

DANSS Detector Upgrade



Dmitry Svirida for the DANSS Collaboration



The 6th international conference on particle physics
and astrophysics, November 29 – December 2 (2022)

DANSS — Detector of reactor AntiNeutrino based on Solid-state Scintillator

Unique location and movability

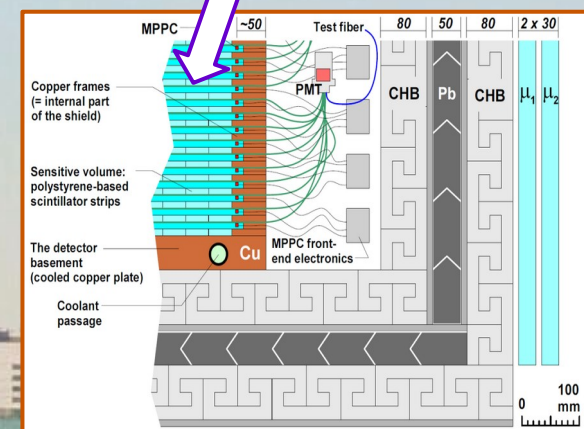
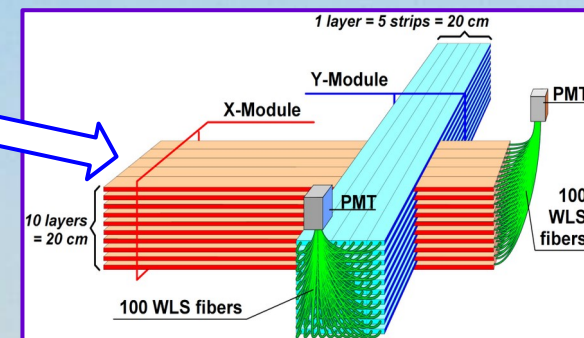
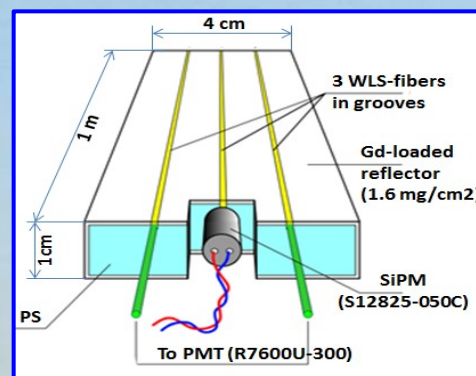
- ✓ 50 m.w.e. overburden
 - ✓ 10.9 – 12.9 m from the core center
 - ✓ Regular movement every week
- ## Safety and fine segmentation
- ✓ 1 m³ of polystyrene based scintillator strips 10x40x1000 mm³ with Gd coating and WLS fiber readout
 - ✓ 25 strips in a layer, 100 layers with alternating direction
 - ✓ Center fiber – SiPM (2500 channels)
 - ✓ Two edge fibers from 50 strips of the same direction – PMT (50 channels)

Powerful shielding

- ✓ Multilayer Cu (5 cm) + CHB (8 cm) + Pb (5 cm) + CHB (8 cm) closed passive shielding
- ✓ 2-layer μ -veto on 5 sides

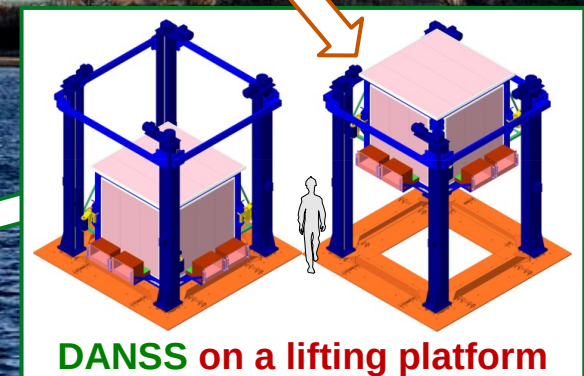
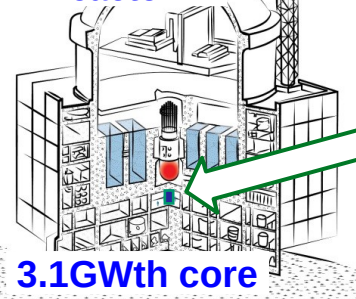
Versatile DAQ

