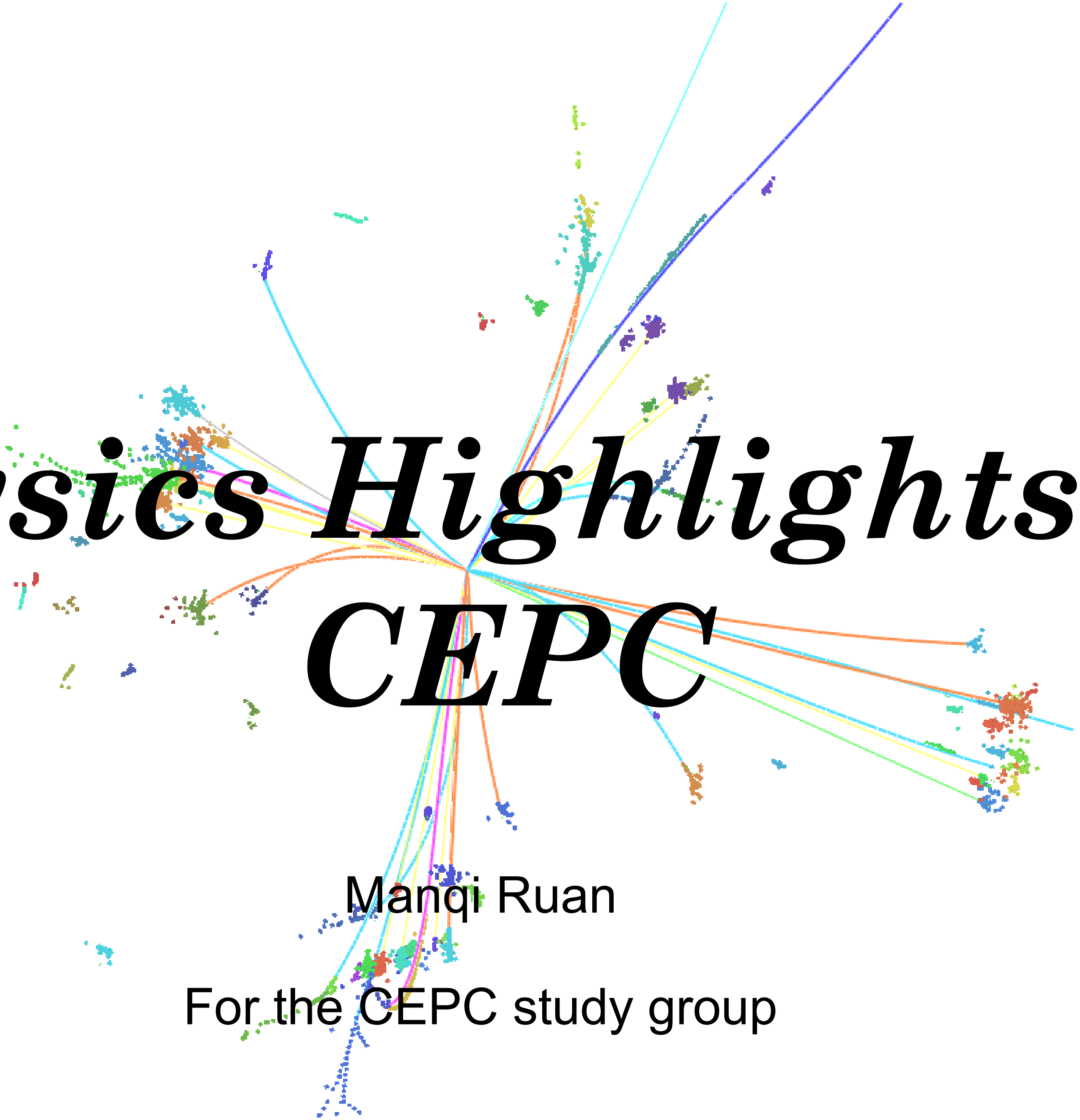
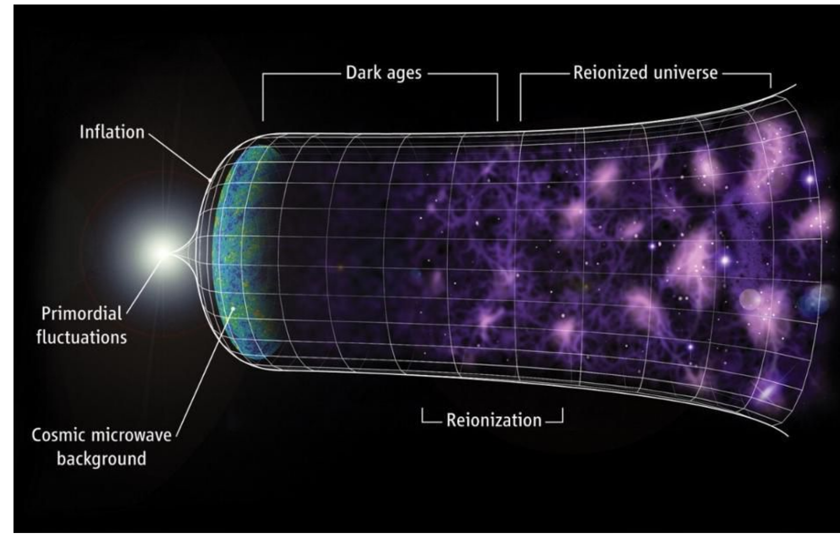


Physics Highlights at CEPC

Manqi Ruan

For the CEPC study group

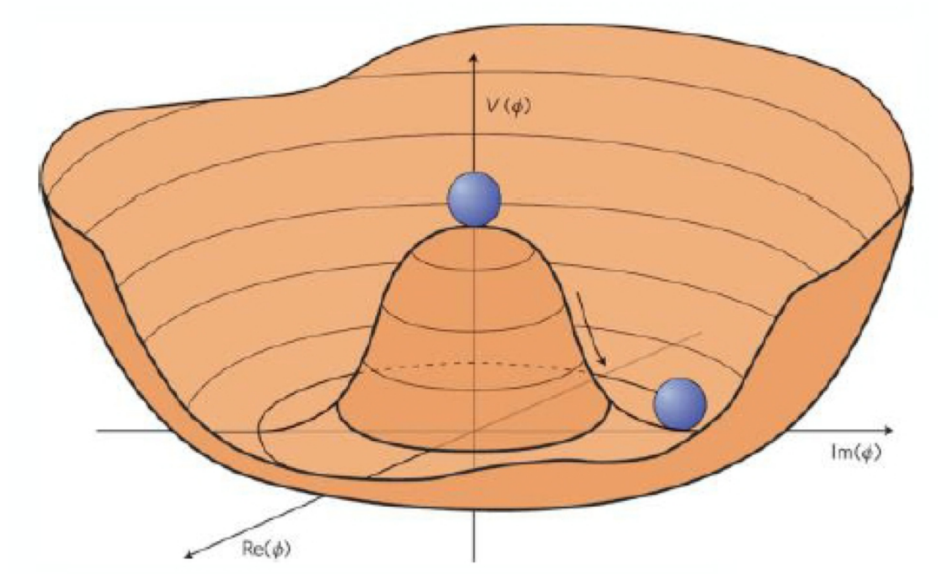
Known Unknowns of the SM



- Inflation
- Mass hierarchy
- Neutrino mass & Oscillation
- Matter anti-matter asymmetry
- Vacuum stabilities: depends on particle mass
- Dark matter, Dark energy: nature & origin of its/their mass
- Naturalness: EW (Higgs mass) V.S. Planck scale
- Flavor Structure: mass & flavor eigenstates
- ...

Known Unknowns of the SM

- The Clue:



- Inflation
- Mass hierarchy
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- Matter anti-matter asymmetry
- Vacuum stabilities: depends on particle mass
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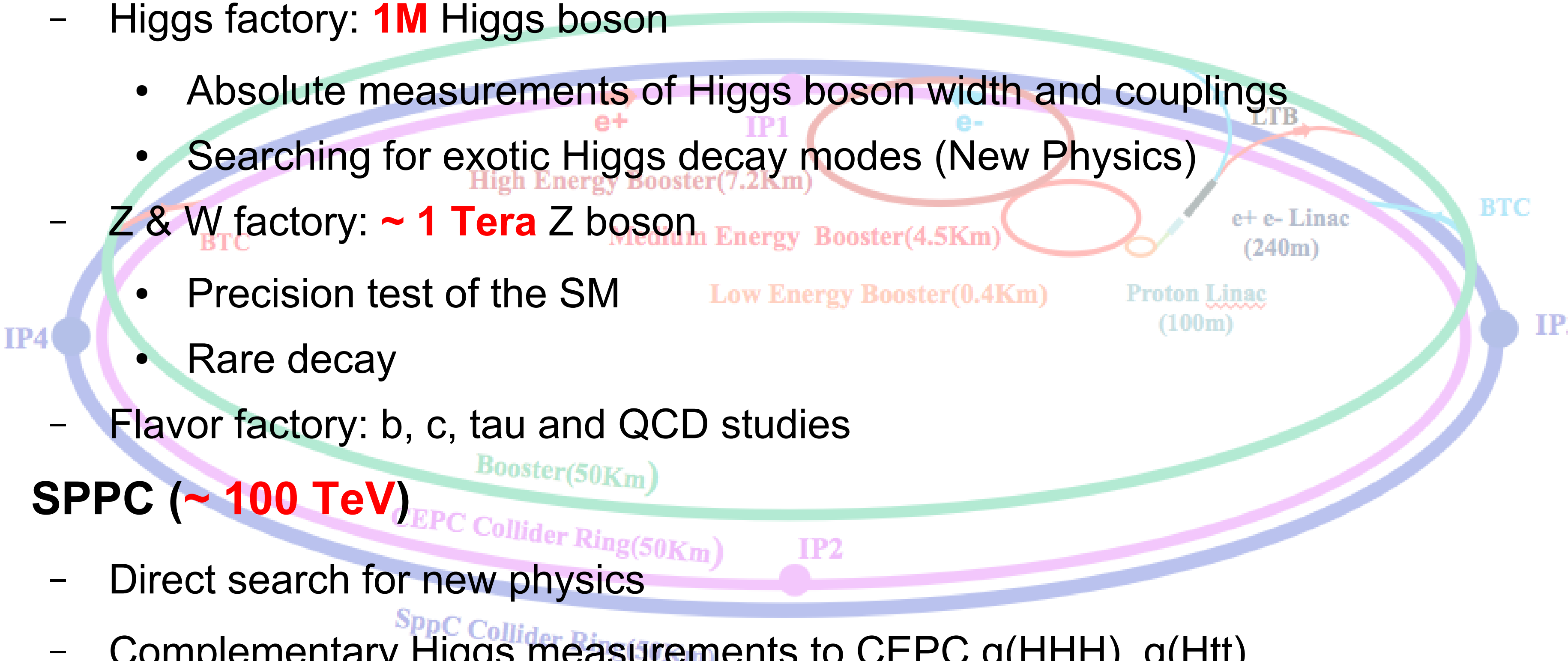
- Naturalness: EW (Higgs mass) V.S. Planck scale
- Flavor Structure: mass & flavor eigenstates
- ...

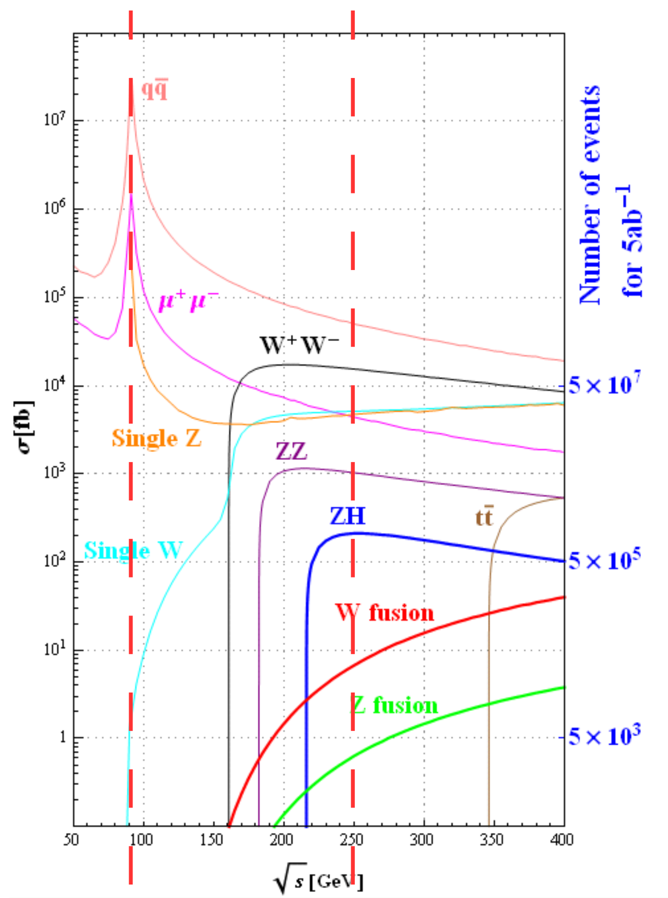
Key parameters of the CEPC-SPPC

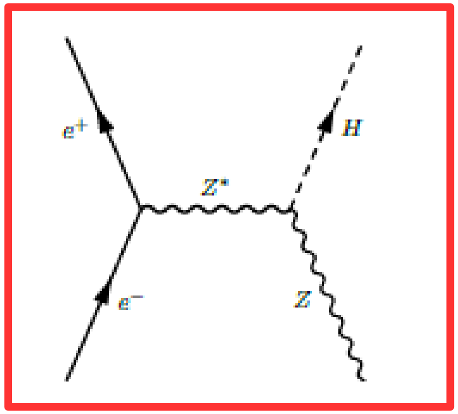
- **Tunnel ~ 100 km**
- **CEPC (90 – 240 GeV)**
  - Higgs factory: **1M** Higgs boson
    - Absolute measurements of Higgs boson width and couplings
    - Searching for exotic Higgs decay modes (New Physics)
  - Z & W factory: **~ 1 Tera** Z boson
    - Precision test of the SM
    - Rare decay
  - Flavor factory: b, c, tau and QCD studies
- **SPPC (~ 100 TeV)**
  - Direct search for new physics
  - Complementary Higgs measurements to CEPC g(HHH), g(Htt)
  - ...
- **Heavy ion, e-p collision...**

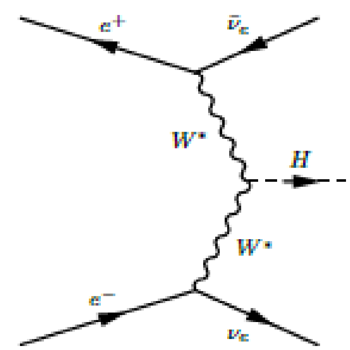


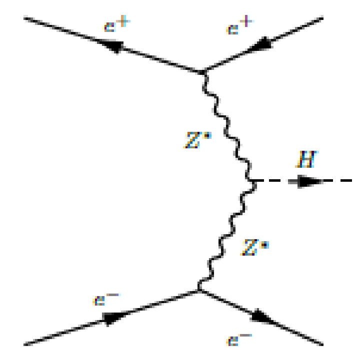
Complementary

Higgs @ CEPC









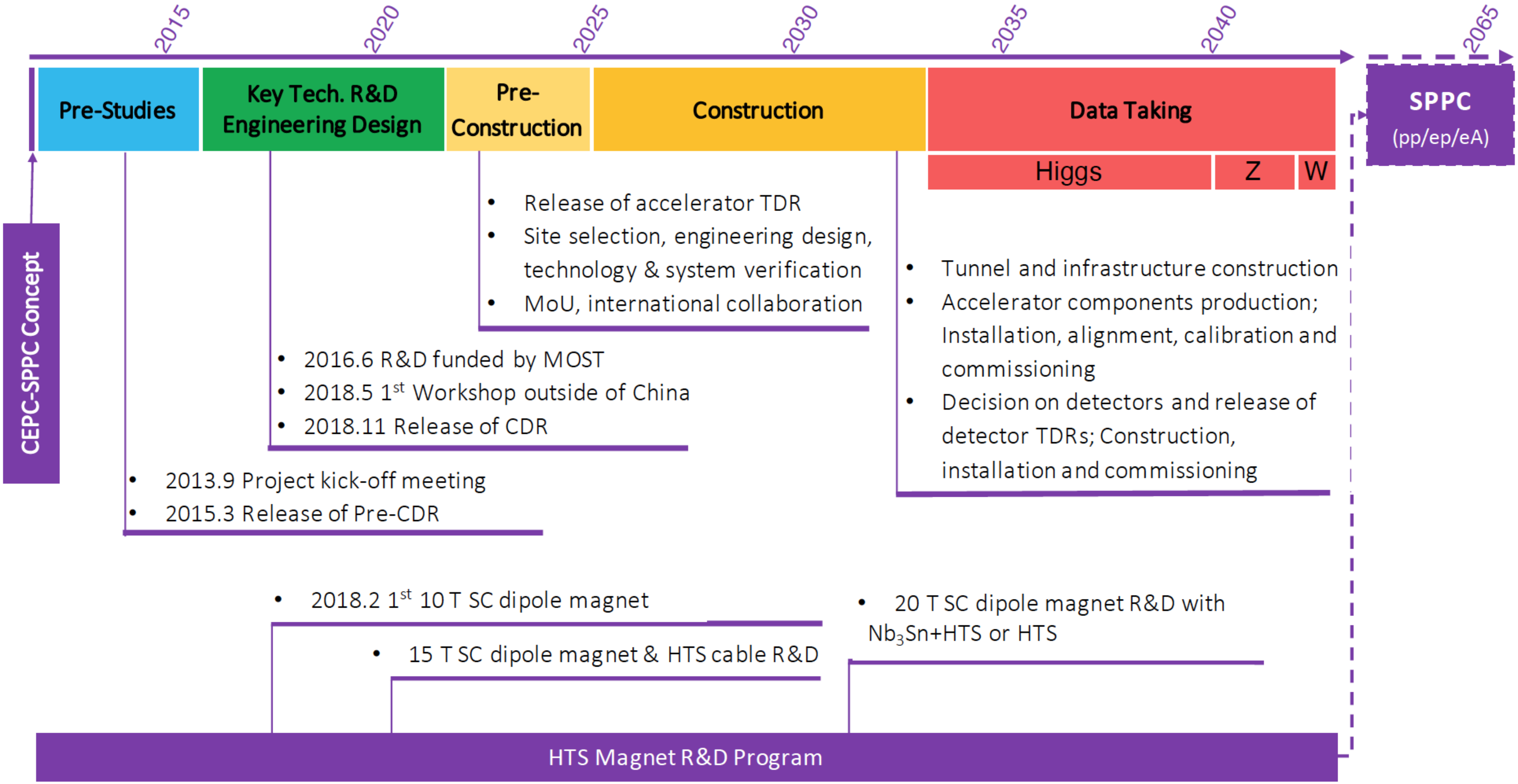
Process	Cross section	Events in 5 ab^{-1}
Higgs boson production, cross section in fb		
$e^+e^- \to ZH$	212	1.06×10^6
$e^+e^- \to \nu\bar{\nu}H$	6.72	3.36×10^4
$e^+e^- \to e^+e^-H$	0.63	3.15×10^3
Total	219	1.10×10^6

