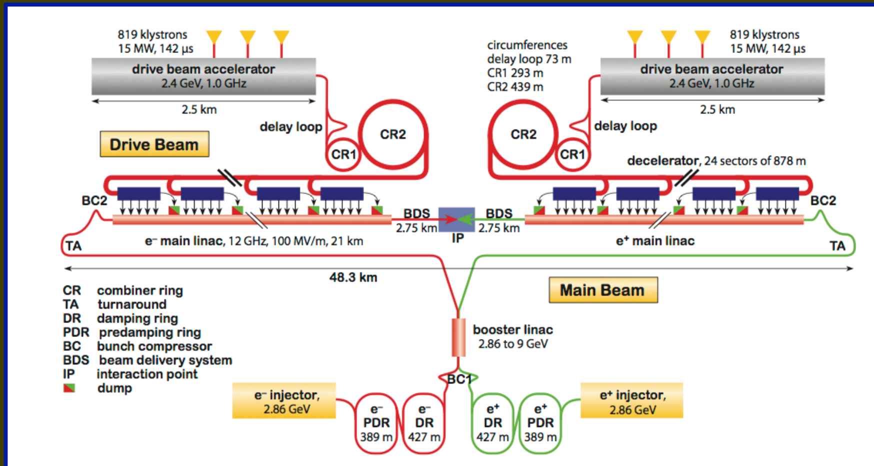
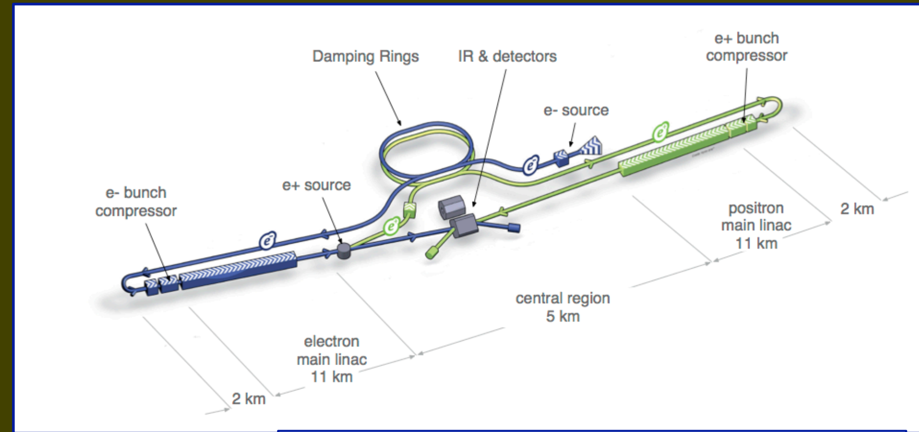
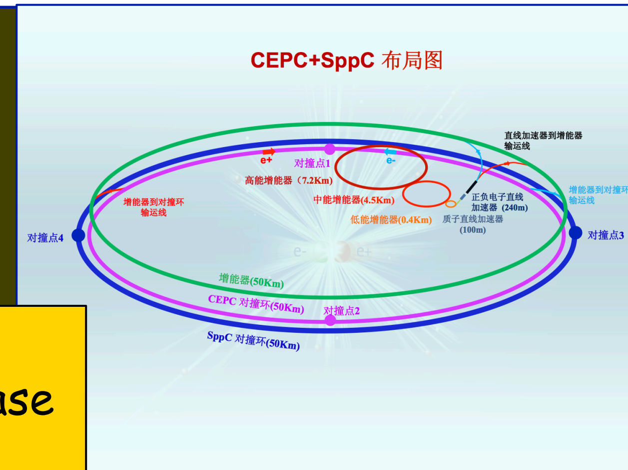
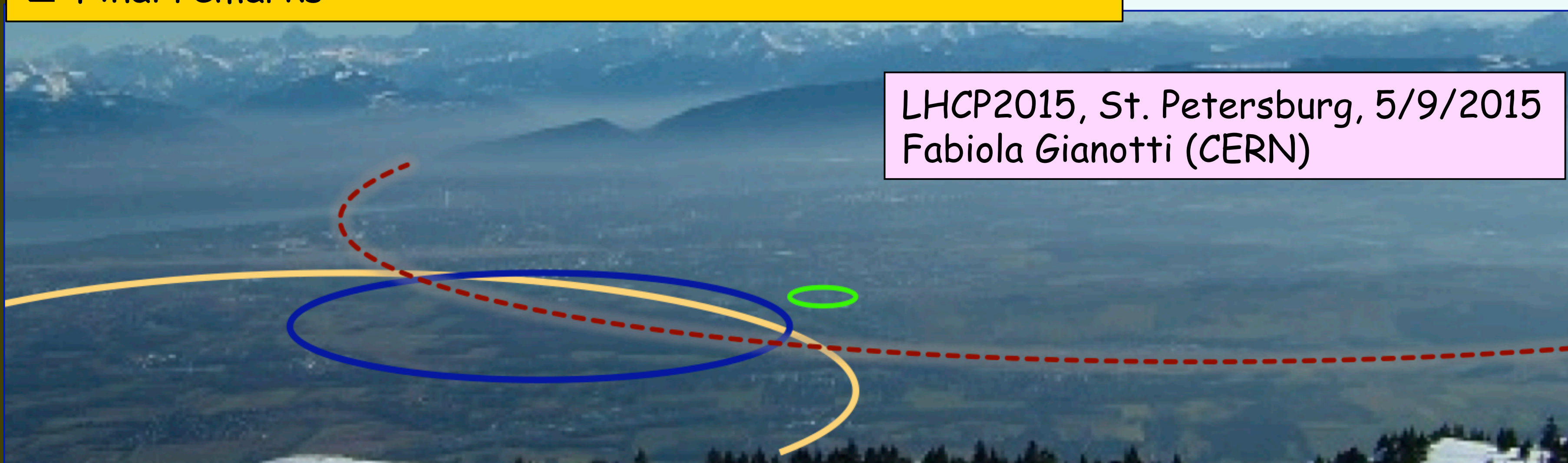




Prospects for future high-E colliders

- ❑ Introduction
- ❑ Main options for future colliders and their physics case
- ❑ Final remarks





LHCP2015, St. Petersburg, 5/9/2015
Fabiola Gianotti (CERN)

With the discovery of the H boson, a triumph for particle physics and high-E colliders, the SM has been completed. Technically, it works up to the Planck scale.

However: many crucial questions, raised also by experimental observations, remain open. They cannot be explained within the SM. The H boson itself is related to some of the deepest questions.

These questions require NEW PHYSICS

Main questions in today's particle physics (a non-exhaustive list ..)

Why is the H boson so light (so-called "naturalness" or "hierarchy" problem) ?

What is the origin of the matter-antimatter asymmetry in the Universe ?

Why 3 fermion families ? How differently do neutral leptons, charged leptons and quarks behave ?

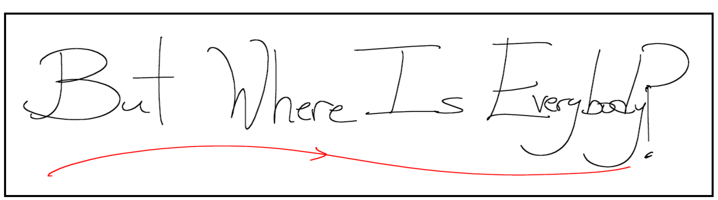
What is the origin of neutrino masses and oscillations ?

What is the composition of dark matter (23% of the Universe) ?

What is the cause of the Universe's accelerated expansion (today, primordial) ?

Why is Gravity so weak ?

However: NO direct evidence for new particles (yet ….) from LHC and other facilities



N. Arkani-Hamed

In other words: at what E scale(s) are the answers to these questions ?

The outstanding questions are compelling, difficult and interrelated → can only be successfully addressed through the variety of approaches we have developed (thanks also to strong advances in accelerator and detector technologies): particle colliders, neutrino experiments (solar, short/long baseline, reactors, $0\nu\beta\beta$ decays, …), cosmic surveys, dark matter direct and indirect detection, precision measurements of rare processes, dedicated searches (e.g. axions, dark-sector particles), …

Main questions and main approaches to address them

	High-E colliders	Dedicated high-precision experiments	Neutrino experiments	Dedicated searches	Cosmic surveys
H, EWSB	x	x		x	
Neutrinos	x (ν_R)		x	x	x
Dark Matter	x			x	x
Flavour, CP, matter/antimatter	x	x	x	x	x
New particles, forces, symmetries	x	x		x	
Universe acceleration					x

Combination of these complementary approaches is crucial to explore the largest range of E scales (directly and indirectly) and couplings, and properly interpret signs of new physics → hopefully build a coherent picture of the underlying theory.

