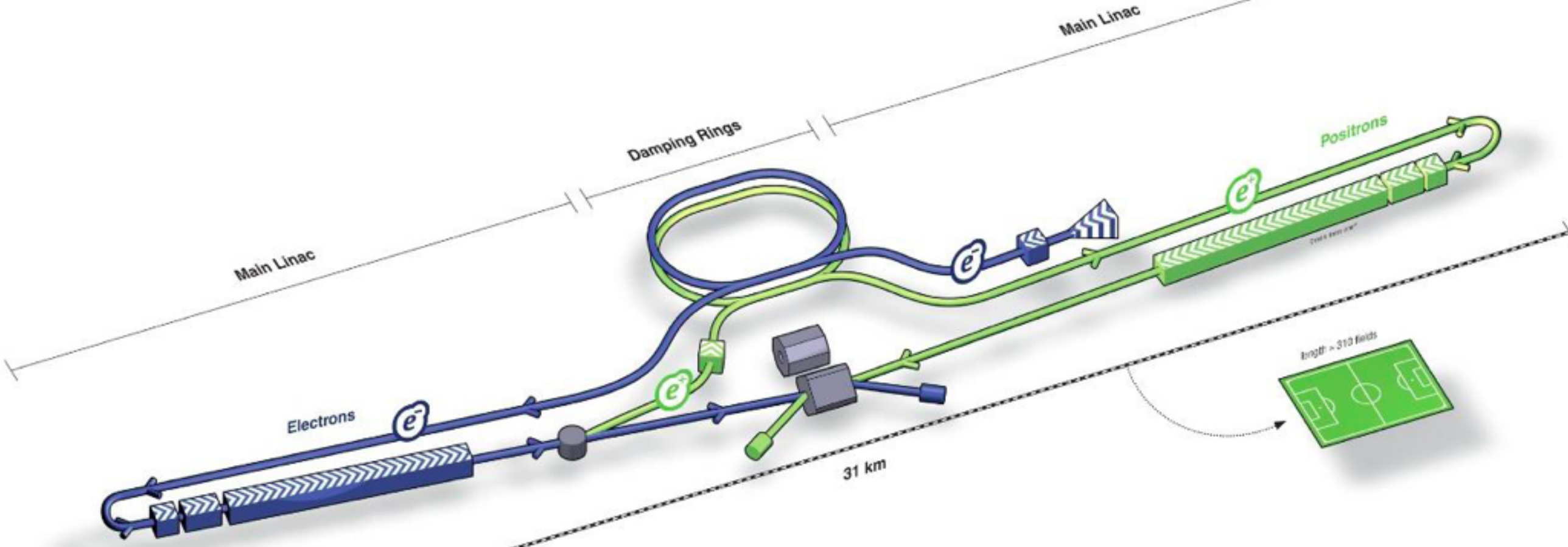


Future Linear Colliders

LINEAR COLLIDER COLLABORATION

Hitoshi Murayama (Berkeley & Kavli IPMU)

Whistler LCWS, Nov 6 2015

BERKELEY CENTER FOR THEORETICAL PHYSICS

BERKELEY LAB

東京大学
THE UNIVERSITY OF TOKYO

TODIAS
東京大学国際高等研究所
TODAI INSTITUTES FOR ADVANCED STUDY

KAVLI IPMU
INSTITUTE FOR THE PHYSICS AND MATHEMATICS OF THE UNIVERSE

From: **Dmitri Denisov** denisovd@fnal.gov
Subject: Talk at LCWS tomorrow
Date: November 5, 2015 at 08:07
To: Murayama Hitoshi hitoshi@berkeley.edu

DD

Hi Hitoshi,

this is a reminder about your talk at LCWS workshop at Whistler tomorrow at ~12:30pm.

The workshop is progressing well with over 200 participants and many interesting talks.

Probably most significant news is that it will take Japan another 2-3 years to evaluate to host or not the ILC - more than many expected. You addressing this on positive side would be great.

Looking forward to see you tomorrow, Dmitri.

What does it mean?

Timeline

Proposed by LCC

- 2013 - 2016
  - Negotiations among governments
  - Accelerator detailed design, R&Ds for cost-effective production, site study, CFS designs etc.
  - Prepare for the international lab.
- 2016 – 2018
  - ‘Green-sign’ for the ILC construction to be given (in early 2016)
  - International agreement reached to go ahead with the ILC
  - Formation of the ILC lab.
  - Preparation for biddings etc.
- 2018
  - Construction start (9 yrs)
- 2027
  - Construction (500 GeV) complete, (and commissioning start)
    (250 GeV is slightly shorter)

The Position of MEXT and the Japanese Government towards the ILC

ILC being studied officially by the MEXT Japan

Science Council of Japan → Recommendation in 2013 → **MEXT**

MEXT

- ILC Taskforce
  formed in 2013
  - **ILC Advisory Panel**
    in JFY 2014 ~ 2015
    - Particle & Nuclear **Phys.** Working Group
      in 2014 ~ 2015
    - **TDR** Validation Working Group
      in 2014 ~ 2015
    - **Human Resources** Working Group
      in **2015**

Commissioned Survey by NRI
(in 2014, and 2015)

planned → **Commissioned Survey by NRI**

planned → **Human Resources** Working Group

Sachio Komamiya

Summary of the ILC Advisory Panel's Discussions to Date

August 2015

As an official process of the Japanese Government towards the approval

☒ **ICFA will respond to this report**

1. Discussion background …
2. Overview of discussions

(1) Science Merit of the ILC Project

The ILC is considered to be important because of its capability to investigate new physics beyond the Standard Model by exploring new particles and precisely measuring the Higgs boson and top quark. It should be also noted that the ILC might be able to discover a new particles which are difficult to be detected in LHC experiments.

ILC experiments are able to search for new particles, different from the ones that LHC experiments have been searching for. In case these new particles are supersymmetric particles, ILC and LHC experiments can study them complementary. On the other hand ILC experiments can carry out more precise measurement of the Higgs boson and the top quark, which are beyond the reach of LHC experiments.

…

(2) Validation of TDR

(3) International Collaboration

(4) Social effect of the ILC Project **Economic effects, Industrial Spin-off**

Sachio Komamiya

Recommendation 1: The ILC project requires huge investment that is so huge that a single country cannot cover, thus it is indispensable to share the cost internationally. From the viewpoint that the huge investments in new science projects must be weighed based upon the scientific merit of the project, a clear vision on the discovery potential of new particles as well as that of precision measurements of the Higgs boson and the top quark has to be shown so as to bring about novel development that goes beyond the Standard Model of the particle physics.

⇒ Discovery is not guaranteed at any frontier machines , but clear vision of discovery potential have been already demonstrated for ILC.

Recommendation 2: Since the specifications of the performance and the scientific achievements of the ILC are considered to be designed based on the results of LHC experiments, which are planned to be executed through the end of 2017, it is necessary to closely monitor, analyze and examine the development of LHC experiments. Furthermore, it is necessary to clarify how to solve technical issues and how to mitigate cost risk associated with the project.

⇒ Surely we will monitor LHC physics.

MEXT is contacting governments during the LHC 13 TeV Run.

Recent "ILC Progress Report" by LCC answers most of the technical items.

Recommendation 3: While presenting the total project plan, including not only the plan for the accelerator and related facilities but also the plan for other infrastructure as well as efforts pointed out in Recommendations 1 & 2, it is important to have general understanding on the project by the public and science communities.

⇒ Public relation will be reinforced by international team and by KEK and the Industry Supporters (AAA).

Discussions with scientists of the other fields have been undertaken by KEK DG.

ICFA/LCB are preparing a document to clarify the issues in the report of the ILC Advisory Panel by the end of this year.

Sachio Komamiya

2 to 3 more years?

- I find it extremely positive that MEXT takes ILC seriously and is trying to follow recommendations from the committees
- clearly MEXT needs to see some hints that other countries would chip in
  - Otherwise Japan would never announce its intent to host
- Does your Minister know about ILC? Will you help your government negotiate?
- meanwhile we should ease their concerns
- if it takes longer, we need to dream bigger!

easing concerns

- demonstrate high yield @ X-FEL, LCLSII
- achieve better emittance @ ATF
- higher gradient (N_2 doping?)
- detailed designs
- train young people through current projects
- standing firm on the existing physics case and stay together

Physics case for LC is very simple and strong

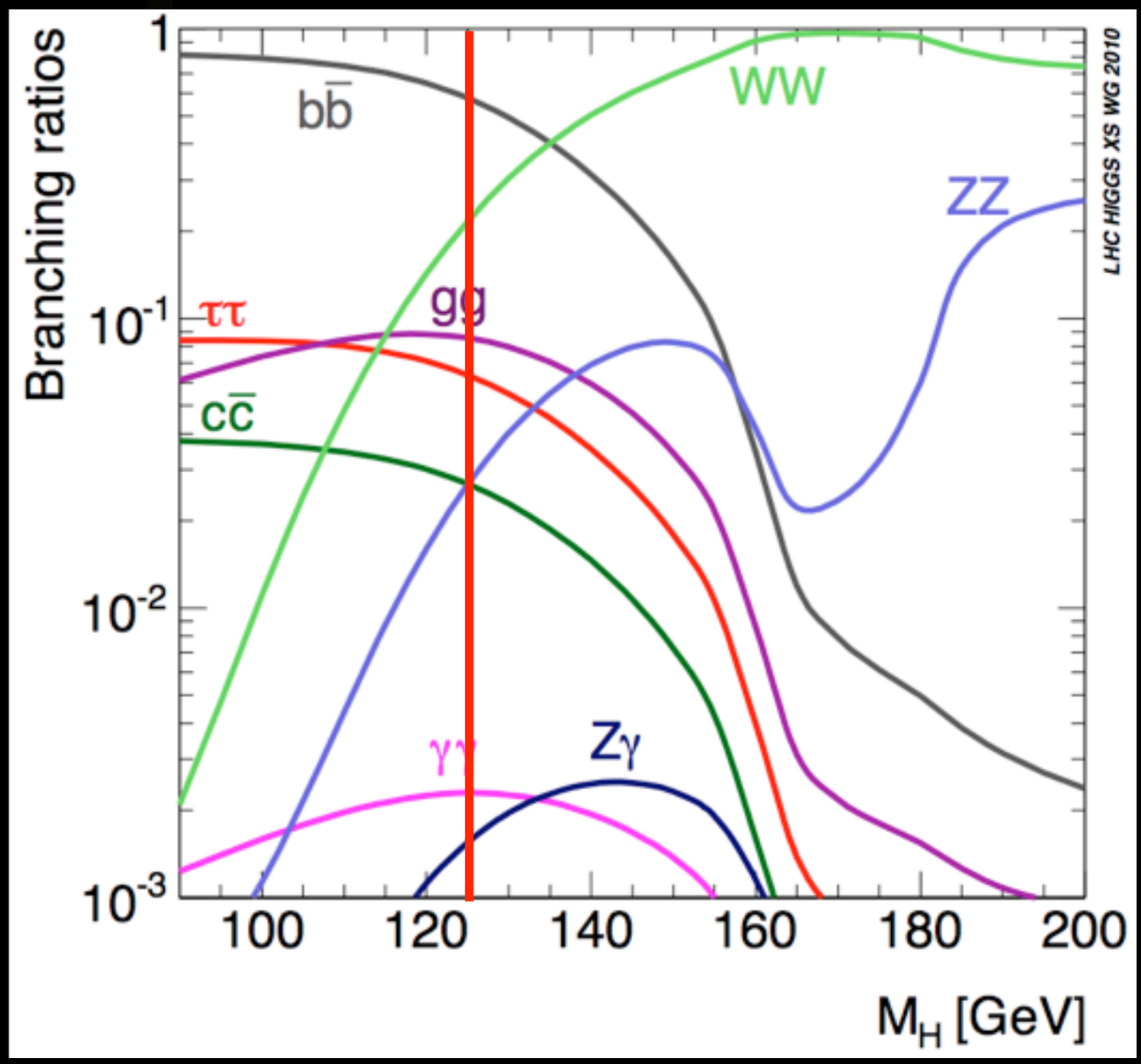
Higgs, top, new physics

- Only two particles not studied precisely at e^+e^- so far: Higgs & top
  - Higgs first of a kind (no spin), most important particle in the theory
  - top can talk to new physics, controls the fate of the Universe
- of course look for (uncolored) new physics

