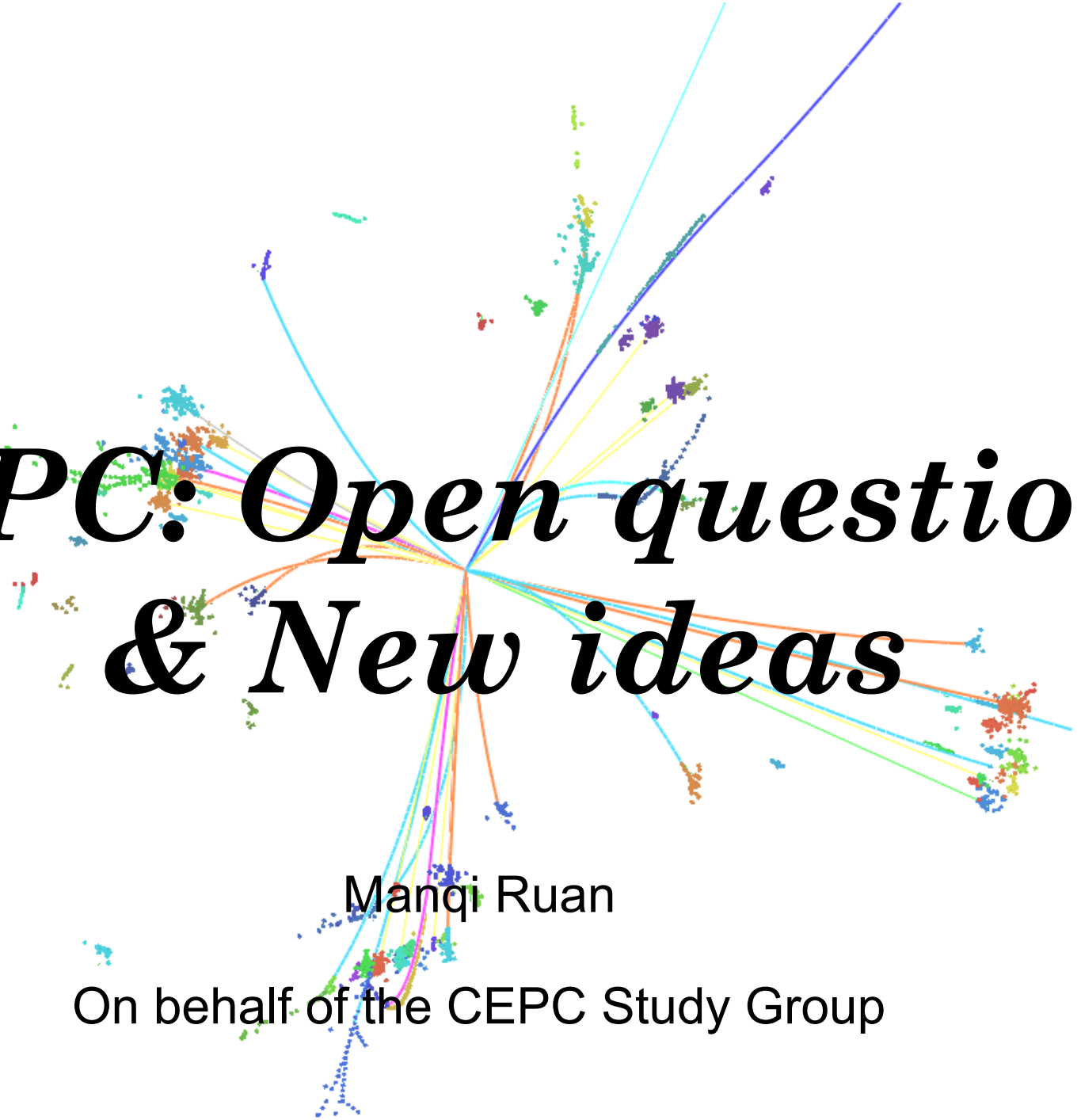


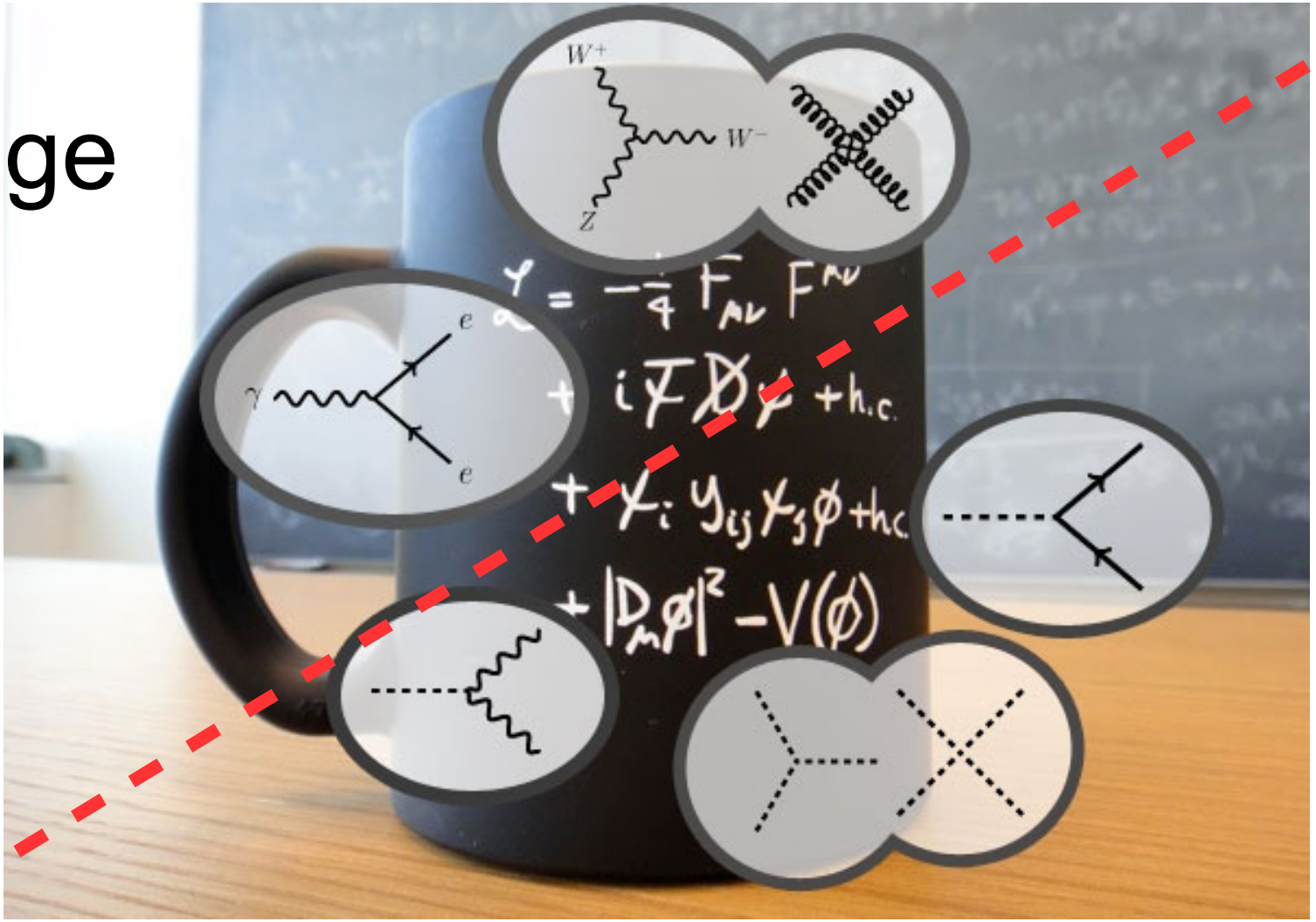
CEPC: Open questions & New ideas

Manqi Ruan

On behalf of the CEPC Study Group

The Higgs field: one of the two SM pillars

Gauge

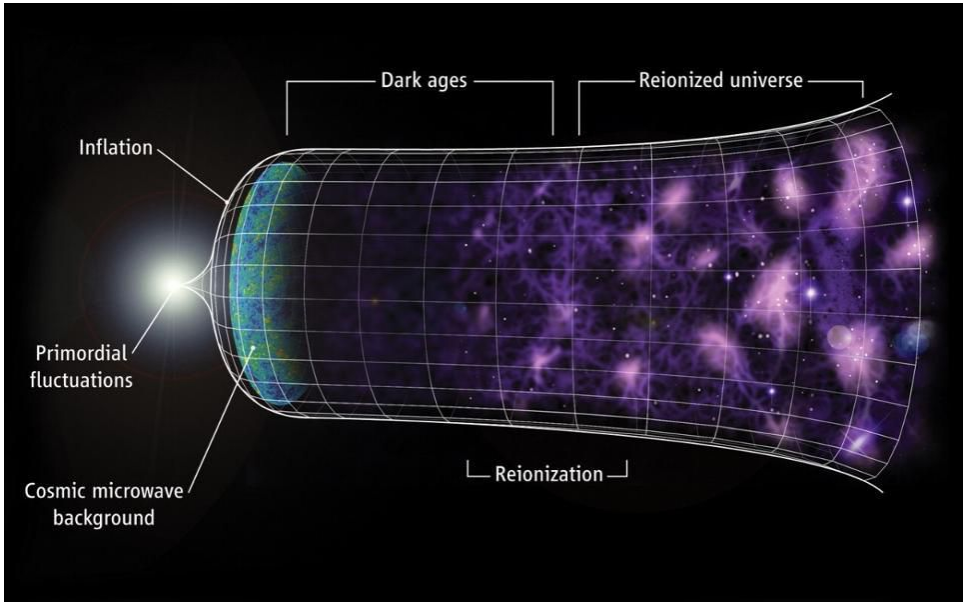


Higgs

Higgs: linked to many known unknowns of the SM

- Hierarchy: From neutrinos to the top mass, masses differs by 13 orders of magnitude
- Naturalness: Fine tuning of the Higgs mass
- Masses of Higgs and top quark: meta-stable of the vacuum
- Unification?
- Dark matter candidate?
- Not sufficient CP Violation for Matter & Antimatter asymmetry

