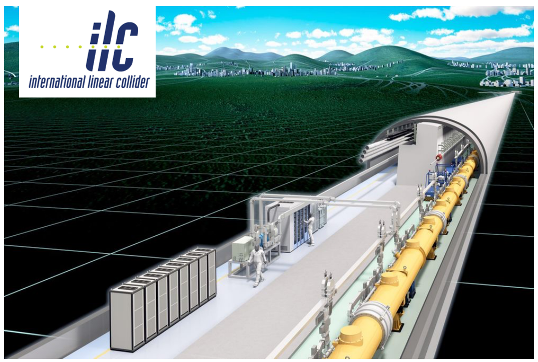
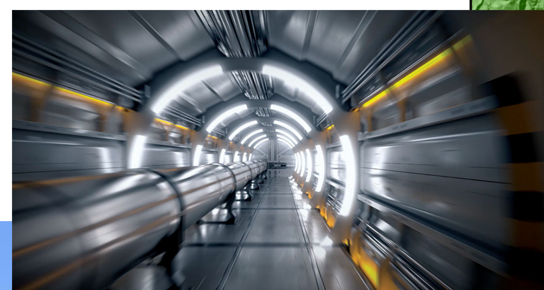
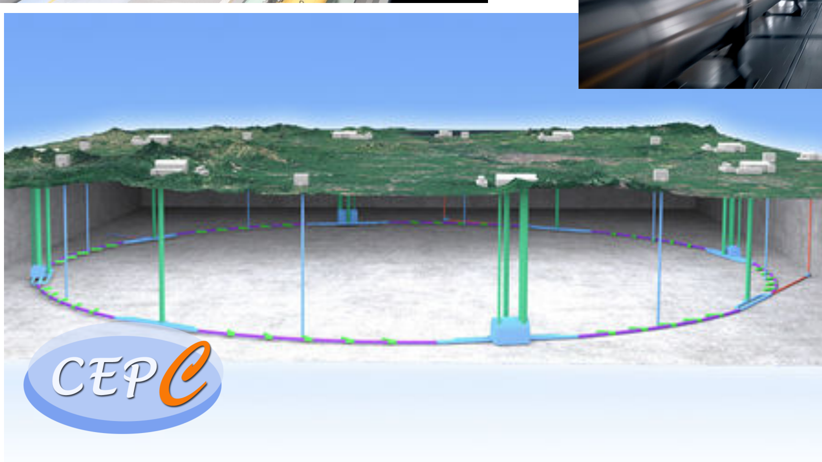
Hwidong Yoo

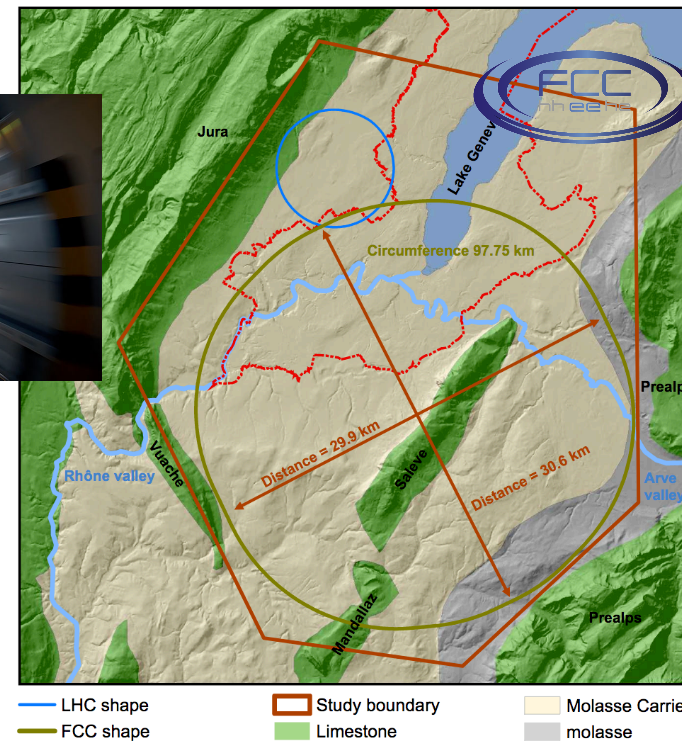
Yonsei University

Future Collider Projects





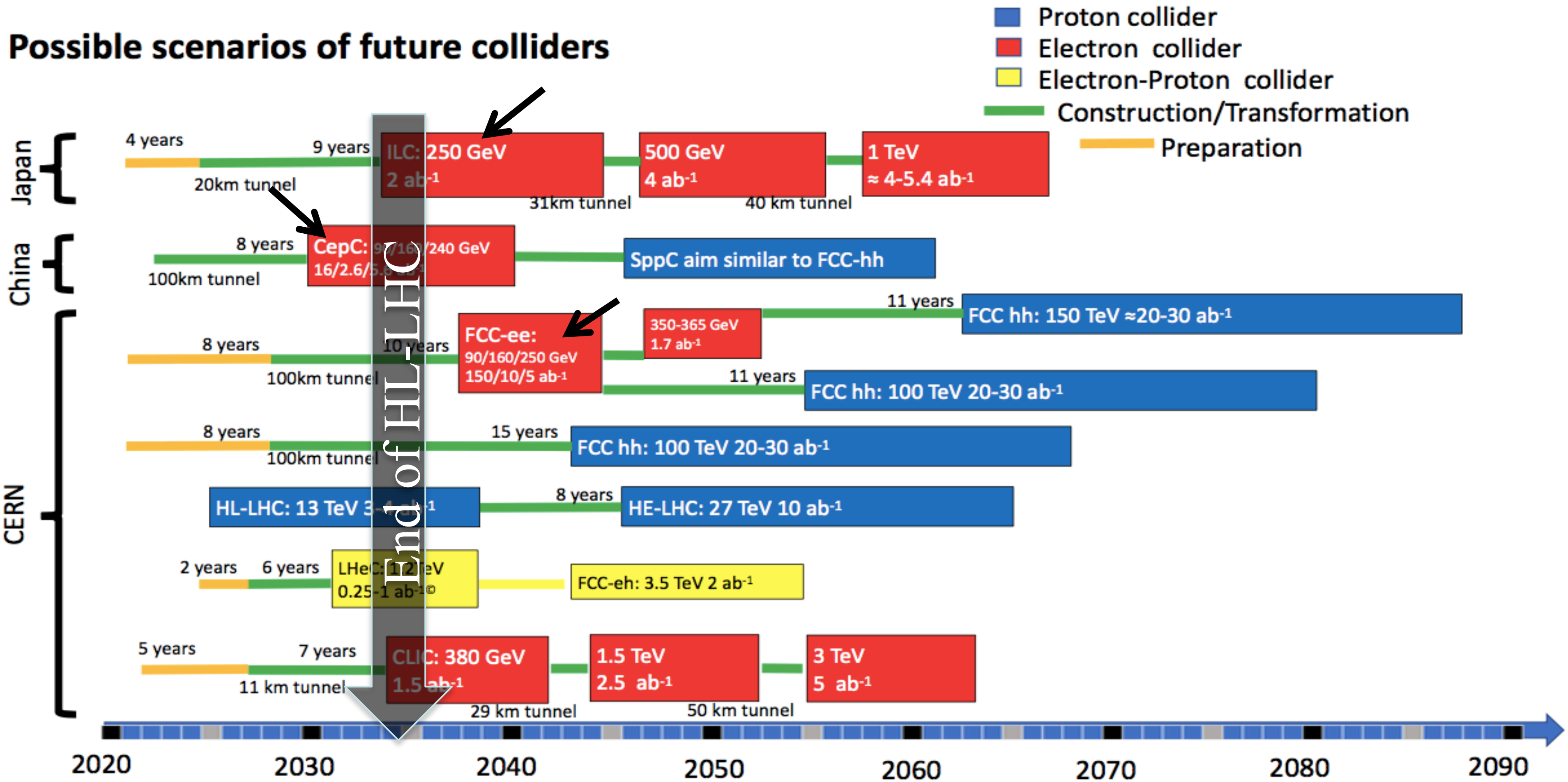




Meeting for long-term strategy of HEP in Korea

September 21st, 2019

Roadmap of Future Collider Projects



Goal of Next Future Colliders

- Z, W, **Higgs** and top factory ➔ precision measurements and beyond
  - Very high luminosities in 100 km tunnel
  - Very small beams and clean experimental conditions
  - Unique precisions and sensitivities to rare processes
- Very mature technology with very large expertise in the world

arXiv: 1906.02693

Working point	Z, years 1-2	Z, later	WW	HZ	$t\bar{t}$	
$\sqrt{s}$ (GeV)	88, 91, 94		157, 163	240	340-350	365
Lumi/IP ($10^{34}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$)	115	230	28	8.5	0.95	1.55
Lumi/year (ab^{-1}, 2 IP)	24	48	6	1.7	0.2	0.34
Physics Goal (ab^{-1})	150		10	5	0.2	1.5
Run time (year)	2	2	2	3	1	4
Number of events	5×10^{12} Z		10^8 WW	10^6 HZ + 25k WW $\rightarrow$ H	$10^6 t\bar{t}$ +200k HZ +50k WW $\rightarrow$ H	

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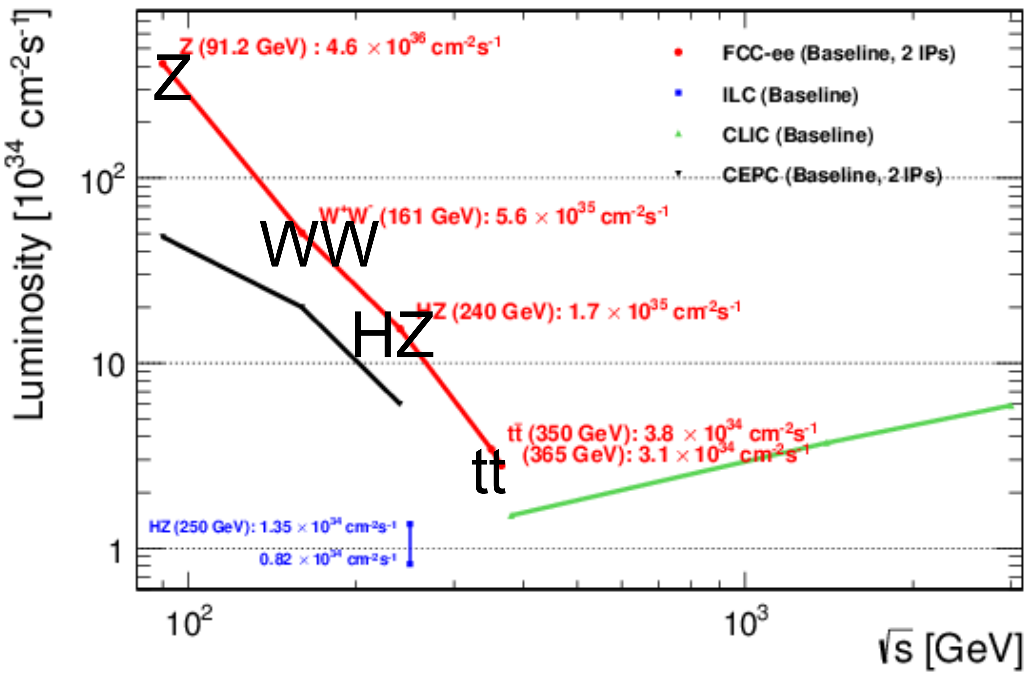
Number of events	$10^6 t\bar{t}$ +200k HZ +50k WW → H	



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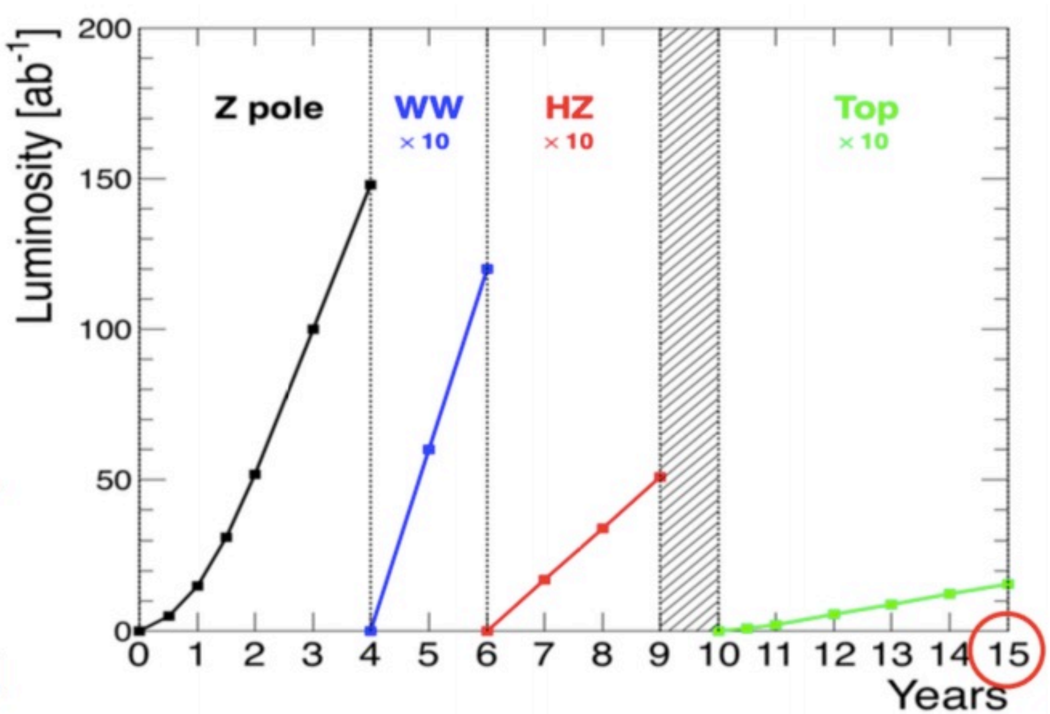


