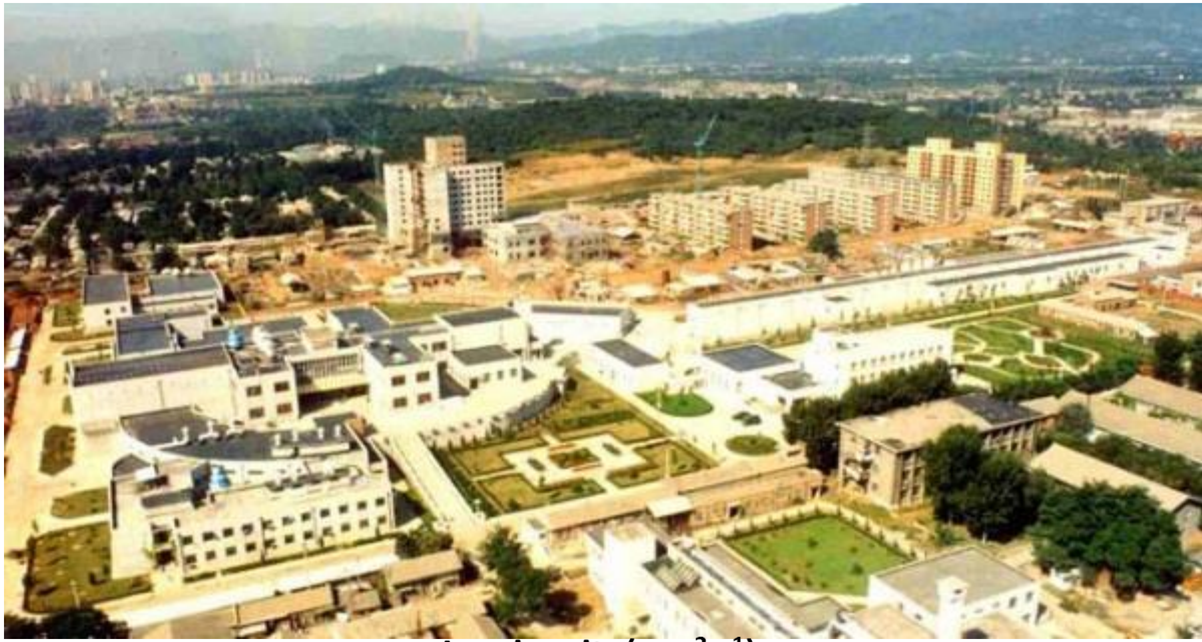
Particle Physics in China

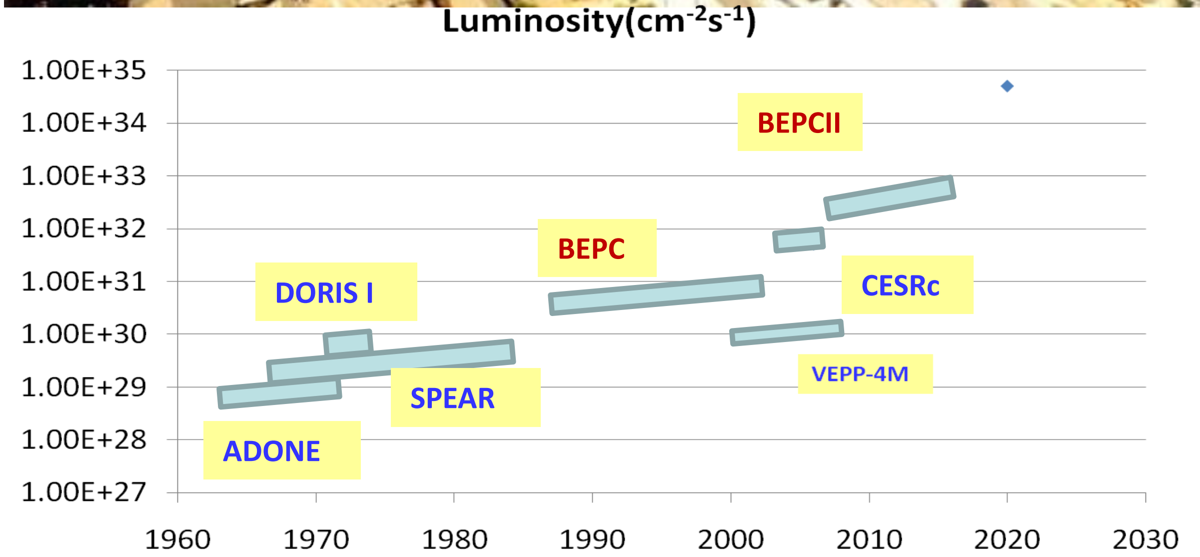
Yifang Wang
Institute of High Energy Physics

AEPSHEP, Oct. 14, 2016

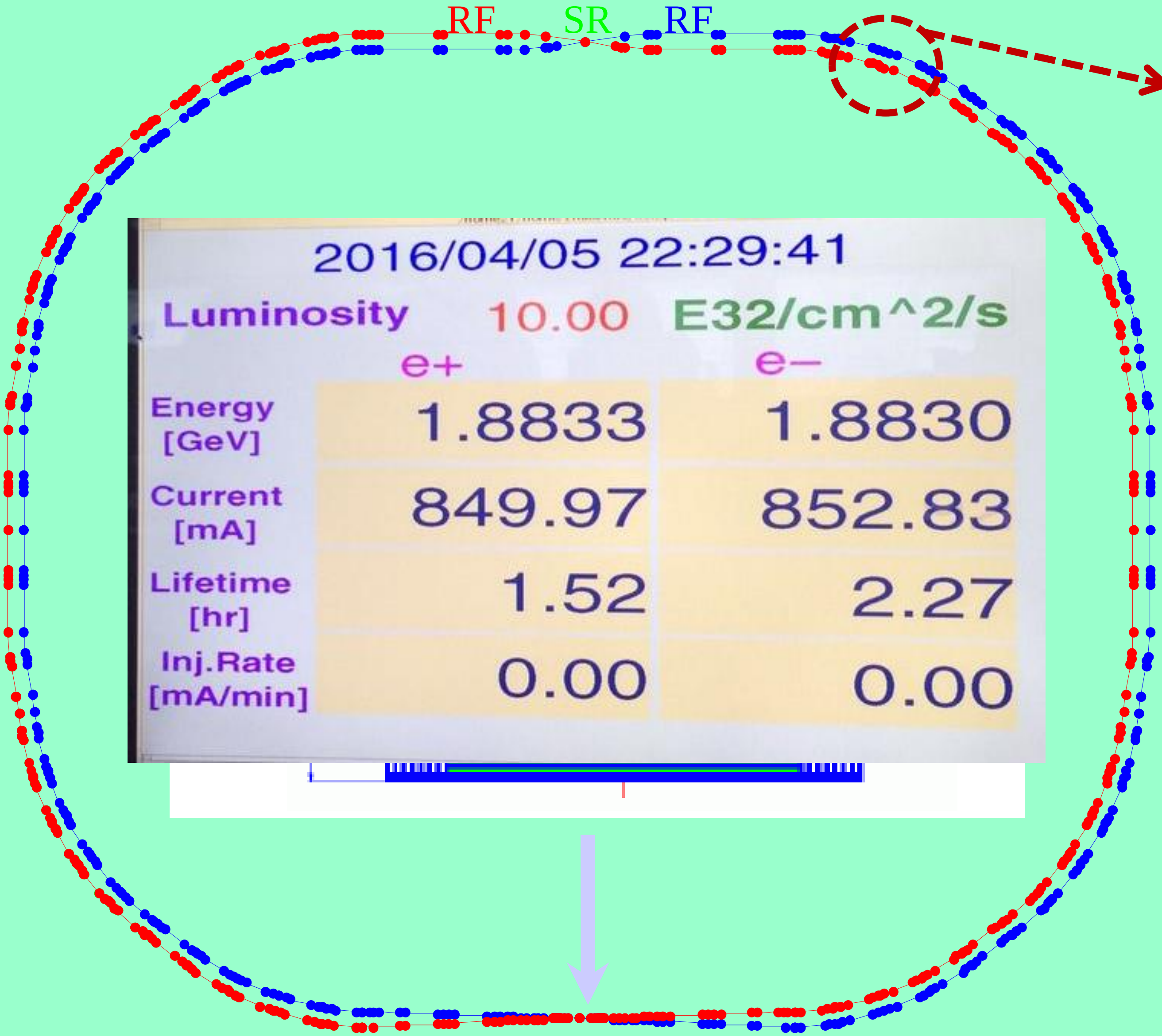
Beijing Electron-Positron Collider(BEPC)

- **The starting point of Particle Physics in China is the construction of BEPC in late 80's**
- **Upgrade of BEPC (BEPCII) is completed in 2008. It leads IHEP to be one of the most active HEP centers in the world.**
- **The research of IHEP now covers particle physics, astrophysics , synchrotron radiation, spallation neutron source and their applications.**





BEPC II: Operational Since 2009



2016/04/05 22:29:41

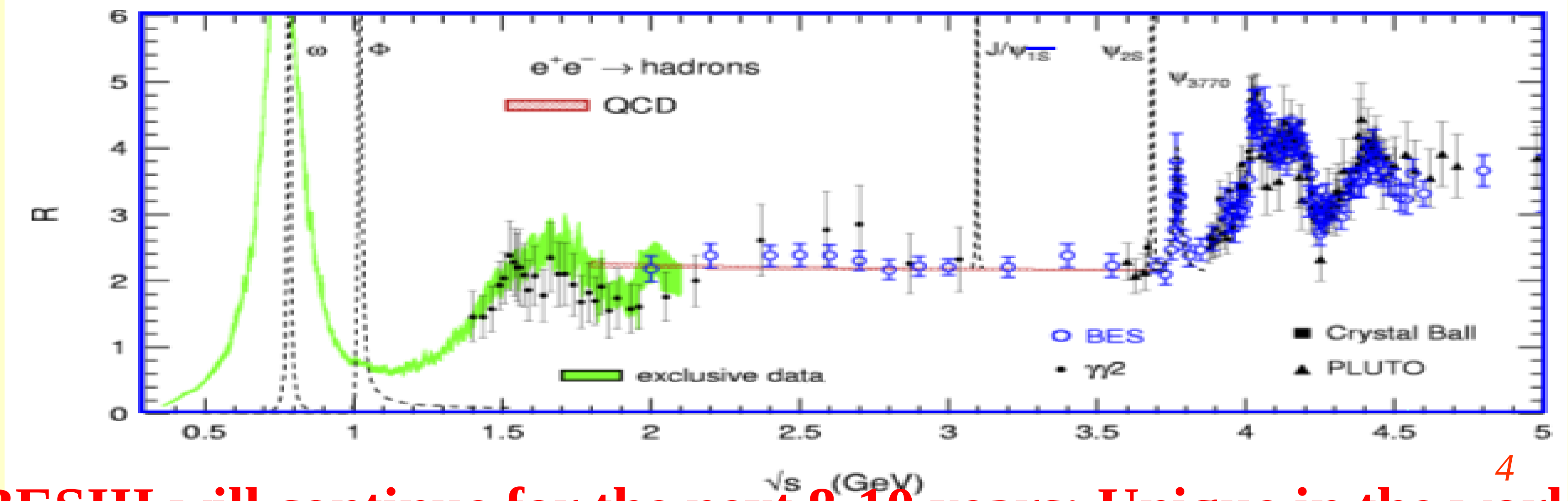
Luminosity 10.00 E32/cm^2/s

	e+	e−
Energy [GeV]	1.8833	1.8830
Current [mA]	849.97	852.83
Lifetime [hr]	1.52	2.27
Inj.Rate [mA/min]	0.00	0.00

Beam energy:
1-2 GeV
Lumi. @ 1.89 GeV:
1×10^{33} $cm^{-2}s^{-1}$
No. of bunches:
93
Total current:
0.91 A
SR mode:
0.25A @ 2.5 GeV

BESIII Data Taking Status & Plan

	Previous Data set	BESIII now	Goal
J/psi	BESII: 58M	1.2 B	10B
Psi’	CLEO: 28 M	0.5 B	3B
Psi”	CLEO: 0.8 /fb	3.0/fb	20 /fb
ψ(4040)/ψ(4160) /X(4260) etc.	CLEO: 0.6/fb @ ψ(4160)	0.5/fb ψ(4040); 2.3/fb @~4260, 0.5/fb@ ~4360; 1/fb@~4420; 0.5/fb@~4600	~ 10 /fb
R scan & Tau	BESII @10K/pnts	105 pnts@3.8-4.6 GeV	100K/pnts

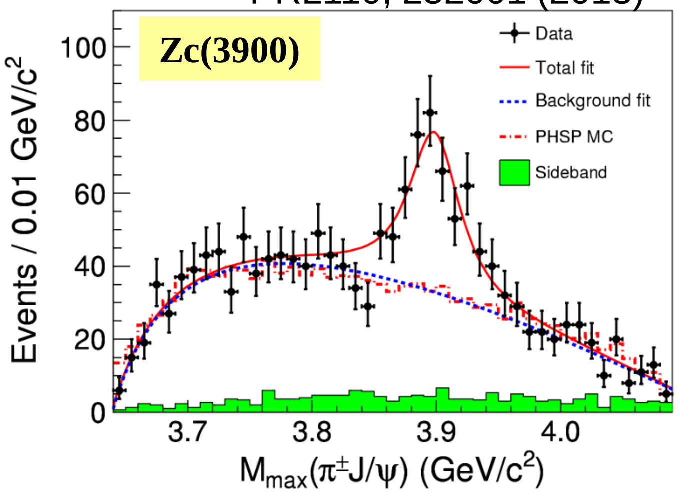


BESIII will continue for the next 8-10 years: Unique in the world

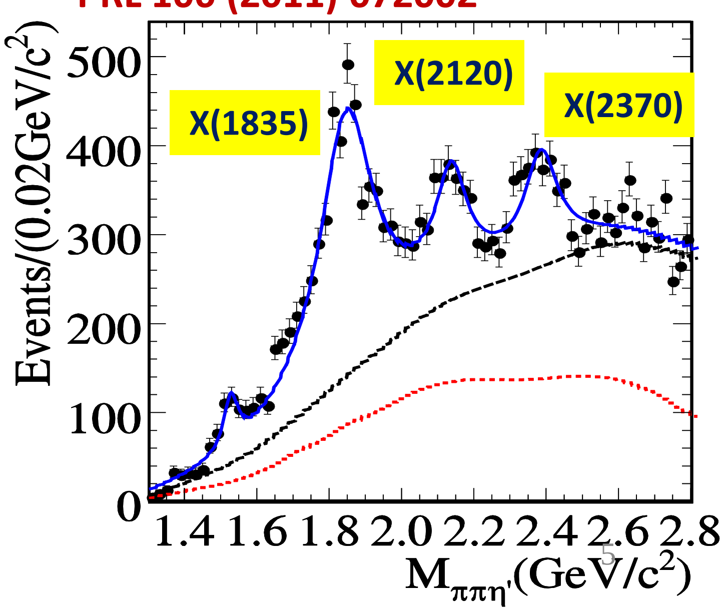
Results from BEPCII/BESIII

- BEPCII/BESIII is the best facility for light hadrons spectroscopy and Charmonium physics: glueballs, m_τ, f_D, f_{Ds}, R, etc.
- ~ 20 papers/year, more than 100 papers in total so far
- Highlights:
  - Tetraquark states(?): Zc(3900), $Z_c(4025)/Z_c(4020)$, ...
  - Exotic light hadrons: X(1835), X(1870), X(2120), ...
  - Charm physics, QCD, etc.
- BESIII will continue to operate for another ~8 years.