Spin

- every elementary particles spin forever
- electrons, photons, quarks, ...
- only Higgs boson doesn't spin
- Faceless! A *spooky particle, a new breed*
- I had proposed "Higgsless theories"
- *Is it the only one?*
- *does it have siblings? relatives?*
- *Maybe it's spinning in extra dimensions?*
- *maybe composite?*
- *why did it freeze in?*

dream case for experiments

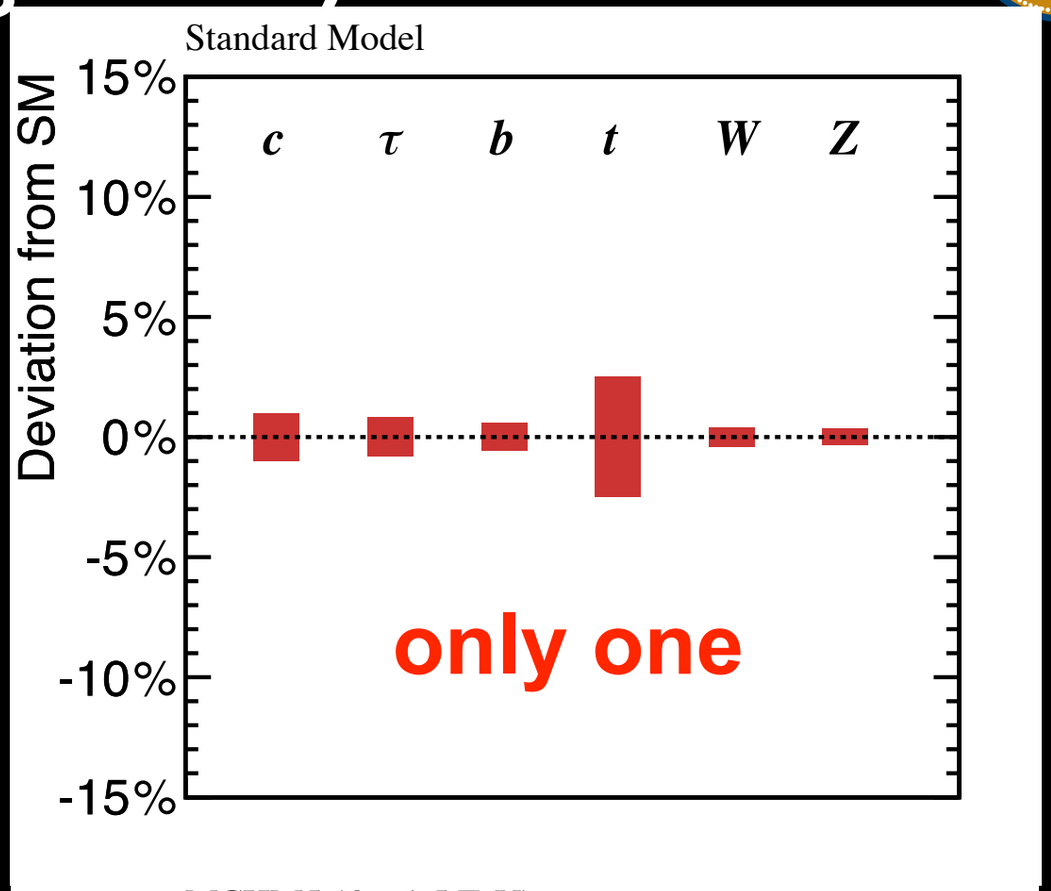


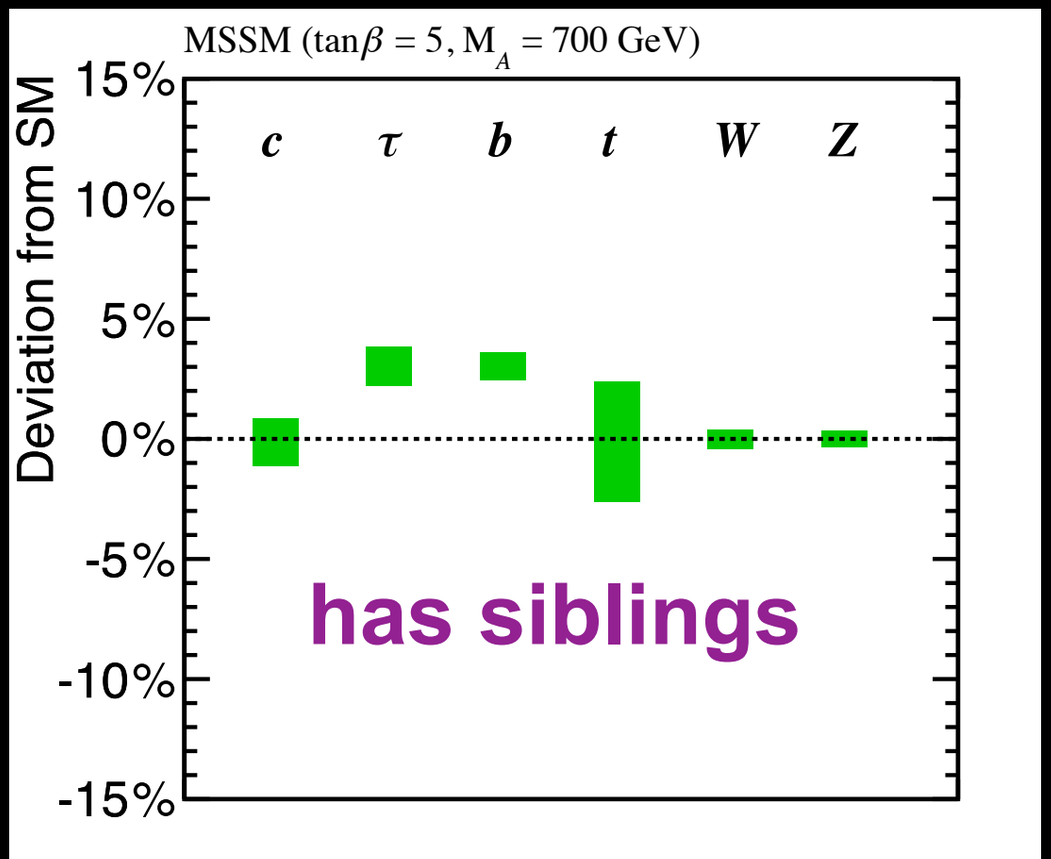
stupid not to do this!

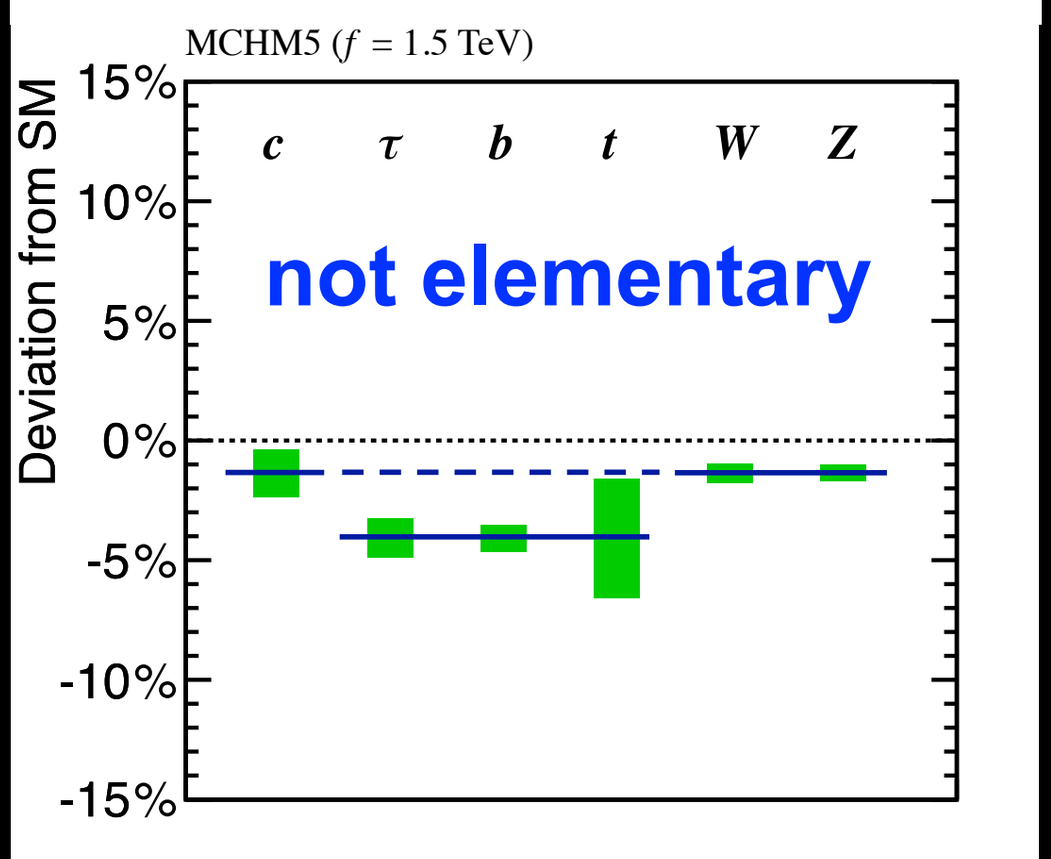
What is Higgs really?

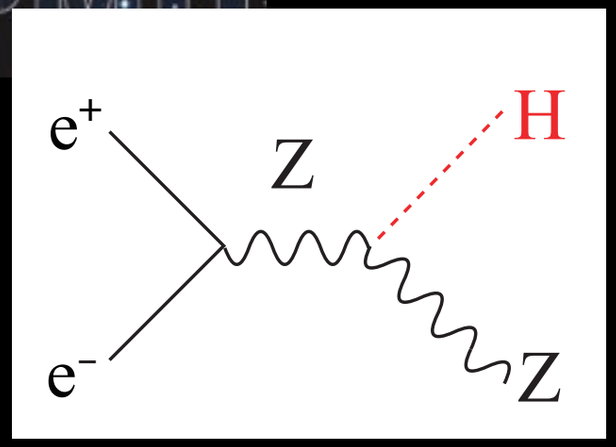
Only one? (SM)
has siblings? (2DHM)
not elementary?

Lumi 1920 fb-1, sqrt(s) = 250 GeV
Lumi 2670 fb-1, sqrt(s) = 500 GeV







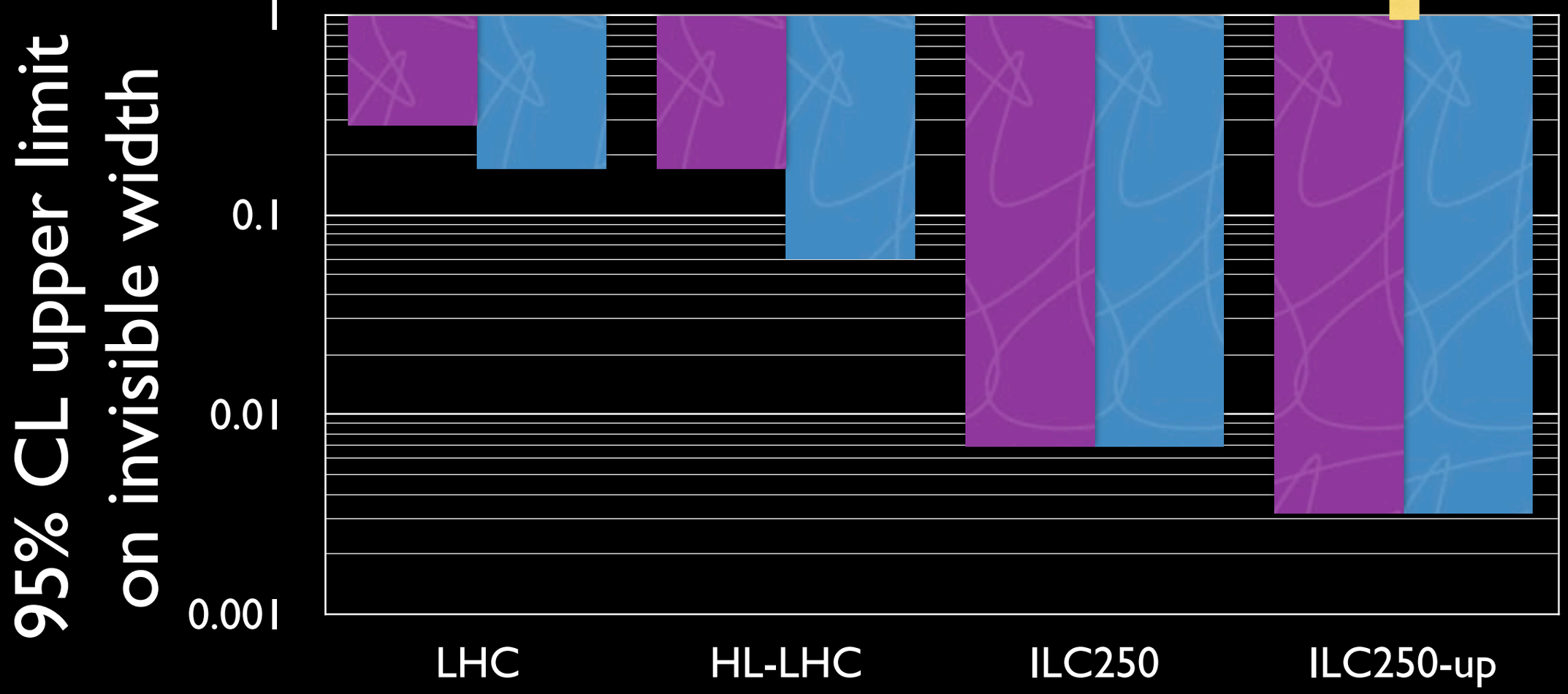


Higgs as a portal

dark matter?

