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Sensitivity of the DANSS detector to short range neutrino oscillations

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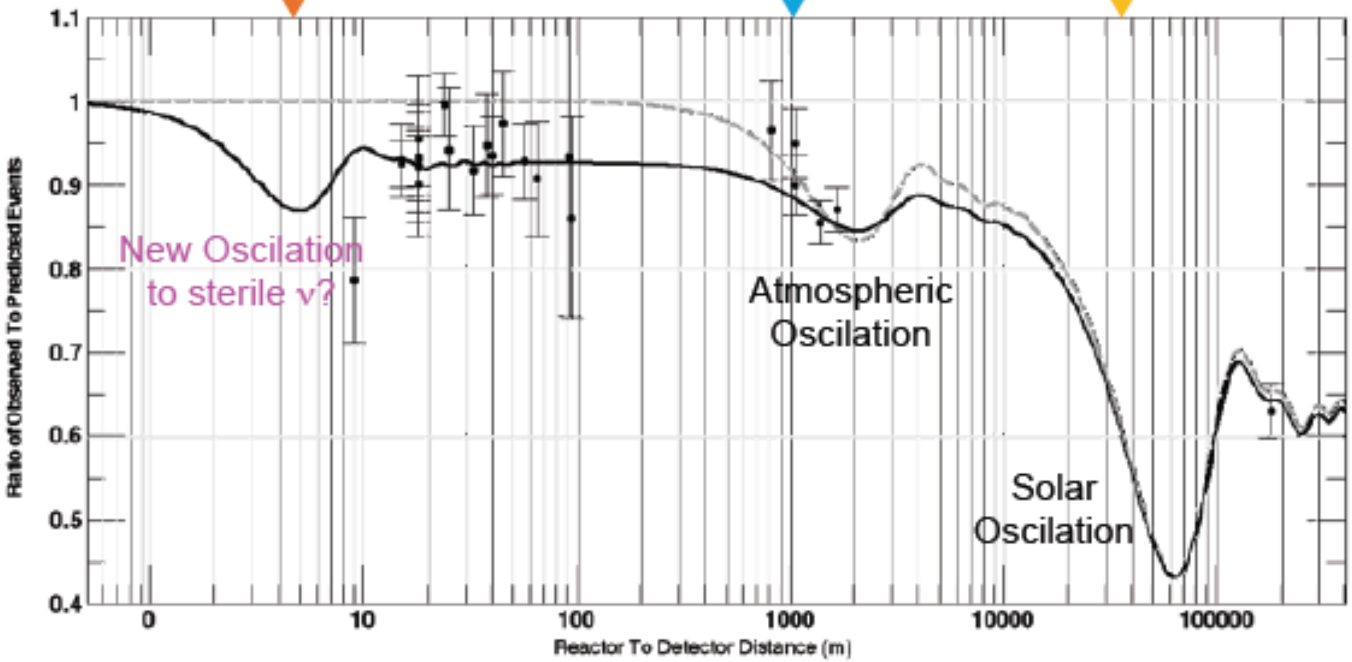
Detector of the reactor AntiNeutrino based on Solid-state plastic Scintillator (DANSS)

There are several ~3σ indications of 4^{th} neutrino

LSND, MiniBoone: $\bar{\nu}_e$ appearance
SAGE and GALEX ν_e deficit
Reactor $\bar{\nu}_e$ deficit

Indication of a sterile neutrino
$\Delta m^2 \sim 1\ eV^2$
$\sin^2 2\theta_{14} \sim 0.17$
=> Short range neutrino oscillations

$$P_{\bar{\nu}_e \to \bar{\nu}_e} = 1 - \sin^2 2\Theta_{14} \sin^2\left(1.27 \Delta m^2_{41} \frac{L}{E}\right) - c^4_{14} \sin^2 2\Theta_{13} \sin^2\left(1.27 \Delta m^2_{31} \frac{L}{E}\right) - c^4_{14} c^4_{13} \sin^2 2\Theta_{12} \sin^2\left(1.27 \Delta m^2_{21} \frac{L}{E}\right)$$



G. Mention et al. Phys Rev D 83 073006 (2011)

DANSS Goals

Reactor monitoring using neutrinos:

1. to measure the thermal reactor power with accuracy of 1.5% per day;
2. to define the fuel composition and amount of the produced 239Pu with accuracy of 6% in 10 days of measurements;

Search for short range neutrino oscillations

DANSS Parameters:

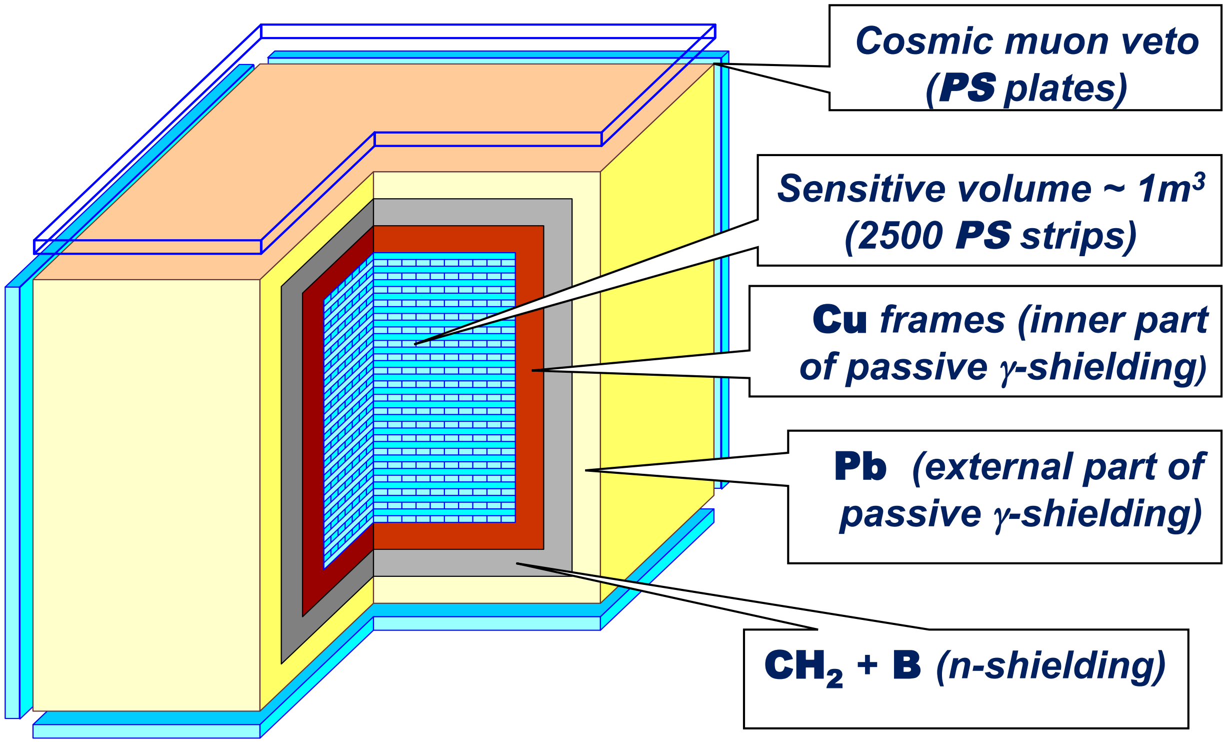
IBD detection efficiency ~70%

$\bar{\nu}$ counting rate up to 10000/day

Background rate ~1%

Distance to reactor core (center to center)
9.7-12.2m (change in 5min)

Energy resolution
~20% at 1MeV



Total weight – 13t + lifting gear

DANSS Design

Each scintillator strip is read out individually by a Silicon Photo Multiplier (SiPM) via a WLS fiber.

