Feedback from HK workshop

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February 2, 2019

中国科学院高能物理研究所
Institute of High Energy Physics
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Program Activities

Date / Time	Event
Jan 9 (Wed) 11:00 - 12:00	**Effective Fields Theory after a New Physics Discovery [Slides]** *Speaker: Matthias NEUBERT (Johannes Gutenberg University Mainz)* **Venue: IAS4042, 4/F, Lo Ka Chung Building, Lee Shau Kee Campus, HKUST**
Jan 9 (Wed) 14:00 - 15:00	**How to Break Electroweak Symmetry Naturally? [Slides]** *Speaker: Jing SHU (Institute of Theoretical Physics, Chinese Academy of Sciences)* **Venue: IAS4042, 4/F, Lo Ka Chung Building, Lee Shau Kee Campus, HKUST**
Jan 10-11 (Thu-Fri)	**Mini-Workshop: Theory - Physics Opportunities and Advanced Tools** **Venue: IAS4042, 4/F, Lo Ka Chung Building, Lee Shau Kee Campus, HKUST**
Jan 14 (Mon) 11:00 - 12:00	**Cosmological Production of Dark Nuclei [Slides]** *Speaker: Andrea TESI (Istituto Nazionale di Fisica Nucleare - Firenze)* **Venue: IAS4042, 4/F, Lo Ka Chung Building, Lee Shau Kee Campus, HKUST**
Jan 14 (Mon) 14:00 - 15:30	**Discussion on "Ultralight Axion-like Dark Matter"** *Discussion Leader: Thomas BROADHURST (University of the Basque Country)* **Venue: IAS4042, 4/F, Lo Ka Chung Building, Lee Shau Kee Campus, HKUST**
Jan 16 (Wed) 11:00 - 12:00	**Searches for Higgs Decays into New Light Bosons [Slides]** *Verena Ingrid MARTINEZ OUTSCHOORN (University of Massachusetts Amherst)* **Venue: IAS2042, 2/F, Lo Ka Chung Building, Lee Shau Kee Campus, HKUST**
Jan 17-18 (Thu-Fri)	**Mini-Workshop: Experiment / Detector - Tracking and Calorimetery at Colliders** **Venue: IAS2042, 2/F, Lo Ka Chung Building, Lee Shau Kee Campus, HKUST**
Jan 17-18 (Thu-Fri)	**Mini-Workshop: Accelerator - Beam Polarization in Future Colliders** **Venue: IAS4042, 4/F, Lo Ka Chung Building, Lee Shau Kee Campus, HKUST**

Theory workshop

Jan 16: Satellite MOST2 Pixel Meeting

Experiment workshop

Experiment/Detector Workshop

Tracking and Calorimetry at
High Luminosity Circular Colliders

Case study:
FCC-ee at Z-pole luminosities

Mini-Workshop: Experiment / Detector - Tracking and Calorimetery at Colliders (Jan 17-18, 2019)

Workshop Program

Time	Event
09:00 - 09:30	***Physics Requirements*** **[Slides]** **Paolo GIACOMELLI** *INFN Bologna*
09:30 - 10:15	***Beam Energy Calibration*** **[Slides]** **Nikolai MUCHNOI** *Budker Institute of Nuclear Physics (BINP)*
10:15 - 10:45	Coffee Break (Venue: Open Area, 2/F)
10:45 - 11:30	***FCC-ee Interaction Region Backgrounds*** **[Slides]** **Georgios VOUTSINAS** *CERN*
11:30 - 12:15	***Operational Experience with the DEPFET Based PXD Pixel Detector at Belle II and Possible Improvements Utilizing Micro-channel Cooling*** **[Slides]** **Ladislav ANDRICEK** *Semiconductor Laboratory of the Max Planck Society*
12:15 - 14:00	Lunch (Self-arranged)
14:00 - 14:45	***Recent Developments in Silicon Tracker Mechanics*** **[Slides]** **Rafael COELHO LOPES DE SÁ** *University of Massachusetts Amherst*
14:45 - 15:30	***Silicon Tracker Designs for Detectors at Future e+e- Colliders (Full Silicon)*** **[Slides]** **Emilia LEOGRANDE** *CERN*
15:30 - 16:00	Coffee Break (Venue: Open Area, 2/F)
16:00 - 16:45	***Drift Chamber at High-luminosity e+e- Colliders*** **[Slides]** **Francesco GRANCAGNOLO** *Istituto Nazionale di Fisica Nucleare - Lecce*
16:45 - 17:30	***Discussion on Silicon Trackers*** **[Slides]**

Requirements and physics conditions

Silicon Detectors

Drift Chamber

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Workshop Program

09:00 - 09:45	***Ultragranular Silicon ECAL at HL e+e- Colliders* [Slides]** **Jean Claude BRIENT** *Université Paris-Saclay*	Calorimeters
09:45 - 10:30	***Ultragranular HCAL at HL e+e- Colliders* [Slides]** **Jianbei LIU** *University of Science and Technology of China*	Calorimeters
10:30 - 11:00	Group Photo and Coffee Break (Venue: Open Area, 2/F)	Calorimeters
11:00 - 11:45	***Dual Readout Calorimetry at HL e+e- Colliders* [Slides]** **Roberto FERRARI** *University of Pavia*	Calorimeters
11:45 - 12:30	***Crystal EM Calorimeter for HL e+e- Colliders* [Slides]** **Sarah ENO** *The University of Maryland*	Calorimeters
12:30 - 14:00	Lunch (Self-arranged)	
14:00 - 14:45	***Discussion on Calorimetry***	
14:45 - 15:30	***Vertex Detector Concept & Technologies for an Apparatus at a Leptonic Collider* [Slides]** **Massimo CACCIA** *University of Insubria*	Silicon Detectors
15:30 - 15:35	***TPC Introduction to Discussion*** **Joao GUIMARAES DA COSTA** *Institute of High Energy Physics, Chinese Academy of Sciences*	TPC
15:35 - 16:20	***TPC Tracker at e+e- Collider and Limitations at HL* [Slides]** **Paul COLAS** *Université Paris-Saclay*	TPC
16:20 - 16:50	Coffee Break (Venue: Open Area, 2/F)	TPC
16:50 - 17:35	***From Gated to Continuous Readout: The Upgrade of the ALICE TPC* [Slides]** **Piotr GASIK** *CERN*	TPC
17:35 - 18:20	***TPC at CEPC and How to Address Its Limitations* [Slides]** **Huirong QI** *Institute of High Energy Physics, Chinese Academy of Sciences*	TPC
18:20 - 19:05	***Final Discussion on TPC and Trackers***	TPC

Points to take home

- **Silicon detectors**
  - Low-material requirements and subsequently mechanics are the most challenging for e^+e^- future silicon trackers
    - Monolithic sensors (sensor/ASIC integrated) — CMOS technology likely available
      - Power consumption a challenge
    - Air cooling is not trivial — requires lots of mechanical design considerations
    - Consider micro-channel cooling or other new advance methods
      - Rafael Coelho (UMass) interested in collaborating with CEPC in this area
    - No existing detector can satisfy CEPC requirements: ALICE ITS uses twice as much material/larger power consumption
  - CEPC sensor R&D in the forefront of current research — readout rates one step ahead of ALICE
  - PID detectors suggested to be integrated into full silicon tracker (Weiming Yao)

