Plans of Particle and Astro-Particle Physics in China

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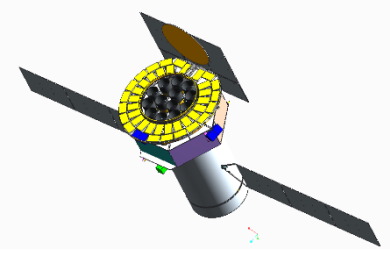
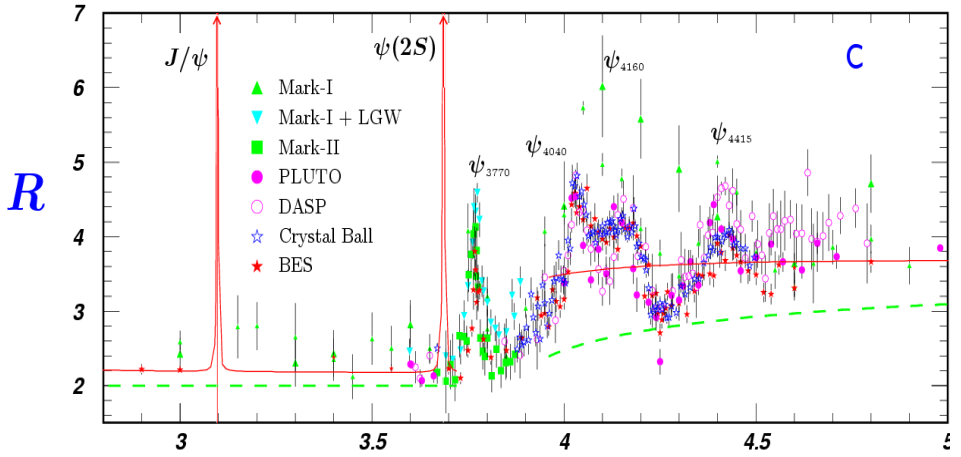


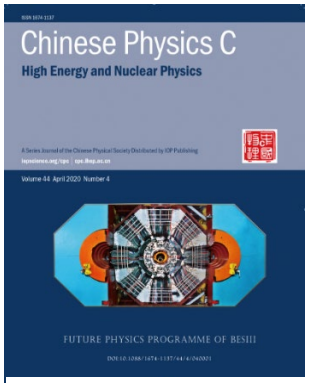
Outline

- Hadrons
- Higgs
- Neutrinos
- Astro-Physics
- Dark matter and other searches
- Strategy study of future large science facilities
- Summary

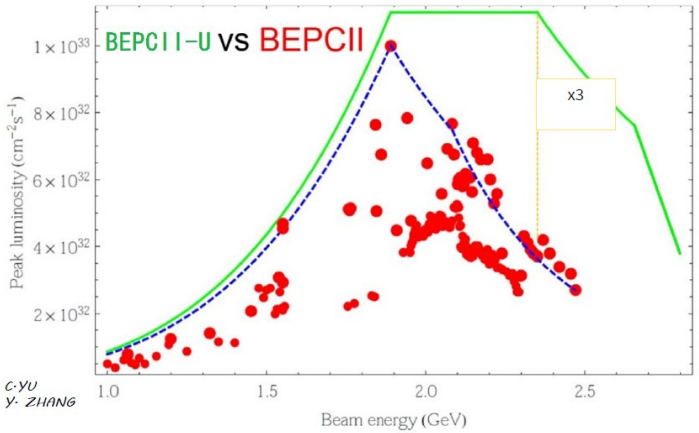
Hadrons: BEPCII/BESIII 2009-2030

- Reach physics at threshold for exotic states, XYZs, EW test, QCD studies, etc.
- More than 500 papers published and 40 fb^{-1} more data requested
- Upgrade to be completed in 2024:
  - Luminosity × ~3
  - Maximum beam energy from 2.45 to 2.8 GeV ➔ for charmed baryons
- Large international collaboration:
  - > 500 members from 74 Institutions in 15 countries

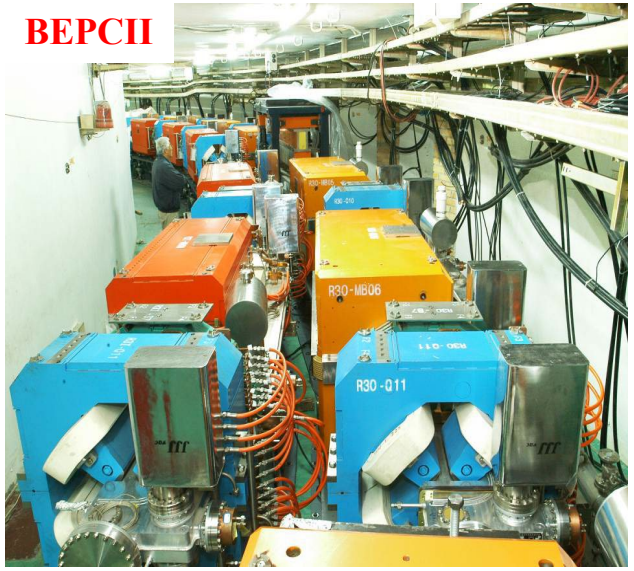




Future physics program of BESIII



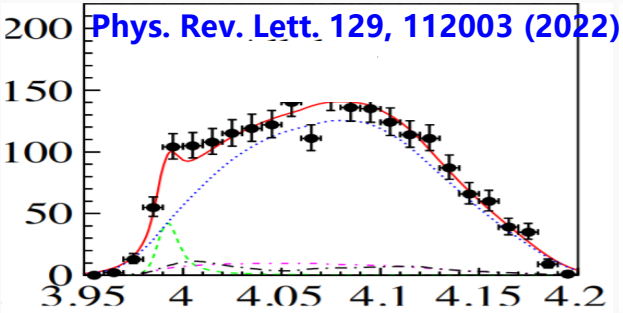
BEPCII

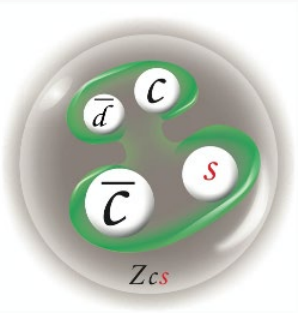


Latest results from BESIII

- **Observation of $Z_{cs}(3985)$**

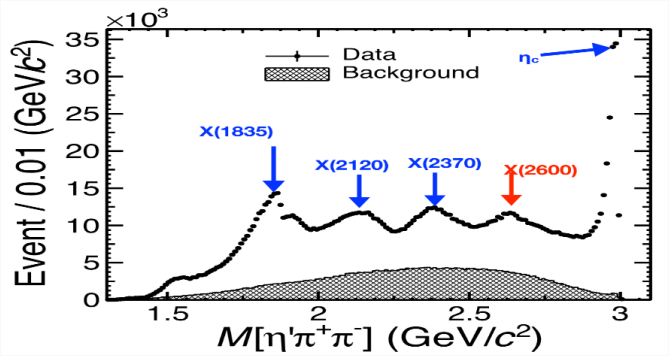
Phys. Rev. Lett. 129, 112003 (2022)





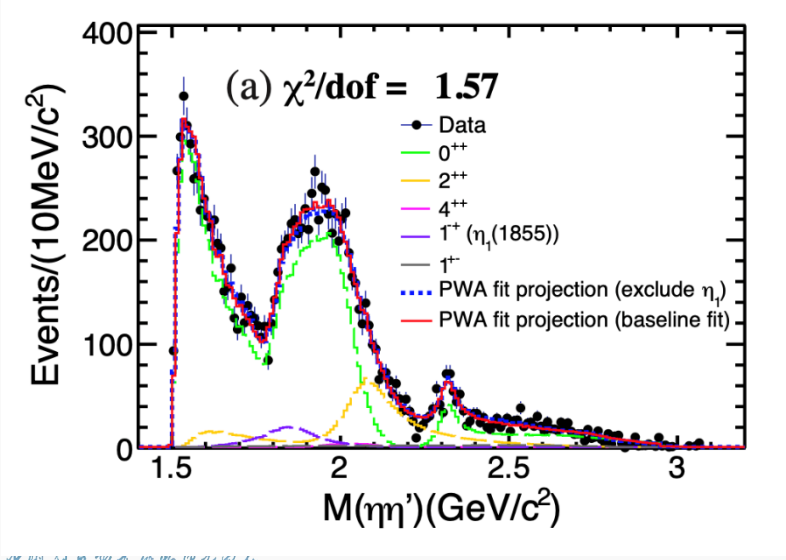
- **Observation of X(2600)**

Phys. Rev. Lett. 129, 042001 (2022)