Higgs Couplings at FC

- Unique measurements at highest precision

arXiv: 1906.02693

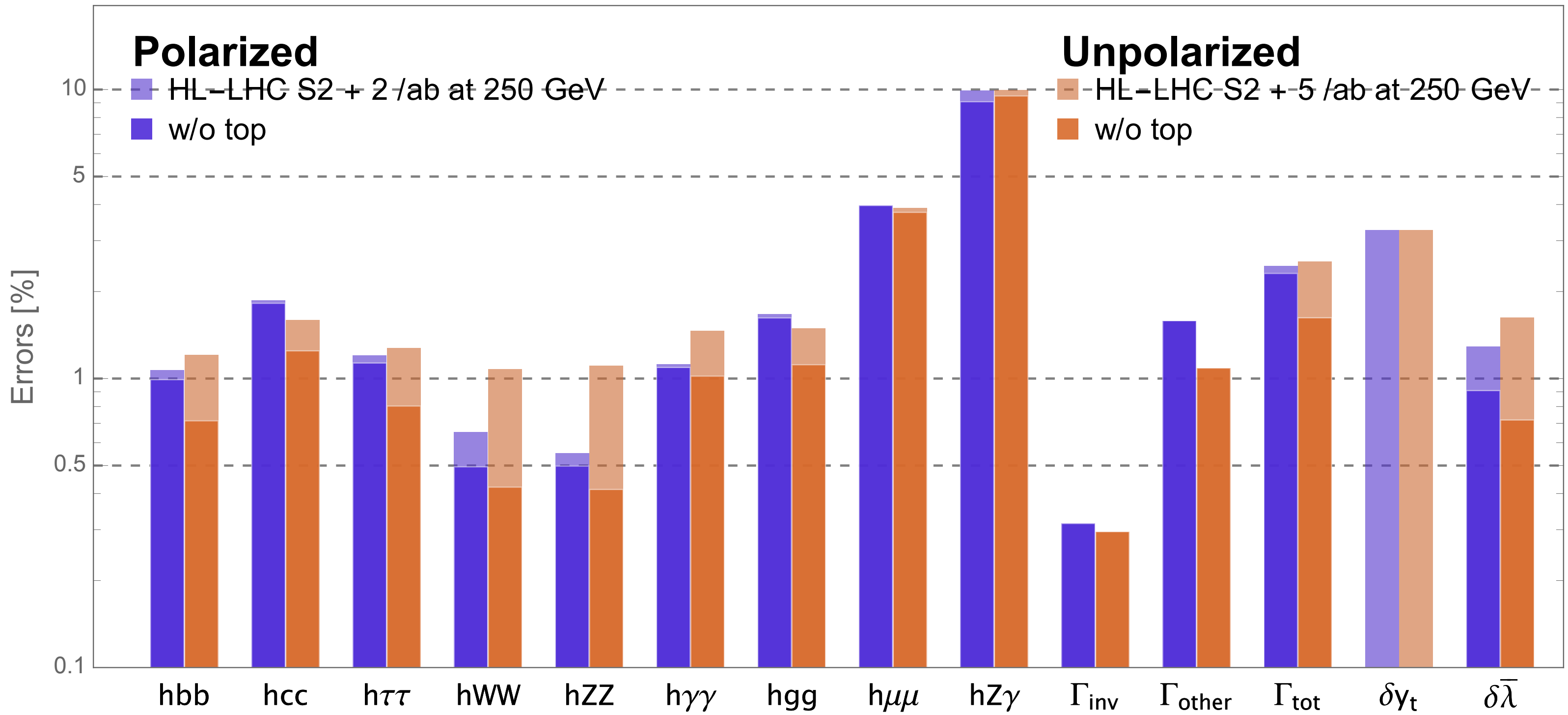
Collider	HL-LHC	ILC_{250}	$CLIC_{380}$	$CEPC_{240}$	$FCC\text{-}ee_{240\rightarrow365}$
Lumi (ab^{-1})	3	2	1	5.6	5 + 0.2 + 1.5
Years		11.5 [5]	8	7	3 + 1 + 4
g_{HZZ} (%)	1.5 / 3.6	0.29 / 0.47	0.44 / 0.66	0.18 / 0.52	**0.17 / 0.26**
g_{HWW} (%)	1.7 / 3.2	1.1 / 0.48	0.75 / 0.65	0.95 / 0.51	**0.41 / 0.27**
g_{Hbb} (%)	3.7 / 5.1	1.2 / 0.83	1.2 / 1.0	0.92 / 0.67	**0.64 / 0.56**
g_{Hcc} (%)	SM / SM	2.0 / 1.8	4.1 / 4.0	2.0 / 1.9	**1.3 / 1.3**
g_{Hgg} (%)	2.5 / 2.2	1.4 / 1.1	1.5 / 1.3	1.1 / 0.79	**0.89 / 0.82**
$g_{H\tau\tau}$ (%)	1.9 / 3.5	1.1 / 0.85	1.4 / 1.3	1.0 / 0.70	**0.66 / 0.57**
$g_{H\mu\mu}$ (%)	4.3 / 5.5	4.2 / 4.1	4.4 / 4.3	3.9 / 3.8	**3.9 / 3.8**
$g_{H\gamma\gamma}$ (%)	1.8 / 3.7	1.3 / 1.3	1.5 / 1.4	1.2 / 1.2	**1.2 / 1.2**
$g_{HZ\gamma}$ (%)	11. / 11.	11. / 10.	11. / 9.8	6.3 / 6.3	**10. / 9.4**
g_{Htt} (%)	3.4 / 2.9	2.7 / 2.6	2.7 / 2.7	2.6 / 2.6	**2.6 / 2.6**
g_{HHH} (%)	50. / 52.	28. / 49.	45. / 50.	17. / 49.	**19. / 34.**
Γ_H (%)	SM	2.4	2.6	1.9	**1.2**
BR_{inv} (%)	1.9	0.26	0.63	0.27	**0.19**
BR_{EXO} (%)	SM (0.0)	1.8	2.7	1.1	**1.0**

- Uncertainties not limited by experimental or theoretical uncertainties with sufficient statistics

Higgs Couplings at FC

- Unique measurements at highest precision

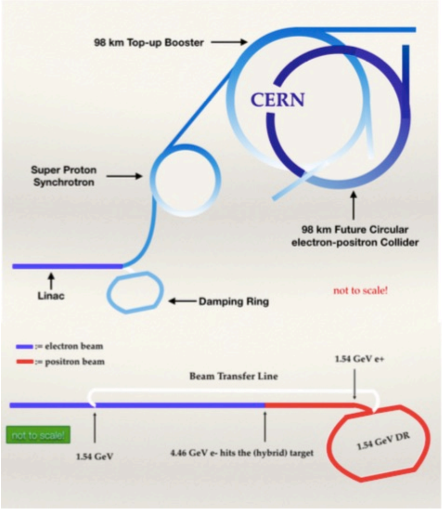
See Prof. SH Jung's talk

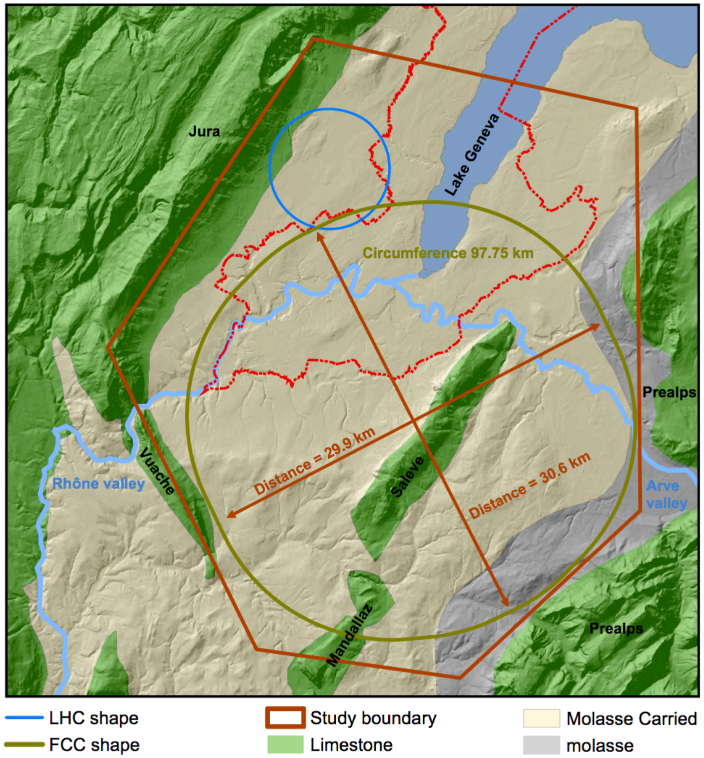


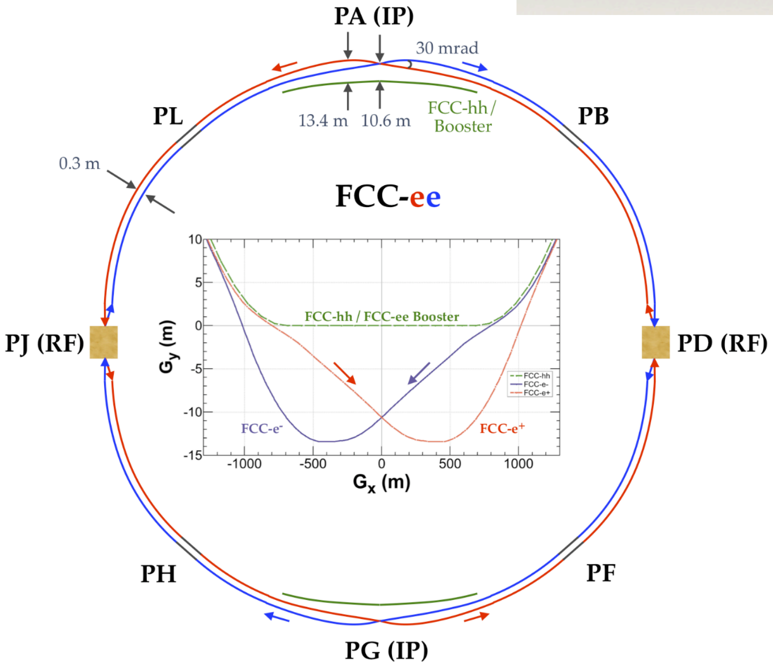
- Uncertainties not limited by experimental or theoretical uncertainties with sufficient statistics

FCC-ee Project

- Program in two phase
  - Phase 1: FCC-ee (Z, W, H, tt) as Higgs, EW and top factory
  - Phase 2: FCC-hh (~100 TeV) as natural continuation at energy frontier (ion and eh options)

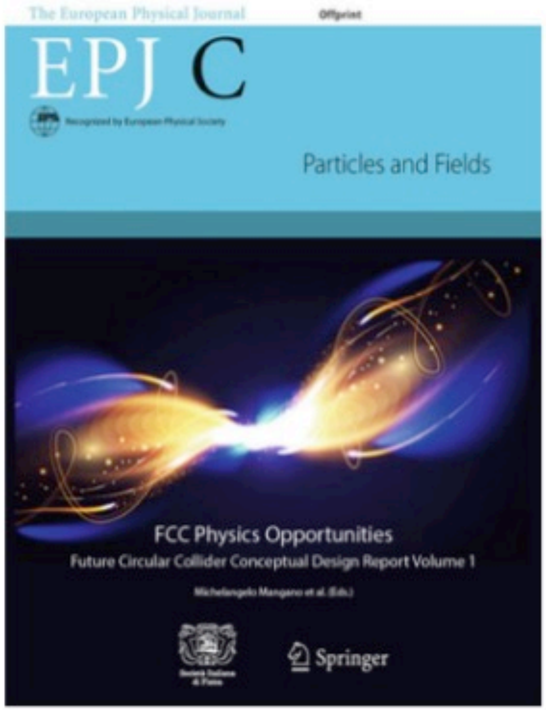




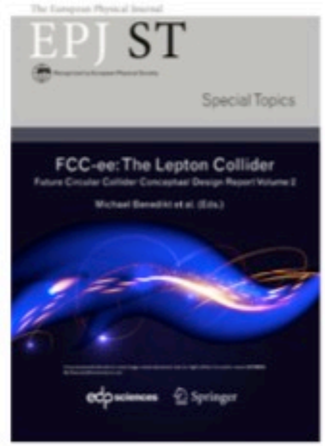


FCC-ee CDR

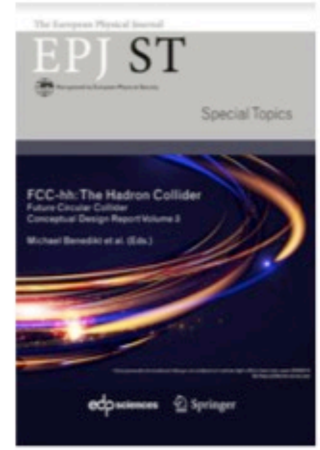
4 CDR volumes submitted to EPJ in December 2018.



