Proposal for prolongation of the project

DANSS

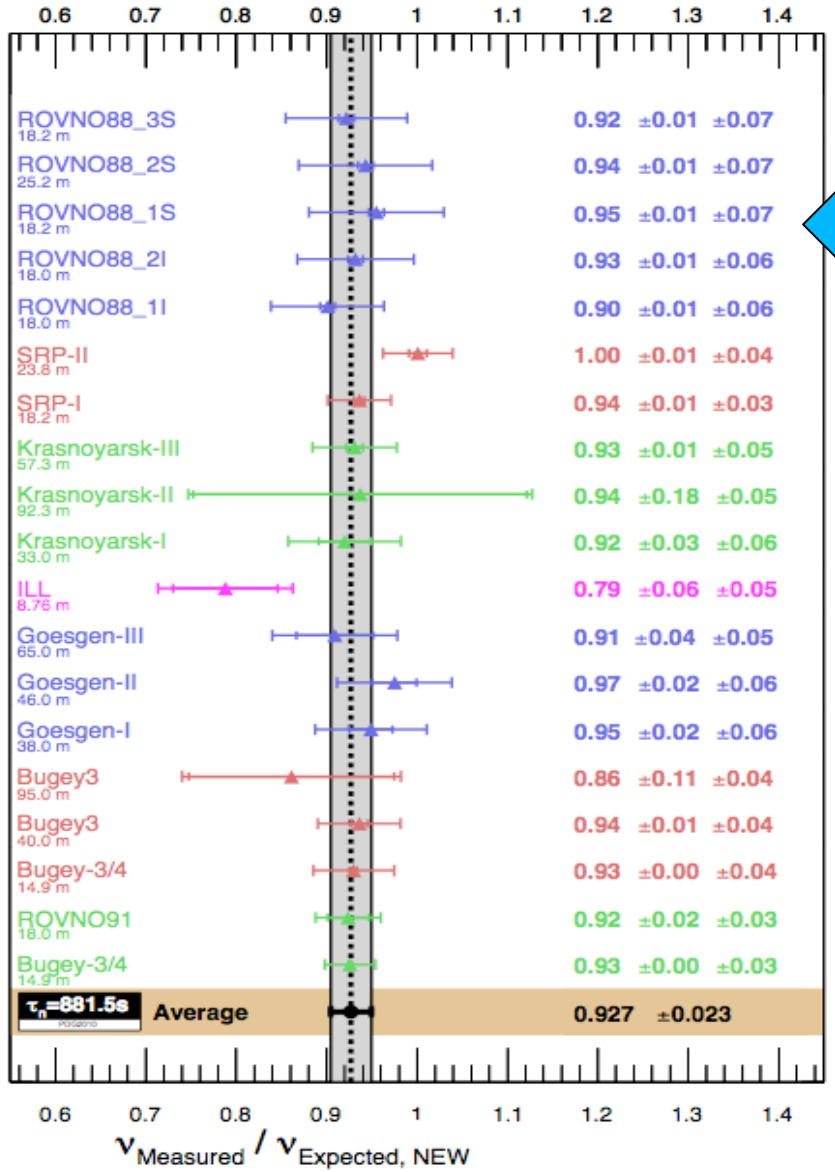
Detector of the reactor AntiNeutrino based on Solid state plastic Scintillator

Theme: 03-2-1100-2010/2024 (non-accelerator neutrino physics and astrophysics)

Yu.A.Shitov

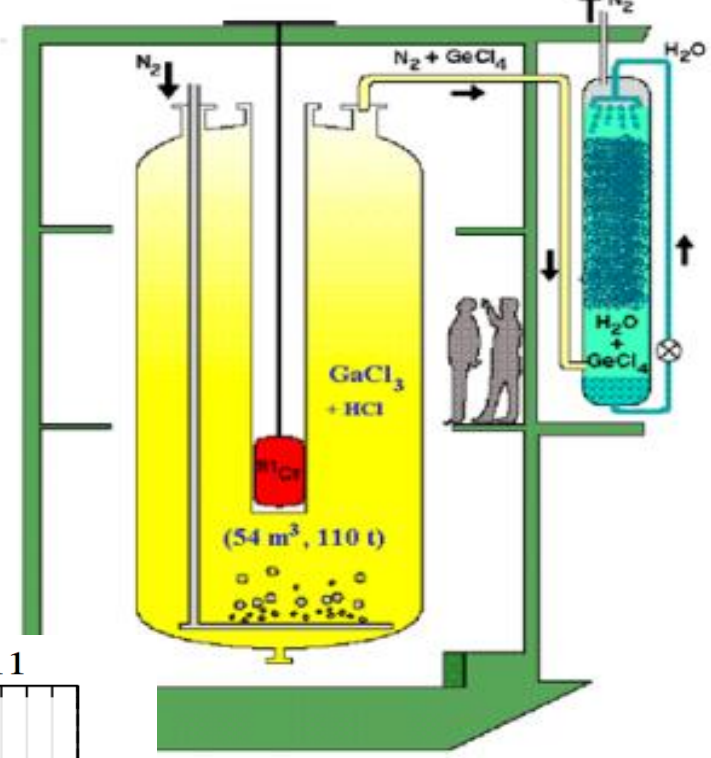
Joint session of the PACs for PP & NP for the assessment of the JINR Neutrino Projects, 21 January 2021, JINR, Dubna, Russia

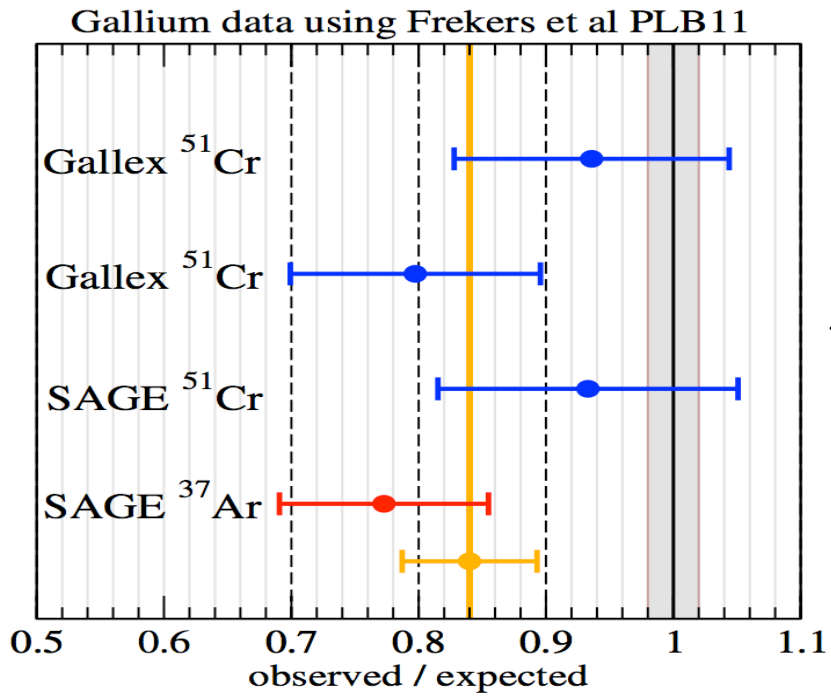
Reactor and Galium Anomalies



Phys. Rev C 83, 054615 (2011)

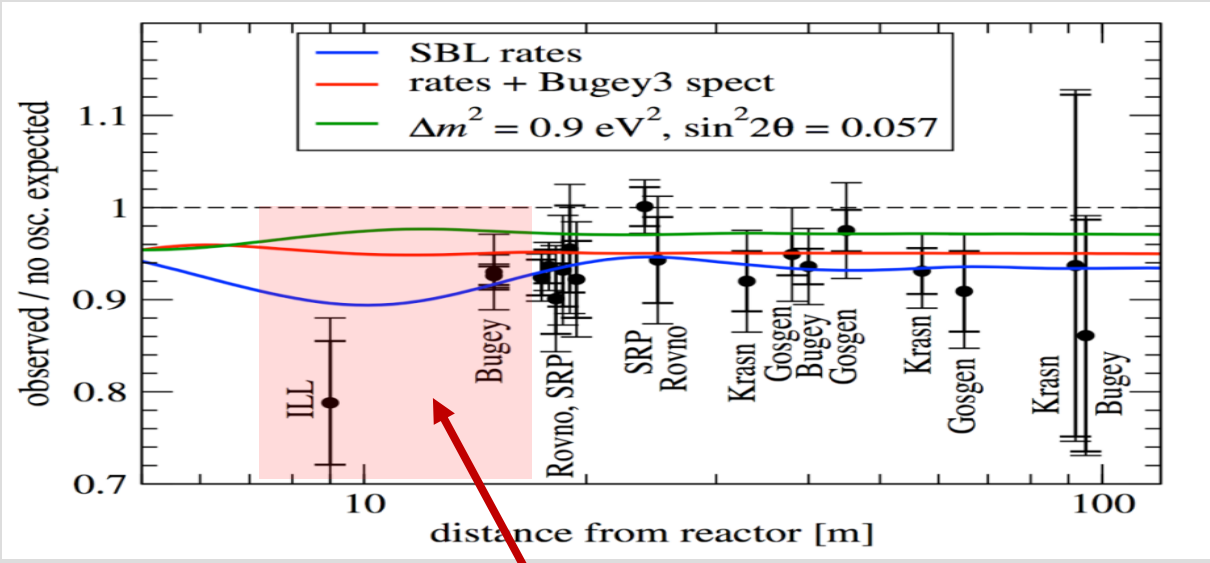
The ratio of the measured neutrino flux to the calculated flux from the reactor : 0.93 ± 0.02 (3σ)



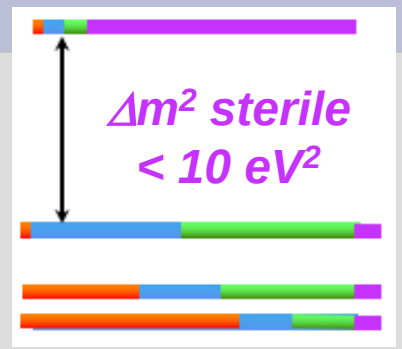


The ratio of measured to calculated: 14 ± 6 % (>2σ)