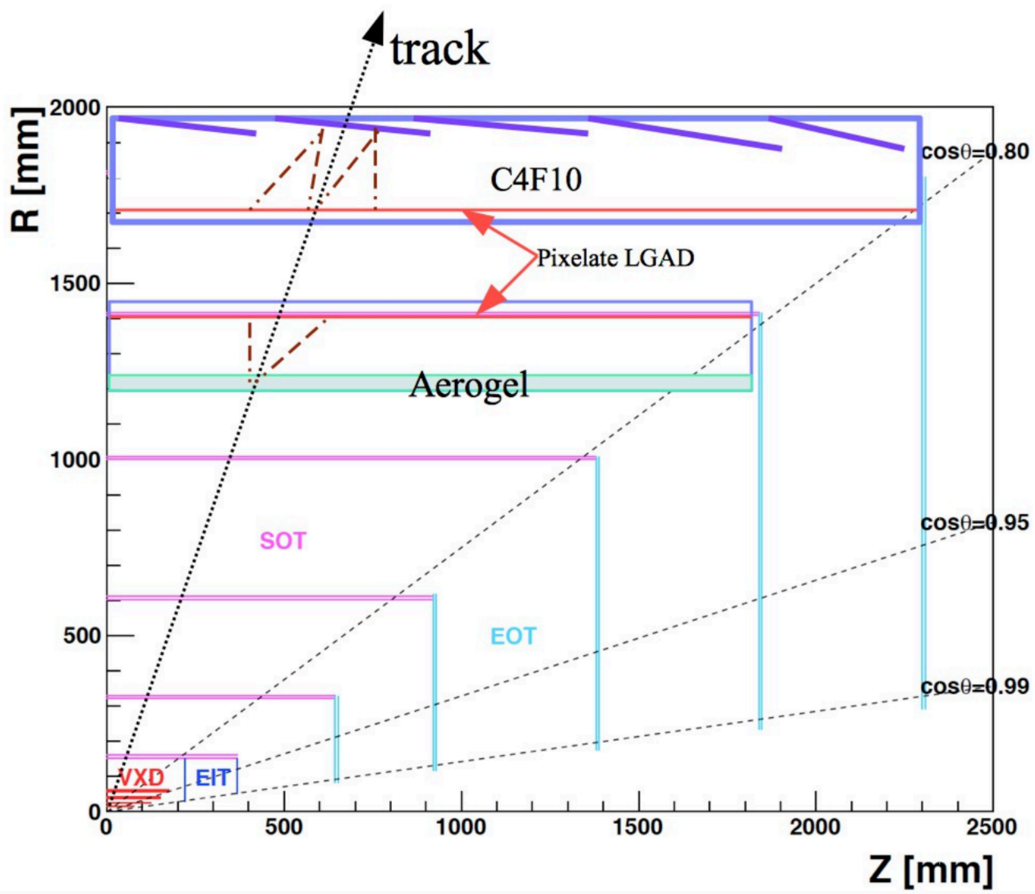
PID with Silicon Trackers

PID with Silicon Trakers

Wei-Ming YAO

- FST in CDR has few concerns:
  - Limited dE/dx
  - Double sided strip layers with higher material budget
- TOF with LGAD pixelate with 10 ps timing:
  - Replacing outer strip layers with LGAD layer to reduce material budget.
  - Providing timing for PID up to 10 GeV.
- RICH for PID up to 50 GeV:
  - Minimizing material budget
  - Cherenkov light detection:
    - MWPC, SiPM, HPDs...
    - LGAD pixelate detector for tracking and photon.

Do we need to go all the way to 50GeV?



- **Pros: PID will help jet-charge and flavor tagging.**
- **Cons: Additional material budget to degrade the detector performance.**

Points to take home

- **Drift Chamber**
  - Close to satisfy required momentum resolution, but need extra silicon layer to achieve full performance
  - Provides decent PID
  - New details of mechanics provided at workshop
- **TPC**
  - Paul Colas present at workshop. Very useful detailed conversations about the TPC operation.
  - Some skepticism that our Ion Back Flow estimation are correct, on the other hand, people are impressed with the progress with our GEM+MM readout boards
  - Jianbei claimed even better IBF results with a different setup than the one used for CDR (to follow up on)

Points to take home

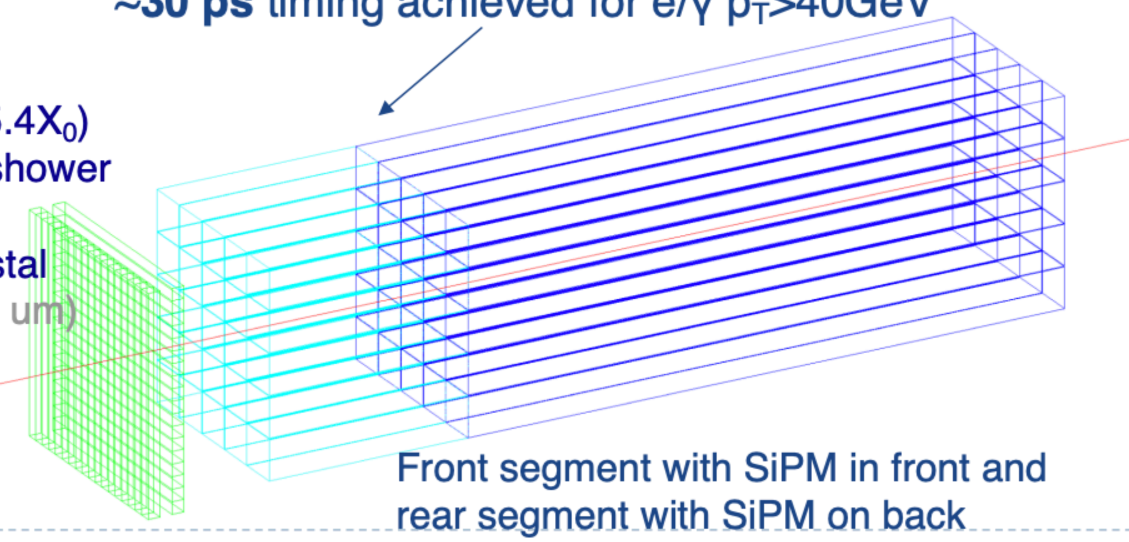
- **Calorimeters**
  - Lengthy discussion about the benefits of high-granularity versus high-resolution
    - In particular, the need for high-resolution electromagnetic calorimeter
    - Cost optimization of Si-based solutions
  - SiPM: Significant interest on SiPM based solution and the potential of lower costs for SiPM
  - Dual-readout calorimeter presented new preliminary results from CERN test beam
    - Need 1 million USD to produce full size prototype
  - First ECal Crystal Calorimeter Concept:

- **Timing layer (2 layers):**
  - LYSO:Ce crystals
  - SiPMs
  - 3x3x54 mm³ active cell
  - 3x3 mm² SiPMs (15-25 um)

To be continue in March…

- **ECAL layer:**
  - PbWO crystals
  - front segment 5 cm (~5.4X_0)
  - rear segment for core shower
  - (15 cm ~16.3X_0)
  - 10x10x200 mm³ of crystal
  - 5x5 mm² SiPMs (10-15 um)

< 5%/sqrt(E) (+) 1%
~30 ps timing achieved for e/γ p_T>40GeV



Front segment with SiPM in front and rear segment with SiPM on back
→ Avoids dead material at shower max

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Conference (Jan 21-24, 2019)

