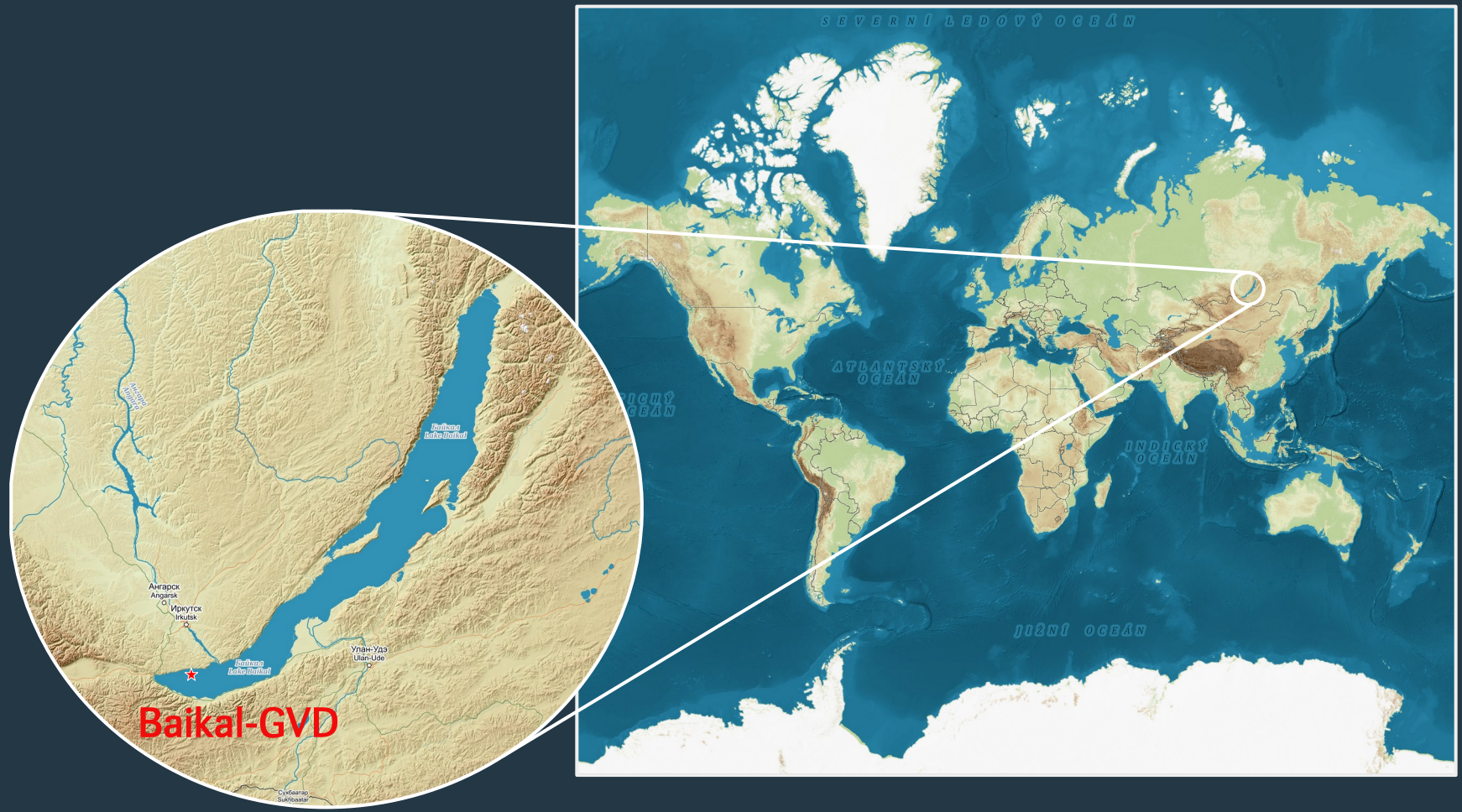
JINR Association of Young Scientists and Specialits Conference «Alushta 2022»

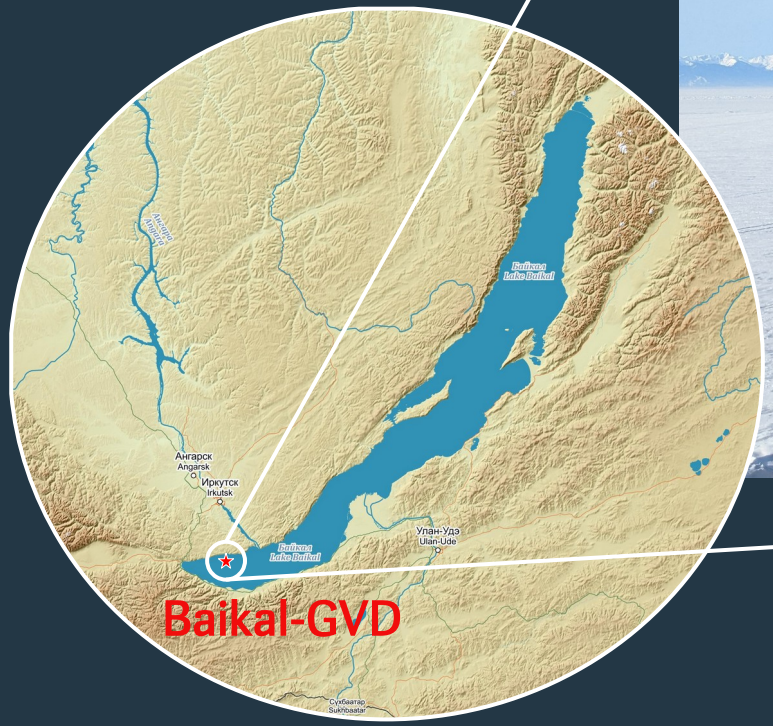
Yury Malyshkin
DLNP JINR

A new software framework for the Baikal-GVD neutrino telescope

Baikal-GVD


SEVERNÍ LEDOVÝ OCEÁN
ATLANTSKÝ OCEÁN
INDICKÝ OCEÁN
JIŽNÍ OCEÁN
Ангарск
Angarsk
Иркутск
Irkutsk
Улан-Удэ
Ulan-Ude
Baikal-GVD

Baikal-GVD

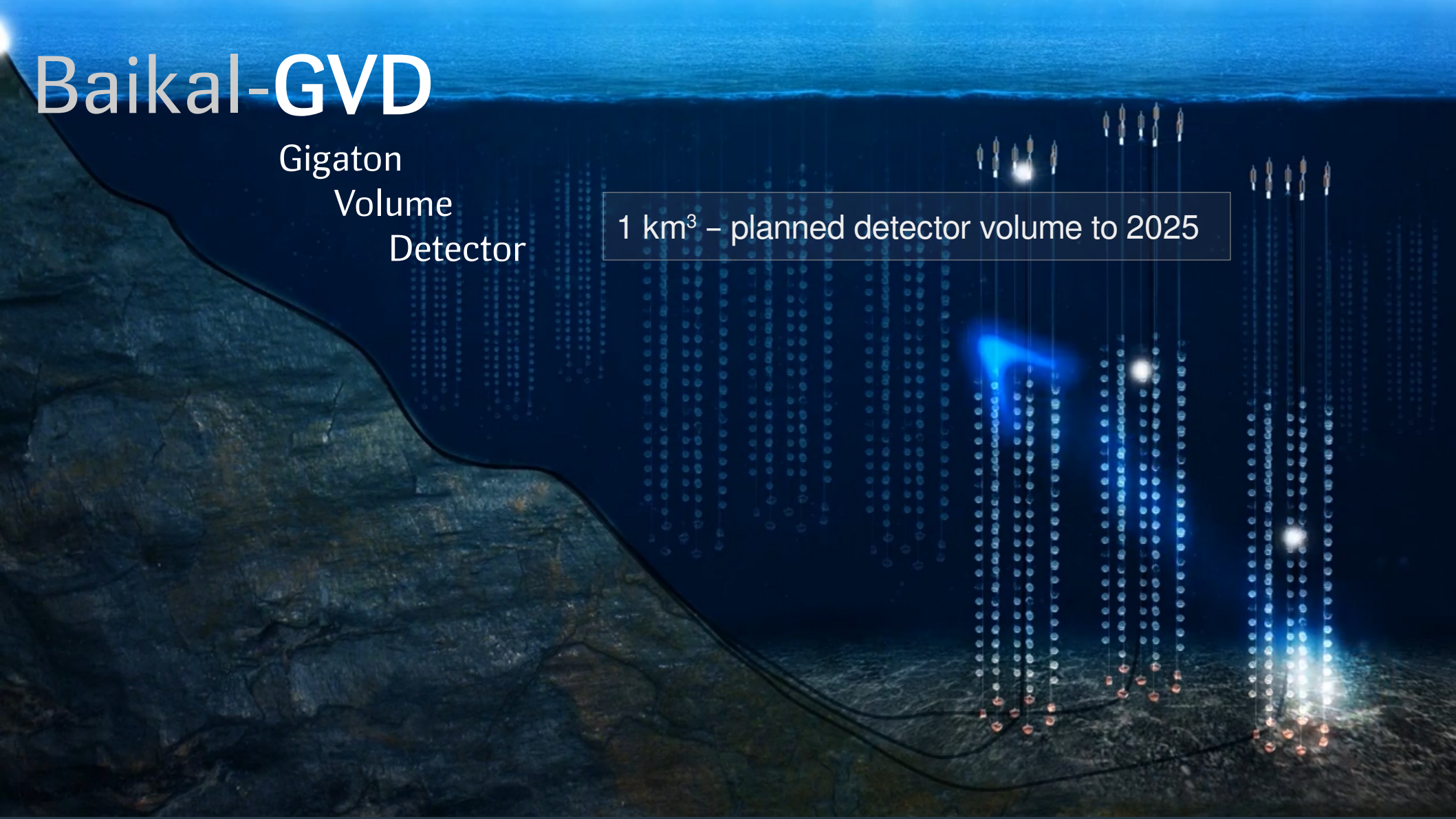

Ангарск
Angarsk
Иркутск
Irkutsk
Байкал
Lake Baikal
Улан-Удэ
Ulan-Ude
Baikal-GVD
Сүхбаатар
Sukhbaatar