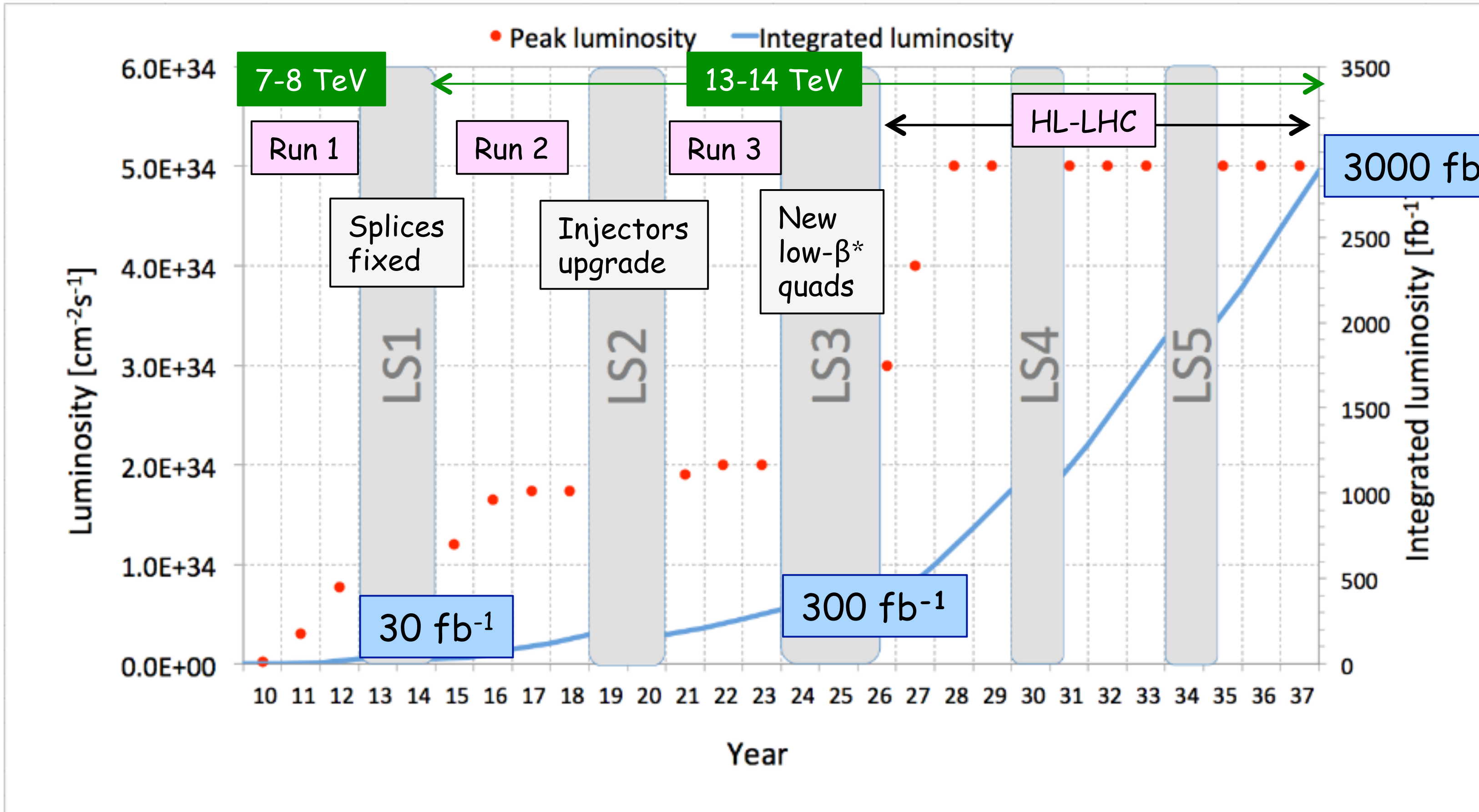
Options for future high-E (and high-L) colliders

Discussed here:

- Linear and circular e^+e^- colliders
- Very high-E proton-proton colliders
- Muon colliders (briefly)

Disclaimer: due to time limitation, I will not discuss other options: e.g. ep, γγ, ion colliders

The present and near/medium-term future: LHC and HL-LHC



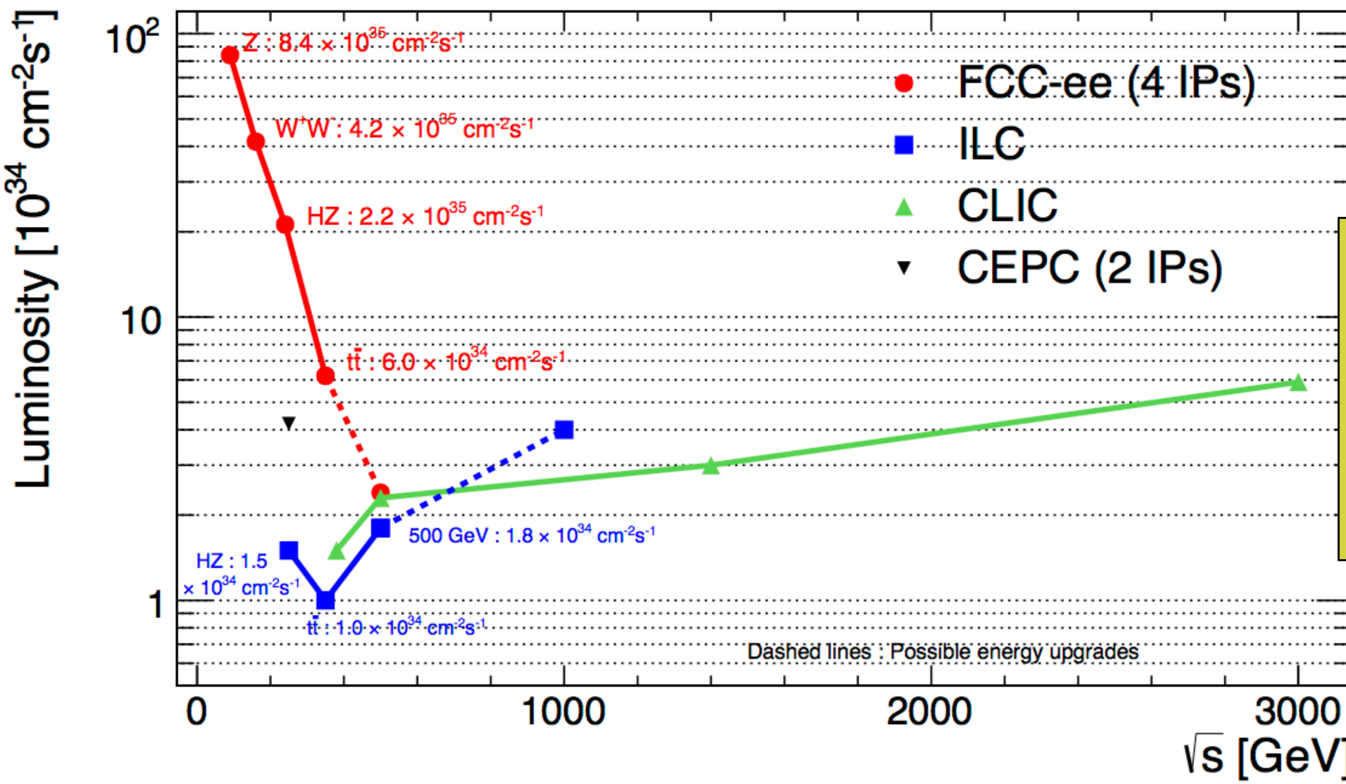
LHC is highest-E, highest-L operational collider → full exploitation ($\sqrt{s}$ ~ 14 TeV, 3000/fb) is mandatory:

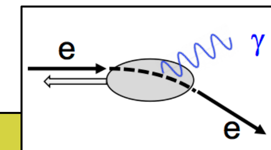
- ❑ If new physics discovered in Run 2-3:
  → first detailed exploration of new physics with well understood machine and experiments
- ❑ If no new physics in Run 2-3:
  → extend direct discovery potential by ~ 20-30% (up to m ~ 8 TeV)

In either case: measure H couplings to few percent (including 2nd generation: Hμμ)

