The Future of High Energy Physics and China's Role

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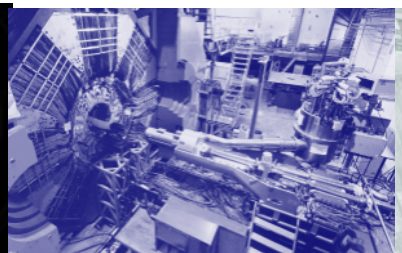
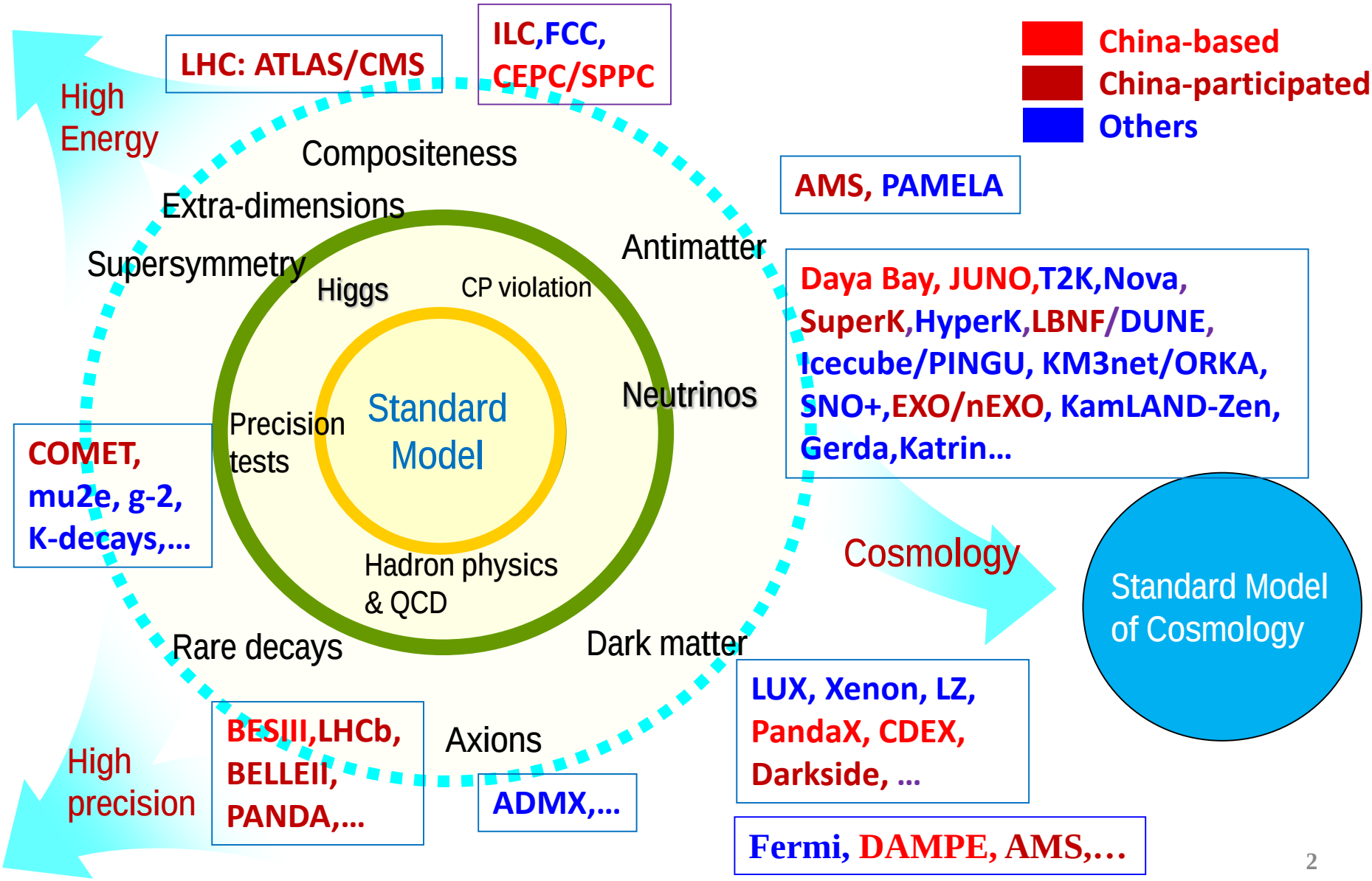
HKUST, Sep. 24, 2018


A Very Active Field



Roadmaps of HEP in the World

- **Japan (2012)**
  - If new particles(e.g. Higgs) are discovered, build **ILC**
  - If θ_{13} is big enough, build **HyperK** and T2HK
- **EU (2013)**
  - Continue **LHC**, upgrade its luminosity, until 2035
  - Study future circular collider **(FCC-hh or FCC-ee)**
- **US (2014)**
  - Build long baseline neutrino facility **LBNF/DUNE**
  - Study future colliders

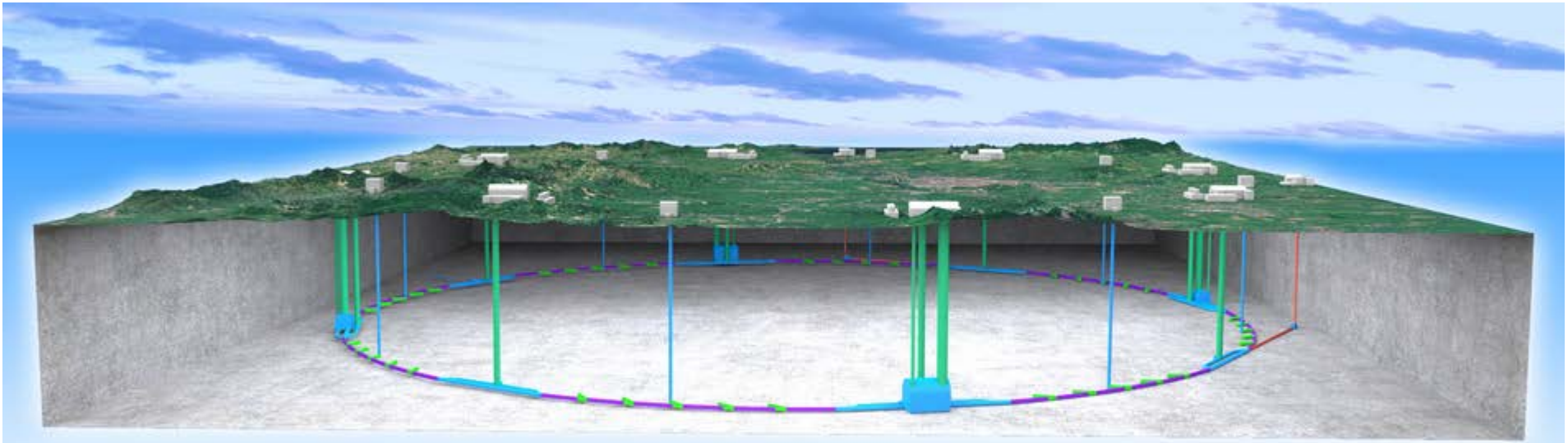
A new round of roadmap study is starting

Where Are We Going ?

- ILC is a machine we planned for ~30 years, way before the Higgs boson was discovered. Is it still the only machine for our future ?
- Shall we wait for results from LHC/HL-LHC to decide our next step ?
- What if ILC could not be approved ?
- What is the future of High Energy Physics ?
- A new route:
  - Thanks to the low mass Higgs, there is a possibility to build a circular e+e- collider(Higgs factory) followed by a proton machine in the same tunnel
  - This idea was reported for the first time at the “Higgs Factory workshop(HF2012)” in Oct. 2012 at Fermilab

CEPC：A Higgs Factory

- Since 80’s, IHEP were working on e+e- colliders: BEPC/BEPCII
- Since 2005, IHEP was discussing the next machine after BEPCII
- The idea of a Circular e+e- Collider(CEPC) followed by a Super proton-proton collider(SPPC) quickly gained the momentum in IHEP and in the world



Science of CEPC-SPPC

- **Electron-positron collider(90, 250 GeV)**
  - **Higgs Factory（10^6 Higgs）:**
    - **Precision study of Higgs(m_H, J^{PC}, couplings)，Similar & complementary to ILC**
    - **Looking for hints of new physics**
  - **Z & W factory（10^{11} Z^0）:**
    - **precision test of SM**
    - **Rare decays ?**
  - **Flavor factory: b, c, τ and QCD studies**
- **Proton-proton collider(~100 TeV)**
  - **Directly search for new physics beyond SM**
  - **Precision test of SM**
    - **e.g., h^3 & h^4 couplings**

Precision measurement + searches:
Complementary with each other !

Higgs：the Window to New Physics

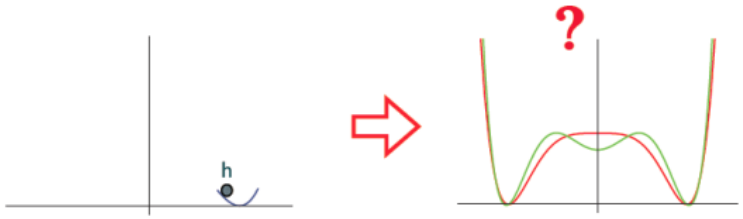
- **A very special particle：**
  - **The only elementary particle with spin 0**
    - **Really elementary ?**
    - **Similar to p, Cooper pair ?**
  - **The only elementary particle with non-gauge interactions**
    - **Self-coupling and Yukawa coupling: anything new ?**
- **Directly related to physics beyond SM & Cosmology**
  - **May interact with dark matter particles**
  - **Origin of the mass of Higgs ?**
  - **Self-coupling may affect the evolution of the universe**
  - **Understand the vacuum: why meta-stable ?**
- **Goal: By detailed and precise measurement of Higgs properties to understand these issues**

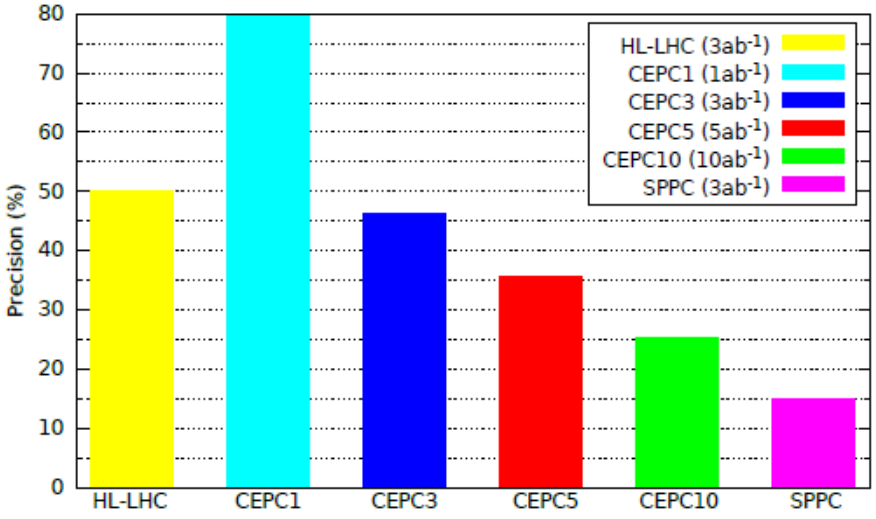
particle	spin
quark: u, d,...	1/2
lepton: e...	1/2
photon	1
W,Z	1
gluon	1
Higgs	0

Detailed study of Higgs can not be skipped

Nature of EW Phase Transition ?

