NOvA/DUNE Project

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for the NOvA/DUNE JINR team

16 March, VBLHEP JINR

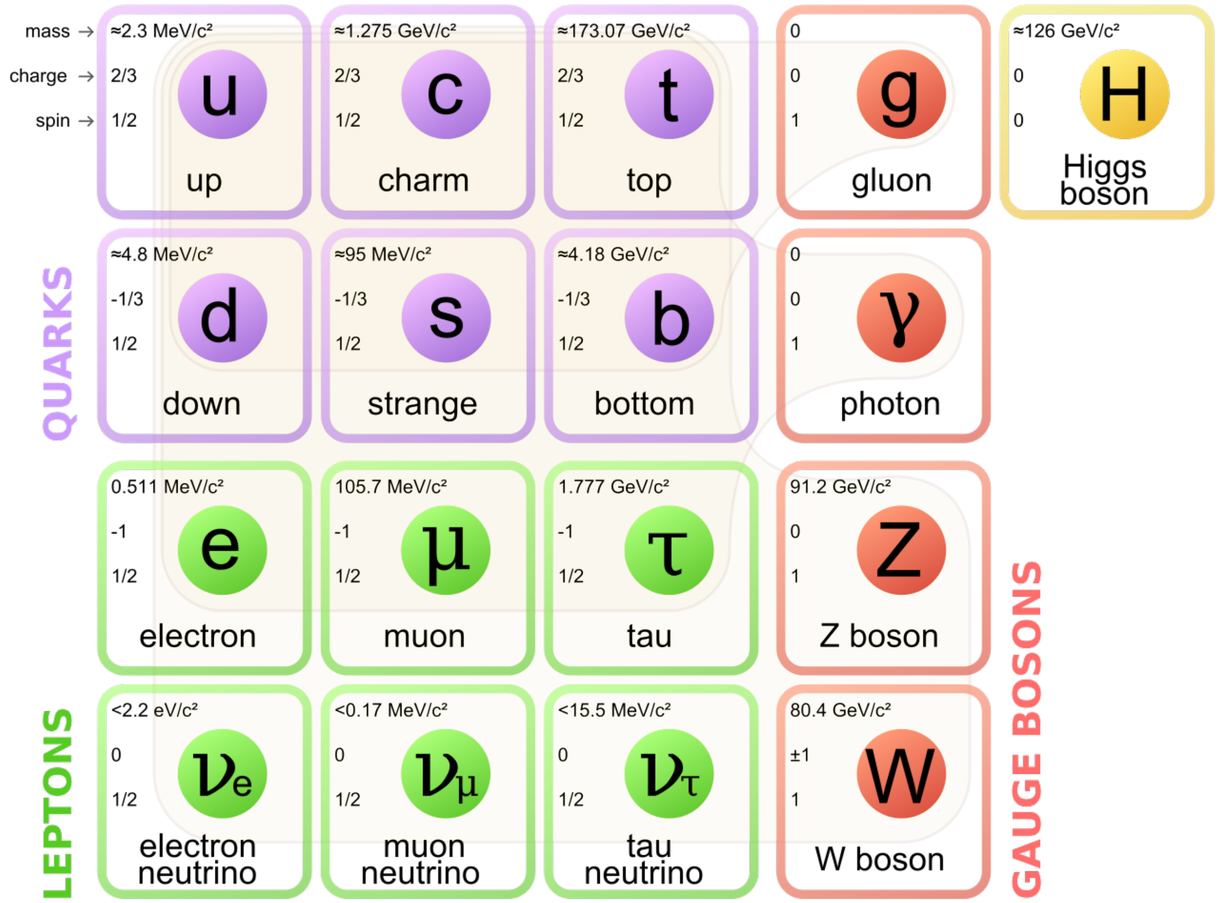
DEEP UNDERGROUND
NEUTRINO EXPERIMENT

Neutrino physics

- Standard Model particle.
- Small but non zero mass.
- Neutrino interactions conserve flavor.
- Interact only via weak (and gravity) force.

Modern hot topics:

- search for sterile neutrinos,
- measurement of absolute neutrino masses,
- search for neutrinoless double beta-decay (are neutrinos Dirac or Majorana particles),
- detection of relic neutrinos,
- study of neutrino oscillations,
- detection of high energy astrophysical neutrinos and spotting their sources,
- ...



Three-flavor neutrino oscillations

ATMOSPHERIC / ACCELERATOR — SHORT BASELINE REACTOR / ACCELERATOR — SOLAR / LONG BASELINE REACTOR

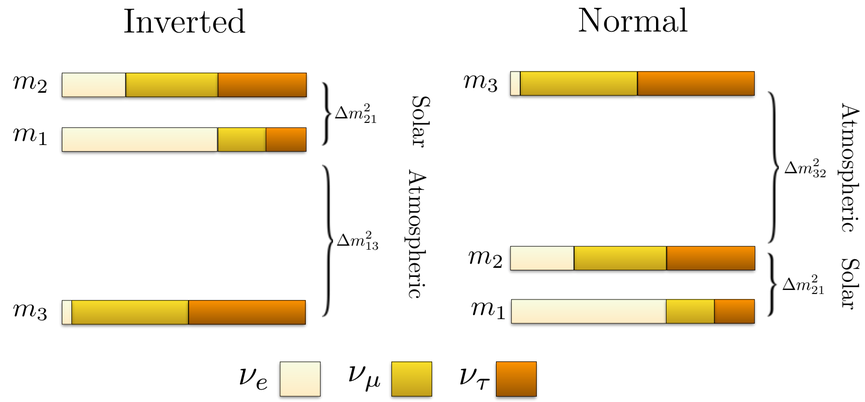
$$\left| \begin{matrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{matrix} \right\rangle = \begin{pmatrix} 1 & & \\ & c_{23} & s_{23} \\ & -s_{23} & c_{23} \end{pmatrix} \begin{pmatrix} c_{13} & & s_{13}e^{-i\delta} \\ & 1 & \\ -s_{13}e^{i\delta} & & c_{13} \end{pmatrix} \begin{pmatrix} c_{12} & s_{12} & \\ -s_{12} & c_{12} & \\ & & 1 \end{pmatrix} \left| \begin{matrix} \nu_1 \\ \nu_2 \\ \nu_3 \end{matrix} \right\rangle$$

Oscillation parameters and how precisely do we know them:

$\theta_{12} \approx 34^\circ$ (4.4%)
$\theta_{23} \approx 49^\circ$ (5.2%)
$\theta_{13} \approx 9^\circ$ (3.8%)
$\Delta m^2_{21} \approx 7.4 \times 10^{-5}$ eV^2 (2.2%)
$\Delta m^2_{32} \approx +2.5 \times 10^{-3}$ eV^2 (1.4%)

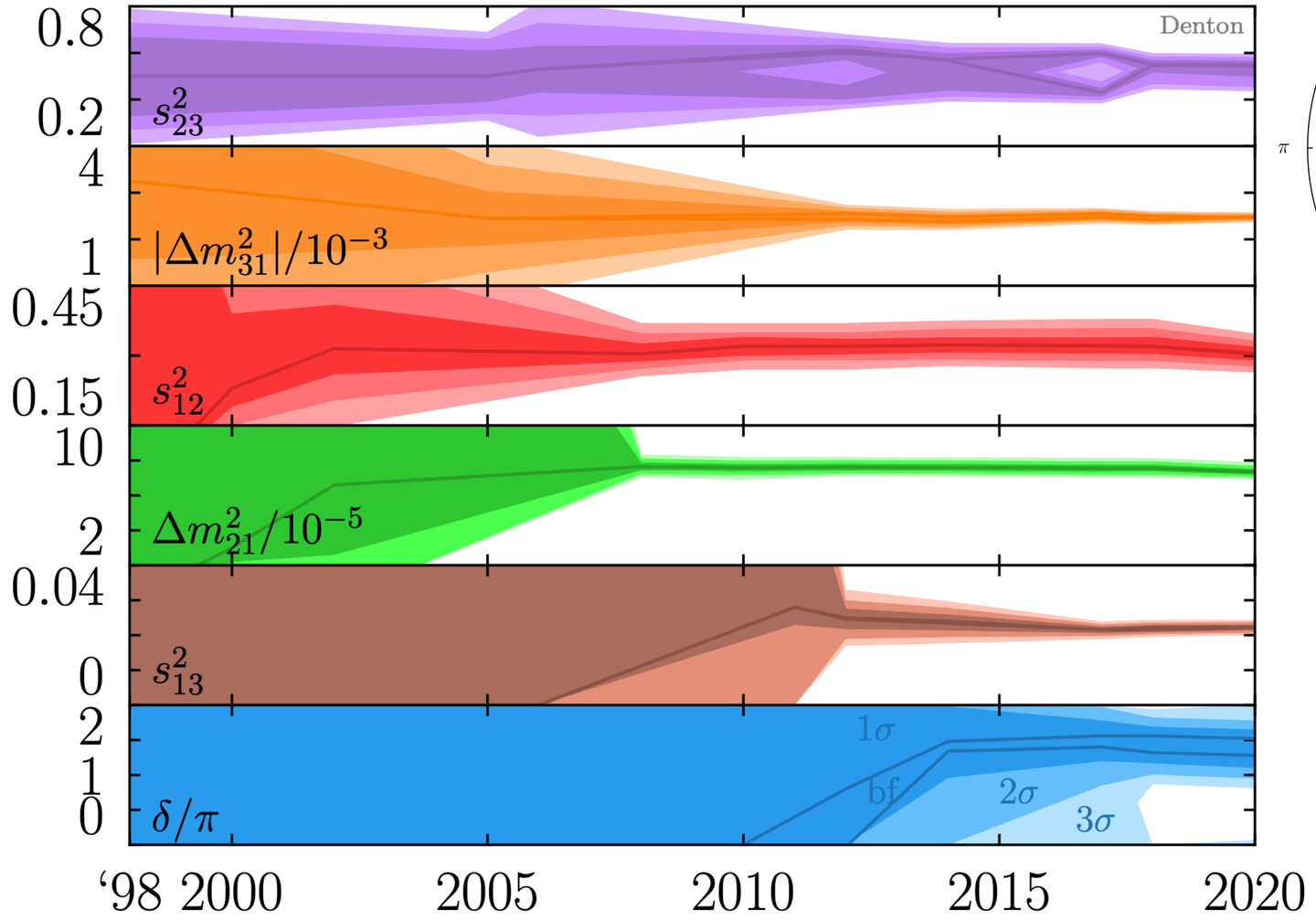
Open questions:

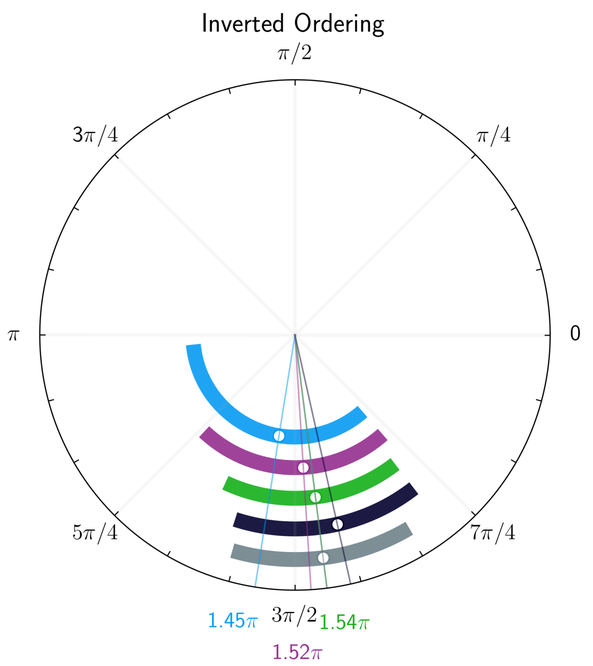
- Is θ_{23} 45°? (possible ν_μ and ν_τ symmetry in ν_3)
- Is there CP violation in lepton sector? (matter-antimatter asymmetry of the Universe (leptogenisis)

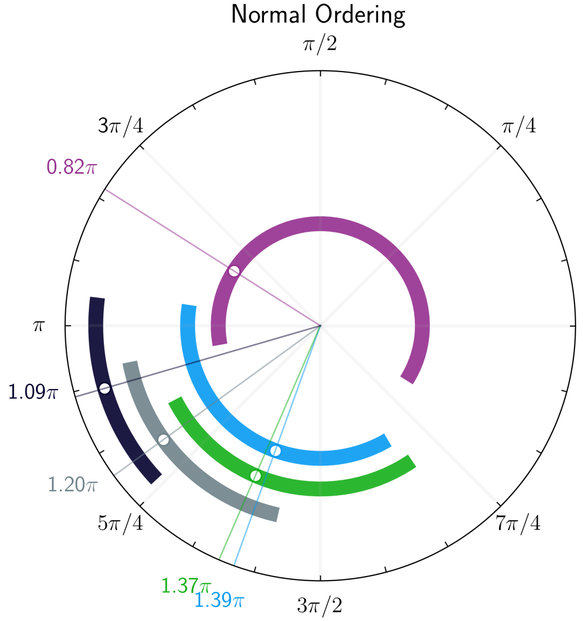


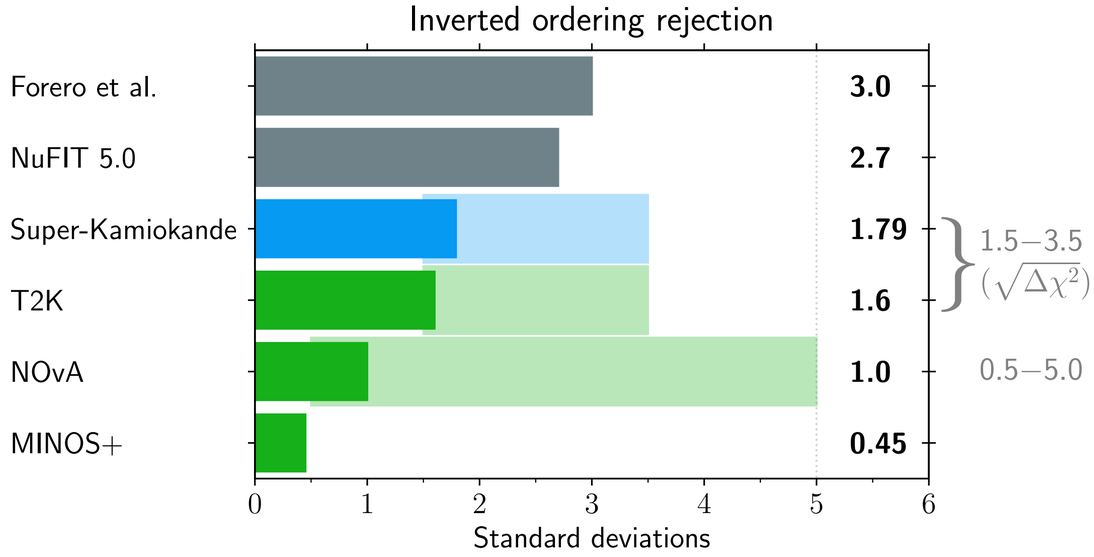
- Neutrino mass hierarchy (ordering) is Normal or Inverted? (neutrinoless double beta-decay searches, supernova simulations, relic neutrinos searches, absolute ν mass measurements etc)

