Brief on ILC & Future e^+e^- collider

$^1/_2$

easier & informative stuff because
it is based on work
already done (I will go over quick)

report on status

the « cartesian » approach

the facts

convincing case about the physics

worldwide scene

summarize the timeline

$^1/_2$

harder & challenging because
it is to plan what to come, so must put egos
at the front door and be honest

articulate a vision

the « real » status of SAP vs HQP

acknowledge fragmentation

more than just physics analysis

Canada's LRP needs inclusion

coordinated resources

ILC & Future e^+e^- Colliders

Contribution to the Canadian Long Range Plan

Subatomic Physics

- ❑ Inform: What is at the horizon
- ❑ Priority: The Physics at a Higgs Factory
- ❑ Synergy: Accelerator and Detector for ILC
- ❑ Strategic Planning: Timeline
- ❑ Going Forward: Engage & Coordinate

IPP Town Hall Meeting

July 21, 2020

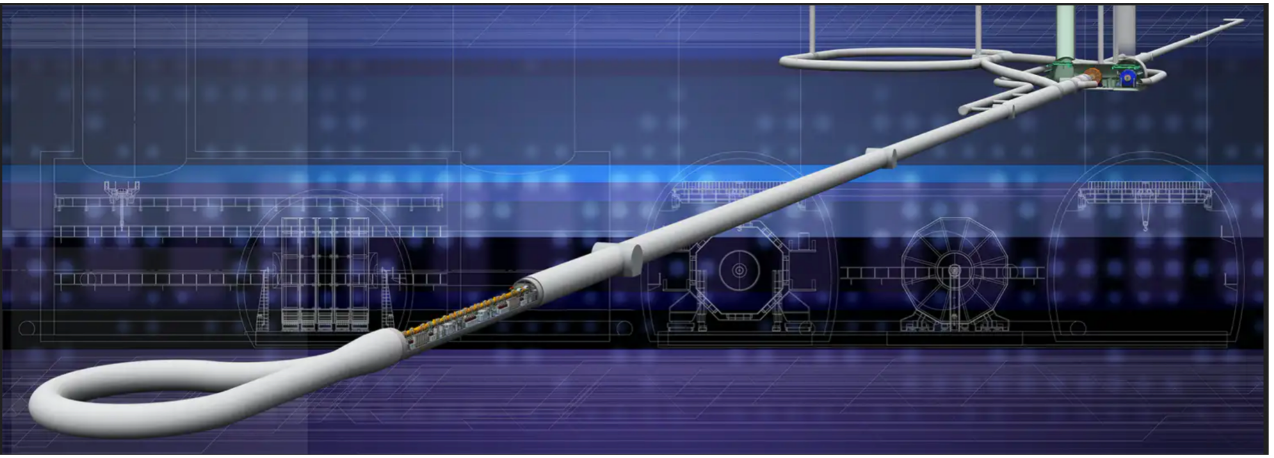
Alain Bellerive

Carleton University

Future e^+e^- Colliders

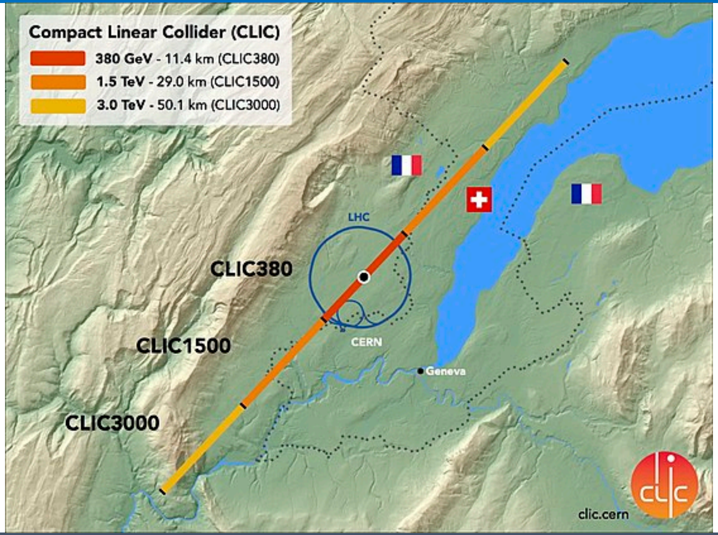
Two Linear Colliders (centre-of-mass-energy can be scaled up)

International Linear Collider (ILC) - Japan

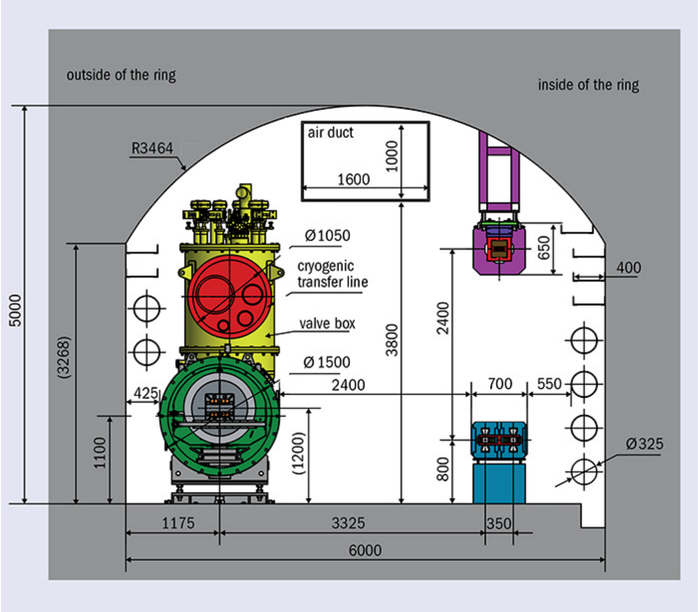


Compact Linear Collider (CLIC)

CERN



Two Circular Colliders (can be converted to hadron machines)

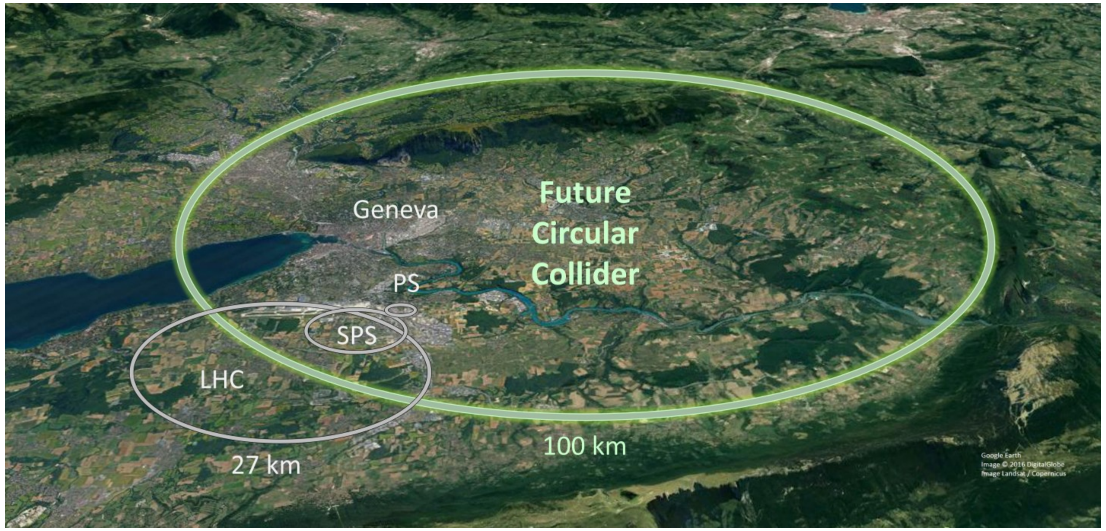


Circular Electron Positron Collider (CEPC)

China

… could be politically challenging (no Canadian group yet engaged)

