中国科学院高能物理研究所
Institute of High Energy Physics
Chinese Academy of Sciences

Large Science Facilities in Asia

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July 11-13, 2022, ICTP, Italy

Introduction

Particle physics seeks answers to following key questions:

- **What are the fundamental building blocks of our universe?**
- **How do they interact with each other to form the universe?**

The Standard Model (SM) is the fundamental theory of particle physics. Very successful.

The SM leaves many un-answered questions: neutrino mass? neutrino oscillation?

dark matter? CP violation? …

Particle physics facilities covered:

- **Neutrino experiment facilities:** (Hyper)-Kamiokande in Japan, RENO in Korea, Daya Bay and JUNO in China
- **Underground Lab:** CLPL (CDEX and PandaX) in China
- **Collider facilities:** KEKB & Super-KEKB in Japan, BEPC & BEPCII in China

I apologize for only covering these facilities.

Kamiokande and Super-Kamiokande Experiments

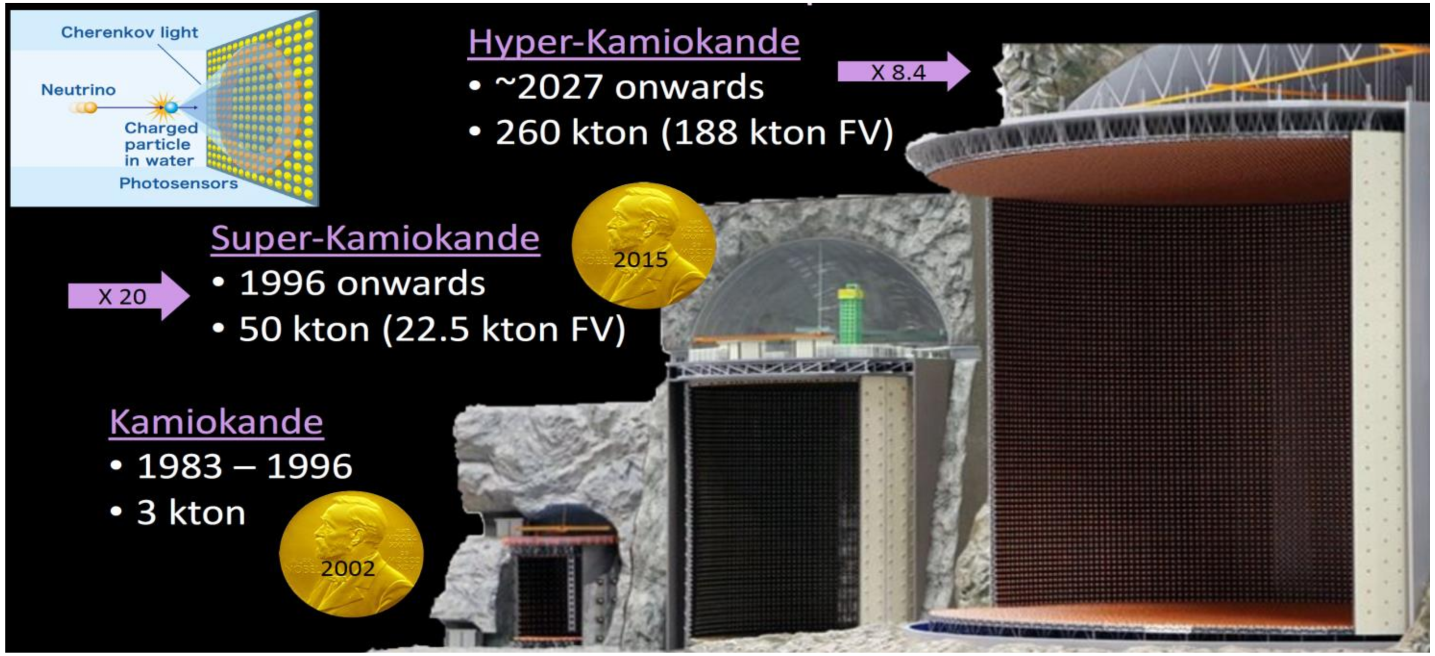
- Neutrino was predicted by W. Pauli and discovered in 1956 by F. Reines and C. Cowan
- Davis detected solar neutrino in 1967

- Kamiokande (1983-1996, 3kton) and Super-Kamiokande (50kton, 1996 -) are underground neutrino detectors in a mine in Japan. Masatoshi Koshiba is the founder of the experiments.
- Masatoshi Koshiba confirmed Davis's results with Kamiokande detector that the Sun produces neutrinos and that fewer neutrinos were found than had been expected (a deficit that was known as the solar neutrino problem) → 2002 Nobel Prize
- Takaaki Kajita discovered neutrino oscillation with Super-Kamiokande → 2015 Nobel Prize
  Later confirmed by K2K, T2K, ….. KamLAND exp. confirmed: really neutrino oscillations!

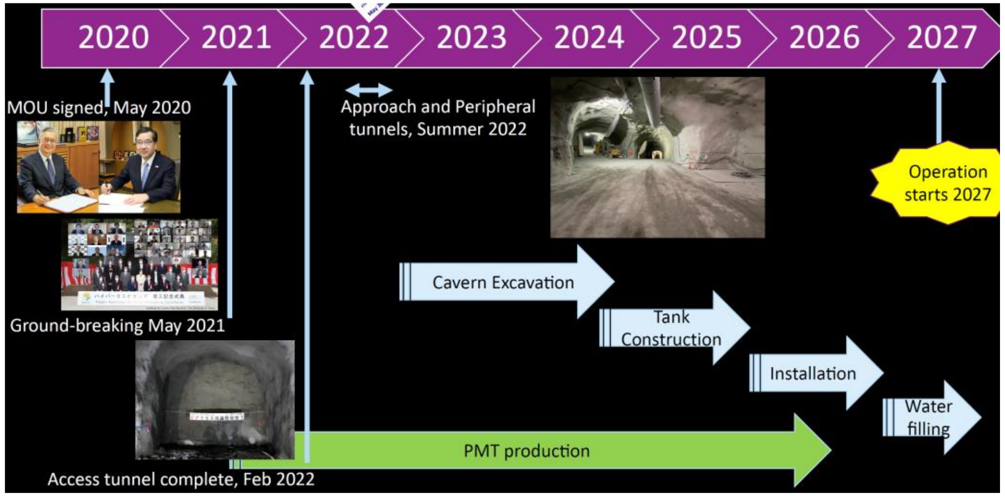
(Hyper)- Kamiokande Experiment – Next Generation of Neutrino Exp.