Reactor Antineutrino Anomaly: the sterile neutrino hypothesis



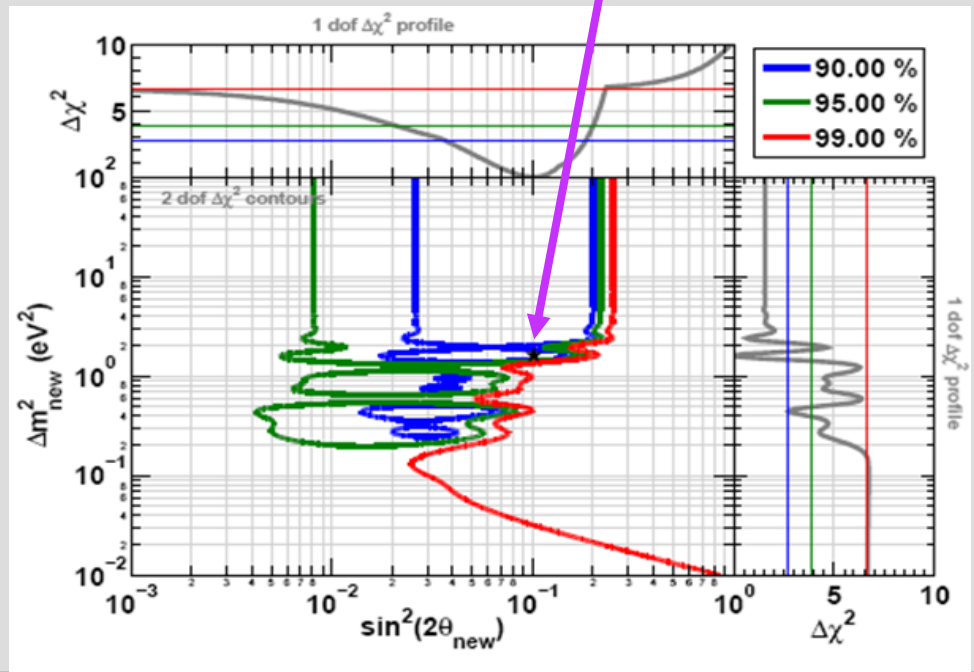
Lack of experimental data in the range



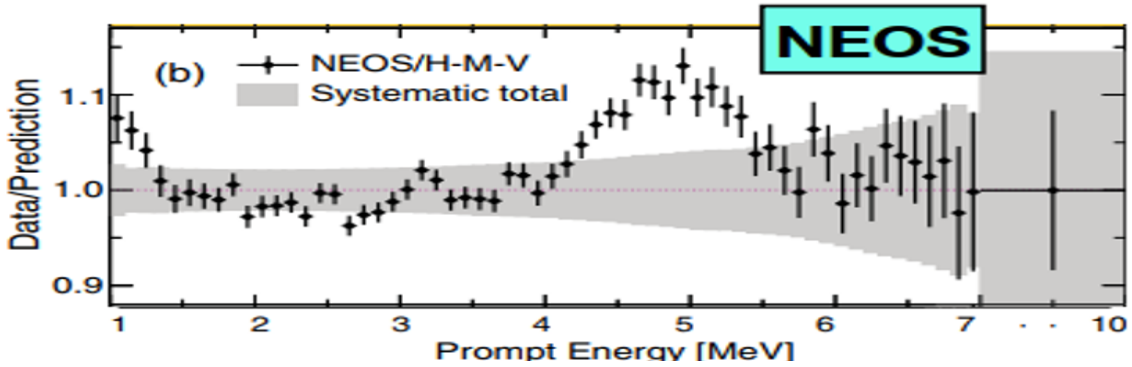
Δm^2 sterile < 10 eV^2

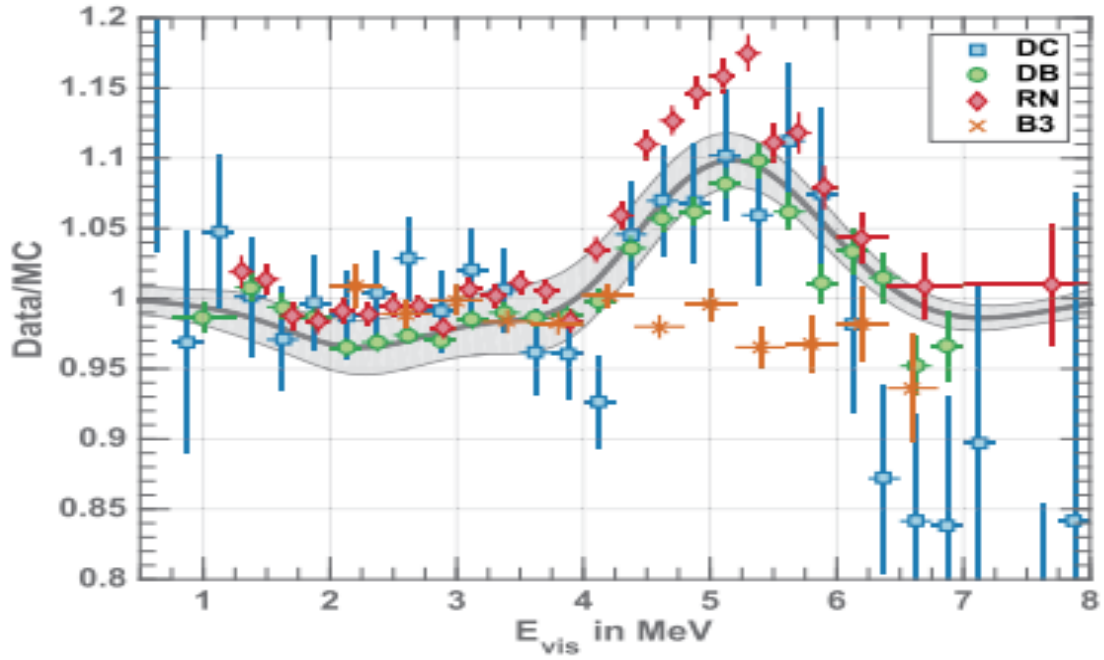
Best fit RAA: $\sin^2(2\theta_{NEW})$~0.1, Δm^2_{NEW}~ 2 eV^2

Reference point for all experiments

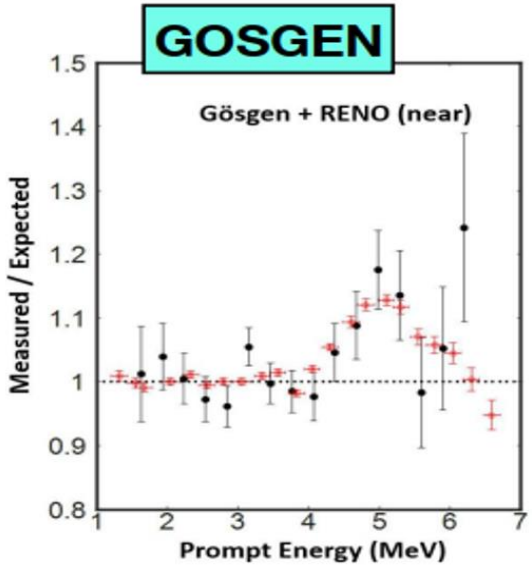


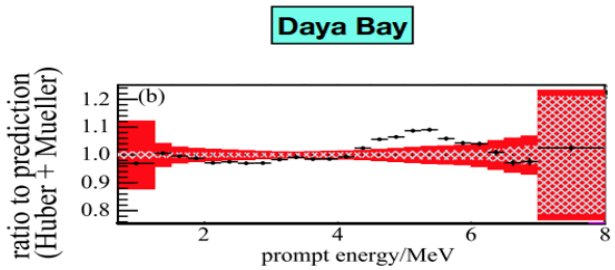
Reactor Spectral Anomaly



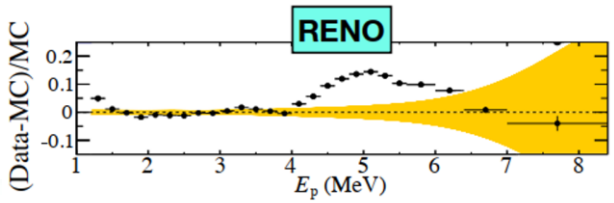


Physics Letters B 773 (2017)

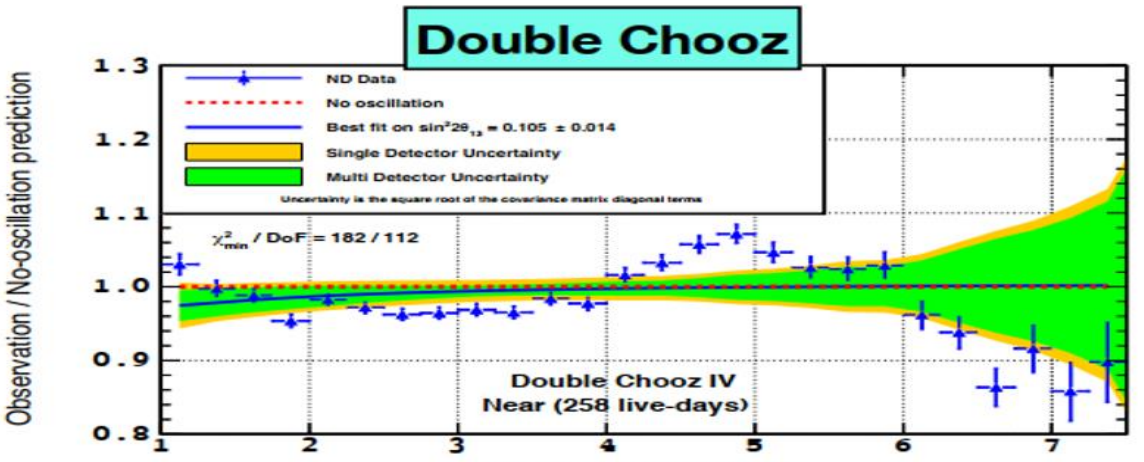




CPC Vol. 41 (1) (2017)



PRD 98, 012002 (2018)



arXiv:1901.09445

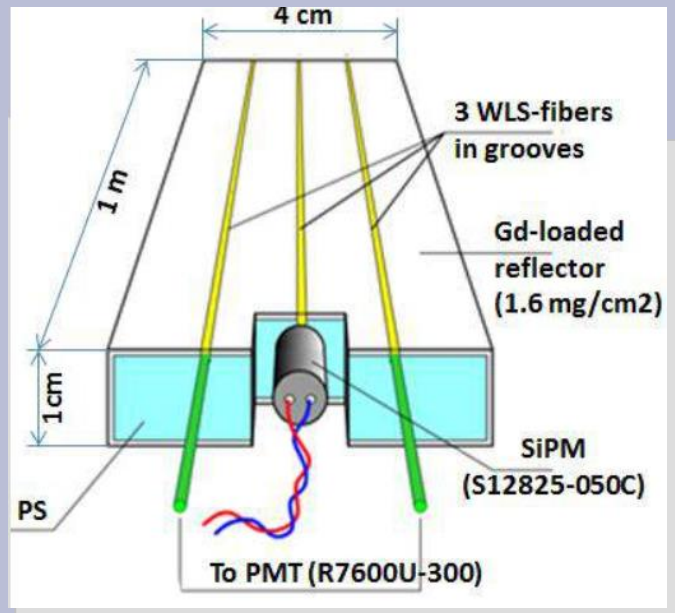
An excess of events - "shoulder", "bump" in the region of 4-6 MeV is observed in most reactor experiments - the effect is being actively studied, but there is still no understanding of its nature.

Motivation

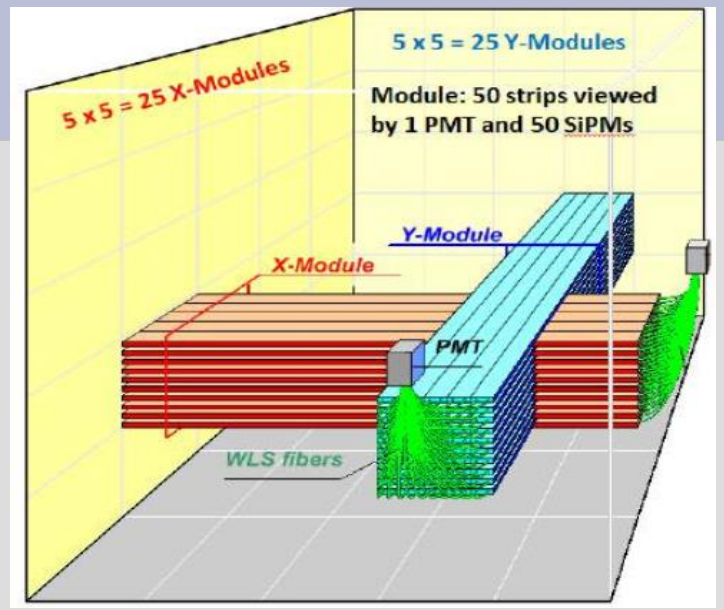
- **High-quality measurements of reactor antineutrinos on a short baseline (5-20 m) are needed to test the sterile neutrino hypothesis - a fundamental issue.**
- **Precision measurement of the spectrum of reactor antineutrinos is critical information for neutrino oscillation experiments (reduction of systematics), solution to the riddle of the spectral anomaly.**
- **Development of technologies for applied monitoring of reactors - non-proliferation of nuclear materials, neutrino tomography of a reactor, etc.**

DANSS design

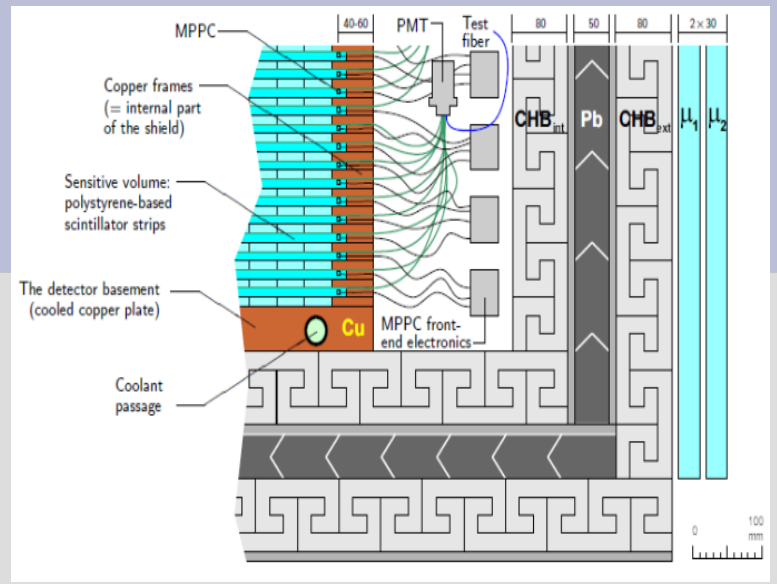
Detection cell (strip)



