FUTURE COLLIDERS & SNOWMASS PLANNING

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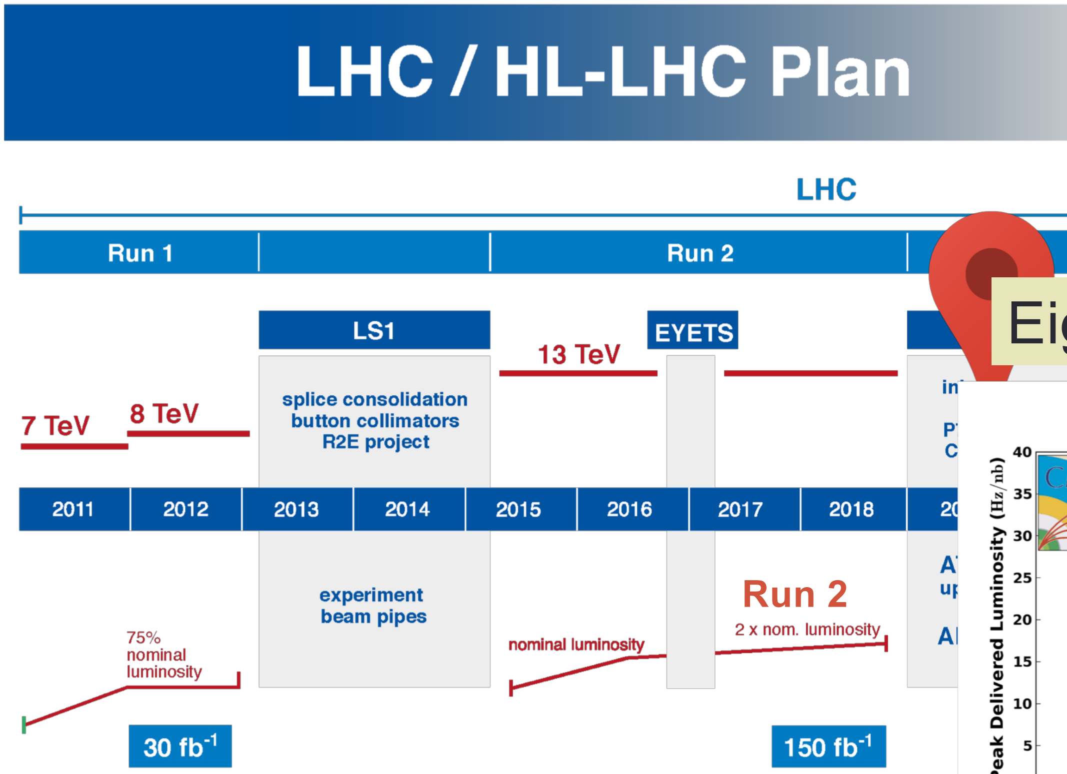
Brown University

October 16, 2019
USLUA meeting

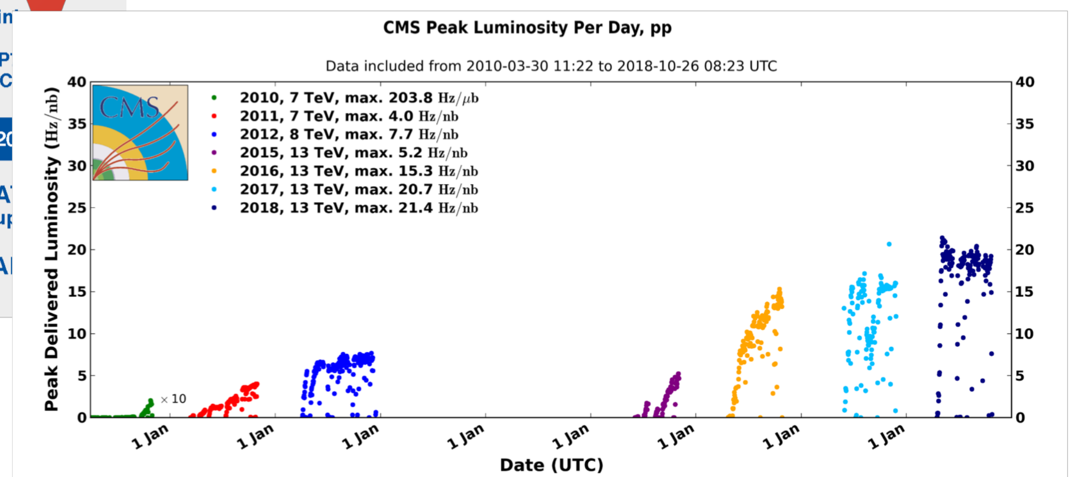
Some important notes:

- Much of what I have to say is derived from
  - The ESG meeting in Granada, May 2019
    - Lots of information, detailed analysis and comparisons of future machines
  - The ESG briefing book, which was released earlier this month
  - The APS/DPF discussion and presentations on upcoming Snowmass 2021 process
- I will concentrate on future collider discussions
  - Much more was discussed in Granada.
- And in the end I will share my perspectives

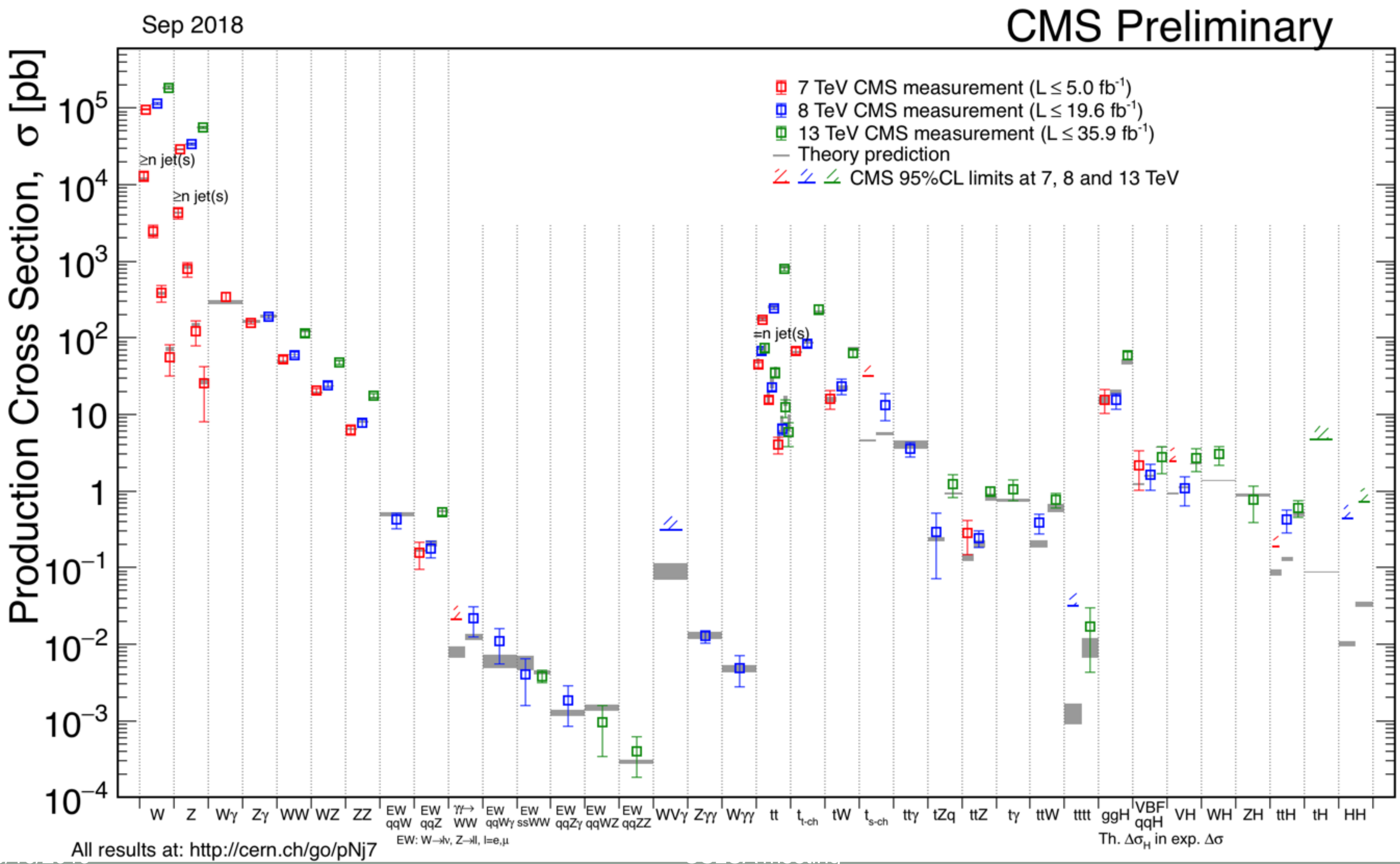
Schedule of LHC Operation



Eight years of excellent performance



SM Stairway…precision tests of the Standard Model



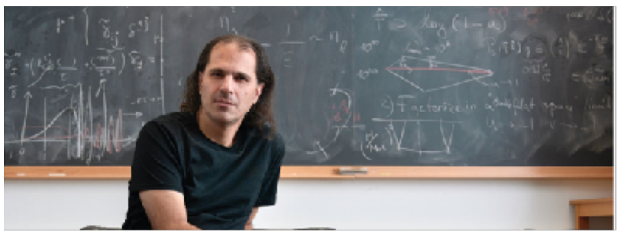
What has the LHC taught us?

- **Higgs mechanism** ✓
- **Supersymmetry** ✗
- **Vector-lik** ✗
- **dimensions** ✗
- **Dark matter** ✗

no new physics at the TeV scale ?!

