CEPC-SPPC opportunities and challenges

Yuanning Gao
Tsinghua University

August 7, 2016

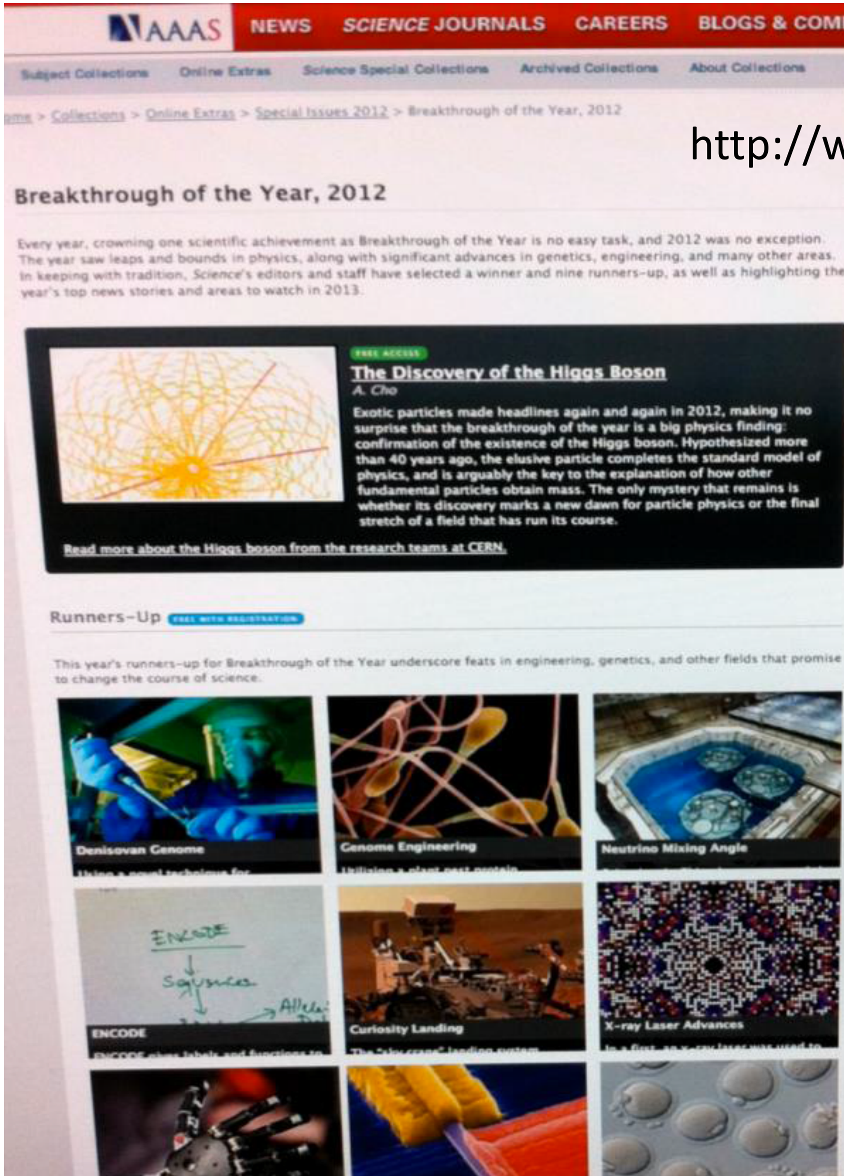
CEPC ＝ Circular Electron Positron Collider
（环形正负电子对撞机）

SPPC ＝ Super Proton Proton Collider
（超级质子对撞机）

PARTICLE PHYSICS IN 21ST CENTURY


WE WERE WARNED
2012

Nature Breakthrough of the Year



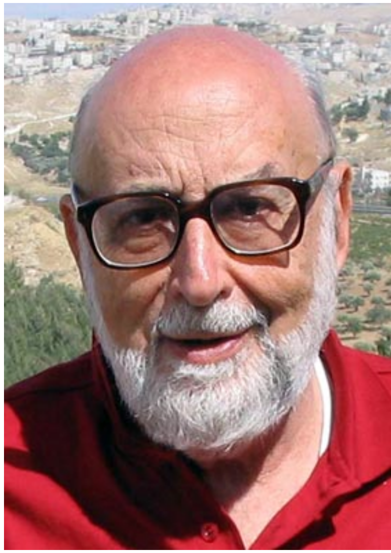
http://www.sciencemag.org/site/special/btoy2012/

The Discovery of the Higgs Boson

Neutrino Mixing Angle

θ_{13}

The Nobel Prize in Physics 2013



2012.7.4

François Englert   Peter W. Higgs

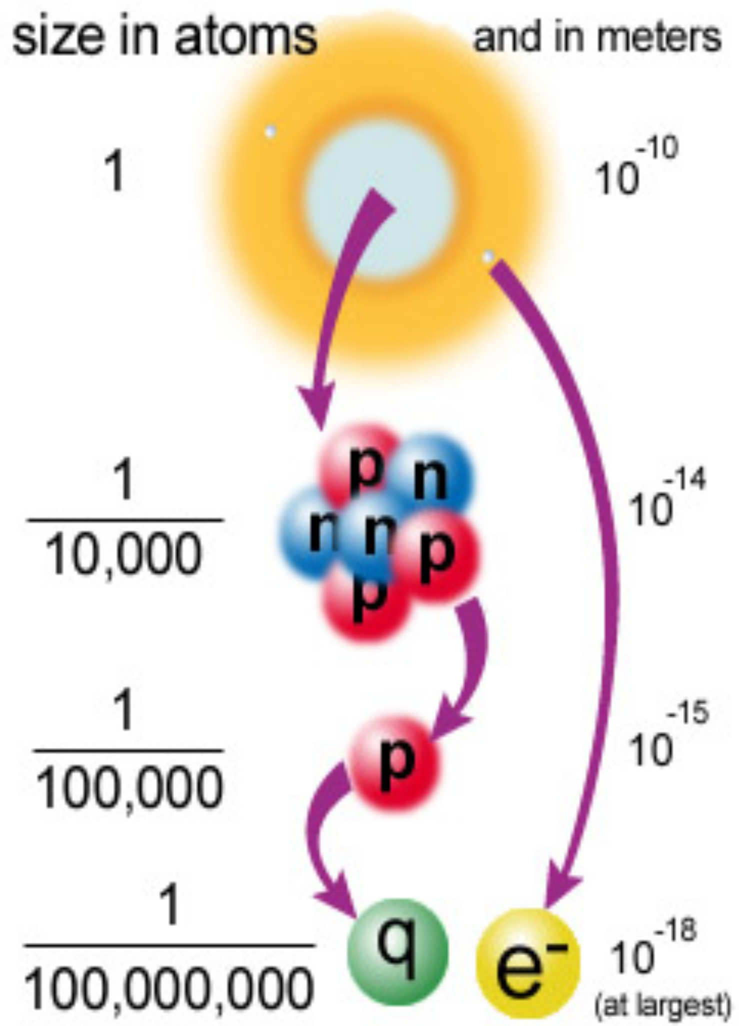
2012.3.8

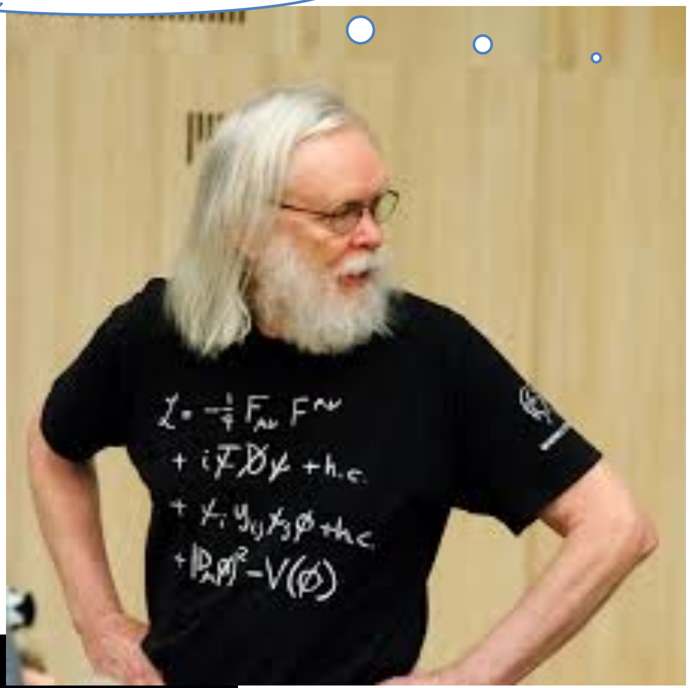
王贻芳

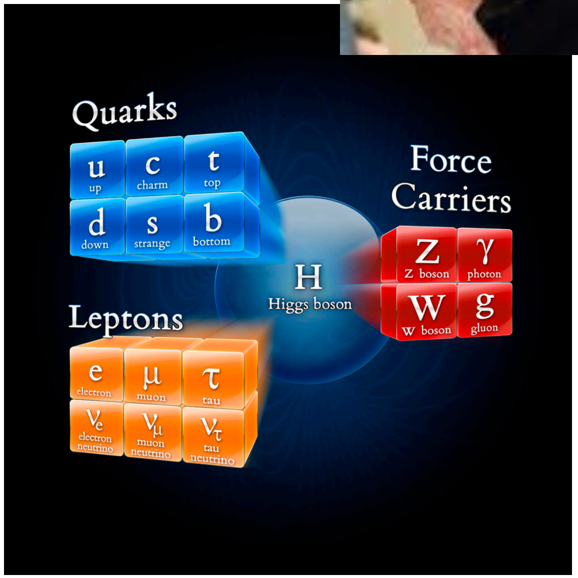
陆锦标

2014 W.K.H. Panofsky Prize

The Standard Model , for professors

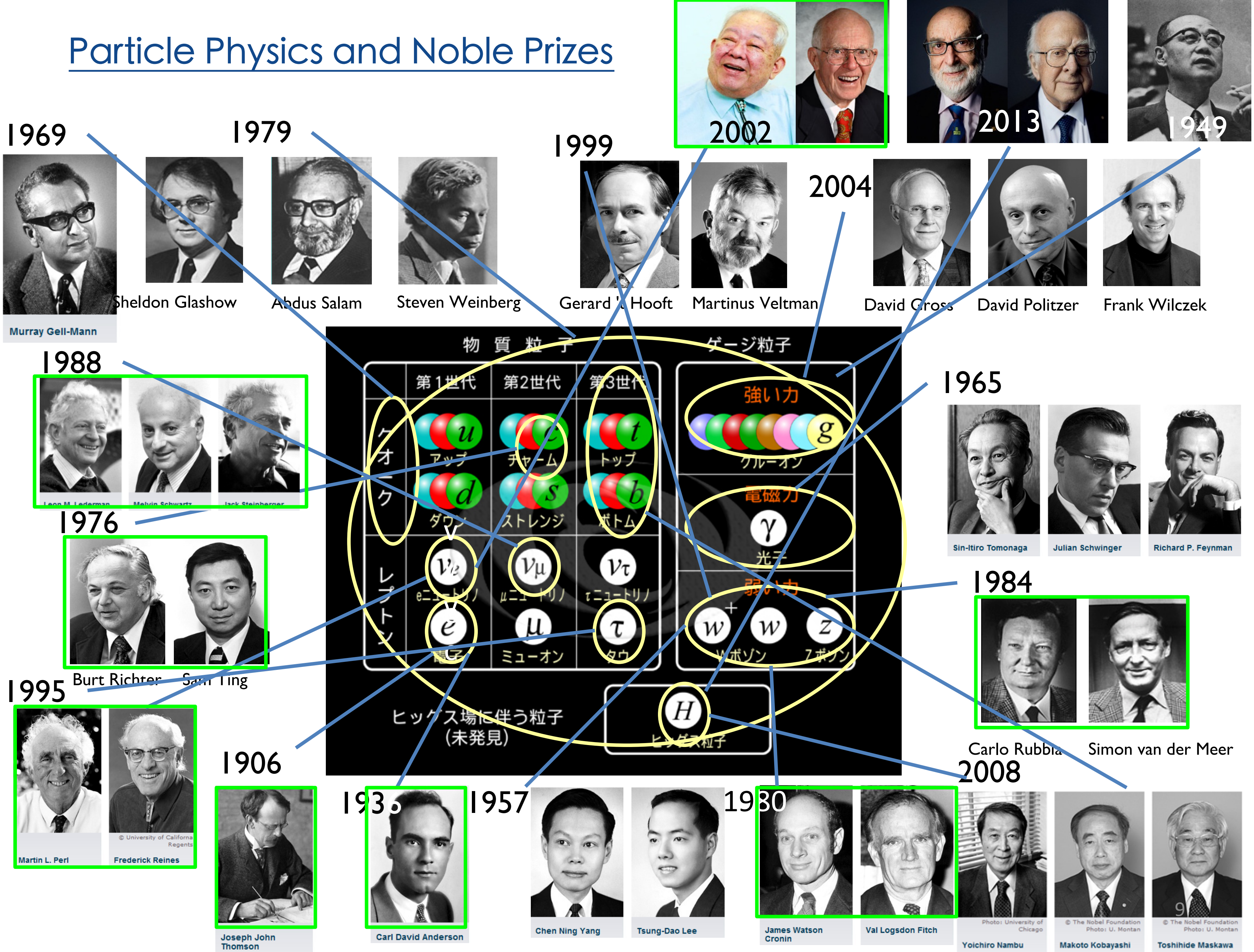




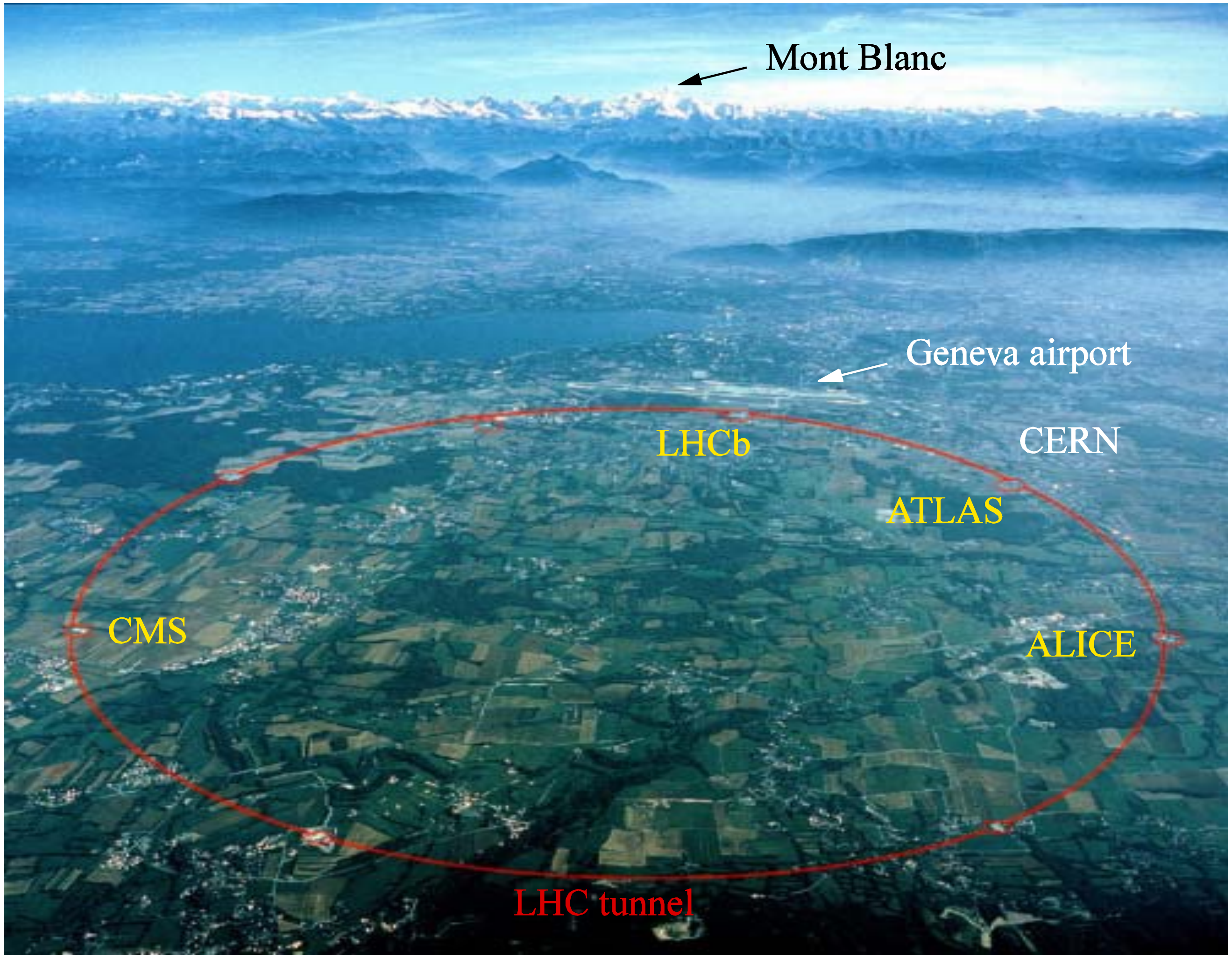


The Standard Model, for students

Particle Physics and Noble Prizes



Large Hadron Collider (LHC)



CERN European Organization for Nuclear Research

- **Founded in 1954**

- **Member States (20) :** **Austria, Belgium, Bulgaria, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Italy, The Netherlands, Norway, Poland, Portugal, Slovak Republic, Spain, Sweden, Switzerland and The United Kingdom**

- **Observer States and Organizations :** **India, Israel, Japan, the Russian Federation, Turkey, the United States of America, the European Commission and UNESCO**

- **Non-Member States currently involved in CERN programmes**

Algeria, Argentina, Armenia, Australia, Azerbaijan, Belarus, Brazil, Canada, China, Croatia, Cyprus, Estonia, Georgia, Iceland, Iran, Ireland, Lithuania, Mexico, Morocco, Pakistan, Peru, Romania, Serbia, Slovenia, South Africa, South Korea, …

European Organization for Nuclear Research (CERN)

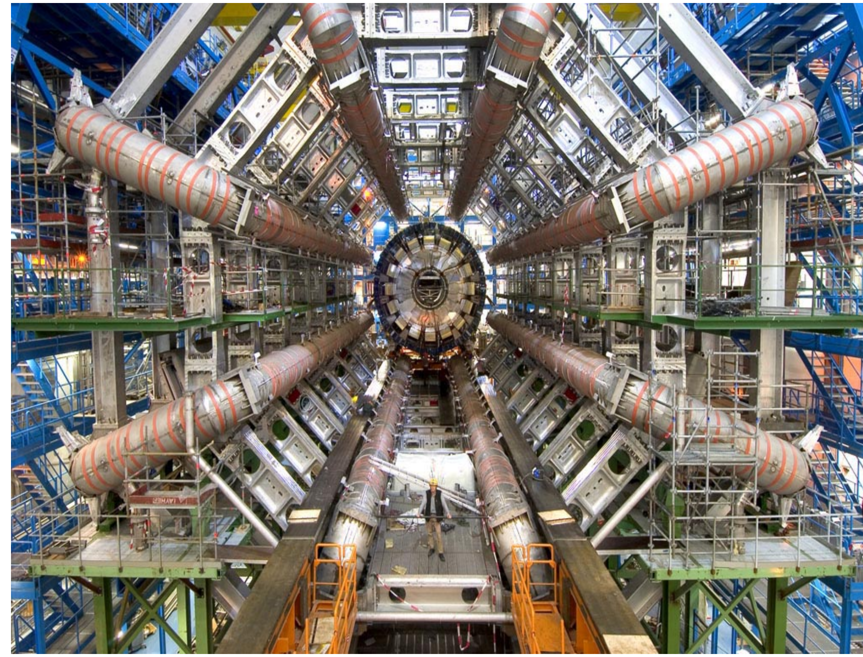
Contributions 2005 au budget du CERN

		%	MCHF
1	Allemagne	20.12%	199.560
2	Royaume Uni	17.80%	176.567
3	France	15.90%	157.676
4	Italie	12.43%	123.289
5	Espagne	7.68%	76.148
6	Pays-Bas	4.24%	42.037
7	Suisse	3.20%	31.756
8	Belgique	2.65%	26.271
9	Suède	2.59%	25.648
10	Autriche	2.18%	21.612
11	Norvège	1.86%	18.400
12	Pologne	1.82%	18.000
13	Danemark	1.69%	16.749
14	Grèce	1.39%	13.800
15	Finlande	1.26%	12.517
16	Portugal	1.11%	11.015
17	Hongrie	0.85%	8.463
18	République Tchèque	0.72%	7.167
19	République Slovaque	0.32%	3.214
20	Bulgarie	0.19%	1.909
		100.00%	991.798

Le barème des contributions est calculé avec une pleine précision, mais les chiffres indiqués sont arrondis

Higgs粒子的发现：历史性的重大事件

全球上万名科学家与工程师三十多年的努力，其中具有极为丰富的科学、工程、管理、国际合作、文化等内涵



社会影响：

全球上千家媒体的报道；

对人类生活和社会发展产生了重大推动作用：在此过程中 发明了World-Wide-Web 和网页浏览器

……这是全人类努力的结果，也是全人类的成功。

没有加速器、探测器、网格计算等诸多方面的卓越表现，不可能实现如此重大的发现。

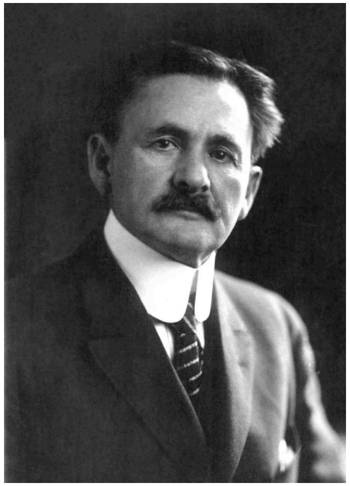
我们发现了一个新粒子，看起来就是Higgs粒子（是哪种Higgs呢？）。

这是一个里程碑 **What next?** 现对未来影响深远……

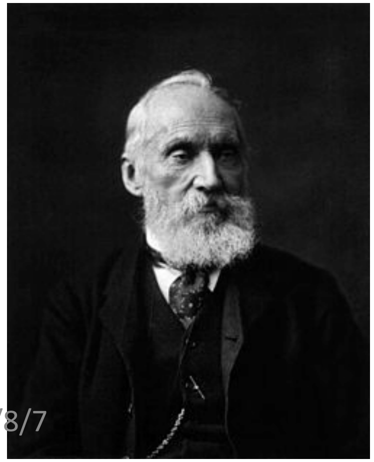
Rolf-Dieter Heuer
Director General of CERN

Historically they were all wrong…

"So many centuries after the Creation, it is unlikely that anyone could find hitherto unknown lands of any value" – Spanish Royal Commission, rejecting Christopher Columbus proposal to sail west, 1492



"The more important fundamental laws and facts of physical science have all been discovered" – Albert Michelson, 1894



"There is nothing new to be discovered in physics now. All that remains is more and more precise measurement"

– Lord Kelvin, 1900

He was wrong too !

