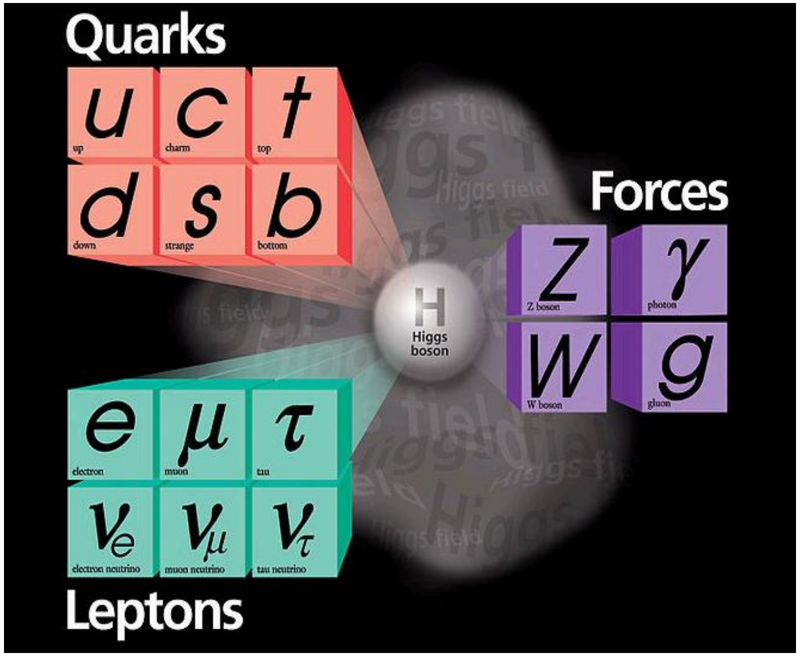
The Vision of CEPC-SppC

Yifang Wang
Institute of High Energy Physics, Beijing
NTU, Dec. 8, 2015

Where Are We Going ?

- After the Higgs, game is over ?
- Shall we wait for results from LHC/HL-LHC ?
- ILC ?
  - If yes, enough ? Next ?
  - If no, then ?



- What is the future of our field ?

Standard Model Is not Complete

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

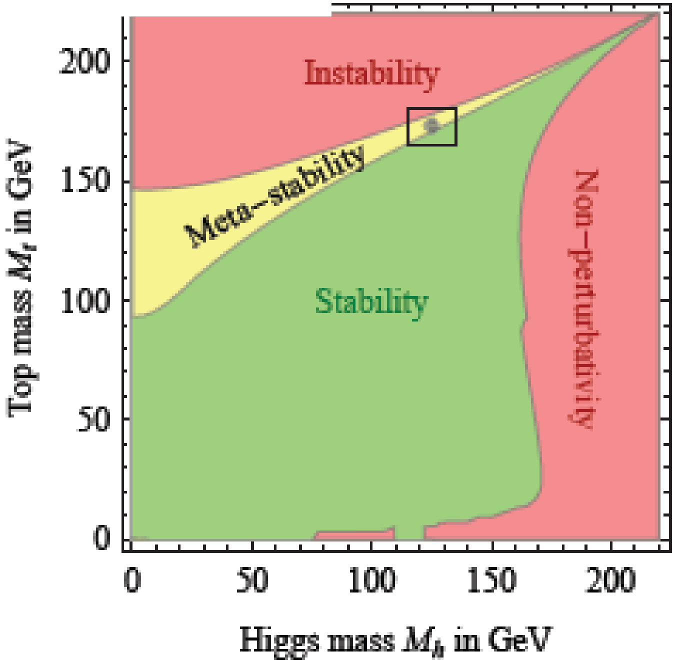
$$m_H^2 - m_{H,0}^2 \sim -\frac{3}{8\pi^2} y_t^2 \Lambda^2$$

A coincidence of 10^{-34} ?
Never before even at 10^{-4}

For Λ(new physics) at the Planck scale ~ 10^{16} TeV:

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 GeV)² ! ?

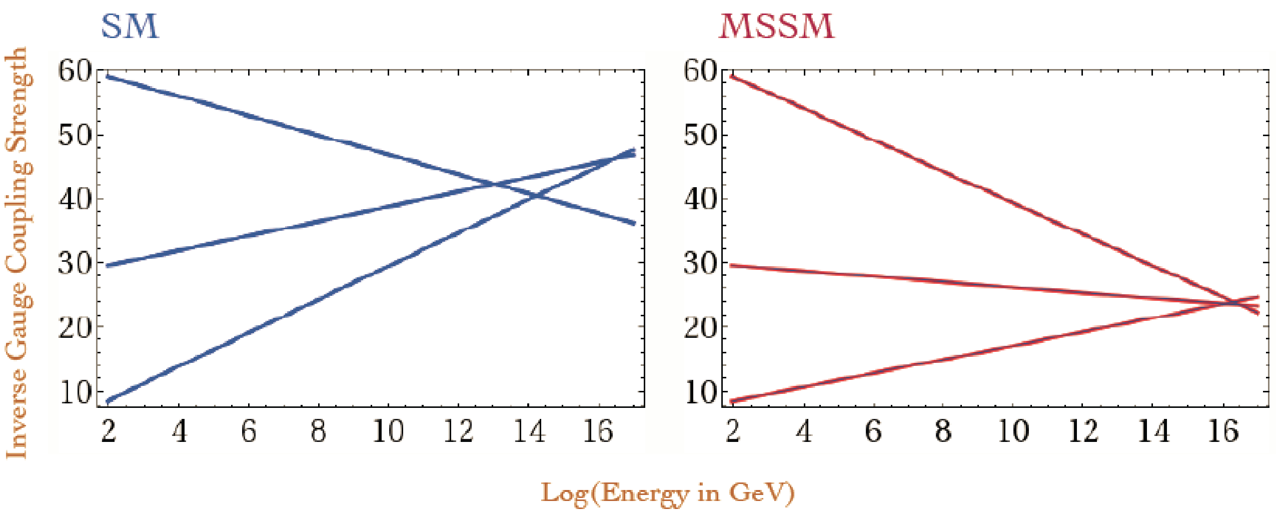
- **Masses of Higgs and top quark are in the meta-stable region, why ? Fundamental reason ?**
- **Many of the free parameters in the SM are related to Higgs. A deeper theory ?**



Fundamental reason(s) beyond SM ?!

Evidence Beyond the Standard Model

- **Unification at a high energy ?**

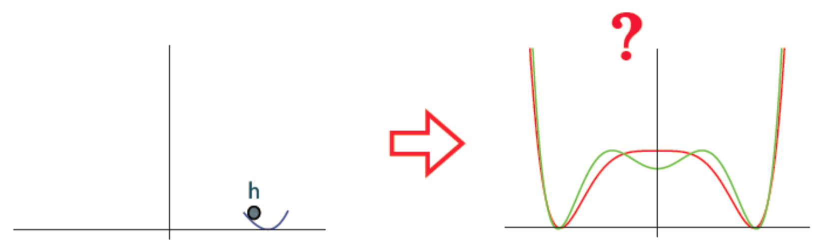


- **No dark matter particles in the SM, Needed ? Where ?**
- **No CP in the SM to explain Matter-antimatter asymmetry, why ?**
- **How to describe neutrinos in the SM ?**
- **SUSY can provide solutions to many of these problems, incident ?**

New Tasks after the Higgs Discovery

- **Open questions about Higgs**
  - Consistent with SM ?
  - Composite or elementary ?
  - Other Higgs ?
  - New properties ?
  - Responsible for CP violation？
  - What type of potential ?

Higgs is the only elementary particle with spin 0 !
Never seen point-like scalars !



- **New type of interactions concerning only the Higgs:**
  - Yukawa coupling through Higgs with spin 0:
    - hττ, hbb, htt coupling constant， ~10% @ LHC
  - Self-coupling h^3 & h^4:
    - ~ 50% @ LHC

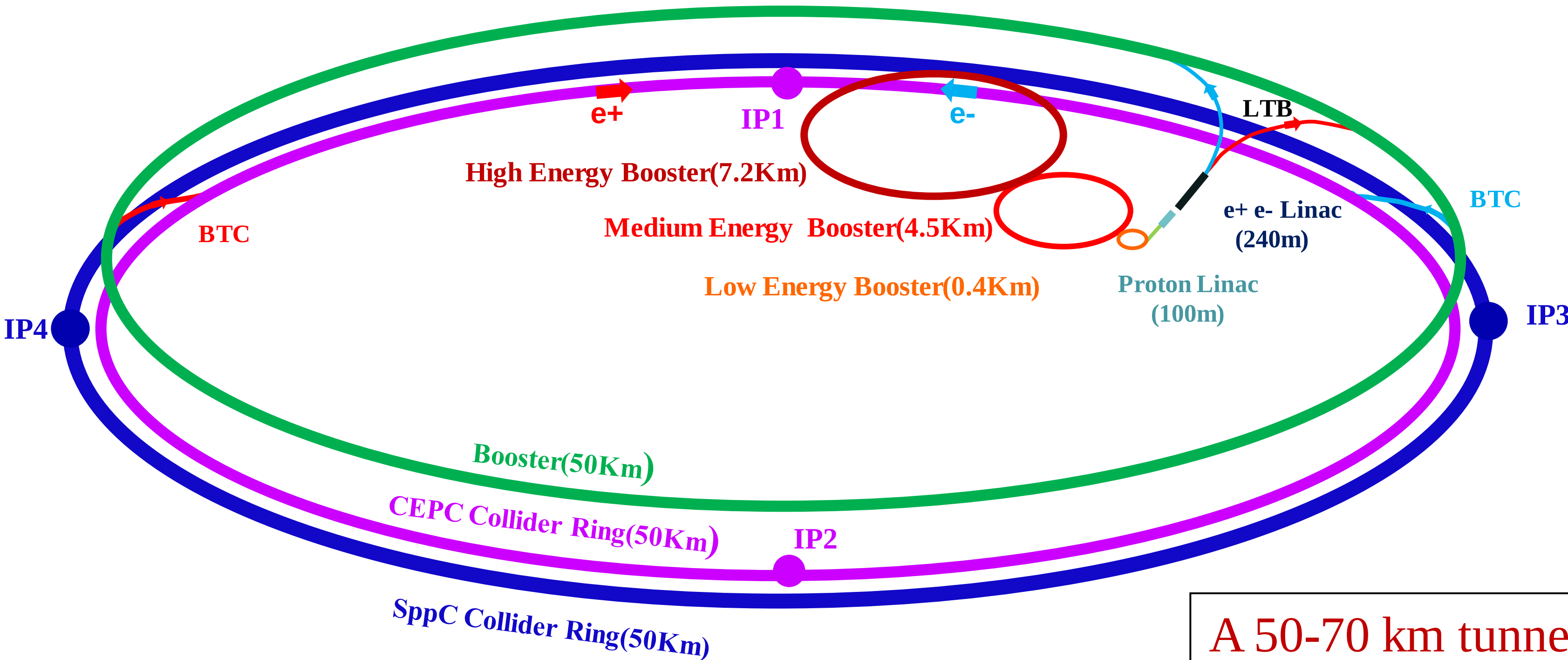
Need a factor of ~10 improvement over LHC !