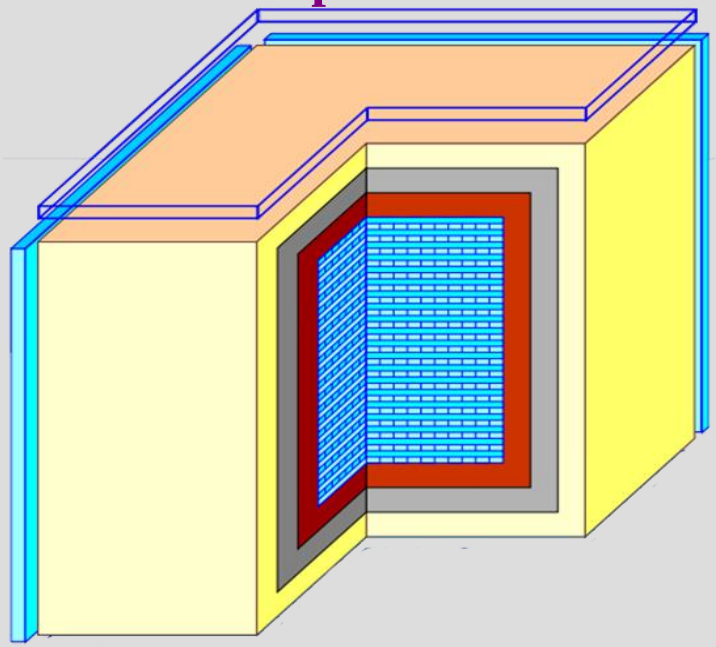
Module



Shield

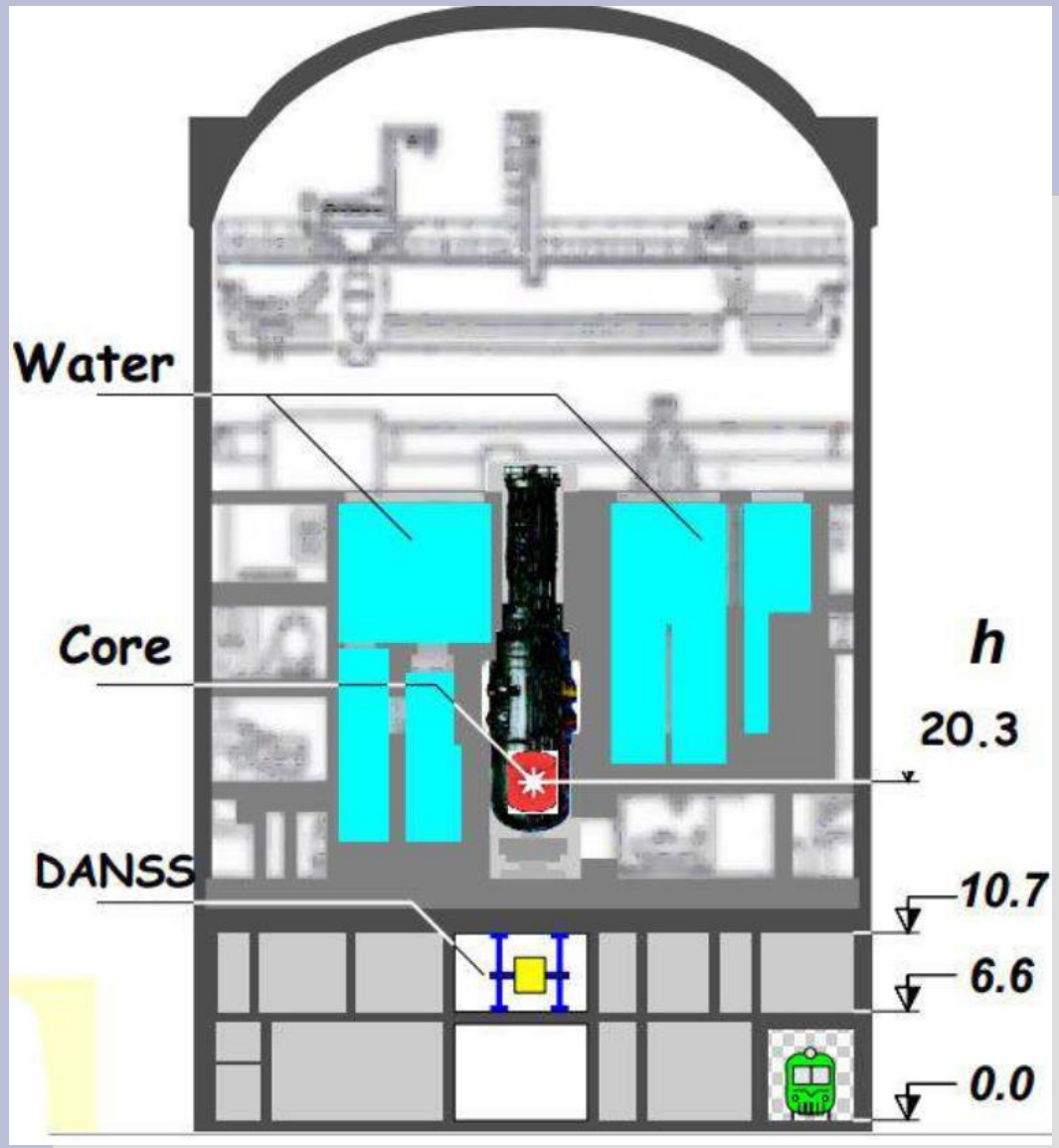


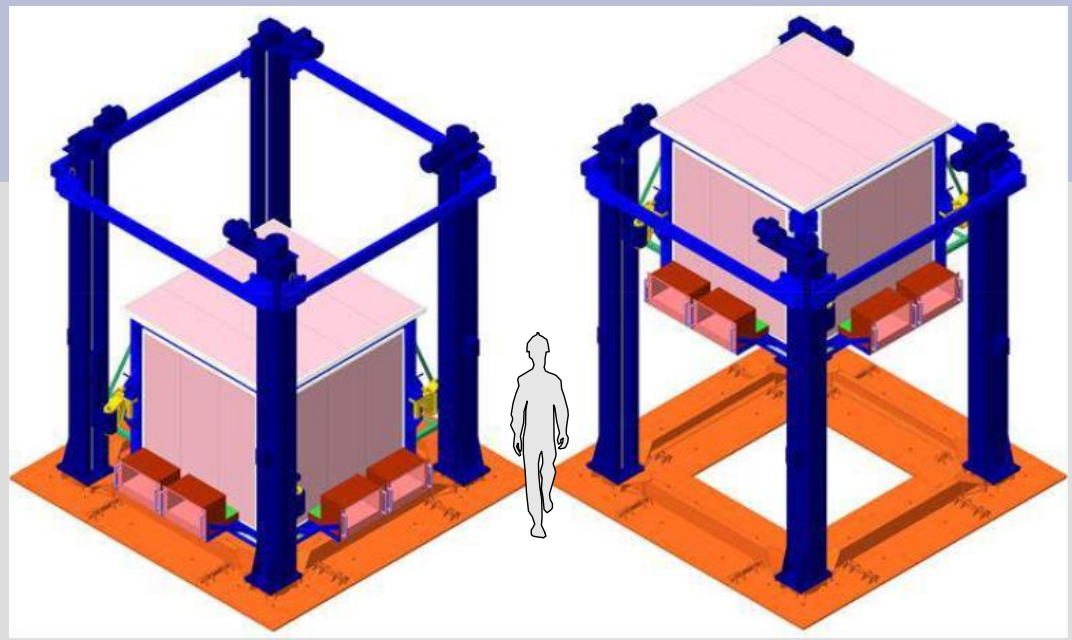
Whole spectrometer



- Cubic meter highly segmented neutrino spectrometer made of 2500 PS strips viewed by 2500 SiPMs & 50 PMTs.
- 2D signal acquisition with 3D reconstruction
- Multilayer passive shielding: Cu/CHB/Pb/CHB=5/8/5/8 cm
- Active muon veto made of 2 x 3 cm PS plates from all sides except bottom.

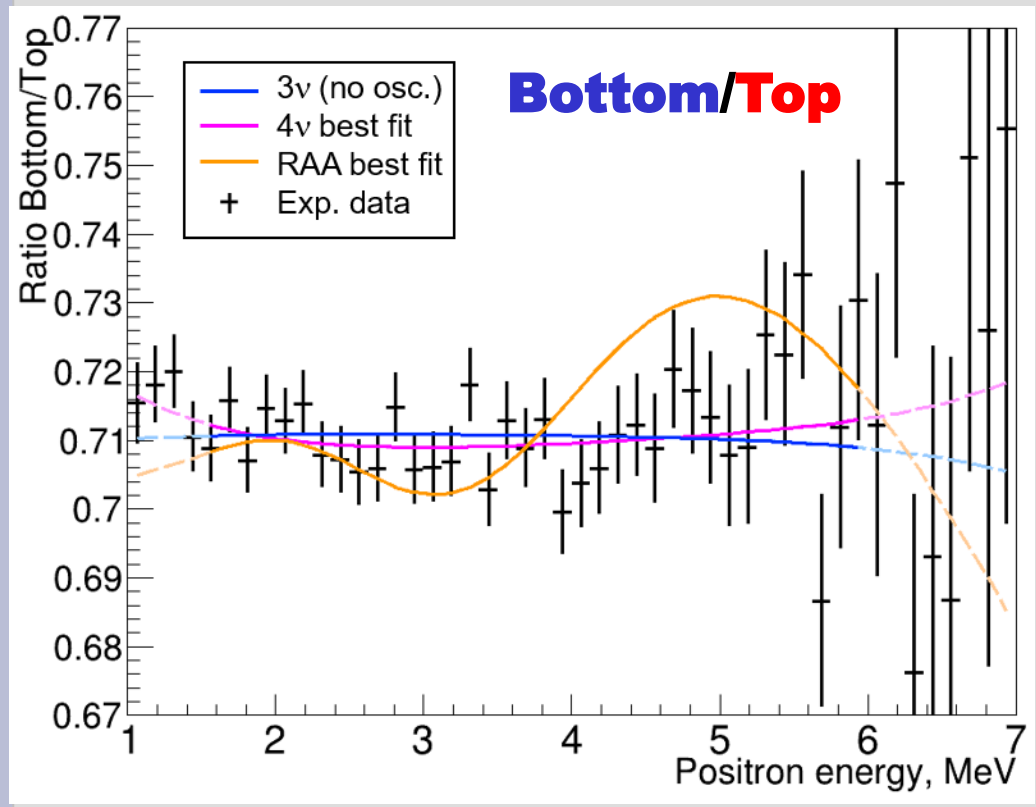
The location and movable platform

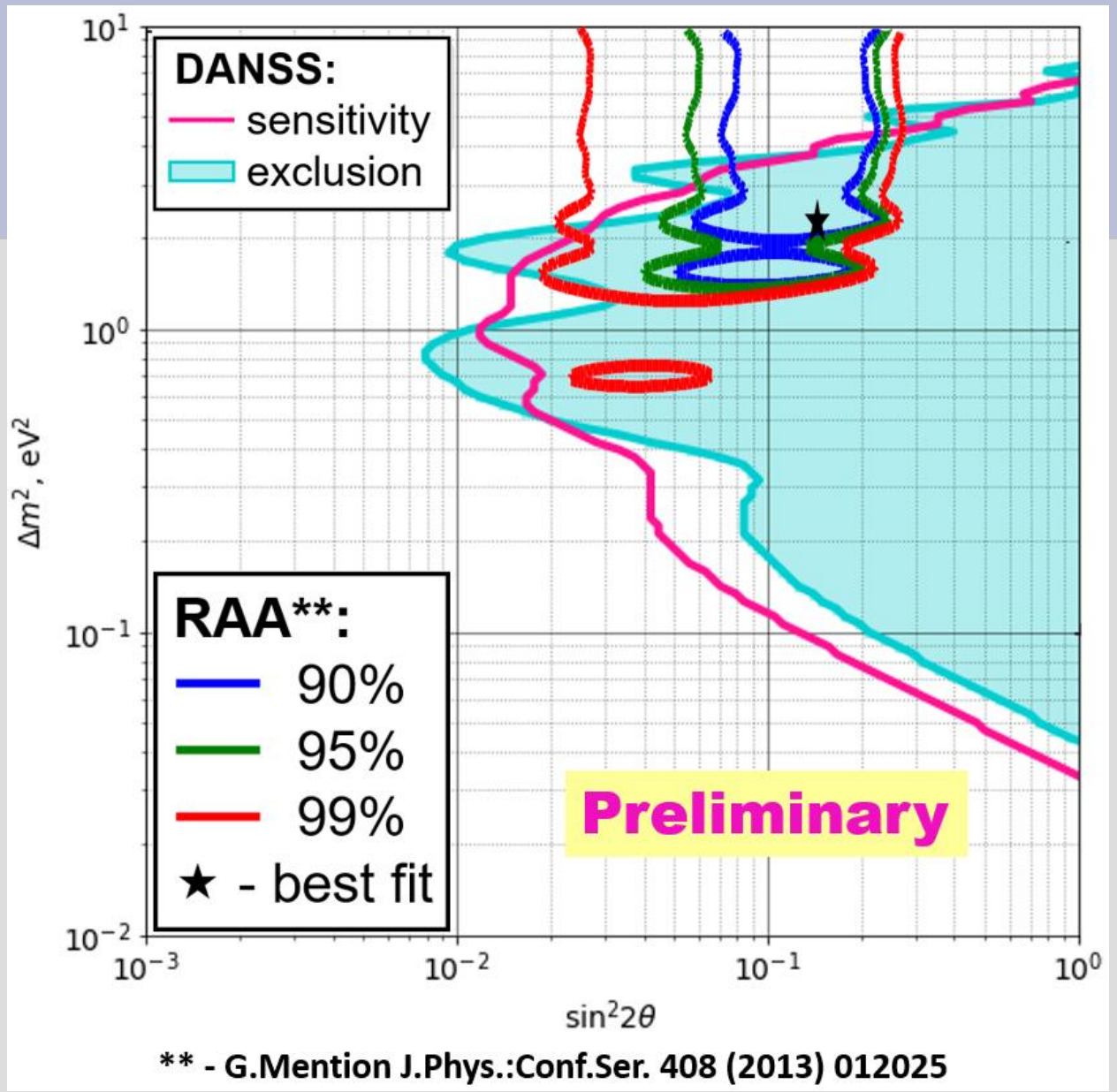




- The DANSS is located at Kalininskaya NPP (KNPP) under 3 GW WWER-1000 reactor (H=3.6 m, ∅ =3.1 m), which provides ~ 50 m.w.e. (6-fold μ reduction and no cosmic n).
- The detector is built on a movable platform. Data are taken at 3 distances 10.9 m (Up), 11.9 m (Middle), and 12.9 m (Down) from the reactor (center to center), changed sequentially 3 times per week.