Future e^+e^- colliders

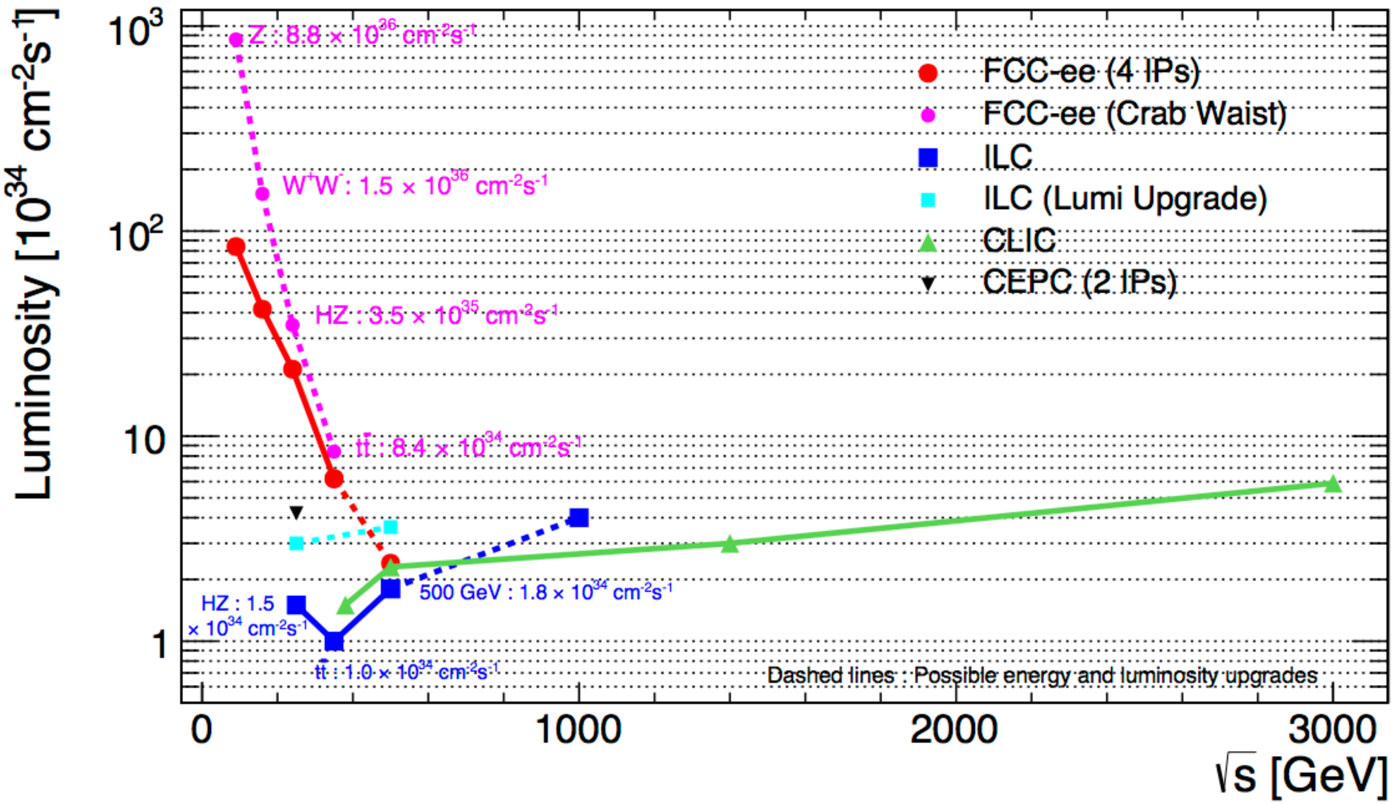
√s (GeV)	Main physics goals
90	Z-pole precision EW measurements beyond LEP, SLC
160	WW precision physics (mass at threshold)
250	H precision physics (HZ)
~350	H (HZ, Hνν) and top (mass, couplings) precision physics
500-3000	ttH, HH (self-couplings), direct searches for new physics





Linear:
- Larger √s reach
- Low repetition rate
  - → L from nm size beams
  - → large beamstrahlung
  - → larger E-spread
- Long. polarization easier

Circular:
- √s limited by SR ~ E^4_{beam}/R
- Large number of circulating bunches → high L (increases at lower √s as less SR → spare RF power used to accelerate more bunches). Note: need top-up injection ring to compensate fast L burn-off (lifetime ~ 30')
- Several interaction regions possible
- Precise E-beam measurement from resonant depolarization

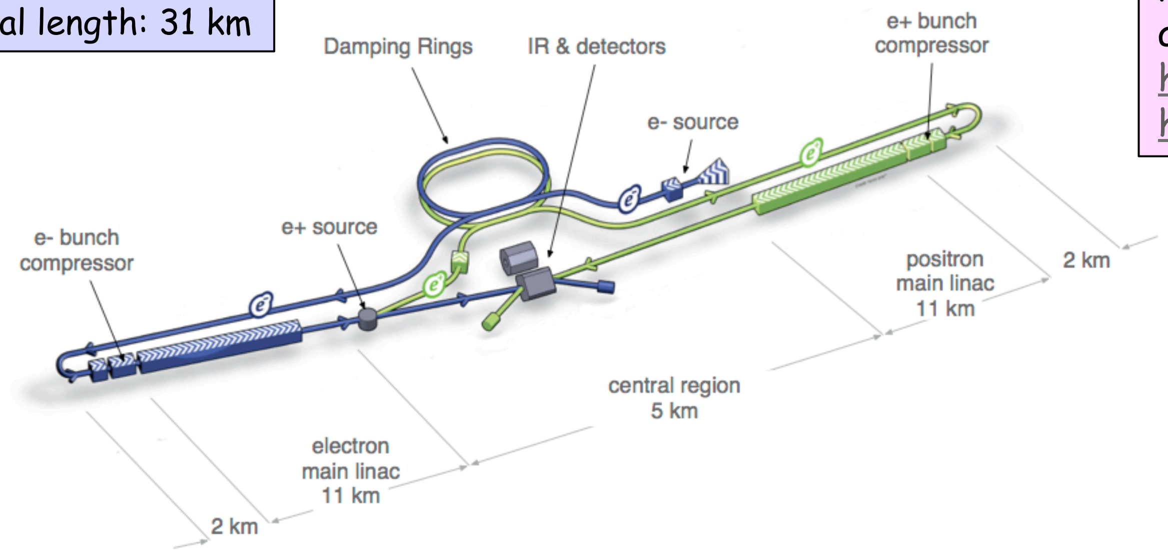


FCC-ee with crab waist scheme

ILC upgrade: 1312→ 2625 bunches per pulse

International Linear Collider (ILC)

Total length: 31 km



Technical Design Report June 2013

Most recent operating scenarios and physics results:
http://arxiv.org/abs/1506.07830
http://arxiv.org/abs/1506.05992

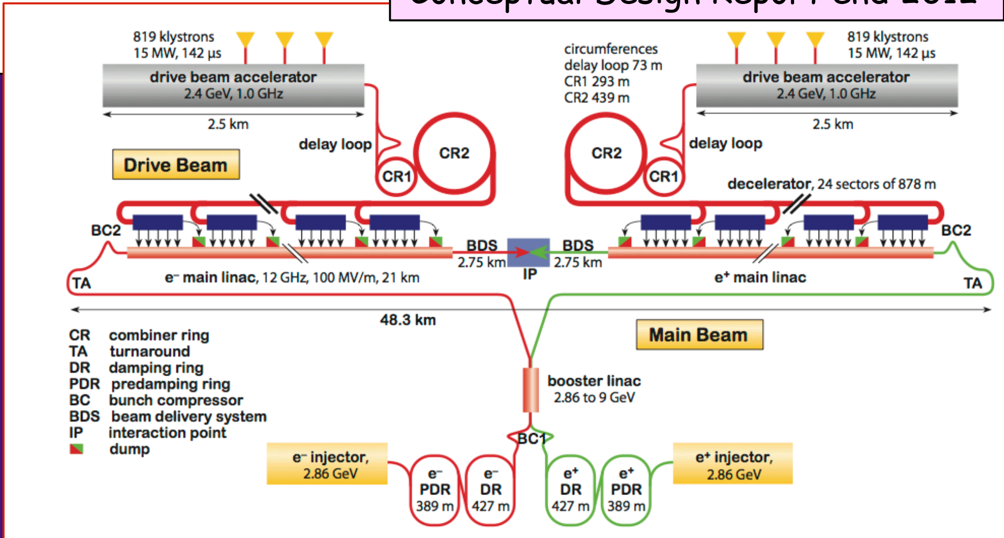
Most recent operating scenarios (~ 20 year programme):
- ❑ start at $\sqrt{s}$= 500 GeV (500 fb^{-1}), then 350 GeV (200 fb^{-1}), then 250 GeV (500 fb^{-1})
- ❑ L upgrade (double # of bunches): add 3500 (1500) fb^{-1} at 500 (250) GeV

