Electroweak and Strong Physics

ECFA Early Career Researchers Meeting
Friday 15th November 2019

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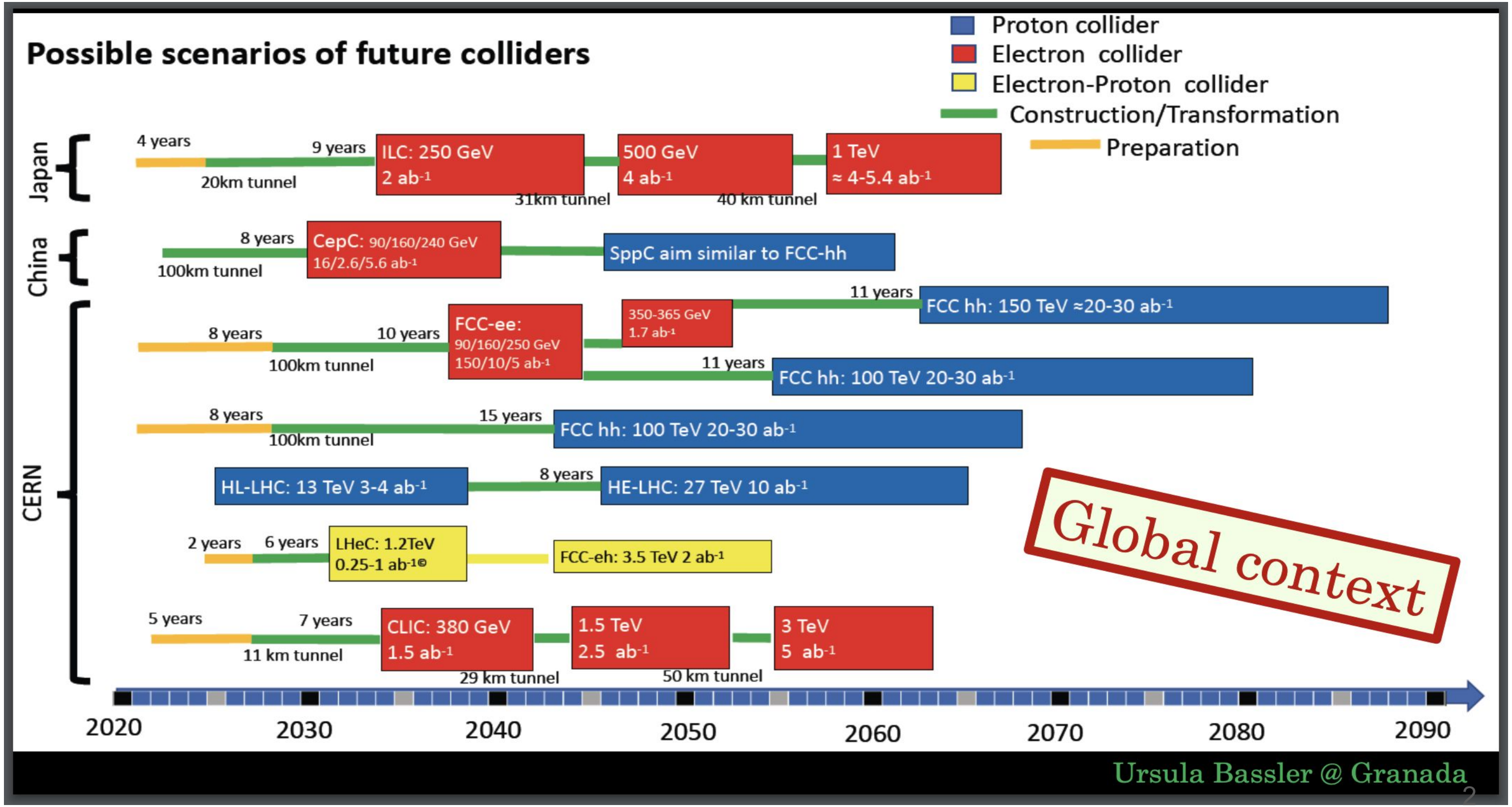
Timeline of Several Collider Options