Attendance

Largest attendance from all editions

Crowd Management

Conference Highlights

09:00 - 12:30	**Session M-1** **Chair: Tao LIU** *Venue: IAS Lecture Theater, G/F, Lo Ka Chung Building, Lee Shau Kee Campus, HKUST*
09:00 - 09:45	**Opening Talk [Slides]** **Geoffrey TAYLOR** *The University of Melbourne*
09:45 - 10:30	**Physics Beyond the SM: Past, Today and Future [Slides]** **Carlos WAGNER** *The University of Chicago*
10:30 - 11:00	Group Photo and Coffee Break (Venue: IAS Lobby, G/F)
11:00 - 11:45	**ILC Status [Slides]** **Shinichiro MICHIZONO** *KEK (High Energy Accelerator Research Organization)*
11:45 - 12:30	**CLIC Status [Slides]** **Andrea LATINA** *CERN*

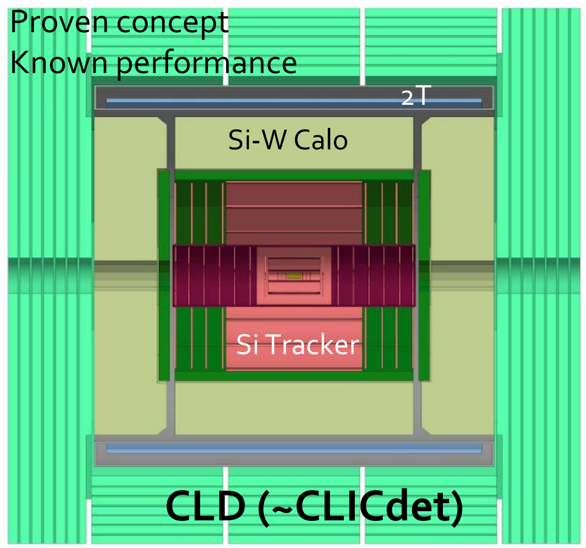
Conference Highlights

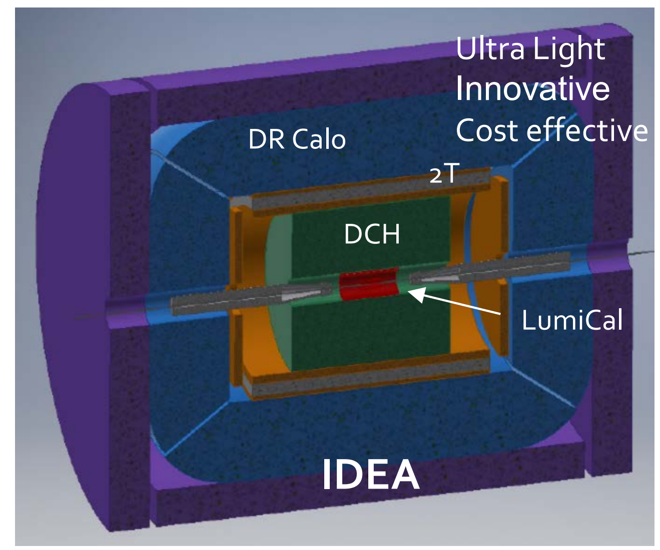
09:00 - 12:45	**Session Tu-1** **Chair: Joao GUIMARAES DA COSTA** *Venue: IAS Lecture Theater, G/F, Lo Ka Chung Building, Lee Shau Kee Campus, HKUST*
09:00 - 09:45	**CEPC Status [Slides]** **Jie GAO** *Institute of High Energy Physics, Chinese Academy of Sciences*
09:45 - 10:15	**FCC Status [Slides]** **Michael KORATZINOS** *CERN*
10:15 - 10:45	**FCC-ee Status [Slides]** **Mogens DAM** *Niels Bohr Institute, University of Copenhagen*
10:45 - 11:15	Coffee Break (Venue: IAS Lobby, G/F)
11:15 - 12:00	**HL-LHC Status [Slides]** **Sarah ENO** *The University of Maryland*
12:00 - 12:45	**HE-LHC + FCC-hh Status [Slides]** **Michelangelo MANGANO** *CERN*

FCC-ee: M. Koratzinos

FCC-ee detector design concepts

- **Two designs studied so far**





Two different concepts have been demonstrated to work, one a proven concept and the other with a thin solenoid and simple calorimeter (and a factor 2 cheaper)

- **It was demonstrated that detectors satisfying the requirements are feasible**
  - **Physics performance, invasive MDI, beam backgrounds**
- **More complete studies, with full simulation, needed**
  - **Towards at least four detector proposals to be made by ~2026**
    - **Light, granular, fast, b and c tagging, lepton ID and resolutions, hadron ID**
    - **Cost effective**
    - **Satisfy constraints from interaction region layout**

We are now open to detector collaborations!

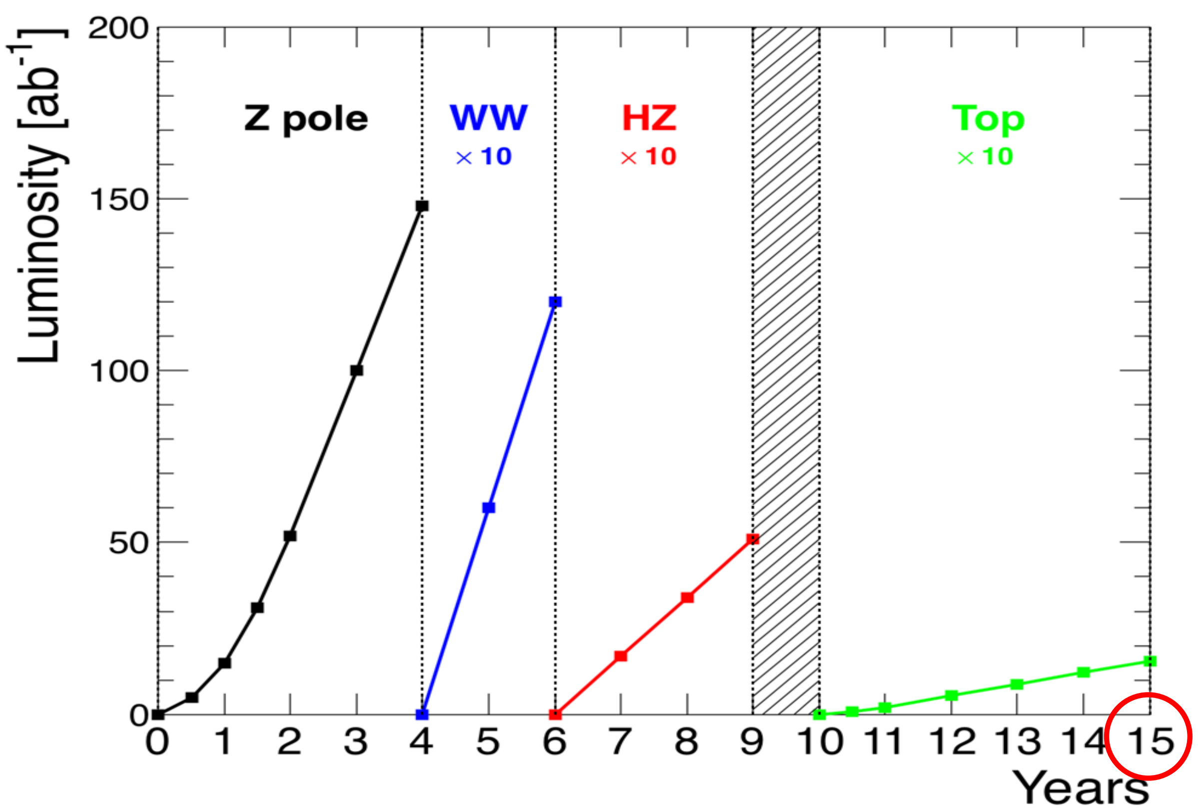
Patrick Janot — FCC-ee workshop: Theory and Experiment, CERN, 7-11 Jan 2019 — 16

