La stratégie européenne pour la physique des particules

une perspective sur les grands projets en HEP

Cristinel Diaconu

Centre de Physique des Particules de Marseille

ÉCOLE DE GIF 2025

Les futurs collisionneurs et leur physique

STRASBOURG 17 — 21 NOV.

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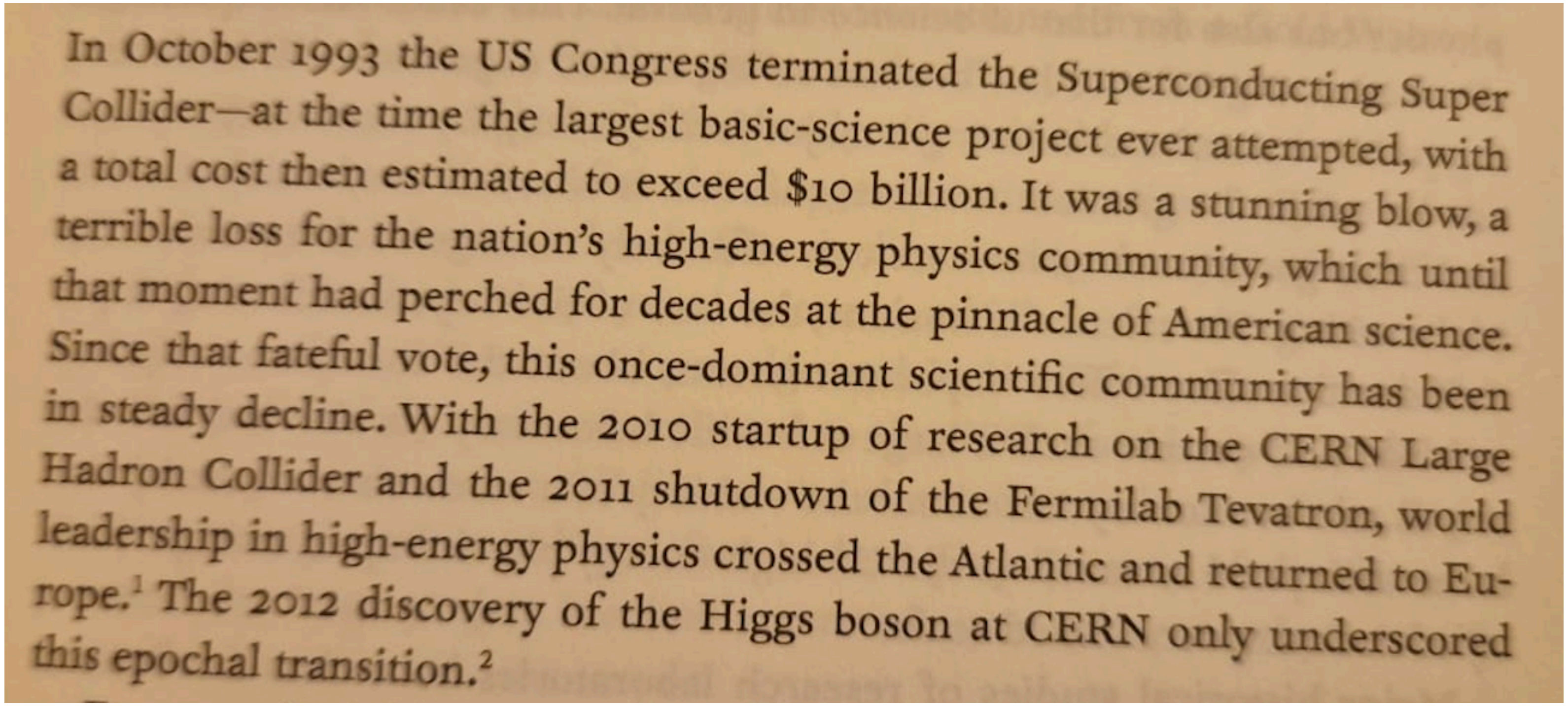
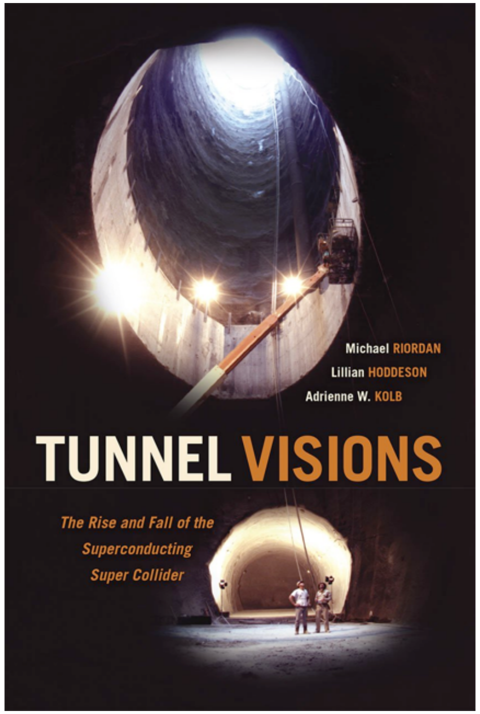
https://indico.in2p3.fr/event/36304

Preamble



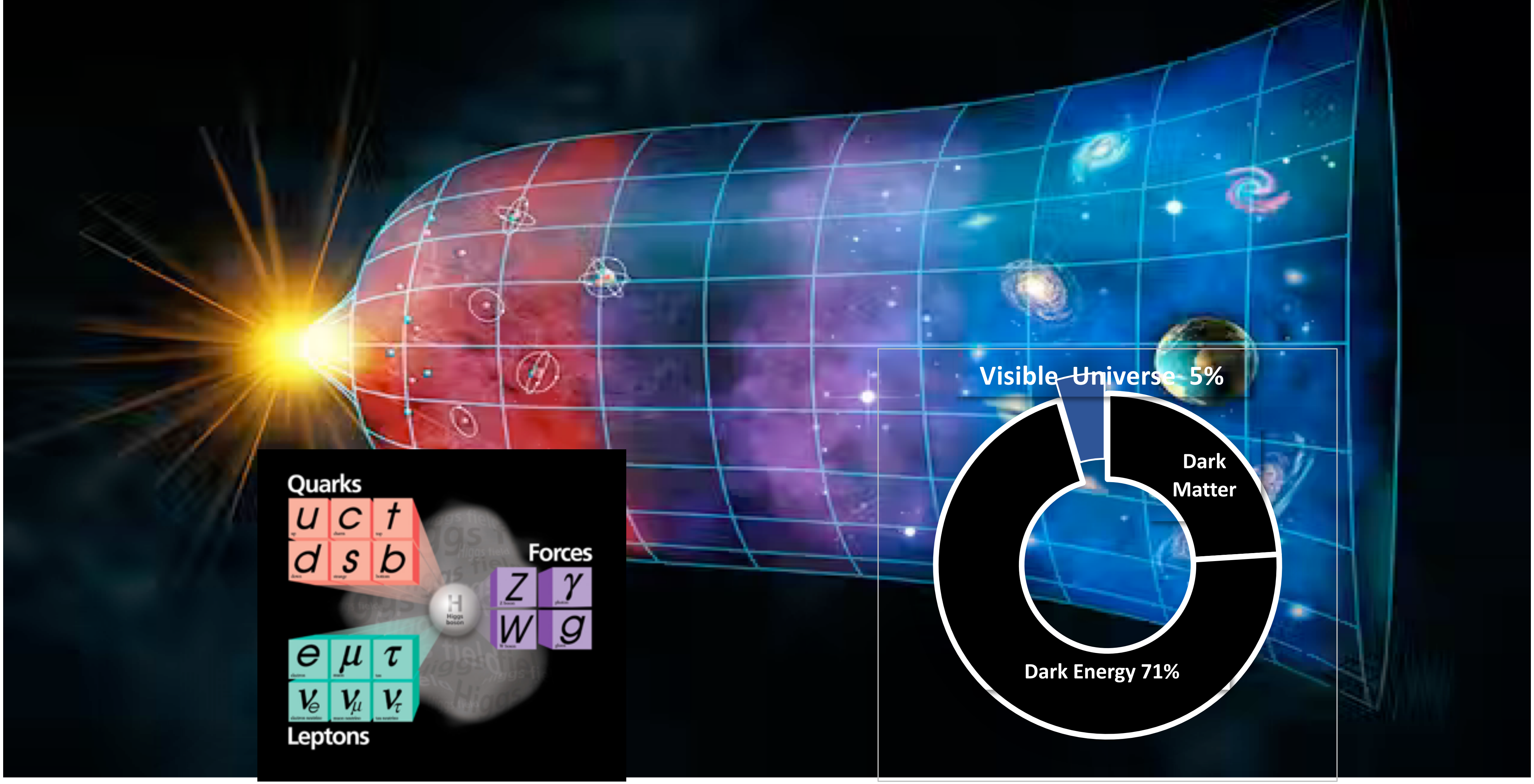
In October 1993 the US Congress terminated the Superconducting Super Collider—at the time the largest basic-science project ever attempted, with a total cost then estimated to exceed $10 billion. It was a stunning blow, a terrible loss for the nation's high-energy physics community, which until that moment had perched for decades at the pinnacle of American science. Since that fateful vote, this once-dominant scientific community has been in steady decline. With the 2010 startup of research on the CERN Large Hadron Collider and the 2011 shutdown of the Fermilab Tevatron, world leadership in high-energy physics crossed the Atlantic and returned to Europe.[1] The 2012 discovery of the Higgs boson at CERN only underscored this epochal transition.[2]



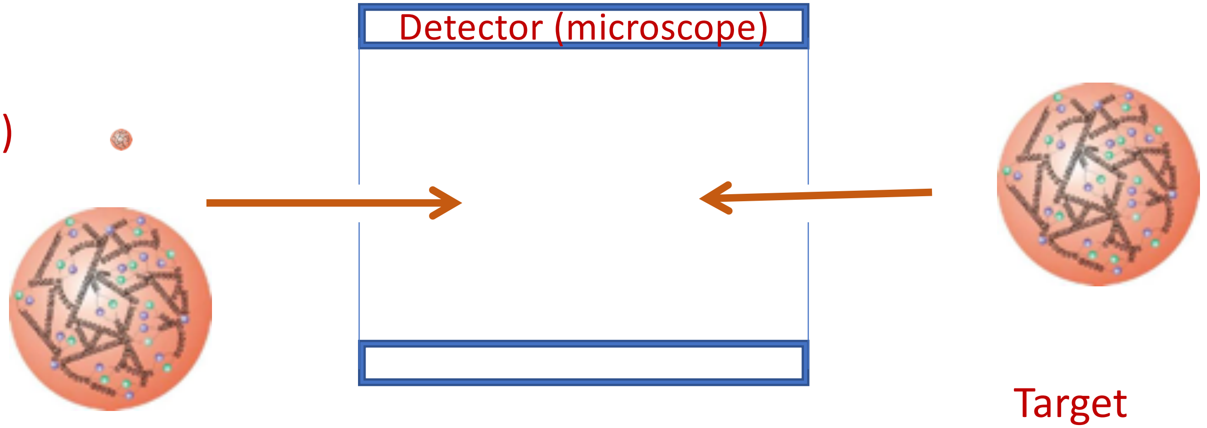
Content

- Building large projects in Particle Physics
- European Strategy in Particle Physics ESPP 2026 (and FR)
- Flagship projects feasibility
- Physics standpoint and projections
- Stairway to decision on future projects

The matter and the Universe



The “test tube” and the “microscope”

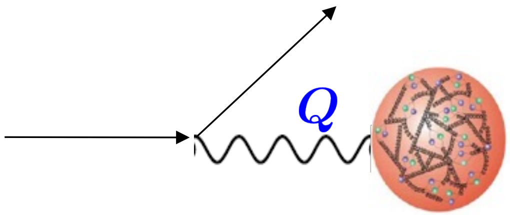


Probe (“observatory”)
or
Bang! (“experiment”)

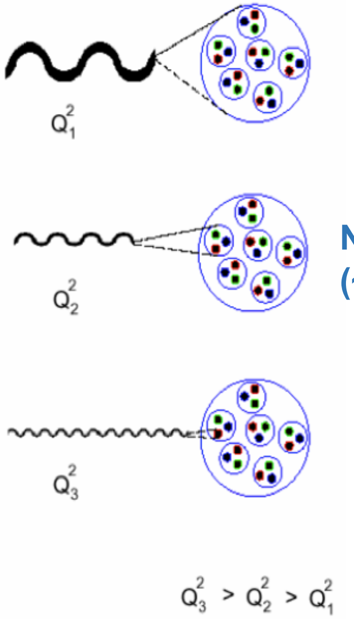
Detector (microscope)

Target

Deep into the matter…..



Precision ↔ Energy

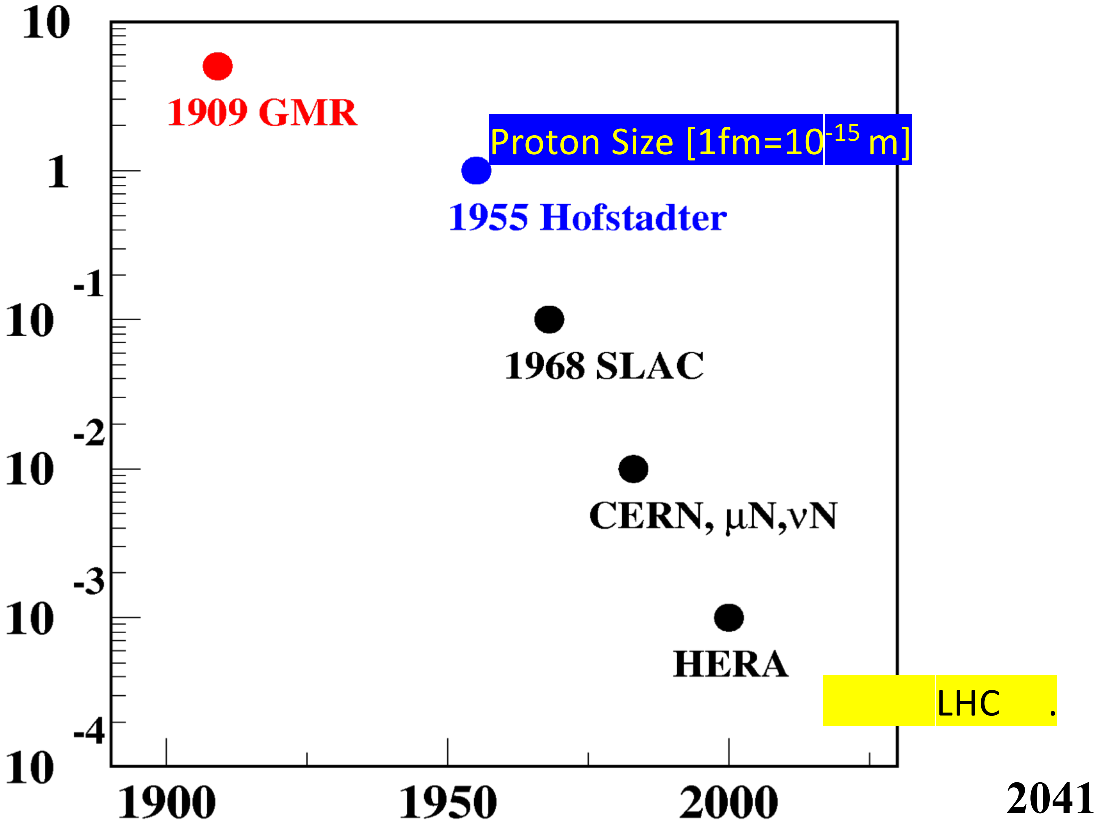


Nucleus (~1910)

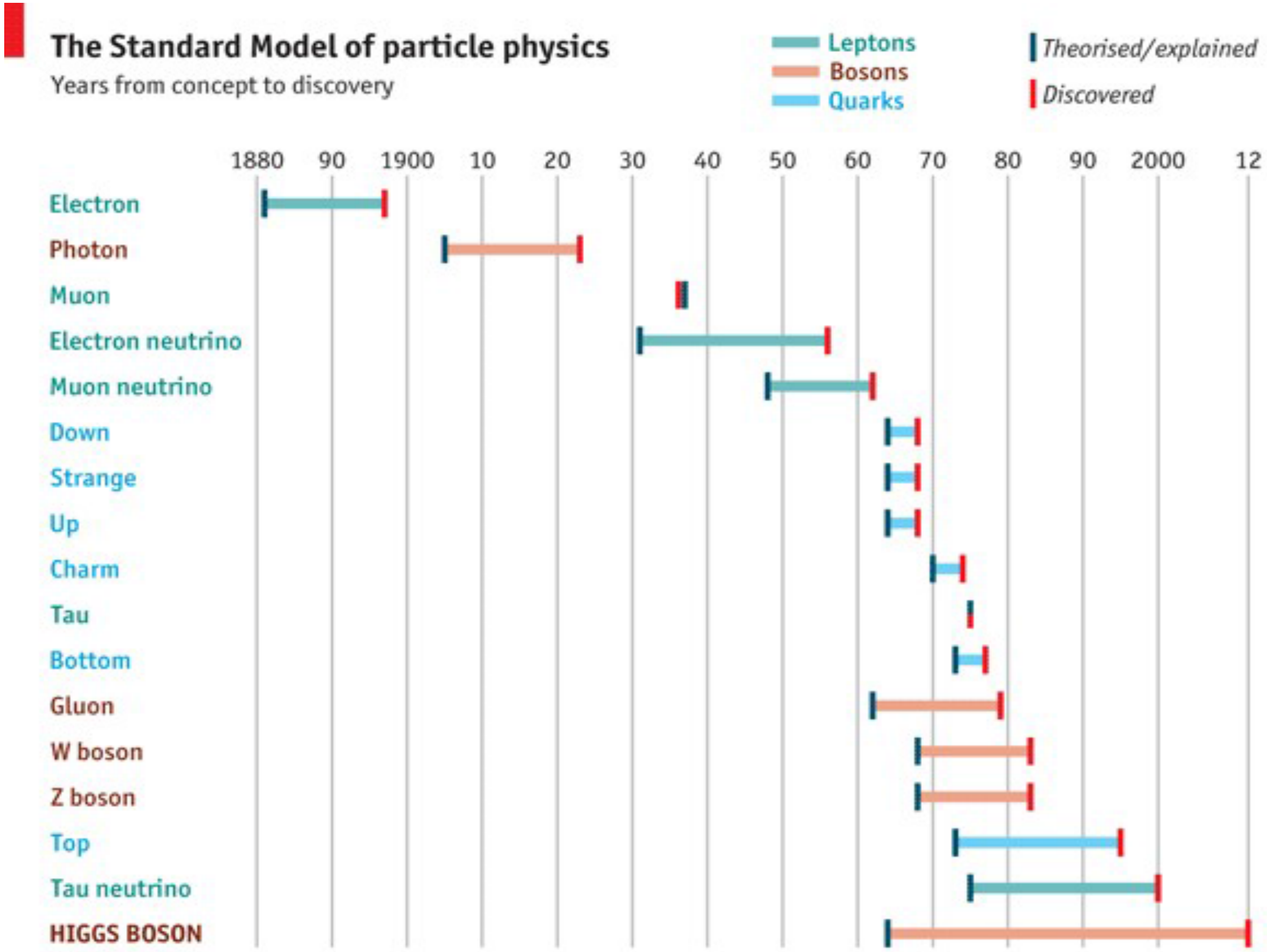
Nucleon (p,n) (~1950)

Quarks (~1970)

$$\delta\ [\mathrm{fm}] \simeq \frac{200\ \mathrm{MeV}}{Q}$$

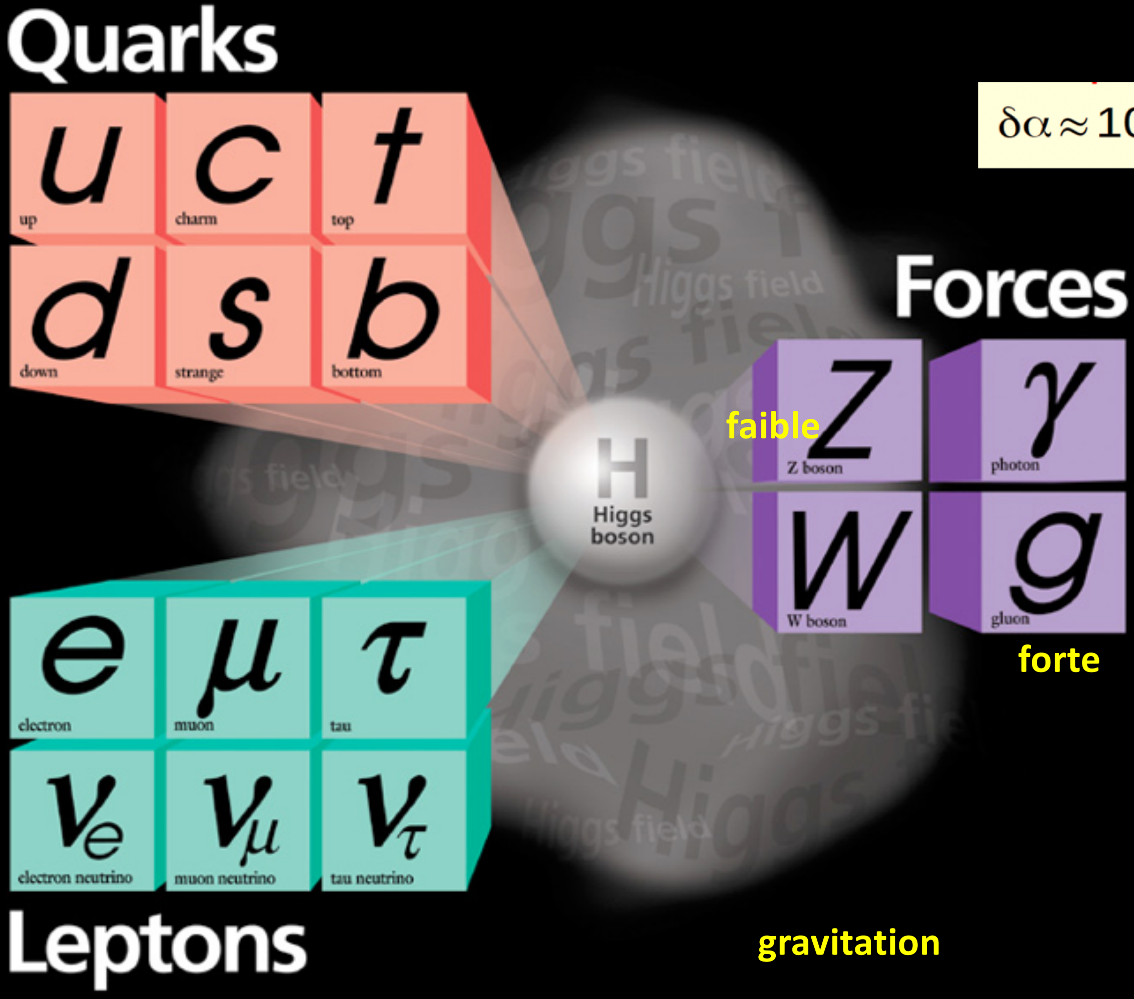


30 years of discoveries…..