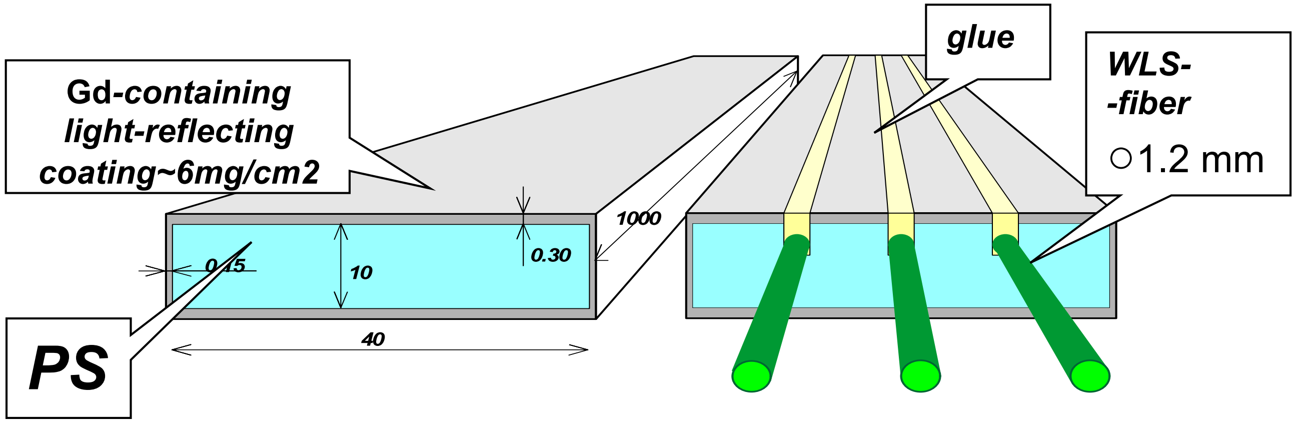
Sensitivity is ~15 p.e./MeV

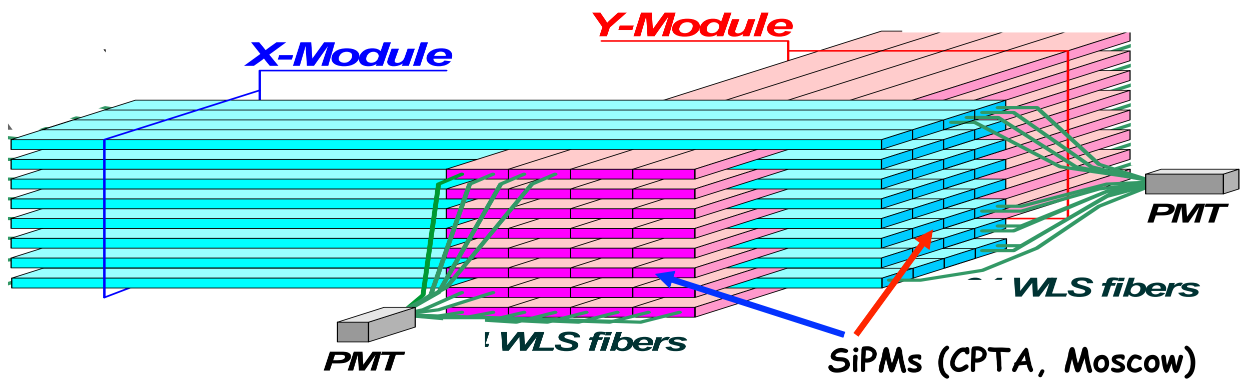
Light attenuation ~20%/m

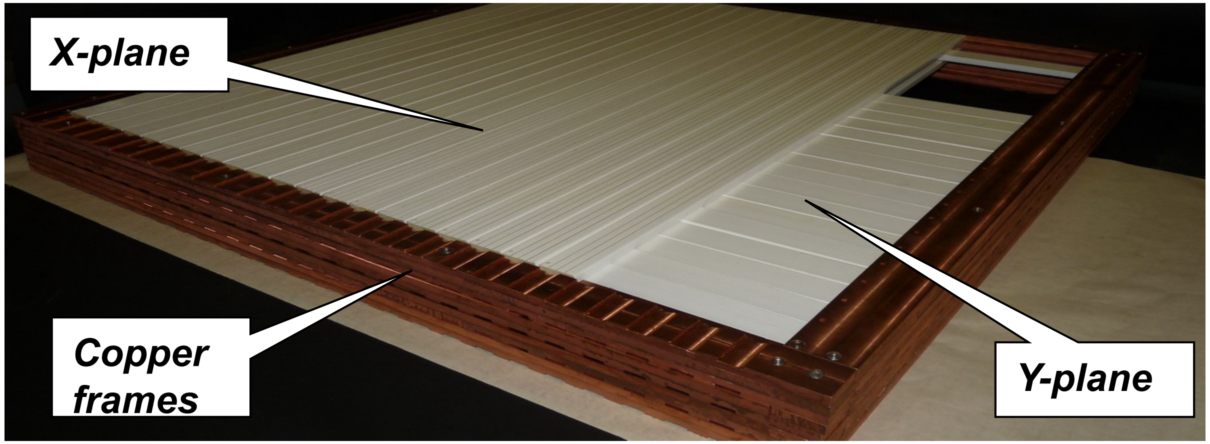
- 50 strips are combined into a Module which is also read out by a small PMT (via 2 additional WLS fibers per strip).

Sensitivity is ~10 p.e./MeV

- **The frame of a Module** is made of radio-pure electrolytic copper and thus **shields the sensitive part** against insufficiently pure components of front-end electronics placed outside the frame.







View of a Module (under construction).

DANSS advantages

Handling is much safer *(non-flammable, non-caustic)*
⇒ no restrictions to move the detector very close to the reactor core
⇒ higher neutrino flux => better sensitivity.

High segmentation (2500 strips) => space information
⇒ better IBD signature => stronger BG suppression.
⇒ possibility of continuose calibration with cosmics for every strip

PS is not doped with Gd, but interleaved with it
⇒ better stability of the scintillator.

Dual readout with SiPM and usual PMT => better control of systematic

Detector on movable platform under reactor => better control of systematic
low cosmic background

DANSS disadvantages

Worse energy resolution in comparison with liquid scintillator

Relatively large number of readout channels

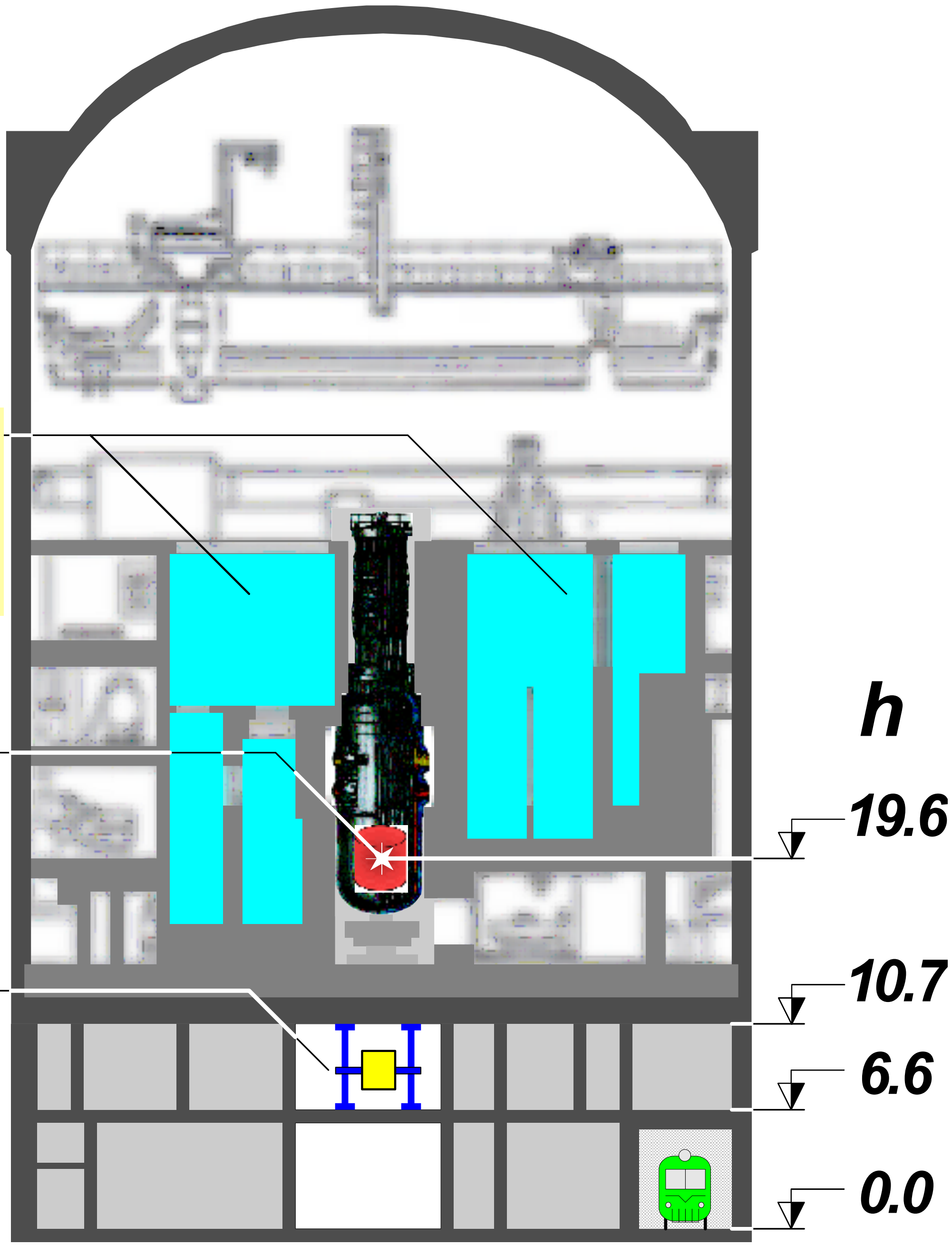
DANSS position under WWER-1000 reactor at Kalinin NPP

Typical reactor building
with WWER-1000
3 GW thermal power
^{238}U + (3.5-5)% ^{235}U
$5 \cdot 10^{13}$ $\bar{\nu}$/s/cm2 @10m

Reservoirs with
Technological liquids
~ 60 mwe

Core:
h =3.5m
∅ = 3.12m

DANSS on a movable
platform with a lifting gear
Detector distance from
reactor core 9.7-12.2 m
(center to center)