- ❑ 500 GeV machine: ~ 15000 SCRF cavities, 31.5 MV/m
  Mature technology (20 years of R&D experience worldwide). European xFEL at DESY is 5% -scale "ILC prototype" (needed gradient 24 MV/m, several cavities reach 30 MV/m)
- ❑ 1 TeV machine requires extension of main Linacs (50 km) and 45 MV/m
- ❑ Challenges: positron source; final focus (squeeze and collide nm-size beams)

- ❑ Japan interested to host → decision based also on ongoing international discussions
- ❑ Construction could technically start as soon as decision taken, duration ~10 years
  → physics could start ~2030

Compact Linear Collider (CLIC)

Conceptual Design Report end 2012



Main challenges:

- ❑ 100 MV/m accelerating gradient needed for compact (50 km) multi-TeV (up to 3 TeV) collider
- ❑ Keep RF breakdown rate small
- ❑ Short (156 ns) beam trains → bunch spacing 0.5 ns to maximize luminosity
- ❑ 2-beam acceleration (new concept): efficient RF power transfer from low-E high-intensity drive beam to (warm) accelerating structures for main beam
- ❑ Power consumption (600 MW at 3 TeV): reduction under investigation
- ❑ nm size beams; final focus
- ❑ Detectors: huge beamstrahlung (20 TeV per train in calorimeters at 3 TeV) → 1-10 ns time stamps needed

Parameter	Unit	380 GeV	3 TeV
Centre-of-mass energy	TeV	0.38	3
Total luminosity	$10^{34}cm^{-2}s^{-1}$	1.5	5.9
Luminosity above 99% of $\sqrt{s}$	$10^{34}cm^{-2}s^{-1}$	0.9	2.0
Repetition frequency	Hz	50	50
Number of bunches per train		352	312
Bunch separation	ns	0.5	0.5
Acceleration gradient	MV/m	72	100

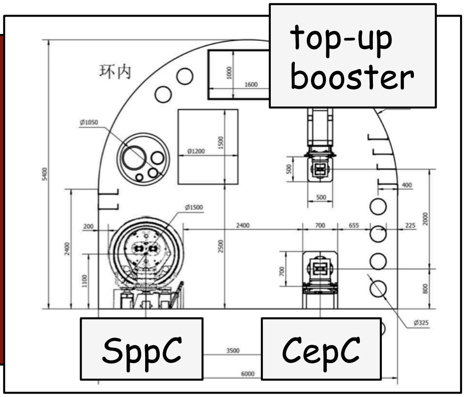
- ❑ Most recent operating scenario: start at $\sqrt{s}$=380 GeV for H and top physics
- ❑ If decision to proceed in ~ 2019 → construction could technically start ~2025, duration ~6 years for $\sqrt{s}$ ~ 380 GeV (11 km Linac) → physics could start before 2035

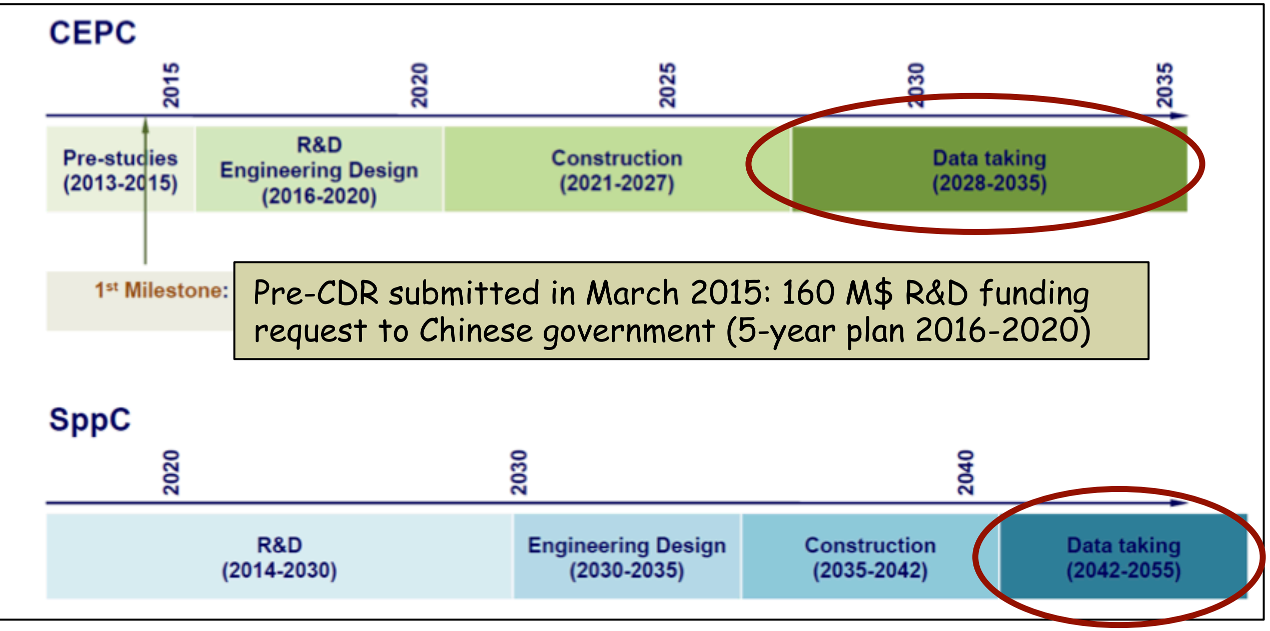
Circular colliders: the Chinese CepC, SppC

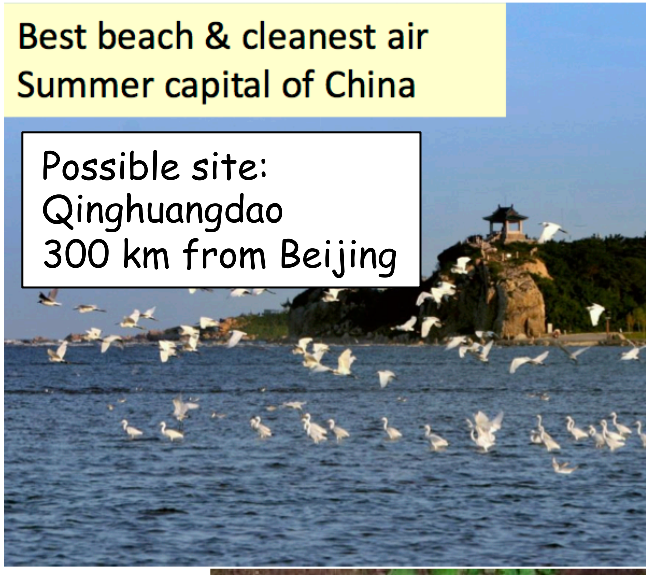
http://cepc.ihep.ac.cn/preCDR/volume.html

Baseline: 54 km ring
- ❑ CepC: $\sqrt{s}$=240 GeV e^+e^- ; L=2×10^{34}; 2 IP
- ❑ SppC: $\sqrt{s}$ = 70 TeV pp collider; L=1.2×10^{35}; 2 IP

If more funding: 100 km ring (→ 100-140 TeV pp) and/or separate pipes for e^+/e^- beams (→ not limited to 50 bunches/beam → higher L)







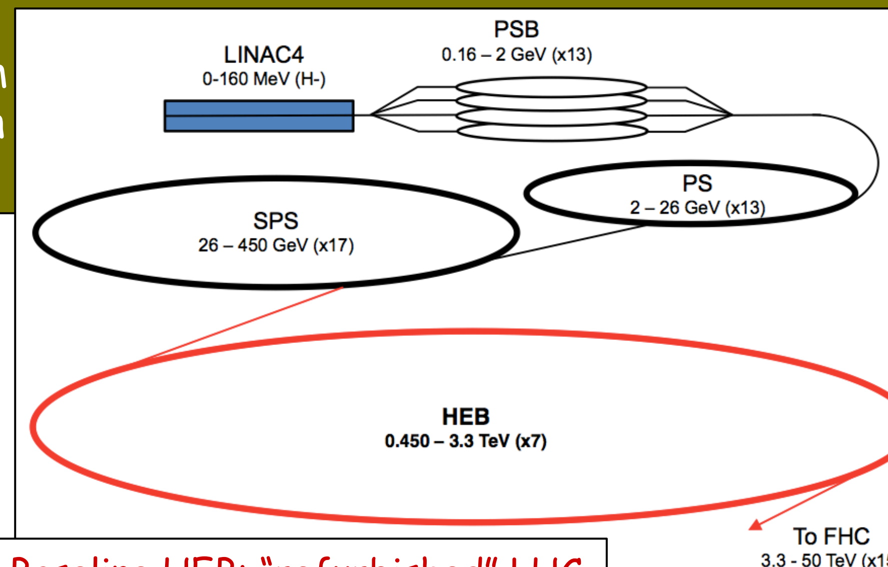
Circular colliders: the CERN FCC project

