Planning for the future of Particle Physics

Paris Sphicas
CERN & NKUA
XVII international Conference on Resistive Plate Chambers and Related Detectors (RPC2024)
Santiago de Compostela, September 10, 2024

- **The LHC handover and the HL-LHC**
- **Long-term future, the global context**
- **The new ESPP update**
- **Outlook**

The LHC handover & the HL-LHC

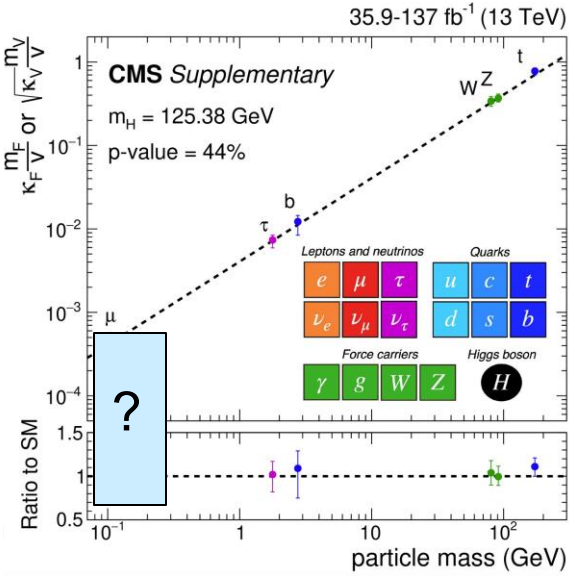
Current running of the LHC

High-Luminosity LHC (HL-LHC)

What the LHC has taught us in Higgs physics: short recap

$$\lambda_f = \kappa_f \left(\frac{m_f}{v}\right)$$

$$\left(\frac{g_V}{2v}\right)^{1/2} = \kappa_v^{1/2} \left(\frac{m_V}{v}\right)$$

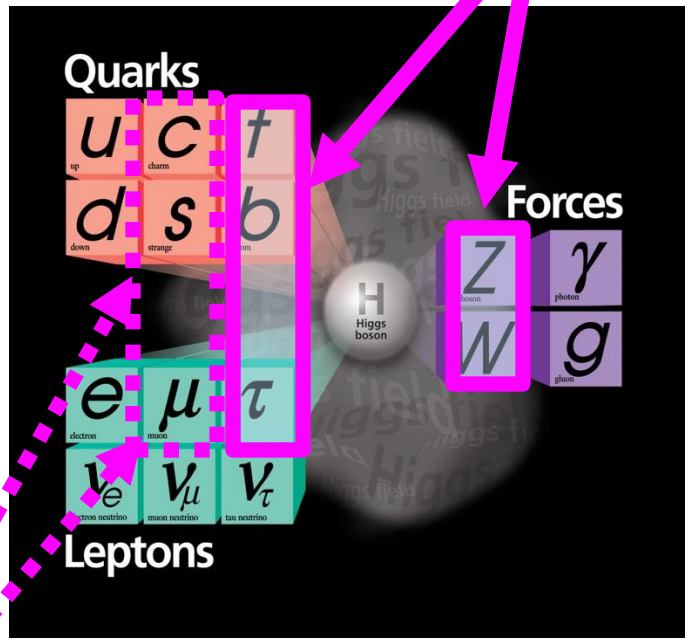


$J^P=0^{++}$ (!!!)

A new kind of "force", with non-universal couplings to matter

A particle like no other

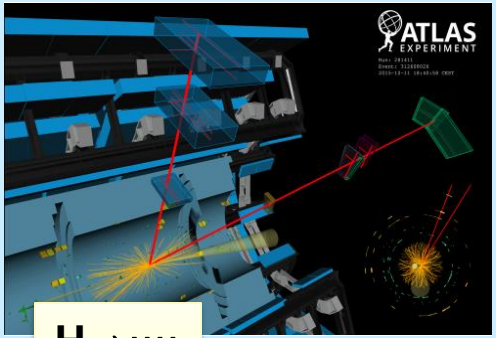
Established



Next goal

SM @ the highest E; EWSB ("Higgs" sector)

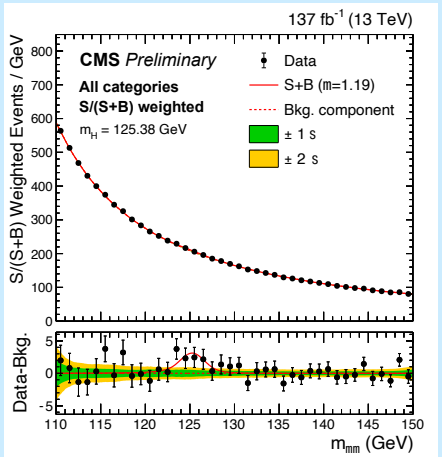
Evidence for H coupling to *2nd-gen fermions: muons*



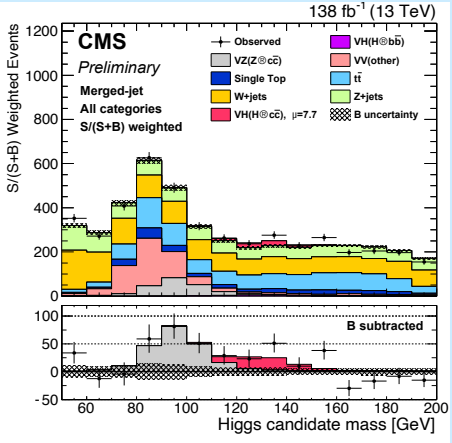
H→μμ

CMS:
obs: 3.0σ (exp: 2.5σ)
ATLAS:
obs: 2.0σ (exp: 1.7σ)

$\mu = 1.2 \pm 0.6$



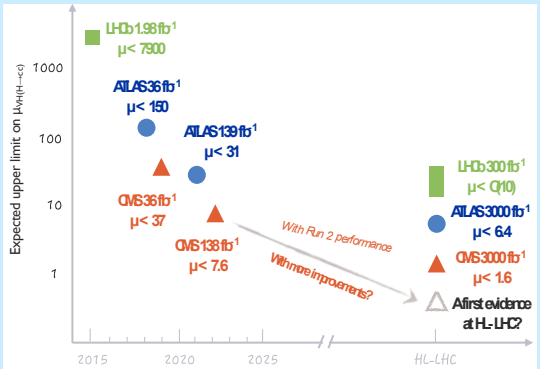
A dream: observe H decaying to charm quarks



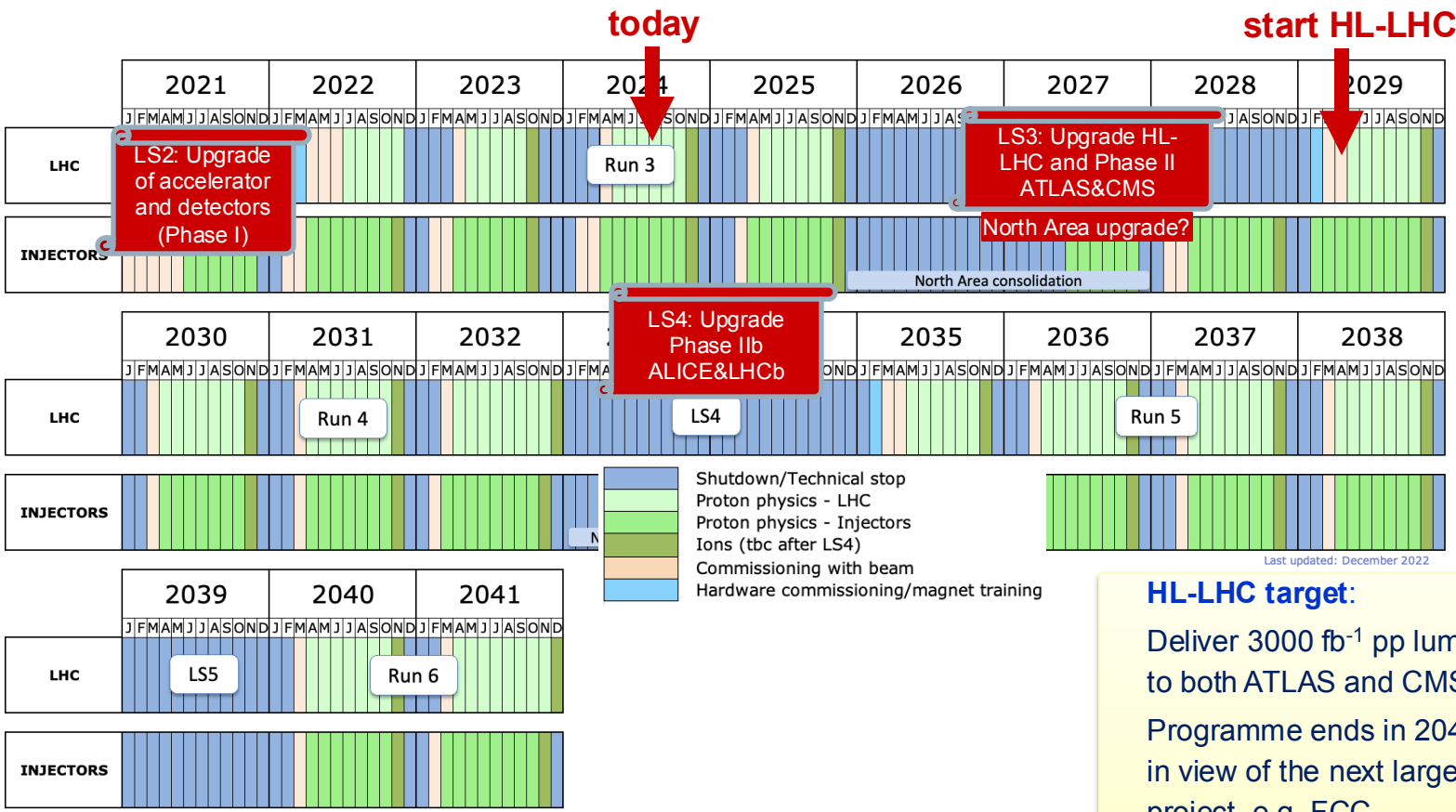
First observation of Z→cc at a hadron collider!

$\mu_{VZ(Z \to cc)} = 1.01^{+0.23}_{-0.21}$

$\mu_{VH(H \to cc)} < 14$ (7.6 exp.)



LHC Timeline



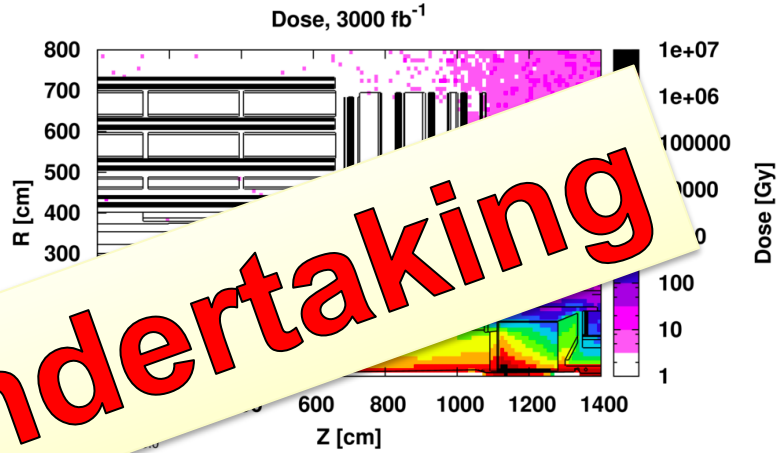
HL-LHC target:

Deliver 3000 fb^{-1} pp luminosity to both ATLAS and CMS

Programme ends in 2041 in view of the next large CERN project, e.g. FCC

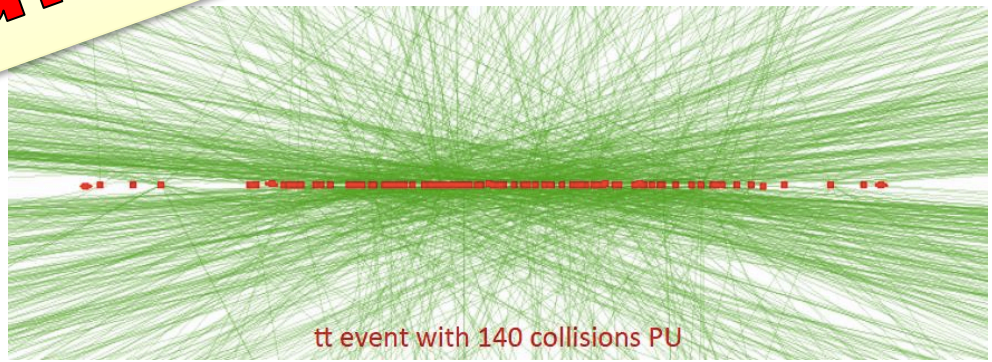
HL-LHC challenges

Annual dose at HL-LHC: similar to total dose from LHC start to LS3



A huge undertaking

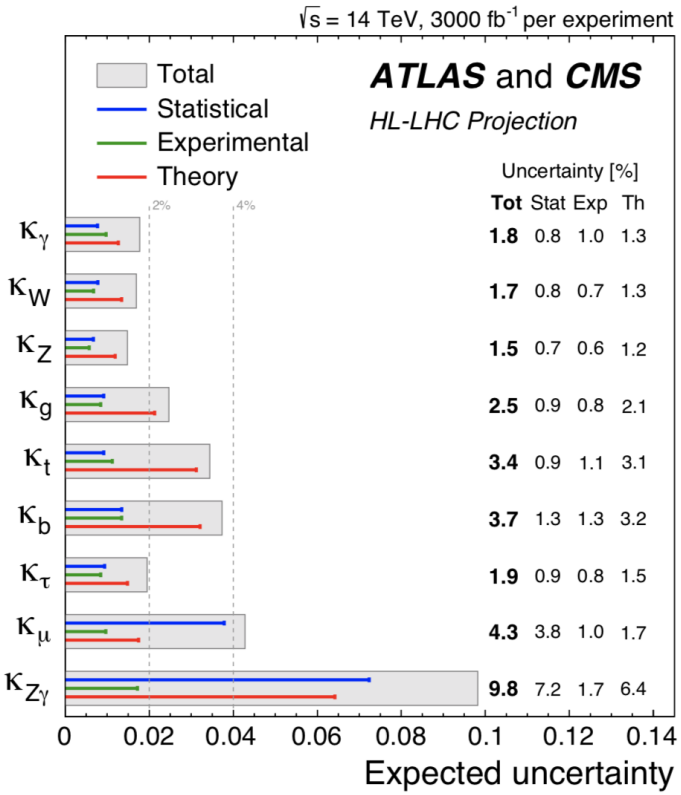
Key t… detect… in the pre… of much higher pileup (140-200!)



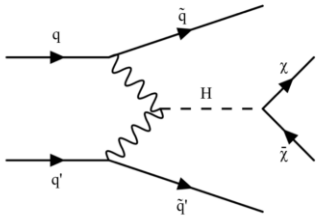
Upgrade several detector components (trackers, calorimeters, redesign some electronics, new detector technologies, Trigger and DAQ

Medium-term Higgs physics: the LHC/HL-LHC program

HL-LHC reach: Higgs

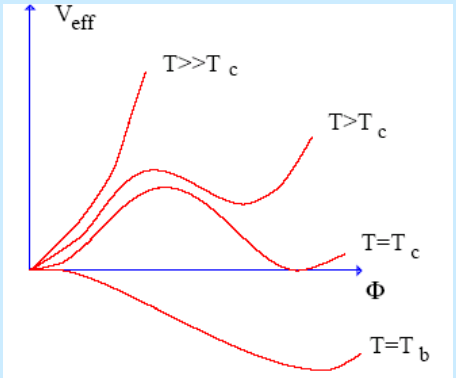


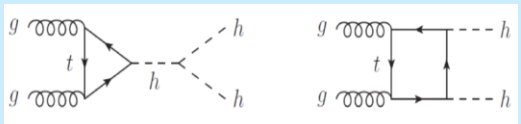
H width to invisible:
h(125)→XX
Includes BSM decays
and rare SM decays: ≤4%

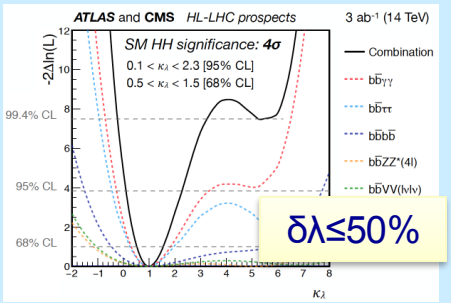


The ultimate frontier: Higgs self-coupling

$$V_h = \frac{m_h^2}{2}h^2 + (1+\kappa_3)\lambda_{hhh}^{SM} v h^3 + \frac{1}{4}(1+\kappa_4)\lambda_{hhhh}^{SM} h^4$$







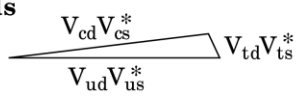
δλ≤50%

Flavor physics: quark sector

$$V_{CKM} = \begin{bmatrix} 1-\lambda^2/2 & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda & 1-\lambda^2/2 & A\lambda^2 \\ A\lambda^3(1-\rho-i\eta) & -A\lambda^2 & 1 \end{bmatrix}$$

$$V_{ui}\,V_{uj}^* + V_{ci}\,V_{cj}^* + V_{ti}\,V_{tj}^* = 0$$

ds



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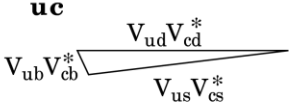
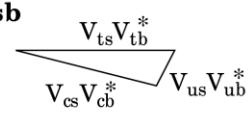


sb



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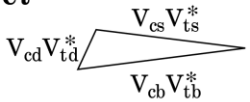

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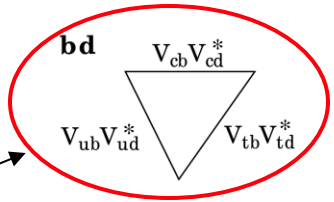
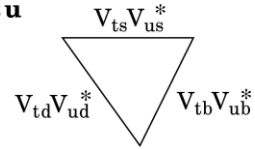
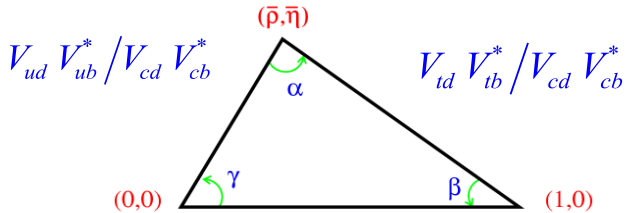
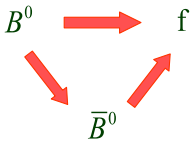


tu



CP ~ sin2ϕ

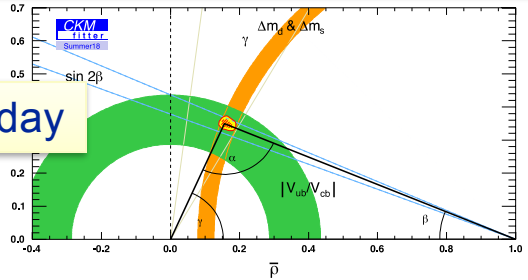




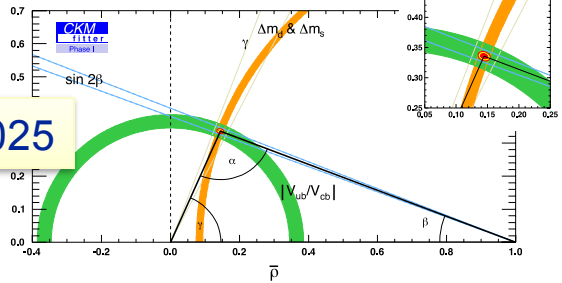
$$\frac{\Gamma(\bar B^0 \to f) - \Gamma(B^0 \to f)}{\Gamma(\bar B^0 \to f) + \Gamma(B^0 \to f)} = -\eta_f \sin(2\phi)\,\sin(\Delta M\, t)$$

CKM triangle: extensive precision program en route

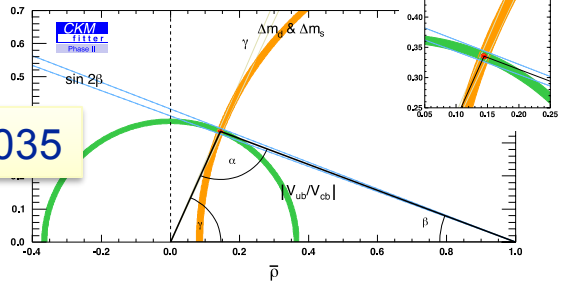
Today



2025

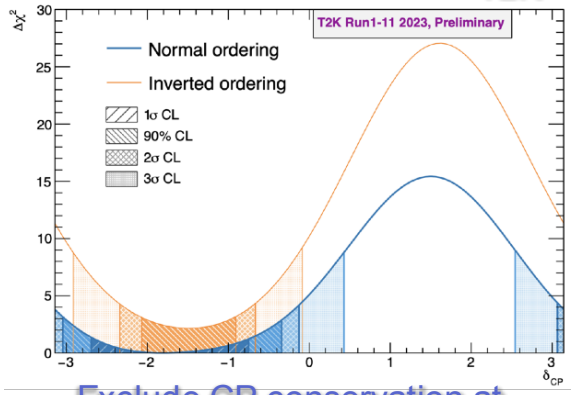


2035

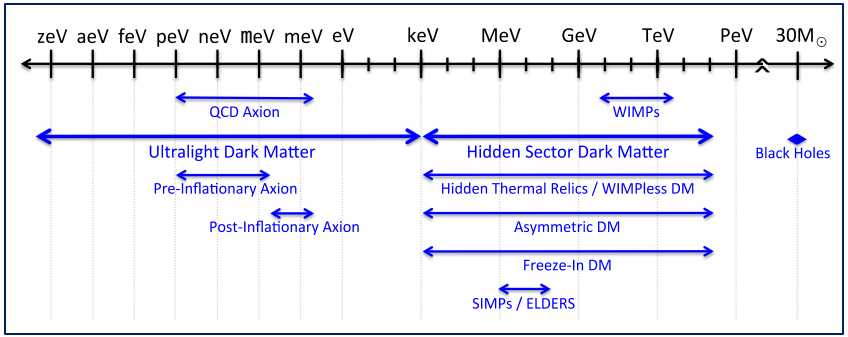


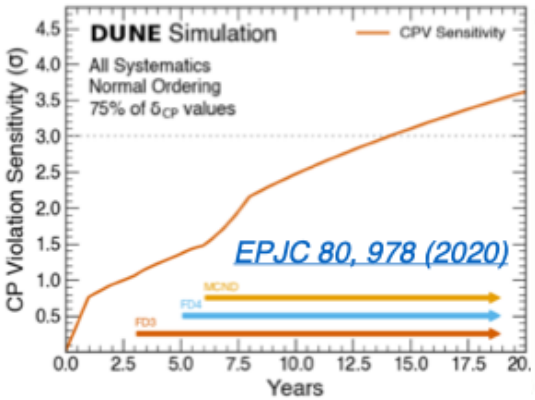
Neutrinos & Dark Matter

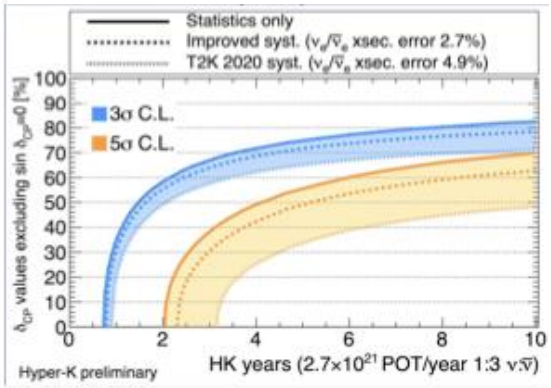
T2K

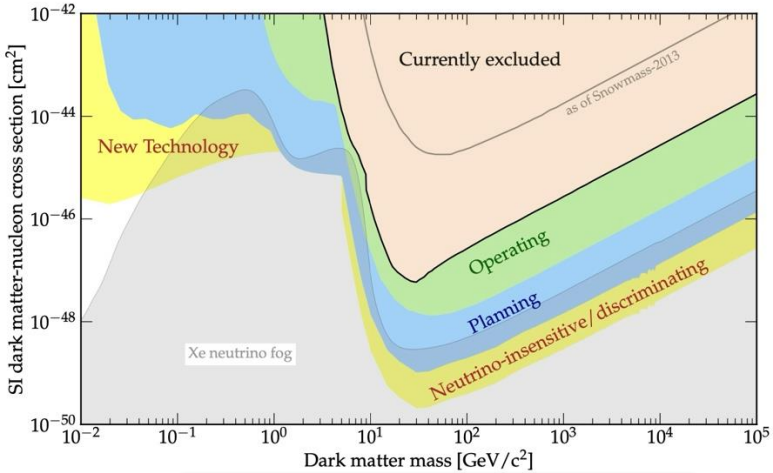


Exclude CP conservation at 90% CL!