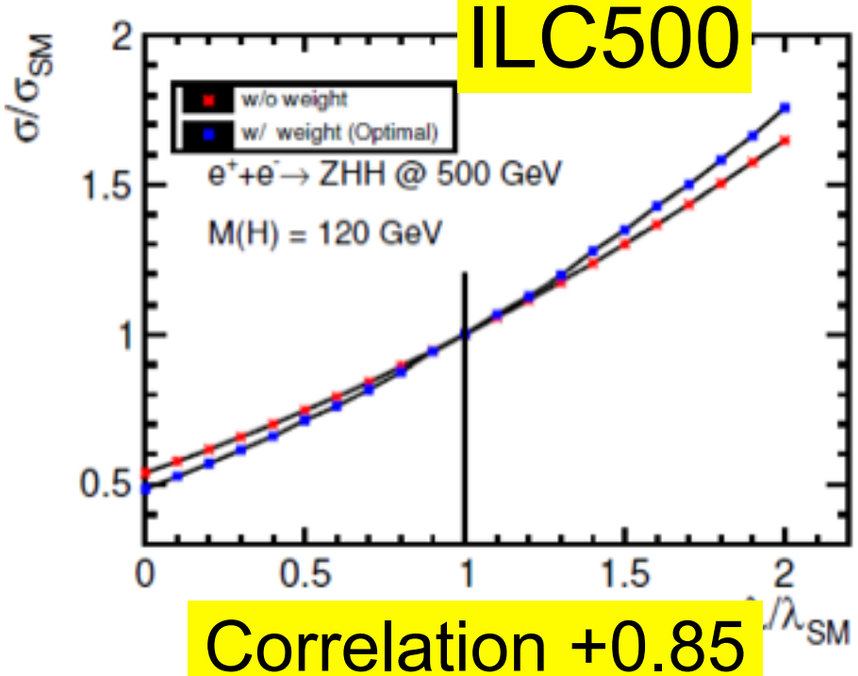
conservative

optimistic



Higgs self-coupling (2/2)

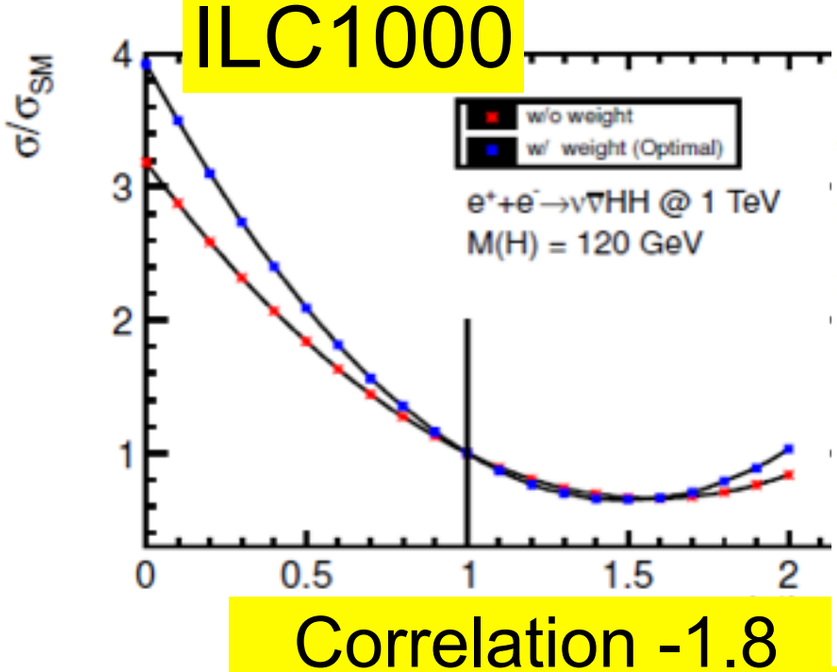
ILC500



Correlation +0.85

36% @ ILC500up

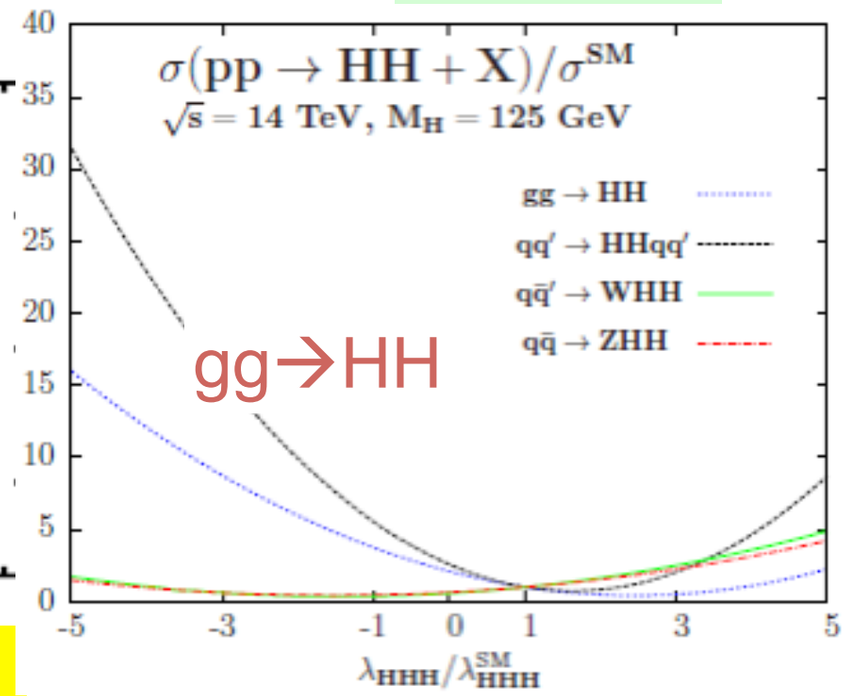
ILC1000



Correlation -1.8

10% @ ILC1000up

HL-LHC



Correlation -0.8

Lumi 2670 fb-1, sqrt(s) = 500 GeV
Lumi 4170 fb-1, sqrt(s) = 1 TeV

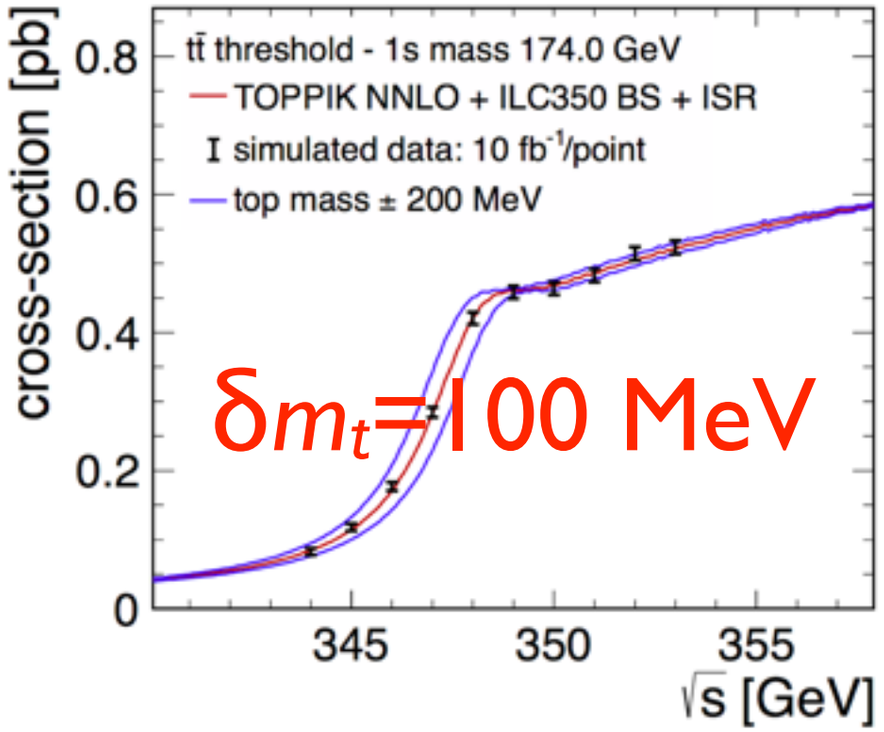
ILC-LHC synergy

- Effect of interfering diagrams:
  - Negative correlation: better sensitivity for λ<1 (HL-LHC)
  - Positive correlation: better sensitivity for λ>1 (ILC500)
- Large deviations predicted by EW baryogenesis scenarios, testable at ILC
- 10% precision achievable with ILC1000

EW top-Neutral VB couplings

projected precision of $t-\gamma,\ t-Z^0$ couplings

Collider	LHC		ILC/CLIC
CM Energy [TeV]	14	14	0.5
Luminosity [fb^{-1}]	300	3000	500
SM Couplings			
photon, F_{1V}^{γ} (0.666)	0.042	0.014	0.002
Z boson, F_{1V}^{Z} (0.24)	0.50	0.17	0.003
Z boson, F_{1A}^{Z} (0.6)	0.058	?	0.005
Non-SM couplings			
photon, F_{1A}^{γ}	0.05	?	?
photon, F_{2V}^{γ}	0.037	0.025	0.003
photon, F_{2A}^{γ}	0.017	0.011	0.007
Z boson, F_{2V}^{Z}	0.25	0.17	0.006
Z boson, ReF_{2A}^{Z}	0.35	0.25	0.008
Z boson, ImF_{2A}^{Z}	0.035	0.025	0.015