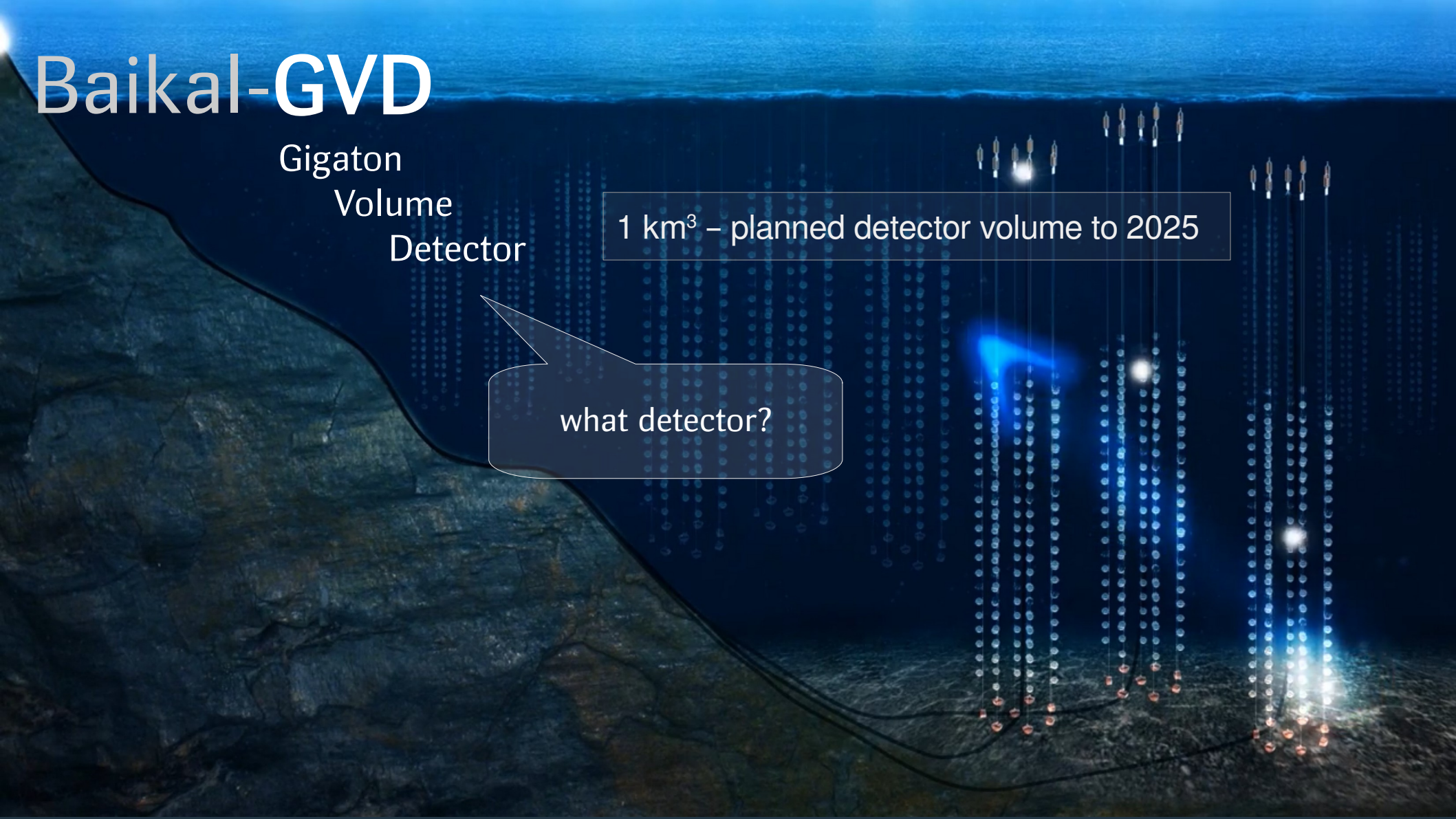
Baikal-**GVD**

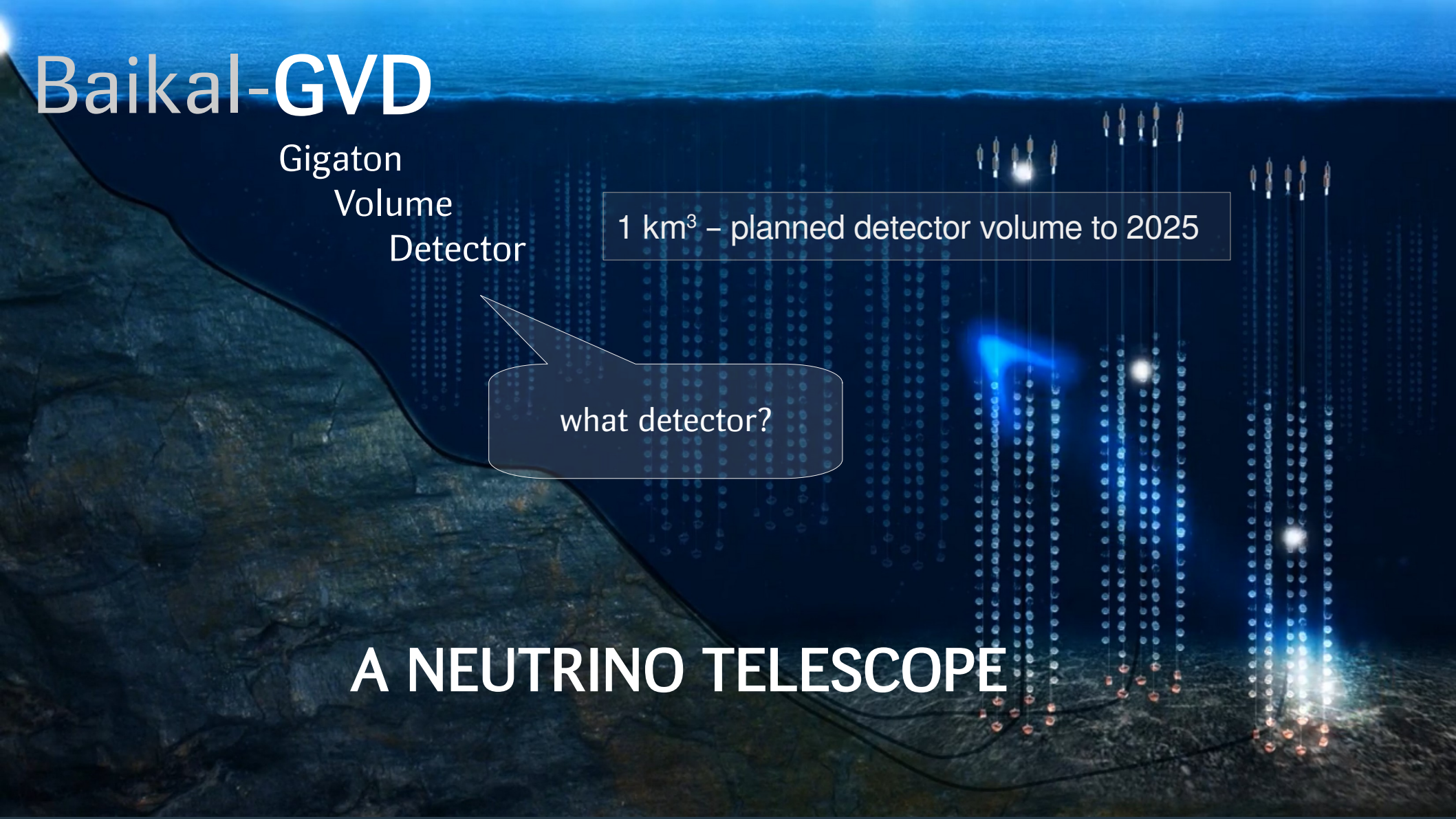
Gigaton

Volume

Detector


Baikal-GVD
Gigaton
Volume
Detector
1 km³ – planned detector volume to 2025


Baikal-GVD
Gigaton
Volume
Detector
1 km³ – planned detector volume to 2025
what detector?


Baikal-GVD
Gigaton
Volume
Detector
1 km³ – planned detector volume to 2025
what detector?
A NEUTRINO TELESCOPE

Neutrino

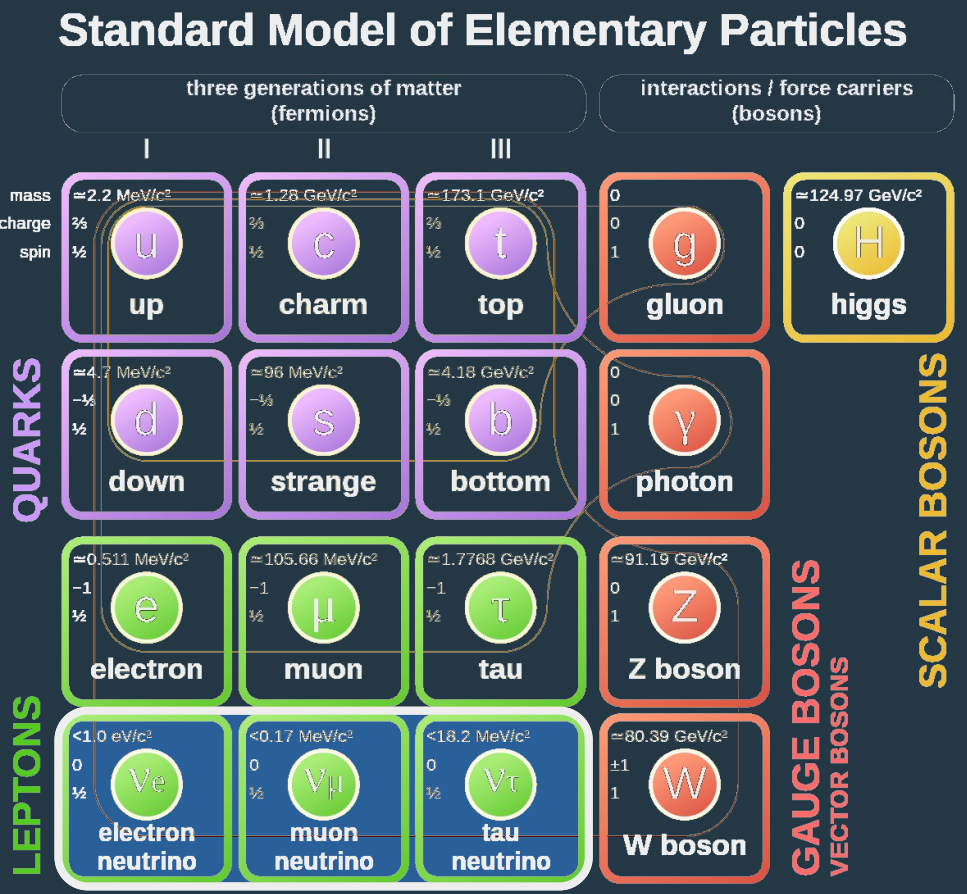
stable

electrically neutral

non-zero mass (yet unknown)

weak interaction only

constantly produced (supernovae, Sun, Earth atmosphere and interior, reactors, etc)



Neutrino

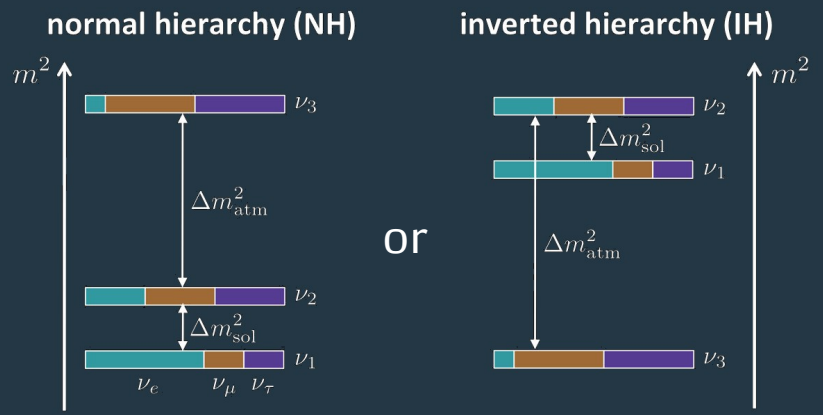
stable

electrically neutral

non-zero mass (yet unknown)

weak interaction only

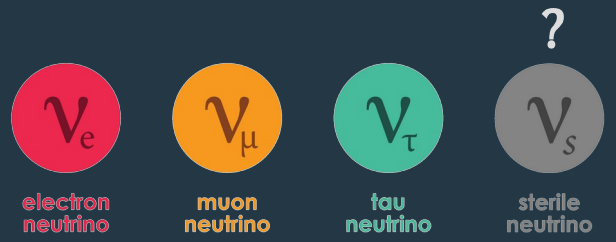
constantly produced (supernovae, Sun, Earth atmosphere and interior, reactors, etc)

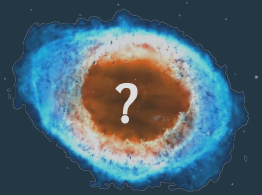


OPEN QUESTIONS:

- mass hierarchy?
- CP violation?
- Majorana or Dirac?
- sterile states?
- precise values of oscillation parameters?
- origin of ultra-high energy neutrinos

$$\nu \overset{?}{=} \bar{\nu}$$





Neutrino of $E \sim O(\text{PeV})$

1 PeV = 10^{15} eV
x100 E @ LHC

also known as **astrophysical neutrino**

stable

electrically neutral

non-zero mass (yet unknown)

weak interaction only

produced in ?

discovered by IceCube in 2013

OPEN QUESTIONS:

- mass hierarchy?
- CP violation?
- Majorana or Dirac?
- sterile states?
- precise values of oscillation parameters?
- **origin of ultra-high energy neutrinos**

Neutrino of $E \sim O$(PeV)

1 PeV = 10^{15} eV
x100 E @ LHC

also known as **astrophysical neutrino**

stable

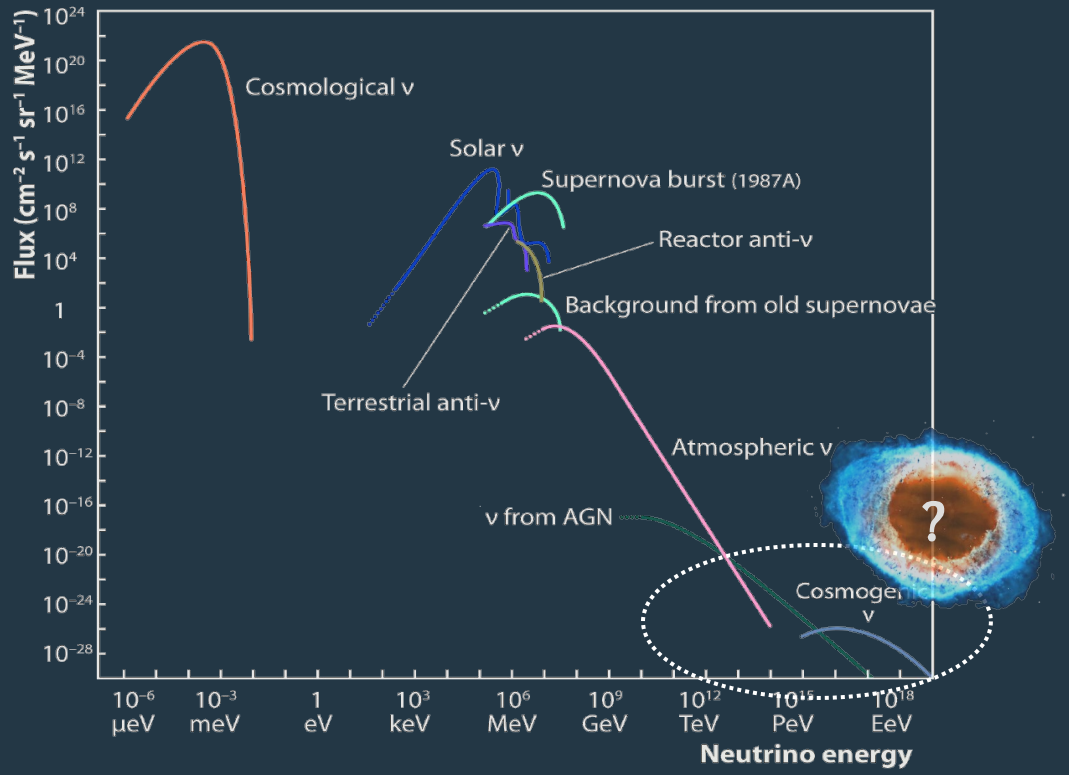
electrically neutral

non-zero mass (yet unknown)

weak interaction only

produced in ?

discovered by IceCube in 2013



OPEN QUESTIONS:

- mass hierarchy?
- CP violation?
- Majorana or Dirac?
- sterile states?
- precise values of oscillation parameters?
- **origin of ultra-high energy neutrinos**

Neutrino of $E \sim \mathcal{O}$(PeV)

1 PeV = 10^{15} eV
x100 E @ LHC

also known as **astrophysical neutrino**

stable

electrically neutral

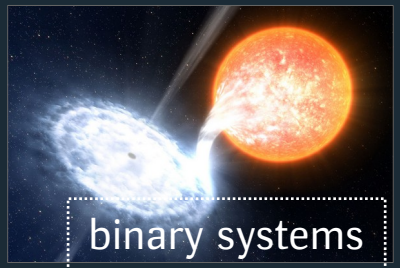
non-zero mass (yet unknown)

weak interaction only

produced in ?

discovered by IceCube in 2013

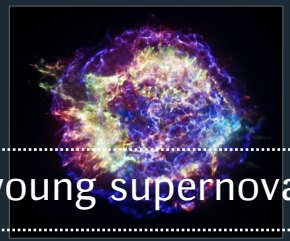
Possible sources:



binary systems

active galactic nuclei

?



