Bostjan Golob
University of Ljubljana/
Jozef Stefan Institute

University
of Ljubljana

"Jozef Stefan"
Institute

European Strategy in Particle Physics Update

STATUS REPORT

Introduction

previous strategy, results

Accelerator project design studies

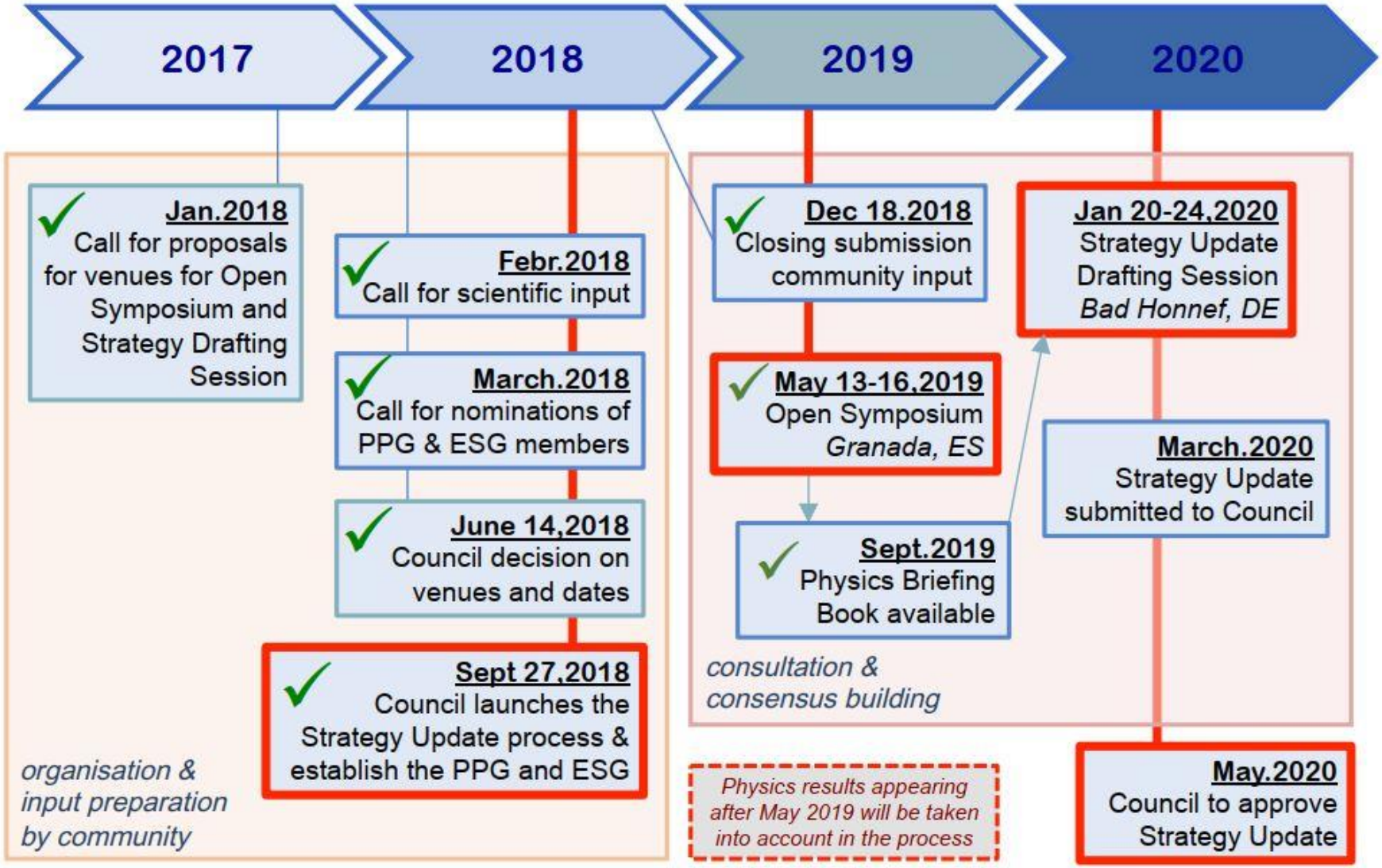
(some) physics

Scenarios

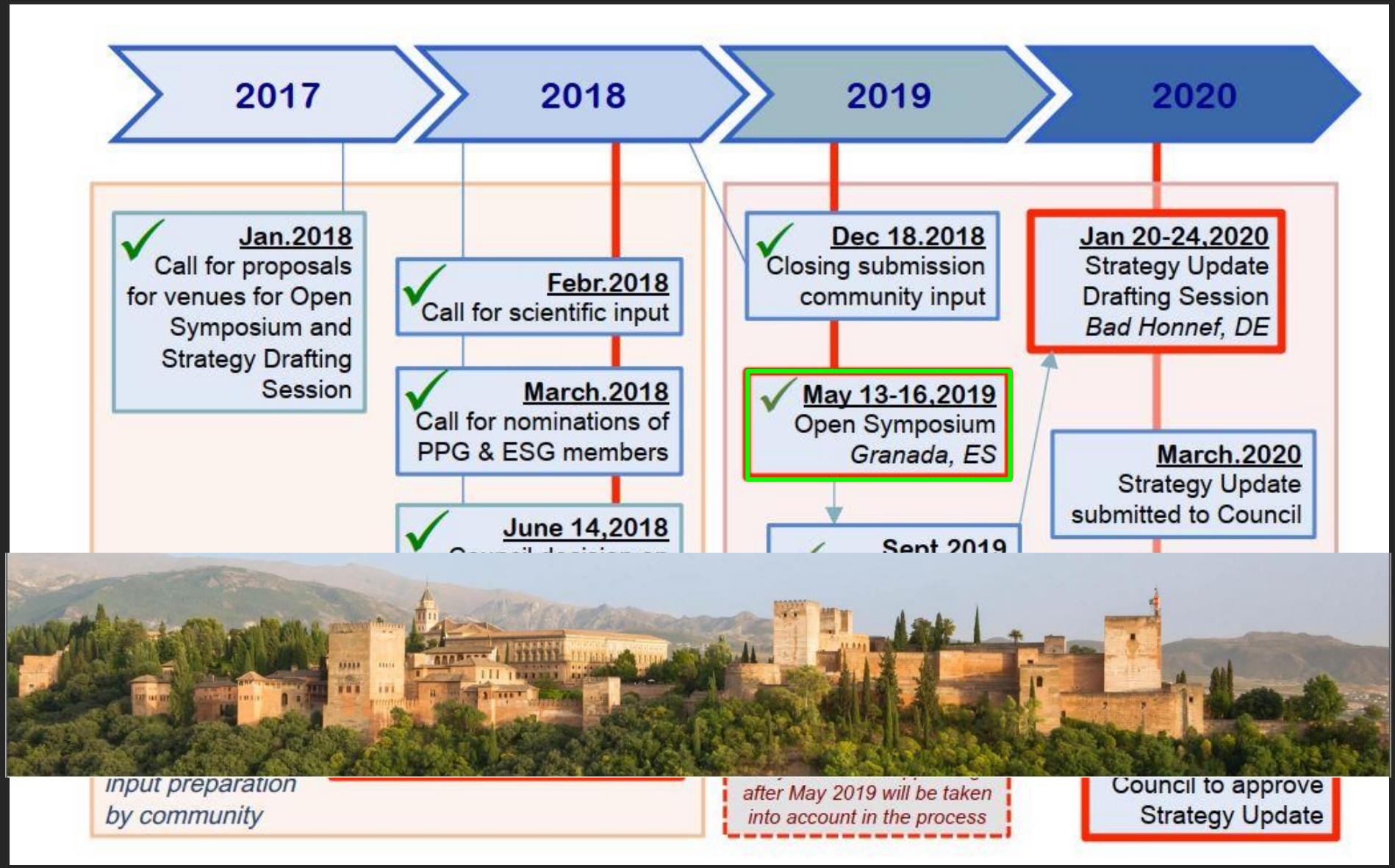
Other elements of strategy

using material from J. D'Hondt's presentation @ EPS-HEPP board (Nov 2019)