A Theorist’s Advice

Nima Arkani-Hamed



“The discovery of the **Higgs particle** – especially with nothing else accompanying it so far – is unlike anything we have seen in any state of nature, and is profoundly “new physics” in this sense. …theoretical attempts to compute the vacuum energy and the scale of the Higgs mass pose gigantic, and perhaps interrelated, theoretical challenges. While we continue to scratch our heads as theorists, the most important **path forward for experimentalists is completely clear: measure the hell out of these crazy phenomena!”**

https://cerncourier.com/in-it-for-the-long-haul/

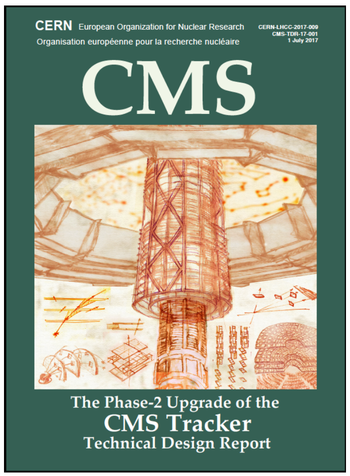
Schedule of LHC Operation

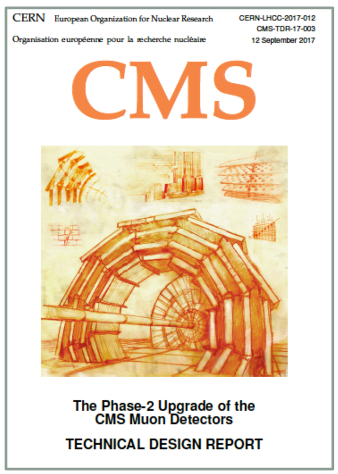
X2 Run 2

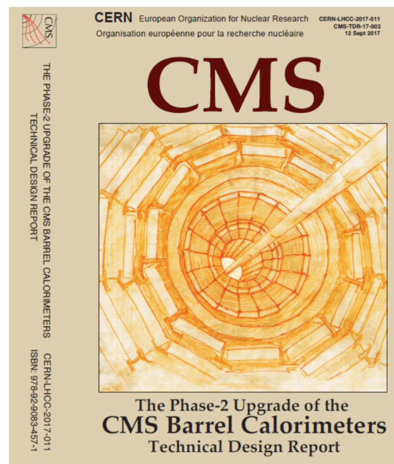
X10 Run 3

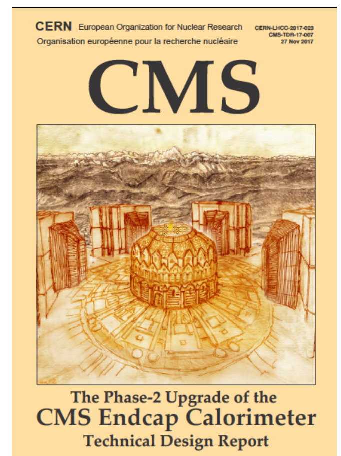
Technical Design Reports

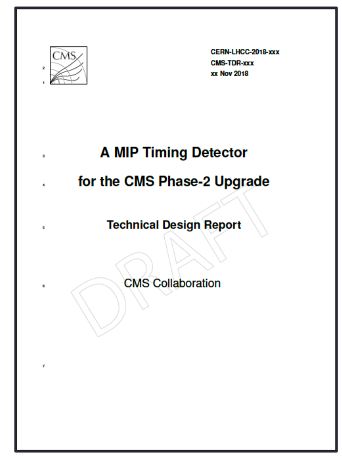
- During the 2017 and 2018 we published the Technical Design Reports
- These also include the performance of each of the detector











Each book with hundreds of pages !!!

Physics at the HL-LHC (and HE-LHC) : “Yellow Report”

- During 2018 we quantified the physics potential of the HL-LHC program
- (1000+ pages)

arXiv:1902.00134 (364 pages)

CERN-LPCC-2018-04
March 20, 2019

Higgs Physics
at the HL-LHC and HE-LHC

Report from Working Group 2 on the Physics of the HL-LHC, and Perspectives at the HE-LHC

arXiv:1902.04070 (219 pages)

CERN-LPCC-2018-03
February 26, 2019

Standard Model Physics
at the HL-LHC and HE-LHC

Report from Working Group 1 on the Physics of the HL-LHC, and Perspectives at the HE-LHC

arXiv:1812.07831 (279 pages)

CERN-LPCC-2018-05
March 19, 2019

Beyond the Standard Model Physics
at the HL-LHC and HE-LHC

Report from Working Group 3 on the Physics of the HL-LHC, and Perspectives at the HE-LHC

arXiv:1812.07638 (292 pages)

CERN-LPCC-2018-06
February 25, 2019

Opportunities in Flavour Physics
at the HL-LHC and HE-LHC

Report from Working Group 4 on the Physics of the HL-LHC, and Perspectives at the HE-LHC

arXiv:1812.06772 (207 pages)

CERN-LPCC-2018-07
February 26, 2019

Future physics opportunities for high-density QCD
at the LHC with heavy-ion and proton beams

Report from Working Group 5 on the Physics of the HL-LHC, and Perspectives at the HE-LHC

What may the HL-LHC teach us?

Higgs: precision msm't +evidence for HH prod.

Supersymm

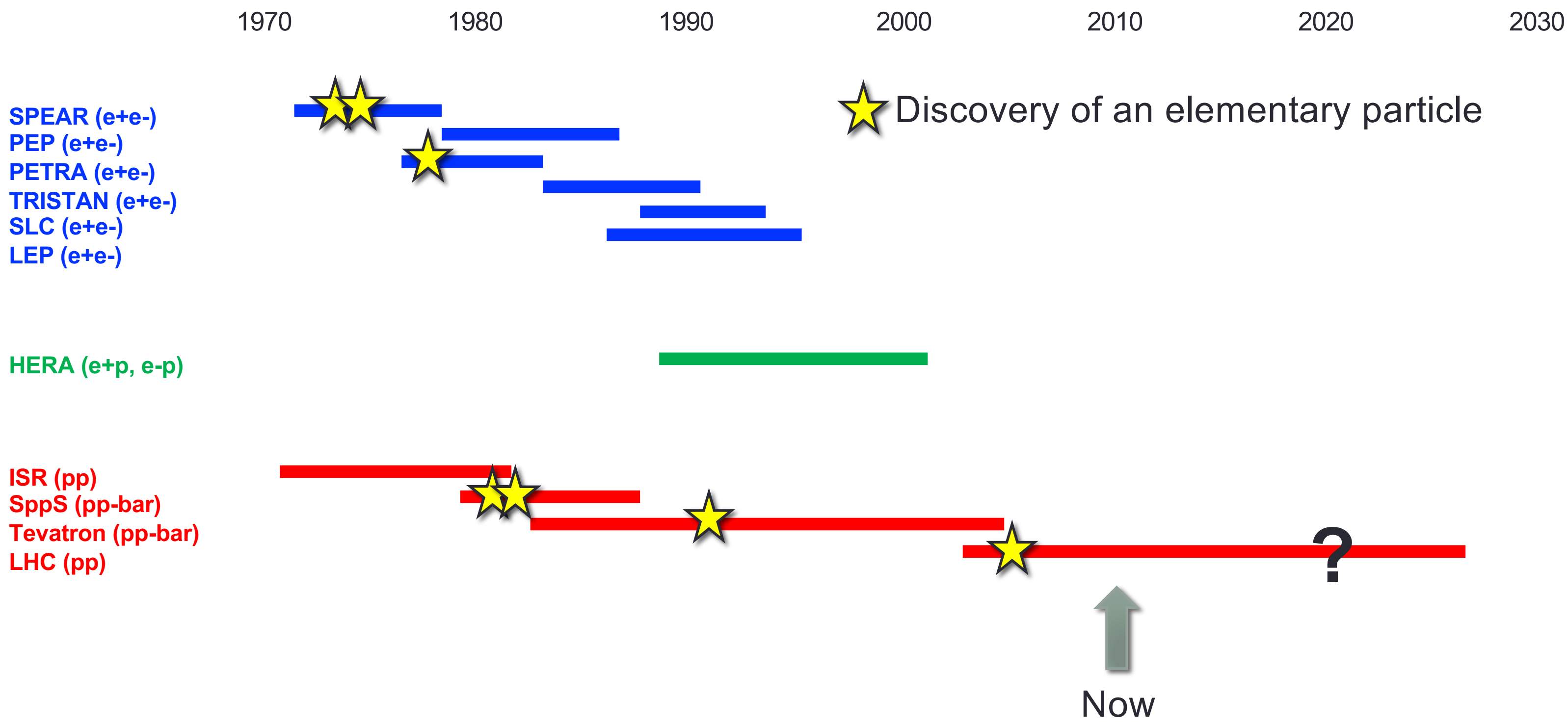
dimensions

Dark matter

Discovery of new physics at the TeV scale !!

Energy Frontier Colliders

Y.K. Kim (DPF Chair Elect)



What should be the next energy frontier collider?

From the presentation: Perspective on the European Strategy Update from the Americas,

Strategic Planning Process and Execution: United States

- P5 Strategic Plan for Particle Physics (2014)
  - 10 year plan in the context of a 20-year vision
  - 2012-2013: Snowmass community-wide studies
    - Organized by DPF (Similar to the PPG process)
  - 2013-2014: P5, Particle Physics Project Prioritization Panel
    - Subpanel of HEPAP, High Energy Physics Advisory Panel for DOE and NSF funding agencies
    - P5 takes the scientific input from Snowmass and formulates a strategic plan to address the science within specified funding constraints

