Particle Physics in China

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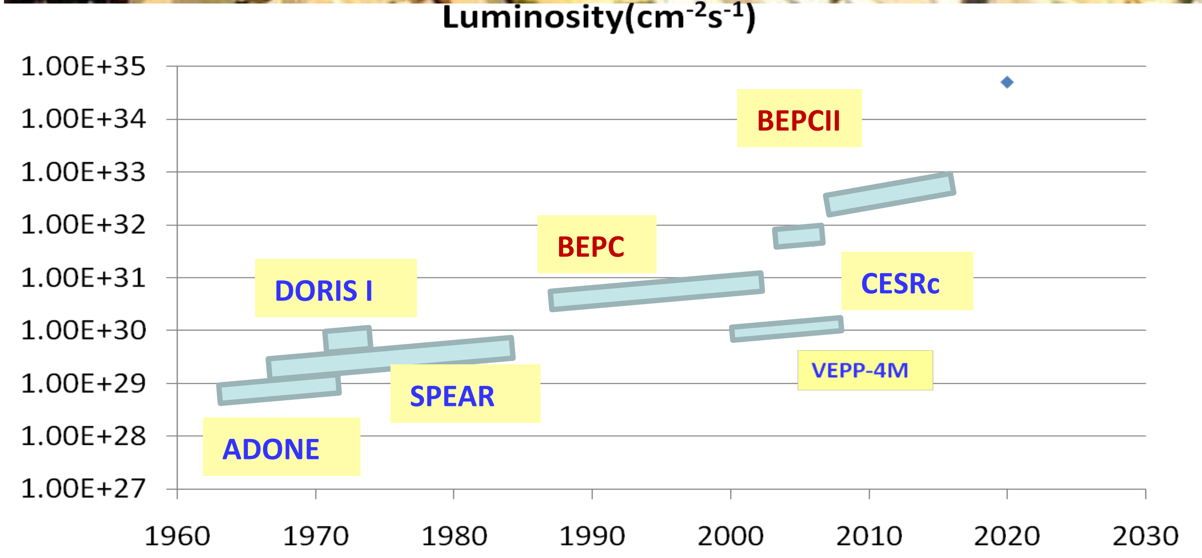
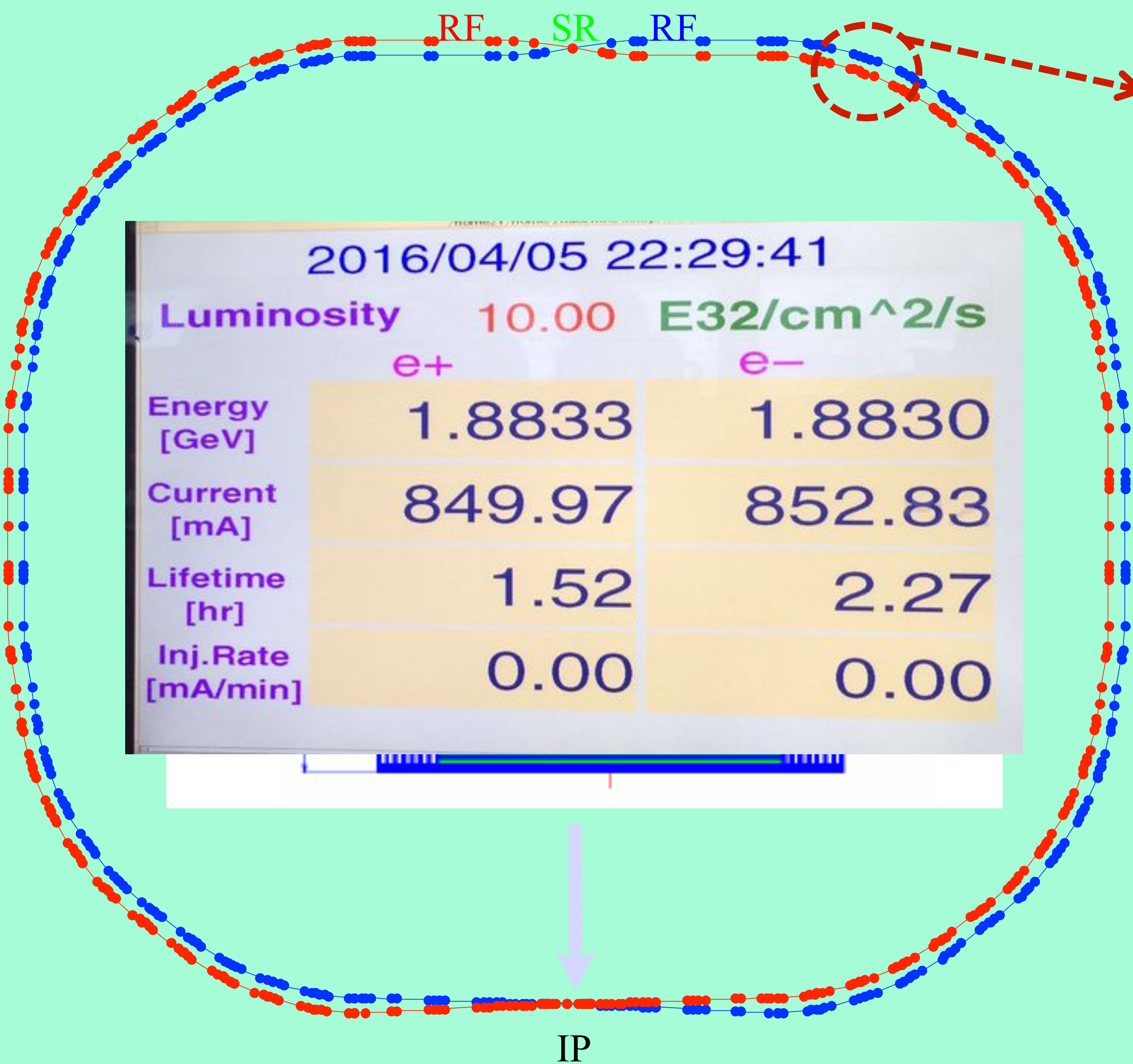
String 2016, Aug. 1, 2016

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



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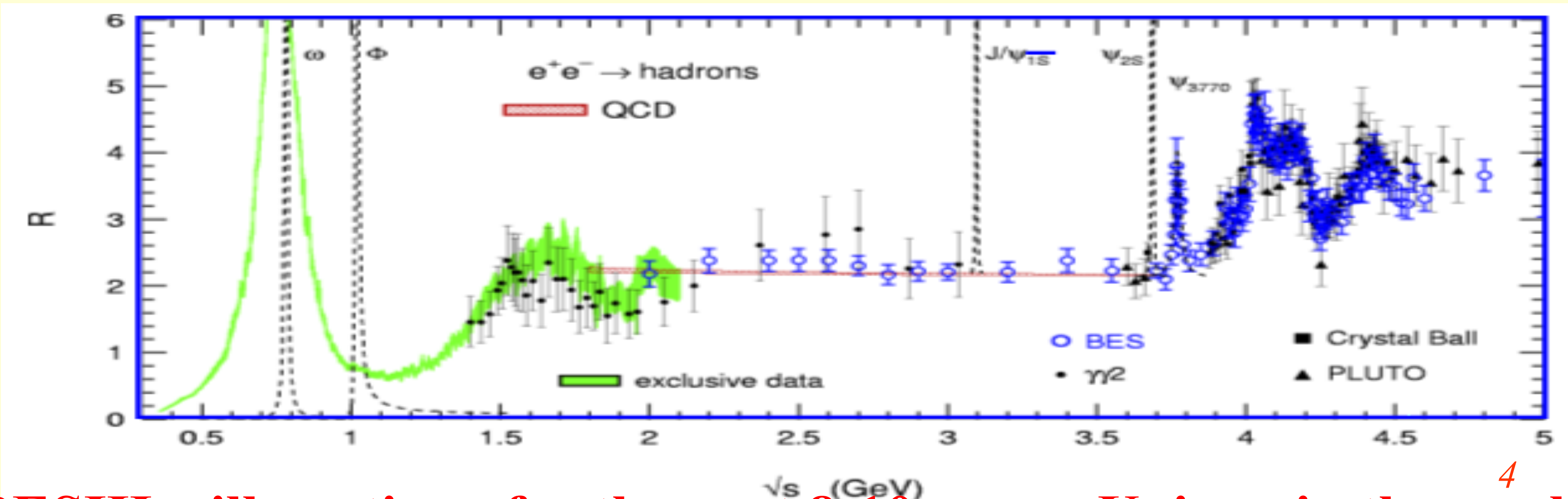
Luminosity 10.00 E32/cm^2/s

	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

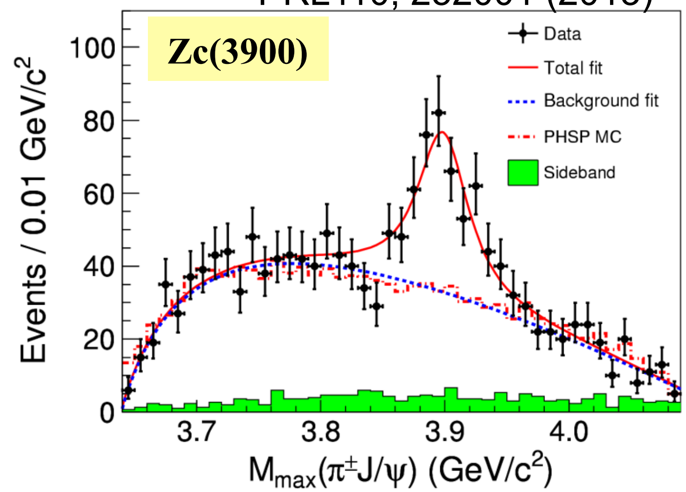


BESIII will continue for the next 8-10 years: Unique in the world

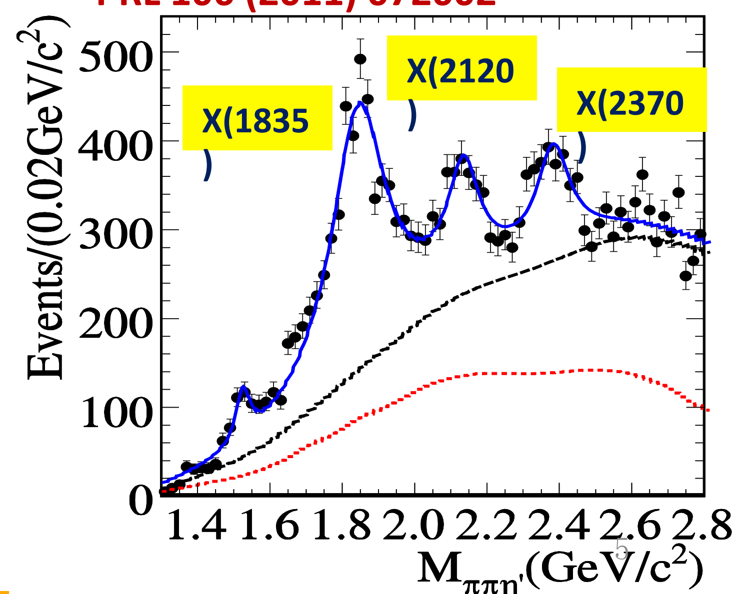
Results from BEPCII/BESIII

- 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), …
  - Absolute Λ_c branching ratios
- 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 (6)

Univ. of Hawaii

Univ. of Washington

Carnegie Mellon Univ.

Univ. of Minnesota

Univ. of Rochester

Univ. of Indiana

Korea (1)

Seoul Nat. Univ.

Japan (1)

Tokyo Univ.

~400 members from

12 countries

54 institutions

Pakistan (2)

Univ. of Punjab

COMSAT CIIT

China(29)

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.

