Future Colliders

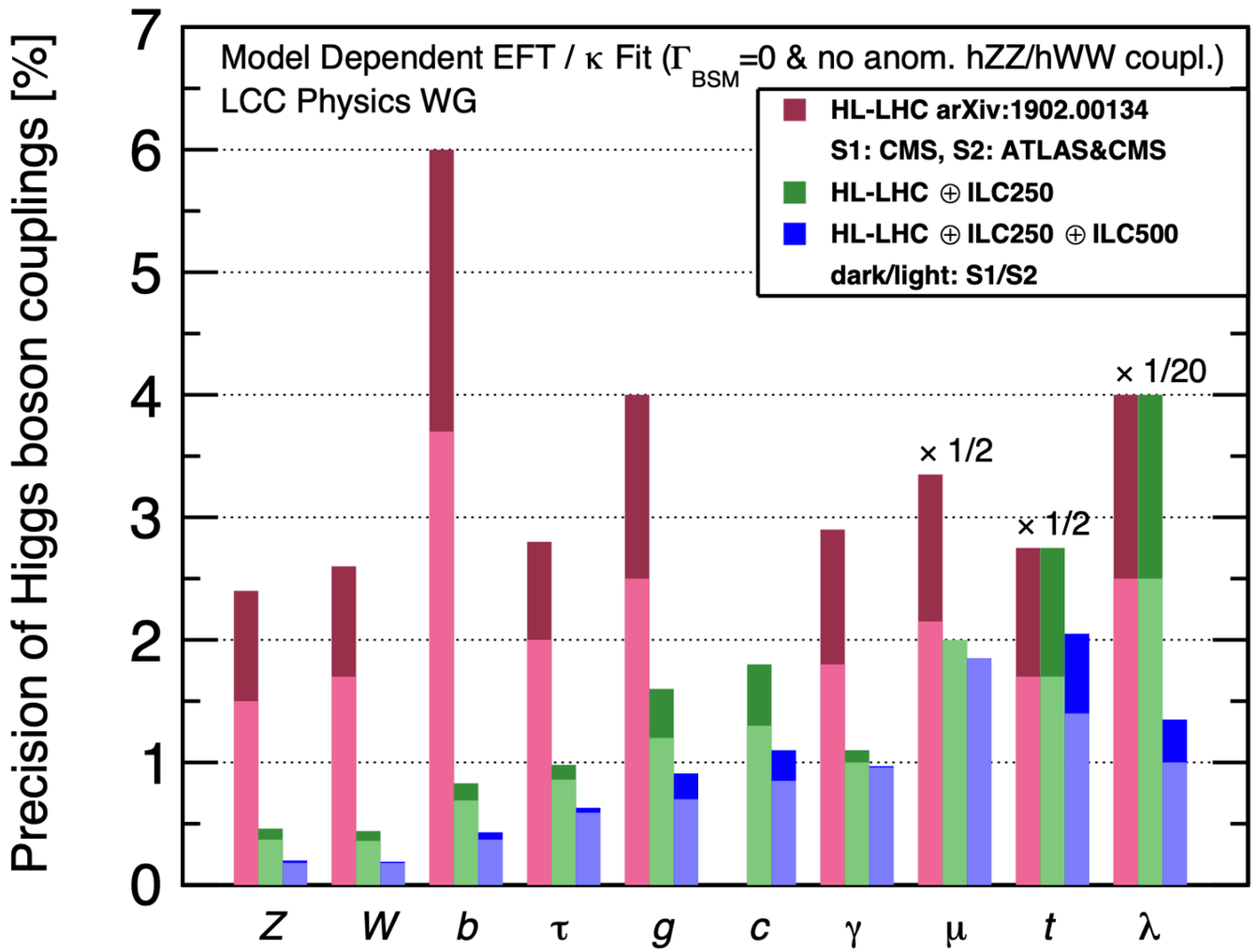
TRIUMF 5YP, Particle Physics

Max Swiatlowski, w/ inputs from many

TRIUMF

The Case for Higgs Factory

arXiv:1903.01629



- The Higgs is our new particle at the LHC: the most unknown, and potentially the best path to new physics

- The HL-LHC will teach us much, but many parameters will still be wide open!