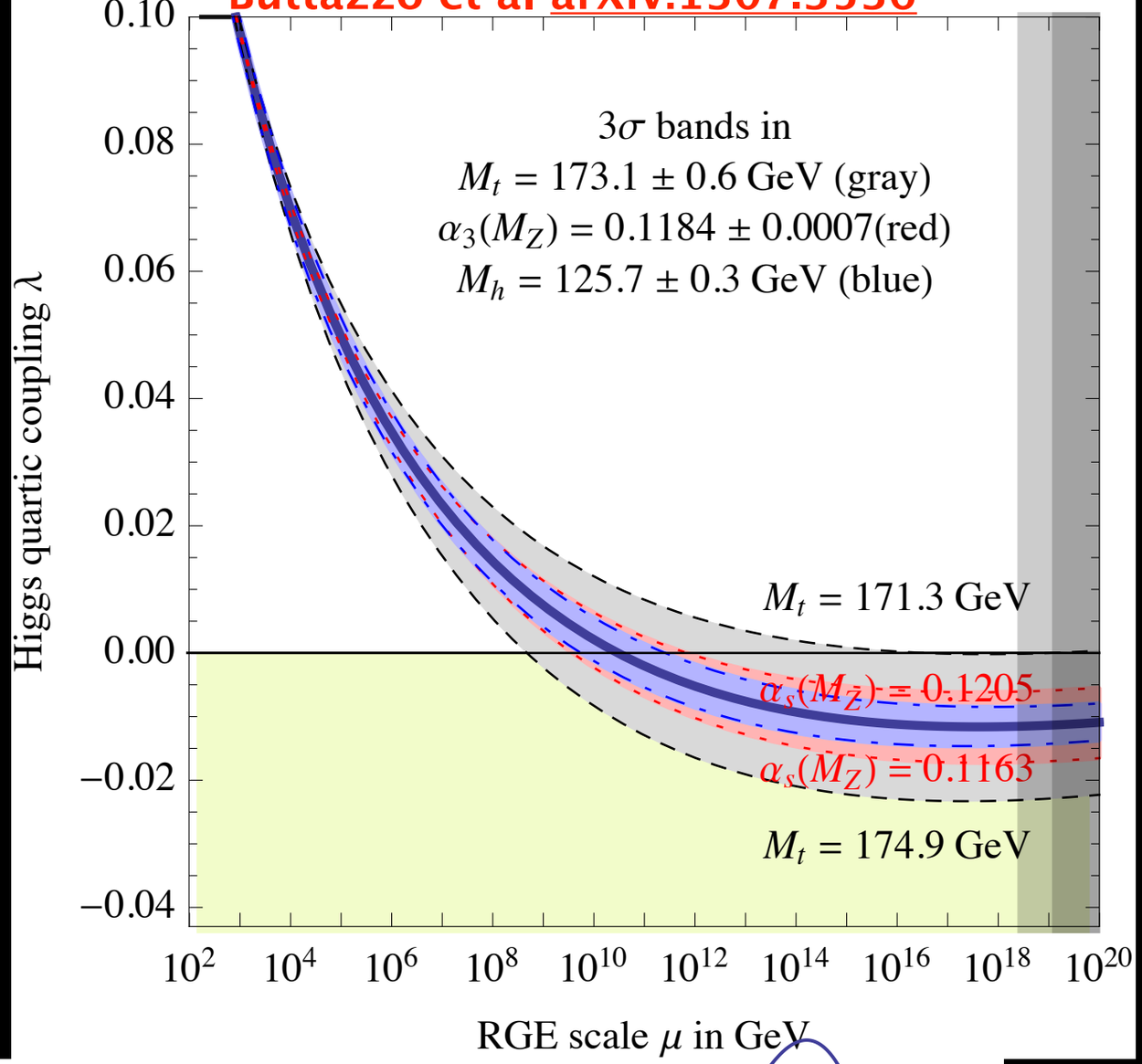


BSM: 2-10 %

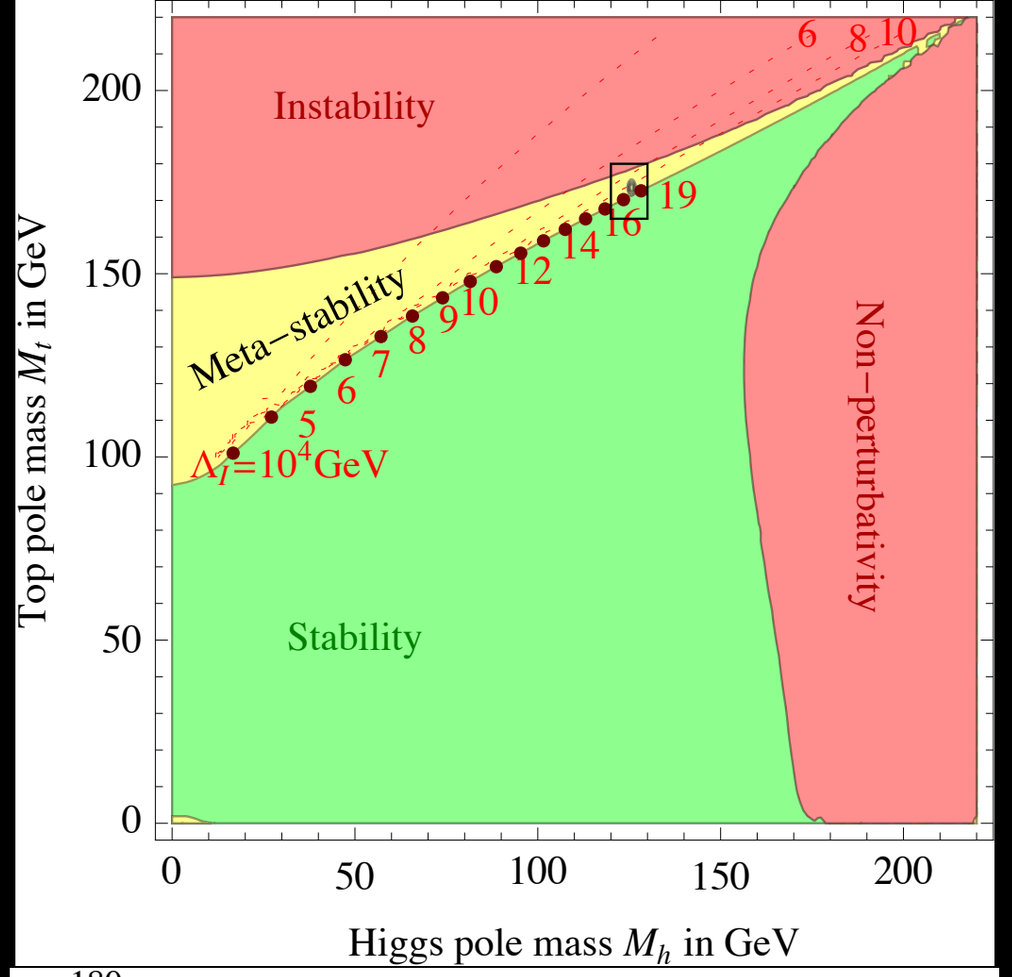
LHC : few %

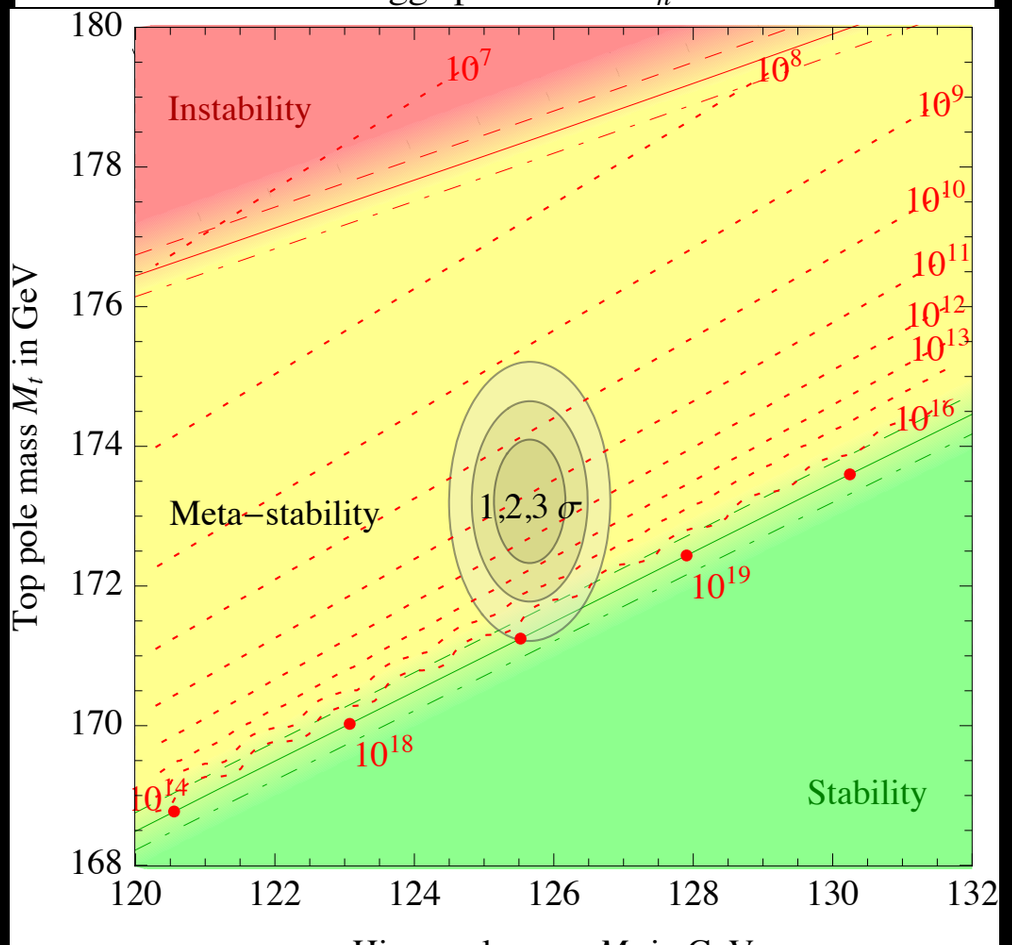
ILC/CLIC: sub-%

Buttazzo et al arXiv:1307.3536



our minimum decays in about 10^{800} years?





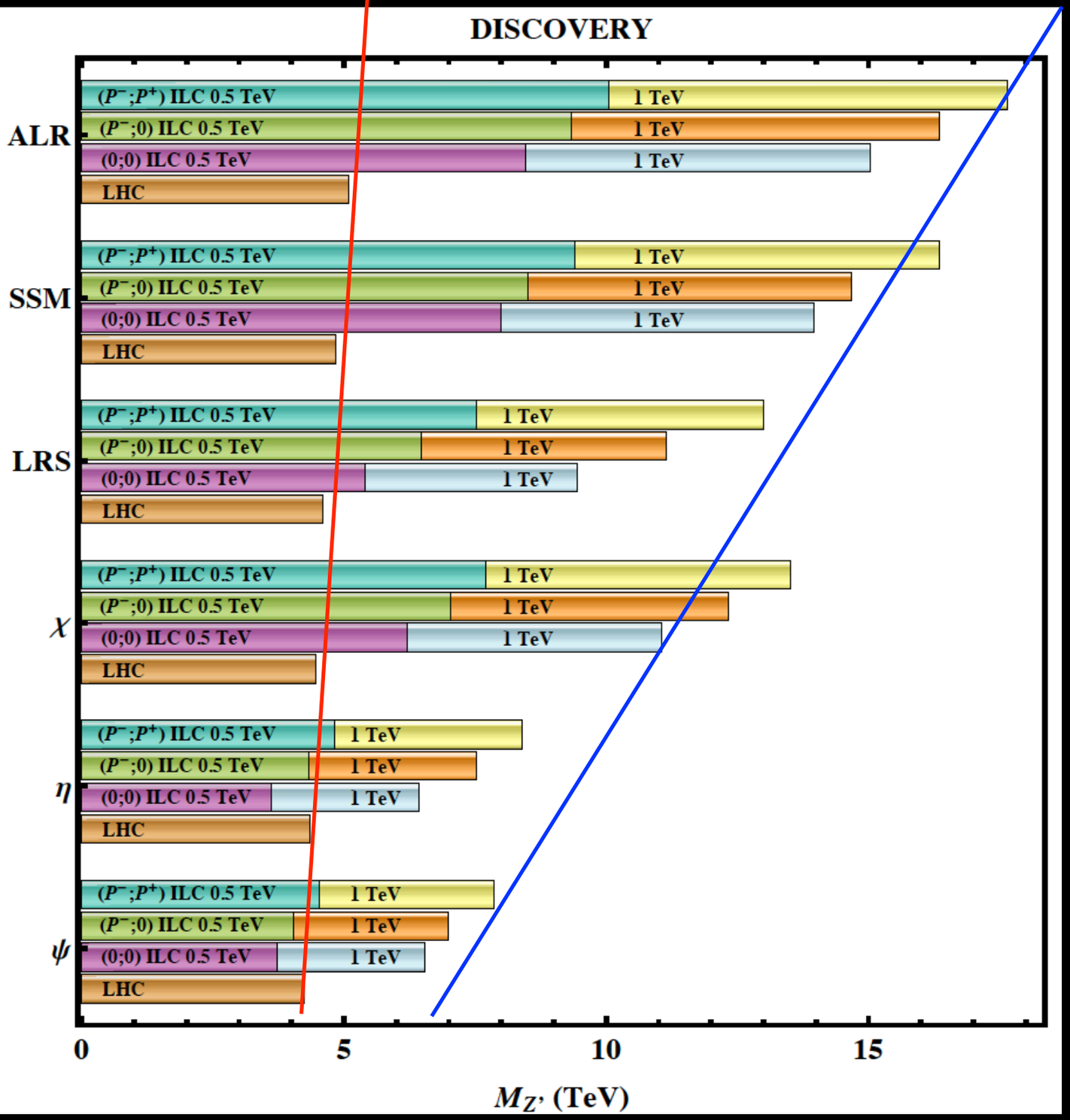
History of Colliders

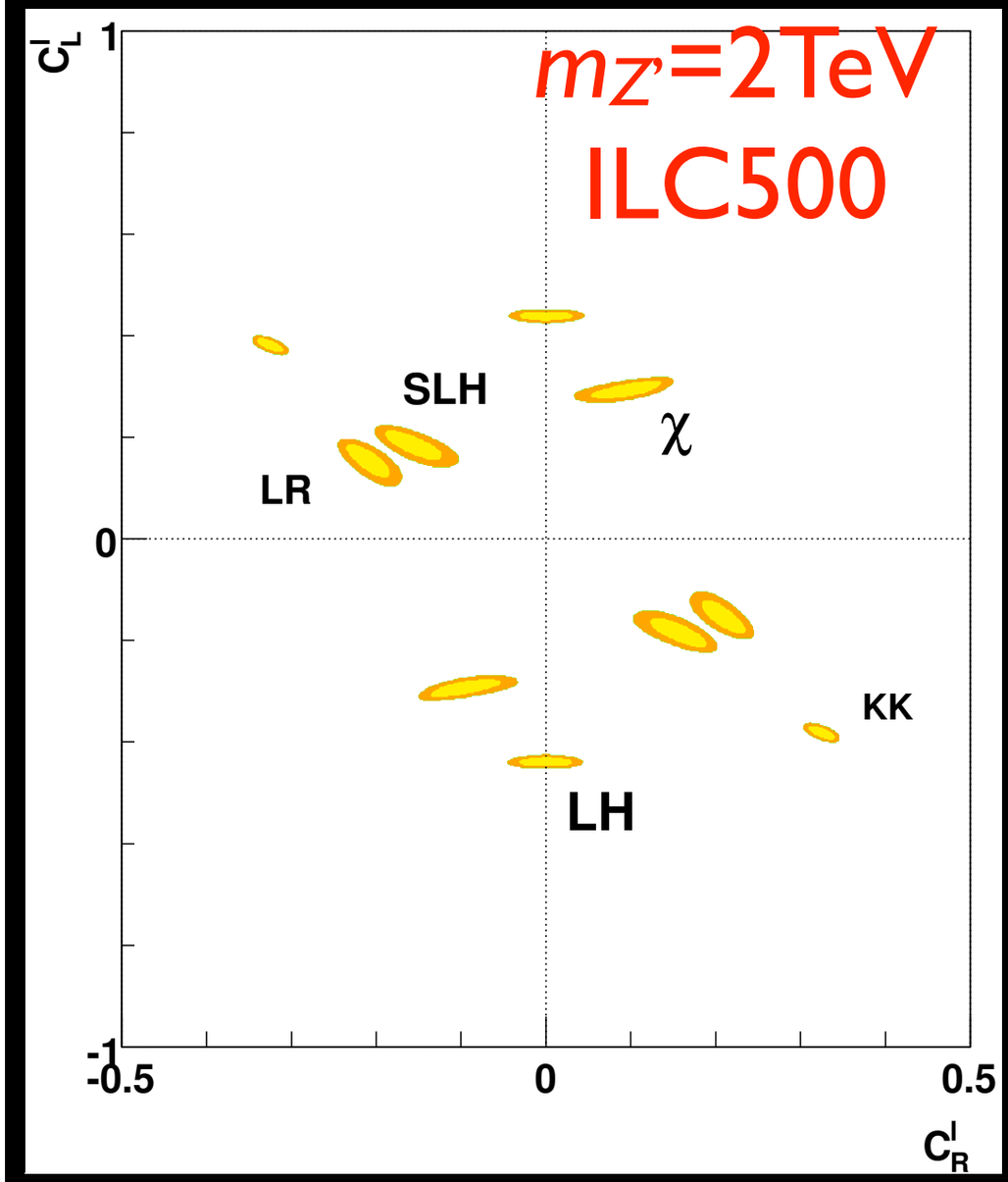
1. precision measurements of neutral current (*i.e.* polarized *e*+*d*) predicted m_W, m_Z
2. UA1/UA2 discovered W/Z particles
3. LEP/SLC *nailed* the gauge sector
1. precision measurements of W and Z (*i.e.* LEP/SLC + Tevatron) predicted m_H
2. LHC discovered *a Higgs particle*
3. LC *nails* the Higgs sector?
1. precision measurements at LC predict ???