Some confusion about number of FCC-ee experiments: 2 or 4

FCC-ee Running Plan

- 185 physics days / year, 75% efficiency, 10% margin on luminosity

Working point	Z, years 1-2	Z, later	WW	HZ	tt threshold...	... and above
√s (GeV)	88, 91, 94		157, 163	240	340 – 350	365
Lumi/IP (10^{34} cm^{-2}s^{-1})	100	200	25	7	0.8	1.4
Lumi/year (2 IP)	24 ab^{-1}	48 ab^{-1}	6 ab^{-1}	1.7 ab^{-1}	0.2 ab^{-1}	0.34 ab^{-1}
Physics goal	150 ab^{-1}		10 ab^{-1}	5 ab^{-1}	0.2 ab^{-1}	1.5 ab^{-1}
Run time (year)	2	2	2	3	1	4



Total : 15 years

Event statistics

5×10^{12} $e^+e^- \to Z$
10^8 $e^+e^- \to W^+W^-$
10^6 $e^+e^- \to HZ$
10^6 $e^+e^- \to t\bar{t}$

√s precision

100 keV
300 keV
1 MeV
2 MeV

total program duration: 15 years - ***including machine modifications***

phase 1 (*Z, W, H*): 9 years, phase 2 (top): 6 years

FCC-ee running plan

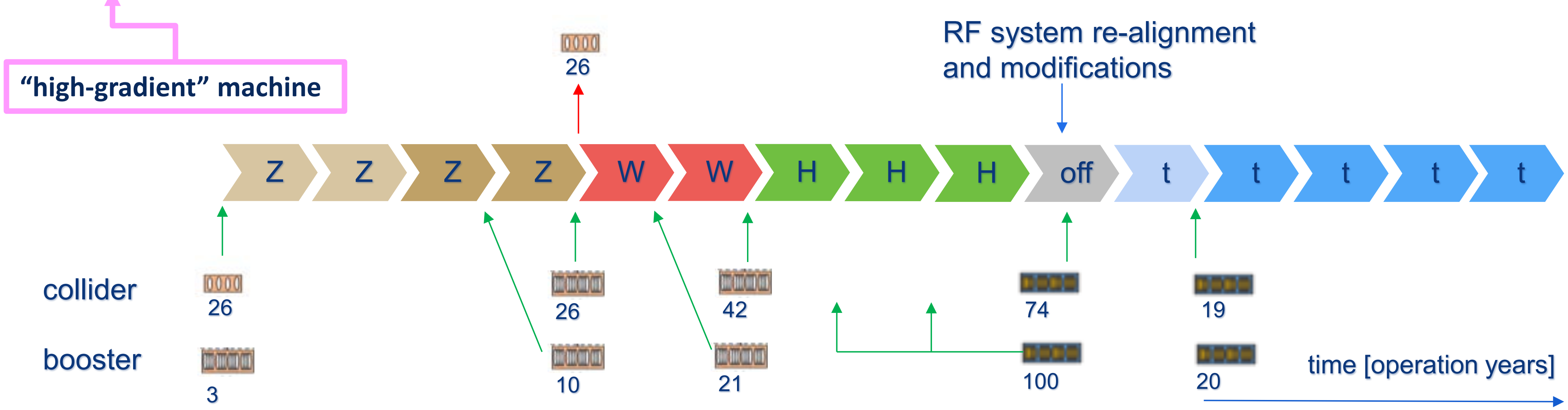
FCC-ee RF staging scenario

"Ampere-class" machine

WP	V_{rf} [GV]	#bunches	I_{beam} [mA]
Z	0.1	16640	1390
W	0.44	2000	147
H	2.0	393	29
ttbar	10.9	48	5.4

three sets of RF cavities to cover all options for FCC-ee & booster:

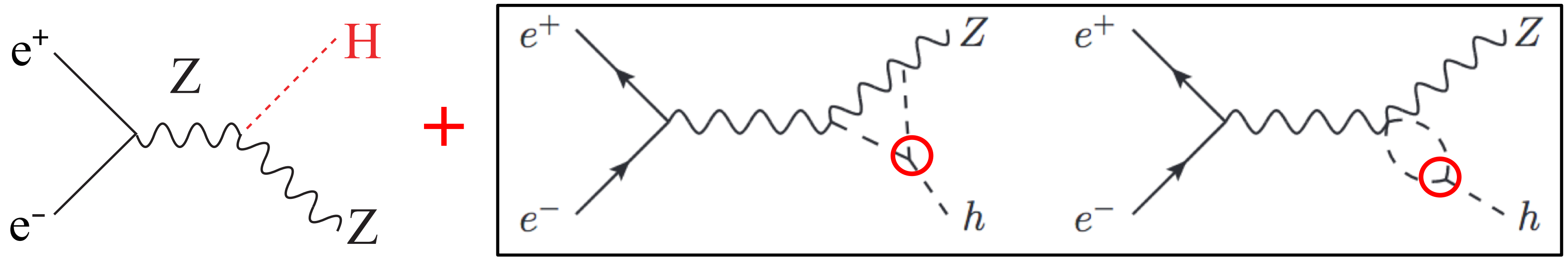
- **high intensity (Z, FCC-hh): 400 MHz mono-cell cavities (4/cryom.)**
- **higher energy (W, H, t): 400 MHz four-cell cavities (4/cryomodule)**
- **ttbar machine complement: 800 MHz five-cell cavities (4/cryom.)**
- **installation sequence comparable to LEP (≈ 30 CM/shutdown)**



Accelerator configurations changed during winter shutdown ?