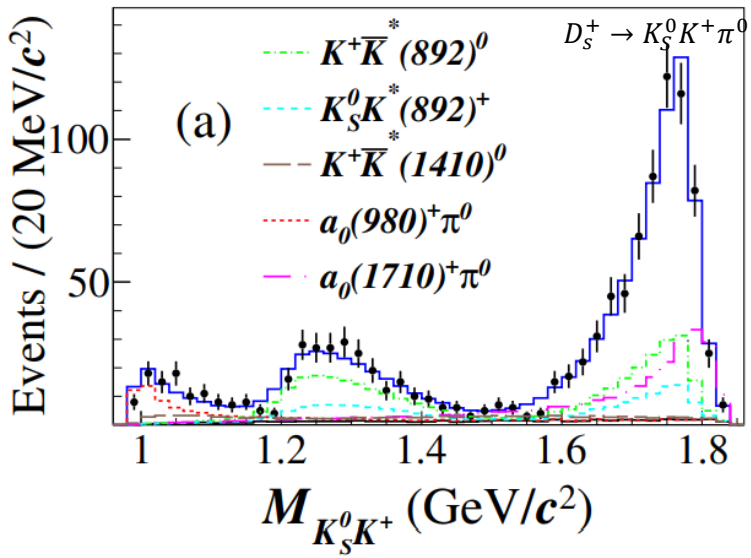
Observation of 1^{-+} $\eta_1(1855)$

Phys. Rev. Lett. Accepted, arXiv:2202.00621



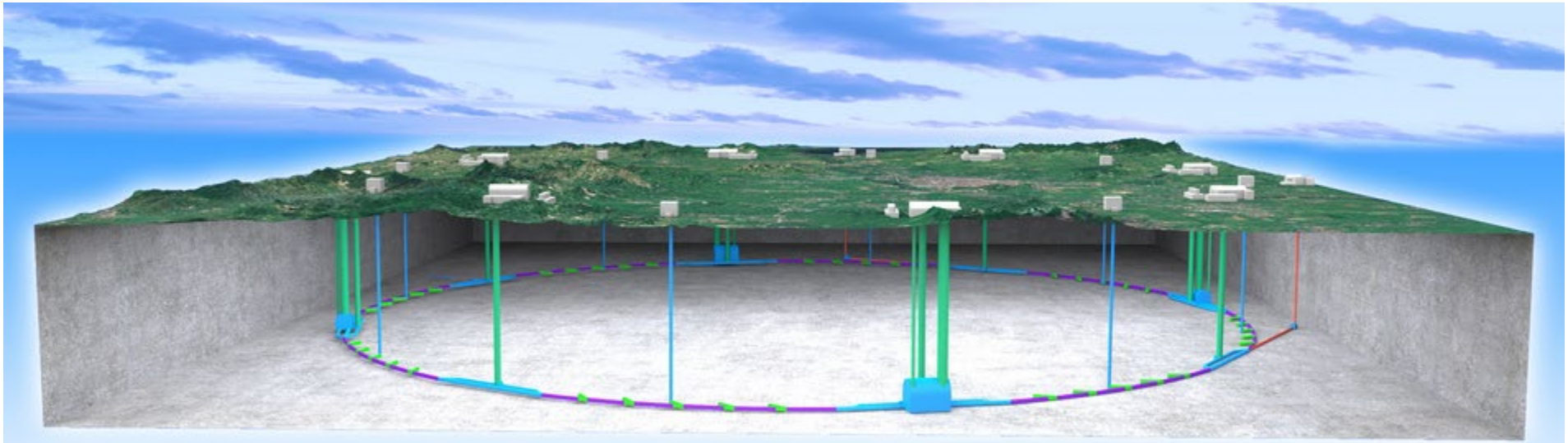
Observation of Isospin=1 scaler $a_0(1817)^+$

Phys. Rev. Lett., arXiv:2204.09614



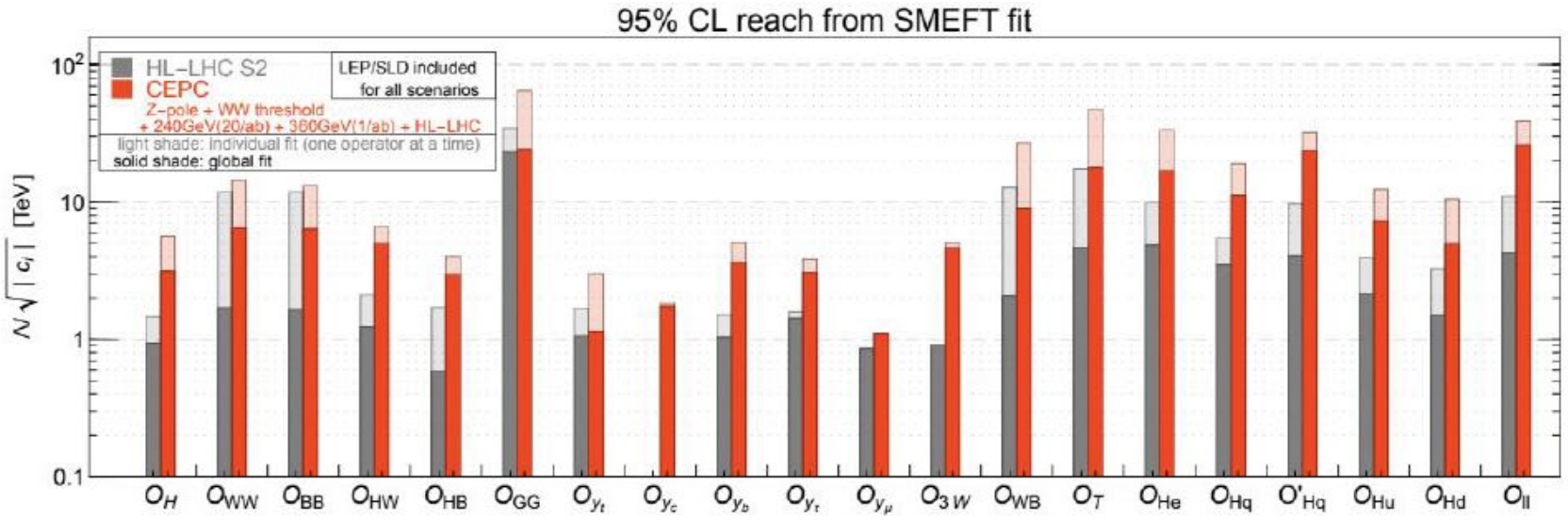
Higgs： CEPC

- The idea of a Circular e+e- Collider(CEPC) followed by a possible Super proton-proton collider(SPPC) was proposed in Sep. 2012, and quickly gained the momentum in IHEP and in the world
  - Higgs is the best portal to new physics:
    - Self-coupling ? Shape of the Higgs potential ? EW phase transition ?
    - Point-like particle ? More Higgs ? Unstable vacuum ?
    - Coupling with dark matter(Higgs mechanism also for dark matter) ?
    - Fine tuning ? Hierarchy ?
    - Flavor symmetry ?



The tunnel can be re-used for pp, AA, ep colliders up to ~ 100 TeV ➔ compatibility study needed now

Precision Higgs Physics at CEPC



Looking for hints of new physics :

$$\mathcal{L} = \mathcal{L}_{SM} + \sum_i \frac{c_i}{M^2}\mathcal{O}_{6,i}$$

$$\delta \sim c_i \frac{v^2}{M^2}$$

No signal at LHC:

Direct searches: M ~ 1 TeV

10% precision: M ~ 1 TeV

At CEPC/FCC:

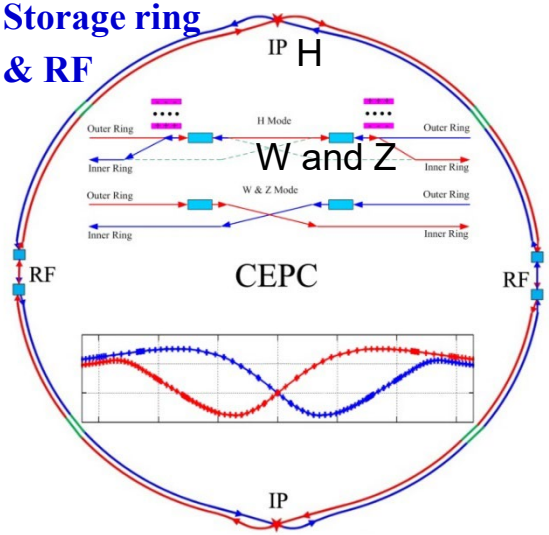
1% precision ➔ M ~10 TeV

Pressing questions best addressed by an e+e- Higgs factory (~1% precision)

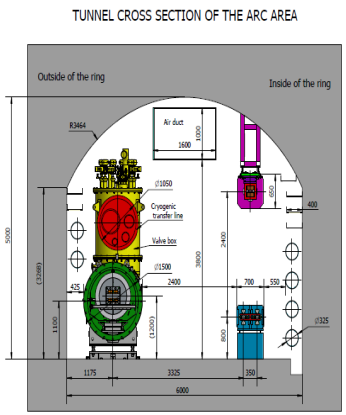
CEPC Accelerator Design

- Strong support from MoST, CAS and NSFC, at a total funding level of > 40 M $
- CDR completed, TDR to be completed soon
- Internationally competitive performance based on the detailed design & studies, such as DA and beam-beam effects

Storage ring & RF



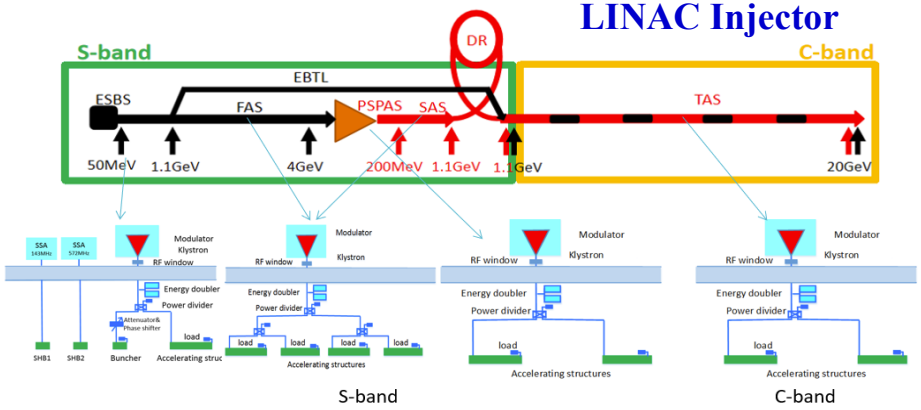
Tunnel



Baseline design(100 km, 30 MW):

