LFC19: Strong dynamics for physics within and beyond the Standard Model at LHC and Future Colliders - 9-13 September 2019, ECT* - Villa Tambosi

Future perspectives in HEP

in the light of the European Particle Physics Strategy Update 2020 (EPPSU 2020)

➜ planning a future large-scale facility in Europe in a global context

INFN Roma

Barbara Mele

* a very exciting (and challenging) time for particle physics !

* quite a few great options available !

* beautiful reviews on first LFC19 day

* here a few (personal) remarks
  (benefitting also from Granada material…)

WHERE ARE WE ?

THEORY + EXP'S

SM works !

nevertheless…

great (although hazy) expectations
for new BSM phenomena at colliders !

✱ two kinds of issues with the SM :

✱ existence of "external" phenomena :

(quantum ?) Gravity + empirical evidences :

- Dark Matter
- Barion asymmetry
- neutrino masses
- . . .

✱ "internal" poor consistency :

mainly connected to the EWSB/Higgs sector

what's so tricky about the Higgs

$$\mathcal{L}_{\text{Higgs}} = (D_\mu\phi)^\dagger(D^\mu\phi) - V(\phi^\dagger\phi) - \bar{\psi}_L\Gamma\psi_R\phi - \bar{\psi}_R\Gamma^\dagger\psi_L\phi^\dagger$$

$$V(\phi^\dagger\phi) = -\mu^2\phi^\dagger\phi + \frac{1}{2}\lambda(\phi^\dagger\phi)^2$$

$$m_H^2 = 2\mu^2 = 2\lambda v^2$$

- the only "fundamental" scalar particle (microscopic interpretation ?)
- not protected by symmetries (the less constrained SM sector):
  - naturalness problem : $m_H \sim g \times \Lambda_{cutoff}$
- many different couplings all fixed by masses (?)
  - proliferation of parameters historically leads to breakdown in TH models
- fermion masses/Yukawa's hierarchy (?)
  - have neutrinos a special role ?!!!
- λ determines shape and evolution of Higgs potential → cosmology !

today four paths to advance in HEP at colliders:

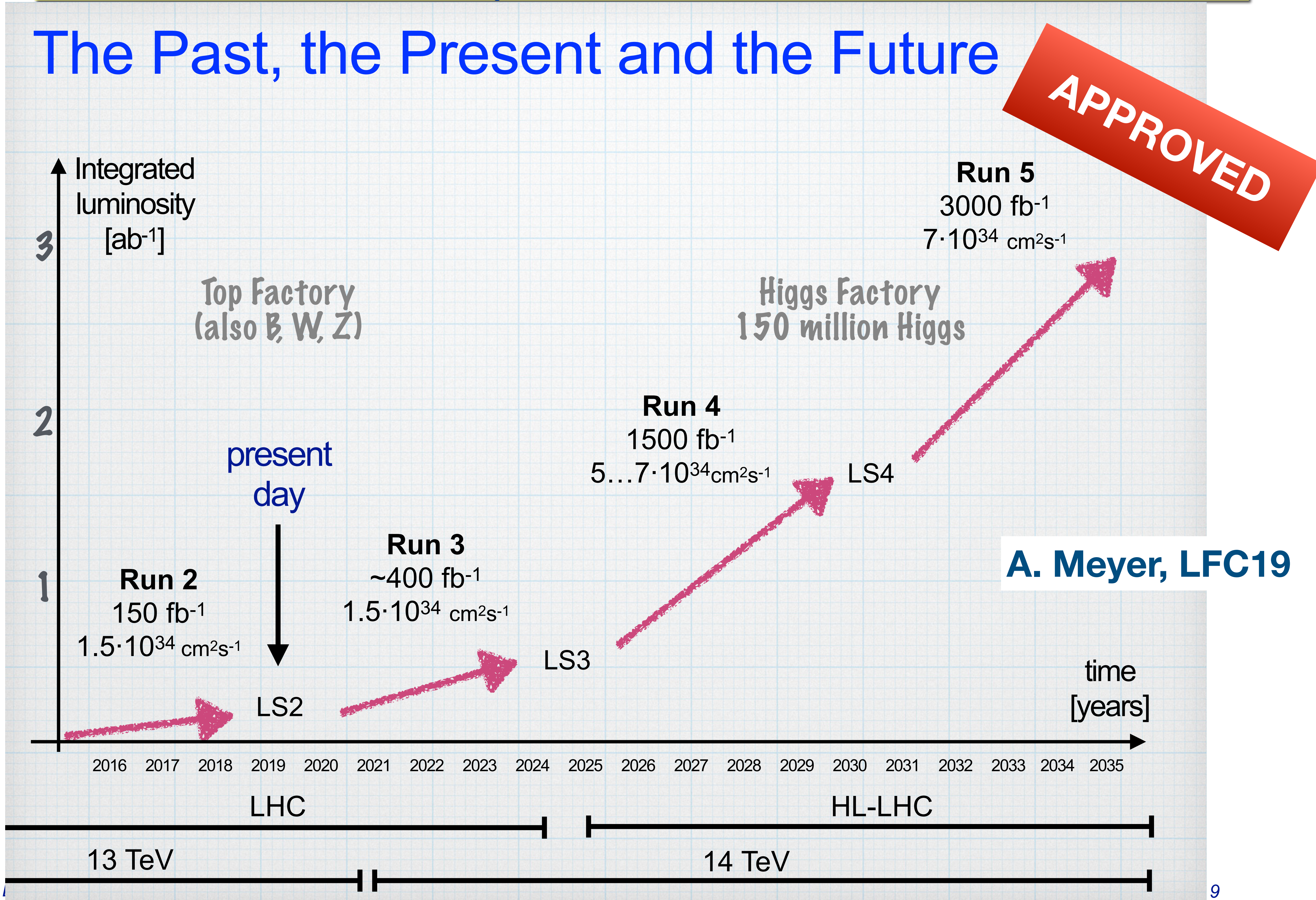
- ✱ by exploring the characteristics of the Higgs sector and confirming/spoiling the SM picture
  (primary relevance since the Higgs sector is so critical !)
- ✱ by searching for new heavy states coupled to the SM,
  [acting as a cut-off for the SM
  possibly solving the naturalness issues and/or
  non-SM phenomena (dark matter, …)]
- ✱ by exploring $\Lambda >> o(1\text{TeV})$ indirect effects through high-accuracy studies of SM x-sections/distributions and searches for rare processes (EFT parametrization)
- ✱ by looking for new "DARK" states (i.e.,uncoupled to SM at tree level) either in production or/and heavy-state (H,t…) decays (elusive signatures, may be long-lived p.les)

today four paths to advance in HEP at colliders:

* Higgs
* new particles
* indirect effects
* "Dark" signals

* every single method is of fundamental importance to make progress !
* e+e- colliders great opportunities in all sectors (cleanness [→ model independence], accuracy…)

our boundary condition : HL-LHC



A. Meyer, LFC19

WHAT NEXT ???

EPPSU process ongoing…

- to conclude with approval of strategy update by CERN Council in May 2020
- Open Symposium took place in Granada in May 2019
- Physics Prepatory Group (PPG) currently drafting the "Briefing Book" (~100 pages) to be submitted to the European Strategy Group (ESG) later this month
- on this basis, should define an overall long-term scenario in the global landscape…

EPPSU 2020 timeline

2017 | **2018** | **2019** | **2020**

organisation & input preparation by community

✓ **Jan.2018**
Call for proposals for venues for Open Symposium and Strategy Drafting Session

✓ **Febr.2018**
Call for scientific input

✓ **March.2018**
Call for nominations of PPG & ESG members

✓ **June 14,2018**
Council decision on venues and dates

✓ **Sept 27,2018**
Council launches the Strategy Update process and establishes the PPG and ESG

consultation & consensus building

✓ **Dec 18.2018**
Closing submission of community input

✓ **May 13-16,2019**
Open Symposium
Granada, ES

Sept.2019
Physics Briefing Book available

Jan 20-24,2020
Strategy Update Drafting Session
Bad Honnef, GE

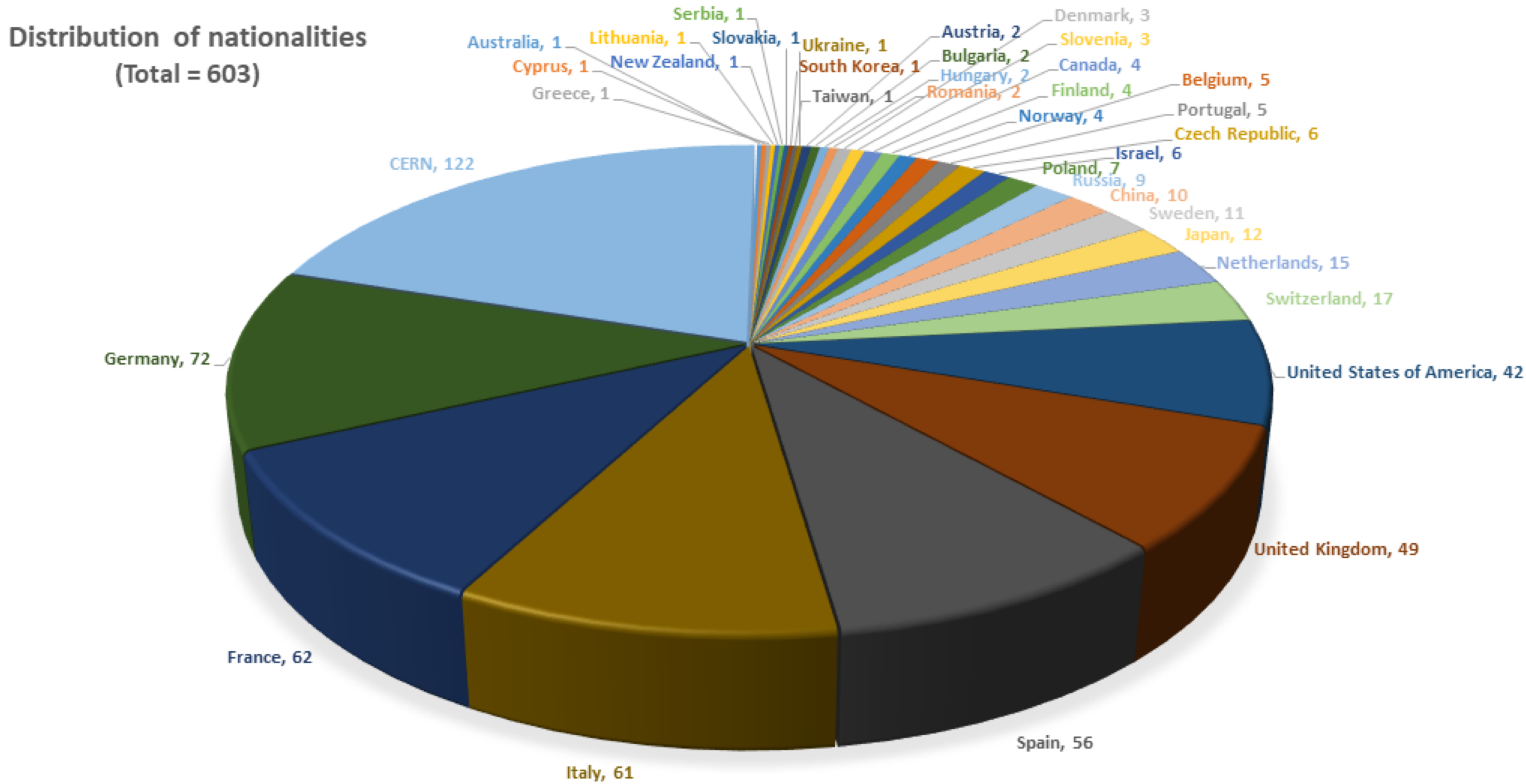
March.2020
Strategy Update to be submitted to Council

May.2020
Council to approve Strategy Update

ECFA/EPS-HEPP session during EPS2019 in Ghent 13/07 afternoon

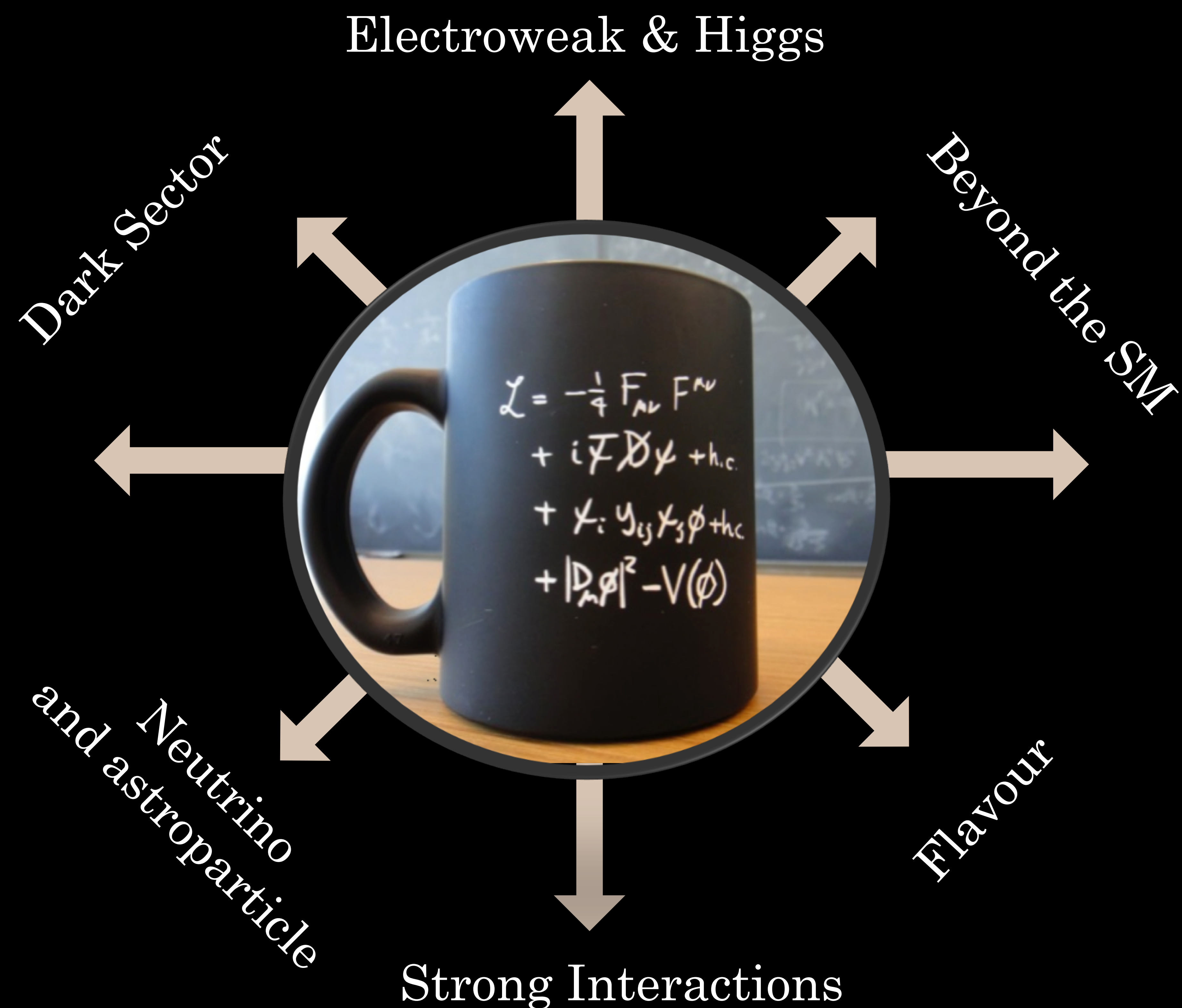
Physics results appearing after May 2019 will be taken into account in the process