Current status

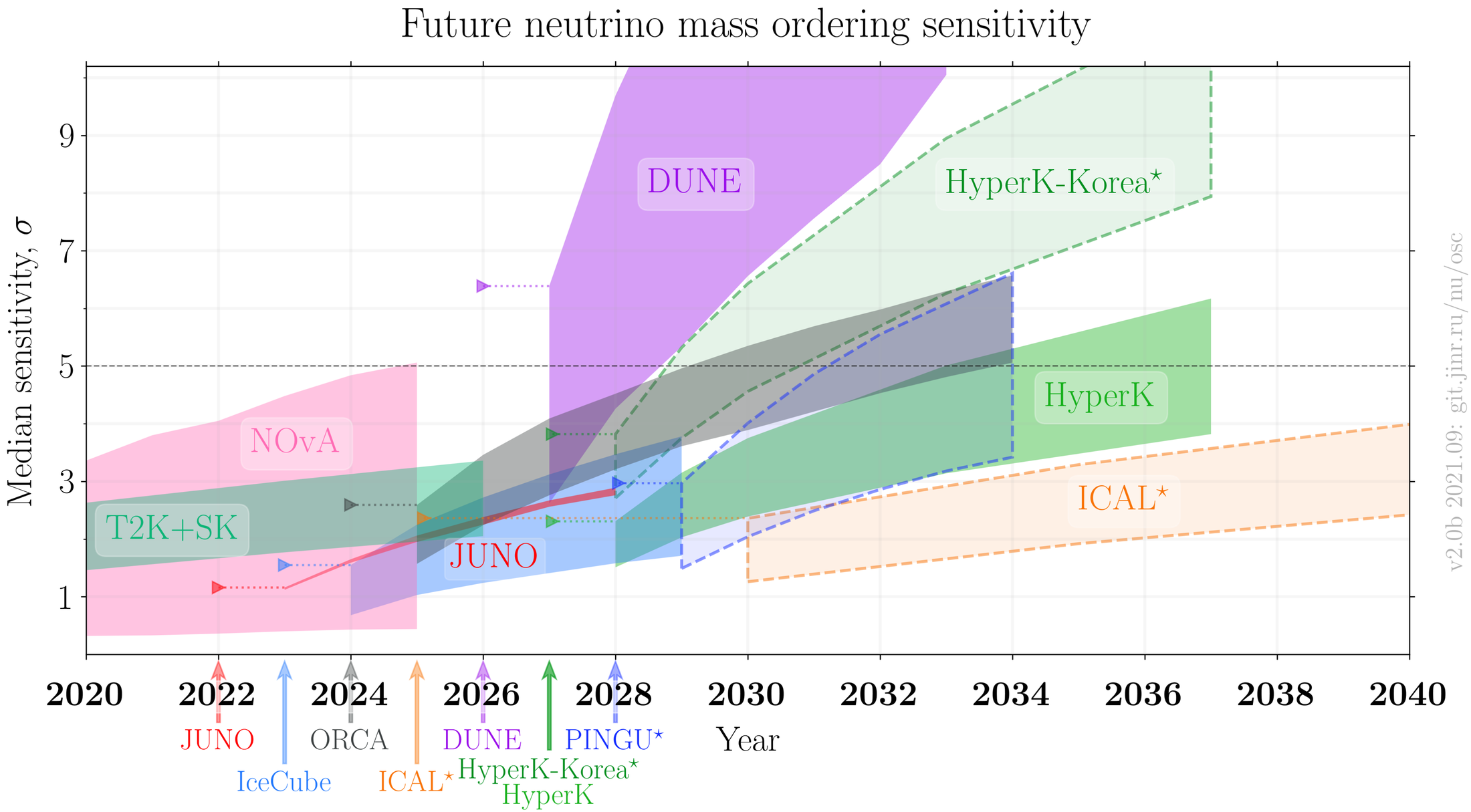








Future prospects



The NOvA Experiment

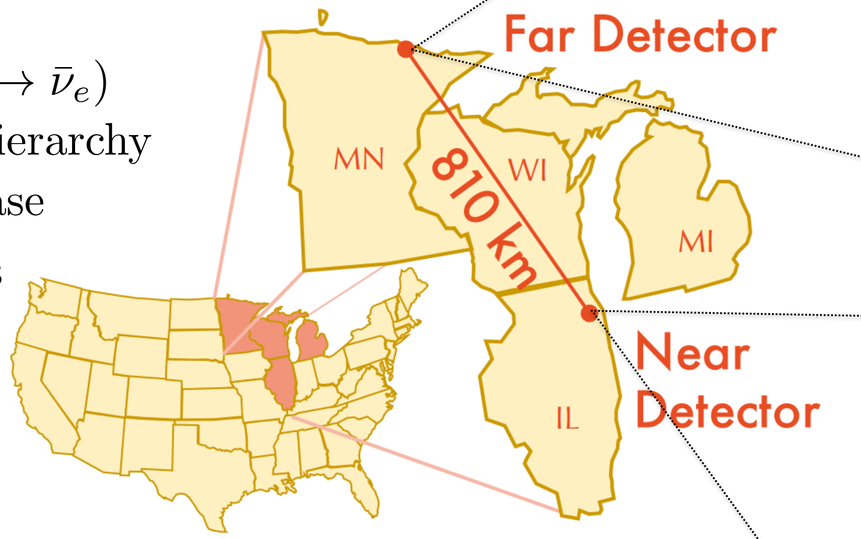
Experiment goals:

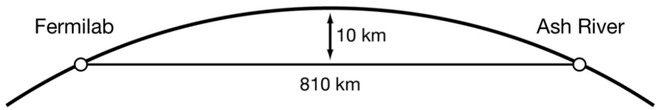
Using $\nu_\mu \to \nu_\mu$ $(\bar{\nu}_\mu \to \bar{\nu}_\mu)$
- Precise measurement Δm^2_{32}
- Mixing angle θ_{23}

Using $\nu_\mu \to \nu_e$ $(\bar{\nu}_\mu \to \bar{\nu}_e)$
- Neutrino mass hierarchy
- CP violating phase
- Mixing angle θ_{23}

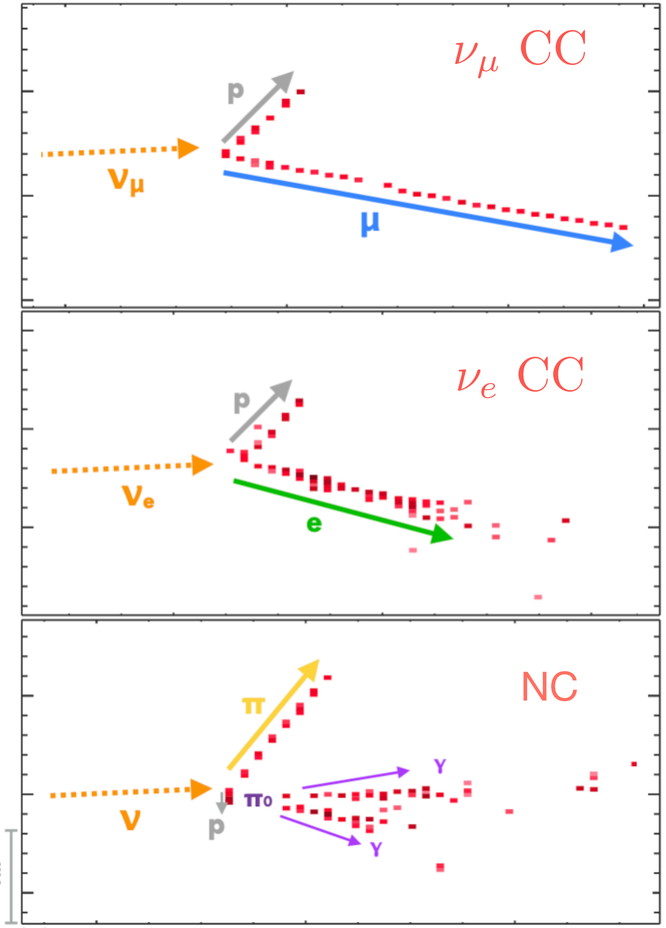
Long-baseline,
beam from Fermilab,
two detectors sit at
14 mrad off-axis

The NuMI Off-Axis ν_e Appearance Experiment





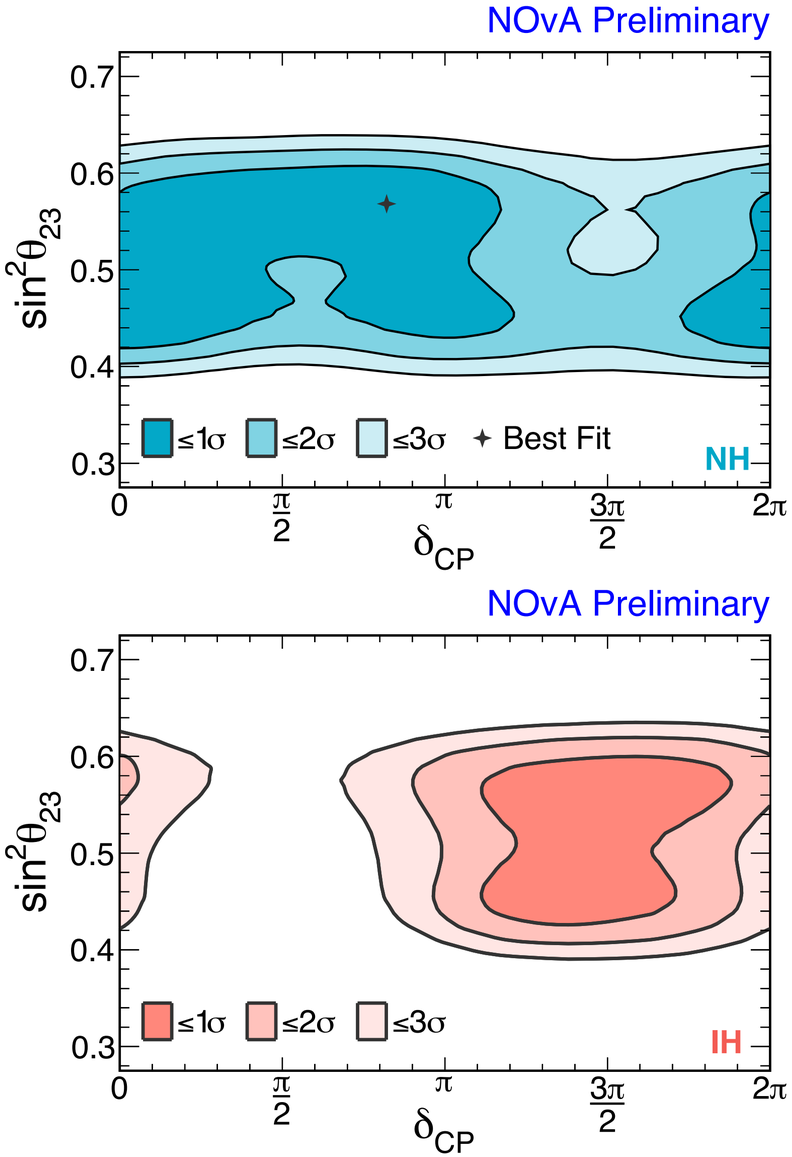
How events look like in det.