Operation mode		ZH	Z	W^+W^-	ttbar
$\sqrt{s}$ [GeV]		~240	~91.2	~160	~360
Run time [years]		7	2	1	7.7
CDR	L/IP[10^{34} $cm^{-2}s^{-1}$]	3	32	10	
Now	L/IP[10^{34} $cm^{-2}s^{-1}$]	5.0	115	15.4	0.5
	Events[2 IPs]	1.7×10^6	2.5×10^{12}	3×10^7	3×10^5

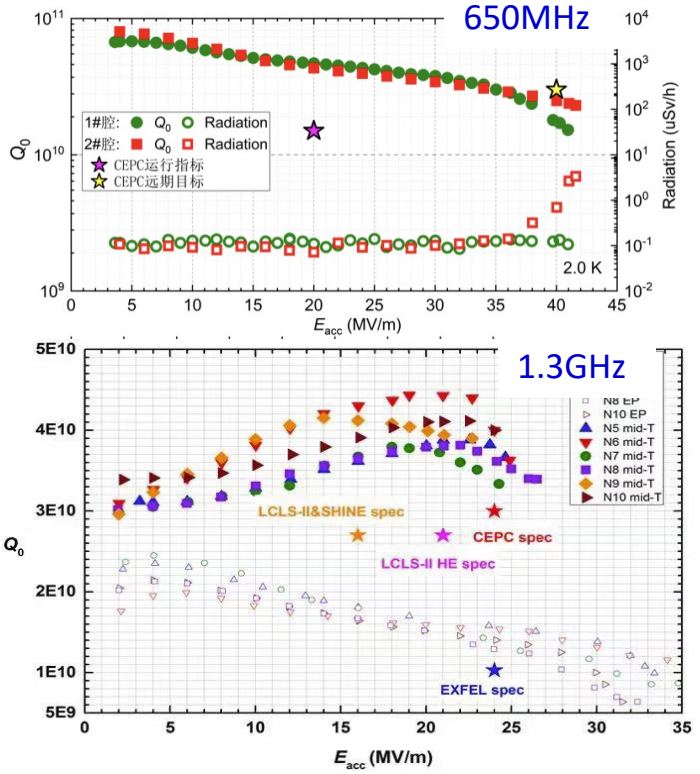
LINAC Injector

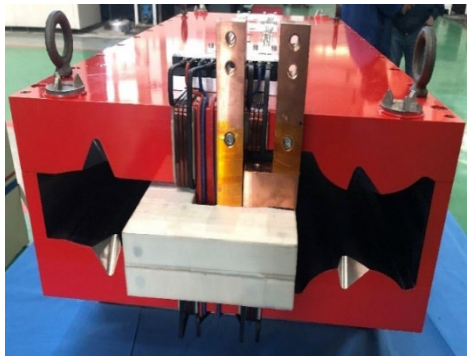


Upgradable to 50 MW, High Lumi Z, ttbar;
Compatible to pp collider

Accelerator R&D and Prototypes

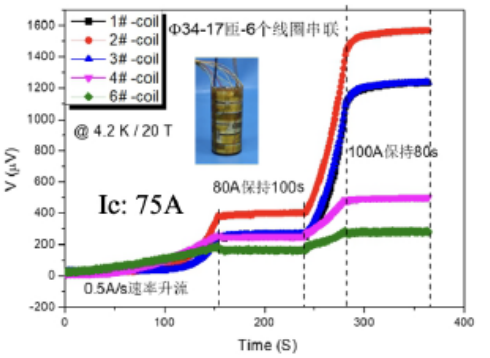
- SRF cavities: 1.3GHz for the booster and 650 MHz for collider rings
  - 1-cell 650MHz@ 40MV/m seems feasible
- High efficiency Klystrons to save energy
- Magnets, vacuum pipes, beam diagnostics, polarized electron gun, positron source, … in good shape
- Plasma wake-field accelerator for the injector to save cost
- Iron-based HTc superconducting tech. for SPPC
- A lot of synergies with HEPS, a 6 GeV light source under construction





magnets

Klystrons

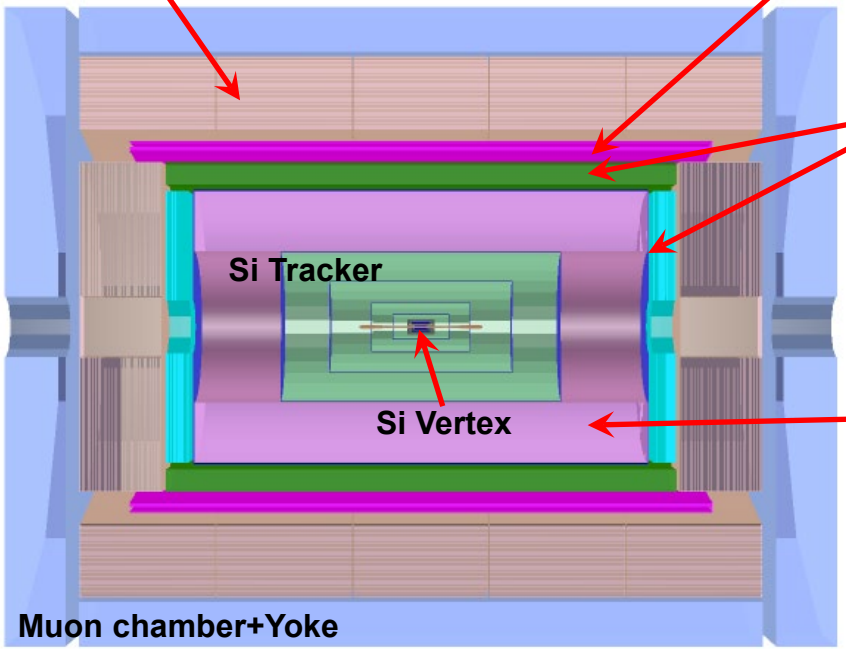


IBS coils

Detector Design and R&D

PFA HCAL based on Scint. Glass/Steel

Advantage: Higher sampling ratio for better energy resolution: < 40%/√E
Challenges: Light yield, transparency, mass production of scint. glass



Solenoid Magnet (3T / 2T)

Advantage: HCAL absorber as the return yoke.

Challenges: thin enough magnet not to affect the jet resolution

PFA ECAL based on Transverse Crystal towers

Advantage: e/γ energy resolution< 3%/√E, 2D readout with timing for 3D capabilities

