Detector DANSS and the problem of sterile neutrinos

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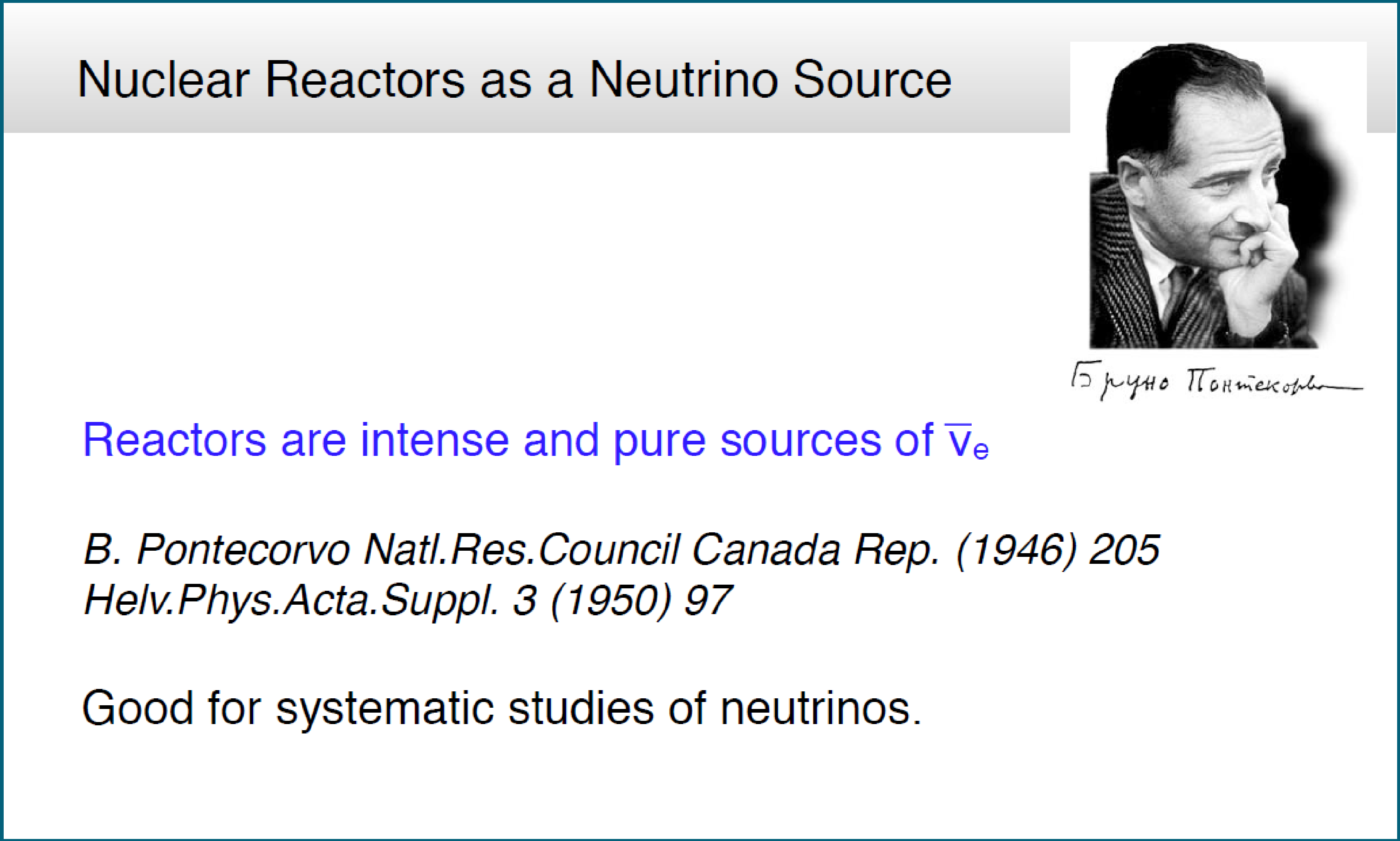
Colloquium Towards CP violation in neutrino physics
Prague, 23-24 May 2013

Outline

- Introduction
- KNPP facility
- DANSS design and parameters
- DANSSino setup and running
- Conclusions

To the Centennial Anniversary of B.Pontecorvo



Nuclear Reactors as a Neutrino Source

Бруно Понтекорво

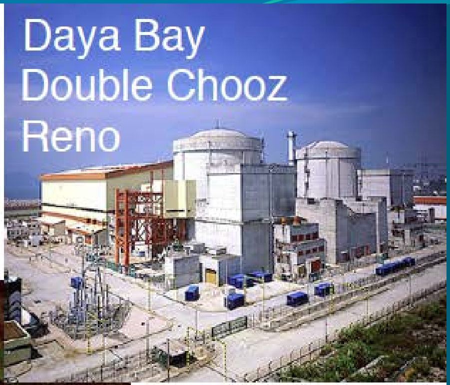
Reactors are intense and pure sources of $\bar{\nu}_e$

B. Pontecorvo Natl.Res.Council Canada Rep. (1946) 205
Helv.Phys.Acta.Suppl. 3 (1950) 97

Good for systematic studies of neutrinos.

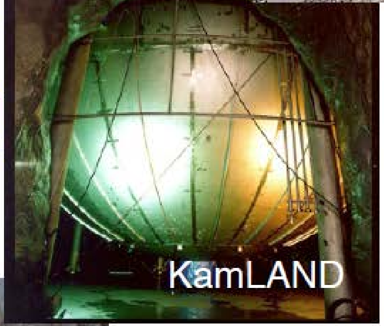
60 years of reactor neutrino physics

2011/2012 - The year of θ_{13}



2008 - Precision measurement of Δm_{12}^2. Evidence for oscillation

2003 - First observation of reactor antineutrino disappearance



1995 - Nobel Prize to Fred Reines at UC Irvine

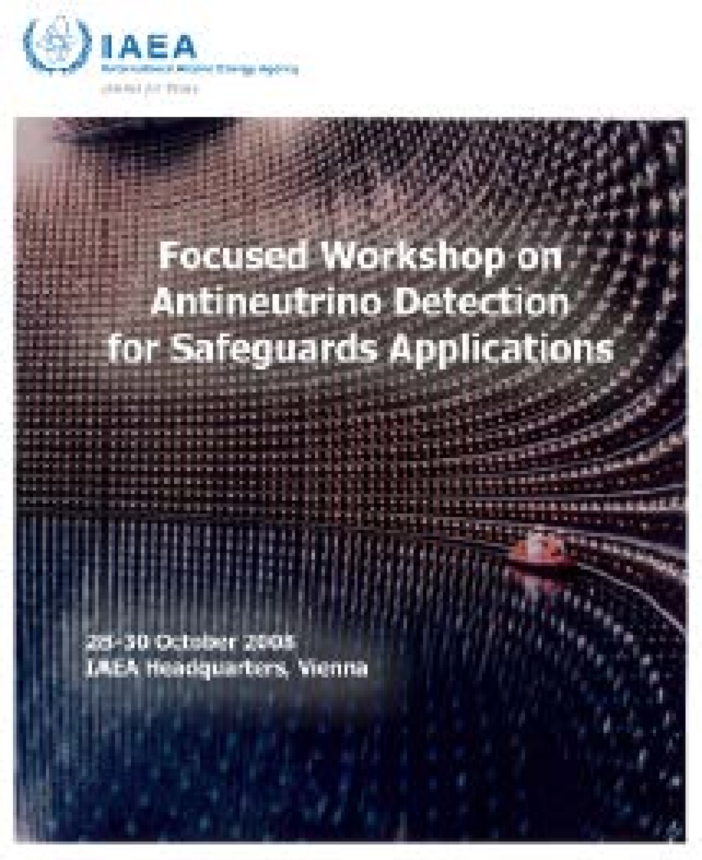
1980s & 1990s - Reactor neutrino flux measurements in U.S. and Europe

1956 - First observation of (anti)neutrinos

Past Reactor Experiments
Hanford
Savannah River
ILL, France
Bugey, France
Rovno, Russia
Goesgen, Switzerland
Krasnoyark, Russia
Palo Verde
Chooz, France

1953 – first experiment at Hanford

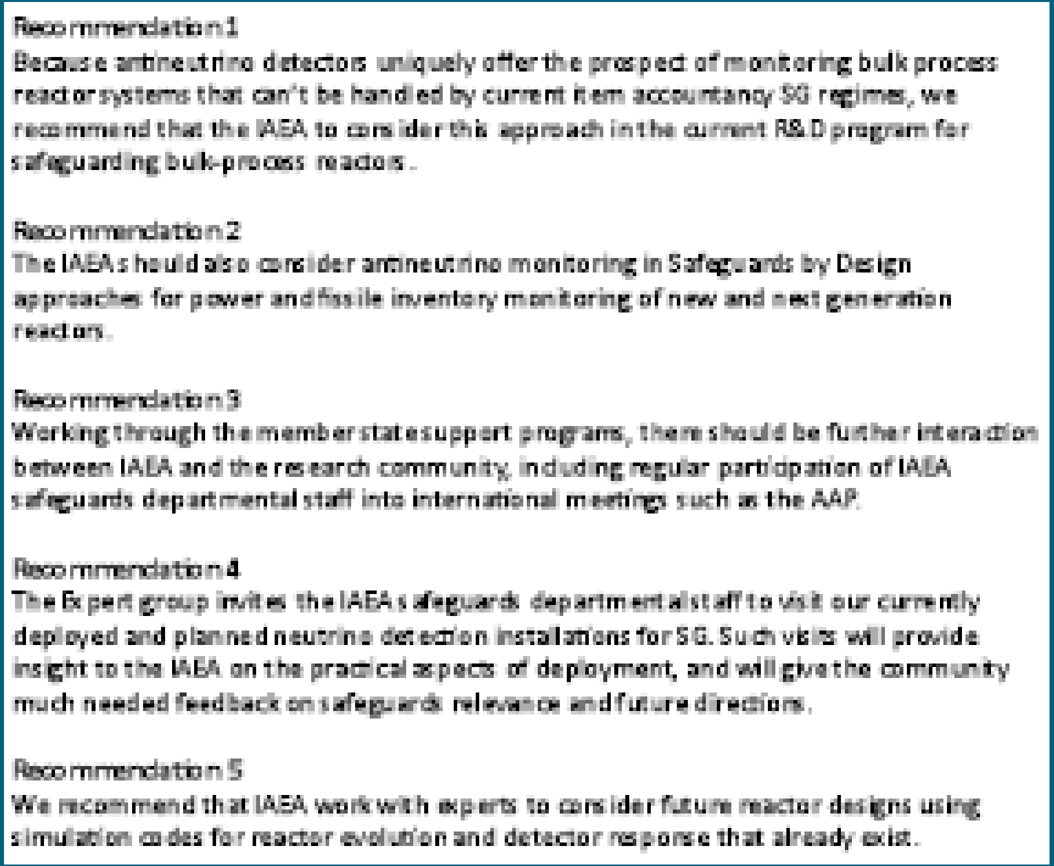
«Applied» Neutrino



IAEA

Focused Workshop on
Antineutrino Detection
for Safeguards Applications

28-30 October 2008
IAEA Headquarters, Vienna



Recommendation 1
Because antineutrino detectors uniquely offer the prospect of monitoring bulk process reactor systems that can't be handled by current item accountancy SG regimes, we recommend that the IAEA to consider this approach in the current R&D program for safeguarding bulk-process reactors.

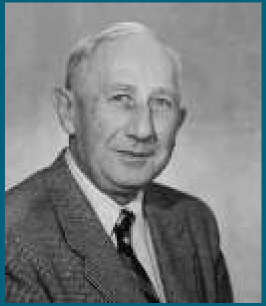
Recommendation 2
The IAEA should also consider antineutrino monitoring in Safeguards by Design approaches for power and fissile inventory monitoring of new and next generation reactors.

