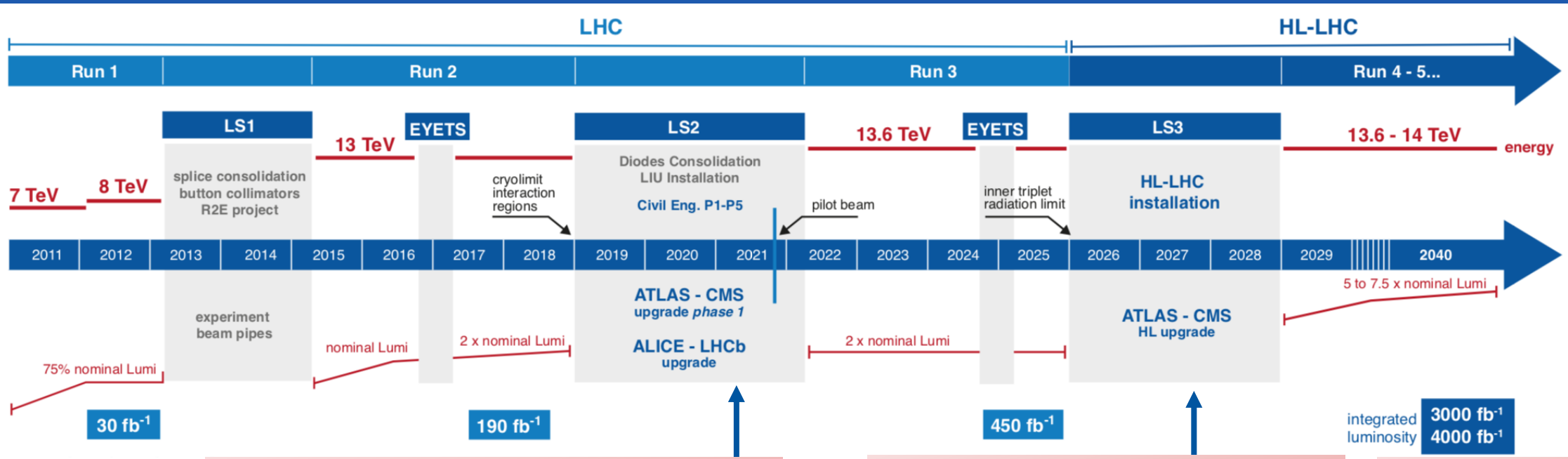
Accelerators for High Particle and Nuclear Physics

- Accelerators being constructed
  - HL LHC, neutrino facilities (US and Japan), EIC, FAIR
- Accelerators being studied – likely next large Particle Physics Machine
  - Higgs factory options
- A few words about the Snowmass process (wrt accelerators) completed this summer
  - HL-LHC, fast Higgs factory (possible timelines), Hadron or Muons – US push for C3 and Muon collider technologies
- Accelerator R&D, European Roadmap process
  - Magnets, RF, Muons, Plasma and Energy Recovery
- A slide on muon collider studies
- Norway and national accelerators
  - Small electron linacs for research – a possibility for us ?

High-Luminosity LHC (HL-LHC)



LS2
LHC Injectors Upgrade (LIU) completed
Phase-1 upgrades: major for LHCb and ALICE

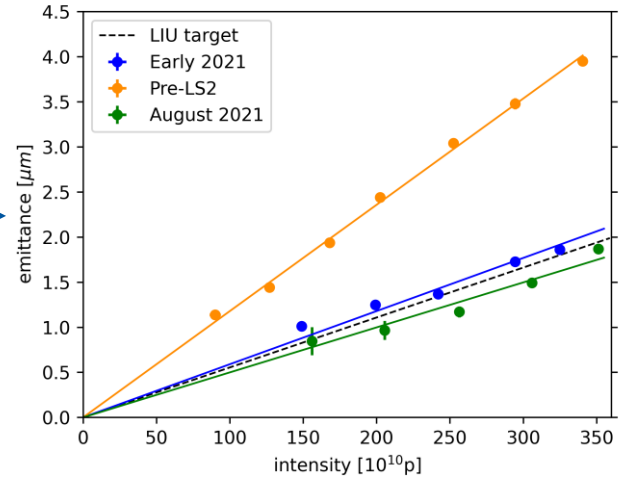
LS3
Installation of HL-LHC machine
Phase-2 upgrades of ATLAS and CMS

LHCb and ALICE plan major upgrades in LS4 (2033-2034)