A small prototype - "DANSSino"

Purpose:

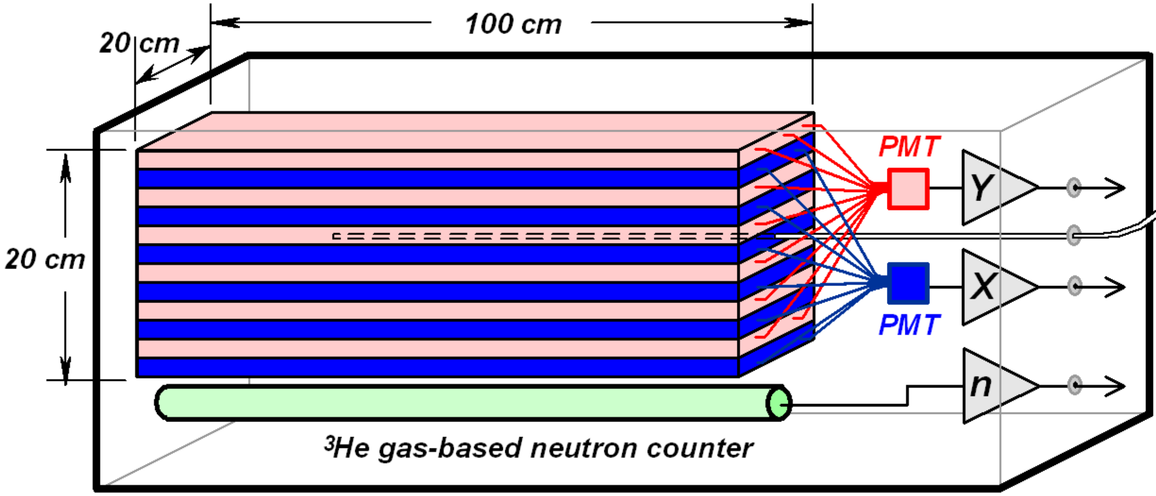
- Study of background conditions
- Tests of shielding efficiency
- Measurements of trigger rates

Properties:

$\bar{\nu}\ p \rightarrow e^{+}\ n$ (Inverse Beta Decay)

Efficiency e^{+} (Prompt) - 47% (E>1MeV)

Efficiency n (Delayed) – 28% (E>1 MeV)



Calibration r/a source:
^{60}Co
^{22}Na
^{137}Cs
^{248}Cm ~3 n

50+50=100 strips

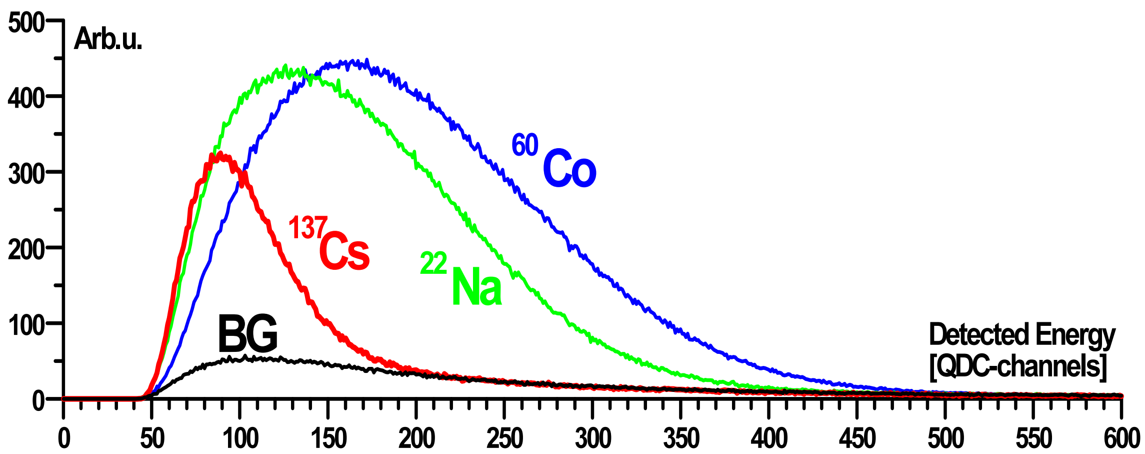
20 cm × 20 cm × 100 cm

1/25 of the DANSS

40 kg (movable)

2 PMT (X → odd, Y → even)

No SiPM readout



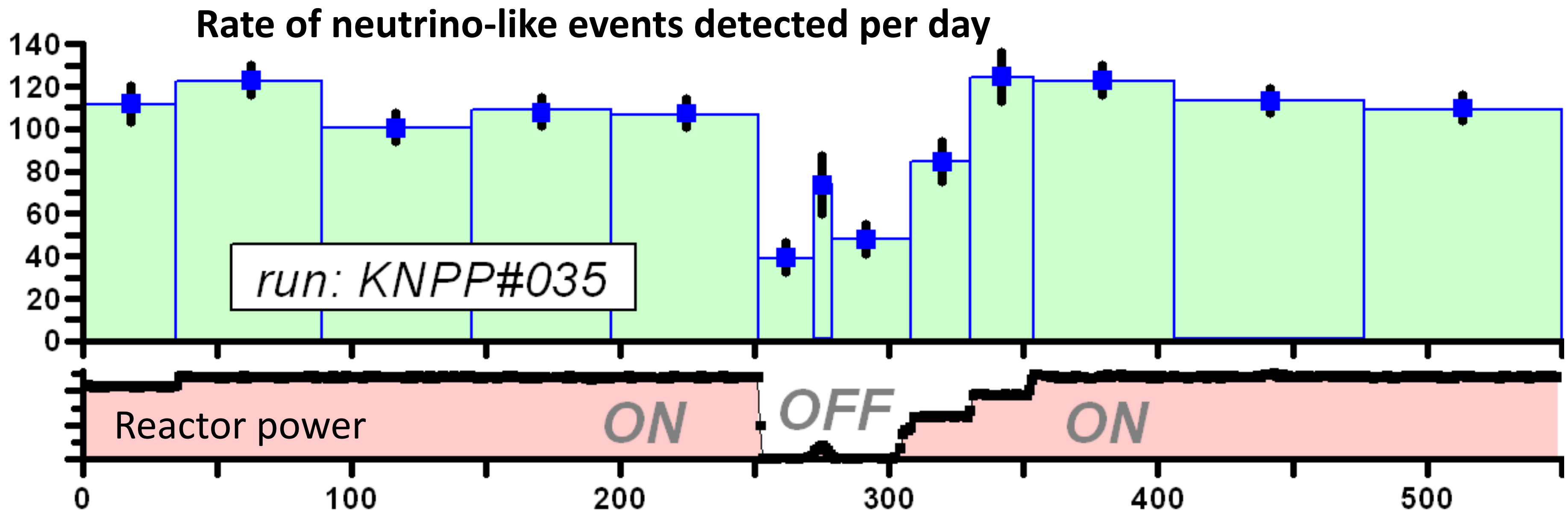
Background under reactor is order of magnitude lower than on surface

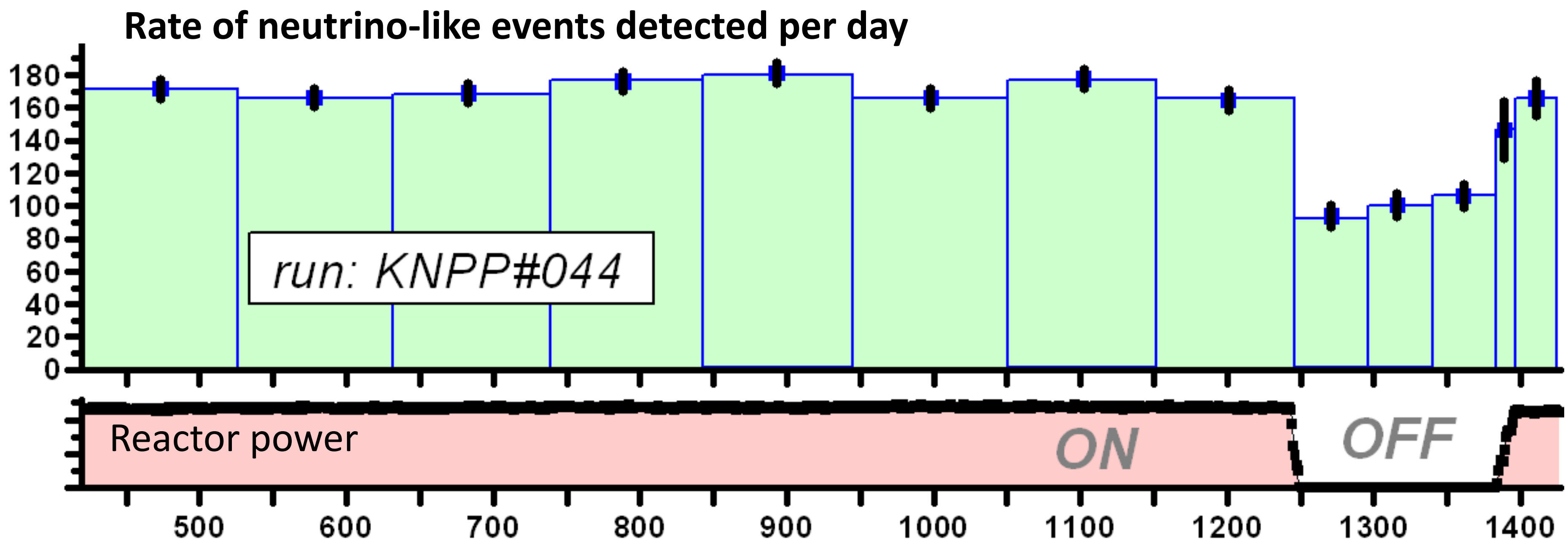
Operation conditions	Detector shielding	Modules count rate, counts per second				(P+D)-pairs per day	
		X $E\geq0.25$ $\gamma+n+\mu$	Y $E\geq0.25$ $\gamma+n+\mu$	$X\wedge Y$ $E\geq0.5$ $n+\mu$	$X\wedge Y$ $E\geq8.0$ $\sim\mu$	NO μ	AND μ
JINR natural BG	no shielding	532	465	235	19	601 400	
	Pb+CHB+μ-veto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