Hyper- Kamiokande Collaboration: ~500 researchers from 20 countries

From Jeanne Wilson, at NEUTRINO 2022



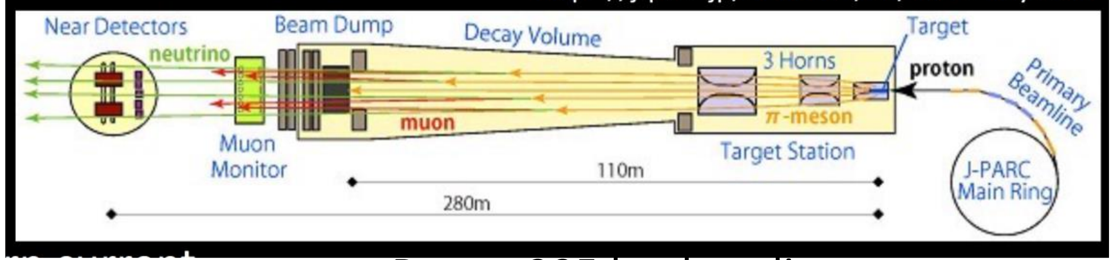
Project status



- δ_{CP}, mass ordering, $\sin^2\theta_{23}$, Δm^2_{32}
- Supernova Bursts
- Proton Decay

Masatoshi Koshiba： Kamiokande, detection of cosmic neutrinos
Takaaki Kajita: Super-Kamiokande, discovery of neutrino ossilation

https://j-parc.jp/Neutrino/en/nu-facility.html



Beam: 295 km baseline

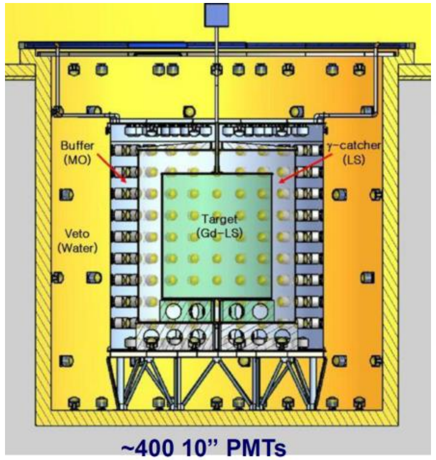
Probe CP-violation through comparison of $P(\nu_\mu \rightarrow \nu_e)$ and $P(\bar{\nu}_\mu \rightarrow \bar{\nu}_e)$

Reactor Neutrino Experiment -- RENO

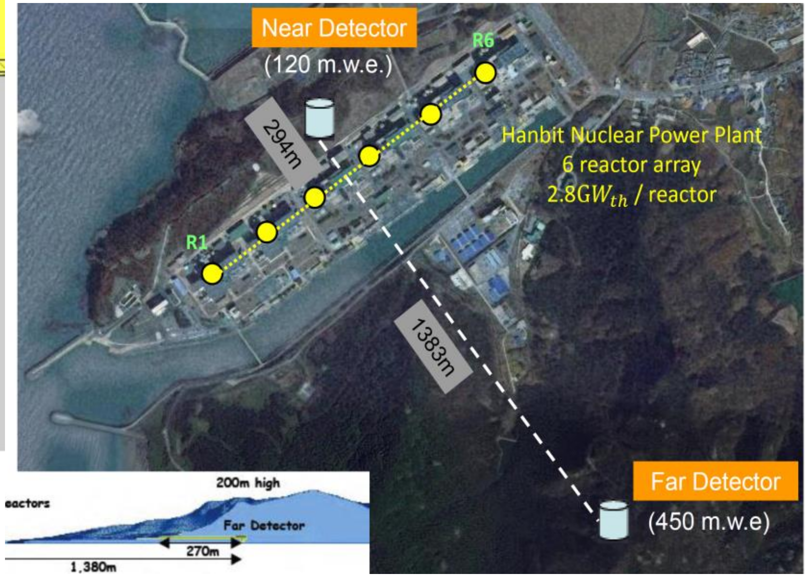
From Kyung Kwang Joo, NEUTRINO 2022

- ~ 30 researchers in 7 institutes from Korea
- Project started in 2006
- Data taking with near and far detectors since 2011

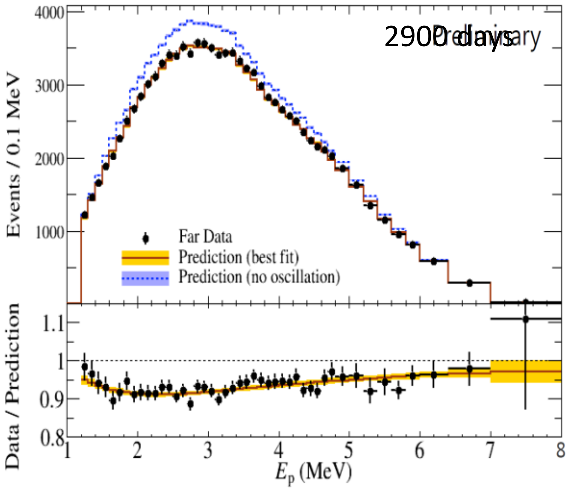
RENO experiment set-up



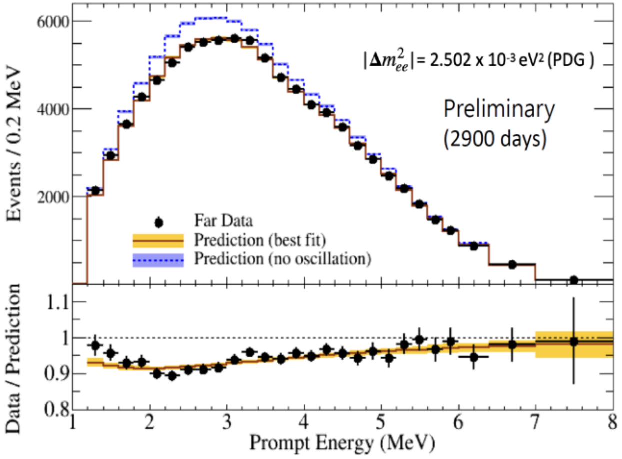
Target (Gd-loaded LS) - 16.5 tons
γ-catcher (LS) - 29 tons
Buffer (Mineral oil) - 64 tons
Veto (Water) - 353 tons



$sin^2 2\theta_{13}$ using n-Gd



$sin^2 2\theta_{13}$ using n-H



$sin^2 2\theta_{13}$=0.0892 ± 0.0044(stat.) ± 0.0045(sys.)
(n-Gd) (± 7.0%)

$sin^2 2\theta_{13}$=0.086 ± 0.006(stat.) ± 0.010(sys.)
(n-H)

(Delayed signal)

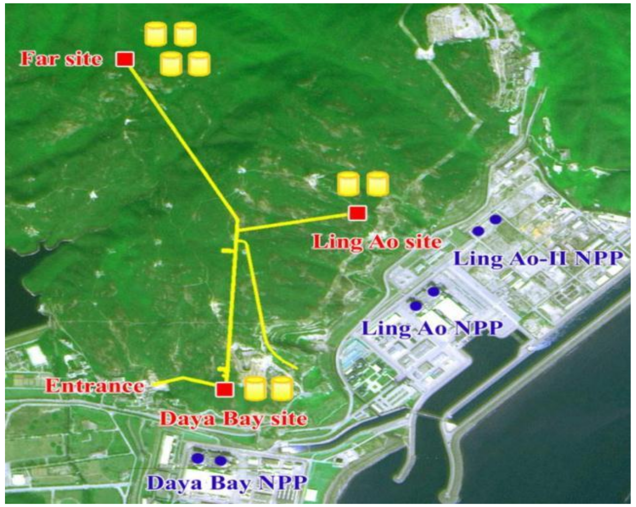
$\bar{\nu}_e$+p → e^+ + n
+ p → D + γ (2.2 MeV)
+ Gd → Gd + γ's (8 MeV)

Inverse Beta Decay

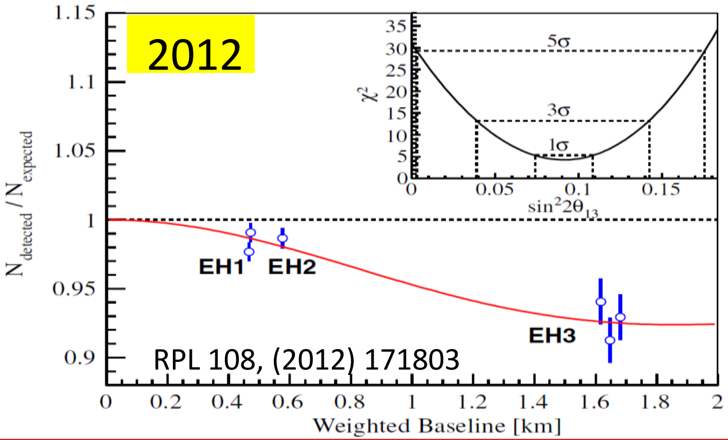
Prospects of $sin^2 2\theta_{13}$: X 2 more data, error → 6.4%

