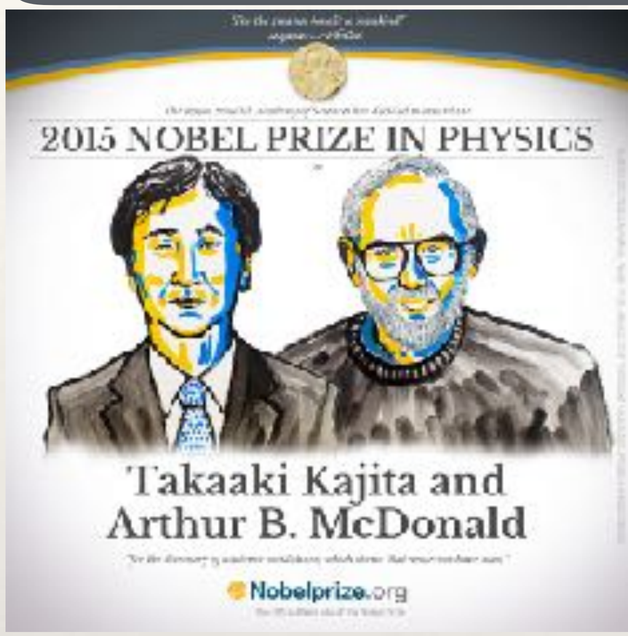
September 28, 2017

JINR cloud computing in the NOvA experiment

Oleg Samoylov
DLNP JINR

Neutrino. The big picture

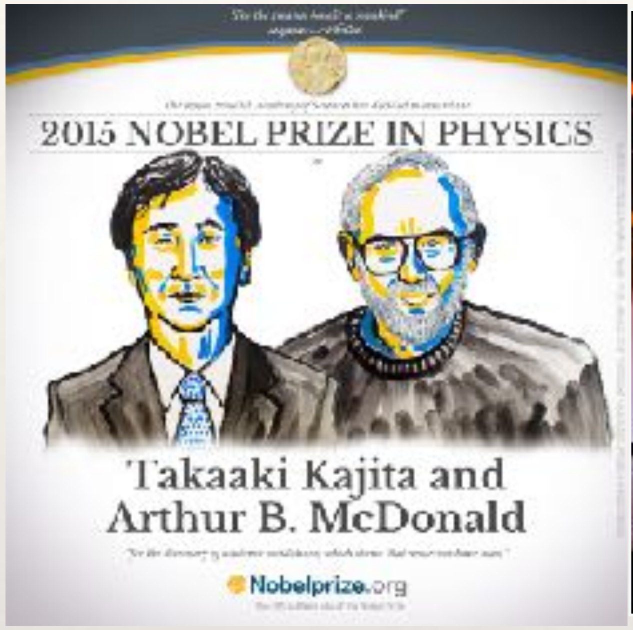
Nobel Prize 2015 and Breakthrough 2016



«The 2016 Breakthrough Prize in Fundamental Physics Awarded to 7 Leaders and 1370 Members of 5 Experiments Investigating Neutrino Oscillation: Daya Bay (China); KamLAND (Japan); K2K / T2K (Japan); Sudbury Neutrino Observatory (Canada); and Super-Kamiokande (Japan)».

Neutrino. The big picture

Nobel Prize 2015 and Breakthrough 2016



- **NOBELS**
  - **1988**, Leon Lederman, Melvin Schwartz, Jack Steinberger — for the neutrino beam method and the demonstration of the doublet structure of the leptons through the discovery of the muon neutrino
  - **1995**, Frederick Reines — for the detection of the neutrino
  - **2002**, Raymond Davis and Masatoshi Koshiba — for pioneering contributions to astrophysics, in particular for the detection of cosmic neutrinos
  - **2015**, Takaaki Kajita and Arthur B. McDonald — for the discovery of neutrino oscillations, which shows that neutrinos have mass

- **SHORT NEUTRINO HISTORY**
  - **1914**, James Chadwick discovered continuous β-spectrum
  - **1930**, Wolfgang Pauli proposed a light neutral particle of spin 1/2 emitted alongside the electron.
  - **1934**, Enrico Fermi published his theory of β-decay.
  - **1956**, Fred Reines and Clyde L. Cowan detected reactor (anti)neutrino.
  - **1957**, Bruno Pontecorvo proposed neutrino-antineutrino oscillations.
  - **1958**, Maurice Goldhaber, Lee Grodzins and Andrew Sunyar found that neutrinos are left handed.
  - **1962**, Leon Lederman, Melvin Schwartz, Jack Steinberger discovered muon nu.
  - **1962**, Ziro Maki, Masami Nakagawa and Shoichi Sakata introduce neutrino flavor mixing and flavor oscillations.
  - **1968**, Raymond Davis got first radiochemical solar neutrino.
  - **1987**, Kamiokande, IMB and Baksan detectors detect burst of antineutrinos from SN1987A in Large Magellanic Cloud (51.474 kpc).
  - **1989**, LEP experiments determine only 3 light neutrinos (via Z-decay).
  - **1998**, Super-Kamiokande found muon neutrino oscillations in atmospheric neutrinos.
  - **2000**, DONUT observed ν_τ.
  - **2001**, SNO announced observation of neutral currents from solar neutrinos.
  - **2002**, KamLAND announces detection of a deficit of electron antineutrinos from reactors at a mean distance of 175 km.
  - **2005**, KamLAND announced first detection of neutrino flux from the Earth.
  - **2010**, OPERA announced observation of the first ν_τ from ν_μ beam.
  - **2011**, Borexino presented a high precision measurement of solar neutrino (Be).
  - **2011**, T2K announces first evidence for a nonzero mixing between the 1st and 3rd neutrino generations.
  - **2012**, Daya Bay announced a precision results on measuring θ13 with significance 5.2σ.

Neutrino oscillations

$\theta_{23} \sim 45^\circ$ $\qquad$ $\theta_{13} \sim 8.5^\circ$ $\qquad$ $\theta_{12} \sim 30^\circ$

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

$|\Delta m^2_{32}| = |m^2_3 - m^2_2|$
$\simeq 2.5 \times 10^{-3}\ \mathrm{eV}^2$
$\nu_\mu \to \nu_\mu$
$\nu_\mu \to \nu_\tau$

atmospheric and
long baseline

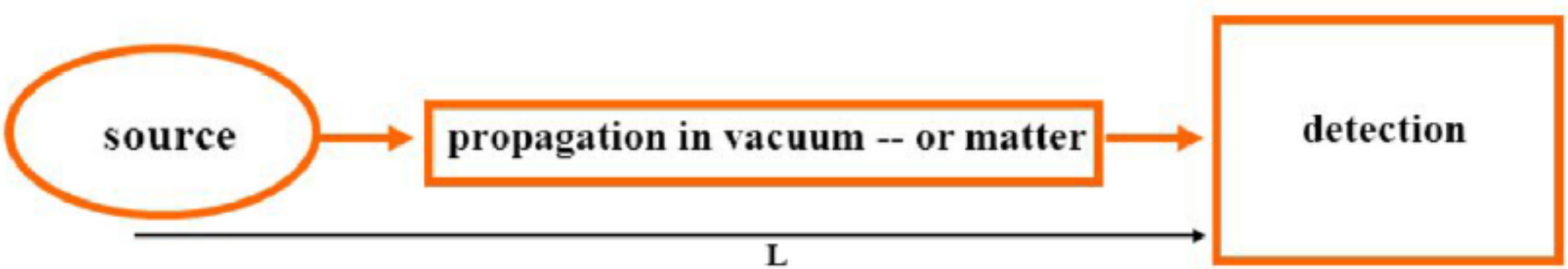
$\Delta m^2_{31} \simeq \Delta m^2_{32}$
$\nu_e \to \nu_e$
$\nu_\mu \to \nu_e$

reactor and
long baseline

$\Delta m^2_{21} = |m^2_2 - m^2_1|$
$\simeq 7.5 \times 10^{-5}\ \mathrm{eV}^2$
$\nu_e \to \nu_e$
$\nu_e \to \nu_\mu, \nu_\tau$

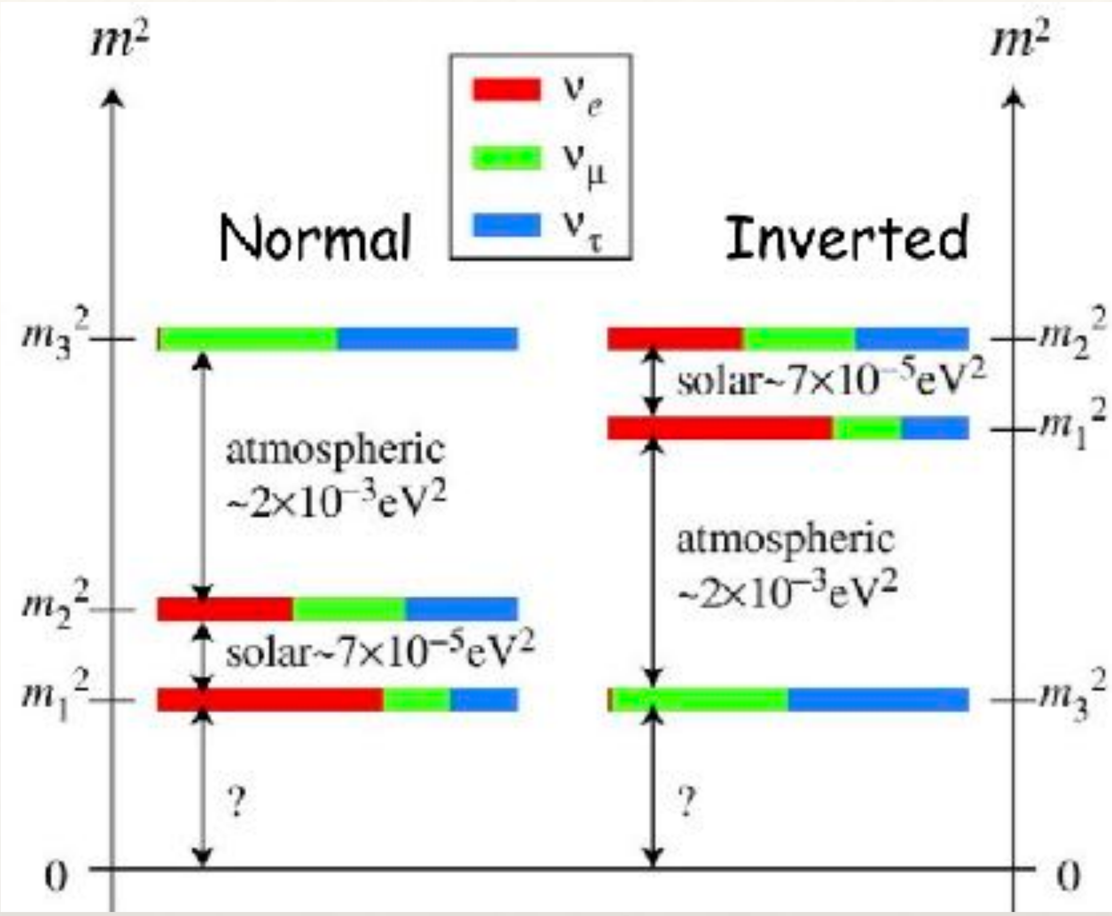
solar and
reactor

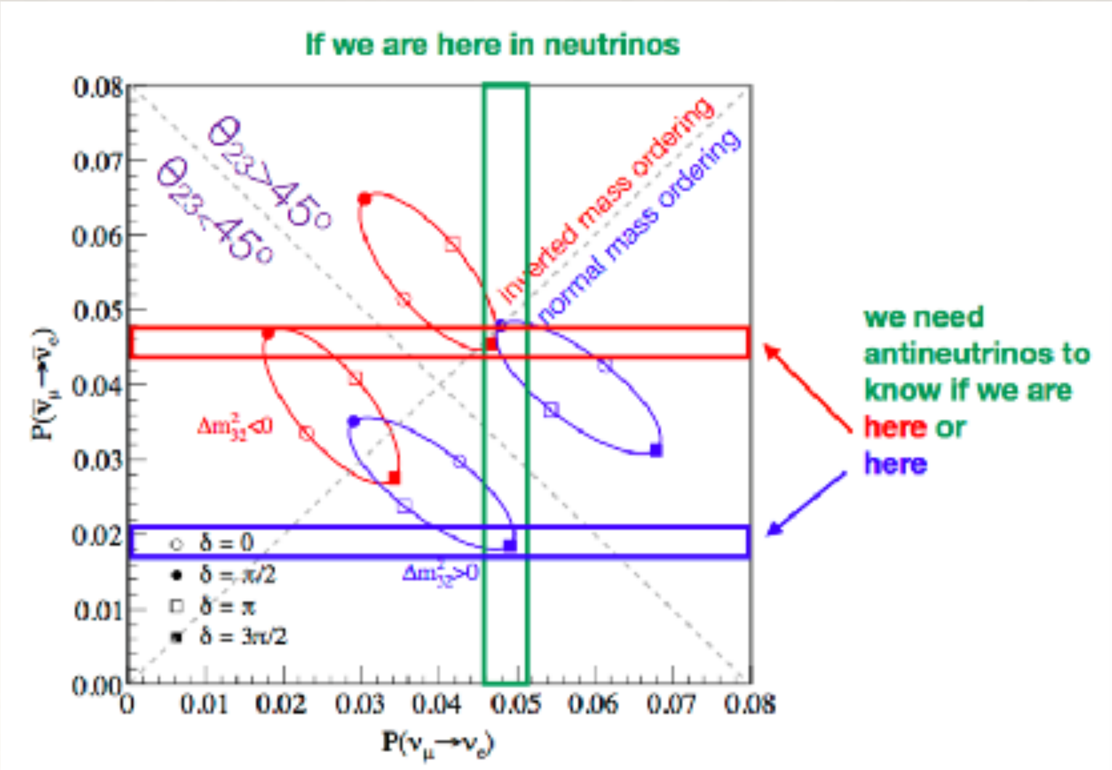
Oscillation parameters: $\theta_{12}, \theta_{23}, \theta_{13}$, CP phase δ, $|\Delta m^2_{13}|$, Δm^2_{12}