Heavy material shielding increases muon induced IBD background (and IBD detection efficiency)

Run#	KNPP#027	KNPP#035	KNPP#044
Shielding	Pb =10 cm CHB =16 cm	CHB =8 cm Pb =10 cm	Cu =5 cm CHB =8 cm Pb =5 cm
Events per day	835±7	214±4	384±4

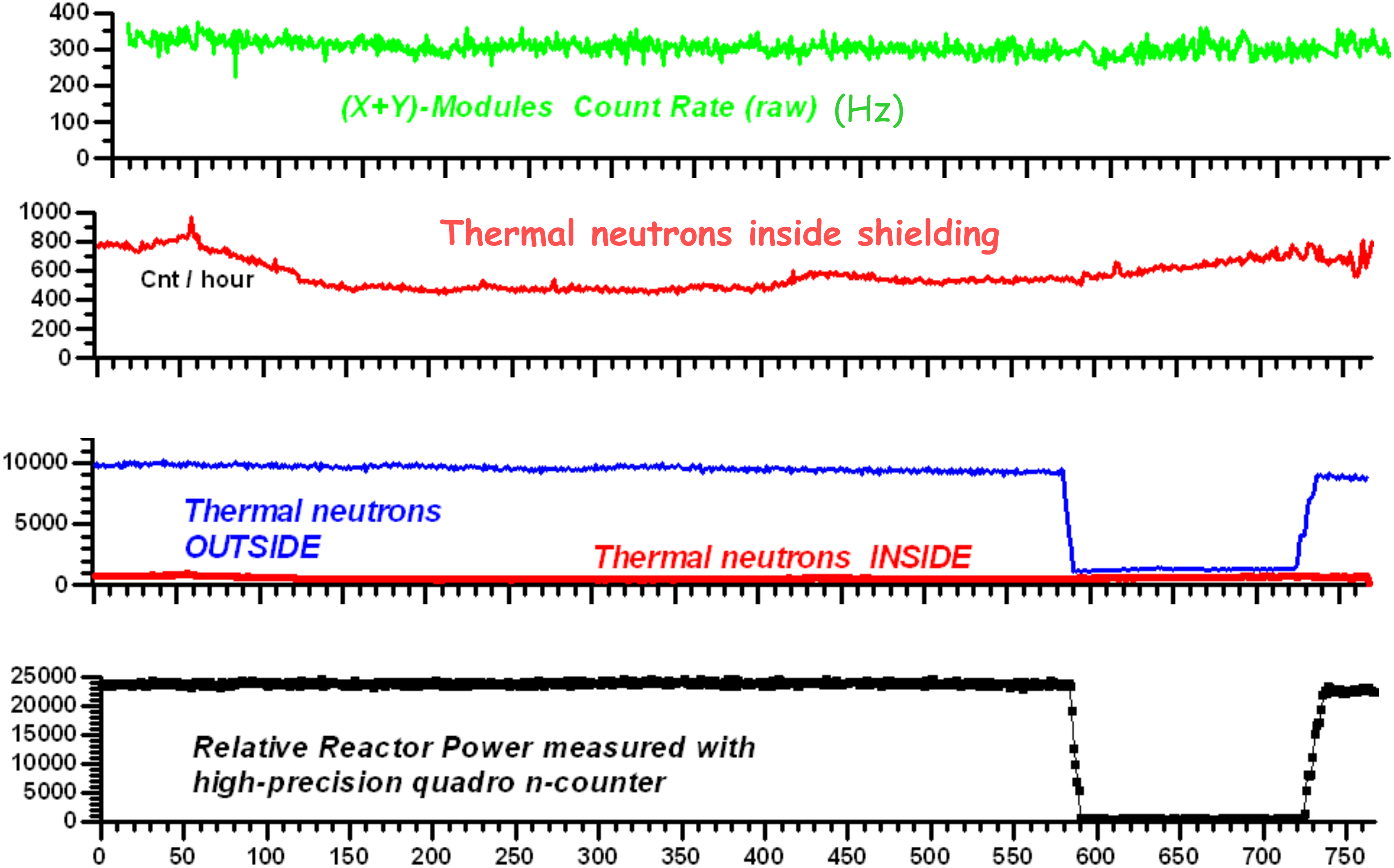
Clear correlation between reactor power and DANSSino counting rate