Source: *The Economist*

Le modèle Standard



faible

Electro-magnetique

forte

gravitation

$$\delta\alpha \approx 10^{-10} \ll \delta G_F \approx 10^{-7} \ll \delta G \approx 10^{-5} \ll \delta\alpha_s \approx 10^{-3}$$

M(Z)= 91.1880±0.0020 GeV

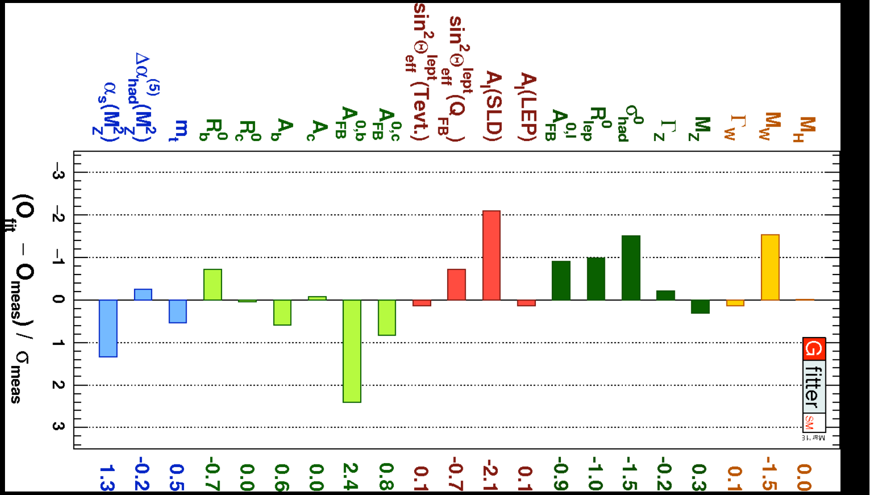
M(W)= 80.3692±0.0133 GeV

M(H)= 125.20±0.11 GeV

M(photon)<1×10^{-18} eV

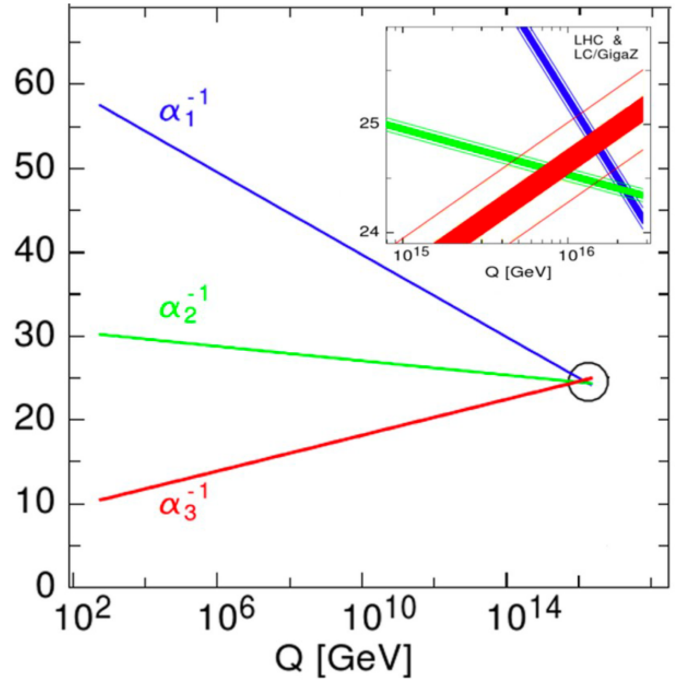
M(g)=0

Precision 10^{-3}-10^{-5}

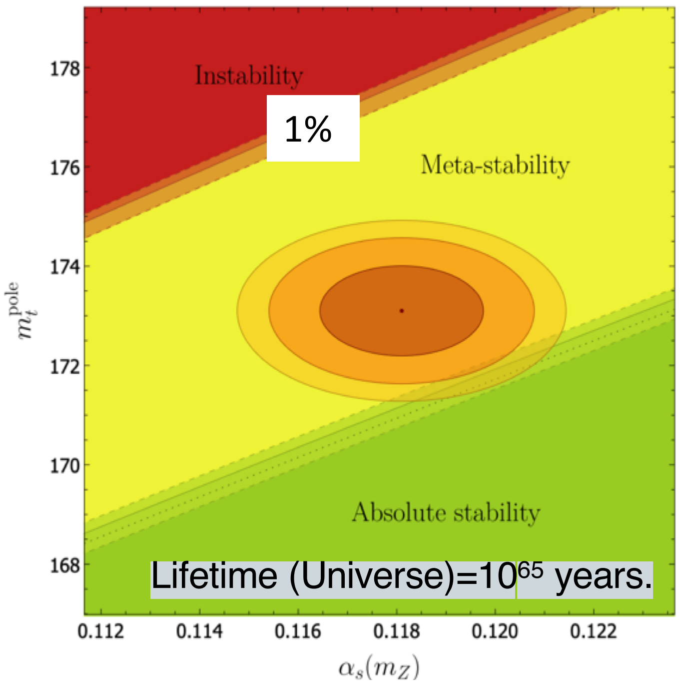


The implications

- Particle physics is at the forefront of the most fundamental questions in science



[hep-ph/0410364]



1%

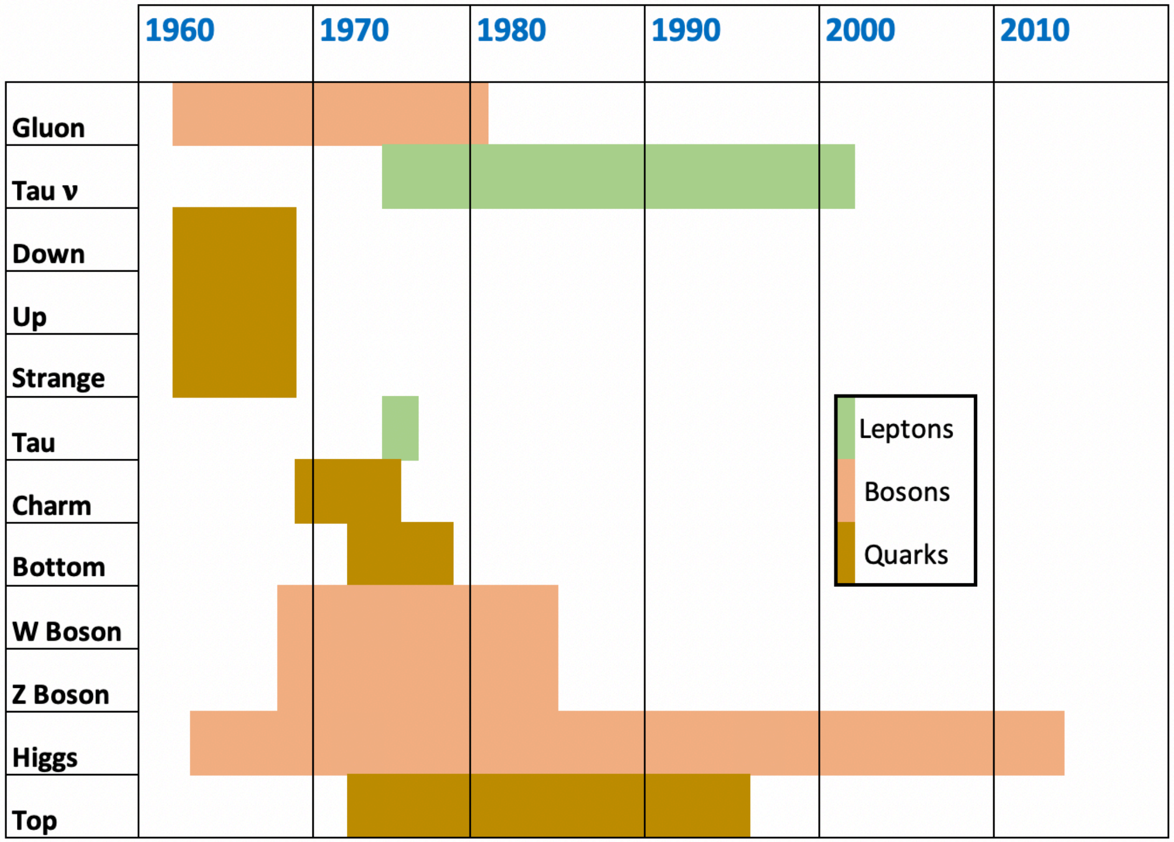
Lifetime (Universe)=10^{65} years.

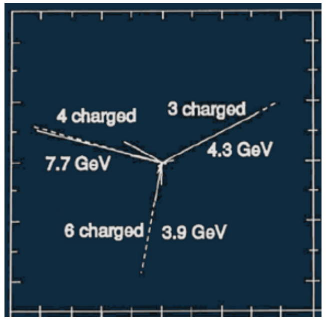
[arXiv:1707.08124]

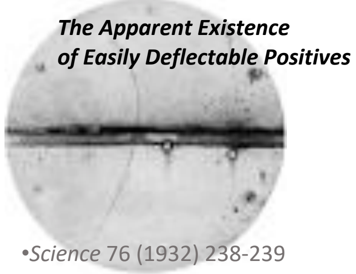
“To rule out absolute stability to 3sigma confidence
Mtop precision 250 MeV
$\boldsymbol{\alpha}_s(m_Z)$ precision below **0.00025**”

How to make a discovery: observe/confront

- The event signature

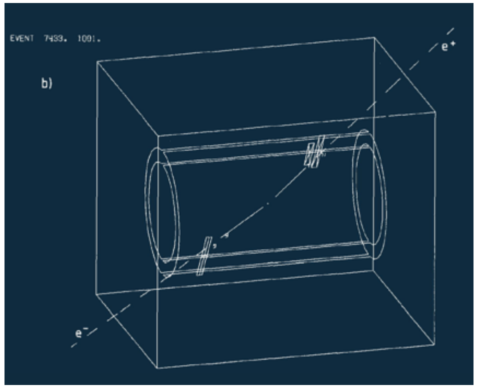




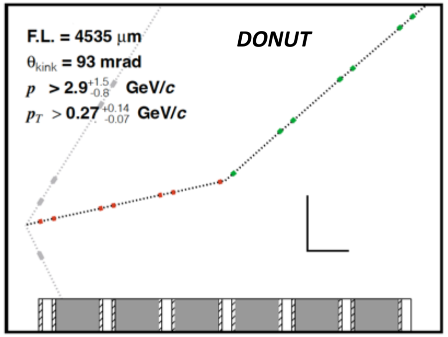


The Apparent Existence of Easily Deflectable Positives

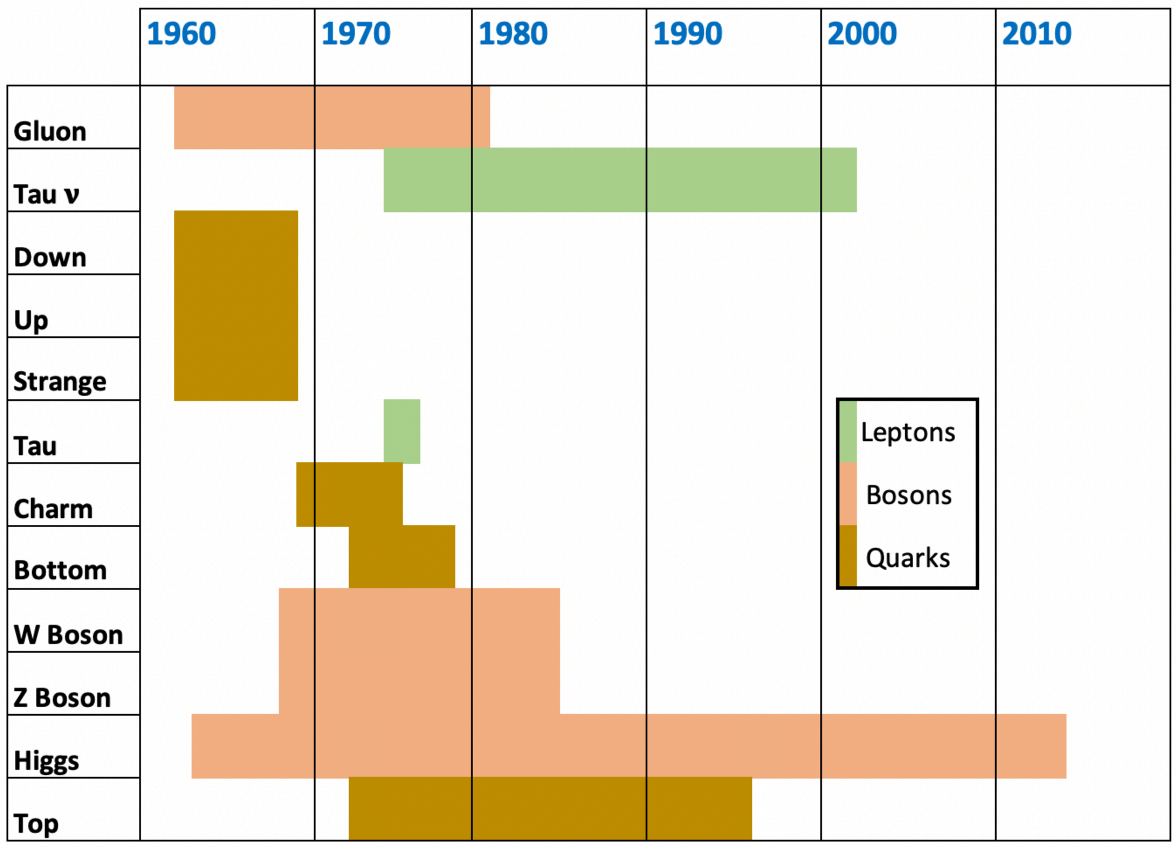
•*Science* 76 (1932) 238-239



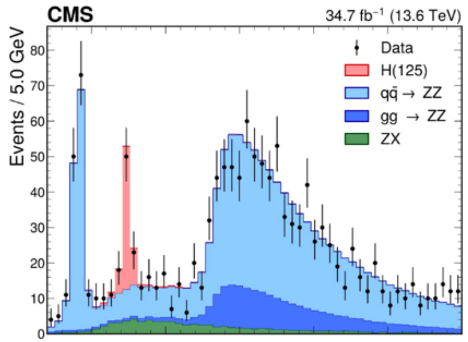
Phys.Lett.B 504 (2001) : hep-ex/0012035

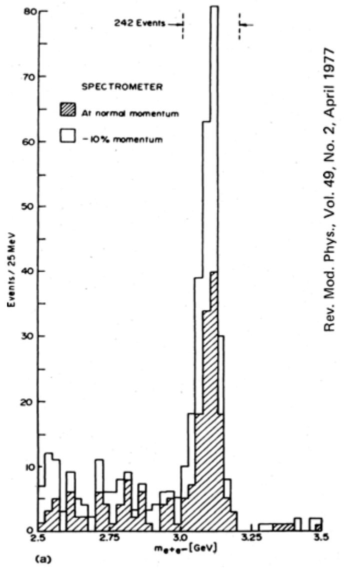


How to make a discovery: observe/confront

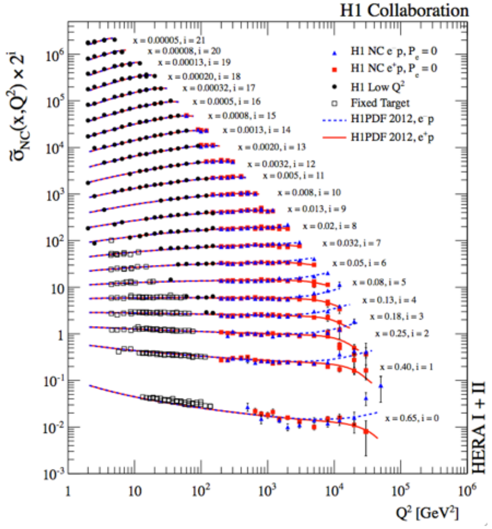


- The cross section
  - Resonance



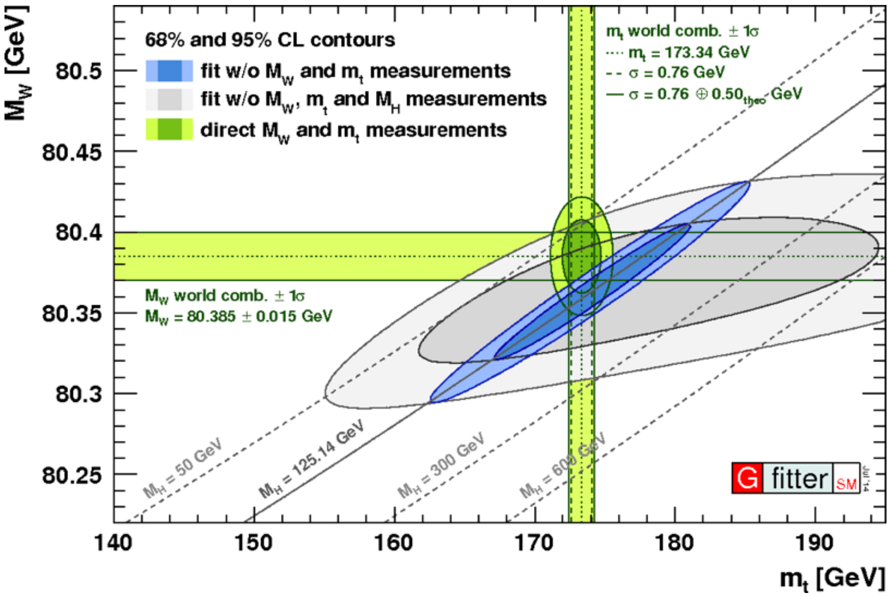


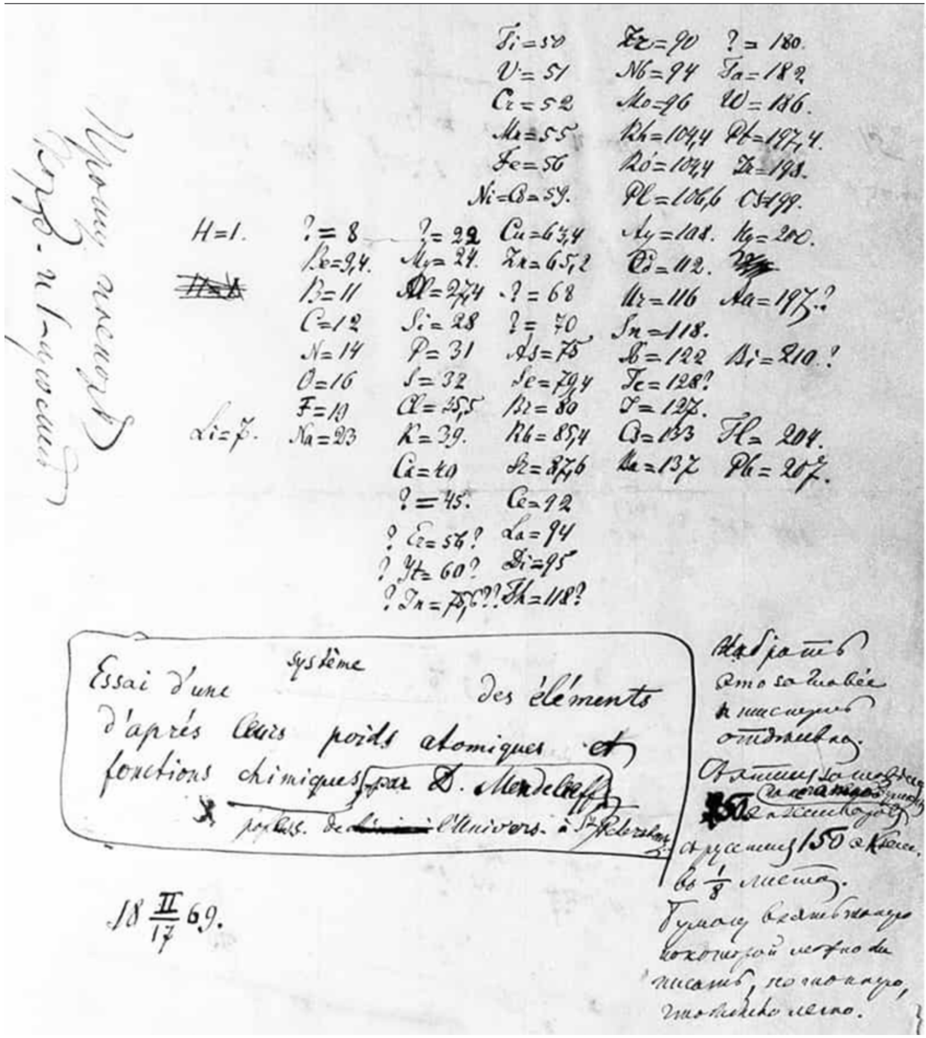
  - Shape



Precision leads to discovery

- Discrepancies and domain “mappings” are place holders for future discoveries
- Crosssing borders in precision and energy are equivalent





H=1.
~~H=1~~
Li=7.