Timelines shown here are for these as stand-alone projects

Budget and resources will affect the schedule of correlated projects



The Five "Strawman" Scenarios

	2020-2040	2040-2060	2060-2080
		1st gen technology	2nd gen technology
CLIC-all	HL-LHC	CLIC380-1500	CLIC3000 / other tech
CLIC-FCC	HL-LHC	CLIC380	FCC-h/e/A (Adv HF magnets) / other tech
FCC-all	HL-LHC	FCC-ee (90-365)	FCC-h/e/A (Adv HF magnets) / other tech
LE-to-HE-FCC-h/e/A	HL-LHC	LE-FCC-h/e/A (low-field magnets)	FCC-h/e/A (Adv HF magnets) / other tech
LHeC-FCC-h/e/A	HL-LHC + LHeC	LHeC	FCC-h/e/A (Adv HF magnets) / other tech

- Nothing set in stone!
- What other scenarios we can come up with that better suit our physics interests?
- Is the European project decision decoupled from decisions elsewhere?
    - The challenges to our discipline require worldwide cooperation

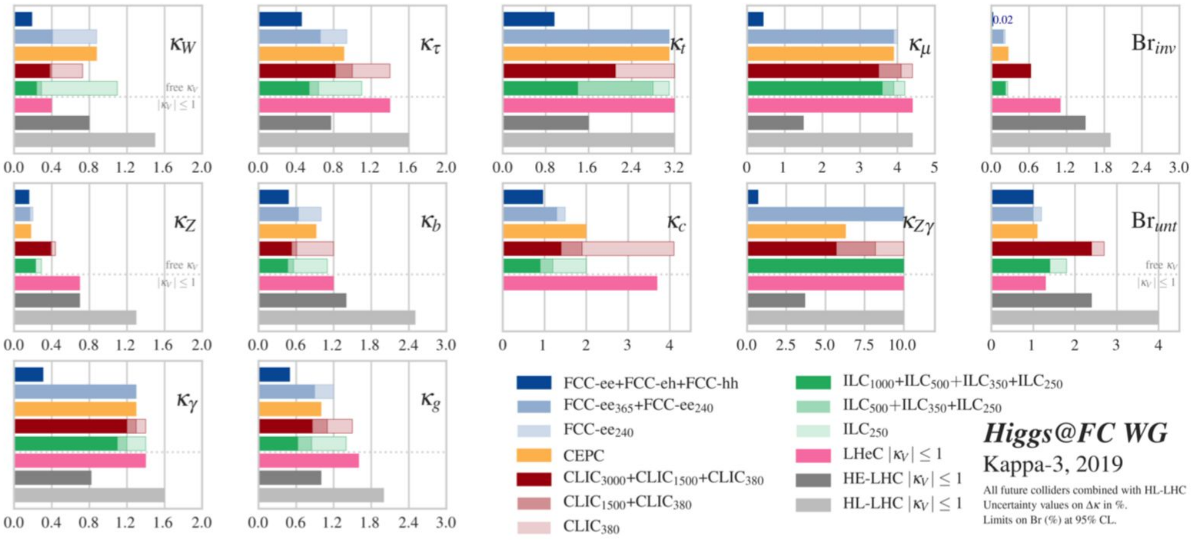
Comments on the Briefing Book - General Comments
(http://cds.cern.ch/record/2691414)

- How will this strategy shape our career prospects?
  - Is the layout of the strategy likely to increase our chances of a career in fundamental research?
  - How to foster the career of ECRs working on instrumentation and computing?
  - Long periods for significant increase in luminosity
  - Long periods with no major colliders operating in Europe

- ECRs should be more involved in the decision making
  - General feeling that we came into this late

