The Cool Copper Collider

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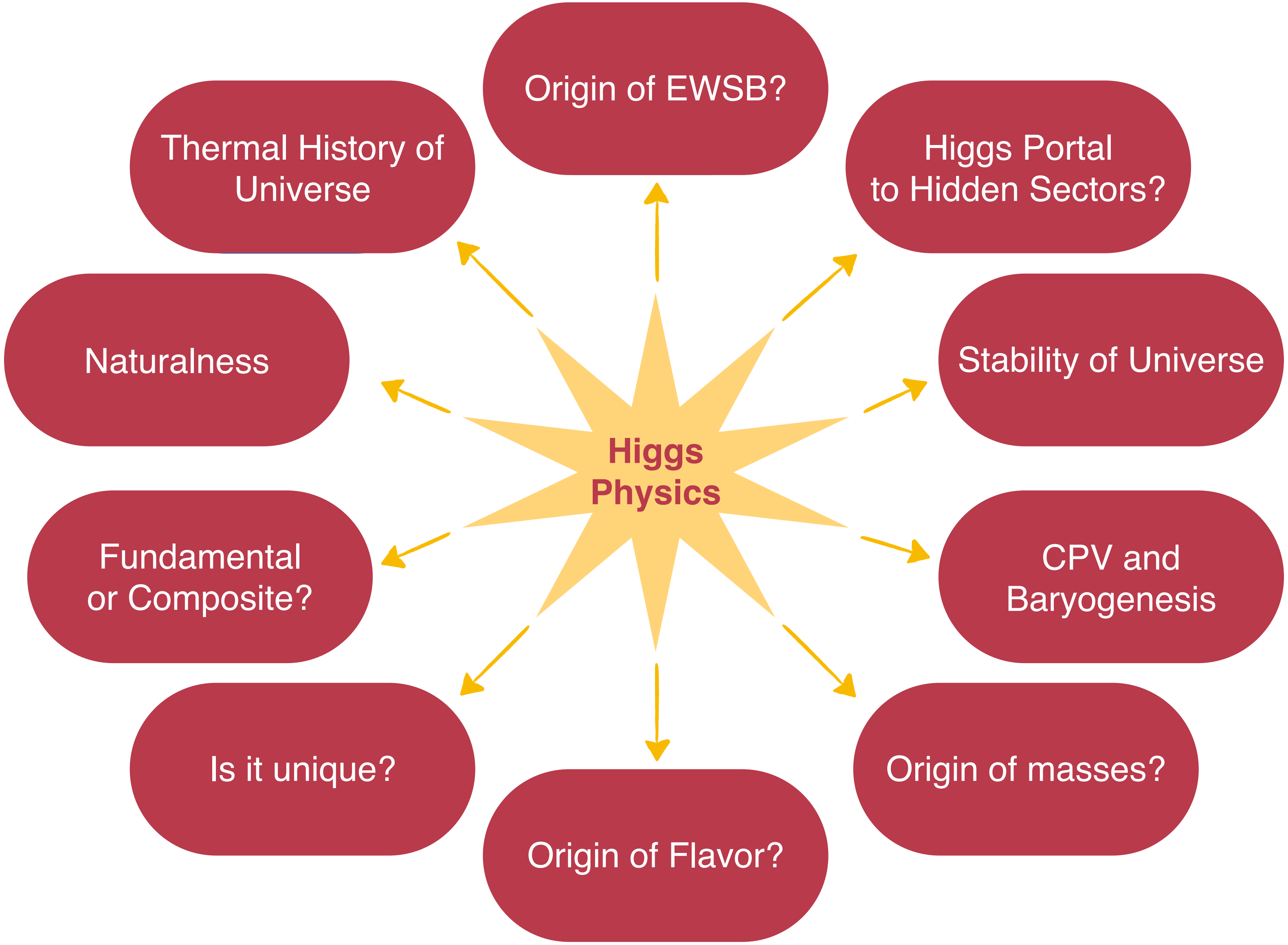
September 1, 2023

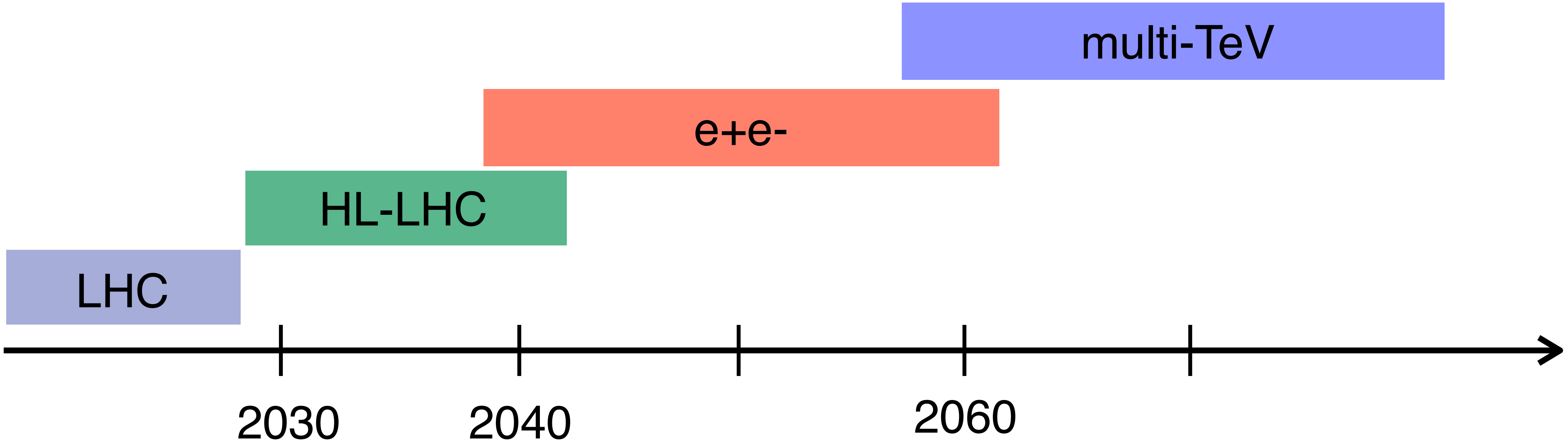
SLAC NATIONAL ACCELERATOR LABORATORY

Stanford University | U.S. DEPARTMENT OF ENERGY



The Energy Frontier 2021 Snowmass Report

A dreamy roadmap



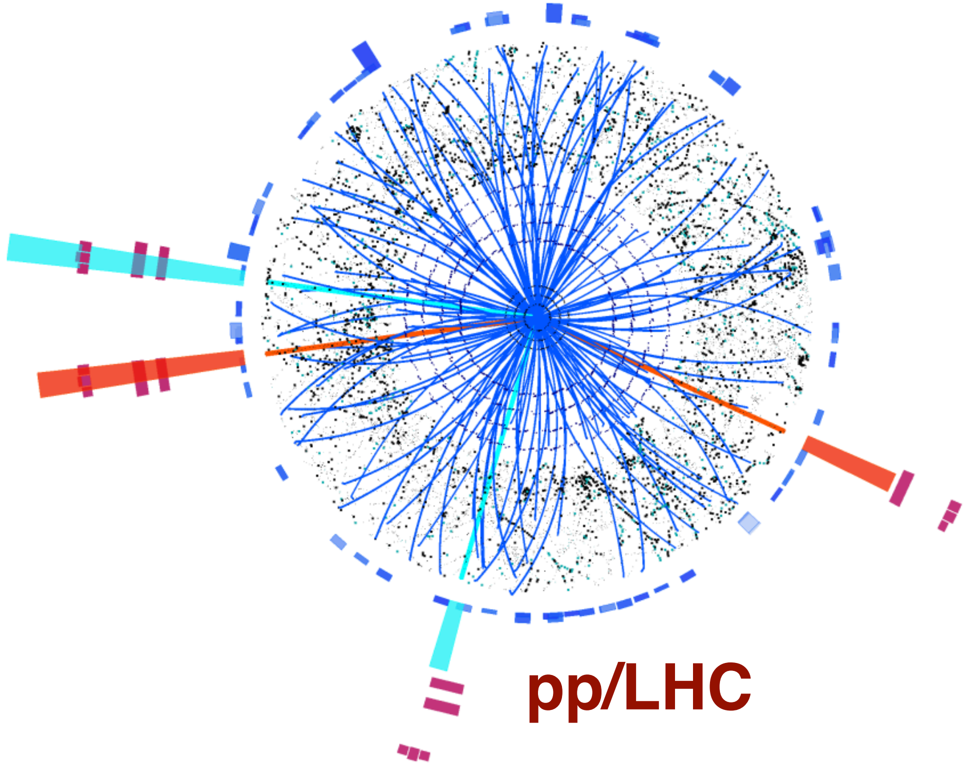
H couplings to: **O(5-10)%** **O(0.1-1)%** **O(1)‰**

Physics goals beyond HL-LHC:

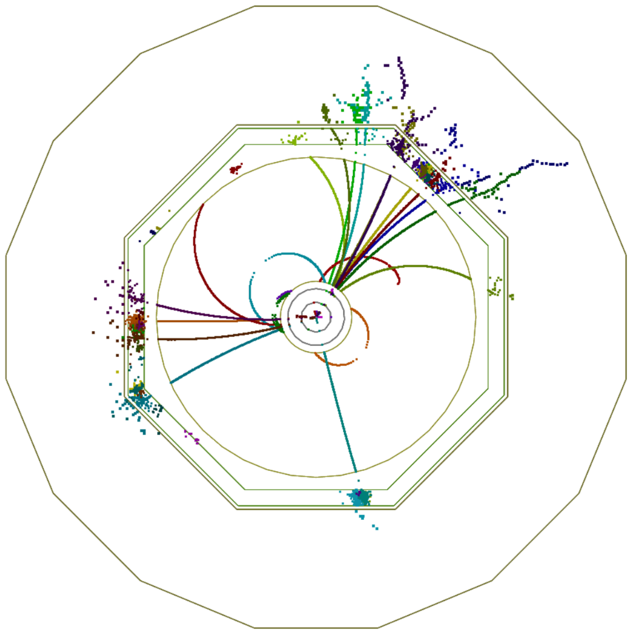
1. Establish Yukawa couplings to light flavor $\Longrightarrow$ precision & lumi
2. Search for invisible/exotic decays and new Higgs $\Longrightarrow$ precision & lumi
3. Establish self-coupling $\Longrightarrow$ > 500 GeV e+e- operations

Precision = e^+e^- collisions

- Initial state well defined & polarization ⟹ High-precision measurements
- Higgs bosons appear in 1 in 100 events ⟹ Clean experimental environment and trigger-less