Daya Bay Reactor Neutrino Experiment (Completed)

- ~270 members
- 6 countries and regions
- 40 institutions



Running: 24 Dec 2011 – 12 Dec 2022



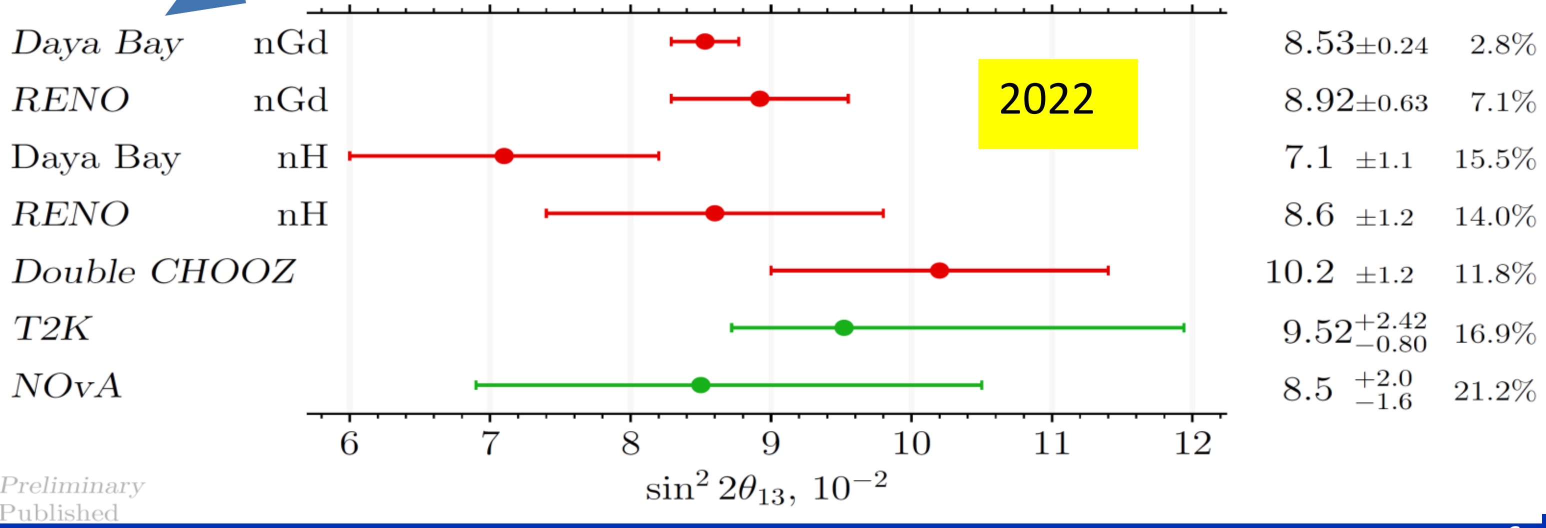
$$\mathrm{Sin}^2 2\theta_{13} = 0.092 \pm 0.016(\mathrm{stat}) \pm 0.005(\mathrm{syst})$$

Daya Bay: PRL 108, 171803 (2012)

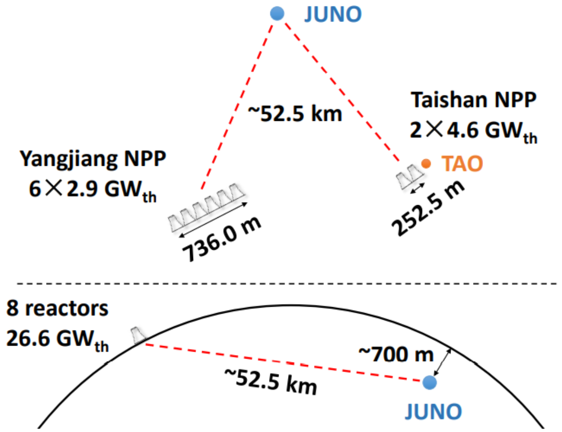
Daya Bay Mission Completion Ceremony (2020.12)

- **Precision oscillation measurement**
  - $\sin^2 2\theta_{13}$ precision : 2.8%
  - Δm^2_{32} precision : 2.3% (under either mass ordering scenario)
- Precise reactor $\overline{\nu}_e$ flux & spectrum meas.
  - "Reactor Anomaly" is likely due to model prediction problems
  - First evidence of reactor $\overline{\nu}_e$ with E>10 MeV
  - Provide model independent $\overline{\nu}_e$ spectrum for other experiments

Will likely be the best measurement in the foreseeable future



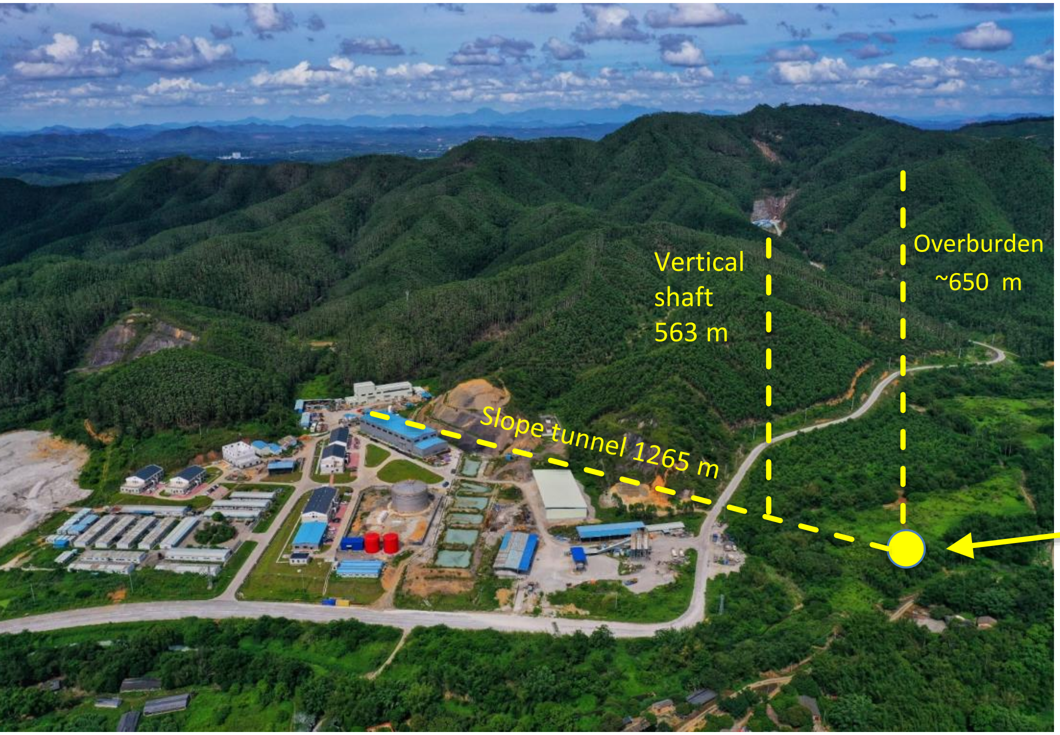
Jiangmen Underground Neutrino Observatory (JUNO)