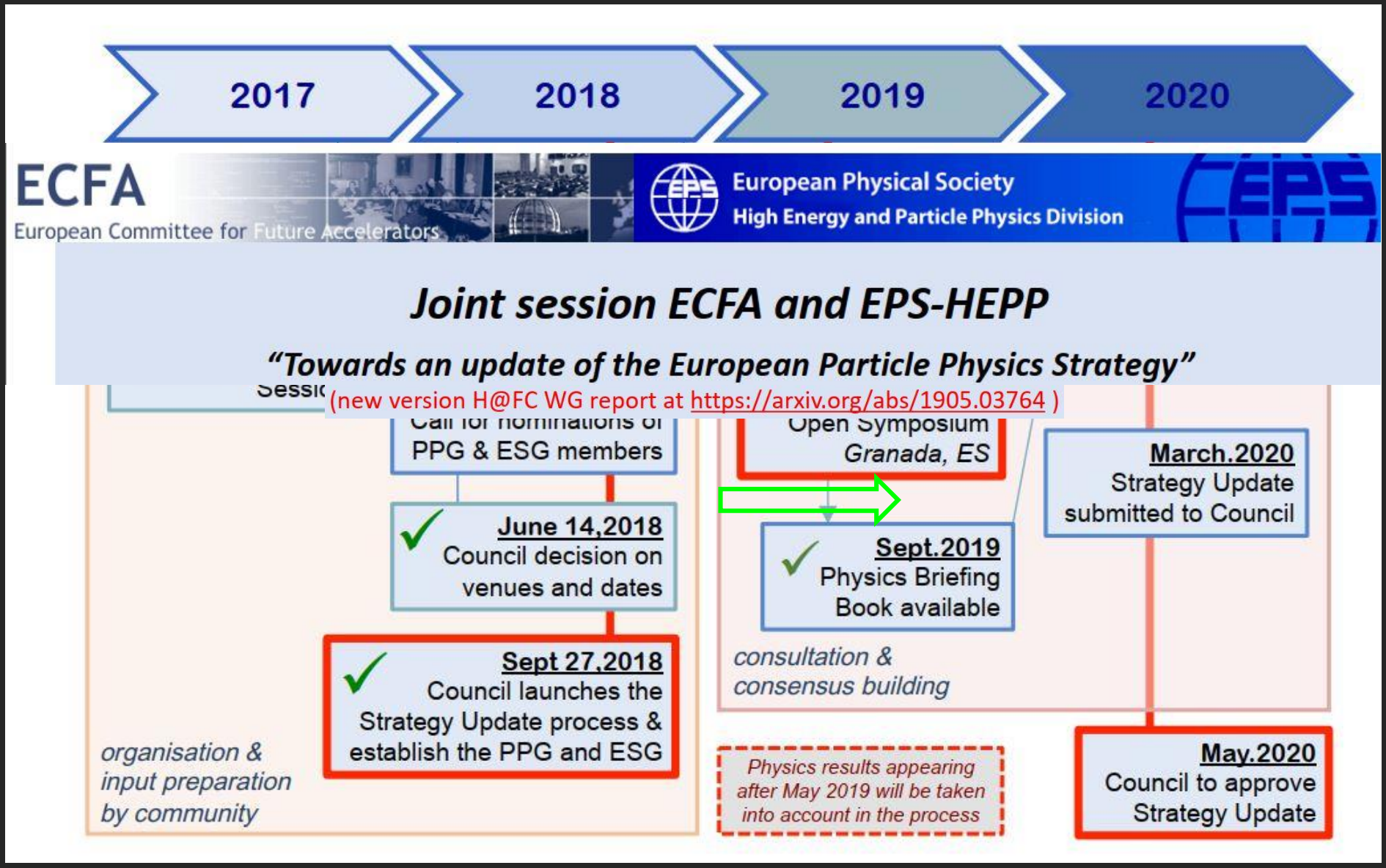
ESPP UPDATE ORGANIZATION



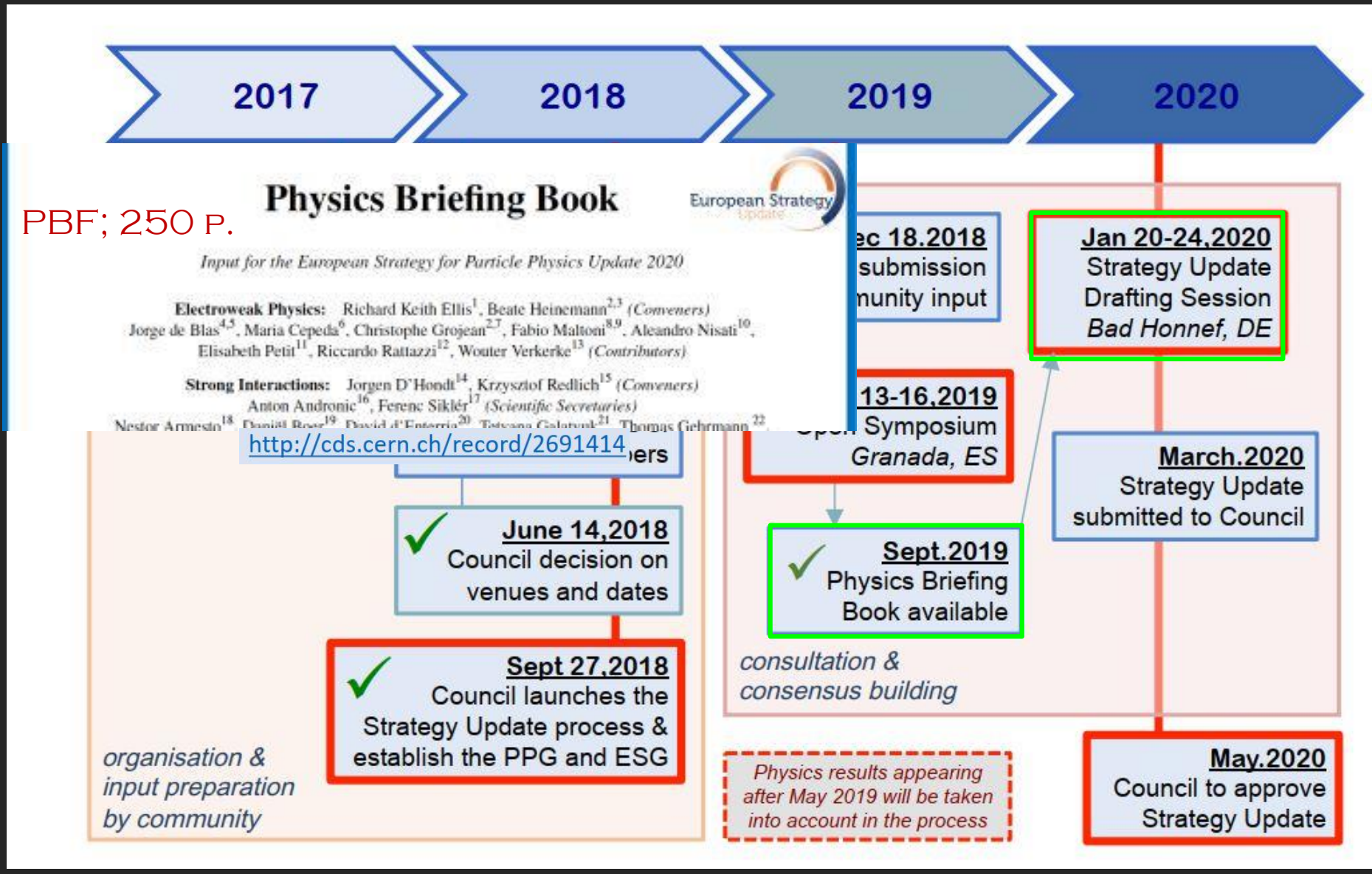
ESPP UPDATE ORGANIZATION



ESPP UPDATE ORGANIZATION



ESPP UPDATE ORGANIZATION



Previous Strategy

European Particle Physics Strategy 2013

https://cds.cern.ch/record/1567258/files/esc-e-106.pdf

NARROW FIELD

1) Europe's top priority should be the exploitation of the full potential of the LHC, including the high luminosity upgrade of the machine and detectors with a view to collecting ten times more data than in the initial design, by around 2030.

2) CERN should undertake design studies for accelerator projects in a global context, with emphasis on proton-proton and electron-positron high-energy frontier machines.

3) Europe looks forward to a [ILC] proposal from Japan to discuss a possible participation.

4) CERN should develop a neutrino programme to pave the way for a substantial European role infuture long-baseline experiments.

European Particle Physics Strategy 2013

https://cds.cern.ch/record/1567258/files/esc-e-106.pdf

Diversity

a) Europe should support a diverse, vibrant theoretical physics programme, ranging from abstract to applied topics, in close collaboration with experiments and extending to neighboring fields such as astroparticle physics and cosmology.

b) Experiments in Europe with unique reach should be supported, as well as participation in experiments in other regions of the world.

c) Detector R&D programmes should be supported strongly at CERN, national institutes, laboratories and universities.

d) In the coming years, CERN should seek a closer collaboration with ApPEC* on detector R&D with a view to maintaining the community's capability for unique projects in this field.
*Astroparticle Physics European Consortium

e) CERN should continue to work with NuPECC** on topics of mutual interest.
**Nuclear Physics European Collaboration Committee

European Particle Physics Strategy 2013 actions

1) HL-LHC:

approved by CERN Council; 2025 - 2038; 13 TeV, 3-4 ab^{-1}; ~10^3 MCHF (new Nb_3Sn IR-quads, 11T Nb_3Sn dipoles); detector upgrades

- ALICE → "A next-generation LHC heavy-ion experiment"
- "Exploring the Energy Frontier with Deep Inelastic Scattering at the LHC" (i.e. LHeC and PERLE; CDR)

2) Accelerator project design studies:

later

3) ILC:

"Following the opinion of the Science Council of Japan (SCJ), MEXT has not yet reached a declaration for hosting the ILC in Japan at the moment." (March 2019)