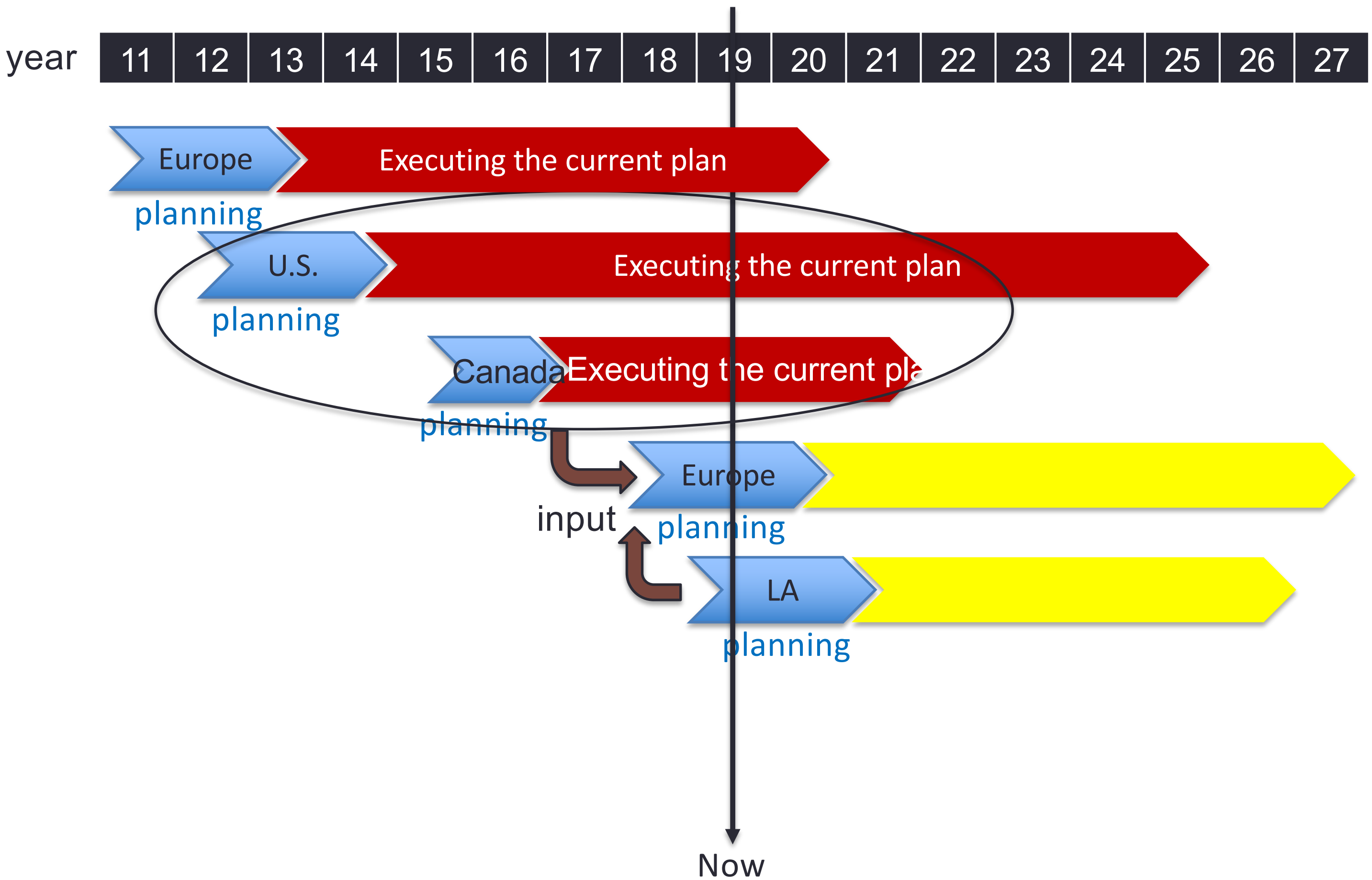
- Long-Range Plan for Nuclear Science (2015)
  - Funded by Nuclear Physics Offices of funding agencies
  - Fundamental Symmetries and Neutrinos
  - QCD: Structure of Hadrons and Phases of Strongly Interacting Matter

- Decadal survey on Astronomy and Astrophysics (2010)
  - Dark Energy
  - Cosmic Microwave Background

Y.K. Kim (DPF Chair Elect)

From the presentation: Perspective on the European Strategy Update from the Americas,
Y.K. Kim (DPF Chair Elect)

Planning and Executing



From the presentation: Perspective on the European Strategy Update from the Americas,

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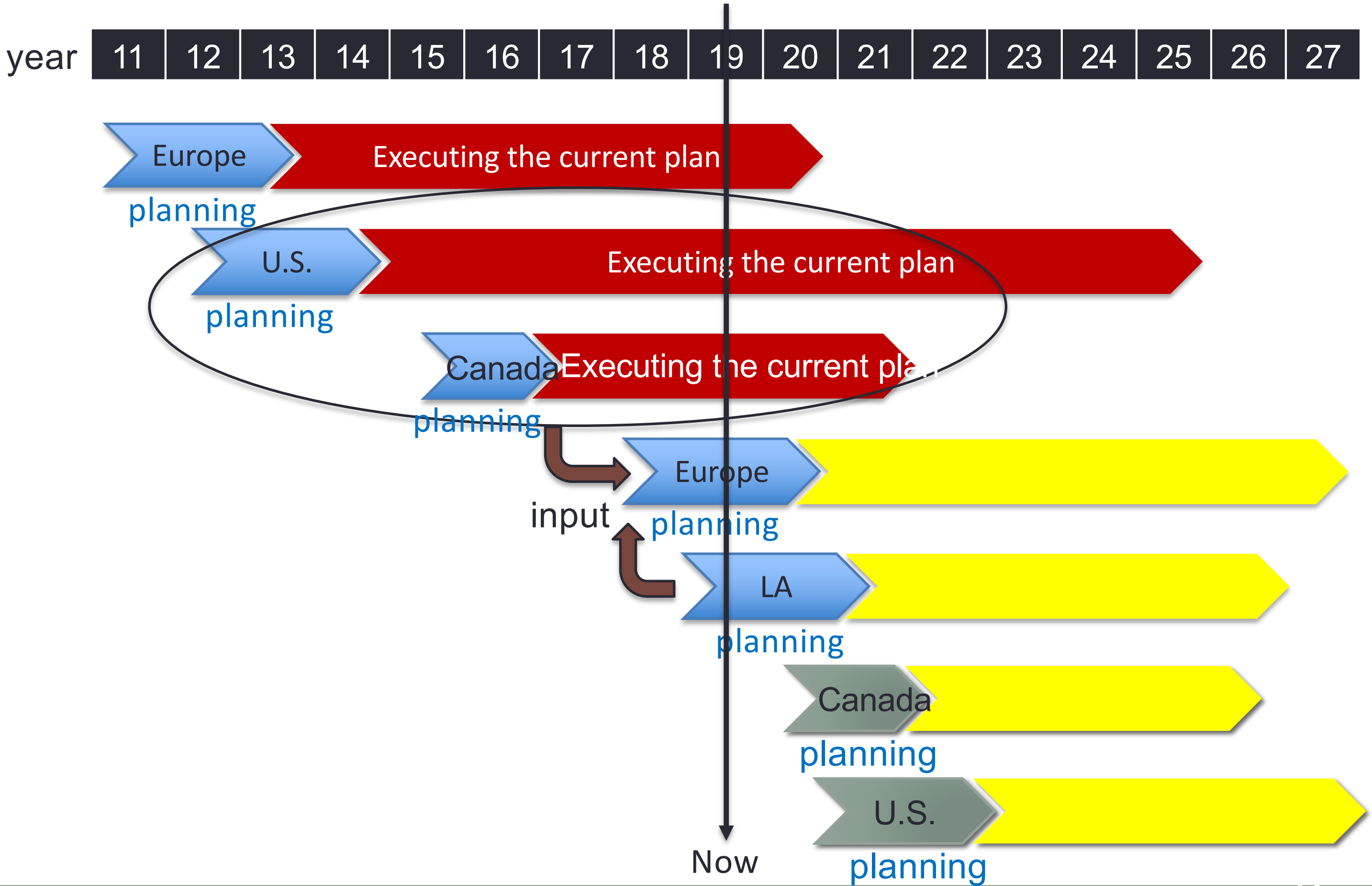


Perspective on the European Strategy Update from the Americas,

From presentation by Y.K. Kim (DPF Chair Elect) @Granada

Conclusions: Towards 2020 ESG

- Support of Americas' current plan
  - Importance of current high-priority projects such as HL-LHC, DUNE, …
- Beyond mid-2020's
  - Scientific drivers of the current plans are still valid
  - More capable facilities and broader programs
  - R&D of enabling technologies for future (accelerator, detector and computing)
- Support of facilities and activities outside of Europe
  - DUNE/LBNF, SNOLAB, CMB-S4, EIC, ….
  - A statement in the ESG document plays a significant role for success of facilities outside of Europe that serves the European / worldwide community
- The American community
  - will continue with its strong partnership with Europe
  - would like to see positive steps toward a new collider: an e+e- collider might be the first one to be realized: O(1000) American community

ESG PROCESS: FUTURE ACCELERATORS

Higgs factories

International Linear Collider (ILC) in Japan
Compact Linear Collider (CLIC) at CERN
Future Circular Collider (FCC-ee) at CERN
Circular Electron Positron Collider (CEPC) in China.

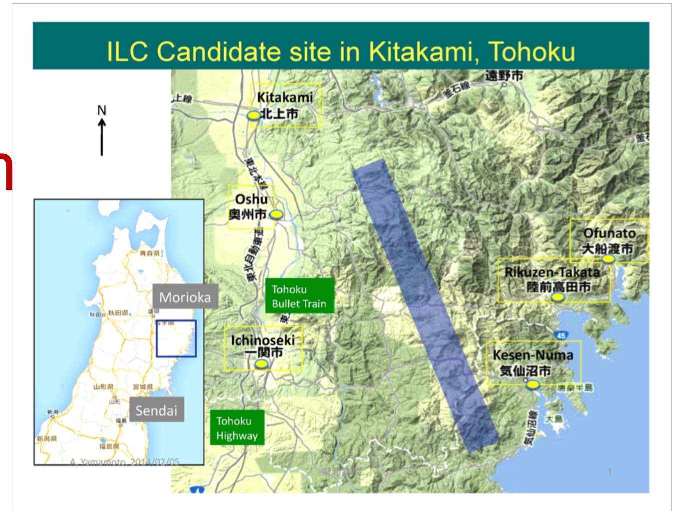
Future Circular Collider (FCC-hh) at CERN
Super proton proton Collider (SppC) in China
High-energy LHC (HE-LHC) at CERN

Linear Colliders

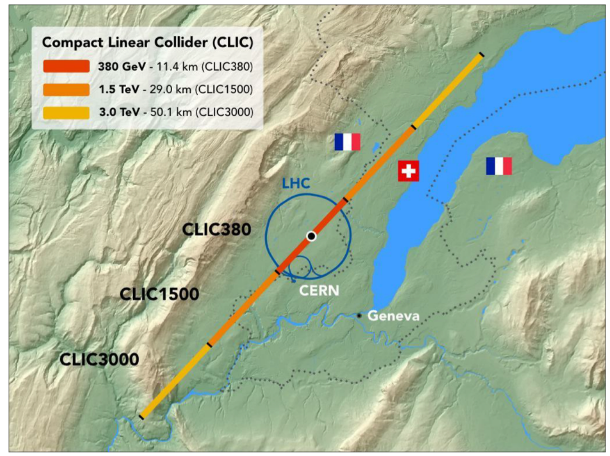
- ILC (Japan)
  - Linear collider with high-gradient superconducting acceleration
  - Ultimate: 0.5-1 TeV
  - Reduce cost by starting at 250 GeV (H factory)
- CLIC (CERN)
  - Linear collider with high gradient normal-conducting acceleration
  - Ultimate: multi-TeV (3) e+e– collisions
  - Use technology to overcome challenges
  - Staged for physics and funding