PRL110, 252001 (2013)



PRL 106 (2011) 072002



BESIII International Collaboration

Europe (13)

Germany: Univ. of Bochum, Univ. of Giessen, GSI
Univ. of Johannes Gutenberg
Helmholtz Ins. In Mainz
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

US (5)

Univ. of Hawaii
Carnegie Mellon Univ.
Univ. of Minnesota
Univ. of Rochester
Univ. of Indiana

Pakistan (2)

Univ. of Punjab
COMSAT CIIT

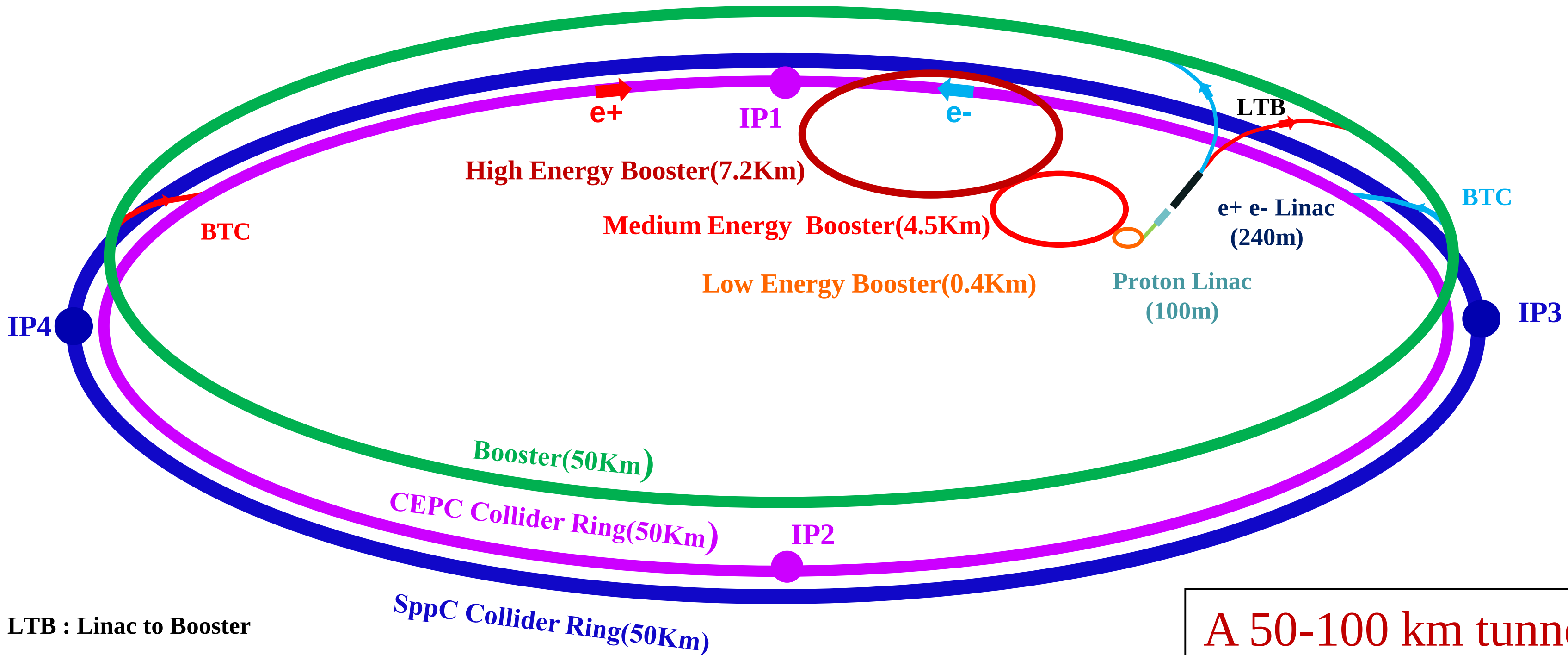
China(31)

IHEP, CCAST, GUCAS, 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., Beihang Univ.
Shanxi Univ., Sichuan Univ., Univ. of South China
Hunan Univ., Liaoning Univ.
Nanjing Univ., Nanjing Normal Univ.
Guangxi Normal Univ., Guangxi Univ.
Suzhou Univ., Hangzhou Normal Univ.
Lanzhou Univ., Henan Sci. and Tech. Univ.

~400 members from 11 countries and 53 institutions

The Future: CEPC+SppC

- For about 8 years, we have been talking about "What can be done after BEPCII in China"
- Thanks to the discovery of the low mass Higgs boson, a circular Higgs factory is feasible, followed by a proton-proton collider in the same tunnel



LTB : Linac to Booster

BTC : Booster to Collider Ring

A 50-100 km tunnel is relatively easier NOW in China

Science Goals

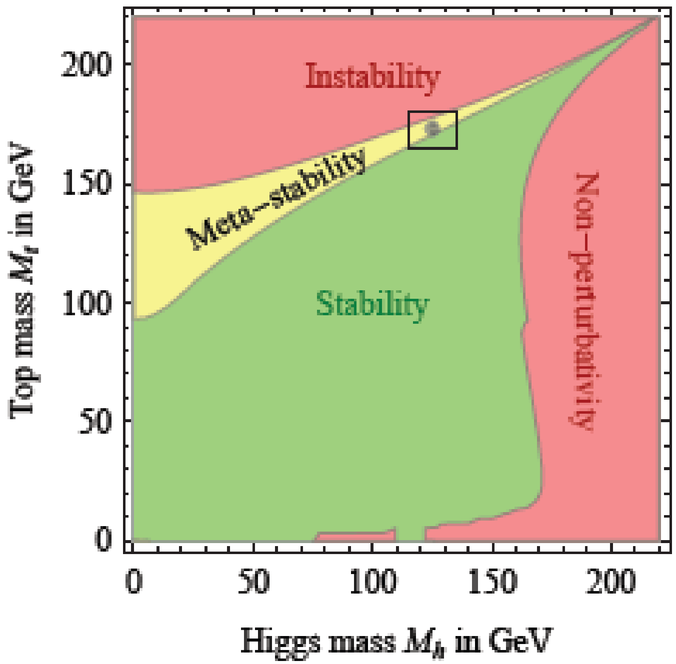
- **CEPC (e+e-: 90-250 GeV)**
  - Higgs Factory: Precision study of Higgs(m_H, J^{PC}, couplings)
    - Same as SM prediction ? Other Higgs ? Composite ? New properties ? CP effect ？
  - Z & W factory: precision test of SM
    - New phenomena ? Rare decays ?
  - Flavor factory: b, c, τ and QCD studies
- **SppC (pp: 50-100 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

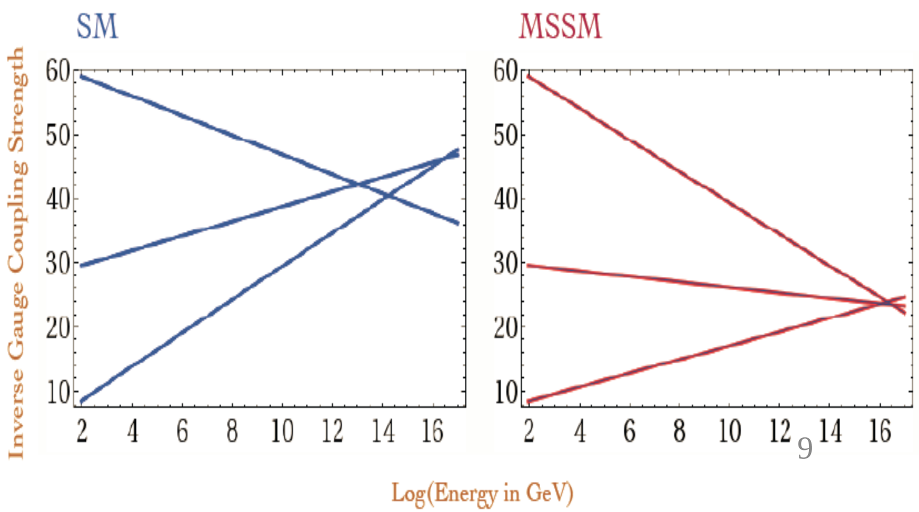
SM is not the End after the Higgs

- **From neutrinos to top quark, masses differs by a factor 10^{13} (Hierarchy)**
- **Fine tuning of Higgs mass(naturalness)**

$$m_H^2 = 36{,}127{,}890{,}984{,}789{,}307{,}394{,}520{,}932{,}878{,}928{,}933{,}023$$
$$-36{,}127{,}890{,}984{,}789{,}307{,}394{,}520{,}932{,}878{,}928{,}917{,}398$$
$$= (125\ \text{GeV})^2\ !\ ?$$



- **Masses of Higgs and top quark are in the meta-stable region**
- **Unification at a high energy ?**
- **Dark matter particles ?**
- **No CP in the SM to explain Matter-antimatter asymmetry**

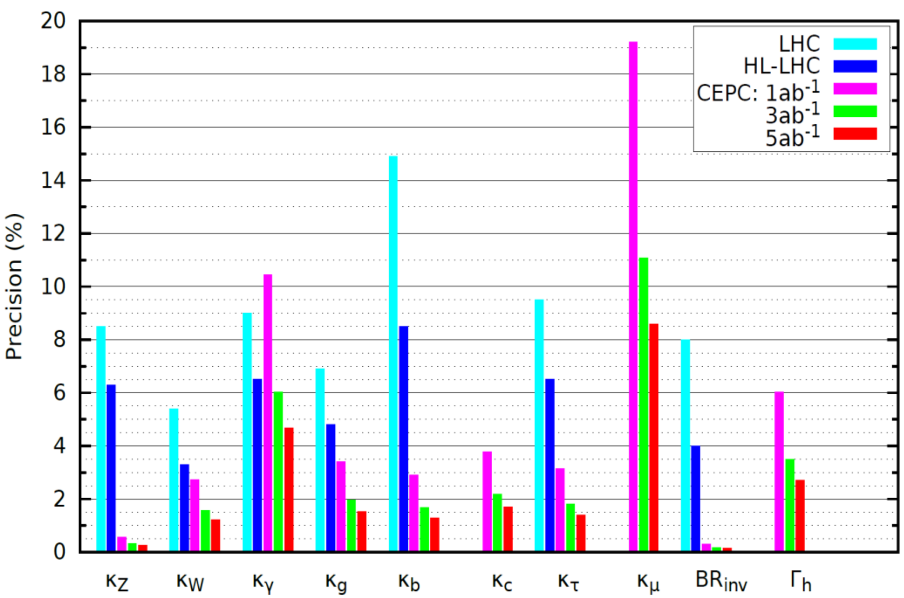


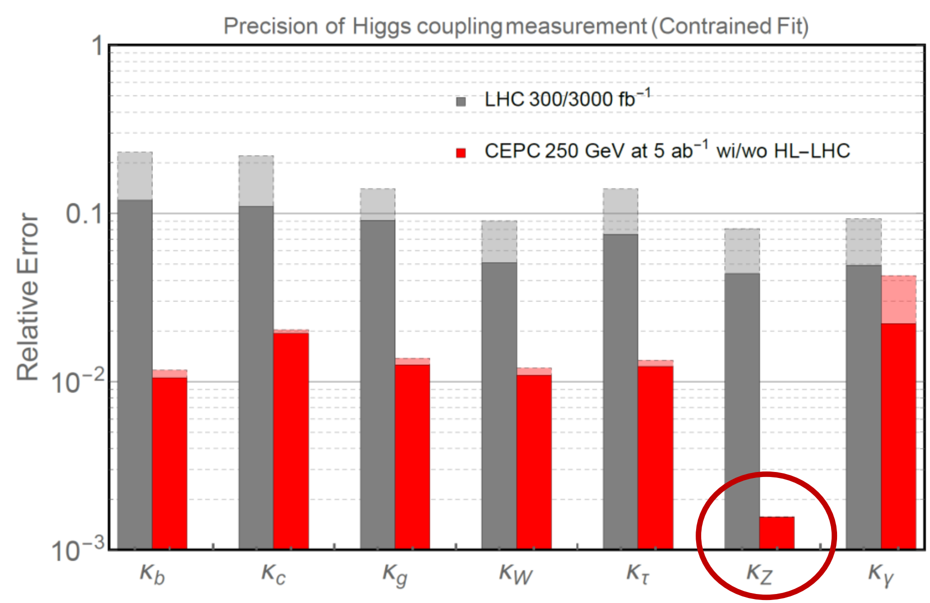
Most of the issues related to Higgs

Precision Higgs Physics by CEPC

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

% precision → M ~ 1 TeV
to new physics → ~ × 10 over LHC

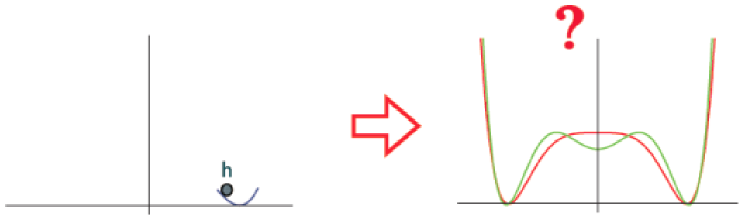


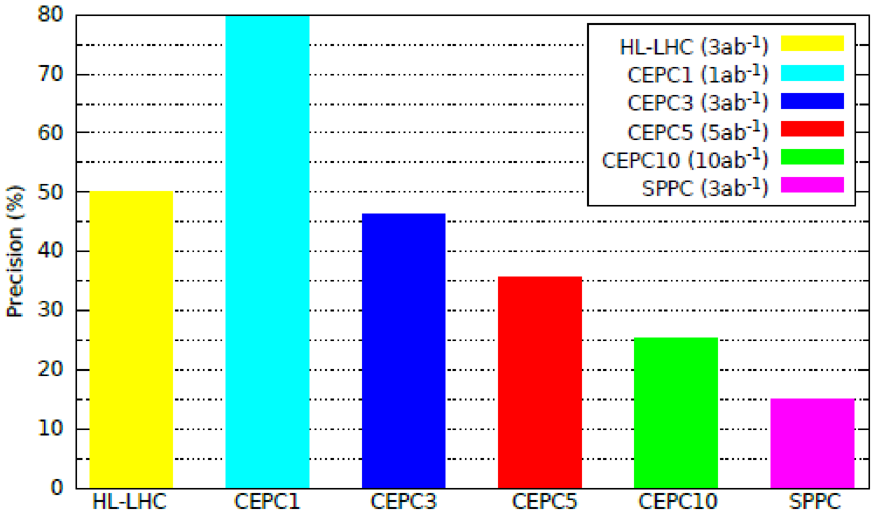


CEPC preCDR Volume 1 (p.9)

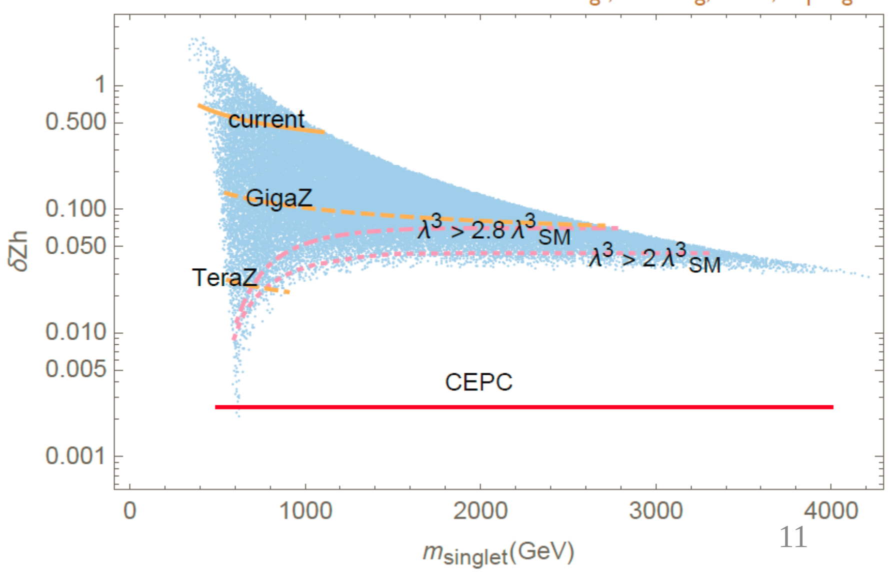
Nature of EW Phase Transition ?