[~600] Participants in Granada



from Vedrana Zorica

The Granada physics themes



J. D'Hondt, LFC19

→ **plus many many other aspects covered in Granada…**

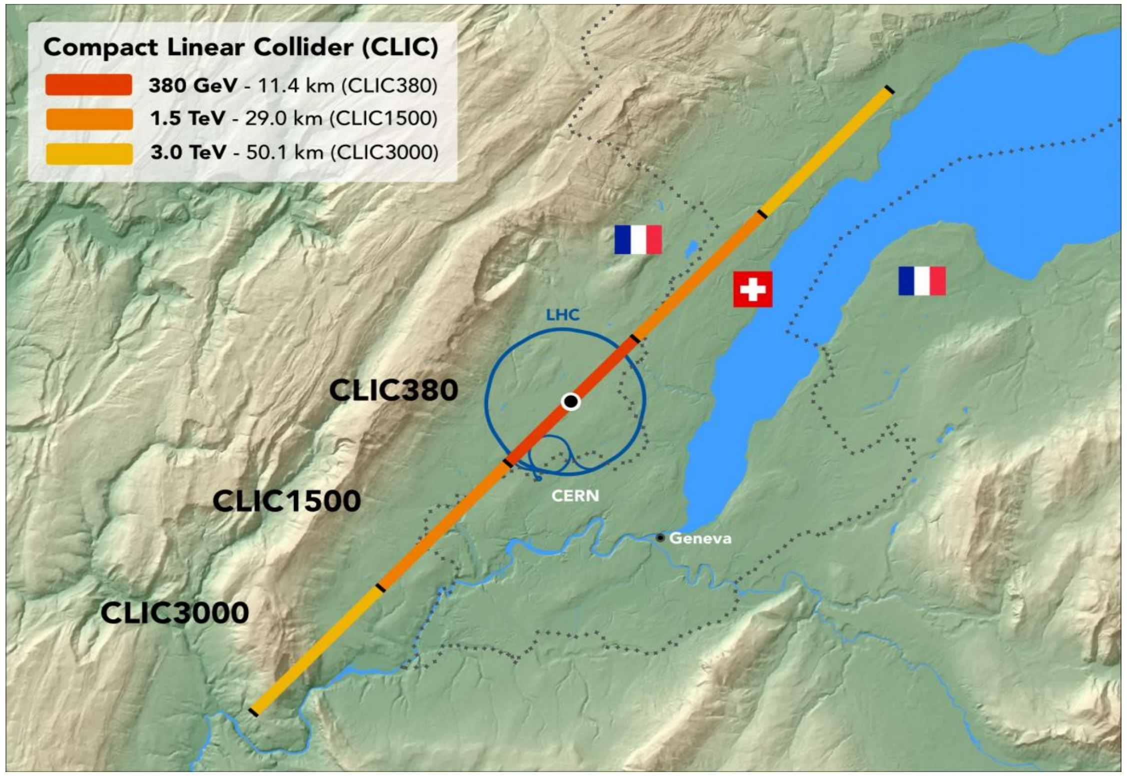
how to assess a large-scale project

[project ==> beam species, energy, lumi, technology]

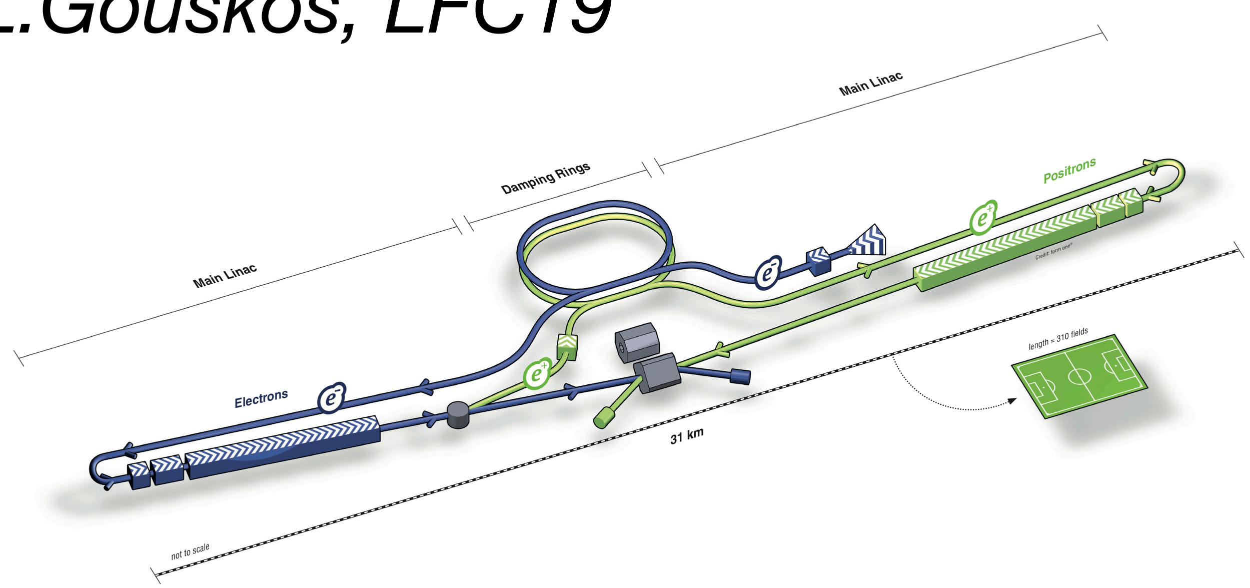
* Physics potential (direct, indirect)
* feasibility → maturity → technical risk
* innovation
* construction/operation costs (vs constrains from fund. agencies)
* power consumption
* start-up time
* total operation time (staging, expandibility)
* location vs infrastructures vs politics (global context !)
* HEP (both regional and global) community support
* fraction of present HEP community involved