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



- **Most issues related to Higgs**

Science at CEPC-SPPC

- **Tunnel ~ 100 km**
- **CEPC (90 – 250 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...**

FERMILAB-CONF-13-037-APC
IHEP-AC-2013-001
SLAC-PUB-15370
CERN-ATS-2013-032
arXiv:1302.3318

Report of the ICFA Beam Dynamics Workshop

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

(HF2012)

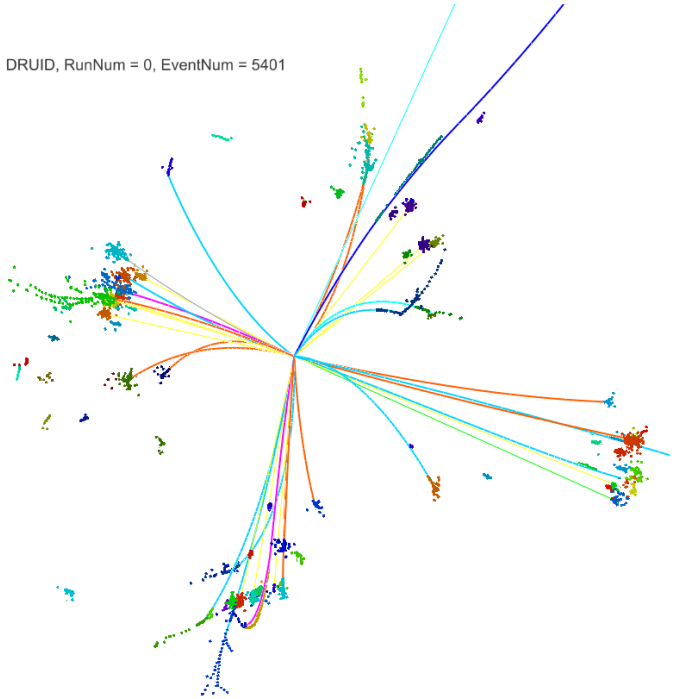
Alain Blondel[1], Alex Chao[2], Weiren Chou[3], Jie Gao[4], Daniel Schulte[5] and Kaoru Yokoya[6]

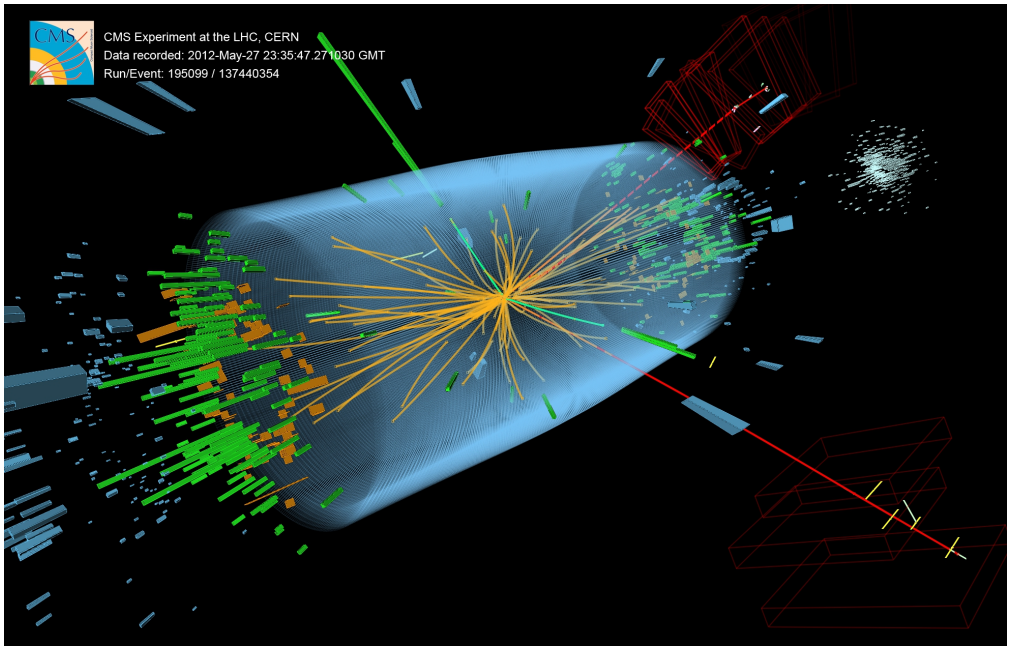
[1] U. of Geneva, Geneva, Switzerland
[2] SLAC, Menlo Park, California, USA
[3] Fermilab, Batavia, Illinois, USA
[4] IHEP, Beijing, China
[5] CERN, Geneva, Switzerland
[6] KEK, Tsukuba, Japan

February 15, 2013

Complementary

Higgs measurement at e+e- & pp

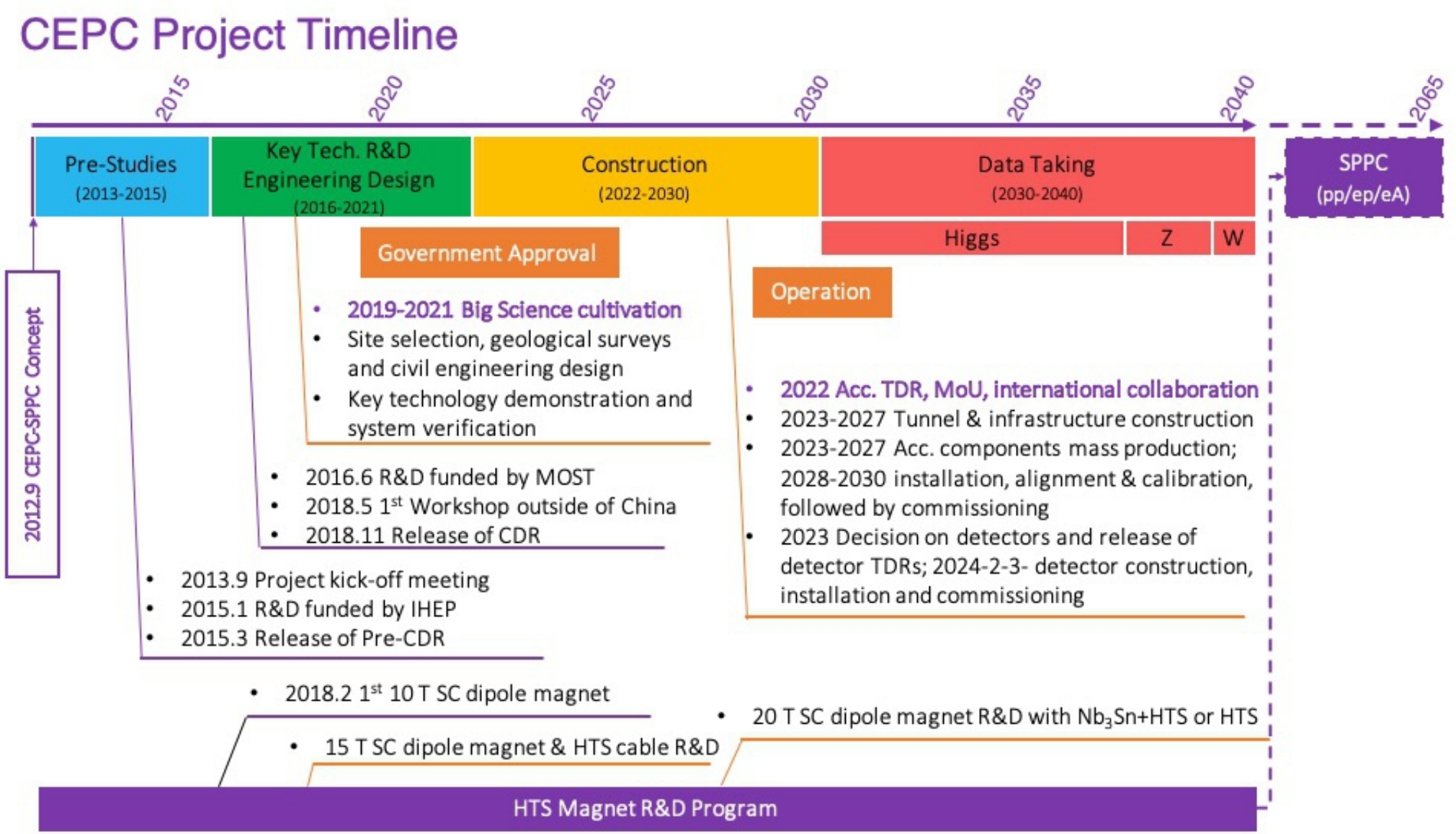




	Yield	efficiency	Comments
LHC	Run 1: 10^6 Run 2/HL: $10^{7\text{-}8}$	~o(10^{-3})	High Productivity & High background, Relative Measurements, Limited access to width, exotic ratio, etc, Direct access to g(ttH), and even g(HHH)
CEPC	10^6	~o(1)	Clean environment & Absolute measurement, Percentage level accuracy of Higgs width & Couplings