a new gauge boson

HL-LHC

ILC



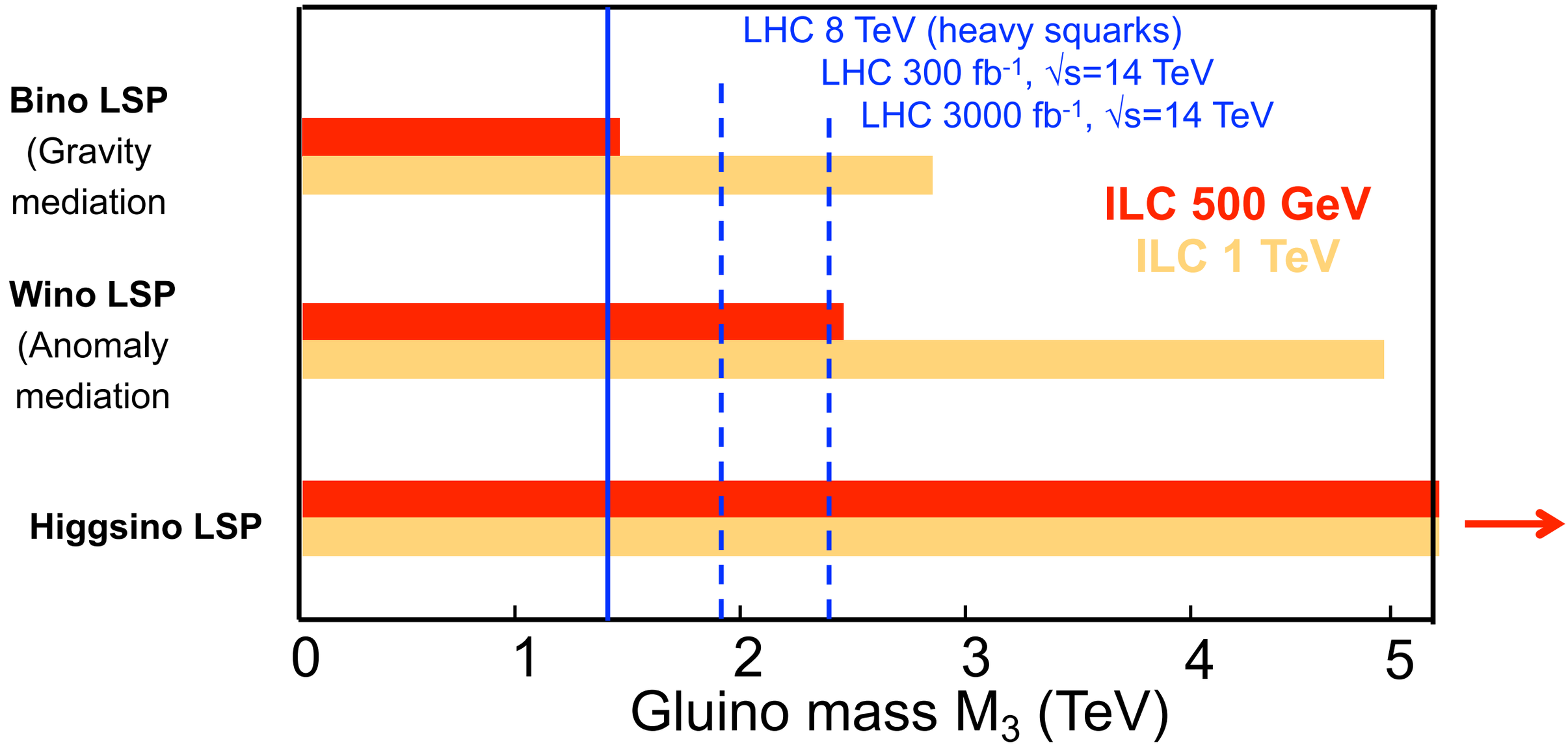


Sensitivity to SUSY

Gluino search at LHC

Chargino/Neutralino search at ILC

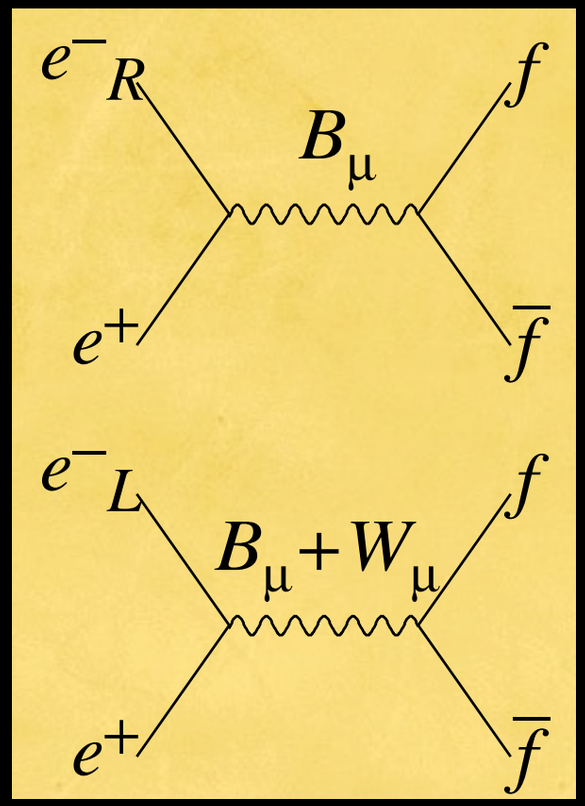
→ Comparison assuming gaugino mass relations



* Assumptions: MSUGRA/GMSB relation $M_1 : M_2 : M_3 = 1 : 2 : 6$; AMSB relation $M_1 : M_2 : M_3 = 3.3 : 1 : 10.5$

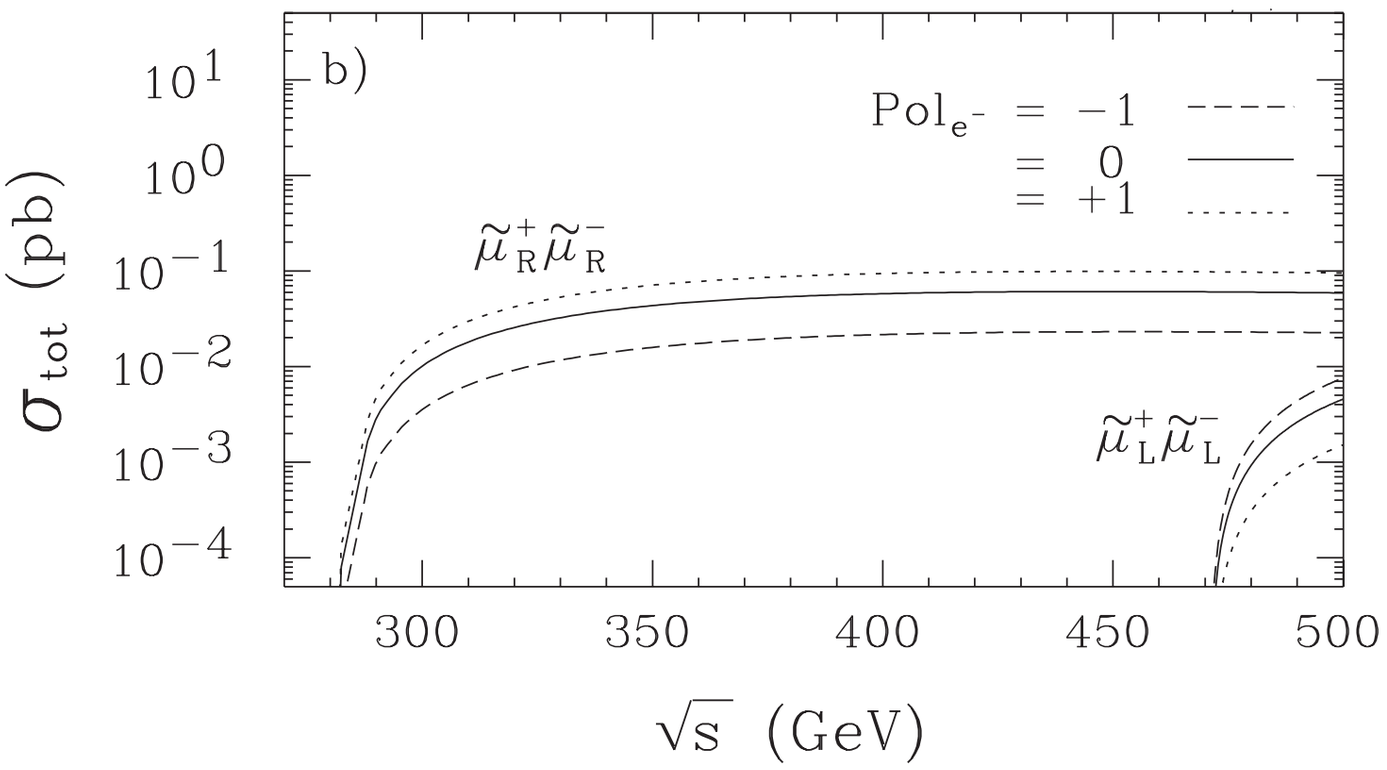
once new particle found

- Use polarized electron beam
- can ignore $m_Z^2 \ll s$
- e_R couples only to B_μ
- e_L couples to $B_\mu + W_\mu^0$
- can determine quantum #s



