C³ Demo and RF Accel. R&D

Emilio Nanni
SLACmass
5/12/2022

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Strategy for Understanding the Higgs Physics: The Cool Copper Collider

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C^3 Demonstration Research and Development Plan

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

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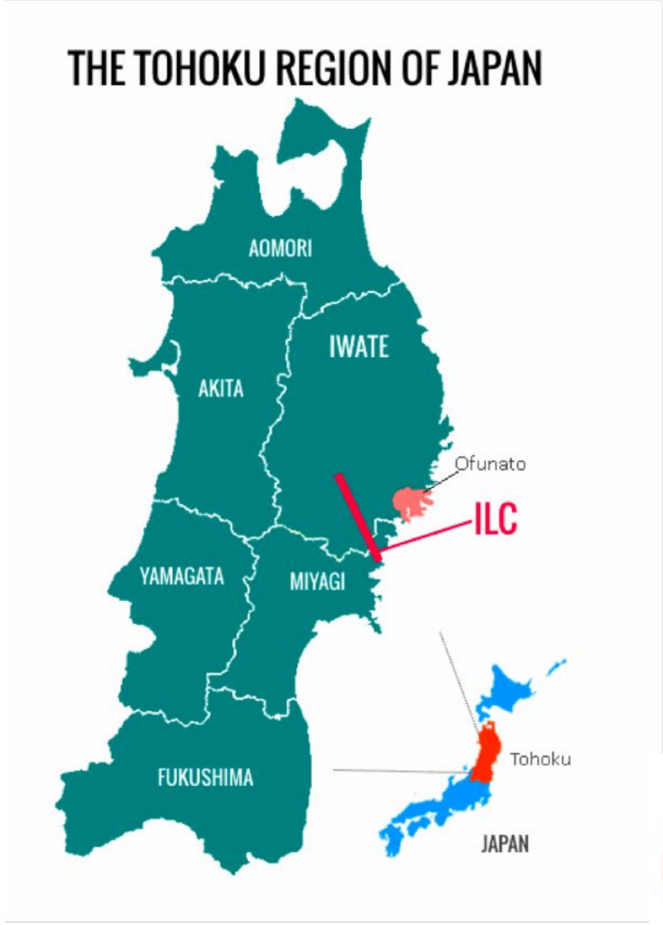
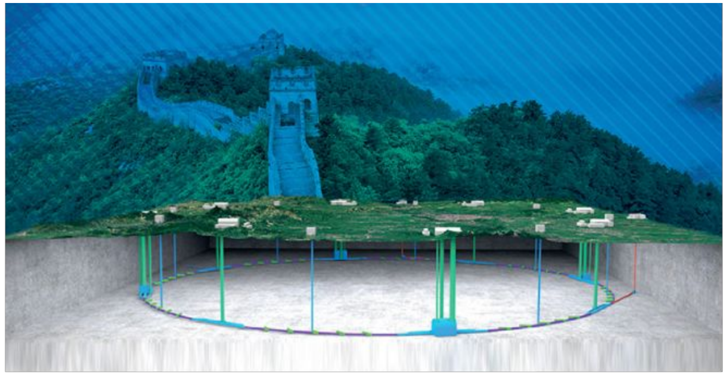
More Details Here (Follow, Endorse, Collaborate):
https://indico.slac.stanford.edu/event/7155/

SLAC SLACmass

Various Higgs Factory Proposals for Next Collider

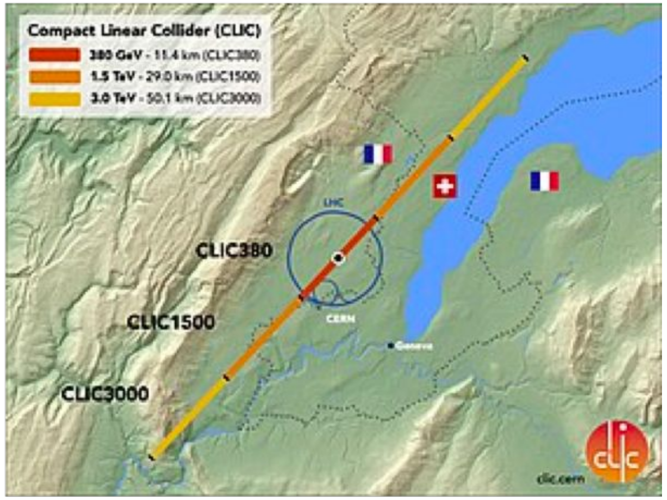


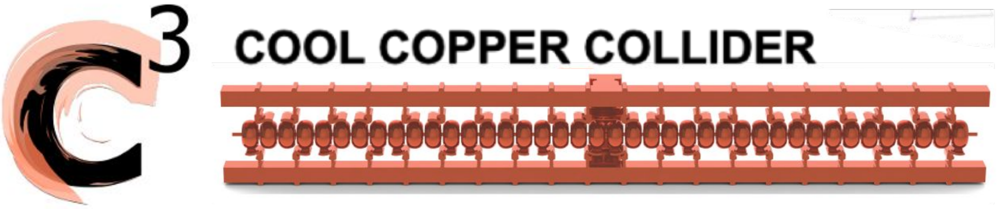
ILC
250/500 GeV



CEPC
240 GeV

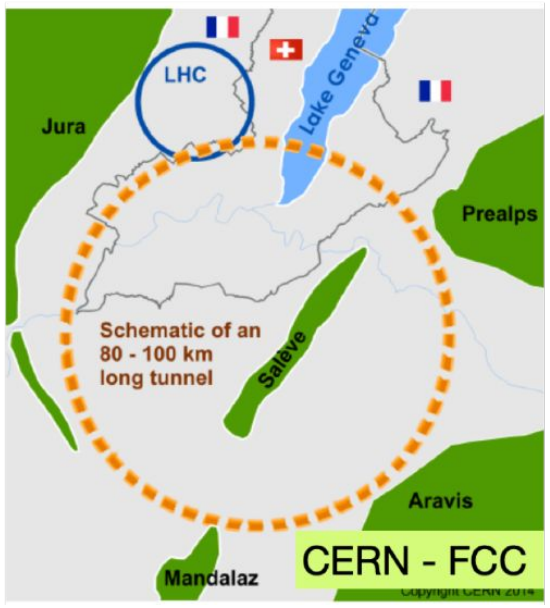
CLIC 380/1000/3000 GeV





250/550 GeV
… > TeV

FCC-ee
240/365 GeV



C^3 Cool Copper Collider

C^3 is based on a new rf technology

- Dramatically improving efficiency and breakdown rate

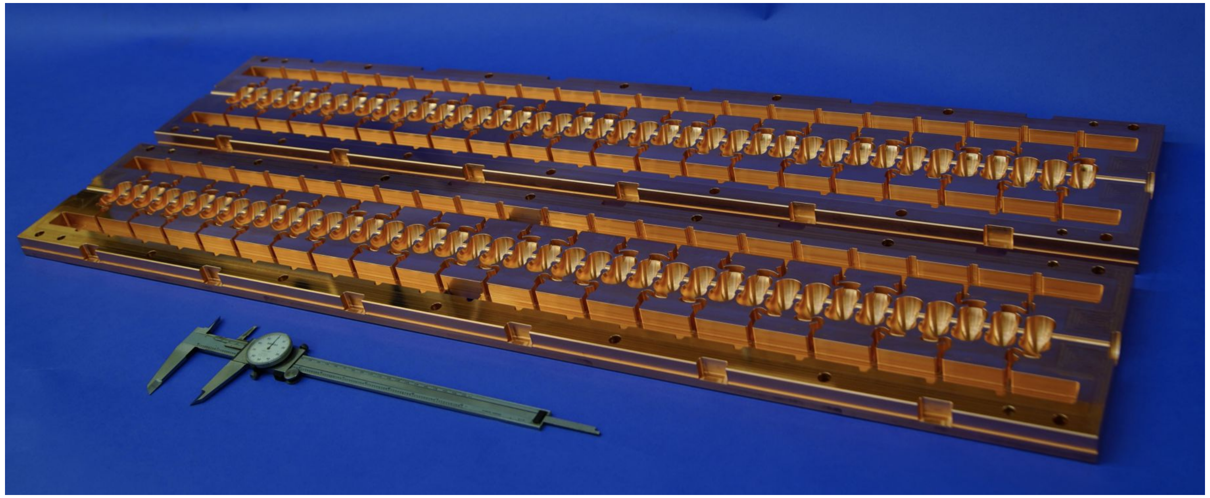
Distributed power to each cavity from a common RF manifold