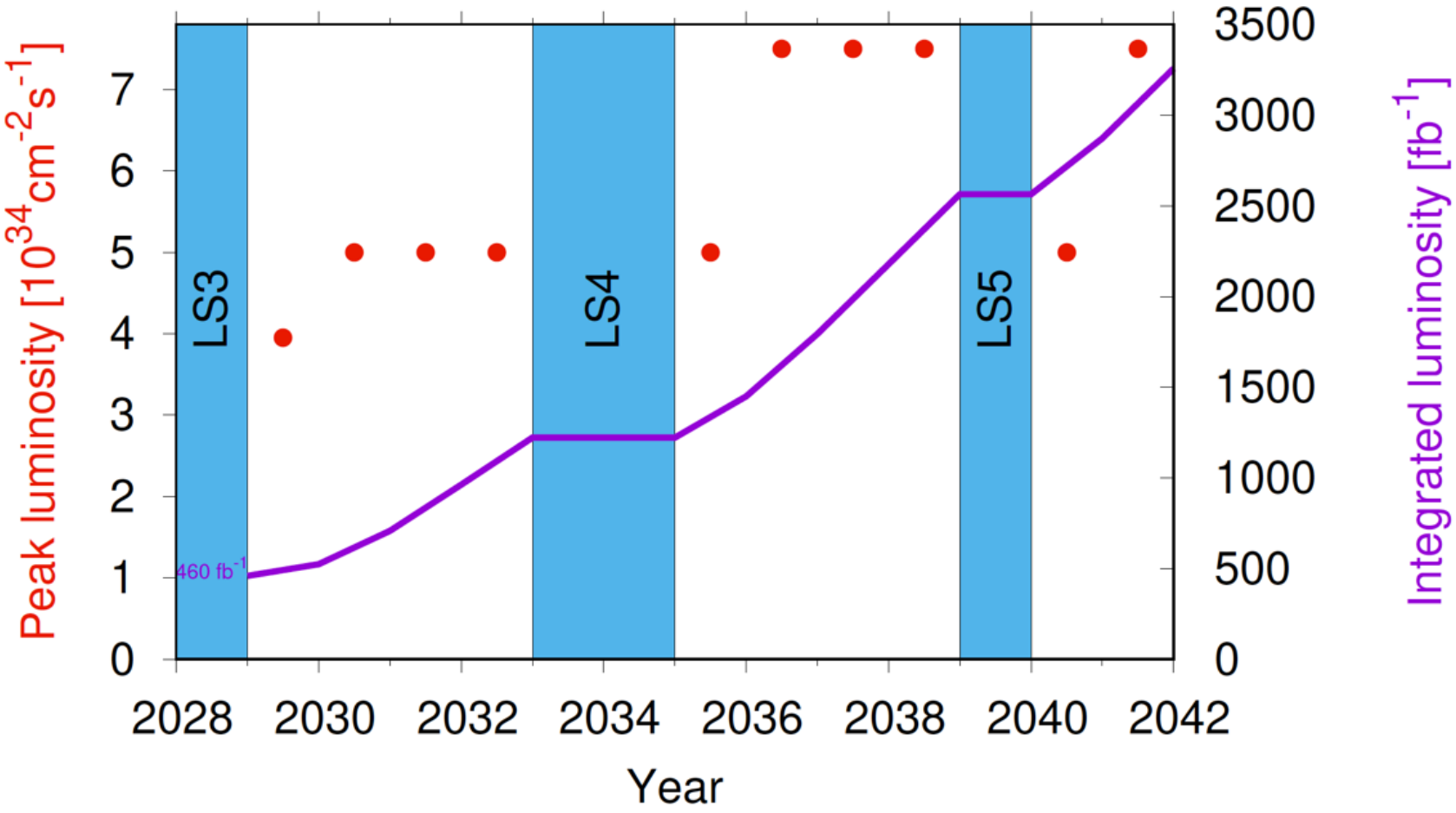
Injectors upgrade in LS2: to provide beams of intensity and brightness needed for HL-LHC: **2.3x10^{11} p/bunch, ε~ 2.1 μm** at LHC injection

Excellent performance upon restart in 2021 → target parameters needed for HL-LHC already achieved/exceeded in some cases

Required brightness for multi-bunch LHC beams already achieved (exceeded!) at the Booster



Luminosity goals until 2042



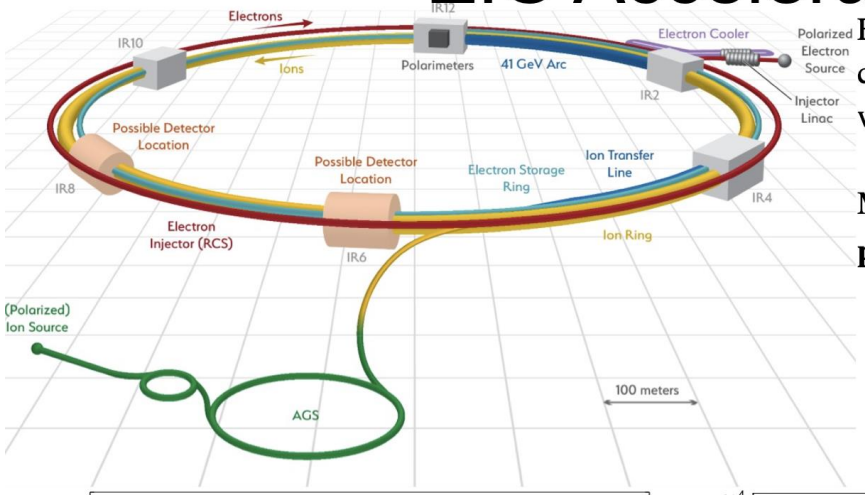
Seem reasonable to assume Norwegian physicists will be involved to the end (including upgrades in LS3 and LS4) – protons and ions

EIC

Please see presentation in Norwegian strategy meeting in March by Alexander (Sasha) Bylinkin

Link to slides

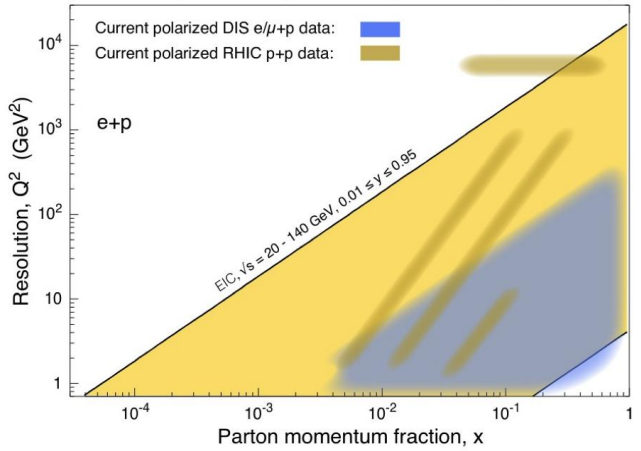
EIC Accelerator

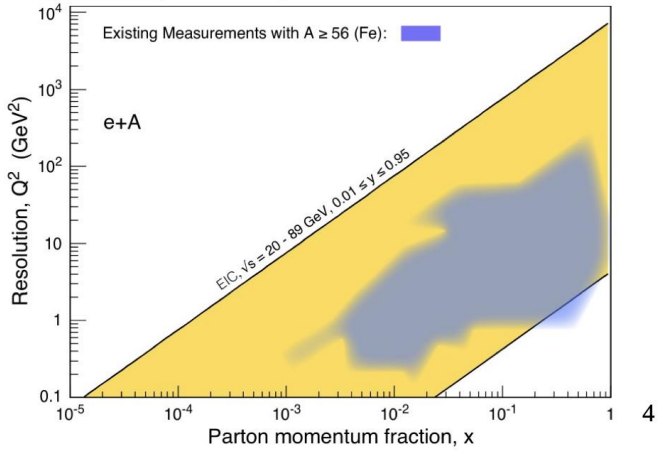


EIC will be the first dedicated facility to collide electron with ions (protons) in a wide range of c.m.s. energies.