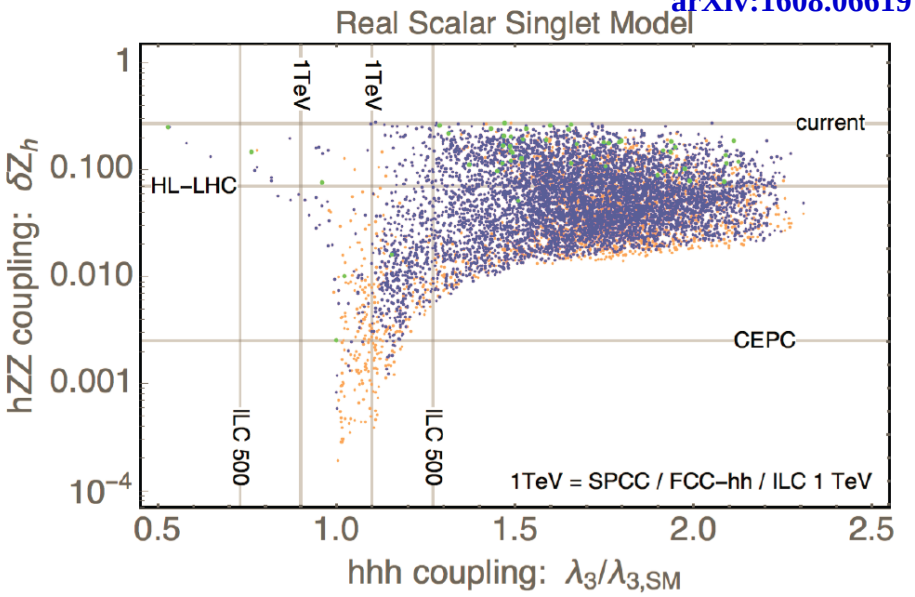
- 1st or 2nd order ➔ Huge implications
  - O(1) deviations in h^3 coupling
  - O(1%) shift in h-Z coupling
- CEPC can determine it:
  - h^3 coupling at CEPC： 20-30%
  - h-Z coupling at CEPC： < 0.2%





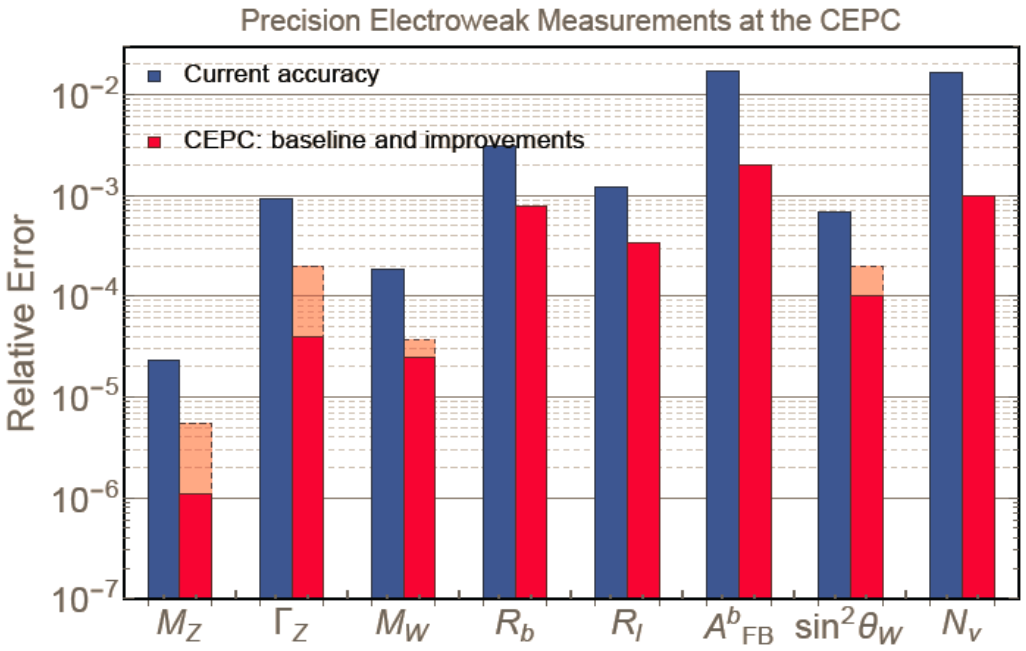
M. McCullough, PRD 90(2014)015001

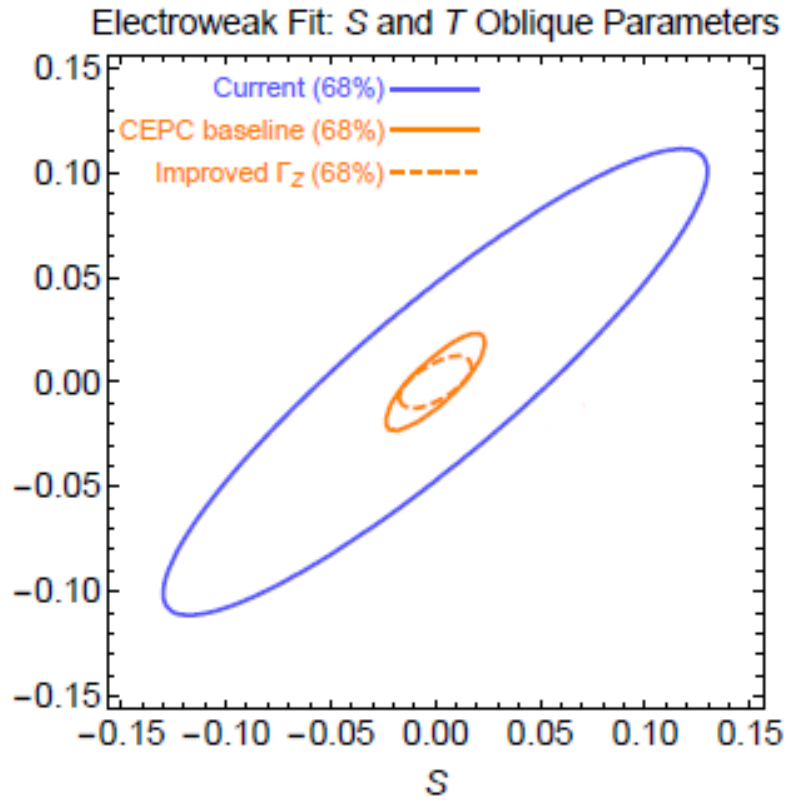
arXiv:1608.06619



Improvement in Electroweak Precision

- A total of 10^{11} Z
- **A detailed study of Z & W to look for deviations from the Standard Model**
- **Can probe new physics up to ~ TeV， better than HL-LHC by a factor of 3**





CEPC preCDR Volume 1 (p.10)

Comparison with Other Machines

	Science	Upgrade	Technology	Cost	Schedule
CEPC	****	****	****	*****	*****
SppC	*****	*	**	***	***
ILC	****	*	***	****	*****
FCC-ee	****	****	****	****	?
FCC-pp	*****	*	**	**	***
CLIC	****	**	***	***	**
VLHC	*****	***	****	**	?
Muon collider	*****	****	*	*	?
New acceleration	*****	?	? ?	?	? ?

CEPC+SPPC is a great combination

CEPC/SPPC and FCC

- It would be great if we can have one of them
- We are happy to collaborate with FCC and even join the FCC if it is approved
- We believe that it is better to start e+e- first and in the meantime to develop the next generation magnet technology
  - Current technology based on $NbSn_3$ is already 60 years old: difficult, expensive and not so high the field
  - Next generation high Tc Superconducting cable should be our goal, in particular Fe-based HTC
- ~ 20 years development time needed for HTC cable is just about right for us to work on the e+e- collider

High Field Magnet based on HTC Cable

- Future FCC_hh/SPPC should based on future technologies
- HTC has a huge impact beyond HEP if we can improve the performance/cost ratio by a factor of ~100
- Hope: Fe-based HTC cable
  - Advantages: metal, easy to process; isotropic; cheap in principle
  - Good start at CAS
    - World highest Tc Fe-based materials
    - World first ~ 115 m Fe-based SC cables: 12000 A/cm^2 @ 10 T
- A collaboration on “HTC SC materials” established
  - IOP, USTC, IOEE, SC cable companies
  - Two approaches:
    - Fe-based HTC cables
    - ReBCO & Bi-2212
  - Funding from CAS(300M RMB/5y)
- A workshop in Hong Kong this Jan. Next one in KEK

Please join CEPC workshops

Workshop on the Circuar Electron Positron Collider-EU edition

May 24-26, 2018, Università degli Studi Roma Tre, Rome, Italy

1/3 international participation

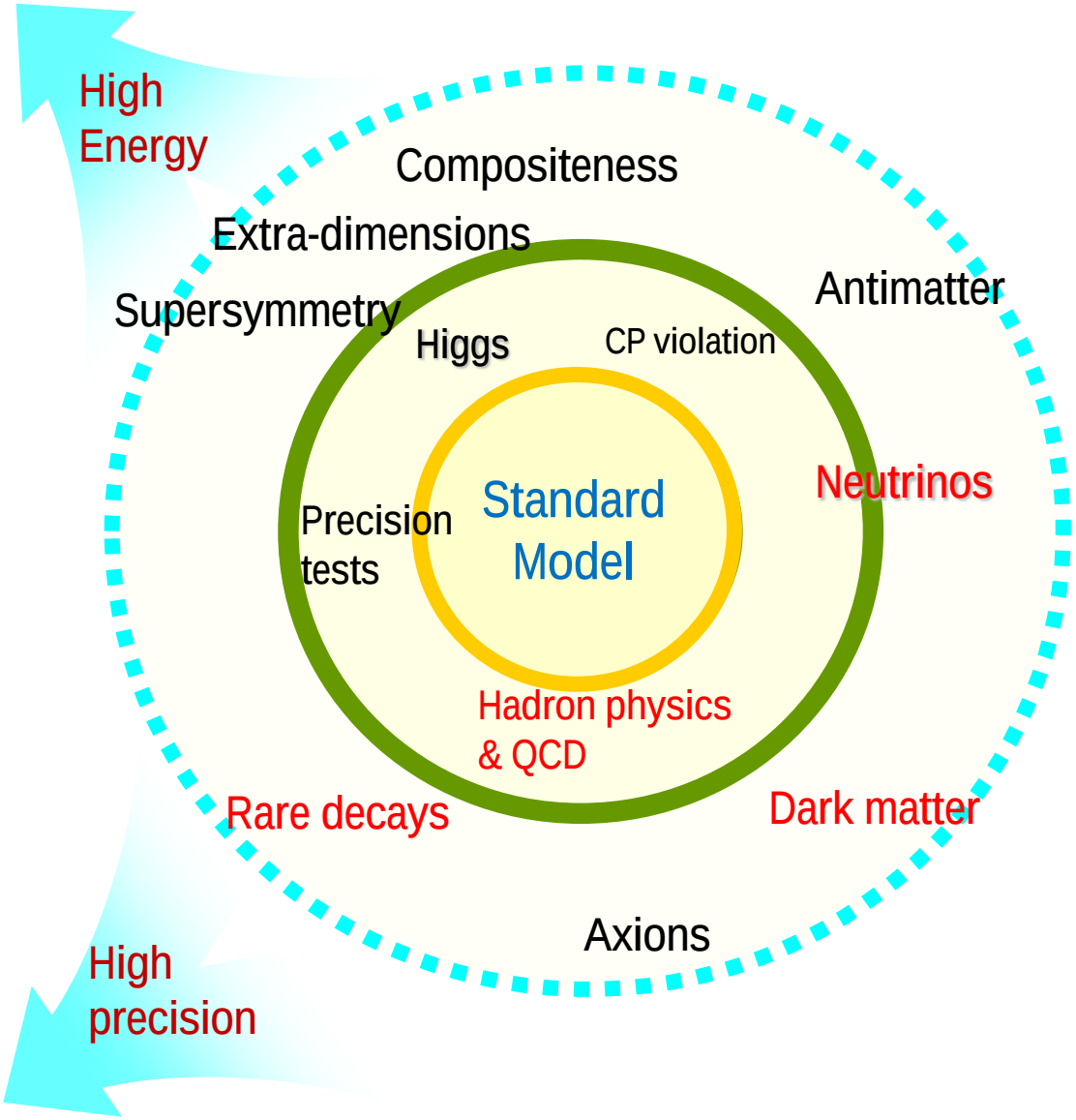
Next EU-Edition:

April 15-17 , 2019, Oxford

Next CEPC week:

Nov. 12-17, 2018, IHEP

Other Activities in China

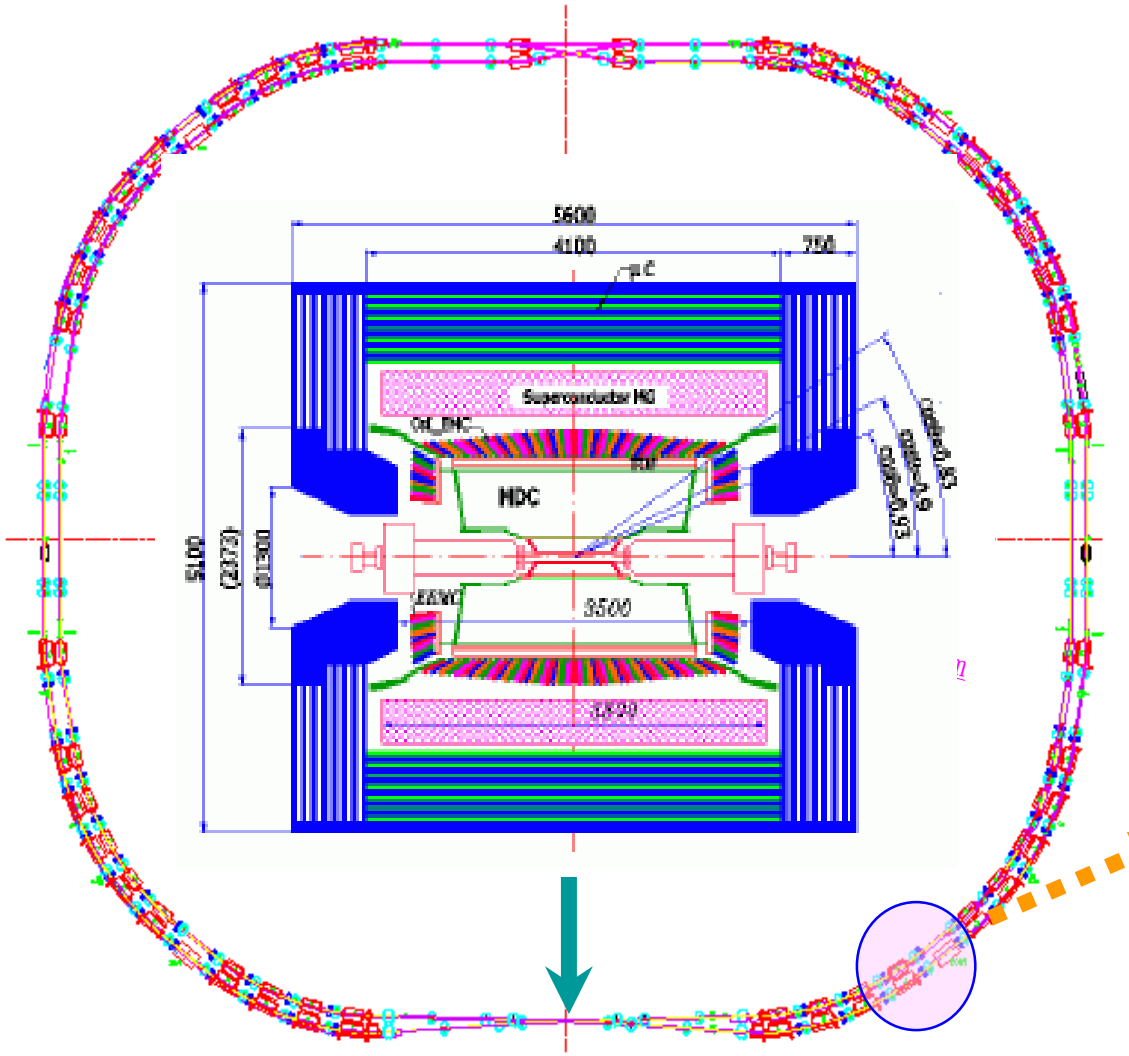


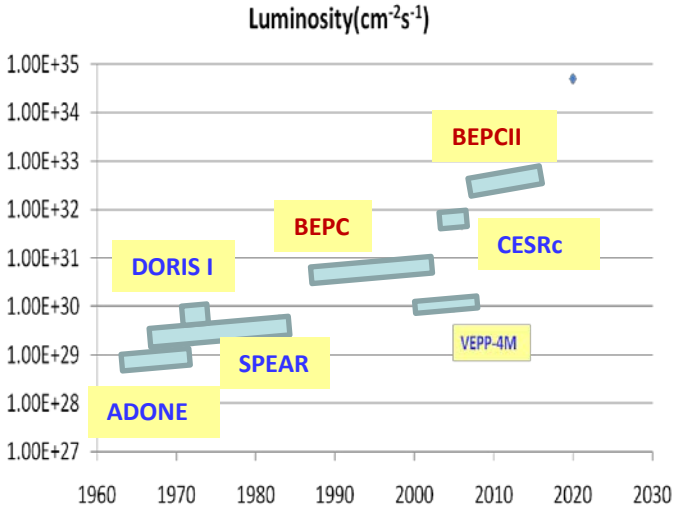
- **Accelerator based experiments**
- **Cosmic-ray physics at high altitude**
- **Space experiments**
- **Underground experiments**

Cosmology

Standard Model of Cosmology

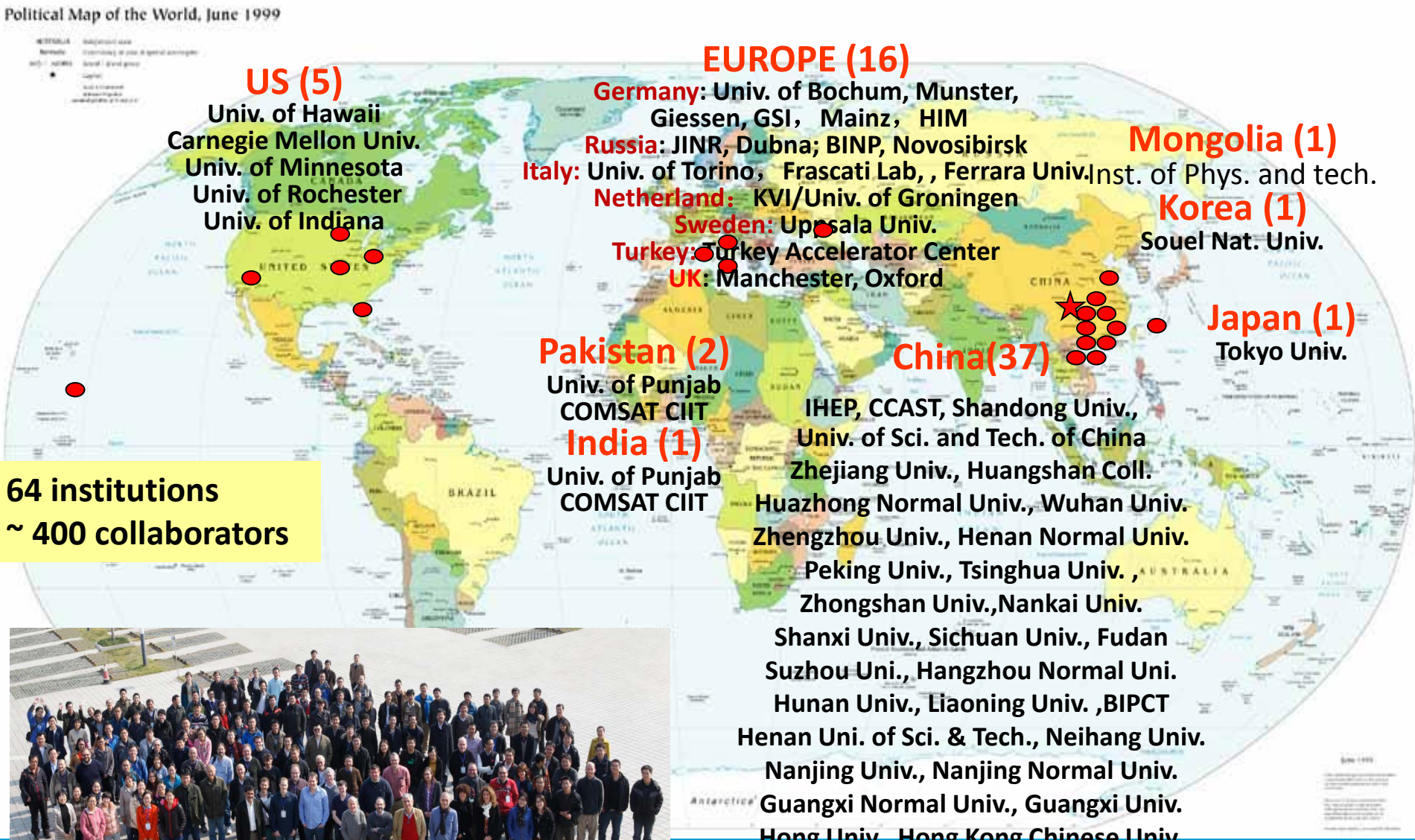
BEPCII Upgrade: 2004-2008





> 30 years of experience on e^+e^- collider !

BESIII Collaboration



US (5)
Univ. of Hawaii
Carnegie Mellon Univ.
Univ. of Minnesota
Univ. of Rochester
Univ. of Indiana

EUROPE (16)
Germany: Univ. of Bochum, Munster, Giessen, GSI， Mainz， HIM
Russia: JINR, Dubna; BINP, Novosibirsk
Italy: Univ. of Torino， Frascati Lab, , Ferrara Univ.
Netherland: KVI/Univ. of Groningen
Sweden: Uppsala Univ.
Turkey: Turkey Accelerator Center
UK: Manchester, Oxford

Mongolia (1)
Inst. of Phys. and tech.

Korea (1)
Souel Nat. Univ.

Japan (1)
Tokyo Univ.

Pakistan (2)
Univ. of Punjab
COMSAT CIIT

India (1)
Univ. of Punjab
COMSAT CIIT

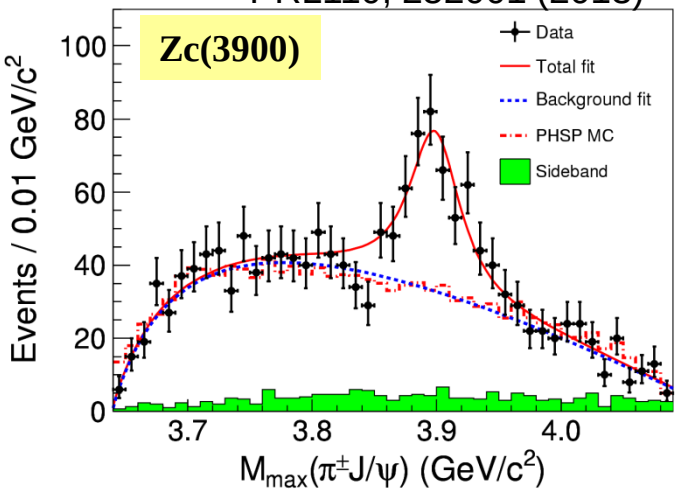
China(37)
IHEP, CCAST, Shandong Univ.,
Univ. of Sci. and Tech. of China
Zhejiang Univ., Huangshan Coll.
Huazhong Normal Univ., Wuhan Univ.
Zhengzhou Univ., Henan Normal Univ.
Peking Univ., Tsinghua Univ. ,
Zhongshan Univ.,Nankai Univ.
Shanxi Univ., Sichuan Univ., Fudan
Suzhou Uni., Hangzhou Normal Uni.
Hunan Univ., Liaoning Univ. ,BIPCT
Henan Uni. of Sci. & Tech., Neihang Univ.
Nanjing Univ., Nanjing Normal Univ.
Guangxi Normal Univ., Guangxi Univ.
Hong Univ., Hong Kong Chinese Univ.