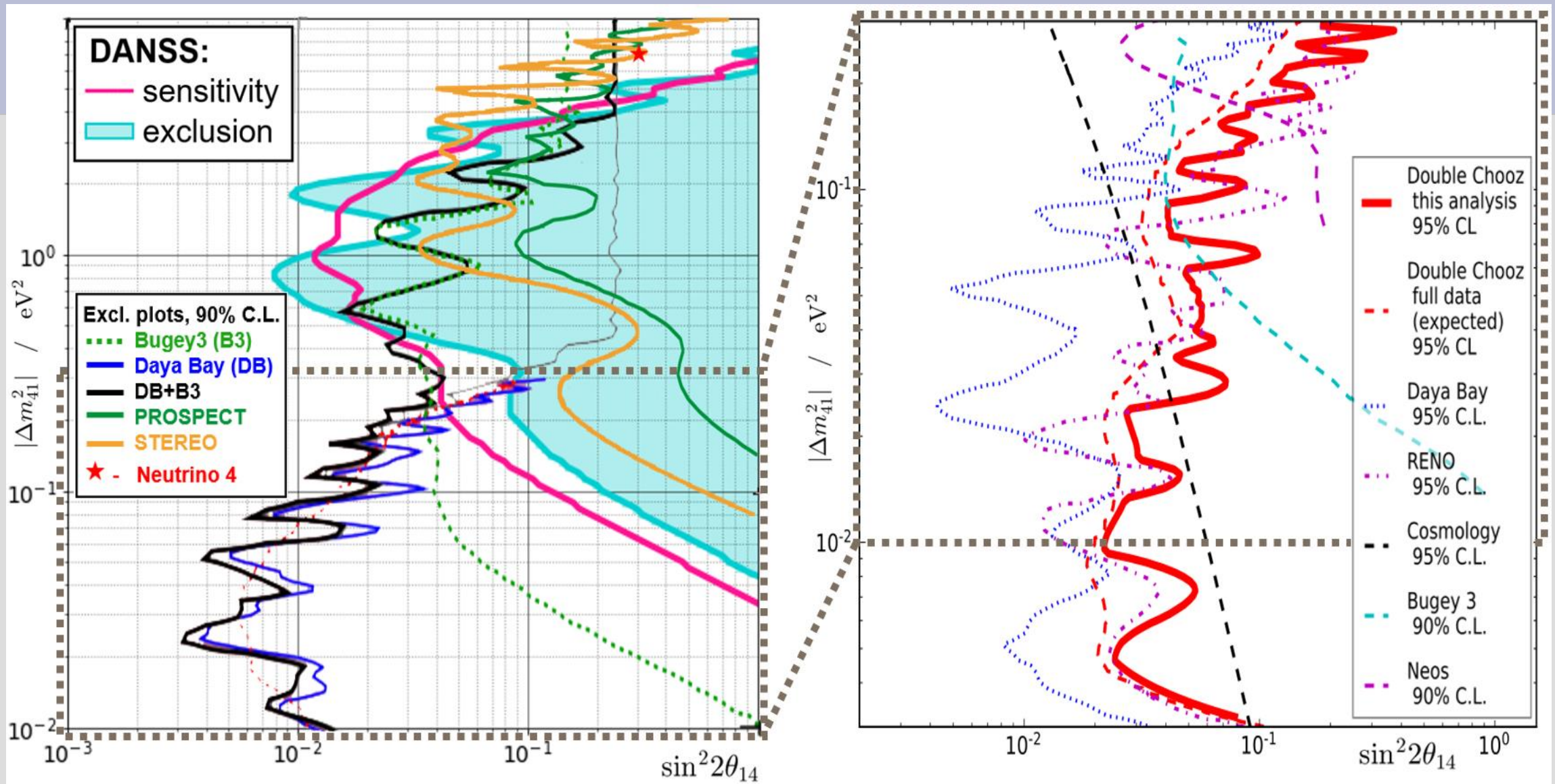
Main result of the DANSS





** - G.Mention J.Phys.:Conf.Ser. 408 (2013) 012025

DANSS vs. competitors



Key DANSS results & JINR contribution

- **Invention of an innovative measurement technique, first applied to neutrino spectrometers (JINR).**
- **Creation of a prototype spectrometer DANSSINO, on which the technique was successfully developed and the energy spectrum of reactor antineutrinos was measured (JINR).**
- **Proposal and implementation of a difference measurement method (mobile platform) free from a number of important systematic errors (JINR).**
- **Construction, tuning and launch of long-term measurements on the full-scale DANSS detector mounted under the fourth power unit of the Kalinin NPP (JINR).**
- **Measurement of the energy spectra of reactor antineutrinos at different distances from the reactor, obtaining the best constraints on the existence of sterile neutrinos in the essential region of the phase space of the 3 + 1 model.**
- **Demonstration of high-precision (1.5% on two-day statistics) monitoring of reactor power using the DANSS detector in long-term measurements.**
- **Demonstration of the sensitivity of the DANSS detector to the structure of nuclear fuel (U / Pu).**

Award 2019

https://clck.ru/Sco94

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First JINR Prize 2019 for "Experimental Research Work" Awarded to the Scientists from the DANSS Group

Category: Главные новости Published: 19 March 2020

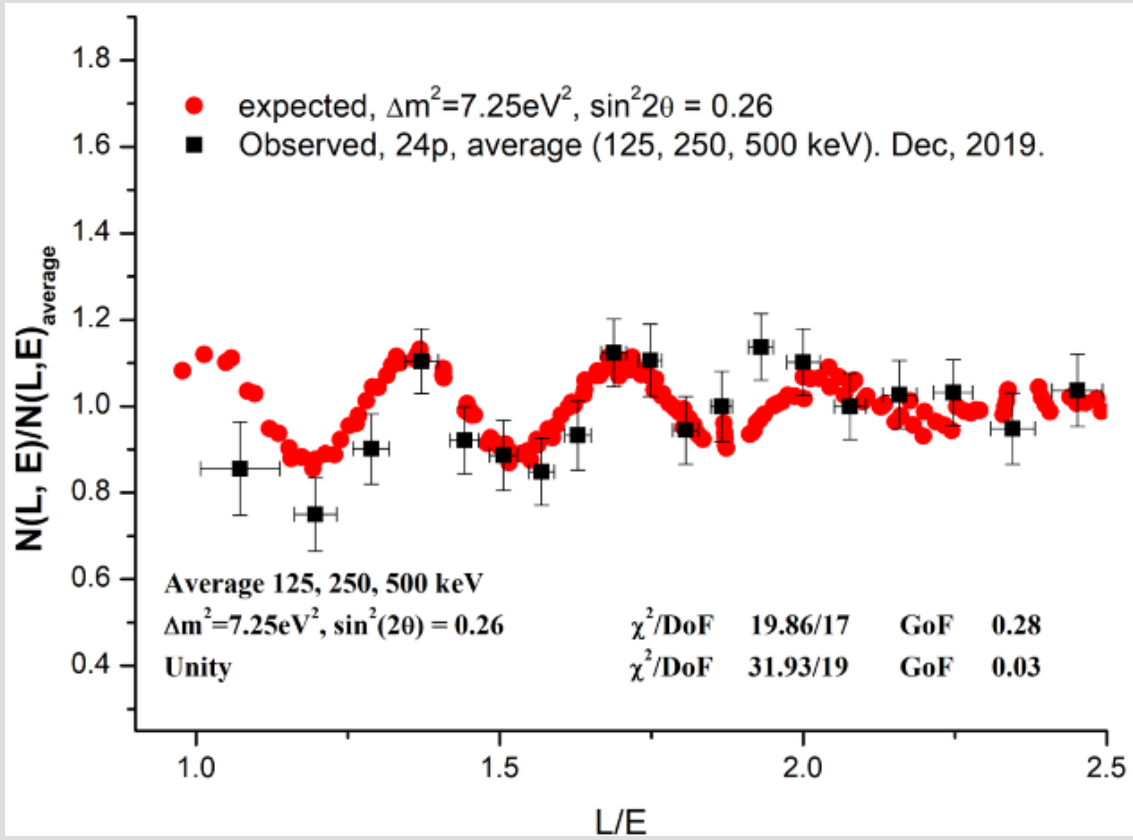
At the 127th session of the JINR Scientific Council, annual JINR Prizes were awarded for the best scientific, methodological and technological applied research projects in 2019. Within the category "Experimental Research Work", the DLNP scientists from the DANSS group received the First Prize for "Measurements of reactor antineutrino energy spectra in the DANSS project". The members of the DANSS group are V.V. Belov, V.B. Brudanin, I.V. Zhitnikov, S.V. Kazartsev, A.S. Kuznetsov, D.V. Medvedev, M.V. Fomina, Ye.A. Shevchik, M.V. Shirchenko, Yu.A. Shitov.

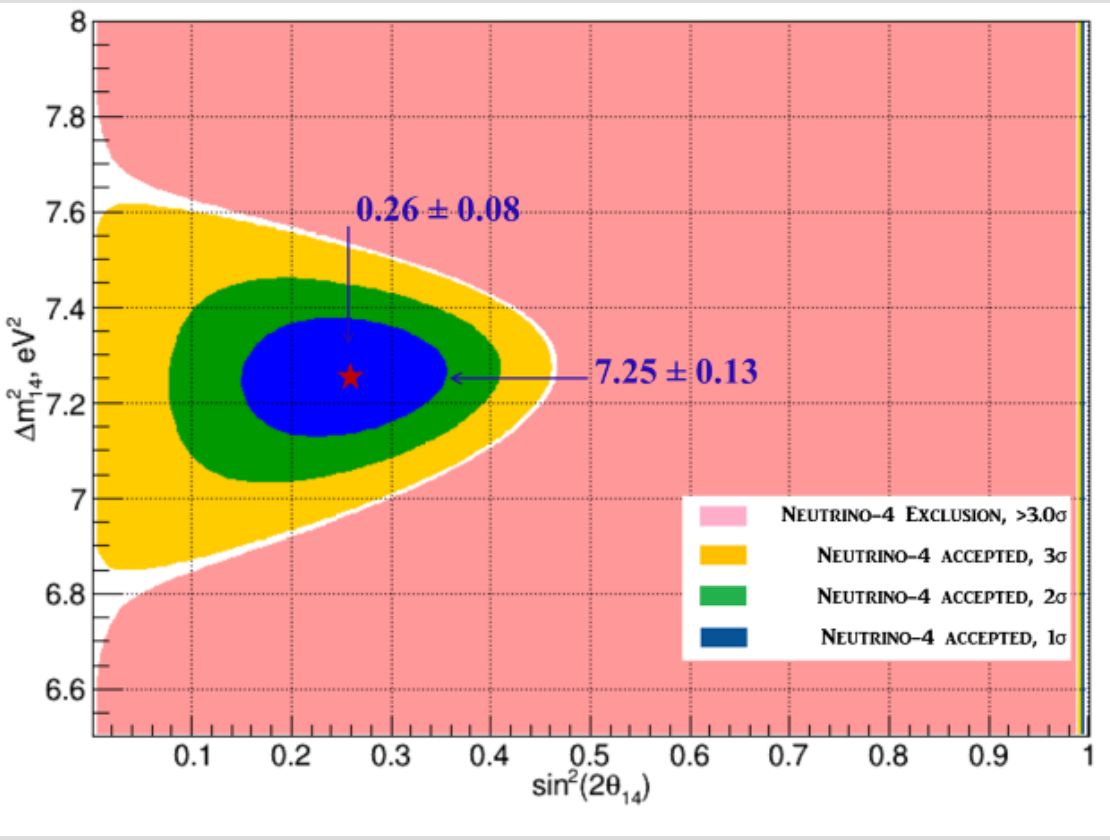
The JINR Prizes are awarded for outstanding advanced experimental, methodological and applied research carried out in accordance with the JINR Topical Plan and completed in the current year. Every year, the Jury of 11 people, including the secretary, is appointed by the JINR Directorate to judge the candidate research projects. This body comprises some representatives from the JINR Directorate, as well as leading scientists. The decision about awarding goes into effect after the approving procedure by the JINR Scientific Council within its Winter Session.

The DANSS neutrino experiment monitors nuclear reactor parameters and searches for sterile neutrinos using the precision analysis of the ratio of the reactor neutrino spectra measured at different distances from the reactor core.

We heartily congratulate our colleagues on receiving this Prize and wish them all the best and new heights of success!

Neutrino-4 – is this a signal?





Tasks for the next period

- Creation of an upgraded DANSS-2 neutrino spectrometer, which has a number of advantages over its predecessor DANSS: better resolution, increased size, greater uniformity with a smaller number of dead layers inside the detector.
- More precise measurement of the spectrum of reactor antineutrinos, important for solving the problem of spectral anomaly.
- An increase in the tested phase space of possible oscillations into a sterile neutrino, including reaching the point of the signal declared in the NEUTRINO-4 experiment.
- Development of a compact spectrometer S^3 for solving applied problems of reactor monitoring.

The DANSS upgrade

Main goal: to reach resolution **15%/√E** w.r.t. current 34%/√E.

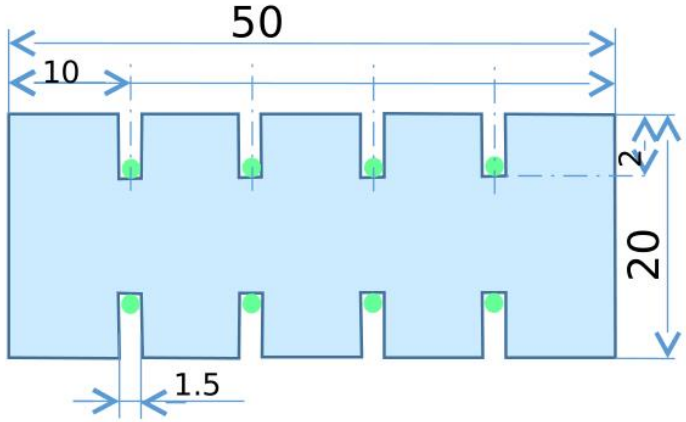
New geometry:

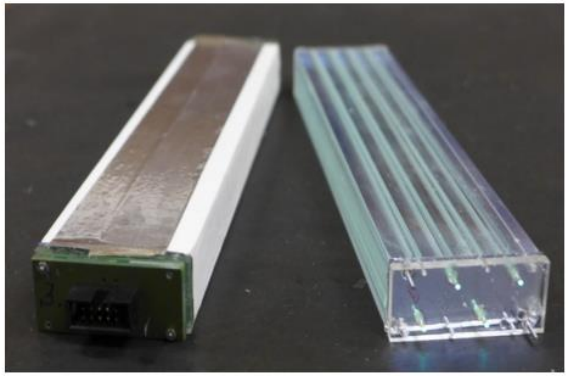
Strips: 2x5x120 cm with **2-side** SiPM readout

Structure: 60 layers x 24 strips: **1.7 m^3** setup used **the same shield and moving platform**.

Gd is in foils between layers.