- Yes, there are new physics, and also “standard” physics to be learned
- ILC is not enough, even if it can be built soon
- High energy frontier is still the center of particle physics

What to do ?

Our Proposal: CEPC+SppC

- Thanks to the low mass Higgs, we can build a Circular Higgs Factory(CEPC), followed by a proton collider(SppC) in the same tunnel
- A natural continuation of BEPC➔BEPCII➔CEPC➔SppC



In Europe, TLEP ➔ FCC

A 50-70 km tunnel is relatively easier NOW in China

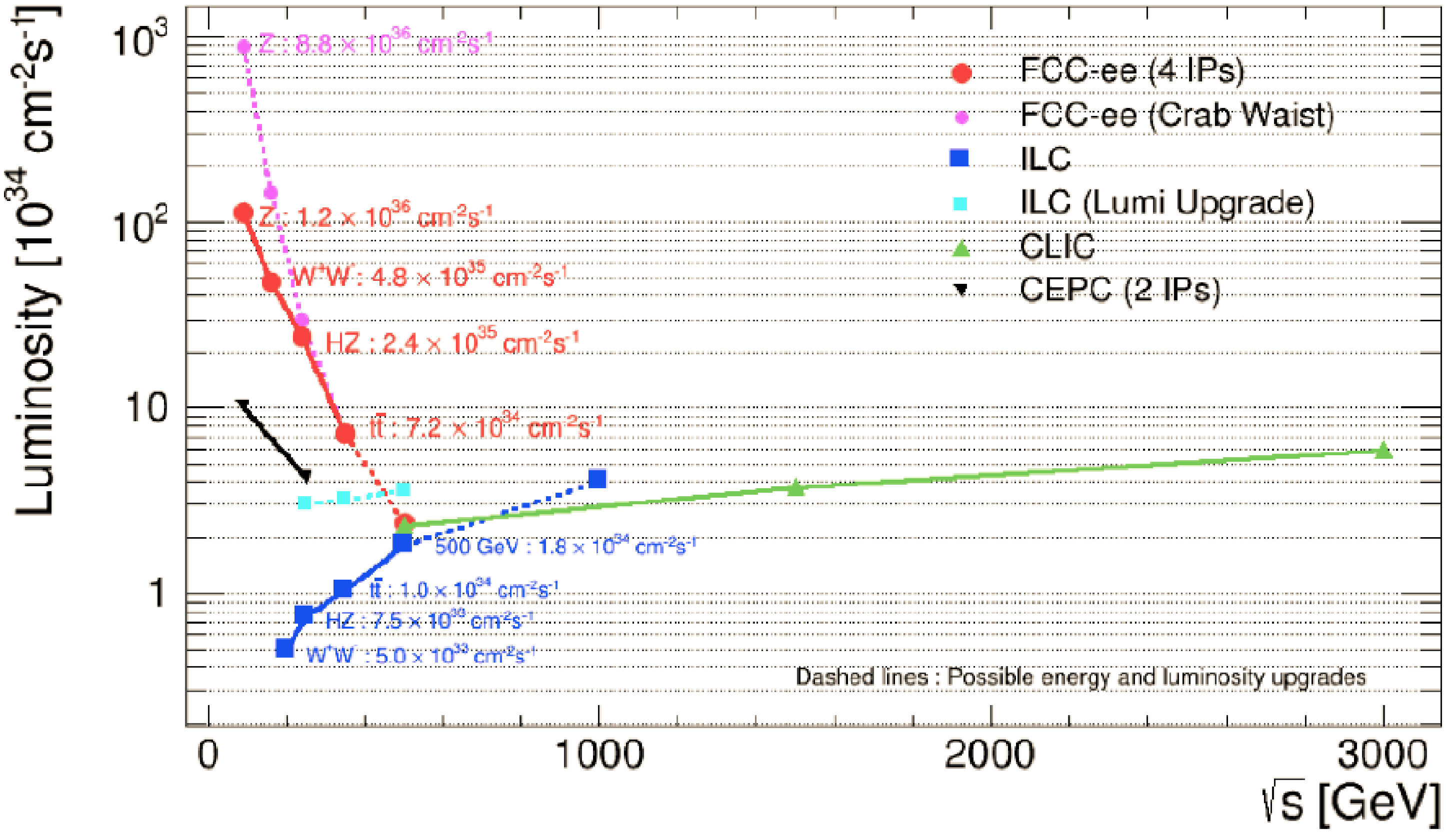
Science

- **Electron-positron collider(90, 250, 350 GeV)**
  - Higgs Factory: Precision study of Higgs(m_H, J^{PC}, couplings)
    - Similar & complementary to ILC
    - Looking for hints of new physics
  - Z & W factory: precision test of SM
    - Deviation from 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 !

Design Goal of CEPC/FCC-ee

- Limit SR power to 50 MW per beam
- CEPC: single ring, head-on collision, up to 250 GeV
- FCC-ee: double ring, large crossing angle, up to 350 GeV



CEPC:
- 10^6 Higgs
- 10^{10} Z

FCC-ee:
- 10^7 Higgs
- 10^{12-13} Z

Design Goal of SPPC/FCC-pp

- Technology to bend the proton beam is limited by the field strength of the dipole magnet. Currently we can only imagine up to 20 T.
- Hence, ~ 100 km ring and ~ 100 TeV is a generic desire

New Physics for Sure ?

Three pillars of future circular colliders

- **EW phase transition**
- **Dark Matter**
- **Naturalness**

$$m_H^2 - m_{H,0}^2 \sim -\frac{3}{8\pi^2} y_t^2 \Lambda^2$$

For Λ(new physics) at the Planck scale ~ 10^{16} TeV:

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 GeV)^2 ! ?

New Physics ≠ New Particles

New Physics = New Phenomena

New Physics = New Principles

- **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

If naturalness does not work, then ?

Shall We Wait for Results from LHC ?

- If LHC finds nothing, we should go to higher energies
  - An e+e- Higgs factory can give us a first indication
  - go directly to 100 TeV pp collider is also a viable option
- If LHC finds something, it is a new era
  - Beyond SM ➔ new energy scale, new spectrum, LHC can not complete it
  - A higher energy pp collider is needed immediately
    - To access the spectra of higher masses
    - To have more statistics since Event No. $\propto E^{\sim 5}_{CM}$
  - An e+e- Higgs factory can give us time to develop technologies for 16-20 T magnet and SC cables

Why in China？

Physics wise，
CEPC+SPPC is ideal

- Timing (after BEPCII)
- Technological feasibility (experience at BEPC/BEPCII)
- Economy → new funding to the community
- Large & young population → new blood to the community
- Affordable tunnel & infrastructure → still cheap in China now
- Money will be taken by somebody anyway → It is a pity if we miss it
- Too expensive ?
  - BEPC cost/4 y/GDP of China in 1984 ≈ 0.0001
  - SSC cost/10y/GDP of US in 1992 ≈ 0.0001
  - LEP cost/8y/GDP of EU in 1984 ≈ 0.0002
  - LHC cost/10y/GDP of EU in 2004 ≈ 0.0003
  - ILC cost/8y/GDP of Japan in 2018 ≈ 0.0002
  - CEPC cost/6y/GDP of China in 2020 ≈ 0.0001
  - SPPC cost/10y/GDP of China in 2036 ≈ 0.0001- 0.0002

CEPC ? ILC ? SPPC ? FCC ?

- CEPC is our main goal now. SPPC is very attractive but at the distant future
- CEPC design has to maintain the possibility for SPPC, but there is no need now to firmly prove the feasibility of SPPC, scientifically or technologically
- We can work together for the future pp machine, SPPC or FCC
- CEPC & ILC are complementary, and can happen at the same time
  - As a fraction of GDP, we are not asking more than what we obtained in 50-90's.
  - HEP after the cold war: need new argument. WWW ?
  - CEPC+ILC: Two machines & two detectors, no push-pull option for ILC
- Some level of competition can only help our case
  - Each continent has a major project
  - ILC approach for selecting SPPC/FCC ?