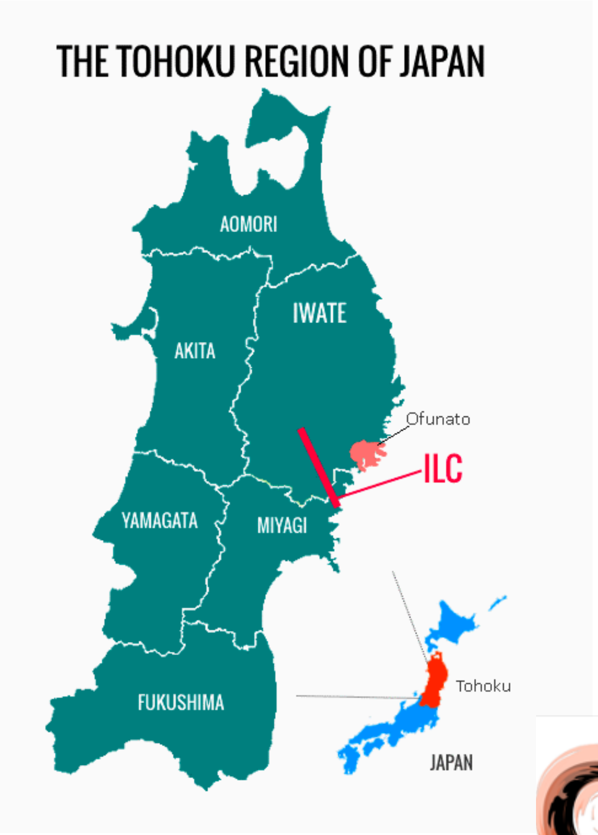


pp/LHC

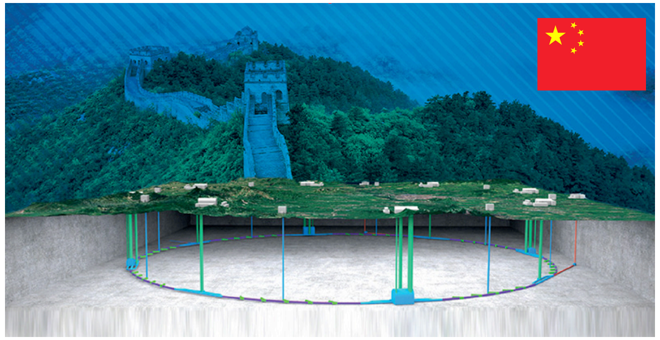


e^+e^-

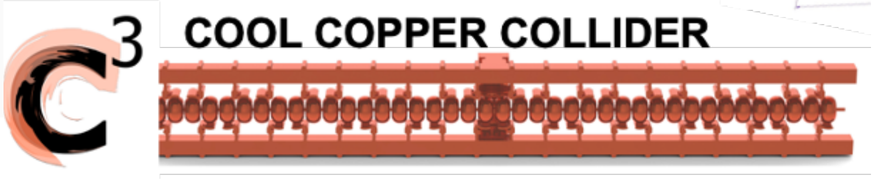
Various proposals around the world



250/500 GeV



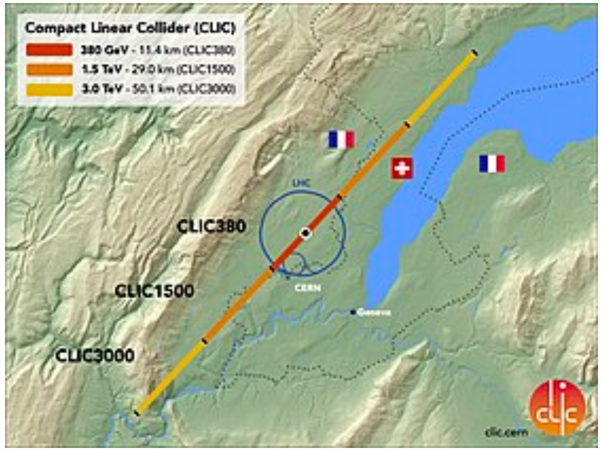
CEPC 240 GeV

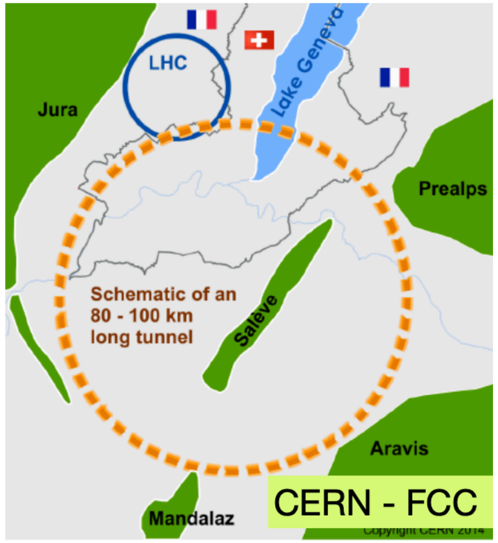


250/550 GeV

… > TeV

CLIC 380/1500/3000 GeV

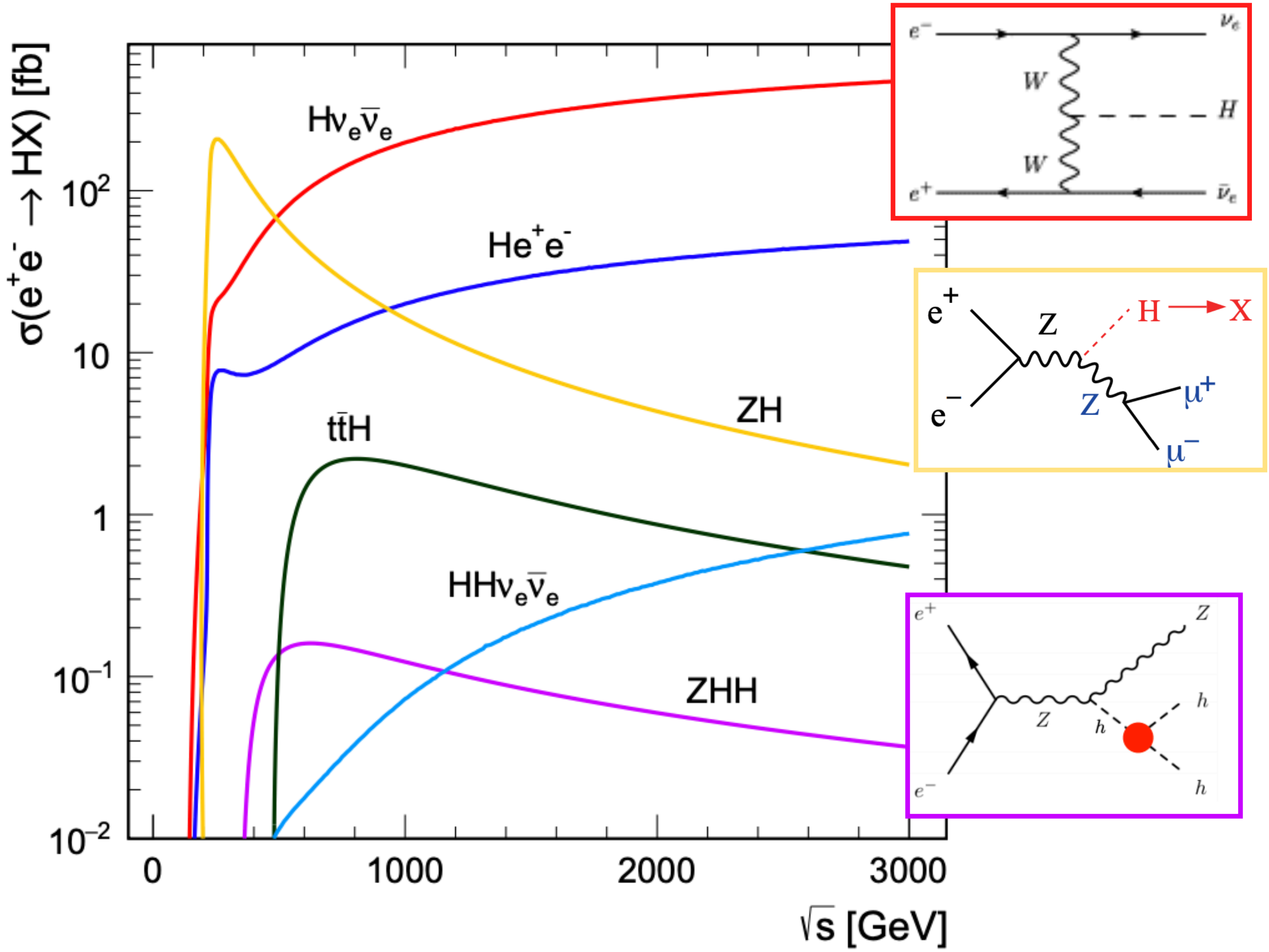




FCC-ee

240/365 GeV

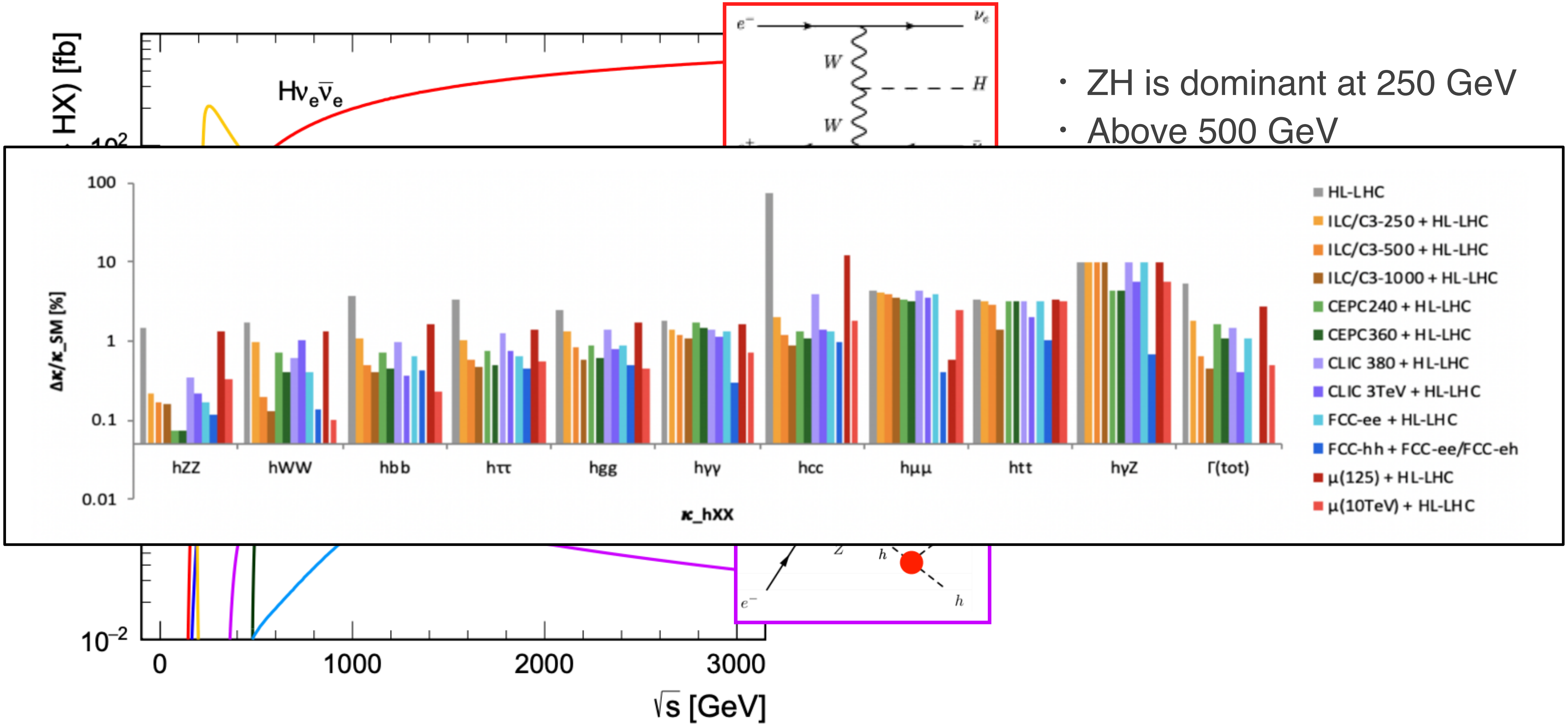
Higgs at e+e-



- ZH is dominant at 250 GeV
- Above 500 GeV
  - Hvv dominates
  - ttH opens up
  - **HH accessible with ZHH**

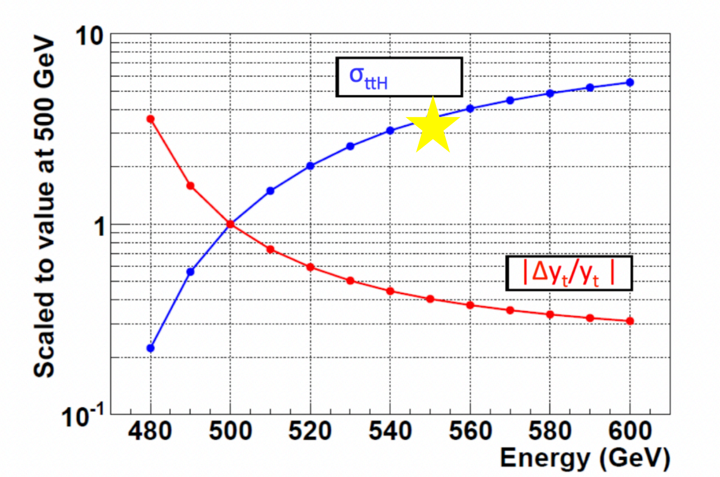
Higgs at e^+e^-

- ZH is dominant at 250 GeV
- Above 500 GeV



Why (>) 550 GeV

- We propose **250** GeV with a relatively inexpensive upgrade to **550** GeV on the same 8 km footprint.
- 550 GeV will offer an orthogonal dataset to cross-check a deviation from the SM predictions observed at 250 GeV
- O(20%) precision on the Higgs self-coupling would allow to exclude/ demonstrate at 5σ models of electroweak baryogenesis



Collider Luminosity Polarization	HL-LHC 3 ab^{-1} in 10 yrs -	C^3 /ILC 250 GeV 2 ab^{-1} in 10 yrs $\mathcal{P}_{e^+} = 30\%$ (0%)	C^3 /ILC 500 GeV + 4 ab^{-1} in 10 yrs $\mathcal{P}_{e^+} = 30\%$ (0%)
g_{HZZ} (%)	3.2	0.38 (0.40)	0.20 (0.21)
g_{HWW} (%)	2.9	0.38 (0.40)	0.20 (0.20)
g_{Hbb} (%)	4.9	0.80 (0.85)	0.43 (0.44)
g_{Hcc} (%)	-	1.8 (1.8)	1.1 (1.1)
g_{Hgg} (%)	2.3	1.6 (1.7)	0.92 (0.93)
$g_{H\tau\tau}$ (%)	3.1	0.95 (1.0)	0.64 (0.65)
$g_{H\mu\mu}$ (%)	3.1	4.0 (4.0)	3.8 (3.8)
$g_{H\gamma\gamma}$ (%)	3.3	1.1 (1.1)	0.97 (0.97)
$g_{HZ\gamma}$ (%)	11.	8.9 (8.9)	6.5 (6.8)
g_{Htt} (%)	3.5	–	3.0 (3.0)*
g_{HHH} (%)	50	49 (49)	22 (22)
Γ_H (%)	5	1.3 (1.4)	0.70 (0.70)

arXiv:1708.08912
arXiv:1801.02840

One note on polarization

FCC-ee and the C3/ILC run plans are rather compatible to study the Higgs Boson

When analyzing Higgs couplings with SMEFT, 2 ab^{-1} of polarized running is essentially equivalent to 5 ab^{-1} of unpolarized running.

- ***Electron polarization* is essential** for this.
- But, there is almost no difference in the expectation with and without positron polarization.
- ***Positron polarization*** allows more cross-checks of systematic errors.
  - It brings a large advantage in multi-TeV running, where the most important cross sections are from $e^-_L e^+_R$

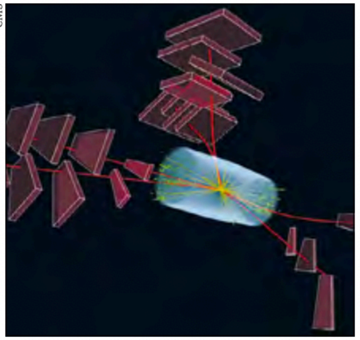
coupling	2/ab-250 pol.	+4/ab-500 pol.	5/ab-250 unpol.	+ 1.5/ab-350 unpol
HZZ	0.50	0.35	0.41	0.34
HWW	0.50	0.35	0.42	0.35
Hbb	0.99	0.59	0.72	0.62
$H\tau\tau$	1.1	0.75	0.81	0.71
Hgg	1.6	0.96	1.1	0.96
Hcc	1.8	1.2	1.2	1.1
$H\gamma\gamma$	1.1	1.0	1.0	1.0
$H\gamma Z$	9.1	6.6	9.5	8.1
$H\mu\mu$	4.0	3.8	3.8	3.7
Htt	-	6.3	-	-
HHH	-	27	-	-
Γ_{tot}	2.3	1.6	1.6	1.4
Γ_{inv}	0.36	0.32	0.34	0.30
Γ_{other}	1.6	1.2	1.1	0.94

C3, a *novel* route to a linear e^+e^- collider

CERNCOURIER.COM

NEWS DIGEST

CMS



A candidate triple-J/ψ event.

Triple treat for CMS
The CMS collaboration has observed three J/ψ particles emerging from a single collision between two protons for the first time, offering a new way to study the evolution of the transverse density of quarks and gluons inside the proton (arXiv:2111.05370). Analysing LHC Run-2 events in which a J/ψ decays into a pair of muons, the team identified five in which three J/ψ particles were produced simultaneously, with a statistical confidence of more than 5σ. The measured cross section is consistent, within the current large uncertainties, with previous measurements of double-J/ψ

three colder than currently used for antihydrogen formation, the Penning-trap scheme is expected to increase the amount of trapped antihydrogen per mixing attempt by up to a factor of five, paving the way for faster and more precise measurements of antihydrogen (*Nat. Commun.* **12** 6139).

Meet the cool copper collider
A team from SLAC and other institutions has presented a proposal for a linear e^+e^- collider with a "compact" footprint of 8 km (arXiv:2110.15800). Based on recent advances in normal-conducting copper accelerator technology, the new "C³" (Cool Copper Collider) concept would provide a rapid path to precision Higgs-boson and top-quark measurements as well as a first step towards multi-TeV e^+e^- physics, write the authors. The machine could in principle be located anywhere in the world, they state, and would enable a staged programme at 250 and 550 GeV similar to that proposed for the ILC. The proposal has been submitted to the US Snowmass community planning exercise (p43).

Physics ABOUT BROWSE PRESS COLLECTIONS Search articles

RESEARCH NEWS

A "Retro" Collider Design for a Higgs Factory

October 6, 2022 • *Physics* 15, 155

The Cool Copper Collider is a new proposal for a Higgs-producing linear collider that would be more compact than other collider designs.

Emilio Nanni/SLAC

A prototype version of the Cool Copper Collider. The photo shows the central region where the particle beams would pass.

https://physics.aps.org/articles/v15/155

C^3 Acknowledgements

WEBSITE web.slac.stanford.edu/c3/

Submitted to the Proceedings of the US Community Study
on the Future of Particle Physics (Snowmass 2021)

SLAC-PUB-17661
April 12, 2022

Strategy for Understanding the Higgs Physics:
The Cool Copper Collider

Submitted to the Proceedings of the US Community Study
on the Future of Particle Physics (Snowmass 2021)

SLAC-PUB-17660
April 12,

C^3 Demonstration Research and Development Plan

SLAC-PUB-17629
November 1, 2021

C^3 : A "Cool" Route to the Higgs Boson and Beyond

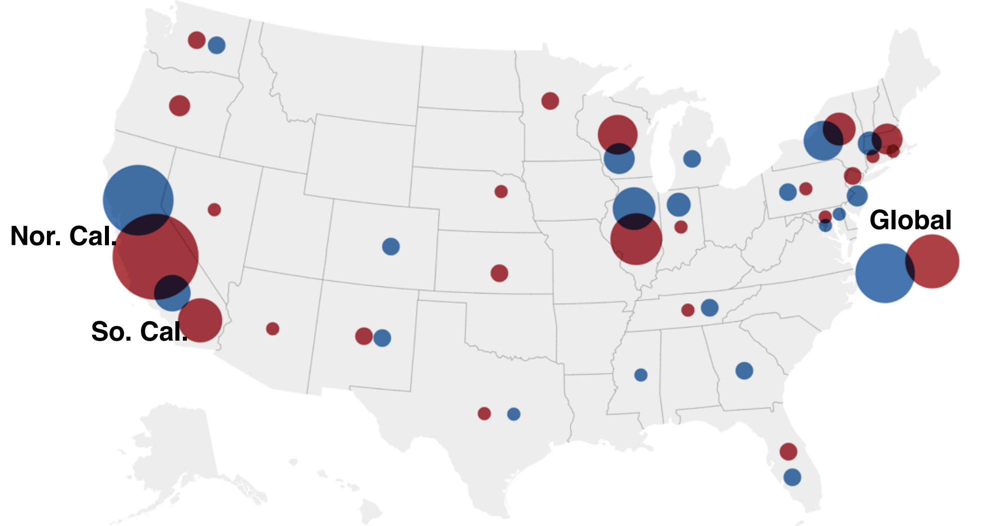
Community Workshops:

Virtual, Fermilab, SLAC, LANL & Cornell University

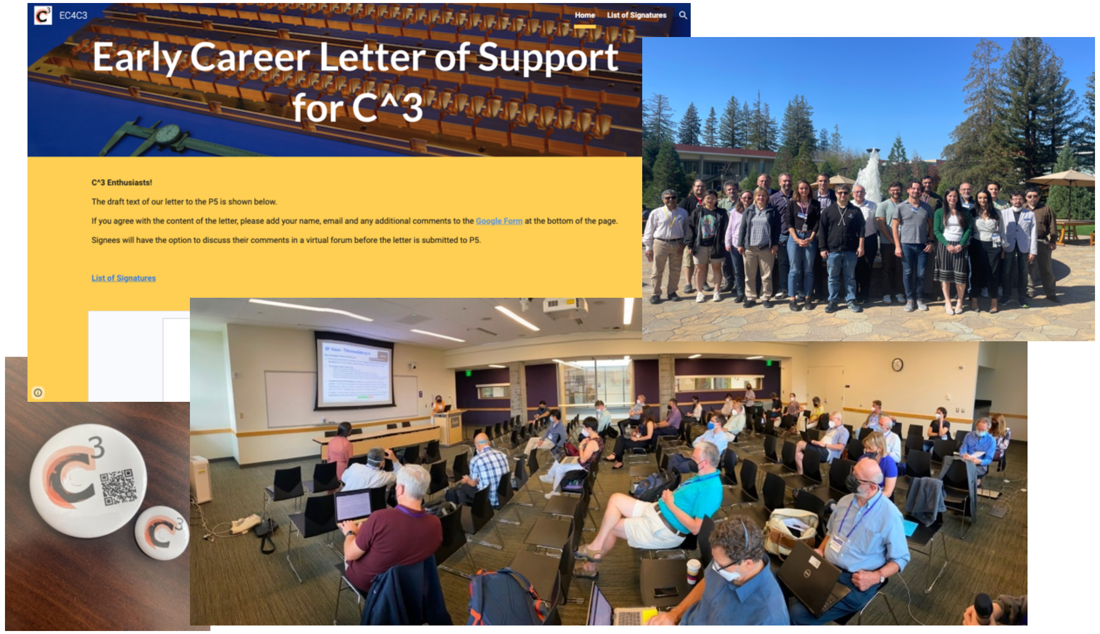
220 Participants 60 Institutions

>150 Supporters of Early Career Letter to P5

>170 Endorsers from >40 Institutions at Snowmass



https://sites.google.com/view/ec4c3



C^3 At Snowmass

- C^3 has been evaluated independently by the Implementation Task Force along with the other proposals
- Strong engagement and support from Energy Frontier

1.7.4 Opportunity for US as a site for a future Energy Frontier Collider

Our vision for the EF can only be realized as a worldwide program, and CERN as host of the LHC has been the focus of EF activities for the past couple of decades. In order for scientists from all over the world to buy into the program, the program has to consider siting future accelerators anywhere in the world. The US community has to continue to work with the international community on detector designs and develop extensive R&D programs, and the funding agencies (DOE and NSF) should vigorously fund such programs (as currently the US is severely lagging behind).

The US community has expressed a renewed ambition to bring back EF collider physics to the US soil, while maintaining its international collaborative partnerships and obligations, for example with CERN. The international community also realizes that a vibrant and concurrent program in the US in EF collider physics is beneficial for the whole field, as it was when Tevatron was operated simultaneously as LEP.

The US EF community proposes to develop plans to site an e^+e^- collider in the US. A Muon Collider remains a highly appealing option for the US, and is complementary to a Higgs factory. For example, some options which are considered as attractive opportunities for building a domestic EF collider program are:

- **A US-sited linear e^+e^- (ILC/CCC) Collider**
- **Hosting a 10 TeV range Muon Collider**
- **Exploring other e^+e^- collider options to fully utilize the Fermilab site**

ArXiv:2211.11084

Proposal Name	Power Consumption	Size	Complexity	Radiation Mitigation
FCC-ee (0.24 TeV)	290	91 km	I	I
CEPC (0.24 TeV)	340	100 km	I	I
ILC (0.25 TeV)	140	20.5 km	I	I
CLIC (0.38 TeV)	110	11.4 km	II	I
CCC (0.25 TeV)	150	3.7 km	I	I
CERC (0.24 TeV)	90	91 km	II	I
ReLiC (0.24 TeV)	315	20 km	II	I
ERLC (0.24 TeV)	250	30 km	II	I
XCC (0.125 TeV)	90	1.4 km	II	I
MC (0.13 TeV)	200	0.3 km	I	II
ILC (3 TeV)	~400	59 km	II	II
CLIC (3 TeV)	~550	50.2 km	III	II
CCC (3 TeV)	~700	26.8 km	II	II
ReLiC (3 TeV)	~780	360 km	III	I
MC (3 TeV)	~230	10-20 km	II	III
LWFA (3 TeV)	~340	1.3 km (linac)	II	I
PWFA (3 TeV)	~230	14 km	II	II
SWFA (3 TeV)	~170	18 km	II	II
MC (14 TeV)	~300	27 km	III	III
LWFA (15 TeV)	~1030	6.6 km	III	I
PWFA (15 TeV)	~620	14 km	III	II
SWFA (15 TeV)	~450	90 km	III	II
FCC-hh (100 TeV)	~560	91 km	II	III
SPPC (125 TeV)	~400	100 km	II	III

ArXiv:2208.06030

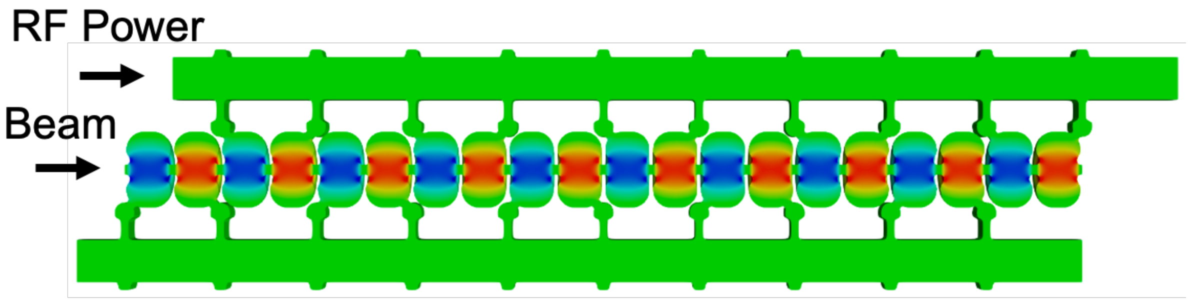
arXiv:2110.15800
Tantawi, S et al. *PRAB* 23.9 (2020) 092001

The Cool Copper Collider

C^3 is a new linac **normal conducting technology**

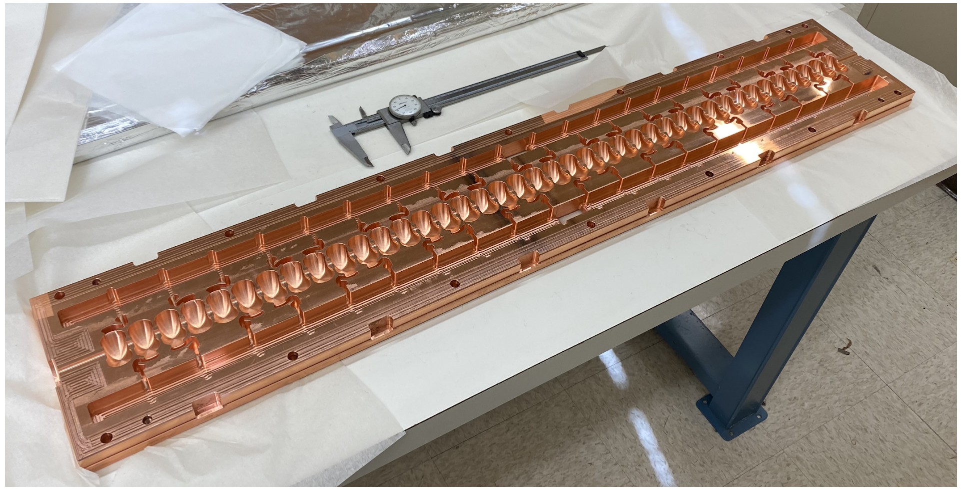
Optimize each cavity for maximum efficiency and lower surface fields

- Relatively small iris such that RF fundamental does not propagate through irises.
- RF power coupled to each cell – no on-axis coupling - required modern super-computing
  - Distributed power to each cavity from a common RF manifold
  - Mechanical realization by modern CNC milling
- Cryogenic temperature elevates performance in gradient
  - Operation at 77 K with liquid nitrogen is simple and practical



Electric field magnitude for equal power from RF manifold

First C^3 structure at SLAC

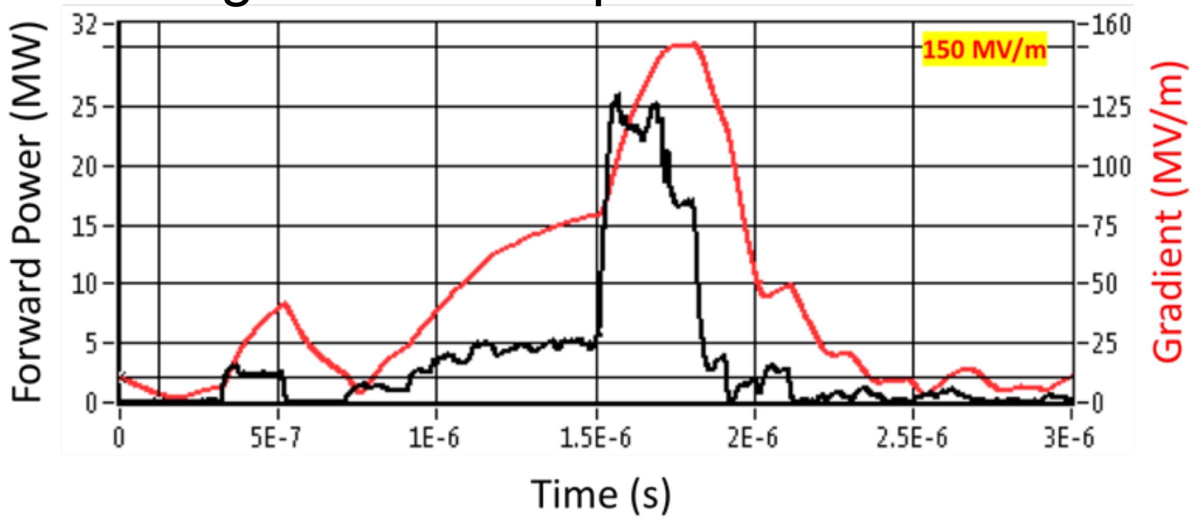


arXiv:2110.15800

Expected gradient

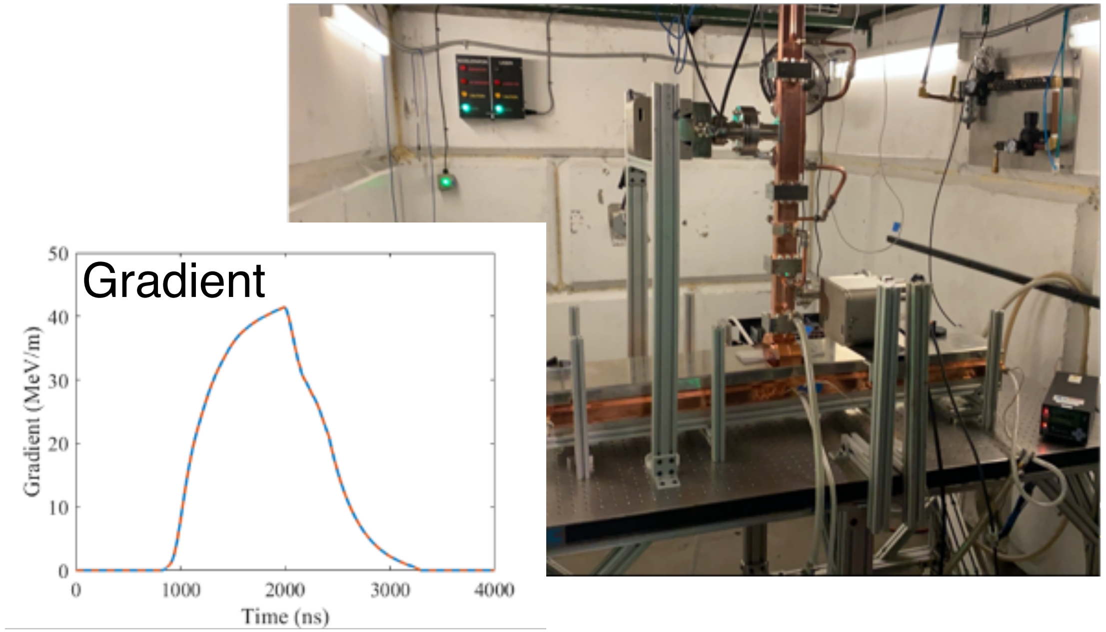
- Robust operations at high gradient: 120 MeV/m
    - Start at 70 MeV/m for C^3-250
- Scalable to multi-TeV operations

High Gradient Operation at 150 MV/m



Cryogenic Operation at X-band

High Power Test at Radiabeam



Accelerator Complex

8 km footprint for 250/550 GeV CoM $\Longrightarrow$ 70/120 MeV/m

- 7 km footprint at 155 MeV/m for 550 GeV CoM – present Fermilab site

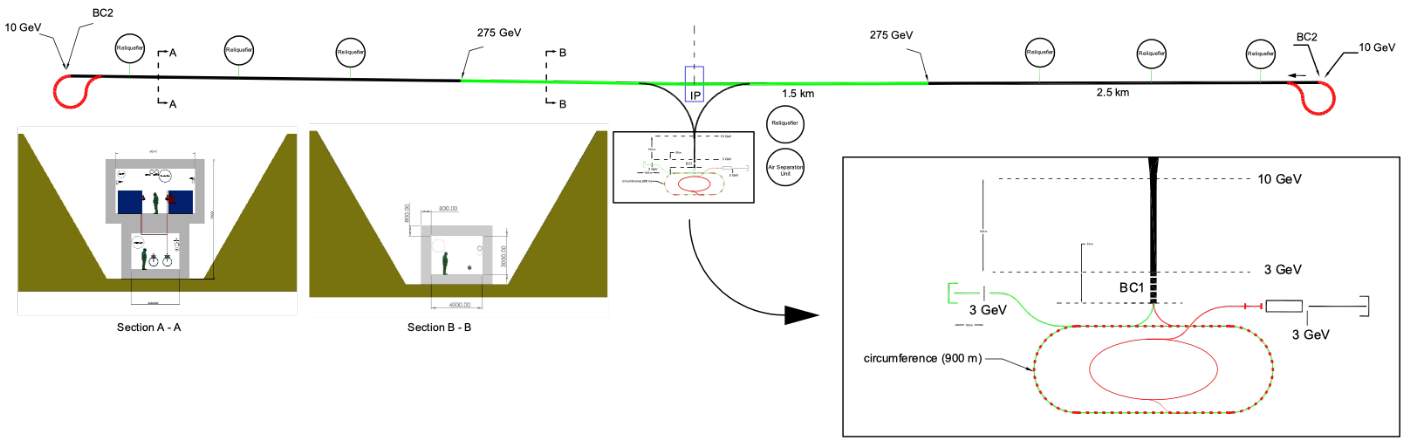
Large portions of accelerator complex compatible between LC technologies

- Beam delivery / IP modified from ILC (1.5 km for 550 GeV CoM)
- Damping rings and injectors to be optimized with CLIC as baseline

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 - 8 km Footprint for 250/550 GeV