Observables: Higgs mass, CP, σ(ZH), event rates (σ(ZH, vvH)*Br(H→X)), Diff. distributions

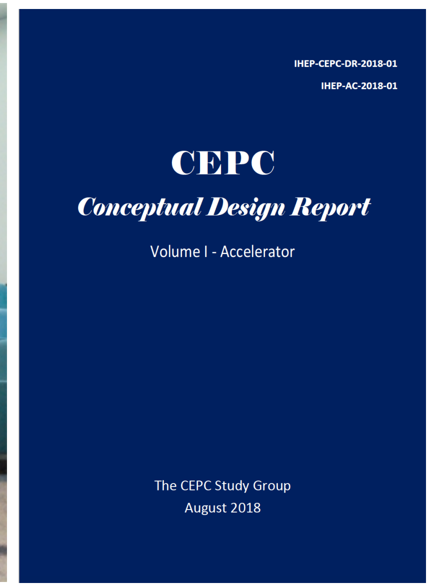
Derive: Absolute Higgs width, branching ratios, couplings

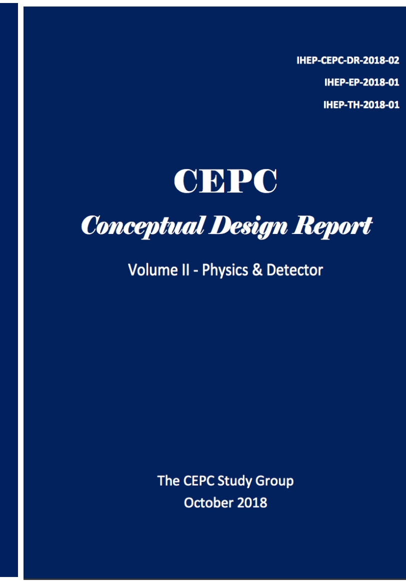
Timeline

CEPC Project Timeline



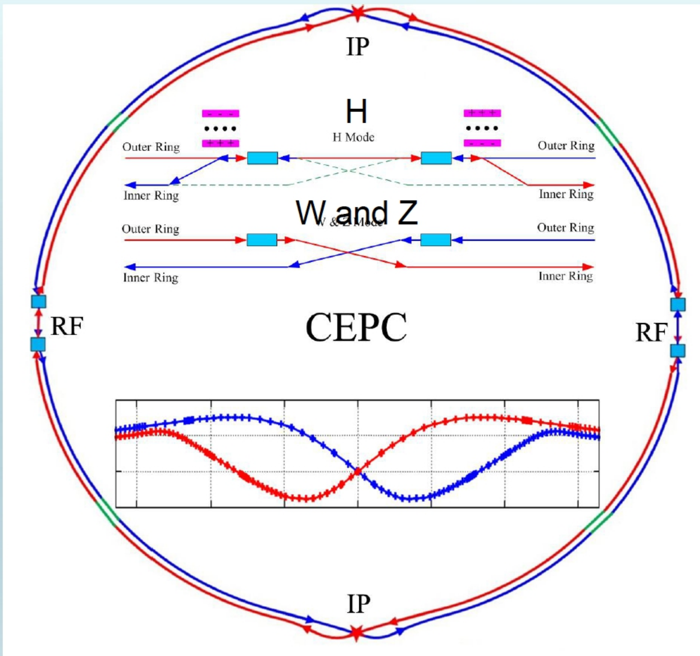
CDR released in Nov. 2018



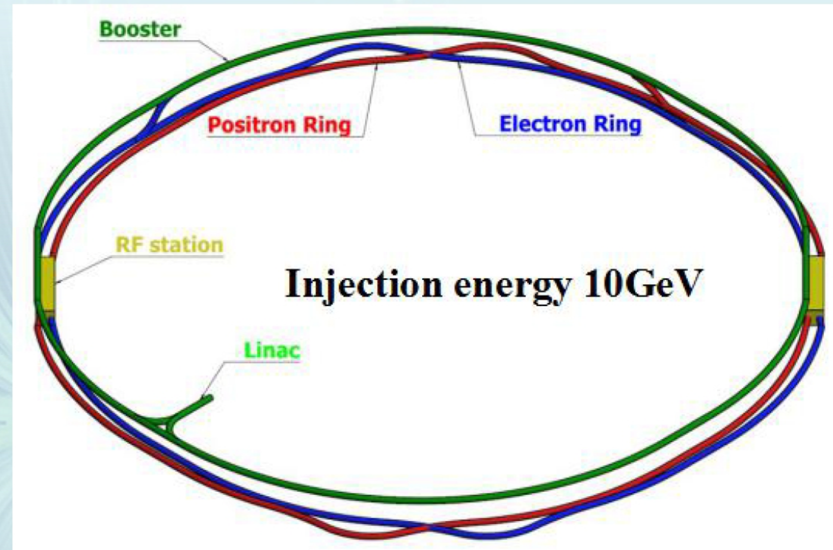


- Baseline designs for the Accelerator, Detector & Software
  - Subsystems' designs supported with Prototype construction & test
- Physics potential
- Significant international participation (~1/3 authors, very senior & influential IAC support)

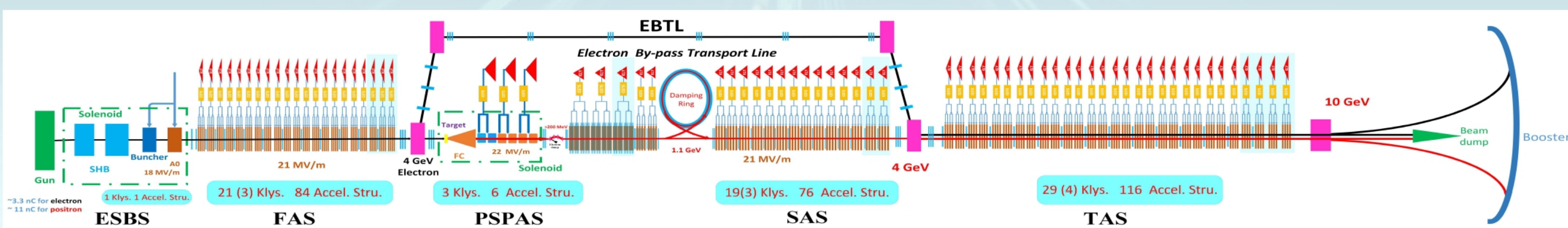
Baseline Collider Design



CEPC collider ring (100km)

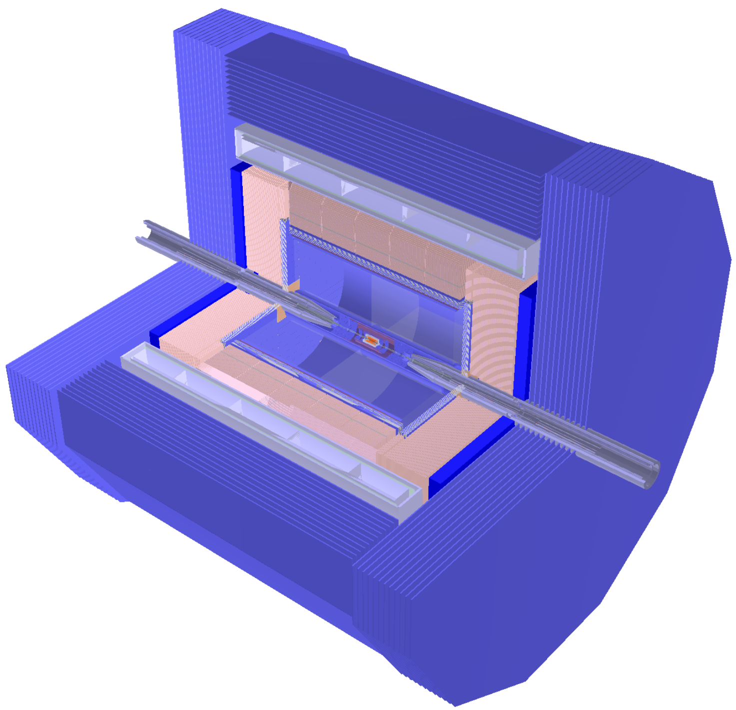


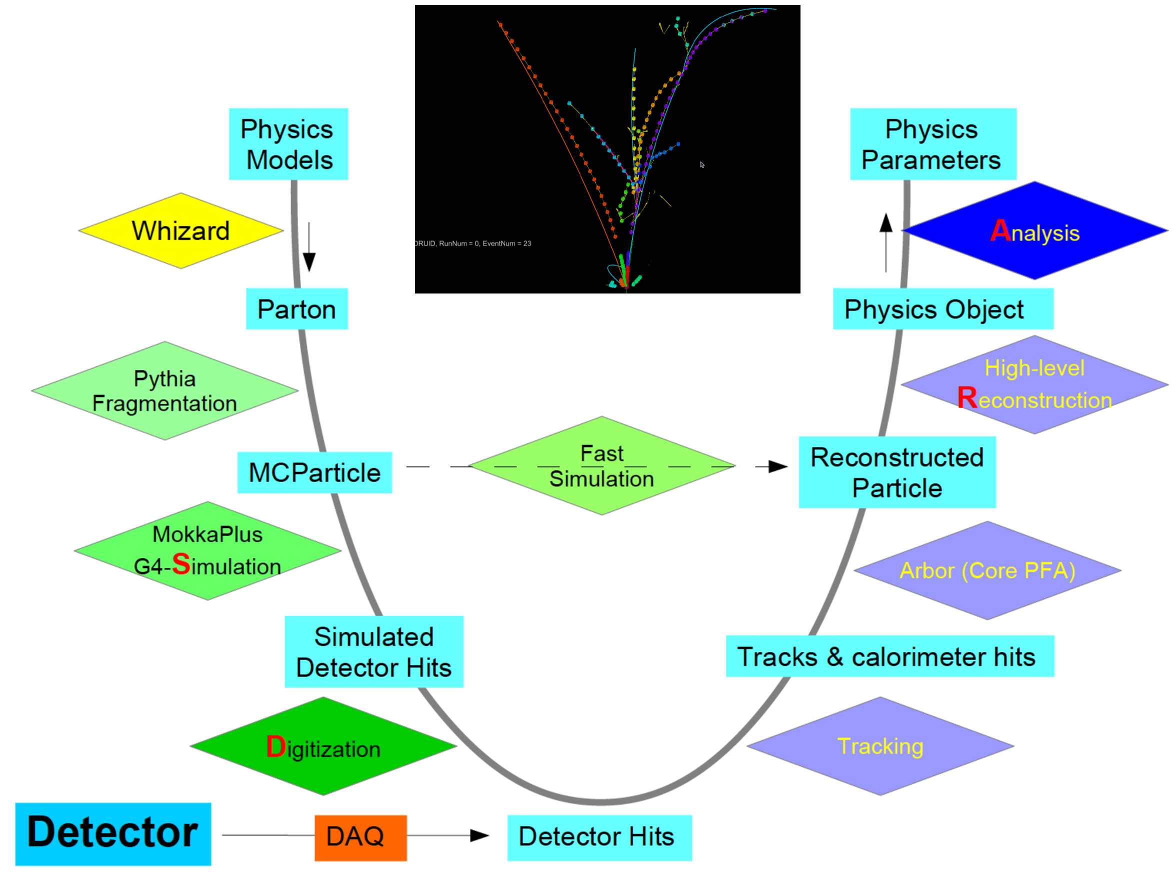
CEPC booster ring (100km)



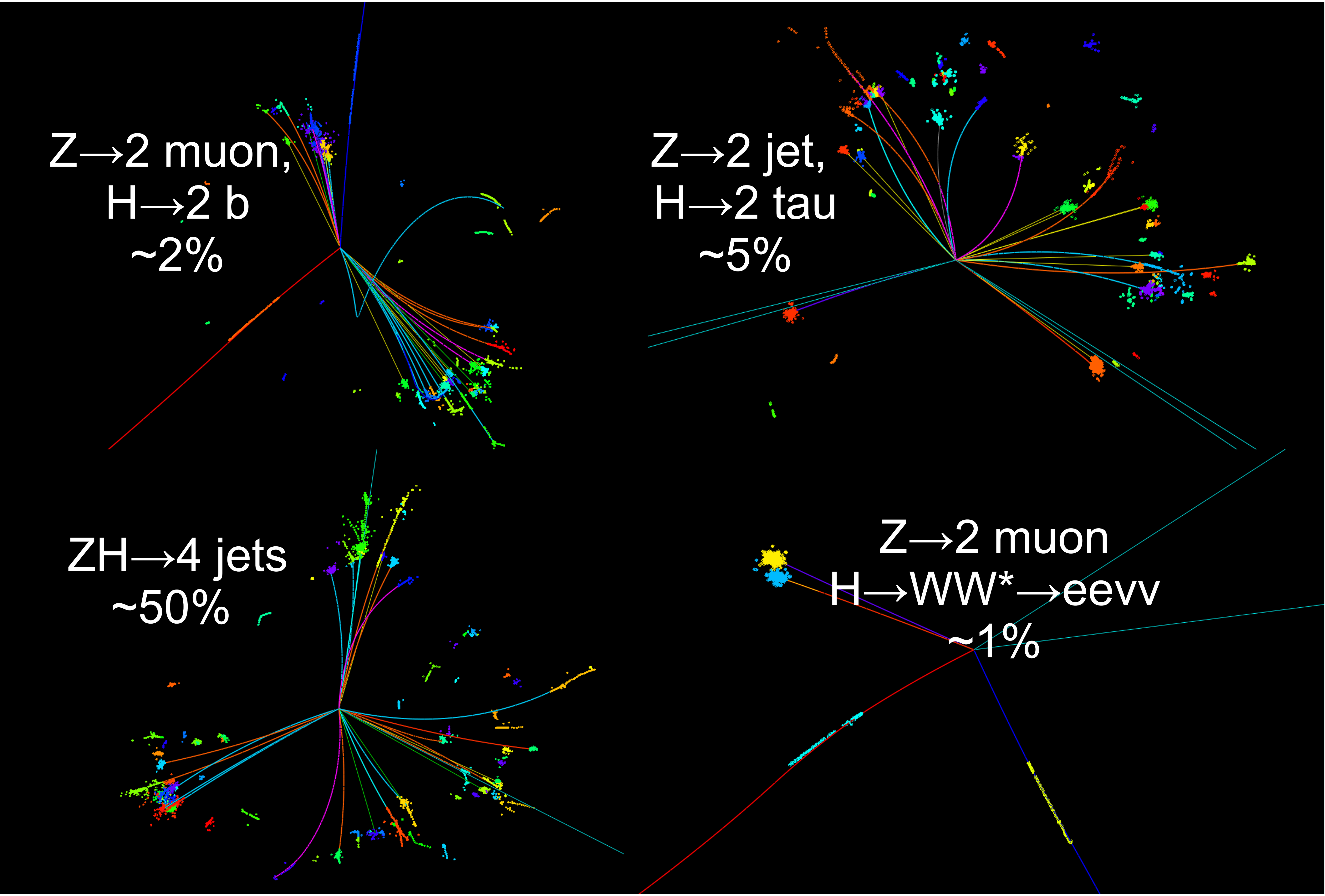
Luminosity/IP ($10^{34}cm^{-2}s^{-1}$)	Higgs	W threshold	Z pole
CDR (2018)	3	10	16 - 32
Now	5	-	115