Snowmass Cosmic Frontier Report
arXiv:2211.09978

Long-term future: the next European Strategy for Particle Physics

The next big accelerator (flagship project)

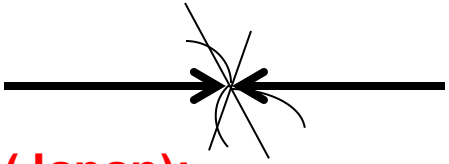
European Strategy for Particle Physics

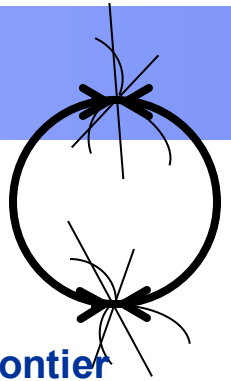
Continuous community-driven process

- **First ESPP in 2006** http://europeanstrategy.cern
- **2013 update: HL-LHC decision**
- **2020 update: post-HL-LHC recommendations:**
  - ***An electron-positron Higgs factory is the highest-priority next collider. For the longer term, the European particle physics community has the ambition to operate a proton- proton collider at the highest achievable energy.***
  - ***Europe, together with its international partners, should investigate the technical and financial feasibility of a future hadron collider at CERN with a centre-of-mass energy of at least 100 TeV and with an electron-positron Higgs and electroweak factory as a possible first stage.***
  - ***Detector R&D programmes and associated infrastructures should be supported at CERN, national institutes, laboratories and universities. Synergies between the needs of different scientific fields and industry should be identified and exploited to boost efficiency in the development process and increase opportunities for more technology transfer benefiting society at large. [... The community should define a global detector R&D roadmap that should be used to support proposals at the European and national levels..***
  - **Successful completion of High-Luminosity LHC must remain key focus**
- **2026 update: just commenced; more on this, later in this talk**

http://dx.doi.org/10.17181/CERN.JSC6.W89E

Collider Crib sheet





- **ILC (Japan):**
  - Linear collider with high-gradient superconducting acceleration
  - Ultimate: 0.5-1(?) TeV
  - To secure (…) funding: reduce cost by starting at 250 GeV (H factory)

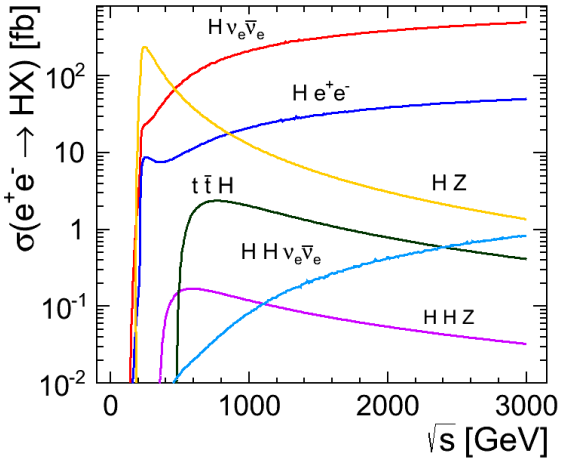
- **CLIC (CERN):**
  - Linear collider with high gradient normal-conducting acceleration
  - Ultimate: multi-TeV (3) e^+e^- collisions
  - Use technology to overcome challenges
  - Stages, for physics and funding

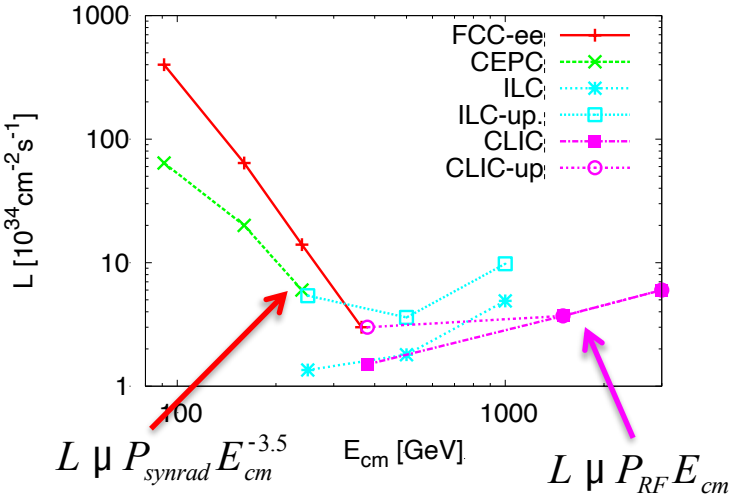
- **FCC-ee/FCC-hh (CERN):**
  - Protons to extend energy frontier
  - 90 km ring with 16T magnets
  - Use FCC-hh tunnel for e^+e^- collider
  - Technology for ee: “standard”

- **CEPC/SppC**
  - Essentially an FCC-ee, then hh with (a) more conservative luminosity estimates and (b) in China

- **Outliers:**
  - “Low-field” (12T) magnets @ FCC (?)
  - Muon Collider (???)

Higgs “factories”





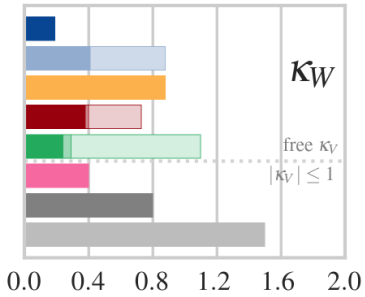
Schemes for increasing luminosity:

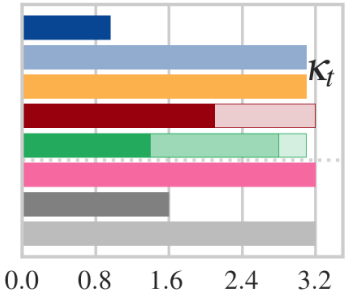
- FCC-ee: consider more IRs/running longer
- ILC: more bunches per pulse, doubling repetition rate?
  - Each: x 2 in lumi; higher power consumption and somewhat higher cost
- CLIC: doubling repetition rate at 380 GeV?
  - Factor 2 in lumi; power increases from 170 MW to 220 MW (+slight cost increase)

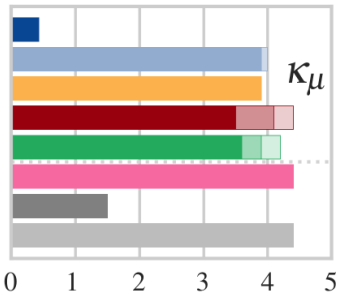
Low energies: circular colliders superior performance Higher energies: CC lumi reduction due to synchrotron radiation; linear colliders better: luminosity per beam power roughly constant

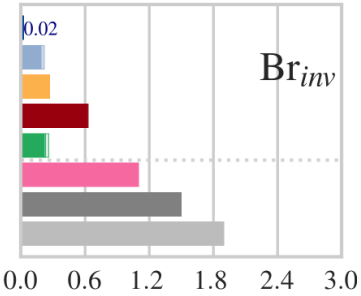
Longit. polarisation: only at Linear Colliders
e^-: 80%; e^+: 30% @ ILC; 0 @ CLIC (not needed)
FCC-ee: transverse polarization for precise E_{beam}

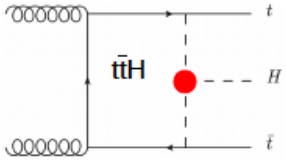
The Higgs sector: from the HL-LHC to the "future"

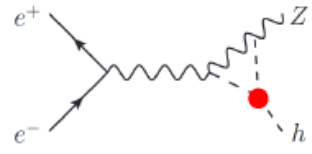


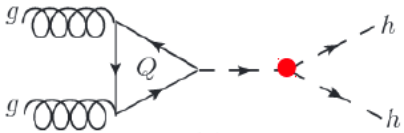


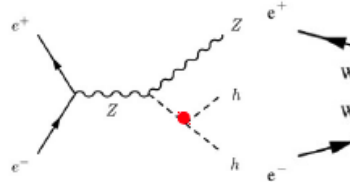


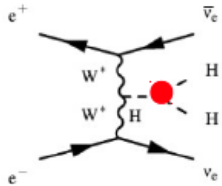


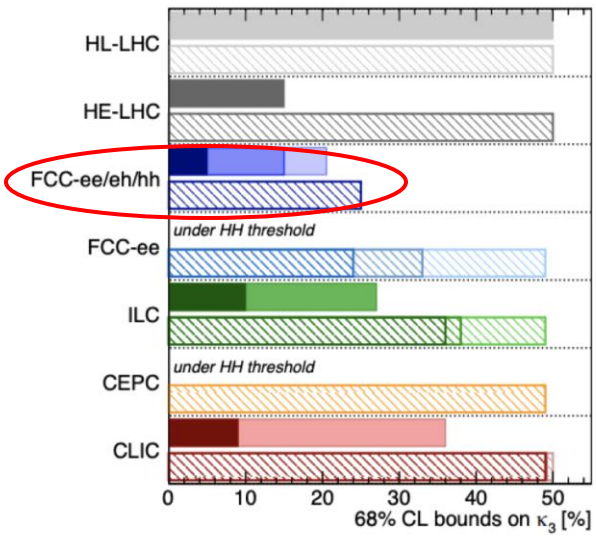


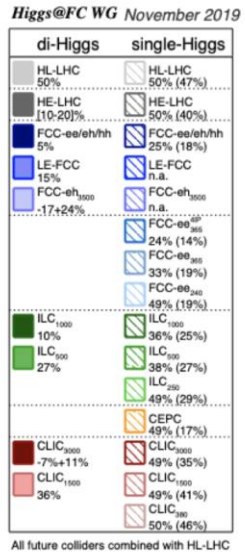








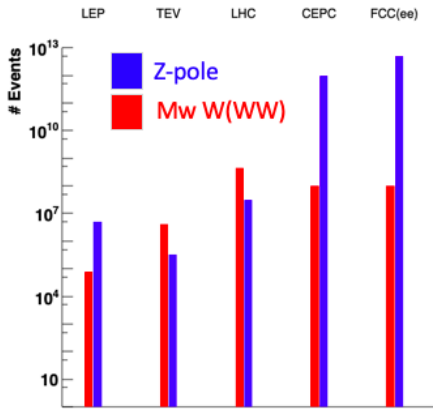




FCC-ee/eh/hh
FCC-ee$_{365}$
FCC-ee$_{240}$
CEPC
CLIC$_{3000}$
CLIC$_{1500}$
CLIC$_{380}$
ILC$_{1000}$
ILC$_{500}$
ILC$_{250}$
LHeC $|\kappa_V| \leq 1$
HE-LHC $|\kappa_V| \leq 1$
HL-LHC $|\kappa_V| \leq 1$

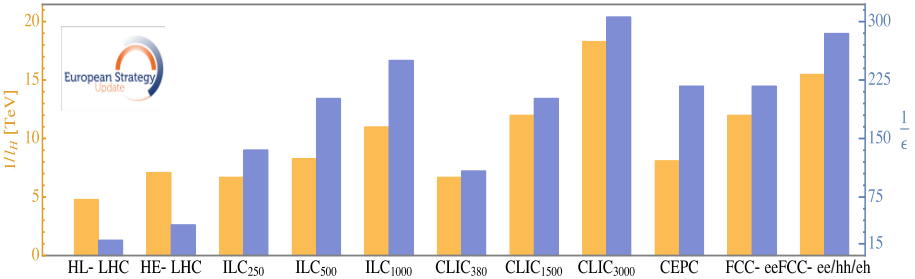
Precision Observables & Searches: examples

- **EWPO: circular ee colliders**
  - **+ linear colliders for $\sin^2\theta_W$.**
  - **Note: currently, discussion/plan for a large Z run for the linear colliders…**

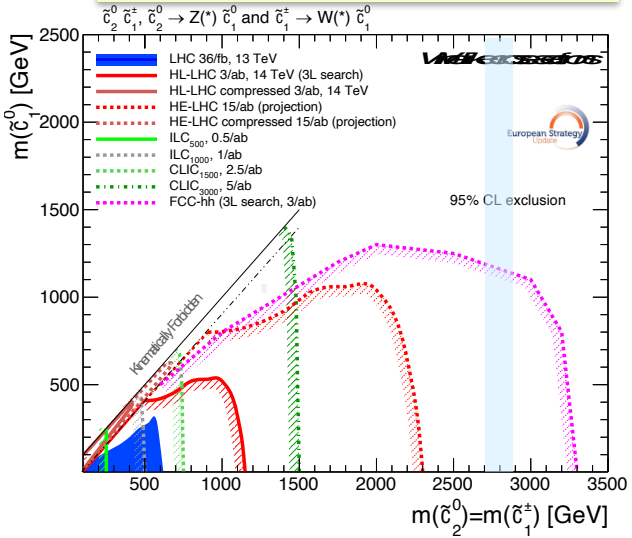


EWPO	Current	CEPC	FCC (ee)
M_Z [MeV]	2.1	0.5	0.1
Γ_Z [MeV]	2.1	0.5	0.1
N_ν [%]	1.7	0.05	0.03
M_W [MeV]	12	1	0.67
$A_{FB}^{0,b}$ [x10^4]	16	1	< 1
$\sin^2\theta_W^{\text{eff}}$ [x10^5]	16	1	0.6
R_b^0 [x10^5]	66	4	2–6
R_μ^0 [x10^5]	2500	200	100