- 1^{st} or 2^{nd} 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%

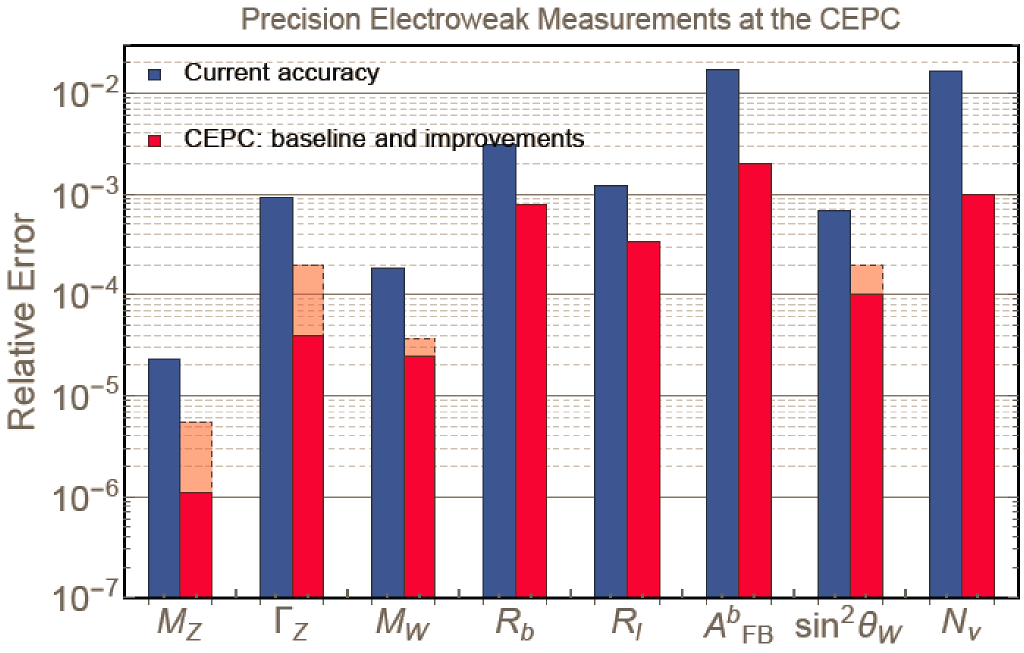


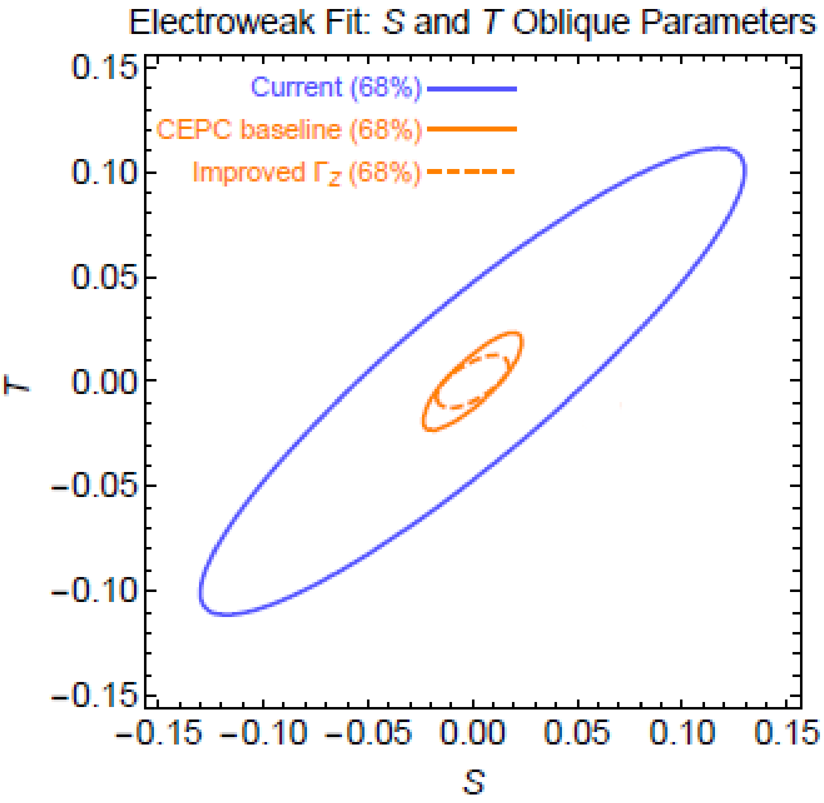


P. Huang , A. Long, LTW, in progress



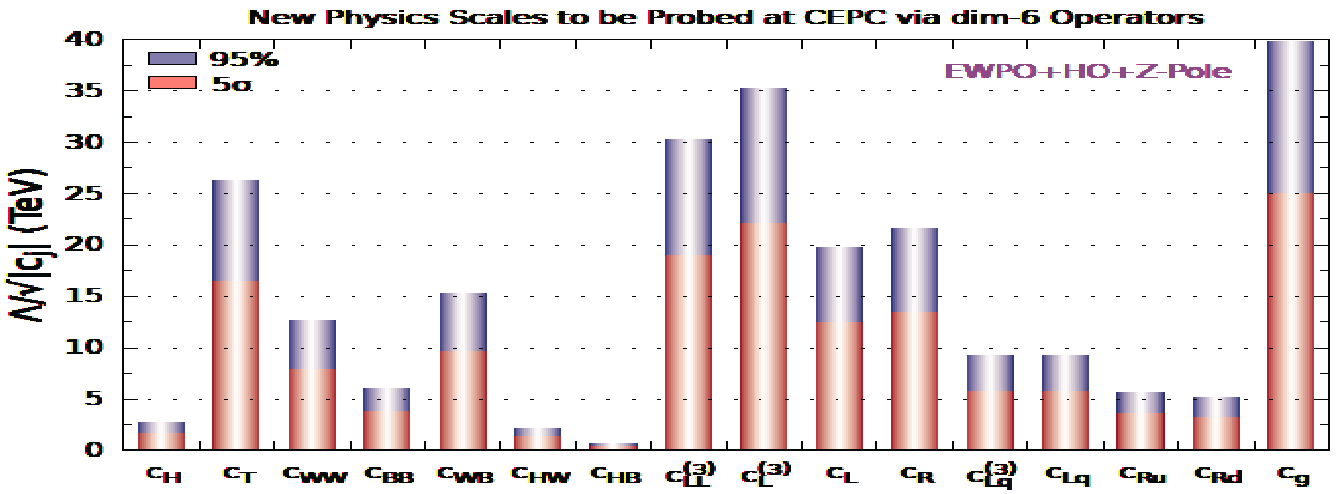
Improvement in Electroweak Precision





CEPC preCDR Volume 1 (p.10)

Probing New Physics



S. Ge, H. He, R. Xiao, 1603.03385

Into the Multi-TeV regime

A window to new physics through top and Higgs

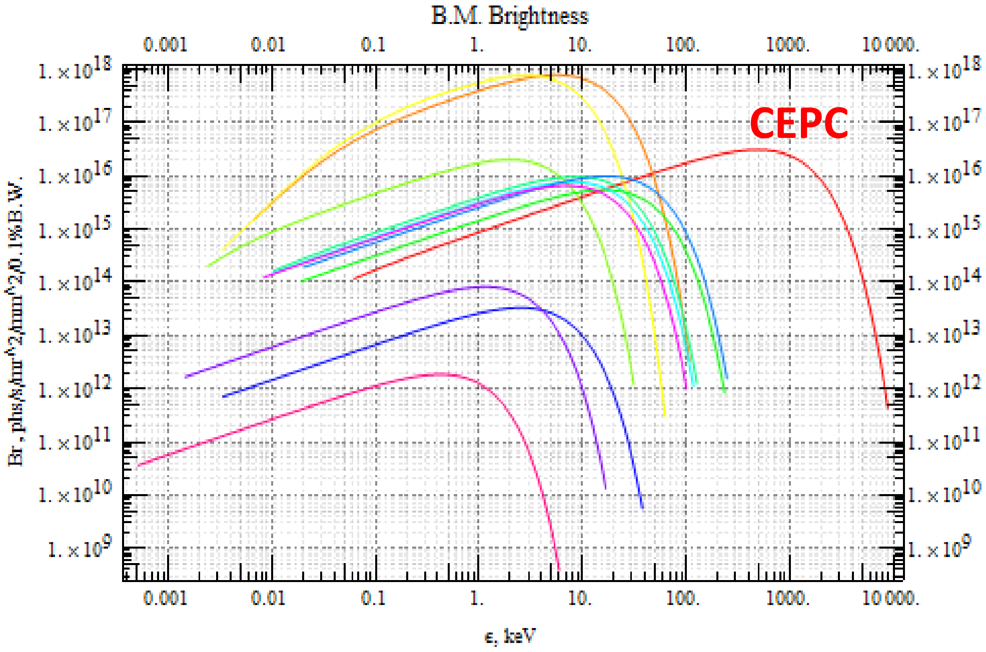
- Both are special
- Important for the vacuum stability & EWSB
- Higgs couplings to the dark sector through BR_{inv}

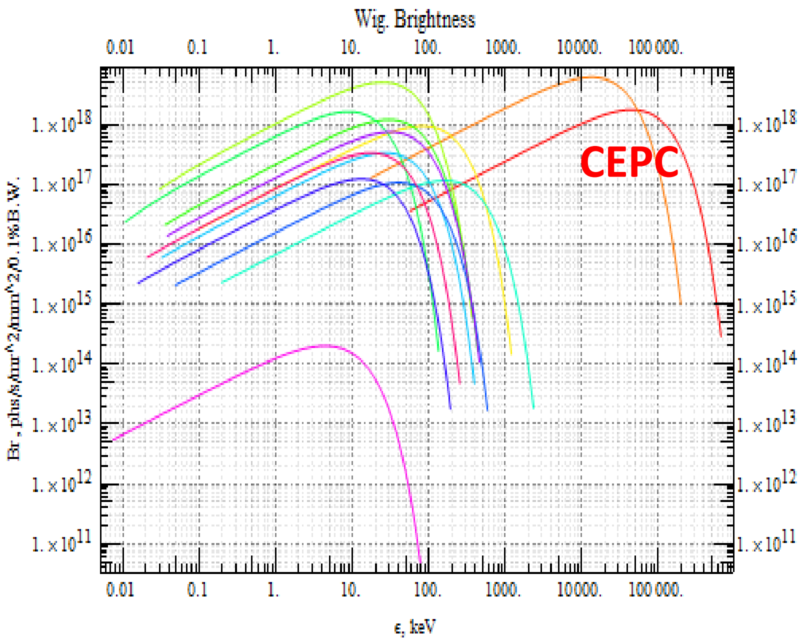
Experiment	κ_Z (68%)	f (GeV)	κ_g (68%)	$m_{\tilde{t}_L}$ (GeV)
HL-LHC	3%	1.0 TeV	4%	430 GeV
ILC500	0.3%	3.1 TeV	1.6%	690 GeV
ILC500-up	0.2%	3.9 TeV	0.9%	910 GeV
CEPC	0.2%	3.9 TeV	0.9%	910 GeV
TLEP	0.1%	5.5 TeV	0.6%	1.1 GeV

Experiment	S (68%)	f (GeV)	T (68%)	$m_{\tilde{t}_L}$ (GeV)
ILC	0.012	1.1 TeV	0.015	890 GeV
CEPC (opt.)	0.02	880 GeV	0.016	870 GeV
CEPC (imp.)	0.014	1.0 TeV	0.011	1.1 GeV
TLEP-Z	0.013	1.1 TeV	0.012	1.0 TeV
TLEP-t	0.009	1.3 TeV	0.006	1.5 TeV

CEPC as a Synchrotron Light Source

- From dipole magnet， synchrotron radiation can have an energy higher than 628keV
- Using wiggler or undulator, photon energy can be more than 20MeV
- Very useful for nuclear physics, material science, micro-processing, etc.





IHEP-CEPC-DR-2015-01

IHEP-EP-2015-01

IHEP-TH-2015-01

Can be downloaded from

http://cepc.ihep.ac.cn/preCDR/volume.html

CEPC-SPPC

Preliminary Conceptual Design Report

Volume I - Physics & Detector

403 pages, 480 authors

The CEPC-SPPC Study Group

March 2015

IHEP-CEPC-DR-2015-01

IHEP-AC-2015-01

CEPC-SPPC

Preliminary Conceptual Design Report

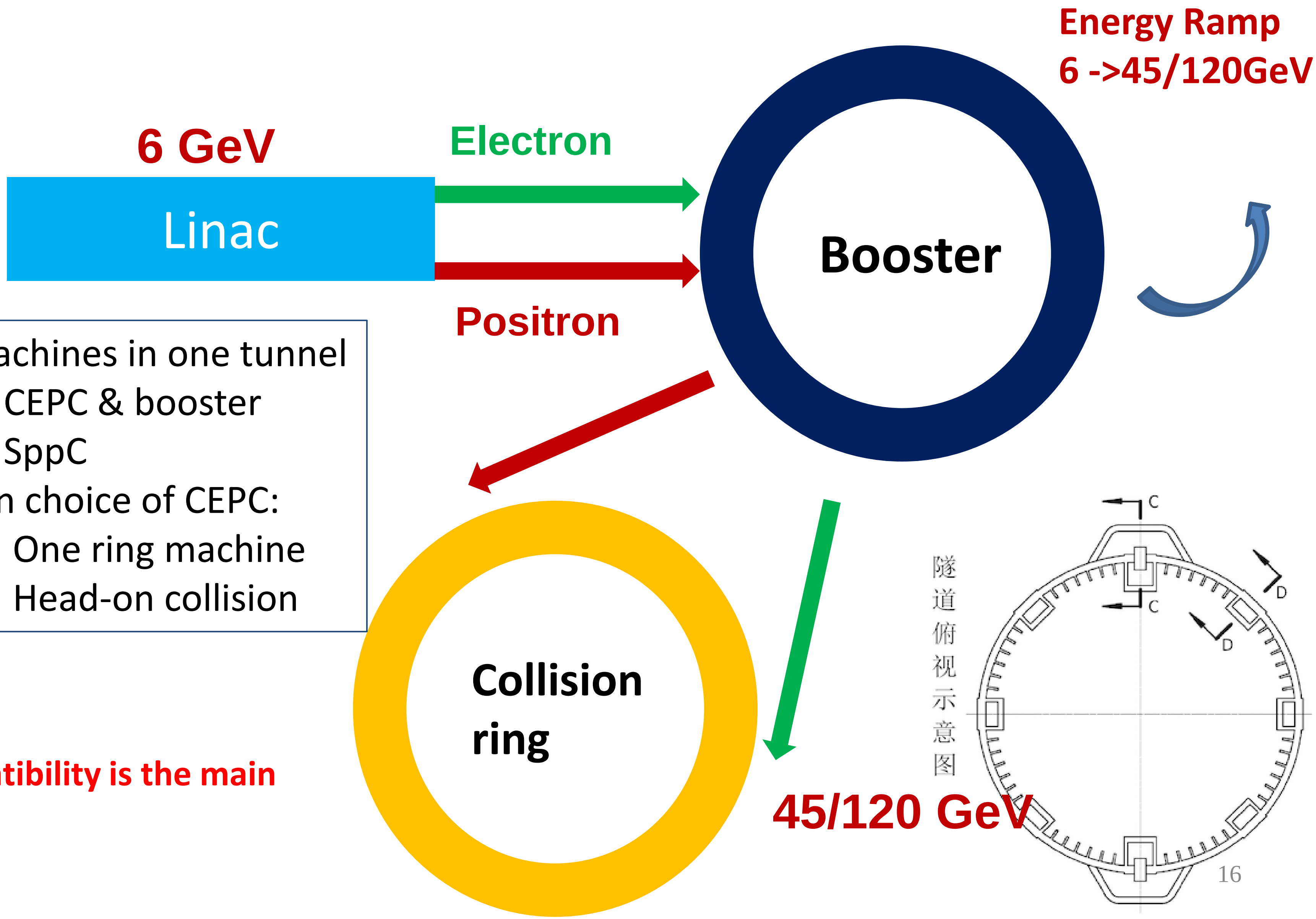
Volume II - Accelerator

328 pages, 300 authors

The CEPC-SPPC Study Group

March 2015

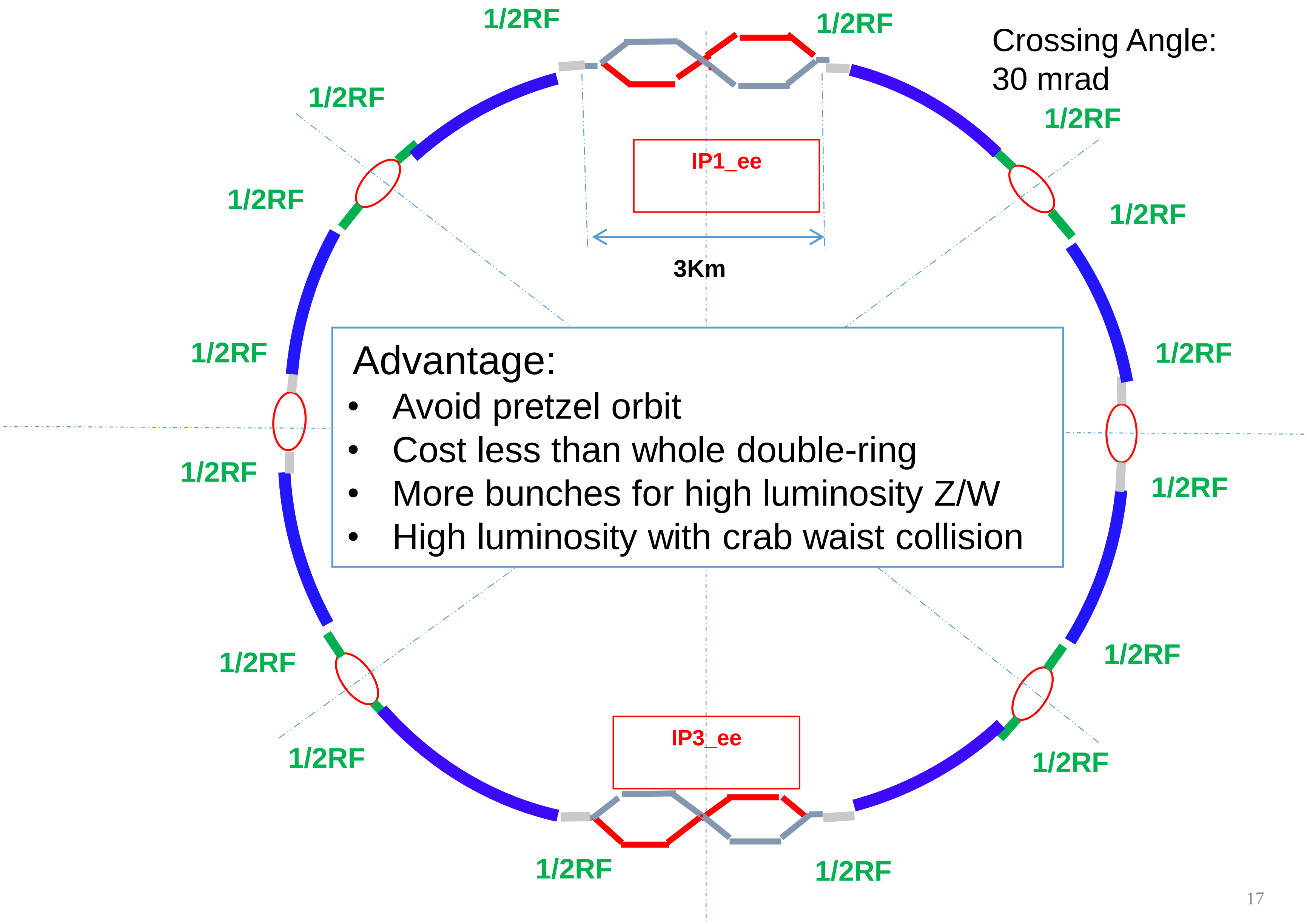
CEPC Accelerator



- 3 machines in one tunnel
  - CEPC & booster
  - SppC
- Main choice of CEPC:
  - One ring machine
  - Head-on collision

