2023 P5:
An Early Career Perspective

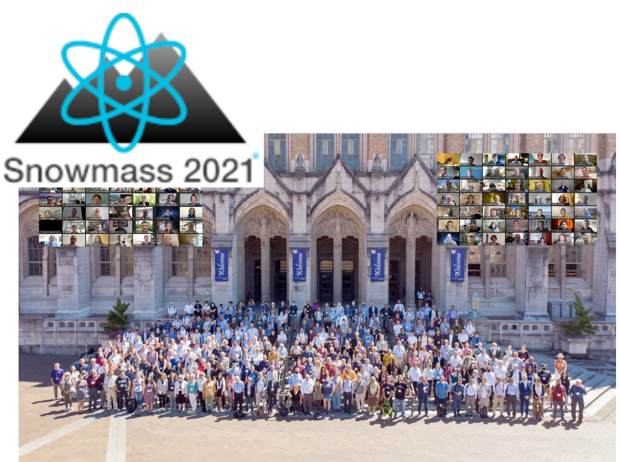
Julia Gonski

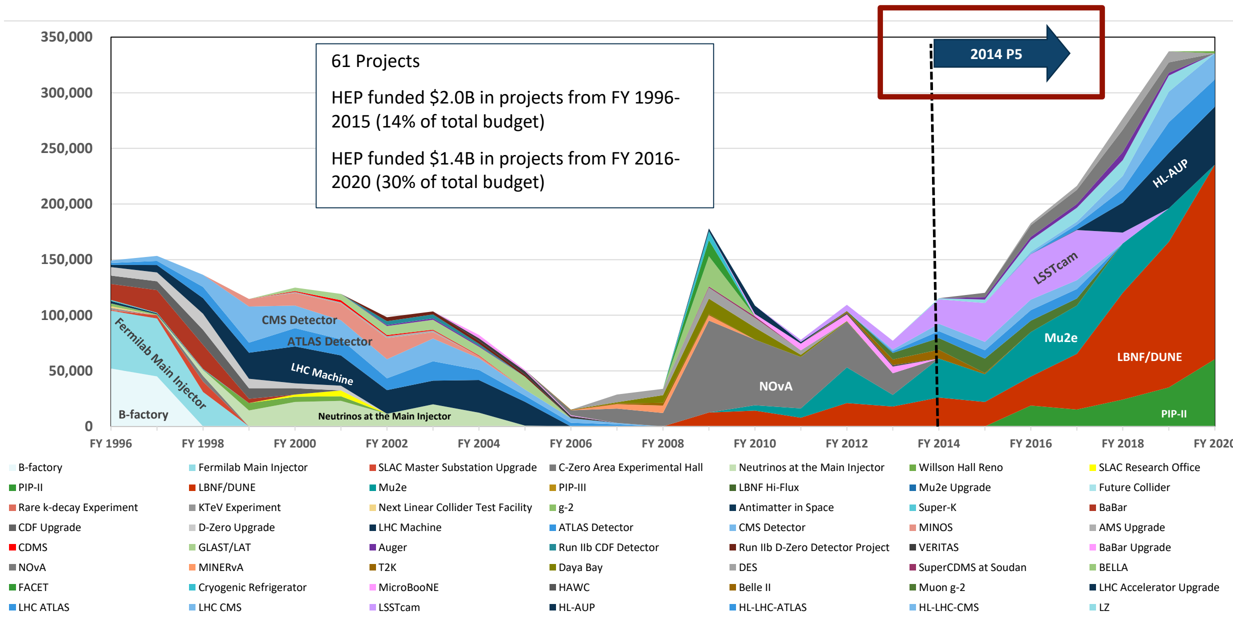
13 December 2023

USLUA Annual Meeting

Background

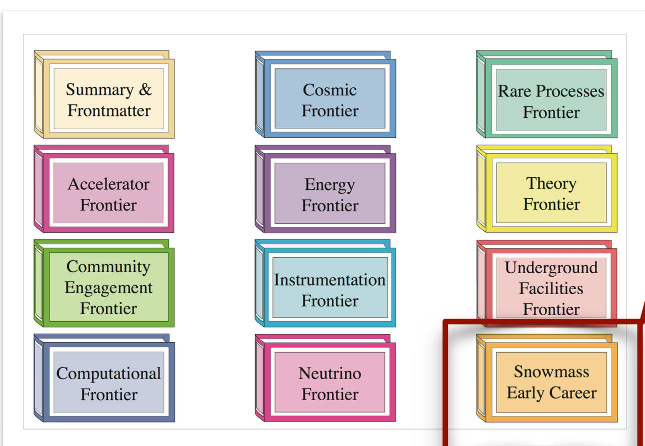
- **Snowmass** [2021-22]: decadal U.S. HEP community effort to express opinions on physics drivers & future experimental facilities
  - Preceded by European Committee for Future Accelerators (ECFA) “European Strategy” update in 2020
- **Particle Physics Project Prioritization Panel (P5):**
  - Subpanel of High Energy Physics Advisory Panel (DOE)
  - Reviews Snowmass material & lays out priorities for the field for the *next 10 years* within a *20-year context*
- Previous P5 report in 2013 identified 5 science drivers for the field
  - Huge success with funding agencies

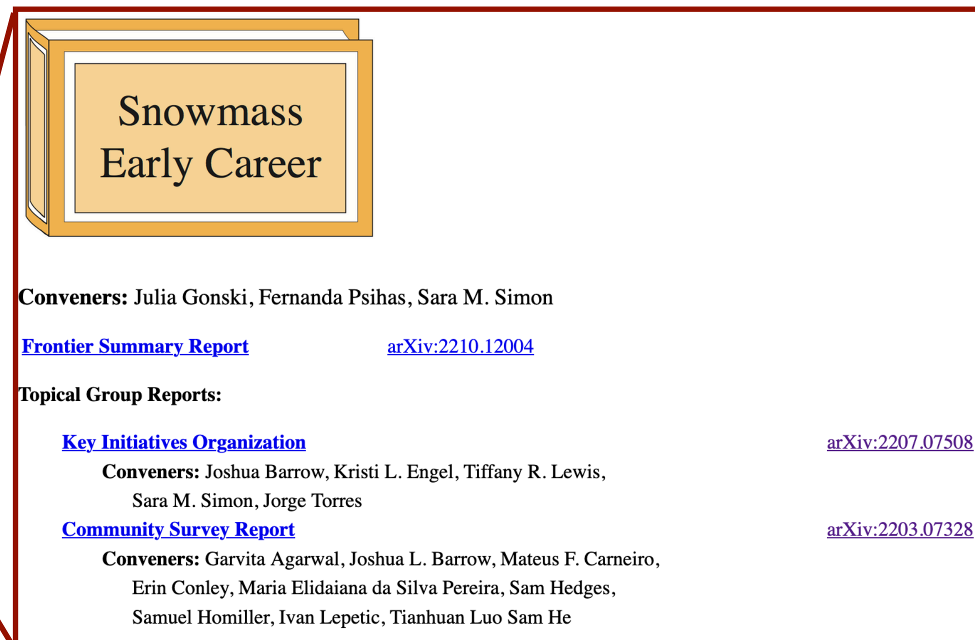




Snowmass Early Career

- For the first time in Snowmass history, the Early Career organization has a chapter in the Snowmass Book! [2210.12004]
  - Includes a summary of the SEC survey report and **early career recommendations for P5**
- P5 1.5: "The panel was especially encouraged by the **active participation of early career members** in the community-driven planning process. They represent the **future of our field** and are essential to the realization of the goals and aspirations detailed in this report."





Snowmass Early Career

Conveners: Julia Gonski, Fernanda Psihas, Sara M. Simon

Frontier Summary Report arXiv:2210.12004

Topical Group Reports:

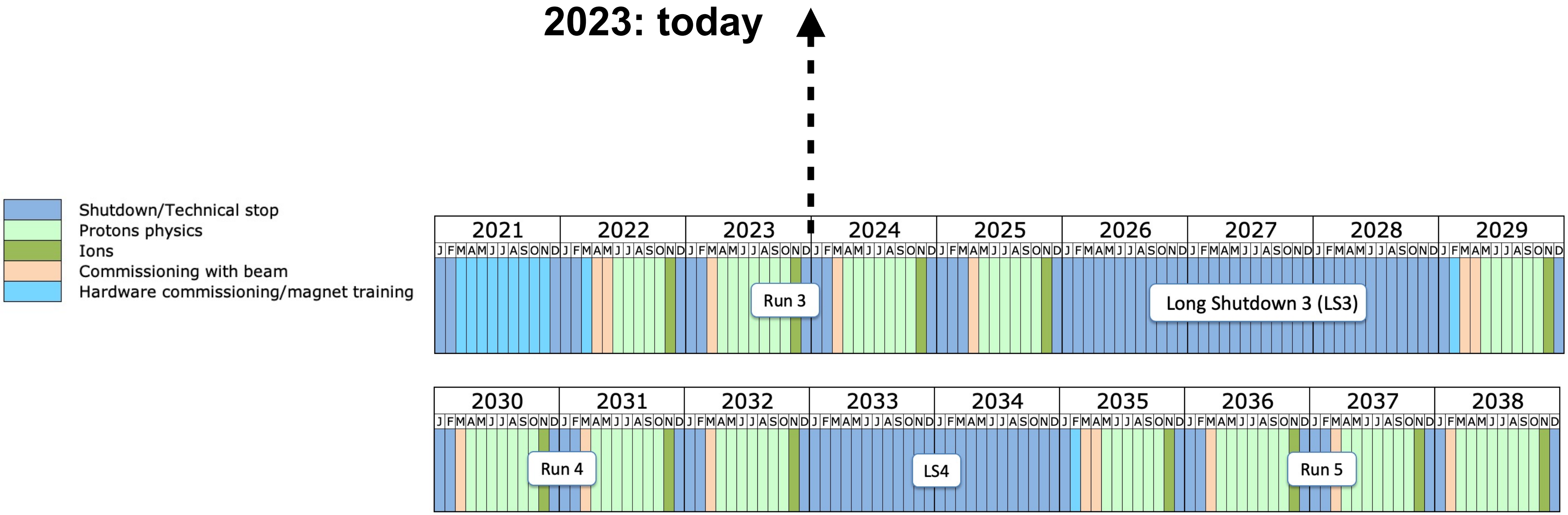
Key Initiatives Organization arXiv:2207.07508
Conveners: Joshua Barrow, Kristi L. Engel, Tiffany R. Lewis, Sara M. Simon, Jorge Torres

Community Survey Report arXiv:2203.07328
Conveners: Garvita Agarwal, Joshua L. Barrow, Mateus F. Carneiro, Erin Conley, Maria Elidaiana da Silva Pereira, Sam Hedges, Samuel Homiller, Ivan Lepetic, Tianhuan Luo Sam He

Getting from Early to Late Career: P5 2023 Projects & Ideas

LHC Timeline

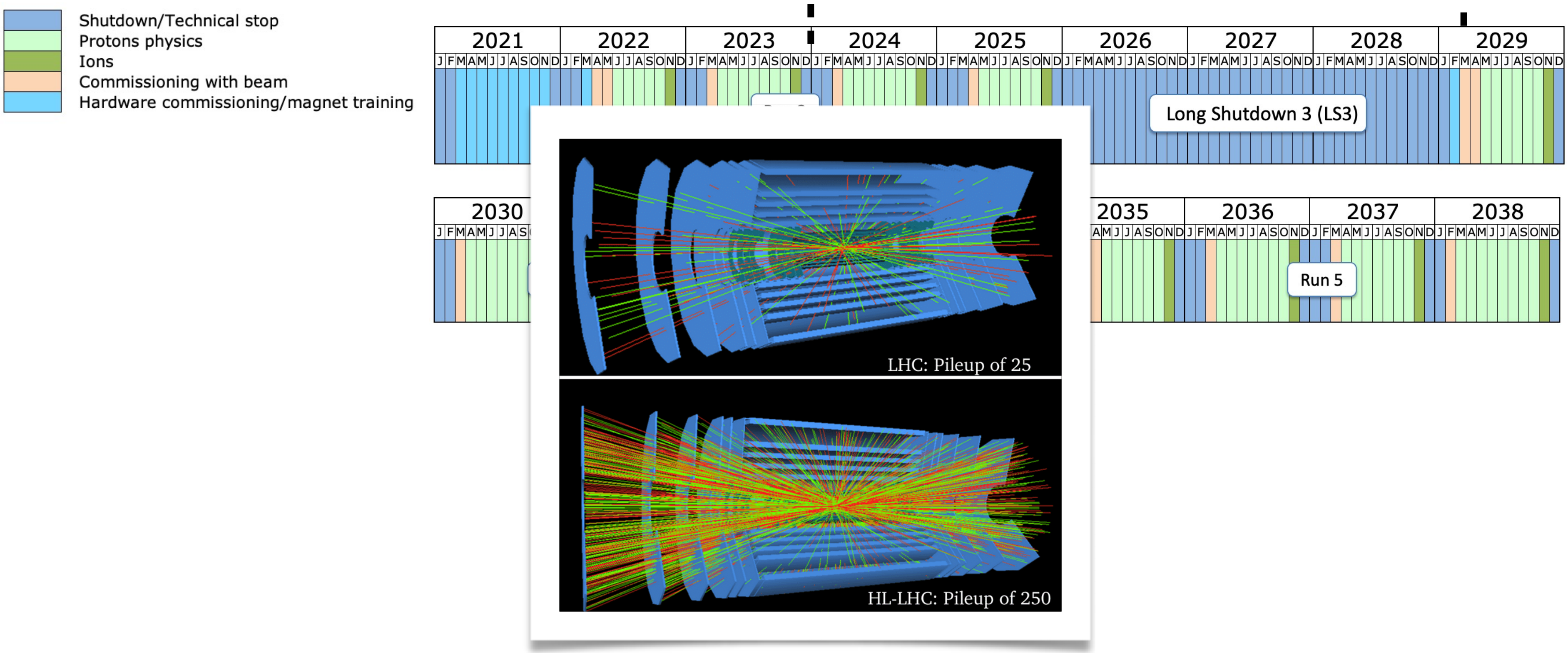
LHC Timeline



LHC Timeline

2023: today

2029: Start of High Luminosity LHC
(our first future collider!)