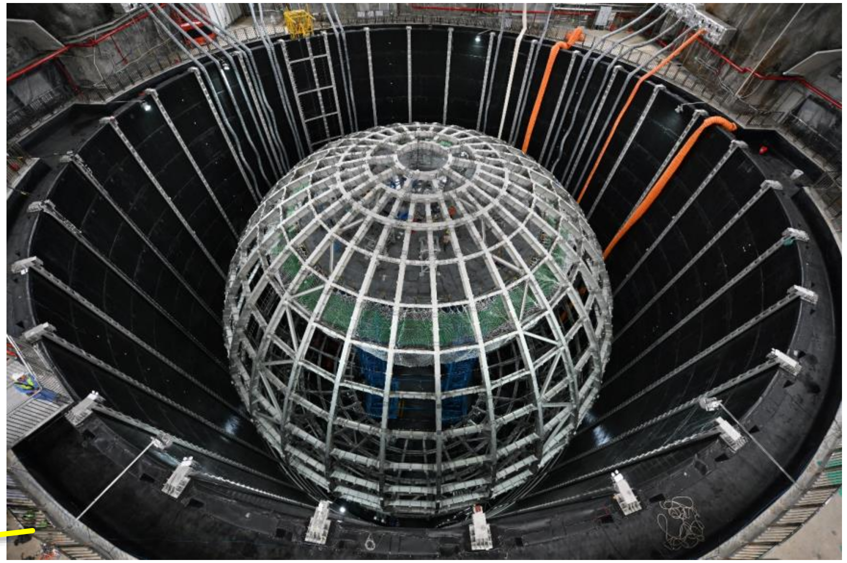


A multiple-purpose neutrino experiment. Rich physics:

- Neutrino mass ordering & precision measurement of oscillation parameters
- Neutrinos from Supernovae, atmosphere, Earth, Sun
- Proton decay, dark matter, other rare searches

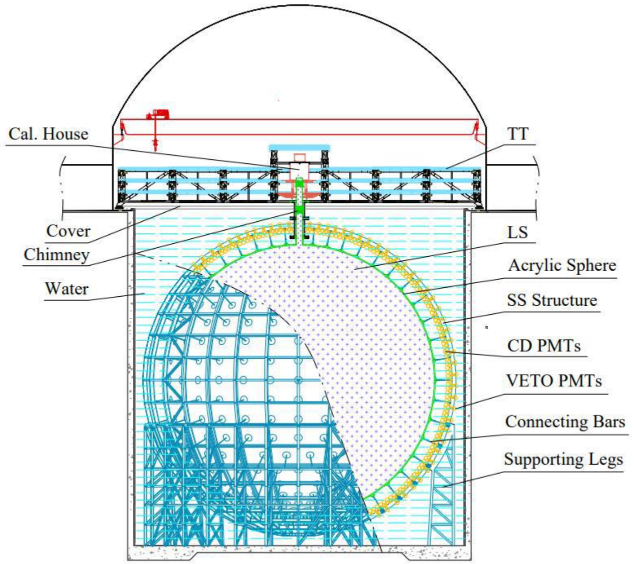
JUNO Physics Book, J. Phys. G43:030401 (2016)
JUNO-TAO CDR: arXiv:2005.08745
JUNO Physics and Detector, arXiv:2104.02565





Civil construction finished in Dec, 2021

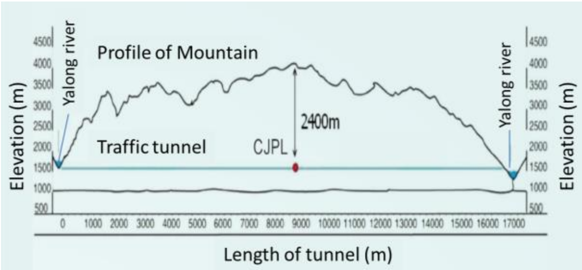
Detector assembly and installation is on-going and will be completed in 2023.

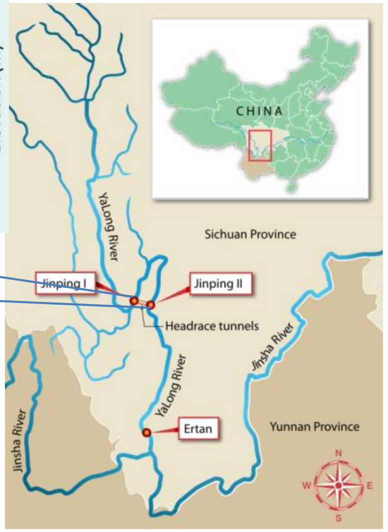


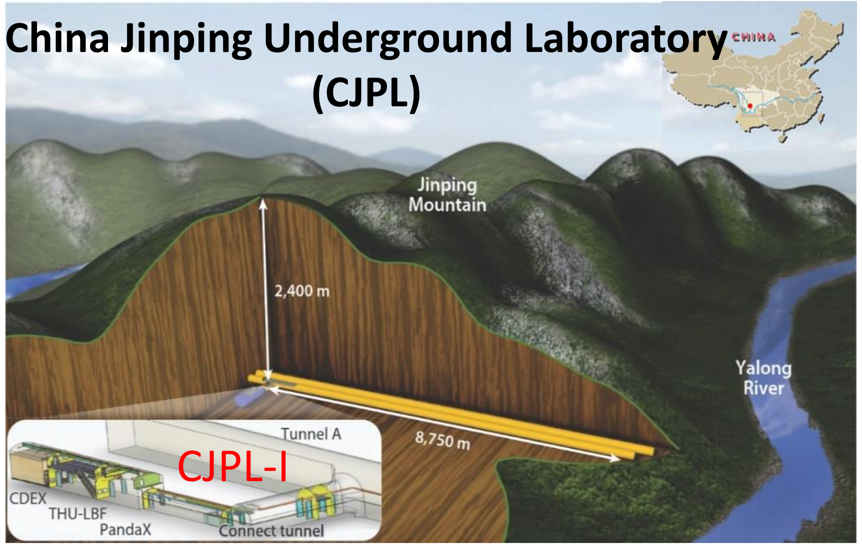
- 20 kton liquid scintillator
- 3% energy resolution
- ~18,000 20” PMTs + 25,600 3” PMTs