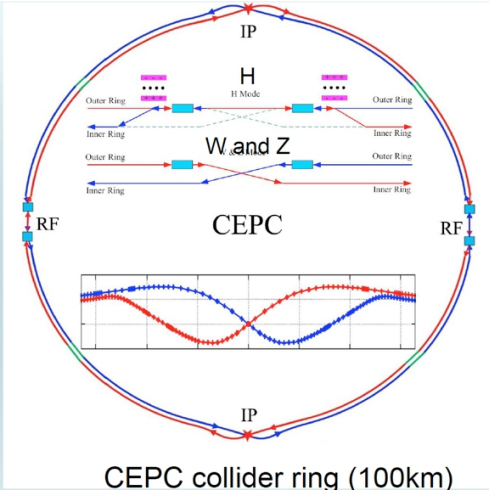
Complementary

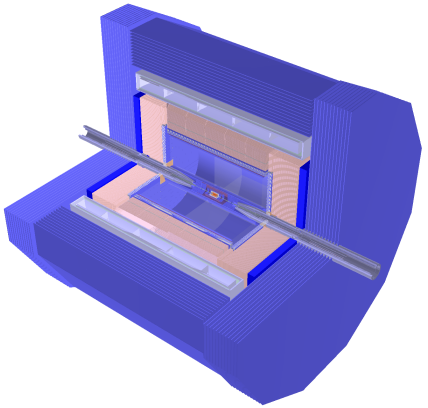
Timeline

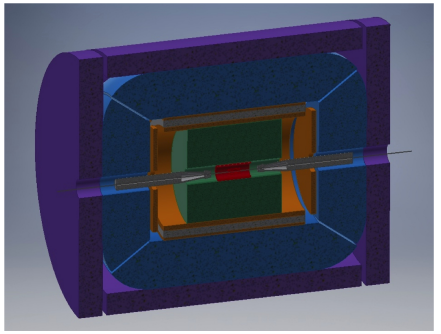

CEPC Project Timeline
2015
2020
2025
2030
2035
2040
2065
Pre-Studies (2013-2015)
Key Tech. R&D Engineering Design (2016-2021)
Construction (2022-2030)
Data Taking (2030-2040)
SPPC (pp/ep/eA)
Higgs
Z
W
Government Approval
Operation
2012.9 CEPC-SPPC Concept
• 2019-2021 Big Science cultivation
• Site selection, geological surveys and civil engineering design
• Key technology demonstration and system verification
• 2016.6 R&D funded by MOST
• 2018.5 1st Workshop outside of China
• 2018.11 Release of CDR
• 2022 Acc. TDR, MoU, international collaboration
• 2023-2027 Tunnel & infrastructure construction
• 2023-2027 Acc. components mass production; 2028-2030 installation, alignment & calibration, followed by commissioning
• 2023 Decision on detectors and release of detector TDRs; 2024-2-3- detector construction, installation and commissioning
• 2013.9 Project kick-off meeting
• 2015.1 R&D funded by IHEP
• 2015.3 Release of Pre-CDR
• 2018.2 1st 10 T SC dipole magnet
• 15 T SC dipole magnet & HTS cable R&D
• 20 T SC dipole magnet R&D with Nb3Sn+HTS or HTS
HTS Magnet R&D Program

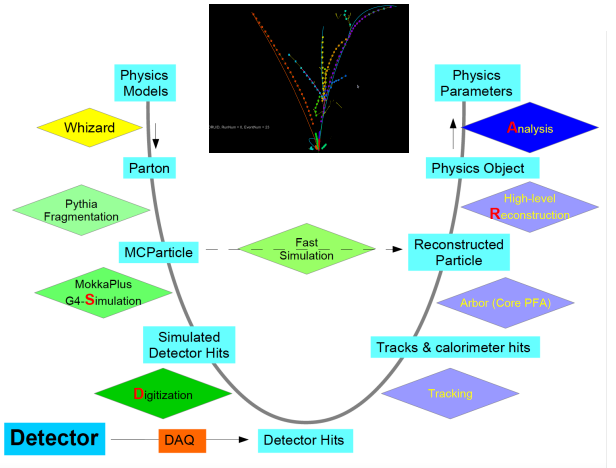
CDR @ 2018

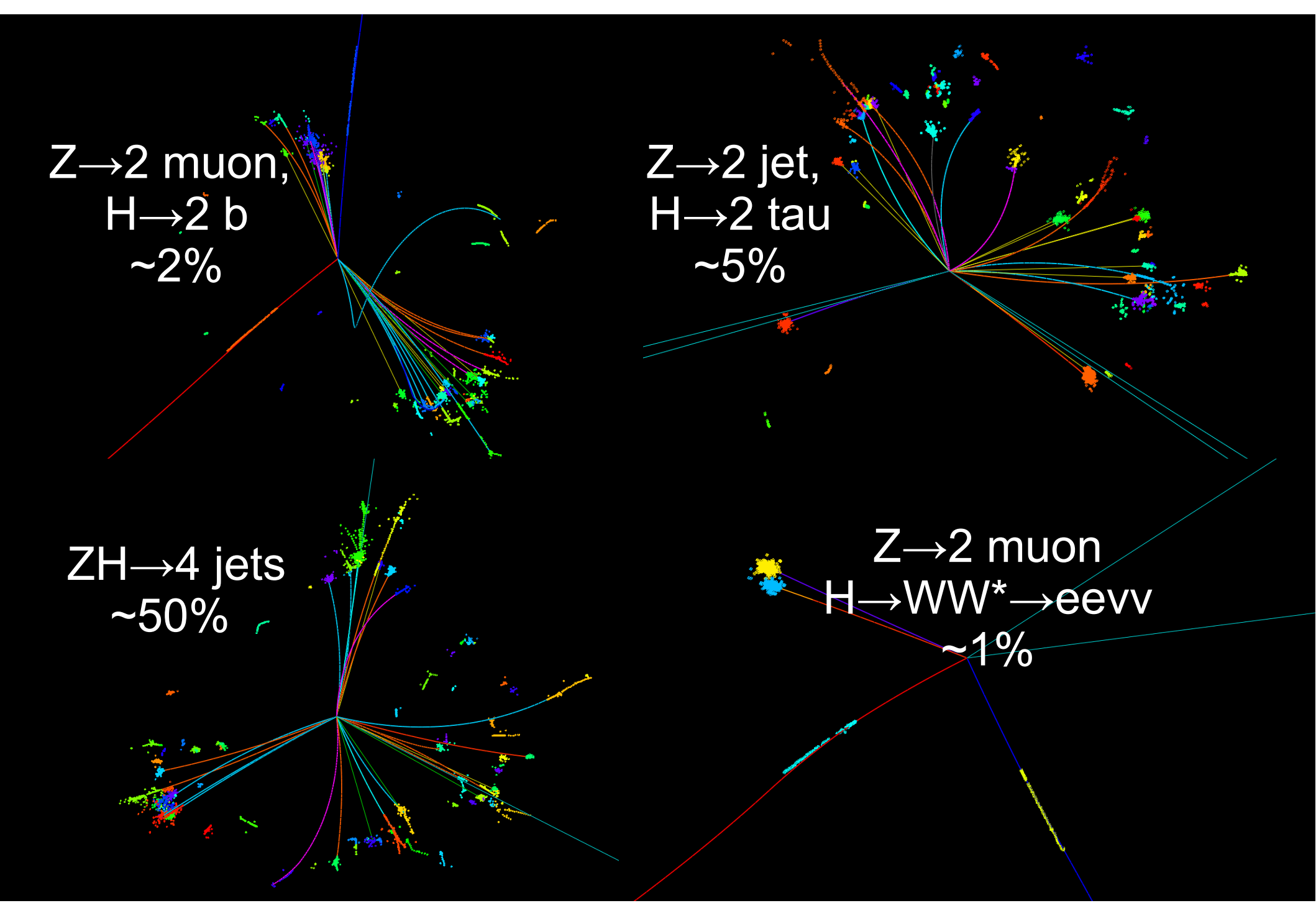
- Baseline Accelerator, Detector, operation scenario
  - 1 Million Higgs boson in 7 years
  - 6E11 Z boson in 2 years
  - WW threshold scan: 1 year (1E7 W bosons)
- Baseline simulation tool:
  - Quantify the physics potential & comparative advantages
  - Guide the design/optimization of the facility & the detector