young supernovae remnants

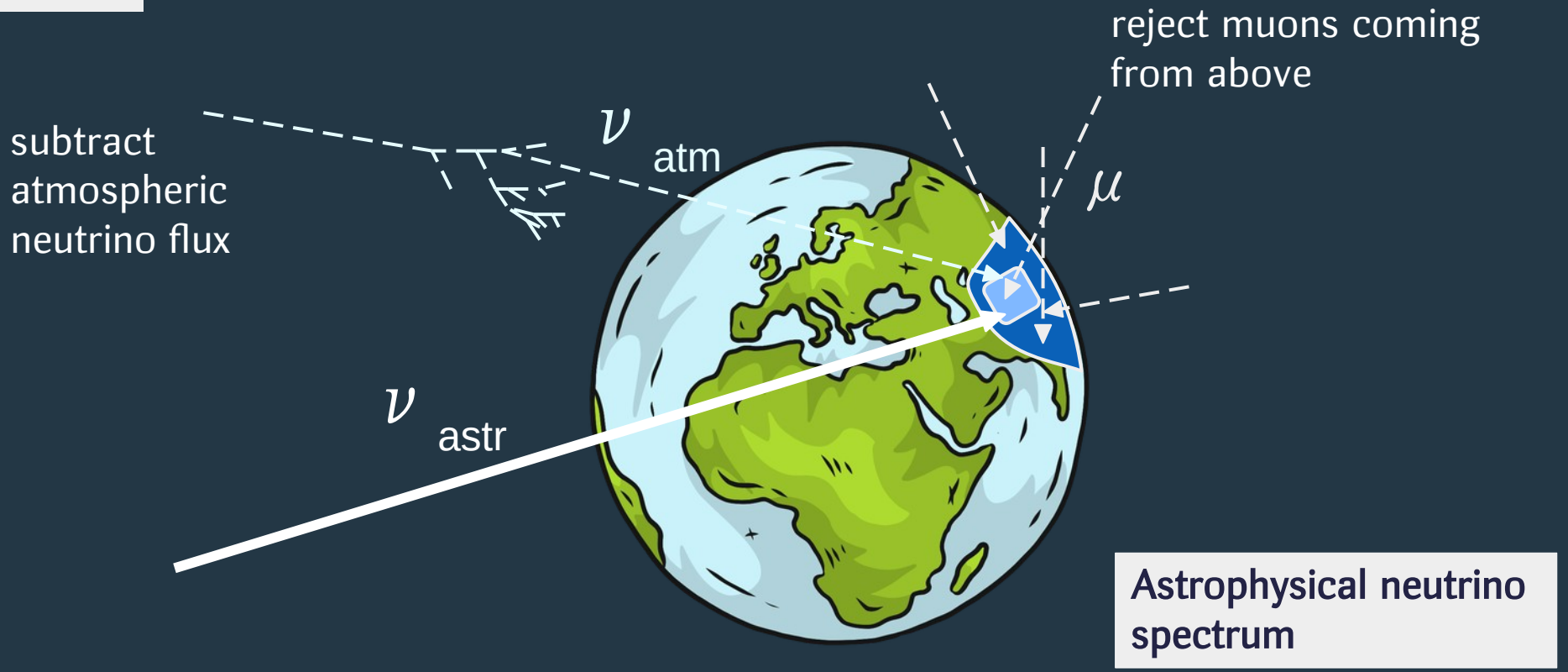
gamma bursts

OPEN QUESTIONS:

- mass hierarchy?
- CP violation?
- Majorana or Dirac?
- sterile states?
- precise values of oscillation parameters?
- **origin of ultra-high energy neutrinos**

How we hunt for them?

option #1



Astrophysical neutrino spectrum

How we hunt for them?

option #2

temporal and directional coincidence
with other telescopes

Astrophysical neutrino events

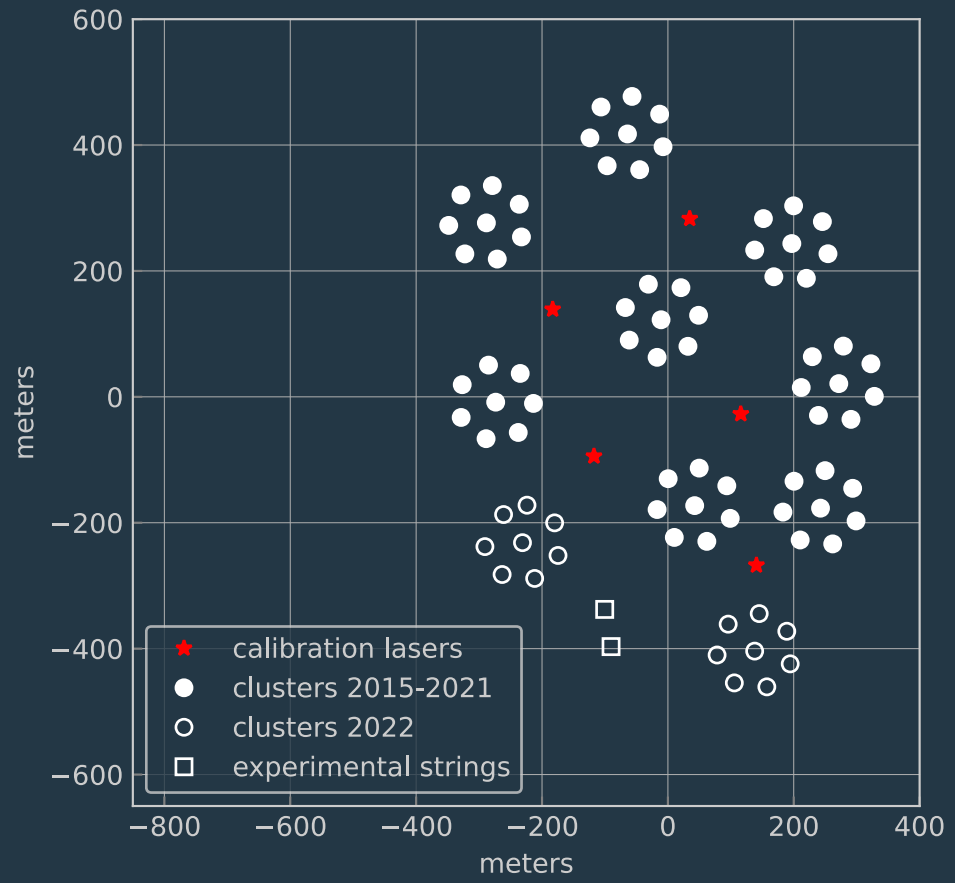
How we hunt for them?

(we still speaking about astrophysical neutrino)

M. Markov (1960) – deploy an array of photo-sensors in a natural transparent media to register light flashes from neutrino interactions.

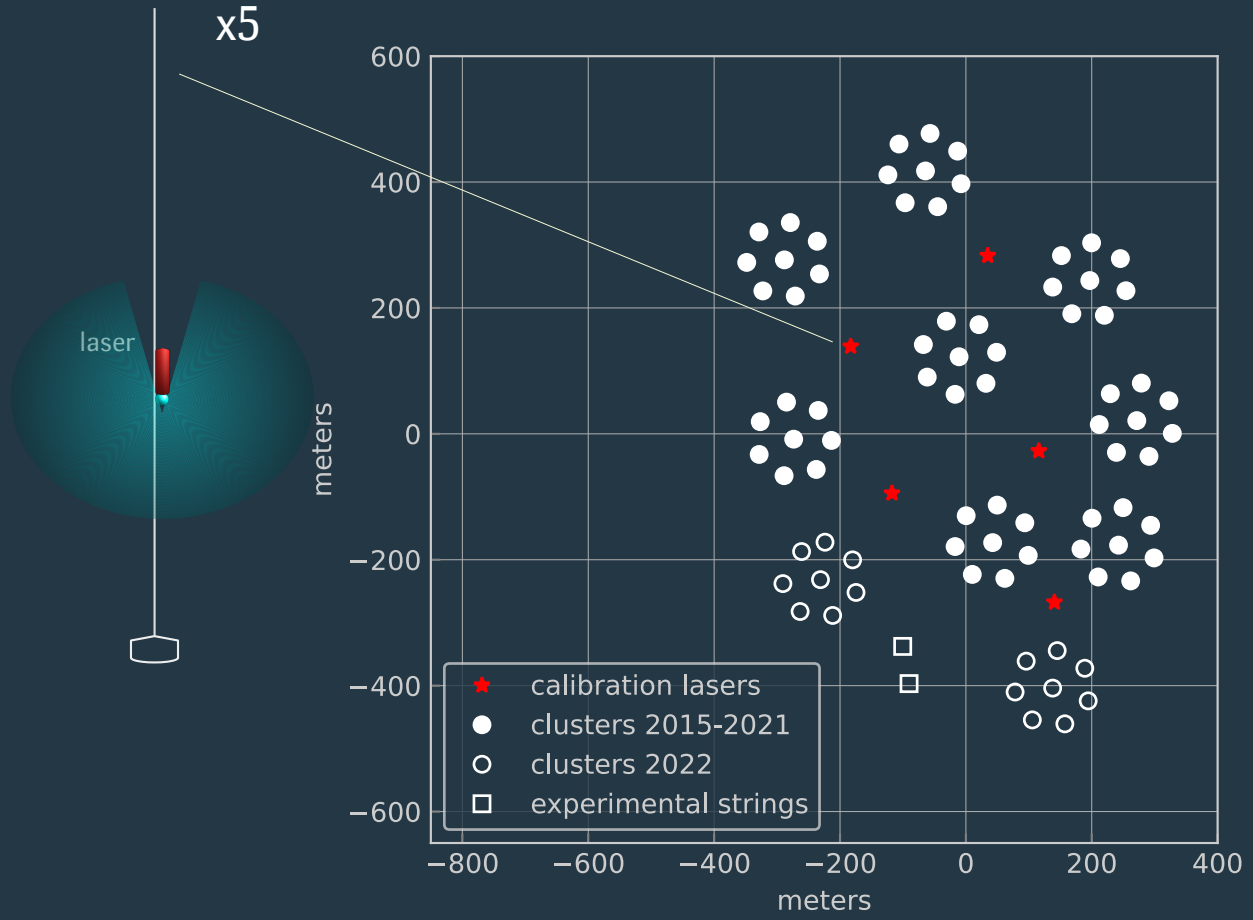
the time order and signal intensity on the photo-sensors brings information on the neutrino direction