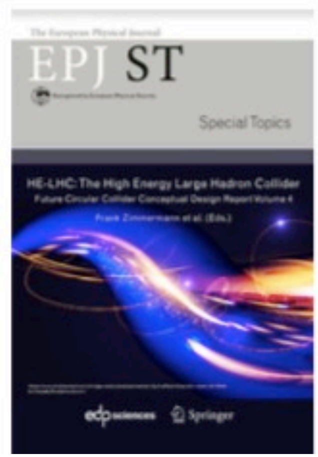
FCC Physics Opportunities



FCC-ee:
The Lepton Collider



FCC-hh:
The Hadron Collider



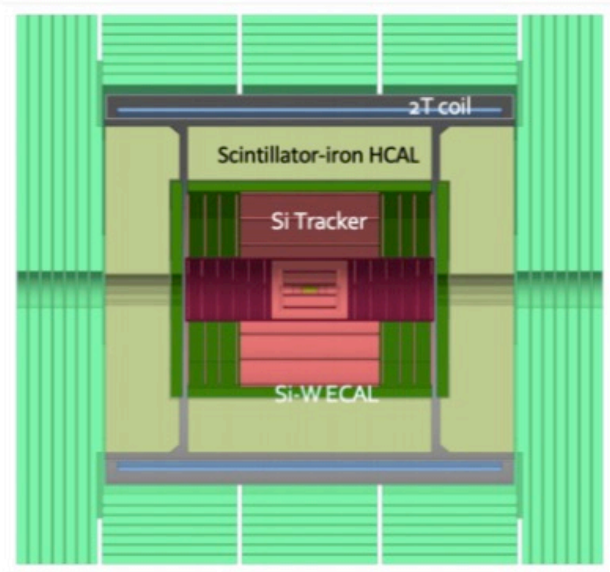
HE-LHC:
The High Energy Large Hadron Collider

Copies can be requested at
http://get-fcc-cdr.web.cern.ch

5

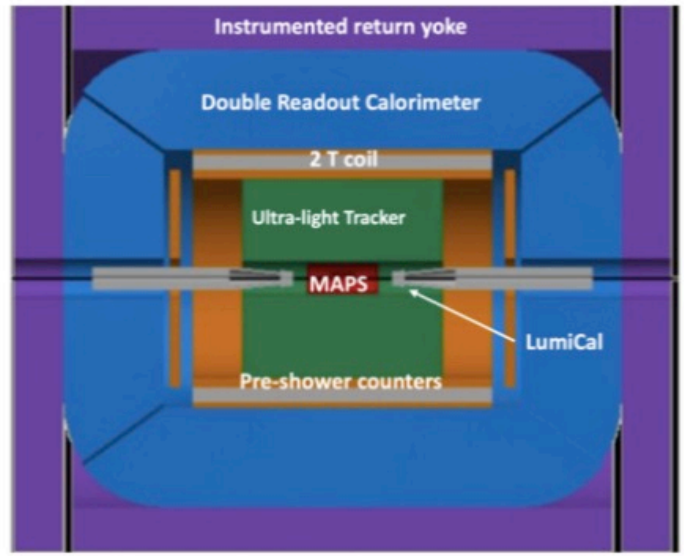
FCC Collaboration

FCC-ee Detector Concepts



CLD

- Consolidated option based on the detector design developed for CLIC
  - All silicon vertex detector and tracker
  - 3D-imaging highly-granular calorimeter system
  - Coil outside calorimeter system
- Proven concept, understood performance

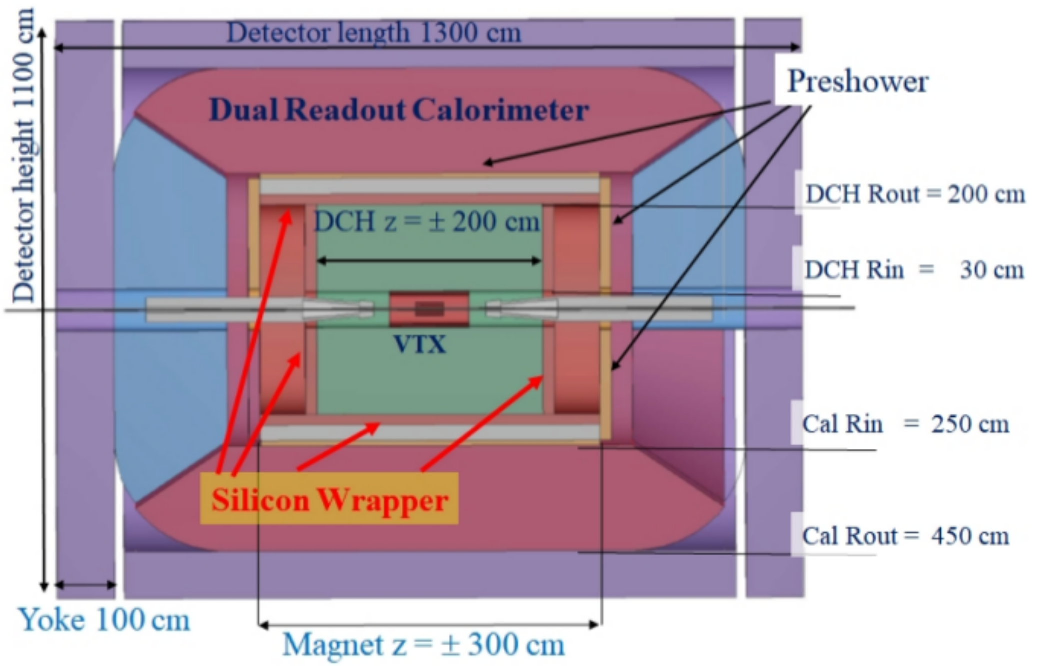


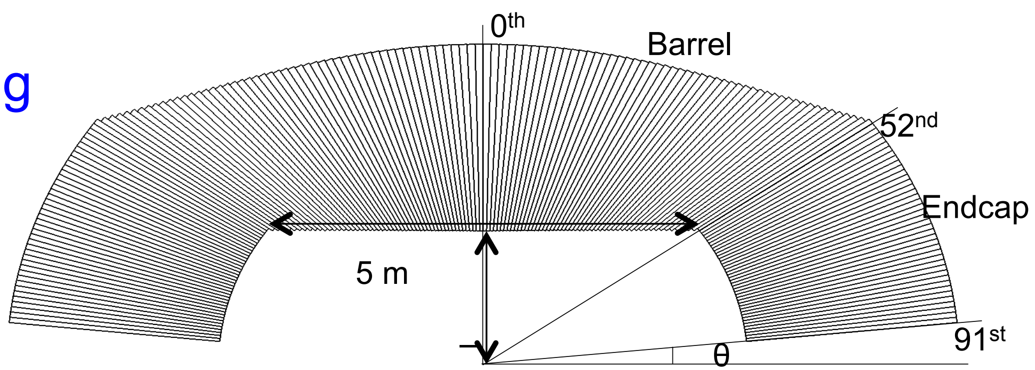
IDEA

- New, innovative, possibly more cost-effective design
  - Silicon vertex detector
  - Short-drift, ultra-light wire chamber
  - Dual-readout calorimeter
  - Thin and light solenoid coil inside calorimeter system

Contribution of Korean Group

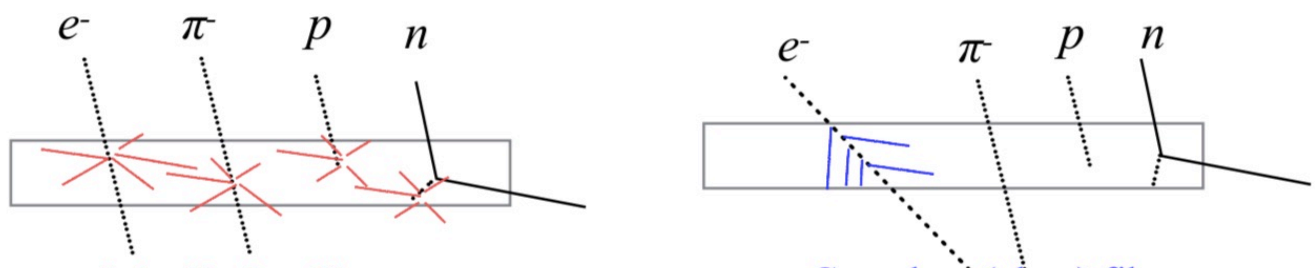
- Dual-readout calorimeter design has been included in the IDEA detector concept
- Korea team (S.W. Lee in KNU and H.D. Yoo in Yonsei Univ.) provided the design and played a leading role of the simulation study in the dual-readout collaboration
- Further studies are on-going toward TDR





Dual-readout Calorimeter

Signal generation: Scintillating & Cerenkov fibers

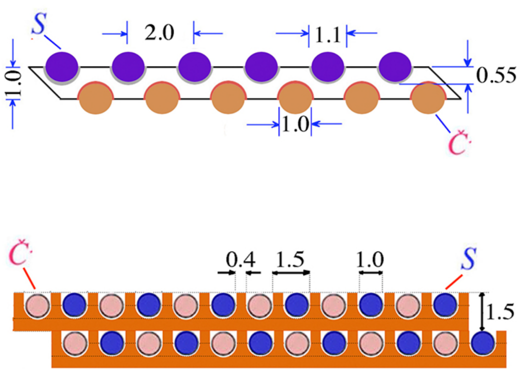


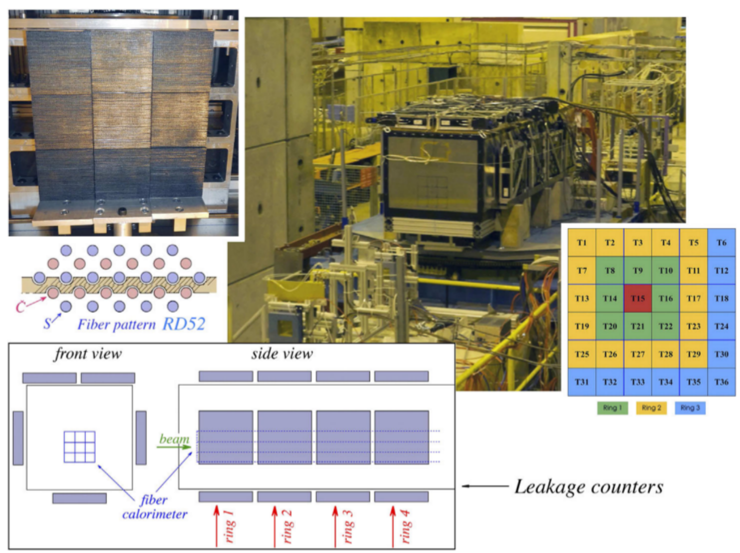
Scintillating fiber:
red light, random

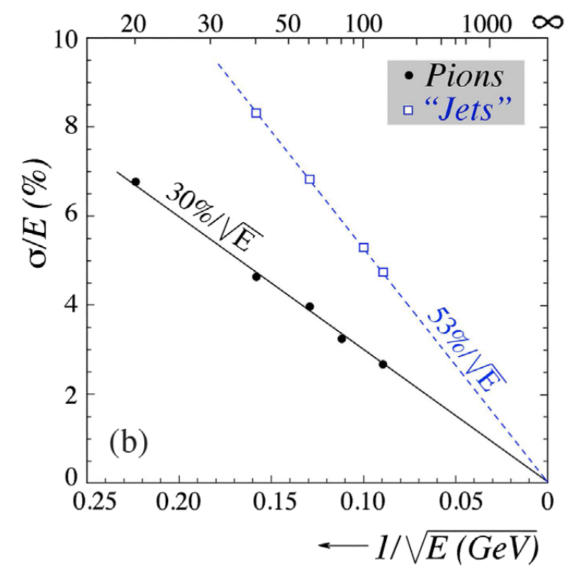
Sci > Cer

Cerenkov (clear) fiber:
blue light, directional

Rev. Mod. Phys. 90 (2018) 025002





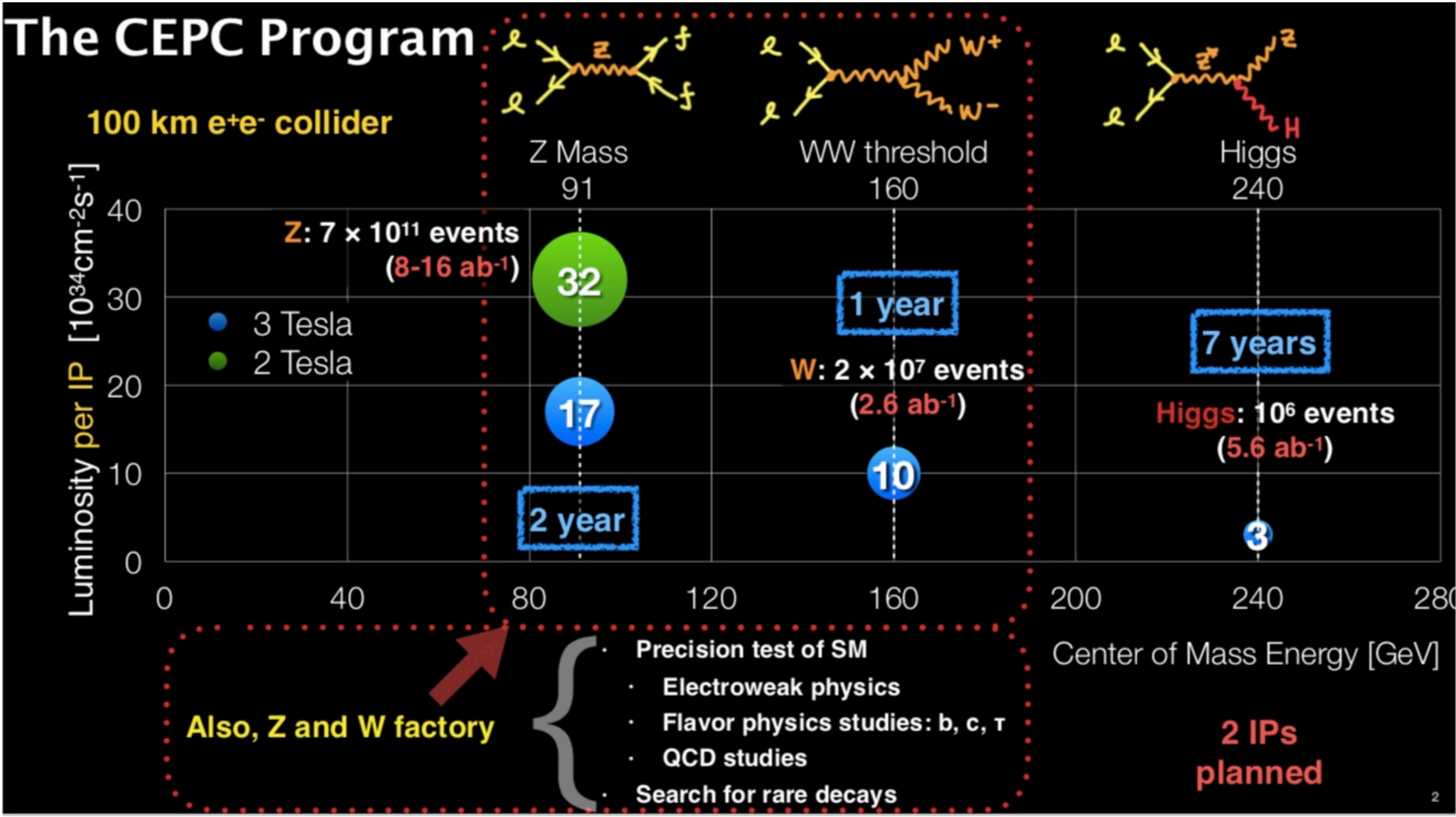


FC Dual-Readout Collaboration

- Current members
  - Korea
    - Yonsei Univ.: Hwidong Yoo
    - KNU: Sehwook Lee
  - USA
    - Iowa State University: John Hauptman
    - Texas Tech.: Richard Wigmans
  - Italy
    - INFN: Roberto Ferrari (Pavia) and many others
- Express interest and want to join this project
  - Korea:
    - Korea Univ.: Suyong Choi
    - KNU: Chang-Seong Moon, Hwanbae Park
  - Japan
    - University of Tokyo: Yuji Enari
  - China
    - (IHEP: Yifang Wang, Manqi Ruan)
  - Taiwan
    - NTU: Rong-Shyang Lu
    - NCU: Chia-Ming Kuo
  - UK
    - Univ. of Sussex: Iacopo Vivarelli

Please express your interest and join us!!

