C³: An Advanced Concept for a e^+e^- Linear Collider

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

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ABSTRACT

We present a proposal for a cold copper distributed coupling accelerator that can provide a rapid route to precision Higgs physics with a compact 8 km footprint. This proposal is based on recent advances that increase the efficiency and operating gradient of a normal conducting accelerator. This technology also provides an e^+e^- collider path to physics at multi-TeV energies. In this article, we describe our vision for this technology and the near-term R&D program needed to pursue it.

Snowmass Contribution
Snowmass LOI

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C³ parameters

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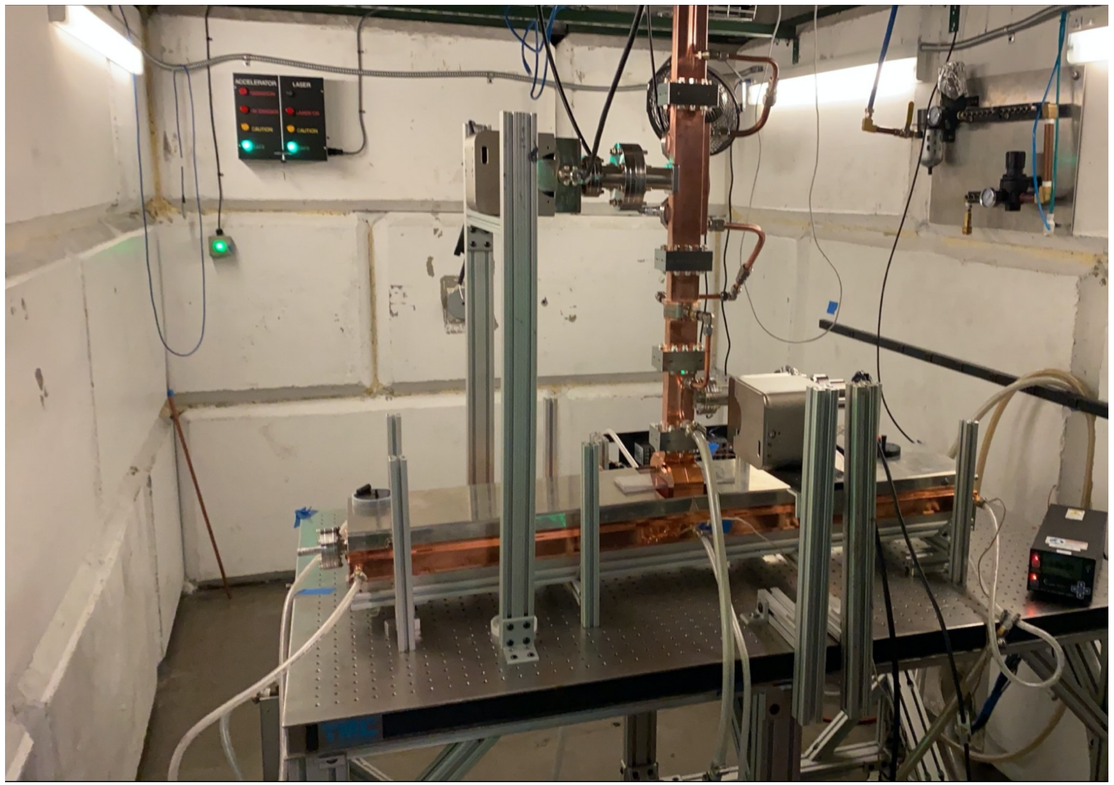
Collider	NLC	CLIC	ILC	C³	C³
CM Energy [GeV]	500	380	250 (500)	250	550
Luminosity [x10^{34}]	0.6	1.5	1.35	1.3	2.4
Gradient [MeV/m]	37	72	31.5	70	120
Effective Gradient [MeV/m]	29	57	21	63	108
Length [km]	23.8	11.4	20.5 (31)	8	8
Num. Bunches per Train	90	352	1312	133	75
Train Rep. Rate [Hz]	180	50	5	120	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