Baikal-GVD 2022



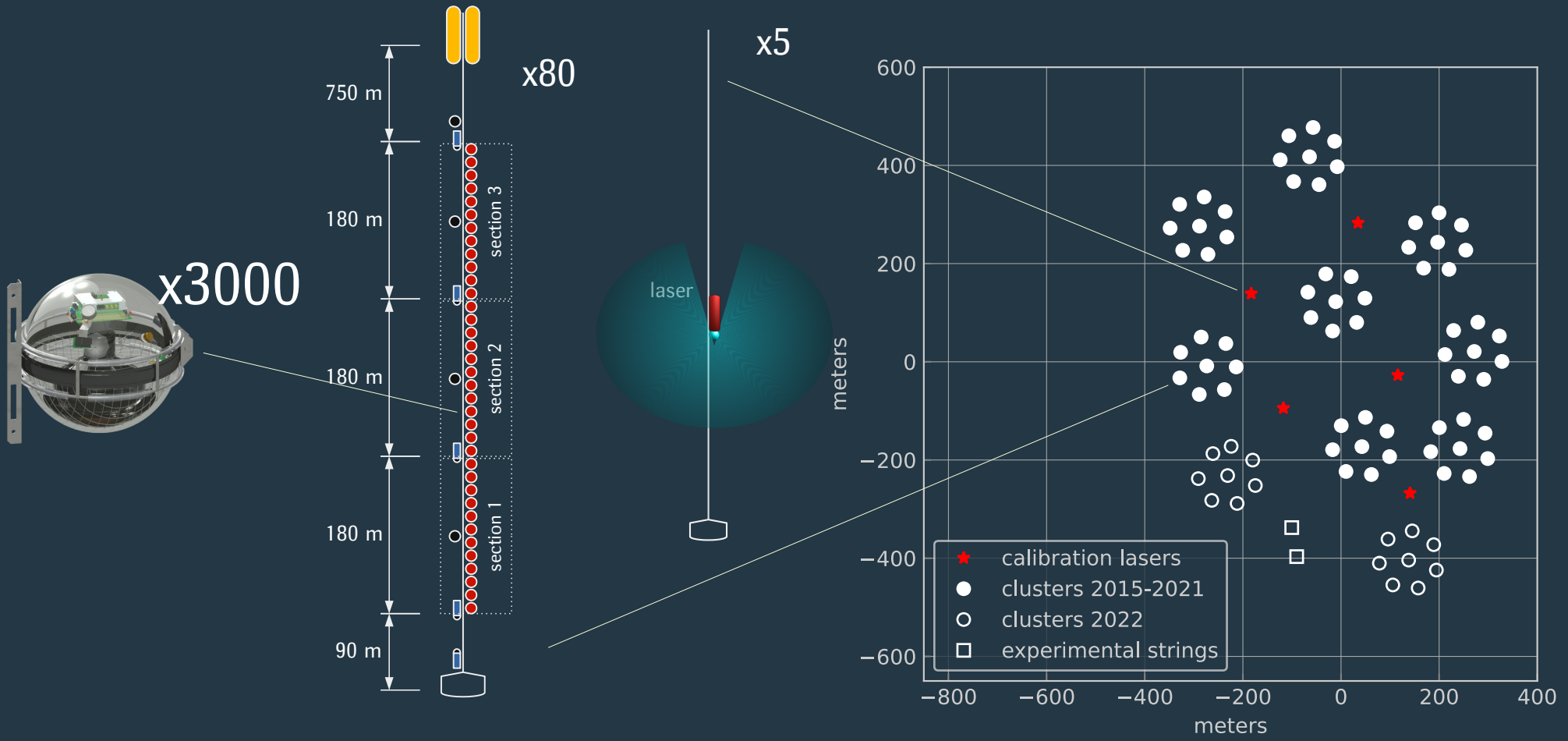
Baikal-GVD 2022

Video: сборка телескопа



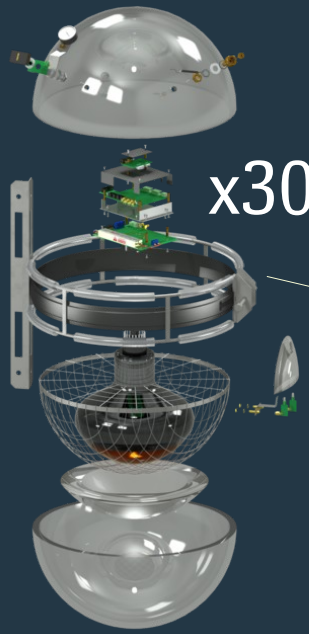
Baikal-GVD 2022

Video: сборка телескопа

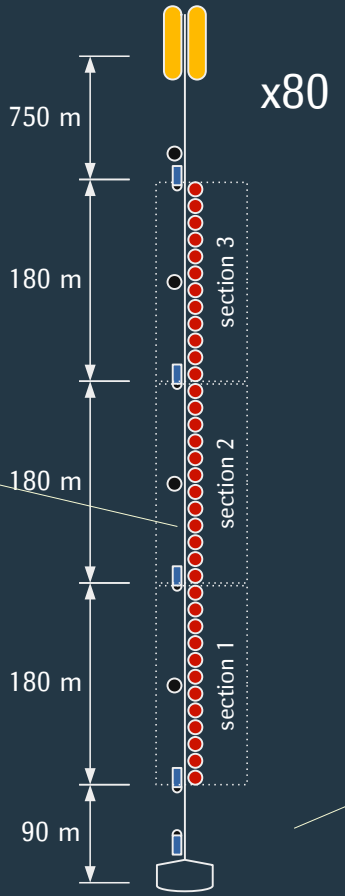


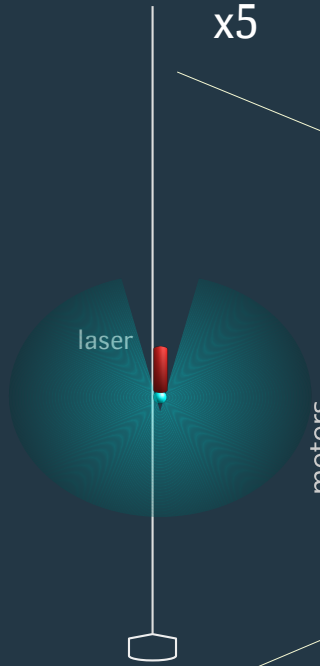
Baikal-GVD 2022

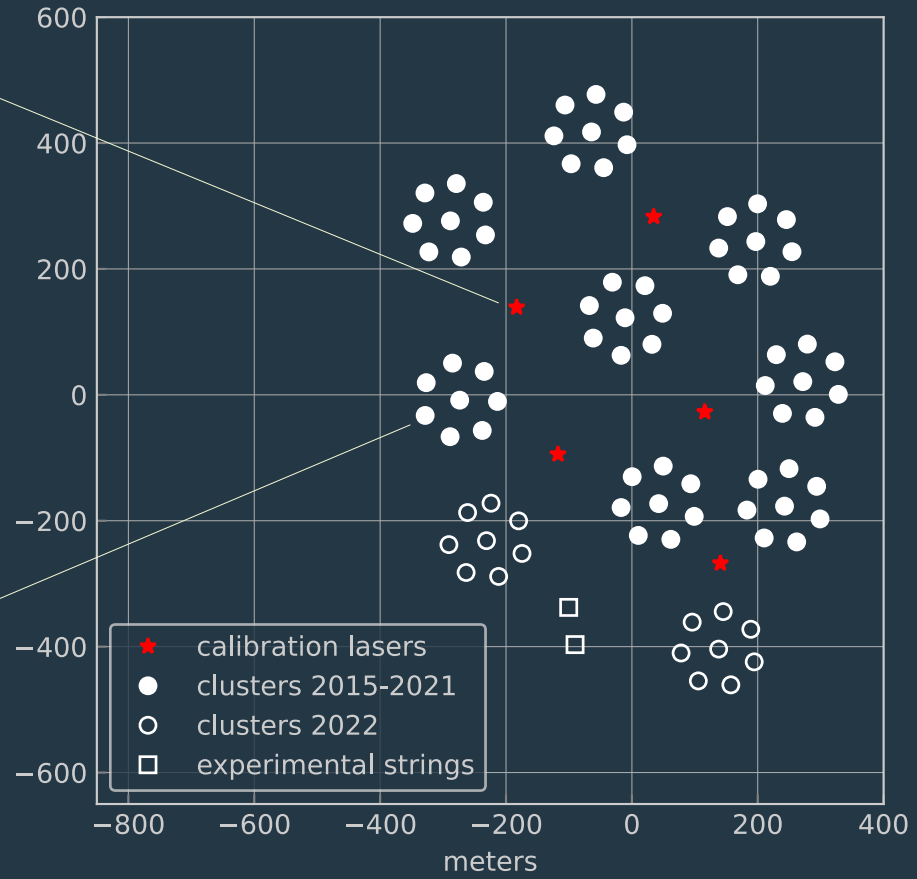
Video: сборка телескопа



x3000







Simulation

a lot easier than taking real data

but still challenging

Simulation

a lot easier than taking real data

but still challenging

ν

Simulation

a lot easier than taking real data
but still challenging

ν

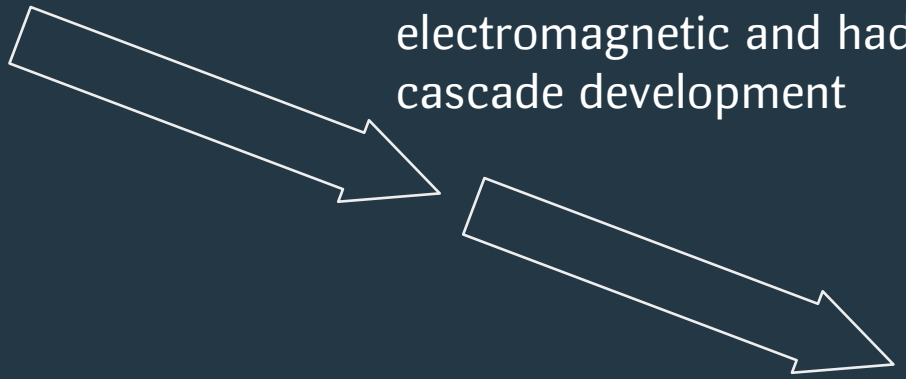
TeV-PeV scale physics

Simulation

a lot easier than taking real data
but still challenging

ν

TeV-PeV scale physics



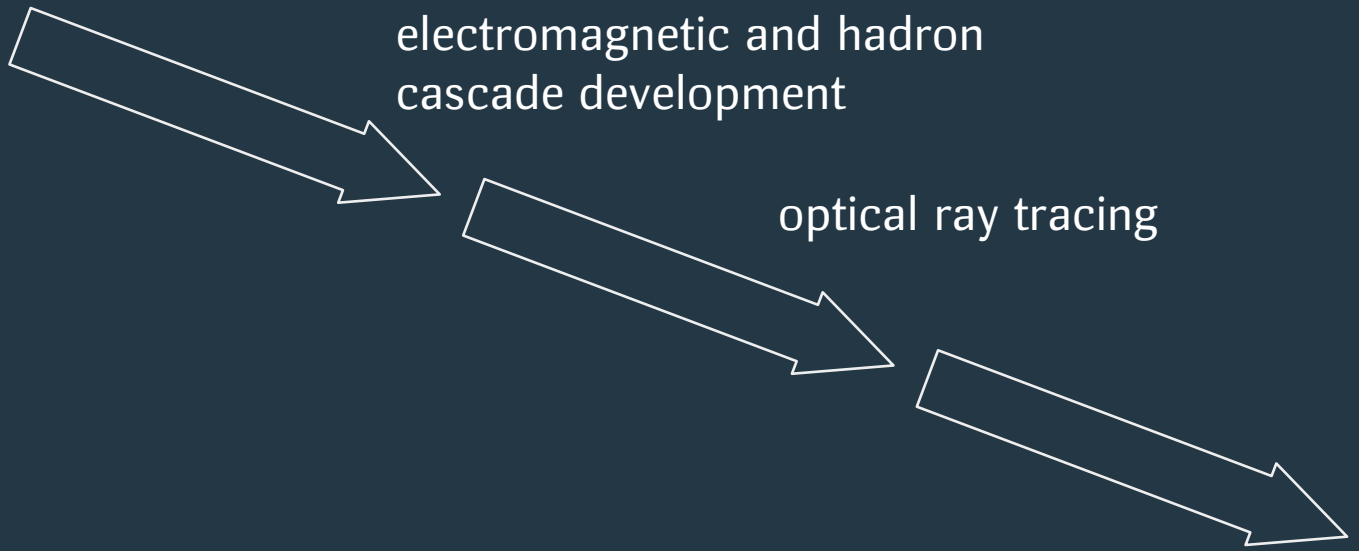
electromagnetic and hadron
cascade development