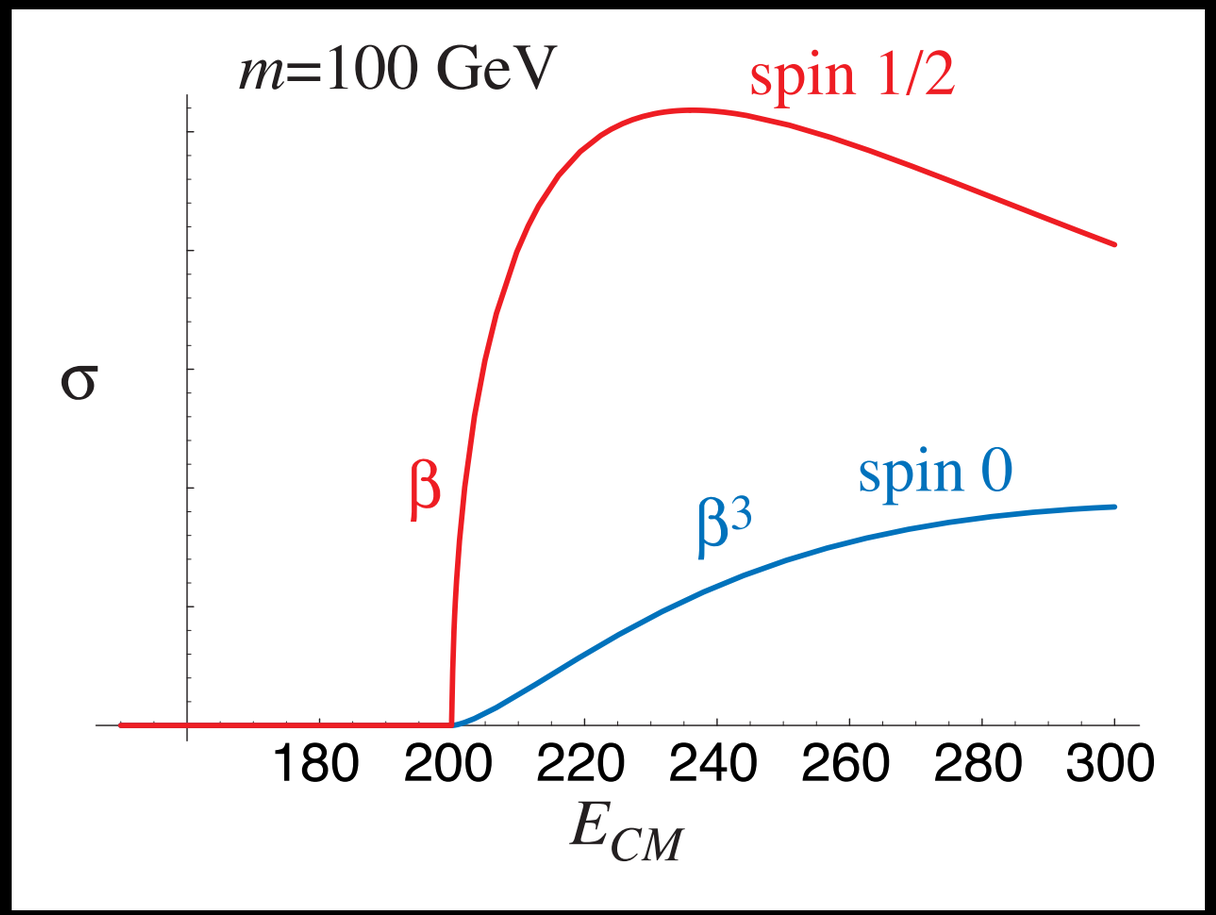
$\propto (g'^2 Y_f)^2$

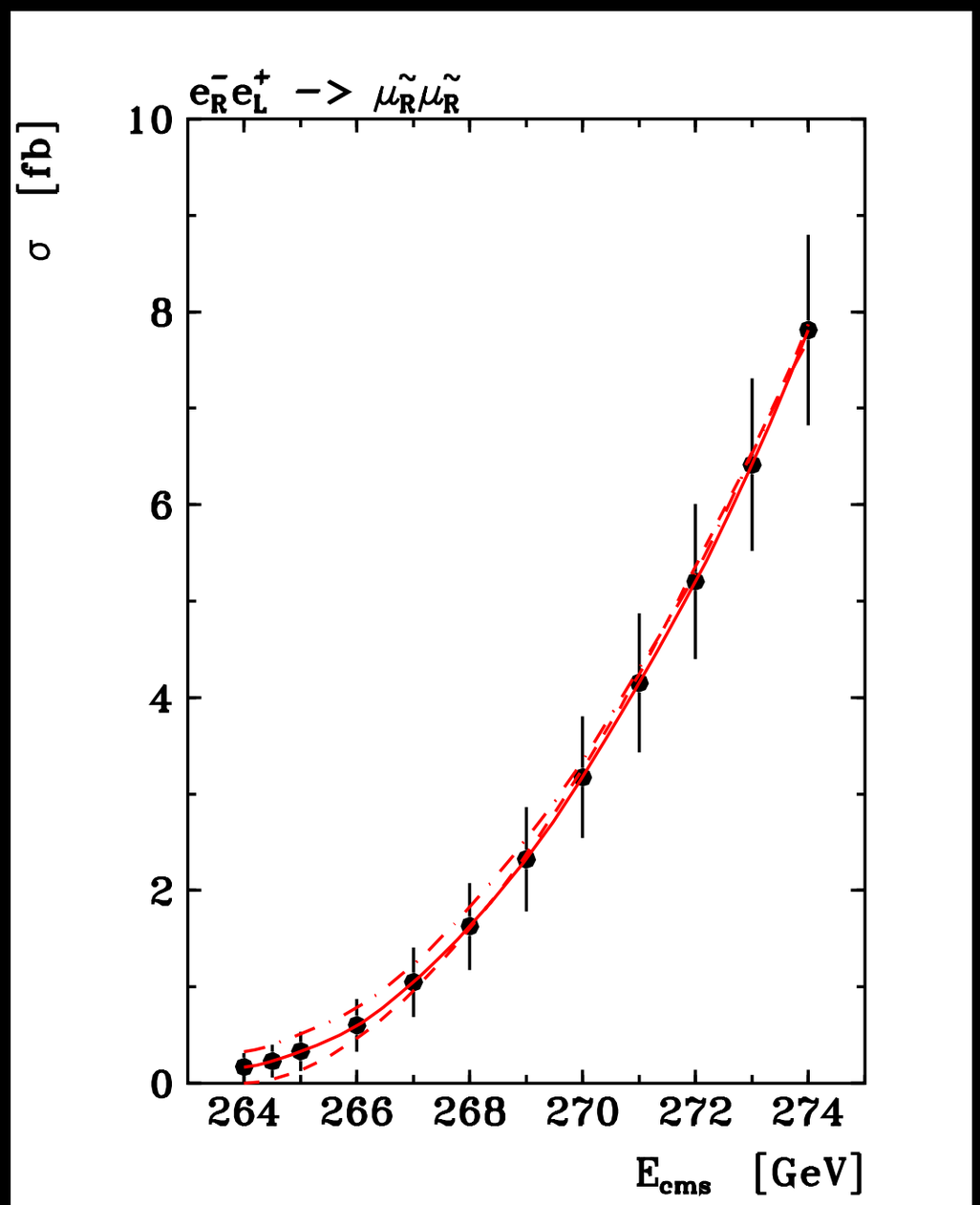
$\propto (g'^2 Y_f + g^2 I_{3f})^2$



Spin

- threshold behavior
  non-relativistic limit: L, S
  separately conserved
- $\sigma \propto \beta^{2L+1}$





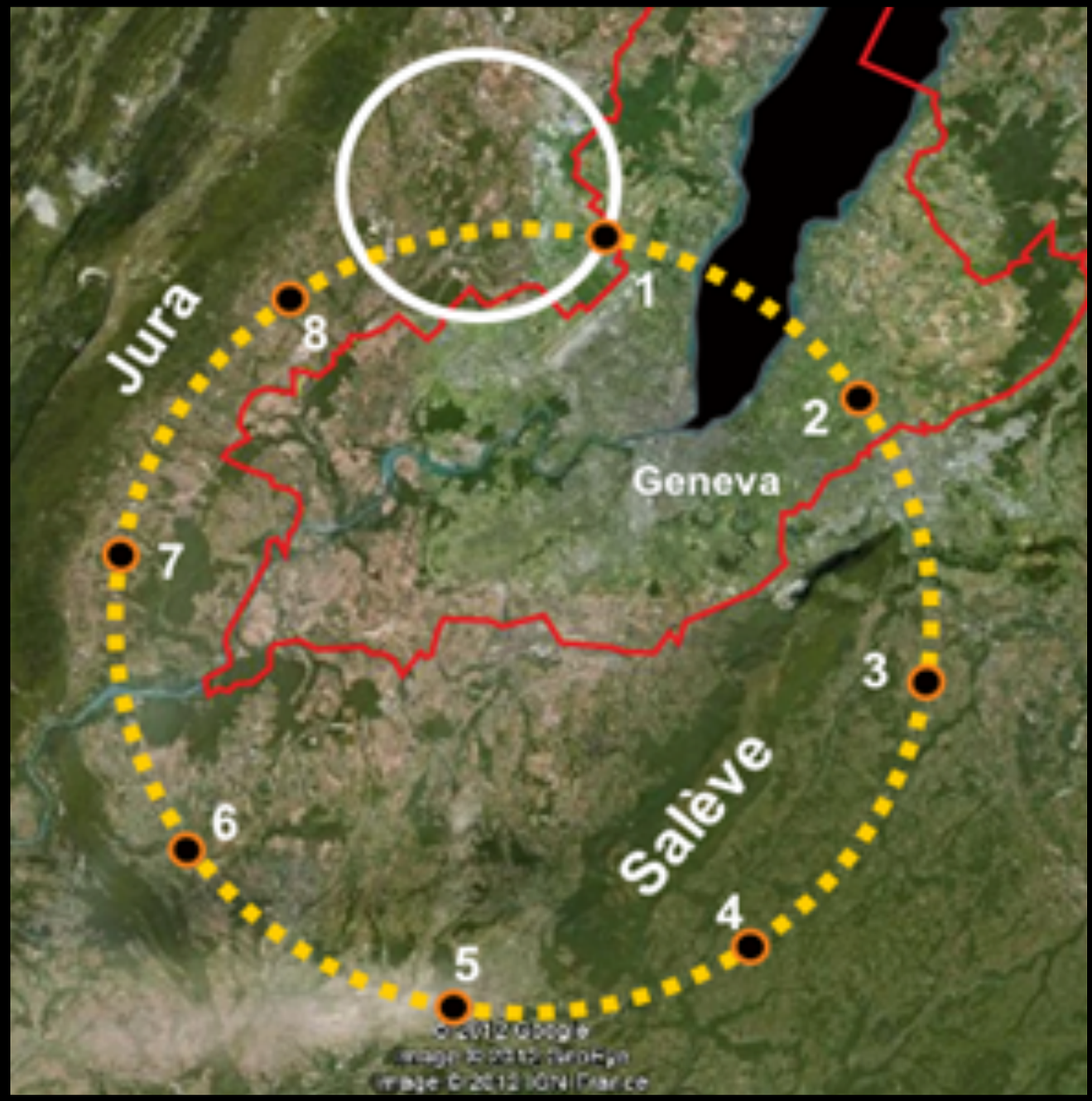
$m_{\tilde{\mu}} = 132.0 \pm 0.09$ GeV

$m_{\tilde{\chi}^0} = 71.9 \pm 0.05$ GeV

Competition?

higher energies?

- We believe we should keep aiming at higher energies
- *100 TeV pp would be great!*
- growing excitement in the community
- but no concrete argument for the energy scale
- exploration



Lepton collider key parameters

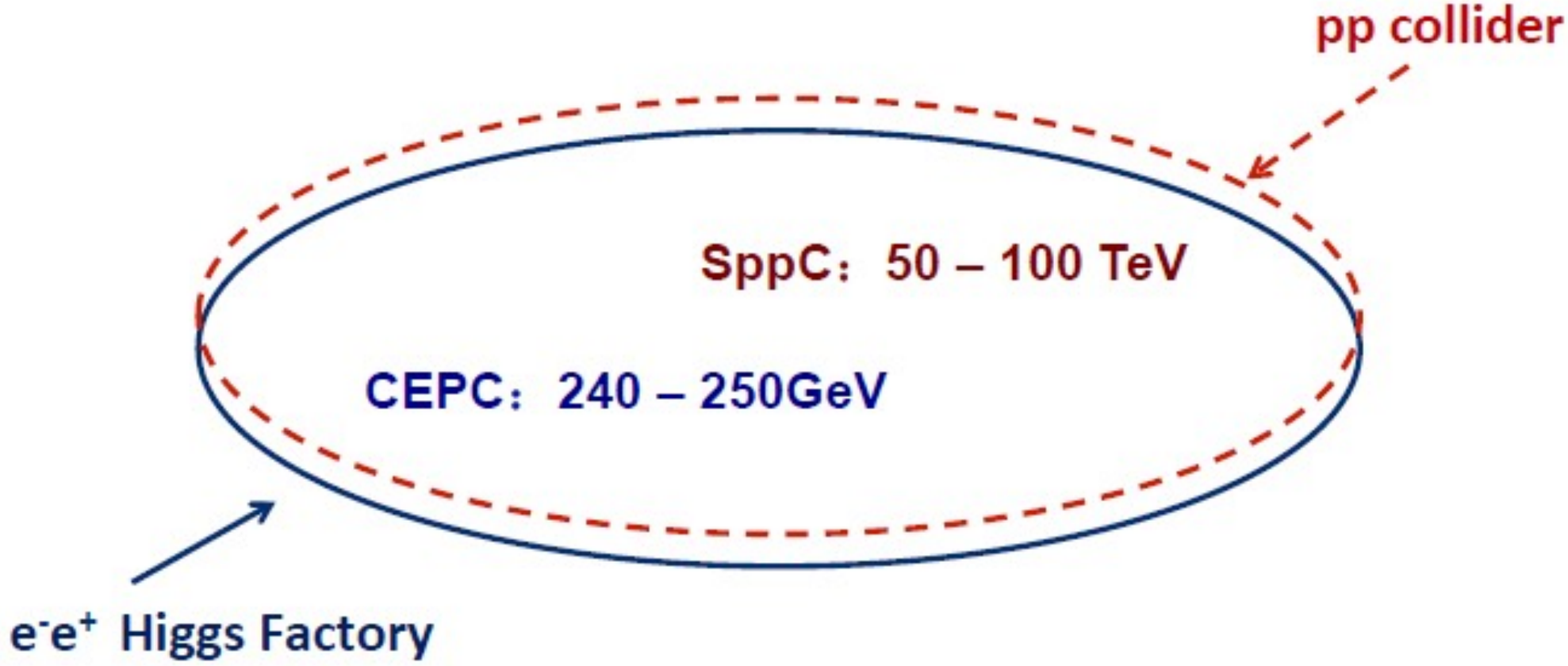
parameter	FCC-ee			CEPC	LEP2
energy/beam [GeV]	**45**	**120**	**175**	**120**	105
bunches/beam	13000-60000	500-1400	51- 98	50	4
beam current [mA]	1450	30	6.6	16.6	3
luminosity/IP x 10^{34} $cm^{-2}s^{-1}$	**21 - 280**	**5 - 11**	**1.5 - 2.6**	**2.0**	0.0012
energy loss/turn [GeV]	0.03	1.67	7.55	3.1	3.34
synchrotron power [MW]	100			103	22
RF voltage [GV]	0.2-2.5	3.6-5.5	11	6.9	3.5

FCC-ee: 2 separate rings **CEPC baseline: single beam pipe like LEP**

Dependency FCC-ee: crab-waist vs. baseline optics and 2 vs. 4 IPs

What is CEPC+SppC ?

- A CEPC (phase I) + SppC (phase II) was proposed in IHEP, Sept. 2012



Qin Qing

中国科学院高能物理研究所
Institute of High Energy Physics

comparison

	ILC	FCCee	CEPC
lumi (250) 10^{34}	0.75 (x2)	6	2.0
lumi (350) 10^{34}	1.0 (x2)	1.6	0
lumi (500) 10^{34}	1.8 (x2)	0	0
polarization	80%/30%	0/0	0/0
max energy	1 TeV	350 GeV	240 GeV
power (MW)	128	280	
cost	$8B	€8B?	