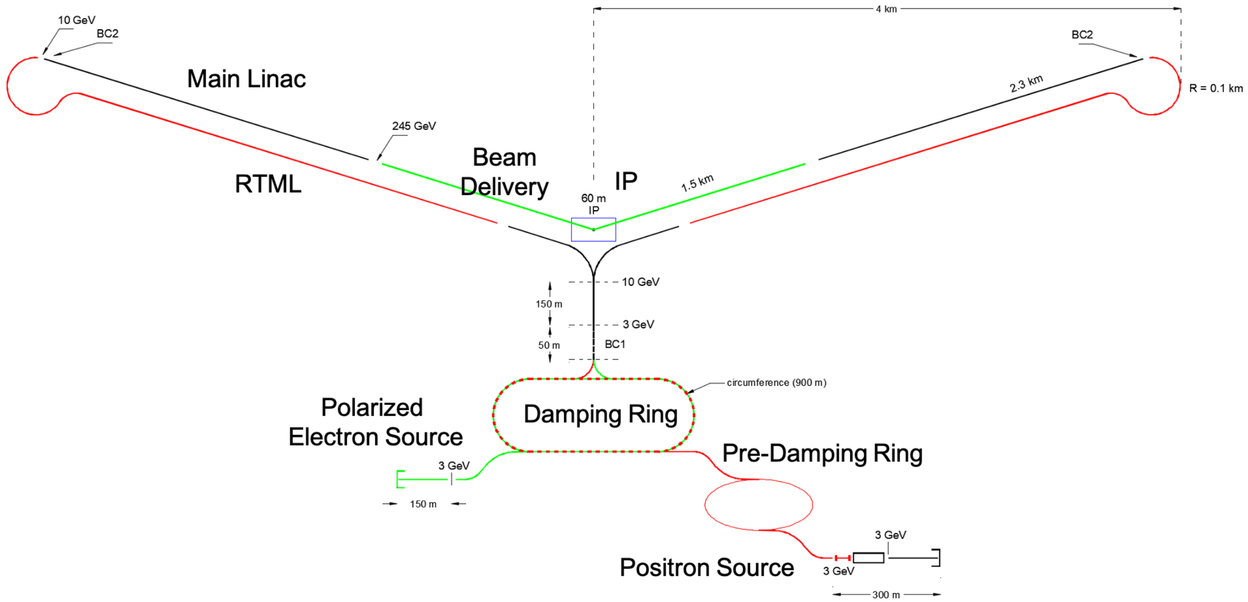
Advancing C³ technical readiness

- Technology demonstration and site layout continue to progress

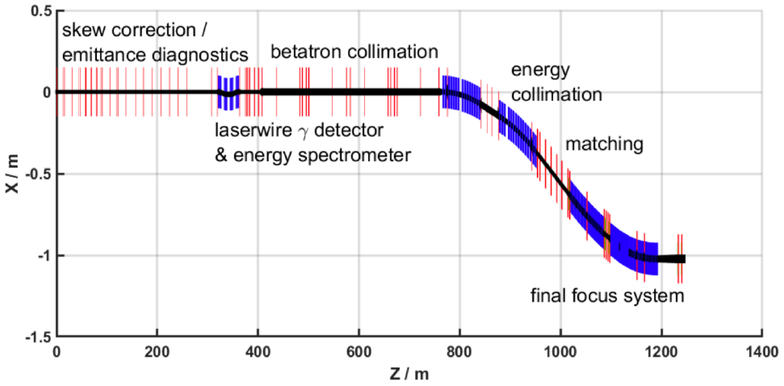
First 300K high power test in progress @ Radiabeam