Compatibility is the main Issue

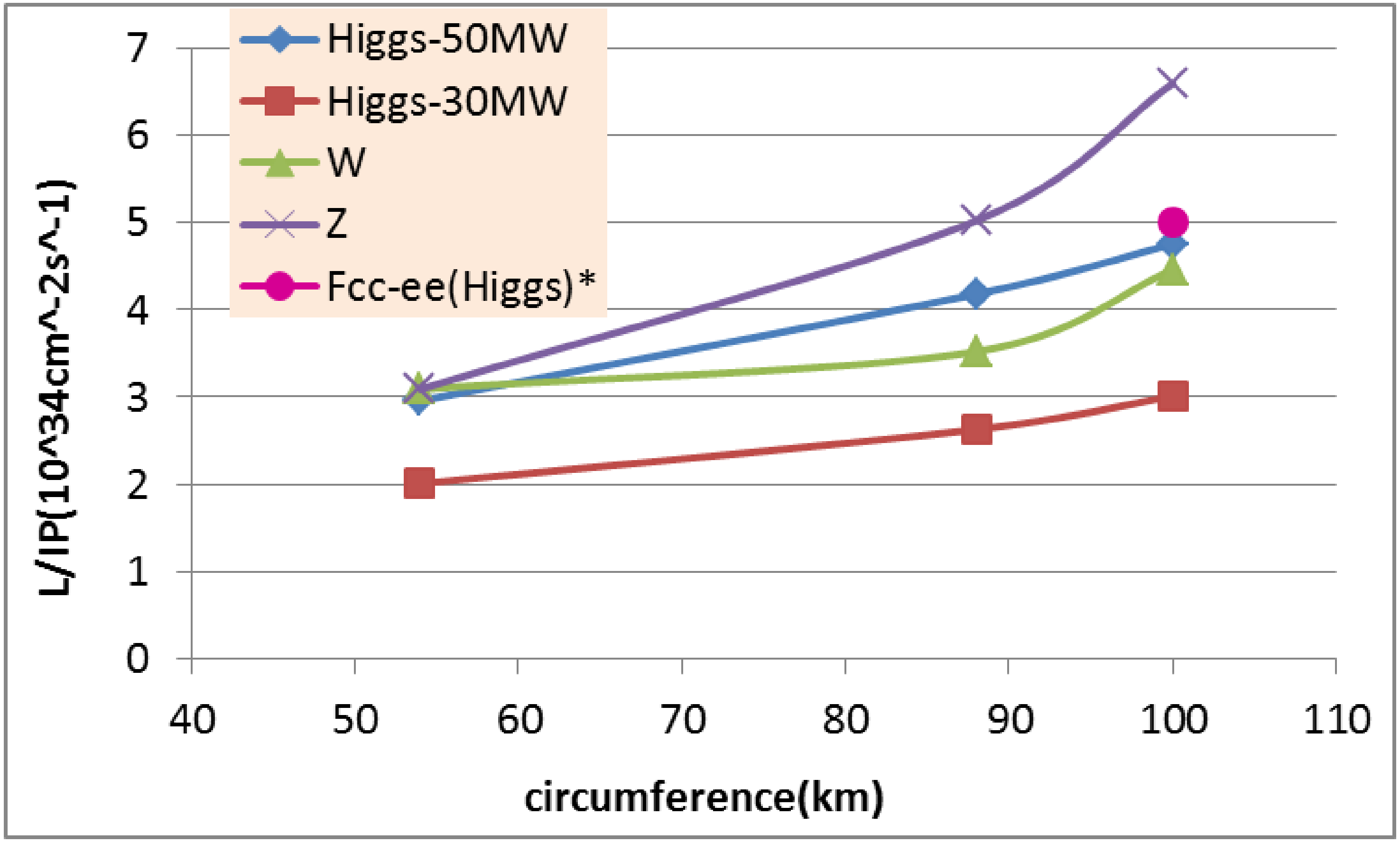
Innovation: Partial Double Ring



Advantage:

- Avoid pretzel orbit
- Cost less than whole double-ring
- More bunches for high luminosity Z/W
- High luminosity with crab waist collision

Partial Double Ring Luminosity

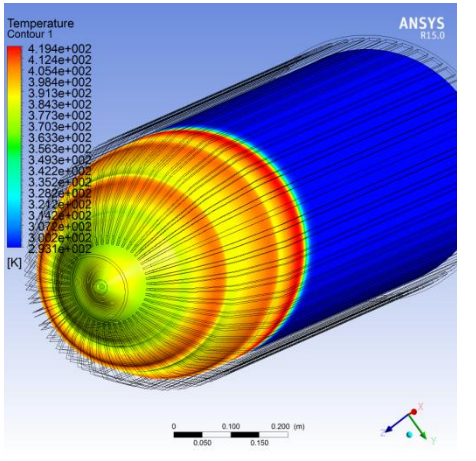


* Fabiola Gianotti, Future Circular ColliderDesign Study, ICFA meeting, J-PARC, 25-2-2016.

Main Challenges

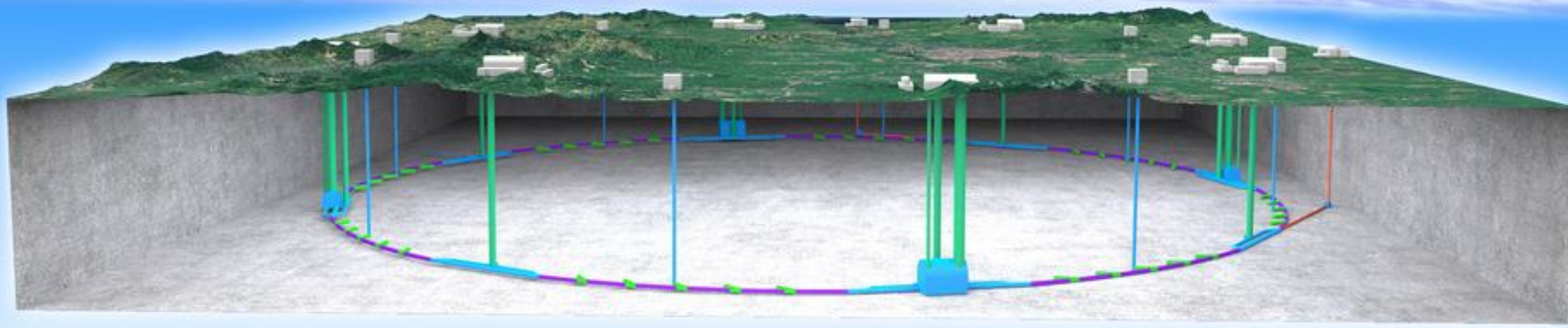
- Beam physics: dynamic aperture, momentum acceptance, electron cloud, pretzel scheme, …
- Superconducting cavities: High-Q cavity, HOM dumping, mass production, power consumption,…
- Total power consumption: Reuse the thermal power, New Klystron, etc.

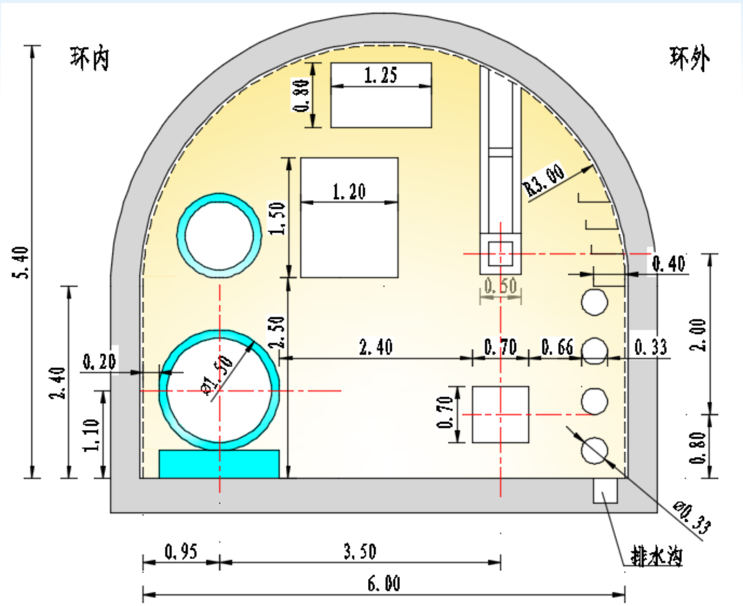
Parameters mode	Now	Future
Centre frequency (MHz)	650+/-0.5	650+/-0.5
Output power (kW)	**800**	**800**
Beam voltage (kV)	80	70
Beam current (A)	16	15
Efficiency (%)	**65**	**80**

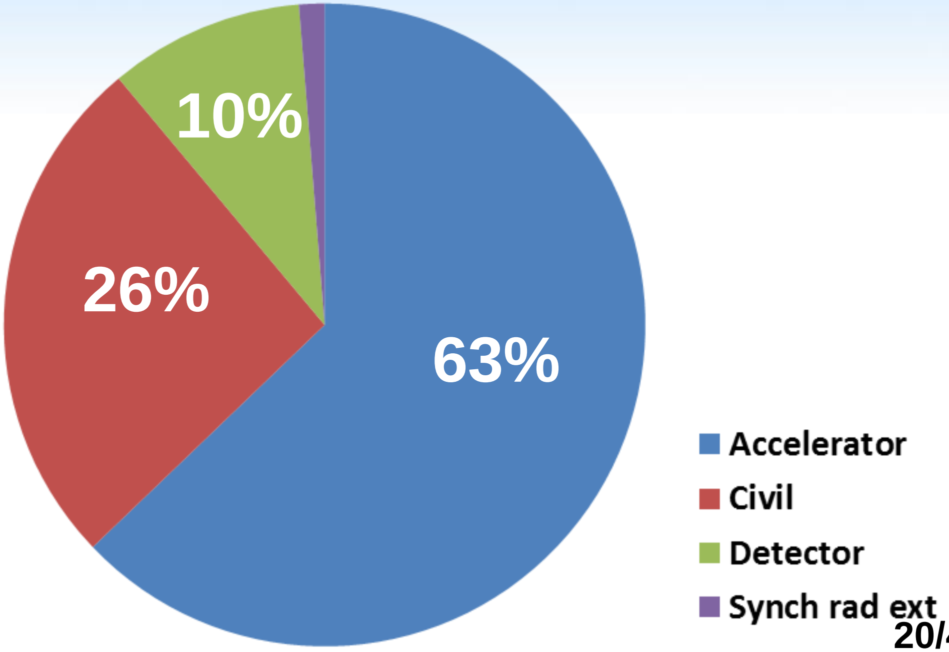


CEPC 650MHz RF power source R&D at IHEP

Civil Construction







Timeline (dream)

- **CPEC**
  - Pre-study, R&D and preparation work
    - Pre-study: 2013-15
      - **Pre-CDR for R&D funding request**
    - R&D: 2016-2020
    - Engineering Design: 2015-2020
  - Construction: 2022-2028
  - Data taking: 2029-2035
- **SppC**
  - Pre-study, R&D and preparation work
    - Pre-study: 2013-2020
    - R&D: 2020-2030
    - Engineering Design: 2030-2035
  - Construction: 2035-2042
  - Data taking: 2042 -

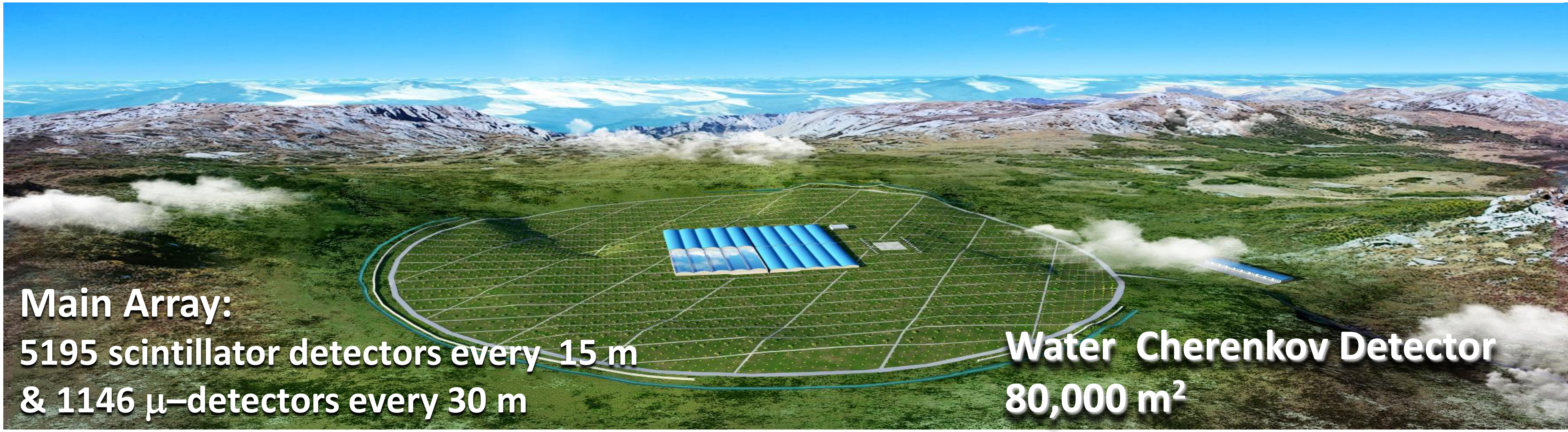
Major Projects: Current and Future

		Current	Future
Accelerator-based	Precision frontier	BESIII	International: ILC CEPC ➔ SppC
		LHCb, Belle II、PANDA、COMET	
	Energy frontier	CMS、ATLAS	
Non-accelerator-based	Underground	Daya Bay	JUNO ➔ JUNO-ββ
		Jinping: PANDAx, CDEX	Many
	Surface	ARGO/ASγ	LHASSO
			Ali for CMB
	Space	AMS	HERD XTP
		HXMT, Polar, DAMPE	

Large High Altitude Air Shower Observatory(LHAASO)

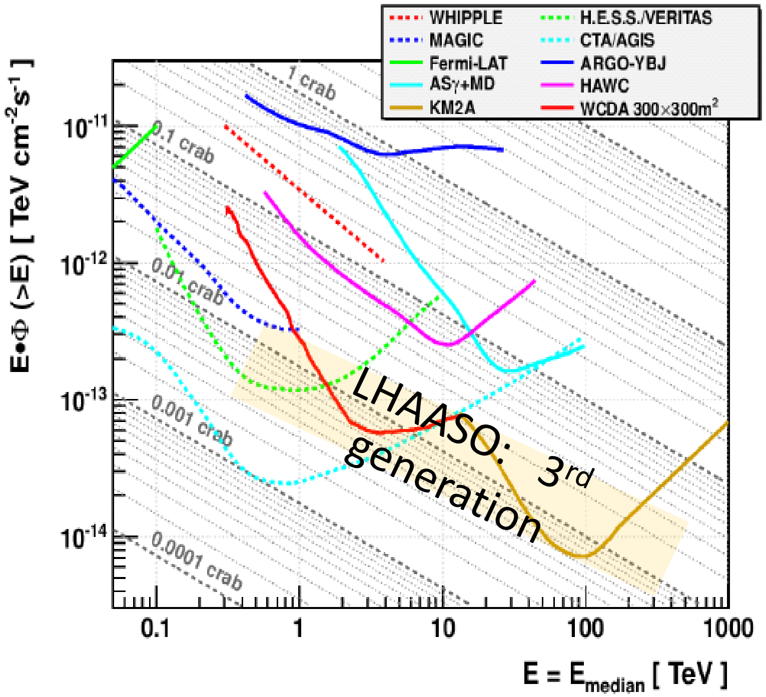
- To be funded for 2016-2020
- Sichuan province provides land & infrastructure
- Construction starts by the end of this year
- International collaboration:
  - China, Italy, France, Switzerland, Russia, Thailand

Sichuan, 4300 m a.s.l.