?=8
Be=9,4.
B=11
C=12
N=14
O=16
F=19
Na=23

?=22
Mg=24.
Al=27,4
Si=28
P=31
S=32
Cl=35,5
K=39.
Ca=40
?=45.
? Er=56?
? Yt=60?
? In=75,6??

Ti=50
V=51
Cr=52
Mn=55
Fe=56
Ni=Co=59.
Cu=63,4
Zn=65,2
?=68
?=70
As=75
Se=79,4
Br=80
Rb=85,4
Sr=87,6
Ce=92
La=94
Di=95
Th=118?

Zr=90
Nb=94
Mo=96
Rh=104,4
Ru=104,4
Pl=106,6
Ag=108.
Cd=112.
Ur=116
Sn=118.
Sb=122
Te=128?
J=127.
Cs=133
Ba=137

?=180.
Ta=182
W=186.
Pt=197,4.
Ir=198.
Os=199.
Hg=200.
Au=197?
Bi=210?
Tl=204.
Pb=207.

Essai d'une système des éléments d'après leurs poids atomiques et fonctions chimiques par D. Mendeleeff professeur de l'Université à St Petersbourg

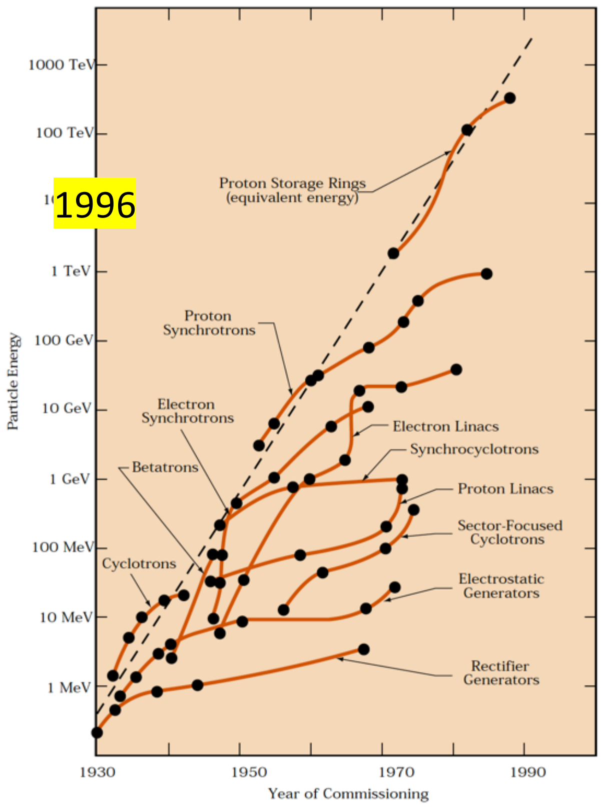
18 II/17 69.

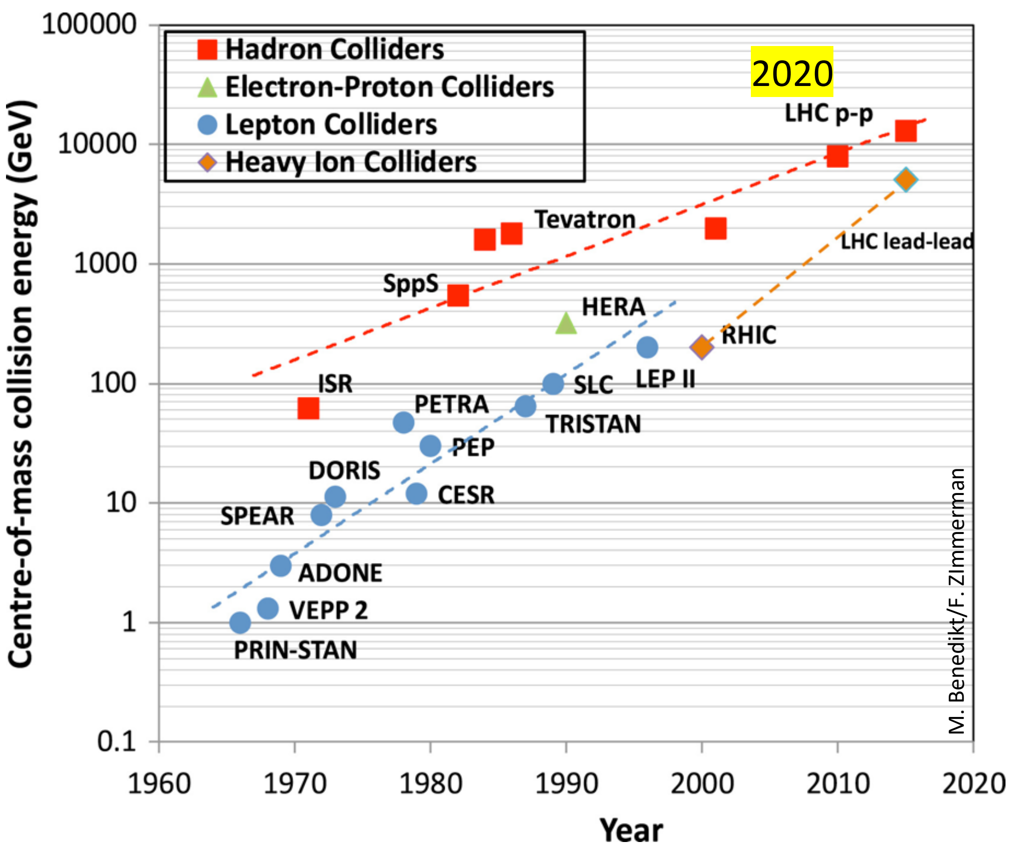
Physics World

Highest energy

Stanley Livingston first noted that advances in accelerator technology increase the energy records achieved by new machines by a factor of 10 every six years. (Panofsky, 1996)

http://www.slac.stanford.edu/pubs/beamline/27/1/27-1-panofsky.pdf





The future?

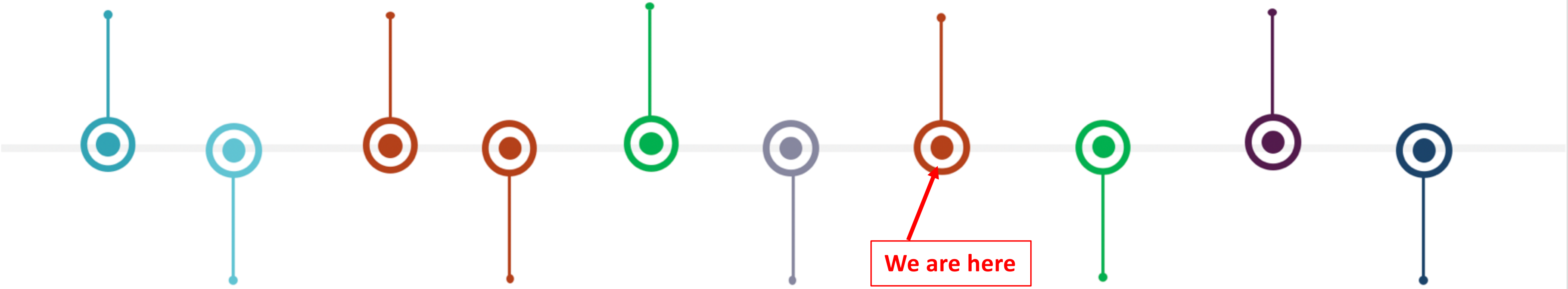
European Strategy for Particle Physics 2026

- *The aim of the Strategy Update should be to develop a **visionary and concrete plan** that greatly advances human knowledge in fundamental physics through the **realisation of the next flagship project at CERN**. This plan should attract and value **international collaboration** and should **allow Europe to continue to play a leading role in the field.”***
  - *The Strategy update should include the **preferred option for the next collider at CERN** (Plan A) and **prioritised alternative options** (Plan B) to be pursued if the chosen preferred plan turns out not to be feasible or competitive.*
  - *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.*

The European Strategy for Particle Physics **is not a project approval process**. Projects are approved by the CERN Council through a separate decision process, taking the Strategy recommendations into account.

- Original Strategy (2006):
  - LHC, mooting of luminosity upgrade of LHC, R&D in accelerator technologies, coordination with a potential ILC project
- 1st Update (2013):
  - High Luminosity LHC, need for a post-LHC programme
- 2nd Update (2020):
  - FCC feasibility study
- 3rd Update (2026) → recommendation for the next large-scale accelerator project at CERN (reach consensus on the preferred option and possible alternatives)

Timeline for the update of the European Strategy for Particle Physics



End September 2024
Council appointment of the members of the **PPG** and decision on the venue for the **Open Symposium**

December 2024
Council decision on the venue for the **ESG Strategy Drafting Session**

31 March 2025
Deadline for the submission of main input from the community

26 May 2025
Deadline for the submission of additional national input in advance of the **Open Symposium**

23-27 June 2025
Open Symposium
(in Venice)

End September 2025
Submission of the "Briefing Book" to the **ESG**

14 November 2025
Deadline for the submission of final national input in advance of the **ESG Strategy Drafting Session**

1-5 December 2025
ESG Strategy Drafting Session
(Monte Verita / Ascona, CH)

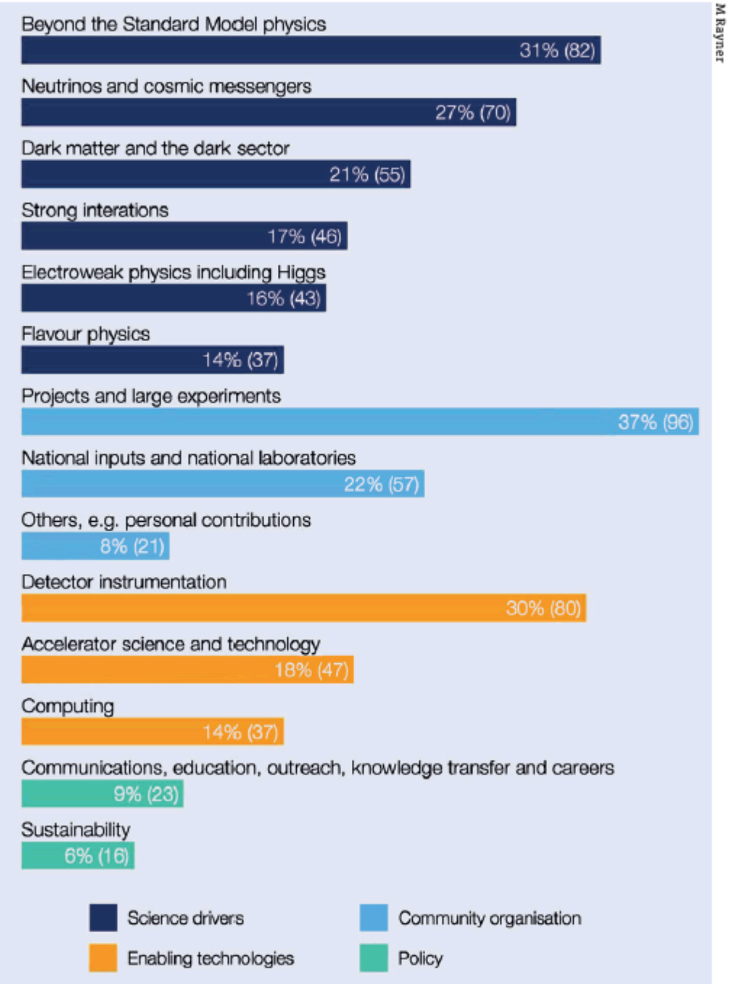
End January 2026
Submission of the draft strategy document to the Council

March and June 2026
Discussion of the draft strategy document by the Council and **updating of the Strategy**

More details on ESPP web page: https://europeanstrategyupdate.web.cern.ch/

The community input

- 266 contributions received
  - https://indico.cern.ch/event/1439855/contributions/
- These submissions are analysed by the
  - Physics Preparatory Group (PPG) and
  - European Strategy Group (ESG)
- Open Symposium Venice
  https://agenda.infn.it/event/44943/



M Rayner

Self-attributed themes of the 263 community inputs

The future accelerator/collider projects submitted

- Important scientific ingredients
  - Initial state
  - Energy
  - Intensity/luminosity
  - Experimental precision
  - Theoretical precision/understanding
  - ….
- Other ingredients
  - Community
  - Funding
  - Societal and envioronmental impact
  - ….
- The “lab” is well equiped!
  - $E_{process}$ ~ GeV ➔ 50 TeV
  - ~6 orders of magnitude

“Probe”

“Target”

	e				
e	Belle II, FCCee, CEPC, STCF, LCF,LEP3	**mu**			
mu	MUonE	mu-coll	**nu**		
nu			Mu-coll	**p**	
p	EIC, LHeC			LHC,FCChh	**A**
A	EIC, LHeC	FPF	FPF	LHC,FCChh	LHC, SPS,FCChh, FAIR

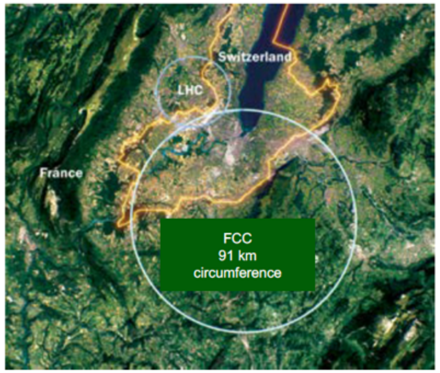
The future is new ideas:

Precision and energy frontier explorers

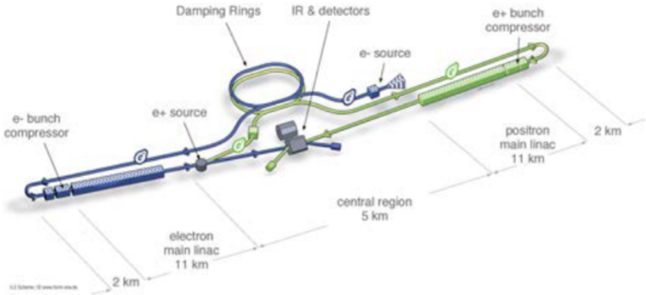
Remember Livingstone: LEP 2: 209 GeV in year 2000.

e^+e^- colliders
("Higgs factories")

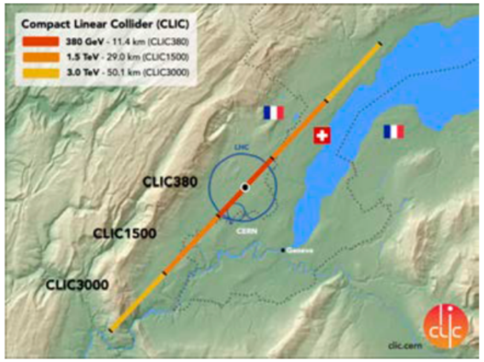
FCC-ee (e^+e^-, circular, 91 – 365 GeV)



LCF (e^+e^-, linear, 91 – 240, 550 GeV)



CLIC (e^+e^-, linear, 380 GeV, 1.5 TeV)

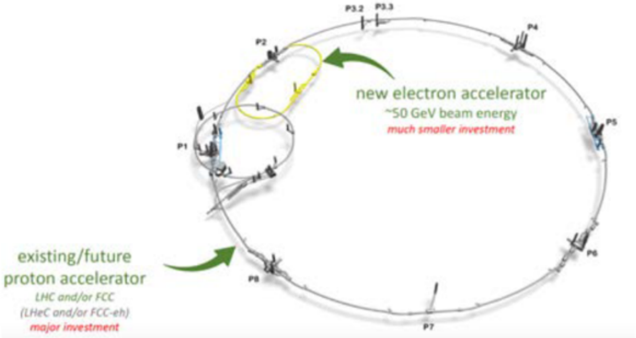


Intermediate projects

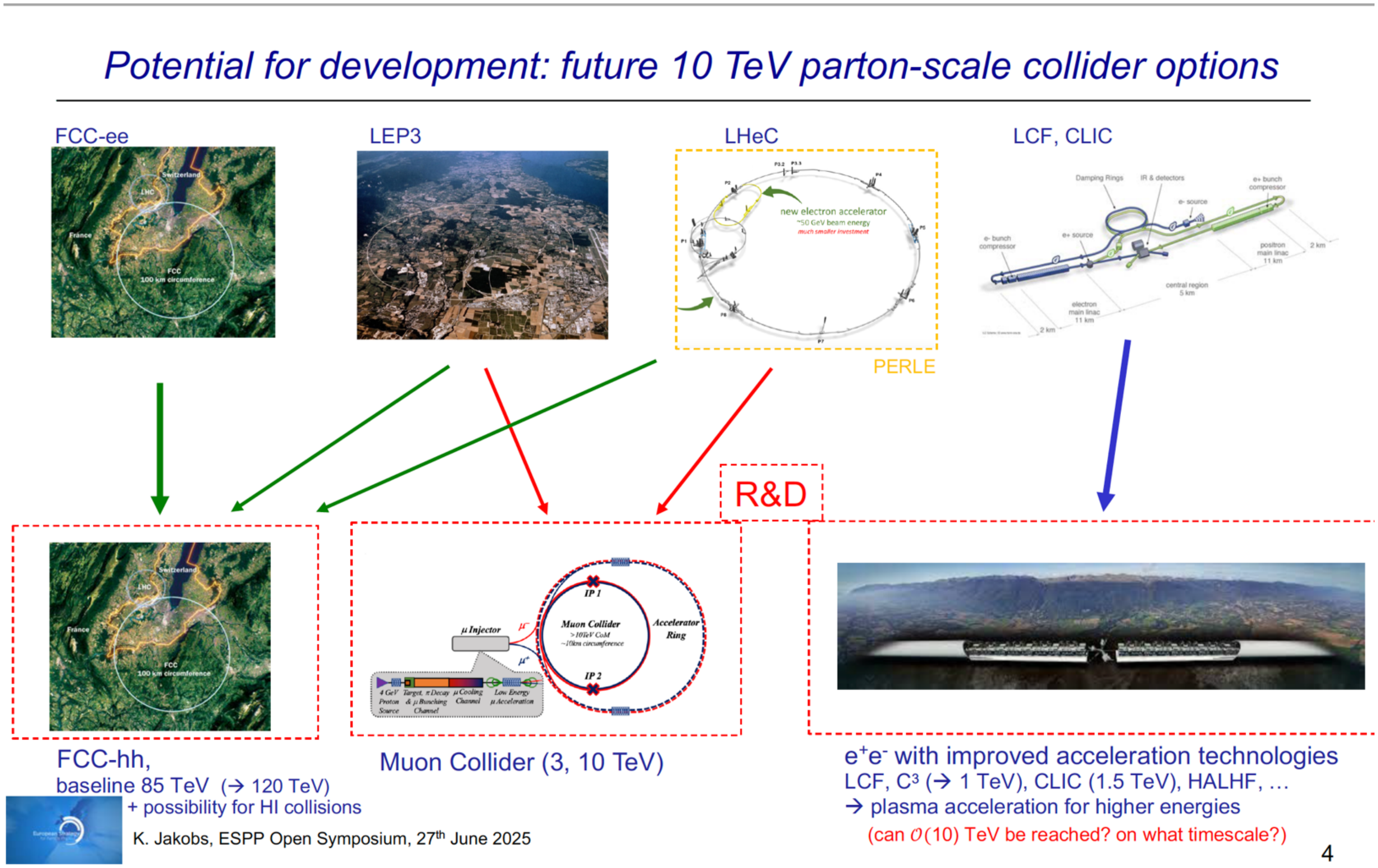
(Leave room (time, budget, resources) for further development of THE machine that can probe directly the energy frontier at the 10 TeV parton scale)

LEP3 (e^+e^-, circular, 91 – 230 GeV)

LHeC (ep, circular, electron ERL, 50 GeV e^-, > 1 TeV ep collisions)



K. Jakobs, ESPP Open Symposium, 27th June 2025



Potential for development: future 10 TeV parton-scale collider options

FCC-ee

LEP3

LHeC

LCF, CLIC

PERLE

R&D

FCC-hh,
baseline 85 TeV (→ 120 TeV)
+ possibility for HI collisions

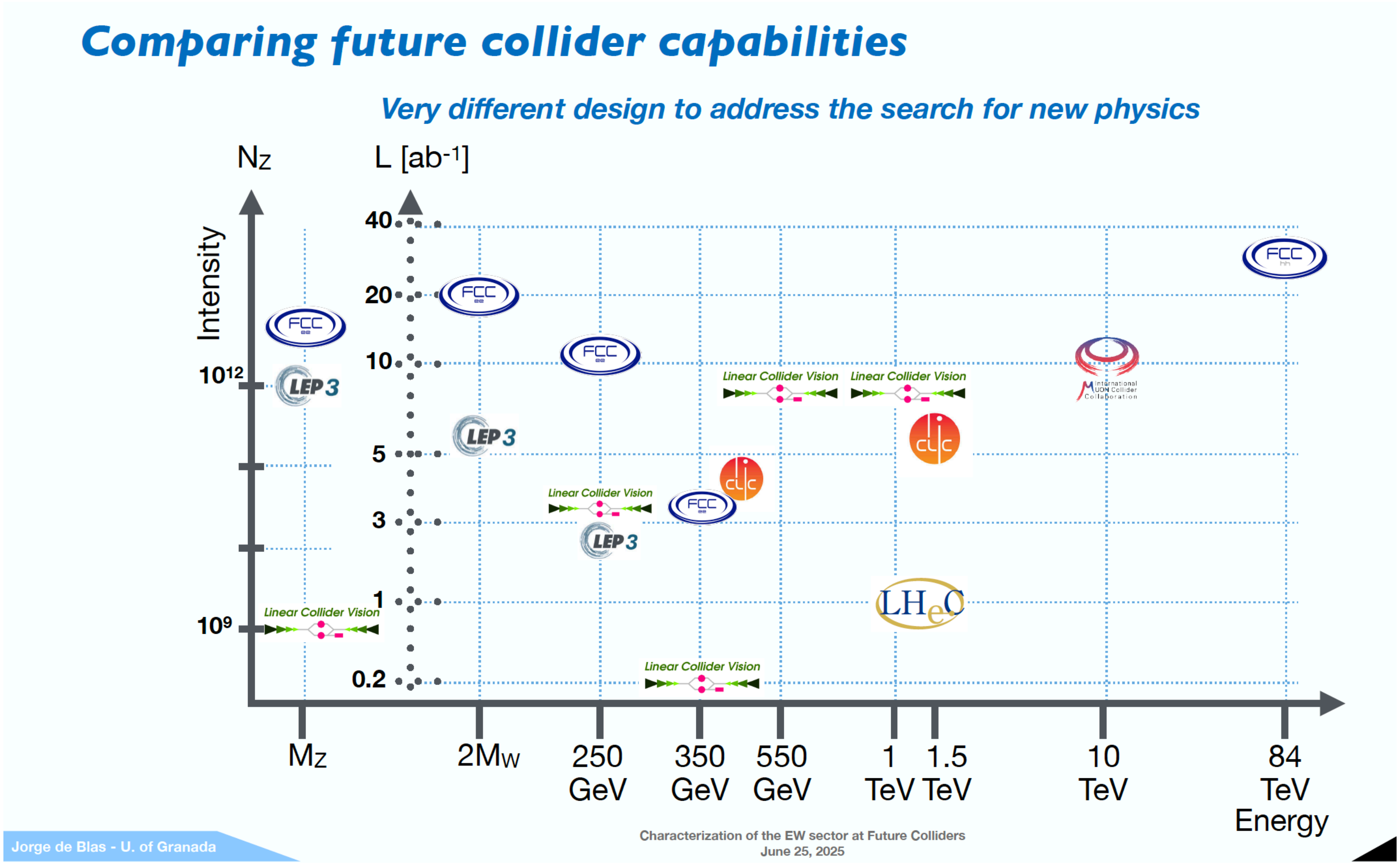
Muon Collider (3, 10 TeV)

e$^+$e$^-$ with improved acceleration technologies
LCF, C³ (→ 1 TeV), CLIC (1.5 TeV), HALHF, …
→ plasma acceleration for higher energies
(can $\mathcal{O}$(10) TeV be reached? on what timescale?)