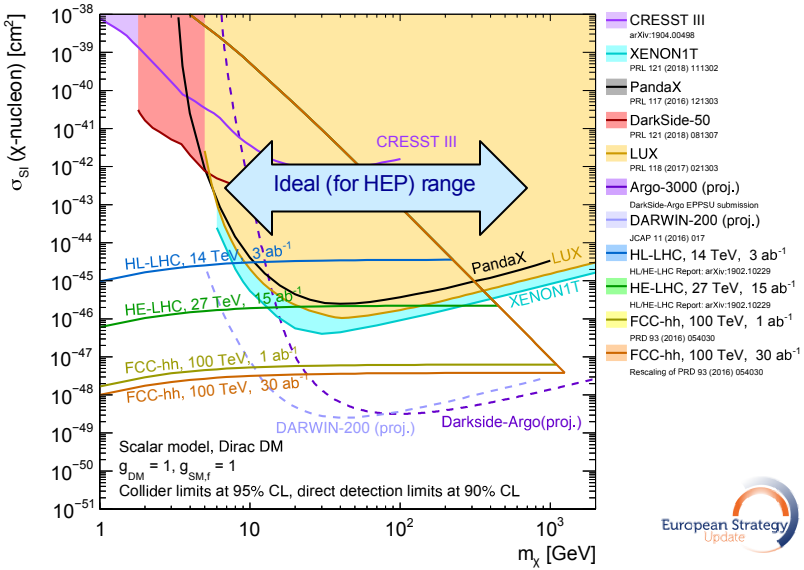
Higgs compositeness (?)

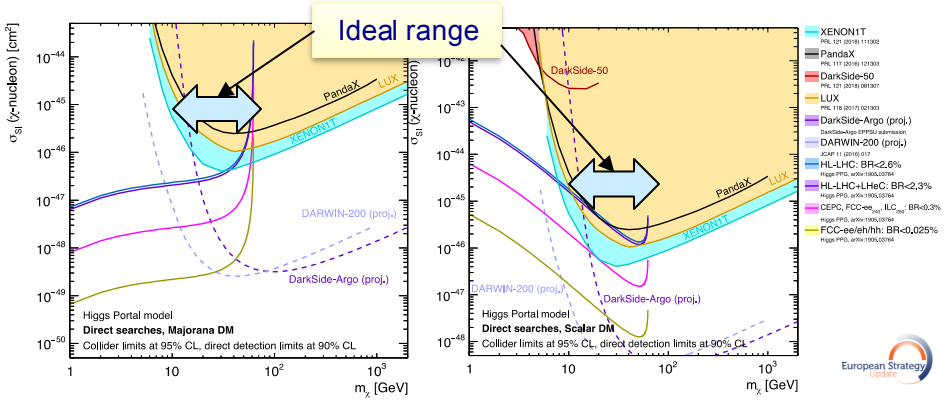


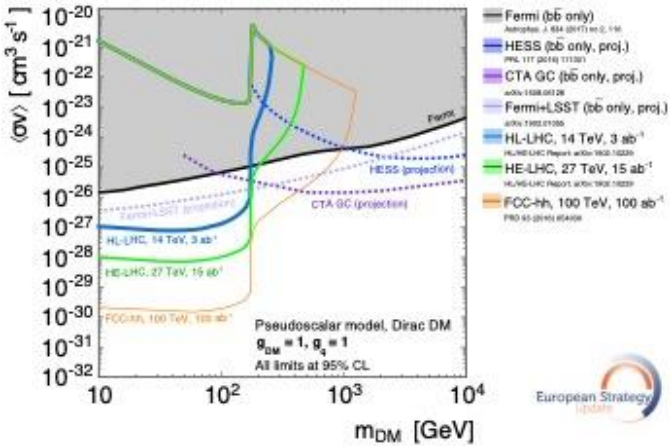
Electroweak SUSY reach



Scalar mediator: Higgs portal and BSM scalar





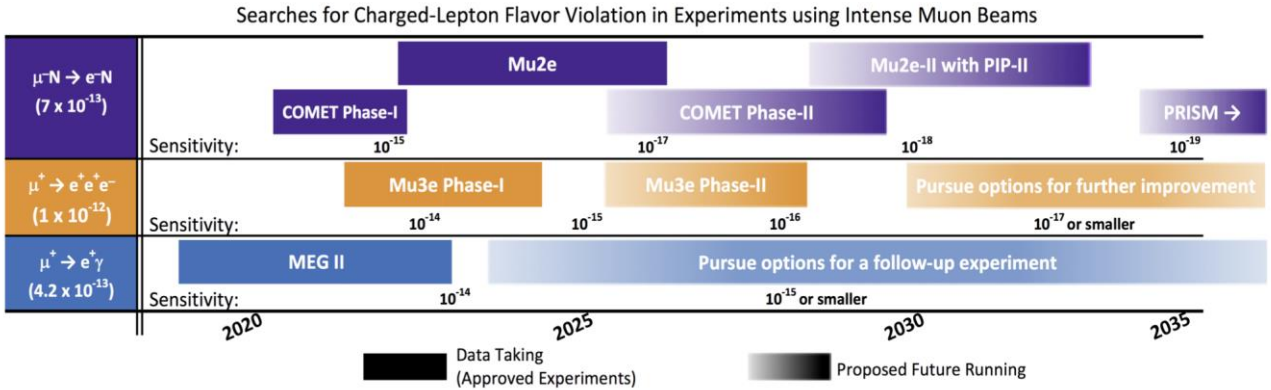


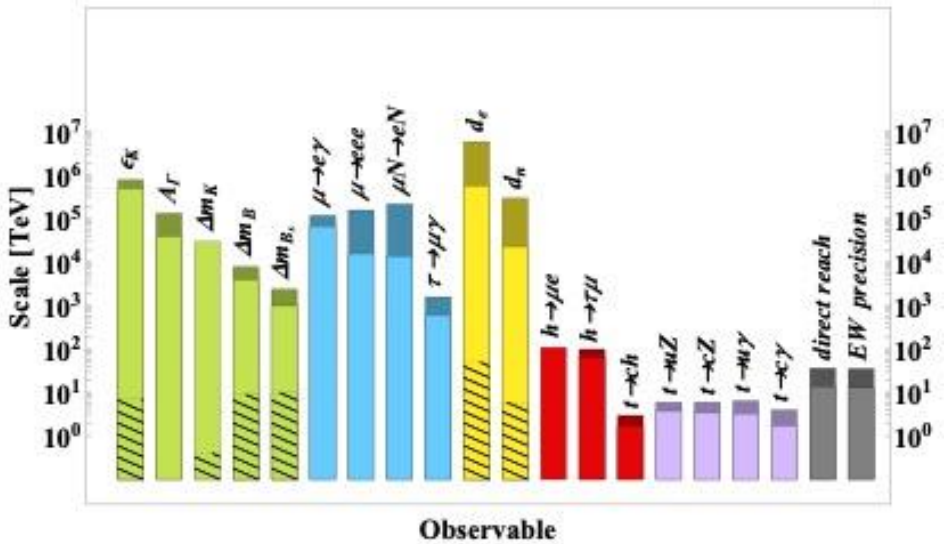
A collider discovery will need confirmation from DD/ID for cosmological origin

A DD/ID discovery will need confirmation from colliders to understand the nature of the interaction

A future collider program that optimizes sensitivity to invisible particles coherently with DD/ID serves us well. Need maximum overlap with DD/ID!

CLFV and Λ_{NP} from flavor experiments

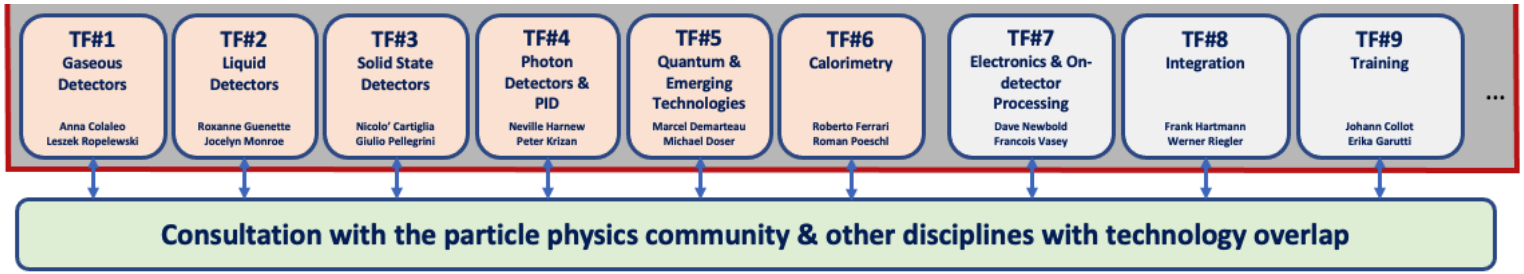




ECFA Detector R&D Roadmap & Implementation plan

2021: ECFA released full roadmap (200 pages) and synopsis (~10 pages) based on a community-driven effort DOI: 10.17181/CERN.XDPL.W2EX

- **Overview of future facilities (EIC, ILC, CLIC, FCC-ee/hh, Muon collider) or major upgrades (ALICE, Belle-II, LHC-b,…) and their timelines**
- **Ten "General Strategic Recommendations" (full list in later slides)**
- **Nine Technology domains with Task Force areas**
  - **Most urgent R&D topics in each domain: Detector R&D Themes (DRDTs)**

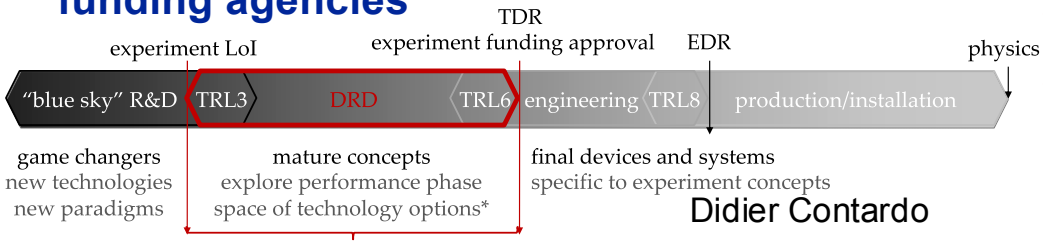


- **Implementation plan: Approved by CERN SPC and Council in Fall 2022 (CERN/SPC/1190 ; CERN/3679)**
  - **CERN to host DRD collaborations**
  - **DRD interface to CERN through DRDC**
  - **DRD interface to ECFA via ECFA Detector panel: https://ecfa-dp.desy.de.**

Strategic R&D

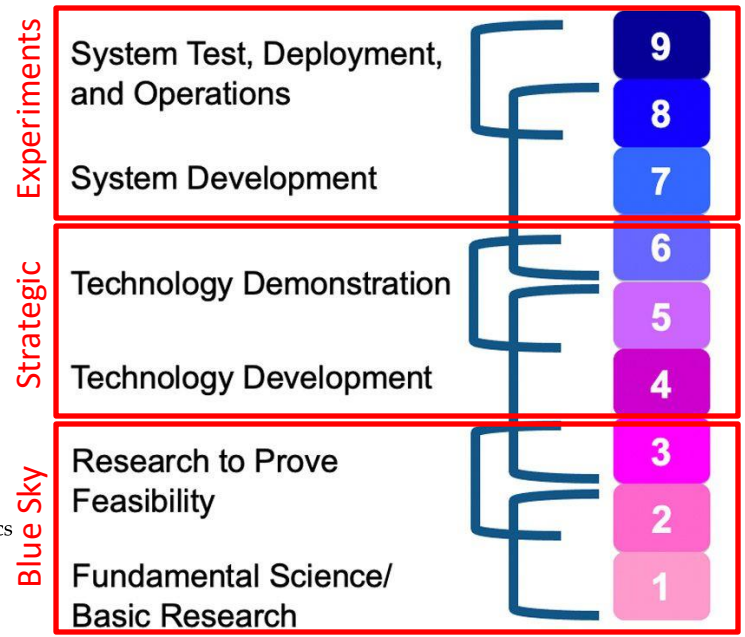
Strategic R&D bridges the gap between the idea ("blue sky research", TRL 1-3) and the deployment and use in a HEP experiment (TRL 8-9)