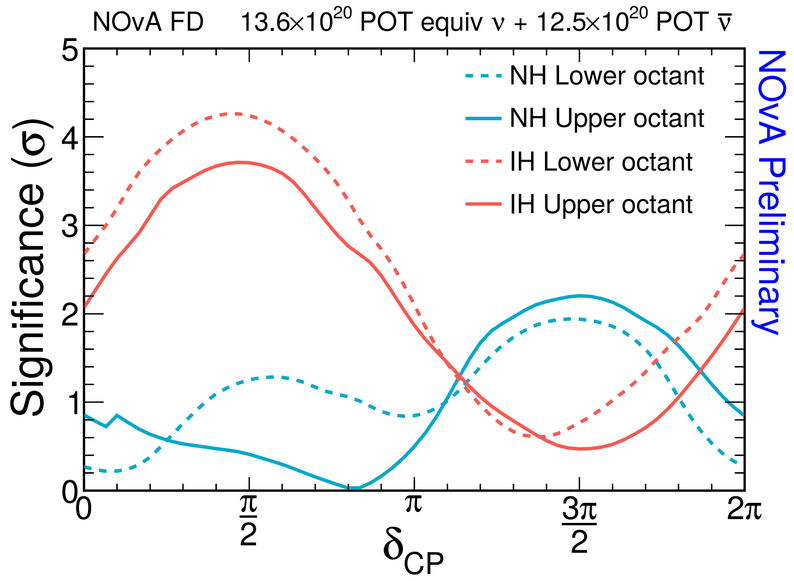


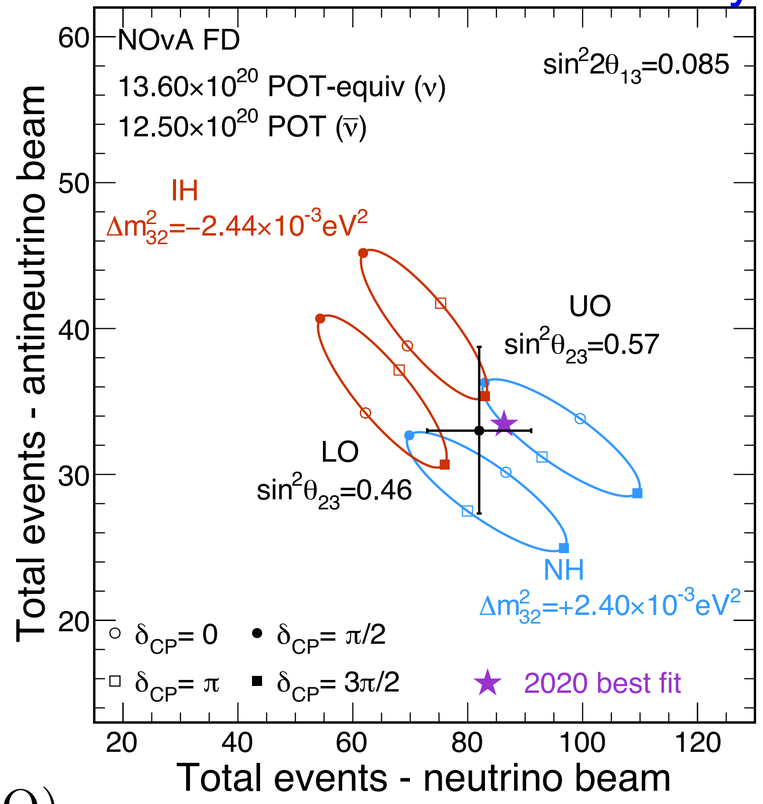
JINR joined NOvA in 2014

200 collaborators from ~40 institutions and over 7 countries

Oscillation results: joint $\nu_\mu + \nu_e$ fit







✳ Best fit:

$$\sin^2\theta_{23} = 0.57^{+0.03}_{-0.04}$$

$$\Delta m^2_{32} = (+2.41 \pm 0.07) \times 10^{-3}\ \text{eV}^2\ \text{(NO)}$$

$$\delta_{CP} = 0.82\pi.$$

✳Disfavor NO, $\delta = 3\pi/2$ at $\sim 2\sigma$.

✳Exclude IO, $\delta = \pi/2$ at $> 3\sigma$.

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No strong asymmetry in the rates of ν_e and $\bar{\nu}_e$ appearance.

NOvA FUTURE

Currently running with neutrino beam.

- ✳ Plan is to run 50:50% $\nu : \bar{\nu}$;
- ✳ NOvA is expected to run until 2026.

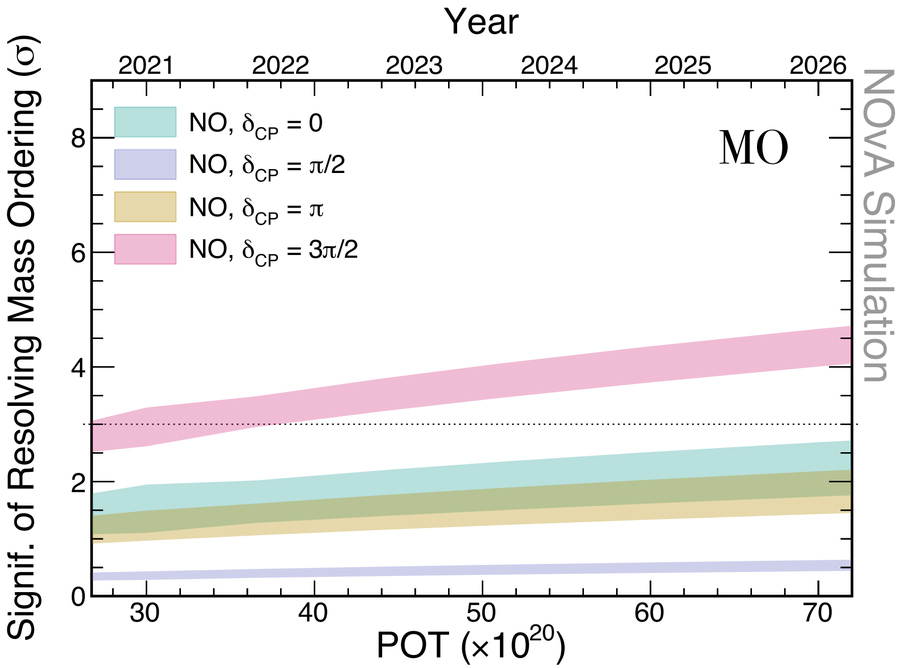
With current analysis, expect:

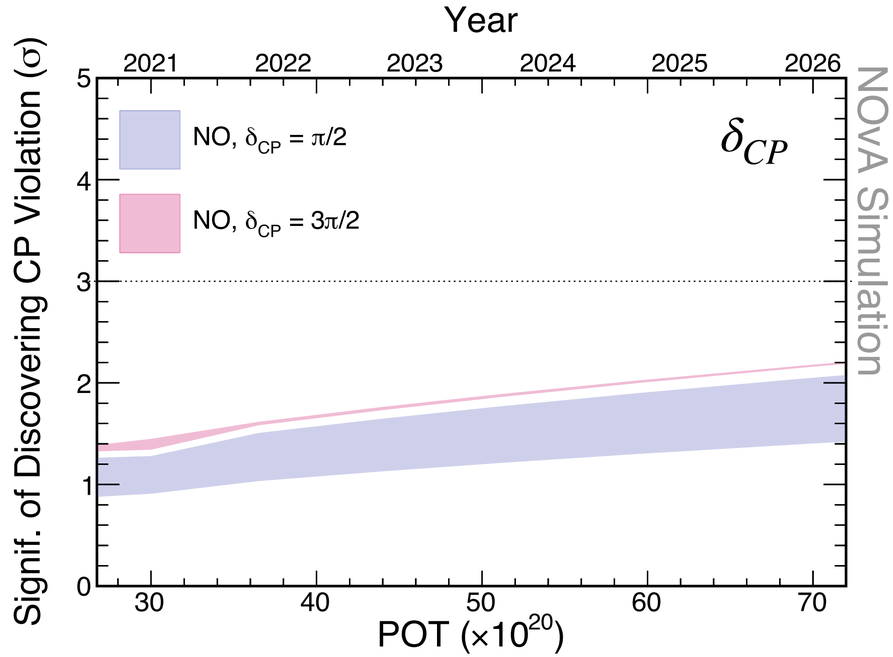
- ✳ potential 3-4σ sensitivity to hierarchy with favorable parameters;
- ✳ possible 2σ sensitivity to CP violation.

Note: sensitivity depends strongly on the true values in nature.

Expected improvements for upcoming analyses:

- ✳ accelerator → $\nu/\bar{\nu}$ beam intensity;
- ✳ test beam → improved det. response model.





JINR contribution to NOvA

Physics

- Three-flavour oscillation analysis (3 people),
- supernova neutrino trigger and analysis development (1 person),
- magnetic monopole search (1 person),
- high-energy muon spectra (1 person),
- east-west asymmetry in muon spectra (1 person),
- theory of neutrino interactions (3 people).