Current Status

- Initiated a global effort for the Conceptual design
- Pre-CDR completed
  - No show-stoppers
  - Technical challenges identified → R&D issues
  - Preliminary cost estimate
- R&D issues identified and funding request underway
  - Seed money from IHEP available: 12 M RMB/3 years
  - MOST: ~ 100 M / 5yr, hopefully next year
  - NCDR: ~1 B RMB / 5 yr, maybe 2017
- Working towards CDR by 2016
  - A working machine on paper
- Site selection
- Internationalization & organization

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: 2021-2027
  - Data taking: 2028-2035
- **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 -

IHEP-CEPC-DR-2015-01

IHEP-EP-2015-01

IHEP-TH-2015-01

IHEP-CEPC-DR-2015-01

IHEP-AC-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

CEPC-SPPC

Preliminary Conceptual Design Report

Volume II - Accelerator

328 pages, 300 authors

The CEPC-SPPC Study Group

March 2015

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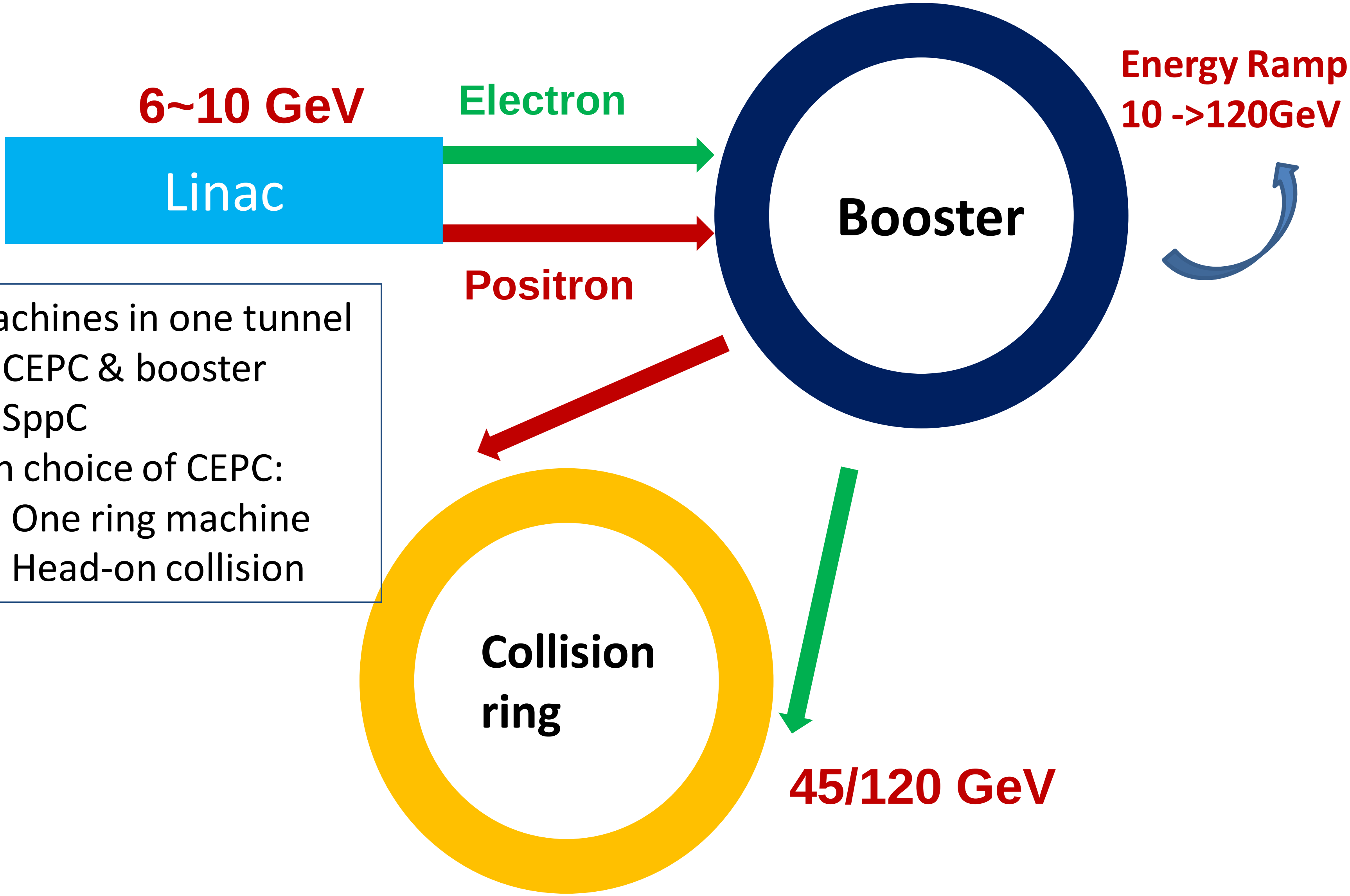
International Review of Pre-CDR

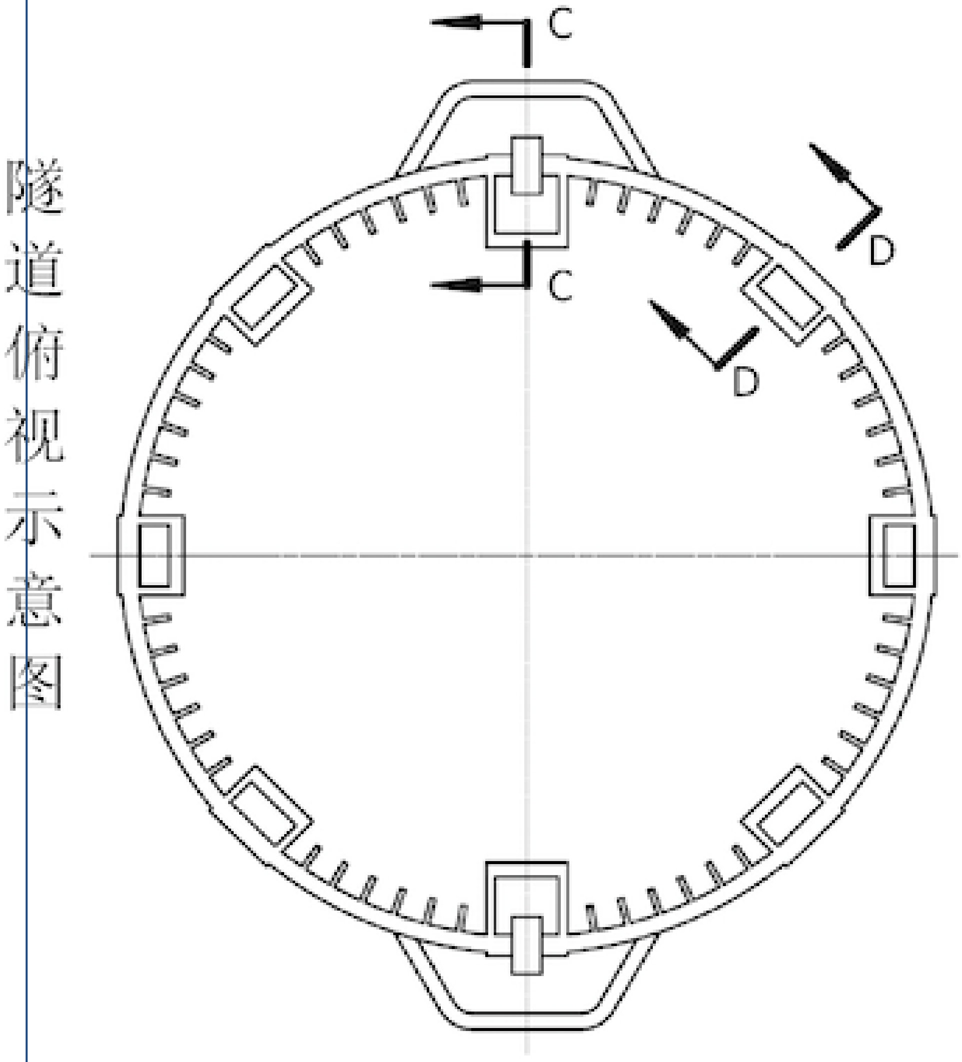
CEPC Accelerator



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

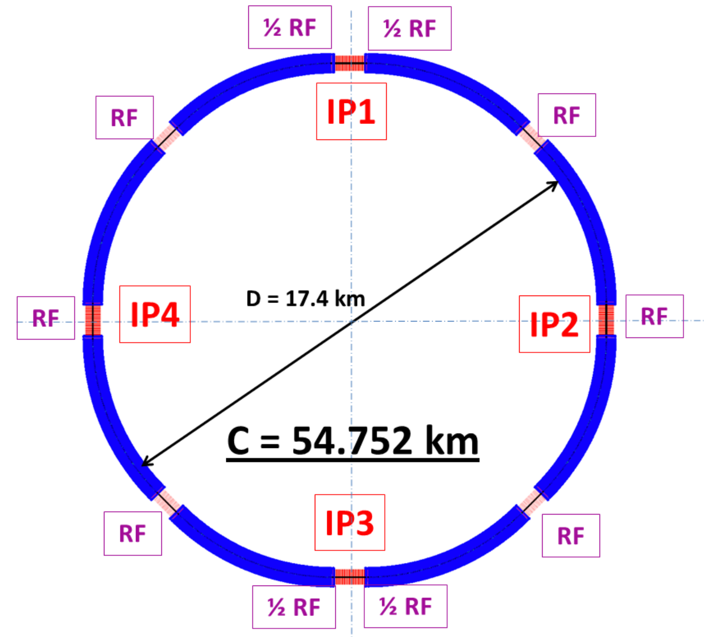
Compatibility: a Complicated Issue

- CEPC Injector
- SPPC injector
- Beam pipe detour for detectors
  - CEPC booster avoid storage ring
  - CEPC avoid SPPC detectors
  - SPPC avoid CEPC detectors
- SR beamlines
- Predict what SPPC needs
  - Collimators
  - Straight sections
  - Tunnel dimensions
  - Access tunnel
  - ....
- To be fully understood in the next 5 years



CEPC Design

- Critical parameters:
  - SR power: 51.7 MW/beam
  - 8*arcs, 2*IPs
  - 8 RF cavity sections (distributed)
  - RF Frequency: 650 MHz
  - Filling factor of the ring: ~70%