Simulation

a lot easier than taking real data
but still challenging

ν

TeV-PeV scale physics



electromagnetic and hadron
cascade development

optical ray tracing

Simulation

a lot easier than taking real data
but still challenging

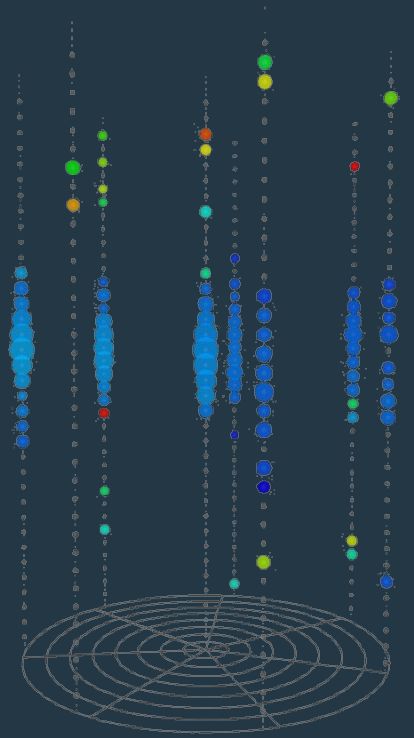
ν

TeV-PeV scale physics

electromagnetic and hadron
cascade development

optical ray tracing

detector response



Simulation

a lot easier than taking real data
but still challenging

ν

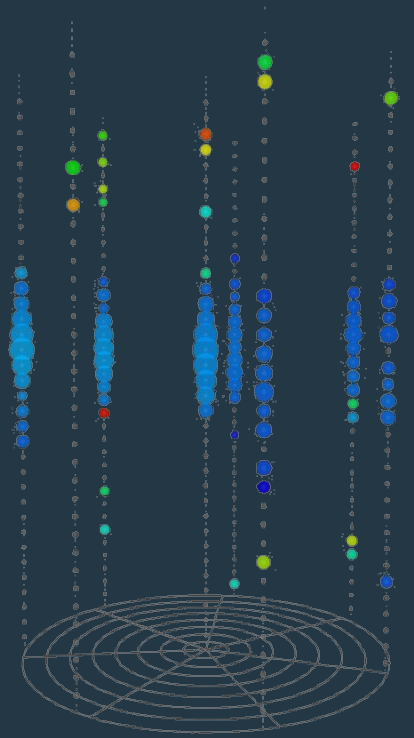
TeV-PeV scale physics

electromagnetic and hadron
cascade development

optical ray tracing

detector response

1 PeV neutrino → O(10^{11}) photons



Simulation

a lot easier than taking real data
but still challenging

ν

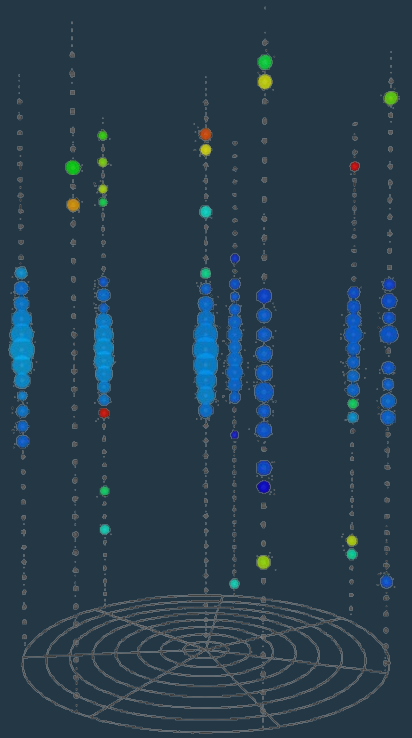
TeV-PeV scale physics

electromagnetic and hadron
cascade development

optical ray tracing

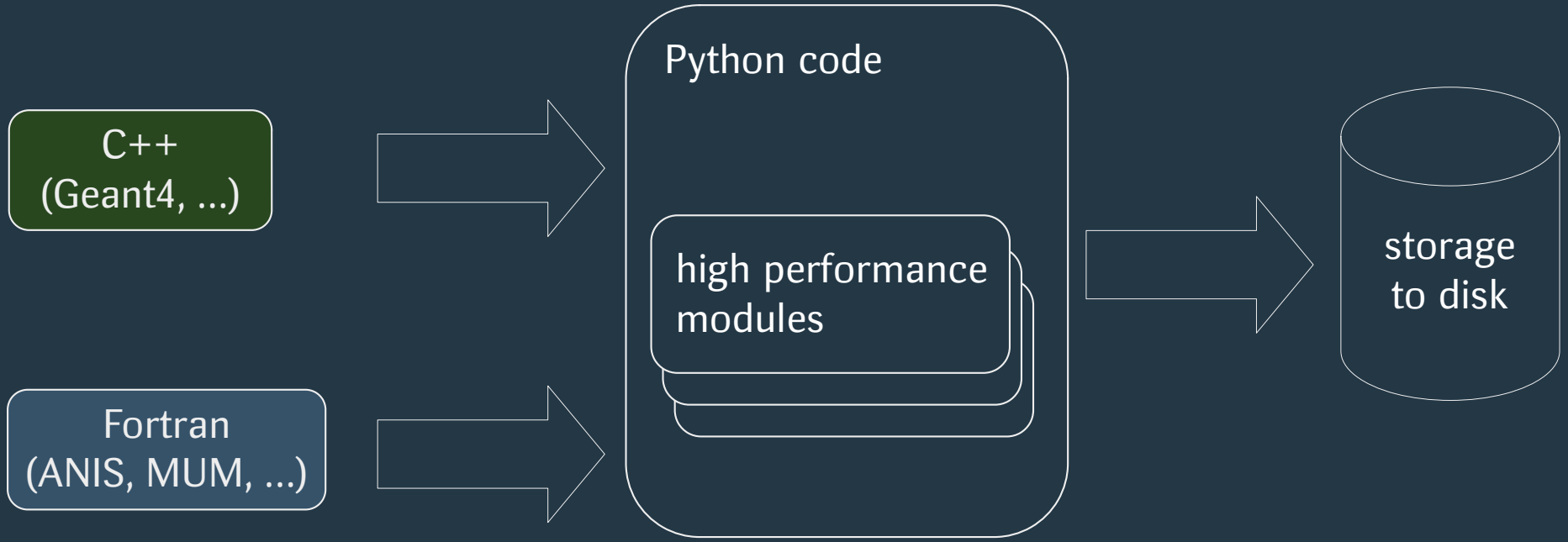
detector response

1 PeV neutrino → O(10^{11}) photons

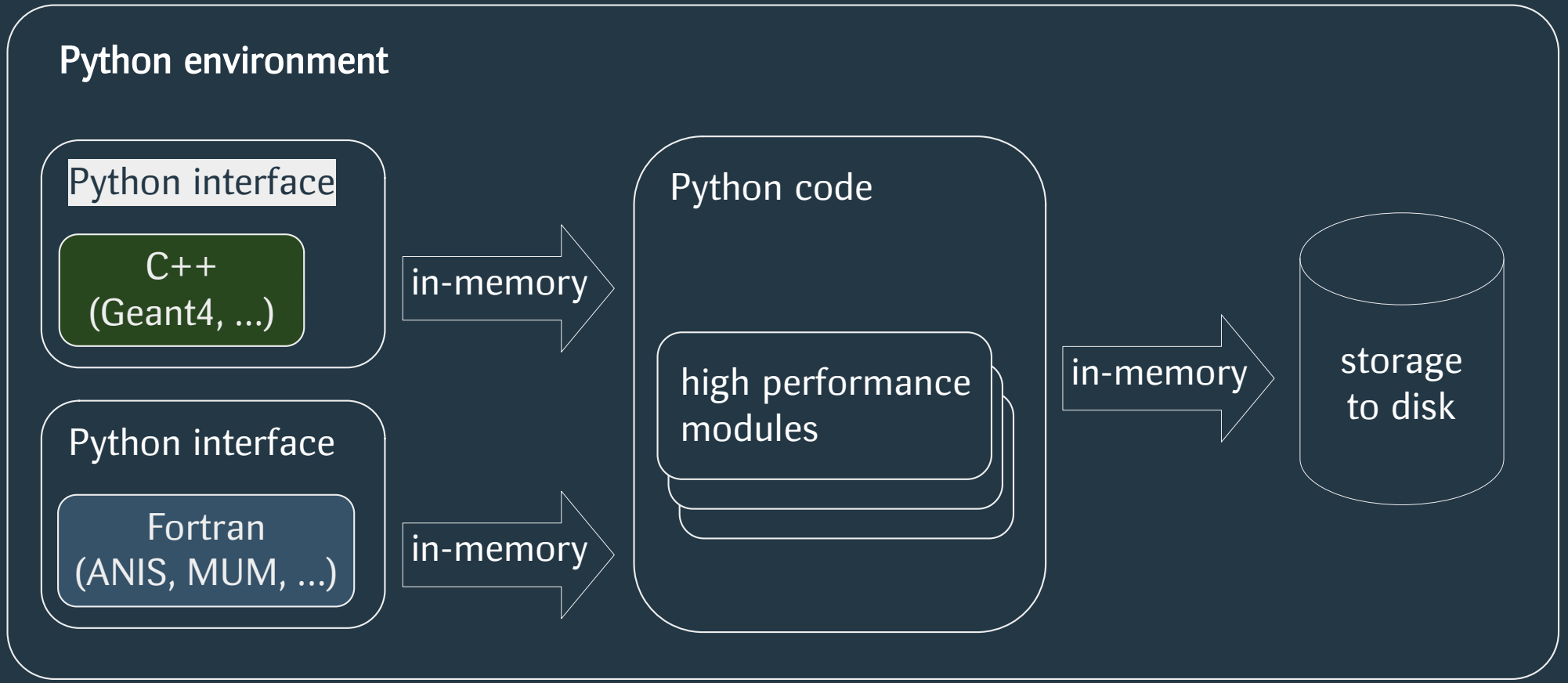


multiple approaches to be glued together

Single framework



Single framework



Single framework

- no intermediate read/write operations → huge speed up
- easy and fast coding (thanks to Python)
- plenty of tools (vector algebra, machine learning, visualization, ...)
- pre-compiled core code
- no need to compile the rest
- flexibility different tools can be easily glued
- integrations, e.g. Jupyter notebooks

New simulation tools

WORK IN PROGRESS

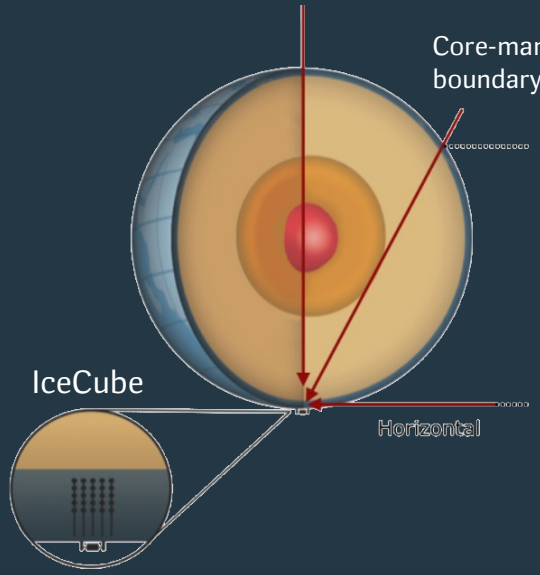
Python interfaces for
- Geant4
- ANIS
- MUM
- CORSIKA (reader, in progress)

Own algorithms
- **MUM**: muon propagation (I. Sokalski)
- **NuProp**: nuetrino generator (V. Allachverdian)
- high energy particle propagation, Geant4-based (Yu. Malyshkin)
- **LiGen**: cascade development and light emission, Geant4-based (Yu. Malyshkin)
- **PRETIRIAN**: hybrid light transport algorithm (W. Noga)
- custom MC ray-tracing (V. Naumov, Yu. Malyshkin)
- analytical light trasnport (V. Allachvedian, V. Naumov)
- machine learning for cascade + light transport (D. Leskov, Yu. Malyshkin)

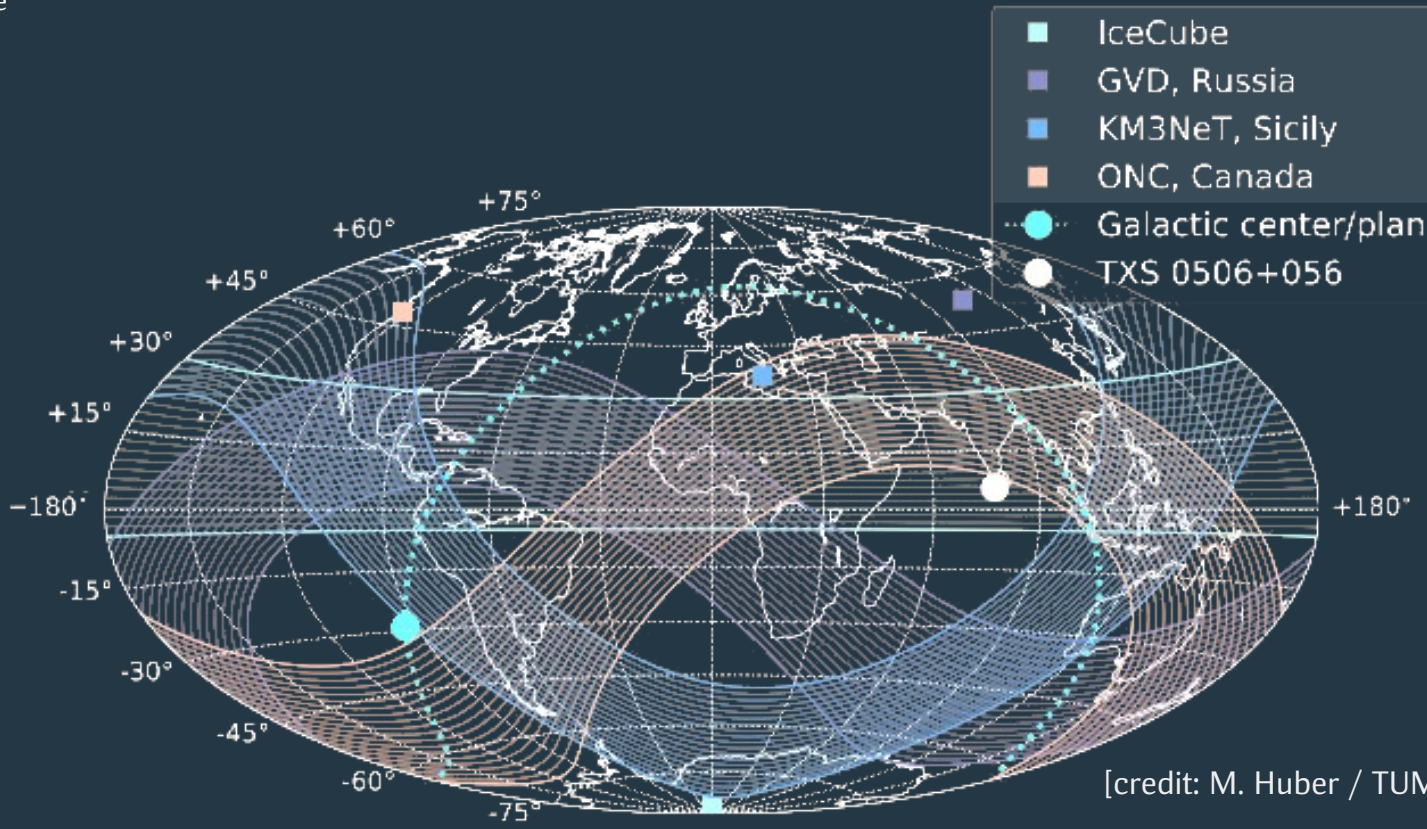
Convenient simulation is a key a for fruitful physical analysis

BACKUP SLIDES

Global Neutrino Network

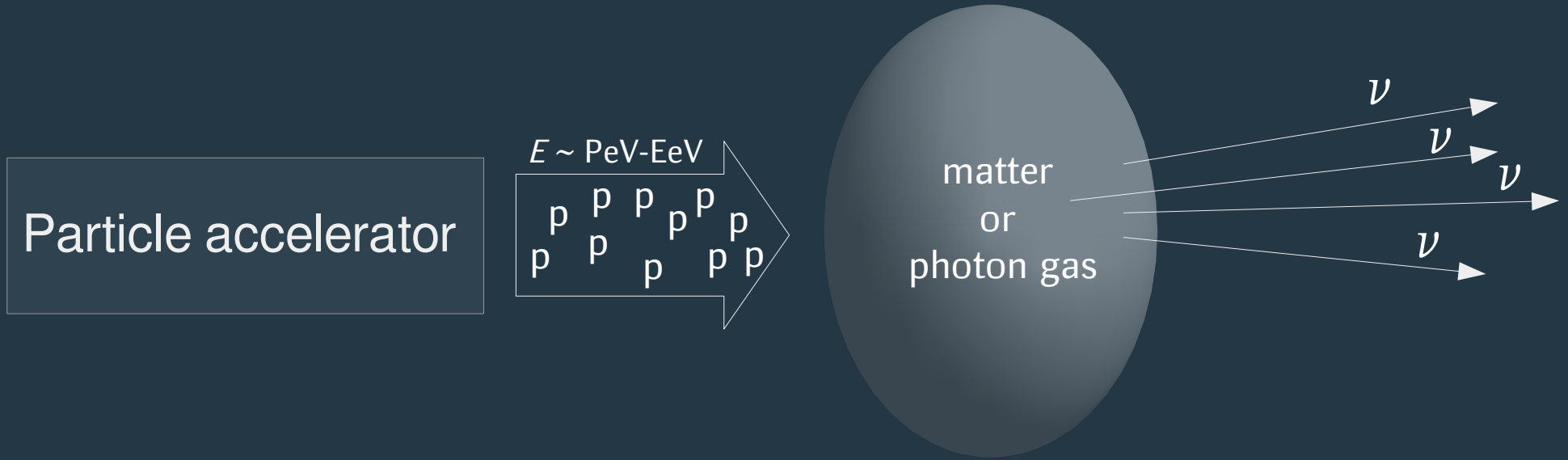


[credit: IceCube collaboration]



[credit: M. Huber / TUM]