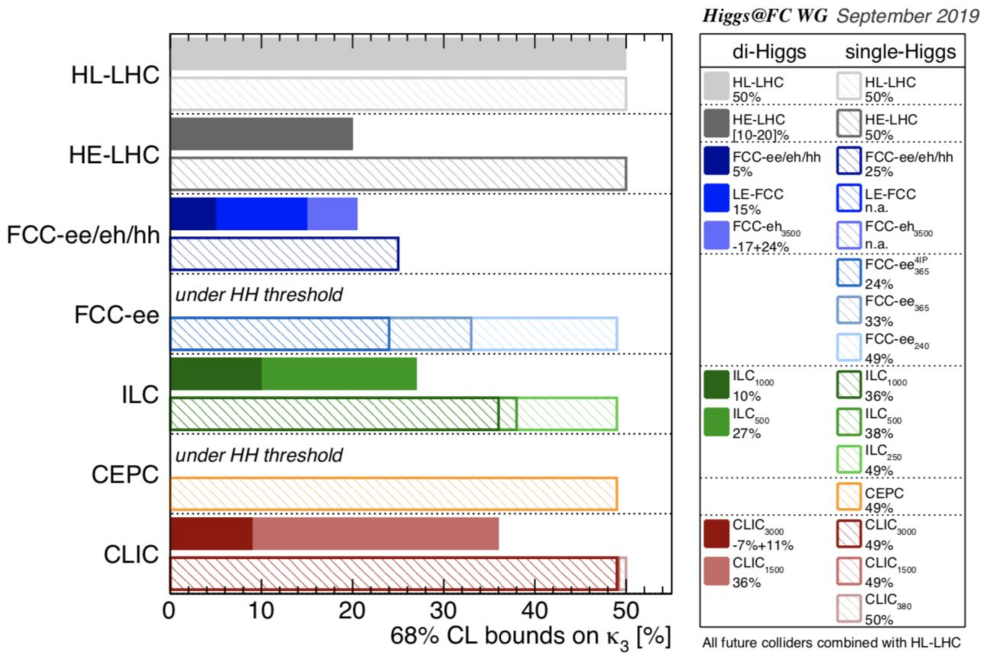
Higgs Couplings

- HH colliders dominant production: gg→H
- e^+e^- colliders dominant production: $e^+e^- \rightarrow$ZH (WW-fusion) at low (high) energies
- Deviations in data from SM would definitively indicate New Physics
- e^+e^- machine gives more direct probe of Higgs couplings, and can directly measure total Higgs width
- FCC-ee and CLIC with similar sensitivities in general
- For many measurements, FCC-hh brings great improvement w.r.t. e^+e^- colliders