Challenges: ambiguity of showers if overlapping; high energy π^0 reconstruction

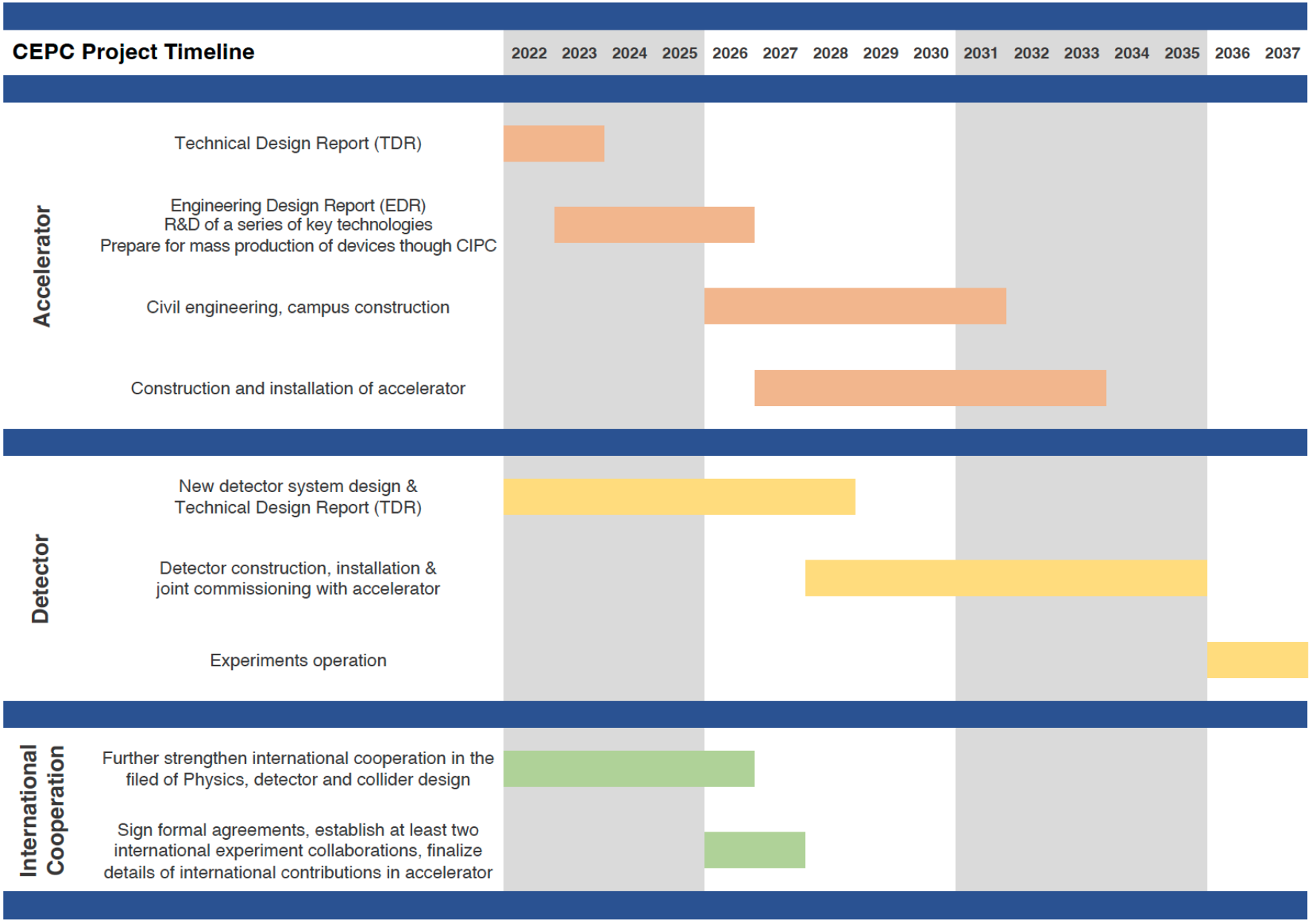
A Drift chamber optimized for PID

Advantage: good PID while improving Si tracking

Challenges: withstand high event rate; good readout for dN/dx

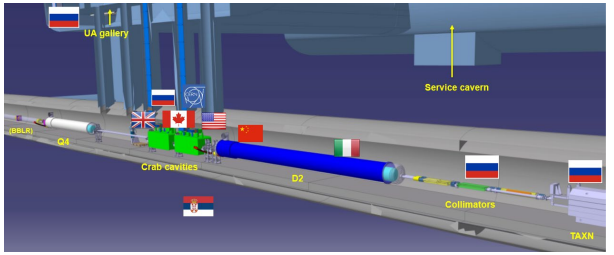
- Silicon pixel sensors and readout chips for better resolution and lower power
- TPC or draft chambers for higher event rate and faster readout(dN/dX & waveform)
- Reconstruction algorithm for showers in Long crystal bars using timing for 3D info.
- Scintillation glass development for higher density and light yield
- Thin solenoid superconducting magnet

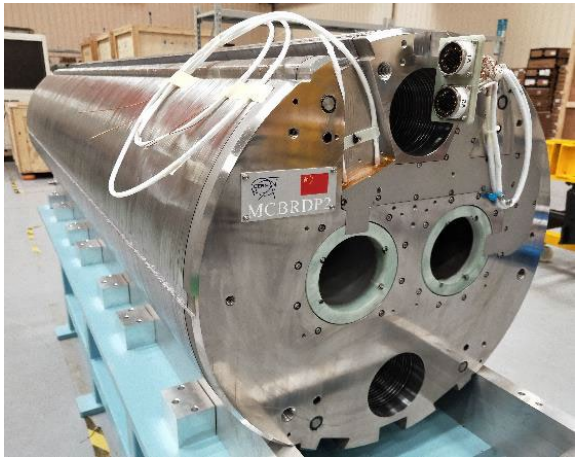
Ideal Schedule

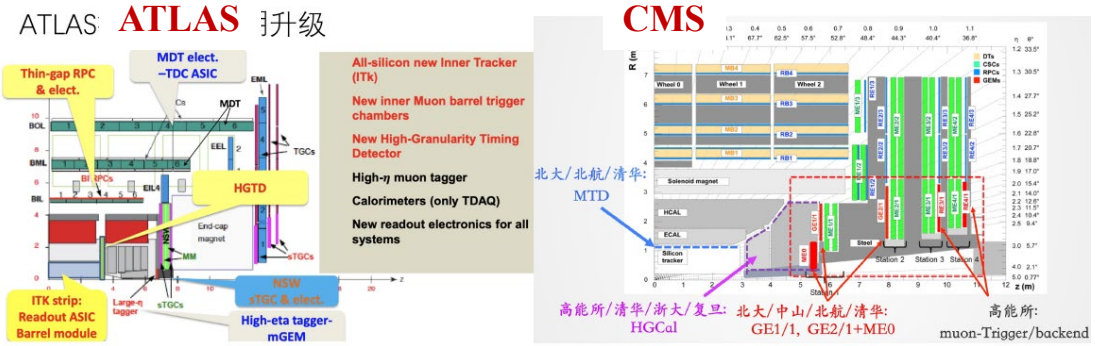


Higgs: International Projects

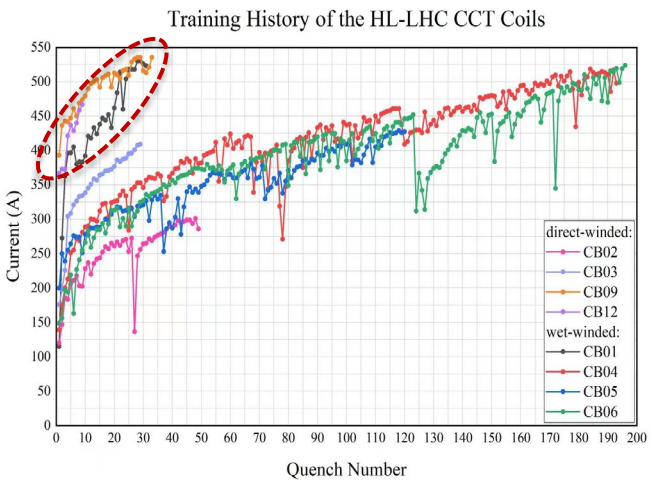
- China is a member of LHC
  - HL-LHC CCT magnets(by IHEP+IMP)
  - LHC experiments: ATLAS, CMS upgrade and physics analysis