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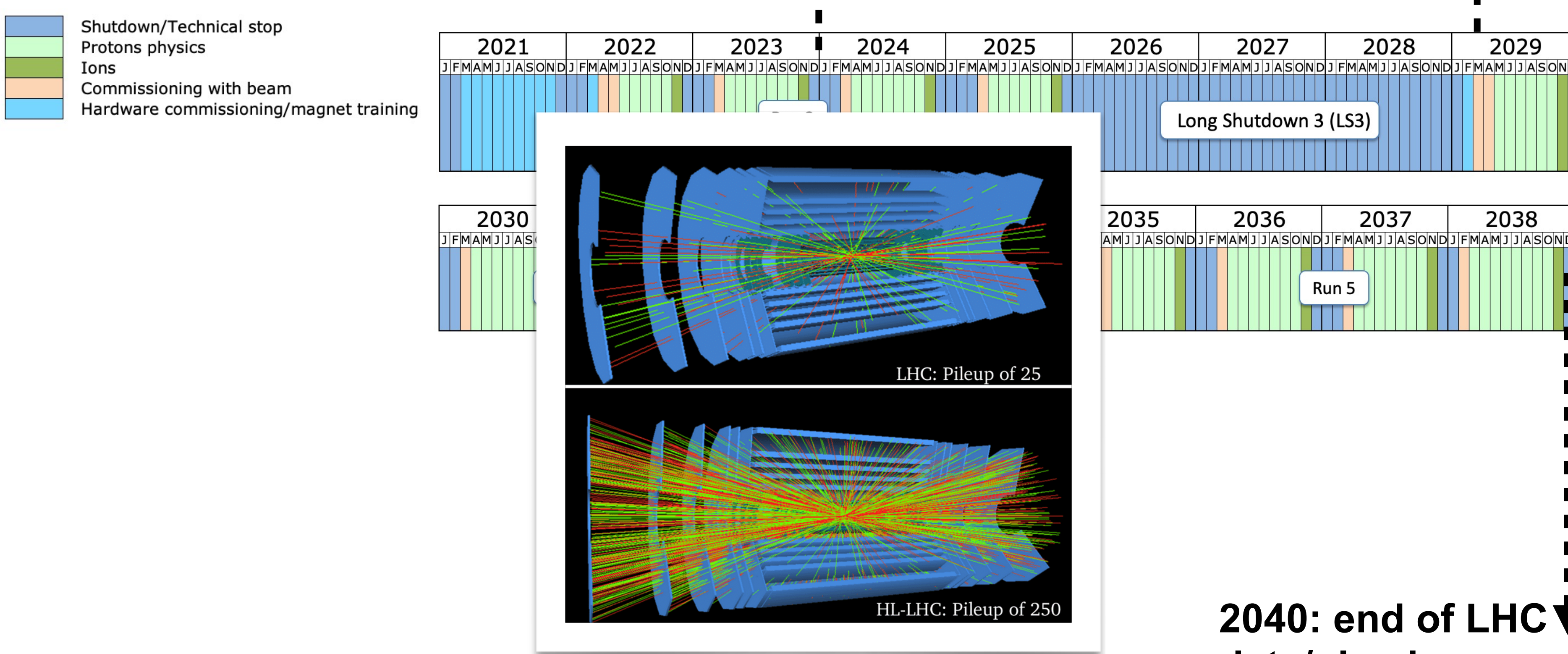
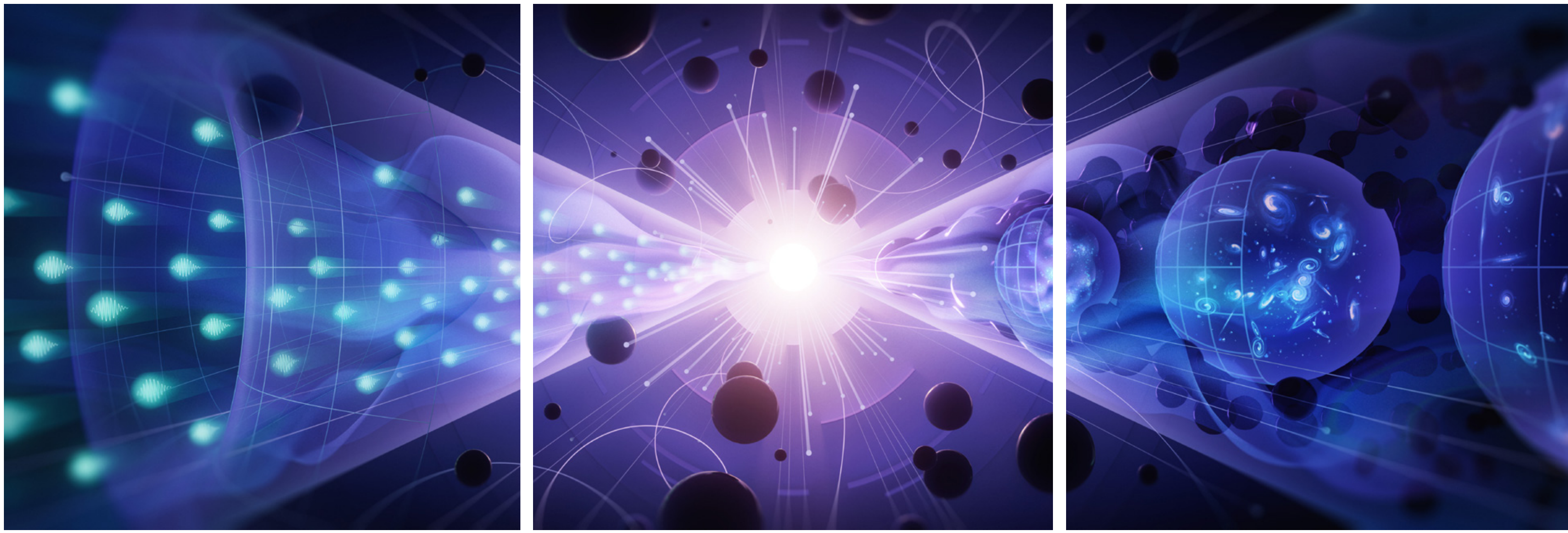


2040: end of LHC data/physics

2023 P5



Decipher the Quantum Realm

Elucidate the Mysteries of Neutrinos

Reveal the Secrets of the Higgs Boson

Explore New Paradigms in Physics

Search for Direct Evidence of New Particles

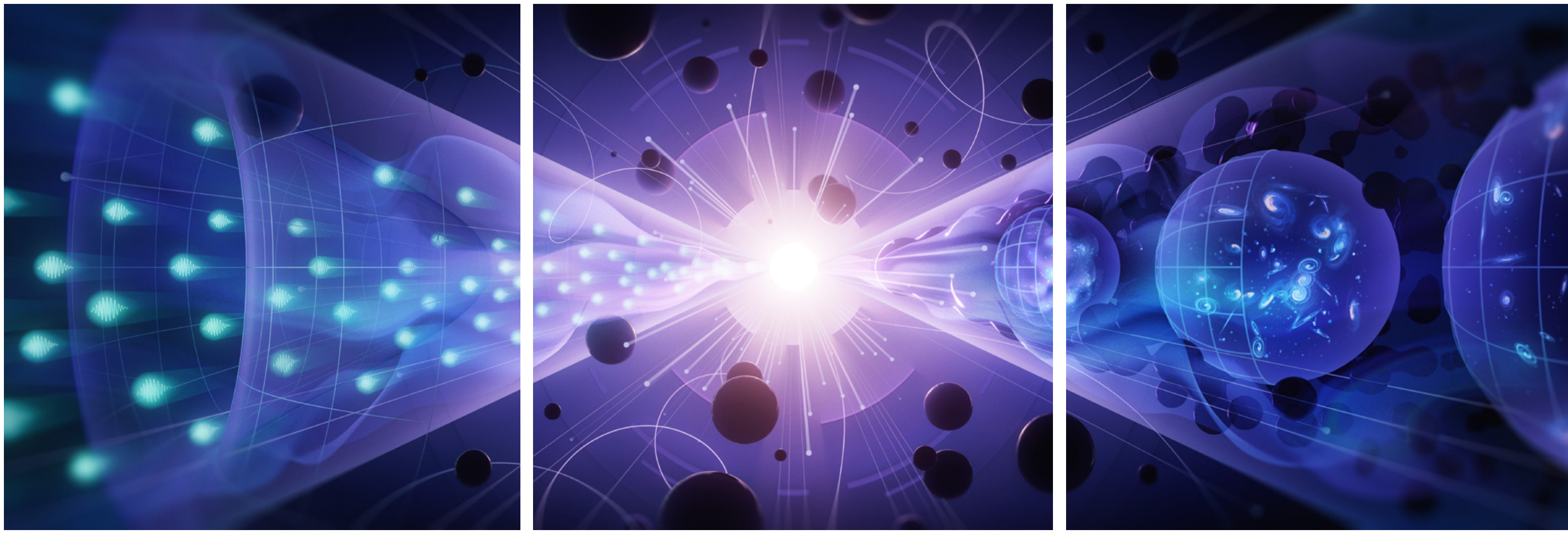
Pursue Quantum Imprints of New Phenomena

Illuminate the Hidden Universe

Determine the Nature of Dark Matter

Understand What Drives Cosmic Evolution

2023 P5



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Priorities (unordered)

Ongoing (Rec 1)

- **HL-LHC**
- Dune Phase 1
- Vera Rubin/LSST
- Smaller projects: ex. NOvA, IceCube, SuperCDMS, Belle II, LHCb, Mu2e, etc.

Priorities (unordered)

SLAC

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Construction (Rec 2)

1. CMB-S4
2. DUNE Phase-II
3. **Off-shore Higgs factory**
4. Gen-3 direct detection DM (preferably US-sited)
5. IceCube-Gen2

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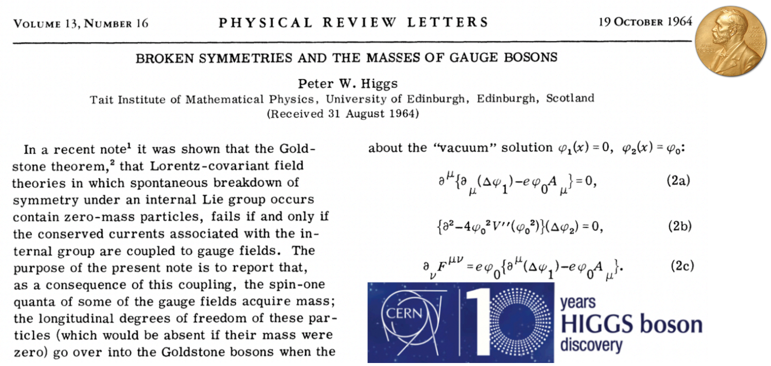
R&D (Rec 4)

- **Cost-effective 10 TeV pCM collider: demonstrator within 10 years**
- Theory
- General Accelerator R&D (GARD)
- Instrumentation for scientific tools
- **Detectors for Higgs factory & 10 TeV pCM**
- Cyberinfrastructure/novel data analysis
- Fermilab accelerator complex

Second Decade of the Higgs Boson

- Higgs boson observation in 2012 by ATLAS & CMS "completes" the Standard Model
  - Measurement of Higgs couplings to bosons (gluons, photons, W/Z) and heaviest fermions (taus, tops, bottoms)
- Higgs has unique connection to remaining BSM questions

➡ P5: "Higgs boson physics can only be studied at high-energy collider experiments"



VOLUME 13, NUMBER 16 PHYSICAL REVIEW LETTERS 19 OCTOBER 1964

BROKEN SYMMETRIES AND THE MASSES OF GAUGE BOSONS

Peter W. Higgs

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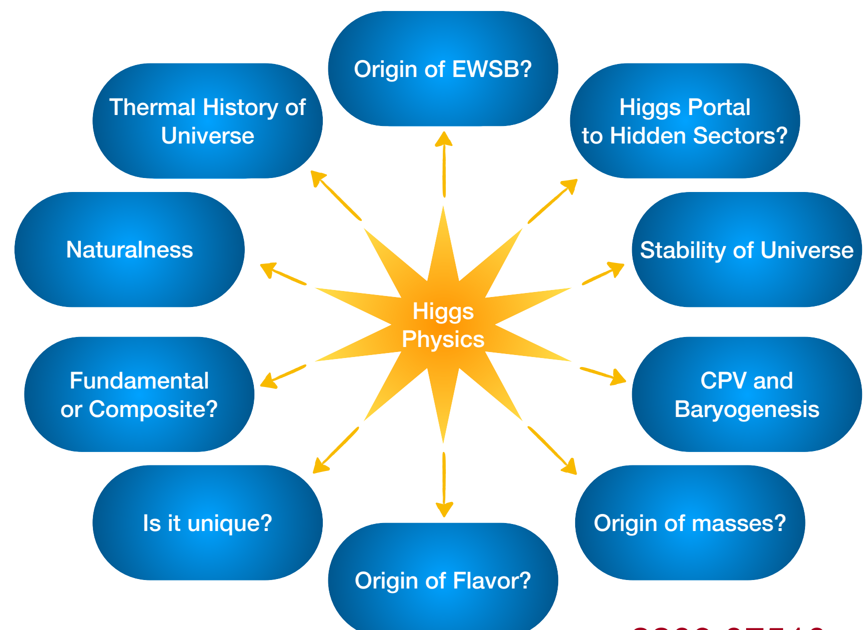


2209.07510

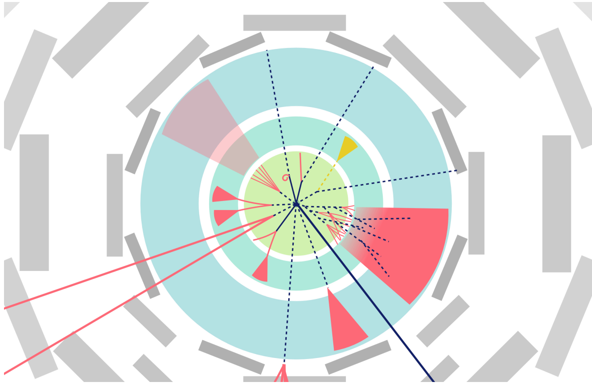
The High Luminosity LHC Era

- Higgs physics:
  - Measure Higgs couplings to 2nd generation fermions (muons, charm, strange?)

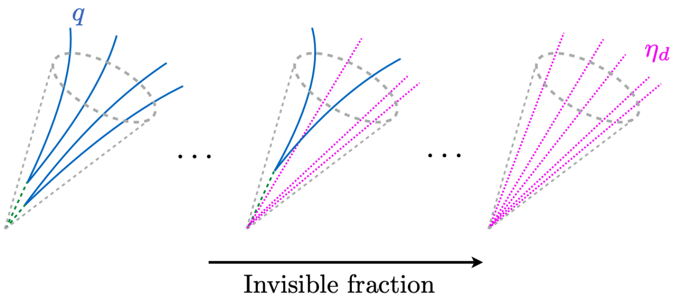
- Direct beyond the SM searches:
  - P5 5.1.2: “Explore challenging signatures such as compressed spectra, boosted topologies, and long-lived particles.”
  - Dark matter: unique collider handle on complex dark sectors (eg. dark QCD)

- Development of new data analysis & reconstruction techniques, eg. advanced AI/ML

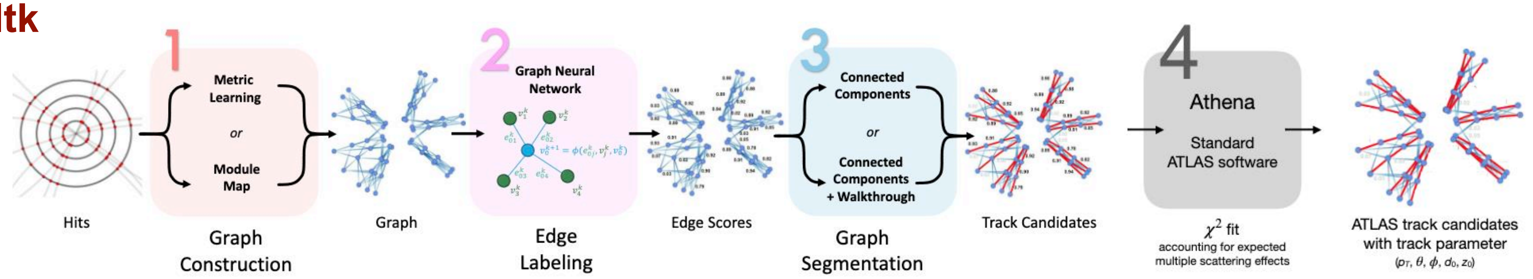
Long-Lived Particles



Dark Jets



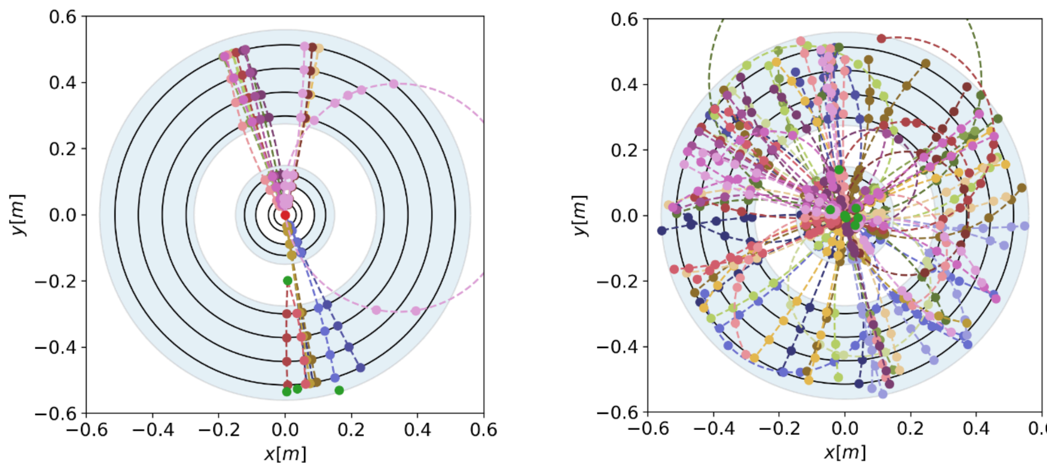
GNN4Itk



Why Higgs Factory?