64 institutions
~ 400 collaborators

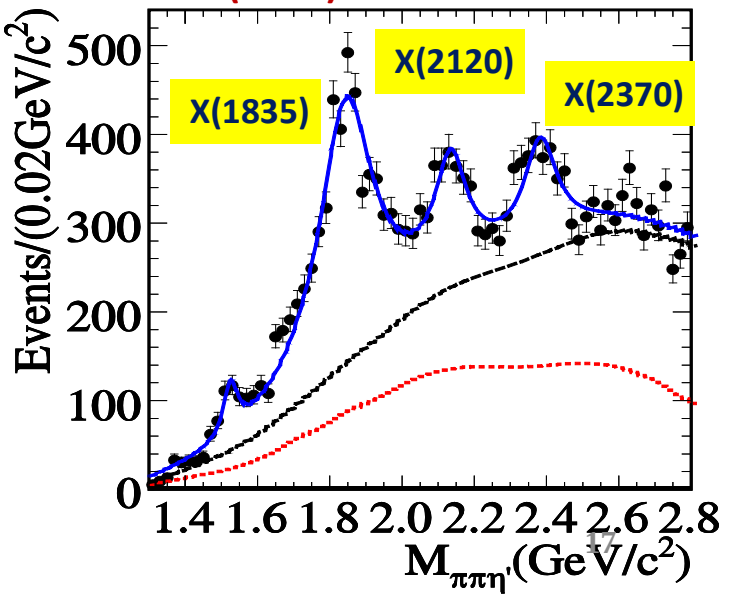
Highlights from BEPCII/BESIII

- Main Highlights:
  - Discovery of $Zc^{\pm}(3900)$: a four-quark states
  - Discovery of accompany states: $Zc^{0}(3900)$, $Z_c(4025)/Z_c(4020)$, …
  - Discovery of structures in Y(4260)
  - Exotic light hadrons: X(1835), X(1870), X(2120), …
  - New decay channels
  - Charm physics, tau, QCD, etc.
- > 20 papers/year, ~ 200 papers in total so far
- BESIII will continue to operate for another ~8 years.

PRL110, 252001 (2013)

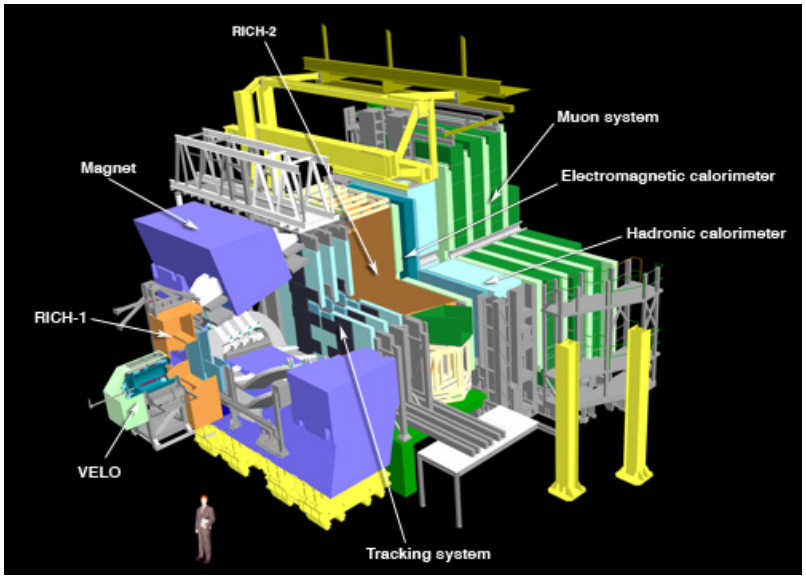


PRL 106 (2011) 072002

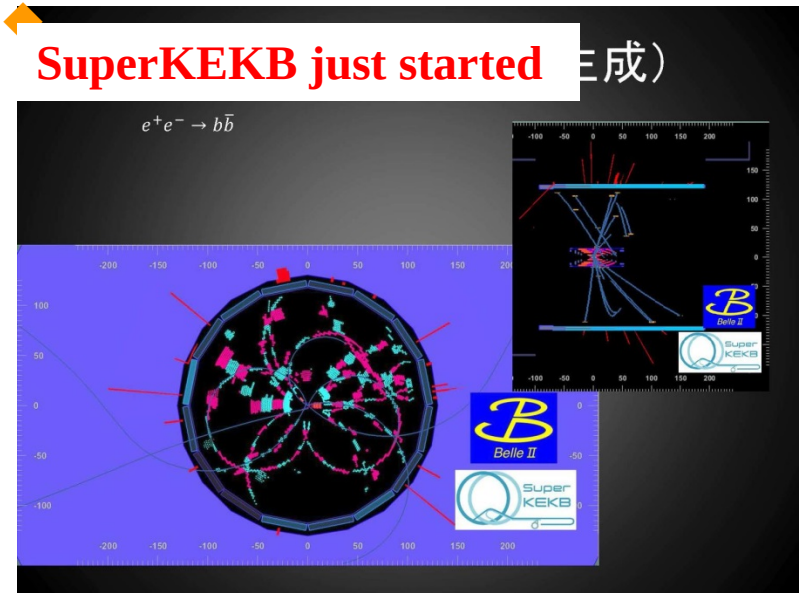


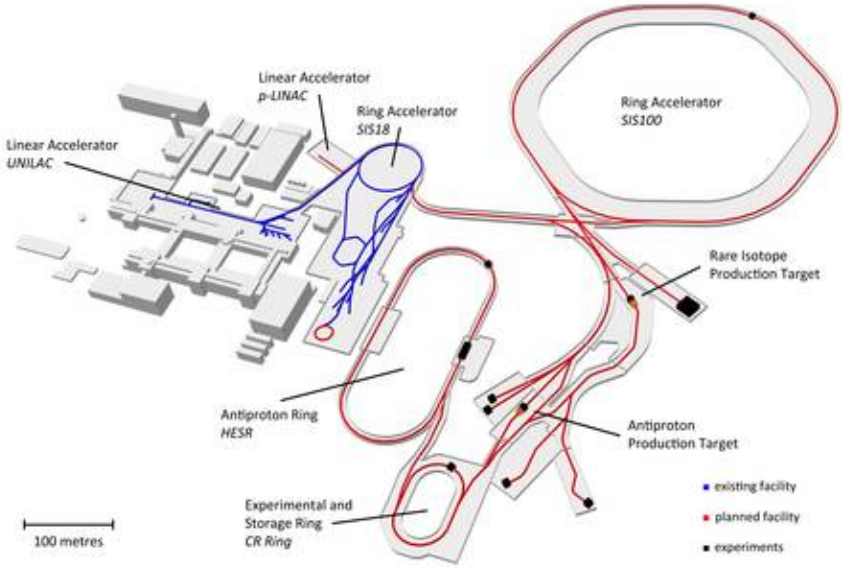
Other Similar Experiments

- Great results from LHCb & BELLE
- New facilities such as BELLEII, GlueX and PANDA will give us more results on hadron physics, exotic states and QCD
- XYZ particles will be understood



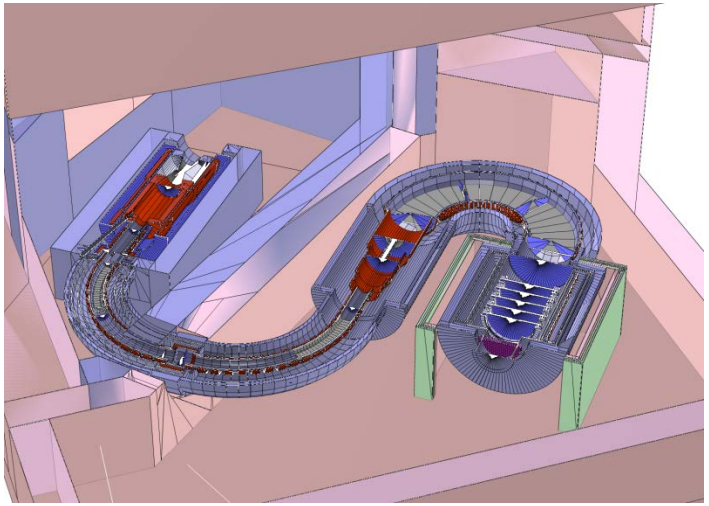
- SuperKEKB just started





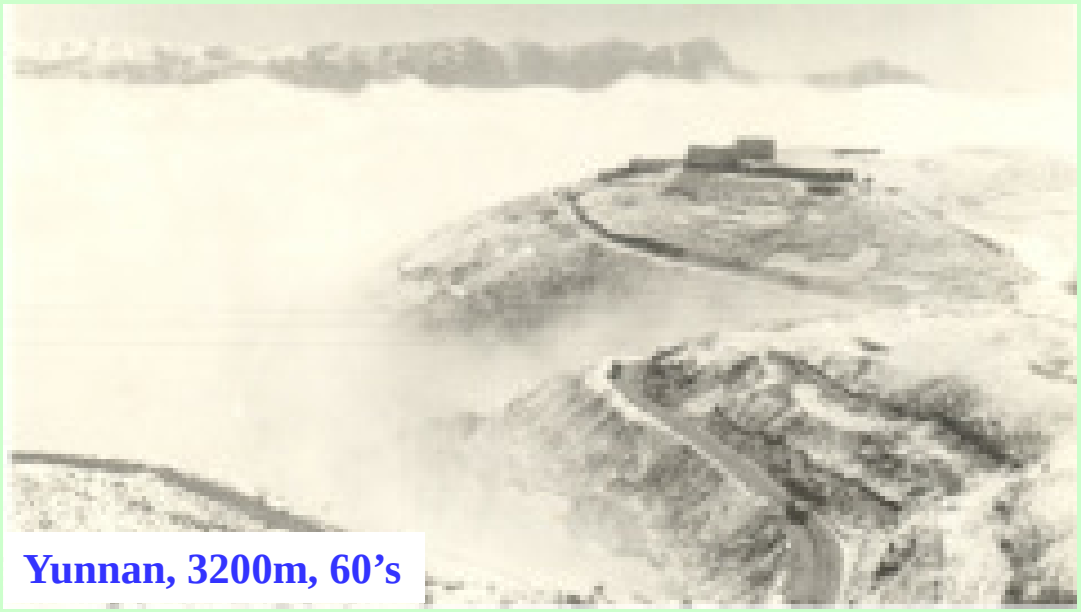
High Precision Test of SM

- **An incomplete list:**
  - ⇨ **Muon conversion: Mu2e, Comet**
  - ⇨ **Muon g-2**
  - ⇨ **K decays**
  - ⇨ **EDM**
  - ⇨ **…**
- **These experiments have or will reached extremely high precisions ➔ much high energy scale than colliders, such as LHC, BELLEII, BESIII, and etc., with a caveat of model dependence**



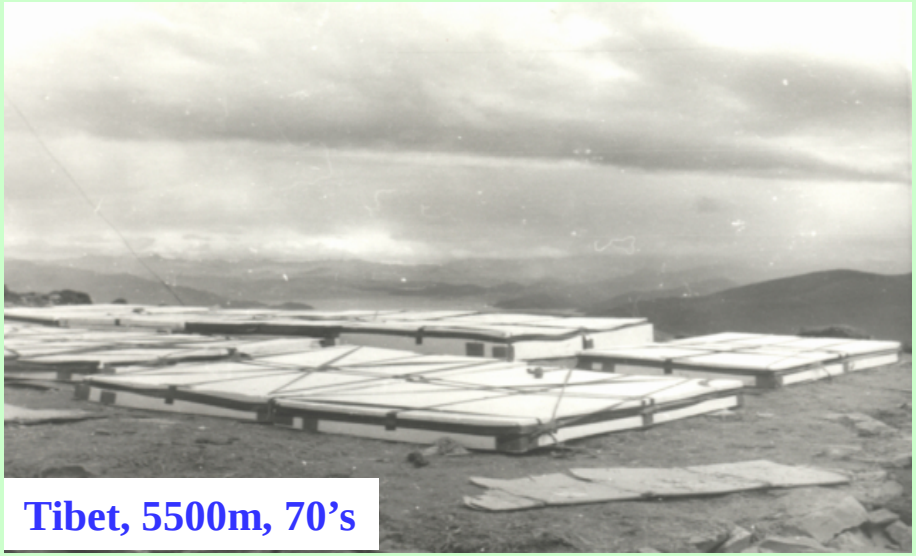
Direct production of new physics can not be replaced !