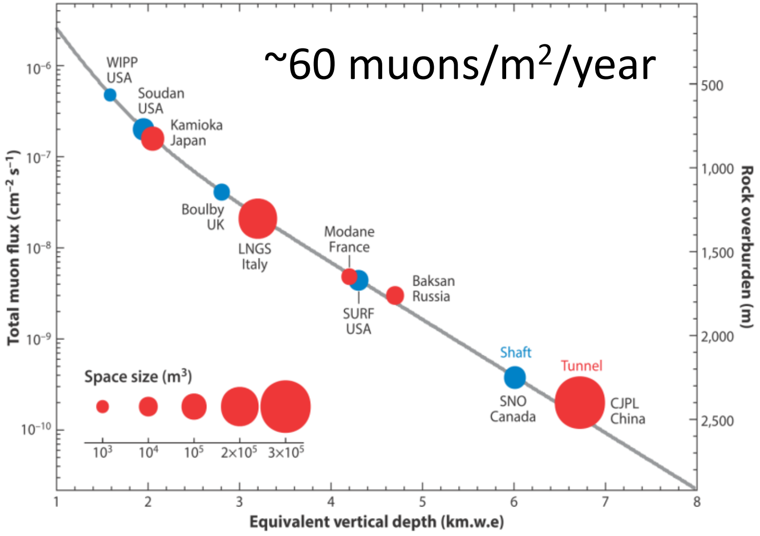
China Jinping Underground Laboratory

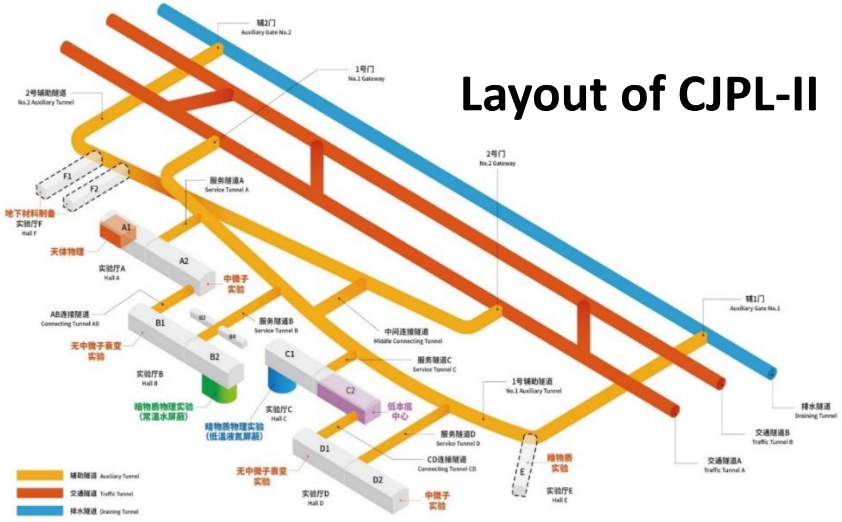
- **World's deepest underground lab, CJPL**
  - ✓ Near Xichang city, Sichuan Province, Southwest China
  - ✓ Rock overburden: 2400m (~6720 m. w. e.)
  - ✓ Main Hall: 6.5m(W) x 6.5m(H) x 42m(L), Total space: ~4000 m^3
  - ✓ Two DM exp. (CDEX, PandaX)+LBF(radio-assay) operated in CJPL-I
  - ✓ **Extension project, CJPL-II (300,000 m^3), final exam and will be completed in 2025**









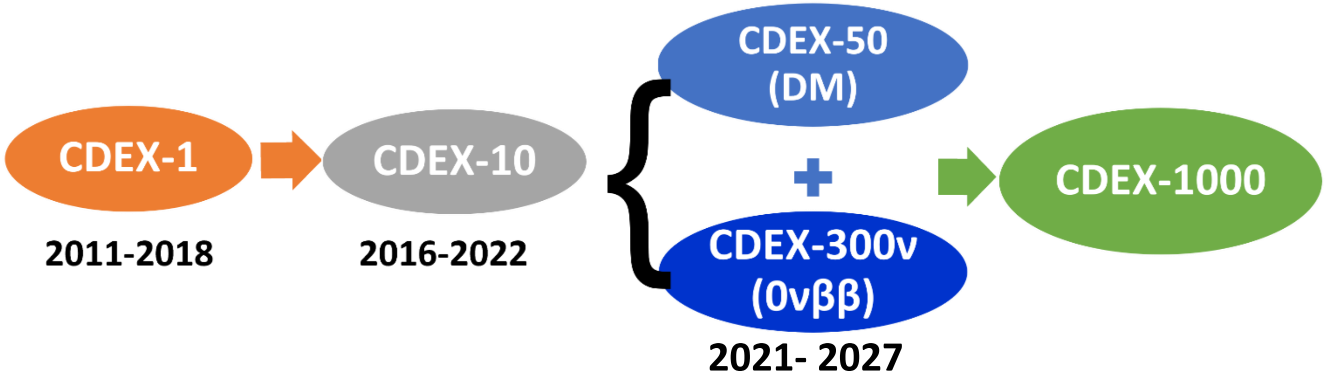


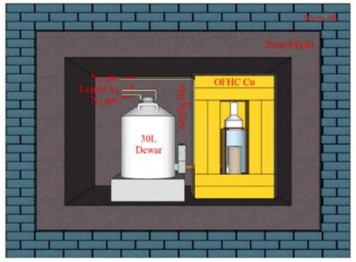
Cheng et al., Annu. Rev. Nucl. Part. Sci. 67:231 (2017) Chinese Physics C 37:086001 (2013) http://cjpl.tsinghua.edu.cn

China Dark matter Experiment --CDEX

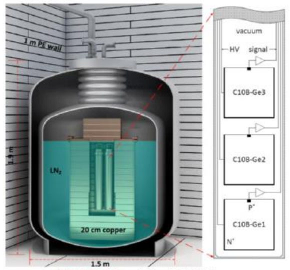
- Formed in 2009, 11 institutions and ~80 people now; http://cdex.ep.tsinghua.edu.cn/
- **Key technology:** P-type Point-Contact (PPC) Ge detectors;
- **Two important physics targets:** Direct detection of light DM + 0νββ Exp.

- **CDEX-50:** 50kg Ge arrays for DM searches
- **CDEX-300ν:** 300kg enriched Ge arrays for 0νββ