K. Jakobs, ESPP Open Symposium, 27th June 2025

4

Remember Livingstone: LHC: 13,6 TeV in year ~2010.



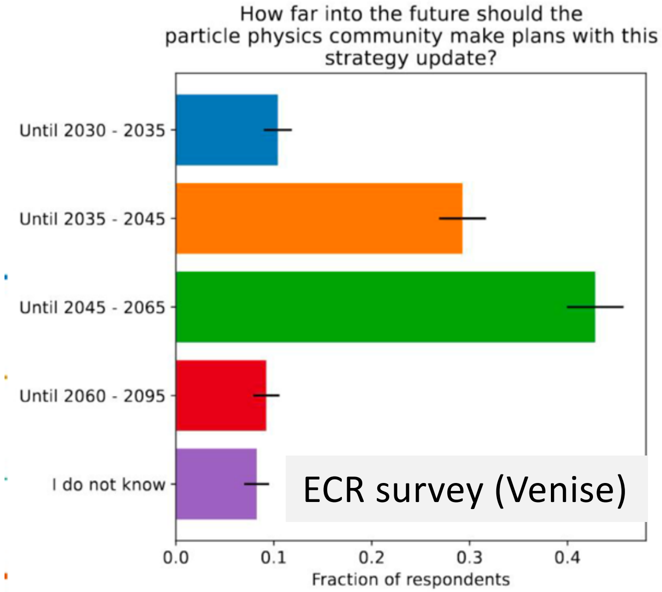
Comparing future collider capabilities

Very different design to address the search for new physics

Jorge de Blas - U. of Granada

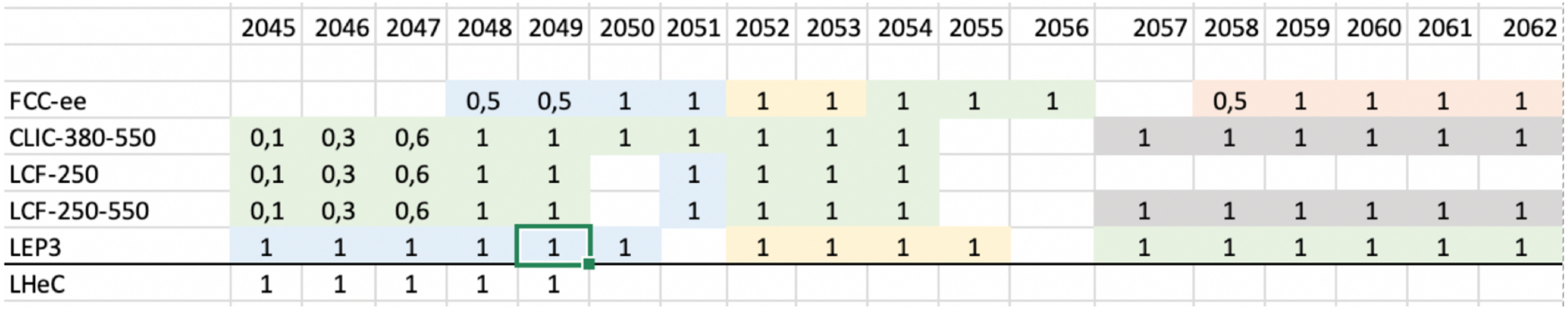
Characterization of the EW sector at Future Colliders
June 25, 2025

Running for 1st generation projects



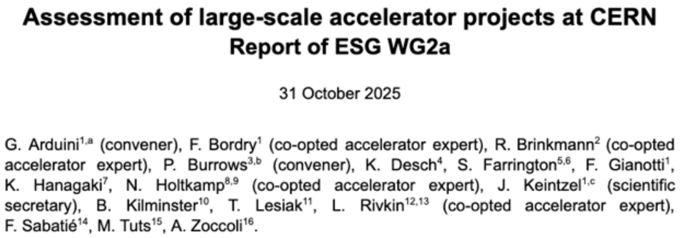
- Our community (you!) plans multiple projects for the next 40 years

Z peak
WW
ZH
tt
550 GeV



	2045	2046	2047	2048	2049	2050	2051	2052	2053	2054	2055	2056	2057	2058	2059	2060	2061	2062
FCC-ee				0,5	0,5	1	1	1	1	1	1	1		0,5	1	1	1	1
CLIC-380-550	0,1	0,3	0,6	1	1	1	1	1	1	1			1	1	1	1	1	1
LCF-250	0,1	0,3	0,6	1	1		1	1	1	1								
LCF-250-550	0,1	0,3	0,6	1	1		1	1	1	1			1	1	1	1	1	1
LEP3	1	1	1	1	1	1		1	1	1	1		1	1	1	1	1	1
LHeC	1	1	1	1	1													

The future

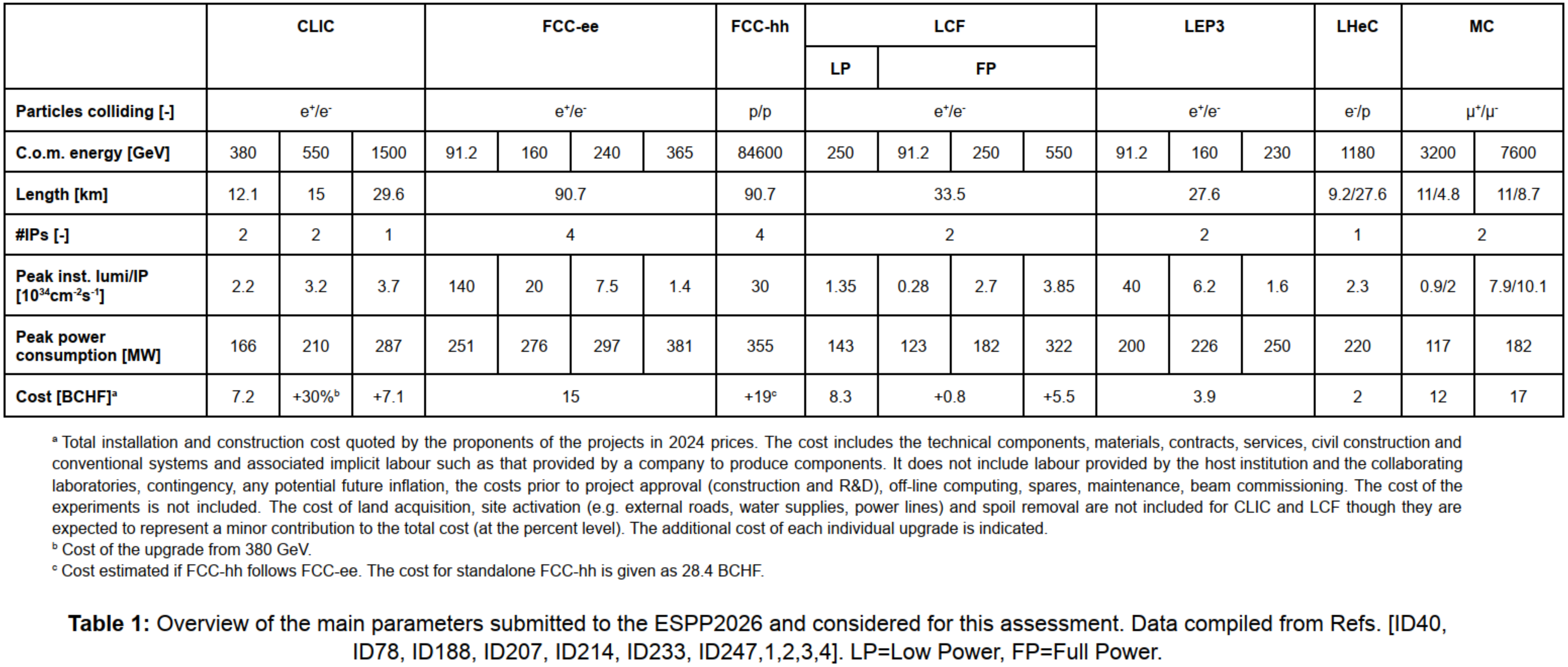


Assessment of large-scale accelerator projects at CERN
Report of ESG WG2a

31 October 2025

G. Arduini[1,a] (convener), F. Bordry[1] (co-opted accelerator expert), R. Brinkmann[2] (co-opted accelerator expert), P. Burrows[3,b] (convener), K. Desch[4], S. Farrington[5,6], F. Gianotti[1], K. Hanagaki[7], N. Holtkamp[8,9] (co-opted accelerator expert), J. Keintzel[1,c] (scientific secretary), B. Kilminster[10], T. Lesiak[11], L. Rivkin[12,13] (co-opted accelerator expert), F. Sabatié[14], M. Tuts[15], A. Zoccoli[16].

https://cds.cern.ch/record/2947728.



	CLIC			**FCC-ee**				**FCC-hh**	**LCF**				**LEP3**			**LHeC**	**MC**	
									LP	**FP**								
Particles colliding [-]	e^+/e^-			e^+/e^-				p/p	e^+/e^-				e^+/e^-			e^-/p	μ^+/μ^-	
C.o.m. energy [GeV]	380	550	1500	91.2	160	240	365	84600	250	91.2	250	550	91.2	160	230	1180	3200	7600
Length [km]	12.1	15	29.6	90.7				90.7	33.5				27.6			9.2/27.6	11/4.8	11/8.7
#IPs [-]	2	2	1	4				4	2				2			1	2	
Peak inst. lumi/IP $[10^{34}cm^{-2}s^{-1}]$	2.2	3.2	3.7	140	20	7.5	1.4	30	1.35	0.28	2.7	3.85	40	6.2	1.6	2.3	0.9/2	7.9/10.1
Peak power consumption [MW]	166	210	287	251	276	297	381	355	143	123	182	322	200	226	250	220	117	182
Cost [BCHF][a]	7.2	+30%[b]	+7.1	15				+19[c]	8.3	+0.8		+5.5	3.9			2	12	17

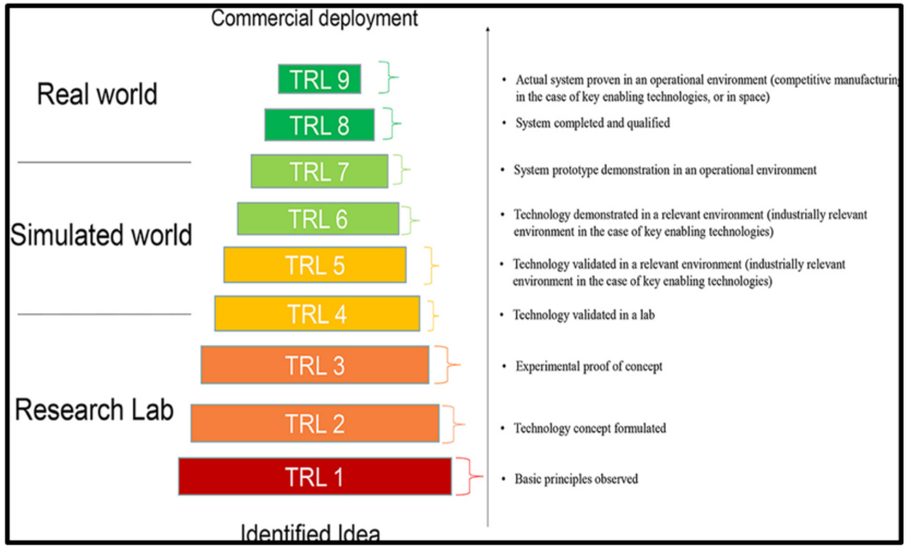
[a] Total installation and construction cost quoted by the proponents of the projects in 2024 prices. The cost includes the technical components, materials, contracts, services, civil construction and conventional systems and associated implicit labour such as that provided by a company to produce components. It does not include labour provided by the host institution and the collaborating laboratories, contingency, any potential future inflation, the costs prior to project approval (construction and R&D), off-line computing, spares, maintenance, beam commissioning. The cost of the experiments is not included. The cost of land acquisition, site activation (e.g. external roads, water supplies, power lines) and spoil removal are not included for CLIC and LCF though they are expected to represent a minor contribution to the total cost (at the percent level). The additional cost of each individual upgrade is indicated.

[b] Cost of the upgrade from 380 GeV.

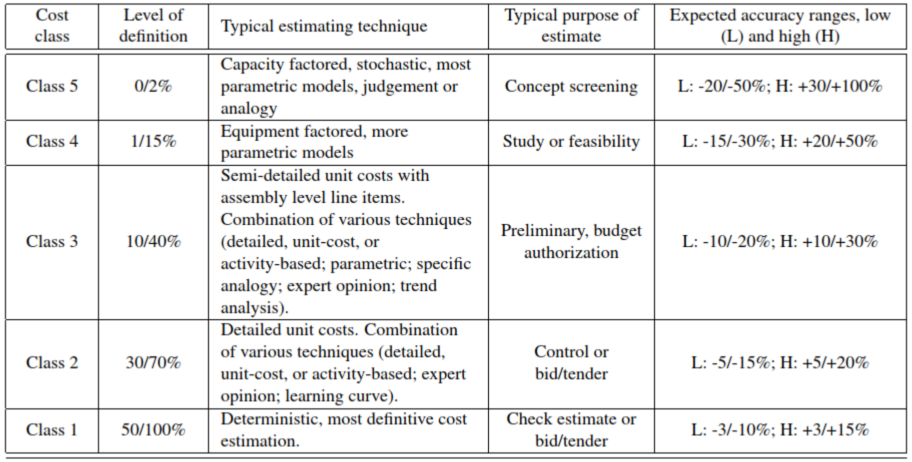
[c] Cost estimated if FCC-hh follows FCC-ee. The cost for standalone FCC-hh is given as 28.4 BCHF.

Table 1: Overview of the main parameters submitted to the ESPP2026 and considered for this assessment. Data compiled from Refs. [ID40, ID78, ID188, ID207, ID214, ID233, ID247,1,2,3,4]. LP=Low Power, FP=Full Power.

Examples of criteriafor accelerator readiness



- Actual system proven in an operational environment (competitive manufacturin in the case of key enabling technologies, or in space)
- System completed and qualified
- System prototype demonstration in an operational environment
- Technology demonstrated in a relevant environment (industrially relevant environment in the case of key enabling technologies)
- Technology validated in a relevant environment (industrially relevant environment in the case of key enabling technologies)
- Technology validated in a lab
- Experimental proof of concept
- Technology concept formulated
- Basic principles observed



Cost class	Level of definition	Typical estimating technique	Typical purpose of estimate	Expected accuracy ranges, low (L) and high (H)
Class 5	0/2%	Capacity factored, stochastic, most parametric models, judgement or analogy	Concept screening	L: -20/-50%; H: +30/+100%
Class 4	1/15%	Equipment factored, more parametric models	Study or feasibility	L: -15/-30%; H: +20/+50%
Class 3	10/40%	Semi-detailed unit costs with assembly level line items. Combination of various techniques (detailed, unit-cost, or activity-based; parametric; specific analogy; expert opinion; trend analysis).	Preliminary, budget authorization	L: -10/-20%; H: +10/+30%
Class 2	30/70%	Detailed unit costs. Combination of various techniques (detailed, unit-cost, or activity-based; expert opinion; learning curve).	Control or bid/tender	L: -5/-15%; H: +5/+20%
Class 1	50/100%	Deterministic, most definitive cost estimation.	Check estimate or bid/tender	L: -3/-10%; H: +3/+15%

- Projects’ assessment based on:
- Scope level-of-definition
- Technical Readiness Level of major sub-systems
- R&D
- Test facilities/demonstrators
- Performance uncertainty
- Site preparation status
- Schedule uncertainty
- Cost uncertainty
- Risk level-of-definition

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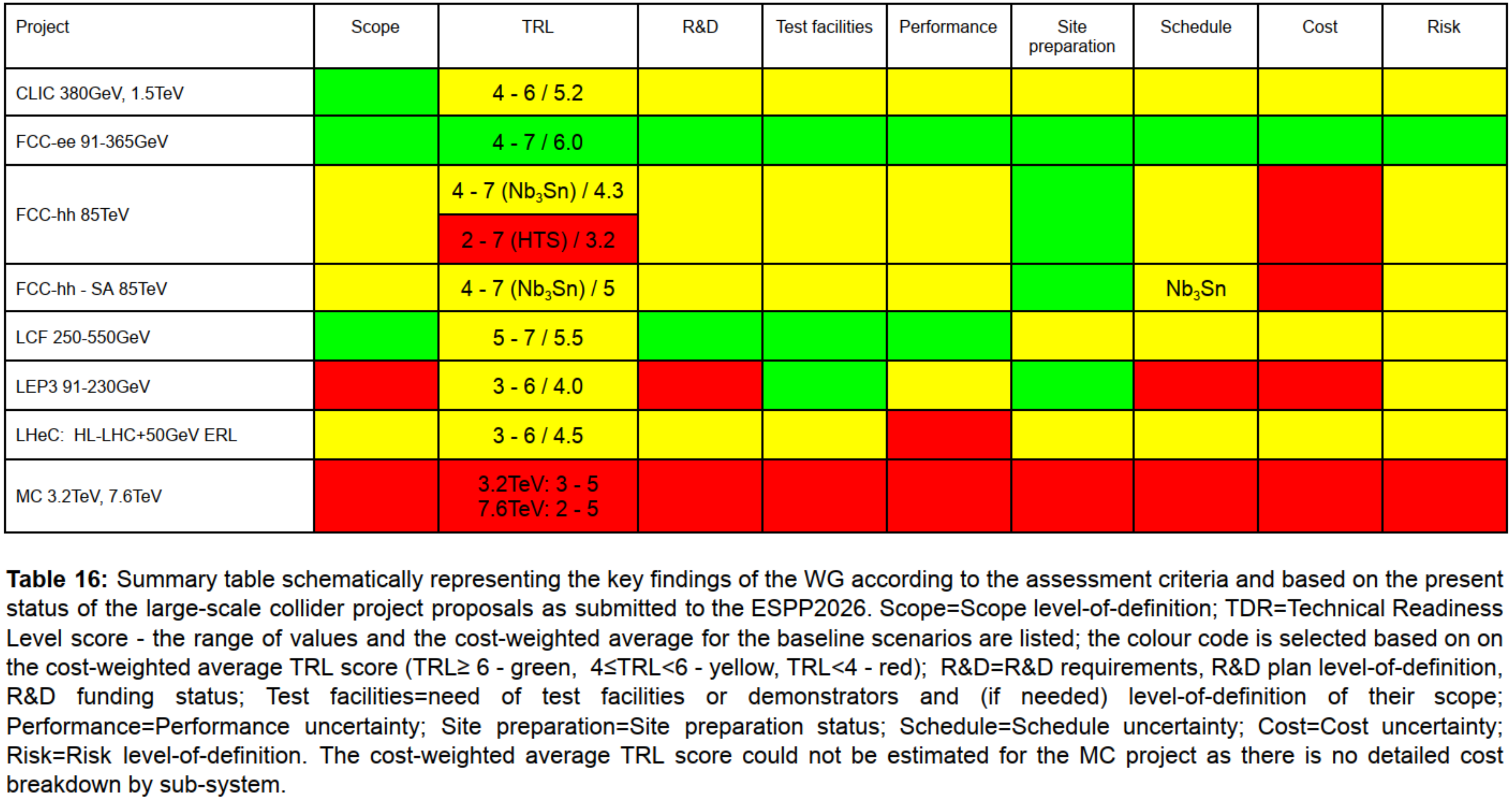
Summary schematic assessment



Project	Scope	TRL	R&D	Test facilities	Performance	Site preparation	Schedule	Cost	Risk
CLIC 380GeV, 1.5TeV	🟩	🟨 4 - 6 / 5.2	🟨	🟨	🟨	🟨	🟨	🟨	🟨
FCC-ee 91-365GeV	🟩	🟩 4 - 7 / 6.0	🟩	🟩	🟩	🟩	🟩	🟩	🟩
FCC-hh 85TeV	🟨	🟨 4 - 7 (Nb_3Sn) / 4.3 🟥 2 - 7 (HTS) / 3.2	🟨	🟨	🟨	🟩	🟨	🟥	🟨
FCC-hh - SA 85TeV	🟨	🟨 4 - 7 (Nb_3Sn) / 5	🟨	🟨	🟨	🟩	🟨 Nb_3Sn	🟥	🟨
LCF 250-550GeV	🟩	🟨 5 - 7 / 5.5	🟩	🟩	🟩	🟨	🟨	🟨	🟨
LEP3 91-230GeV	🟥	🟨 3 - 6 / 4.0	🟥	🟩	🟨	🟩	🟥	🟥	🟨
LHeC: HL-LHC+50GeV ERL	🟨	🟨 3 - 6 / 4.5	🟨	🟨	🟥	🟨	🟨	🟨	🟨
MC 3.2TeV, 7.6TeV	🟥	🟥 3.2TeV: 3 - 5 7.6TeV: 2 - 5	🟥	🟥	🟥	🟥	🟥	🟥	🟥

Table 16: Summary table schematically representing the key findings of the WG according to the assessment criteria and based on the present status of the large-scale collider project proposals as submitted to the ESPP2026. Scope=Scope level-of-definition; TDR=Technical Readiness Level score - the range of values and the cost-weighted average for the baseline scenarios are listed; the colour code is selected based on on the cost-weighted average TRL score (TRL≥ 6 - green, 4≤TRL<6 - yellow, TRL<4 - red); R&D=R&D requirements, R&D plan level-of-definition, R&D funding status; Test facilities=need of test facilities or demonstrators and (if needed) level-of-definition of their scope; Performance=Performance uncertainty; Site preparation=Site preparation status; Schedule=Schedule uncertainty; Cost=Cost uncertainty; Risk=Risk level-of-definition. The cost-weighted average TRL score could not be estimated for the MC project as there is no detailed cost breakdown by sub-system.