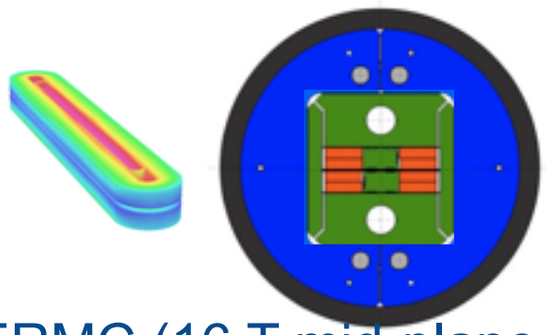
time table for decisions

- CEPC pre-CDR; R&D proposal of 1B RMB submitted for the coming 5-year plan
  - will know by mid 2016?
  - FCCee will have CDR by 2018
    - to be discussed by next Strategy update
    - FCCpp won't be ready for discussions
  - ILC has TDR
    - committees in Japan will finish this year
    - government negotiations for 2–3 years

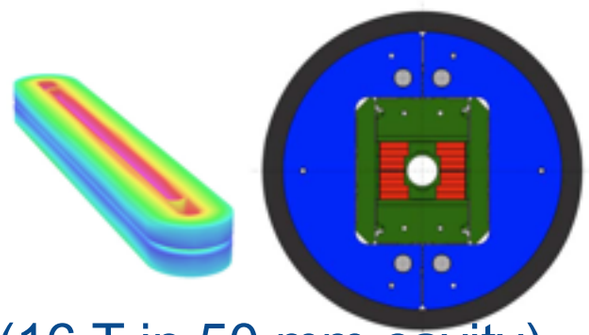
FCC magnet technology program

Main Milestones of the FCC Magnets Technologies

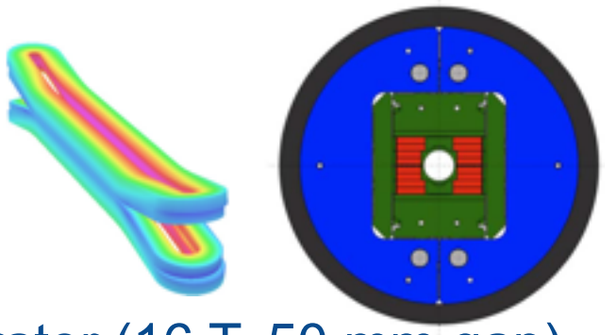
Milestone	Description	15	2016		2017		2018		2019		2020		21
M0	High J_c wire development with industry	■	■	■	■	■	■	■	■	■	■	■	■
M1	Supporting wound conductor test program	■	■	■	■	■	■	■	■	■	■	■	■
M2	Design & manufacture 16T ERMC with existing wire	■	■	■	■								
M3	Design & manufacture 16 T RMM with existing wire		■	■	■	■							
M4	Procurement of 35 km enhanced wire			■	■	■							
M5	Design & manufacture 16T demonstrator magnet			■	■	■	■	■					
M6	Procurement 70 km of enhanced high J_c wire				■	■	■	■	■				
M7	EuroCirCol design 16T accelerator quality model	■	■	■	■	■	■	■	■				
	Manufacture and test of the 16 T EuroCirCol model									■	■	■	■



ERMC (16 T mid-plane field)

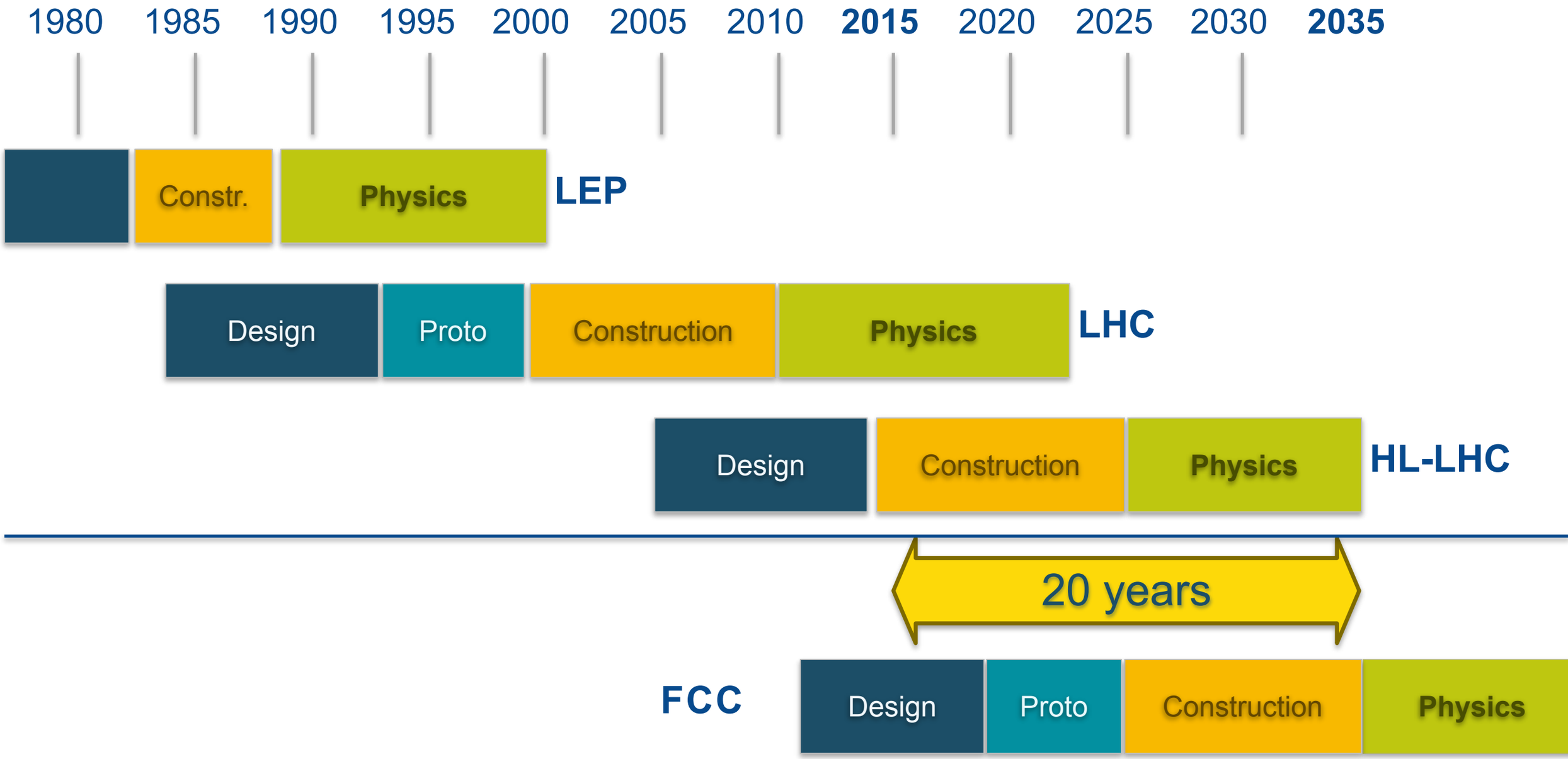


RMM (16 T in 50 mm cavity)

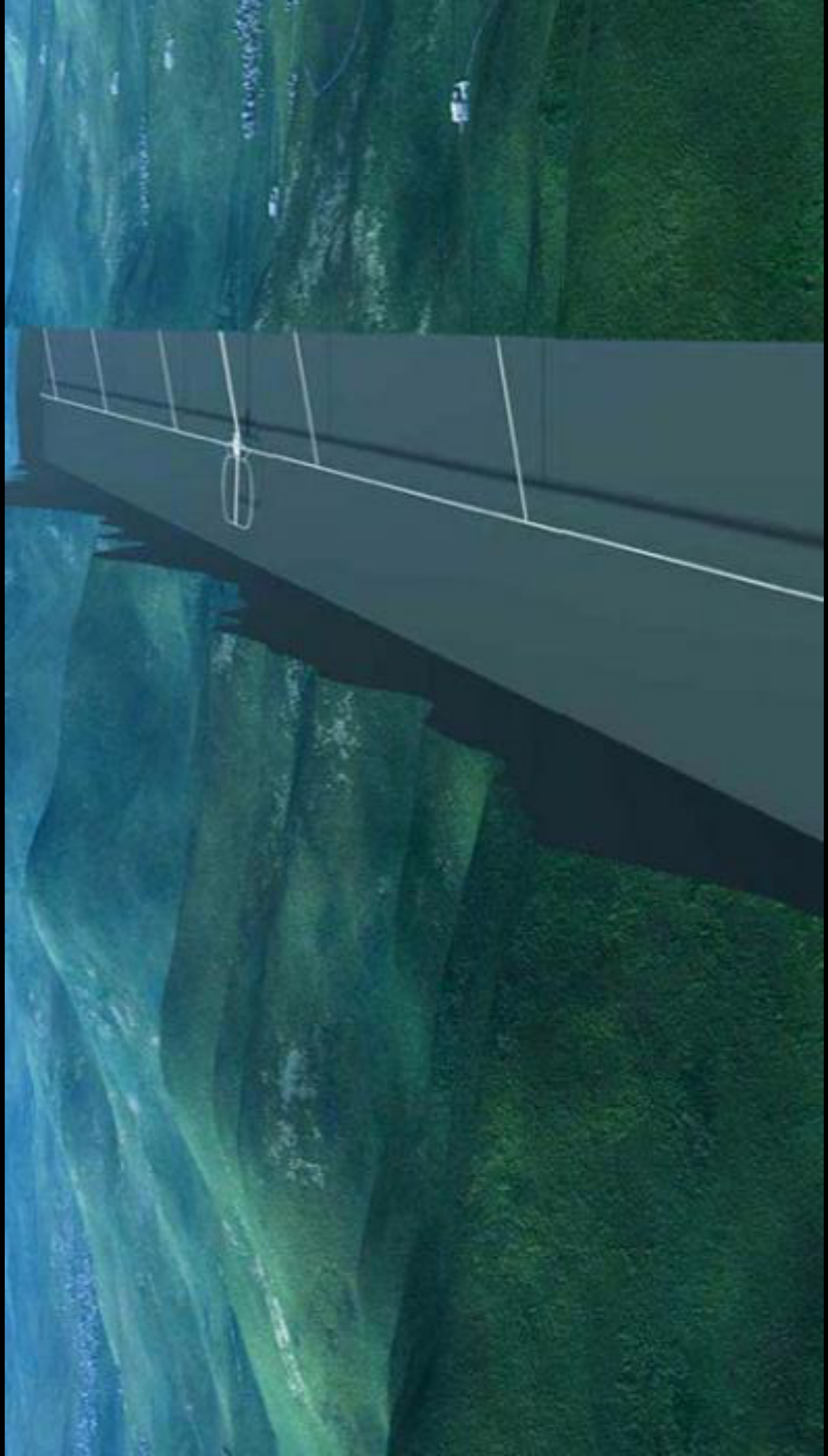


Demonstrator (16 T, 50 mm gap)