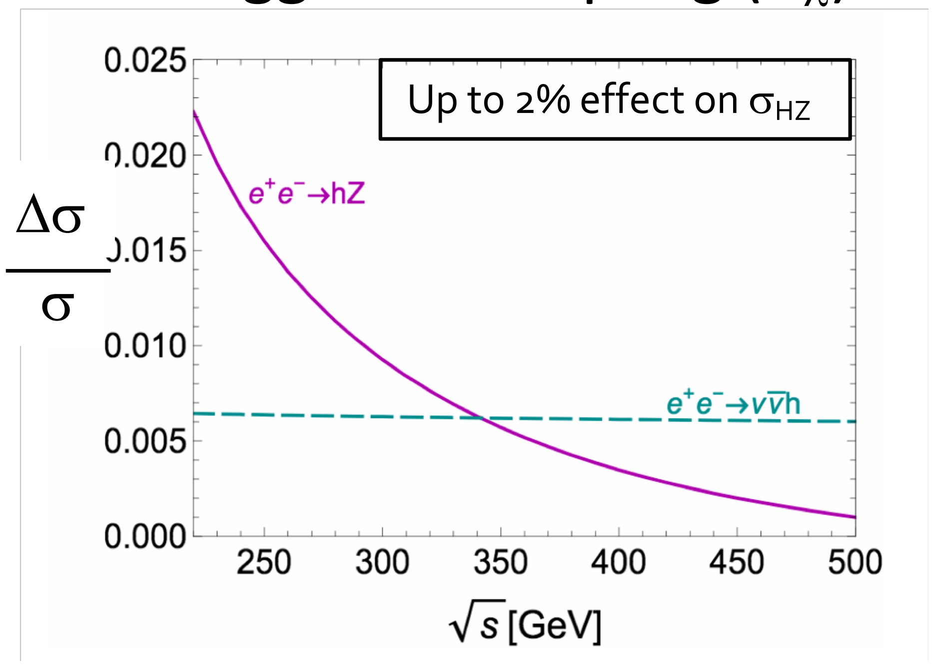
Higgs self-coupling at FCC-ee

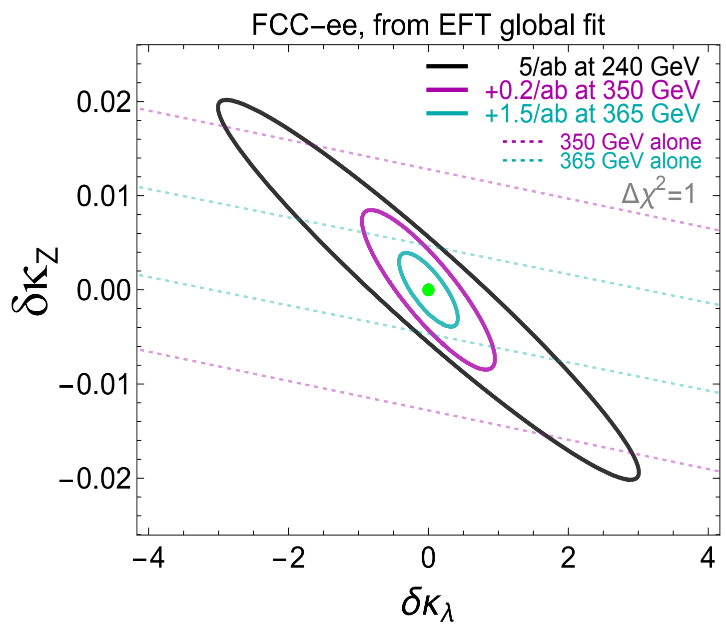
- FCC-ee does not produce Higgs pairs, from which self coupling can be extracted
- But, loops including Higgs self coupling contribute to Higgs production



M. McCullough
arXiv:1312.3322

- Effect of Higgs self coupling (κ_λ) on σ_{ZH} and $\sigma_{\nu\nu H}$ depends on √s





C. Grojean et al.
arXiv:1711.03978

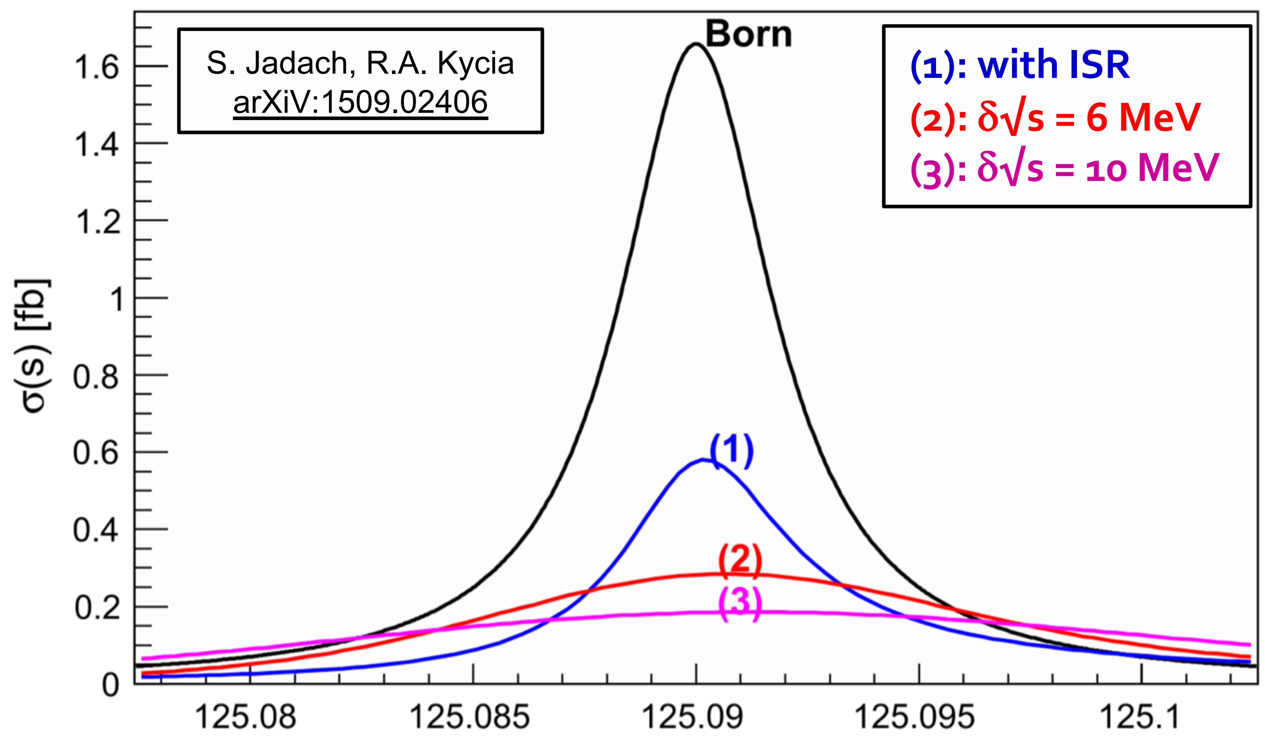
- Two energy points (240 and 365 GeV) lift off the degeneracy between $\delta\kappa_Z$ and $\delta\kappa_\lambda$
  - Precision on κ_λ with 2 IPs at the end of the FCC-ee (91+160+240+365 GeV)
    - Global EFT fit (model-independent) : ±34% **(3σ)** ; in the SM : ±12%
  - Precision on κ_λ with 4 IPs : ±21% (EFT fit) **(5σ)** ; ±9% (SM fit)
    - **5σ discovery** with 4 IPs instead of 2 (much less costly than 500 GeV upgrade)

A. Blondel, P. Janot
arXiv:1809.10041

H→ee, a long term plan…

And if there is time …

- Spend few years at $\sqrt{s}$ = 125.09 GeV with high luminosity
  - For s-channel production $e^+e^- \to H$ (a la muon collider, with 10^4 higher lumi)



- FCC-ee monochromatization setups
  - Default: $\delta\sqrt{s}$ = 100 MeV, 25 ab^{-1} / year
    - No visible resonance
  - Option 1: $\delta\sqrt{s}$ = 10 MeV, 7 ab^{-1} / year
    - $\sigma(e^+e^- \to H)$ ~ 100 ab
  - Option 2: $\delta\sqrt{s}$ = 6 MeV, 2 ab^{-1} / year
    - $\sigma(e^+e^- \to H)$ ~ 250 ab
  - Backgrounds much larger than signal
    - $e^+e^- \to q\bar{q}, \tau\tau, WW^*, ZZ^*, \gamma\gamma$, …

- Expected signal significance of ~0.4σ / √year in both option 1 and option 2
  - Set a electron Yukawa coupling upper limit : $\kappa_e < 2.5$ @ 95% C.L.
  - Reaches SM sensitivity after five years (or 2.5 years with 4 IPs)