- ✓ Dedicated WFD-based DAQ system



Kalininskaya NPP
Unit 4

WWER-1000
reactor



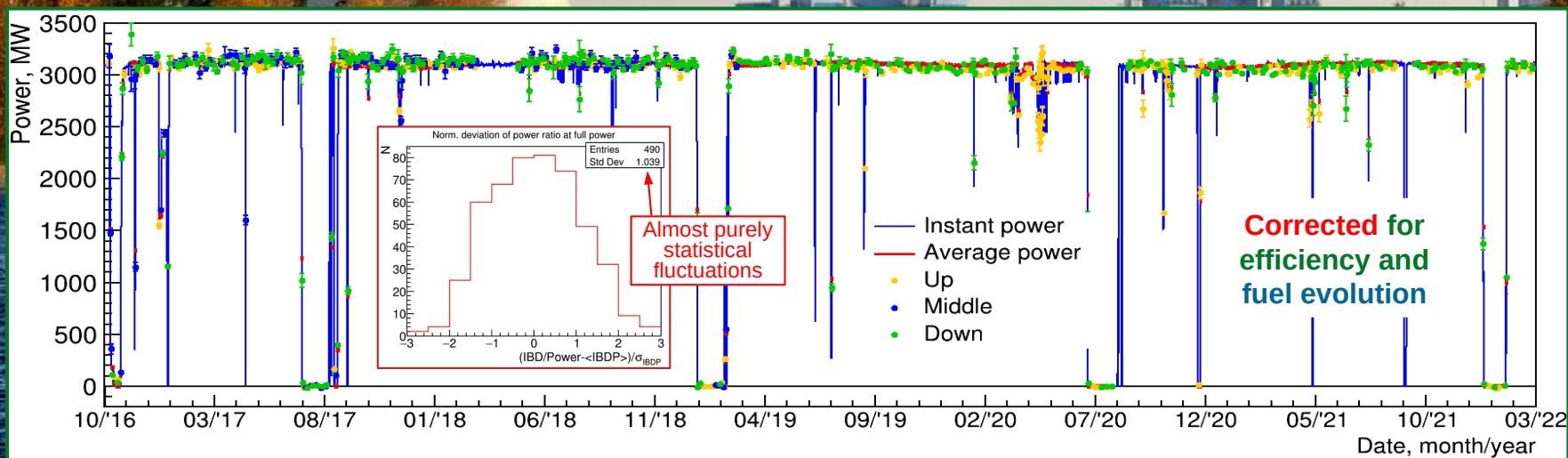
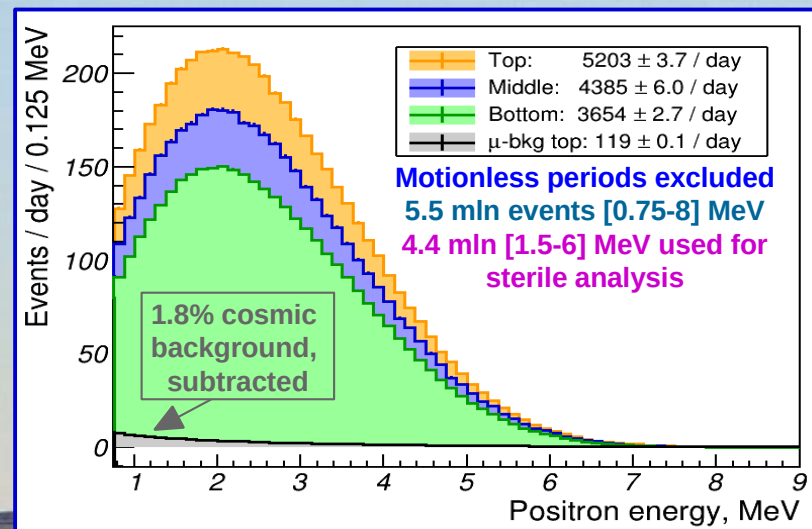
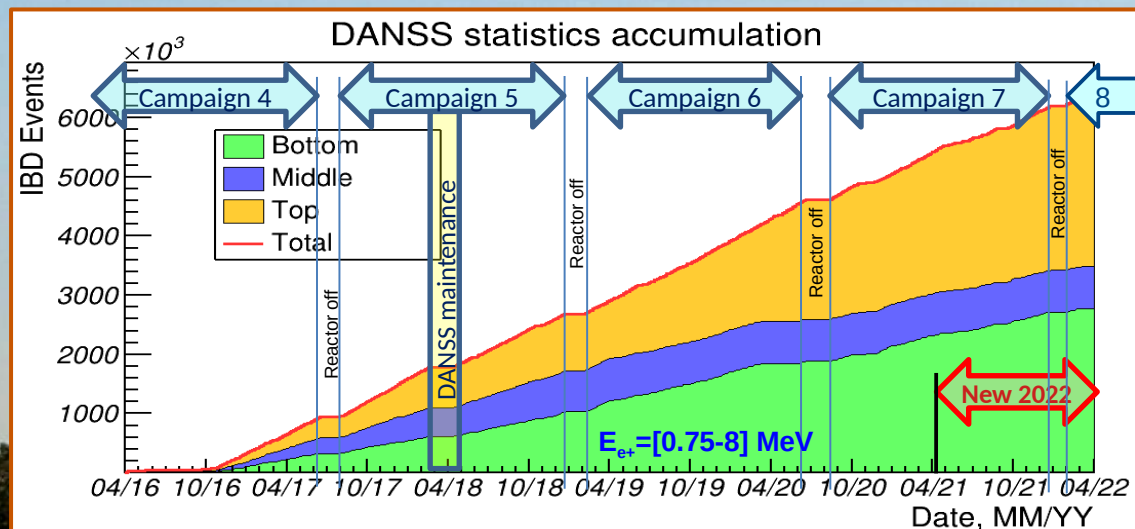
DANSS on a lifting platform

JINST 11 (2016) P11011



Setting World Records

- ✓ 6 years of stable and almost continuous running, > 6 mln. neutrino events recorded and analyzed
- ✓ > 5000 events/per day in the closest position, > 50:1 signal to noise ratio
- ✓ Monitoring the reactor power with 1.5% in 2-day measurement, 3 full campaigns, 4 R-OFF periods
- ✓ Changes in absolute detector efficiency are known with accuracy better than 1% during 5+ years
- ✓ IBD rate and spectrum dependence on fuel composition is clearly seen ... and many more