CEPC Project



CEPC CDR

Released November 2018

IHEP-CEPC-DR-2018-02
IHEP-EP-2018-01
IHEP-TH-2018-01

CEPC

Conceptual Design Report

Volume II - Physics & Detector

http://cepc.ihep.ac.cn/

The CEPC Study Group
October 2018

405 pages

CEPC CDR, Vol. 2 — Physics and Detector

➡ Executive Summary
1. Introduction
2. Overview of the Physics Case for CEPC
3. Experimental Conditions, Physics Requirements and Detector Concepts
4. Tracking System
5. Calorimetry
6. Detector Magnet System
7. Muon Detector System
8. Readout Electronics, Trigger and Data Acquisition
9. Machine Detector Interface and Luminosity Detectors
10. Simulation, Reconstruction and Physics Object Performance
11. Physics Performance with Benchmark Processes
12. Future Plans and R&D Prospects
13. Summary
➡ Glossary
➡ Author List

CEPC CDR

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CEPC

Conceptual Design Report

Volume II - Physics & Detector

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The CEPC Study Group
October 2018

405 pages

CEPC CDR, Vol. 1 and Vol. 2 — authorship

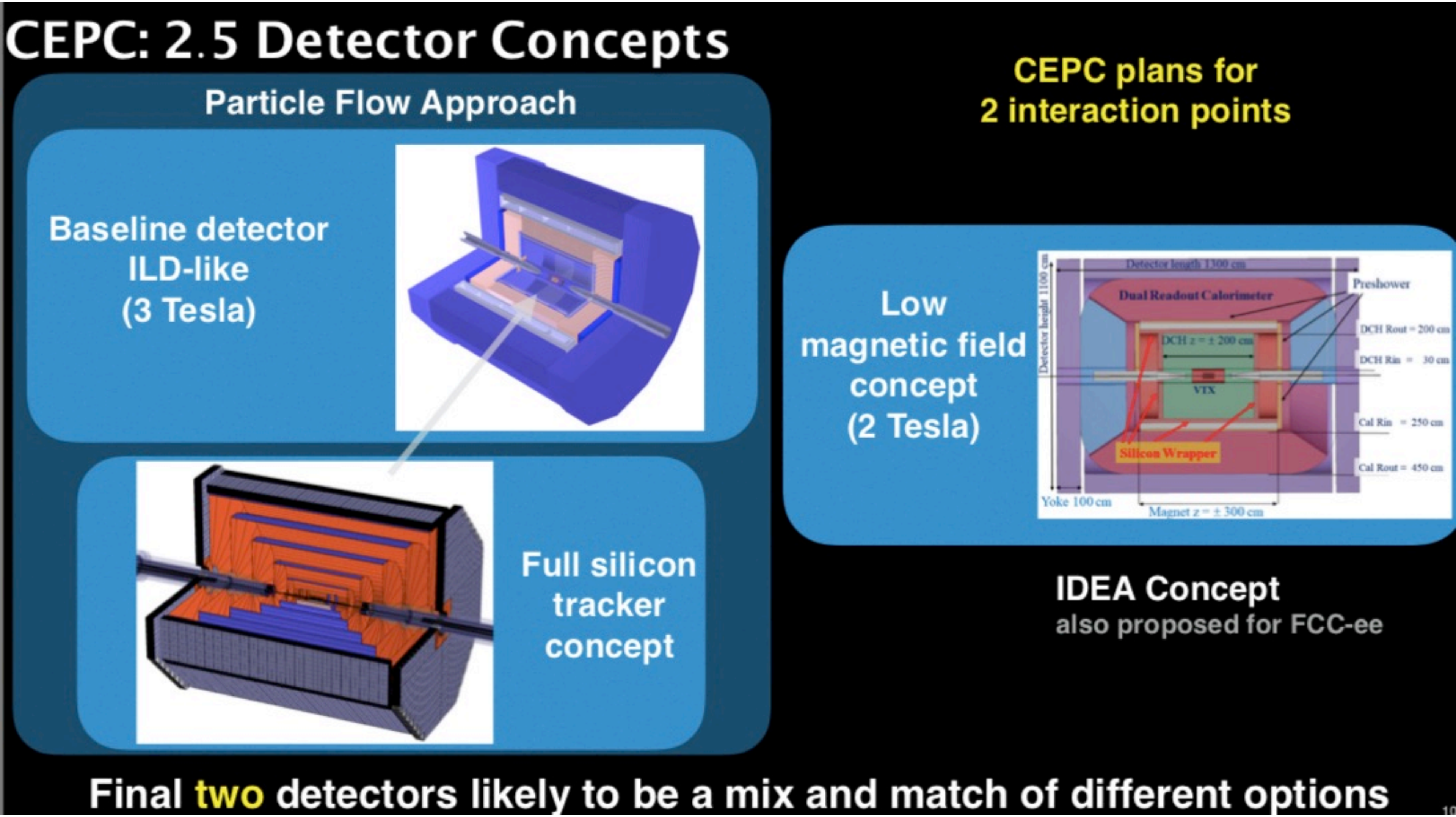
1149 authors from 222 institutions

29% from foreign institutions

24 countries

Australia	3
Belgium	3
Canada	3
Denmark	1
France	18
Germany	11
Indian	1
Israel	4
Italy	95
Japan	6
Korea	14
Mexico	1
Morocco	1
Netherlands	1
Pakistan	2
Russia	11
Serbia	6
South Africa	2
Spain	5
Sweden	2
Switzerland	9
UK	16
US	119

CEPC Detector Concepts



Status of Dual-Readout Calorimeter

CEPC CDR (4π Projective Geometry)

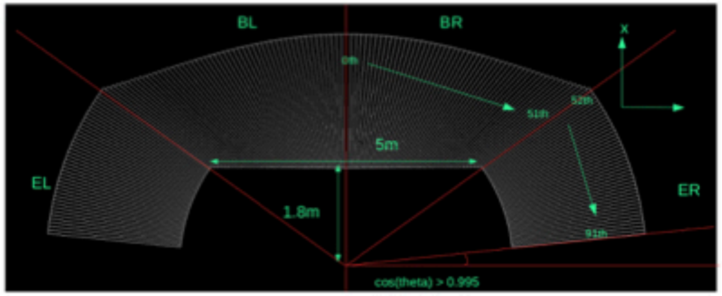
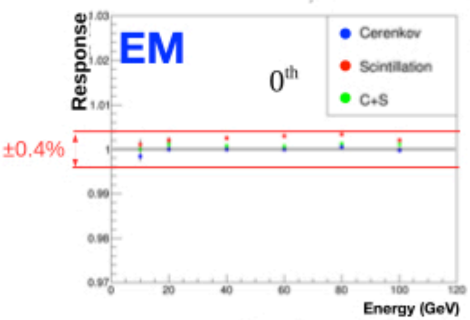


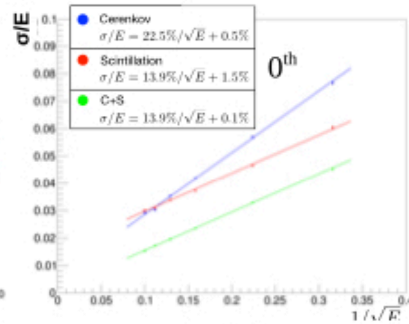
Figure 5.36: A possible 4π solution (called "wedge" geometry).

52k towers and 104k channels

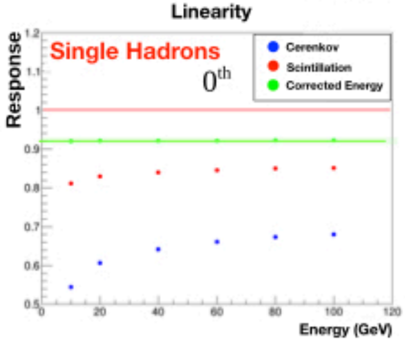
Linearity



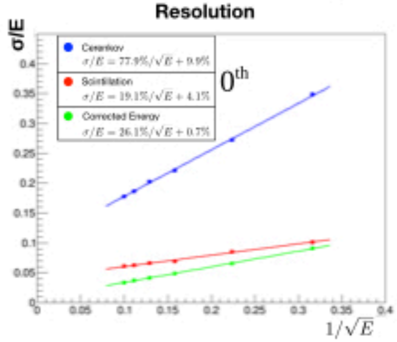
Resolution



Linearity



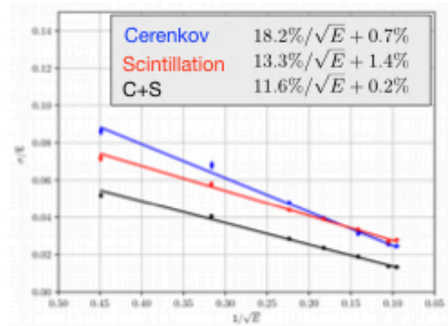
Resolution



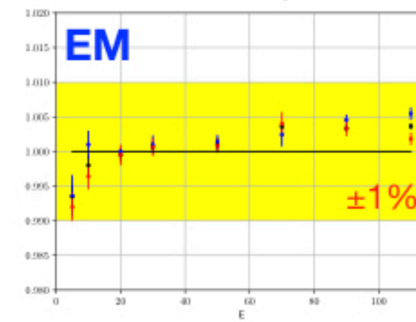
Toward TDR (Ongoing)

52k towers and total ~63 million channels (Stick SiPM to each fiber)

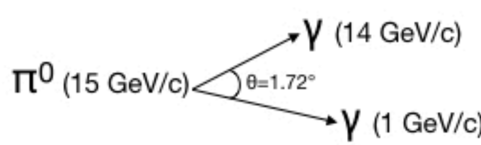
Resolution

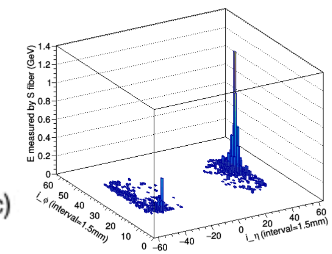


Linearity



High Granularity

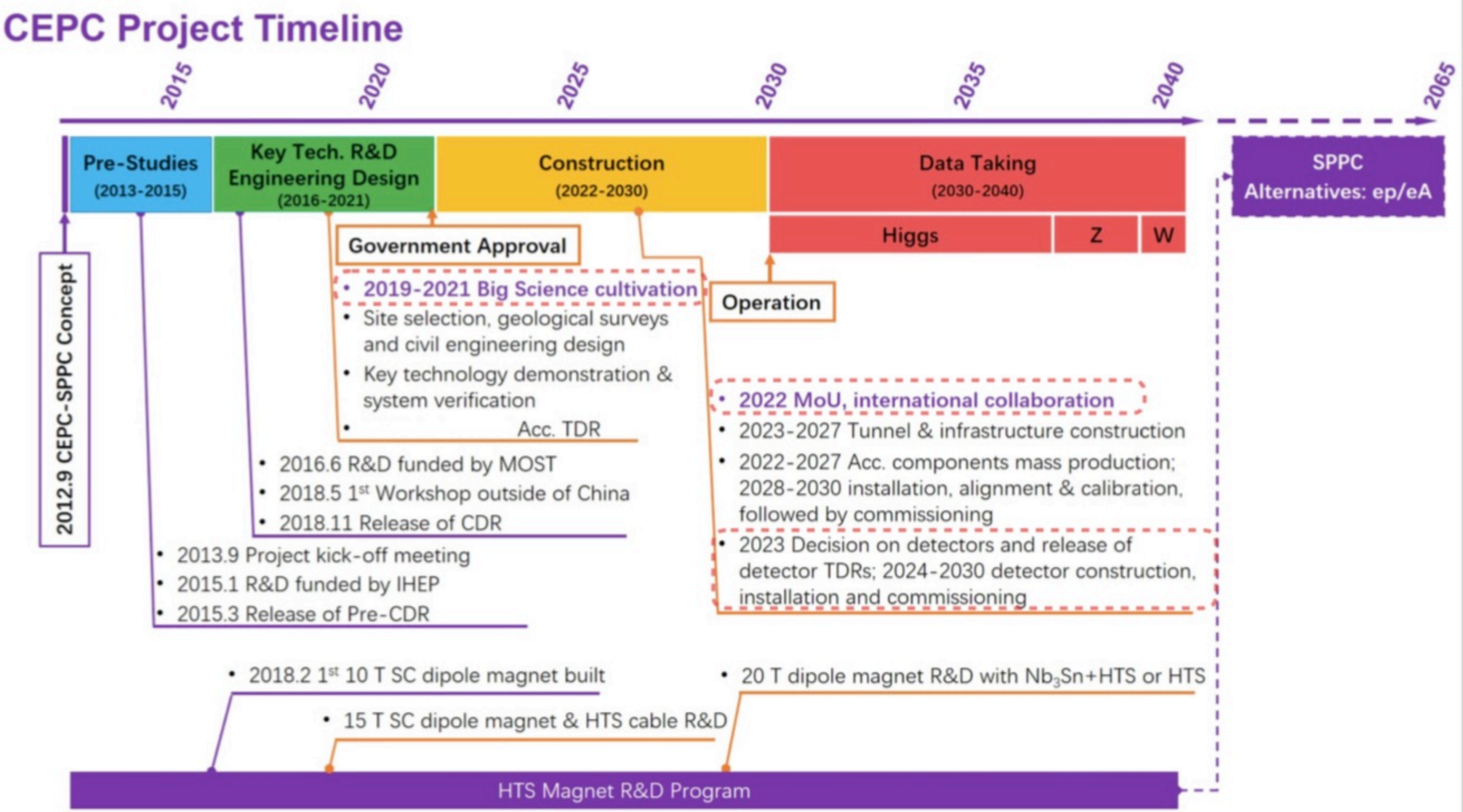




Preparation of Beam Tests

- Sticking SiPM to each fiber
- Proof of EM and hadronic energy resolutions
- Proof of Ultimate ability of dual-readout fiber calorimeter for the separation of two gammas from neutral pions