International conceptual design study for Future Circular Colliders in a ~100 km ring:

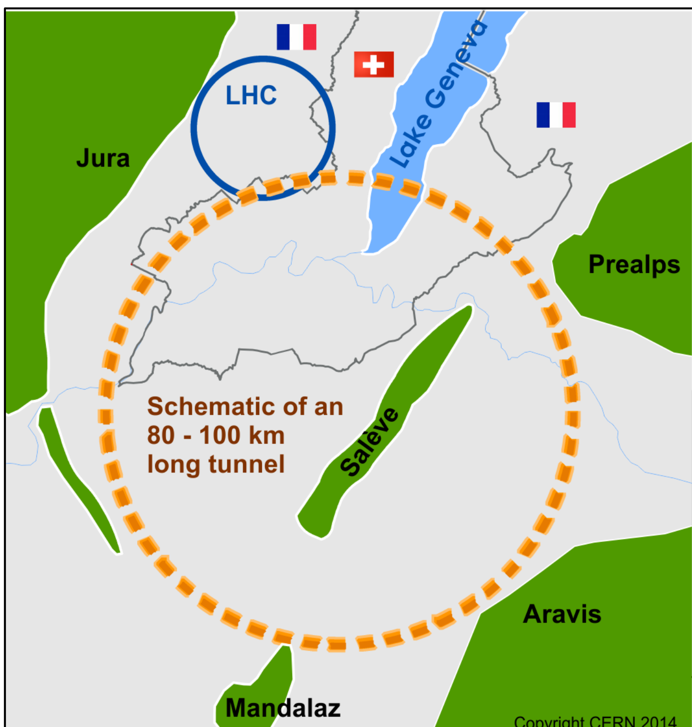
- goal: pp, $\sqrt{s}$ = 100 TeV (FCC-hh), L~2.5x10^{35}; 4 IP (some general-purpose, some specific)
- possible intermediate step: e^+e^-, $\sqrt{s}$=90-350 GeV (FCC-ee), L=2x10^{36}-2x10^{34}, 2-4 IP
- option: ep, $\sqrt{s}$= 3.5 TeV (FCC-eh), L~10^{34}

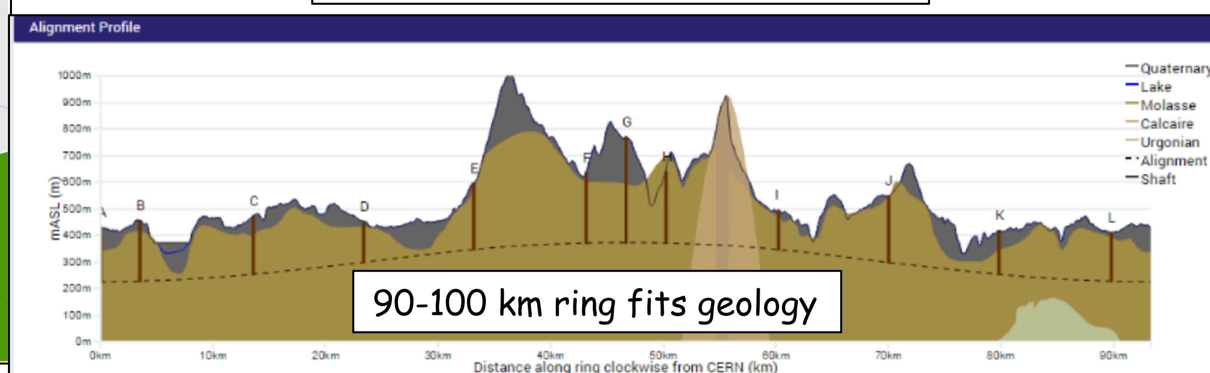
Goal of the study: CDR in ~2018

Machine studies are site-neutral.
However, FCC at CERN would greatly benefit from existing infrastructure (e.g. FCC-hh injector chain would be based on existing accelerator complex)



Baseline HEB: “refurbished” LHC





Future pp colliders

Pioneering work started in the US in 1998 with VLHC: http://vlhc.org/vlhc/

	Ring (km)	$\sqrt{s}$ (TeV)	Field (T)	Magnet technology	L (10^{34})
LHC (for comparison)	27	14	8.3	NbTi	up to 5
HE-LHC	27	26-33	16-20		~5
SppC If enough funds	54 100	70 100-140	20	Nb_3Sn with HTS inserts	12
FCC-hh	100	100	16	Nb_3Sn (with NbTi)	5-20

$5x10^{34}$ operation	HL-LHC	FCC-hh
Bunch spacing	25	25*
N. of bunches	2808	10600
Pile-up.x-ing	140	170
E-loss/turn	7 keV	5 MeV
SR power/ring	3.6 kW	2.5 MW
Interaction Points	4	4
Stored beam energy	390 MJ	8.4 GJ

* 5 ns considered for $L=2x10^{35}$ to mitigate pile-up

Many big technical challenges: technology of bending dipoles (Nb_3Sn ok up to ~16T, HTS needed for 20T), SR and beam screen, stored beam energy, radiation, …

Projected integrated luminosities for current operating scenarios

Integrated luminosities (ab^{-1})

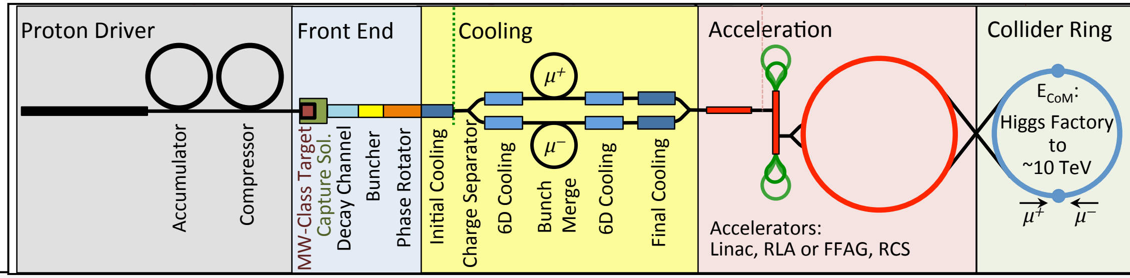
$\sqrt{s}$	90 (GeV)	~240 (GeV)	350-380 (GeV)	500 (GeV)	1.4 (TeV)	3 (TeV)	70 (TeV)	100 (TeV)	Total $\int L\,dt$ at $\sqrt{s}$>240 GeV	# of years	# H events at production
FCC-ee	90(*)	10	3						13	~7-15	2 M
CepC		5							5	~10	1 M
ILC		2	0.2	4					6.2	~20	1.6 M
CLIC			0.5		1.5	2			4	~20	1.5 M
SppC							30		30	~10	30 B
FCC-hh								40	40	~25	40 B

(*) 4×10^{12} Z

2 experiments assumed for CepC, SppC and FCC-hh, 2-4 for FCC-ee
L upgrade assumed for ILC and crab waist option for FCC-ee
FCC-ee run at 160 GeV not included

Note:
- Scenarios (revised after H discovery) will evolve based also on future LHC results
- Different definitions of "year" across projects: assumed physics data-taking time varies over 0.5-1.6×10^7 s/year
  Note: LHC 2012: 0.6×10^7 s of machine operation in physics with stable beams
- pp colliders: usable H events are ~ 10% of total cross-section due to large backgrounds
- H studies are only one of several physics goals

Muon colliders



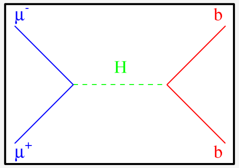
Synergies with neutrino factories

Main advantage compared to e^+e^- colliders: $m_\mu \sim 200\ m_e$

→ negligible SR → can reach multi-TeV with (compact !) circular colliders:
300 m ring for $\sqrt{s}$ = 125 GeV, 4.5 km for $\sqrt{s}$ = 3 TeV