Recommendation 3
Working through the member state support programs, there should be further interaction between IAEA and the research community, including regular participation of IAEA safeguards departmental staff into international meetings such as the AAP.

Recommendation 4
The Expert group invites the IAEA safeguards departmental staff to visit our currently deployed and planned neutrino detection installations for SG. Such visits will provide insight to the IAEA on the practical aspects of deployment, and will give the community much needed feedback on safeguards relevance and future directions.

Recommendation 5
We recommend that IAEA work with experts to consider future reactor designs using simulation codes for reactor evolution and detector response that already exist.

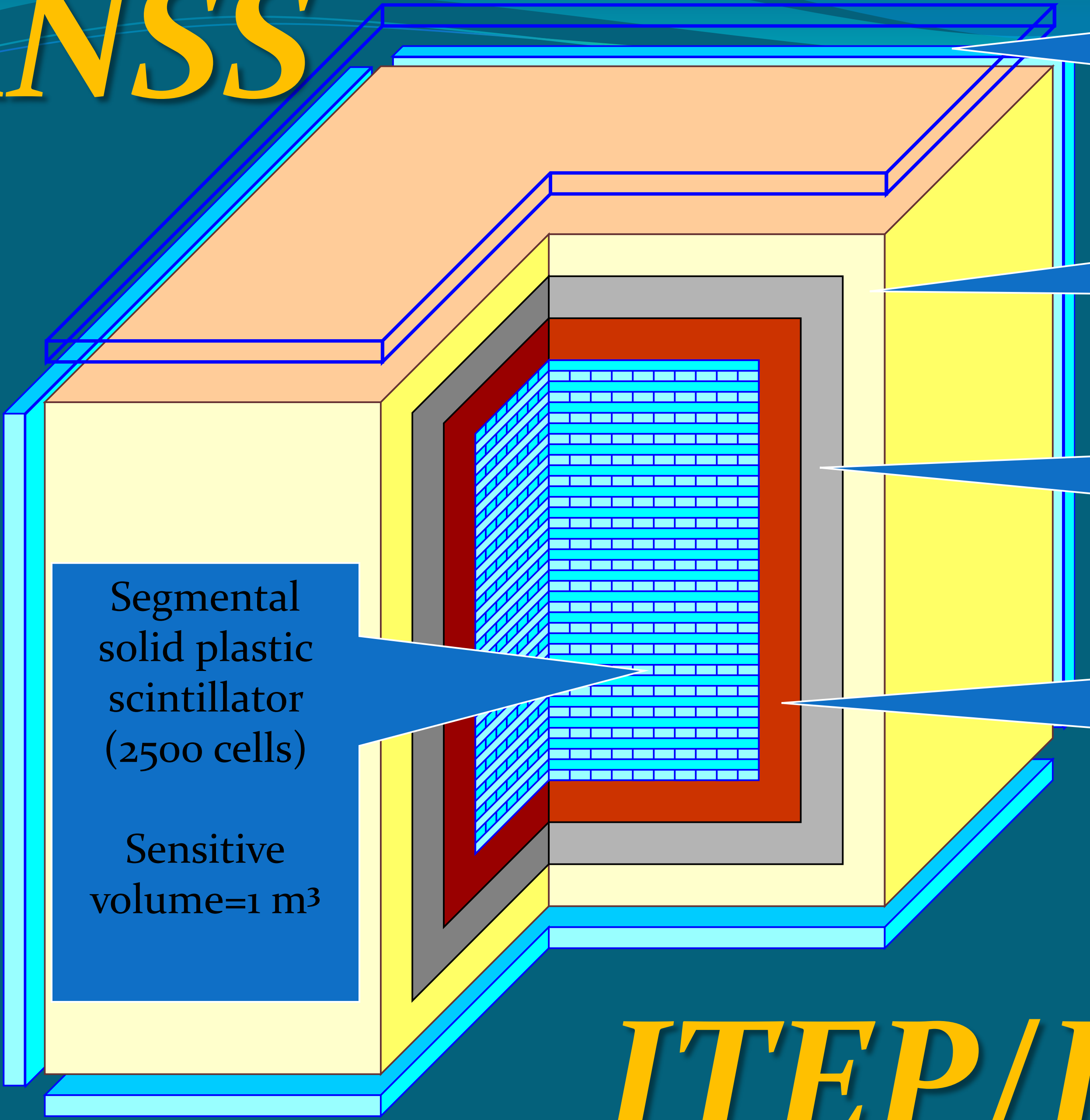
In striking contrast with what
Wolfgang Pauli wrote to Walter Baade
"Today I have done something which no theoretical physicist should ever do in his life: I have predicted something which shall never be detected experimentally!"



Direct detection of the reactor (anti) neutrino would allow:

- **Measure the actual reactor power (N_ν)**
- **Deduce the actual fuel composition (E_ν)**
- **On-line reactor monitoring (tomography)**
- **Non-proliferation *(prevent unauthorized extraction of ^{239}Pu)***

DANSS



Plast. scnt.
(μ-shield)

CH_2 + B
(n-shield)

Pb
(γ-shield)

Cu (carriage frames = γ-shield)

Segmental solid plastic scintillator (2500 cells)

Sensitive volume=1 m³

ITEP/JINR

Kalinin Nuclear Power Plant (KNPP)

4 cores with 3GW Thermal power each

JINR *(Dubna)* + ITEP *(Moscow)*

GEMMA *Germanium Experiment on searching for the Magnetic Moment of the reactor Antineutrino*

Overburden

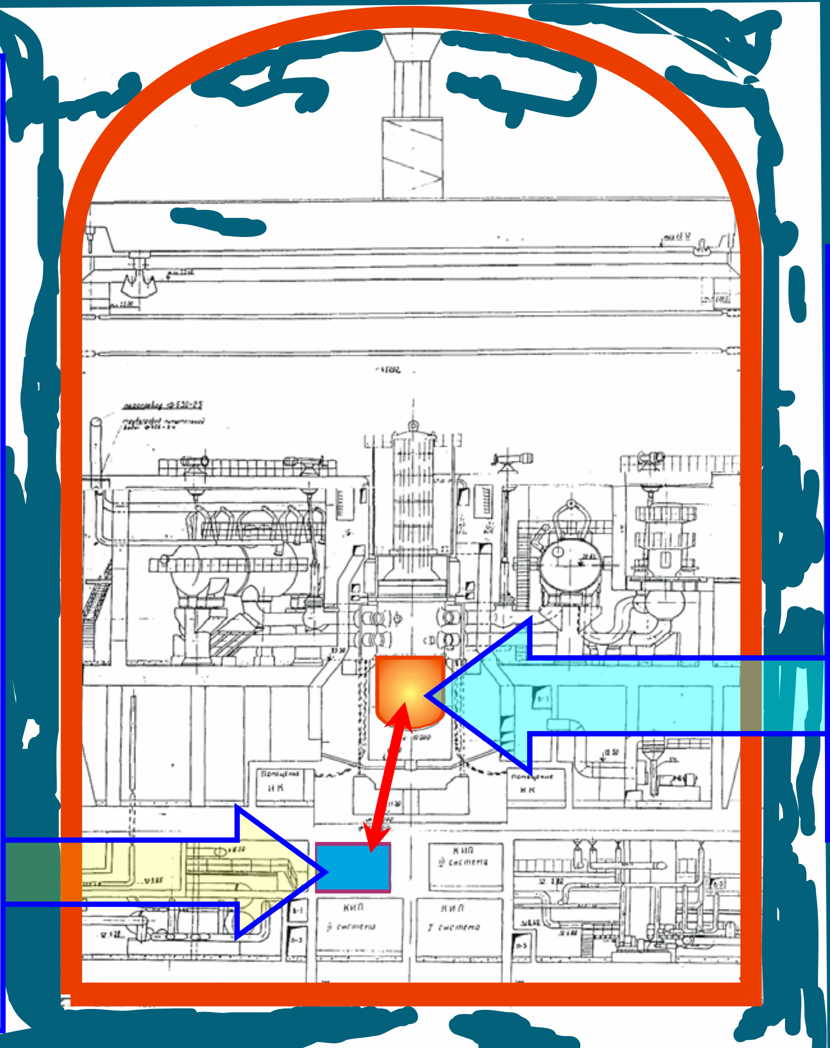
(reactor, equipment, etc.):

~70 m of W.E.

Technological room just under reactor

13.9 m only!

2.7×10^{13} ν/cm²/s



Reactor #2

ON: 315 days/y

OFF: 50 days/y

GEMMA: Results and Plans

HpGe detector
1.5 kg, 14m

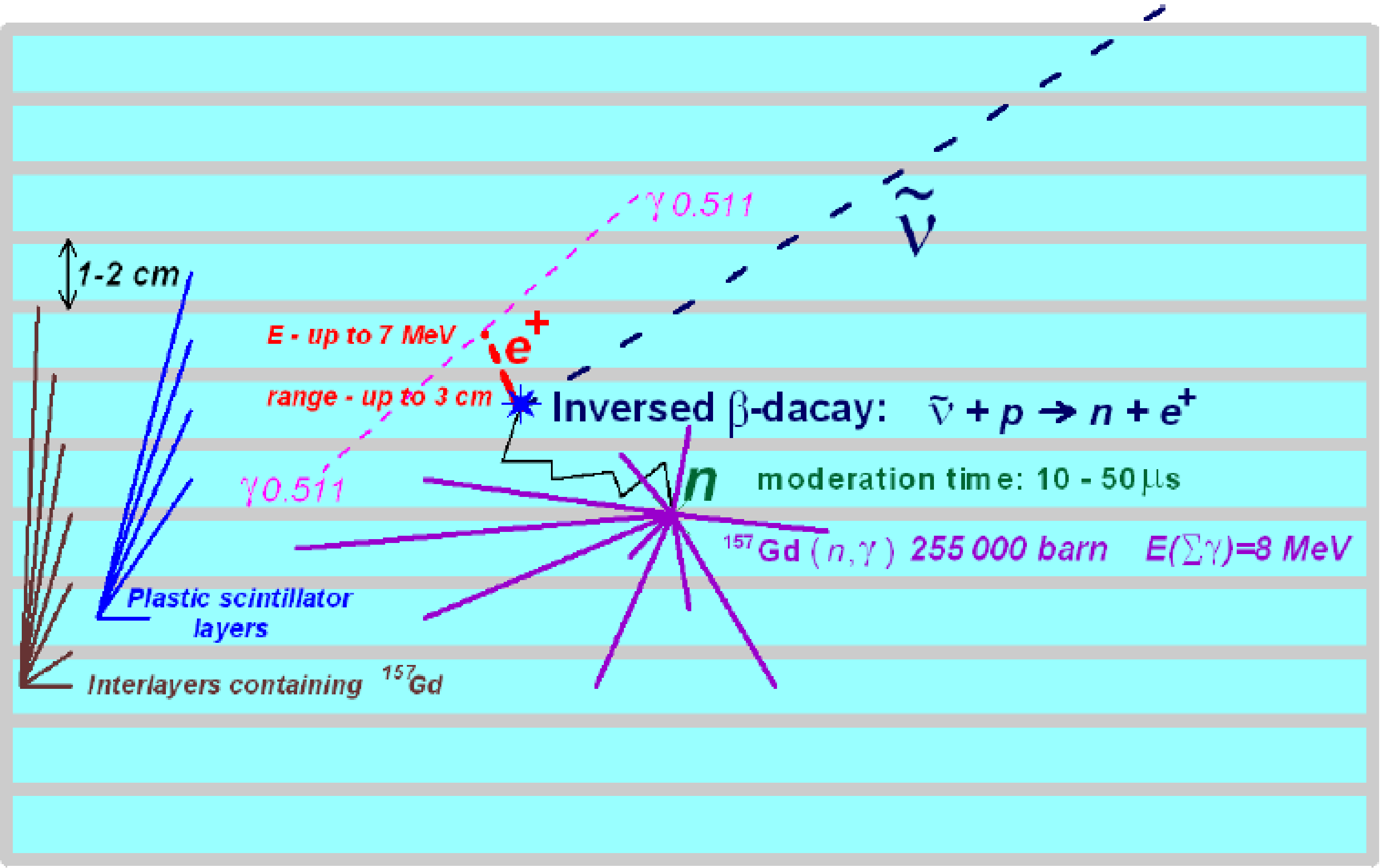
Phase-1: $\mu_\nu \leq 5.8\times10^{-11}\ \mu_B$