Possible future colliders

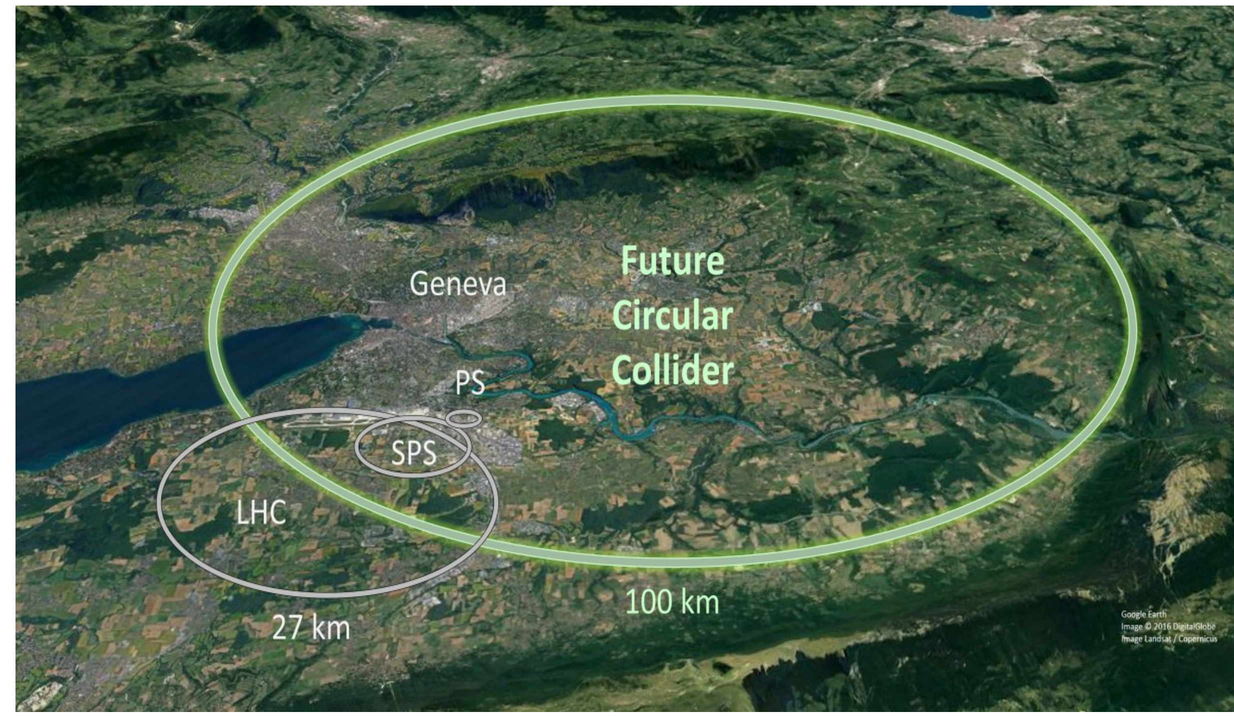
Linear (e^+e^-) colliders



L.Gouskos, LFC19

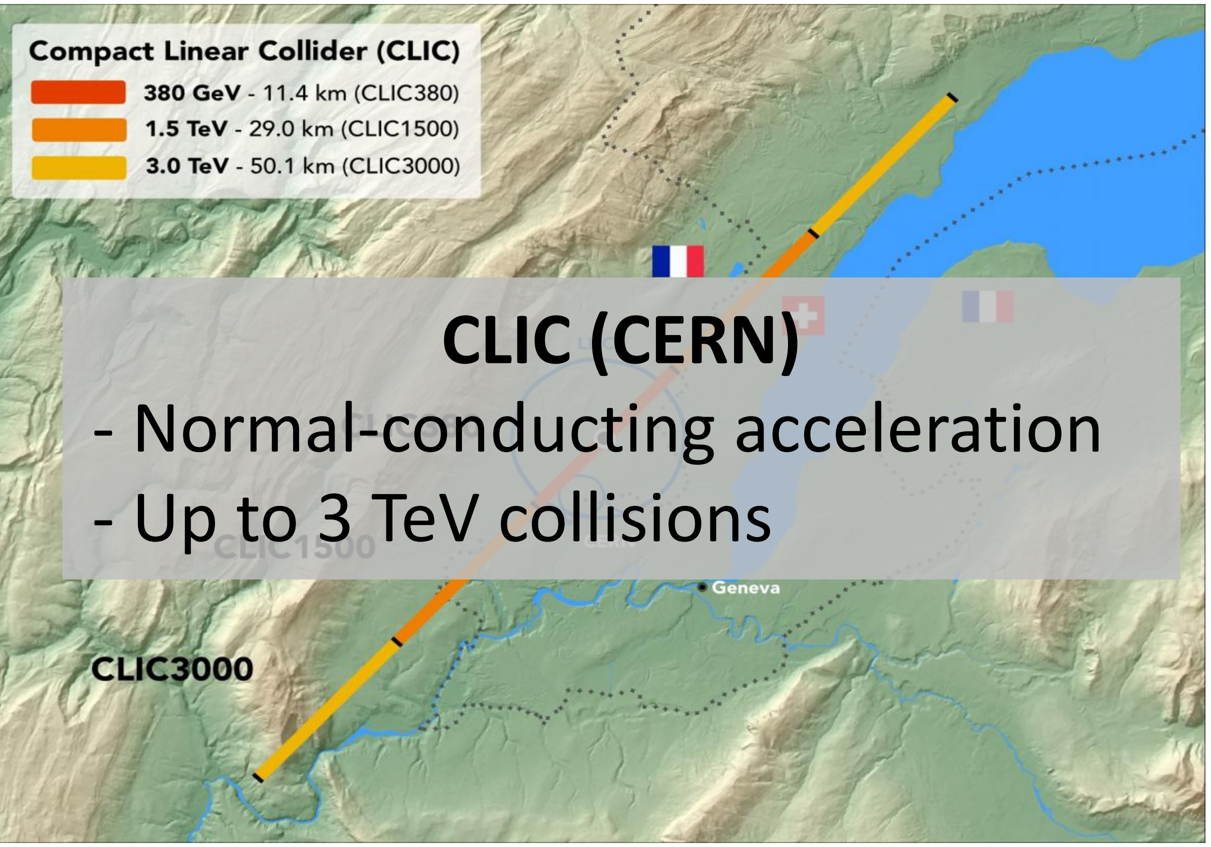


Circular (e^+e^-/hh) colliders



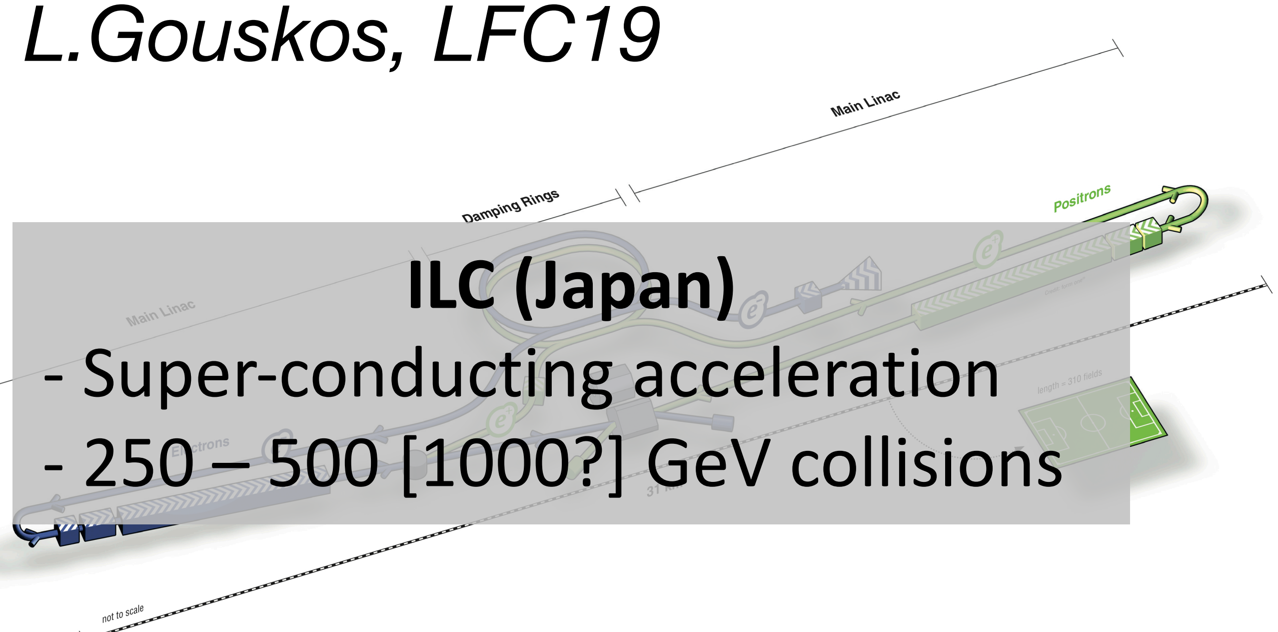
Possible future colliders

Linear (e^+e^-) colliders



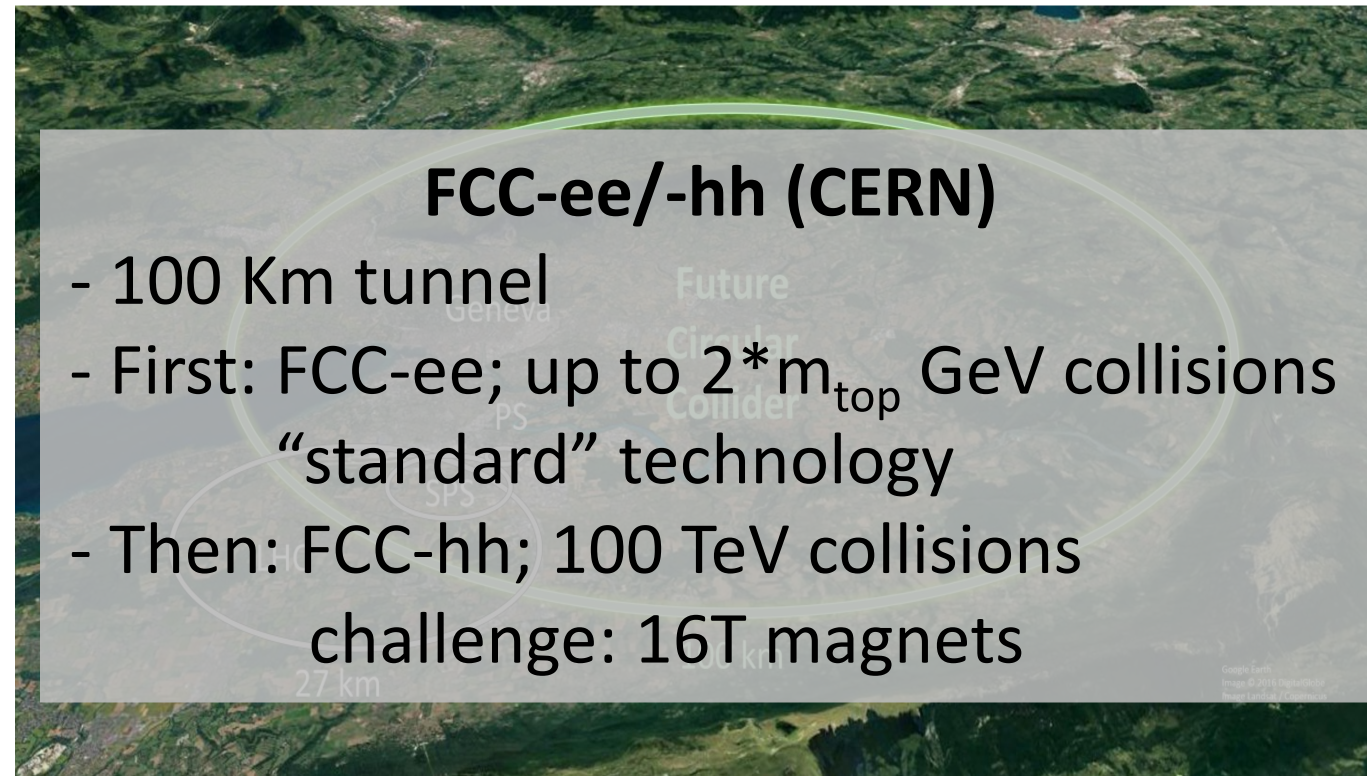
CLIC (CERN)
- Normal-conducting acceleration
- Up to 3 TeV collisions

L.Gouskos, LFC19



ILC (Japan)
- Super-conducting acceleration
- 250 – 500 [1000?] GeV collisions

Circular (e^+e^-/hh) colliders



FCC-ee/-hh (CERN)
- 100 Km tunnel
- First: FCC-ee; up to $2*m_{top}$ GeV collisions
  "standard" technology
- Then: FCC-hh; 100 TeV collisions
  challenge: 16T magnets

CEPC/SppC (China)
- 100 Km tunnel
- Essentially an FCC-ee/ FCC-hh
- More conservative luminosity scenarios

LHC ➜ 150 MW, 4 GCHF

Project	Type	Energy [TeV]	Int. Lumi. [a^{-1}]	Oper. Time [y]	Power [MW]	Cost
ILC	ee	0.25	2	11	129 (upgr. 150-200)	4.8-5.3 GILCU + upgrade
		0.5	4	10	163 (204)	7.8 GILCU
		1.0			300	?
CLIC	ee	0.38	1	8	168	5.9 GCHF
		1.5	2.5	7	(370)	+5.1 GCHF
		3	5	8	(590)	+7.3 GCHF
CEPC	ee	0.091+0.16	16+2.6		149	5 G$
		0.24	5.6	7	266	
FCC-ee	ee	0.091+0.16	150+10	4+1	259	10.5 GCHF
		0.24	5	3	282	
		0.365 (+0.35)	1.5 (+0.2)	4 (+1)	340	+1.1 GCHF
LHeC	ep	60 / 7000	1	12	(+100)	1.75 GCHF
FCC-hh	pp	100	30	25	580 (550)	17 GCHF (+7 GCHF)
HE-LHC	pp	27	20	20		7.2 GCHF

post-Granada addition → FCC-NbTi...

Project	Type	Energy [TeV]	Int. Lumi. [a^{-1}]	Oper. Time [y]	Power [MW]	Cost
ILC	ee	0.25	2	11	129 (upgr. 150-200)	4.8-5.3 GILCU + upgrade
		0.5	4	10	163 (204)	7.98 GILCU
		1.0			300	?
CLIC	ee	0.38	1	8	168	5.9 GCHF
		1.5	2.5	7	(370)	+5.1 GCHF
		3	5	8	(590)	+7.3 GCHF
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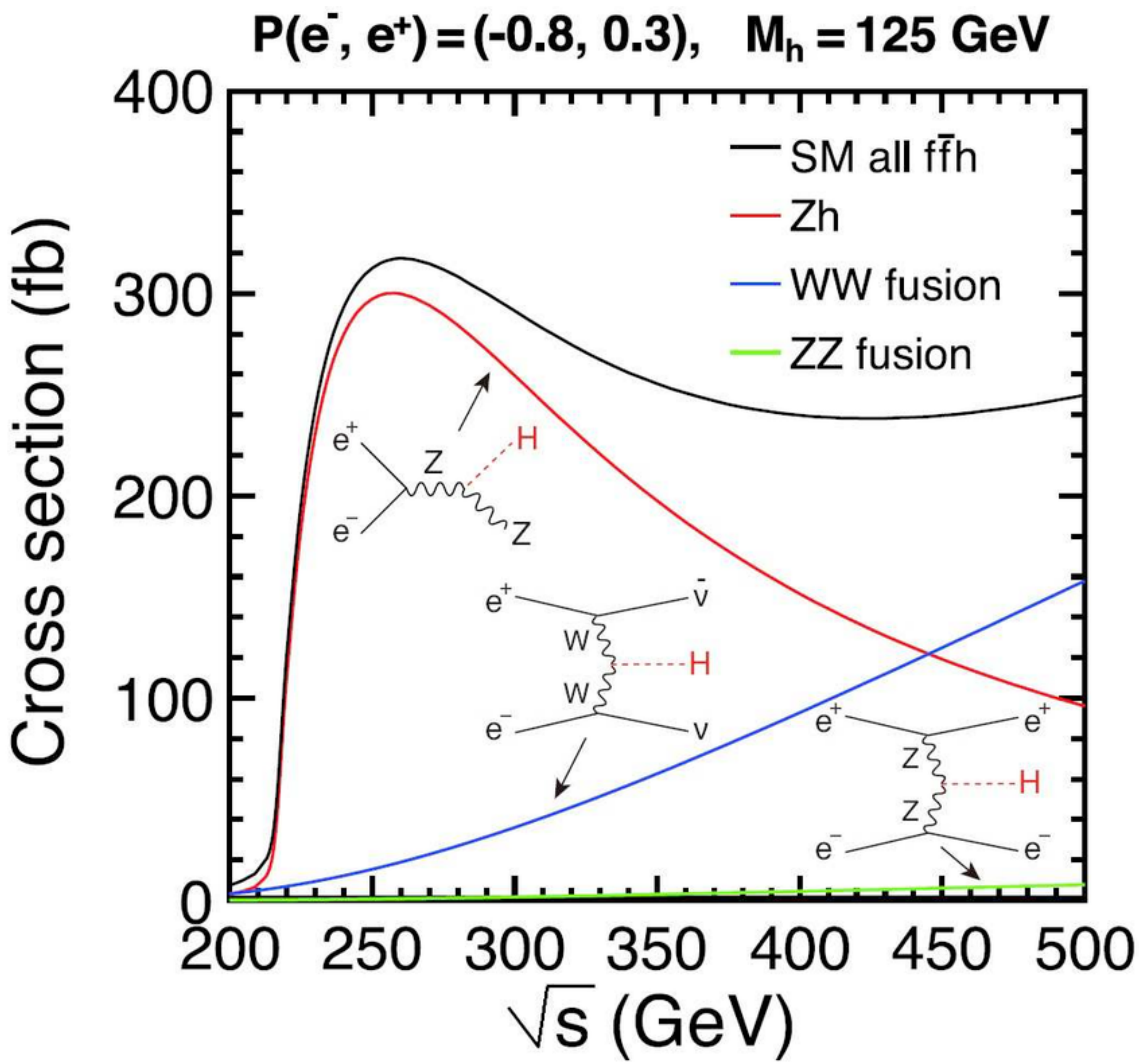
		0.365 (+0.35)	1.5 (+0.2)	4 (+1)	340	+1.1 GCHF
LHeC	ep	60 / 7000	1	12	(+100)	1.75 GCHF
FCC-hh	pp	100	30	25	580 (550)	17 GCHF (+7 GCHF)
FCC-NbTi	*pp*	*37.5*	*10*	*20*	*240*	*14 GCHF (including tunnel)*
HE-LHC	pp	27	20	20		7.2 GCHF

general consensus by now on next machine

250GeV e+e- Higgs Factory



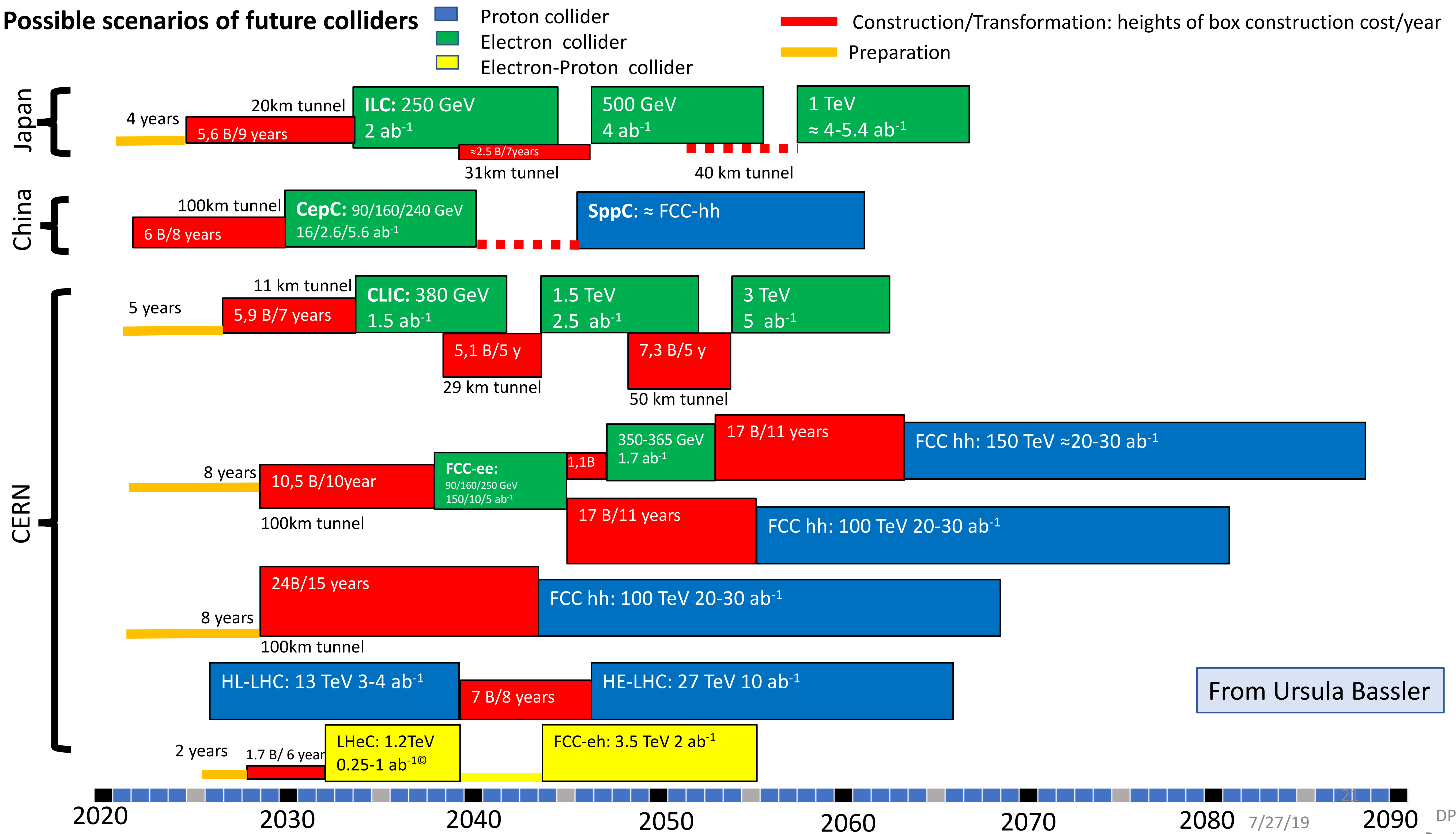
Next Big Machine should be an e+e- collider "Higgs Factory"