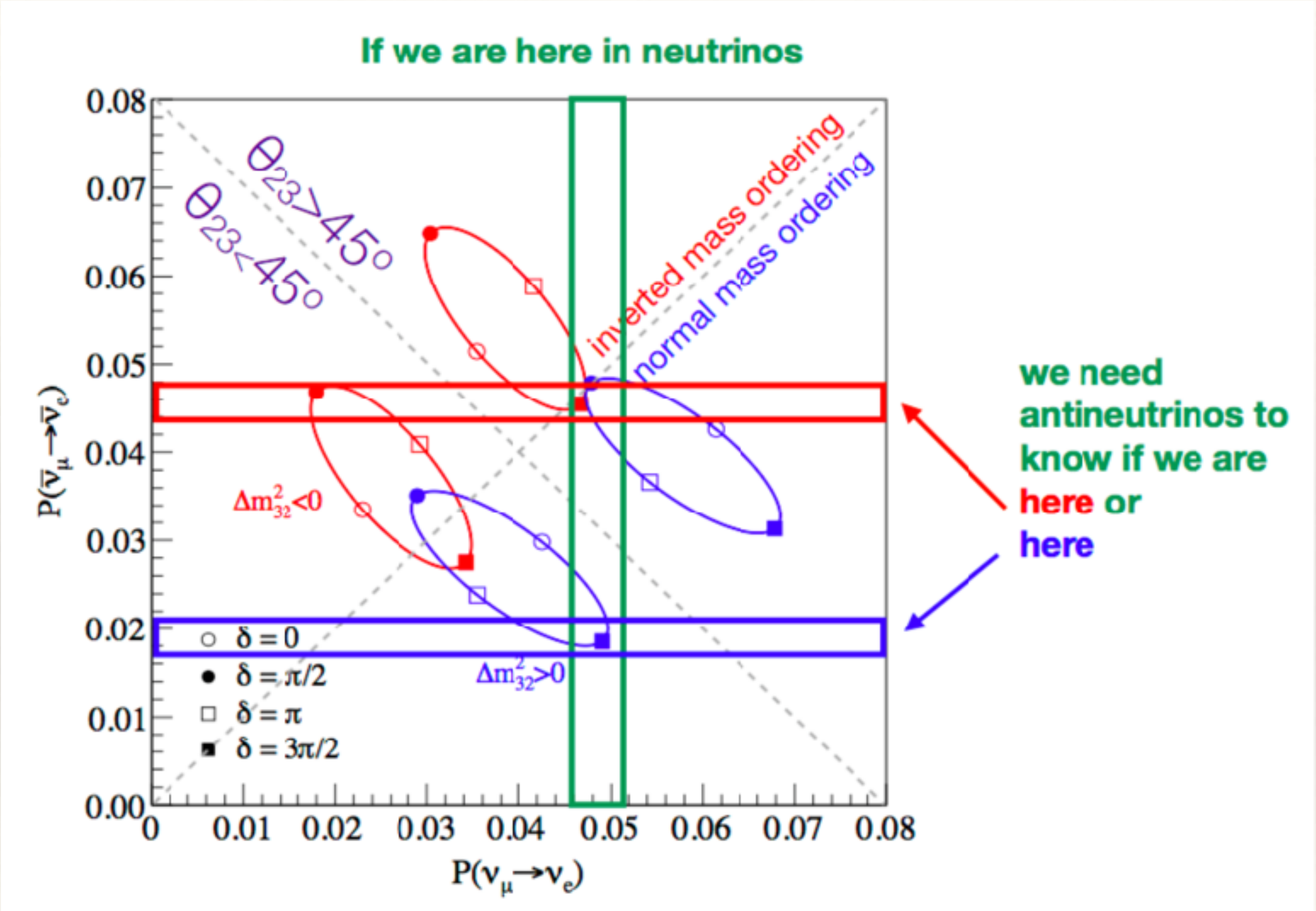
Neutrino. The big picture and NOvA

- Neutrino mass hierarchy (**NOvA** is about 2020, JUNO/ DUNE >2025, PINGU)
- CP violating phase (T2K and **NOvA** 2020, DUNE > 2025)
- Precise measurements of oscillation parameters (**NOvA** for θ_{23} 2020)
- Dirac or Majorana ($0\nu\beta\beta$ experiments)
- Absolute mass (KATRIN)
- Sterile neutrinos (reactor or radioactive source short baseline experiments, long baseline accelerator neutrino experiments looking for NC including **NOvA**)
- Supernova neutrinos (large volume detectors as **NOvA**, SNEWS)
- High energy cosmic neutrinos (IceCube, Baikal, KM3NET)
- Detection of the Cosmic Neutrino Background / CNB (no idea for the moment)



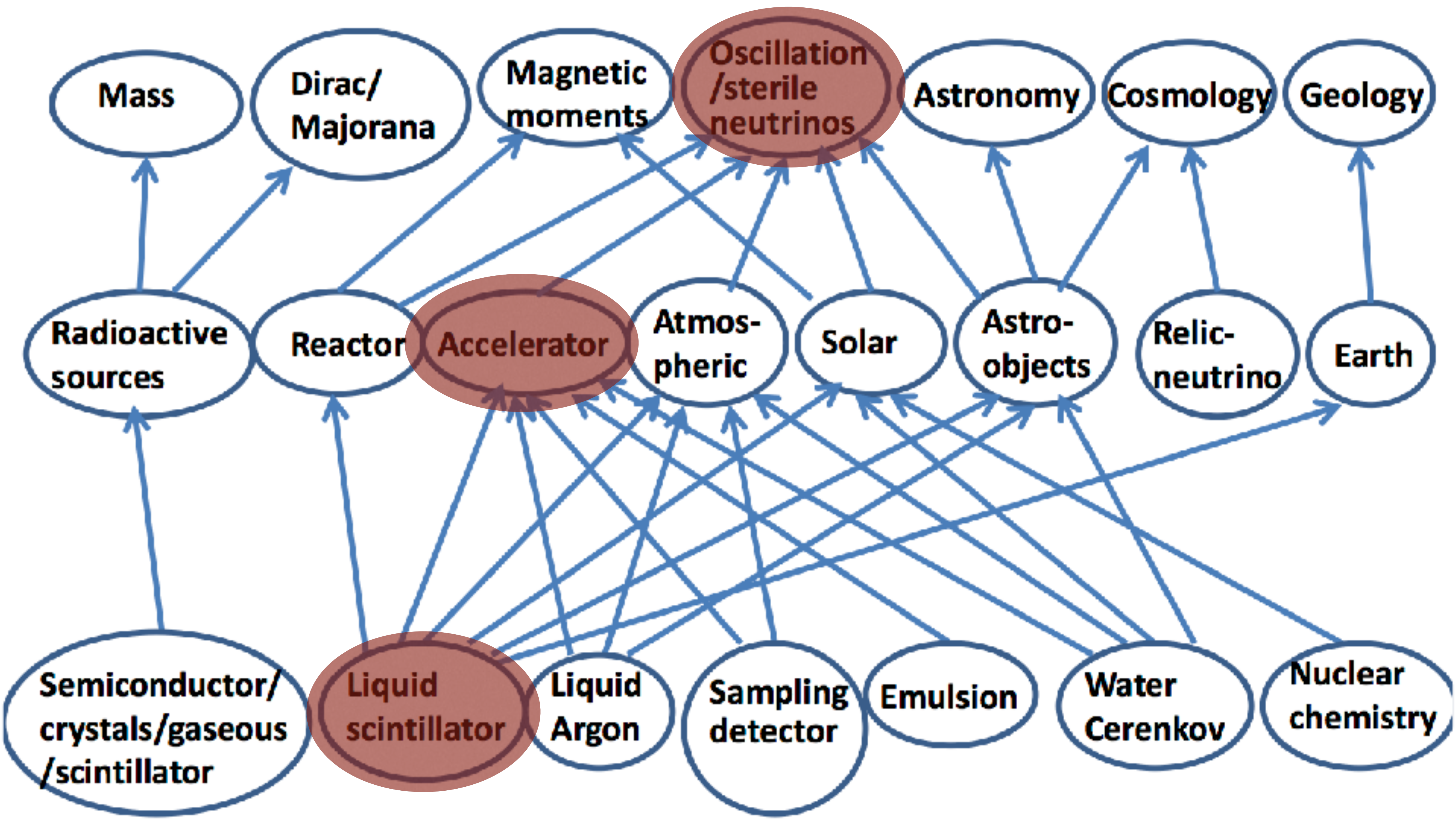


Neutrino. The big picture and NOvA



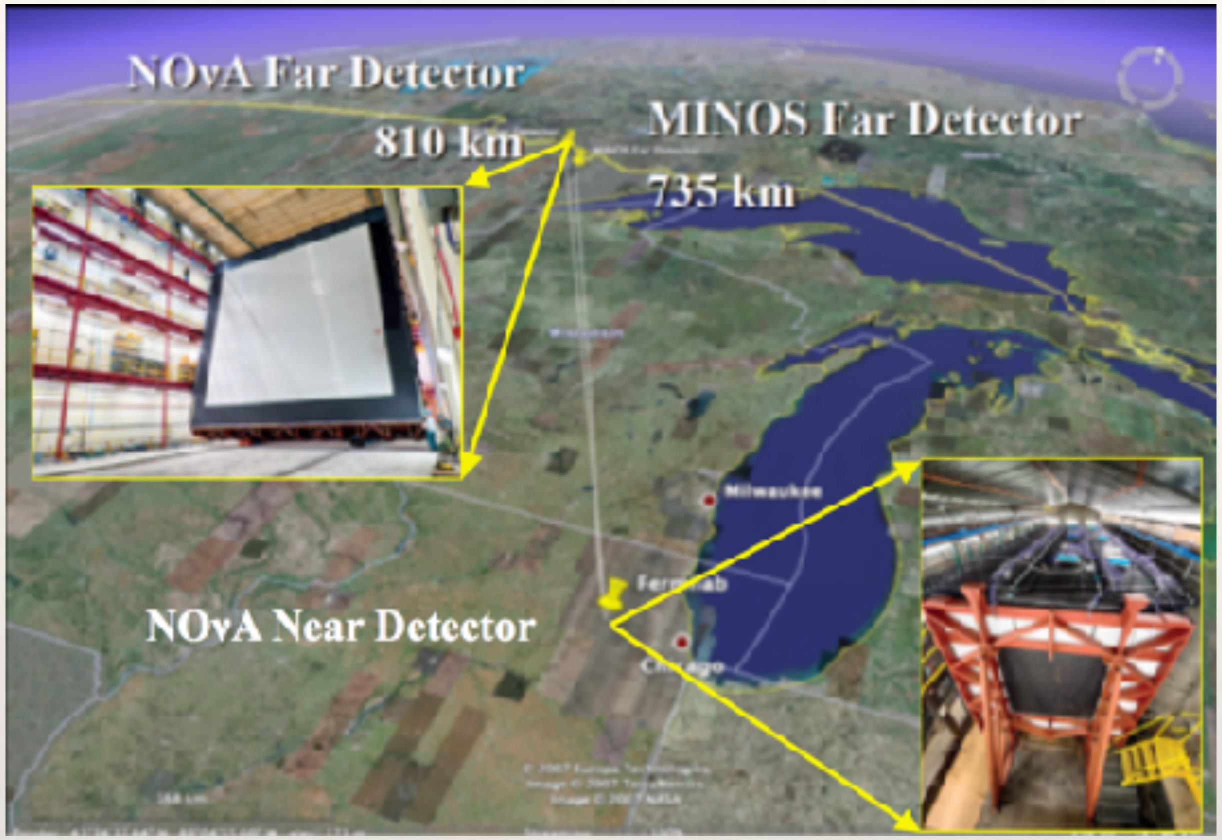
- Neutrino mass hierarchy
- CP violating phase
- Precise measurements of θ_{23}

Neutrino. The big picture and NOvA



- NOvA studies neutrino oscillation with an accelerator beam and active, segmented, highly purified liquid scintillator detectors