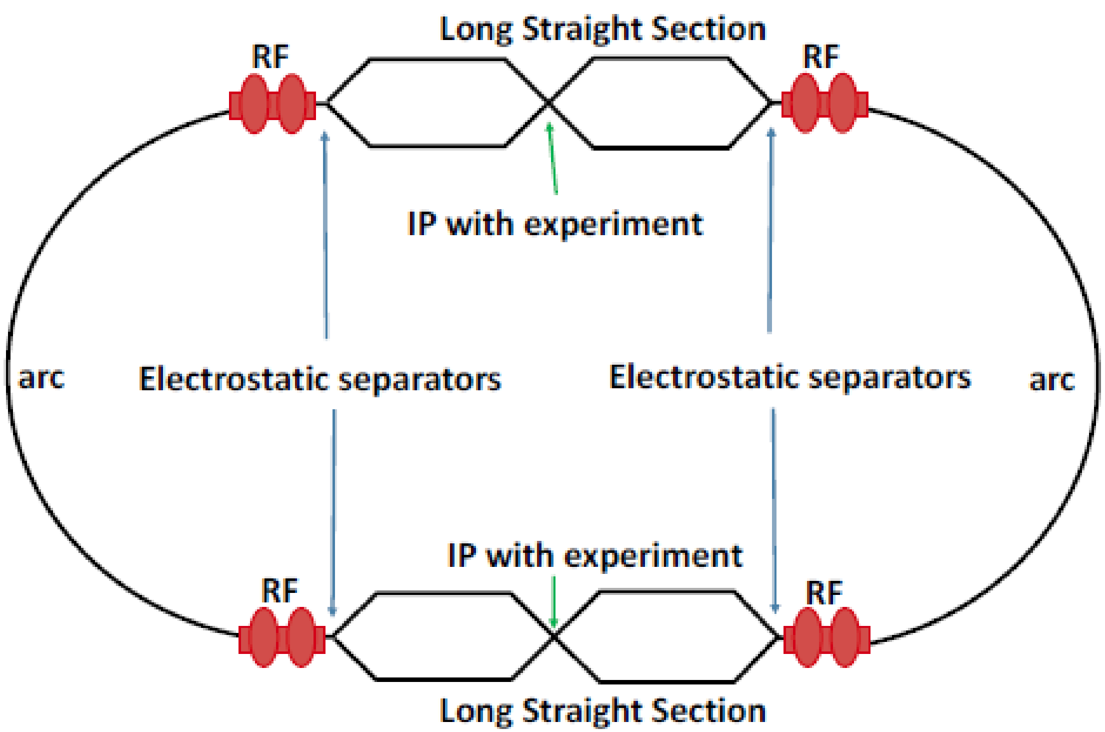
Parameter	Unit	Value	Parameter	Unit	Value
Beam energy [E]	GeV	120	**Circumference [C]**	m	54752
Number of IP[N_{IP}]		2	**SR loss/turn [U_0]**	GeV	3.11
Bunch number/beam[n_B]		50	**Energy acceptance RF [h]**	%	5.99
SR power/beam [P]	MW	51.7	**Beam current [I]**	mA	16.6
emittance (x/y)	nm	6.12/0.018	**β_{IP}(x/y)**	mm	800/1.2
Transverse size (x/y)	μm	69.97/0.15	**Luminosity /IP[L]**	$cm^{-2}s^{-1}$	2.04E+34

Main Challenges

- Beam physics: dynamic aperture, momentum acceptance, electron cloud, pretzel scheme, …
- Superconducting cavity: High-Q cavity, HOM dumping, mass production, power consumption,…
- Total power consumption: ~ 500 MW ! ➔ need a green machine
  - Reuse the thermal power, ~ 200 MW
    - Heating of houses ➔ close to a big city, summer ?
    - Gasifying liquified natural gas ➔ close to a harbor
    - Agricultural greenhouse ➔ summer ?
  - Increase the efficiency of the RF power supply to more than 70%, even 80%
  - ICFA established a panel this summer for this issue
  - Partial double ring for reduced power and higher luminosity ?

Partial Double-Ring Machine ?

- ~ 10% double-ring
- Large crossing angle & Crab waist & small β_y
- O(1000) bunches
- Luminosity close to double-ring machine ?
- Issues
  - Electrostatic separators
  - RF systems
  - Electron Cloud Issues



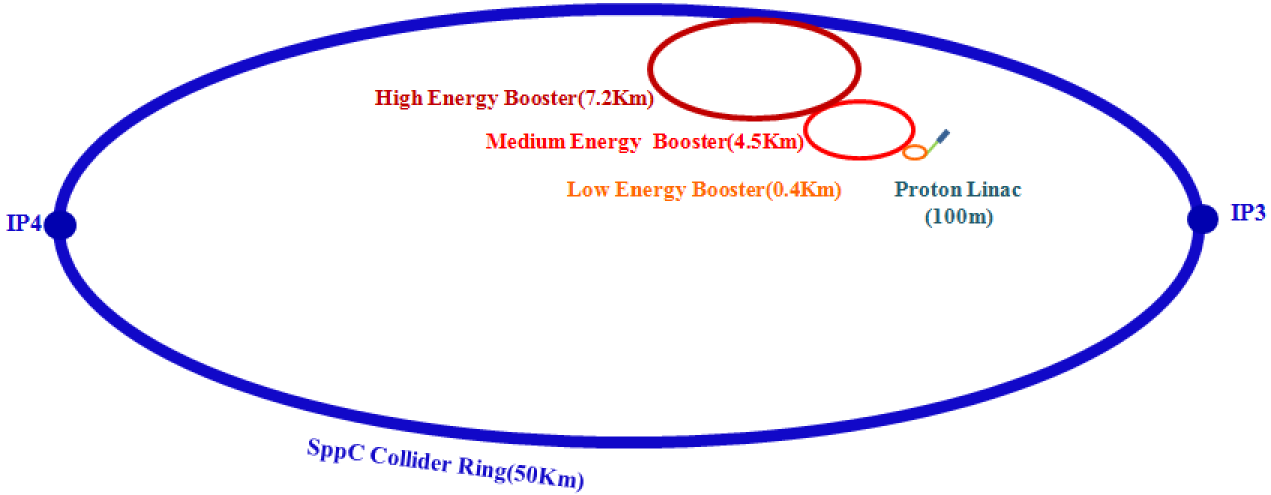
M. Koratzinos, talk given at HF2014, Beijing
M. Koratzinos & F. Zimmermann, this Conf.
J. Gao, IHEP-AC-LC-Note2013-012

SRF Parameters and R&D Goals

Parameters	CEPC-Collider	CEPC-Booster
Cavity Type	650 MHz 5-cell Nitrogen-doped Nb	1.3 GHz 9-cell Nitrogen-doped Nb
Operating E_{acc}	15.5 MV/m	19.3 MV/m
Operating Q_0	4E10 @ 2K	2E10 @ 2K
Cavity vertical test qualification	20 MV/m @ 4E10	23 MV/m @ 2E10
Input coupler power (CW)	320 kW	20 kW (DF 20%)
HOM damper power (CW)	10 kW ferrite + 1 kW hook	50 W (hook + ceramic)
Cavity number	384	256
Cryomodule number	96 (4 cav. / module)	32 (8 cav. / module)

And cryomodule heat load …

SppC Design



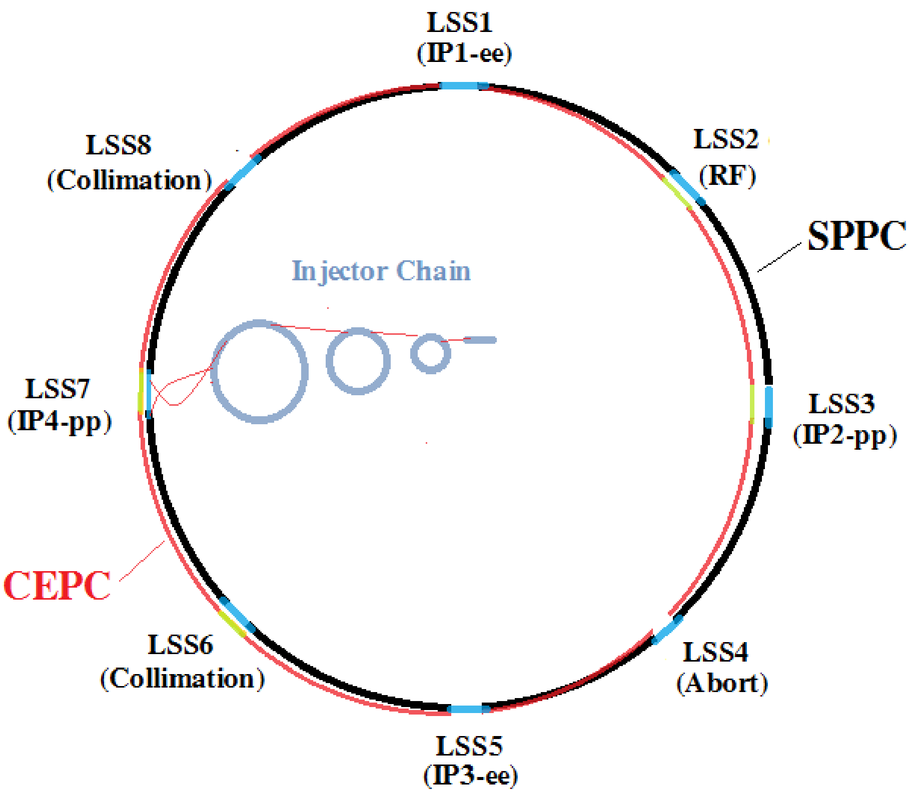
- Proton-proton collider luminosity

$$L_0 = \frac{N_p^2 N_b f_{rep} \gamma}{4\pi \varepsilon_n \beta_{IP}} F \qquad \left(F = \sqrt{1 + \left(\frac{\theta_c \sigma_z}{2\sigma_{x,IP}}\right)^2}\right) \qquad \xi = \frac{N_p r_p}{4\pi \varepsilon_n} \leq 0.004$$