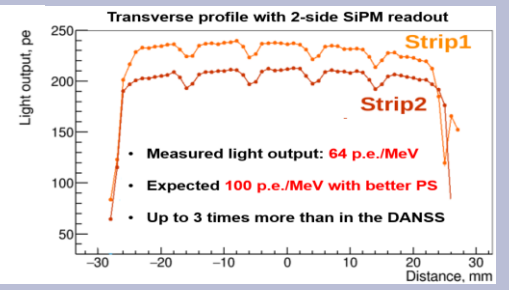
Upgraded strip:

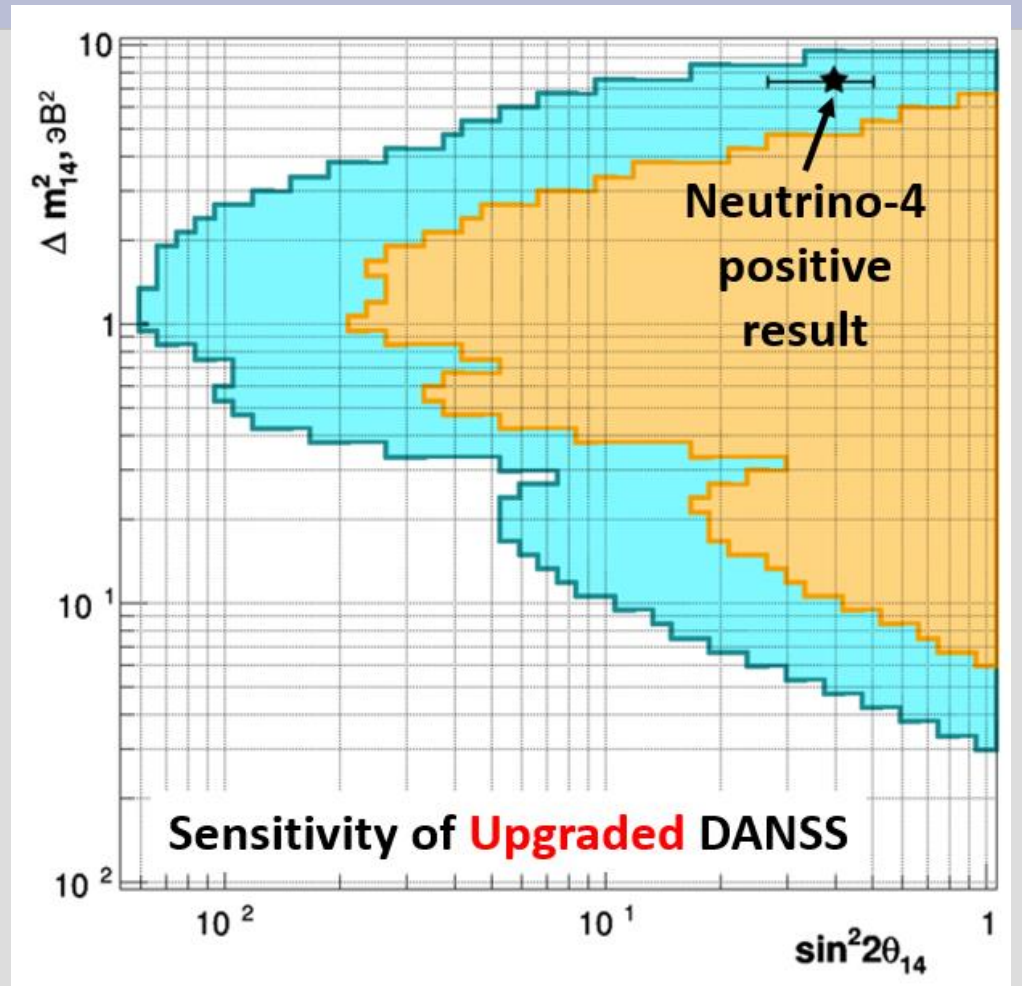




Strip prototypes are testing on π-beam

Upgrade timescale: ~2 years.





Plans

- **2021 - mid-2022** R&D on DANSS-2 design, manufacturing of 1440 DANSS-2 strips (the process is detailed in the document).
- **Mid 2022 - Late 2022** Dry build for final testing and tuning of DANSS-2 fully loaded (excluding protection).
- **Beginning 2022 - mid 2023**. DANSS disassembly. Construction, tuning and launch of DANSS-2 at KNPP.
- **From mid-2023** - the data taking on DANSS-2, the planned exposition is at least 2.5 years.
- **Throughout the entire time** - maintaining the operation of installations at the KNPP, data analysis, creation of a compact spectrometer S^3 for applied monitoring tasks.

DANSS: JINR team

- **JINR DANSS team includes 17 people, 5.6 FTE**
- **Total number of people in the DANSS collaboration: 36.**

JINR member			DANSS		DANSS-2		
			Types of work on neutrino spectrometers				
Surname, Name	*Position*	*FTE portion*	*Service of the spectrometer*	*Data analysis, simulation*	*R & D*	*Installation*	*Data analysis, simulation*
Brudanin V.B.	leading researcher	0.1	Coordination of all works				
Shitov Yu.A.	head of sector	0.5	Management of all works				
Belov V.V.	junior researcher	0.3	+	+	+	+	+
Volnyh V.P.	leading engineer	0.1		+			+
Zhitnikov I.V.	researcher	0.5	+	+	+	+	+
Kazartsev S.V.	junior researcher	0.2	+		+	+	+
Kiyanov S.P	senjor engineer	0.2	+		+	+	
Kuznetsov A.S.	engineer	0.9	+		+	+	+
Mamedov F.	senior researcher	0.5		+	+	+	+
Machihilyan I.V.	senjor engineer	0.5		+			+
Medvedev D.V.	researcher	0.3	+			+	
Pushkov D.S.	senjor engineer	0.3	+			+	
Rozov I.E.	engineer	0.4			+	+	
Salamatin A.V.	senior researcher	0.1		+	+	+	
Filosofov D.V.	head of sector	0.1			+	+	
Fomina M.V.	junior researcher	0.4		+	+	+	+
Shevchik EA	senjor engineer	0.2	+		+	+	+
Total FTE		**5.6**					

DANSS: finance

Form No. 26

Schedule proposal and resources required for the prolongation of the Project

Detector of the reactor antineutrino based on solid state plastic scintillator

DANSS

Expenditures, resources, financing sources			Costs (k$) Resource Require-ments	Proposals of the Labora-tory on the distribution of finances and resources		
				1st yr	2nd yr	3rd yr
Expenditures		Materials for the DANSS-2 detector (strips, SiPM, fibers, etc.)	520	180	160	180
		Consumables (optical glue, connectors, cable, etc.)	30	10	10	10
		Materials for S^3 (fibers, electronics, computers)	30	10	10	10
		Total	**580**	**200**	**180**	**200**
Required resources	Standard hour	Resources of – Laboratory design bureau – Laboratory experimental workshop	300 600	100 200	100 200	100 200
Financing sources	Budgetary resources	Budget expenditures including foreign-currency resources.	**580**	**200**	**180**	**200**
	External resources	Contributions by collaborators. Grants.	0	0	0	0

Estimated expenditures for the Project

Detector of the reactor antineutrino based on solid state plastic scintillator

DANSS

NN	Expenditure items	Units	Full cost	1st yr	2nd yr	3rd yr
	Direct expenses for the Project					
1.	Computer connection	k$	6	2	2	2
2.	Design bureau	std.h.	300	100	100	100
3.	Experimental Workshop	std.h.	600	200	200	200
4.	Materials	k$	360	140	100	120
5.	Equipment	k$	220	60	80	80
6.	Transportation of equipment	k$	25	15	10	0
7.	Collaboration meetings and workshops	k$	15	5	5	5
8.	Travel allowance, including:	$k	90	30	30	30
	a) non-rouble zone countries	-	-	-	-	-
	b) rouble zone countries	$k	90	30	30	30
	c) protocol-based	-		-	-	-
	Total direct expenses:	k$	716	252	227	237

Expected salary of the DANSS team is 95.2 kUS$ per year. **Estimation based on 2020 data and includes spending on technical personnel not listed in the project. 1US$ = 64RUB assumed in the estimation.**

Publications

1. I.G. Alekseev et al., DANSSino: a pilot version of the DANSS neutrino detector, Phys.Part.Nucl.Lett. 11 (2014) 473-482, DOI: 10.1134/S1547477114040050
2. I.G. Alekseev et al., DANSS: Detector of the reactor AntiNeutrino based on Solid Scintillator, JINST 11 (2016) no.11, P11011, DOI: 10.1088/1748-0221/11/11/P11011
3. I.G. Alekseev et al., DANSS Neutrino Spectrometer: Detector Calibration, Response Stability, and Light Yield, Phys.Part.Nucl.Lett. 15 (2018) no.3, 272-283, DOI: 10.1134/S1547477118030020
4. I.G. Alekseev et al., Search for sterile neutrinos at the DANSS experiment, Phys.Lett. B787 (2018) 56-63, DOI: 10.1016/j.physletb.2018.10.038
5. И.Г.Алексеев и др., Мониторирование мощности промышленного реактора по счету антинейтрино в детекторе DANSS, Ядерная физика, Том 82, номер 5, 2019, стр. 371-381, DOI: 10.1134/S0044002719050040
6. D. Svirida et al., Searches for sterile neutrinos at the DANSS experiment, PoS NOW2018 (2019) 066, DOI: 10.22323/1.337.0066
7. N.A. Skrobova et al., Calibration of the DANSS Detector with Cosmic Rays, Bull.Lebedev Phys.Inst. 45 (2018) no.10, 325-328, DOI: 10.3103/S106833561810010X
8. Mikhail Danilov et al., Recent results of the DANSS experiment, Nuovo Cim. C41 (2019) 162, DOI: 10.1393/ncc/i2018-18162-0
9. I.G. Alekseev et al., Reactor antineutrino physics with DANSS experiment, PoS ICHEP2018 (2019) 060, DOI: 10.22323/1.340.0060
10. I.G. Alekseev et al., Measurements of the Reactor Antineutrino with Solid State Scintillation Detector, Int.J.Mod.Phys.Conf.Ser. 46 (2018) 1860044, DOI: 10.1142/S2010194518600443
11. D. Svirida et al., Electronics of the data acquisition system of the DANSS detector based on silicon photomultipliers, Phys.Part.Nucl. 49 (2018) no.1, 84-85; Fiz.Elem.Chast.Atom.Yadra 49 (2018) no.1, DOI: 10.1134/S1063779618010367
12. Machikhiliyan et al., Reconstruction and initial calibration of silicon photomultipliers response in the DANSS experiment, Phys.Part.Nucl. 49 (2018) no.1, 70-72, Fiz.Elem.Chast.Atom.Yadra 49 (2018) no.1, DOI: 10.1134/S1063779618010276
13. N. Pogorelov et al., Light output distribution in scintillator strips with wave length shifting fibers of DANSS spectrometer, J.Phys.Conf.Ser. 934 (2017) no.1, 012055, DOI: 10.1088/1742-6596/934/1/012055
14. I.G. Alekseev et al., Detector of the reactor AntiNeutrino based on Solid-state plastic Scintillator (DANSS). Status and first results. J.Phys.Conf.Ser. 798 (2017) no.1, 012152, DOI: 10.1088/1742-6596/798/1/012152
15. Zdenek Hons, Jakub Vlášek , Data Acquisition System for Segmented Reactor Antineutrino Detector, JINST 12 (2017) no.01, P01022, DOI: 10.1088/1748-0221/12/01/P01022
16. M.Danilov et al., Sensitivity of the DANSS detector to short range neutrino oscillations, PoS EPS-HEP2013 (2013) 493, Nucl.Part.Phys.Proc. 273-275 (2016) 1055-1058, DOI: 10.22323/1.180.0493
17. I.G. Alekseev et al., DANSSino: a pilot version of the DANSS neutrino detector, Phys.Part.Nucl.Lett. 11 (2014) 473-482, DOI: 10.1134/S1547477114040050
18. V. Belov et al., Registration of reactor neutrinos with the highly segmented plastic scintillator detector DANSSino, JINST 8 (2013) P05018, DOI: 10.1088/1748-0221/8/05/P05018

PhD Theses

- Two DANSS project participants successfully defended their dissertations in 2019. Daniya Zinatulina (http://ftp.jinr.ru/dissertation/Zinatulina_autoref.pdf) and Mark Shirchenko (http://159.93.39.20/dissertation/Shirchenko_autoref.pdf). They are currently leading their own MONUMENT project, which is now carrying on under the same theme as current project.
- Currently, two PhD thesis planned to be completed within 2 years.
  - I. Zhitnikov “Development, creation and characterization of the DANSS detector based on plastic scintillators for the study of reactor antineutrinos”
  - V. Belov.” Background studies, measurements and discrimination in the DANSS reactor neutrino experiment”

Conferences (JINR team)

1. I.Zhitnikov, Status of the DANSS experiment. International Session-Conference of the Nuclear Physics Section of the Physical Sciences Division of the Russian Academy of Sciences "Physics of Fundamental Interactions" dedicated to the 50th anniversary of the Baksan Neutrino Observatory.
2. LXVIII International conference NUCLEUS 2018: Actual status of “DANSS” project
New Trends in High-Energy Physics 2018: Actual status of “DANSS” project V.Belov, M.Fomina.
3. International Workshop on Particle Physics at Neutron Sources 2018, DANSS, M.Shirchenko
4. 6th Symposium on Neutrinos and Dark Matter in Nuclear Physics 2018. https://indico.ibs.re.kr/event/212/, M.Shirchenko, DANSS
5. Yu. Shitov Status of the DANSS project / AAP 2018, 14th International Workshop on Applied Antineutrino Physics, 10-11 October 2018, Livermore, California, USA https://neutrinos.llnl.gov/content/assets/docs/workshops/2018/AAP2018-DANSS-Shitov.pdf
6. Yu. Shitov New results from the DANSS experiment / LP2019 XXIX International Symposium on Lepton Photon Interactions at High Energies, 5-10 August 2019, Toronto Canada, https://indico.cern.ch/event/688643/contributions/3429530/
7. Yu. Shitov Search for a light sterile neutrino at SBL reactor experiments / Seminar at University of Comenius, Bratislava, Slovakia, 14 November 2018. https://fmph.uniba.sk/detail-novinky/back_to_page/fakulta-matematiky-fyziky-a-informatiky-uk/article/translate-to-english-nuklearny-seminar-yuri-shitov-14112018/
8. Yu. Shitov, The DANSS project: resent status / Colloquium Prague 19, 24-25 October 2019, J. Heyrovsky Institute of Physical Chemistry https://indico.cern.ch/event/802062/timetable/#all.detailed
9. Yu. Shitov, Recent results from DANSS / NuPhys2019, Prospects in Neutrino Physics, 16-18 December 2019, London, UK, Invited oral talk is foreseen https://indico.cern.ch/event/818781/timetable/#all.detailed
10. Yu.Shitov, Recent results from the DANSS experiment, Neutrino-2020, Chicago, online, June 22-July 2, 2020 https://indico.fnal.gov/event/43209/timetable/#20200622.detailed
11. Irina Machikhiliyan The DANSS neutrino spectrometer: the results of reactor antineutrino studies, Nucleus-2020, https://indico.cern.ch/event/839985/timetable/#all.detailed