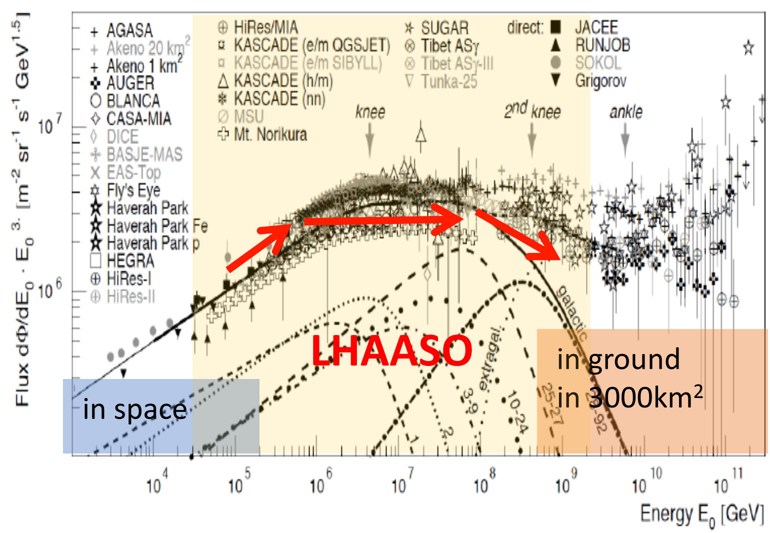
Science at LHAASO

- Unique for 10 TeV γ astronomy with the highest sensitivity in the world
- Window for discovering the hadronic origins of cosmic rays
- Crucial CR data covering a very wide energy region of knees
- Exploring for new physics, such as DM or quantum gravity



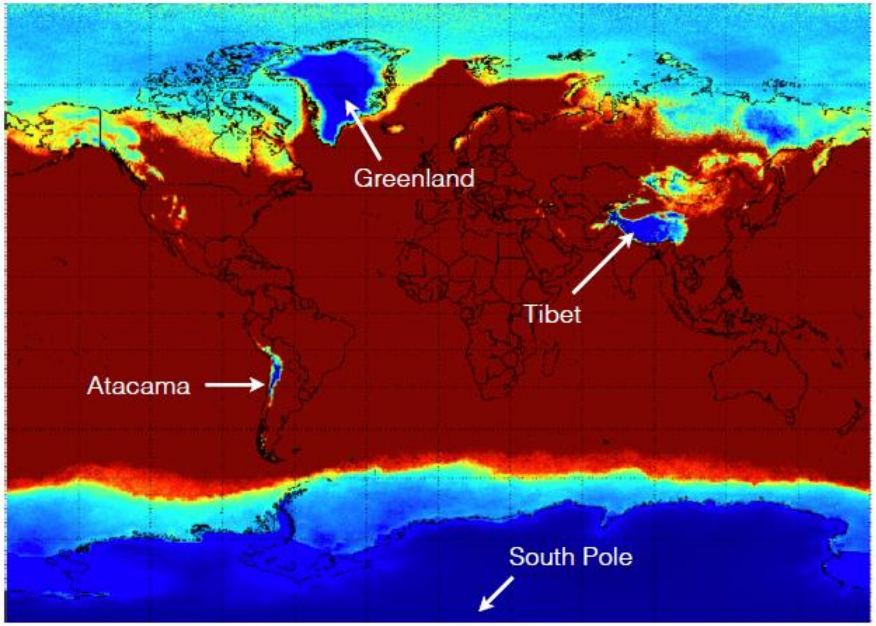
Complementary to CTA:

- ➢ All the time
- ➢ All the sky
- ➢ Time-variant sources
- ➢ Extended sources
- ➢ Fast indication for CTA



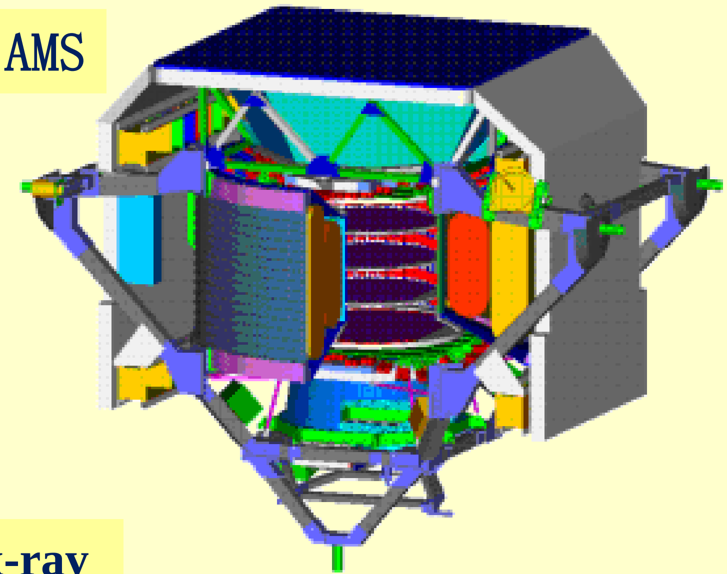
CMB at Tibet： Ali/BICEPx

- Measuring CMB polarization to look for signals of primordial gravitational waves; a prove of inflation
- Ali(5100m) is the best observatory in the north hemisphere
  - Moisture in winter: 1.0 mm(0.5mm at(~6000m)
    - Comparable or even better than South Pole/Chile
  - Existing infrastructure
  - Good sky coverage
- Collaboration with BICEPx:
  - China participate BICEPx & G4 planning at Chile/South pole
  - US & China establish a new site in Tibet

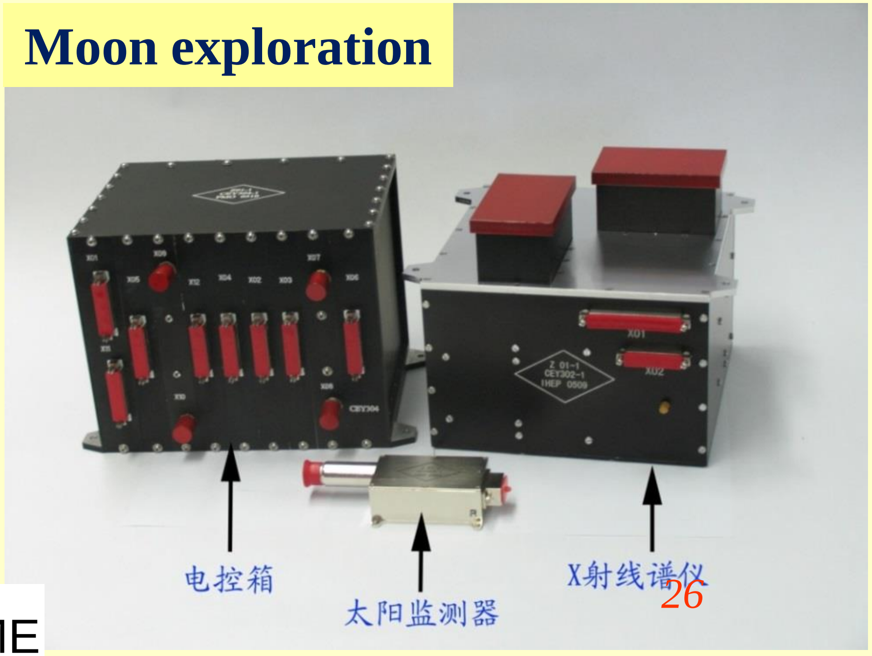


Space Projects

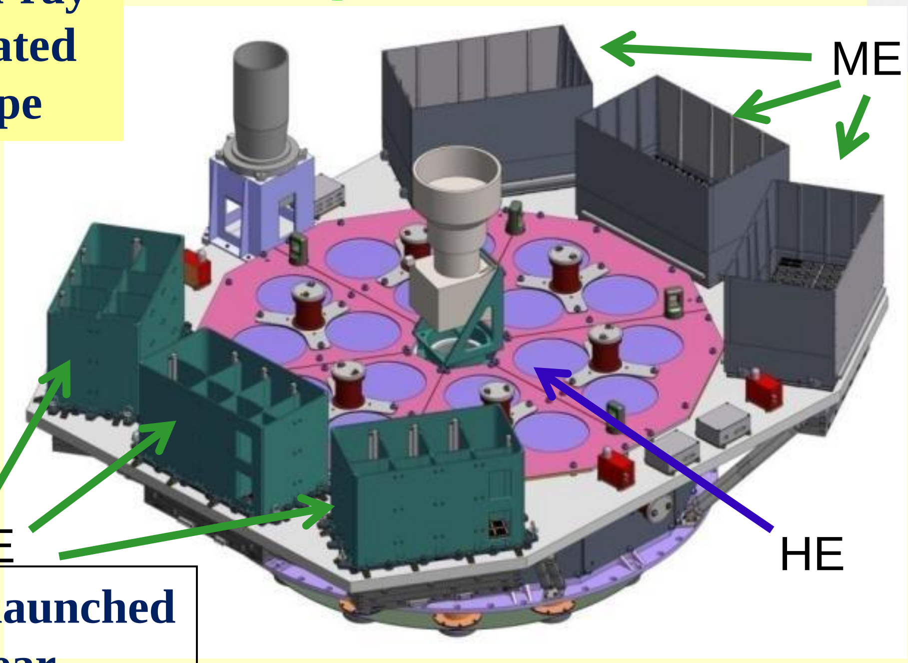
AMS



Moon exploration

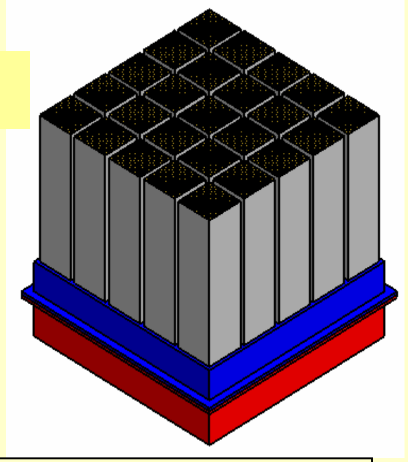


Hard x-ray modulated telescope



To be launched next year

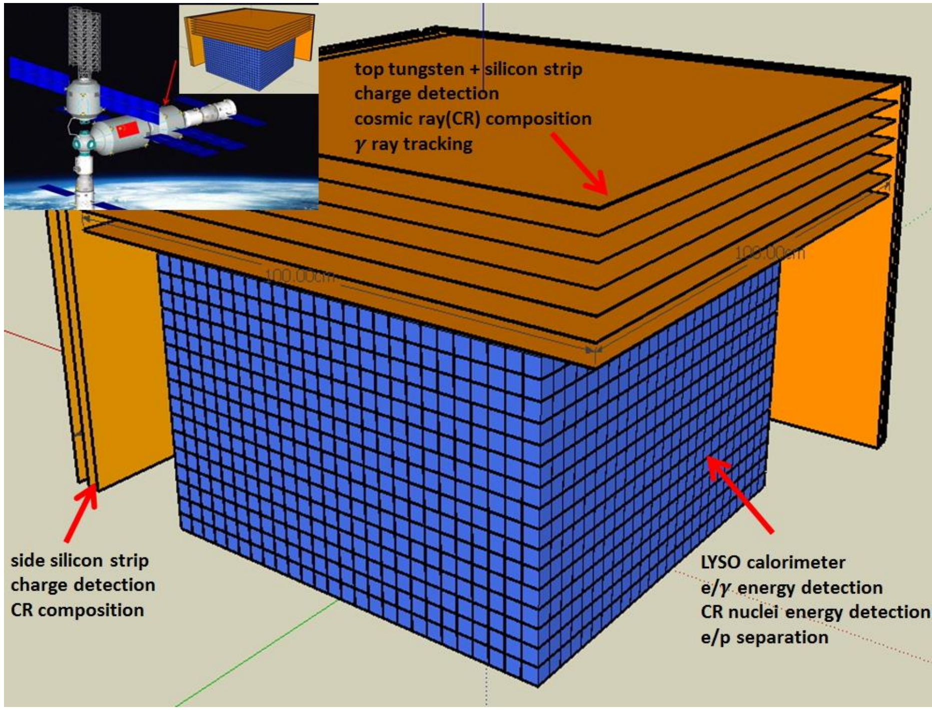
POLAR



successfully launched last month

HERD @ the China's Space Station

- Science
  - Dark matter search: γ from 100 – 10,000 GeV
  - γ-ray astronomy: GRBs, microquasars, Blazars and other transients down to 100 MeV
  - Spectral and composition measurements of CRs between 300 GeV to PeV with a large geometrical factor
  - Complementary to LHAASO: directly measured composition & spectrum in space
- Status
  - Groups from China, Italy, Switzerland, Sweden,…
  - Launch in ~2023

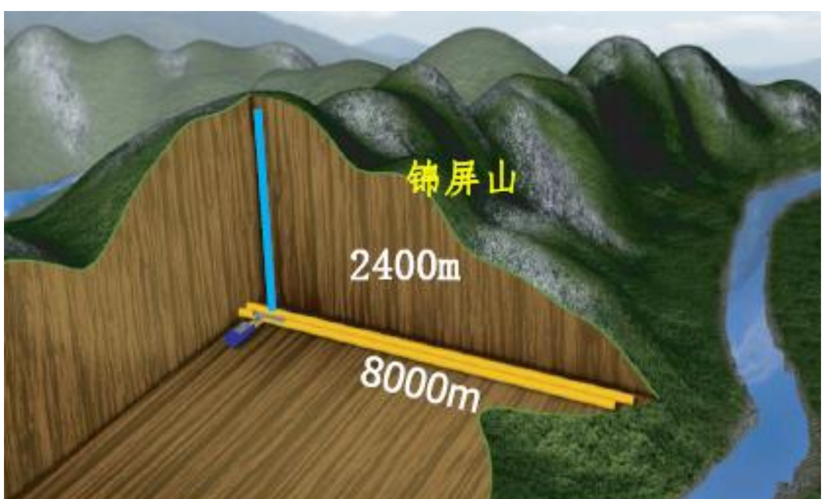


	X0(λ)	ΔE/E for e	e/p sep	e GF m^2sr@ 200GeV	p GF m^2sr@100TeV
HERD (2020)	55(3)	1%	10^{-6}	3.1	2.3
Fermi (2008)	10	12%	10^{-3}	0.9	--
AMS02 (2011)	17	2%	10^{-6}	0.12	--
DAMPE (2015)	31	1%	10^{-4}	0.3	--
CREAM (2015)	20(1.5)	--	--	--	0.2

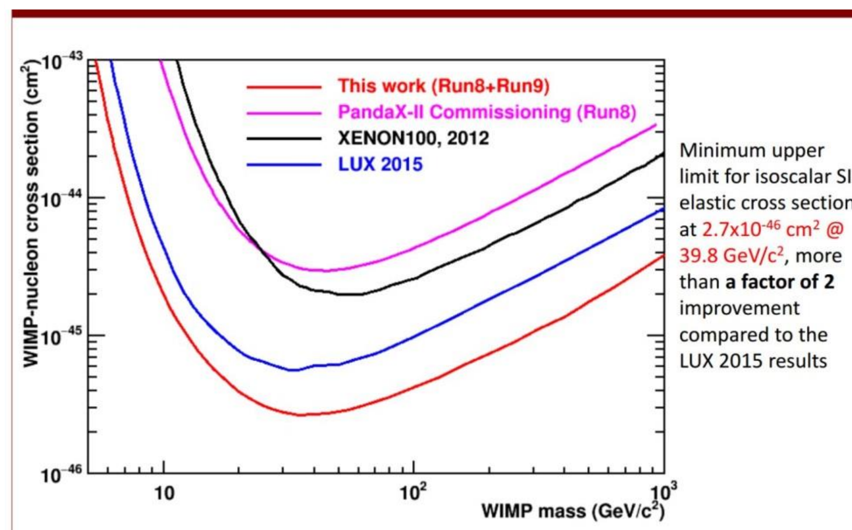
Acceptance & H-energy > 10X all others

JinPin Underground Laboratory

- The deepest underground laboratory in the world: 2400 m
- Current experiments: dark matter searches
  - Xe-based PandaX
  - Ge-based CDEX
- Future
  - Approved for the infrastructure construction: 4 large experimental halls, 12m×12m×100m
  - Next generation Xe- & Ge-based dark matter & ββ decay searches
  - Other possible experiments

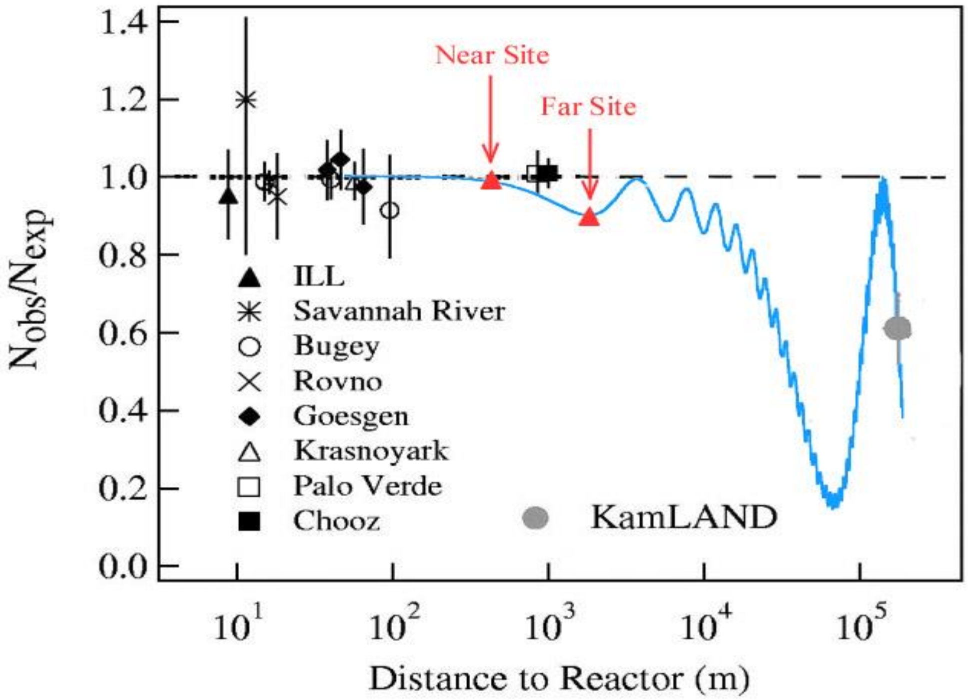


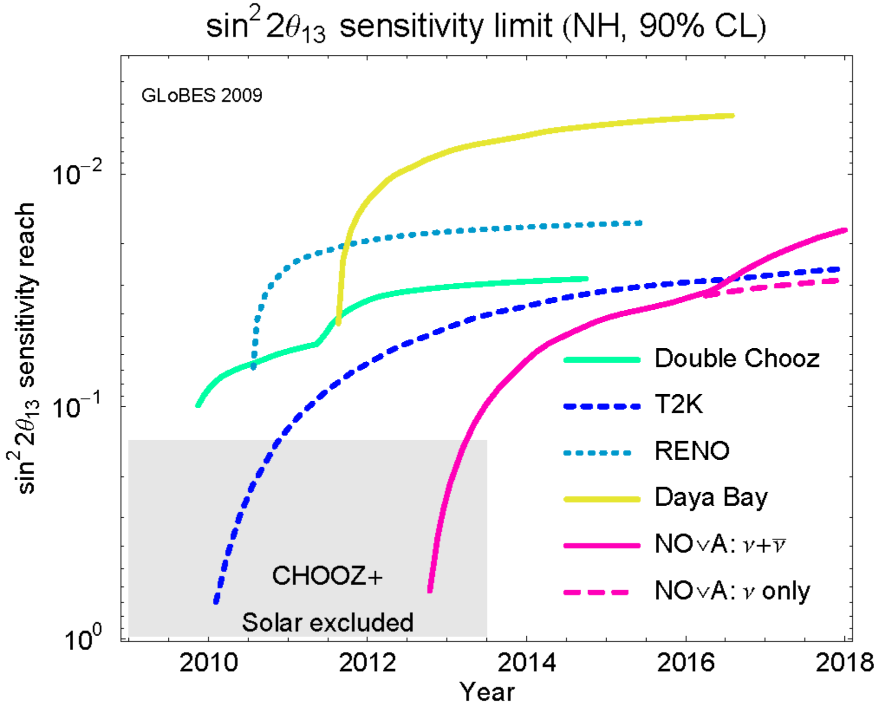
Recent PandaX results



Daya Bay Experiment for θ_{13}

$$P_{e\to e} \approx 1 - \sin^2 2\theta_{13} \sin^2(1.27\Delta m^2_{13} L/E) - \cos^4\theta_{13} \sin^2 2\theta_{12} \sin^2(1.27\Delta m^2_{12} L/E)$$