Timeline of CEPC

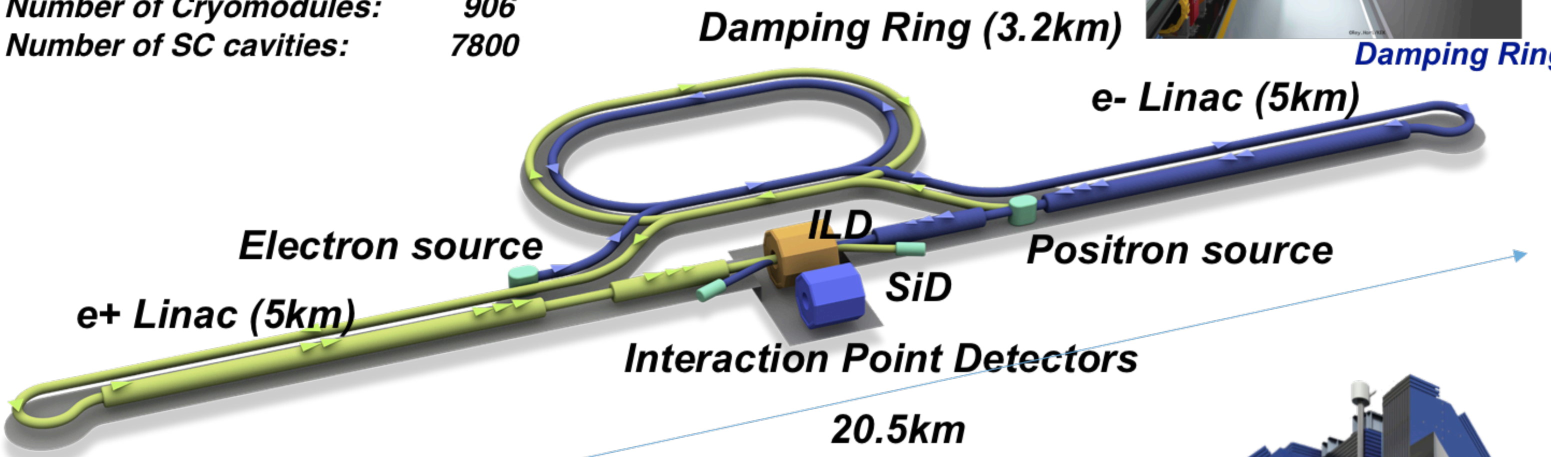


ILC Project

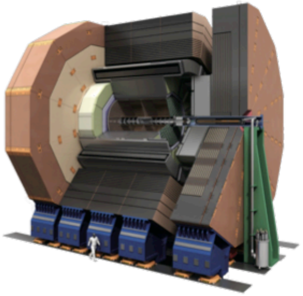
e+, e- Main Linac

Beam Energy : 125GeV + 125GeV = 250 GeV
Total accelerator: 20.5km
SRF Accelerator: 5km + 5km
Number of Klystrons: 218
Number of Cryomodules: 906
Number of SC cavities: 7800

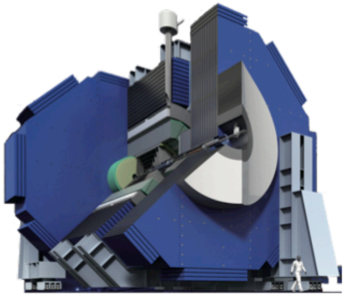
Damping Ring



Main Linac Accelerator



ILD Detector



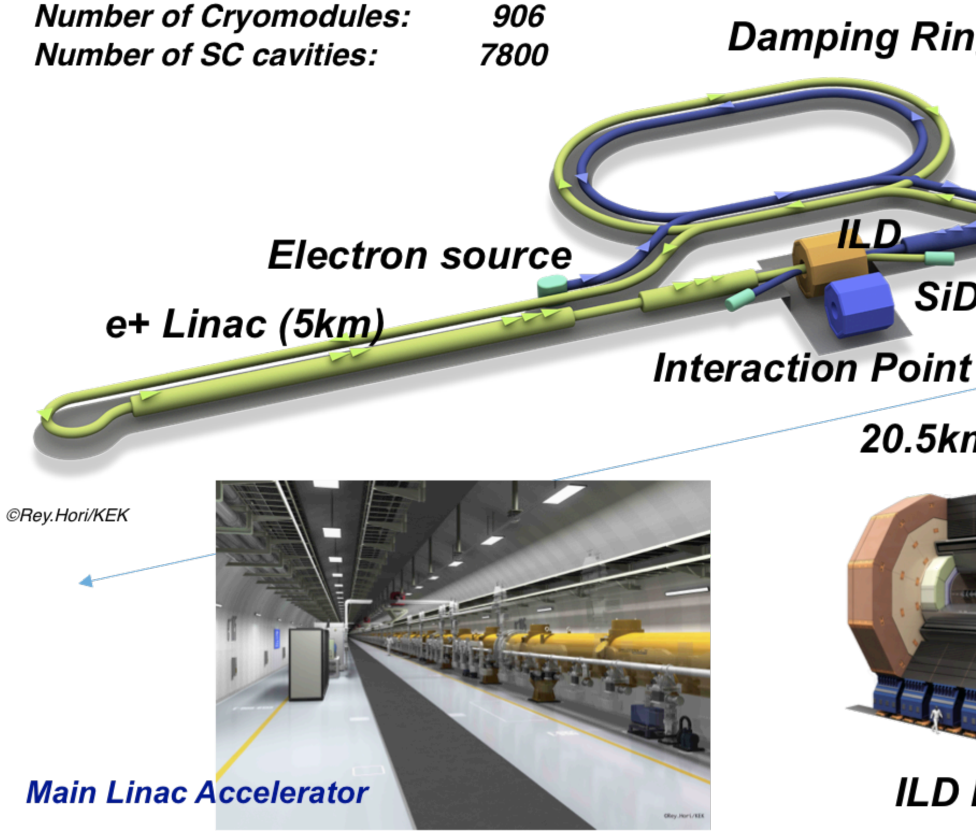
SiD Detector

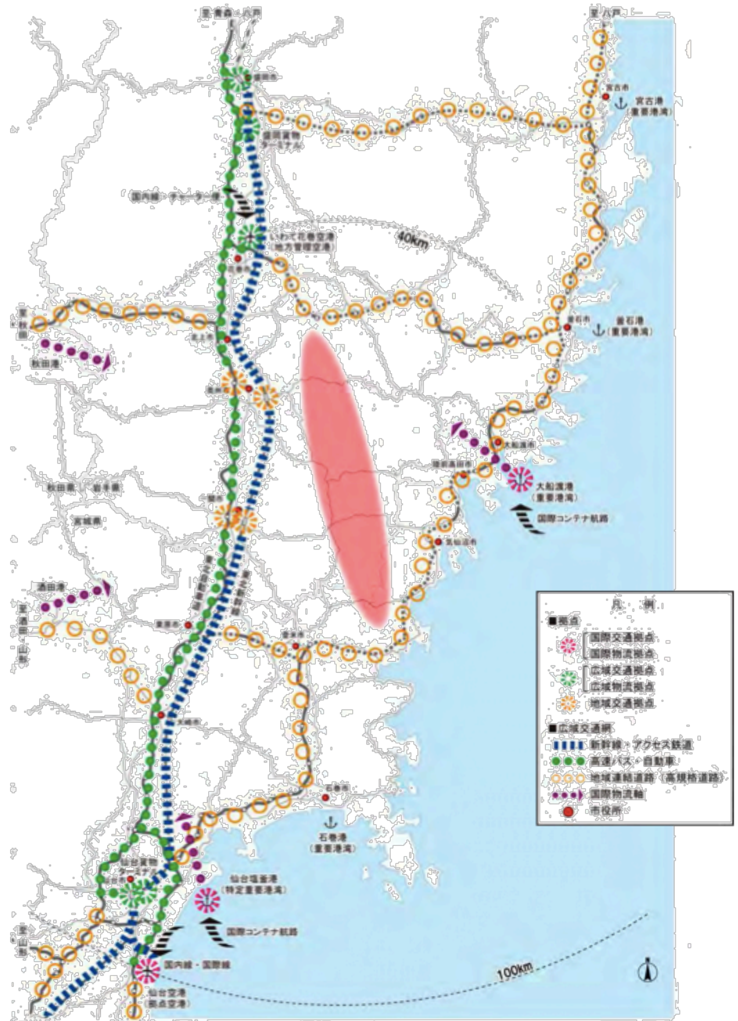
4

ILC Project

e+, e- Main Linac

Beam Energy : *125GeV + 125GeV = 250 GeV*
Total accelerator: *20.5km*
SRF Accelerator: *5km + 5km*
Number of Klystrons: *218*
Number of Cryomodules: *906*
Number of SC cavities: *7800*





Current Status

MEXT announcement at ICFA/LCB meeting

MEXT's view in regard to the ILC project

Executive Summary

March 7, 2019

Research Promotion Bureau, MEXT

- Following the opinion of the SCJ, MEXT has not yet reached declaration for hosting the ILC in Japan at this moment. The ILC project requires further discussion in formal academic decision-making processes such as the SCJ Master Plan, where it has to be clarified whether the ILC project can gain understanding and support from the domestic academic community.

- MEXT will pay close attention to the progress of the discussions at the European Strategy for Particle Physics Update.

- The ILC project has certain scientific significance in particle physics particularly in the precision measurements of the Higgs boson, and also has possibility in the technological advancement and in its effect on the local community, although the SCJ pointed out some concerns with the ILC project. Therefore, considering the above points, MEXT will continue to discuss the ILC project with other governments while having an interest in the ILC project.

16

SCJ Master Plan

Have interest in the ILC project

Continue to discuss ILC project

This is the first official announcement of MEXT about ILC

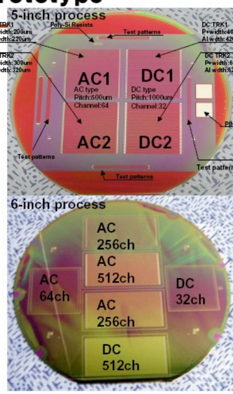
Activities of Korean Group

- Had huge efforts more than a decade

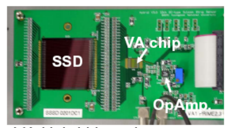
AC/DC SSD Prototype

AC-coupled Single-sided Silicon Strip Detector

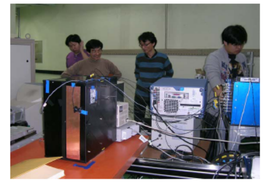
	5-inch		6-inch	
thckness(μm)	380		400	
Area (μm^2)	35000 × 35000		55610 x 29460	
Effective area (μm^2)	31970 × 31970		51264 x 25178	
SiO_2 layer thickness (nm)	1000		250	
Polysilicon length (μm)	10		8	
Polysilicon width (μm)	13500		480	
sheet resistance(kΩ)	~25		~400	
	Type 1	Type2	Type 1	Type2
Number of strips	64	64	256	512
Strip pitch (μm)	500	500	100	50
Strip width (μm)	200	300	8	8
readout width (μm)	220	320	12	12

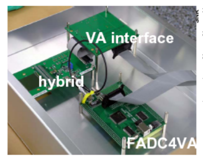


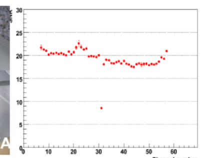
Beam Test

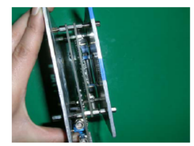


VA Hybrid board



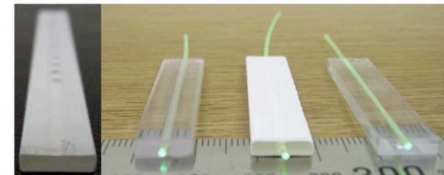




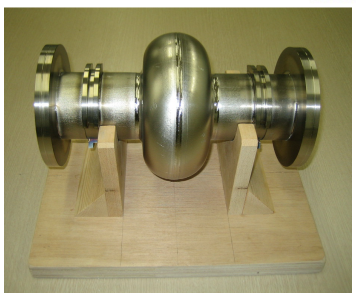


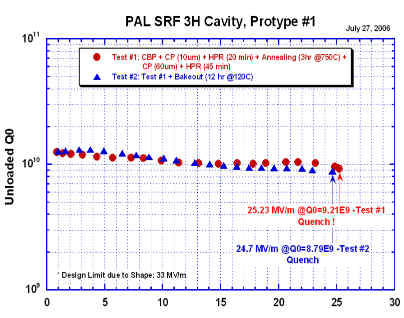
Extruded Plastic Scintillator

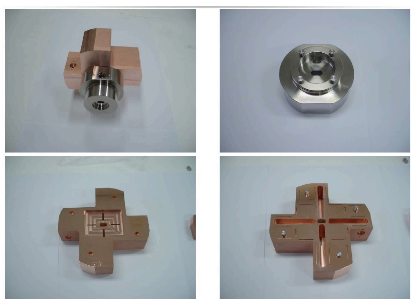
- Extrusion is easy to make numerous type of scintillator
- Lower cost than casting method
  - primary dopants: PPO
  - secondary dopants: POPOP