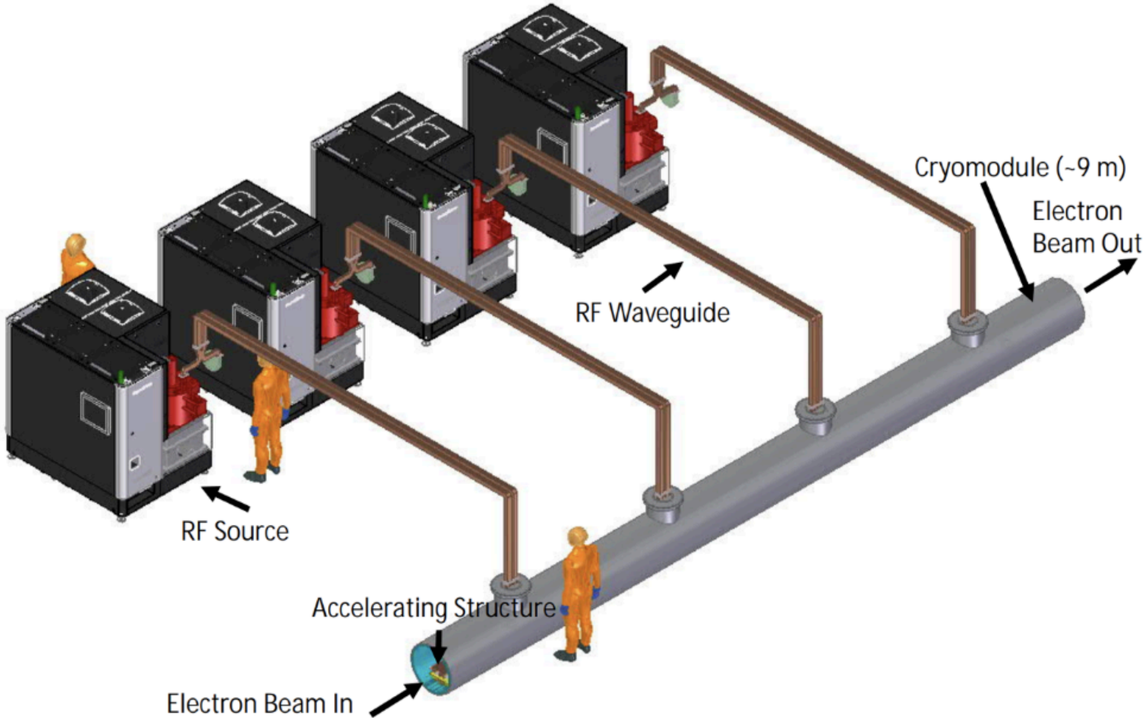


Tunnel Layout for Main Linac 250/550 GeV CoM

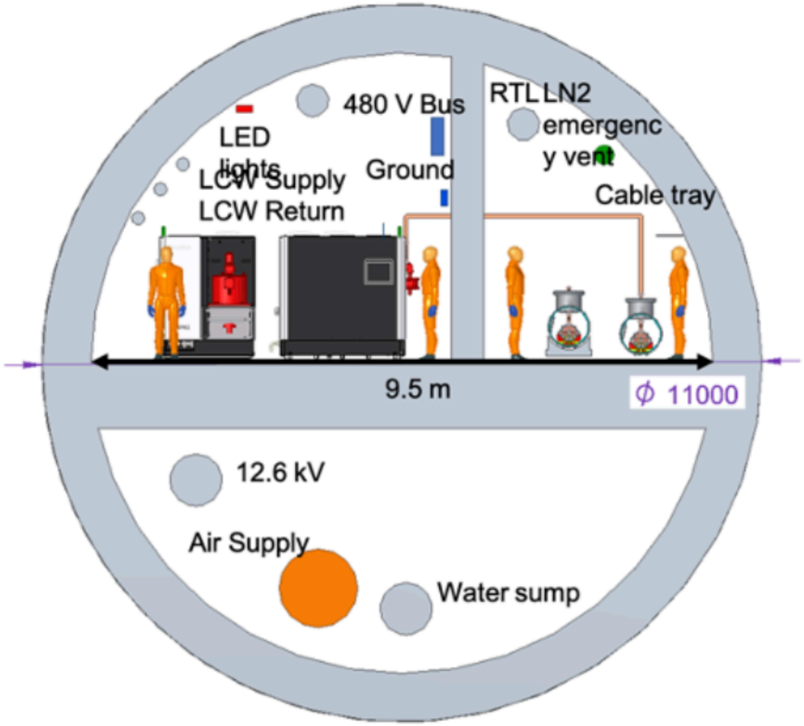
First study looked at 9.5 m inner diameter in order to match ILC costing model

- Must minimize diameter to reduce cost and construction time
- Surface site (cut/cover) provides interesting alternative – concerns with length of site for future upgrade

Cryomodule Unit - 9 m
(630 MeV/1 GeV)

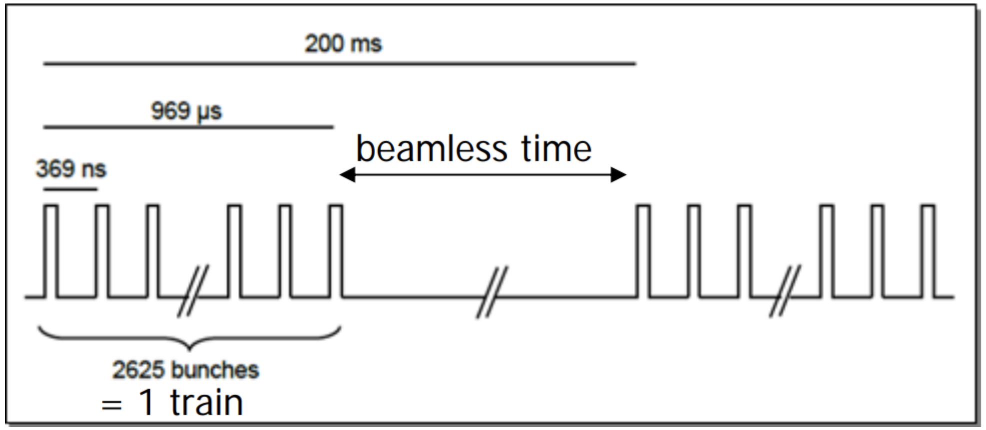


Usable Tunnel Width - 9.5 m
(Same tunnel width as ILC)



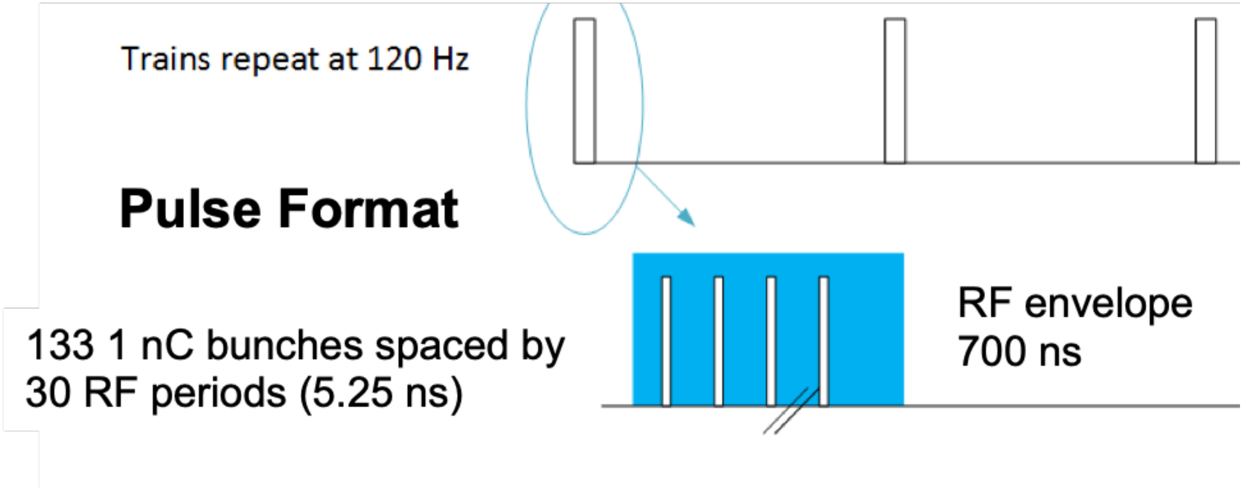
Beam Format and Detector Design Requirements

ILC timing structure



1 ms long bunch trains at 5 Hz
308ns spacing

C³ timing structure



ILC/C³ timing structure: Fraction of a percent duty cycle

- **Power pulsing possible**, significantly reduce heat load
  - Factor of 100 power saving for FE analog power
- Tracking detectors **don't need active cooling**
  - Significantly reduction for the material budget

- **Joint simulation/detector optimization effort with ILC groups**
- **Common US R&D initiative for future Higgs Factories 2306.13567**

C³ time structure is compatible with ILC-like detector overall design and ongoing optimizations.

Accelerator Design and Challenges

Accelerator Design

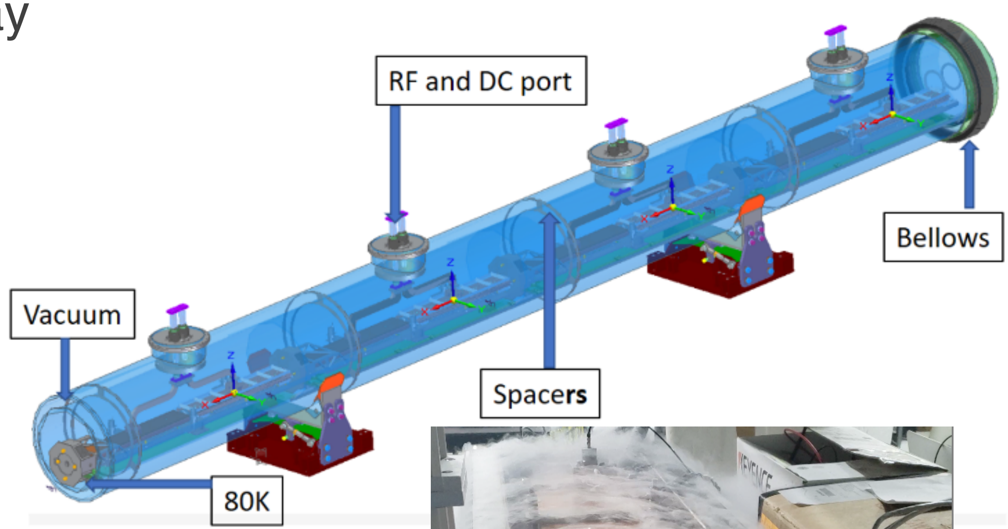
- Engineering and design of prototype cryomodule underway

Focused on challenges identified with community through Snowmass (all underway)

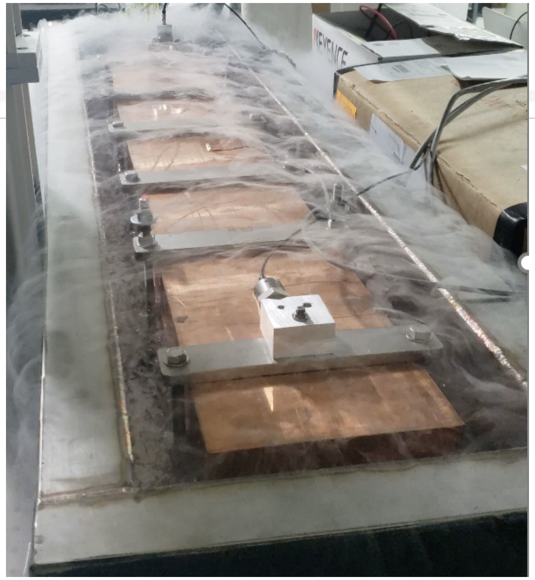
- Gradient – Scaling up to meter scale cryogenic tests
- Vibrations – Measurements with full thermal load
- Alignment – Working towards raft prototype
- Cryogenics – Two-phase flow simulations to full flow tests
- Damping – Materials, design and simulation
- Beam Loading and Stability - Beam test with thermionic gun
- Scalability – Cryomodules and integration

Laying the foundation for a demonstration program to address technical risks beyond CDR level

Cryomodule Concept

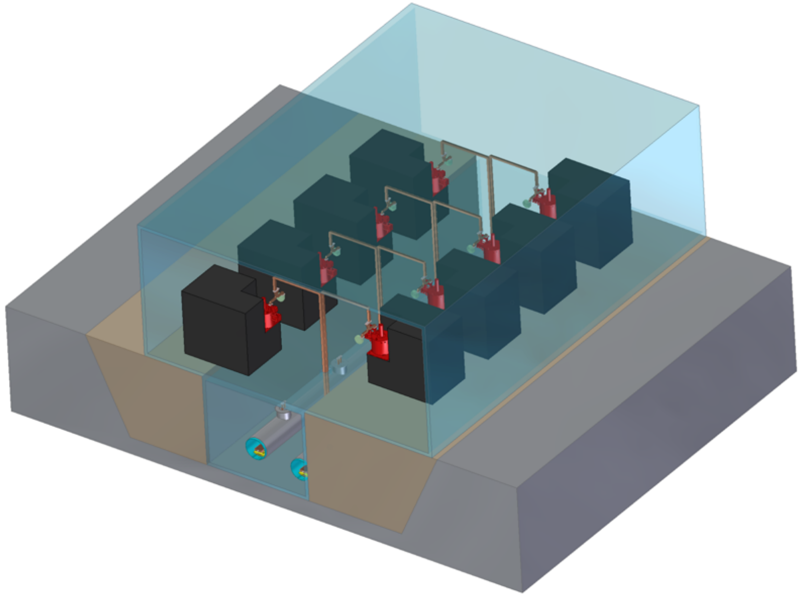


Vibration Studies



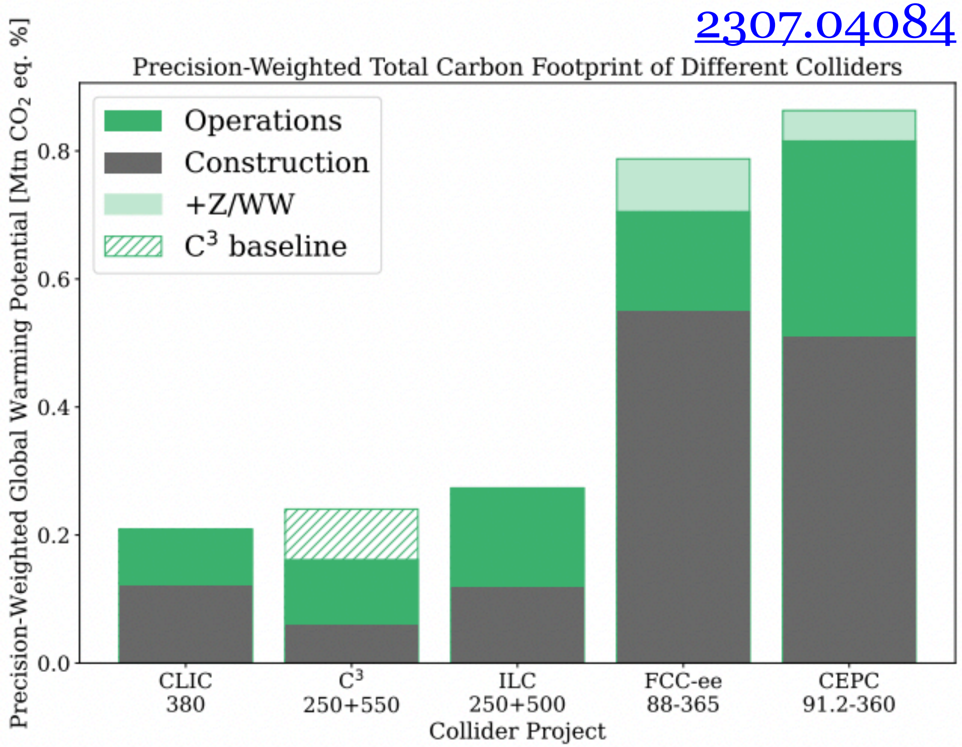
Power Consumption and Sustainability

- Compact footprint < 8 km for both underground and surface sites
- **Sustainability - construction + operations CO_2 emissions per % sensitivity on couplings**
  - Polarization and high energy to account for physics reach
  - Construction CO_2 emissions → minimize excavation and concrete
  - Main Linac Operations → limit power, decarbonization of the grid and dedicated renewable sources