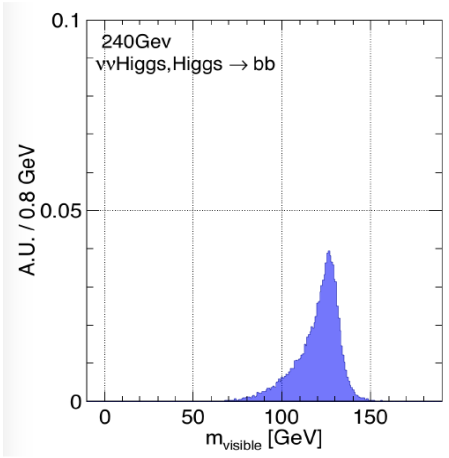


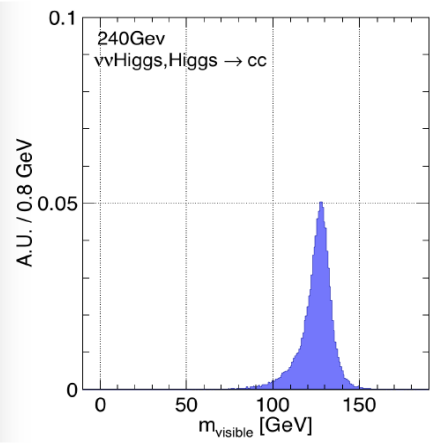


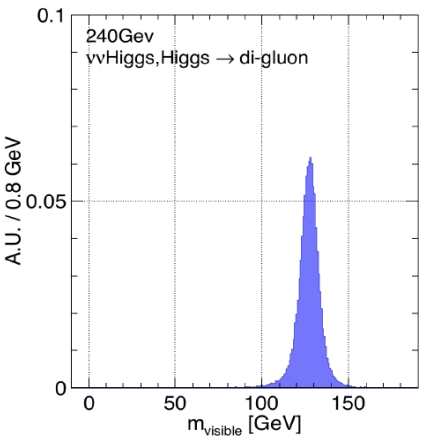


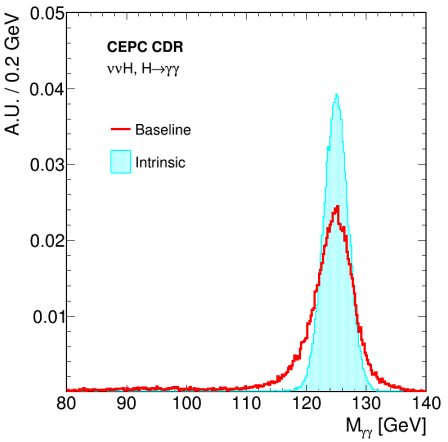

Z→2 muon,
H→2 b
~2%
Z→2 jet,
H→2 tau
~5%
ZH→4 jets
~50%
Z→2 muon
H→WW*→eevv
~1%

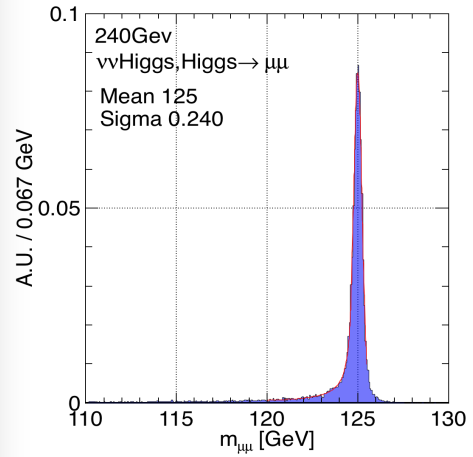
Reconstructed Higgs Signatures

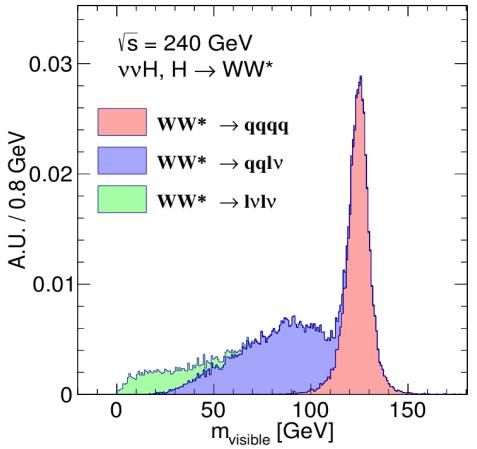


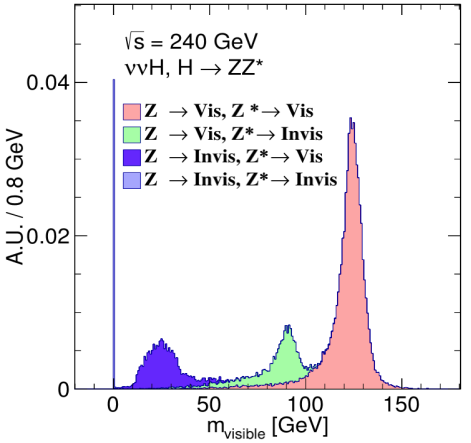


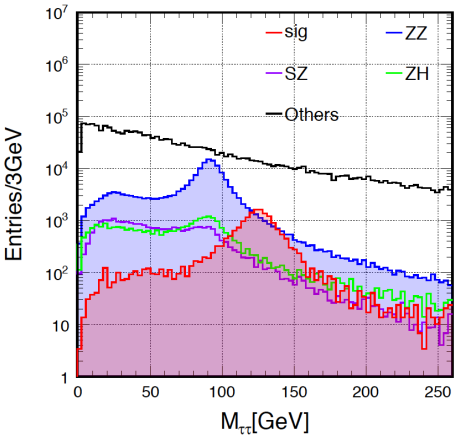










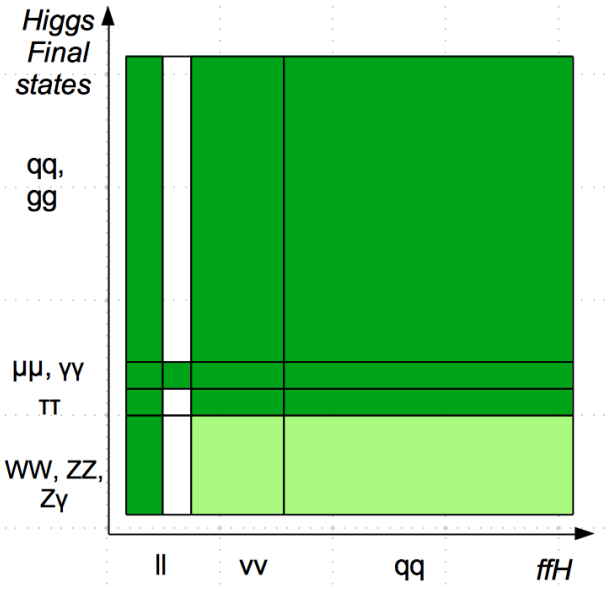


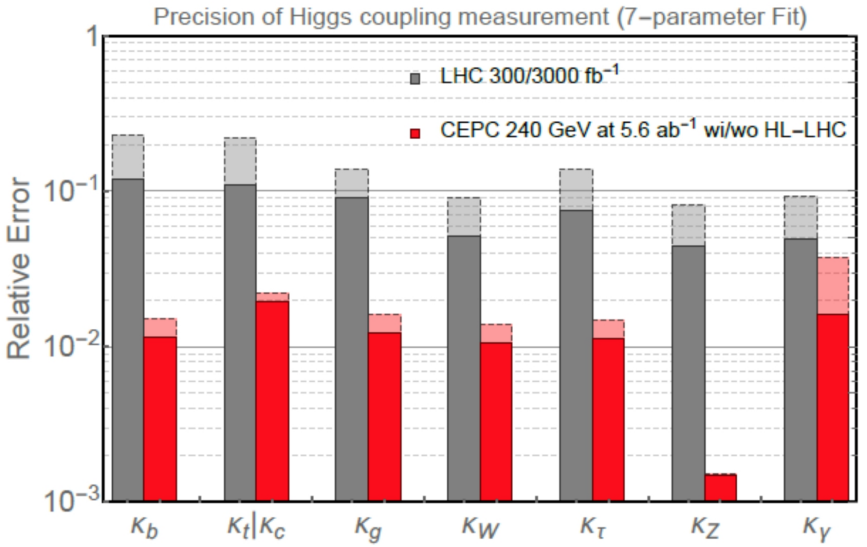
Clear Higgs Signature in all SM decay modes

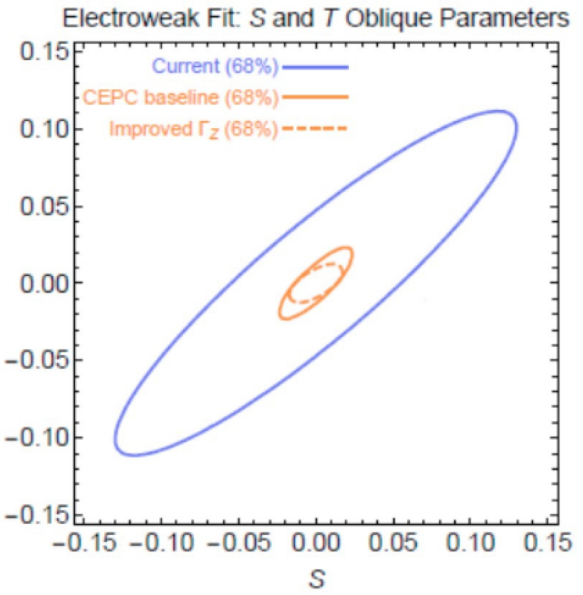
Massive production of the SM background (2 fermion and 4 fermions) at the full Simulation level

