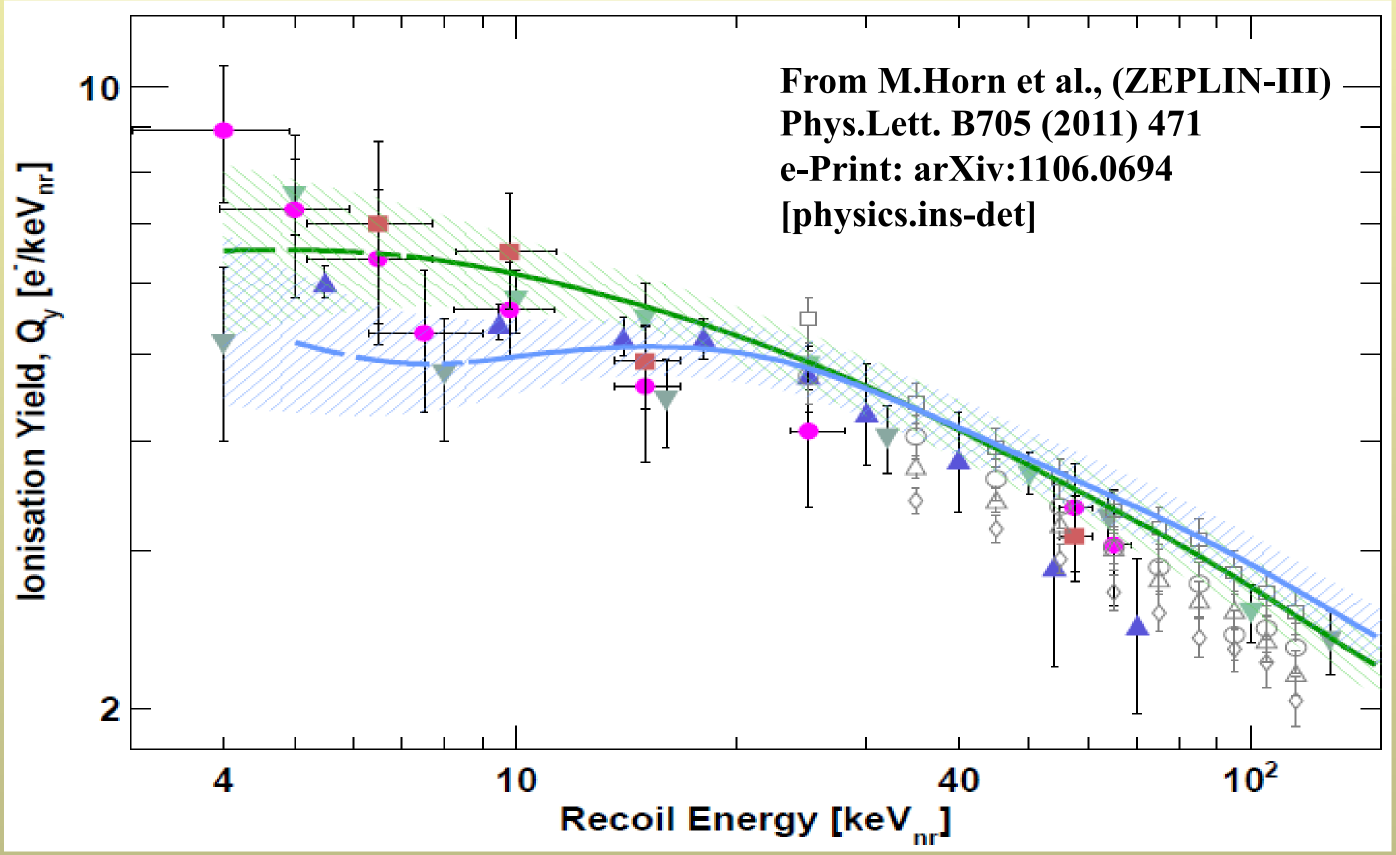




Ionization yield of the LXe for NR

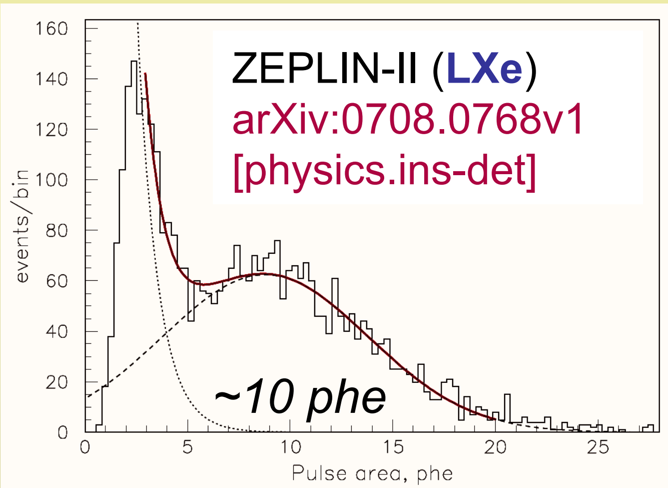
is a very important parameter!

Experimental data on ionization yield for NR are available for ≥4 keV for LXe

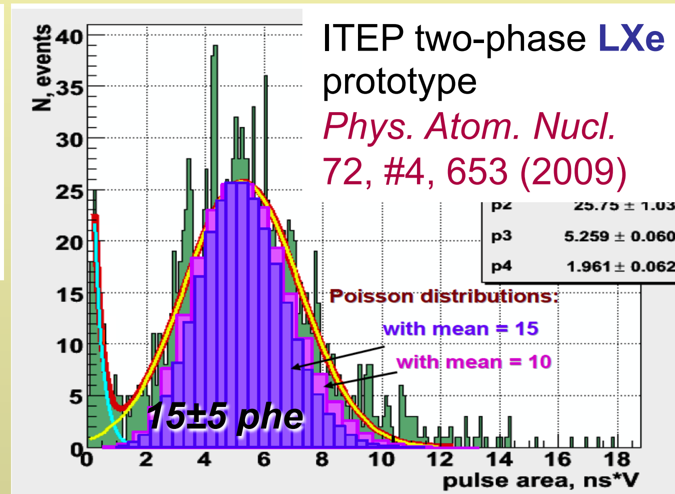


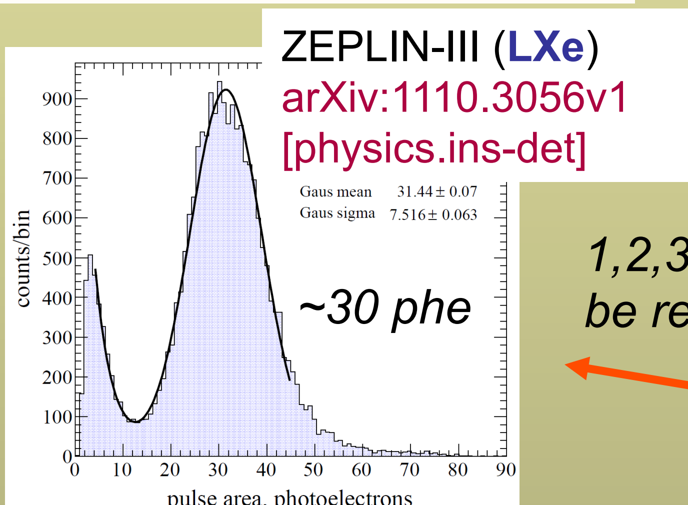
A detector must have single electron sensitivity

Two-phase noble gas detectors can do this.
They possess the large mass and the good amplification capability in gas phase:
avalanche multiplication (wires, GEM, THGEM, micropixels etc.)
electroluminescence - can provide SE “spectroscopy”

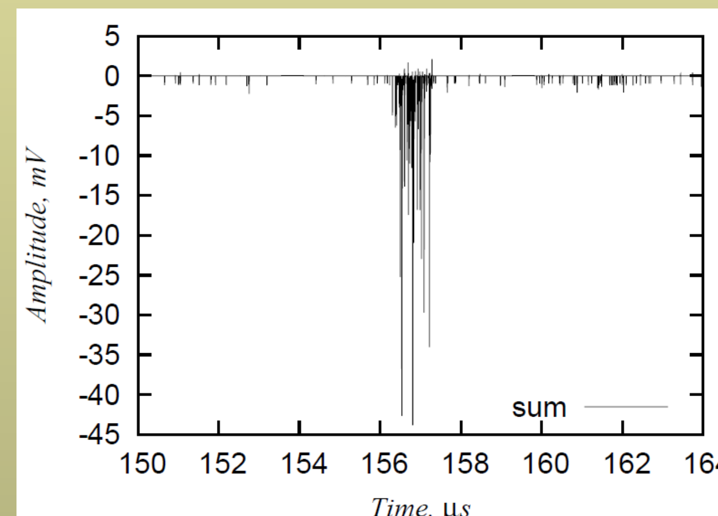


Xenon10:
24±7 phe
arXiv:
0807.0459v
1 [astro-ph]



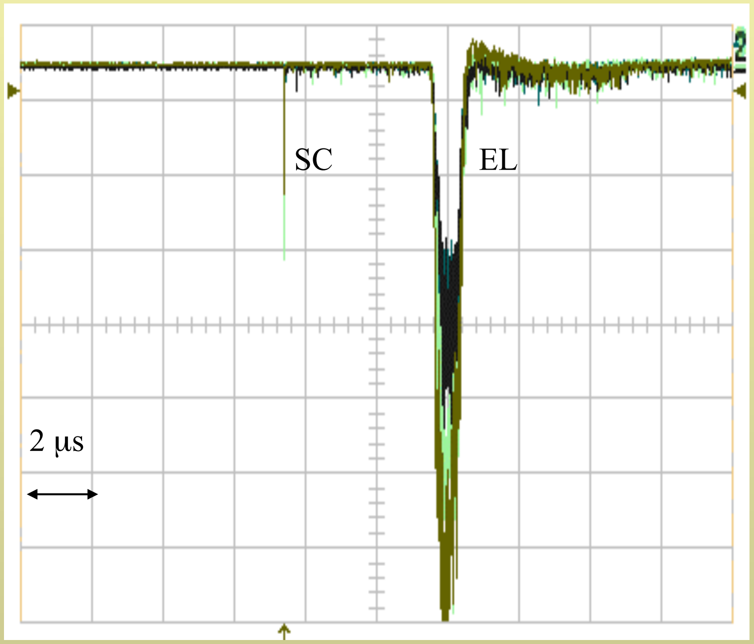


1,2,3,… e^- can be resolved

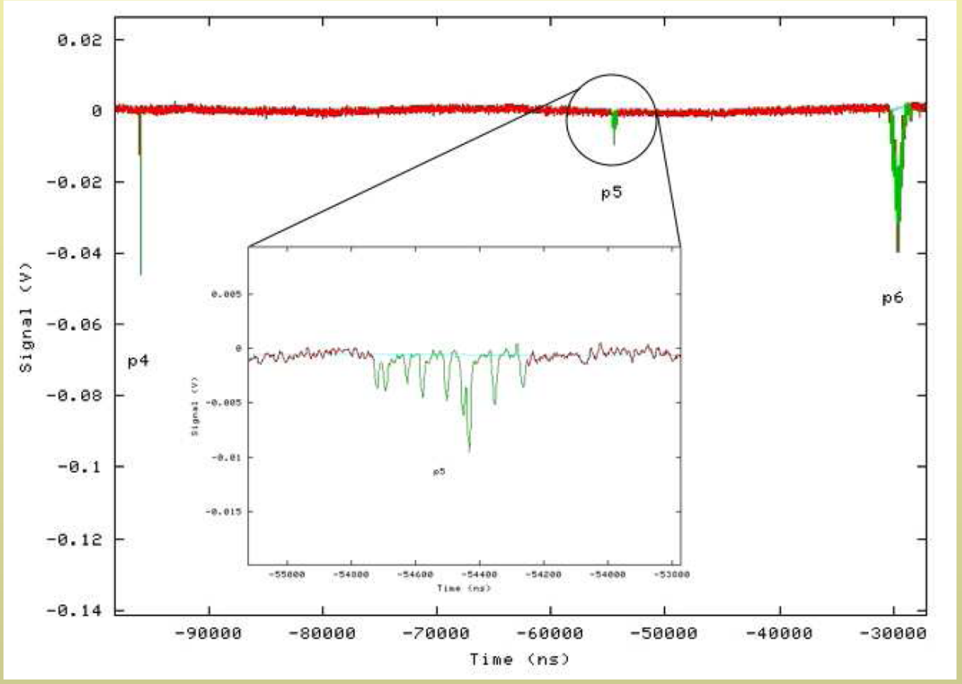


SE noise have been discovered for LXe two-phase detectors!