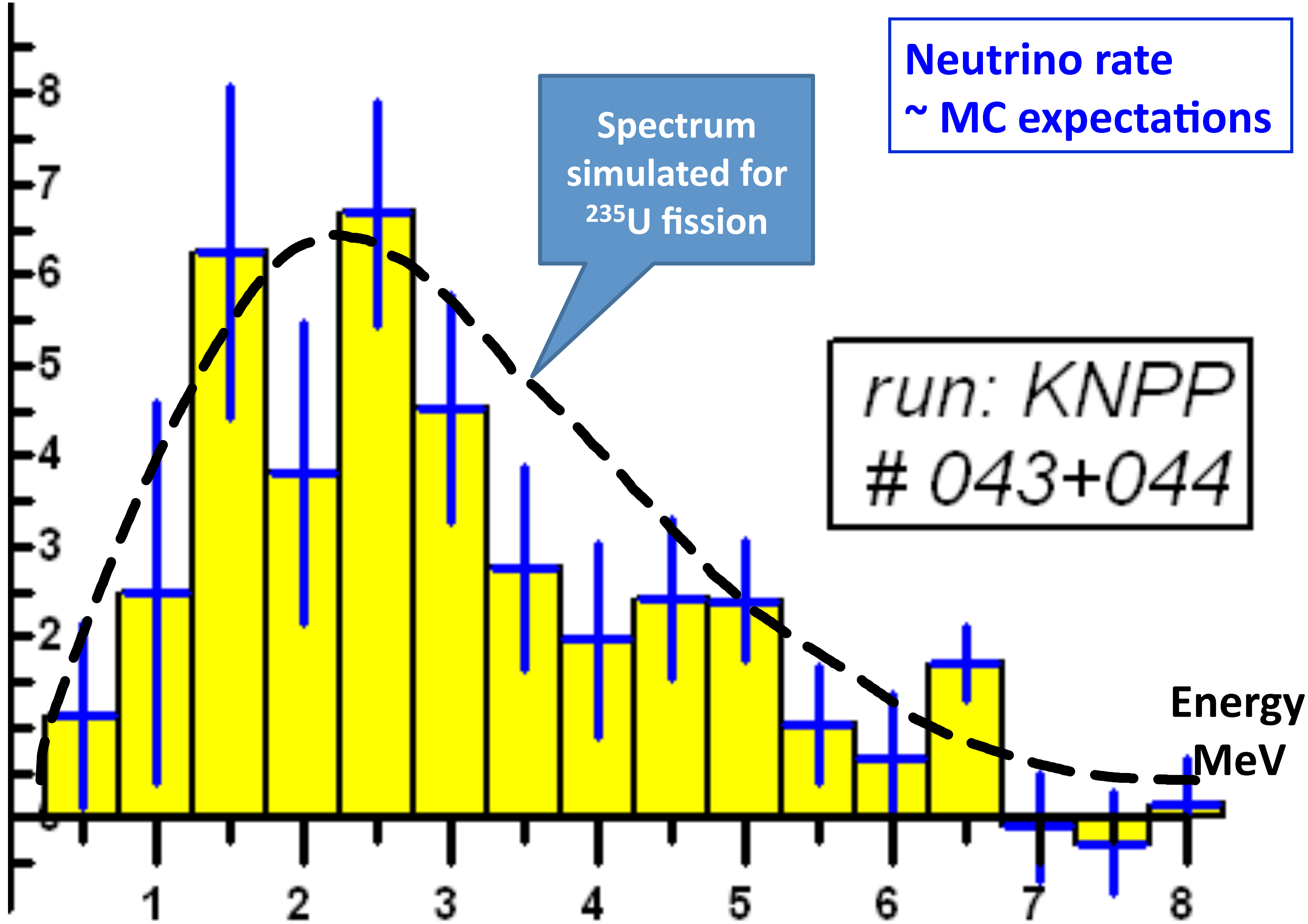


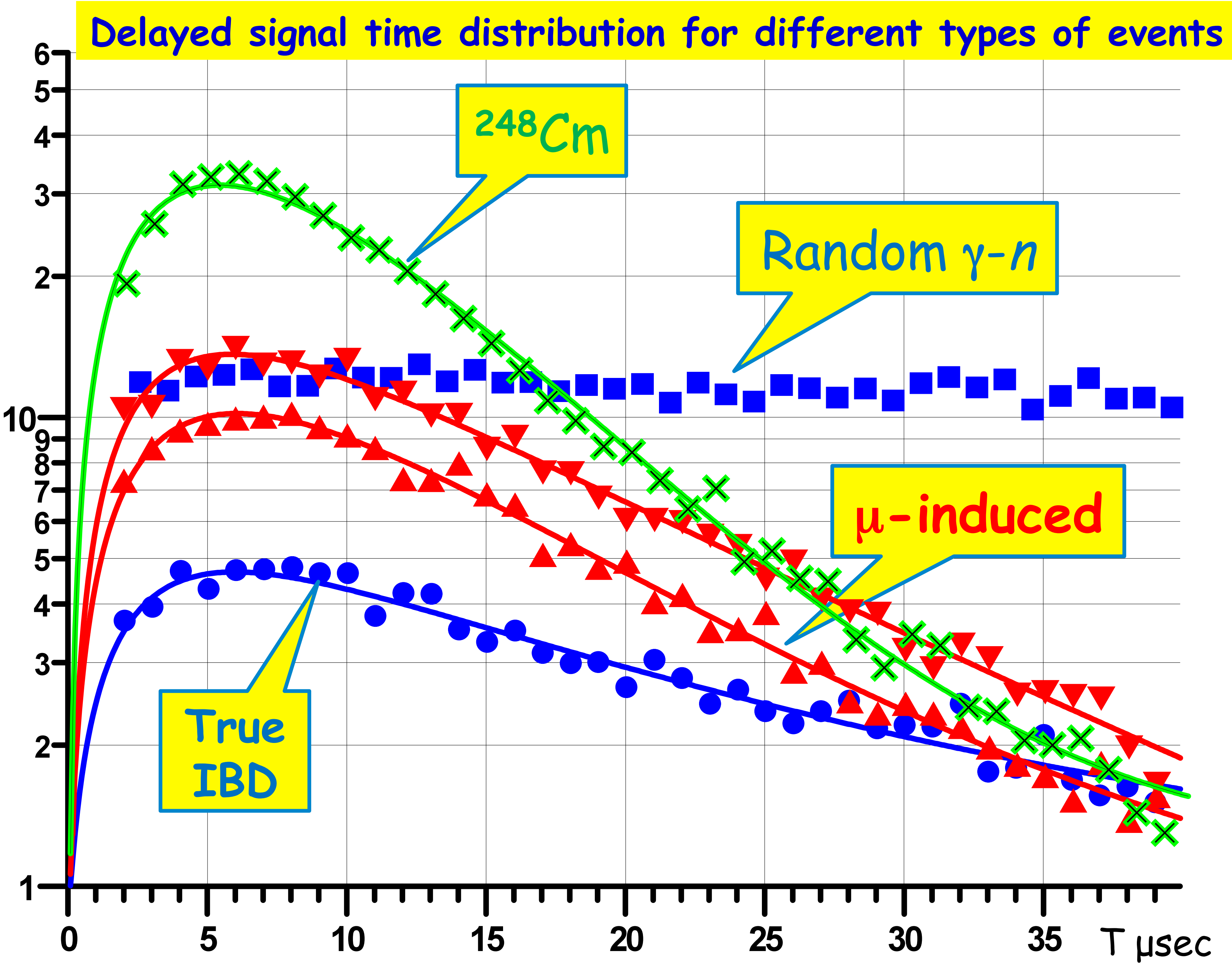
Raw counting rates during reactor ON and OFF periods

No change inside shielding!



Background subtracted rate of neutrino-like events / 0.5 MeV / day





Delayed signal time distribution for different types of events
^{248}Cm
Random γ-n
μ-induced
True IBD
T μsec
0
5
10
15
20
25
30
35
1
2
3
4
5
6
7
8
9
10

Comparison of counting rates for reactor On and OFF periods for different selection criteria

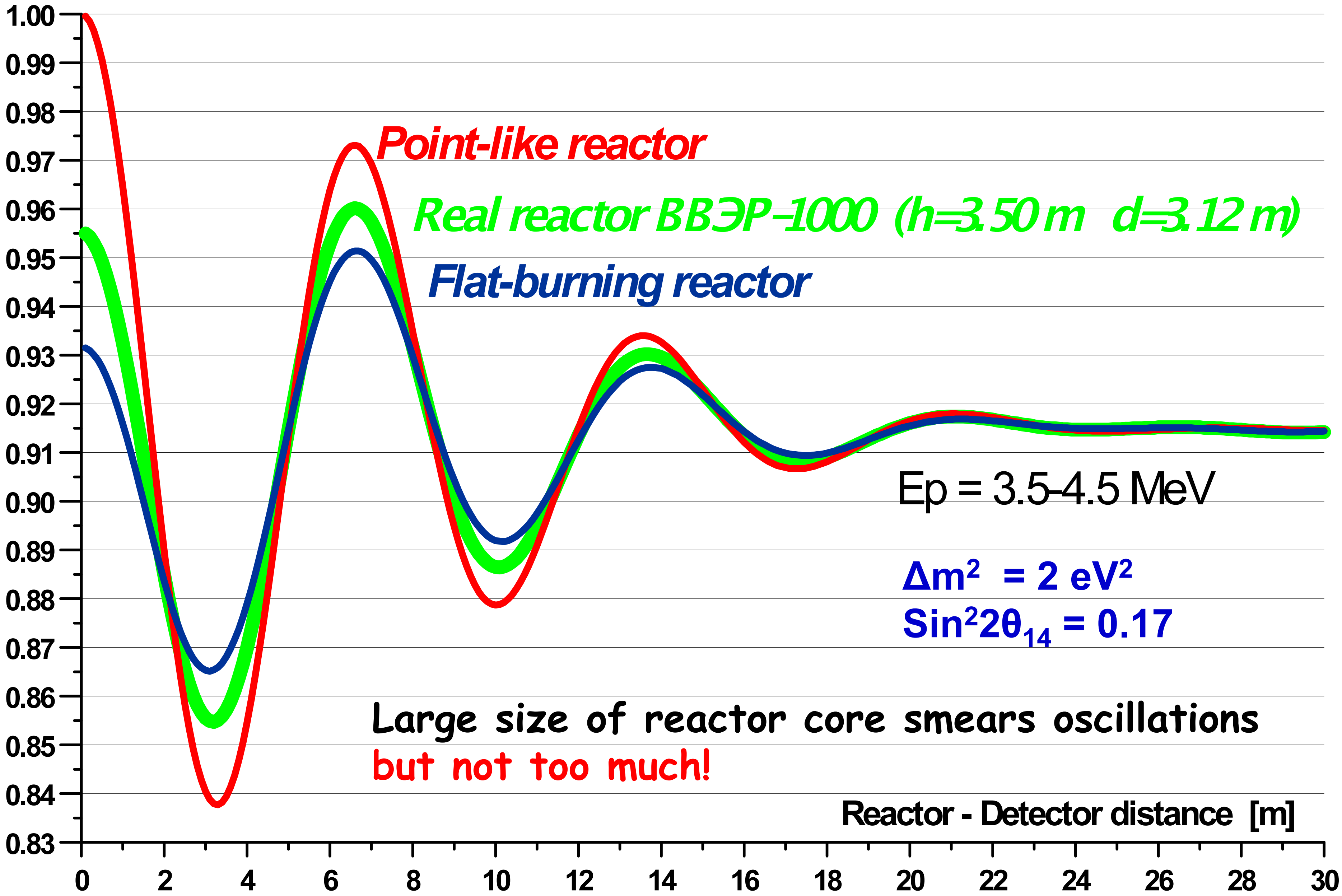
Evidence for neutrino detection (~70/day) with S/B~ 1

RUN# shielding structure	P-signal E_P^{min} MeV	P-signal X_P-Y_P logic	Number of neutrino-like events per day: tagged by μ-veto ON	tagged by μ-veto OFF	free of μ-veto ON	free of μ-veto OFF	S = ON–OFF	S/B ratio (≈)
KNPP#035	0.5	$X_p \oplus Y_p$	169±3	173±9	361±4	249±11	112±12	0.45
		$X_p \wedge Y_p$	129±3	133±8	69±2	38±4	30±5	0.79
CHB 8 cm	1.0	$X_p \oplus Y_p$	92±2	95±7	125±3	66±6	59±6	0.89
Pb 10 cm		$X_p \wedge Y_p$	123±3	126±8	60±2	31±4	29±4	0.92
	1.5	$X_p \oplus Y_p$	59±2	63±6	62±2	29±4	34±4	1.16
		$X_p \wedge Y_p$	108±2	105±7	48±2	20±3	28±4	1.43
KNPP#043	0.5	$X_p \oplus Y_p$	301±4	300±7	487±5	401±9	86±10	0.44
+ #044		$X_p \wedge Y_p$	243±3	246±7	112±2	76±4	36±4	0.46
Cu 5 cm	1.0	$X_p \oplus Y_p$	156±3	158±5	188±3	130±5	58±6	0.44
CHB 8 cm		$X_p \wedge Y_p$	228±3	231±6	99±2	64±3	35±4	0.54
Pb 5 cm	1.5	$X_p \oplus Y_p$	94±2	99±4	93±2	52±3	42±4	0.80
		$X_p \wedge Y_p$	195±3	201±6	77±2	44±3	33±3	0.74