Moreover, it will allow studies with **highly polarized beams (not possible at HERA)**

- E_e: 5 … 18 GeV
- E_p: 41, 100 … 275 GeV
- E_{ion}: 41 … 110 GeV/n
- Ions: from p to U
- Pol (e,p,He, etc): >70%
- Lum: up to 10^{34} cm^{-2} s^{-1}



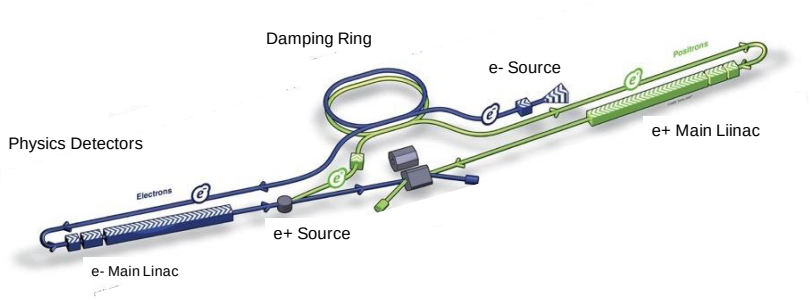


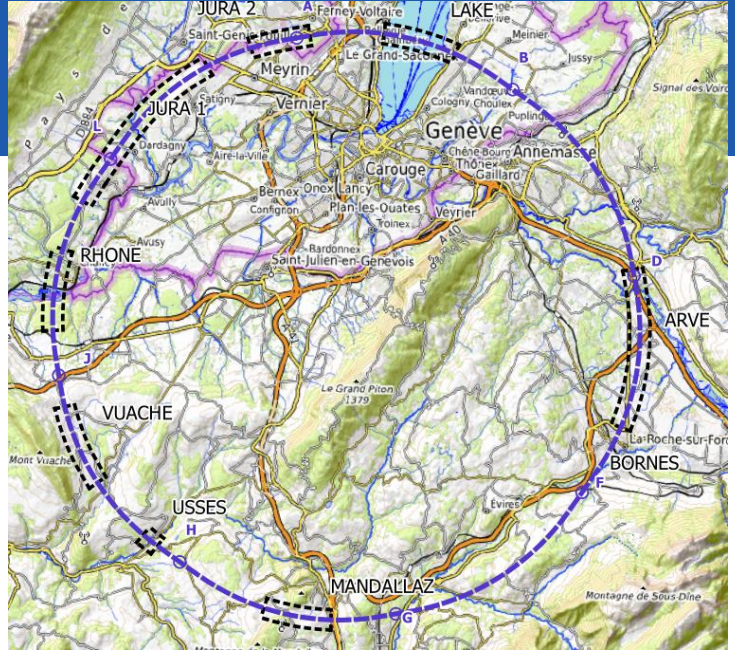
Colliding electrons to ions gives access to unexplored kinematic regions with the lowest possible x values.

4

Plannned for 2030-32, do we (and CERN) get involved – and if yes how much?

Higgs factories





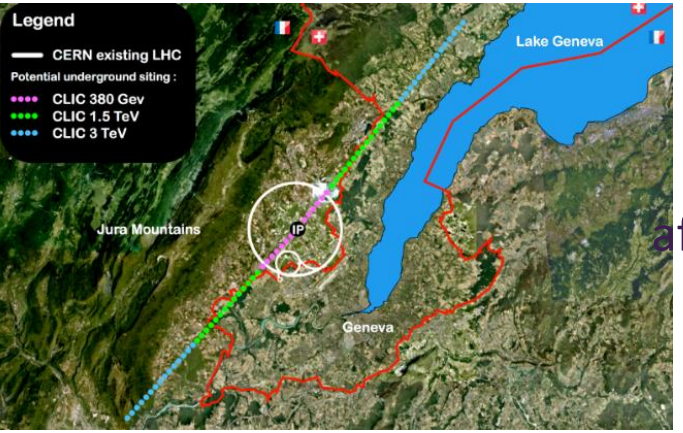
Need e+e- collisions at least at 250 GeV, four main alternatives (plus various less developed ideas):

ILC in Japan (linear)

FCC at CERN (ring)

CLIC at CERN (linear)

CEPC in China (ring)



Linear colliders: 13 (Higgs) -> 50 (max) km to get to 1-3 TeV

Rings ~100km, can be used for protons after

Link to talk in our Strategy meeting in the Spring: slides `

Higgs factories – a few comments

ILC:
International effort led by ICFA, with strong European participation from many laboratories.
For the first time the Science Ministry in Japan has submitted a request to the Finance ministry for more technology development funding.
If sucessful will lead to increased European (and US) efforts from 2023.

CLIC:
Collaboration continue towards readiness report 2025-26.
Focus on X-band RF systems (including many initiatives on smaller linacs for the technology), power reductions and nanobeams (the two latter overlapping with ILC).

FCC-ee:
Feasibility study towards 2025-26, focus on layout in the local area and financial feasibility (and lately also power/energy concerns).
Complemented by technical studies for acc. and detector. By now a large study.

CEPC:
Moves forward towards a TDR ~end of the year – needed for seeking any level of approval later.
Very large effort across academia, research institutes and industries. Significant regional interest for hosting.
Less international (including European) involvement than ~3-4 years ago (access and funding difficult).

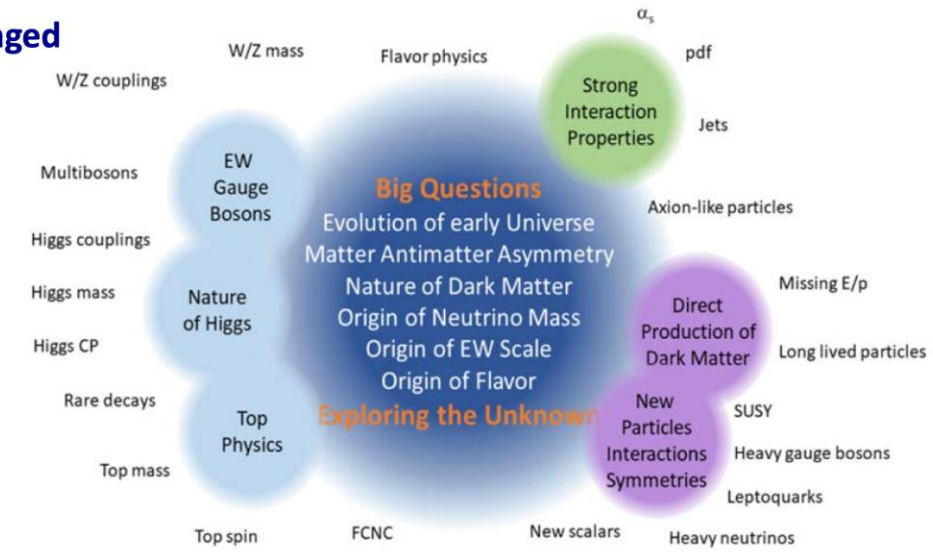
Comments:
- Several projects with various pluses and minuses.
- Will take time before the dust settles but hopefully clearer in ~5 years. Current energy/inflation situation does not help.
- Norwegian involvement limited (largest one CLIC acc. development).
- Will be important also for us in Norway to outline the longer term acc. future (in the Higgs area) in ~5-7 years

