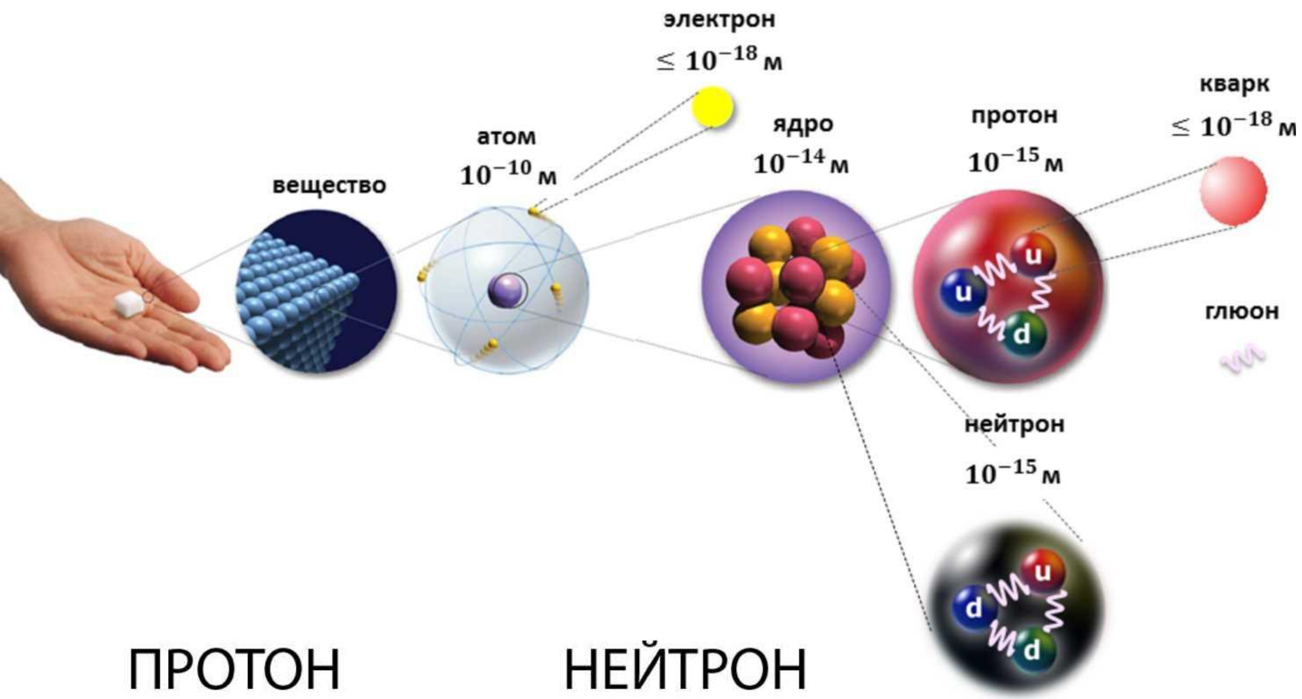
JOINT INSTITUTE FOR NUCLEAR RESEARCH

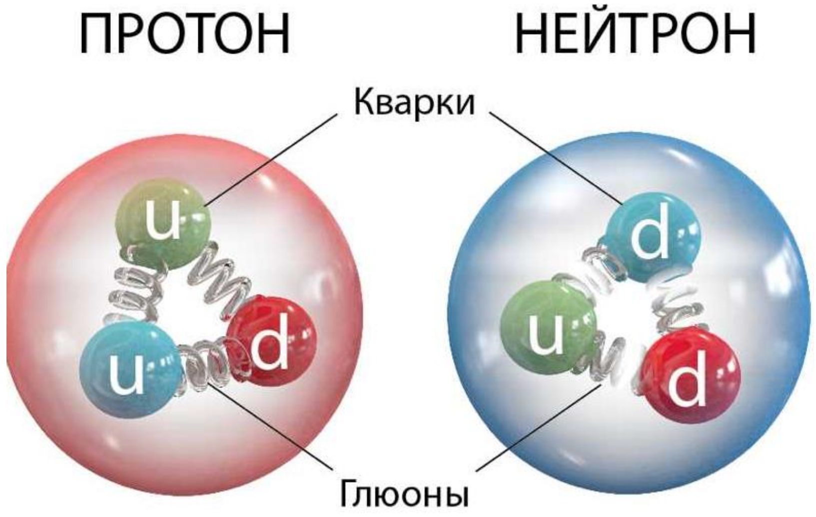
International Intergovernmental Organization

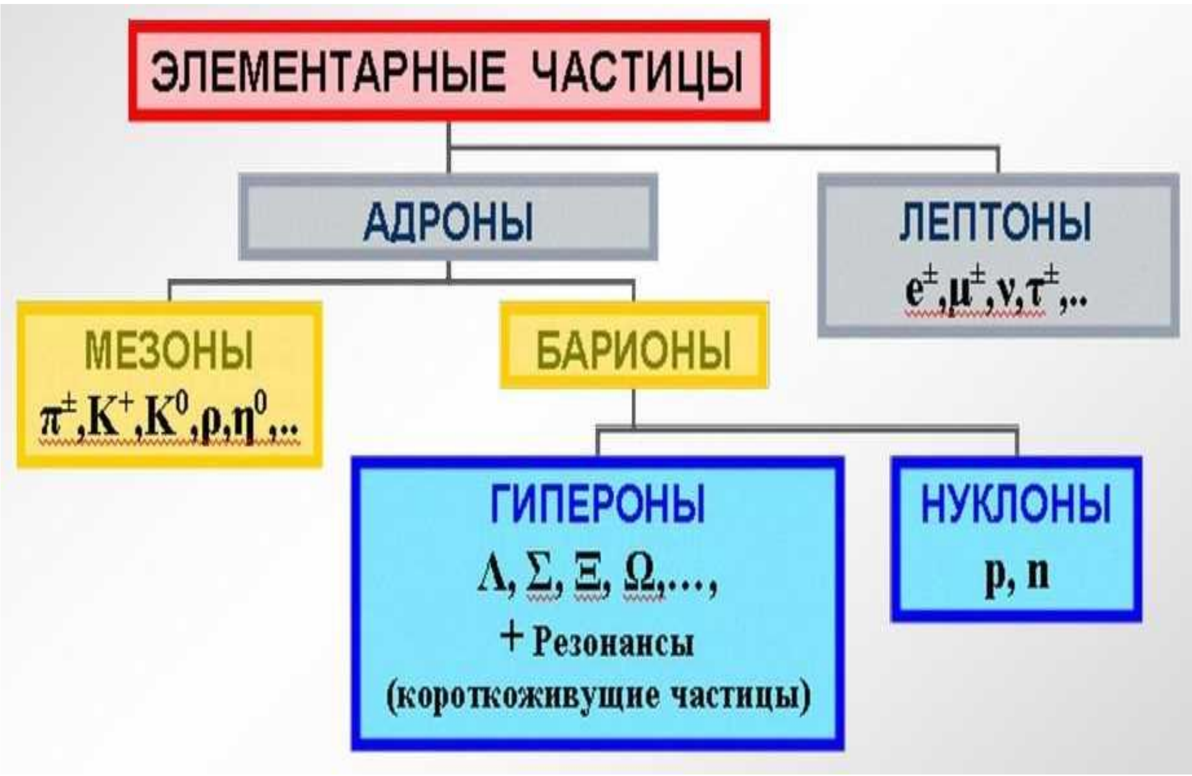
Future experiments in high energy physics

Grigory Trubnikov, JINR

After 14 billion years. Ideas about the structure of nuclear matter: Nucleons, quarks, gluons.

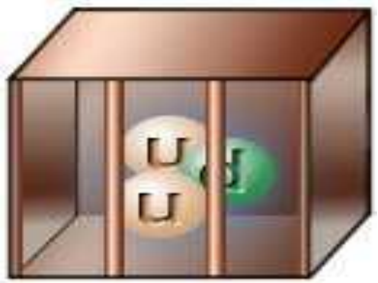




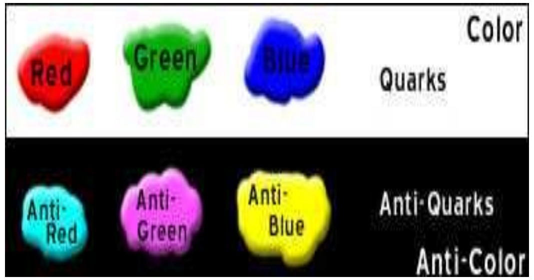


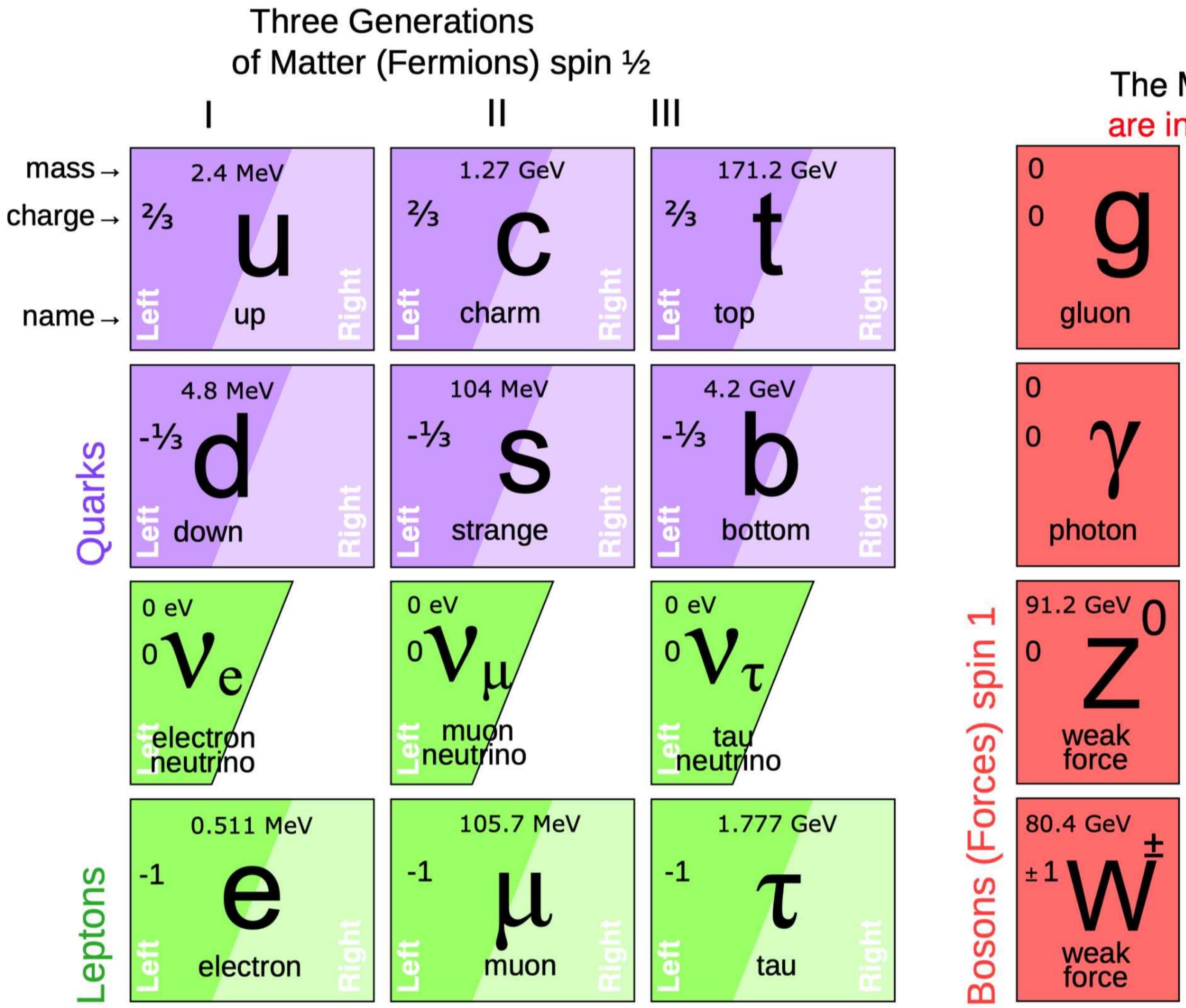
$$\mathcal{L} = -\frac{1}{4}F_{\mu\nu}F^{\mu\nu} + i\bar{\psi}\not{D}\psi + \psi Y \psi\phi + D_\mu\phi D^\mu\phi - V(\phi)$$

Comfinment :



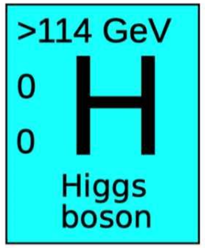
Quantum chromodynamics





The Matter generations are indistinguishable by electric weak and strong forces

distinguishable by gravity and Yukawa forces



spin 0

$m_H \approx 125\,\text{GeV}$

Standard Model + GR : Major Problems

Gauge and Higgs fields (interactions): γ, $W^{\pm}$, Z, g, G, and h

Three generations of matter: $L = \binom{\nu_L}{e_L}$, e_R; $Q = \binom{u_L}{d_L}$, d_R, u_R

- Describes all experiments dealing with
  - electroweak and strong interactions (anomalies: $g-2$?, LHC?, B-physics..)
- Does not describe

(PHENO)

- Neutrino oscillations -3 (and anomalies. . .)
- Dark matter (Ω_{DM}) - ?
- Baryon asymmetry (Ω_B) -?
- Why the Universe is flat and homogeneous? -?
- Where did the matter perturbations come from?-?

(THEORY)-1

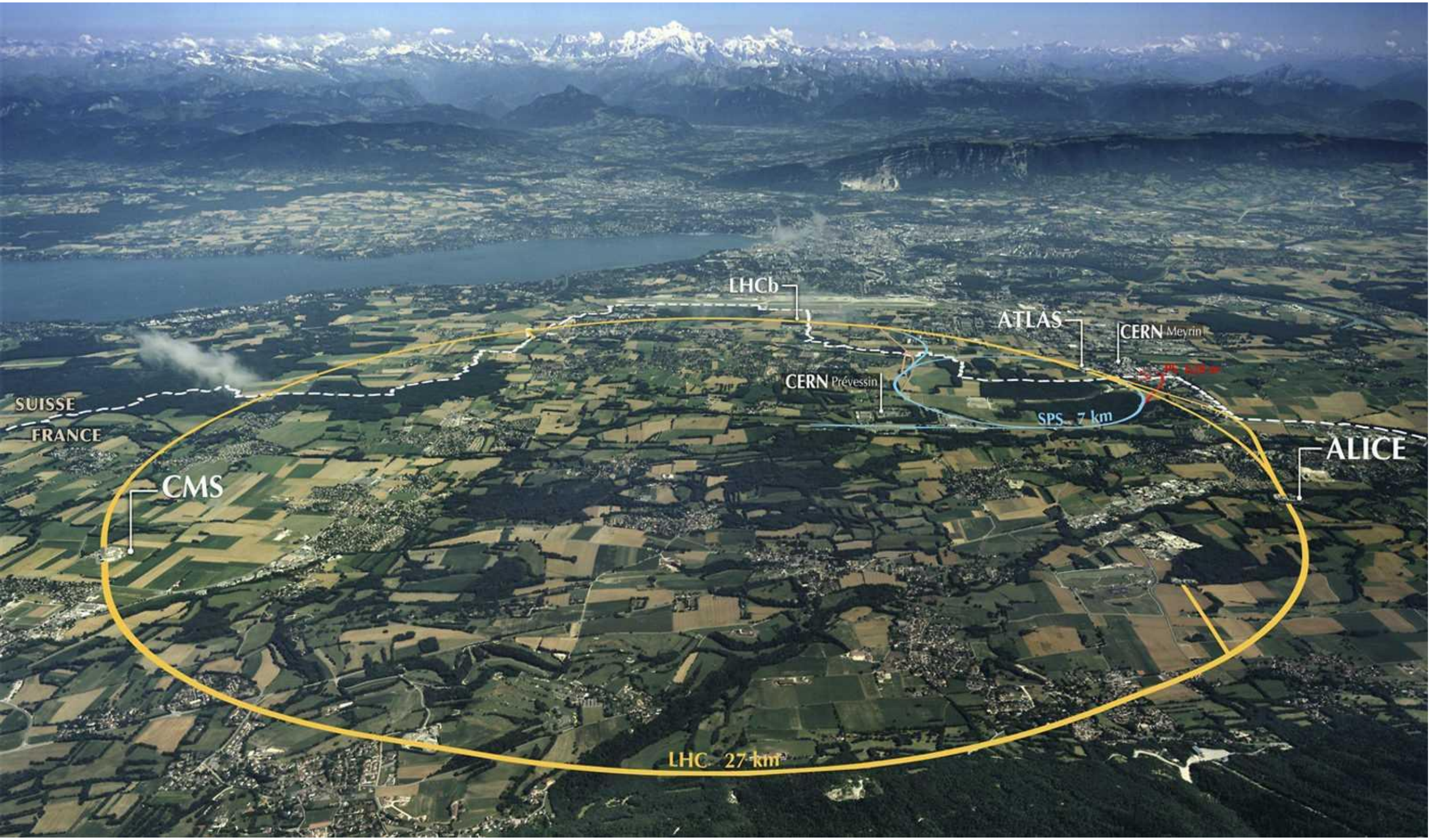
- Dark energy (Ω_Λ)
- Strong CP-problem
- Gauge hierarchy
- Quantum gravity
- Why 3 generations?
- Why $Y_e \ll Y_\mu \ll .. \ll Y_t$

Courtesy of A.Bondar', V.Rubakov

Verification of the Standard Model and quest for New Physics

- Precision tests of the Standard Model: measuring properties of Higgs boson, top quark, search for rare and forbidden decays:
  - – Experiments at frontier high energy accelerators;
- Study of CP violation, precision tests of QCD, nucleon structure study:
  - – Precision experiments at hadron factories;
- Properties of hadronic matter and physics of critical phenomena in strong interactions (confinement problem, chiral symmetry, quark-gluon plasma):
  - – Experiments with relativistic heavy ions;
- Search for New Physics

LHC

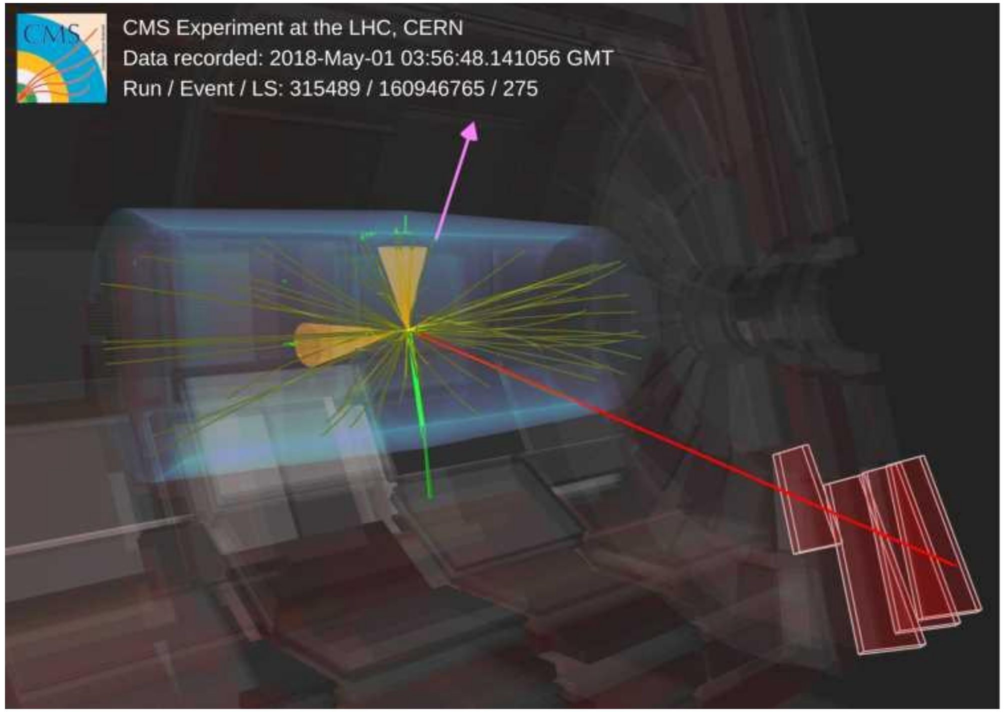


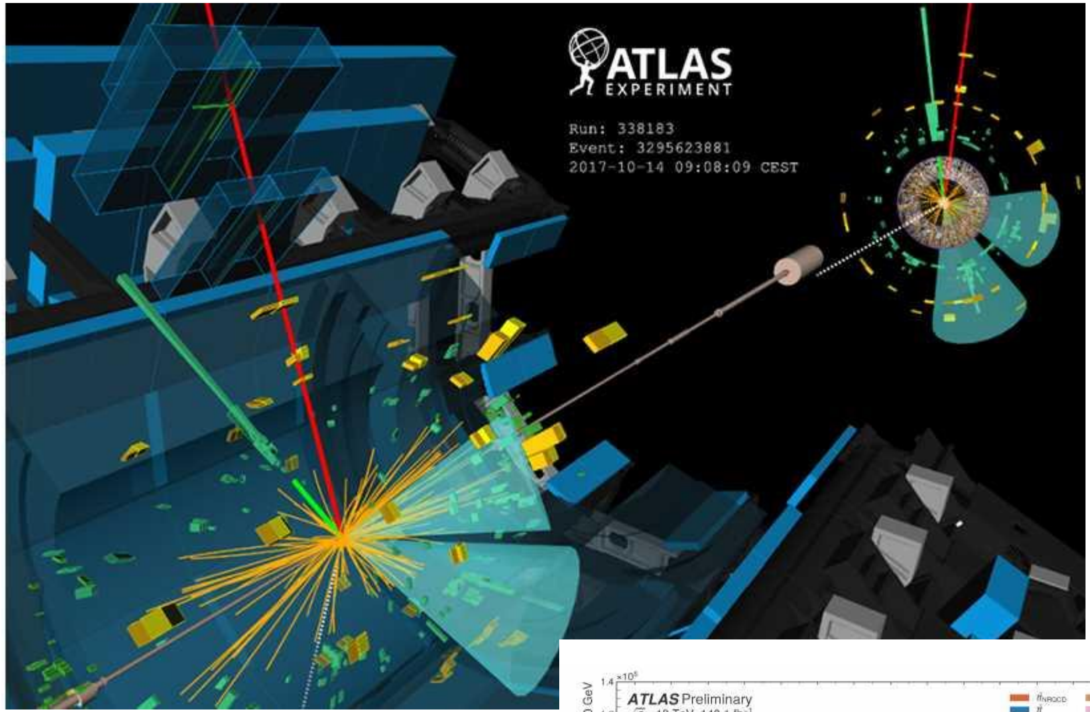
- Large Hadron Collider;
- CERN (Geneva, Switzerland);
- Runs since 2009;
- p+p, Pb+Pb;
- 13 TeV;
- Remains the main source of HEP experimental data.