Operation at cryogenic temperatures (LN_2 ~80 K)

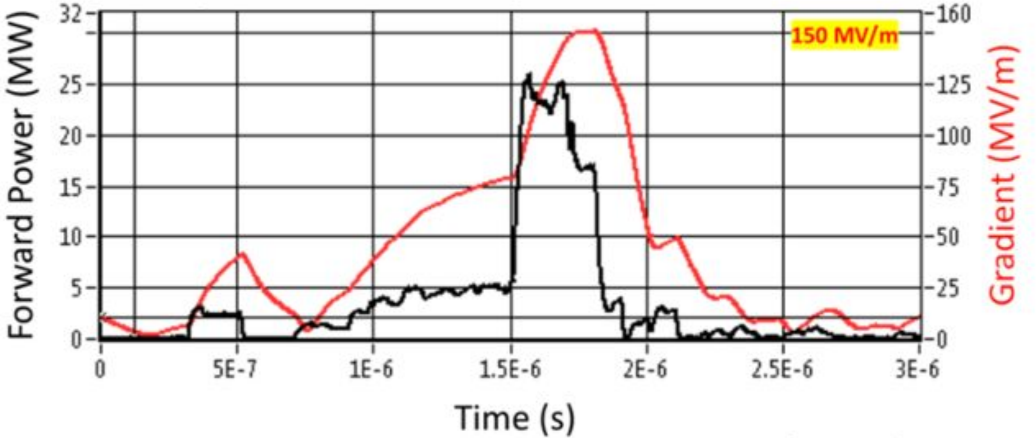
Robust operations at high gradient: 120 MeV/m

Scalable to multi-TeV operation

C^3 Prototype One Meter Structure

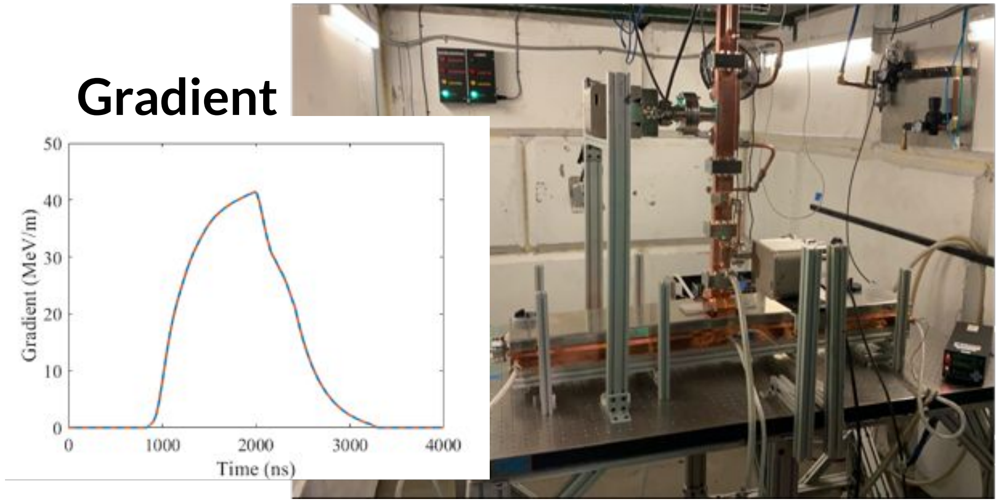


High Gradient Operation at 150 MV/m



Cryogenic Operation at X-band

High power Test at Radiabeam



Cryo-Copper: Enabling Efficient High-Gradient Operation

Cryogenic temperature elevates performance in gradient

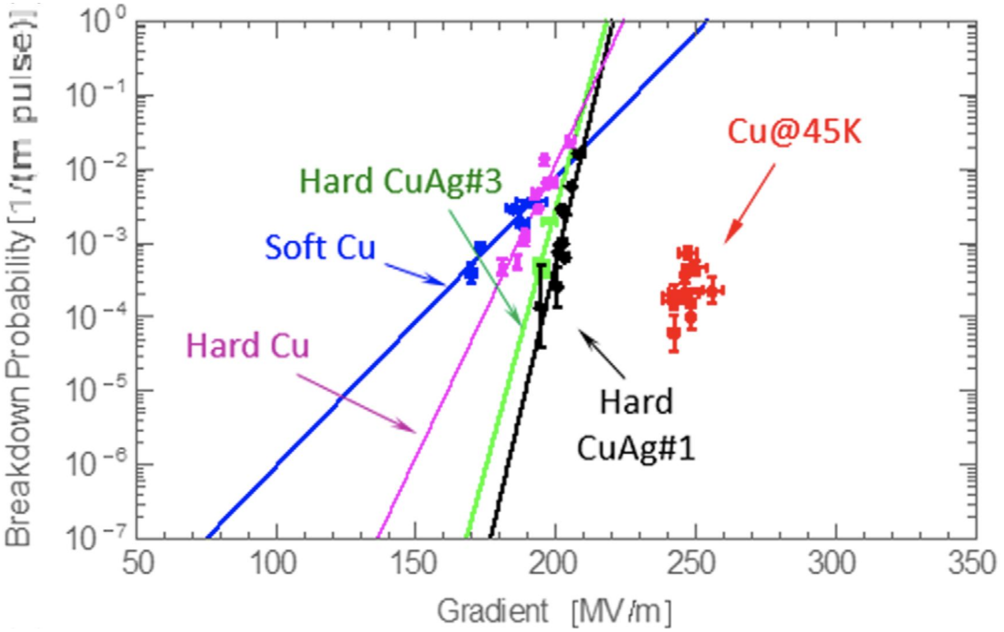
- Increased material strength is key factor
- Increase electrical conductivity reduces pulsed heating in the material

Operation at 77 K with liquid nitrogen is simple and practical

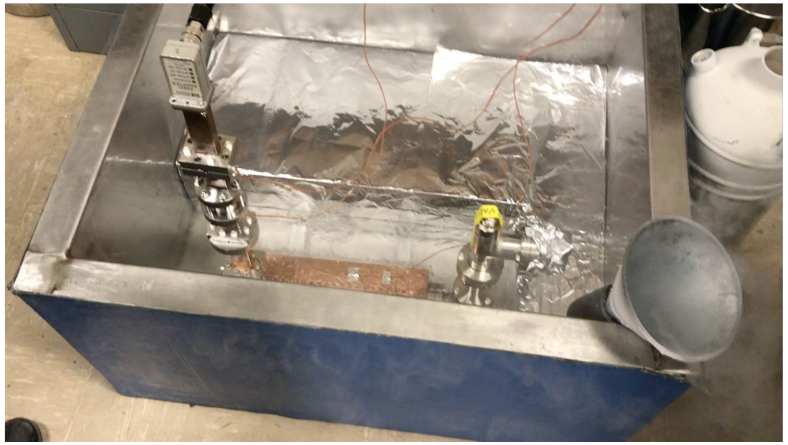
- Large-scale production, large heat capacity, simple handling
- Small impact on electrical efficiency

$$\eta_{cp} = LN\ Cryoplant$$
$$\eta_{cs} = Cryogenic\ Structure$$
$$\eta_k = RF\ Source$$

$$\frac{\eta_{cs}}{\eta_k}\eta_{cp} \approx \frac{2.5}{0.5}[0.15] \approx 0.75$$



Cahill, A. D., et al. *PRAB* 21.10 (2018): 102002.