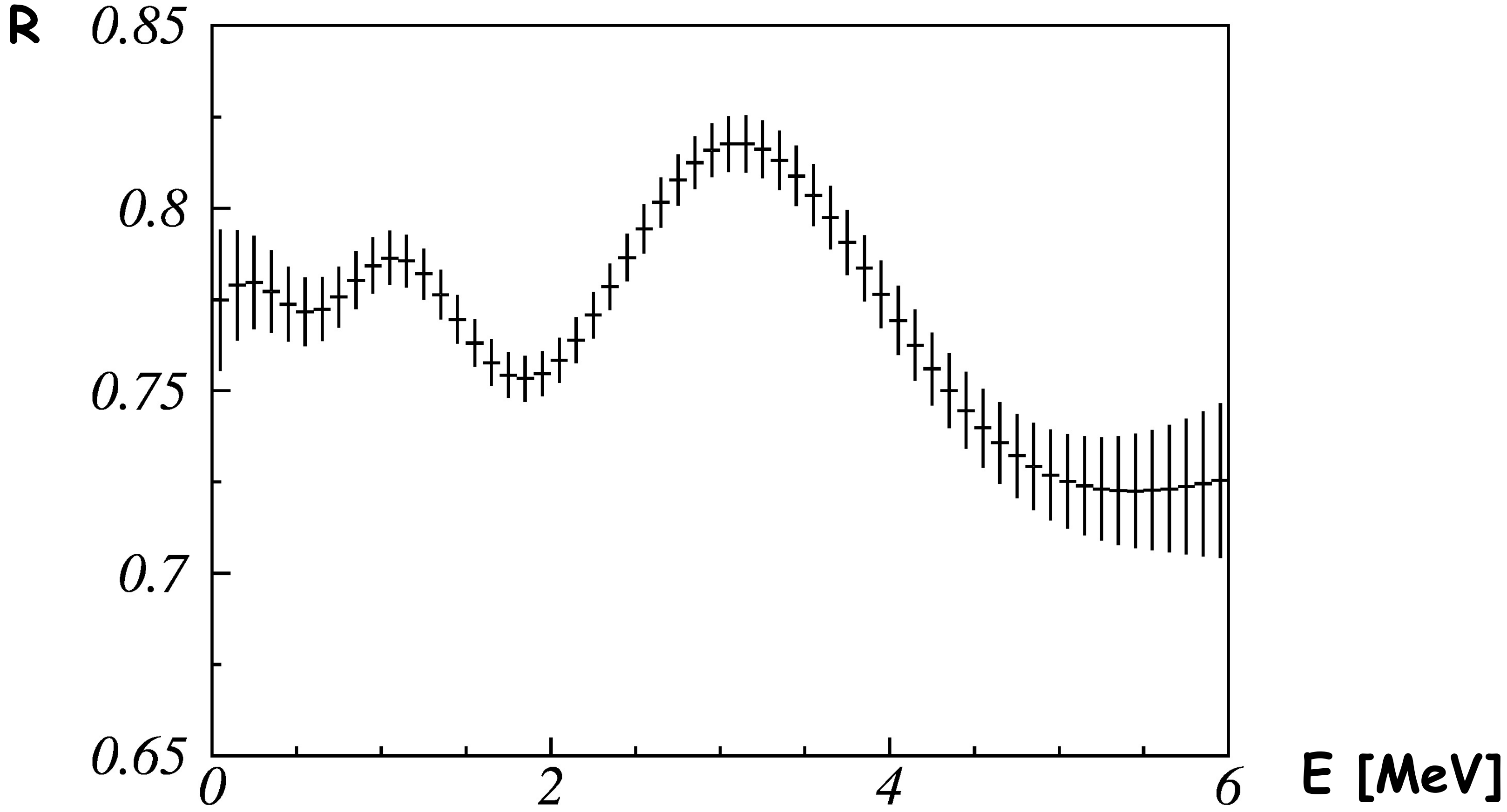
DANSSino confirmed DANSS design parameters

⇒ **Reliable estimates of DANSS sensitivity**

The role of the source dimensions



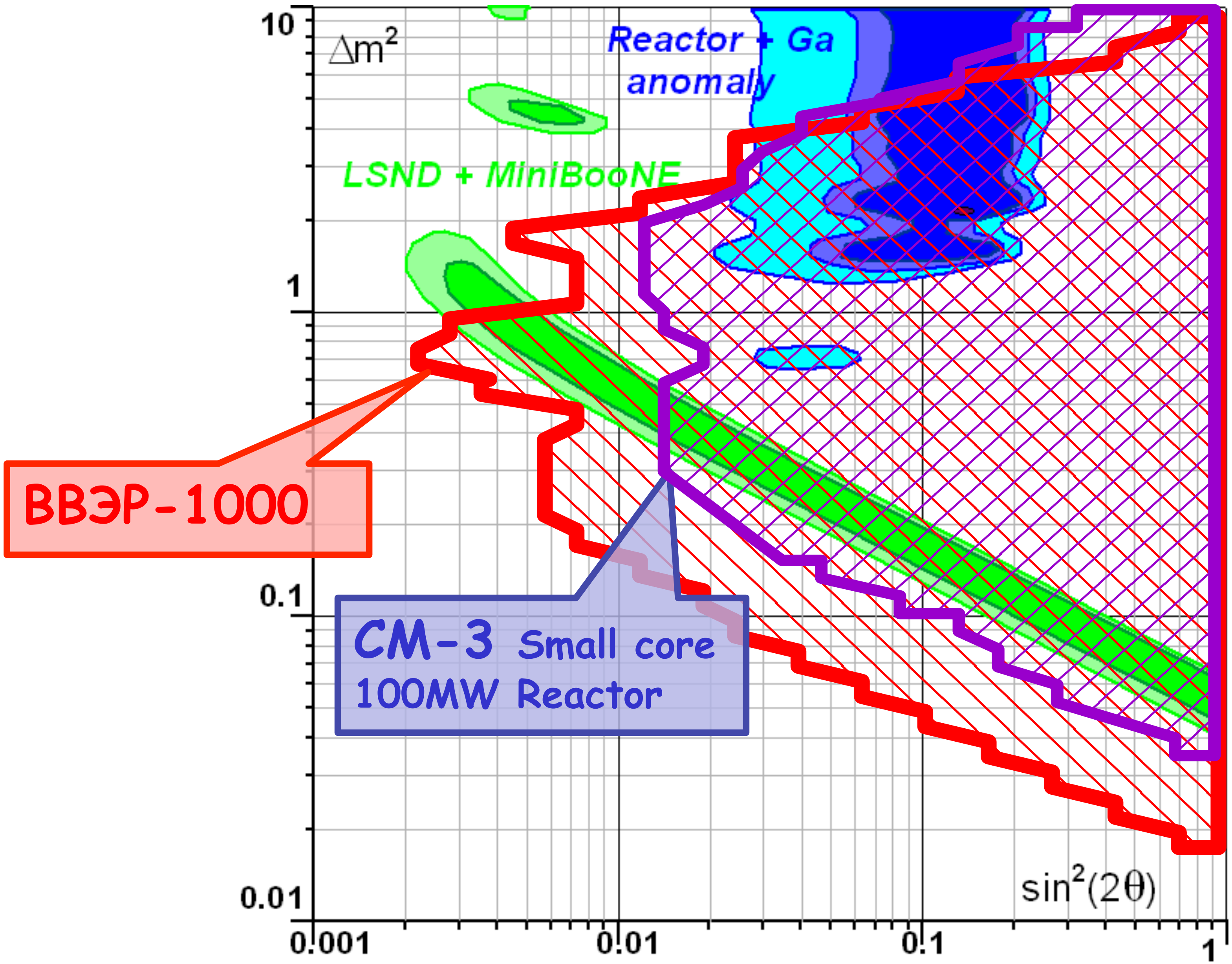
Ratio of positron spectra at 11m and 9.7m for $\Delta m^2 = 2eV^2$, $Sin^2 2\theta_{14} = 0.2$ (errors correspond to 8 months of running)



Distortions are perfectly seen

Sensitivity estimates (shape only) for 1 year (without systematics)

Most interesting parameter space is well covered



Summary

High granularity, good stability, very low background,
high neutrino flux and changeable distance to reactor core
should allow DANSS to study the most interesting parameter region of possible oscillations to the 4th neutrino.

