CERN Council Open Symposium on the Update of

European Strategy for Particle Physics

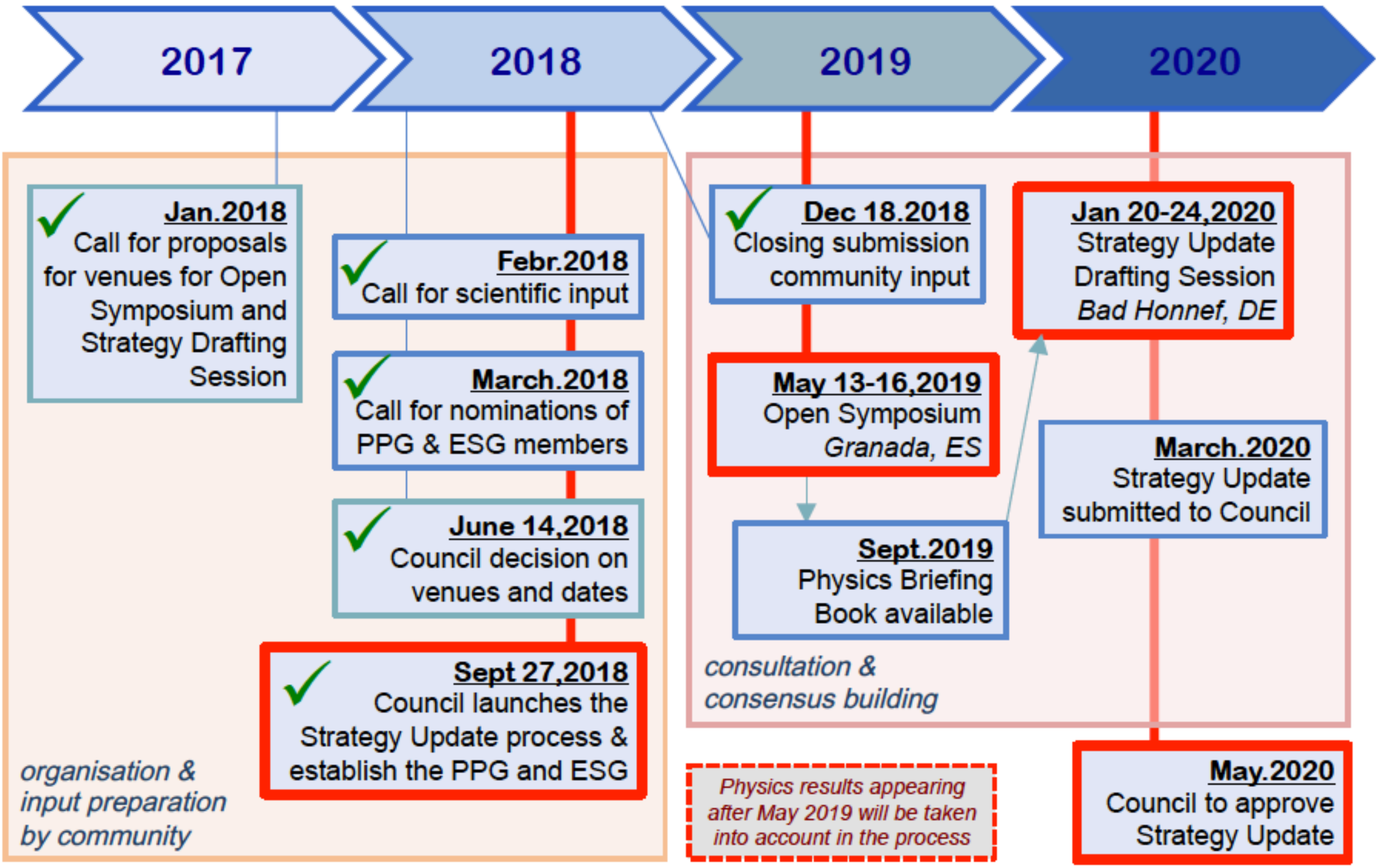
13-16 May 2019 - Granada, Spain

European Strategy Update

European Strategy Update

EPPSU 2020

Timeline



Classification of the ESPP 2013 "recommendations"

2013 update of ESPP provided 17 "recommendations":

2 : General issues
4 : High-priority large-scale scientific projects
5 : Other essential scientific activities
3 : Organisational issues
3 : Wider impact on society

In the following: brief overview of the implementation

ESPPU 2013

c) *Europe's top priority should be the exploitation of the full potential of the LHC, including the high-luminosity upgrade of the machine and detectors with a view to collecting ten times more data than in the initial design, by around 2030. This upgrade programme will also provide further exciting opportunities for the study of flavour physics and the quark-gluon plasma.*

d) *CERN should undertake design studies for accelerator projects in a global context, with emphasis on proton-proton and electron-positron high-energy frontier machines. These design studies should be coupled to a vigorous accelerator R&D programme, including high-field magnets and high-gradient accelerating structures, in collaboration with national institutes, laboratories and universities worldwide.*

e) There is a strong scientific case for an electron-positron collider, …
The initiative from the Japanese particle physics community to host the ILC in Japan is most welcome … *Europe looks forward to a proposal from Japan to discuss a possible participation.*

f) CERN should develop a neutrino programme to pave the way for a substantial European role in future long-baseline experiments. Europe should explore the possibility of major participation in leading long-baseline neutrino projects in the US and Japan.

ESPPU 2013

Other essential scientific activities

g) Europe should support a diverse, vibrant theoretical physics programme, ranging from abstract to applied topics, in close collaboration with experiments and extending to neighbouring fields such as astroparticle physics and cosmology. Such support should extend also to high-performance computing and software development.

- Great progress since last ESPP in development of (NLO) MC generators and higher-order calculations (e.g. Higgs production at N3LO, NNLO for 2→2 QCD processes) to match precision of LHC (and other) data. Vibrant community in Europe, which also contributed significantly to the study of future facilities. Crucial funding from H2020 (e.g. MCnet).
  Note: strong support for theory is crucial for the future of the field: theoretical ideas have led to ground breaking developments in the understanding of nature and have inspired many experimental searches; MC developments and higher-order (signal and background) calculations are fundamental for current and future projects → HEP theory should be supported in Universities and labs and should be an integral part of planning for and funding of future colliders and other projects.

h) Experiments studying quark flavour physics, dipole moments, charged-lepton violation and performing other precision measurements ... with neutrons, muons and antiprotons may give access to higher energy scales than direct particle production ... They can be based in national laboratories, with a moderate cost … Experiments in Europe with unique reach should be supported, as well as participation in experiments in other regions of the world.