Detector & Reconstruction

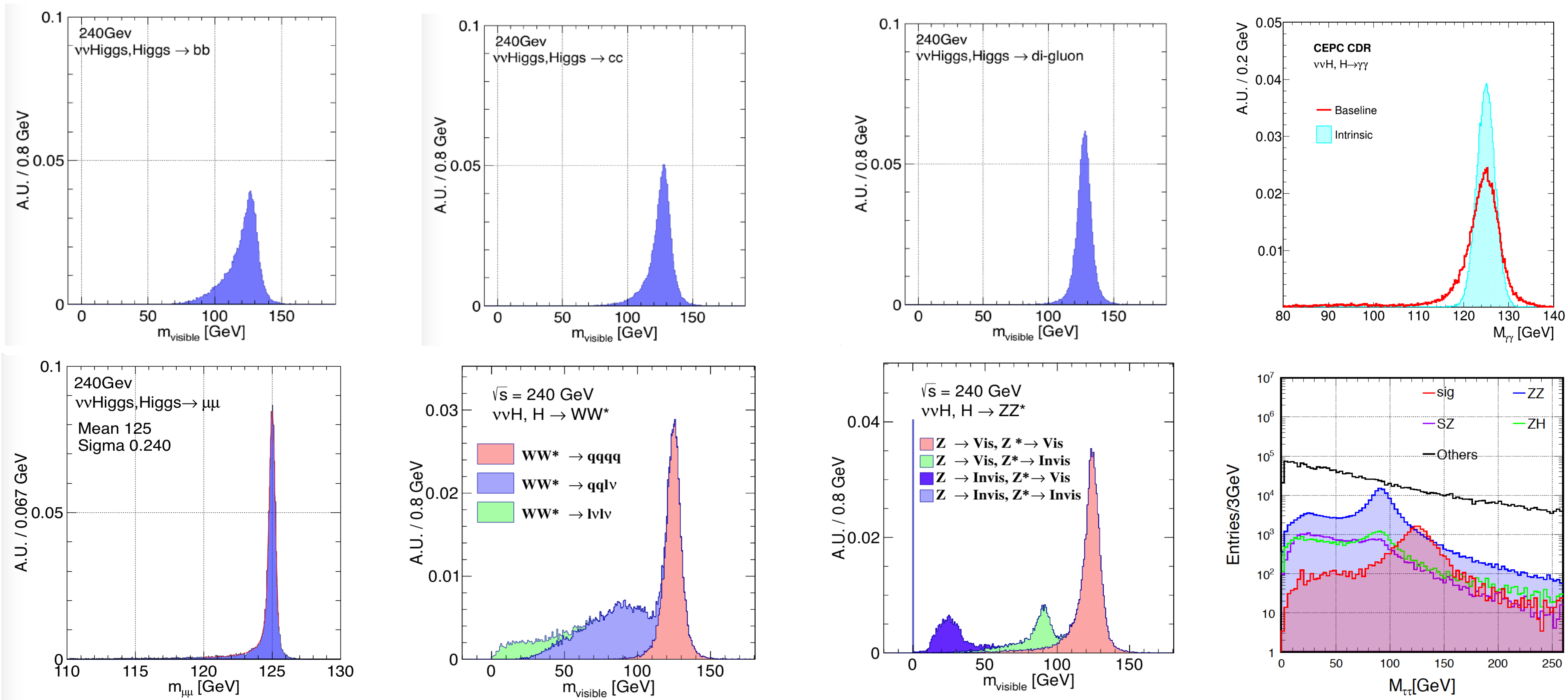




PFA oriented design: originated from ILC studies
Alternative design uses dual readout calorimeter & wire chamber


Z→2 muon,
H→2 b
~2%
Z→2 jet,
H→2 tau
~5%
ZH→4 jets
~50%
Z→2 muon
H→WW*→eevv
~1%

Reconstructed Higgs Signatures



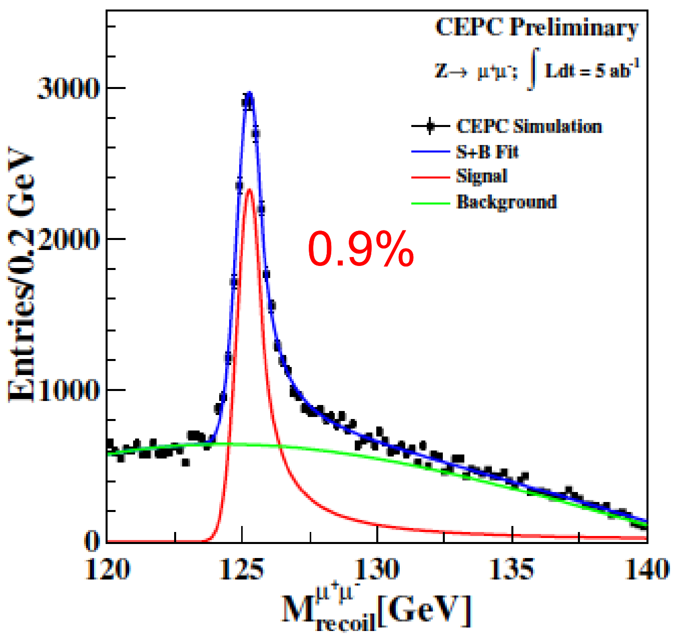
Clear Higgs Signature in all SM decay modes

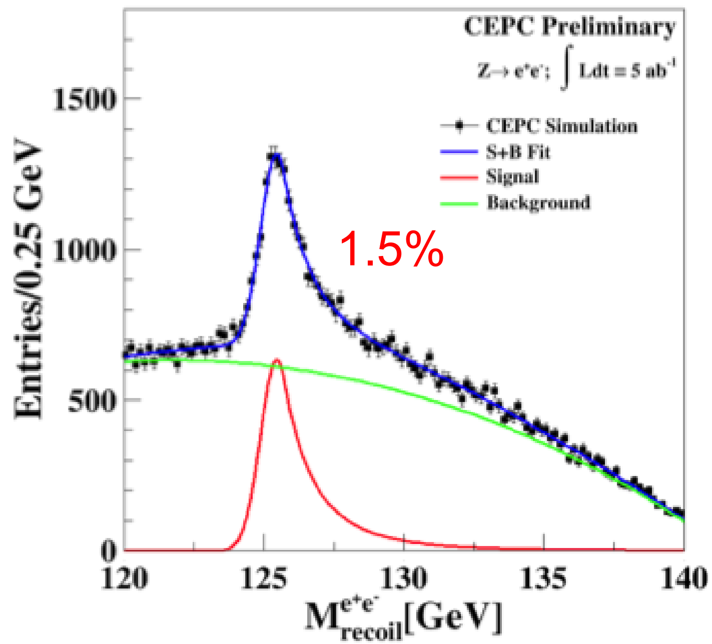
Massive production of the SM background (2 fermion and 4 fermions) at the full Simulation level

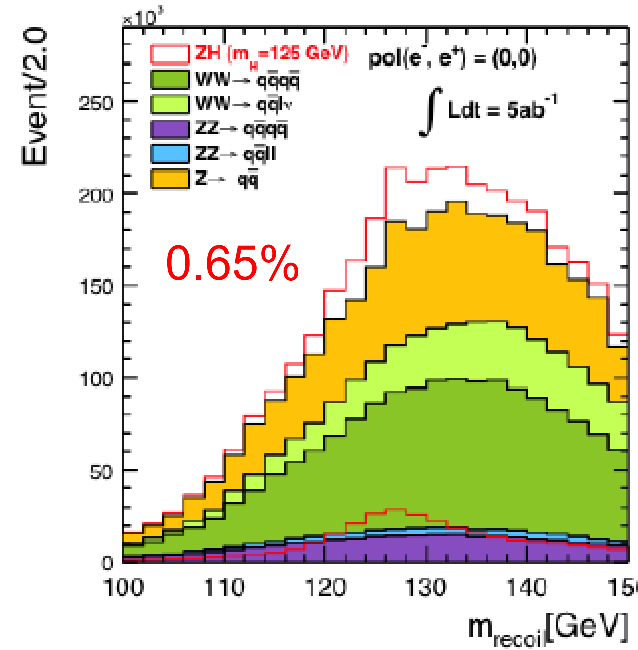
Right corner: di-tau mass distribution at qqH events using collinear approximation

Model-independent measurement of σ(ZH)

Zhenxing Chen & Yacine Haddad

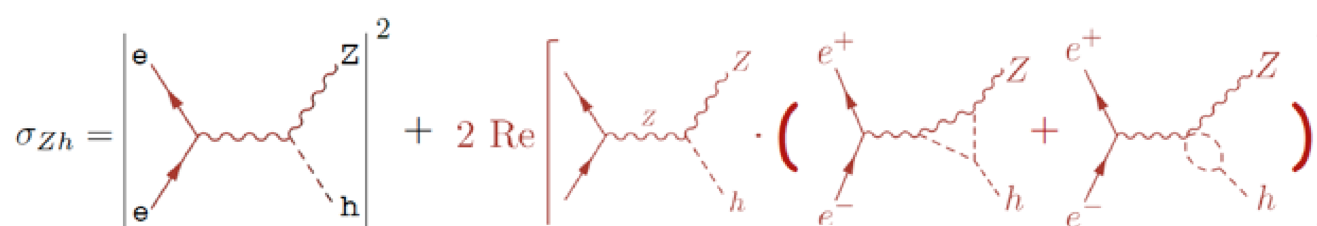






- Recoil mass method. Combined precision:
  δσ(ZH)/σ(ZH) = 0.5% -
  δg(HZZ)/g(HZZ) = 0.25%

- Indirect Access to g(HHH)



$$\delta_\sigma^{240} = 100\,(2\delta_Z + 0.014\delta_h)\,\%$$

- *M. McCullough, 1312.3322*

Higgs benchmark analyses

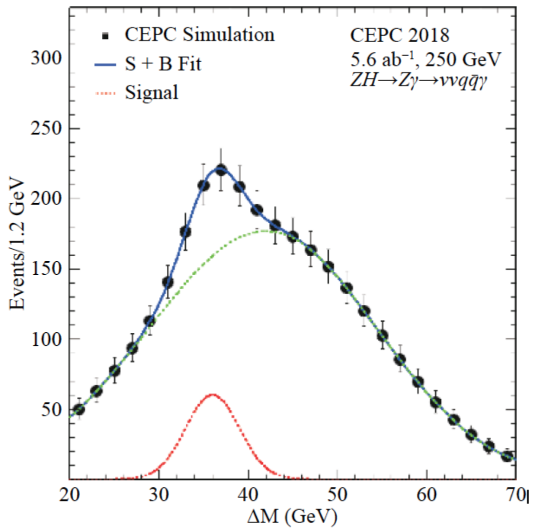
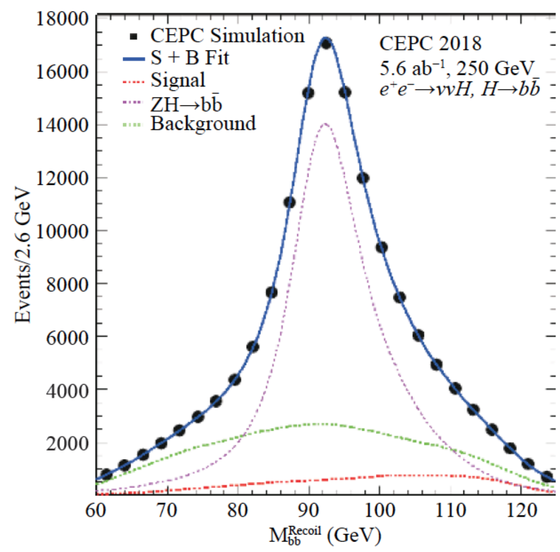
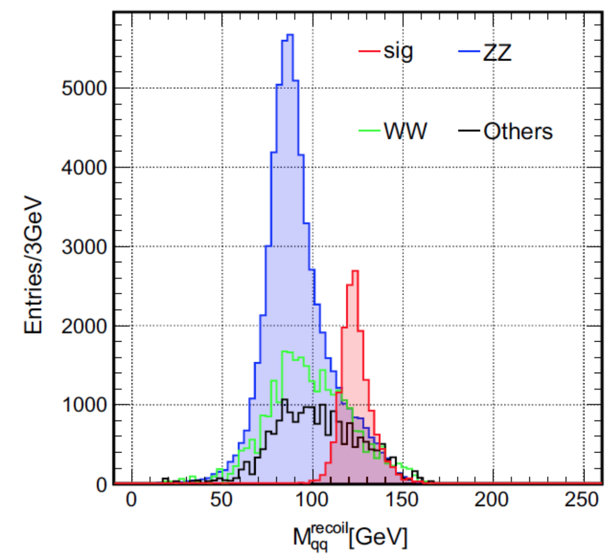
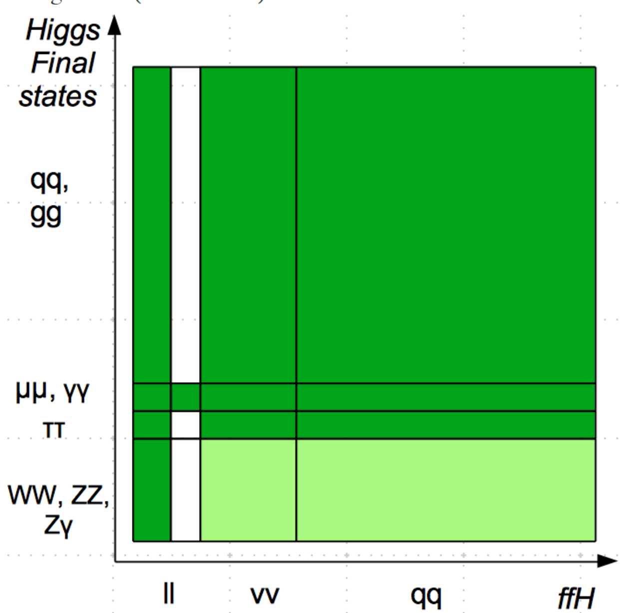
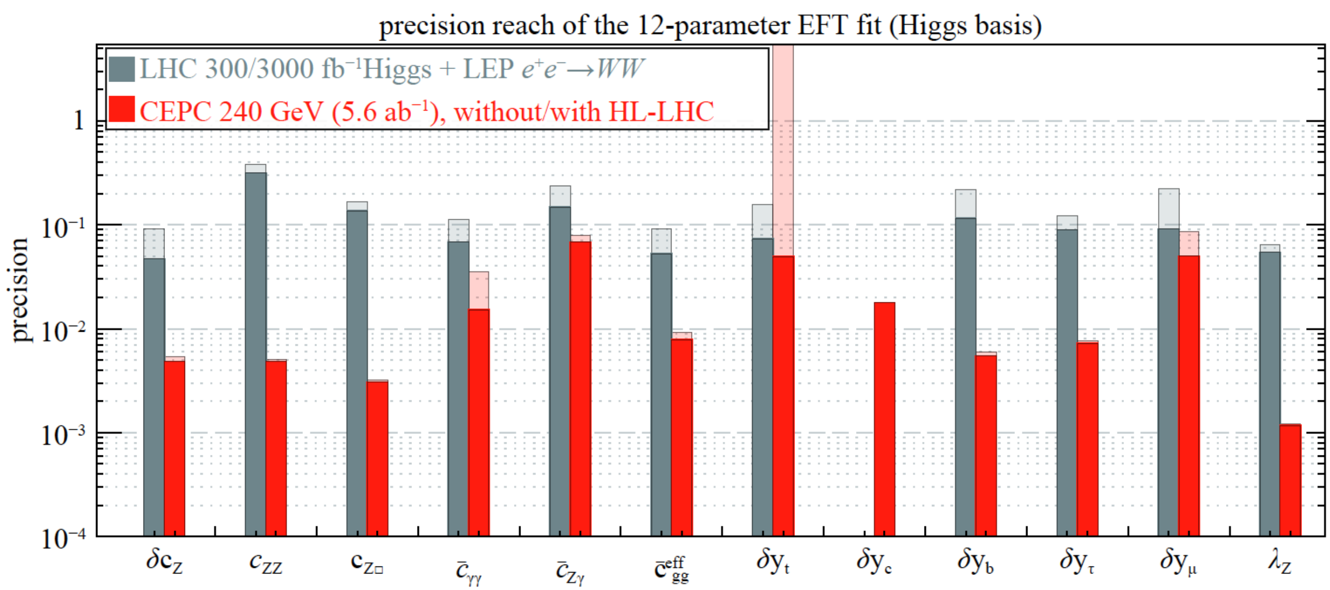


Fig. 15. (color online) The distribution of the mass differ-

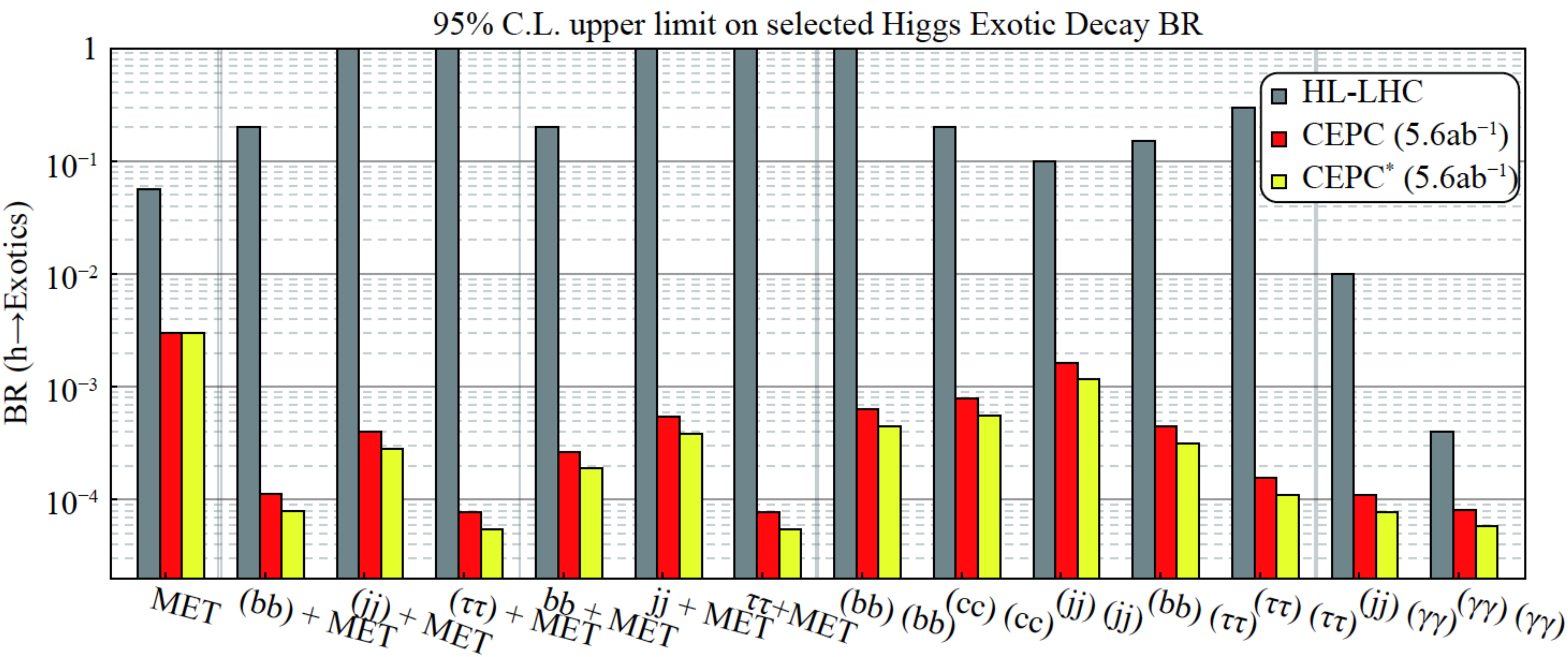








Higgs BSM Decay modes



Chinese Physics C Vol. 43, No. 4 (2019) 043002

Measuring Higgs width

- **Method 1: Higgs width can be determined directly from the measurement of σ(ZH) and Br. of (H->ZZ*)**

$$\Gamma_H \propto \frac{\Gamma(H \to ZZ^*)}{\mathrm{BR}(H \to ZZ^*)} \propto \frac{\sigma(ZH)}{\mathrm{BR}(H \to ZZ^*)}$$