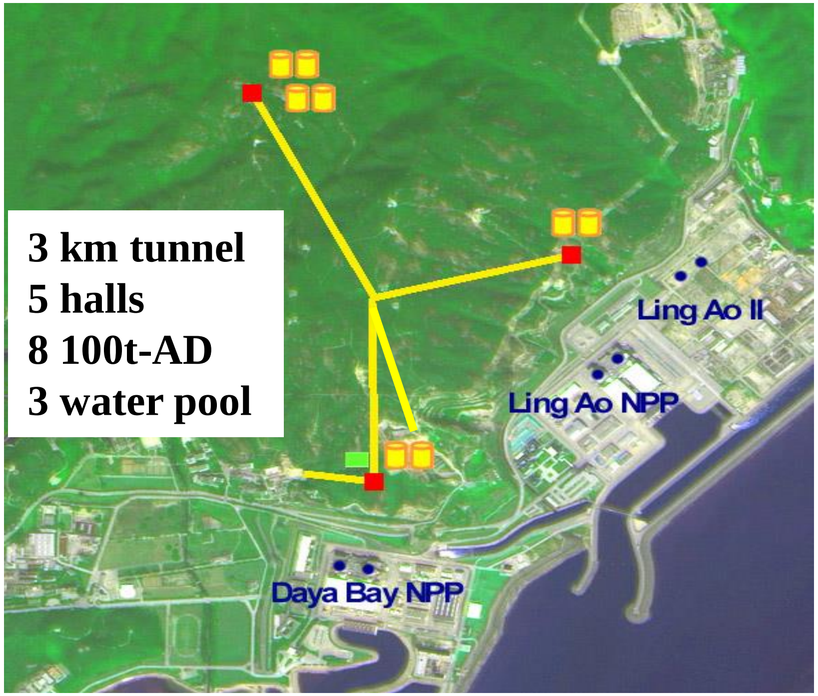


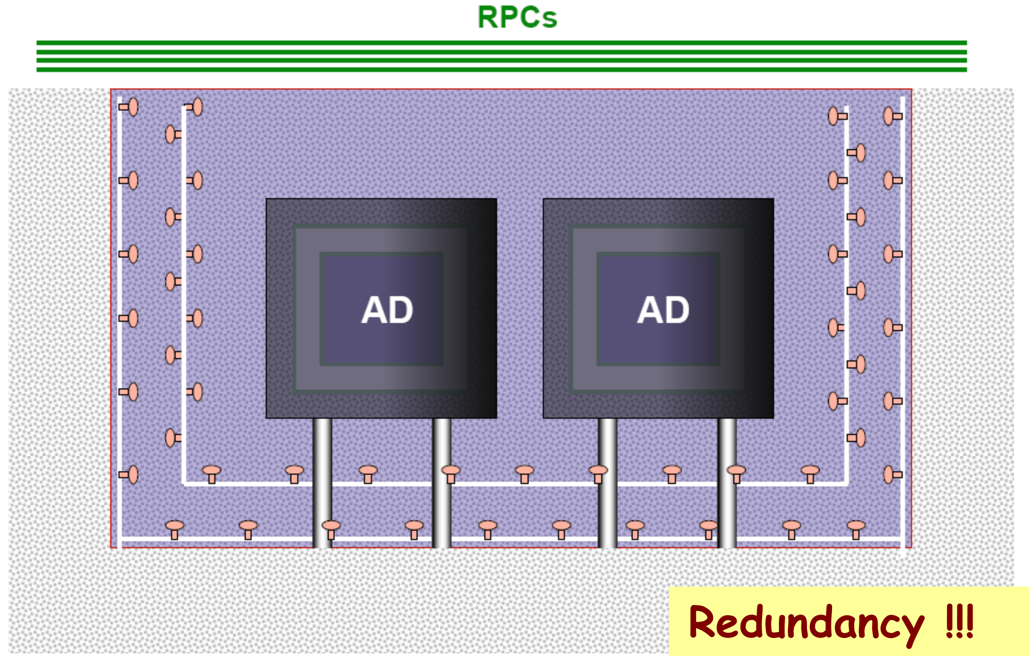
Past searches: $\sin^2 2\theta_{13} < 0.15$ @ 90%C.L.

Model prediction: $\sin^2 2\theta_{13} \sim 0\text{-}0.20$, but mostly around 0.01

Our design goal: $\Delta(N_{obs}/N_{exp}) \sim 0.4\%$ ➔ ÷10 improvement !

Experiment Layout



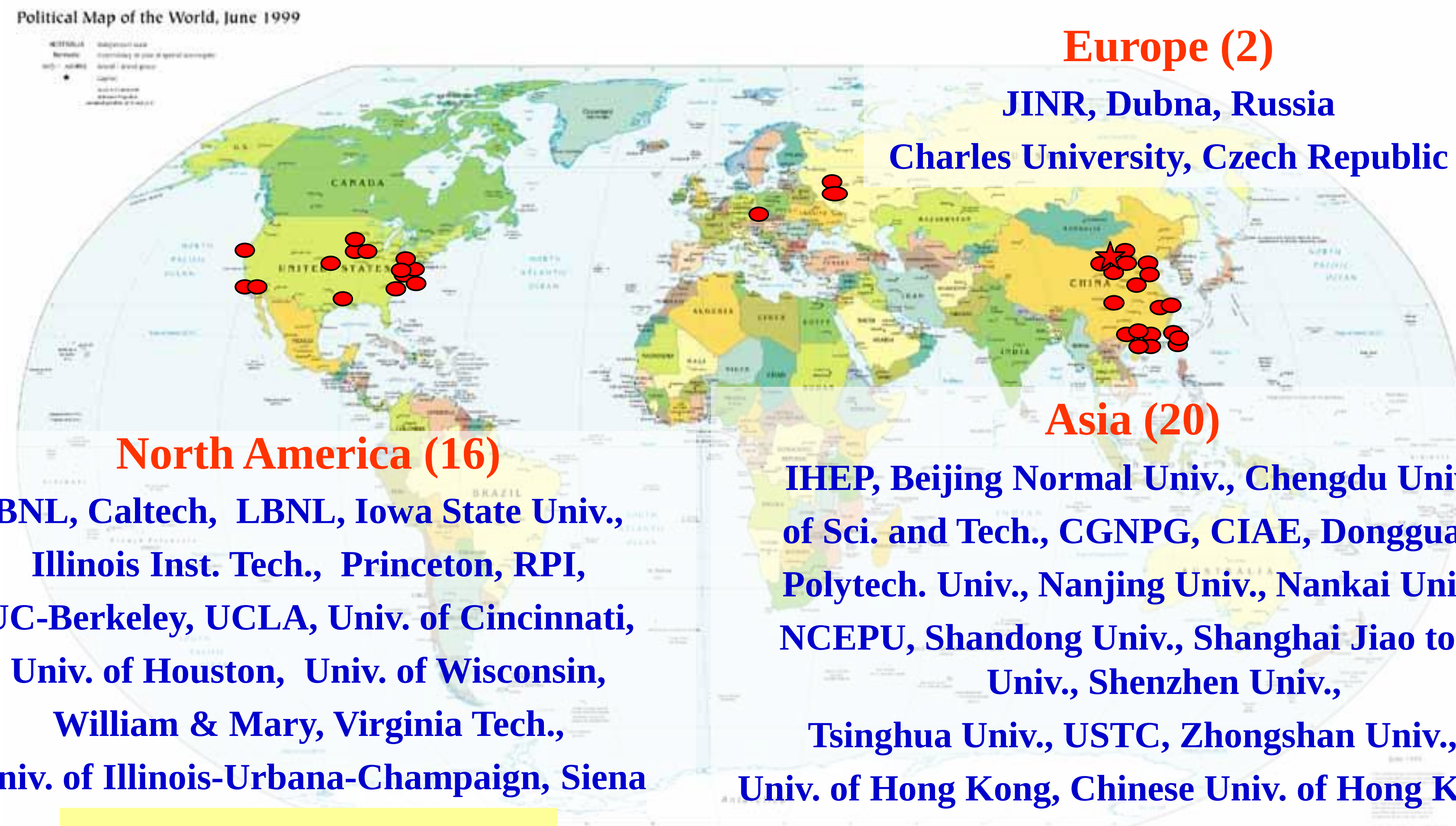


- Relative measurement to cancel Corr. Syst. Err.
  - ⇨ 2 near sites, 1 far site
- Multiple AD modules at each site to reduce Uncorr. Syst. Err.
  - ⇨ Far: 4 modules， near: 2 modules

Cross check; Reduce errors by $1/\sqrt{N}$

- Multiple muon detectors to reduce veto ineff. ➔ goal 0.5%
  - ⇨ Water Cherenkov： 2 layers
  - ⇨ RPC： 4 layers at the top + telescopes

The Daya Bay Collaboration



Europe (2)

JINR, Dubna, Russia
Charles University, Czech Republic

North America (16)

BNL, Caltech, LBNL, Iowa State Univ., Illinois Inst. Tech., Princeton, RPI, UC-Berkeley, UCLA, Univ. of Cincinnati, Univ. of Houston, Univ. of Wisconsin, William & Mary, Virginia Tech., Univ. of Illinois-Urbana-Champaign, Siena

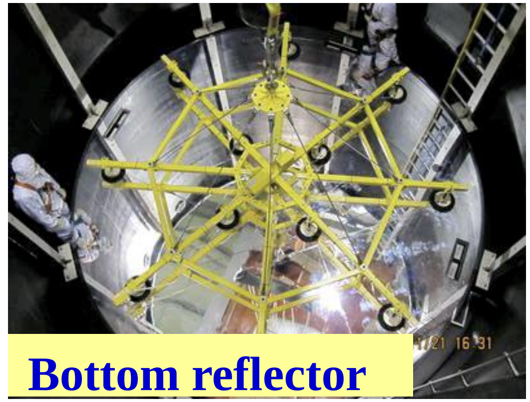
~250 Collaborators

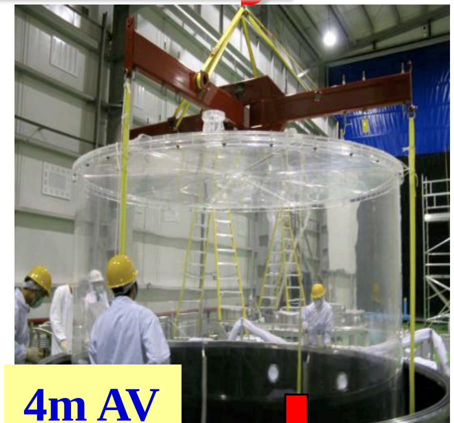
Asia (20)

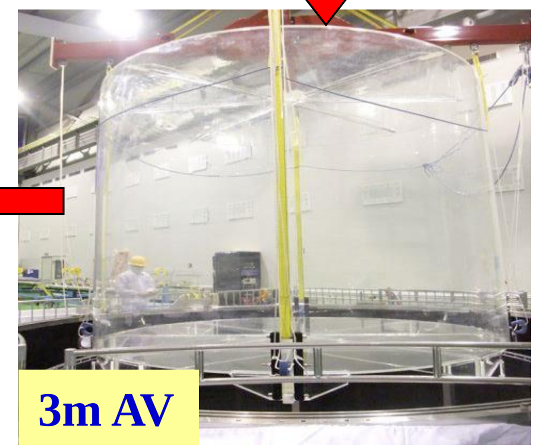
IHEP, Beijing Normal Univ., Chengdu Univ. of Sci. and Tech., CGNPG, CIAE, Dongguan Polytech. Univ., Nanjing Univ., Nankai Univ., NCEPU, Shandong Univ., Shanghai Jiao tong Univ., Shenzhen Univ., Tsinghua Univ., USTC, Zhongshan Univ., Univ. of Hong Kong, Chinese Univ. of Hong Kong, National Taiwan Univ., National Chiao Tung Univ., National United Univ.