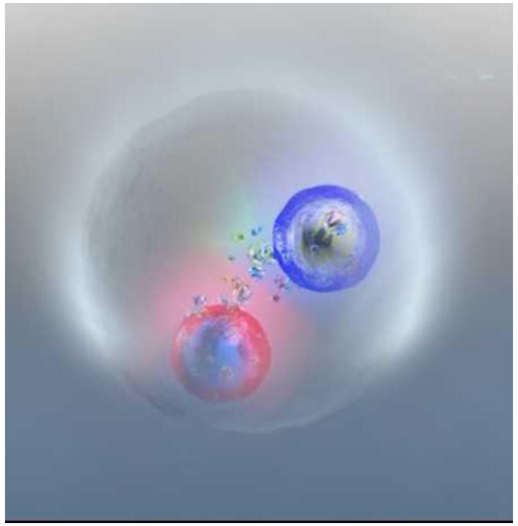
Main LHC results

- Higgs boson discovery (2012) and study of its properties;
- Study of W and Z bosons, and top quark;
- A lot of precise measurements of production cross-sections and branching ratio of particles (for example, rare decay of Bs –> μ+μ-;) – put hard limits on alternative theories.
- Observation of more than 50 new hadron states, including pentaquarks (2015, LHCb) — hadrons containing 5 quarks ($qqqq\bar{q}$), and mesons of 4 quarks ($qq\bar{q}\bar{q}$) observed before only in e^+e^- reactions.
- Confirmation of quark-gluon plasma existence (ALICE: Pb+Pb) with extreme high T and zero viscosity;
- Supersymmetric (SUSY) and exotic particles/objects like microscopic BH or leptoquarks NOT (yet?) observed.

Recent result: evidenice of bound top-antitop state

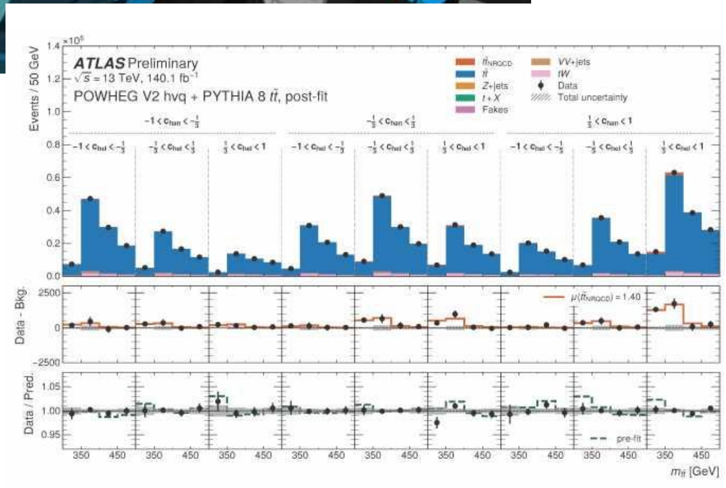




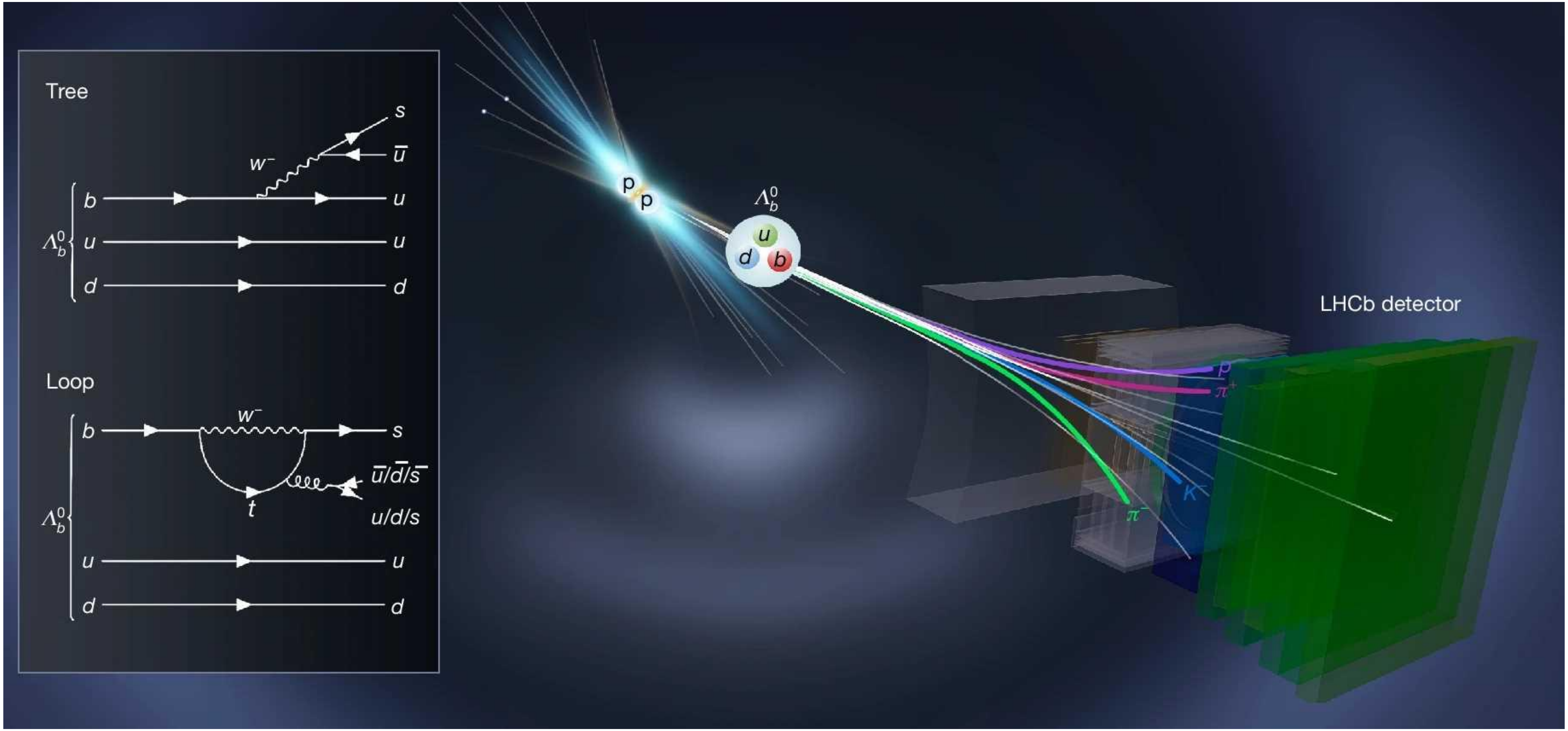


EPS-HEP 2025

Observation of a pseudoscalar excess at the top quark pair production threshold.
https://arxiv.org/abs/2503.22382

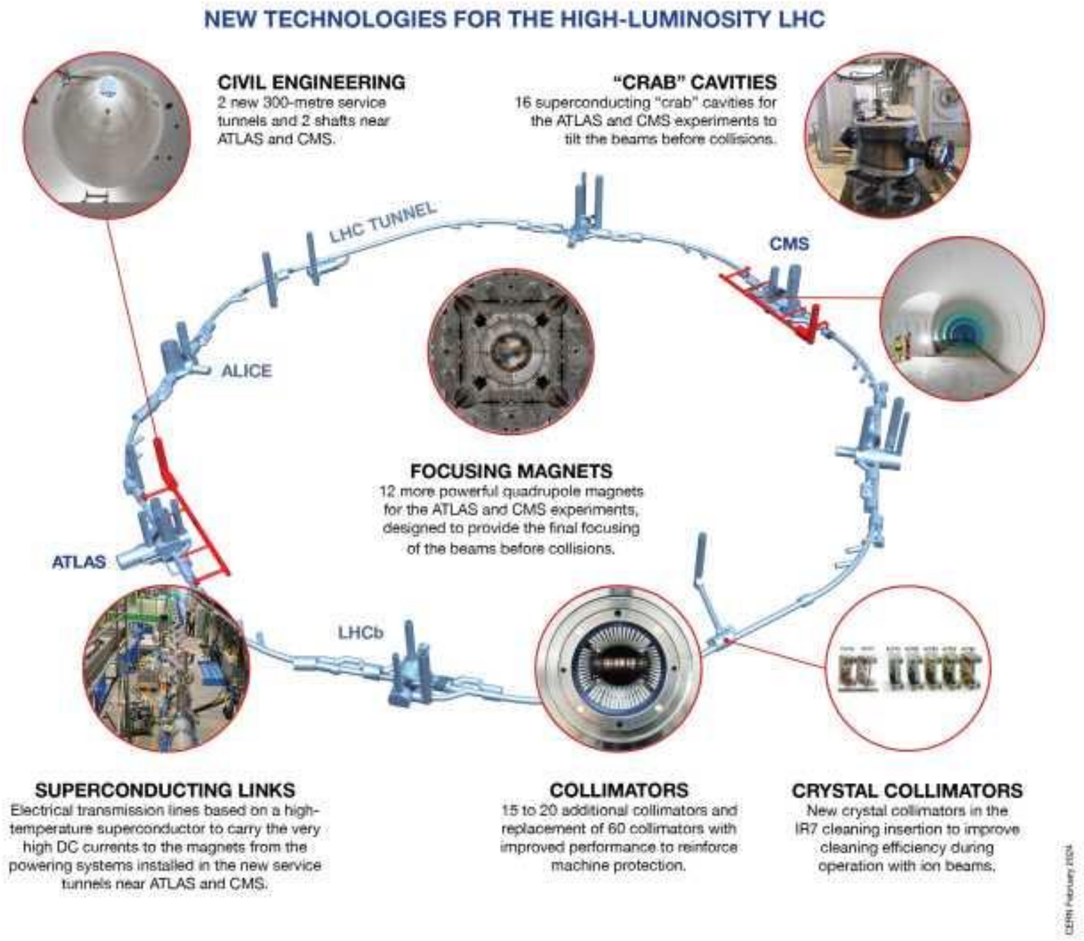


https://www.nature.com/articles/s41586-025-09119-3



Scientists analyzed almost a trillion decay events of lambda baryons containing the b quark (Λb0) and their antiparticles. These baryons decayed into protons, kaons, and pions. If CP symmetry were preserved, the decay probability should have been the same for a particle and its antiparticle. However, it is recorded a consistent difference of 2.5%, with a statistical significance level of 5.8 sigma — more than enough to officially recognize the discovery.

HL-LHC (planned for 2029)



Luminosity increase

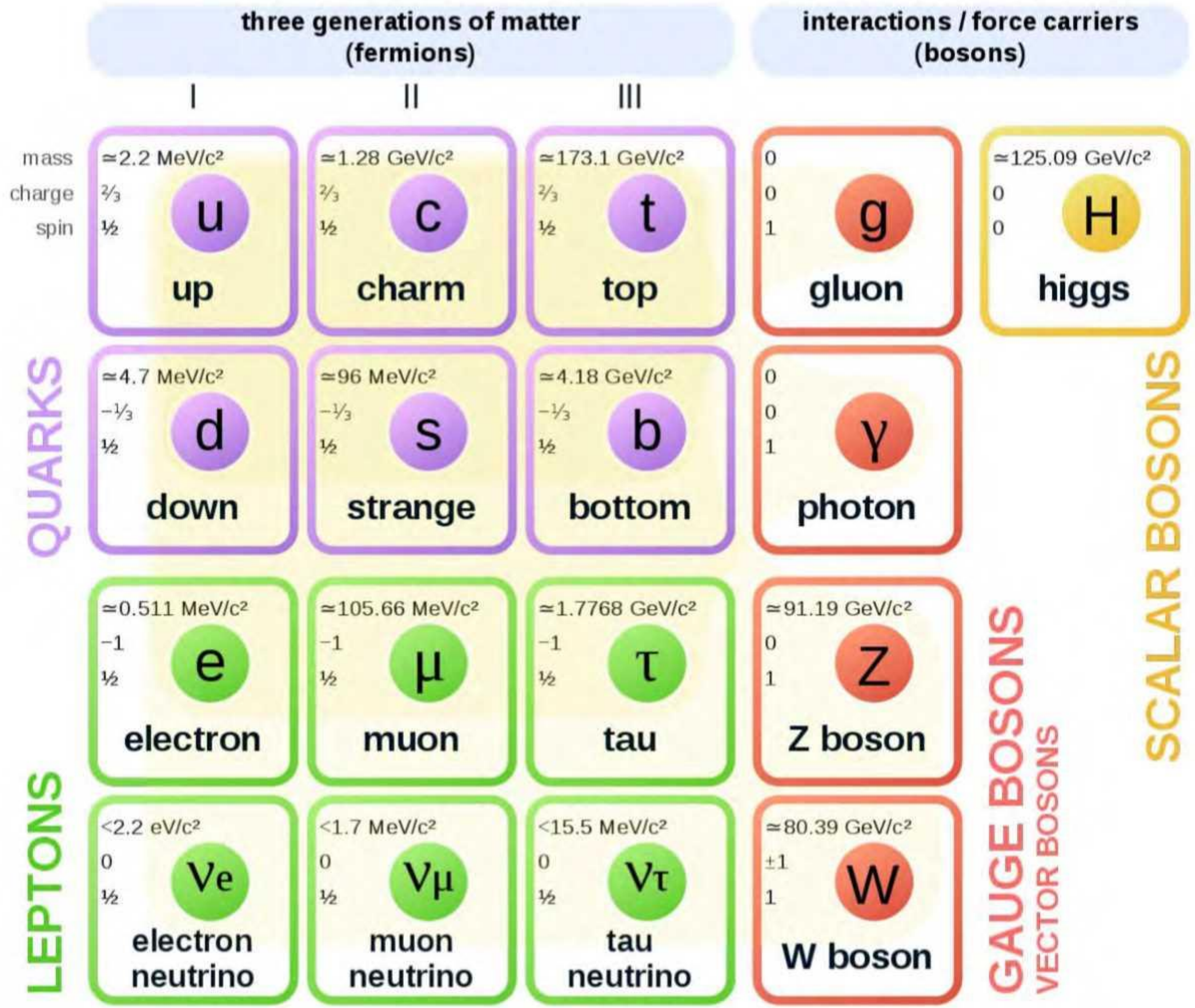
- Target integrated luminosity: 4000 fb^{-1} for 12 years.
- Peak luminosity: 5×10^{34} $cm^{-2}s^{-1}$ (versus ~2×10^{34} $cm^{-2}s^{-1}$ in Run 3).

New magnets and infrastructure

- New superconducting magnets (11 T) at the interaction points.
- Upgrade of vacuum chambers and collimators to operate with high intensity beams.
- Optimization of cryogenics (1.9 K) for stable magnet cooling.

Detector upgrade

- Replace ATLAS and CMS inner trackers to radiation hard and high granularity detectors.
- Upgrade of trigger and DAQ to handle high data rate.



- We have to study the Higgs boson it self in as much detail as possible, searching for signs of a larger Higgs sector and the effects of new heavy particles.
- We must search for the imprint of the Higgs boson and its possible partners on the couplings of the W and Z bosons and the top quark.
- We must search directly for new particles with TeV masses that can address important problems in fundamental physics.

Courtesy of A.Bondar'

After LHC

Electron-positron collider: «higgs-factory» and «top-factory»

ILC

Japan

Linear

500 GeV, 1 TeV

CLIC

CERN

Linear, 11–50 km

380 GeV, 1.5 TeV, 3 TeV

FCC

CERN

100 km circular

88–380 GeV (FCC-ee)

100 TeV (FCC-hh)

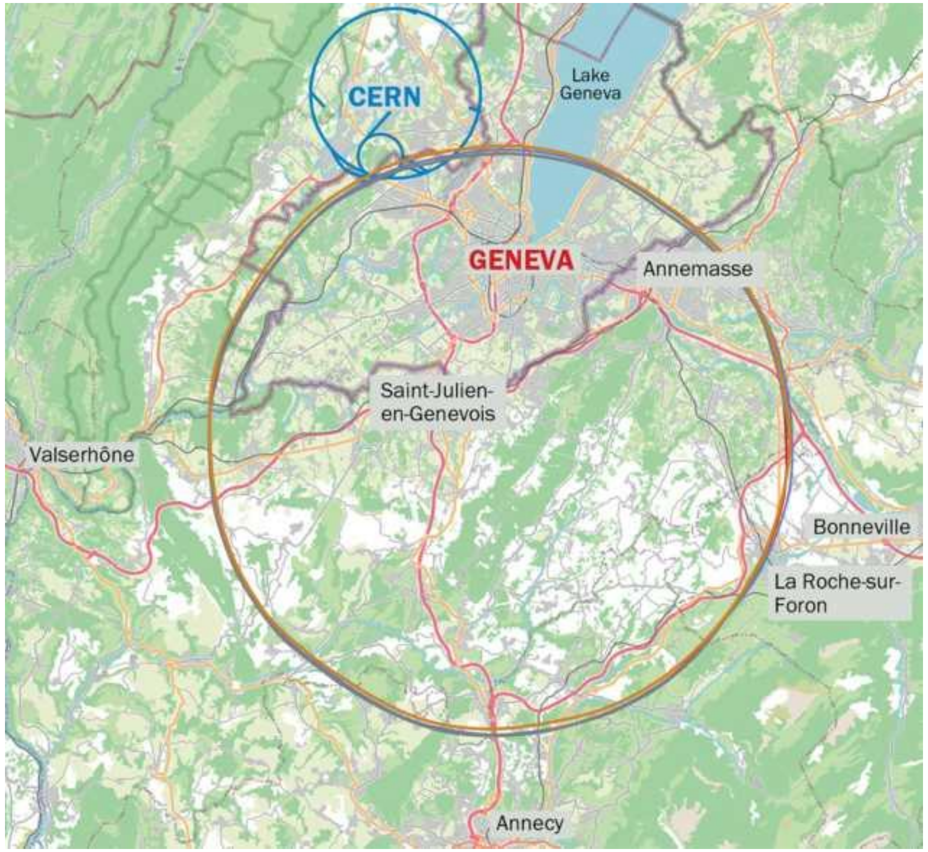
CEPC

Huairou, China

52–100 km circular

240 GeV (higgs-factory)

FCC and CEPC



2040+

E_{cm} = 240 GeV, C = ~ 50 km
L = 1.8×10^{34} $cm^{-2}s^{-1}$
I_b = 17 mA, P_{SR} =100 MW
Ready for e+e- in 2030+
For pp ~ 2042 ?