Detectors, Beam and Data taking

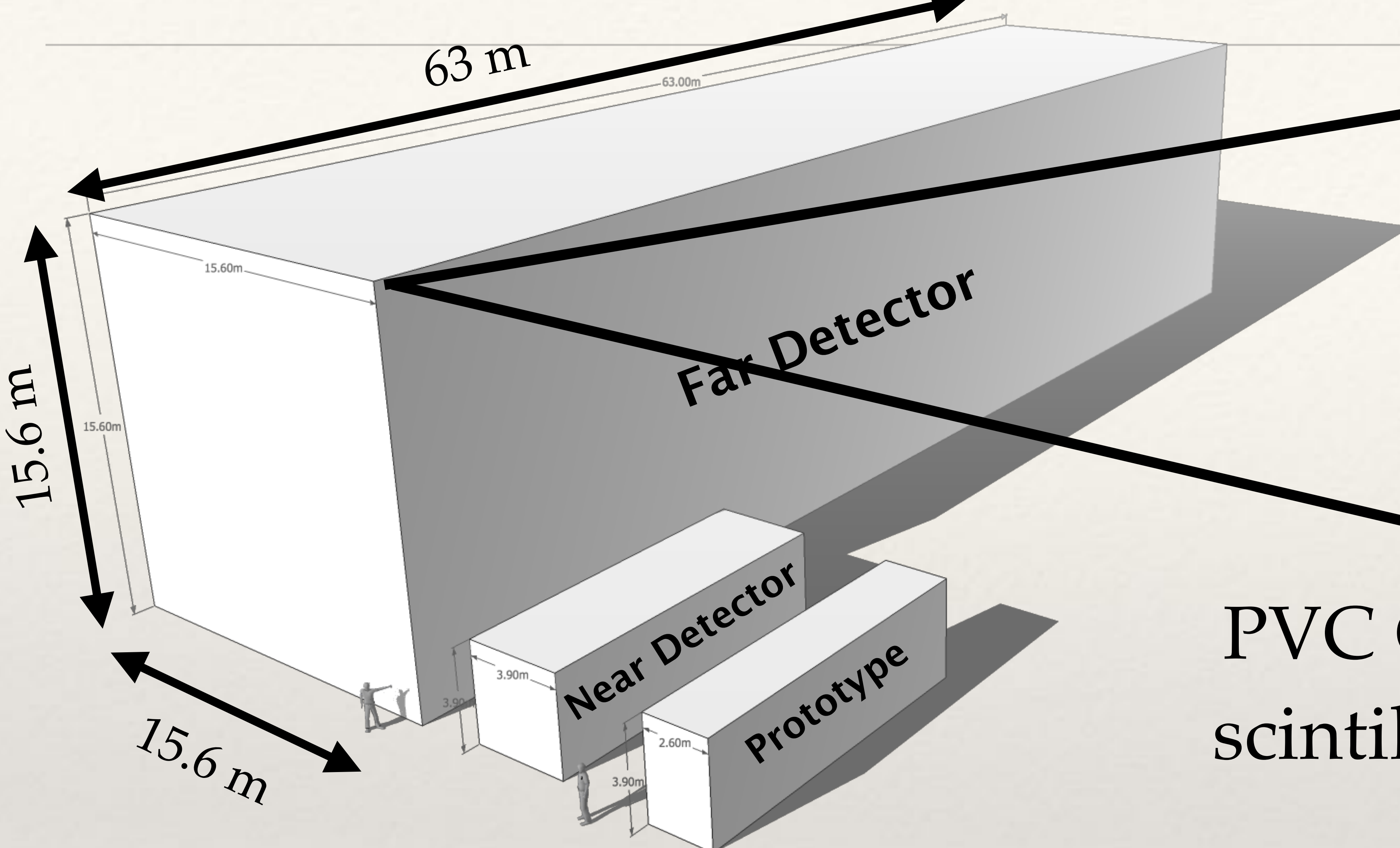


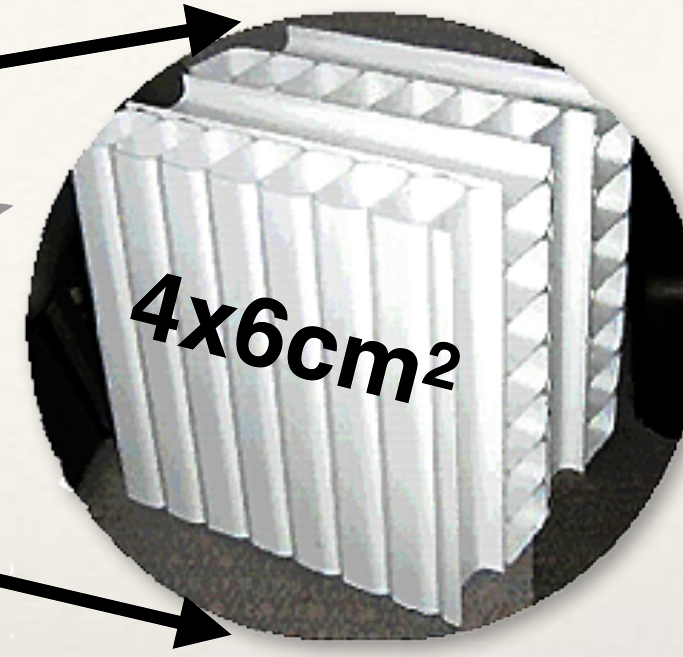
- Precision is achieved by placing a detector close to the source (Near Detector) and one at or close to the oscillation maximum (Far Detector)

$$ND(\nu_\mu) = \boxed{\Phi(E_\nu) \times \sigma(E_\nu, A)} \times \epsilon_{ND}$$
$$FD(\nu_\mu) = \boxed{\Phi(E_\nu) \times \sigma(E_\nu, A)} \times \epsilon_{FD} \times P_{osc}$$

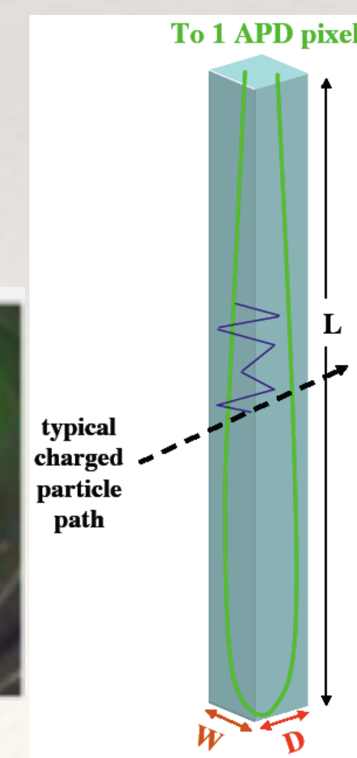
- 14 mrad off the NuMI beam axis, yields a narrow 2-GeV spectrum at the NOvA detectors
- A distance of 810 km provides covering the first oscillation maximum
- Far Detector: 14-kton, fine-grained, low-Z, highly-active tracking calorimeter (344,064 channels)
- Near Detector: 0.3-kton version of the same
- Collected up to now 9e20 POT in neutrino mode (6e20 for the current published analysis), running in anti-neutrino mode since 20 February 2017

NOvA Detectors





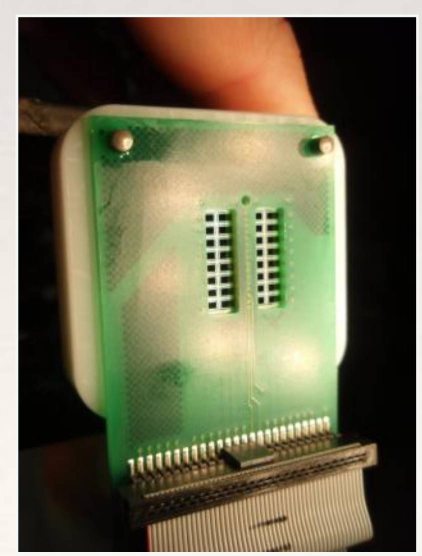
PVC Cell filled w/ liquid scintillator, w/ WLS Fiber



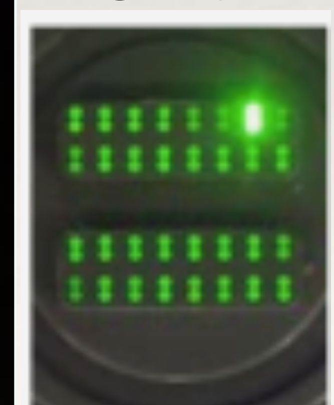
FEB / DCMs / Buffer Nodes

FEB

APD

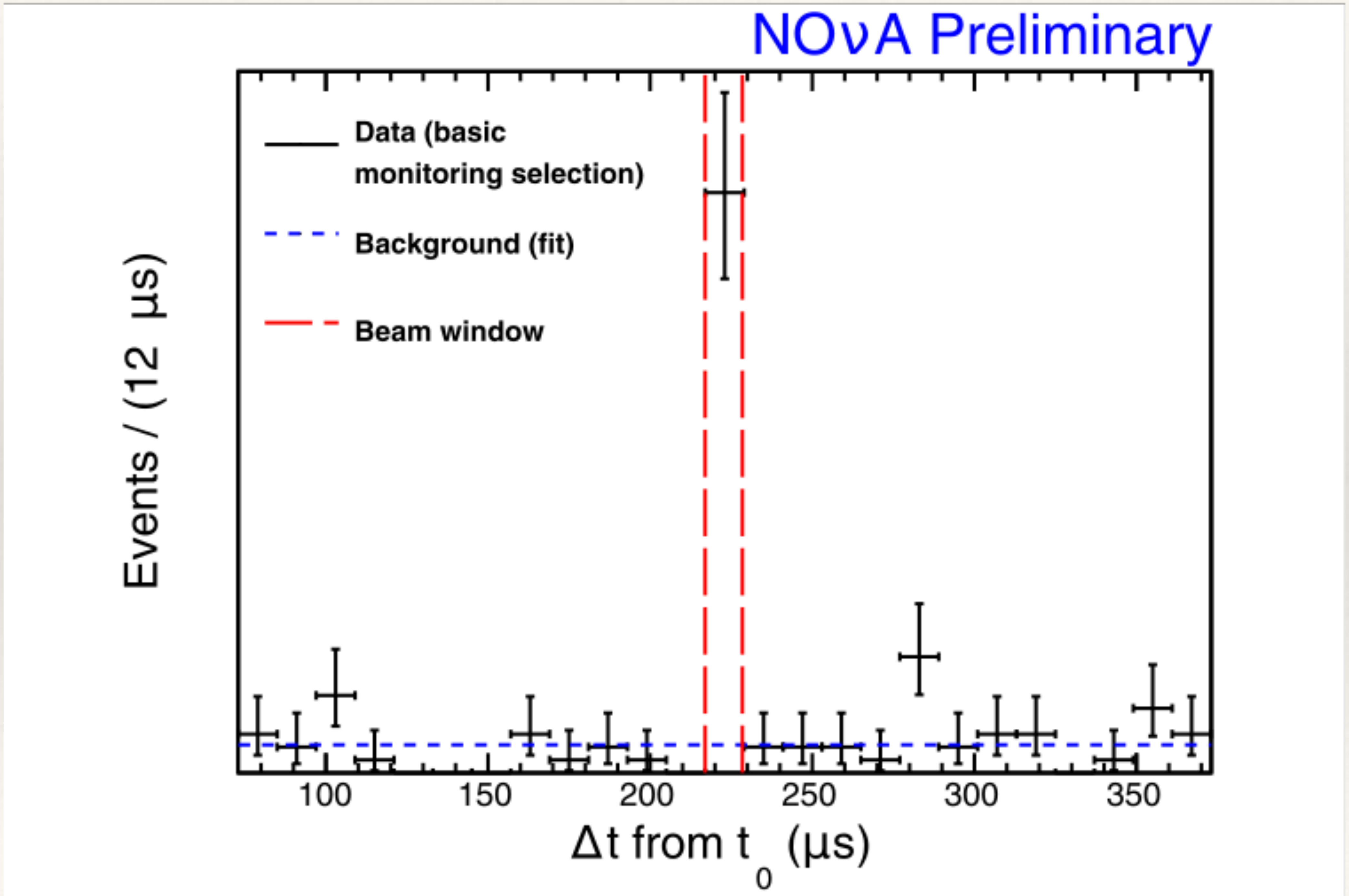


Fiber end



FD Beam Peak

- Trigger structure: 550 μs window, NuMI neutrinos arrive for 10 μs starting at 218 μs



NOvA Goals

- Within electron neutrino appearance NOvA catches mass hierarchy and CP-violation phase
- Within muon neutrino disappearance NOvA precisely measures θ_{23} octant
- Search beyond the Standard Model
  - Sterile neutrino(s)
  - Dark Matter
  - Magnetic monopoles
- Look into the Universe
  - Cosmic rays
  - Supernova neutrinos
  - Gravitational waves coincidence
- Within high intensity neutrino beam NOvA Near Detector measures neutrino cross-sections

Oscillation publications by NOvA

Constraints on Oscillation Parameters from ν_e Appearance and ν_μ Disappearance in NOvA