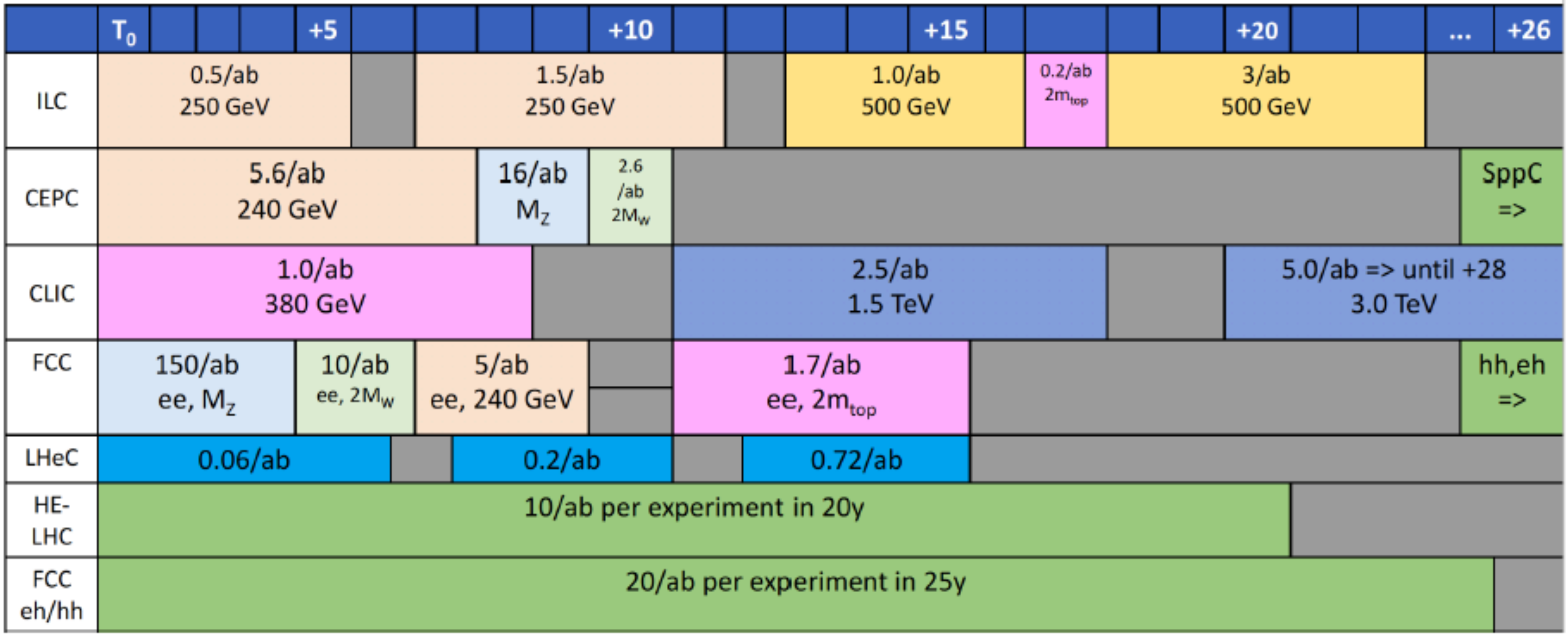
i) Detector R&D programmes should be supported strongly at CERN, national institutes, laboratories and universities. Infrastructure and engineering capabilities for the R&D programme and construction of large detectors, as well as infrastructures for data analysis, data preservation and distributed data-intensive computing, should be maintained and further developed.

j) In the coming years, CERN should seek a closer collaboration with ApPEC on detector R&D with a view to maintaining the community' s capability for unique projects in this field.

k) A variety of research lines at the boundary between particle and nuclear physics require dedicated experiments. *The CERN Laboratory should maintain its capability to perform unique experiments. CERN should continue to work with NuPECC on topics of mutual interest.*

Fabiola Gianotti

Proposed Schedules and Evolution

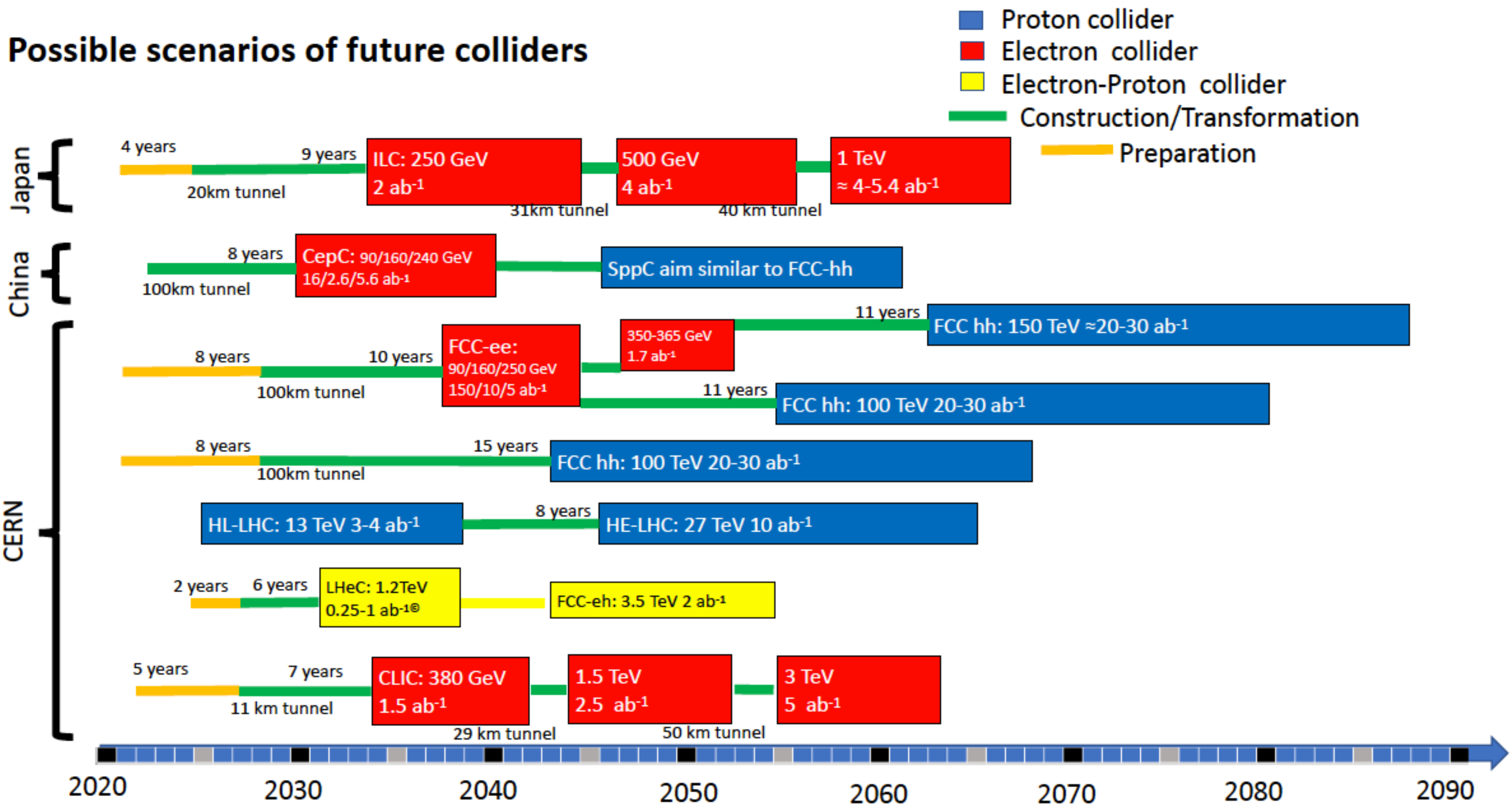


Project	Start construction	Start Physics (higgs)
CEPC	2022	2030
ILC	2024	2033
CLIC	2026	2035
FCC-ee	2029	2039 (2044)
LHeC	2023	2031

Proposed dates from projects

Would expect that technically required time to start construction is O(5-10 years) for prototyping etc.