Decision is expected in January 2026

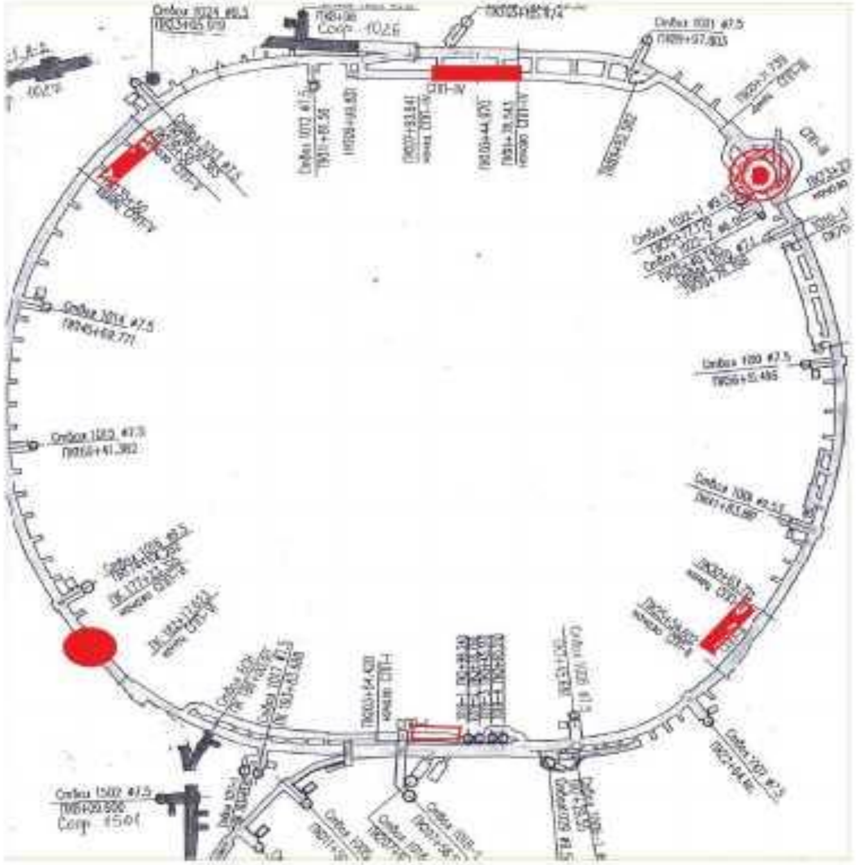
ZUNK: Z - factory in Protvino (Russia)

Proposal by NRC KI and BINP

New e^+-e^- collider in the old UNK tunnel

Precision measurements at Z peak
45.6 GeV + 45.6 GeV
Crab Waist

Design luminosity ~10^{35}см$^{-2}$ с$^{-1}$ (4 orders of magnitude above LEP1, ~5% of FCC-ee at Z peak)

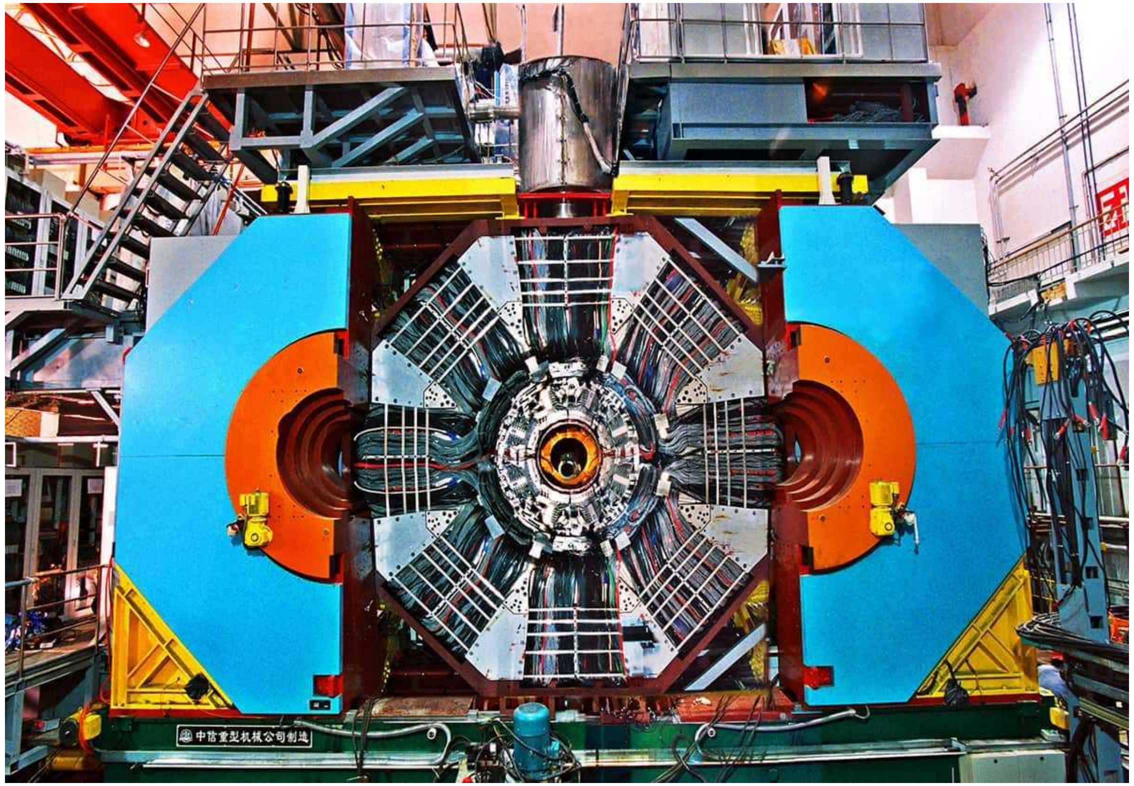


Flavor factories:

ultra high precision with record L, generators of b, c, s particles. Check of SM QCD with J/psi, psi', psi", exotic hadron states, etc

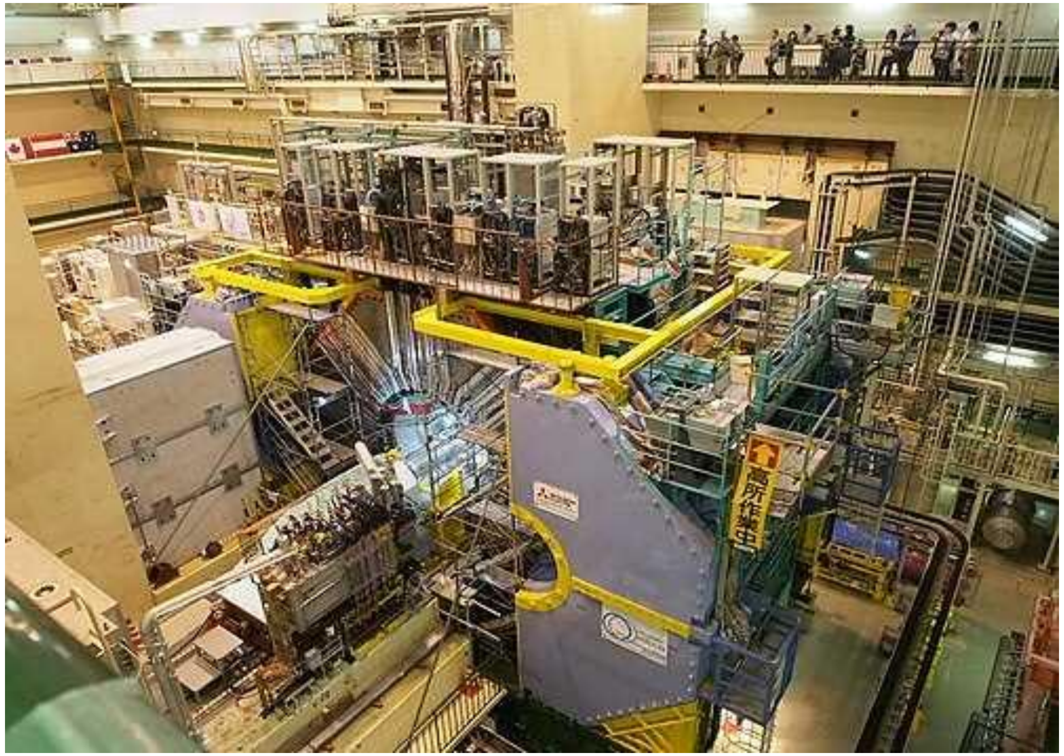
BES-III (Beijing, China).
E_{cm} 2–5 GeV

Charmonium, D and Ds mesons, hadron spectroscopy, tau leptons



BELLE-II (Tsukuba, Japan).
E_{cm} 4+7 GeV

Bottomonium, B-mesons, CP-violation in Bs decay, tau leptons



Future flavor factories

STCF (Hefei, China)

Luminosity: 10^{33} cm^{-2}s^{-1}(BESIII)→ 5×10^{34} cm^{-2}s^{-1} (STCF)

BELLE-II Upgrade

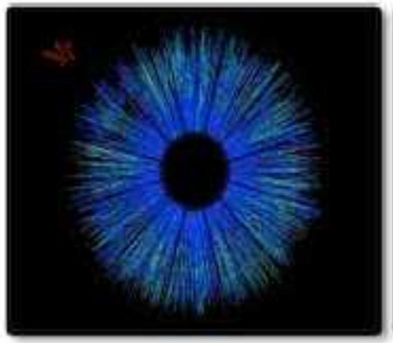
Luminosity: 5.1×10^{34} cm^{-2}s^{-1}(2024)→ 6×10^{35} cm^{-2}s^{-1} (2030)

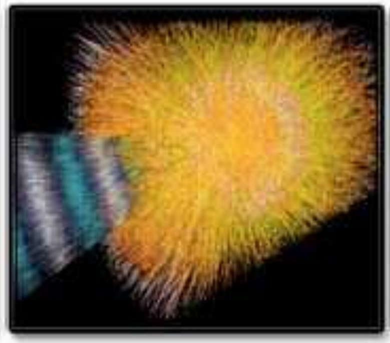
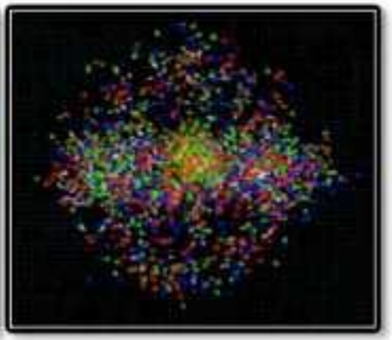
Three Broad Scientific Thrusts of Nuclear Science

Quantum Chromodynamics (QCD) seeks to develop a complete understanding of how quarks and gluons assemble themselves into protons and neutrons, how nuclear forces arise, and what forms of bulk strongly interacting matter can exist in nature, such as the quark-gluon plasma.

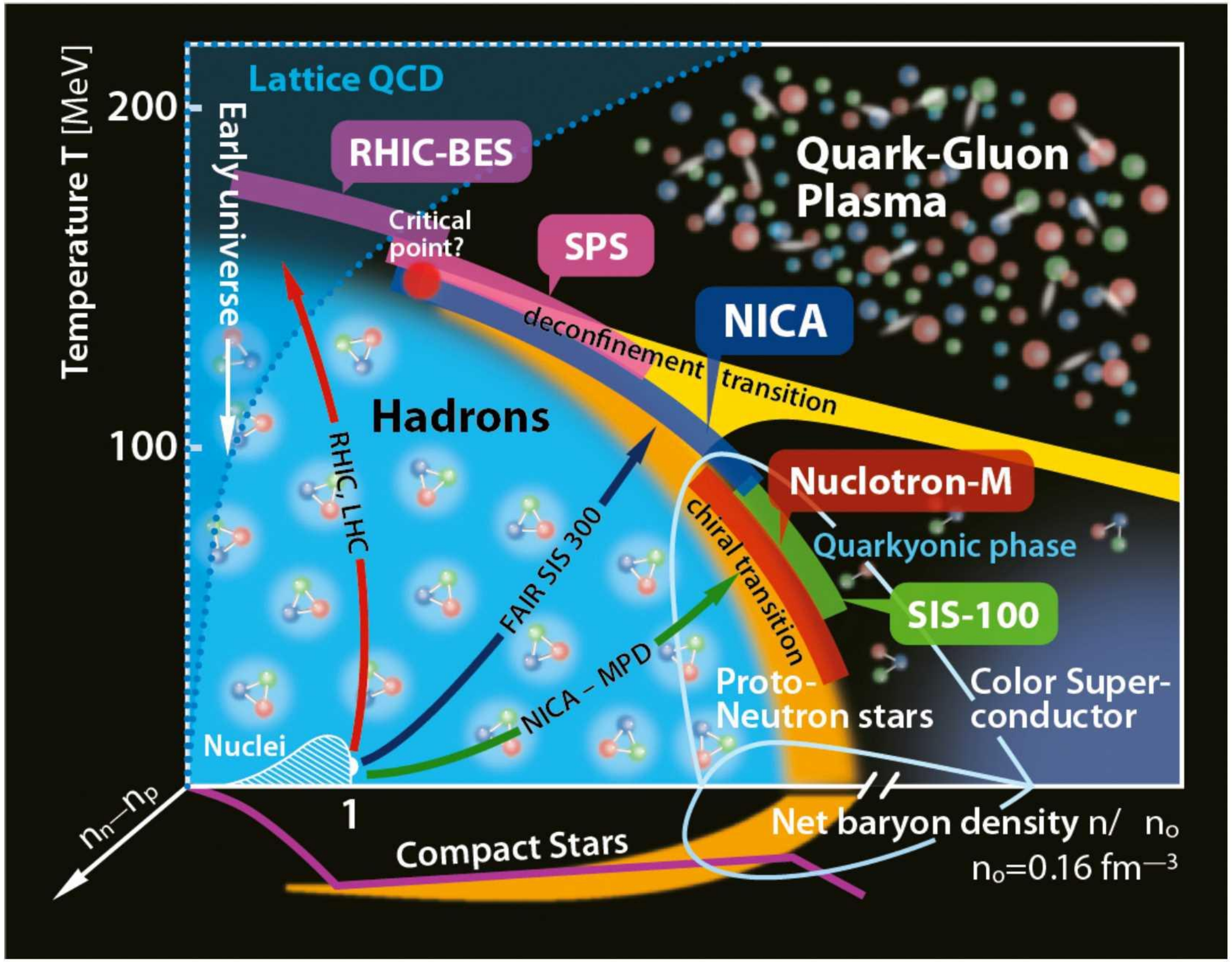
Nuclei and Nuclear Astrophysics seeks to understand how protons and neutrons combine to form atomic nuclei, including some now being observed for the first time, and how these nuclei have arisen during the 13.8 billion years since the birth of the cosmos.

Fundamental Symmetries of neutrons and nuclei seeks to develop a better understanding of fundamental interactions by studying the properties of neutrons and targeted, single focus experiments using nuclei to study whether the neutrino is its own anti-particle.



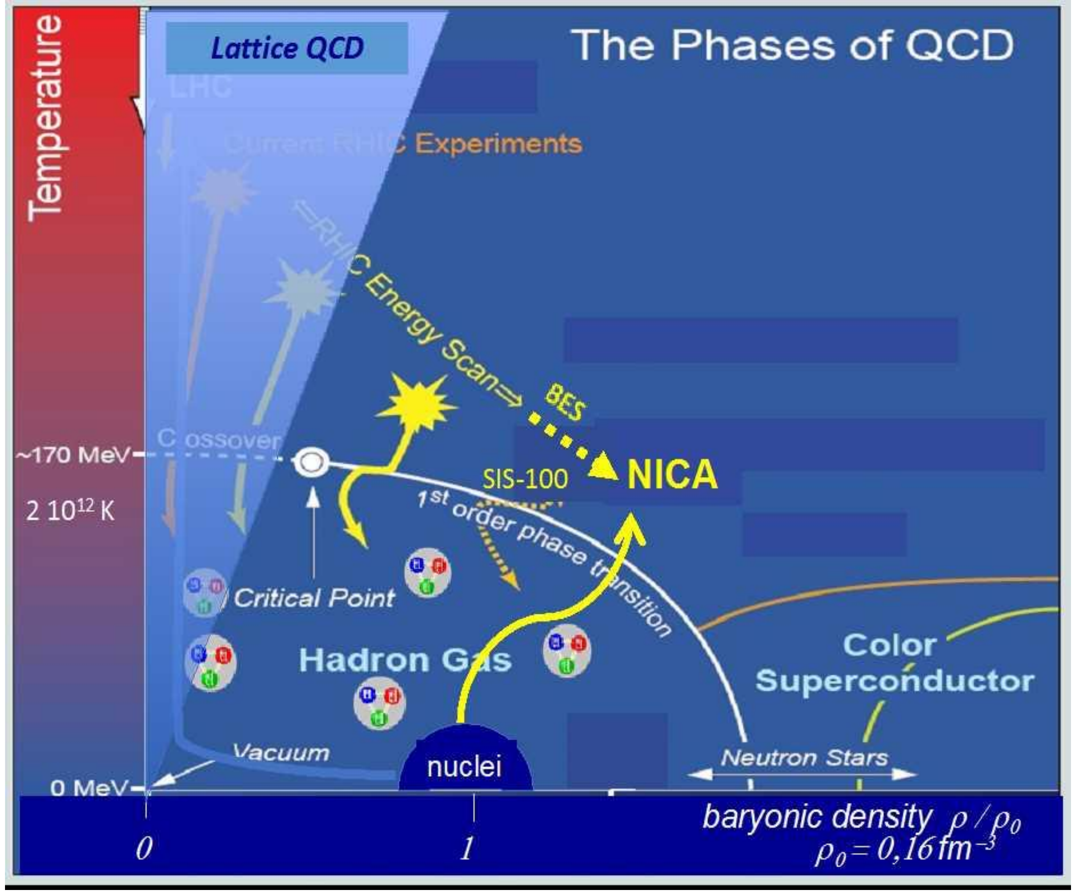
Experiments with relativistic heavy ions



- Hadronic matter in extreme conditions;
- Confinement;
- Chiral symmetry;
- Quark-gluon plasma.

NICA

BM@N & MPD



Achieving the maximum density of nuclear matter, inaccessible to other laboratories in the world: the nature of neutron stars, the early Universe, spin effects.

MPD covers this interesting region providing powerful combination of **large luminosity, collision energy and system size scan** (including isobars), large and consistent **acceptance,** full **centrality** range.