Energy Frontier (Message)

- **Compared to Snowmass 2013 the physics landscape has significantly changed**
  - The program of measuring the Higgs boson properties is well underway at the LHC with growing precision
  - A broad range of searches have explored multiple BSM scenarios without convincing evidence of new physics
  - The HL-LHC is an approved project

- **Without a robust support for the HL-LHC and a clearly defined path towards a Higgs factory we leave critically important physics unchecked and crucial questions unanswered**

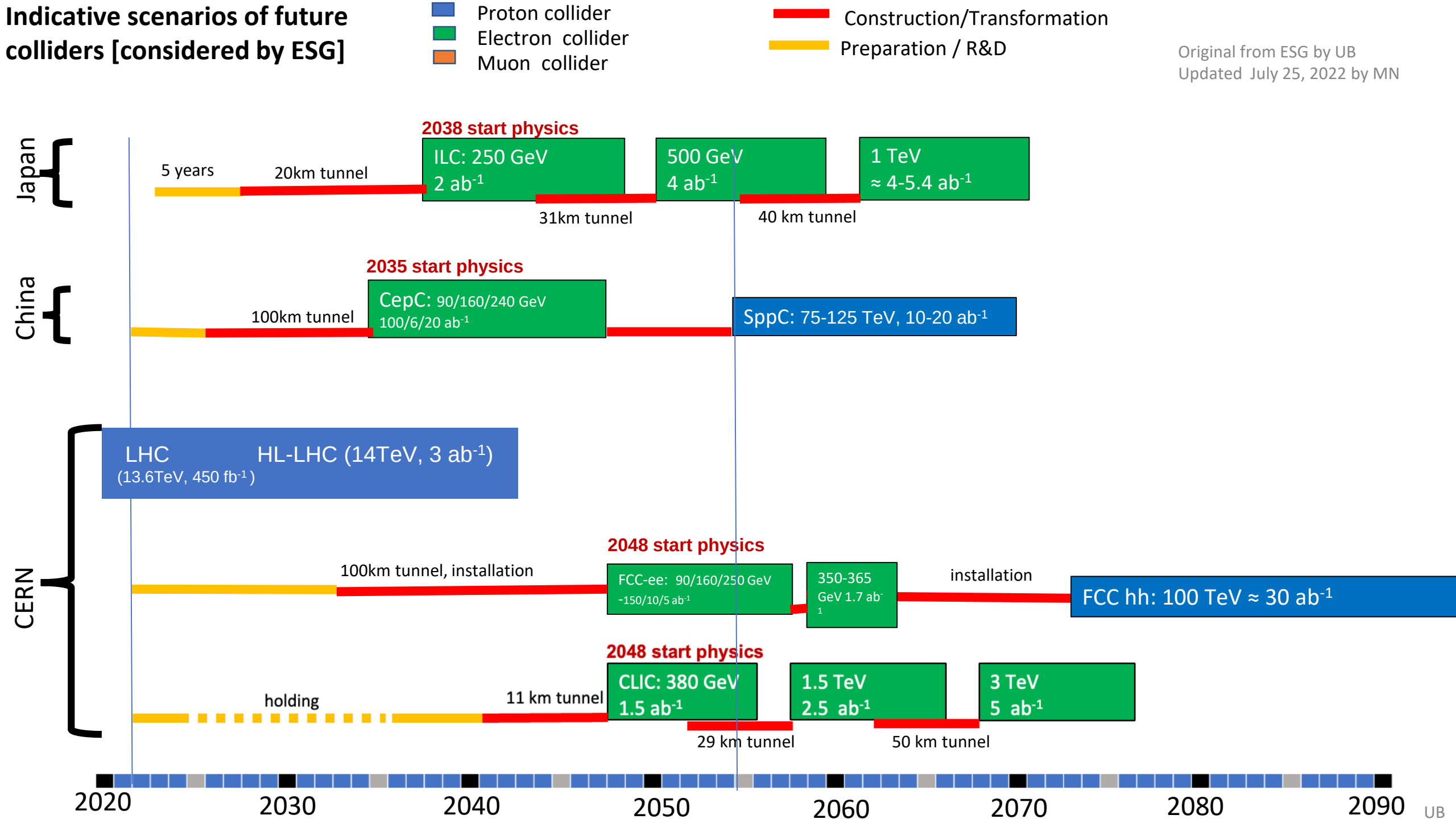
- **The EF community should be prepared to explore a broad range of BSM phenomena at the 10 TeV mass scale**



The Energy Frontier community voices a strong support for

1. **HL-LHC operations and 3 ab^{-1} physics program, including auxiliary experiments**
2. **The fastest path towards an e^+e^- Higgs factory (linear or circular) in a global partnership**
3. **A vigorous R&D program for a multi-TeV collider (hadron or muon collider)**

Indicative scenarios of future colliders [considered by ESG]