But …

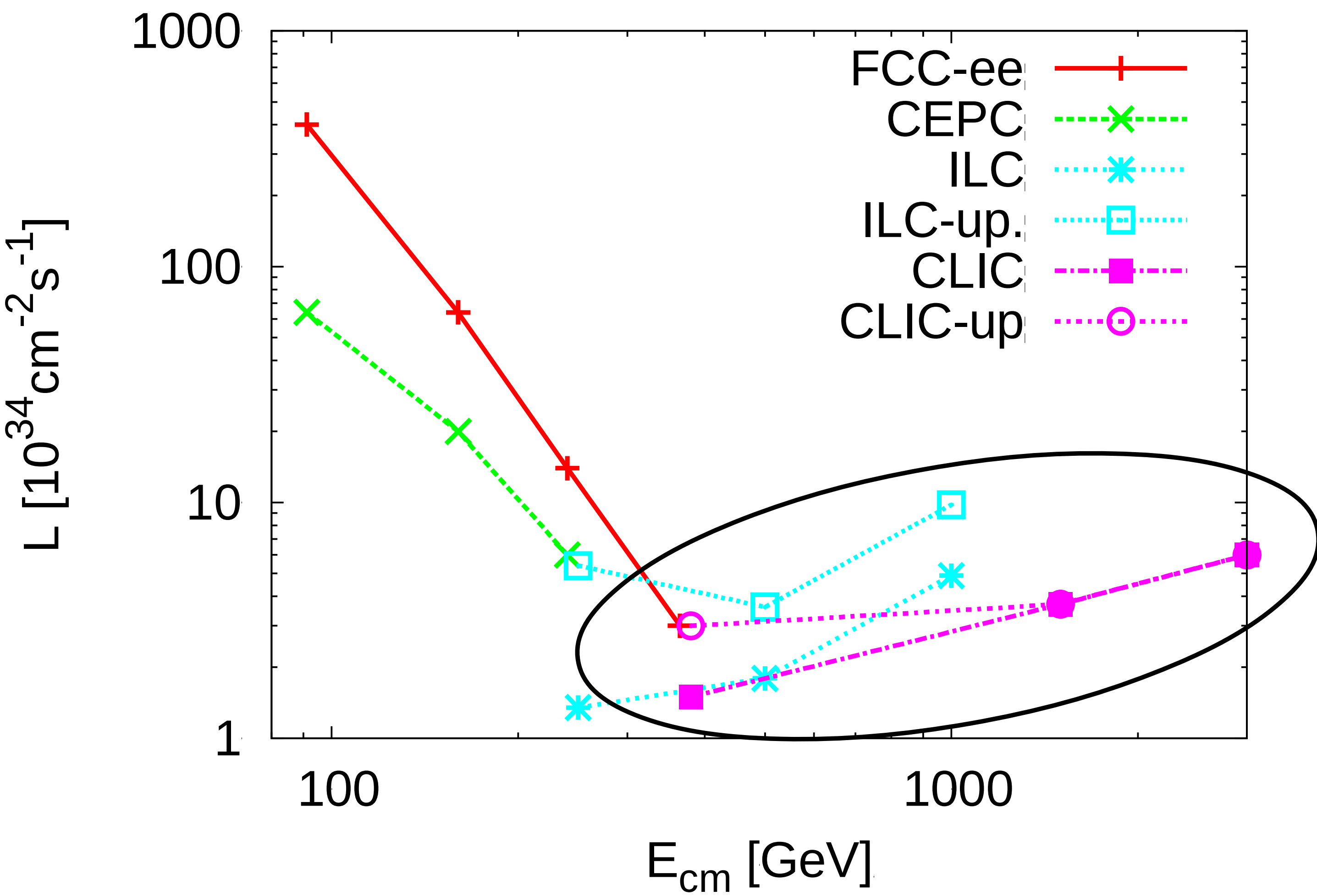
Which Higgs Factory?

Geoffrey Taylor, LP2019, Toronto, CA

10th August, 2019 17



Possible scenarios of future colliders
Proton collider
Electron collider
Electron-Proton collider
Construction/Transformation: heights of box construction cost/year
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
From Ursula Bassler
2 years
1.7 B/ 6 year
LHeC: 1.2TeV
0.25-1 ab-1©
FCC-eh: 3.5 TeV 2 ab-1
2020
2030
2040
2050
2060
2070
2080
7/27/19
2090



e+e- "optimized" schedule

Project	Start construction	Start Physics (higgs)
CEPC	2022	2030
ILC	2024	2033
CLIC	2026	2035
FCC-ee	2029	2039 (2044)
LHeC		

potential on Higgs couplings

Various collider options relative to HL-LHC

of "largely" improved H couplings (EFT)

		Factor ≥2	Factor ≥5	Factor ≥10	Years from T_0
Initial run	CLIC380	9	6	4	7
	FCC-ee240	10	8	3	9
	CEPC	10	8	3	10
	ILC250	10	7	3	11
2^{nd}/3rd Run ee	FCC-ee365	10	8	6	15
	CLIC1500	10	7	7	17
hh	HE-LHC	1	0	0	20
2nd/3rd Run ee	ILC500	10	8	6	22
	CLIC3000	11	7	7	28
ee,eh & hh	FCC-ee/eh/hh	12	11	10	>50

13 quantities in total

NB: number of seconds/year differs: ILC 1.6×10^7, FCC-ee & CLIC: 1.2×10^7, CEPC: 1.3

ILC Status & Recent Activities

- Project under serious consideration by the Japanese Government
  - Statement/Decision expected by the end of 2019 or early 2020
  - Japan is aware of the urgency and milestones (e.g., upcoming European Strategy Update)
- Encouraging interactions of Japanese Officials with agencies/ governments in the US and in Europe have taken place
- An International Working Group has been formed; the group is developing a report on ILC governance
- Strong ongoing efforts in Japan with outreach to public, media, science community and industry

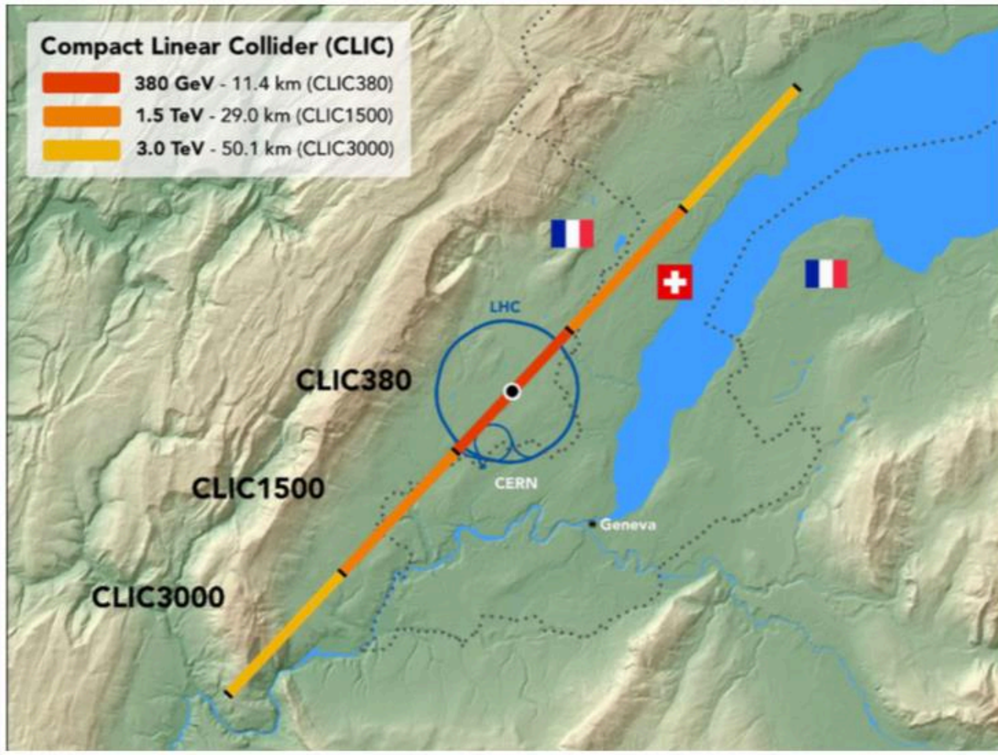
Geoffrey Taylor, LP2019, Toronto, CA 10th August, 2019 25

but a political decision on the ILC is really slowly converging…

Gianotti

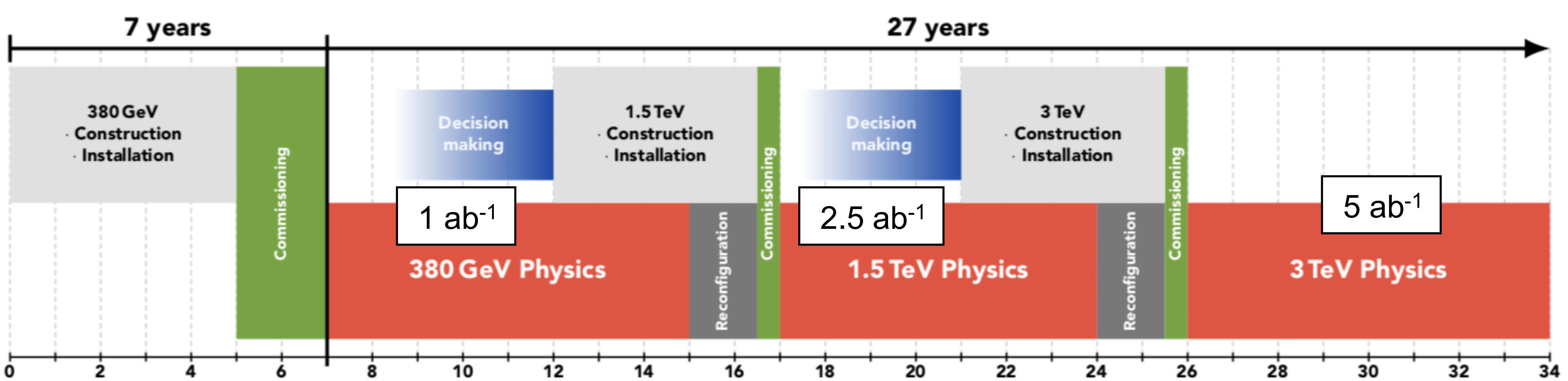
CLIC: multi-TeV e^+e^- linear collider

Parameter	Unit	Stage 1	Stage 2	Stage 3
$\sqrt{s}$	GeV	380	1500	3000
Tunnel length	km	11	29	50
Gradient	MV/m	72	72/100	72/100
Luminosity (above 99% of $\sqrt{s}$)	10^{34} $cm^{-2}s^{-1}$	1.5 0.9	3.7 1.4	5.9 2
Beam size at IP (σ_y/σ_x)	nm	2.9/149	1.5/60	1/40
Annual energy consumption CERN today: 1.2 TWh	TWh	0.8	1.7	2.8
Power consumption	MW	170	370	590
Construction cost	BCH	5.9	+5.1	+7.3



Since last ESPP: development of key technologies, progress towards demonstration of design parameters:
- ❑ 100 MV/m accelerating structures with low breakdown rate
- ❑ two-beam acceleration scheme demonstrated (CTF3) up to 145 MV/m
- ❑ R&D on alignment and vibration stabilization systems
- ❑ reduction of energy consumption (optimisation ongoing for 1.5 and 3 TeV) and cost

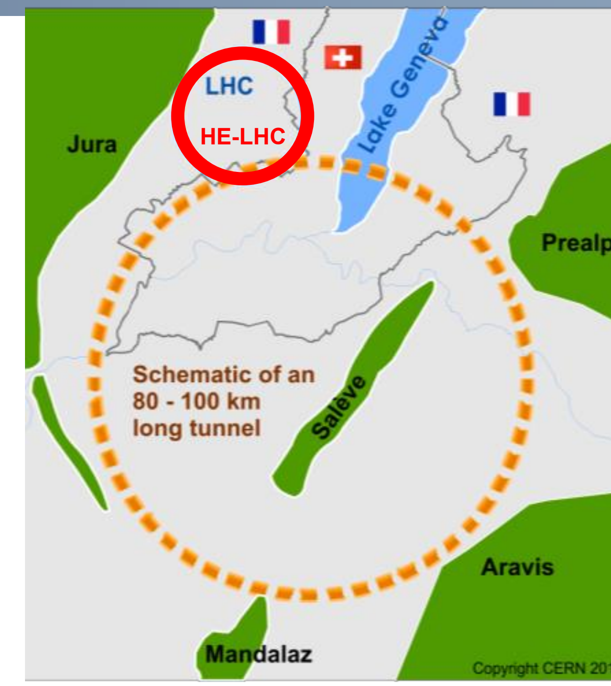
Technically:
construction could start in ~2026 (TDR in 2025)
→ start operation at $\sqrt{s}$=380 GeV in ~2035



FCC: Future Circular Collider

Gianotti

	$\sqrt{s}$	L /IP ($cm^{-2} s^{-1}$)	Int. L /IP(ab^{-1})	Comments
e^+e^- FCC-ee	~90 GeV Z 160 WW 240 H ~365 top	230 $\times 10^{34}$ 28 8.5 1.5	75 ab^{-1} 5 2.5 0.8	2 experiments Total ~ 15 years of operation
pp FCC-hh	100 TeV	5 x 10^{34} 30	2.5 ab^{-1} 15	2+2 experiments Total ~ 25 years of operation
PbPb FCC-hh	$\sqrt{s_{NN}}$ = 39 TeV	3 x 10^{29}	65 nb^{-1}/run	1 run = 1 month operation
ep Fcc-eh	3.5 TeV	1.5 10^{34}	2 ab^{-1}	60 GeV e- from ERL Concurrent operation with pp for ~ 20 years
e-Pb Fcc-eh	$\sqrt{s_{eN}}$ = 2.2 TeV	0.5 10^{34}	1 fb^{-1}	60 GeV e- from ERL Concurrent operation with PbPb



Also studied: HE-LHC: $\sqrt{s}$=27 TeV using FCC-hh 16 T magnets in LHC tunnel; L~1.6x10^{35} → 15 ab^{-1} for 20 years operation

Parameter	Unit	FCC-ee	FCC-hh
Annual energy consumption CERN today: 1.2 TWh	TWh	1.9	4
Power consumption	MW	~300	550
Construction cost (tunnel included)	BCH	11.6	17 if after FCC-ee; otherwise 24

Preliminary, purely technical schedule for integrated programme (FCC-ee followed by FCC-hh), assuming green light to preparation work in 2020.