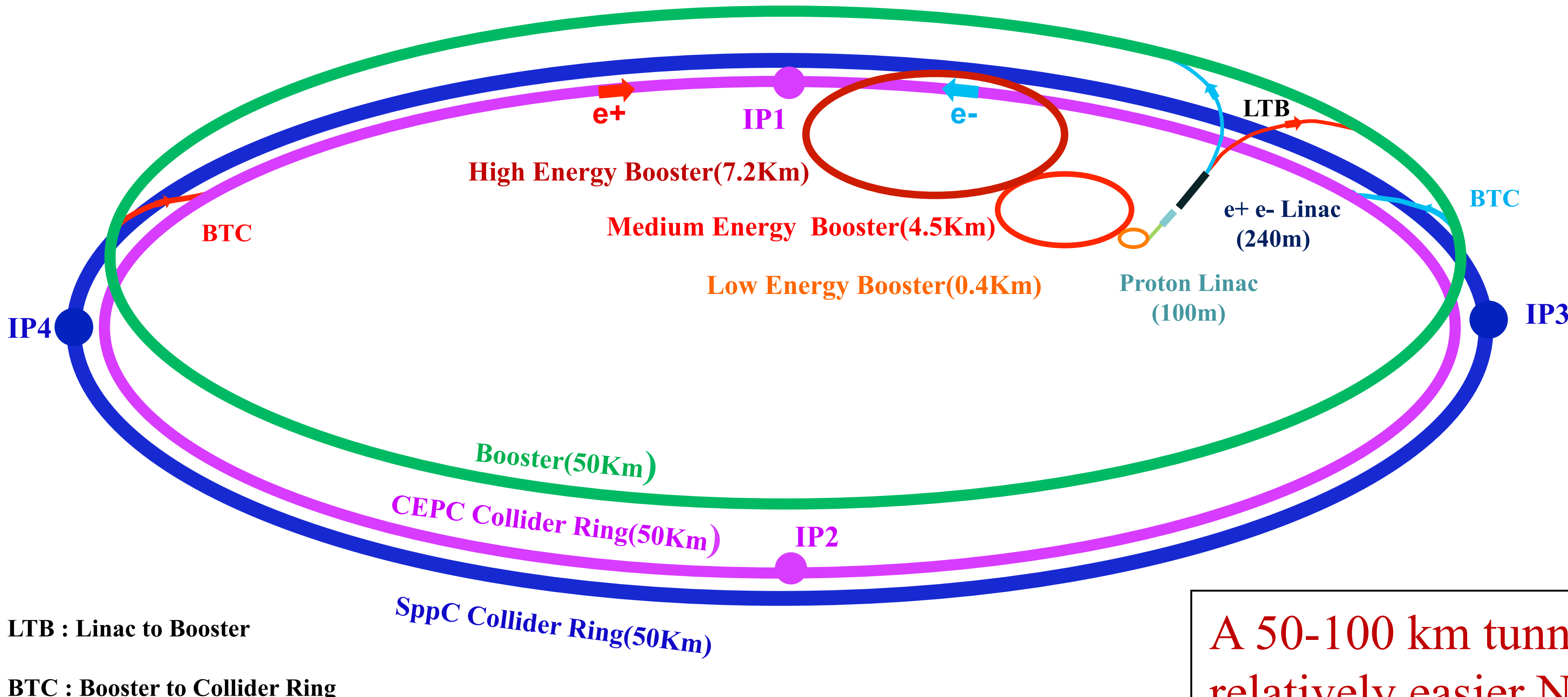
Guangxi Normal Univ., Guangxi Univ.

Suzhou Univ., Hangzhou Normal Univ.

Lanzhou Univ., Henan Sci. and Tech. Univ.

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



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

Science Goals

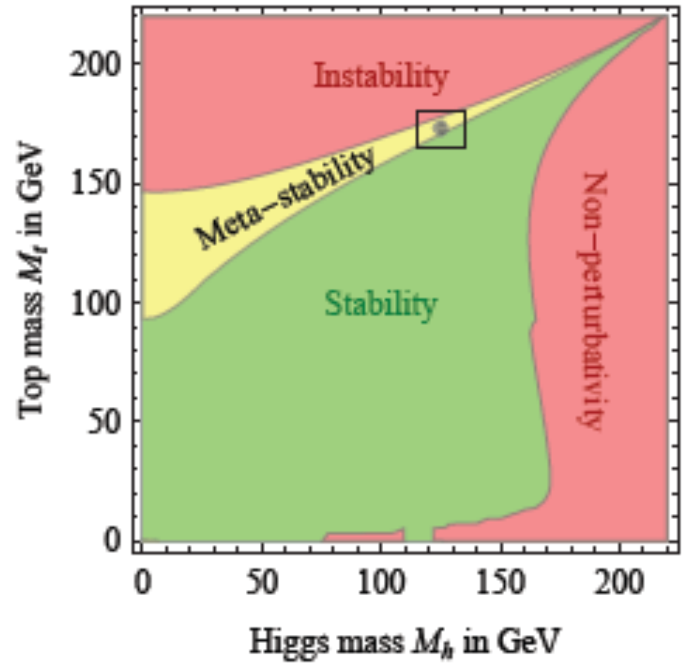
- **CEPC (e+e-: 90-250 GeV)**
  - Higgs Factory: Precision study of Higgs(m_H, J^{PC}, couplings)
    - Same as SM prediction ? Other Higgs ? Composite ? New properties ? CP effect ？
  - Z & W factory: precision test of SM
    - New phenomena ? Rare decays ?
  - Flavor factory: b, c, τ and QCD studies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

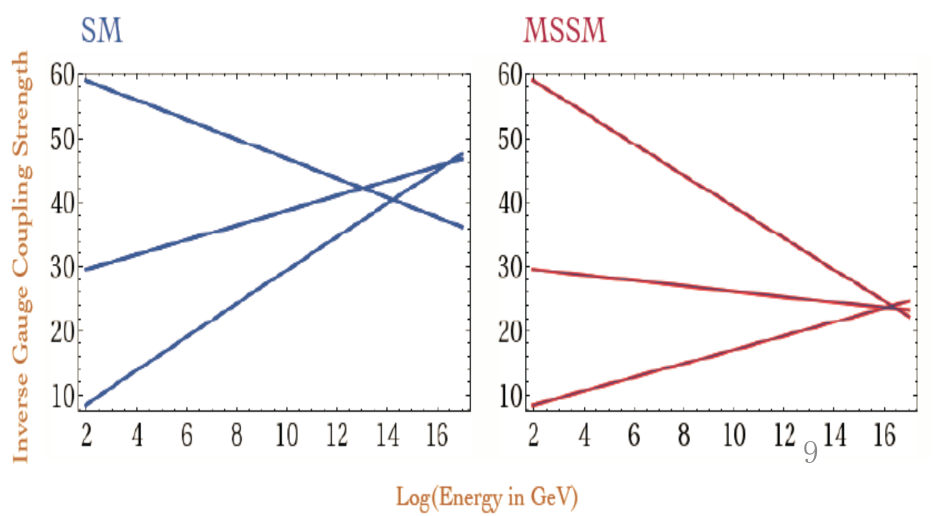
SM is not the End after the Higgs

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

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



- **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**

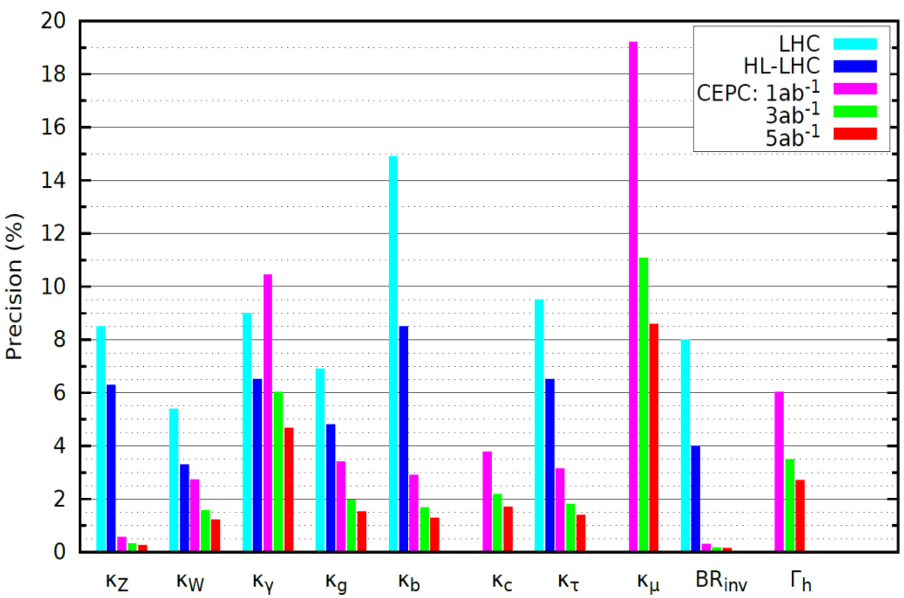


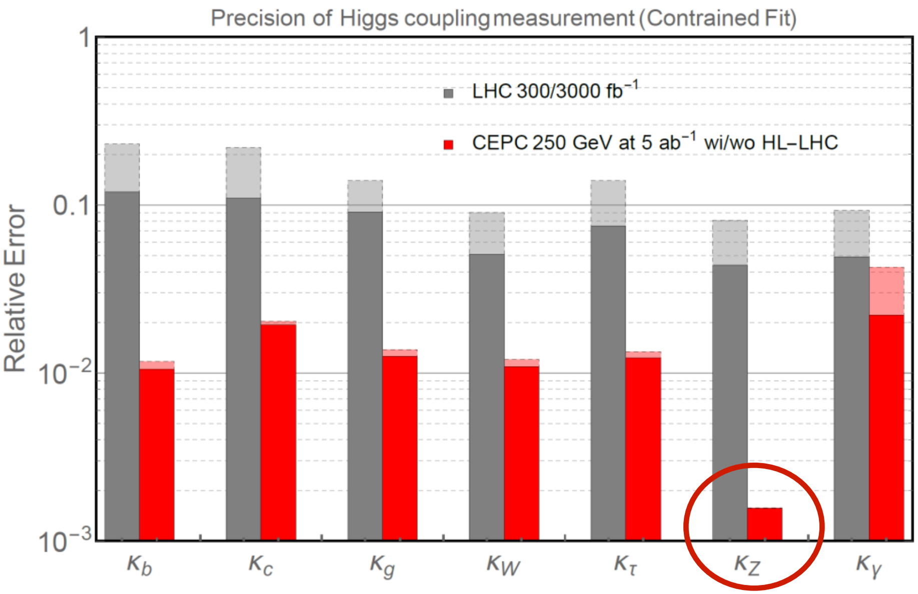
Most of the issues related to Higgs

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

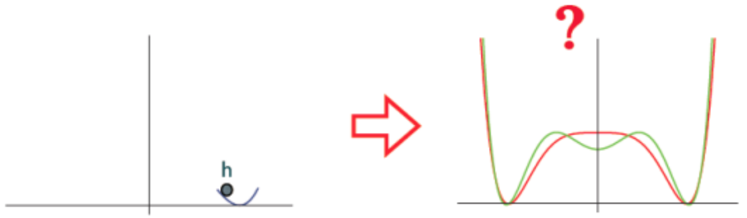


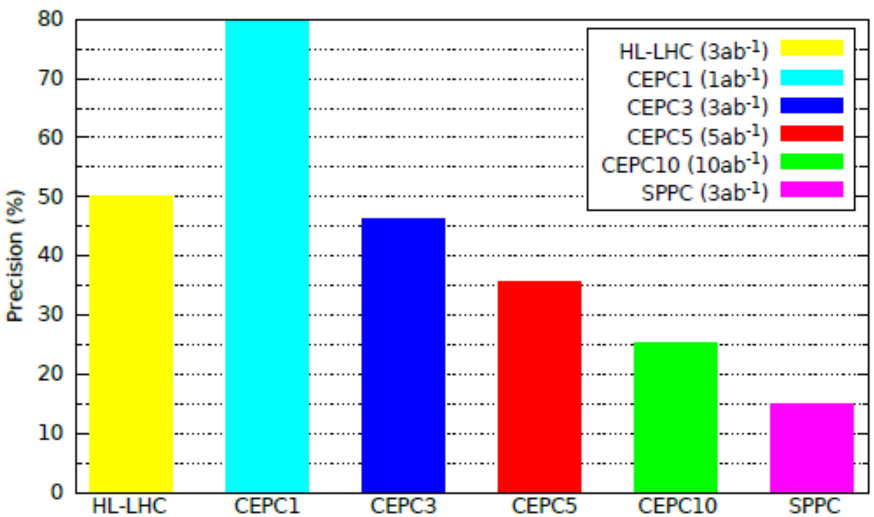


CEPC preCDR Volume 1 (p.9)

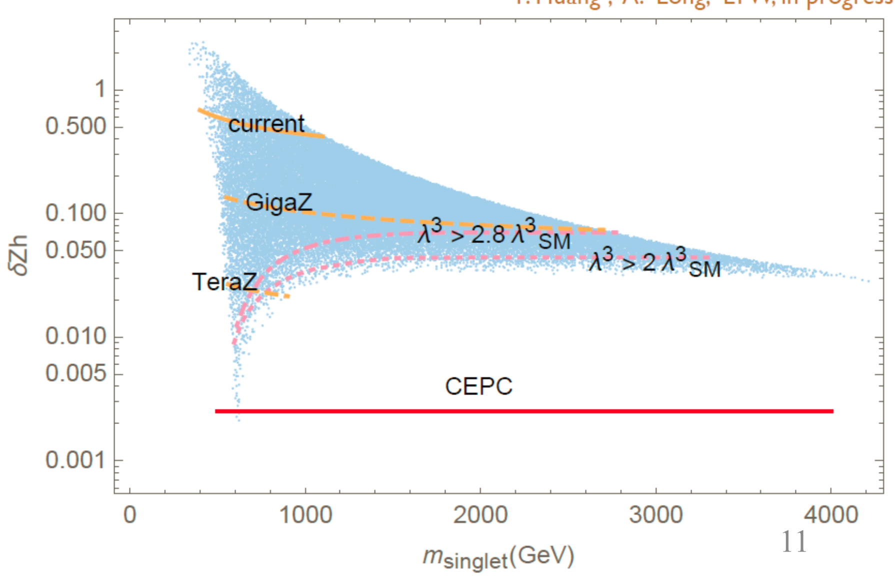
Nature of EW Phase Transition ?