- Electron-positron factory with CoM energy range of 90-350 GeV (scanning Z, WW, H, top production)
- Higgs/precision physics:
  - 10x improvement on Higgs mass/couplings; indirect evidence of new physics through deviations in high-precision measurements
- Beyond the SM searches:
  - Unique sensitivity via clean environment & large luminosities to light, feebly coupled, and/or long-lived particle final states
    - Higgs decay to invisible (ex. dark matter) improved 10x over HL-LHC

e+e- pp

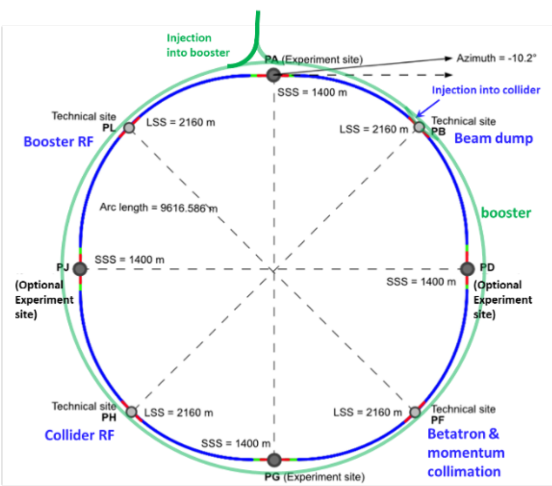


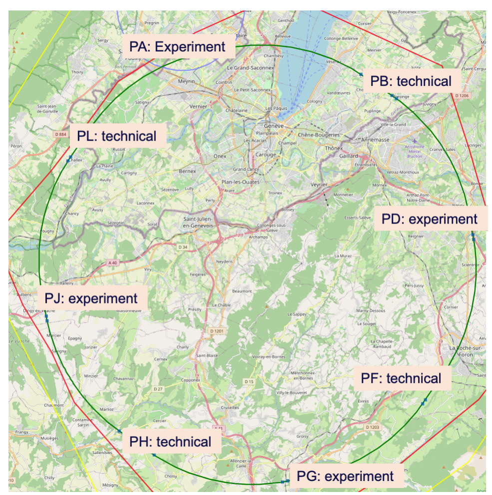
(a) $e^+e^- \to \chi_1^+\chi_1^-$ (b) $pp \to \chi_1^+\chi_1^-$

Off-Shore Higgs Factory Options

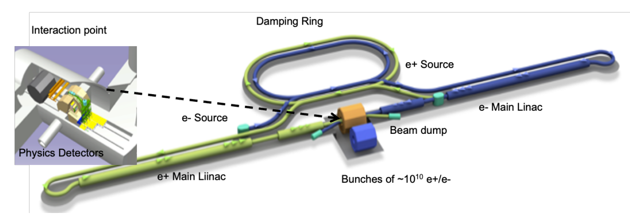
- P5: "The US should actively engage in design studies to establish the technical feasibility and cost envelope of Higgs factory designs."
    - **Future Circular Collider (FCC) ee**: hosted by CERN
        - "From European Strategy: "An **electron-positron Higgs factory** is the highest-priority next collider. For the longer term… a **proton-proton collider at the highest achievable energy**."
    - **International Linear Collider (ILC)**: funded four-year ILC Technology Network (ITN) program with developing European/Japanese agreement

FCC





ILC

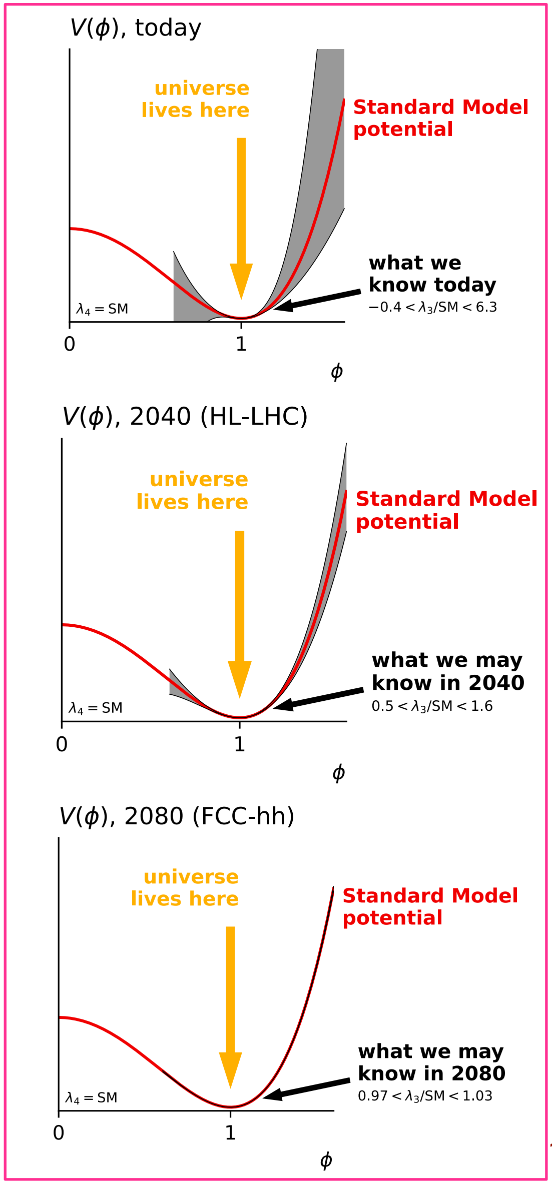


Towards 10 TeV pCM

- Ultimate direct discovery reach of TeV scale phenomena
- Possible with hadron (FCC-hh @ 100 TeV) or muon colliders, but R&D is needed

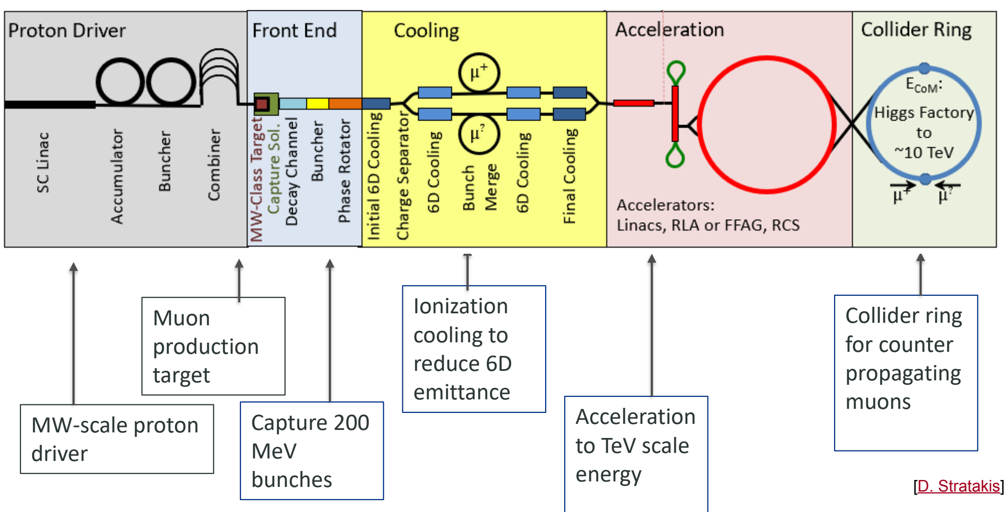
- Higgs physics:
  - Probe the electroweak phase transition; Higgs self coupling measurements to 5% precision

- Direct beyond the SM searches:
  - Direct discovery of the particles responsible for any deviations observed in Higgs factory
  - Dark matter: "reach the thermal WIMP target for minimal WIMP candidates"

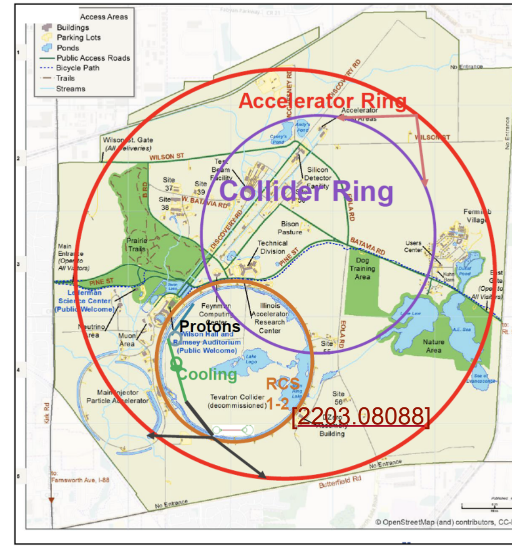


Muon Collider

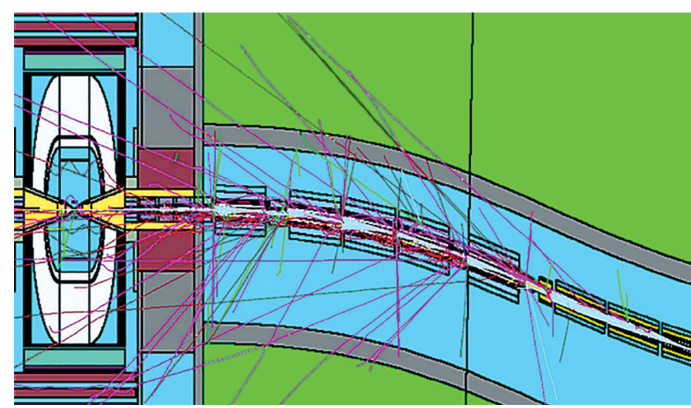
- Best of both worlds: cleanness of leptons, no PDFs as in hadron collider
  - But muons decay! Considerable challenge to accelerate & build detectors
- P5 2.3: “This P5 plan outlines an aggressive R&D program… **for a muon collider test facility by the end of the decade**. This facility would test the feasibility of **developing a muon collider in the following decade**.”
- P5 2.5: “…synergies between muon and proton colliders, especially in the area of development of **high-field magnets**. R&D efforts in the next 5-year timescale → initiating demonstrator facilities within a 10-year timescale.”



μC @ Fermilab



μC Beam- Induced Background



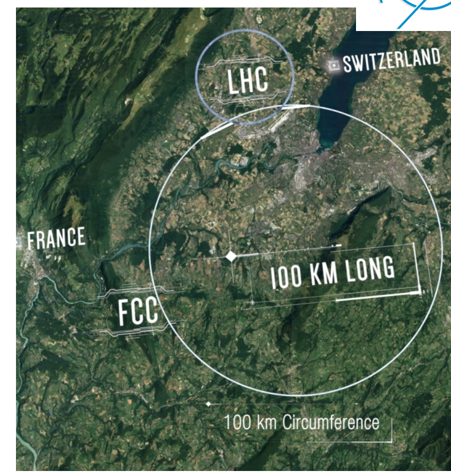
International Considerations

- Off-shore Higgs factory requires continued partnership with CERN and Japanese governments
- Unified FCC proposal: ee 2045-2060 and hh 2070-2095 [100 TeV]
- **The Chinese proposal**: Circular Electron Positron Collider (CEPC) [91, 160, 240, 360 GeV] → Super proton-proton Collider (SppC) [62.5 TeV]
  - CEPC Accelerator International TDR/Cost Review in 2023; potential selection by Chinese government in 2025, physics in 2035
- Significant global participation in DUNE & potential future muon collider at Fermilab → renewed lobbying effort on visa/immigration policy well in advance

➡ *“Science is not political”*

ILC Siting, Japan

FCC



CEPC Siting, China

What’s Next?

Future Colliders: Get Involved!

SLAC

- P5 6.5: "To enable targeted R&D before specific collider projects are established in the US, an investment in collider **detector R&D funding at the level of $20M per year** and collider **accelerator R&D at the level of $35M per year** in 2023 dollars is warranted."

- Detector R&D: APS DPF Coordinating Panel on Advanced Detectors (CPAD) organizing R&D Collaborations (RDCs) to coordinate progress on key DOE Basic Research Needs topics: **ongoing now**
  - High channel density, high data rate, spatial constraints, high radiation, cryogenic temperatures…

- Future Circular Collider:
  - Feasibility study ongoing (eg. tunnel implementation done), full report expected by 2025
  - US FCC organization well underway: second annual workshop @ MIT in April 2024 (abstract submission is open!)

- "The US should participate in the International Muon Collider Collaboration (IMCC) and take a leading role in defining a reference design."

APS | DIVISION OF PARTICLES & FIELDS

FUTURE CIRCULAR COLLIDER

International MUON Collider Collaboration

Looking Forward

Today — Community endorsement of P5!
➡R&D collaborations are forming for generic detector studies

2025 — FCC Feasibility Study report

2028 — Update to European Strategy *(CERN Council FCC endorsement?)*

2030 — *Demonstrator results from μC?*
Recommendation 6: "targeted panel.. that makes decisions on the US accelerator-based program" (DOE CD0?)

2031 — *Next Snowmass?*

* *speculative*

Timelines

"But all these timelines are so long!

I'll be retired by the time we get data from any of these machines!

How will we maintain the pipeline of early career scientists?"