- Challenges
- Acceleration gradient ILC: 30 MV/m; CLIC: 72 MV/m
- Luminosity (to be partially recovered by polarization)
  - +loss: e.g. at 3000 GeV, 1/3 at 0.99√s
- Tiny beam spot:
  - v: 8nm for ILC; 3 nm for CLIC3000.
- Power consumption
  - ILC: 130-300 MW
  - CLIC: 170-590 MW

ILC
20km



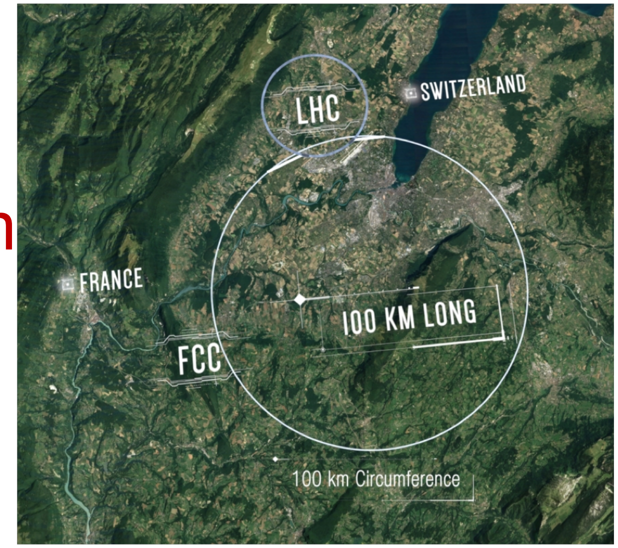
CLIC
11km;
29km;
50km



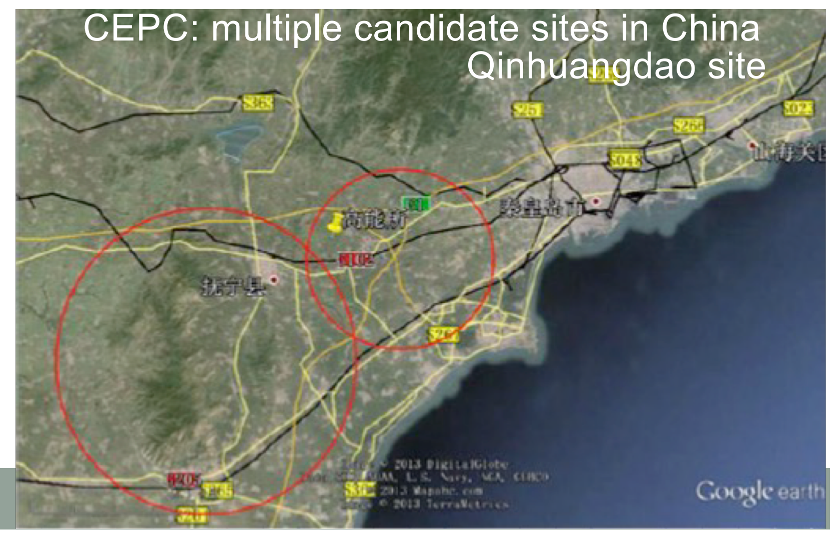
Circular Colliders

- FCC-ee & FCC-hh (CERN)
  - 100 km ring with 16T magnets
  - Use FCC-hh tunnel for e+e– collider
  - Technology for ee: “standard”
- CEPC & SppC (China)
  - Similar to FCC-ee, FCC hh with more conservative luminosity estimates
- Challenges
- Circular ee collider:
  - Power consumption: 260-350 MW
  - Luminosity drops with E
- Circular hh collider:
  - Demand next-generation superconducting dipole magnets
    - Requires R&D for magnets with 16 TeV (x2 LHC)
  - High stored beam energy (8-9 GJ)
    - Beam handling, beam dumping
    - Collimation
  - High synchrotron radiation inside magnets: several MW
  - Beam screen design and cryogenic efficiency;
  - Power consumption: 580 MW

FCC
100 km

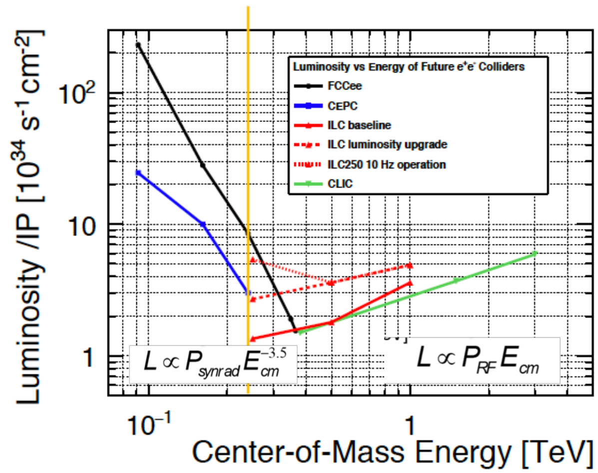


CepC
100 km



ESG Process: Future Accelerators

Collider	Type	$\sqrt{s}$	$\mathscr{P}$ [%] $[e^-/e^+]$	N_{Det}	$\mathscr{L}_{\text{inst}}$/Det. $[10^{34}\text{cm}^{-2}\text{s}^{-1}]$	$\mathscr{L}$ $[\text{ab}^{-1}]$	Time [years]	Ref.
HL-LHC	pp	14 TeV	–	2	5	6.0	12	[23]
HE-LHC	pp	27 TeV	–	2	16	15.0	20	[23]
FCC-hh	pp	100 TeV	–	2	30	30.0	25	[631]
FCC-ee	ee	M_Z	0/0	2	100/200	150	4	[631]
		$2M_W$	0/0	2	25	10	1-2	
		240 GeV	0/0	2	7	5	3	
		$2m_{top}$	0/0	2	0.8/1.4	1.5	5	
		(1y SD before $2m_{top}$ run)					(+1)	
ILC	ee	250 GeV	±80/±30	1	1.35/2.7	2.0	11.5	[335]
		350 GeV	±80/±30	1	1.6	0.2	1	[339]
		500 GeV	±80/±30	1	1.8/3.6	4.0	8.5	
		(1y SD after 250 GeV run)					(+1)	
CEPC	ee	M_Z	0/0	2	17/32	16	2	[502]
		$2M_W$	0/0	2	10	2.6	1	
		240 GeV	0/0	2	3	5.6	7	
CLIC	ee	380 GeV	±80/0	1	1.5	1.0	8	[632]
		1.5 TeV	±80/0	1	3.7	2.5	7	
		3.0 TeV	±80/0	1	6.0	5.0	8	
		(2y SDs between energy stages)					(+4)	
LHeC	ep	1.3 TeV	–	1	0.8	1.0	15	[630]
HE-LHeC	ep	1.8 TeV	–	1	1.5	2.0	20	[631]
FCC-eh	ep	3.5 TeV	–	1	1.5	2.0	25	[631]

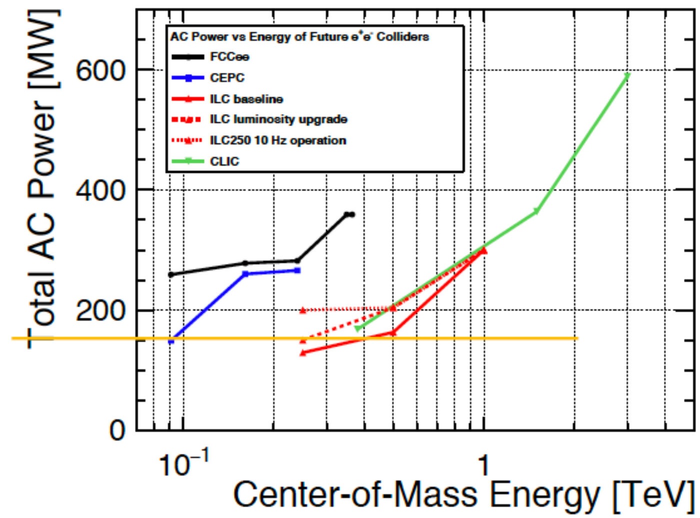


Low energies: circular colliders superior perf.
Higher energies: CC lumi reduction due to synchrotron radiation; Linear colliders better: luminosity per beam power roughly constant

Schemes for increasing luminosity:
FCC-ee: consider more IRs/running longer
ILC: more bunches per pulse, doubling repetition rate? Each: x 2 in lumi; higher power consumption
CLIC: doubling repetition rate at 380 GeV, factor 2 in lumi; power increases from 170 MW to 220 MW