SWOT

- No restriction to place near industrial reactors
- Record antineutrino flux at a record short distance from the reactor
- Reactor works as shield against cosmic muons
- High segmentation – good PID
- Relative measurements on mobile platform – insensitive to many systematic effects

- Creation of DANSS-2 with twice improved resolution thanks to better:
  - scintillator quality
  - light collection by SIPM only readout with more WLS-fibers
  - homogeneity and minimal number of dead layers
  - bigger detector
- testing a larger area of ν-sterile oscillations including the declared signal from Neutrino4
- more precise measurement of the reactor n-spectrum to solve the reactor spectral anomaly

- Low resolution due to poor quality of plastic scintillator strips and limited readout
- large inhomogeneity and a large number of dead layers
- outdated optical signal collection system using a PMTs

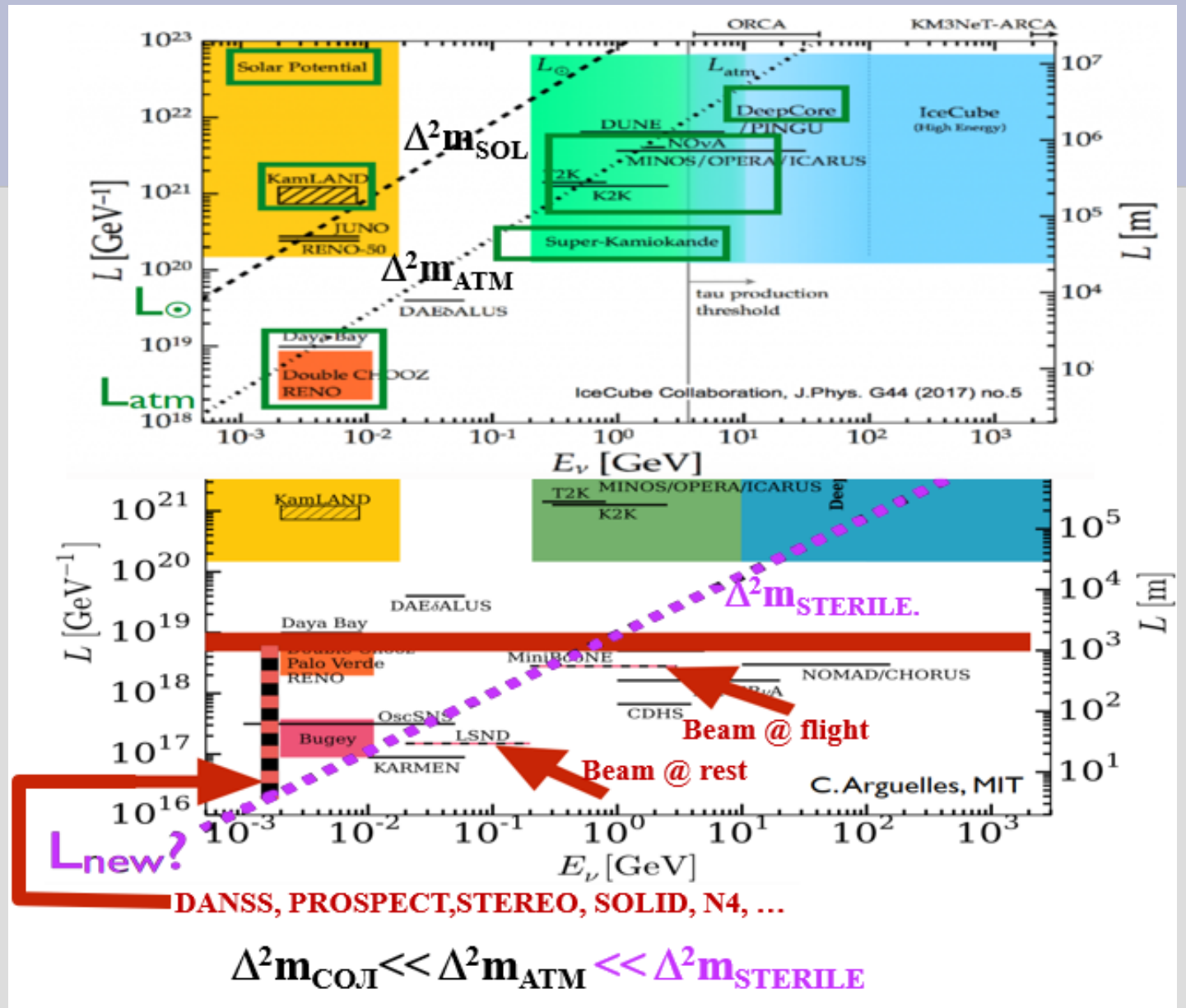
- Limited funding
- Tightening of the rules for work at the KNPP by the management, which will lead to the complication or impossibility of work at the host

Summary

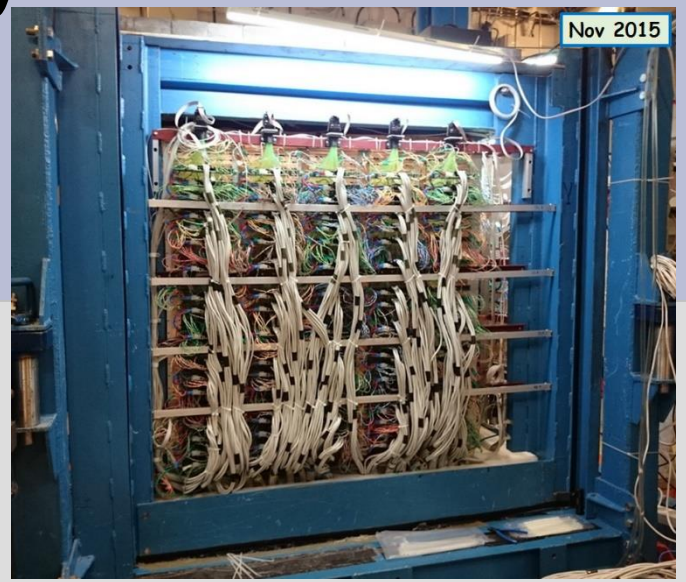
- **Within the framework of this project, a relatively compact and safe neutrino spectrometer DANSS based on plastic scintillators (PS) with a sensitive volume of 1 m^3 has been developed and created, capable of operating near powerful industrial reactors.**
- **The spectrometer has successfully operated 10-12 meters from the KNPP reactor for 4 years (2016-2020), record statistics of 4M reactor antineutrinos have been collected.**
- **Oscillations into sterile neutrinos were not detected, the world's best restrictions on this process were established, long-term precision monitoring of a nuclear reactor and sensitivity to the composition of nuclear fuel were demonstrated.**
- **During the new period of work, it is planned to create, tune and launch the upgraded DANSS-2 spectrometer. In two years of work, the search area (phase space) of sterile oscillations will be significantly increased, including the area of the signal declared by NEUTRINO-4. In addition, a better-quality spectrum of reactor antineutrinos will be obtained, which is important for investigating the reactor antineutrino spectral anomaly.**