8 years preparation	10 years tunnel and FCC-ee construction	**15 years FCC-ee operation**	11 years preparation for FCC-hh and installation	**25 years FCC-hh operation pp/PbPb/eh**
2020-2028		**2038-2053**		**2064-2090**

Finding *Common Denominators* * – Three Factors

** to be further discussed in the Symposium's accelerator sessions*

- ***F1*** **"Technology Readiness" :**

Green	-	TDR
Yellow	-	CDR
Red	-	R&D

- ***F2*** **"Energy Efficiency"**

Green	:	100-200 MW
Yellow	:	200-400 MW
Red	:	> 400 MW

- ***F3*** **"Cost" :**

Green	:	< LHC
Yellow	:	1-2 x LHC
Red	:	> 2x LHC

Shiltsev

Fermilab

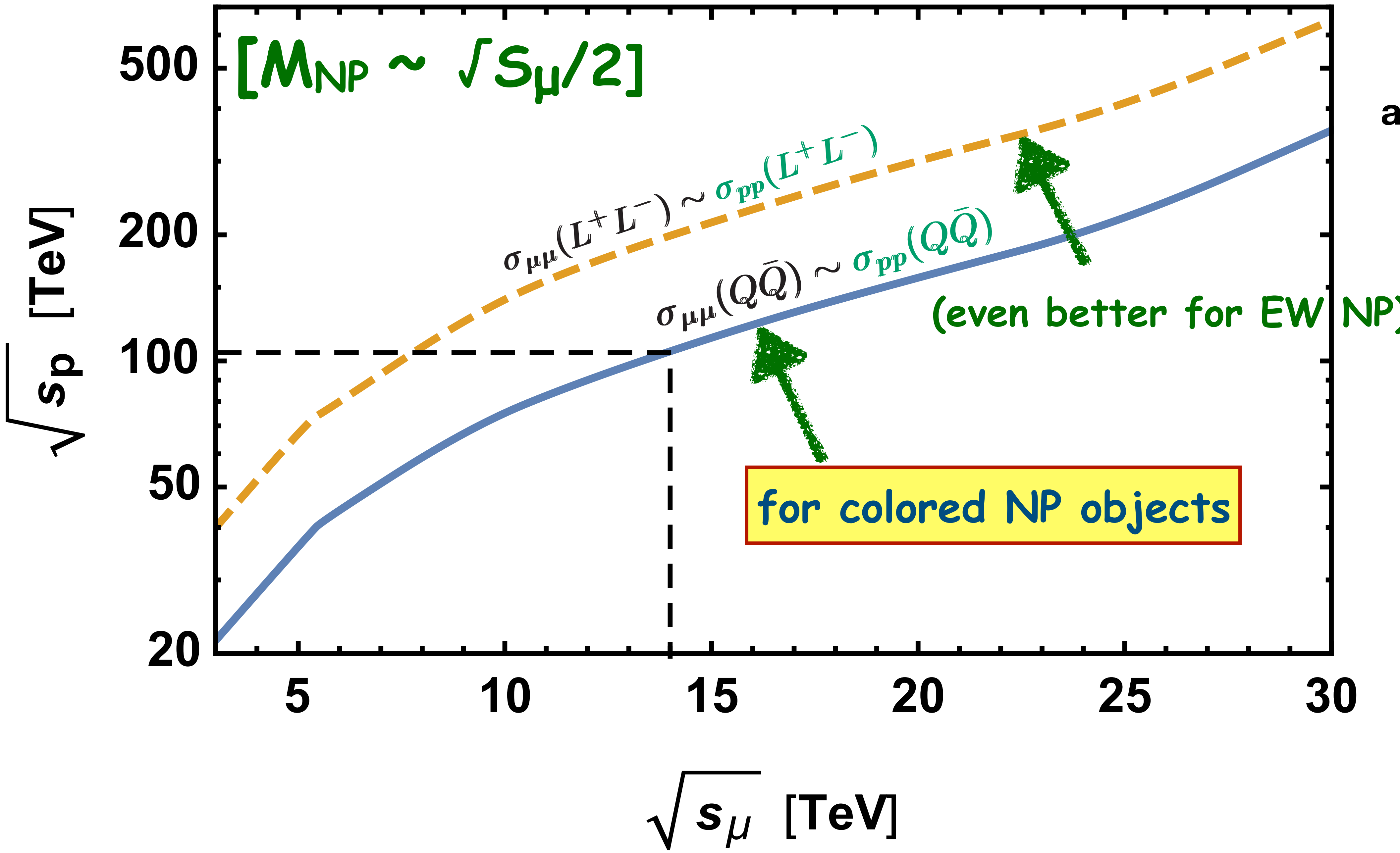
23 5/13/2019 Shiltsev I EPPSU 2019 Future Colliders

Shiltsev

Higgs Factories	Readiness	Power-Eff.	Cost
ee Linear *250 GeV*			
ee Rings *240GeV/tt*			
μμ Collider *125 GeV*			*
Highest Energy			
ee Linear *1-3TeV*			
pp Rings *HE-LHC*			
FCC-hh/SppC			
μμ Coll. *3-14 TeV*			*

A MULTI-TEV
MUON COLLIDER (???)

"equivalent" reach in pp after rescaling for pdf's



arXiv:1901.06150

- $\mu\mu$ @ 14 TeV → pp @ 100 $(200)_{EW}$ TeV !
- $\mu\mu$ @ 30 TeV → pp @ 350 $(600)_{EW}$ TeV !!

yet unexplored pheno !!!

Brief history

- The **muon collider idea** was first introduced in **early 1980's**
  [A. N. Skrinsky and V. V. Parkhomchuk, D. Neuffer]
- the idea was further developed by a **series of world-wide collaborations**
- **US Muon Accelerator Program – MAP,** created in **2011,** was killed in **2014**
  MAP developed a ***proton driver scheme*** *and addressed the feasibility of the novel technologies required for Muon Colliders and Neutrino Factories*

  "Muon Accelerator for Particle Physics," JINST,
  https://iopscience.iop.org/journal/1748-0221/page/extraproc46
- **LEMMA (Low EMittance Muon Accelerator)** concept was proposed in **2013**
  a new end-to-end design of a ***positron driven scheme*** *is presently under study by INFN-LNF et al. to overcome technical issues of initial concept ➔ arXiv soon*
- an **input document** was submitted to the European Particle Physics Strategy Update on existing muon collider studies, to support further R&Ds

  "Muon Colliders," arXiv:1901.06150

High Energy μ+μ- Colliders

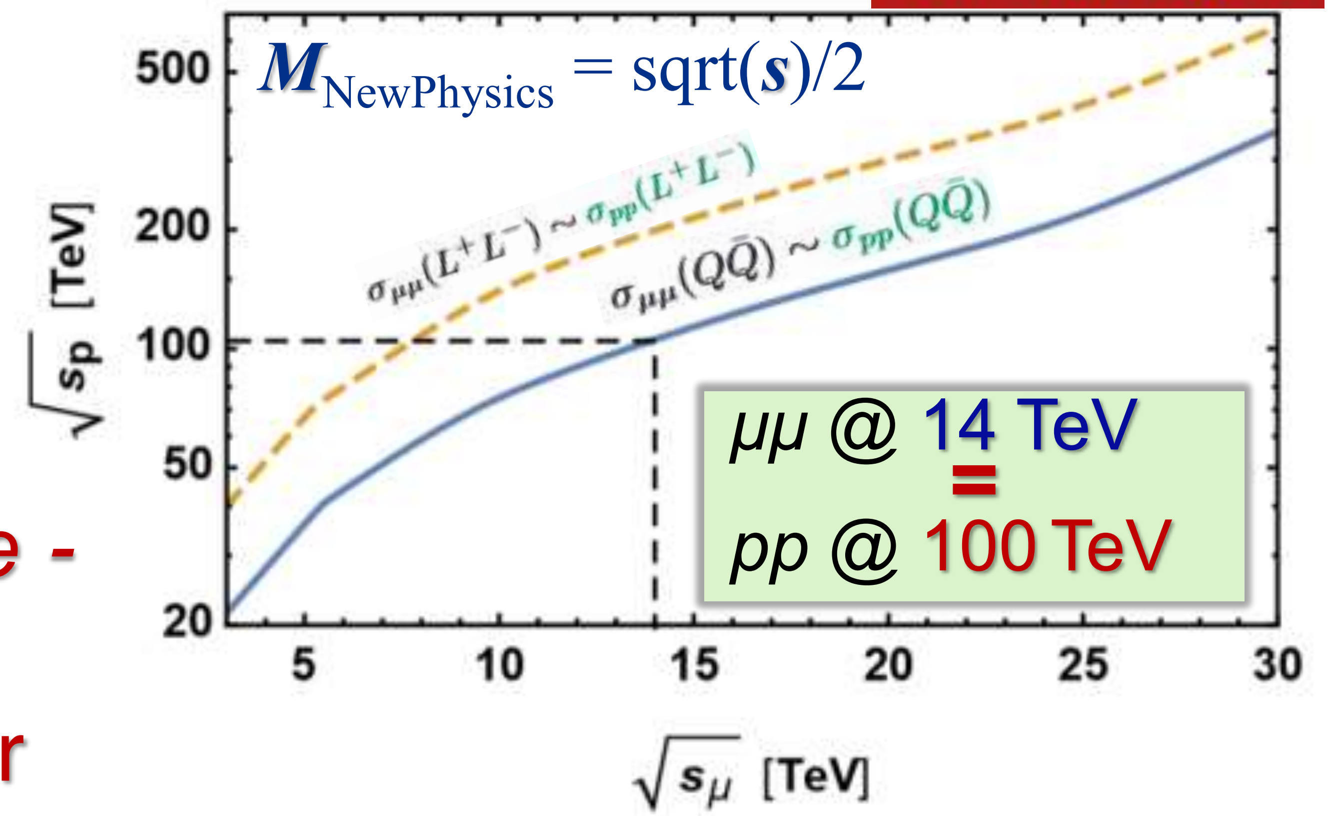
Shiltsev

JINST Special Issue (*MUON*)

arXiv:1901.06150

Advantages:

- ***μ***'s do not radiate / no beamstrahlung→ acceleration in rings → *low cost & great power efficiency*
- ~ *x7* energy reach vs *pp*



Offer *"moderately conservative - moderately innovative"* path **to cost affordable** energy frontier colliders:

- US MAP feasibility studies were very successful → MCs can be built with present day SC magnets and RF; there is a well-defined path forward
- ZDRs exist for 1.5 TeV, 3 TeV, 6 TeV and 14 TeV * in the LHC tunnel

** more like "strawman" parameter table*

Key to success:

- Test facility to demonstrate performance implications - muon production and 6D cooling, study LEMMA e^+-45 GeV + e^- at rest →μ^+-μ^- , design study of acceleration, detector background and neutrino radiation

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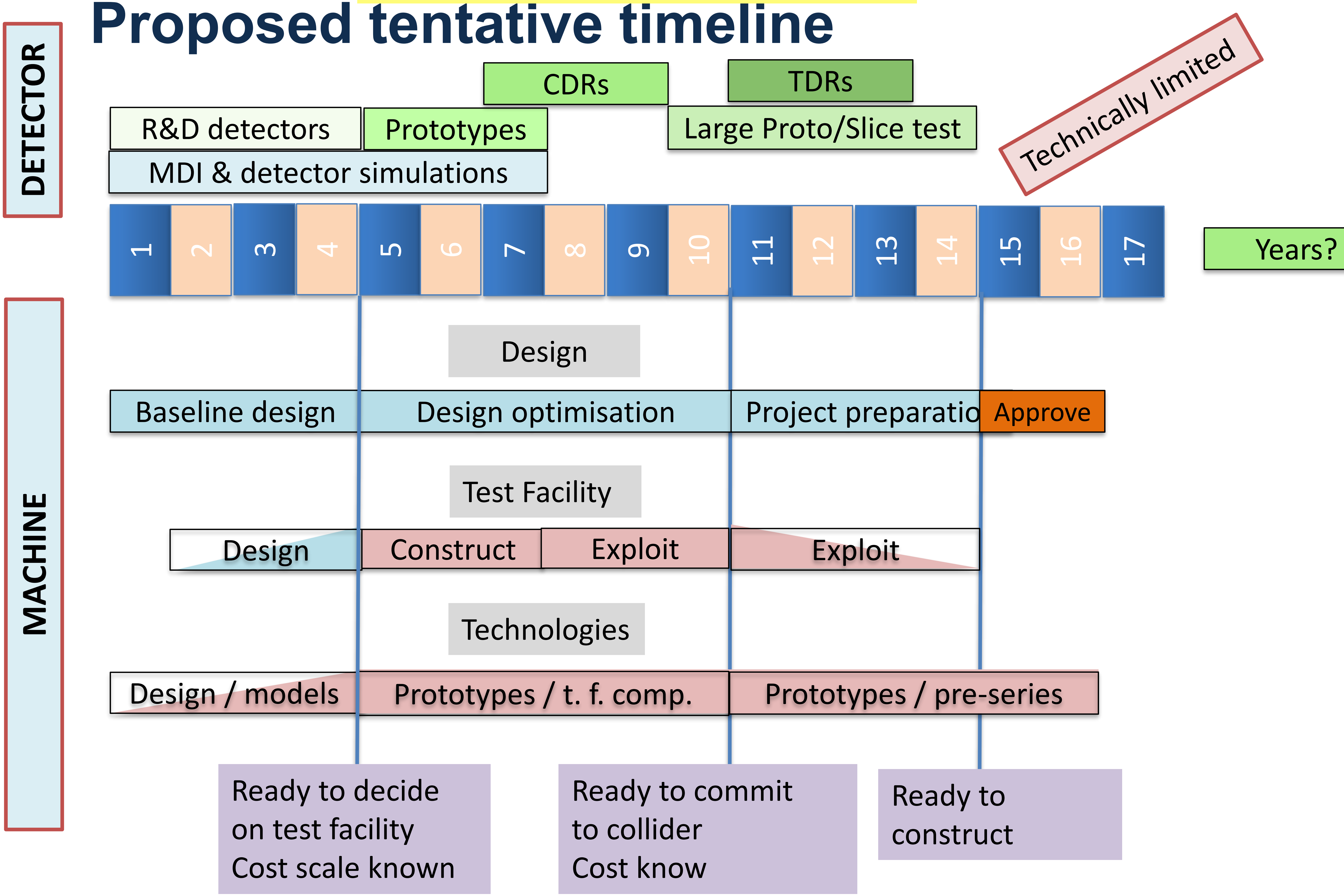
MUON COLLIDERS