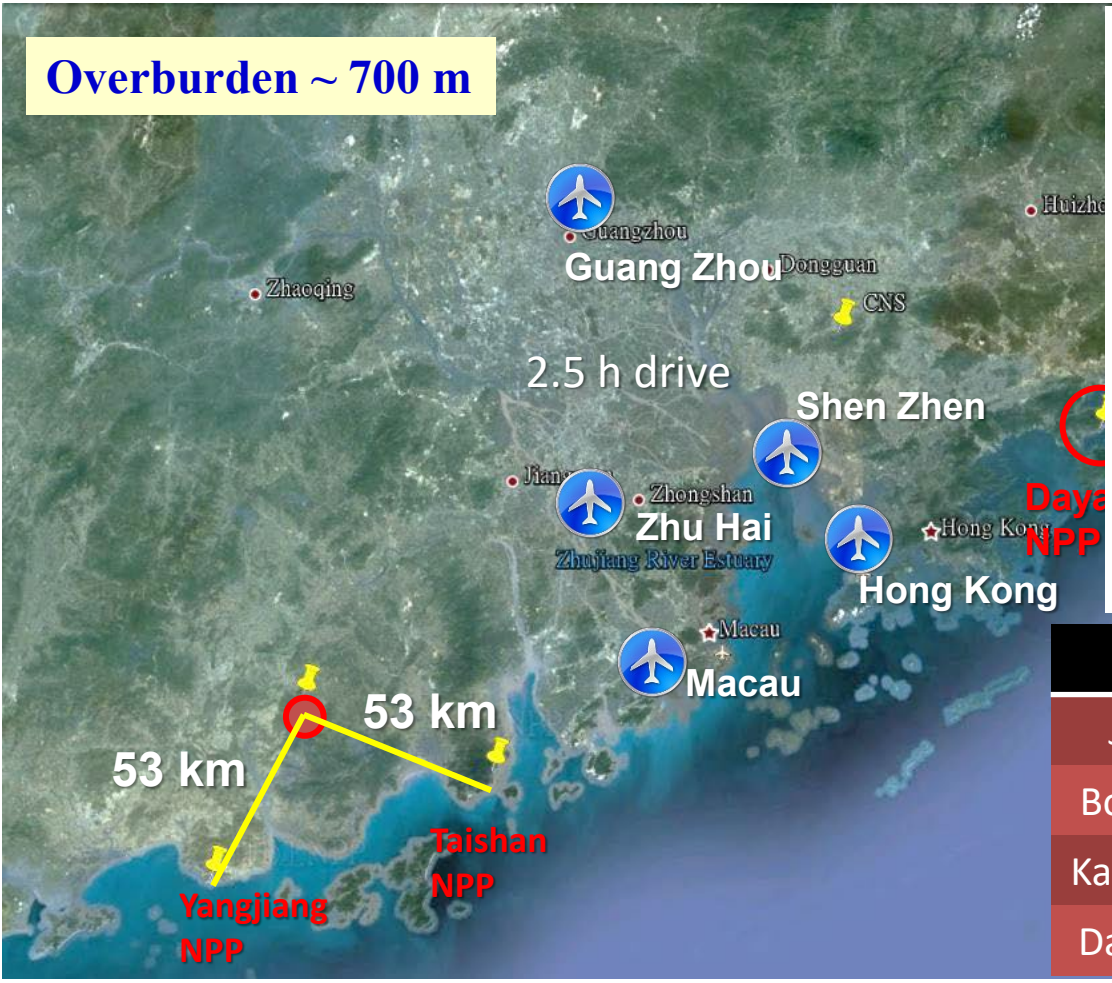


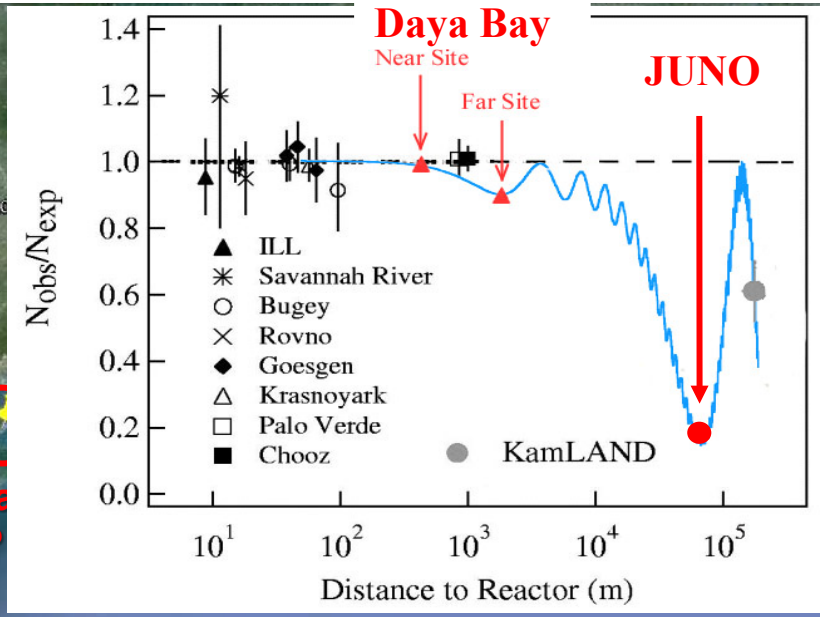
- China is eager and happy to join international projects, ILC, FCC, etc.
- China will be happy to join any US-leading major HEP projects, if possible



Neutrinos: JUNO Experiment

- A 20 kt liquid scintillator detector at ~53 km baseline from reactors
- A collaboration of >700 members from 79 Institutions in 14 countries and regions

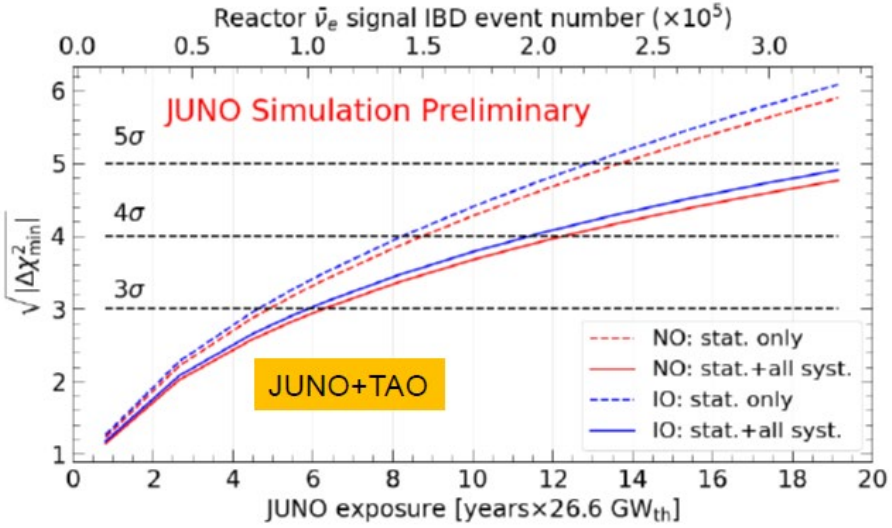




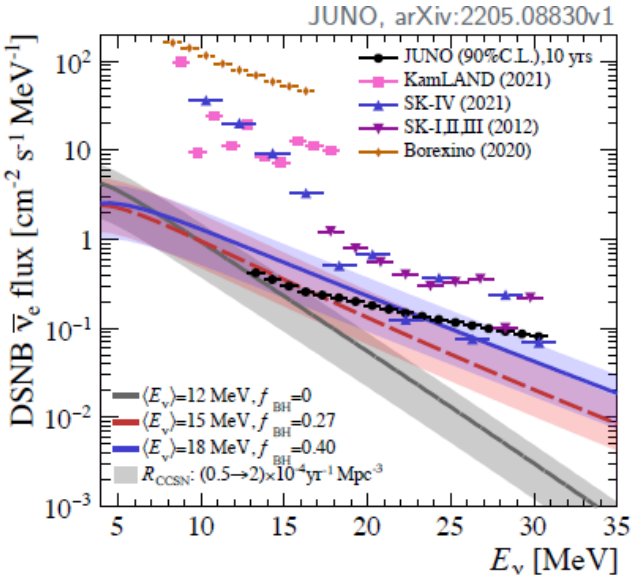
	Target mass [t]	energy resolution
JUNO	20,000	3% @ 1 MeV
Borexino	300	5% @ 1 MeV
KamLAND	1,000	6% @ 1 MeV
Daya Bay	20	8% @ 1 MeV

Physics at JUNO

- Energy resolution of ~3%@1 MeV leads to a sensitivity of NMO at 3σ@ 6 yrs*26.6 GW
- Atmospheric neutrinos contribute another ~ 1 σ @ 6 yrs
- Most of neutrino oscillation parameters can be improved to a sub-percent level
- Solar, supernova and geoneutrinos



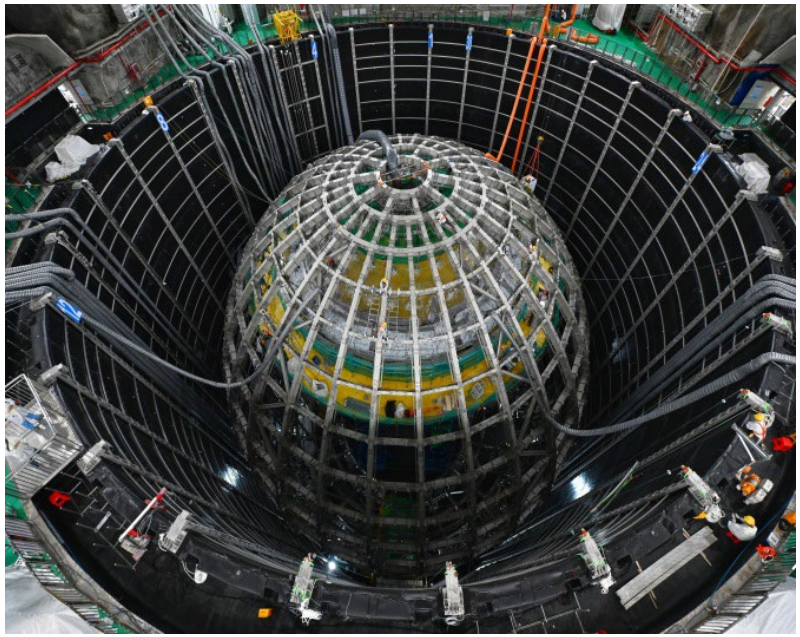
- huge stat. if burst SNν nearby
- high prob. to discover diffused SNν

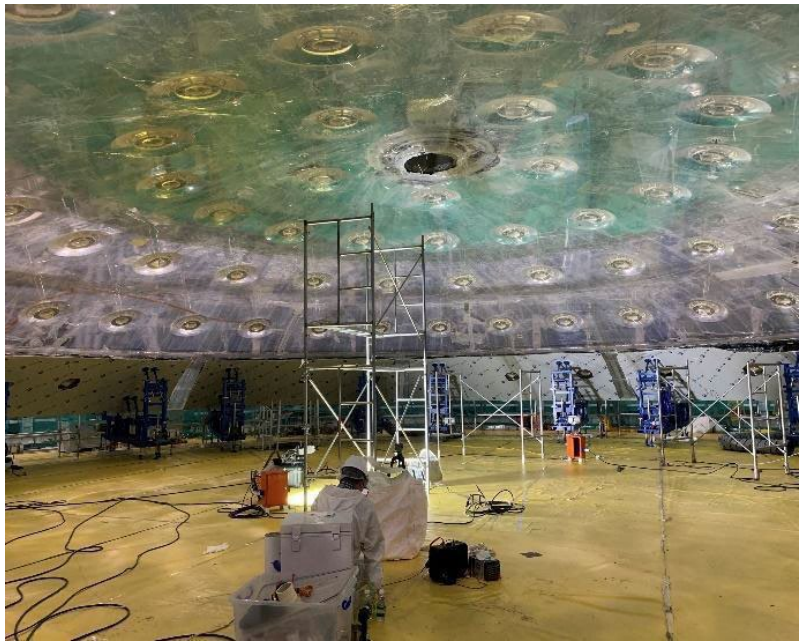


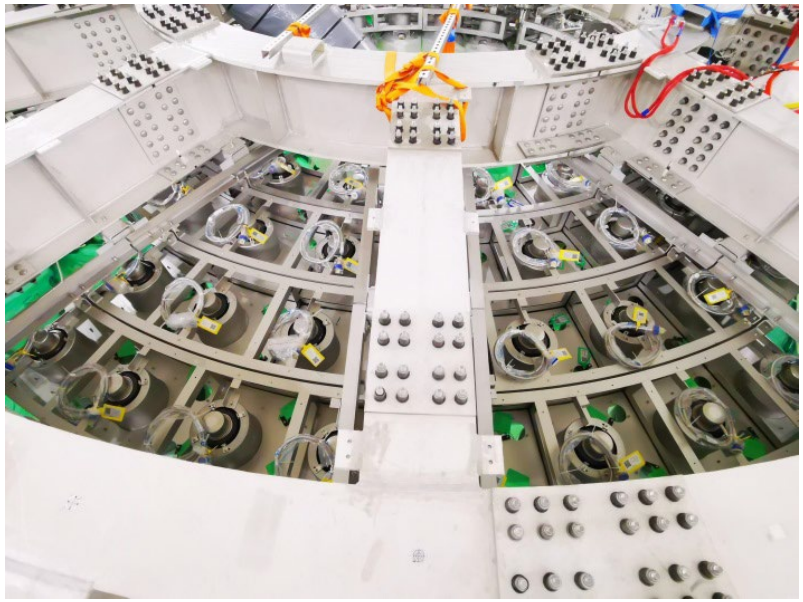
	Current (PDG2020)	JUNO (100 d)	JUNO (6 y)
Δm^2_{31} Δm^2_{32}	1.3%	0.8%	0.2%
Δm^2_{21}	2.4%	1.0%	0.3%
$\sin^2\theta_{12}$	4.2%	1.9%	0.5
$\sin^2\theta_{13}$	3.2%	47.9%	12.1%