Timelines

1964

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CERN 10 years HIGGS boson discovery

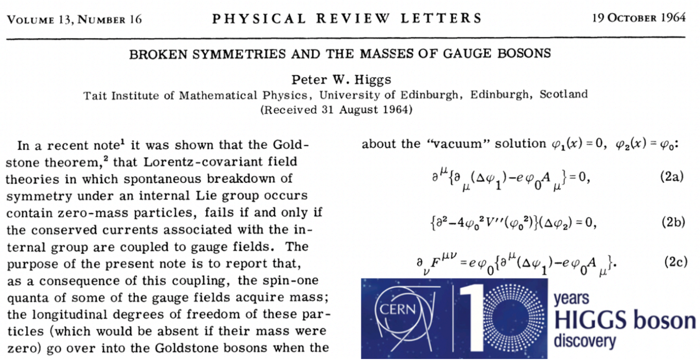
→

2012

Timelines

SLAC

1964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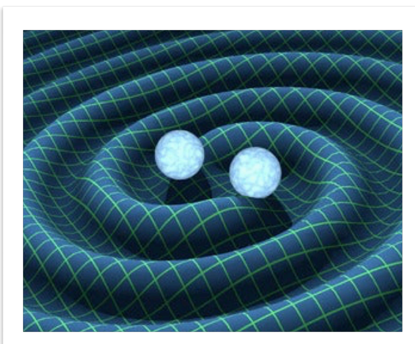
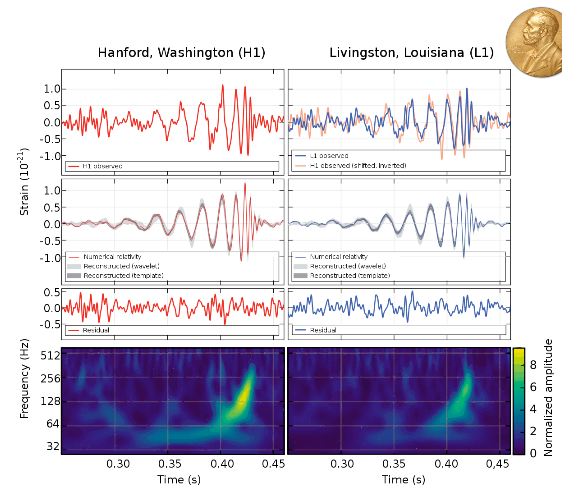
2012

1916

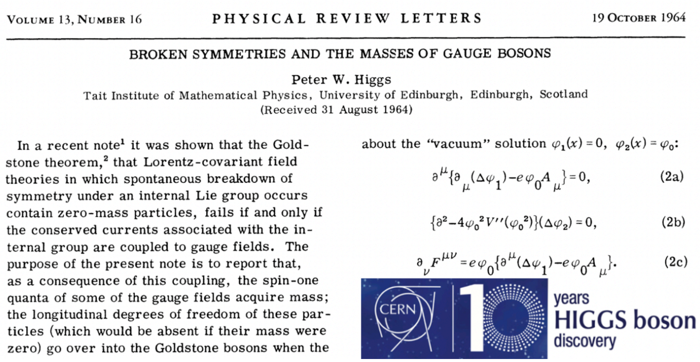


2015



Timelines

1964



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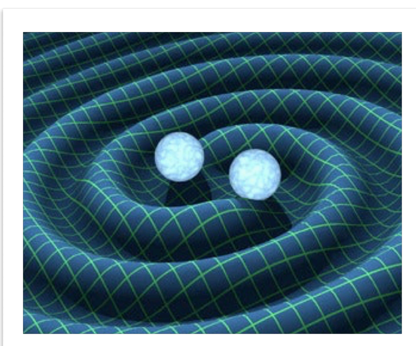

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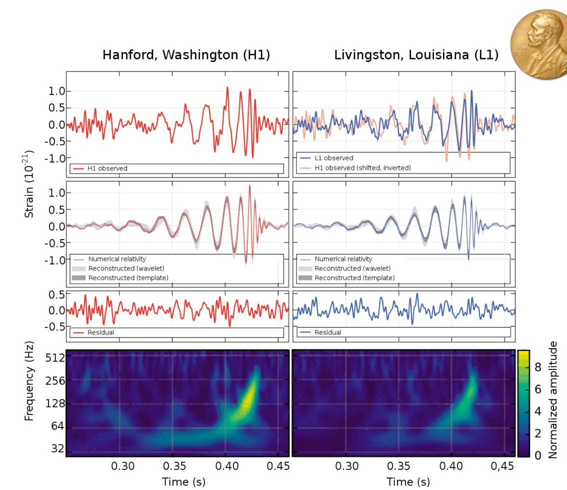
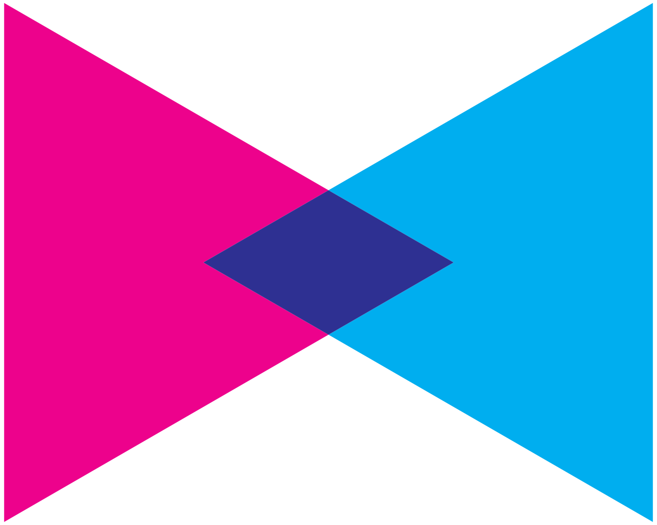
2015



→ Particle physics is a marathon, not a sprint

Conclusions

- 2023 P5 is here!
- **Now is the time to start actively preparing for future colliders**
  - Engage in generic detector & accelerator R&D: pave the way for long-term future of the field
  - As more information becomes available about collider proposals, be ready to capitalize on opportunities
- **An exciting century of colliders & discoveries ahead!**



Backup

P5 2023 Figure 1: Experiments

SLAC

Figure 1 – Program and Timeline in Baseline Scenario (B)

Index: Operation | Construction | R&D, Research | P: Primary | S: Secondary

§ Possible acceleration/expansion for more favorable budget situations

Science Experiments

Timeline 2024–2034; Science Drivers

Experiment	Neutrinos	Higgs Boson	Dark Matter	Cosmic Evolution	Direct Evidence	Quantum Imprints	Astronomy & Astrophysics
LHC		P	P		P	P	
LZ, XENONnT			P				
NOvA/T2K	P				S		
SBN	P				S		
DESI/DESI-II	S		S	P			P
Belle II			S		S	P	
SuperCDMS			P				
Rubin/LSST & DESC	S		S	P			P
Mu2e						P	
DarkSide-20k			P				
HL-LHC		P	P		P	P	
DUNE Phase I	P				S	S	S
CMB-S4	S		S	P			P
CTA			S				P
G3 Dark Matter §	S		P				
IceCube-Gen2	P		S				P
DUNE FD3	P				S	S	S
DUNE MCND	P				S	S	
Higgs factory §		P	S		P	P	
DUNE FD4 §	P				S	S	S
Spec-S5 §	S		S	P			P
Mu2e-II						P	
Multi-TeV § (DEMONSTRATOR)		P	P		P	S	
LIM	S		P	P			P

Advancing Science and Technology through Agile Experiments

Experiment	Neutrinos	Higgs Boson	Dark Matter	Cosmic Evolution	Direct Evidence	Quantum Imprints	Astronomy & Astrophysics
ASTAE §	P	P	P	P	P	P	

P5 2023 Figure 1: Initiatives

Figure 1 – Program and Timeline in Baseline Scenario (B)

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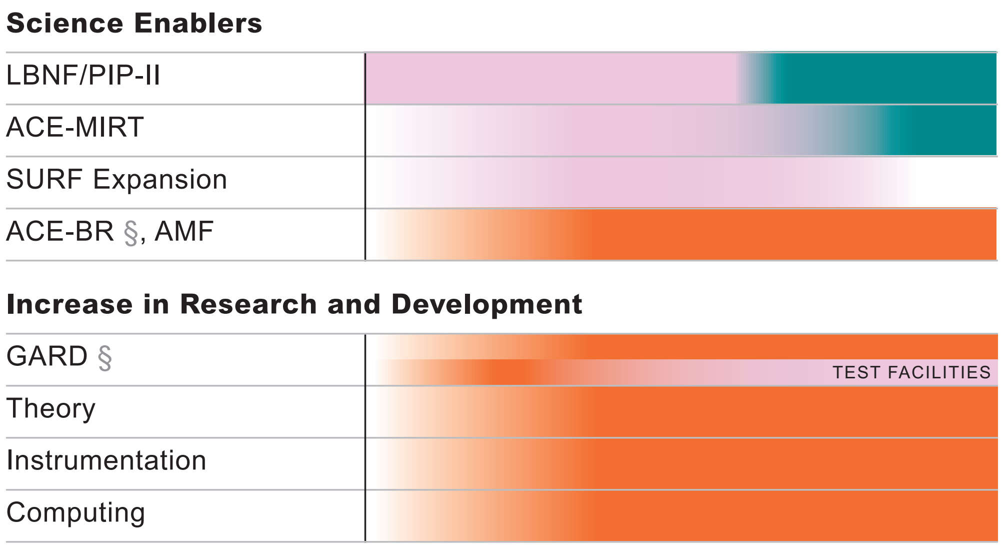
§ Possible acceleration/expansion for more favorable budget situations



Approximate timeline of the recommended program within the baseline scenario. Projects in each category are in chronological order. For IceCube-Gen2 and CTA, we do not have information on budgetary constraints and hence timelines are only technically limited. The primary/secondary driver designation reflects the panel's understanding of a project's focus, not the relative strength of the science cases. Projects that share a driver, whether primary or secondary, generally address that driver in different and complementary ways.

P5 2023 Figure 2: Construction

Figure 2 – Construction in Various Budget Scenarios

Index: N: No Y: Yes R&D: Recommend R&D but no funding for project C: Conditional yes based on review P: Primary S: Secondary

Delayed: Recommend construction but delayed to the next decade

Can be considered as part of ASTAE with reduced scope

Scenarios	Less	Baseline	More	Neutrinos	Higgs Boson	Dark Matter	Cosmic Evolution	Direct Evidence	Quantum Imprints	Astronomy & Astrophysics
				Science Drivers						
US Construction Cost >$3B										
on-shore Higgs factory	N	N	N		P	S		P	P	
$1–3B										
off-shore Higgs factory	Delayed	Y	Y		P	S		P	P	
ACE-BR	R&D	R&D	C	P				P	P	
$400–1000M										
CMB-S4	Y	Y	Y	S		S	P			P
Spec-S5	R&D	R&D	Y	S		S	P			P
$100–400M										
IceCube-Gen2	Y	Y	Y	P		S				P
G3 Dark Matter 1	Y	Y	Y	S		P				
DUNE FD3	Y	Y	Y	P				S	S	S
test facilities & demonstrator	C	C	C		P	P		P	P	
ACE-MIRT	R&D	Y	Y	P						
DUNE FD4	R&D	R&D	Y	P				S	S	S
G3 Dark Matter 2	N	N	Y	S		P				
Mu2e-II	R&D	R&D	R&D						P	
srEDM	N	N	N						P	
$60–100M										
SURF Expansion	N	Y	Y	P		P				
DUNE MCND	N	Y	Y	P				S	S	
MATHUSLA #	N	N	N			P		P		
FPF #	N	N	N	P		P		P		

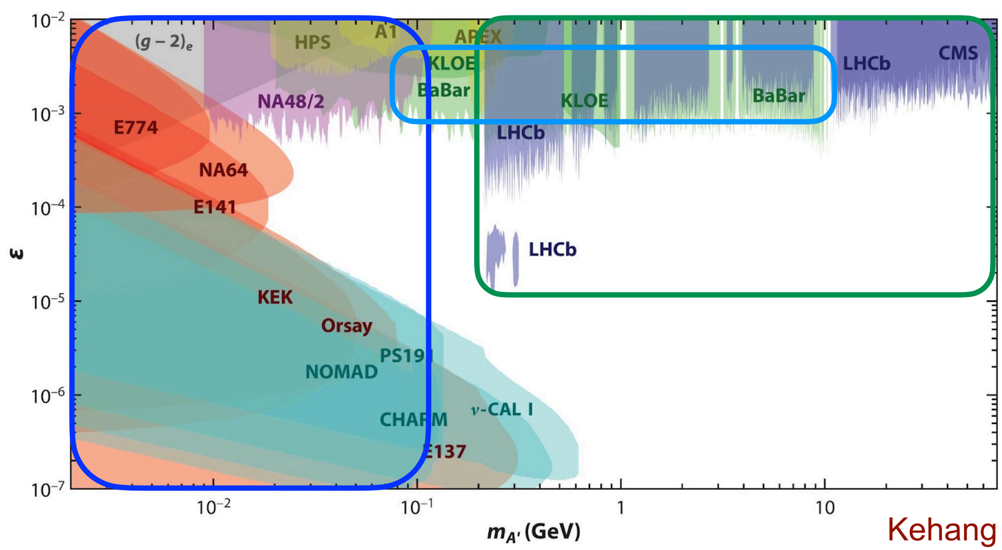
Medium and large-scale US investments in new construction projects for possible budget scenarios. The projects are ordered in three budget brackets according to the number of "N" entries and then by approximate budget sizes. For the off-shore Higgs factory, test facilities & demonstrators, see Recommendation 6. See the caption of Figure 1 concerning the science drivers, and Section 8 for the rationale behind these choices.

Balanced Program (Rec 3)

- P5 6.2: New small-project portfolio @ DOE "Advancing Science and Technology through Agile Experiments" (ASTAE) [$35 million/year]
- LHC-adjacent experiments and/or proposed Forward Physics Facility (FPF) @ CERN: several decades improvement on LLP benchmarks
- Extracting physics from excess particles at PIP-II or in wakefield demonstrators: new opportunity for beam dump experiments

➡ *Small-scale experiments offer unique physics reach, opportunity for leadership, & invaluable experience with instrumentation*

Dark Photon Exclusion



e+e- colliders & B factories

Beam dumps, meson decay, fixed target, …

LHC Experiments

Kehang Bai

Graham M, et al. 2021 Annu. Rev. Nucl. Part. Sci. 71:37–58

Detector R&D

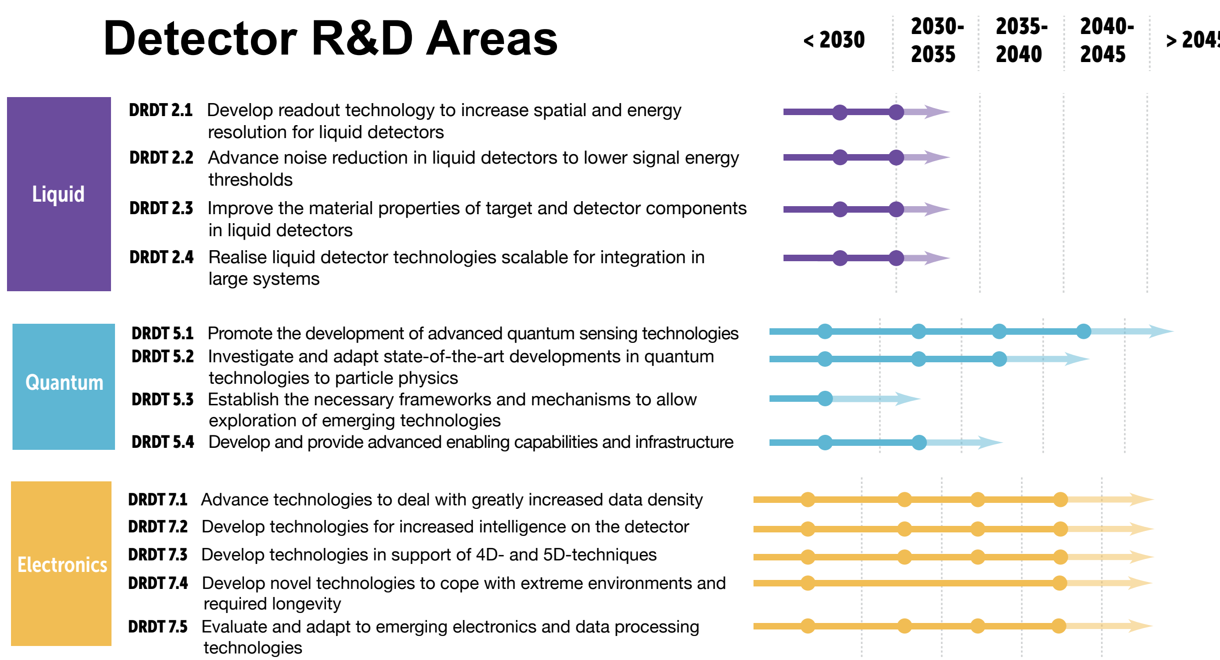
- Need to **R&D detector technologies** that can meet the pressing requirements of future collider environments [$20 million/year]
    - High channel density, high data rate, spatial constraints, high radiation, cryogenic temperatures…
- APS DPF Coordinating Panel on Advanced Detectors (CPAD) organizing R&D Collaborations (RDCs) to coordinate progress on key DOE Basic Research Needs topics: **ongoing now**

