Dmitry V.Naumov

BAIKAL GVD

Neutrino Telescope

IHEP Webinar

July 23, 2020

GVD = Gigaton-volume-detector

BAIKAL GVD

Neutrino Telescope

Introduction

The site

- Baikal Lake.
- 106 km of Circum-Baikal Railway
- 3.6 km from the shore
- 1366 m depth
- Stable ~1m thick ice cover (Feb-Mar)

Introduction
Short History

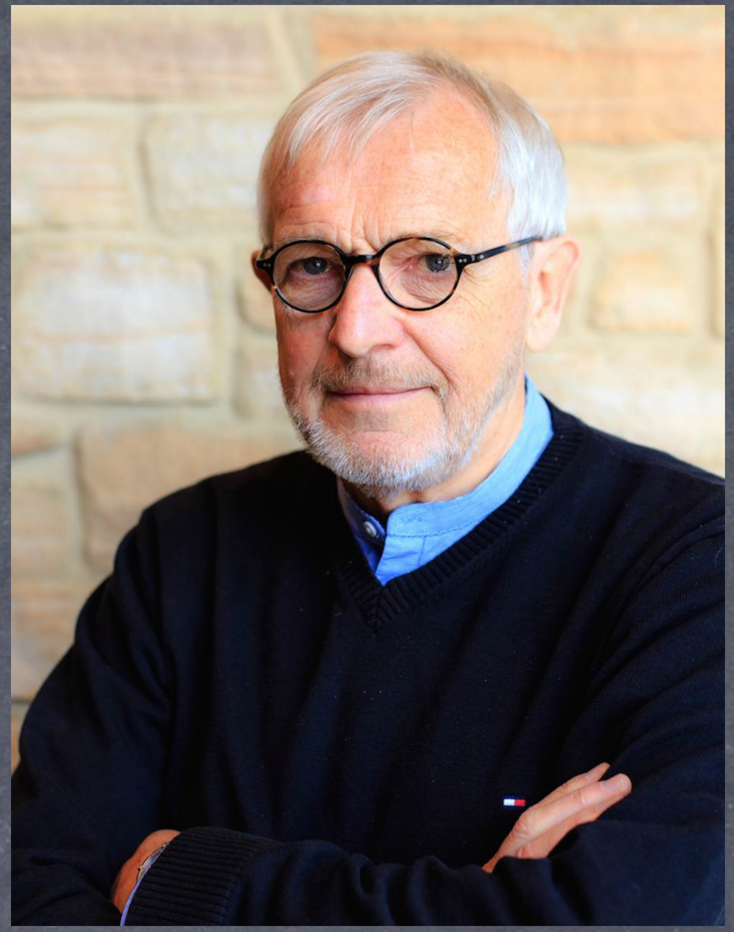
M.A. Markov. 1960

«We propose to install detectors deep in a lake or in the sea and determine the direction of charged particles with the help of Cherenkov radiation». ICHEP, Rochester. p578

Introduction

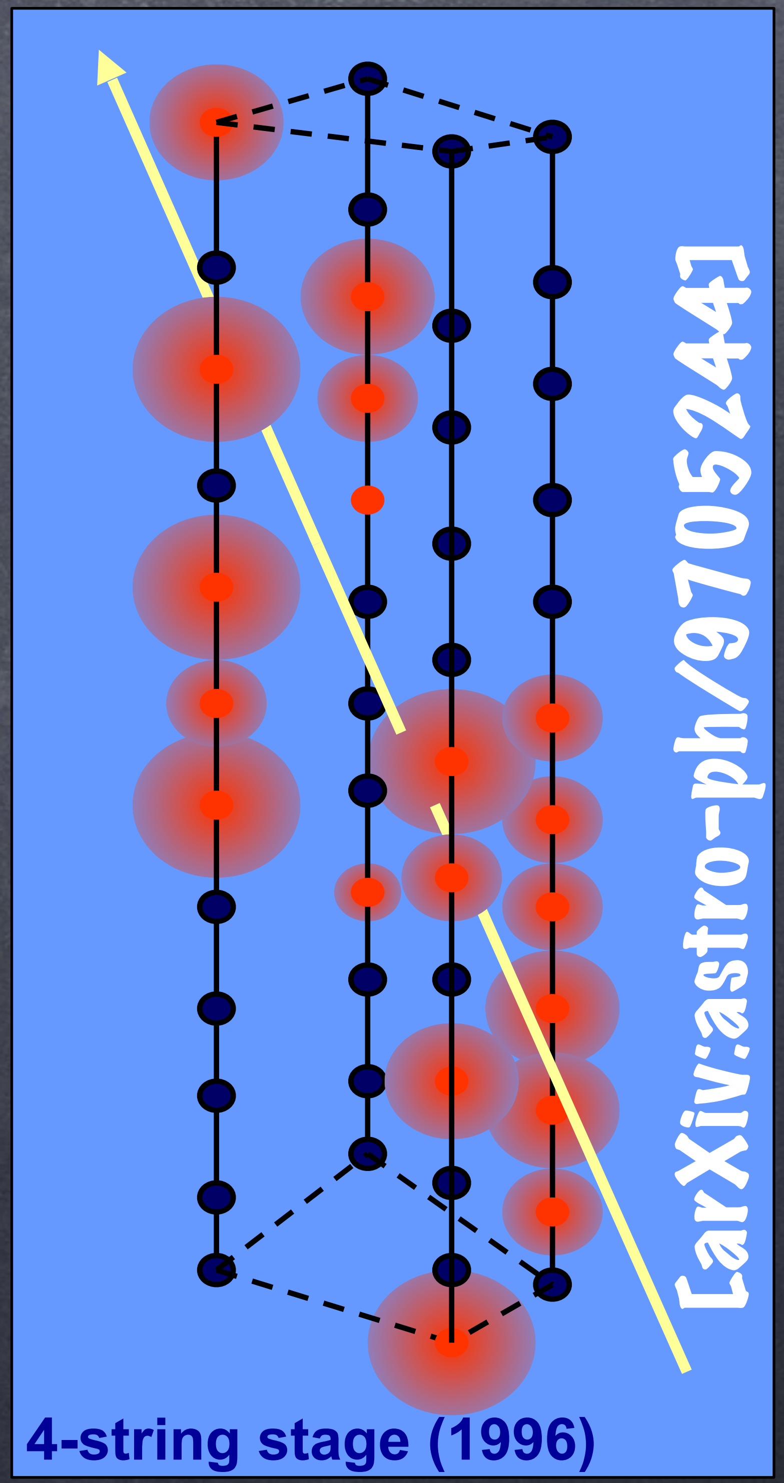
Short History

- 1960 - M.Markov - main idea.
- 1976 - Discussions of DUMAND project
- 1980 - Start of works on construction of BAIKAL Detector lead by G.V.Domogatsky (GVD)
- 1993 - NT-36 (36 OM) @BAIKAL
- 1996 - NT-96 (96 OM)
- 1997 - AMANDA B10 (302 OM) @SouthPole
- 1998 - NT-200 (192 OM)
- 2000 - AMANDA II (677 OM)
- 2005 - NT-200+ (228 OM)
- 2005 - IceCube (first string)



- F. Halzen to C. Spiering:

„Congratulations for winning the 3-string race!“
(NT-36 vs TRIAD vs AMANDA)

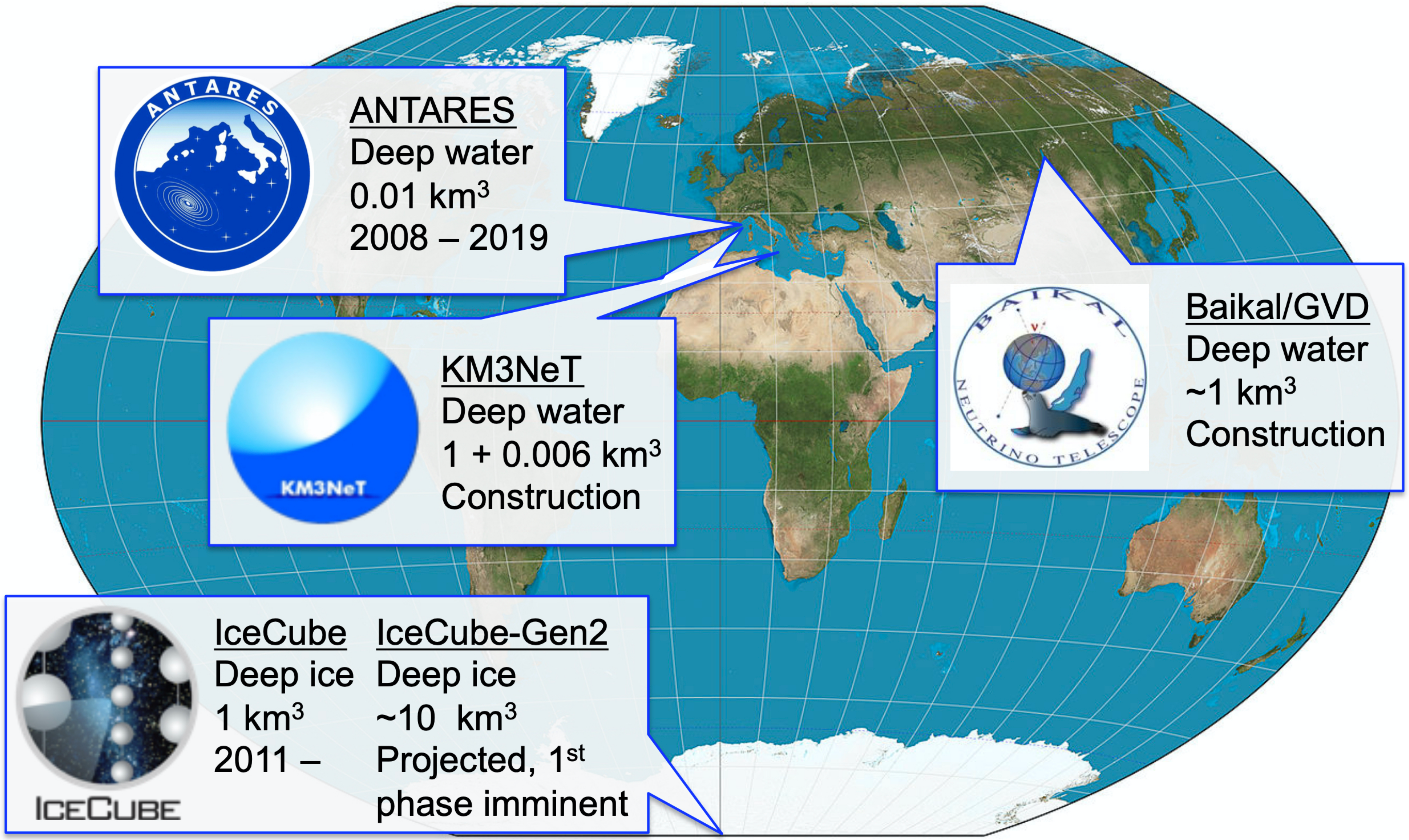


- 2010 - IceCube (last string)
- 2013 - IceCube detects «Big Three» events
- 2015 - BAIKAL GVD («Dubna» cluster)

Introduction

Short History

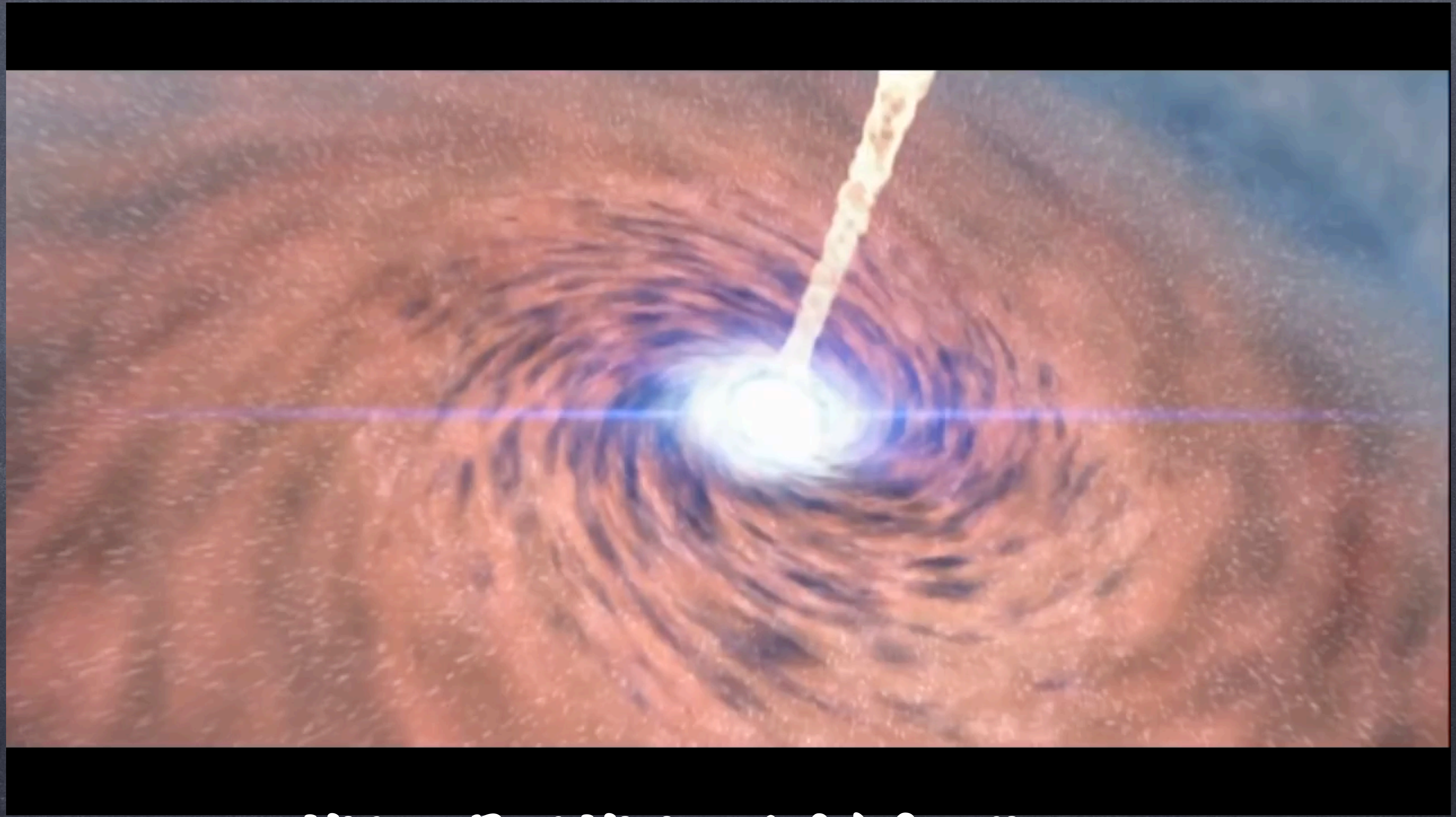
Ice/water Cherenkov neutrino telescopes - global view



Introduction

Main Motivations

- In past: atmospheric neutrinos
- Now: cosmic neutrinos as messengers about the Universe past
  - Galaxy formation
  - Universe evolution
  - Sources of ultra-high energy particles
  - Neutrino is an important new messenger

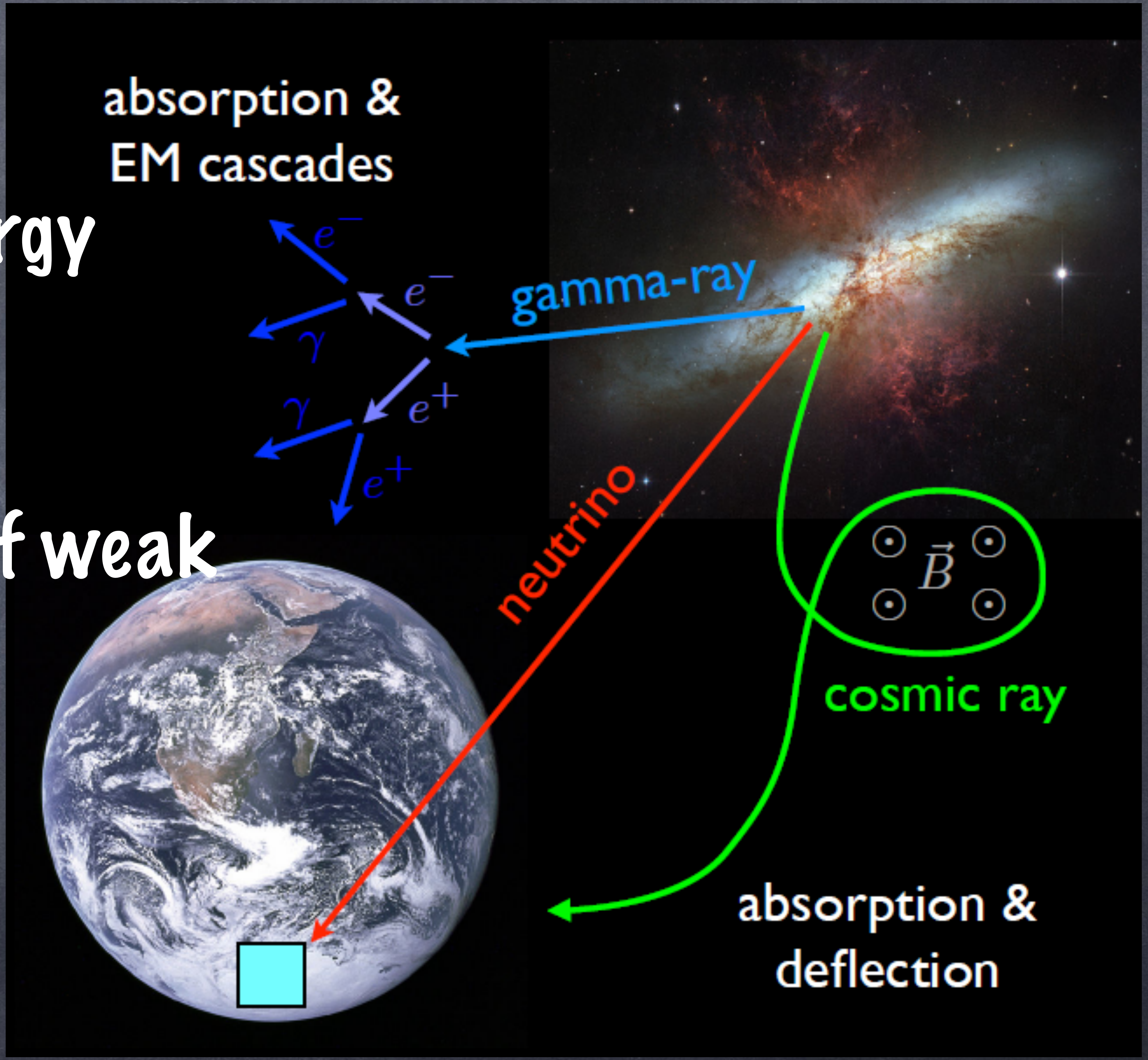


Video: Red Vision & C4 Studios

Introduction

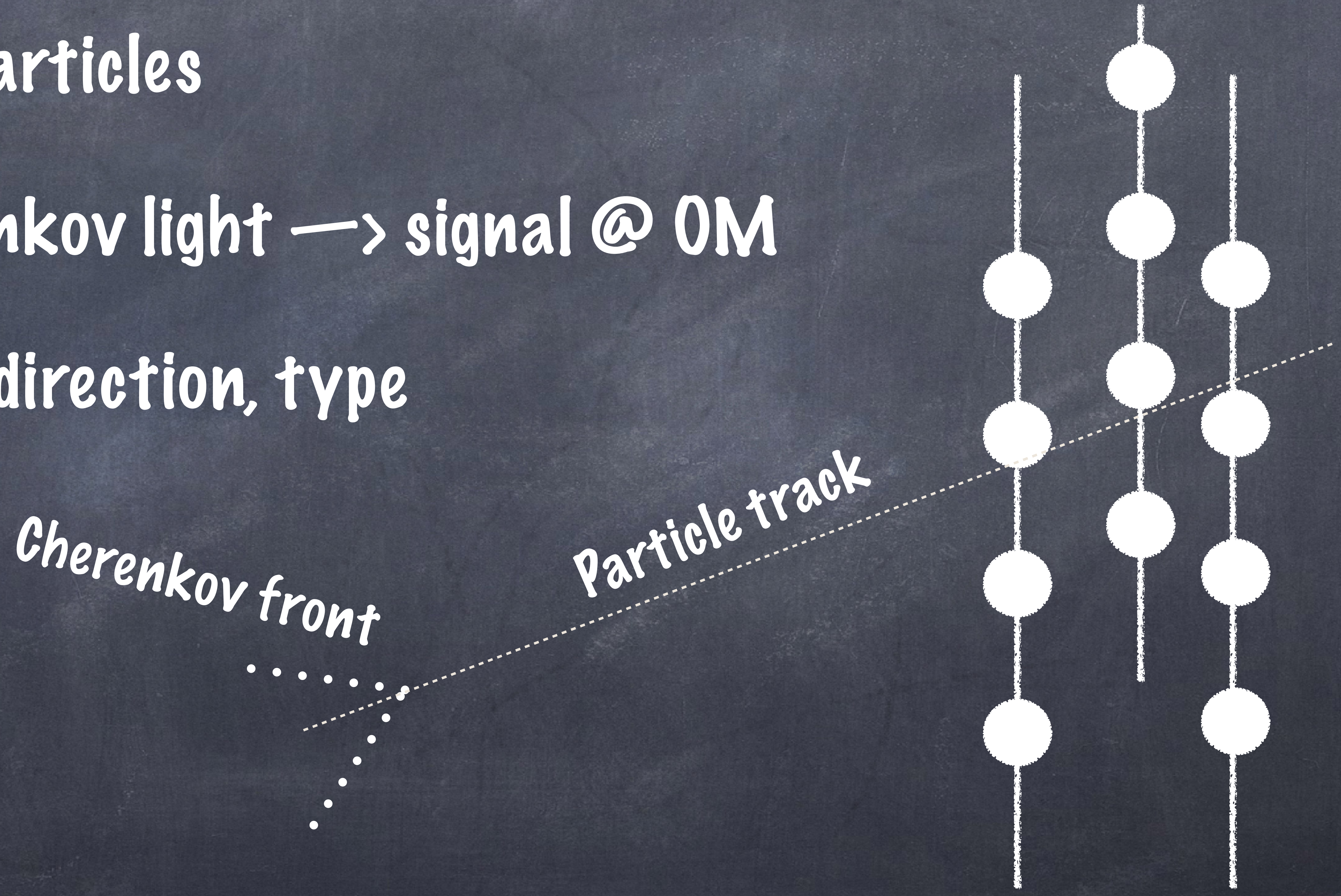
Neutrino Astronomy

- Charged particles loose direction and energy
- High energy photons get absorbed
- Neutrino astronomy is possible because of weak interaction neutrino



Introduction
General Principles

- Neutrino interactions —> particles
- Charged particles —> Cherenkov light —> signal @ OM
- Amplitude, time —> Energy, direction, type



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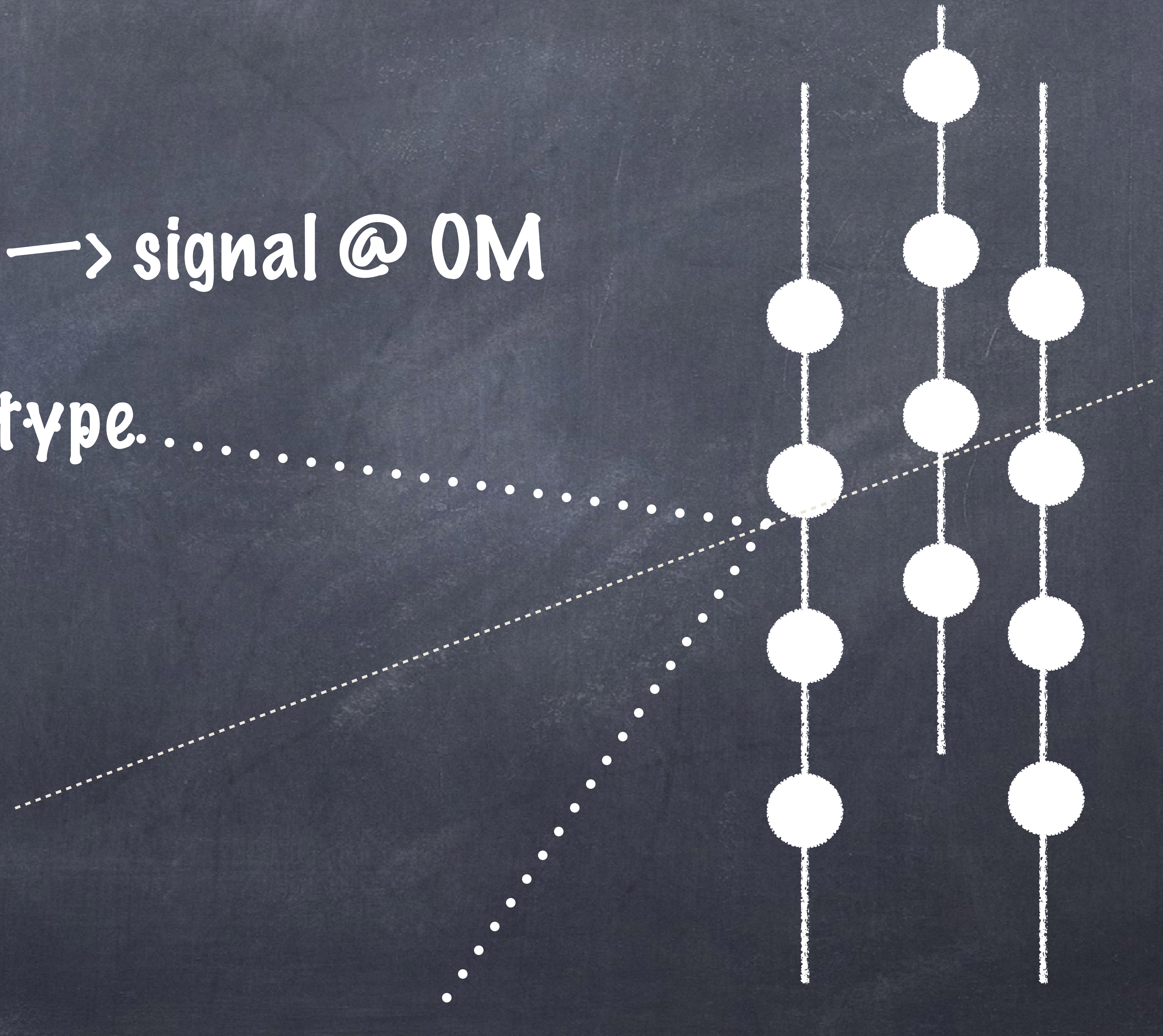