Status of JUNO

- Installation in progress:
  - SS structure completed
  - Acrylic sphere bonding in progress
  - PMT installation started
  - To be completed next year
- LS mixing and purification system mostly ready, will start operation next year
- Good energy resolution(3%@1MeV) and cleanness(10^{-17} g/g) seems realizable

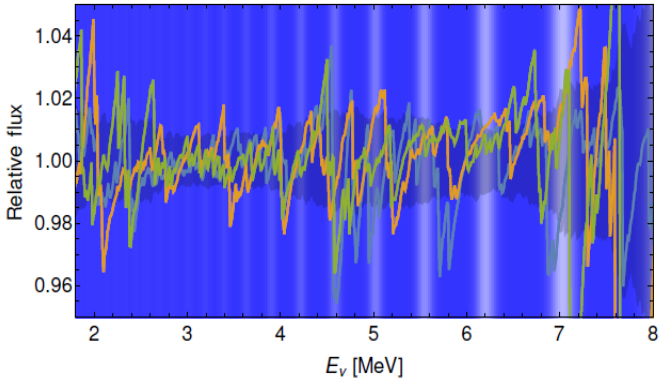


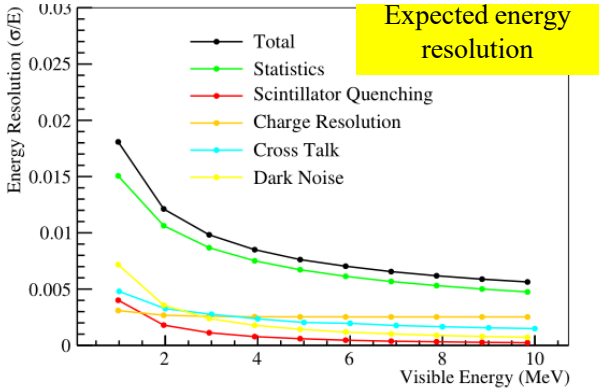


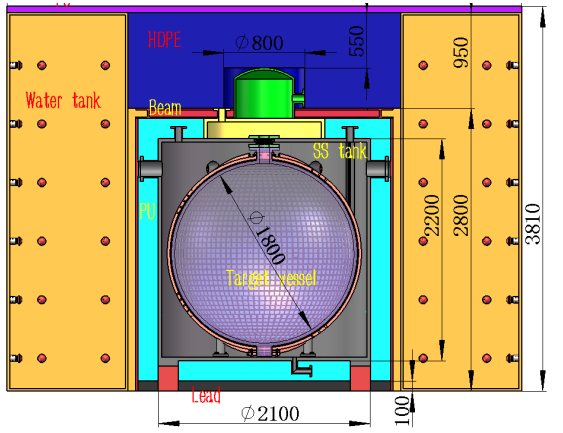


JUNO-TAO: a LS detector at -50℃

- A high precise neutrino detector located at the Taishan Nuclear Power Plant, ~30m from a 4.6GW reactor core
  - ⇨ A reference neutrino spectrum to improve MH and constrain uncertainties(arXiv:2005.08745)
  - ⇨ Sterile neutrino searches
  - ⇨ Nuclear data
- Highest possible energy resolution ~ 1.5%/√E:
  - ⇨ Large area SiPM:
    - PDE > 50%, >90% coverage, 10 m^2
    - 4500 p.e./MeV ➔ × 3 JUNO;
  - ⇨ Operate at -50℃ to reduce SiPM dark noise by 3 orders of magnitude to 100 Hz/mm^2
  - ⇨ Gadolinium-doped liquid scintillator working at -50℃ ➔ a new recipe
- ~2000 IBD/day with ~2% bkg
- To be operational in 2023

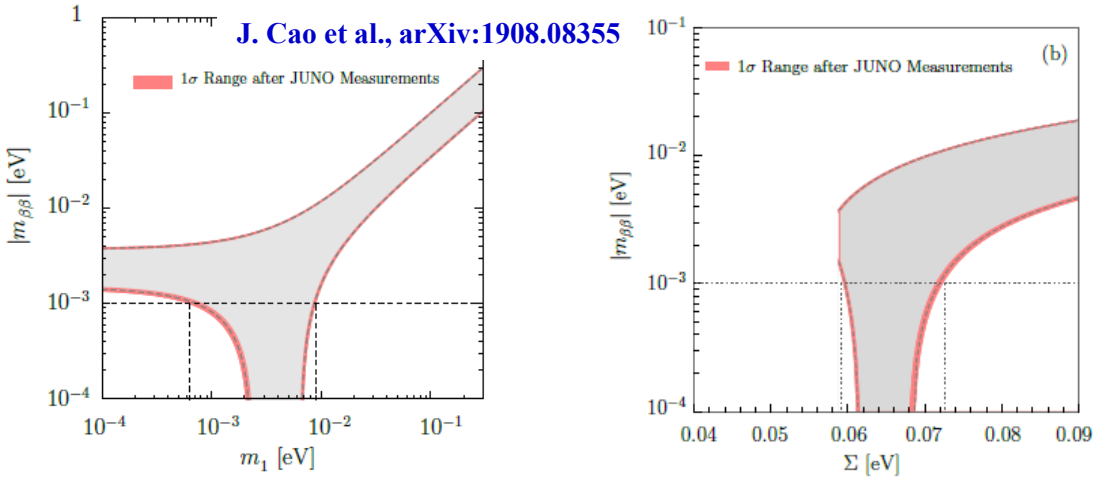




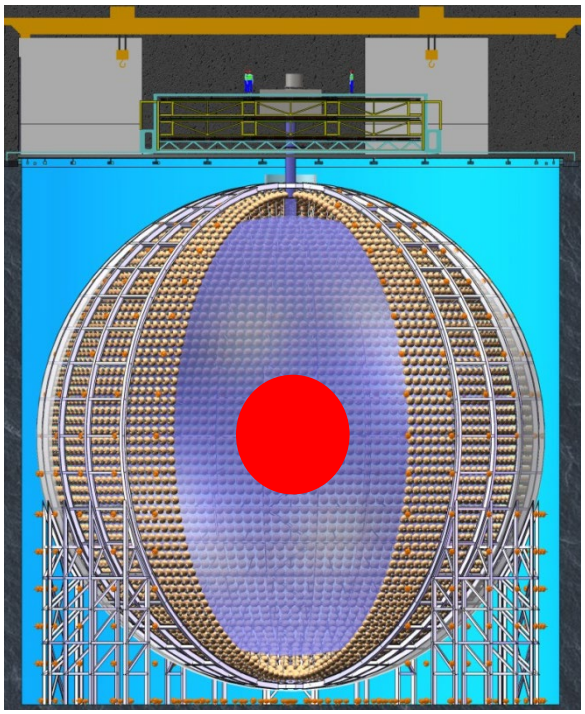


JUNO-ββ

- In 10-20 years from now, oscillation will be mostly understood
- 0ν ββ decay will be the next focus:
  - Dirac-Majorana nature and the absolute ν mass



	Isotope	Mass(t)	$<m_{\beta\beta}>$,meV
KamLAND-Zen	^{136}Xe	0.8	36-156
EXO-200	^{136}Xe	0.2	93-286
nEXO	^{136}Xe	5	7-22
Cupid-1T	^{100}Mo	1	4-7
Legend-1000	^{76}Ge	1	10-40
SNO+	^{130}Te	8	19-46
JUNO-ββ	^{136}Xe	50	4-12
	^{130}Te	100-200	2-6 ?



Load ^{136}Xe or ^{130}Te into the LS of JUNO: good self-shielding, resolution, etc.