Accelerator Complex

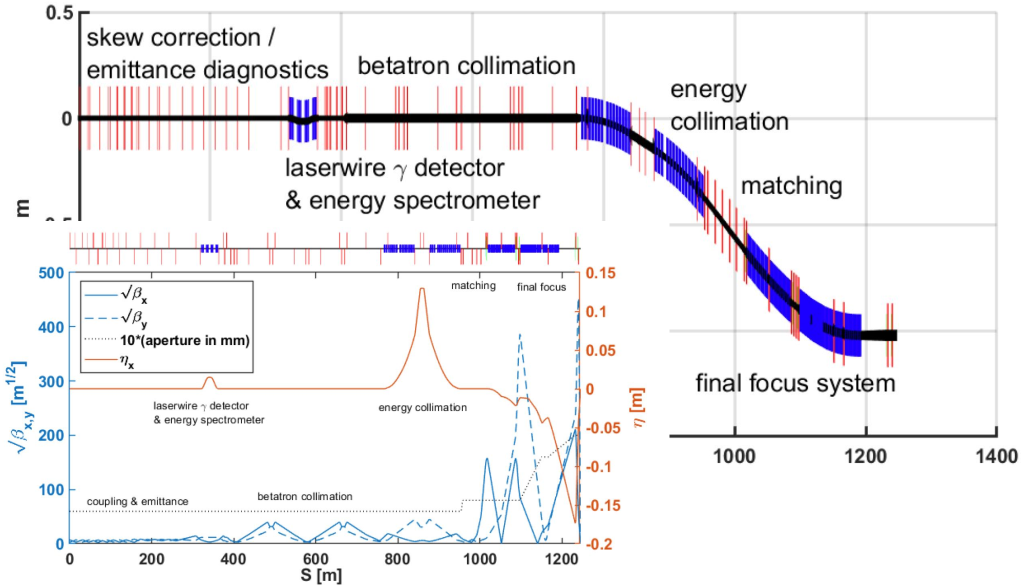
8 km footprint for 250/550 GeV CoM ⟹ 70/120 MeV/m

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

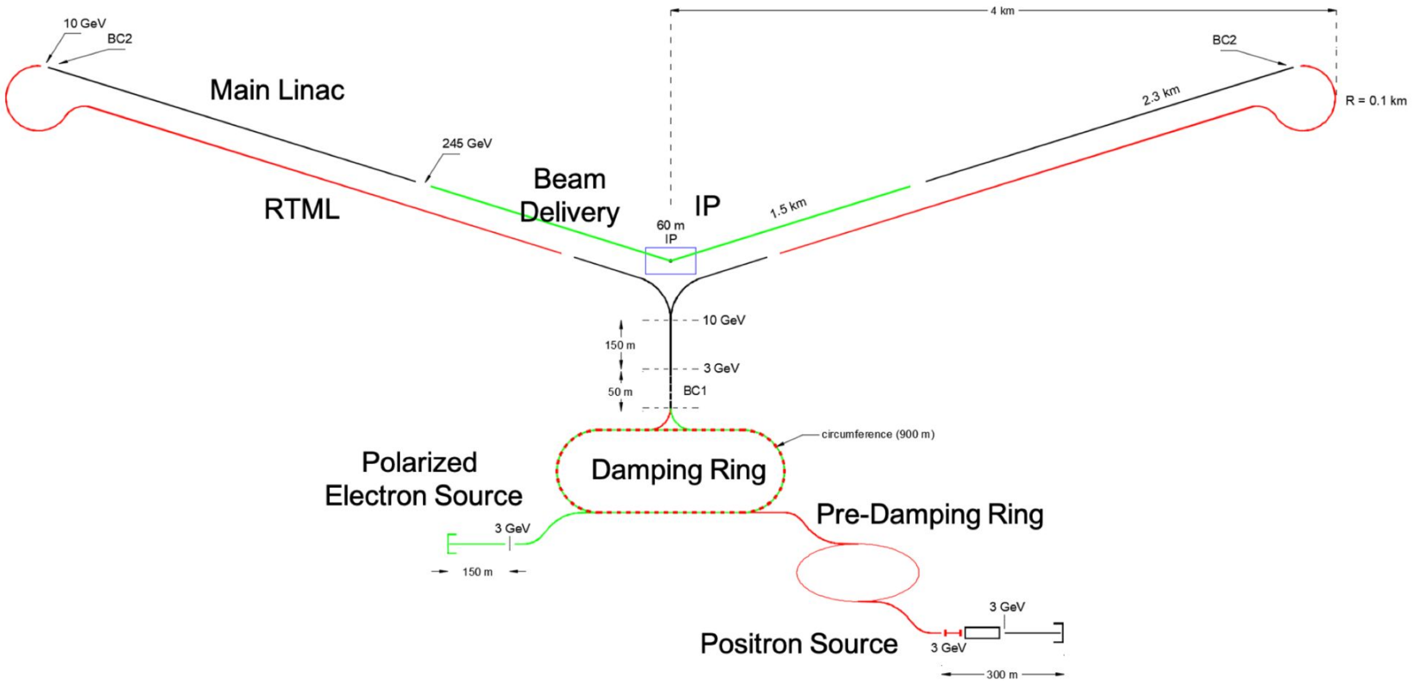
Large portions of accelerator complex are compatible between LC technologies

- Beam delivery and IP modified from ILC (1.5 km for 550 GeV CoM)
- Damping rings and injectors to be optimized with CLIC as baseline
- Costing studies use LC estimates as inputs

C^3 - Investigation of Beam Delivery (Adapted from ILC/NLC)



C^3 - 8 km Footprint for 250/550 GeV



Cryomodule Design and Alignment

Up to 1 GeV of acceleration per 9 m cryomodule; ~90% fill factor with eight 1 m structures