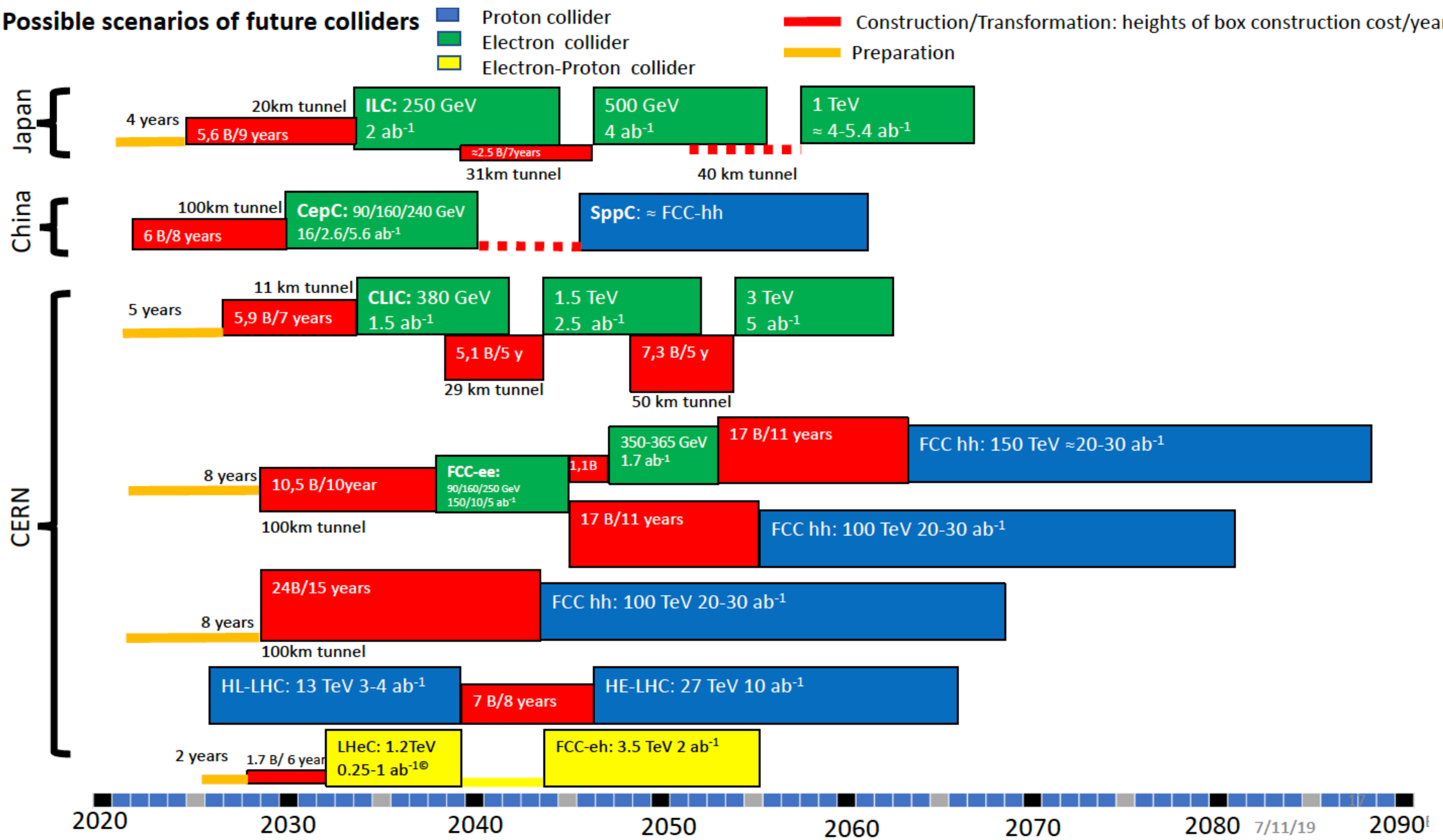
ESG Process: Future Accelerators

Project	Type	Energy [TeV]	Int. Lumi. [a^{-1}]	Oper. Time [y]	Power [MW]	Cost
ILC	ee	0.25	2	11	129 (upgr. 150-200)	4.8-5.3 GILCU + upgrade
		0.5	4	10	163 (204)	7.98 GILCU
		1.0			300	?
CLIC	ee	0.38	1	8	168	5.9 GCHF
		1.5	2.5	7	(370)	+5.1 GCHF
		3	5	8	(590)	+7.3 GCHF
CEPC	ee	0.091+0.16	16+2.6		149	5 G$
		0.24	5.6	7	266	
FCC-ee	ee	0.091+0.16	150+10	4+1	259	10.5 GCHF
		0.24	5	3	282	
		0.365 (+0.35)	1.5 (+0.2)	4 (+1)	340	+1.1 GCHF
LHeC	ep	60 / 7000	1	12	(+100)	1.75 GCHF
FCC-hh	pp	100	30	25	580 (550)	17 GCHF (+7 GCHF)
HE-LHC	pp	27	20	20		7.2 GCHF
LE-FCC	pp.	37.5	15	20		14.9 GCHF. New at request of ESG.



LHC: 150 MW

Possible scenarios of future colliders

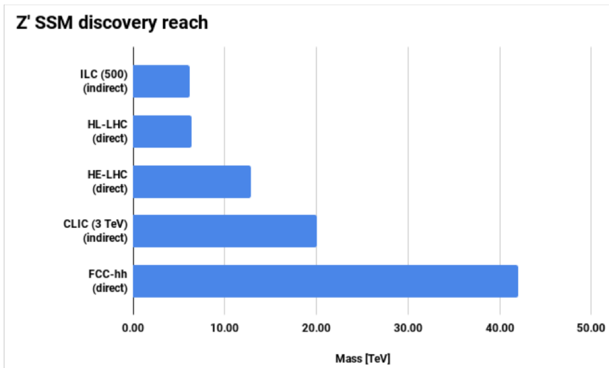


ESG Process – BSM: The Four Big Questions

- Beyond the Standard Model
  1. To what extent can we tell whether the Higgs is fundamental or composite?
  2. Are there new interactions or new particles around or above the electroweak scale?
  3. What cases of thermal relic WIMPs are still unprobed and can be fully covered by future collider searches?
  4. To what extent can current or future accelerators probe feebly interacting sectors?

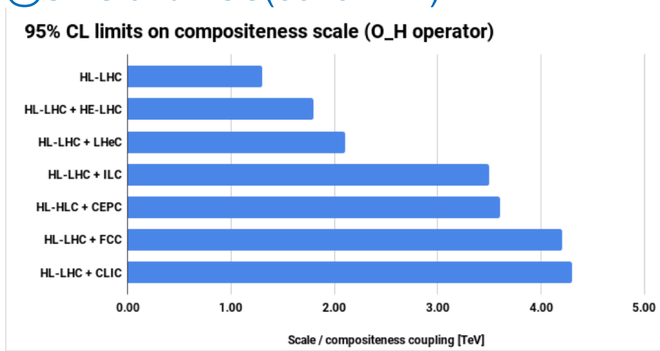
Beyond the Standard Model at Colliders

Search for new resonances

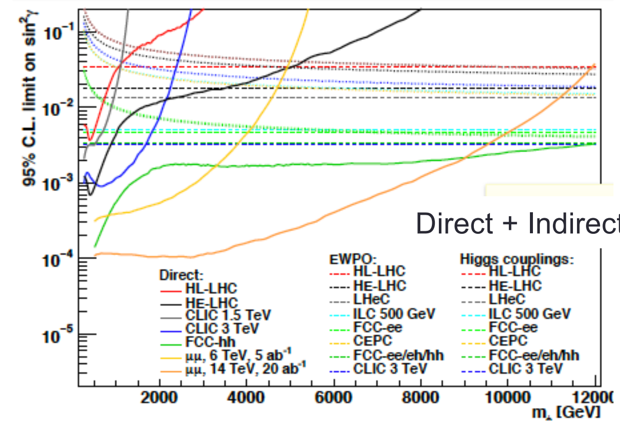


Higgs Compositeness Scale

Maximum sensitivity:
@CLIC and FCC(ee+eh+hh)

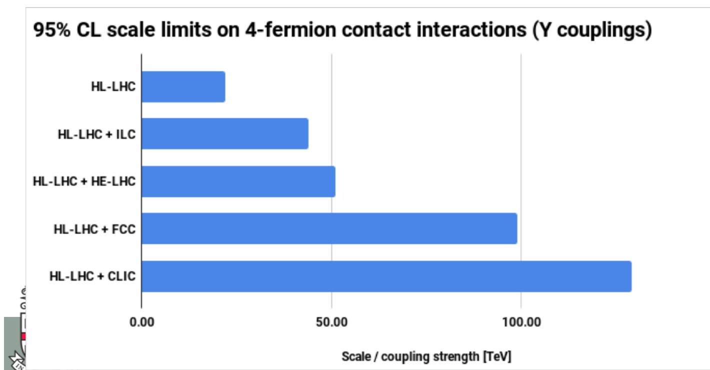


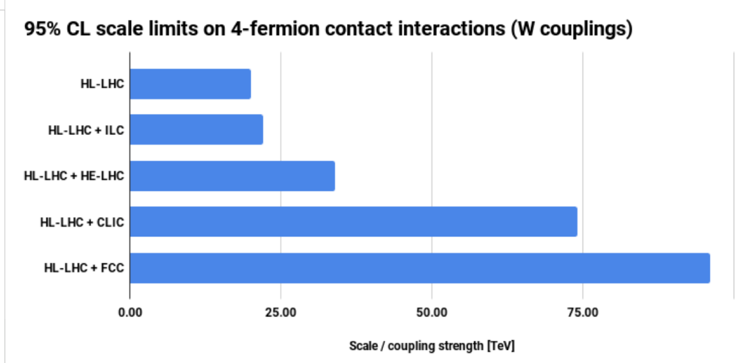
Extended Scalar Sector



Contact Interactions:

Sensitivity for ee colliders enhanced for couplings ≳ 1
(weak couplings → direct searches become more sensitive)
Searches for W’ & charged fermion currents more effective at hadron colliders





Direct & Indirect:

provide complementary info (HL-LHC, HE-LHC & CLIC)

Direct reach at FCC-hh better than precision H couplings for mφ<12 TeV

ESG Process: The Four Big Questions

- Beyond the Standard Model
  1. To what extent can we tell whether the Higgs is fundamental or composite?
  2. Are there new interactions or new particles around or above the electroweak scale?
  3. What cases of thermal relic WIMPs are still unprobed and can be fully covered by future collider searches?
  4. To what extent can current or future accelerators probe feebly interacting sectors?

- It is a bit difficult to answer these questions completely.
- The answers (or what we learn) are expressed in terms of BSM energy/mass scale and some other parameters of the models.
  - More work is ongoing.

ESG Process - Higgs: The Four Big Questions

- The discovery of the Higgs boson was a fundamental moment for HEP, and the precise study of its properties remains key to understanding EWK symmetry breaking and going beyond the limits of the SM
- H as a scalar couples to all the fundamental particles
- Whatever the style of the future HEP collider, exploring the Higgs sector will be one of the primary objectives of the field.

- Higgs Physics: 4 questions
  1. How well can the Higgs boson couplings to fermions, gauge bosons and to itself be probed at current and future colliders?
  2. How do precision electroweak observables inform us about the Higgs boson properties and/or BSM physics?
  3. What progress is needed in theoretical developments in QCD and EWK to fully capitalize on the experimental data?
  4. What is the best path towards measuring the Higgs potential?