P. Adamson *et al.* (NOvA Collaboration)
Phys. Rev. Lett. **118**, 231801 – Published 5 June 2017

Measurement of the Neutrino Mixing Angle θ_{23} in NOvA

P. Adamson *et al.* (NOvA Collaboration)
Phys. Rev. Lett. **118**, 151802 – Published 10 April 2017

First Measurement of Electron Neutrino Appearance in NOvA

P. Adamson *et al.* (NOvA Collaboration)
Phys. Rev. Lett. **116**, 151806 – Published 13 April 2016

First measurement of muon-neutrino disappearance in NOvA

P. Adamson *et al.* (NOvA Collaboration)
Phys. Rev. D **93**, 051104(R) – Published 25 March 2016

arXiv.org > hep-ex > arXiv:1706.04592

High Energy Physics – Experiment

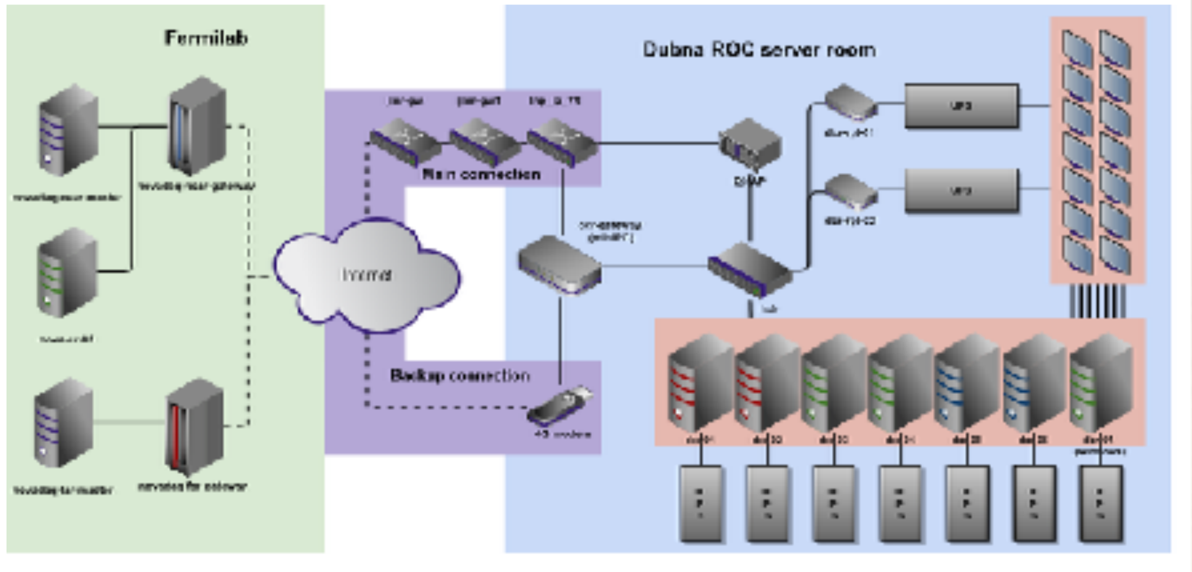
Search for active-sterile neutrino mixing using neutral-current interactions in NOvA NOvA Collaboration: *(Submitted on 14 Jun 2017)*

NOvA at JINR

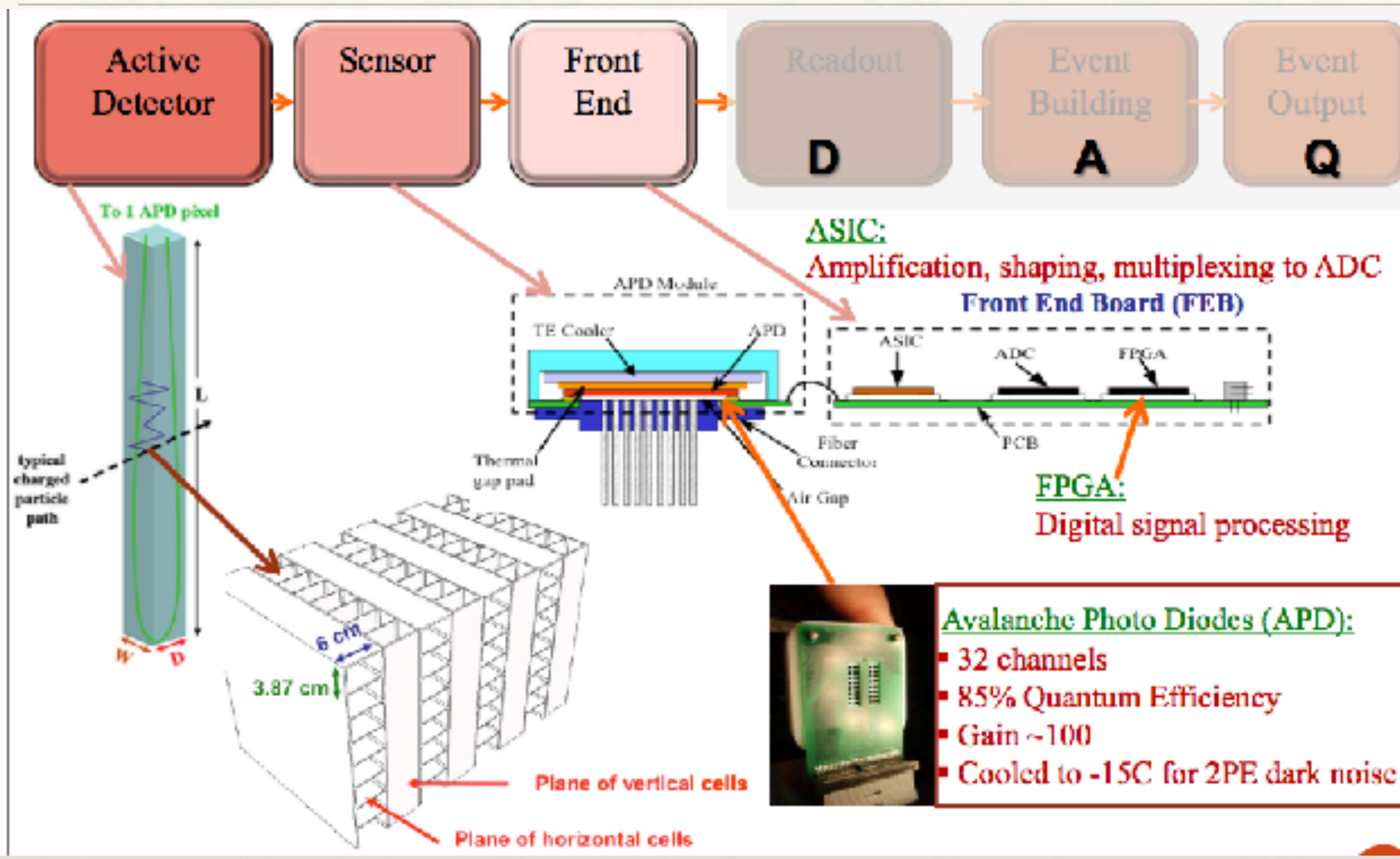
- Remote Operation Center at Dubna (ROC-Dubna)
- NOvA test Bench at JINR
- Computing Infrastructure including LIT resources
- MC Simulation and Theory effort from BLTP
- ν_e Analysis optimization
- Neutrino signal from Supernova
- Study of the Cosmic Ray (Muons)
- Search for Slow Monopole
- Near Detector Measurements

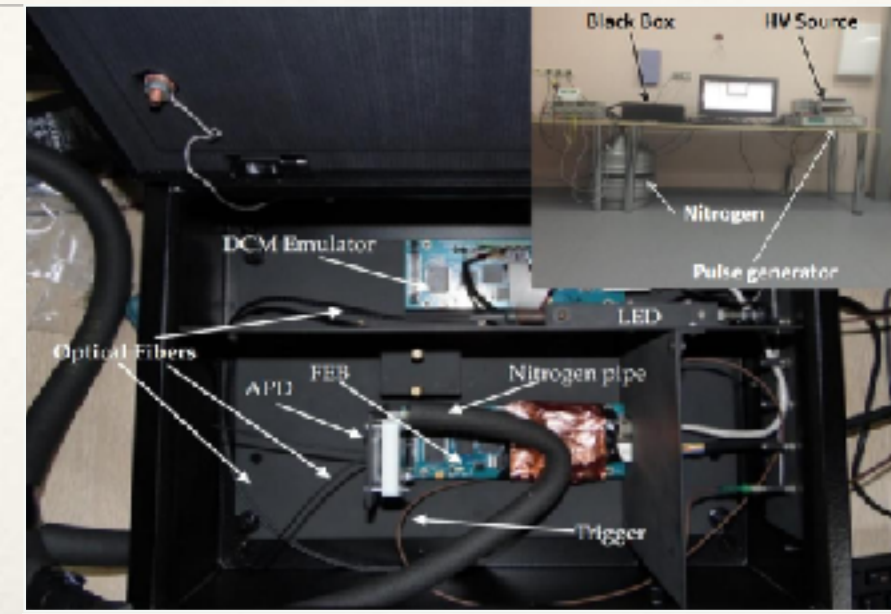
Remote Operation Center at Dubna

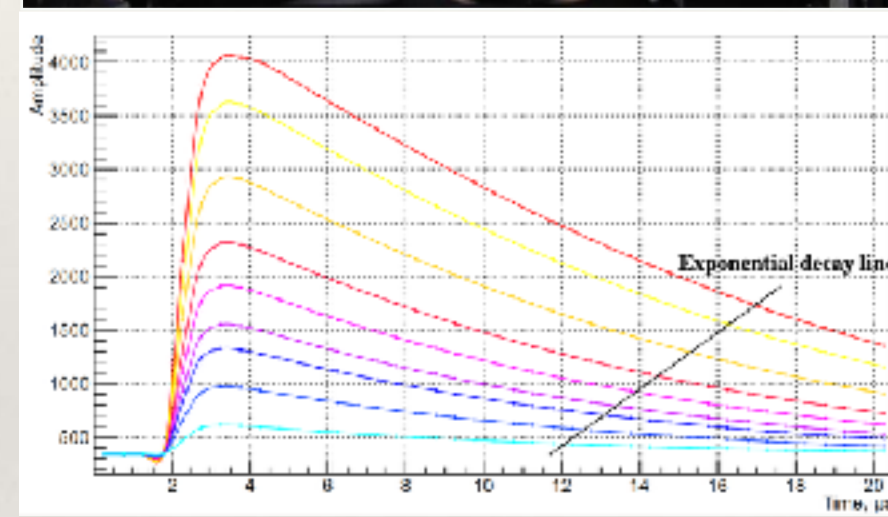
- Developed infrastructure of the ROC-Dubna allows for non-interruptible continuous work
- Includes: stable and backed up internet connection, communication tools including international land-line, kitchen, etc.
- A computing monitoring system, based on Nagios, controls ROC-Dubna equipment and notifies JINR experts in case of trouble.