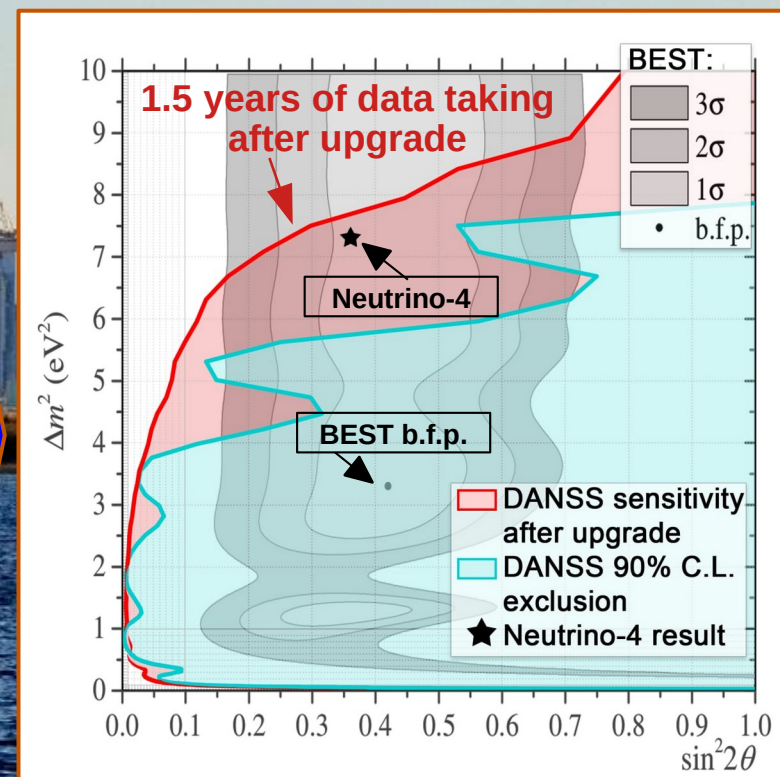
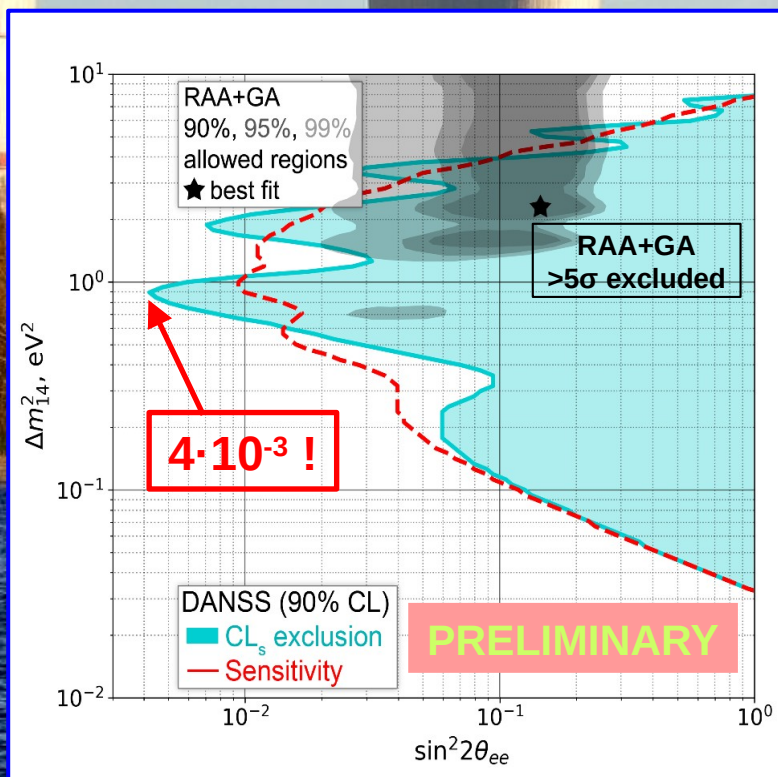
Why Upgrade ?

One but significant drawback:

- ✓ Energy resolution **34% @ 1 MeV**
- ✓ **18.9 (SiPM) + 15.3 (PMT) = 34.2 p.e./MeV**, light collection nonuniformity **8% r.m.s.**
- ✓ Other inhomogeneities, like fluctuations of Gd coating thickness
- ✓ Single hit events (**~30%**) prevent from longitudinal attenuation correction
- ✓ Limits sensitivity to the sterile neutrino, though much is already achieved !