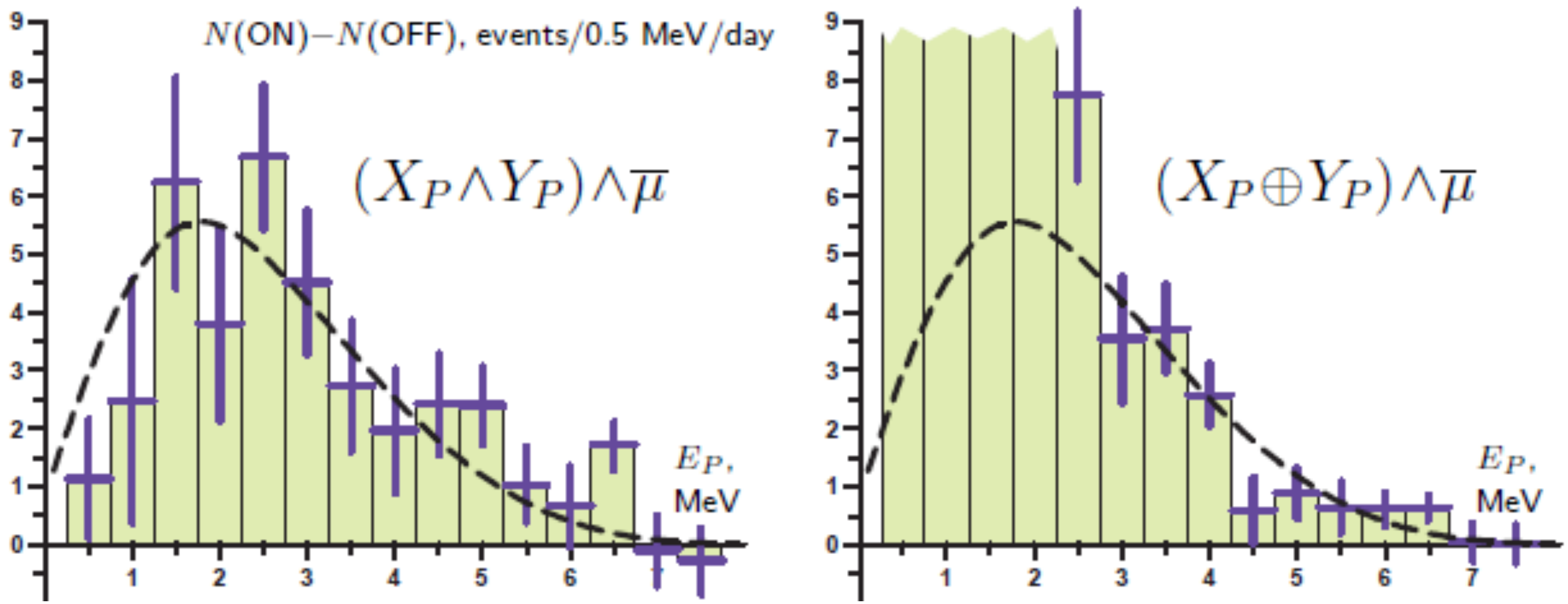
DANSS design parameters have been confirmed by the DANSSino results

In spite of a small size (4% of DANSS),
non perfect shielding and μ veto
DANSSino detected about 70 events/day with S/B ~ 1.

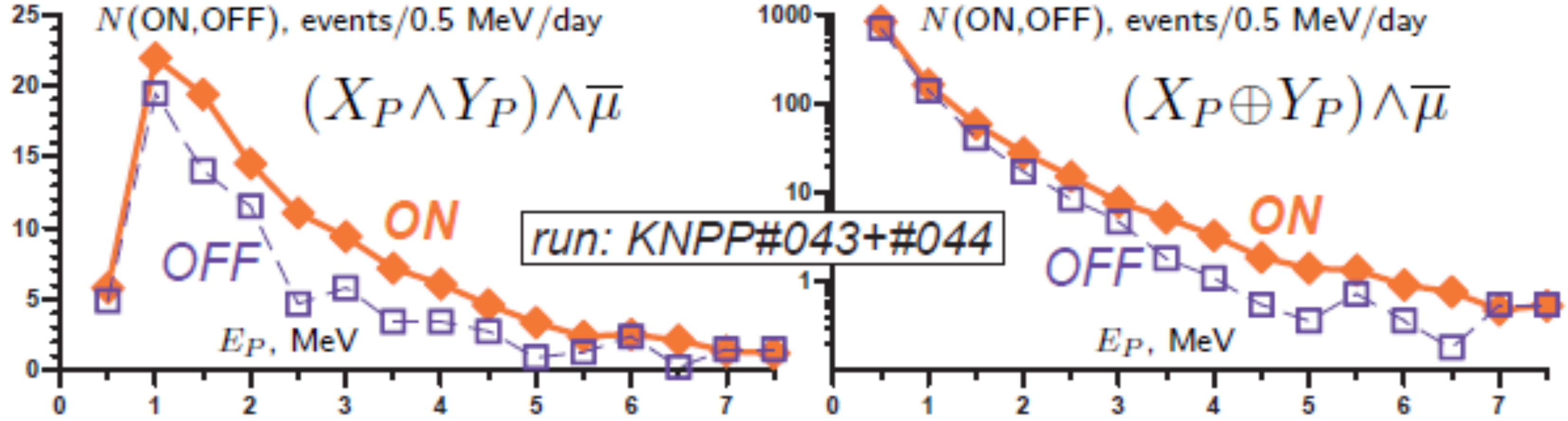
DANSS data taking will start in 2014

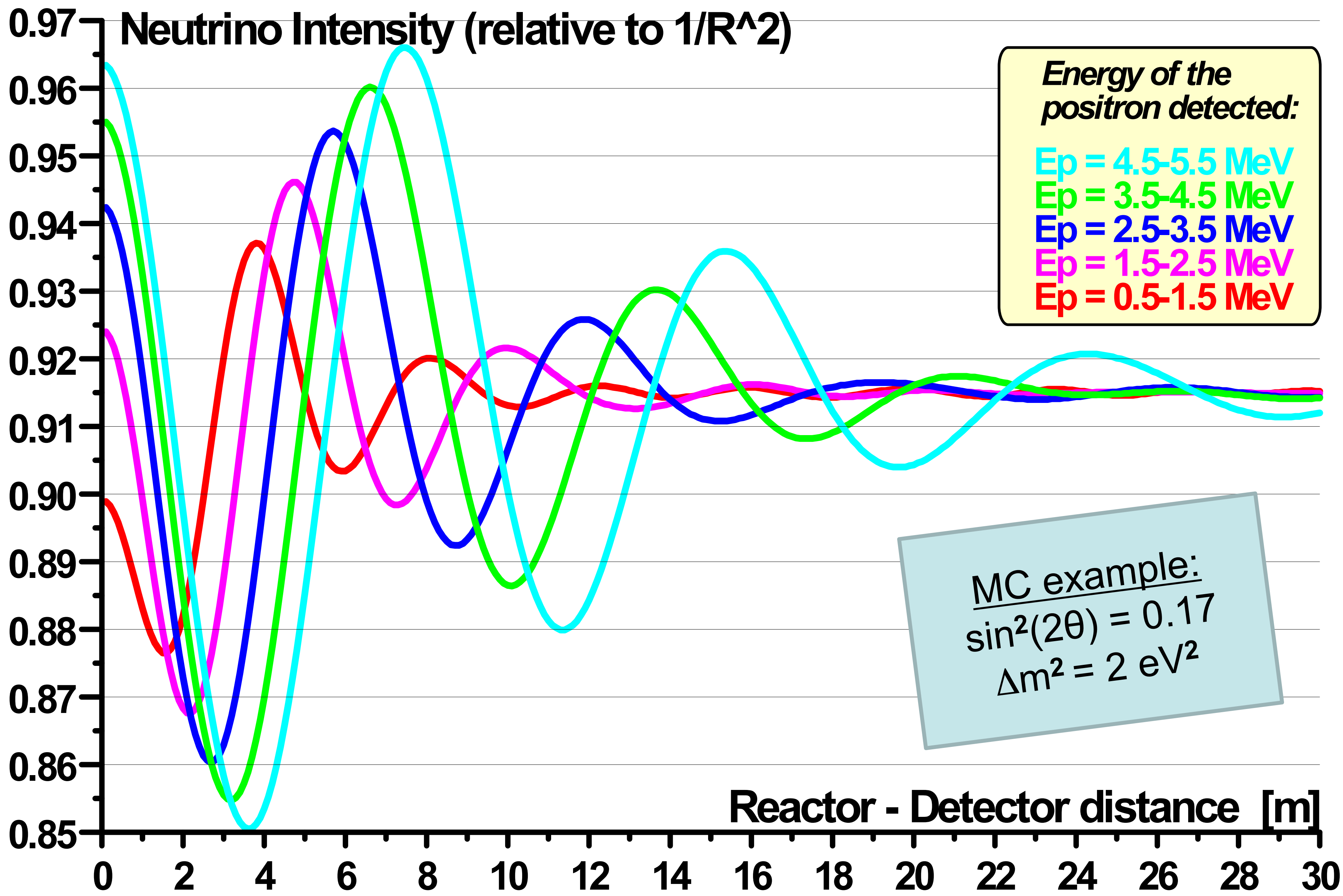
Details can be found in arXiv:1305.3350 [physics.ins-det]