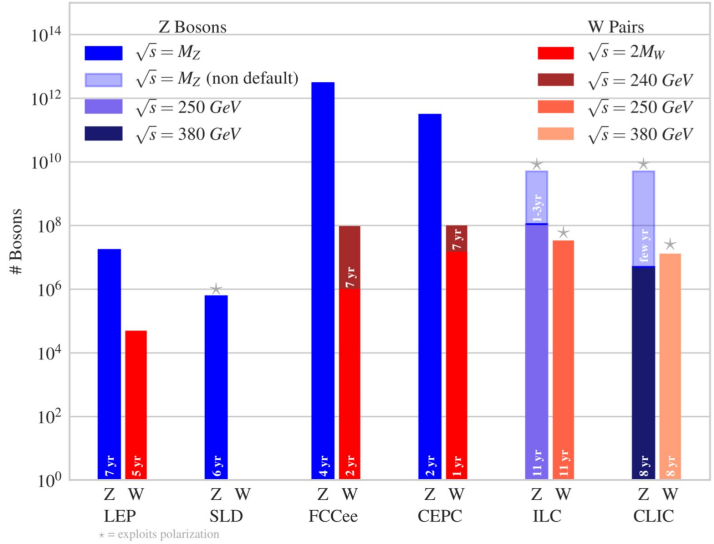


Higgs Self-Coupling

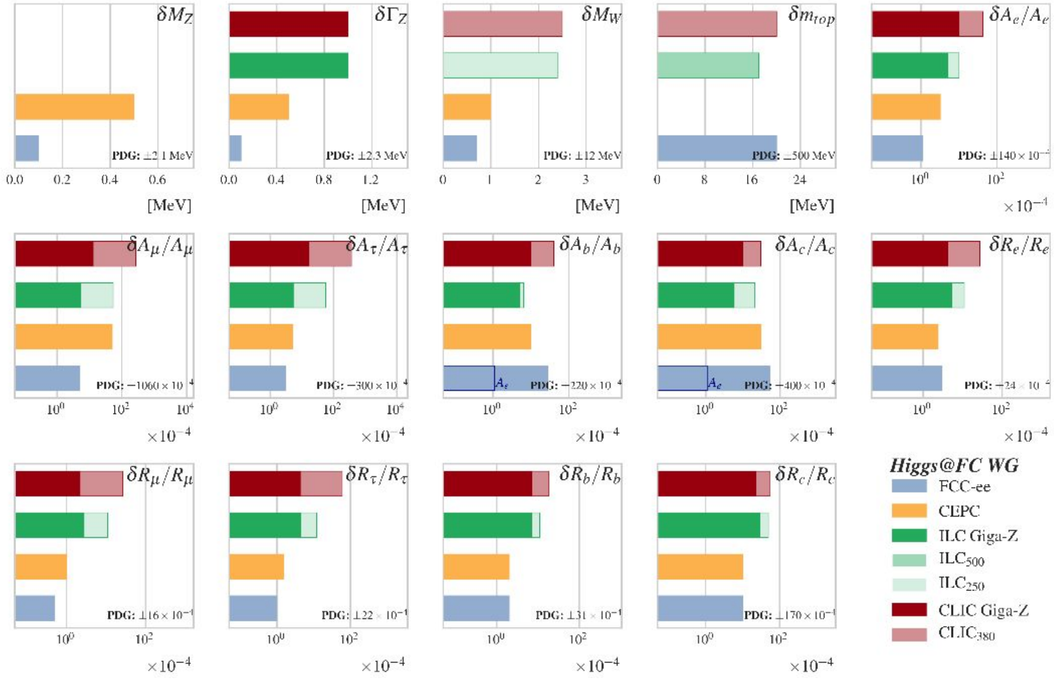
- Defines the Higgs potential
  - Higgs self-interactions λ_3 and λ_4
- Direct via Higgs pair production
- Single Higgs production, indirect
- In hh colliders (HL/HE LHC, FCC-hh) dominant production is gg→HH
- ee colliders dominant production is ZHH (double Higgs-strahlung)
- Circular linear colliders below the HH threshold. Indirect constraint is the only option
- FCC-hh could reach λ_4 Higgs quartic coupling
- General motivation for pp or high energy e^+e^- LC



Z and W Measurements



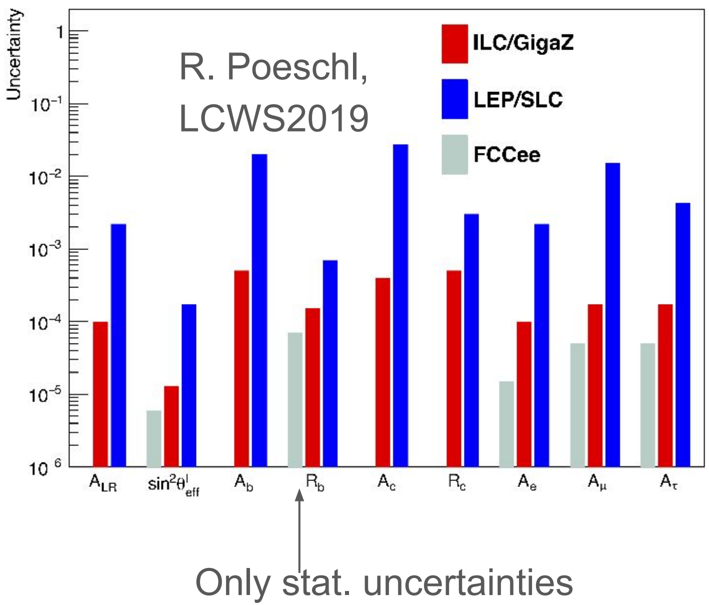
Numbers of Z bosons and W pairs for different e^+e^- colliders