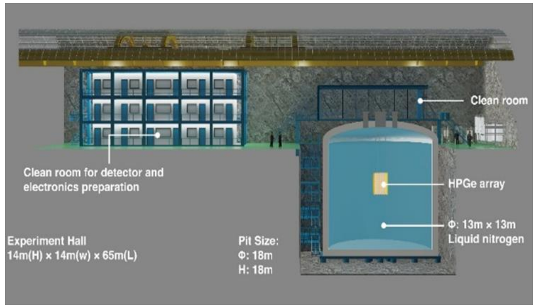


CDEX-1A&B: 1kg PPC Ge×2



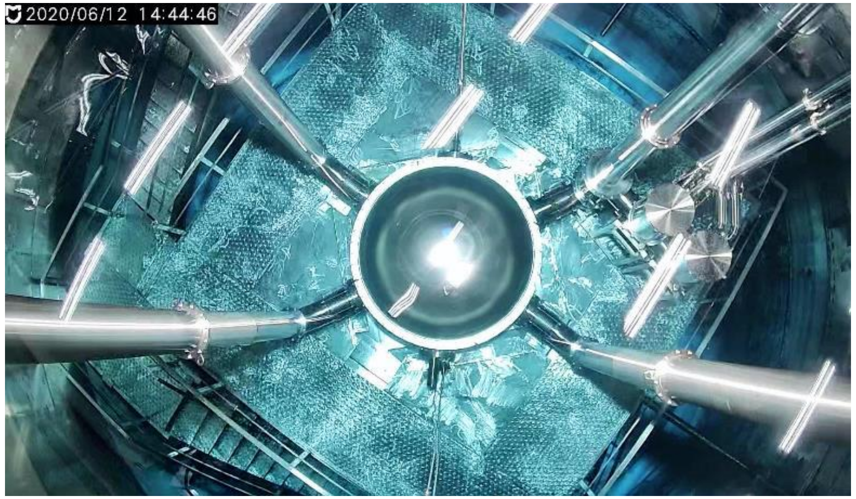
CDEX-10: ~10kg PPC Ge array

CJPL-I



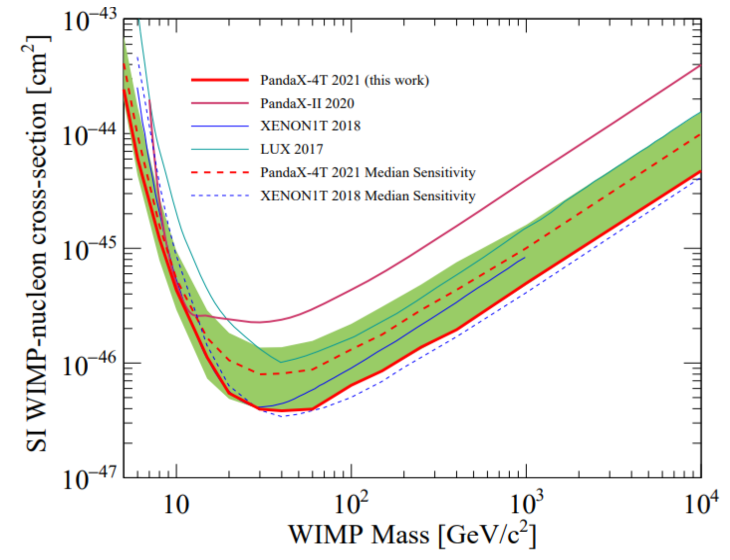
CJPL-II

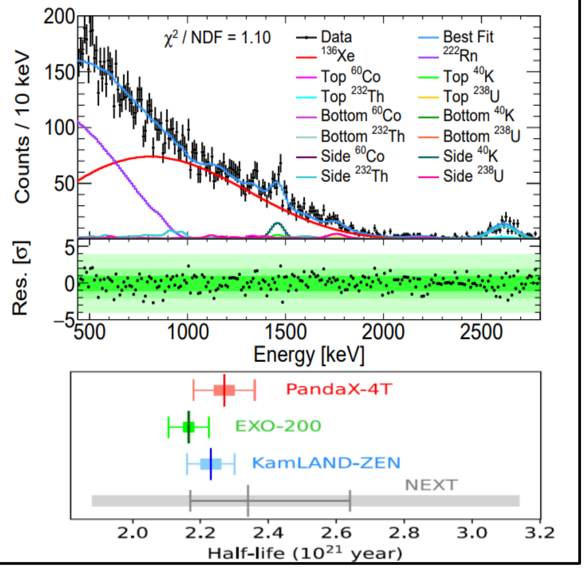
New Generation of PandaX-4T is under operation at CJPL



- 4-ton TPC, with brand new infrastructure
- On-site installation in 2019, commissioning late 2020, first physics run late 2021
- **Multi-purpose experiment**, expected to run till 2025
- Next generation upgrade under planning

New results from PandaX-4T

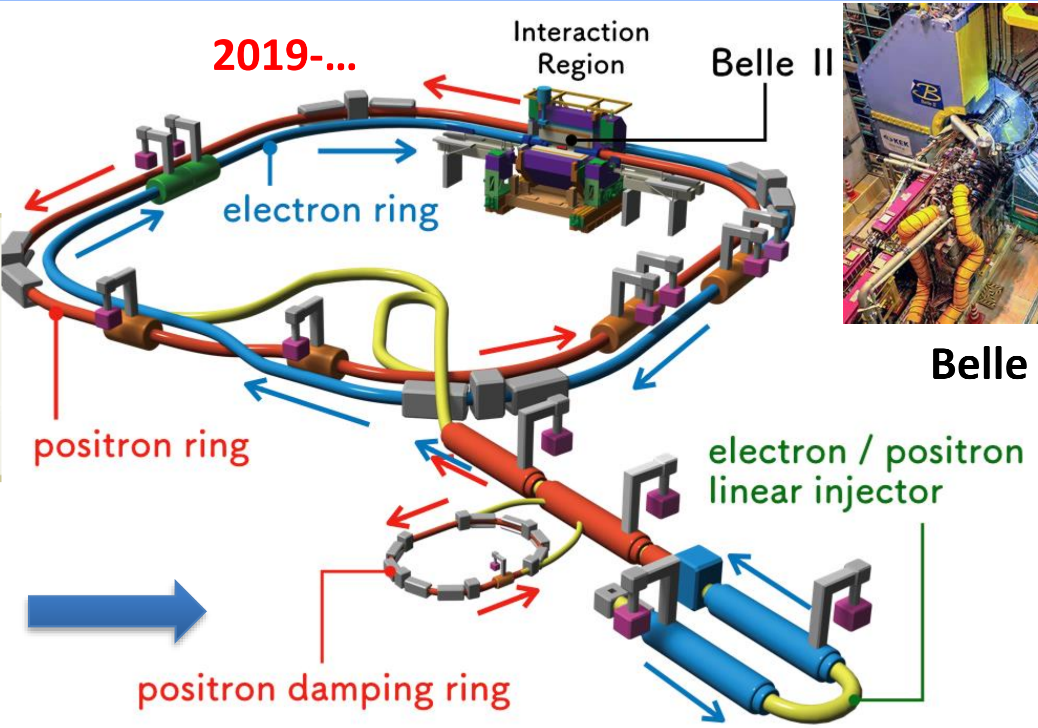




Results using first 95-day commissioning run

- Strongest WIMP-nucleon SI interaction limit (PRL 127, 261802, 2021, Editor's Suggestion)
- First ^{136}Xe double-β-decay measurement **with natural liquid xenon TPC** (arXiv:2205.12809)

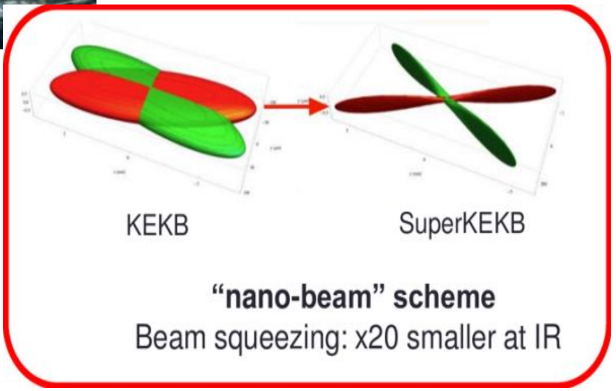
Belle @ KEKB and BelleII @ SuperKEKB



Belle II detector

Belle Experiment:

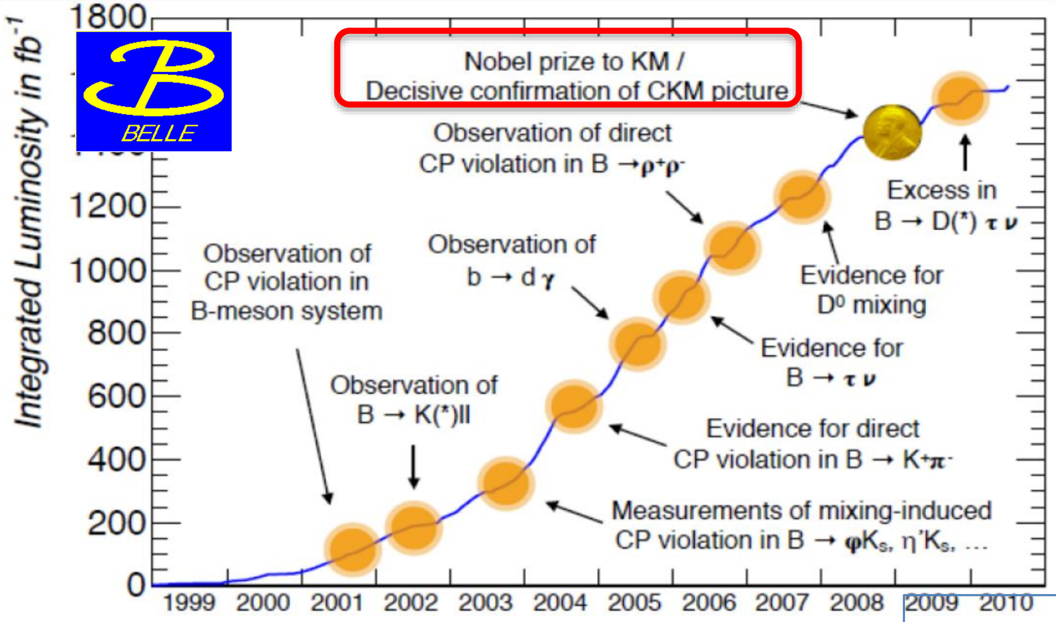
- 22 countries/regions, 100 institutions, 456 physicists
- $3\ \mathrm{GeV}(e^+) \times 8\ \mathrm{GeV}(e^-)$
- $1999 - 2010$, $\sim 1\ ab^{-1}$ data
- Lum. Record: $2.1 \times 10^{34} cm^{-2} s^{-1}$