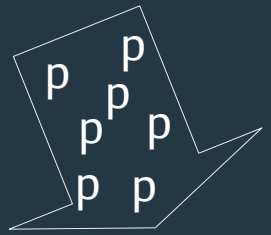
Production of astrophysical neutrino



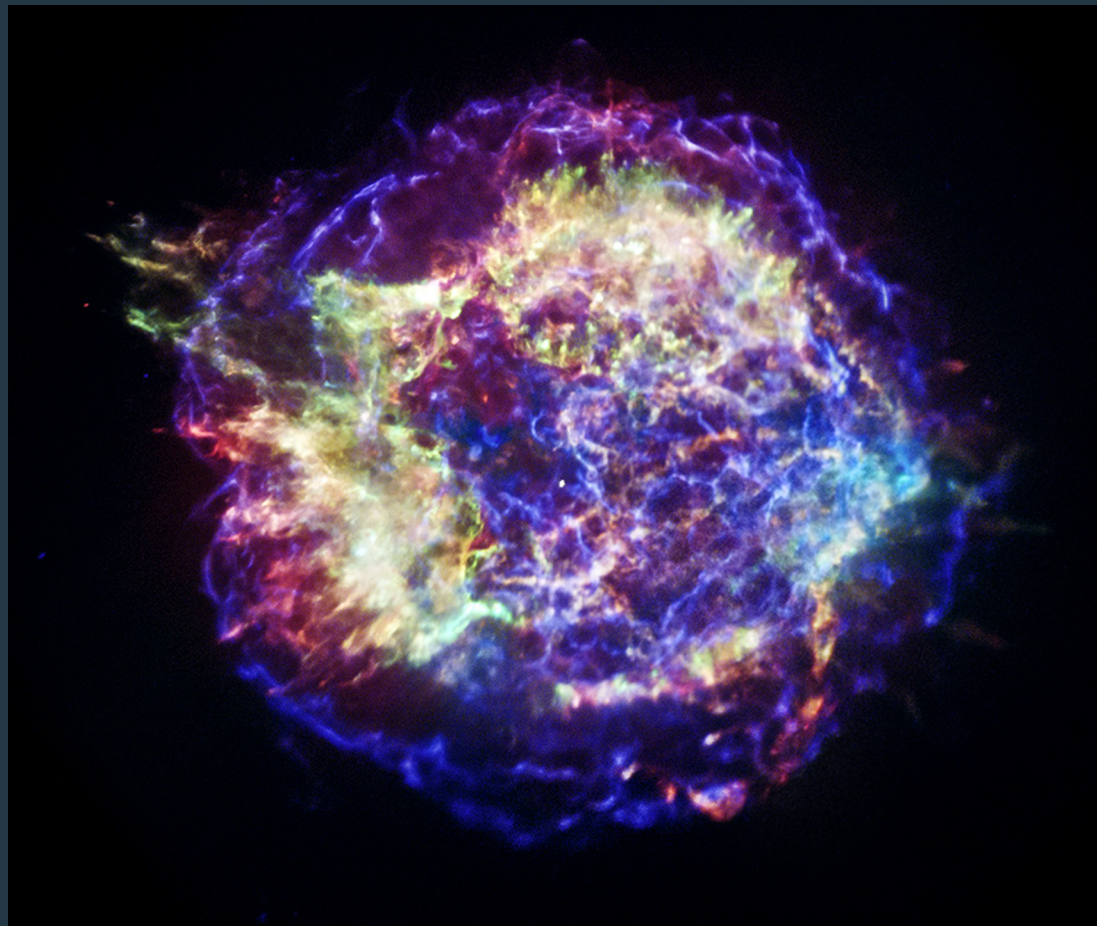
Возможные источники нейтрино

Молодые остатки сверхновых

протоны ускоряются магнитным полем быстро вращающейся нейтронной звезды



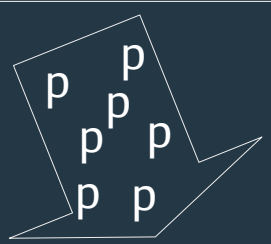
расширяющаяся оболочка служит мишенью



Возможные источники нейтрино

Активные галактические ядра

протоны ускоряются ударными волнами в джетах или в аккреционном диске



аккреционный диск служит мишенью

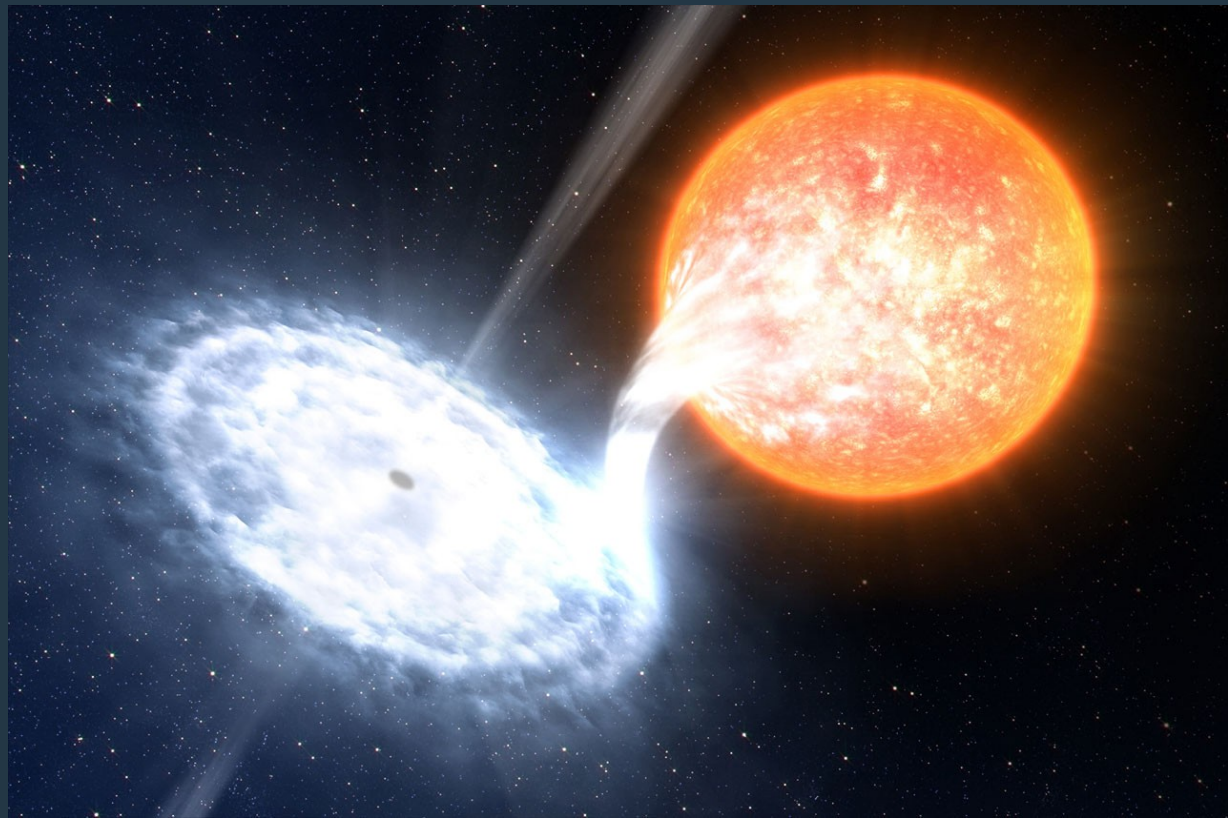
Возможные источники нейтрино

Двойные системы

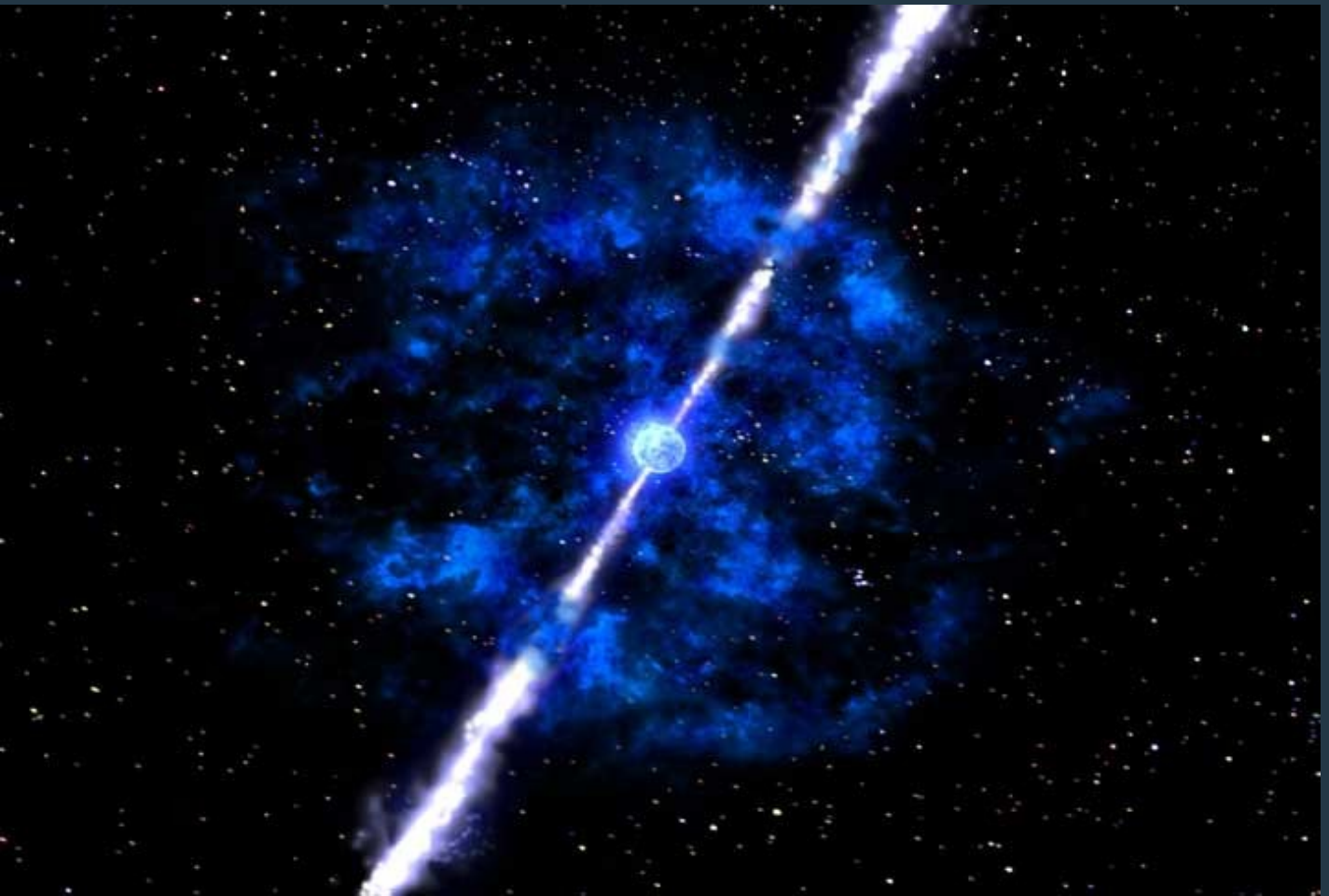
протоны ускоряются в сильном магнитном поле пульсара (черной дыры)

p p p p p p p

аккреционный диск служит мишенью



Возможные источники нейтрино



Гамма-всплески

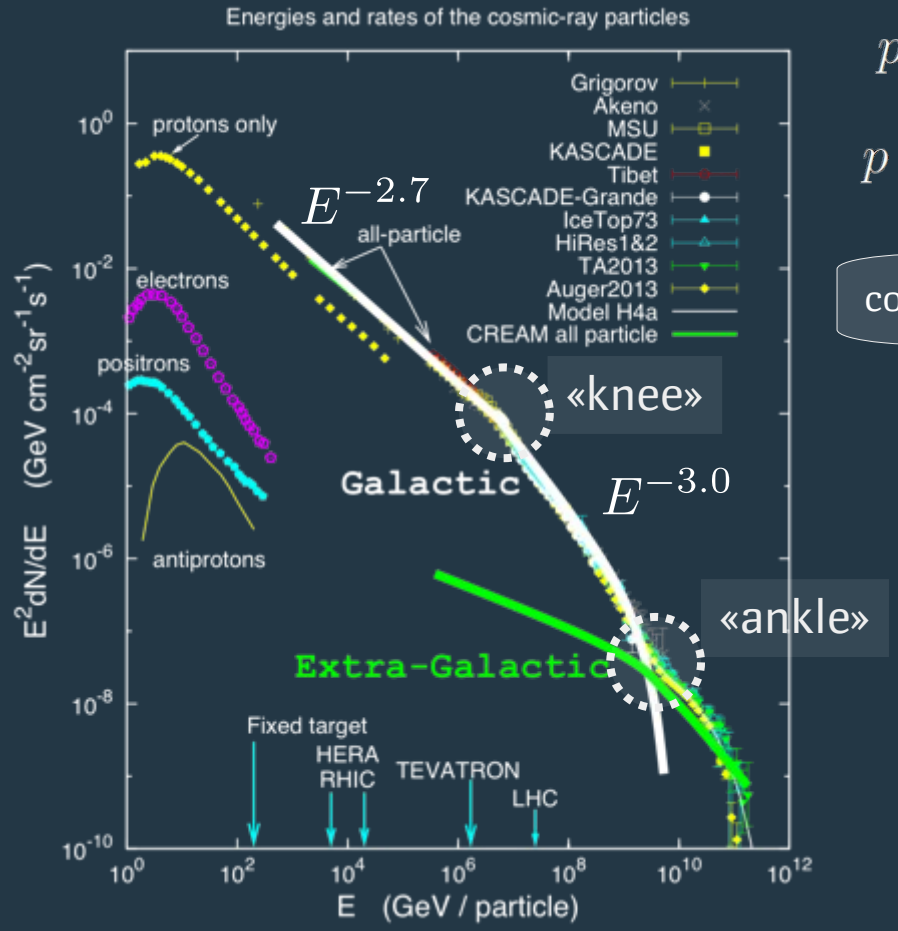
Самые масштабные известные космические выбросы энергии.

Кандидаты:

- гиперновые
- столкновения двух нейтронных звезд
- поглощение нейтронной звезды черной дырой

за доли секунды выделяется столько же энергии, сколько излучит Солнце за все свое существование

Cosmic rays → neutrino



$$p + \gamma_{CMB} \rightarrow \Delta^+ \rightarrow p + \pi^0 \qquad (E_p > 50 \text{ EeV})$$

$$p + \gamma_{CMB} \rightarrow \Delta^+ \rightarrow n + \pi^+$$

$$\pi^+ \rightarrow \mu^+ + \nu_\mu$$

$$\mu^+ \rightarrow e^+ + \nu_e + \bar{\nu}_\mu$$

cosmic microwave background

$$p + N \rightarrow \pi^0 + \pi^+ + \pi^- + X$$

$$\pi^- \rightarrow \mu^- + \bar{\nu}_\mu$$

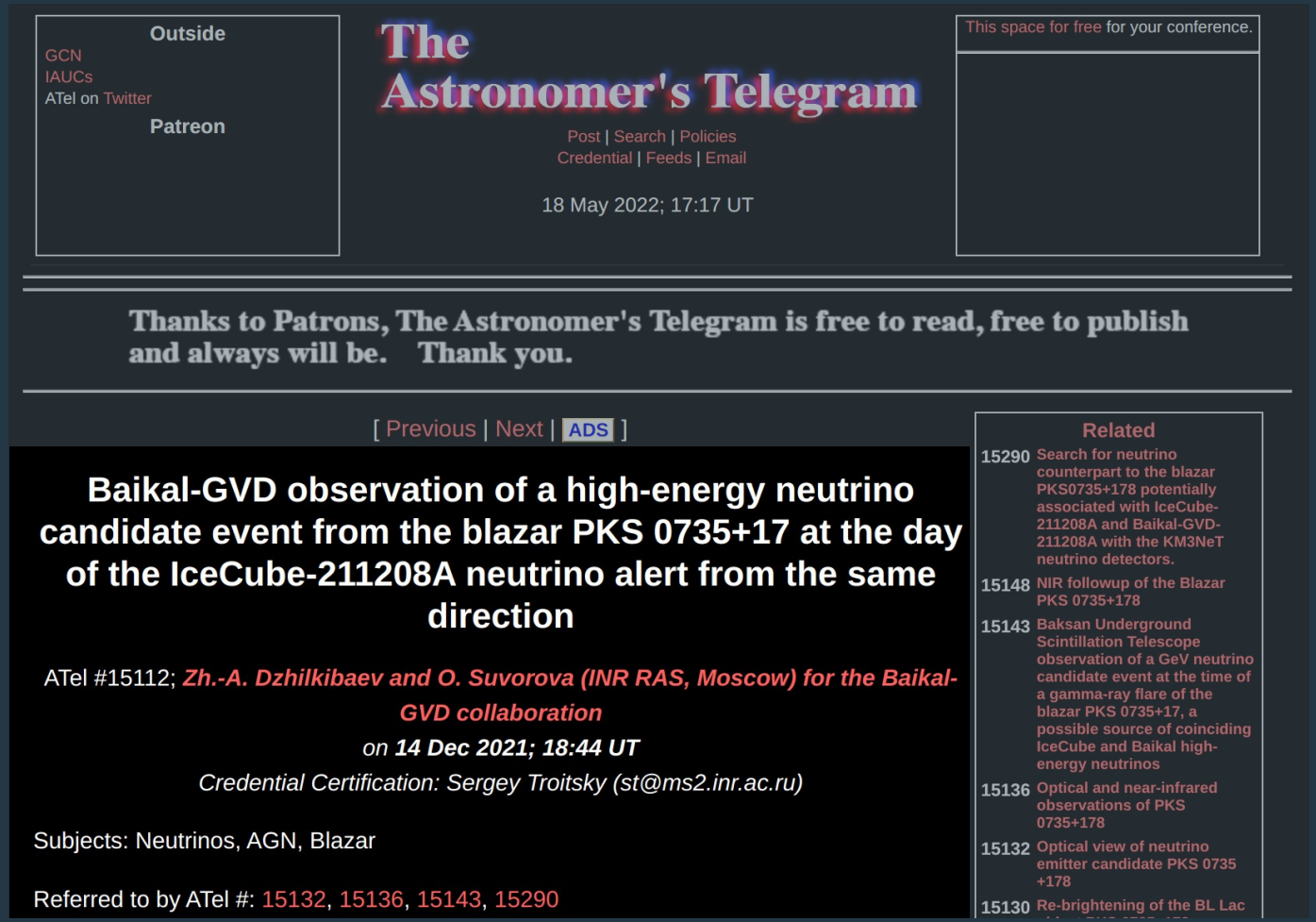
$$\mu^- \rightarrow e^- + \bar{\nu}_e + \nu_\mu$$

matter

$$K^+ \rightarrow \mu^+ + \nu_\mu$$

$$K^- \rightarrow \mu^- + \bar{\nu}_\mu$$

The first BaikalGVD's astro-telegram



Outside
GCN
IAUCs
ATel on Twitter
Patreon

The Astronomer's Telegram

Post | Search | Policies
Credential | Feeds | Email

18 May 2022; 17:17 UT

This space for free for your conference.