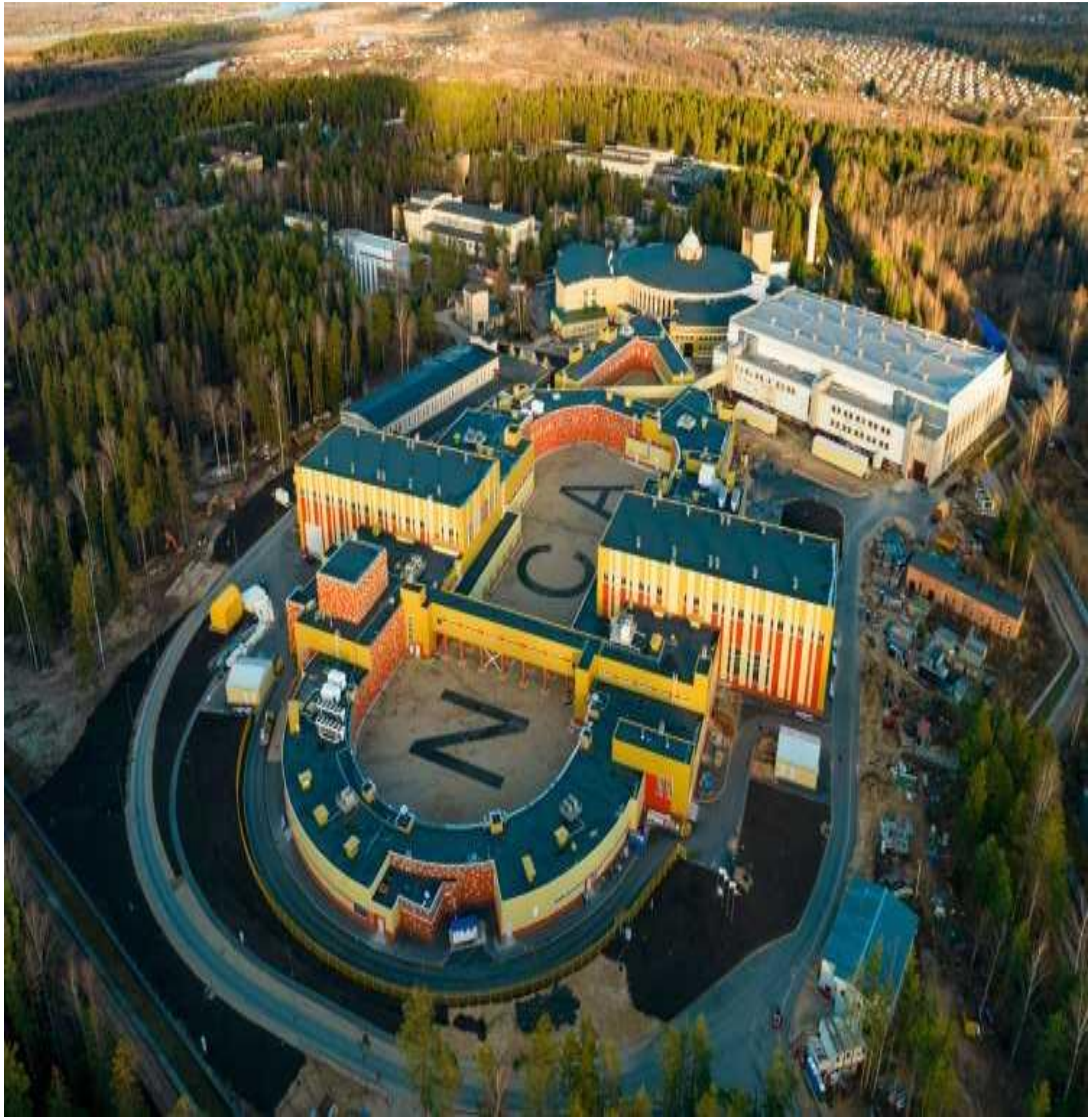
SPD

The SPD experiment is aimed at studying the properties of strong interactions in the nonperturbative region, at measuring the proton and deuteron spin structures, and at the development of a three-dimensional model of the nucleon. It is unique in its methodology, breadth of coverage and variety of tasks.

Experimental facility	SPD @NICA	RHIC	EIC	AFTER @LHC	SpinLHC
Scientific center	JINR	BNL	BNL	CERN	CERN
Operation mode	collider	collider	collider	fixed target	fixed target
Colliding particles & polarization	$p^\uparrow$-$p^\uparrow$ $d^\uparrow$-$d^\uparrow$ $p^\uparrow$-d, p-$d^\uparrow$	$p^\uparrow$-$p^\uparrow$	$e^\uparrow$-$p^\uparrow$, $d^\uparrow$, $^3He^\uparrow$	p-$p^\uparrow$, $d^\uparrow$	p-$p^\uparrow$
Center-of-mass energy $\sqrt{s_{NN}}$, GeV	≤27 (p-p) ≤13.5 (d-d) ≤19 (p-d)	63, 200, 500	20-140 (ep)	115	115
Max. luminosity, 10^{32} cm^{-2} s^{-1}	~1 (p-p) ~0.1 (d-d)	2	1000	up to ~10 (p-p)	4.7
Physics run	>2025	running	>2030	>2025	>2025

NICA

(Nuclotron based Ion Collider fAcility)



4 Major international collaborations have been formed and necessary conditions for their effective functioning at JINR have been created

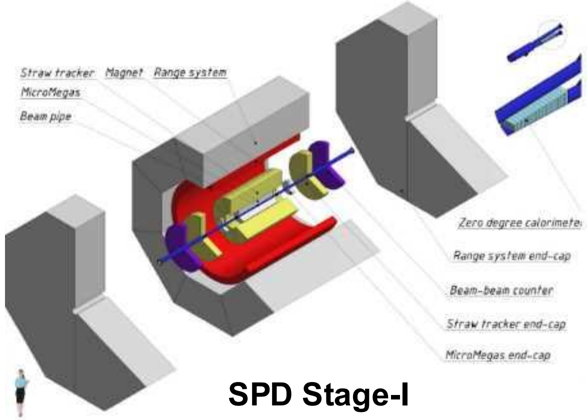
MPD: 12 countries, 44 institutes, >500 participants

	Year 2023	
12	Jan 15 - April 15th	Preparation for Vacuum test of Solenoid with Cryostat
13	April 20 - May 20th	Vacuum tests
14	May 25 - June 15th	Solenoid cooling down to Liquid Nitrogen temperature (-80K)
15	April 20 June 15th	Electronic Platform construction
16	June 15 – September 15	Activities in the MPD Hall will be stopped
17	October – December	Cooling down to the He temperature
	Year 2024	
18	January. - February 15	Supplying the current to the solenoid and Correction coils
19	March - May 15	Magnetic Field measurements
20	June 1 - June 10	Support Frame installation
21	June 20 – August 30th	Installation ECal sectors, Insertion devices mounting
22	Sept 1 – September 20th	Installation TOF modules, FHCal into poles
23	Sept 15 - Nov 20	TPC installation
24	Sept 18 - Nov 20	Cabling
25	Oct 20 - Nov 25	Installation of beam pipe
26	Nov 30 - Dec 10th	Move the MPD on Collider beam line, Commissioning

116 conference papers
65 publications

SPD: 14 countries, 32 institutes, ~300 participants

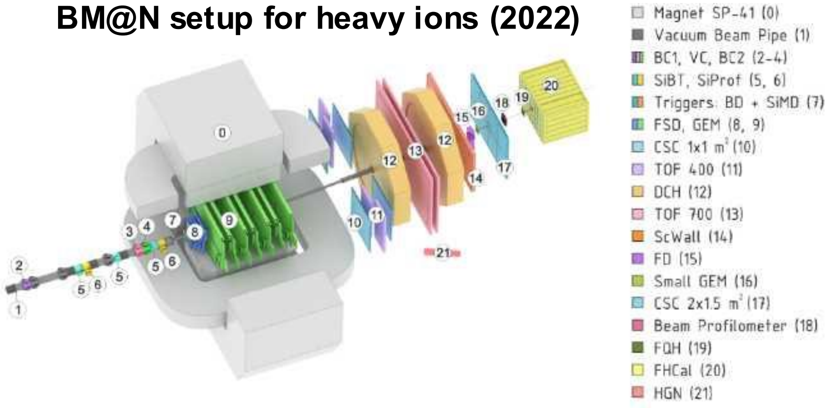
- SPD CDR was approved in Jan'2022;
- detectors prototyping/tests are ongoing;
- new version of **TDR** – Jan'2024;
- start of operation (Stage-I) – **2028**;
- **50** papers and **70** conference reports.



SPD Stage-I

BM@N: 10 countries, 19 institutes, >250 participants

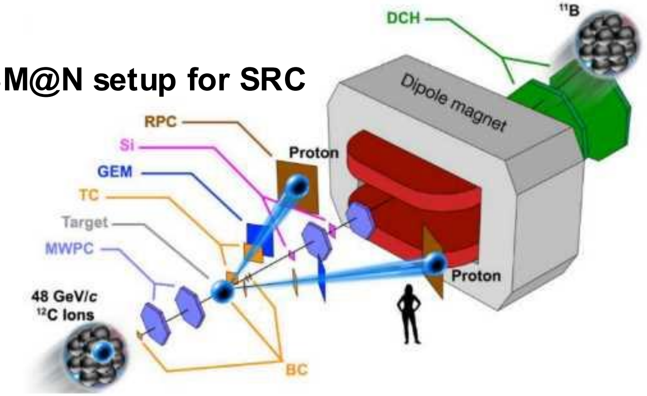
BM@N setup for heavy ions (2022)



4th NICA run (2022-2023):

- **550M events Xe+CsI at 3.0A, 3.8A GeV;**
- **analysis is ongoing;**
- **so far: 80 publications and 80 reports, including "Quark Matter", "Strangeness in Quark Matter", etc.**

BM@N setup for SRC



First observation of the Short-Range Correlations in inverse kinematics:

$^{12}C + p \rightarrow 2p + {}^{10}B\ /\ {}^{10}Be + (n\ /\ p)$

26 ^{10}B events

3 ^{10}Be events → *np* pair dominance

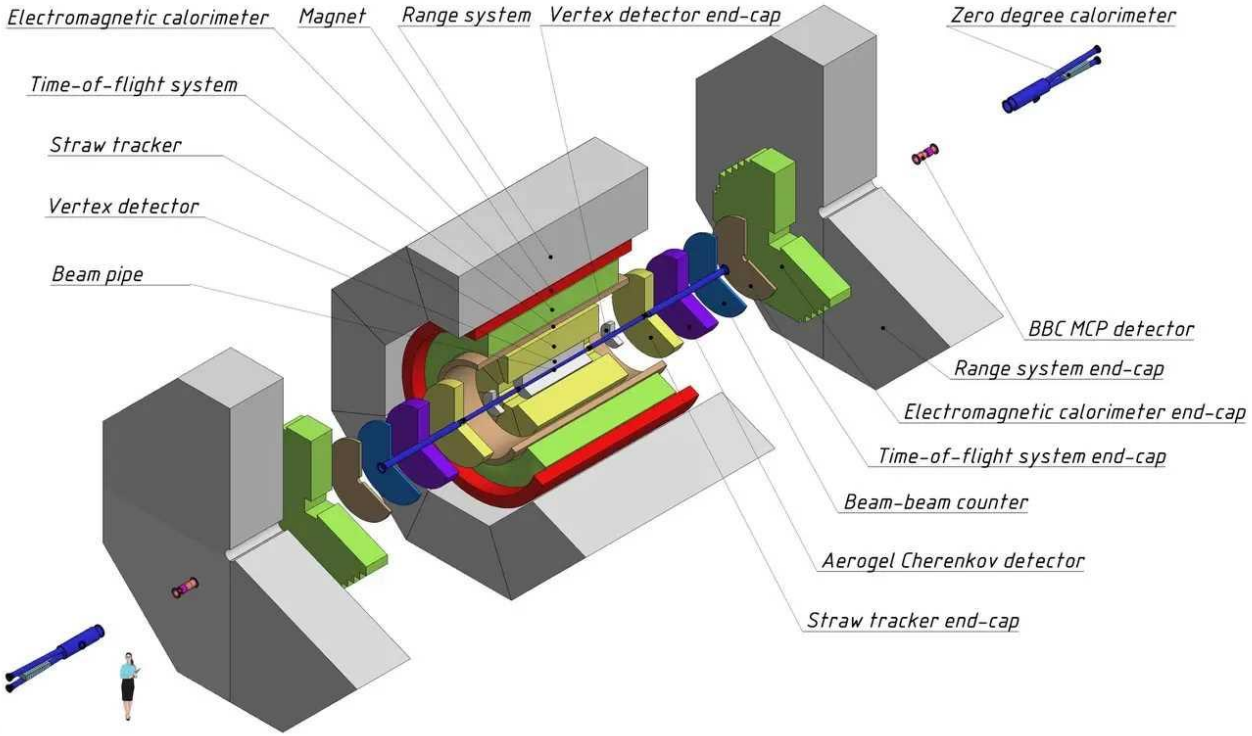
Paper was published in **Nature Physics, 17 (2021)**

Precise study of Nucleon structure

The AMBER experiment (Apparatus for Meson and Baryon Experimental Research) is designed for precision measurements in the field of hadron physics, studying the distribution of partons using muon beams from SPS in the energy range of 100-280 GeV. Measuring the electromagnetic form factors of the proton, studying Compton scattering on protons through the Primakov effect, and searching for exotic hadron states. SPD is the study of the spin structure of nucleons and hyperons, with an emphasis on the measurement of birth–asymmetric particles using polarized beams. Both: studies of the structure of hadrons and spin dynamics in various energy ranges, providing data for QCD in the nonperturbative mode and refinement of the parameters of the PDF.

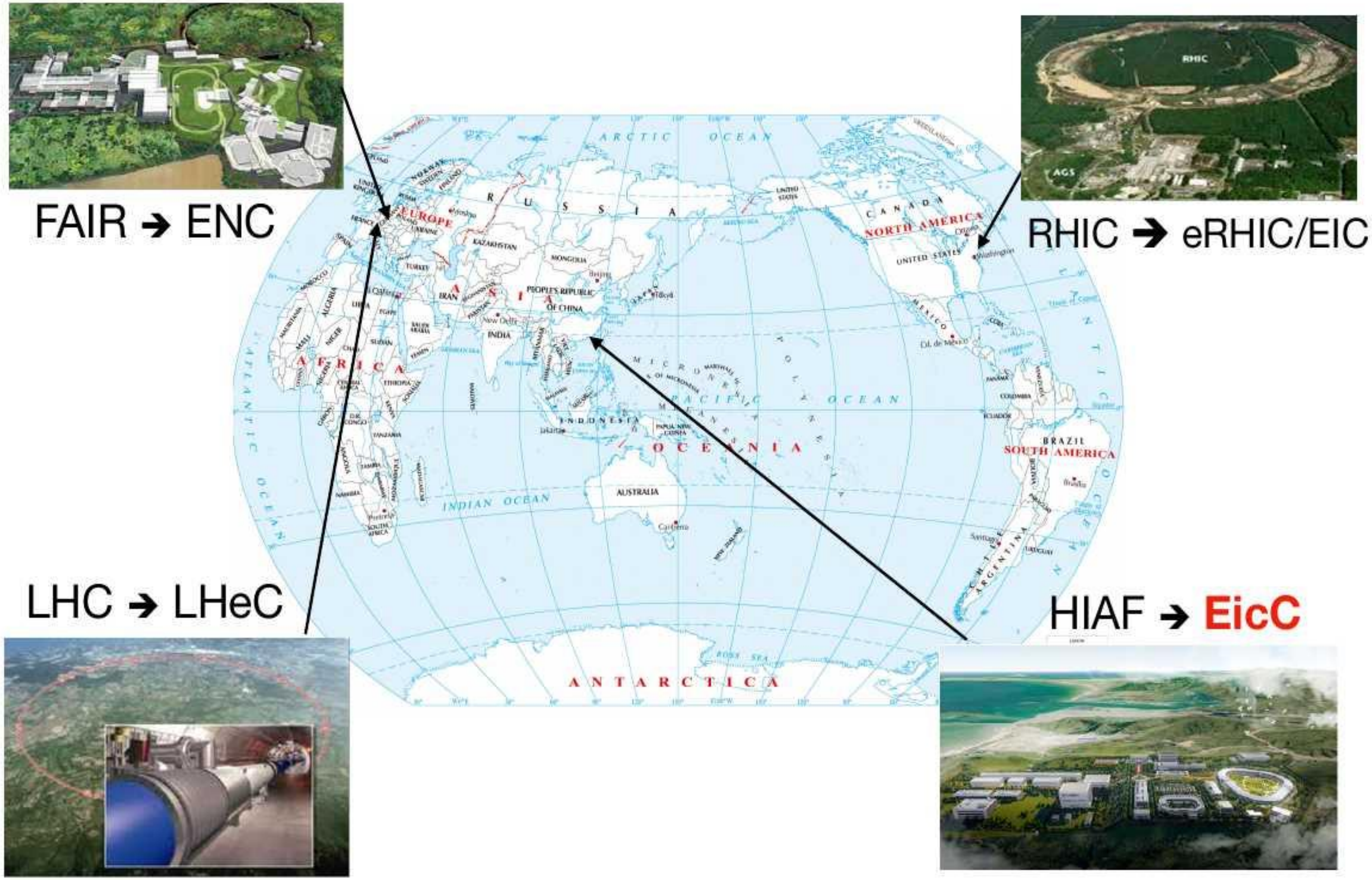
AMBER (CERN)

NICA/SPD (JINR)



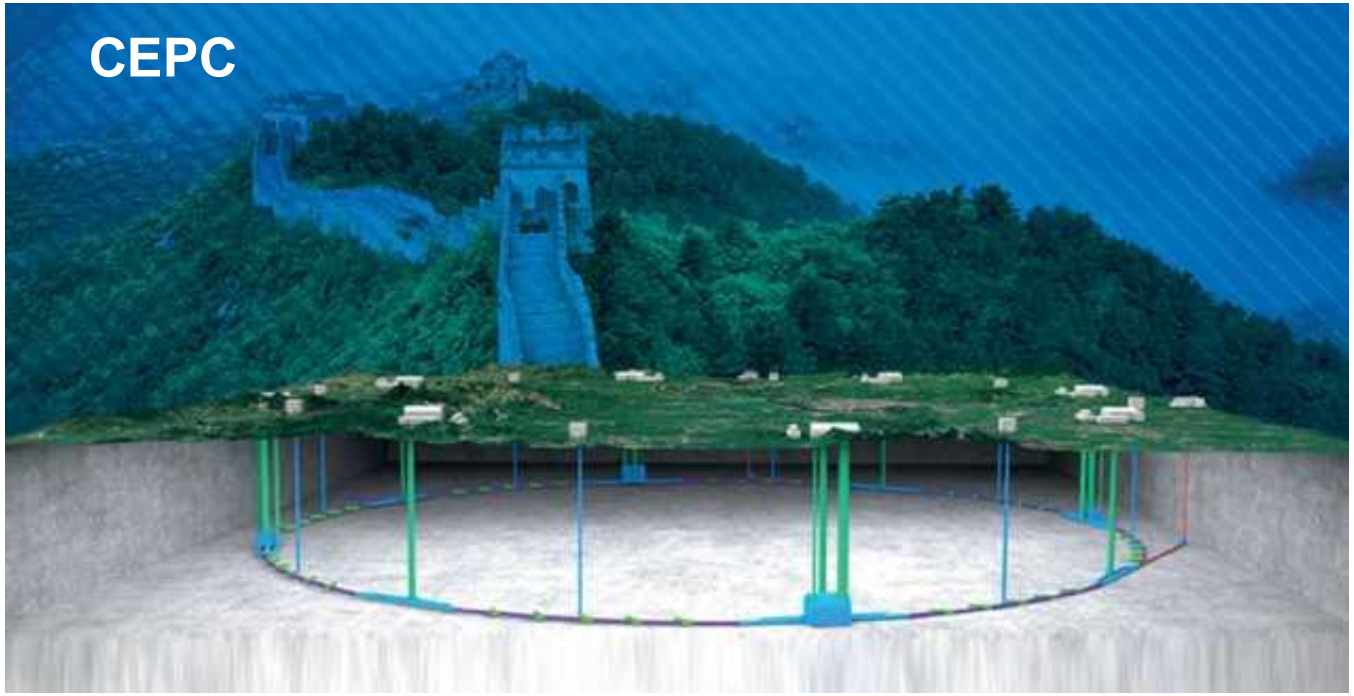
Also LHCspin at CERN

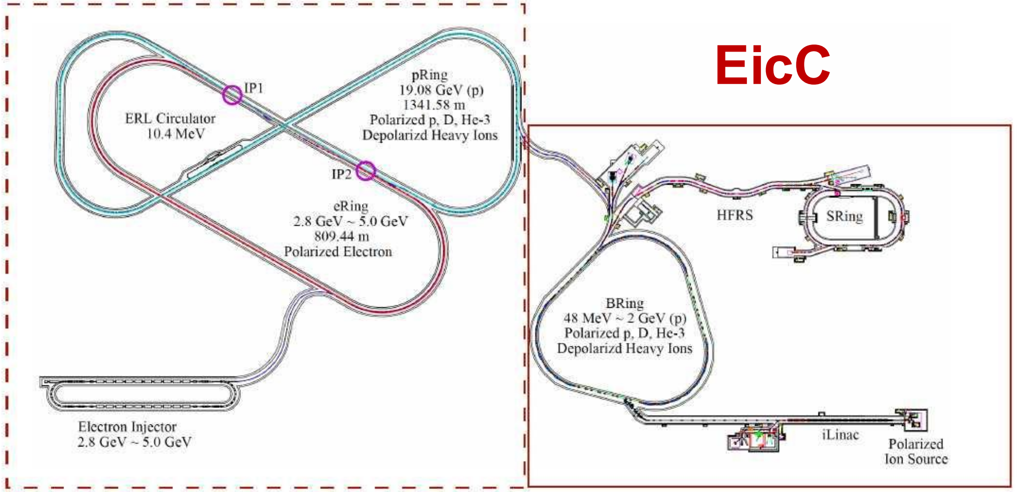
Electron-ion colliders



Program: to collide electrons with energies of 5-20 GeV with protons and heavy ions (up to 100 GeV/nucleon), which will make it possible to study the spatial distribution of partons, including gluons and sea quarks, with unprecedented resolution ($\sim 10^{-4}$ fm). The main physical tasks include measuring the parton distribution functions (TMD, GPD), studying the mechanism of hadronization, and searching for gluon field saturation in the mode of low momentum transmission ($x < 10^{-3}$).