M. Yamauchi @ ESG (CERN, December 2019), private comm.:

MEXT, members of Federation of Diet Members for the ILC → Federal Ministry of Education and Research (Germany), Ministry of Higher Education, Research and Innovation (France) → establish a discussion group (DG)

DG → DOE (US) → exchange opinions and conduct collaborative R&D

International cost-sharing

Civil engineering and land acquisition are responsibility of the host state.

Accelerator components should be provided by all the member states as in-kind cont.

The operational cost should be shared among the member states.

MEXT → LCB meeting Feb 2020 to update its view on the ILC after the SCJ master plan has become available

European Particle Physics Strategy 2013 actions

2) neutrino programme:
since 2014 the CERN Neutrino Platform fosters the collaboration of ~90 European institutions in detector R&D and construction.
e.g. DUNE@LBNF (US) and ND280@T2K (Japan)

b) diversity:
Experiments in Europe with unique reach should be supported, as well as participation in experiments in other regions of the world. Examples: quark flavour physics, dipole moments, charged-lepton flavour violation, etc.

Listed below facilities/experiments in Europe in the realm of particle physics
- Beam Dump Facility (SHiP, TauFV)
- eSPS (LDMX)
- COMPASS/AMBER as QCD facility, MUonE, KLEVER, nuSTORM, MATHUSLA, FASER, CODEX-b, milliQan, LHCSpin, REDTOP, DIRAC, ...
- CPEDM@Julich, ESSvSB@ESS, PERLE@Saclay, LFV@PSI, ...

Should diversity be emphasized as one of main priorities in the update?

d) APPEC:
private observation: CERN DG seems not to be very enthusiastic

European Particle Physics Strategy 2013 actions

2) Accelerator project design studies:

„natural way“:
high energy (hadronic) machine →
discovery (SPS; *W, Z* discovery)
precision (electron) machine →
precision property measurements (LEP; *Z, W* factory)

LHC (*h* discovery) → ??? (*h* factory)

major difference:
@ end of 20th century we had SM →
param. to be measured, new phenomena (*h*) at $\Lambda < \mathcal{O}$(TeV)
@ start of 21st century
param. of SM (m_h) such that Λ < 10^{19} GeV (m_ν; 10^{15} GeV)

h naturalness: $\varepsilon \sim (m_h/\Delta m_h)^2$; $\Delta m_h \sim \Lambda \sim 10^{19}$ GeV $\varepsilon \sim 10^{-34}$ (fine tunning)

meas. mass *quantum corr.*

Accelerator / Abbrev.