→ negligible beamstrahlung → much smaller E spread

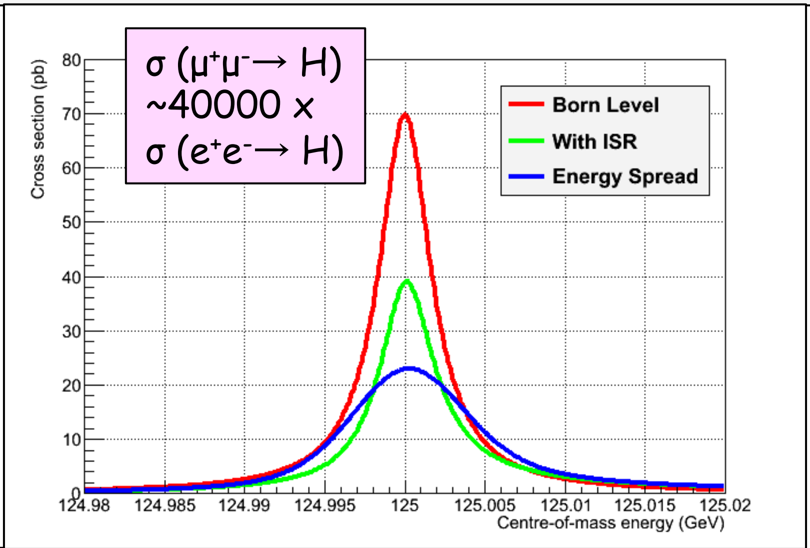
→ σ ($\mu\mu$ → H) ~ 20 pb (s-channel resonant production) → H factory



Main challenge: produce high-intensity, low E-spread beams:

- $m_\mu \sim 200\ m_e$ → SR damping does not work → novel cooling methods (dE/dx based) needed to reach beam energy spread of ~ 3×10^{-5} (for precise line shape studies) and high L
- $\tau_\mu \sim 2.2\ \mu s$ → production, collection, cooling, acceleration, collisions within ~ ms

Beam spread of ~ 3×10^{-5} would allow Γ_H measurement from line shape to 5% (0.2 MeV)
→ resolve (possible) resonances



However, with currently projected L (~10^{32}):
~ 20000 H/year → not competitive with e^+e^- colliders for coupling measurements
(except H$\mu\mu$ ~ 1%)

More R&D needed to demonstrated feasibility, in particular cooling:
linear systems (MICE at RAL), rings (recently re-ignited by C.Rubbia)

Physics motivations and potential

- H boson measurements
- Direct and indirect sensitivity to new physics

The H boson is not just … "yet another particle"

- Profoundly different from all elementary particles discovered so far
- Related to the most obscure sector of SM
- Linked to some of the deepest structural questions (flavour, naturalness, vacuum, …)

↓

Its discovery opens new paths of exploration, and a very broad and challenging experimental programme

Every problem of the SM originates from Higgs interactions

$$\mathcal{L} = \lambda H \psi \bar{\psi} + \mu^2 |H|^2 - \lambda |H|^4 - V_0$$

↑ flavour ↑ naturalness ↑ stability ↑ C.C.

G.F. Giudice

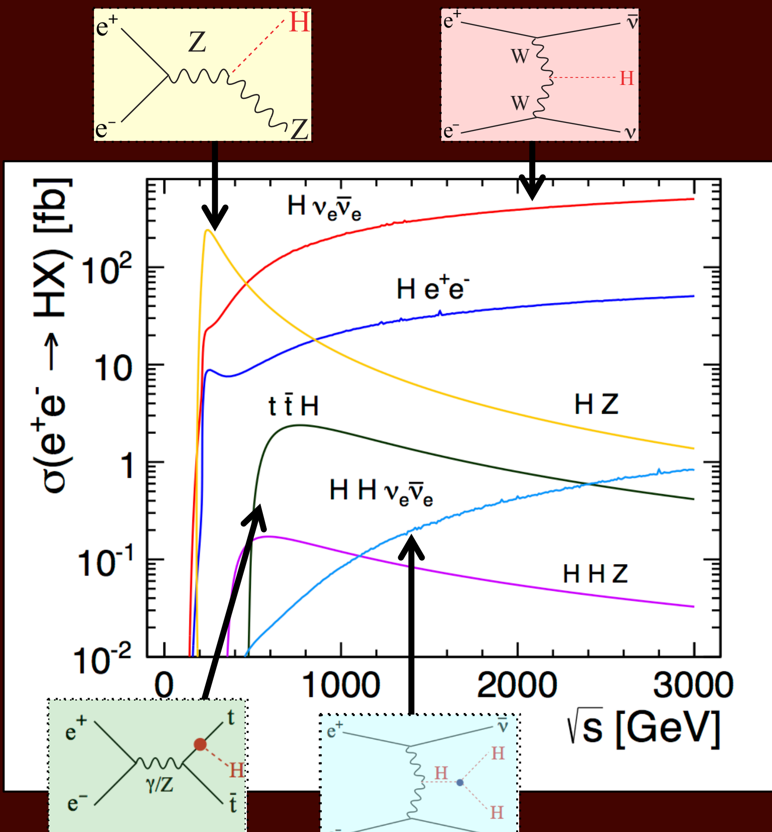
- Precision measurements of couplings (as many generations as possible, loops, …)
- Forbidden and rare decays (e.g. H→ τμ)
  → flavour structure and source of fermion masses
- H potential (HH production, self-couplings):
  → EWSB mechanism (strong dynamics ?)
  → EW phase transition → baryogenesis ?
- Exotic decays (e.g. H→ E_T^{miss}) → new physics ?
- Other H properties (width, CP, …)
- Searches for additional H bosons
- …

Impact of new physics on couplings:

$\Delta\kappa/\kappa \sim 5\%/\Lambda^2_{NP}$ (Λ_{NP} in TeV)

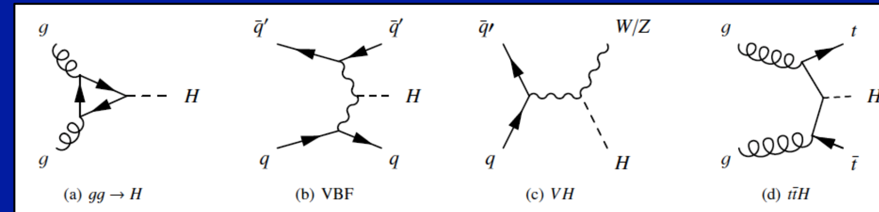
→ 0.1-1% exp. precision needed

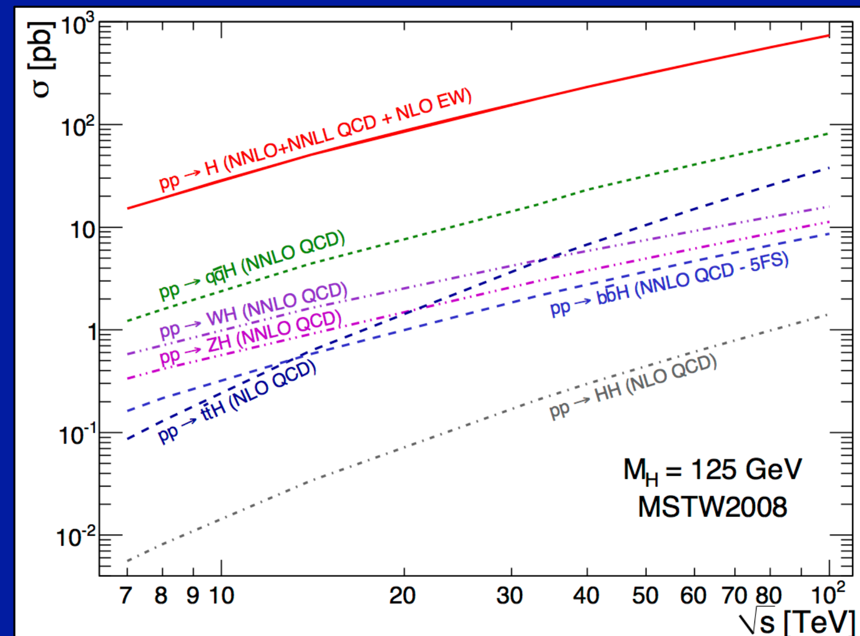
e^+e^- colliders



- ❑ Low backgrounds → all decay modes (hadronic, invisible, exotic) accessible
- ❑ Model-indep. coupling measurements: σ(HZ) and Γ_H from data (ZH → μμ/qq+X recoil, Hνν → bbνν)
- ❑ ttH and HH require $\sqrt{s} \geq 500$ GeV

pp colliders





- ❑ High energy, huge cross-sections
  → optimal for (clean) rare decays and heavy final states (ttH, HH)
- ❑ Huge backgrounds → not all channels accessible
- ❑ Model-dep. coupling measurements: Γ_H and σ (H) from SM