- Detector R&D Collaborations should address TRLs from 3 to 7, before experiment-specific engineering takes over
- Covers the development and maturing of technologies, e.g.
  - Iterating different options
  - Improving radiation hardness
  - Scaling up detector area, number of layers,..
- Backed up by strategic funding, agreed with funding agencies



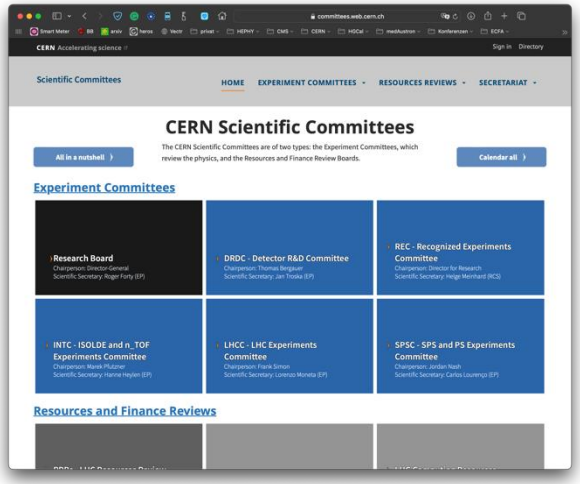
Technology Readiness Levels (TRLs) 1-9:

Method for estimating the maturity of technologies

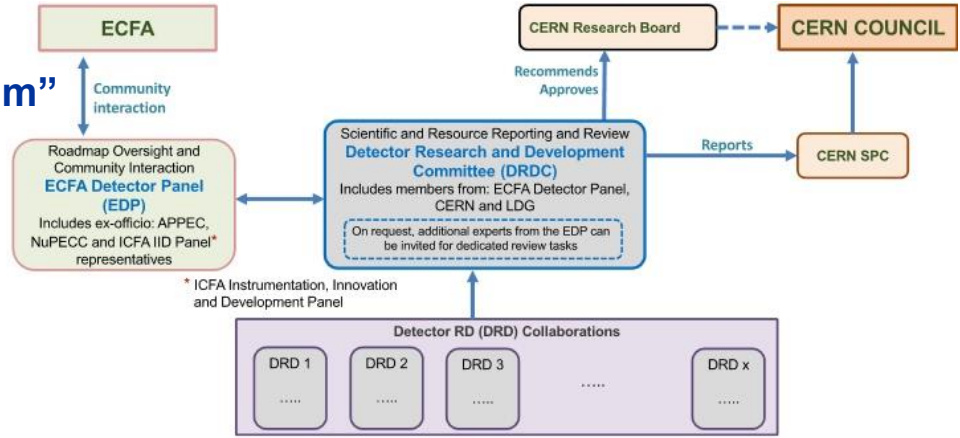


DRD Committee (DRDC)

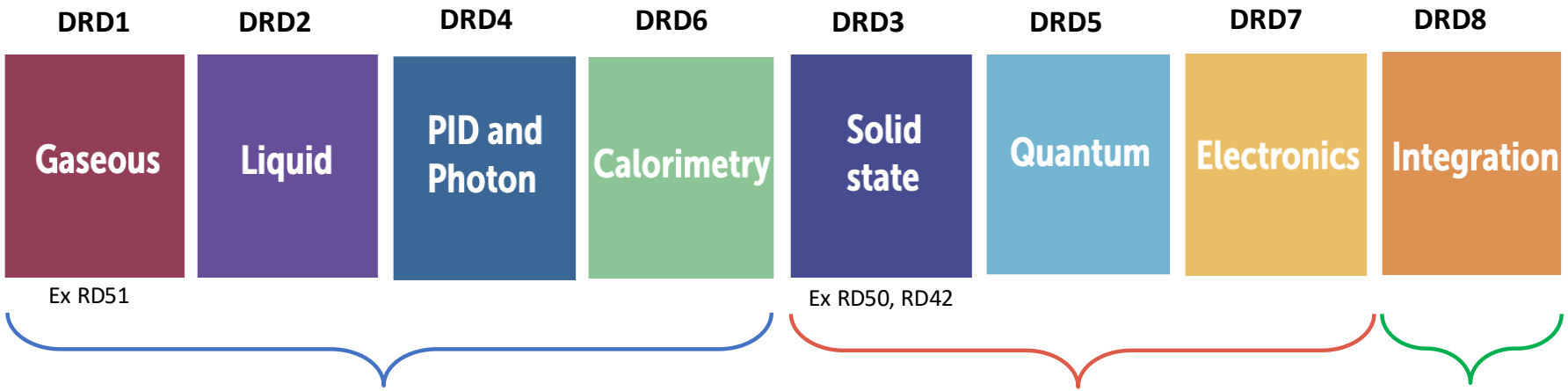
- **Autumn 2023: DRDC**
  - Detector R&D Committee: new CERN committee, same level as SPSC and LHCC.
- **Detector R&D Committee (DRDC):**
  - "Reviewing body"
  - Monitoring milestones and deliverables
  - Embedded in "CERN hierarchy", reporting to RB



- **ECFA Detector Panel (EDP):**
  - "Advising body", full mandate here.
  - Organizes (recently) "DRD Managers Forum"
    - Organizing exchange across different DRDs
    - Define common terminology
    - Heritage from "full panel" meetings during proposal preparation
  - Providing input to European Strategy for Particle Physics Update 2026



Status of DRD collaborations



- **DRD reports at open session of last DRDC meeting**
- **Indico: Category "Experiments / R&D"**
- **Full DRD proposals in CERN CDS**
  - **Contents: strategic R&D needs and definition of work packages, milestones & deliverables**
  - **Strategic funding to be agreed with funding agencies/institutions**
  - **Next step is to prepare and sign DRD MoUs**
  - **Proposal by DRD8 by the end of this year**

Long-term future: the next European Strategy for Particle Physics

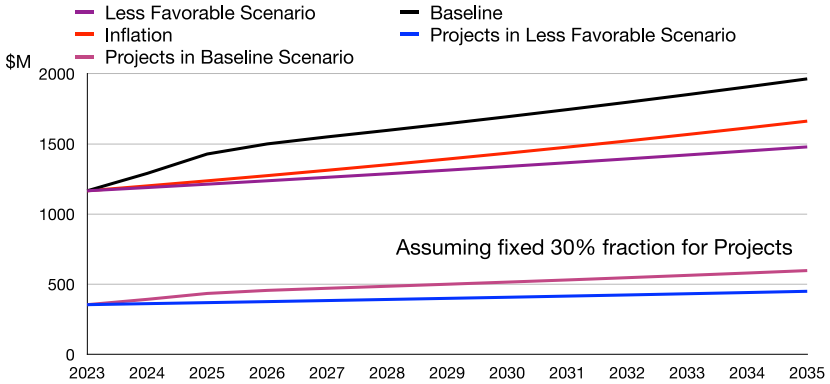
A brief summary

US P5 process

Credit: H. Murayama

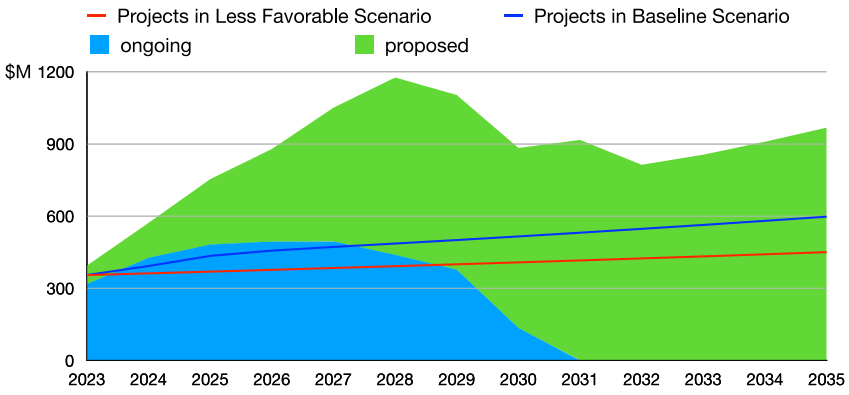
Exploring the Quantum Universe

Budget Scenarios



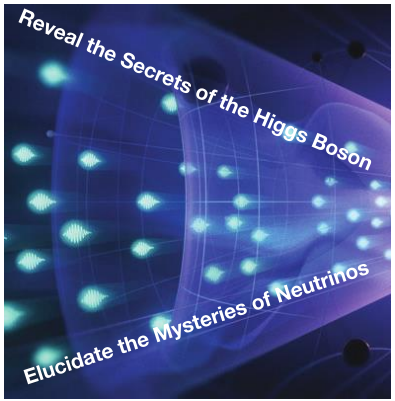
DOE only

Budget Scenarios and Projects

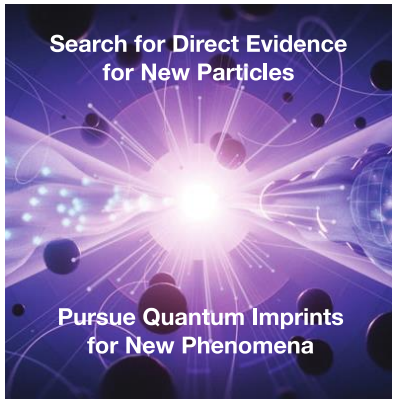


not including on-shore Higgs factory

DOE only



Decipher the Quantum Realm



Explore New Paradigms in Physics

Illuminate the Hidden Universe

US P5 process (II)

Credit: H. Murayama

Exploring the Quantum Universe

Recommendation 1

Not Rank-Ordered

Reaffirm critical importance of the ongoing projects

As the highest priority independent of the budget scenarios, complete construction projects and support operations of ongoing experiments and research to enable maximum science. We reaffirm the previous P5 recommendations on major initiatives:

a. **HL-LHC** (including ATLAS and CMS detectors, as well as Accelerator Upgrade Project) to start addressing why the Higgs boson condensed in the universe (reveal the secrets of the Higgs boson, section 3.2), to search for direct evidence for new particles (section 5.1), to pursue quantum imprints of new phenomena (section 5.2), and to determine the nature of dark matter (section 4.1). DOE & NSF PHY

b. **The first phase of DUNE and PIP-II** to determine the mass ordering among neutrinos, a fundamental property and a crucial input to cosmology and nuclear science (elucidate the mysteries of neutrinos, section 3.1). Mostly DOE

c. **The Vera C. Rubin Observatory** to carry out the LSST, and the LSST Dark Energy Science Collaboration, to understand what drives cosmic evolution (section 4.2).