- *"In the next ten years, the most important discovery in high-energy physics is that `the party's over'."* - C.N.Yang, 1980

- W, Z (1983-1984)

- top quark (1995)

- neutrino oscillations (2000) ?

- Higgs (2012)

Is it the end, or new beginning ?

Future will tell us !

Frontiers of particle physics

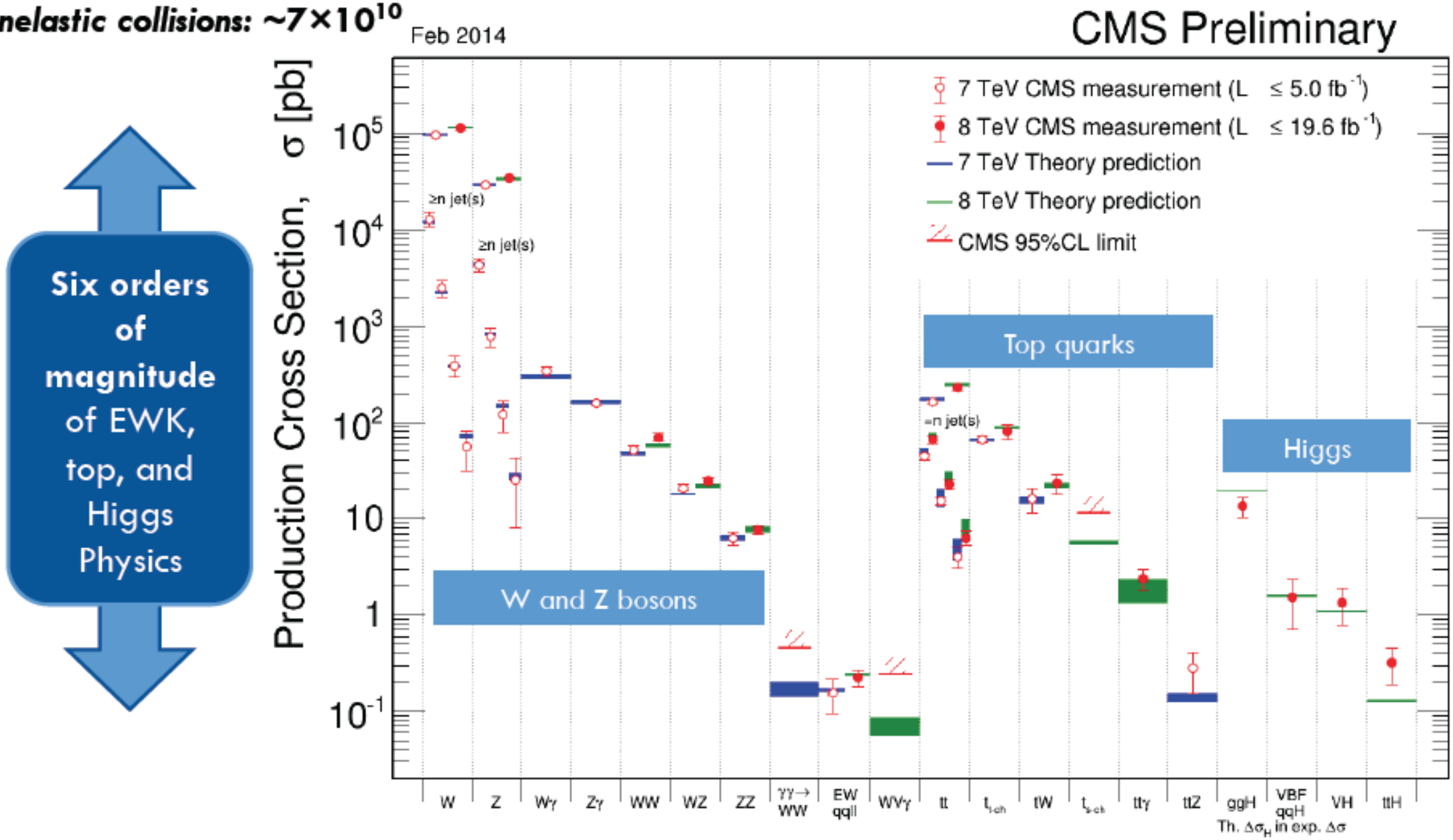
- High energy frontier
  - LHC RUN2 (2015-2020)
  - HL-LHC (2023-2032)
  - ~100 TeV pp collider?
- High precision frontier
  - Flavor physics, neutrino physics…
  - Higgs： LHC + Higgs Factory?

II

HIGGS FACTORY

Experimental tests of SM

Inelastic collisions: ~7×10^10



Summary

- Search for new resonances in diphoton final state (2015 data)
  - Spin-2: Randall-Sundrum graviton
  - Spin-0: Higgs-like
- Spin-0 analysis updated with combined 2015 + 2016 dataset
  - Data consistent with background-only hypothesis over the full mass range
    - No excess with a global significance above 1σ
  - Broad excess around 750 GeV in 2015 data not seen in 2016 data for spin-0 analysis
- More work needed to complete the analysis in the extended acceptance of the spin-2 selection

C.Rovelli, INFN Roma
On behalf of the CMS Collaboration

Conclusions

Search for new resonances decaying to di-photon pairs presented, based on 12.9/fb of 13TeV CMS 2016 data

- Mass region between 0.5 and 4.5 TeV
- Tested hypothesis: spin-0 and spin-2 resonances with different widths

Data consistent with Standard Model expectations

Modest excess presented based on 2015 (+ 8TeV) data in the region around 750 GeV not confirmed by the new data

- Results at 750GeV compatible at level of 2.4σ

2016 data combined with 2015 and 8TeV data

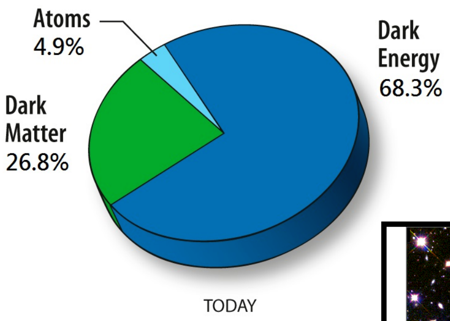
Limits set on the production cross section times di-photon branching ratio

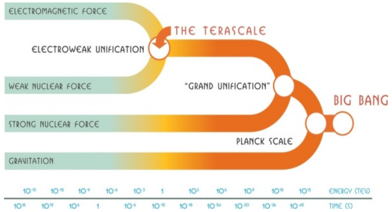
- Negligible contribution of the 8TeV dataset
- 2016 data dominating limits and significances

当代粒子物理：挑战

- 标准模型在极高能标依然自洽

- 标准模型不可能是终极理论
  - 暗物质和暗能量
  - 宇宙中正反物质的不对称
  - 标准模型的规范等级问题
  - 引力的量子理论
  - 是否存在超对称粒子，额外维度
  - 是否可以大统一
  - ……



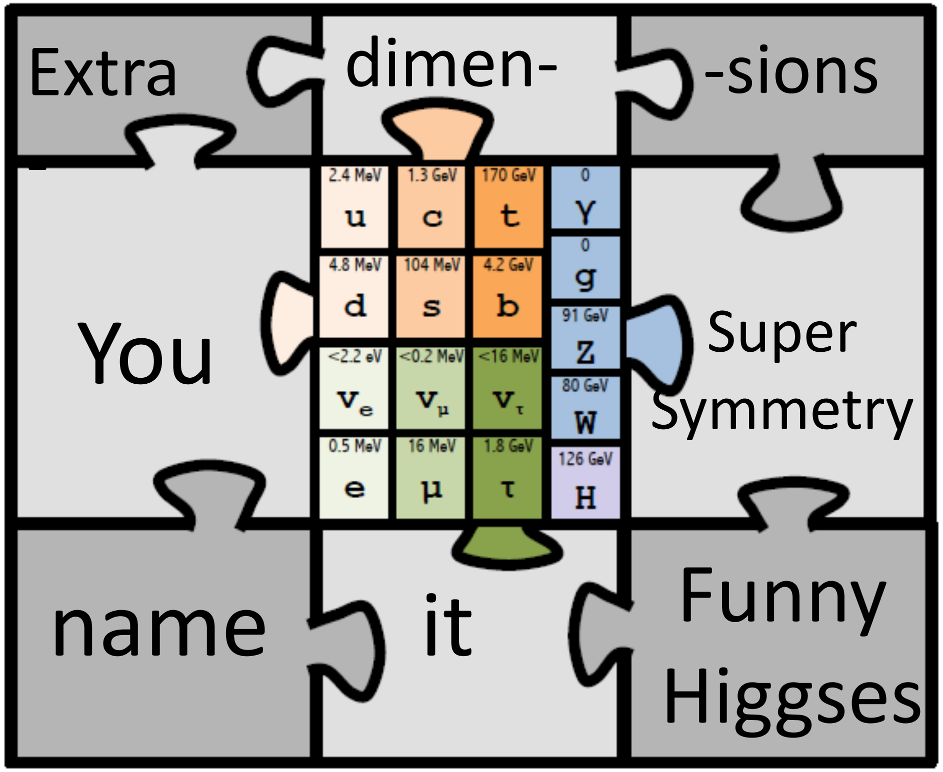


What Next？

- 理论的指导能力有限

- 实验探索发现
  - 新粒子
  - 新作用力

How?



五花八门的新物理模型

实验探索新物理(1)

- 继续运行LHC

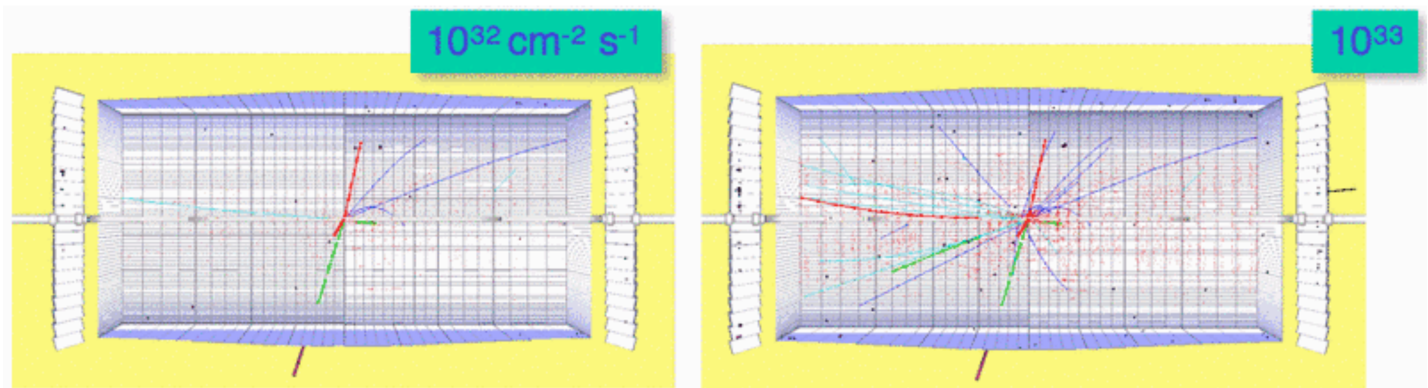
  - LHC 13-14TeV （2015-2020）

- LHC 升级
  - 高亮度升级 HL-LHC （2023-2032）
  - 高能量升级?

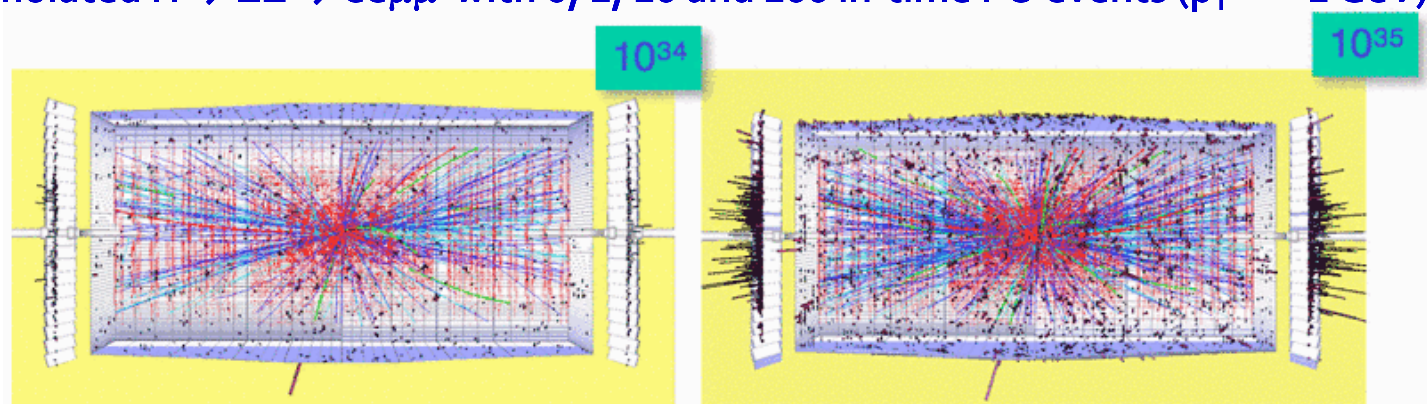
→ 技术上极具挑战性!

HL-LHC

- **挑战加速器技术：亮度增加～10倍**
- **挑战探测技术**

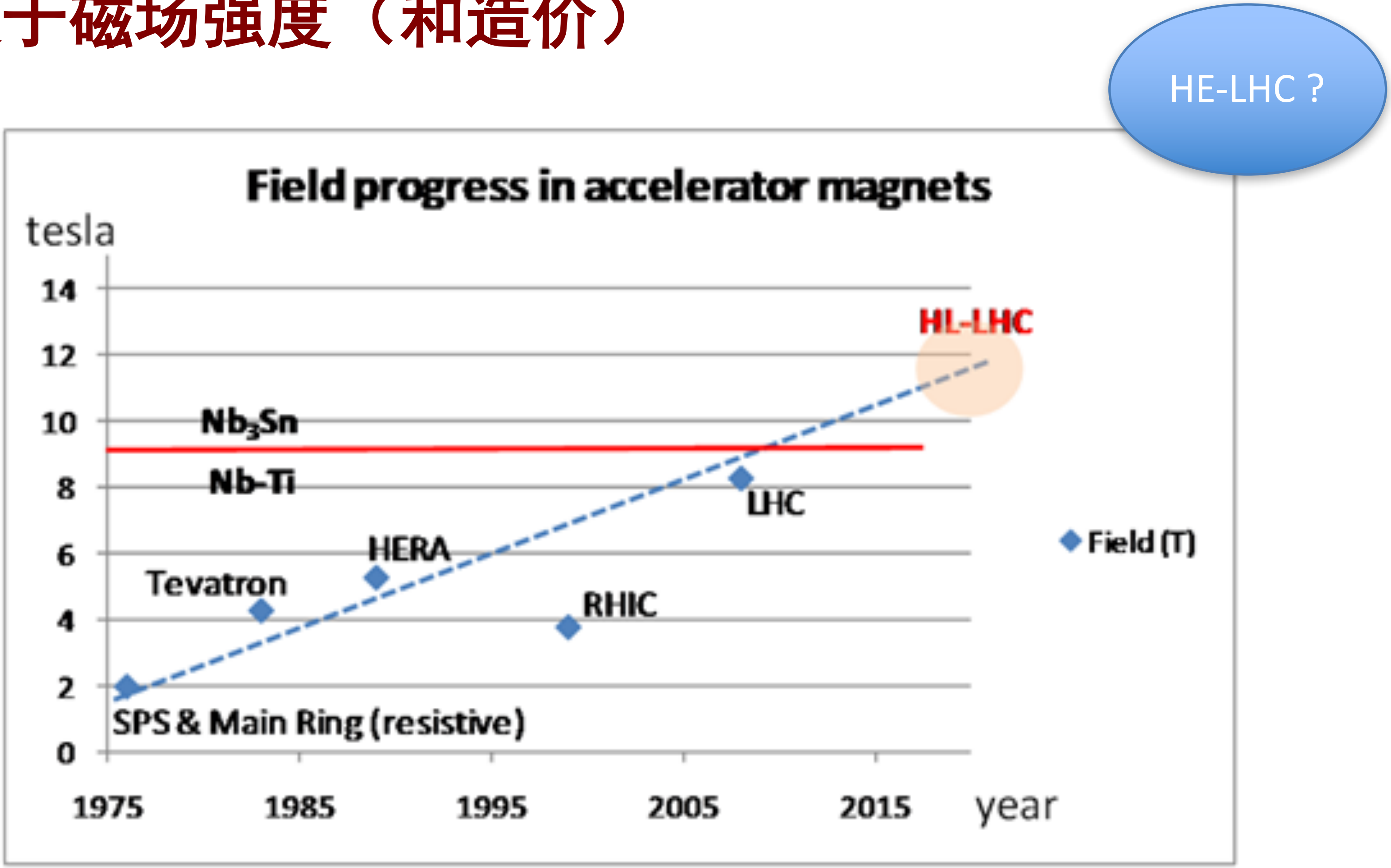


- A simulated H → ZZ → eeμμ with 0, 2, 20 and 200 in-time PU events (p_T^{cut} = 1 GeV)



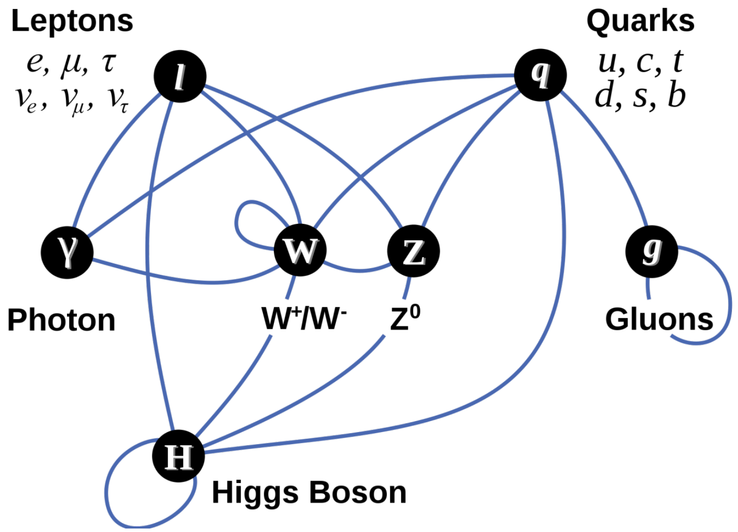
HE-LHC

- 受限于磁场强度（和造价）



实验探索新物理(2)

- 研究Higgs粒子的性质是探索新物理的窗口
  - Higgs 粒子是唯一的标量（自旋 = 0）基本粒子
  - Higgs 机制 解释所有基本粒子质量的起源
  - Higgs 场 引入了一种全新的基本粒子间的相互作用

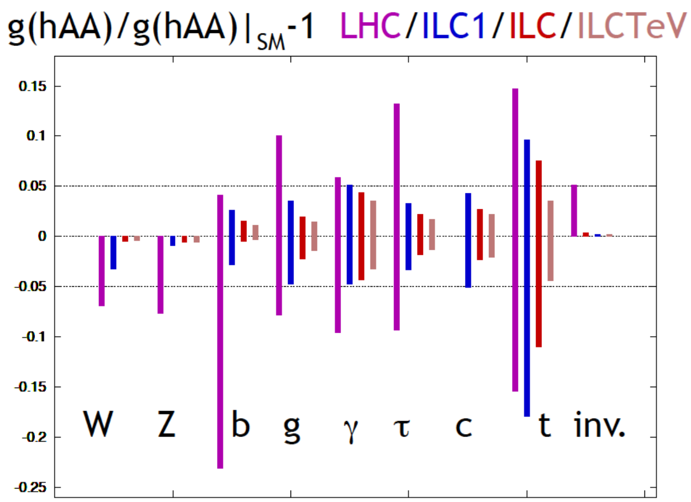


强子对撞机和正负电子对撞机

- 强子对撞机有利于发现新粒子，正负电子对撞机更适合做精确测量

新物理模型预言

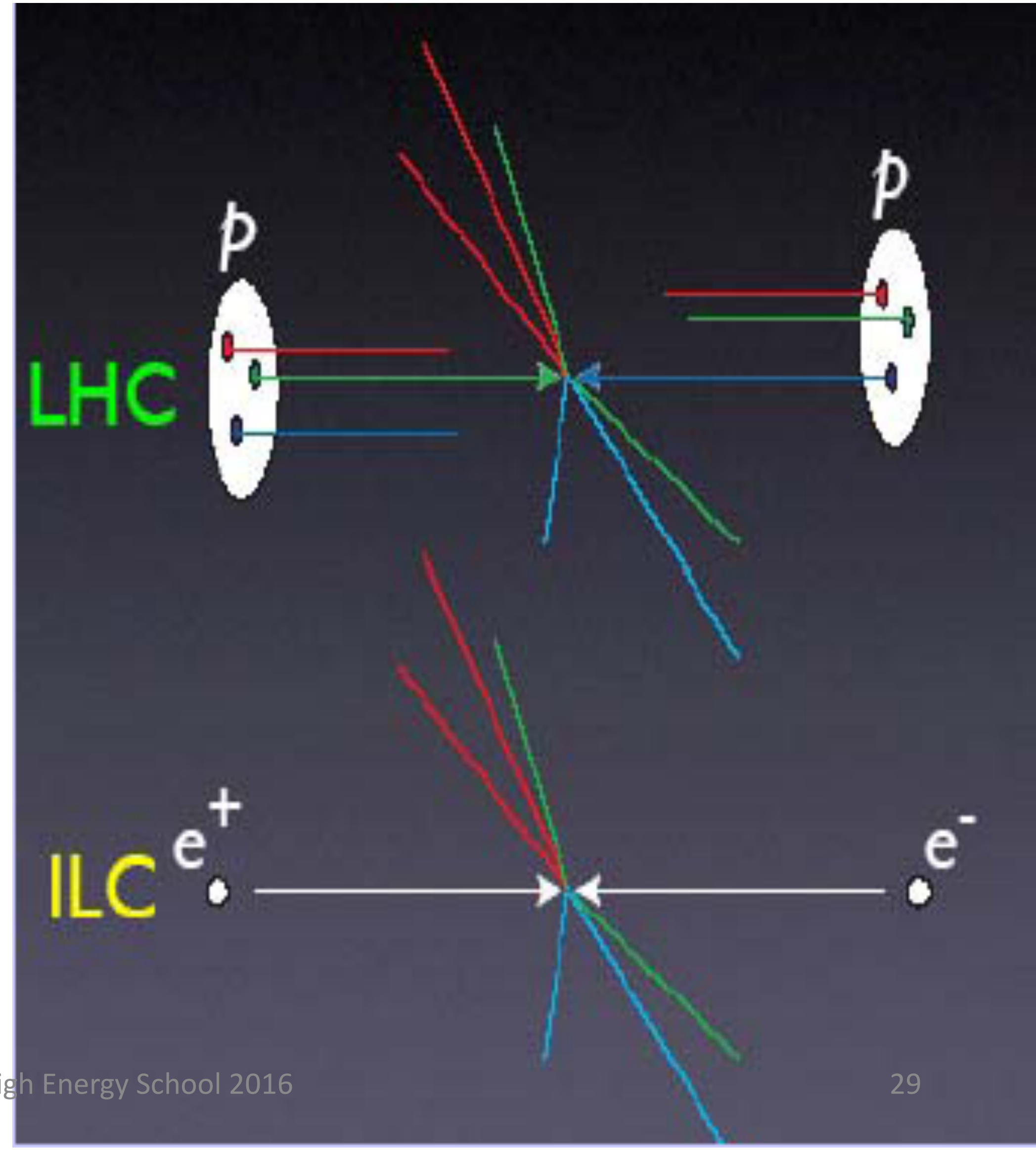
$$\frac{g_{Hxx}}{g_{Hxx}^{SM}}-1=\pm(1-5)\%$$