Precision : 5.1%

  - **But the uncertainty of Br(H->ZZ*) is relatively high due to low statistics.**

- **Method 2: It can also be measured through:**

$$\Gamma_H \propto \frac{\Gamma(H \to bb)}{BR(H \to bb)} \qquad \sigma(\nu\bar{\nu}H \to \nu\bar{\nu}b\bar{b}) \propto \Gamma(H \to WW^*) \cdot \mathrm{BR}(H \to bb) = \Gamma(H \to bb) \cdot \mathrm{BR}(H \to WW^*)$$

3.0%

$$\Gamma_H \propto \frac{\Gamma(H \to bb)}{\mathrm{BR}(H \to bb)} \propto \frac{\sigma(\nu\bar{\nu}H \to \nu\bar{\nu}b\bar{b})}{\mathrm{BR}(H \to b\bar{b}) \cdot \mathrm{BR}(H \to WW^*)}$$

Precision : 3.5%

- **These two orthogonal methods can be combined to reach the best precision.**

Precision : 2.8%

Higgs white paper delivered

Chinese Physics C Vol. 43, No. 4 (2019) 043002

Precision Higgs physics at the CEPC*

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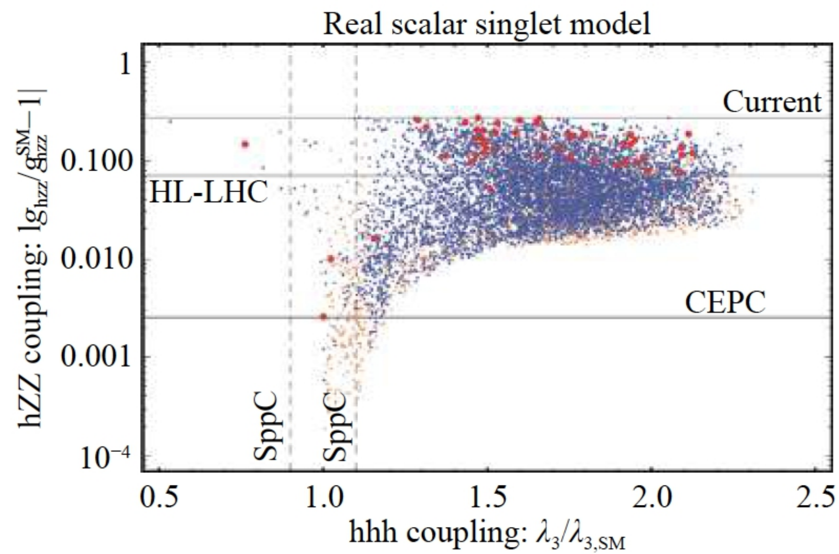
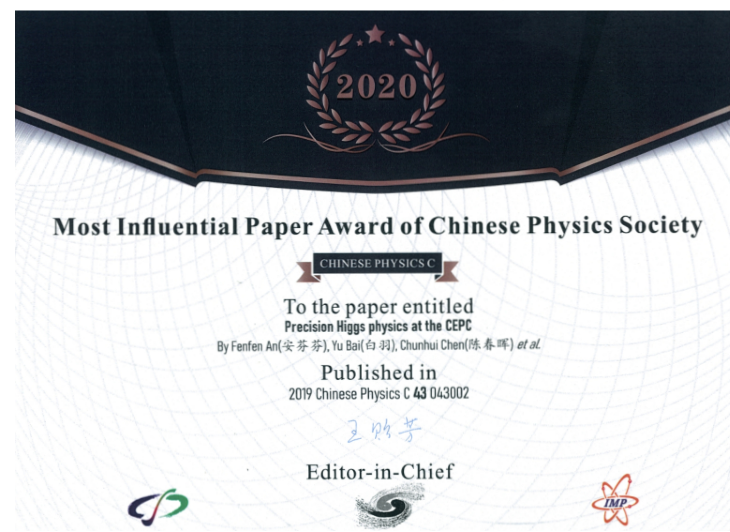
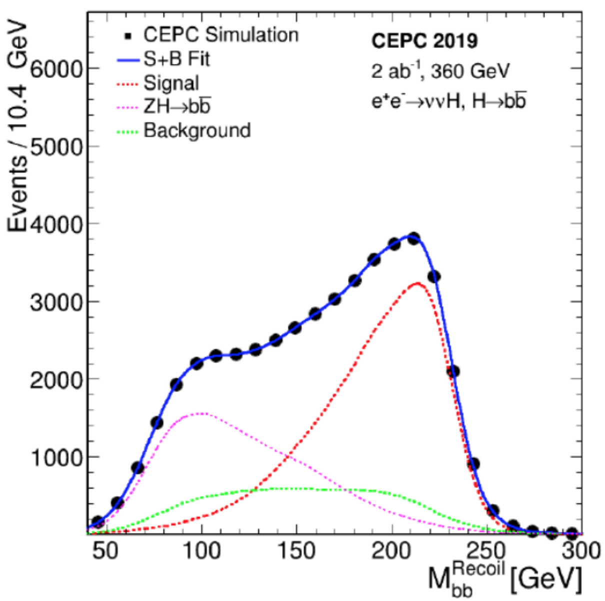
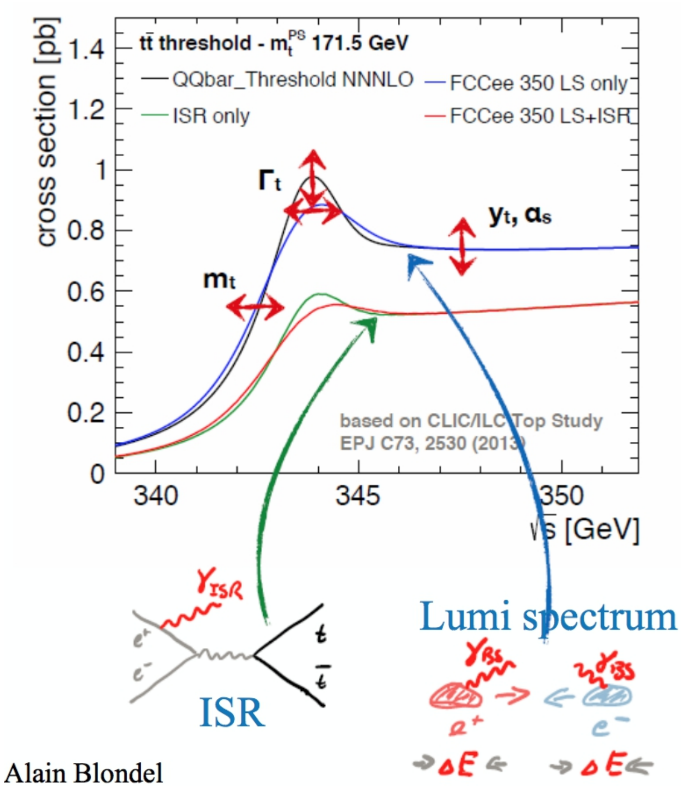




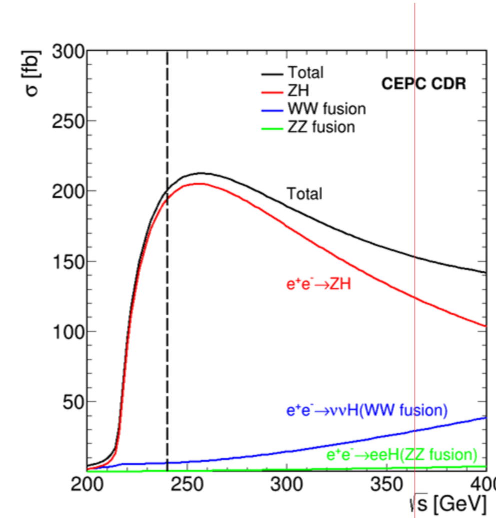
CEPC upgrading option: 360 GeV Run

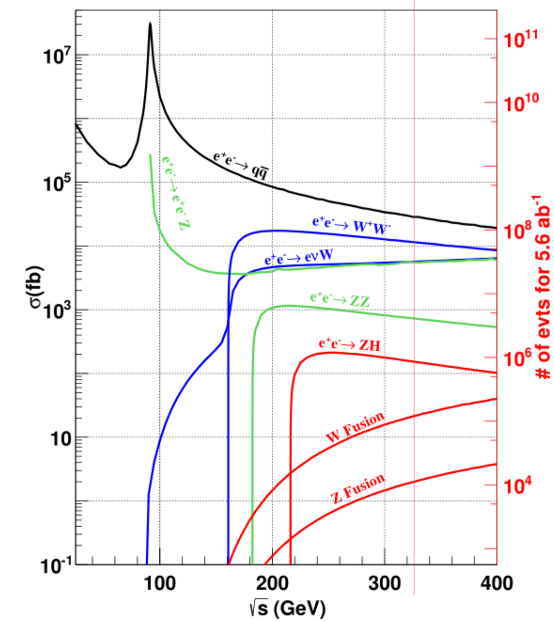
- 2 ab^{-1} @ 360 GeV
- For Higgs
  - 30% more Higgs events
  - Higgs width accuracy improves by 2 times (2.8%→1.4%)
  - ...
- For Top, For NP...



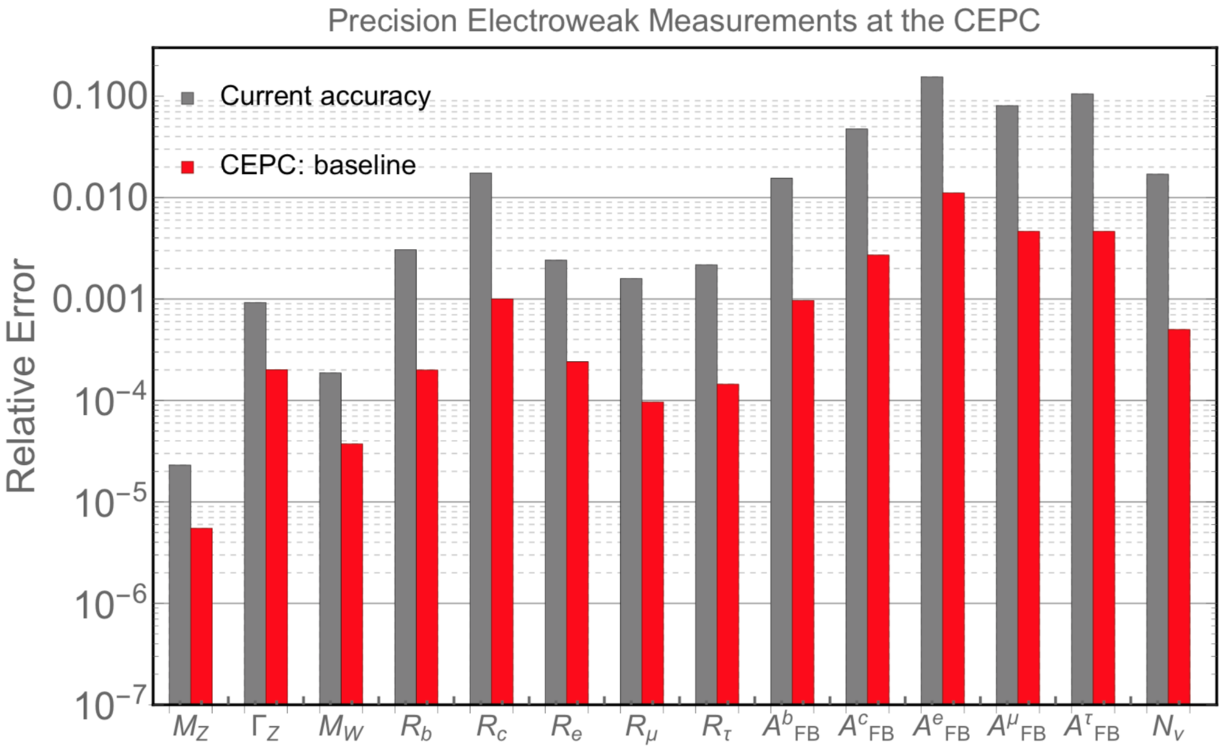


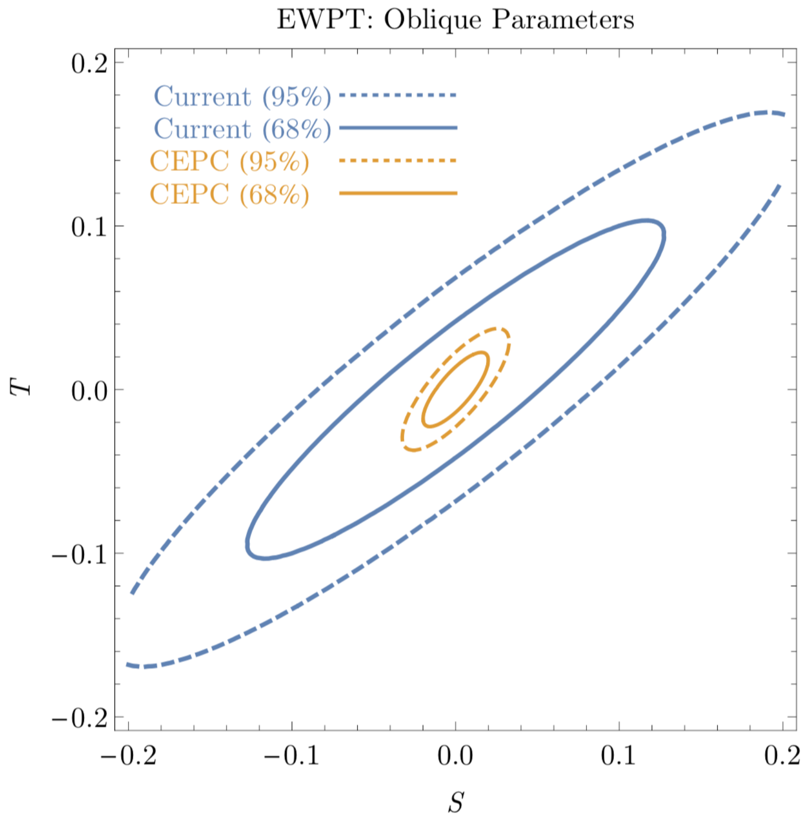
Alain Blondel





EW





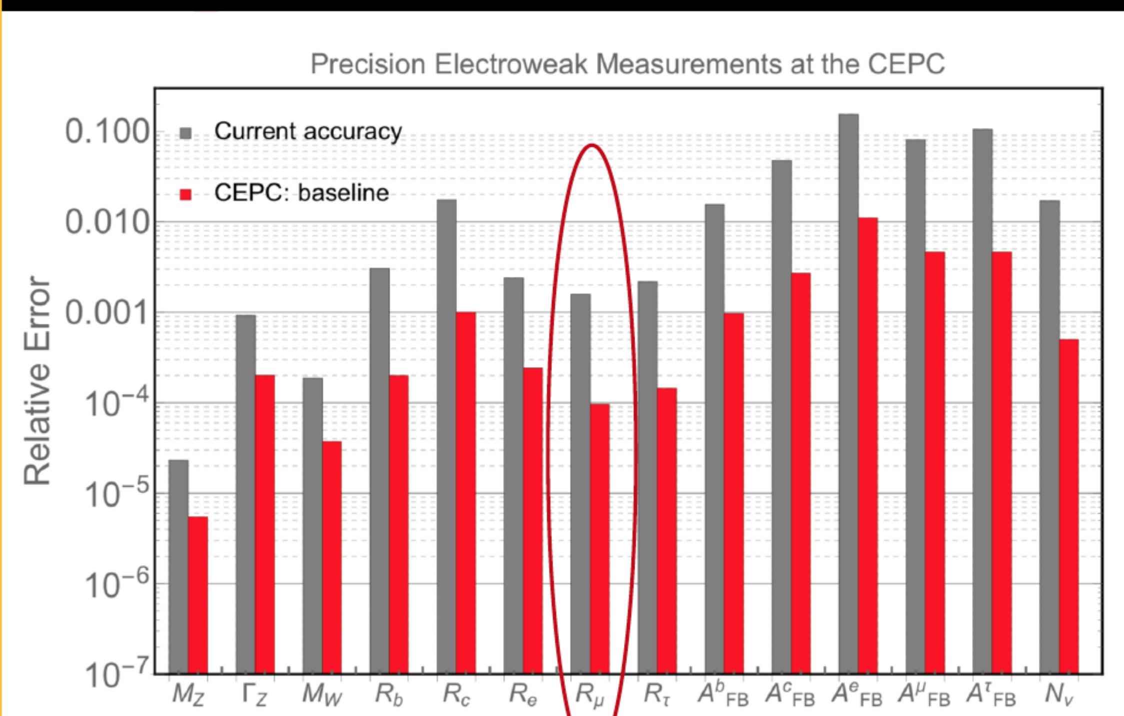
With 2 years of Z pole operation (~ 1 Tera Z) and 1 year of W mass scan (~1E7 W)