- Rule of thumb: aim for 1% precision to have best sensitivity to BSM

- **We can reach the 1% threshold with a Higgs factory**

International Planning

- ***Europe, together with its international partners, should investigate the technical and financial feasibility of a future hadron collider at CERN with a centre-of-mass energy of at least 100 TeV and with an electron-positron Higgs and electroweak factory as a possible first stage. Such a feasibility study of the colliders and related infrastructure should be established as a global endeavour and be completed on the timescale of the next Strategy update.***

The timely realisation of the electron-positron International Linear Collider (ILC) in Japan would be compatible with this strategy and, in that case, the European particle physics community would wish to collaborate. European Strategy

Canadian LRP

The development of a future Higgs factory is identified by the international community as a top priority. The ILC is the most advanced and mature proposal on the world-stage that, if approved, would be located in Japan. There are also complementary proposals for electron-positron machines, such as the post HL-LHC Future Circular Collider (FCC-ee) that could eventually be transformed into the next energy frontier hadron machine. In the past 5 years,

- Snowmass/P5 outcome to come, but endorsement of Higgs factory concept expected

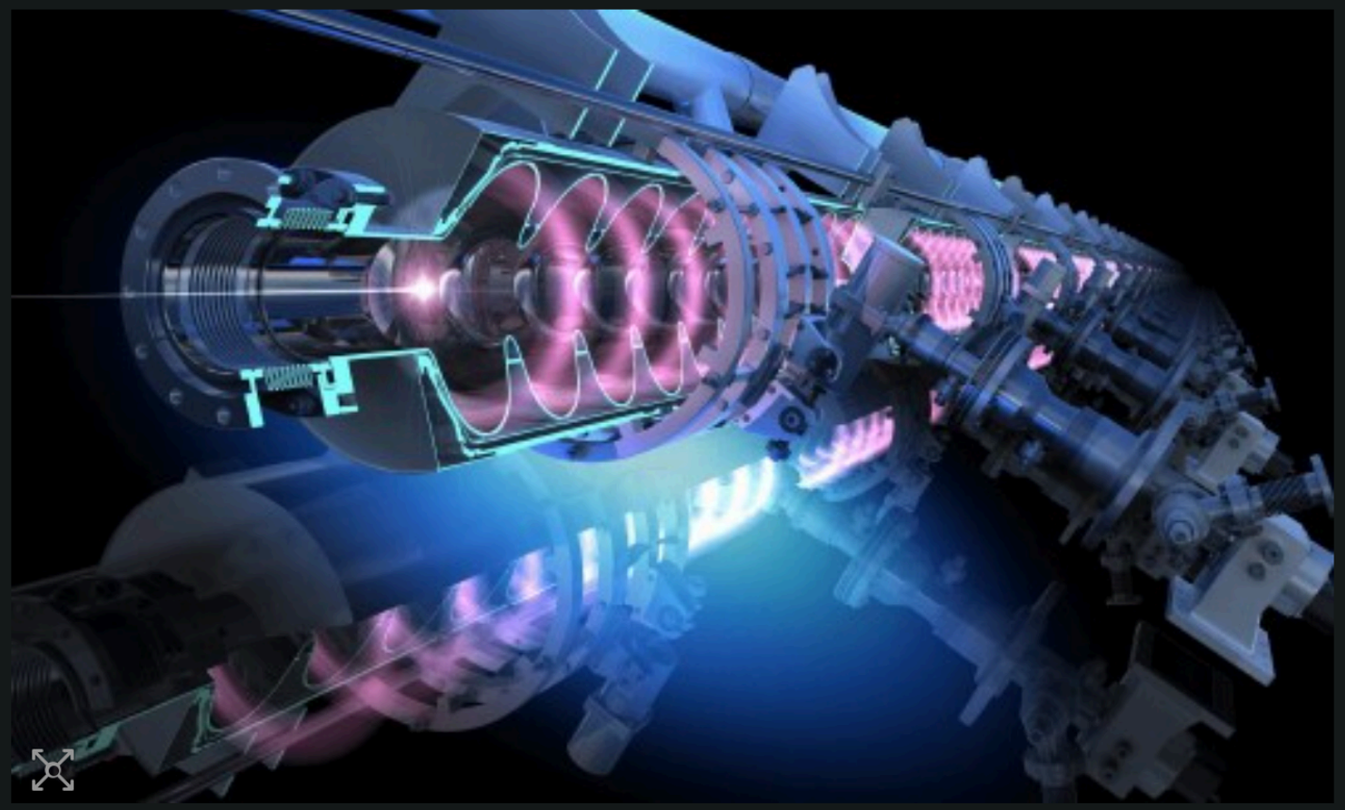
- International consensus on Higgs factory to complement HL-LHC

Recent Challenges…

Panel calls on physicists to ‘shelve’ notion of Japan hosting the International Linear Collider

01 Mar 2022 Michael Banks

Physics World



The International Linear Collider aims to study the Higgs boson, which was discovered in 2012 at CERN's Large Hadron Collider. (Courtesy: ILC)

- Maybe not quite so bad as it sounds?
  - But no Japanese funding for pre-lab: path to Japanese hosting seems very uncertain
  - Is FCC-ee the only choice?