- 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%

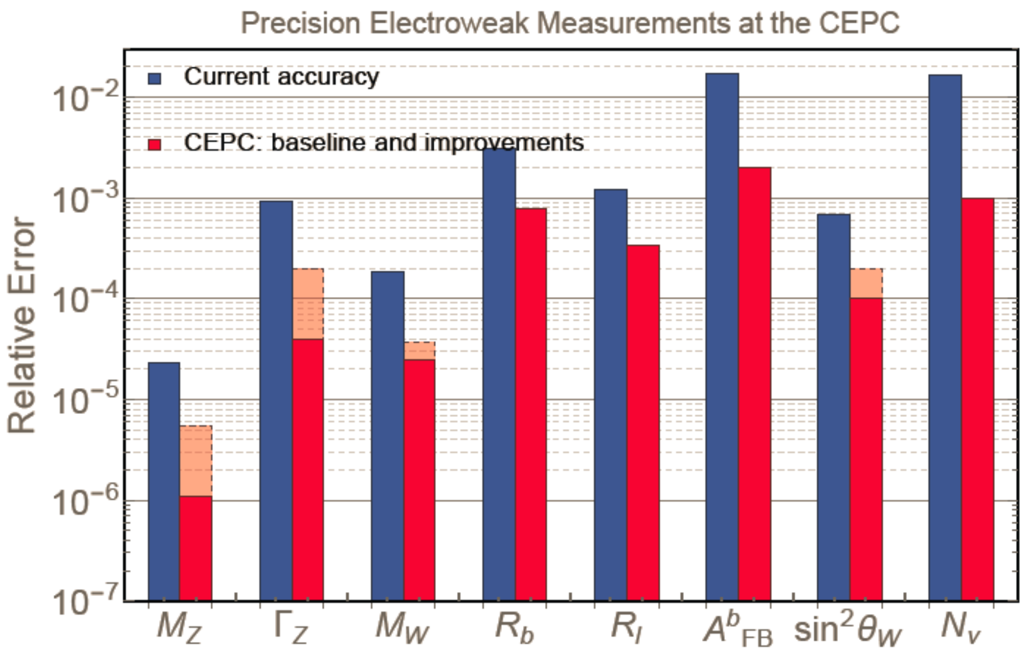


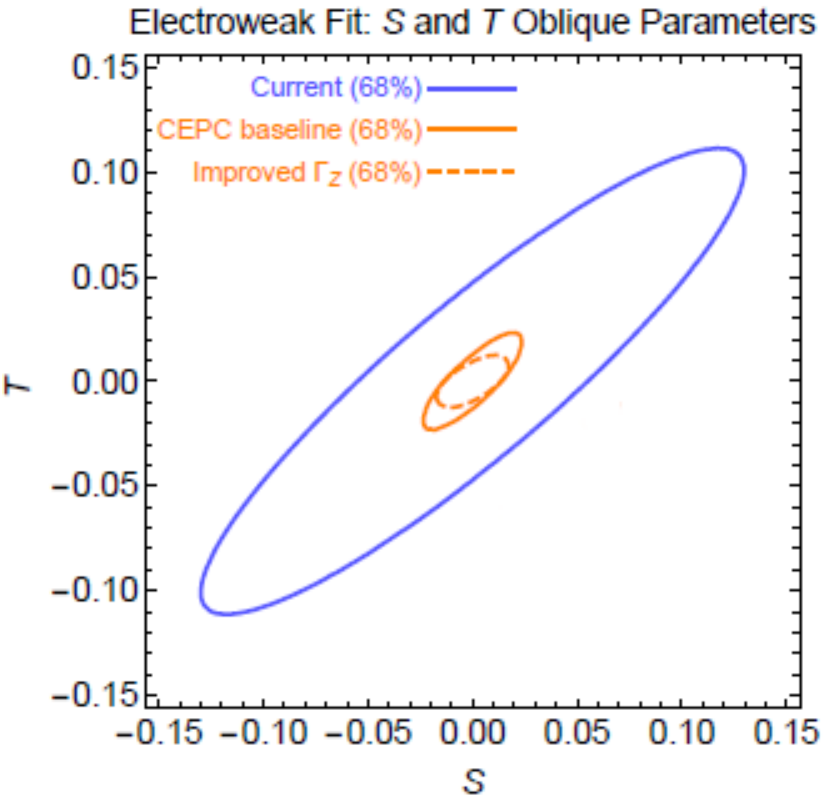


P. Huang , A. Long, LTW, in progress



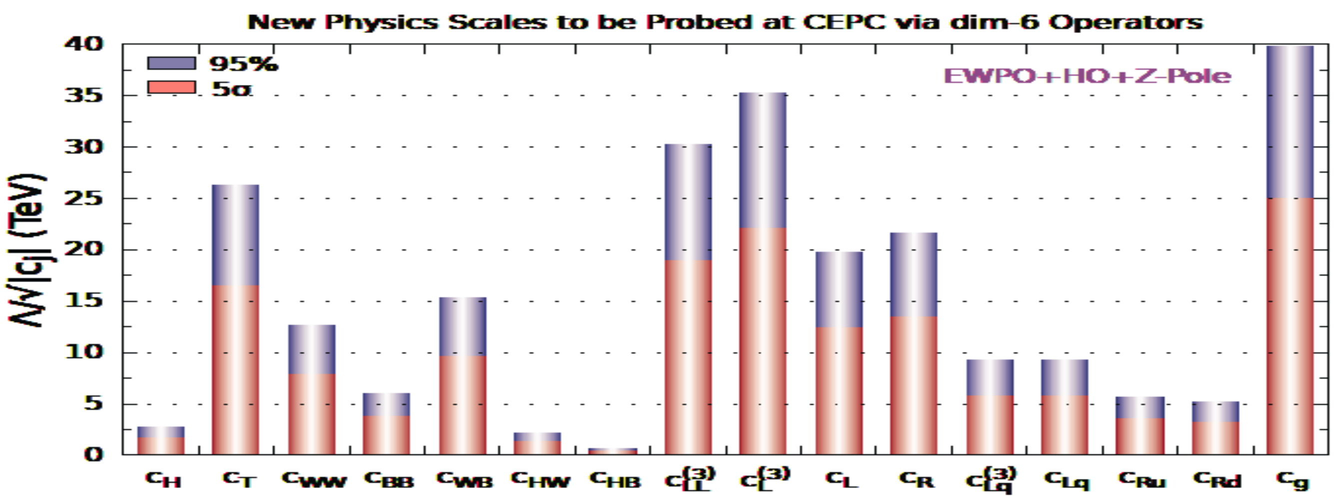
Improvement in Electroweak Precision





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}

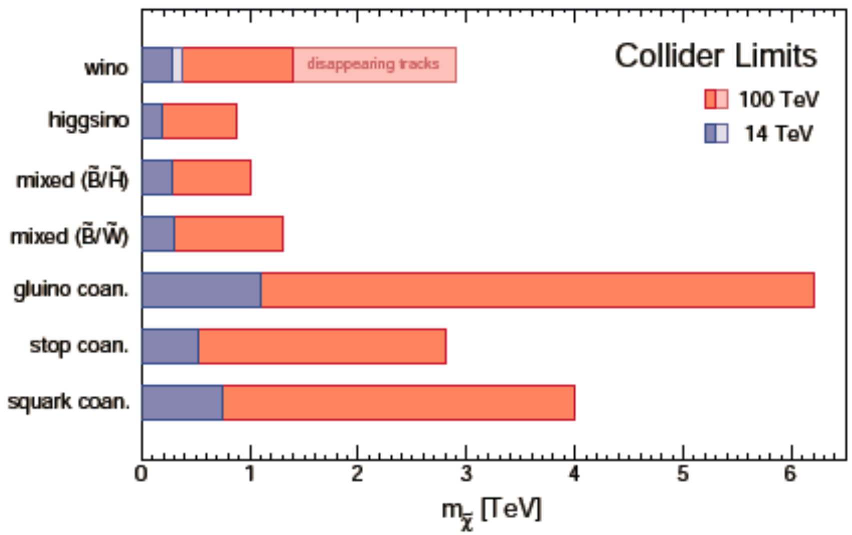
Experiment	κ_Z (68%)	f (GeV)	κ_g (68%)	$m_{\tilde{t}_L}$ (GeV)
HL-LHC	3%	1.0 TeV	4%	430 GeV
ILC500	0.3%	3.1 TeV	1.6%	690 GeV
ILC500-up	0.2%	3.9 TeV	0.9%	910 GeV
CEPC	0.2%	3.9 TeV	0.9%	910 GeV
TLEP	0.1%	5.5 TeV	0.6%	1.1 GeV

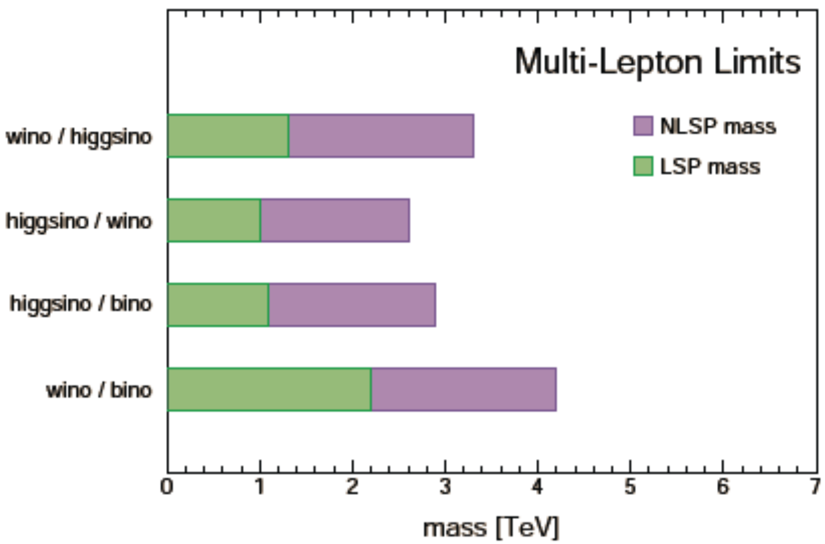
Experiment	S (68%)	f (GeV)	T (68%)	$m_{\tilde{t}_L}$ (GeV)
ILC	0.012	1.1 TeV	0.015	890 GeV
CEPC (opt.)	0.02	880 GeV	0.016	870 GeV
CEPC (imp.)	0.014	1.0 TeV	0.011	1.1 GeV
TLEP-Z	0.013	1.1 TeV	0.012	1.0 TeV
TLEP-t	0.009	1.3 TeV	0.006	1.5 TeV

Searches @ 100 TeV SPPC

- Great improvement over LHC
- ~ TeV region is much more interesting and most probable for simplest possibilities

- If no new physics at LHC
  - Λ~ 1 TeV ➔ 10^{-2} fine tuning
- If no new physics at 100 TeV
  - Λ~ 10 TeV ➔ 10^{-4} fine tuning
  - Never before