In our early tests in ITEP:



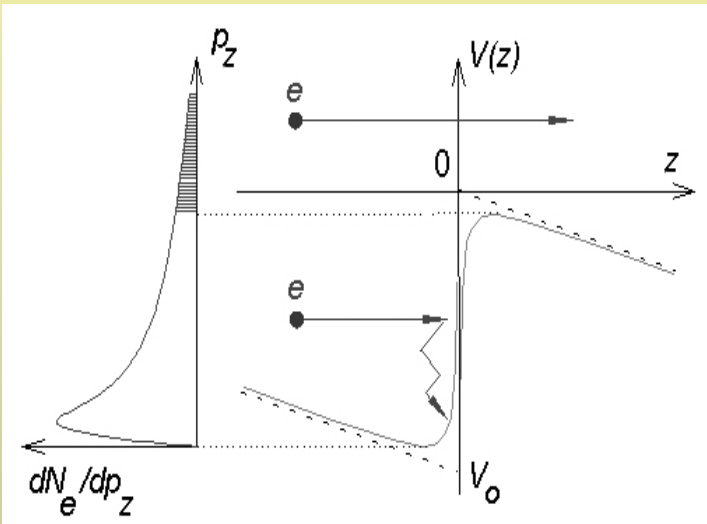
In ZEPLIN-II:



Later it was found that SE may be not correlated with the events, and the rate is significant ~ tens Hz!

Origin of the SE noise

E. Aprile, A.E. Bolotnikov, A.I. Bolozdynya, and T. Doke
Noble Gas Detectors
WILEY-VCH Verlag GmbH & Co. KGaA, 2006:



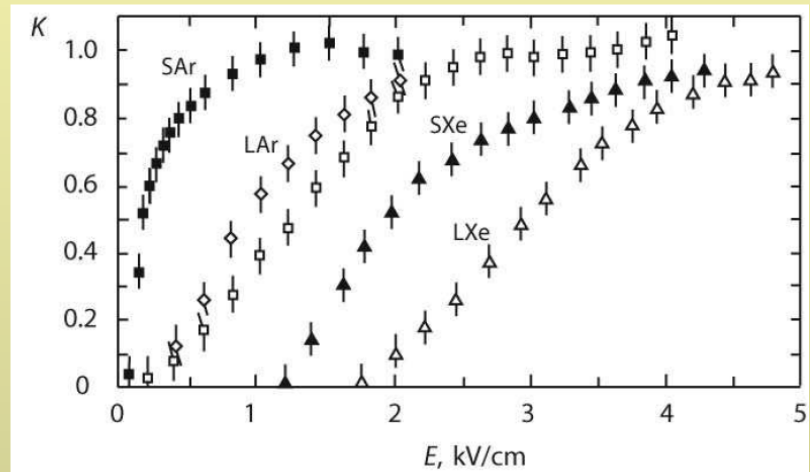


Fig. 3.21 Coefficients of quasifree electron emission from solid argon (SAr, $T = 80$ K), liquid argon (LAr, $T = 90$ K), closed circles is the fast component, open circles is the slow component, solid xenon (SXe, $T = 160$ K), and liquid xenon (LXe, $T = 165$ K) dependent on the electric field in the condensed phases. Redrawn from [148].

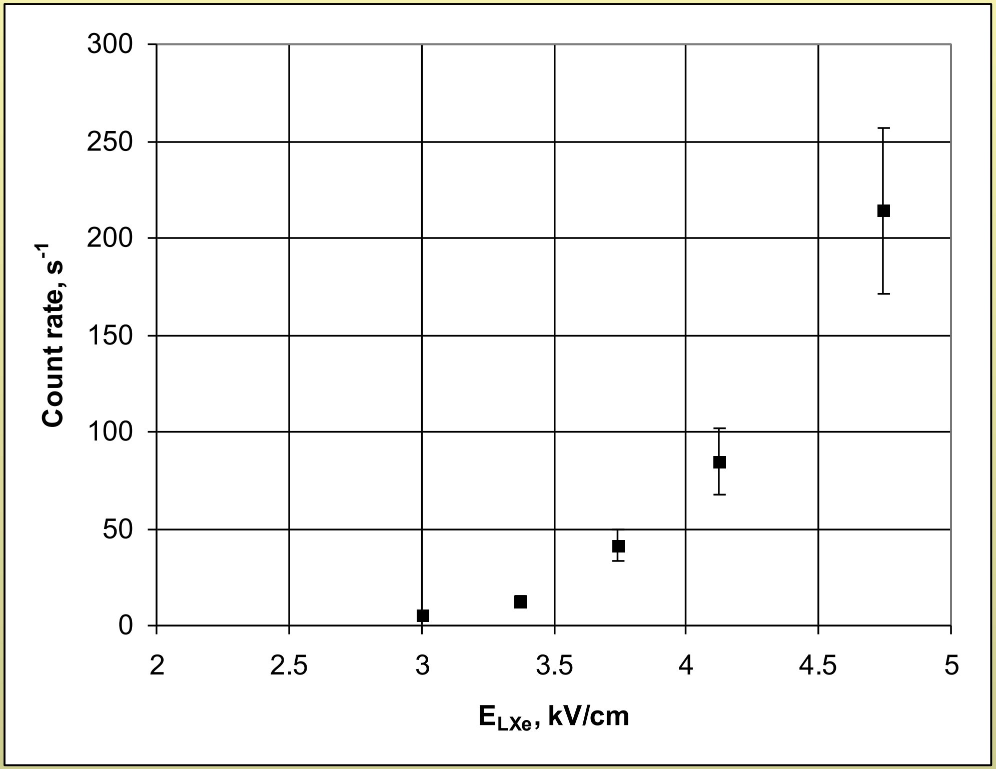
K ≠1.0 for the operation fields

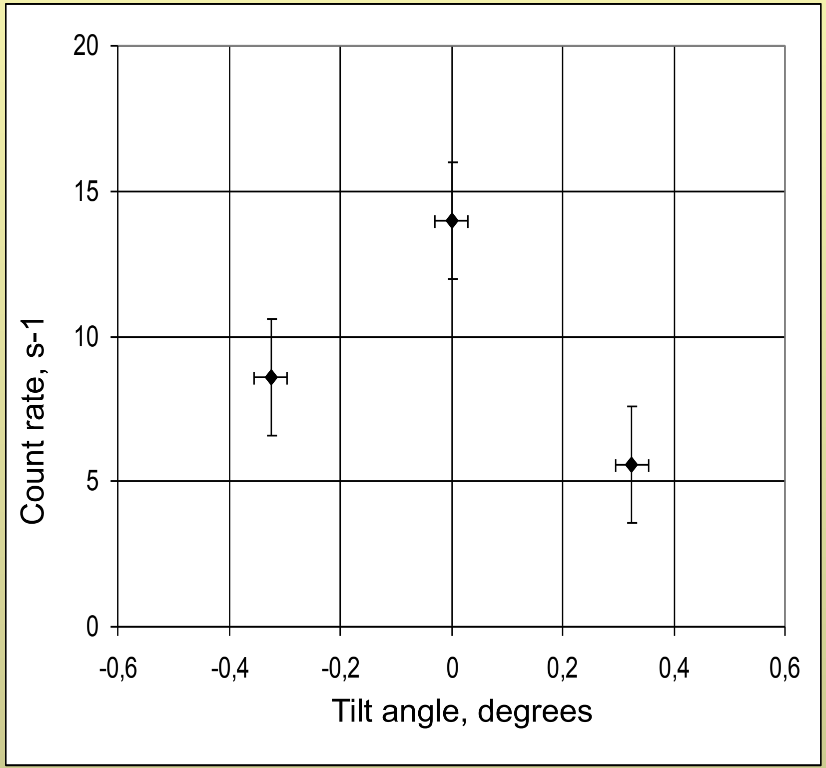
The charge is stored under the surface

SE rate vs E (in LXe)

SE rate vs angle of tilt

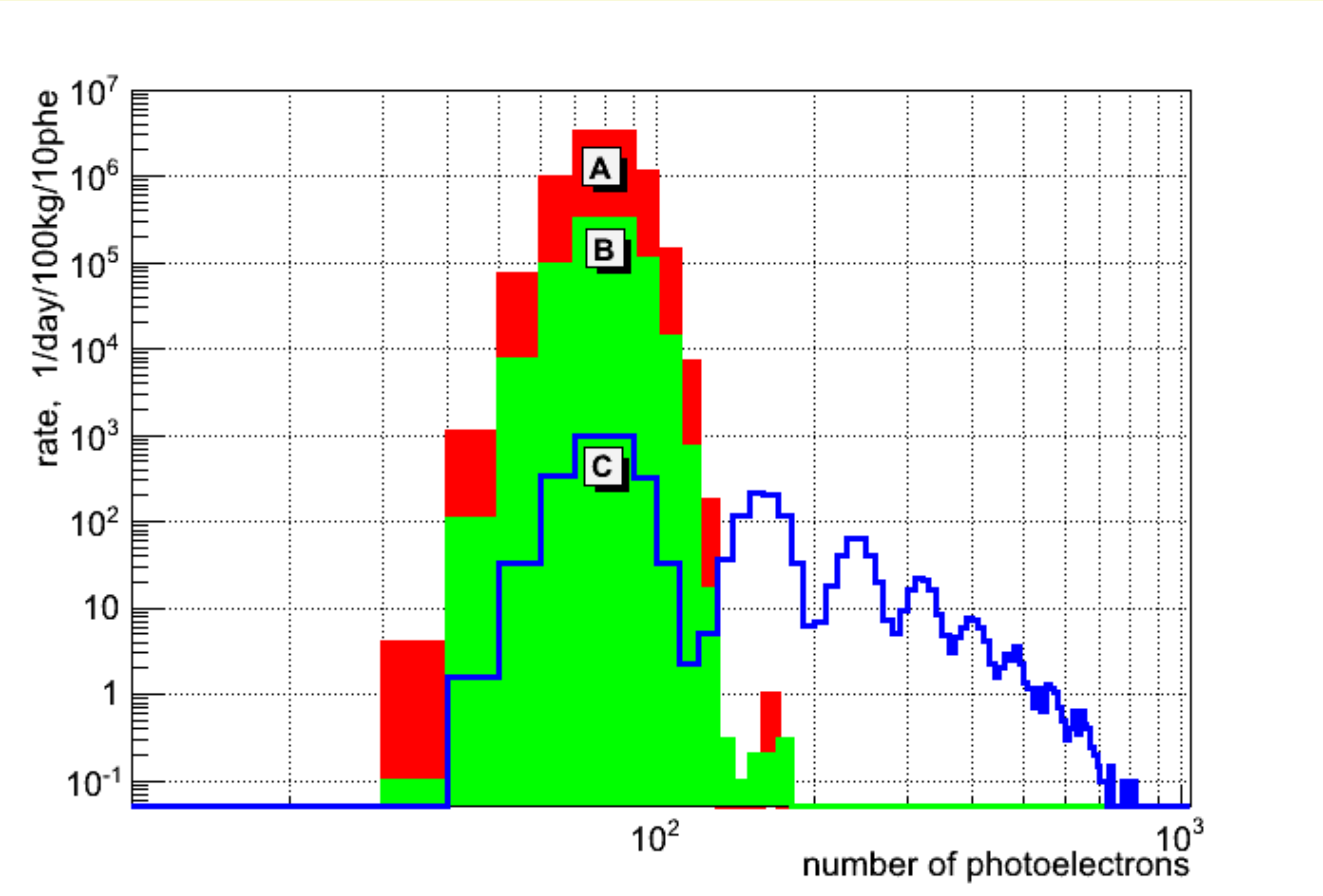
In the tests with ITEP two-phase prototype (RED1):





The SE rate also increases when the detector is irradiated by a radioactive source [ZEPLIN-III arXiv:1110.3056v1 [physics.ins-det]]

RED100: calculated count rate for CS and SE rate (10 and 100 Hz)



For RED100, the expected # SPE per SE = 80

For threshold >2 SE, ~ 400 day^{-1}

Subconclusion

Obstacle: SE noise

A detector for CS must have excellent single electron resolution to reject SE noise:
only detectors with EL and/or very limited avalanche multiplication can be used!