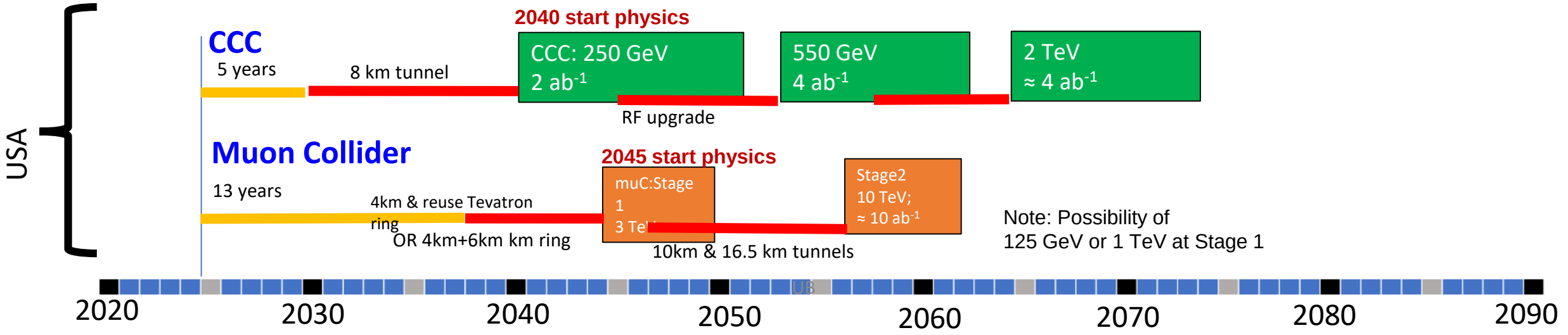
Possible scenarios of future colliders

Proton collider
Electron collider
Muon collider

Construction/Transformation
Preparation / R&D

Original from ESG by UB
Updated July 25, 2022 by MN

Proposals emerging from this Snowmass for a US based collider



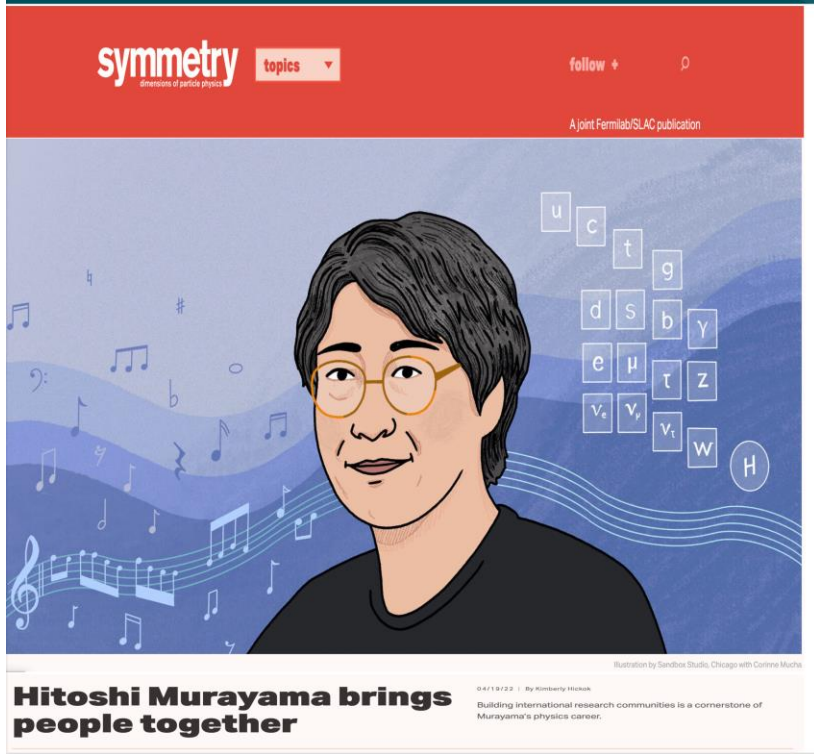
- **Timelines technologically limited**
- Uncertainties to be sorted out
  - Find a contact lab(s)
  - Successful R&D and feasibility demonstration for CCC and Muon Collider
  - Evaluate CCC progress in the international context, and consider proposing an ILC/CCC [ie CCC used as an upgrade of ILC] or a CCC only option in the US.
  - International Cost Sharing

- Consider proposing hosting ILC in the US.

P5 chair

Hitoshi Murayama

Put Captions Here



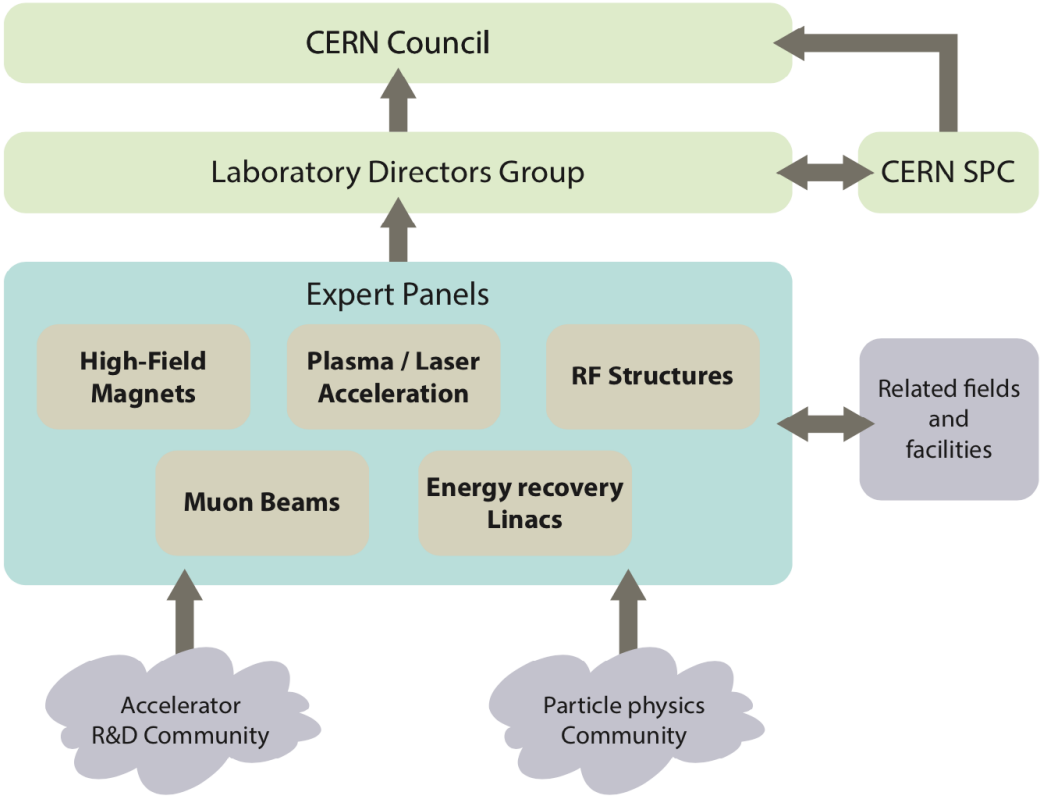
- MacAdams Professor of Physics at the University of California, Berkeley
- Faculty Senior Staff at Lawrence Berkeley National Lab
- University Professor, Kavli Institute for the Physics and Mathematics of the Universe, University of Tokyo
  - Member, American Academy of Arts and Sciences
  - Fellow, American Association for the Advancement of Science
  - Fellow, American Physical Society
  - Humboldt Research Prize
  - Breakthrough Prize (KamLAND)
  - Yukawa Commemoration Prize
  - Sloan Research Fellowship
  - Served on SLAC Policy Committee, HEPAP & subpanels, Fermilab Physics Advisory Committee, CERN Scientific Policy Committee, CEPC/SppC International Advisory Committee

5

Snowmass outcome for the Energy Frontier puts emphasis on fast Higgs-factory (anywhere), muon alternative or complement to hadrons longer term, and no coupling between them (in time and space) …. plus many other physics topics outside the EF ....