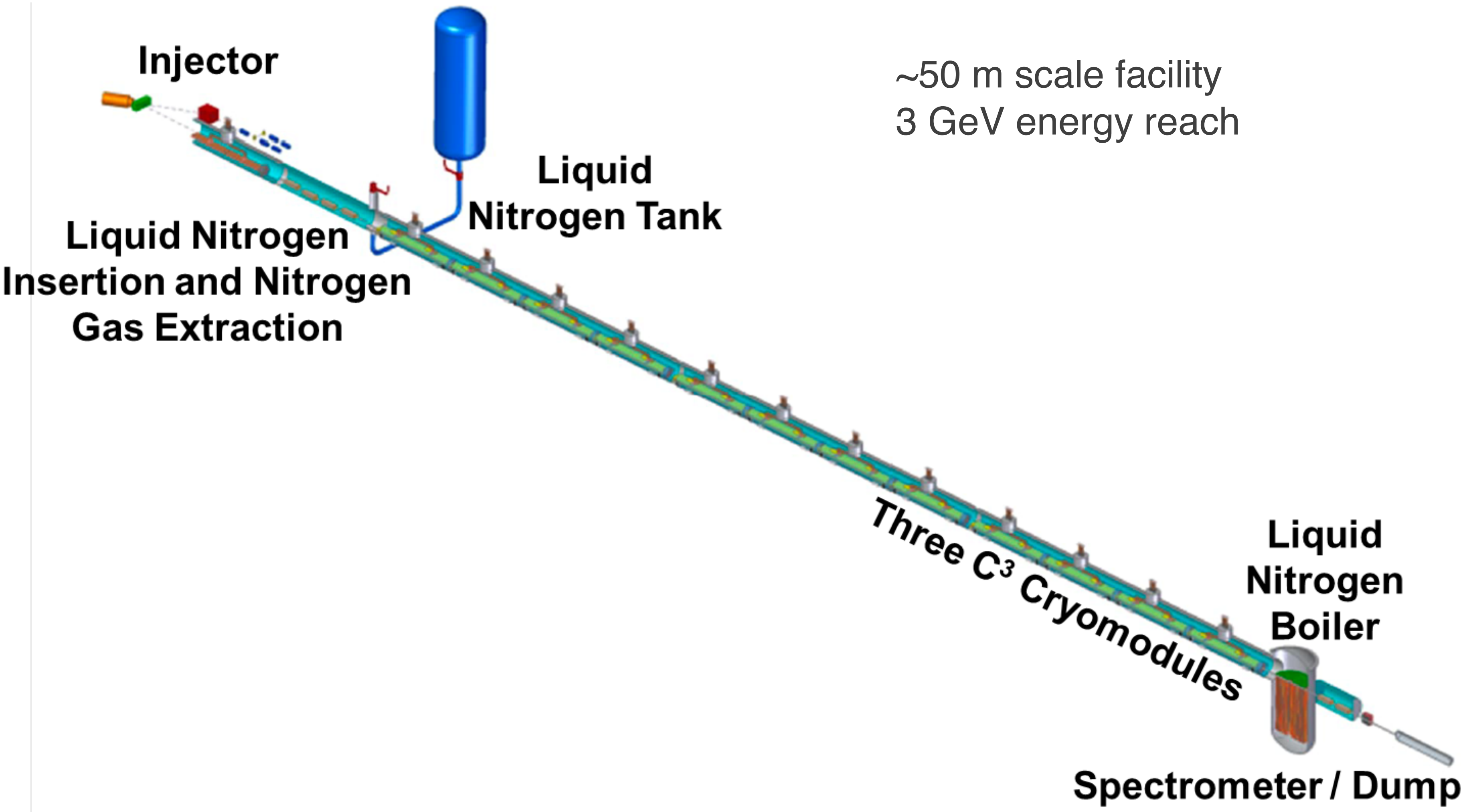


Surface-Site Mockup

2307.04084

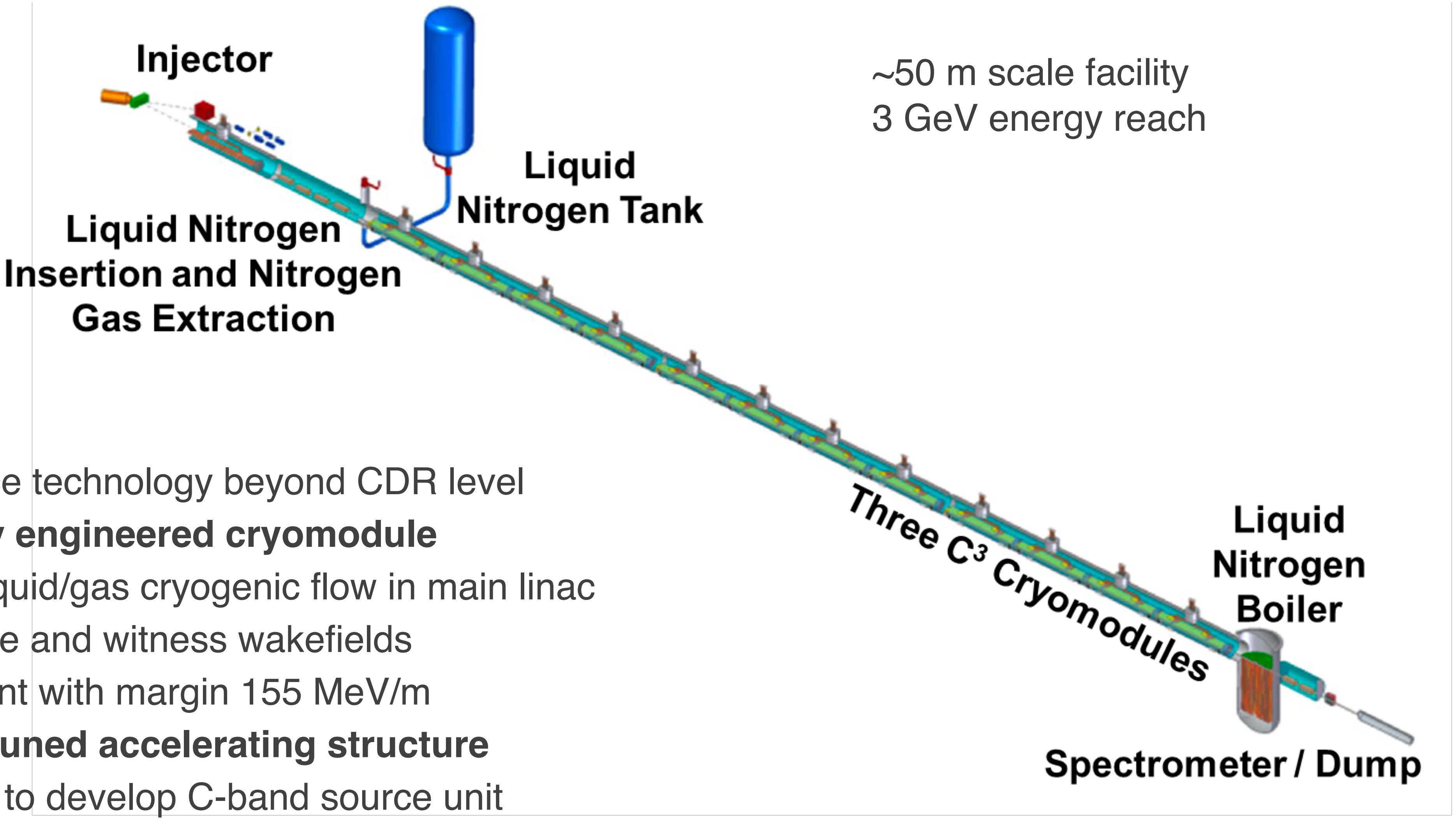


The Complete C^3 Demonstrator



~50 m scale facility
3 GeV energy reach

The Complete C³ Demonstrator

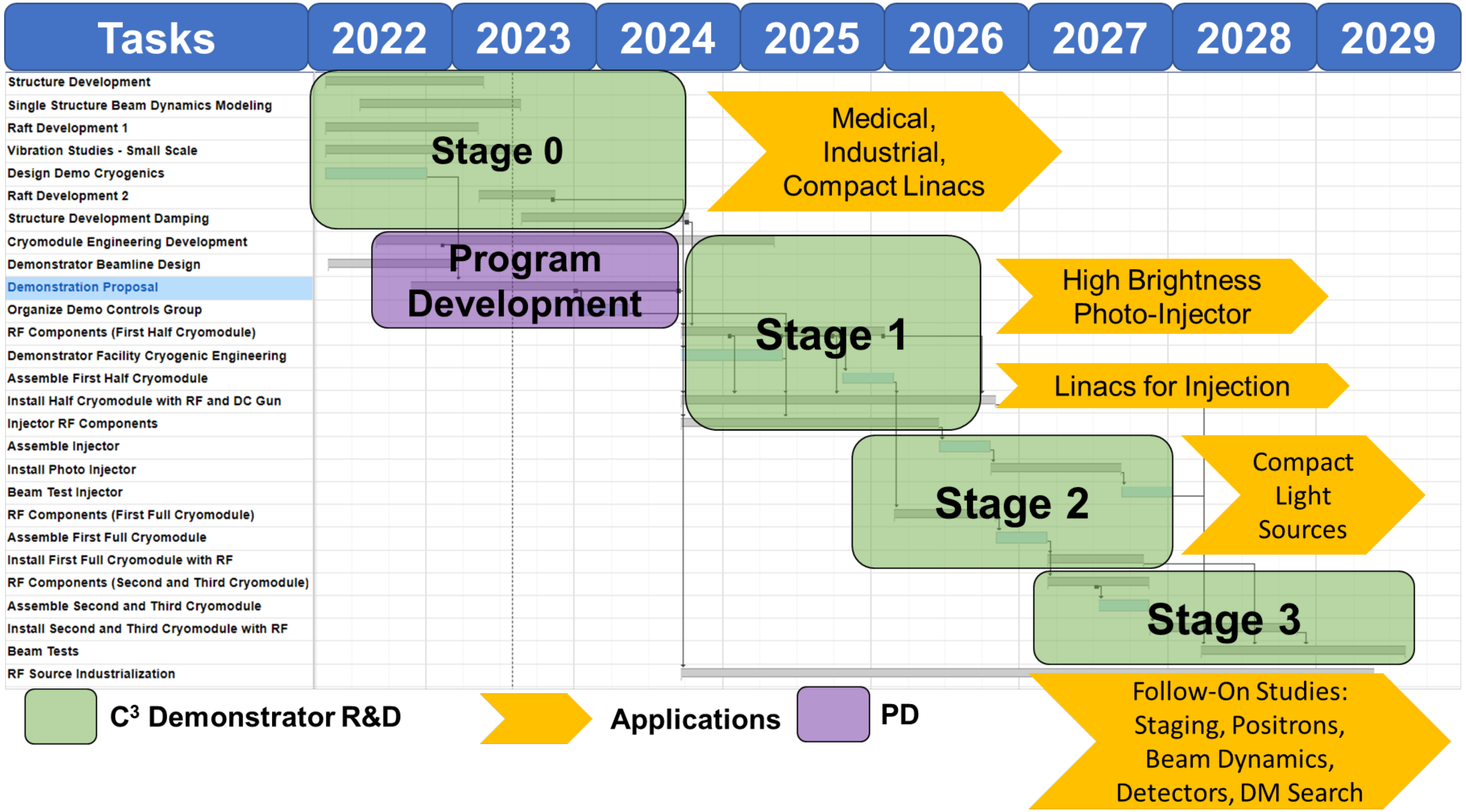


~50 m scale facility
3 GeV energy reach

R&D needed to advance technology beyond CDR level

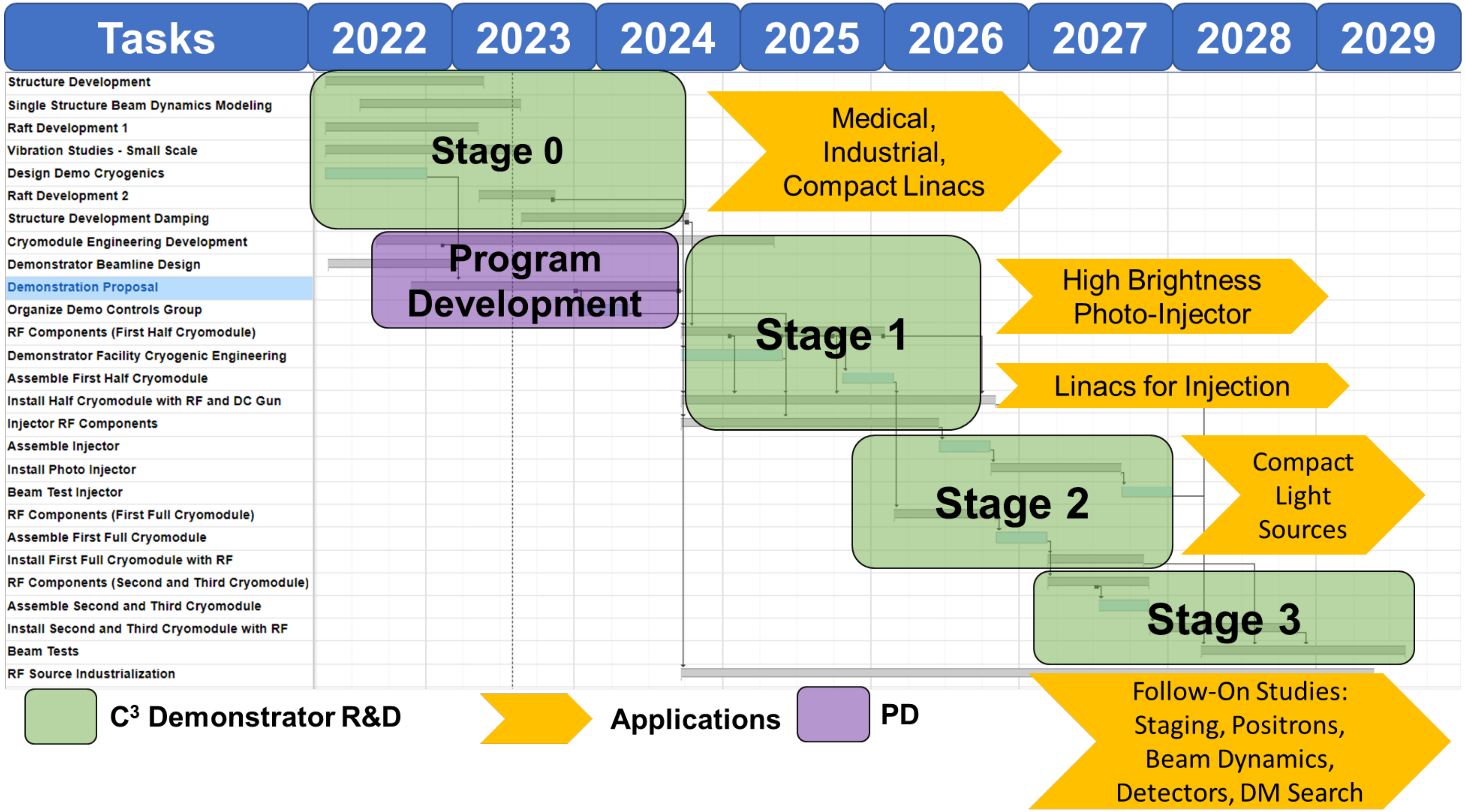
- **Demonstrate fully engineered cryomodule**
- Demonstrate full liquid/gas cryogenic flow in main linac
- Multi-Bunch: Induce and witness wakefields
- Operational gradient with margin 155 MeV/m
- **Fully damped-detuned accelerating structure**
- Work with industry to develop C-band source unit optimized for installation with main linac