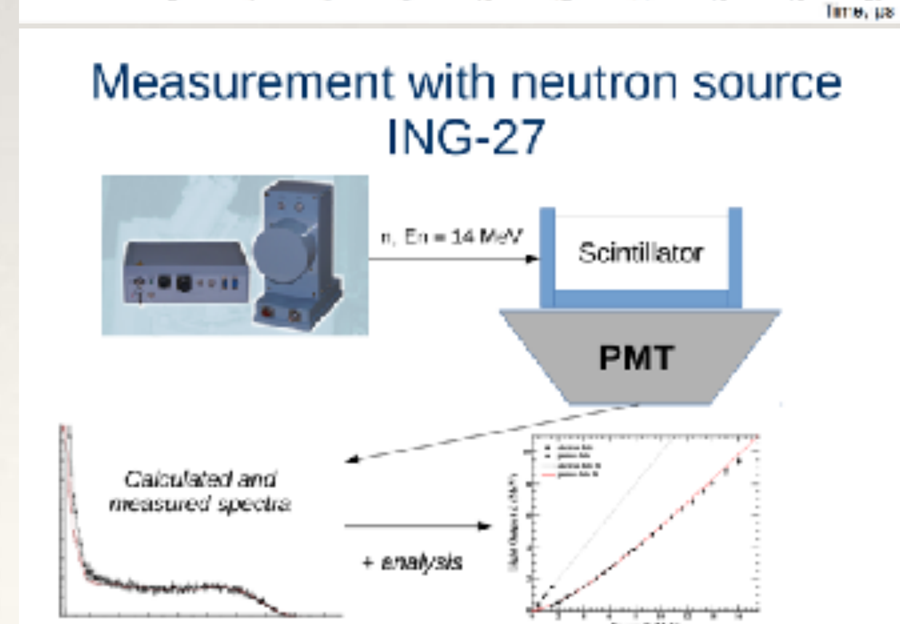


NOvA test Bench at JINR





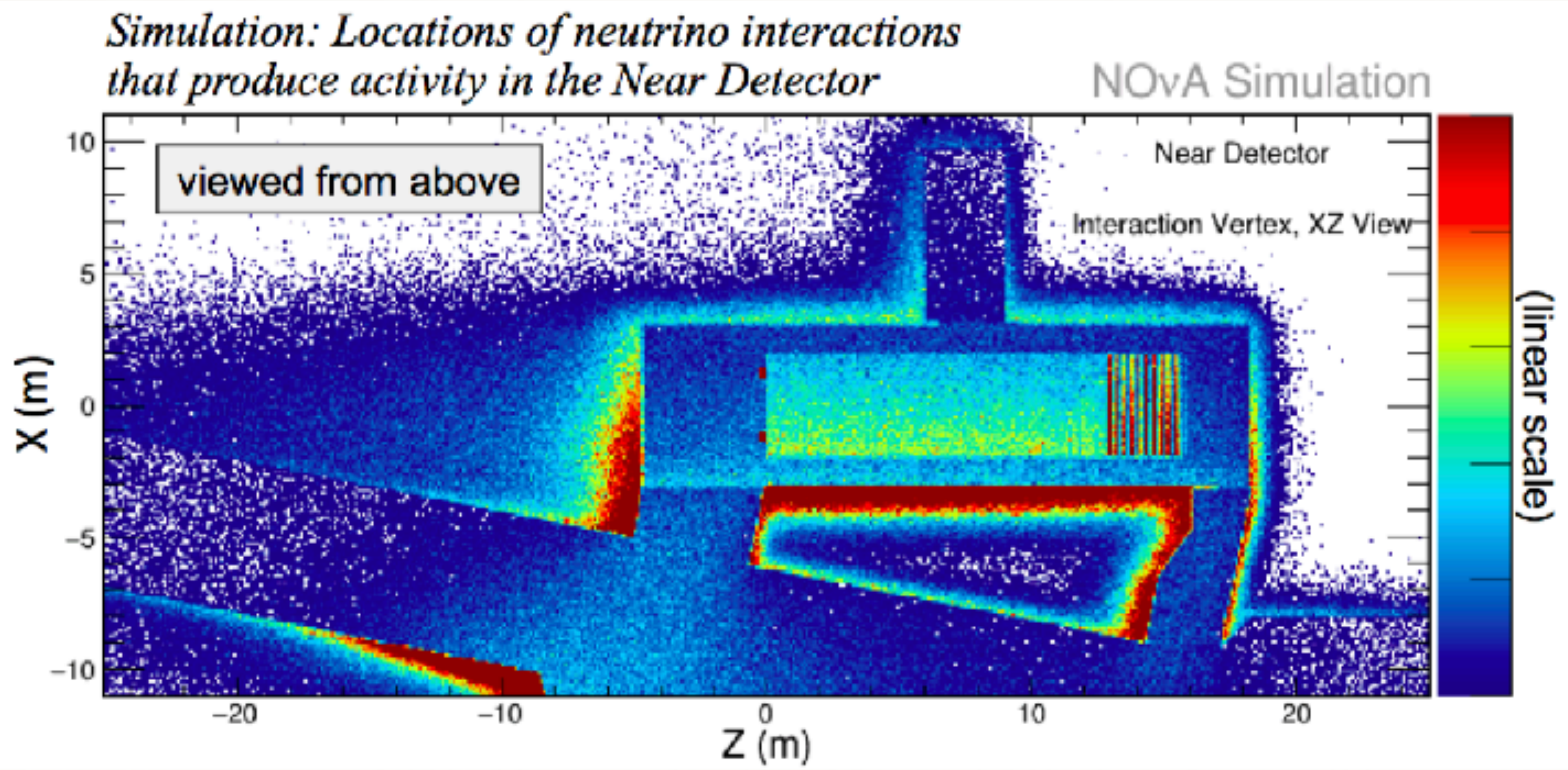




- Several important measurements were performed at the JINR NOvA electronics test bench, and more are planned.
- We performed precise measurements of signal shaping parameters for both FD/ND by a request from NOvA collaboration.
- We also study special responses from very high signals and long signals.
- We are going to make a study of the quenching factor for the NOvA scintillator.

Simulation

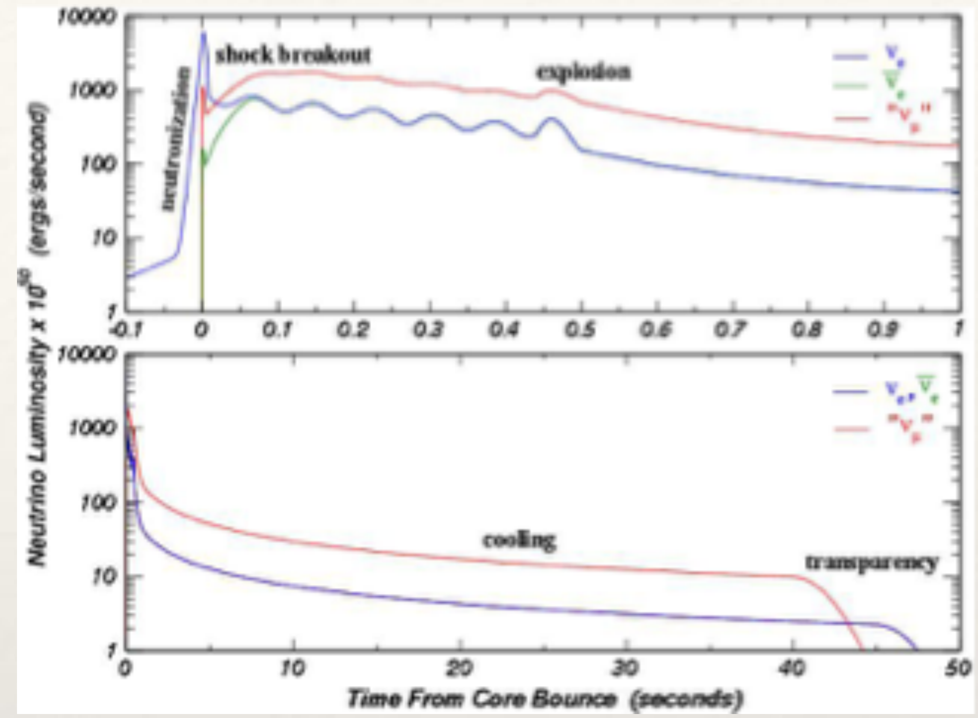
- Beam hadron production, propagation; neutrino flux: FLUKA / FLUGG
- Cosmic ray flux: CRY
- Neutrino interactions and FSI modeling: GENIE
- Detector simulation: GEANT4
- Readout electronics and DAQ: Custom simulation routines

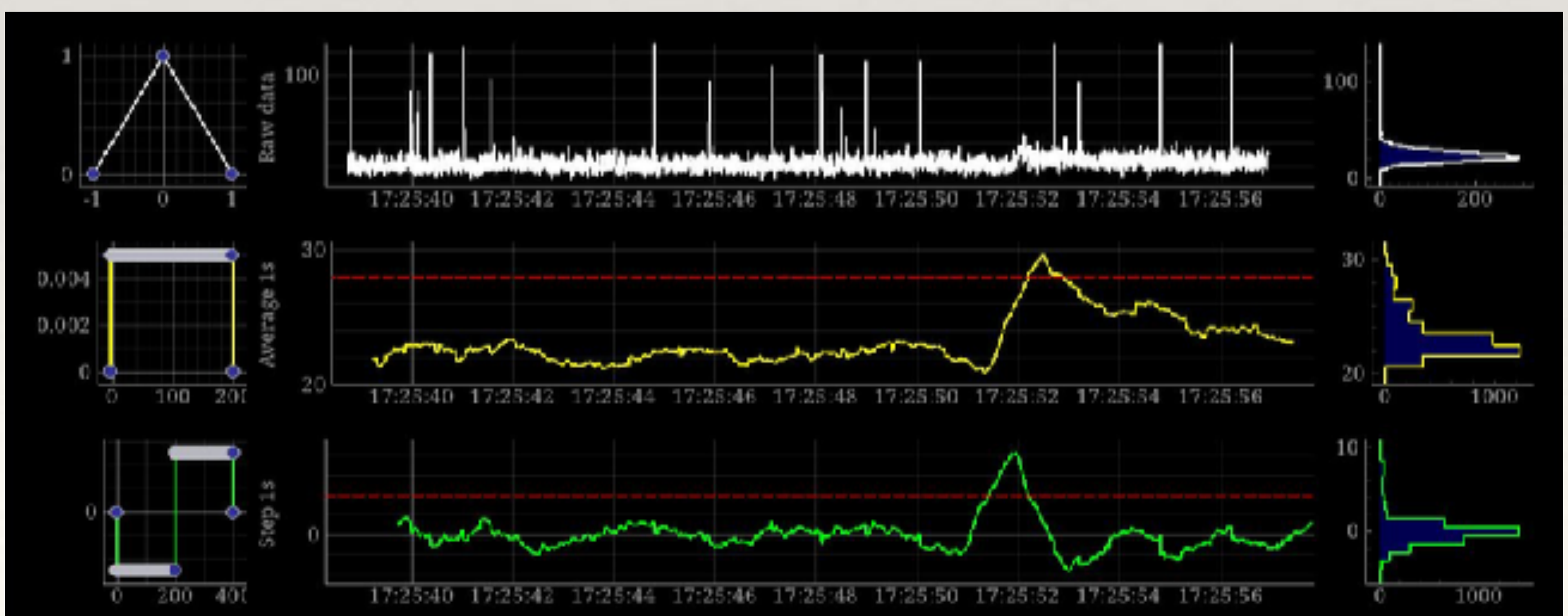


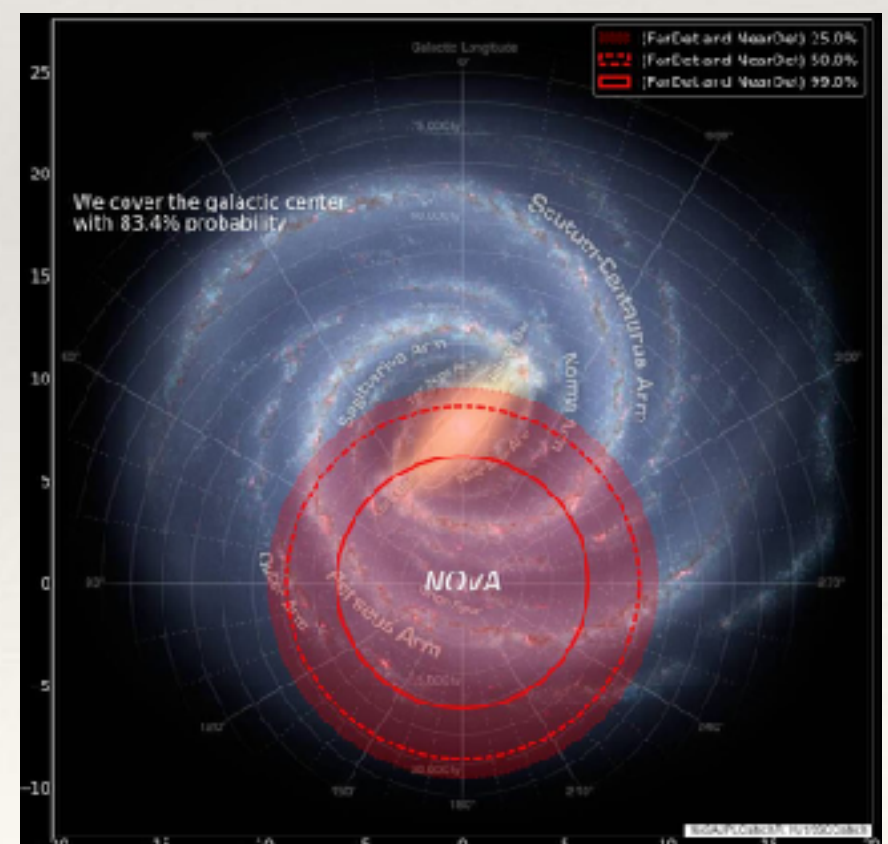
➡ The JINR group is working on several parts of the simulation in the NOvA experiment: neutrino- nucleon cross sections, electronics readout, supernova fluxes and cosmic ray muons.

Detection of Supernova neutrino signal

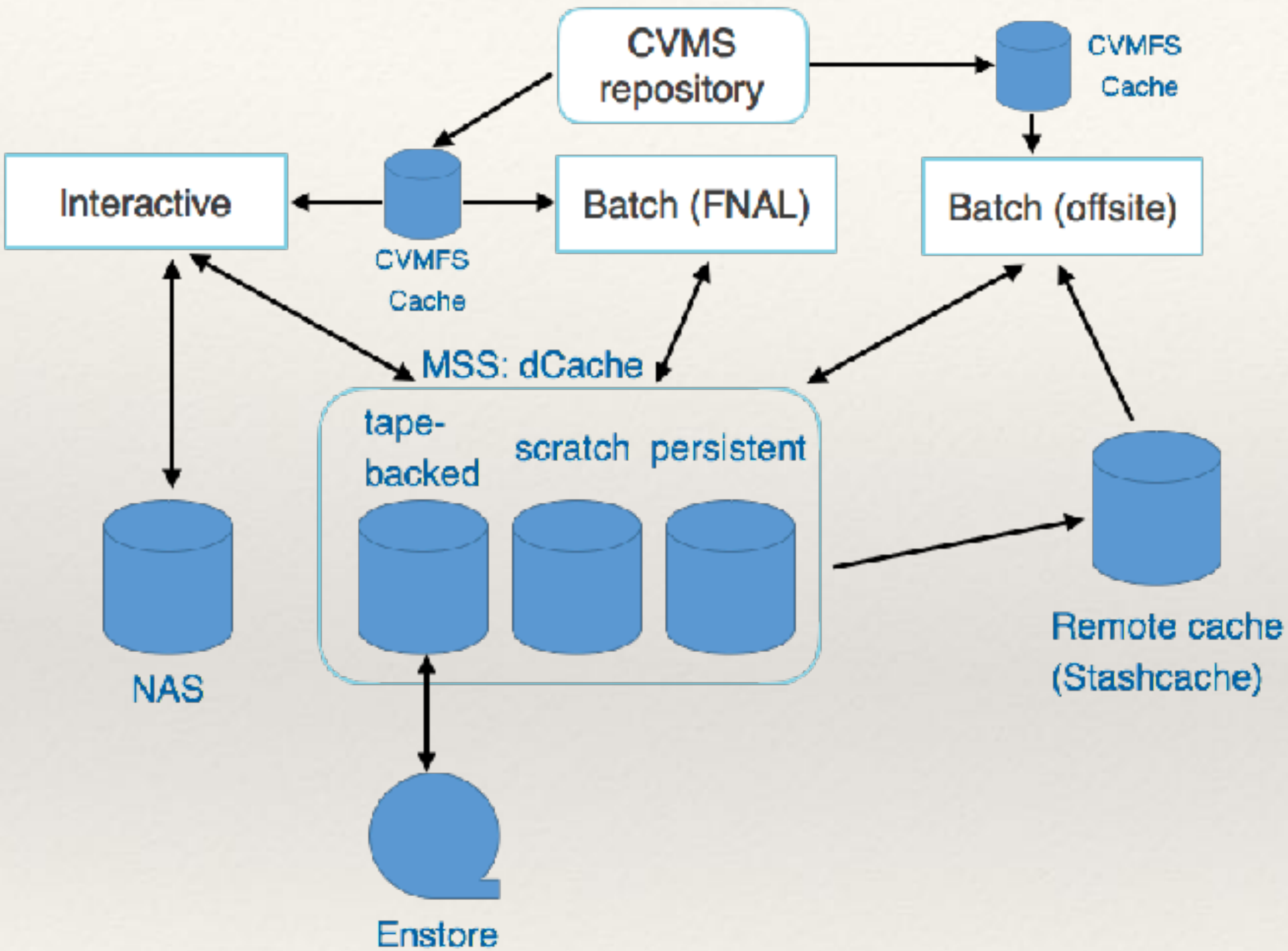
- A dedicated software package was developed to simulate interactions of supernova neutrinos inside the NOvA detectors (GenieSNova).
- Supernova trigger infrastructure was developed and deployed on both Far and Near Detectors
- Selection criteria optimize statistical significance
- Detection efficiency of IBD positrons was evaluated
- NOvA sensitivity region covers Galactic Center
- Plan to integrate with SNEWS
- Stay tuned for improvements of current algorithms