Main linac will require 5 micron structure alignment

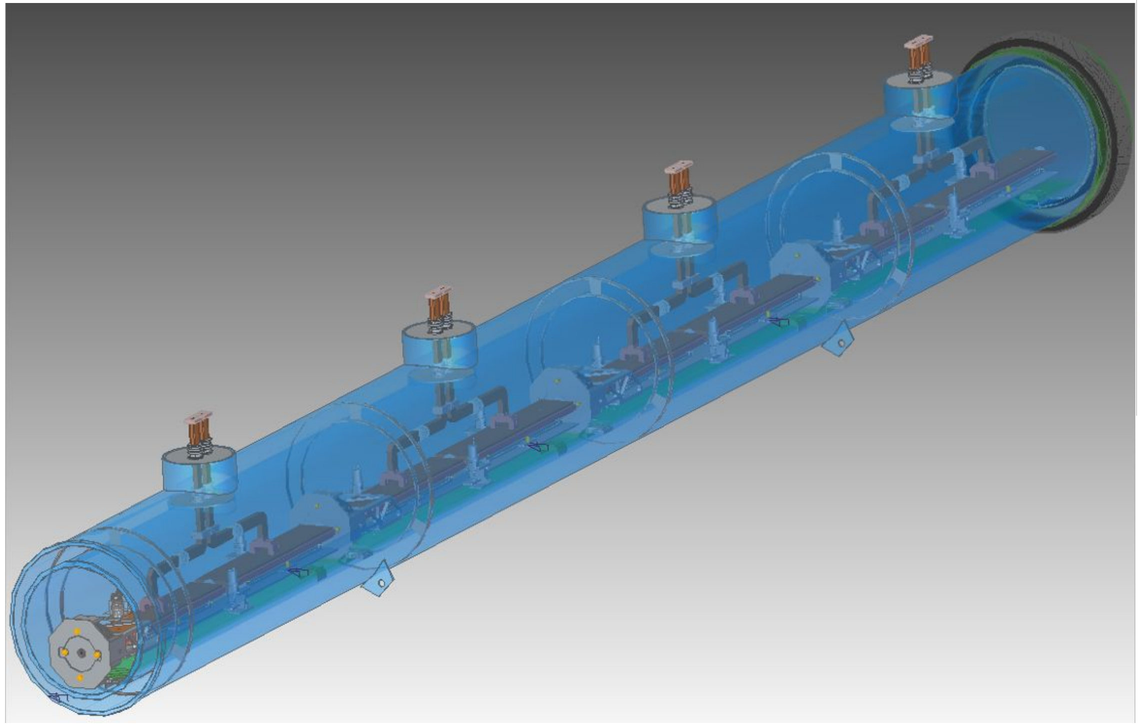
- Combination of mechanical and beam based alignment

Pre-alignment warm, cold alignment by wire, followed by beam based

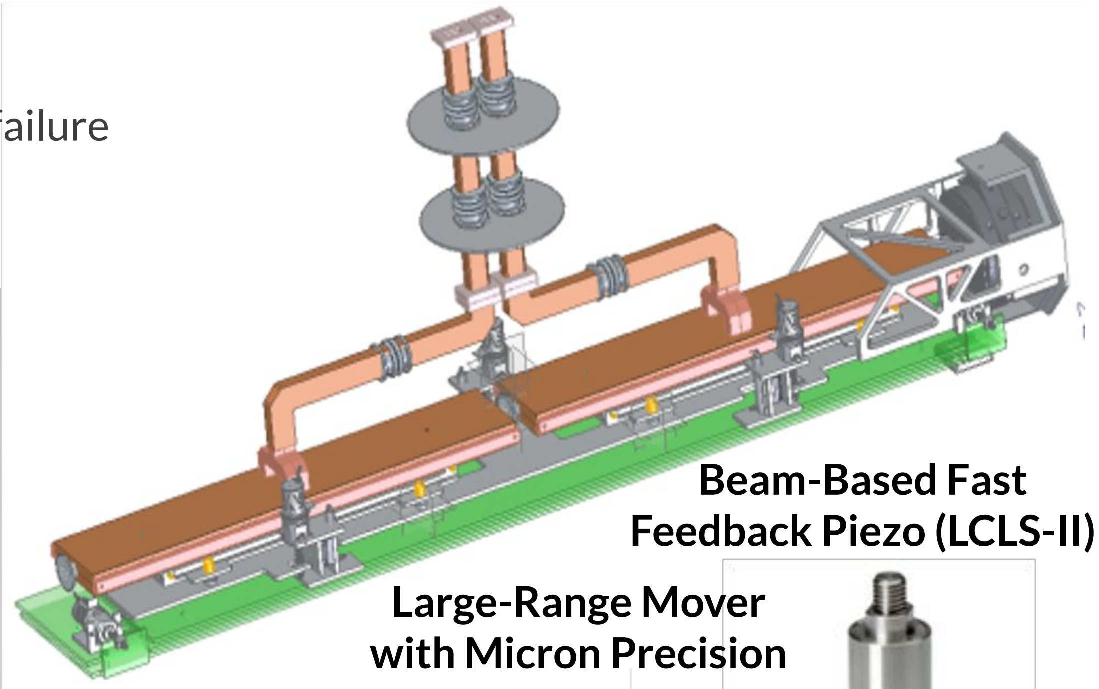
- Mechanical motor runs warm or cold – no motion during power failure
- Piezo for active alignment

Investigating support and assembly design

Cryomodule Concept



Two Meter Raft and Quad w/ BPM



Large-Range Mover with Micron Precision

Beam-Based Fast Feedback Piezo (LCLS-II)

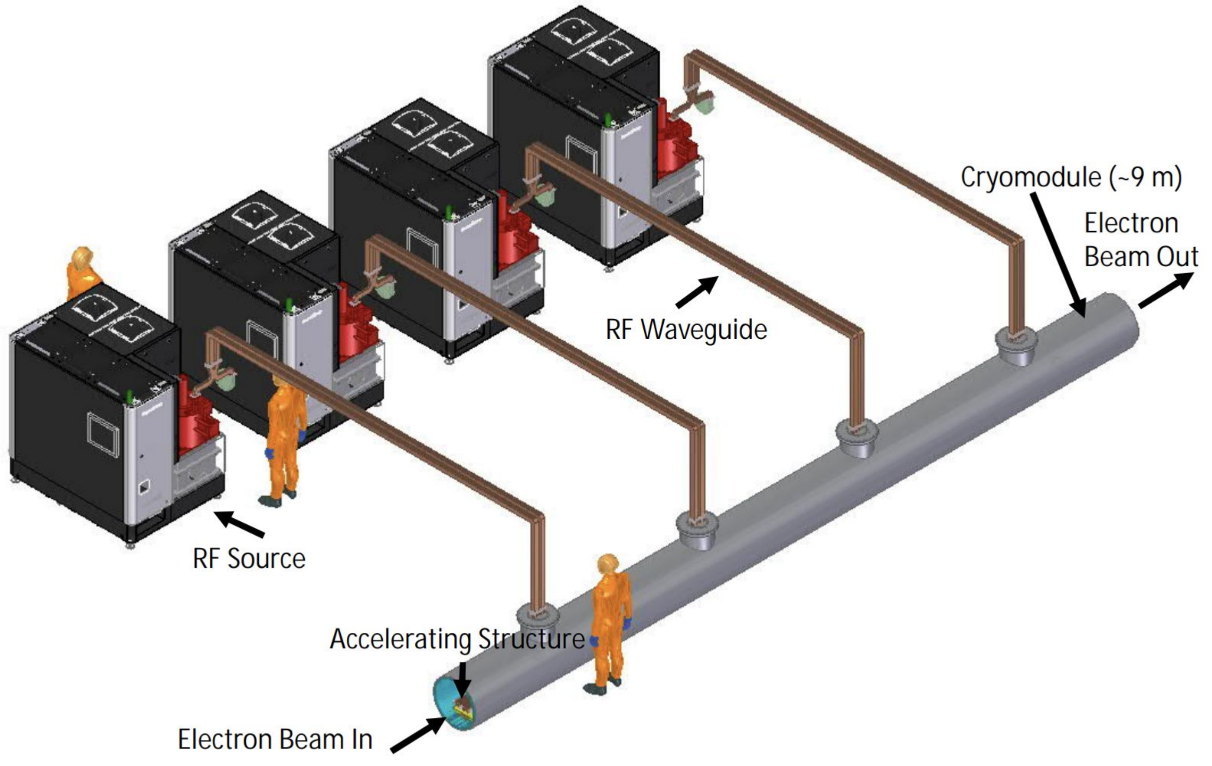
Tunnel Layout for Main Linac 250/550 GeV CoM