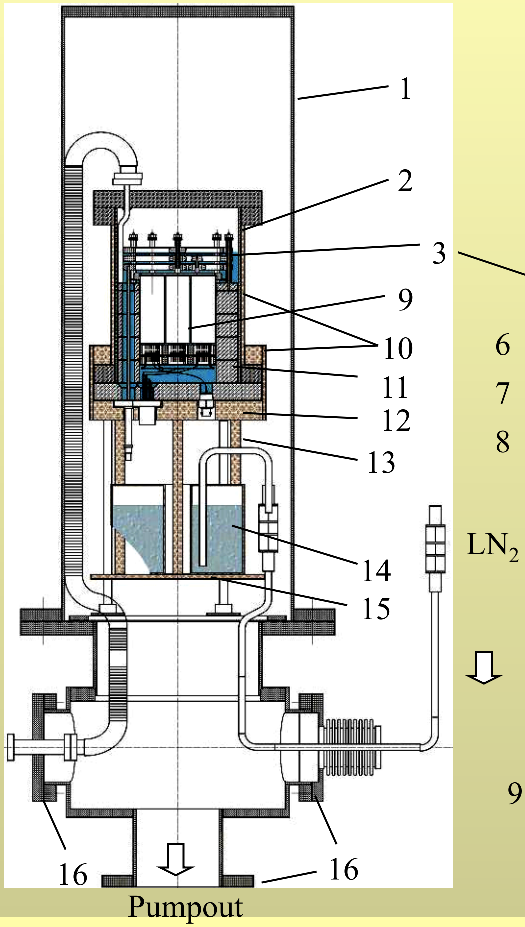
Success: we know how to deal with it

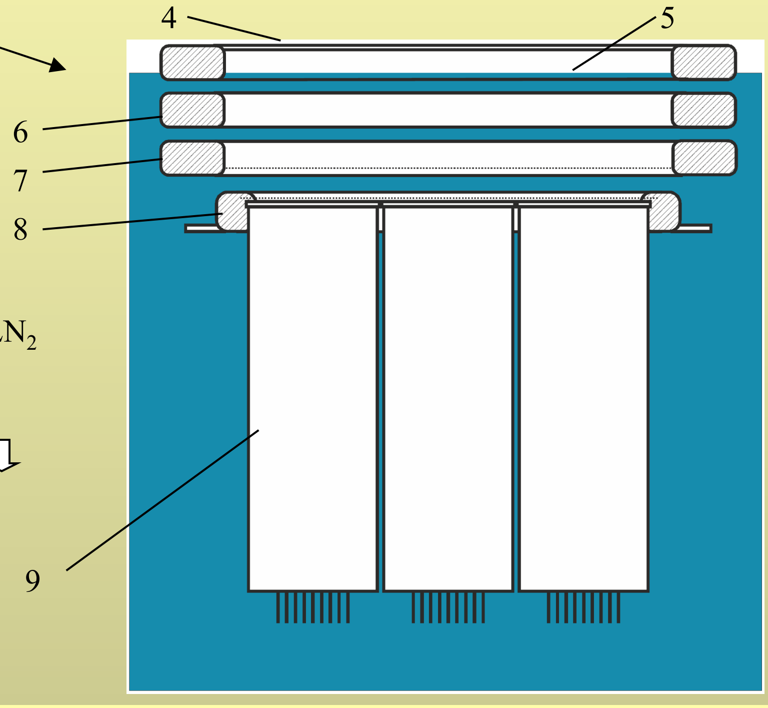
2-d obstacle: LXe purity

Since there is NO (or very small) SC signal, the requirement for purity is much stronger than that for DM detectors because the Q cannot be corrected for Z

Although many experimental groups (Xenon, ZEPLIN, LUX, EXO) have reached e-lifetime of >hundreds μs, there may be unexpectable obstacles on this way!

Detector prototype (RED-1)





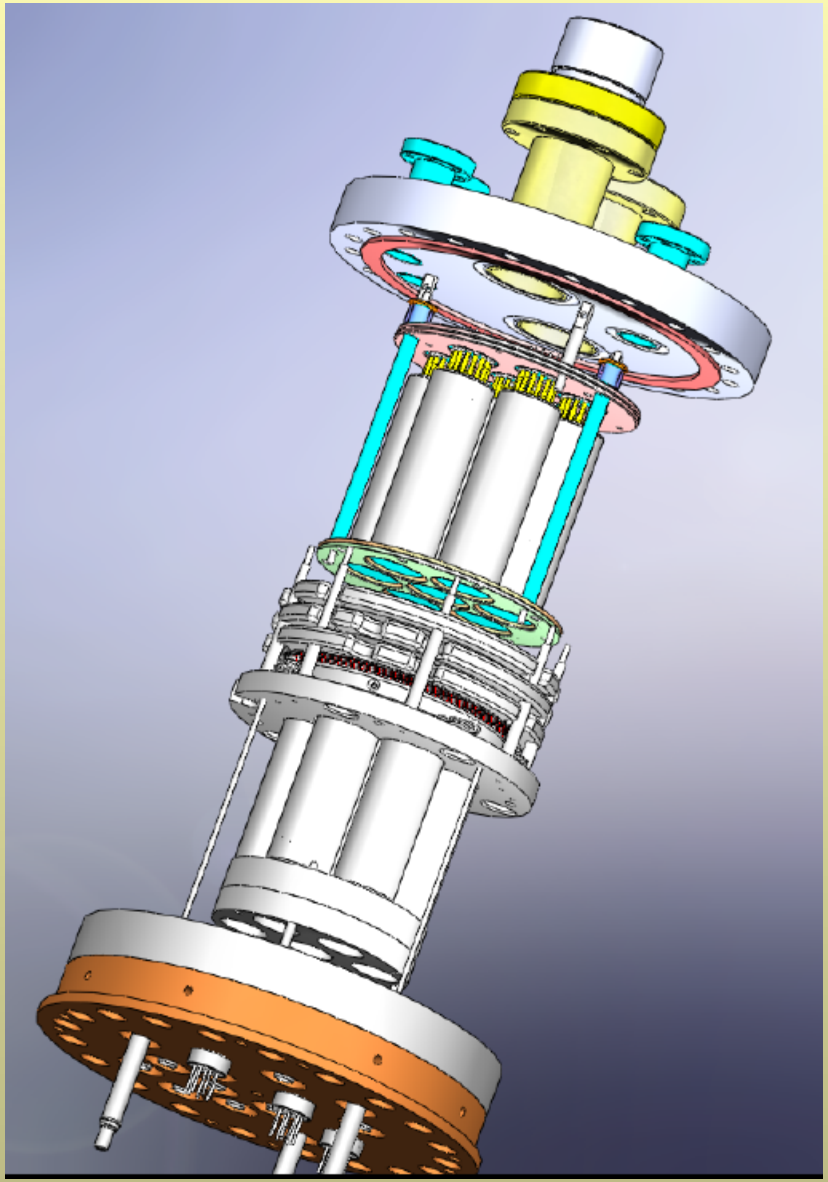
7 PMTs with MgF_2 windows; QE ~ 15%

Two-phase emission detector for measurements of the LXe, LAr response at the sub-keV energies of nuclear recoils.

1 – vacuum jacket; 2 – chamber for LXe/LAr filling; 3 – electrode structure; 4 – mirror anode; 5 – surface of LXe/LAr; 6 – intermediate field shaping ring; 7 – wire cathode (0.1 mm diam., 1 mm pitch); 8 – screening electrode (0.1 mm diam., 1 mm pitch); 9 – PMTs; 10 – copper jacket; 11 – LXe displacers; 12 – copper base; 13 – copper fingers; 14 – LN_2 vessel; 15 – copper base of LN_2 vessel; 16 – vacuum ports.

This detector had been built as a prototype of ZEPLIN-III DM detector

RED-1 upgrade

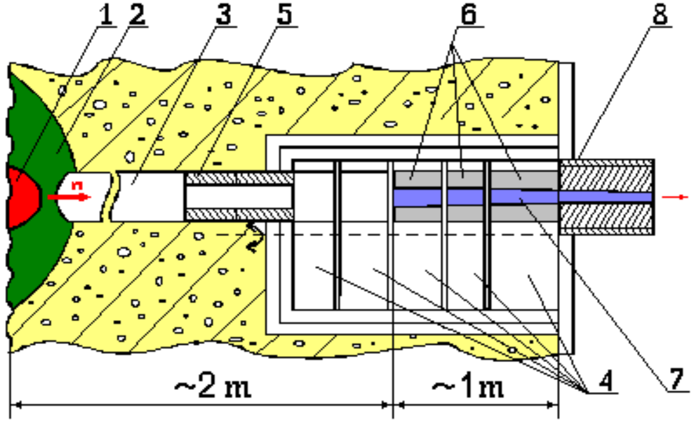


We plan to upgrade the RED-1 in the next 2013y by installing the top array of PMTs.

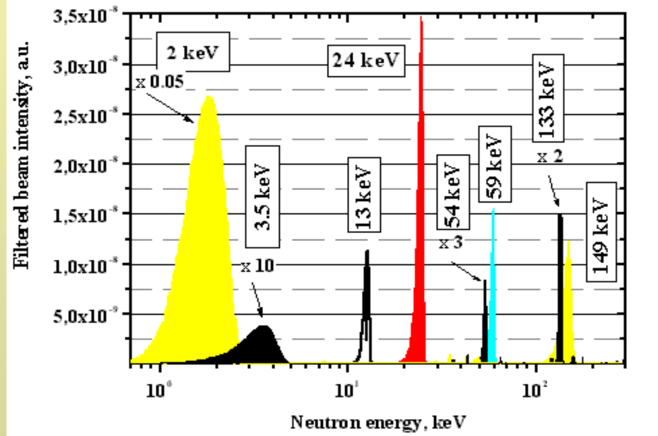
After that we will have ~30 SPE/SE

A filter is installed in a neutron channel to produce a quasy-monoenergetic neutron beam

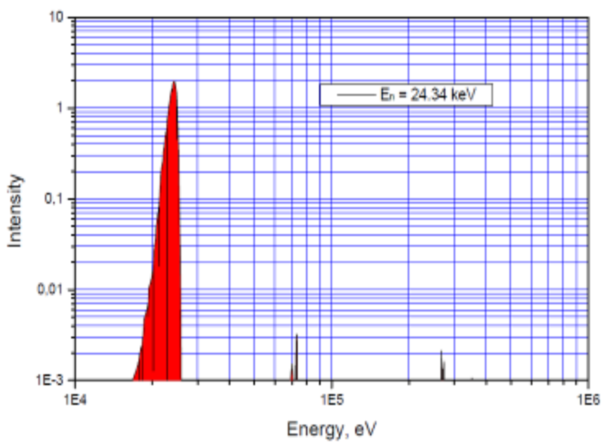
O.Gritsai talk at NPAE-Kyiv2010 "Reactor Neutron Filtered Beams for Precision Neutron Cross Section Measurements"

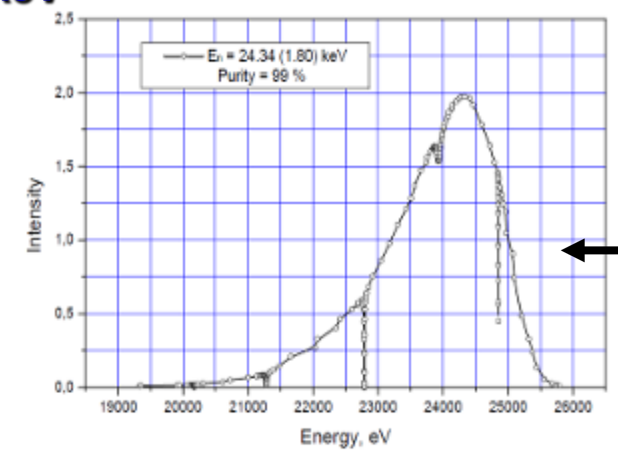


Quasy-lines from different filters:



Fe-Al filter: 24 ± 1.5 keV



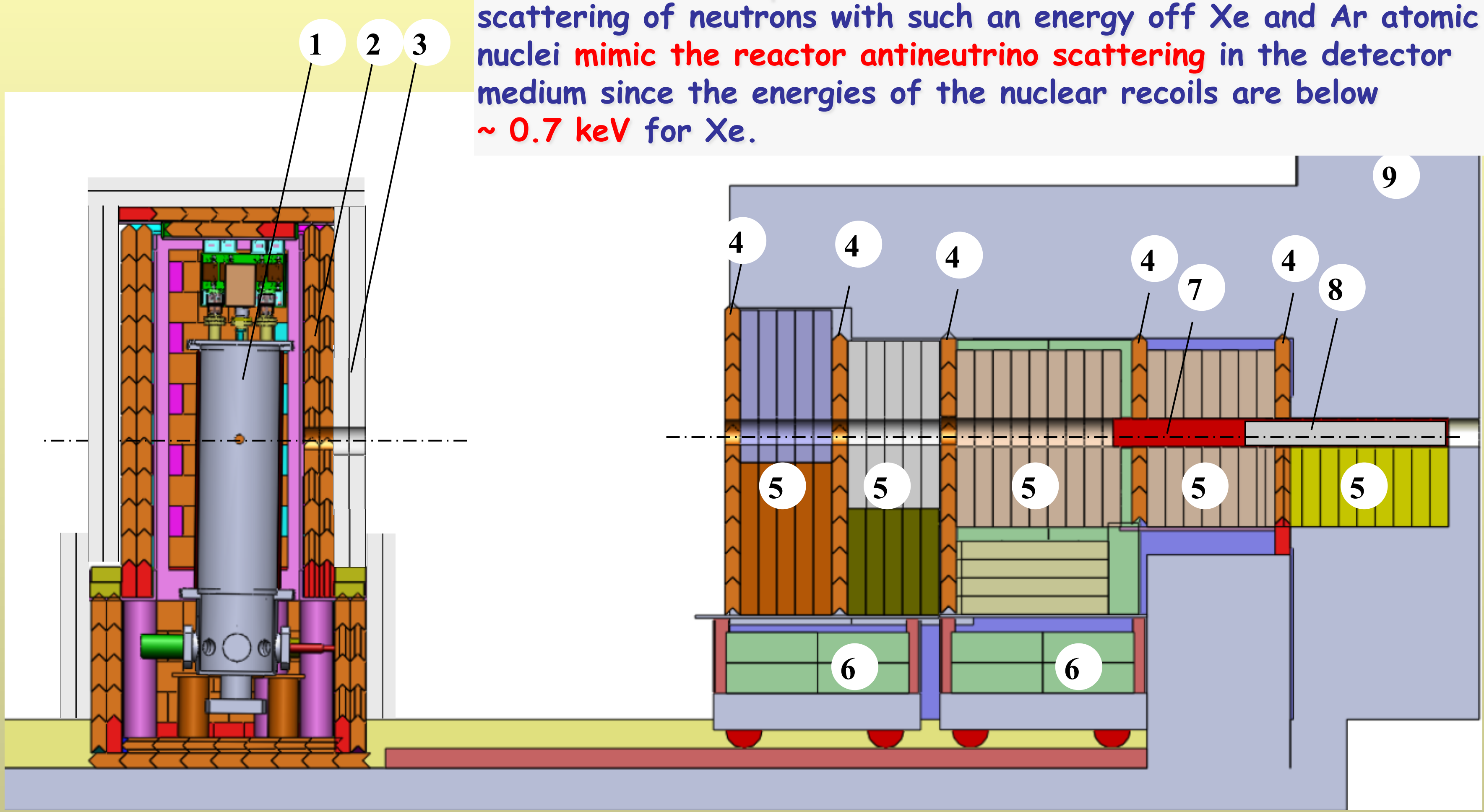


Obtained with LND 281 hydrogen-filled counter

Another possibility: Si-Ti (54 ± 1.5 keV and 149 ± 7 keV)

Experiment at the MEPhI research reactor

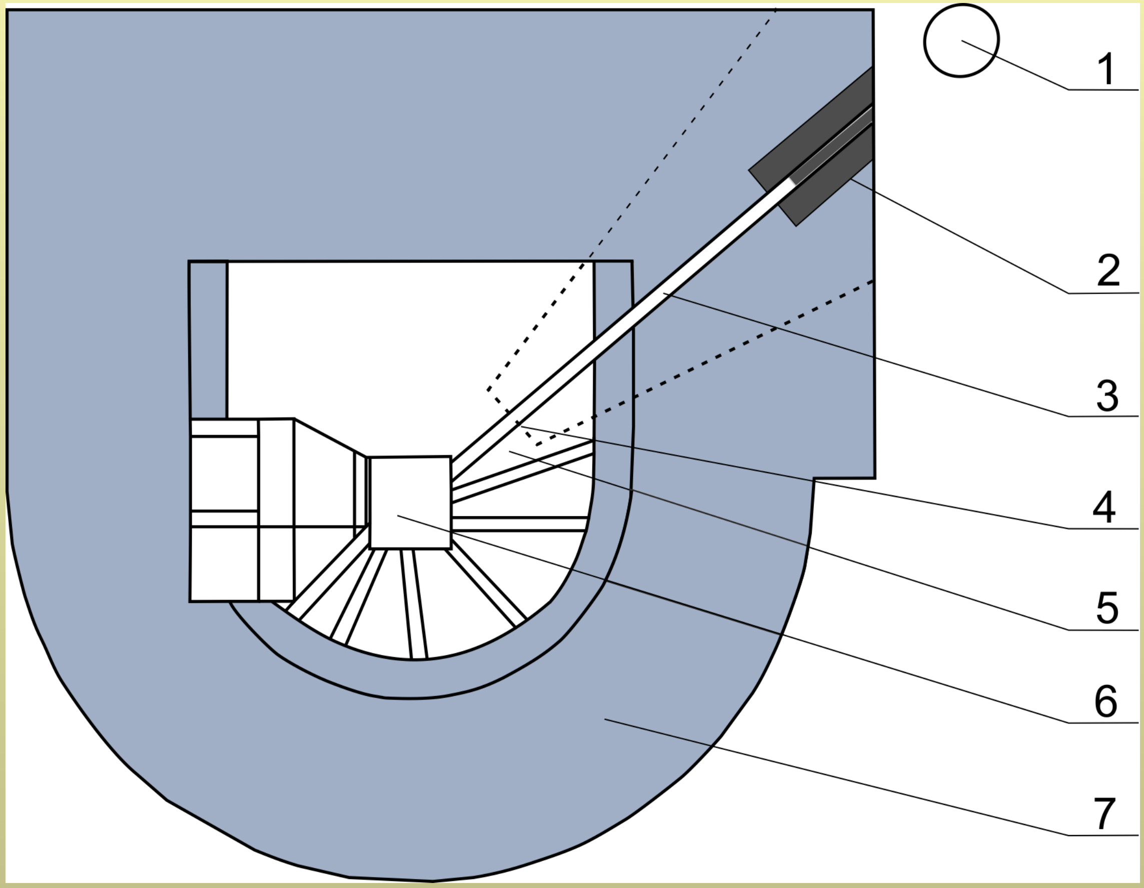
Fe-Al filter which produces a 24-keV neutron beam. Elastic scattering of neutrons with such an energy off Xe and Ar atomic nuclei **mimic the reactor antineutrino scattering** in the detector medium since the energies of the nuclear recoils are below **~ 0.7 keV** for Xe.



1 – **RED-1** detector, 2,3 – detector passive lead (10 cm) and borated polyethylene (10 cm) shield, 4 – lead layers (5 cm each), 5 – polyethylene blocks made of 5-cm slabs, 6 – paraffin, 7,8 – **Fe (30 cm)** and **Al (70 cm)** parts of the filter, correspondently, 9 – reactor concrete shield.

The beam energy profile will be measured with LND 281 hydrogen-filled counter (coming soon)

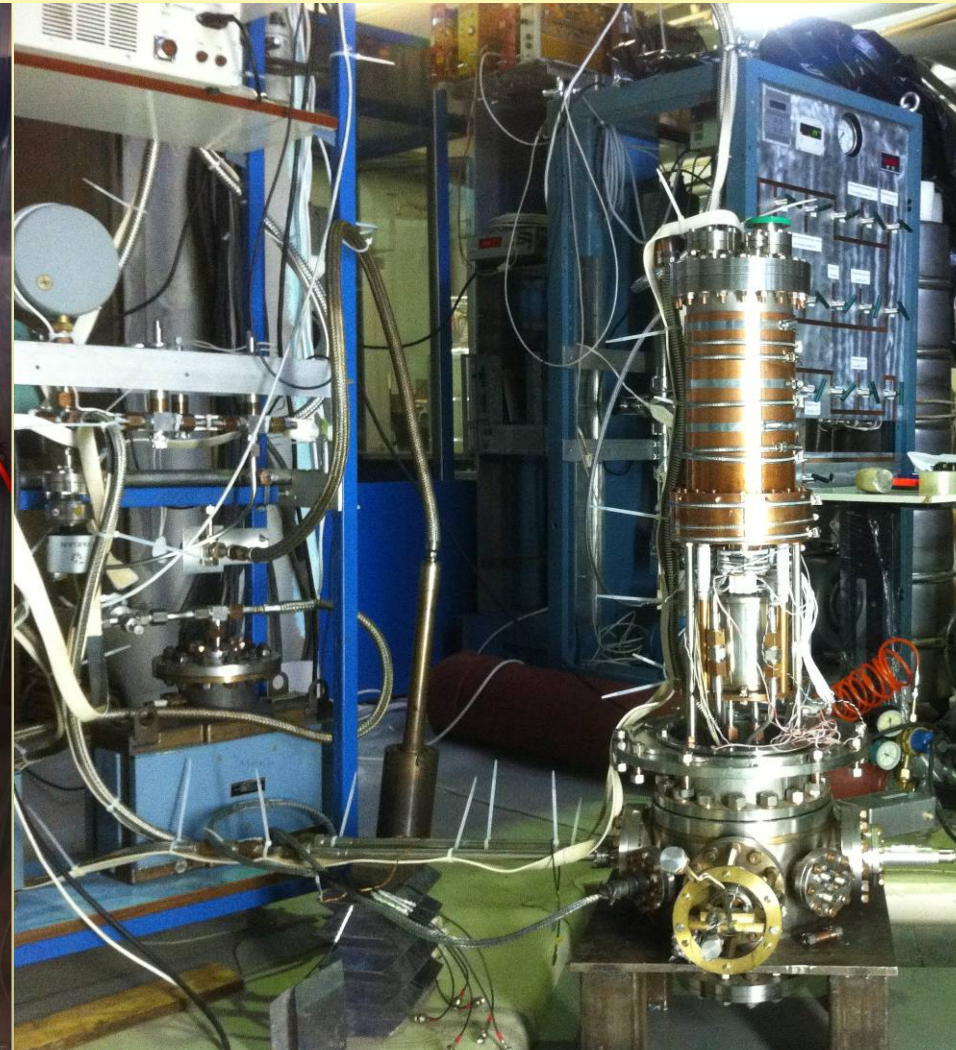
Scheme of the MEPhI research reactor



1 – detector area;
2 – Fe-Al filter;
3 – horizontal channel #10;
4 – the region taken for MC simulation of the filter+shield+ collimator;
5 – water;
6 – the reactor core;
7 – reinforced radiation shield

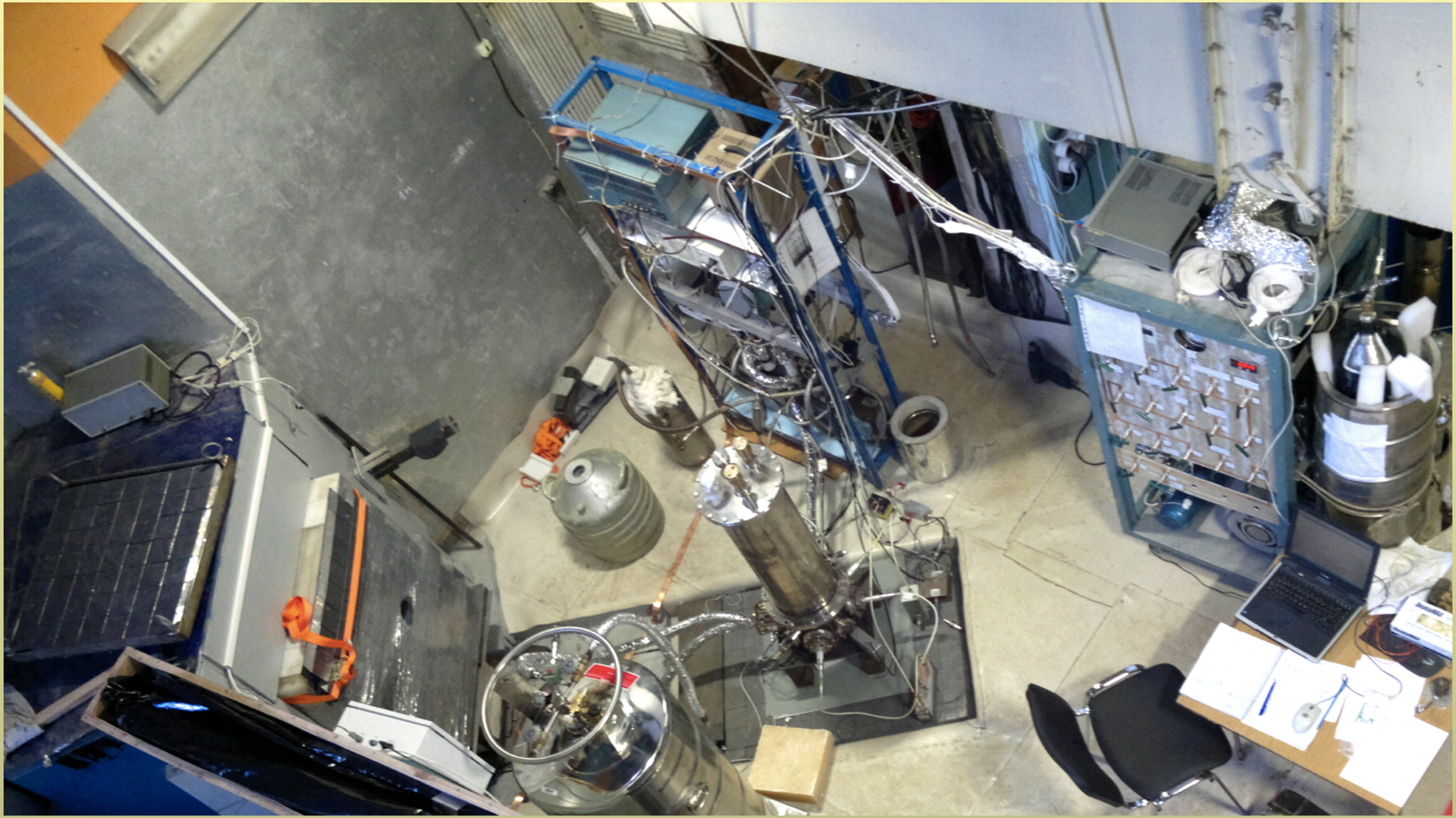
RED-1 assembling

Detector assembling in a portable soft-wall clean room at the beam location



Detector (without vacuum jacket) and gas system at the beam location

Detector at the beam site (MEPhI reactor)



Detector at the beam site (MEPhI reactor)

NaI(Tl) and
Bicron BC511

for background
measurements

Electronics

The electronics of the RED-1 is based on VME, NIM and CAMAC modules.