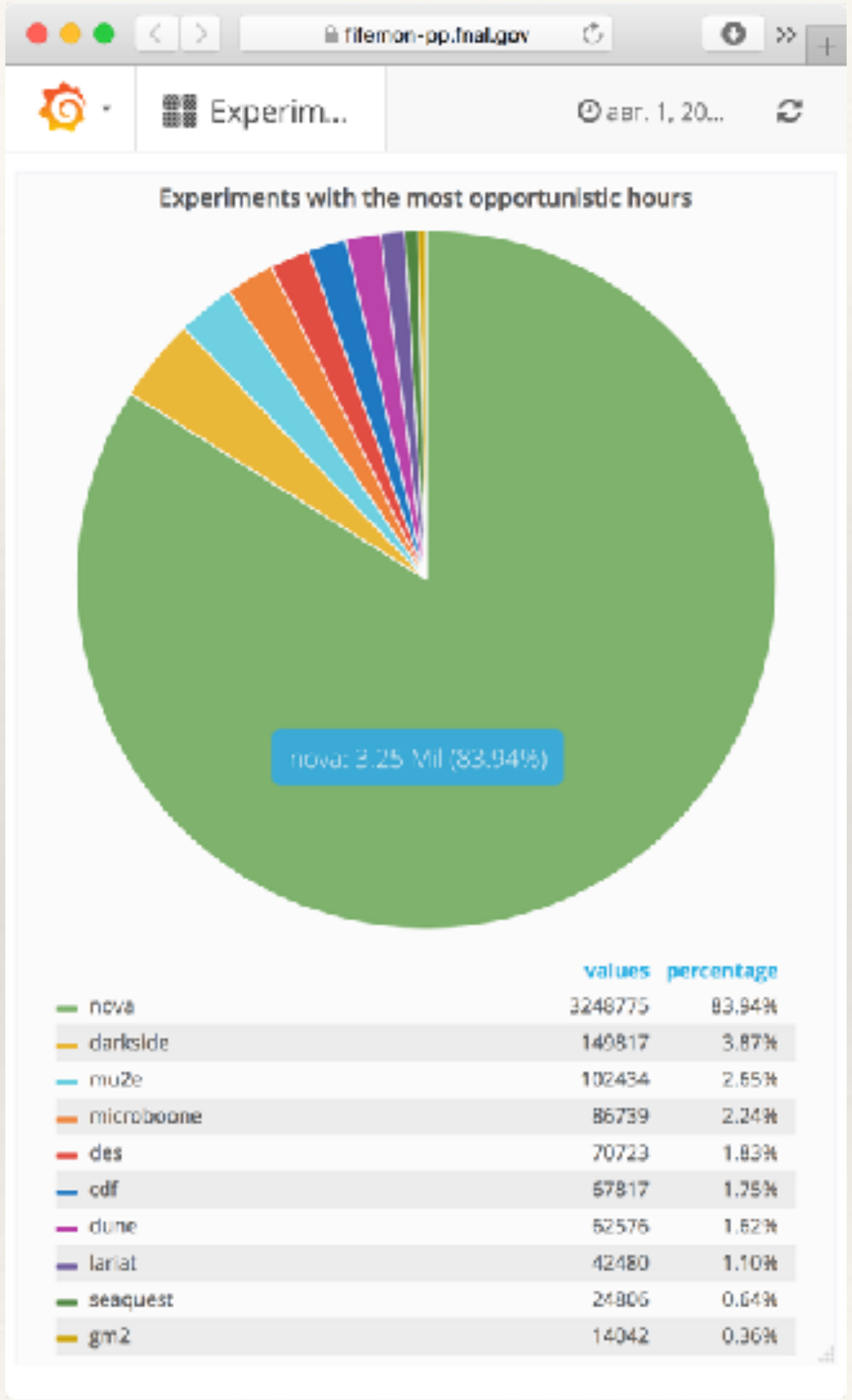






NOvA computing through FIFE

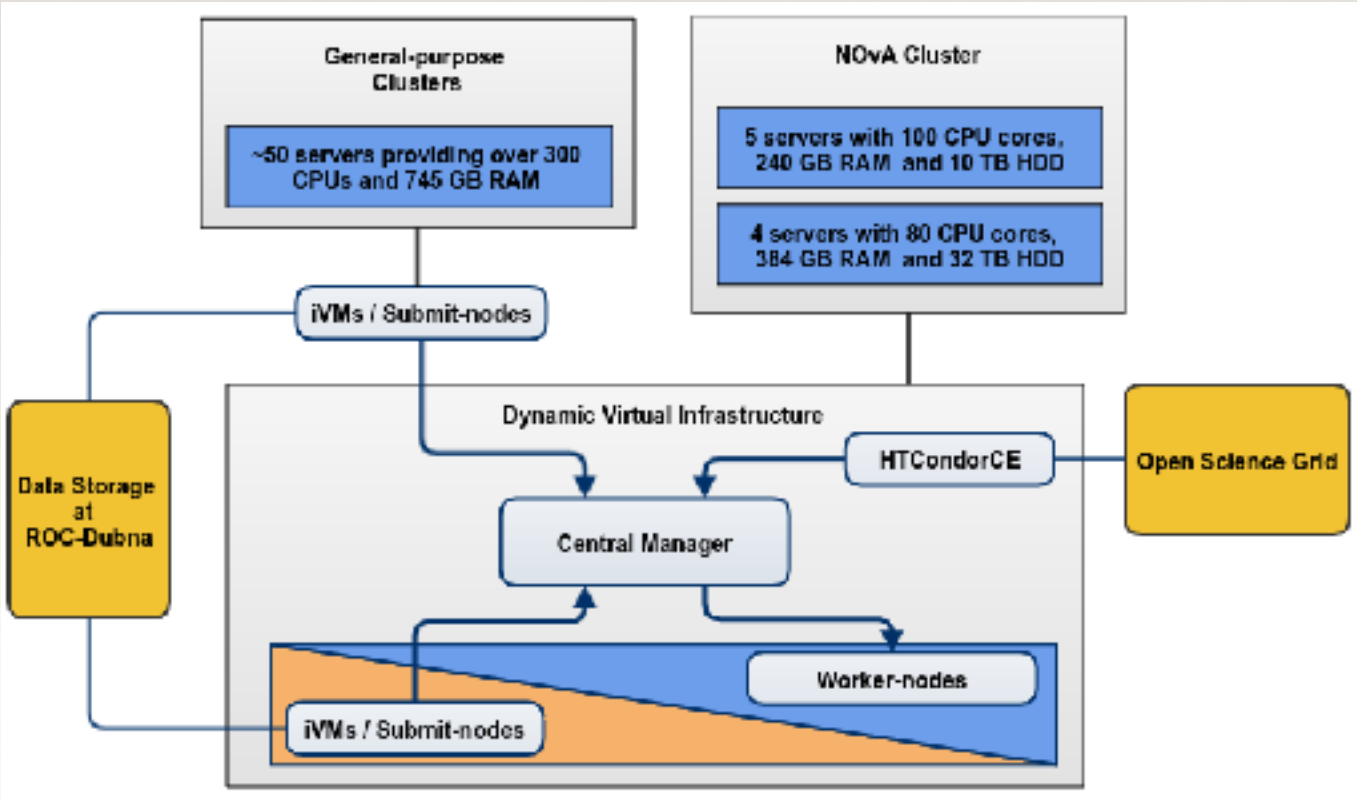


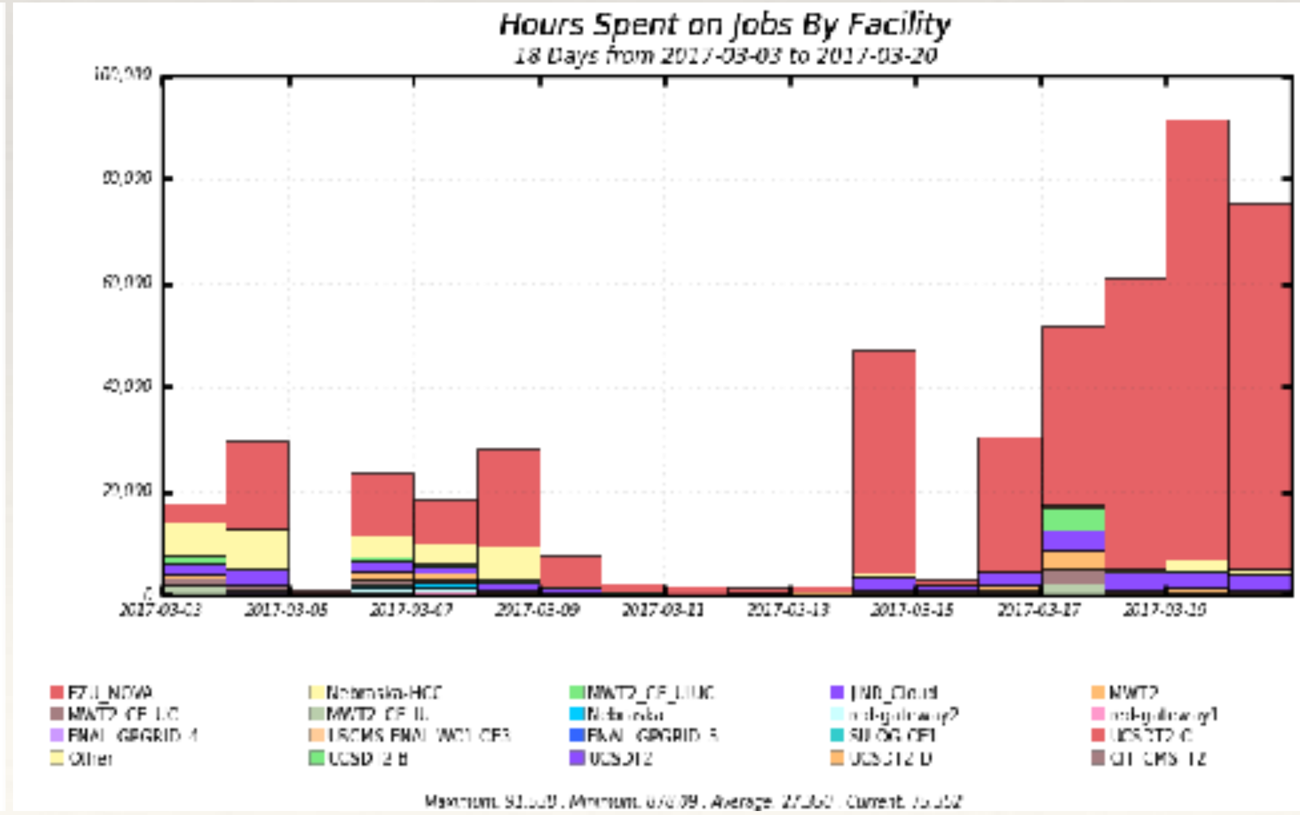


See Ken slides on the NEC'2017
more details http://fife.fnal.gov

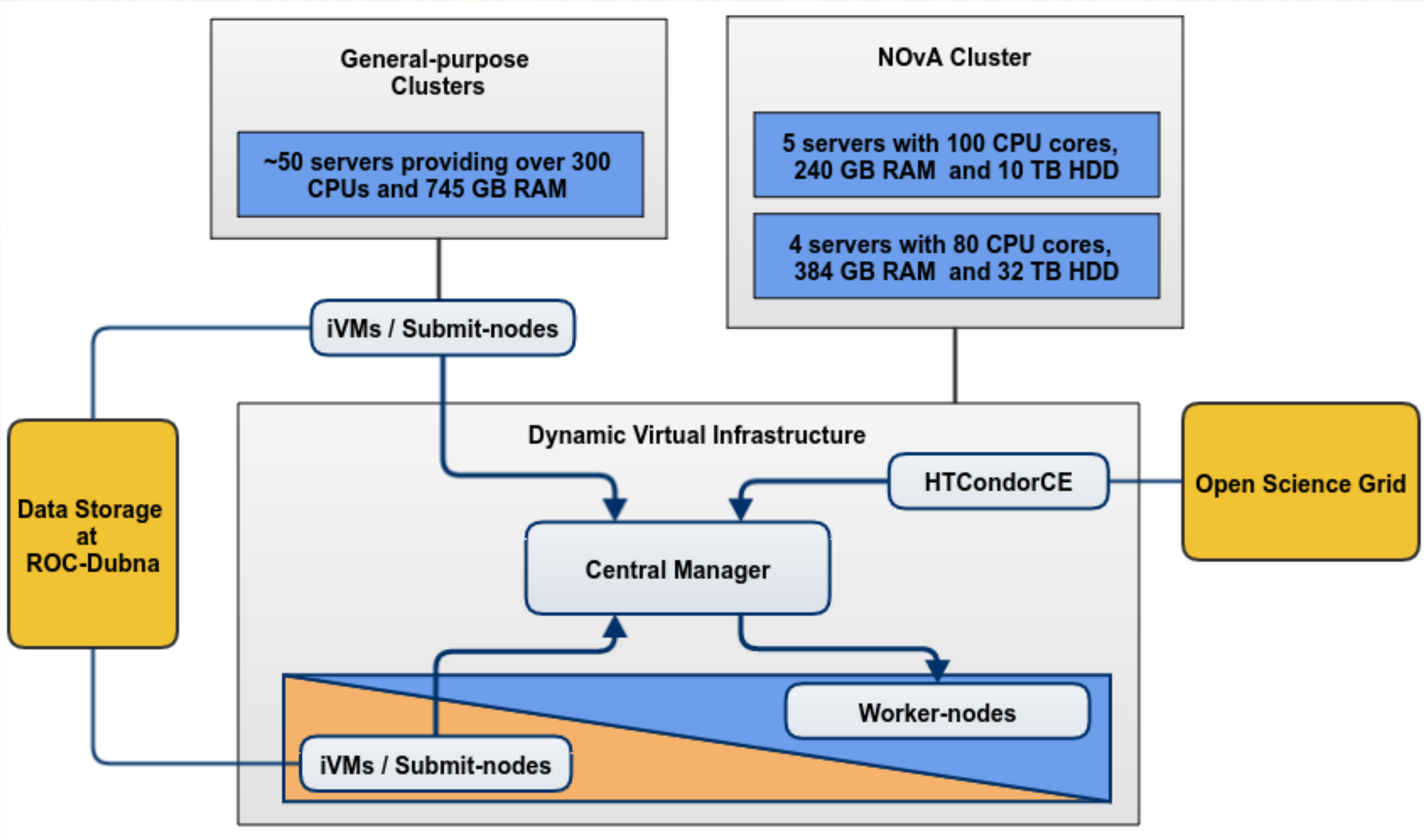
Computing Infrastructure in JINR

- We prepared universal virtual machine (VM) images containing all the necessary NOvA software.
- We integrated our Cloud into OSG to support NOvA production.
- JINR Tier-2 infrastructure was also integrated into OSG in opportunistic mode.
- We are going to extend the infrastructure.
- Setting up storage and data-cache.





JINR cloud resources for NOvA



Interactive Virtual Machines

OpenNebula Virtual Machines

☐	28092	samoylov	nova	angara-28092	RUNNING	vm221-25.jinr.ru