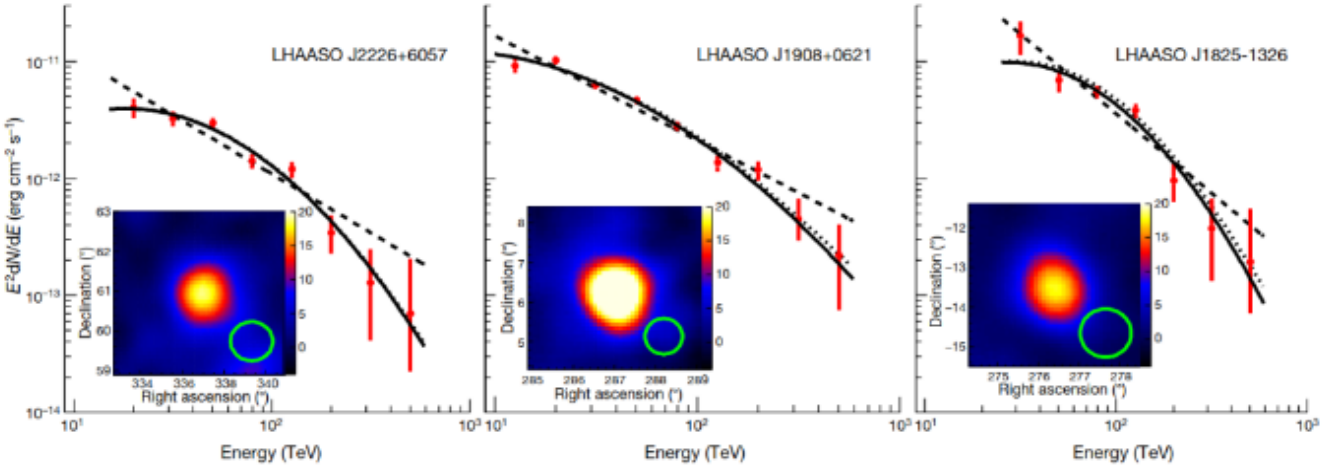
Zhao et al., arXiv: 1610.07143, CPC 41（2017）5

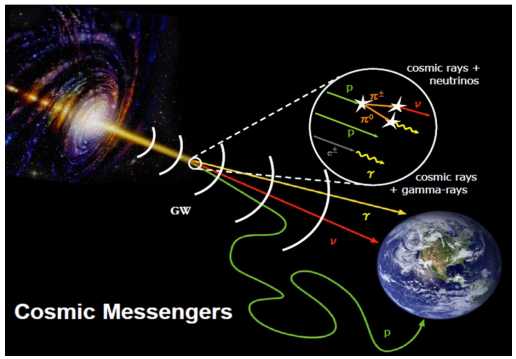
AstroPhysics: Cosmic-Rays and γ-astronomy

— Large High Altitude Air Shower Observatory(LHAASO)

- World largest air shower array(with e, μ, water Č detectors and Č telescope) for the high energy γ-astronomy and cosmic-ray physics
- Construction just completed and interesting results obtained:
  - Highest γ-rays from the Milky Way: 1.4 PeV
  - many γ-ray sources up to ~1 PeV identified → PeVatrons in Milky Way
- Future
  - Large Array of Cherenkov Telescopes (LACT)
  - Under-water neutrino telescope

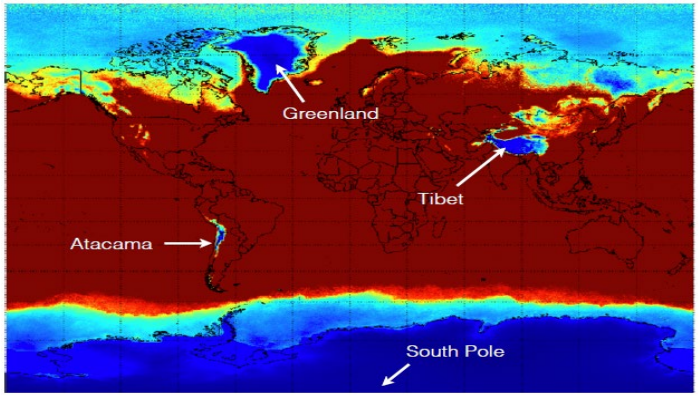
Sichuan, 4410m above the sea

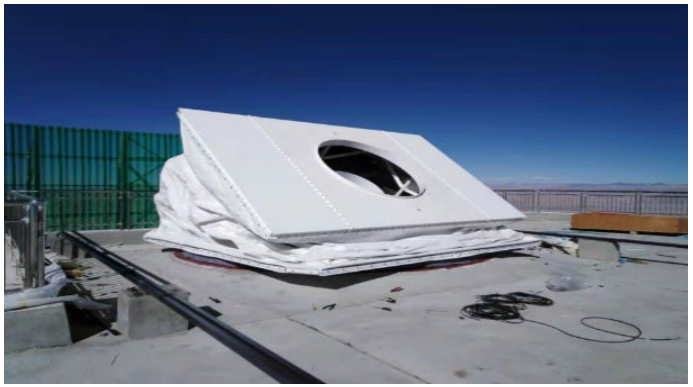




CMB: ALICPT

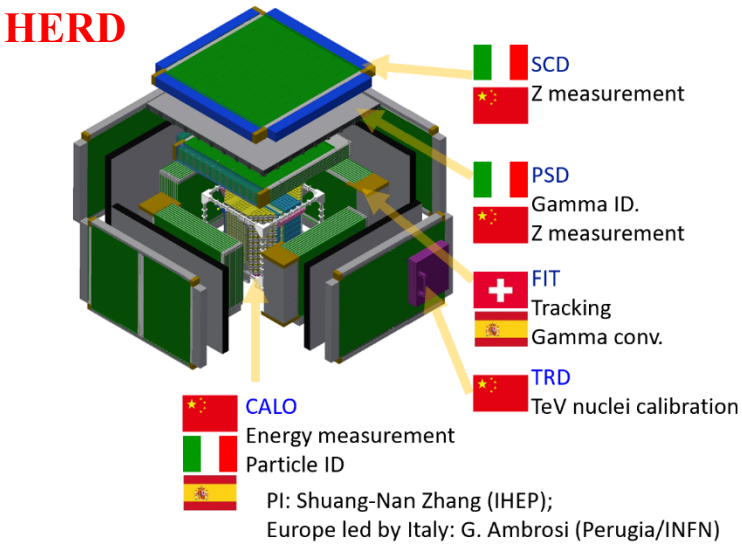
- located in Ali, Tibet with an altitude of 5250m
  - Best site in the north hemisphere for CMB
  - can be a very important node of an international network
- a collaboration with the Stanford University and other international partners
- Hopefully to start the observation next year with 1 module (the telescope can house 19 modules)



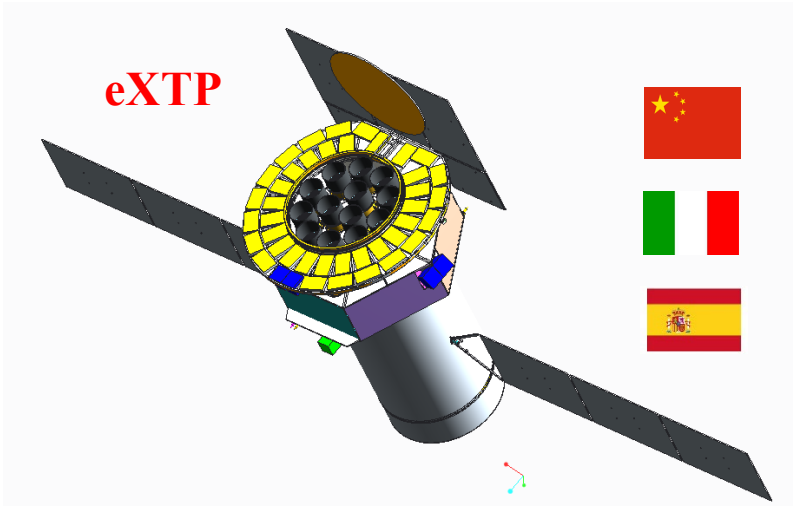


Future Space Programs

- A 3D crystal calorimeter for ×10 acceptance and ×10 higher energy on board of the Chinese Space Station, to be launched in ~2027
  - dark matter searches
  - Gamma-ray sky survey
  - Precise cosmic ray spectrum and composition to calibrate LHAASO
- Large international collaboration