国际高能物理学界共识：在LHC运行的同时，需要建造一个高能正负电子对撞机，两台对撞机的相互补充是发现新物理的关键。

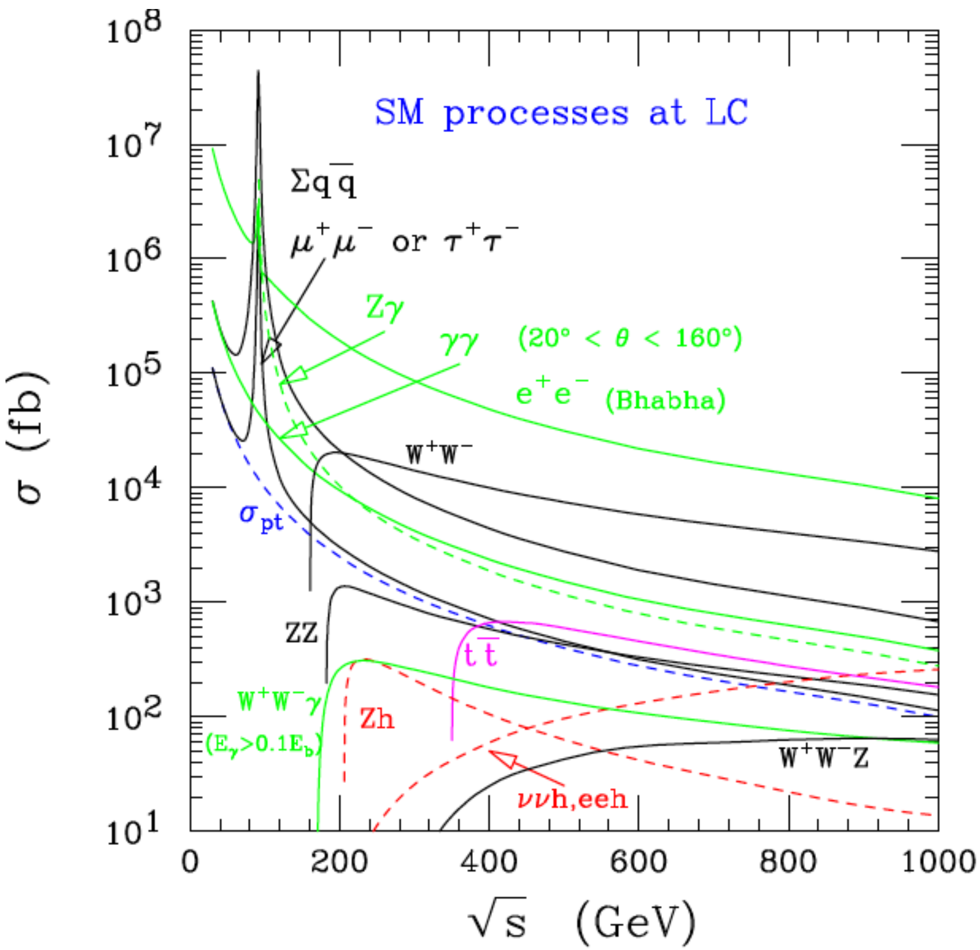
Why e^+e^- Collisions?

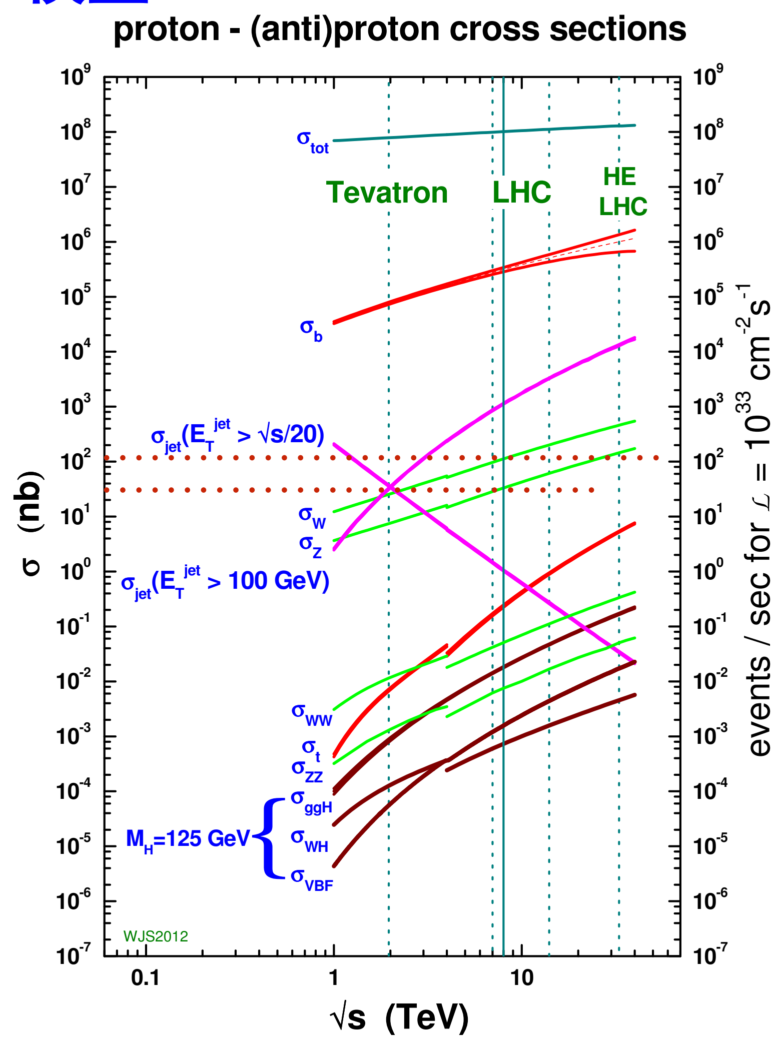
- 对撞粒子是基本粒子
- 准确的对撞能量和角动量
- 利用全部质心系能量
- 能最充分地重建信号事例



Higgs Factory

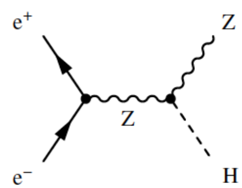
- 正负电子对撞机上可以精确检验标准模型

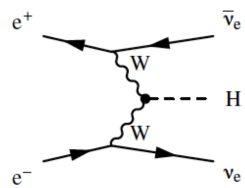




正负电子对撞机上的物理研究

- 丰富的研究内容





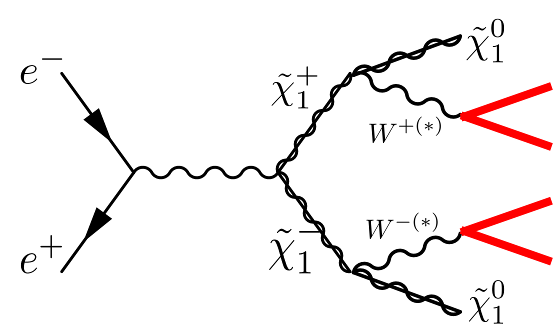
Higgs工厂
10^5-10^6 H
精确测量Higgs粒子的性质：
质量、自旋、耦合常数…

90　160　**240**　350　500　能量(GeV)

（超级）Z工厂
10^9-10^{12} Z
- 高阶量子效应
（2圈图修正）
稀有衰变
味物理，QCD
…

top工厂
10^5-10^6 ttbar
t 质量和宽度
耦合常数
自旋关联
CP破坏
…

暗物质
新粒子寻找



W工厂：10^6-10^8 WW
W质量…

直线正负电子对撞机

- 历史上大型正负电子对撞机（LEP）达到的最高能量～210GeV

- 同步辐射效应限制了环形对撞机能量的提升

$$P \quad \frac{1}{R^2} \quad \frac{E}{m}^{4}$$

- 过去20年间国际高能界关注直线对撞机的研究
  - 国际直线对撞机（ILC，500-1000GeV）
  - 紧凑型直线对撞机（CLIC，3000GeV）

国际直线对撞机（ILC）

1980': Basic Study

- 国际高能界多年努力，成果丰硕

2004

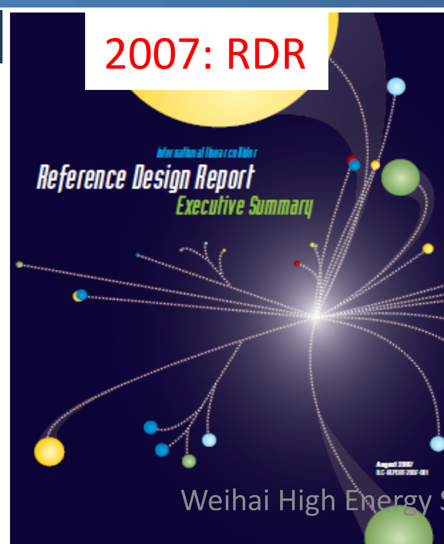
2005 2006 2007 2008 2009 2010 2011 2012 2013

ILC - GLOBAL DESIGN EFFORT (GDE)

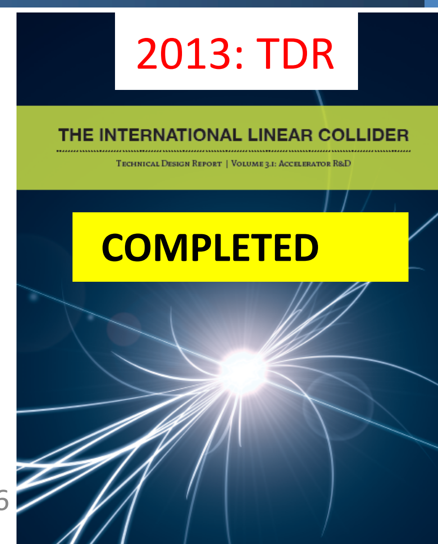
LCC

Ref. Design Report (RDR)

2007: RDR



2013: TDR



Linear Collider Collaboration

ILC TDR: 加速器设计

Ring to Main Linac
(including bunch compressors → reduce σz to eliminate hourglass effect at IP)

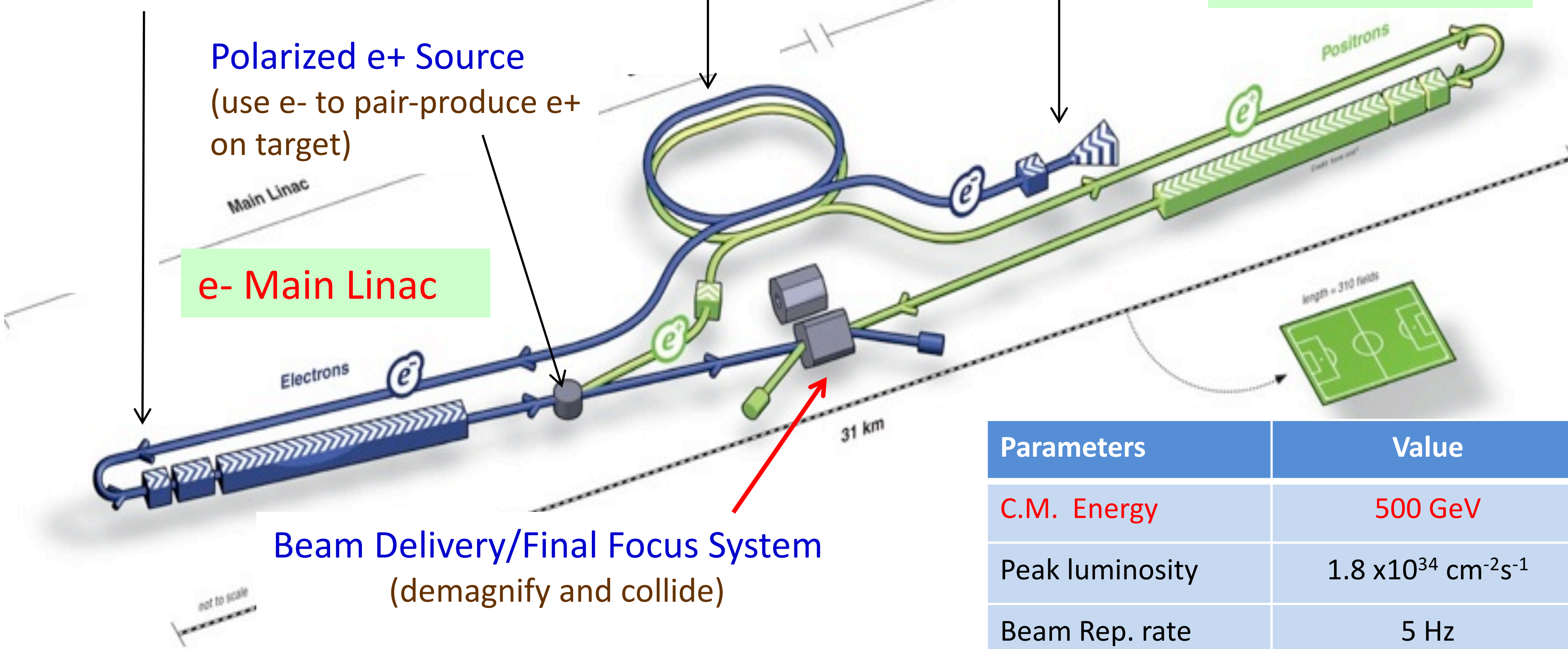
Damping Rings
(reduce emittance → smaller transverse IP size achievable)

Polarised Electron Source
(deliver stable beam current)

e+ Main Linac

Polarized e+ Source
(use e- to pair-produce e+ on target)

e- Main Linac



Beam Delivery/Final Focus System
(demagnify and collide)

Two detectors ("Push-Pull" option)

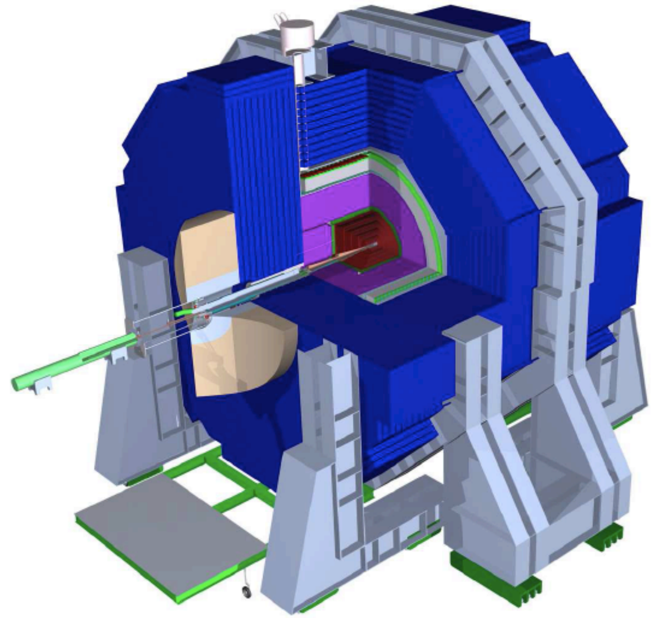
Parameters	Value
C.M. Energy	500 GeV
Peak luminosity	1.8 x10^{34} $cm^{-2}s^{-1}$
Beam Rep. rate	5 Hz
Pulse duration	0.73 ms
Average current	5.8 mA (in pulse)
E gradient in SCRF acc. cavity	31.5 MV/m +/-20% Q_0 = 1E10

ILC TDR: key accelerator technologies in hand after extensive R&D

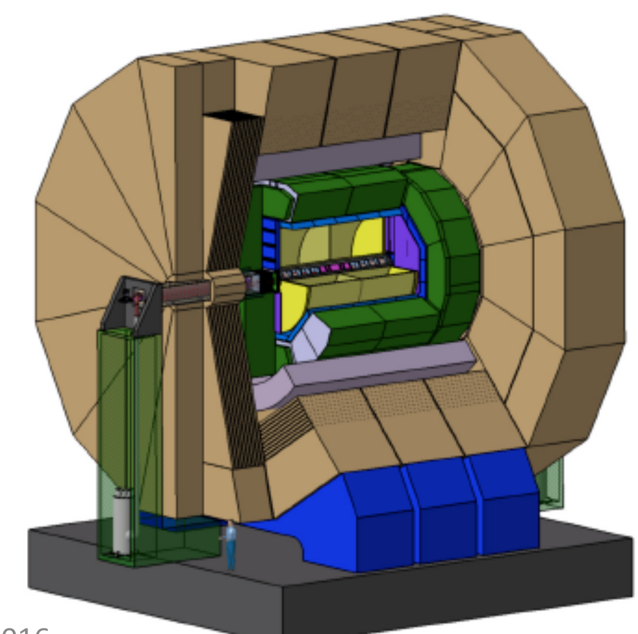
ILC Scheme | © www.form-one.de

ILC TDR: 探测器设计

- SiD
  - High B field (5 Tesla)
  - Small ECAL ID (p resolution)
  - Small calorimeter volume
    - Finer ECAL granularity
  - Silicon main tracker

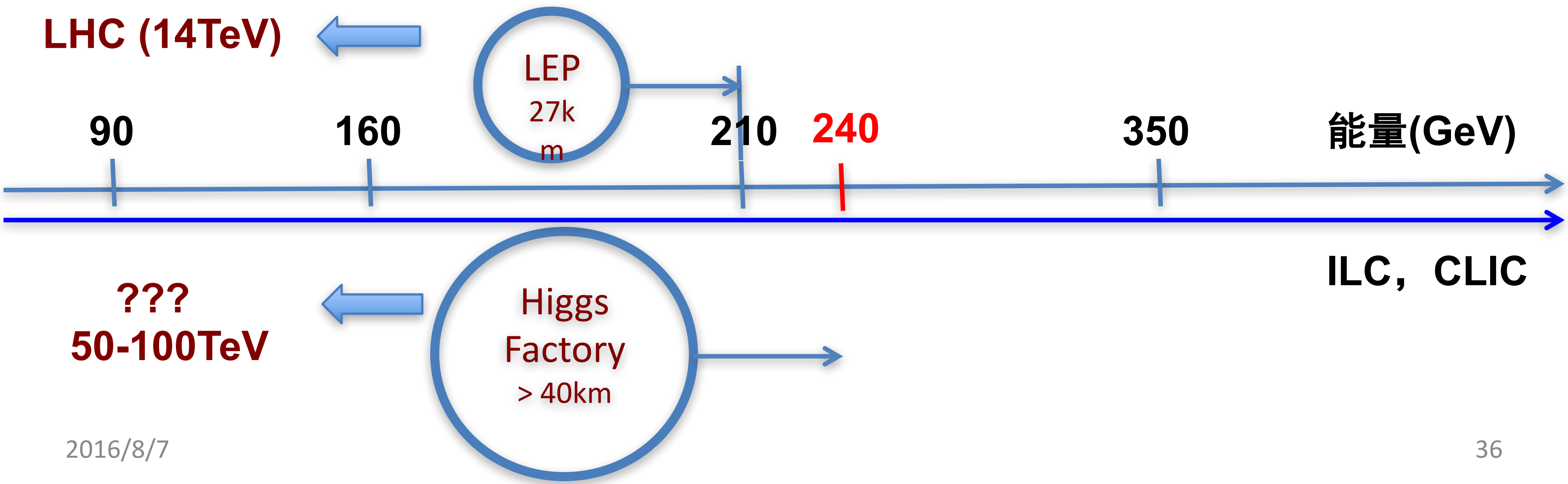


- ILD
  - Medium B field (3.5 Tesla)
  - Large ECAL ID (cost)
    - Particle separation for PFA
  - TPC for main tracker



环形正负电子对撞机

- Higgs粒子质量较轻（～125GeV）使得环形对撞机再次引起关注
- 较低的造价，较高亮度，但不易到高能区
- 可以升级到下一代高能强子对撞机
- 欧洲的TLEP/FCC，中国的CEPC/SppC，…



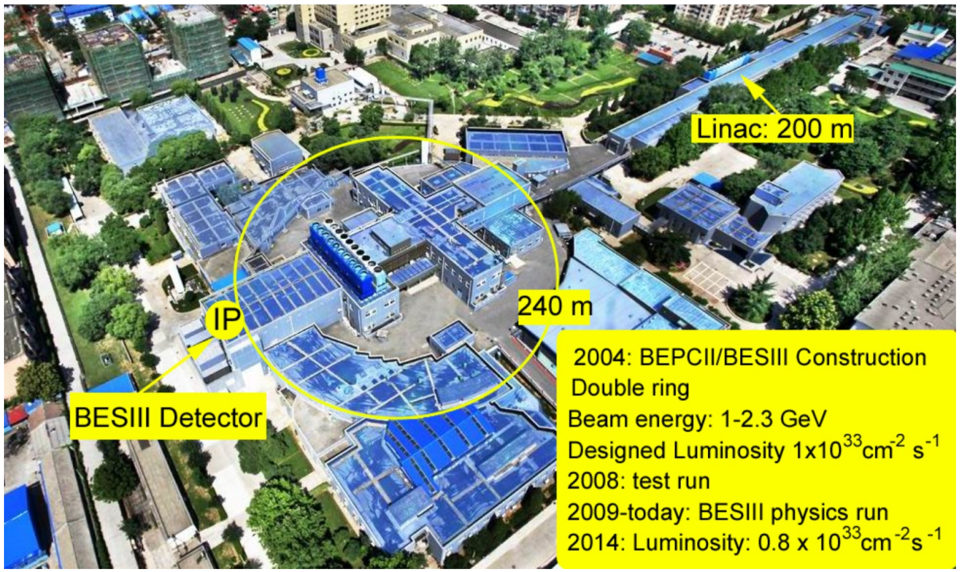
III

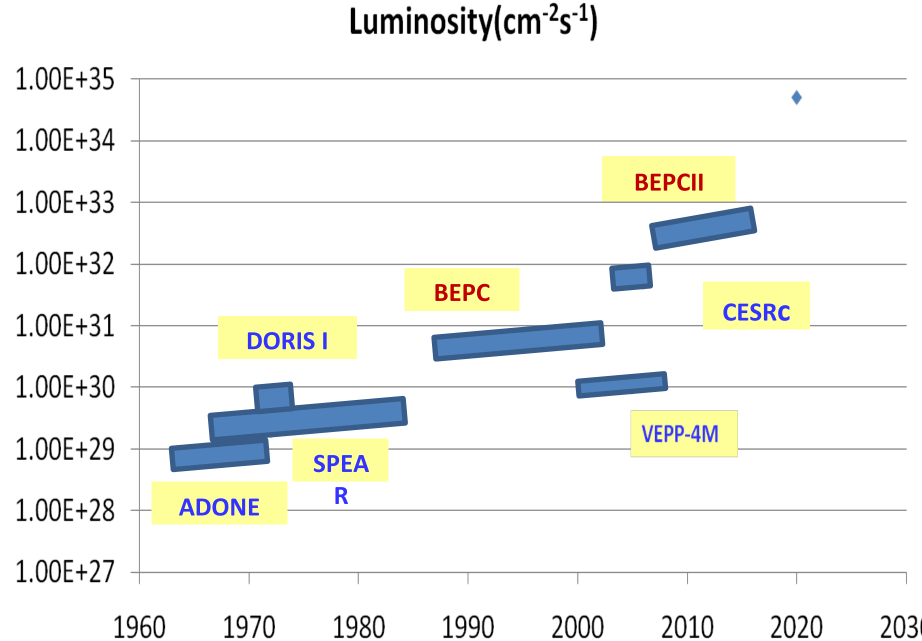
CEPC-SPPC：机遇

各国粒子物理发展计划

- 日本
  - 积极争取建设国际直线对撞机(ILC)
  - 积极争取建设HyperK
- 欧洲
  - 继续运行大型强子对撞机(LHC)并改进提高(至 ~ 2035年)
  - 探索建设未来环形高能加速器(FCC)的可能
    - 主要目标：100 TeV pp，可能有一个e^+e^-的中间阶段
- 美国
  - 长基线中微子设施(LBNF/DUNE)
  - 积极参与未来能量前沿大型加速器(ILC，FCC，CEPC)