D. d'Enterria
arXiV:1701.02663

- Unique opportunity to constrain first generation Yukawa's

The case for FCC-hh

Higgs couplings after FCC-ee / hh

	HL-LHC	FCC-ee	FCC-hh
$\delta\Gamma_H / \Gamma_H$ (%)	SM	**1.3**	tbd
$\delta g_{HZZ} / g_{HZZ}$ (%)	1.5	**0.17**	tbd
$\delta g_{HWW} / g_{HWW}$ (%)	1.7	**0.43**	tbd
$\delta g_{Hbb} / g_{Hbb}$ (%)	3.7	**0.61**	tbd
$\delta g_{Hcc} / g_{Hcc}$ (%)	~70	**1.21**	tbd
$\delta g_{Hgg} / g_{Hgg}$ (%)	2.5 (gg->H)	**1.01**	tbd
$\delta g_{H\tau\tau} / g_{H\tau\tau}$ (%)	1.9	**0.74**	tbd
$\delta g_{H\mu\mu} / g_{H\mu\mu}$ (%)	4.3	9.0	**0.65 (*)**
$\delta g_{H\gamma\gamma} / g_{H\gamma\gamma}$ (%)	1.8	3.9	**0.4 (*)**
$\delta g_{Htt} / g_{Htt}$ (%)	3.4	–	**0.95 (**)**
$\delta g_{HZ\gamma} / g_{HZ\gamma}$ (%)	9.8	–	**0.9 (*)**
$\delta g_{HHH} / g_{HHH}$ (%)	50	~30 (indirect)	**6.5**
BR_{exo} (95%CL)	$BR_{inv} < 2.5\%$	**< 1%**	**$BR_{inv} < 0.025\%$**

End of century

* From BR ratios wrt B(H→4lept) @ FCC-ee

** From pp→ttH / pp→ttZ, using B(H→bb) and ttZ EW coupling @ FCC-ee

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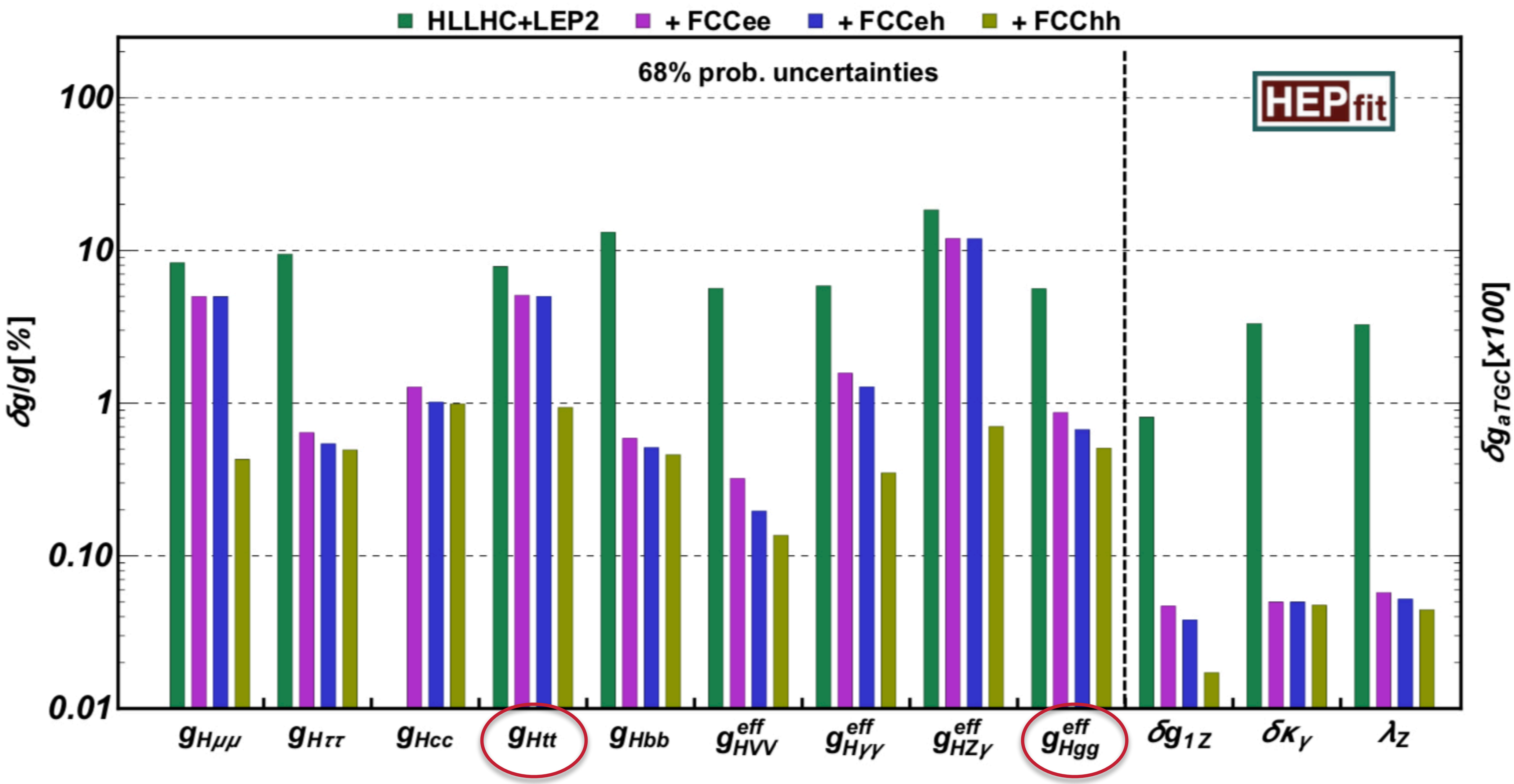
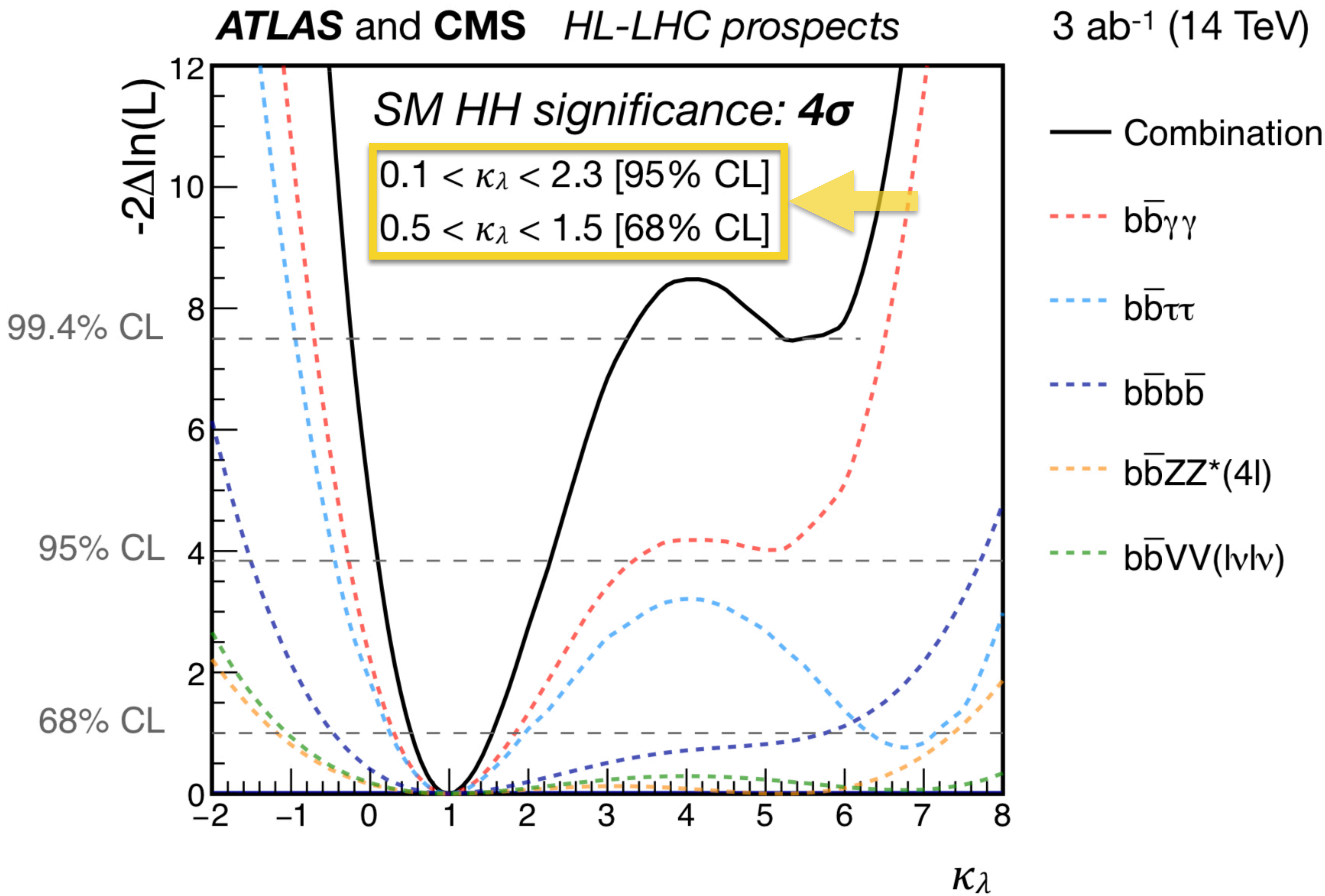