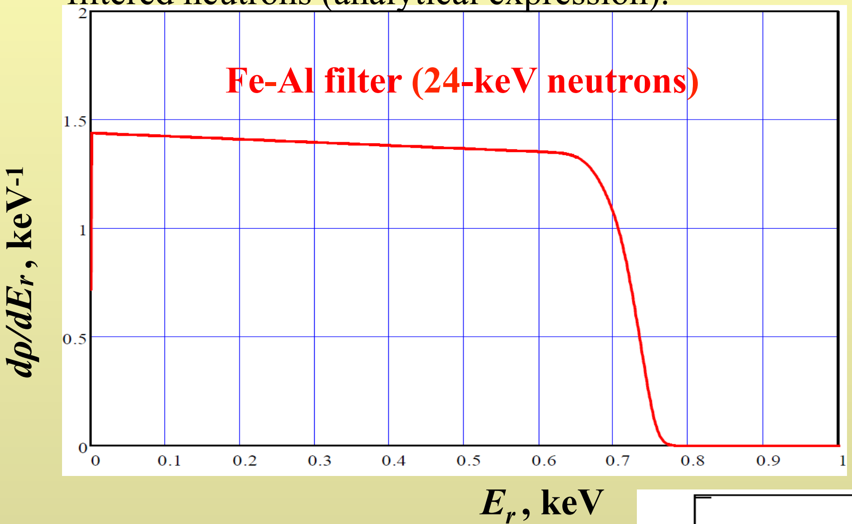
DAC – is performed on the basis of Struck **SIS3350** 500 Ms/s (12 bit)

and CAEN **V1720** 250 Ms/s (12 bit) digitizers

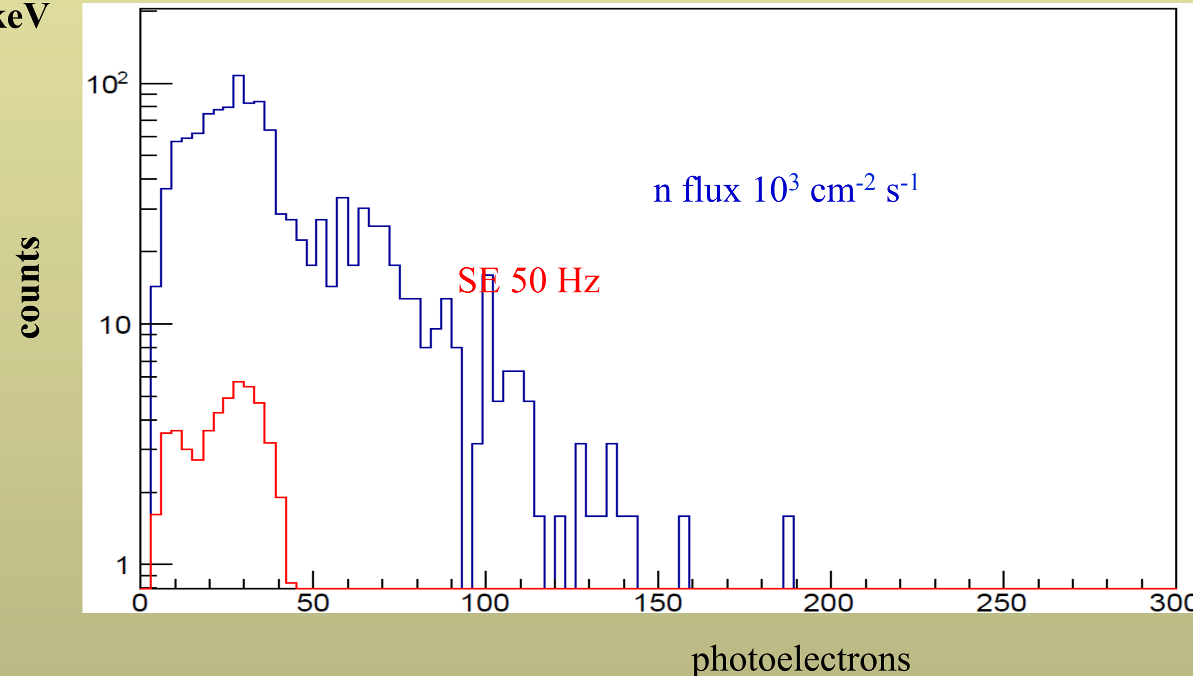
for the high (with additional amplification) and low sensitivity channels, correspondently

Measurement of ionisation yield

Differential energy spectrum of nuclear recoils from filtered neutrons (analytical expression).



Obtaining of the specific ionisation yield will be done by comparison of the measured charge spectrum with the expected one where this value will be used as a free parameter:



MC simulated response of the RED-1 detector for 24-keV neutrons.

1^{st} test run

1^{st} test run – 18 ÷ 24 June 2012

Liquefaction process + slow control

+ recuperation back to cylinder - OK

Trigger and DAC - OK

HV electrodes - OK (up to 15 kV!)

HV PMTs - small corona discharges started at the end of run

Circulation system - is not working yet, need heat exchanger

LXe purity - not very good: ~ 2 μs

Injection of ^{85m}Kr - OK

Reduction of gamma bckg by the shield - OK (by a factor of 30÷40!)

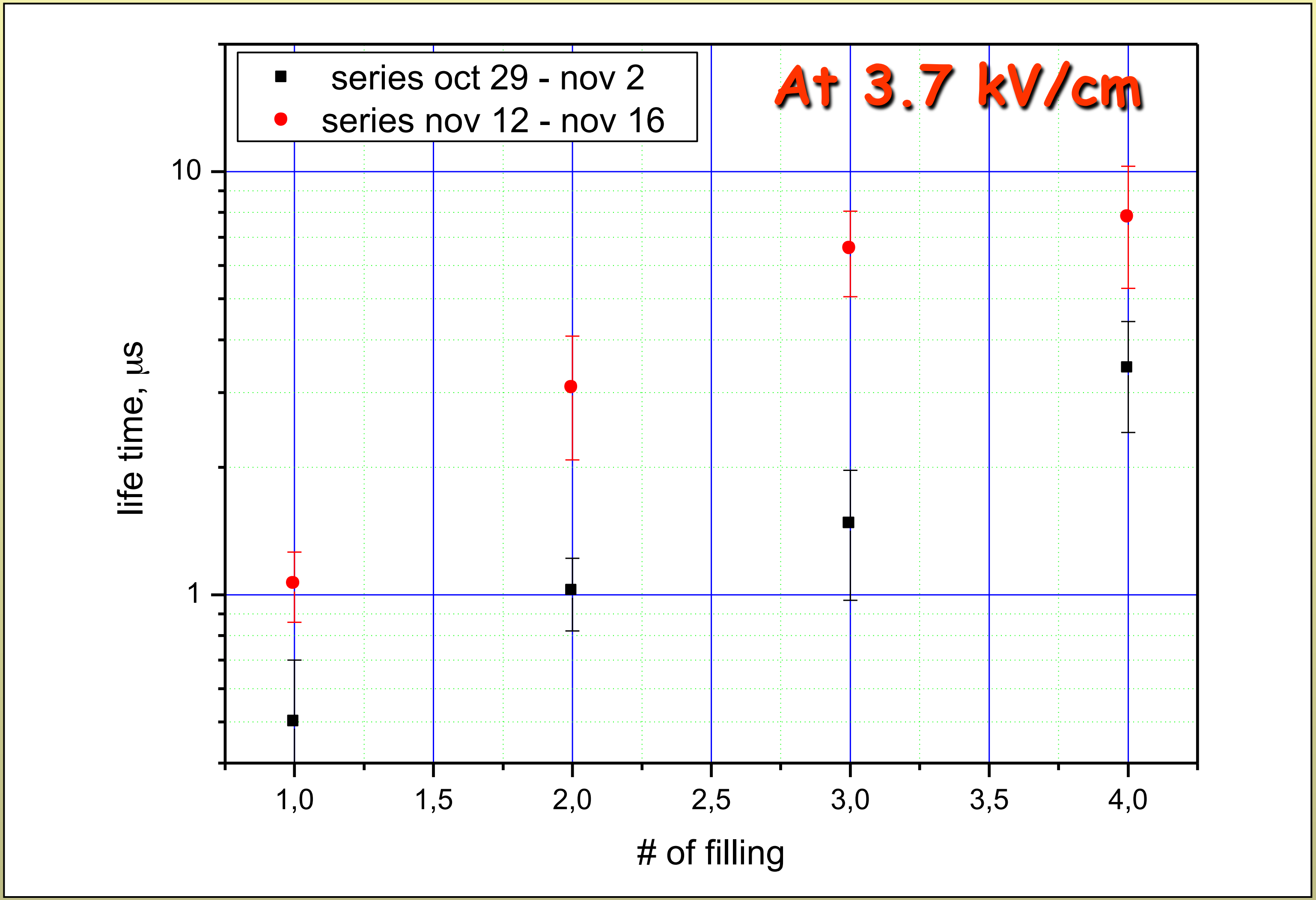
2^{nd} series of test runs (sep – nov 2012)

After opening the chamber in the august 2012 we encountered unexpectedly with a purity problem:

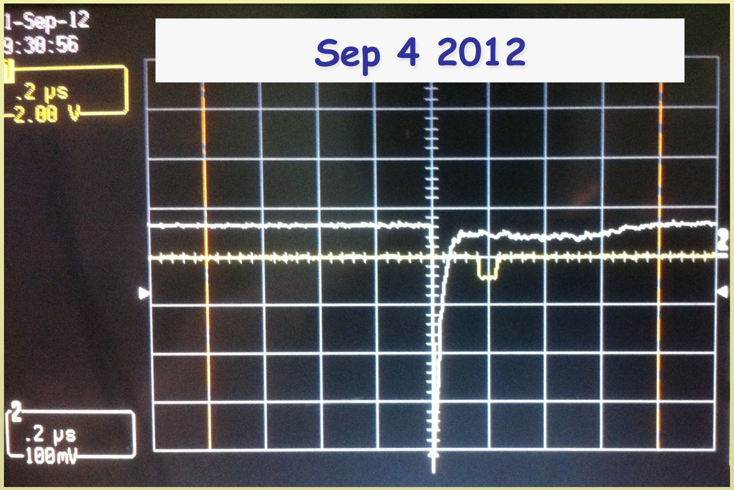
the life time has dropped down to dozens of nanoseconds!