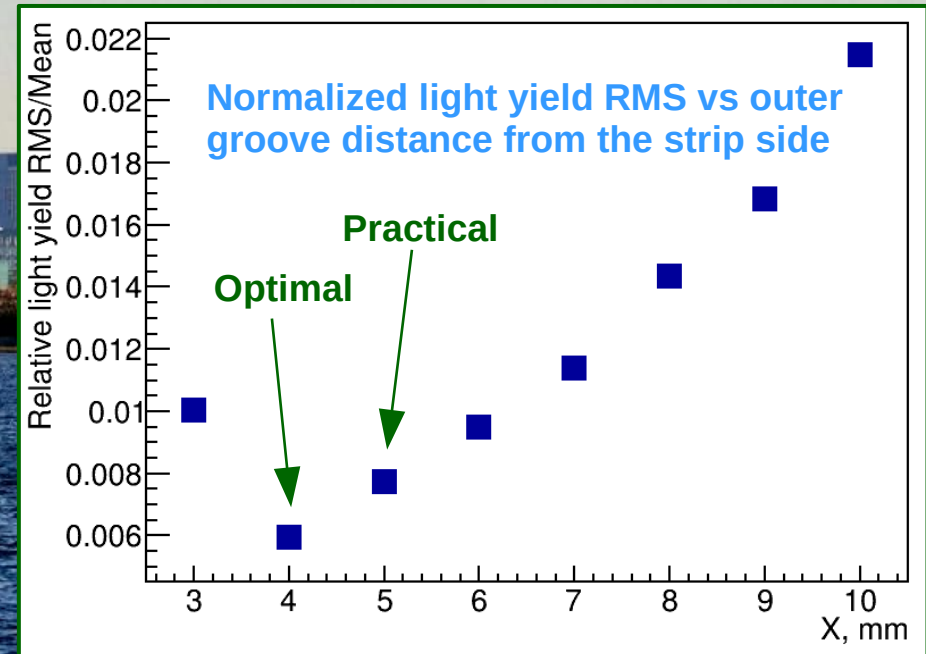
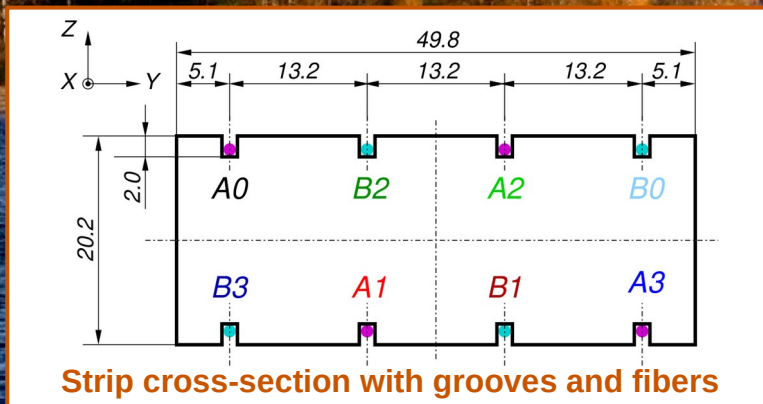
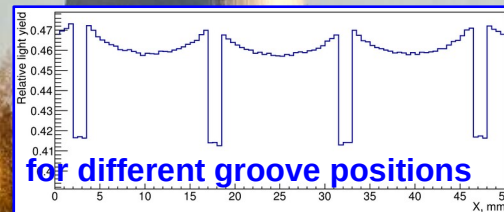
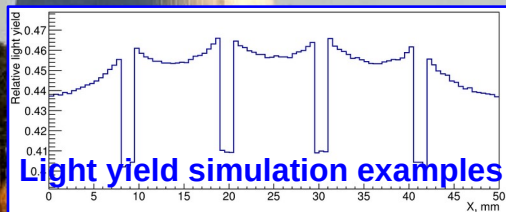
Upgrade goals and expectations:

- ✓ Improve energy resolution to **12% @ 1MeV** – expand sensitivity to higher Δm^2
- ✓ Increase sensitive volume – nearly **x2** higher counting rates
- ✓ Longitudinal coordinate from timing – real **3D** picture
- ✓ Probe Neutrino-4 and BEST results, already in **1.5** years of running