DICTIONARY OF MAIN ACC. ABBREVIATIONS:

HL-LHC: High Luminosity LHC (CERN)
HE-LHC: High Energy LHC (CERN; LHC tunnel with high field magnets)

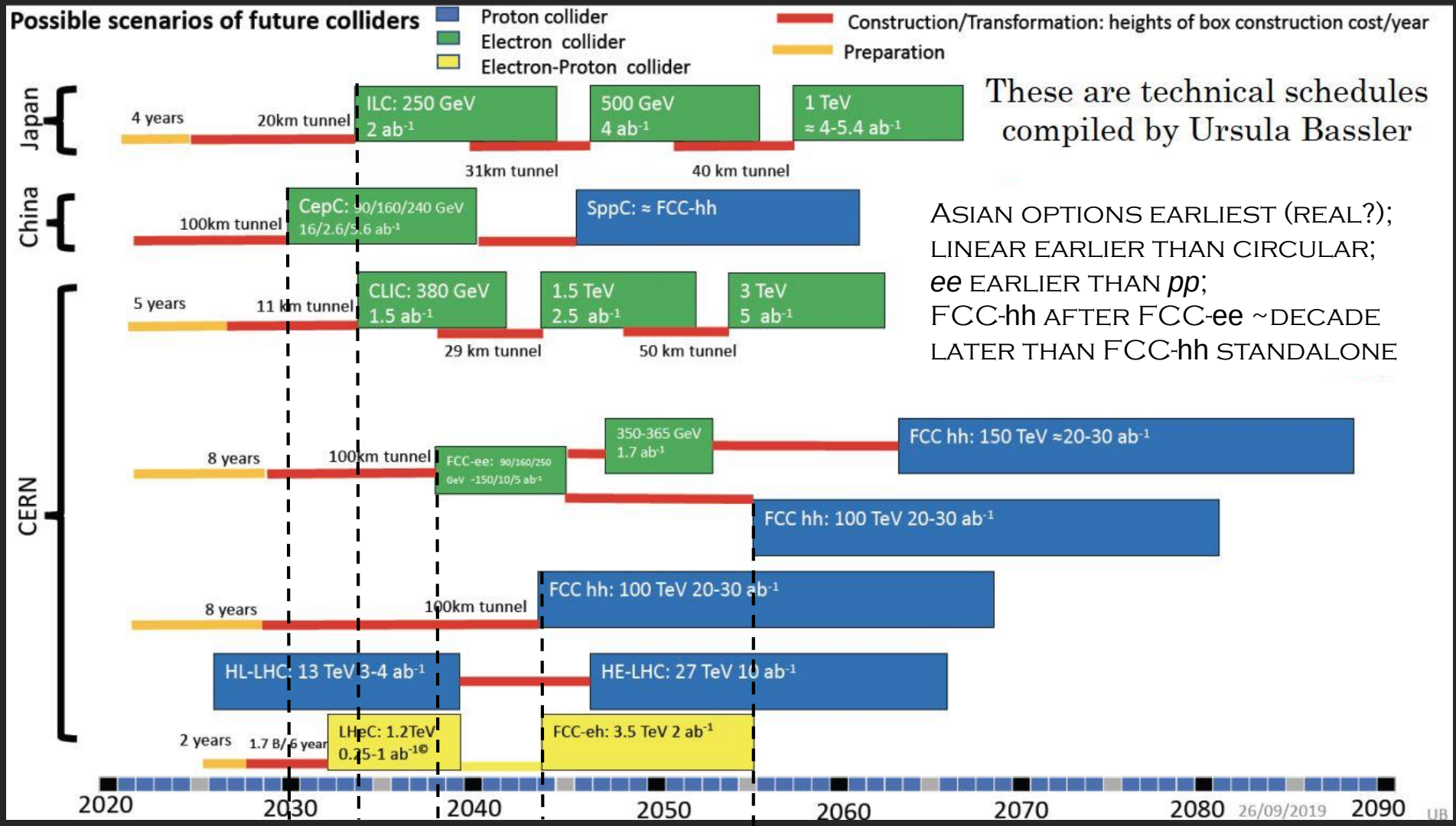
FCC: Future Circular Collider (CERN; e^-e^+ option, -ee; *pp* option, -hh; *ep* option, -eh)
CepC: Circular Electron Positron Collider (China)

ILC: International Linear Collider (Japan)
CLIC: Compact Linear Collider (CERN)

LE-FCC: Low Energy FCC (CERN; FCC tunnel - 100 km - with LHC-like magnets)
SppC: Super Proton Proton Collider (China; possible upgrade of CepC)

Accelerator / Projects

2) Accelerator project design studies:



Accelerator / Parameters

Accelerator parameters:

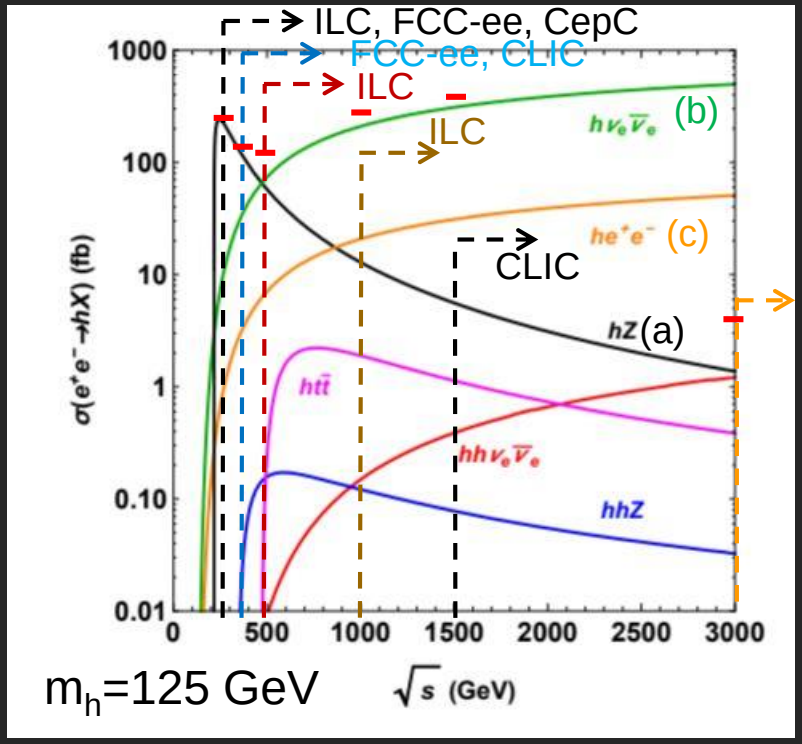
Collider	Type	$\sqrt{s}$	$\mathscr{P}$ [%] $[e^-/e^+]$	N_{Det}	$\mathscr{L}_{inst}$/Det. $[10^{34}cm^{-2}s^{-1}]$	$\mathscr{L}$ $[ab^{-1}]$	Time [years]	
HL-LHC	*pp*	14 TeV	–	2	5	6.0	12	APPROVED
HE-LHC	*pp*	27 TeV	–	2	16	15.0	20	LOWER √S THAN FCC-hh
FCC-hh	*pp*	100 TeV	–	2	30	30.0	25	16 T MAGNET TECHNOLOGY?
FCC-ee	*ee*	M_Z	0/0	2	100/200	150	4	*Z* FACTORY
		$2M_W$	0/0	2	25	10	1-2	*WW* FACTORY
		240 GeV	0/0	2	7	5	3	*h* FACTORY
		$2m_{top}$	0/0	2	0.8/1.4	1.5	5	*tt* FACTORY
		(1y SD before $2m_{top}$ run)					(+1)	
ILC	*ee*	250 GeV	±80/±30	1	1.35/2.7	2.0	11.5	*h, WW* FACTORY
		350 GeV	±80/±30	1	1.6	0.2	1	*tt* FACTORY
		500 GeV	±80/±30	1	1.8/3.6	4.0	8.5	
		(1y SD after 250 GeV run)					(+1)	
CEPC	*ee*	M_Z	0/0	2	17/32	16	2	~ FCC-ee, LOWER $\mathscr{L}_{INST}$
		$2M_W$	0/0	2	10	2.6	1	NO *tt*
		240 GeV	0/0	2	3	5.6	7	
CLIC	*ee*	380 GeV	±80/0	1	1.5	1.0	8	*h, WW, tt* FACTORY
		1.5 TeV	±80/0	1	3.7	2.5	7	
		3.0 TeV	±80/0	1	6.0	5.0	8	
		(2y SDs between energy stages)					(+4)	
LHeC	*ep*	1.3 TeV	–	1	0.8	1.0	15	
HE-LHeC	*ep*	1.8 TeV	–	1	1.5	2.0	20	
FCC-eh	*ep*	3.5 TeV	–	1	1.5	2.0	25	