Chinese initiative





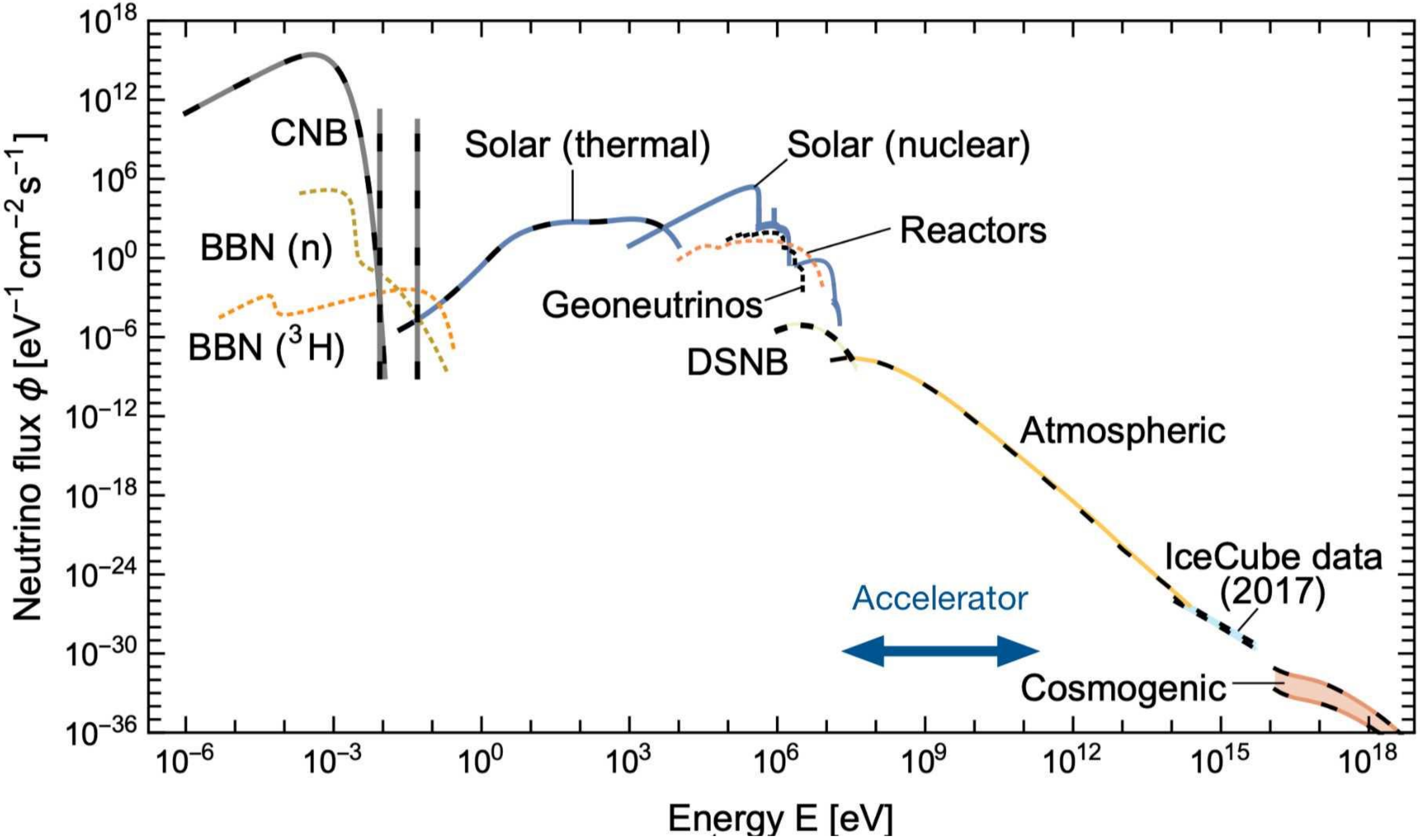
+ JUNO, LHAASO, HXMT, ...

China is striving to become a leader in high-energy physics!

Neutrino physics

- Neutrino mass hierarchy;
- Direct neutrino mass measurement;
- Search for CP violation in the lepton sector;
- Dirac or Majorana?
- Neutrino properties (cross-section, etc).

Neutrino sources



Courtesy of L.Kolupaeva

Accelerator-based experiments (p 2-120 GeV)

Oscillation parameters and how precisely do we know them:

$\theta_{12} \approx 34^\circ$ (4.4%)

$\theta_{23} \approx 49^\circ$ (5.2%)

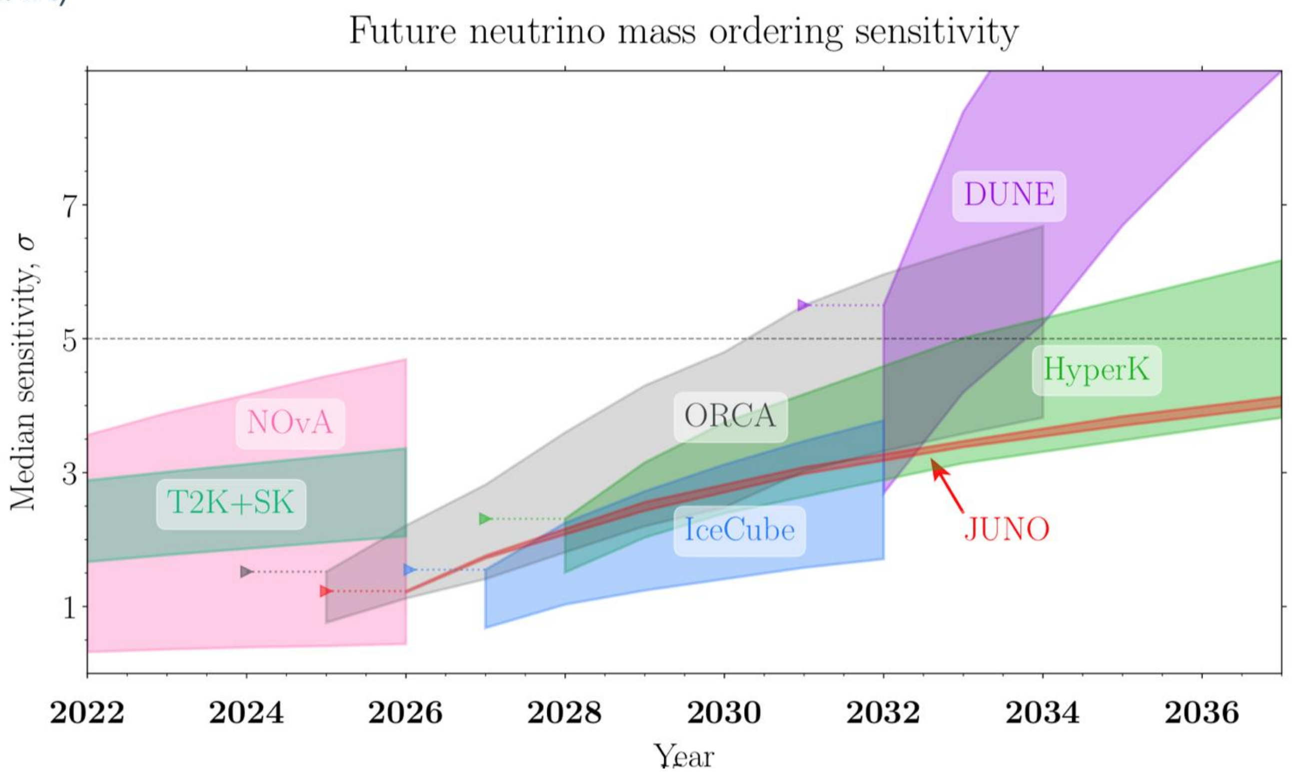
$\theta_{13} \approx 9^\circ$ (3.8%)

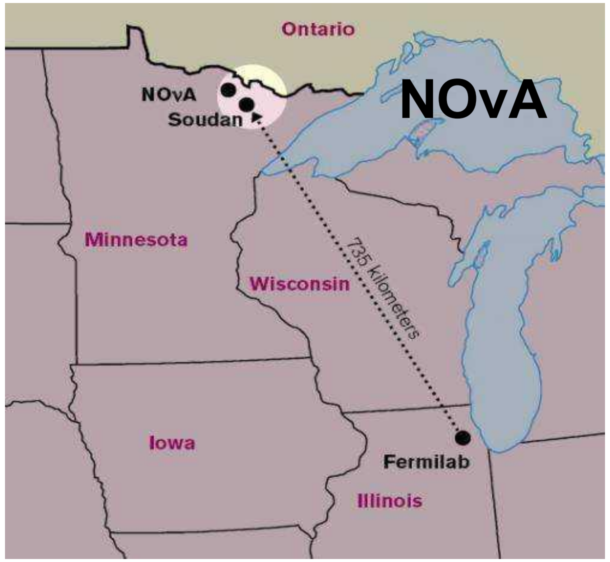
$\Delta m^2_{21} \approx 7.4 \times 10^{-5}\ \mathrm{eV}^2$ (2.2%)

$\Delta m^2_{32} \approx +2.5 \times 10^{-3}\ \mathrm{eV}^2$ (1.4%)

atmospheric / accelerator	short baseline reactor / accelerator	solar / long baseline reactor

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



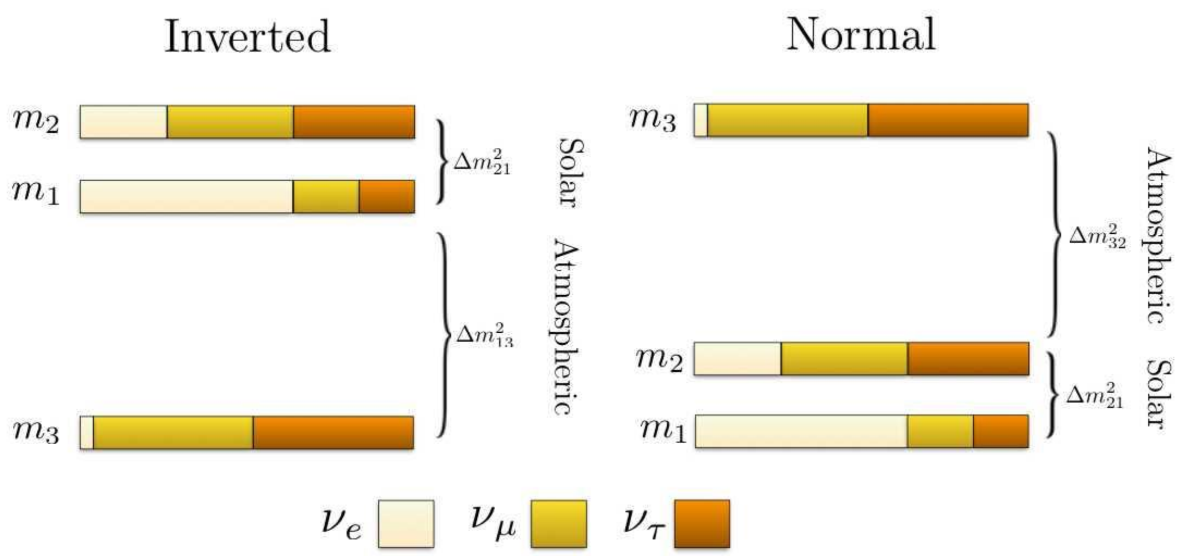


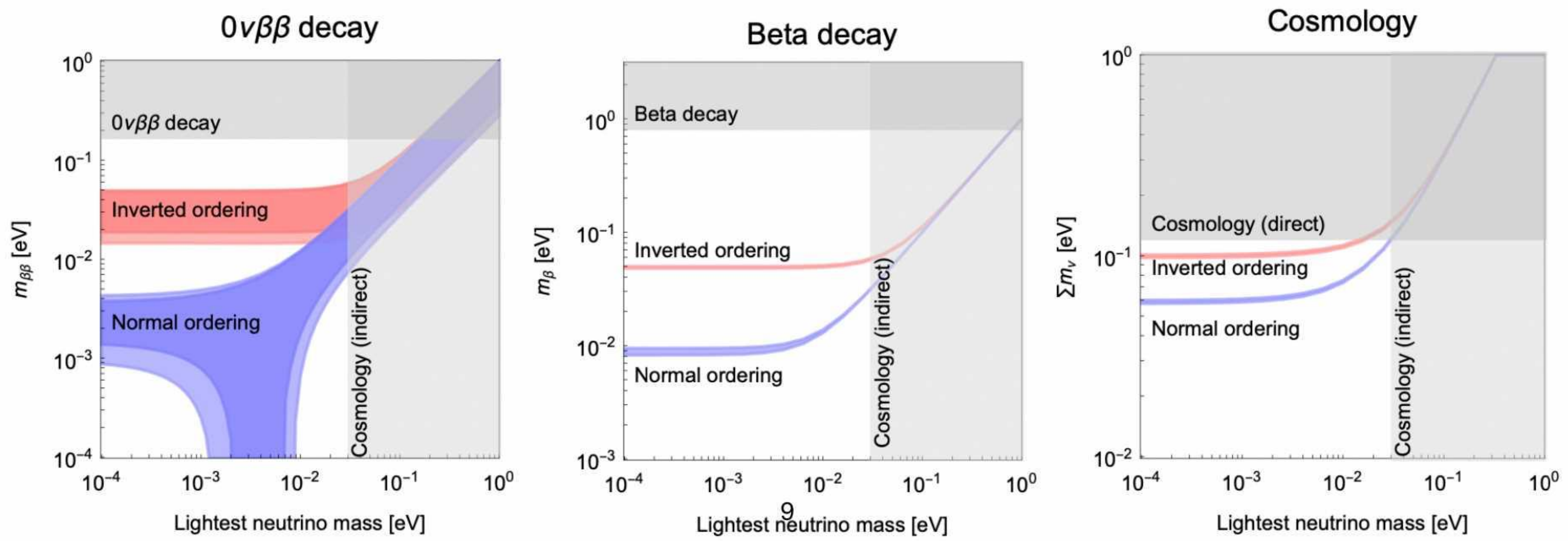
Neutrino mass ordering

Mass hierarchy/ordering plays important role for:

- ✳ neutrinoless double beta-decay searches,
- ✳ supernova simulations,
- ✳ relic neutrinos searches,
- ✳ absolute ν mass measurements etc.

So it affects everything connected with ν masses

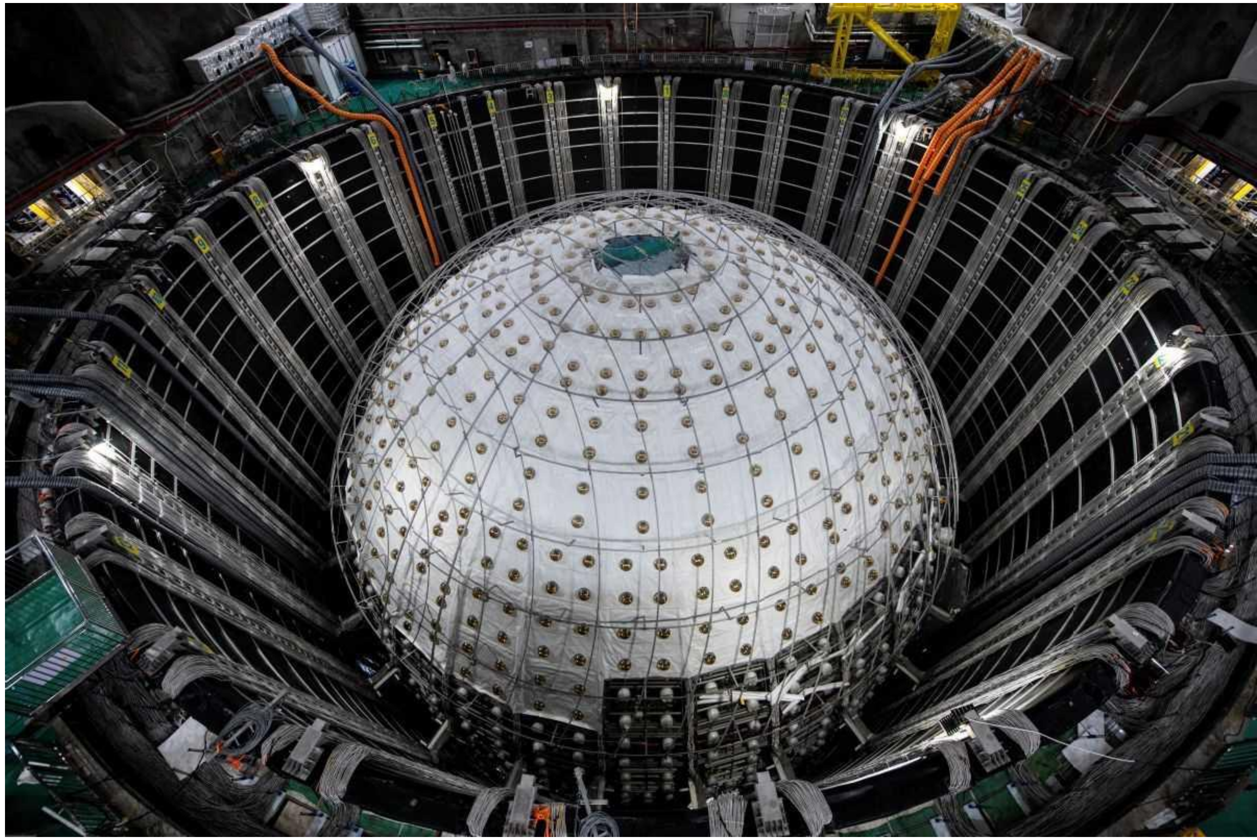




Courtesy of L.Kolupaeva

JUNO

20 kt of liquid scintillator, 18000 PM



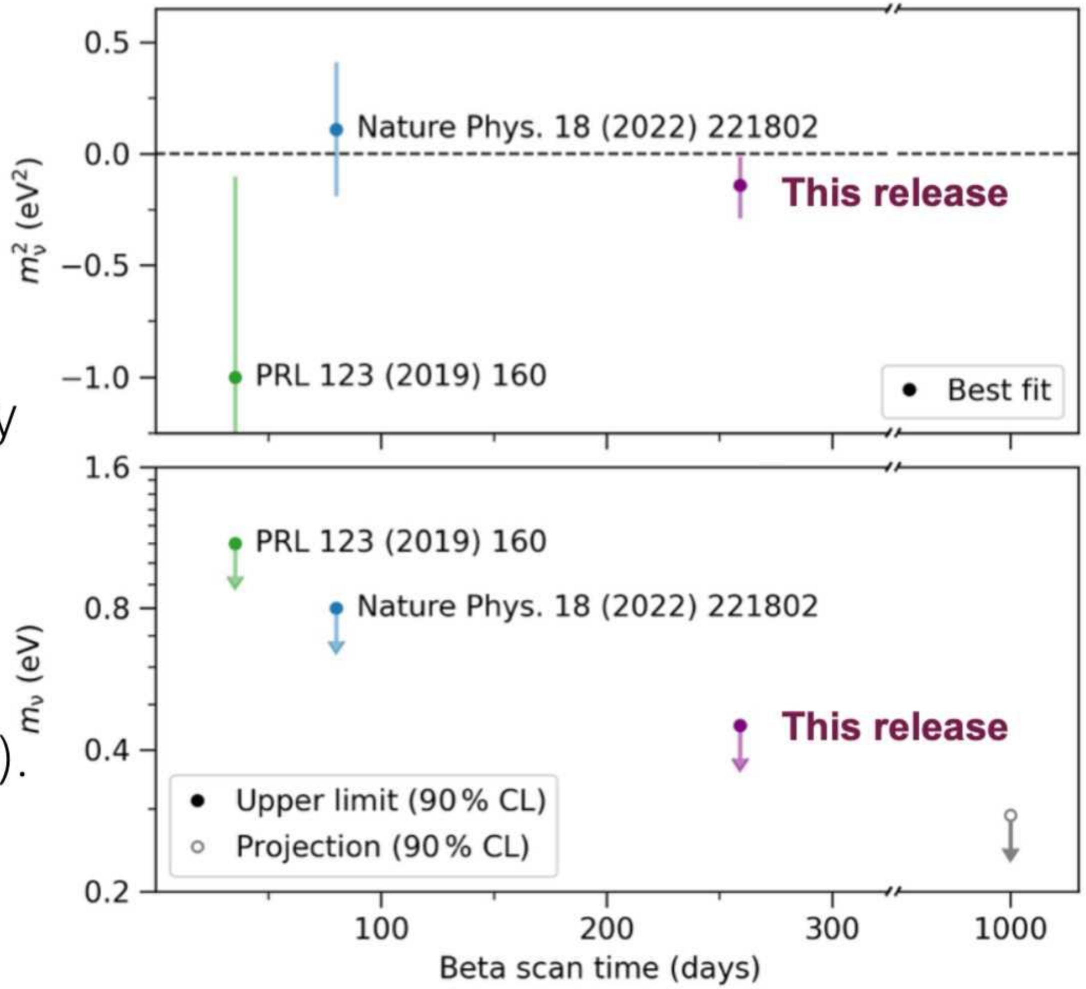
Modern detectors (Daya Bay, RENO, Double Chooz) use liquid scintillators doped with gadolinium or lithium. JUNO's largest reactor experiment (20 kt liquid scintillator), already built in China and has started data collection, aims to determine the hierarchy of masses through spectrum distortions using high energy resolution reaching 3% at 1 MeV, accurate measurement of Δm^2_{21} и θ_{12}, study of atmospheric and solar neutrino oscillations, search for sterile neutrinos.