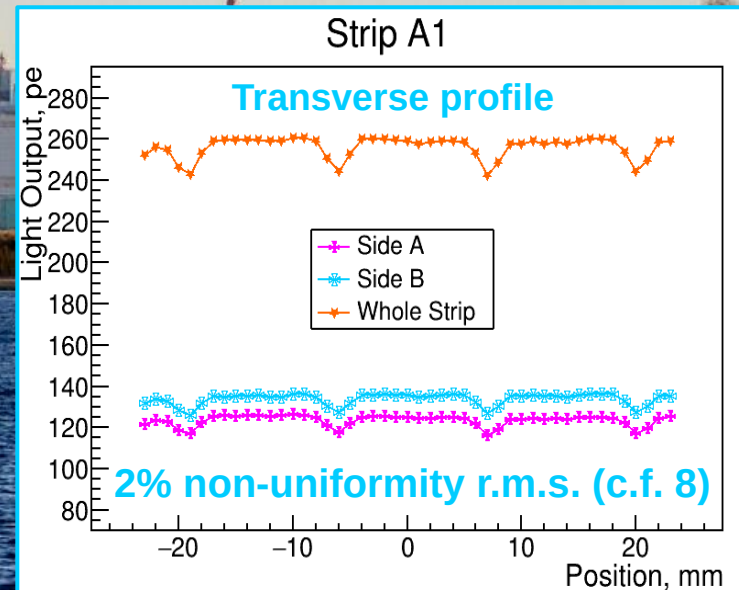
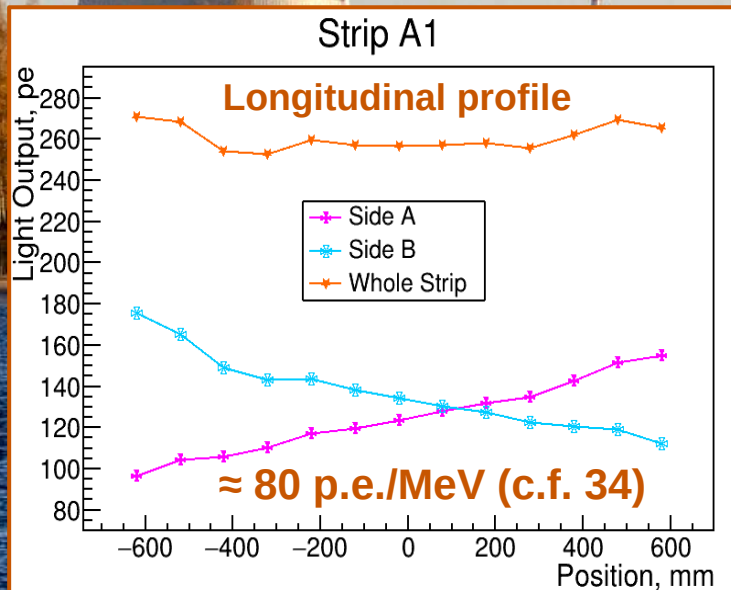
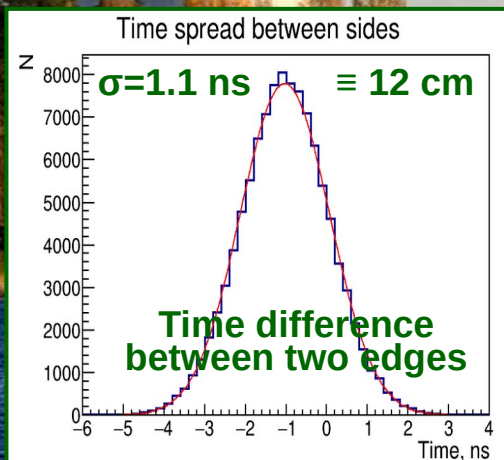
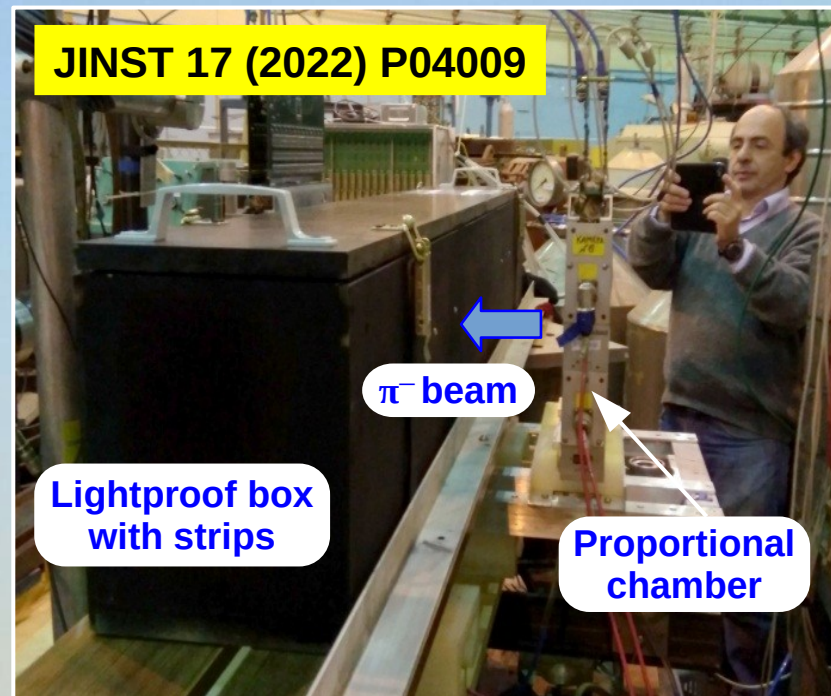
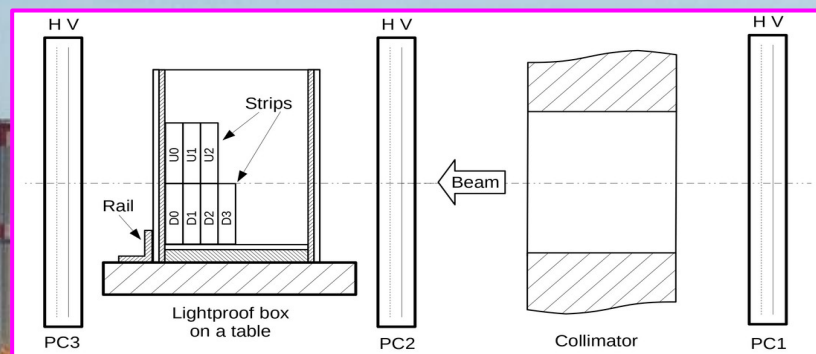
How to Upgrade

- ✓ New scintillation strips from **bulk** polystyrene (IPTP, Dubna, Russia) – higher light output
- ✓ **8** WLS fibers, groove positions optimized through toy **MC** – improved homogeneity
- ✓ Chemical whitening of strips – **foaming** – no large dead layer with titanium and gadolinium
- ✓ **Gadolinium** in separate polyethylene **film** between layers – well controllable thickness
- ✓ 60 layers of 24 strips $20 \times 50 \times 1200$ mm³ – cube (120 cm)³ – **70%** larger sensitive volume
- ✓ No PMT – **SiPM** readout from both strip edges
- ✓ Longitudinal coordinate from propagation **time difference** in each strip
- ✓ **Triggerless** DAQ – all hits seen from both strip edges taken for further analysis
- ✓ New front end electronics – **low power** inside shielding – cool SiPMs to **10°C** for lower noise
- ✓ **Keep** the same support structure, lifting gear and passive shielding
- ✓ Think of new veto system as upgrade stage II, preserve the current one so far



First Try – Promising !