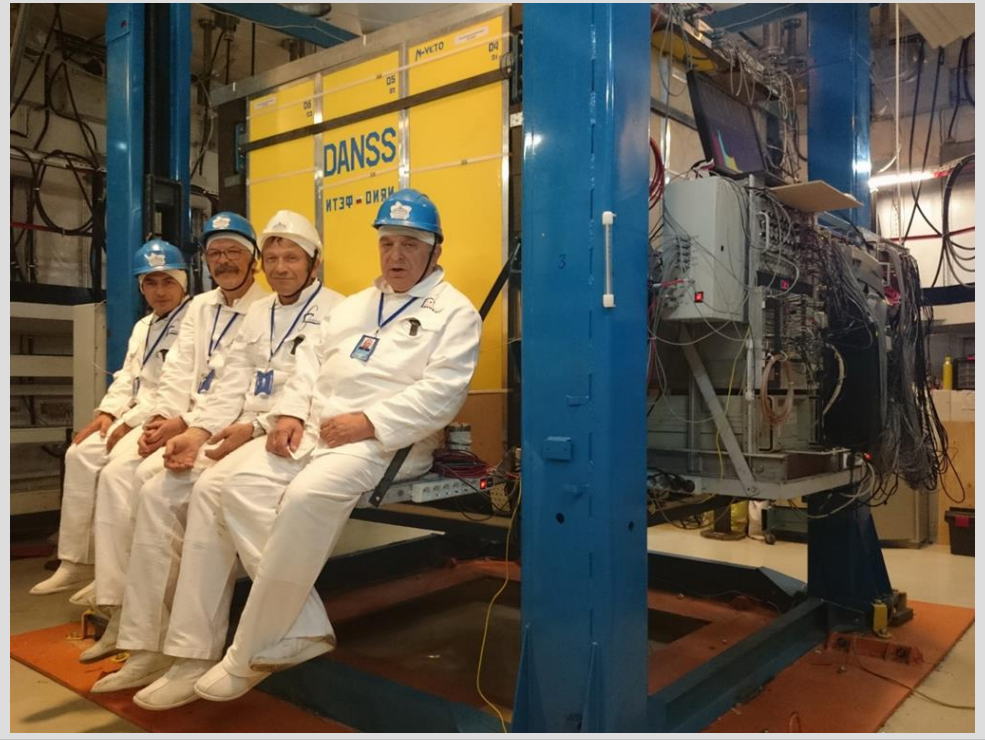
Bonus slides

Neutrino landscape: the sterile neutrino hypothesis

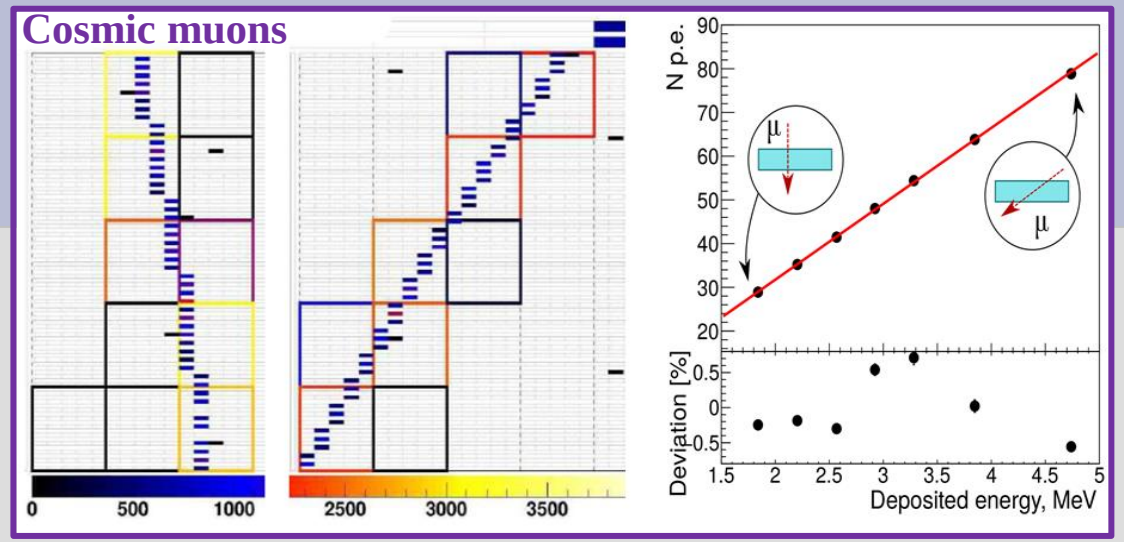


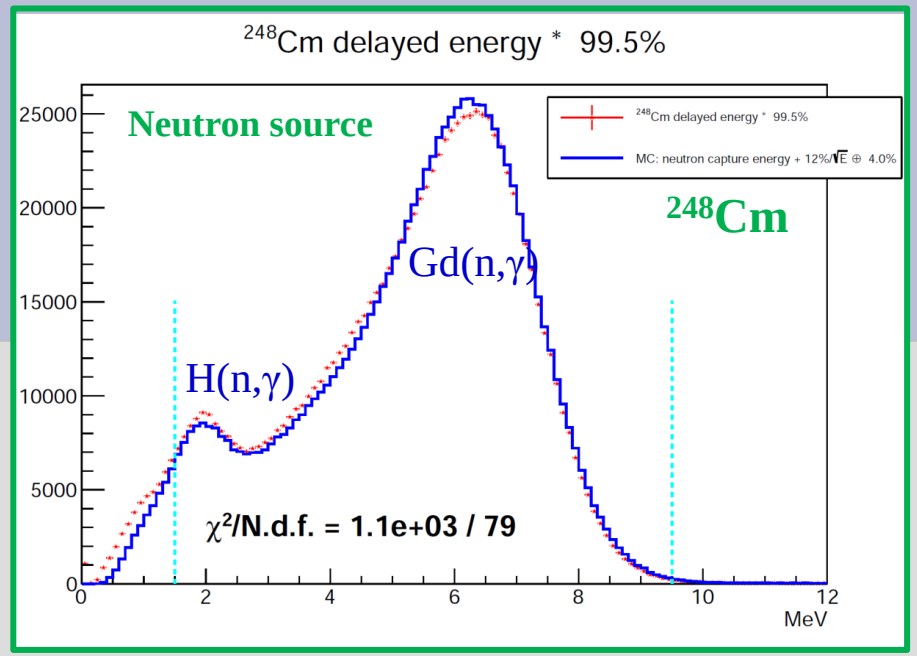
Detector Assembly

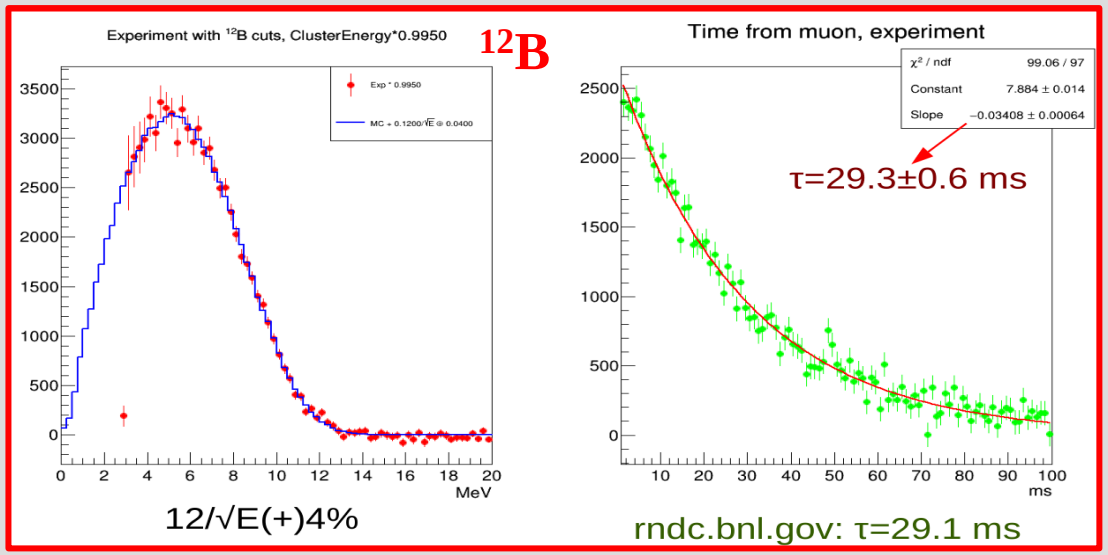


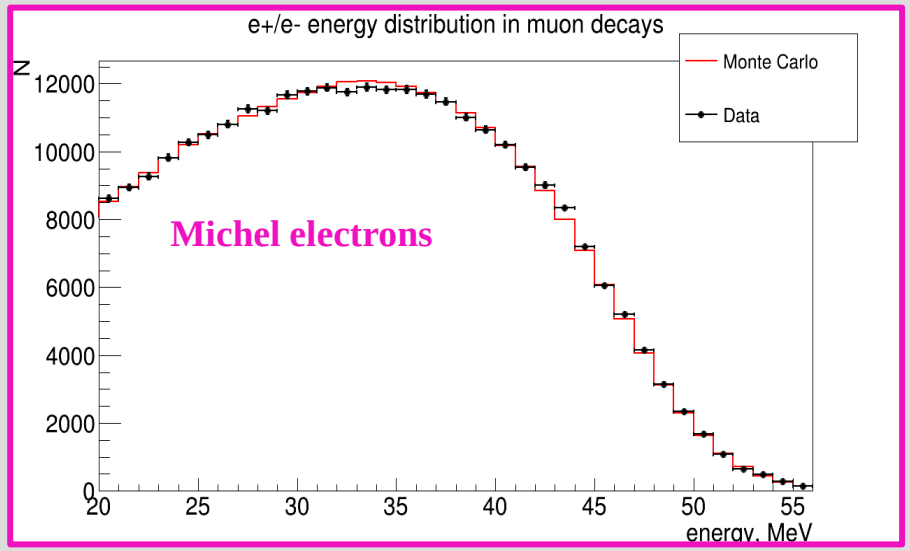


Calibrations



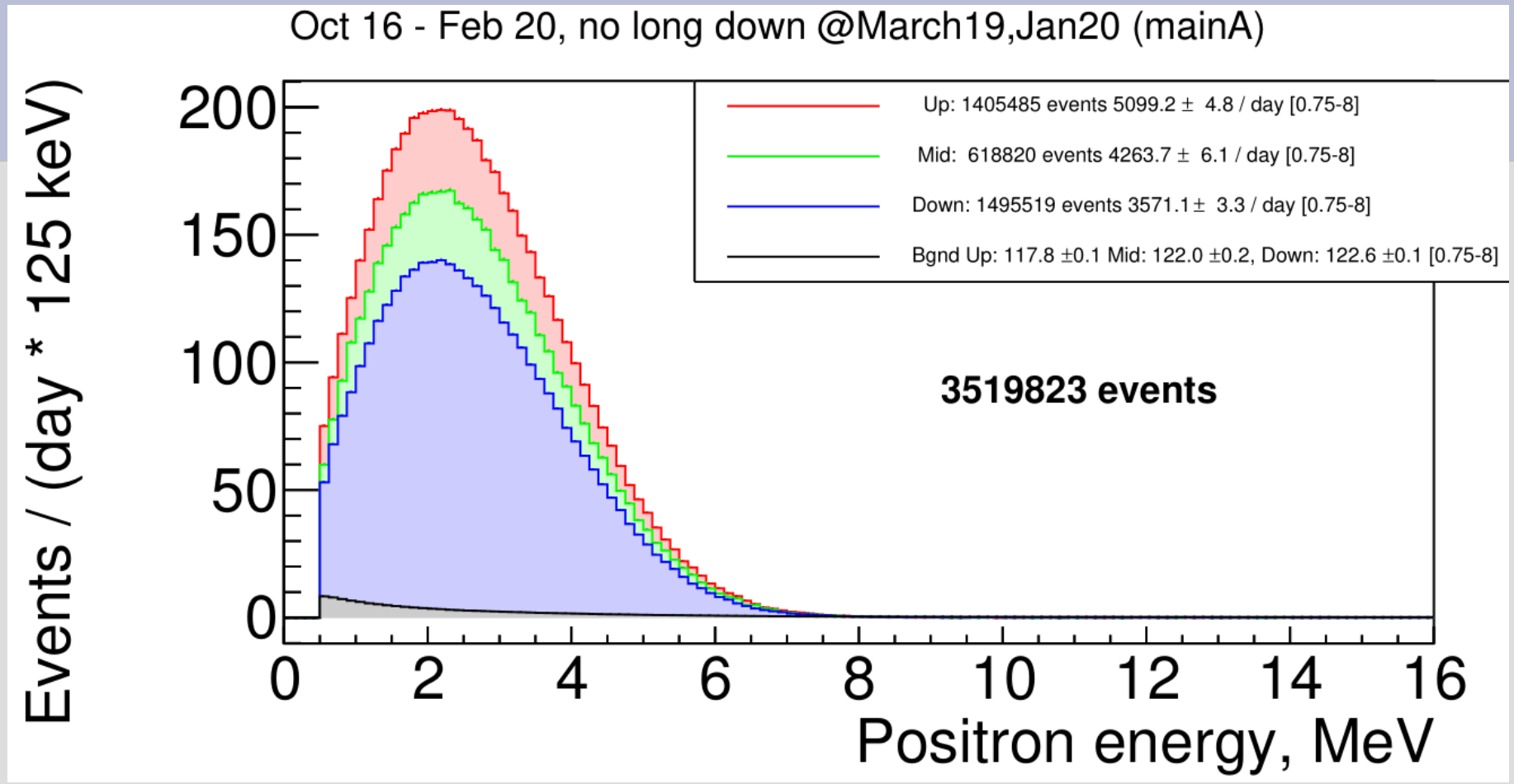






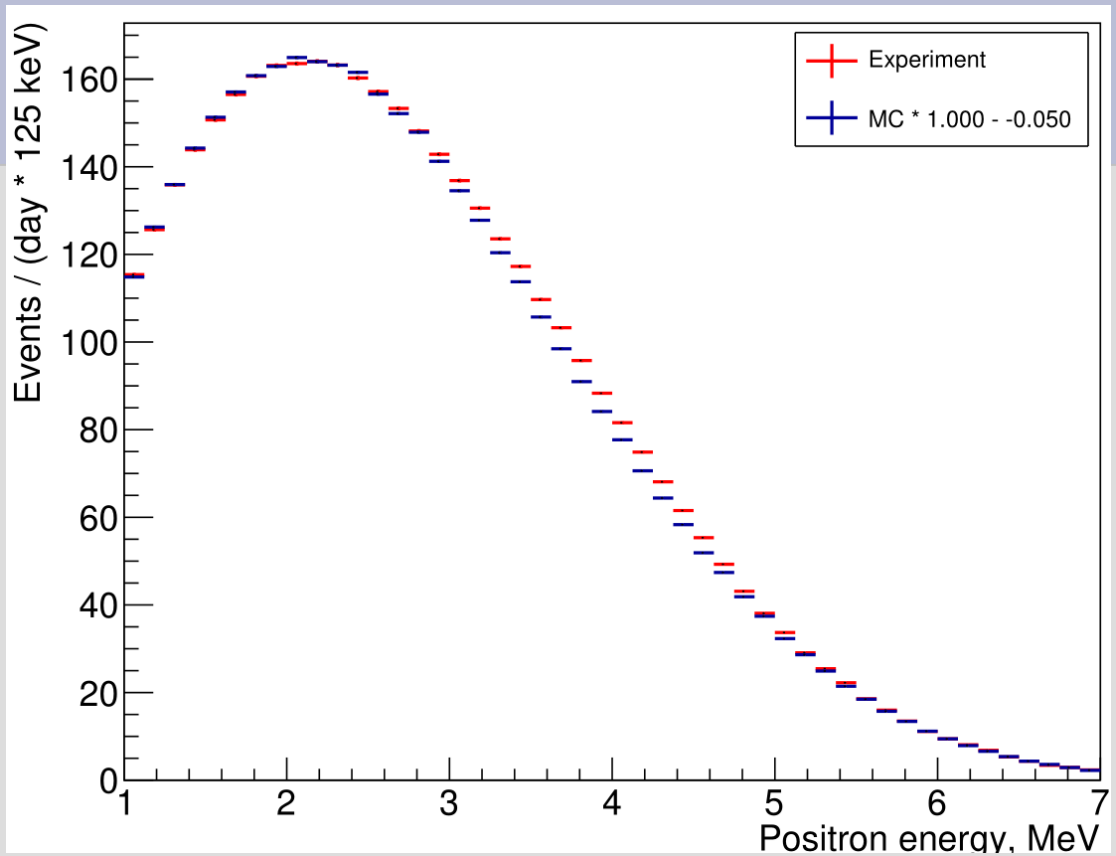
- Energy scale has been fixed using β-spectrum of ^{12}B, which is similar to positron signal
- Systematic error on E scale of +/-2% (will be reduced soon) has added due to source response uncertainties

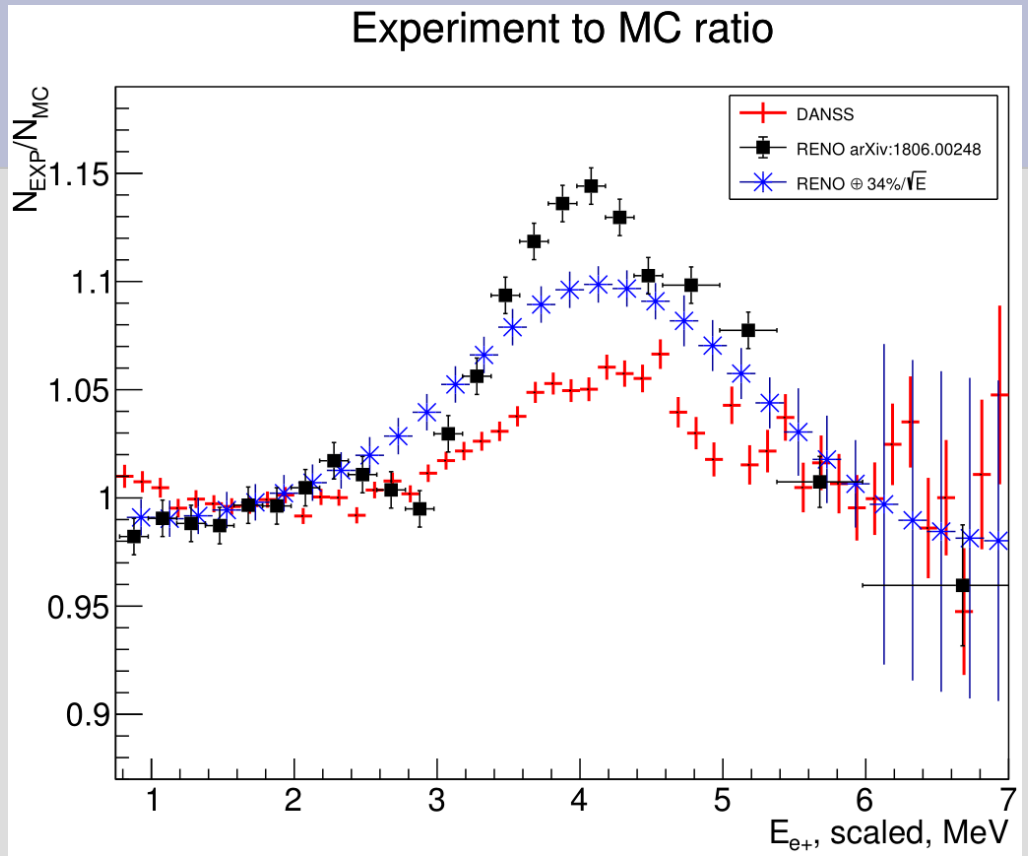
Positron spectrum of IBD-signal



- **Pure positron spectra @ 3 positions (no annihilation photons)**
- **~5000 eve/d (~4000 eve/d in previous analysis) in detector fiducial volume (78% of full volume) @ 'Up' position (closest to the reactor).**