Demonstration R&D Plan Timeline *



* Technically Limited

Demonstration R&D Plan Timeline *

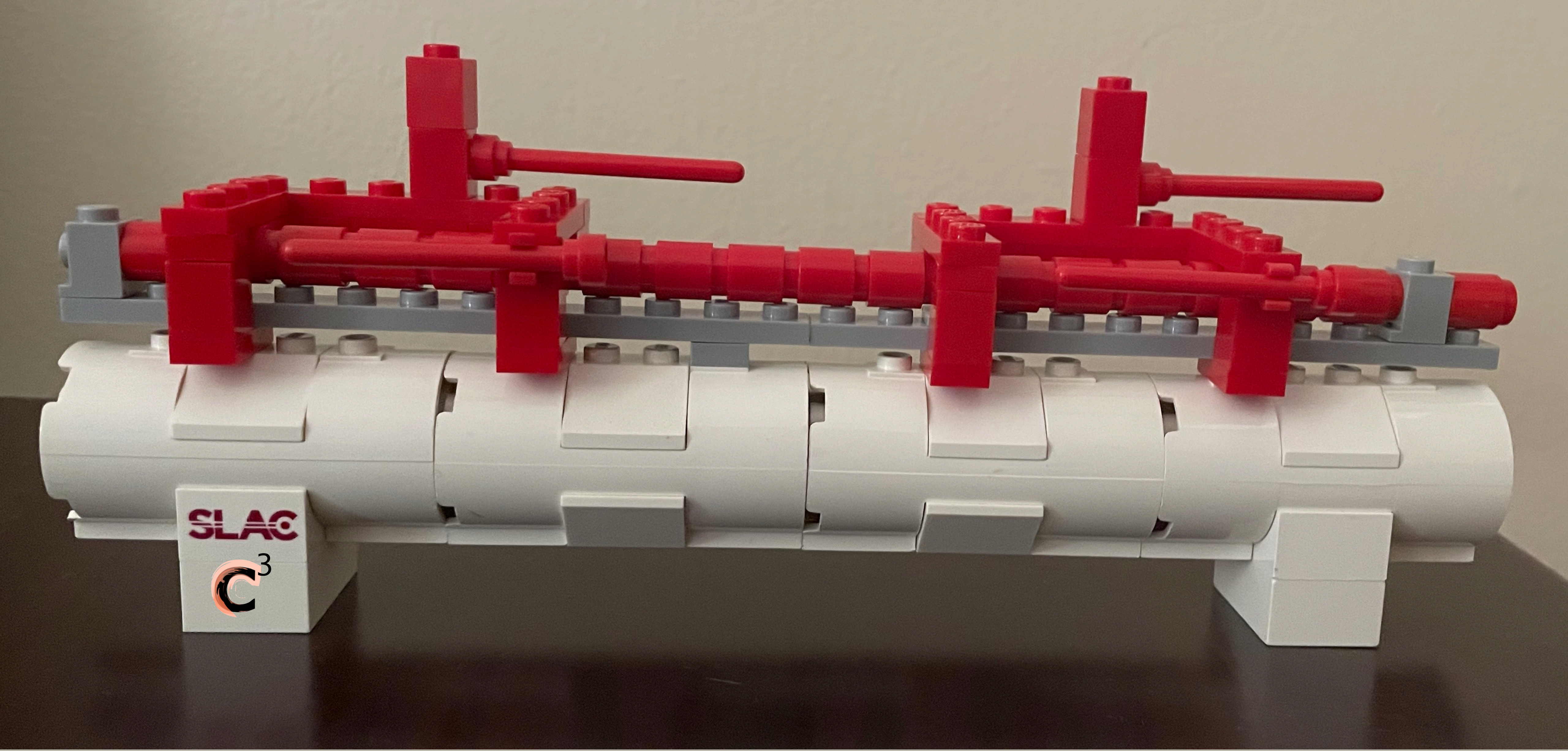


Stage 1 will answer the most pressing technical questions - beam loading, damping, alignment required to complete the engineering to a level appropriate for a **CDR - by 2025**

* Technically Limited

Conclusions & Perspectives

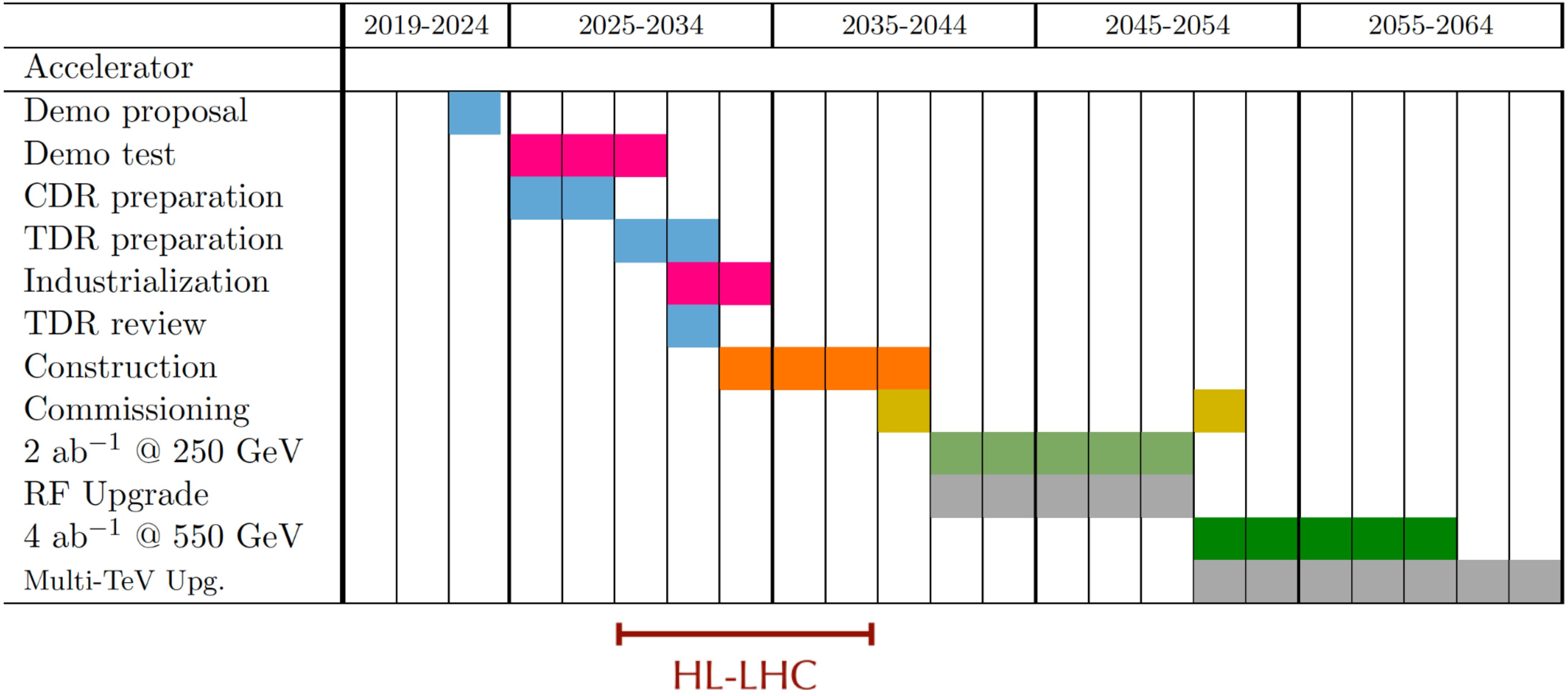
- C^3 provides a rapid route to precision Higgs physics with a compact 8 km footprint
  - Higgs physics run by 2040
  - US-hosted facility possible
- C^3 time structure is compatible with ILC-like detector design and optimizations are ongoing
- C^3 upgrade to 550 GeV with only added RF sources
  - Higgs 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
- Energy and Luminosity upgrades to be investigated as part of the demo.

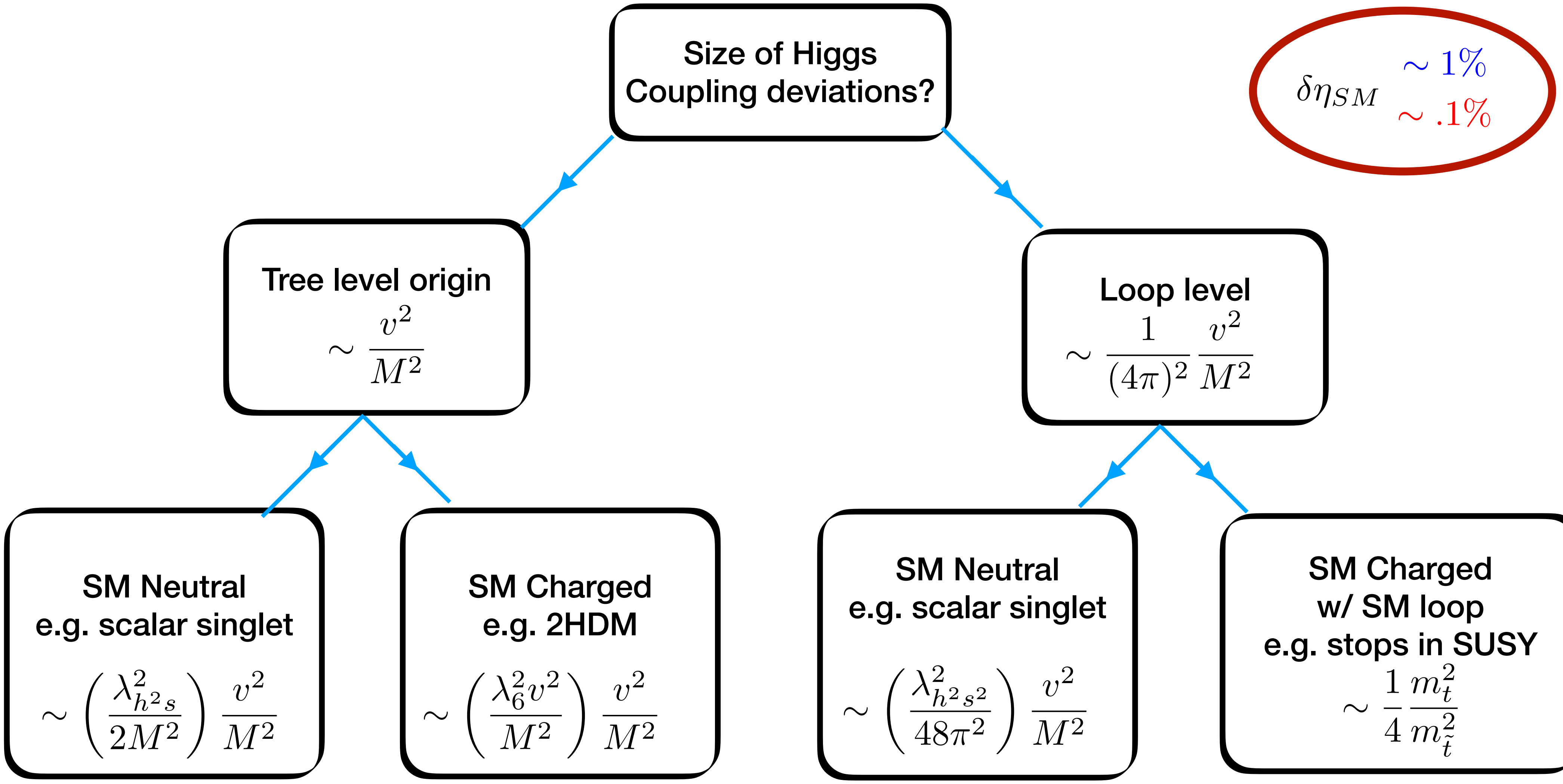


thank you!

Technical Timeline for 250/550 GeV CoM

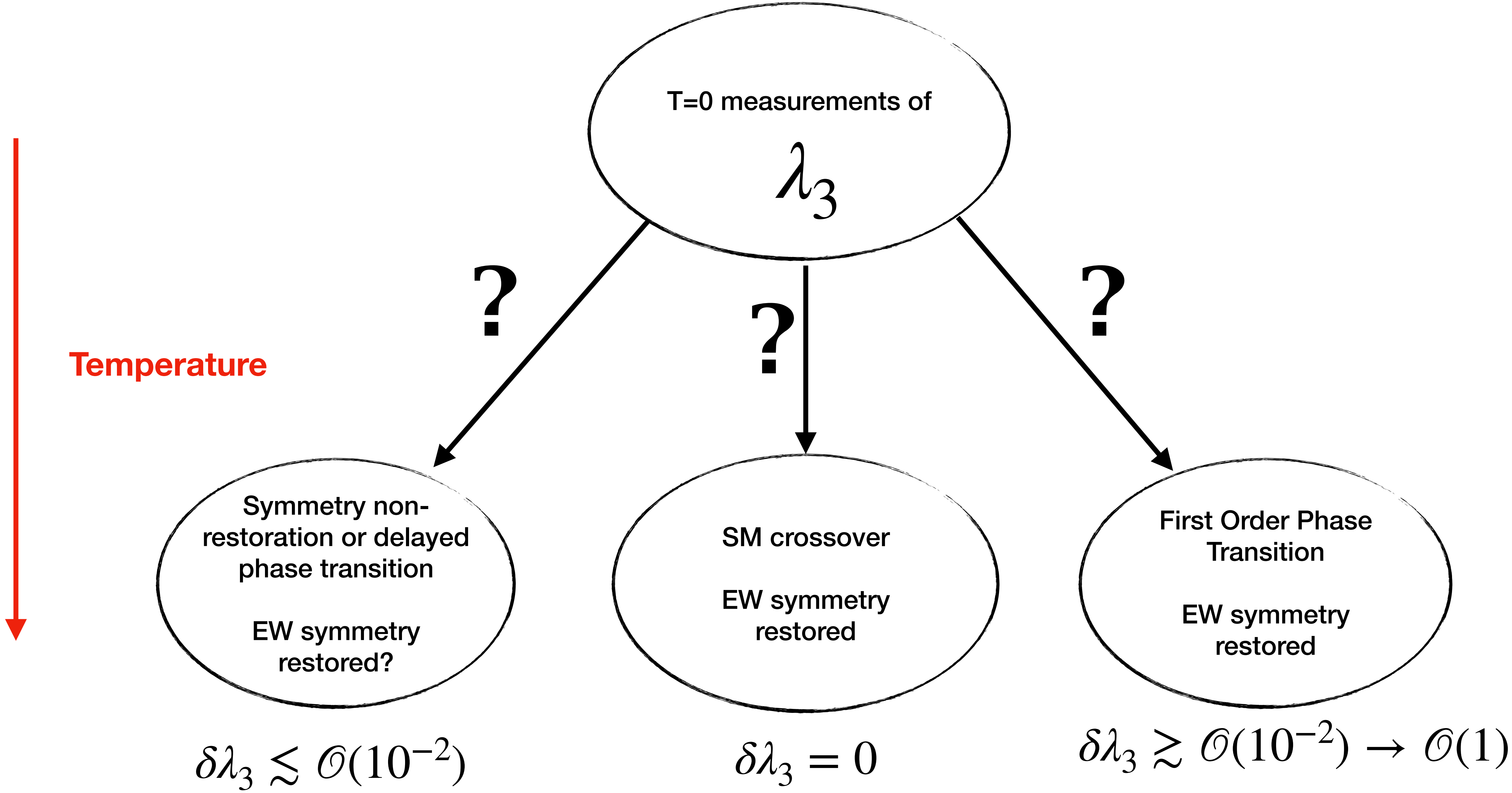
Energy upgrade in parallel to operation with installation of additional RF power sources





$M \lesssim 1.7\,\text{TeV}$	$M \lesssim 0.8\,\text{TeV}$	$M \lesssim 0.1\,\text{TeV}$	$M \lesssim 0.9\,\text{TeV}$
$M \lesssim 5.5\,\text{TeV}$	$M \lesssim 1.4\,\text{TeV}$	$M \lesssim 0.4\,\text{TeV}$	$M \lesssim 2.8\,\text{TeV}$

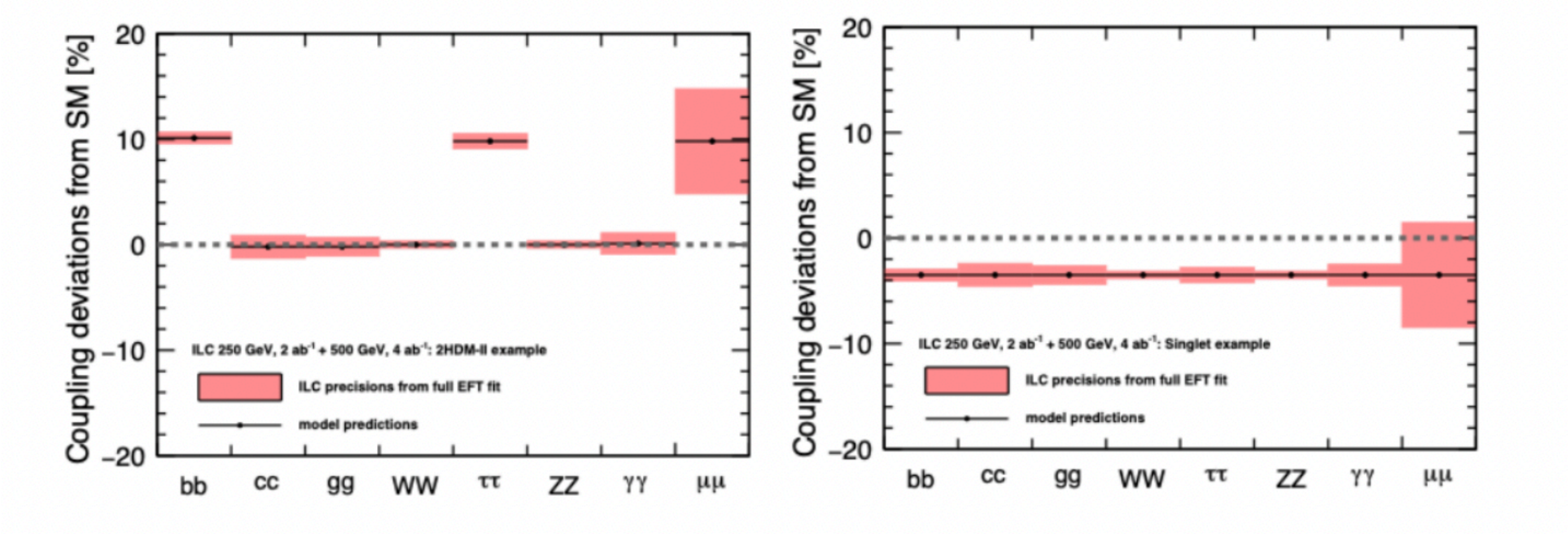
Conservative Scaling for Upper Limit on Mass Scale Probed by Higgs Precision