US leadership in key areas of particle physics

DOE & NSF AST

US P5 process (III)

Credit: H. Murayama

Exploring the Quantum Universe

Recommendation 2

Rank-Ordered

New exciting initiatives

a. **CMB-S4**, which looks back at the earliest moments of the universe to probe physics at the highest energy scales. It is critical to install telescopes at and observe from both the South Pole and Chile sites to achieve the science goals (section 4.2). DOE & NSF AST

b. **Re-envisioned second phase of DUNE** with an early implementation of an enhanced 2.1 MW beam—ACE-MIRT—a third far detector, and an upgraded near-detector complex as the definitive long-baseline neutrino oscillation experiment of its kind (section 3.1). Mostly DOE

c. **An off-shore Higgs factory**, realized in collaboration with **international partners**, in order to reveal the secrets of the Higgs boson. The current designs of FCC-ee and ILC meet our scientific requirements. The US should actively engage in feasibility and design studies. Once a specific project is deemed feasible and well-defined (see also Recommendation 6), the US should aim for a contribution at funding levels commensurate to that of the US involvement in the LHC and HL-LHC, while maintaining a healthy US on-shore program in particle physics (section 3.2). DOE & NSF PHY

d. **An ultimate Generation 3 (G3) dark matter direct detection experiment** reaching the neutrino fog, in coordination with international partners and preferably sited in the US (section 4DOE & NSF PHY

e. **IceCube-Gen2** for study of neutrino properties using non-beam neutrinos complementary to DUNE and for indirect detection of dark matter covering higher mass ranges using neutrinos as a tool (section 4.1). NSF PHY

US P5 process (III)

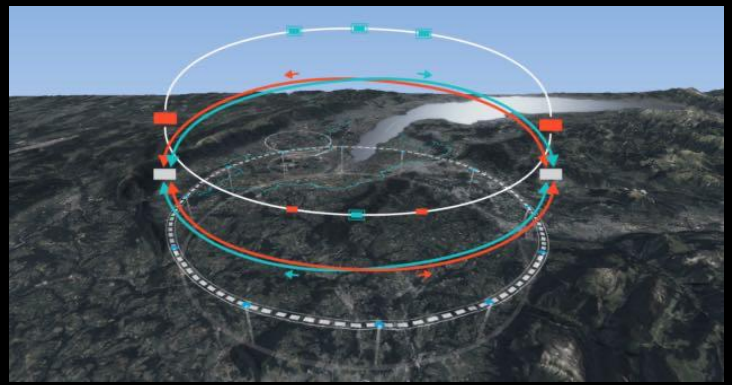
Credit: H. Murayama

An Offshore Higgs Factory

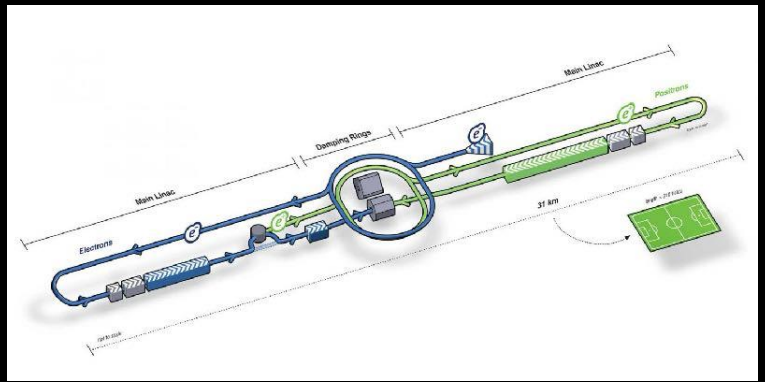
An electron-positron collider covering center-of-momentum energy range 90 - 350 GeV

- Precision measurements of couplings and some production modes
- Order of magnitude improved access to Higgs → invisible decays
- EW sector consistency checks, testing through quantum loops that relate W & Z bosons, the top quark, and the Higgs
- Improve knowledge of coupling to charm quark, potentially provide access to coupling to strange quark

FCC ee



ILC



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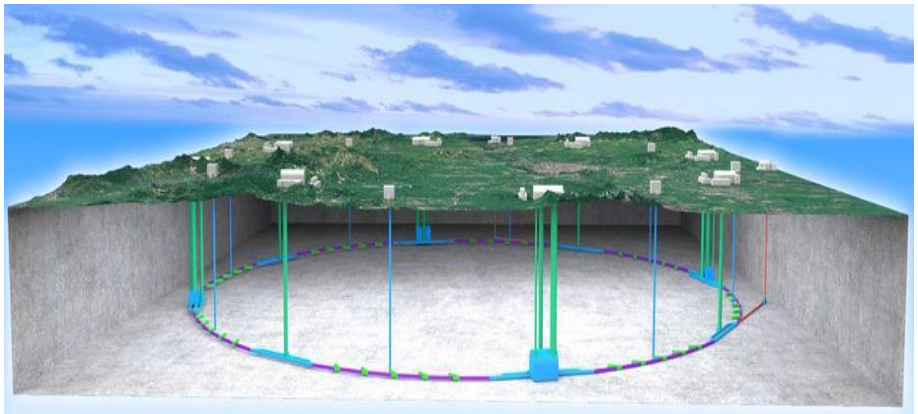
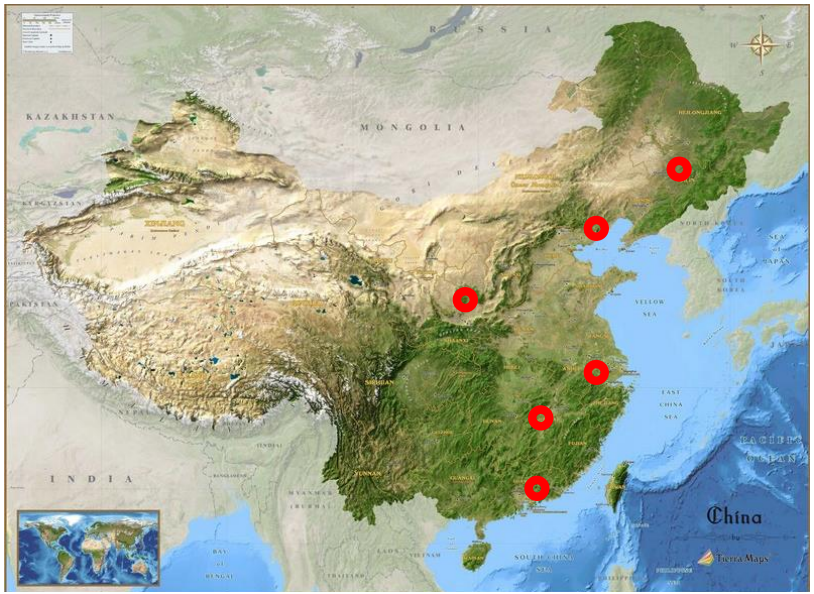
Chinese plans for a Circular e^+e^- collider: CEPC

- **Concept: 100 km ring**
  - CEPC idea, followed by a possible Super proton-proton collider (SPPC): proposed in Sep. 2012; quickly gained momentum
  - Looking for hints @ e^+e^- Collider: If yes, direct search at pp collider
  - Tunnel can be re-used for pp, AA, ep colliders up to ~ 100 TeV e^+e^- collider
    - This was the very successful LEP → LHC recipe





Four sites investigated in detail:
Qing-Huang-Dao, Chang-Sha, Chang-Chun, Hu-Zhou
Geologically good, reasonable transport and local support.
Final decision: negotiation between central and local governments

Chinese plans for a Circular e^+e^- collider: CEPC (II)

- **Cost & Schedule**

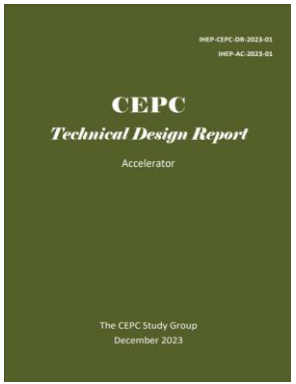
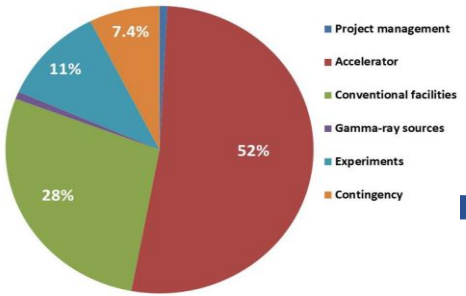


Table 12.1.2: CEPC project cost breakdown, (Unit: 100,000,000 yuan)

Total	364	100%
Project management	3	0.8%
Accelerator	190	52%
Conventional facilities	101	28%
Gamma-ray beam lines	3	0.8%
Experiments	40	11%
Contingency (8%)	27	7.4%



Distribution of CEPC Project total TDR cost of **36.4B RMB (~ 5B €)**

CEPC accelerator TDR has been completed and formally released on December 25, 2023
CEPC accelerator TDR link: arXiv 2312.14363
CEPC accelerator TDR releasing news:
http://english.ihep.cas.cn/nw/han/y23/202312/t20231229_654555.html

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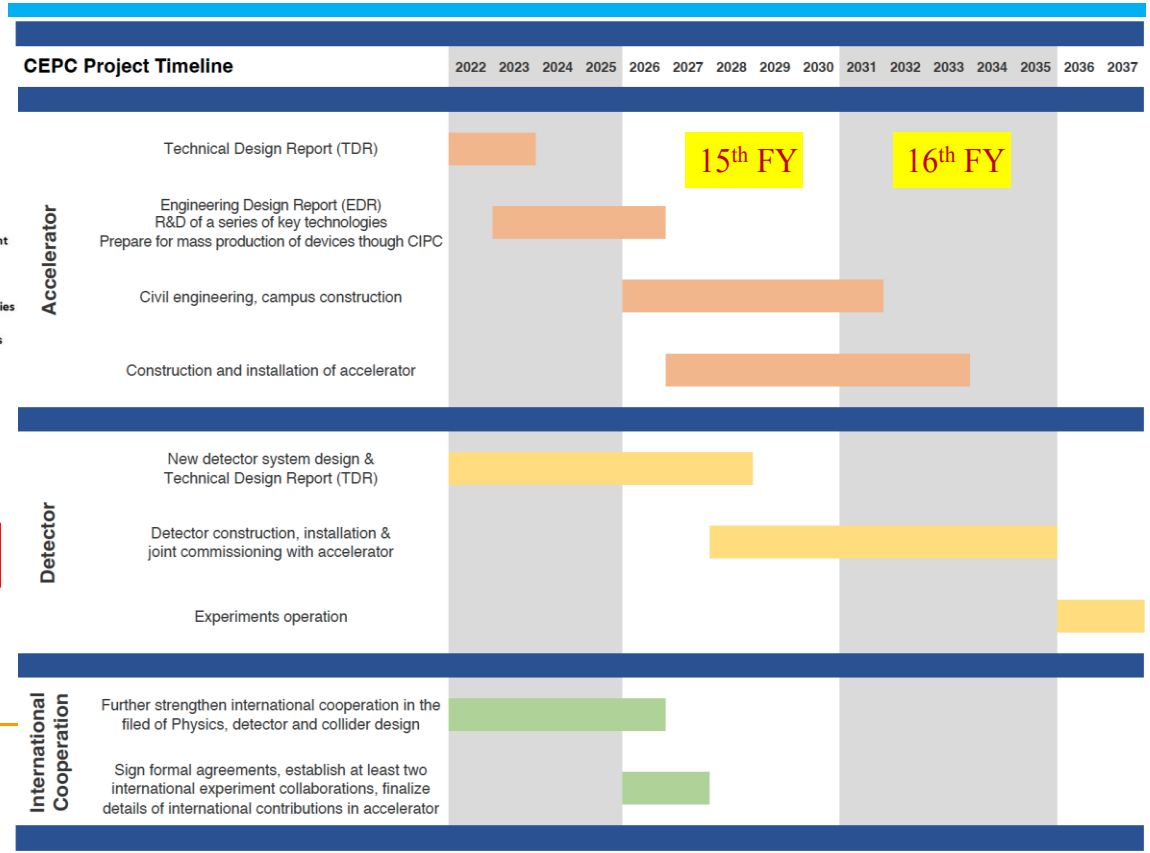
Ideal Schedule



Next update of the ESPP (European Strategy for Particle Physics)

Next ESPP

- **In March 2024 CERN Council launched the new ESPP process, with the following timeline:**
  - **Announcement, and call for contributions to the ESPP: End March 2024**
  - **Three bodies:**
    - **"Secretariat": secretary (Karl Jakobs), CERN SPC chair (Hugh Montgomery), ECFA chair (PS), Lab Directors' Group chair (Dave Newbold)**
    - **Physics Preparatory Group (PPG): secretariat + 4 nominees by ECFA, 4 by SPC, 2 by Americas, 2 by Asia, 1 CERN (to be appointed by CERN Council in Sep)**
    - **European Strategy Group: secretariat (secretary chairs ESG); One rep per CERN member state; One rep per lab in LDG; CERN DG**
      - **Invitees: PPG, President of Council, 1 rep from each Associate Member State and Observer State, 1 rep from EC; chairs of ApPEC, NuPECC, ESFRI**
  - **Deadline for submission of contributions to the ESPP: March 2025**
  - **Symposium: end June 2025**
  - **Briefing Book: Sep 2025**
  - **Drafting session: Dec 2025 1-5 Dec 2025.**
  - **Final approval by CERN Council: June 2026**

ESPP: Some lessons learned from 2020 update

- **Last time: there was a round of receiving "national inputs"**
  - Responses varied widely:
    - For small(er) countries, feedback was ~uniform and easy to interpret.
    - For large(r) countries, feedback was non-uniform, often favoring multiple priorities (e.g. type of next collider)
  - Wide range of responses made it difficult to summarize the "opinion" or "position" of several countries
    - And clearly, this is not a popular vote
  - Lesson learned: while it will always be difficult to summarize the "position" of an entire country, at least we can aim at uniform responses
- **Plan for ECFA: facilitate wide discussion(s);**
  - Engage maximum number of colleagues, especially ECRs
  - Major component of overall input to ESPP: "national inputs", collected individually by the national community in each country (or groups of countries/region).
  - Formulated set of questions and issues for discussion by national
    - Clearly, not an exclusive list, countries/groups could/should add their own issues/concerns/wishes etc