Uncertainties on various EW observables in e^+e^- colliders

Linear Colliders and Beam Polarisation

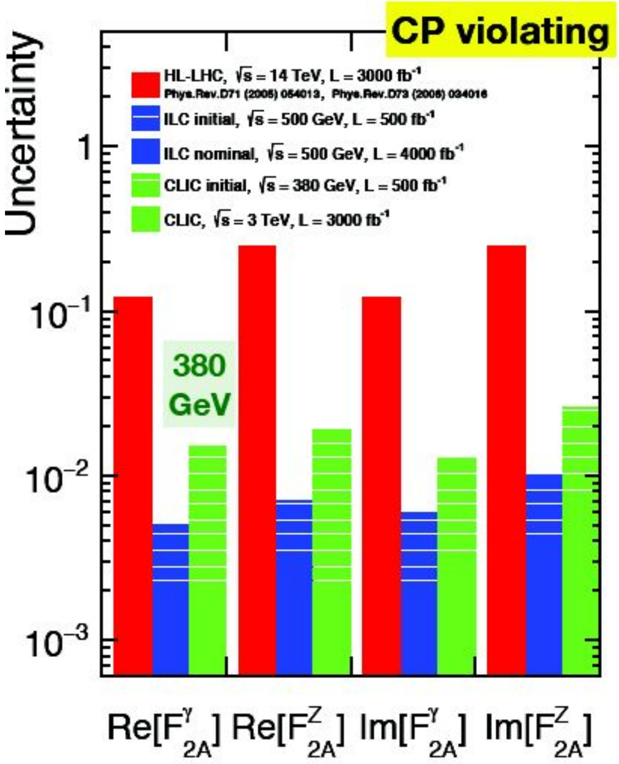
- For a number of EW measurements, SLC was more precise than LEP despite having a much lower luminosity
- Beam polarization increases the xsec of various processes, and the number of observables
- New colliders can be 10x better than LEP/SLD
- LC have access to more observables (polarization)
  - + No need of lepton universality assumption
  - + Separation of the contribution from the different chiralities (and also from Z-y couplings)
  - Polarization compensates for ~30 times luminosity
  - A_{LR} can benefit from hadronic Z-decays
- Circular have better expectations for the others

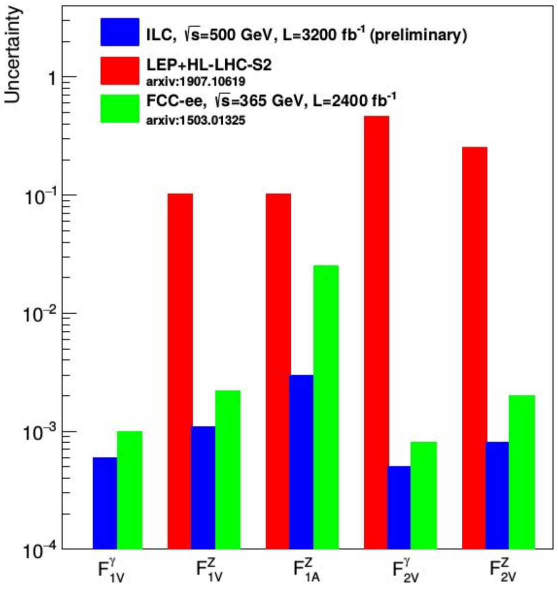


e^+e^- colliders provide deep and unrivaled tests of the EW couplings to all fermions (top-quark in the next slide)

Top Quark Physics (EW Couplings)

- $e^+e^- \rightarrow tt$ just above threshold
  - Little sensitivity to axial couplings
- ILC has best precision on many of the couplings
- Beam polarization disentangle Z-y exchanges (as with the other quarks)
- Upgradability of energy of LCs allows to enhance EW couplings to the top quark
  - Reminder: the top-quark is one of the BSM candles together with the Higgs
- FCC-hh prospects on this?
  - Will it be better than LHC?
  - In what possible time scale?





arXiv:1908.11299, Eur.Phys.J. C78 (2018) no.2, 155

Emphasis on BSM Physics

- Discovery of new resonances requires higher energies
- Focusing in high precision measurements?
- Study of Higgs decays to invisible particles, and measurement of Higgs width possible with e^+e^- machine
- EW measurements test naturalness problem
  - Fine-tuning and naturalness problem two of the main motivations for new physics at the EW-scale
- Benchmark scenarios? How important are they? Can we see ourselves as explorers of the energy frontier or do we need a fixed model goal?