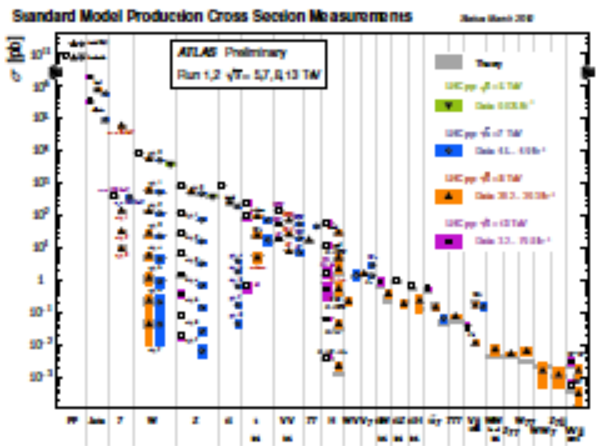
Possible scenarios of future colliders

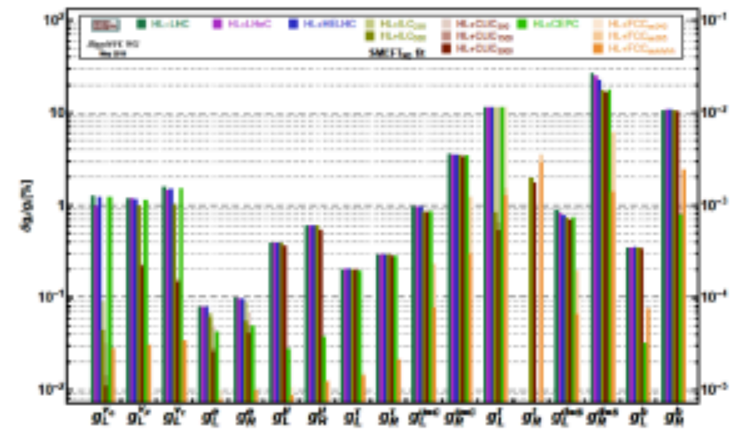


13/05/2019 UB

all options aimed at **attobarn physics**

Strong Interactions





precise measurements

precise exploration

Methods & Tools

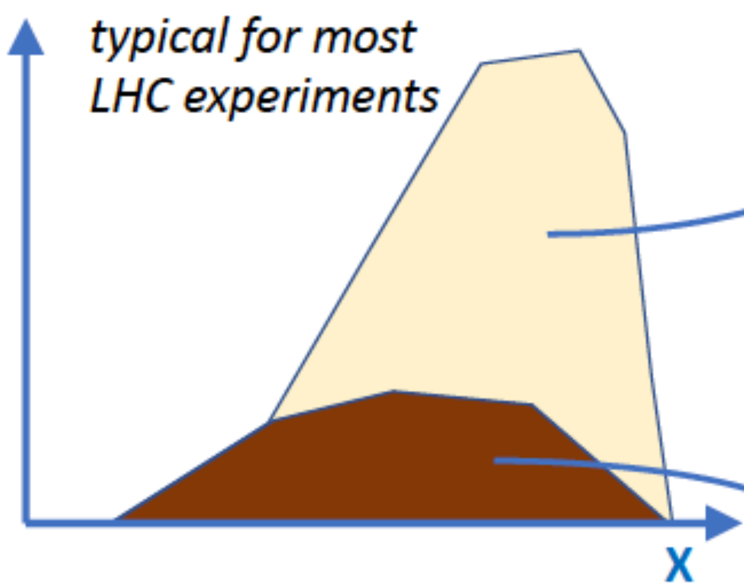
e.g. EFT, PDFs, generators, N^{X}O calculations, Lattice, α_s, ...

Profound experimental knowledge and theoretical understanding of QCD will be vital to succeed in our exploration with the LHC and HL-LHC, and all future colliders

(for both Direct & Indirect searches)

Jorgen D'Hondt & Krzysztof Redlich

QCD theory for particle physics, i.e. for all other physics themes this week



the QCD impact is typically the limiting factor for many LHC analysis

acceptance of the signal (SM and BSM)

examples

- *need N^3LO precision for many $2 \rightarrow 1$ and $2 \rightarrow 2$ processes (including top quark processes)*
- *coherent approach for higher-order calculations and parton shower*
- *interpretations like the top quark mass*

modelling of the background

Substantial further theory progress is needed to allow a precise interpretation for a wide range of HL-LHC data

- sustain the strong and concerted support for QCD theory work (e.g. *MCnet* Horizon 2020 network)
- foster a community-wide and long-term close collaboration between the experimental and theoretical communities (e.g. inter-experiment workshops with theoreticians)

European institutions observe a leading and successful role to face these challenges, and hence have a leading responsibility

Jorgen D'Hondt & Krzysztof Redlich

Need for precision @ HL-LHC

- illustrated in the case of Higgs physics
- theory uncertainty (PDF + strong coupling + missing higher orders) dominates in 7/9 channels
- this is **with the assumption of reduction by x2 in today's uncertainties**
- depending on channel, it can be the uncertainties for the signal or the background that dominates.