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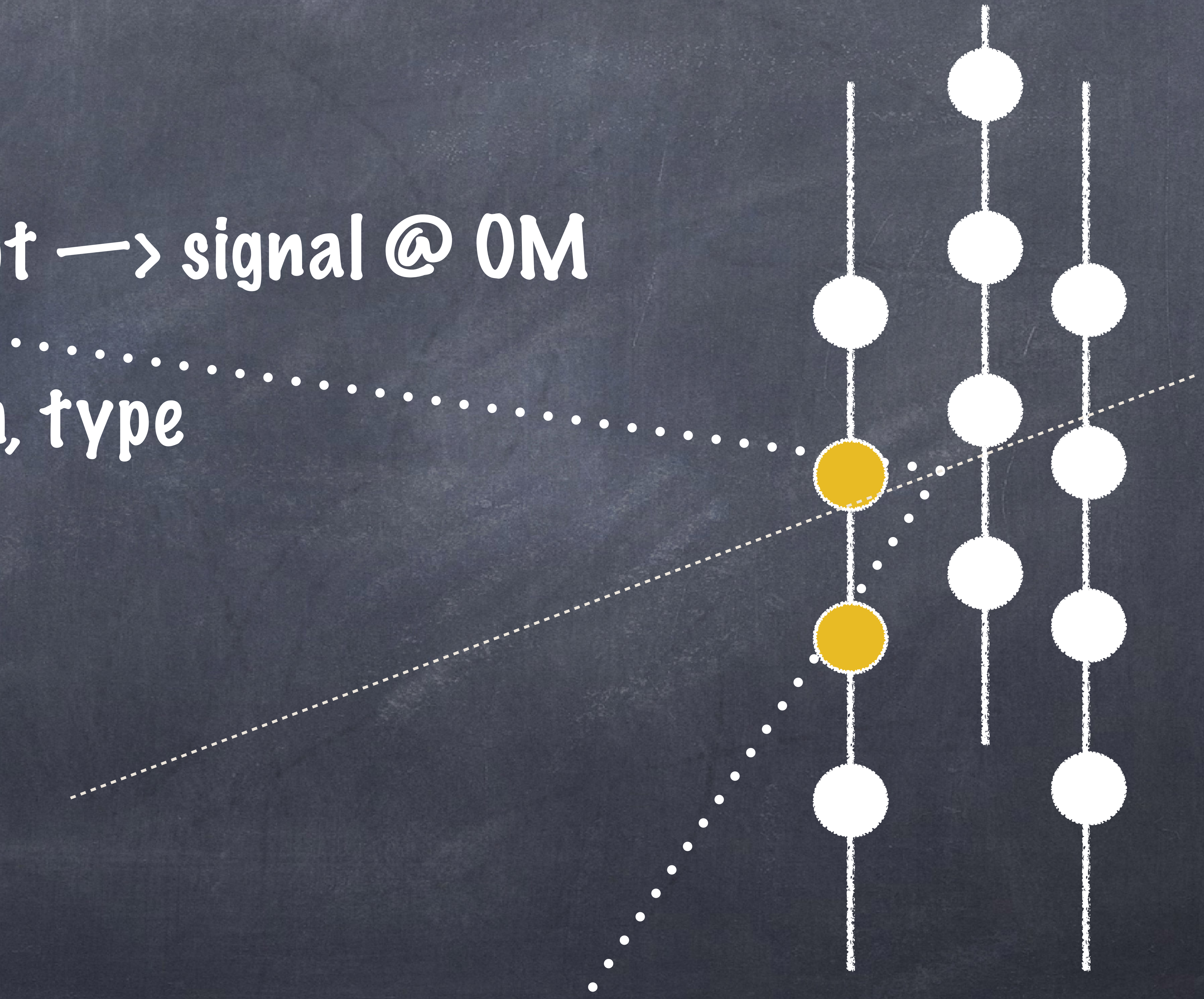

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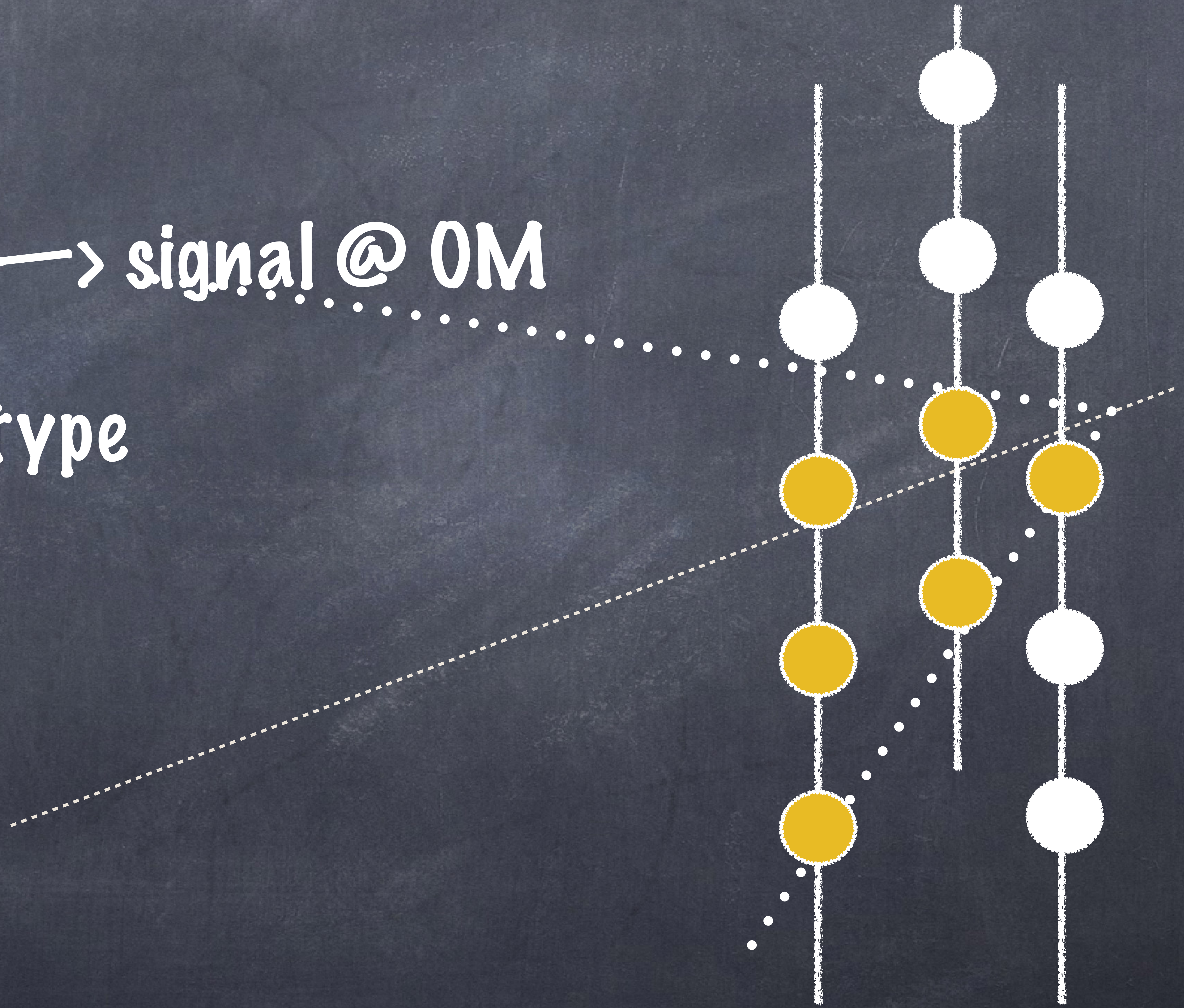


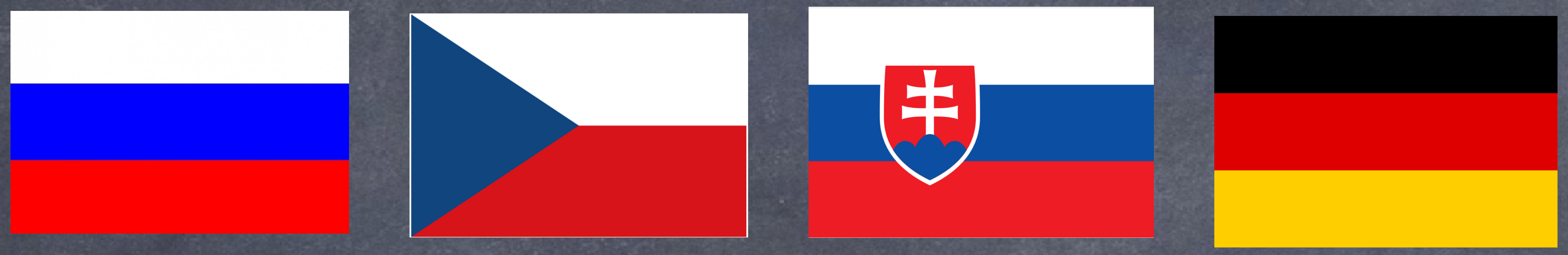
Introduction

↳ Neutrino Telescope Science Case


Neutrino Telescope Science
AstroPhysics
Cosmic Accelerators
SuperNova
Cosmic Rays
Cosmic Muons
Neutrino Astronomy
MultiMessenger
Gamma Astronomy
Cosmic Weather
Neutrino Physics
Sterile Neutrino
Non-standard Properties
PMNS Unitarity
Neutrino Decoherence
Neutrino Oscillations
Exotics
SYSU
Stranglets
Axions
Monopoles
Earth Sciences
Atmospheric Science
Limnology
Earth Tomography
Dark Matter
DM annihilation
Neutrino DM interaction
Fundamental Symmetries
Lorentz Symmetry
Quantum Space-time

Introduction

BAIKAL COLLABORATION



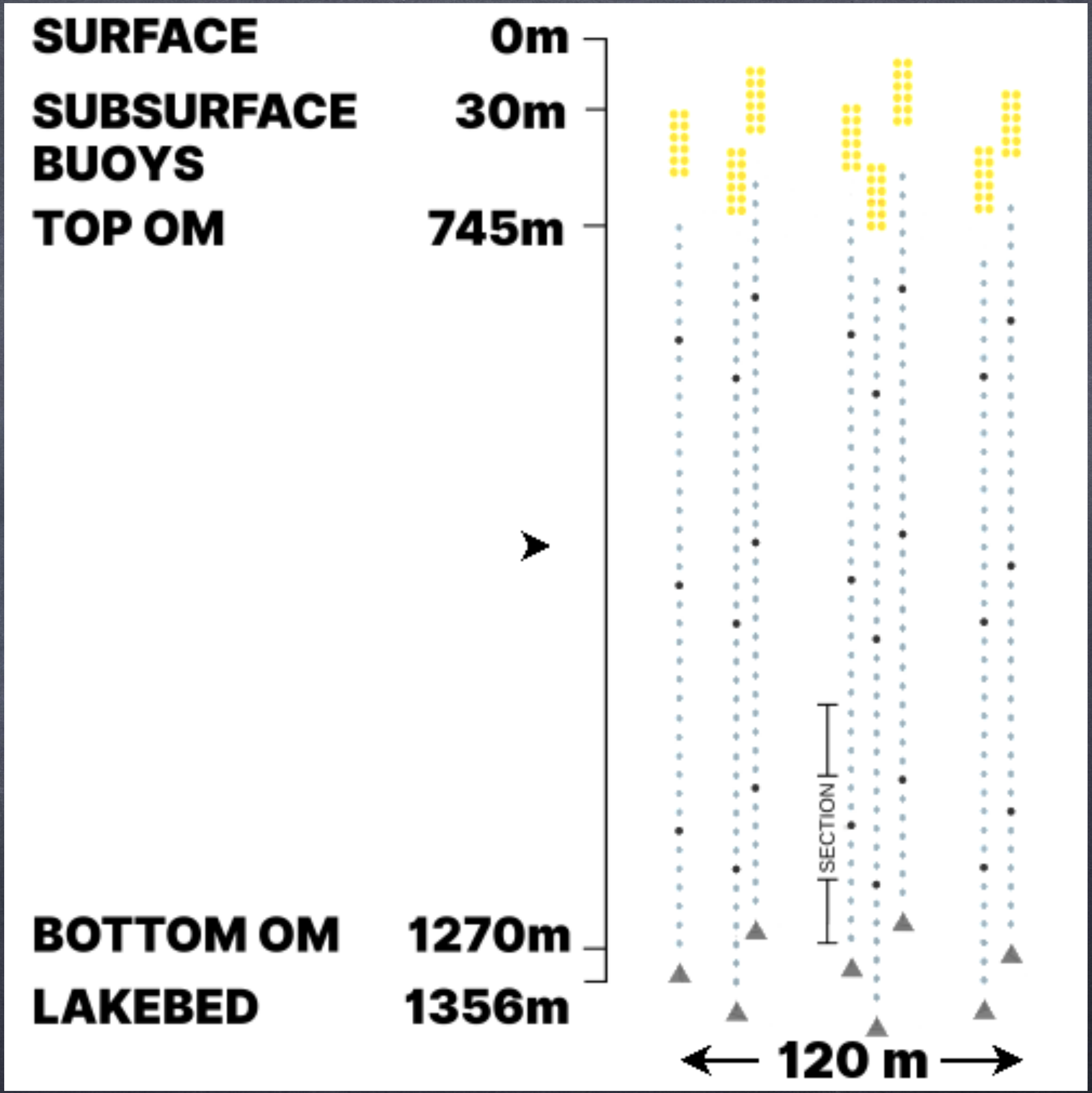
9 institutions, 55 members

1. Institute for Nuclear Research, Moscow, Russia
2. Joint Institute for Nuclear Research, Dubna, Russia
3. Irkutsk State University, Irkutsk, Russia
4. Skobeltsyn Institute of Nuclear Physics MSU, Moscow, Russia
5. Nizhny Novgorod State Technical University, Russia
6. Saint Petersburg State Marine University, Russia
7. Institute of Experimental and Applied Physics, Czech Technical University, Prague, Czech Republic
8. Comenius University, Bratislava, Slovakia
9. EvoLogics, Berlin, Germany
10. Krakow Institute for Nuclear Research, Poland

Introduction

The plan

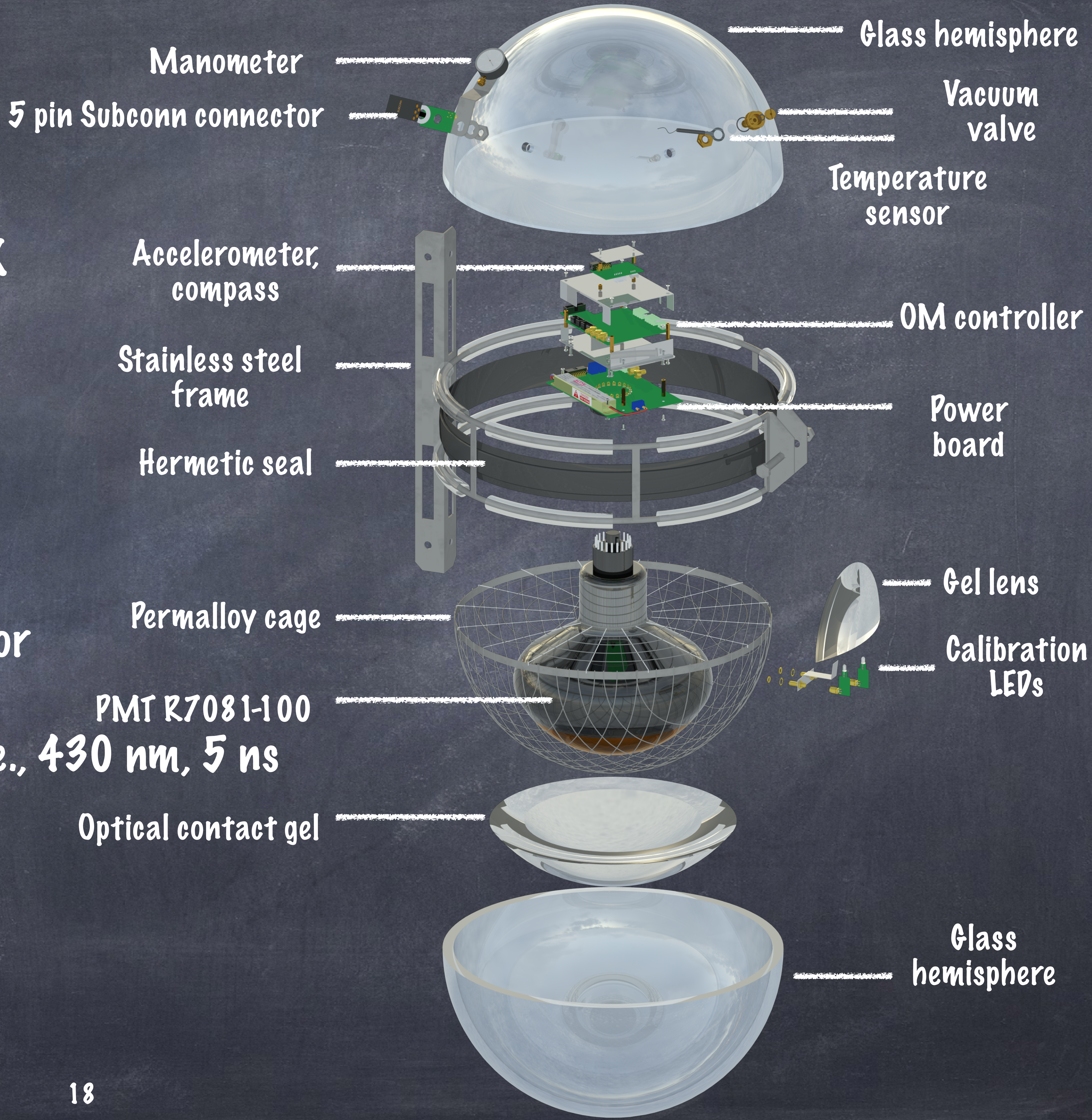
- Main Goal
  - Point sources of UHE neutrino
- 3D Array of photo-sensors
  - Phase I: 0.45 km3 (by 2021)
  - Phase II: 1.5 km3 (by 2027)
- Installation site
  - South Baikal
  - Depth 1.4 km
  - Distance from shore 3.5 km
- Requirements
  - Adjustable structure
  - Synchronization < 1ns



Baikal Neutrino Detector
→ Optical Module

Baikal Neutrino Detector
→ Optical Module

- 17" Glass pressure-resistant sphere VITROVEX
- 10" Hamamatsu PMT R7081HQE, $Q_{eff} \approx 0.35$
- Mu-metal cage
- OM electronics: amplifier, HV DC-DC, controller
- Underwater 5-pin industrial SubConn connector
- 2 on-board LED flashers for calibration: 10^8 p.e., 430 nm, 5 ns



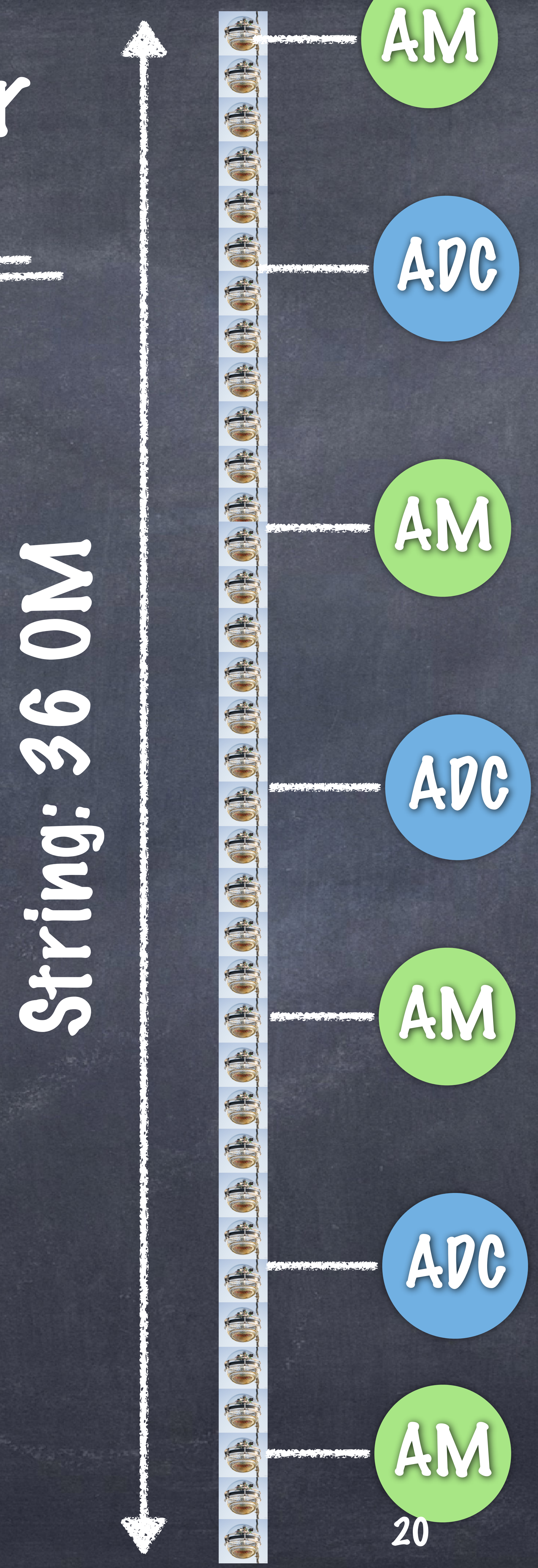
Baikal Neutrino Detector

The string

Section: 120M

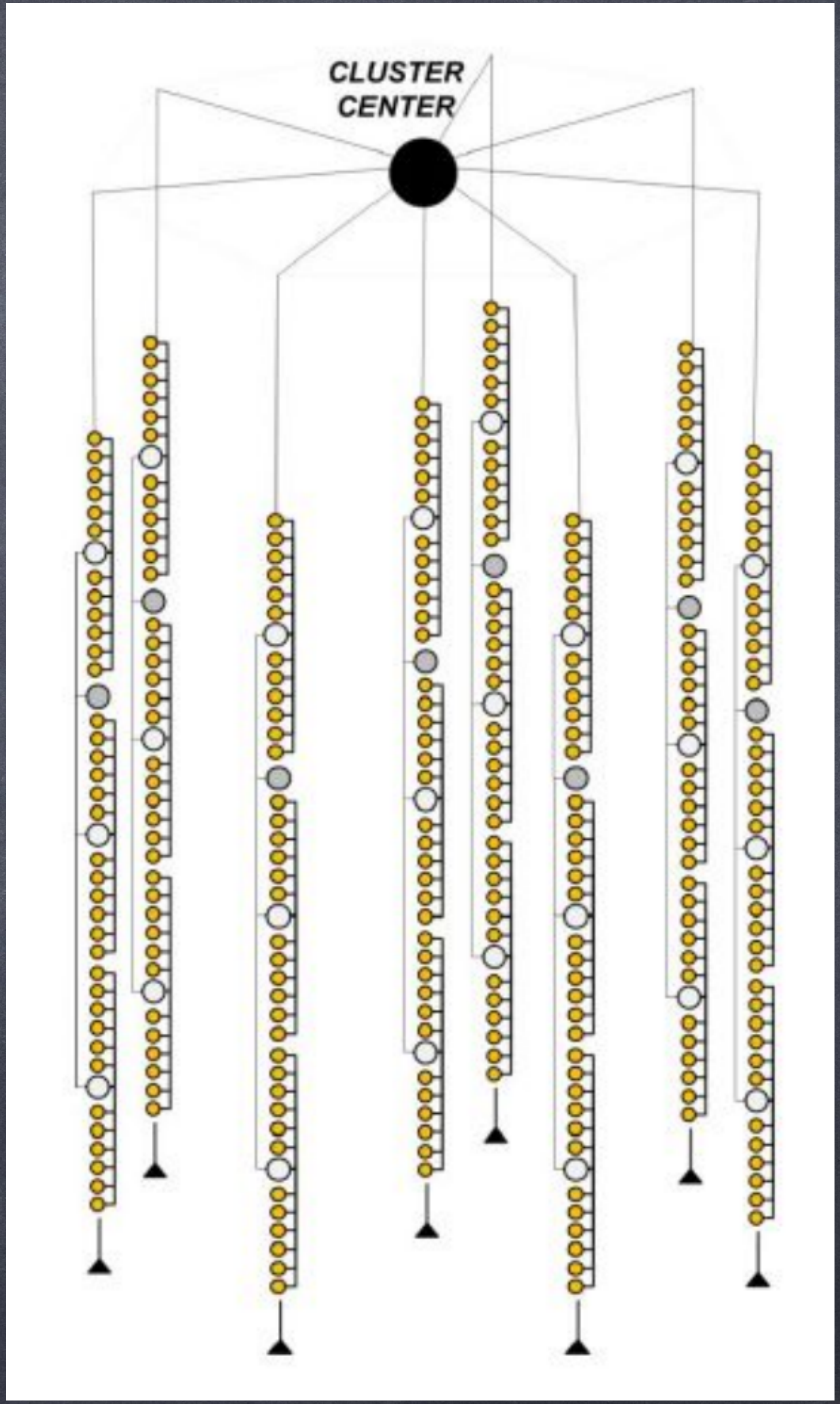
Baikal Neutrino Detector

The string

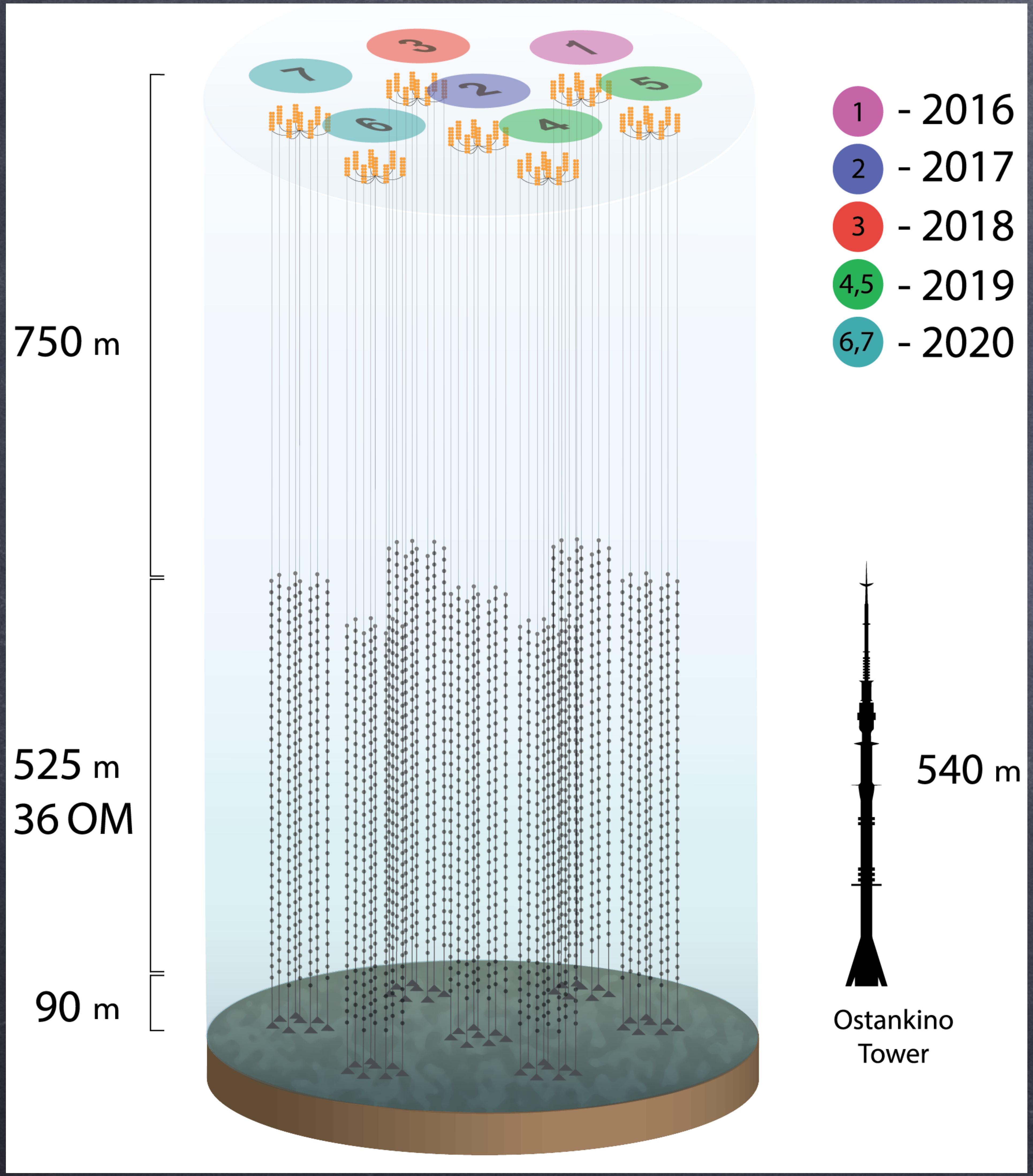


Baikal Neutrino Detector
→ The cluster

- 8 strings anchored to the bottom
- Cluster center @ 30 m from the surface
- OM spacing 15 m
- String spacing 60 m
- Trigger electronics
- Power & data transfer