Neutrino mass measurement

KATRIN latest results

- ✳ 259 measurement days collected in 2019 - 2021;
  - ✳ already has x4 more data to analyse.
- ✳ New upper limit $m_\nu < 0.45$ eV (90% CL).
- ✳ Future plans:
  - ✳ Ongoing data taking through 2025, target sensitivity below 0.3 eV (90% CL).
  - ✳ 2026 - 2027: TRISTAN@KATRIN for sterile keV neutrino search.
  - ✳ 2028 - 2034 R&D for the next apparatus (< 0.045 eV).

Technique limitation: gaseous tritium source is already nearly opaque to the electrons.



Courtesy of L.Kolupaeva

Experiments at Kalinin NPP

DANSS

Search for electron neutrino oscillation

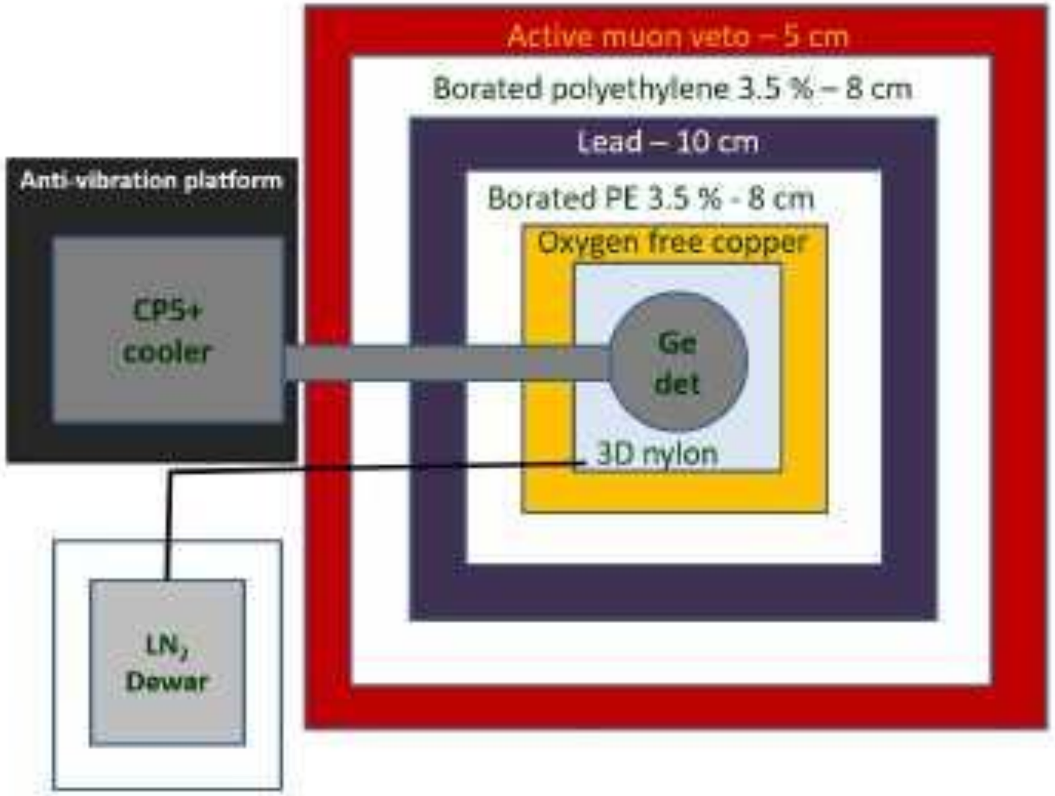
at the very short range

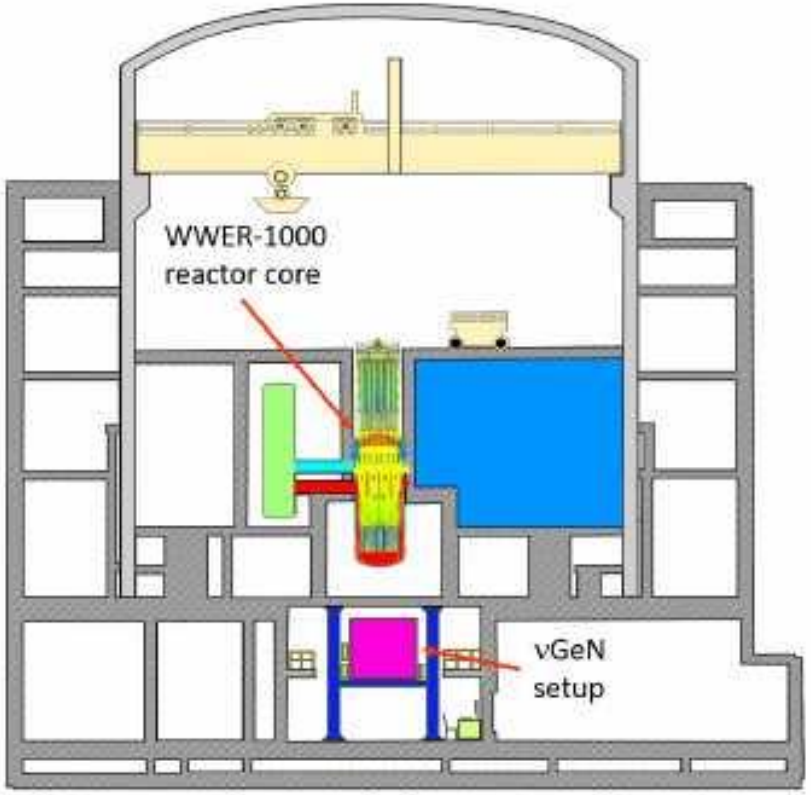
vGen

Search for coherent elastic neutrino

scattering on nuclei

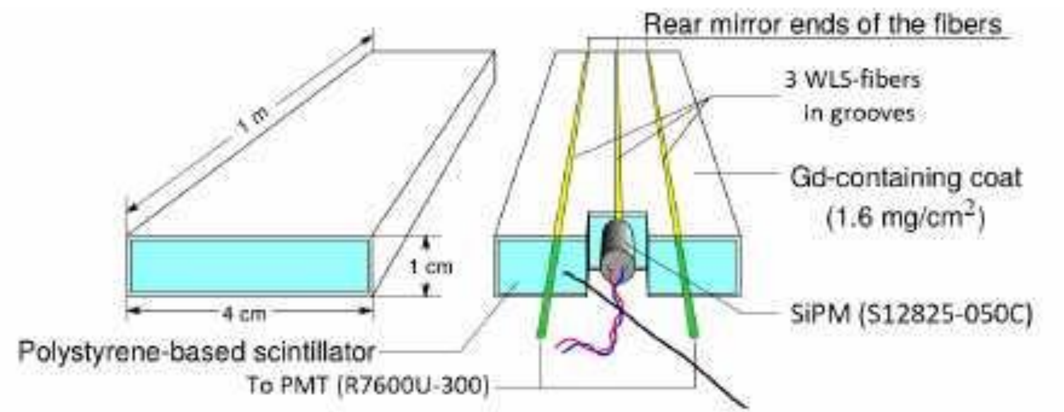
vGen experiment

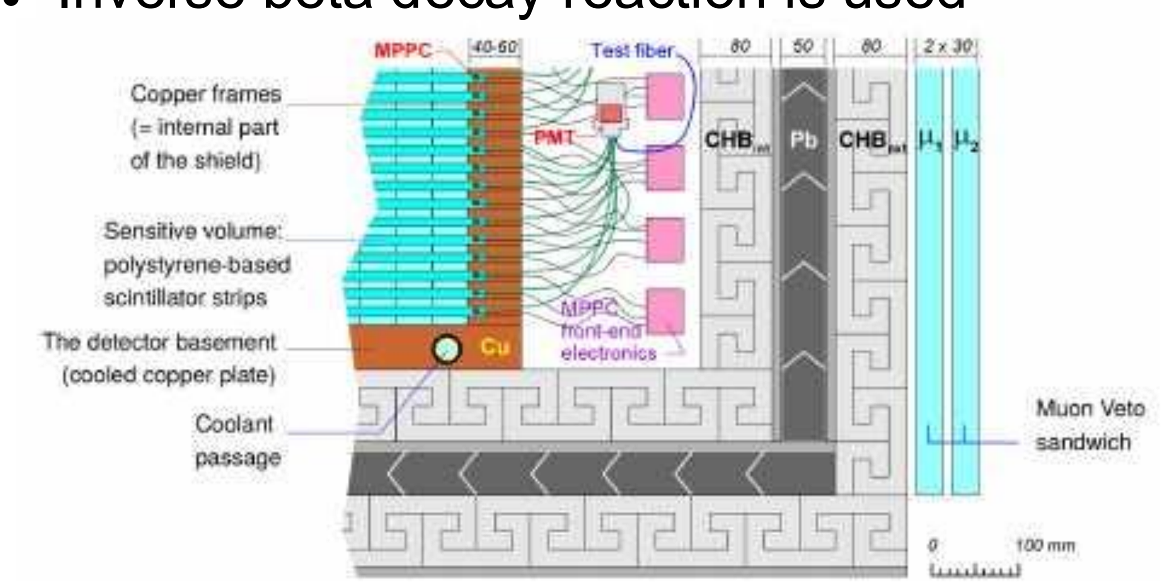


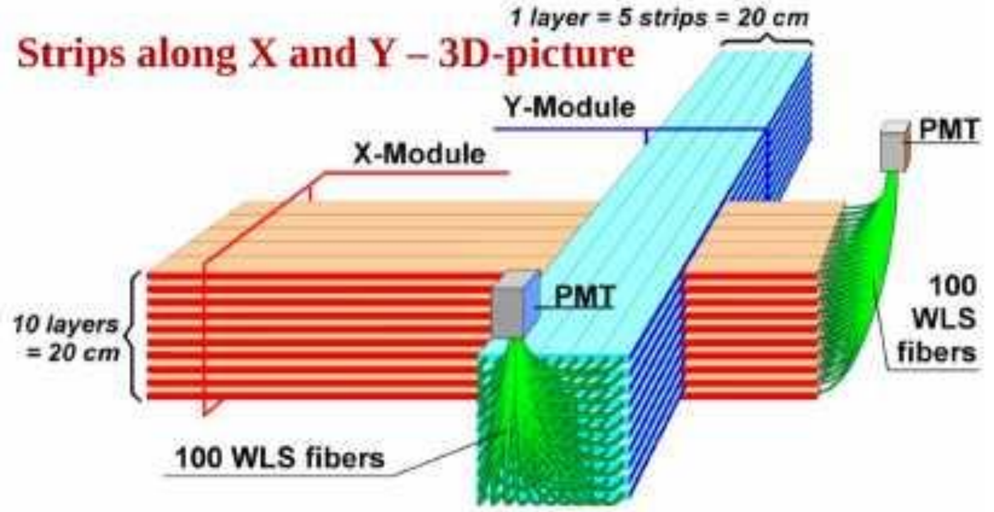


DANSS experiment

- Double PMT (groups of 50) and SiPM (individual) readout
- SiPM: 18.9 p.e./MeV & 0.37 X-talk
- PMT: 15.3 p.e./MeV
- 2500 strips = 1 m^3 of sensitive volume
- Inverse beta decay reaction is used







[JINST 11 (2016) no.11, P11011]

Neutrino physics challenges

Modern facilities (GERDA, CUORE, EXO-200, KamLAND-Zen) use various detection techniques: enriched isotopes of ^{76}Ge (germanium detectors), ^{130}Te (cryogenic bolometers) and ^{136}Xe (liquid xenon).

Key technological challenges include suppression of the radioactive background to 10^{-} events/kg/year (LEGEND-200, 200 kg ^{76}Ge) and improvement of energy resolution (2-3% FWHM at Qßß≈2.5 MeV).

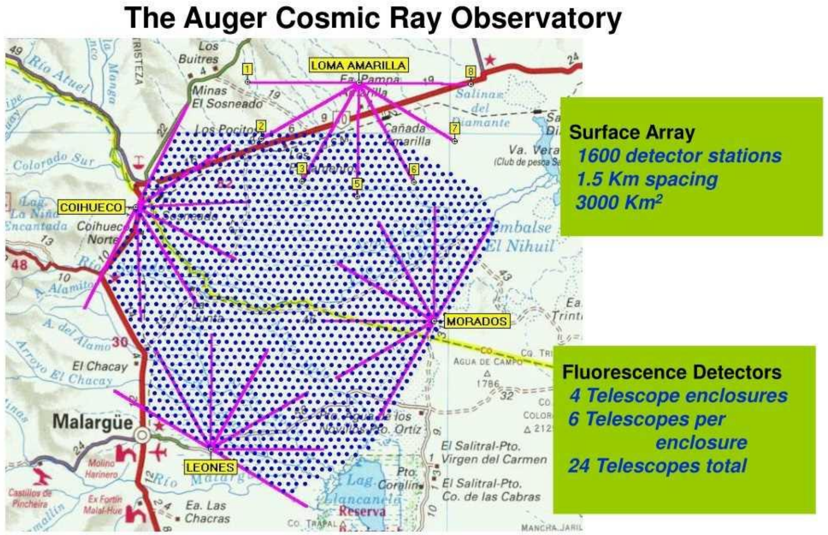
Perspective projects (nEXO, CUPID, NEXT) plan to increase the mass of detectors to a ton scale with a further reduction in the background, which will achieve sensitivity of m~0.01 eV, covering the area of the normal hierarchy.

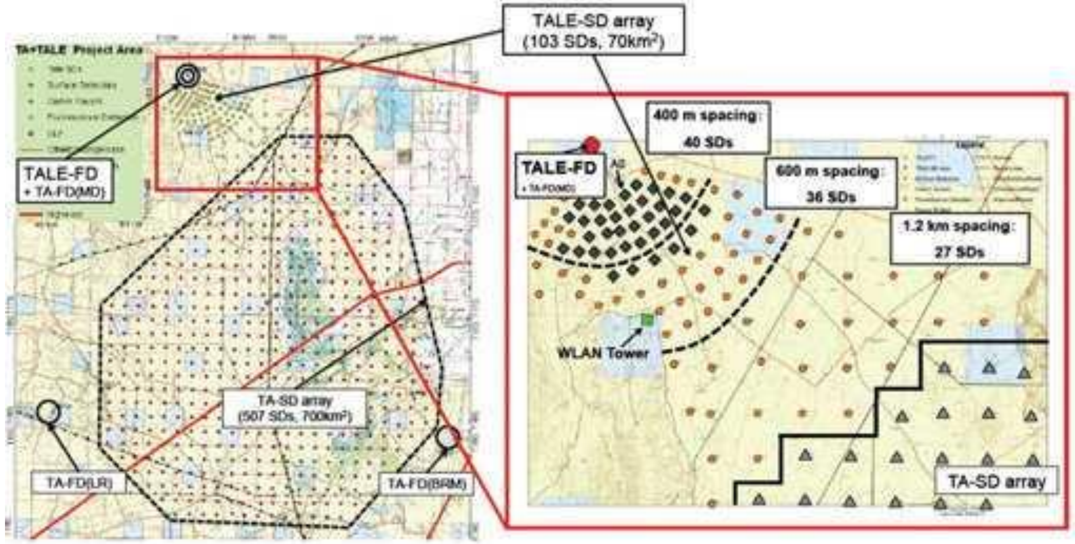
In parallel, alternative mechanisms of 0vßß (heavy particle exchange, Lorentz invariance violation) are being investigated through the analysis of angular correlations and spectral shapes. Confirmation of the $0\nu\beta\beta$ observation would have fundamental implications for physics beyond the Standard Model, including the lepton number and the origin of neutrino masses.

Astroparticle physics

- Ultra high energy cosmic rays;
- High energy neutrino from space;
- The nature of dark matter;
- Gravitational waves.