Thanks to Patrons, The Astronomer's Telegram is free to read, free to publish and always will be. Thank you.

[Previous | Next | ADS]

Baikal-GVD observation of a high-energy neutrino candidate event from the blazar PKS 0735+17 at the day of the IceCube-211208A neutrino alert from the same direction

ATel #15112; *Zh.-A. Dzhilkibaev and O. Suvorova (INR RAS, Moscow) for the Baikal-GVD collaboration*
*on **14 Dec 2021; 18:44 UT***
Credential Certification: Sergey Troitsky (st@ms2.inr.ac.ru)

Subjects: Neutrinos, AGN, Blazar

Referred to by ATel #: 15132, 15136, 15143, 15290

Related
15290 Search for neutrino counterpart to the blazar PKS0735+178 potentially associated with IceCube-211208A and Baikal-GVD-211208A with the KM3NeT neutrino detectors.
15148 NIR followup of the Blazar PKS 0735+178
15143 Baksan Underground Scintillation Telescope observation of a GeV neutrino candidate event at the time of a gamma-ray flare of the blazar PKS 0735+17, a possible source of coinciding IceCube and Baikal high-energy neutrinos
15136 Optical and near-infrared observations of PKS 0735+178
15132 Optical view of neutrino emitter candidate PKS 0735 +178
15130 Re-brightening of the BL Lac

ATel #15112

Time coincidence with a blare of blazar **PKS 0735+17**

Another neutrino seen by IceCube: **IC211208A**

Bursts are detected in gamma, X-ray, oprical and radio channels

https://www.astronomerstelegram.org

History

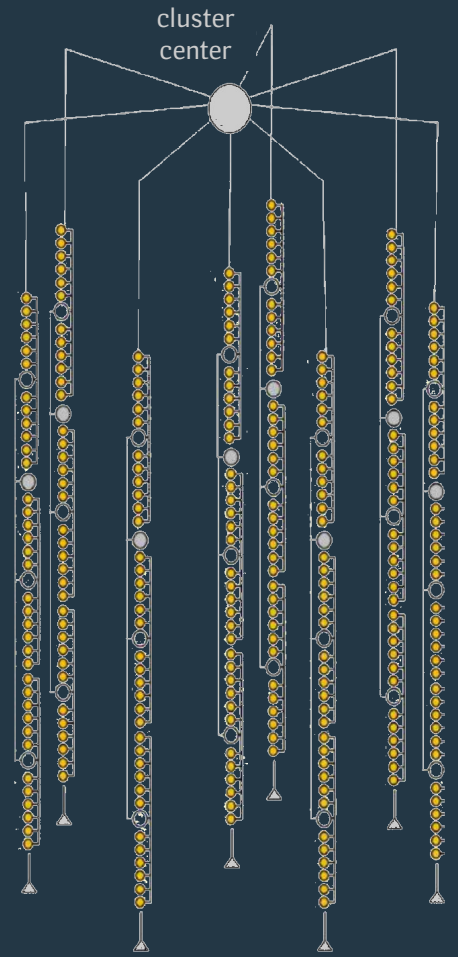
1979:	A. Chudakov proposed to carry out methodological works on Lake Baikal
1980-1995:	NT-36
1995-1998:	NT-72, NT-96, NT-144, NT-200
2004-2005:	NT-200+
2015-2021:	Baikal-GVD phase I (8 clusters, 34M $USD)
2025:	Baikal-GVD full (16 clusters)

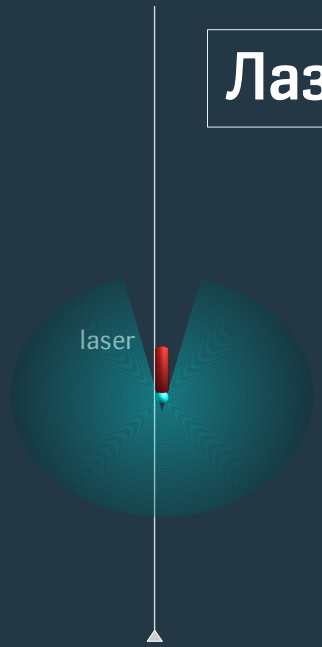
History

Baikal-GVD: expedition 2022

ice camp

Компоненты

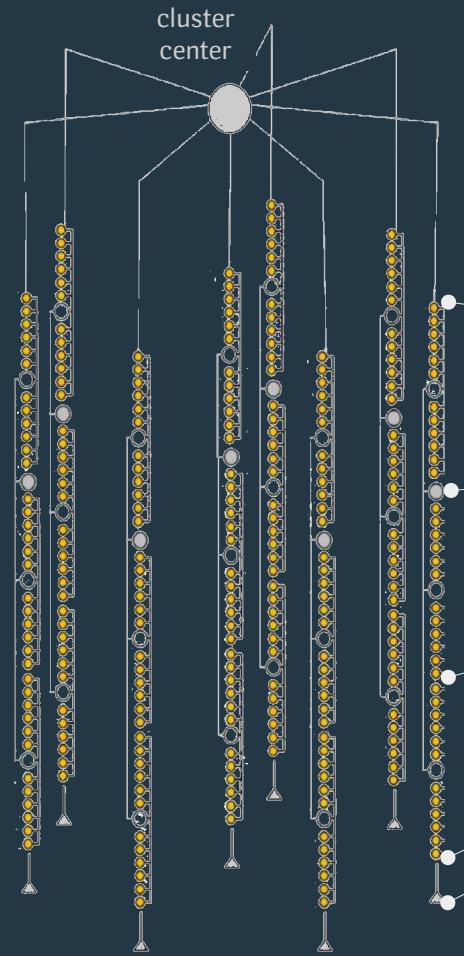




Лазер

Назначение:
измерение оптических свойств воды, калибровки

Компоненты

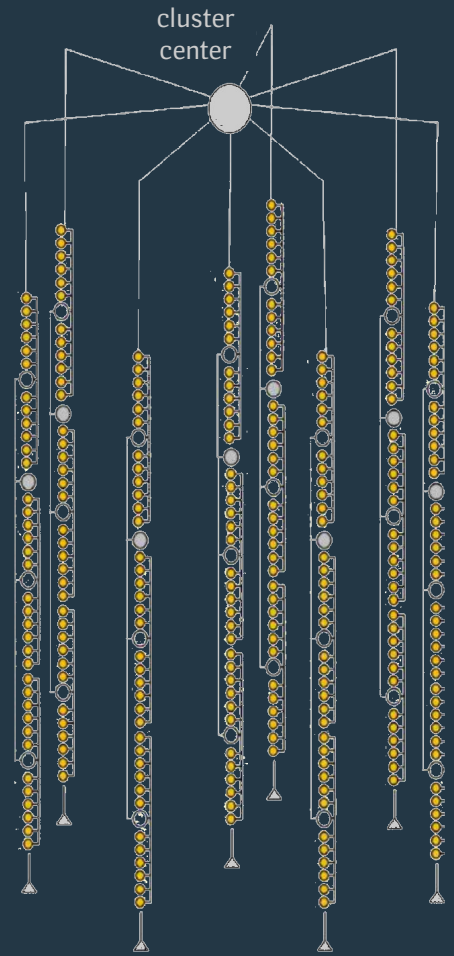


Акустический модем

4-5 на каждой гирлянде

Назначение:
точное позиционирование (20-30 см)

Компоненты



Оптический модуль

36 на каждой гирлянде

Назначение: регистрация черенковского света

Зимняя экспедиция

Вывоз на лед и тестирование оптических модулей

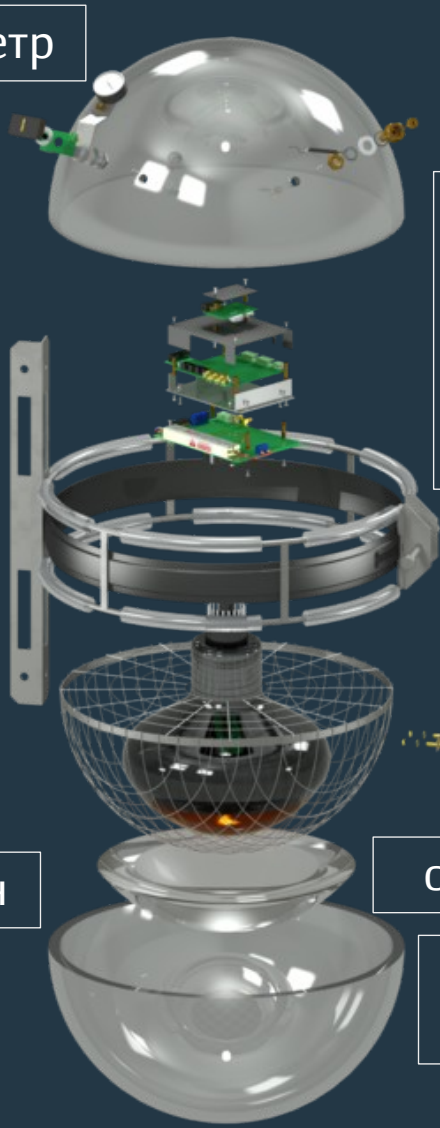
Монтаж гирлянд

Монтаж гирлянд

Монтажная бригада состоит из 3-5 человек

В последние годы одновременно работает около 4 бригад, каждая может независимо монтировать новую гирлянду или ремонтировать старую

Оптический модуль



манометр

глубоководный разъем

вакуумный клапан

акселерометр, компас, контроллер ОМ, управление питанием

монтажная рама

линза

ФЭУ Hamamatsu R7081-100 (10 дюймов)

Калибровочные LED

магнитный экран

оптический гель

стеклянная полусфера

регистрирует отдельные фотоны

эффективность ~25%

Производство оптических модулей

Альфа-зал на площадке ЛЯП

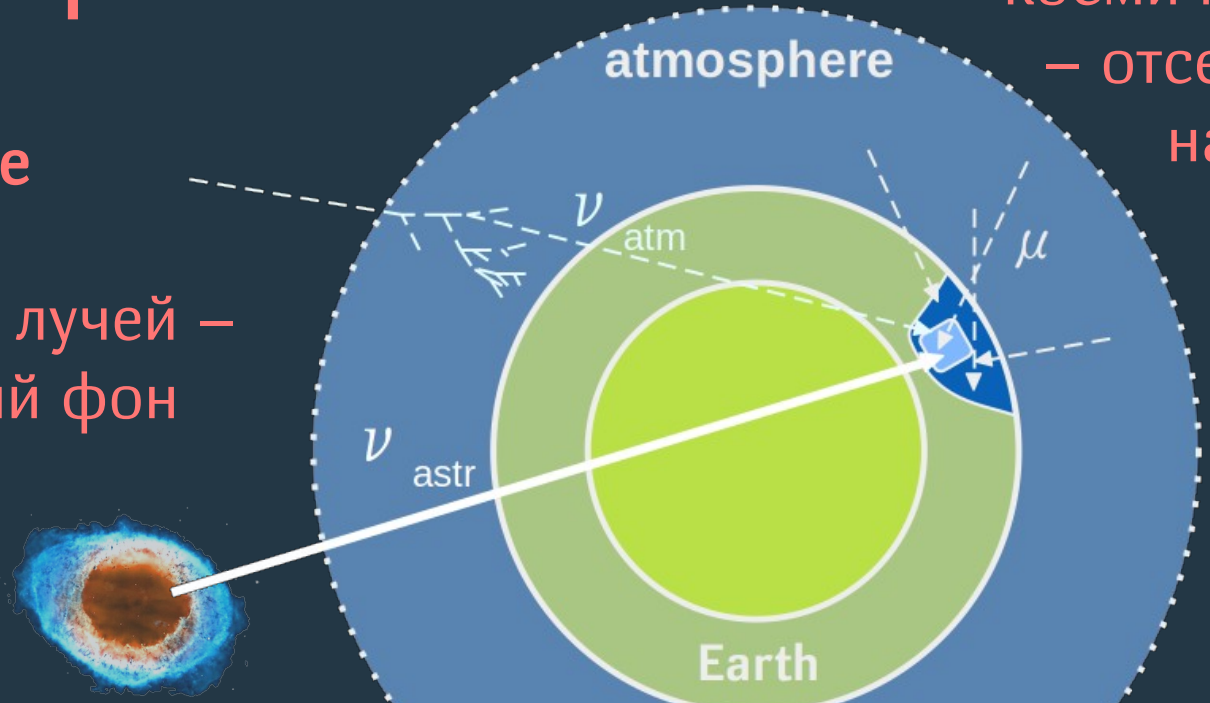
~600 модулей в год

Video: Сборка оптических модулей

Сигнал и фон

Мюоны от космических лучей – отсеиваются по направлению прихода

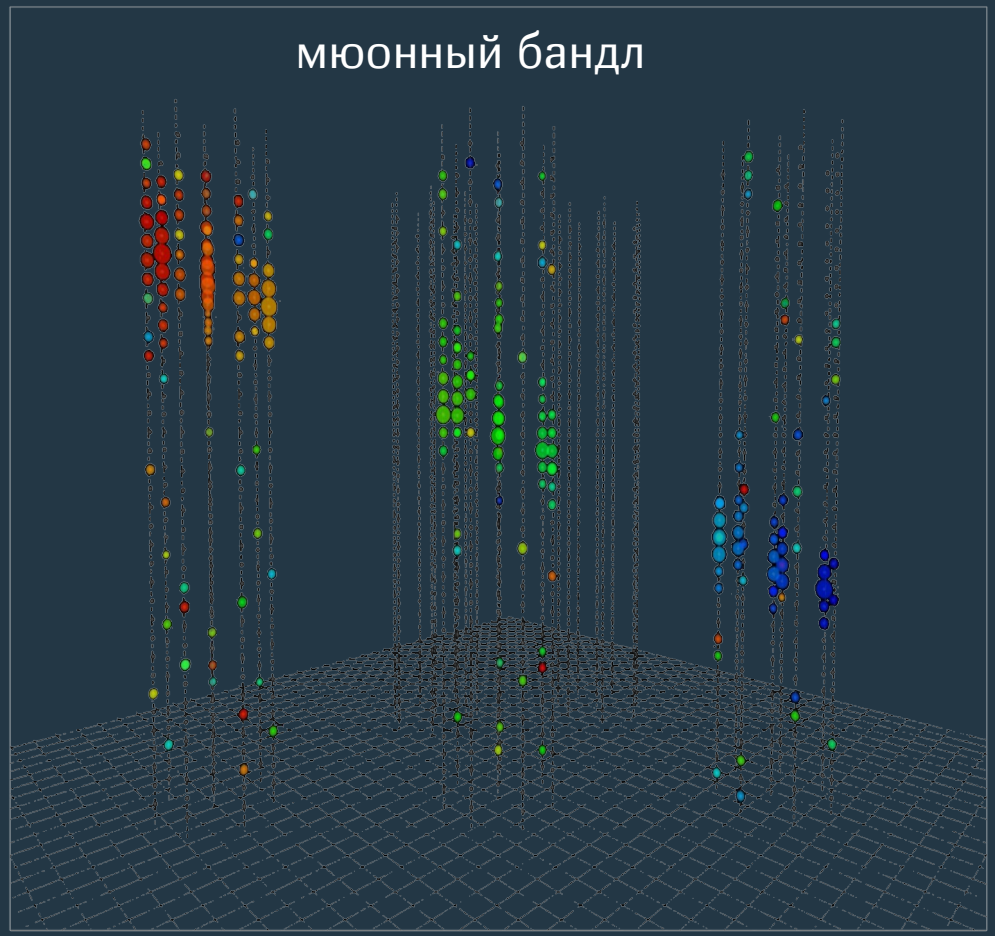
Атмосферные нейтрино от космических лучей – неустранимый фон