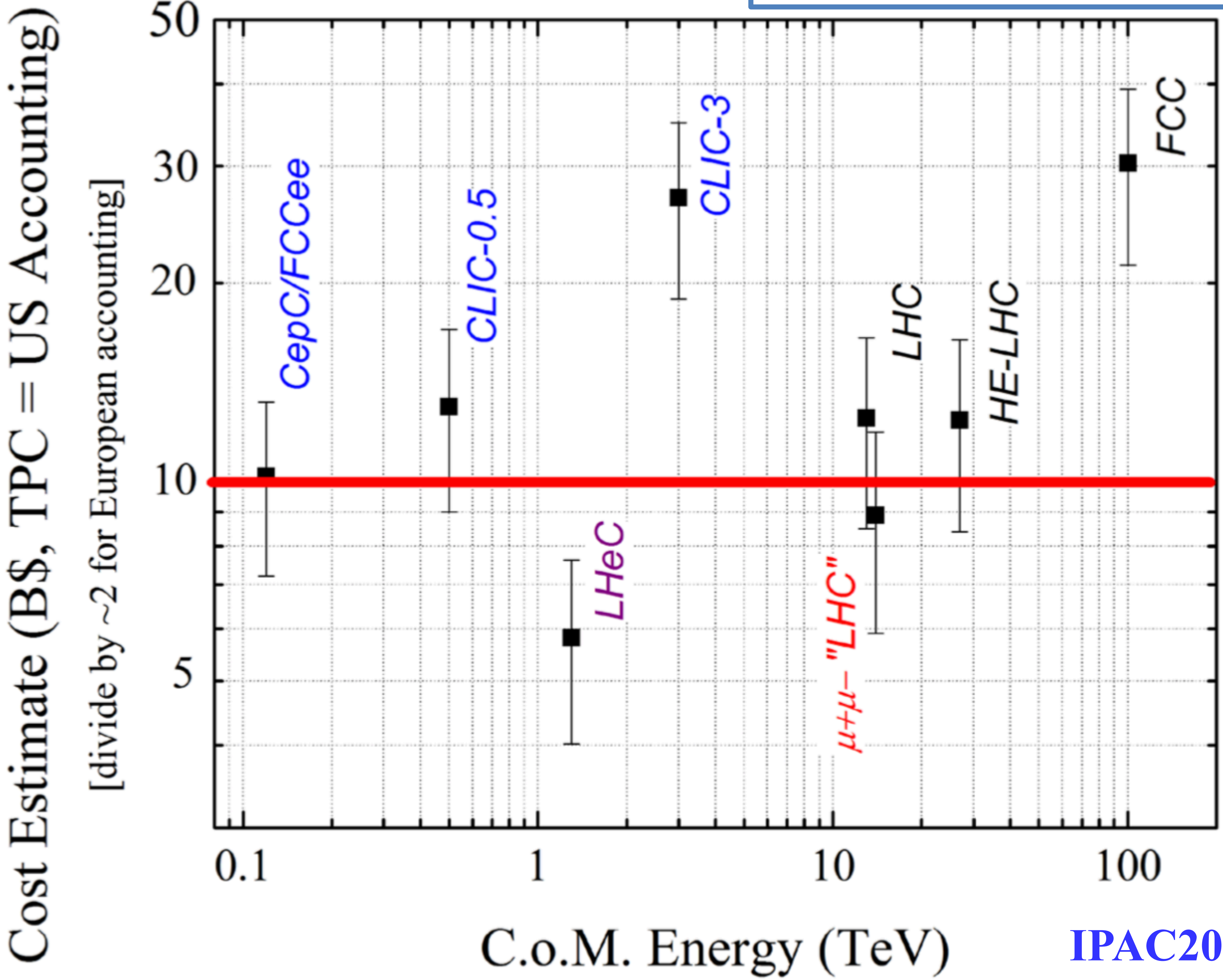
Schulte

Proposed tentative timeline



NB: all $$ - "US Accounting" (divide by 2-2.4 at CERN)

Vladimir SHILTSEV,David NEUFFER (Fermilab)



IPAC2018 - MOPMF072

VBF events (green) + $\sigma_{WW\to X} / \sigma_{\mu\mu\to X}$ (red)

# events	3 TeV/5/ab	(VBF)/(s-ch)3TeV	14 TeV/20/ab	(VBF)/(s-ch)14TeV	30 TeV/100/ab	(VBF)/(s-ch)30TeV
H	2,5E+06		1,9E+07		1,2E+08	
HZ	4,9E+04	7	9,0E+05	700	7,4E+06	5300
HZZ	6,0E+02	1,5	3,2E+04	180	3,7E+05	1500
HWW	1,5E+03	0,3	6,8E+04	30	7,6E+05	190
HH	4,1E+03		8,8E+04		7,4E+05	
HHZ	4,7E+01	0,3	2,8E+03	40	3,3E+04	300
HHZZ	4,6E-01	0,1	7,8E+01	16	1,2E+03	130
HHWW	1,2E+00	0,02	1,8E+02	1	2,9E+03	1
HHH	1,5E+00		1,4E+02		1,9E+03	
HHHZ	2,4E-02	0,3	3,8E+00	12	5,1E+01	100

[MadGraph]

tt	2,6E+04	0,3	4,2E+05	24	3,1E+06	160
ttH	6,5E+01	0,03	3,0E+03	5	3,1E+04	40
ttZ	5,5E+02	0,07	2,6E+04	7	2,8E+05	50
ttHH	1,7E-01	0,006	1,3E+01	1	1,6E+02	10
ttHZ	1,8E+00	0,01	2,0E+02	2	2,7E+03	14
ttZZ	7,0E+00	0,03	1,2E+03	4	1,7E+04	30
ttWW	1,4E+01	0,008	2,2E+03	0,8	3,0E+04	5
tttt	3,4E-01	0,01	2,2E+01	0,4	2,1E+02	2

Higgs self-interaction couplings

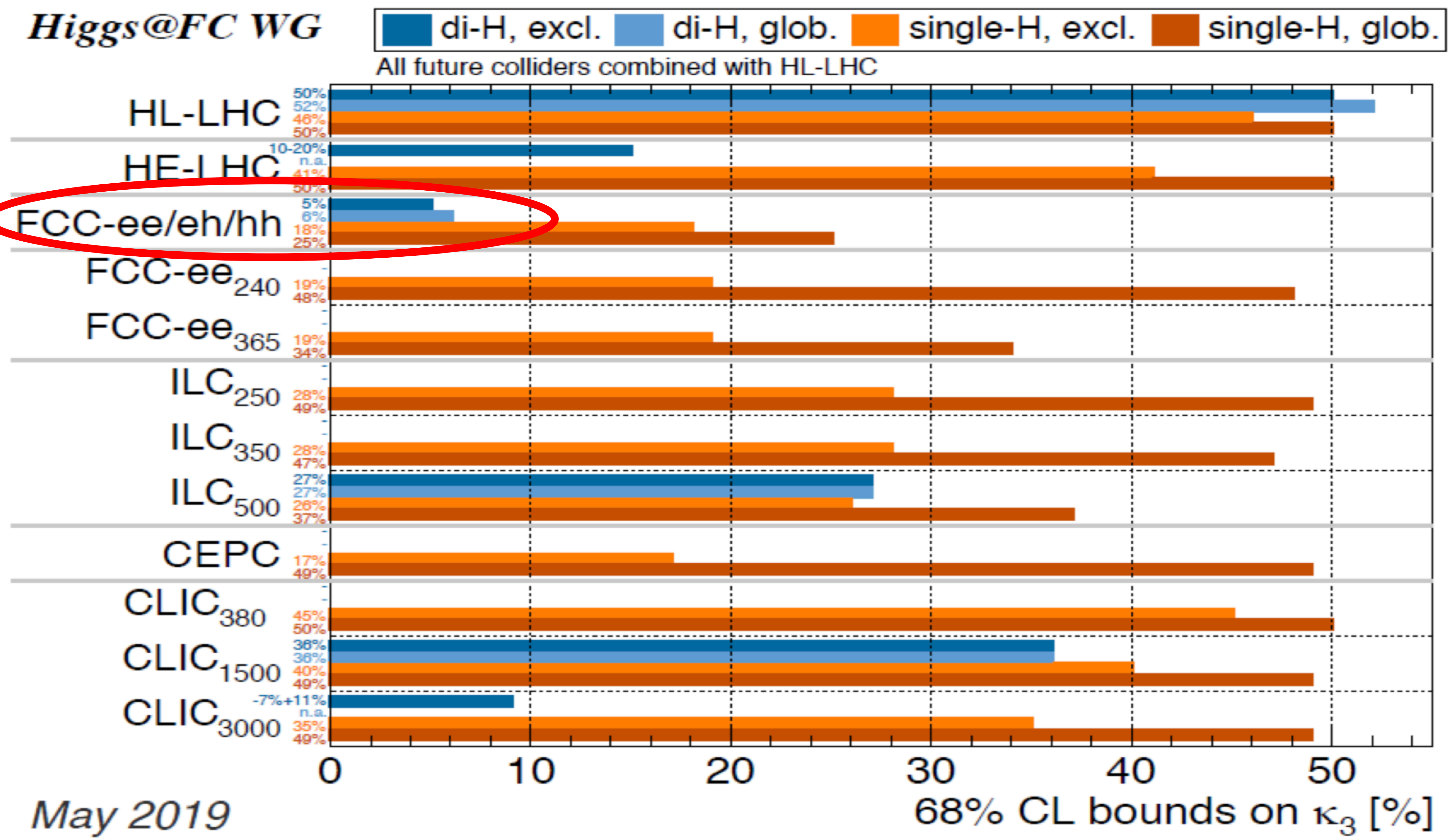
- the "tough topic" even at "most-future" colliders
- most interesting to measure from theory side....

$$\mathcal{L} = -\frac{1}{2} m_h^2 h^2 - \boxed{\lambda_3} \frac{m_h^2}{2v} h^3 - \boxed{\lambda_4} \frac{m_h^2}{8v^2} h^4$$

$$\lambda_3^{SM} = \lambda_4^{SM} = 1$$

Grand summary: HH coupling

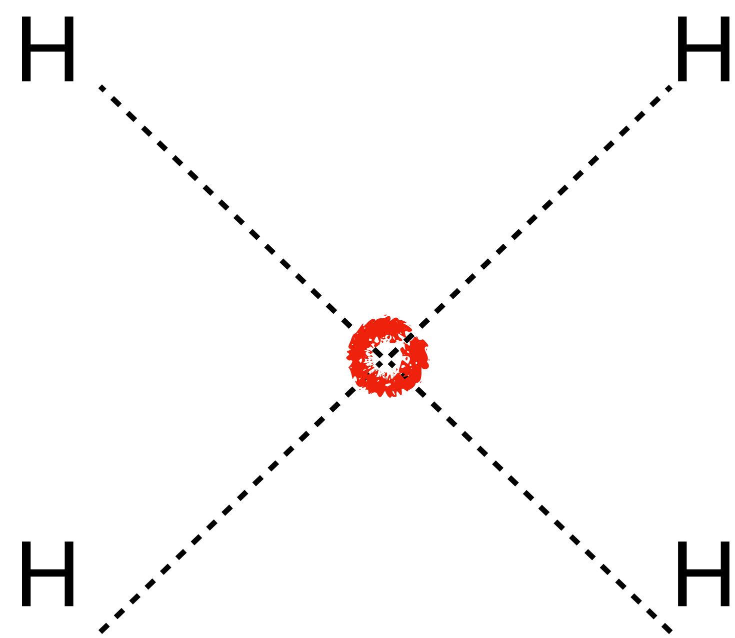
Ref: 1905.03764



- HH coupling down to 5% for the full FCC program
  - Improvement of a factor ~10 wrt HL-LHC; Almost a factor of ~2 improvement wrt CLIC