Future Circular Collider (FCC-ee) - CERN



International Linear Collider (ILC) at $\sqrt{s}$ = 250 GeV

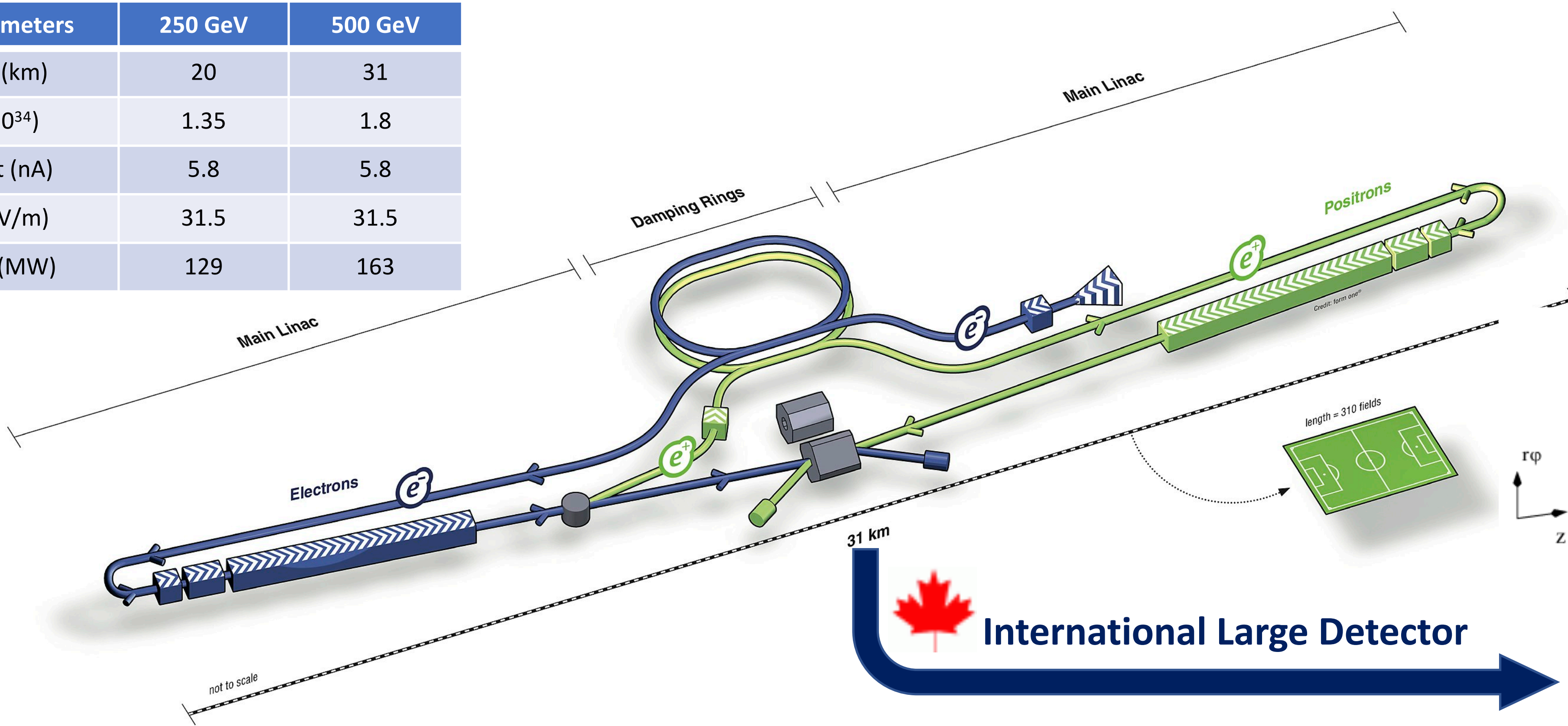
Japan still plans for a major demographic recovery plan for Great Easter Japan, with ILC as a possible component

An electron-positron Higgs Factory listed as one of Europe's main particle physics priorities

ILC is the most mature and timely-ready Higgs Factory to be deployed (while you are still an active physicist)

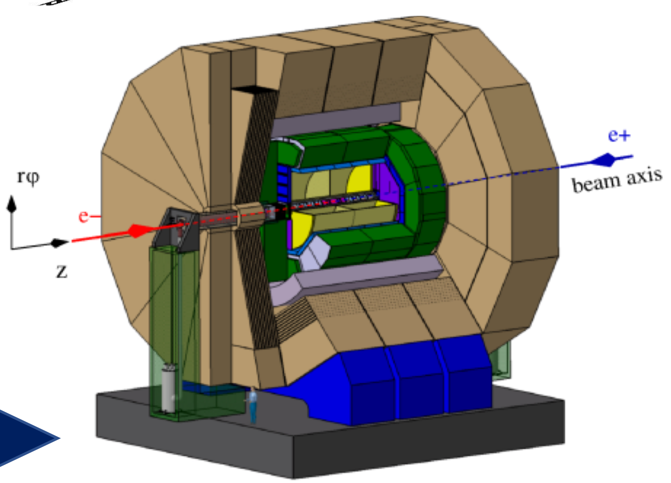
The Linear Collaboration Board (LCB) responded to the request from the International Committee for Future Accelerator (ICFA) to put in place an ILC Pre-Lab Development Team (**now** August 2020 ICHEP)

Parameters	250 GeV	500 GeV
Lenght (km)	20	31
Lumi (10^{34})	1.35	1.8
Current (nA)	5.8	5.8
SFR (MV/m)	31.5	31.5
Power (MW)	129	163

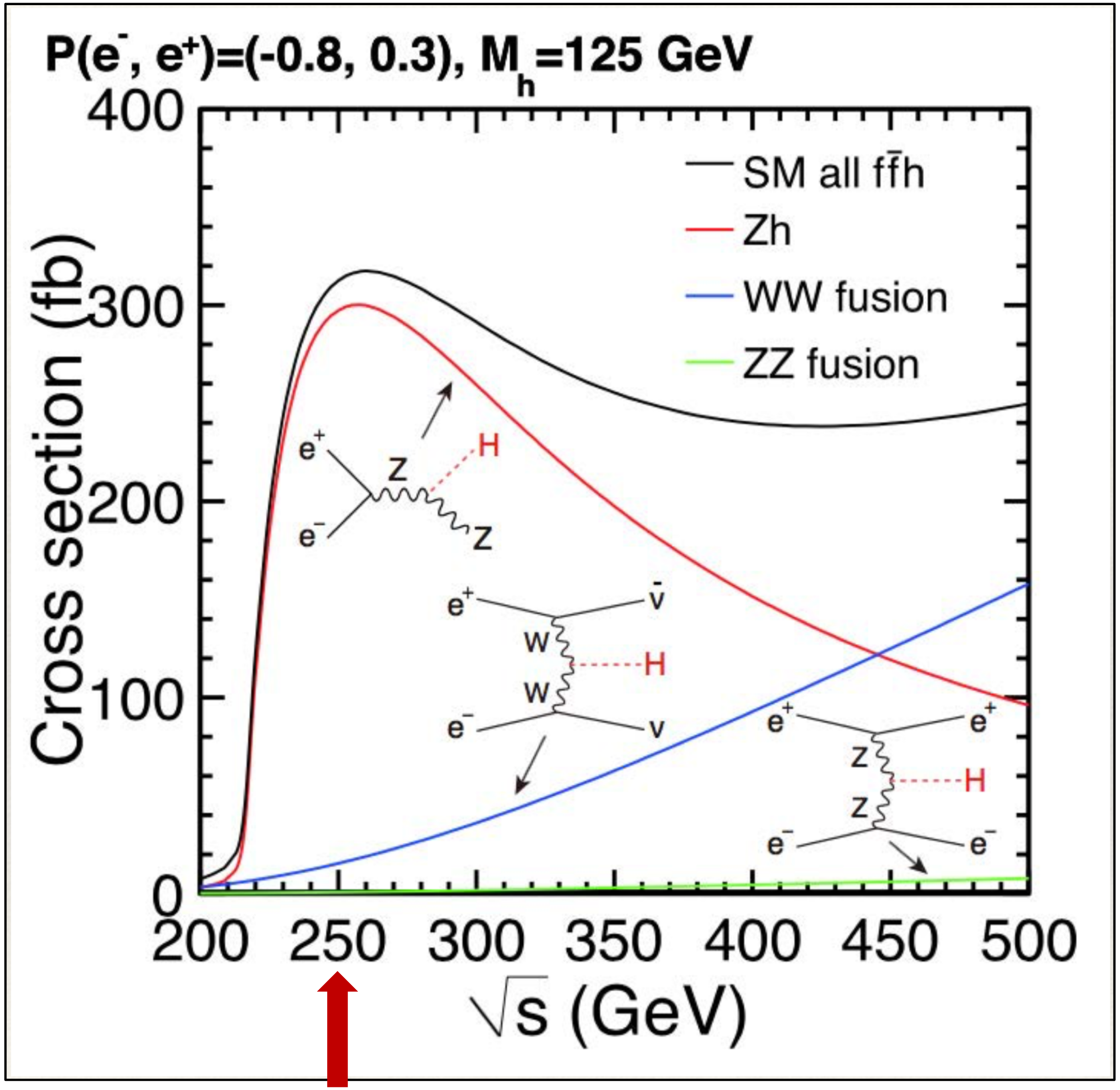


ILD

- **Momentum resolution**: $\delta(1/p_T) < 2\times10^{-5}$ GeV^{-1}
- **Impact parameters**: $\sigma(r\phi) < 5\ \mu m$
- **Jet energy resolution:** $\sigma_E/E \sim 3\text{-}4\%$



The physics of electron-position collision at high energy



ILC@250 GeV = single Higgs production cross section maximum

The International Linear Collider
A Global Project

Prepared by: Hiroaki Aihara[1], Jonathan Bagger[2], Philip Bambade[3], Barry Barish[4], Ties Behnke[5], Alain Bellerive[6], Mikael Berggren[5], James Brau[7], Martin Breidenbach[8], Ivanka Bozovic-Jelisavcic[9], Philip Burrows[10], Massimo Caccia[11], Paul Colas[12], Dmitri Denisov[13], Gerald Eigen[14], Lyn Evans[15], Angeles Faus-Golfe[3], Brian Foster[5,10], Keisuke Fujii[16], Juan Fuster[17], Frank Gaede[5], Jie Gao[18], Paul Grannis[19], Christophe Grojean[5], Andrew Hutton[20], Marek Idzik[21], Andrea Jeremie[22], Kiyotomo Kawagoe[23], Sachio Komamiya[1,24], Tadeusz Lesiak[25], Aharon Levy[26], Benno List[5], Jenny List[5], Shinichiro Michizono[16], Akiya Miyamoto[16], Joachim Mnich[5], Hugh Montgomery[20], Hitoshi Murayama[27], Olivier Napoly[12], Yasuhiro Okada[16], Carlo Pagani[28], Michael Peskin[8], Roman Poeschl[3], Francois Richard[3], Aidan Robson[29], Thomas Schoerner-Sadenius[5], Marcel Stanitzki[5], Steinar Stapnes[15], Jan Strube[7,30], Atsuto Suzuki[31], Junping Tian[1], Maksym Titov[12], Marcel Vos[17], Nicholas Walker[5], Hans Weise[5], Andrew White[32], Graham Wilson[33], Marc Winter[34], Sakue Yamada[1,16], Akira Yamamoto[16], Hitoshi Yamamoto[35] and Satoru Yamashita[1].