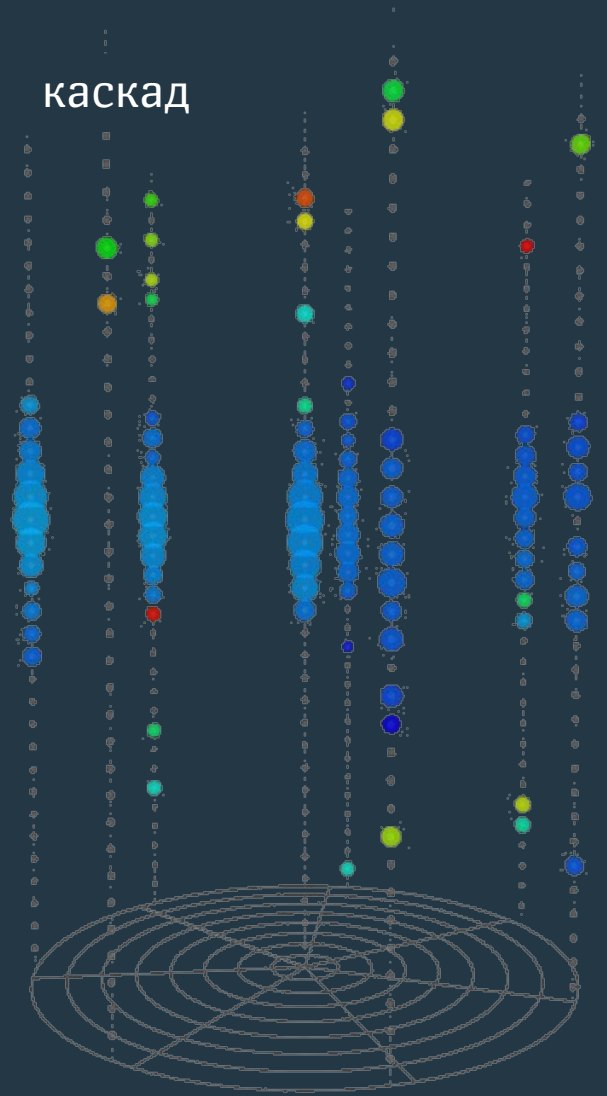


Астрофизические нейтрино

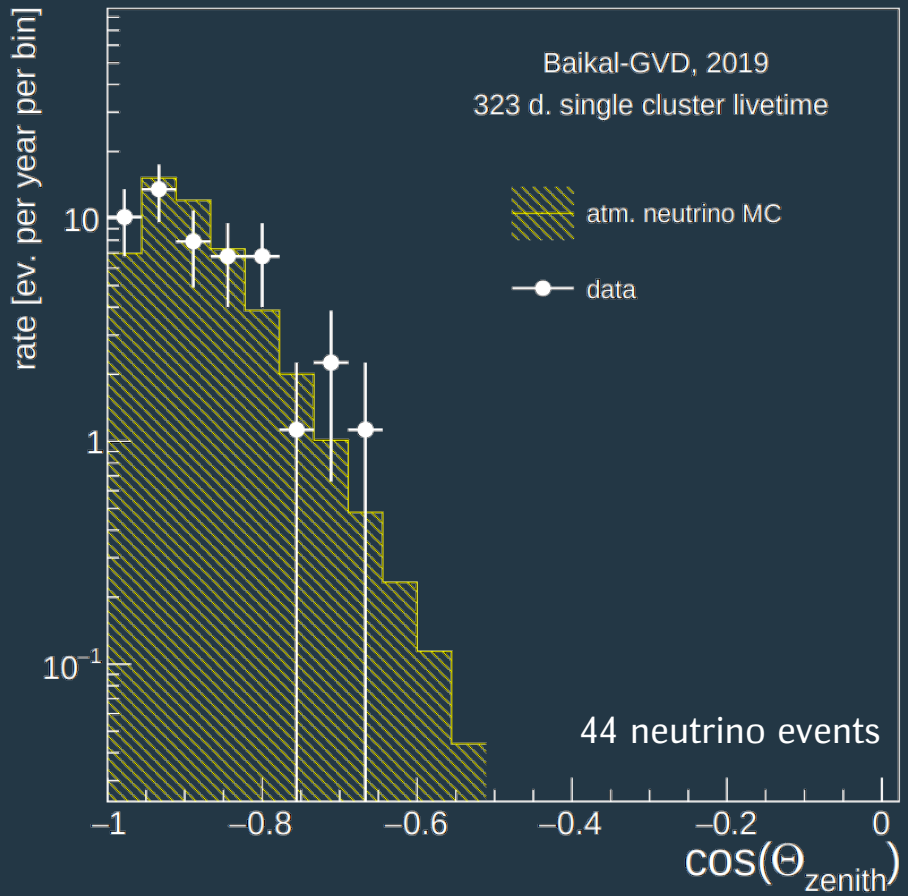
- Превышение над ожидаемым потоком атмосферных нейтрино
- Корреляция по времени и направлению с астрофизическими событиями и объектами

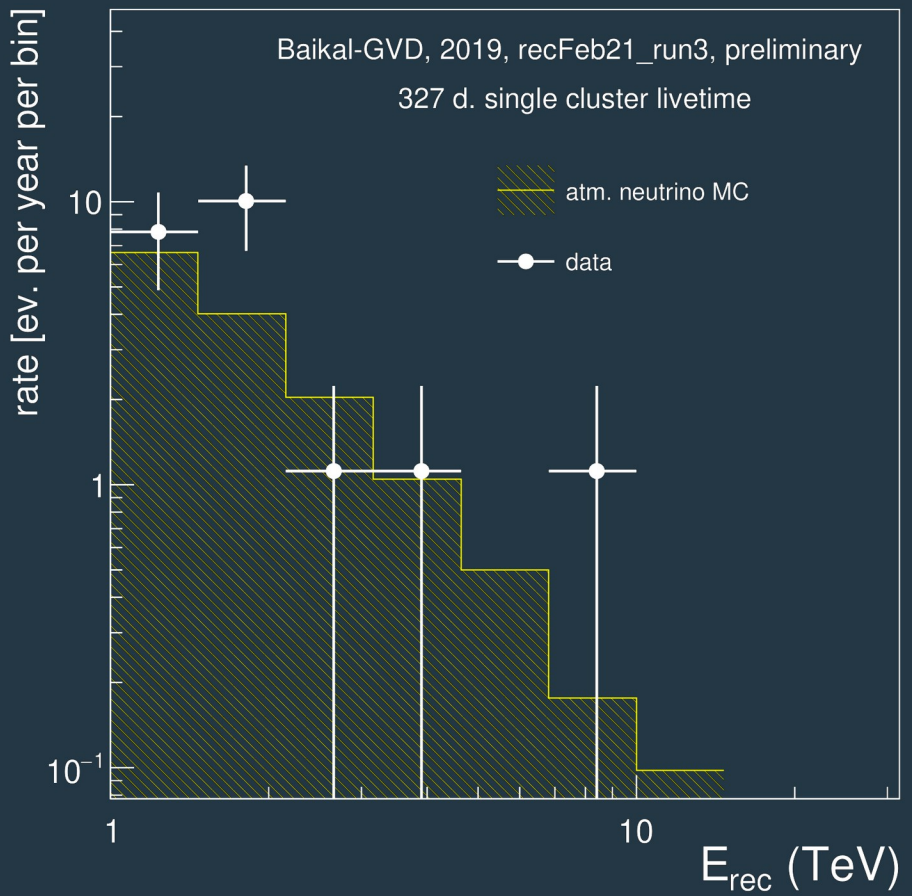
Примеры событий





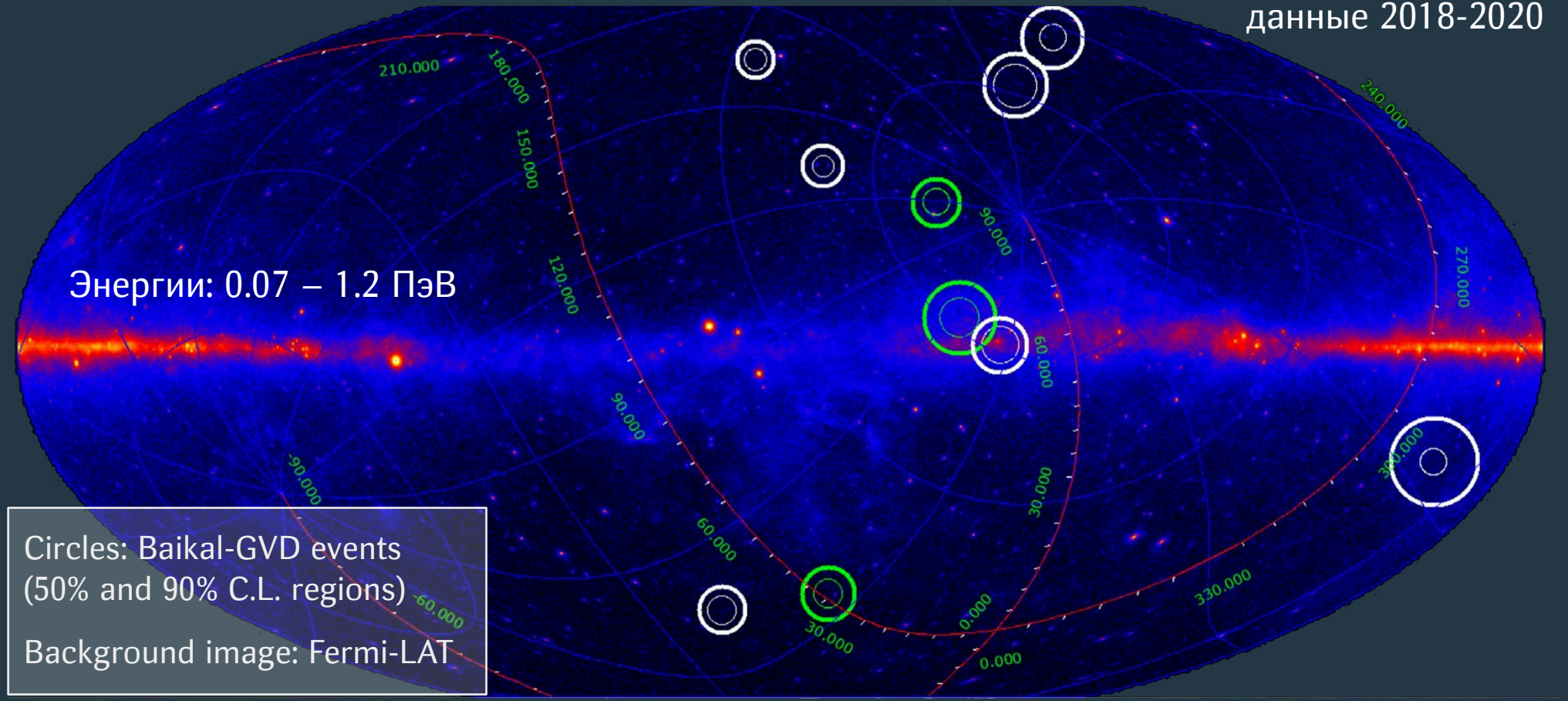
Восходящие трековые события



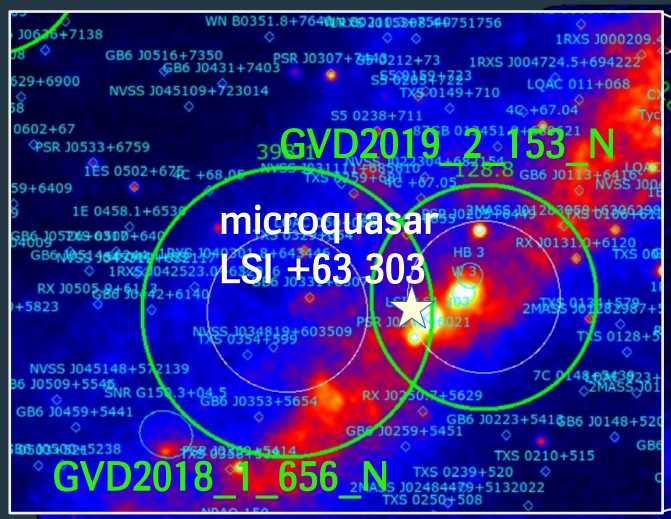


Каскадные события

данные 2018-2020



Каскадные события



Circles: Baikal-GVD events (50% and 90% C.L. regions)

Background image: Fermi-LAT

Микроквазар LSI +63 303 – это двойная система (Be звезда + компактный невидимый объект), излучающая от радио до ТэВ диапазона. В Млечном пути известно всего 4 подобных объекта.