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

Quantify the physics potential







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

Precision Higgs physics at the CEPC*

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Jun Gao(高俊)[10] Yanyan Gao(高艳彦)[22] Yuanning Gao(高原宁)[3] Shaofeng Ge(葛韶锋)[15,29]
Jiayin Gu(顾嘉荫)[13;2] Fangyi Guo(郭方毅)[1,4] Jun Guo(郭军)[10] Tao Han(韩涛)[5,31] Shuang Han(韩爽)[4]
Hongjian He(何红建)[11,10] Xianke He(何显柯)[10] Xiaogang He(何小刚)[11,10,20] Jifeng Hu(胡继峰)[10]
Shih-Chieh Hsu(徐士杰)[32] Shan Jin(金山)[8] Maoqiang Jing(荆茂强)[4,7] Susmita Jyotishmati[33] Ryuta Kiuchi[4]
Chia-Ming Kuo(郭家铭)[21] Peizhu Lai(赖培筑)[21] Boyang Li(李博扬)[5] Congqiao Li(李聪乔)[3] Gang Li(李刚)[4,34;3)]
Haifeng Li(李海峰)[12] Liang Li(李亮)[10] Shu Li(李数)[11,10] Tong Li(李通)[12] Qiang Li(李强)[3] Hao Liang(梁浩)[4,6]
Zhijun Liang(梁志均)[4] Libo Liao(廖立波)[4] Bo Liu(刘波)[4,23] Jianbei Liu(刘建北)[1] Tao Liu(刘涛)[14]
Zhen Liu(刘真)[26,30;4)] Xinchou Lou(娄辛丑)[4,8,33,34] Lianliang Ma(马连良)[12] Bruce Mellado[17,18] Xin Mo(莫欣)[4]
Mila Pandurovic[16] Jianming Qian(钱剑明)[24;5)] Zhuoni Qian(钱卓妮)[19] Nikolaos Rompotis[22]
Manqi Ruan(阮曼奇)[4;6)] Alex Schuy[32] Lianyou Shan(单连友)[4] Jingyuan Shi(史静远)[9] Xin Shi(史欣)[4]
Shufang Su(苏淑芳)[25] Dayong Wang(王大勇)[3] Jin Wang(王锦)[4] Liantao Wang(王连涛)[27;7)]
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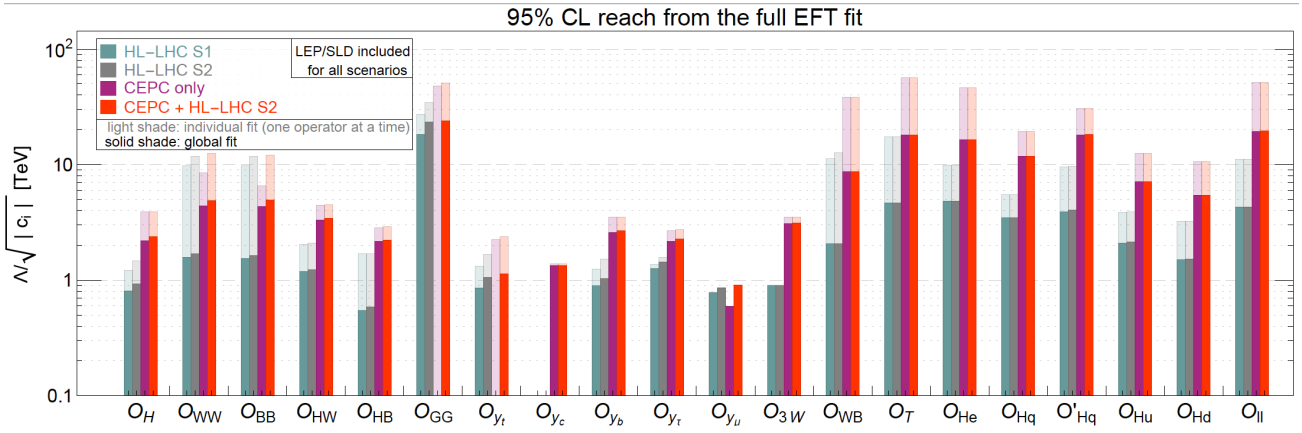
Weiming Yao(姚为民)[28] Dan Yu(于丹)[4] Kaili Zhang(张凯栗)[4,6,8)] Zhaoru Zhang(张照茹)[4]
Mingrui Zhao(赵明锐)[2] Xianghu Zhao(赵祥虎)[4] Ning Zhou(周宁)[10]



https://arxiv.org/pdf/1810.09037.pdf

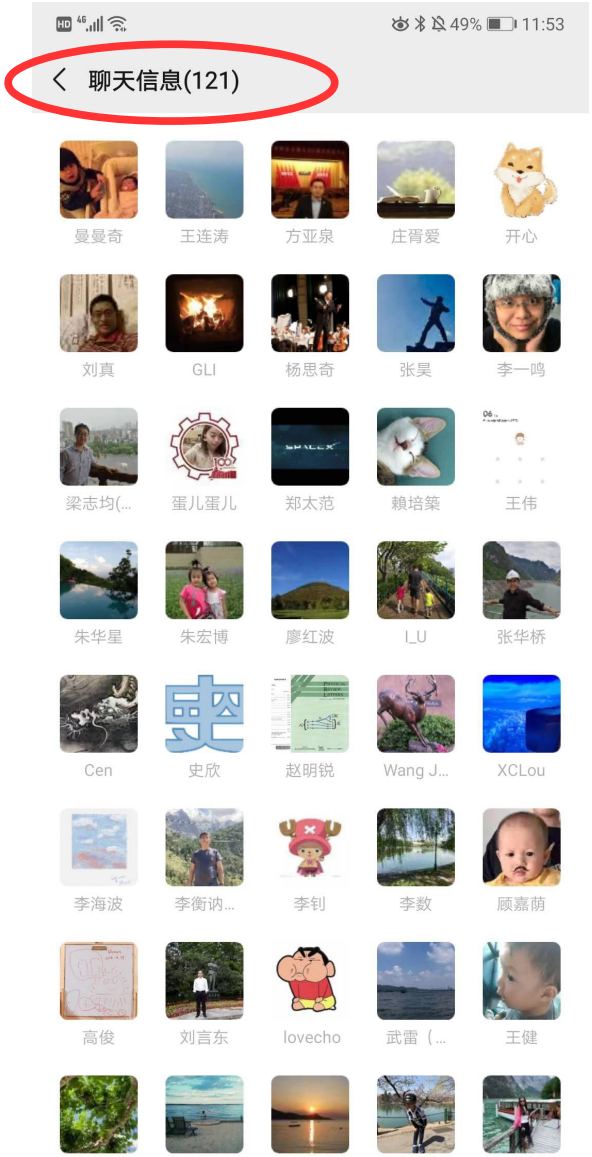
http://ias.ust.hk/program/shared_doc/2020/202001hep/workshop/exp/20200116_1038_am_Jiayin_GU.pdf

New ideas

- CDR contains the big picture
- Going forward:
  - Validate/refine critical projections
  - Covering new ground, uncovering new opportunities

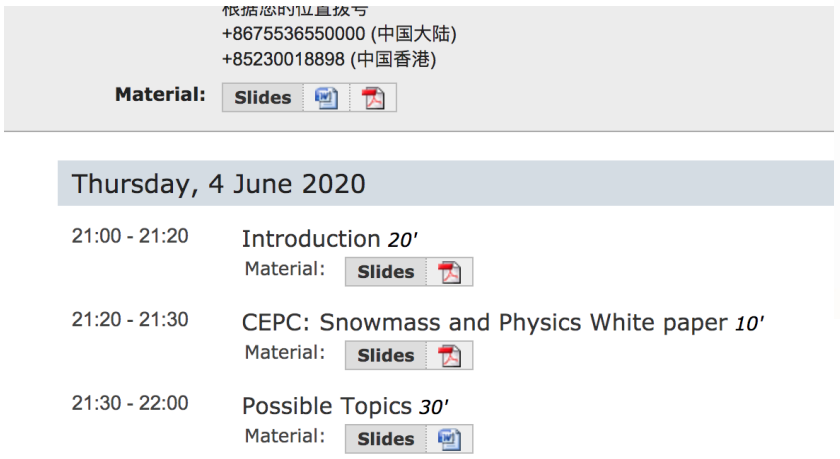
- The snowmass platform is highly appreciated for the CEPC open questions' study. ~o(100) physicists, from more than 20 institutes, are actively joining these study, mainly focus on the Energy Frontier.

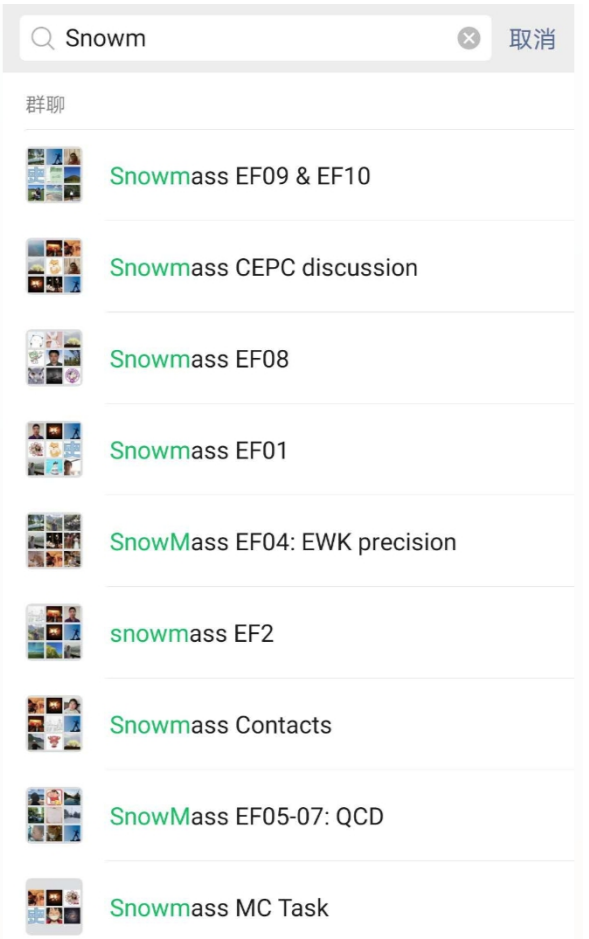
Active community



Topical Group Pages

- EF01: EW Physics: Higgs Boson properties and couplings
- EF02: EW Physics: Higgs Boson as a portal to new physics
- EF03: EW Physics: Heavy flavor and top quark physics
- EF04: EW Precision Physics and constraining new physics
- EF05: QCD and strong interactions: Precision QCD
- EF06: QCD and strong interactions: Hadronic structure and forv
- EF07: QCD and strong interactions: Heavy Ions
- EF08 - BSM: Model specific explorations
- EF09 - BSM: More general explorations
- EF10: BSM: Dark Matter at colliders



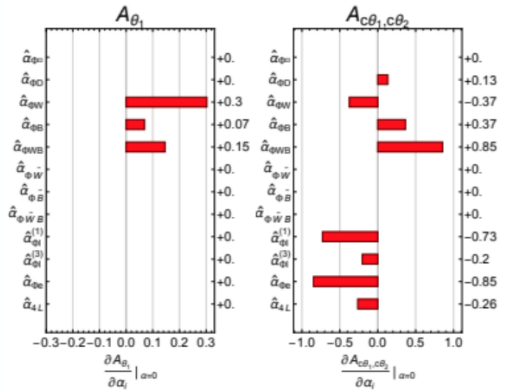


Welcome to join...