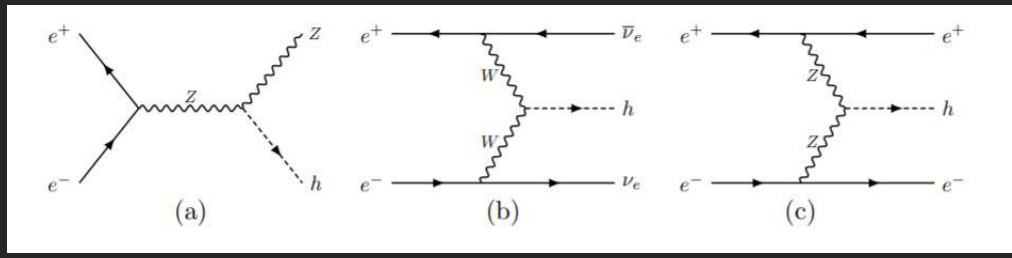
PRIVATE OBSERVATION:
$\mathscr{L}_{DES}^{BELLE2} = 8 \cdot 10^{35}\ cm^{-2}\ s^{-1}$
FAR FROM TRIVIAL (FOR e^+e^-)

PBF

Higgs production at e^+e^-

Main production mechanisms





Higgs strahlung Vector boson fusion

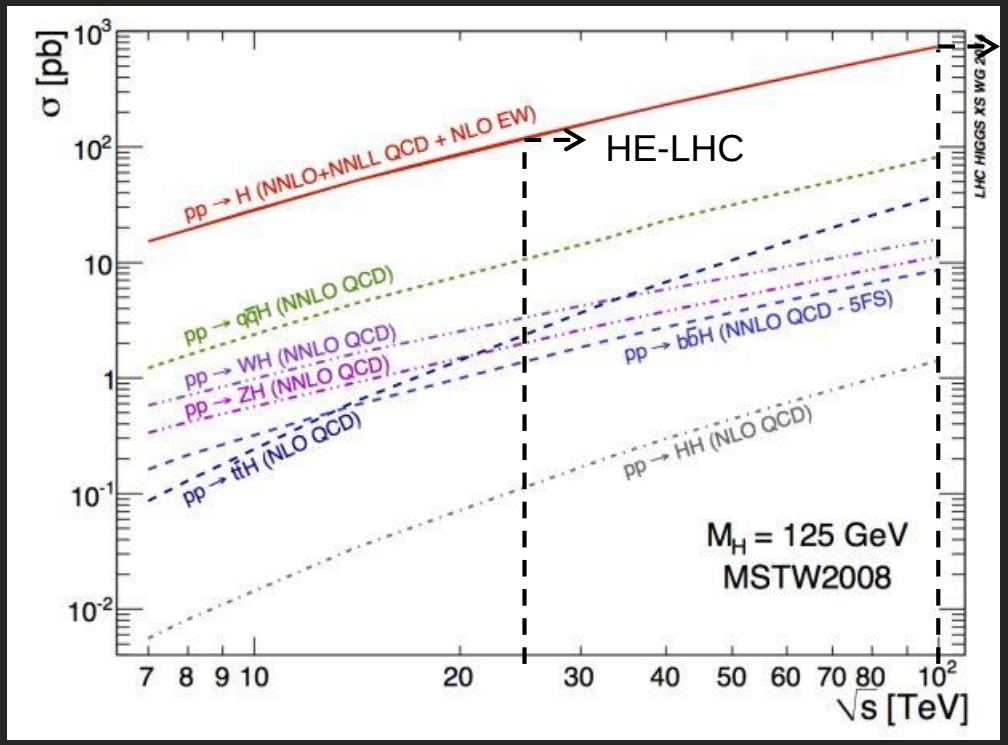
- ~ TOTAL σ

ALL OPTIONS: σ ~ FEW 10^2 FB

B. Li et al., arXiv:1710.00184

Higgs production at *pp*

Main production mechanisms



HE-LHC

FCC-hh, SppC

- ~ TOTAL σ

σ(√s>30 TeV) ~ few 10^2 pb

PBF

Direct Searches

General physics options for BSM physics:

Direct searches

HE-LHC: $\sqrt{s}_{MAX}$ = 27 TeV
FCC-hh: $\sqrt{s}_{MAX}$ = 100-150 TeV
SppC (from CepC): ~ FCC-hh

$$m_{\tilde{g}} \leq 17\ TeV;\ m_{\tilde{t}} \leq 10\ TeV;\ m_{h'} \leq 5-20\ TeV$$