- Main constraint: high-field superconducting dipole magnets
  - **50 km**: B_{max} = 12 T, E = 50 TeV
  - **50 km**: B_{max} = 20 T, E = 70 TeV
  - **70 km**: B_{max} = 20 T, E = 90 TeV

$$B_{min} = \frac{2\pi (B\rho)}{C_0}$$

SppC General design



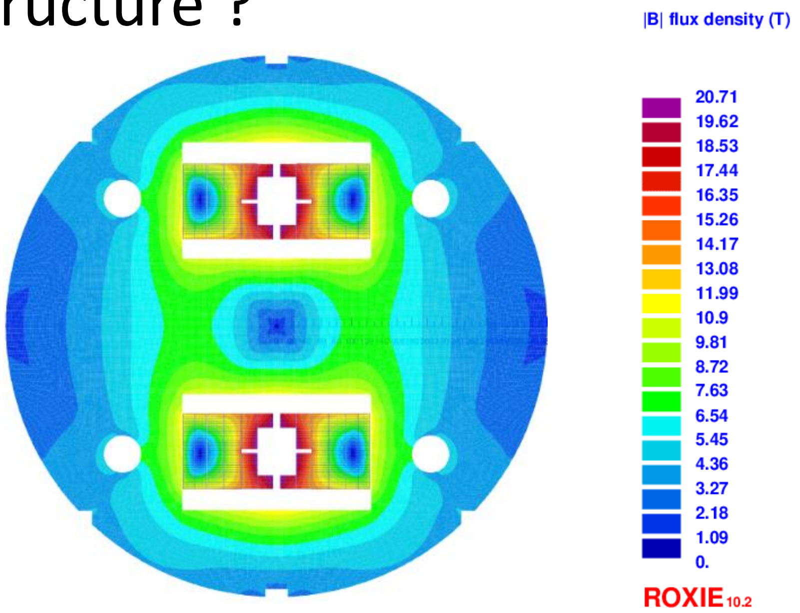
Parameter	Value
Circumference	54.36 km
Beam energy	35.3 TeV
Dipole field	20 T
Injection energy	2.1 TeV
Number of IPs	2 (4)
Peak luminosity per IP	**1.2E+35 $cm^{-2}s^{-1}$**
Beta function at collision	0.75 m
Circulating beam current	1.0 A
Max beam-beam tune shift per IP	0.006
Bunch separation	25 ns
Bunch population	2.0E+11
SR heat load @arc dipole (per aperture)	56.9 W/m

- 8 arcs (5.9 km) and long straight sections (850m*4+1038.4m*4)

Challenges

- High field magnets: both dipoles (20 T) and quadrupoles (pole tip field: 14-20 T).
- Beam screen and vacuum: very high synchrotron radiation power inside the cold vacuum:
- Collimation system: high efficiency collimators in cold sections: new method and structure ?
- ……

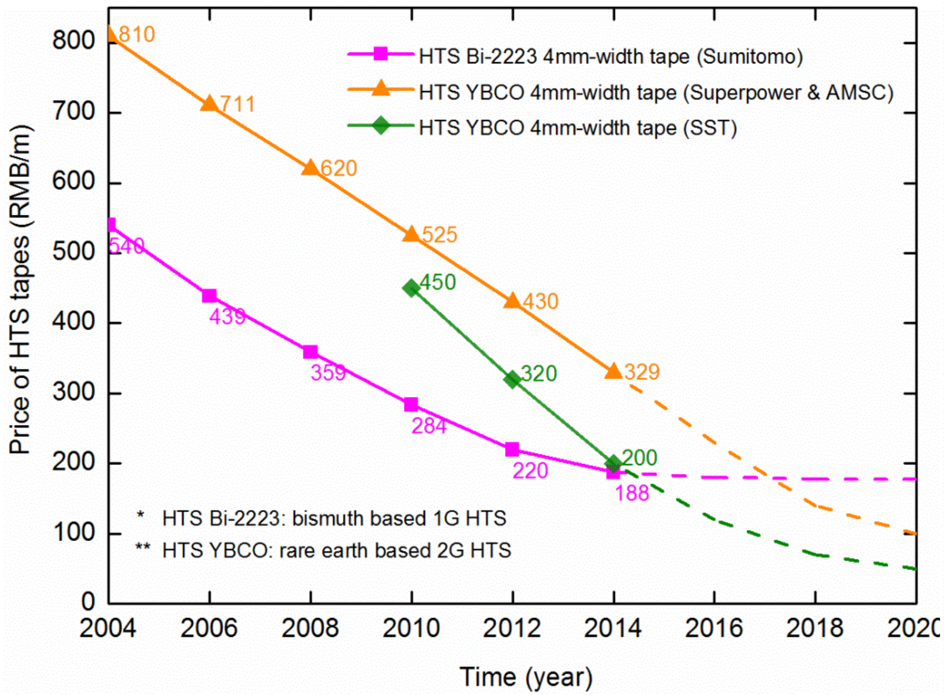
A R&D plan is developed.
Main focus is the magnet

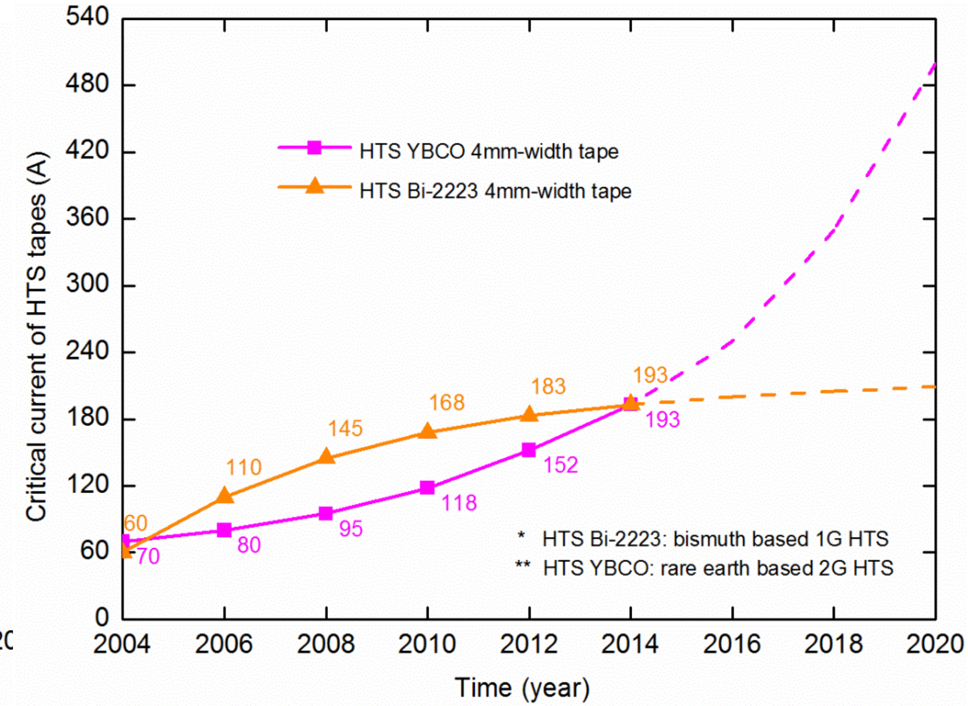


A Conceptual design of *20-T Nb_3Sn + HTS common coil dipole magnet* from IHEP

HTS ?

- Cost per meter decreased by ~ 2.5 times per 10 years
- Current limit per unit area increased by ~3 times per 10 years
- Unit price per (A•meter) can improve by ~50 times over 20 years, if past data can be used for prediction !
- 20T Full HTS magnet ???





Let's KEEP OPTIMISTIC !!!

Superconductor Price Comparison

Steve Gourlay – Superconductor price paid by LBNL to the US companies some years ago :

NbTi ~ $300/kg
Nb_3Sn ~ $2000/kg
Bi-2212 ~ $20,000/kg

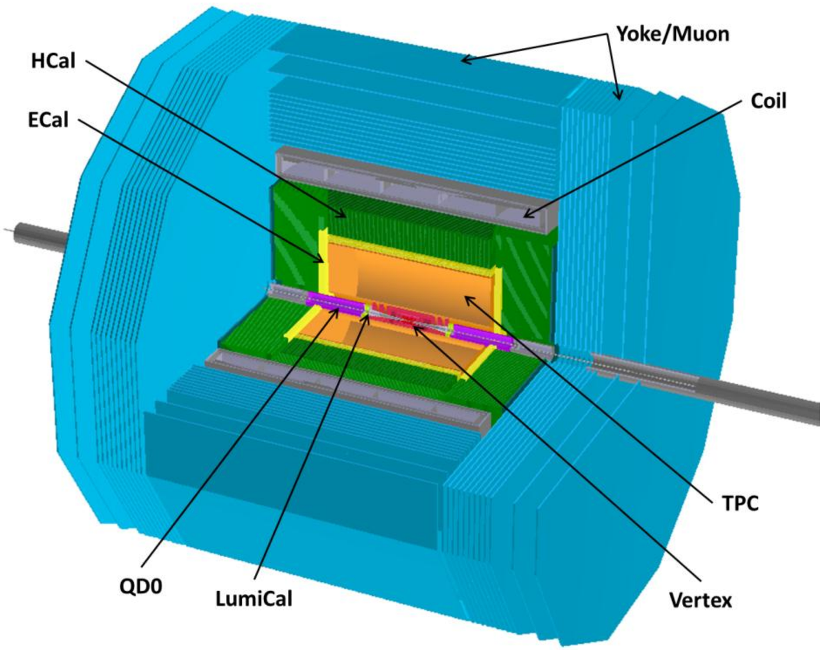
Superconductor price quoted by the Chinese companies now:

- Bi-2223: RMB 15,000/kg ⇔ USD 2,400/kg
- YBCO: RMB 20,000/kg ⇔ USD 3,300/kg

By Weiren Chou

CEPC Detector

- **Similar performance requirements to ILC detectors**
  - **Momentum:** $\sigma_{1/p} < 5\times10^{-5}\ \mathrm{GeV}^{-1}$ ← **recoiled Higgs mass**
  - **Impact parameter:** $\sigma_{r\phi} = 5 \oplus 10/(p\cdot\sin^{\frac{3}{2}}\theta)\ \mu\mathrm{m}$ ← **flavor tagging, BR**
  - **Jet energy:** $\frac{\sigma_E}{E} \approx 3-4\%$ ← **W/Z di-jet mass separation**
- **Beneficial from 20 years of ILC study**



ILD-like detector but (*incomplete*):

- Shorter L* (1.5m) → constraints on space for the Si/TPC tracker
- No power-pulsing → cooling issues
  Limited CoM (up to 250 GeV) → calorimeters of reduced size
- Lower radiation background → vertex detector closer to IP
- …

CEPC Detector R&D

Device:

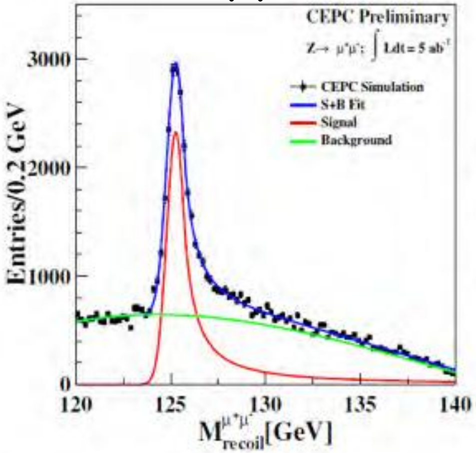
- Vertex
- Tracking device
- EM calorimeter
- Hadorn calorimeter
- SC magnet
- Muon Chamber
- Readout, trigger, DAQ
- Physics & software

Technology:

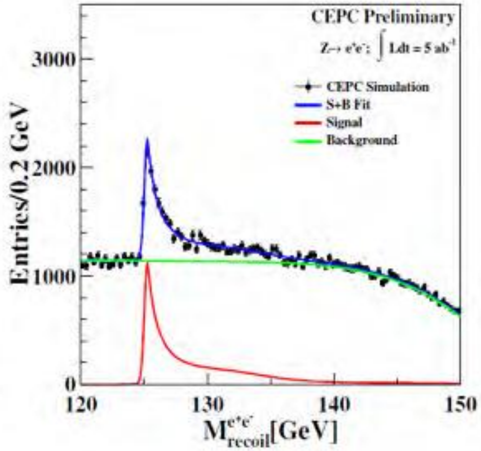
- Silicon pixel
- Silicon strips
- Silicon pads
- Scintillator pads
- RPC

Simulation and Physics

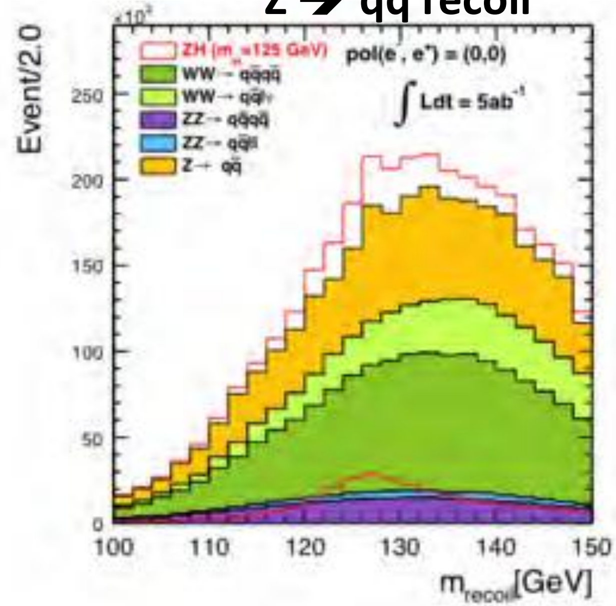
Z → μμ recoil



Z → ee recoil



Z → qq recoil

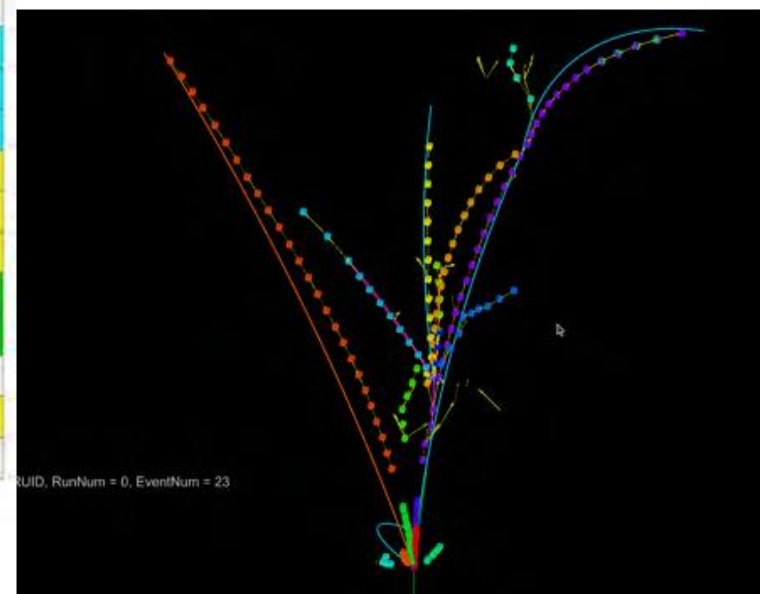


	di-muon	di-electron	di-neutrino	di-jets
σ(ZH)			-	
M_H				
σ(ZH)*Br(H→bb)				
σ(ZH)*Br(H→cc)				
σ(ZH)*Br(H→gg)				
σ(ZH)*Br(H→WW)				
σ(ZH)*Br(H→ZZ)				
σ(ZH)*Br(H→ττ)				
σ(ZH)*Br(H→γγ)				
σ(ZH)*Br(H→μμ)				
σ(ννH)*Br(H→bb)	-	-		-
Br(H→invisible)			-	
Br(H→exotic)				

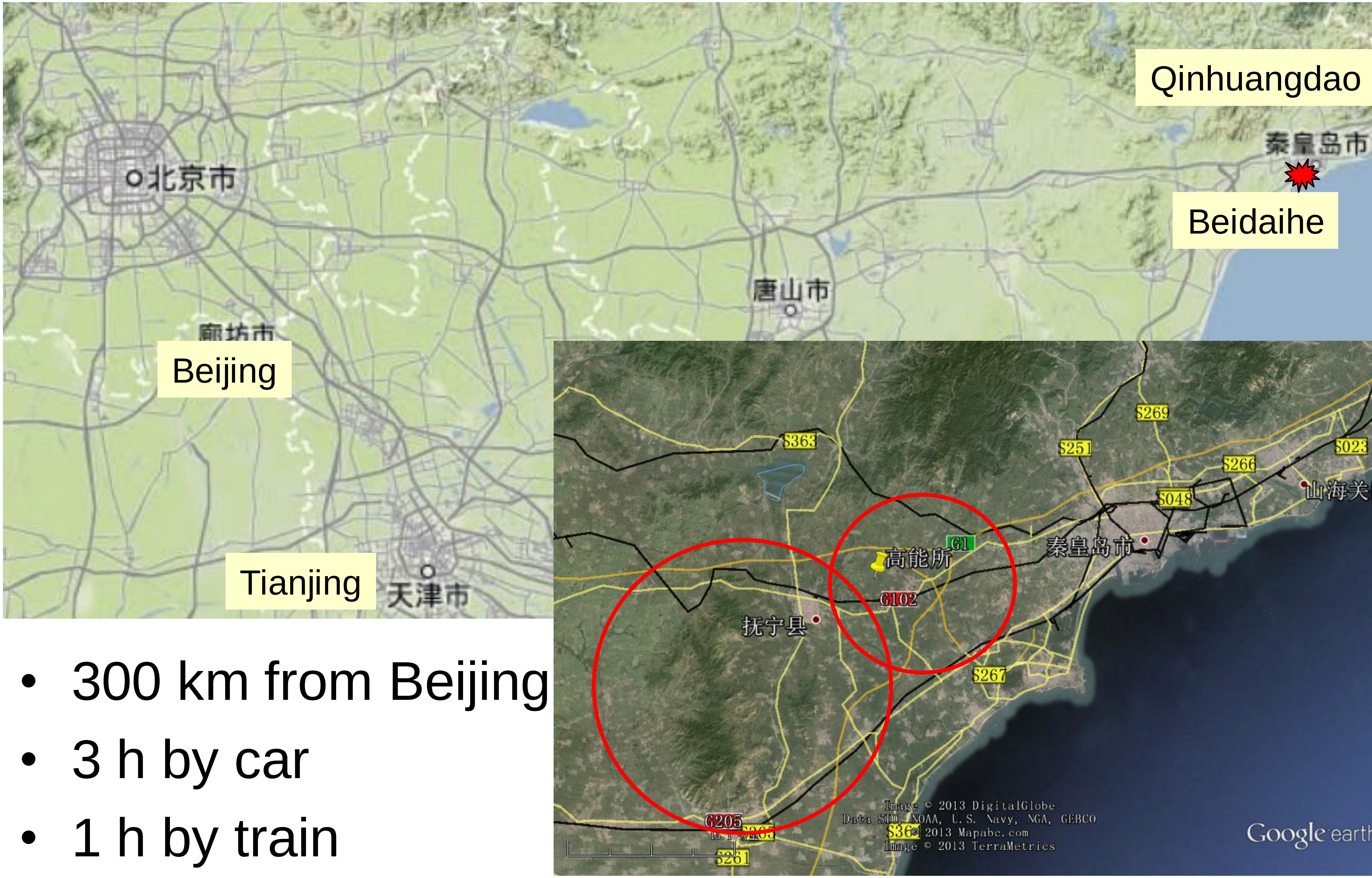
Signal with CEPC Full Simulation, Bkgrd with Fast Simulation

CEPC Fast Simulation

Extrapolated from ILC/FCC-ee results



A Candidate Site



- 300 km from Beijing
- 3 h by car
- 1 h by train

Good Thing About This Site

Best beach & cleanest air
Summer capital of China

Starting point of the Great Wall

Wine yard

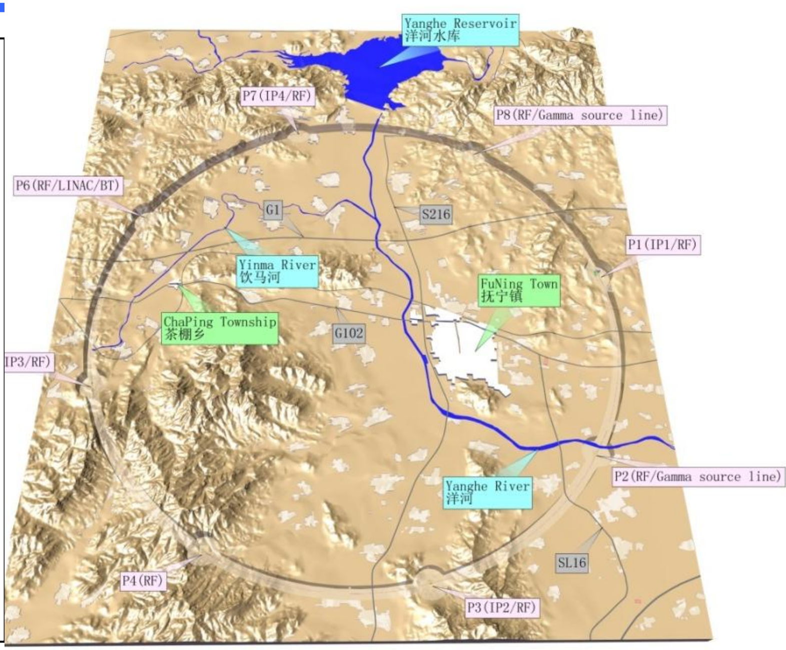
Good geology:
- granite ~ few meters underground
- seismic intensity < 0.1g
- extremely small earth vibration