北京正负电子对撞机（BEPC & BEPCII）





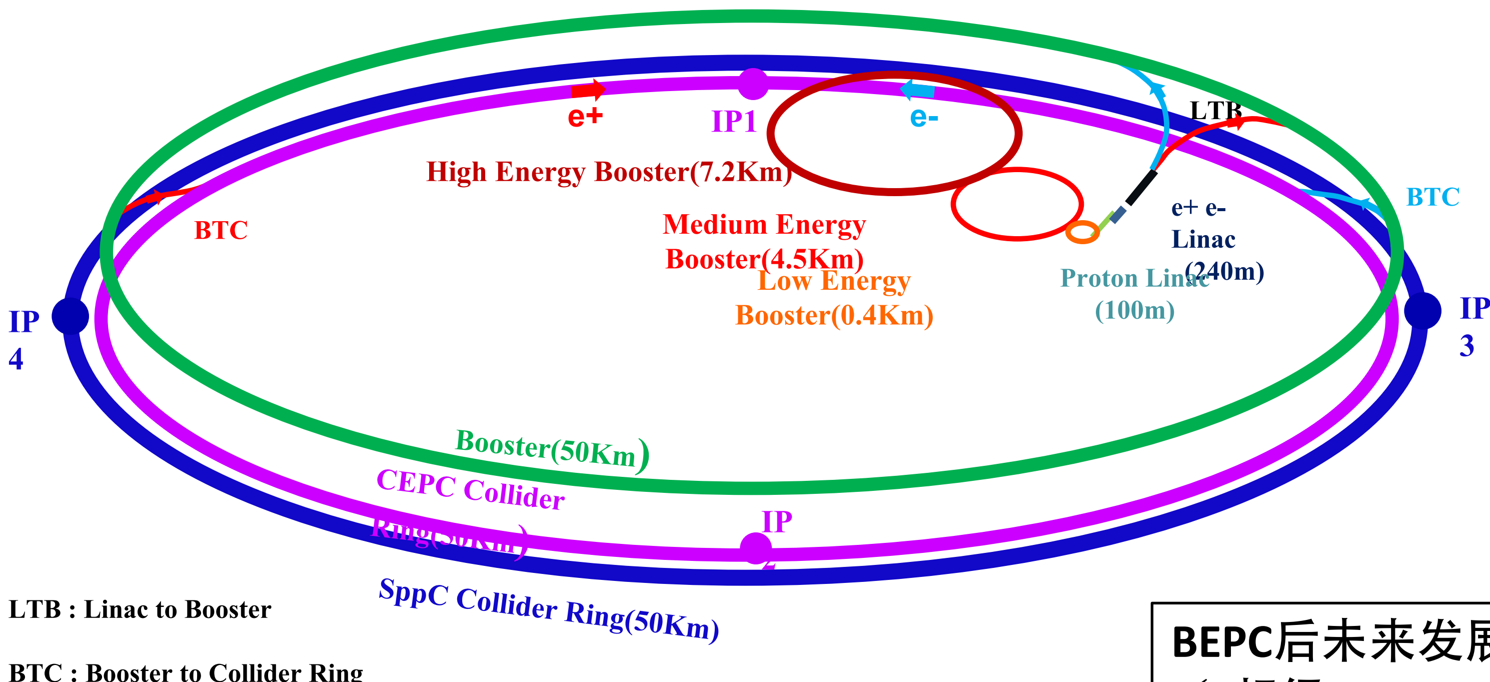
当年北京正负电子对撞机的正确选择：

- 现在看来仍是最具有科学意义的选择
- 取得多项具有国际影响的重大成果，获得了长达20年的发展空间，在国际高能物理领域占领了一席之地
- 队伍和技术获取延伸到其他学科（光源，天体物理，应用....)
- 培养了一支具有国际水平的研究和装置建设队伍，其经验推动了国内其他大科学装置的建设

"中国必须在世界高科技领域占有一席之地"

一个重大机遇

- 在希格斯粒子被发现以后，作为BEPC后的未来发展，我们有一个重大机遇：
  - 建设一个大型环形正负电子对撞机(2022-2028年)，详细研究Z和Higgs 粒子
  - 该方案的未来发展可能性很多，在同一隧道中还可以建设 pp,ep,AA, eA 对撞机 (2035-2045年)



BEPC后未来发展的其它选项
- ✓ 超级BEPC
- ✓ Z 工厂

Development of Ideas

- **Initial ideas of e^+e^- circular Higgs factories:**
  - LEP3
  - TLEP
  - Super-TRISTAN
  - Fermilab Site-Filler
- **CHF: pp is added**
  - Circular Higgs factory + pp collider
- **FCC: European strategy**
  - FCC-hh, FCC-ee, FCC-eh, …

CERN-OPEN-2011-047
20 January 2012
Version 2.9
arXiv:1112.2518v1 [hep-ex]

A High Luminosity e^+e^- Collider in the LHC tunnel to study the Higgs Boson

Alain Blondel[1], Frank Zimmermann[2]
[1]DPNC, University of Geneva, Switzerland; [2]CERN, Geneva, Switzerland

FERMILAB-CONF-13-037-APC
IHEP-AC-2013-001
SLAC-PUB-15370
CERN-ATS-2013-032
arXiv:1302.3318 [physics.acc-ph]

Report of the ICFA Beam Dynamics Workshop

"Accelerators for a Higgs Factory: Linear vs. Circular"

(HF2012)

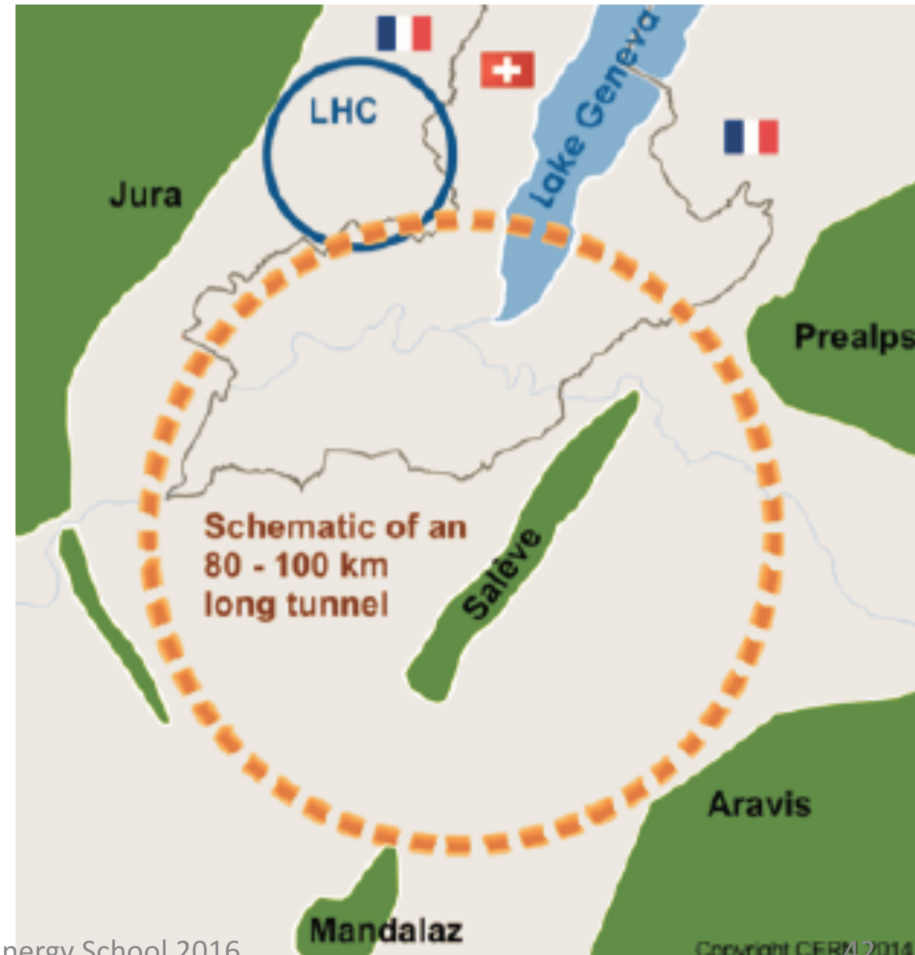
Alain Blondel[1], Alex Chao[2], Weiren Chou[3], Jie Gao[4], Daniel Schulte[5] and Kaoru Yokoya[6]

http://www-bd.fnal.gov/icfabd/HF2012.pdf

Two Major Efforts Developed

China， 50-100 km

Europe， 80-100 km



国内外广泛共识

- 2013年6月12-14日香山会议共识："环形正负电子对撞机Higgs工厂(CEPC)+ 超级质子对撞机(SppC)是我国高能物理发展的**重要选项和机遇**"
- 随后的第三届和第四届"中国高能加速器物理战略发展研讨会"结论："环形正负电子对撞机Higgs工厂(CEPC) + 超级质子对撞机(SppC)是我国未来高能物理发展的**首要选项**"
- 2014年2月在汉堡召开的国际未来加速器委员会(ICFA)做出如下结论

> **ICFA supports studies of energy frontier circular colliders and encourages global coordination**
>
> **ICFA支持能量前沿环形对撞机研究并鼓励全球的协调**

- 2014年7月的ICFA会上再次对环形对撞机及其与ILC的关系，未来高能物理发展方向等作了专门讨论。结论：

> **… ci**
>
> **ICFA继续鼓励国际环形对撞机的研究，其最终目的是能量远超过LHC的质子质子对撞**
>
> **collisions at energies much higher than those of the LHC.**

国际影响

- 2012 年 11 月 在 “Workshop on Accelerators for Higgs Factory: Linear vs Circular” 上报告，引起很大反响
- 2014年国际高能物理大会，专门对此进行讨论

2014年国际高能物理大会关于未来的讨论

- 国外许多科学杂志和报纸均报道和评论了此事。如时任ICFA主席，美国费米国家实验室主任Nigel Lockyer 在《自然》（V504,18 Dec.2013）发表文章，评述此事

ILLUSTRATION BY SCOTT GARRETT

Together to the next frontier

As emerging players jostle old ambitions, **Nigel Lockyer** calls for the next generati… …nated on a global scale.

> **“If China does jump ahead, it will change the landscape of science.”**

This year was a wa… physics. The de… discover the Hi… tially complete. Still abu… for the Higgs prediction… community is feeling s… pause, reflect and consi…

The Higgs boson is th… the standard model of … the model does not expl… tal aspects of our Unive… trino's very small mass… dark energy, we know … on. But where might th…

Illinois, I have spent the past six months in discussions about the future of US particle physics. But particle physics is an international pursuit, with projects in and participants from many different countries. The United States is well positioned to take the lead in some areas, such as neutrino physics, but the global landscape is uncertain. Resources need to be pooled, and new players are emerging. China's and India's talent, infrastructure and ambitions must now be factored into the global equation.

We are at a critical moment for the field. Each country and major project ▸

… origin of their tiny ma… the early Universe. Fer… is heading a US proposal to build a long ne…rino-beam experiment, running 1,300 kilomet… from Fermilab to the Homestake mine in Sou… Dakota. An ambitious 35-kilotonne liquid argon detector located nearly 1,500 metres below the surface emerged as the preferred project when the US community met in Minnesota for a ten-day planning symposium in July. It would help us to understand neutrino masses and whether these particles contribute to the matter–antimatter asymmetry of the Universe.

With the total construction budget nearing $1 billion, the experiment will require international partners — a new approach for US domestic science. The US Department of Energy's Office of Science has indicated that it would support such a major proposal if there was involvement from …

… up in the 2030s.

And the United States still ha… ambitions to host a high-energy fr…tier machine, …fter turning off the Fermilab's Tevatron accelerator in 2011 and failing to realize the Superconducting Super Collider in the 1990s. Perhaps the high-energy baton could be passed back to the United States. Fermilab is still a world leader in high-field magnets for proton accelerators, which would be necessary for any 100-TeV proton–proton collider.

> *“If China does jump ahead, it will change the landscape of science.”*

To add to the suspense, there is the changing role of China. Historically a small player in particle physics, it last year stepped onto the world stage with …

Fermilab and the High Energy Accelerator Research Organization (KEK) in Tsukuba, Japan: these are the only places where large particle-physics projects are currently feasible. Demands from emerging economies such as China to host other projects will challenge the long-term plans of the existing leaders. Scientists in the United States and Europe will have to find out how best to use international competition as a spur for advancing projects on their own soil while still being good international partners. This may become tricky.

Higgs bosons are not export-controlled, nor are pictures of deep space from advanced telescopes. But the technologies developed, often through international collaborations, may have dual use — for defence applications or for economic gains, for example, as well as for basic science. Countries will have to decide how to oversee and exploit these …

… another has neutrinos travelling across Japan. But the world can afford only one.

Japan is perhaps the stiffest competitor, with leading programmes in neutrino physics, a bottom-quark ('b-quark') factory and kaon and muon experiments. The country …

… symmetry differences between neutrinos and antineutrinos might be observable in a long-baseline experiment, telling us about matter and antimatter imbalances in the early Universe. Emboldened, might the Chinese leapfrog the world by hosting …

… understand how the Universe works. ■

Nigel Lockyer *is director of the Fermi National Accelerator Laboratory in Batavia, Illinois.*
e-mail: lockyer@fnal.gov

368 | NATURE | VOL 504 | 19/26 DECEMBER 2013

III

CEPC-SPPC：科学目标

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 -

Timeline (dream)

- **CPEC**
  - Pre-study, R&D and preparation work

分两步走：

- ~2020建成CEPC， 作为 Higgs / Z/W 工厂精确检验标准模型
- 在条件成熟时（~2036？）建造SppC

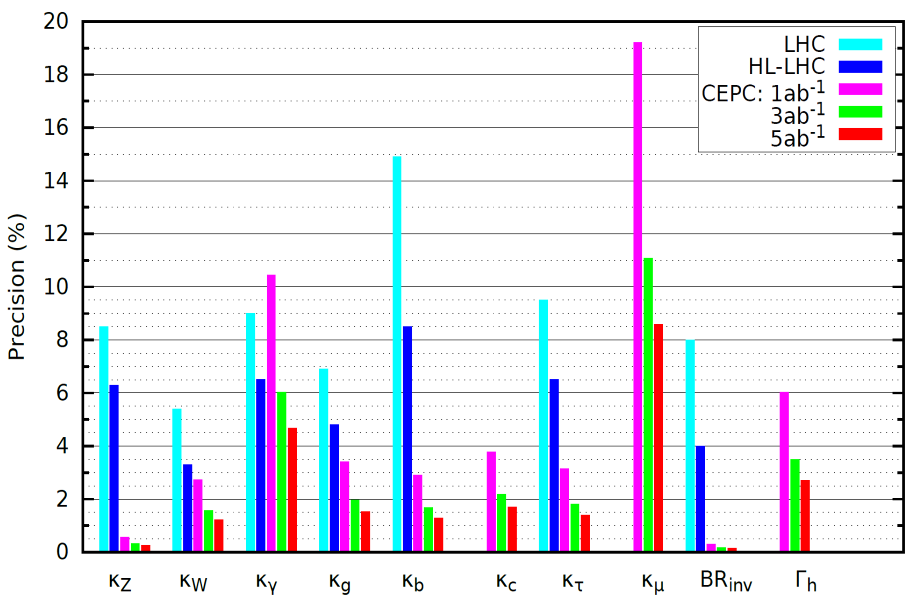
-
  - Construction: 2035-2042
  - Data taking: 2042 -

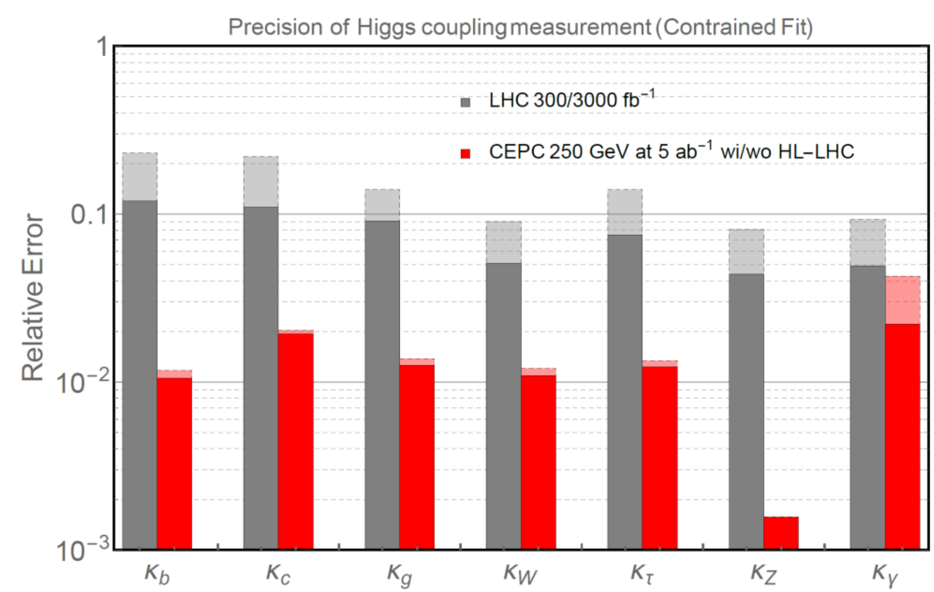
CEPC的科学目标

- 正负电子对撞(90 - 250 GeV)
  - Higgs工厂(240- 250 GeV 处产生 ~ 10^6 个Higgs粒子）
    - 精确测量与研究Higgs粒子(质量、自旋、宇称、耦合等）
  - Z & W 工厂(90 GeV 处产生每年 10^{10}个Z 粒子)
    - 精确检验标准模型
    - 寻找偏离标准模型的迹象，稀有衰变等
  - 味工厂(Z衰变产生大量的B介子，粲介子与tau 轻子）

Higgs粒子的精确测量

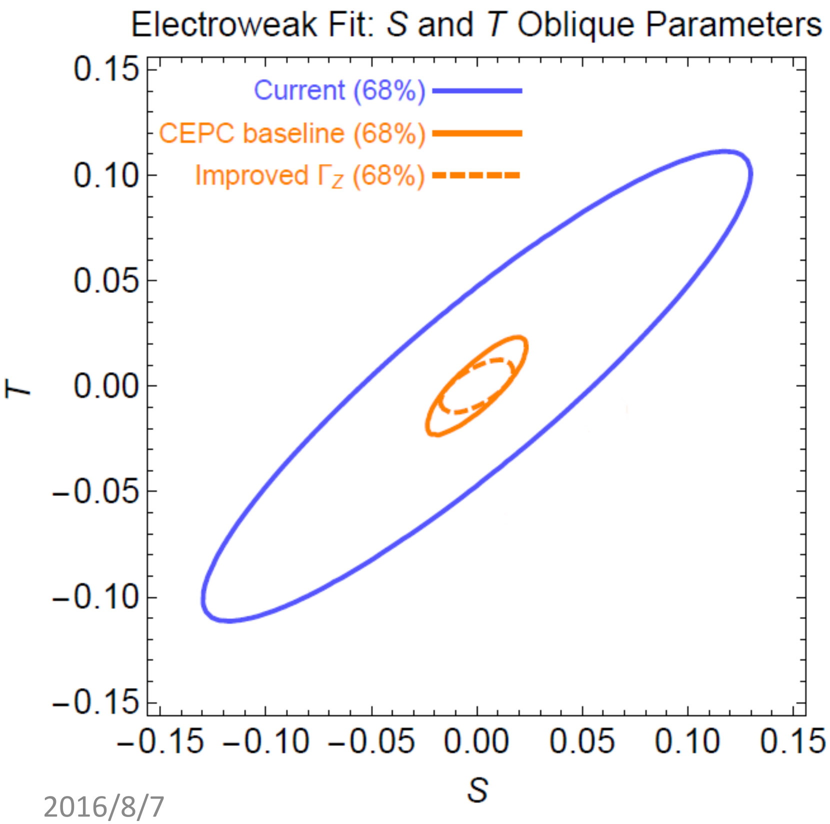
- **240-250 GeV 处产生 ~ 10^6 个Higgs粒子**
- 精度比HL-LHC 好10倍以上
- 该精度可以探究的新物理能标达 ~ TeV左右