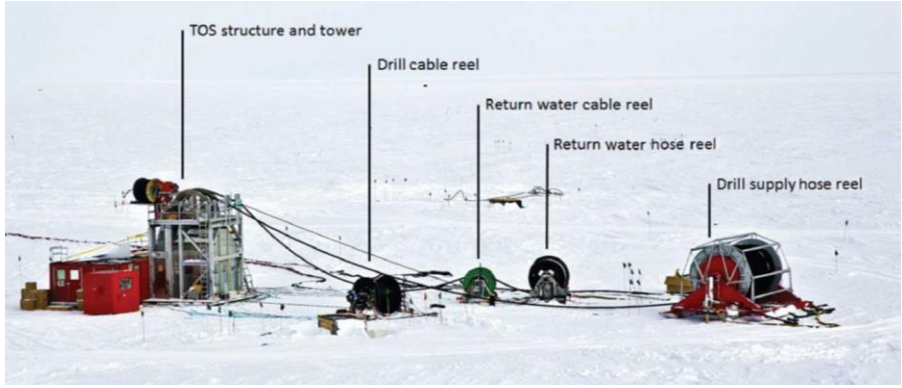
Ground-based observatories of extensive atmospheric showers

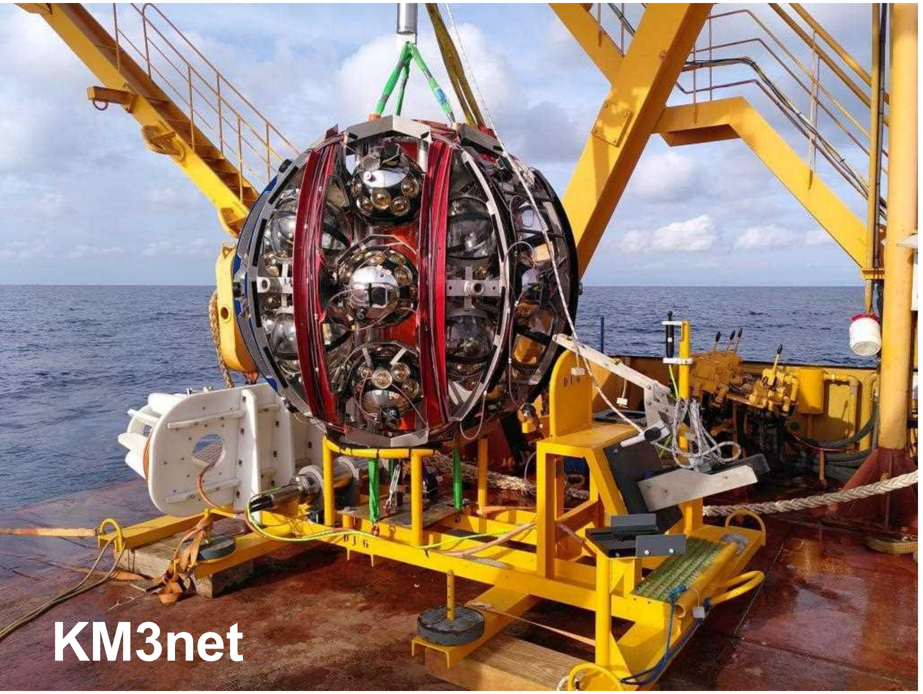




Deep water neutrino telescopes

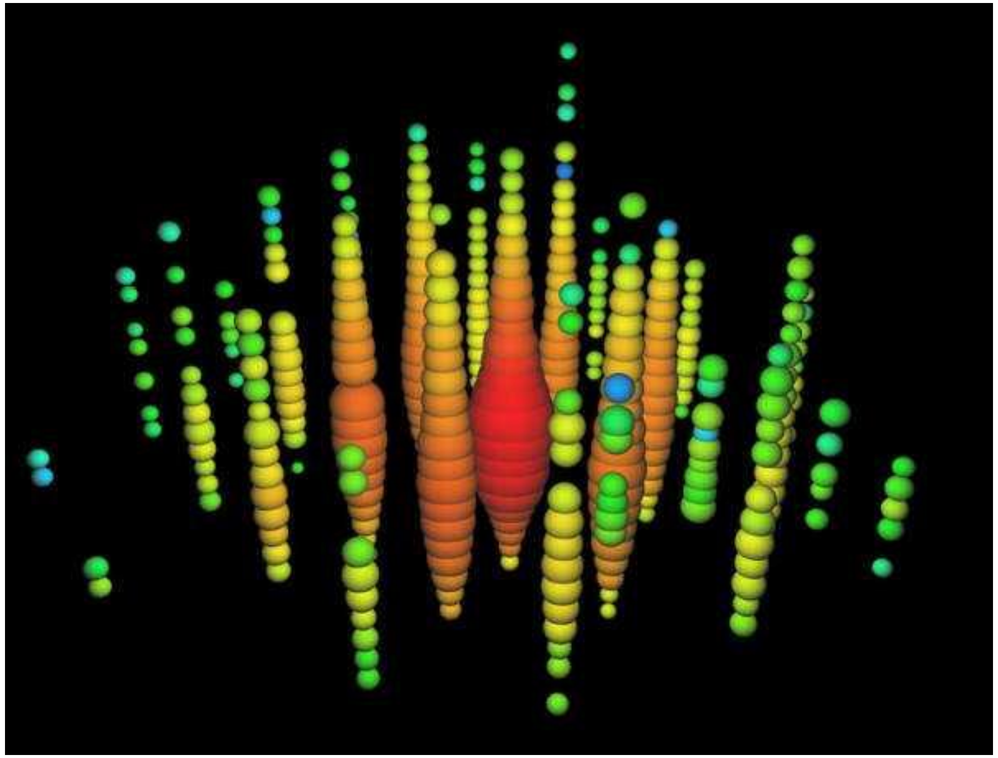
Diffuse fluxes of astrophysical neutrinos and identification of point sources (blazars).
The goal: a fiducial volume of ≥1 cubic kliometer.



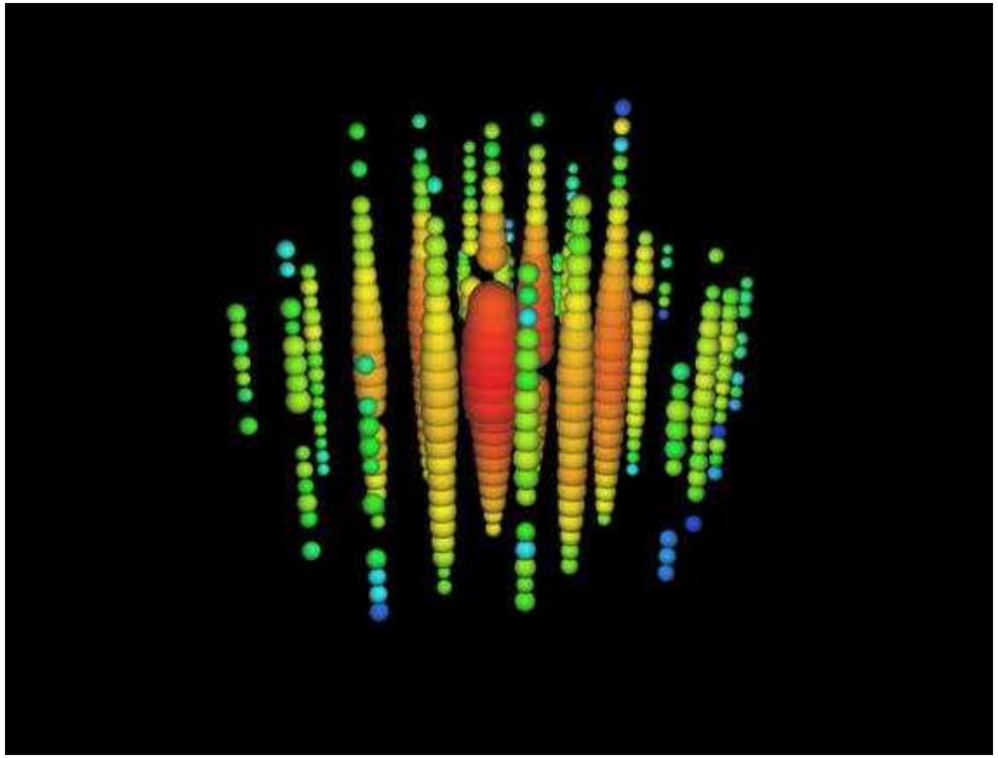


Events with the energy of ~ 1 PeV

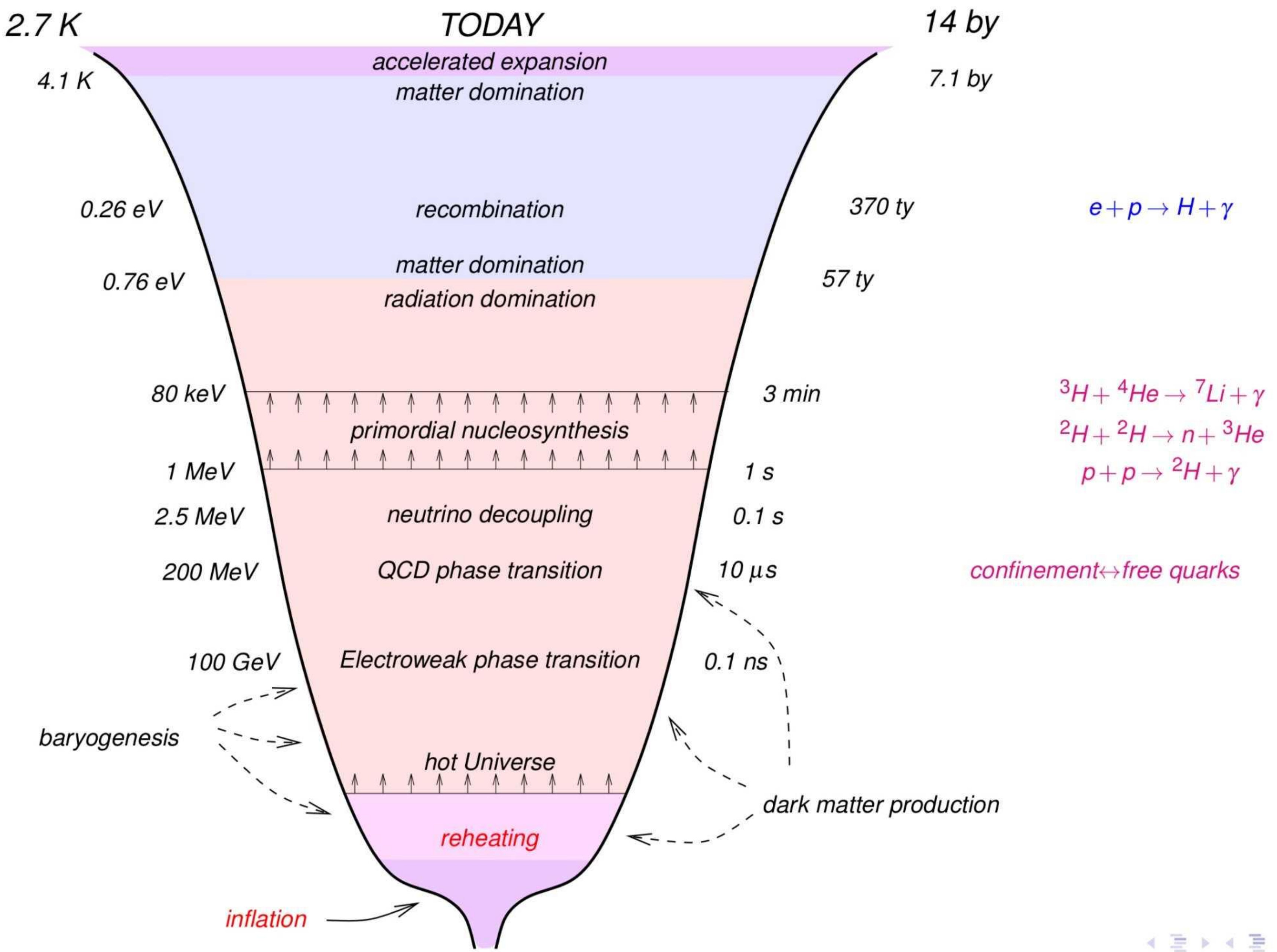
August 2011



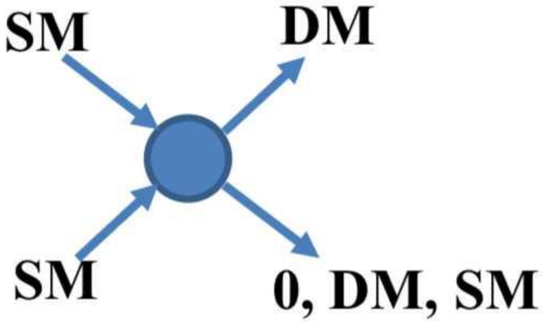
January 2012

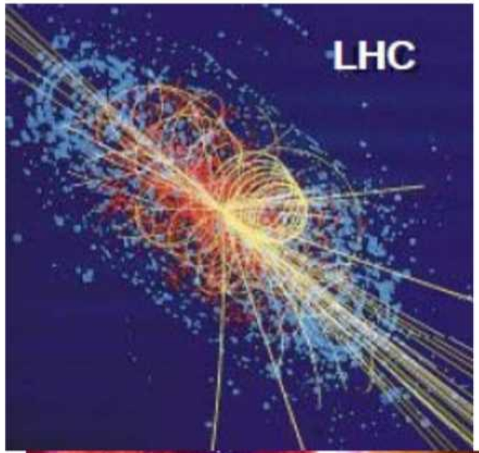


"First observation of PeV-energy neutrinos with IceCube."
IceCube Collaboration. MG.Aartsen et al. Physical Review Letters 111 (2013)

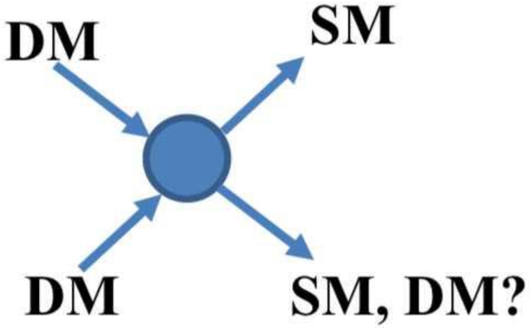

2.7 K
TODAY
14 by
accelerated expansion
4.1 K
7.1 by
matter domination
0.26 eV
recombination
370 ty
$e+p \to H+\gamma$
0.76 eV
matter domination
57 ty
radiation domination
80 keV
3 min
$^3H + ^4He \to ^7Li + \gamma$
primordial nucleosynthesis
$^2H + ^2H \to n + ^3He$
1 MeV
1 s
$p+p \to ^2H + \gamma$
2.5 MeV
neutrino decoupling
0.1 s
200 MeV
QCD phase transition
10 μs
confinement↔free quarks
100 GeV
Electroweak phase transition
0.1 ns
baryogenesis
hot Universe
dark matter production
reheating
inflation

Эксперименты на ускорителях (БАК):
Возможно удастся увидеть недостачу энергии, однако будет трудно доказать, что новая частица(ы) стабильна и именно эта частица образует темную материю.



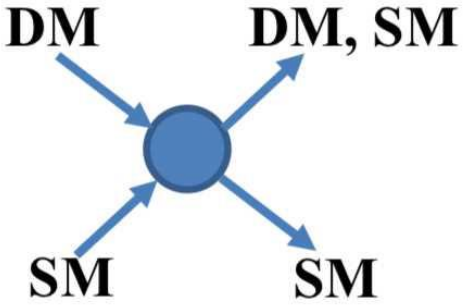


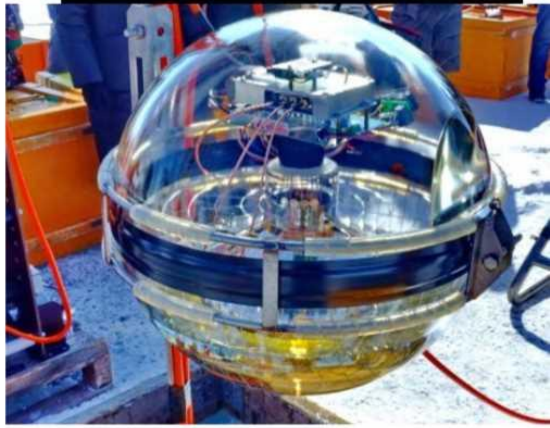
Косвенные методы обнаружения (сигналы из Космоса):
Высокоэнергичные нейтрино от Солнца (Земли), антиматерия (e^+,…) от аннигиляции пар в гало нашей галактики, γ-лучи от аннигиляции пар в центре галактики, …



Прямой поиск:

наблюдение рассеяния частиц темной материи на мишени в лаборатории



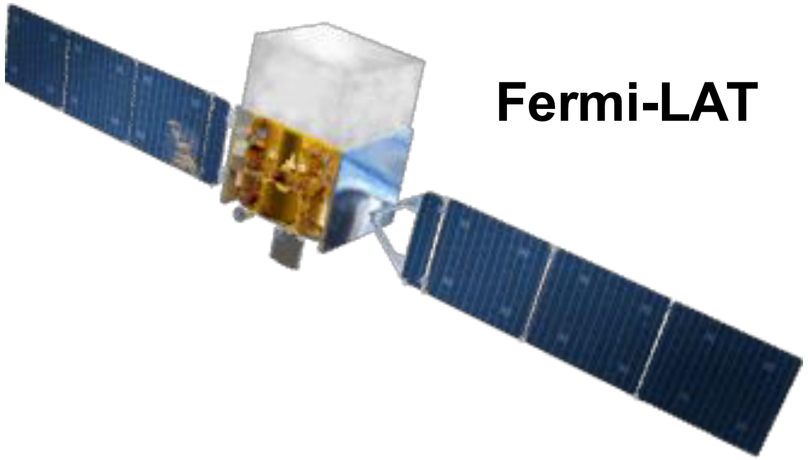


Два подхода:
1) как можно полное подавление фона;
2) поиск признаков дополнительного сигнала при значительном фоне: измерения с низким порогом + поиск полугодовых модуляций сигнала

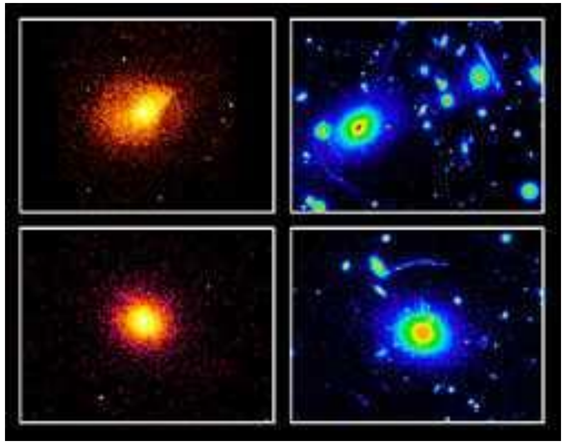
Прямые измерения дадут прямые доказательства, однако не смогут дать точные значения массы и сечения – т.к. интерпретация результатов сильно зависит от модели.