After several cycles of gas circulation (at room temperature) and filling – refilling of the chamber we've got ~ 10μs lifetime

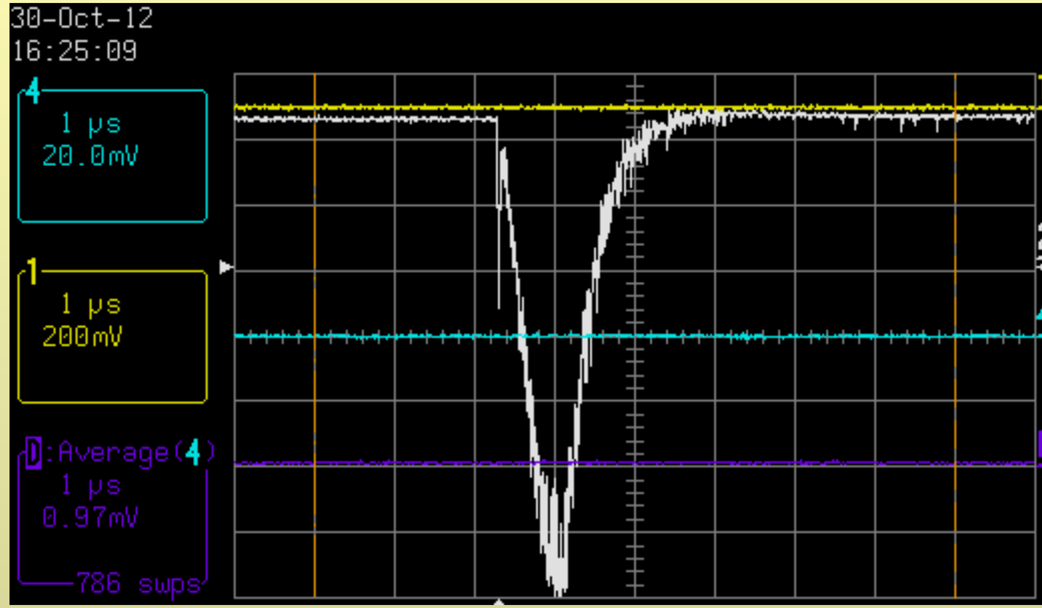
Evolution of life time in series of filling-refilling

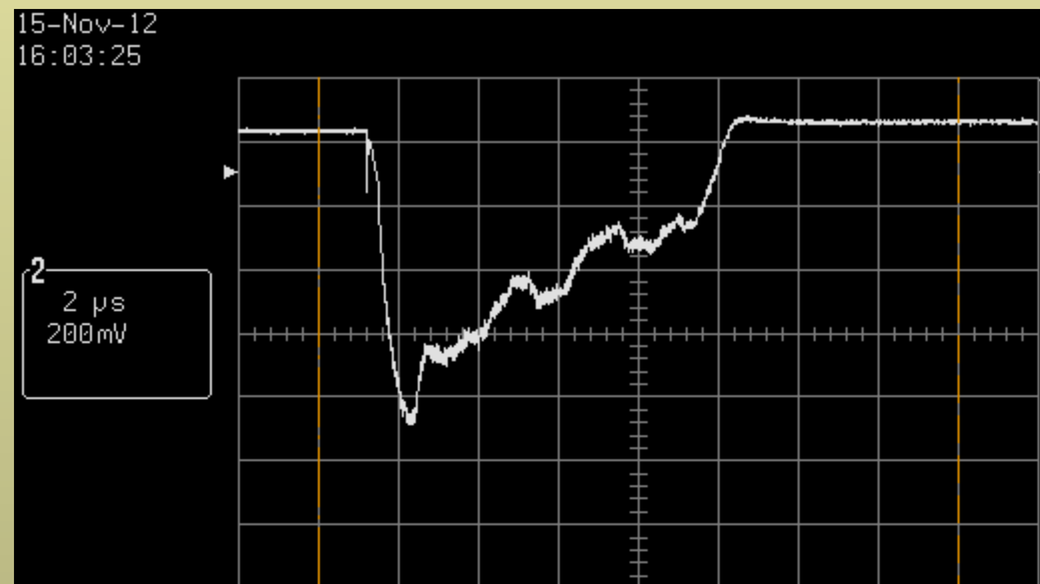


Evolution of life time in series of filling-refilling



Muon signals





Nearest future plans

To repeat the June run with and without shielding (now with good lifetime)

To start measurements when reactor will be ON (~ March 2013)

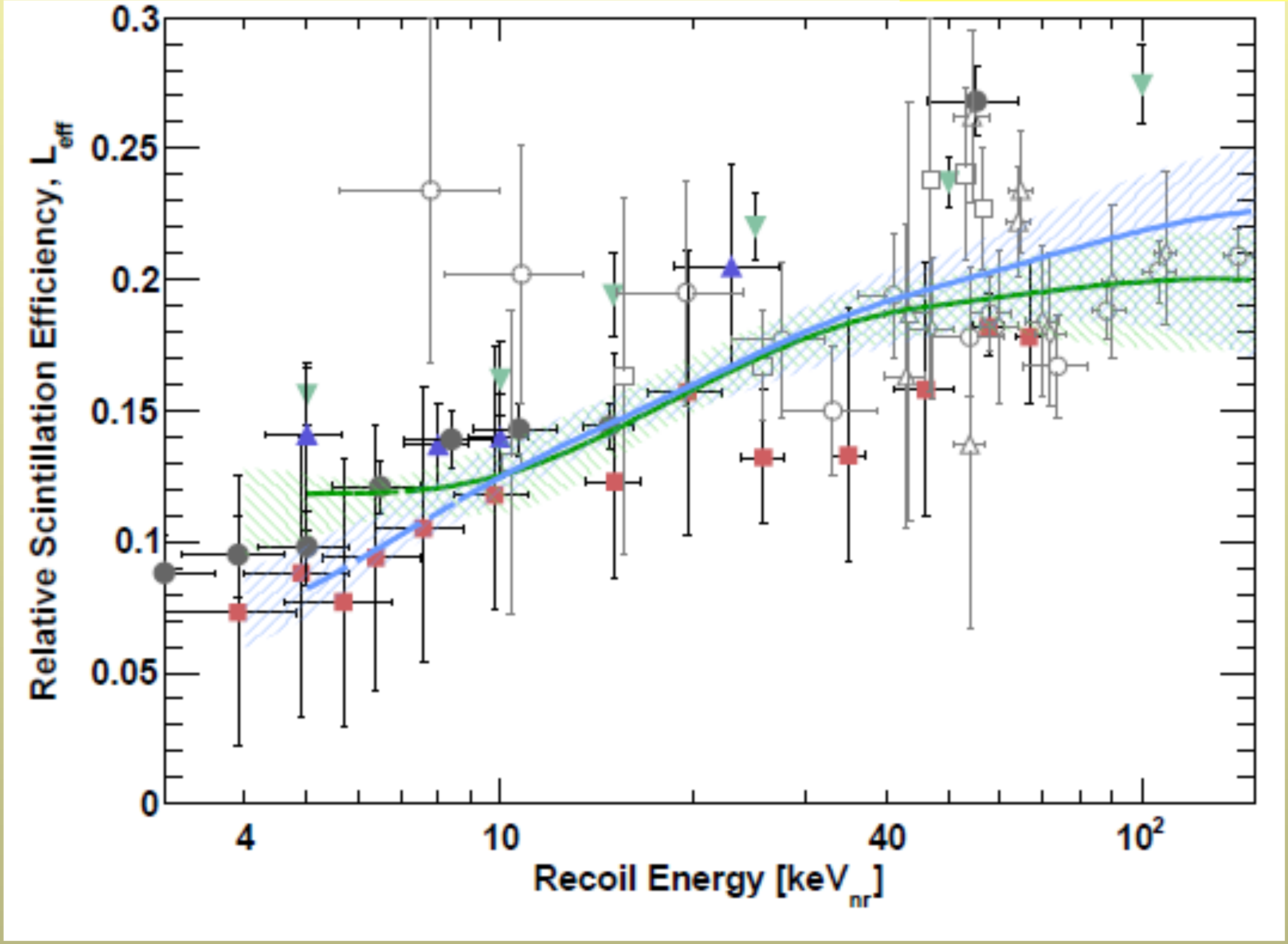
The setup is ready for measurements of the ionization yield of NR in LXe

Thank you for attention !

BACKUP SLIDES

Scintillation efficiency

Compilation from M.Horn et al., (ZEPLIN-III) Phys.Lett. B705 (2011) 471
e-Print: arXiv:1106.0694 [physics.ins-det]



Scintillation efficiency

At E_r <~ 1 кэВ one has a few sc photons

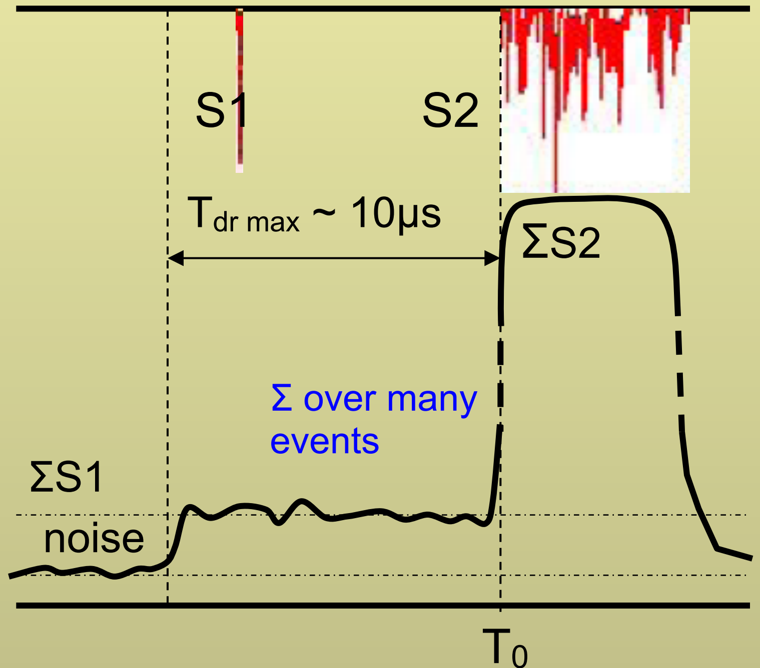
N spe < 1   =>   impossible to measure L_{eff} directly!

Will select the events with ionisation in the certain region.

Better closer to the maximum energy.

Will sum the recorded traces, with T_0 at the beginning of S2

The accidental spes from PMTs will give a "substrate"



Measured mean spe frequency F ~ 35000 Hz for all (7) PMTs

$$S = L_{eff} \cdot \frac{S_n}{S_e} \cdot L_y \cdot E_r \qquad \sigma_{noise} = \sqrt{F \cdot T_{dr\max} \cdot N}$$

$S \geq 10\,\sigma$

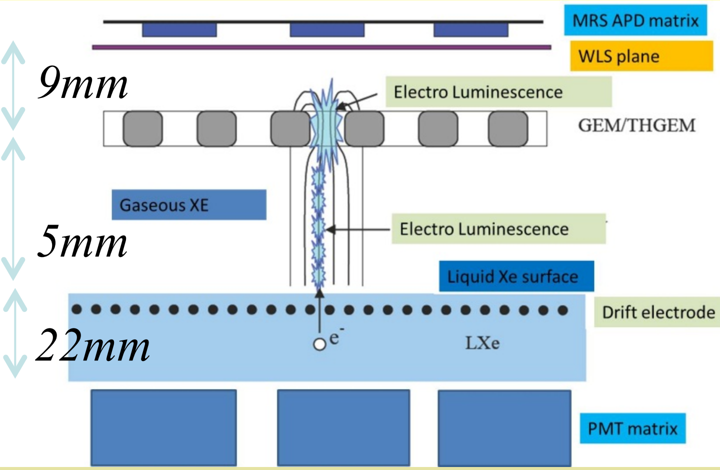
$$N \cdot L_{eff} \cdot \frac{S_n}{S_e} \cdot L_y \cdot E_r \geq 10\sqrt{F \cdot T_{dr\max} \cdot N}$$