Link to ECFA guidelines

ECFA guidelines for national inputs to the ESPP

- **Suggest two national ("town-hall" or similar) meetings (clearly, each country/region remains at liberty to decide on the number):**
  - **After contributions are in (end March 25) and before Open Symposium (end June 25)**
  - **After release of Briefing Book (end Sep 25)**
    - **National inputs to the ESPP update can be sent at different points in time:**
      - **Prior to the deadline of 31 March 2025 for the submission of input to the ESPP;**
      - **After March 2025 deadline and by 26 May, in time for Open Symposium;**
      - **After Briefing Book, by 14 Nov 2025, in time for ESPP Drafting Session.**
- **Central element of the next ESPP: the choice of next collider at CERN.**
  - **ESG remit: "The Strategy update should include the preferred option for the next collider at CERN and prioritised alternative options to be pursued if the chosen preferred plan turns out not to be feasible or competitive".**
    - **A set of questions on the preferred and alternative options for this "next collider at CERN", along with an explanation of any specific prioritisation.**
  - **Remit: "The Strategy update should also indicate areas of priority for exploration complementary to colliders and for other experiments to be considered at CERN and at other laboratories in Europe, as well as for participation in projects outside Europe."**

Link to ECFA guidelines

ECFA Early Career Researchers' (ECR) panel

- **Career Prospects and Diversity in Physics**
  - Launched survey to collect information on
    - Impact of collaboration size on ECRs?
    - Assess the career prospects of ECRs, how ECR panel help, what are the main problems?
  - Circulated to ECR community (760 responses!)
  - Analysis of answers: written report here.
- **ESPP update and ECR involvement; From ECFA to national communities**
  - Organize event with national, in-person events on future colliders, directing discussions into the ECFA countries as some issues are country-dependent
    → Blueprint ready on zenodo (link)
    - First events have already taken place

Example 1: Nordic event (May 14); Talks:
Physics Landscape and Motivation
Experimental overview of future colliders
Status and Physics of EIC
Report from ECFA ECR panel
Summary of activities in the Nordics
Panel Discussion

Example 2: Austria event (May 23)


EARLY CAREER RESEARCHERS IN PARTICLE PHYSICS IN AUSTRIA

THE LONG-TERM FUTURE OF PARTICLE PHYSICS IN EUROPE

The European strategy for Particle Physics will be updated early 2025, shaping the upcoming years for high energy physics. Since projects like the FCC will last for many years, inclusion and participation of PhDs and early postdocs is crucial. This meeting will contain talks from senior experts about current and future experiments, as well as discussion rounds to evaluate the view of the next generation of scientists. Additionally, alumnis will give insight on career opportunities in industry and academia.

23 May 2024, 10:00 to 17:00
Agenda and Registration: https://indico.cern.ch/event/1409061/
Registration requested but not mandatory

Austrian Representatives:
Maximilian Babeluk
Yannick Dengler
Andreas Gsponer

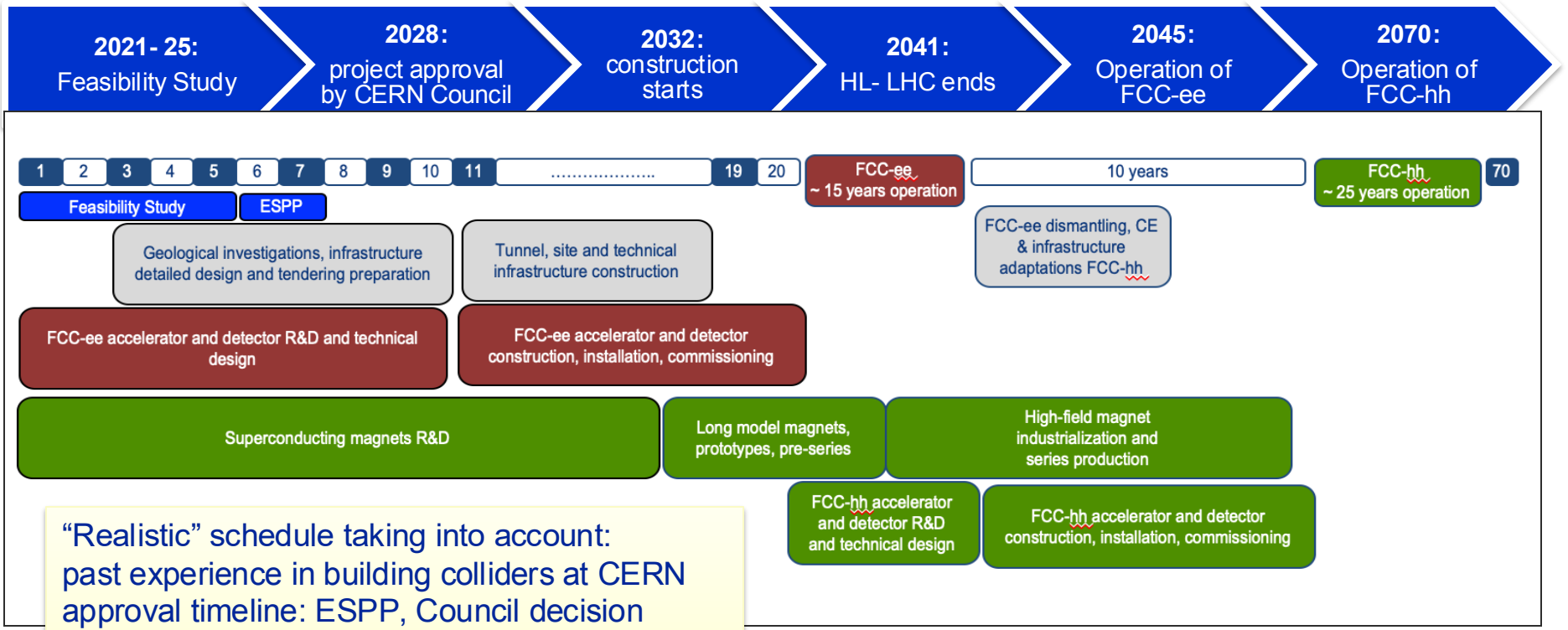
CERN
UNI GRAZ
HEPHY

Long-term future

A very brief summary of the FCC feasibility study

FCC integrated program - timeline

FCC Conceptual Design Study started in 2014 leading to CDR in 2018



"Realistic" schedule taking into account:
past experience in building colliders at CERN
approval timeline: ESPP, Council decision
that HL-LHC will run until 2041
Can be accelerated if more resources available

FCC Feasibility study: placement

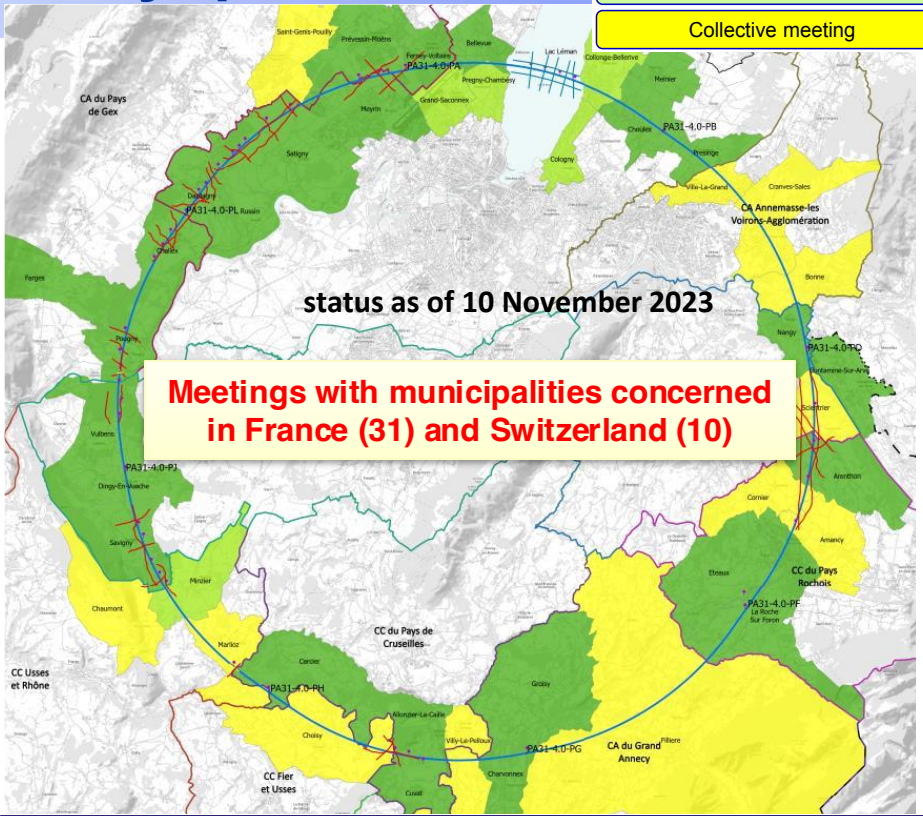
Individual meeting
Individual meeting planned
Collective meeting

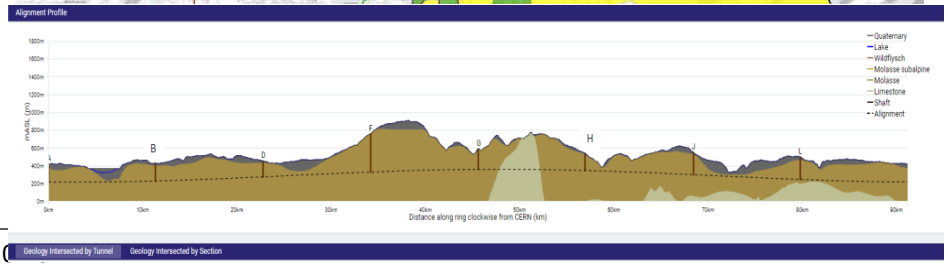
Site investigations in areas with uncertain geological conditions:

- Optimisation of localisation of drilling locations ongoing with site visits since end 2022.
- Alignment with FR and CH on the process for obtaining authorisation procedures.
- Ongoing for start of drillings in Q2/2024.

Sondage A89 (2007) incliné de 45° de 125 ml (surface plateforme estimée : 12 x 12 m soit environ 150 m²)

Drilling works on the lake





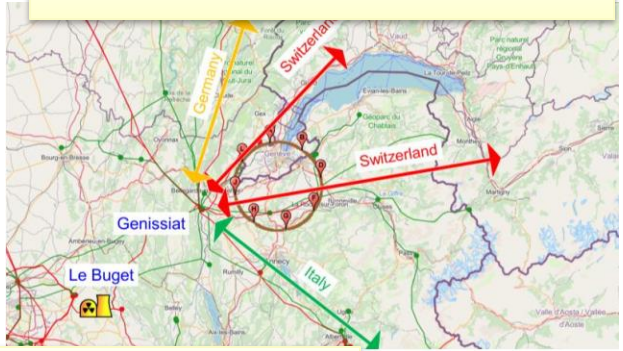
Tunnel implementation summary

- 91 km circumference
- 95% in molasse geology for minimising tunnel construction risks
- 8 surface sites with ~5 ha area each.

Tremendous amount of work on several fronts

Updated FCC-ee energy consumtion	Z	W	H	TT
Beam energy (GeV)	45.6	80	120	182.5
Max. Power during beam operation (MW)	222	247	273	357
Average power / year (MW)	122	138	152	202
Total FCC-ee yearly consumption (TWh)	**1.07**	**1.2**	**1.33**	**1.77**
Yearly consumption CERN & SPS (TWh)	0.70	0.70	0.70	0.70
Total yearly consumpt. CERN & SPS & FCC-ee (TWh)	**1.77**	**1.90**	**2.03**	**2.47**

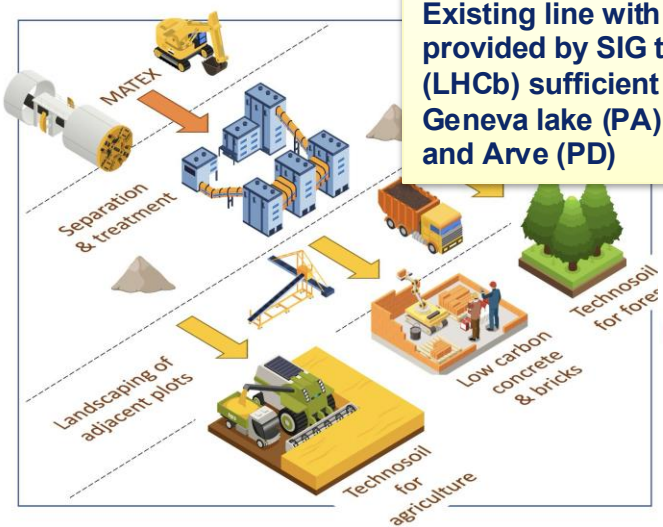
Connection to Electrical Grid



Excavated material FCC: 6.5 Mm^3 in situ, 8.4 Mm^3 excavated (bulk factor 1.3)

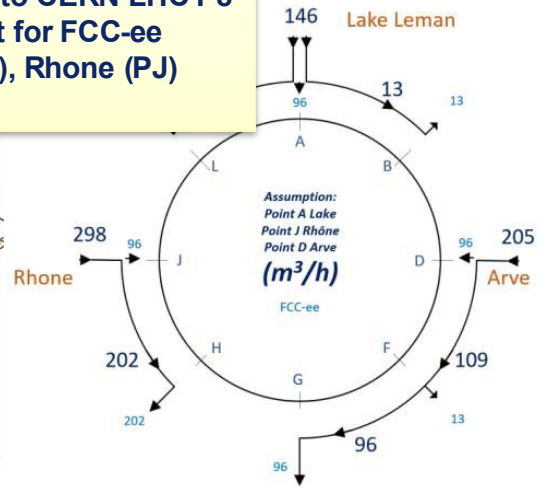
2021-2022: International competition "Mining the Future", (EU Horizon 2020 support): find innovative & realistic ideas for the reuse of Molasse (96% of excavated materials)

2023: "OpenSky Laboratory" project: Objective: Develop and test an innovative process to transform sterile "molasse" into fertile soil for agricultural use and afforestation.