Baikal Neutrino Detector
→ Seven clusters @2020



Year	Number of Clusters	Number of OMs
2016	*1*	*288*
2017	*2*	*576*
2018	*3*	*864*
2019	*5*	*1440*
2020	7	2016
2021	*9*	*2592*

- ~300 m between clusters
- + experimental string with optical link
  - Lower trigger thresholds
  - 1GB/s
  - Synchronized clocks
  - New FPGA Zync
- $V_{shower} = 0.35\ \mathrm{km}^3$

Baikal Neutrino Detector
→ Calibrations

- Geometry calibrations since OMs drift (0.5-3 cm/s) up to 50m (flows)
- Time synchronization
  - Between OMs in one section
  - Between sections
  - Between clusters
- Water properties
  - Absorption length
  - Scattering length, anisotropy

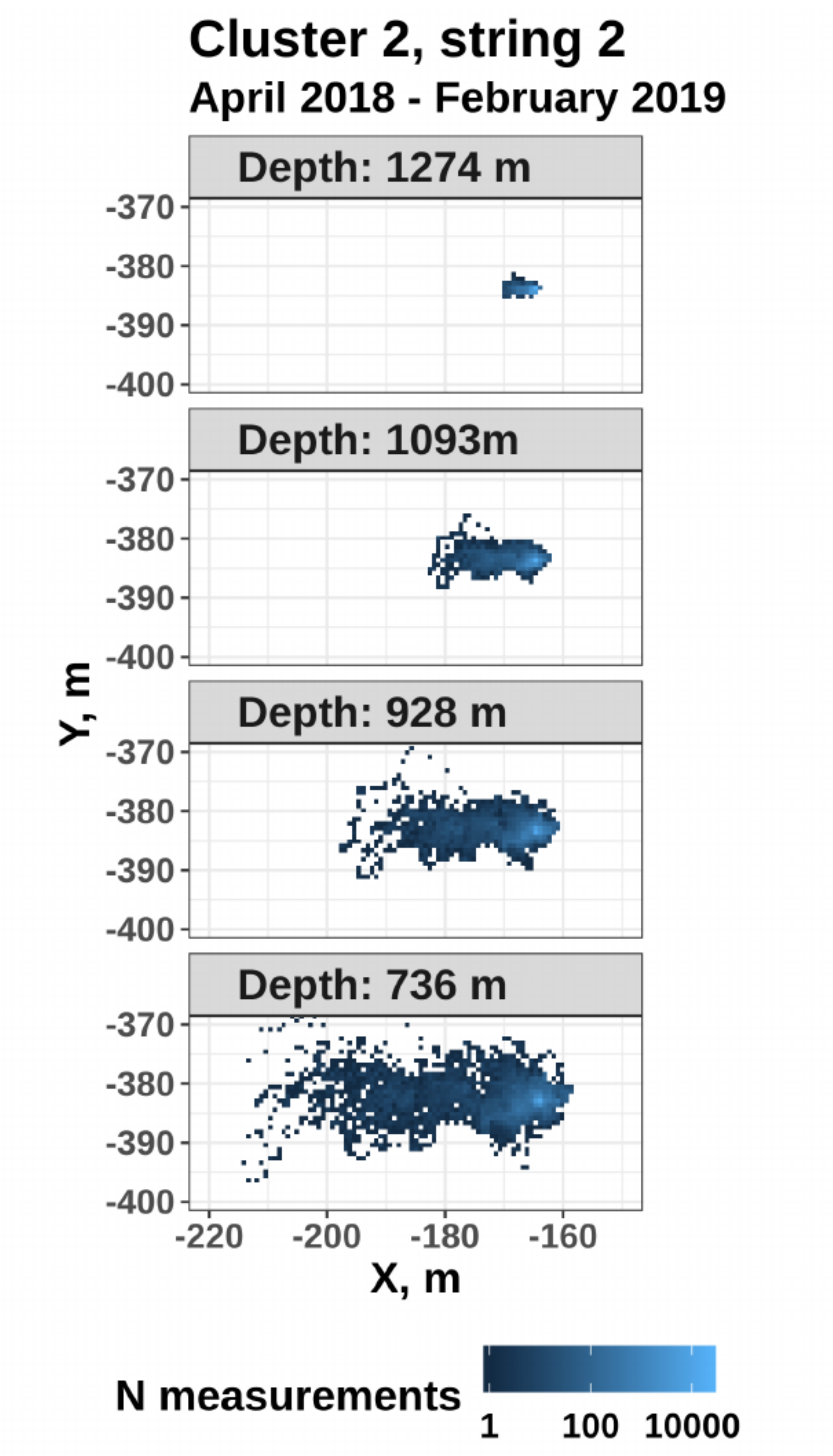
- Amplitude and charge

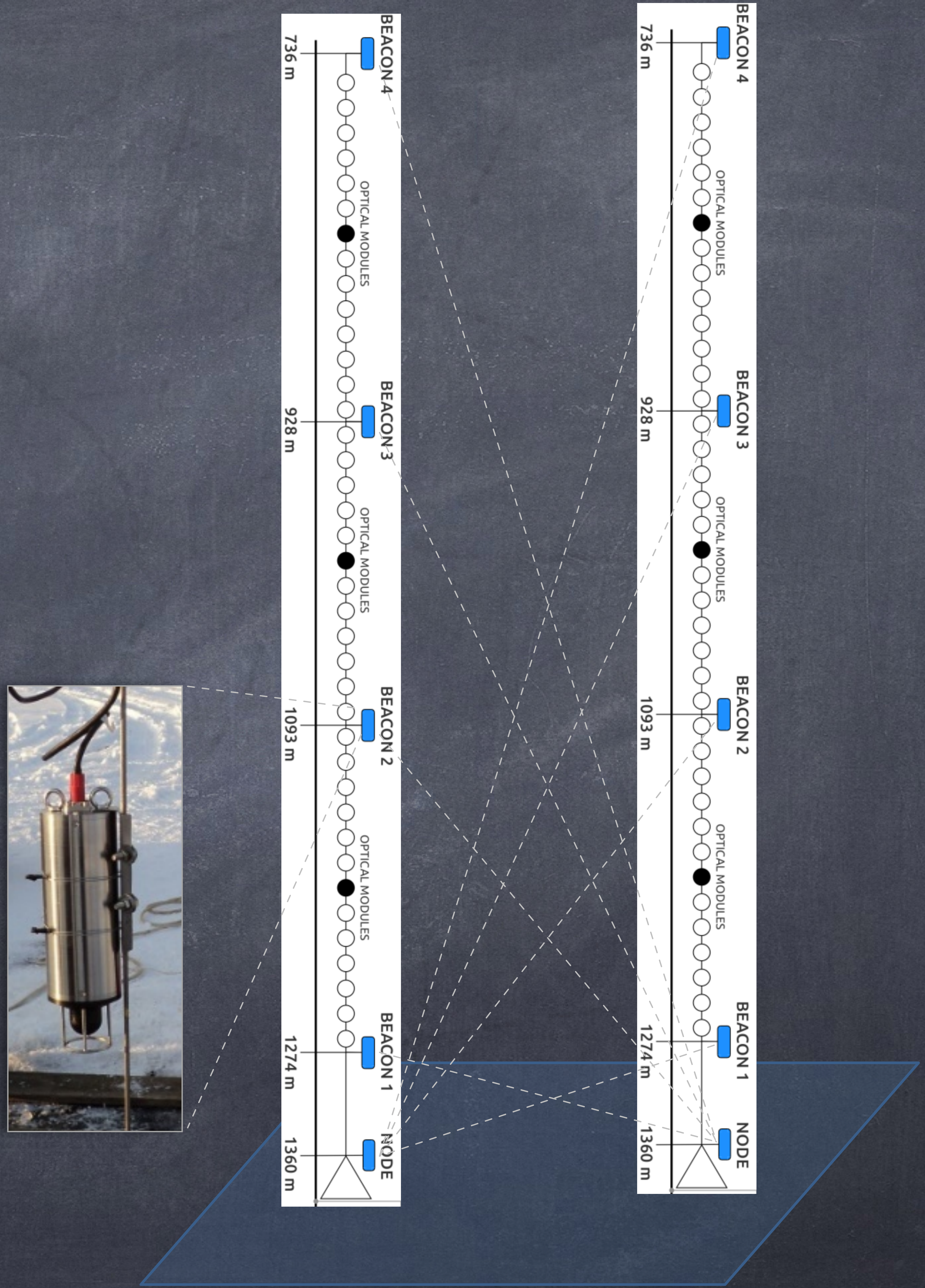
Baikal Neutrino Detector
Calibrations. Geometry

- Acoustic modems by EvoLogics (Germany)
- Polls every two-three minutes
- Accuracy in OM's position determination < 20 cm
- 3D Accelerometer & compass in each OM with comparable precision

Baikal Neutrino Detector
→ Calibrations. Geometry

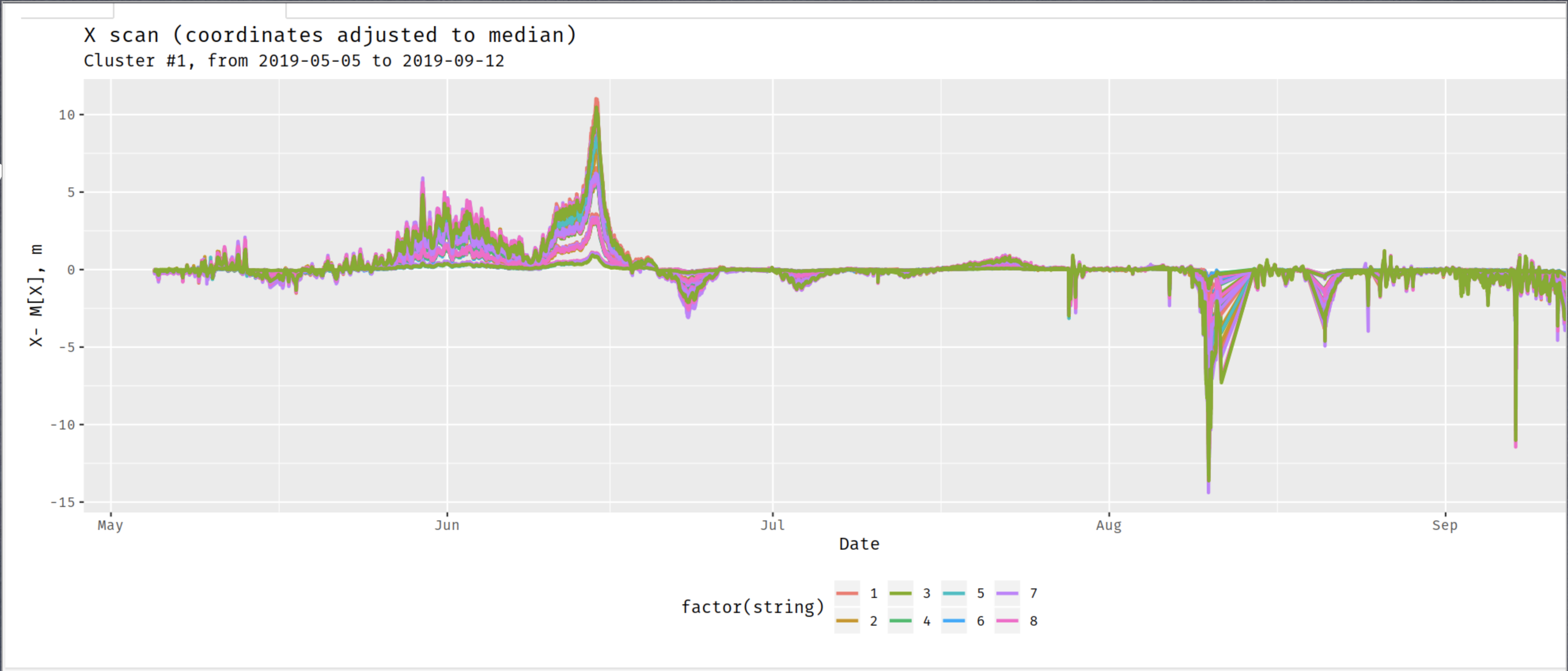
An example from data





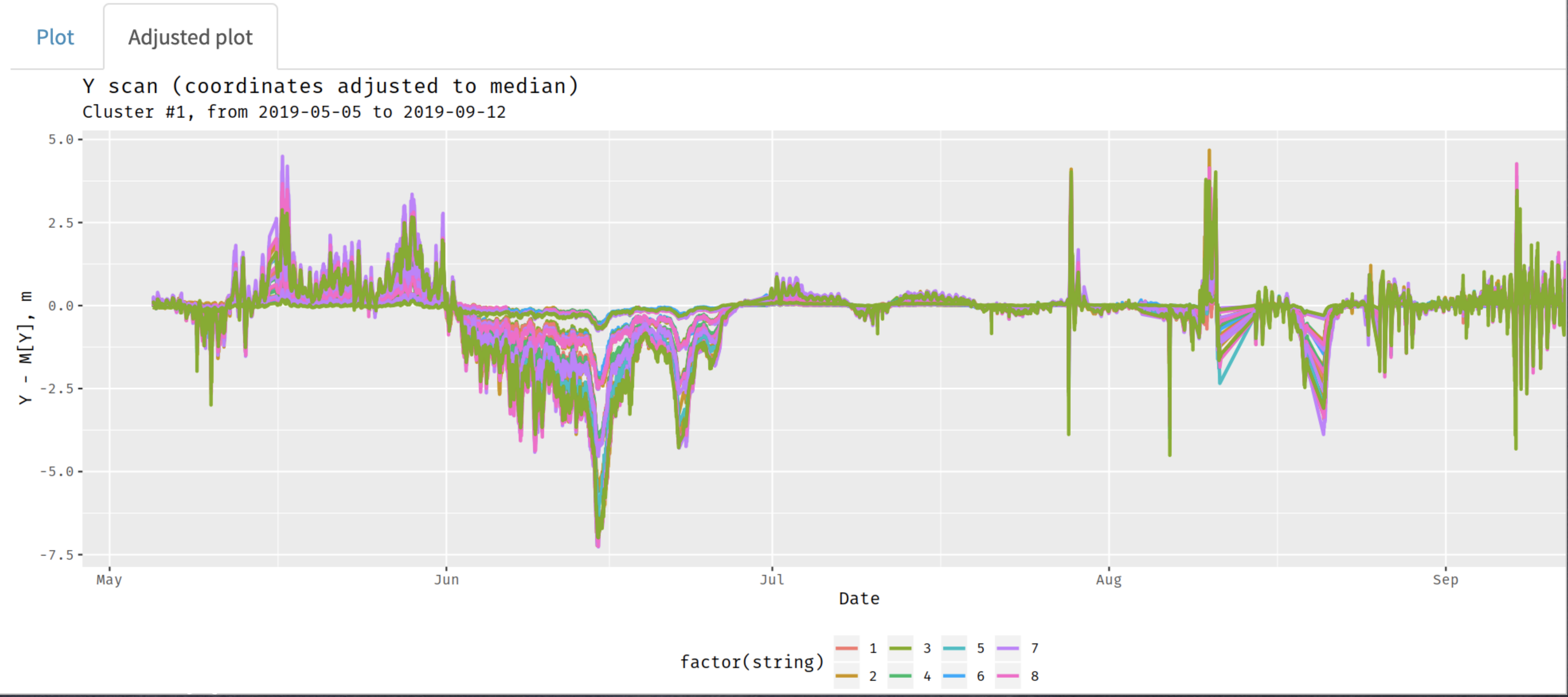
Baikal Neutrino Detector

→ Calibrations. Geometry



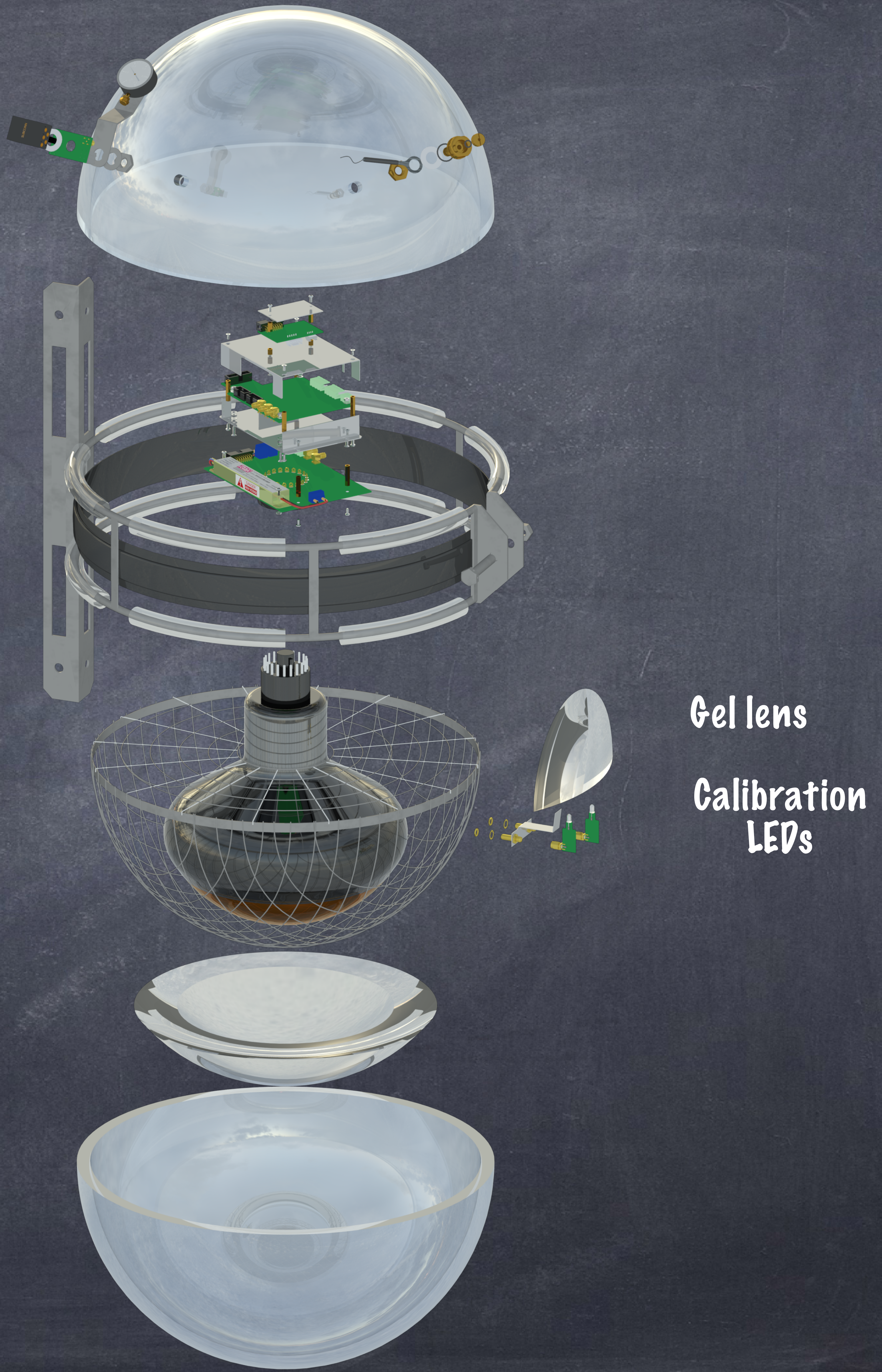
Variation of OM position

Y scan

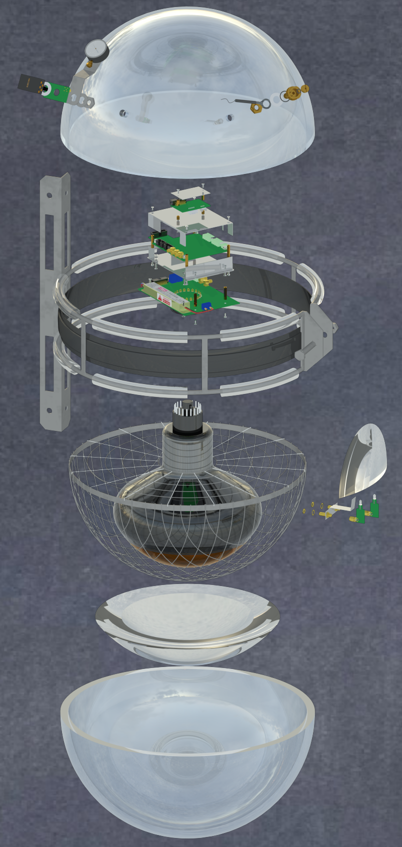


Baikal Neutrino Detector
→ Calibrations. Time

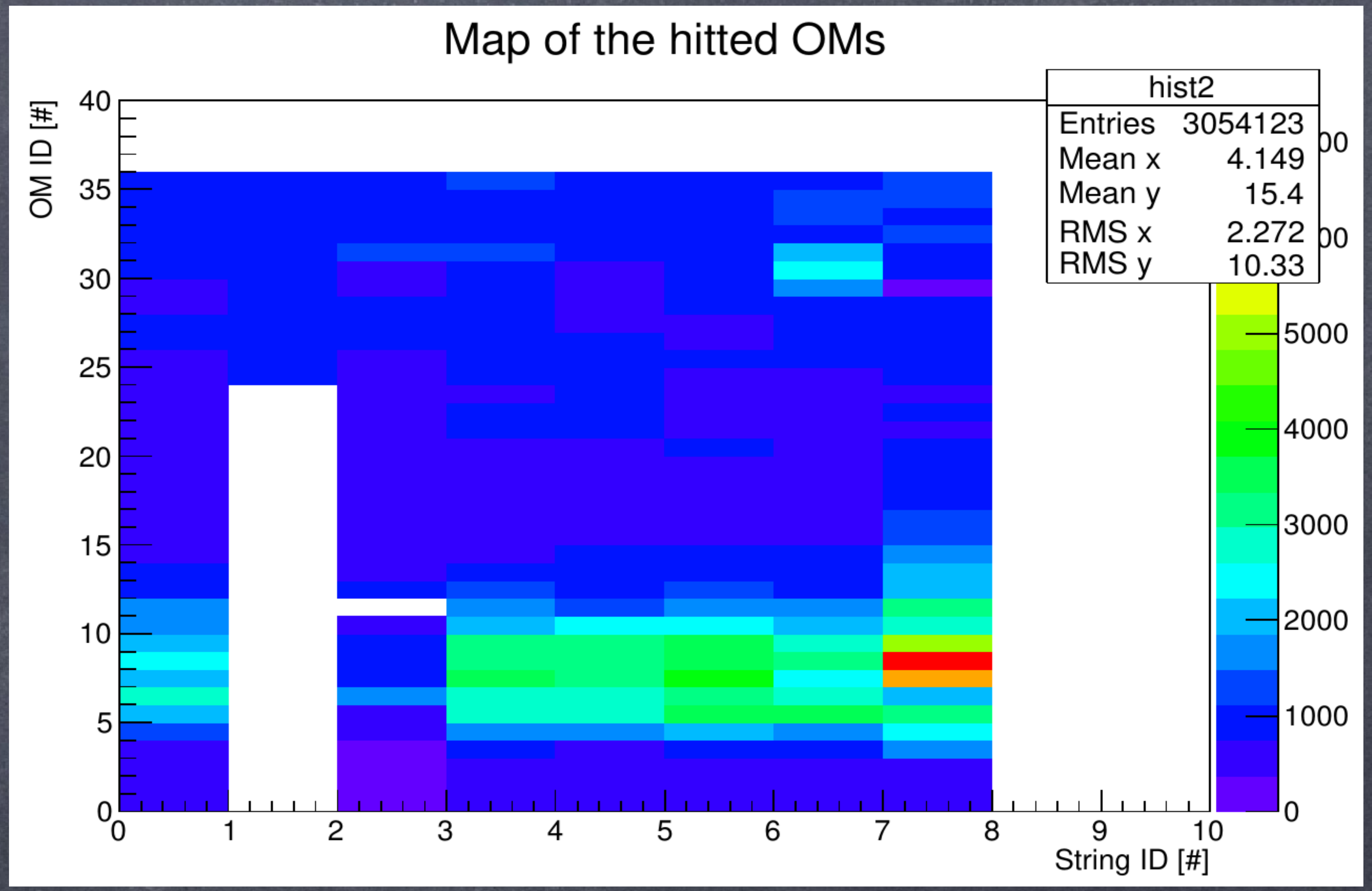
- Time synchronization
  - Between OMs in one section