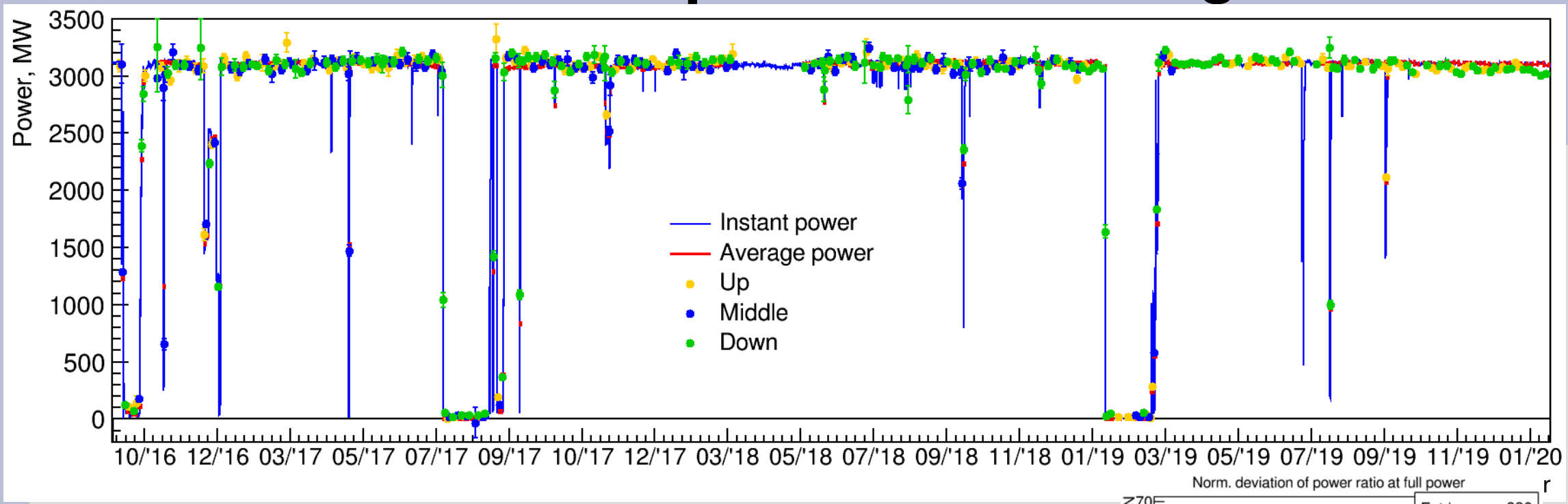
Positron spectrum: experiment vs. theory

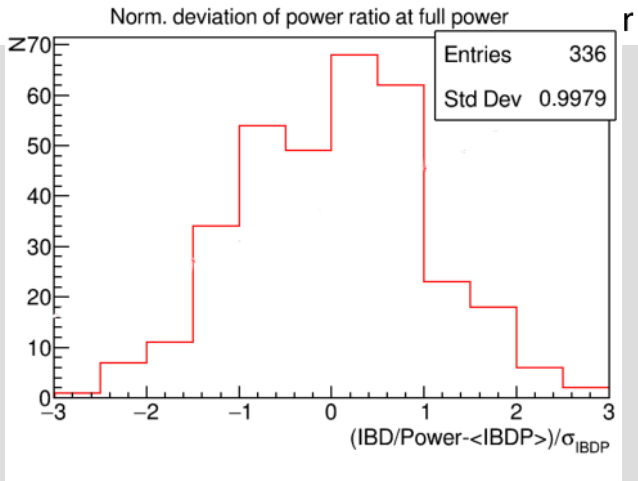




- In order to reach best agreement with H-M model our MC spectrum was shifted on +50 keV w.r.t. experimental data. The nature of this shift is still under investigation.
- With such a shift we see a bump in e+ spectrum similar to other experiments.
- However, we can not claim its existence yet because of high sensitivity of the shape on E scale and shift.

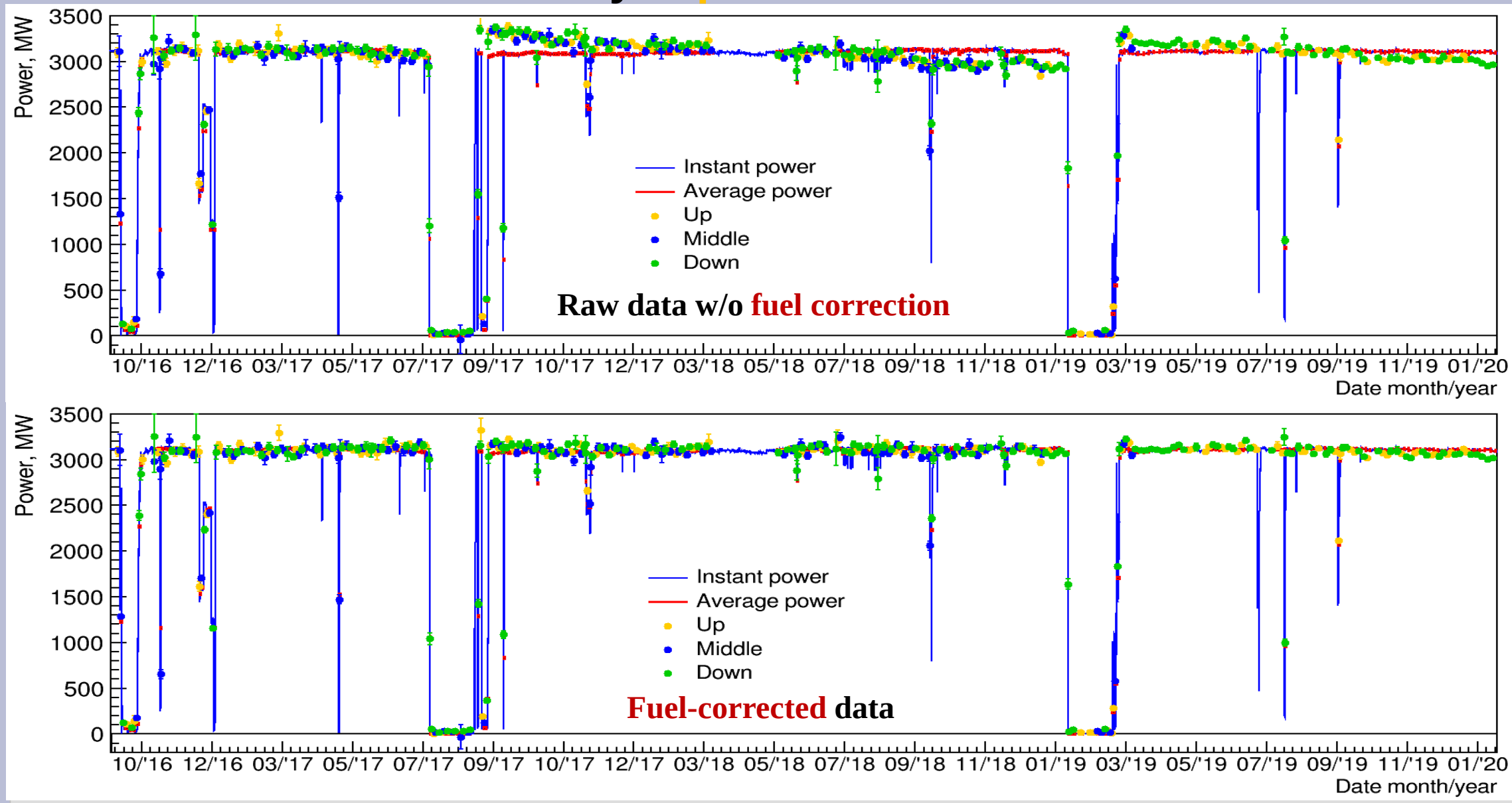
Reactor power monitoring



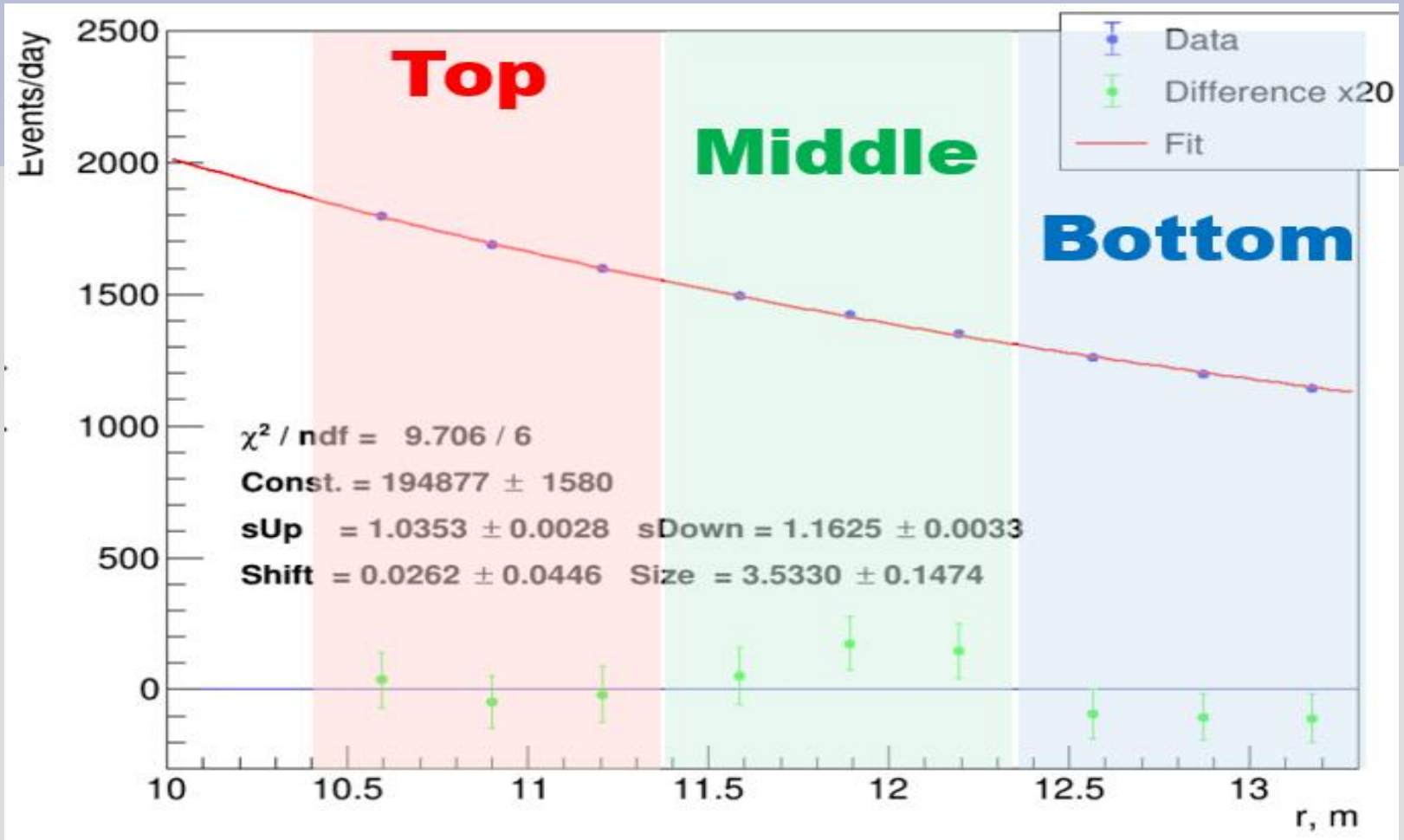


- **DANSS points after all corrections (all backgrounds including adjacent reactor fluxes (0.6%), fuel composition, etc.).**
- **Reactor power is measured by the DANSS with neutrino flux with 1.5% accuracy in 2 days during 3+ years, no evidence for systematic effects has been observed.**

Fuel sensitivity: Up – Middle – Down data

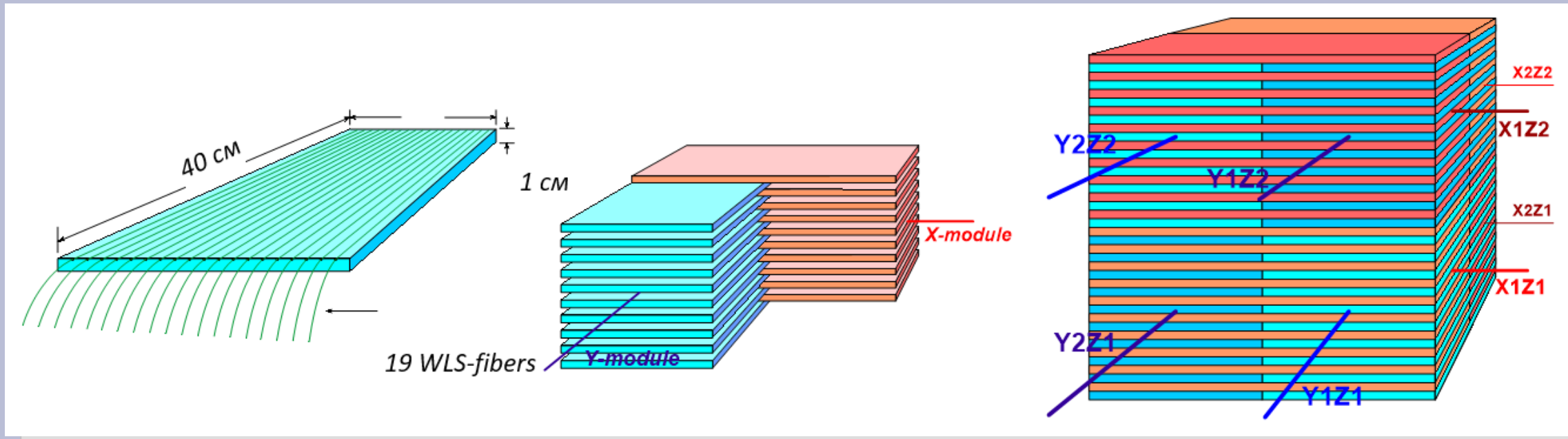


IBD total rate vs. effective distance



- **IBD intensity follows reasonably the $1 / L^2$ dependence.**
- **Detector was divided on 3 parts in each position.**

Mini ν-spectrometer S^3



Scintillator plates combined to intersecting X- and Y-modules with the total volume of 64 liter.

- 80 polystyrene-based scintillator plates of 40×20×1 cm dimension produced by the firm NUVIA with the "*between glass*" technology, form a cube of 40×40×40 cm
- The neighboring plates are interlayed with Gd-containing film produced by the same firm on the Tyvek basis.
- SiPM readout.

Stand to test the DANSS-2 strips