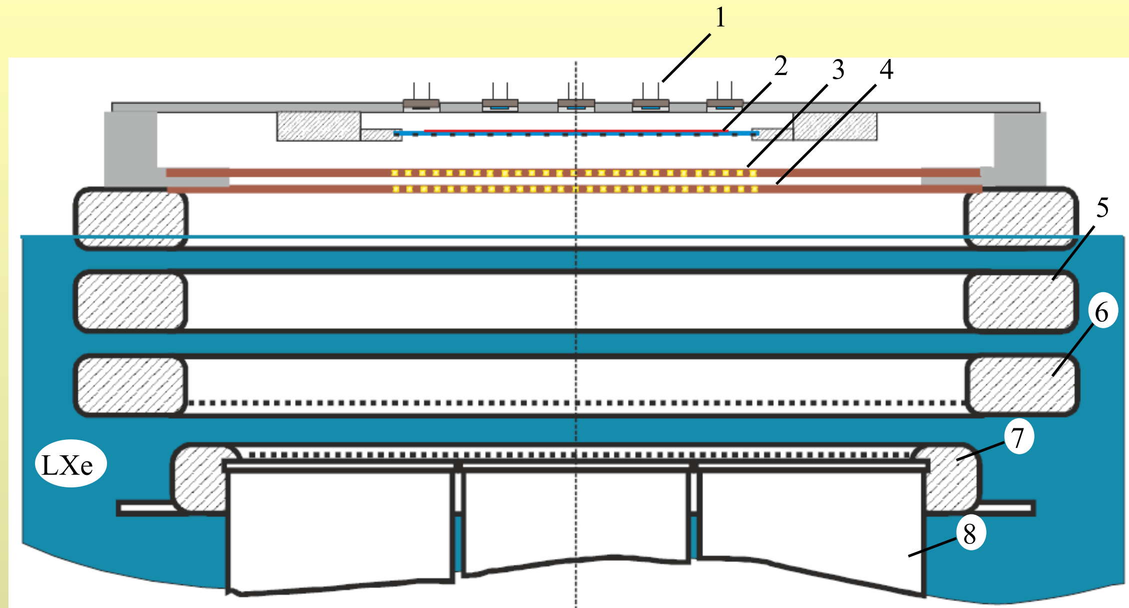
$S_n = 0.95$ $S_e = 0.4$

Measured for the RED1: L_y = 0.6 spe/keV

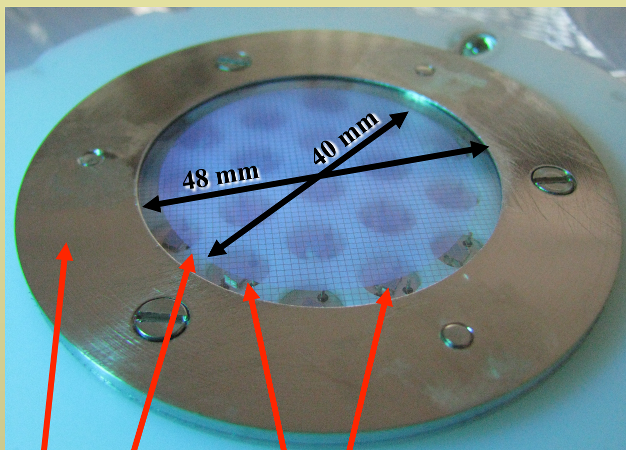
$$L_{eff\,\min} = \frac{2.46}{E_r \cdot \sqrt{N}}$$

For E_r = 0.5 keV, N = 100000 ev.: $L_{eff\ \min} \approx 0.015$





Schematic view of the two-phase detector. 1 – array of MGPDs, 2 – WLS on a sapphire window and with optically transparent metal mesh (on the bottom), 3 and 4 – 2-d and 1-st THGEM, correspondently, 5 – intermediate field-shaping ring, 6 – cathode, 7 – photocathodes protection screen, 8 – array of seven PMTs.

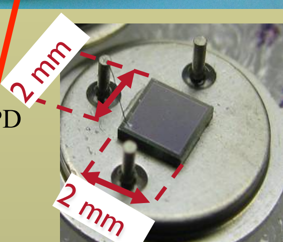


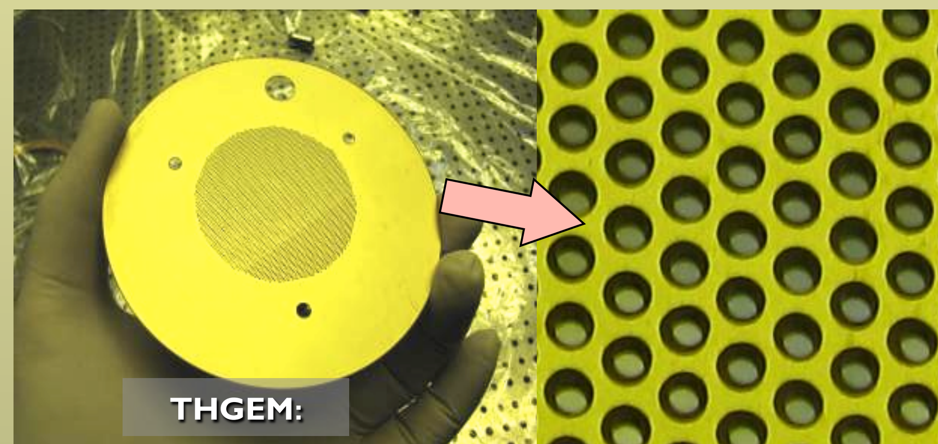
metal mesh

ss frame

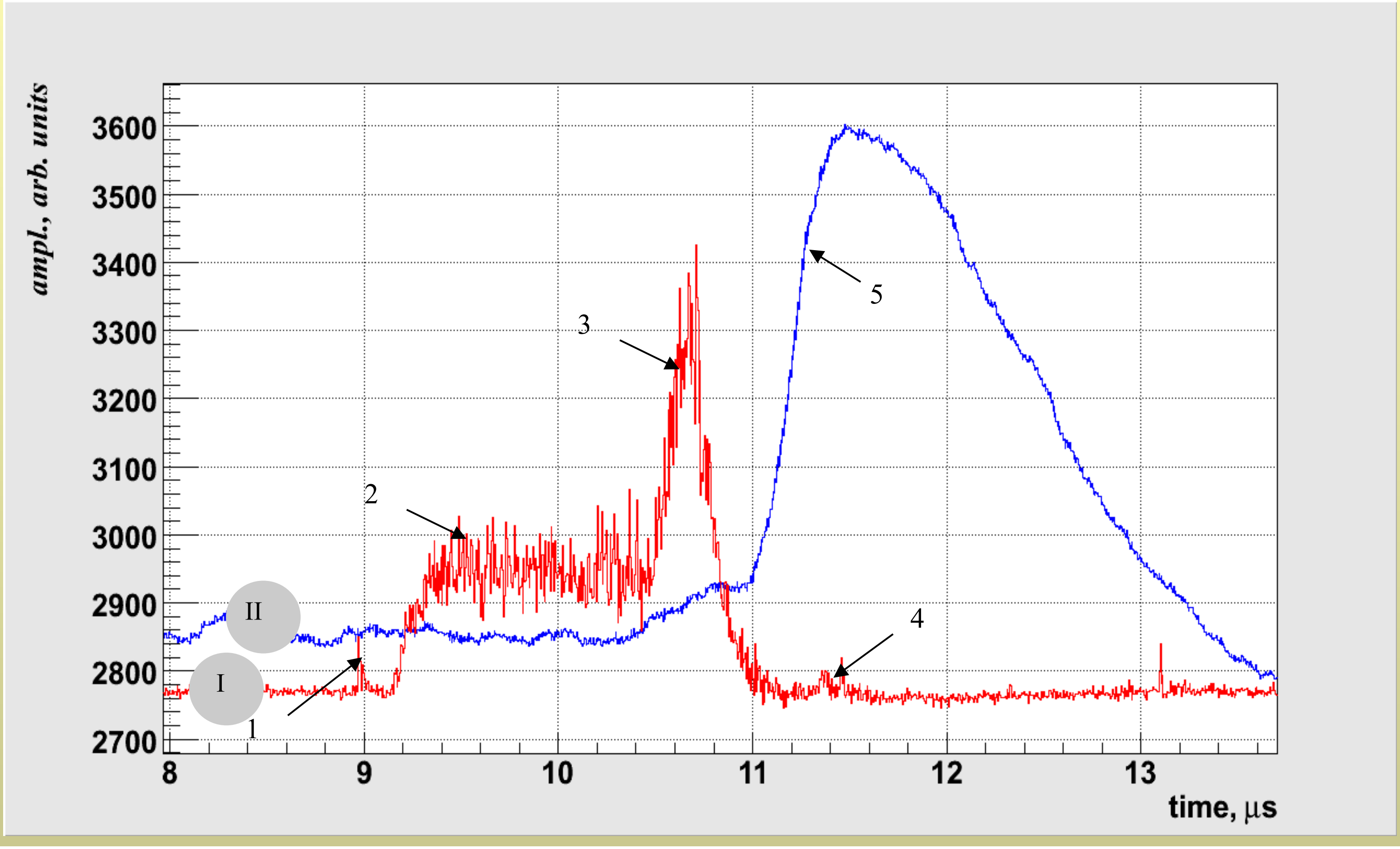
array of 19 MRS APD
2x2 mm

(CPTA production)





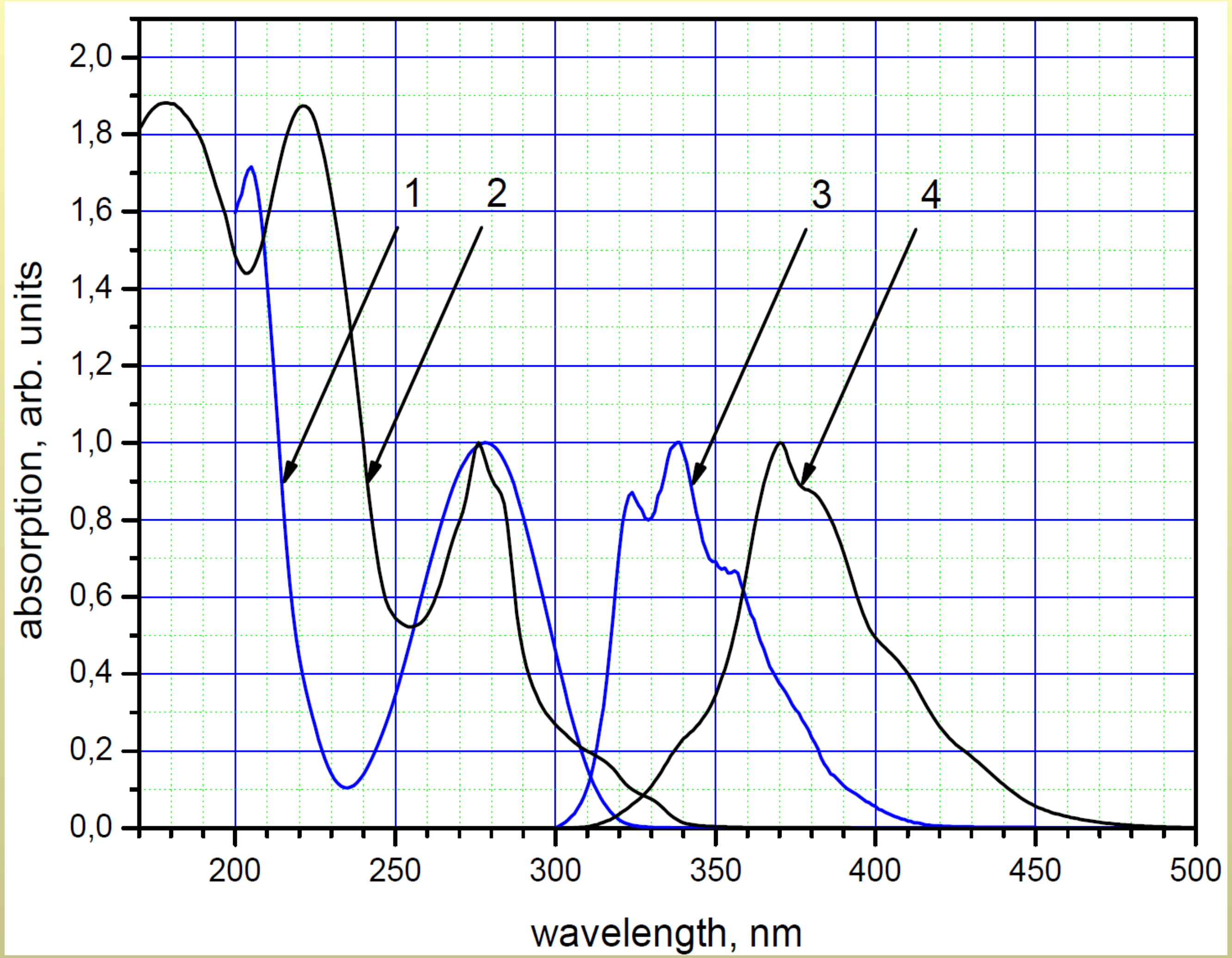
Step - 0.7 mm,
Diameter. 0.4 mm, thickness
0.25 mm



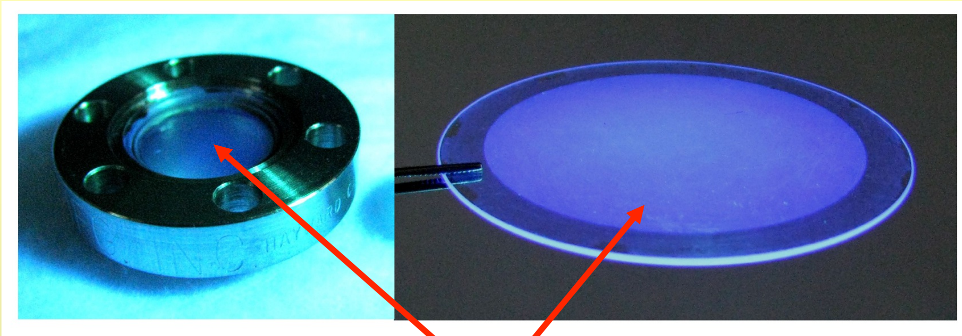
Typical sum waveforms from the PMTs (curve I), and from MGPDs for the case of double THGEM (curve II). 1 – scintillation signal, 2 – electroluminescence in the gas gap between the LXe surface and 1-st THGEM, 3 – electroluminescence in the 1-st THGEM, 4 and 5 – electroluminescence in the 2-d THGEM, (*see explanation in text*).