Accuracies mainly limited by Systematic uncertainties (i.e. Beam energy Calibration, etc)

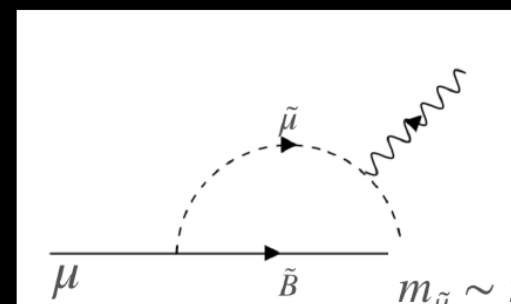
EW

Probing new physics behind muon g-2 at CEPC

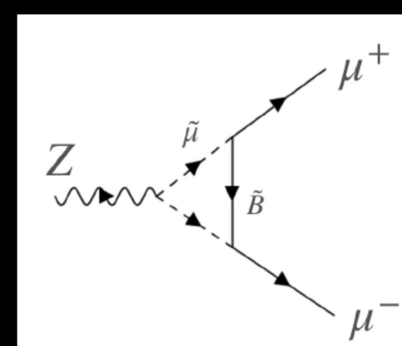
- From Liantao, if new physics behind muon g-2 @ one loop
- Expect to see disagreement with SM at Z->μ μ branching ratio at 10^{-4} to 10^{-5}
- Within the reach of CEPC Z pole physics



From Liantao



$$m_{\tilde{\mu}} \sim m_{\tilde{B}} \sim 100 - 500 \text{ GeV}$$



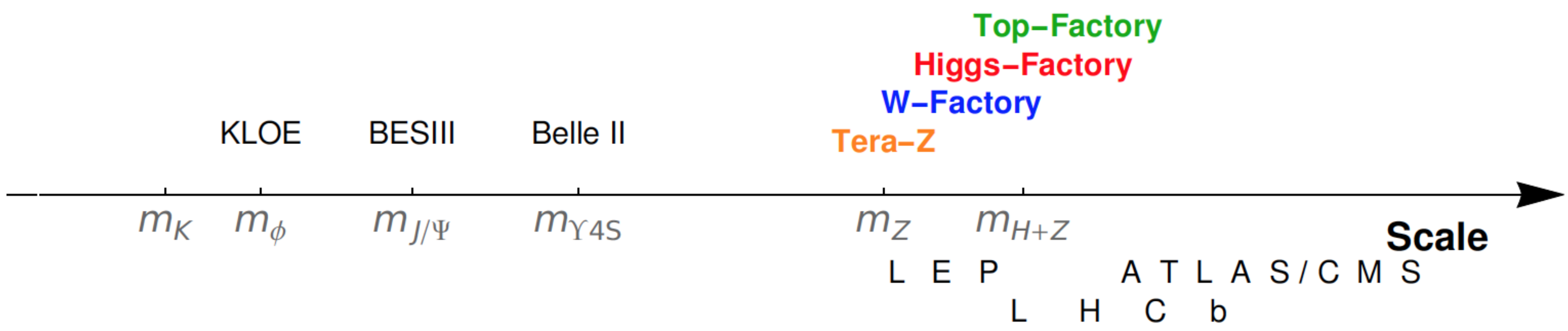
$$\frac{\delta\Gamma_\mu}{\Gamma_\mu} \sim 10^{-4} - 10^{-5}$$

Flavor Physics at CEPC

Z Factory $\supseteq$ Flavor Factory

Particle-ID $\supseteq$ Flavor-ID!

Channel	Belle II	LHCb	Giga-Z	CEPC (Tera-Z)
$B^0,\ \bar{B}^0$	5.3×10^{10}	$\sim 6\times10^{13}$	1.2×10^{8}	1.2×10^{11}
$B^{\pm}$	5.6×10^{10}	$\sim 6\times10^{13}$	1.2×10^{8}	1.2×10^{11}
$B_s,\ \bar{B}_s$	5.7×10^{8}	$\sim 2\times10^{13}$	3.2×10^{7}	3.2×10^{10}
$B_c^{\pm}$	-	$\sim 4\times10^{11}$	2.2×10^{5}	2.2×10^{8}
$\Lambda_b,\ \bar{\Lambda}_b$	-	$\sim 2\times10^{13}$	1.0×10^{7}	1.0×10^{10}
$c,\ \bar{c}$	2.6×10^{11}	$\gtrsim 10^{14}$	2.4×10^{8}	2.4×10^{11}
$\tau^+,\ \tau^-$	9×10^{10}	-	7.4×10^{7}	7.4×10^{10}



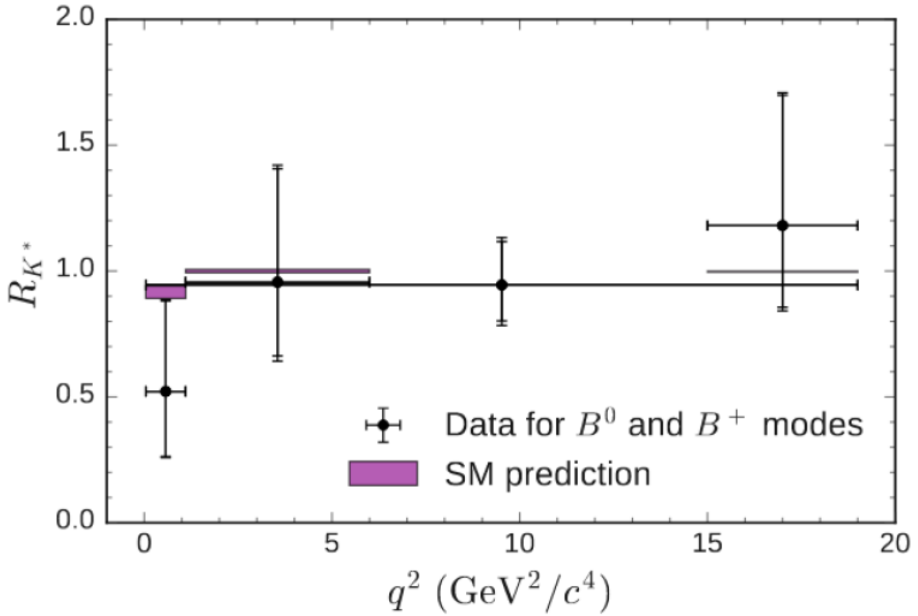
VS. B Factories

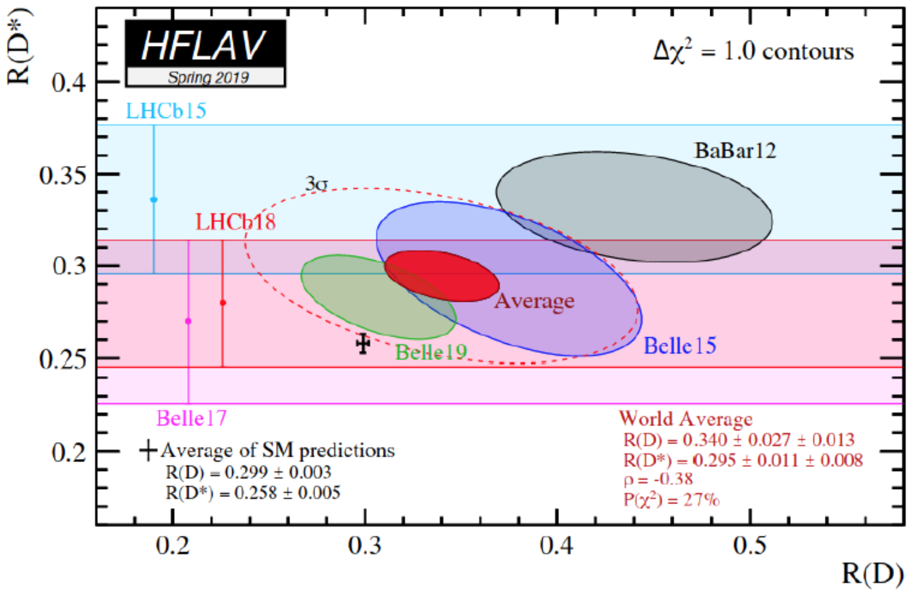
- Much higher b quark boost
- Abundant heavy b hadron

VS. Hadron Colliders

- Clean environment
- Direct missing momenta measurement

B Anomalies Indicating LFUV

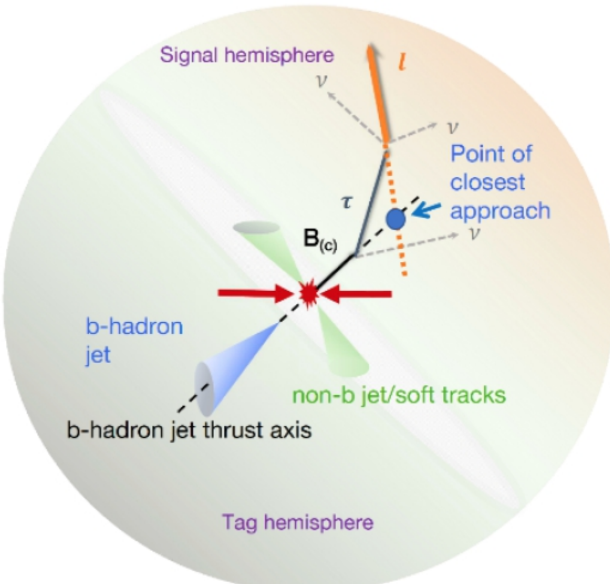




	Experimental	SM Prediction	Comments
R_K	$0.745^{+0.090}_{-0.074} \pm 0.036$	1.00 ± 0.01	$m_{\ell\ell} \in [1.0, 6.0]$ GeV^2, via $B^\pm$.
R_{K^*}	$0.69^{+0.12}_{-0.09}$	0.996 ± 0.002	$m_{\ell\ell} \in [1.1, 6.0]$ GeV^2, via B^0.
R_D	0.340 ± 0.030	0.299 ± 0.003	B^0 and $B^\pm$ combined.
R_{D^*}	0.295 ± 0.014	0.258 ± 0.005	B^0 and $B^\pm$ combined.
$R_{J/\psi}$	$0.71 \pm 0.17 \pm 0.18$	0.25-0.28	

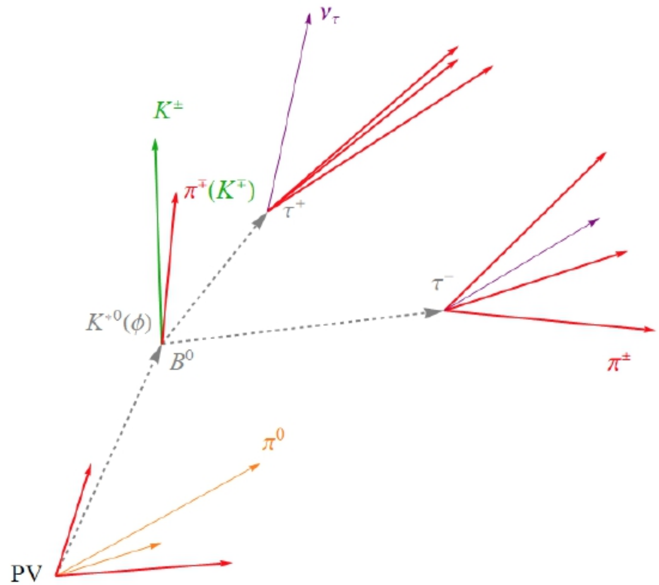
[Tanabashi et al., 2018][Altmannshofer et al., 2018].

Current Progress in LFU Tests



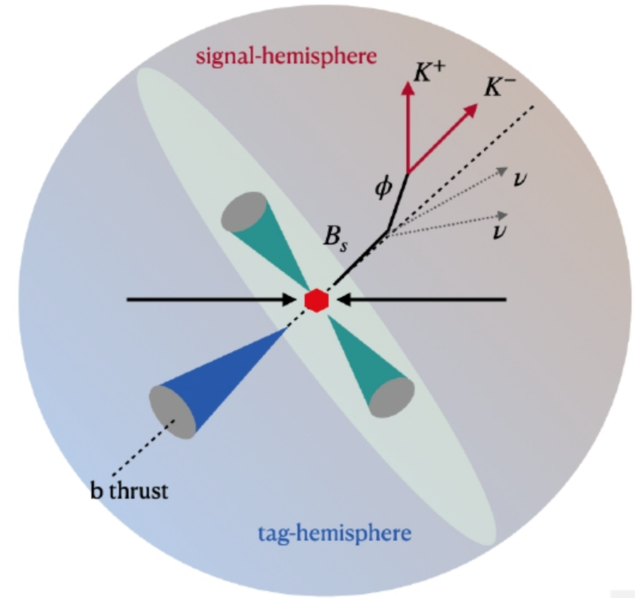
Charged current $B_c \to \tau\nu$ decays [Zheng et al., 2020b].

Absolute precision $\sim 10^{-4}$.



Neutral current $b \to s\tau\tau$ decays [Li and Liu, 2020].

Absolute precision $\lesssim 10^{-6}$: $\sim 10^3 - 10^4$ improvement from current limits.

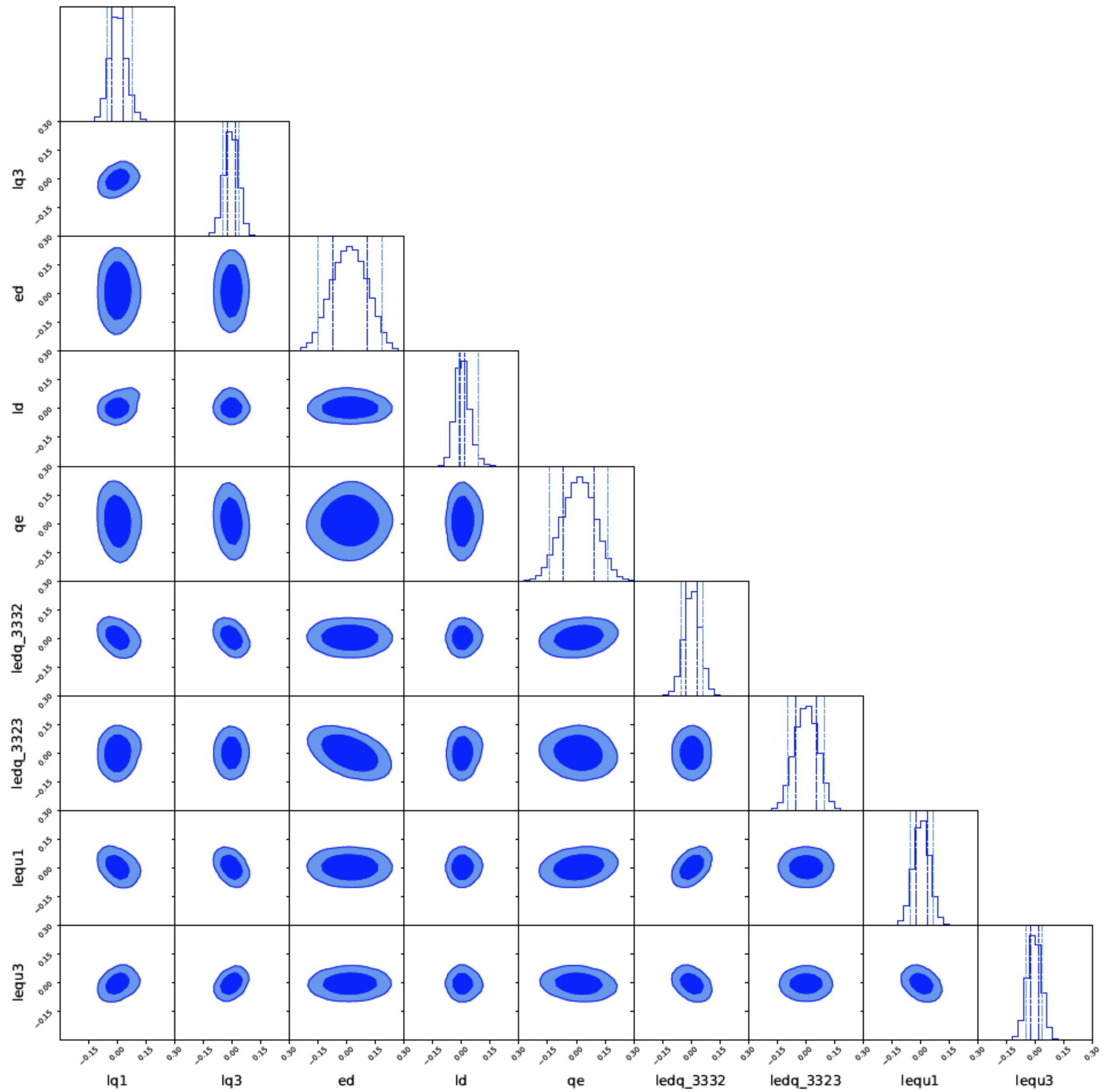


Neutral current $B_s \to \phi\nu\bar{\nu}$ decay [In preparation]

Absolute precision $\sim 10^{-7}$.