T=0 measurements of
λ_3
Temperature
?
?
?
Symmetry non-restoration or delayed phase transition
EW symmetry restored?
SM crossover
EW symmetry restored
First Order Phase Transition
EW symmetry restored
$\delta\lambda_3 \lesssim \mathcal{O}(10^{-2})$
$\delta\lambda_3 = 0$
$\delta\lambda_3 \gtrsim \mathcal{O}(10^{-2}) \to \mathcal{O}(1)$

An example of complementarity

arXiv:2203.07622

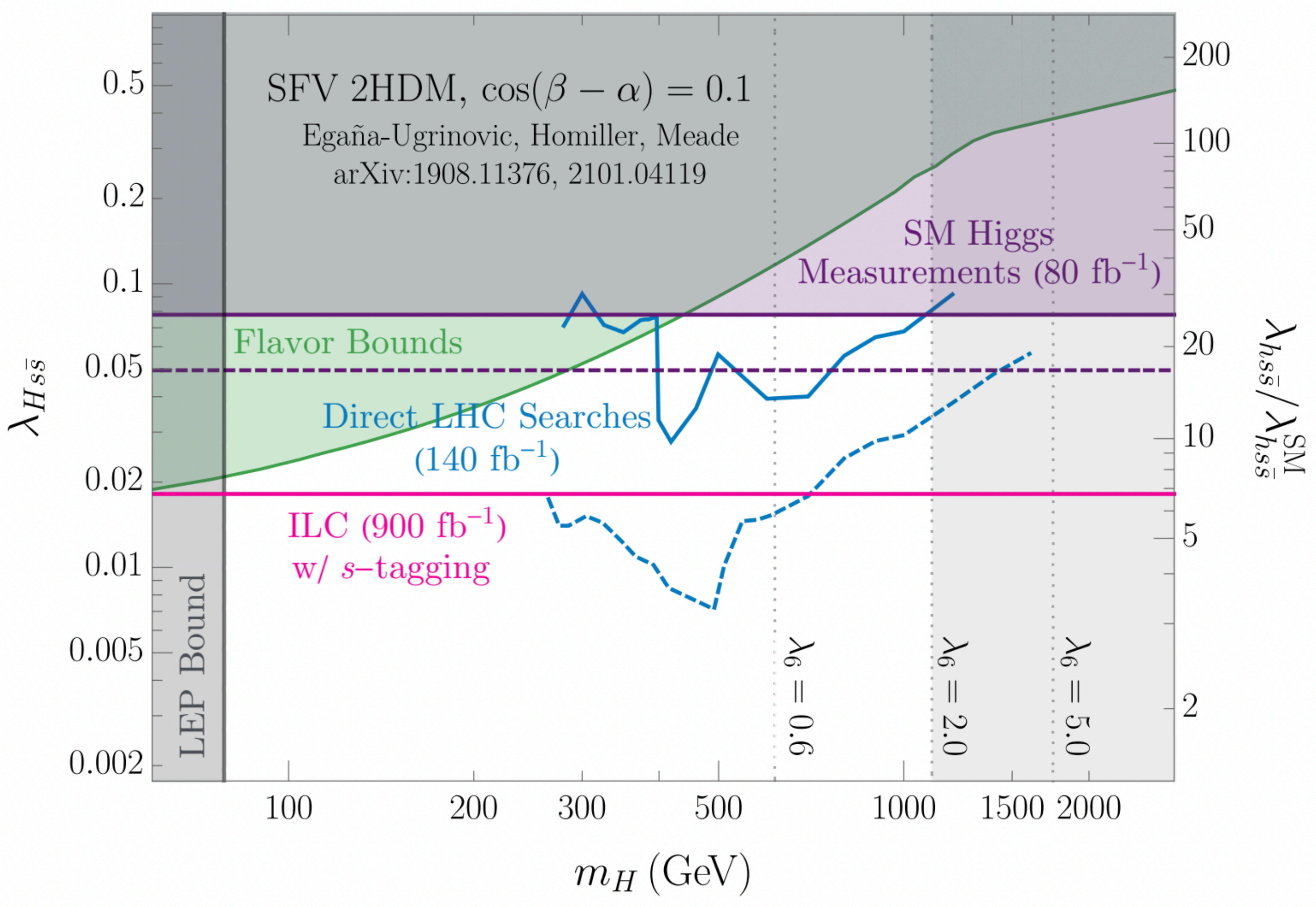
Pattern of deviations associated with a particular parameter point in a 2HDM model is quite different from a singlet model



- 2HDM with a 600 GeV mass scale and asinglet with a 2.8 TeV scalar. Both of these are clearly out of the direct search reach of circular e+e– Higgs factories despite having the precision to test them via Higgs couplings
- High energy collisions would be then required to study such new particles

arXiv:2203.07535

Flavor violating 2HDM

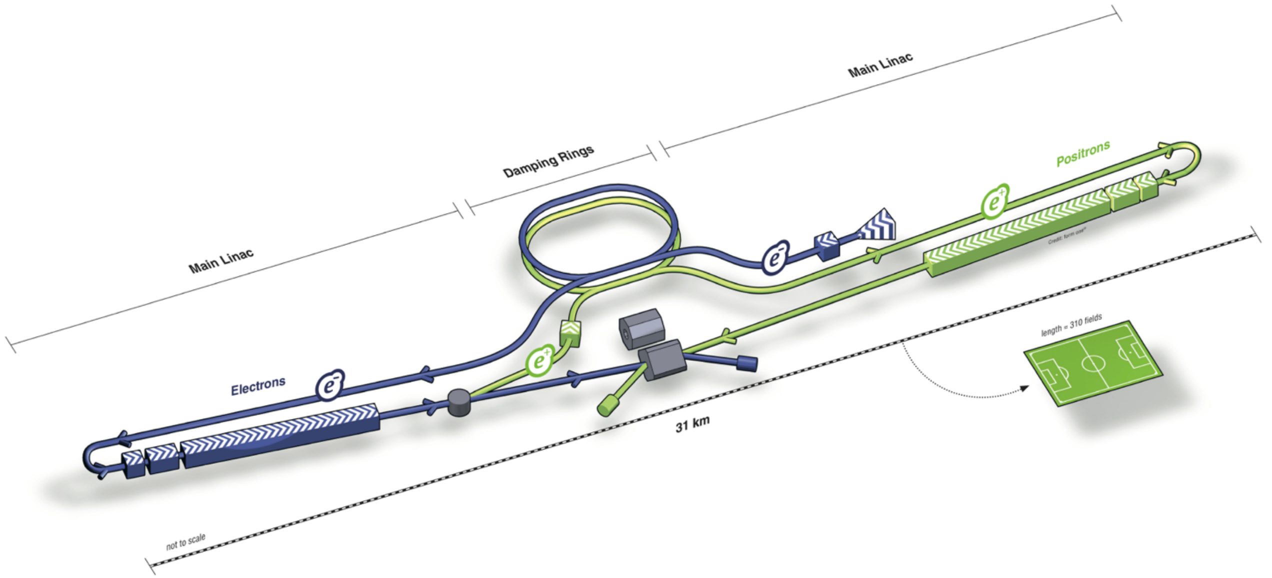


A spontaneous flavour violating (SFV) 2HDM allows for large couplings of additional Higgs to strange/light quarks while suppressing flavor-changing neutral currents

Linear vs. Circular

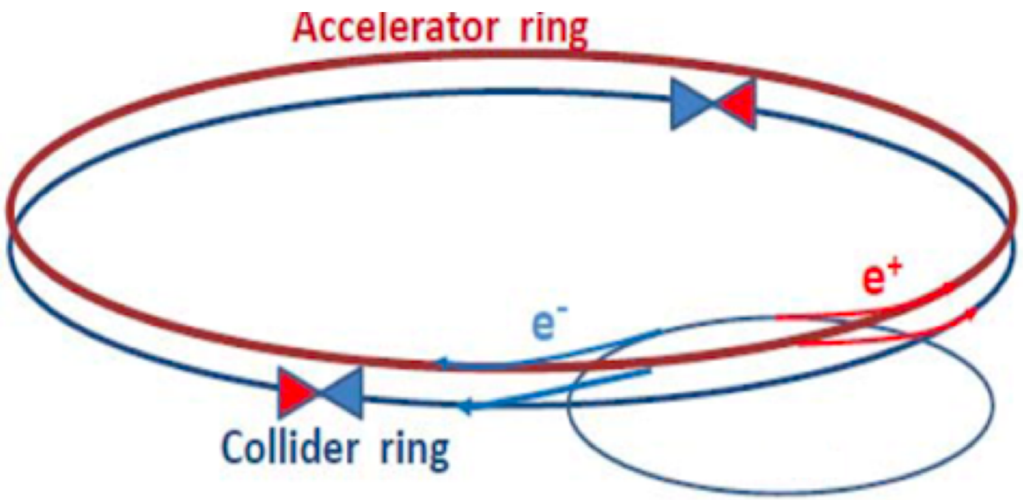
Linear e^+e^- colliders: ILC, C^3, CLIC

- Reach higher energies (~TeV), ar can use polarized beams
- Relatively low radiation
- Collisions in bunch trains



Circular e^+e^- colliders: FCC-ee, CEPC

- Highest luminosity collider at Z/WW/ ZH
- limited by synchrotron radiation above 350 – 400 GeV
- Beam continues to circulate after collision



Upgrade Options

Luminosity

- Beam power can be increased for additional luminosity
- C³ has a relatively low current for 250 GeV CoM (0.19 A) - Could we push to match CLIC at 1.66 A? (8.5X increase?)
- Pulse length and rep. rate are also options

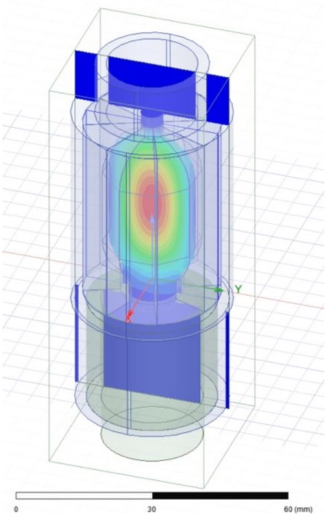
Parameter	Units	Baseline	High-Lumi
Energy CoM	GeV	250	250
Gradient	MeV/m	70	70
Beam Current	A	0.2	1.6
Beam Power	MW	2	16
Luminosity	$x10^{34}$	1.3	10.4
Beam Loading		45%	87%
RF Power	MW/m	30	125
Site Power	MW	~150	~180

Caution: Requires serious investigation of beam dynamics - great topic for C³ Demonstration R&D

Energy

- Scalability studied to 3 TeV
- Requires rf pulse compression for reasonable site power
- Higher gradient option (155 MeV/m) in consideration

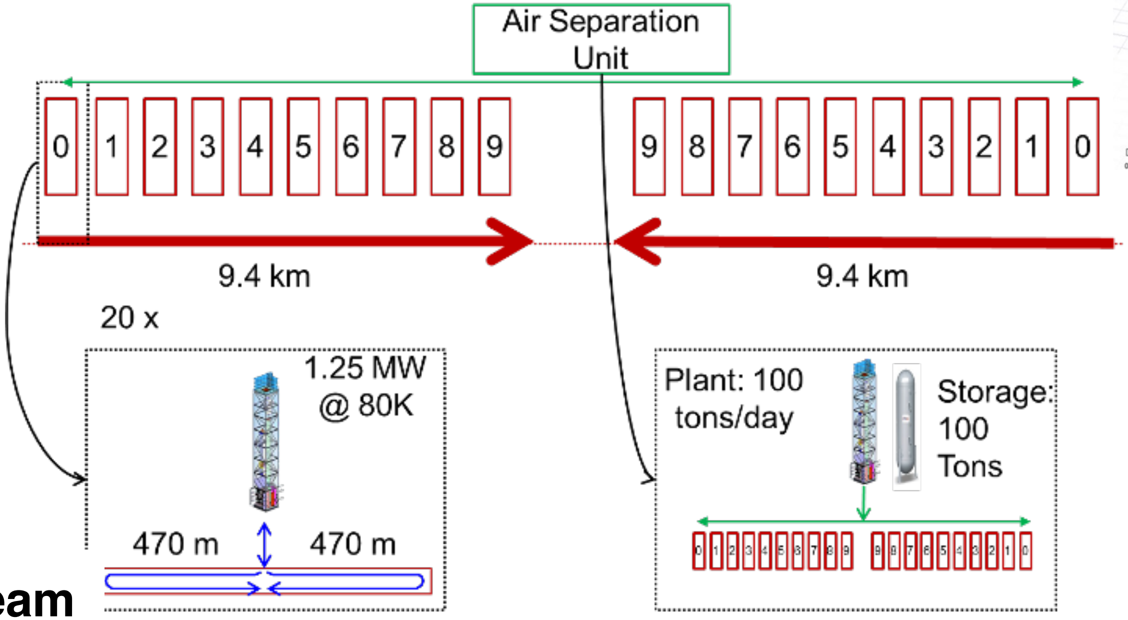
HTS Pulse Compressor
REBCO Coatings



Qo ~ 400k

Le Sage, CERN Collaborators

Cryogenics Scale to multi-TeV



arXiv:1807.10195 (2018)

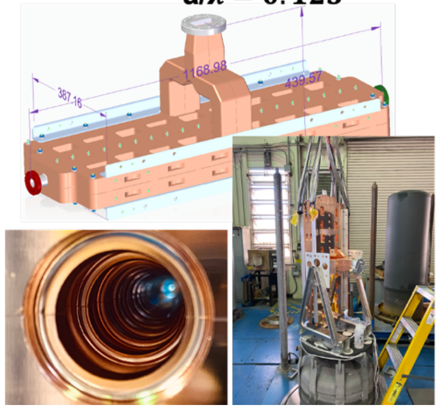
Synergies with Future Colliders

RF Accelerator Technology Essential for All Near-Term Collider Concepts

C^3 Demo is positioned to contribute synergistically or directly to all near-term collider concepts

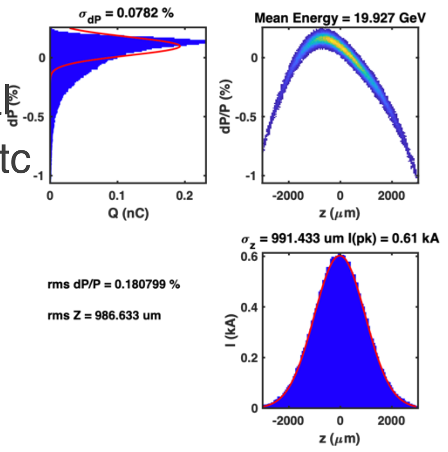
- CLIC - components, damping, fabrication techniques
- ILC - options for electron driven positron source based C^3 technology
- Muon Collider - high gradient cryogenic copper cavities in cooling channel, alternative linac for acceleration after cooling
- AAC - C^3 Demo utilized for staging, C^3 facility multi-TeV energy upgrade reutilizing tunnel, $\gamma\gamma$ colliders
- FCC-ee - common electron and positron injector linac from 6 to 20 GeV
  - **reduce length 3.5X <u>OR</u> reduce rf power 3.5X**

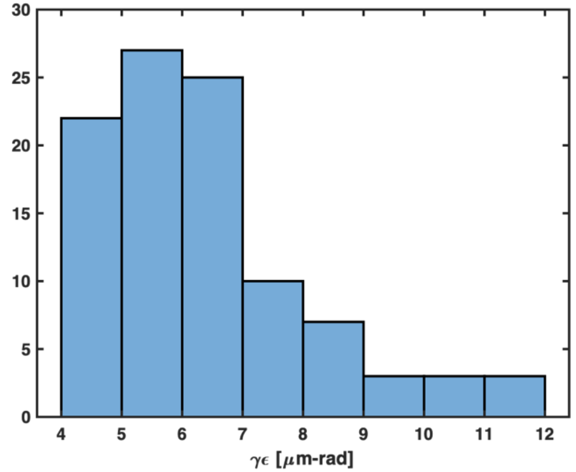
Wide Aperture S-band Injector Linac
$a/\lambda = 0.125$



- Planned test at Argonne
- Tracking with Lucretia includes longitudinal and transverse wakes, chromatic effects etc.
- Error study is 100 seeds, 100 µm element offsets, 300 µrad element rolls (rms)
  - No corrections applied

90% seeds < 8 um-rad with lattice errors





C^3 cryomodule provides significant improvements to size and sustainability of FCC-ee high energy linac
C^3 Demo timeline <u>needs to be</u> compatible with selection of FCC-ee injector

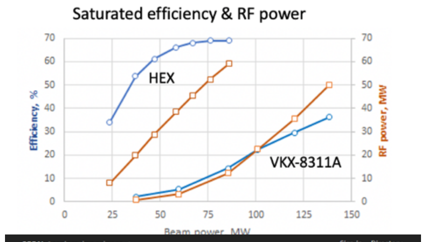
Global Contributions

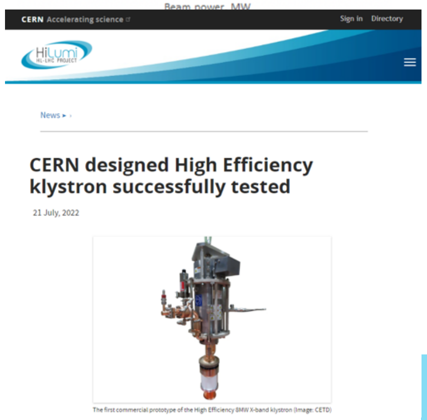
C3 Technical Timeline Only Possible with the Exceptional Progress of ILC and CLIC

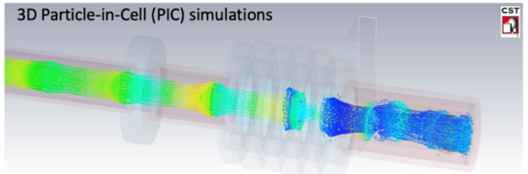
- Benefit from injector complex and beam delivery concepts
- Continue to benefit from technological improvement by ILC and CLIC

High Efficiency RF Sources (CLIC)

Retro-fit High Efficiency 50 MW, 12 GHz klystron (CERN/CPI).