EL from PMTs 850 e^- corresponds to ~150 cells from SiPMs

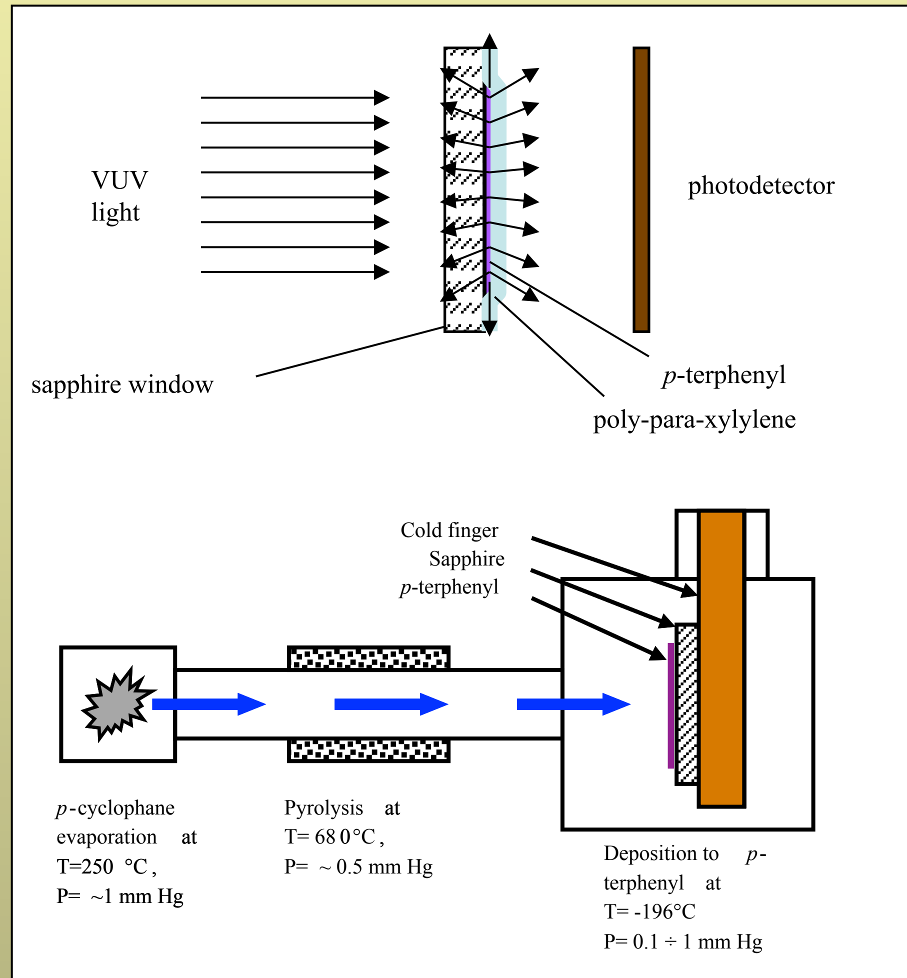
WLS



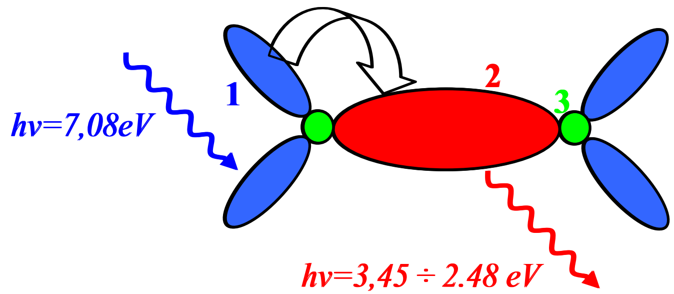
1 – *p*-terphenyl in solvent, absorption spectrum
2 – polycrystalline *p*-terphenyl, absorption spectrum
3 – *p*-terphenyl in solvent, emission spectrum
4 – polycrystalline *p*-terphenyl, emission spectrum



p-terphenyl


VUV
light
photodetector
sapphire window
p-terphenyl
poly-para-xylylene
Cold finger
Sapphire
p-terphenyl
p-cyclophane
evaporation at
T=250 °C,
P= ~1 mm Hg
Pyrolysis at
T= 680°C,
P= ~ 0.5 mm Hg
Deposition to *p*-
terphenyl at
T= -196°C
P= 0.1 ÷ 1 mm Hg

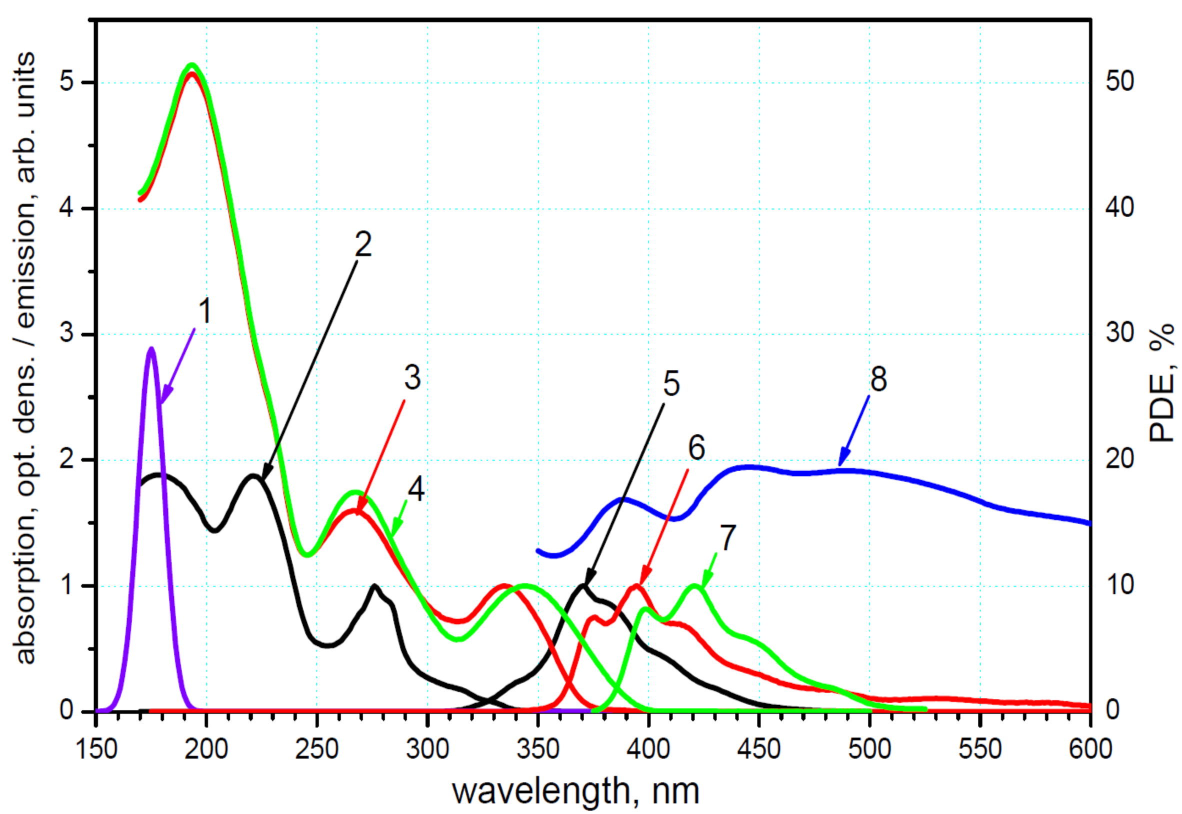
New WLS materials: Nanostructured Si-organic WLS (NSIWLS)



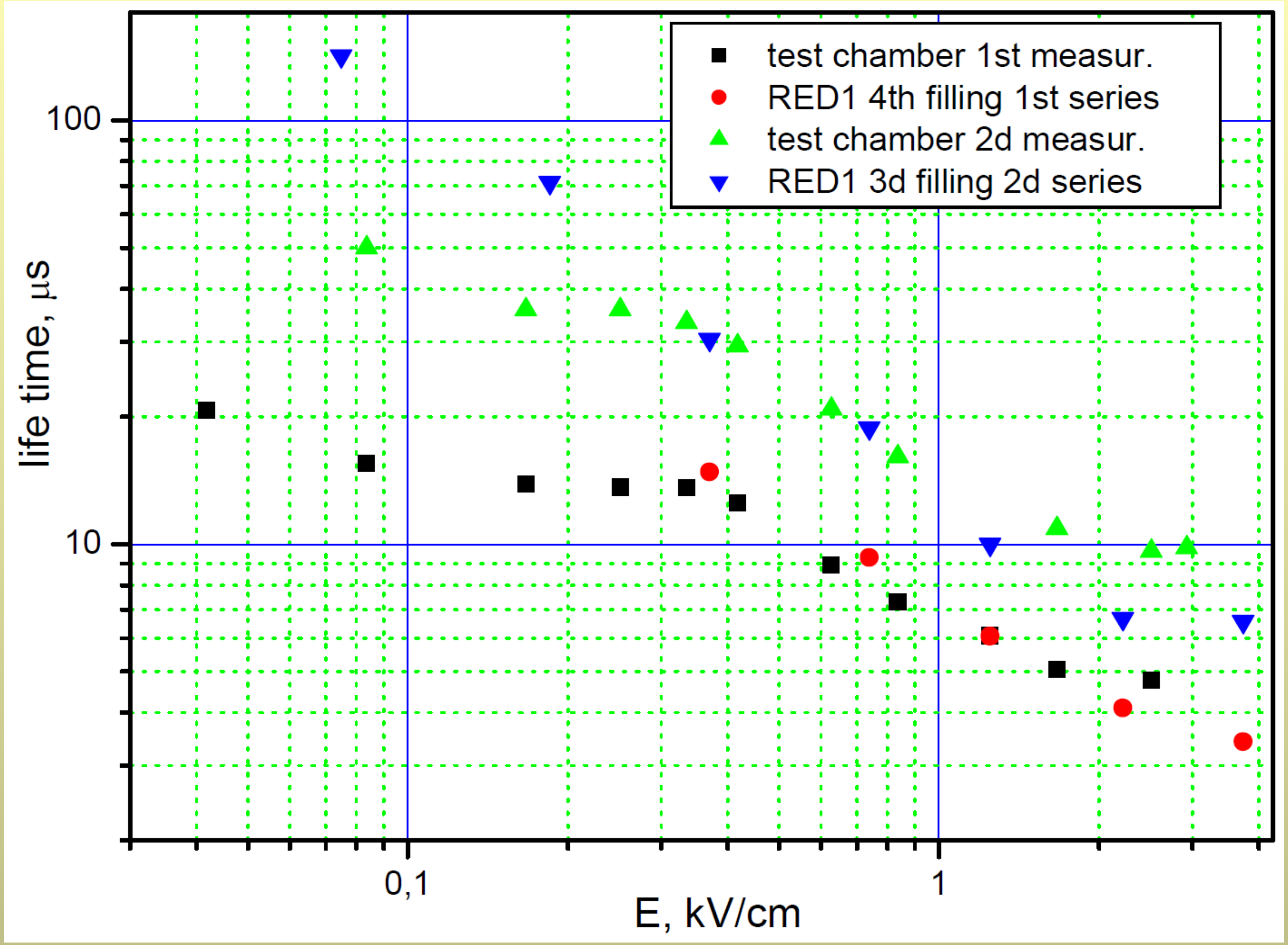
1 – absorption fragment (modified *p*-terphenyl)

2 – emission fragment

3 – Si atoms



1 – emission spectrum of LXe
2 – absorption spectrum of *p*-terphenyl
3 – absorption spectrum of NSIWLS-I
4 – absorption spectrum of NSIWLS - II
5 – emission spectrum of *p*-terphenyl
6 – emission spectrum of of NSIWLS-I
7 – emission spectrum of NSIWLS-II
8 – photon detection efficiency (PDE) of the CPTA “blue-sensitive” MRS APD, right axis.



Measured electron lifetime versus electric field strength in LXe in the test chamber and in RED1.