Coupling √s (TeV)→ L (fb^{-1}) →	LHC 14 3000(1 expt)	CepC 0.24 5000	FCC-ee 0.24 +0.35 13000	ILC 0.25+0.5 6000	CLIC 0.38+1.4+3 4000	FCC-hh 100 40000
K_W	2-5	1.2	0.19	0.4	0.9	
K_Z	2-4	0.26	0.15	0.3	0.8	
K_g	3-5	1.5	0.8	1.0	1.2	
K_γ	2-5	4.7	1.5	3.4	3.2	< 1
K_μ	~8	8.6	6.2	9.2	5.6	~ 2
K_c	--	1.7	0.7	1.2	1.1	
K_τ	2-5	1.4	0.5	0.9	1.5	
K_b	4-7	1.3	0.4	0.7	0.9	
$K_{Z\gamma}$	10-12	n.a.	n.a.	n.a.	n.a.	
Γ_h	n.a.	2.8	1%	1.8	3.4	
BR_{invis}	<10	<0.28	<0.19%	<0.29	<1%	
K_t	7-10	--	13% ind. tt scan	6.3	<4	~ 1 ?
K_{HH}	?	35% from K_Z model-dep	20% from K_Z model-dep	27	11	5-10

Few preliminary estimates available
SppC : similar reach

from K_γ/K_Z, using K_Z from FCC-ee

rare decays → pp competitive/better

from ttH/ttZ, using ttZ and H BR from FCC-ee

- LHC: ~20% today → ~ 10% by 2023 (14 TeV, 300 fb^{-1}) → ~ 5% HL-LHC
- HL-LHC: -- first direct observation of couplings to 2nd generation (H→ μμ)
  -- model-independent ratios of couplings to 2-5%
- Best precision (few 0.1%) at FCC-ee (luminosity !), except for heavy states (ttH and HH) where high energy needed → linear colliders, high-E pp colliders
- Complementarity/synergies between ee and pp

Theory uncertainties (presently few percent e.g. on BR) need to be improved to match expected superb experimental precision

New physics: hiding well or beyond present reach ?

e+e- colliders:

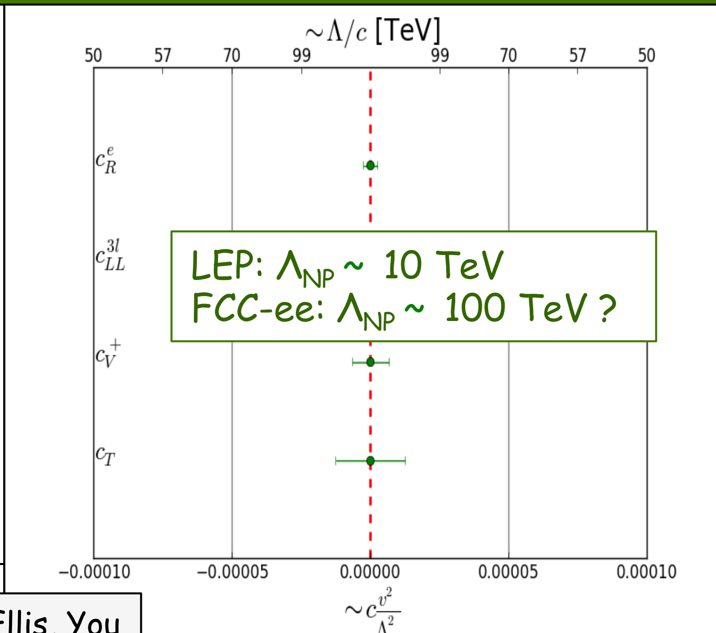
- Direct, model-independent discovery of new particles coupling to Z/γ^* up to $m \sim \sqrt{s}/2$; precise measurements of the new particles and theory
- Low backgrounds → can fill possible "blind spots" in searches at pp colliders
- Indirect sensitivity to high-E scale → CepC, FCC-ee, ILC, CLIC can probe $\Lambda \sim O(100)$ TeV
- Sensitivity to very weakly coupled physics
- Polarised beams: powerful tool to constrain underlying theory

Example: FCC-ee (assuming matching th. precision)

- 10^{12} Z → x 20-100 higher precision on EW observables
- 10^{8} WW → $\Delta m_W < 1$ MeV; 10^{6} tt → $\Delta m_t \sim 10$ MeV

→ probe higher-dimensional operators from new physics

$$L_{\text{eff}} = \sum_n \frac{c_n v^2}{\Lambda^2} O_n$$



LEP: $\Lambda_{NP} \sim$ 10 TeV
FCC-ee: $\Lambda_{NP} \sim$ 100 TeV ?

Ellis, You

New physics: hiding well or beyond present reach ?

e+e- colliders:
- Direct, model-independent discovery of new particles coupling to Z/γ* up to m ~ √s/2; precise measurements of the new particles and theory
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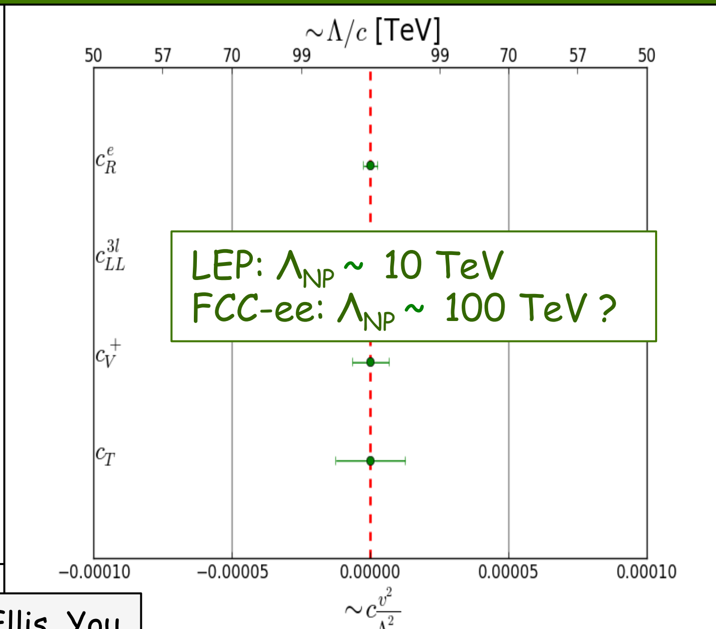
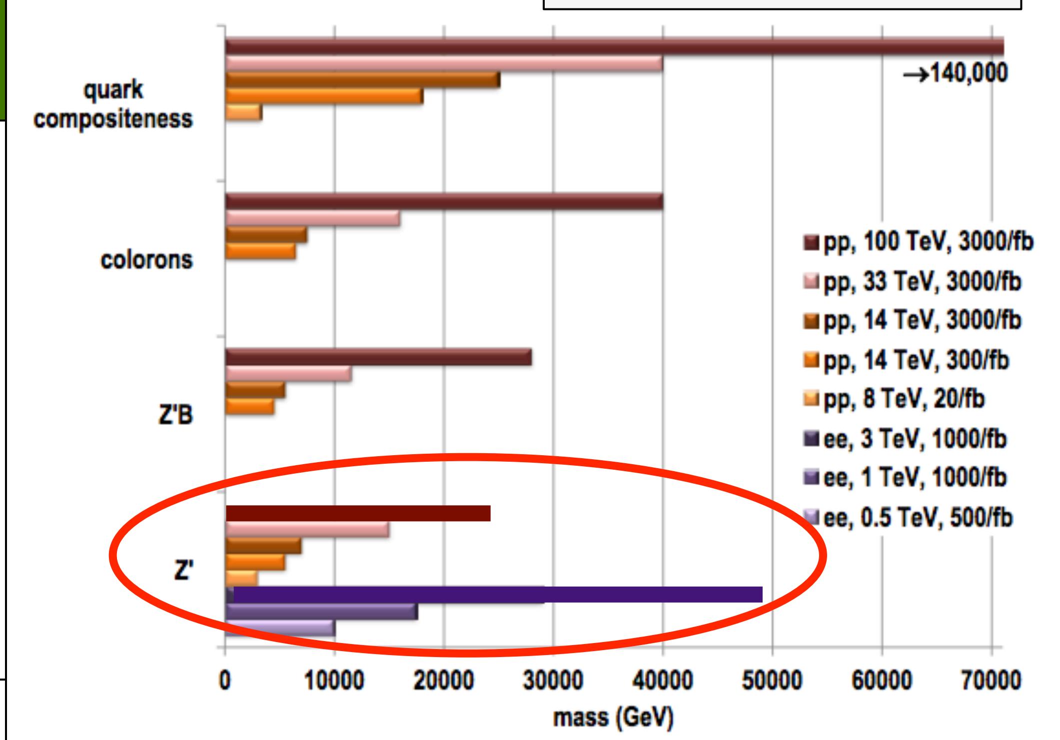