➡ Accelerator-generic detector R&D can facilitate the latest & greatest instrumentation for the benefit of all HEP subfields

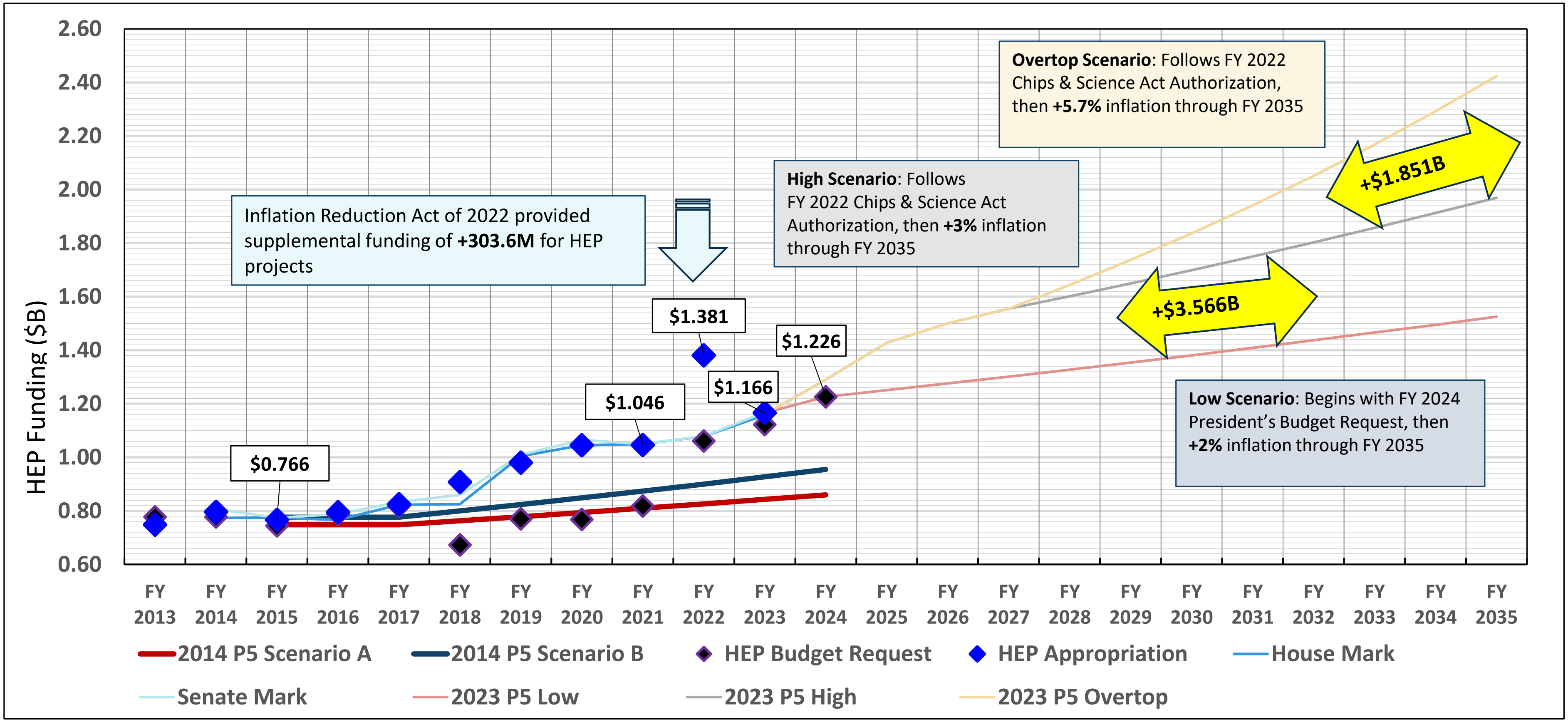
Next-gen neutrino/LAr TPC detectors

Quantum sensor/ infrastructure for dark matter/computing

"Fast ML" for neutrino/ cosmology experiments & monitoring



P5 Budget Scenarios



Collider Implementation Task Force Report

- Comprehensive evaluation & comparisons of collider options from Snowmass Accelerator Frontier
- Assessment categories:
  1. Years of pre-project R&D needed (technical risk and maturity)
  2. Years until first physics (technically limited schedule)
  3. Project cost in 2021B$ w/o contingency and escalation (cost)
  4. Total operating electric power consumption in MW (environmental impact)

Higgs Factories

Proposal Name	CM energy nom. (range) [TeV]	Lum./IP @ nom. CME [10^{34} $cm^{-2}s^{-1}$]	Years of pre-project R&D	Years to first physics	Construction cost range [2021 B$]	Est. operating electric power [MW]
FCC-ee[1,2]	0.24 (0.09-0.37)	7.7 (28.9)	0-2	13-18	12-18	290
CEPC[1,2]	0.24 (0.09-0.37)	8.3 (16.6)	0-2	13-18	12-18	340
ILC[3] - Higgs factory	0.25 (0.09-1)	2.7	0-2	<12	7-12	140
CLIC[3] - Higgs factory	0.38 (0.09-1)	2.3	0-2	13-18	7-12	110
CCC[3] (Cool Copper Collider)	0.25 (0.25-0.55)	1.3	3-5	13-18	7-12	150
CERC[3] (Circular ERL Collider)	0.24 (0.09-0.6)	78	5-10	19-24	12-30	90
ReLiC[1,3] (Recycling Linear Collider)	0.24 (0.25-1)	165 (330)	5-10	>25	7-18	315
ERLC[3] (ERL linear collider)	0.24 (0.25-0.5)	90	5-10	>25	12-18	250
XCC (FEL-based $\gamma\gamma$ collider)	0.125 (0.125-0.14)	0.1	5-10	19-24	4-7	90
Muon Collider Higgs Factory[3]	0.13	0.01	>10	19-24	4-7	200

[T. Roser]

An Early Career From Here

Today — *Run 3* — **2029** — *Run 4* — **2035** — *Run 5* — **2040**

PhD	Postdoc	Tenure
Successful installation & commissioning of HL-LHC Detector R&D for Higgs factory/10 TeV pCM detectors	HL-LHC Operations (upgrades for Run 5?) Auxiliary/small-scale experiments at LHC or future beam dumps Experiment-specific detector prototypes for future colliders	Build Higgs factory detectors & design muon collider ones!

Notes to Senior Community

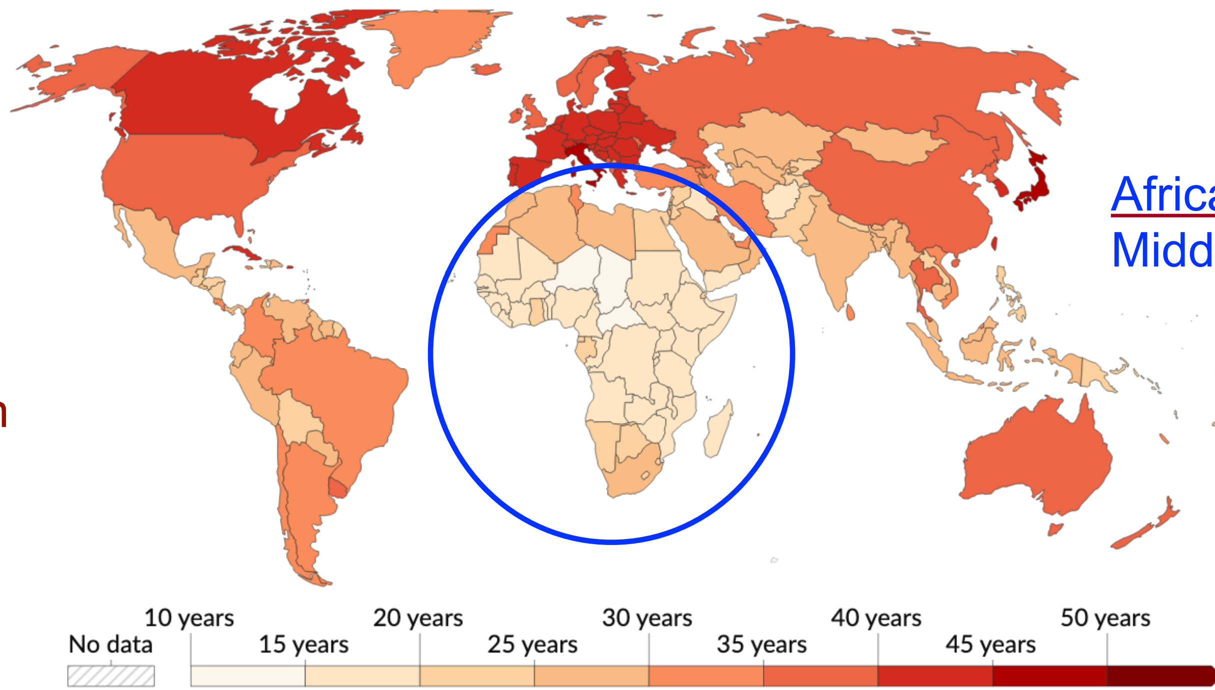
➡ Consider that *operating* today's detectors and *project management* for new ones is as important as physics results (and convince your departmental colleagues)

➡ P5 Rec 5: " Funding agencies should strategically increase support for research scientists, research hardware and software engineers, technicians…"

Global Early Career Pipeline

- In order to fully pursue the bold aspirations of 2023 P5, we need a robust *global* pipeline of early career scientists to take on future collider projects
- Now more than ever, we need to step up outreach to the leading populations/economies of tomorrow

Mean Age of Global Population



Africa & the Middle East

Collider Implementation Task Force Report

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  2. Years until first physics (technically limited schedule)
  3. Project cost in 2021B$ w/o contingency and escalation (cost)
  4. Total operating electric power consumption in MW (environmental impact)

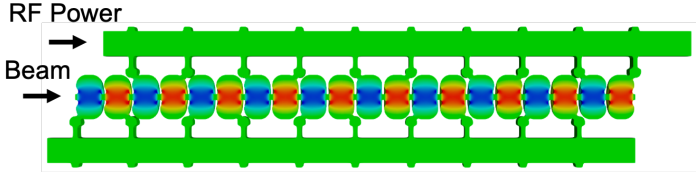
Multi-TeV Colliders

Proposal Name	CM energy nom. (range) [TeV]	Lum./IP @ nom. CME [10^{34} cm^{-2}s^{-1}]	Years of pre-project R&D	Years to first physics	Construction cost range [2021 B$]	Est. operating electric power [MW]
Muon Collider	10 (1.5-14)	20 (40)	>10	>25	12-18	~300
LWFA - LC (Laser-driven)	15 (1-15)	50	>10	>25	18-80	~1030
PWFA - LC (Beam-driven)	15 (1-15)	50	>10	>25	18-50	~620
Structure WFA (Beam-driven)	15 (1-15)	50	>10	>25	18-50	~450
FCC-hh	100	30 (60)	>10	>25	30-50	~560
SPPC	125 (75-125)	13 (26)	>10	>25	30-80	~400

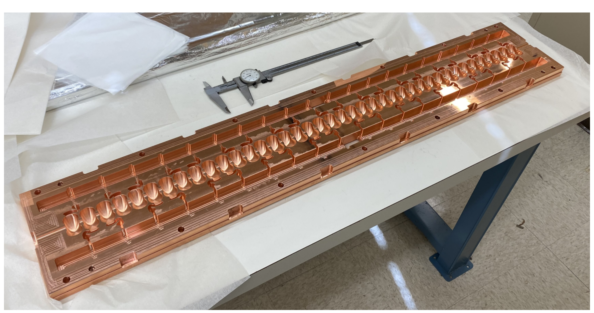
[T. Roser]

C³ (Cool Copper Collider)

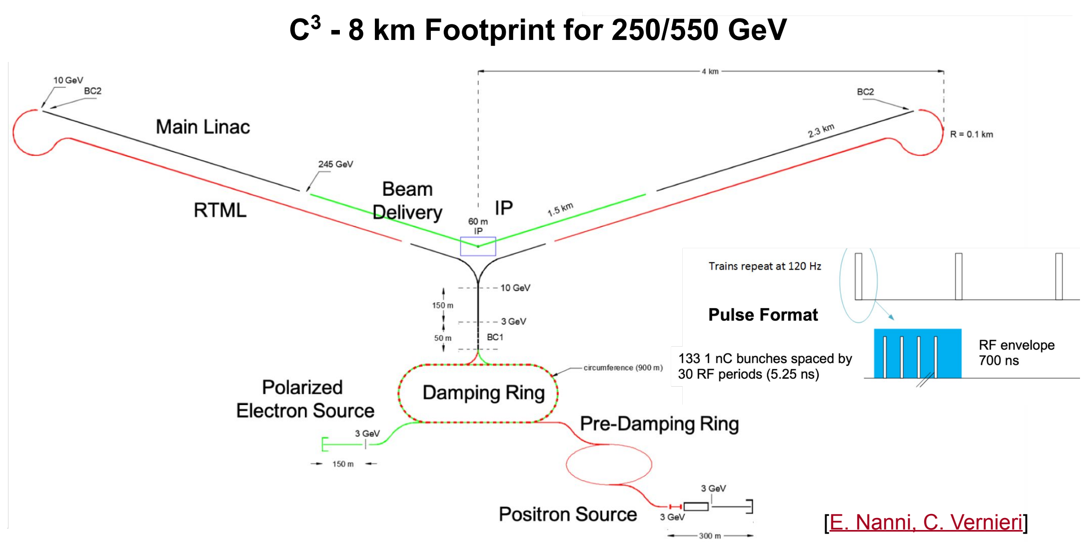
- New concept for linear e+e- collider with "normal-conducting" RF cavities for a more compact design than superconducting options
  - Minimize surface fields, low breakdown at high gradient (70-110 MeV/m)
  - 7 km footprint possible (fits on Fermilab site)
- **Estimated start of physics**: 2040 (technically limited)
- **Cost:** $7-12 B
- **Primary unknown:** new technology requires demonstrator facility (~5 year/50 m scale/$120 M)
  - *Compatible with FCC-ee injector selection timeline*



Electric field magnitude for equal power from RF manifold



JINST (2023) P07053, 18(07)



[E. Nanni, C. Vernieri]