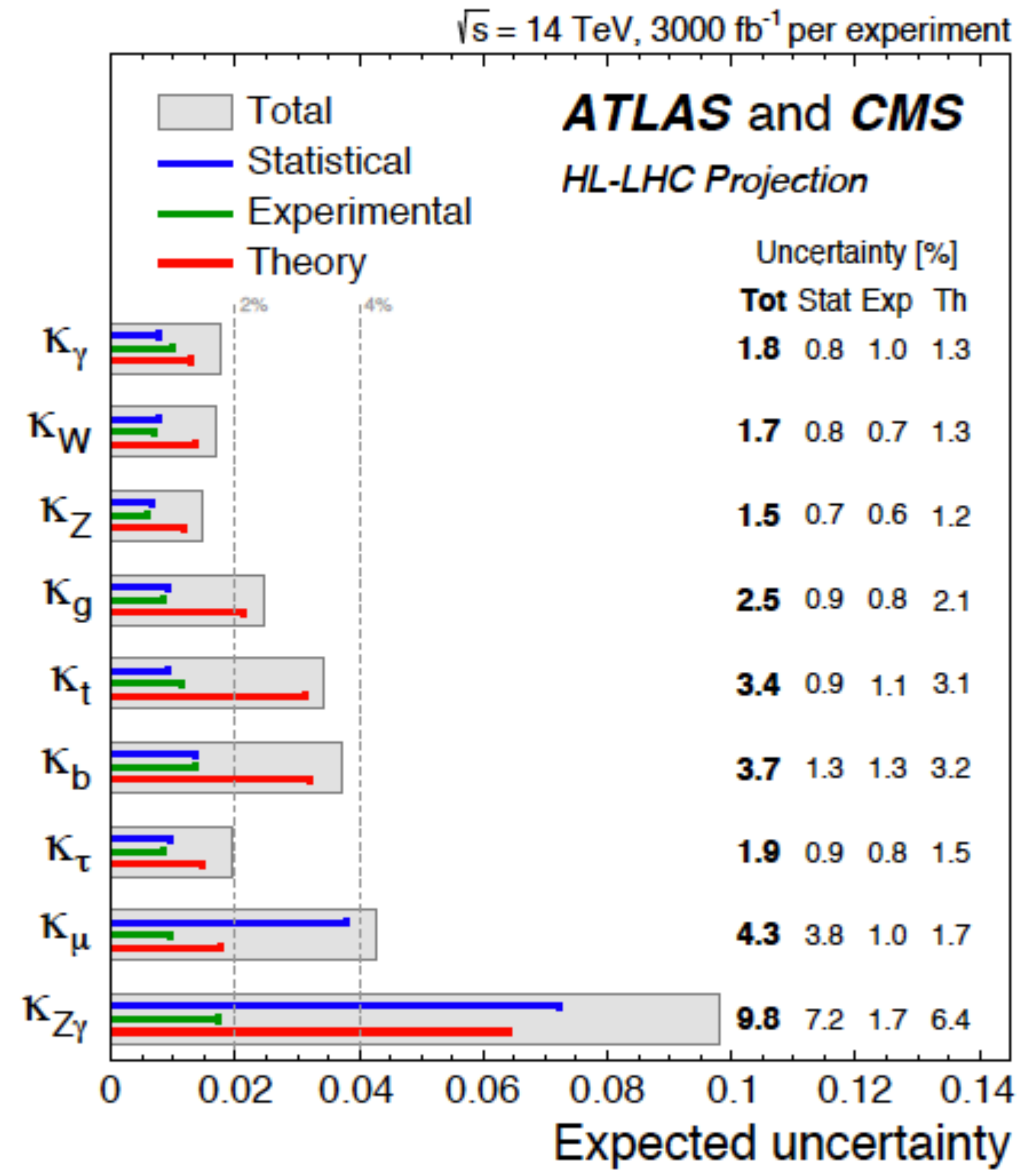


Figure 1. Projected uncertainties on κ_i, combining ATLAS and CMS: total (grey box), statistical (blue), experimental (green) and theory (red). From Ref. [2].

Gavin Salam

future e^+e^- colliders

- 3-loop and partial 4-loop calculations of Zff vertex for Tera-Z for EW pseudo-observables
- precision for decays, e.g. in Higgs physics and top-quark physics
- new generations of MC programs for QED and EW effects, understanding two-photon physics

	$\delta\Gamma_Z$ [MeV]	δR_l $[10^{-4}]$	δR_b $[10^{-5}]$	$\delta \sin^{2,l}_{eff}\theta$ $[10^{-6}]$
Present EWPO theoretical uncertainties				
EXP-2018	2.3	250	66	160
TH-2018	0.4	60	10	45
EWPO theoretical uncertainties when FCC-ee will start				
EXP-FCC-ee	0.1	10	$2 \div 6$	6
TH-FCC-ee	0.07	7	3	7

Table 1: *Comparison for selected precision observables of present experimental measurements (EXP-2018), current theory errors (TH-2018), FCC-ee precision goals at the end of the Tera-Z run (EXP-FCC-ee) and rough estimates of the theory errors assuming that electroweak 3-loop corrections and the dominant 4-loop EW-QCD corrections are available at the start of FCC-ee (TH-FCC-ee). Based on discussion in [2].*

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QCD theory summary

- Advances in QCD theory are essential to exploit HL-LHC and future colliders (and already built into some projections!)
- They will involve a wide range of topics, spanning calculations of amplitudes to Monte Carlo event generations, including phenomenological work to connect with data
- Theory advances can bring light also on many topics of intrinsic interest in QCD, including proton structure, exotic hadrons, connections with "theorists's theories" like N=4 SUSY
- Continued support of QCD theory is essential for success of European collider programme, and community needs to keep in mind
  - recognition of contributions of early-stage researchers as teams grow larger
  - funding structure for increasingly long-term theory projects
  - positions and career development for individuals who provide essential "support" roles (maintenance of widely used tools, interfacing with & support for users, …)
  - computing (access to hardware and expertise)

Gavin Salam

Principal Components for QCD

Jorgen D'Hondt & Krzysztof Redlich

Hot & Dense QCD

A coherent and complementary "hot & dense QCD program" at the SPS brings valuable and unique contributions in the exploration of the QCD phase diagram.

An (HL-HE-)LHC/FCC based AA/pA/fixed-target program is unique and provides essential science at the frontline towards a profound understanding of particle physics.

Precision QCD

A globally concerted "precision QCD program" provides a unique avenue to find new physics that breaks the Standard Model.

A high-luminosity e^+e^- collider at the EW scale and a high-energy ep collider provide a unique environment for high-precision QCD, essential for most of our aspirations in particle physics.

Partonic Structure

A "hadronic structure program" exploring the complementarity of ep/pp/eA colliders provides vital ingredients for the high precision exploration in searches for new physics and as well steps into uniquely unknown territories of QCD.

Theory

It is vital to support coherently the QCD theory community to succeed in all these programs and to link QCD to the rest of the particle physics research program, especially for our HL-LHC exploration.

Organization

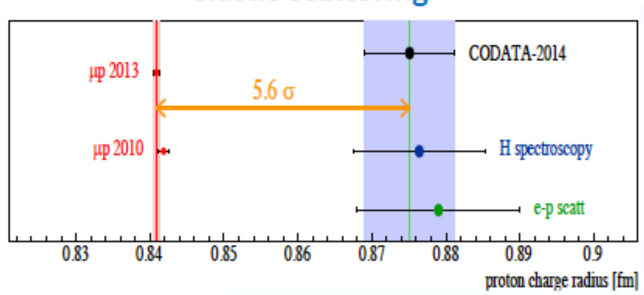
Strengthening the synergies in research and technology with adjacent fields will reinforce our efforts.

Global platforms, networks and institutes have the potential to enhance the research exchange among experts worldwide and to provide essential training opportunities.