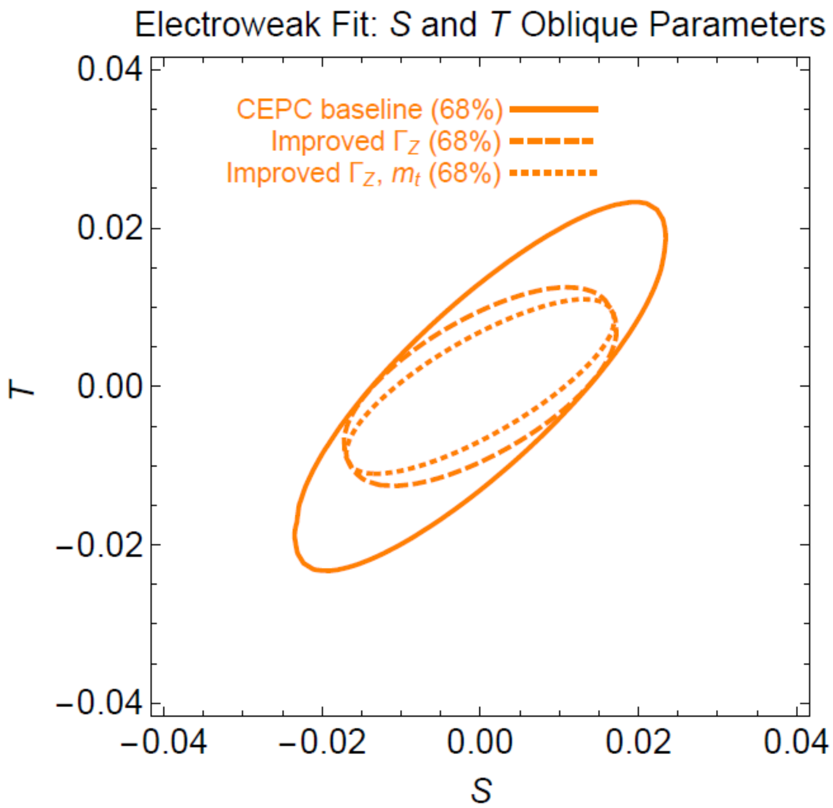




精确检验标准模型

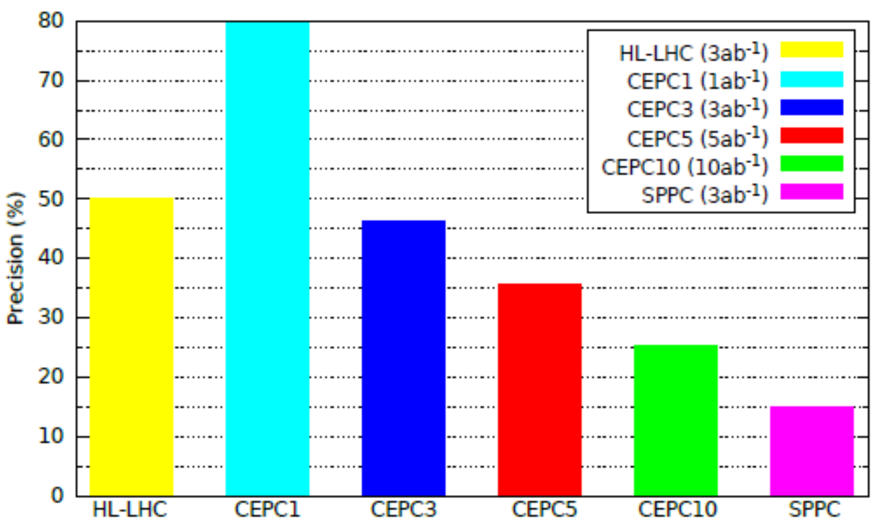
- 90 GeV 处产生每年 10^{10}个Z 粒子
- 精确测量Z/W与各种粒子的耦合，寻找偏离标准模型的迹象
- 可以探究新物理至 ~ TeV，比现有水平高10倍左右，比HL-LHC高1-3倍左右。

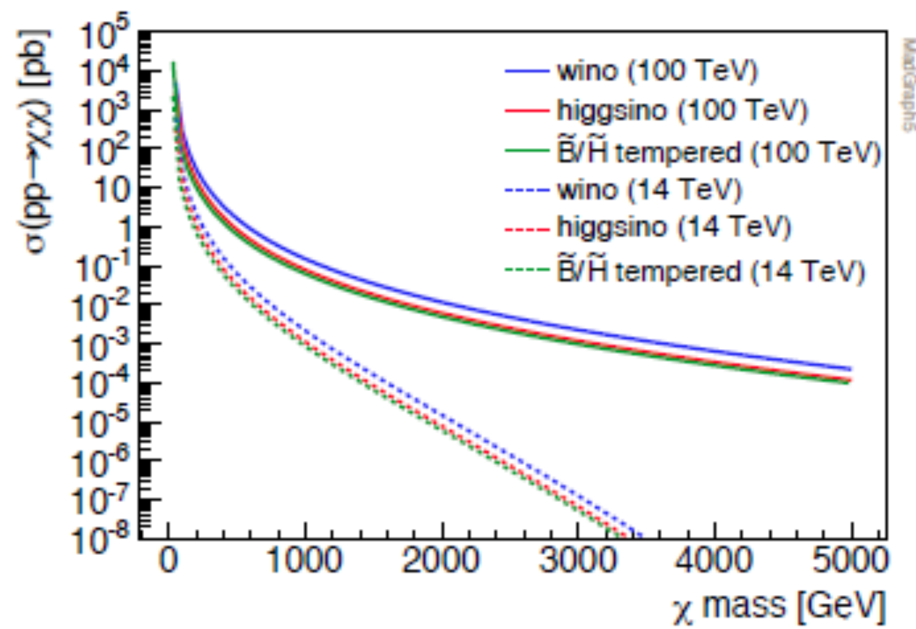




SPPC的科学目标

- 质子质子对撞(~100 TeV)
  - CEPC 无法完成的测量：$Ht\bar{t}, H^3, H^4$, 进一步精确检验标准模型
  - 直接寻找超出标准模型的新物理、新现象和新粒子





与未来国际上的大型装置的比较

	科学意义	可扩展性	技术成熟度	经济性	时间进度
CEPC	****	****	****	*****	*****
SppC	*****	*	**	***	***
ILC	****	*	***	****	*****
FCC-ee	****	****	****	****	?
FCC-pp	*****	*	**	**	**
CLIC	****	**	**	**	?
VLHC	*****	***	***	**	?
Muon collider	*****	****	*	？？	?

CEPC+SppC 是一个很好的组合

SPPC 的技术挑战

- 高场磁铁: 偏转二极铁 (B=20 T)

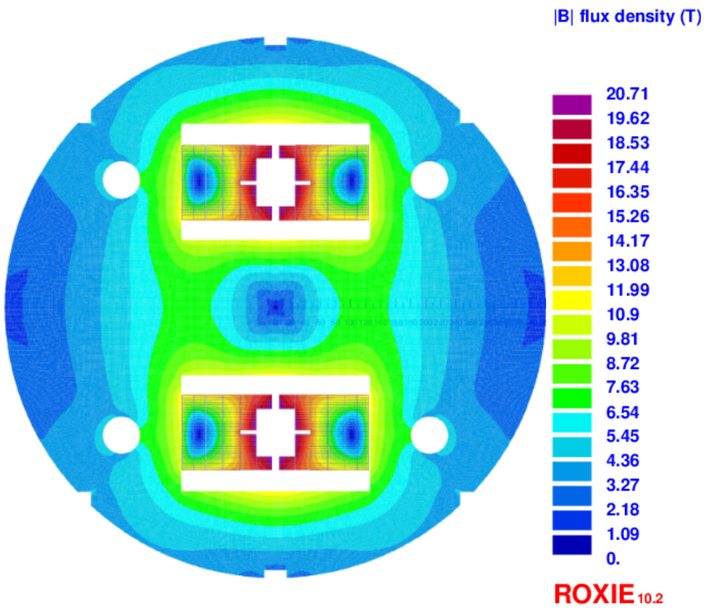
  聚焦四极铁 (B_{pole}= 14-20 T)
- 真空与束流屏蔽。。。
- 超导

➢ 超导是未来的战略技术

➢ 中国是超导原材料的大国

➢ 在超导线与超导磁体技术上领先国际？

➢ 二十年的预研计划



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

SPPC 的技术挑战

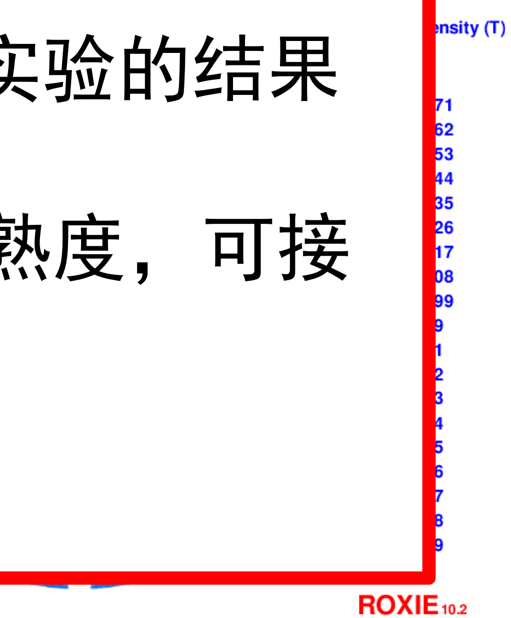
- 高场磁铁: 偏转二极铁 (B=20 T)

  聚焦四极铁 (B_{pole}= 14-20 T)
- 真空与束流屏蔽。。。
- 超导

  - 超导是
  - 中国是
  - 在超导
    领先国
  - 二十年

SPPC的建造将依赖:

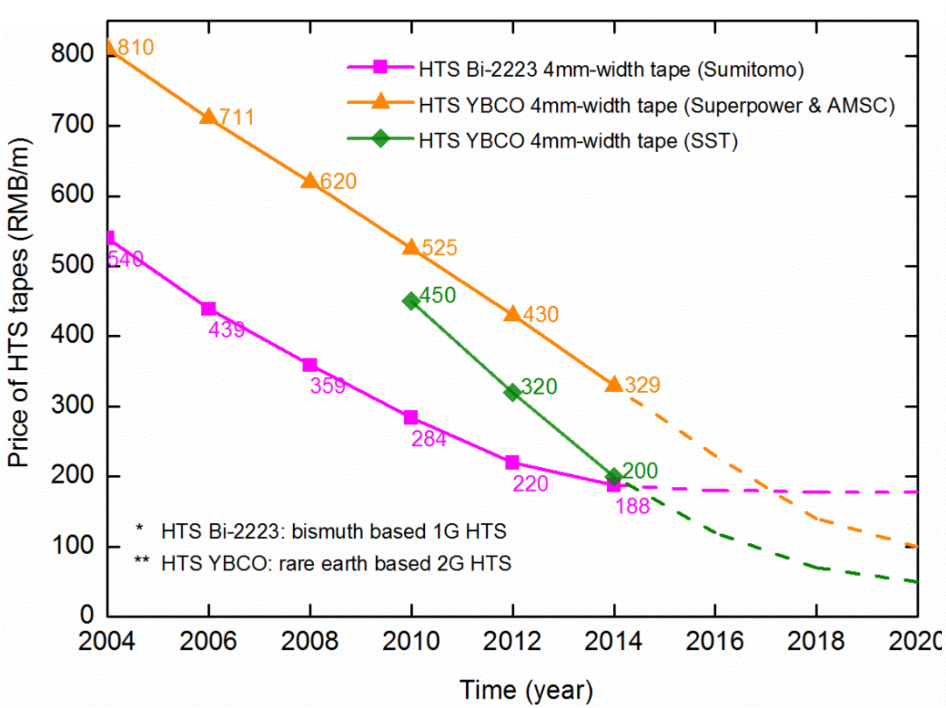
- LHC，CEPC 和其它实验的结果
- 关键技术的成熟度
- 关键部件工业化成熟度，可接受的造价
- …

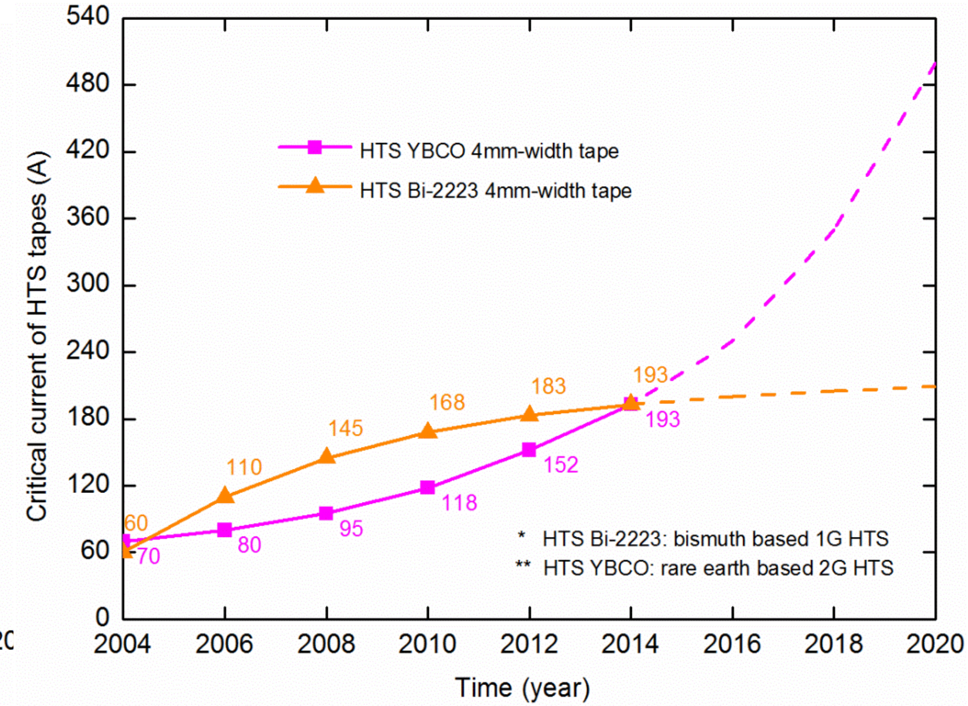


A Conceptual design of *20-T Nb_3Sn + HTS common coil dipole magnet* from IHEP

Future of HTS Superconducting cables

- 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 can improve by ~50 times over 20 years, if past data can be used for prediction !
- 20T Full HTS magnet ???





PLEASE KEEP OPTIMISTIC !!!

IV

CEPC的设计

CEPC Design –Higgs Parameters

Parameter	Design Goal
Particles	e+, e-
Center of mass energy	240 GeV
Luminosity (peak)	2*10^34/cm^2s
No. of IPs	2

CEPC Design – Z-pole Parameters

Parameter	Design Goal
Particles	e+, e-
Center of mass energy	45.5 GeV
Integrated luminosity (peak)	>1*10^34/cm^2s
No. of IPs	2
Polarization	Consider in the second round

CEPC 加速器设计

6~10 GeV

直线加速器

Electron

Positron

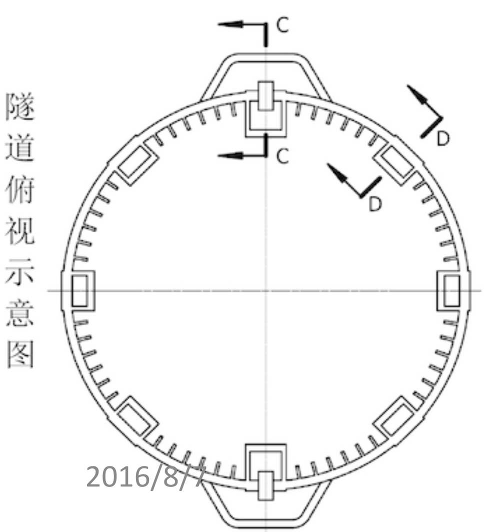
增强环

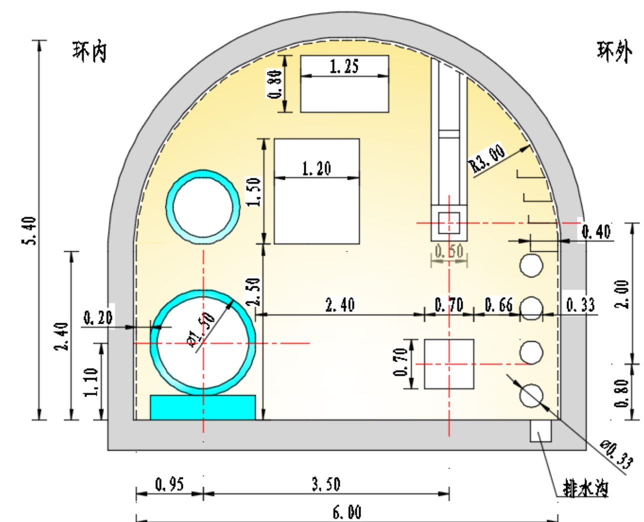
Energy Ramp
10 ->120GeV

同一隧道中3 台机器：
- CEPC & booster
- SppC

对撞环

45/120 GeV



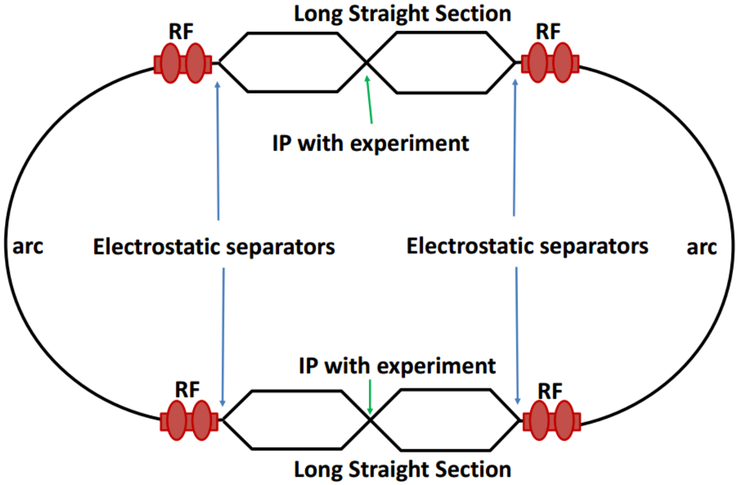


CEPC 加速器设计中的重要问题

- Luminosity - Power Consumption - Cost

  - single ring + pretzel
  - double ring
  - local double ring

- Z pole
- SppC in the same tunnel
- …



Parameter for CEPC partial double ring

（wangdou20160325）

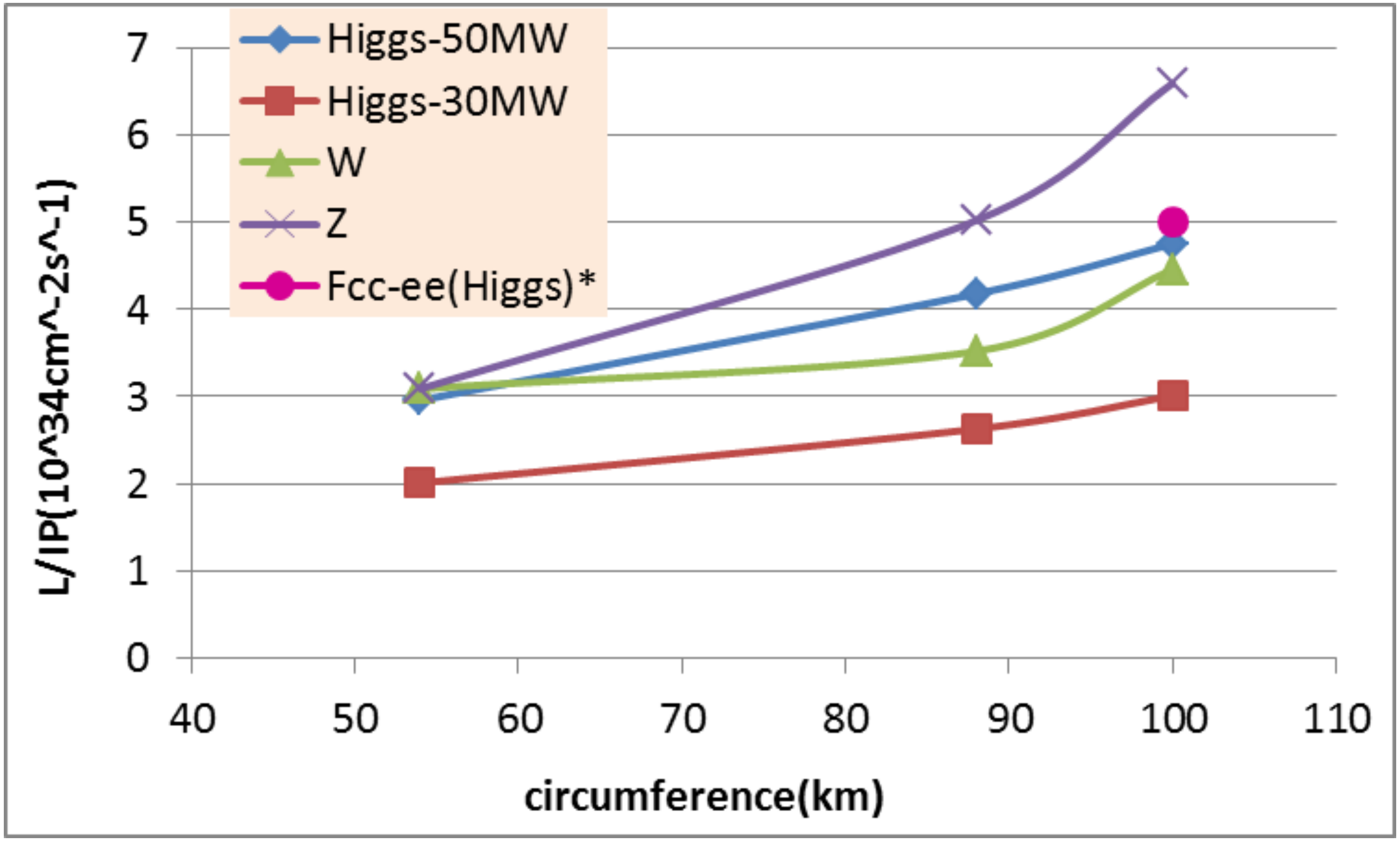
	Pre-CDR	*H-high lumi.*	*H-low power*	*W*	*Z*
Number of IPs	2	2	2	2	2
Energy (GeV)	120	120	120	80	45.5
Circumference (km)	54	54	54	54	54
SR loss/turn (GeV)	3.1	2.96	2.96	0.59	0.062
Half crossing angle (mrad)	0	15	15	15	15
Piwinski angle	0	2.5	2.6	5	8.5/7.6
N_e/bunch (10^{11})	3.79	2.85	2.67	0.74	0.46
Bunch number	50	67	44	400	1100
Beam current (mA)	16.6	16.9	10.5	26.2	45.4
SR power /beam (MW)	51.7	50	31.2	15.6	2.8
Bending radius (km)	6.1	6.2	6.2	6.1	6.1
Momentum compaction (10^{-5})	3.4	2.5	2.2	2.4	3.5
β_{IP} x/y (m)	0.8/0.0012	0.25/0.00136	0.268 /0.00124	0.1/0.001	0.1/0.001
Emittance x/y (nm)	6.12/0.018	2.45/0.0074	2.06 /0.0062	1.02/0.003	0.62/0.0028
Transverse σ_{IP} (um)	69.97/0.15	24.8/0.1	23.5/0.088	10.1/0.056	7.9/0.053
ξ_x/IP	0.118	0.03	0.032	0.008	0.005/0.006
ξ_y/IP	0.083	0.11	0.11	0.074	0.084/0.073
V_{RF} (GV)	6.87	**3.62**	**3.53**	**0.81**	**0.12**
f_{RF} (MHz)	650	650	650	650	650
Nature σ_z (mm)	2.14	**3.1**	**3.0**	**3.25**	**3.9**
Total σ_z (mm)	2.65	4.1	4.0	3.35	4.0
HOM power/cavity (kw)	3.6	2.2	1.3	0.99	0.99
Energy spread (%)	0.13	0.13	0.13	0.09	0.05
Energy acceptance (%)	2	2	2		
Energy acceptance by RF (%)	6	**2.2**	**2.1**	**1.7**	**1.1**
n_γ	0.23	0.47	0.47	0.3	0.27/0.24
Life time due to beamstrahlung_cal (minute)	47	36	32		
F (hour glass)	0.68	0.82	0.81	0.92	0.95
L_{max}/IP ($10^{34}cm^{-2}s^{-1}$)	2.04	2.96	2.01	3.09	3.61/3.09