Baikal Neutrino Detector
→ Calibrations. Time



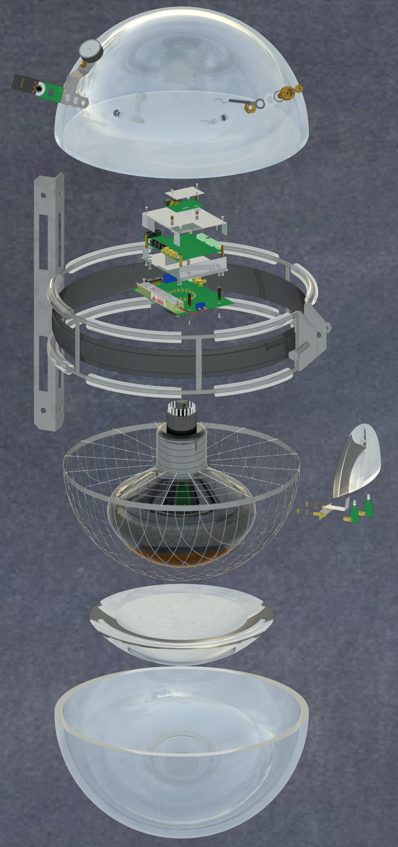
- Time synchronization
    - Between OMs in one section
    - Between sections

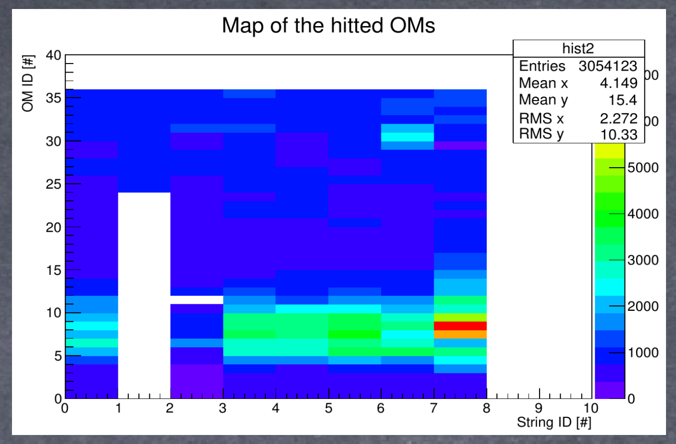


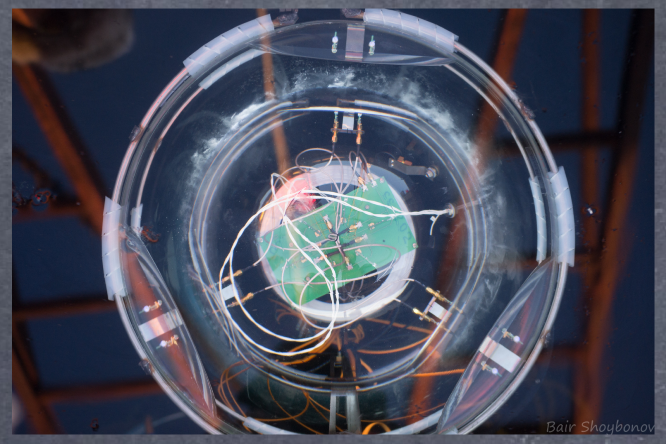
Baikal Neutrino Detector

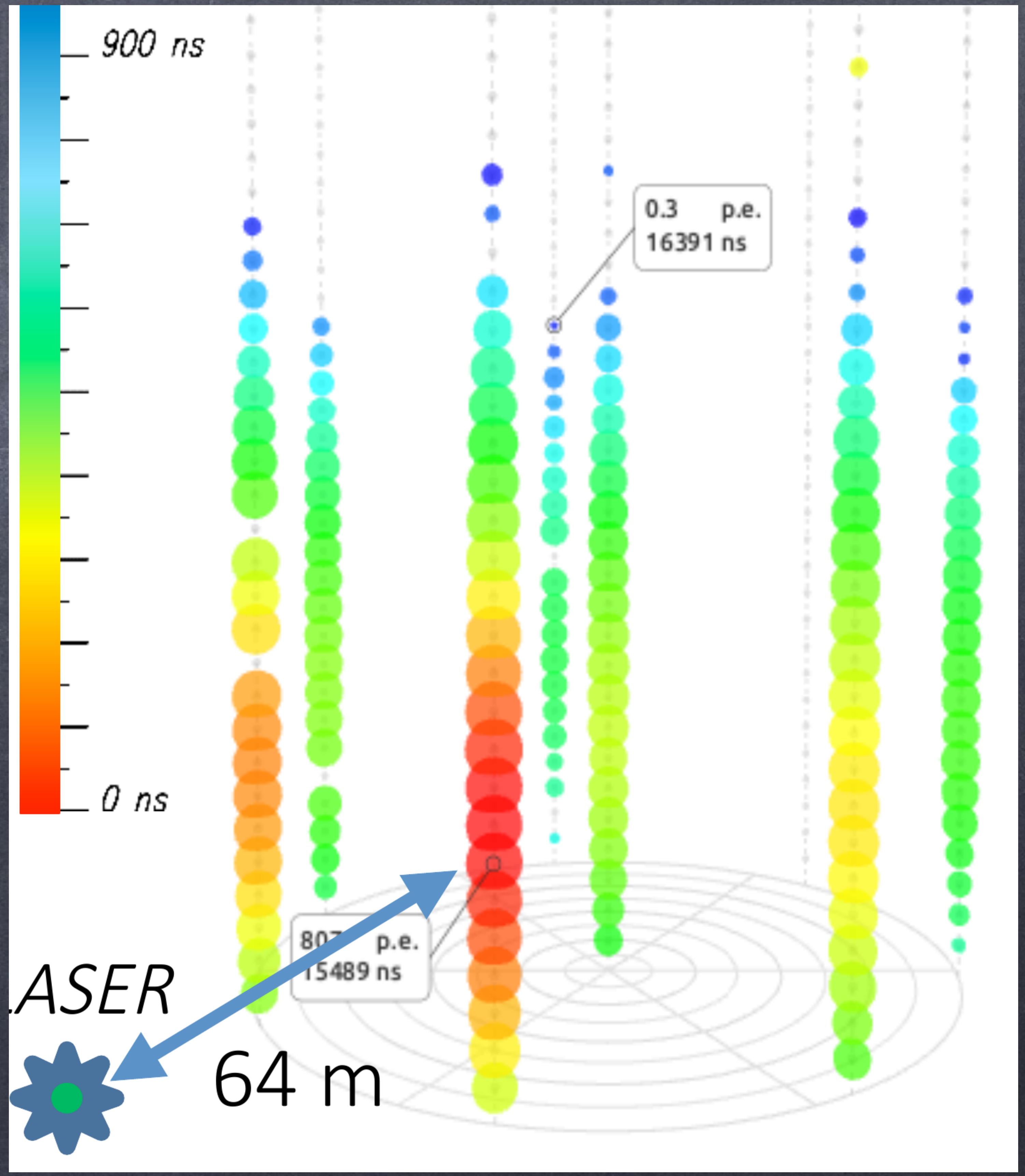
→ Calibrations. Time

- Time synchronization
  - Between OMs in one section
  - Between sections
  - Between clusters
    - Isotropic lasers (532 nm, 10^{15} photons, 1 ns
    - 2.5 ns inter- and extra-section synchronization
    - Few ns between clusters



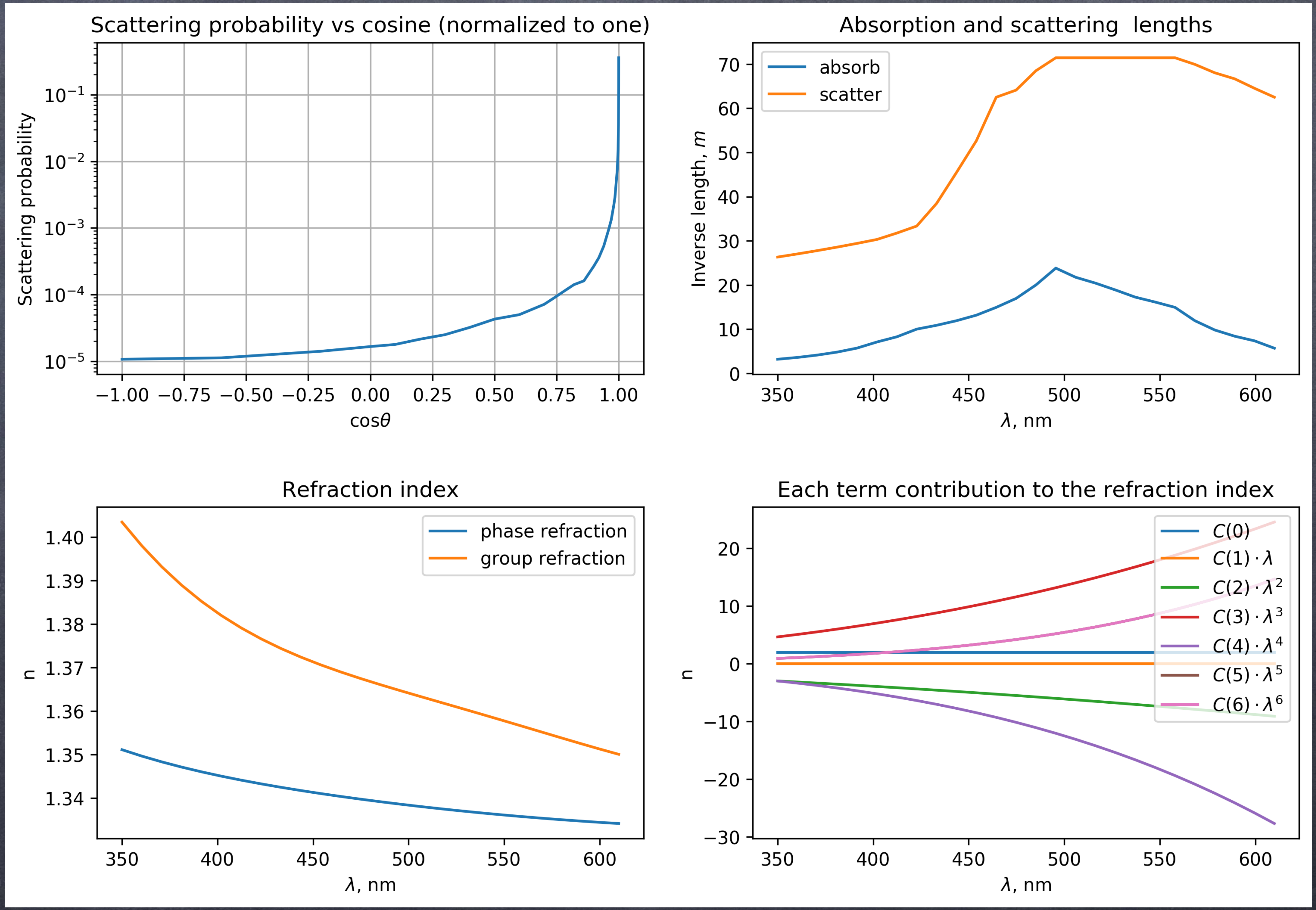






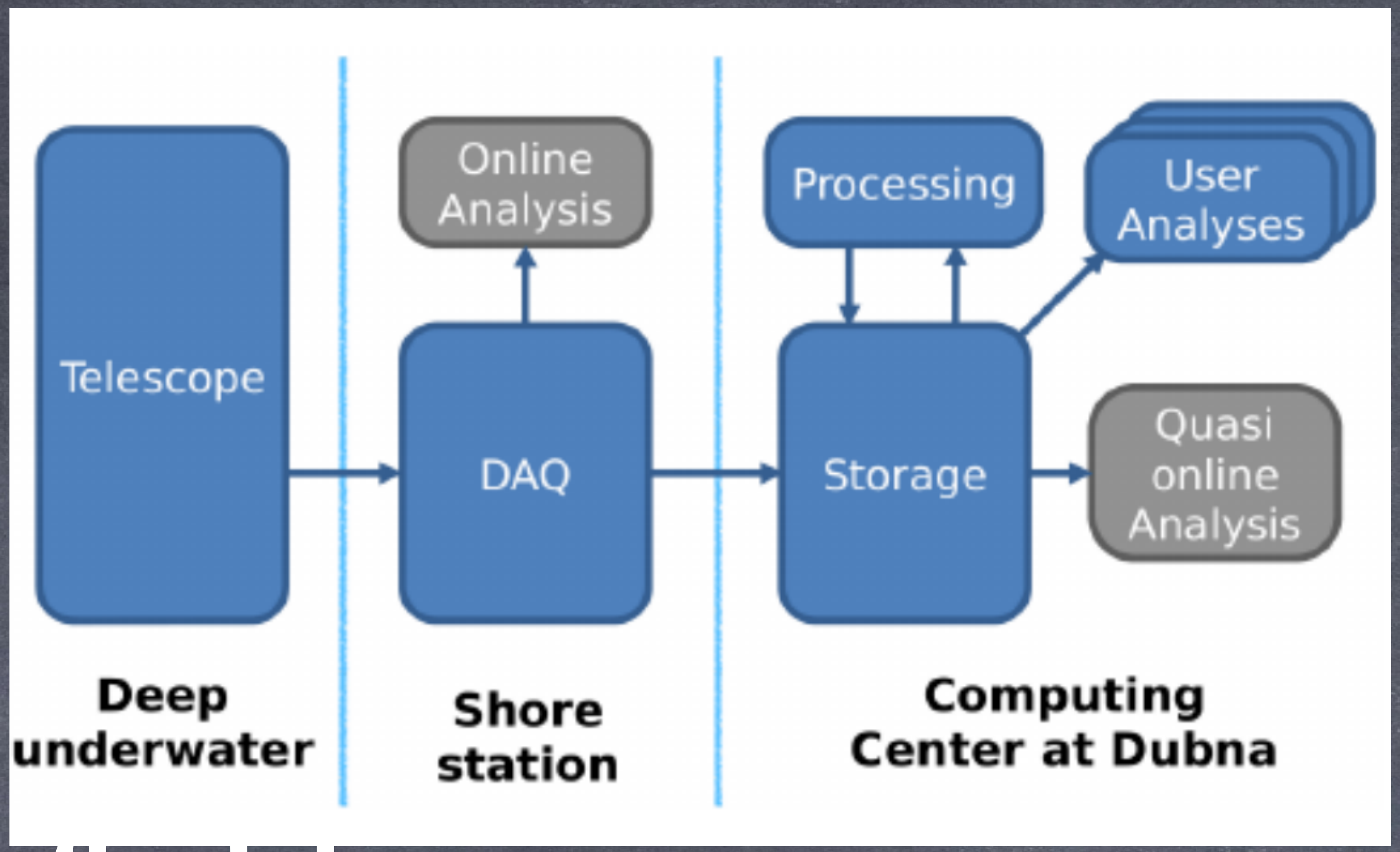
Baikal Neutrino Detector
↳ Calibrations. Water properties

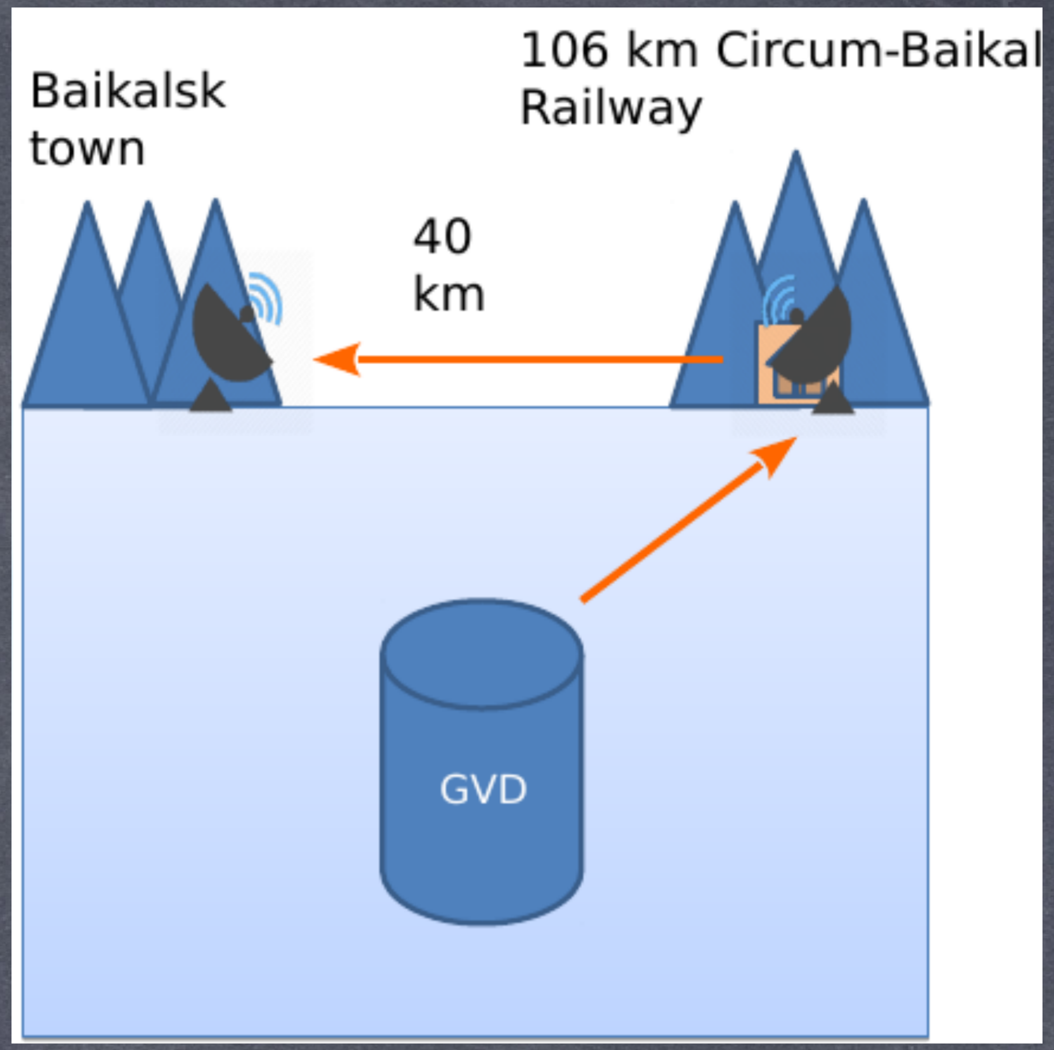
- Water properties
  - Absorption length
  - Scattering length, anisotropy
- Past measurements
- Use existing lasers
- Preparing new system for online monitoring



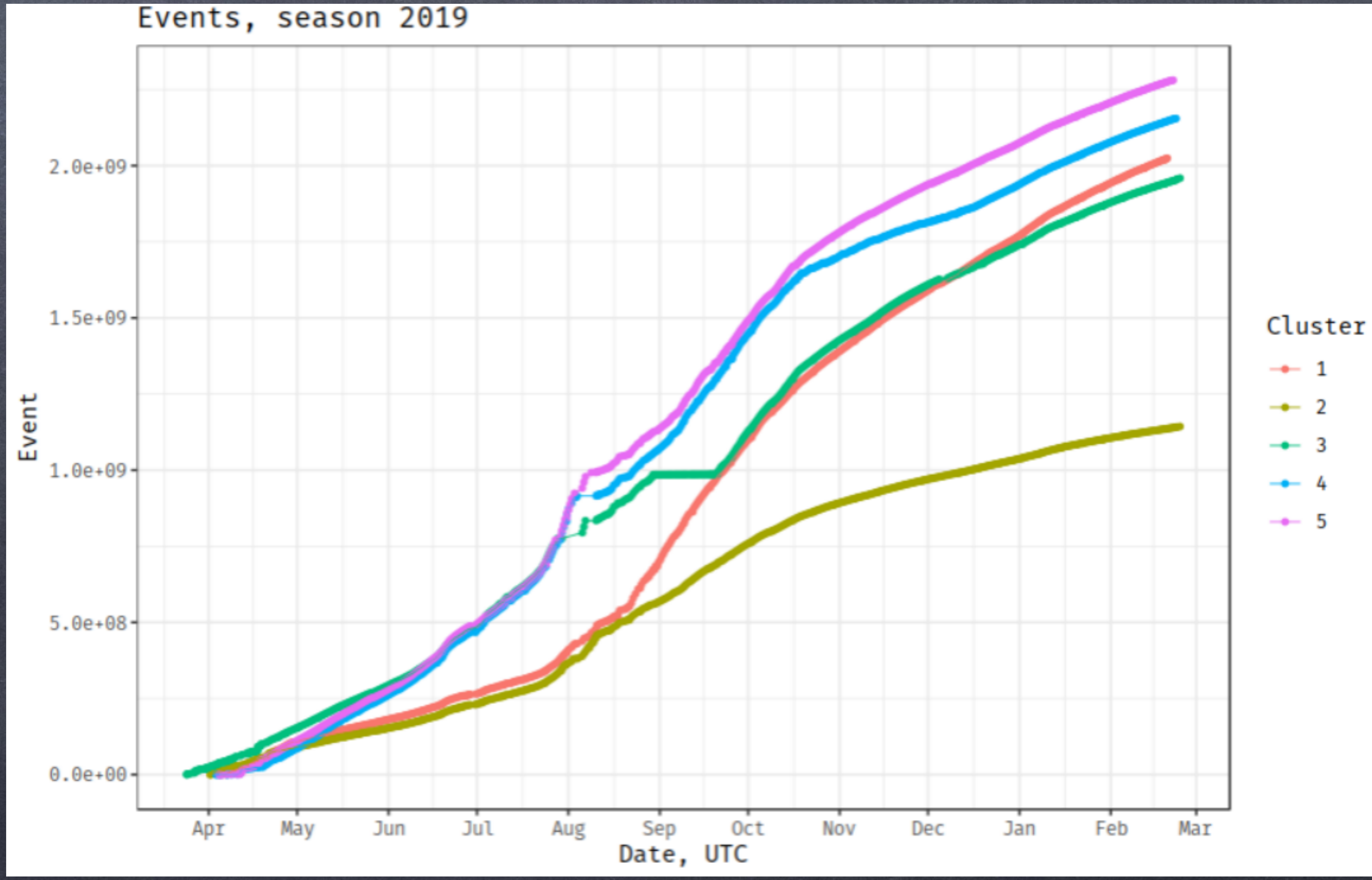
Baikal Neutrino Detector
→ Data transfer

накопление событий
2019





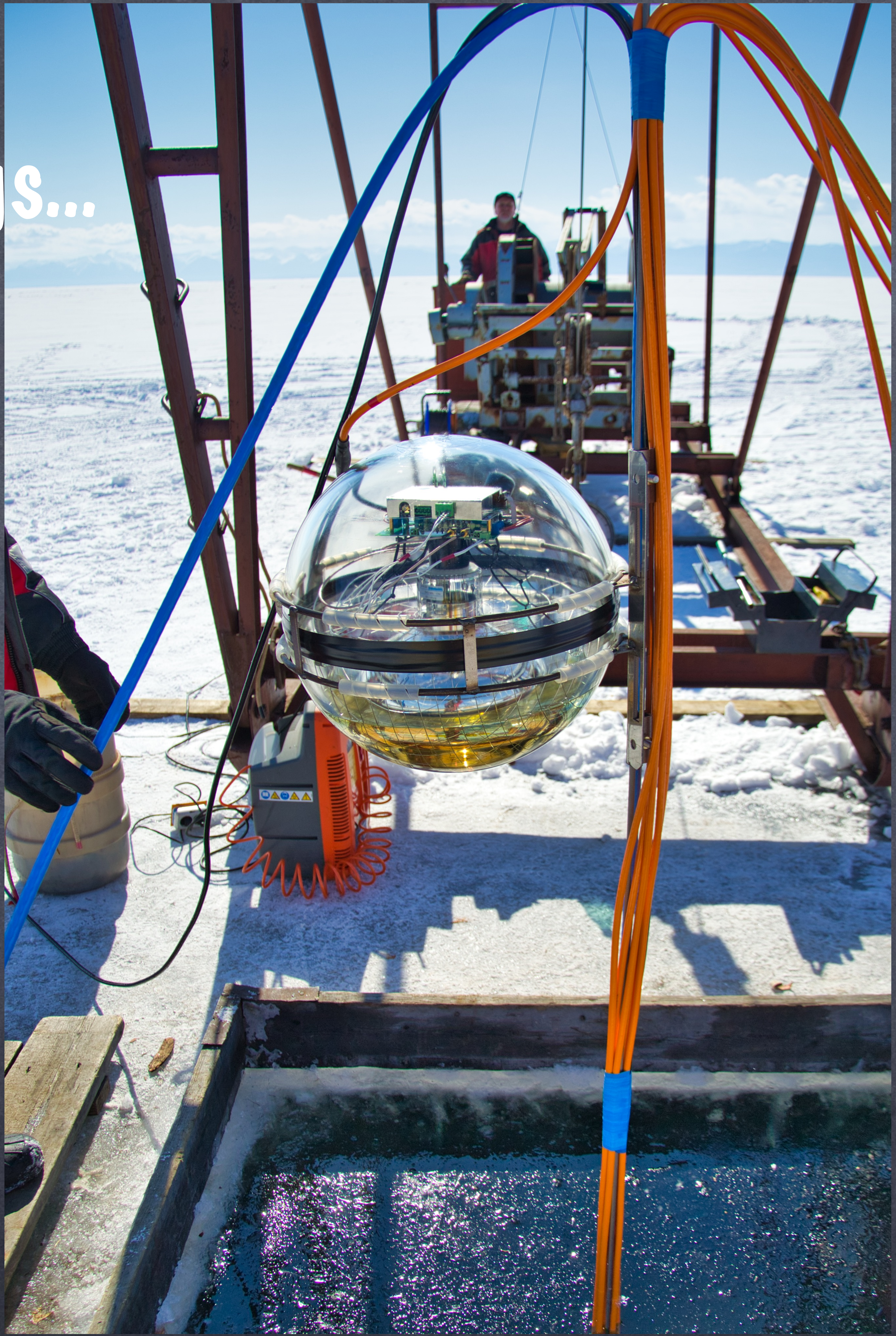
- 40 Gb/day/cluster
- 250 Mb/s radiochannelx with Baikalsk
- Transfer data to JINR
- Automatic data processing @JINR
- Data analysis @ computer farm @JINR



GVD Deployment

↳ Works on the site

GVD Deployment
↳ OMs, strings...