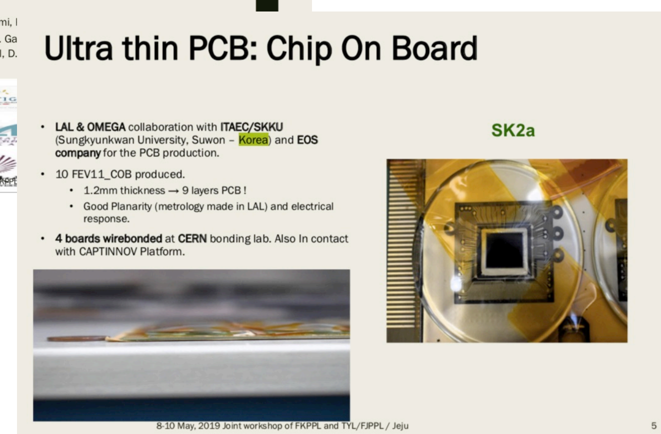


KNU strip with TiO_2 w/o hole	KNU strip w/o TiO_2 with hole	KNU strip with TiO_2 with hole	Kuraray tile with groove



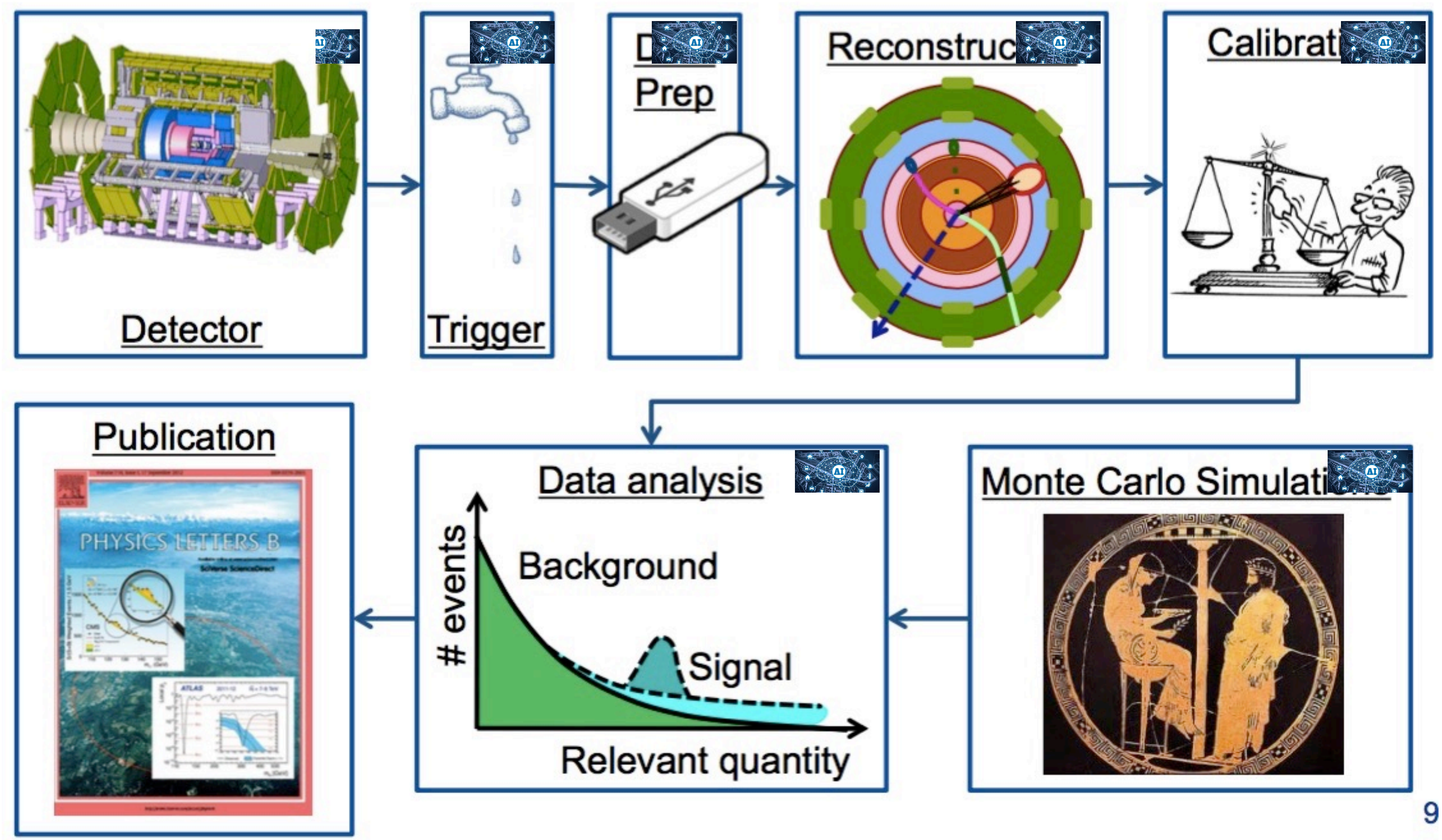






Machine Learning in HEP

- All aspects of AI applications with ML and DL techniques are under development in HEP explosively



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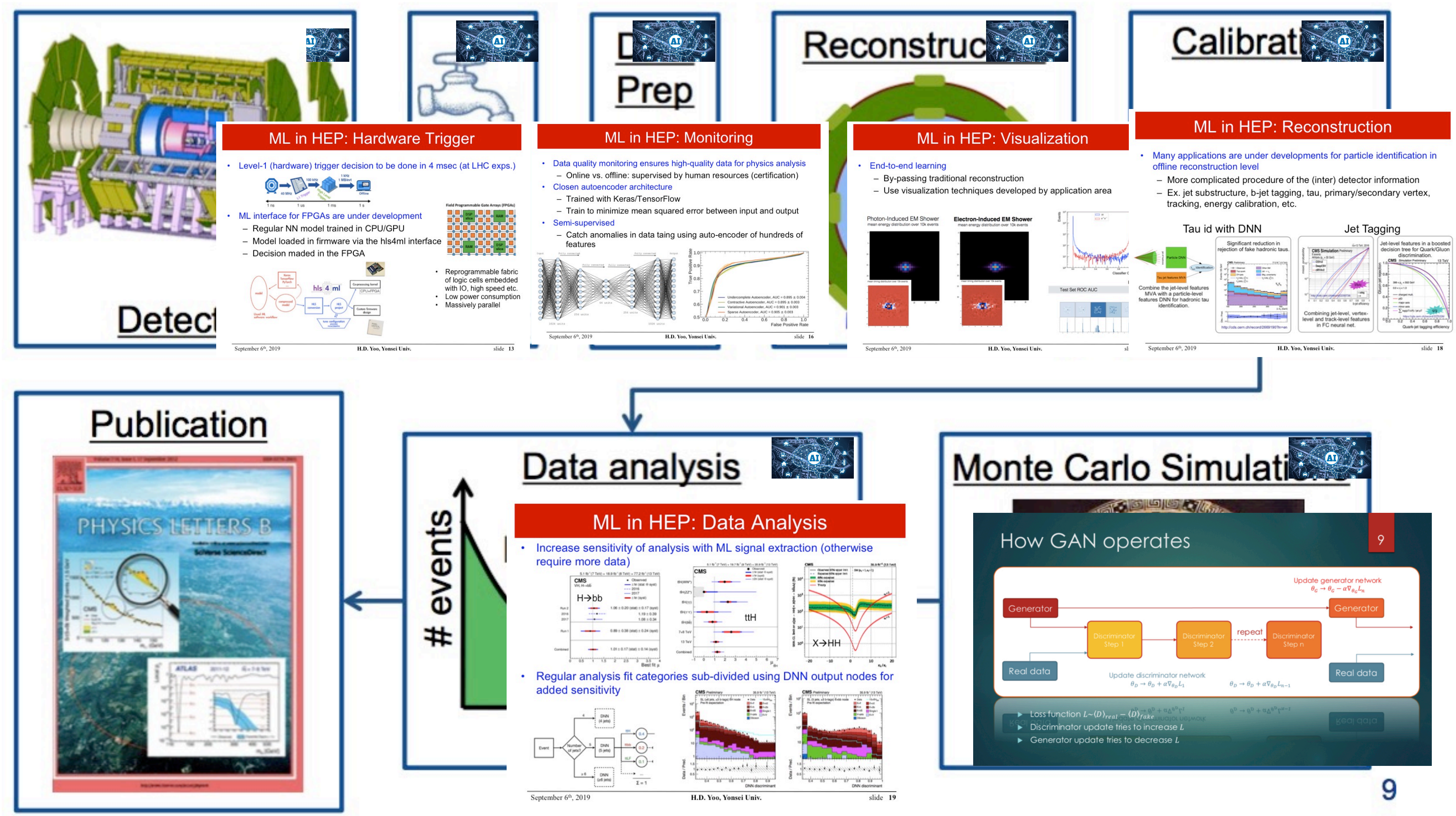
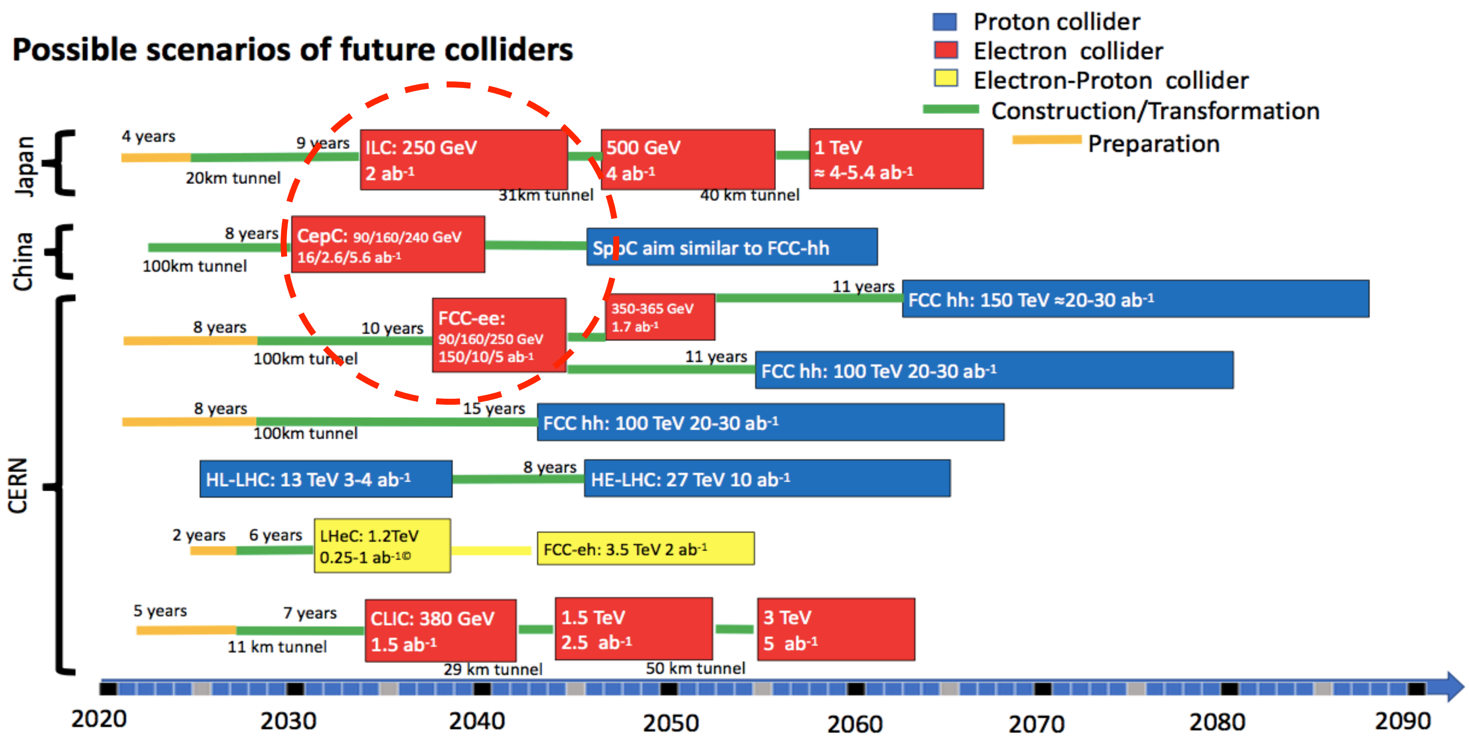


Machine Learning in HEP

- HL-LHC: test partial/semi-supervised AI system
  - L1/HLT triggering, offline object reconstruction, signal/background discriminant etc.
- Future Collider: playground to re-design all platform and frameworks based on AI friendly system



Things to Think Together

- Want to bring the following questions to K-HEP community with my personal keywords, based on Future Collider projects
- what kind of things can we (experimentalists) do?
  - Ownership of a detector
- what kind of big physics question do we want to ask?
  - Seek answers from talent our Korean theorists!! We can reflect this idea to the detector design
- which project, CEPC (China) vs FCC-ee (CERN)?
  - Do not separate two projects between CEPC and FCC-ee (neither project has been accepted yet)
  - Activities are well linked between two projects
  - CEPC targets to start early (2030s, FCC-ee right after HL-LHC)
- who can work for the future project?
  - We have abundant experts: combination of KCMS and KBelle collaborations