[1]U. Tokyo, [2]TRIUMF, [3]LAL-Orsay/CNRS, [4]Caltech, [5]DESY, [6]Carleton U., [7]U. Oregon, [8]SLAC, [9]INN VINCA, Belgrade, [10]Oxford U., [11]U. Insubria, [12]CEA/Irfu, U. Paris-Saclay, [13]Fermilab, [14]U. Bergen, [15]CERN, [16]KEK, [17]IFIC, U. Valencia-CSIC, [18]IHEP, [19]Stony Brook U., [20]Jefferson Lab, [21]AGH, Kraków, [22]LAPP/CNRS, [23]Kyushu U., [24]Waseda U., [25]IFJPAN, Kraków, [26]Tel Aviv U., [27]U. California, Berkeley, [28]INFN, [29]U. Glasgow, [30]PNNL, [31]Iwate Prefecture U., [32]U. Texas, Arlington, [33]U. Kansas, [34]IPHC/CNRS, [35]U. Tohoku

(***Representing the Linear Collider Collaboration and the global ILC community.***)

(Dated: January 29, 2019)

Abstract

A large, world-wide community of physicists is working to realise an exceptional physics program of energy-frontier, electron-positron collisions with the International Linear Collider (ILC). This program will begin with a central focus on high-precision and model-independent measurements of the Higgs boson couplings. This method of searching for new physics beyond the Standard Model is orthogonal to and complements the LHC physics program. The ILC at 250 GeV will also search for direct new physics in exotic Higgs decays and in pair-production of weakly interacting particles. Polarised electron and positron beams add unique opportunities to the physics reach. The ILC can be upgraded to higher energy, enabling precision studies of the top quark and measurement of the top Yukawa coupling and the Higgs self-coupling.

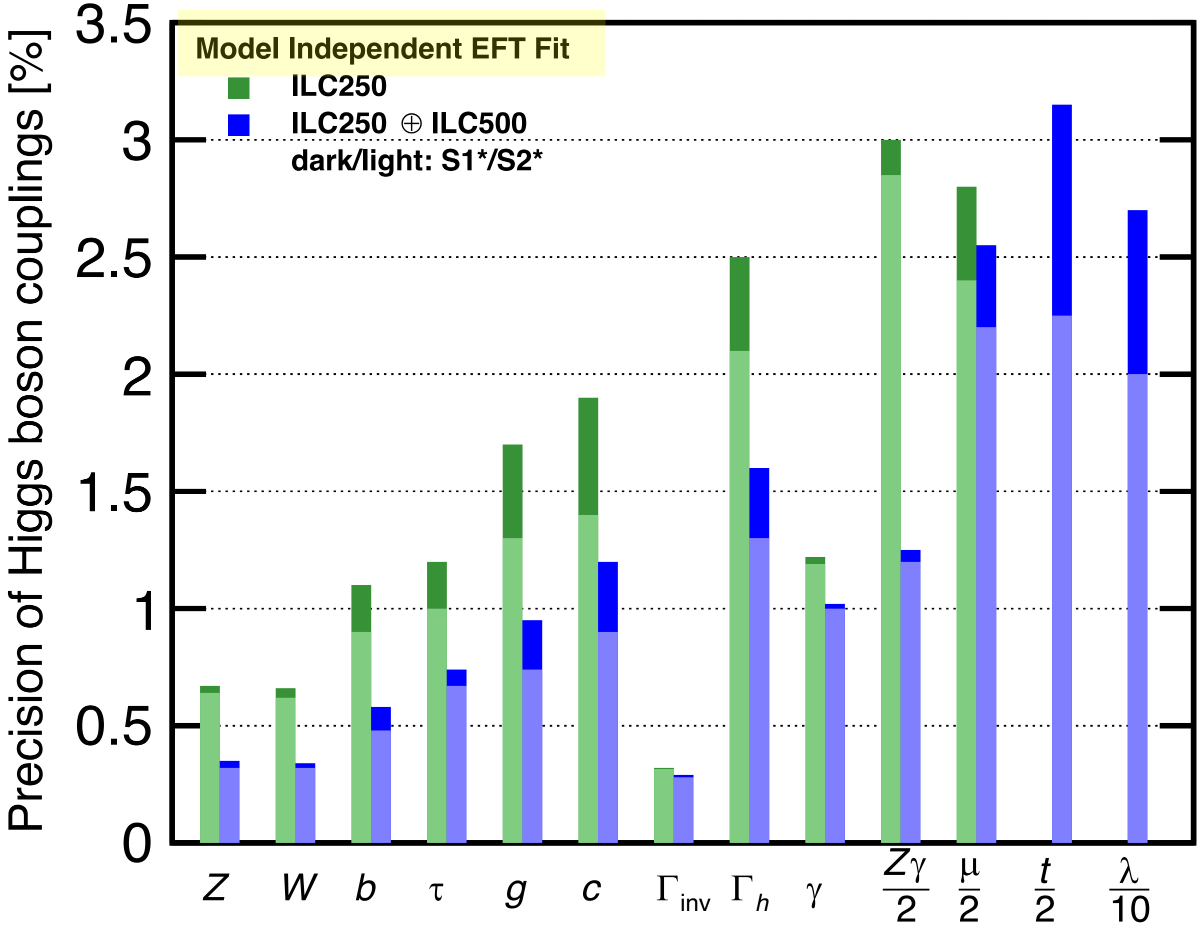
The key accelerator technology, superconducting radio-frequency cavities, has matured. Optimised collider and detector designs, and associated physics analyses, were presented in the ILC Technical Design Report, signed by 2400 scientists.

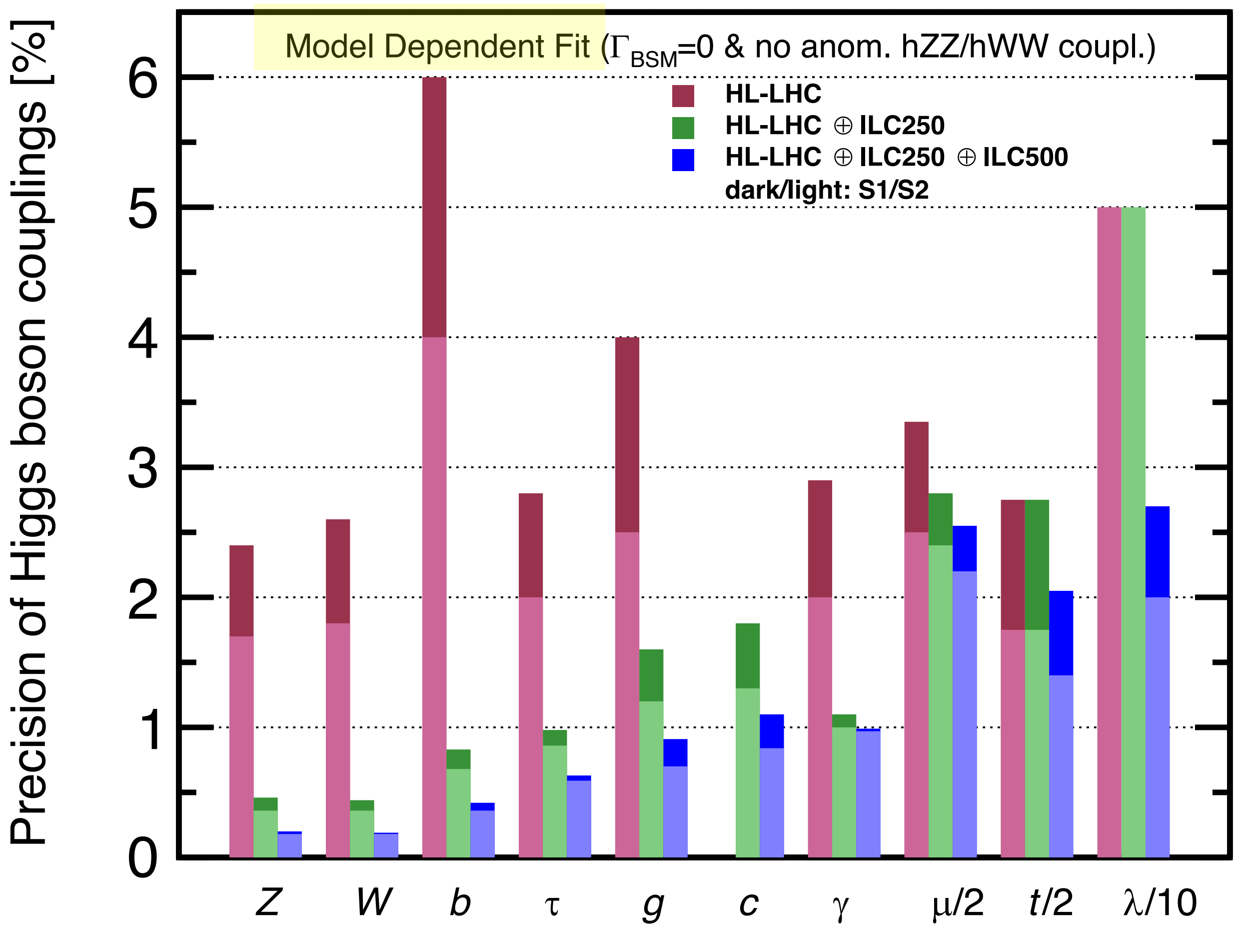
There is a strong interest in Japan to host this international effort. A detailed review of the many aspects of the project is nearing a conclusion in Japan. Now the Japanese government is preparing for a decision on the next phase of international negotiations, that could lead to a project start within a few years. The potential timeline of the ILC project includes an initial phase of about 4 years to obtain international agreements, complete engineering design and prepare construction, and form the requisite international collaboration, followed by a construction phase of 9 years.