Need to optimize tunnel layout – first study looked at 9.5 m inner diameter in order to match ILC costing model

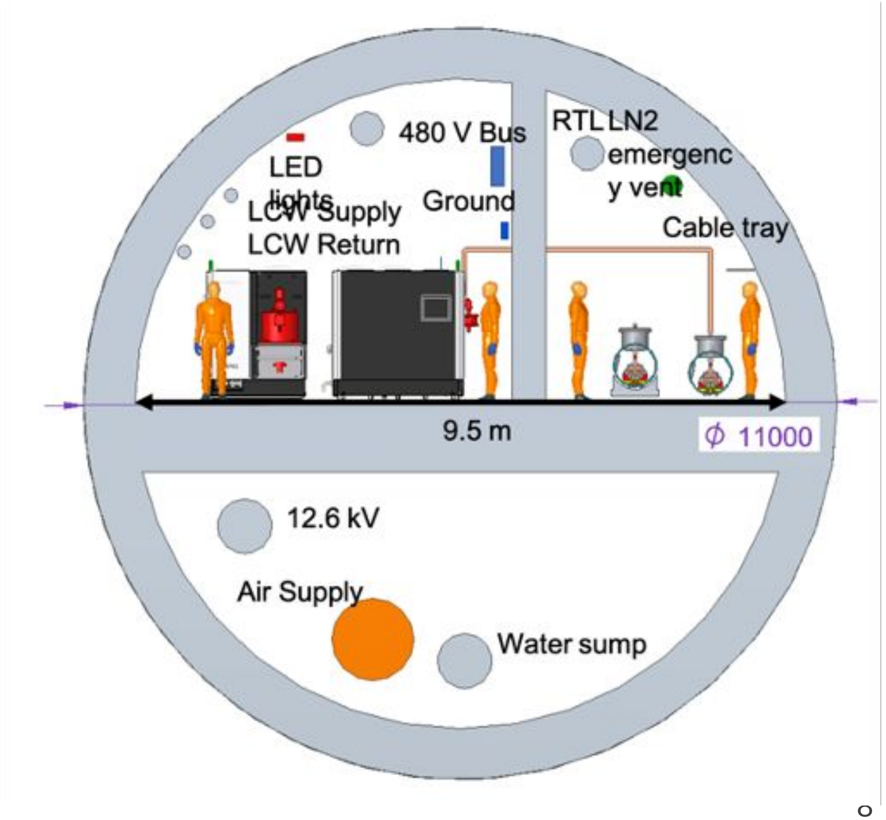
- Must minimize diameter to reduce cost and construction time

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)



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:

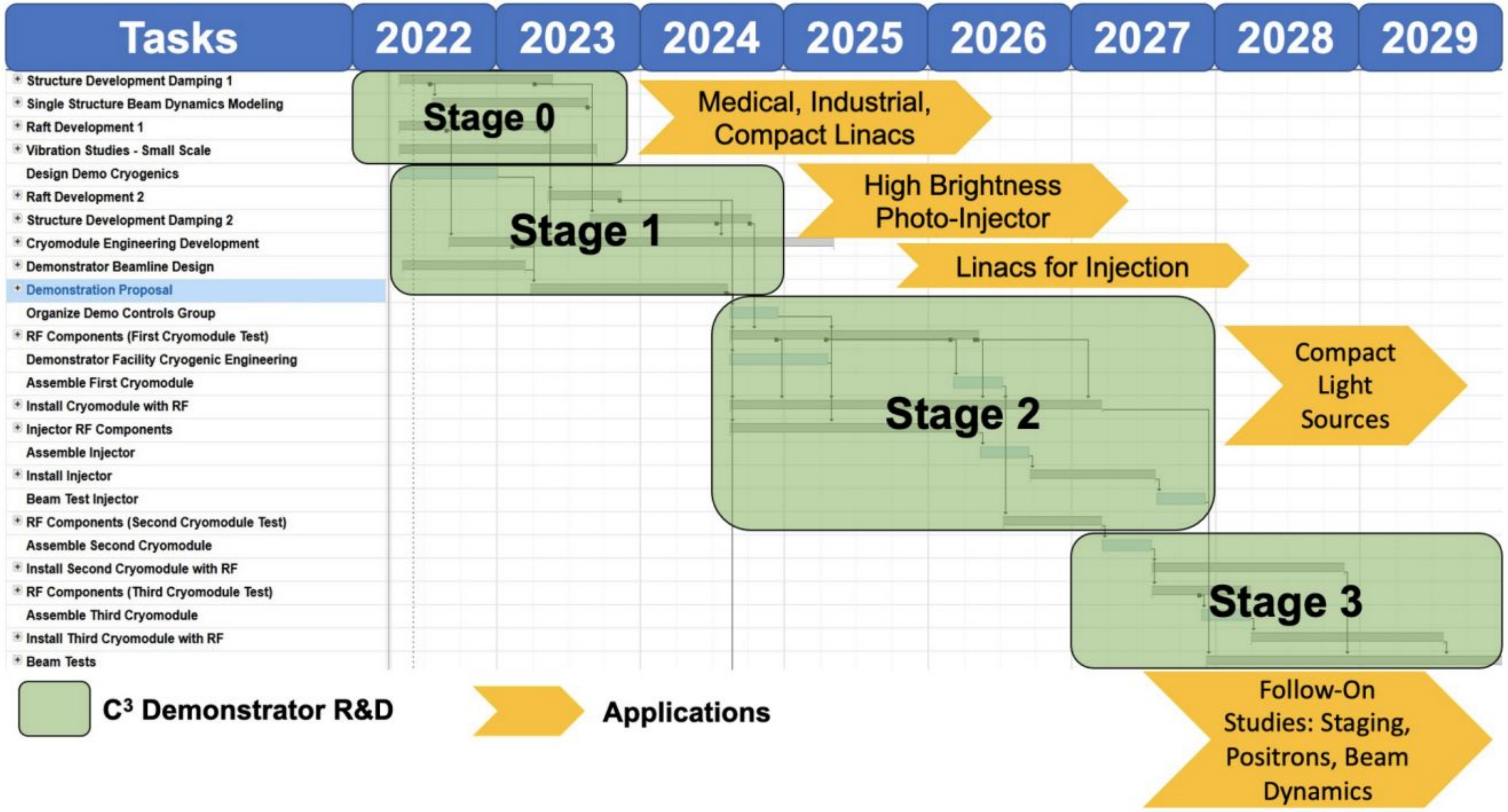
- **Demonstrate operation of fully engineered and operational cryomodule**
  - Simultaneous operations of min. 3 cryomodules
- Demonstrate operation during cryogenic flow equivalent to main linac at full liquid/gas flow rate
- Operation with a multi-bunch photo injector - high charges bunches to induce 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