New Opportunities?

SLAC-PUB-17629
November 1, 2021

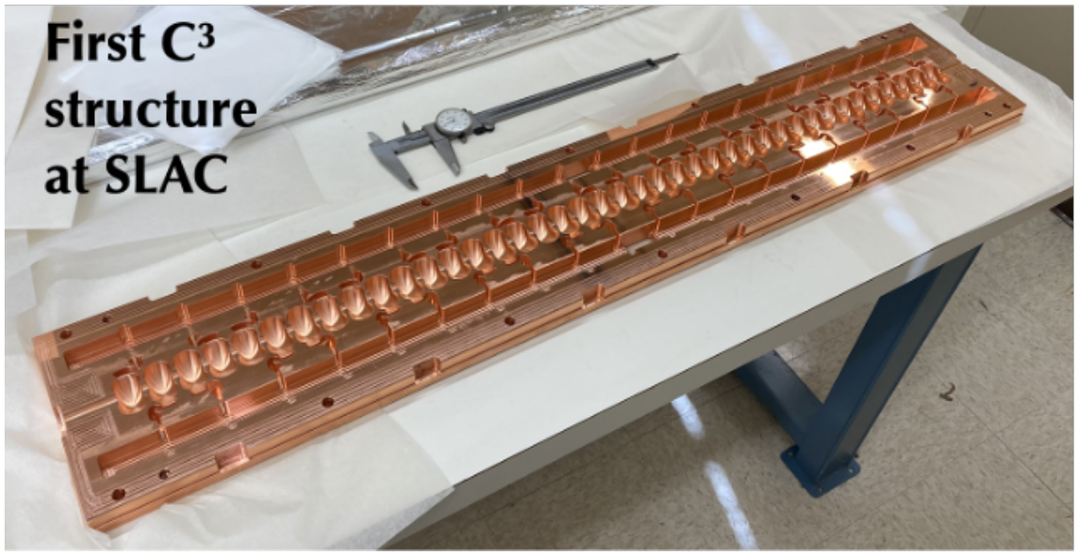
C^3 : A "Cool" Route to the Higgs Boson and Beyond

Mei Bai, Tim Barklow, Rainer Bartoldus, Martin Breidenbach*, Philippe Grenier, Zhirong Huang, Michael Kagan, Zenghai Li, Thomas W. Markiewicz, Emilio A. Nanni*, Mamdouh Nasr, Cho-Kuen Ng, Marco Oriunno, Michael E. Peskin*, Thomas G. Rizzo, Ariel G. Schwartzman, Dong Su, Sami Tantawi, Caterina Vernieri*, Glen White, Charles C. Young

- New ideas are emerging for Snowmass, like the Cool Copper Collider (C3)
  - Two stage approach: 8 km machine at 250 GeV, then upgrade RF systems (~cheap) to 550 GeV with no tunnel expansion needed
  - Could nearly fit on-site at Fermilab, or easily fit on site at PNNL (5 hour drive from Vancouver!)
- Kate and I participated in a workshop in January
- Obviously still very early, but seems like a promising idea!
  - Emilio Nanni will be giving a colloquium at TRIUMF on April 14— accelerator department invited, keen to learn and potentially collaborate