Unique opportunities at the Z-pole

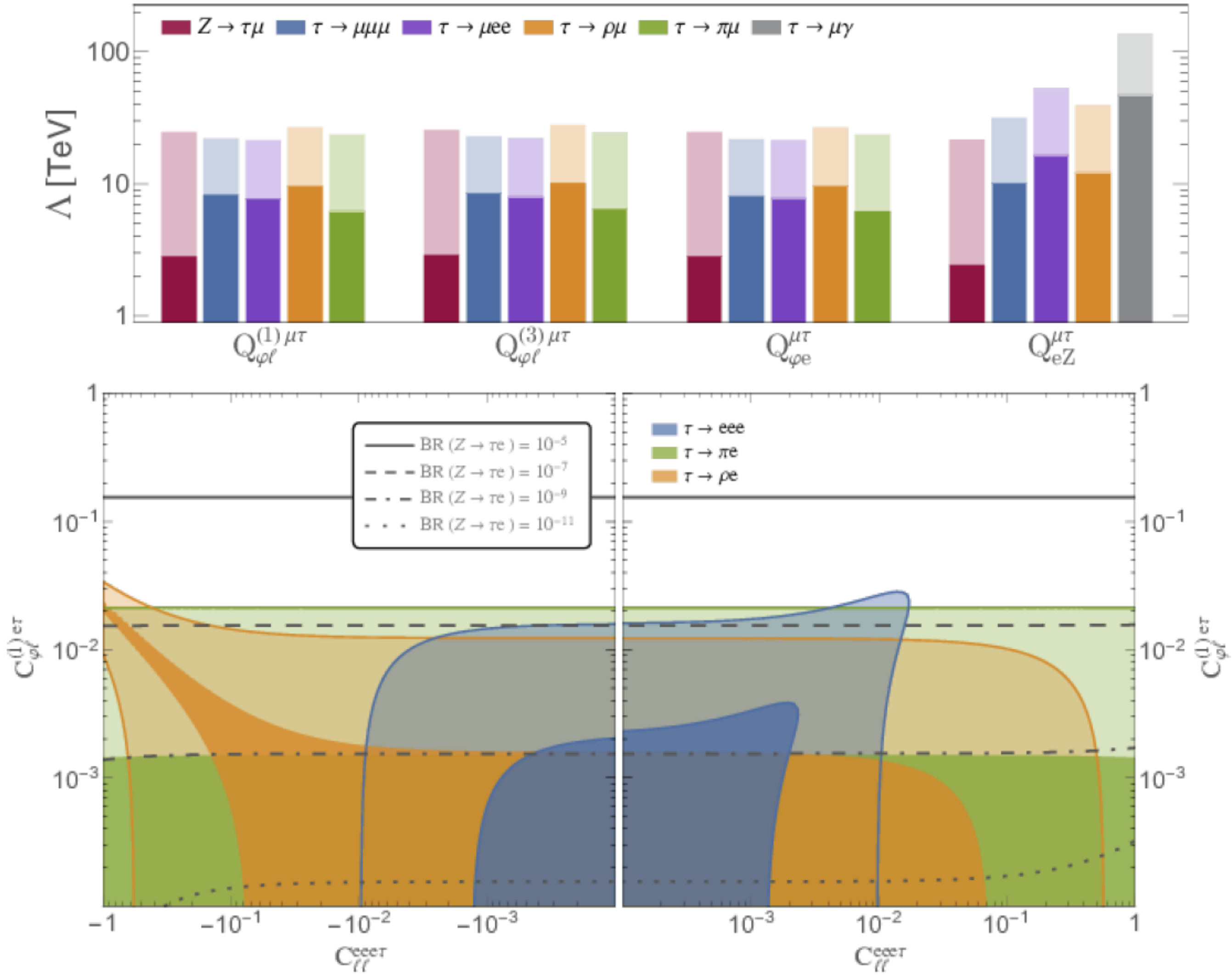
Current Progress in LFU Tests (II)



Preliminary: 9 effective channels:($R_{J/\psi}$, R_{D_s}, $R_{D_s^*}$, R_{Λ_c}, $B_c \to \tau\nu$, $B \to K\nu\bar{\nu}$, $B_s \to \phi\nu\bar{\nu}$, $B^0 \to K\tau\tau$, $B^+ \to K^+\tau\tau$, $B_s \to \tau\tau$...)

Dim-6 SMEFT basis at NP scale Λ=3 TeV.

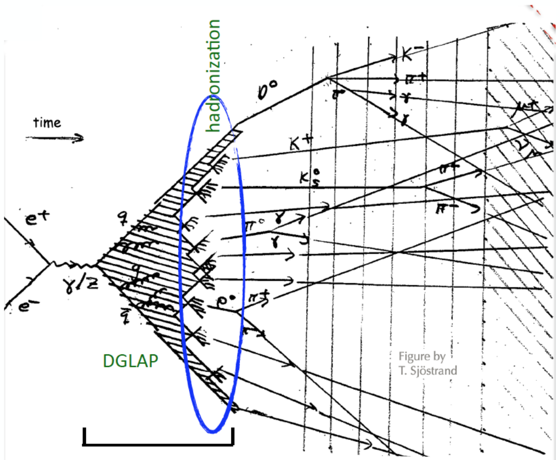
Lepton Flavor Violation (II)



[Calibbi et al., 2021]

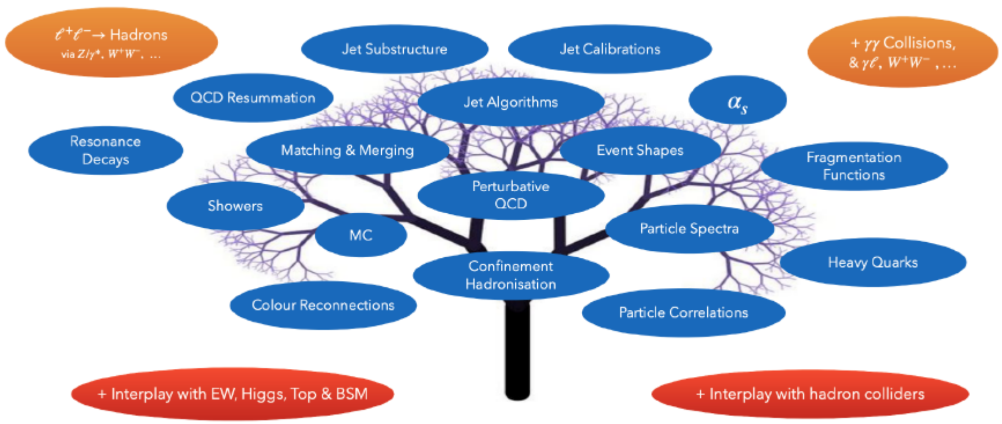
QCD

- How to achieve the ultimate precision for alphaS at the CEPC ?
- Can we see gluon spin interference at the CEPC ??
- How to observe entanglement from non-global observables at the CEPC ???
- Can we quantitatively understand hadronization ????



art work

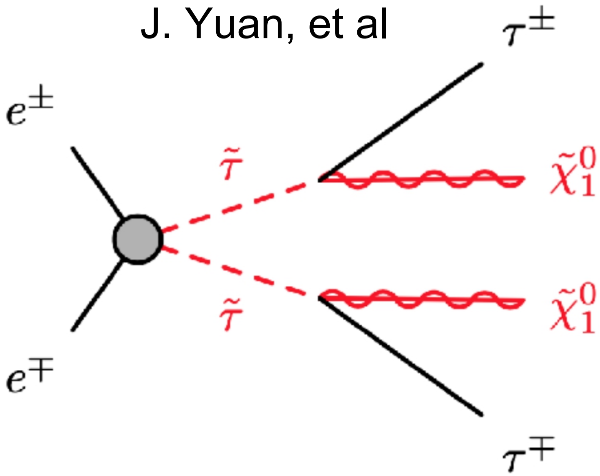
- QCD at e+e- colliders remain exciting
- New potential for ultimate precision
- Novel QCD phenomena awaiting discovery
- Deep theory puzzle calls for new data

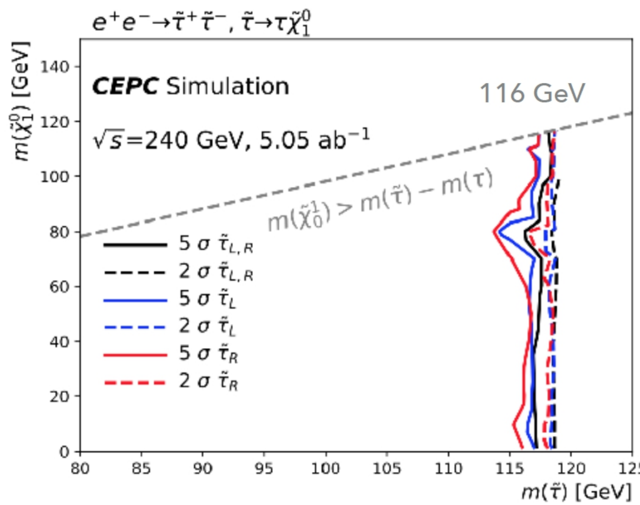


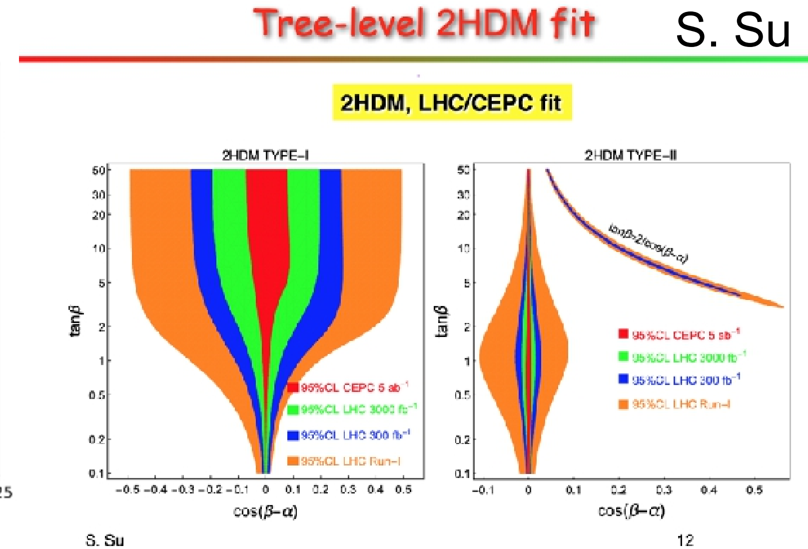
credit: Peter Skands

BSM

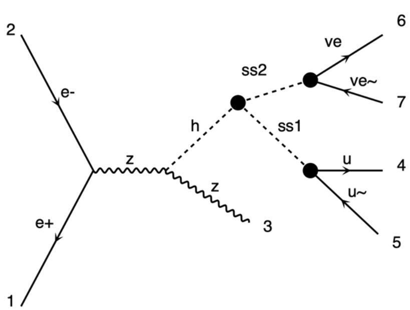
J. Yuan, et al

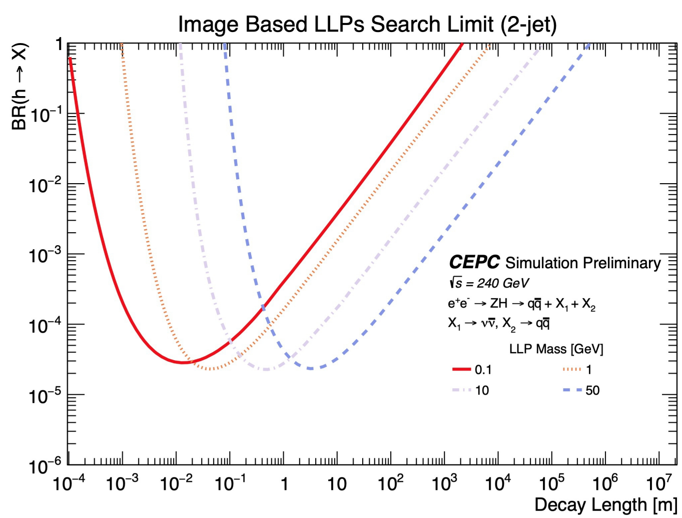


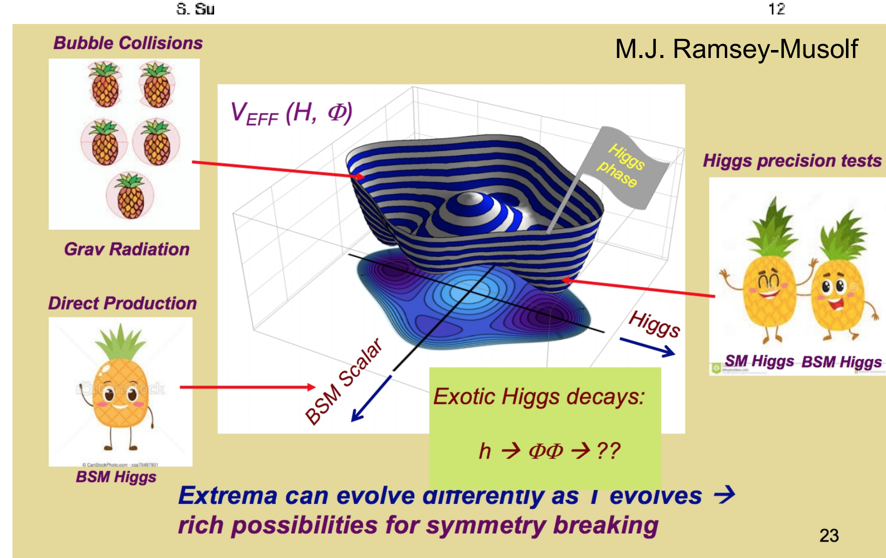




Y. Zhang, et al







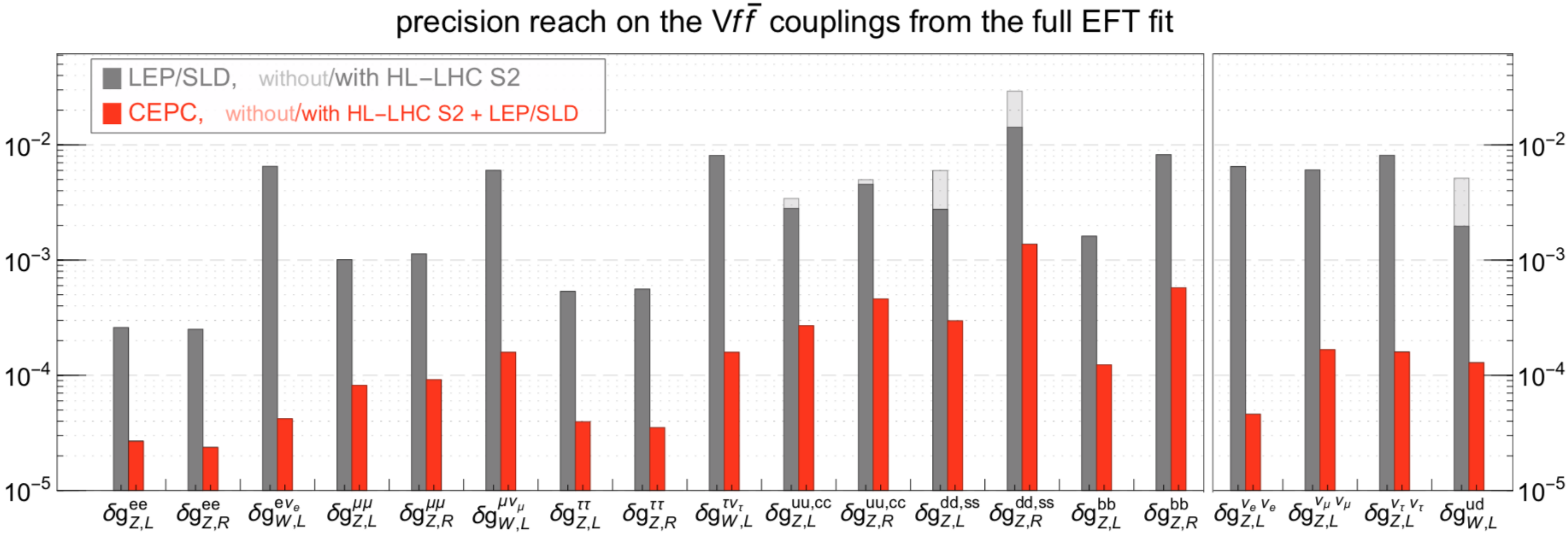
https://indico.ihep.ac.cn/event/13888/session/15

Physics @ CEPC

- CEPC is not only a high precision Higgs factory, but also a Discovery machine!
  - Boost the Higgs/EW precision by ~ 10 times w.r.t HL-LHC/current boundary
  - Huge potential on QCD, Flavor, BSM
- Promoting dedicated physics studies,
  - To quantify CEPC physics potential with benchmark analyses, and Global interpretation
  - To guide the design/optimization of the facility & Maximize the physics output: to quantify the requirements on Luminosity, beam quality, & detector performance
  - Your idea & inputs are more than welcome!
- Giving the importance of electron positron Higgs/Z factory, we hope at least one of them (ILC, CLIC, CEPC, FCC) can be realized.