Physics Briefing Book:

Input for the 2026 update of the European Strategy for Particle Physics

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4 November 2025

Physics Briefing Book

Input for the 2026 update of the European Strategy for Particle Physics

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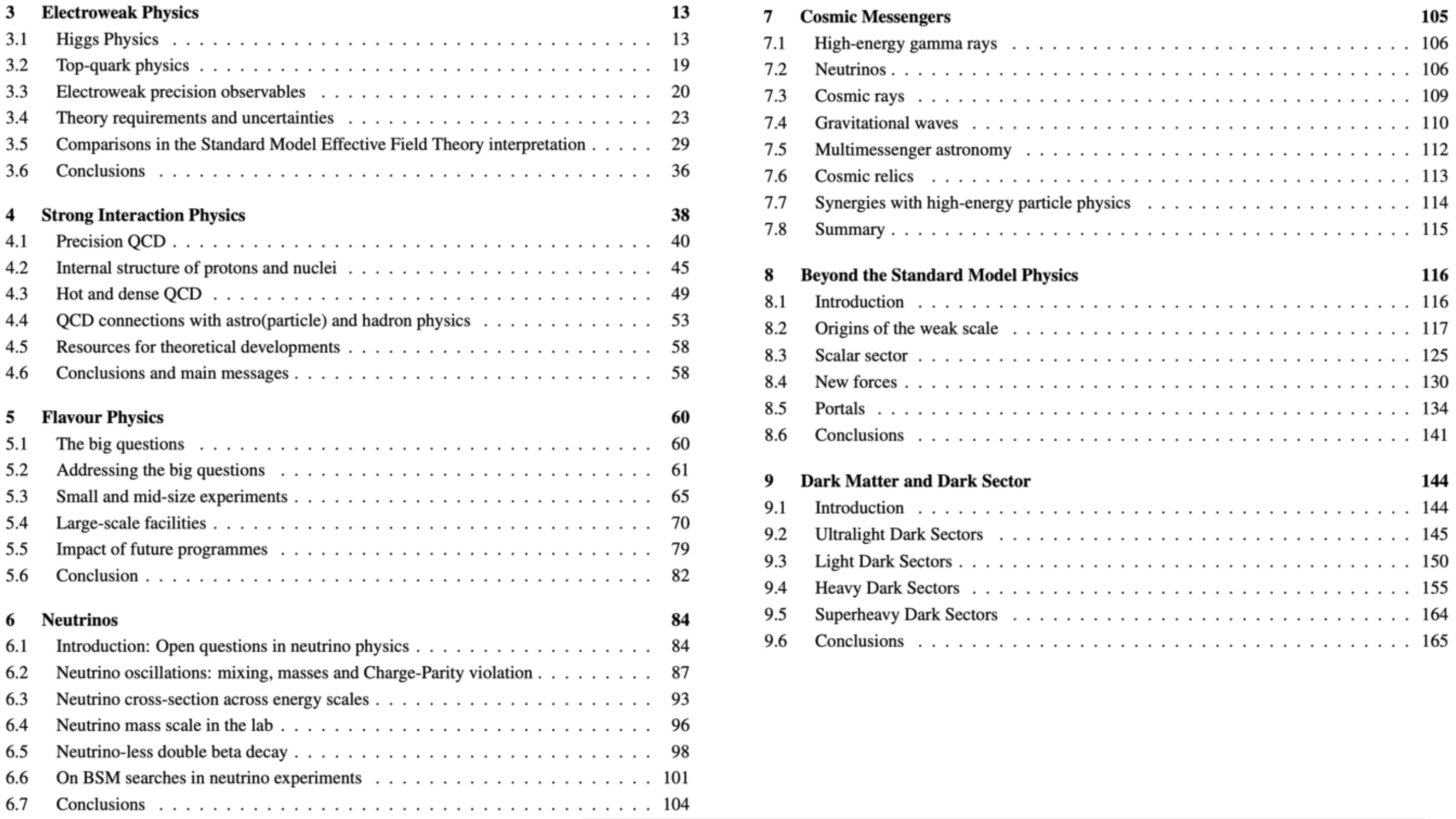

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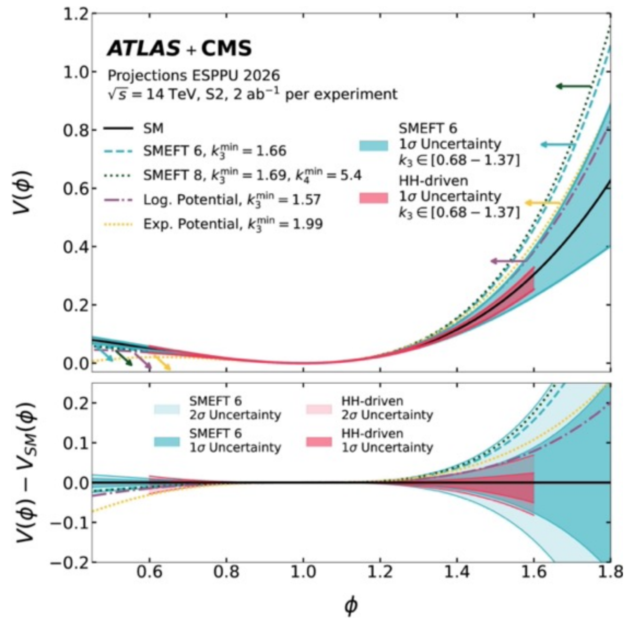
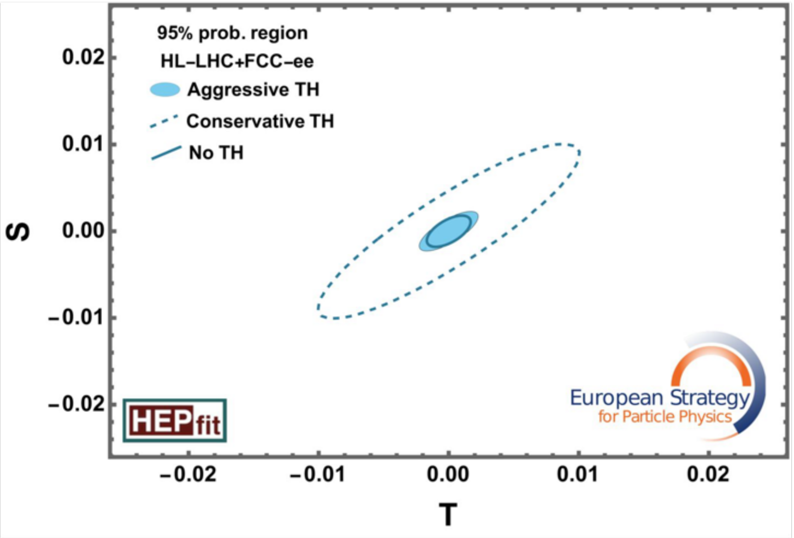
Next slides: a few examples
With a subliminal question: how do you choose?

Key points - all areas

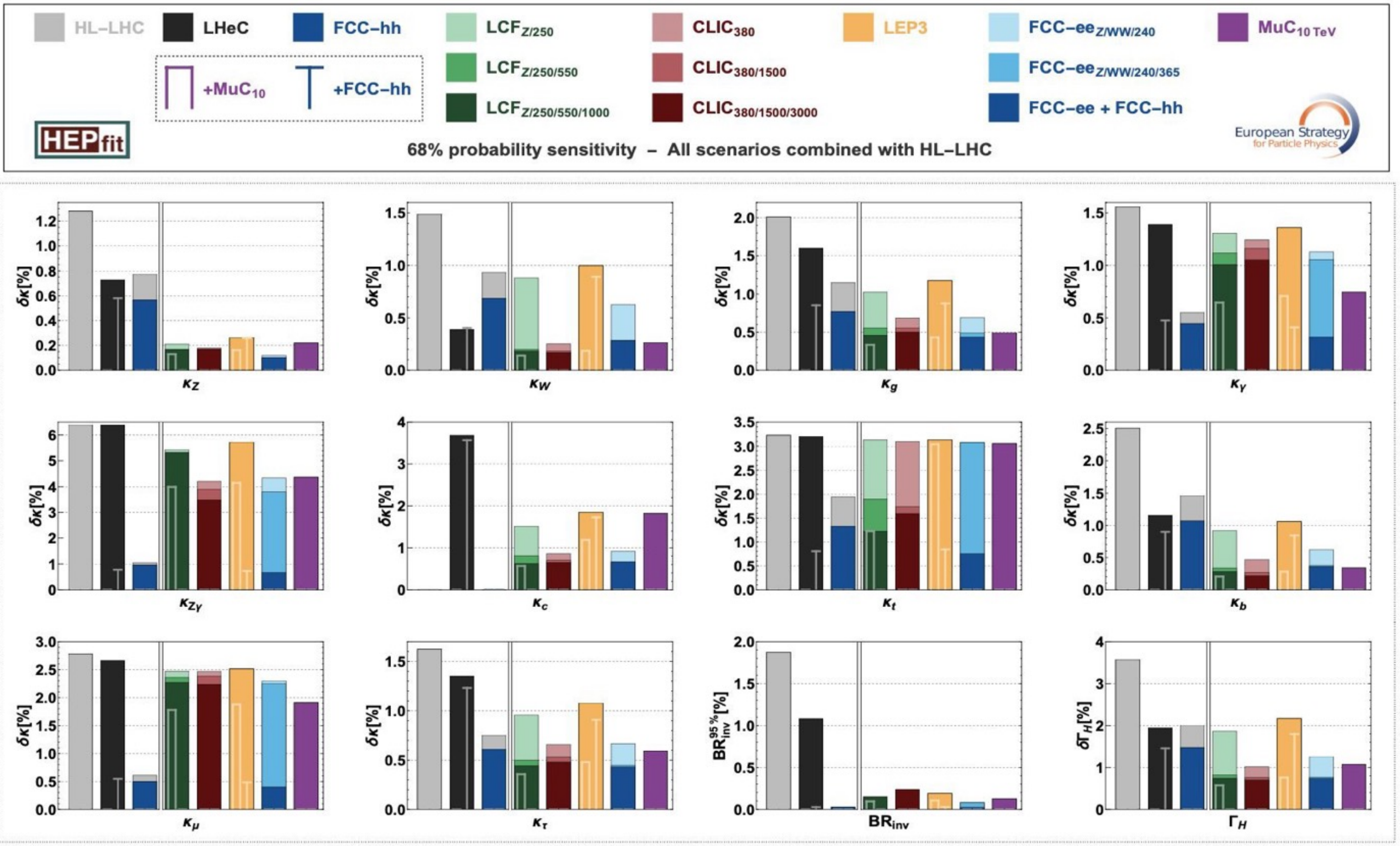
- **The full run of the HL-LHC is vital as the foundation to any future project**
- Theory plays an indispensable role and we can not achieve our physics goals without significant investment and advancement in theory
- **Scientific diversity** across many areas from BSM, QCD, Flavor, neutrinos, DM searches, etc, is critical given the richness of new physics possibilities to also achieve our physics goals





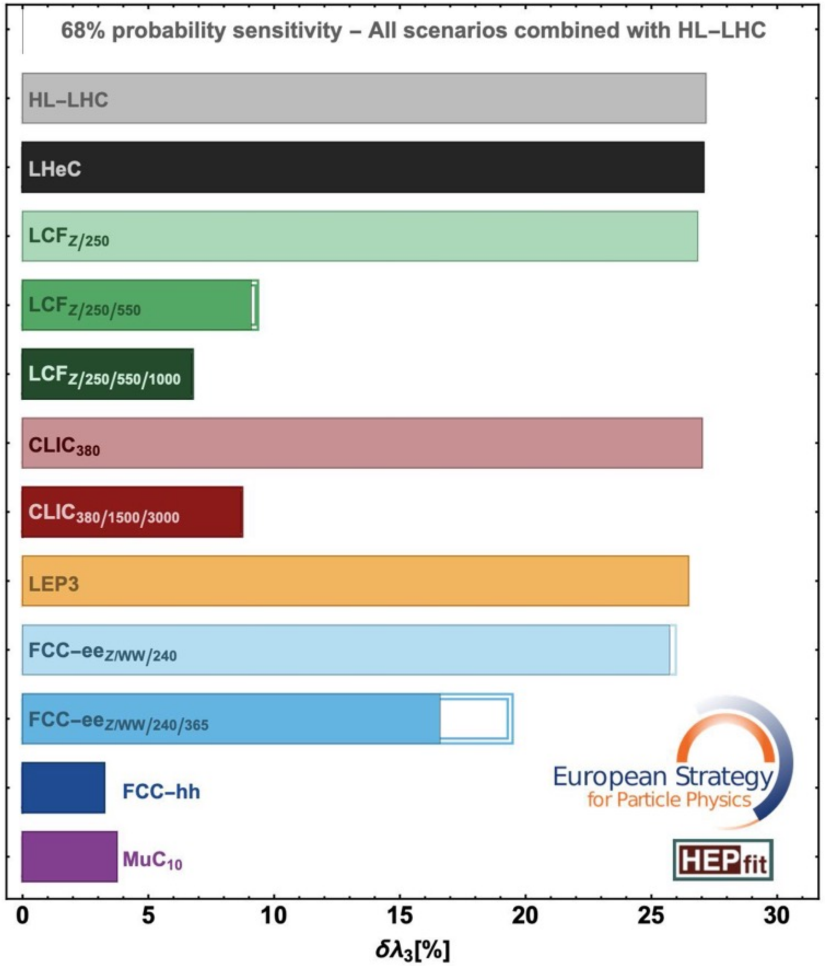
Higgs: Key points

- All e+e- machines provide precision results in the Higgs sector
- Key exceptions are top Yukawa and rare decays where FCChh or to a lesser extent a muon collider are needed



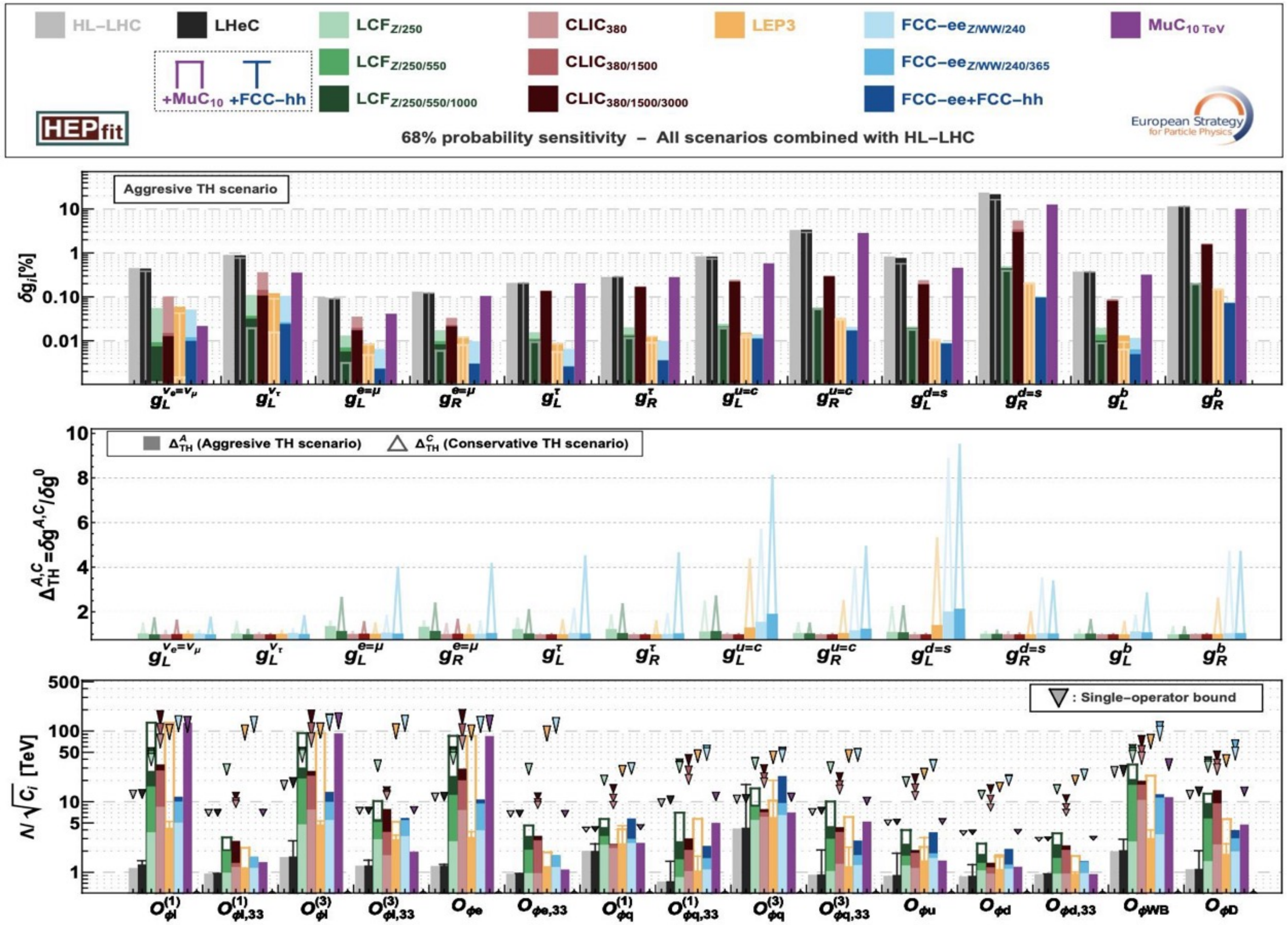
Higgs self-coupling

- All e+e- machines provide precision results in the Higgs sector
- The full potential of e+e- machines require at least one energy point above 250 GeV
- FCCee - has high luminosities, its precise measurements of Higgs and EWPO are very constraining for the SM
- LC - benefits from higher energies such as in HH production and top physics



Electroweak

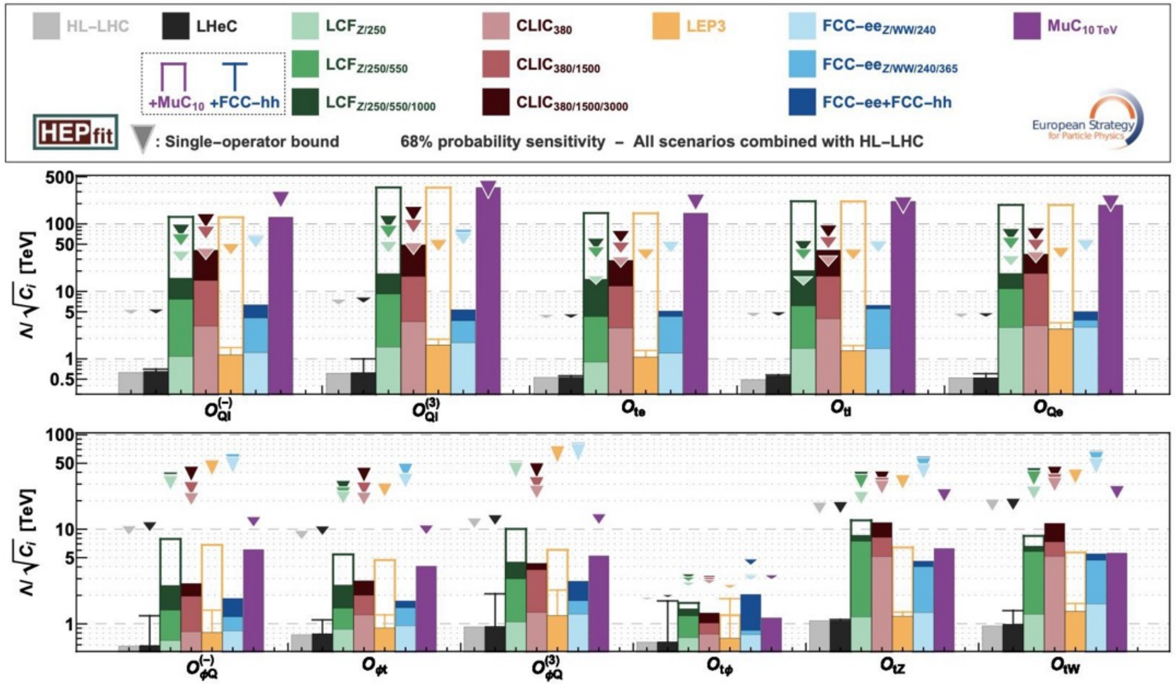
EW Operators



- The Tera-Z run provides a large energy reach to many EW operators
- High-energy di-boson measurements high-energy LC or the MuC (and FCChh) provide complementary information and in some cases comparable energy reach