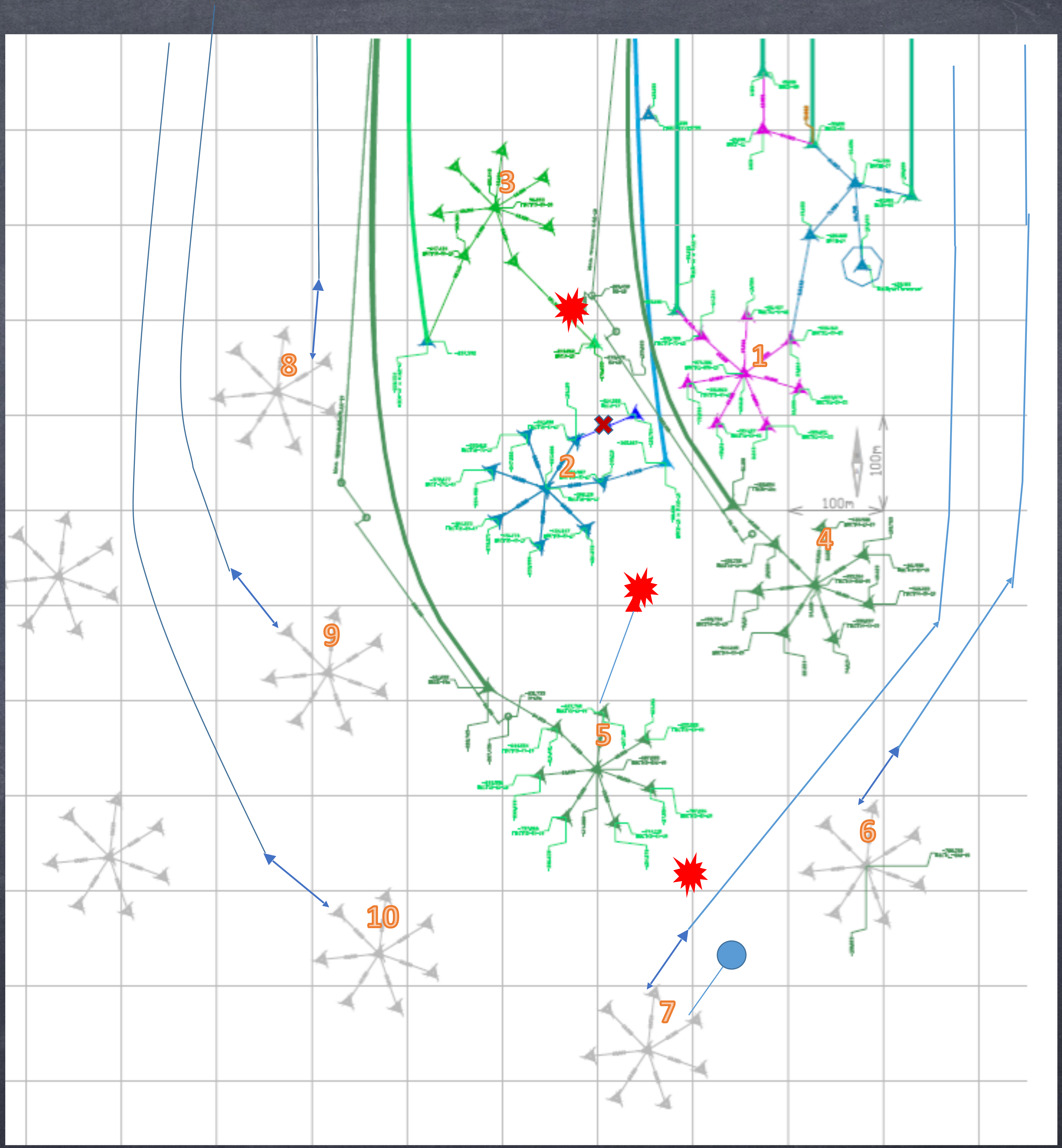


GVD Deployment

→ Cabling

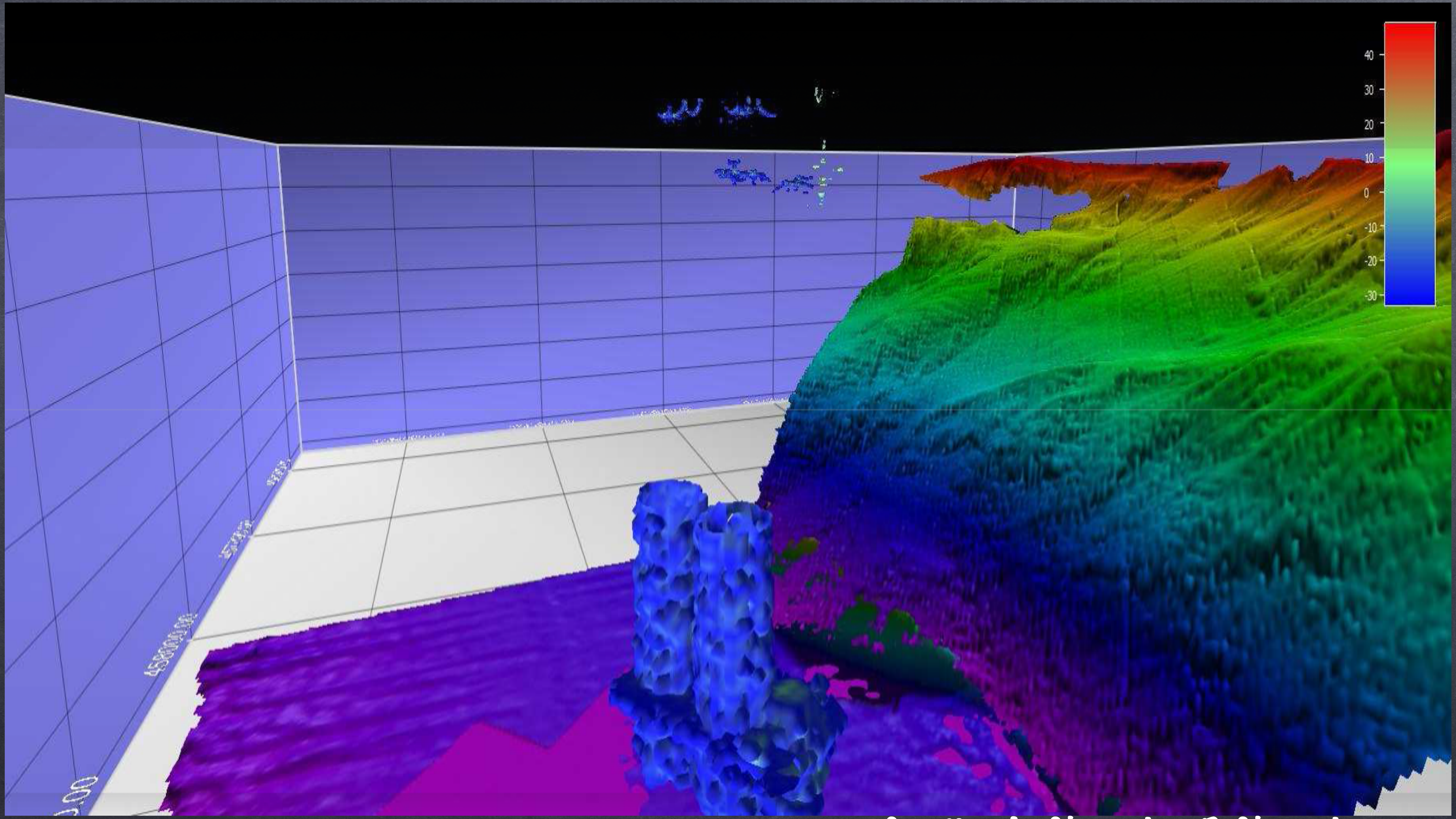
GVD Deployment
→ Cabling

- Cables are several km long
- Calculation of cable's routes is a difficult engineer task
- Installation of cables is always a challenge
- Optics (data, control) + HV cables



GVD Deployment

→ Real sonar underwater image



Credit: A. Chensky, D. Chensky

GVD Deployment

→ Facilities


OM production line @JINR (12 OM/day)

The control center

The local lab & storage @Baikalsk

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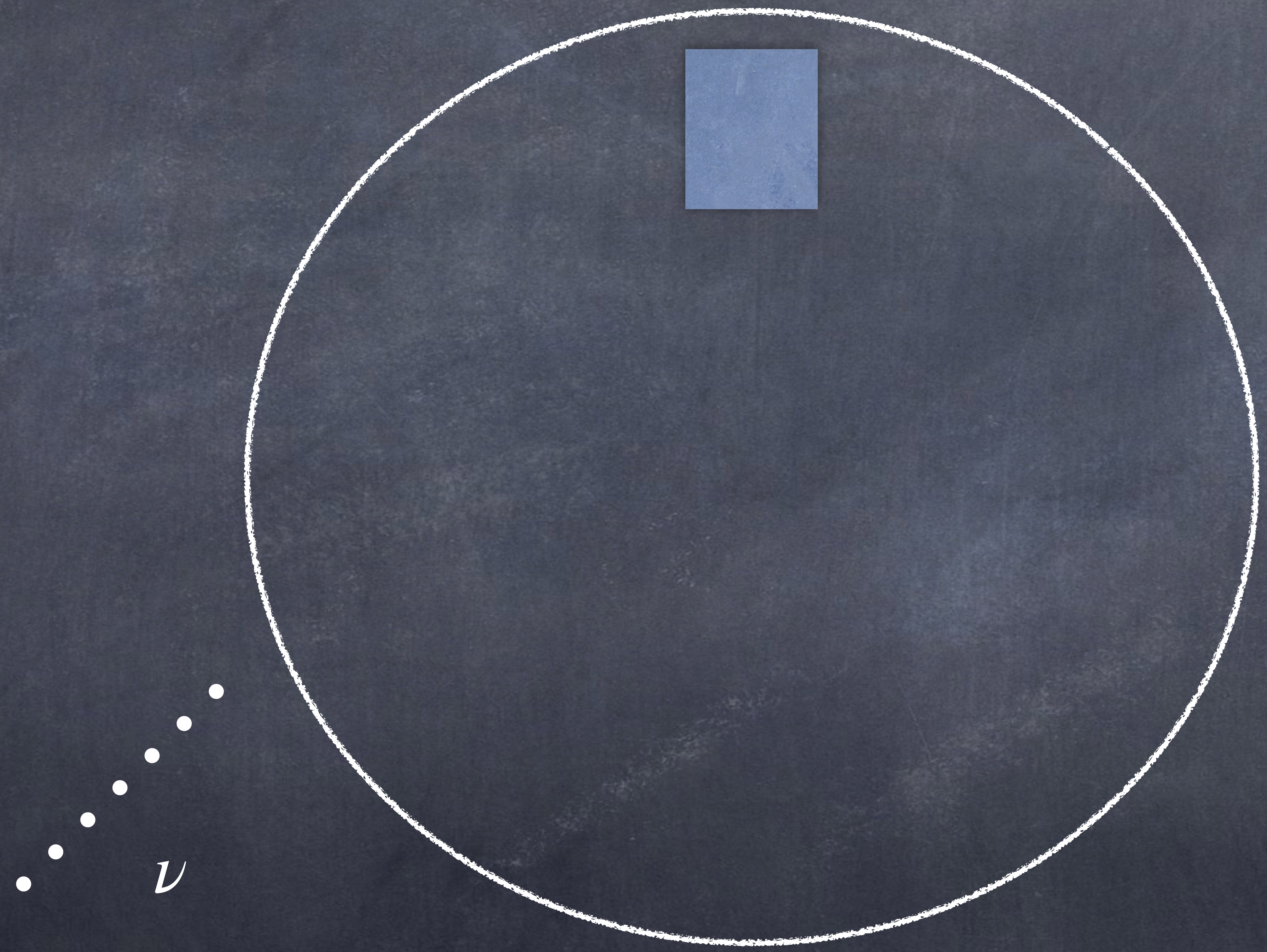
GVD Deployment

→ Ice cover during expedition 2020

Despite the terrible ice everything was accomplished according the plan

Data analysis

↳ Simulations. Signal expectation



Data analysis

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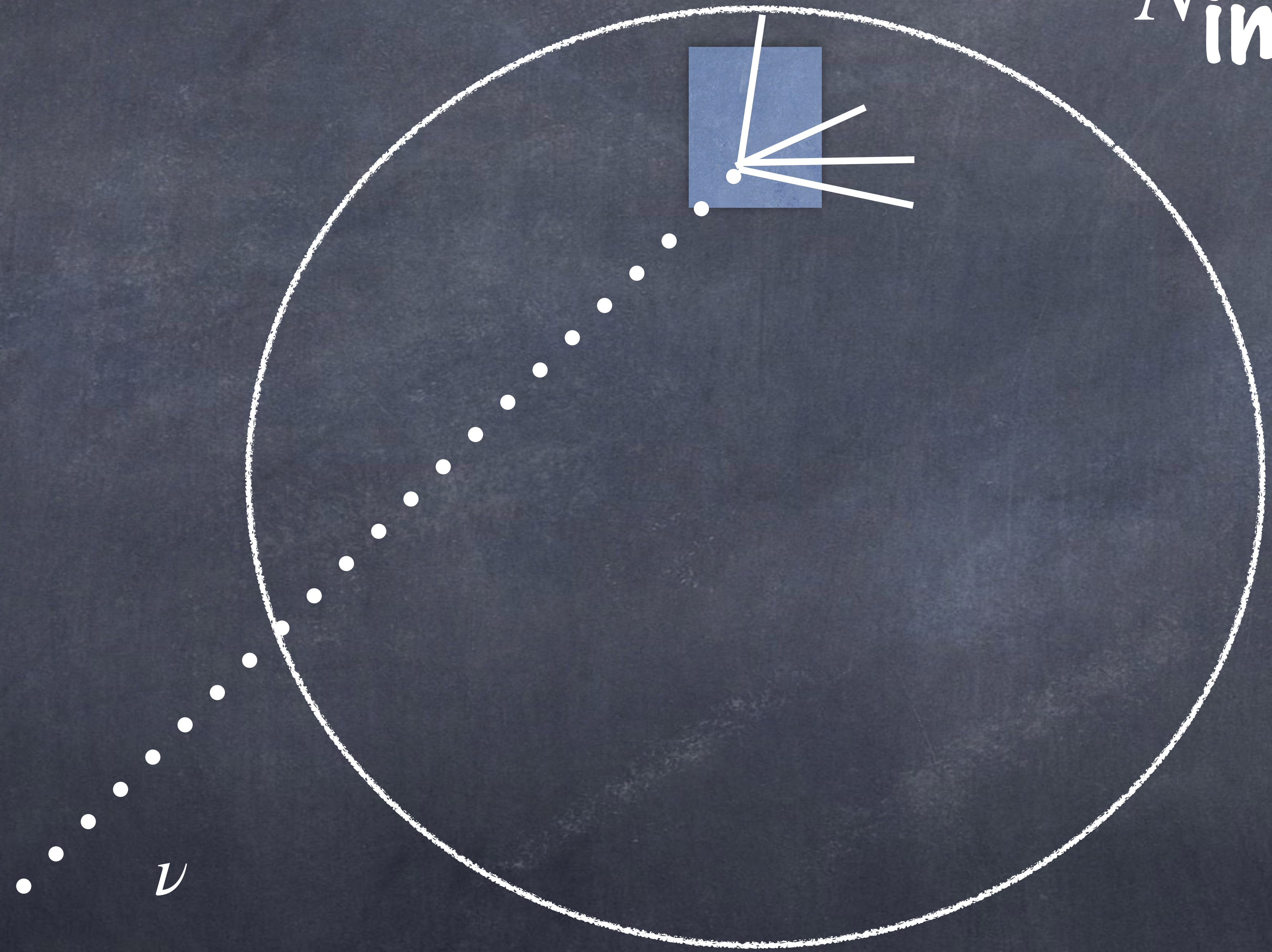


$$N_{\text{int}} \propto \Phi_\nu \times \sigma \times \text{mass} \times \text{time}$$

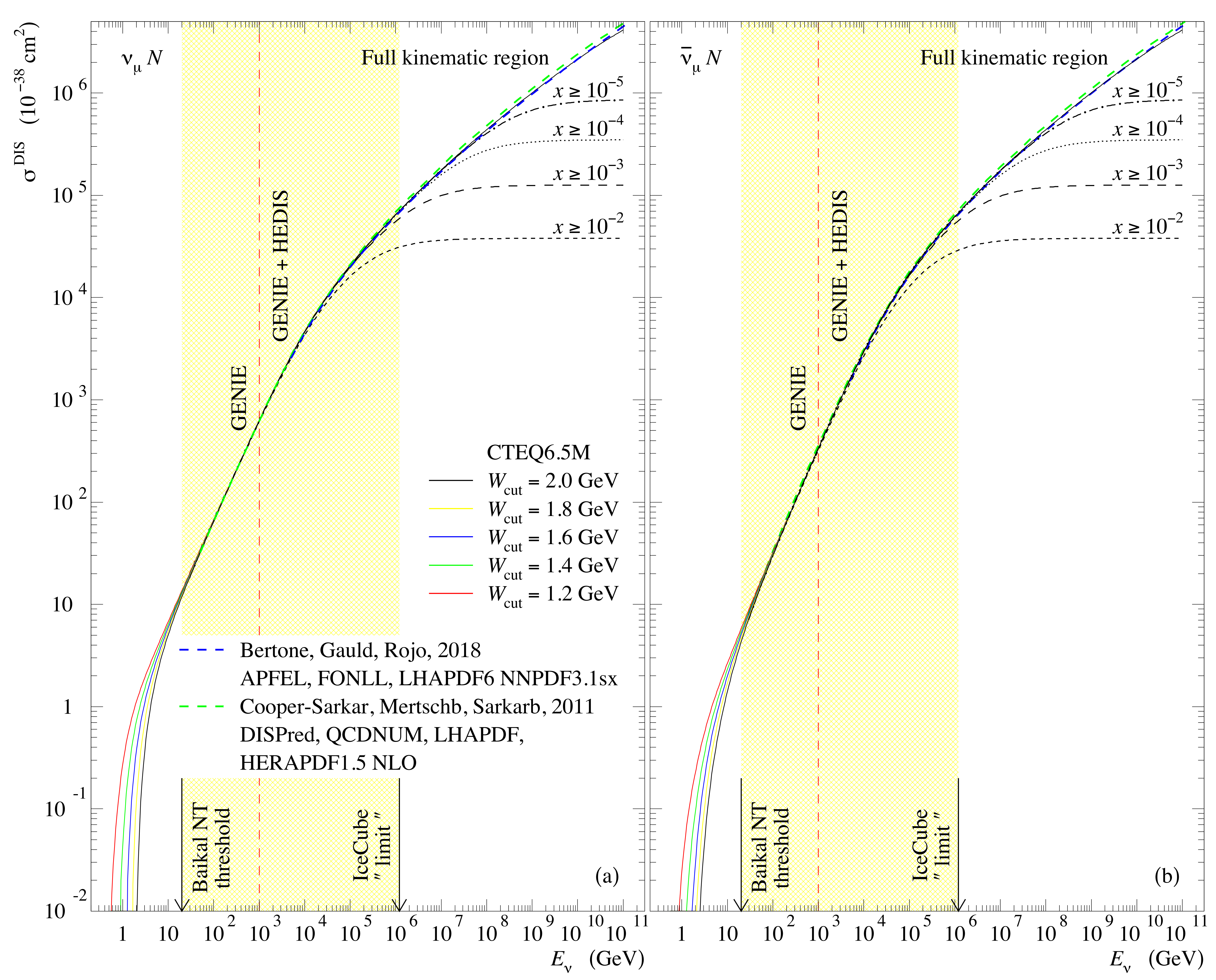
- Φ_ν = neutrino flux
- σ = neutrino-target cross-section
- mass = detector mass
- time = obs. time

Data analysis

→ Simulations. Neutrino-nucleon Deep-inelastic (DIS) cross-section (via W-exchange)

$$\frac{d^2\sigma}{dxdy} \propto \frac{G_F^2 m_N E_\nu}{\pi}\left(\frac{m_W^2}{Q^2+m_W^2}\right)^2\left(\sum_{i=d,s,b} q_i(x) + (1-y)^2 \sum_{j=u,c,t} \overline{q_j}(x)\right)$$

- G_F = Fermi constant
- y = fraction of the neutrino momentum transferred to hadrons
- x = fraction of the nucleon momentum carried by a target quark
- $q(x)$ = probability to find a quark in the nucleon with x

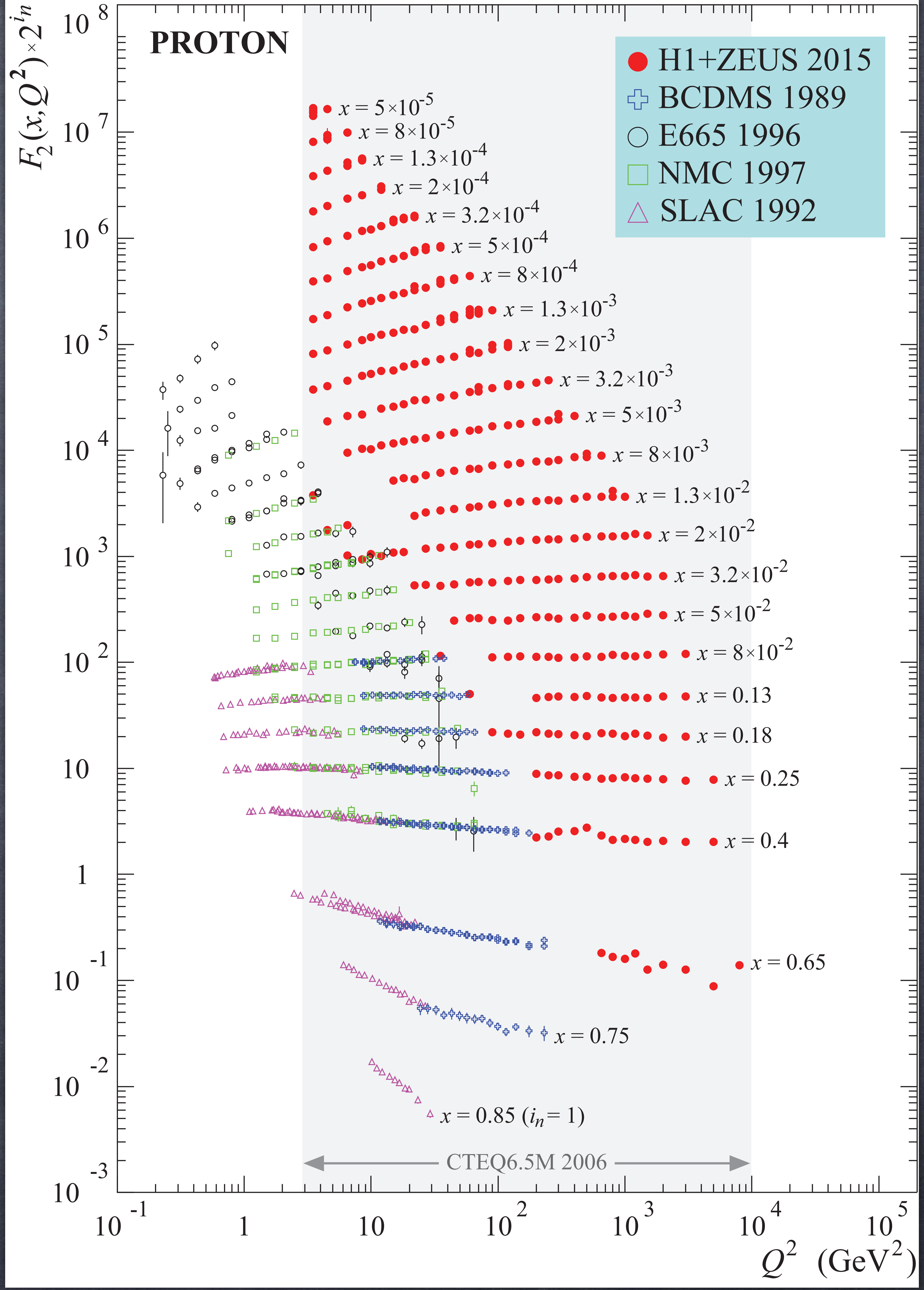


Credit: K.Kuzmin

Data analysis

→ Simulations. Neutrino-nucleon Deep-inelastic (DIS) cross-section (via W-exchange)

- The data is available for Neutrino Telescopes energies
- ANIS Neutrino Generator
- GVD Neutrino Generator (under development)
- Neutrino propagation through Earth



Credit: K.Kuzmin

Data analysis

→ Simulations. Muons

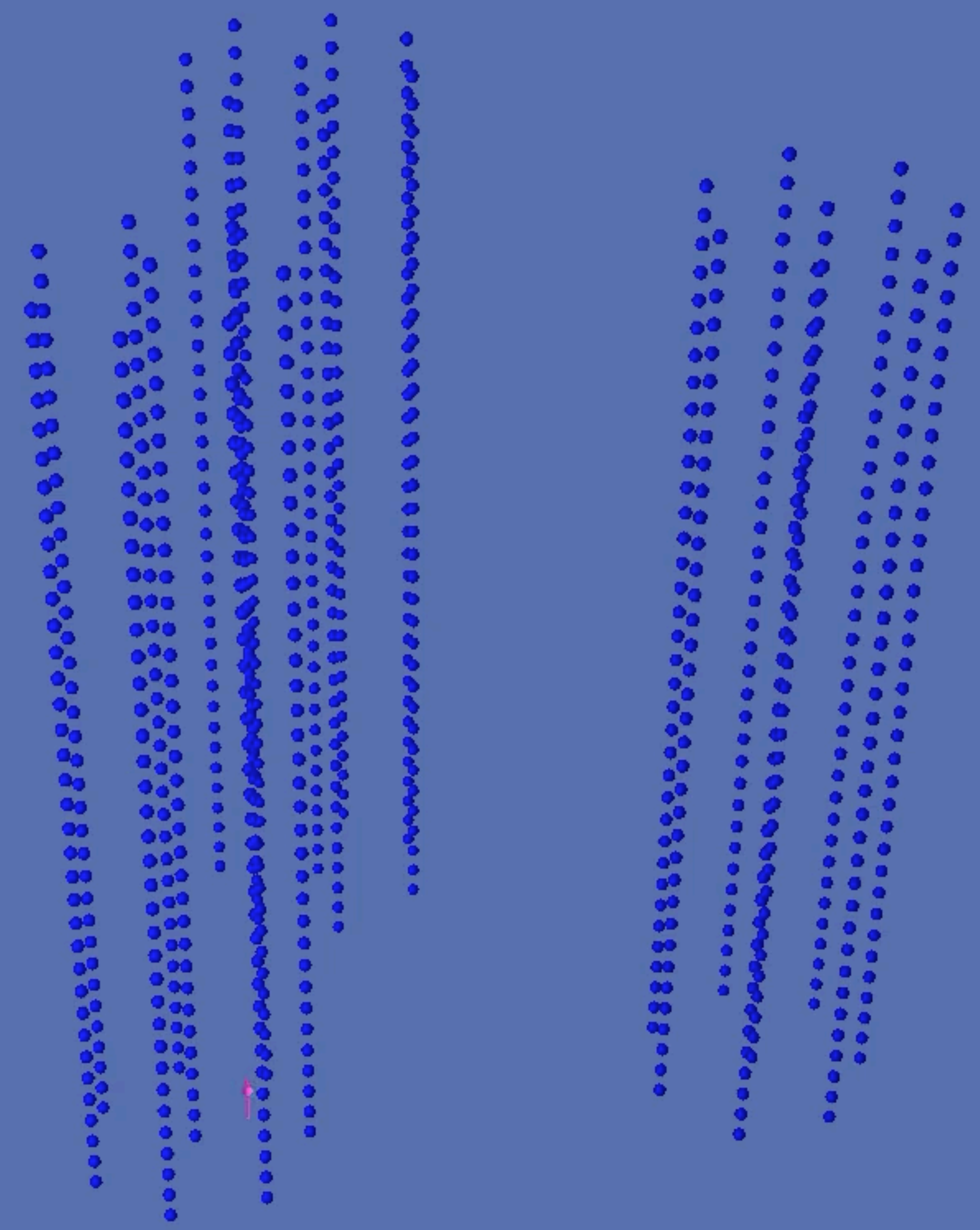
- Muons are the most significant background $\frac{N_\mu}{N_\nu} \simeq \frac{10^6}{1}$
- Flux calculation
  - Transport equation
  - CR fluxes + CORSIKA
- Muon transport
  - MUM PHYSICAL REVIEW D, VOLUME 64, 074015
  - Geant4