Phases 1+2: $\mu_\nu \leq 3.2\times10^{-11}\ \mu_B$

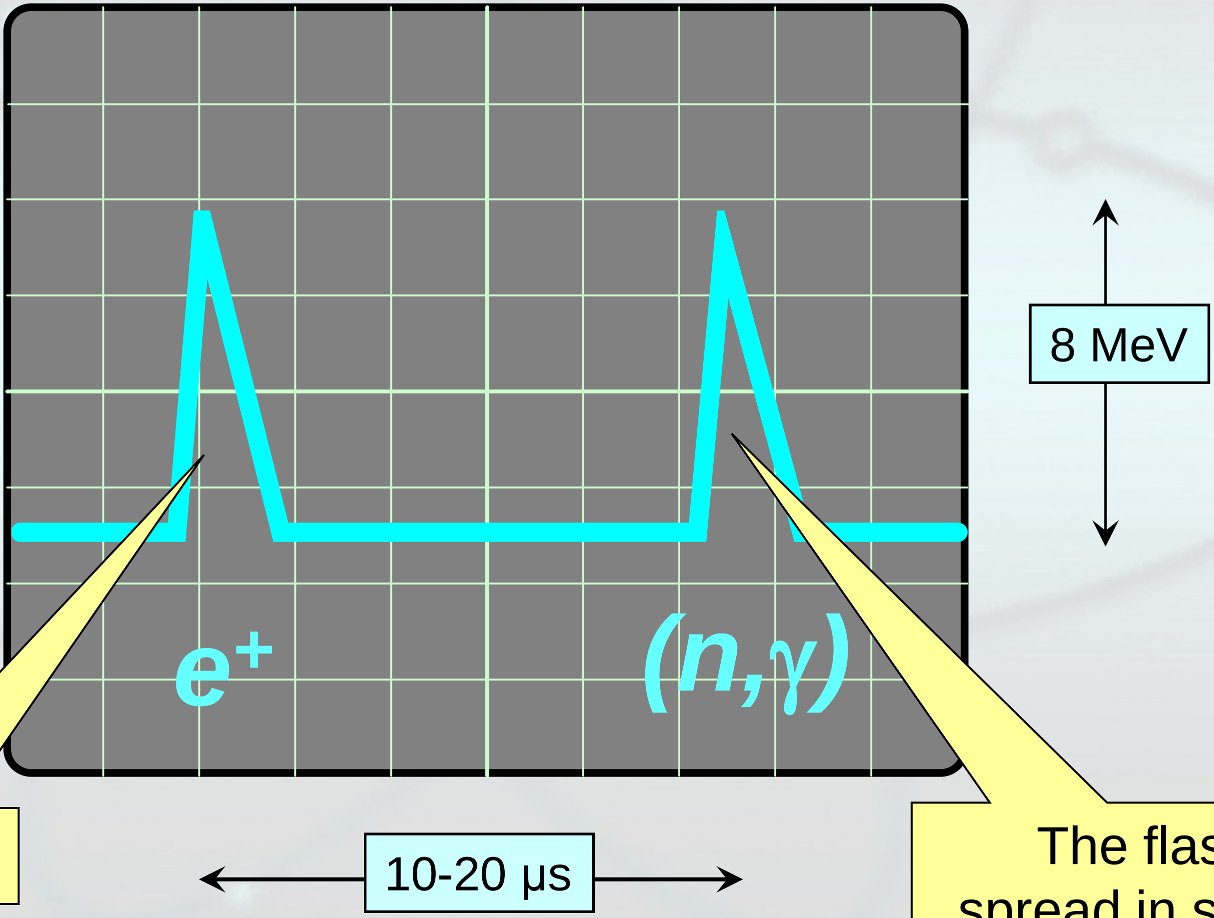
Phases 1+2+3: $\mu_\nu \leq 2.9\times10^{-11}\ \mu_B$

New Phase (6kg, 10m): $\mu_\nu \leq 1.0\times10^{-11}\ \mu_B$

Detection idea: Inversed Beta-Decay

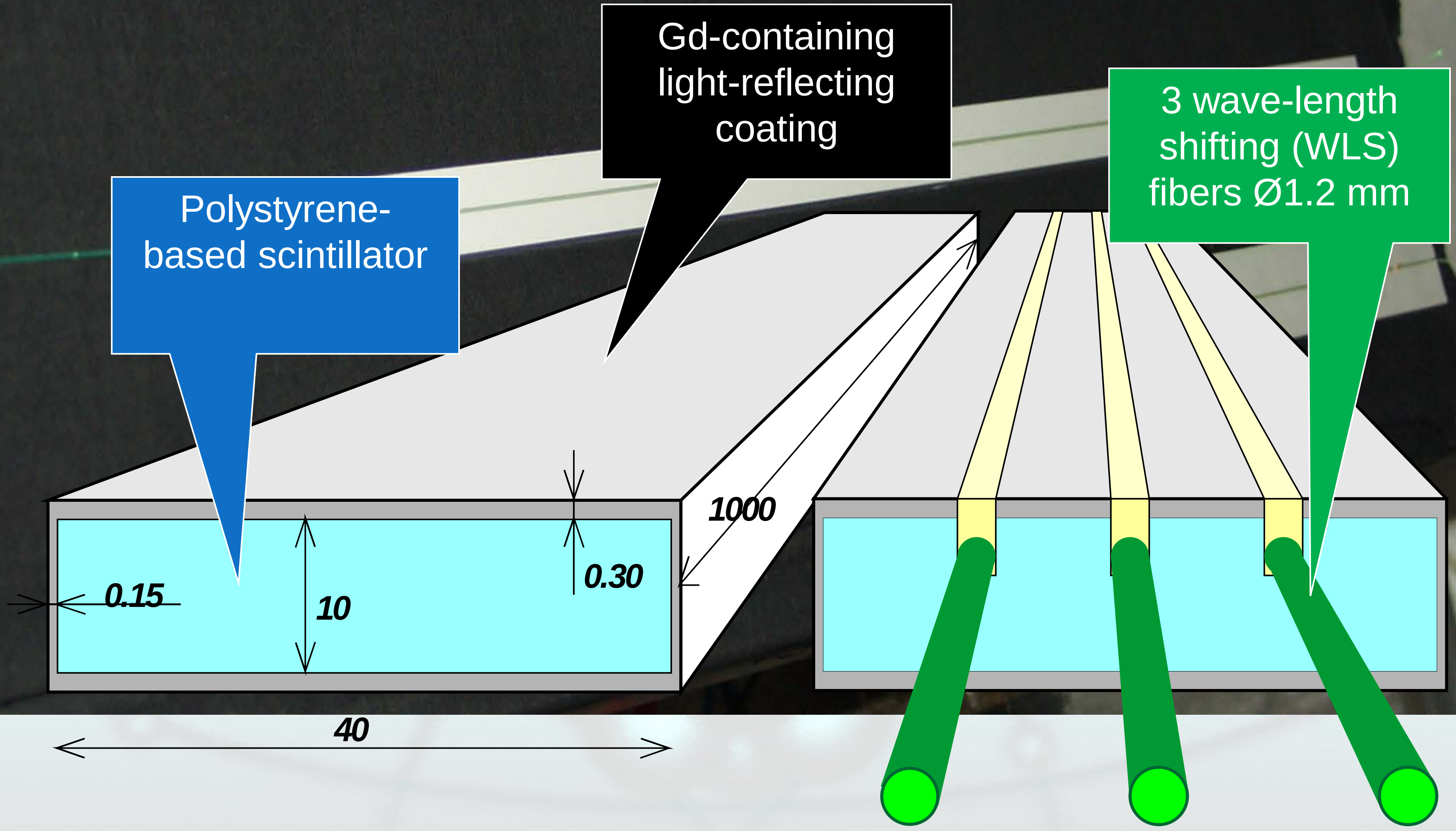


Signature of the IBD registration



Local flash

The flash spread in space



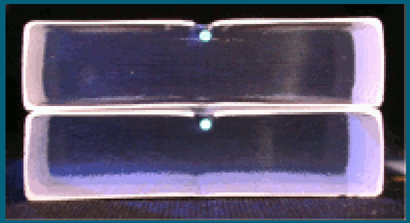
Polystyrene-based scintillator

Gd-containing light-reflecting coating

3 wave-length shifting (WLS) fibers Ø1.2 mm

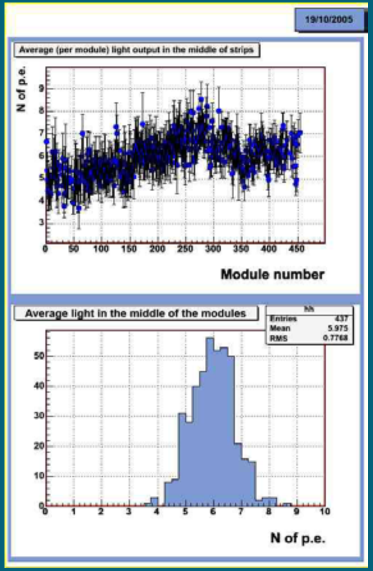
Strip production technology

From MINOS to OPERA to DANSS



MINOS:

Extrusion from pellets;
Co-extrusion with TiO2;