Parameter for CEPC PDR-100km

（wangdou20160329）

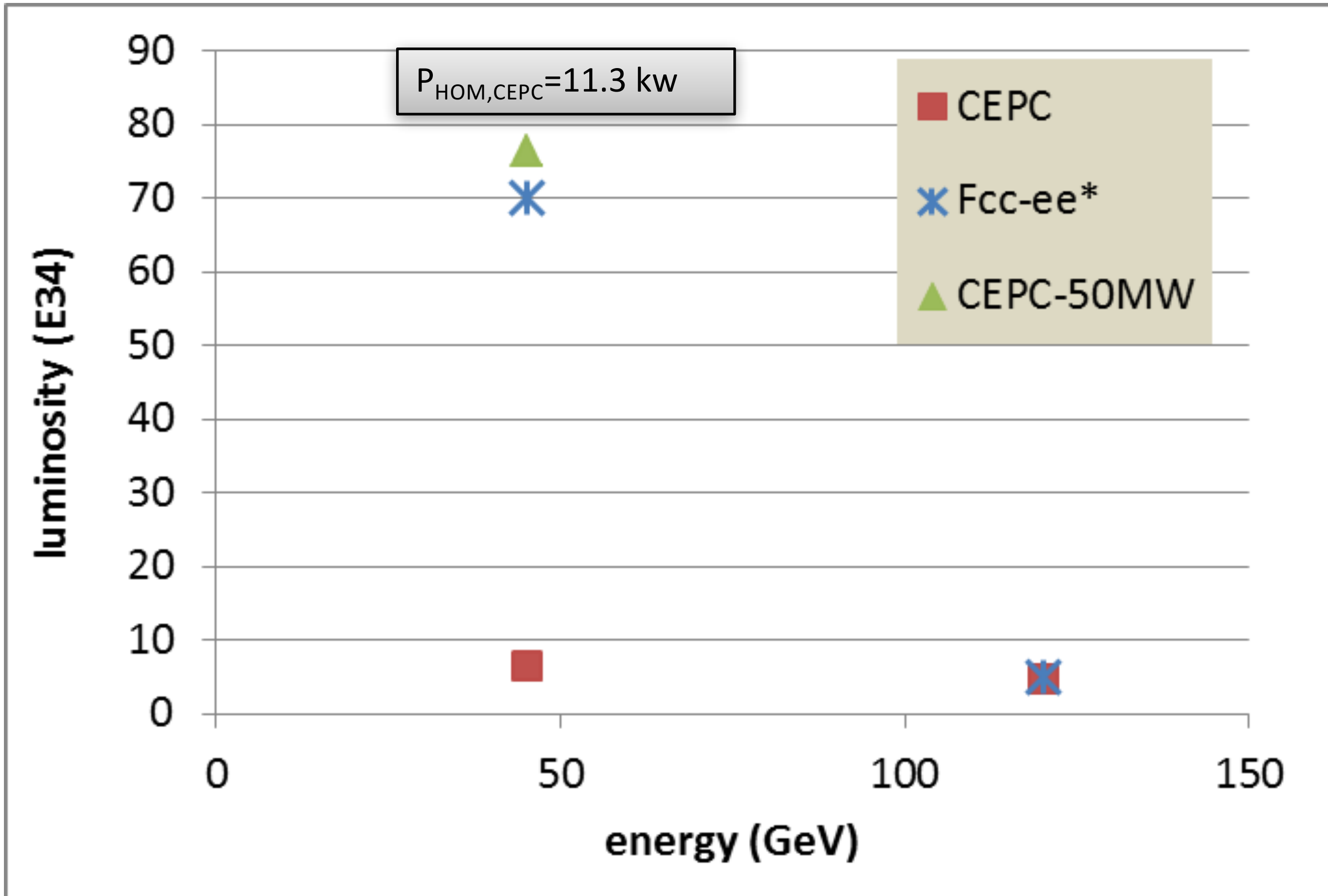
	H-high lumi.	*H-low power*	*W*	*Z*	
Number of IPs	2	2	2	2	
Energy (GeV)	120	120	80	45.5	
Circumference (km)	100	100	100	100	
SR loss/turn (GeV)	1.7	1.7	0.33	0.034	
Half crossing angle (mrad)	15	15	15	15	
Piwinski angle	2.0	2.83	8.65	15.8	
N_e/bunch (10^{11})	1.43	1.22	0.42	0.165	
Bunch number	436	307	2400	15800	182260
Beam current (mA)	30	18	48.7	125.3	1449.7
SR power /beam (MW)	50	30	16.0	4.3	50
Bending radius (km)	11	11	11	11	
Momentum compaction (10^{-5})	1.8	1.4	1.4	1.3	
β_{IP} x/y (m)	0.297/0.0011	0.3/0.0011	0.1/0.001	0.1/0.001	
Emittance x/y (nm)	1.63/0.0049	1.03/0.003	0.46/0.0014	0.14/0.00065	
Transverse σ_{IP} (um)	22/0.074	17.6/0.59	6.8/0.037	3.8/0.026	
ξ_x/IP	0.033	0.025	0.003	0.002	
ξ_y/IP	0.083	0.083	0.055	0.054	
V_{RF} (GV)	**3.1**	**2.25**	**0.41**	**0.053**	
f_{RF} (MHz)	650	650	650	650	
Nature σ_z (mm)	**2.45**	**2.77**	**3.8**	**3.94**	
Total σ_z (mm)	2.94	3.33	3.9	4.0	
HOM power/cavity (kw)	2.3	1.1	0.98	0.97	11.3
Energy spread (%)	0.1	0.1	0.065	0.037	
Energy acceptance (%)	1.46	1.4			
Energy acceptance by RF (%)	**3.5**	**2.2**	**0.9**	**0.7**	
n_γ	0.27	0.28	0.26	0.18	
Life time due to beamstrahlung_cal (minute)	40	49			
F (hour glass)	0.8	0.85	0.96	0.985	
L_{max}/IP (10^{34}cm^{-2}s^{-1})	4.75	3.01	4.46	6.59	76.4

CEPC PDR Luminosity vs circumference



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

100km CEPC PDR vs Fcc-ee



- The large difference of Z is due to the constraint for RF HOM power

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

CEPC vs LEP2

Parameter	CEPC			LEP2	
Physics working point	H		Z		Z
Energy/beam [GeV]	120		45.5	105	45.6
Circumference [km]	54		54	27	
Single ring/double ring	Partial double			Single	
Pretzel scheme	No			Yes	
Bunches/beam	67	44	1100	4	12
Bunch population [10^{11}]	2.85	2.67	0.46	4.2	1.96
Emittance [nm]	2.45/0.0074	2.06 /0.0062	0.62/0.0028	38	
IP beta [mm]	250/1.36	268 /1.24	100/1	1500/50	2000/50
Beam current [mA]	16.9	10.5	45.4	3	4.2
Luminosity/IP x 10^{34}cm^{-2}s^{-1}	2.9	2.0	3.1	0.0012	0.0034
Energy loss/turn [GeV]	2.96		0.062	3.34	0.12
Synchrotron power [MW]	50	31	2.8	22	1.1
RF voltage [GV]	3.6	3.5	0.12	3.5	
f_{RF} [MHz]	650			352	352

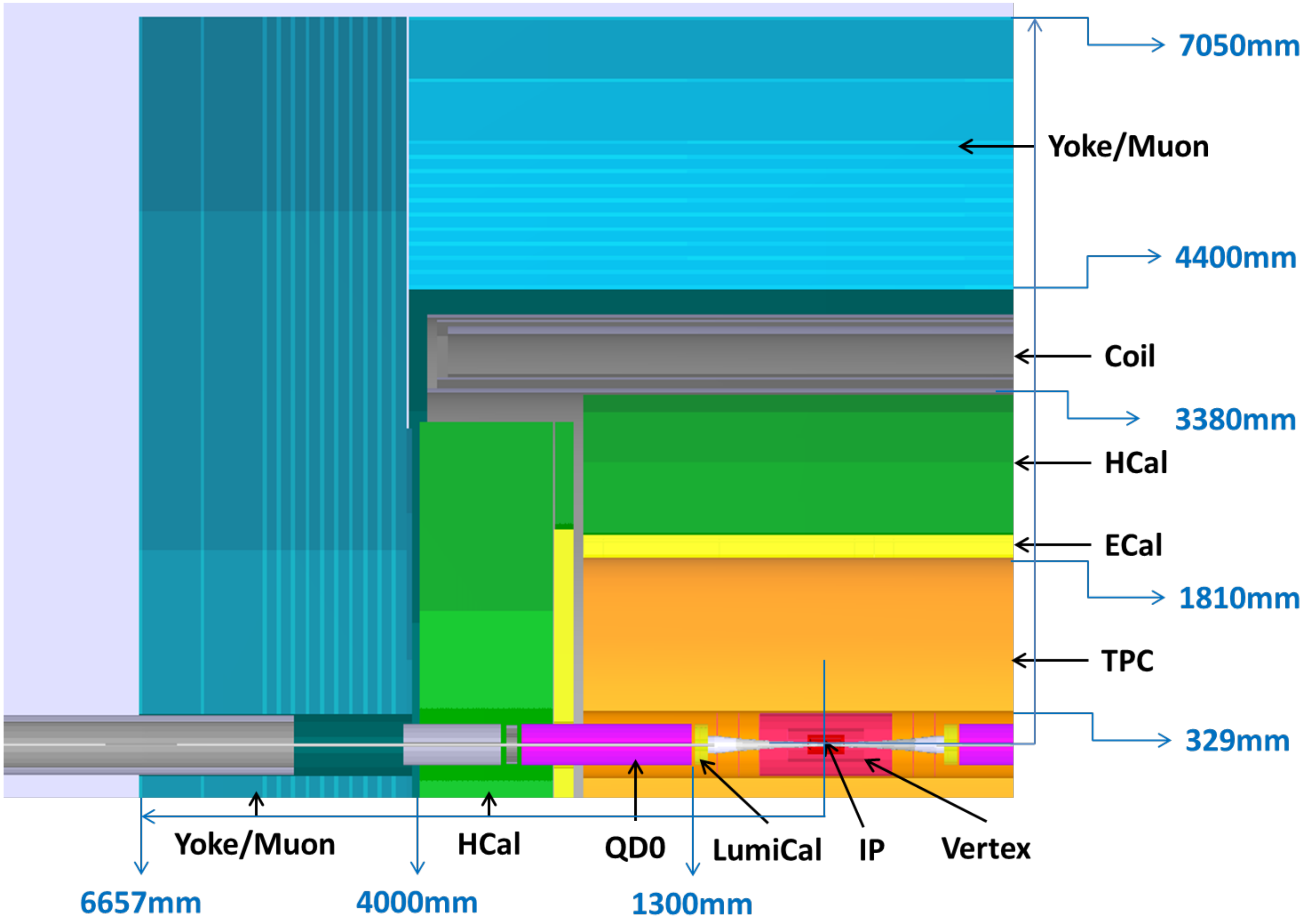
CEPC vs ILC

Parameter	CEPC		ILC	
Physics working point	H	Z	H	
Energy/beam [GeV]	120	45.5	125	250
Linear/circular	circular		linear	
Bunches/beam	67	1100	1312	1312
Bunch population [10^{11}]	2.85	0.46	0.2	0.2
Normalized emittance [nm]	575342/1738	55205/249	10000/35	10000/35
IP beta [mm]	250/1.36	100/1.0	13/0.41	11/0.48
IP RMS veritcal beam size [nm]	100	53	7.7	5.9
Beam current [mA]	16.9	45.4	5.8	5.8
Luminosity/IP x $10^{34}cm^{-2}s^{-1}$	2.9	3.1	0.97	2.05
Energy loss/turn [GeV]	2.96	0.062	No	
f_{RF} [MHz]	650	650	1300	1300
Average number of photons / particle n_γ	0.47	0.24	1.16	1.72

技术挑战

- 加速器物理：动力学孔径，单环麻花轨道方案, 低能的亮度，...
- 超导高频腔: 高次膜吸收与导出，高频腔批量生产与质量控制，功率消耗，...
- 国产化：大功率低温制冷机，微波功率源，束测，半导体探测器，。。。
- 总功率消耗： 目前技术为 ~ 500 MW ! ➔ 需要降低到400 MW以下
  - 热能再利用 ~ 100-200 MW
    - 暖气 ➔ 夏天？
    - 液化气气化 ➔ 靠近港口
    - 农业大棚 ➔ 夏天 ?
  - 把目前~50% 的微波功率源效率提高到 ~70%？
  - 采用部分双环方案

CEPC 探测器设计



7050mm
Yoke/Muon
4400mm
Coil
3380mm
HCal
ECal
1810mm
TPC
329mm
Yoke/Muon
HCal
QD0
LumiCal
IP
Vertex
6657mm
4000mm
1300mm

CEPC 探测器设计

- Vertexing $(h \to b\bar{b}, c\bar{c}, \tau^+\tau^-)$
  - ~1/5 $r_{beampipe}$,~1/30 pixel size (wrt LHC)

$$_{ip} = 5 \quad m \quad 10 \quad m / p \sin^{3/2}$$

- Tracking $(e^+e^- \to Zh \to \ell^+\ell^- X; \quad \text{incl.}\, h \to \text{nothing})$
  - ~1/6 material, ~1/10 resolution (wrt LHC)

$$(1/p) = 5 \cdot 10^{\;\;5} / GeV \quad \text{or better}$$

- Jet energy (Higgs self-coupling, W/Z separation)
  - ~1/2 resolution (wrt LHC)

$$_{E} / E = 0.3 / \sqrt{E(GeV)}$$

Baseline Design in PreCDR

ILD-like with some modifications and considerations

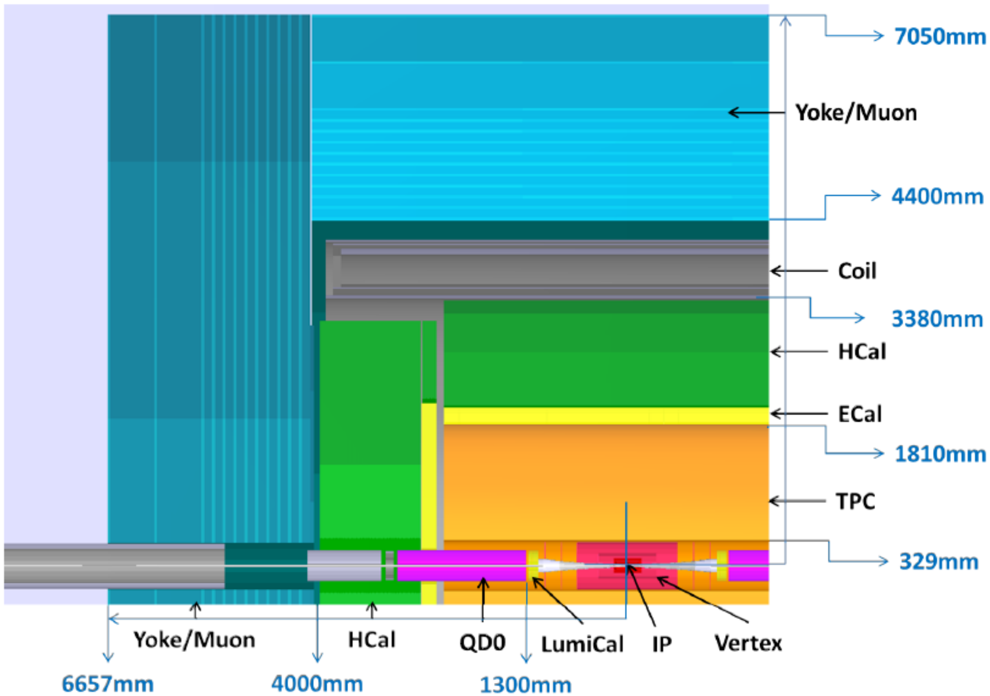
- No push-and-pull → Less Yoke

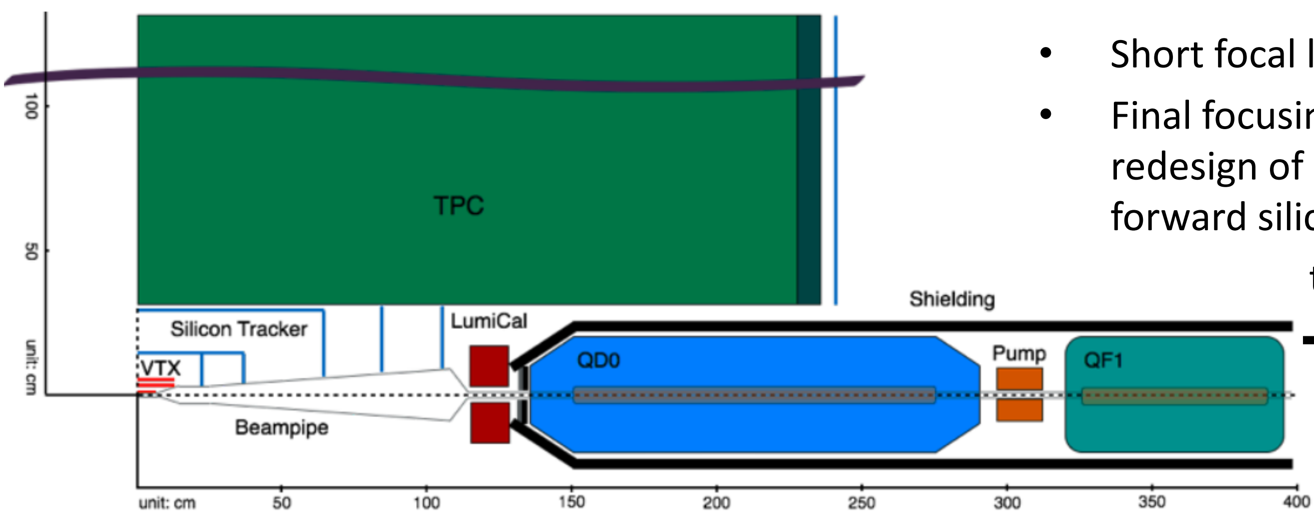
- Shorter L*=1.5m → Challenges for Machine-Detector-Interface (MDI)

- No Power-pulsing → more power consumpti & needs active cooling

- CEPC preCDR

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





- Short focal length L*=1.5m
- Final focusing magnets inside the detector, redesign of QD0/QF1, LumiCal, and reduce forward silicon tracker disk (FTD) to 5

→ beam induced background studies

CEPC Vertex and Tracker

➔ **CEPC detector design is driven by critical physics benchmarks.**

- Vertexing $(h \to b\bar{b}, c\bar{c}, \tau^+\tau^-)$
  - ~1/5 $r_{beampipe}$, ~1/30 pixel size (wrt LHC)

$$\sigma_{ip} = 5\mu m \oplus 10\mu m / p\sin^{3/2}\theta$$

✔ CEPC

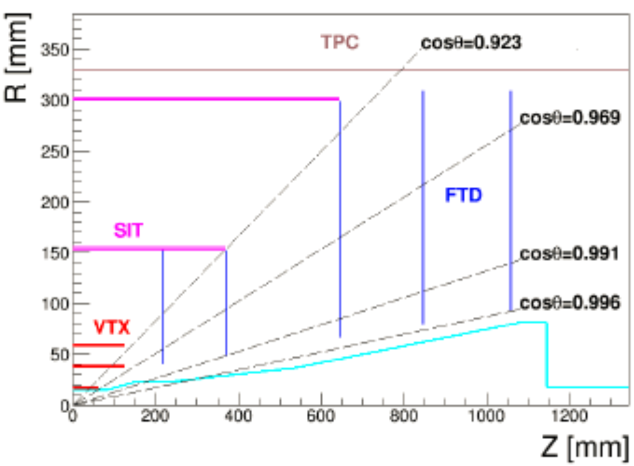
- Tracking $(e^+e^- \to Zh \to \ell^+\ell^- X;\ \text{incl. } h \to \text{nothing})$
  - ~1/6 material, ~1/10 resolution (wrt LHC)

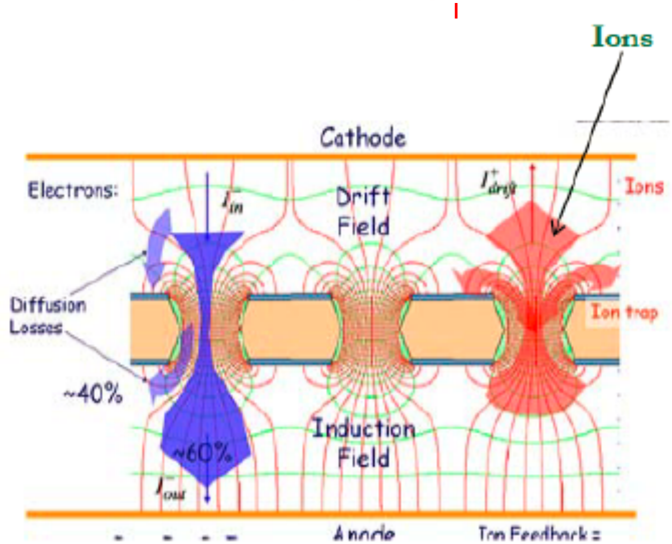
$$\sigma(1/p) = 5\times10^{-5}/GeV$$ or better

✔ CEPC

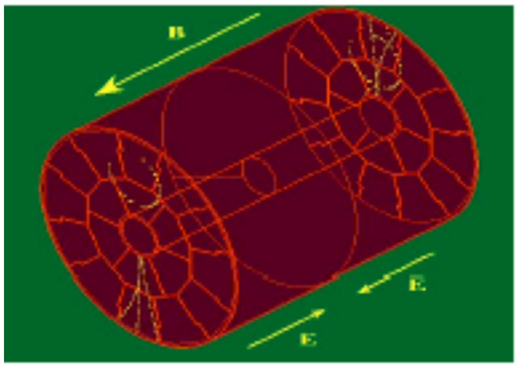
Vertex detector specifications:

- σ_{SP} near the IP: $\leq 3\ \mu m$
  - → small pixels 16×16μm² or below, digital
- material budget: $\leq 0.15\% X_0$/layer
  - → low power circuits, air cooling
- pixel occupancy: $\leq 1\ \%$
- radiation tolerance:
  - Total Ionising Does ≤ 100 krad/year
  - Non-Ionising Energy Loss $\leq 3\times10^{11} n_{eq}/(cm^2\ year)$
- first layer located at a radius: ~1.6 cm





IBF of GEM



➔ GEM+Micromegas hybrid detector to significantly reduce TPC ion back flow

CEPC Electromagnetic Calorimeter

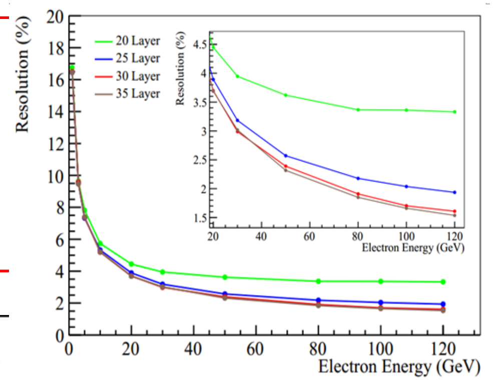
➔Concept of Particle Flow Algorithm (PFA) based calorimeters with very fine granularity, compare to ILC, it's less demanding at CEPC.