(...wechat is NOT a pre-request...)

Higgs physics (EF01 - 02)

- Status: Most of the existing Higgs analyses are rate based (SM).
- Topics:
  - Differential Higgs analysis, CP, etc;
  - Higgs recoil analysis via qqH channel;
  - Key requirements on the Tracker/VTX (Flavor Tagging);
  - Higgs mediated heavy neutrino search;
  - Go beyond k and EFT, i.e., cases in which EFT does not apply, etcs;
  - Simultaneous analysis approach, improvement using Machine Learning;
  - ...
- Contacts:
  - Z.Liu (Maryland), G.Li, J.Wang, Y.Fang, M. Chen(IHEP)



Example: angular variables

Craig, Gu, Liu, Wang, 1512.06877

Flavor Opportunities (EF-03)

- CEPC: A Z/flavor factories. Potential described
- Goal: To quantify
  - The comparative advantage w.r.t existing flavor factories
  - What kind to detector/performance is needed? (dP/P, dE/E, Pid, VTX...)
- Topics
  - Z and Higgs flavor changing decays
  - B hadron decays
  - Tau flavor physics
  - Rare decays
  - New hadron structure?
  - ...
- Contact: H.Zhang, H.Li (IHEP)

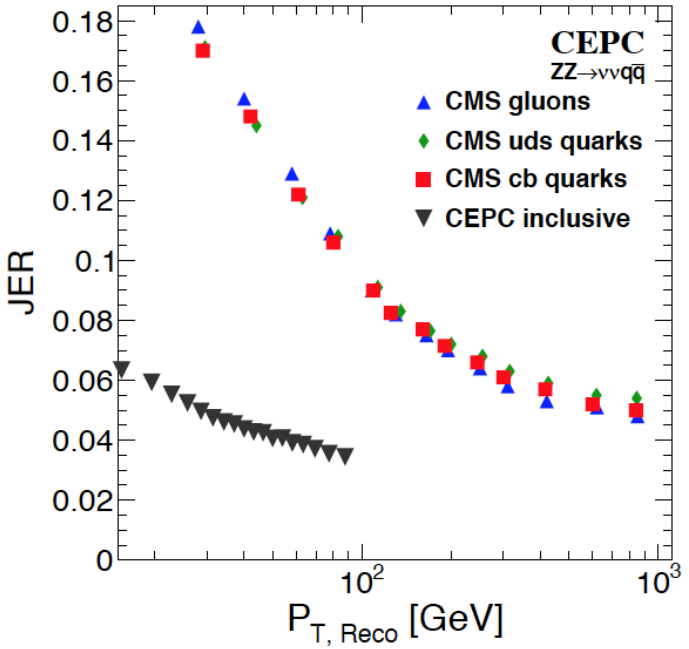
Particle	@ Tera-Z	@ Belle II		@ LHCb
b hadrons				
B^+	6×10^{10}	3×10^{10}	($50\,\mathrm{ab}^{-1}$ on $\Upsilon(4S)$)	3×10^{13}
B^0	6×10^{10}	3×10^{10}	($50\,\mathrm{ab}^{-1}$ on $\Upsilon(4S)$)	3×10^{13}
B_s	2×10^{10}	3×10^{8}	($5\,\mathrm{ab}^{-1}$ on $\Upsilon(5S)$)	8×10^{12}
b baryons	1×10^{10}			1×10^{13}
Λ_b	1×10^{10}			1×10^{13}
c hadrons				
D^0	2×10^{11}			
D^+	6×10^{10}			
D_s^+	3×10^{10}			
Λ_c^+	2×10^{10}			
τ^+	3×10^{10}	5×10^{10}	($50\,\mathrm{ab}^{-1}$ on $\Upsilon(4S)$)	

From CEPC's CDR using fragmentation ratios from Amhis et al, 17

- Similar statistical sample of $B^{0,\pm}$, τ's at Belle 2 and CEPC
- Two order of magnitude more B_s at CEPC wrt to Belle 2
- b-baryon physics possible at the CEPC
- Limited possibilities for charm physics at Belle 2

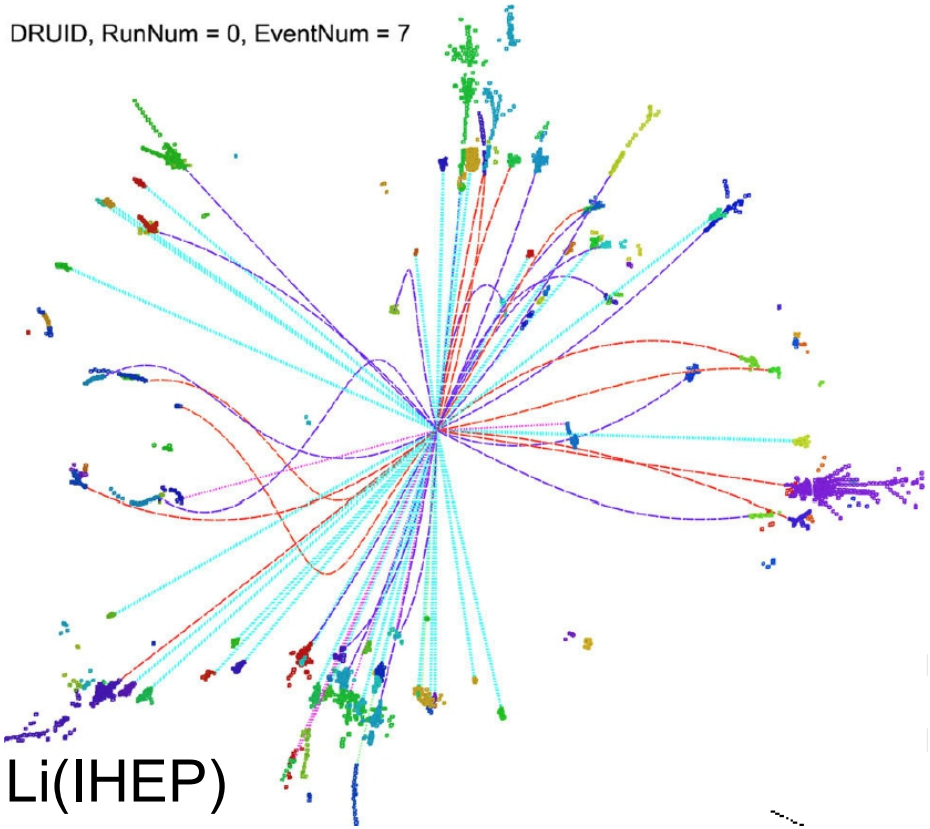
EW Precision (EF-04)

- Status: Many projections are simple extrapolation of statistic/systematic
- Goal: Refine key projections
- Topics:
  - WW production
  - TGC
  - Rb measurement
  - Afb_b measurements
  - NNLO EW correction to HZ production
  - ...
- Contact: J.Gu(Mainz), Z.Liang(IHEP)



QCD under microscope (EF05 - 07)

- A High energy electron positron collider provides ideal condition to study QCD
- Topics:
  - Strong coupling
  - quark-gluon
  - Exotic hadrons
  - Color Singlet Identification
  - Color reconnection
  - ...
- Contact: Y.Ma(PKU), H.Zhu(ZJU), Z.Li(IHEP)



BSM/Exotic (EF08-10)

- Status
  - Rich physic program, great potential
  - Most existing analysis are SM oriented...
- Goal: better quantification the corresponding potential/detector requirements
- Topics:
  - Specific benchmarks (SUSY, Composited Higgs), i.e., stau search
  - Z rare decays
  - Long Lived Particles
  - ALPs
  - DM Search via mono photon, mono V/H/Scalar, Dijet, etc
  - Higgs portal DM Study
  -
- Contact: J.Liu (PKU), H.Zhang (IHEP), X.Shi (IHEP), X.Zhuang (IHEP)

Challenges to theorists

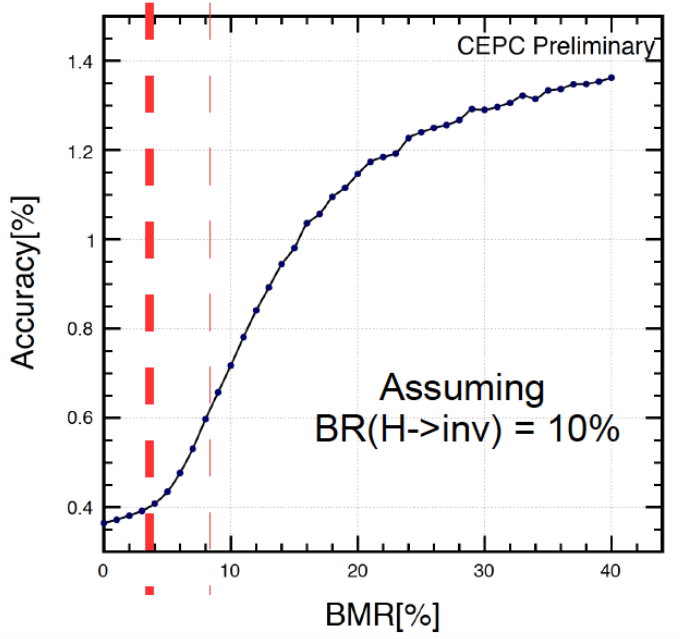
- To fully realize the potential of the precision measurements, theory prediction needs to be significantly improved.
- Contacts: L.Yang (ZJU), Y.Jia(IHEP)