Things to Think Together

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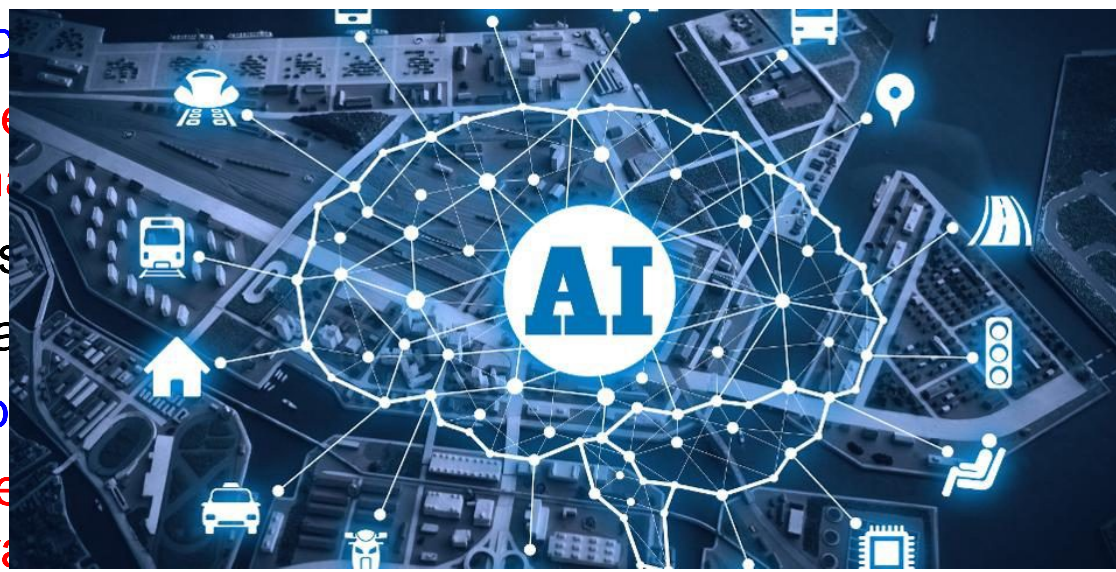
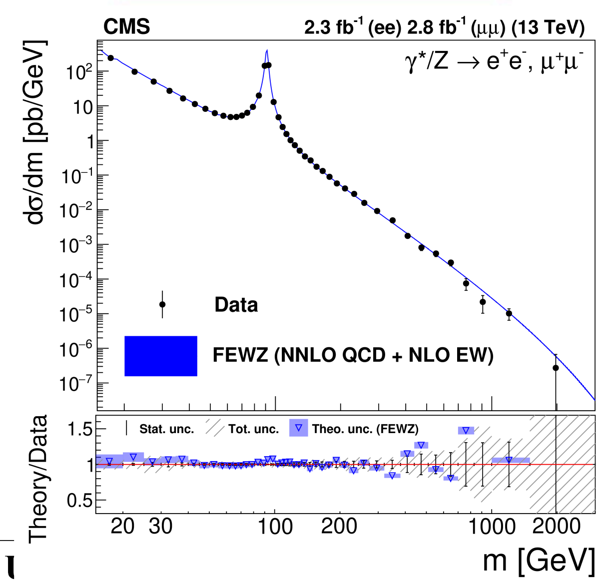


KCMS Collaboration

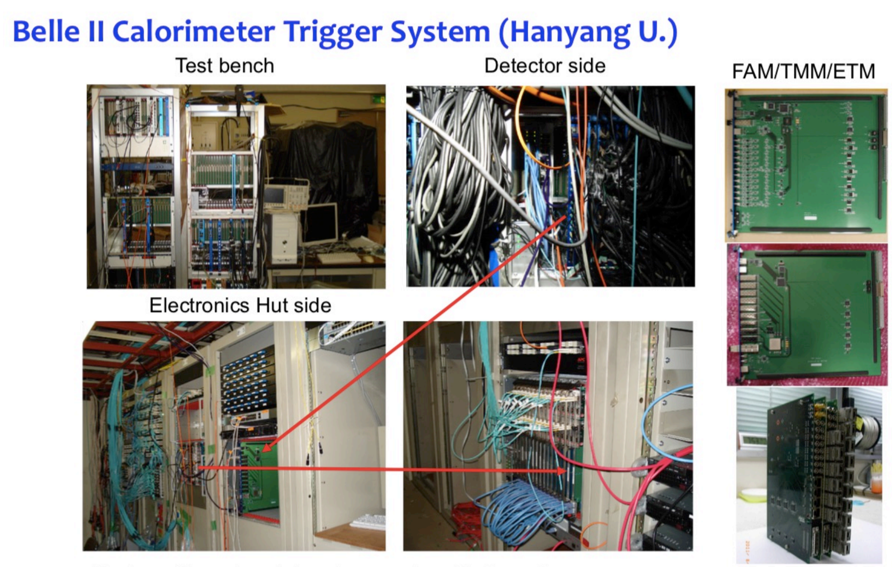
- Biggest exp. collaboration in Korea
  - 9 institutions, 18 faculties, 20 post-docs, ~70 Ph.D. students (+9 tech. staffs)
- Detector: RPC, GEM, trigger
- More than 30 papers during Run II (over 10% of entire CMS publications)
  - EXO searches: Z’, heavy neutrino, excited lepton, SUSY
  - Top quark property
  - SM precision measurement
  - Heavy ion
- Aggressive activities on ML

Exp. In 2020



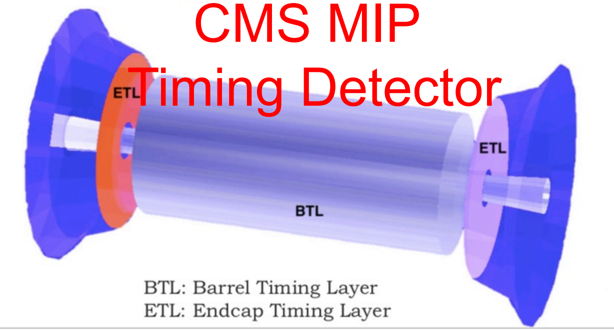
KBELLE Collaboration

- Very successful exp. collaboration in Korea
  - 9 institutions, 11 faculties, ~3 post-docs, 20-30 Ph.D. students
  - Current Belle co-spokesperson (2018-present): Prof. Y.J. Kwon (Yonsei. Univ.)
    - Former physics coordinator (2010-2018)
  - Former Belle II IB Chair (2013-2015): Prof. E. I. Won (Korea Univ.)
  - Hoam prize (2017): Prof. S.K Choi (Gyeongsang NU)
    - Discover X(3872), Y(3940), Z(4430) particles
- Detector: trigger, DAQ and monitoring, vertex detector
- Exotic hadrons, dark-sector search, B and Charm rare decays etc.

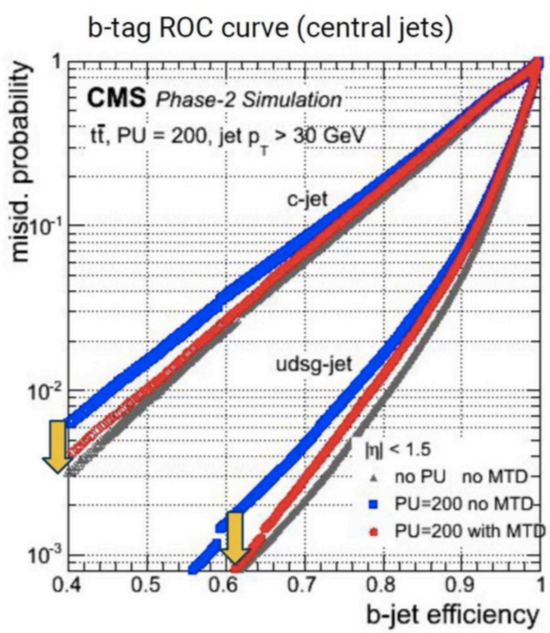


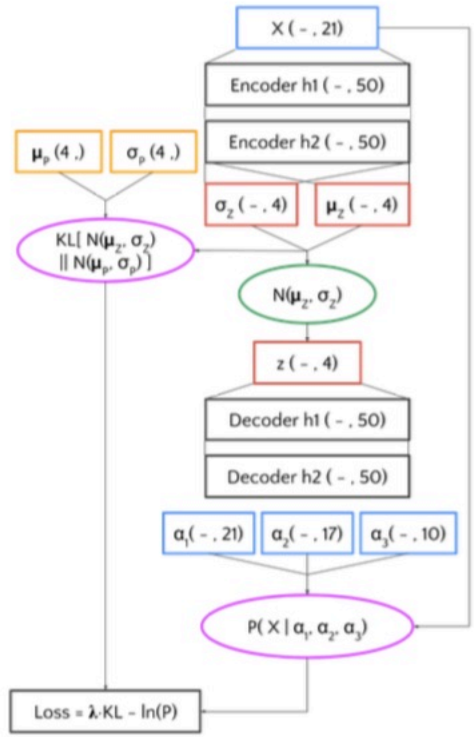
Good Examples (and many more …)

CMS MIP Timing Detector

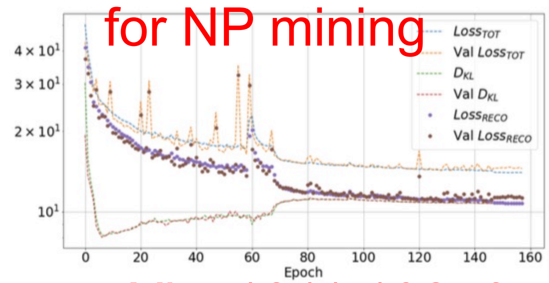


- Time tagging tracks with 30-50 ps resolution
- 3D→4D vtx reconstruction
- LLP search for BSM

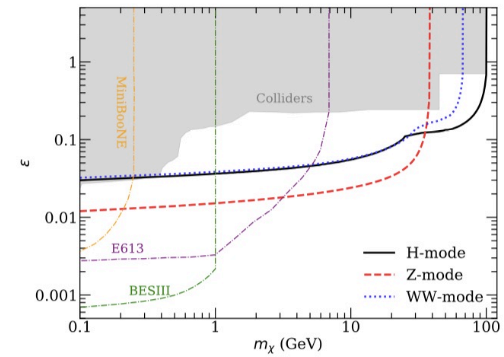




Variational autoencoders for NP mining



arXiv: 1811.10276




Probing dark matter particles at CEPC

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[b] Center for High Energy Physics, Peking University, Beijing 100871, China
[c] CAS Center for Excellence in Particle Physics, Beijing 100049, China
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Abstract: We investigate the capability of the future electron collider CEPC in probing the parameter space of several dark matter models, including millicharged dark matter models, Z' portal dark matter models, and effective dark matter operators. In our analysis, the monophoton final state is used as the primary channel to detect dark matter models at CEPC. To maximize the signal to background significance, we study the energy and angular distributions of the monophoton channel arising from dark matter models and from the standard model to design a set of detector cuts. For the Z' portal dark matter, we also analyze the Z' boson visible decay channel which is found to be complementary to the monophoton channel in certain parameter space. The CEPC reach in the parameter space of dark matter models is also put in comparison with Xenon1T. We find that CEPC has the unprecedented sensitivity to certain parameter space for the dark matter models considered; for example, CEPC can improve the limits on millicharge by one order of magnitude than previous collider experiments for $\mathcal{O}(1) - 100$ GeV dark matter.

Keywords: Beyond Standard Model, Cosmology of Theories beyond the SM

ArXiv ePrint: 1903.12114

Open Access, © The Authors. Article funded by SCOAP[3].

https://doi.org/10.1007/JHEP06(2019)009

JHEP06(2019)009

Millicharged DM
arXiv:1903.12114

Cost Est.: Dual-Readout Calorimeter

- Total cost estimated: ~2000억원
- Aim to reduce current estimated cost (by half) by various R&D (optical fiber, SiPM, etc.): 1000 ~ 1500억원
- Korean contribution: about 25% of total cost (250~400억원)
  - China: 50% (?)
  - Other countries: 25% (?)
- Partial detector prodcution before mass production: 25억원
- Fruitful collaboration is expected with various industries in Korea for R&D and the production of components
  - Need dedicated facilities to assemble the detector components
  - Train young generations

INFN PAVIA

accountability – some numbers

	Quantity	U.C.(€)	Cost (M€)
Total volume	474 m^3		
External surface	382 m^2		
Fibre length	230k km	250	57.4
Lead	3338 ton	2000	6.7
# of fibre / SiPM	191M	0.25	47.7
# of ASIC	6M	3	17.9
# of FPGA	23k	500	11.6
Services at al.			13.0
	Total		154.3

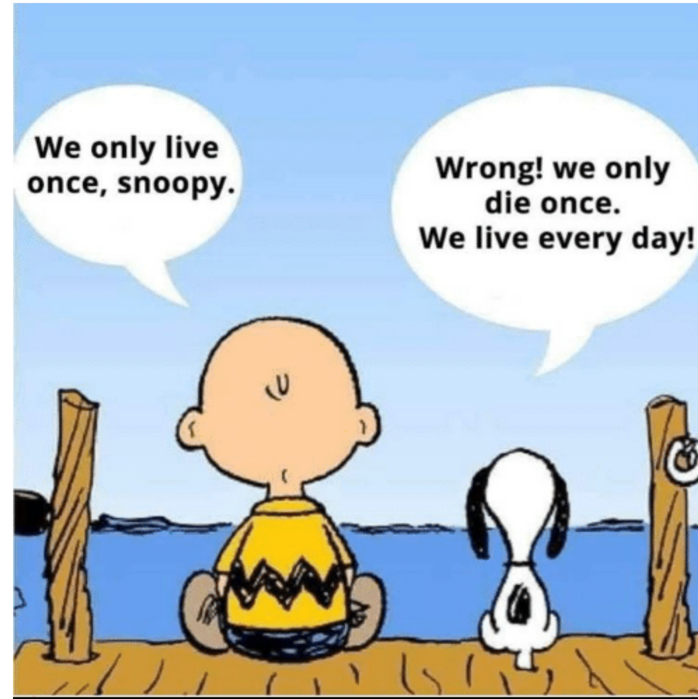
+ 3.7 (8.4) M for Iron (Copper)

CepC Calorimety Workshop, IHEP, Mar 13, 2019 60

By R. Ferrari (INFN)