ILC contribution European Strategic Planning arXiv:1901.09829

The Higgs coupling (Effective Field Theory)

Precision studies of Z, W, *b*, tau and *c* at 250 GeV, while ILC also opens top Yukawa and Higsgs self-coupling (λ) below 500 GeV
Polarized ILC beams 2 ab^{-1} integrated luminosity is roughly equivalent to unpolarized 5 ab^{-1}





Absolute & model-independent Higgs coupling measurements possible with ILC 250 GeV data alone

ILC & HL-LHC complementory. ILC significantly improves LHC precisions so much higher sensitivity to BSM physics

arXiv:1901.09829

SCRF Industrialization Critical for future e^+e^- colliders

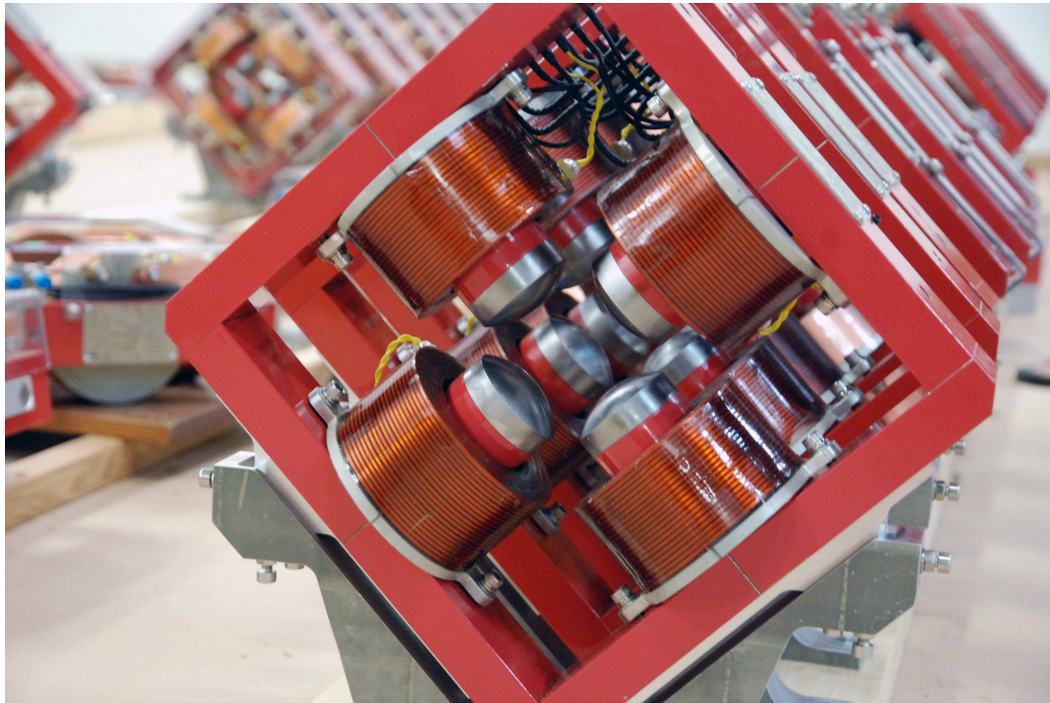
TRIUMF's e-linac - Electron Linear Accelerator

Many accelerator projects (light sources, medical isotope) world-wide are applying and advancing Superconducting Radiofrequency (SCRF) technology, SCRF cavity production and thus pushing SCRF performance (*e.g.* field gradient)

The second driver for TRIUMF's beam program is the world's highest power e-linac for rare isotope production, which will come fully online in 2021

Technology used in e-linac is similar to what is intended to be used for a future International Linear Collider (ILC)

Funding for ILC accelerator components should follow same model than the LHC & HL-LHC Industry/NRC/TRIUMF partnership



TRIUMF

Time Projection Chamber (TPC) for ILD

Main activities on micropattern gas detector (MPGD & RD51)

- Two options with similar resolution for endplate readout with **pads**:
  - **GEM:** 1.2×5.8 mm² pads (smaller pad – more electronics)
  - **Resistive Micromegas:** 3×7 mm² pads (larger pads – less electronics)
- Alternative: **pixel** readout with pixel size ~55×55 µm²

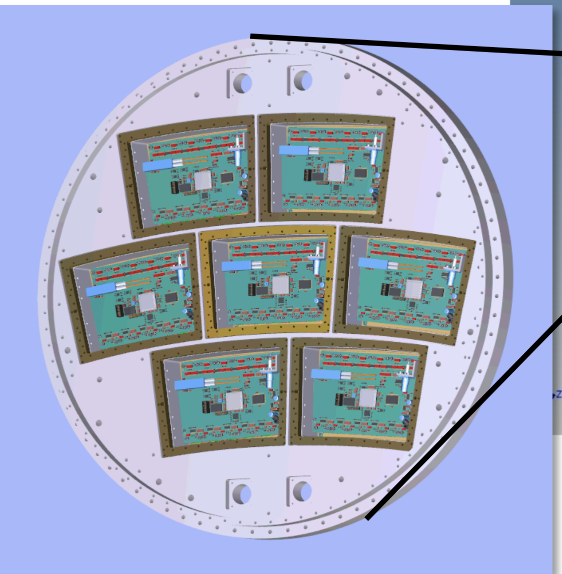
Group led by Alain Bellerive (Carleton)

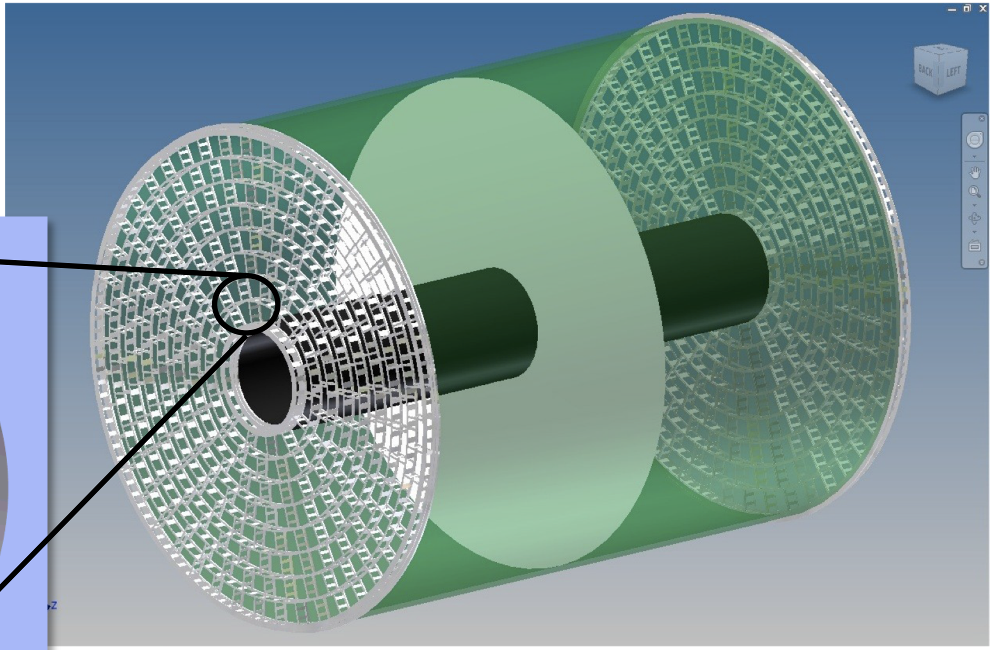
Carleton UNIVERSITY

HQP on detector R&D:

3 graduate students
11 undergraduate students

Large Prototype TPC
Endplate of 7 panels, ø = 80 cm





ILD TPC

Funding since early-2000:

Original NSERC Project Grant M. Dixit and D. Karlen
Several testbeams campaign at KEK and DESY
Publications on GEM, Micromegas and pixel
Completed LCTPC main R&D on resistive readout
Readout scheme similar to ATLAS sTGC

LCTPC Collaboration on calorimetry R&D:

3 regions (America, Asia, Europe), 25 member institutions, 22 observer institutions
A. Bellerive co-spokeperson