Data analysis

└→ Simulations. Optics

- Fortran code (legacy from NT200)
- New Geant4 based under development

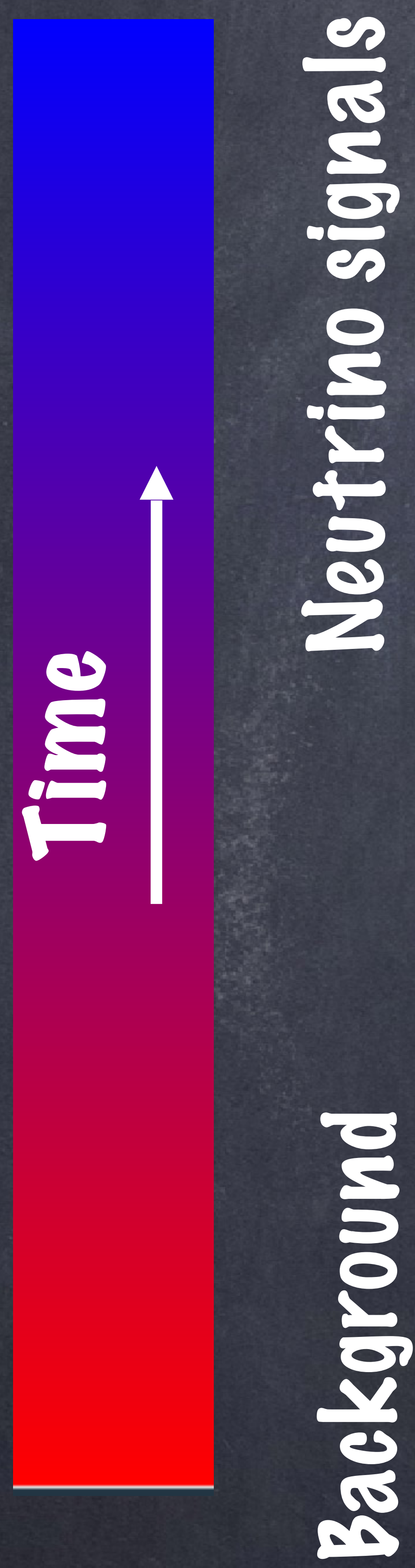
- 1 TeV muon + any light in Geant4
- OM response
- Mayavi viewer

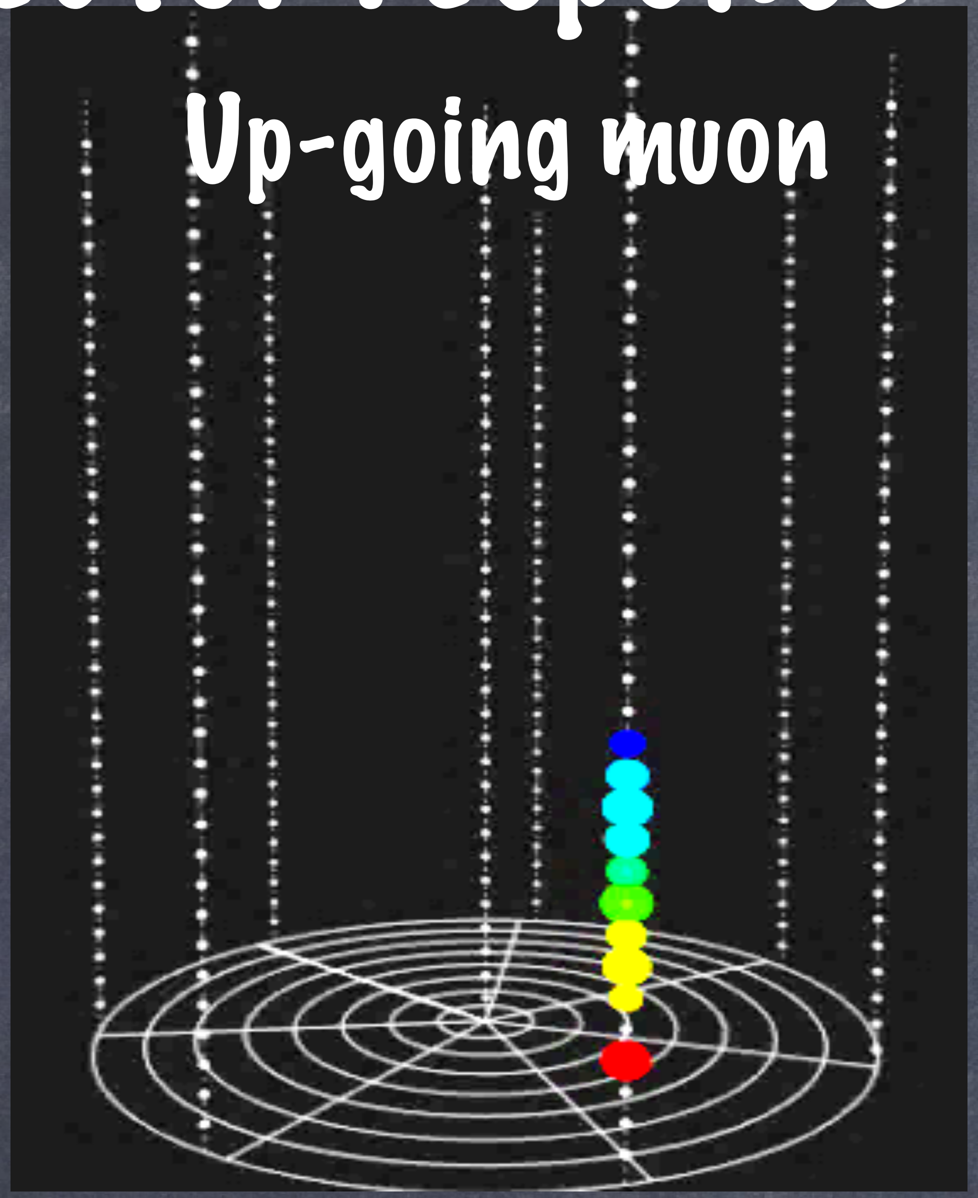


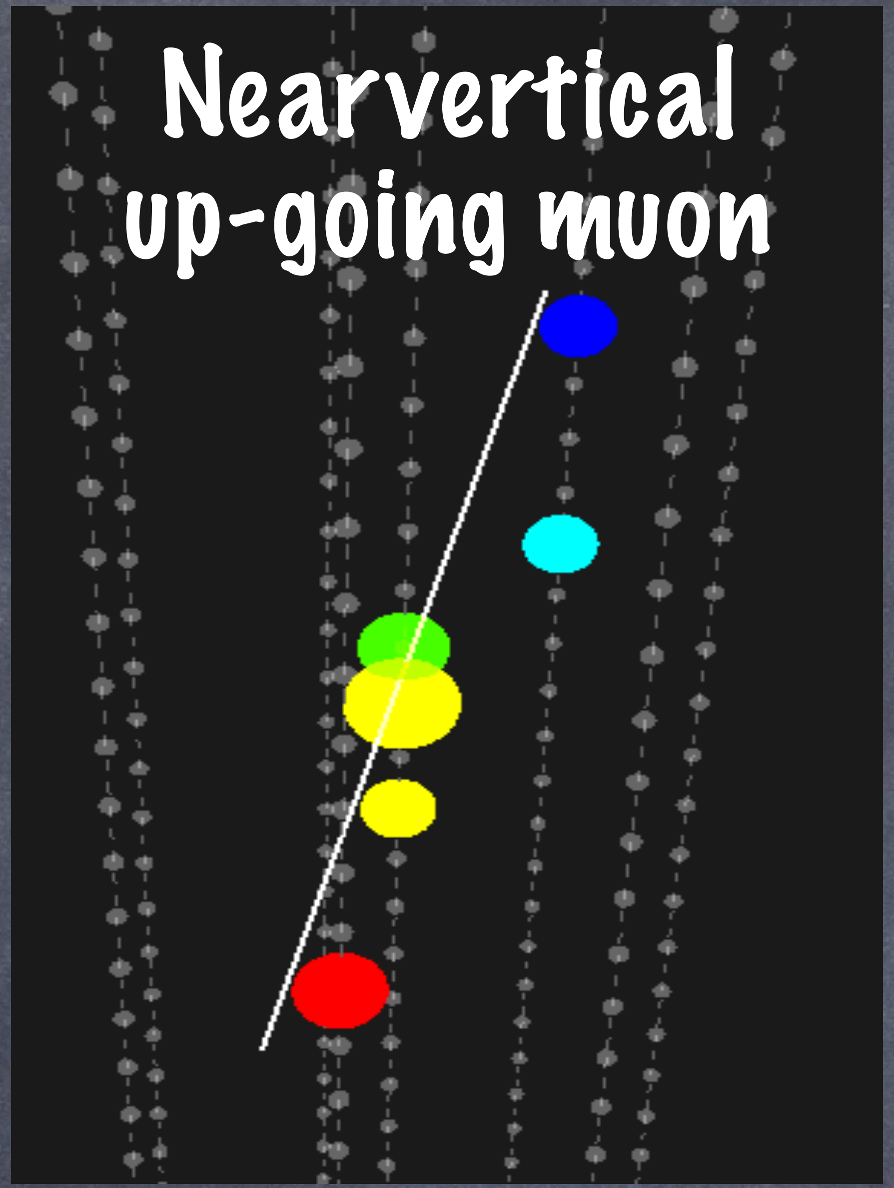
Credit: Yu. Malyshkin

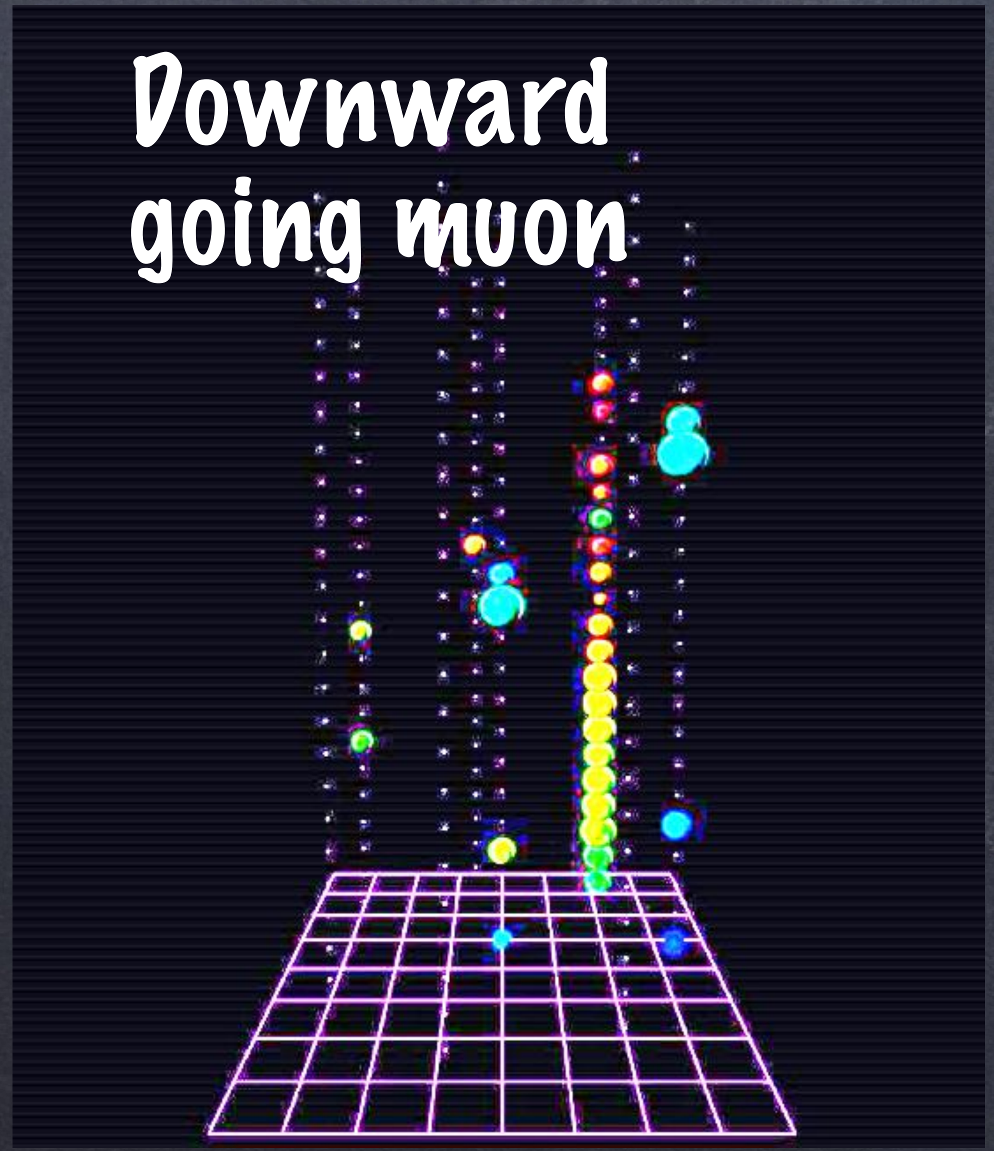
Data analysis

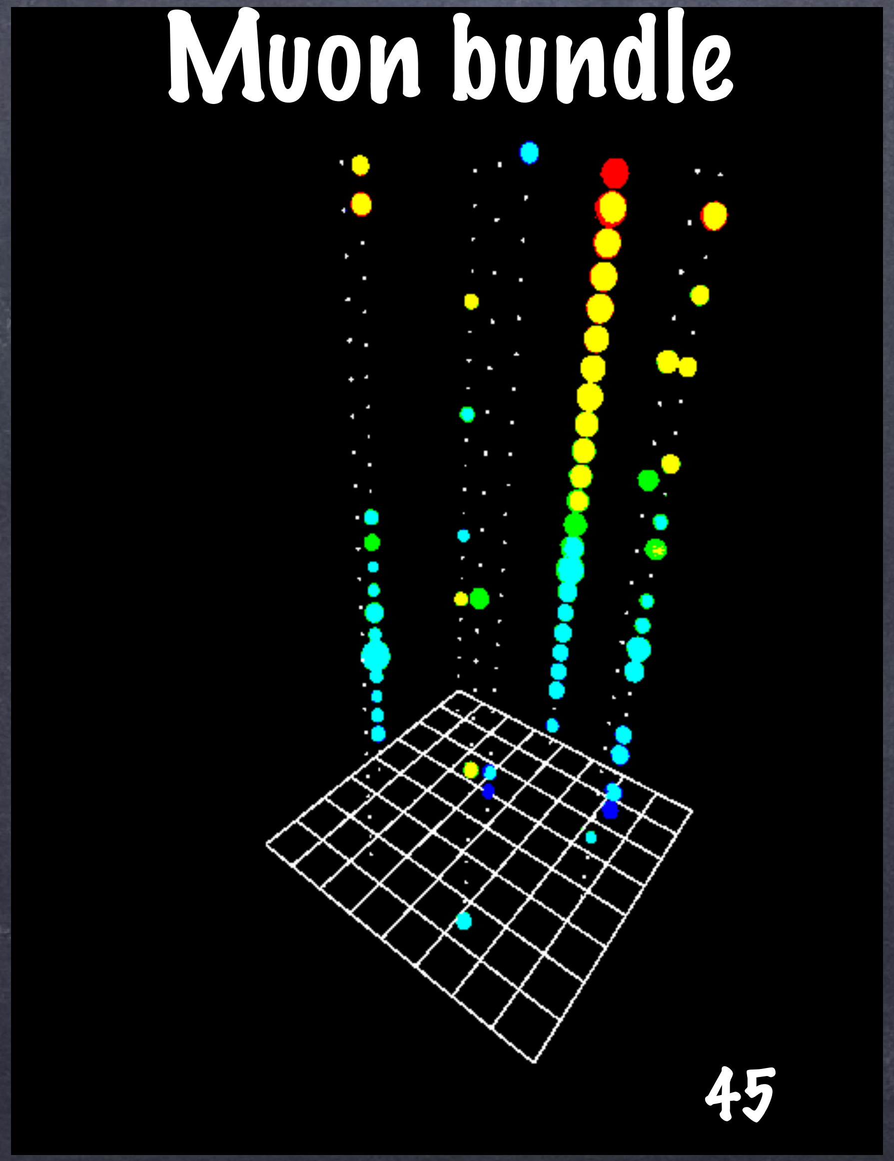
↳ Detector response



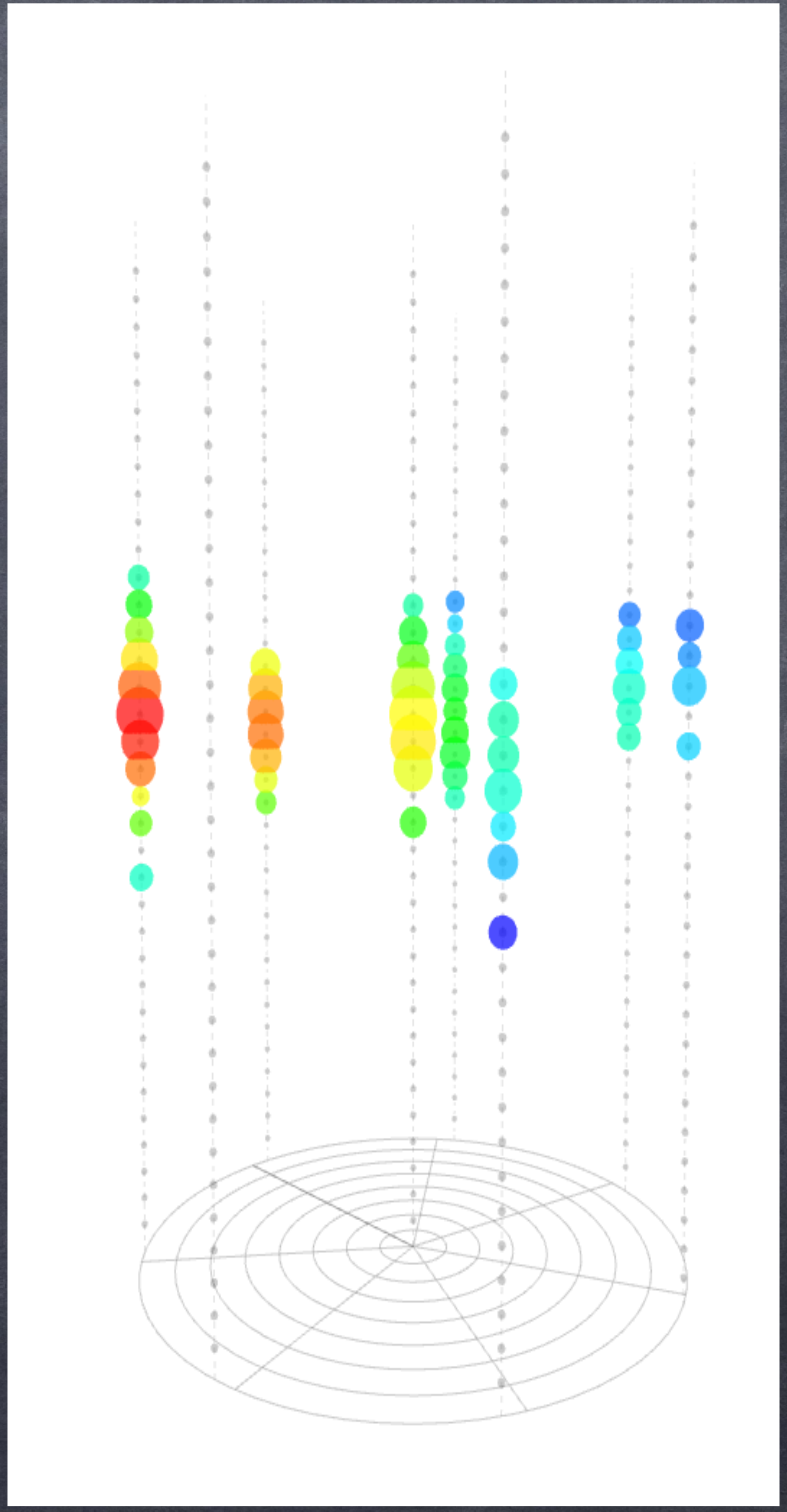








High-energy cascade



Data analysis

Alert signal < 20 min

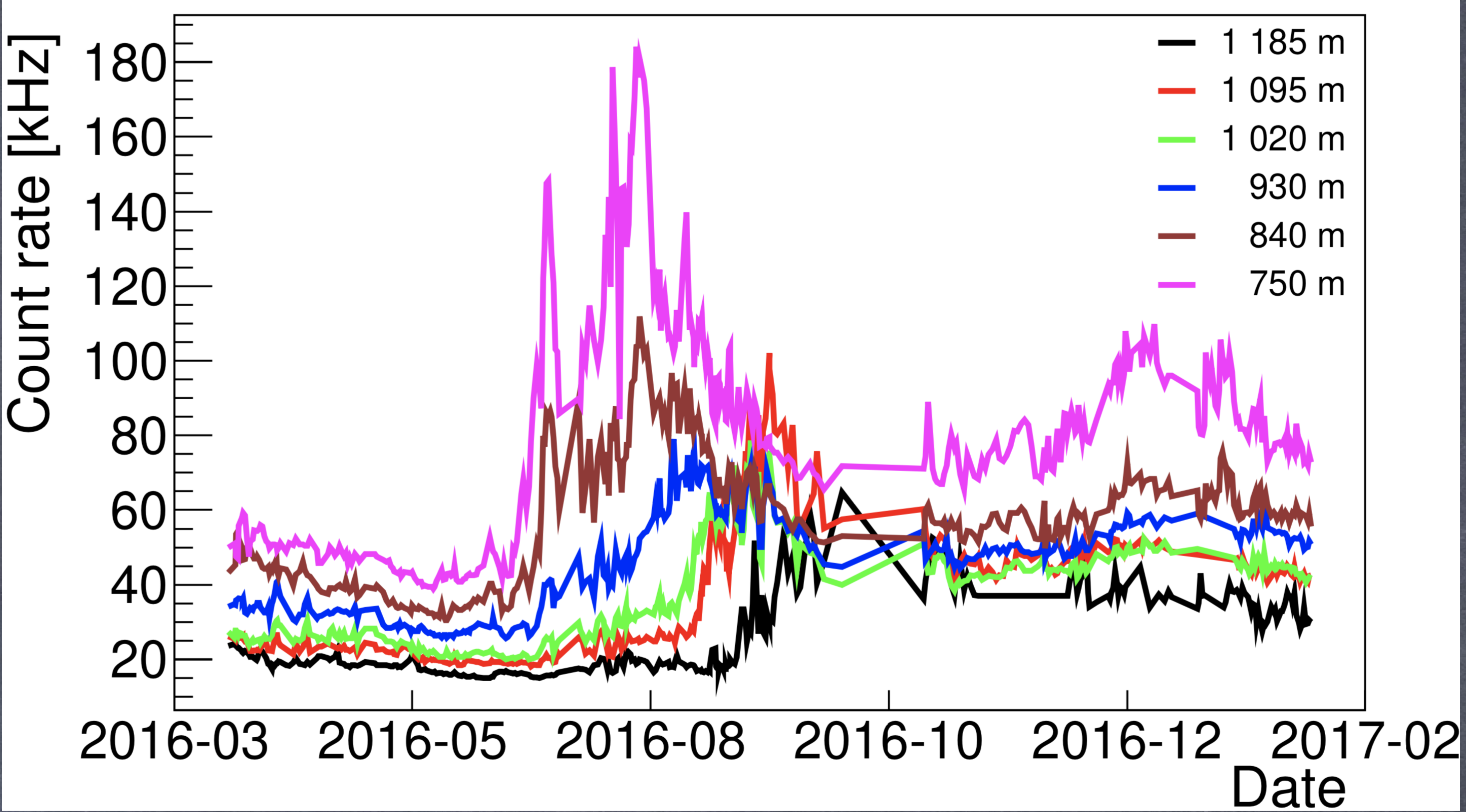
Data processing and analysis scheme

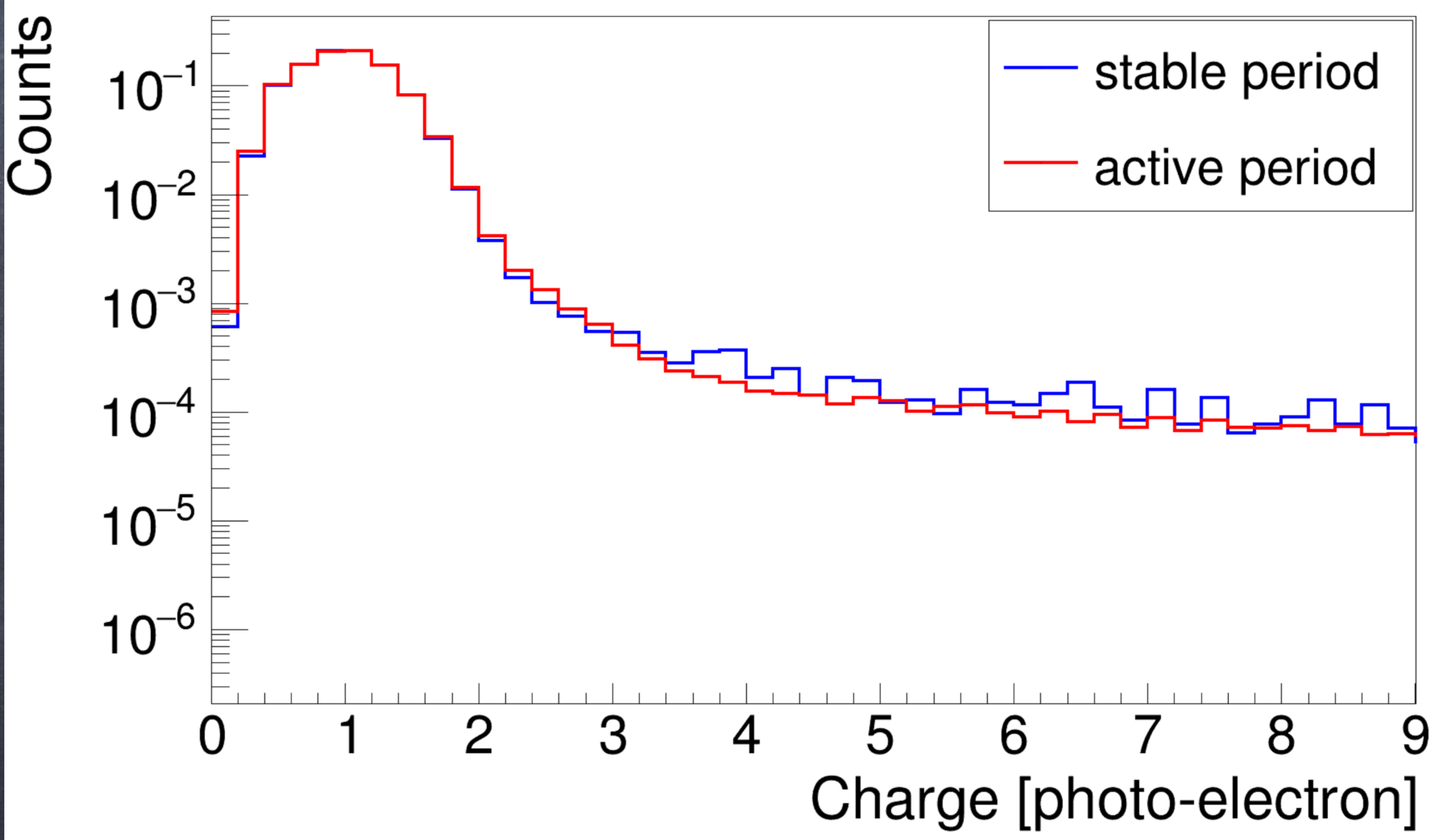
Courtesy: B.Shaibonov

Data analysis

Simulations. Lake noise

- Lake chemiluminescence level varies during a year
- It has one-p.e. nature
- 20-40 kHz for "low noise" period
- The noise level varies with depth
- The same charge distributions for low noise and active periods