Figure 8.4: One-sigma precision reach at the FCC on the 12 effective single Higgs couplings and aTGC. An absolute precision in the EW measurements is assumed. The different bars illustrate the improvements that would be possible by combining each FCC stage/collider with the previous knowledge at that time (the precisions, not reported here, at each FCC stage/collider considered individually would obviously be quite different). Note that, without a run above the $t\bar{t}H$ threshold, circular e^+e^- colliders alone do not directly constrain the $g^{\rm eff}_{Hgg}$ and g_{Htt} couplings individually. The combination with LHC measurements however resolves this flat direction.

FYI: Higgs self-coupling projections @ HL-LHC *



* M. Cepeda, S. Gori, P. J. Ilten, M. Kado, and F. Riva, (conveners), et al, *Higgs Physics at the HL-LHC and HE-LHC*, CERN-LPCC-2018-04, https://cds.cern.ch/record/2650162.

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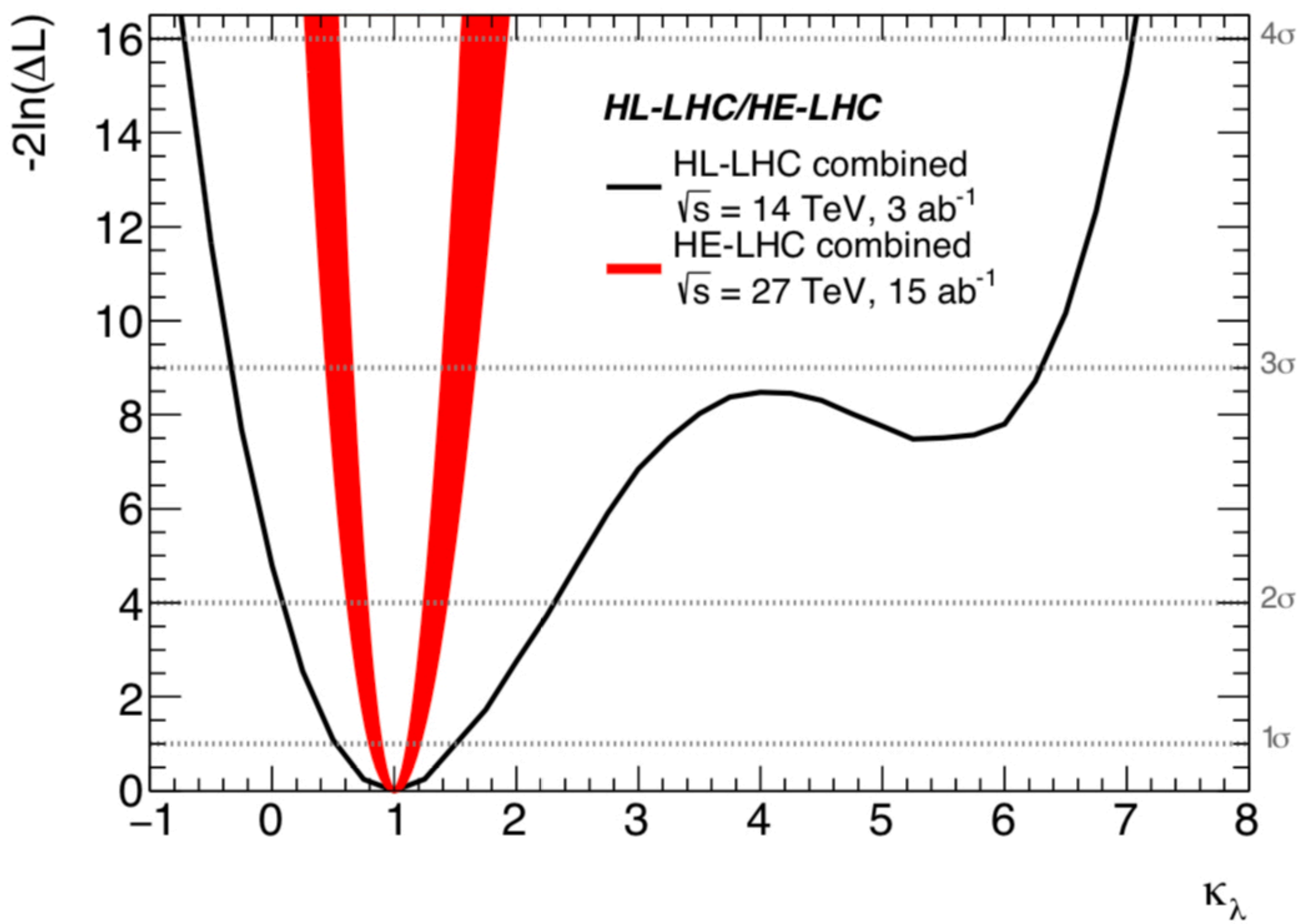
The case for HE-LHC

Higgs self-coupling at HE-LHC vs HL-LHC

HL-LHC: λ/λ_{SM} ~1±0.5 (68%CL)

HE-LHC: λ/λ_{SM} ~1±0.15 (68%CL)