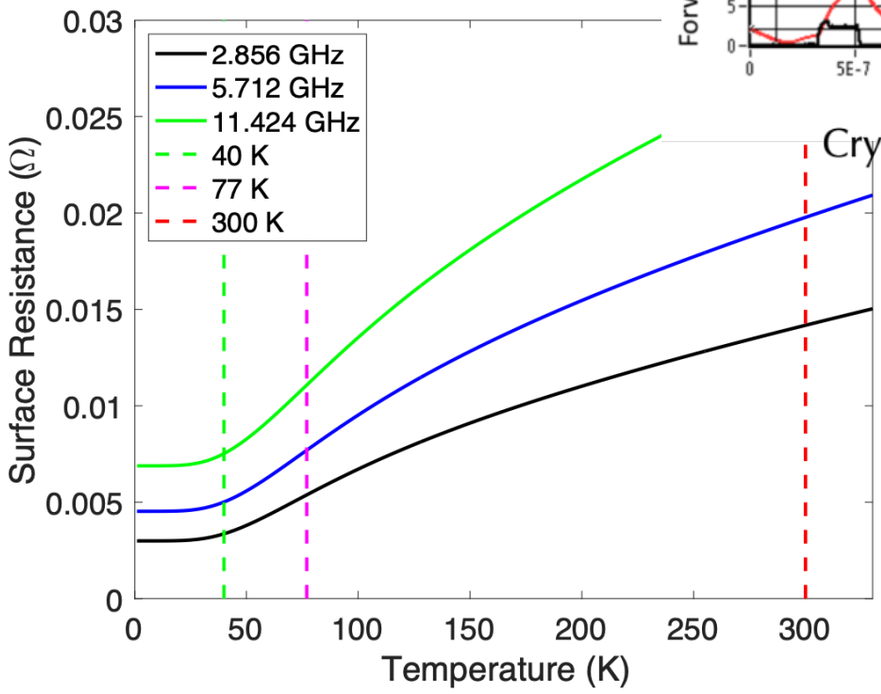
C3 Design Innovations

- Using a "distributed coupling" for RF cavities
- "Cool" LN2 instead of superconducting or room temperature
  - Most of the benefits of superconducting, substantially cheaper
  - Significantly more stable than room temperature copper cavities (downfall of NLC design)
- Significantly higher energy gradient: 70-120 MeV/m
  - Compared to ~30 MeV/m for ILC!



High Gradient Operation at 150 MV/m

Cryogenic Operation at X-band



Summary Table

Collider	NLC[28]	CLIC[29]	ILC[5]	C^3	C^3
CM Energy [GeV]	500	380	250 (500)	250	550
σ_z [μm]	150	70	300	100	100
β_x [mm]	10	8.0	8.0	12	12
β_y [mm]	0.2	0.1	0.41	0.12	0.12
ϵ_x [nm-rad]	4000	900	500	900	900
ϵ_y [nm-rad]	110	20	35	20	20
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
Beam Power [MW]	5.5	2.8	2.63	2	2.45
Crossing Angle [rad]	0.020	0.0165	0.014	0.014	0.014
Crab Angle	0.020/2	0.0165/2	0.014/2	0.014/2	0.014/2
Luminosity [x10^{34}]	0.6 (w/ IP dil.)	1.5 (max is 4)	1.35	1.3	2.4
Gradient [MeV/m]	37	72	31.5	70	120
Effective Gradient [MeV/m]	29	57	21	63	108
Shunt Impedance [MΩ/m]	98	95		300	300
Effective Shunt Impedance [MΩ/m]	50	39		300	300
Site Power [MW]	121	168	125	~150	~175
Length [km]	23.8	11.4	20.5 (31)	8	8
L* [m]	2	6	4.1	4.3	4.3