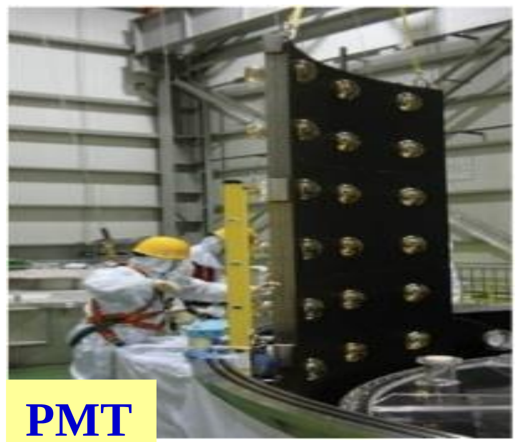
Neutrino Detector Assembly

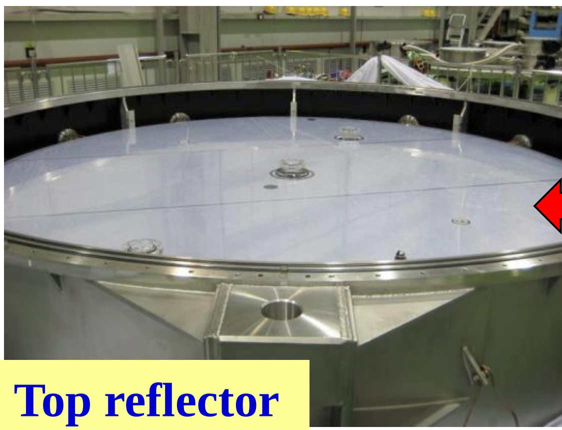

SSV


Bottom reflector


4m AV


3m AV


PMT


Top reflector


SSV lid


Leak check


ACU

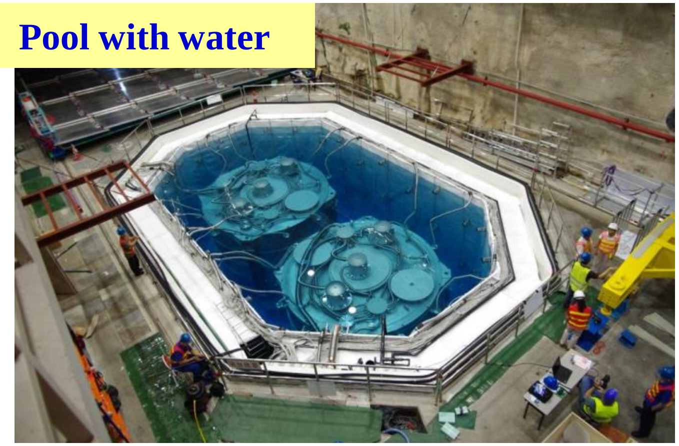
Water Cerenkov Detector Installation

PermaFlex painting

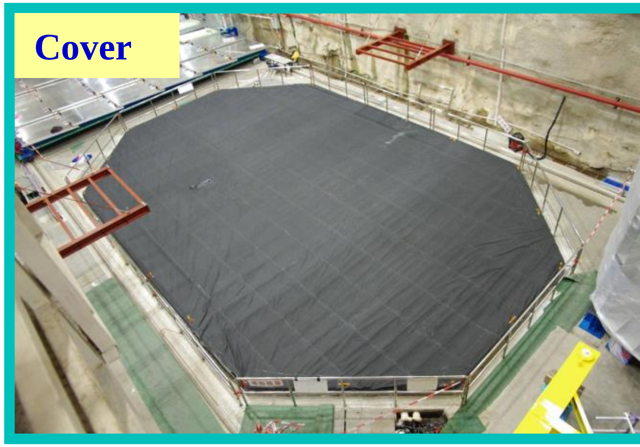
PMT frame & Tyvek

Completed pool

Install AD

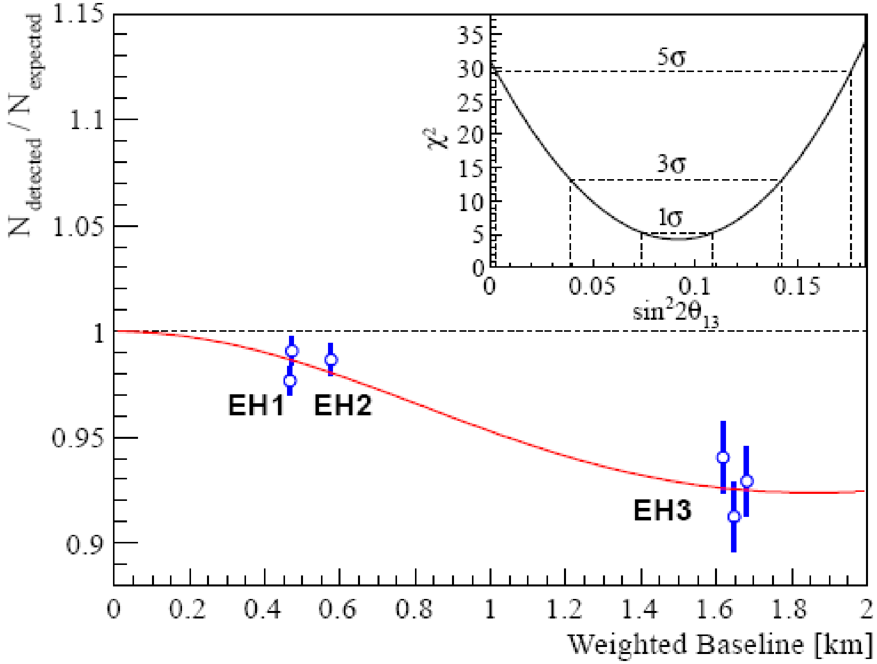


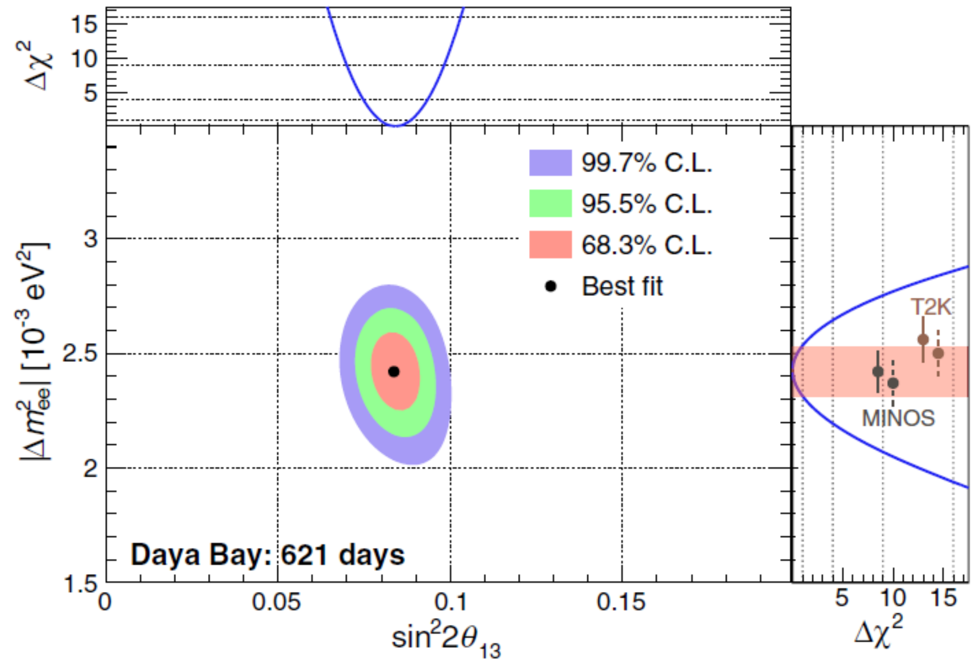
Pool with water



Cover

Resutls from Daya Bay





$\mathrm{Sin}^2 2\theta_{13} = 0.092 \pm 0.016(\mathrm{stat}) \pm 0.005(\mathrm{syst})$
$\chi^2/\mathrm{NDF} = 4.26/4$, 5.2 σ for non-zero θ_{13}

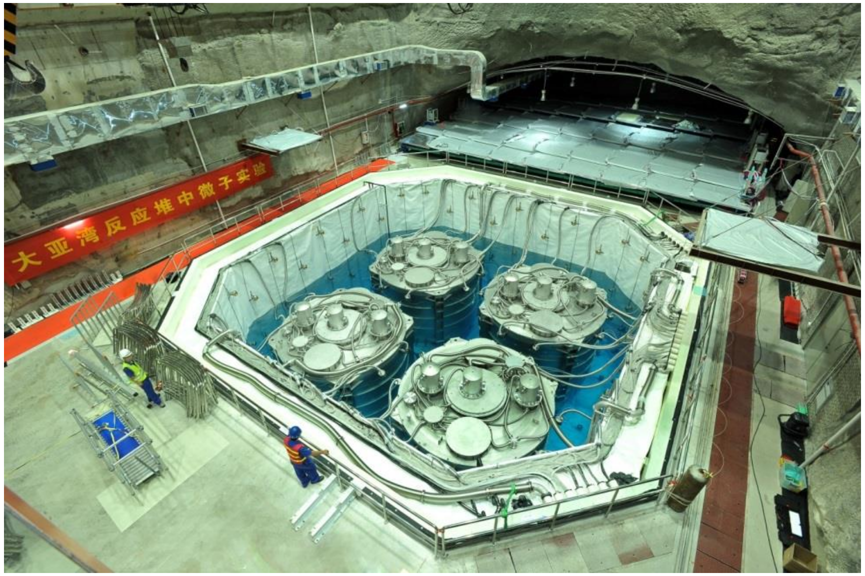
$\mathrm{Sin}^2 2\theta_{13} = 0.084 \pm 0.005$
$|\Delta M^2_{ee}| = (2.42 \pm 0.11) \times 10^{-3}\ \mathrm{eV}^2$

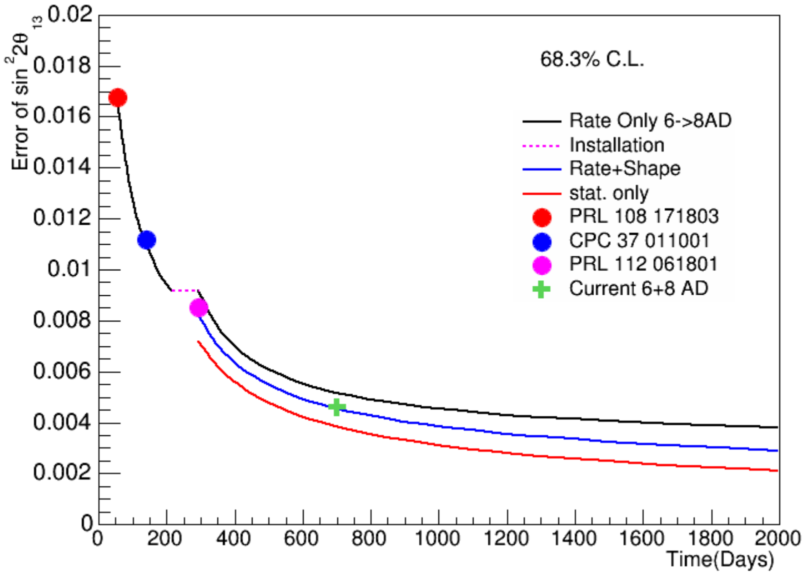
F.P. An et al., Phys. Rev. Lett. 108, (2012) 171803; citation > 1300

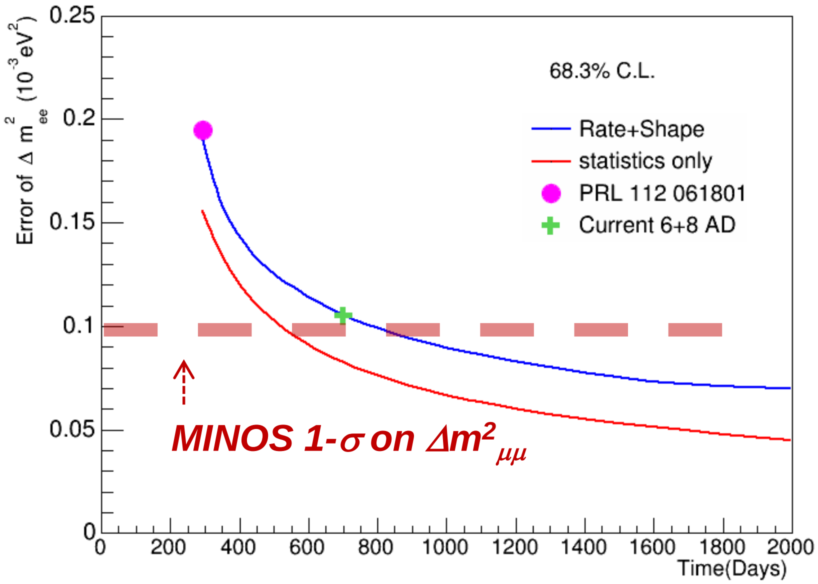
arXiv: 1505.03456; 1603.03549

Future Prospects

- Data taking for θ_{13} until 2020
- Precision can reach $\Delta(\sin^2 2\theta_{13})$ ~ 3%; the best for the foreseeable future
- Other physics topics:
  - ⇨ Cosmogenic isotope production
  - ⇨ Supernova neutrinos
  - ⇨ Correlated cosmic-ray events

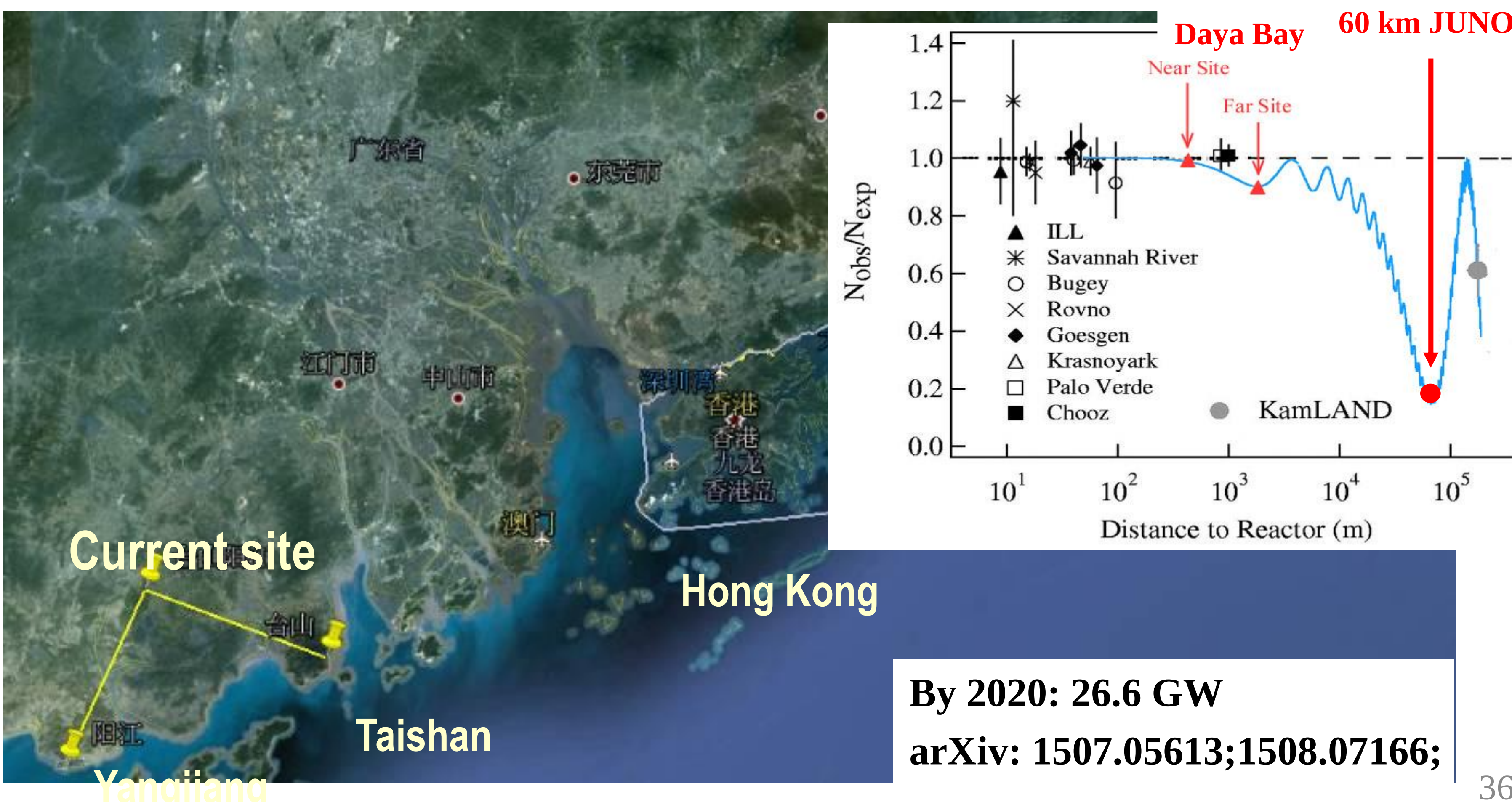






JUNO

	Daya Bay	Huizhou	Lufeng	Yangjiang	Taishan
Status	running	planned	approved	Construction	construction
power/GW	17.4	17.4	17.4	17.4	18.4

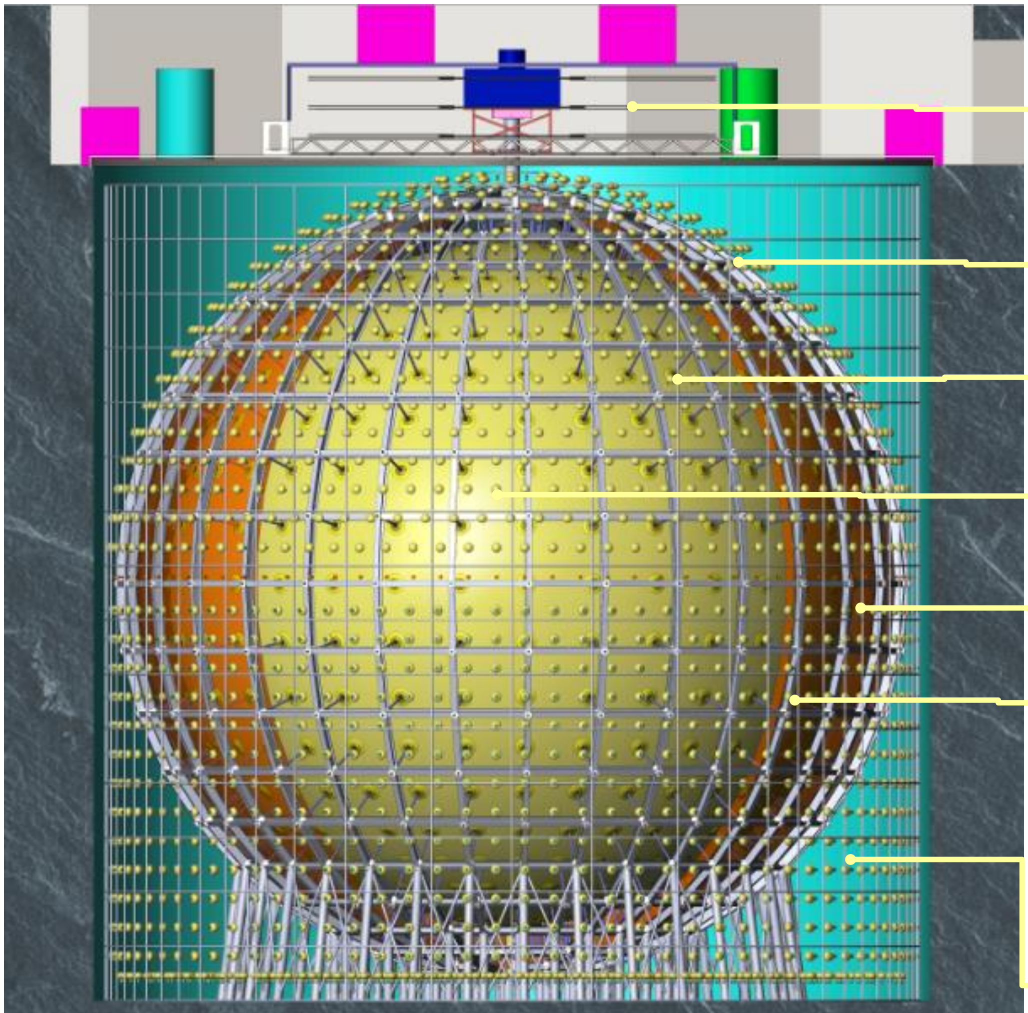


By 2020: 26.6 GW

arXiv: 1507.05613;1508.07166;

Largest LS Detector

- LS volume: × 20 ➔ for more statistics (40 events/day)
- light(PE) × 5 ➔ for better resolution ($\Delta M^2_{12}/\ \Delta M^2_{23}$ ~ 3%)