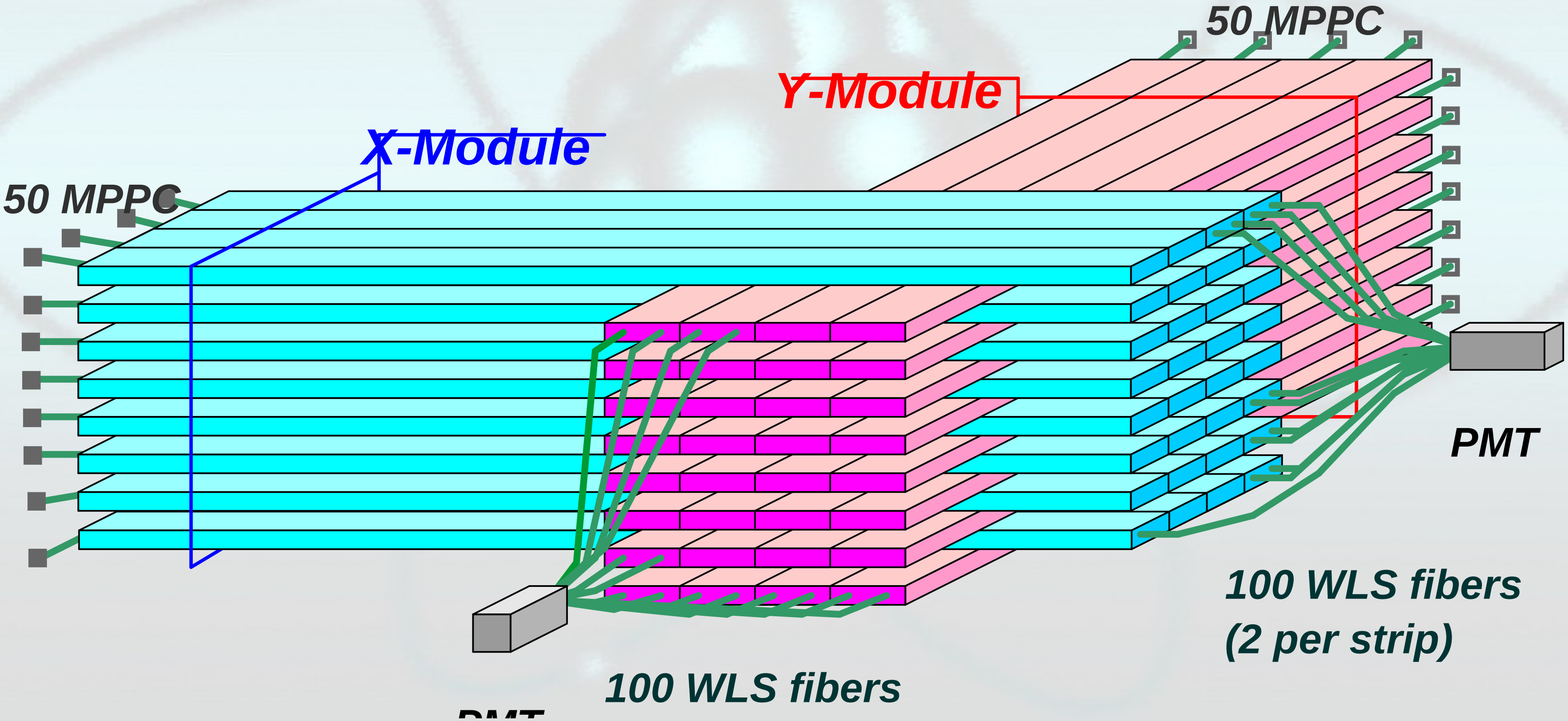


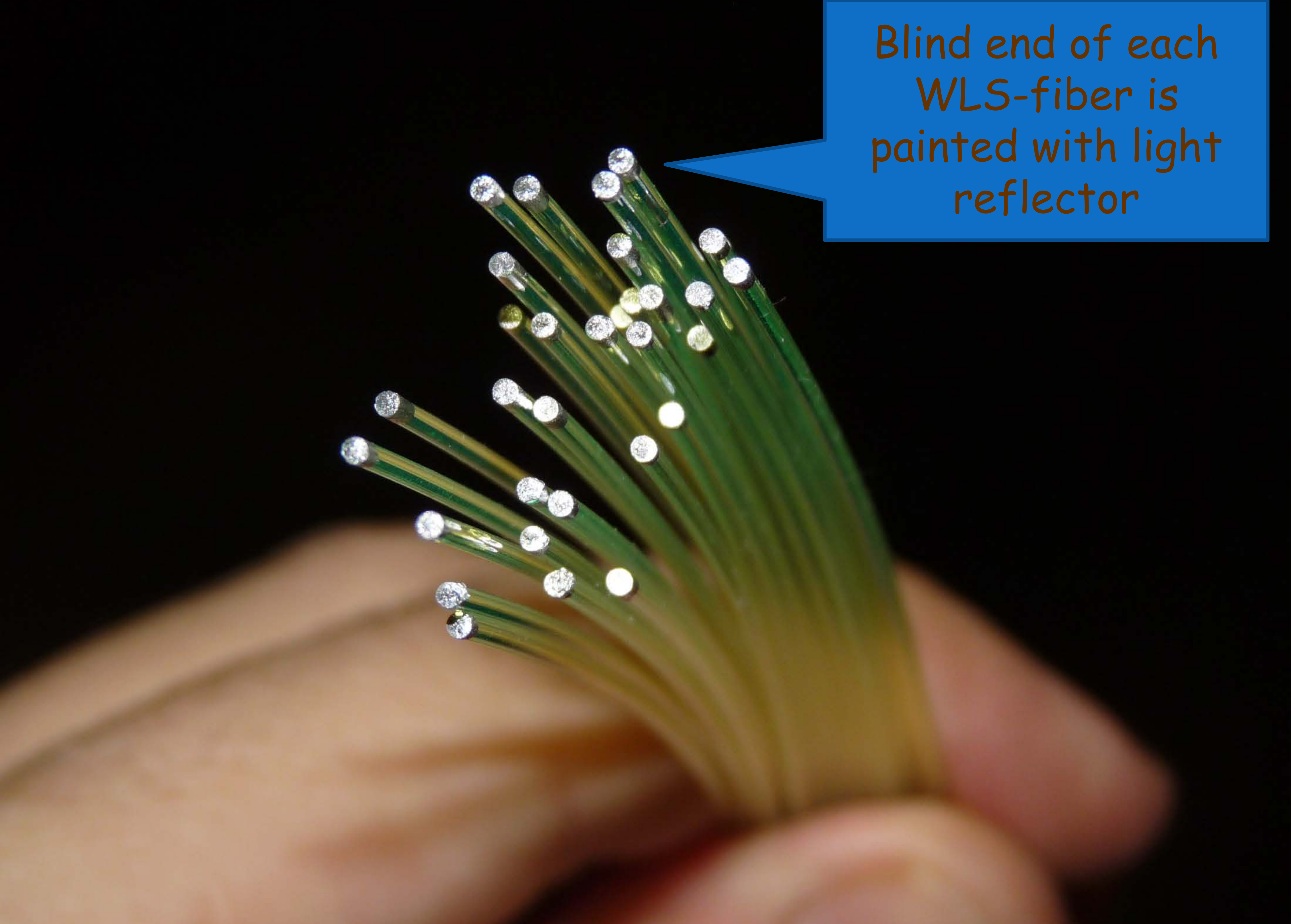
OPERA:
Extrusion from bulk polymerization material;
Co-extrusion with TiO2;

DANSS:
Co-extrusion with TiO2 and Gd doping ($1.6\ mg/cm^2$);

Modular structure of the detector:

A number of strips are combined into intercrossing X- and Y-modules (20×20×100 cm)

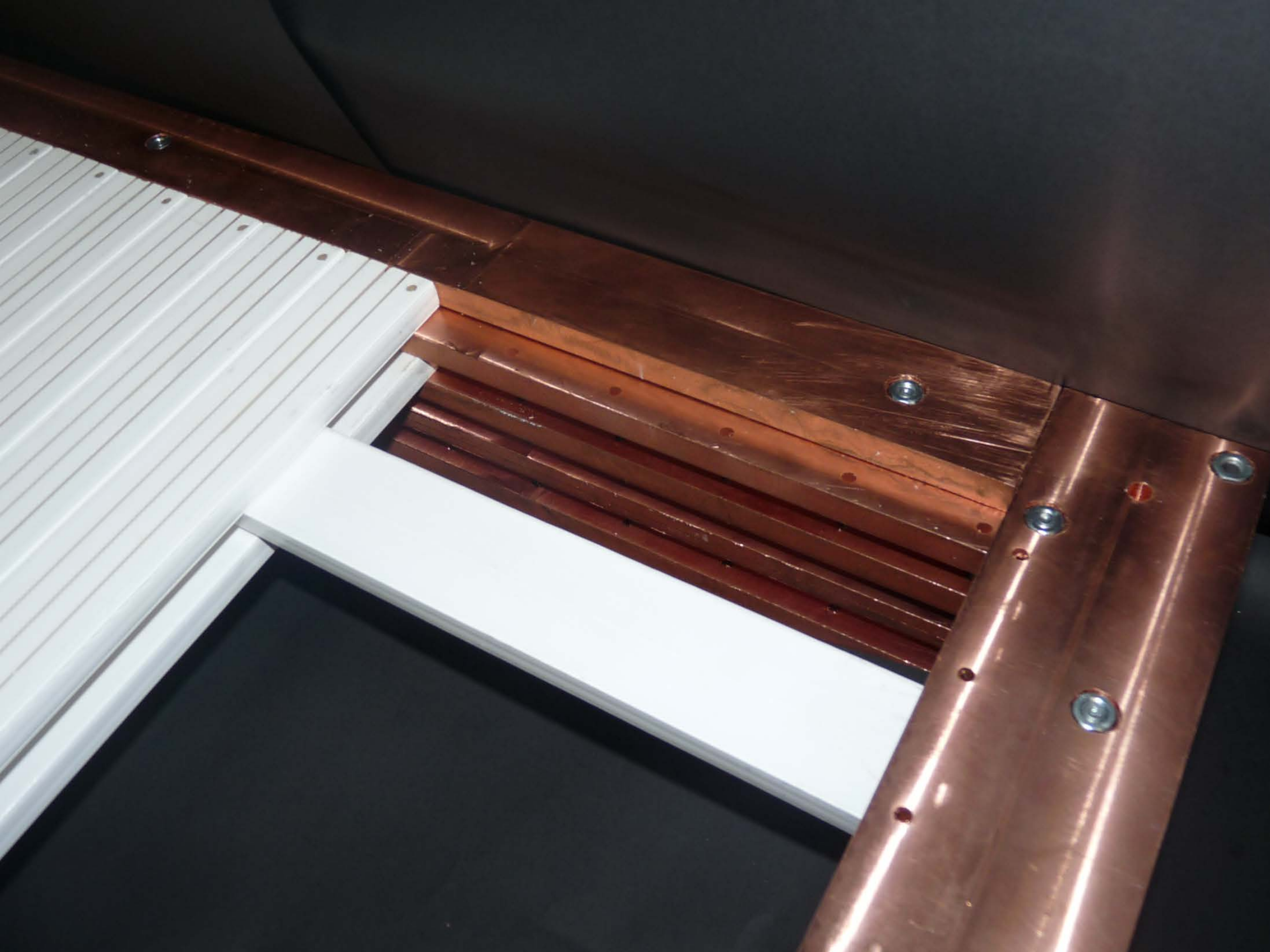


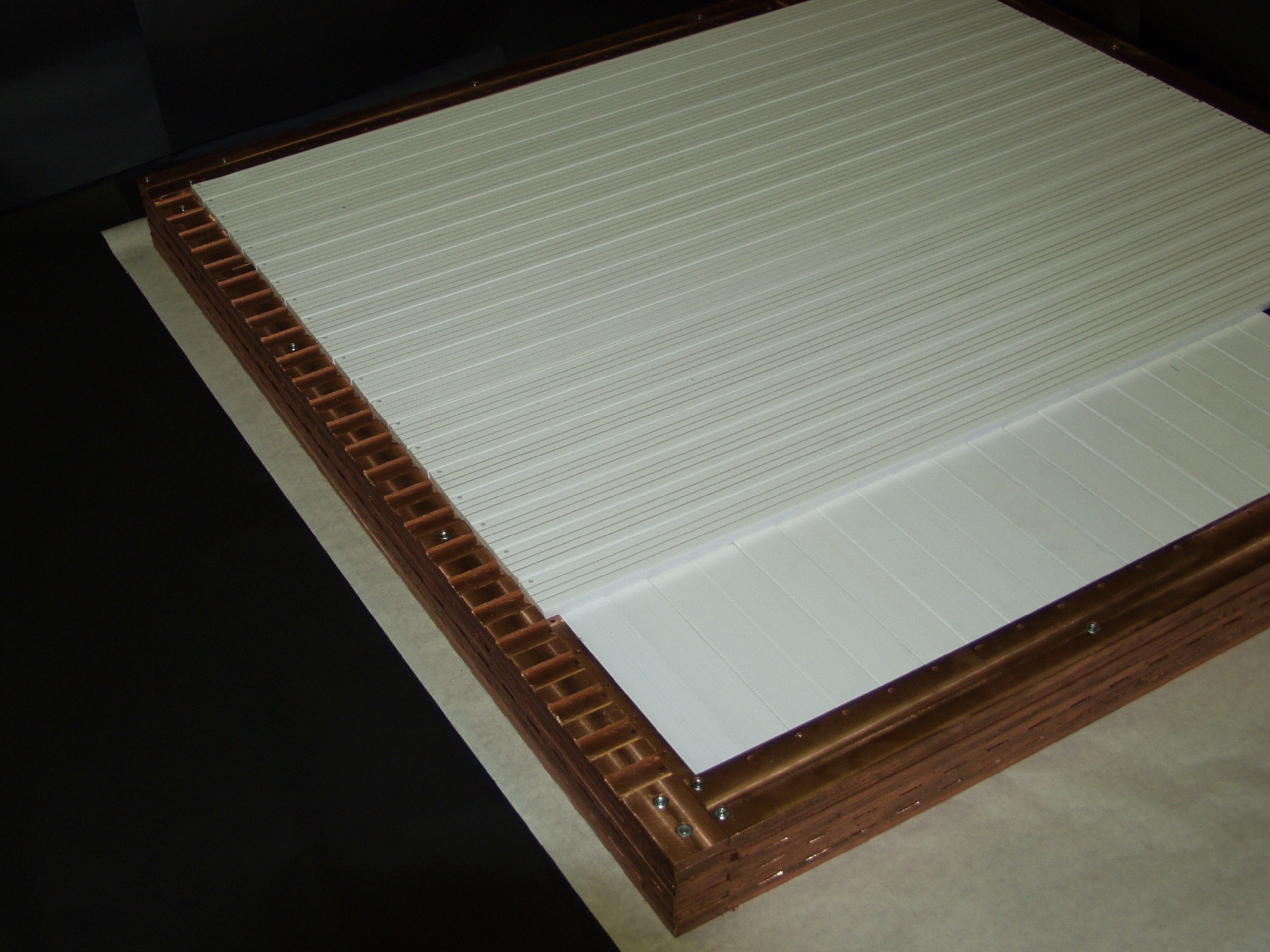


Blind end of each WLS-fiber is painted with light reflector

Expected parameters:

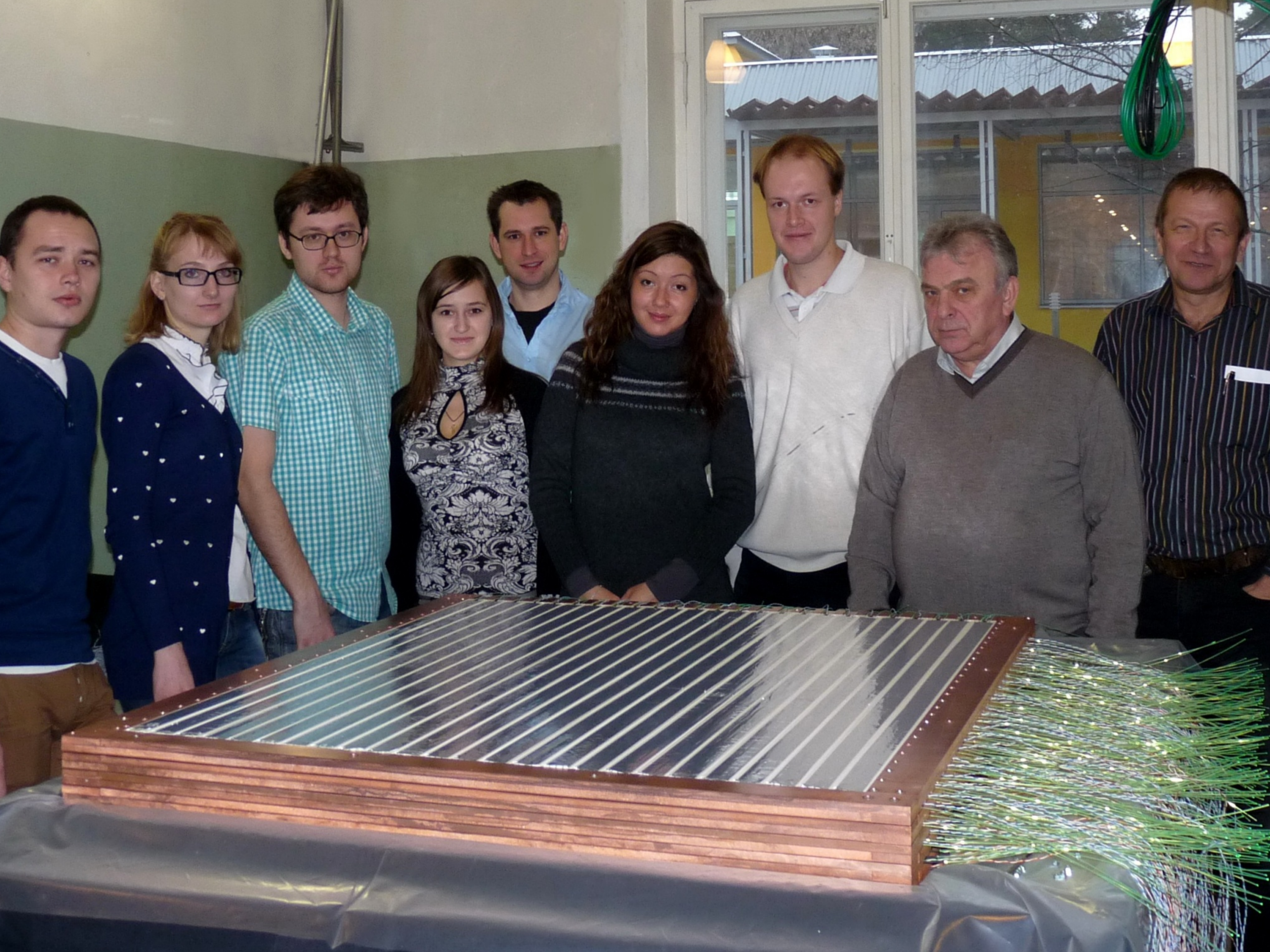
- Sensitive volume: 1 m^3
- Total mass: 13 t + lift + ...
- Composition: 5 sections (1m × 1m × 0.2m)
  of (5X + 5Y) modules = 2500 cells
  { 1 module = 5 × 10 = 50 cells }
- IBD detection efficiency: ~72%
- Count rate: **~10^4 IBD-events/day @11 m**
- Background: 40-50 events/day
- Energy resolution: ***$\sigma \leq 30\%$ @ $E_\nu = 4$ MeV***
- Due date: section №0 - 4 – ***2010 – 2012***
- Installation at KNPP
  DANSS+lifting gear + shielding – ***2012***
- Start tests and data taking – ***2013***



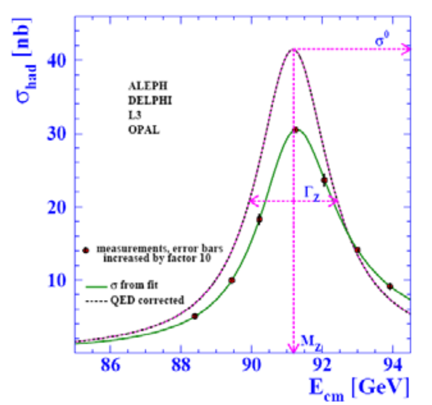



R7600U-200
NO. FA0066
2009-06
MADE IN JAPAN
CAUTION

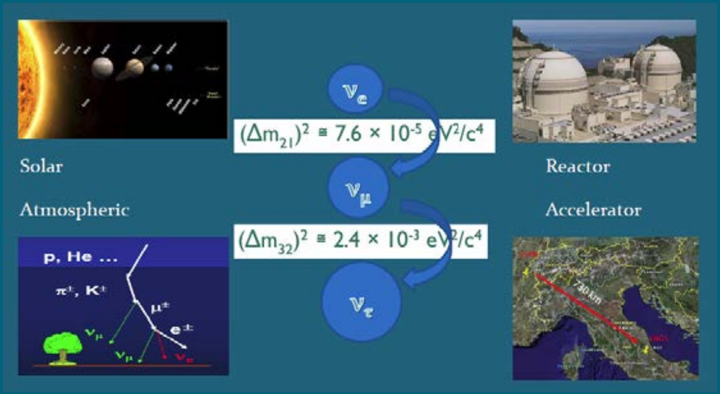

LOMOND

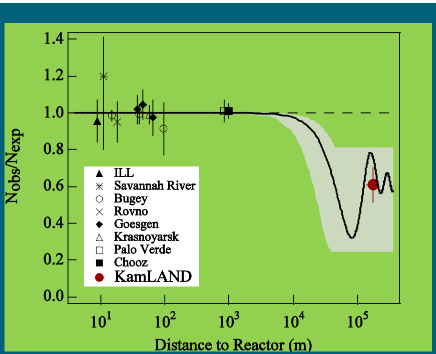


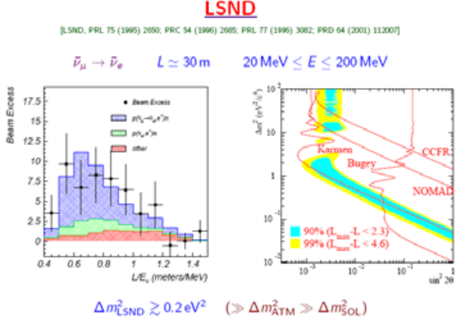
N_ν = ??

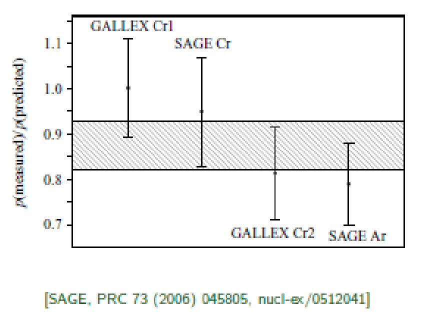


LEP: N_ν = 2.9840±0.0082



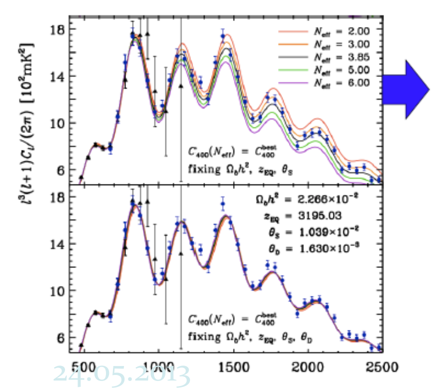






Another

$\Delta m^2 \sim 1 eV^2$??