Top physics

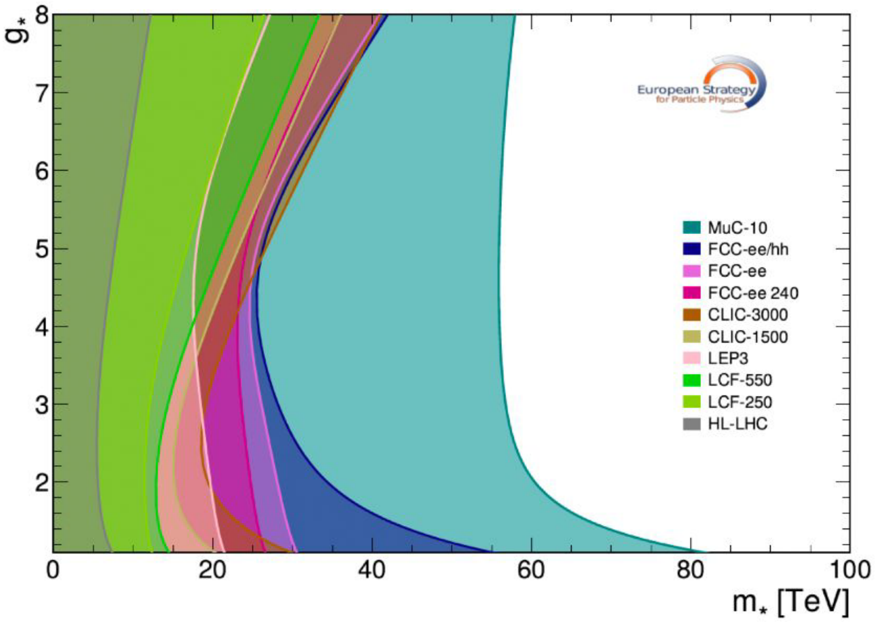
Top Sector Operators

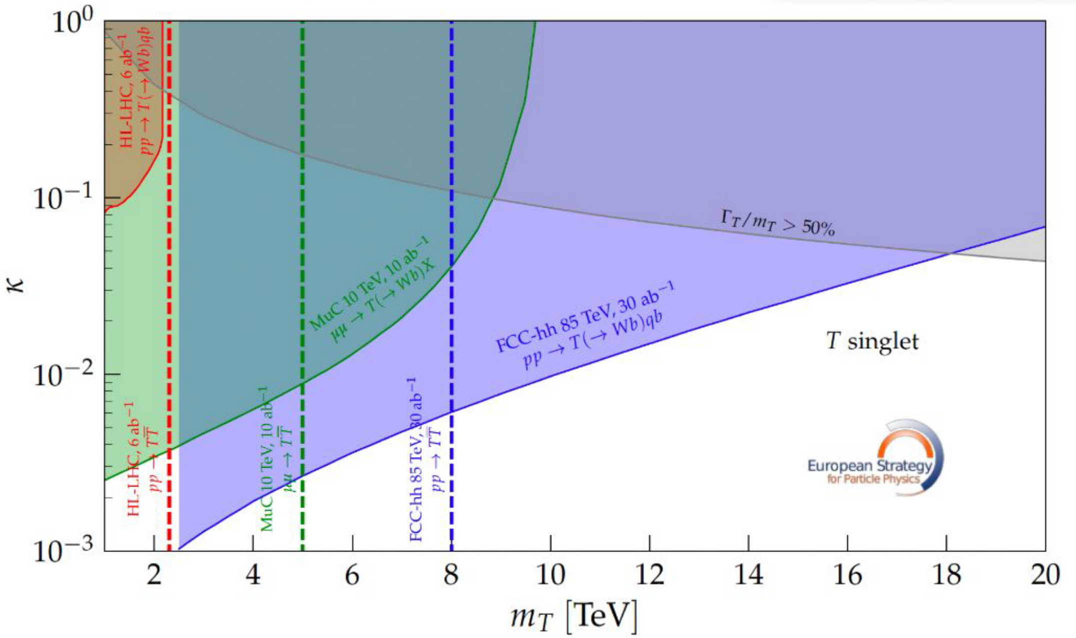


- Top benefits from a lever arm in energy
- Precision machines when coupled with a high energy machine (FCChh or to a lesser extent muon collider) yield overall the best results
- Top Yukawa is best measured at FCChh
- (not shown): muon vs hadron colliders are complementary probes at high energy (i.e. lepton couplings vs. QCD currents)

BSM Key points

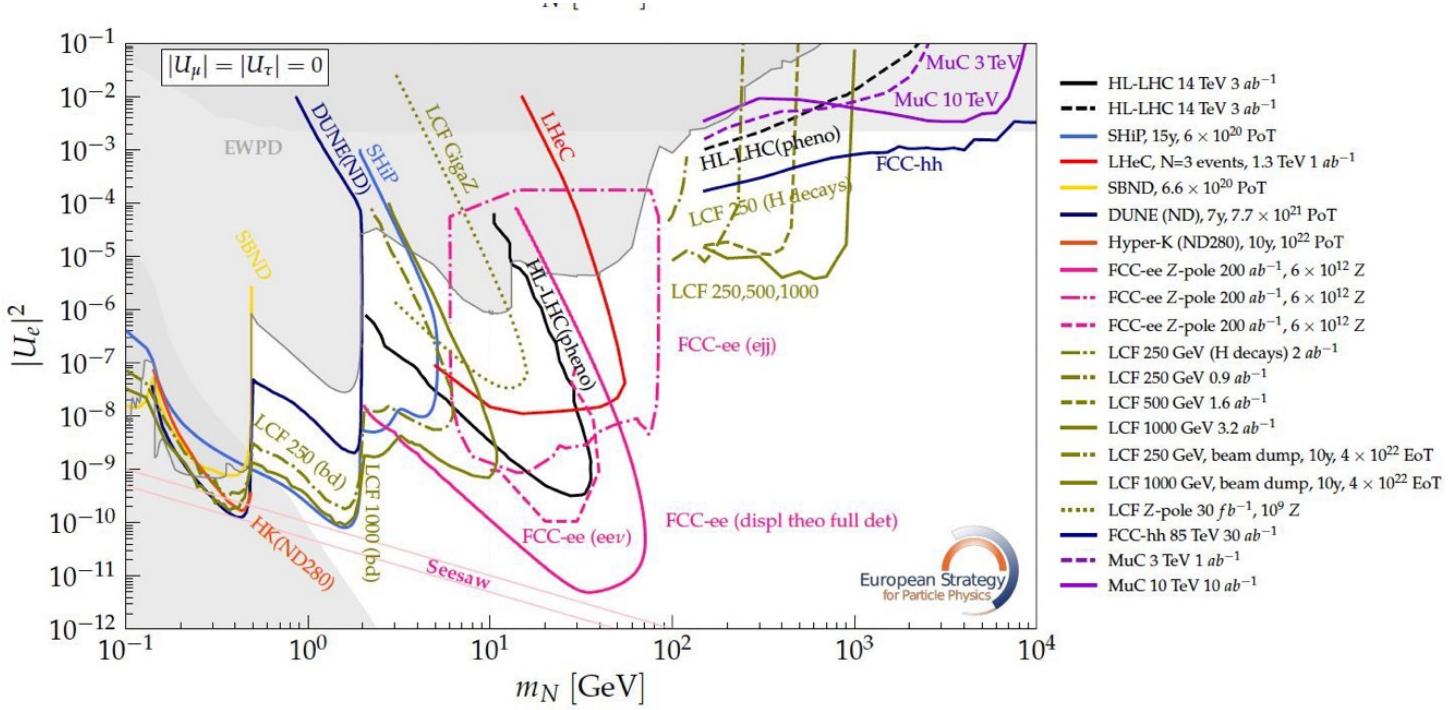
- The search for composite structure of the Higgs (and W,Z,top) can give very high-scale limits and a very nice complementarity between precision and direct searches for associated new states (like vector-like tops)





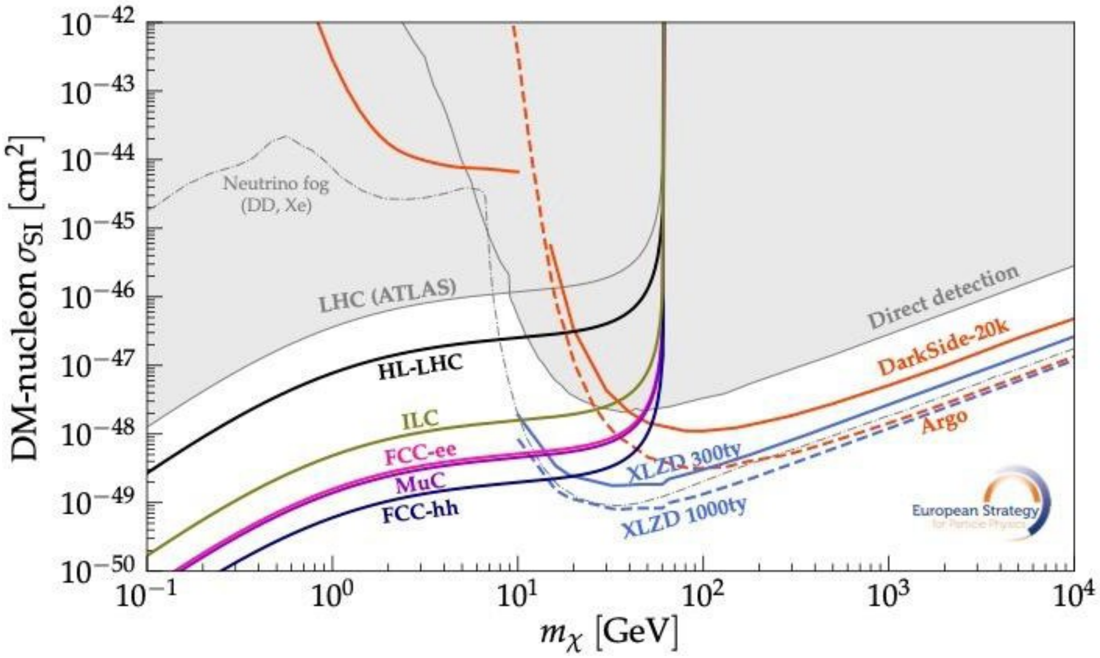
BSM Key points

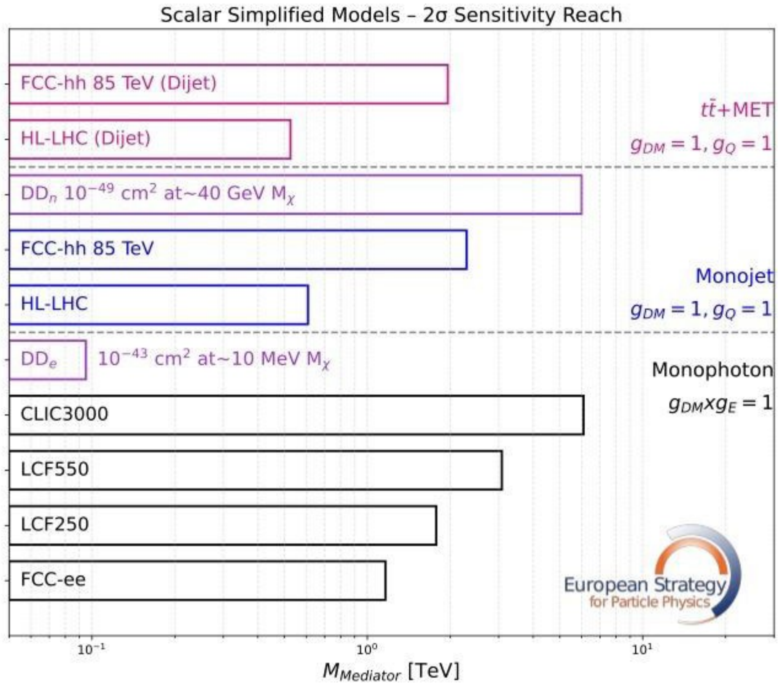
- Direct discovery potential from high-intensity runs at lepton colliders for Portal interactions (ALPs, dark scalars, HNLs) connect visible and hidden sectors; FCC-ee Tera-Z run offers exceptional sensitivity.



Dark Matter: Key points

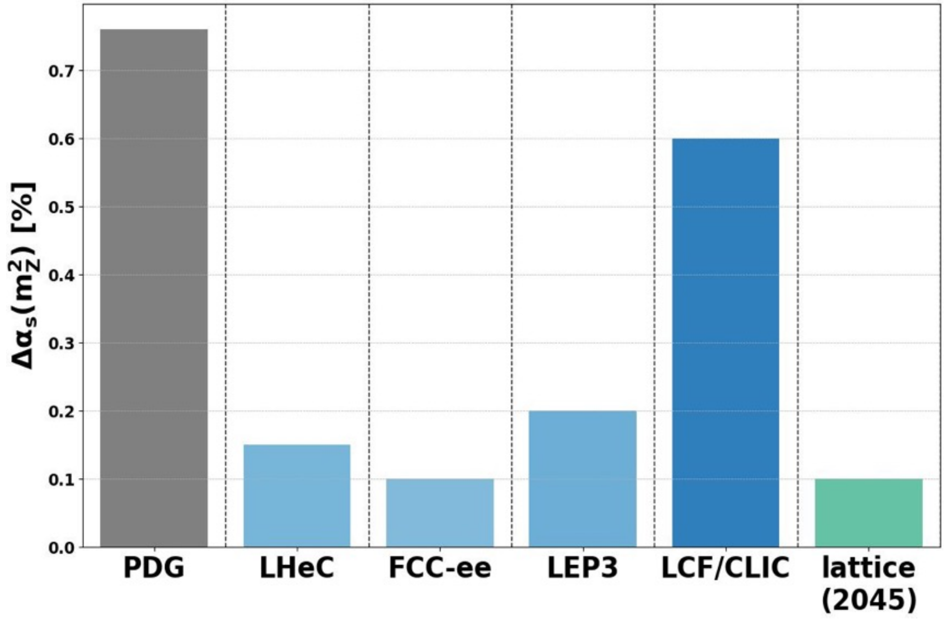
- The most comprehensive possible coverage of dark matter requires diversity of experimental approaches. Non-accelerator searches offer complementary reach and should be supported in any scenario.



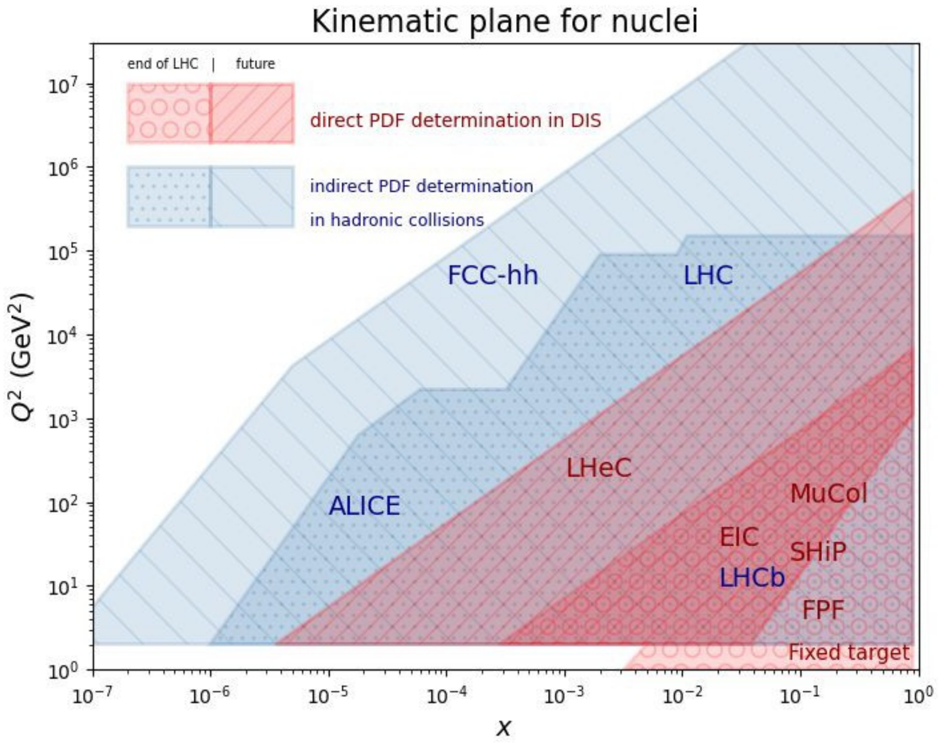


QCD: Key points

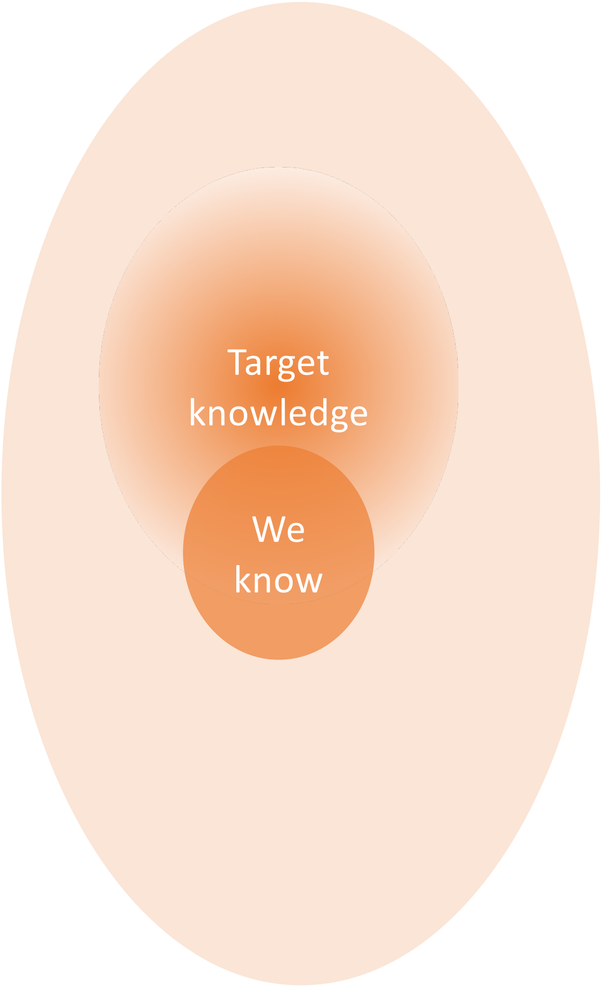
- The strong coupling/interaction is the least known, significant progress is a must for future projects.
- Precise QCD (experiment and theory) is necessary for all sectors and all future projects



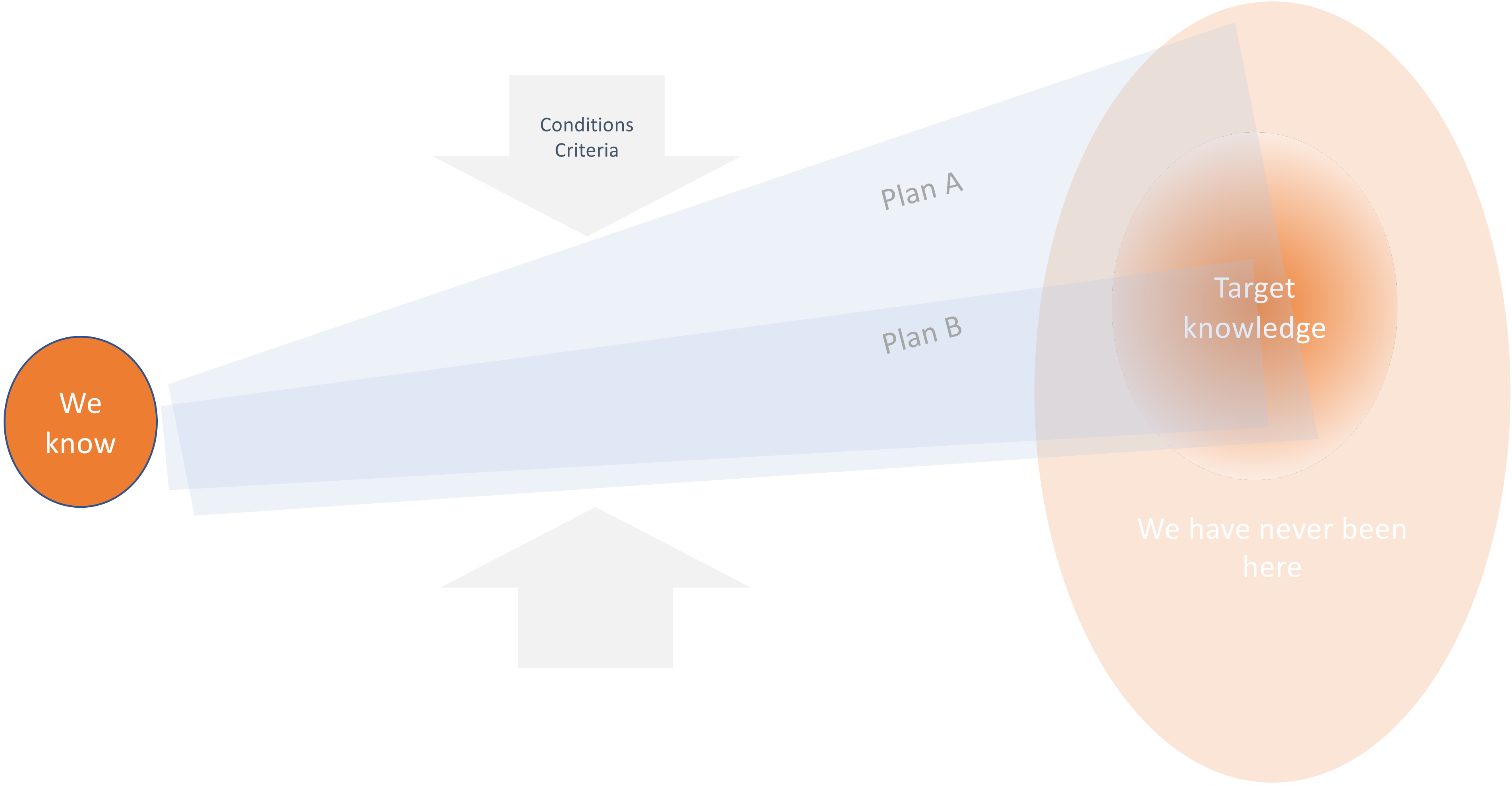
- The proton/nucleus structure understanding is key to all hadron machines and instrumental for ultimate precision in the EWK sector. Also plays a key role to other sectors/programs (astrophysics, neutrino physics, etc)


Kinematic plane for nuclei

Making plans to further knowledge: what's the plan?