M. Low et al., JHEP1408(2014)161

S. Gori et al., JHEP1412(2014)108

Can be downloaded from

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

IHEP-CEPC-DR-2015-01

IHEP-EP-2015-01

IHEP-TH-2015-01

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

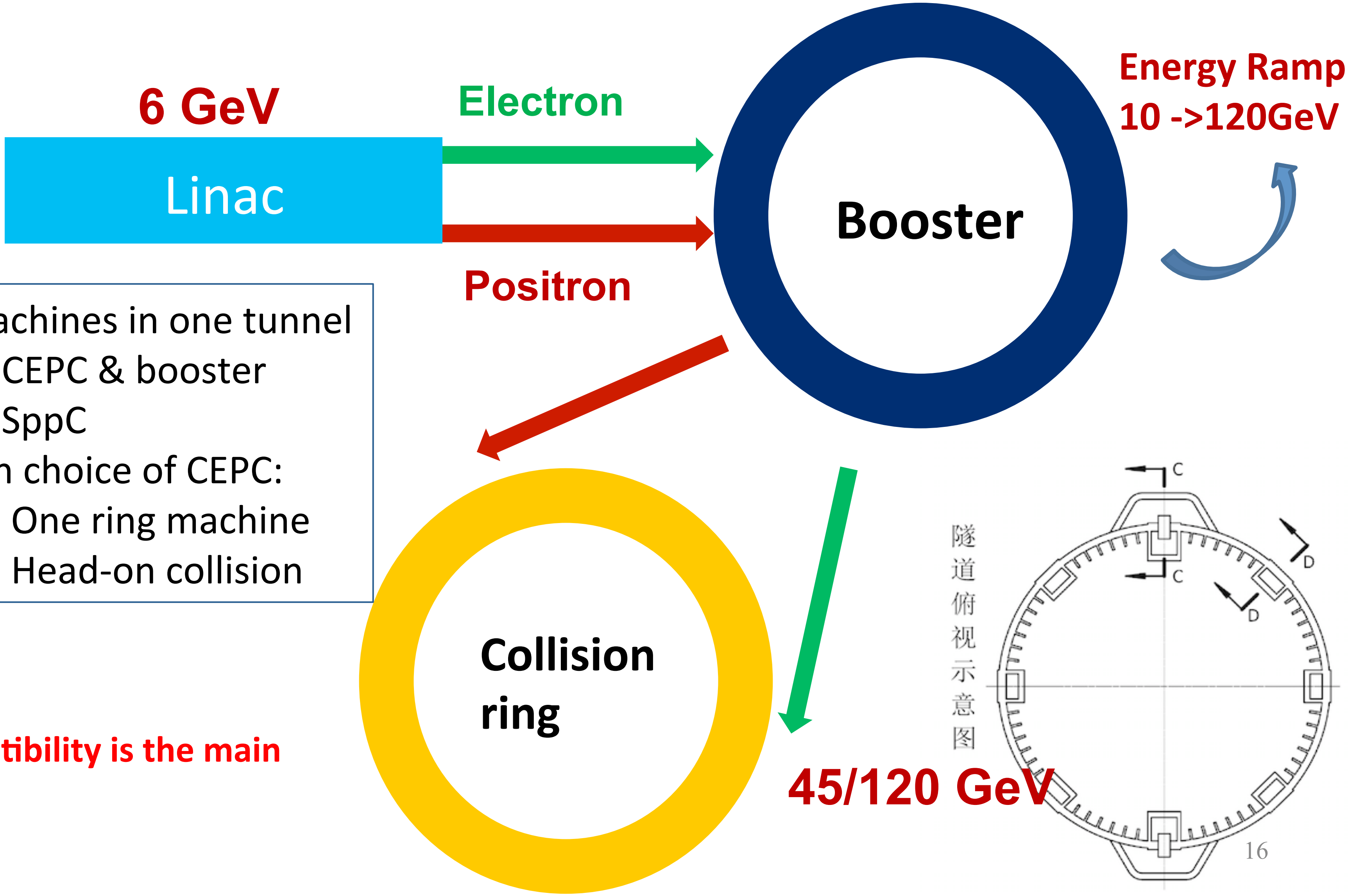
Volume II - Accelerator

328 pages, 300 authors

The CEPC-SPPC Study Group

March 2015

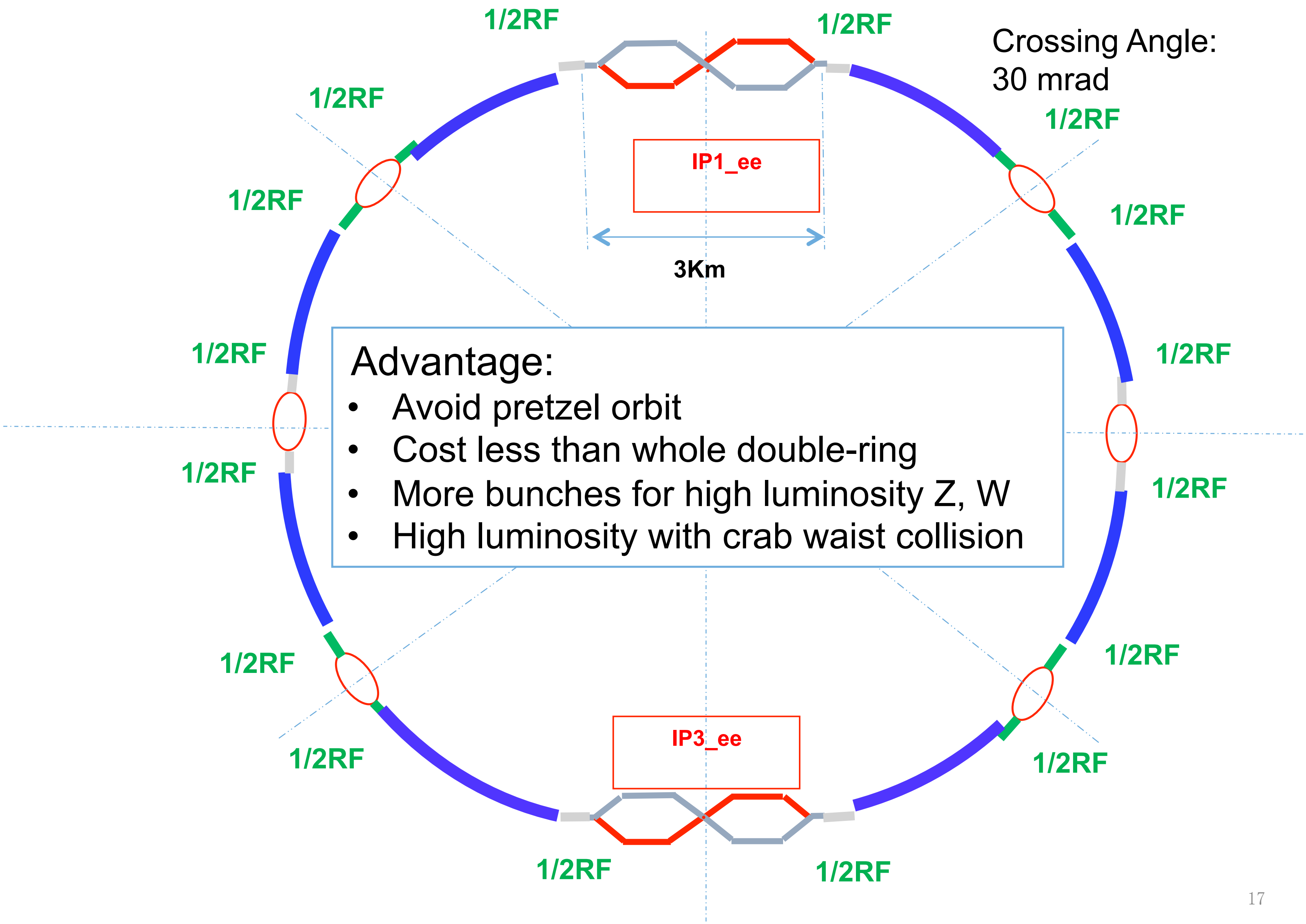
CEPC Accelerator



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

Compatibility is the main Issue

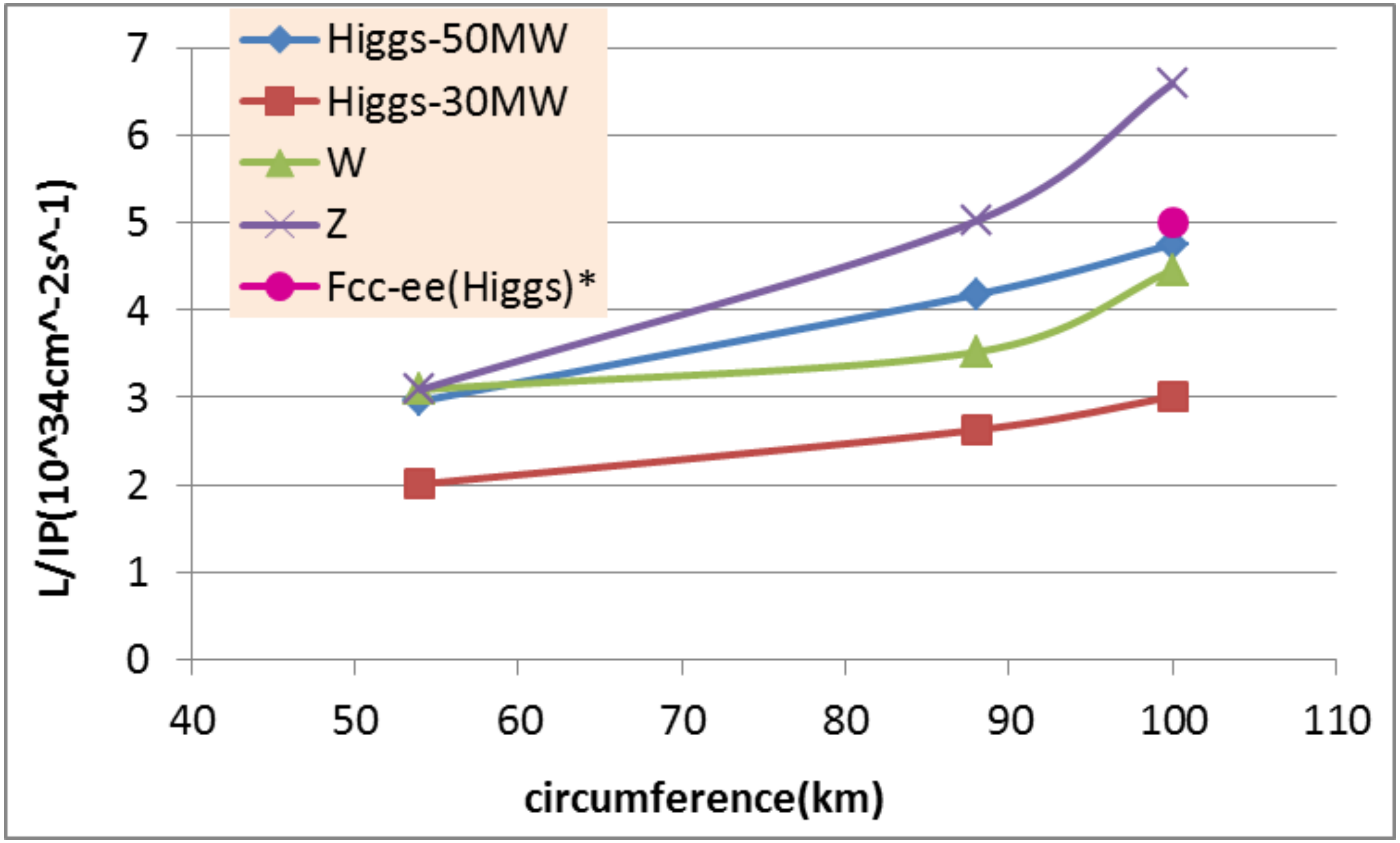
Innovation： Partial Double Ring



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

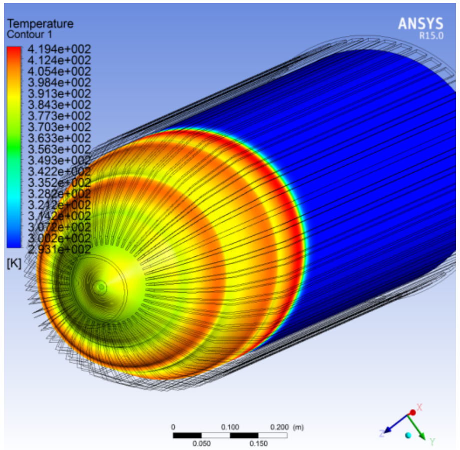


* Fabiola Gianotti, Future Circular ColliderDesign Study, ICFA meeting, J-PARC, 25-2-2016.