Astrophysics in China Since 50's



Yunnan, 3200m, 60's

Cloud Chamber, 60's

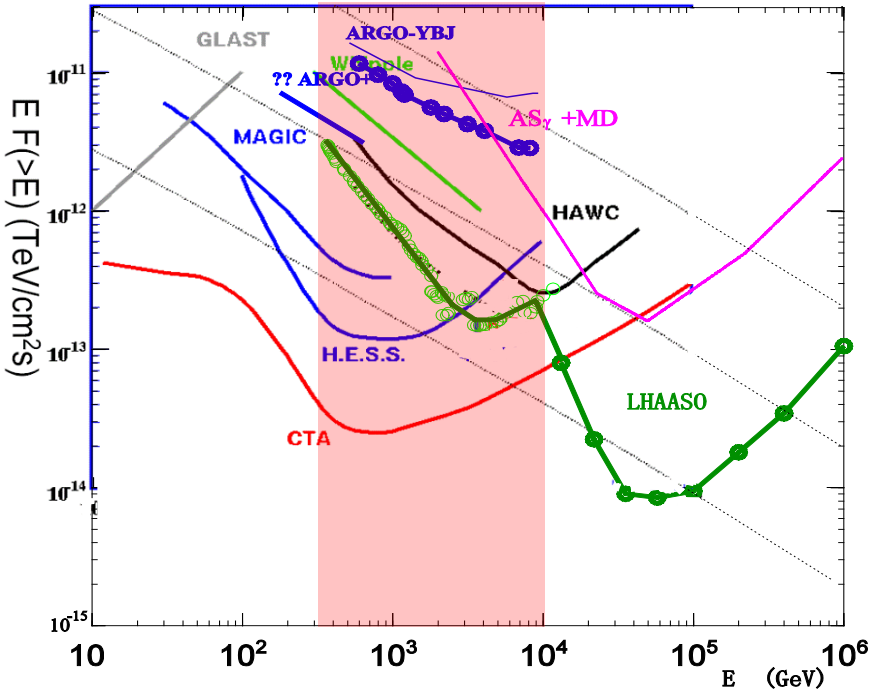


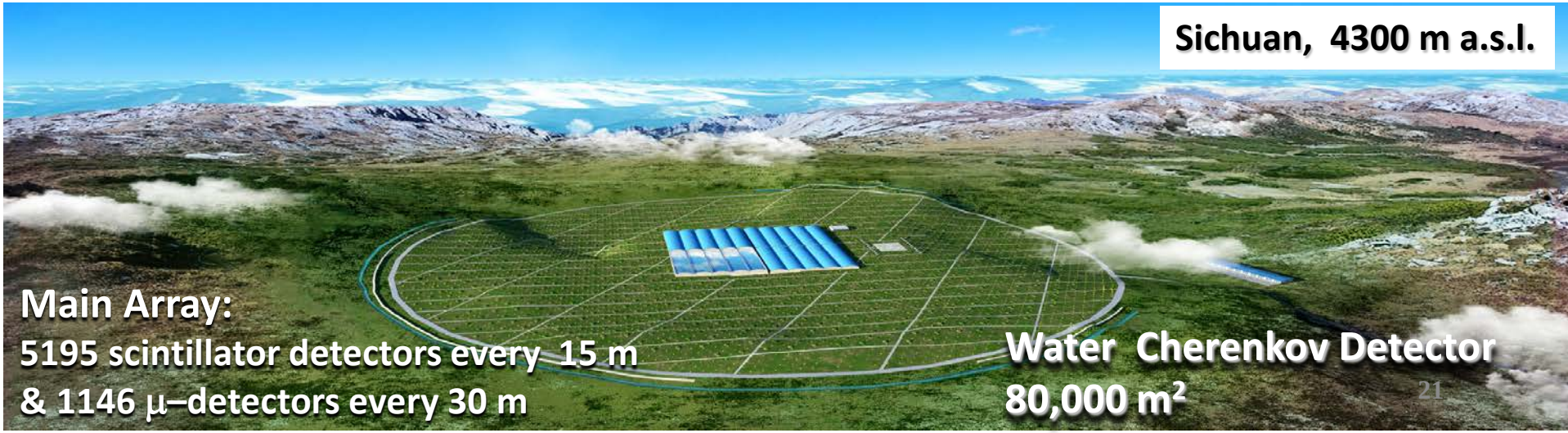
Tibet, 5500m, 70's

Tibet, 4200m, 90's

Large High Altitude Air Shower Observatory(LHAASO)

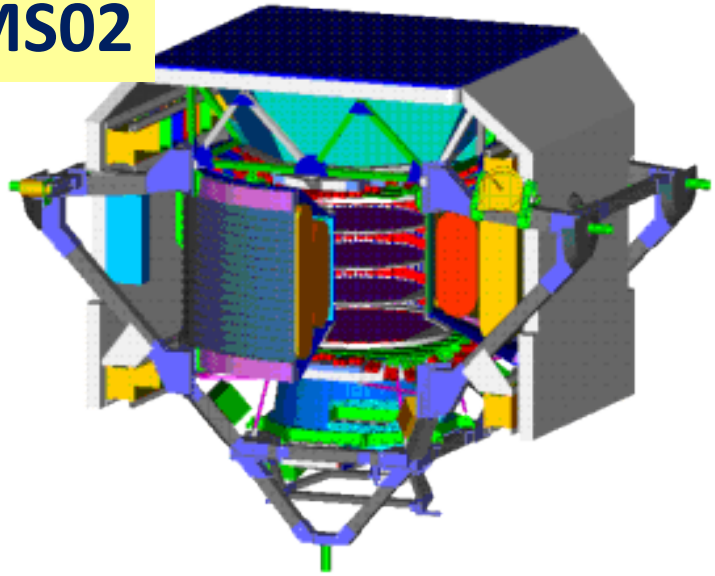
- A large air shower array for cosmic rays and γ-astronomy
- Construction just started, partial data taking starting from next year
- Complementary to CTA :
  - All the time, all the sky
  - Time-variant and extended sources
  - Fast indication for CTA





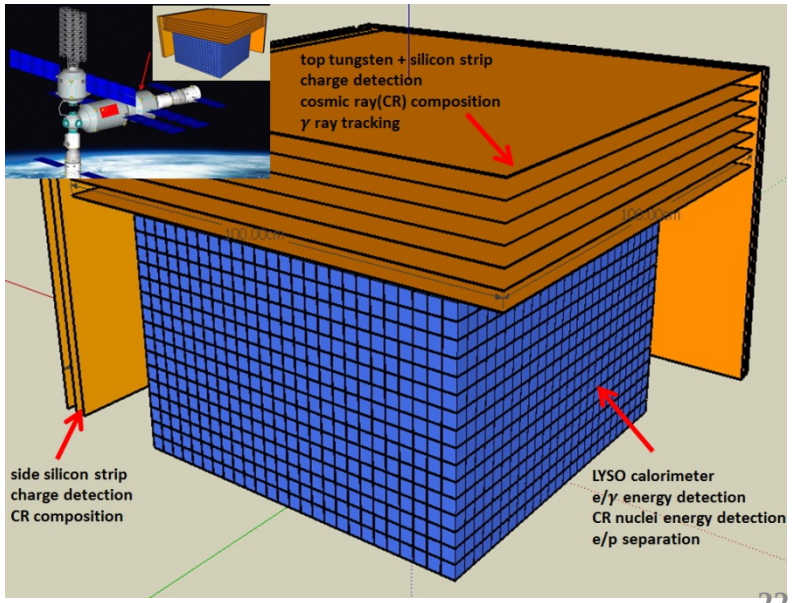
Cosmic-Ray in Space

AMS02



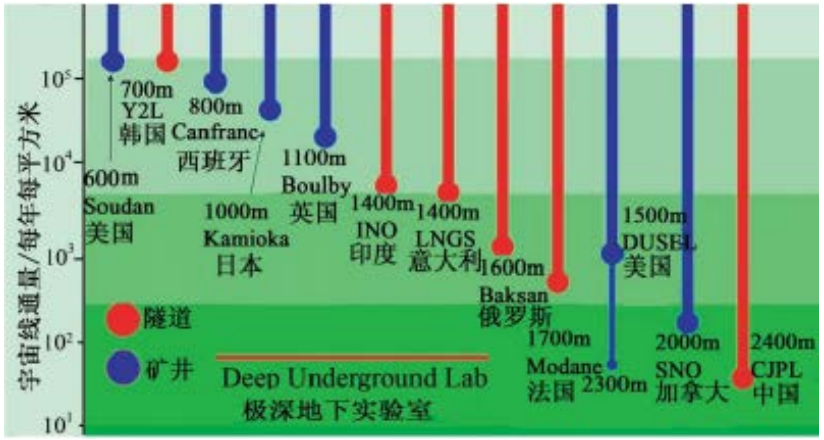
- 3D crystal calorimeter for dark matter searches and cosmic-ray physics
- Acceptance & energy range × 10
- Collaboration with Italy, Sweden, Switzerland, …
- To be launched in 2025

	X0(λ)	ΔE/E for e	e/p sep	GF m^2sr
HERD (2020)	55(3)	1%	10^{-6}	3.1
Fermi (2008)	10	12%	10^{-3}	0.9
AMS02 (2011)	17	2%	10^{-6}	0.12
DAMPE (2015)	31	1%	10^{-4}	0.3
CREAM (2015)	20(1.5)	--	--	--

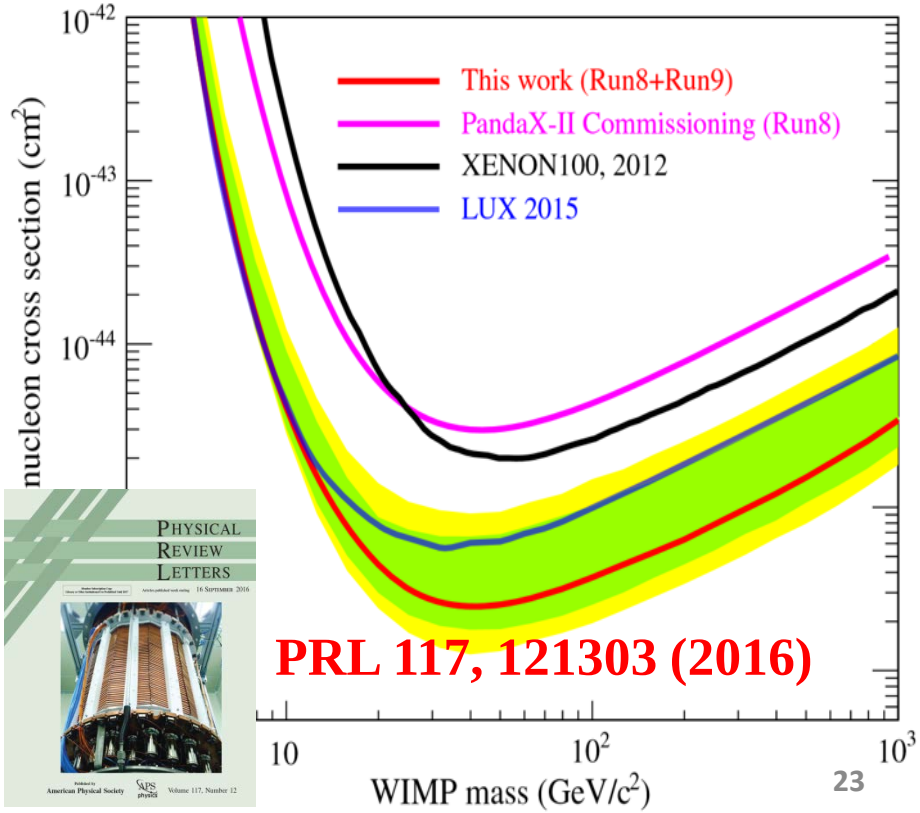


JinPin Underground Laboratory

- The deepest underground laboratory in the world: 2400 m
- Current experiments: dark matter searches
  - Xe-based PandaX
  - Ge-based CDEX