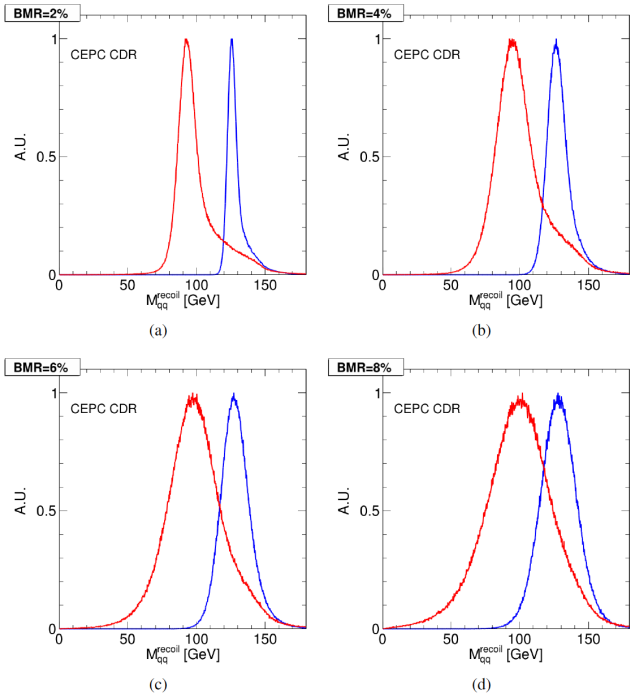
Quantity	ILC	CEPC/FCC-ee	Current intrinsic unc.		Projected unc.
M_W [MeV]	3	0.5	4	$(\alpha^3, \alpha^2\alpha_s)$	1
$\sin^2\theta^\ell_{\text{eff}}$ $[10^{-5}]$	1.3	0.6	4.5	$(\alpha^3, \alpha^2\alpha_s)$	1.5
Γ_Z [MeV]	1	0.1	0.5	$(\alpha^3, \alpha^2\alpha_s, \alpha\alpha_s^2)$	0.2 (?)
R_b $[10^{-5}]$	15	6	15	$(\alpha^3, \alpha^2\alpha_s)$	7 (?)
R_l $[10^{-3}]$	10??	1	5	$(\alpha^3, \alpha^2\alpha_s)$	1.5 (?)

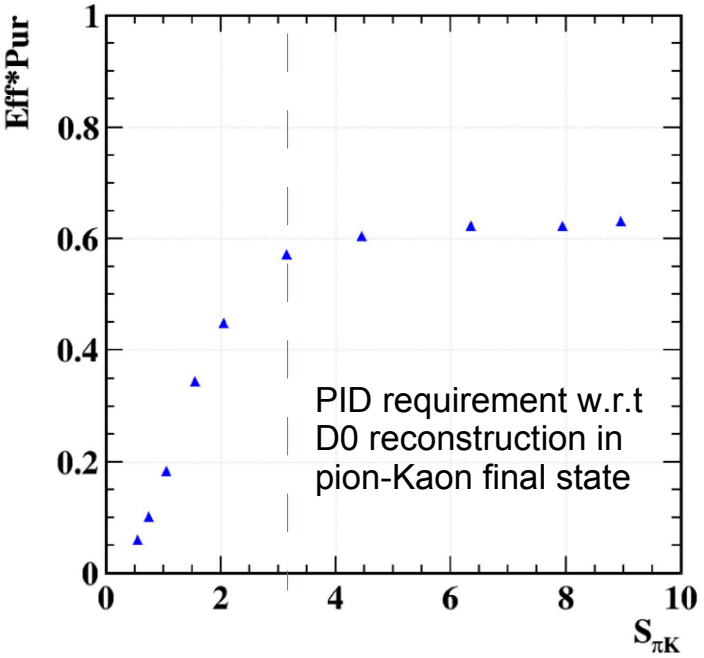
Talk by S. Heinemeyer, 2019 CEPC workshop

Performance study: bridging the physics & detector

- To bridging the physics reach & detector requirements – design/optimization...
- Contacts: M.Ruan, G.Li(IHEP)







Summary

- CEPC, a productive and clean Higgs/W/Z factory,
  - Boost the Higgs/EW precision by ~ 10 times w.r.t HL-LHC/current boundary
  - Huge potential on QCD, Flavor, BSM
- CDR released: Baseline defined
  - Accelerator baseline secures high productivity for Higgs, Z and W bosons.
  - Detector baseline fulfills the requirements: clear physics objects + Higgs signal
  - Alternative designs, New ideas are always welcome
- Many open questions, new ideas are identified, and community are activated.
- The Snowmass platform is highly appreciated in these studies, contributions & communications are highly welcome.
- *...A joint lepton collider forum?...*

Backup

MC Task

- The CEPC MC Studies is supported by the Computing Center of IHEP
- The access of sample & software support is not ideal
  - Most works are operated with IHEP Cluster
  - Software releases at: http://cepcsoft.ihep.ac.cn/
- The Communication between the analyzer + pheno/theory, the MC Force, the CEPC sim team is essential:
  - What scientific problem the analyzer focus, what synergies can be made with existing/on going studies, what support she/he actually needs
- Depends on the actual demands/needs, the CEPC simulation group are happy to collaborate, to overcome the technical difficulties
  - Accessibility of Samples
  - Production of New Samples
  - Allocation on computing resource
- EF Conveners will play an important role...

Self-organization with external potential

Names

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LoI for Snowmass 2021. Deadline: end of August

1. LoI two pages. It should be an indication of a topic one would like to work on (should be **deliverable**) . Snowmass conveners will use these as a way of assessing the landscape of ideas.

2. After submitting the LoI, subsequent work should lead to a set of results. These can be publishable papers. It will also be contribution to the Snowmass. Such contribution due end of July 2021.

Topics

Possible topics

1. Higgs properties

Interference effect in higgs coupling measurement.
Refined predictions.
Differential observables.
Higgs Self Couplings
Key requirement on Tracker & VTX (Flavor Tagging)

2. Electroweak precision

Systematics study: focusing on one or two
WW process
TGC (remark: Jet can be measured to energy resolution of 4%, direction resolution of 1%)
Afb(b) – sin^2(theta_W) (remark: Jet Charge Measurement)

3. Flavor

Rare B decay channel study, e.g. b->sll, b->c l nu and so on
Z and Higgs flavor violating decay
Physics Object at Jet and corresponding Benchmarks:
- Tau in the Jet: Bc->Tauv
- Lepton in the Jet: B/C meson Leptonic decay
- Pi-0: Z->tautau, Br(tau->X)
- MET at Jet: leptonic decay of Heavy Flavor Mesons, Bs->Phi+vv

…

4. Precision calculation

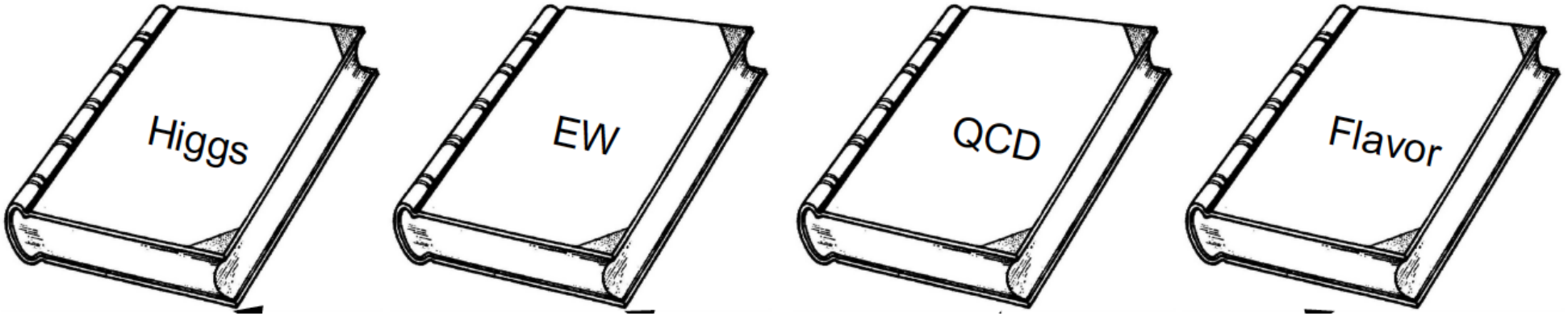
Corrections to Zh and other EW observables, ttbar. Not full calculation. Is there a doable (on a year scale) project here?

5. QCD

Alpha_s projection (c.f. FCC-ee)
Gluon/quark differentiation
Other event shape
Quarkonium physics?