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.

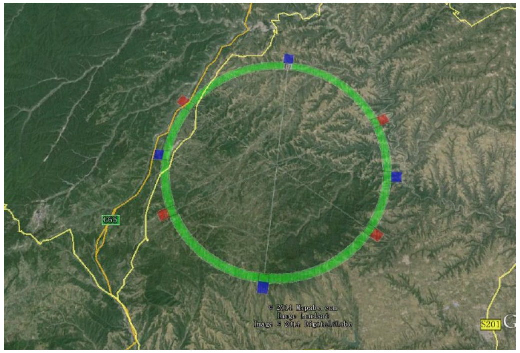
Parameters mode	Now	Future
Centre frequency (MHz)	650+/-0.5	650+/-0.5
Output power (kW)	**800**	**800**
Beam voltage (kV)	80	70
Beam current (A)	16	15
Efficiency (%)	**65**	**80**



CEPC 650MHz RF power source R&D at IHEP

Site selections (a few main candidates)

1)



2)

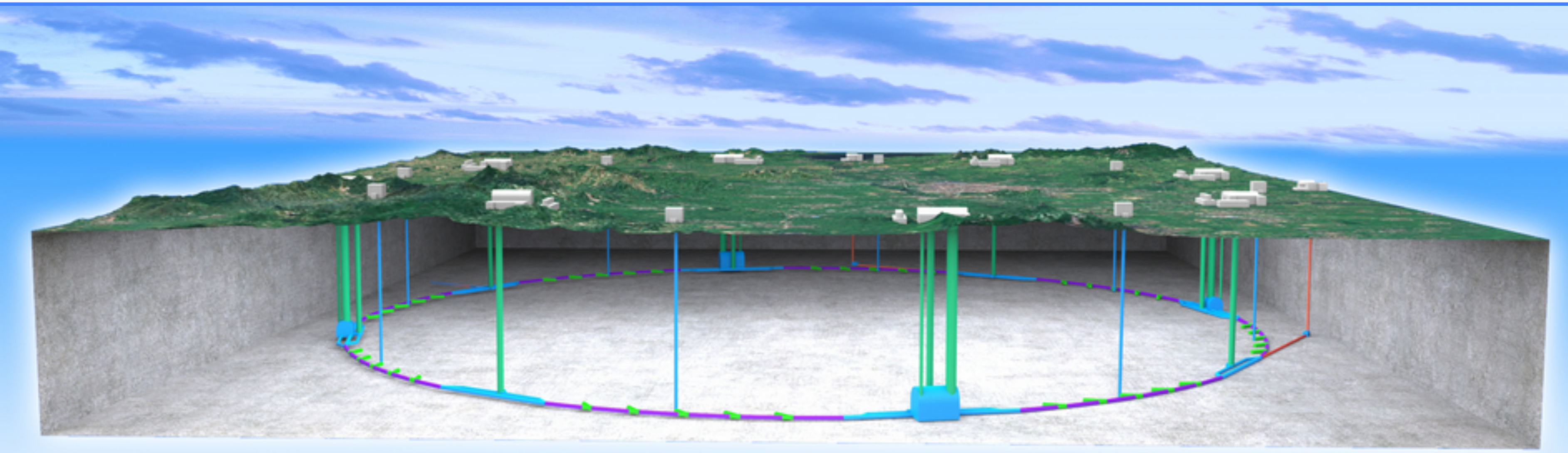
3)

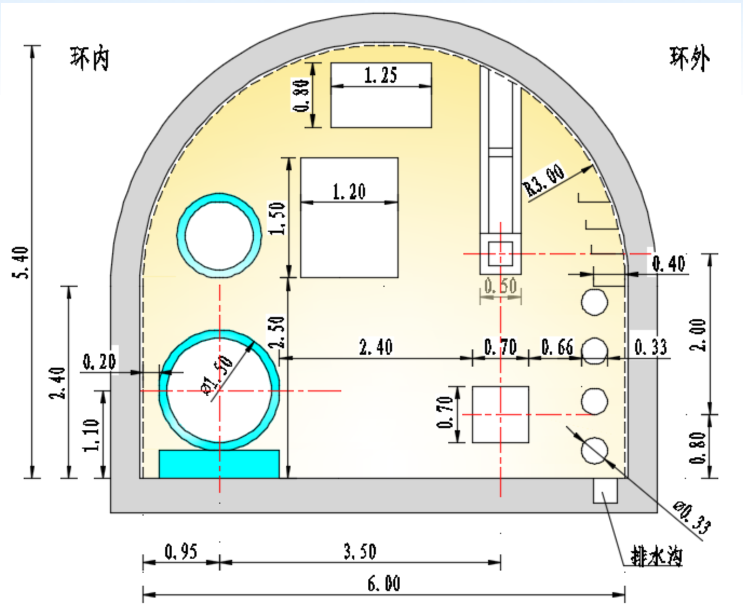
1) Qinhuangdao

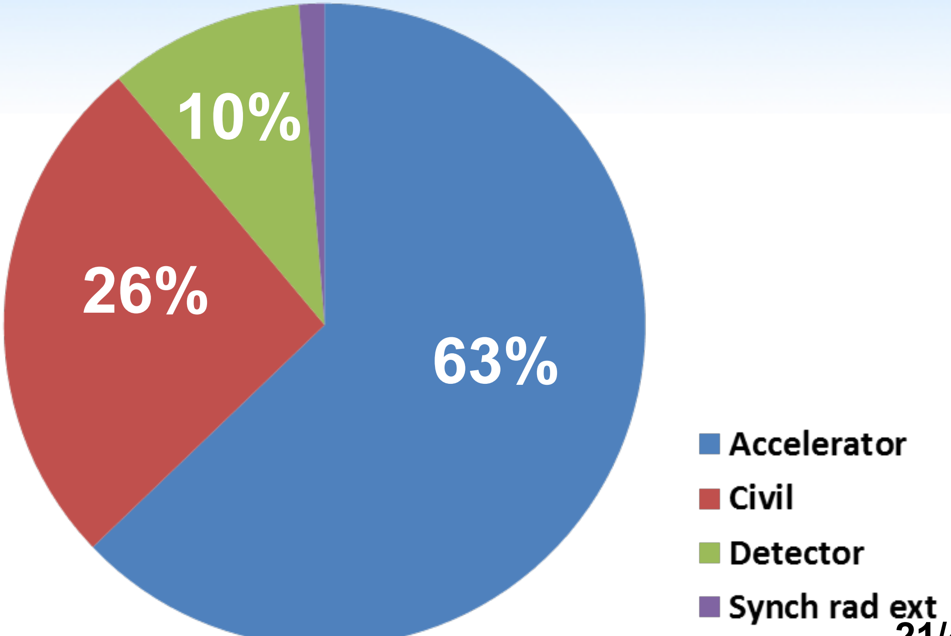
2) Shanxi Province

3) Near Shenzhen and Hongkong

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 -

Current Status and the Plan

- **Pre-CDR completed**
  - No show-stoppers
  - Technical challenges identified → R&D issues
  - Preliminary cost estimate
- **Working towards CDR**
  - A working machine on paper
  - Ready to be reviewed by government at any moment
- **R&D issues identified and funding request underway**
  - Seed money from IHEP: 12 M RMB/3 years
  - MOST: 35 M/5 yr approved, ~40 M to be asked next year
  - NCDR: ~0.8 B RMB/5 yr, failed in a voting process
  - CAS & CNSF: under discussion

International Collaboration

- **A new international organization for CEPC will be organized after (at least some) funding is available**
  - **A new format: not ITER, CERN, ILC, …**
- **An international advisory board is formed to discuss in particular this issue, together with others**
- **Many MOU and meeting minutes signed with collaborating institutions/organizations**
- **International coordination**

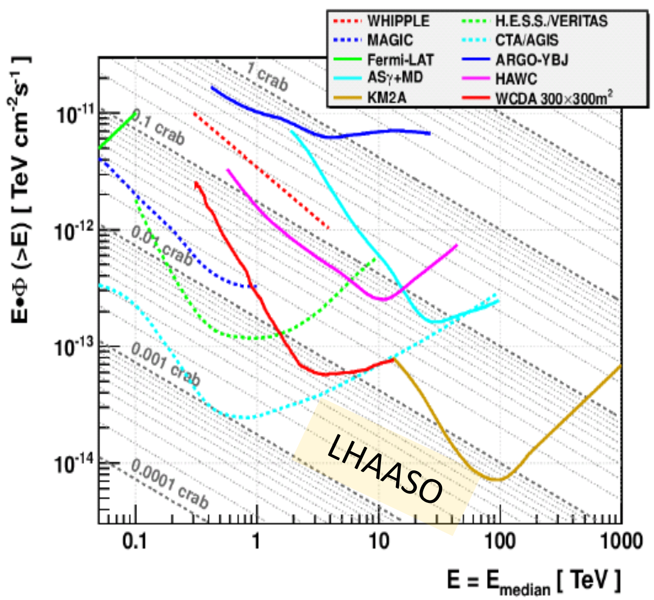
AsiaHEP/ACFA Statement on ILC + CEPC/SPPC

AsiaHEP and ACFA reassert their strong endorsement of the ILC, which is in a mature state of technical development. The aim of ILC is to explore physics beyond the Standard Model by unprecedented precision measurements of the Higgs boson and top quark, as well as searching for new particles which are difficult to discover at LHC. The Higgs studies at higher energies are especially important for measurement of WW fusion process, to fix the full Higgs decay width, and to measure the Higgs self-coupling. In continuation of decades of world-wide coordination, we encourage redoubled international efforts at this critical time to make the ILC a reality in Japan. The past few years have seen growing interest in a large radius circular collider, first focused as a "Higgs factory", and ultimately for proton-proton collisions at the high energy frontier. We encourage the effort lead by China in this direction, and look forward to the completion of the technical design in a timely manner.

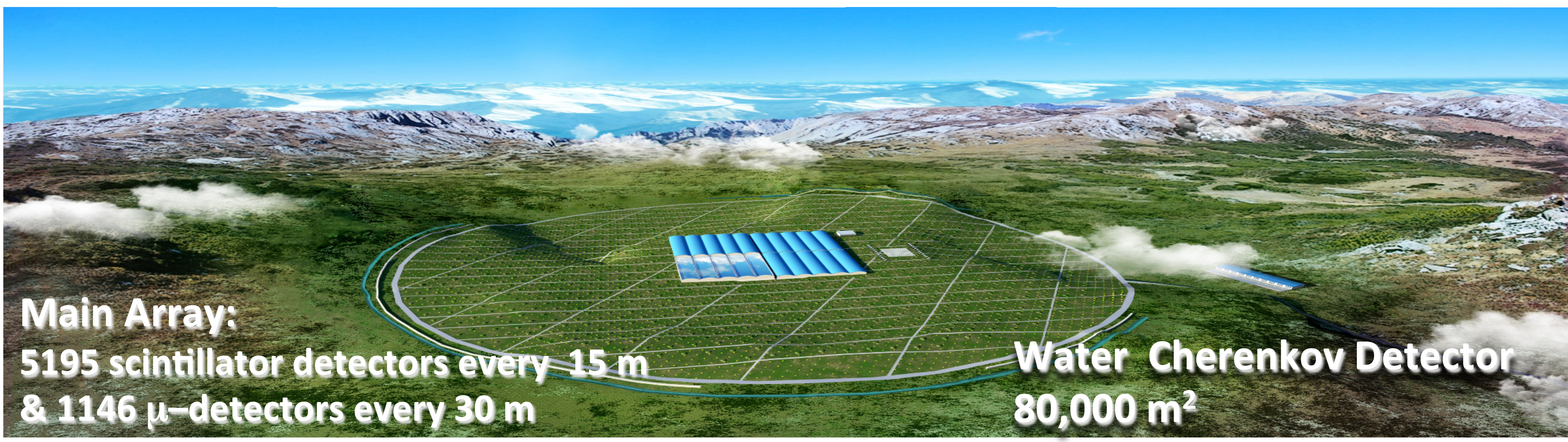
Major Projects: Current and Future

		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-$\beta\beta$
		Jinping: PANDAx, CDEX	Many
	Surface	ARGO/ASγ	LHASSO
	Space	AMS	HERD XTP
		HXMT,Polar,DAMPE	

A new Phase: LHAASO
—— Large High Altitude Air Shower Observatory

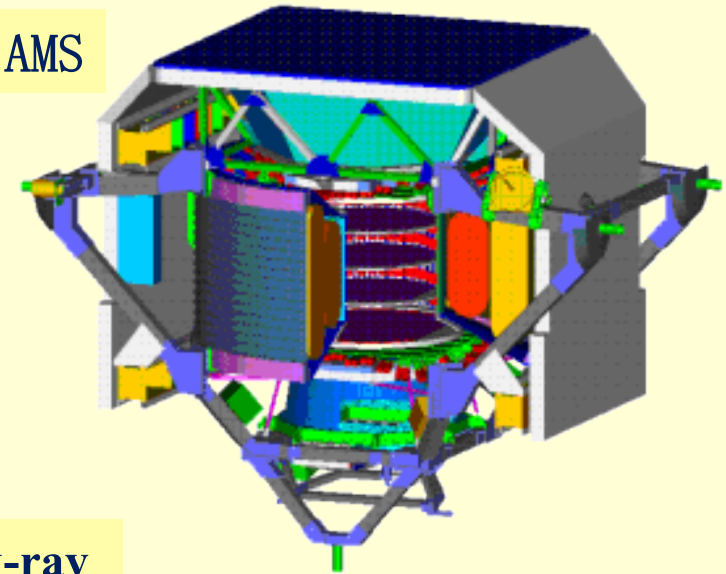


Sichuan, 4300 m a.s.l.