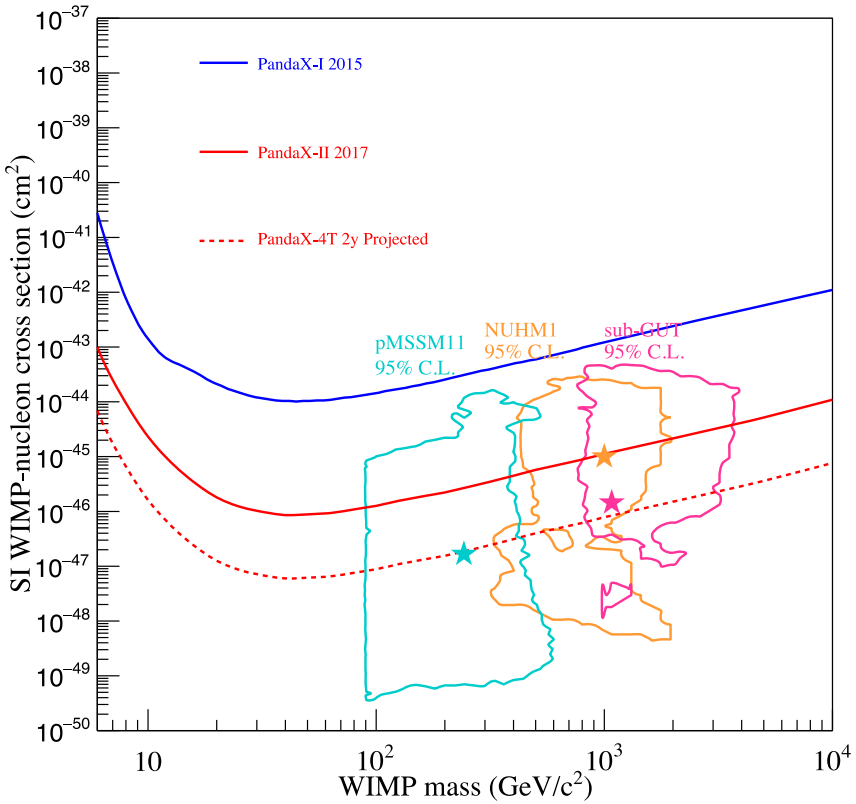
Latest PandaX results



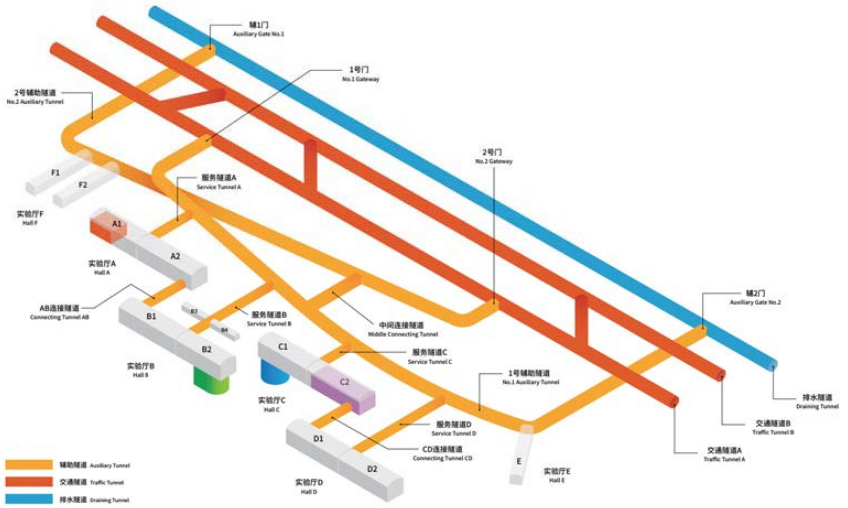
PRL 117, 121303 (2016)

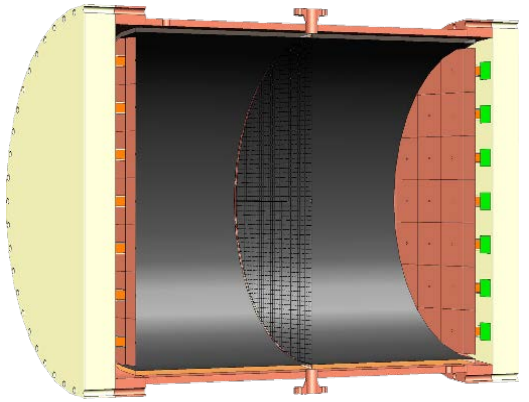
New Jinpin Underground Laboratory

- Continue dark matter searches
- Start double beta-decay experiments



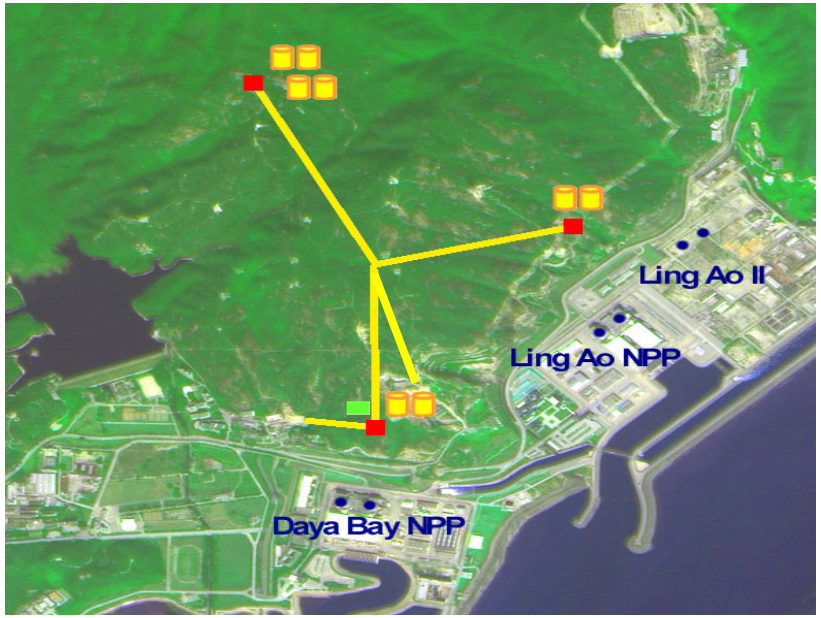
Expected 4t PandaX performance

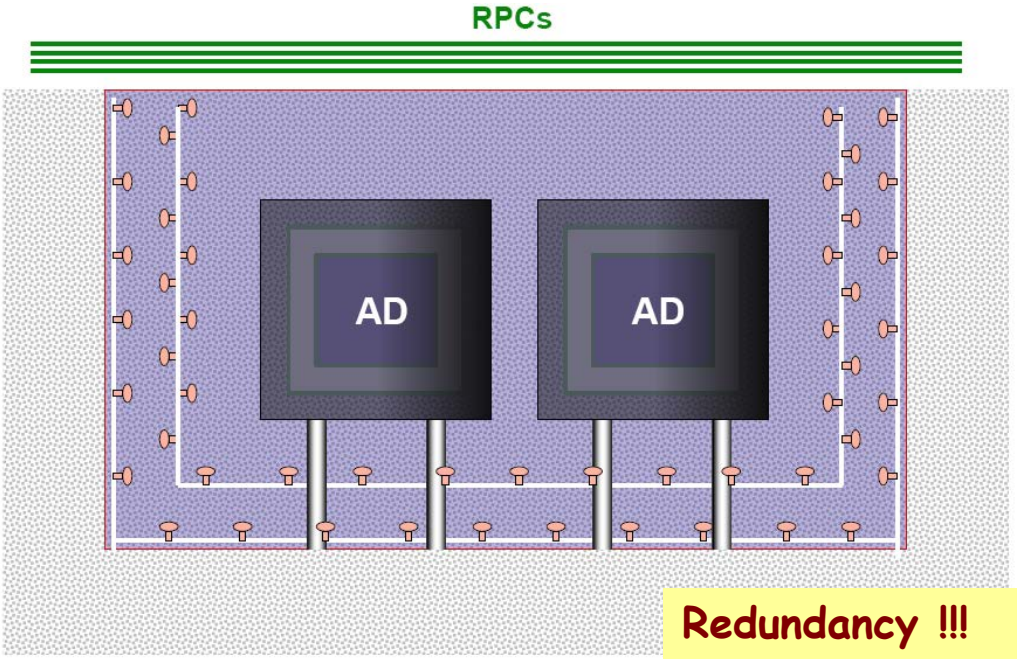




PandaX-III: 0.2-1 t high pressure gaseous ^{136}Xe TPC for ββ decays

Daya Bay Experiment





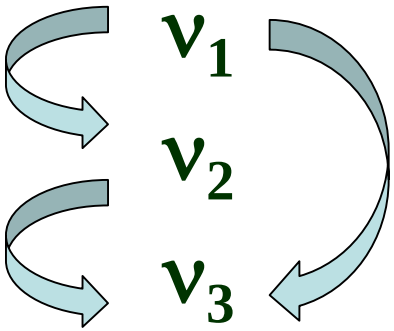
Redundancy !!!

Solar ν Oscillation

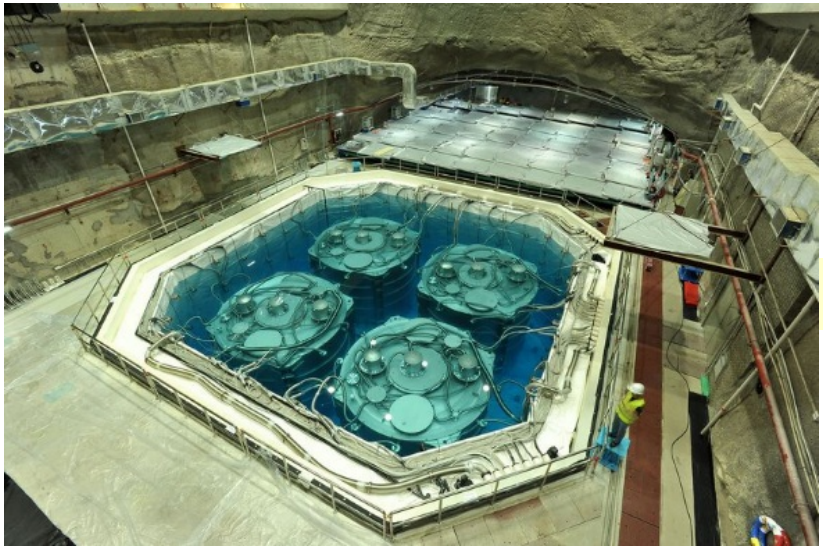
$\sin^2 2\theta_{12} \sim 0.9$

Atm. ν Oscillation

$\sin^2 2\theta_{23} \sim 1$

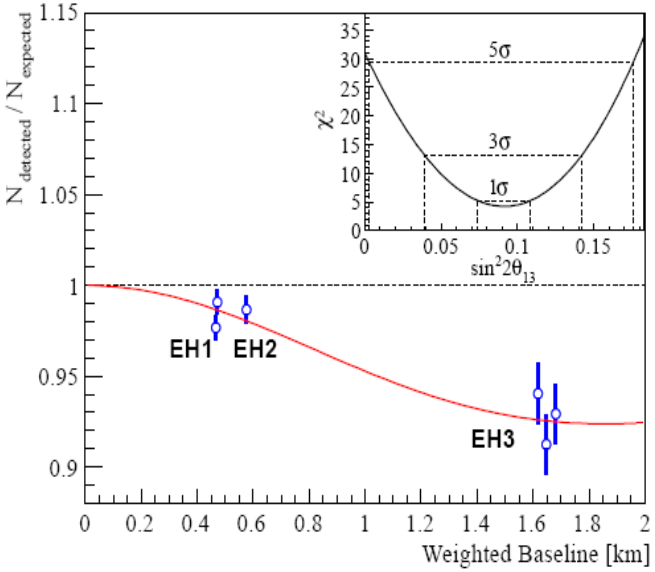


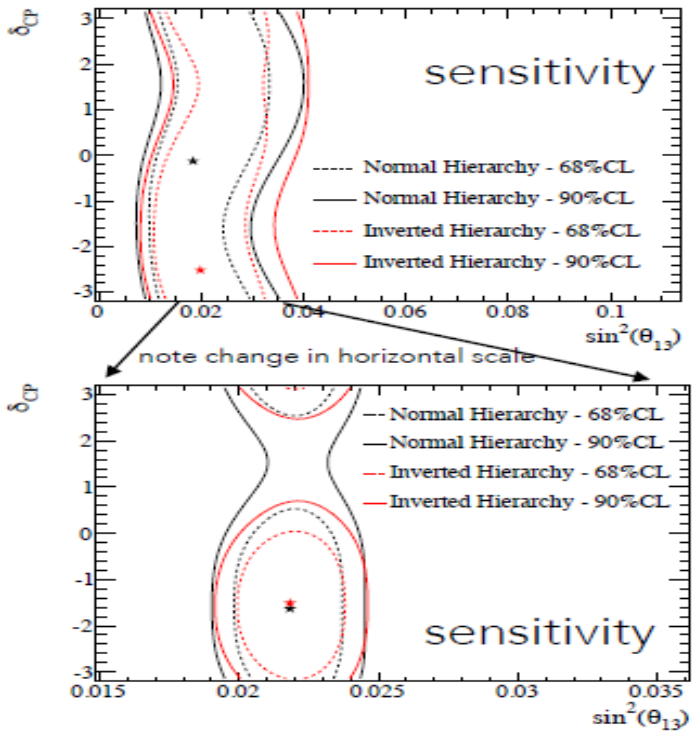
θ_{13} ?