Cosmology:

Num of Nus:

N_{eff} = 3.62 ± 0.48 (SPT+WMAP7)

N_{eff} = 3.71 ± 0.35 (SPT+WMAP7+H_0+BAO)

N_{eff} = 2.97 ± 0.56 (ACT+WMAP7)

N_{eff} = 3.50 ± 0.42 (ACT+WMAP7+H_0+BAO)

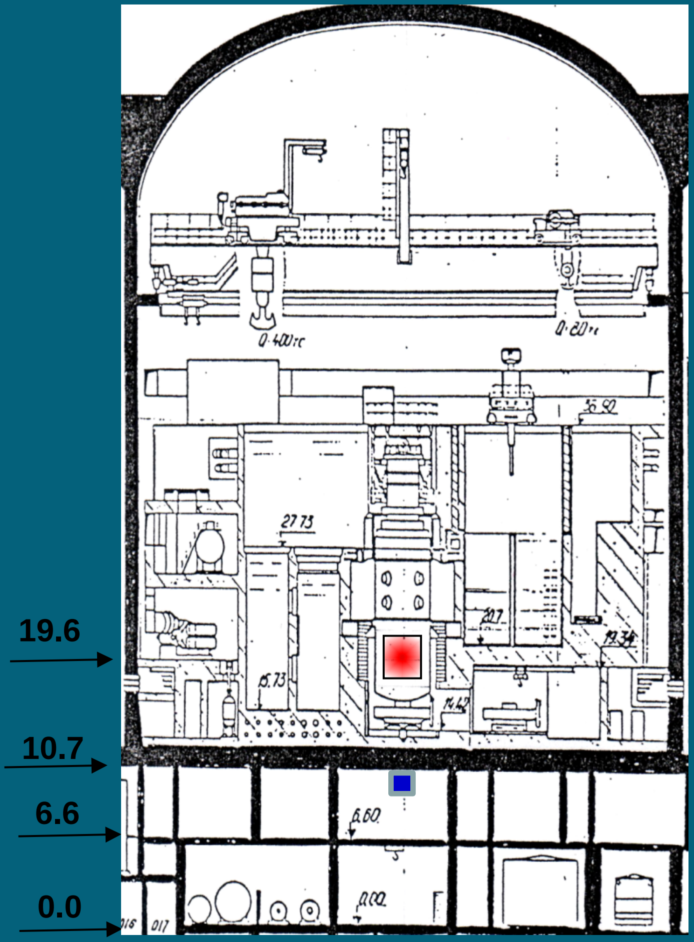
Search of oscillation signal at a (very) small distances from the reactor is interesting

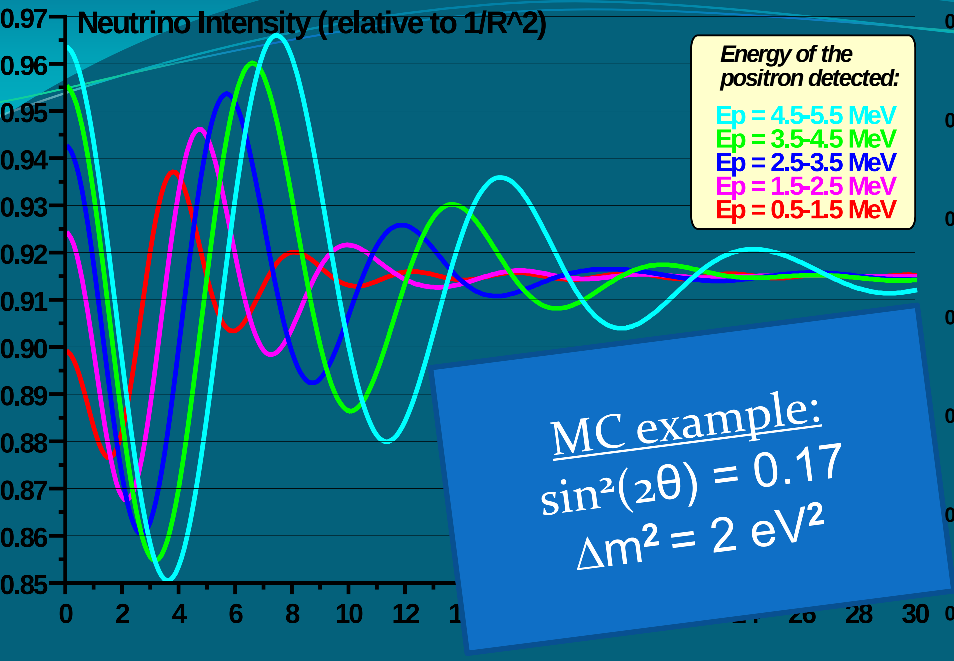
Studying the anomaly

- Tests in a short distance accelerator experiments
  - ICARUS at CERN, others…
- Tests with calibration sources
  - BAKSAN, Borexino, …
- Tests in reactor short distance experiments
  - Nucifer, DANSS, …

- Possible to move DANSS by ~2.5 m (from 9.7 to 12.2) <u>on-line</u>

- Or by longer distance (up to 18.8 m), but with partial dismounting ☹

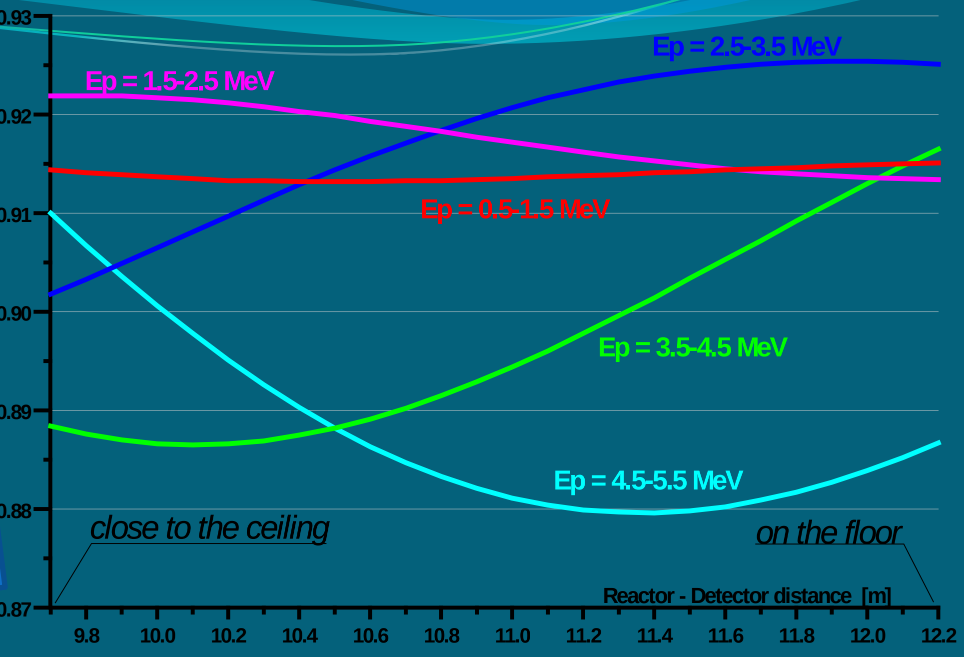


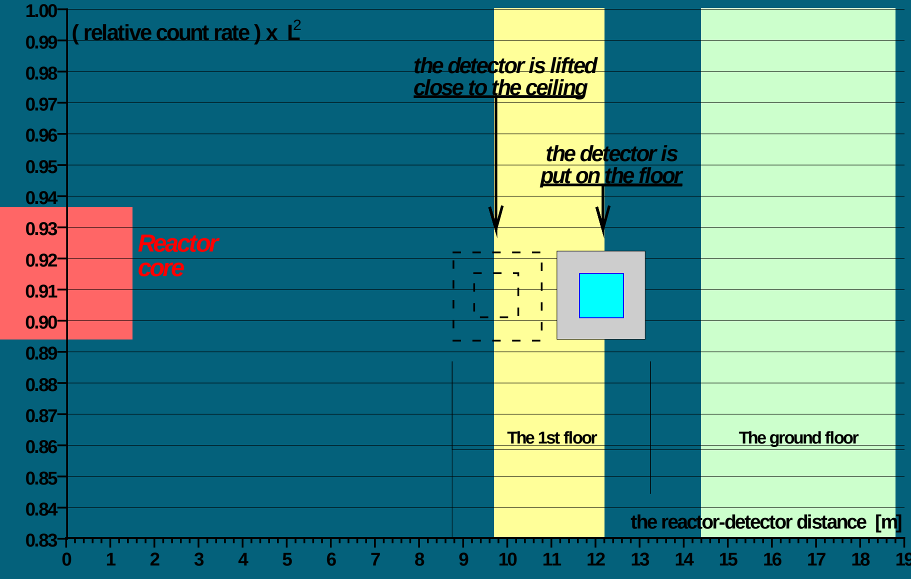


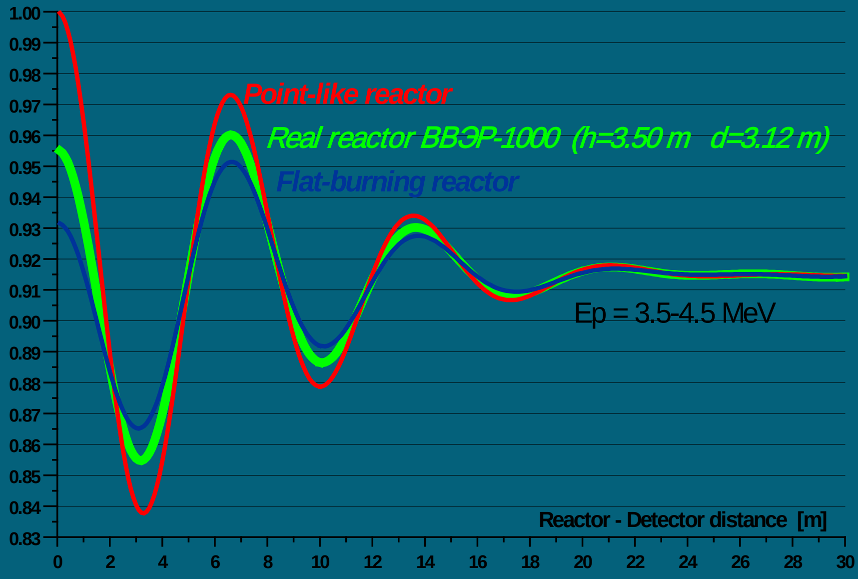
MC example:

$\sin^2(2\theta) = 0.17$

$\Delta m^2 = 2\ \mathrm{eV}^2$







CM-3
research reactor

(НИИАР, Димитровград)

Operation: since 1961

Reconstructions: 1965, 1974, 1992

Core: 35x42x42 cm

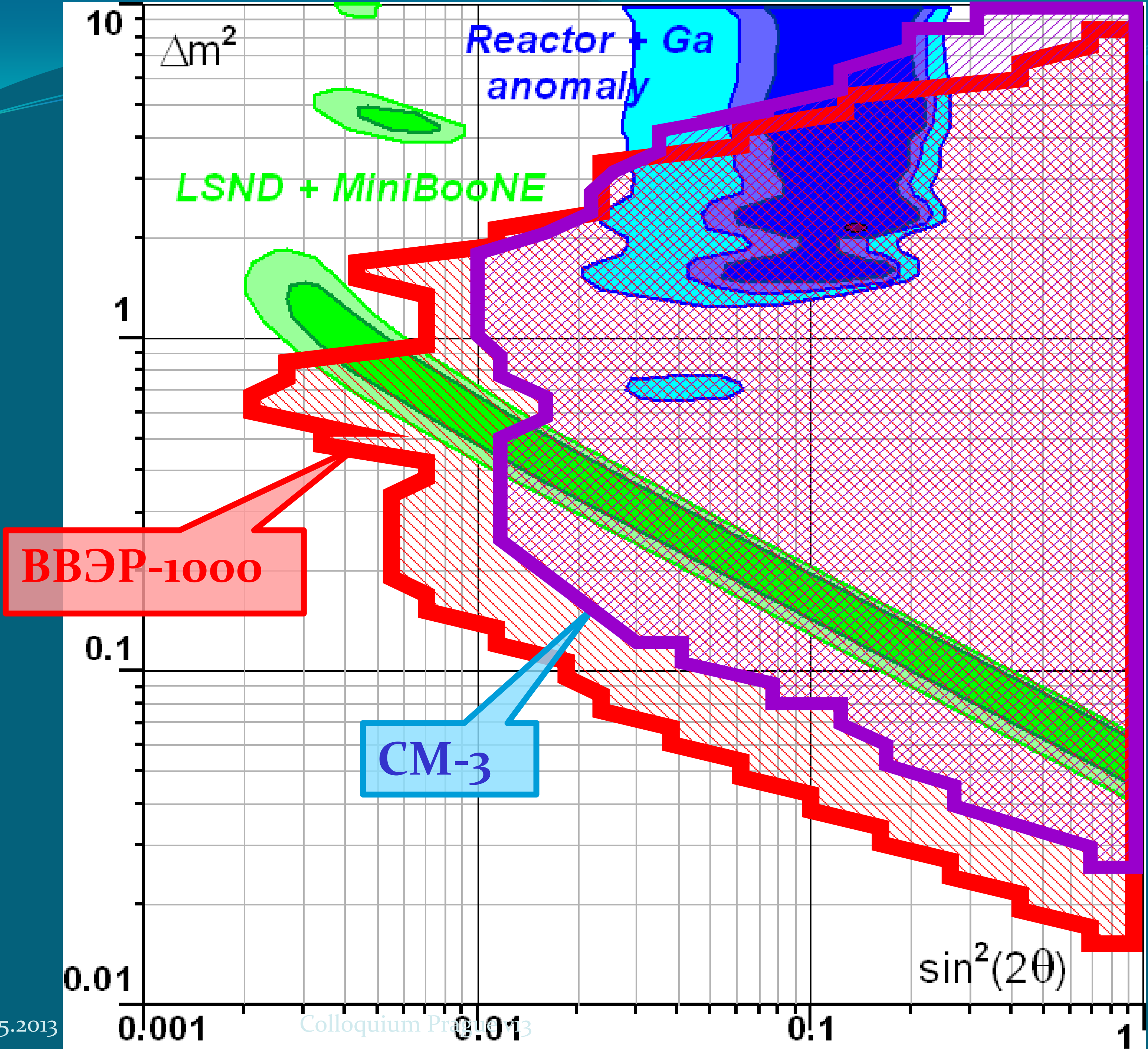
Thermal power: 100 MW

Fuel: ^{235}U (90%)