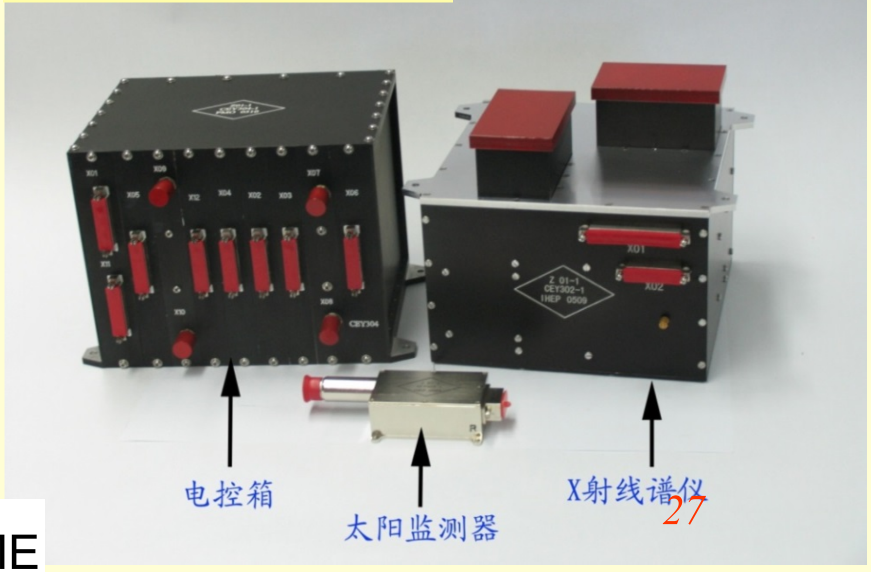


Space Projects

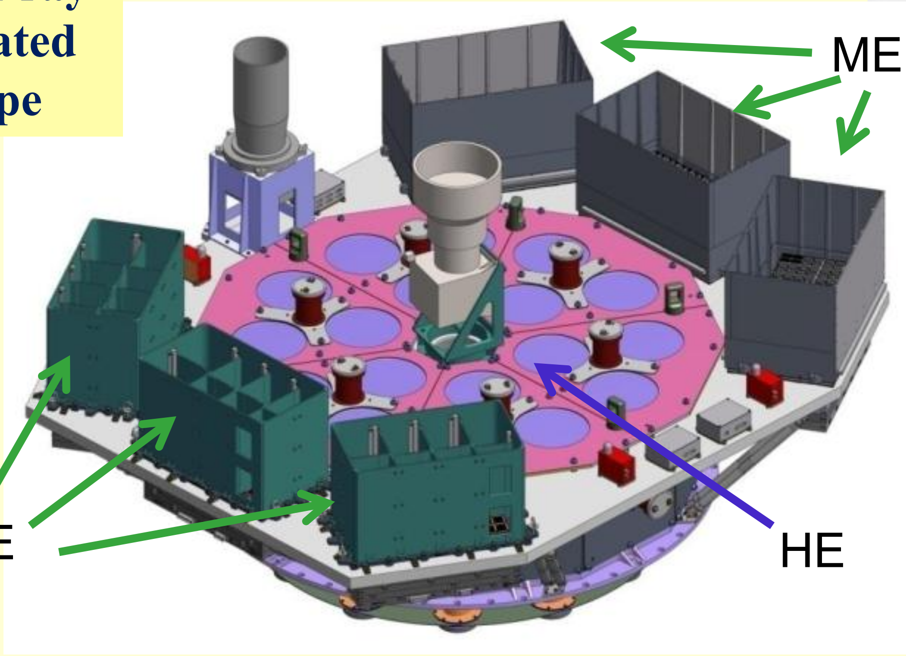
AMS



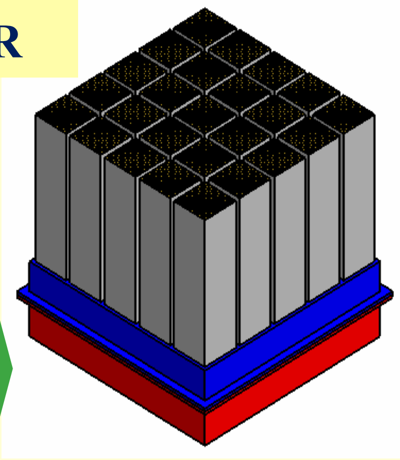
Moon exploration



Hard x-ray modulated telescope



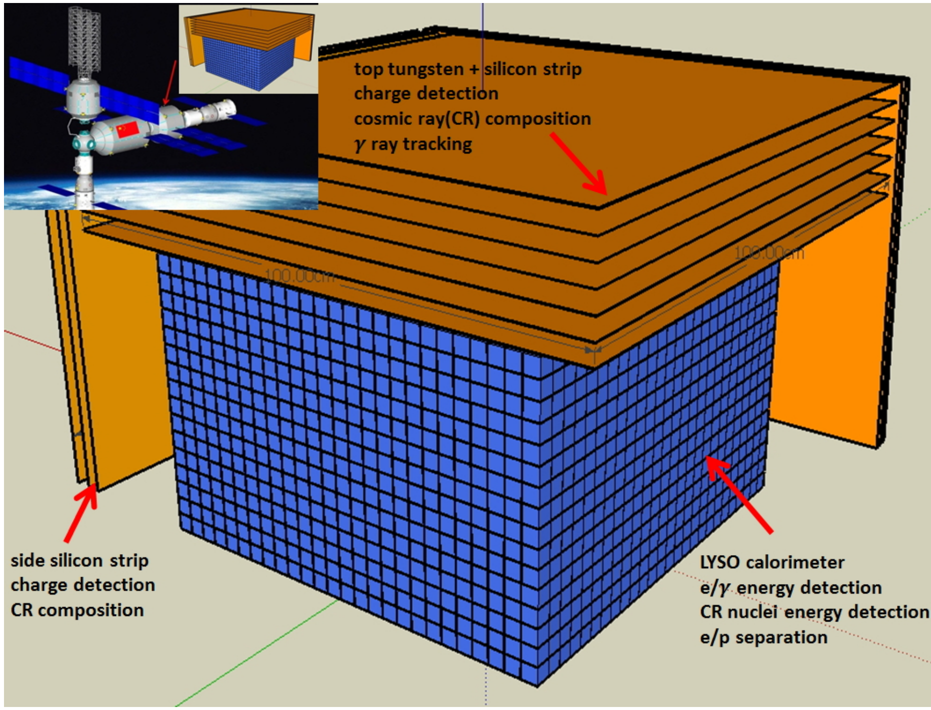
POLAR



To be launched this year

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

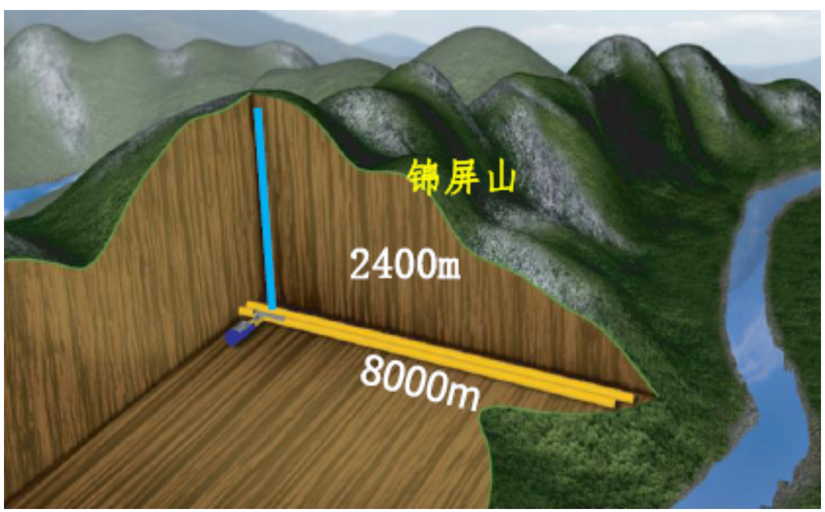


	X0(λ)	ΔE/E for e	e / p sep	e GF m^2sr@ 200GeV	p GF m^2sr@100TeV
HERD (2020)	55(3)	1%	10^{-6}	3.1	2.3
Fermi (2008)	10	12%	10^{-3}	0.9	--
AMS02 (2011)	17	2%	10^{-6}	0.12	--
DAMPE (2015)	31	1%	10^{-4}	0.3	--
CREAM (2015)	20(1.5)	--	--	--	0.2

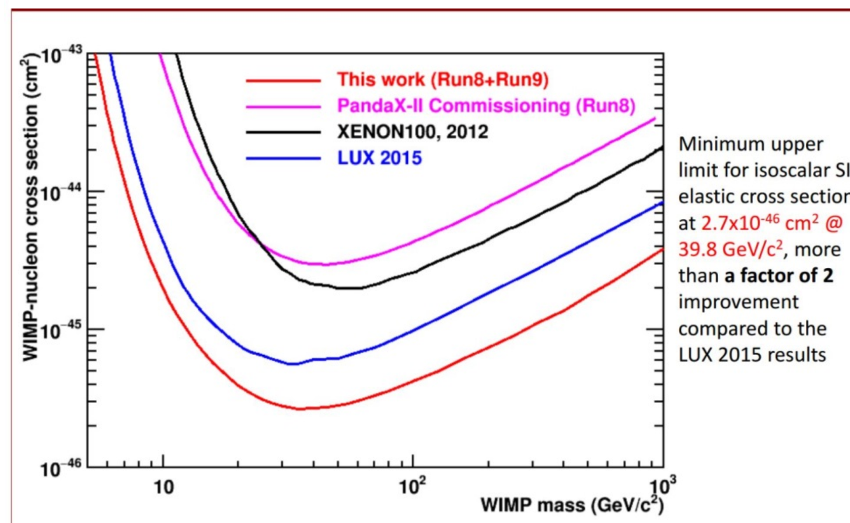
Acceptance & H-energy > 10X all others

JinPin Underground Laboratory

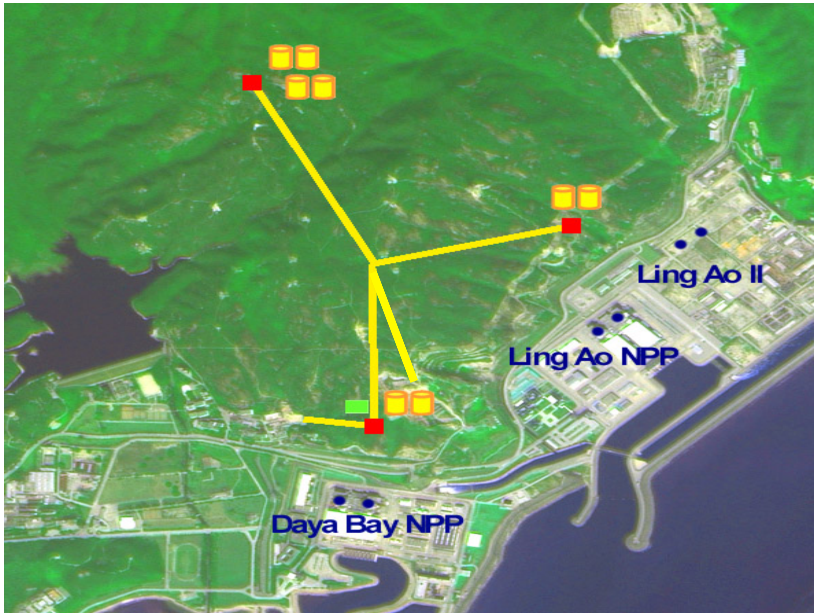
- The deepest underground laboratory in the world: 2400 m
- Current experiments: dark matter searches
  - Xe-based PandaX
  - Ge-based CDEX
- Future
  - Approved for the infrastructure construction: 4 large experimental halls, 12m×12m×100m
  - Next generation Xe- & Ge-based dark matter & ββ decay searches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