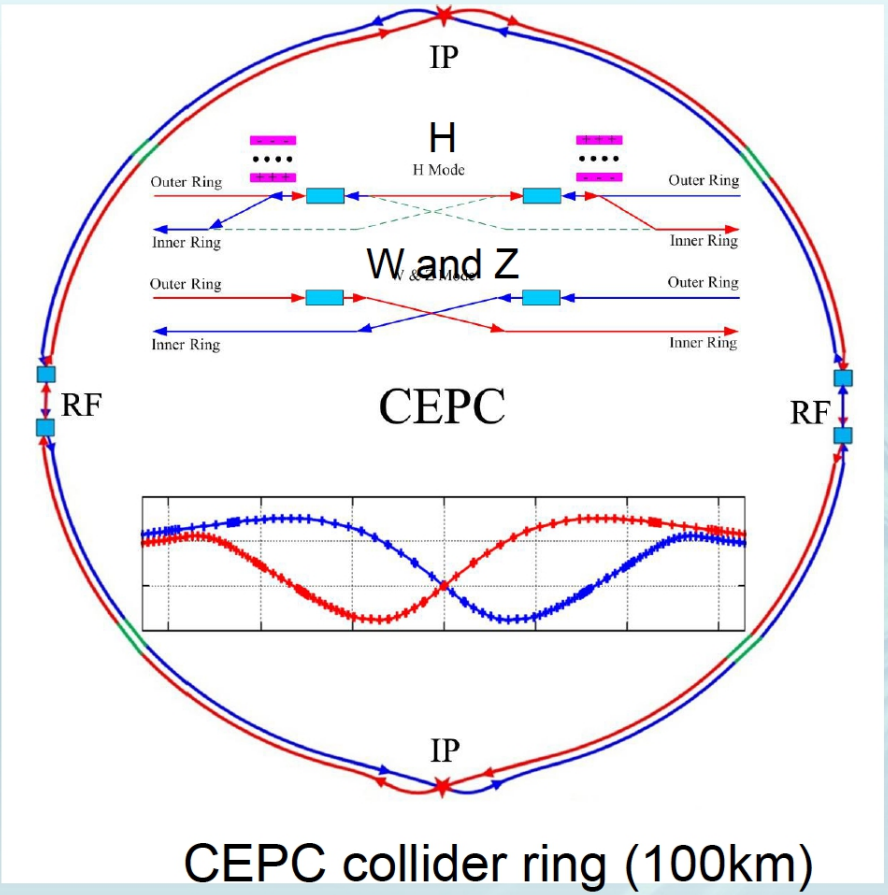
http://ihepbox.ihep.ac.cn/ihepbox/index.php/s/x9L1ITEJaBoZac6

Ongoing physics potential studies

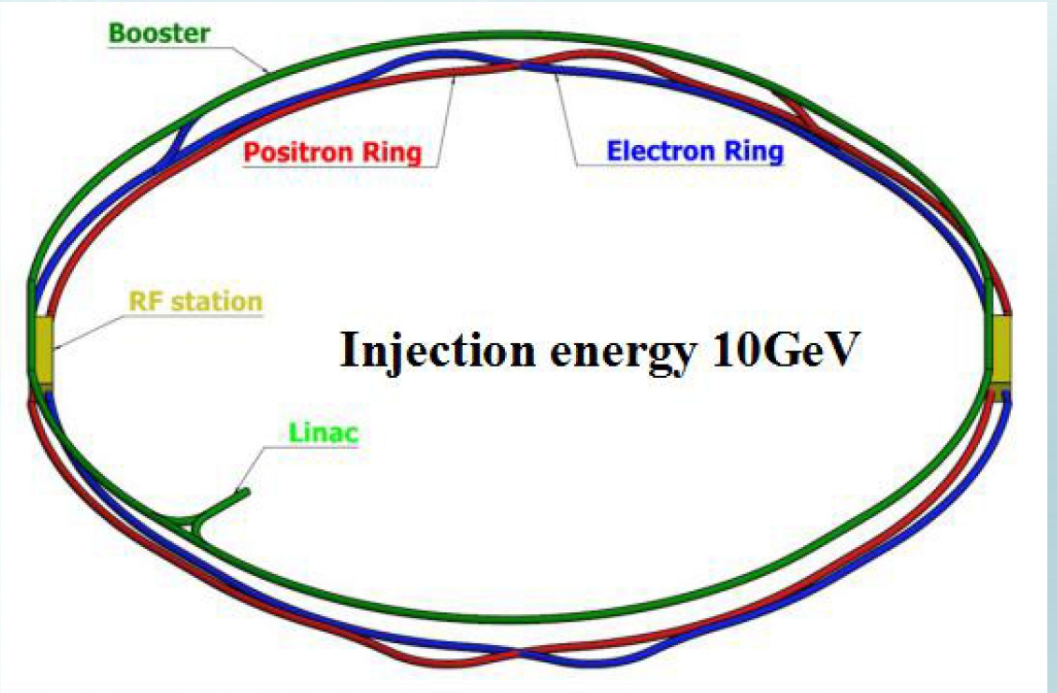


- To promote the physics study at TDR & to converge to the Physics White Papers
- Physics white papers:
  - Physics handbooks for new comers: PostDoc/Student
  - Official references for the physics potential
  - Guideline for future detector design/optimization
- Current Focus: Flavor

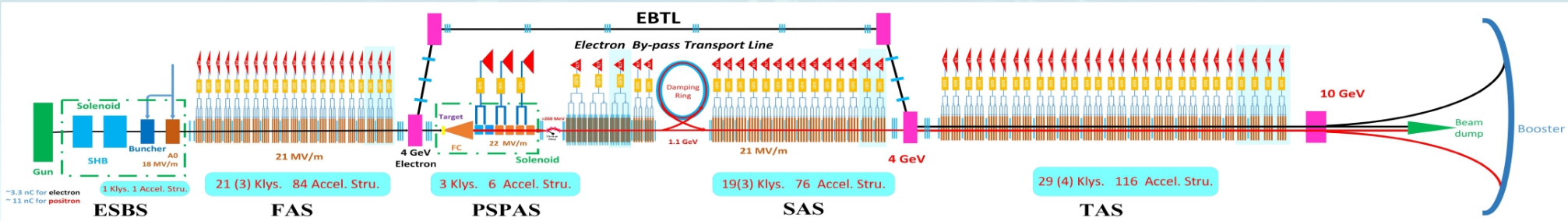
CEPC Accelerator Baseline Layout



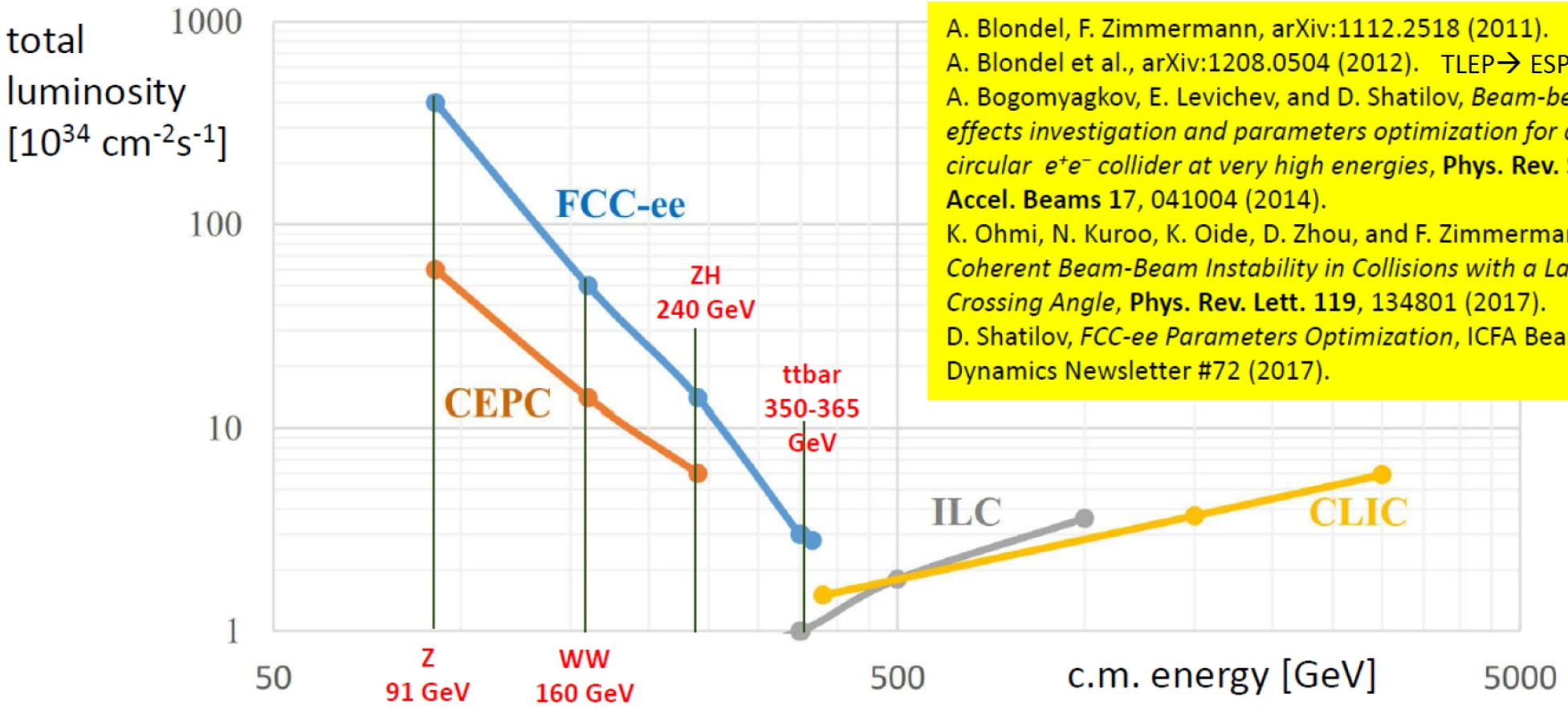
CEPC collider ring (100km)



CEPC booster ring (100km)



Comparison: Linear & Circular



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From A. Blondel's presentation at CEPC Oxford WS