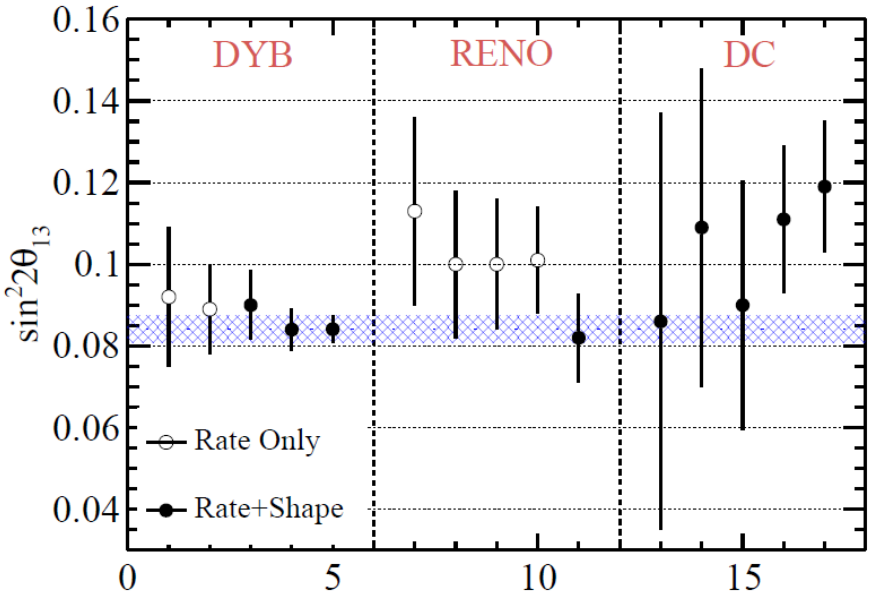


Results and Prospects

- $\sin^2 2\theta_{13}$ is determined to be non-zero
- Precision improved from ~ 20% to ~ 4%
- Daya Bay will operate until 2020, precision expected: < 3%
- Combined with T2K & Nova, CP Phase is estimated to be ~ **-90°**

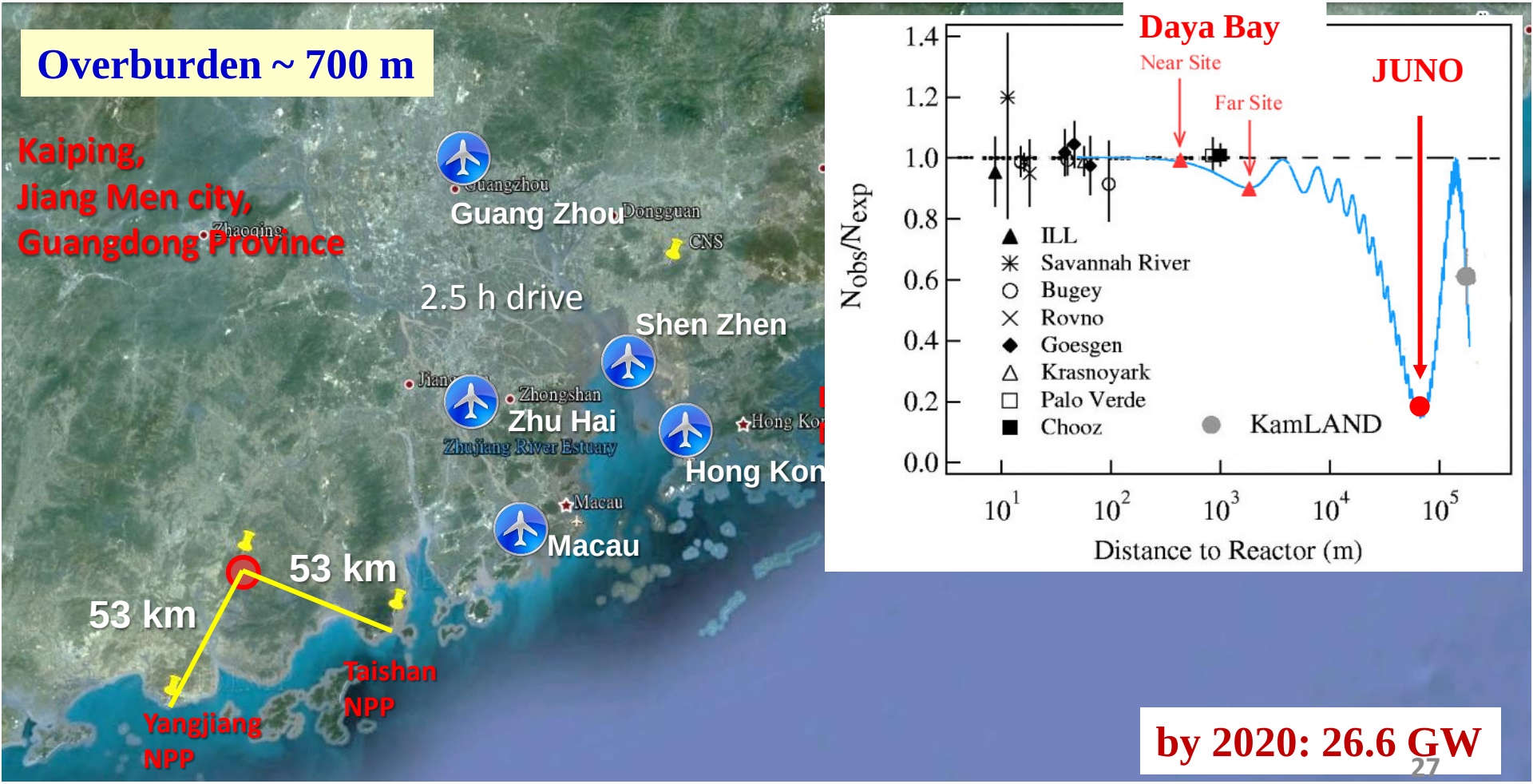






The JUNO Experiment

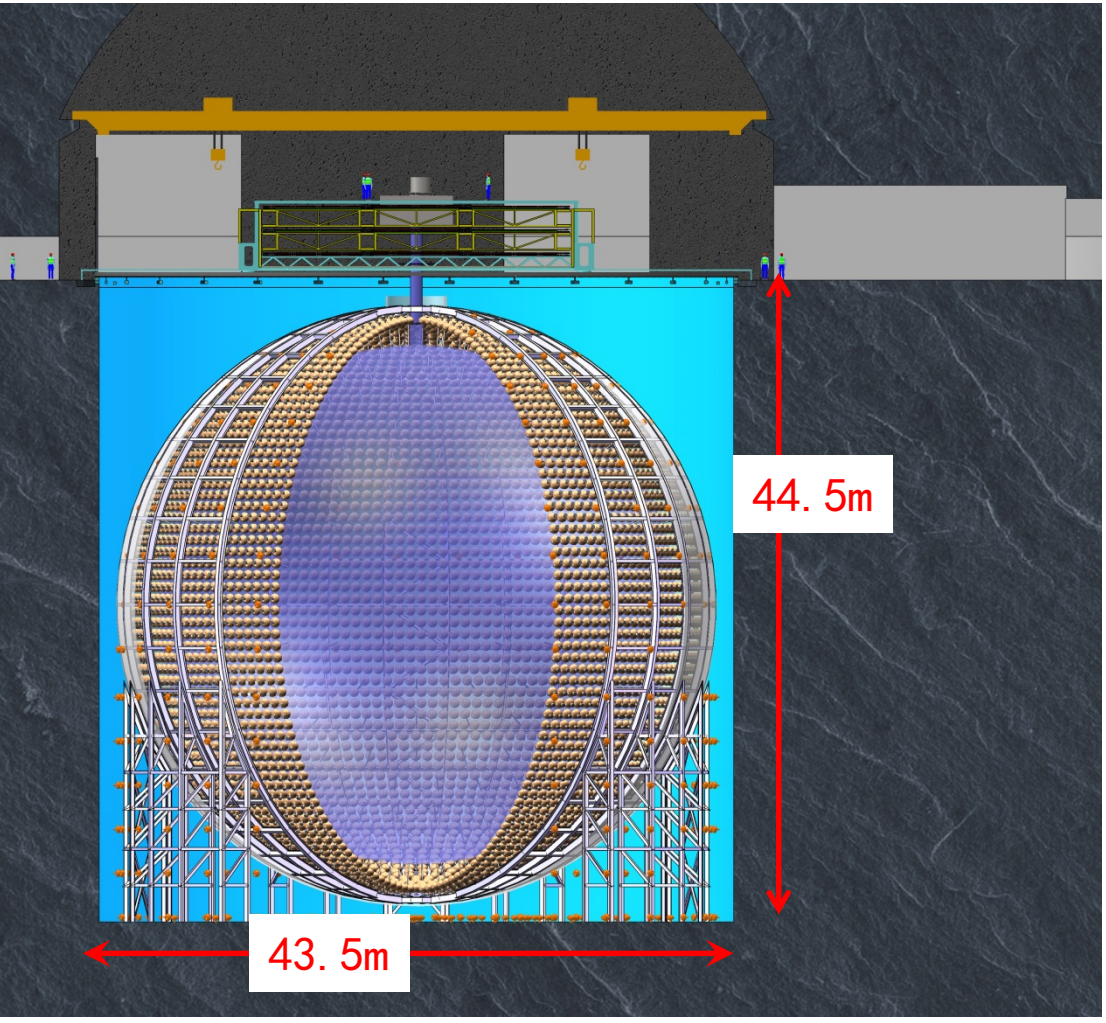
NPP	Daya Bay	Huizhou	Lufeng	Yangjiang	Taishan
Status	Operational	Planned	Planned	Under construction	Under construction
Power	17.4 GW	17.4 GW	17.4 GW	17.4 GW	18.4 GW



by 2020: 26.6 GW

JUNO Detector and Challenges

- Largest LS detector ➔ × 20 KamLAND， × 40 Borexino
- Highest light yield ➔ × 2 Borexino， × 5 KamLAND



- **Mass Hierarchy**
- Oscillation parameters
- Supernova neutrinos
- Geo-neutrinos
- Solar neutrinos
- Double beta decays

- Hugh cavern:
  - ~ 48m× 70m
- Largest Acrylic tank:
  - Φ 35.4m(13m@SNO)
- 20 kt LS
  - Best attenuation length: 25m (15m @ Daya Bay)
- 20000 20” PMT
  - Highest photon detection efficiency : 30%*100% = 30% （25%*60%=15% @ SuperK）

JUNO Collaboration

17 contries/regions， 72 institutions， 550 mmebers

Europe (28)

Belgium(1)
ULB

Czech(1)
Charles U

Latvia(1)
IECS

Finland(1)
U.Oulu

France(5)
APC Paris
CPPM Marseille
IPHC Strasbourg
Subatech Nantes
CENBG-IN2P3

Italy(8)
INFN-Catania
INFN-Frascati
INFN-Ferrara
INFN-Milano
INFN-Mi-Bicocca
INFN-Padova
INFN-Perugia
INFN-Roma 3

Germany(7)
FZ Jülich
RWTH Aachen
TUM
U.Hamburg
IKP FZI Jülich
U.Mainz
U.Tuebingen

Russia(3)
INR Moscow
JINR
MSU

Slovakia (1)
FMPICU

America(6)

US(2)
UMD
UMD-Geo

Chile(2)
PCUC
UTFSM

Brazil（2）
PUC-Rio
UEL

Asia (38)

China（33）
BJ Nor. U.
CAGS
Chongqing U.
Shanghai JT U.
DGUT
ECUST
Guangxi U.
HIT
IHEP
U. Of South China
Ninan U.
Nanjing U.
Natl. Chiao-Tung U.
Natl. Taiwan U.
Natl. United U.
Nankai U.
NCEPU
Pekin U.
SDU
Sichuan U.
CIAE
SYSU
Tsinghua U.
UCAS
USTC
Jilin U.
Wuhan U.
Wuyi U.
Xi'an JT U.
Xiamen U.
NUU.