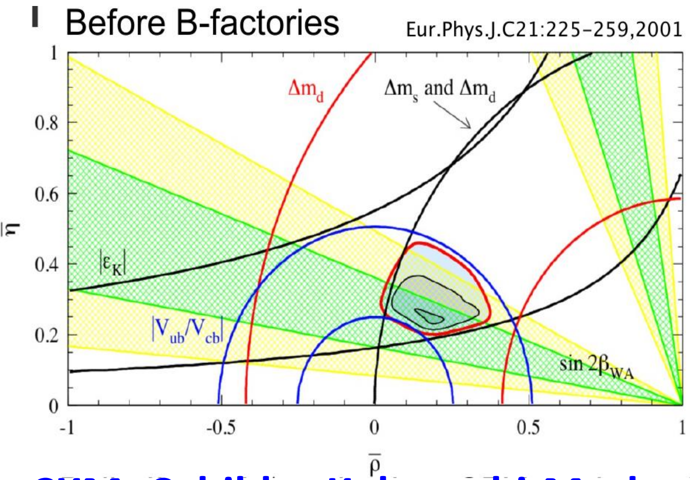


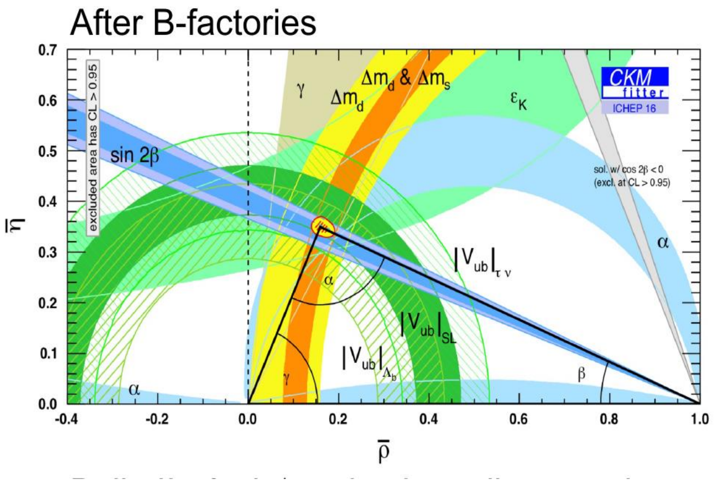
Belle II Experiment:

- 26 countries/regions, 124 institutions, 1151 physicists
- $3\ \mathrm{GeV}(e^+) \times 8\ \mathrm{GeV}(e^-)$
- $2019 -$, $\sim 50\ ab^{-1}$ data
- Designed Lum. 40 × KEKB

Belle achievements and Belle II proepects

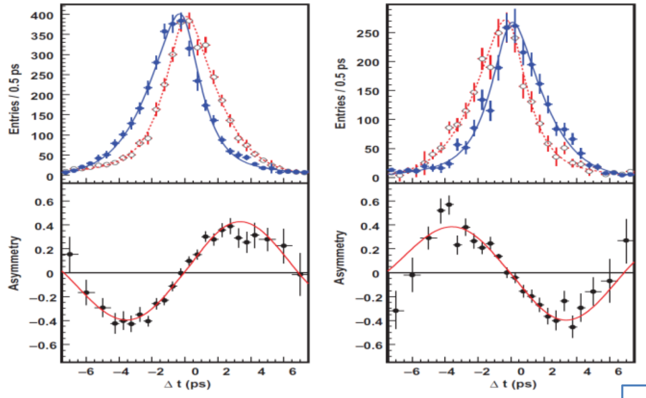






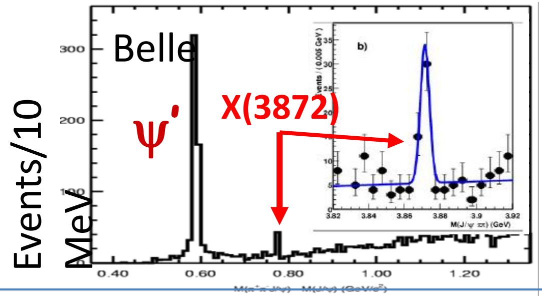
CKM: Cabibbo-Kobayashi-Maskawa

2008 Nobel Prize to KM
Decisive confirmation of CKM picture



CPV in $c\bar{c}K_S$ and $J/\psi K_L$

CP violation observed in B decays



Observation of X(3872) inspired the observation of lots of exotic hadrons in many exps.
Opened a new era of exotic spectroscopy.

Targets of Belle II experiment:

- **Test SM processes with high precision.**
- **Search for New Physics beyond SM.**
- **Search for new sources of CPV.**

Expected precisions of CKM param parameters:

- α: 0.6°
- $|V_{cb}|$: 1 – 1.5%
- β: 0.4°
- $|V_{ub}|$: 2 – 3%
- γ: 1.5°

BES(I, II, III) @ Beijing Electron Positron Collider (BEPC)

- BEPC operation: 1989-2004, L_{peak}=1.0x10^{31} /cm^2s

  BESI: 1989 – 1997, BESII: 1998 - 2004
- BEPCII (double ring): 2009 -- , L_{peak}= 1.0 x10^{33}/cm^2s