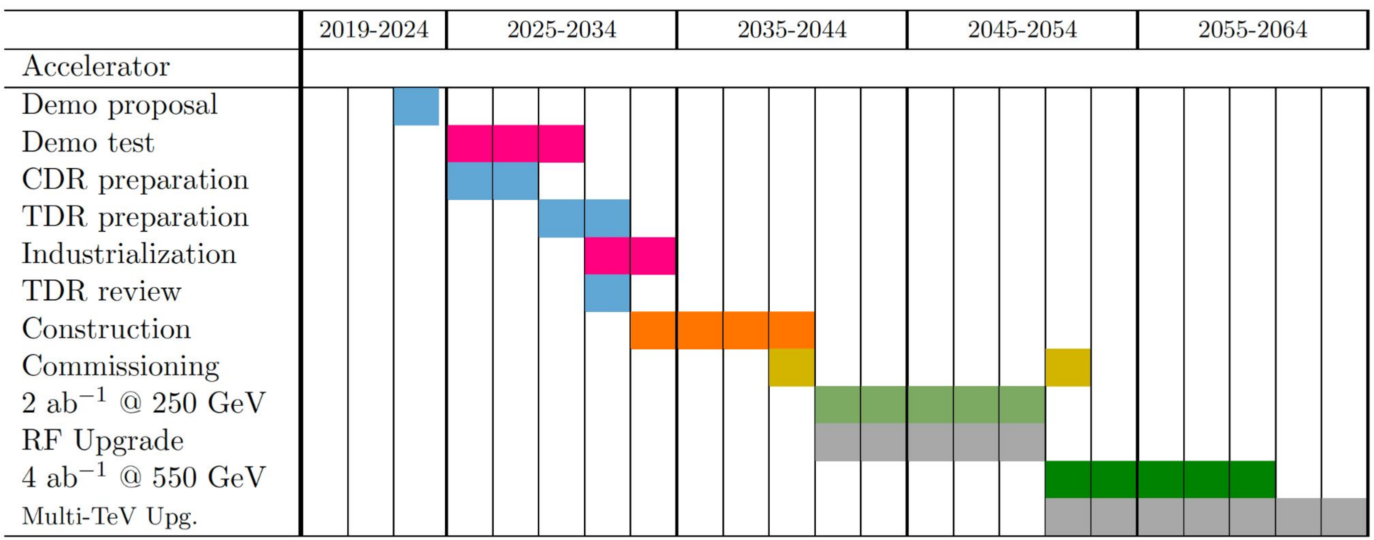
C^3 Specs & Timeline

SLAC

C^3 Parameters

Collider	C^3	C^3
CM Energy [GeV]	250	550
Luminosity [x10^{34}]	1.3	2.4
Gradient [MeV/m]	70	120
Effective Gradient [MeV/m]	63	108
Length [km]	8	8
Num. Bunches per Train	133	75
Train Rep. Rate [Hz]	120	120
Bunch Spacing [ns]	5.26	3.5
Bunch Charge [nC]	1	1
Crossing Angle [rad]	0.014	0.014
Site Power [MW]	~150	~175
Design Maturity	pre-CDR	pre-CDR

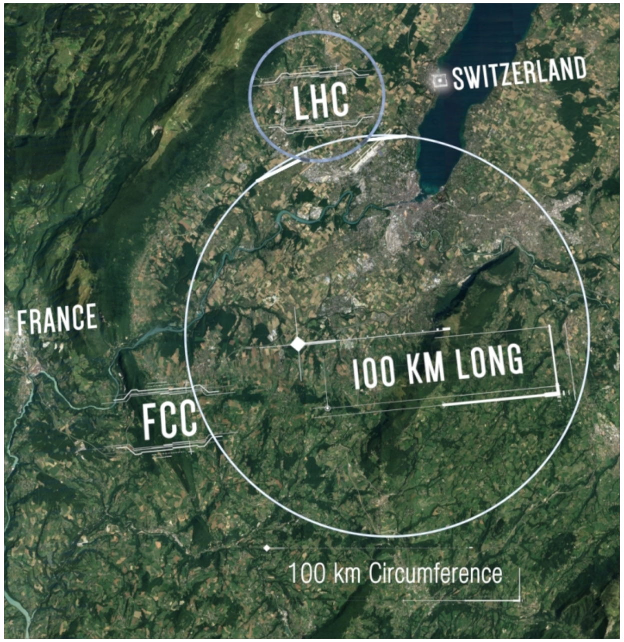
- C^3 provides a rapid route to precision Higgs physics with a compact 8 km footprint
  - Higgs physics run by 2040
  - US-hosted facility possible
- C^3 time structure is compatible with ILC-like detector design and optimizations ongoing
- C^3 upgrade to 550 GeV with only added rf sources
  - Higgs self-coupling and expanded physics reach
- C^3 is scalable to multi-TeV
- C^3 Demo advances technology beyond CDR level
  - 5 year program, followed by completion of TDR and industrialization
  - Three stages with quantitative metrics and milestones for decision points
  - Direct and synergistic contributions to near-term collider concepts



[E. Nanni, C. Vernieri]

Future Circular Collider (ee)

- From European Strategy: "An **electron-positron Higgs factory** is the highest-priority next collider. For the longer term… a **proton-proton collider at the highest achievable energy**."
  - CERN hosted: take advantage of existing injection system/ infrastructure
- **Estimated start of physics**: 2045
- **Cost**: 12 BCHF for tunnel and FCC-ee (tunnel excavation is large percentage of total cost) (Conceptual Design Report [2018])
- ~~Primary unknown~~ Established technology, but R&D can increase efficiency/reduce cost
  - ❗ FCC-ee @ 250 GeV ≃ 300 MW (~2% of annual electricity consumption in Belgium)



	$\sqrt{s}$		L /IP ($cm^{-2} s^{-1}$)	Int L/IP/y (ab^{-1})	Comments
e^+e^- FCC-ee	~90 GeV	Z	182 x 10^{34}	22	2-4 experiments
	160	WW	19.4	2.3	
	240	H	7.3	0.9	Total ~ 15 years of operation
	~365	top	1.33	0.16	

LEP statistics in ~few minutes!

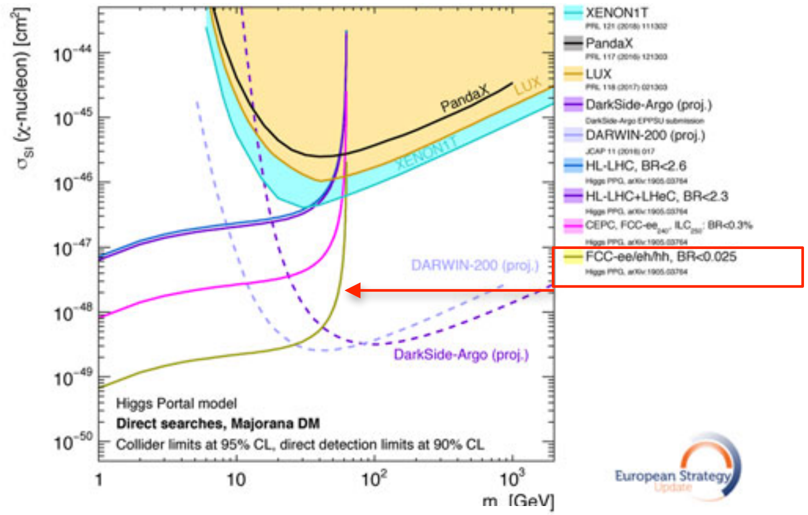
[F. Gianotti]

Future Circular Collider (hh)

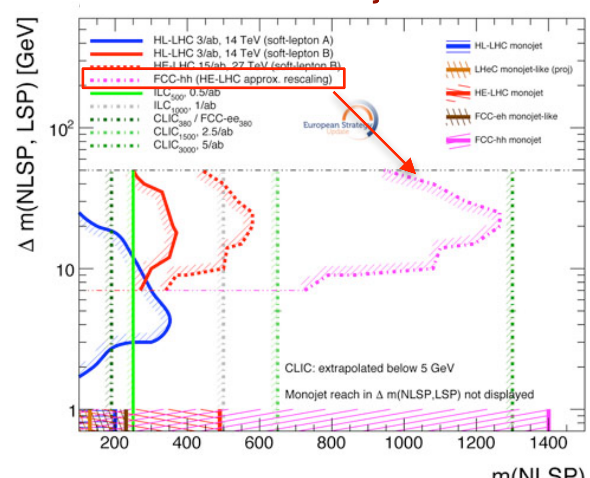
- Proton-proton synchrotron with √s = 100 TeV
- **Estimated start of physics**: 2070
- **Cost**: 17 BCHF additional for FCC-hh (CDR [2018])
- **Primary unknowns**:
  - Very high-field superconducting magnets: 14 - 20 T
  - Stored beam energy: 8 GJ → machine protection
  - High energy consumption: 4 TWh/year

➡FCC Feasibility Study
  - Geological, technical, environmental and administrative feasibility of the tunnel and surface areas
  - Mid-term review 2023; final results 2025

WIMP Simplified Model Projections

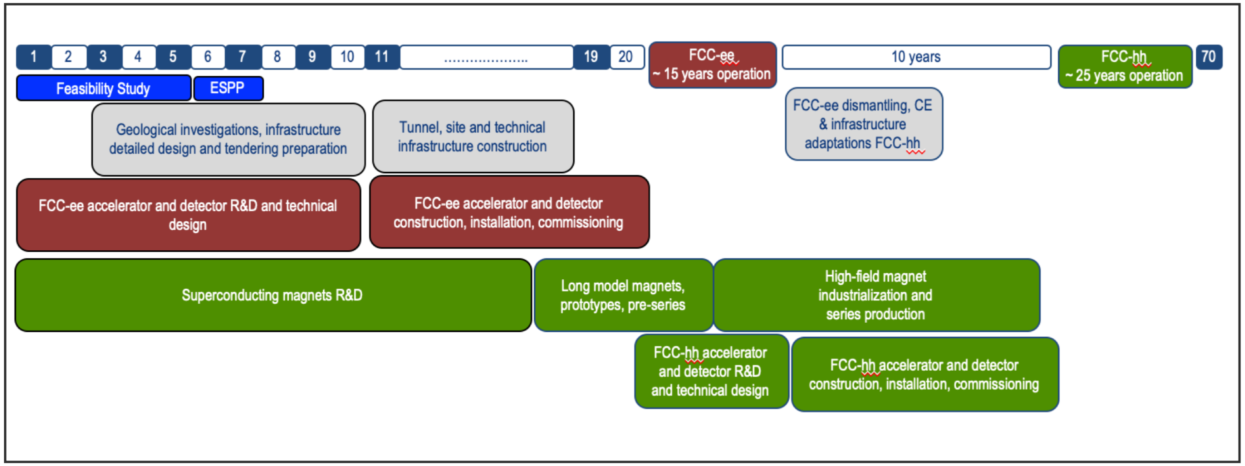


EWK SUSY Projections



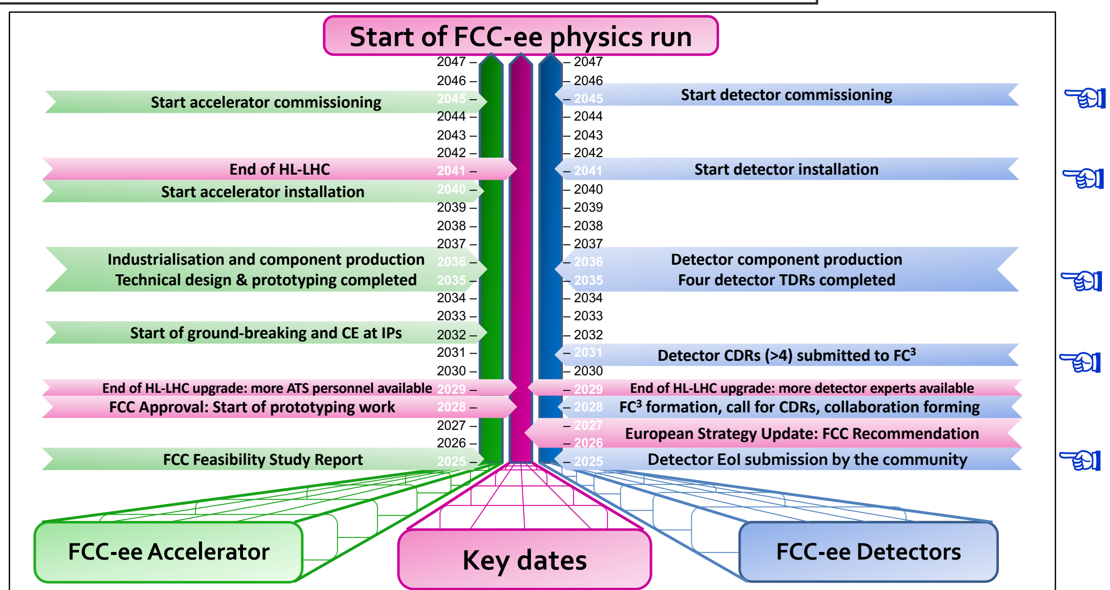
[2306.12897]

FCC Scheduling & Timeline



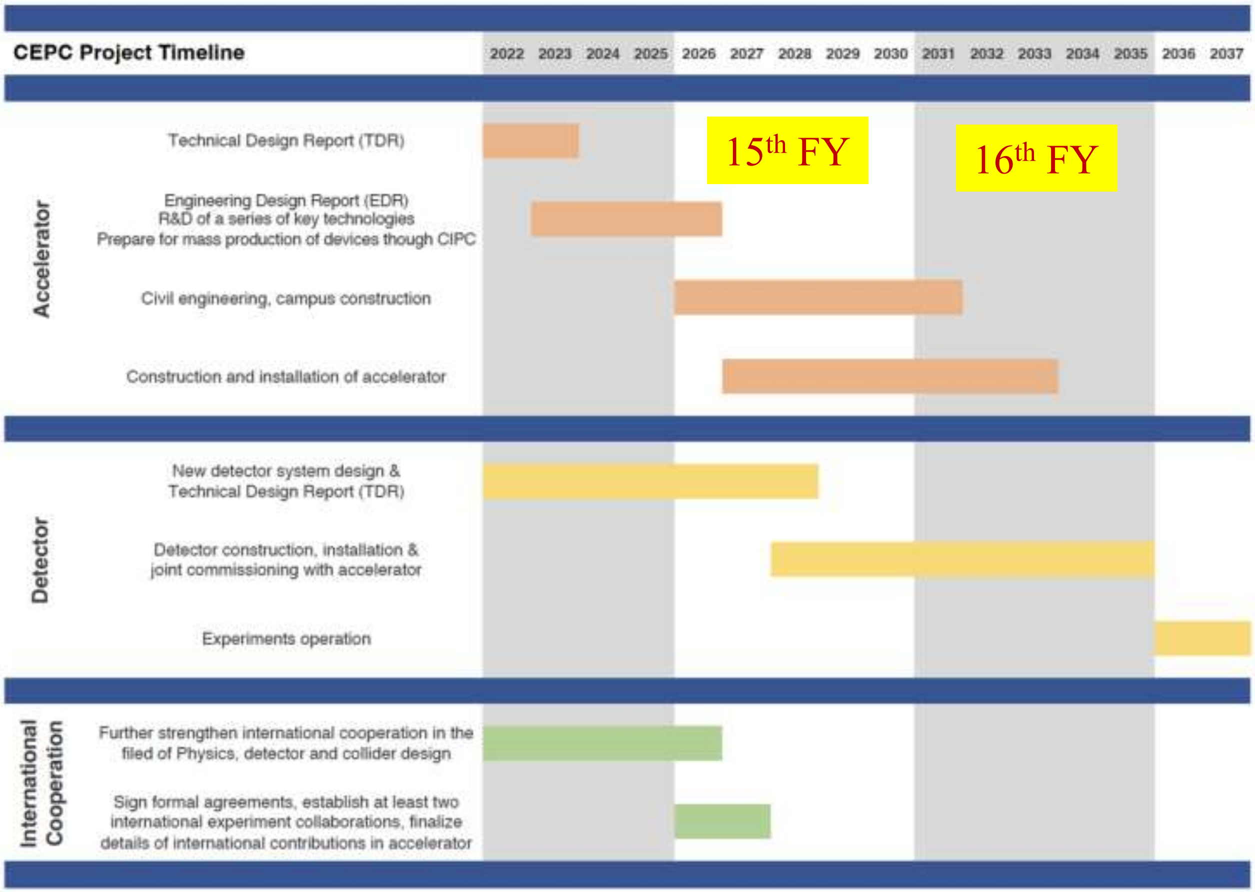
Technical schedule:
FCC-ee could start operation **in 2040 or earlier**