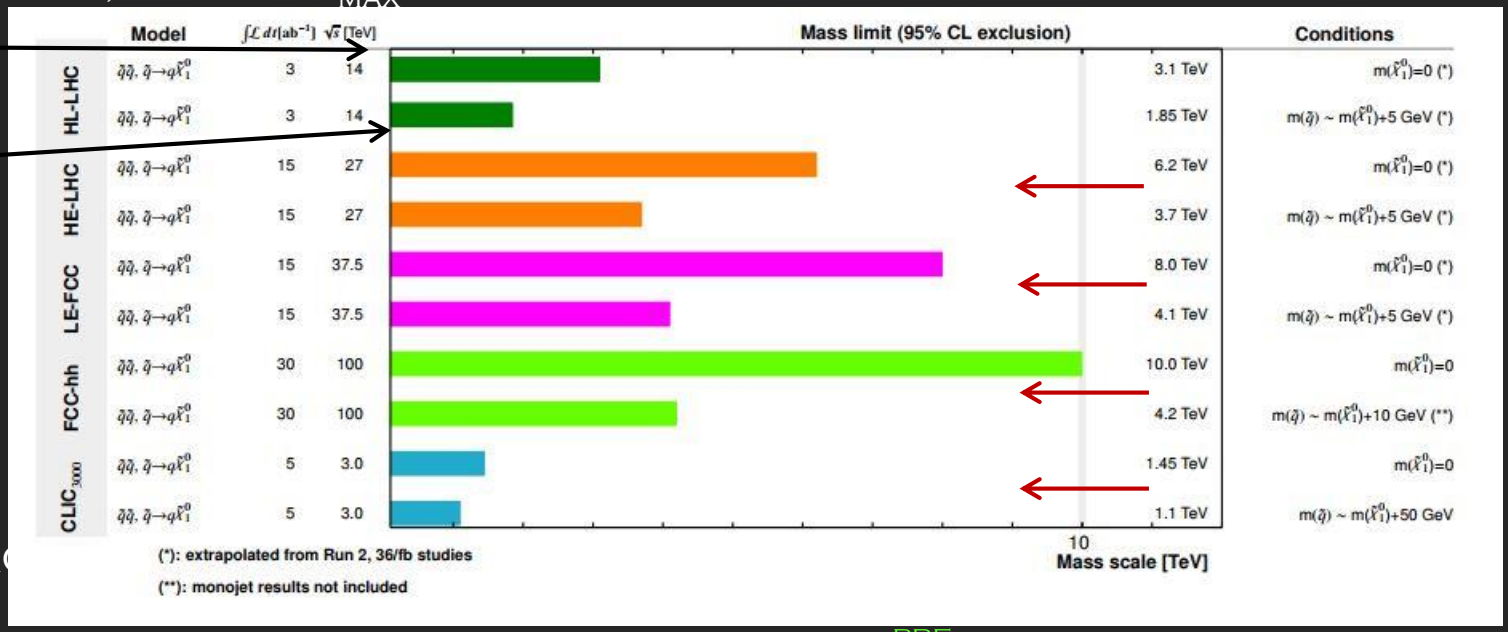
FCC-hh ~ 1.5xHE-LHC
FCC-hh ~ 1.2xLE-FCC
LINEAR NOT COMPETITIVE

LINEAR COLL: REACH ~ $\sqrt{s}/2$
(ILC: $\sqrt{s}_{MAX}$ = 1 TeV, CLIC: $\sqrt{s}_{MAX}$ =3 TeV)