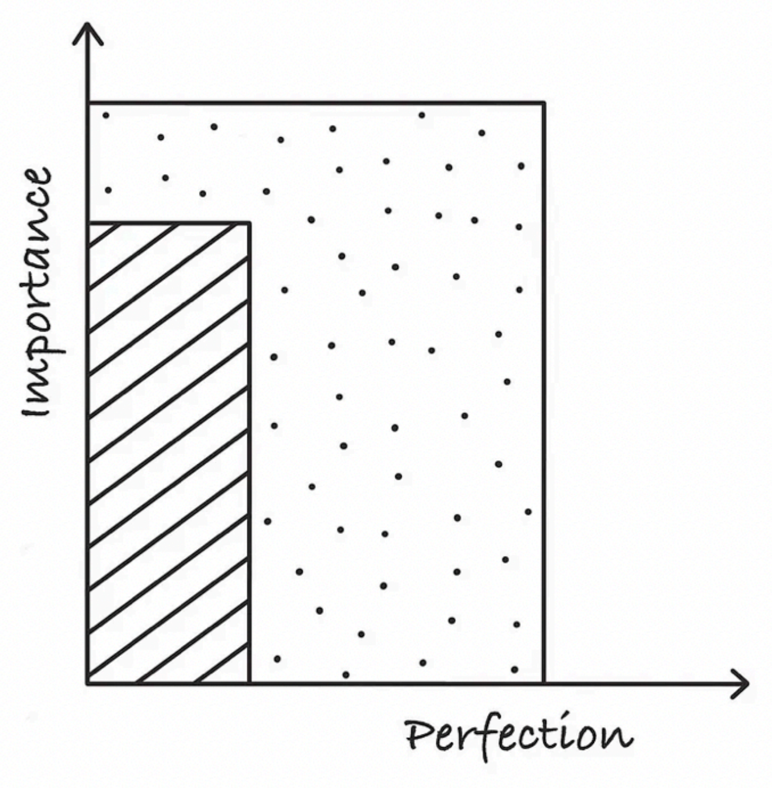


Build a future : scenarios



Question: can we rank the physics case? An attempt.

- Physics sector k
  - Importance (Energy) I(k)
  - Perfection (Precision) P(k)
  - ....
- Metrics possible:
  - Isophysical $\sum_{k:1,N_{fields}} P(k)$
  - Surface $\sum_{k:1,N_{fields}} P(k) * I(k)$
  - ....
- But:
  - “We're Not Laying Pipe. We're Talking About Physics”



- A practical example

Proton/nucleon structure

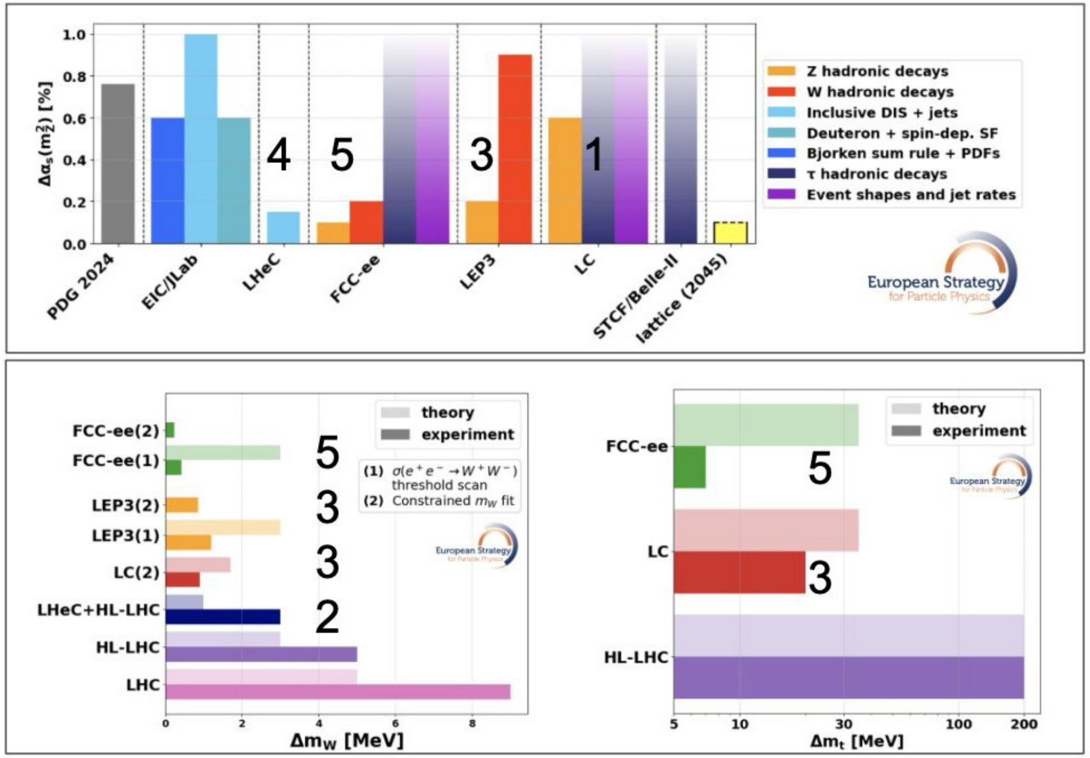
Table 4.3: Schematic comparison of the impact and complementarities between facilities in accessing selected physics benchmarks. Dark/light/white shading indicates highest/significant/negligible contributions of the experiment to the quantities. Comments in each cell provide simplified explanations of the assessment (see the text and Fig. 4.4).

Quantity of interest	**LHC: fixed target mode** *D*, *B*, quarkonium, light hadrons	**(HL-)LHC: collider mode** *D*, *B*, quarkonium, light hadrons, UPCs, DY	**ALICE FoCal** Photons, pions, quarkonium, jets, UPCs	**SHiP** DIS of ν from c decays on fixed target	**EIC** NC, CC and jets in DIS, light and heavy flavour ID, excl. diffraction
PDFs	Most info. avail.	Most info. avail.	Simultaneous fit of proton and nuclei	Simultaneous fit of proton and nuclei; F_4, F_5	Covered by HERA
nPDFs	Most info. avail.	Most info. avail.	Complementary e.m. probes; region overlapping with current *p*Pb	Simultaneous fit of proton and nuclei; F_4, F_5	Cleanliness
TMDs	DY, jets	DY, jets	Limited PID		Particle ID
GPDs	Currently UPCs	Currently UPCs			Particle ID
Small-x dynamics	Indirect, from precision at large-x	Large kinematic extent	Large kinematic extent	Indirect, from precision at large-x	Kinematic reach

Quantity of interest	**FPF** ν DIS of ν from c decays on fixed target	**LHeC** NC, CC and jets in DIS, heavy flavour ID, excl. diffraction	**FCC-ee/LEP3/LC** FFs of light and heavy quarks, jets, γ–γ	**MuCol** DIS of ν from μ decays on fixed target	**FCC-hh** *D*, *B*, quarkonium, light hadrons, UPCs, DY
PDFs	Simultaneous fit of proton and nuclei; F_4, F_5	Cleanliness; precision		Simultaneous fit of proton and nuclei	Kinematic reach
nPDFs	Simultaneous fit of proton and nuclei; F_4, F_5	Cleanliness; precision		Simultaneous fit of proton and nuclei	Kinematic reach
TMDs		Limited PID in detector design	FFs needed for PDFs, and TMDs in jets		DY, jets
GPDs		Kinematic reach	γ–γ (transition GPDs)		Currently UPCs
Small-x dynamics	Kinematic reach	Kinematic reach in *ep* and *eA*	γ–γ processes	Indirect, from precision at large-x	Kinematic reach in *pp* and *pA*

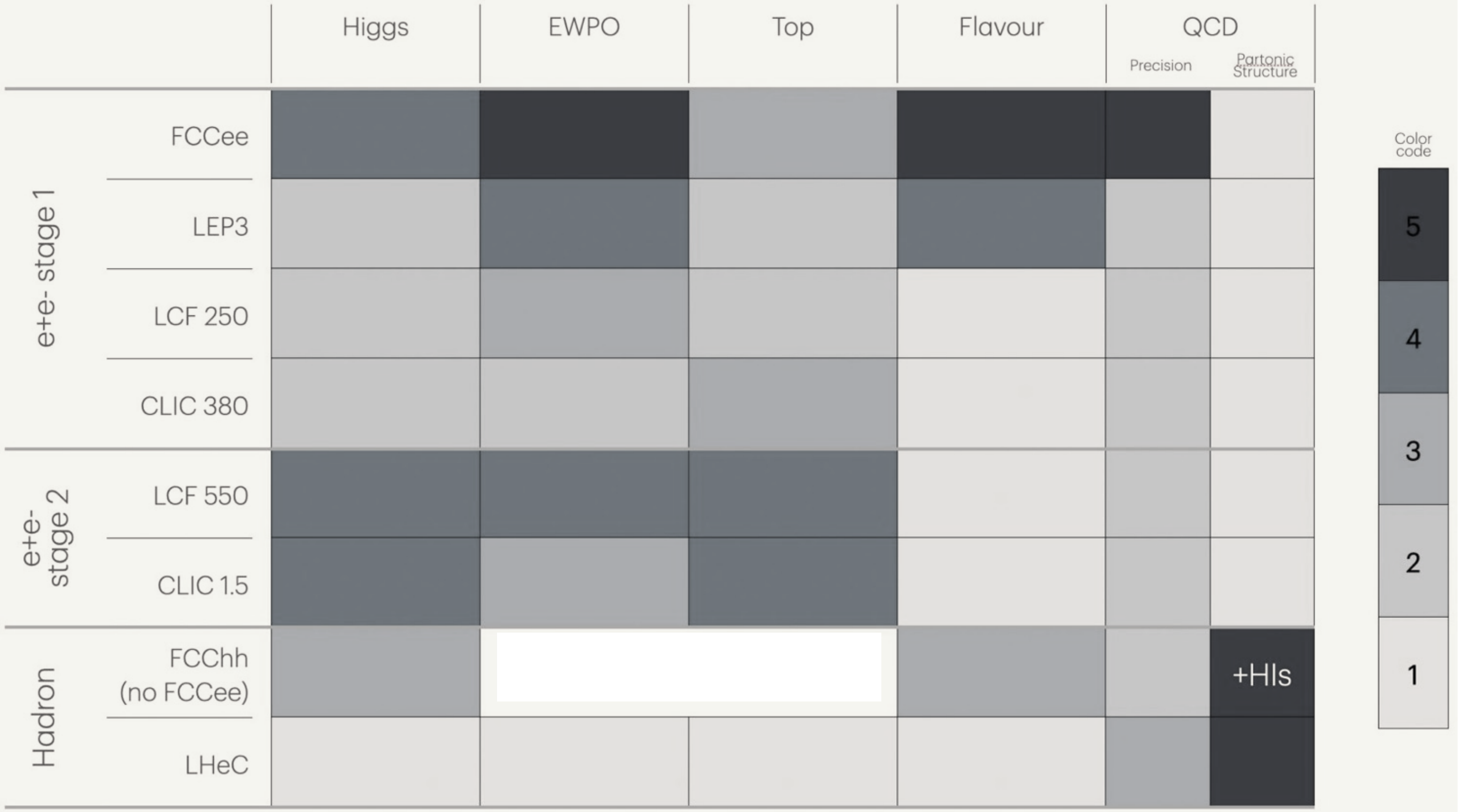
Criteria - QCD

- Precision QCD (α_S, m_{top}, m_W benchmarks)
  - 5: Best precision
  - 4: Reduce precision compared to level 5
  - 3: Precision x2 worse compared to level 5
  - 1: No major improvements w.r.t HL-LHC



Gedanken ranking

- These rankings are fictious, just to illustrate the point



		Higgs	EWPO	Top	Flavour	QCD	
						Precision	Partonic Structure
e+e- stage 1	FCCee	4	5	3	5	5	1
	LEP3	2	4	2	4	2	1
	LCF 250	2	3	2	1	2	1
	CLIC 380	2	2	3	1	2	1
e+e- stage 2	LCF 550	4	4	4	1	2	1
	CLIC 1.5	4	3	4	1	2	1
Hadron	FCChh (no FCCee)	3			3	2	5 +HIs
	LHeC	1	1	1	1	3	5

Color code

5	Best including with high energy option
4	
3	
2	
1	Marginal/narrow contribution

Build the future / a future : the decision process

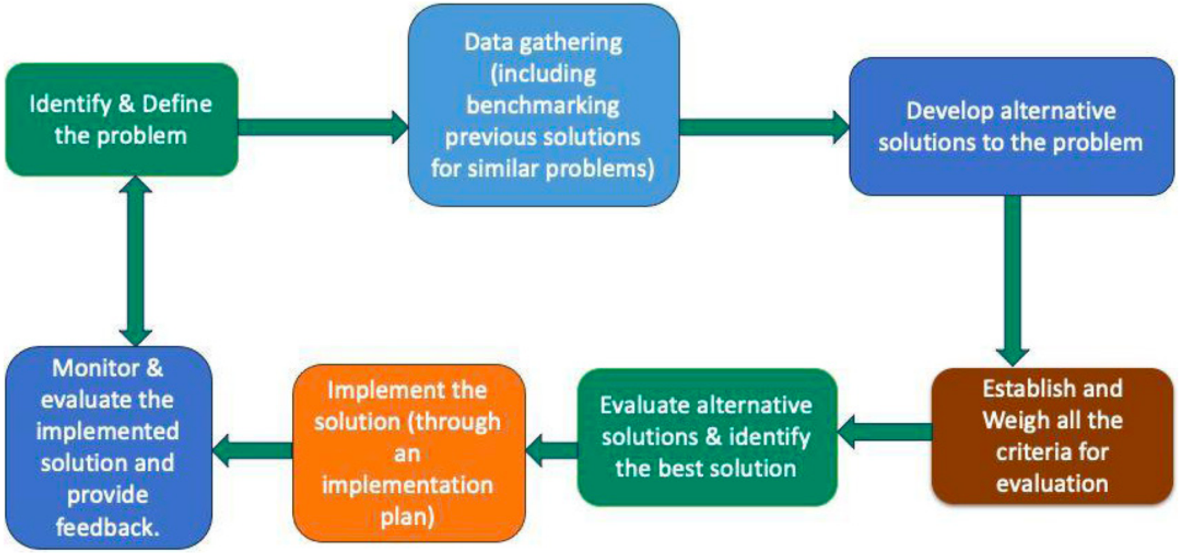


Figure 1: The stages of rational decision-making

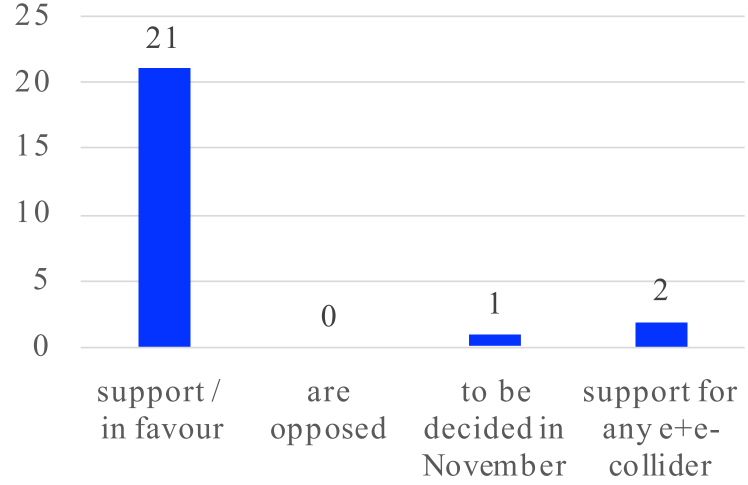
Source: Preda (2006)

The decision process is a complex process depending on internal and external conditions, some of which are only partially available/known during the process.

- National input / roadmaps
- Comparisons across proposed projects (Project assessment, Physics Potential)
- Strategy Implementation
- Relation with other fields of physics
- Sustainability and environmental impact
- Public engagement, education and communication
- Knowledge and technology transfer

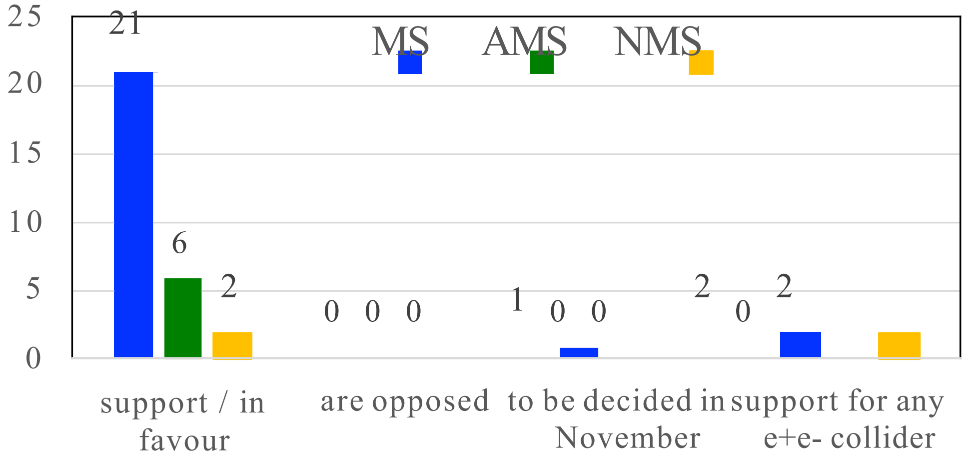
What is the preferred large-scale accelerator for CERN

CERN Member States (MS)



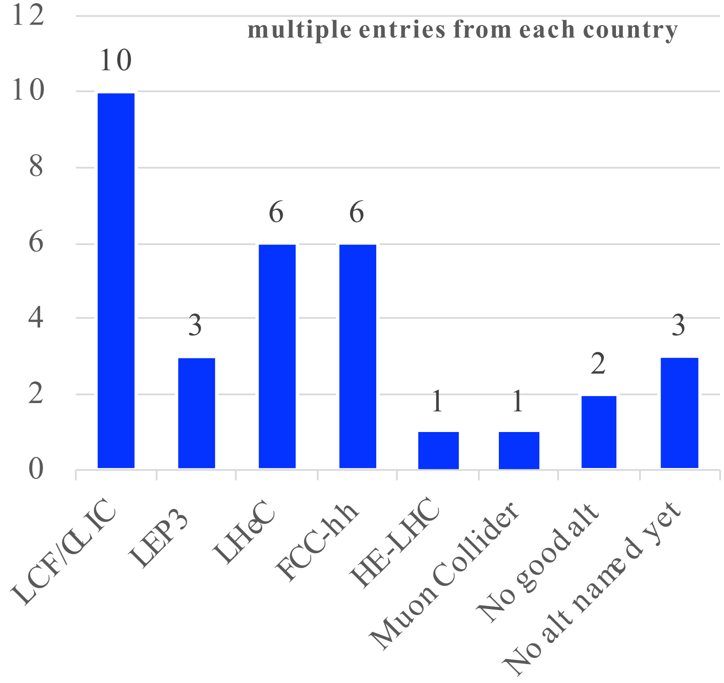
- Overwhelming support (21/24 CERN MS HEP communities) in favour of the integrated FCC-ee/hh programme

… incl. Associate- and Non-Member States (MS)



- Support as well from Associate Member states (AMS) and Non-member states (NMS)

What is the alternative if the preferred option is not feasible?

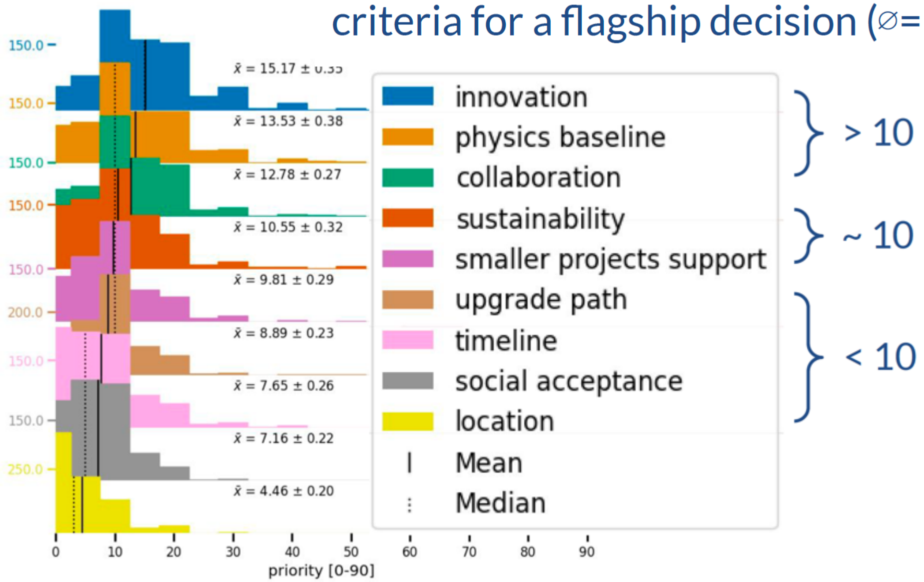


CERN Member States (MS) (multiple entries allowed)

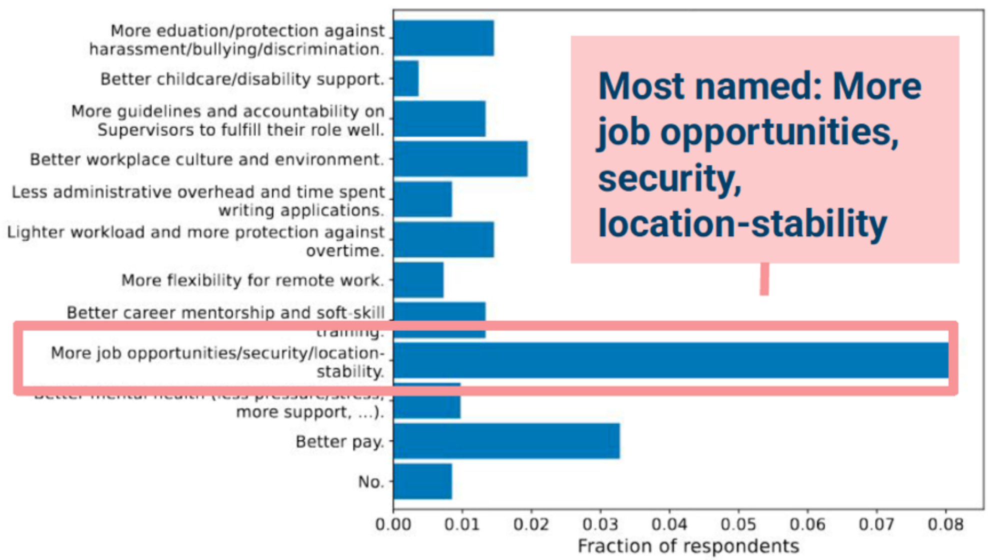
- 10 MS HEP communities list a Linear Collider (LCF, CLIC) as second best choice
  (LCF is preferred to be realised with 550 GeV)
- 3 MS HEP mention LEP3 as a genuinely less costly alternative to FCC-ee
- 6 MS HEP communities support LHeC
- 6 MS HEP communities support a lower-energy hadron collider
- 2 MS HEP see no reason for another option, as they would be equally costly.