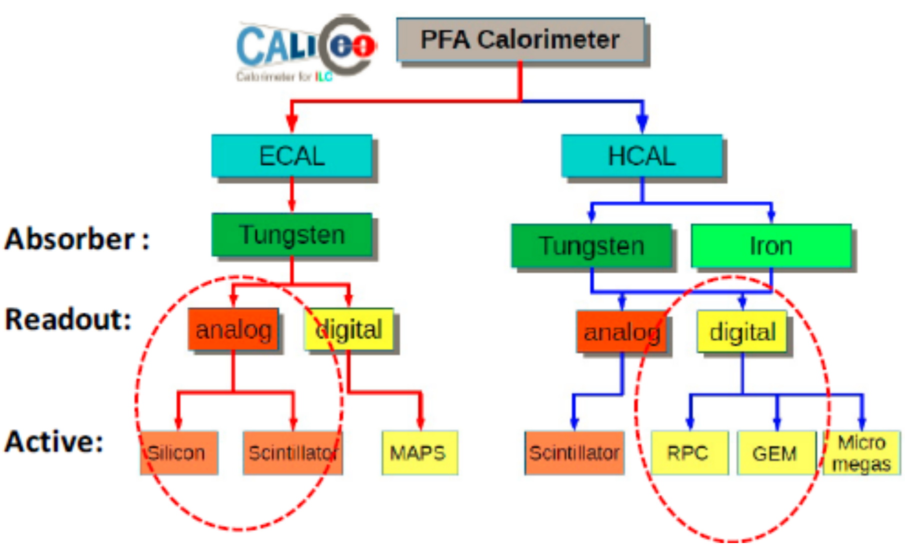
➔Re-optimization, exploring new design and active cooling, …

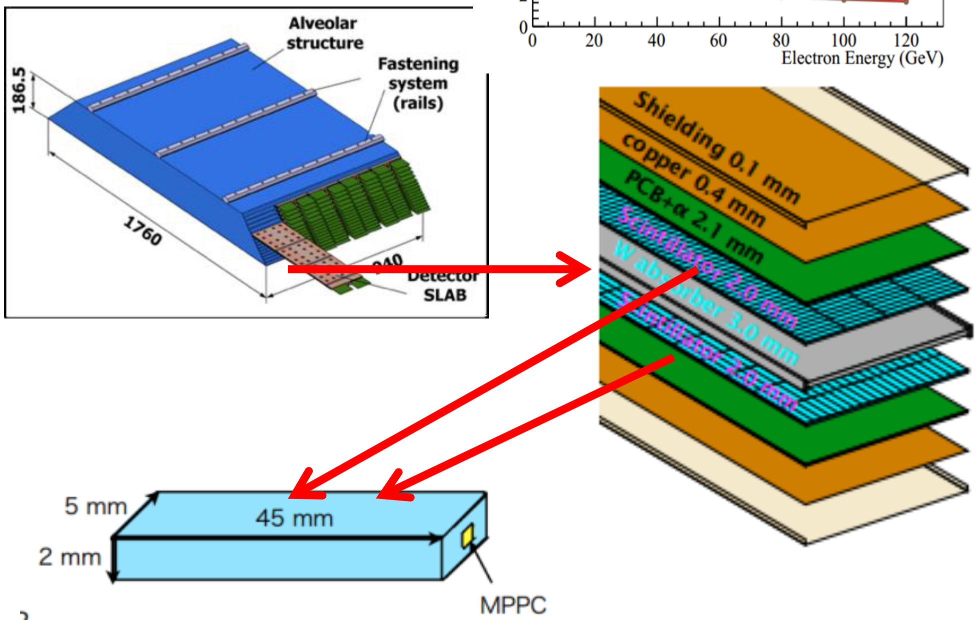
- Jet energy (Higgs self-coupling, W/Z separation)
  - ~1/2 resolution (wrt LHC)

$$\sigma_E / E = 0.3 / \sqrt{E(GeV)}$$

less demanding at CEPC







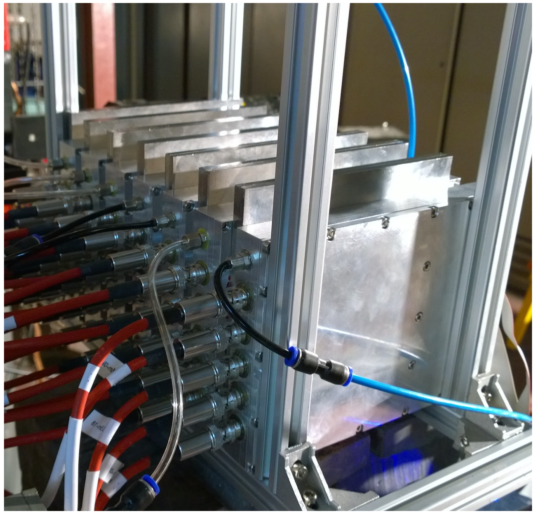
ECAL: Scintillator + W + Scintillator

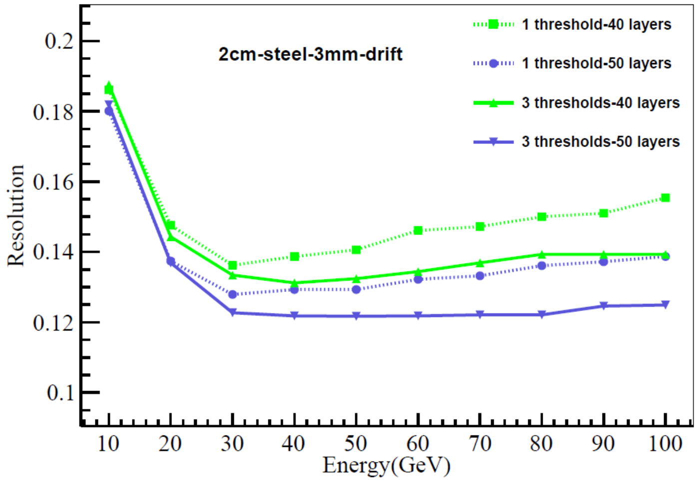
CEPC Hadron Calorimeter

➔Concept of Particle Flow Algorithm (PFA) based calorimeters with very fine granularity, compare to ILC, it's less demanding at CEPC.

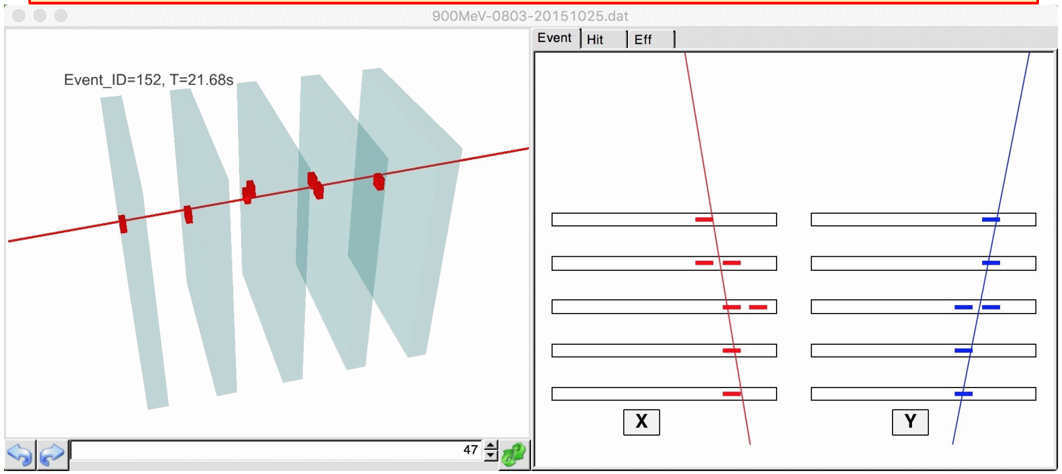
➔DHCAL based on gaseous detector (eg. RPC, THGEM).

- The HCAL consists of a cylindrical barrel system and two endcaps with self-support & negligible dead zone
- Absorber: Stainless steel
- Active sensor: large area RPC or (Thick) GEM
- Digital readout with cell size: 1×1 cm^2



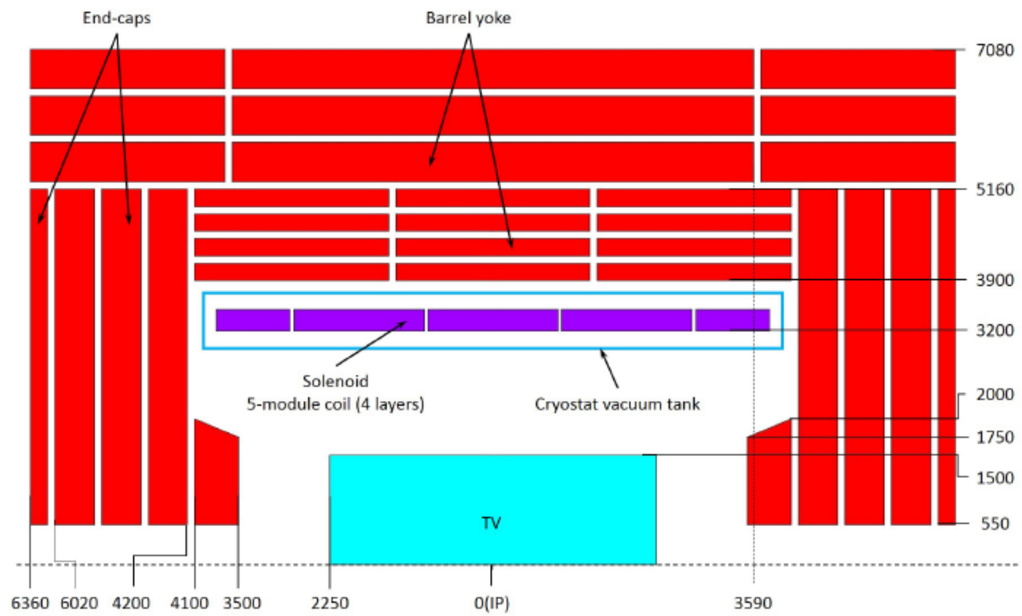


Test beam of THGEM at IHEP, Beijing in Oct. 2015

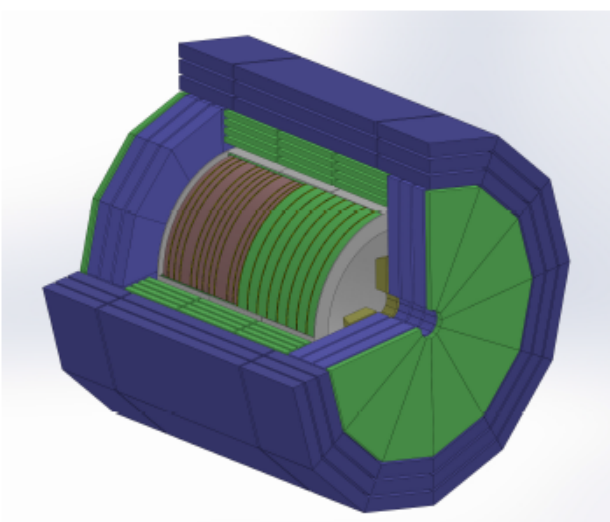


CEPC Magnet

Based on CEPC detector, a **3.5T** central field of superconducting solenoid (similar to CMS design) is required in a warm aperture diameter of 6m and length of 8.05m.



Schematic view of the CEPC detector magnet cross section (Half of the magnet section)



Cryostat inner radius(mm)	3400	Barrel yoke outer radius(mm)	7240
Cryostat outer radius(mm)	4250	Yoke overall length(mm)	13966
Cryostat length(mm)	8050	Barrel weight(t)	5775
Cold mass weight(t)	165	End cap weight(t)	6425
Barrel yoke inner radius(mm)	4400	Total yoke weight(t)	12200

The solenoid central field(T)	3.5	Nominal current(KA)	18.575
Maximum field on conductor(T)	3.85	Total ampere-turns of solenoid(MAt)	23.925
Coil inner radius(mm)	3600	Inductance(H)	10.4
Coil outer radius(mm)	3900	Stored energy(GJ)	1.8
Coil length(mm)	7600	Stored energy per unit of cold mass(KJ/kg)	10.91

MDI layout and issues : single → local double ring

Beam background

Shielding design

Collimator design

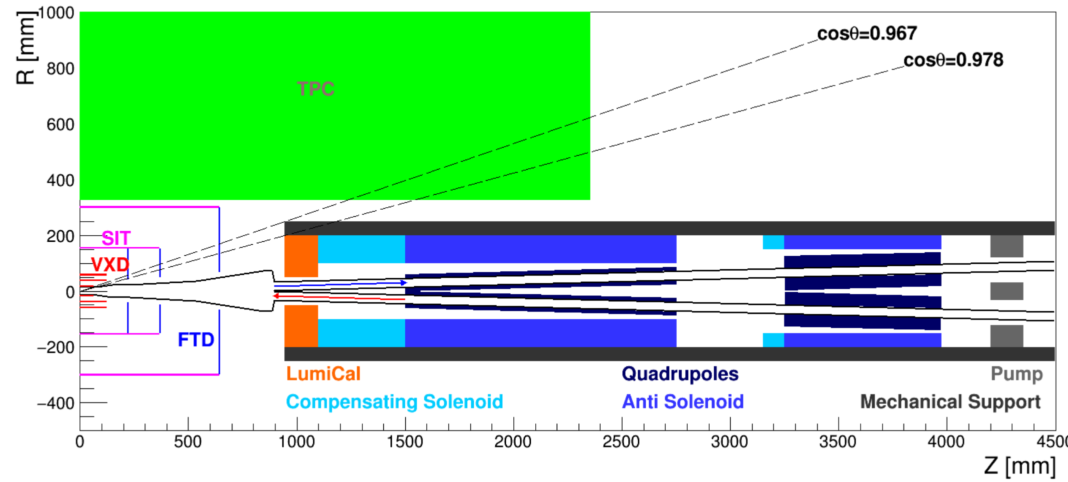
SC magnet design

Beam pipe

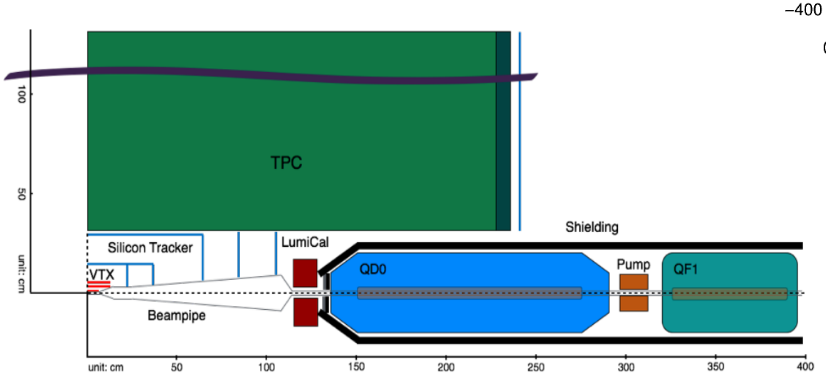
Solenoid compensation

Lumical & fast lumi measurement & feedback

……..



Partial double ring MDI



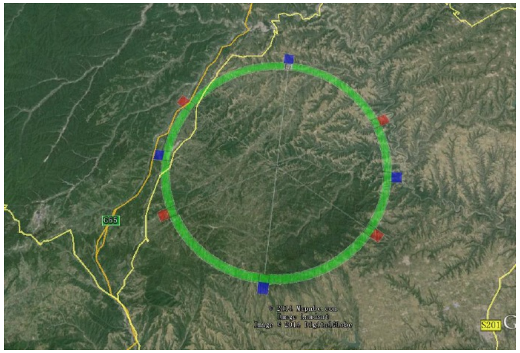
Single ring MDI

选址

- 根据未来发展的定位与目标，考虑如下需求：
  - 科学园区：5000-10000亩地，50-100公里环形地下隧道，地面设备竖井或平洞，配套辅助设施
  - 地质：微震动，地形地貌（基岩深度 <100m），水文地质
  - 社情：教育、就业、环境、交通、文化等适合建设国际科学城
  - 经济配套需求：与城市长期规划与经济发展目标相符合，与城市开发计划相符合，配套土地、经费等支持
- 在天津宝坻、河北保定、承德、秦皇岛、张家口、河南信阳、广东、陕西、江苏等地开展了初步选址工作

Site selections (a few main candidates)

1)



2)

3)

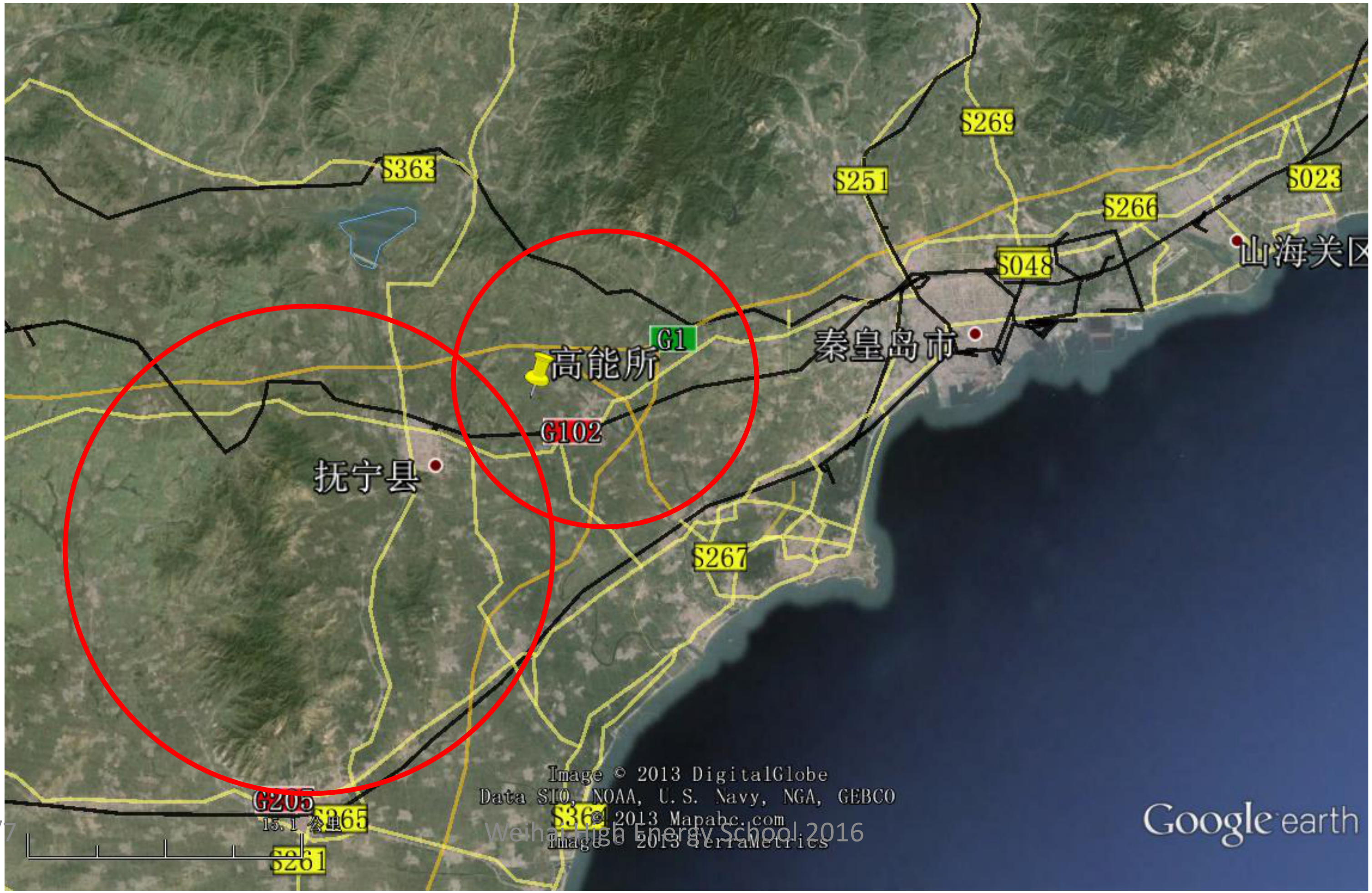
1) Qinhuangdao

2) Shanxi Province

3) Near Shenzhen and Hongkong

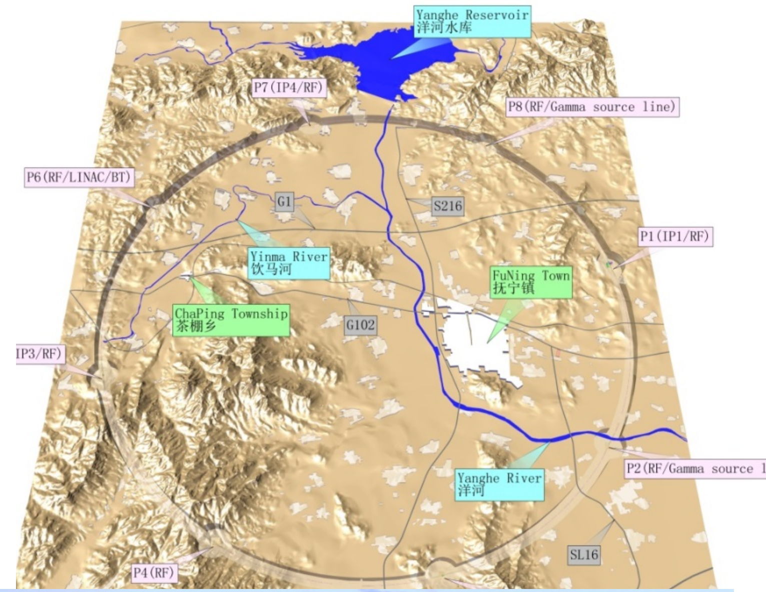
选址例：秦皇岛

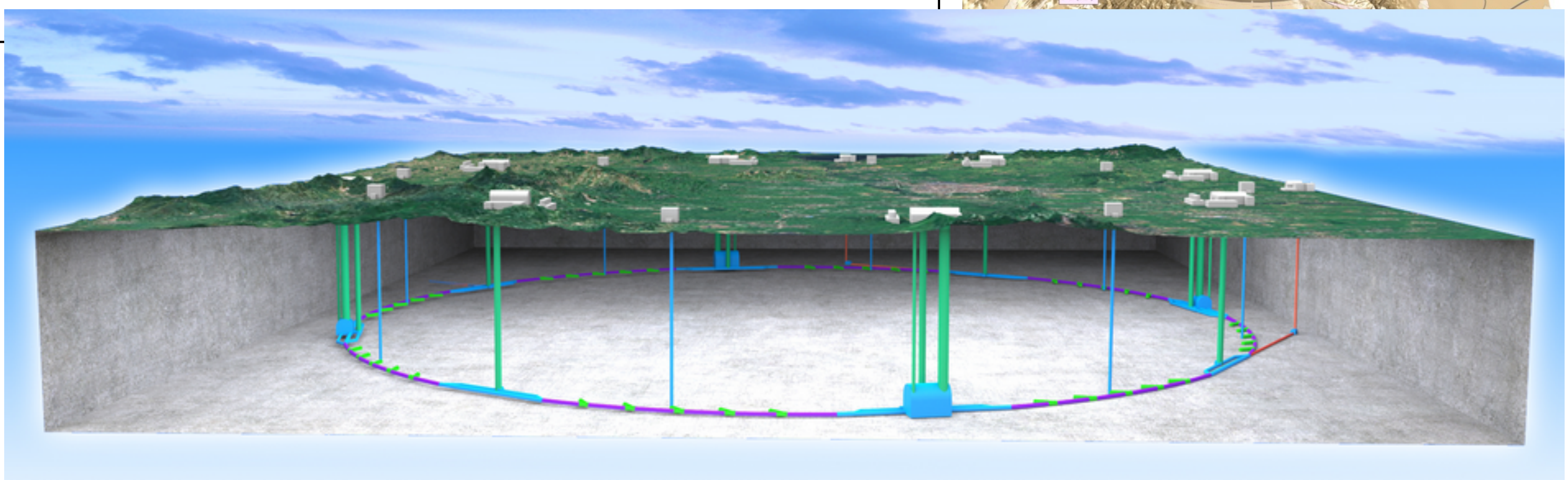
- 距北京300 km，3小时汽车，1小时高铁
- 地质条件极为优越: 微震动极小，基岩几乎裸露
- 环境条件极好