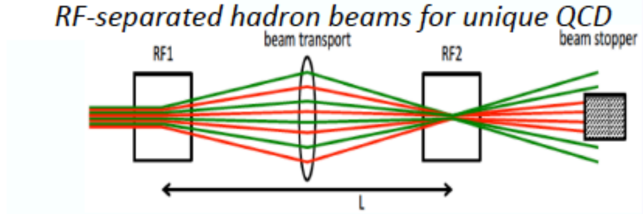
The low-energy precision puzzle…

From the report of the Physics Beyond Colliders working group: COMPASS++/AMBER, DIRAC++, MUonE

persistent discrepancies on proton charge radius determined from spectroscopy (H, muonic H) and ep elastic scattering

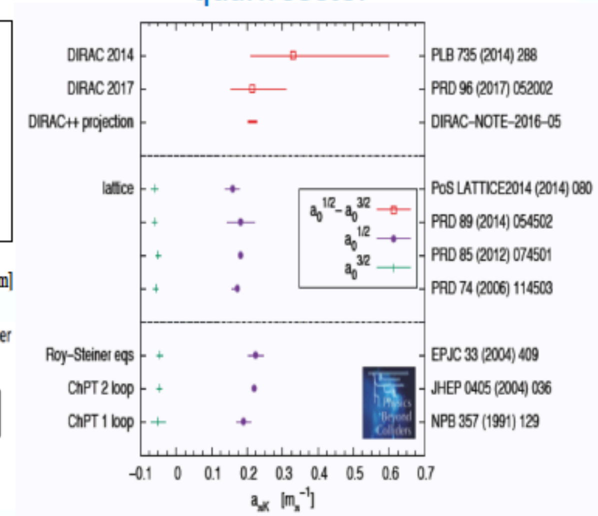


RF-separated hadron beams for unique QCD



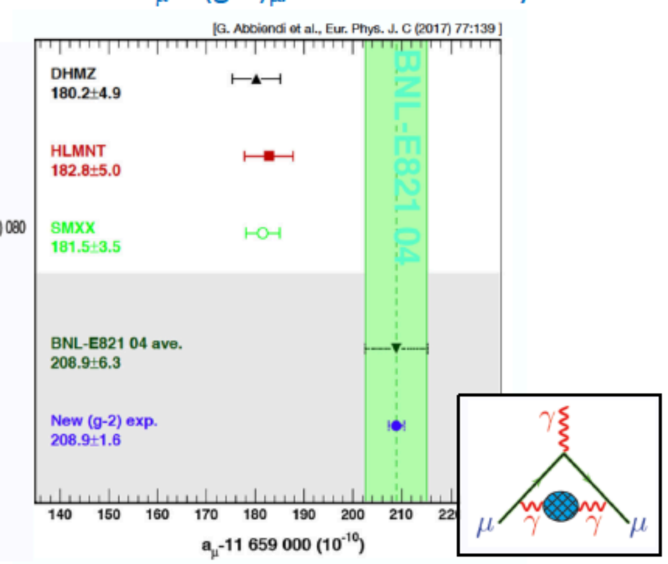
A long-term multipurpose hadron structure facility **COMPASS++/AMBER** at the M2 beam line beyond 2021 (muon and hadron beams)

πK scattering lengths are benchmark quantities for chiral symmetry breaking in the strange-quark sector



Study of πK atoms with **DIRAC++** would yield an experimental uncertainty comparable with the theoretical one

persistent discrepancy between measured anomalous magnetic moment $a_\mu = (g-2)_\mu/2$ and SM theory



With 2-years of elastic muon scattering **MUonE** aims for an independent measurement of the hadronic vacuum polarization

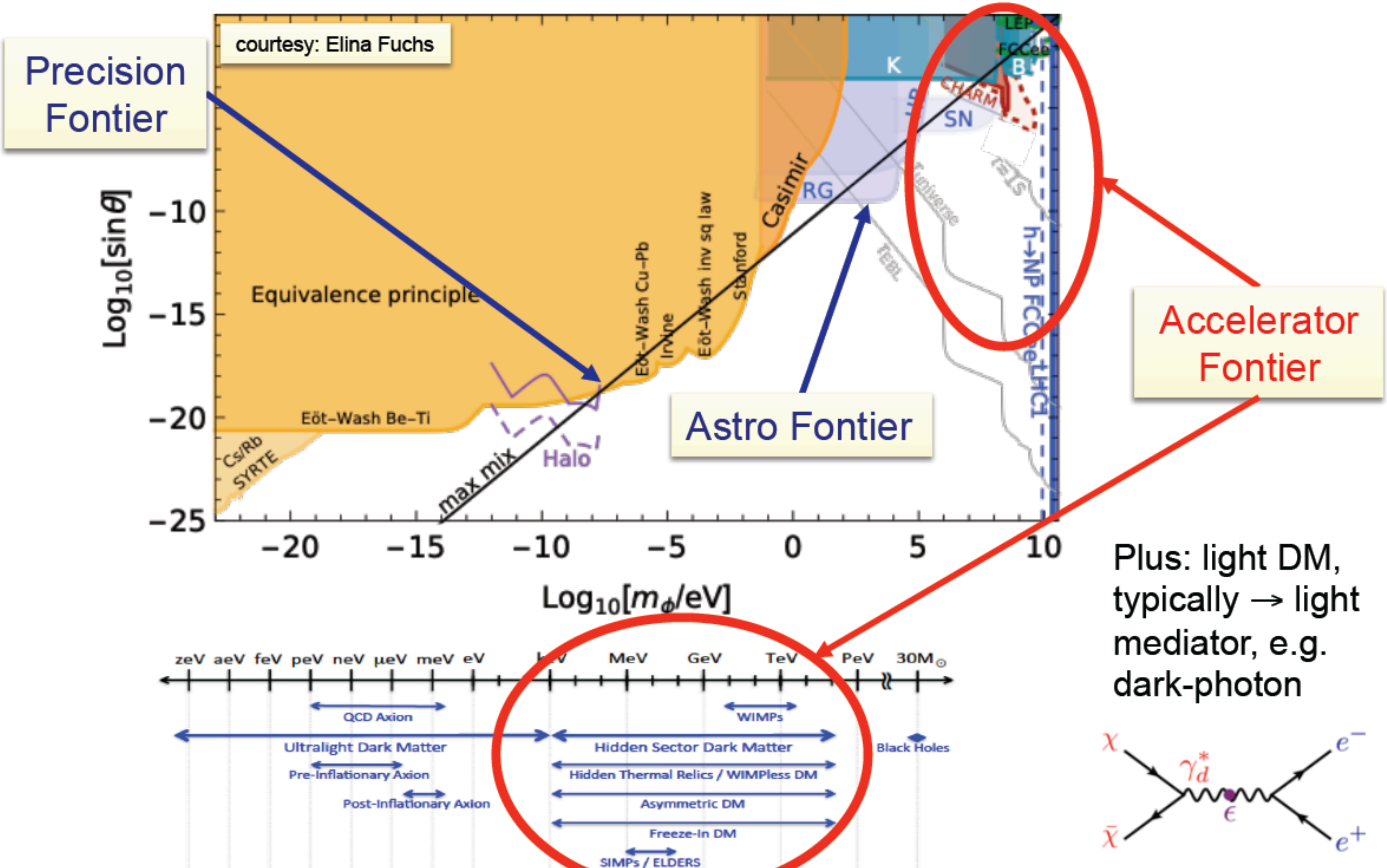
Beyond the Standard Model at colliders

The Big Questions (BQs)