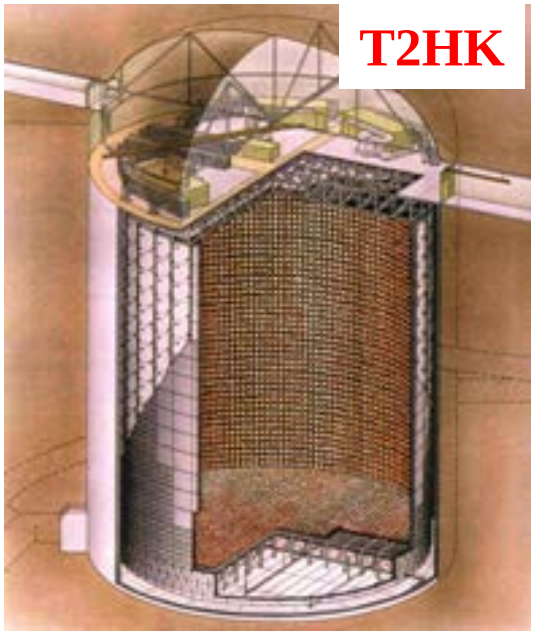
Armenia(1)
Yerevan Phys. Inst.

Thailand(3)
SUT
PPRLCU
NARIT

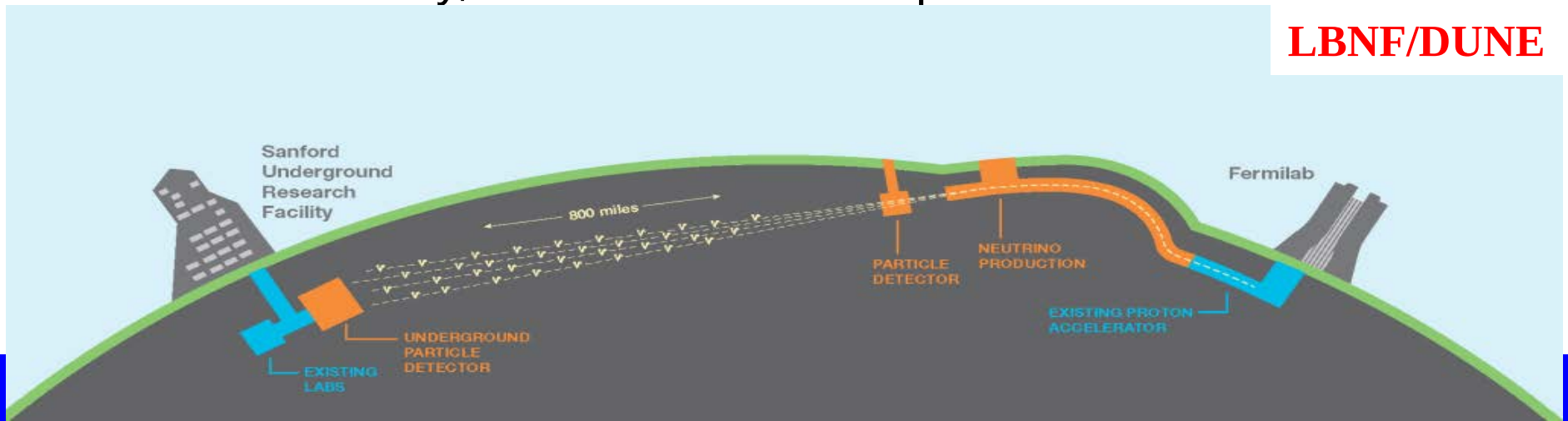
Parkistan(1)
PINSTECH

Other Neutrino Oscillation Projects

- There are tens of neutrino projects under operation, construction and planning
- LBNF/DUNE is under construction right now. Operation in about ~ 10 years
- HyperK is just approved. Construction will start in ~2020.
- Hints of mass hierarchy & CP phase: T2K/Nova + many Exp.s, including Daya Bay
- In ten years from now, oscillation will be completed understood: JUNO+ORCA+DUNE ➔ mass hierarchy; DUNE+T2HK ➔ CP phase



LBNF/DUNE



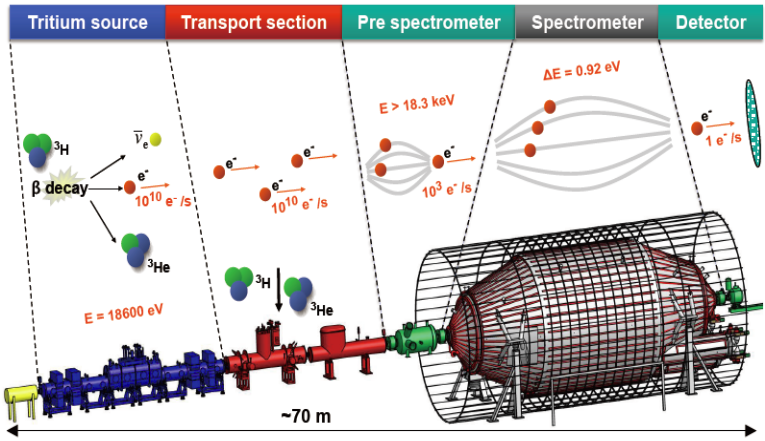
Absolute Neutrino Mass

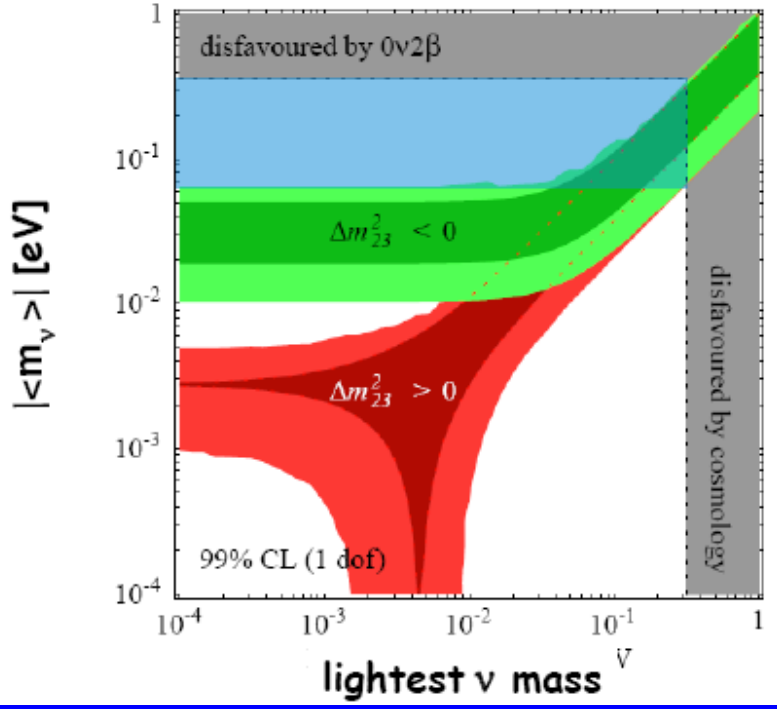
- Hints from cosmology: <~1 eV
- Guess from Oscillation: ~1 meV
- Katrin is starting its operation just now. The absolute neutrino mass will be probed to ~ 0.2 eV (probably not enough)

$$(m_{\nu_e})^{eff} = [\Sigma_i \mid U_{ei} \mid^2 m^2_{\nu_i}]^{1/2}$$

- 0ν ββ decay could be the next breakthrough with a target of ~ 1meV

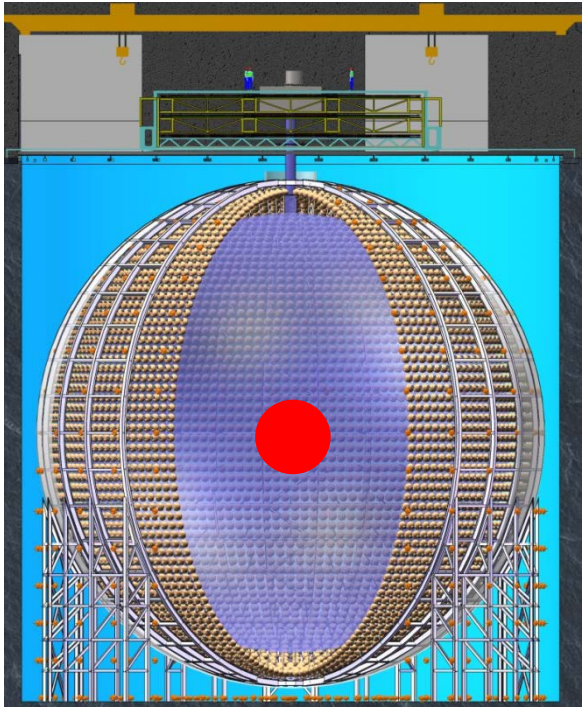
$$<M_{ee}> = \mid \Sigma_i \; (U_{ei})^2 \, m_{\nu_i} \mid$$



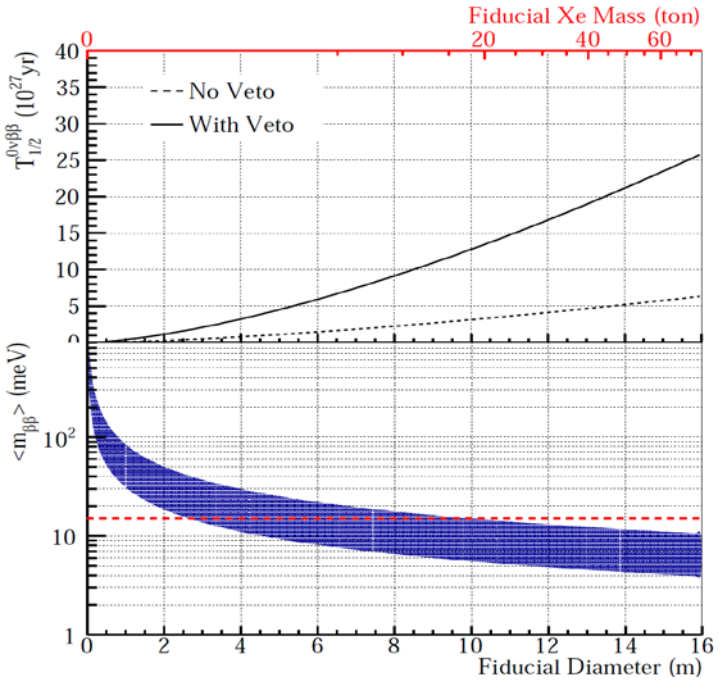


JUNO-ββ

- Insert a balloon filled with ^{136}Xe-loaded LS (or ^{130}Te) into the JUNO detector
- Cosmic-induced backgrounds are removed by cutting a volume around the muon track
- Yes, sensitivity scales with the mass



	Isotopes	Mass(t)	$<m_{\beta\beta}>$,meV
nEXO	^{136}Xe	5	7-22
GERDA	^{76}Ge	1	10-40
Majorana	^{76}Ge	1	10-40
SNO+	^{130}Te	8	19-46
KamLAND-Zen	^{136}Xe	1	~20
JUNO-ββ	^{136}Xe	50	4-12



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

Summary

- **Particle Physics is a great field**
  - **Incredible success in the past**
  - **More to come in the future**
- **We are now at a critical point: which accelerator is the next one ?**
  - **CEPC + SPPC (or FCC_ee+FCC_hh) is the best choice**
- **China may play a very important role:**
  - **Great success in the past and a number of new initiatives**
  - **Good opportunities: economics, political support, …**
- **Let's work together**