☐	21605	sheshuk	nova	cloud-snova	RUNNING	Hostname resolve failed
☐	3503	samoylov	nova	nova	RUNNING	cldvm120.jinr.ru
☐	3423	kakorin	nova	debian_with_genie	RUNNING	cldvm129.jinr.ru
☐	1420	samoylov	nova	nova	RUNNING	cldvm121.jinr.ru
☐	1418	samoylov	nova	nova	RUNNING	cldvm117.jinr.ru

Interactive Virtual Machines

- 3 nova cloud VMs (4 cores, 8 Gb memory), identical to novagpvm's nodes at FNAL
  - NOvA offline analysis
  - Software synchronises via CVMFS
  - 1 VM has got installed Jupyter Hub
- 1 cloud supernova VM (4 cores, 8 Gb memory)
- 1 cloud GENIE tuning VM (12 cores, 24 Gb memory)

How we now usually work in JINR

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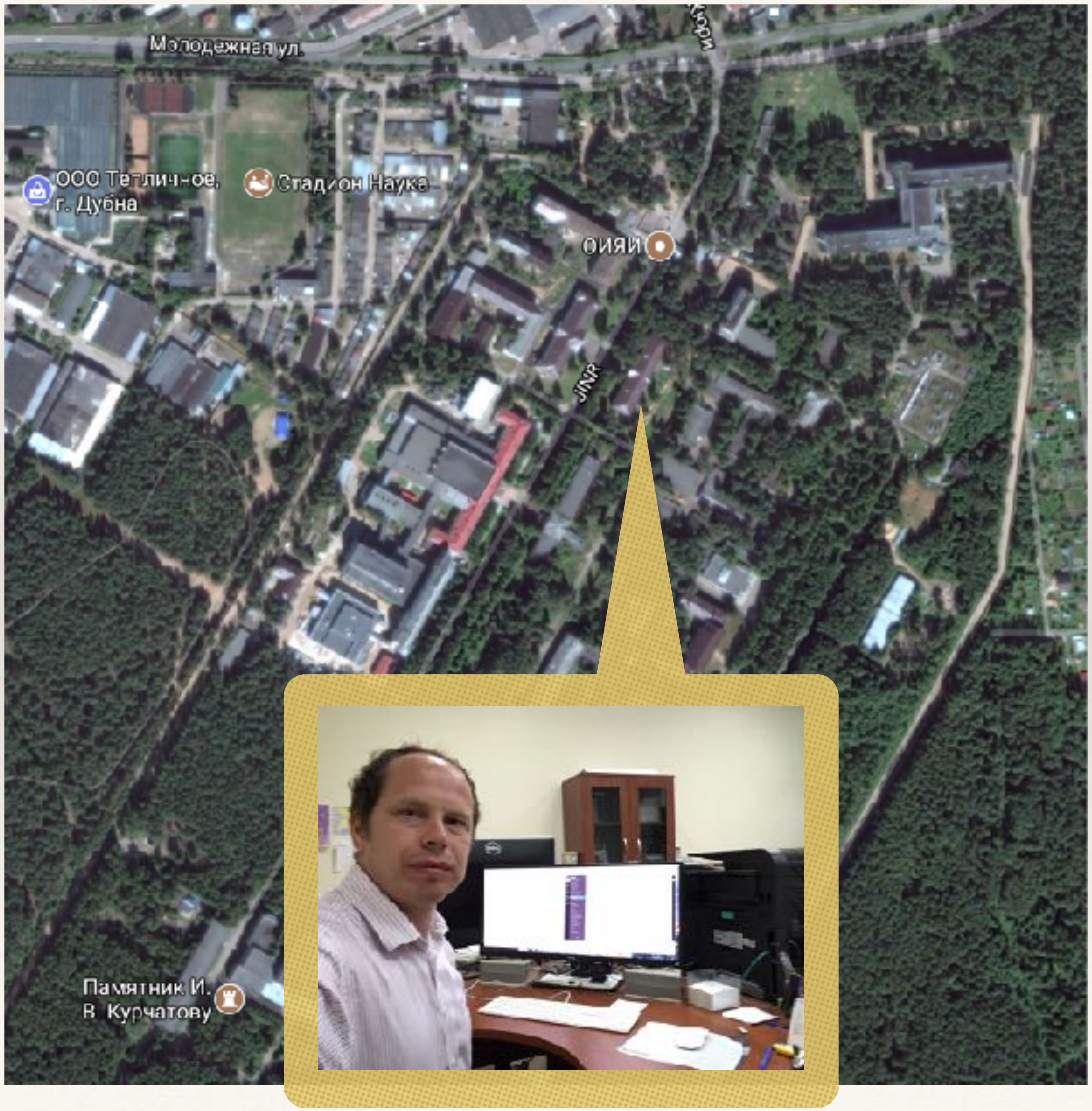
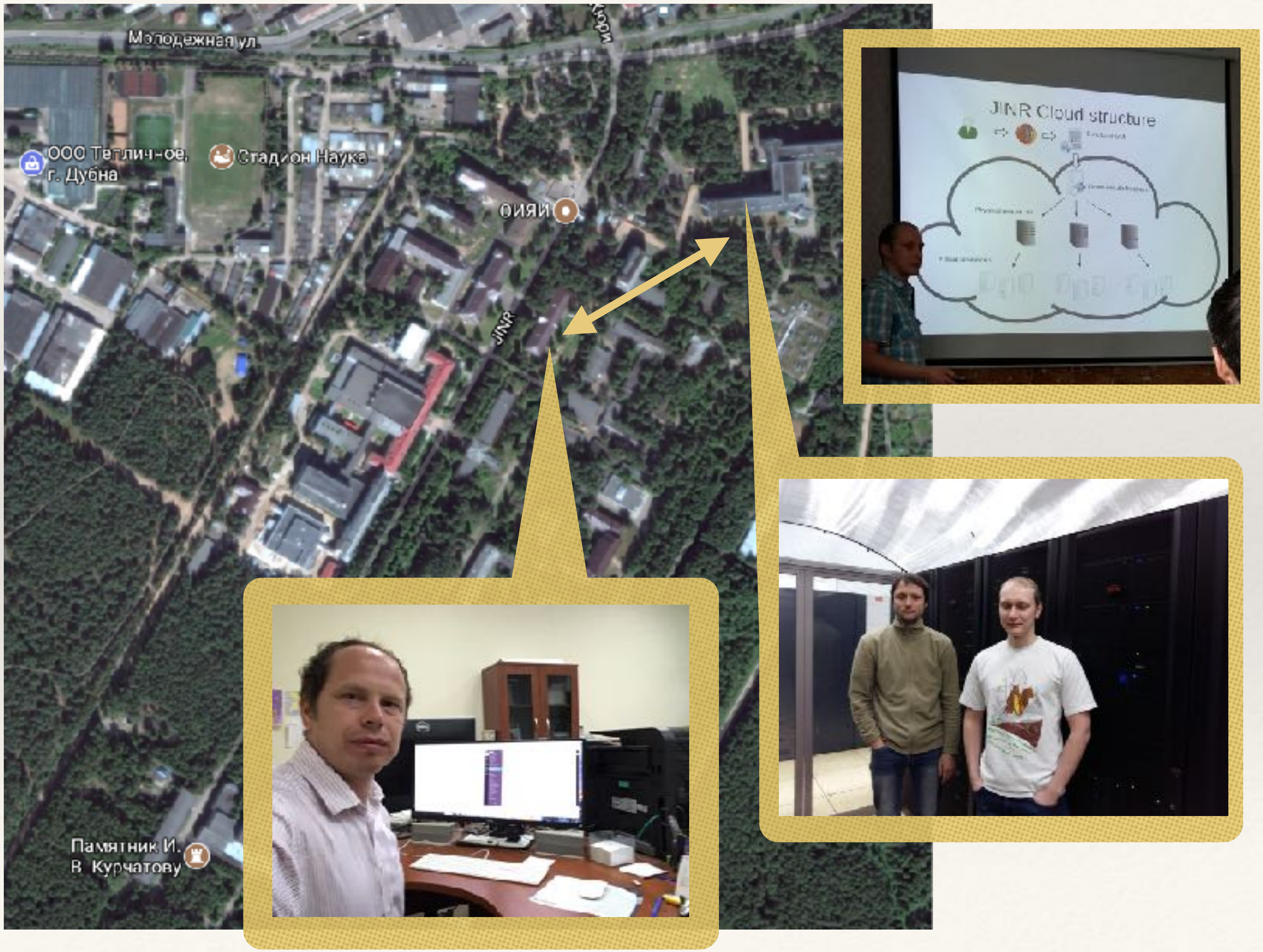
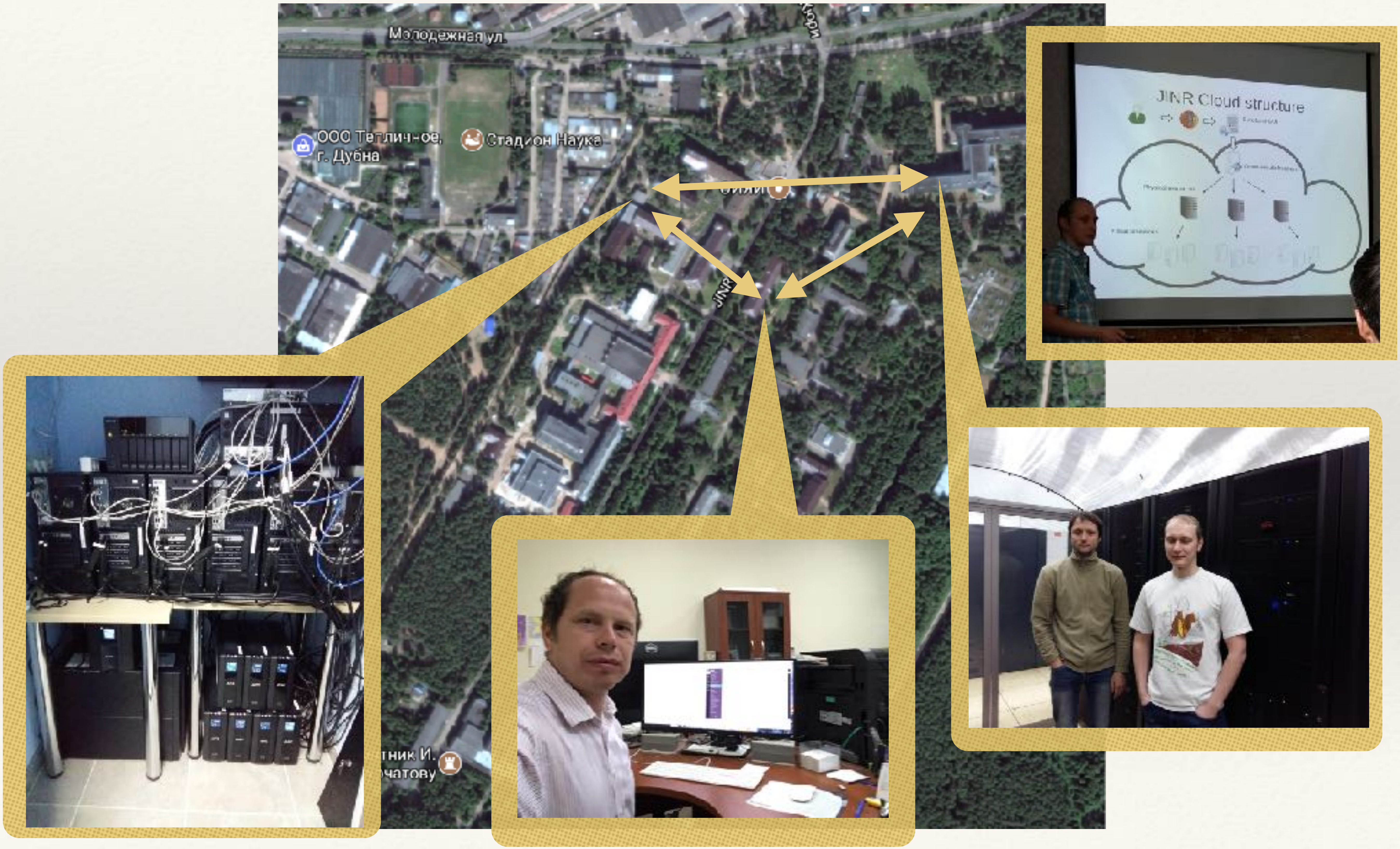