- **The four big questions for BSM (@colliders):**
  - To what extent can we tell whether the Higgs is fundamental or composite?
    - EWSB/NewReson, SUSY
  - Are there new interactions or new particles around or above the electroweak scale?
    - EWSB/NewReson, SUSY, Ext-H/FlavorDyn, DM, FIPs
  - What cases of thermal relic WIMPs are still unprobed and can be fully covered by future collider searches?
    - DM, FIPs, SUSY
  - To what extent can current or future accelerators probe feebly interacting sectors?
    - FIPs, SUSY

Gian Giudice & Paris Sphicas

Feebly Interacting Particles (FIPs)



Plus: light DM, typically → light mediator, e.g. dark-photon

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Big Questions

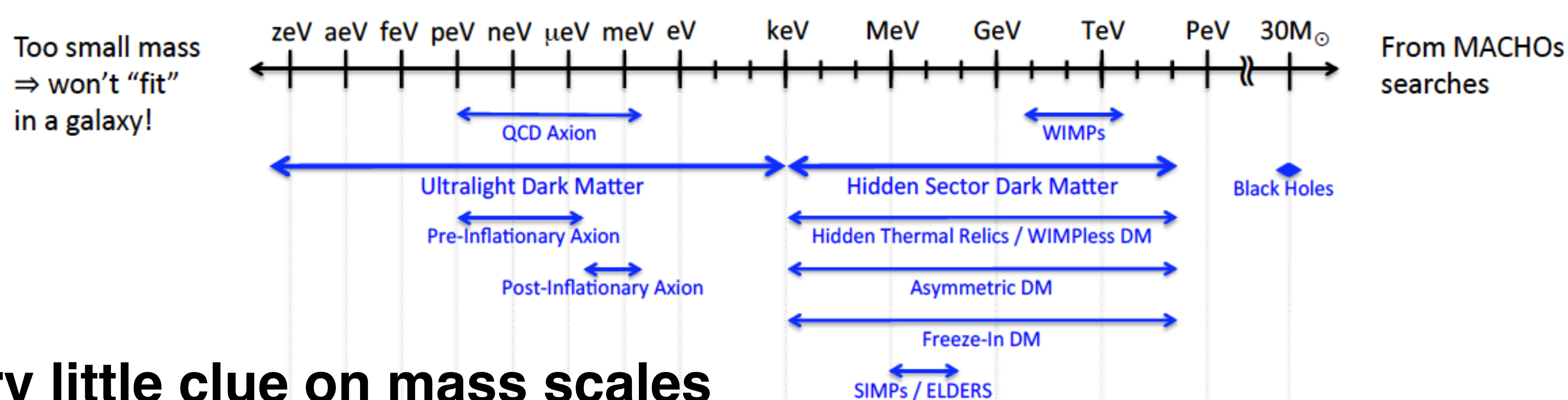
Dark Matter - Dark Sector

1) How do we search for DM, depending on its properties?
What are the main differences between light Hidden Sector DM and WIMPs?
How broad is the parameter space for the QCD axion?

2) What are the most promising experimental programs, approved or proposed, to probe the different DM possibilities in a compelling manner?

3) How to compare results of different experiments in a more model-independent way?

4) How will direct and indirect DM Detection experiments inform/guide accelerator searches and vice-versa?



very little clue on mass scales

Marcela Carena & Shoji Asai

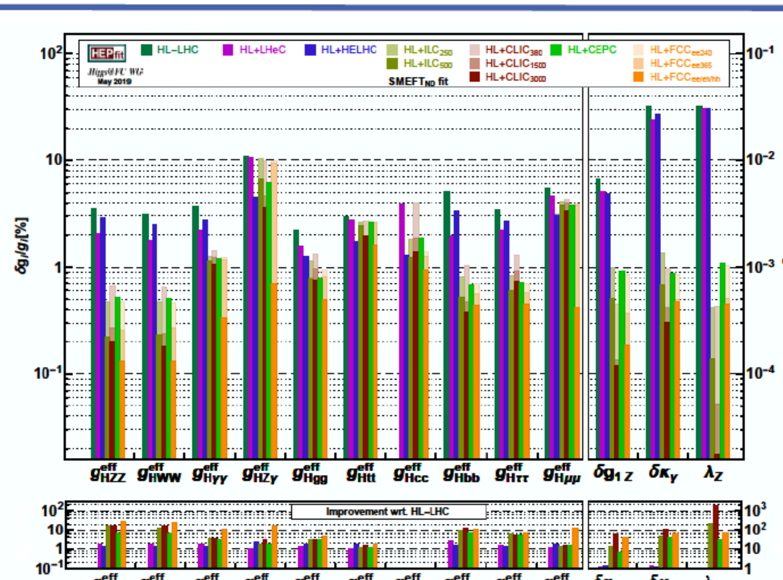
Electroweak Physics

Keith Ellis & Beate Heinemann

Answers to Big Questions

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 (!) + $\kappa_c \sim 2\%$ + 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 (δg_Z) 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 $d^3V/d^3\phi$ near minimum
   - Seems conceivable to determine it with sufficient precision to test 1st order EWΦT

Comparison of Colliders: EFT



arXiv:1905.03764

Effective Higgs couplings
- Constraints approach 0.1% precision for gauge bosons
- Major improvement w.r.t. HL-LHC for many colliders for fermions

Trilinear gauge couplings
- Will achieve precision 10^{-3}-10^{-4}
- About 2-3 orders of magnitude better than LEP

Theoretical Uncertainties: production

Production at hadron colliders
- For HL-LHC uncertainties expected to be improved by factor 2 w.r.t. current
- HE-LHC: another factor of 2
- FCC-hh: well below 1%

Requires e.g.
- Improved PDFs
- Higher precision calculations
- Improved non-perturbative aspects
- …

Higgs self-coupling sensitivity interesting for electroweak phase transition:

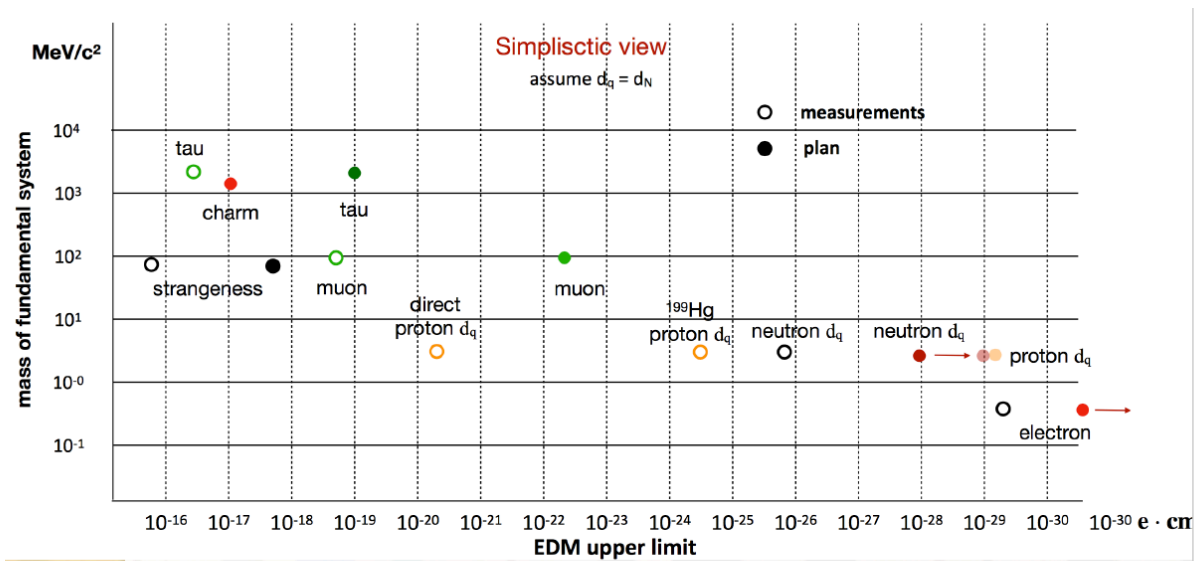
di-Higgs process probes κ_λ to 50% at HL-LHC => Improvements from HE-LHC (~15%), ILC_{500} (~27%), $CLIC_{3000}$ (~9%), FCC-hh (~5%)

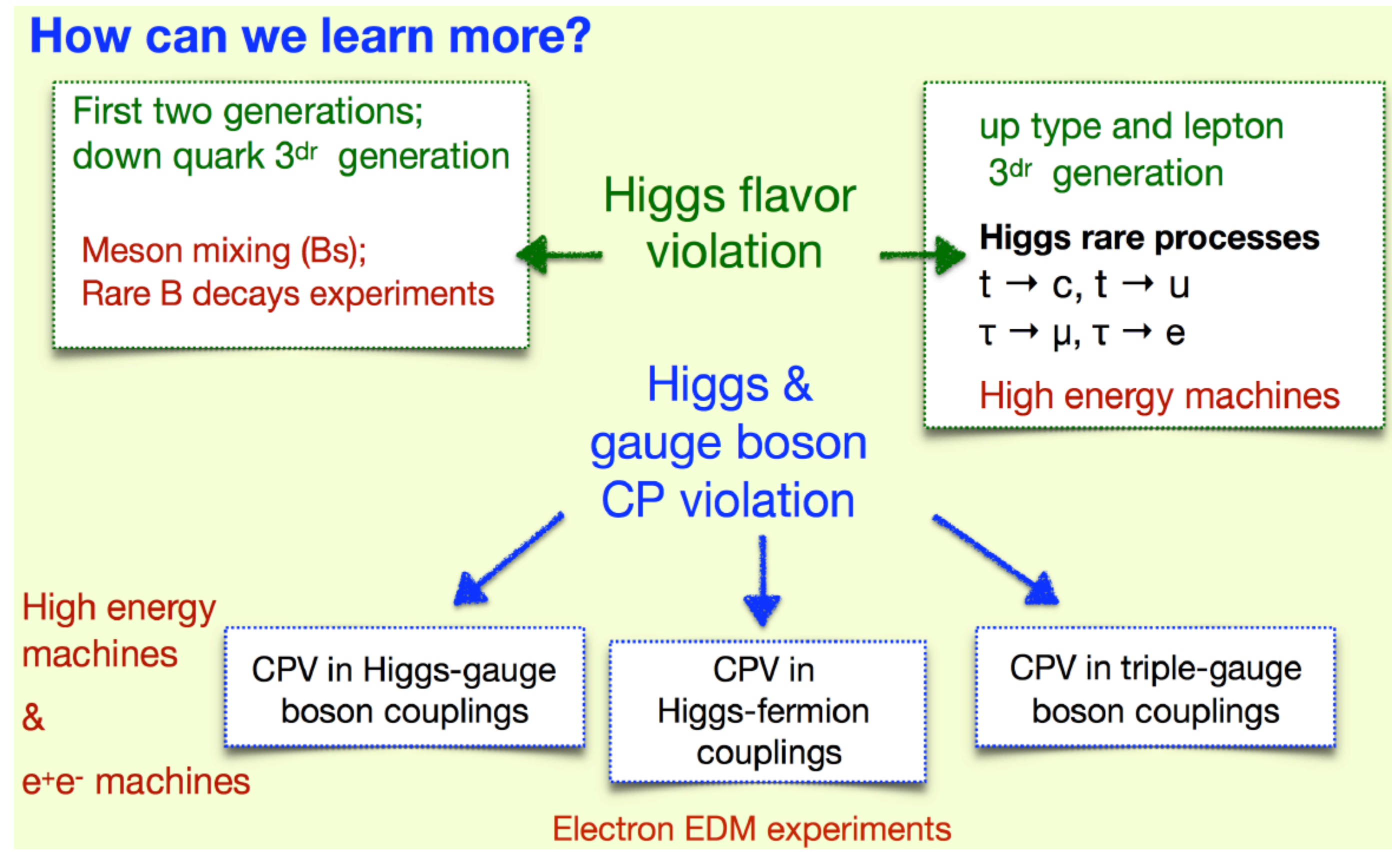
Single Higgs production also sensitive through loop effects

Flavour Physics

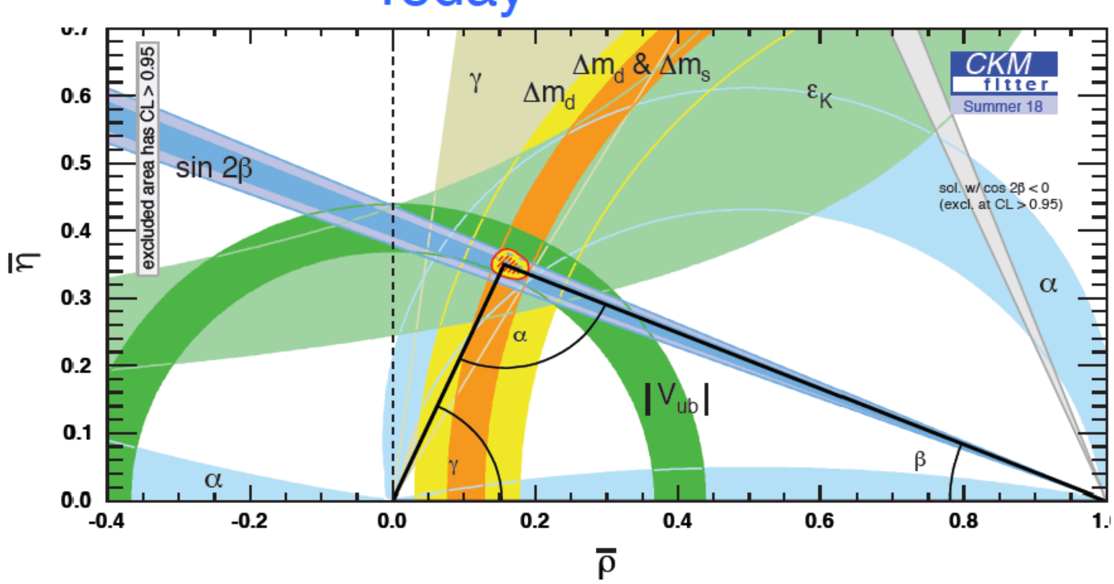
Antonio Zoccoli & Belen Gavela

1. EDMs [d_e, d_n, d_N,.]	Strong CP EW CP	new: Storage rings
2. μ→e processes	1 → 2 Gen Lep. Mix.	Intense μ beams
3. Rare K decays	1 → 2 Gen. Quark Mix.	Intense K beams