Detector related

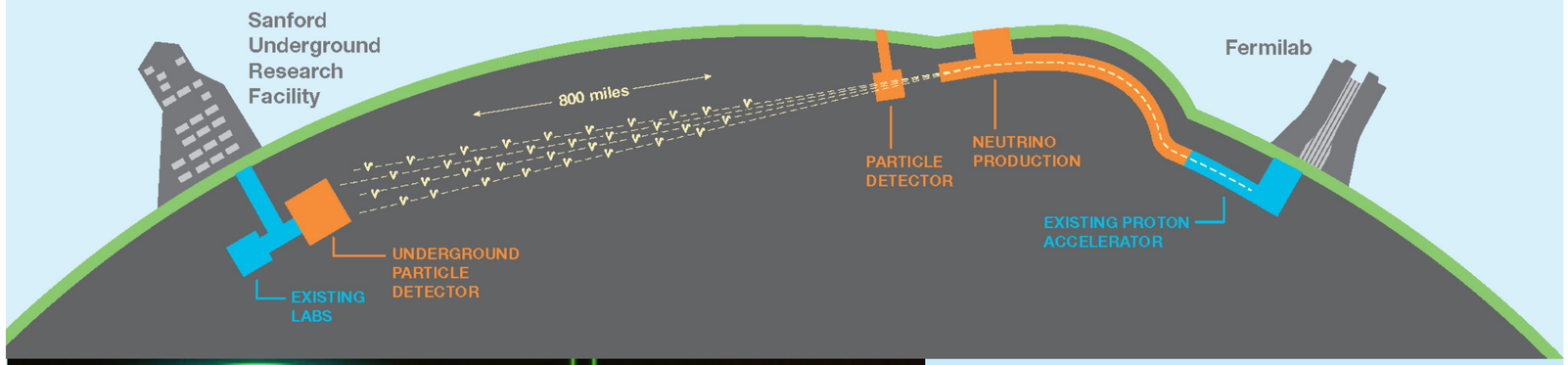
- Test bench for measurement of NOvA scintillator properties (3 people),
- test bench with detector electronics (2 people).

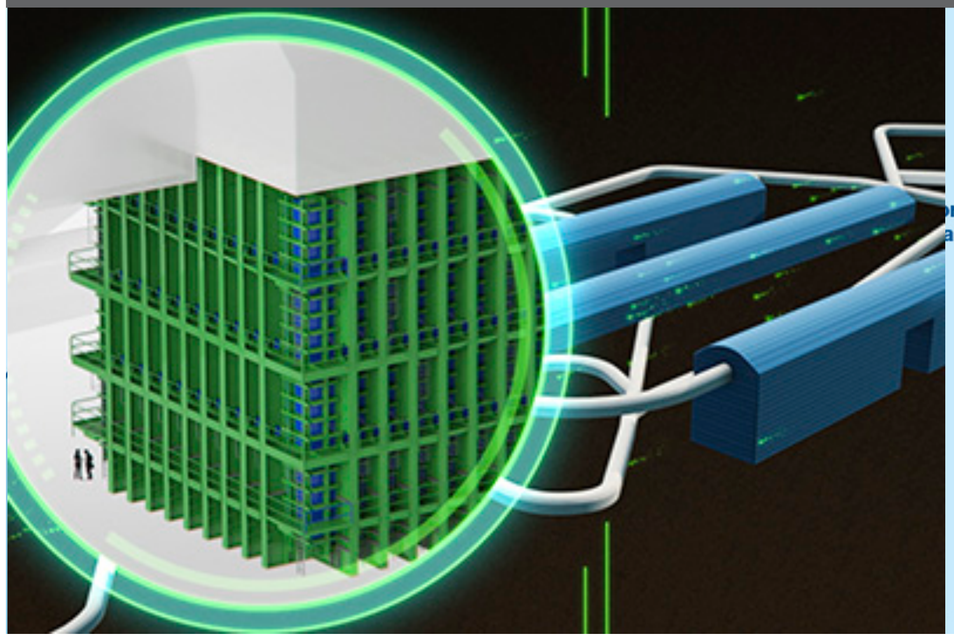
JINR infrastructure

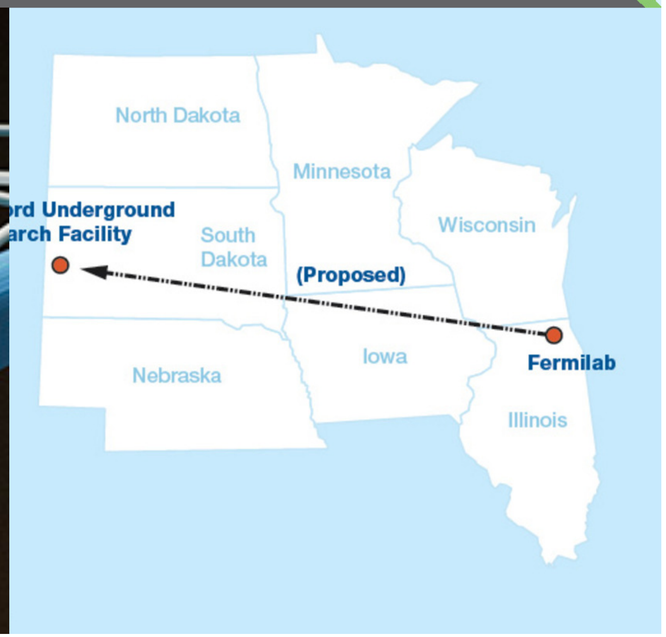
- Computing: 1k CPU and 0.09Pb storage (group needs + experiment production jobs).
- Remote Operation Center (ROC Dubna) for experiment running and taking shifts from JINR.

The DUNE Experiment

JINR joined DUNE in 2020*







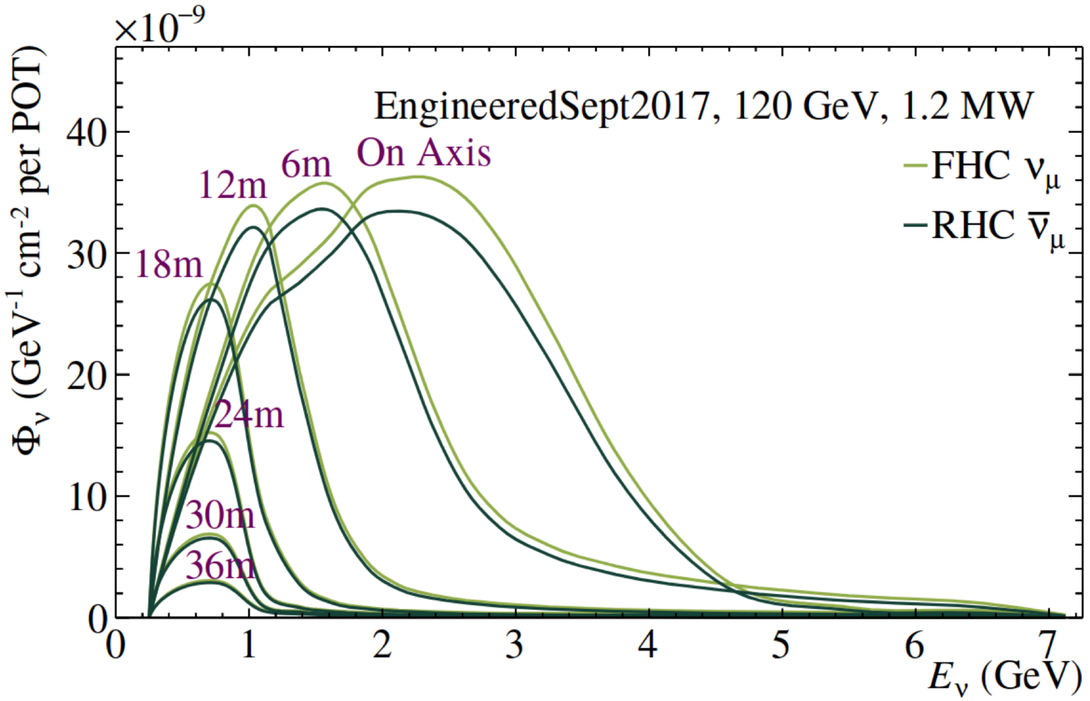
- 1400 collaborators from ~200 institutions and over 30 countries.