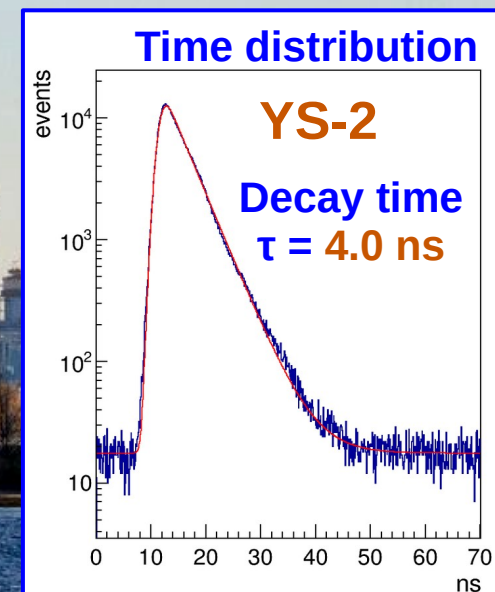
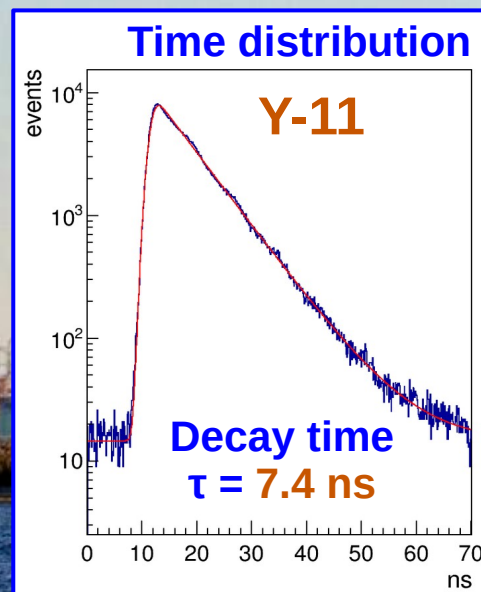
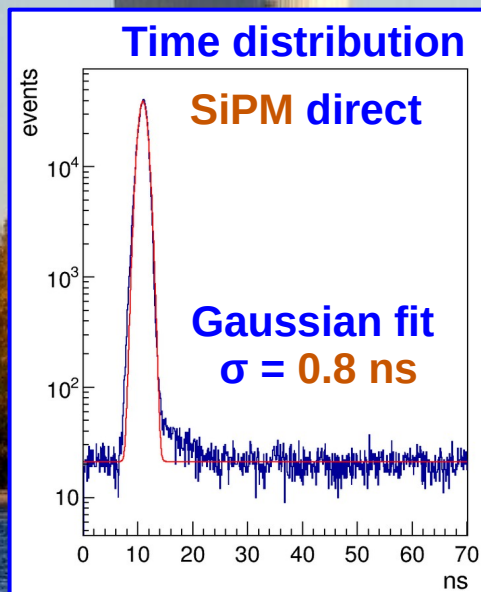
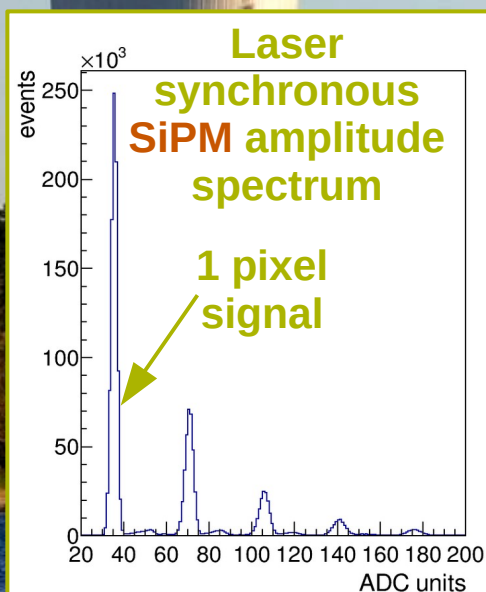
- ✓ 730 MeV/c pion beam of PNPI synchrocyclotron SC-1000
- ✓ Tracking with 1 mm XY proportional chambers
- ✓ 4 SiPm coupled to every second fiber on each strip edge
- ✓ May use both time difference and amplitude correspondence for longitudinal coordinate



Even Better with Kuraray YS-2

- ✓ New KURARAY YS-2 WLS fiber compared to widely used Y-11
- ✓ **Light output and attenuation** at least as good as of Y-11 – from tests with cosmic rays and ^{90}Sr β -source
- ✓ Pulsed UV laser illuminated fibers or SiPM directly, with intensity ~ 1 p.e. per pulse
- ✓ Only **single pixel** events selected to form timing distributions
- ✓ Constant amplitude excludes time walk effects and other systematics
- ✓ Distributions fitted to extract the hardware timing resolution and the fibers emission decay time
- ✓ **YS-2** is almost twice faster than **Y-11** and much preferable for timing measurements