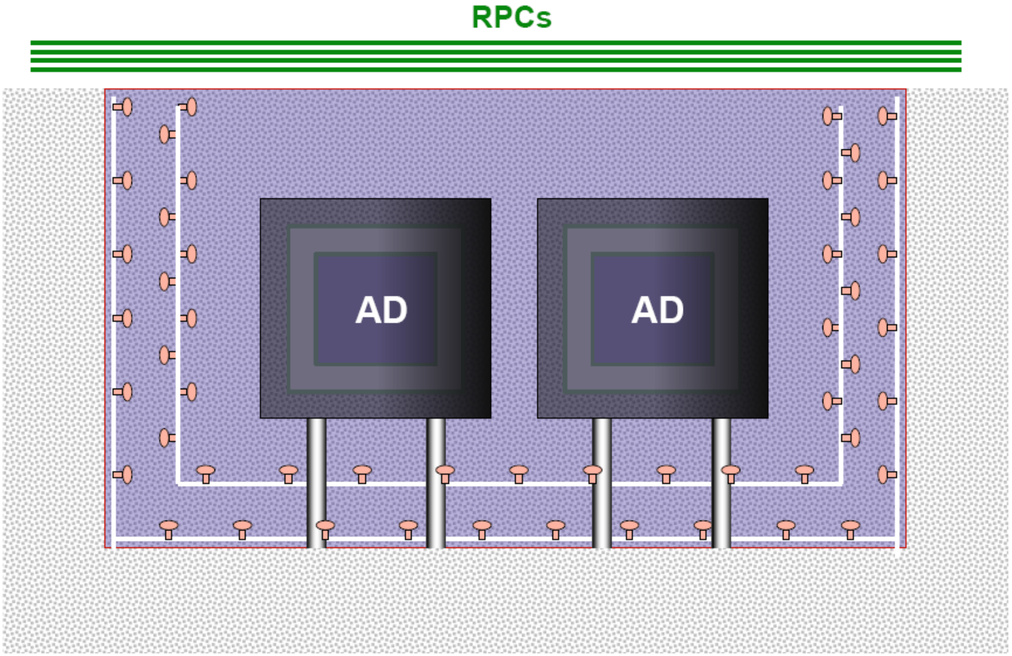


Recent PandaX results

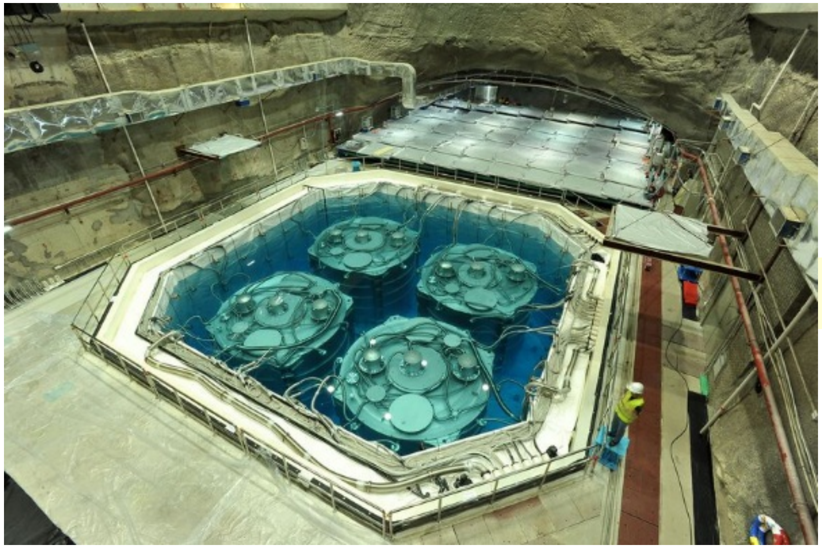


Daya Bay Experiment

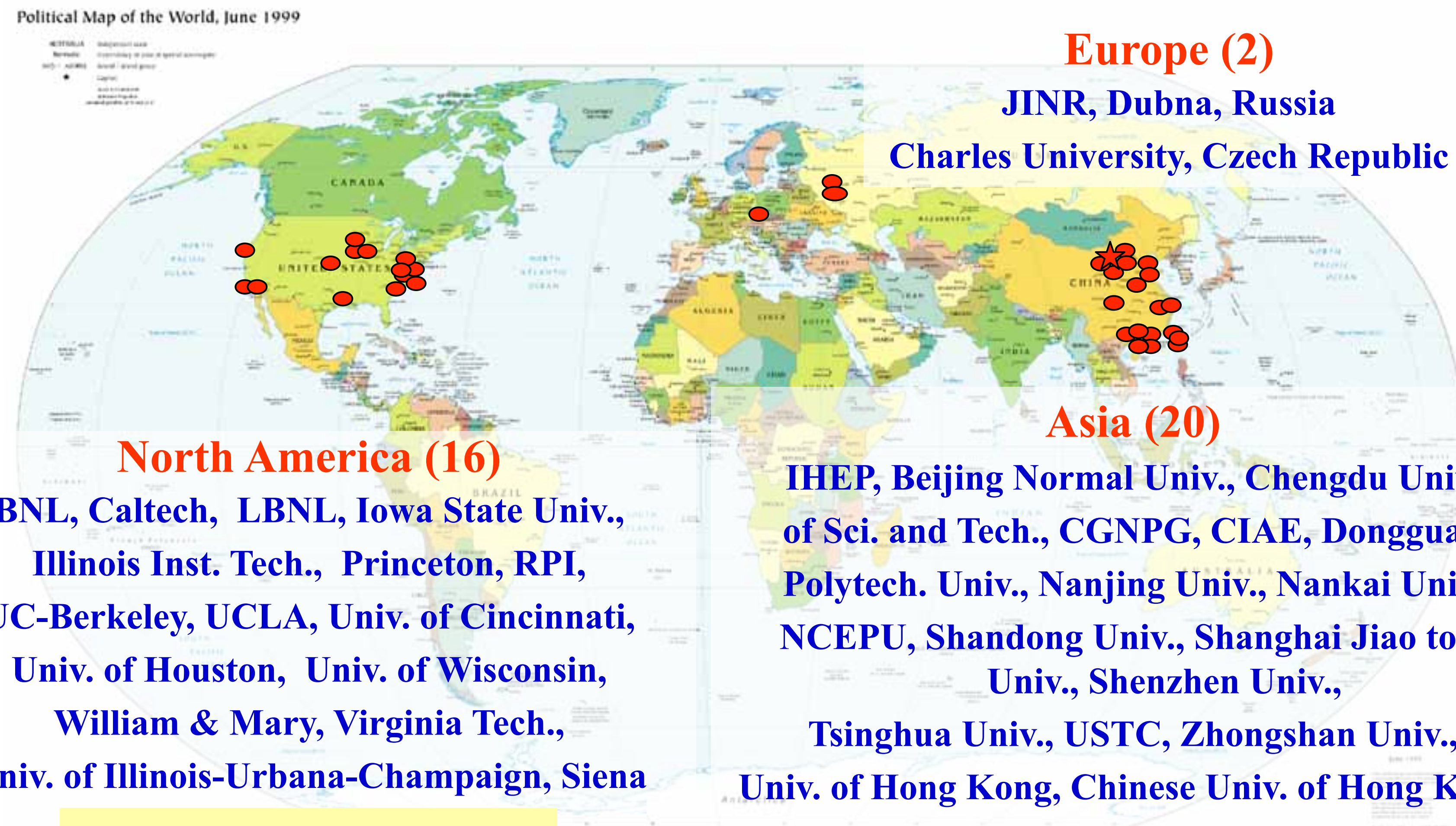




- The Idea proposed in 2003: multi-detectors at different sites and in each site
- Successful implementation:
  - ⇨ 3 km tunnel, 5 halls
  - ⇨ 200t Gd-loaded LS, 8 identical detector modules, 3 water Č detectors
  - ⇨ Calibration, readout, etc.



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

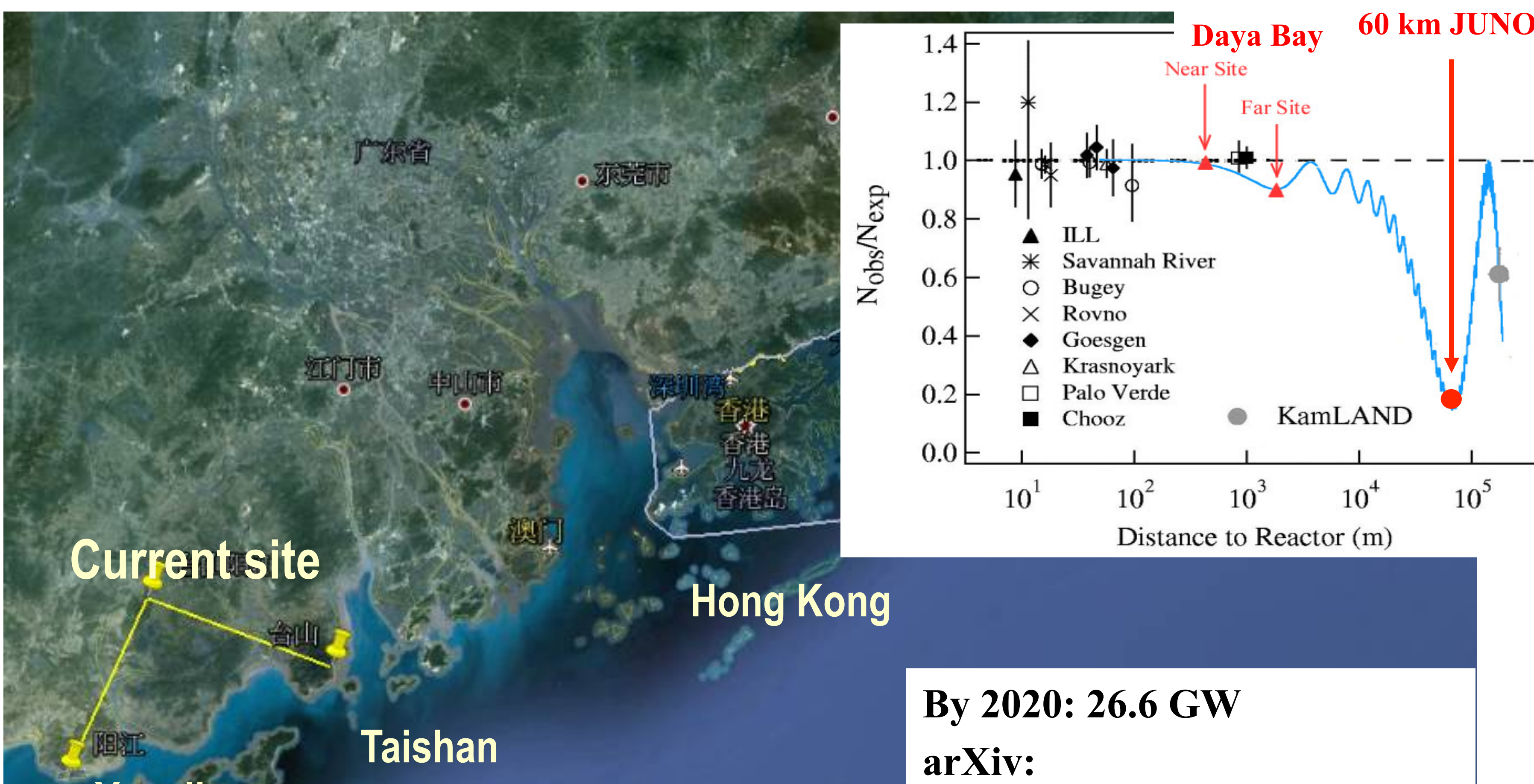
~250 Collaborators

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.