Back up

EW interpretation



Electron Positron Higgs factories

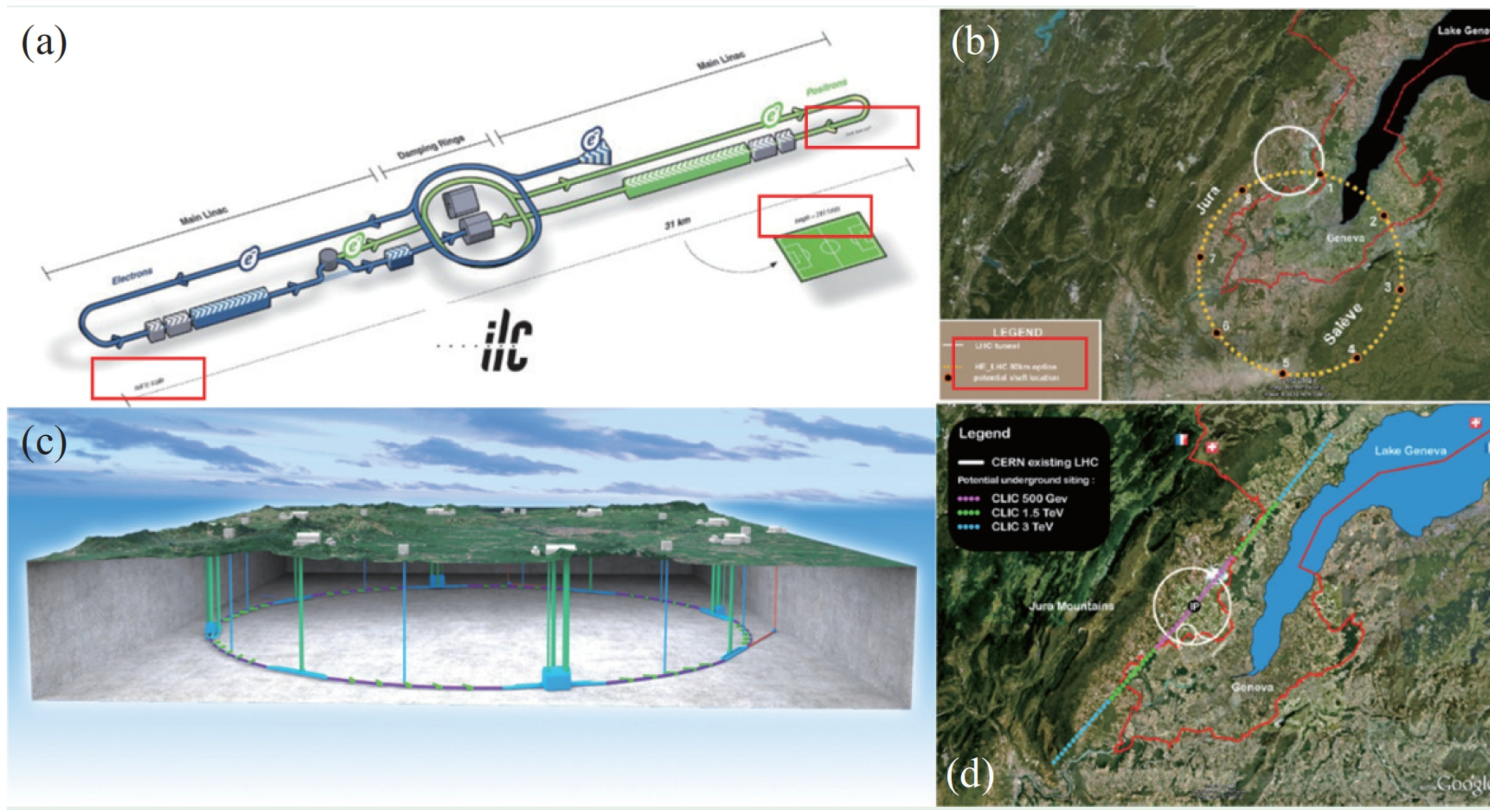
High-priority future initiatives

2020

An electron-positron Higgs factory is the highest-priority next collider. For the longer term, the European particle physics community has the ambition to operate a proton-proton collider at the highest achievable energy. Accomplishing these compelling goals will require innovation and cutting-edge technology:

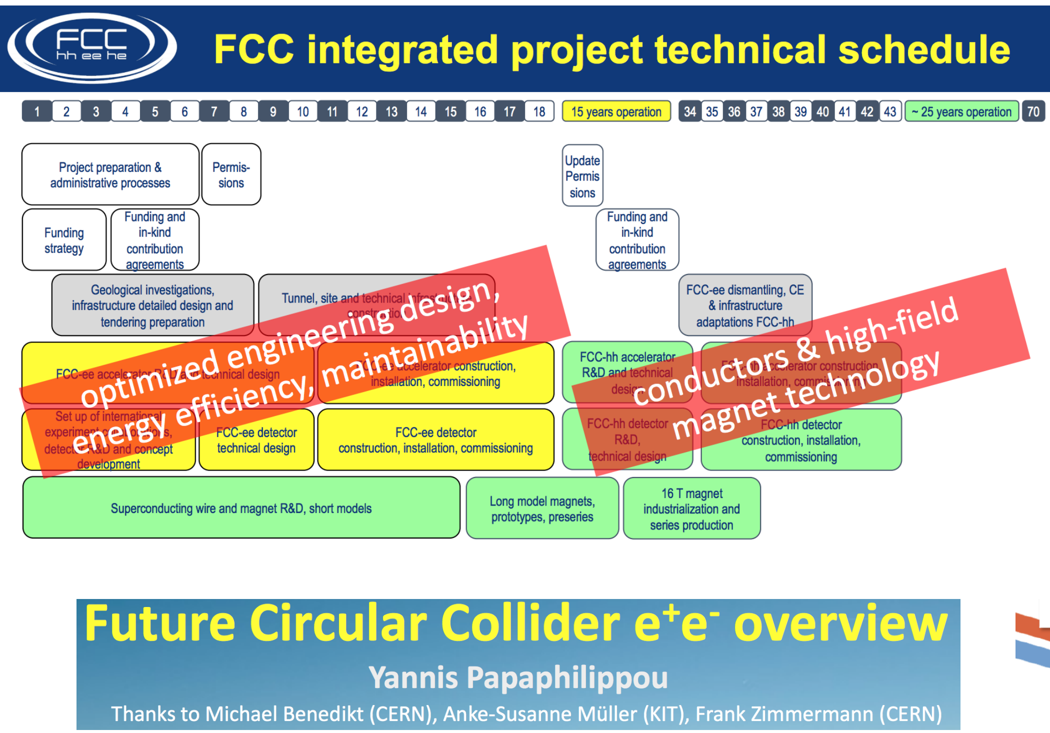
ILC (a): TDR @ 2013
FCC (b): CDR @ 2019
CEPC (c): CDR @ 2018
CLIC (d): CDR @ 2013

Direct Competition!

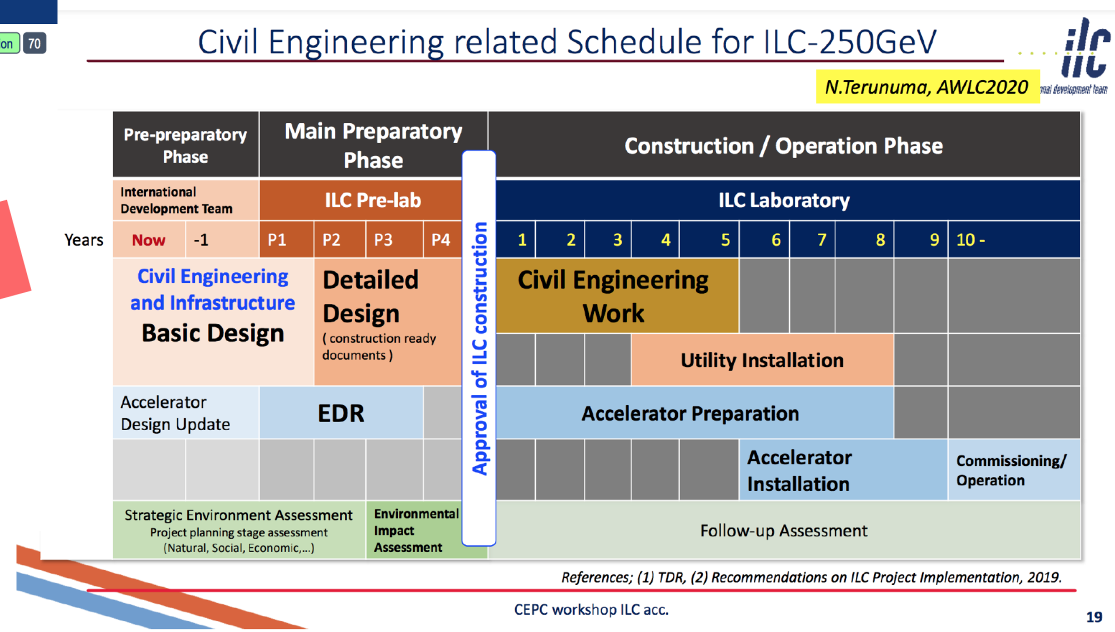


Aug 2016，中国高能物理分会： CEPC 是我国未来加速器首选项目

Electron Positron Higgs factories



ILC timeline



https://indico.ihep.ac.cn/event/11444/session/6/contribution/10/material/slides/0.pdf

ILC: Prelab proposal released

CERN: significantly invest into the FCC studies...

New beam parameters: in progress

- Luminosity @ Higgs: increases by 60% ($3 \rightarrow 5 * 10^{34}\ cm^{-2}s^{-1}$/IP) by squeezing the beam size at IP
- Luminosity @ Z: increased by ~4 times ($32 \rightarrow 115 * 10^{34}\ cm^{-2}s^{-1}$/IP) by increasing bunch charge
- Upgrading option: Luminosity @ top ~ $0.5 * 10^{34}\ cm^{-2}s^{-1}$/IP

Stage 1 (H/W run)

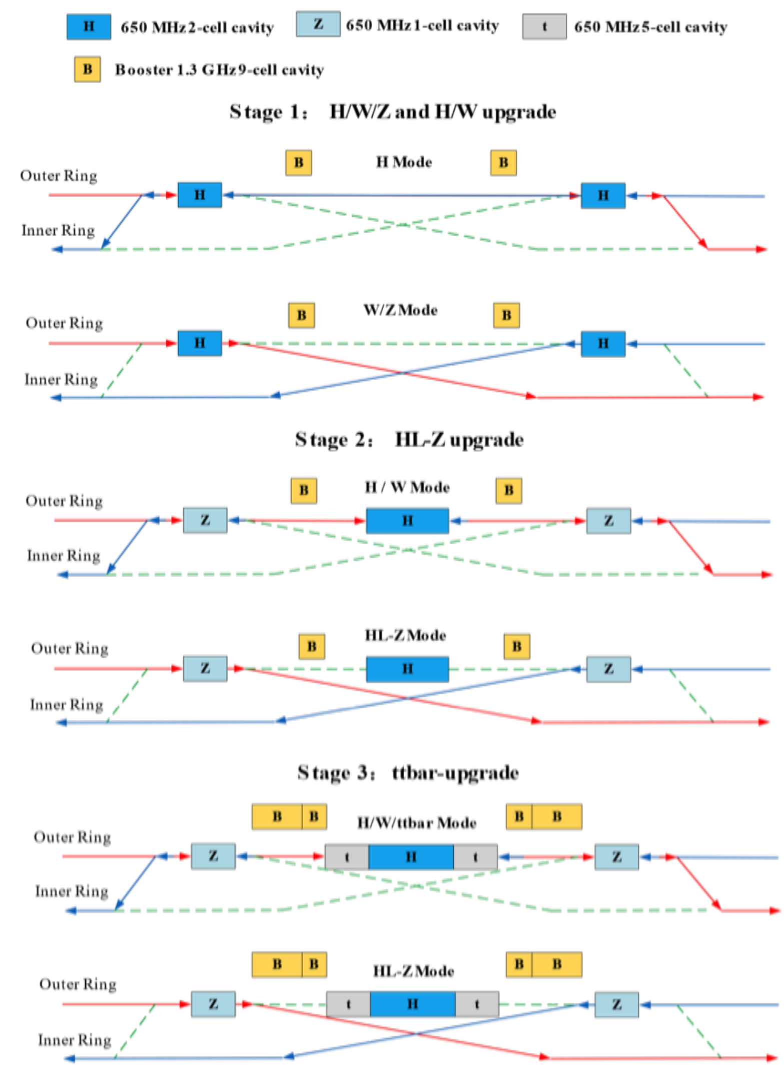
- Layout and parameters are same with CDR except longer central part
- Medium or low luminosity at Z

Stage 2 (HL-Z upgrade)

- Move Higgs cavities to center and add high current Z cavities.
- By-pass low current H cavities.

Stage 3(ttbar upgrade)

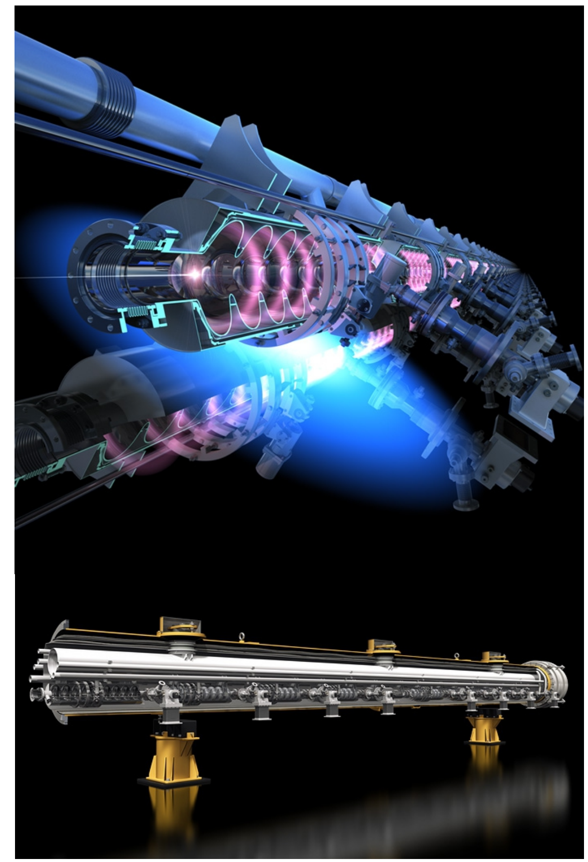
- Add ttbar cavities (low current, high gradient, high Q)
- Nb3Sn@4.2 K or others to significant reducing the cost of cryo-system and AC power.



Energy Flow in the Collider

Electricity

High energy beam, SR light, ...



Heat

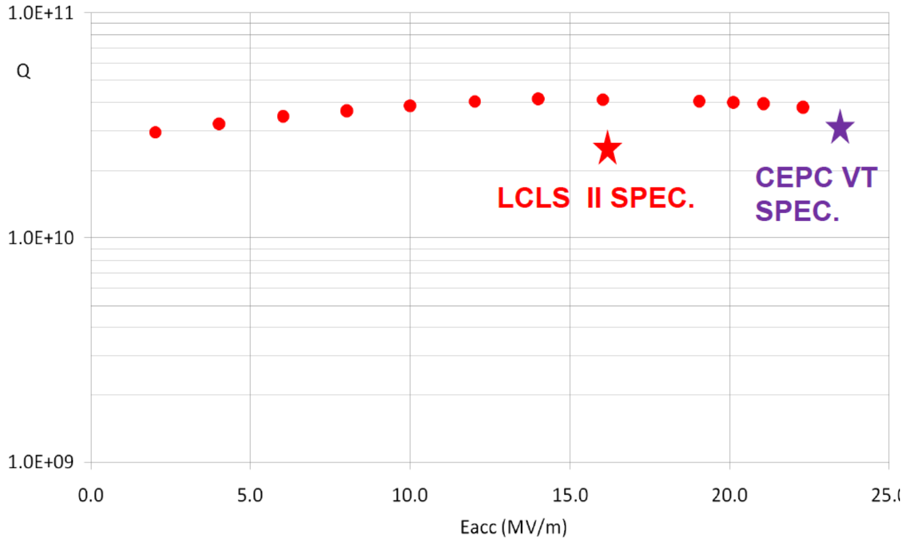
Heat

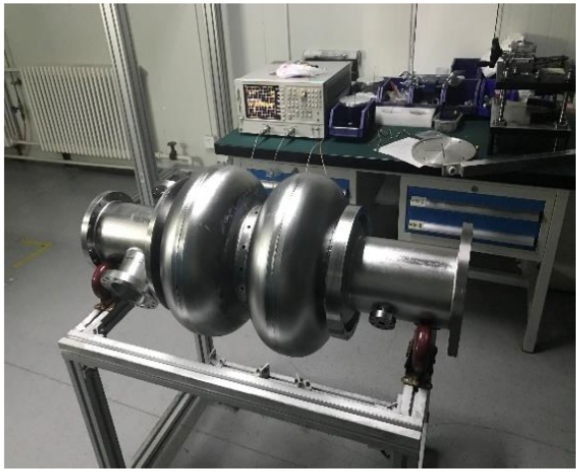
RF Wave

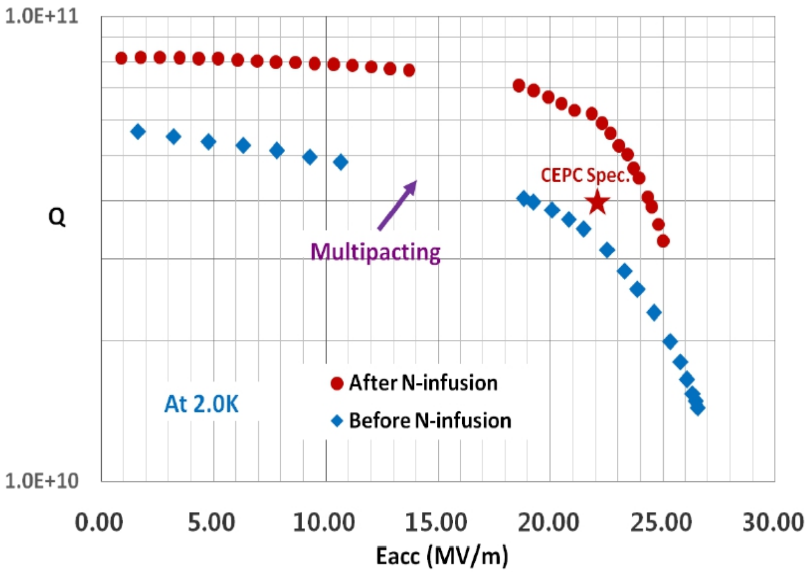
Klystron (Photon from SNS, ORNL, US)

RF Cavities (Photon From ILC design)

SRF Cavity: design goal reached







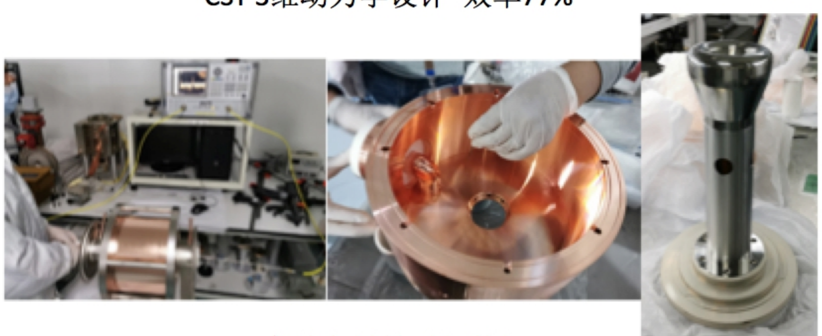
RF Cavity for both Booster & Collider ring reaches Design goal