How we now usually work in JINR

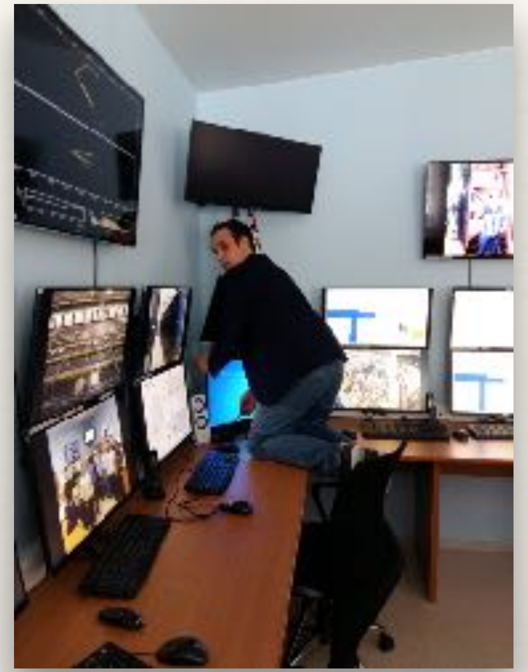


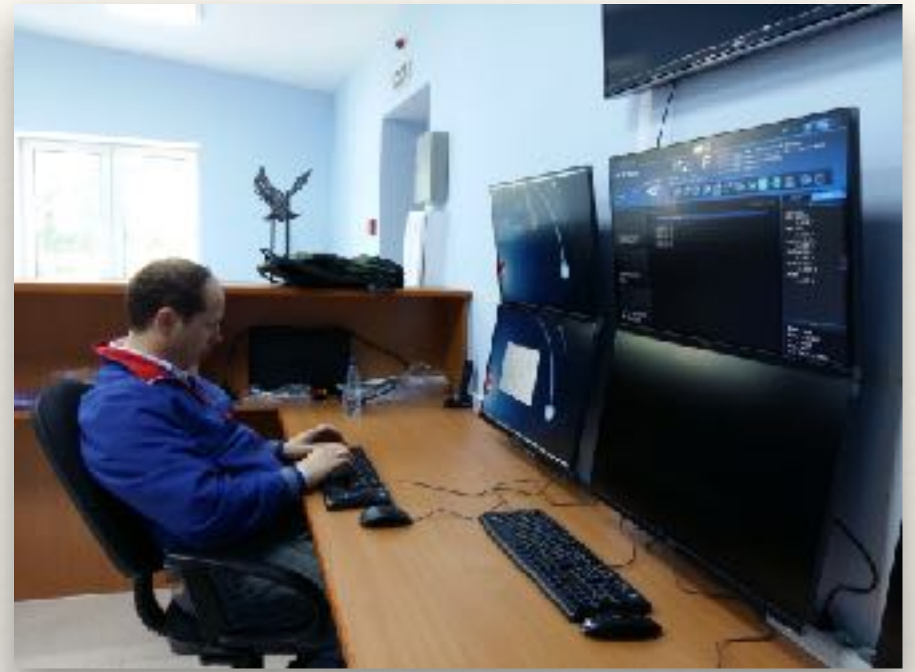
How we now usually work in JINR

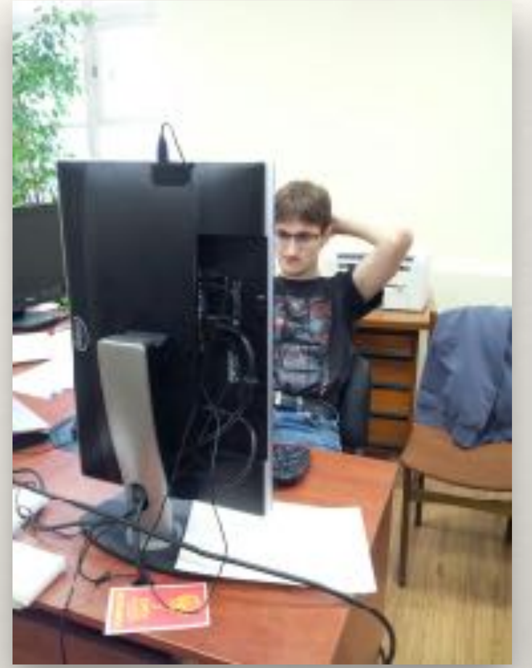


How we now usually work in JINR

We are working, stay tuned

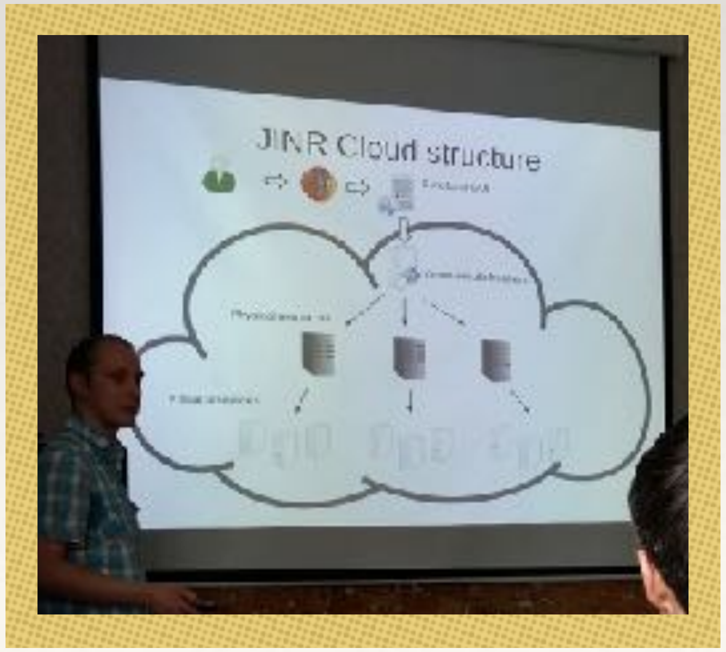






Refreshing of old Experiments

- The NOMAD Experiment at CERN
- Search for neutrino oscillation in 1995-1998
- Strong contribution from JINR group
- Still now NOMAD has big amount of neutrino interactions with Carbon (about 2 M) and Fe (about 20 M)
- We cloned one of our NOMAD node (32bit, 4 Cores, 4 Gb Memory) working since 2006 at DLNP JINR and ported to JINR cloud, checked. It works perfect.



People and Tasks

Name	Labor	Tasks	FTE	Name	Labor	Tasks	FTE
Allakhverdian, V.	DLNP	ND Physics, s-quark prop	0.4	Kuznetsov, E.	LIT	Computing, hardware	0.1
Amvrosov, V,	DLNP	Numu oscillation analysis	0.1	Matveev, V.	BLTP	Theory, Coll management	0.1
Anfimov, N.	DLNP	Det operations, test stand	0.3	Morozova, A.	DLNP	Exotics, CR muons	0.3
Antoshkin, A.	DLNP	Det operations, test stand	0.3	Naumov, V.	BLTP	Osc and cross sec theory	0.3
		Exotics, slow monopoles	0.3	Olshevskiy, A.	DLNP	Coll and JINR manag, IBrep	0.5
		Det control, ROC-liaison	0.1	Petrova, O.	DLNP	Exotics, CR muons	0.7
Balashov, N.	LIT	Computing	0.3			Det sim, cross sec calc	0.3
Baranov, A.	LIT	Computing, Cloud	0.1	Samoylov, O.	DLNP	Det sim, co-convener	0.5
Bolshakova, A.	DLNP	Reco, Proton ID	0.5			Det control, ROC-manag	0.3
		Det sim, ADC thresholds	0.5			JINR ana coordinations	0.1
Bilenky, S.	BLTP	Oscillation theory	0.1			Coll manag, deputy at JINR	0.1
Dolbilov, A.	LIT	Computing, network	0.1	Sheshukov, A.	DLNP	DAQ, software dev/support	0.3
Kakorin, I.	VLHE	Det sim, GENIE	0.5			DDT, supernova trigger dev	0.3
Klimov, O.	DLNP	Reco, Proton ID	0.6			Exotics, supernova detect	0.3
Kolupaeva, L.	DLNP	Nue oscillation analysis	0.8			Det control, ROC software	0.1
		Software, release manag	0.2	Sotnikov, A.	DLNP	Det operations, test stand	0.1
Kullenberg, K.	DLNP	ND Physics, con pion	0.6	Velikanova, D.	DLNP	Det operations, test stand	0.1
Kuzmin, K.	BLTP	Det sim, cross sec theory	0.1	**TOTAL 24**			**10.3**

- The average age of the JINR NOvA team is ~35 years. There are 5 bachelor and master students, 8 young scientists preparing PhD, 4 engineers, 4 staff members with PhD degree and 3 professors.

People and Tasks

Name	Labor	Tasks	FTE	Name	Labor	Tasks	FTE
Allakhverdian, V.	DLNP	ND Physics, s-quark prop	0.4	Kuznetsov, E.	LIT	Computing, hardware	0.1
Amvrosov, V,	DLNP	Numu oscillation analysis	0.1	Matveev, V.	BLTP	Theory, Coll management	0.1
Anfimov, N.	DLNP	Det operations, test stand	0.3	Morozova, A.	DLNP	Exotics, CR muons	0.3
Antoshkin, A.	DLNP	Det operations, test stand	0.3	Naumov, V.	BLTP	Osc and cross sec theory	0.3
		Exotics, slow monopoles	0.3	Olshevskiy, A.	DLNP	Coll and JINR manag, IBrep	0.5
		Det control, ROC-liaison	0.1	Petrova, O.	DLNP	Exotics, CR muons	0.7
Balashov, N.	LIT	Computing	0.3			Det sim, cross sec calc	0.3
Baranov, A.	LIT	Computing, Cloud	0.1	Samoylov, O.	DLNP	Det sim, co-convener	0.5
Bolshakova, A.	DLNP	Reco, Proton ID	0.5			Det control, ROC-manag	0.3
		Det sim, ADC thresholds	0.5			JINR ana coordinations	0.1
Bilenky, S.	BLTP	Oscillation theory	0.1			Coll manag, deputy at JINR	0.1
Dolbilov, A.	LIT	Computing, network	0.1	Sheshukov, A.	DLNP	DAQ, software dev/support	0.3
Kakorin, I.	VLHE	Det sim, GENIE	0.5			DDT, supernova trigger dev	0.3
Klimov, O.	DLNP	Reco, Proton ID	0.6			Exotics, supernova detect	0.3
Kolupaeva, L.	DLNP	Nue oscillation analysis	0.8			Det control, ROC software	0.1
		Software, release manag	0.2	Sotnikov, A.	DLNP	Det operations, test stand	0.1
Kullenberg, K.	DLNP	ND Physics, con pion	0.6	Velikanova, D.	DLNP	Det operations, test stand	0.1
Kuzmin, K.	BLTP	Det sim, cross sec theory	0.1	**TOTAL 24**			**10.3**

- The average age of the JINR NOvA team is ~35 years. There are 5 bachelor and master students, 8 young scientists preparing PhD, 4 engineers, 4 staff members with PhD degree and 3 professors.

Summary

- We prepared universal virtual machine (VM) images containing all the necessary NOvA software.
- We integrated our Cloud into OSG to support NOvA production.
- JINR Tier-2 infrastructure was also integrated into OSG in opportunistic mode.
- We are going to extend the infrastructure.
- Setting up storage and data-cache.
- Stay tuned, and join to study your physics on CLOUD

Thank you for your attention!