C^3 Demonstration R&D Plan timeline



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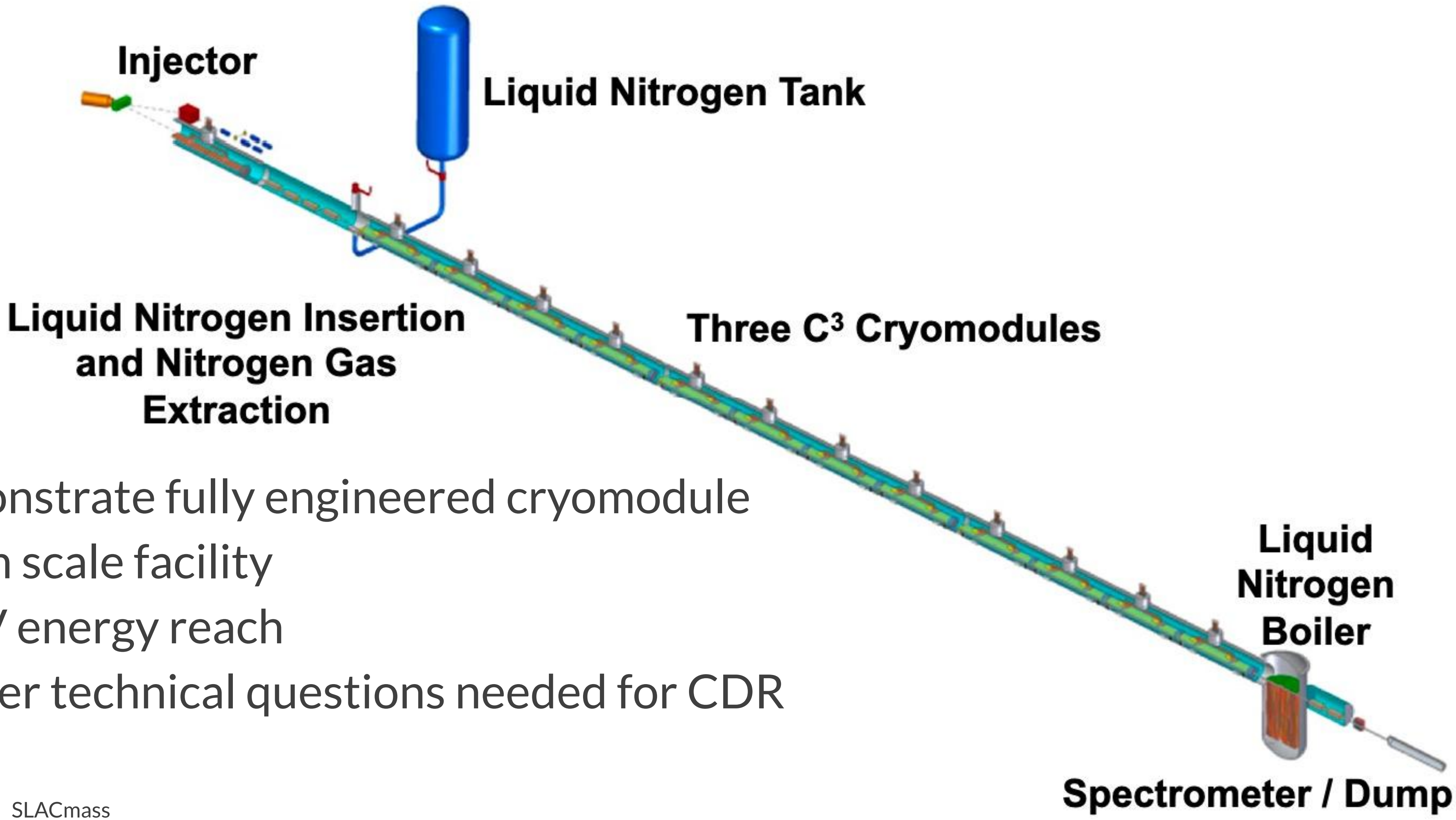
C^3 R&D, System Design and Project Planning are ongoing

- Early career scientists should help drive the agenda for an experiment they will build/use
- Many opportunities for other institutes to collaborate on:
  - beam dynamics, vibrations and alignment, cryogenics, rf engineering, controls, detector optimization, background studies, etc.

The Complete C^3 Demonstrator



Demonstrate fully engineered cryomodule

~50 m scale facility

3 GeV energy reach

Answer technical questions needed for CDR

Conclusion

Next C^3 Workshop in Planning - May 17-18th @ Fermilab (https://forms.gle/QoepjKu1j9AuDf6j8)

C^3 can provide a rapid route to precision Higgs physics with a compact 8 km footprint

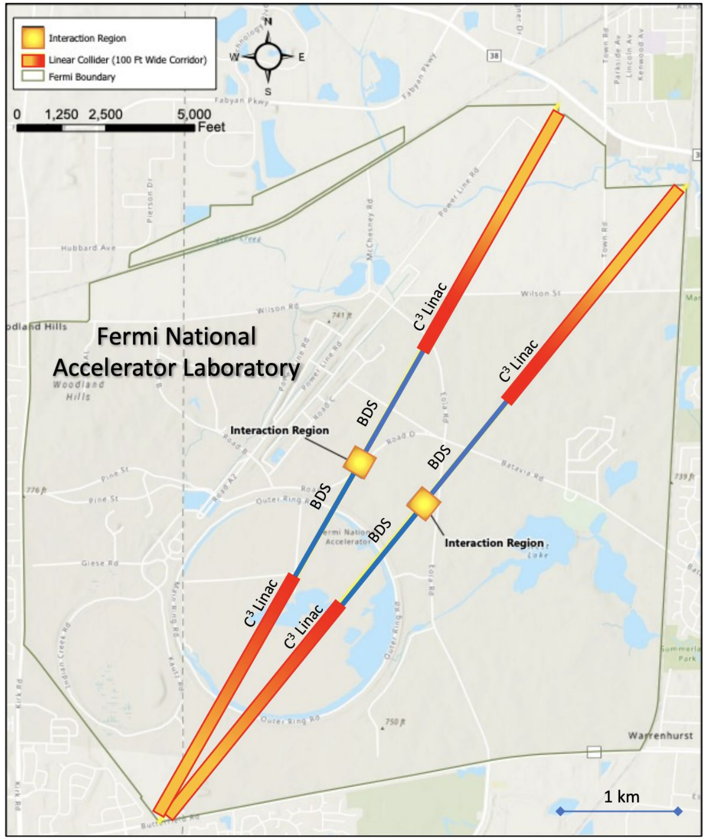
- Higgs physics run by 2040
- Possibly, a US-hosted facility

C^3 time structure is compatible with SiD-like detector overall design and ongoing optimizations.

C^3 can be quickly be upgraded to 550 GeV

C^3 can be extended to a 3 TeV e+e- collider with capabilities similar to CLIC

With new ideas, the C^3 lab can provide physics at 10 TeV and beyond



More Details Here (Follow, Endorse, Collaborate):
https://indico.slac.stanford.edu/event/7155/

XCC

Acknowledgements

SLAC-PUB-17659
May 12, 2022

XCC: An X-ray FEL-based $\gamma\gamma$ Collider Higgs Factory

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Abstract

This report describes the design of a $\gamma\gamma$ Higgs factory in which 62.8 GeV electron beams collide with 1 keV X-ray free electron laser (XFEL) beams to produce colliding beams of 62.5 GeV photons. The Higgs boson production rate is 34,000 Higgs bosons per 10^7 second year, roughly the same as the ILC Higgs rate. The electron accelerator is based on cold copper distributed coupling (C^3) accelerator technology. The 0.7 J pulse energy of the XFEL represents a 300-fold increase over the pulse energy of current soft x-ray FEL's. Design challenges are discussed, along with the R&D to address them, including demonstrators.

XCC – Near Term R&D - 1nC/pulse 120 nm-rad RF Gun

2017 TOPGUN cold Cu RF gun design study indicated that 200 nm-rad emittance could be achieved with 1 nC/pulse

Now, an S-band cold Cu RF gun design study with a goal of 1 nC/pulse and 100 nm-rad emittance at 120 Hz is being considered as an LCLS-X initiative.