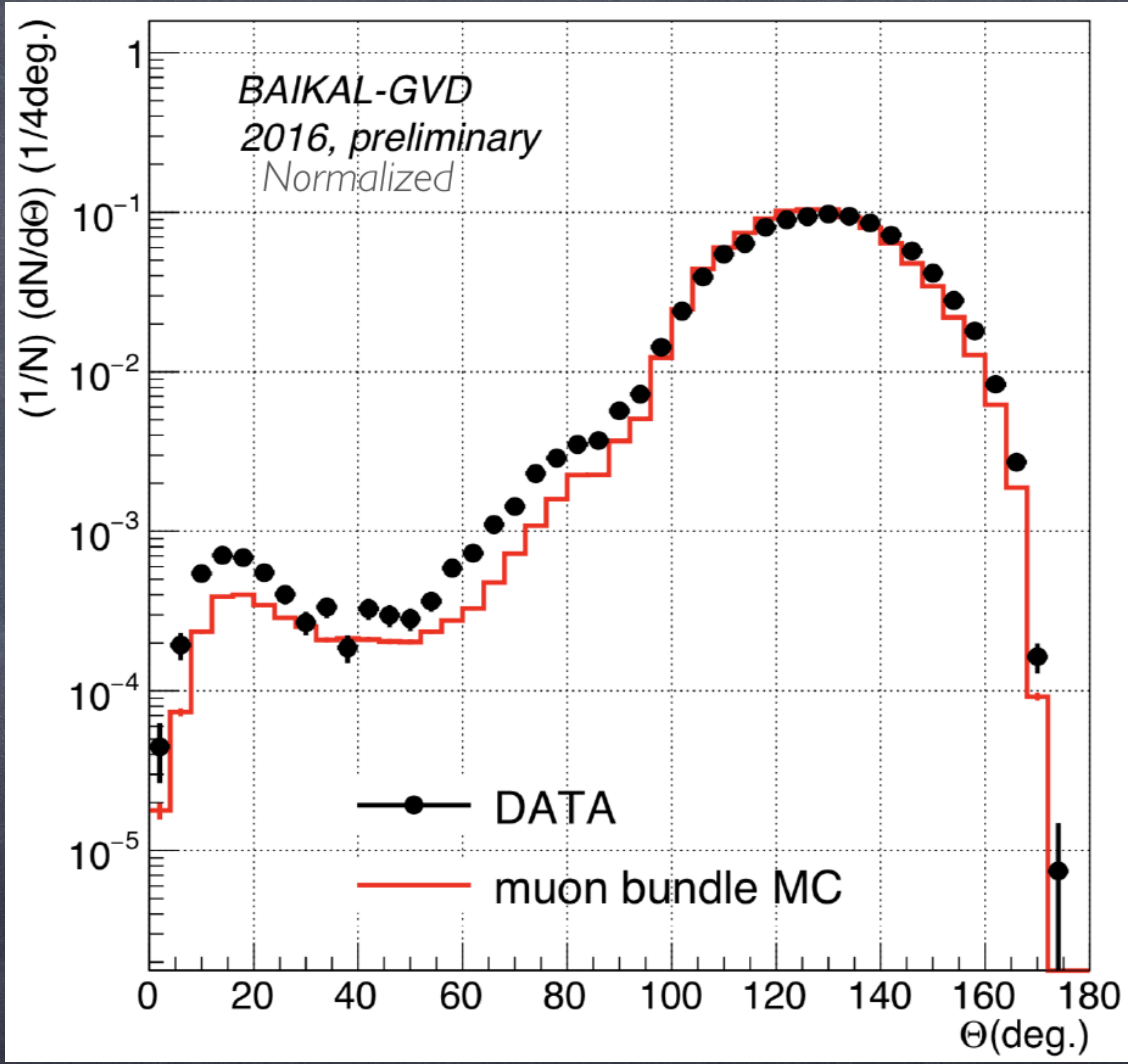


Courtesy: B.Shaibonov

Data analysis

→ Reconstruction

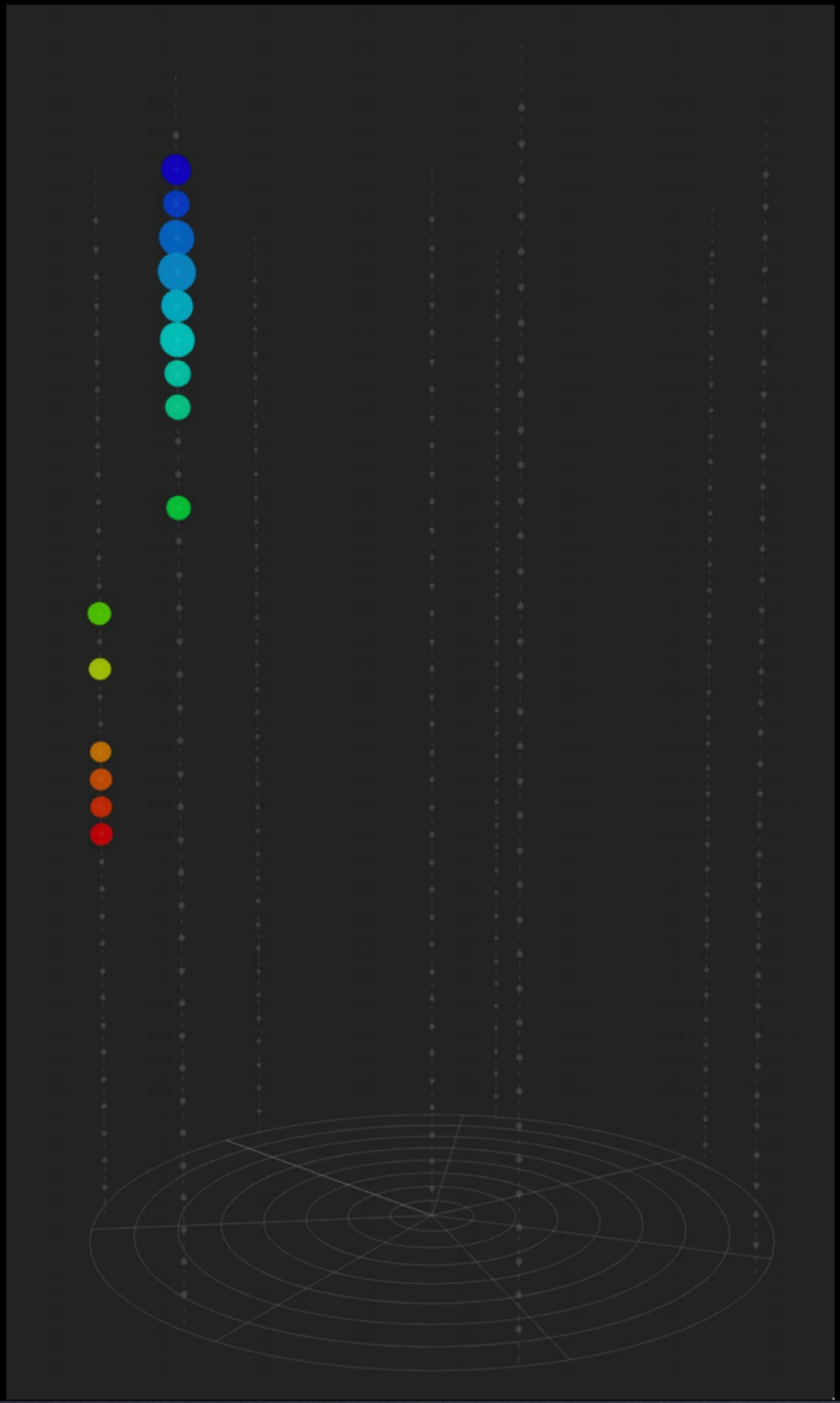
- Muon tracks
- Showers
- Neutrino events

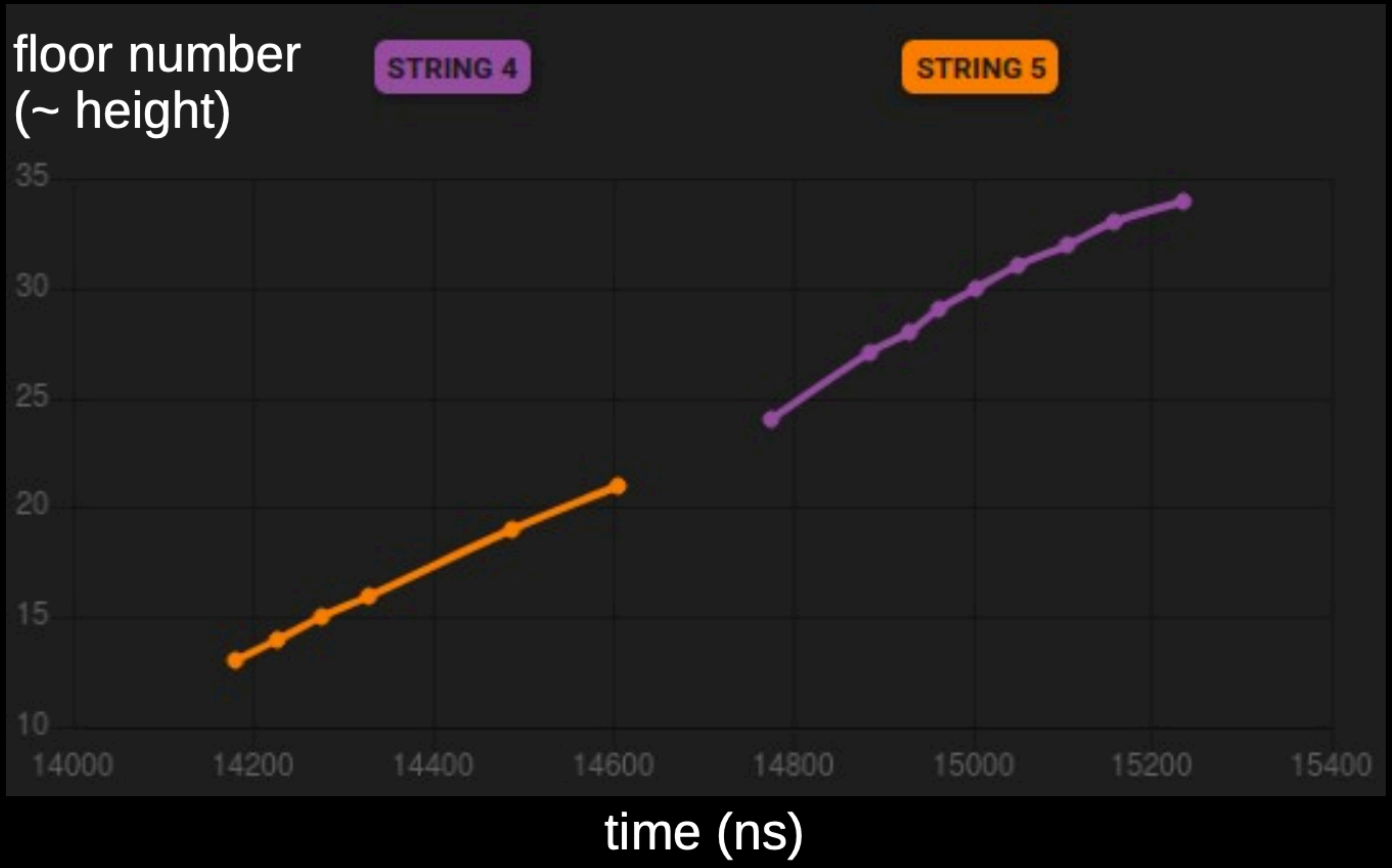


Credit: G. Safronov

Data analysis
→ Inspiring events

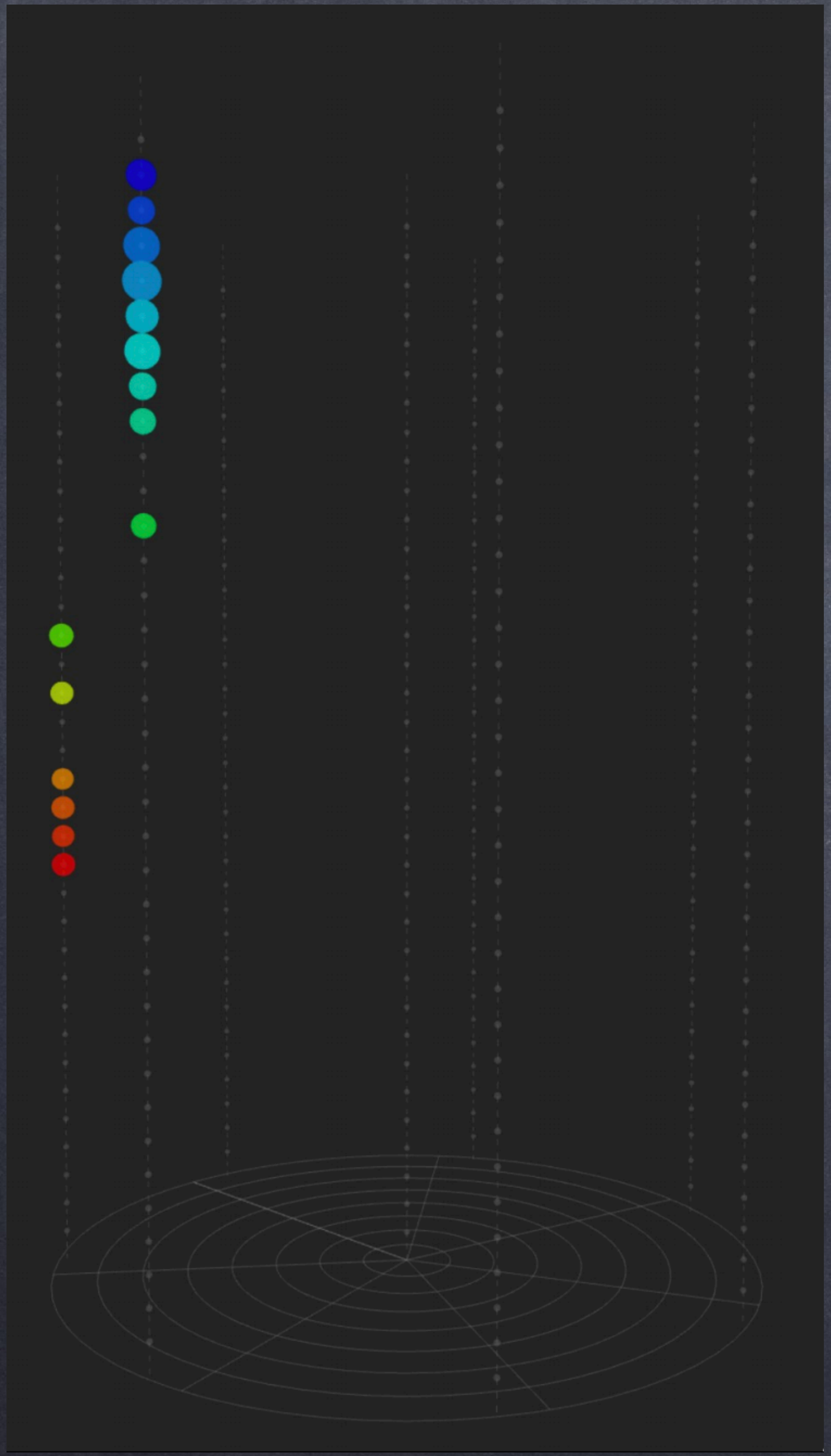
The largest event in 2016

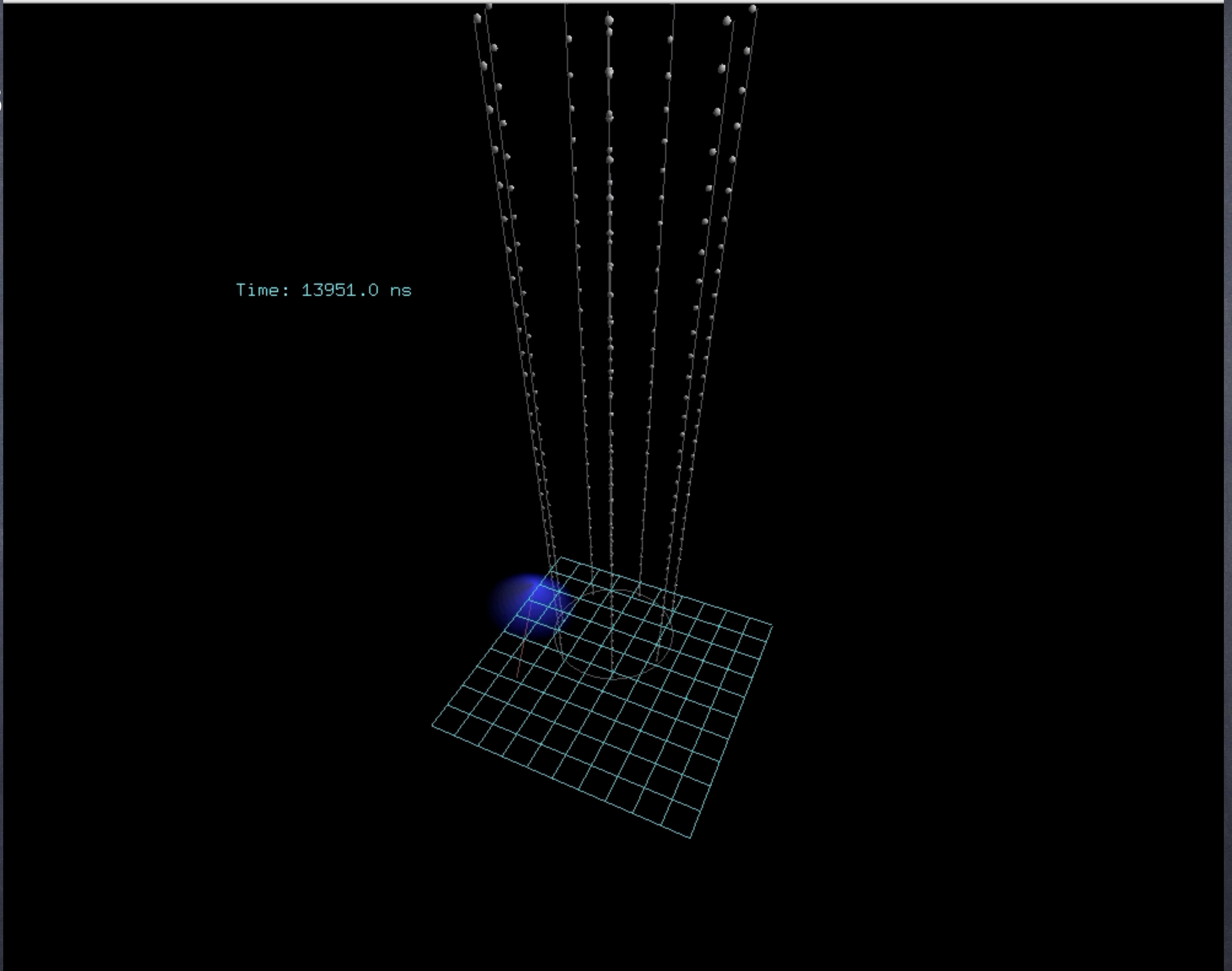




reconstructed zenith = 169 deg (11 deg from vertical)
reconstructed track length = 400 m