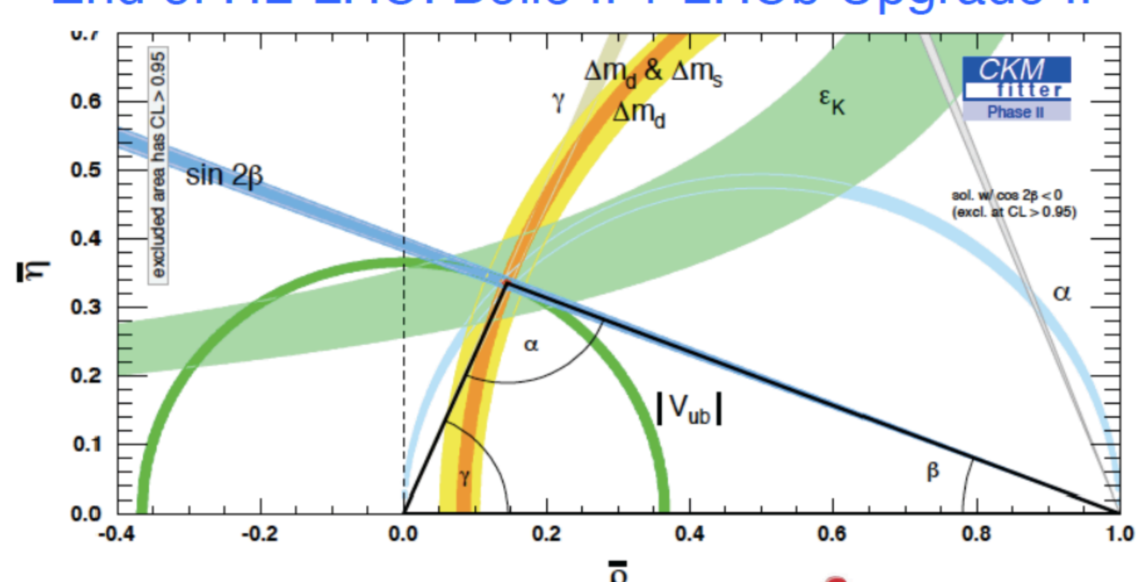




Today



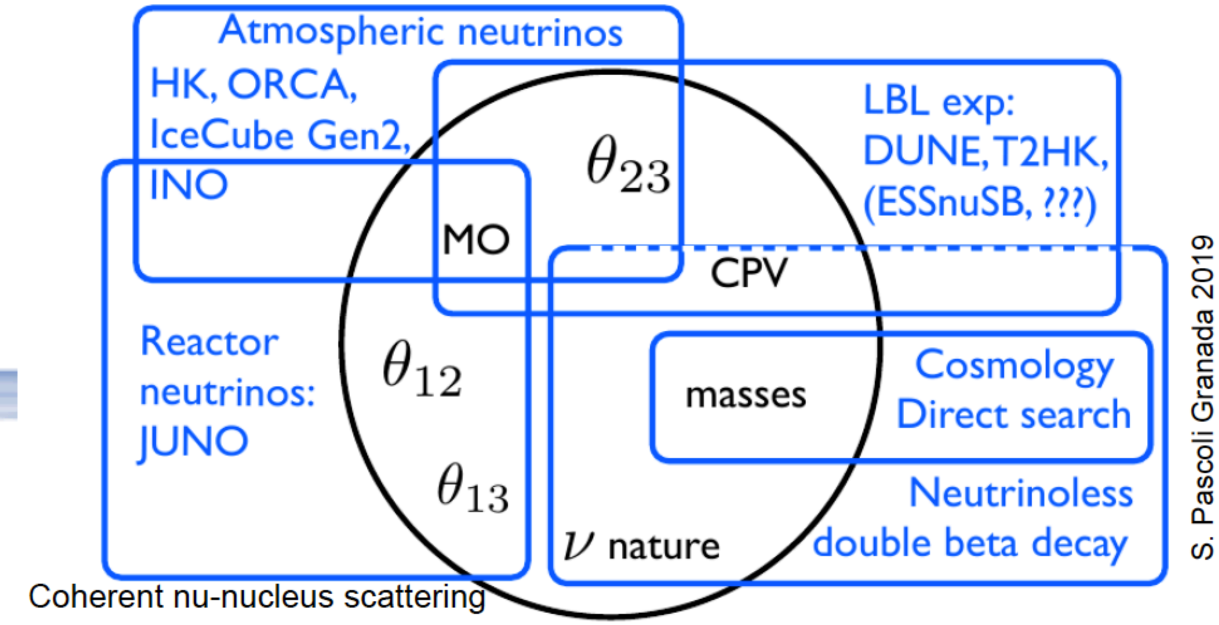
End of HL-LHC: Belle II + LHCb Upgrade II



Neutrino Physics

Stan Bentvelsen, Marco Zito

A very diverse experimental approach



Big questions

What is the origin of the neutrino masses ? And of the leptonic mixing ?

What is the optimal strategy towards a complete set of measurements of neutrino oscillation parameters and towards a precision global fit of the PMNS matrix ?

Is the existing experimental program (reactor, SBL) sufficient to confirm or exclude the existence of sterile neutrino states with masses in the eV/c² range ?

How to search for heavy neutral leptons with present and future facilities ?

Is gravity described by the Einstein theory of general relativity?

How do gravitational waves help to understand Dark Sector of the universe?

What is the proton-proton cross section at ultra-high energies?

How can cosmic neutrino's help to pin-down their properties - oscillations and mass hierarchy?

"Big questions"

European Strategy Update

Instrumentation:

(a) What **areas of instrumentation R&D** should be supported, and how, in order to meet the needs of future experimental programs?

(b) How to preserve knowledge, technical expertise and train the future generation of experts in detector R&D?

Computing:

(a) How should **HEP computing evolve** in order to support future scientific programs and their specific needs?

(b) What **R&D activities** must be supported, and how, in order to enable this computing evolution?

Xinchou Lou & Brigitte Vachon

#83: Input to the European Strategy Update: Ensuring the Future of Particle Physics in a More Sustainable World: 3 recommendations

Submitted 319 signatures

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