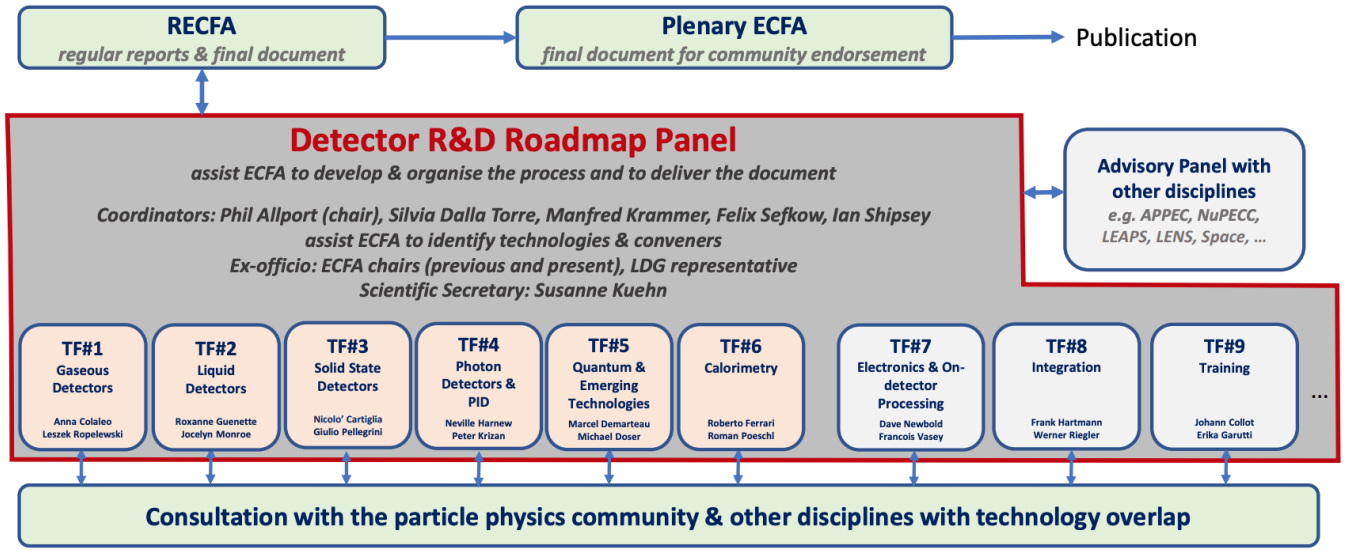
European Accelerator and Detector R&D

Following ESPP recommendation, roadmaps developed in Europe (with US participation) → approved by CERN's Council Dec. 2021



Implementation plans being developed and organizational structures being established (US participation in these collaborations would be very much welcome).

Investment in R&D is essential for the future of the field!