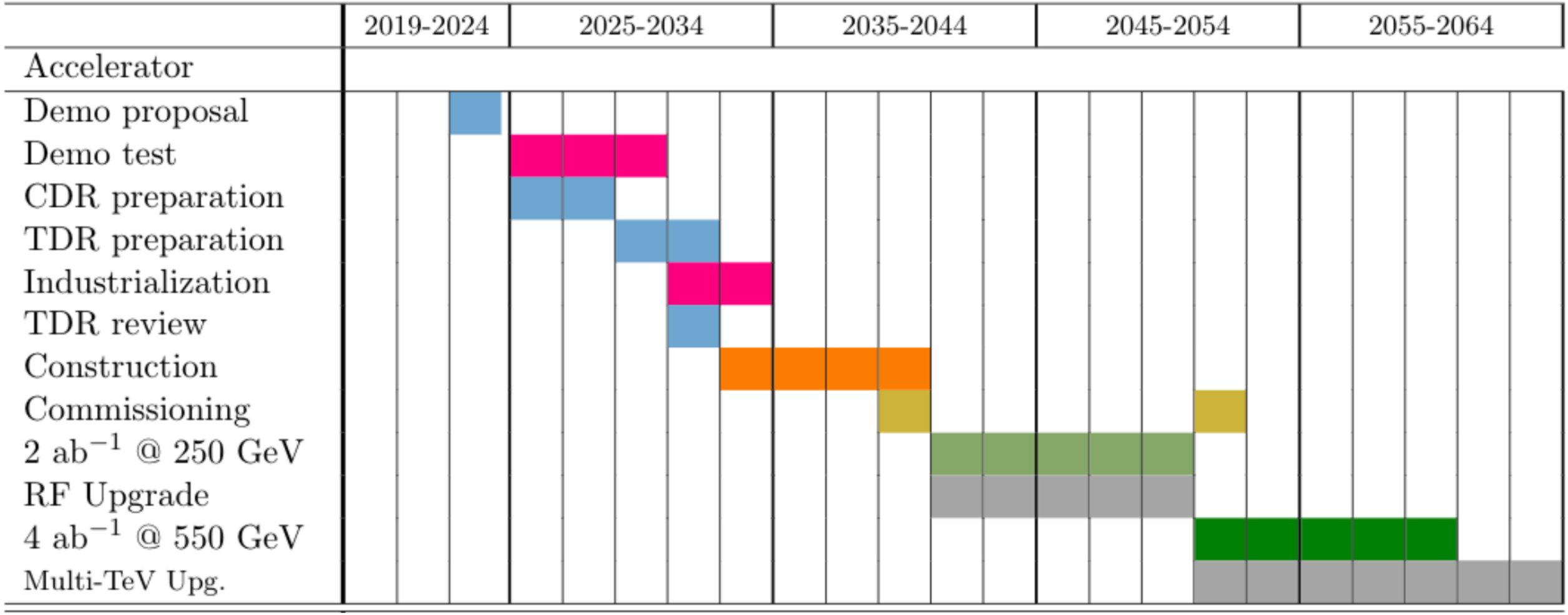
C³ - 8 km footprint for 250/550 GeV



C³ - Investigation of Beam Delivery Adapted from ILC/NLC - G



C³ timeline



HL-LHC

Higgs couplings expected precision

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We propose **250** GeV with a relatively inexpensive upgrade to **550** GeV

- An **orthogonal dataset** at 550 GeV to cross-check a deviation from the SM predictions observed at 250 GeV
- From 500 to 550 GeV a factor 2 improvement to the **top-Yukawa** coupling
- 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)

Getting Involved C^3 R&D

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

- Early career scientists should drive the agenda for an experiment they will build/use
- Many opportunities for other institutes to collaborate on:
  - (SiD) detector optimization, background studies, beam dynamics, vibrations and alignment, cryogenics, rf engineering, controls, etc
- Research opportunities at SLAC for short-long term:
  - Undergraduate Research Opportunities
    - DOE SULI https://science.osti.gov/wdts/suli
  - Graduate Research Opportunities
    - DOE SCGSR https://science.osti.gov/wdts/scgsr