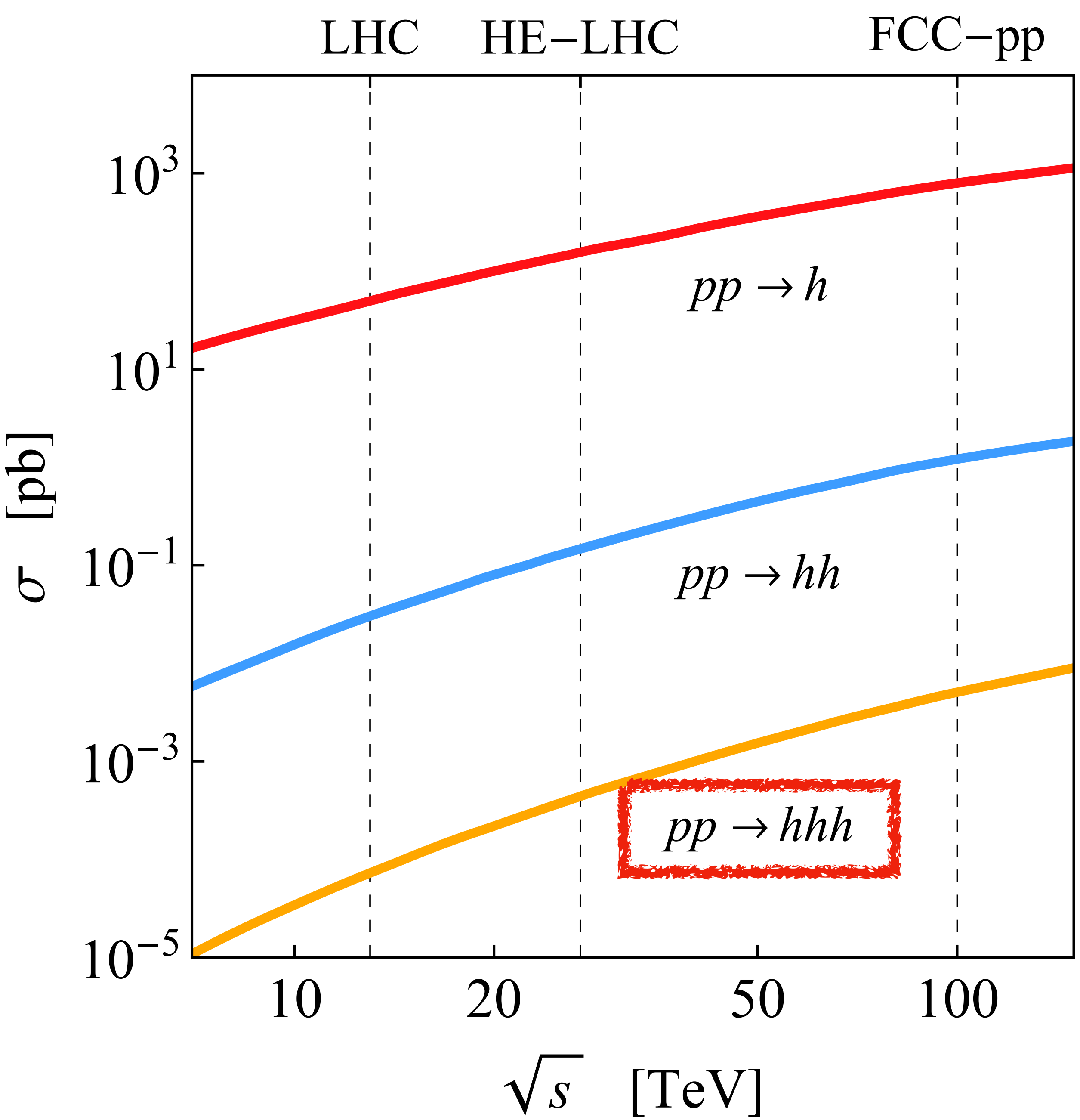
L.Gouskos, LFC19

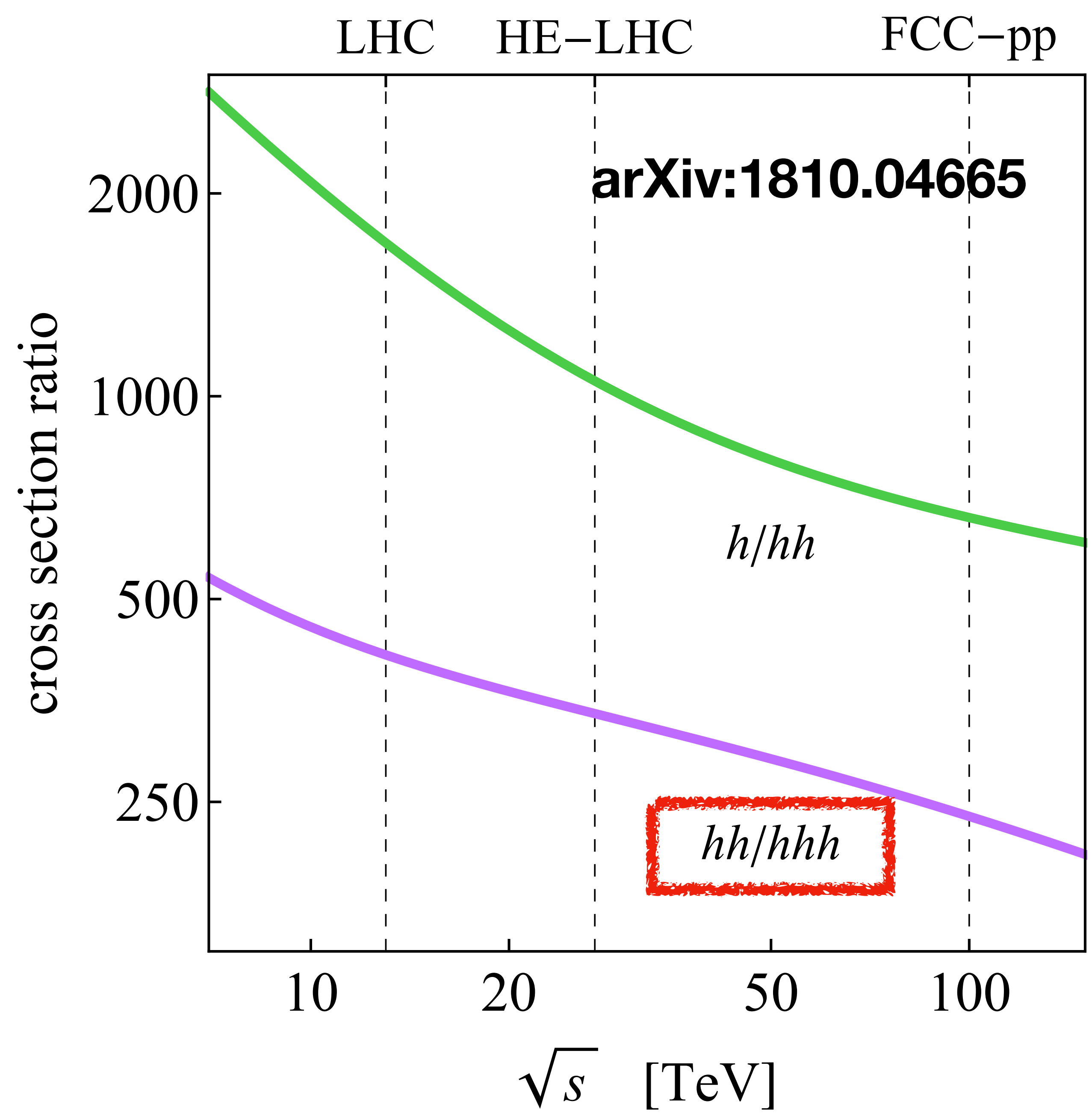
what about the quartic coupling ?



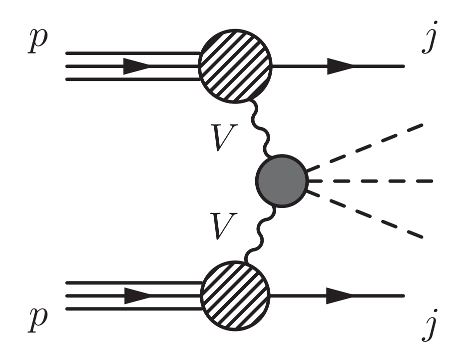
FCC-pp : λ_4

$$\mathcal{L} = -\frac{1}{2}m_h^2 h^2 - \lambda_3 \frac{m_h^2}{2v} h^3 - \lambda_4 \frac{m_h^2}{8v^2} h^4$$





hhh → $(b\bar{b})(b\bar{b})(\gamma\gamma)$ [optimistic scenario !!!] :



$\lambda_4 \in [\sim -4, \sim +16]$ **(68%C.L.)**

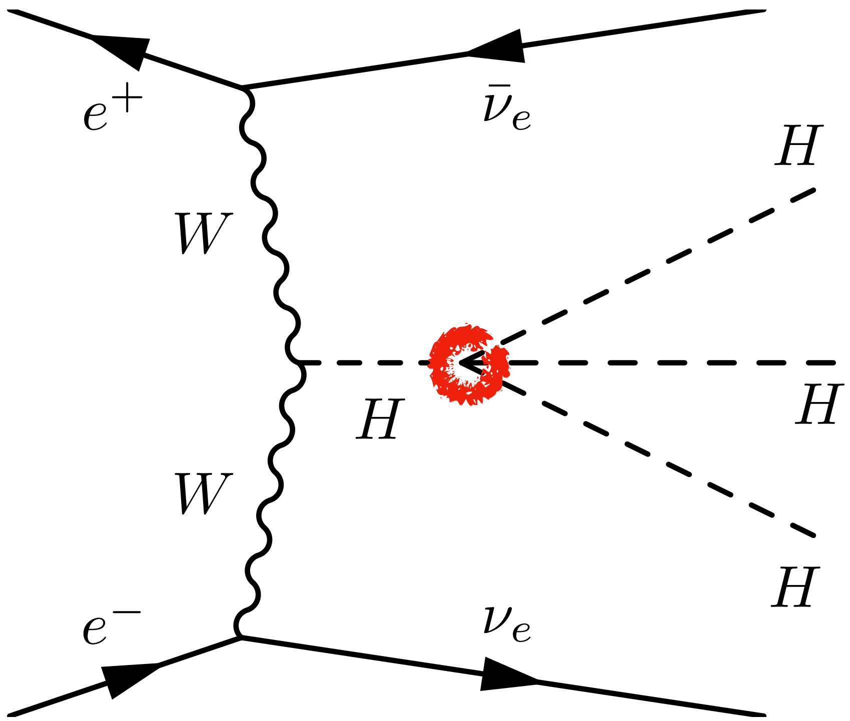
at 100 TeV, 30 ab^{-1}

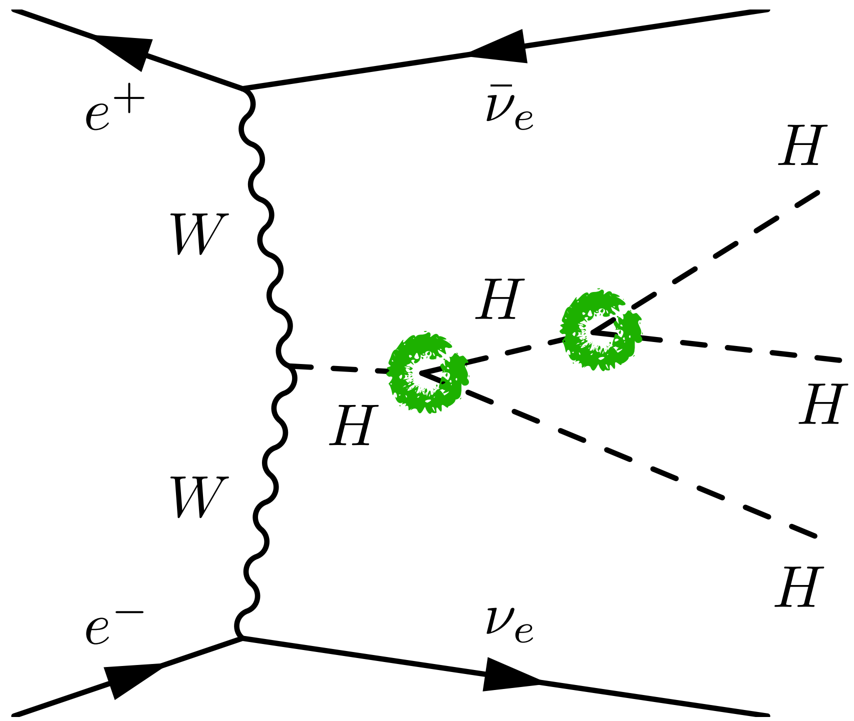
arXiv:1606.09408

see also arXiv:1907.02078

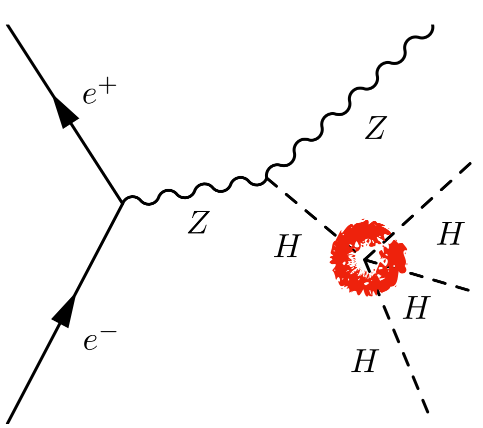
$\mu^+\mu^- \to HHH\nu\bar{\nu}, \; (\nu = \nu_e, \nu_\mu, \nu_\tau)$

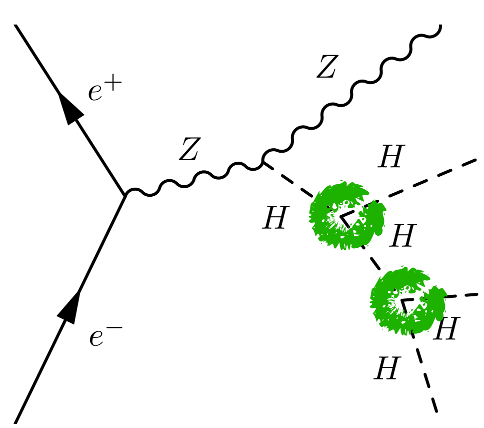
$$V_{\rm h} = \frac{m_h^2}{2} h^2 + (1 + \kappa_3)\lambda_{hhh}^{\rm SM} v h^3 + \frac{1}{4}(1 + \kappa_4)\lambda_{hhhh}^{\rm SM} h^4$$





$$\Delta = \frac{N - N_{SM}}{\sqrt{N_{SM}}} = \left(c_1\kappa_3 + c_2\kappa_4 + c_3\kappa_3\kappa_4 + c_4\kappa_3^2 + c_5\kappa_4^2 + c_6\kappa_3^3 + c_7\kappa_3^2\kappa_4 + c_8\kappa_3^4\right)$$



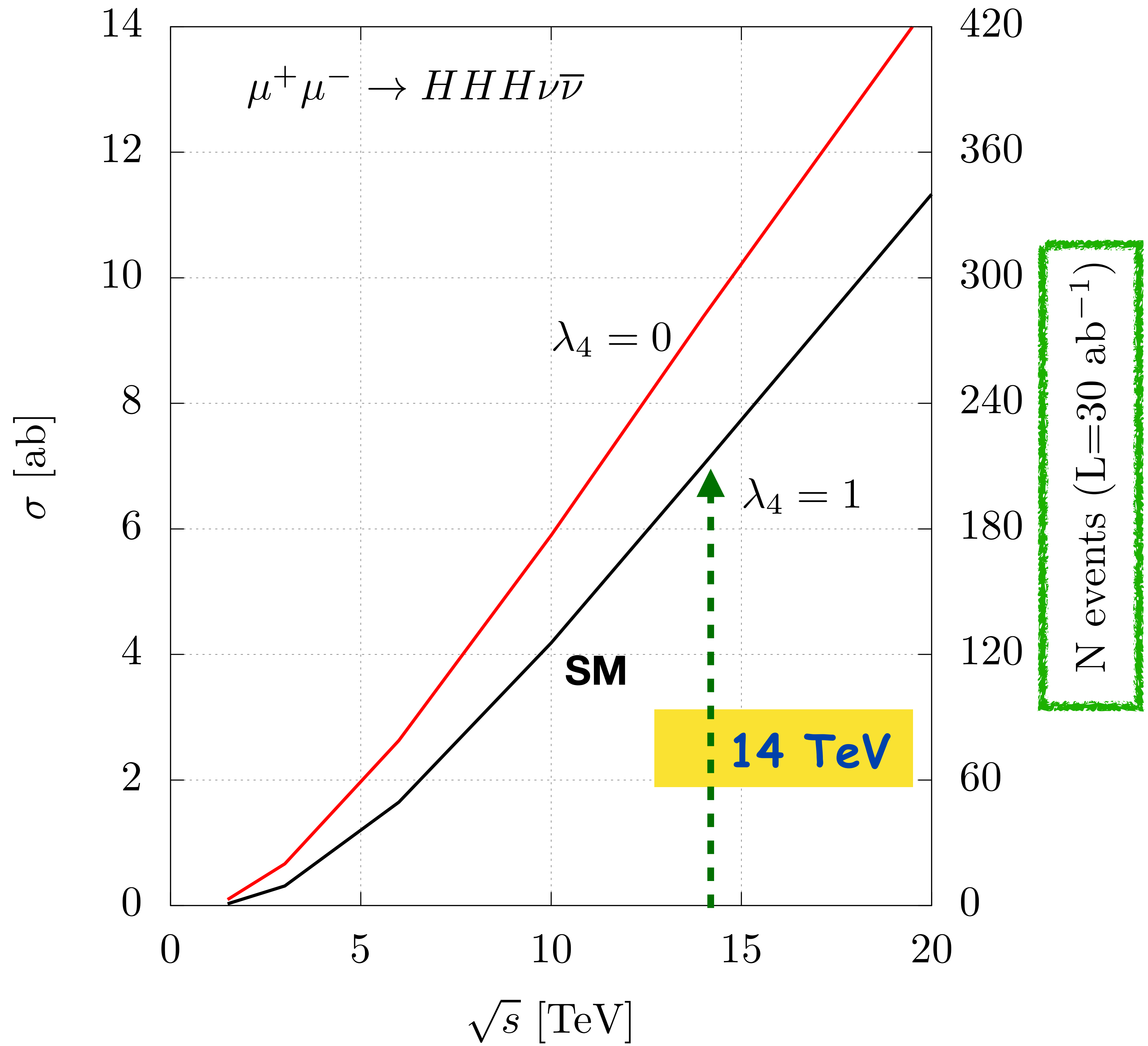


HHHZ negligible !