Physics Reach

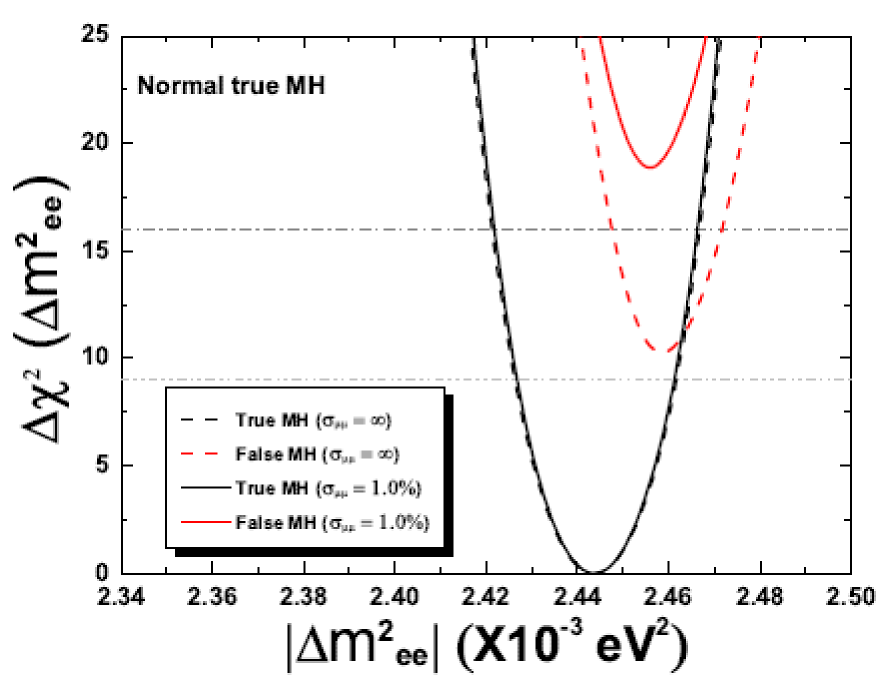
Thanks to a large θ_{13}

- **Mass hierarchy**
- Precision measurement of mixing parameters
- Supernova neutrinos
- Geoneutrinos
- Sterile neutrinos
- ……

	Current	JUNO
Δm^2_{12}	4%	0.6%
Δm^2_{23}	4%	0.6%
$\sin^2\theta_{12}$	6%	0.7%
$\sin^2\theta_{23}$	10%	N/A
$\sin^2\theta_{13}$	6% ➔ 4%	~ 15%

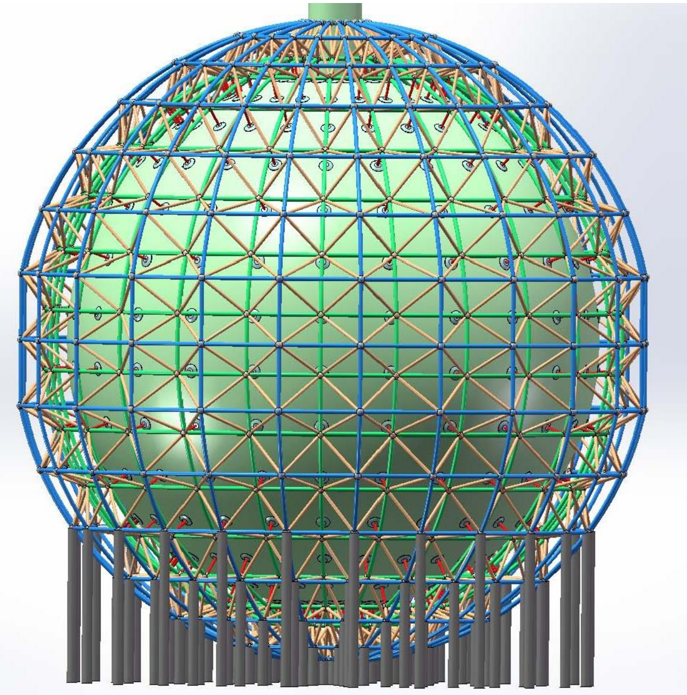
MH sensitivity with 6 years' data:

Ref: Y.F Li et al, PRD 88, 013008 (2013)	Relative Meas.	[a]Use absolute Δm^2
Ideal case	4σ	5σ
[b]Realistic case	3σ	4σ



Challenge I：Central Detector

- **A huge detector in the water pool:**
  - Mechanics，optics, chemistry, …
  - How to keep it clean ?
  - Possibility of assembly within 1 years
- **Two main options: acrylic vs balloon**
- **Final choice: A SS structure to hold the acrylic sphere and to mount PMTs**
  - Detailed calculation in agreement with experimental data
  - Acrylic sheets: 9m × 3m ×12 cm
- **Prototyping:**
  - Thermal shaping of acrylic sheets
  - Bonding of large sheets: ~ 1/100 in area

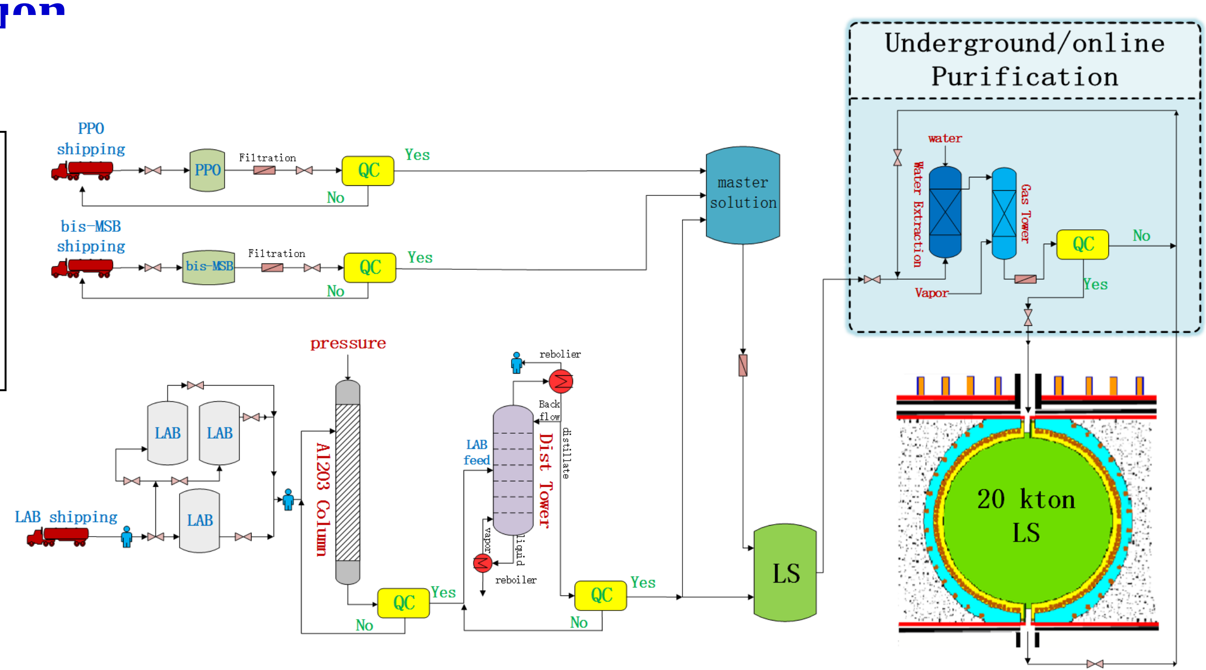


Challenge II: Liquid Scintillator

- **Current Choice: LAB+PPO+BisMSB**
- **Requirements and R&D:**
  - ⇨ **Long attenuation length: 15m ➔ 30m**
    - ✓ **Improve raw materials**
    - ✓ **Improve the production process**
    - ✓ **Purification**
      - **Distillation, Filtration, Water extraction, Nitrogen stripping…**
  - ⇨ **High light yield: Optimization of PPO & BisMSB concentration**

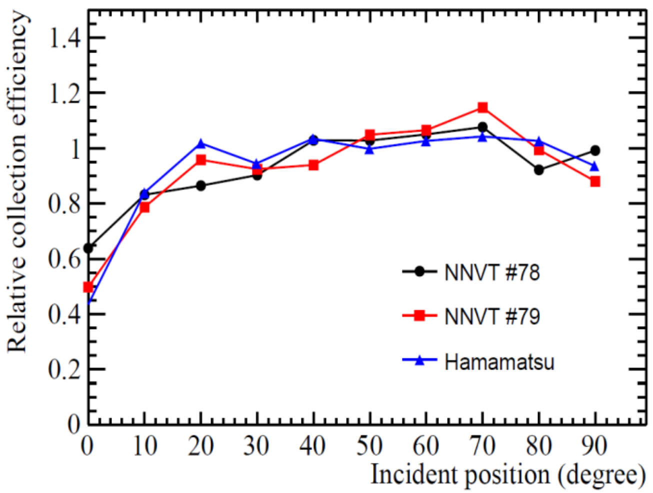
Linear Alky Benzene	Atte. L(m) @ 430 nm
RAW	14.2
Vacuum distillation	19.5
SiO_2 coloum	18.6
Al_2O_3 coloum	22.3
LAB from Nanjing, Raw	20
Al_2O_3 coloum	25

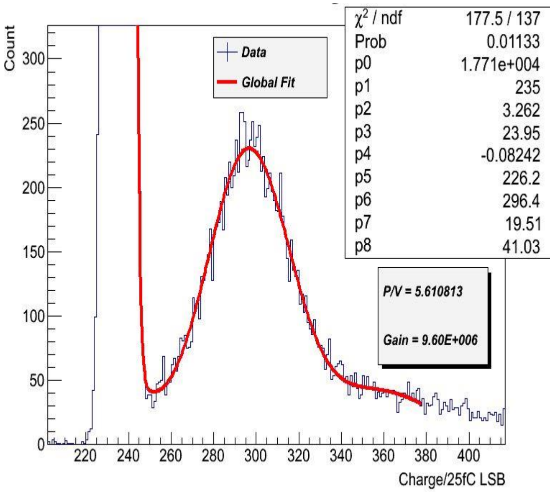
Engineering issues:
Equipment & handling for 20kt
Raw material selection:
BKG & purity issues



Challenge III: Photomultipliers

- Large, High QE PMT's badly needed
- Efforts started in 2009 to develop MCP-PMT, with a goal of QE > 35%
- Partnered with NNVC, XIOPM and others
- Successful development:
  - NNVC: QE(30%)*DE(100%) > 27%
  - Hamamatsu: QE(30%)*DE(90%) > 27%
- Purchase plan completed:
  - 15000 from NNVC
  - 5000 from Hamamatsu





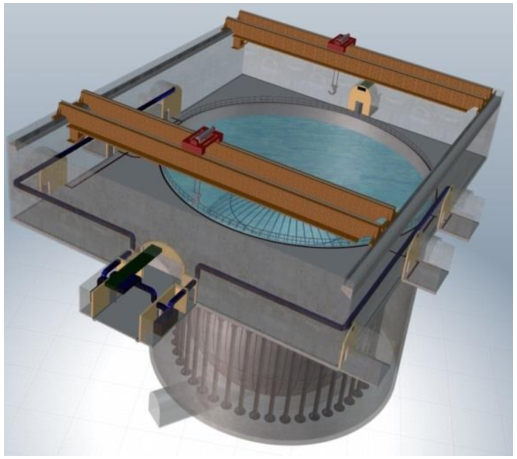
Challenge IV: Civil Construction

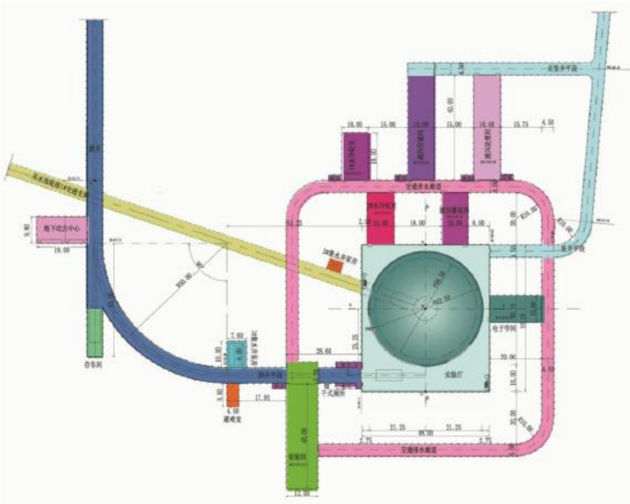
620 米竖井，1300米斜井
50米跨度，80高地下大厅

Schedule & Current Status

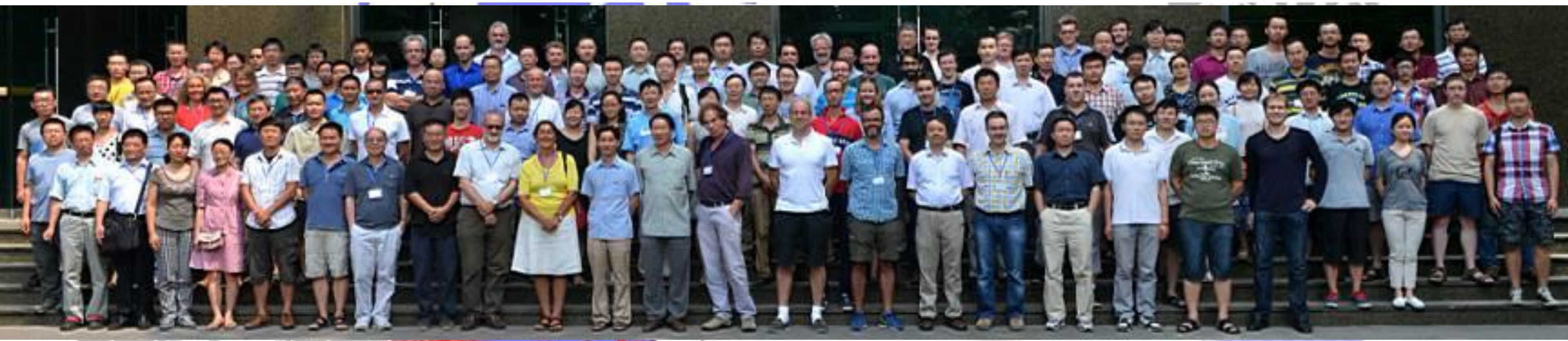
Schedule:

- Civil preparation：2013-2014
- Civil construction：2014-2017
- Detector component production：2016-2017
- PMT production：2016-2019
- Detector assembly & installation：2018-2019
- Filling & data taking：2020





JUNO collaboration established



Europe (27)

Armenia(1)
Yerevan Phys. Inst

Belgium(1)
ULB

Czech(1)
Charles U

France(5)
APC Paris
CPPM Marseille
IPHC Strasbourg
LLR Paris
Subatech Nantes

Finland(1)
U.Oulu

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

America(4)

US(2)
UMD
UMD-Geo

Chile(2)
Catholic Univ. of Chile
BISEE

Thailand(1)
SUT

Asia (31)

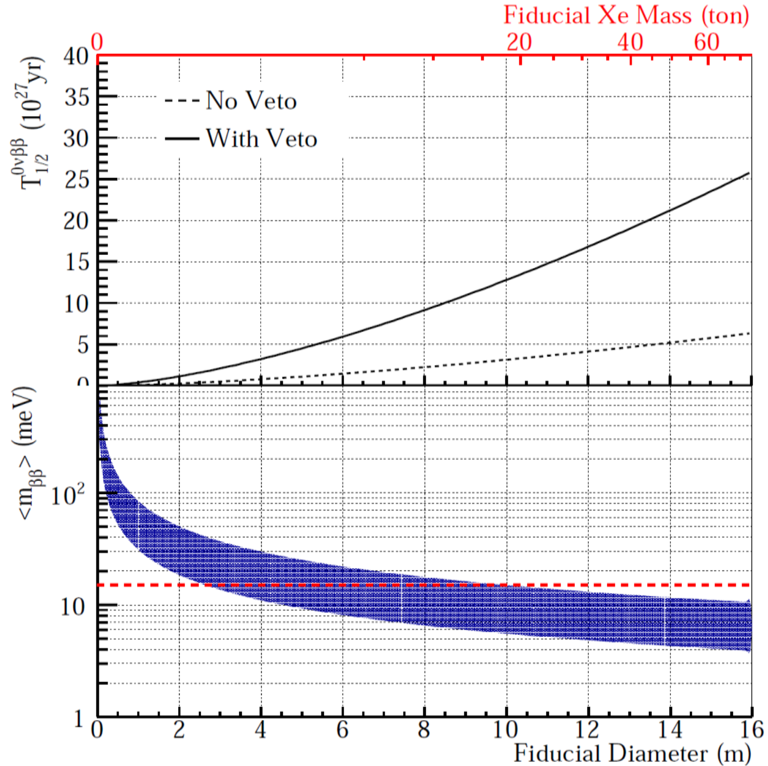
BJ Nor. U.
CAGS
Chongqing U.
CIAE
DGUT
ECUST
Guangxi U.
HIT
IHEP
Jilin U.
Ninan U.
Nanjing U.
Natl. Chiao-Tung U.
Natl. Taiwan U.
Natl. United U.
Nankai U.
NCEPU
Pekin U.
Shandong U.
Shanghai JT U.
Sichuan U.
SYSU
Tsinghua U.
UCAS
USTC
U. Of South China
Wuhan U.
Wuyi U.
Xi'an JT U.
Xiamen U.

Future of JUNO ?

- **Insert a Balloon into the JUNO detector, and fill the balloon with ^{136}Xe-loaded LS**
- **Benefit from great experience of KamLAND-Zen**
- **Benefit from good energy resolution of JUNO**
- **Too shallow ? Cut active volume around the muon track**

	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

Preliminary !



Major Projects: Current and Future

		Current	Future
Accelerator-based	Precision frontier	BESIII	International: ILC CEPC → SppC
		LHCb, Belle II、PANDA、COMET	
	Energy frontier	CMS、ATLAS	
Non-accelerator-based	Underground	Daya Bay	JUNO → JUNO-ββ
		Jinping: PANDAx, CDEX	Many
	Surface	ARGO/ASγ	LHASSO
			Ali for CMB
	Space	AMS	HERD XTP
		HXMT, Polar, DAMPE	