Comments on the Briefing Book - EW Physics

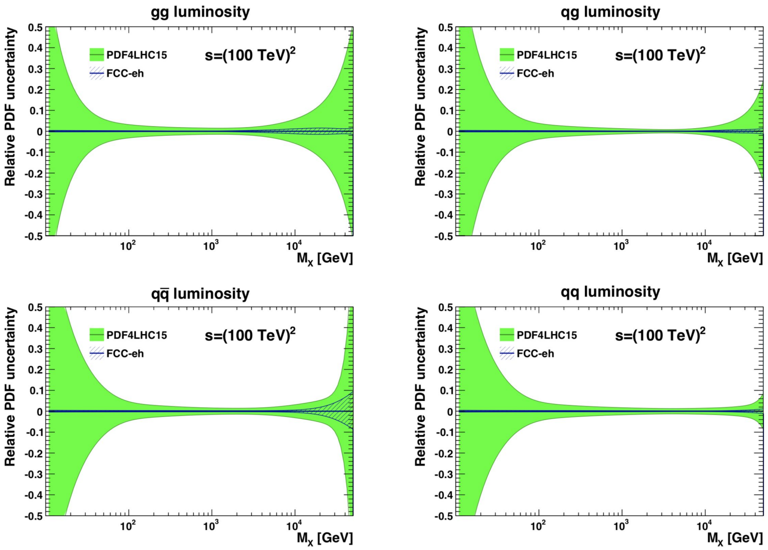
(http://cds.cern.ch/record/2691414)

- Could benefit from better synergy between searches and measurements
  - E.g. unfolding of search CRs used to improve MC modelling
  - General preference for final state-driven physics group structures (rather than model-driven)
  - Discuss EFT more
- Clear need for significant development on the theoretical side to maximise physics potential
  - Will there be more investment for this?
  - Where can better use be made of data-driven techniques for background estimations?
- Not much mention of top measurements
- Are there studies with separate FCC-ee, FCC-eh and FCC-hh results?
- Expected results are missing for the LE-FCC. Would it be preferable to FCC-ee?
- Are the studies of all accelerators compared in equal footing (same level of realism)?
- No mention of colliders probing the extremes of QED, acting as high energy broad-band photon-photon collider (recent observation of light-by-light scattering)
- Currently no distillation of the results into conclusions

Physics Briefing Book on Strong Physics 1

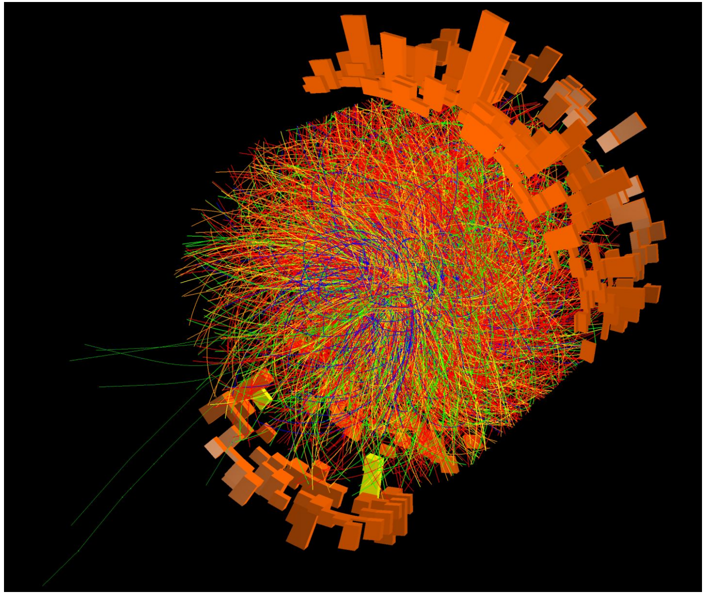
"QCD is not the main driving force behind future colliders. / … / An incomplete knowledge of PDFs is one of the main limitations in searches of new physics at the LHC." Physics Briefing Book