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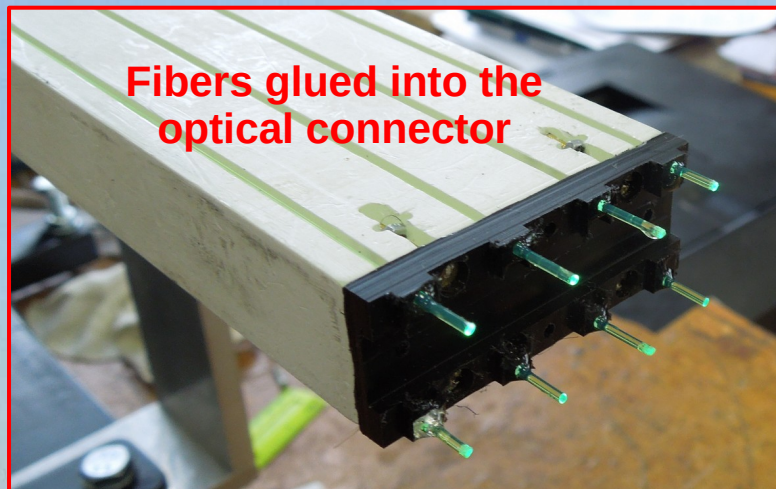


Fit function in case of Gaussian hardware response with width σ and exponential emission decay with time τ

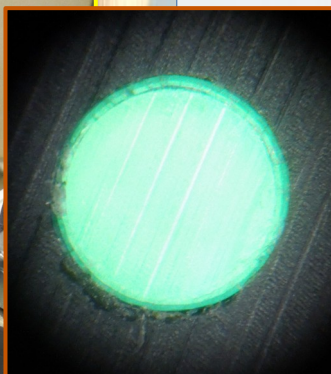
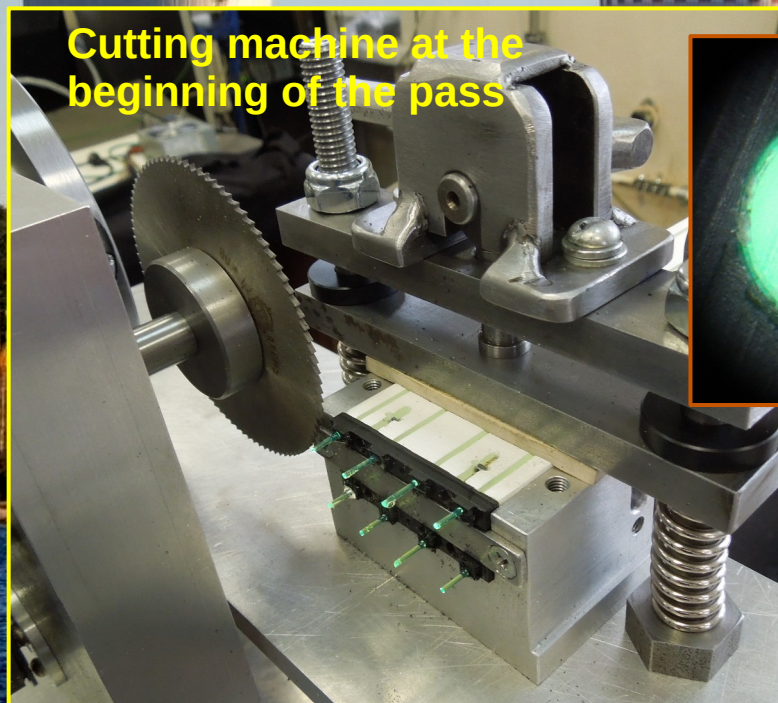
$$N(t) = C \left(1 + \operatorname{erf} \left(\frac{t - t_0 - \sigma^2/\tau}{\sqrt{2}} \right) \right) e^{-(t-t_0)/\tau}$$