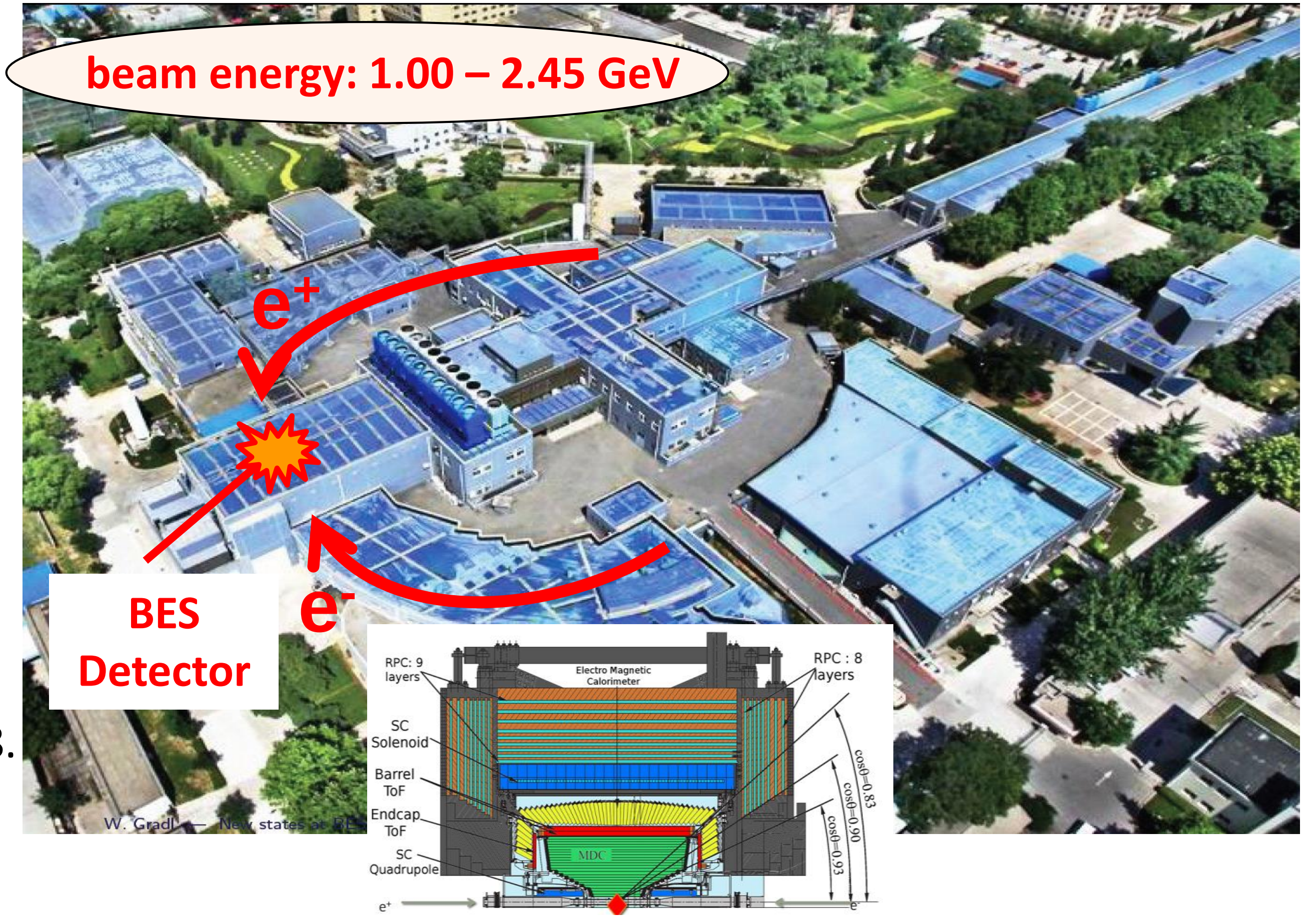
  BESIII: 2009 to now

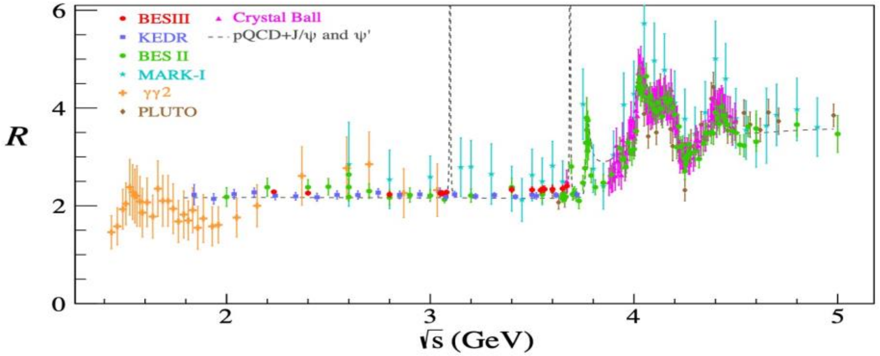
BESI Experiment:

- 10 institutions from US and 3 from China, ~120 physicists
- Achieved most precise Mτ when published, validated the universality of leptonic μ-τ coupling.

BESII Experiment

- 16 institutions from US, Korea, UK, China, ~170 physicists
- Reduced the uncertainties of R from ~20% to ~6%., in 1998.
- Crucial to the estimation of Higgs mass from SM fit.





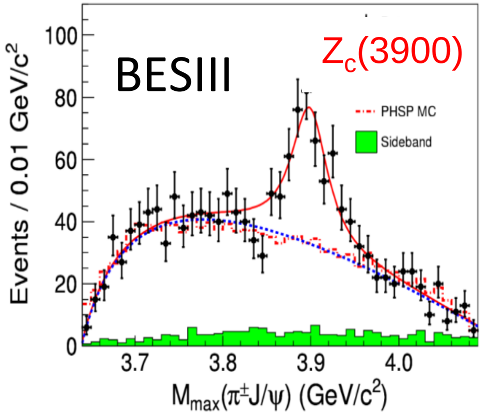
Science questions:

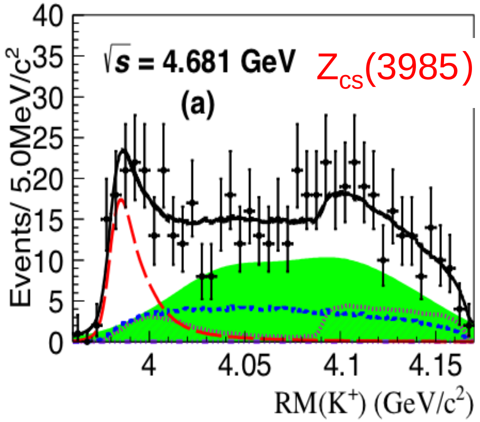
- Are there exotic hadrons beyond Quark Model?
- How do quarks form the hadrons ? → Strong interaction
- Are there new physics beyond SM? → QCD and EW

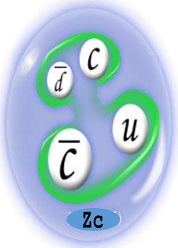
BESIII Experiment:

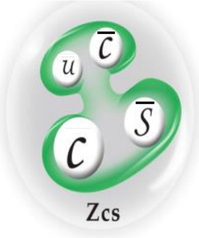
83 institutions from 17 countries, ~500 physicists

Observed $Z_c(3900)$ and $Z_{cs}(3985)$





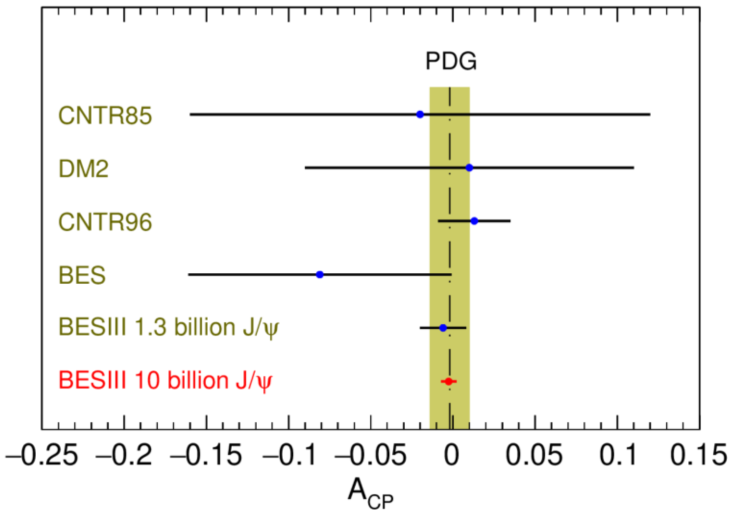




The CP violation was observed in meson sector

- **in kaon sector in 1964 (PRL 13, 138 (1964))**
- **in beauty sector by BaBar and Belle in 2001 (BaBar: PRL 87, 091801 (2001), Belle: PRL 87, 091802)**
- **in direct charm decays by LHCb in 2019 (LHCb: PRL 122, 211803 (2019))**

Achieved most precise CP violation parameters in baryons



- **Large facilities all over the world provide ideal laboratories for physicists to understand the most basic questions**.

- **International collaboration is crucial.**

Thanks for your attention.