Discussion on Future Colliders

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

Dec 2018: ILC?
- Explore the Higgs with high precision (eventually going to top threshold?) -> May start program towards the end of HL-LHC

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

FCC-hh?: scan for NP at high energy
- Motivation if no sign of NP?
- No no-lose theorem...

FCC-ee? Longer timescale?

CLIC? Much longer timescale?

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

Magnet development needed!

SppC? A stepping stone?
<table>
<thead>
<tr>
<th>The 5 P’s</th>
<th>ILC (250)</th>
<th>CLICino</th>
<th>FCC-ee</th>
<th>CEPC</th>
<th>FCC-hh</th>
<th>SppC</th>
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<tbody>
<tr>
<td><strong>Physics case</strong></td>
<td></td>
<td>Precision exploration of Higgs Can probe BSM indirectly -&gt; point to a scale?</td>
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<td>Triple-Higgs coupling at 5%... Possible direct access to BSM No no-lose theorem, but broader exploration</td>
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<td>Top threshold</td>
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<td>Beam E measurement -&gt; better precision Z program</td>
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<td><strong>Progress needed</strong></td>
<td>shovel ready ?</td>
<td>Design report by the end of the year?</td>
<td>No CDR yet</td>
<td>No TDR yet</td>
<td>Magnet development needed</td>
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<td>HE-LHC as a first step?</td>
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<td><strong>Price</strong></td>
<td>40% cost reduction =&gt; descope 1st energy goal</td>
<td>~FCC-ee</td>
<td>Tunnel = cost of HE-LHC</td>
<td>Smaller need of international funding?</td>
<td>x 2-3 FCC-ee/CEPC [1]?</td>
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<td><strong>Politics</strong></td>
<td>Needs Japanese ok by the end of 2018</td>
<td>CERN: existing center / maintain</td>
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<td>Multiple international centers</td>
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<td>e^+e^- easier to ‘sell’ ? / stepping stone while waiting for magnet development?</td>
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<td><strong>Possibilities for the future</strong></td>
<td>Increase to 500 GeV; or new acc. techniques?</td>
<td>-&gt; 1.5 TeV -&gt; 3 TeV</td>
<td>Stepping stone for future hadronic collider</td>
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<td>Far future...</td>
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[1] [https://arxiv.org/abs/1509.08369](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/