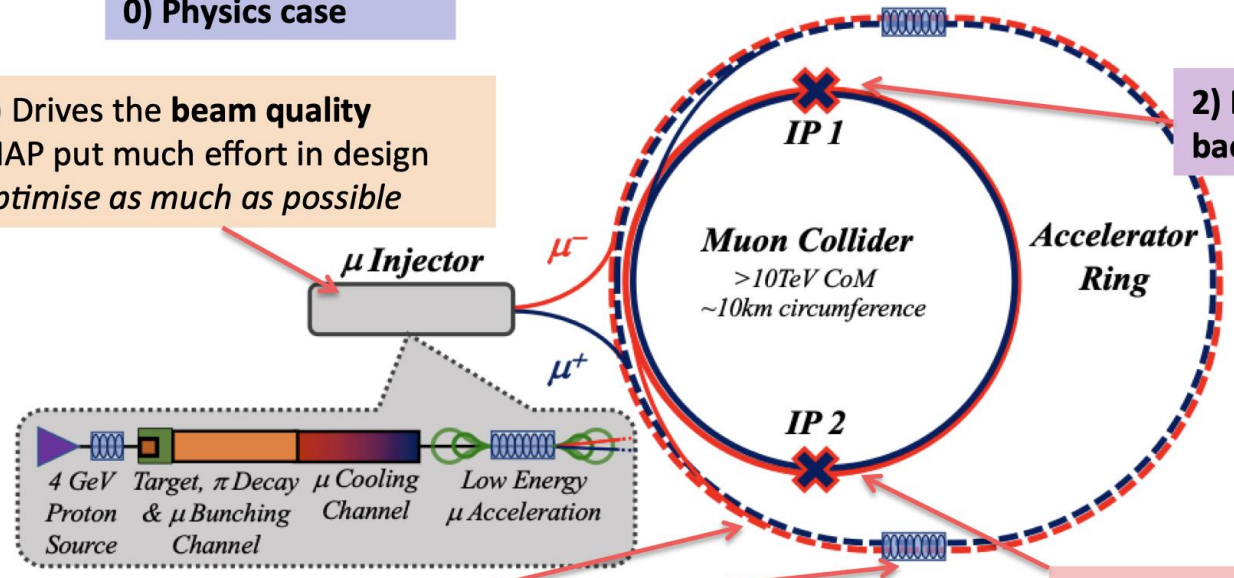


Muon collider collaboration

Key Challenges

0) Physics case

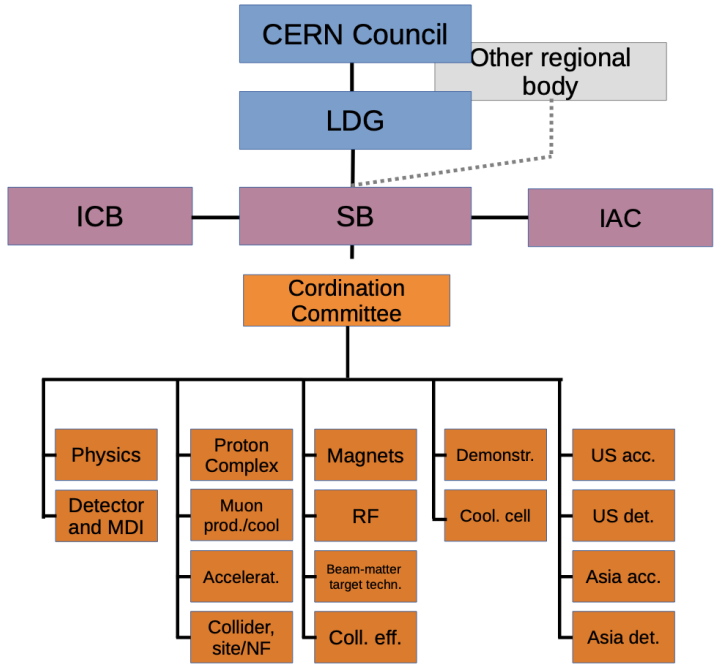
4) Drives the **beam quality**
MAP put much effort in design
optimise as much as possible



2) Beam-induced background

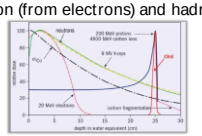
1) Dense neutrino flux
mitigated by mover system and site selection

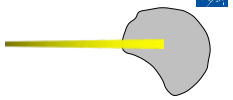
3) Cost and **power** consumption limit energy reach
e.g. 35 km accelerator for 10 TeV, 10 km collider ring
Also impacts **beam quality**

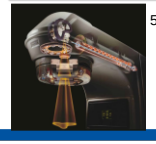


Possible to join muon collaboration (acc or phys/det), also an EU design study
ESS and Uppsala members

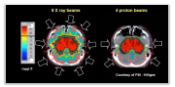
Photon (from electrons) and hadron therapy (protons and ions)







50 mill patients treated with photons



NTNU 2021 - Steinar Stapnes

FLASH VHEE (very high energy electron) therapy

CLIC technology for a FLASH VHEE facility being designed in collaboration with Lausanne University Hospital (CHUV)

An intense beam of electrons is produced in a photoinjector, accelerated to around 100 MeV and then is expanded, shaped and guided to the patient.

Flash: Very short and intense radiation, sparing of healthy tissue

NTNU 2021 - Steinar Stapnes

Synchrotron Light Sources: about 50 storage ring based

60‘000 users world-wide

Established, mature technology

NTNU 2021 - Steinar Stapnes

From L.Rivkin EPFL

X-Ray Free Electron Lasers

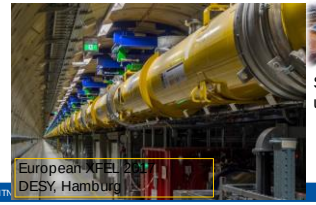
From L.Rivkin EPFL

PAL XFEL 2015

SwissFEL 2017

LCLS I, II 2009, 2019

SACLA 2011
8.5 GeV, 60 Hz NC



European XFEL 2017
DESY, Hamburg

SHINE, Shanghai,
under construction

NTNU 2021 - Steinar Stapnes

Most easily identifiable societable impacts related to medical accelerators and lightsources (and neutron sources)

Trend towards compact machines – in Norway too?

Local accelerators for research as basis for innovations

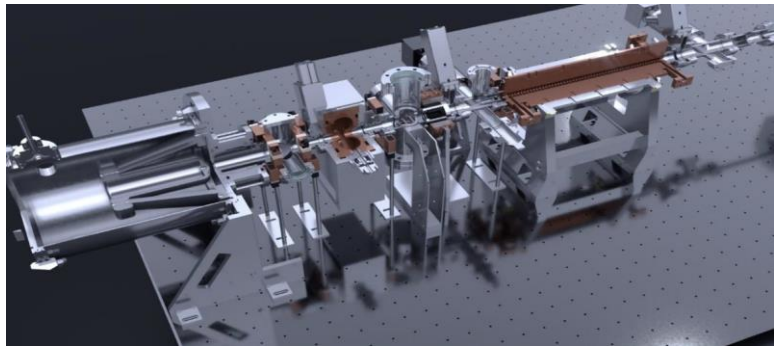
Place in existing University (<100 MNOK), fit in modest building, broad user community

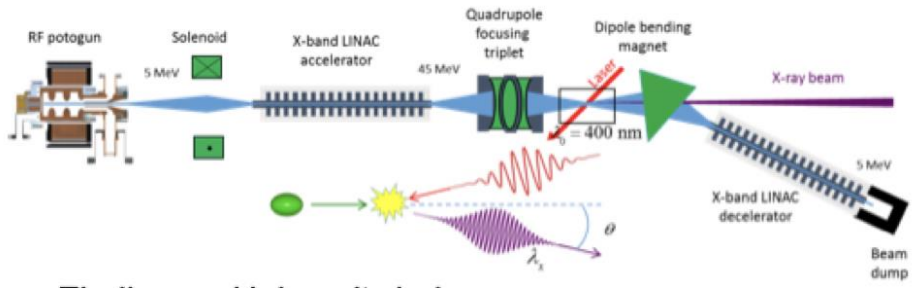
Example:

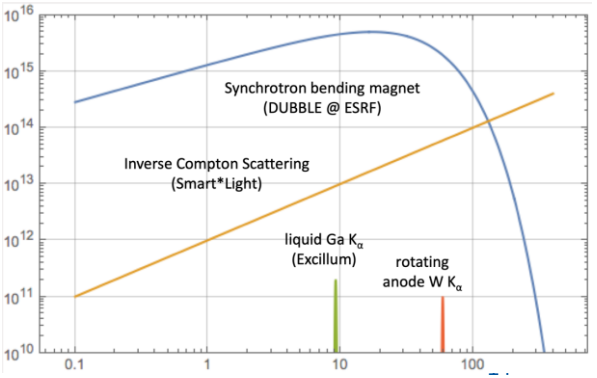
Compact electron linac 30-200 MeV

- Collider with laser, Inv. Compton Scattering, small ligthsource (materials, pharma, drugs, bilogical samples, imaging, R&D for use in silicon industry)
- Collide with neutron target: TOF neutrons (materials mostly)
- Isotopes
- Cleaning and inspection
- Tests bench for medical acc. (e.g Flash theraphy)
- Accelerator R&D (e.g. plasma to make even more compact) and detector system irradiation and testbeam

At some point we should or could consider a research accelerator in Norway ..