1. Precision QCD program:
   - New constraints on α_s and parton distributions
   - New PDFs are crucial for any new physics e.g. MC simulation and background estimation
   - Lattice QCD: g-2, α_s, quark-mixing, exotic states
   - Low energy: CP problem, dipole moment, nucleon radius
   - ep and e^+e^- colliders are needed
2. Hadronic structure
   - Small-x and saturation physics
   - High-x and heavy quark content of PDFs
   - Nucleon spin puzzle
   - Nuclear PDFs
   - ep, pp, eA, pA colliders are needed
   - Polarized beams? Not all colliders have p or A beams



Physics Briefing Book on Strong Physics 2

"The development of a broad QCD programme … between different machines and collision systems, pp/pA/AA and ep/eA, should be encouraged. / … / The long-term measurements in heavy-ion collisions will benefit from a sustained support from the theory community." Physics Briefing Book



3. Hot and dense QCD program:
   - Thermodynamics of quark-gluon plasma
   - Phase diagram of QCD and neutron stars
   - Collectivity in small system
   - Jet quenching
   - Ultra-strong magnetic fields and chiral magnetic effect
   - Photon-photon collision in ultra peripheral collisions
   - pp, pA, AA collisions are needed, but not all plans provides them
4. QCD theory development:
   - MC generators: higher order calculations (fixed order and resummed logs); improve underlying event and hadronization description
   - Lattice QCD: g-2, nucleon structure and high temperature QCD
   - Encouraging EFT formalism

Comments on the Briefing Book - Strong Physics
(http://cds.cern.ch/record/2691414)

- No mention of polarized beams in the strong physics part of the book. Will be there any?
- What type of ions and energies could be used in the different collider concepts for heavy-ions?
- More than half of the QCD studies require ion beam, although not all colliders can provide them. Will there be any alternatives for heavy-ion studies at the TeV scale beyond the ECFA proposals?
- Many practical development in theory was mentioned (MC in higher orders, LQCD). How to complete these tasks? How can ECRs contribute?
- Additional low-energy studies were mentioned. What about theory developments in their field?
- Thorough discussion in briefing book on LQCD, but no mention of dispersive techniques e.g. muon g-2 or vacuum polarization

What are Early Career Researchers (YOU!) Excited About?

- Going to higher energy to find new physics?
- Precision measurements are required (specially since no clear hints of new physics are observed)
  - Deviations from expectation could lead to new physics!
- A new collider ASAP or wait after the HL-LHC results?
- A collider in Europe? Happy to be stationed abroad?
  - Further developing of online tools to reduce the need of being physically located in the hosting institute? What is the experience of european ECRs in Belle 2 or other ongoing asian-based projects?
- Less money to massive colliders? Invest more diverse program of smaller experiments?
- Career prospects?
- Star wars movies until 2060 or new sci-fi franchises?
- ….?

Back-up

Higgs factories comparison (technological)

Shiltsev, Granada Meeting.

Finding *Common Denominators* * – Three Factors

** to be further discussed in the Symposium's accelerator sessions*

- ***F1* "Technology Readiness"** :
  - Green - TDR
  - Yellow - CDR
  - Red - R&D
- ***F2* "Energy Efficiency"**
  - Green : 100-200 MW
  - Yellow : 200-400 MW
  - Red : > 400 MW
- ***F3* "Cost"** :
  - Green : < LHC
  - Yellow : 1-2 x LHC
  - Red : > 2x LHC

Higgs Factories	Readiness	Power-Eff.	Cost
ee Linear *250 GeV*	Green	Green	Green→Yellow
ee Rings *240GeV/tt*	Yellow→Green	Yellow	Yellow
μμ Collider *125 GeV*	Red	Yellow	Green *
Highest Energy			
ee Linear *1-3TeV*	Yellow→Green	Yellow→Red	Red
pp Rings *HE-LHC*	Red→Yellow	Green	Yellow
FCC-hh/SppC	Red→Yellow	Red	Red
μμ Coll. *3-14 TeV*	Red	Yellow	Green→Yellow *