[F. Gianotti]



CEPC/SppC

TDR (2023), EDR(2027), start of construction (2027-8)

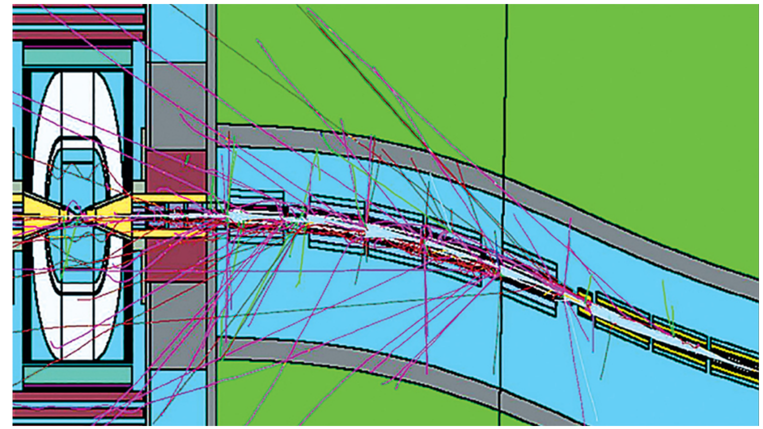


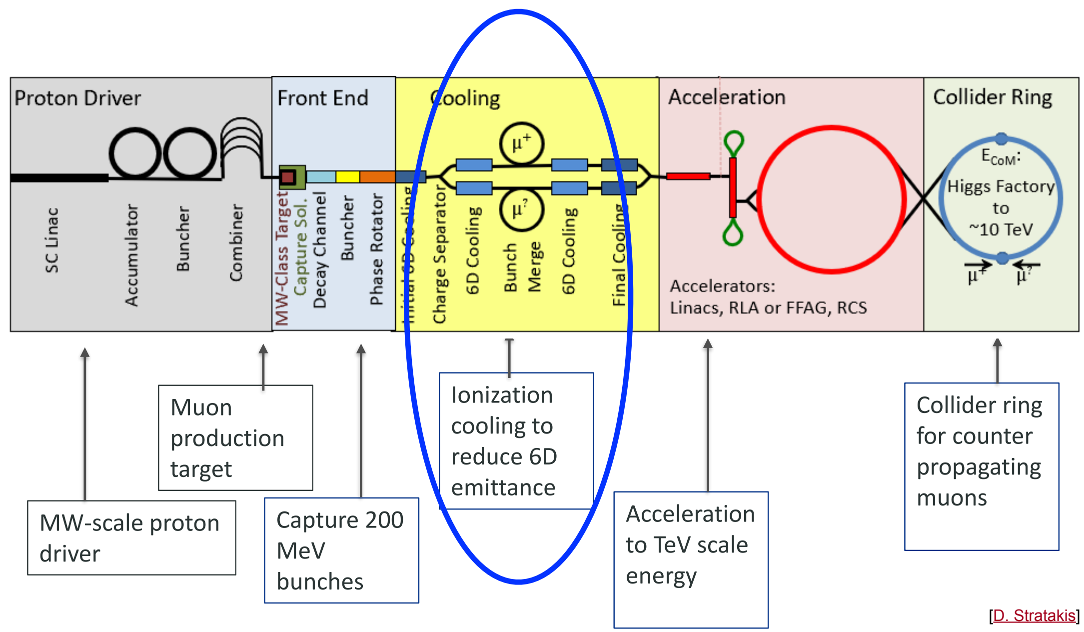
[J. Gao]

Muon Collider (μC)

- Muons are point particles (all energy used in collision) and heavier than electrons (less synchrotron radiation, feasible in circular accelerator)
  - Can provide precision of lepton collider as well as energy reach (10 TeV)
  - *But muons decay!* (τ = 2.2μs) → challenges of accelerating muons & high detector backgrounds
- **Estimated start of physics**: 2045 (technically limited schedule)
  - Needs demonstrator (Technical Design Report in 2030); TDR for final facility in 2040
- **Cost**: $12-18 B
- **Primary unknown:** investment needed to address undemonstrated technologies (eg. muon source and ionization cooling)

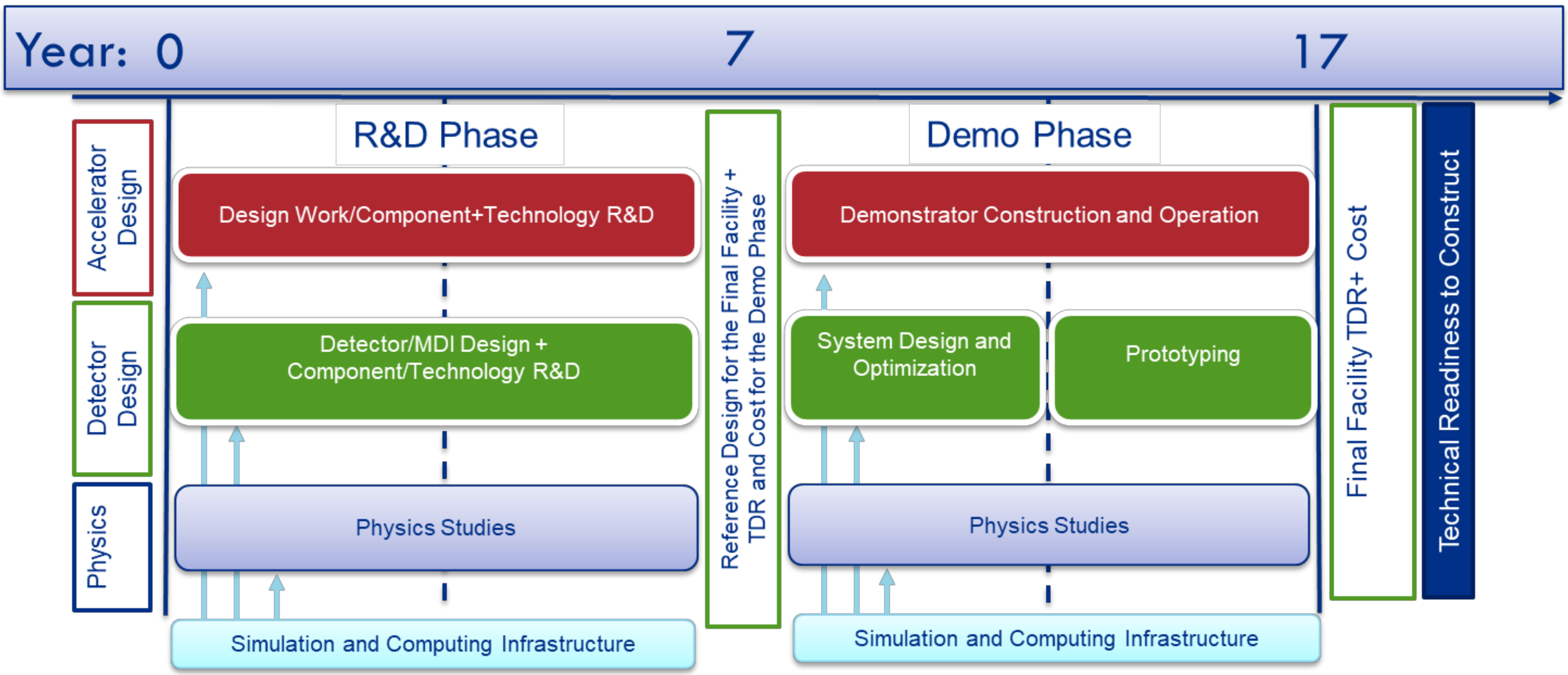
μC Beam-Induced Background





[D. Stratakis]

μ-C Scheduling & Timeline



Future Accelerator Technology

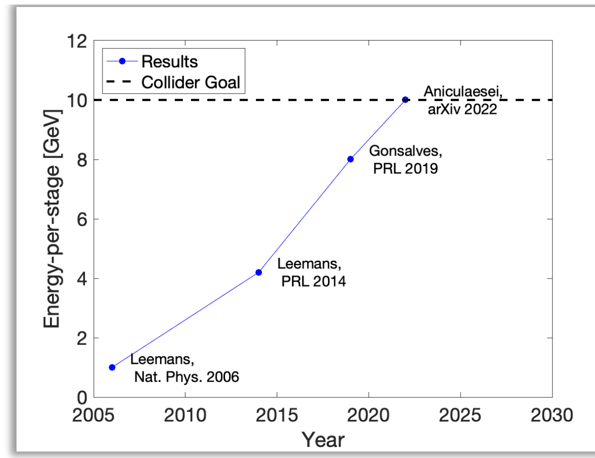
SLAC

➡Current collider technology is not sustainable for long-term

- DOE General Accelerator Research & Development (**GARD**): supports new accelerator concepts & technologies
  - Plasma wakefield accelerators (eg. FACET-II, BELLA): ultra-large gradients (1-100 GeV/m)
    - Recent performance of single-stage accelerators meeting collider goals (right)
  - High-field superconducting magnets (FCC requirement)
  - Superconducting radio frequency (SRF)

S. Gessner

Laser-Driven Plasma



➡*US-based accelerator R&D has exciting potential to enable smaller, cheaper, greener collider options*

Laser-driven Plasma Wakefield Channel *BELLA at LBNL*

Niobium-Tin Quadrupole Magnet for HL-LHC
Developed by Fermilab, BNL, LBNL

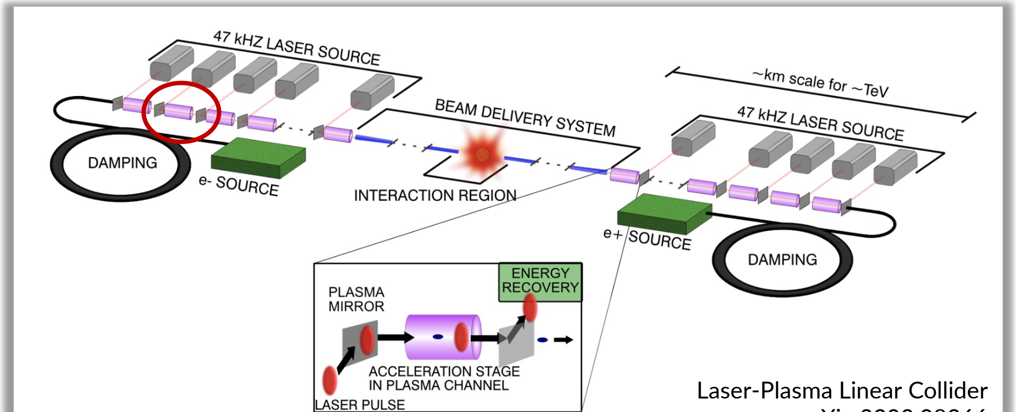
LCLS-II SRF Cavity Processing
Photo credit: Fermilab

Plasma WakeField Accelerators (PWFA)