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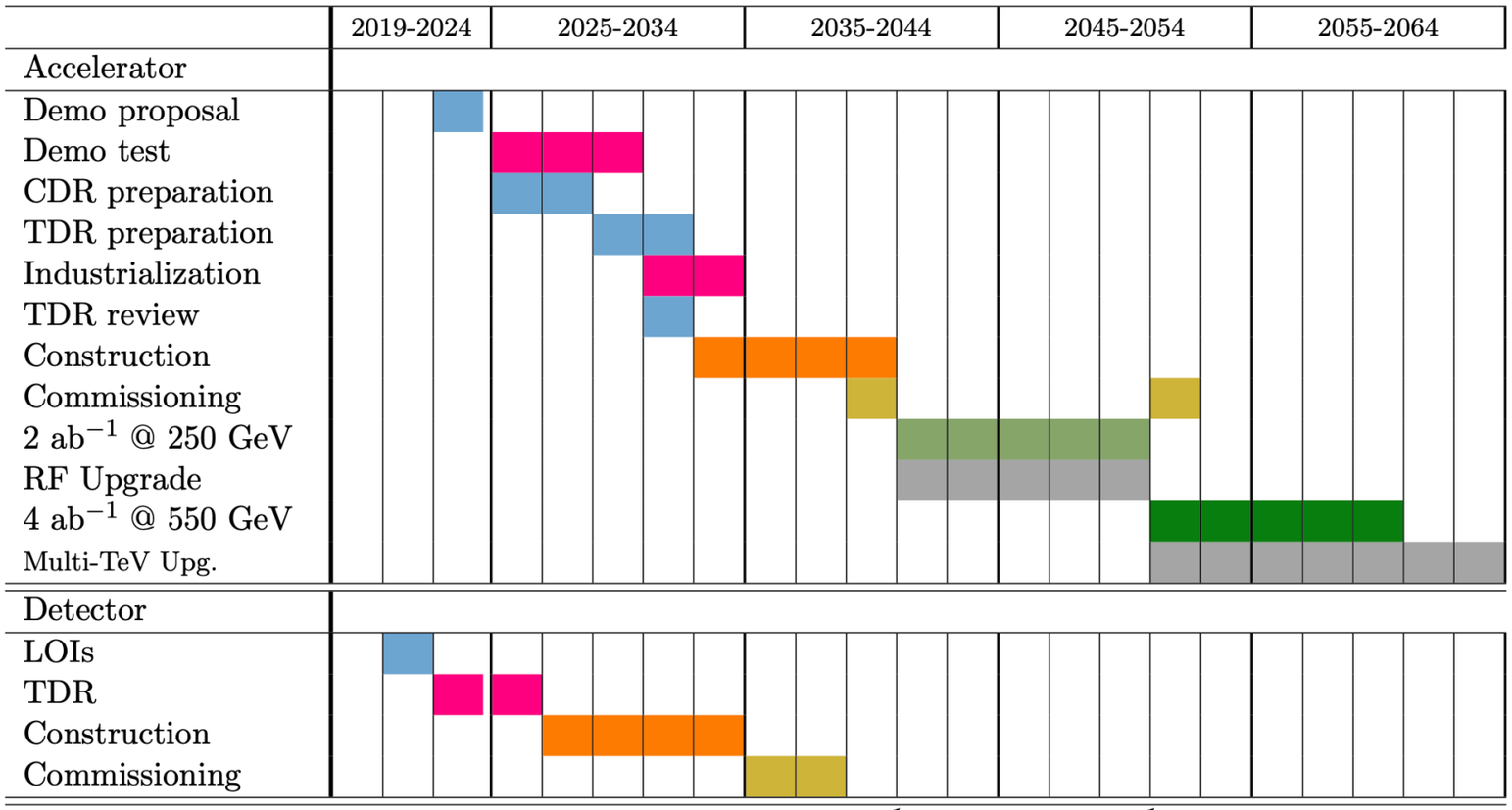
Main differences to ILC: higher gradient, smaller bunch spacing (ILD TPC won't work— need all silicon detector)

Timelines and Costs



CCC		GeV	250		
		MeV/m	70		
	Sub-Domain		M$	%	%
Sources	Injectors		301	8	35
	Damping Rings		461	12	
	Beam Transport		563	15	
Main Linac	Cryomodule		357	10	33
	C-band Klystron		871	23	
IP	Beam Delivery and FF		295	8	13
	IR		184	5	
Support Inf.	Civil Eng		204	5	19
	Common Facilities		396	11	
	Cryo-plant		101	3	
	Total		3733	100	

HL-LHC ends here

FCC-ee earliest data (s9)

$4b capital costs
($10b ILC?)

- Obviously early and naive planning, but advantages compared to both FCC-ee (timeline) and ILC (cost)

The Accelerator Landscape

	Timeline	Energy	Pros	Cons
ILC	2035?	250 GeV	Mature design, TRIUMF SRF	No host?
C3	2040?	250 GeV	Cheaper than ILC, faster than FCC?	Need demo still
CLIC	2040-2045?	380 GeV	Mature concept	Little support?
FCC-ee	2045-2050?	365 GeV	Weight of CERN, no showstoppers	Timelines? Funding?
FCC-hh	Far future	100 TeV	“Existing” tunnel	Magnet R&D Timelines…
μ-collider	Far future	3-14 TeV	“Clean”, high energy lepton collisions	Muon decay

The 5-Year Plan

- Which accelerator? We don't need to make a choice for the 5-year plan
    - But the 5-Year Plan should let us help contribute to the choice the world makes
- Detector R&D plan is excellent strategy to keep up expertise, attract funding before next project is approved
    - But the sooner we know which collider, the better we can design the detector! (i.e. powering, cooling, etc.)
- Can we join a "full detector" collaboration that seems likely to make an impact regardless of accelerator choice?
    - E.g. SiD design for ILC/C3, related CLD design for CLIC/FCC-ee…
- Need to keep close contact/collaboration with accelerator division: what are they interested in? What can they contribute to?
- **No need for decisions now, but hope to capture in the 5YP our excitement for the physics opportunities and international collaboration ahead!**
    - What about a joint hire with university targeting future colliders? Back half of next 5YP?