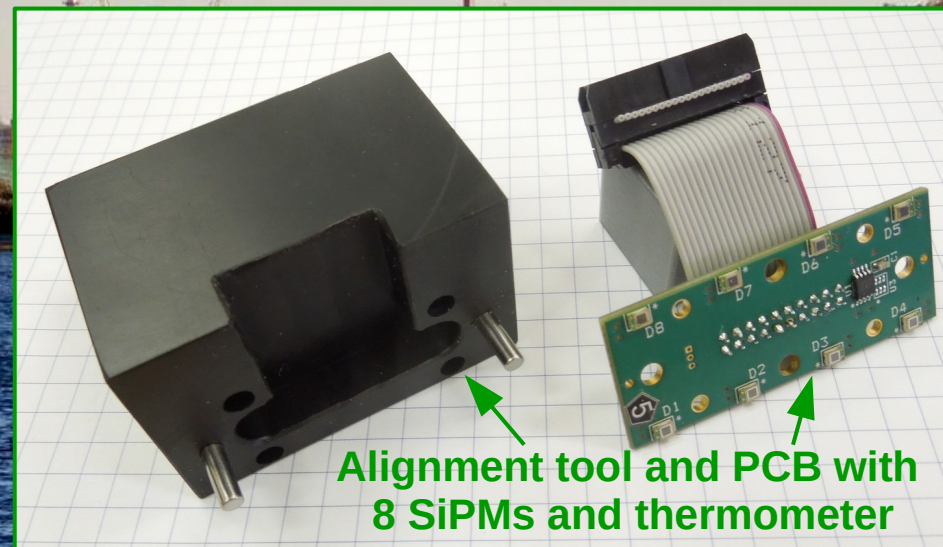
Double Sided Readout



- ✓ Readout of each fiber from both ends increases total light collection by 20-30%
- ✓ Main problem – to cut all 8 fibers at the same length for simultaneous coupling with 8 SiPMs
- ✓ Solution: glue fibers into an “optical connector” and cut them flat in a single pass of an instrument
- ✓ PCB with SiPMs is then attached to the optical connector using special alignment tool
- ✓ Alignment accuracy is better than 50 μm
- ✓ Totally 16 SiPMs per strip with individual power adjustment
- ✓ 8 SiPMs on each side analogously united to form a single digitization channel

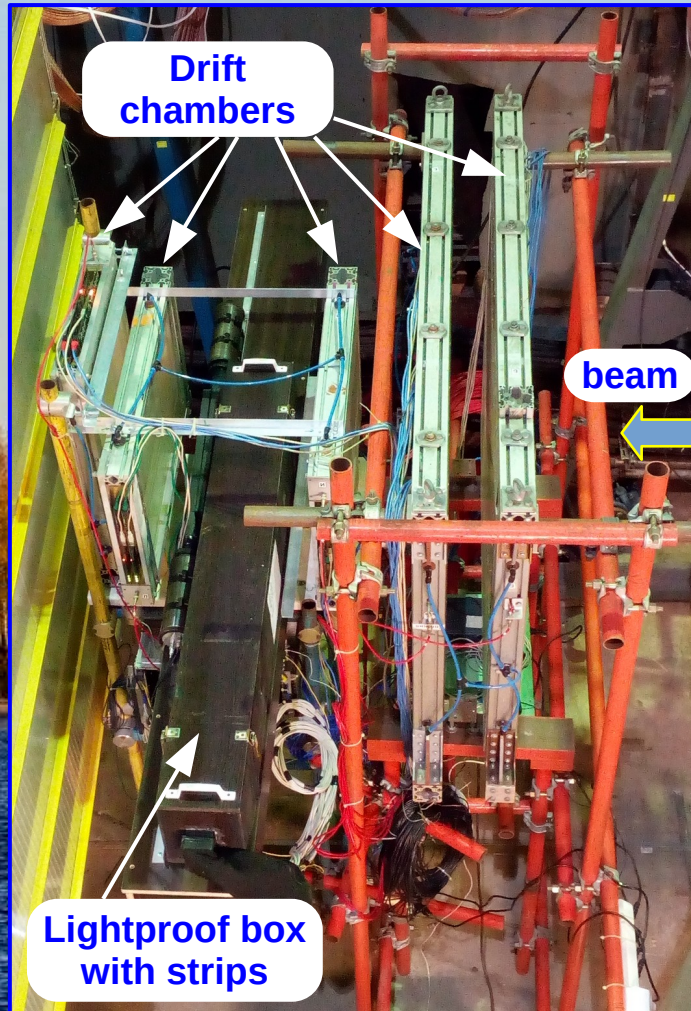
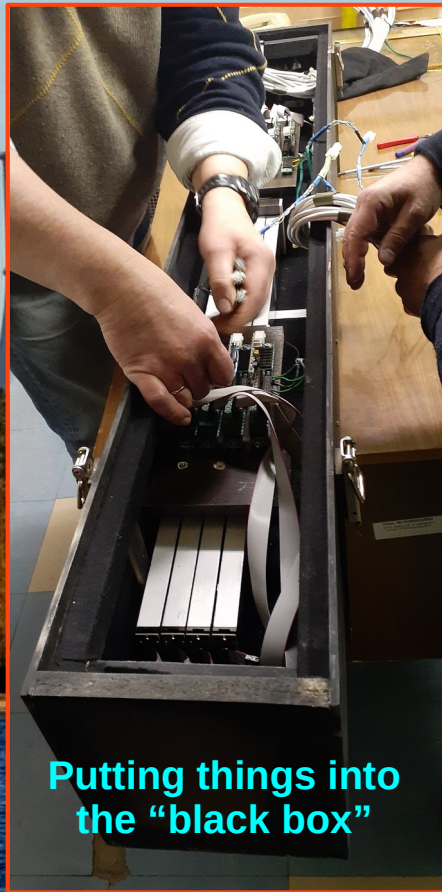


Microscopic view of the fiber edge after cutting



Latest Tests at U-70

- ✓ First 10 strips fully equipped with double sided technology
- ✓ Tests completed a week ago at the 25 GeV pion/muon beam at channel 14 of U-70 synchrotron at IHEP, Protvino
- ✓ Tracking with wire drift chambers with hexagonal cells
- ✓ Not yet analyzed, but even more promising



Status and Plans

- ✓ Preparations for DANSS upgrade continue at full pace
- ✓ Strip bodies will be polymerized and machined by the end of the year
- ✓ 50% of YS-2 fibers delivered, remaining half under purchase procedure
- ✓ Double side readout technology fully developed and first samples tested, mass production expected to start soon
- ✓ New FE electronics, inner frame and cooling system are under design



Thank you for your attention !