Summary

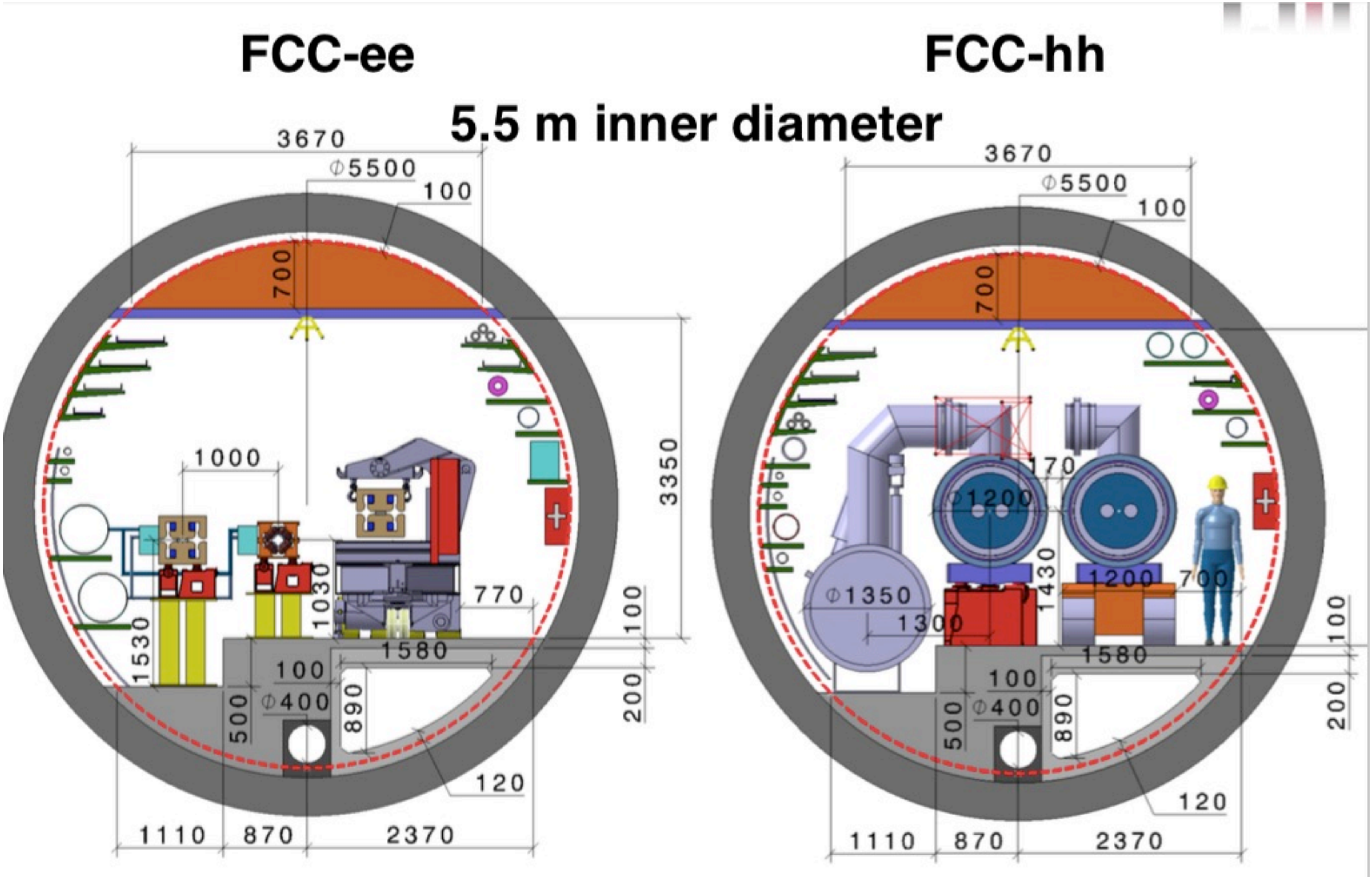
- It is obvious the collider-based experiment and future collider projects are **unique** and **irreplaceable** in the world



- Unique and abundant physics programs can be performed, particularly **Higgs factory**
- Based on successful achievements and well-trained person-power from KCMS and KBELLE collaborations, we should aim an ownership of a detector in future collider projects: **heritage from previous experiments and their expertise!!**
- **AI** will be a game changer => 4^{th} industrial revolution
  - Develop new system needed: future collider is a right playground

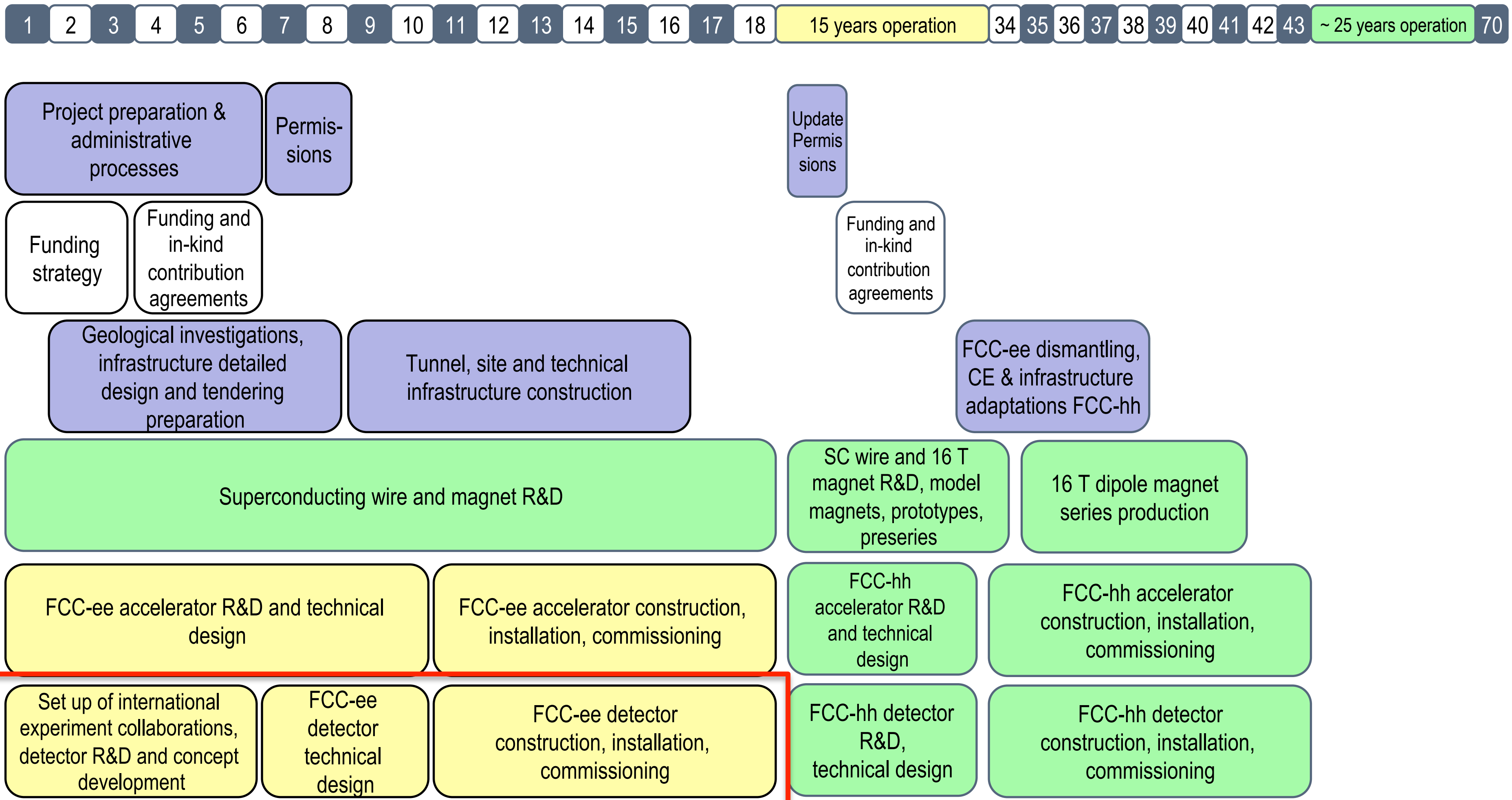
Back Up

FCC Tunnel



FCC-ee
FCC-hh
5.5 m inner diameter
3670
Φ5500
100
700
3350
1000
1030
770
1580
100
200
Φ400
500
890
1530
120
1110
870
2370
170
Φ1200
1430
1200
700
Φ1350
1300

FCC integrated project timeline

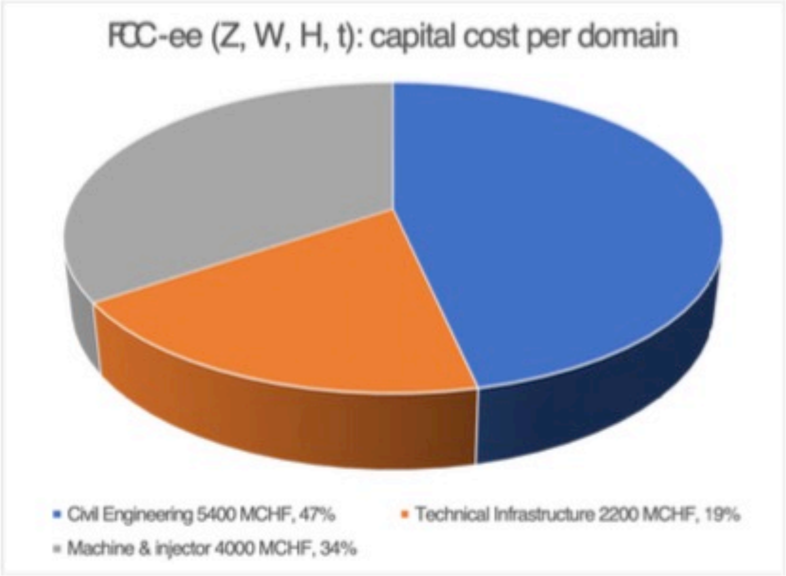


work is cut out for physics and detectors

ESPP

70 years seems like a long time!

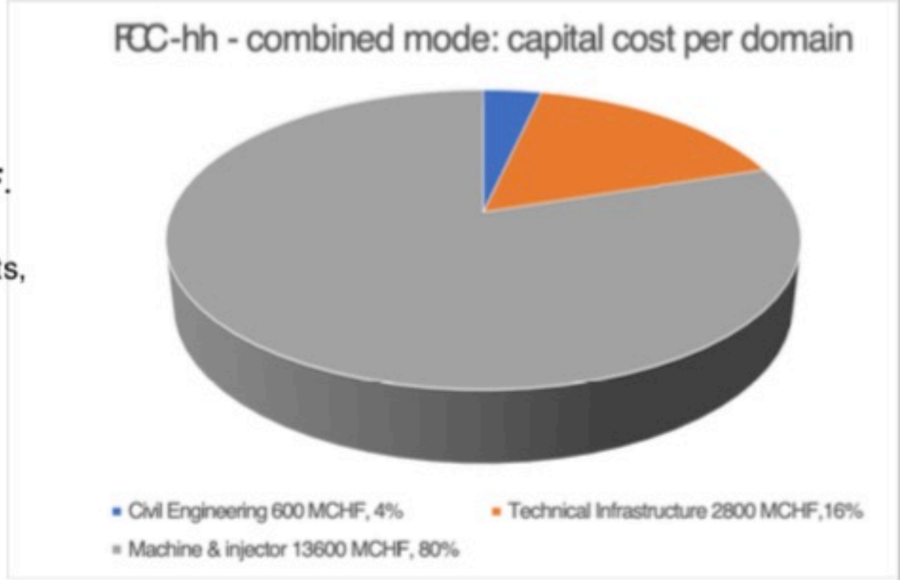
FCC Cost Estimate



Construction cost Phase 1 (FCC-ee) is 11.6 BCHF
- 5.4 BCHF for civil engineering (47%)
- 2.2 BCHF for technical infrastructure (19%)
- 4.0 BCHF accelerator and injector (34%)

Construction cost Phase 2 (FCC-hh) is 17.0 BCHF.
- 13.6 BCHF accelerator and injector (57%)
  - Major part for4,700 Nb_3Sn 16 T main dipole magnets, totalling 9.4 BCHF, targeting 2 MCHF/magnet.
- CE and TI from FCC-ee re-used
  - 0.6 BCHF for adaptation
- 2.8 BCHF for additional TI, driven by cryogenics

(Cost FCC-hh stand alone would be 24.0 BCHF.)



FCC-ee collider parameters

parameter	Z	WW	H (ZH)	ttbar
beam energy [GeV]	45	80	120	182.5
beam current [mA]	1390	147	29	5.4
no. bunches/beam	16640	2000	393	48
bunch intensity [10^{11}]	1.7	1.5	1.5	2.3
SR energy loss / turn [GeV]	0.036	0.34	1.72	9.21
total RF voltage [GV]	0.1	0.44	2.0	10.9
long. damping time [turns]	1281	235	70	20
horizontal beta* [m]	0.15	0.2	0.3	1
vertical beta* [mm]	0.8	1	1	1.6
horiz. geometric emittance [nm]	0.27	0.28	0.63	1.46
vert. geom. emittance [pm]	1.0	1.7	1.3	2.9
bunch length with SR / BS [mm]	3.5 / 12.1	3.0 / 6.0	3.3 / 5.3	2.0 / 2.5
luminosity per IP [10^{34} $cm^{-2}s^{-1}$]	>200	>25	>7	>1.4
beam lifetime rad Bhabha / BS [min]	68 / >200	49 / >1000	38 / 18	40 / 18

My view on all choices

	Science	Upgradability	Technology maturity	Low cost ?	Available now ?
ILC	****	*	****	****	*****
CLIC	****	**	***	***	****
CEPC	*****	****	****	*****	*****
SppC	****	*	*	**	*
FCC-ee	*****	****	****	****	*****
FCC-pp	****	*	**	*	**
VLHC(40 TeV)	***	**	****	***	*****
Muon collider	*****	**	?	?	?
Plasma	*****	**	? ?	***	?

By Yifang Wang at Kaix workshop

Strategy: My Personal View

- Highest priority: Higgs coupling to 1%
  - FCC-ee and CEPC should proceed in parallel until one is approved:
    - Competition can enhance the chance for both
    - Higgs factory is too important to miss
  - Try to get one of the ILC and CLIC
    - Linear technology can not be ignored
    - High energy lepton collider(~10 TeV) will be needed, if new physics is discovered
    - Continue to lobby for ILC, and continue the CLIC effort
    - Only ILC/CLIC is not enough, multi-detectors needed anyway: we should forget about the push-pull option
- Major R&D effort for pp collider:
  - Aiming for (iron-based) HTC magnet(~ 10-15 yrs): FCC-hh/SPPC
  - Low energy FCC-hh(40 TeV) option lacks the technology impact
- Maintain R&D effort for $\mu^+\mu^-$ and wake-field acceleration

By Yifang Wang at Kaix workshop