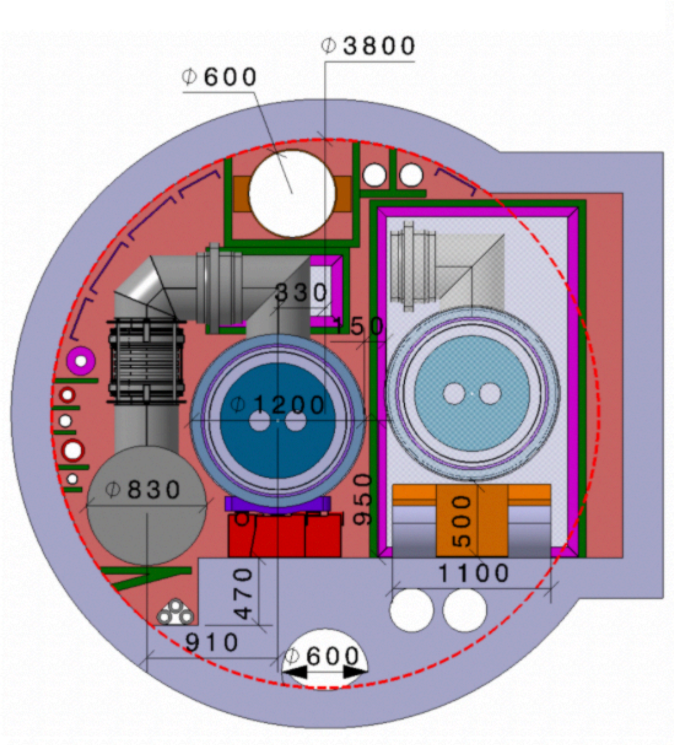


Around 2060?

See also: D. Gonçalves, T. Han, F. Kling, T. Plehn, and M. Takeuchi, *Higgs Pair Production at Future Hadron Colliders: From Kinematics to Dynamics*, arXiv:1802.04319 [hep-ph].

HE-LHC: the challenges

- 16T Nb_3Sn magnets: more challenging than for FCC-hh, due to reduced space in the tunnel (requires dedicated R&D)



- SPS upgrade, to SC technology, to allow injection at 0.9-1.3 TeV
- Full replacement and strengthening of all infrastructure on the surface and underground cryogenics
- Significant civil engineering work both on the surface and in the tunnel (new SPS transfer lines, new caverns for cryogenics, 2 new shafts, …)
- Overhaul/full replacement of detectors (radiation dama limited lifetime of key systems like magnets, use of new
- …

23 years implementation
Earliest starting date late 2040's

Domain	Cost in MCHF
Collider	5,000
Injector complex	1,100
Technical infrastructure	800
Civil Engineering	300
TOTAL cost	**7,200**

Table 2: Summary of capital cost for implementation of the HE-LHC project.

Conference Highlights

09:00 - 12:30	**Session W-1** **Chair: Joao GUIMARAES DA COSTA** *Venue: IAS Lecture Theater, G/F, Lo Ka Chung Building, Lee Shau Kee Campus, HKUST*
09:00 - 09:45	**SppC Status [Slides]** **Jie GAO** *Institute of High Energy Physics, Chinese Academy of Sciences*
09:45 - 10:30	**Summary (Theory) [Slides]** **Liantao WANG** *The University of Chicago*
10:30 - 11:00	Coffee Break (Venue: IAS Lobby, G/F)
11:00 - 11:45	**Summary (Experiment/Detector) [Slides]** **Massimo CACCIA** *University of Insubria*
11:45 - 12:30	**Summary (Accelerator Physics) [Slides]** **Yuhong ZHANG** *Thomas Jefferson National Accelerator Facility*

Conference Highlights

09:00 - 12:55	**Session Th-1** **Chair: Tao LIU** *Venue: IAS Lecture Theater, G/F, Lo Ka Chung Building, Lee Shau Kee Campus, HKUST*
09:00 - 09:45	**US HEP Planning and Strategy [Slides]** **Andrew LANKFORD** *University of California, Irvine*
09:45 - 10:30	**China HEP Strategy [Slides]** **Yifang WANG** *Institute of High Energy Physics, Chinese Academy of Sciences*
10:30 - 11:15	**Road to European HEP Strategy [Slides]** **Jorgen D'HONDT** *Vrije Universiteit Brussel*
11:15 - 11:45	Coffee Break (Venue: IAS Lobby, G/F)
11:45 - 12:45	**Forum** **- Jorgen D'HONDT (Vrije Universiteit Brussel)** **- John ELLIS (CERN and King's College London; IAS Senior Visiting Fellow)** **- Andrew LANKFORD (University of California, Irvine)** **- Yifang WANG (Institute of High Energy Physics, Chinese Academy of Sciences)** **- Hitoshi YAMAMOTO (Tohoku University) [Slides]**
12:45 - 12:55	**Closing Remarks [Slides]** **Tao LIU** *HKUST*

FCC-ee precision

Sample of EW observables, experimental precisions

Region	Observable	Measurement	Current precision	FCC-ee stat.	FCC-ee syst.	Dominant exp. error
Z pole	m_Z (keV)	Z Lineshape	91187500 ± 2100	5	< 100	Beam energy
Z pole	Γ_Z (MeV)	Z Lineshape	2495200 ± 2300	8	< 100	Beam energy
Z pole	R_l ($\times 10^3$)	Z Peak ($\Gamma_{had}/\Gamma_{lep}$)	20767 ± 25	0.06	0.2 – 1	Detector acceptance
Z pole	R_b ($\times 10^6$)	Z Peak (Γ_{bb}/Γ_{had})	216290 ± 660	0.3	< 60	$g \rightarrow bb$
Z pole	N_ν ($\times 10^3$)	Z Peak (σ_{had})	2984 ± 8	0.005	1	Lumi measurement
Z pole	$\sin^2\theta_W^{eff}$ ($\times 10^6$)	$A_{FB}^{\mu\mu}$ (peak)	231480 ± 160	3	2 – 5	Beam energy
Z pole	$1/\alpha_{QED}(m_Z)$ ($\times 10^3$)	$A_{FB}^{\mu\mu}$ (off-peak)	128952 ± 14	4	< 1	Beam energy
Z pole	$\alpha_s(m_Z)$ ($\times 10^4$)	R_l	1196 ± 30	0.1	0.4 – 1.6	Same as R_l
WW thresh.	m_W (MeV)	WW Threshold scan	80385 ± 15	0.6	0.3	Beam energy
WW thresh.	Γ_W (MeV)	WW Threshold scan	2085 ± 42	1.5	0.3	Beam energy
WW thresh.	N_ν ($\times 10^3$)	$e^+e^- \rightarrow \gamma Z$, $Z \rightarrow \nu\nu$, ll	2920 ± 50	0.8	small	?
WW thresh.	$\alpha_s(m_W)$ ($\times 10^4$)	$B_l = (\Gamma_{had}/\Gamma_{lep})_W$	1170 ± 420	2	small	CKM Matrix
$t\bar{t}$ thresh.	m_{top} (MeV)	Top Threshold scan	173340 ± 760 ± 500	17	< 40	QCD corr.
$t\bar{t}$ thresh.	Γ_{top} (MeV)	Top Threshold scan	?	45	< 40	QCD corr.
$t\bar{t}$ thresh.	λ_{top}	Top Threshold scan	μ = 1.28 ± 0.25	0.10	< 0.05	QCD corr.
$t\bar{t}$ thresh.	ttZ couplings	$\sqrt{s}$ = 365 GeV	± 30%	0.5 – 1.5%	< 2%	QCD corr