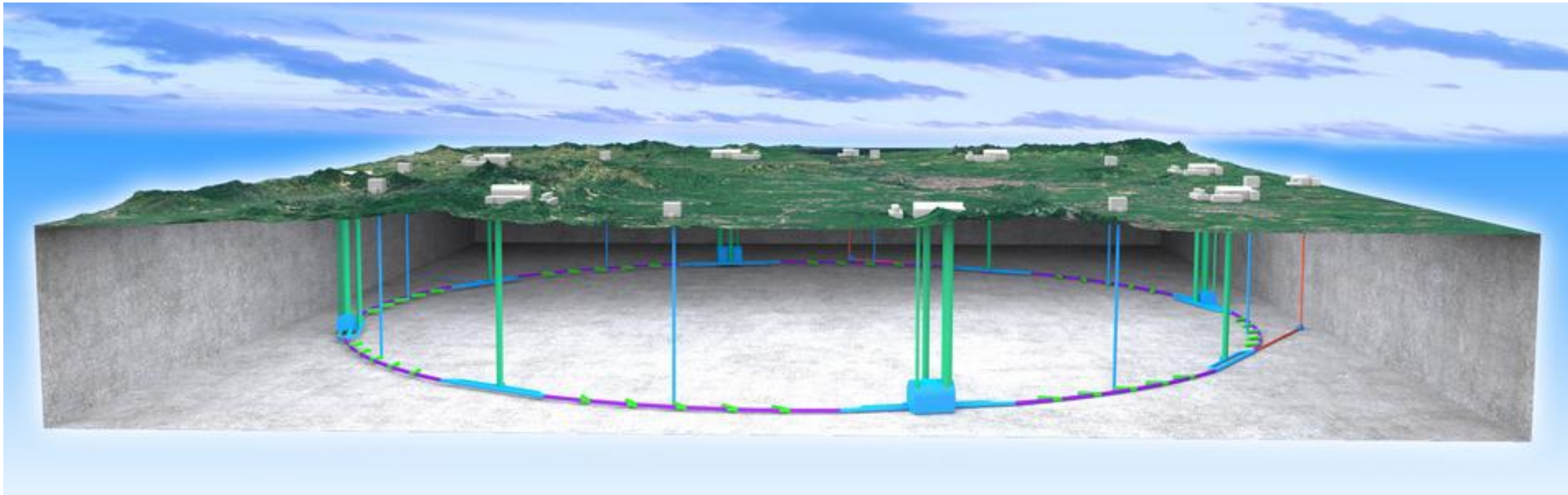
Good environment
- for living, international science city,…

Strong support from local government

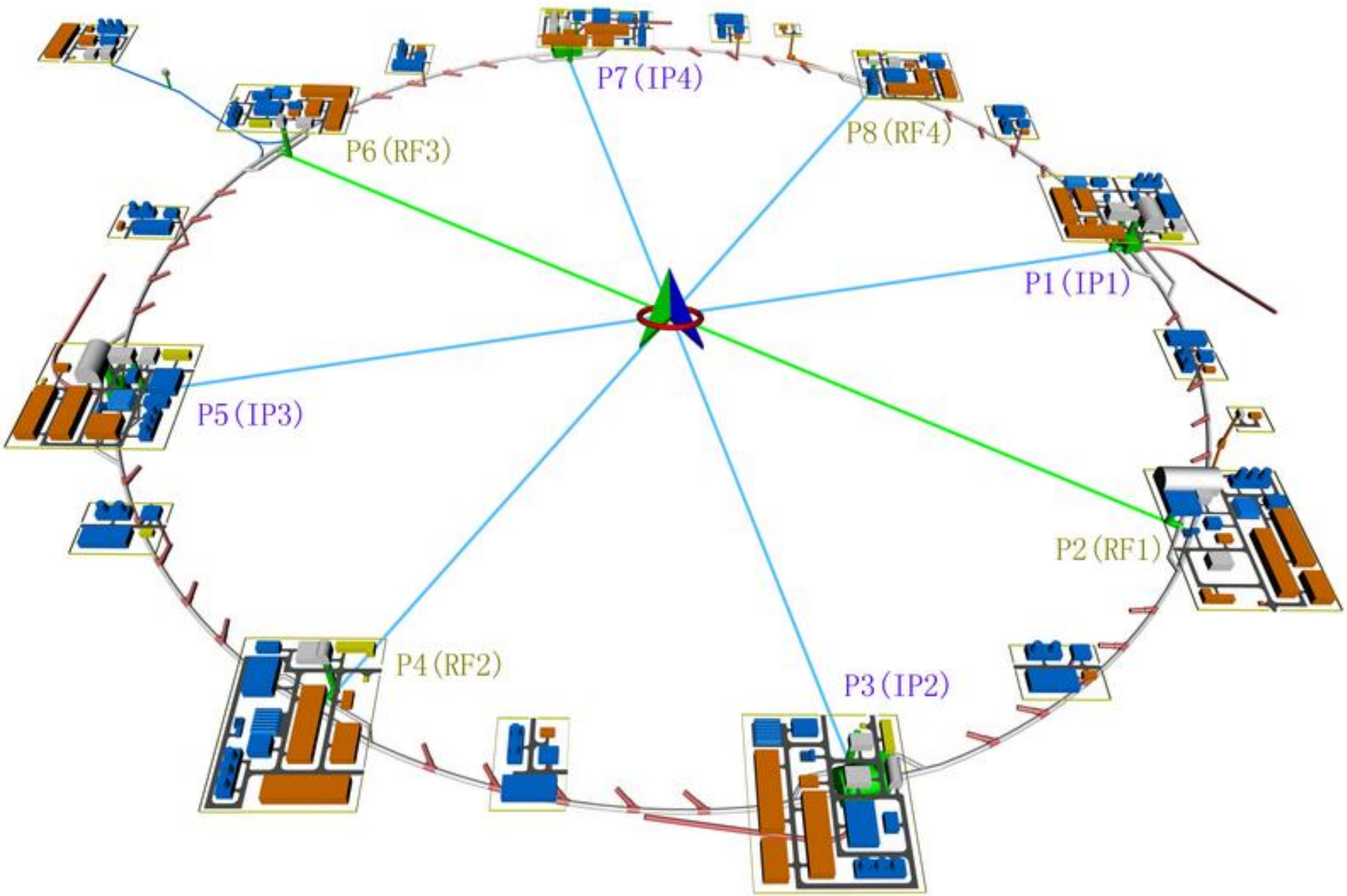
Civil Construction

- A credible design with cost estimate
- The key to keep the cost low
  - Find a site geologically the best(granite)
  - Optimize of the design
  - Choose the right designer & construction contractor
  - Management



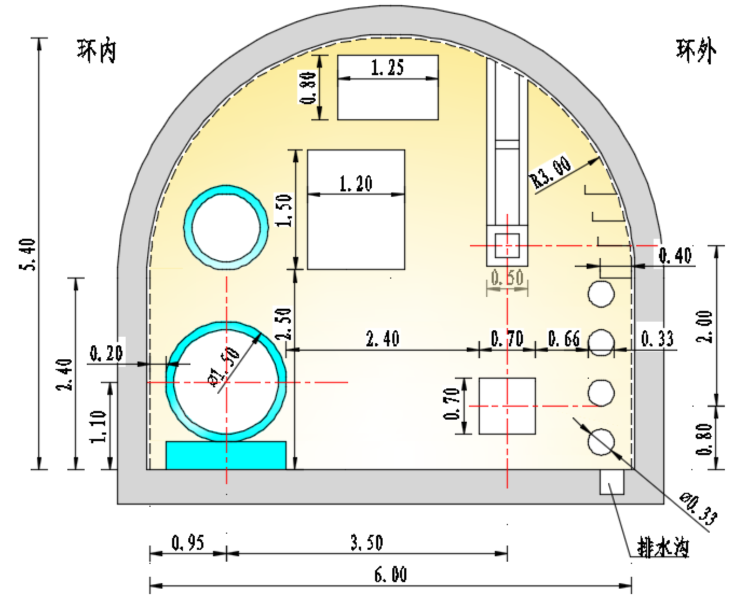


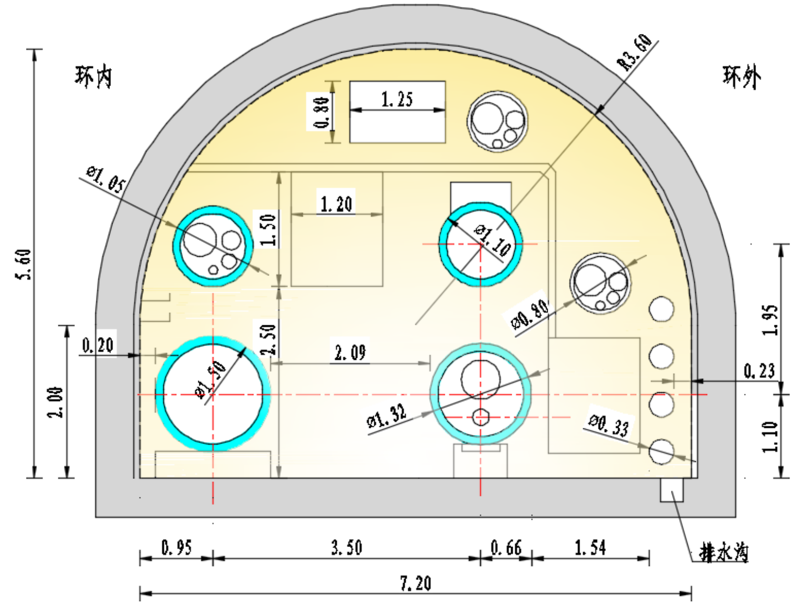
Surface and Underground Construction



Tunnel

- Concrete/Steel is not needed in granite for the stability of the structure
- Water leaks are mainly cured by Concrete + water proof material
- Concrete/Steel could bear more than half of the tunnel cost
- Solution: steel plate ➔ ~ 50% cost saving