$$m_{\tilde{\chi}_1^0} = 0(\ jets + p_T^{miss}\ )$$

$$m_{\tilde{q}} \sim m_{\tilde{\chi}_1^0} + 5GeV$$

$(monojets)$

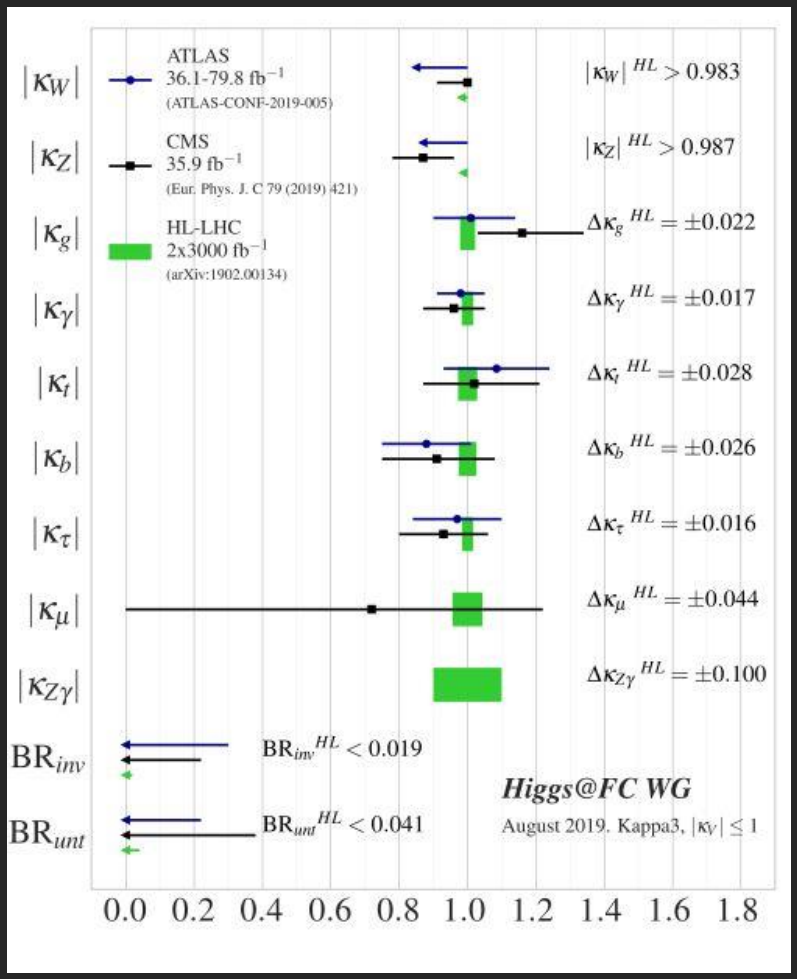


INDIRECT SEAR

PBF

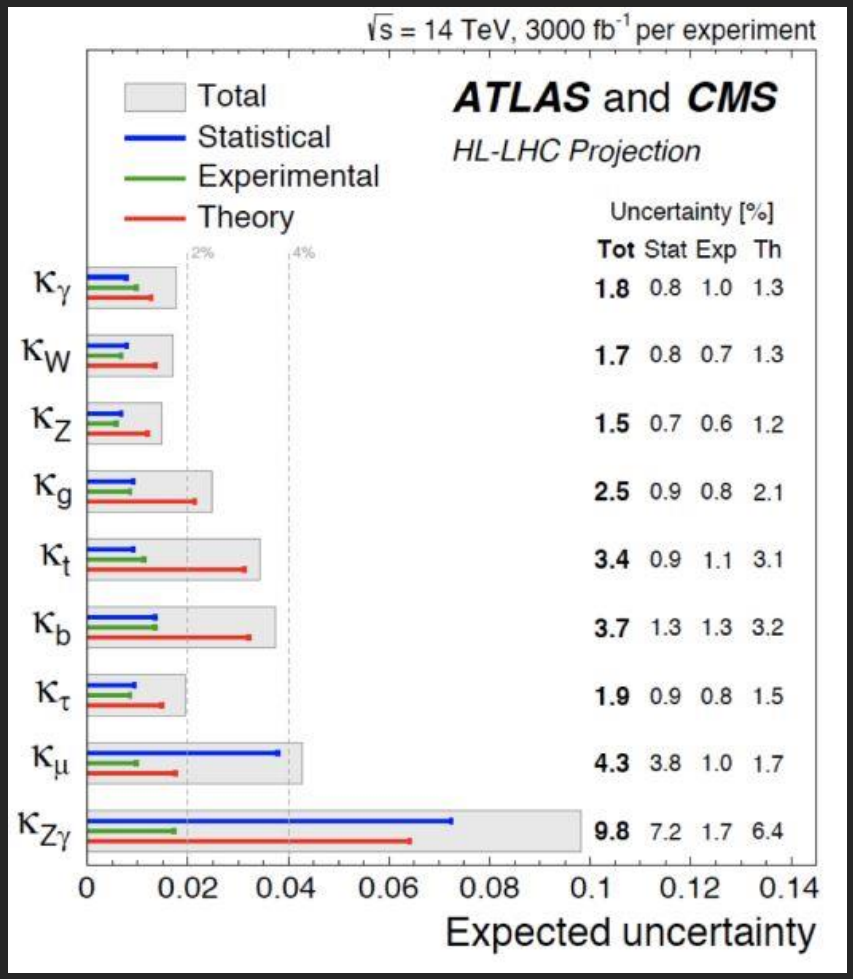
Indirect Searches

BROAD PHYSICS OPTIONS FOR BSM PHYSICS:
INDIRECT SEARCHES
FOCUS ON *h* COUPLINGS
HL-LHC: CURRENT / EXPECTED



PBF

EXPECTED / THEORY

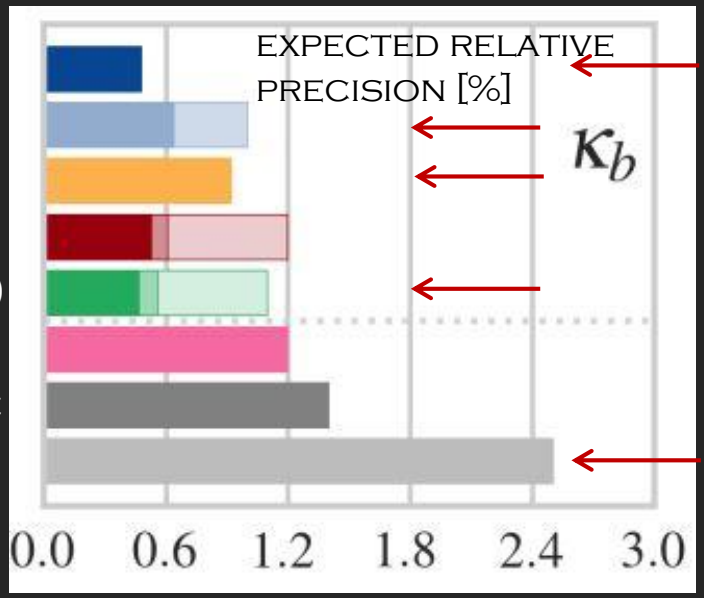


Indirect Searches

BROAD PHYSICS OPTIONS FOR BSM PHYSICS:
INDIRECT SEARCHES
FOCUS ON *h* COUPLINGS

EXAMPLE OF *h* - *b* COUPLING
EXPECTED RELATIVE PRCISION

FCC-ee/eh/hh
FCC-ee(365, 240)
CepC
CLIC(3, 1.5, 0.38)
ILC(1, 0.5, 0.25)
LHeC
HE-LHC
HL-LHC



PBF

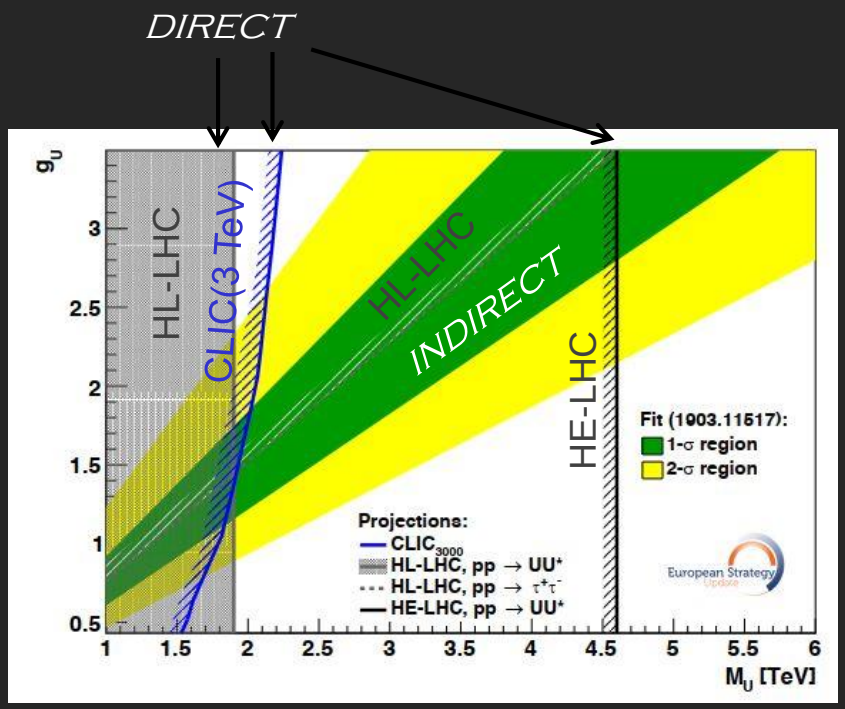
FCC-ee ~ CepC ~ ILC

FCC-ee ~ 1/2 HL-LHC

FCC-hh ~ 1/2 FCC-ee

(SIMILAR FOR OTHER COUPLINGS)

Direct / indirect detection



PBF

vector singlet LQ U_1

Technology

Magnet technology

14 - 16 T (25-28 TeV @ LHC, 90 -100 TeV @ FCC):
Nb_3Sn, 20-30 years b.c. (before construction)

12 - 14 T (21 - 25 TeV @ LHC, 75-90 TeV @ FCC):
Nb_3Sn, 15-20 years b.c. (14 T demonstrated recently)

9 - 12 T (16 - 21 TeV @ LHC, 55 - 75 TeV @ FCC):
Nb_3Sn, 5 -10 years b.c. (needed for HL-LHC)

6 - 8 T (35 - 50 TeV @ FCC):
NbTi (similar to existing magnets @ LHC)

SCENARIOS

ESG TO DISCUSS (AT LEAST) FOLLOWING SCENARIOS WITH FOCUS ON 1ST GENERATION

SCENARIO NAME	2020-2040	2040-2060	2060-2080
		1st gen technology	2nd gen technology
CLIC-all	HL-LHC	**CLIC380-1500**	CLIC3000 / other tech
CLIC-FCC	HL-LHC	**CLIC380**	FCC-h/e/A (Adv HF magnets) / other tech
FCC-all	HL-LHC	**FCC-ee (90-365)**	FCC-h/e/A (Adv HF magnets) / other tech
LE-to-HE-FCC-h/e/A	HL-LHC	**LE-FCC-h/e/A (low-field magnets)**	FCC-h/e/A (Adv HF magnets) / other tech
LHeC-FCC-h/e/A	HL-LHC + LHeC	**LHeC**	FCC-h/e/A (Adv HF magnets) / other tech