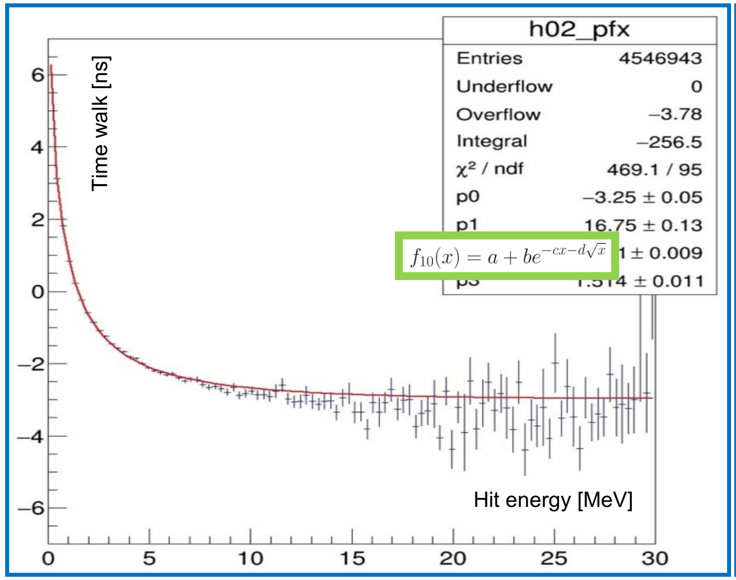
Calorimetry R&D at CALICE for ILD

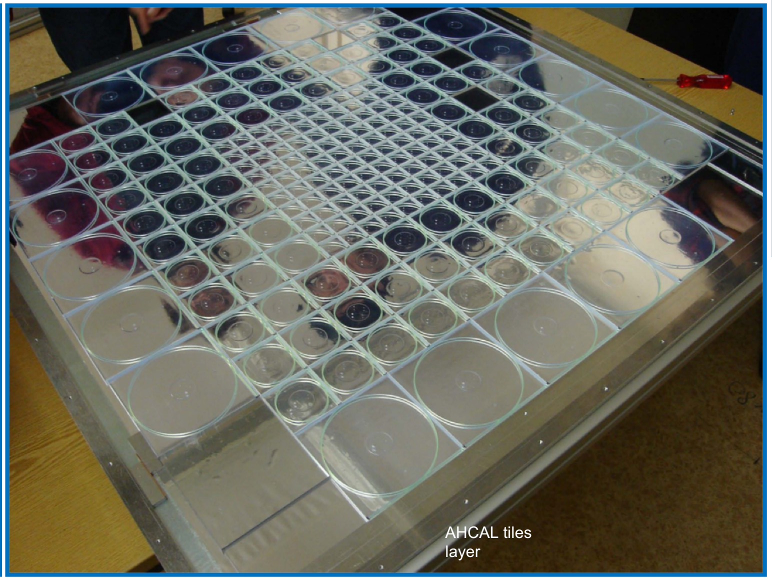
Main activities on very high granularity detectors (few cm^2):

Started in 2006 working on the **Analog Hadronic Calorimeter (AHCAL)** with simulation, alignment and performance analyses.

With NSERC funding, McGill joined Argonne (ANL) to design, build and test the novel Digital Hadronic Calorimeter (DHCAL) prototype until completion. Several publications followed.

Now on the improved AHCAL with added accurate timing information for each hit to discriminate background and further particle ID. The new CMS forward detector is based on this technology.





Group led by François Corriveau (IPP/McGill)

INSTITUTE OF PARTICLE PHYSICS

HQP on detector R&D:

4 graduate students
16 undergraduate students

Funding since 2010:

NSERC individual Discovery Grant renewed (-2024)
2× contracts with ANL for visiting M.Sc. students
5× DAAD German summer student awards
5× NSERC USRA summer student awards
2× DAAD 3-month fellowships at MPP Munich (FC)

CALICE Collaboration on calorimetry R&D:

17 countries, 57 institutes, 336 physicists/engineers
Originally for ILC experiments, now also generic R&D

Training of Highly Qualified Personnel (HQP)

ILC examples

- One graduate student now permanent Staff Research Scientist at Argonne National Lab (Detector Division)
- Former coop undergraduate engineer physics student with Siemens (Train Division)
- Several undergraduate student continue to graduate school (M.Sc. & Ph.D. and even postdoc)
- Development of very practical skills, hardware, analytical thinking and advanced experiential learning

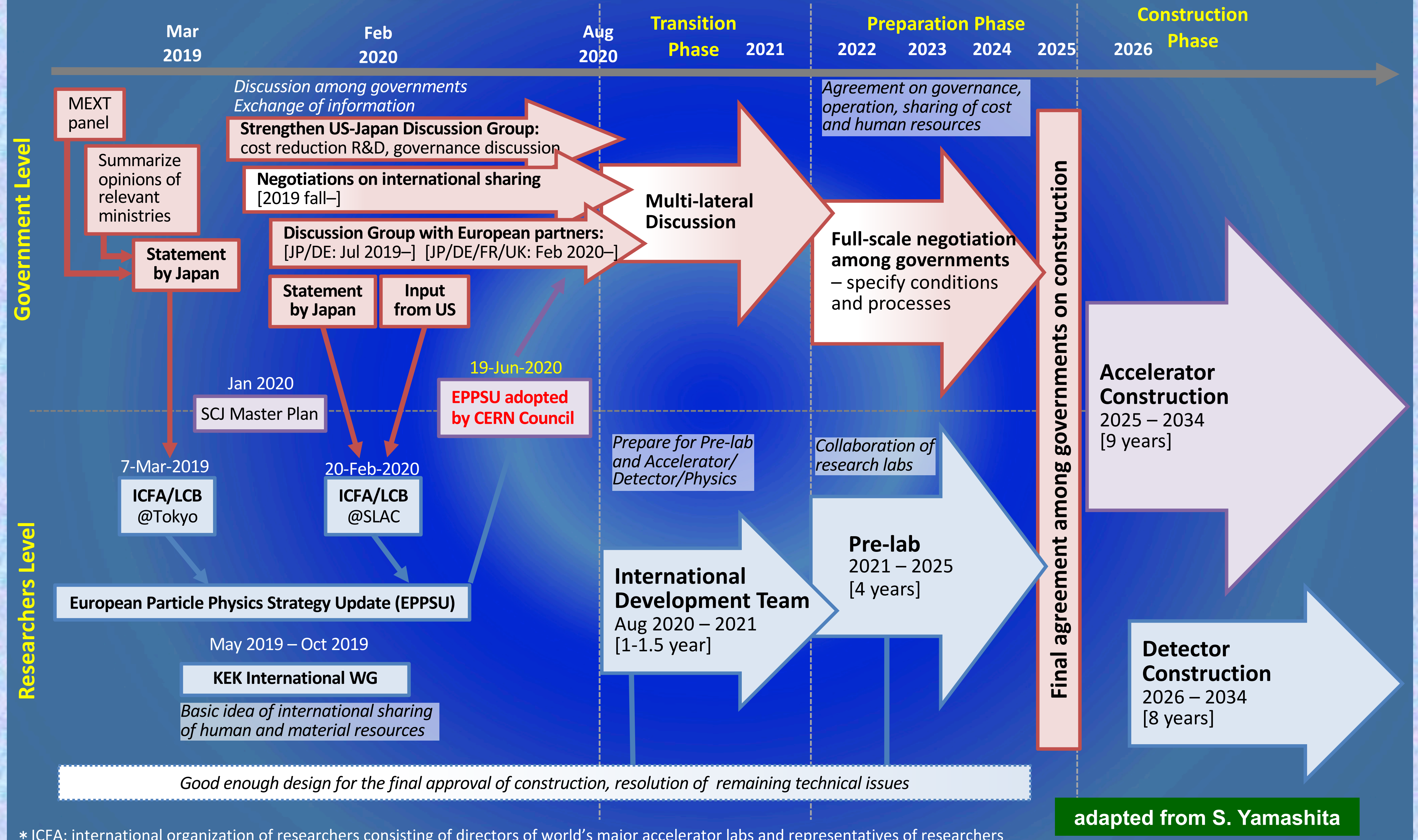
Long Range Plan More Critical Aspects

In complex long-term experimental projects, it will be a challenge to keep expertise in Canada because of the change and evolution of:

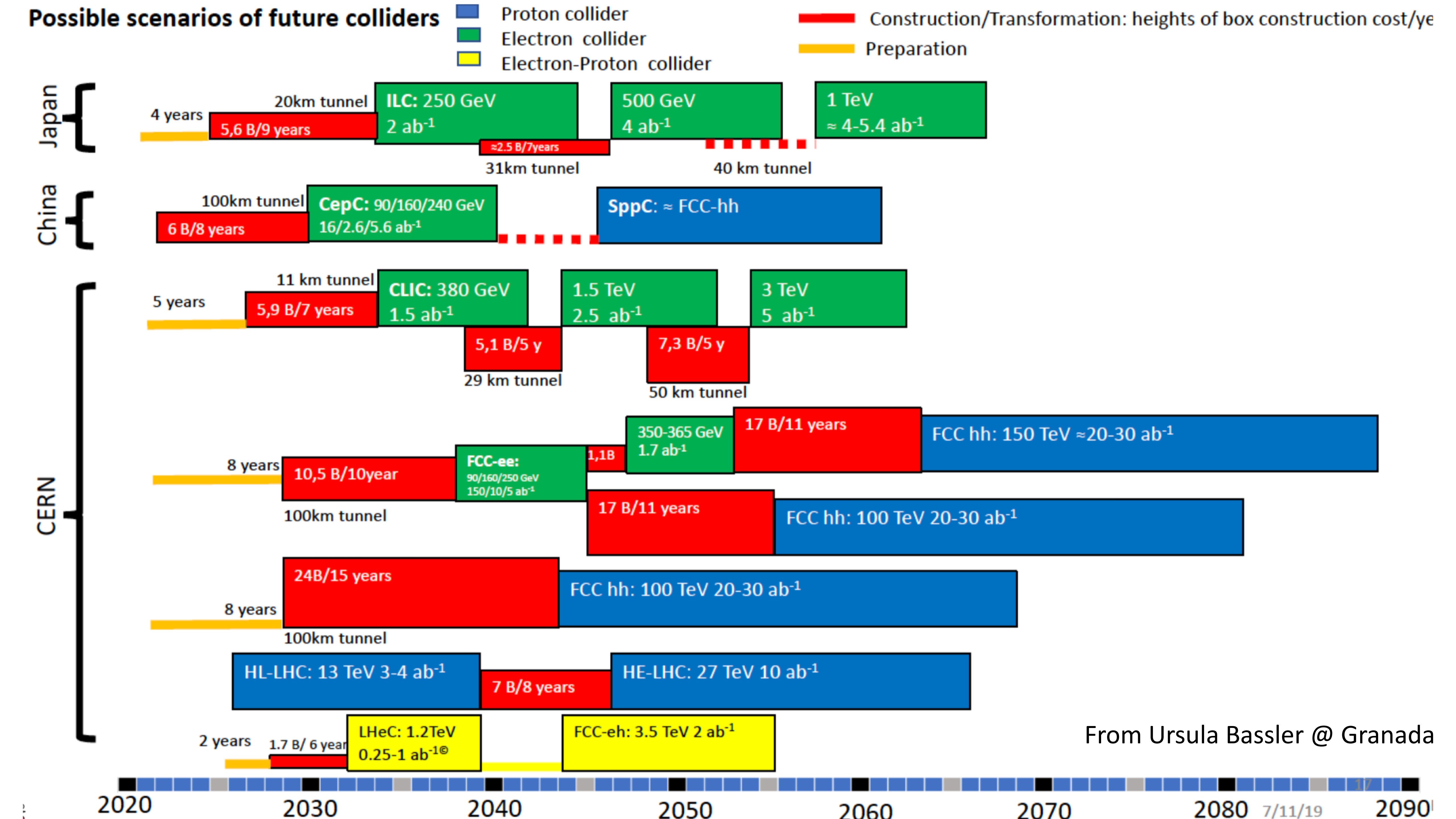
i. **career paths of the people engaged in particle physics (not just 'contractual' labour)**
ii. **timescale of experimentation**
iii. **demography of our community**

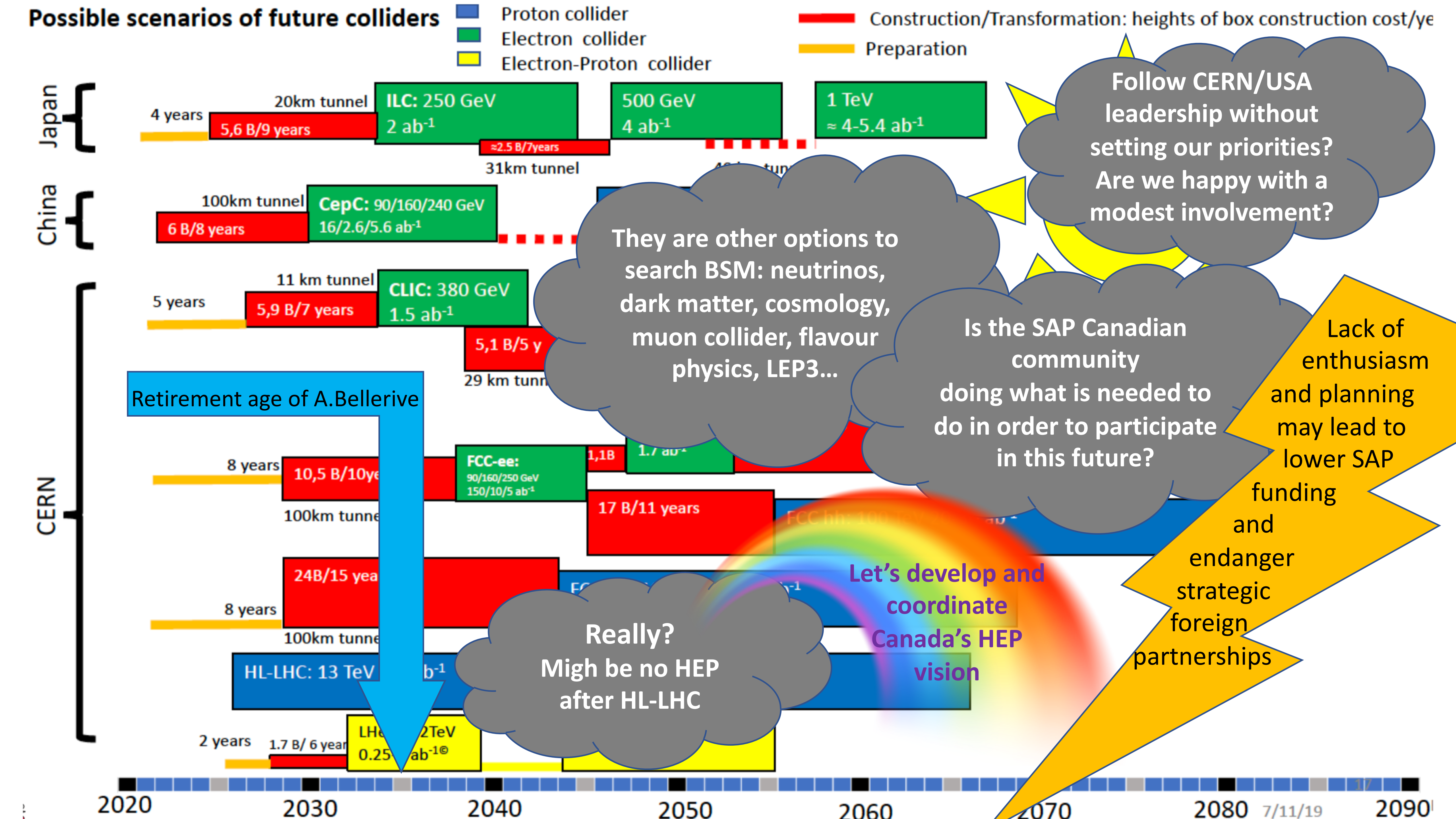
So let's not only brag about how good we are at training people! Let's also use this opportunity to globally look at how we keep and nurture expertise and continuity in order to sustain our ability to deploy large-scale instrumentation over an extended period of time.

Processes and Approximate Timelines Towards Realization of ILC



* ICFA: international organization of researchers consisting of directors of world's major accelerator labs and representatives of researchers
* ILC pre-lab: International research organization for the preparation of ILC based on agreements among world's major accelerator labs such as KEK, CERN, FNAL, DESY, etc.


Possible scenarios of future colliders
Proton collider
Electron collider
Electron-Proton collider
Construction/Transformation: heights of box construction cost/ye
Preparation
Japan
4 years
20km tunnel
5,6 B/9 years
ILC: 250 GeV
2 ab-1
≈2.5 B/7years
31km tunnel
500 GeV
4 ab-1
40 km tunnel
1 TeV
≈ 4-5.4 ab-1
China
100km tunnel
6 B/8 years
CepC: 90/160/240 GeV
16/2.6/5.6 ab-1
SppC: ≈ FCC-hh
CERN
5 years
11 km tunnel
5,9 B/7 years
CLIC: 380 GeV
1.5 ab-1
5,1 B/5 y
29 km tunnel
1.5 TeV
2.5 ab-1
7,3 B/5 y
50 km tunnel
3 TeV
5 ab-1
8 years
10,5 B/10year
100km tunnel
FCC-ee:
90/160/250 GeV
150/10/5 ab-1
1,1B
350-365 GeV
1.7 ab-1
17 B/11 years
FCC hh: 150 TeV ≈20-30 ab-1
17 B/11 years
FCC hh: 100 TeV 20-30 ab-1
8 years
24B/15 years
100km tunnel
FCC hh: 100 TeV 20-30 ab-1
HL-LHC: 13 TeV 3-4 ab-1
7 B/8 years
HE-LHC: 27 TeV 10 ab-1
2 years
1.7 B/ 6 year
LHeC: 1.2TeV
0.25-1 ab-1©
FCC-eh: 3.5 TeV 2 ab-1
From Ursula Bassler @ Granada
2020
2030
2040
2050
2060
2070
2080
2090
7/11/19



Possible scenarios of future colliders
Proton collider
Electron collider
Electron-Proton collider
Construction/Transformation: heights of box construction cost/ye
Preparation
Japan
4 years
20km tunnel
5,6 B/9 years
ILC: 250 GeV
2 ab-1
≈2.5 B/7years
31km tunnel
500 GeV
4 ab-1
1 TeV
≈ 4-5.4 ab-1
China
100km tunnel
6 B/8 years
CepC: 90/160/240 GeV
16/2.6/5.6 ab-1
CERN
11 km tunnel
5 years
5,9 B/7 years
CLIC: 380 GeV
1.5 ab-1
5,1 B/5 y
29 km tunn
Retirement age of A.Bellerive
8 years
10,5 B/10ye
FCC-ee:
90/160/250 GeV
150/10/5 ab-1
1,1B
100km tunne
17 B/11 years
24B/15 yea
8 years
100km tunne
HL-LHC: 13 TeV
2 years
1.7 B/ 6 year
Follow CERN/USA leadership without setting our priorities? Are we happy with a modest involvement?
They are other options to search BSM: neutrinos, dark matter, cosmology, muon collider, flavour physics, LEP3…
Is the SAP Canadian community doing what is needed to do in order to participate in this future?
Lack of enthusiasm and planning may lead to lower SAP funding and endanger strategic foreign partnerships
Let's develop and coordinate Canada's HEP vision
Really? Migh be no HEP after HL-LHC
2020
2030
2040
2050
2060
2070
2080
7/11/19
2090

Is there an electron-positron collider in *your* future?