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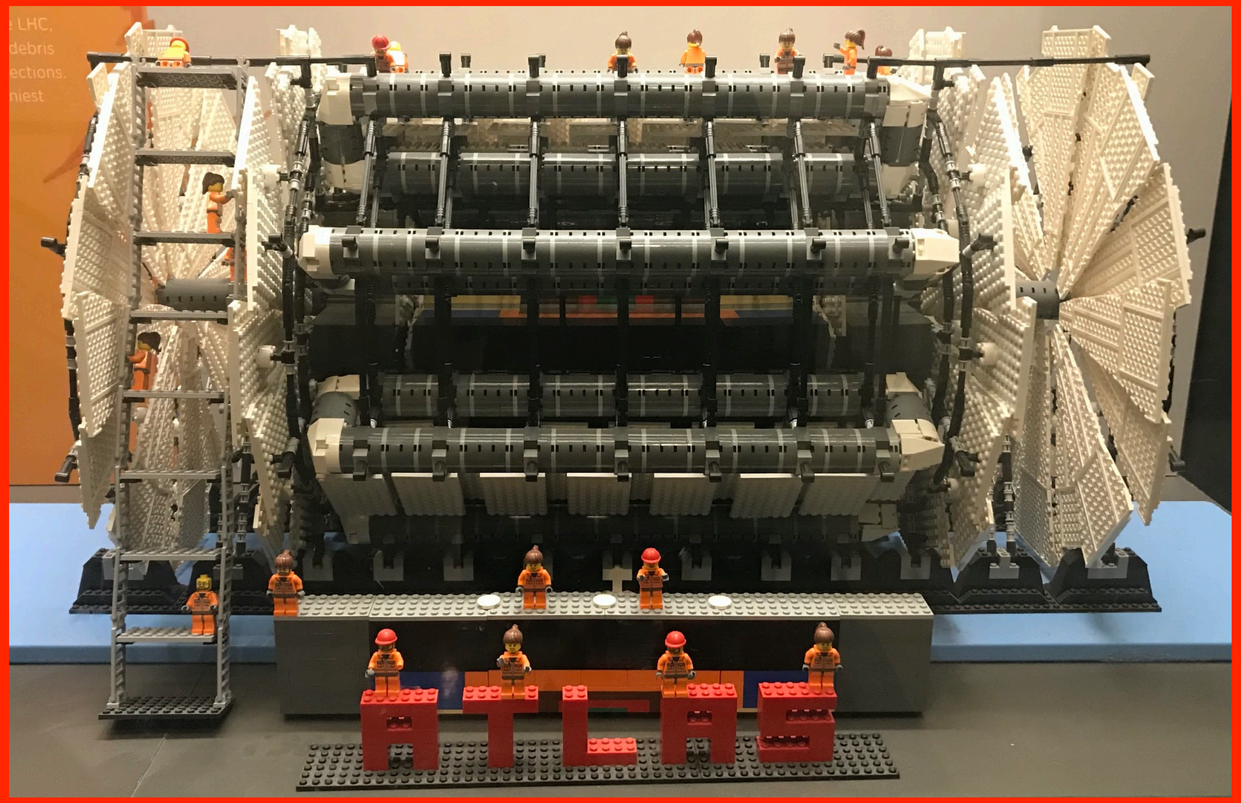
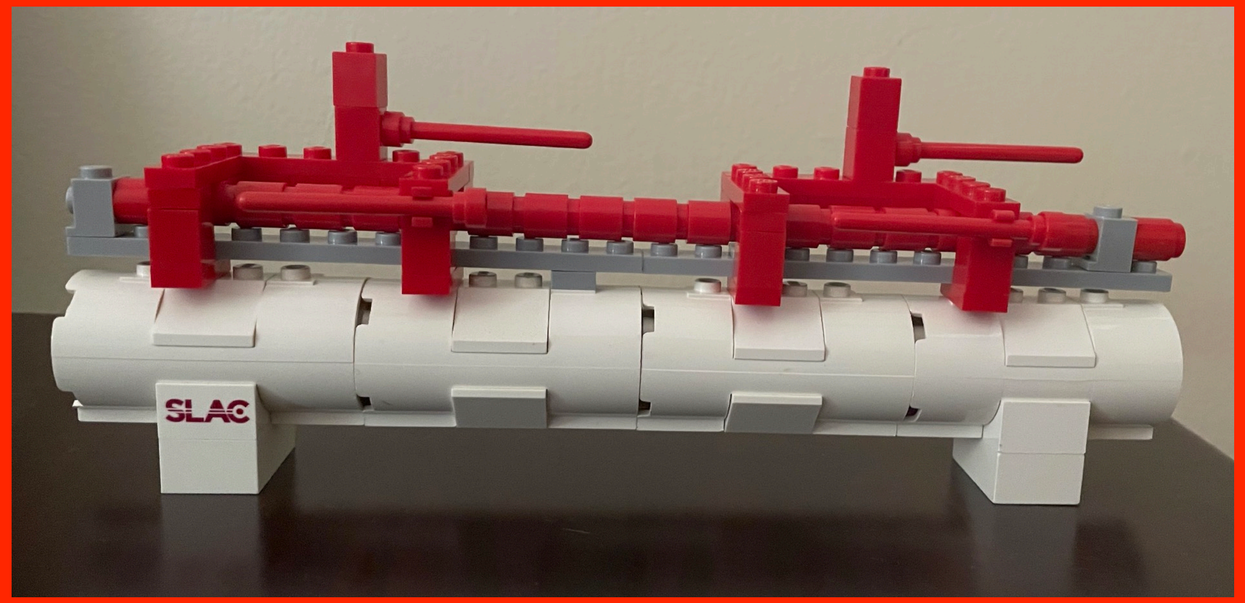
Conclusions