CERN Circular Colliders and FCC

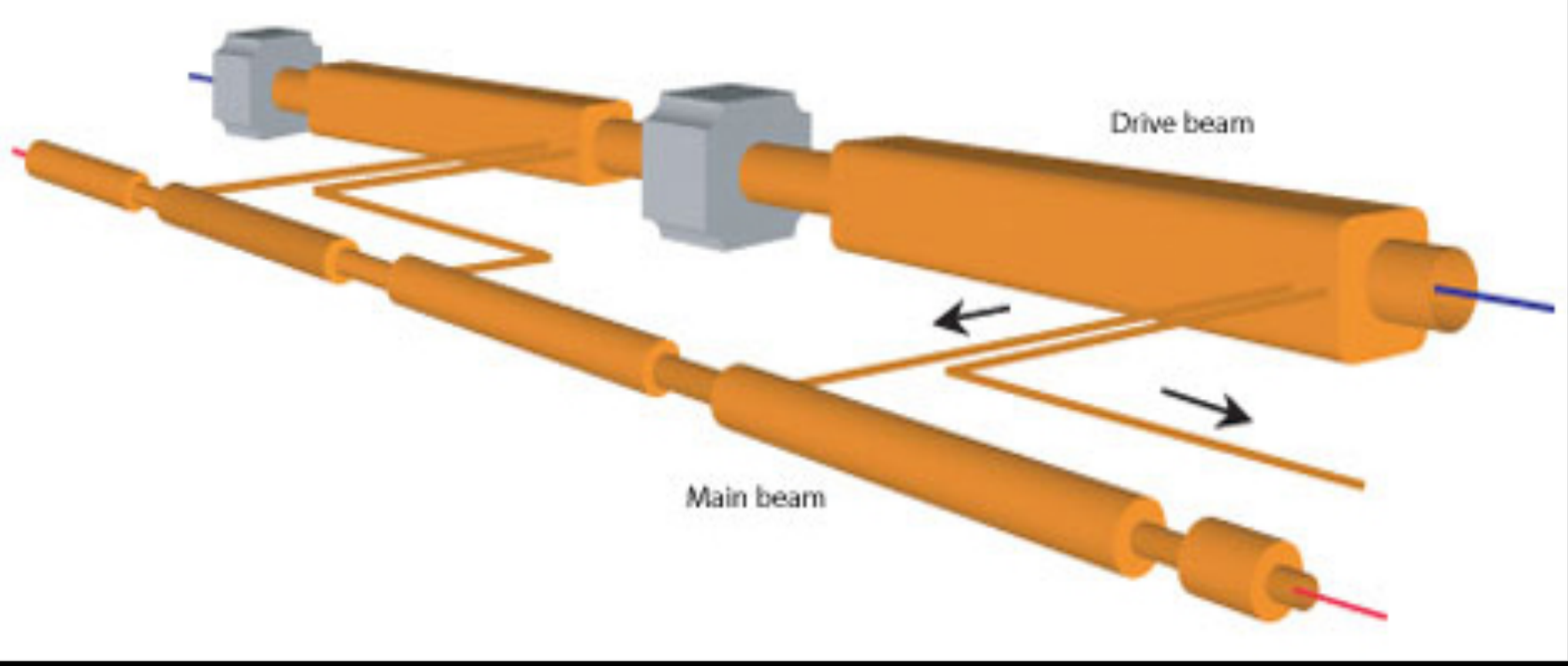


CDR by end 2018 for strategy upade

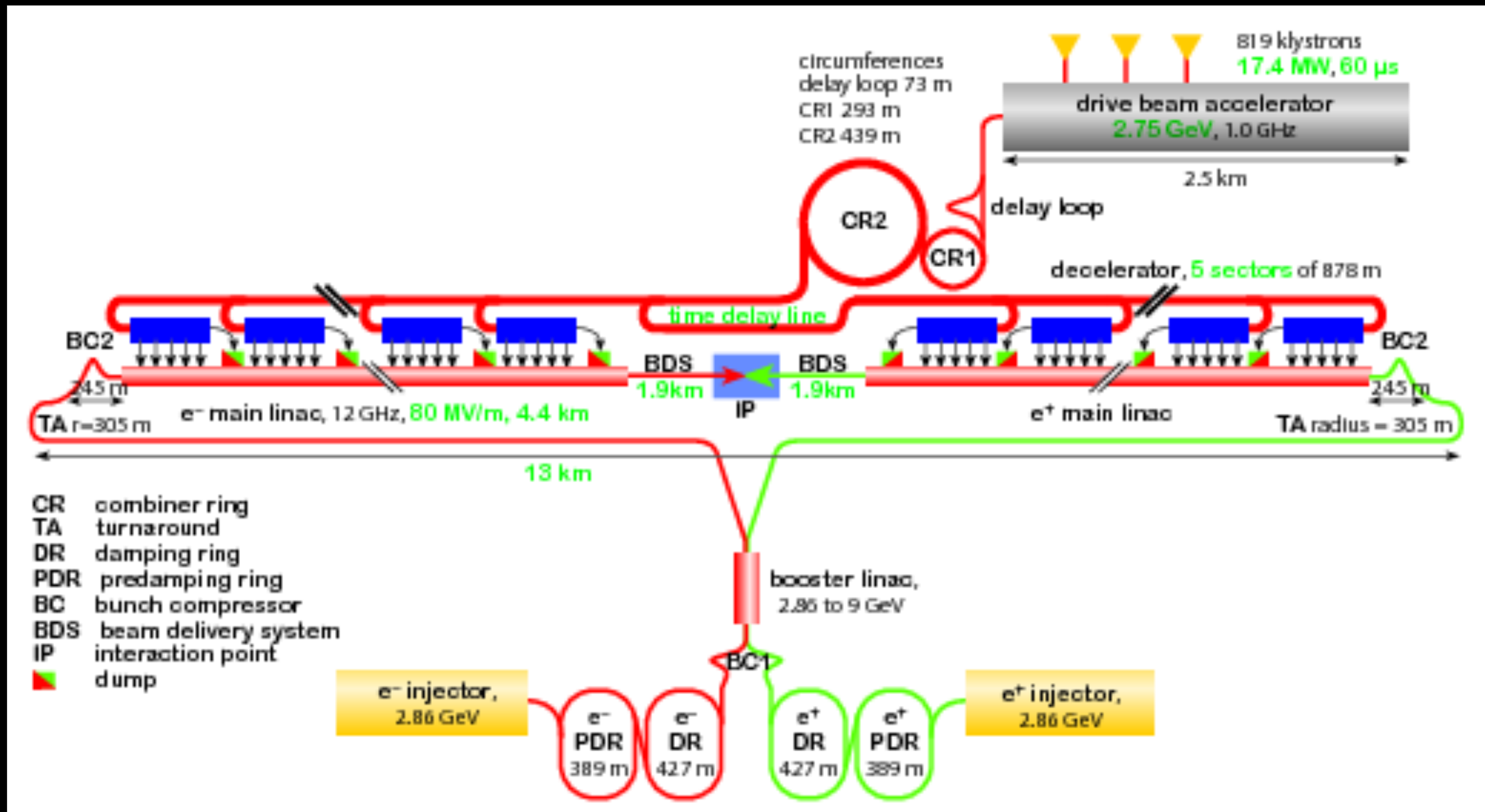


future upgrades

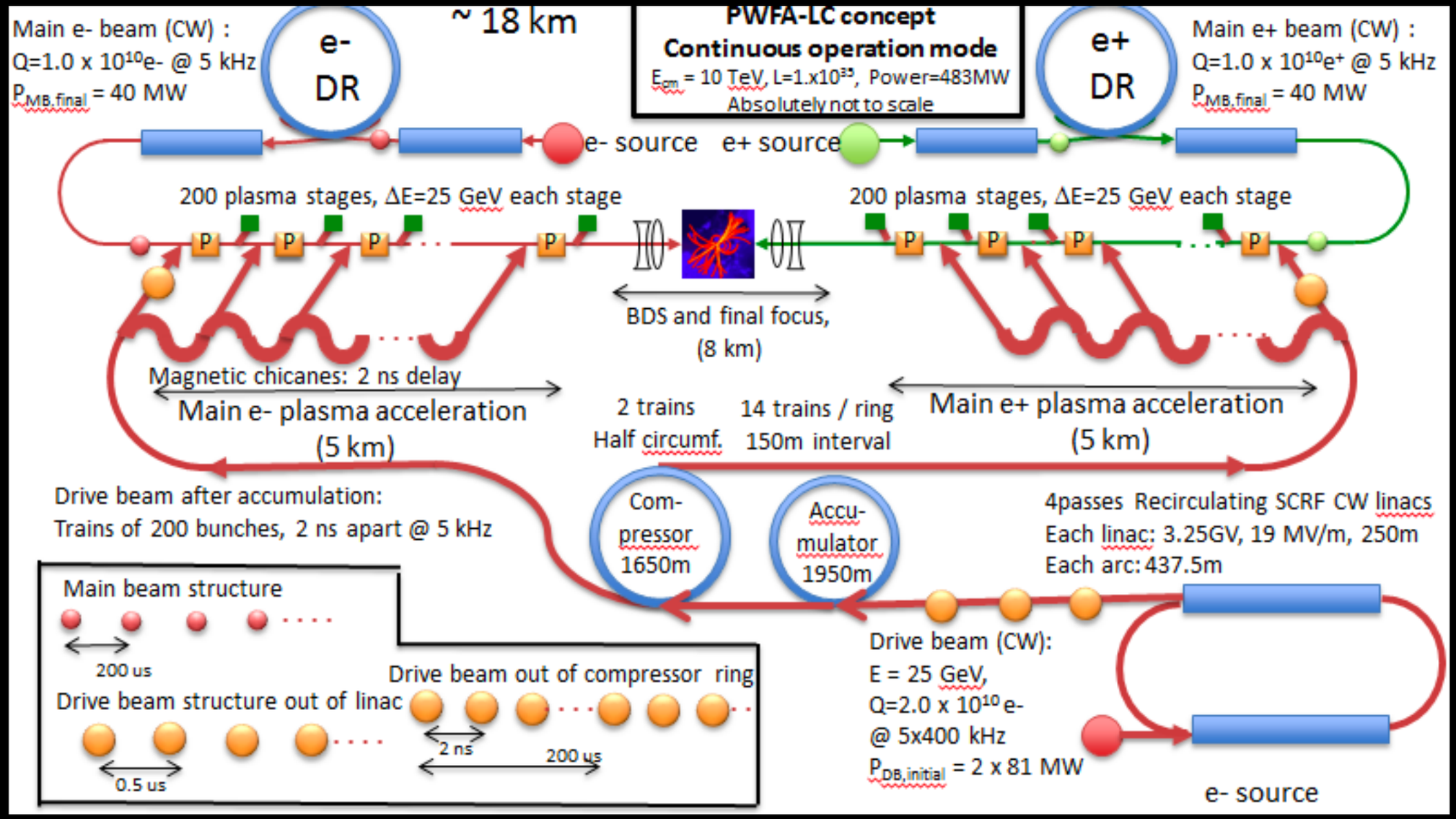
ILC	40MV/m	1TeV
CLIC	100MV/m	3TeV
PWFA	1GV/m	30TeV


Drive beam
Main beam

CLIC


circumferences
delay loop 73 m
CR1 293 m
CR2 439 m
819 klystrons
17.4 MW, 60 μs
drive beam accelerator
2.75 GeV, 1.0 GHz
2.5 km
delay loop
CR2
CR1
decelerator, 5 sectors of 878 m
time delay line
BC2
245 m
TA r=305 m
BDS
1.9km
IP
BDS
1.9km
e⁻ main linac, 12 GHz, 80 MV/m, 4.4 km
e⁺ main linac
BC2
245 m
TA radius = 305 m
13 km
CR combiner ring
TA turnaround
DR damping ring
PDR predamping ring
BC bunch compressor
BDS beam delivery system
IP interaction point
dump
booster linac,
2.86 to 9 GeV
BC1
e⁻ injector,
2.86 GeV
e⁻ PDR 389 m
e⁻ DR 427 m
e⁺ DR 427 m
e⁺ PDR 389 m
e⁺ injector,
2.86 GeV

Plasma Wakefield

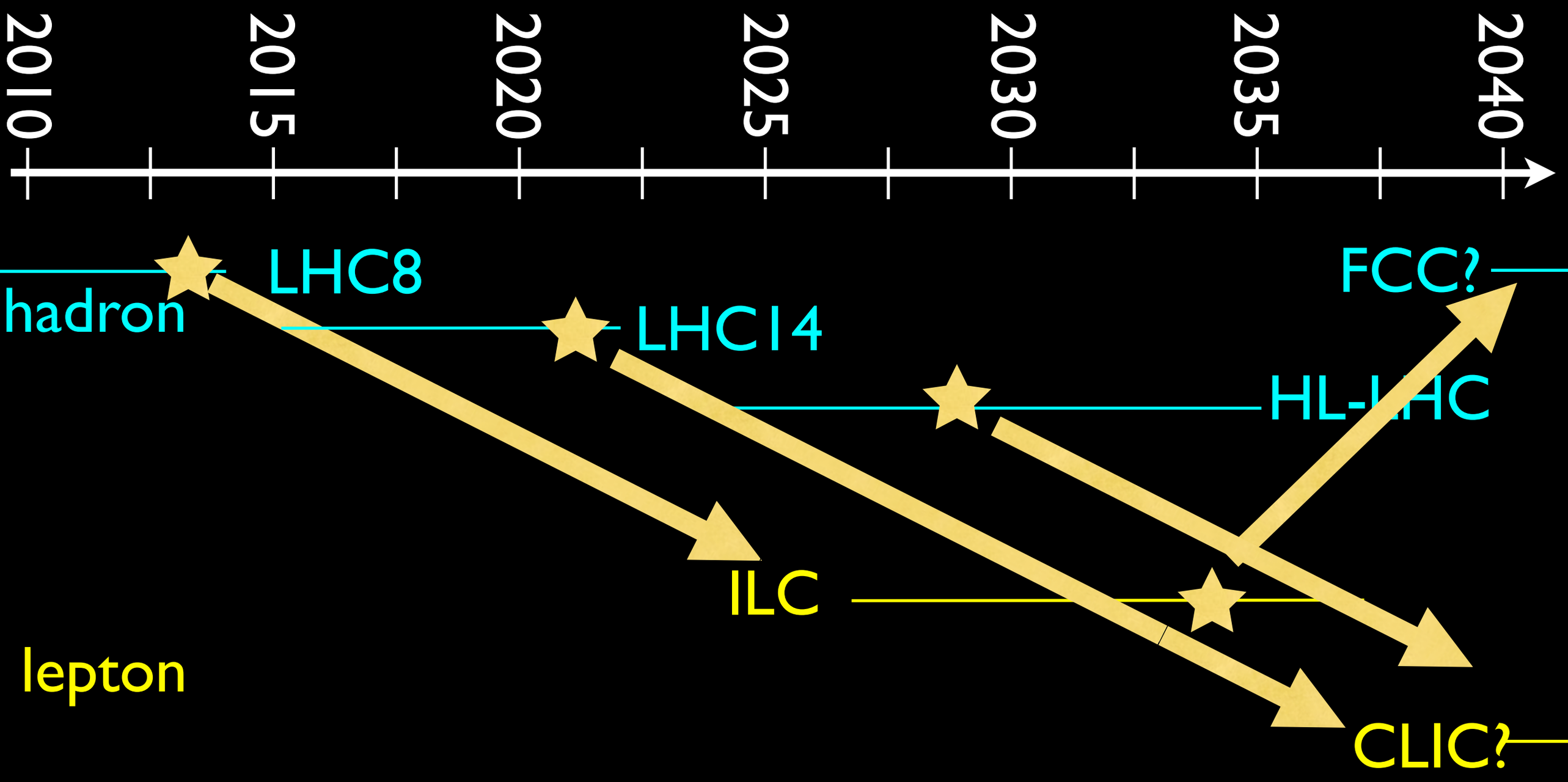


Delahaye et al, IPAC 2014

only machine

- If we require
  - guaranteed solid physics case
  - possible discovery in new physics beyond LHC
  - potential upgrade into future dream machine(s)
- ILC is the only immediate option

timeline?


2010
2015
2020
2025
2030
2035
2040
hadron
LHC8
LHC14
HL-LHC
FCC?
lepton
ILC
CLIC?

Stay Firm!