Discussion on Future Colliders

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26 September 2018

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Lessons from the Past

- Last of the no-lose theorems
- Make the best physics case possible
- Ignore political realities at your peril
- A bird in the hand is worth two in the bush

The current status of particle physics

- With the discovery of the Higgs boson, we have entered a new era of particle physics

  - There is no longer a no-lose theorem to guarantee future discoveries
  - We are in a data-driven era—i.e., we depend on new data to guide future directions in BSM physics
  - The principle of naturalness, although not dead, is under tension.
  - So how do we motivate the next generation of colliders?

- Do we really know the particle content of the TeV-scale effective theory?
  - The scalar sector of the SM has a single Higgs boson. Why not multiple families of Higgs scalars?
  - What about vector-like quarks and leptons?
  - Flavor anomalies have revived interest in leptoquarks.
  - Are there new gauge bosons lurking in the region of 1—10 TeV?
  - Dark matter may be the tip of the iceberg. The structure of the dark sector could be highly non-minimal. Future colliders may provide opportunities to access the dark sector (e.g., via the Higgs portal).

So, where do we go from here?

- Explore the Higgs sector as thoroughly as possible (since, you have never seen anything like it before).
  - Experimental studies at present and future colliders
  - Implications for early universe cosmology

- Precision, precision, precision.

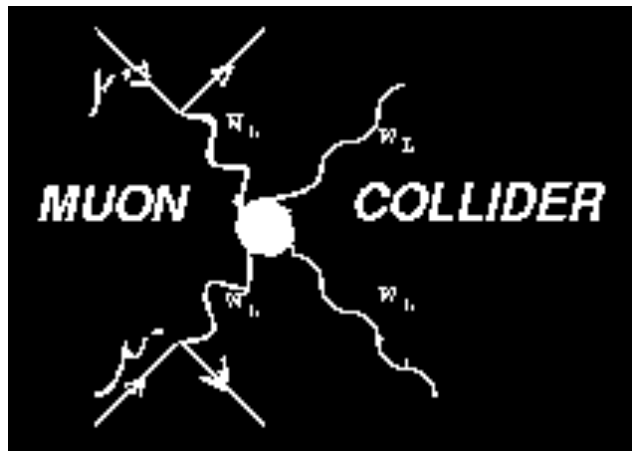
- Exploit the LHC to its maximum.

- Provide a roadmap for future energy-frontier facilities.


ilc


FCC
hh ee he


clic


MUON
COLLIDER


CEPC

Of course any significant deviation seen in other sectors could have the same impact – there is a **lot** of data left to analyse!

NOW

2019-2020: LHCb, Belle II could confirm anomalies: pointing to a scale?*
(g-2) : 1st new measurement

2025-2035(9?): HL-LHC running

Transition to HE-LHC - as soon as magnets ready to change the data taking slope? (price vs gain?)

Motivation if no sign of NP? No no-lose theorem…

FCC-hh?: scan for NP at high energy

e (60 GeV) - p in HL-LHC (PDFs…)?
Price vs gain?

A stepping stone?

Dec 2018: ILC?

Explore the Higgs with high precision (eventually going to top threshold?)
-> May start program towards the end of HL-LHC

FCC-ee? Longer timescale?

CLIC? Much longer timescale?

CEPC? Longer timescale?
Funding possibly ok **but # international experts an issue for parallelization?**

SppC?

Magnet development needed!

The 5 P's

	ILC (250)	CLICino	FCC-ee	CEPC	FCC-hh	SppC
Physics case	Precision exploration of Higgs Can probe BSM indirectly -> point to a scale?				Triple-Higgs coupling at 5%... Possible direct access to BSM No no-lose theorem, but broader exploration	
		Top threshold				
			Beam E measurement -> better precision Z program			
Progress needed	shovel ready ?	Design report by the end of the year?	No CDR yet	No TDR yet	Magnet development needed	
			detector needs > ILC		HE-LHC as a first step?	
Price	40% cost reduction => descoped 1st energy goal	~FCC-ee	Tunnel = cost of HE-LHC	Smaller need of international funding?	x 2-3 FCC-ee/CEPC [1]?	
Politics	Needs Japanese ok by the end of 2018	CERN: existing center / maintain		Multiple international centers		
	e^+e^- easier to 'sell' ? / stepping stone while waiting for magnet development?					
Possibilities for the future	Increase to 500 GeV; or new acc. techniques?	-> 1.5 TeV -> 3 TeV	Stepping stone for future hadronic collider		Far future…	

[1] https://arxiv.org/abs/1509.08369 by the director of APC Fermilab

Future scenarios

How would CERN respond to:

- Japan willing to host the ILC
- China going forward with CEPC (possibly followed by SppC)

Possible combinations?

- ILC + HE-LHC
- ILC + FCC-hh(+ee?)
- ILC + CEPC (#experts?)
- FCC-ee + FCC-hh / CEPC + SppC
- CLIC + CEPC (#experts?)
- CLIC

Thinking outside the box

- muon colliders [2]: proton on target (and then cool) vs positron on target at production threshold; energies from Higgs threshold up to 30 TeV
- high gradient, high power e^+e^- linear collider in the TeV class [3]

[2] see e.g. https://indico.cern.ch/event/719240/
[3] see e.g. https://arxiv.org/abs/1807.10195