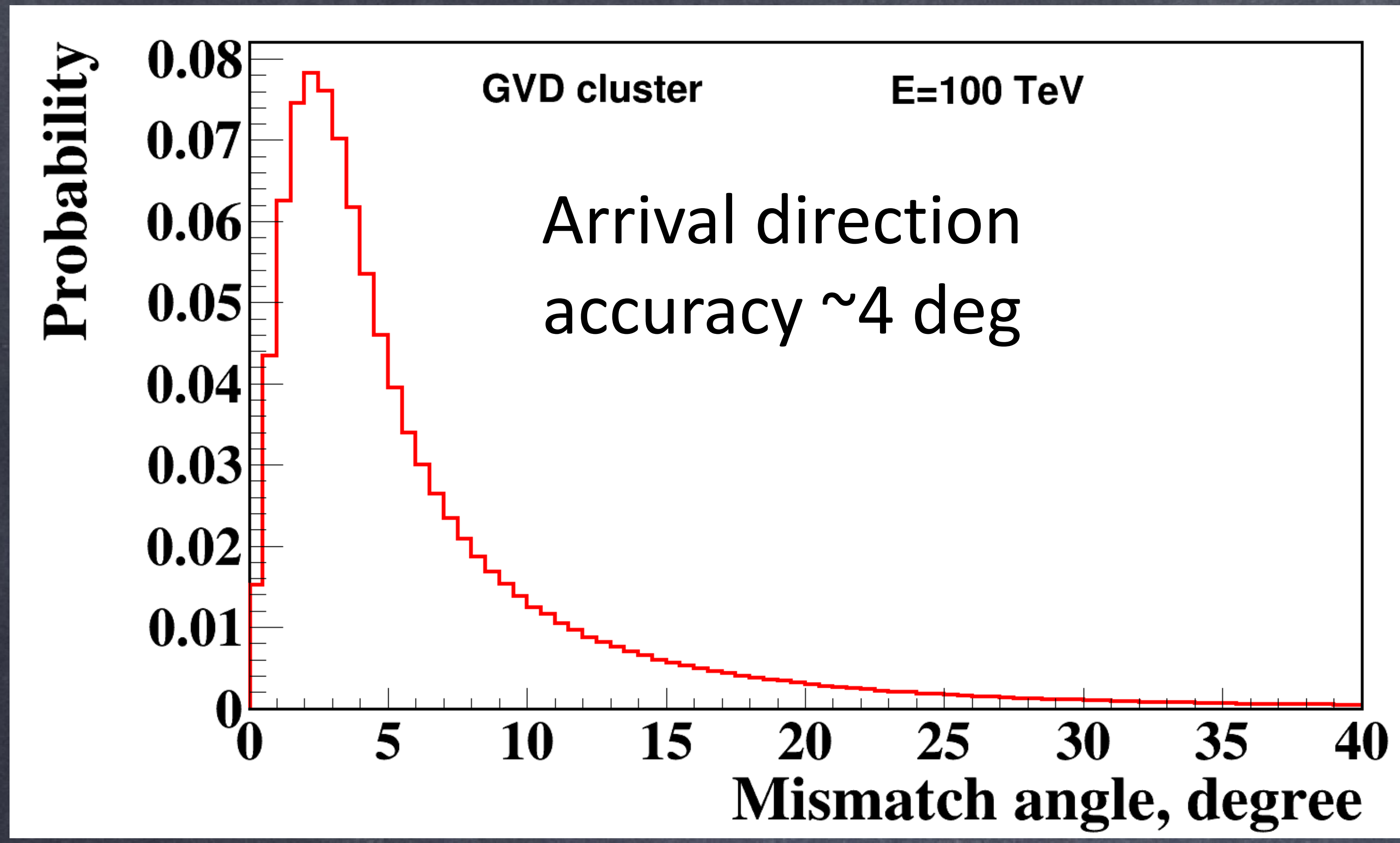
Data analysis
Inspiring events





Data analysis

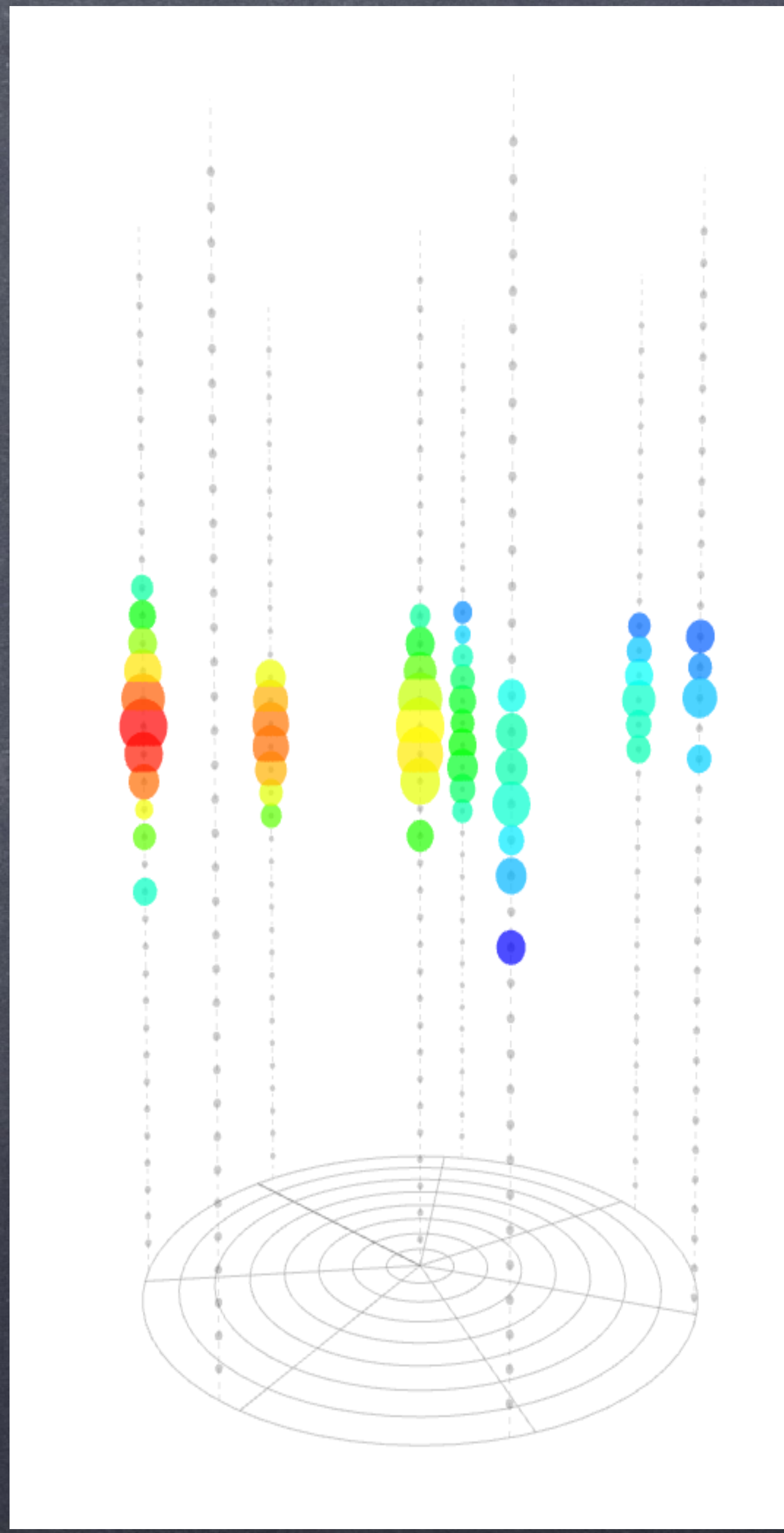
⟶ Inspiring events. High energy showers

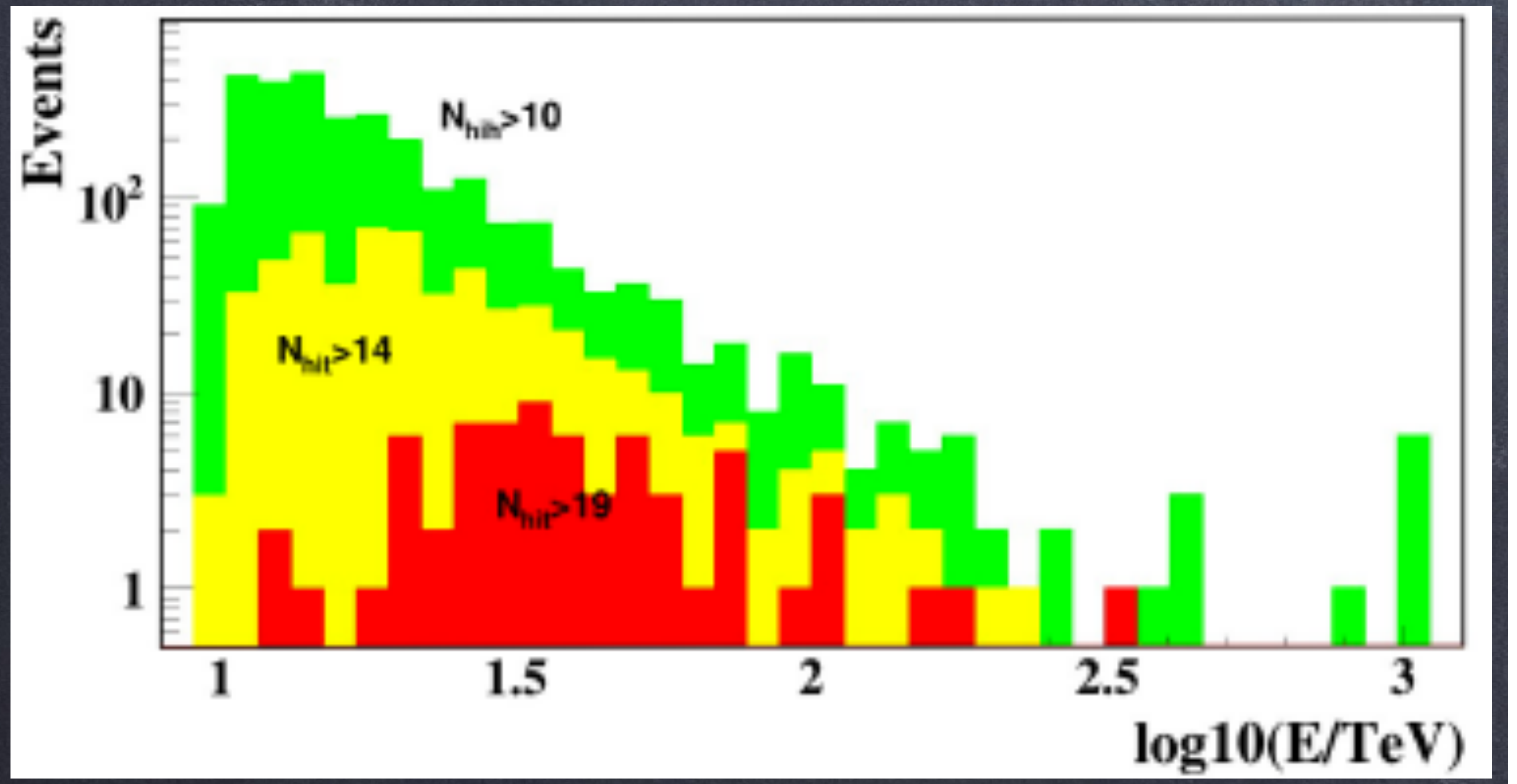


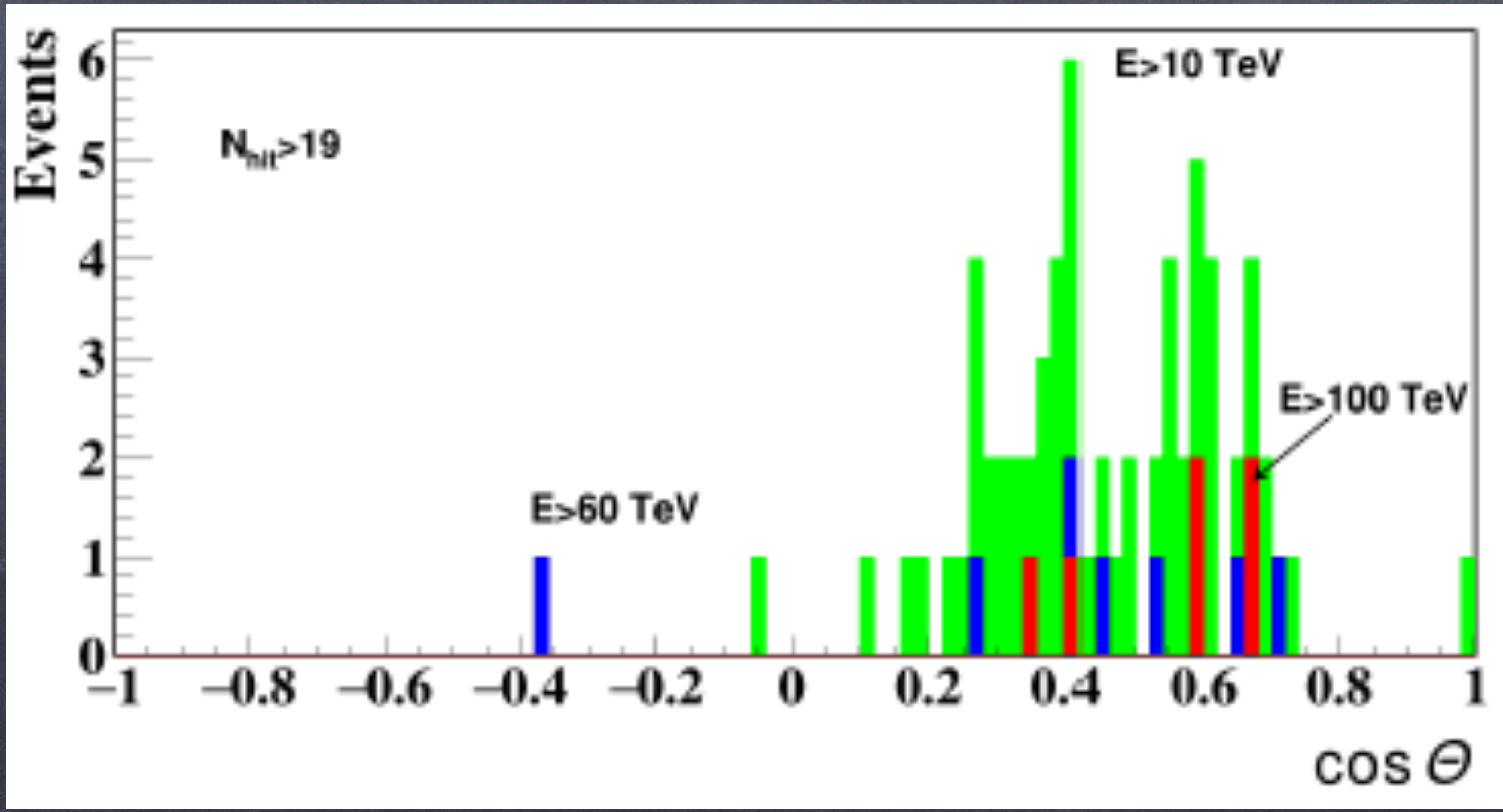
- Exposure: 1364 days. 2016, 2018 и 2019 (4 months)
- Found 7 candidates with E > 100 TeV and number of hits >19
- Found upgoing shower with E = 71 TeV

Shower

53 hitted OMs
E = 157 TэВ
θ = 57 °







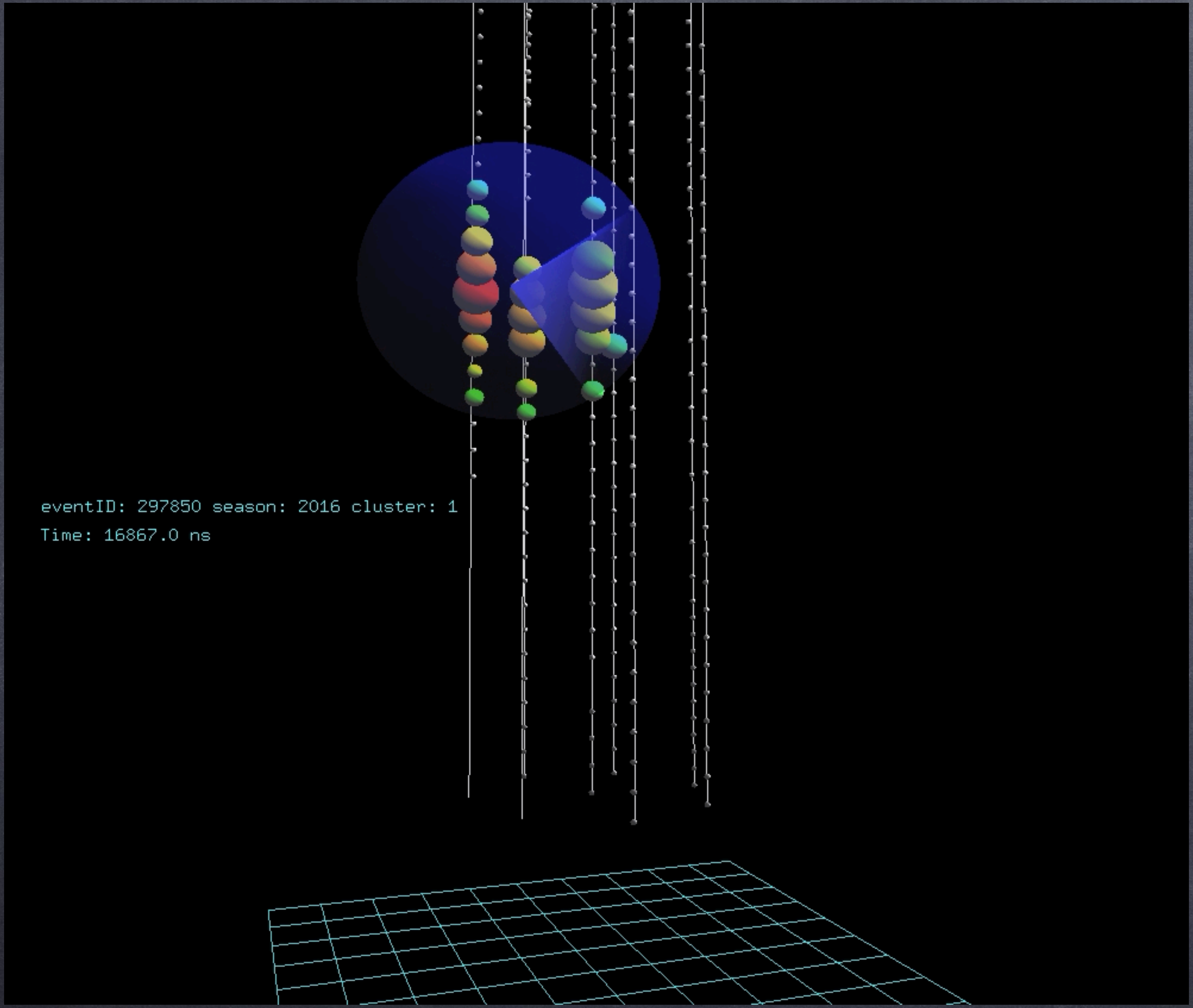
Upgoing

Downgoing

Credit: Z.Djilkibaev

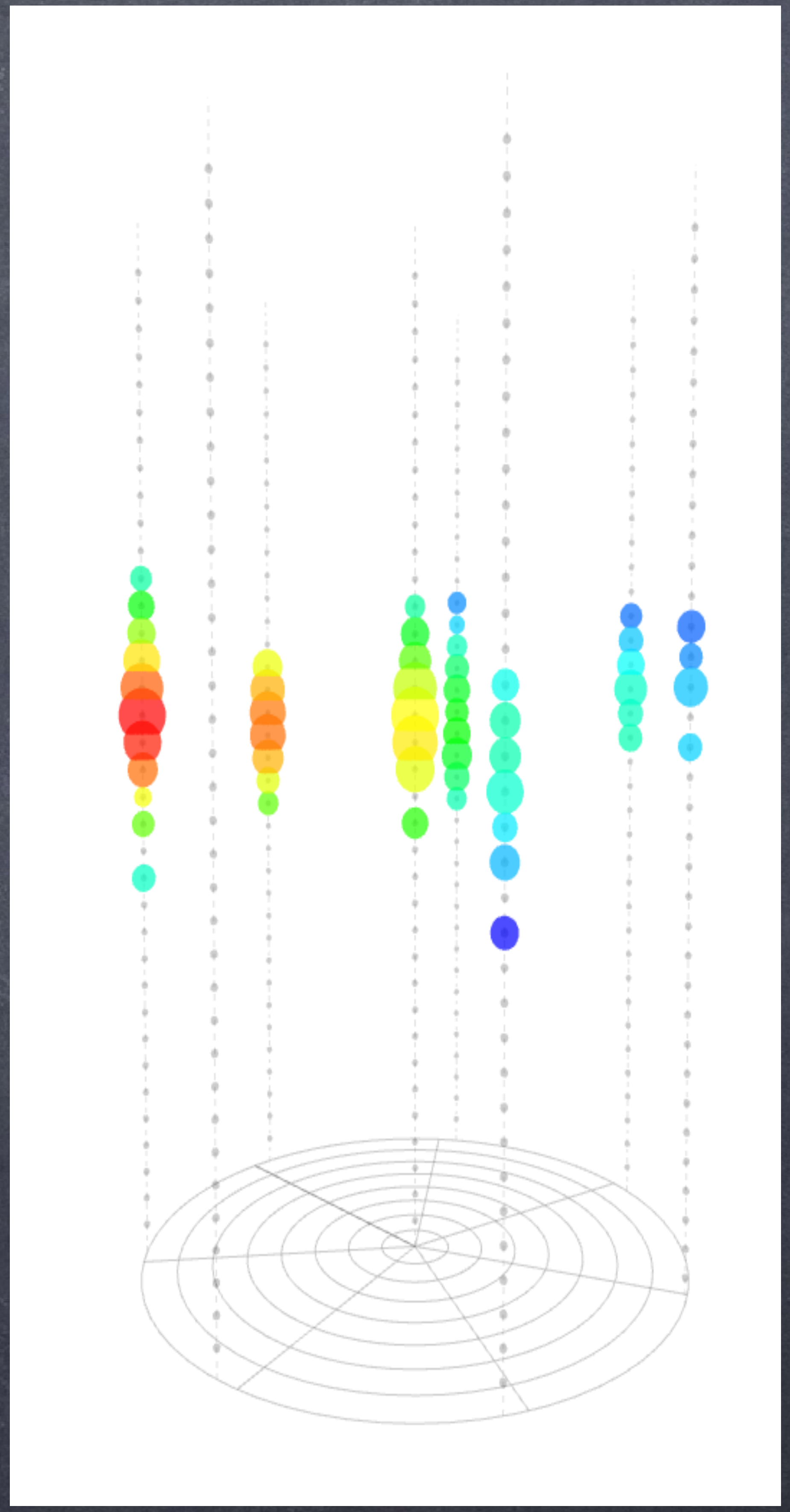
Data analysis

Inspiring events. High energy showers



Shower

53 hitted OMs
E = 157 ТэВ
θ = 57 °



Credit: B. Shaibonov

Data analysis

Alerts

- From Dec. 2018 MoU with ANTARES
  - No coincidence was found with 25 ANTARES alerts
  - Three interesting alerts are under study
- An interface to the global alert system is under development

Summary

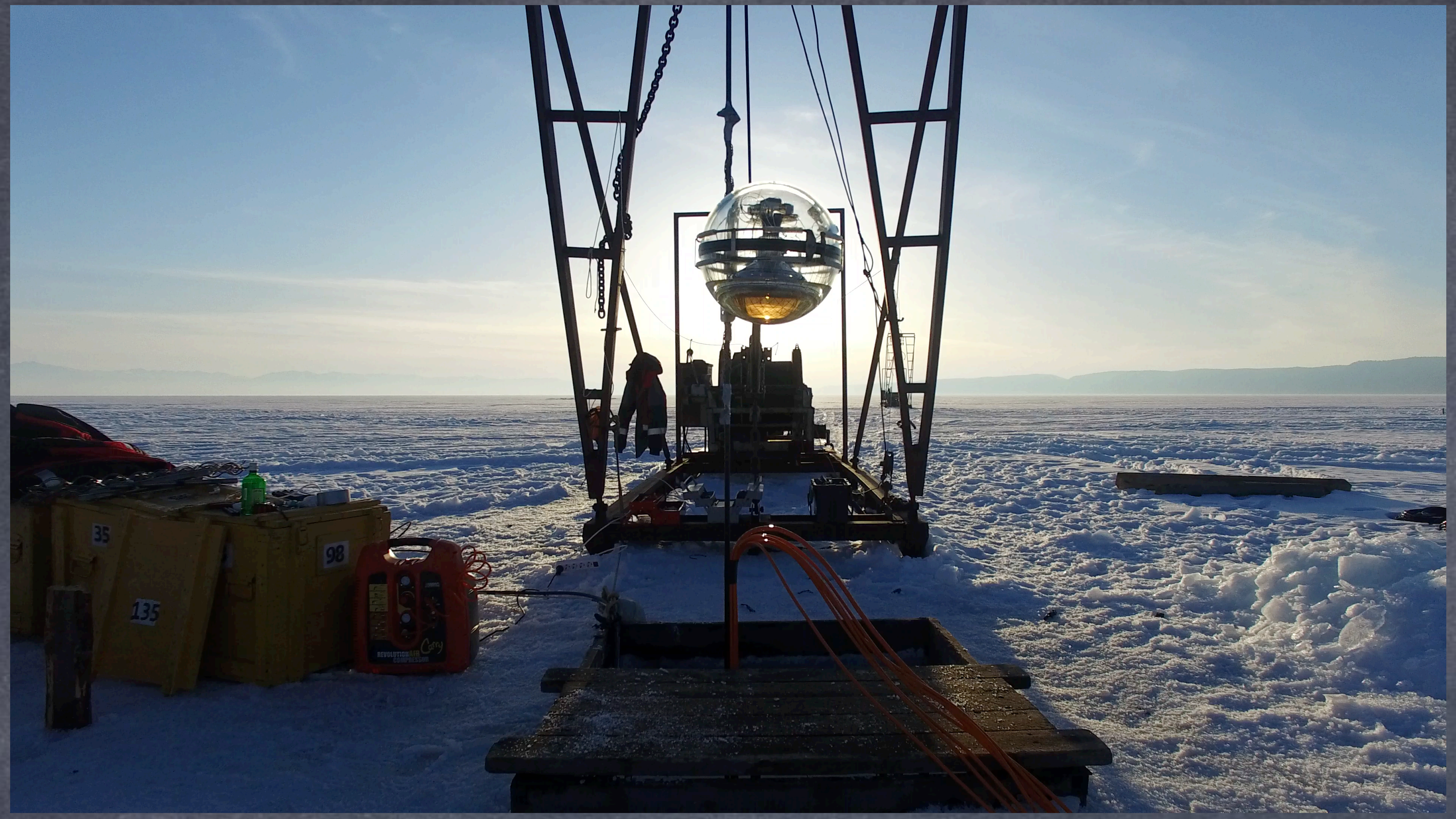
- Seven clusters installed by 2020
- Baikal GVD is the largest NT in Northern hemisphere from 2016
- Its effective volume for shower events (E>100 TeV) is 0.35 km^3
- 8 shower events with E>100 TeV (one with 87 TeV) are found
- ALERT system is under development
- Many interesting analyses are ongoing
- Many newcomers

Acknowledgements to

- All Baikalists
- In particular:

  G.V. Domogatsky, I. Belolaptikov, B. Shaibonov, G. Safronov, O. Suvorova, C.Spiering, A. Avrorin

The most romantic experiment ever



Women's day!

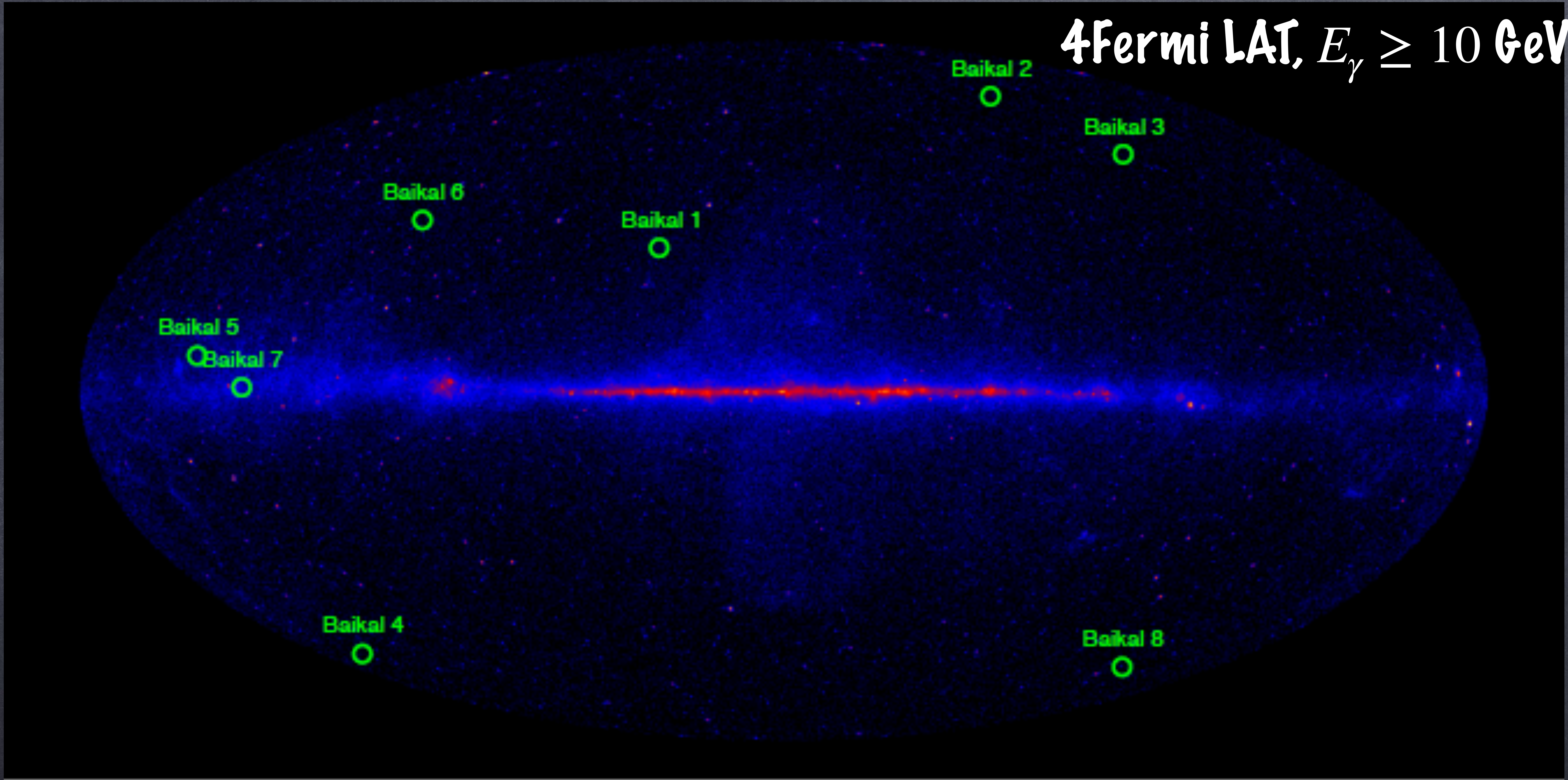
Way for lunch

Enjoy more at http://dlnp.jinr.ru/ru/bajkalskij-dnevnik/bajkalskij-dnevnik-dmitriya-naumova

Backup slides

Data analysis
└→ Alerts

8 GVD events in Galactic coordinates



Credit: A. Neronov, D.Semikoz