OPTIONS, IF TECHNOLOGY AVAILABLE (PLASMA ACC., MUONS, HTS, ...);

→ DECISSION ABOUT AVAILABLE TECHNOLOGIES

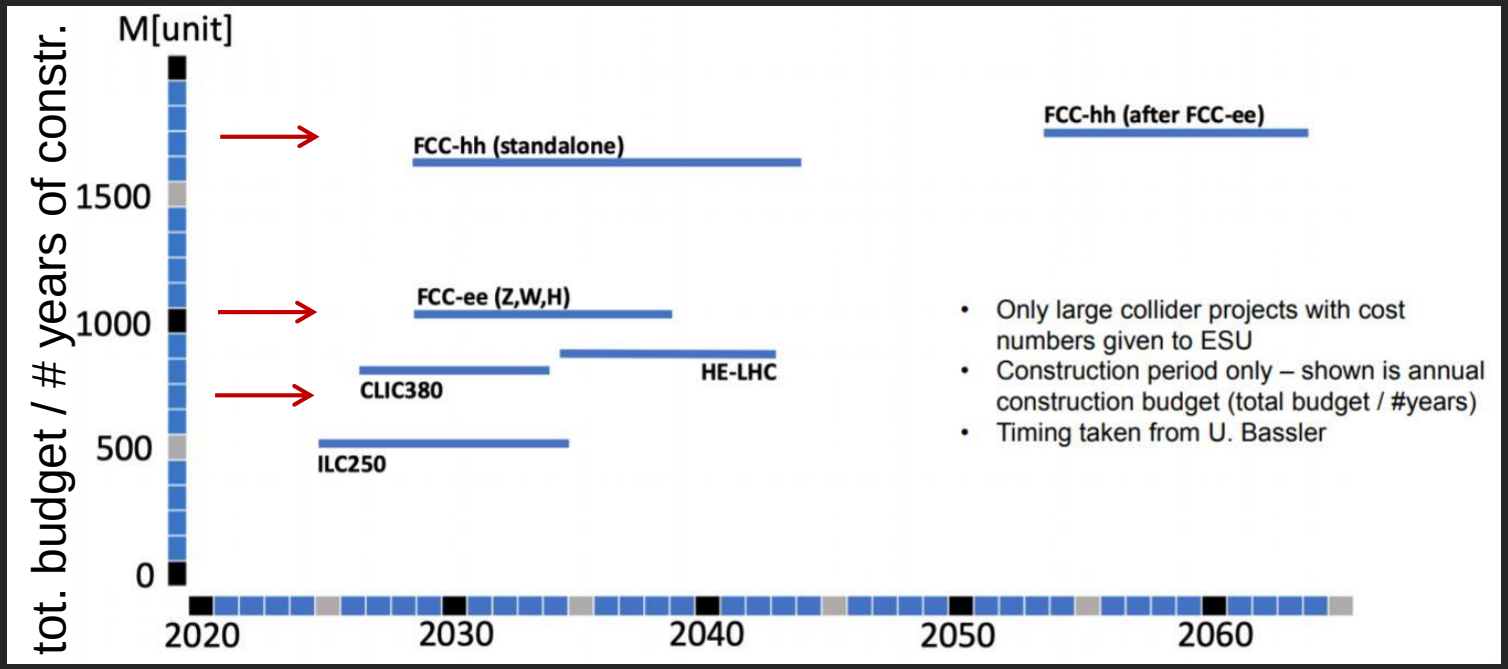
Accelerator / costs

Approx. costs
(units= CHF/EUR/USD;
typical accuracy estmated to ±30%)

SHIP: 70 M; Super Tau Charm Fact.:
415 M; Einstein telescope: 1 G

CLIC(380 GeV): 6 G, detect. 400 M
ILC: 5 G + 10 kFTE - 700 M (250 GeV), 8 G + 13.5 kFTE - 1 G (500 GeV), detect. 400M
FCC-ee (*Z, WW, h*): 10 G (incl. civil eng. 5.5 G), 85 M / year operational, +1 G (*tt*)
FCC-hh (after FCC-ee): 17 G, 180 M / year operational
FCC-hh (standalone): 24 G, 180 M / year operational
HE-LHC: 7 G, 55 M / year operational
LE-FCC (6T, 40 TeV): 5 GCHF w/o tunnel

J. Mnich, ESG meeting June 2019



ILC ~ CLIC
FCC-ee ~ 2x ILC
FCC-hh ~
2x FCC-ee

Other Elements of Strategy

PRIVATE OBSERVATION:
MOST IMPORTANT FOR CURRENT STRATEGY: KEEP YOUNG POPLE IN THE FIELD

ON PAPER: HL-LHC END ∪ FCC-ee START; REALITY?
NEED WORK ON DETECTOR DEVELOPMENT (UNTIL ~ 2045) W/ ONLY HL-LHC RUNNING (UNLESS LINEAR OR CEPC?)

DIVERSITY
COLL. WITH APPEC?

WORKING GROUP ON PUBLIC ENGAGEMENT, EDUCATION AND COMMUNICATION (CHAIR: S. DE JONG)

...FUNDING OF ALL SCIENCE RESEARCH ... ACCOMPANIED BY RESOURCES FOR PUBLIC ENGAGEMENT ACTIVITIES.

...COOPERATION BETWEEN EPPCN AND THE COMMUNICATION ARM OF APPEC.

...EDUCATION RESEARCH HUB IS CREATED AT CERN.

...COMMUNITY MUST ENGAGE MORE .... WITH SCIENTISTS FROM OTHER DISCIPLINES IN ORDER TO ENHANCE THE UNDERSTANDING .... OF PARTICLE PHYSICS.

BASIC KNOWLEDGE OF THE SM ... ADOPTED IN THE REGULAR SCHOOL CURRICULUM.

Other Elements of Strategy

Working group on Relation with other groups and organisations & CERN support for nuclear and astroparticle physics (Chair: T. Nakada)

... The Working Group 3 recommends that the approval process for obtaining technical support from CERN to follow a similar transparent process as for the Recognised Experiment.

PRIVATE OBSERVATION:
very scarce at the moment...

Working group for governance and funding around CERN hosting a next generation collider, as a globally funded project; governance and funding of a European contribution to a next generation collider constructed outside Europe;

Given the known pressures on the CERN budget and the ambitions for CERN to retain its lead of the energy-frontier, it seems likely that a European contribution to a future collider outside Europe would need a significant component of direct national contributions

...it is hard to decouple governance of the next collider from CERN

Directions
(acc. to H. Abramowicz, ESG meeting Dec 2019)

Should not commit to a detailed roadmap beyond 2060

Next facility after LHC should be an e^+e^- collider
(Higgs factory – precision frontier)

Europe should lead the energy frontier (pretty much unanimous)

Strong support for broad R&D in accelerator technologies

High priority for "diversity" programme with no explicit ranking