High efficiency Klystron

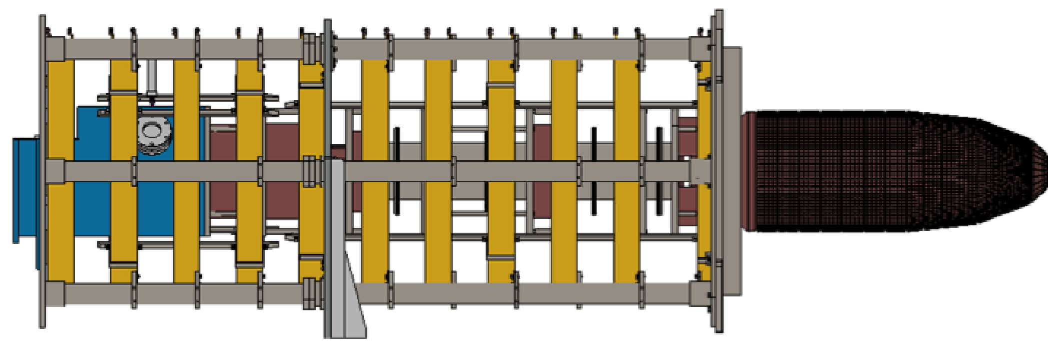
Tests show Zusheng, etc

- **the output power reaches pulsed power of 800kW (400kW CW due to test load limitation)**
- **efficiency 62% and band width ±0.5Mhz.**

CST 3维动力学设计 效率77%



高效率样管零部件加工

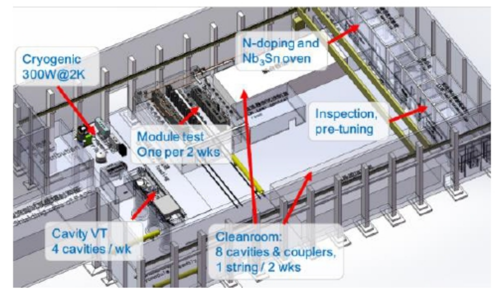


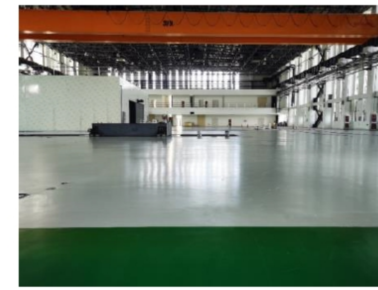
多注速调管三维机械图

- High efficiency prototype (eff~77%) in construction: to be tested within this year!
- Multi-beam concept (eff ~ 80.5%): mechanic design finished. Hopefully to be delivered by the end of 2022.

IHEP SC Lab @ Huairou: in operation

Facility: CEPC SCRF test facility (lab) is located in IHEP Huairong Area of 4500m^2





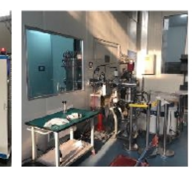
New SC Lab Design (4500m^2)

New SC Lab will be fully functional in 2021

Crygenic system hall in Jan. 16, 2020


Vacuum furnace (doping & annealing)

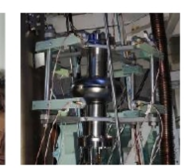

Nb3Sn furnace


Nb/Cu sputtering device


Cavity inspection camera and grinder


9-cell cavity pre-tuning machine


Temperature & X-ray mapping system


Second sound cavity quench detection system

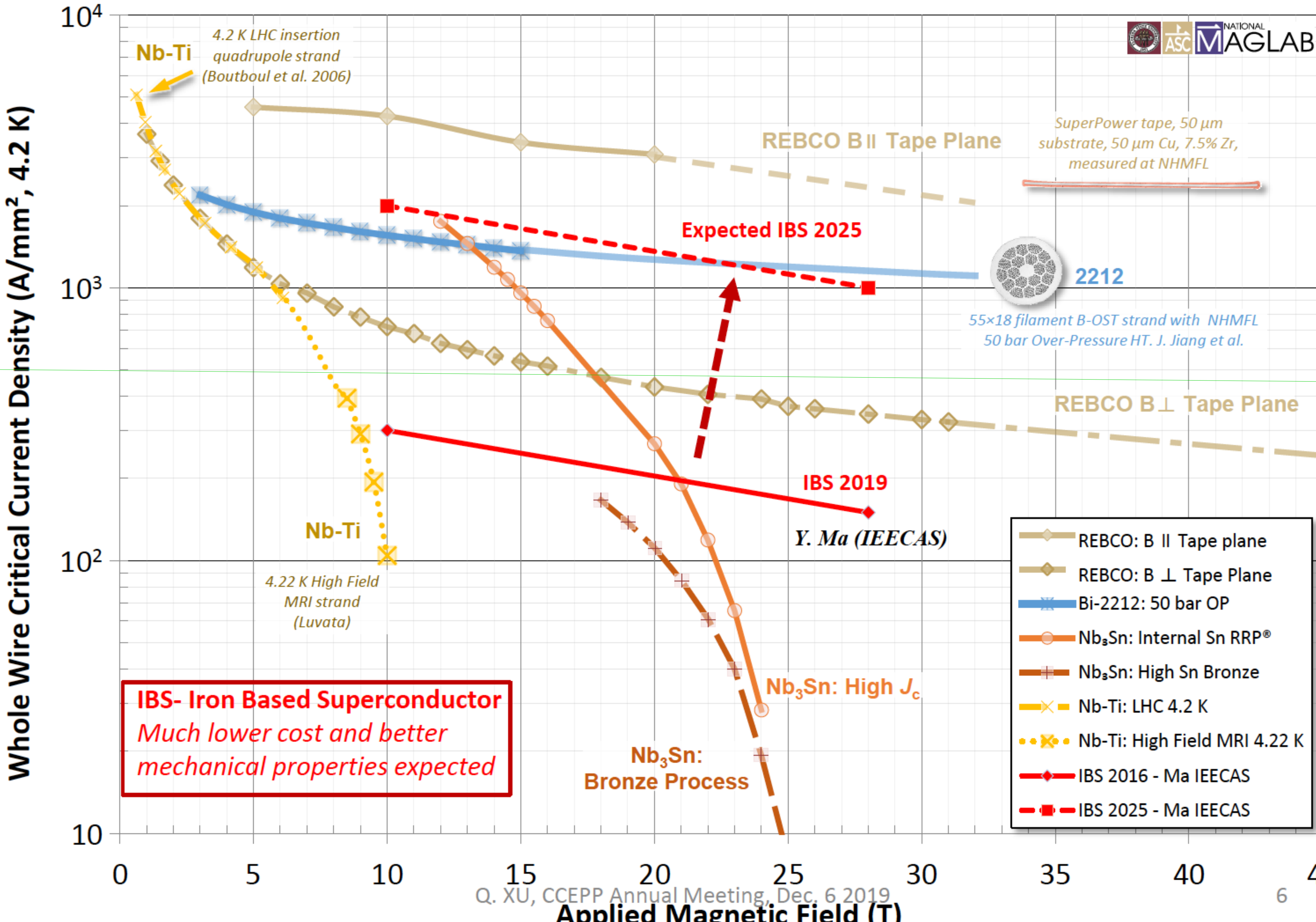

Helmholtz coil for cavity vertical test


Vertical test dewars


Horizontal test cryostat

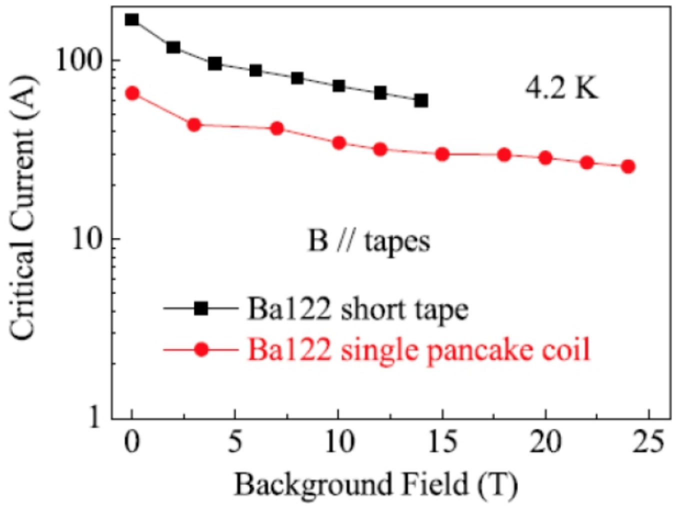

Sha Peng, etc
(b)
Distribution valve box
DC photocathode gun
• 10~15 MeV
• 1~10 mA
Beam
650 MHz test cryomodule

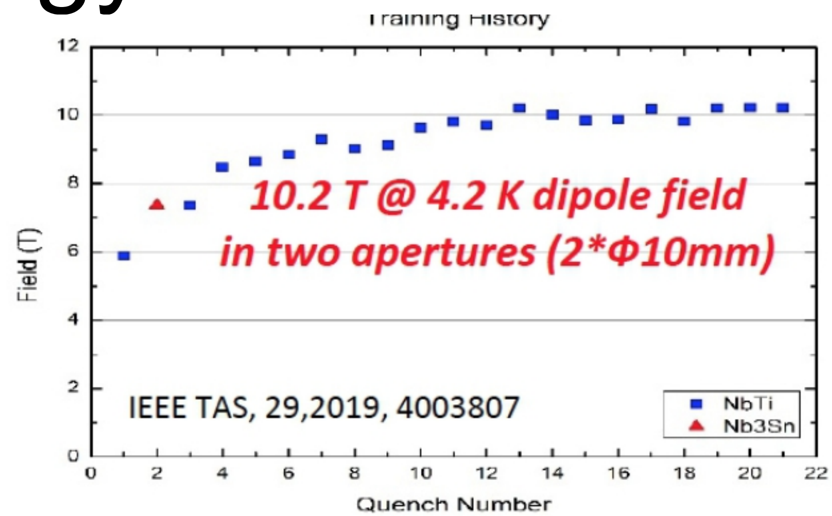
J_e of IBS: 2016-2025

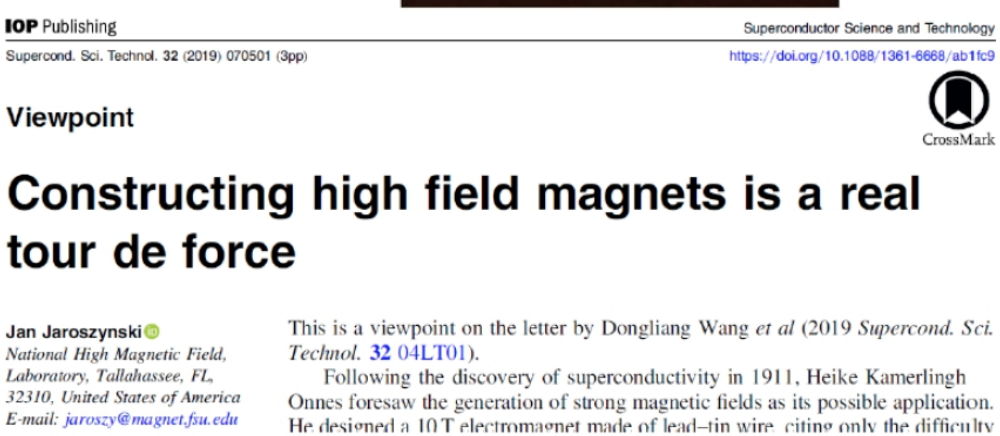


Iron based high-T super conducting technology

Qingjin's team







IOP Publishing Superconductor Science and Technology

Supercond. Sci. Technol. 32 (2019) 070501 (3pp) https://doi.org/10.1088/1361-6668/ab1fc9

Viewpoint

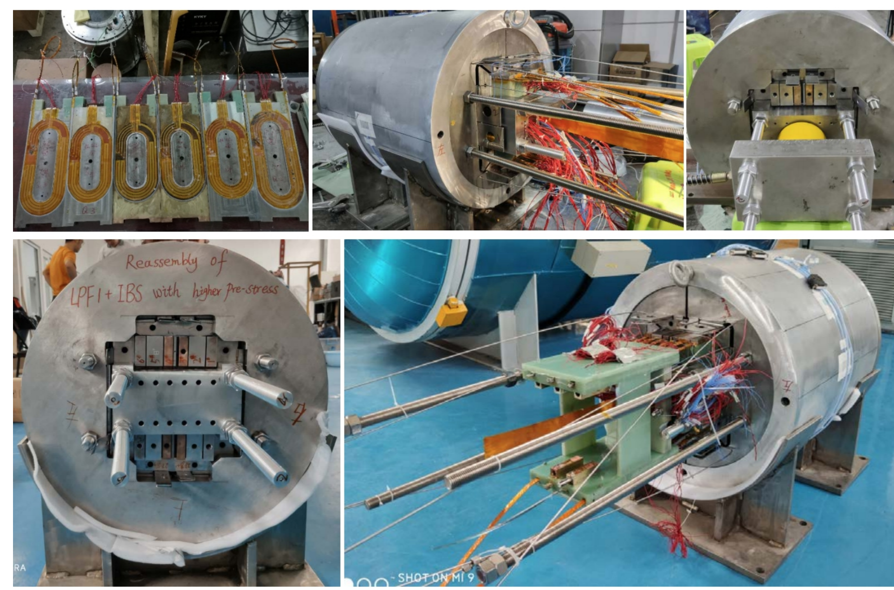
CrossMark

Constructing high field magnets is a real tour de force

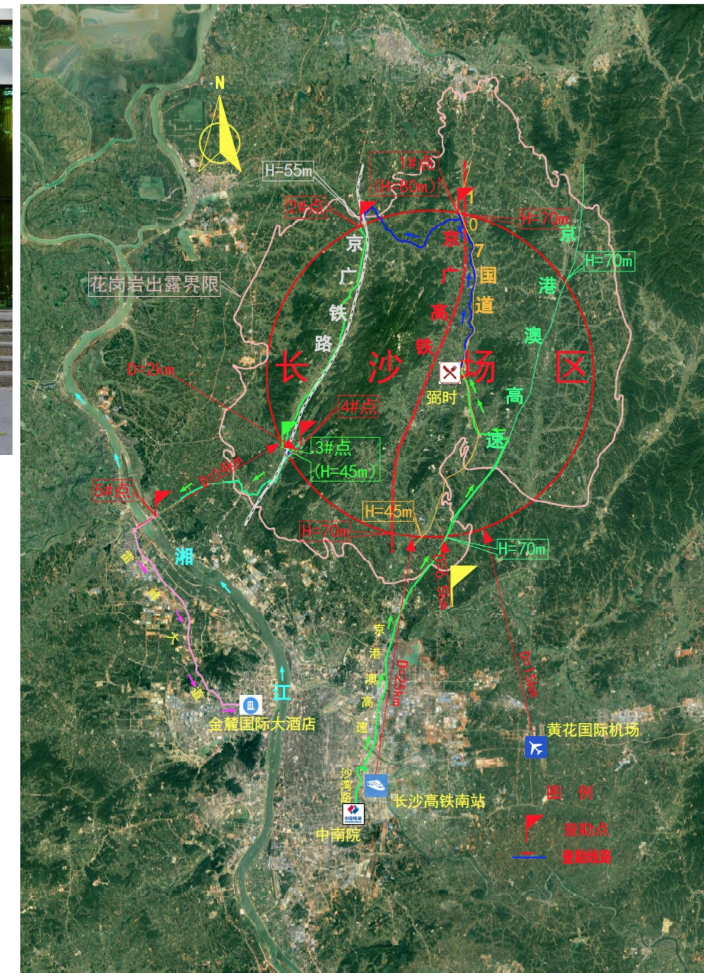
Jan Jaroszynski
National High Magnetic Field, Laboratory, Tallahassee, FL, 32310, United States of America
E-mail: jaroszy@magnet.fsu.edu

This is a viewpoint on the letter by Dongliang Wang *et al* (2019 *Supercond. Sci. Technol.* 32 04LT01).

Following the discovery of superconductivity in 1911, Heike Kamerlingh Onnes foresaw the generation of strong magnetic fields as its possible application. He designed a 10 T electromagnet made of lead–tin wire, citing only the difficulty



CIPC & Candidate sites



The CEPC Industrial Promotion Consortium (CICP) is established in Nov 2017.
Till now, ~ 70 companies joined CICP, covering superconductor, superconducting cavities, cryogenics, vacuum, klystron, electronics, power supply, civil engineering, precise machinery, etc.
The CIPC serves as a communication forum for the industrial and the HEP community.

Candidate sites: Qinghuadao, Huangling, Shenshan, Huzhou, Changchun, Changsha...

Better understood detector Performance

- Acceptance: |cos(θ)| < 0.99
- Tracks:
  - Pt threshold, ~ 100 MeV
  - δp/p ~ o(0.1%)
- Photons:
  - Energy threshold, ~ 100 MeV
  - δE/E: 3 – 15%/sqrt(E)
- BMR: 3.7%
- b-tagging: eff*purity @ Z→qq: 70%
- c-tagging: eff*purity @ Z→qq: 40%
- Pi-Kaon separation: 3-sigma (requirement)
- Pi-0: eff*purity @ Z→qq > 60% @ 5GeV
- Jet charge: eff*$(1-2\omega)^2$ ~ 15%/30% @ Z→bb/cc

- Lepton inside jets: eff*purity @ Z→qq ~ 90% (energy > 3 GeV): slight degrading in jet
- Tau: eff*purity @ WW→tauvqq: 70%, mis id from jet fragments ~ o(1%)
- Reconstruction of simple combinations: Ks/Lambda/D with all tracks @ Z→qq: 60/75 – 80/85%
- Missing Energy: Consistent with BMR.