SLAC

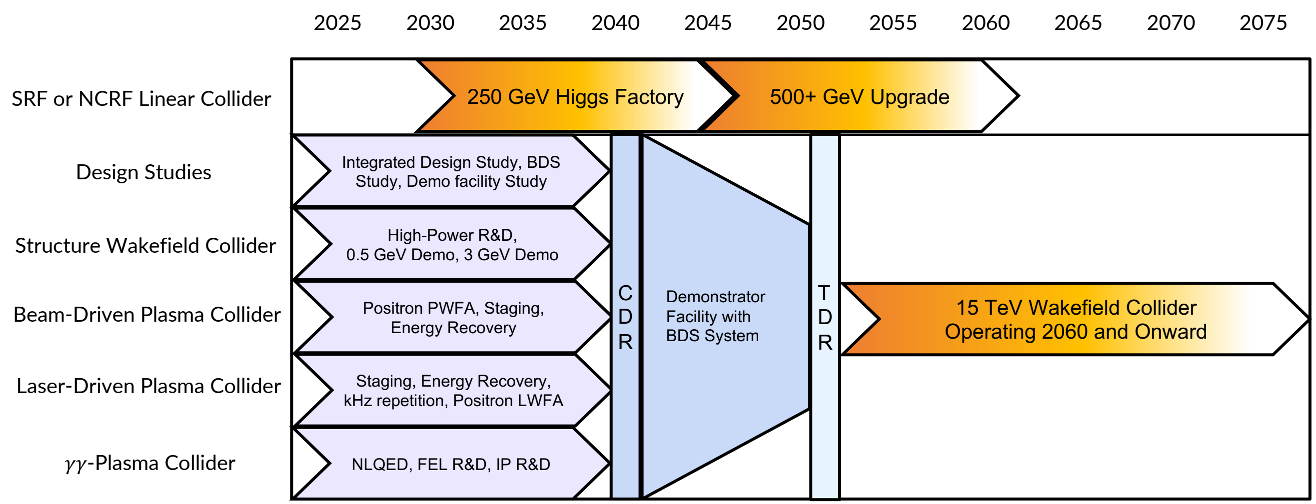
Goals

High-Gradient High-Efficiency Low-Emittance

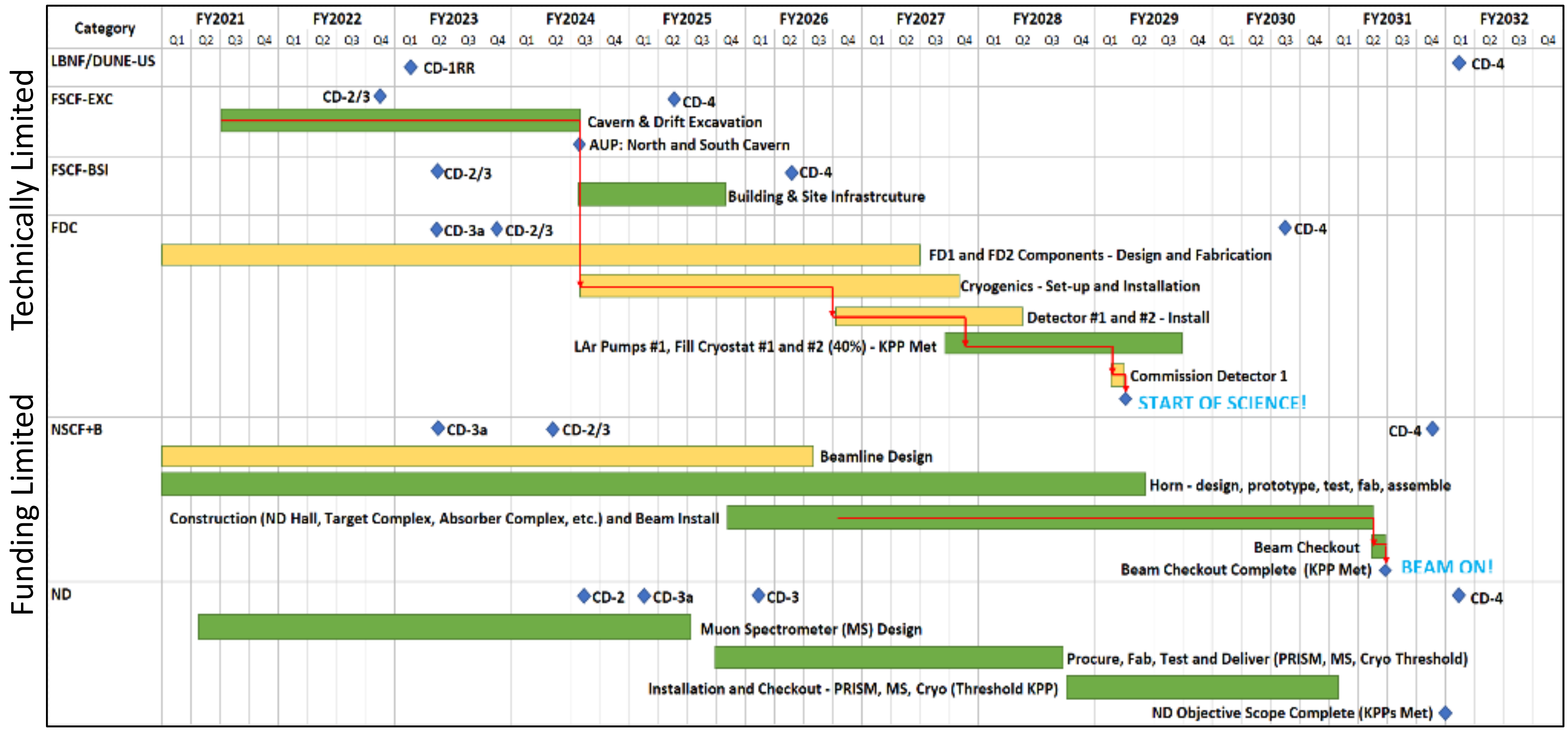


Laser-Plasma Linear Collider
arXiv 2203.08366

S. Gessner



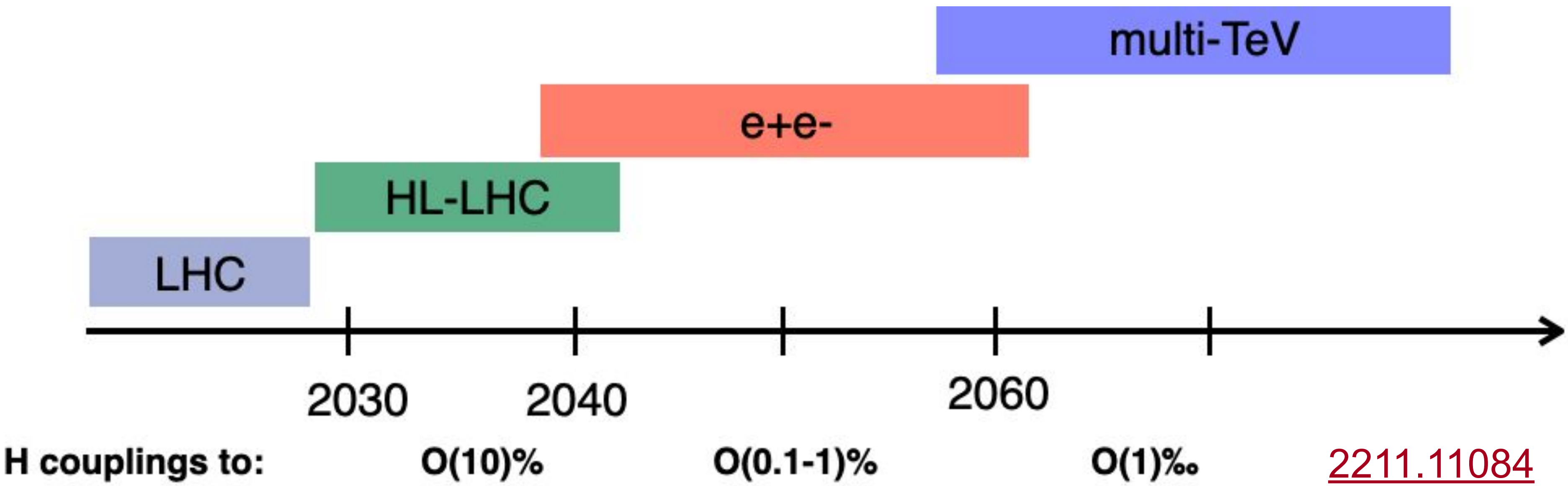
LBNF/DUNE Project Schedule FY21-32



Project CD-4 is defined as Near Detector CD-4 date (last Subproject to finish Early CD4 12/2031 (Dec 2034 late finish at 90% CL)

Snowmass Energy Frontier Vision

1. "Fast start for construction of an e^+e^- Higgs factory"
2. "Significant R&D program for multi-TeV colliders"
3. "Renewed interest and ambition to bring back energy-frontier collider physics to the **US soil**"

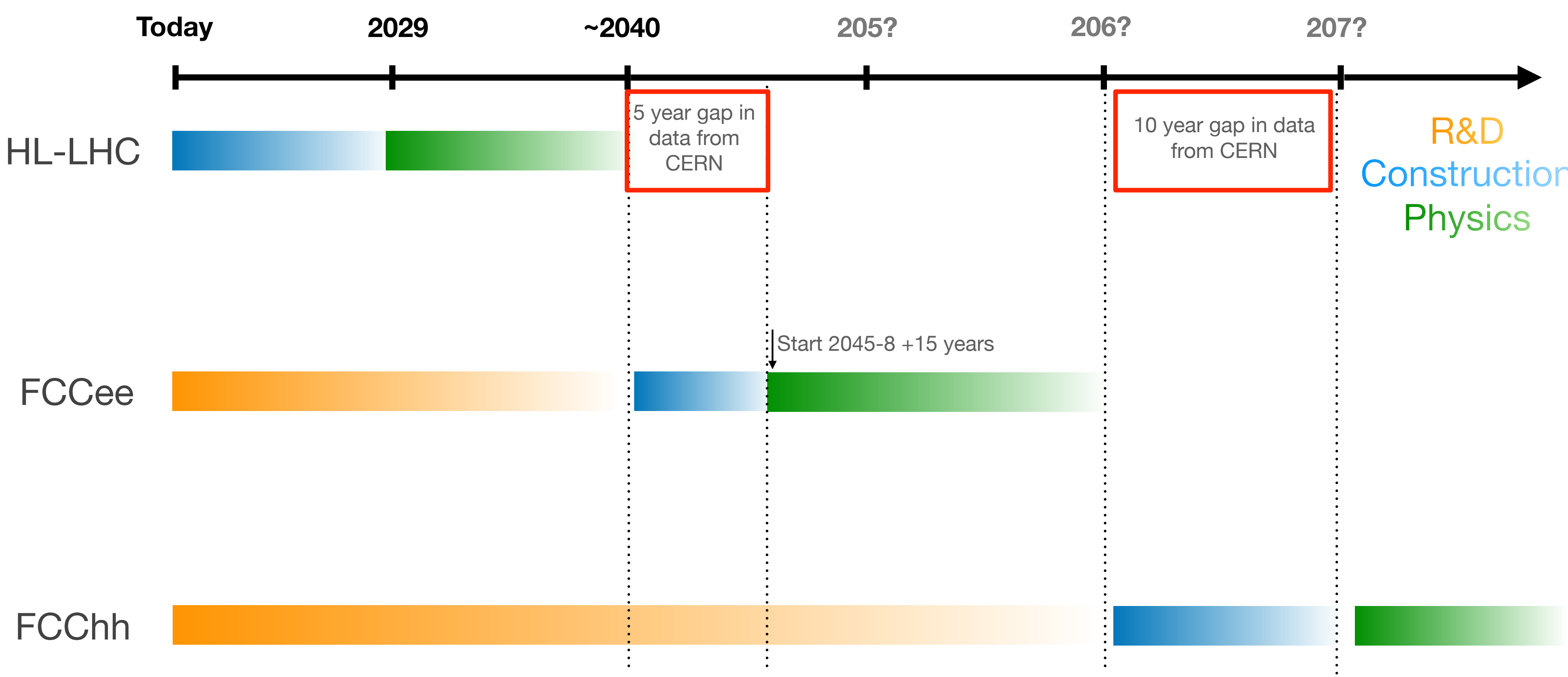


2211.11084

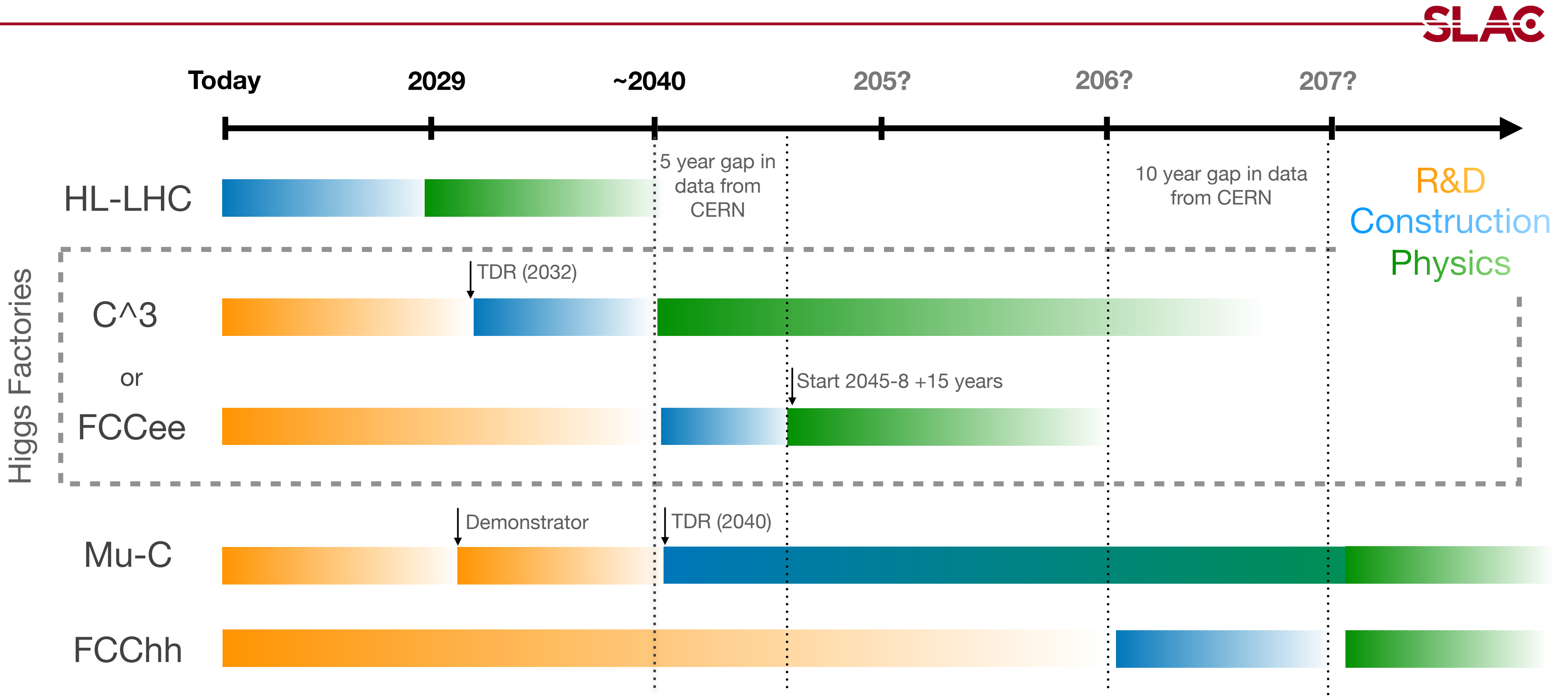
HEP in Africa

K. Assamagan

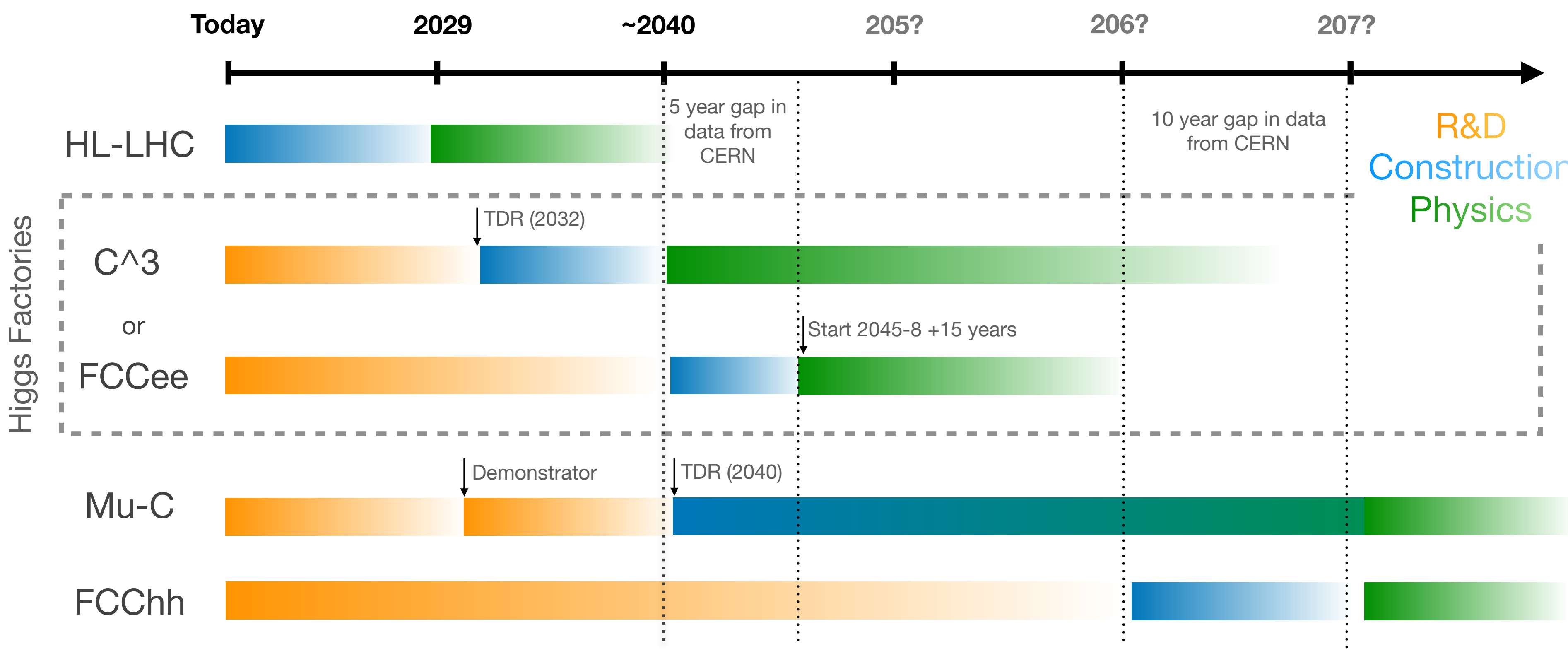
An Inclusive Timeline



An Inclusive Timeline



An Inclusive Timeline



- Interleaved R&D, construction, and physics so there is *no gap in data across global collider HEP*
- **This is not a flat budget:** leave flexibility for increased lobbying efforts & positive changes in funding expectations

➡ This principle holds for interleaving experiments across frontiers as well!