$\sigma_{HHHZ} \sim 1/2\; \sigma_{HHH}$ @ 3TeV

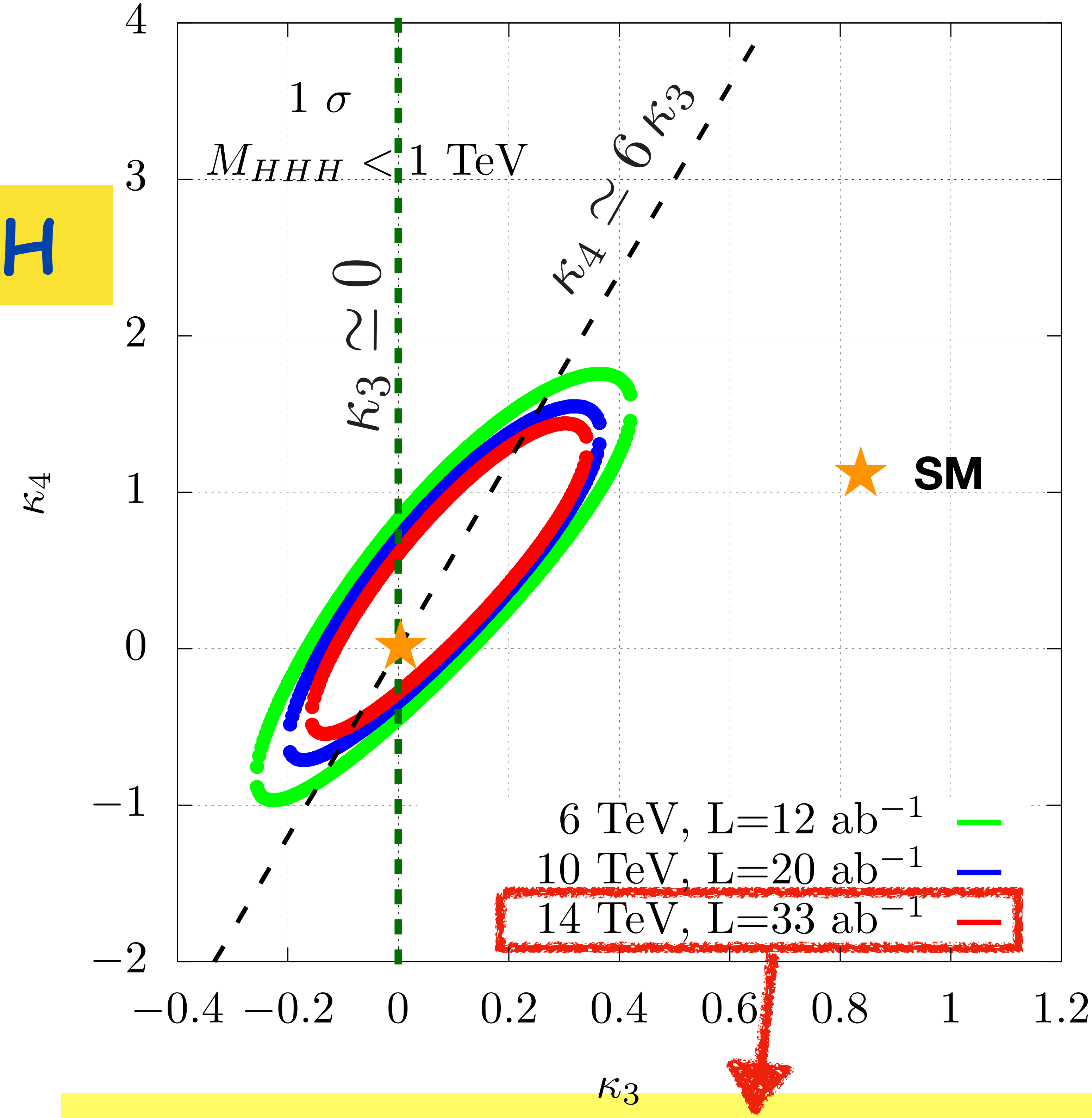
$\sim 1/50\; \sigma_{HHH}$ @ 30TeV

VBF→HHH x-section vs √S



$(N-N_{SM})/\sqrt{N_{SM}}$ versus (κ_3, κ_4)

VBF→HHH



Chiesa et al

[$\kappa_3=0$] $-0.3 < \kappa_4 < 0.5$ (68%CL) !!!

Grand summary: Single-H couplings

Ref: 1905.03764

kappa-3 scenario	HL-LHC+								
	ILC_{250}	ILC_{500}	$CLIC_{380}$	$CLIC_{1500}$	$CLIC_{3000}$	CEPC	FCC-ee_{240}	FCC-ee_{365}	FCC-ee/eh/hh
κ_W (%)	1.1	0.29	0.75	0.4	0.38	0.95	0.95	0.41	0.2
κ_Z(%)	0.29	0.23	0.44	0.39	0.39	0.18	0.19	0.17	0.17
κ_g(%)	1.4	0.84	1.5	1.1	0.86	1.1	1.2	0.89	0.53
κ_γ (%)	1.3	1.2	1.5*	1.3	1.1	1.2	1.3	1.2	0.36
$\kappa_{Z\gamma}$ (%)	11.*	11.*	11.*	8.4	5.7	6.3	11.*	10.	0.7
κ_c (%)	2.	1.2	4.1	1.9	1.4	2.	1.6	1.3	0.97
κ_t (%)	2.7	2.4	2.7	1.9	1.9	2.6	2.6	2.6	0.95
κ_b (%)	1.2	0.57	1.2	0.61	0.53	0.92	1.	0.64	0.48
κ_μ (%)	4.2	3.9	4.4*	4.1	3.5	3.9	4.	3.9	0.44
κ_τ (%)	1.1	0.64	1.4	0.99	0.82	0.96	0.98	0.66	0.49
BR_{inv} (<%, 95% CL)	0.26	0.22	0.63	0.62	0.61	0.27	0.22	0.19	0.024
BR_{unt} (<%, 95% CL)	1.8	1.4	2.7	2.4	2.4	1.1	1.2	1.	1.

- Full FCC program:
  - An order of magnitude improvement in precision with respect to HL-LHC for all couplings
  - All couplings better than 1% level
    - Couplings to W/Z and Inv. down to 10^{-3}
  - Allows to probe small modifications to Higgs couplings from BSM

L. Gouskos, LFC19

assume you find a deviation in H couplings…

- Deviation from SM: $\delta \sim v^2/M^2$
  - M scale of new physics
  - $M \sim 1 - 10$ TeV → $\delta \sim 6 - 0.06\%$

* in order to figure out what's going on you will need an energy-frontier facility to explore the corresponding M scale in a direct way.

* R&D for future high-energy colliders (new technologies ?)

* hadron collider beyond LHC ? muon collider ? plasma acceleration ?

s.c. magnet technology

A. Yamamoto

- Nb_3Sn superconducting magnet technology for hadron colliders, still requires **step-by-step** development to reach **14, 15, and 16 T**.
- It would require the following **time-line** (in my personal view):
  - **Nb_3Sn, 12~14 T:** 5~10 years for short-model R&D, and the following 5~10 years for prototype/pre-series with industry. It will result in **10 – 20 yrs** for the construction to start,
  - **Nb_3Sn, 14~16 T:** 10-15 years for short-model R&D, and the following 10 ~ 15 years for protype/pre-series with industry. It will result in **20 – 30 yrs** for the construction to start, (consistently to the FCC-integral time line).
  - **NbTi , 8~9 T:** proven by LHC and **Nb_3Sn, 10 ~ 11 T** being demonstrated. It may be feasible for the construction to begin in > ~ 5 years.
- **Continuing R&D effort** for high-field magnet, present to future, should be critically **important**, to realize highest energy frontier hadron accelerators in future.

Intensify HTS accelerator magnet development

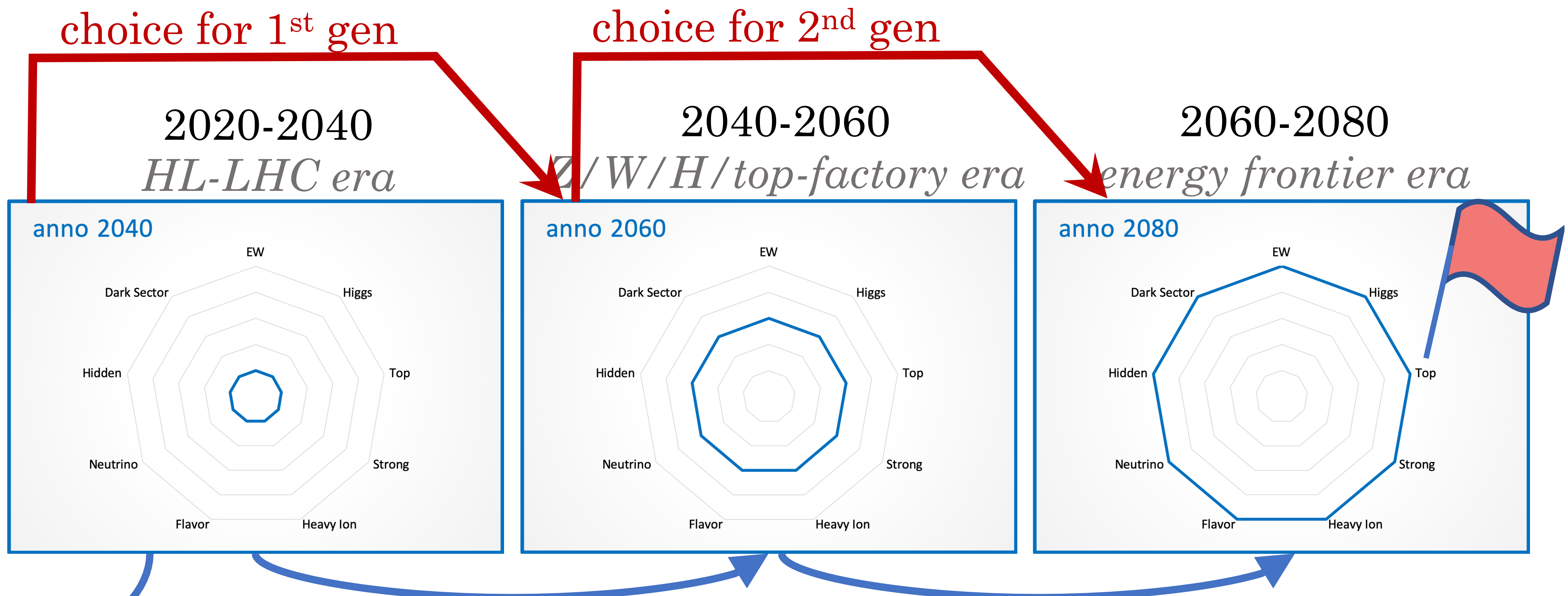
Shiltsev

7-10 YEARS FROM NOW

WITH PROPOSED ACTIONS / R&D DONE / TECHNICALLY LIMITED

- ***ILC:***
  - Some change in cost (~6-10%)
  - All agreements by 2024, then
  - **Construction** (2024-2033)
- ***CLIC:***
  - TDR & preconstr. ~2020-26
  - **Construction** (2026-2032)
  - 2 yrs of commissioning
- ***CepC:***
  - Some change in cost & power
  - TDR and R&D (2018-2022)
  - **Construction** (2022-2030)
- ***FCC-ee:***
  - Some change in cost & power
  - **Preparations** 2020-2029
  - Construction 2029-2039
- ***HE-LHC:***
  - **R&D and prepar'ns** 2020-2035
  - Construction 2036-2042
- ***FCC-hh*** (w/o FCC-ee stage)***:***
  - **16T magnet prototype** 2027
  - Construction 2029-2043
- ***μ^+-μ^- Collider :***
  - **CDR completed** 2027, cost known
  - Test facility constructed 2024-27
  - Tests and TDR 2028-2035

Choices for 1^{st} gen collider(s) beyond the HL-LHC have to be made without knowing the HL-LHC results & choices for the 2^{nd} gen without knowing the results of the 1^{st} gen experiments



HL-LHC era

1^{st} generation: at least include an exploration of the Higgs sector (very few major colliders)

2^{nd} generation: the options might depend on choices made for the 1^{st} generation (one major global collider)

J. D'Hondt, LFC19

next extra step in EPPSU 2020

- given the long-term impact of strategic choices, ECFA is organising a full-day event in the Main Auditorium at CERN on 15 Nov 2019, to enable (a few invited) early-career scientists to debate the Strategy
- up to 10 PhD or postdoc researchers /each ECFA member
- will be mandated to deliver a brief document overviewing their thoughts on the Strategy, covering all the topics discussed during the meeting (no need to reach a consensus on all aspects). ECFA Chair will bring this document to the attention of the ESG.

finally…

* ESG will gather for one week in Jan 2020 in Bad Hoffen, GE to draft the Strategy update, which will be submitted to the CERN Council for consideration in its March session, and then tabled for approval in May 2020

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STAY TUNED !!!