Organization and Activities

- International workshops
  - ICFA Higgs factory workshop, Oct. 2014
  - Workshop on CEPC organized by IAS HKUST, Jan. 2015
  - ICFA workshop on SC Magnet, June 2015
  - IHEP-DOE CEPC physics workshop in Aug. 10-12, 2015
  - Beijing-Chicago workshop on CEPC in Sep. 2015
  - More in 2016
- Training & professional development
- Communication, education & Outreach

International Collaboration

- **Why we need international collaboration ?**
  - Not only because we need technical help
  - But also for financial & political support in China
    - A way to integrate China better to the international community
    - A way to modernize China's research system("open door" policy)
- **A machine for the community**
- **Right now the pre-CDR is mainly Chinese efforts with international help**
  - **An excise for us**
  - **Build confidence for the Chinese HEP community**

International Collaboration(con't)

- A new scheme of international collaboration to be explored:
  - Not the same as ITER, ILC, CERN, …
  - A new institution, a consortium, or just a new project ?
- An international advisory board is formed to discuss in particular this issue, together with others
  - Working groups
  - Workshops
  - Preliminary organizations next year
  - …

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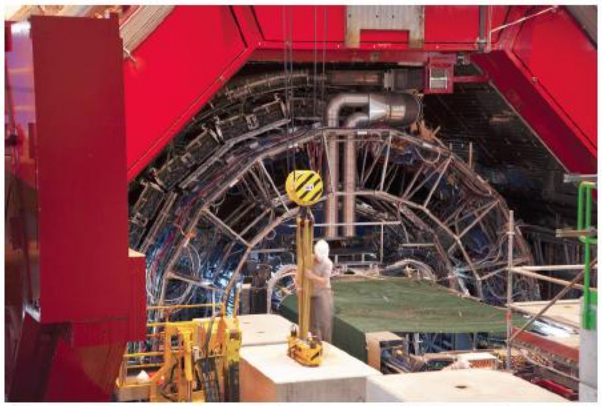
http://www.wsj.com/articles/chinas-great-scientific-leap-forward-1443136976

OPINION | COMMENTARY

China's Great Scientific Leap Forward

Completion of a planned 'Great Collider' would transform particle physics.



Atlas, one of two general-purpose detectors at CERN's Large Hadron Collider below the Switzerland border near Geneva. *PHOTO: GETTY IMAGES*

By **DAVID J. GROSS** And **EDWARD WITTEN**
Sept. 24, 2015 7:22 p.m. ET

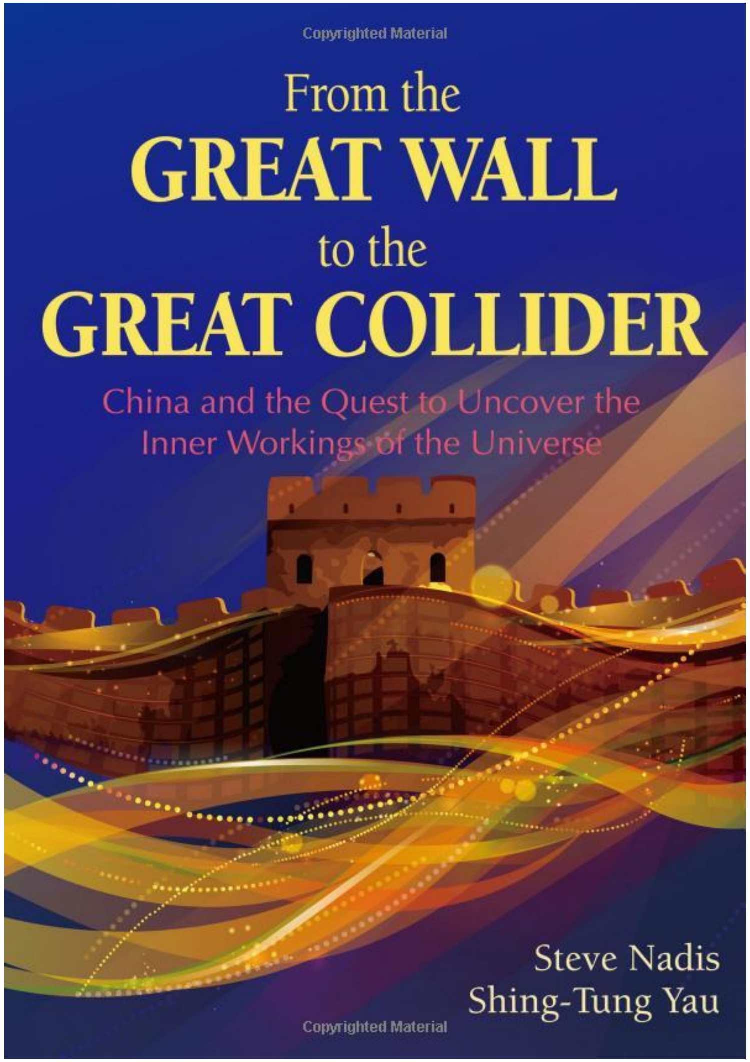
Chinese President Xi Jinping's visit to Washington is an excell opportunity to recognize China's scientific contributions to th community, and to foster more cooperation between the U.S. a China in many areas of science, especially particle physics.

The discovery of the Higgs particle at Europe's Large Hadron C in 2012 began a new era. It confirmed an essential feature of th year-old Standard Model of particle physics, a missing ingredi was needed to make the whole structure work. But the discove left many questions unanswered. These include the mass of th particle, the unification of all subatomic forces, and the incorp of quantum gravity—issues that must be addressed if scientist to understand the origin of the universe.

There are also great potential benefits for U.S. science in collaborating on this project. Currently, the U.S. high-energy physics program is concentrated on exploring the properties of the mysterious neutrino, with no plan for a large collider. But many of our high-energy experimenters, currently working at CERN, and a phenomenal amount of U.S. accelerator physics talent could contribute to and benefit from collaboration with the Chinese.

There is another enormous benefit of a Great Collider in China that attracts U.S. and international scientists. Competition and conflict between China and the U.S. could easily spiral into a new Cold War where distrust becomes the norm. Finding ways to cooperate and collaborate are essential. International facilities are marvelous settings for such collaborations.

CERN, which was founded in 1954, attracted scientists from around the globe and played an important role in establishing harmony in Europe after World War II. Scientific contacts between physicists in the U.S. and the U.S.S.R. helped dampen the dangerous tensions between the two superpowers. With China emerging as a superpower in its own right, U.S.-Chinese collaboration on the Great Collider could play a similar role.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China and the Quest to Uncover the
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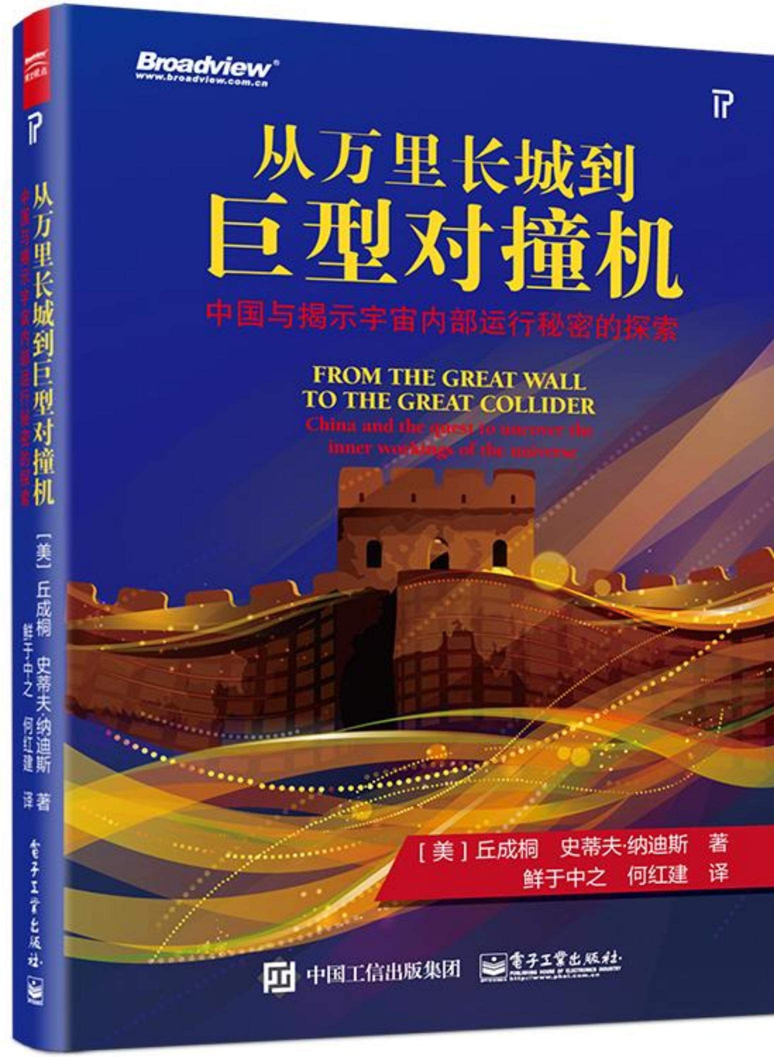
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Summary

- It is difficult but very exciting
- Tremendous efforts up to now with real progress in all fronts
- A promising future: please be optimistic !
- Let work together to make it happen

Even if it is not in China, it is still very beneficial to our field and to the Chinese HEP & Science community. We fully support a global effort