*1st **Working Draft** of Quad Chart for High Brightness Gun LCLS-X initiative to be discussed tomorrow, May 13, 2022:*

Emittance: 100 nm at undulator (NCRF)

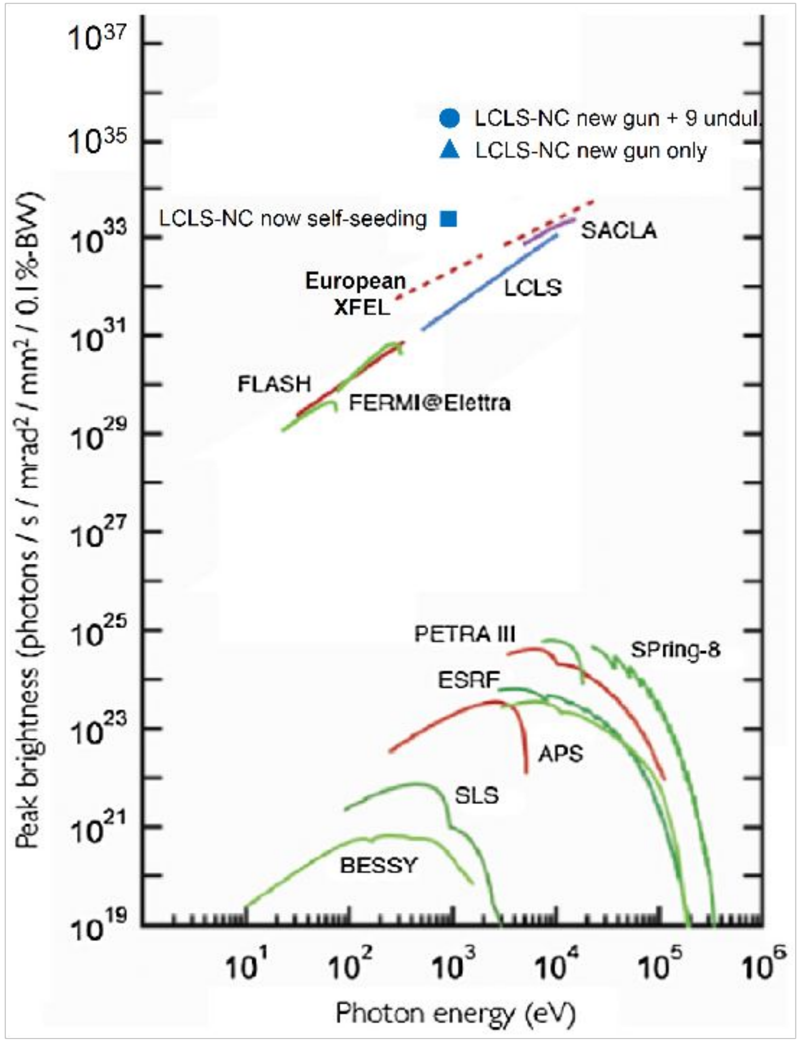
D. Nguyen

What: 1. Design a 50-nm emittance S-band gun 2. Pursue low-MTE photocathode R&D 3. Develop a photocathode transfer for NCRF gun 4. Multi-pulse (in a train) laser R&D 5. Study beam dynamics from gun to undulator to identify & prevent beam emittance dilution	Why: Electron beam emittance has a strong impact on the number of photons per pulse generated by the CuRF linac FEL. The low-emittance gun producing a train of electron bunches will enable the generation of multiple, >100-mJ x-ray pulses at 1 keV photon energy for gamma-gamma collider X-ray optics demonstration. Also photon science applications in single molecule imaging, warm dense matter and high energy density science
Who: List who is involved and at what fraction (FTE) & identify who the lead will be • Lead: Tor Raubenheimer • Gun design: Glen, Bruce, Emilio, Dinh, Mohamed • Low-MTE photocathodes: Bruce, John Smedley • Photocathode transfer: John Smedley • Multi-pulse laser: Dinh • Beam dynamics: Glen • Collider & photon science applications: Tim, Dinh	When: List intermediate milestones and expected completion dates

XCC – Near Term R&D - Production & Focusing of 100 mJ/pulse 1 keV X-rays

Assuming a 1nC/pulse 120 nm-rad emittance gun can be built, LCLS-NC Linac and undulator simulations indicate that the existing LCLS soft x-ray undulator (SXU) could deliver ~33 mJ/pulse with < 0.01% FWHM bandwidth. Add 9 more undulator segments to the SXU and 110 mJ/pulse could be achieved.

- XCC specifies that 700 mJ/pulse 1 keV x-ray beam be focused from 9000 nm at undulator exit to 70 nm at Compton IP
- Soft x-rays are harder to focus to sub-micron spot sizes than hard x-rays, so that two difficult problems (soft x-ray focussing and high power) have to be addressed.
- 100 mJ/pulse 1 keV photon beam from LCLS-NC can be used to design and validate high power soft x-ray optics. Photon science applications using 100 mJ/pulse soft x-ray beams will also need such focussing systems.



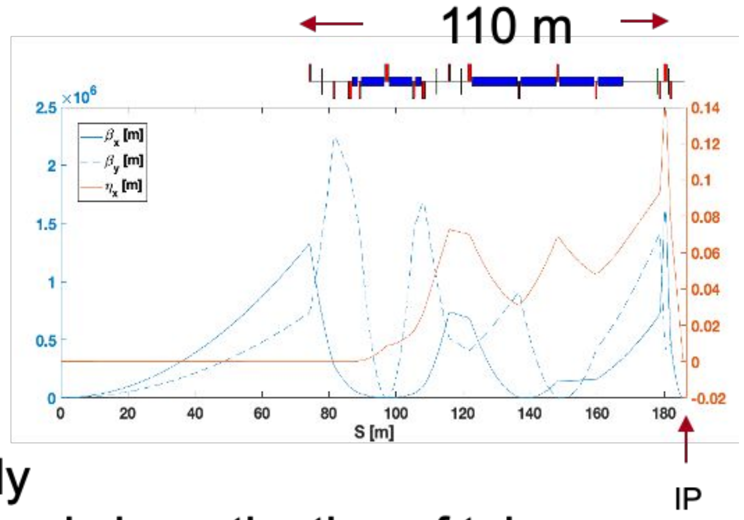
XCC – Near Term R&D - Accelerator design and beam dynamics

- High compression accelerator optics w/ low beam energy spread of 0.05% needs to be investigated in conjunction with gun design

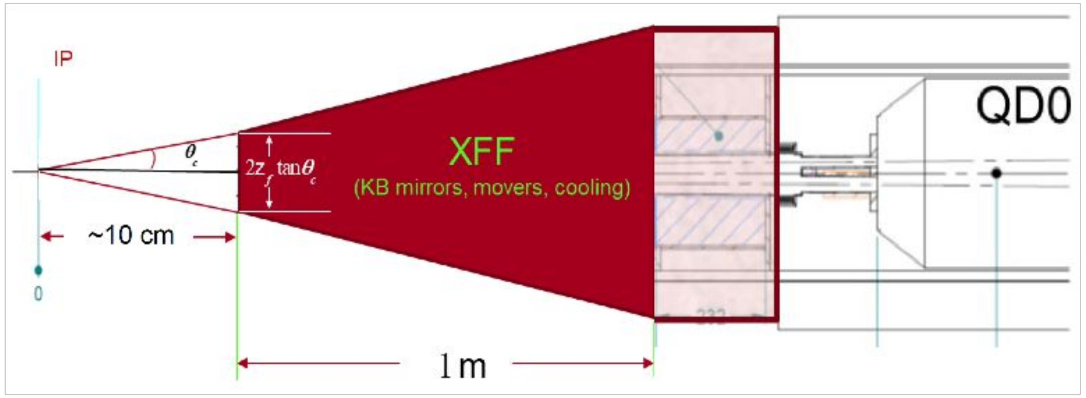
- Final Focus:

Design Parameters

Final Focus Parameter	Value
E	62.8 GeV
$\beta^*_{x,y}$	0.03 mm
$\gamma\varepsilon_{x,y}$	120 nm-rad
δ_E/E	0.05 %
L^* (Q0 exit to e^- IP)	3.5 m
$\sigma^*_{x,y}$	5.4 nm
η'^*_x	20 mrad



- Round beam FF, not tested experimentally
- 5X smaller beta function than CLIC; demands investigation of tolerances
- Integration of FF with X-ray optics, L* optimization, etc.