- 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 and inexpensively 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 beyon
- May be possible to do physics at an intermediate stage in the construction at 91 GeV
  - We do not consider this a part of our baseline, but we mention the possibility in case there is community interest for a Giga-Z (2 yrs) program.





Extra

Demonstration Facility

- We are proposing a demonstration facility to carry out a “string test” of three C^3 cryomodules.
- Minimum requirement for Demo Facility:
  - Demonstrate operation of fully engineered and operational cryomodule
    - Will iterate on cryomodule design (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) in single bunch mode (1GeV)
  - **Fully damped-detuned accelerating structure**
  - Work with industry to develop C-band source unit (3 vendors for klystron / 3 vendors for modulator and integration)
- This step is included in our timeline. The cost is O(100) M$.
  - This demonstration directly benefits development of compact FELs for photon science.
- The other elements needed for a linear collider - the sources, damping rings, and beam delivery system - already have mature designs created for the ILC and CLIC.
  - Our current baseline uses these directly although we will look for further cost-optimizations for the specific needs of the C^3

Detector Design Requirements

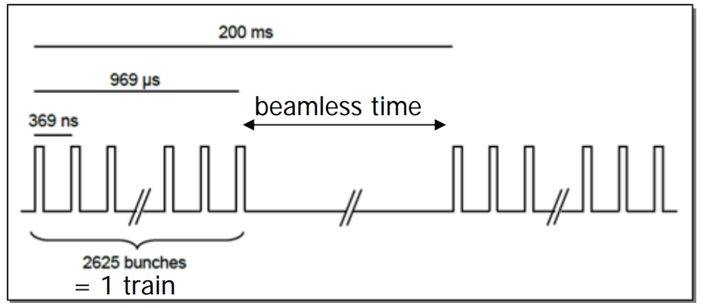
ILC timing structure: Fraction of a percent duty cycle

- **Power pulsing possible**, significantly reduce heat load
  - Factor of 50-100 power saving for FE analog power
- Tracking detectors **don't need active cooling**
  - Significantly reduction for the material budget
- **Triggerless readout** is the baseline

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

Collider	ILC	CCC
σ_z	300 μm	100 μm
β_x	8.0 mm	13 mm
β_y	0.41 mm	0.1 mm
ϵ_x	500 nm/rad	900 nm/rad
ϵ_y	35 nm/rad	20 nm/rad
N bunches	1312	133
Repetition rate	5 Hz	120 Hz
Crossing angle	0.014	0.020
Crab angle	0.014/2	0.020/2

ILC timing structure



1 ms long bunch trains at 5 Hz
2820 bunches per train
308ns spacing

C³ timing structure