And more parameters : Early Career Survey

Task: distribute 90 points among 9 criteria for a flagship decision (∅=10)



Measures to improve your personal situation?

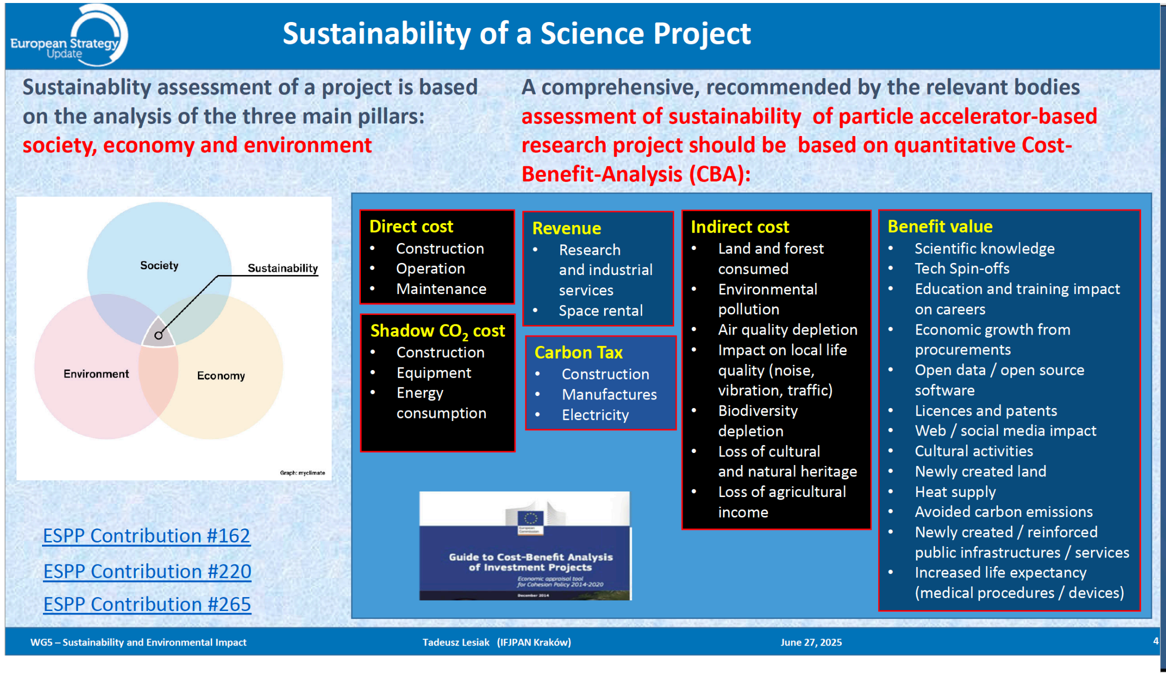


Most named: More job opportunities, security, location-stability

Sustainability and social acceptance should be smaller drivers for the flagship decision, but are necessary conditions for any flagship

Sustainability

T. Lesziak Open Symposium Venise june 2025



Sustainability of a Science Project

Sustainablity assessment of a project is based on the analysis of the three main pillars: **society, economy and environment**

A comprehensive, recommended by the relevant bodies **assessment of sustainability of particle accelerator-based research project should be based on quantitative Cost-Benefit-Analysis (CBA):**

Direct cost
- Construction
- Operation
- Maintenance

Shadow CO_2 cost
- Construction
- Equipment
- Energy consumption

Revenue
- Research and industrial services
- Space rental

Carbon Tax
- Construction
- Manufactures
- Electricity

Indirect cost
- Land and forest consumed
- Environmental pollution
- Air quality depletion
- Impact on local life quality (noise, vibration, traffic)
- Biodiversity depletion
- Loss of cultural and natural heritage
- Loss of agricultural income

Benefit value
- Scientific knowledge
- Tech Spin-offs
- Education and training impact on careers
- Economic growth from procurements
- Open data / open source software
- Licences and patents
- Web / social media impact
- Cultural activities
- Newly created land
- Heat supply
- Avoided carbon emissions
- Newly created / reinforced public infrastructures / services
- Increased life expectancy (medical procedures / devices)

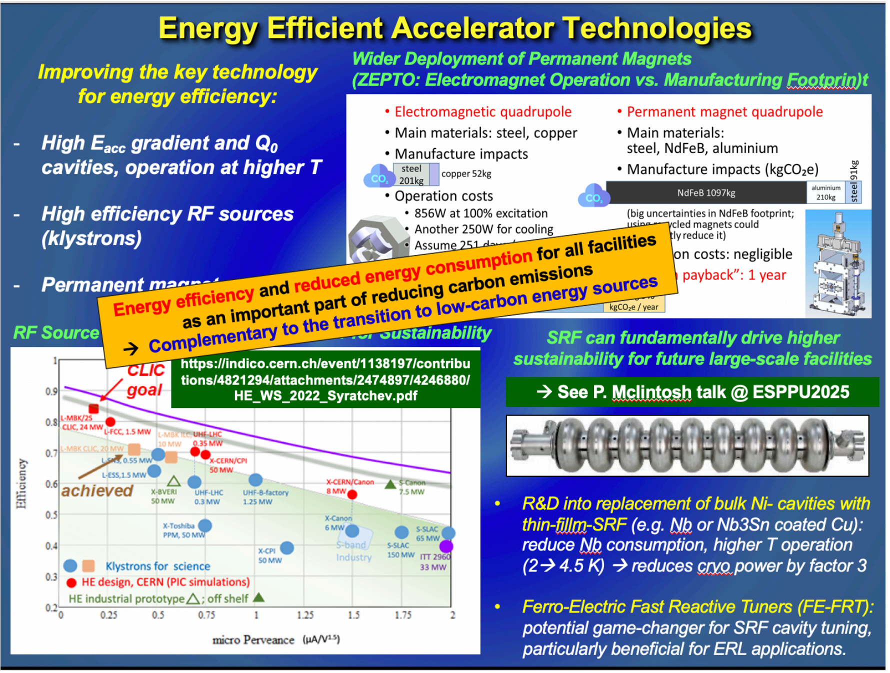
ESPP Contribution #162

ESPP Contribution #220

ESPP Contribution #265

WG5 – Sustainability and Environmental Impact Tadeusz Lesiak (IFJPAN Kraków) June 27, 2025 4

M. Titov EPS-HEP 2025 Marseille, July 2025



Energy Efficient Accelerator Technologies

Improving the key technology for energy efficiency:

- *High E_{acc} gradient and Q_0 cavities, operation at higher T*
- *High efficiency RF sources (klystrons)*
- *Permanent magn*

Wider Deployment of Permanent Magnets (ZEPTO: Electromagnet Operation vs. Manufacturing Footprin)t

- Electromagnetic quadrupole
- Main materials: steel, copper
- Manufacture impacts
- Operation costs
  - 856W at 100% excitation
  - Another 250W for cooling
  - Assume 251 da

- Permanent magnet quadrupole
- Main materials: steel, NdFeB, aluminium
- Manufacture impacts ($kgCO_2e$)

(big uncertainties in NdFeB footprint; using ycled magnets could tly reduce it)

on costs: negligible

payback": 1 year

Energy efficiency and reduced energy consumption for all facilities as an important part of reducing carbon emissions

→ Complementary to the transition to low-carbon energy sources

RF Source … for Sustainability

https://indico.cern.ch/event/1138197/contributions/4821294/attachments/2474897/4246880/HE_WS_2022_Syratchev.pdf

SRF can fundamentally drive higher sustainability for future large-scale facilities

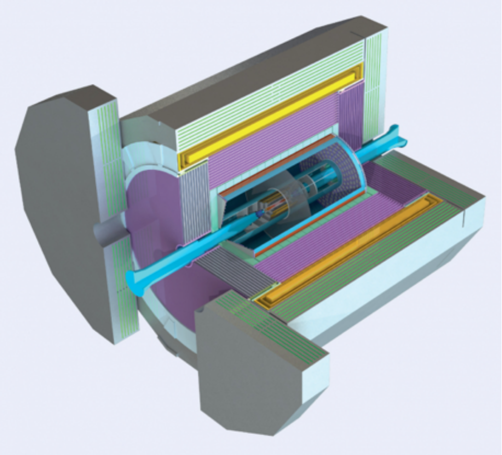
→ See P. Mclintosh talk @ ESPPU2025

- *R&D into replacement of bulk Ni- cavities with thin-fillm-SRF (e.g. Nb or Nb3Sn coated Cu): reduce Nb consumption, higher T operation (2→ 4.5 K) → reduces cryo power by factor 3*
- *Ferro-Electric Fast Reactive Tuners (FE-FRT): potential game-changer for SRF cavity tuning, particularly beneficial for ERL applications.*

https://indico.in2p3.fr/event/33627/contributions/153159/attachments/95165/145657/2025_07_MARSEILLE-FRANCE_EPS-HEP2025_CONFERENCE_ENVIRONMENTAL-IMPACT_ACCELERATOR-FACILITIES_10072025.pdf

Europe competiveness and geopolitical situation

- Oct. 2025 “Although our proposal that **CEPC** be included in the next five-year plan was not successful, IHEP will continue this effort, which an international collaboration has developed for the past 10 years,” says study leader Wang Yifang, of the Institute of High Energy Physics (IHEP) in Beijing. “We plan to submit CEPC for consideration again in 2030, unless FCC is officially approved before then, in which case we will seek to join FCC, and give up CEPC.”



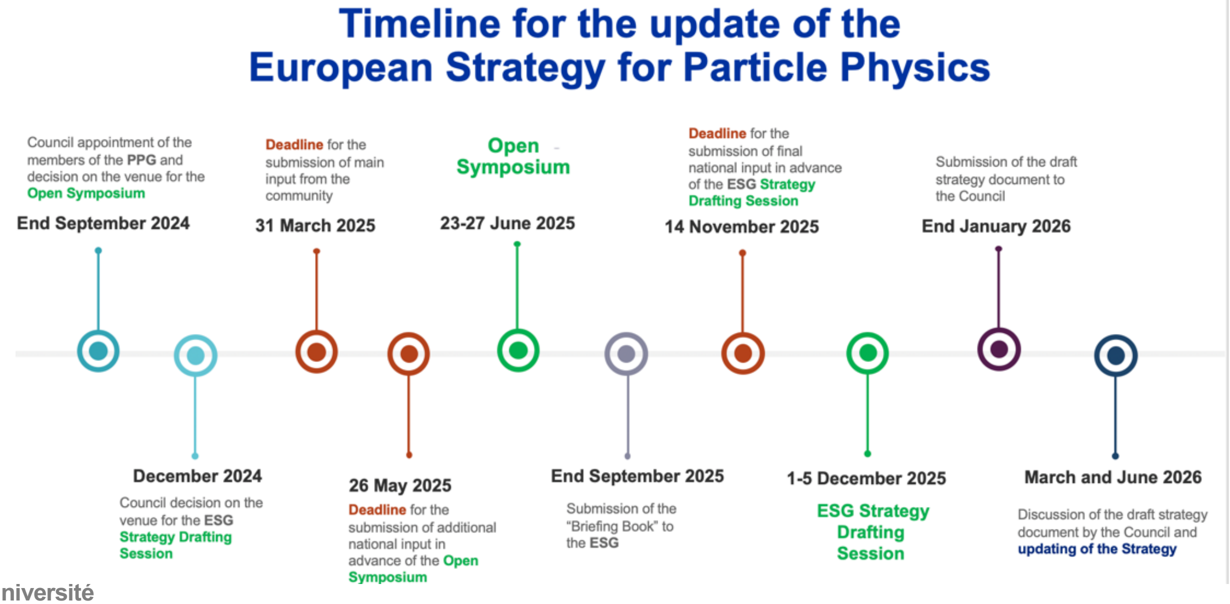
CEPC Study Group 2025 arXiv:2510.05260

- Nov 2024: “One of CERN’s most promising current projects, with significant scientific potential, is the construction of the **Future Circular Collider (FCC):** a 90-km ring designed initially for an electron collider and later for a hadron collider. **Refinancing CERN and ensuring its continued global leadership in frontier research should be regarded as a top EU priority …”**

https://commission.europa.eu/topics/competitiveness/draghi-report_en

The future? Stay tuned !

- *"Nobody can really guarantee the future. The best we can do is size up the chances, calculate the risks involved, estimate our ability to deal with them and then make our plans with confidence."* Henri Ford
- *Before the flood, Noah's idea of designing and building an ark on a mountain was believed to be absurd, however in a changed context, in the flood, his decision became ideal and the other resolutions were downgraded to the level of absurdity* (Preda, 2006).



Timeline for the update of the European Strategy for Particle Physics

End September 2024: Council appointment of the members of the **PPG** and decision on the venue for the **Open Symposium**

December 2024: Council decision on the venue for the **ESG Strategy Drafting Session**

31 March 2025: **Deadline** for the submission of main input from the community

26 May 2025: **Deadline** for the submission of additional national input in advance of the **Open Symposium**

23-27 June 2025: **Open Symposium**

End September 2025: Submission of the "Briefing Book" to the **ESG**

14 November 2025: **Deadline** for the submission of final national input in advance of the **ESG Strategy Drafting Session**

1-5 December 2025: **ESG Strategy Drafting Session**

End January 2026: Submission of the draft strategy document to the Council

March and June 2026: Discussion of the draft strategy document by the Council and **updating of the Strategy**

Your future, your vote

- https://qruiz.net/Q/?ehojnr

Pathways for New Physics

- https://qruiz.net/Q/?u94FjR

How do you believe the Particle Physics will evolve?

- The future of particle physics
- https://qruiz.net/Q/?iUjatb

Backup

French community input

- **Preferred Option for the Next Collider at CERN: FCCee:**
  - **Strong support from the French community for the Future Circular Collider (FCCee) project.**
    - FCCee aims to advance knowledge of Higgs boson couplings, electroweak and strong gauge couplings, and prominent electroweak observables.
    - Operation at the Z pole is expected to improve fundamental measurements by factors of 10-100 compared to LEP1.
    - Potential for a future ~100 TeV hadron collider reusing the FCCee tunnel.
    - CERN is considered the best place to host FCCee due to its expertise, infrastructure, and sustainability practices.

- **Fall-back Options if FCCee is Not Feasible**:
  - **If no comparable e+e–e+e– collider is established outside Europe**:
    - A linear e+e–e+e– collider facility (LCF) at CERN as the next best option for a Higgs factory.
    - Consideration of LEP3 as a last-resort fallback, with limitations in luminosity and energy range.
  - **If a comparable e+e– collider is established outside Europe**:
    - Development of a high-energy hh/eh program in a new tunnel, with reduced energy reach.
    - Complement both FCChh and HL-LHC with an electron-hadron collider such as the LHeC.
- **Scientific Complementarity and Return**:
  - Fall-back scenarios offer faster scientific return and increased complementarity.
  - Programs including ee, pp, and ep collisions on similar timescales can compensate for the scientific loss compared to the FCC program.

ESPP Organisation and decision process

- "Secretariat”:
  - Secretary (chair): K. Jakobs
  - CERN SPC chair: H. Montgomery
  - ECFA chair: P. S
  - LDG chair: D. Newbold
    - M. Seidel from 1/1/2025

- European Strategy Group (ESG): ~60 persons
  - Secretariat (secretary chairs ESG);
  - One rep per CERN member state;
  - One rep per lab in LDG;
  - CERN DG, CERN DG-elect;
  - Invitees: PPG, President of Council, 1 rep from each Associate Member State and Observer State, 1 rep from EC; chairs of ApPEC, NuPECC, ESFRI

PPG:
Physics + Technology working groups

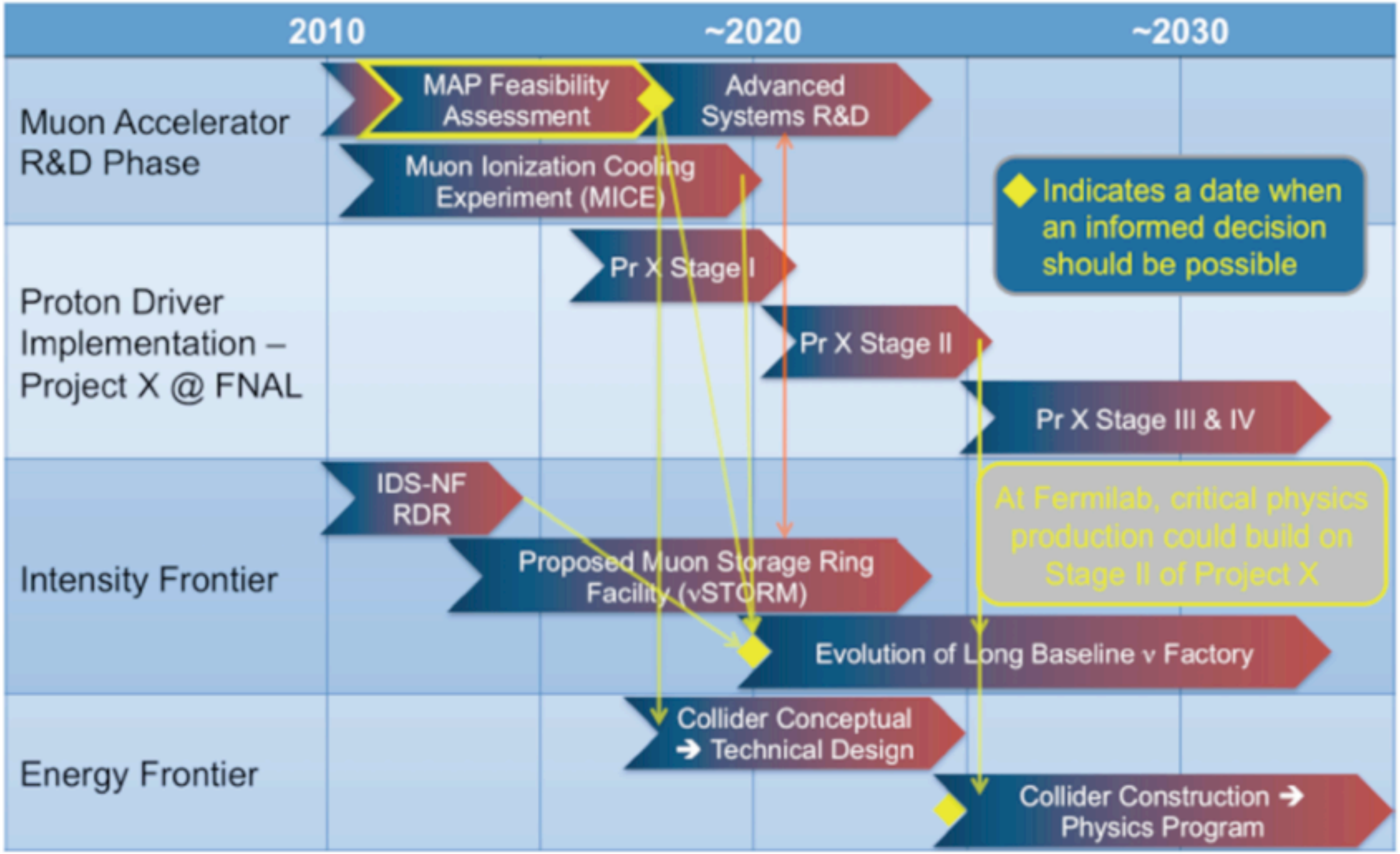
- Electroweak physics (including Higgs physics)
- Strong interaction
- Flavour physics
- Beyond the Standard Model physics
- Neutrino physics and cosmic messengers
- Dark matter and dark sector
- Accelerator science and technology
- Detector instrumentation
- Computing

à Physics Briefing Book

ESG: Overarching topics

- **National input / roadmaps (à strategic)**
- **Projects (FCC, LC, LE-FCC-hh, MC, ..)**
  (timeline, costs, …. (physics à PPG))
  - Comparisons across proposed projects
- Relations with other fields of physics
- Implementation of the Strategy
  (role of CERN and National Labs, coordination of European participation in projects sited outside Europe, …)
- Knowledge and Technology transfer
- Sustainability, environmental impact
- Public engagement, education, communication
- …

Don’t look back (snowmass 2013)



◆ Indicates a date when an informed decision should be possible

At Fermilab, critical physics production could build on Stage II of Project X