Cooling Water

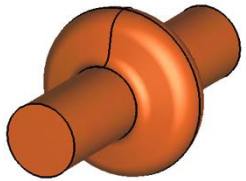
Existing line with lake water provided by SIG to CERN LHC P8 (LHCb) sufficient for FCC-ee Geneva lake (PA), Rhone (PJ) and Arve (PD)



FCC-ee baseline RF configuration so far

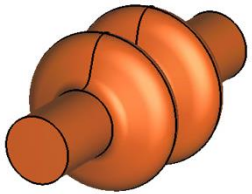
Z — **1-cell 400 MHz, Nb/Cu**

low R/Q, HOM damping, powered by 1 MW RF coupler and high efficiency klystron



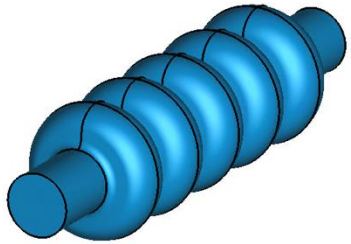
W, H — **2-cell 400 MHz, Nb/Cu**

moderate gradient and HOM damping requirements; 500 kW / cavity, allowing reuse of klystrons already installed for Z

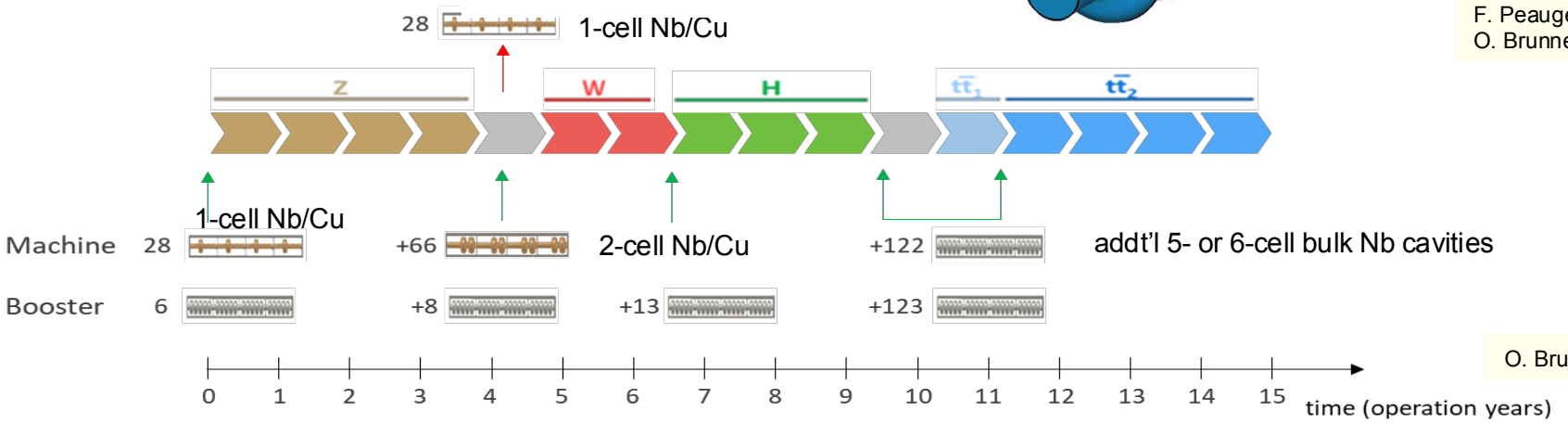


ttbar, booster — **5-cell 800 MHz, bulk Nb**

high RF voltage and limited footprint thanks to multicell cavities and higher RF frequency; 200 kW/ cavity



F. Peauger, O. Brunner



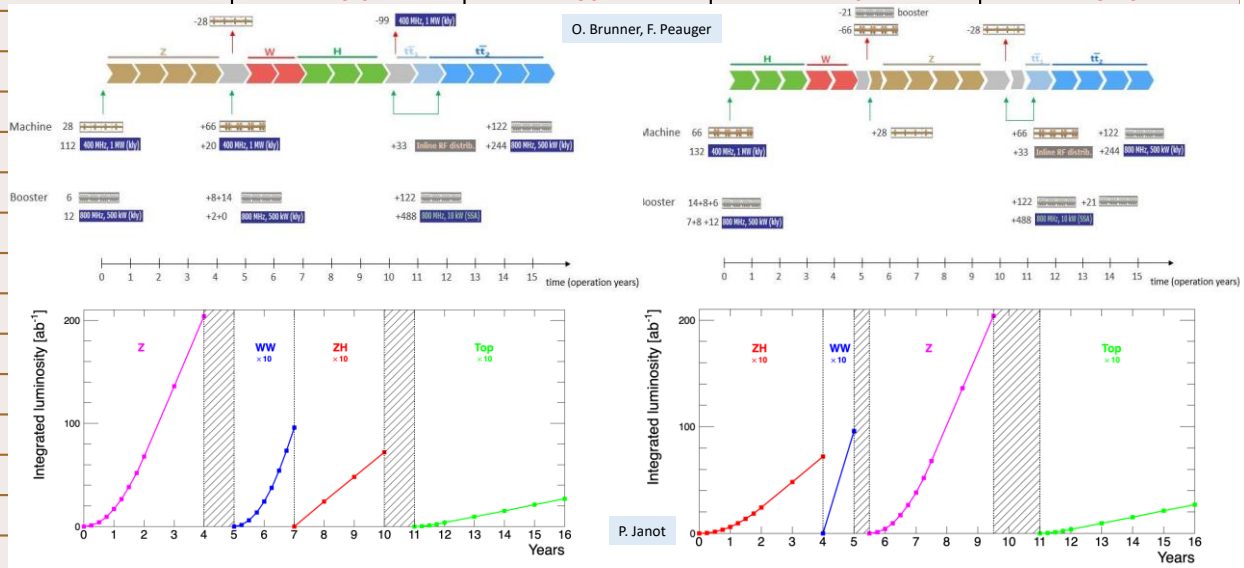
O. Brunner

Looking into two-cell RFs for ALL energies: Reverse phase operation (RPO)
→ higher RF cavity voltage *(Y. Morita et al., SRF, 2009)*

- **Experimentally verified** with high beam loading in KEKB *(Y. Morita et al., IPAC, 2010)*
- **Baseline solution for EIC ESR** *(e.g., J. Guo et al., IPAC, 2022)*

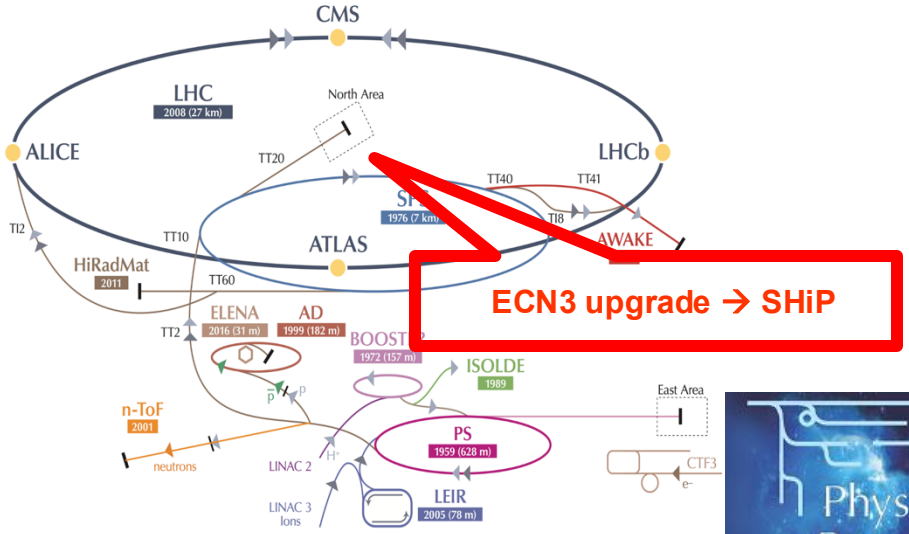
FCC-ee operation

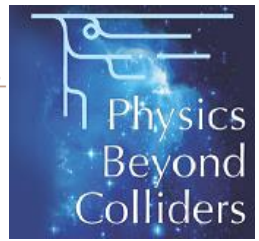
Parameter	Z	WW	H (ZH)	ttbar
beam energy [GeV]	45.6	80	120	182.5
beam current [mA]				
number bunches/beam				
bunch intensity [10^{11}]				
SR energy loss / turn [GeV]				
total RF voltage 400/800 MHz [GV]				
long. damping time [turns]				
horizontal beta* [m]				
vertical beta* [mm]				
horizontal geometric emittance [nm]				
vertical geom. emittance [pm]				
horizontal rms IP spot size [mm]				
vertical rms IP spot size [nm]				
beam-beam parameter x_x / x_y				
rms bunch length with SR / BS [mm]				
luminosity per IP [10^{34} cm^{-2}s^{-1}]	140	20	5.0	1.25
total integrated luminosity / IP / year [ab^{-1}/yr]	17	2.4	0.6	0.15
beam lifetime rad Bhabha + BS [min]	15	12	12	11



x 10-50 improvements on all EW observables
up to x 10 improvement on Higgs coupling (model-indep.) measurements over HL-LHC
x10 Belle II statistics for b, c, τ
indirect discovery potential up to ~ 70 TeV
direct discovery potential for feebly-interacting particles over 5-100 GeV mass range
Up to 4 interaction points ❼ robustness, statistics, possibility of specialised detectors

CERN Diversity Programme





Future of the diversity programme discussed in the Physics Beyond Collider study

Topics include:

- ❑ LHC injectors
- ❑ Low energy facilities
- ❑ High energy fixed target
- ❑ Opportunities gamma-factory
- ❑ Precision measurement and rare decays
- ❑ High energy beam dumps
- ❑ Low energy hidden sector (axions, EDM)
- ❑ QCD and Heavy Ion

AD Experiments: Antiproton Decelerator for antimatter studies

AWAKE: proton-induced plasma wakefield acceleration

CLOUD: impact of cosmic rays on aeorosols and clouds

COMPASS → AMBER: hadron structure and spectroscopy

ISOLDE: radioactive nuclei facility

NA61/SHINE: ions and neutrino targets

NA62: rare kaon decays

NA63: radiation processes in strong EM fields

NA64: search for dark photons

NA65: study of tau neutrino production

Neutrino Platform: ν detector R&D for experiments in the US, Japan

n-TOF: n-induced cross-sections

~20 projects with > 1200 scientists

Pseudo-summary

Pseudosummary/Outlook

- **The major particle physics countries have determined their path to the future**
  - **CN (CEPC), JP (ILC) and US (Off-shore Higgs factory)**
  - **It's now Europe's turn**

- **We expect the next ESPP to converge on a definite, unambiguous recommendation for the next big collider at CERN (flagship project)**
  - **National inputs will be a very important component of the process**
  - **PPG/physics groups to be approved by Council in Sep 2024. Organizational work begins right after**

- **Meanwhile, work is proceeding:**
  - **FCC feasibility report well enroute to March 2025 completion**
  - **DRD Collaborations up and running, enroute to MoUs**

- **First major step onto the long-term future: the HL-LHC.**