Higgs Couplings: two frameworks - kappa vs EFT

- Complementarity between the two approaches
- Kappa Framework:

$$g_{hXX} = \kappa_X \, g_{hXX}^{\mathrm{SM}}$$

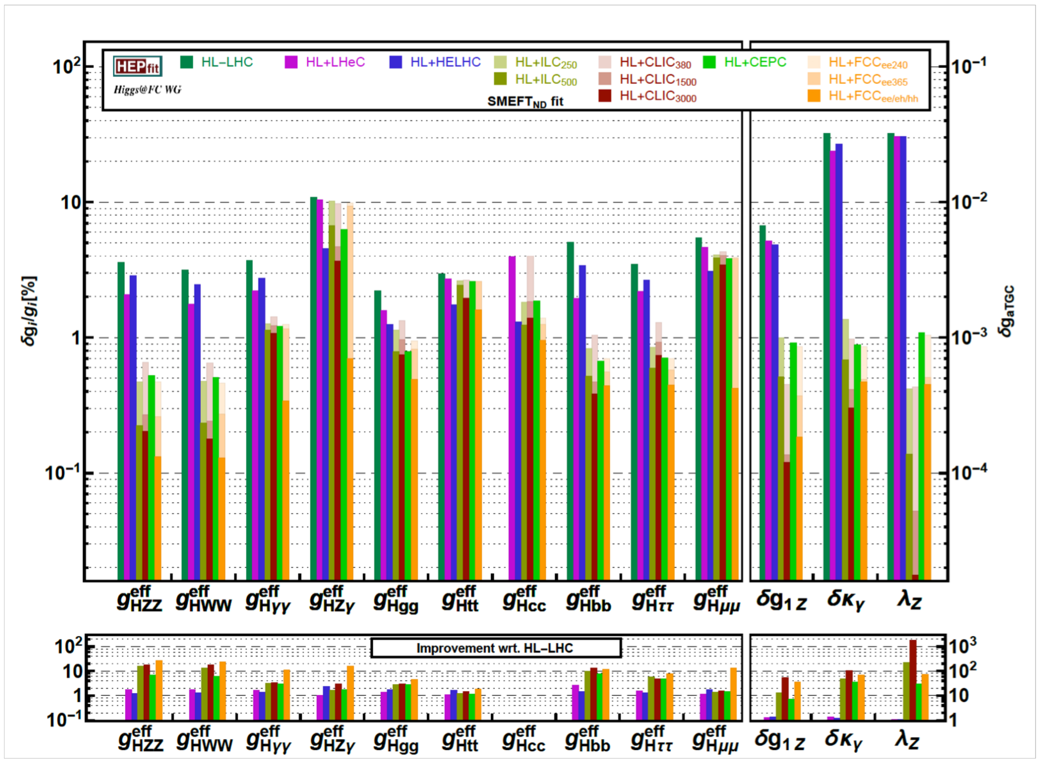
  - Well known and widely used characterization of Higgs coupling properties in terms of a series of Higgs coupling strength modifier parameters κ
  - Directly related to experimental measurements of the Higgs production and decay
  - Doesn't require BSM theoretical computations
  - Could still valid even with light new physics, i.e. exotic decays
  - Captures leading effects of UV motivated scenarios (SUSY, composite)
- EFT:
  - Allows to put Higgs measurements in perspective with other measurements (EW, diboson, flavour…)
  - Connects measurements at different scales (particularly relevant for high-energy colliders CLIC, FCC-hh)

$$\mathcal{L} = \mathcal{L}_{\mathrm{SM}} + \sum_{d,i} \frac{c_i \, \mathcal{O}_d^i}{\Lambda^{d-4}}$$

  - Fully exploits more exclusive observables (polarization, angular distributions…)
  - Fully QFT consistent framework
  - Valid only if heavy new physics

Higgs Couplings: EFT Framework

- Global fit including not only Higgs but also di-boson and EWK precision observables



Improvement factor in different channels wrt. HL-LHC

	LHeC	HE-LHC	ILC_{250}	ILC_{500}	$CLIC_{380}$	$CLIC_{1500}$	$CLIC_{3000}$	CEPC	$FCCee_{240}$	$FCCee_{365}$	FCCee/eh/hh
g^{eff}_{HZZ}	1.7	1.2	7.7	≥ 10	5.5	≥ 10	≥ 10	6.9	7.7	≥ 10	≥ 10
g^{eff}_{HWW}	1.8	1.3	6.7	≥ 10	4.9	≥ 10	≥ 10	6.3	7.0	≥ 10	≥ 10
$g^{eff}_{H\gamma\gamma}$	1.7	1.3	2.8	3.4	2.6	3.1	3.4	3.1	3.1	3.1	≥ 10
$g^{eff}_{HZ\gamma}$	1.1	2.4	1.1	1.6	1.1	2.3	3.0	1.7	1.1	1.2	≥ 10
g^{eff}_{Hgg}	1.4	1.7	2.0	2.8	1.7	2.3	2.9	2.8	2.3	2.7	4.5
g^{eff}_{Htt}	1.1	1.7	1.1	1.2	1.1	1.4	1.4	1.1	1.1	1.1	1.8
g^{eff}_{Hcc}	⋆		⋆	⋆	⋆	⋆	⋆	⋆	⋆	⋆	⋆
g^{eff}_{Hbb}	2.7	1.5	6.1	9.8	5.1	≥ 10	≥ 10	7.6	7.3	9.1	≥ 10
$g^{eff}_{H\tau\tau}$	1.6	1.3	4.1	5.8	2.7	3.8	4.8	5.0	5.0	6.1	7.8
$g^{eff}_{H\mu\mu}$	1.2	1.8	1.3	1.4	1.3	1.4	1.6	1.4	1.4	1.4	≥ 10
$\delta g_{1Z}[\times 10^2]$	1.3	1.4	6.7	≥ 10	≥ 10	≥ 10	≥ 10	7.3	7.8	≥ 10	≥ 10
$\delta\kappa_\gamma[\times 10^2]$	1.3	1.2	≥ 10	≥ 10	≥ 10	≥ 10	$\geq 10^2$	≥ 10	≥ 10	≥ 10	≥ 10
$\lambda_Z[\times 10^2]$	1.1	1.0	≥ 10	$\geq 10^2$	≥ 10	$\geq 10^2$	$\geq 10^3$	≥ 10	≥ 10	≥ 10	≥ 10

SMEFT ND (⋆) not measured at HL-LHC

Stat. limited

Top quark channels (LHC is a top factory and it is not so easy to outperform)

If no deviation seen at HL-LHC 5σ discovery still possible at a Future Collider

Which Machine?

- Exploration machines are at the heart of HEP
- As Higgs factories, all four machines have similar reach, though with different time schedules and with differing potentials for physics topics at other energies.

- Current consensus towards European Strategy Update:
- the best way to go to energy frontier is to start with a e+e- Higgs factory
- in the global context, CLIC and FCC-ee are competing with the ILC and with CEPC.

Circular or Linear?

Can be extended in energy
Polarized beams

Higher luminosity
Z-pole run

- Three relevant questions to help make the decision:
  - Impact of Z pole measurements. [helps HVV with FCC-ee, CepC; ILC limited by LP EW msm'ts, though mitigated by higher energy msmt's.]
  - Benefit of beam polarizations [positron pol. does not play a big role in Higgs coupling determination]
  - Is low energy a limitation?

Higgscouplings whose sensitivity improves compared to HL-LHC

		Factor ≥2	Factor ≥5	Factor ≥10	Years from T_0
Initial run	CLIC380	9	6	4	7
	FCC-ee240	10	8	3	9
	CEPC	10	8	3	10
	ILC250	10	7	3	11
2nd/3rd Run ee	FCC-ee365	10	8	6	15
	CLIC1500	10	7	7	17
hh	HE-LHC	1	0	0	20
2nd/3rd Run ee	ILC500	10	8	6	22
	CLIC3000	11	7	7	28
ee,eh & hh	FCC-ee/eh/hh	12	11	10	>50

13 quantities in total

NB: number of seconds/year differs: ILC 1.6×10^7, FCC-ee & CLIC: 1.2×10^7, CEPC: 1.3×10^7

This table should be interpreted with some caution
Nobody knows what BSM is!
So impossible to compute the figure of merit*.
*Specific BSM models may care even more about correlations

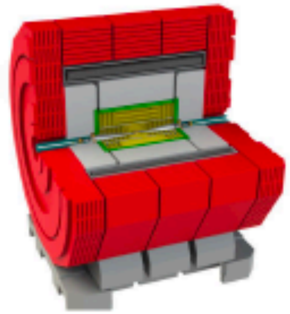
Precision Physics with the Higgs Boson

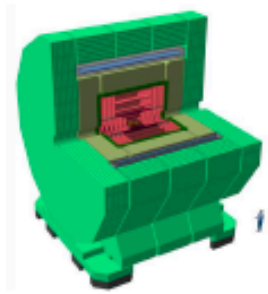
EWK Summary@Granada

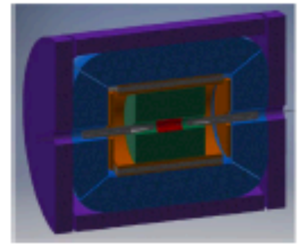
1. How well can the Higgs boson couplings to fermions, gauge bosons and to itself be probed at current and future colliders?
   - Current colliders: ~1-3% for 3rd gen fermions and gauge bosons, 4% to μ, 50% to itself
   - Future colliders: factors of ~2-10 better! + κ_c~2% + model-independent $\sigma(ZH)$
2. How do precision electroweak observables inform us about the Higgs boson properties and/or BSM physics?
   - Important to make sure precision H measurements (δgZ) not limited by these
   - Themselves probe new physics in interesting and complementary way
3. What progress is needed in theoretical developments in QCD and EWK to fully capitalize on the experimental data?
   - A lot of progress needed! Plan exists but lots of work/people needed!!
   - In some cases, new ideas are needed => and unclear when/if new ideas come
4. What is the best path towards measuring the Higgs potential?
   - Di-Higgs and single Higgs production are sensitive to derivative $d3V/d3\phi$ near minimum
   - Seems conceivable to determine it with sufficient precision to test 1st order EWΦT

- All future colliders have a rich potential to outperform (HL-)LHC in Higgs physics:
  - Legacy measurements that will go into textbook
  - Reach in BSM discoveries
  - Refinements in our understanding of Nature (EW phase transition, naturalness…)