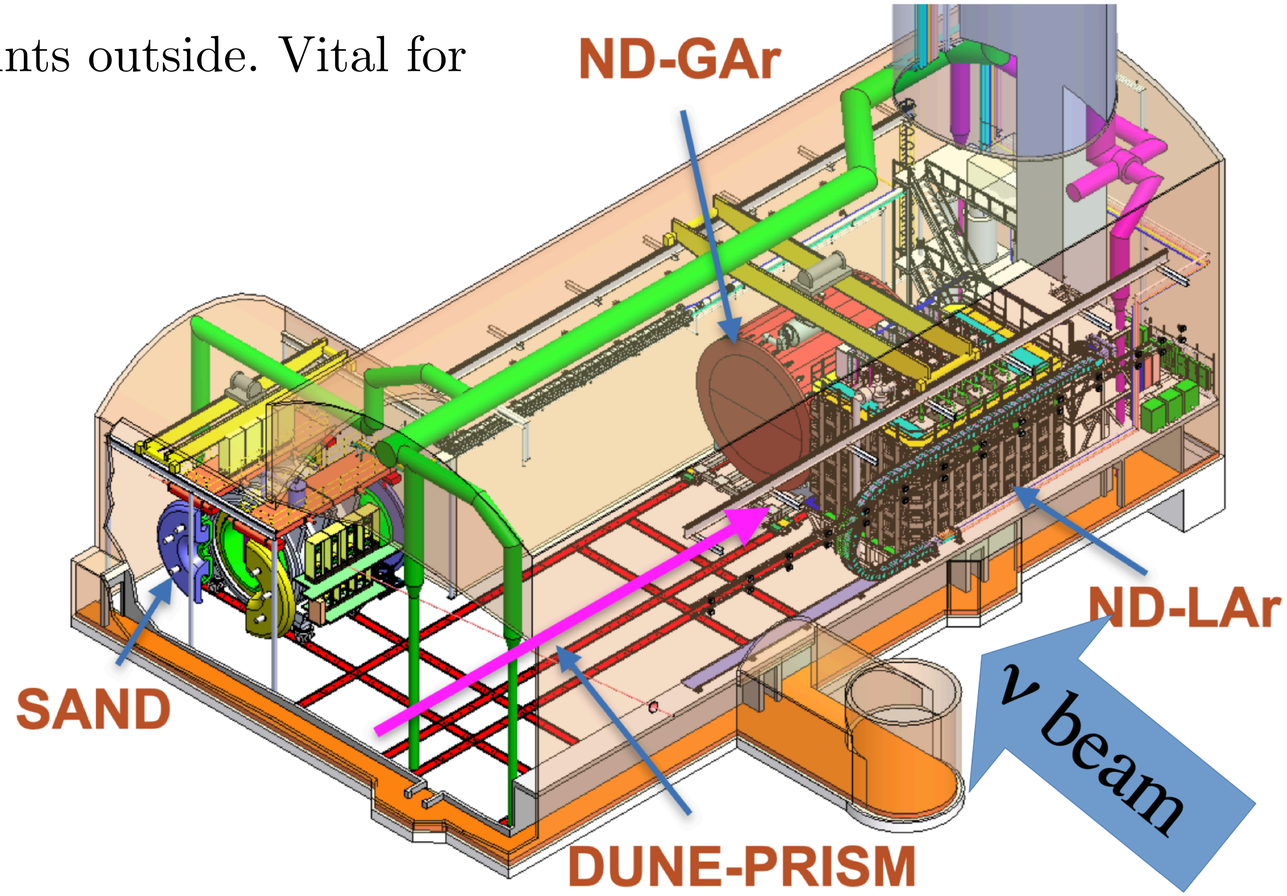
- DUNE will start ”in late 2020s” (this is official statement).
- Baseline 1300 km,
- δ_{CP} sensitivity, MO and all PMNS parameters.

- On-axis experiment;
- E at peak ~2.5 GeV;
- 70 kt FD LArTPC with single/dual phase under consideration;
- Start with 1.2 MW proton beam at 60-120 GeV (10^{20} POT/ year),
- up to 2.4 MW beam power by ~2035.

Near Detector complex

- ND complex with three detectors to scan the beam in the best possible way:
  - NDLAr
  - NDGAr (TMS at the beginning)
  - SAND
- Spend half of year on axis and half at several points outside. Vital for systematics control (DUNE-Prism).





JINR contribution to DUNE

Detector related

✳ NDLAr - full responsibility for light collection module development and production (12 people).
✳ SAND - straw-tube R&D and organization of production for STT tracker (13 people).

Physics

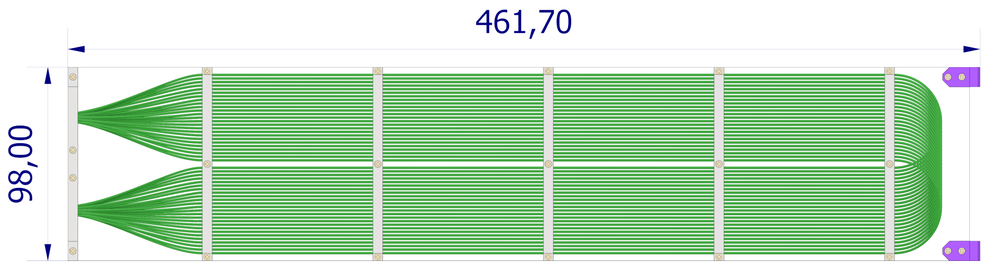
✳ Reconstruction in SAND, resonance and strange particles, beam monitoring (2 people).
✳ Physics with 2x2 prototype: cross sections, charged particle multiplicity etc (2 people)
✳ Oscillation physics, DUNE-PRISM (2 people)
✳ Transfer of NOvA exotics analyses (2 people)

Computing

✳ 1k CPU (shared w/ NOvA), 0.7Pb storage + 0.5k CPU and 0.8Pb storage in the next three years

JINR CONTRIBUTION: NDLAr

JINR responsibility is complete light readout system (modules, Front-End electronics (preamplifiers), ADC, power supply system, signal/power lines, DAQ and Slow Control)

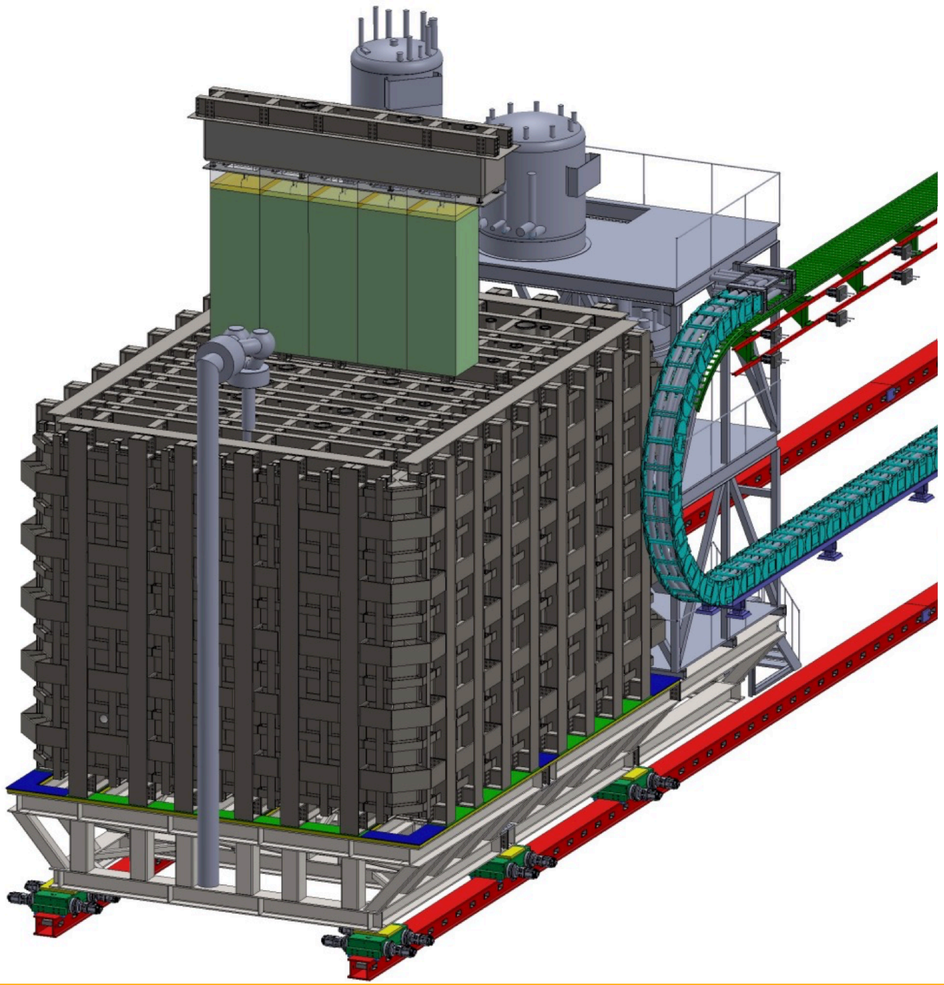


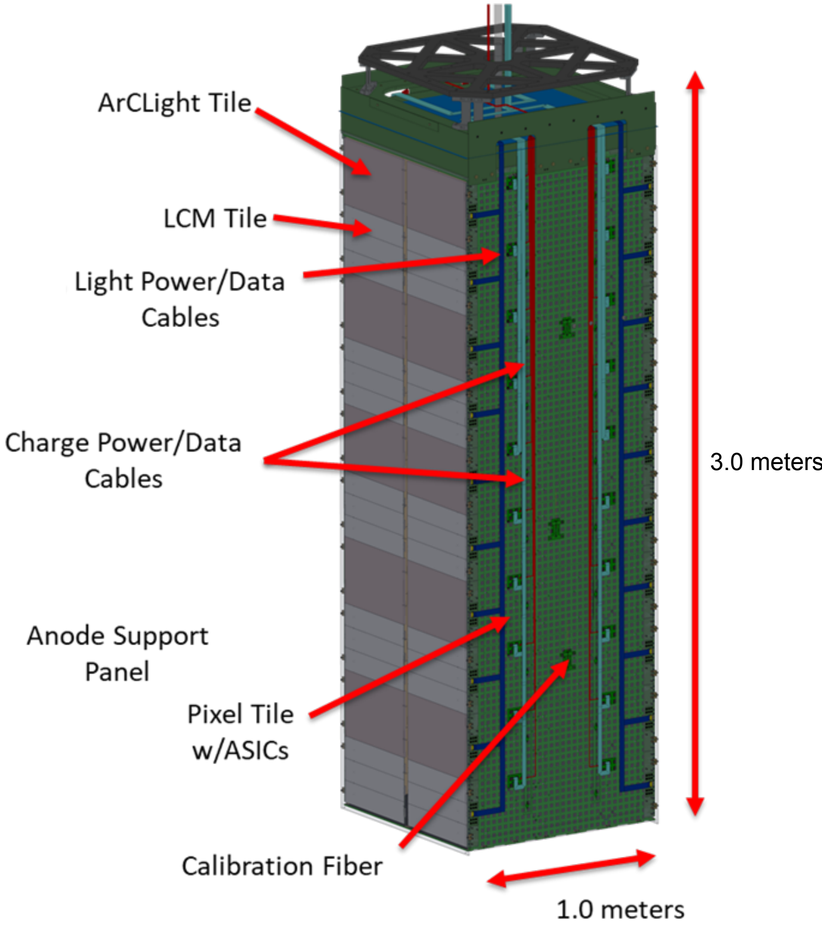
Tasks for this system:

- Provide t0-trigger for track correction
- Resolve pile-ups and associate tracks in time
- Assign detached energy events (~ns)

Prototypes:

- 2x2 at Fermilab with ν beam (2023-2024),
- full scale module (2024-2025).



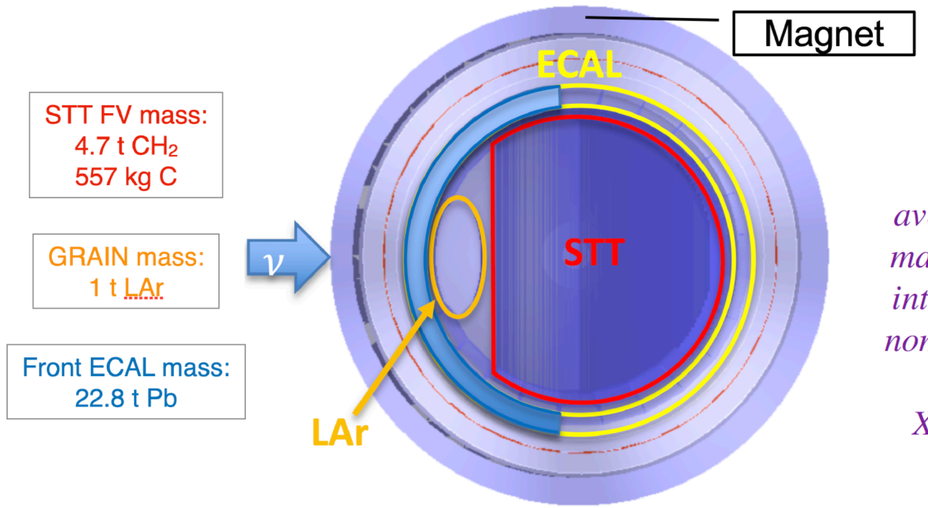


JINR CONTRIBUTION: SAND

The primary goals of SAND are the following:

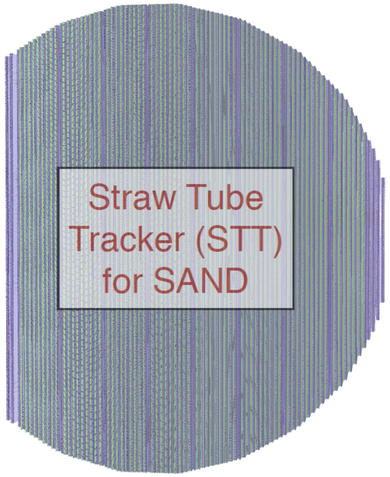
- ✳ continuous monitoring of the event rates, beam profiles and spectra over time;
- ✳ precision in-situ flux measurements of all neutrino flavors initially present in the beam;
- ✳ constraining systematics from nuclear effects and related smearing

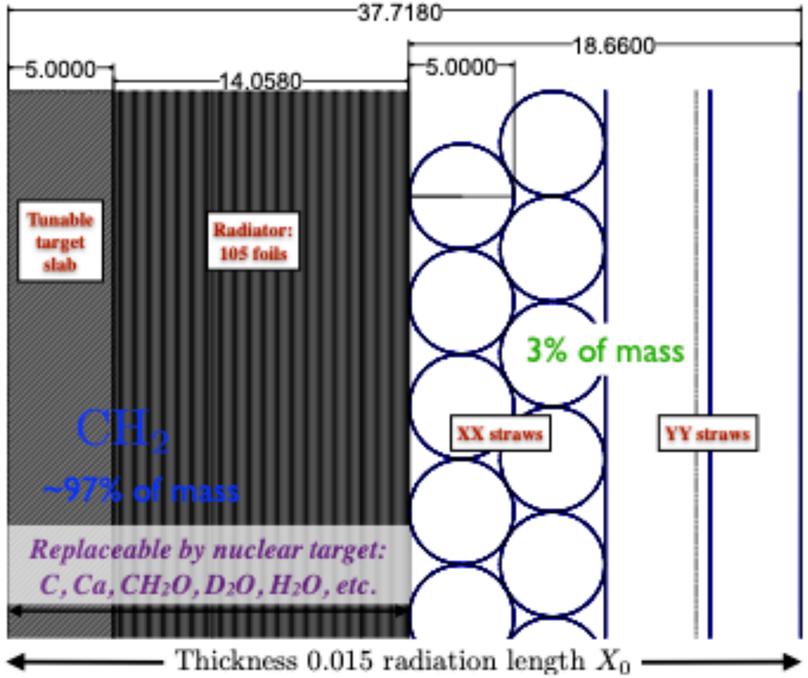
Due to detector construction a lot of particle physics can be done (spin physics, particle multiplicity and production yields, neutrino interaction cross-sections on different targets that can be placed inside the detector, Weinberg angle, quasi-elastic and resonance interactions etc).



84 modules
~220,000 straws

average straw length 3.2 m
maximal straw length 3.8 m
internal gas volume ~14 m³
nominal gas pressure ~2 bar
Gas mixtures:
Xe/CO_2 & Ar/CO_2 70/30





JINR CONTRIBUTION: SAND

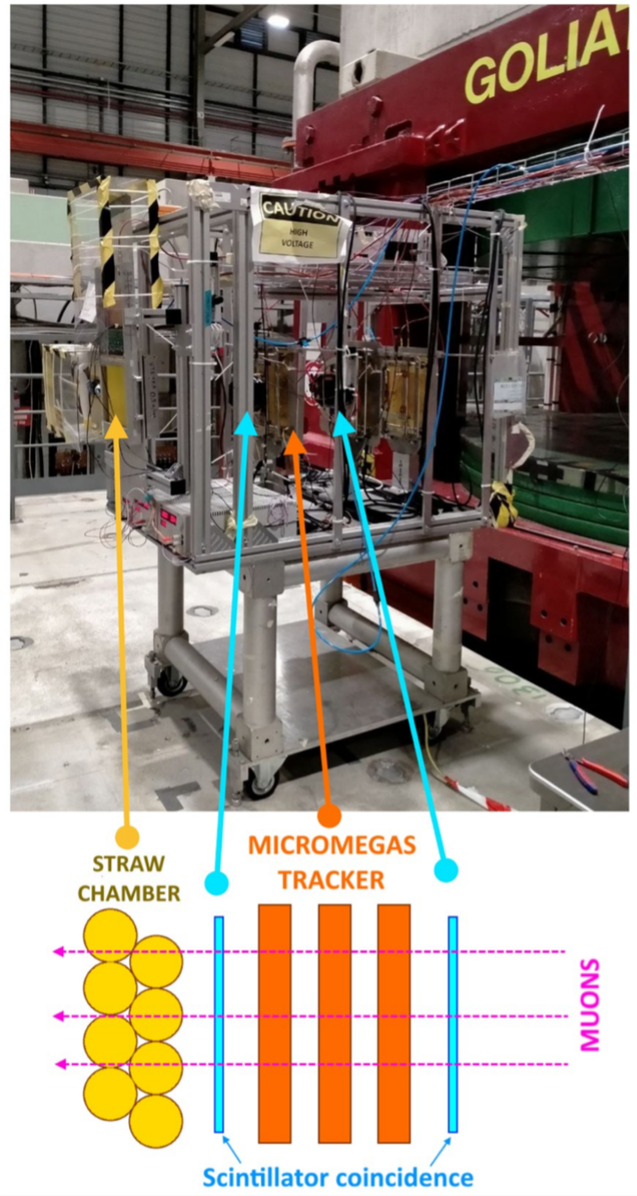
VBLHEP has already contributed with expertise and R&D results to the choice of STT in SAND

Plans:

- PDR - end of 2023, TDR of all ND complex - 2024, final design and review - 2025.
- Production start - 2026.