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

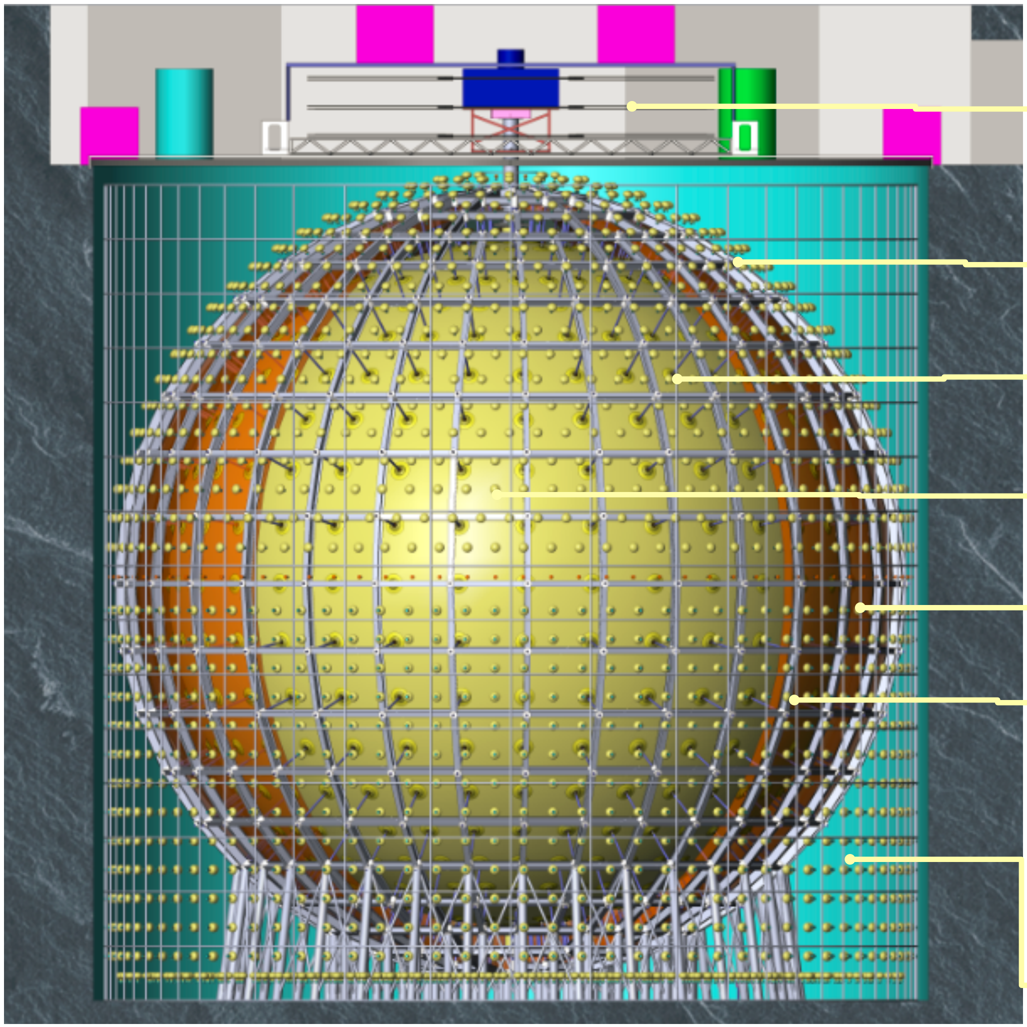


By 2020: 26.6 GW

arXiv: 1507.05613;1508.07166;

Largest LS Detector

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



Muon detector

Stainless Steel Structure

Φ35m Acrylic tank

20 kt LS(A_L> 25 m)

40kt pure water(A_L> 50 m)

~18000 20" PMTs, ~75% coverage; ~36000 3" PMTs; 3% coverage

2000 20" VETO PMTs

Physics Reach

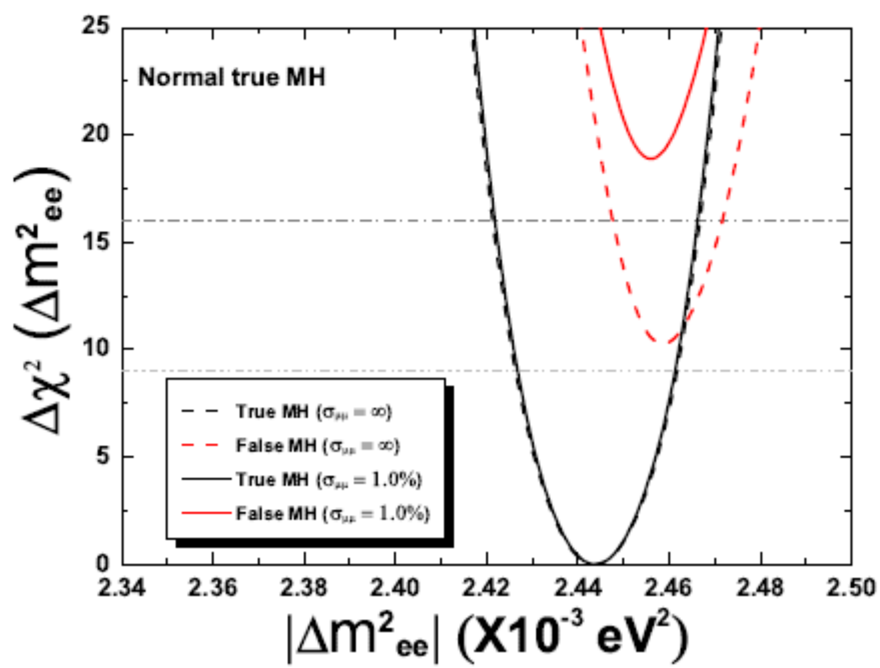
Thanks to a large θ_{13}

- **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

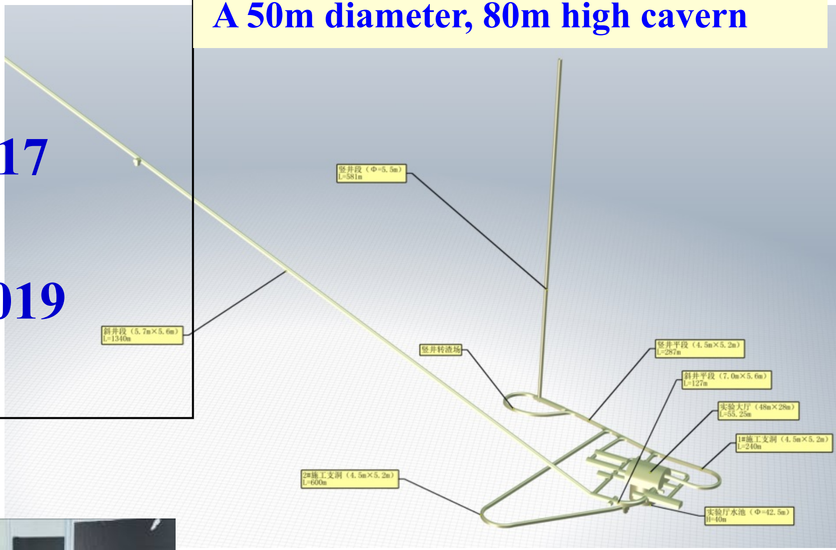


Schedule & Current Status

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

A 600m vertical shaft
A 1300m long tunnel(40% slope)
A 50m diameter, 80m high cavern

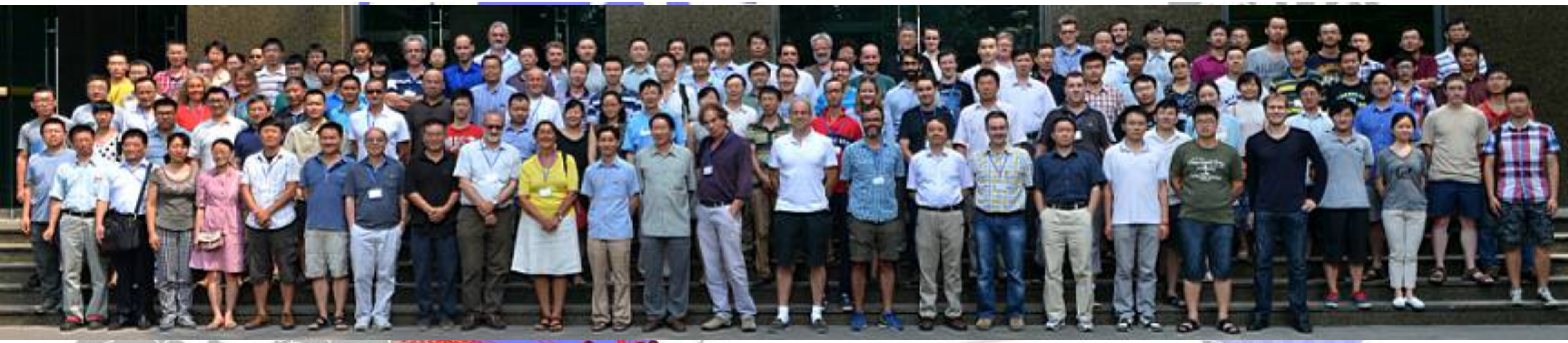


1/100 Prototype of the Acrylic tank

Domestically produced 20” PMTs

vertical shaft done: 400/600 m
Sloped tunnel done: 950/1300 m

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)

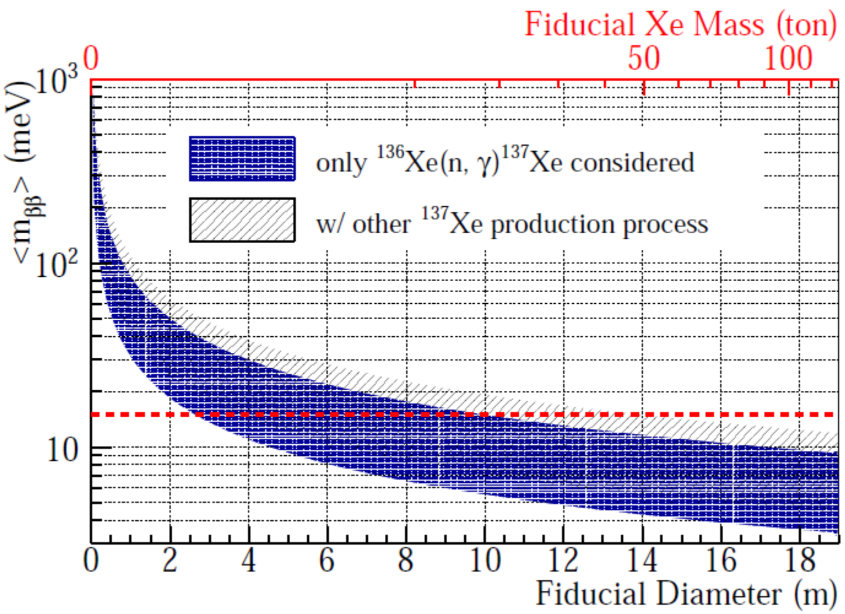
BJ Nor. U.
CAGS
Chongqing U.
CIAE
DGUT
ECUST
Guangxi U.
HIT
IHEP
Jilin U.
Ninan U.
Nanjing U.
Natl. Chiao-Tung U.
Natl. Taiwan U.
Natl. United U.
Nankai U.
NCEPU
Pekin U.
Shandong U.
Shanghai JT U.
Sichuan U.
SYSU
Tsinghua U.
UCAS
USTC
U. Of South China
Wuhan U.
Wuyi U.
Xi'an JT U.
Xiamen U.

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)	$\langle m_{\beta\beta} \rangle$,meV
nEXO	^{136}Xe	5	15-25
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	5-15

Preliminary !



Muon tracking is important !

Major Projects: Current and Future

		Current	Future
Accelerator-based	Precision frontier	BESIII	International: ILC CEPC ➔ SppC
		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
	Space	AMS	HERD XTP
		HXMT,Polar,DAMPE	