High Energy e^+e^- Collider Detectors:

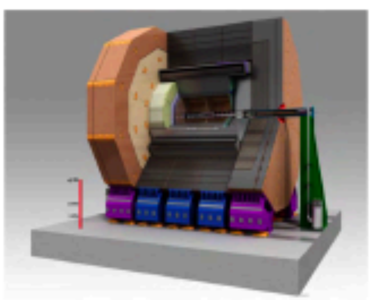


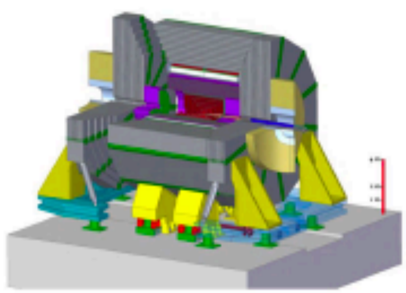


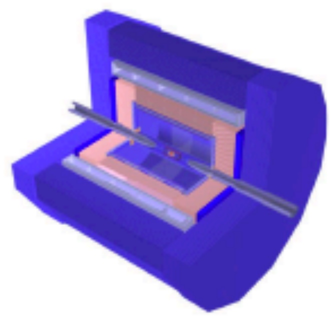


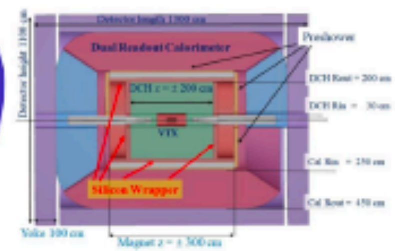
CLIC => **CLICdet**,
√s: 380 GeV, 1.5 TeV, 3 TeV

FCC-ee => **CLD** and **IDEA**
√s: 90 - 365 GeV







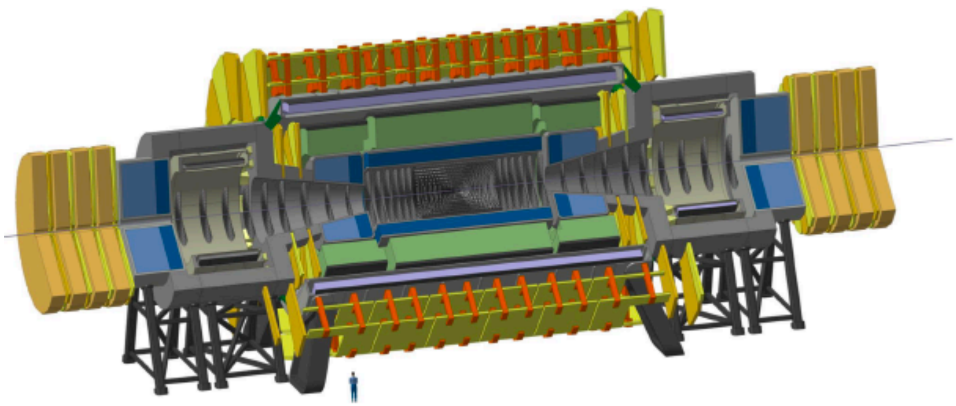


ILC => **ILD** and **SiD**:
√s: 250 – 500 GeV (1 TeV)

CEPC => **baseline** and **low-B**
√s: 90-240 GeV

FCC-hh Reference Collider Detector:

- .

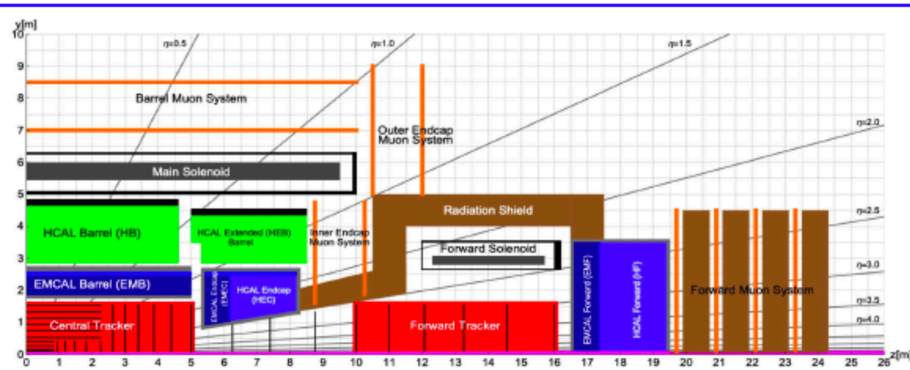


- 4T, 10m solenoid, unshielded
- Forward solenoids, unshielded
- Silicon tracker
- Barrel ECAL LAr
- Barrel HCAL Fe/Scint
- Endcap ECAL/HCAL LAr
- Forward ECAL/HCAL LAr

50 m long, 20 m diameter

'general' purpose detector with very large η acceptance and extreme granularity

Muon detection up to η = 4 ($\theta \approx 2°$) Calorimetry up to η = 6 ($\theta \approx 0.5°$)



Detector Challenges: FCC-hh as an example

Radiation dosages

- For FCC-hh tracker: The radiation for <40 cm radius of the tracker for FCC-hh is up to 100 times larger than what present sensors can sustain.
- For most parts of the calorimeter Liquid Argon is only viable known technology, but requires development towards high granularity $\Delta\eta \times \Delta\phi$ of 0.01x0.1 in ECAL, 0.025x0.025 in HCAL).
- Silicon or scintillator technologies could be used in regions with milder radiation levels.

Pile-up and boost:

- Requires much increased granularity in most regions of the detector
- High precision timing required (~5ps per track) and computing power for reconstruction, both significantly above HL-LHC
- Very accurate tracker hit position resolution (<5 μm), for 2-track separation in boosted objects

Data rate:

- High collision rate and high granularity => data rate of 1-2 Pbyte/s, mostly dominated by the tracker. Studies to be done whether this is possible and what triggering is required (year 20xx)

Performance requirements for e+e- detectors

Note: differences between requirements ILC, CLIC, FCC-ee, CEPC rather small

★ **momentum resolution:**
e.g, HZ recoil, $g_{H\mu\mu}$, Smuon endpoint

$$\sigma_{p_T}/p_T^2 \sim 2 \times 10^{-5}\ \mathrm{GeV}^{-1}$$

★ **jet energy resolution:**
e.g. W/Z/H di-jet mass separation, Z and W width, HZ with Z→qq, background reduction

$$\frac{\sigma_E}{E} \sim 3.5 - 5\ \%$$

(for high-E jets, light quarks)

★ **impact parameter resolution:**
e.g. c/b-tagging, Higgs branching ratios

$$\sigma_{r\phi} = 5 \oplus 15/(p[\mathrm{GeV}]\sin^{\frac{3}{2}}\theta)\ \mu\mathrm{m}$$

★ **angular coverage, very forward electron tagging**

- What's the impact of Machine Learning on detector designs?

Detector Requirements (generic)

- Future experiments require very challenging detector technologies
- Depending on the application
  - Much improved spatial resolutions (few μm per hit, low mass)
  - Much improved time resolutions (down to ~10 ps per hit)
  - High-performance photodetectors
  - Very high tolerance to radiation
  - Combined features in the same detector (5D imaging)
  - Very large numbers of channels, very high readout speed
  - Very large area coverage at low cost
  - Accompanied with a large diversity of engineering challenges
  - Electronics (CMOS technologies), high speed links and optoelectronics play increasingly important roles
  - Advanced detector simulation tools are necessary to reach ultimate perform
  - Advanced detector technologies are essential for the progress in particle physics.
    - They require high-level professional physics and engineering skills, the ability to generate original ideas and dedicated effort over many years!!
- The detector concepts proposed should be viewed as points for discussion and optimization.
- *How do we – ie US physicists – contribute and engage in innovative R&D? Funding scenarios?*

P. Cushman and Y.K. Kim @ DPF 2019

Timeline for updating the U.S. Strategy

- **May 2014 P5 report was successful because it was well informed by the science community**, including information from:
  - Astronomy and Astrophysics, Japan HEP Future Projects
  - 2013 European Strategy for Particle Physics Report
  - 2013 U.S. Particle Physics Community-driven “Snowmass” process
- **The timeline of processes that impact the next strategic plan:**
  - 2018-20: New NAS Astronomy and Astrophysics Decadal Survey
  - 2019: Start of European Strategy for Particle Physics process
  - 2019/20: Anticipated Japanese decision on ILC
  - 2020: Release of updated European Strategy for Particle Physics
  - 2020: Earliest opportunity for National Science Board to approve obligating MREFC for HL-LHC
- New Snowmass Process will be officially inaugurated at the 2020 April APS Mtg.
- Yearlong sequence of workshops culminating in a 10-day Summer Study in 2021

Snowmass Process

- .

Call for
convener nominations

Draft Timeline for Snowmass 2021

DPF Program committee is currently reviewing the old topics
https://www.aps.org/units/dpf/governance/committees/program.cfm

Late August: Begin the process of community involvement on new draft topics
Call for site selection proposals for summer 2021

October: Finalize topics and cross-cutting categories.
DPF Exec will establish detailed job descriptions for co-conveners
Program Committee will accept nominations, collate recommendations
and submit to DPF Exec for convener selection
Sub-conveners will also be selected by DPF exec, after convener nomination

Spring 2020: Secure funding for workshops and overall plan
Choose 2021 site, date, and duration

Spring 2020 – Spring 2021: Conduct workshops, prepare initial white papers

Summer 2021: Snowmass Summer Study Final Collation

Report due by December 2021

8/1/19 P. Cushman and Y-K Kim DPF 2019 34

Snowmass topics: for the NOMINATION PROCESS

Those which are interest to hopefully the bulk of us!