Backup slides

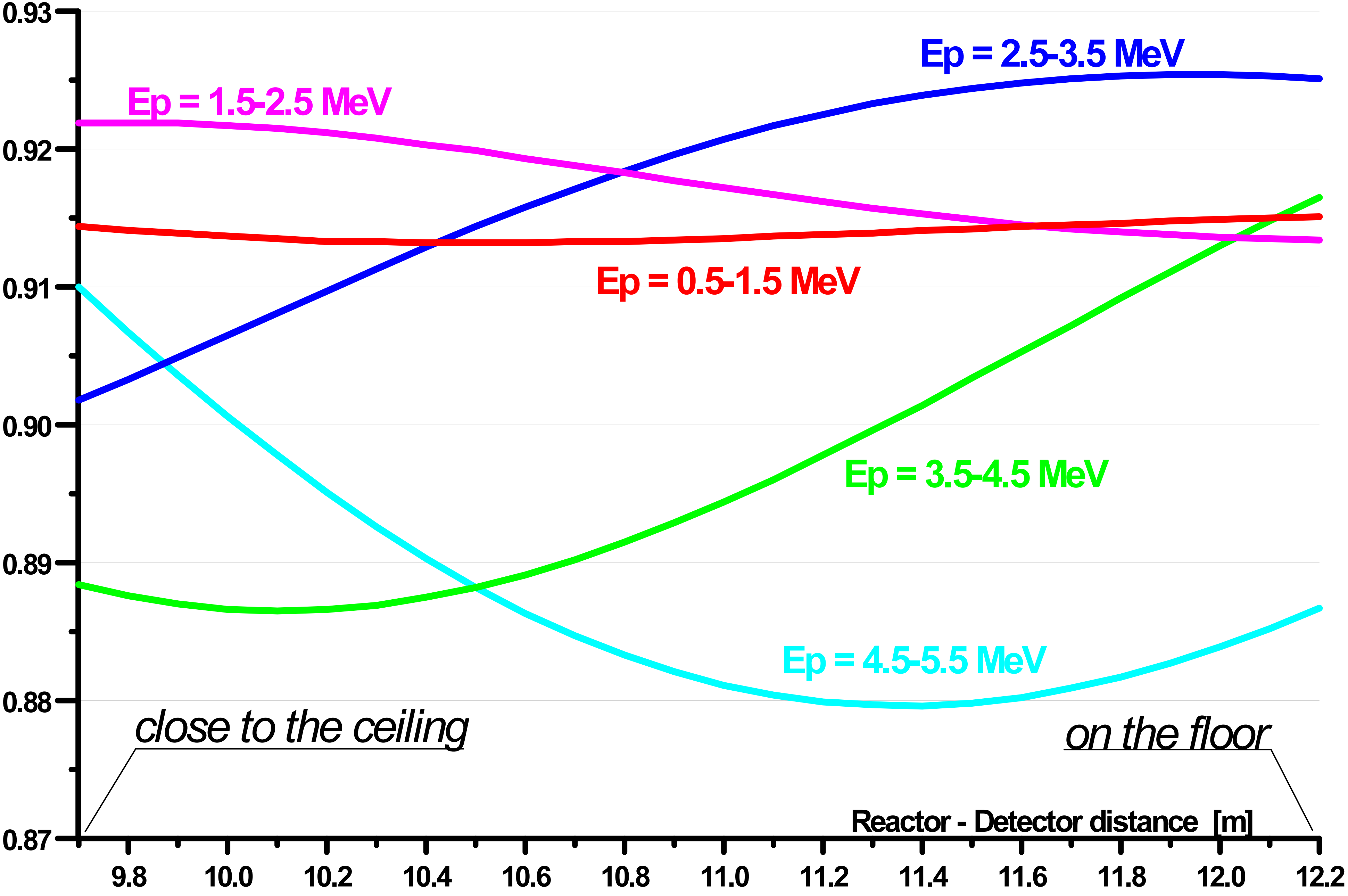


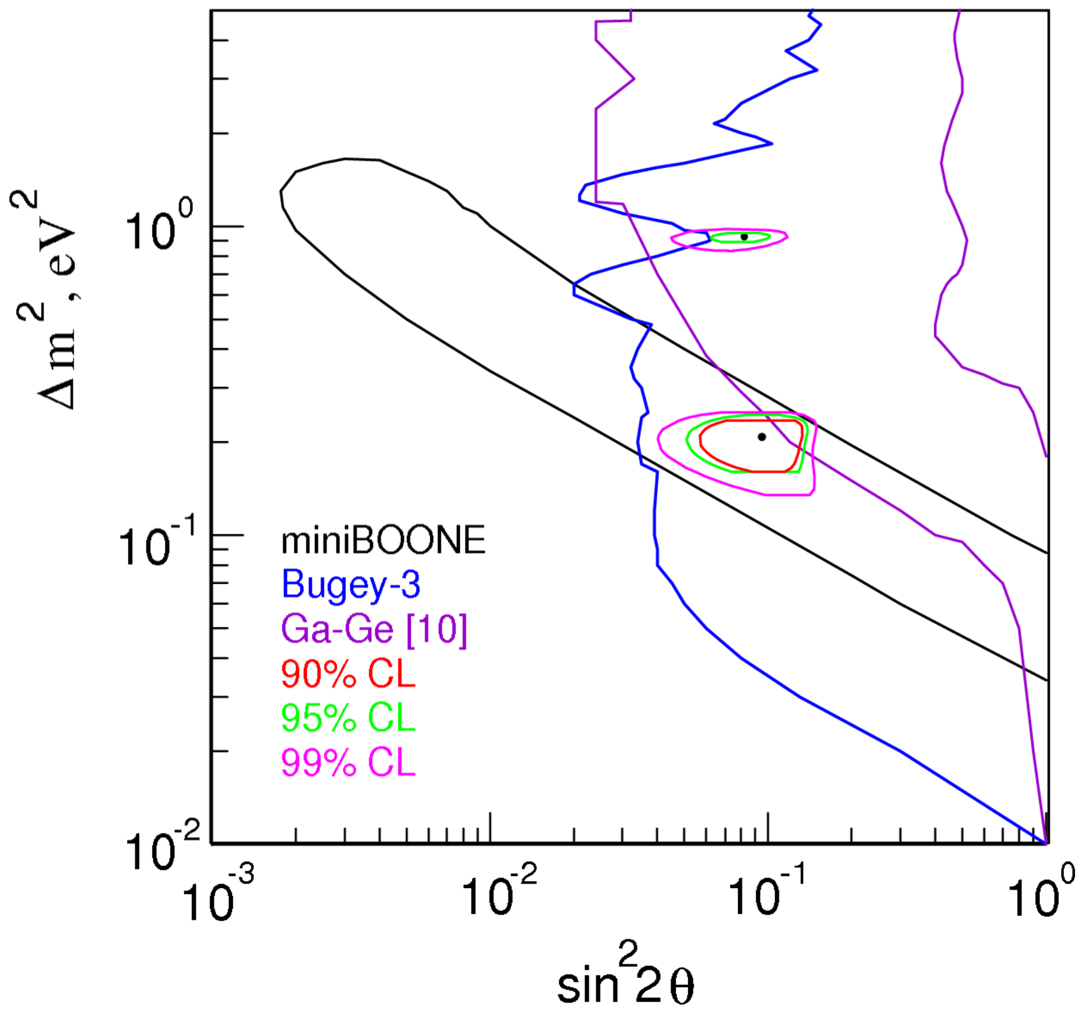
N(ON)$-N$(OFF), events/0.5 MeV/day
$(X_P \wedge Y_P) \wedge \overline{\mu}$
E_P,
MeV
$(X_P \oplus Y_P) \wedge \overline{\mu}$
E_P,
MeV


N(ON,OFF), events/0.5 MeV/day
$(X_P \wedge Y_P) \wedge \overline{\mu}$
ON
OFF
E_P, MeV
N(ON,OFF), events/0.5 MeV/day
$(X_P \oplus Y_P) \wedge \overline{\mu}$
ON
OFF
E_P, MeV
run: KNPP#043+#044


Neutrino Intensity (relative to 1/R^2)
Energy of the positron detected:
Ep = 4.5-5.5 MeV
Ep = 3.5-4.5 MeV
Ep = 2.5-3.5 MeV
Ep = 1.5-2.5 MeV
Ep = 0.5-1.5 MeV
MC example:
sin²(2θ) = 0.17
Δm² = 2 eV²
Reactor - Detector distance [m]
0.97
0.96
0.95
0.94
0.93
0.92
0.91
0.90
0.89
0.88
0.87
0.86
0.85
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30

Zoom of oscillation curves in the measured range





miniBOONE
Bugey-3
Ga-Ge [10]
90% CL
95% CL
99% CL
10^{0}
10^{-1}
10^{-2}
10^{-3}
$\Delta m^2, eV^2$
$\sin^2 2\theta$