Distance available: 5.17 - ~15 m

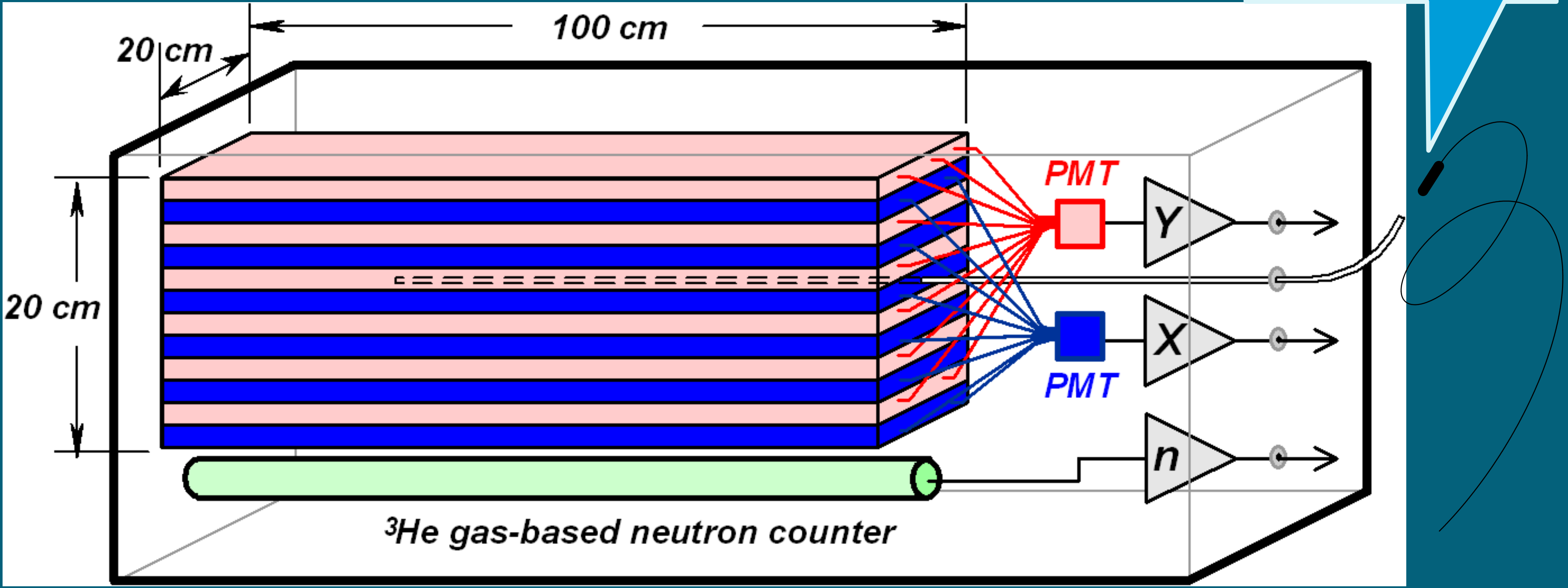
Background in the room: ~x4

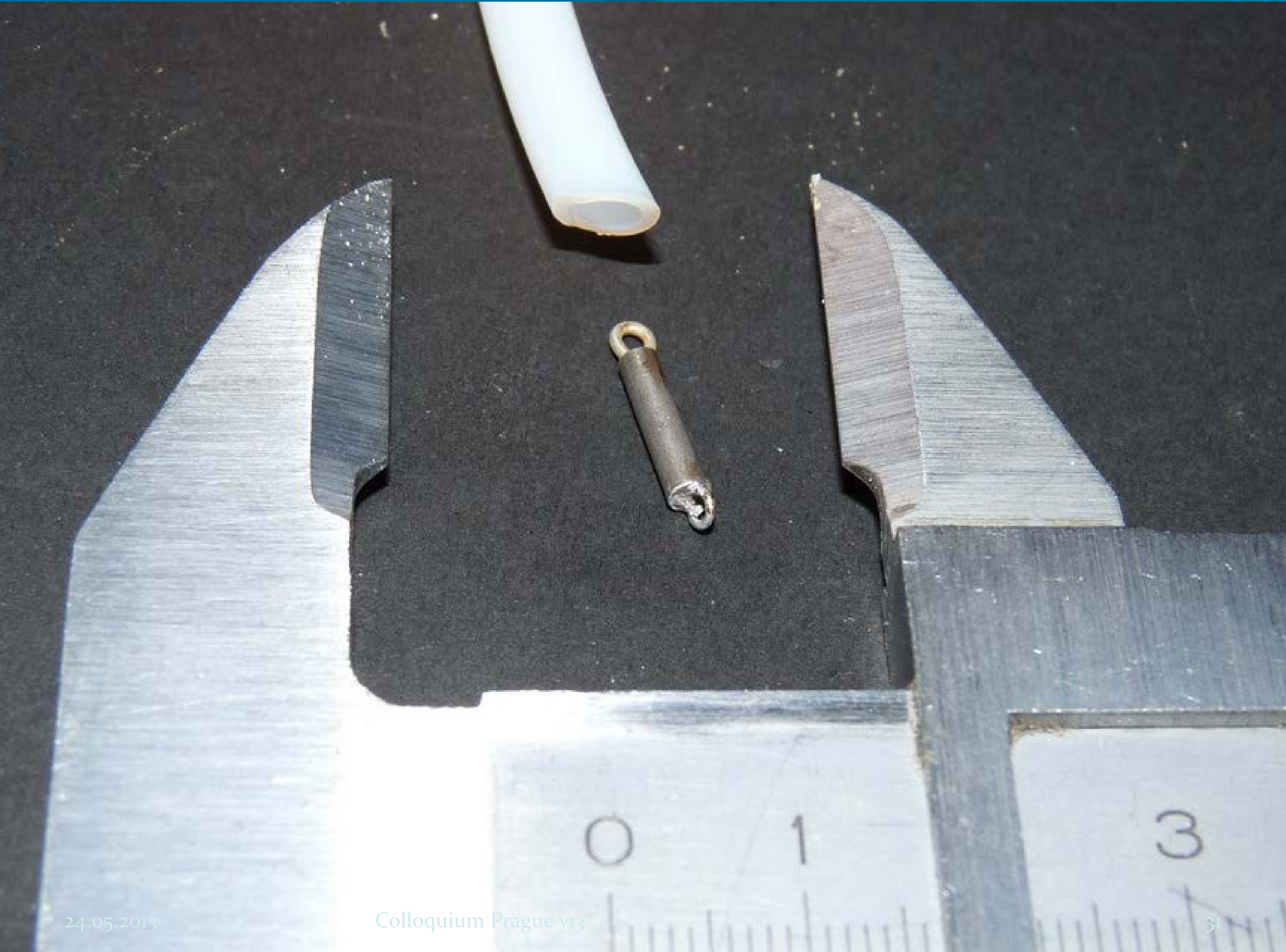
ON/OFF: ~2/1


10
Δm²
Reactor + Ga anomaly
LSND + MiniBooNE
1
0.1
0.01
ВВЭР-1000
СМ-3
sin²(2θ)
0.001
0.01
0.1
1

DANSSino – test module of the DANSS

Calibration r/a sources (few Bq):
^{60}Co
^{22}Na
^{137}Cs
^{248}Cm

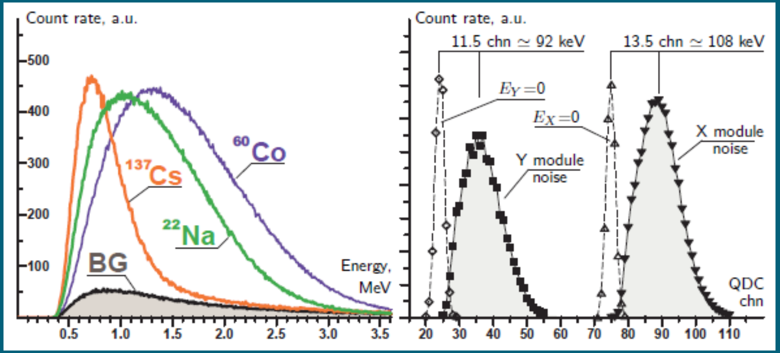



0
1
3

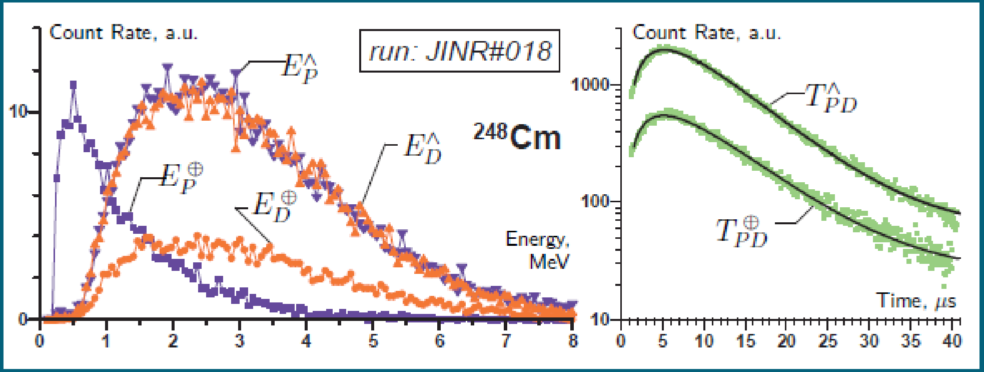

DANSSino


ν-ДЕТЕКТОР
DANSSino

DANSSino tests at Dubna Laboratory



1) γ-sources tests and energy calibration (~100 keV/p.e.)