XCC

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arXiv:2203.07622 [pdf, other] physics.acc-ph hep-ex hep-ph

The International Linear Collider: Report to Snowmass 2021

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Abstract: The International Linear Collider (ILC) is on the table now as a new global energy-frontier accelerator laboratory taking data in the 2030s. The ILC addresses key questions for our current understanding of particle physics. It is based on a proven accelerator technology. Its experiments will challenge the Standard Model of particle physics and will provide a new window to look beyond it. This docu... ▽ More

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Report number: DESY-22-045, IFT--UAM/CSIC--22-028, KEK Preprint 2021-61, PNNL-SA-160884, SLAC-PUB-17662

arXiv:2204.02536 [pdf, other] physics.acc-ph

Next-Generation Superconducting RF Technology based on Advanced Thin Film Technologies and Innovative Materials for Accelerator Enhanced Performance and Energy Reach

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Abstract: Superconducting RF is a key technology for future particle accelerators, now relying on advanced surfaces beyond bulk Nb for a leap in performance and efficiency. The SRF thin film strategy aims at transforming the current SRF technology by using highly functional materials, addressing all the necessary functions. The community is deploying efforts in three research thrusts to develop next-generat... ▽ More

Submitted 5 April, 2022; **originally announced** April 2022.

Comments: Contribution to Snowmass 2021

arXiv:2203.09718 [pdf] physics.acc-ph hep-ex

An Impartial Perspective for Superconducting Nb3Sn coated Copper RF Cavities for Future Accelerators

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Abstract: This Snowmass21 Contributed Paper encourages the Particle Physics community in fostering R&D in Superconducting Nb3Sn coated Copper RF Cavities instead of costly bulk Niobium. It describes the pressing need to devote effort in this direction, which would deliver higher gradient and higher temperature of operation and reduce the overall capital and operational costs of any future collider. It is un... ▽ More

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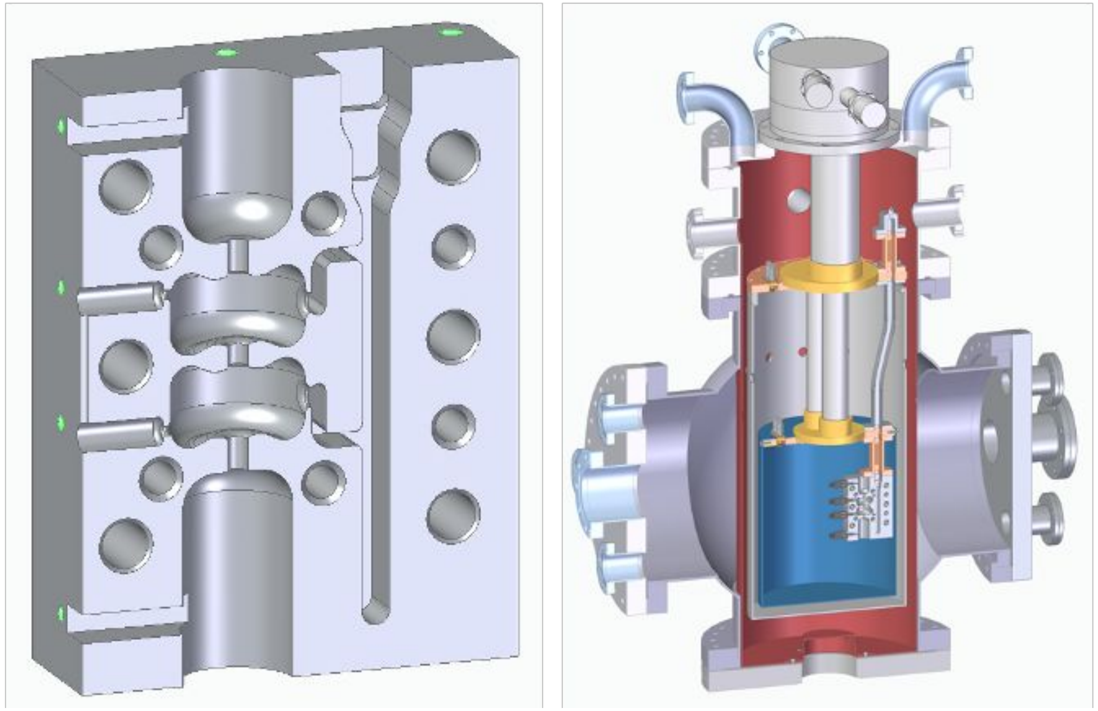
Comments: Contribution to Snowmass 2021

Report number: FERMILAB-CONF-22-134-TD

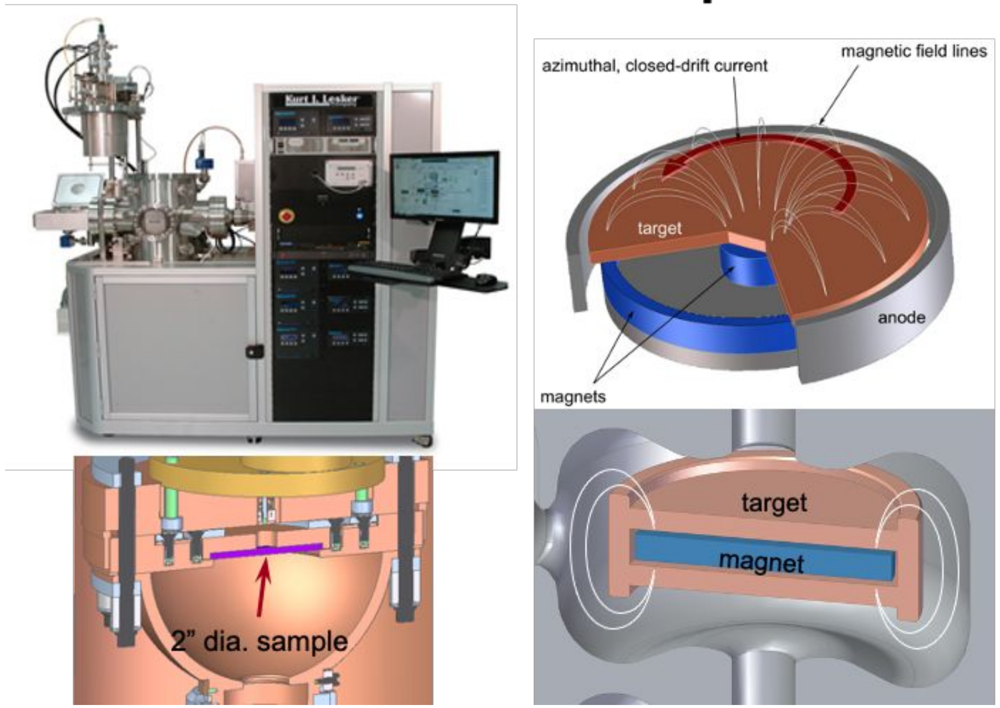
Transformation of SRF Accelerator Technology with Distributed Coupling Topology & Materials Research

High gradient, higher temperature of operation, lower power consumption

SRF Parallel-Feed Linac Structure



SRF Materials Development



Questions?