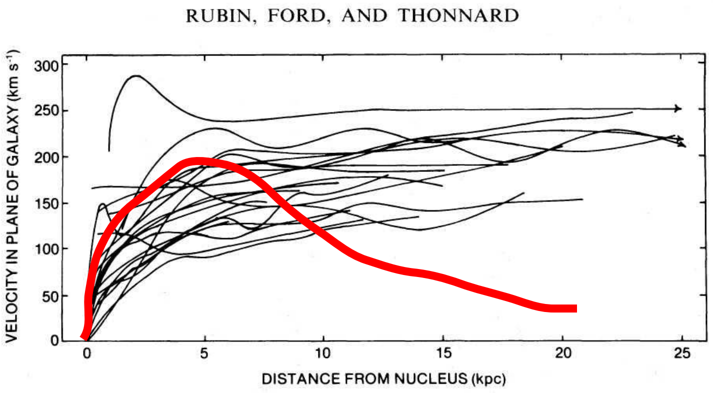
Courtesy of E.Yakushev

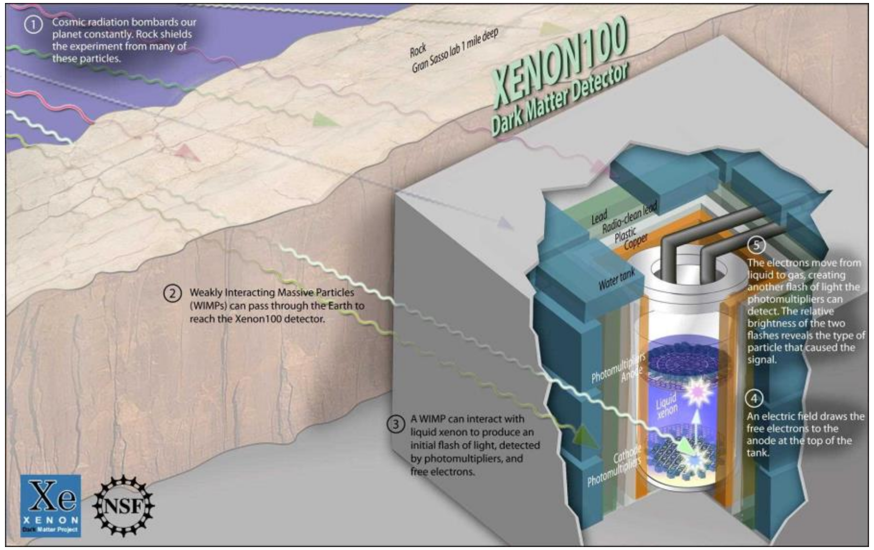
Dark matter search



Fermi-LAT





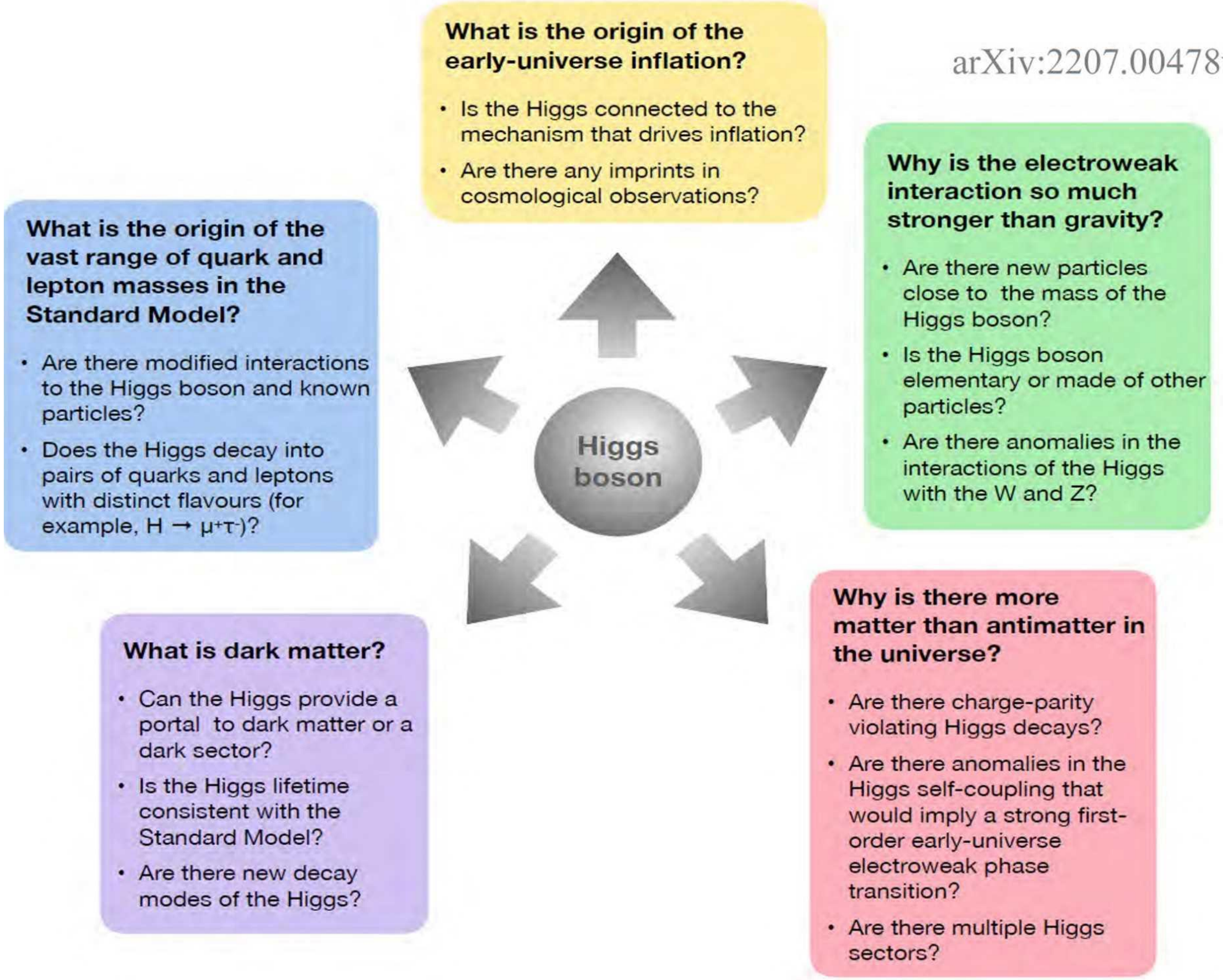


• Colliders continue to drive precision tests of the Standard Model

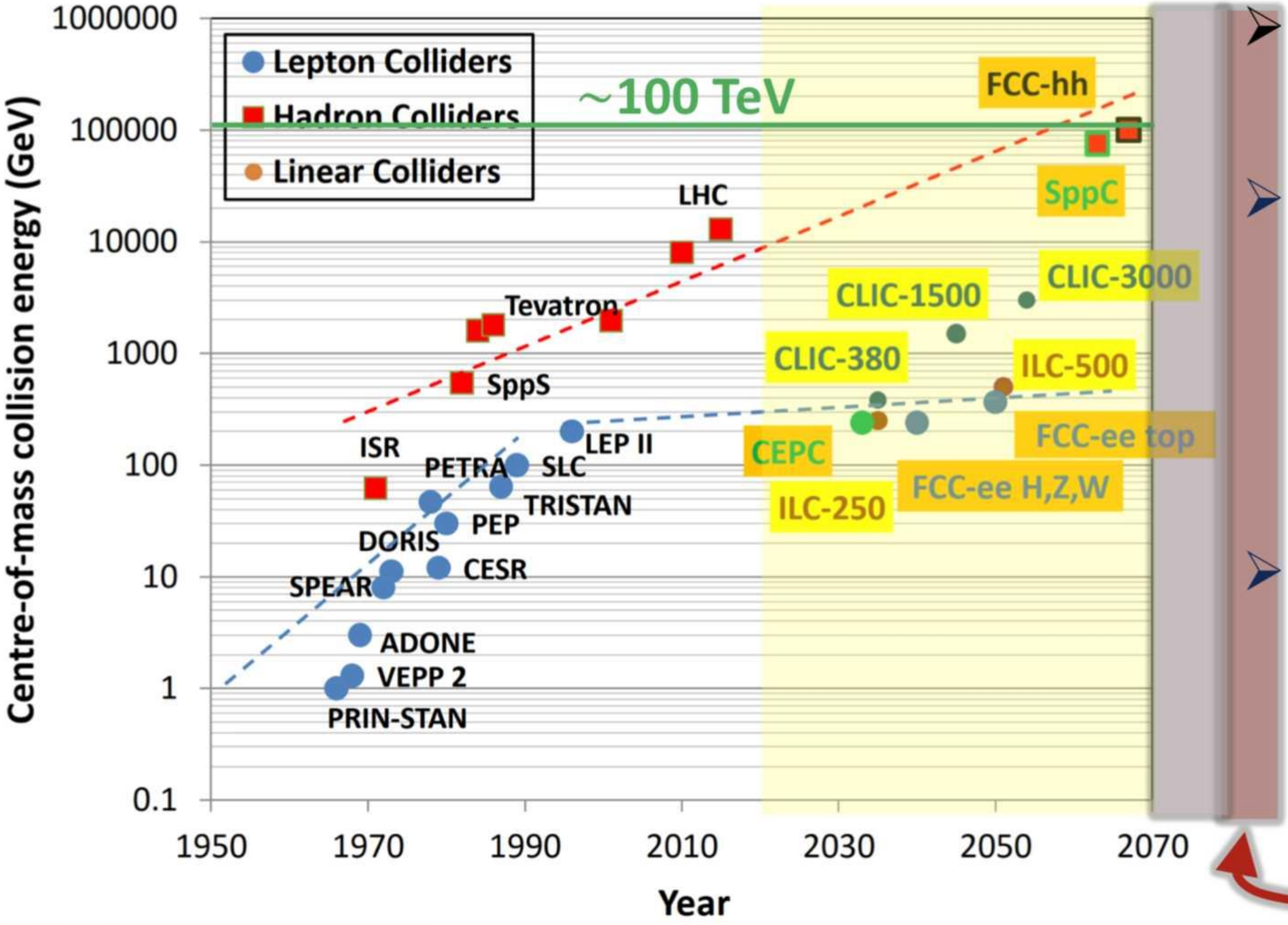
• Further progress in this direction is associated with e+e- colliders in the energy region from the Z-boson to the production threshold of the $t\bar{t}$ quark pair

• Lower energy colliders remain and will remain an essential research tool

arXiv:2207.00478

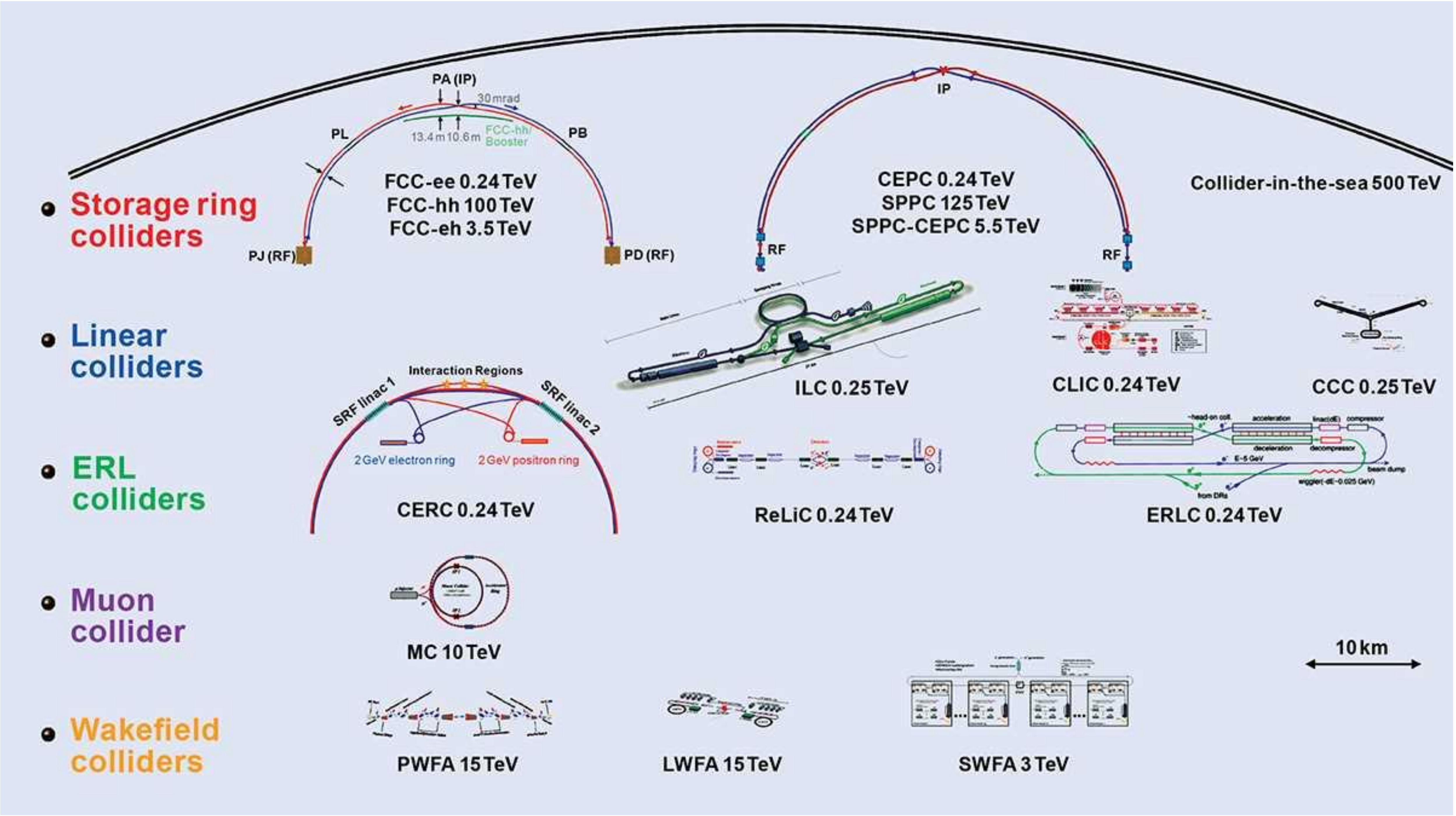


next-generation high energy colliders under study



- **Linear e⁺e⁻ colliders** (CLIC, ILC)
  E_{CM} up to ~ **3 TeV**
- **Circular e⁺e⁻ colliders** (CEPC, FCC-ee)
  E_{CM} up to ~ **400 GeV**
  limited by $e^{\pm}$ synchrotron radiation
  $\Delta E/\mathrm{turn} \propto \gamma^4/\rho$
  → **precision measurements**
- **Circular p-p colliders** (SppC, FCC-hh)
  E_{CM} up to ~ **100 TeV**
  energy (momentum) limited by $p = eB\rho$
  → **direct discoveries energy frontier**

next-next(-next) generation:
ERL based colliders?
muon colliders ?
plasma-based colliders?



Courtesy of V.Shiltsev

Four accelerator and beam physics grand challenges were identified:

Grand Challenge #1: Beam Intensity – “How do we increase beam intensities by orders of magnitude?”
- Deliver an order of magnitude increase or more in secondary particle fluxes from proton and heavy-ion driver applications;
- Enable ultrashort electron bunches for collider applications;
- Enable first generation of accelerator-driven energy systems;

Grand Challenge #2: Beam Quality – “How do we increase the beam phase space density by an order of magnitude, towards the quantum degeneracy limit?”
- Create new paths for dramatically increased collider luminosity;
- Enable compact wakefield-based colliders;
- Significantly enhance the brightness and wavelength reach of modern X-ray sources;

Grand Challenge #3: Beam Control – “How do we measure and control the beam distribution down to the individual particle level?”
- Substantially increase luminosity in future colliders;
- Mitigate beam losses;
- Enable table-top coherent light sources;
- Enable quantum science experiments.

Grand Challenge #4: Beam Prediction – “How do we develop predictive ‘virtual particle accelerators’?”
- Deliver an integrated ecosystem of predictive tools for accurate, complete and fast modeling of particle accelerators and beams;
- Enable virtual accelerators to predict the behavior of particle beams in accelerators;
- Develop mathematical and algorithmic tools that benefit from — and contribute to

Unsolved problems

1. The nature of dark matter

2. Baryon asymmetry in the Universe

3. Particle mass hierarchy

4. Unification of forces

There are a few more (confinement, spin of proton, etc)

Summary

- High-energy physics has made significant progress over the past two decades and continues to be a key area in the study of the fundamental properties of matter.
- However, science faces large-scale challenges, the solution of which will require the construction of next-generation experimental facilities and research infrastructure.
- Today, CERN remains the world leader in experimental high-energy physics. In the US, the scale of research has decreased, with efforts focused primarily on studying neutrinos and astrophysical phenomena. China is emerging as a promising new player: if implemented, its projects could significantly influence the development of this field. JINR is looking seriously and ambitious with home projects in NP/PP (NICA, BAIKAL, SHE), also being large contributor to CERN, FNAL, JUNO, BES-III, and intending to contribute to T2K/HyperK, CePC, etc.

Thank you for your attention !

Thanks to A.Zhemchugov and my JINR colleagues for assistance with slides

IUPAP Report, WG-9 and C-12 (Summer 2023):

Key problems in physics that should determine the development of new facilities and programs in nuclear science:

- Nuclear physics: nuclear structure and nuclear reactions, formation of elements in the Universe, including superheavy elements
- Structure of the nucleon, consisting of quarks and gluons within the Standard Model
- Fundamental symmetries leading to physics beyond the Standard Model and to the study of neutrino properties (study of neutrinoless double beta decay and neutrino oscillations)
- Nuclear energy in the era of climate change and global warming
- Application of nuclear physics for the benefit of society, e.g. nuclear medicine.

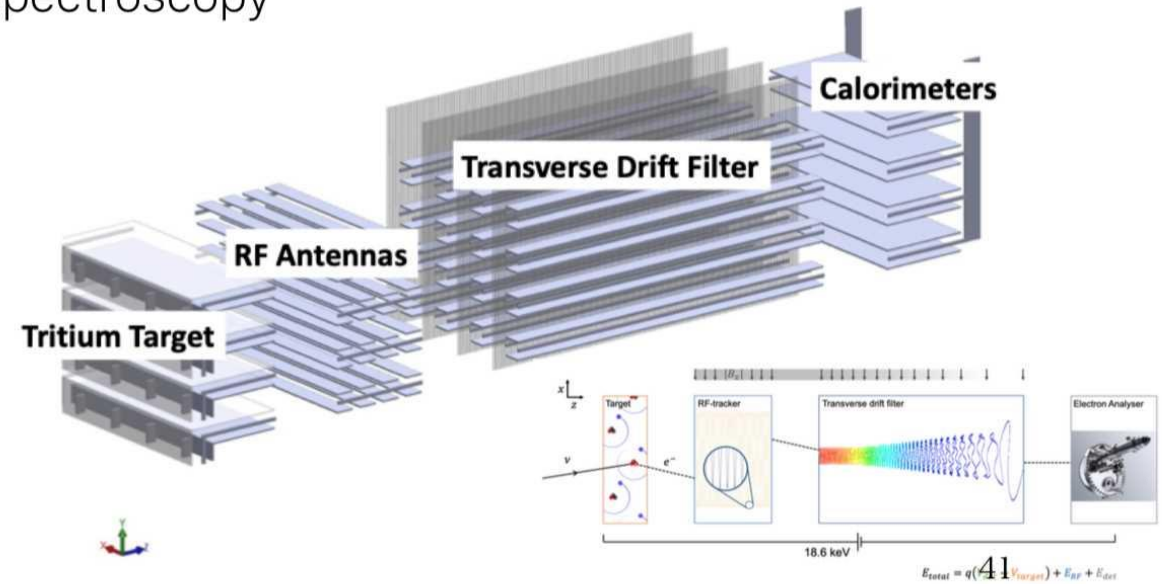
Objectives and Prospects at JINR:

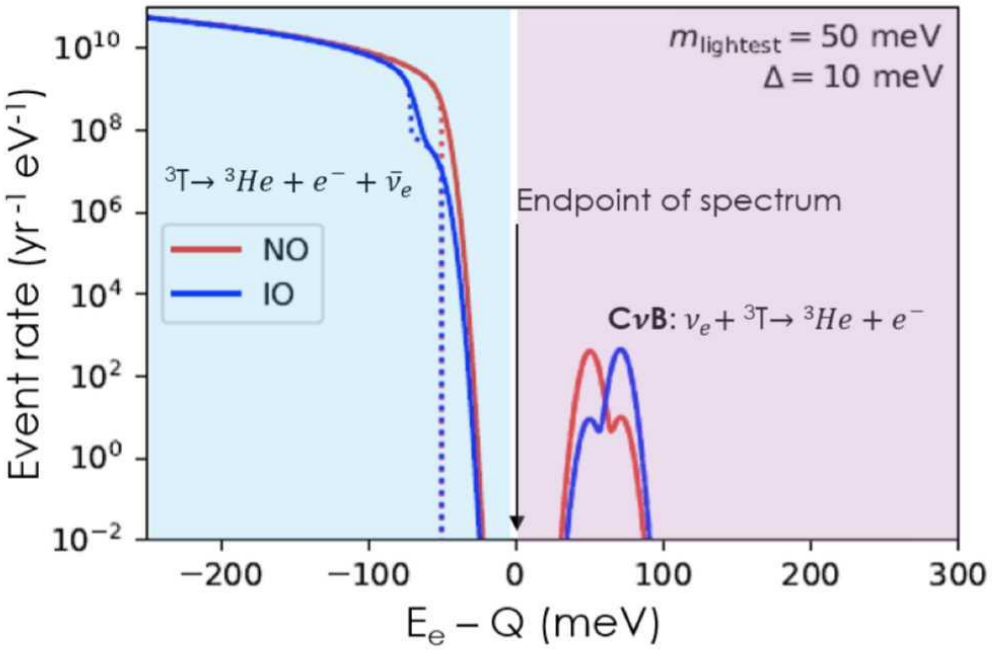
- Borders of the existence of nuclear matter, extreme states of nuclear matter: neutron “paste”, quark matter and color superconductivity. The nature of neutron stars and “deconfinement energy”.
- Study of nuclear structure, nuclear reactions and properties of new nuclei at ultra-small cross sections (up to 1 fb) and ultra-short lifetimes (< μsec);
- Obtaining record intensities of beams of highly charged heavy ions and operating with them (beam power, high luminosity, backgrounds);
- Highly active targets and beams;
- Superconducting technologies and devices (ion sources, linacs, cyclotrons, synchrotrons, channels and detectors);
- High-intensity sources of heavy ions;
- Highly intelligent beam cooling and beam gymnastics (ultra-short times < 1 sec, and maximum intensities up to 10^10).

Relic neutrinos aka Cosmic Neutrino Background

- ✳No evidence so far, but they should exist according to the Standard Cosmology Model.
- ✳Average number density: 339 particles/cm^3; T = 1.95 K, <E> = 10^{-4} eV.
- ✳Detection method in lab: neutrino capture on beta-decaying nuclei.
  PTOLEMY experiment (prototype to be installed at LNGS in 2025, demonstrator at Princeton) combining:
  - ✳ CRES to determine electron energy
  - ✳ transverse drift filter to select and decelerate end-point electrons
  - ✳ low temperature microcalorimeters for hi-res spectroscopy

First physics results are expected by 2030





Courtesy of L.Kolupaeva