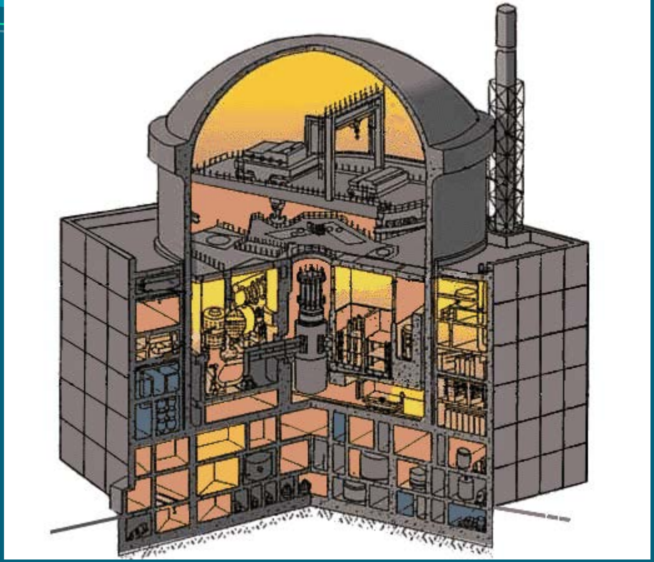
2) ^{248}Cm n-source tests provide the same signature with fast n-p scattering or γ –cascade as a Prompt signal

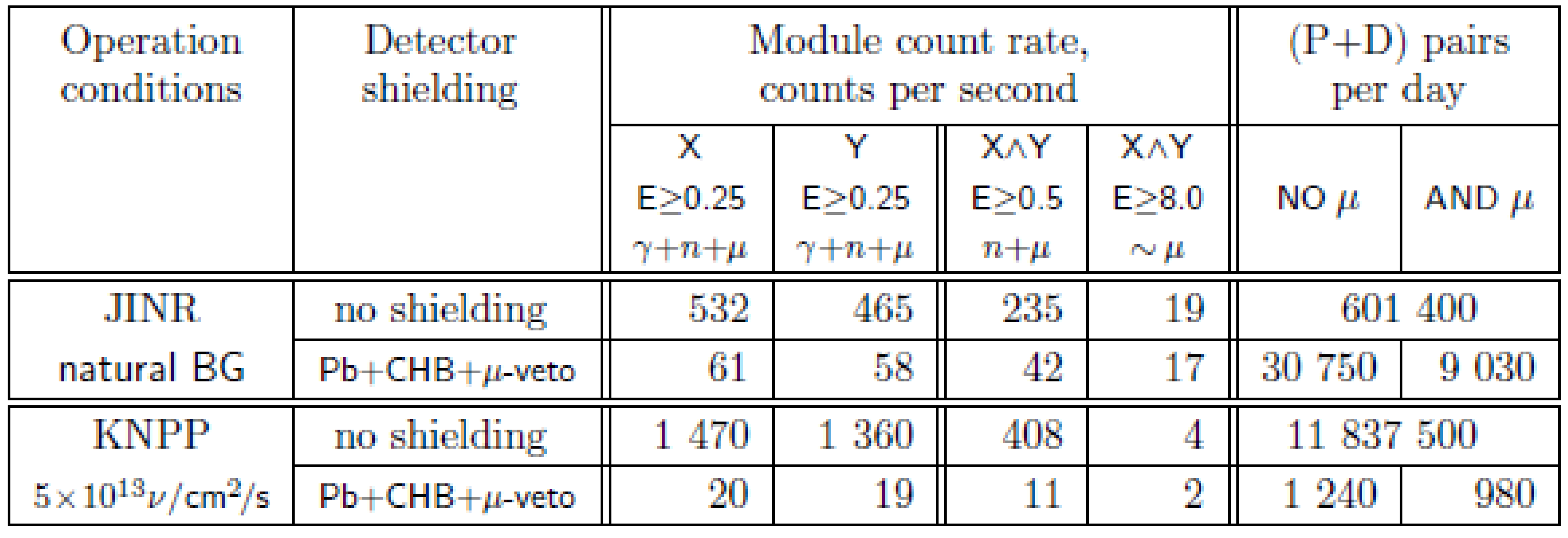
3) Tests with different passive shielding show that:

- ~ 10 cm of Cu and Pb are enough to suppress natural γ background
- ~ 10 cm of CHB reject thermal neutrons
- still significant IBD-like background from fast neutrons from hadronic component of cosmic rays (≥ 20 m.w.e. are required)

DANSSino tests at KNPP

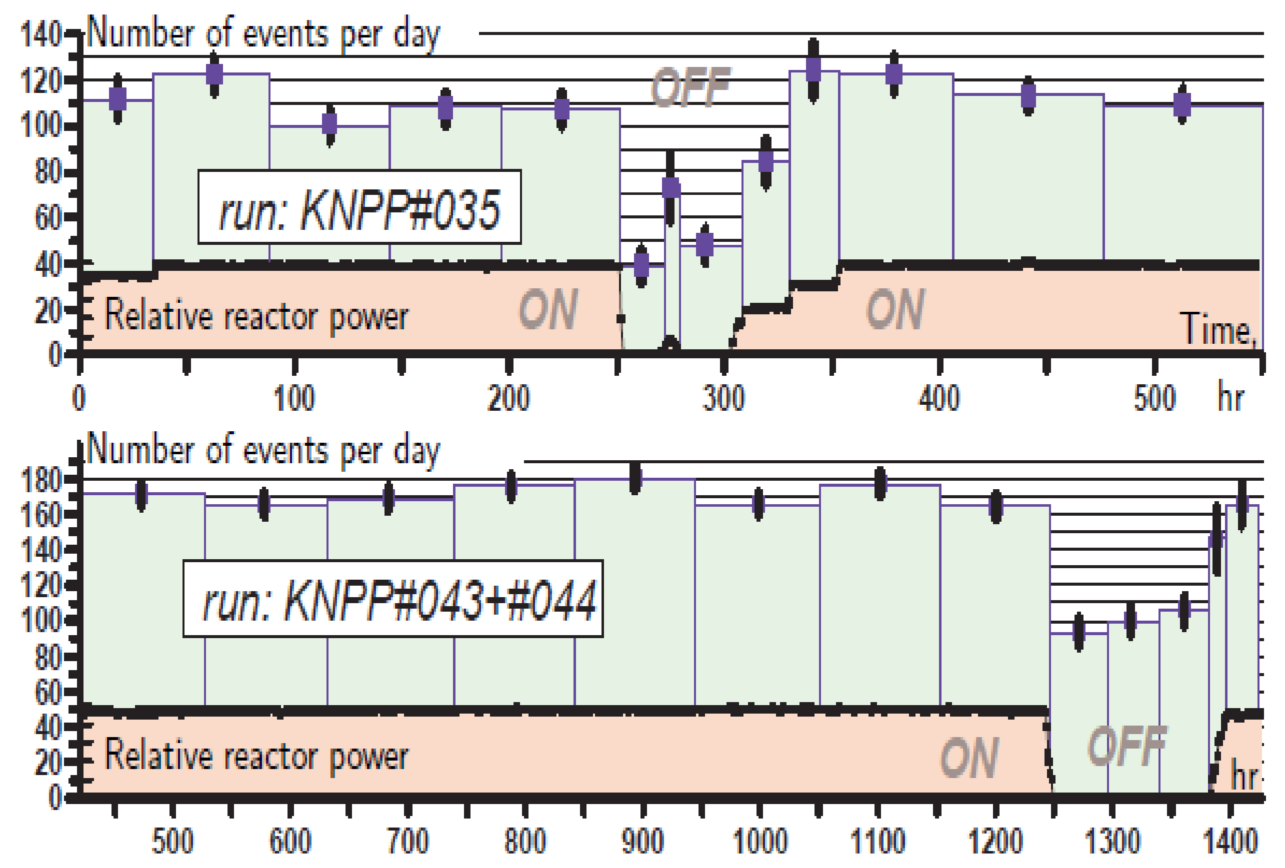
Muon component of a CR is suppressed by a factor of ~ 6, which corresponds to ~ 50 m.w.e. – enough to remove fast cosmic neutron background.





Operation conditions	Detector shielding	Module count rate, counts per second				(P+D) pairs per day	
		X $E\geq0.25$ $\gamma+n+\mu$	Y $E\geq0.25$ $\gamma+n+\mu$	$X\wedge Y$ $E\geq0.5$ $n+\mu$	$X\wedge Y$ $E\geq8.0$ $\sim\mu$	NO μ	AND μ
JINR	no shielding	532	465	235	19	601 400	
natural BG	Pb+CHB+μ-veto	61	58	42	17	30 750	9 030
KNPP	no shielding	1 470	1 360	408	4	11 837 500	
$5\times10^{13}\nu/cm^2/s$	Pb+CHB+μ-veto	20	19	11	2	1 240	980

DANSSino tests at KNPP



Event Selection:

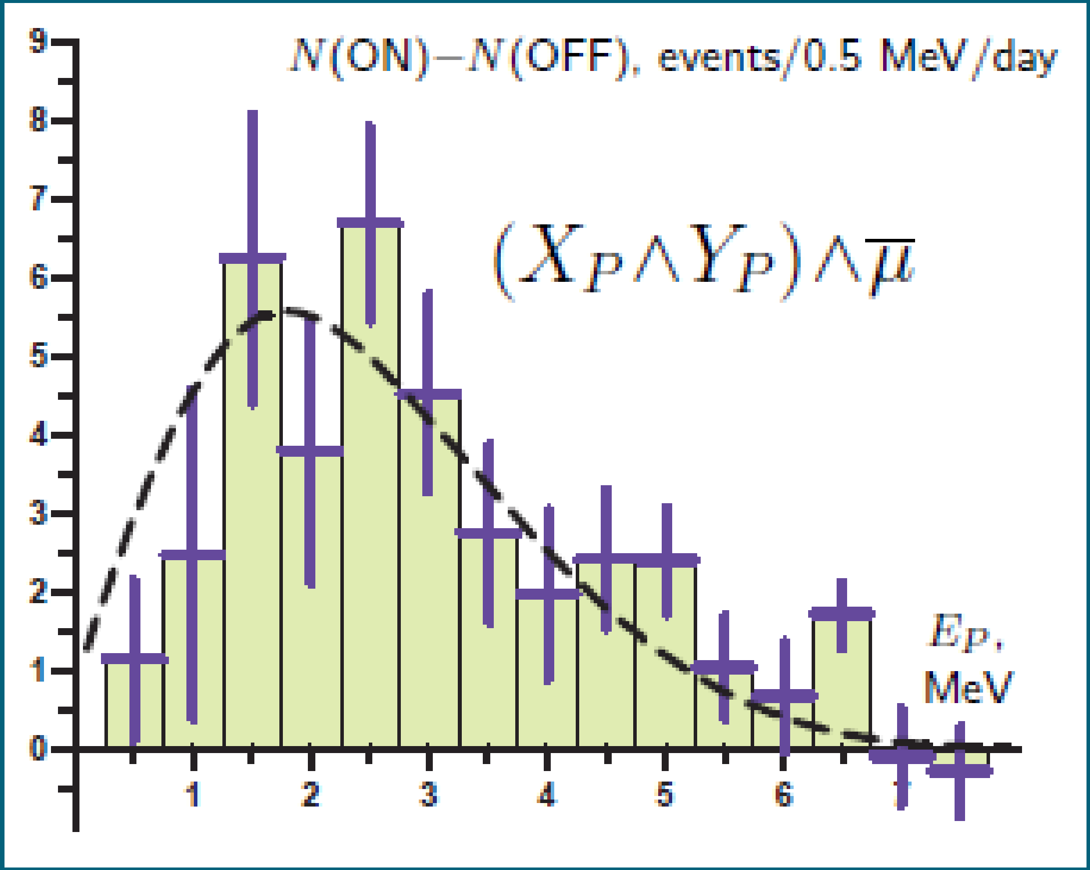
1)
Prompt E=1-7 MeV

2)
Delayed E=1-8 MeV

3)
Correct time between prompt and delayed signals (1.5-30 μs)

4)
Delayed E distributed in both X and Y modules

DANSSino tests at KNPP



E_p energy spectra of the neutrino-like events detected by DANSSino

Dashed curve – expected spectra normalized to the number of events

75 events/day expected
70+-5 detected

Compared to DANSS:
10% vs 70% efficiency
and 1:25 mass

Conclusions

- A solid-state detector of reactor (anti)neutrinos, DANSS, is planned to be installed under the $3GW_{th}$ reactor of the Kalinin Nuclear Power Plant in Russia.

- Expected parameters of DANSS allow to monitor the work of the reactor and perform measurements of a possible effect of short-range neutrino oscillations to the sterile state with $\Delta m^2 \sim 1\ eV^2$.

- Numerous tests performed with the pilot (reduced) version of the detector, DANSSino, demonstrate operability of the chosen design (arXiv:1305.3350 [physics.ins-det]).

Thank you