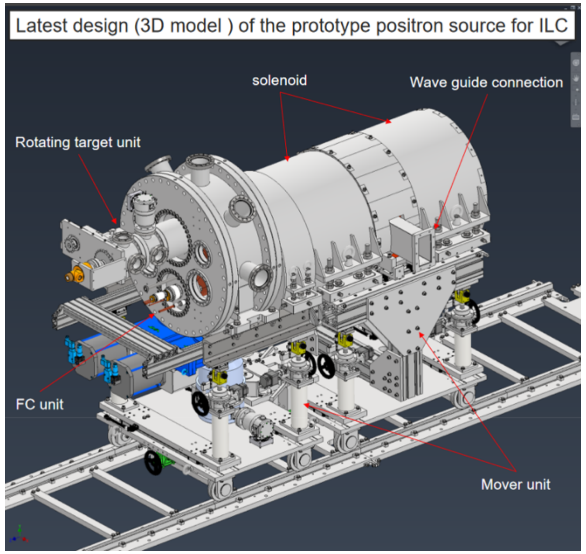

CERN Accelerating science
HiLumi
News
CERN designed High Efficiency klystron successfully tested
21 July, 2022
The first commercial prototype of the High Efficiency 8MW X-band klystron (Image: CERN)



	VKX-8311A	HEX COM_M (CERN/CPI)
Voltage, kV	420	420
Current, A	322	204
Frequency, GHz	11.994	11.994
Peak power, MW	49	59
Sat. gain, dB	48	59
Efficiency, %	36.2	69
Life time, hours	30 000	85 000
Solenoidal magnetic field, T	0.6	0.37
RF circuit length, m	0.316	0.316

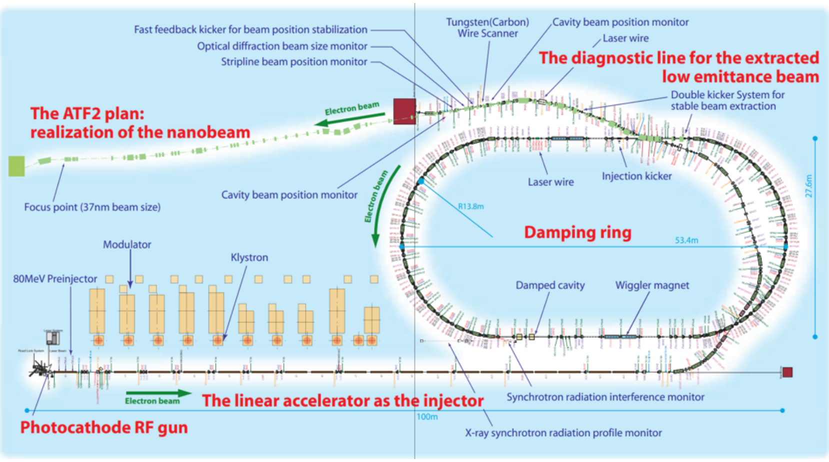
I. Sarchev, CERN

Electron Driven Positron Source



Courtesy of Y. Enomoto

Nanobeams for IP (ATF)



https://www-atf.kek.jp/atf/

Vibrant International Community for Future Colliders is Essential
National Future Colliders R&D in the US to Optimize Efforts

Table of Parameters

Collider	NLC	CLIC	ILC	C^3	C^3
CM Energy [GeV]	500	380	250 (500)	250	550
Luminosity [x10^{34}]	0.6	1.5	1.35	1.3	2.4
Gradient [MeV/m]	37	72	31.5	70	120
Effective Gradient [MeV/m]	29	57	21	63	108
Length [km]	23.8	11.4	20.5 (31)	8	8
Num. Bunches per Train	90	352	1312	133	75
Train Rep. Rate [Hz]	180	50	5	120	120
Bunch Spacing [ns]	1.4	0.5	369	5.26	3.5
Bunch Charge [nC]	1.36	0.83	3.2	1	1
Crossing Angle [rad]	0.020	0.0165	0.014	0.014	0.014
Site Power [MW]	121	168	125	$\sim$150	$\sim$175
Design Maturity	CDR	CDR	TDR	pre-CDR	pre-CDR

Requirements for a High Energy e+e- Linear Collider

Using established collider designs to inform initial parameters

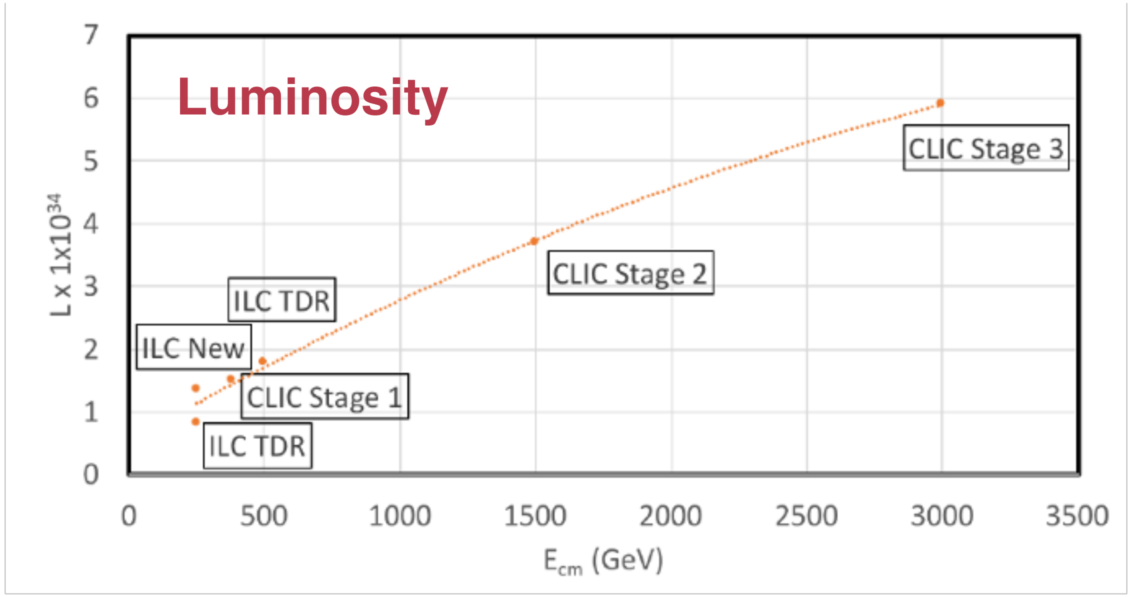
Quantifying impact of wakes requires detailed studies

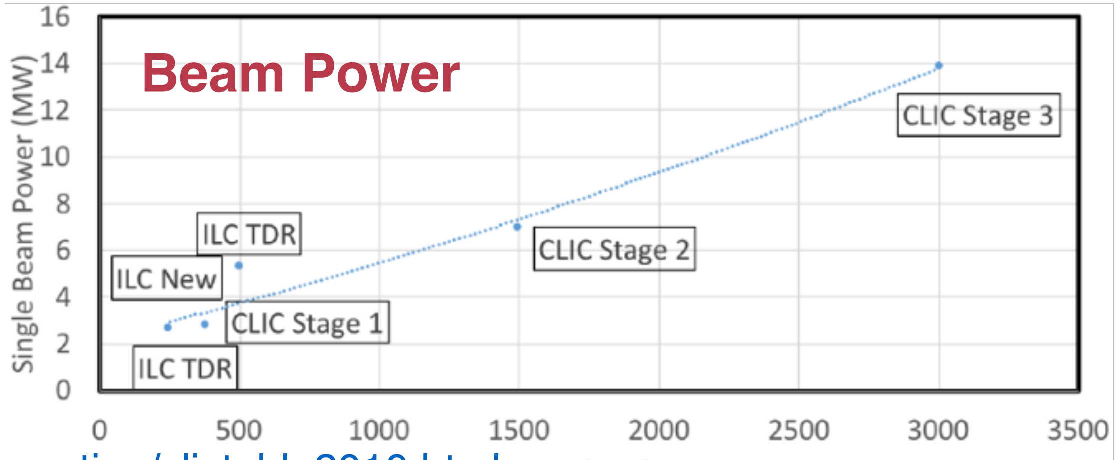
- Most important terms – aperture, bunch charge (and their scaling with frequency)

Target initial stage design at 250 GeV CoM

- 2 MW single beam power

Machine	CLIC	NLC	C3
Freq (GHz)	12.0	11.4	5.7
a (mm)	2.75	3.9	2.6
Charge (nC)	0.6	1.4	1
Spacing (λ)	6	16	30/20
# of bunches	312	90	133/75





https://clic-meeting.web.cern.ch/clic-meeting/clictable2010.html

NLC, ZDR Tbl. 1.3,8.3

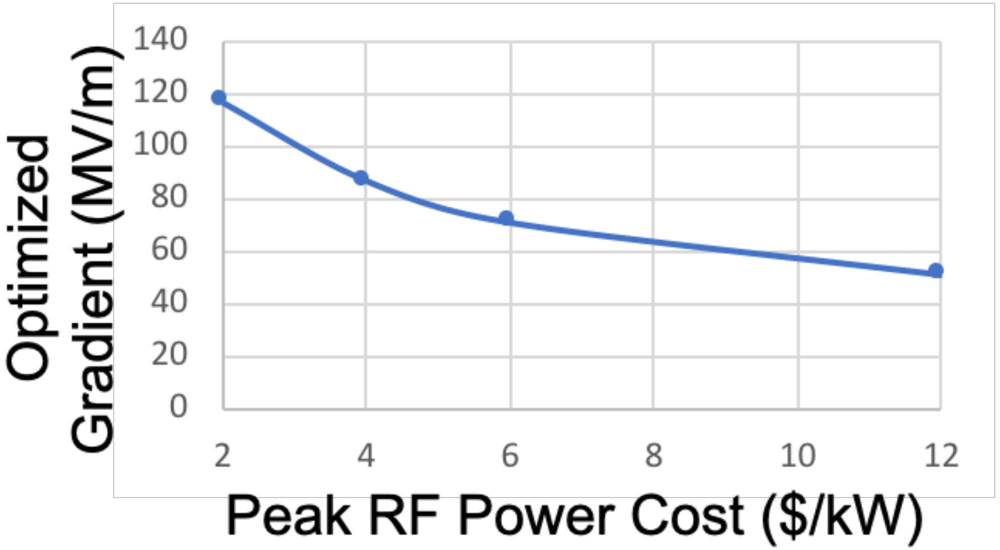
RF Source R&D Over the Timescale of the Next P5

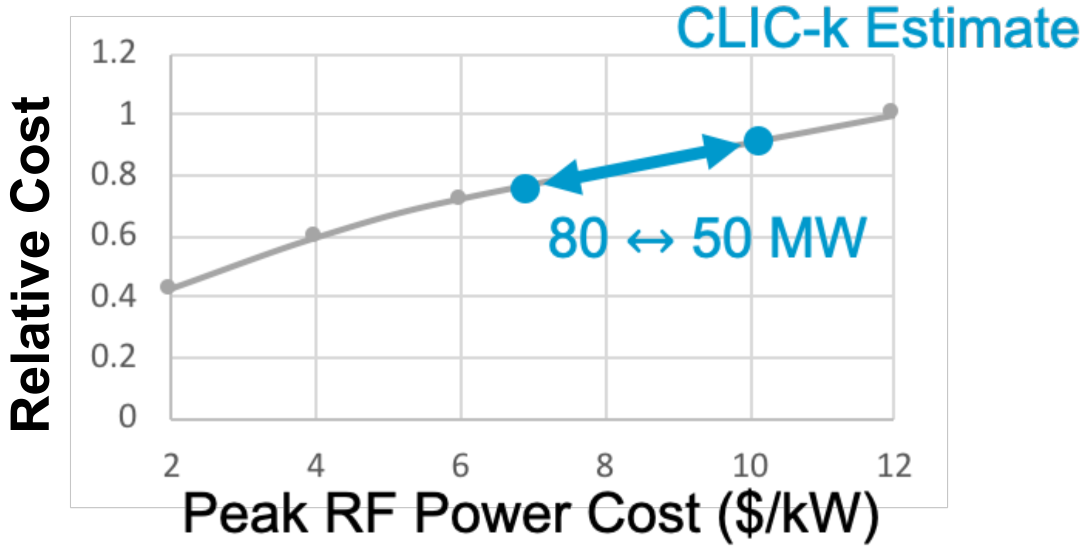
RF source cost is the key driver for gradient and cost

Significant savings when items procured at scale of LC

Need to focus R&D on reducing source cost to drive economic argument for high gradient

Gradient/Cost Scaling vs. RF Source Cost for Main Linac





Understand the Impact on Advanced Collider Concept Enabled by the Goals Defined in the DOE GARD RF Decadal Roadmap

https://science.energy.gov/~/media/hep/pdf/Reports/DOE_HEP_GARD_RF_Research_Roadmap_Report.pdf

C^3 Demonstration R&D Plan

C^3 demonstration R&D needed to advance technology beyond CDR level

Minimum requirement for Demonstration R&D Plan:

- **Demonstrate operation of fully engineered and operational cryomodule**
  - Simultaneous operations of min. 3 cryomodules
- Demonstrate operation during cryogenic flow equivalent to main linac at full liquid/gas flow rate
- Operation with a multi-bunch photo injector - high charges bunches to induce wakes, tunable delay witness bunch to measure wakes
- Demonstrate full operational gradient 120 MeV/m (and higher > 155 MeV/m) w/ single bunch
  - Must understand margins for 120 - targeting power for (155 + margin) 170 MeV/m
  - 18X 50 MW C-band sources - off the shelf units
- **Fully damped-detuned accelerating structure**
- Work with industry to develop C-band source unit optimized for installation with main linac

This demonstration directly benefits development of compact FELs, beam dynamics, high brightness guns, *etc.*

The other elements needed for a linear collider - the sources, damping rings, and beam delivery system – more advanced from the ILC and CLIC – need C^3 specific design

- Our current baseline uses these directly; will look for further cost-optimizations for of C^3