# New scintillation strip design for the DANSS detector upgrade











### **DANSS** — Detector of reactor Anti-**Neutrino 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** m<sup>3</sup> of polystyrene based scintillator strips 10x40x1000 mm<sup>3</sup> 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 DAO**

**Dedicated WFD-based DAQ system** 

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### **Setting World Records**

- 7 years of stable and almost continuous running, > 7 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 6+ 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<sup>2</sup>
- 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 V
- Chemical whitening of strips foaming no large dead layer with titanium and gadolinium V
- **Gadolinium** in separate polyethylene film between layers well controllable thickness ~
- 60 layers of 24 strips 20x50x1200 mm<sup>3</sup> cube (120 cm)<sup>3</sup> 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





### **Even Better with Kuraray YS-2**

New KURARAY YS-2 WLS fiber compared to widely used Y-11

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- Light output and attenuation at least as good as of Y-11 from tests with cosmic rays and <sup>90</sup>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



Fit function in case of Gaussian hardware response with width  $\sigma$  and exponential emission decay with time  $\tau$ 

**TIPP2023** 

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



### **Double Sided Readout**

# Fibers glued into the optical connector



- Readout of each fiber from both ends doubles the total light collection (expected 30-40%)
- Main problem to cut all 8 fibers at the same length for simultaneous coupling with 2x8 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 combined to form a single digitization channel

Alignment tool and PCB with 8 SiPMs and thermometer





### Latest Tests at U-70

- First 10 strips fully equipped with double sided technology ~
- Tests completed in November 2022 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, accuracy 300-500 µm V
- Defocused beam, 4 box positions divided into 10 longitudinal ranges ~



### Light Output Characterization



- Each longitudinal range divided transversely into 1mm bands
- Light output distributions for individual bands and totals, various combinations of fiber ends
- Distributions are of various shapes, median is the only reasonable measure
- With 2 cm strip thickness, MIP produces 3.7 MeV in terms of median





### **Transverse Profiles**



Toy MC is not fully identical to the experiment, but reflects main features

As measured: central fibers see more light, side fibers better see far periphery

- The grooves are more shallow in measurements due to spatial accuracy
- DANSS will not measure the transverse coordinate grooves only contribute to the energy resolution: profile non-uniformity R.M.S. ~(3.5 - 4)%





### **Longitudinal Profiles**



- Reasonable uniformity fiber to fiber, SiPM to SiPM
- ~ ~30-35% attenuation at 1.2 m for YS-2 in real application
- Attenuation is approximately linear
- ✓ Only ≤ ±3% longitudinal non-uniformity if no attenuation correction
- Attenuation is measurable and will be corrected



## Longitudinal Coordinate from Timing



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### Transverse Coordinate from Asymmetry



- If one can afford readout of individual channels (DANSS will not do this)
- Simple asymmetry between side fibers already gives 3-5 mm accuracy
- Can be sufficiently better if all 8 fibers involved, may be AI can help ?



### Cross-Talk between Opposite Ends





### **Status and Plans**

- Preparations for the DANSS upgrade continue at full pace
- Double sided readout doubles the light output and much improves the timing resolution
- Double sided technology fully developed and first samples tested
- Challenging upgrade goal of energy resolution 12% @ 1 MeV may be even surpassed with measured light output
- Mass production of strips expected to start soon
  - New FE electronics, inner frame and cooling system are under design

## Thank you for your attention !