Canada currently has a strong high-energy physics effort at the LHC and a solid past experience of physics exploration at other colliders. The detector assembly for ATLAS Phase1 is almost completed, while the design for the HL-LHC upgrades is to leading order finished with funding in place. Aligned with ITk expertise. The Canadian LRP process of documenting possible future accelerator options and their physics potential has begun. **One exciting possibility is the construction of a new electron-positron collider. Here, four current options are discussed with the ILC as the most advanced and mature concept - ready for deployment by 2034 and before the end of HL-LHC. ILC provides an amizing physics potential, and challenging design requirements for the needed detectors.**

- Inpired by a recent talk from Sarah Eno (https://indico.cern.ch/event/925104/) « I say thanks Sarah! »

- Canada has the expertise to design, assemble & deploy ILD (it is a natural fit)
- Why ***you*** should consider exploring these exciting machines for ***this*** LRP (I was surprised)
- How to get involved with others in the electron-positron community (… click here)

Why an electron-positron collider – ILC in particular?

- Very clean collisions and perfect environment (this is why a Higgs Factory is top priority for Europe & highly regarded by Japan as a social benefits - it is not because of historical reason)

- ILC is a concrete achievable realistic practically shovel-ready with lots of potential coupled with synergy with light-sources in Europe & US and TRIUMF e-linac

- 25 signatories from 11 Canadian institutions supported the ILC Technical Design Report (TRD)

- Fits Canada's expertise and offer great future for our MRS facilities and HQP training

- Of course, the most important question is: **do *you* really want an electron-positron future?**

- Is the absolute probe a proton-proton machine so shall *you* wait 2044 for the 100 TeV FCC-hh?

- **Do *you* want the next e^+e^- machine to be 2034 (ILC) or around 2040 (FCC-ee)?**

Can Canada participate in ILC?

- **Does Canada has the resource to operate HL-LHC and build ILC?**
- Can we engage ourselves in both ILC and FCC? Is our community big enough?
- Should we simply wait for bigger players like Europe, USA, Japan and China to drive the international priority and make the decisions?
- Or should we clearly articulate how we can engaged our community, and even grow, so that it is beneficial for subatomic physics?
- **Are we just to fragmented with the multiplication of small-scale projects? Minds engage in shorter-term projects for immediate "return" on investment?**
- Why are we not repeating the OPAL & SNO success stories?
- This LRP should set priorities… not let entropy set the landscape

Demography, HQP, training and career in SAP

- In few year, lot of the people with major expertise to build detectors (and funding) will retire

- In 1970’s a person doing a Ph.D. in particle physics could inspired to stay in academia or in a national lab or in a close research domain. University were still for an elite.
- University population has greatly grown and society acknowledge the economy of knowledge

- Nowadays, major laboratories are justifying their existence based on the fact that they train people and push the cutting edge technology. LCC is acquiring data on diversity.
- So a large fraction of the people we employed in SAP will not stay in our field of research

- We need to be <u>responsible</u>; enable mentorship program; embrace dignity, inclusion, equity, diversity; give a future; allow people to shine in all aspects that are needed in SAP

- Make connection with electronics departments, engineering physicists, computer scientists…
- Open our community to welcome technical institutions on large-scale HEP project?
- What about enabling Data Science M.Sc. and PhD. programs with HEP data? NSERC CREATE?

Resources (MRS, TRIUMF & SNOLAB vs IPP)

- We absolutely need to share the resources at our disposal (MRS, TRIUMF & SNOLAB)
- I applaud and say « yes » for IPP & the TRIUMF Detector Group to coordinate a common board for all MRS in Canada

- Yes to IPP ’approved’ projects. Allow Canada to have a critical mass on a few flag-ship projects
- I am concerned about the number of SAP projects that Canada is hoping to achieve

- Could it possibly work to have non-Canadian, theorists, and a few local experimentalists to secure ILC/ILD or FCC? Little sense to just show up to do physics once the detectors are built. At the start of ATLAS most institutes were present, but can we spare time for something else?

- Should we get involved in government programs (*e.g.* CANARIE) for HEP software?

- Particle physics is more than data analysis: it is instrumentation, hardware, sensors, software, computing, R&D, simulation, DAQ, data mining, data storage.
- Get inspired by the ESP Instrumentation & Computing WG (co-chaired by B. Vachon)

Summary Get involved if *you* want an e^+e^- collider!

- ❑ LRP committee and/or IPP to identify the tasks at hands and set the boundary
- ❑ For complex endeavour, it is all about finding the right people

- ❑ American Workshop on Linear Collider (AWLC virtual hosted by SLAC): October 19-23, 2020

- ❑ Join **ILC Study Questions for the Canadian LRP 2022-2027 and Snowmass 2021**

To aid **detector design** at the International Linear Collider, and other proposed e^+e^- colliders, a list of study questions is presented that could be the basis of M.Sc. theses for faculty/student wanted to be engaged. Find links to references and resources on e^+e^- physics, description of a new software framework and physics samples to accompany ***you*** getting involved with ILC physics. Go to https://arxiv.org/abs/2007.03650.

- ❑ Contact A. Bellerive if you seek funding. NSERC NOI before August 4, 2020.

- ❑ A two-years window for ILC Pre-lab

extra

Why an ILC in Japan?

The International Linear Collider (ILC) is only machine Higgs Factory that can
e^+e^- collision at 250 GeV addresses compelling physics questions: EW symmetry breaking and Higgs physics.
Electron-positron machines allow many probes of naturalness. Probes of “naturalness” can come from direct searches at the energy frontier, precision measurements of Higgs couplings, or precision *Z* studies!!!

250 GeV ILC is a new particle discovery machine!

Direct New Particle Searches

- **$>10^3$ higher luminosity than LEP2**
- **beam polarizations**
- **much better detectors (keep HEP at the cutting edge of knowledge & tehnology)**
- **natural evolution to higher electron-positron CM energy 350/380 GeV, 500 GeV, and beyond**

Enhance sensitivities to regions with small cross sections and compressed mass spectrum, which are challenging at LHC

Precision measurements

Past colliders whose energy regime has been explored before (LEP, HERA, Babar, CLEO, BELLE) still, though increased luminosity, enable a wealthy of physics to be studied and measured. Benefits from expertise of others (SNO, T2K, etc).

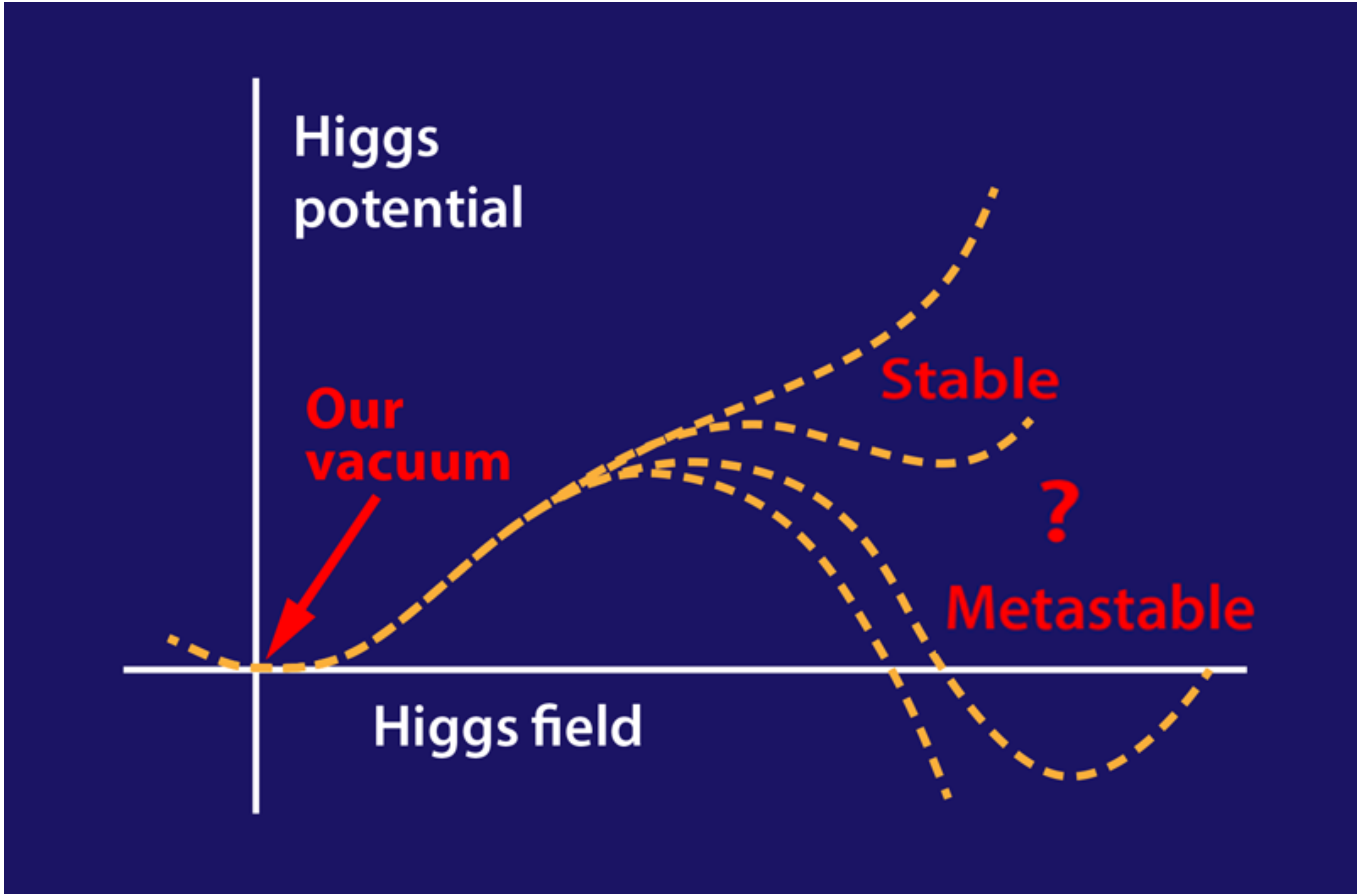
A dark sector particle could mix with the Higgs or *Z* bosons