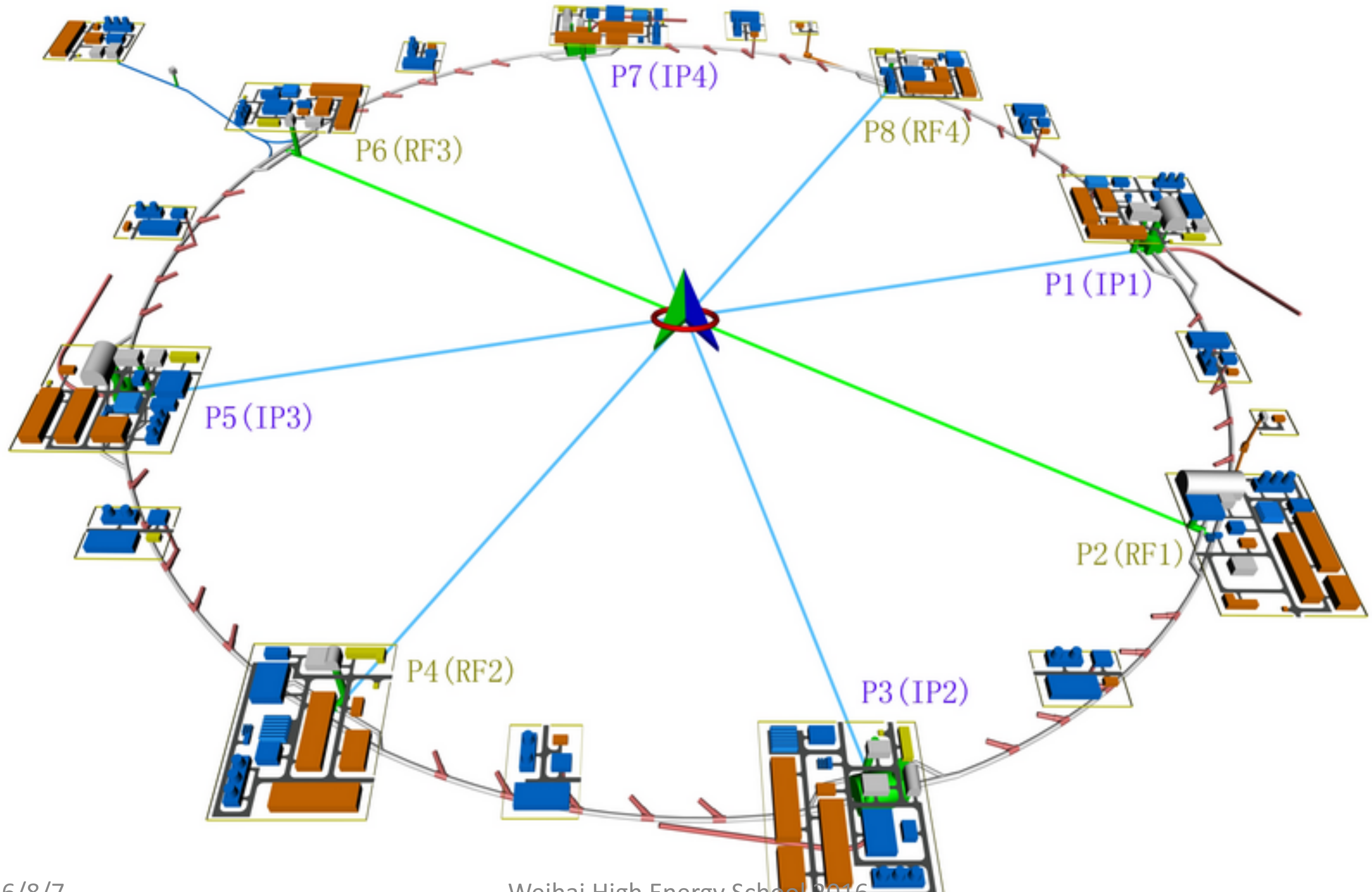
土建

- 完成了一个地下与地面建筑布置图
- 通过初步地质调查与勘探，完成了选址地的比较，及初步的隧道摆布
- 需求分析与初步的隧道、实验厅及地面建筑物概念设计
- 初步的通用系统设计
- 造价估计





地面与地下建筑物概念设计



CEPC的社会影响

- **社会发展**：地方的社会与经济发展；
- **前沿技术**：相关领域世界领先；同步辐射、自由电子激光等多学科大型研究平台
- **创新人才**：大型的、世界一流的科学研究和技术发展人才聚集地和培养基地
- **国际科研中心**：全面领先世界的高能物理和相关技术研究中心；国际化的管理方式及其推广；科学思想及其理念的普及推广；
- **世界聚焦**：“中国的伟大加速器，会和万里长城一样引人瞩目”—— 诺贝尔奖获得者David Gross；国际合作与科技外交；提高中国的国际威望，加强话语权与软实力

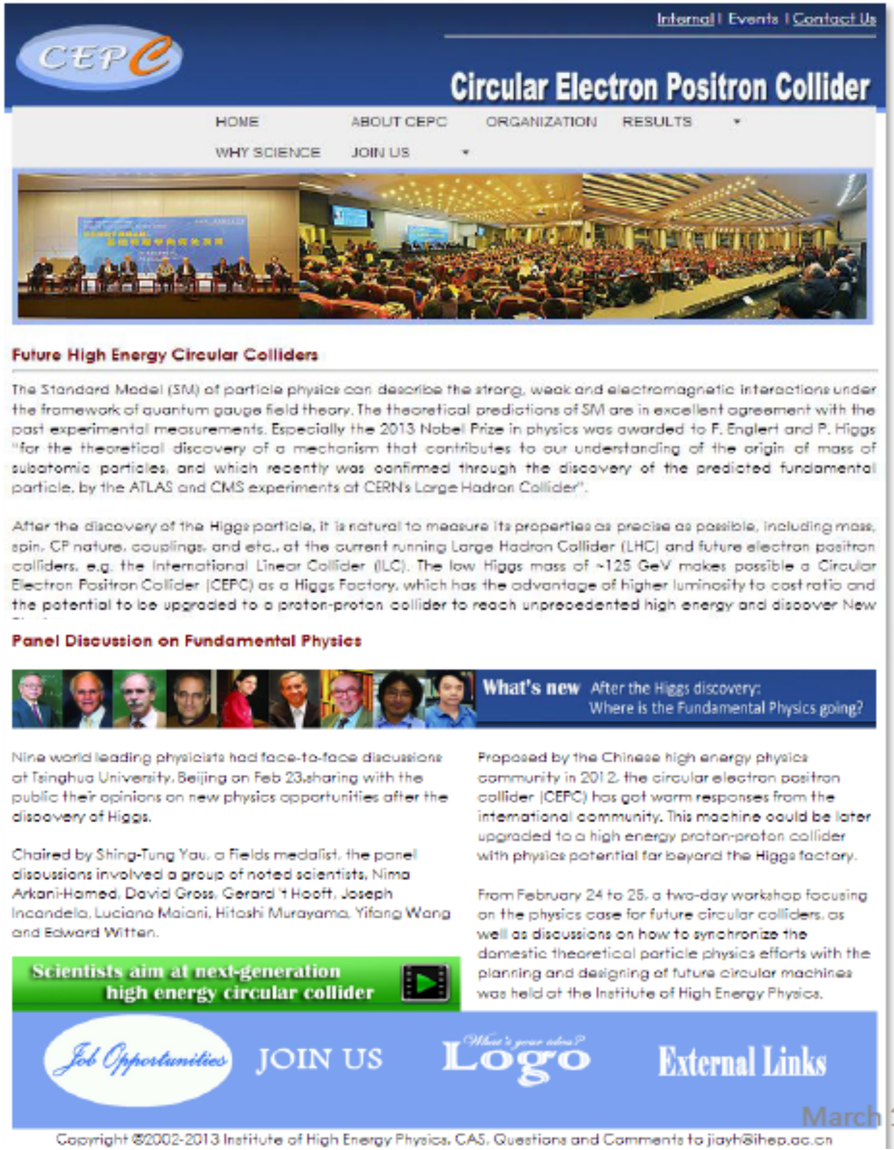
建设一个国际科学城：成为世界文明中心的一个标志

- 大型科学设施：
  - 正负电子对撞机CEPC，质子对撞机SppC
  - 同步辐射光源(CEPC)，自由电子激光(注入器), …
- 研究中心：
  - 粒子物理研究
  - 多学科研究：物理、化学、材料、生物、医药、。。。
  - 先进技术：加速器、探测器、精密机械、微波、低温、超导、电子、自动控制、计算机、。。。
- 科学城
  - 上万名世界各地的科学家、工程师、学生
  - 设备供应商：精密机械、微波、低温、超导、电子、。。。
  - 研究单位与企业研究院：物理、材料、生物、医药、。。。
  - 辅助与生活服务、教育培训设施

对技术的辐射带动作用

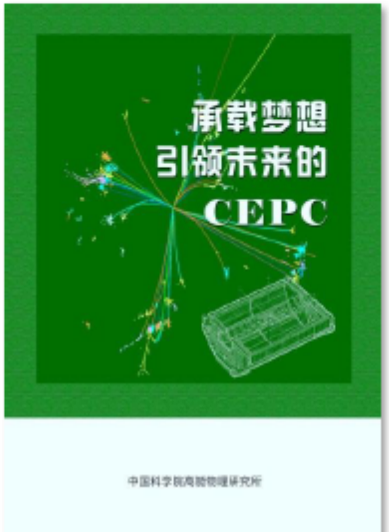
- 粒子物理研究不仅是科学的最前沿，也是技术的最前沿
  - 加速器物理与技术，核探测与核电子学技术，网络与计算技术等
- 典型事例：
  - CERN：互联网、WWW与浏览器的发明与传播
  - 高能所： email、互联网的引入；加速器及低温超导技术的应用
- CEPC几项关键技术及其转化目标
  - 大型低温制冷机与理化所合作，实现国产化
    - 广泛应用于加速器、航天航空中的氢液化装置以及天然气液化等
  - 高功率微波功率源与电子所、4404厂、北广等合作，实现国产化
    - 广泛应用于加速器、广播、雷达等领域
  - 超导线实现国产化并引领国际,占领部分超导磁铁市场
    - 广泛应用于加速器、发电、医疗成像、工业磁分离等领域
  - 硅像素探测器：掌握集成电路芯片、抗辐照技术，实现国产化
    - 广泛应用于同步辐射、加速器物理、军事等领域

Communication & outreach



Outreach & education

CEPC Outreach



～ 30000字

～ 6700字

～ 27000字

～ 5600字

CEPC建议
引起巨大国际反响

～10000字

CEPC
大事记

高能物理的
社会效益

进行中

未来的
希格斯工厂

进行中

From Xinchou Lou

Y. Y. Zhong

V

CEPC-SPPC 筹备组织

CEPC-SPPC Working Group

Established since September 2014

Institutional Board
Chair: Y. N. GAO (Tsinghua U)
Deputy: J. GAO (IHEP)

Steering Committee
Chair: Yifang WANG (IHEP)
J. Gao, Y.N. GAO(Tsinghua U), Nu XU (CCNU), J. SHAN (IHEP), H.J. YANG (SJTU), Q. QIN(IHEP), H.J. HE(Tsinghua), Y.J. MAO(PKU), J. B. LIU(USTC), W.R.CHOU(FNAL/IHEP),X.C.LOU(IHEP),...

Project Directors
X.C. LOU(IHEP)
N. XU(CCNU), Q. QIN(IHEP)

Theory
H.J. HE(Tsinghua)
J.P.MA(ITP)
X.G.HE(SJTU)

Accelerator
Q. QIN(IHEP)
J. GAO (IHEP)
J.Y. TANG(IHEP)

Detector
Y.N.GAO(Tsinghua)
S. SHAN(IHEP)
N. XU(CCNU)

IHEP-CEPC-DR-2015-01

IHEP-EP-2015-01

IHEP-TH-2015-01

IHEP-CEPC-DR-2015-01

IHEP-AC-2015-01

2015年初完成初步概念设计报告：

涵盖科学目标、加速器和探测器、初步地质调查、需求分析和隧道及辅助设施

CEPC-SPPC

Preliminary Conceptual Design Report

Volume I - Physics & Detector

The CEPC-SPPC Study Group

March 2015

CEPC-SPPC

Preliminary Conceptual Design Report

Volume II - Accelerator

The CEPC-SPPC Study Group

March 2015

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

Accelerator Review

- Review happened in Feb.14 – 16
- Chaired by K. Oide
- Members:

Katsunobu Oide	KEK
Zhao Zhengtang	SSRC
Ilan Ben-zvi	BNL
John Seeman	SLAC
Eugene Levichev	BINP
Mike Koratzinos	CERN/U. Geneva
Bob Rimmer	Jlab
Marica Biagini	INFN
Ralph Assmann	DESY

Review Committee Report

The design work of CEPC has started just about a year ago. Tremendous effort has been made to prepare the *Preliminary Conceptual Design Report,* which is now nearly ready, and covers the entire project comprehensively. **The Committee has been very impressed with the progress during such a short period of time, as well as the work and presentations shown, mostly done by the young generation, who are the ones that can devote their carriers to this project through the coming decades.**

The committee believes that the CEPC project and the required R&D will strengthen China's technological capacities in several areas, for example high-efficiency solid-state amplifiers, high-temperature superconducting materials and superconducting RF technology. Important spin-offs for industrial applications can be expected.

The committee appreciates the efforts to maximize the synergy with possible worldwide collaborators for an eventual CEPC consortium. This approach is applauded and the committee thinks that a strong international consortium can form around this approach, involving the leading accelerator laboratories of the world.

frontier. **The merit of this proposal is that the e+e- experiment starts as early as possible and will run concurrently with the HiLumi LHC. The construction of CEPC will not wait for the completion of the R&D for SPPC, relying on its progress during the CEPC construction and running period.**

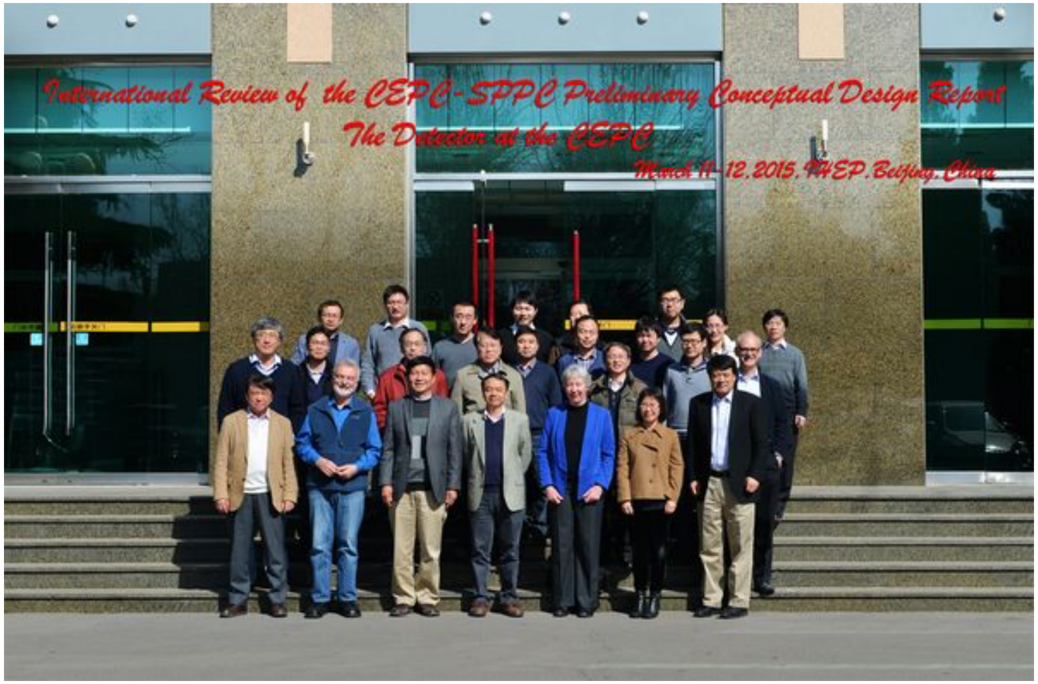
Response to the Charge Letter

1. The committee considers the CEPC-SPPC to be well aligned with the future of China's HEP program, and in fact the future of the global HEP program.
2. The design goals are well defined and comprehensive. We provided remarks and recommendations to improve the design, but we definitely consider this design to be credible and with sufficiently conservative assumptions.
3. The great majority of the accelerator physics issues are adequately addressed, and after addressing our recommendations, we expect that all the accelerator physics issues would be adequately addressed.
4. The designs of the technical systems and conventional facilities are effective for achieving the performance goals.
5. We find the CEPC design compatible with the future upgrade to the SPPC.
6. Technical risks and their potential impact were presented together with mitigation measures, while in some cases more study and R&D are needed.
7. The R&D program is clearly defined, and while we recommended a few additional R&D items, the program is adequate. We further believe that this R&D program will be highly beneficial to the science and technology infrastructure in China and will contribute to its economy.
8. We made a few suggestions for improvements of the design.

Detector Review

- Review happened in March 11 – 12
- Chaired by Hendrik J. (Harry) Weerts
- Members:

Marcel Demarteau	ANL
Young-Kee Kim	Univ. Chicago
Rick Van Kooten	Indiana Univ.
Hendrik J. Weerts	ANL
Phillippa Wells	BINP
Hitoshi Yamamoto	Tohoku Univ.
Zheng Li	Xiang Tan Univ



Report of
Review of CEPC-SppC Detector preCDR
Beijing, March 11-12, 2015

Introduction

A review of the CEPC-SPPC Preliminary Conceptual Design Report for a detector at the CEPC was held at the Institute for High-Energy Physics in Beijing on March 11 and 12, 2015. The committee received two separate documents prior to the meeting titled "CEPC-SppC, Preliminary Conceptual Design Report: Physics and Detector", one describing the physics goals and the physics performance of the proposed detector and the other providing technical details of the detector subsystems. The review was organized around a series of overview talks covering aspects of the experimental program, the detector and all its subsystems

Observations

The assembled, local team was well organized, young, focused and enthusiastic with excellent leadership and vision. They made excellent, effective use of existing studies and the software framework resulting in an impressive achievement, given the short time scale. They are also either part of existing R&D collaborations (LCTPC) or associated with them (CALICE). Optimizing for the study on Higgs final states in a limited center-of-mass energy region has helped focus the effort. The proposed R&D program based on the current preCDR, resulting in a CDR in the next 5 years, followed by a TDR which enables a construction start in 2021 seems challenging but feasible.

Review of Civil Construction and Utilities

环形正负电子对撞机（CEPC）土建及通用系统配套工程

初步概念设计报告评审意见

中国科学院高能物理研究所于2015年3月5日在高能所组织召开了“环形正负电子对撞机（CEPC）土建及通用系统配套工程初步概念设计报告”评审会。专家组（名单附后）听取了黄河勘测规划设计有限公司(以下简称黄河设计公司)的汇报。经过讨论，形成评审意见如下：

一、黄河设计公司开展了大量工作，提出了选址方案，设计内容及深度基本满足高能所提出的初步概念设计阶段要求。

二、黄河设计公司通过资料搜集、现场调查及部分勘察工作，经过研究和评价，该选址区的区域稳定性分级为基本稳定，外动力地质现象不发育，无制约工程建设的重大地质问题。

专家认为，选址区适宜大范围地下工程建设。

三、总体布置满足工艺需求，方案设计基本可行。

四、基本同意报告推荐的结构选型和施工方案，以及电气、通风空调、给排水和消防等系统设计方案。

五、工程投资估算基本合理，编制深度满足本阶段要求。

六、建议

（1）进一步开展地质工作，优化隧道线路和实验大厅的布置；

（2）结合地质勘察资料，深化施工方案研究，优化工程筹划；

（3）根据场址环境条件，补充完善施工渣场规划；

（4）下阶段应根据工程需求，尽量做到永临结合；

（5）根据调整优化后的方案，进一步细化投资估算。

专家组长签名：

2015. 3. 5

- **The current design, including surface and underground construction, electricity, water, HVAC & firefight system as well as the construction method & organization satisfy all the requirements by IHEP at current stage**
- **The studied candidate site has no geological issues and is suitable for this project**
- **The level of details and the total budget estimate is adequate at this stage**

International Advisory Committee

Established since September 2015

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: 36 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

We choose to go to the moon. We choose to go to the moon in this decade and do the other things, not because they are easy, but because they are hard, because that goal will serve to organize and measure the best of our energies and skills, because that challenge is one that we are willing to accept, one we are unwilling to postpone, and one which we intend to win, and the others, too.

J.F.Kennedy, 1961

选择CEPC-SppC作为中国高能物理的未来计划，不是因为它简单，而是因为它困难，因为这个目标将有益于组织和分配我们的优势能力和技能，因为这个挑战是我们乐于接受的，因为这个挑战是我们不愿推迟的，因为这个挑战是我们打算赢得的。