JINR group plans for 2023-2026:

- 2023-2026: development of FE readout electronics including ASIC revision, testbeam exposure of small 0.35 m x 0.35 m prototypes at CERN to evaluate the performance of different FE readout options/prototypes
- 2024: assembly and test of full size prototype with one dimension of 4 m
- 2024-2026: preparation of a JINR straw production center for the STT fabrication.



Project details: personnel

Theme: 1099
Project NOvA opened in 2014
Changed to NOvA/DUNE in 2020

✳ DLNP (32):
A.Olshevsky, N.Anfimov, O.Samoylov, A.Chukanov, V.Tchalyshev, A.Bolshakova, L.Kolupaeva, A.Antoshkin, O.Klimov, O.Petrova, A.Rybnikov, A.Selyunin, V.Sharov, A.Sheshukov, D. Shkirmanov, S.Vasina, V.Gromov, S.Sokolov, V.Kozhukalov, K.Kuznetsova, D.Fedoseev, A.Chetverikov, A.Sotnikov, A.Kalitkina, A.Morozova, Yu.Ivaneev, A.Ivanova, A.Stepanova, P.Lensky, A.Kolesnikov, A.Paulau, N.Shirokov

✳ VBLHEP (11):
T.Enik, S.Movchan, G.Kekelidze, D.Baygarashev, K.Salamatin, Y.Mukhamedzhanov, Yu.Kovalev, E.Vasilieva, N.Azorsky, V.Bautin, I.Kambar

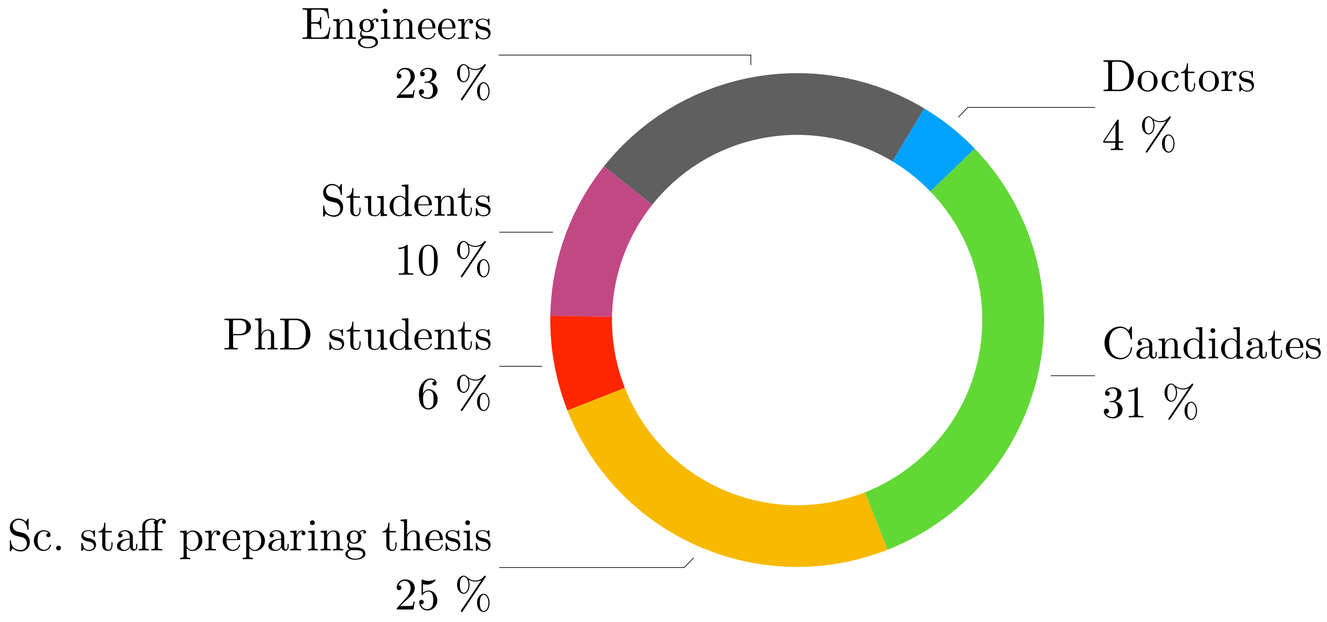
✳ BLTP:
I.Kakorin, K.Kuzmin, V.Matveev, V.Naumov

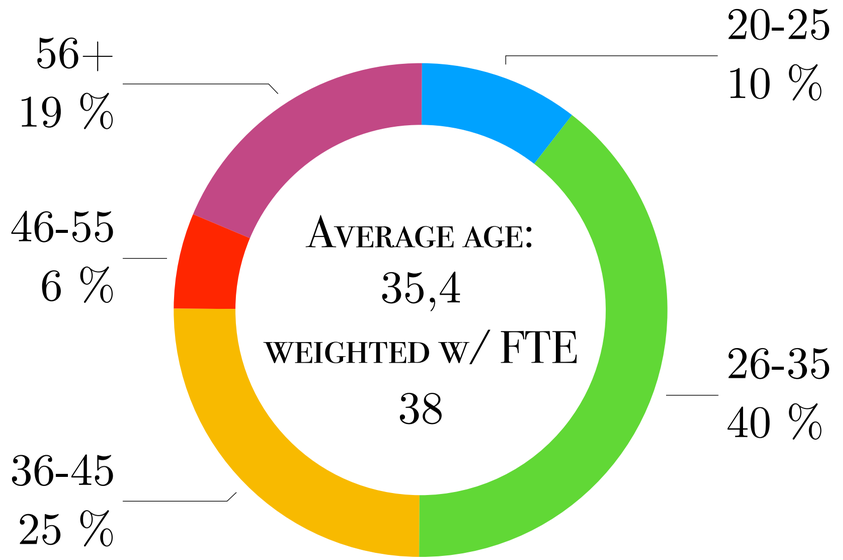
✳ MLIT:
N. Balashov

In total: 48 people with FTE=27.0

Project details: personnel, statistics

- 48 people from DLNP, VBLHEP, BLTP, MLIT with total FTE = 27.0 (0.56 FTE per group member)
- 4 management positions in NOvA and DUNE:
  - DUNE's light readout NDLAr (L3 manager)
  - NOvA's exotics co-convener
  - NOvA's production co-convener
  - NOvA's three-flavor code review taskforce leader
- Over the last three years 8 student's diploma were defended, 3 PhD thesis.





Project details: publications, reports

Over the last three years:

- JINR group members contributed significantly to 8 collaboration papers and, in addition, published 17 papers on NOvA/DUNE topics with small author list.
- Conference presentations: 31
  - Posters: 6
  - Talks at parallel sessions: 21
  - Plenary talks: 4
- Internal collaboration talks: dozens per year from actively working group members.

Project details: resources

Names of costs, resources, sources of funding		Cost (thousands of dollars) resource requirements	Cost, distribution by year				
			1st year	2nd year	3rd year	4th year	5th year
	International cooperation (IC)	540	150 +30	150 +30	150 +30		
	Materials	350	100 +30	80+ 30	80+ 30		
	Equipment and third-party services (commissioning)	140	50+ 10	30+ 10	30+ 10		
	Commissioning work	30	10	10	10		
	Services of research organisations	70	20	30	20		
	Acquisition of software	60	20	20	20		
	Design/construction	15	5	5	5		
	Service costs (*planned in case of direct project affiliation)*	15	5	5	5		
• • •							
Sources of funding	**Budgetary resources**	JINR budget *(budget items)*	1220	430	400	390		

Project details: SWOT analysis

	Helpful	Harmful
Internal	**STRENGTHS** ▸ Already fully operational NOvA experiment ▸ Approved NOvA running until 2026 and changeover to DUNE ▸ Tested and confirmed DUNE ND-LAr modules approach (approved at PDR level) ▸ JINR responsibility for two major subsystems in DUNE ND (Light detection, Straw-tracker) ▸ Rich non-oscillation program	**WEAKNESSES** ▸ Systematic error sources depending on unknown cross-sections and detector features ▸ Late DUNE start >2031 ▸ Restrictions for Russian fellows to enter DOE laboratories ▸ Export/Import restrictions in the Russian Federation.
External	**OPPORTUNITIES** ▸ Supernova burst, new physics existence ▸ Systematic errors reduction due to new measurements or theory improvement ▸ Development of new methods and technologies ▸ World's best management standards	**THREATS** ▸ Major accident with detectors or beam hardware ▸ Unexpected change of Fermilab plans due to significant budget cuts ▸ Major changes in the world situation

Summary

✳ Neutrino physics is very exciting and rapidly developing area of high energy physics, with a good chance for fundamental discoveries. We have just entered a precision era for many directions.

✳ JINR has a long tradition and expertise of studying the wide scope of neutrino physics subjects, including oscillations.

✳ NOvA is current experiment which will take data until 2026. It is producing interesting physics with JINR very noticeable participation. Gained expertise will be used in DUNE.

✳ DUNE is a future neutrino mega-science project, next worldwide flagship that can finalize fundamental oscillation parameters measurement. The JINR involvement in detector and physics of DUNE is very appreciated by the collaboration due to huge expertise in corresponding areas.