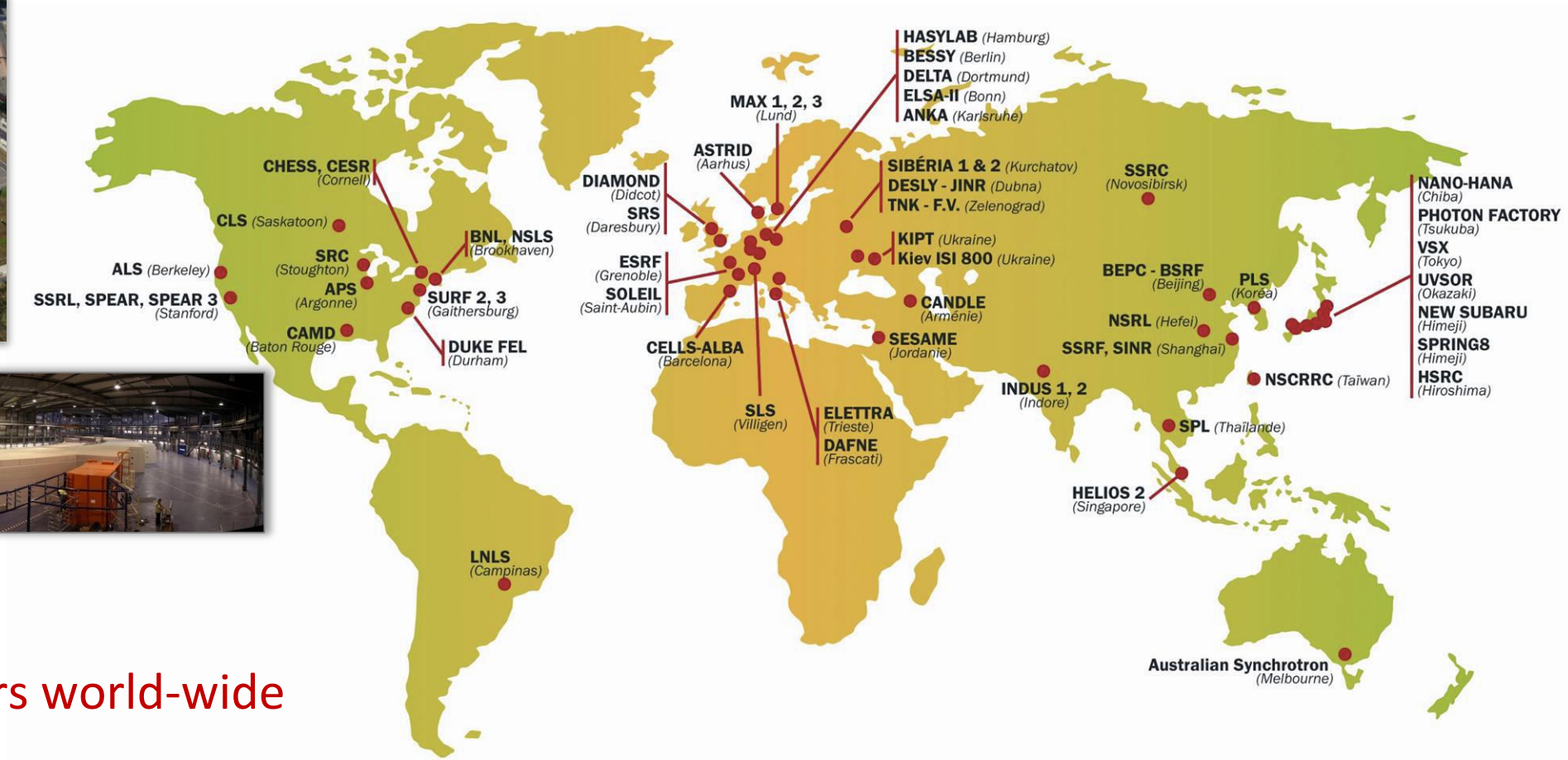


Summary

- Next decade or two our programme will be linked to LHC and HL LHC
- Nuclear physics community will/can benefit from EIC (and FAIR)
- Higgs factory progress slow but interesting acc. R&D – timeline a concern
- For acc. beyond: Plasma interesting, we are active, muon factory studies maybe also of interest (very difficult to make meaningful contributions to FCC-hh magnets – at least until HTS becomes the main focus)
- Acc. R&D roadmap probably adds little, our focus on RF and plasma well justified already

- Should we consider more seriously a small research machine in Norway (placed in a University)? Then we need to talk seriously to a potential user community.

Synchrotron Light Sources: about 50 storage ring based



60‘000 users world-wide

Established, mature technology

From L.Rivkin EPFL

X-Ray Free Electron Lasers

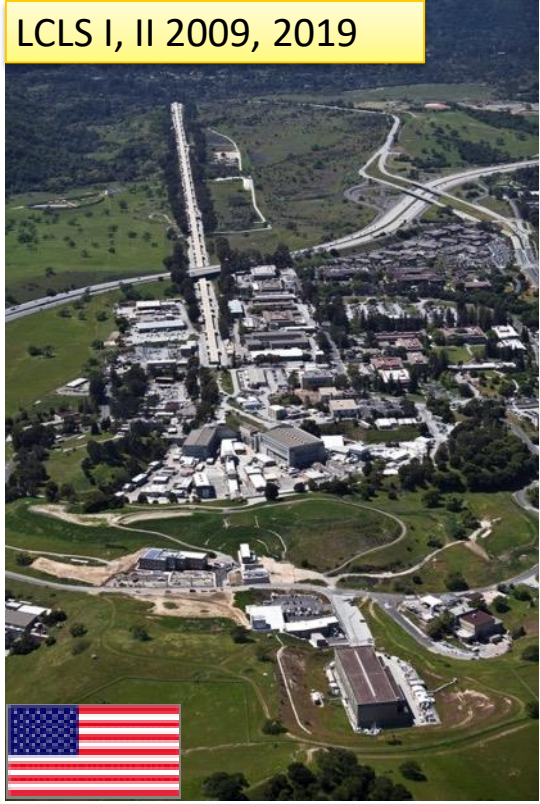
From L.Rivkin EPFL

PAL XFEL 2016

SACLA 2011
8.5 GeV, 60 Hz NC

SwissFEL 2017

European XFEL 2017
DESY, Hamburg



LCLS I, II 2009, 2019

SHINE, Shanghai, under construction