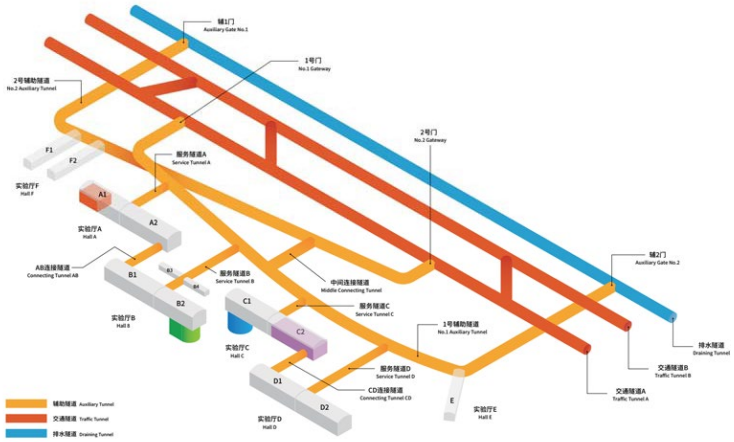


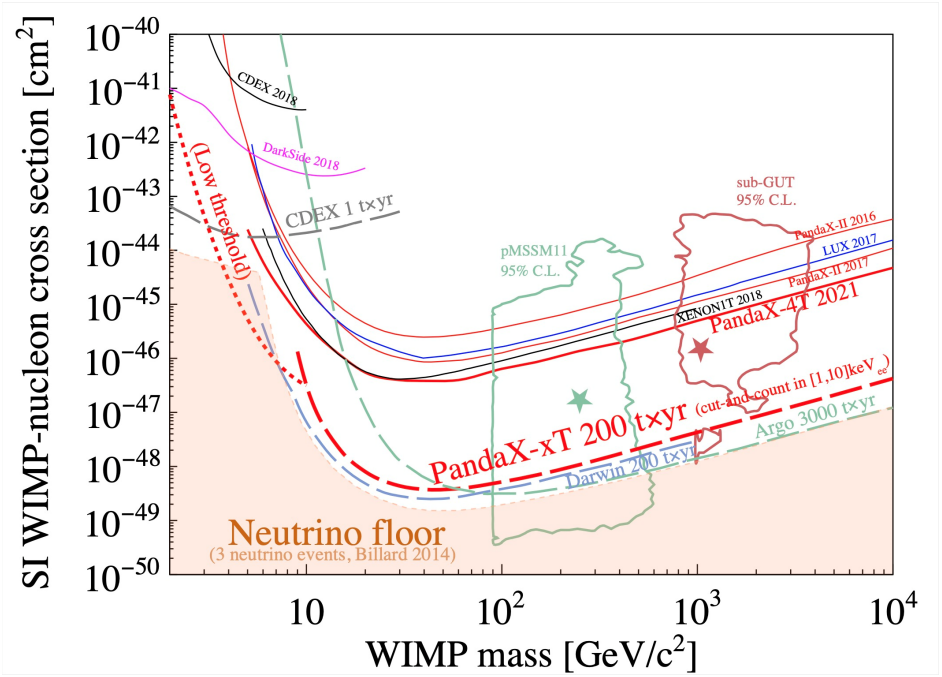
- Enhanced X-ray Timing and Polarimetry satellite for
  - Neutron stars, black holes, etc. to study extreme gravity, magnetism, density, etc.
- With cutting-edge technologies:
  - Large eff. Area (~3.5 m^2@6 keV)
  - High spectral resolution (<180 eV@6 keV)
  - Polarimetry
- Large international collaboration

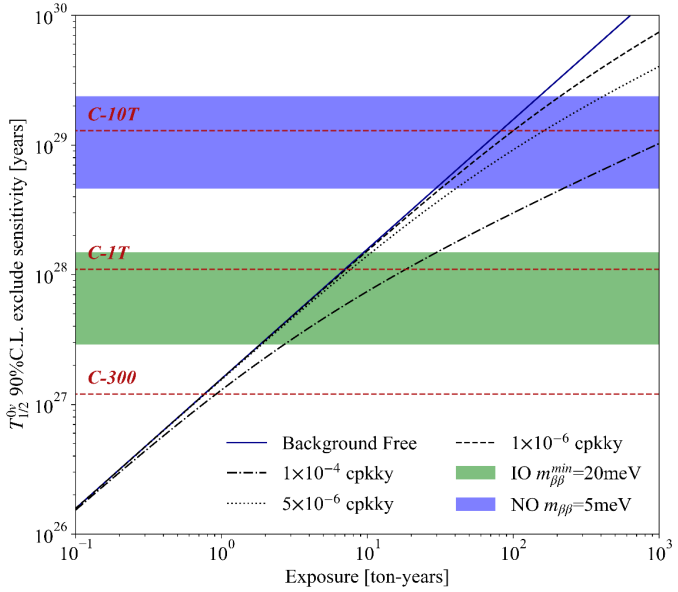


Dark Matter： JinPin Underground Lab

- The deepest underground laboratory in the world with an overburden of 2400 m
- Current experiments: dark matter searches and $0\nu\beta\beta$ searches
  - Xe-based PandaX-4t (4t LXe)
  - Ge-based CDEX-300 (300 kg)
- Future：
  - PandaX-xT (~50t LXe)
  - CDEX-1T (1t ^{76}Ge)



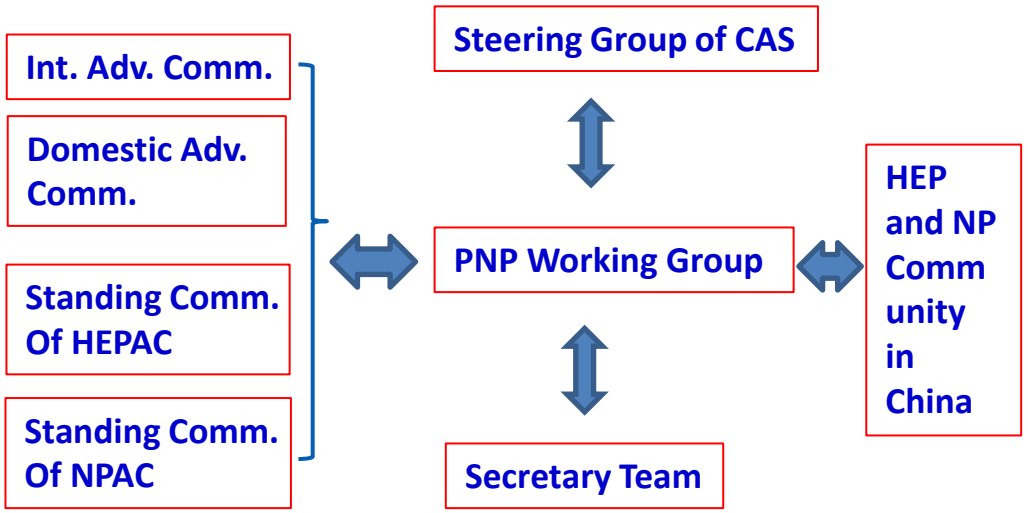




Strategy Study of Future Large Science Facilities

- To better seize opportunities in Science and follow the 5-yrs funding cycle, CAS organized a study of the future large science facilities
- This study is organized with 8 groups, such as particle and nuclear physics, astronomy and space, multidiscipline, etc.
- The charge is to foresee the direction of the field, and propose possible short (~ 2025-2030), mid (2030-2035) and long term(>2035) projects

NO.	Project title
1	“Beijing Isotope-Separation-On-Line Neutron-Rich Beam Facility”
2	"The Circular Electron Positron Collider"
3	"China advanced NUclear physics research Facility, CNUF-An upgrade project for the HIAF and CiADS"
4	"High energy neutrino telescope"
5	"Search for neutrinoless double-beta decays at JUNO"
6	“PandaX-xT: Deep UndergroundMulti-ten-tonne Liquid Xenon Observatory”
7	"A SuperTau-Charm Facility (STCF)"
8	“Laser Compton Scattering Gamma Source Based on Hard X-ray Free Electron Laser Device (LCGS@SHINE)”
9	“CDEX-0vββprogram”



Conclusion will be given by Feb. 2023

Proposed Criteria

An evaluation form is created by the PNP-WG in order to measure the status of the proposed project.

粒子物理和核物理大科学装置设施建设项目建议书评分表

Evaluation form for proposals for the large science facility constructions in particle and nuclear physics in China

Project title:

Section	Subsection	Criteria	Notes	Point
1.科学目标、科学意义和战略价值（**16** 分） 1. Scientific goals, scientific significance and strategic value (16 points)	1.科学目标(**4** 分) 1. Scientific goals (4 points)	科学目标清晰、前瞻、引领： 1.国际引领（4 分）；2. 国际先进（3 分）；3. 国际平均（2 分）；4.低于国际平均（1 分）；5. 差（0） The scientific goals of the project in terms of clarity, prospects, and progressiveness are ranked as: 1. Internationally leading (4 points); 2. Internationally advanced (3 points); 3. International average (2 points); 4. Below international average (1 point); 5. Not qualified (0 point)	The scientific goals of the project in terms of clarity, prospects, and progressiveness should be compared with the counterpart project in e.g. Snowmass 2022, or European particle physics development strategies.	
	2.科学意义(**4** 分) 2. Scientific significance (4 points)	科学目标在粒子物理或核物理领域内的重要性： 1.最重要（4 分）；2. 非常重要（3 分）；3. 重要（2 分）；4. 一般（1 分）；5. 不重要（0） The impact of the scientific objectives in the field of particle and/or nuclear physics can be ranked as: 1. Extremely high (4 points); 2. Very high (3 points); 3. High (2 points); 4. Average (1 point); 5. No impact (0 point)	This criterion is based on such a consideration that given the success of the project, whether its outcomes would bring significant impact on the development of the relevant fields.	

- **Evaluation by Chinese groups completed. Evaluation by IAC will complete in Dec.**
- **Data Analysis will follow and results will be released in Feb.**

Summary: Current and Future

		Current	Future
Accelerator-based	Precision frontier	BESIII	ILC, FCC CEPC
		LHCb, Belle II, PANDA, COMET, GlueX,…	
	Energy frontier	CMS、ATLAS	
Non-accelerator-based	Underground	Daya Bay, JUNO	JUNO-ββ
		EXO, Darkside	nEXO, ARGO
		PANDAx, CDEX	Panda-xT, CDEX-1T
	Surface	ARGO/Asγ, LHASSO	LACT
	Space	AMS, SVOM	HERD eXTP
		HXMT,Polar,DAMPE	

Applications

- High Energy Photon Sources(HEPS) in north of Beijing is under construction, operational in 2025
  - 6 GeV, 0.036nm·rad emittance, 1260m Circumference,
  - Brilliance: >10^{22}phs/s/mm^2/mrad^2/0.1BW
- China Spallation Neutron Source(CSNS) operational since 2018 at 100 kW beam power, to be upgraded to 500 kW with more beamlines
- A possible light source(SAPS) next to CSNS
- Shanghai hard X-ray free electron laser(SHINE) with 8GeV e- beam under-construction
- Possible new ideas:
  - Table top photon sources based on wake-field acceleration
  - Laser+beam facilities