- Energy Frontier
- Higgs Physics
  - Properties (mass and width)
  - Decay channels
  - Production processes (VBF, associated etc.)
- Top Quark physics
- BSM: new bosons, new fermions
- BSM: SUSY and MET
- Accelerator Searches for DM and long-lived particles
  - ATLAS & CMS
  - Dedicated experiments
- Electroweak
  - W = production, mass and Z Production processes
- QCD
  - Pdf measurements
  - Precision X-section measurements
  - Use of QCD and Lattice in extraction of CKM elements and pseudoscalar decay constants
- Heavy Ions
- Hadron spectroscopy
  - light meson, b b-bar, c c-bar, exotic tetraquark, pentaquark states

- Instrumentation
  - Quantum information science theory
  - Quantum sensors
  - Photon Detectors
  - Phonon Sensors
  - Precision Timing
  - Particle/Radiation Detectors for General Applications
  - Trigger and DAQ
  - Muon systems
  - Calorimetry
  - Electronics
  - Charge/e-/Ionization Collection
- Computation
  - Computational Physics and Algorithms
  - Machine and Deep Learning
  - Statistical Techniques
  - Distributed and High Performance Computing
  - Networking
  - Computing/software infrastructure
  - Quantum Computing
  - Quantum Communication

MY PERSPECTIVES ON THE FUTURE OF COLLIDER PHYSICS & EXPECTATIONS FOR SNOWMASS 2021

LHC/ HL-LHC community engagement in Snowmass (1)

- Why and how should "we = LHC/ HL-LHC community" engage in this process?
  - Whether it is a Linear OR a Circular collider, ee vs hh, our community has the expertise to plan, design, build an make it work! [An obvious note: some of us will retire while designing…]

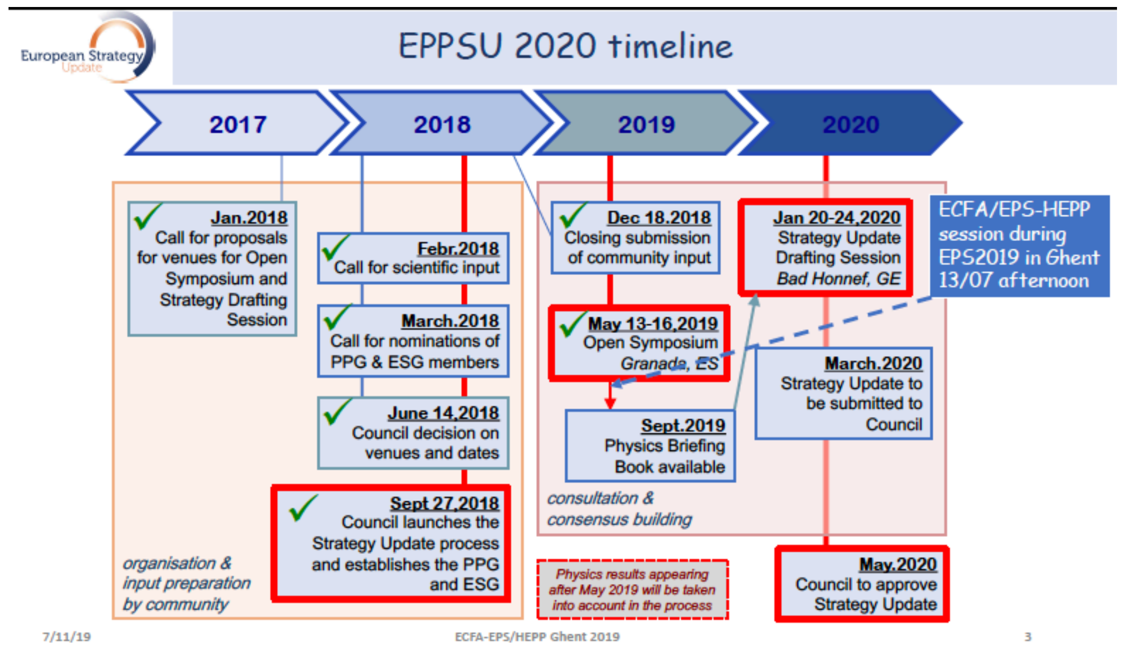
- Some considerations for Snowmass
- Physics
  - For the last 2+ years, the ESG process has received a large set of inputs to the physcs case by the various collider proponents [and organizations].
  - The "preparatory group" invested a good amount of effort to understand these inputs by the various collider options and put them on the same footing to be able to make direct comparisons of physics sensitivity reach!
  - One may then ask --- Is it all done? What is lacking ? what can we add to these studies at Snowmass ? What would be our physics focus?

LHC/ HL-LHC community engagement in Snowmass (2)

- ESG is expected to define its strategy by May 2020.
  - Thus it may have recommended a collider option (or preference) by the time of Snowmass 2021
  - It will probably influence our Snowmass studies relating to EF (and Instrumentation+Computing].
  - How do we define our message and activities at Snowmass?

- Your input is needed.
  - A discussion topic for this afternoon
- Provide the feedback

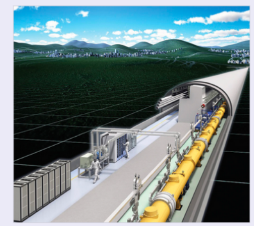
  as input to the Snowmass process



Collider choices/recommendations:

- What about alliances- where do the US/America's stand?
  - If circular collider – then China vs CERN
    - How would that be resolved?
  - If Linear – CERN vs Japan
    - We have a the America's ILD vision and participation.
- We may be in a situation where countries may make their own choices.
  - CERN is a "Lab" and needs to define its own future
    - It could choose to go ahead with CLIC or FCC-ee
  - What if China decides to build the CEPC?
    - The ESG endorsement of a e+e- collider will cement their case to their politicians and funding agencies!
  - What if Japan proceeds with the ILC?
    - Does it make sense to have another ee collider? If yes, what type of ee collider?
  - What about an intermediate energy inexpensive FCC-hh? @ 37.5 TeV?

New working group to address ILC concerns



An illustration of the ILC in Japan. Credit: R Hori/KEK.

On 17 May in Granada, following the open symposium of the European Strategy for Particle Physics, the first meeting of a new international working group on the International Linear Collider (ILC) took place. The ILC is the most technologically mature of all current future-collider options, and was at the centre of discussions at the previous strategy update in 2013. Although its technology and costs have been revised since then, there is still no firm decision on the project's location, governance or funding model. The new working group was set up by Japan's KEK laboratory in response to a recent statement on the ILC from Japan's Ministry of Education, Sports, Culture, Science and Technology (MEXT) that called for further discussions on these thorny issues. Comprising two members from Europe, two from North America and three from Asia (including Japan), the group will investigate and update several points, including: cost sharing for construction and operation; organisation and governance of the ILC; and the international sharing of the remaining technical preparations. The working group will submit a report to KEK by the end of September 2019 and the final report will be used by MEXT for discussions with other governments.

Role /Focus of USLUA/EF scientists during Snowmass:

- How do US Scientists / USLUA play a role in the dialogue?
    - We (USLUA) are a large community with expertise, and spending the time to train the next-generation as stellar collider physicists.
- Should (or Can) the US fund multiple choices? Can we afford the luxury or even the “sell” to congress during our yearly visits?
    - ILC in Japan
    - FCC-ee at CERN
        - (unless the environment changes drastically CepC collaboration would be difficult to invest US DOE/NSF funds).
- Do we even want to consider or DREAM about the next collider in the US? Or we have been boxed into neutrinos@FNAL/US and ee/hh Collider @CERN or elsewhere scenario forever.
    - Sound too naïve asking this question? However, the young scientists should be fully aware of this fact.
- Given we will not have many physics frontier studies to push or document at Snowmass, maybe EF should concentrate on providing
    - the sociological, political, economic benefit case as an Snowmass outcome and input to P5
    - Effect of large timescales - potential loss of expertise (accelerator/detectors), N generations
    - Personal aside -- I am really not excited about looking at yet another corner of phase space where we know we can eventually succeed to look for new physics once we know what we are building (and possibly where)?
- Build the case or rethink, if there is one to bring EF back to the US?
    - Food for thought.. It is always good to reconsider traditions and folklore, before re-embracing them.
- How do we – ie US physicists – contribute and engage in innovative R&D? Funding scenarios?

Thank you

- For providing me the opportunity to share my perspective.

- Many thanks to all from who I have shamelessly borrowed slides…
  - Applauds and credits to the colleagues
  - Any mistake is mine [sorry

Backup

Next Collider Options

ILC

Statement by American Linear Collider Committee (US+Canada)

ALCC stance vis-a-vis discussions concerning the International Linear Collider in the context of the European Strategy for Particle Physics (2020)

ALCC, March 27, 2019

The Americas Linear Collider Committee supports the ICFA position confirming the international consensus that *"the highest priority for the next global machine is a 'Higgs Factory' capable of precision studies of the Higgs boson."* We remain convinced that the ILC best meets all of the requirements needed to probe detailed properties of the Higgs boson. The ILC has the potential for a future upgrade in energy, can sustain beam polarizations that increase its ability to do precision measurements, and is the most technically mature proposal for an electron-positron collider now available.

The recent statement by MEXT in Japan stated that further consideration by the Science Council of Japan and intergovernmental discussions are necessary before Japan would be in a position to make a bid to host the ILC. Unfortunately, this does not fit naturally into the timetable for finalizing the European Strategy recommendation. On the other hand, it appears that high-level interactions between the U.S. DOE and the Japanese principals, government and DIET, continue to be positive. We understand that the DOE remains interested in discussing with senior Japanese officials about ILC and the possibility of hosting it in Japan.

The ALCC is supportive of any electron-positron project that can distinguish the Standard Model from new physics models through precision measurements of the Higgs production and decay couplings. However, given the strengths of the ILC noted above and the recent progress in obtaining support for it within Japan, we urge that the European Strategy group support the completion of the process underway in Japan to decide on a bid to host the ILC.

CLIC

- CLIC and normal conducting high-gradient activities
- O(200) signatories for CDR
- Detector design and R&D
- Ongoing studies on physics potential

FCC-ee, ep, pp

- Deep expertise in accelerator technologies including high field magnets and SCRF
- O(500) engaged; O(100) co-authored European Strategy Documents
- Ongoing studies on physics potential and detector design
- Long and productive cooperation on joint projects in US and at CERN

CEPC

- Pre-CDR & CDR on arXiv with international contributions
- O(100) participated
- Detector design and R&D

Electron-Ion Collider (U.S.)

- DOE Office of Nuclear Physics (not Office of High Energy Physics)
- Science Drivers
  - How does the mass of the nucleon arise?
  - How does the spin of the nucleon arise?
  - What are the emergent properties of dense system of gluons?
- Status
  - Two concepts being developed: Realization could be as early as 2028-2030
  - CD-0 (Approve Mission Need) is planned for FY 2019