- **Higgs decaying to missing energy and a few SM particle**
- **Benefits of improved performance of the detectors**

But isn’t dark matter today’s Higgs?

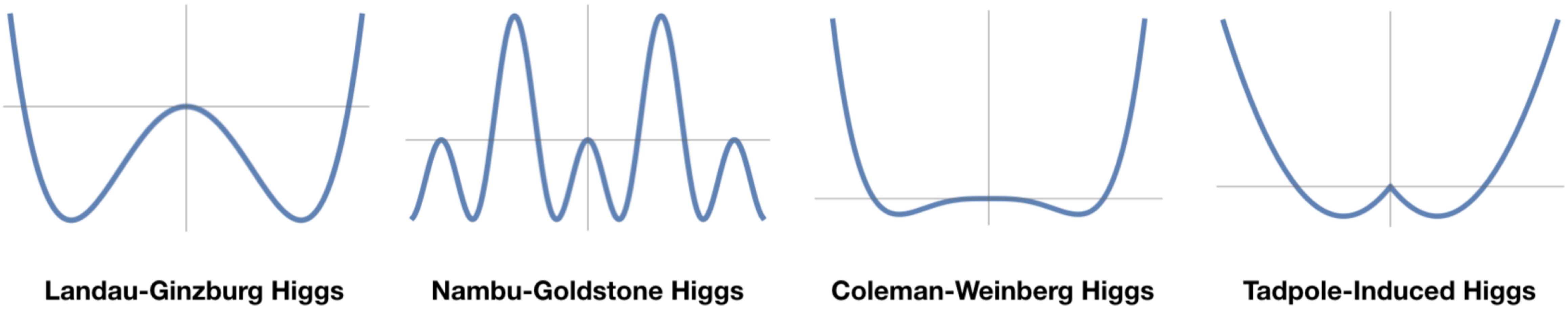
If it is lighter than half the Higgs mass and couples to it! This is done via the “missing mass” technique.

The shape of the Higgs potential



The shape of the Higgs potential

$$V(H) \simeq \begin{cases} -m^2 H^\dagger H + \lambda (H^\dagger H)^2 + \frac{c_6 \lambda}{\Lambda^2}(H^\dagger H)^3, & \text{Elementary Higgs} \\ -a \sin^2(\sqrt{H^\dagger H}/f) + b \sin^4(\sqrt{H^\dagger H}/f), & \text{Nambu-Goldstone Higgs} \\ \lambda (H^\dagger H)^2 + \epsilon (H^\dagger H)^2 \log \frac{H^\dagger H}{\mu^2}, & \text{Coleman-Weinberg Higgs} \\ -\kappa^3 \sqrt{H^\dagger H} + m^2 H^\dagger H, & \text{Tadpole-induced Higgs} \end{cases}$$



Higgs potential can be related to the three Sakharov conditions for a matter/anti-matter asymmetry.
Two are fulfilled if:

- **A strongly first order phase transition**
- **A new mechanism for CP violation**

IPP brief 2005 LRP

Focussed scientific program

I gave the ILC talk at the IPP AGM (2005-2006) and then later in 2010-20011 I used the expression "keep our foot in the door". This time in 2020-2021… it is now or never.

The IPP Experimental Programme

	Timescale		Investigators	
Experiment	Start	End	IPP Scientists	Signatories(FTE)
ATLAS	2007 (1996)	2020?	2.5	31 (22)
BaBar	2000 (1998)	2009	2.3	9 (8)
CDF	1992 (1992)	2008	0	6 (4)
E949	1988 (1988)	2000	0	10 (2)
HERMES	1990 (1990)	2007	0	2 (1)
PICASSO	1997 (2005)	2010+	0	8 (5)
SNO	1998 (1990)	2007	1	34 (25)
T2K	2009 (2004)	2015+	0.4	19 (9)
VERITAS	2006 (2004)	2010	0	2 (2)
ZEUS	1989 (1984)	2007	1.8	4 (3)

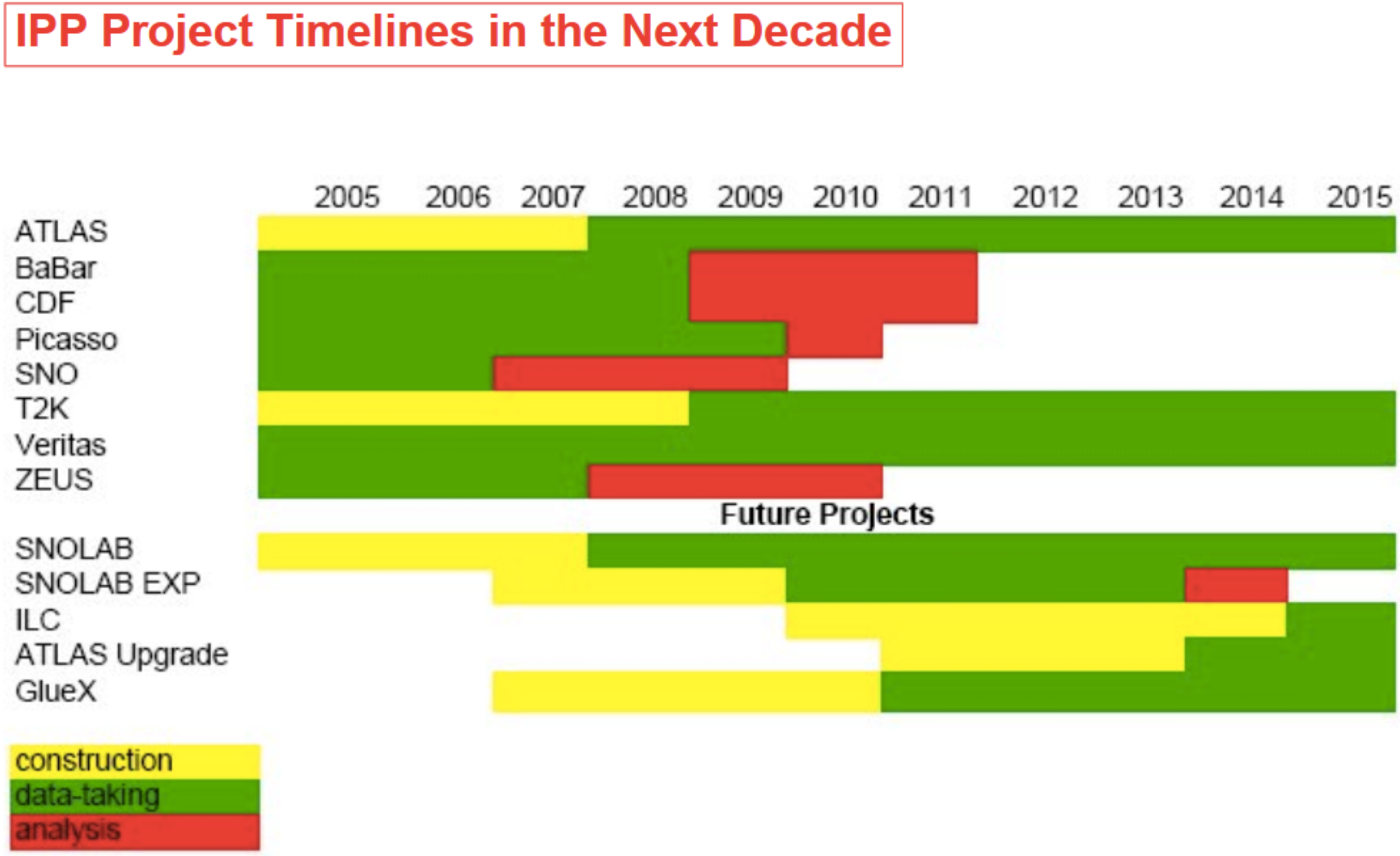
- Is the IPP programme serving the community? (Yes, 81 FTEs)
- Are all projects currently viable?
- Links to the theory community (50 members of the IPP are theorists)

from William Trischuk

IPP brief 2005 LRP

ILC has been in the planning for over 15 years!!!

In 2020, I see many more projects but a community of about same size (slightly larger)



ILC

William Trischuk