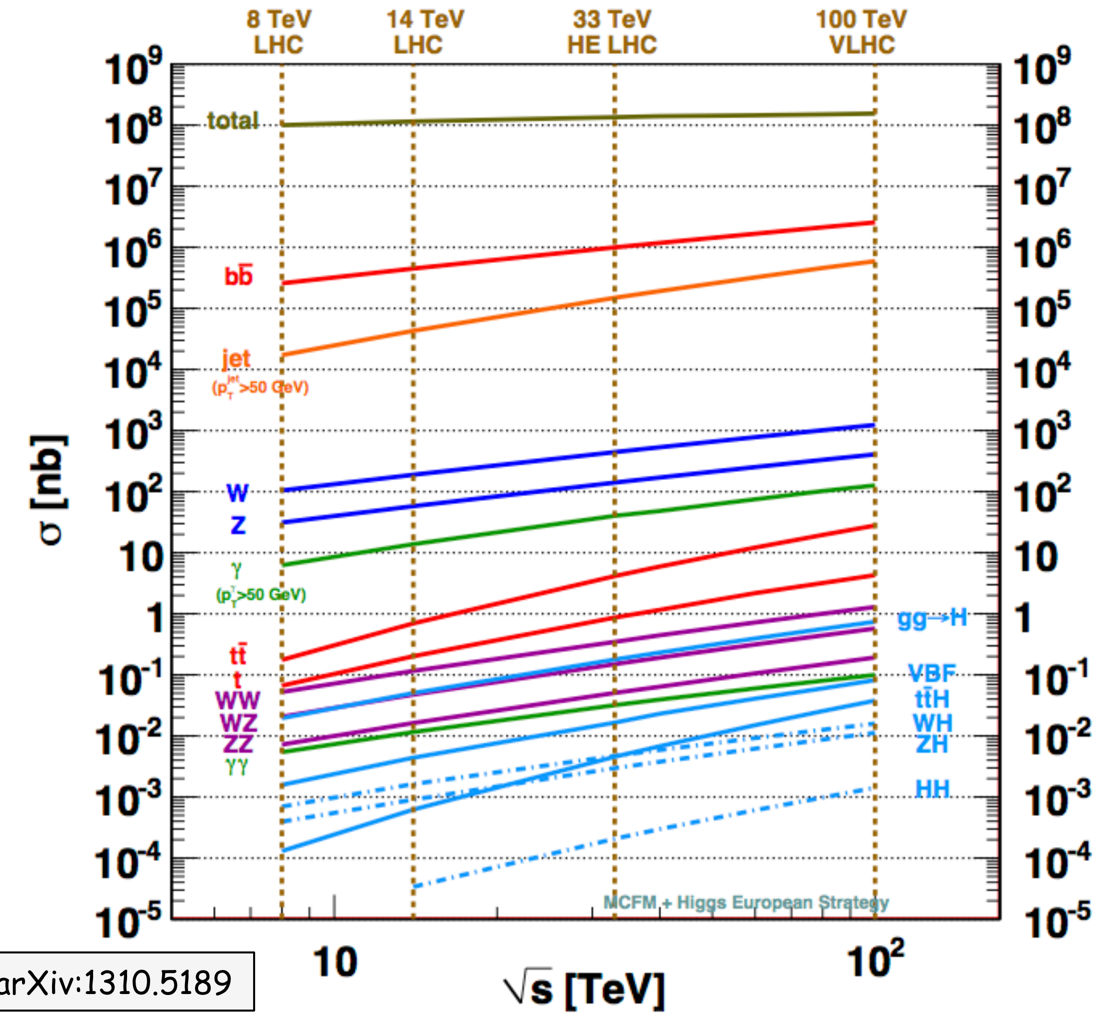
LEP: Λ_{NP} ~ 10 TeV
FCC-ee: Λ_{NP} ~ 100 TeV ?

Ellis, You

Modified from arXiv: 1311.0299



Hadron colliders: direct exploration of the "energy frontier"



arXiv:1310.5189

Process	σ (100 TeV)/σ (14 TeV)
Total pp	1.25
W	~7
Z	~7
WW	~10
ZZ	~10
tt	~30
H	~15 (ttH ~60)
HH	~40
stop (m=1 TeV)	$\sim10^3$

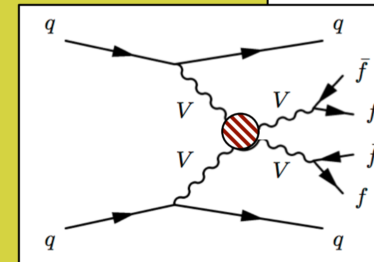
With 40/ab at $\sqrt{s}$=100 TeV expect: $\sim10^{12}$ top, 10^{10} H bosons, 10^5 m=8 TeV gluino pairs, ...

If new (heavy) physics discovered at the LHC → completion of spectrum is a "no-lose" argument for future ~ 100 TeV pp collider: extend discovery potential up to m~50 TeV

Other (equally strong) arguments for 100 TeV pp colliders: capability of addressing "structural issues"

Few examples.
Preliminary estimates

Conclusive elucidation of EWSB mechanism:
→ probe SM in regime where EW symmetry is restored ($\sqrt{\hat{s}} \gg v=246$ GeV)

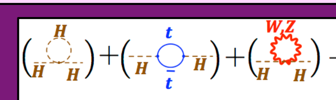


Without H: $V_L V_L$ scattering violates unitarity at m_{VV} ~TeV

- ❑ H regularizes the theory fully → a crucial "closure test" of the SM
- ❑ Else: new physics shows up: anomalous quartic couplings (VVVV, VVhh) and/or new heavy resonances

100 TeV pp: direct discovery potential of new resonances in the O(10 TeV) range

Naturalness:

$\Delta M_H^2 \sim$  $\cdots \sim \Lambda^2$

- ❑ If no new physics at end of LHC → ~ 1% fine-tuning
- ❑ 100 TeV pp: direct sensitivity to stops and other top partners up to O(10) TeV → fine-tuning pushed to 10^{-4}

(Distinguished) theorist 1: "Never seen 10^{-4} level of tuning in particle physics: qualitatively new, mortal blow to naturalness". (Distinguished) theorist 2: "Naturalness is a fake problem"

Nature of EW phase transition:
if first order (faster than in SM) could give rise to baryogenesis → need modification of the H potential, e.g. by adding a scalar singlet:

$$\mathcal{L} = \mathcal{L}_{SM} - \frac{1}{2}\partial_\mu\phi\partial^\mu\phi - \frac{1}{2}m_\phi^2\phi^2 - c_\phi v h \phi^2$$

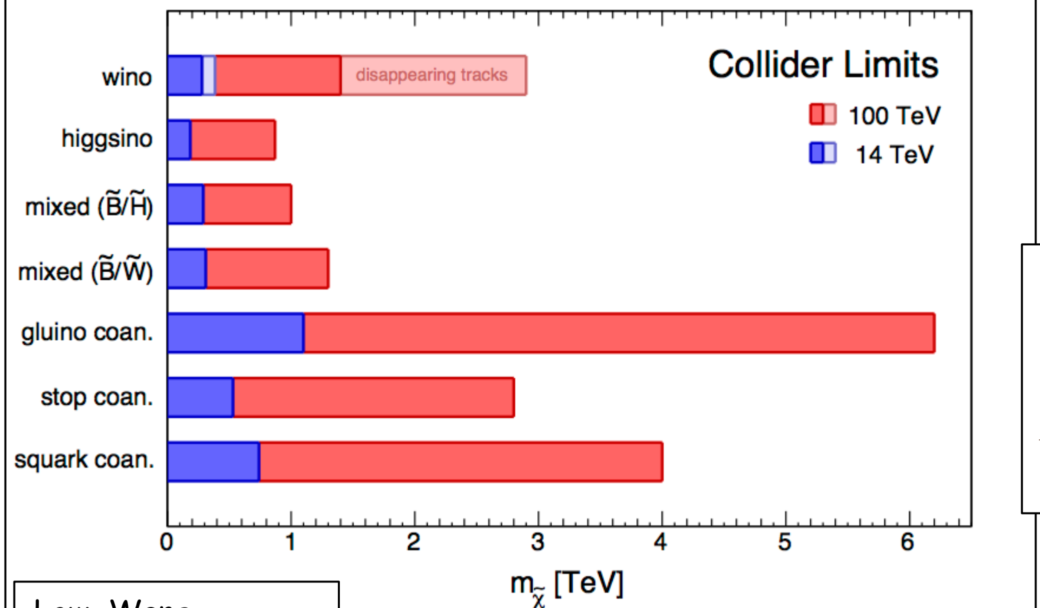
→ this (difficult) model can be constrained from precise measurements of HZ coupling at e^+e^- and H self-coupling at 100 TeV pp, and direct searches for new (invisible) particles at 100 TeV pp.

CepC-SppC http://cepc.ihep.ac.cn/preCDR/volume.html; see also Curtin et al., arXiv:1409.0005v4

Conclusive searches of TeV-scale WIMP dark matter ?

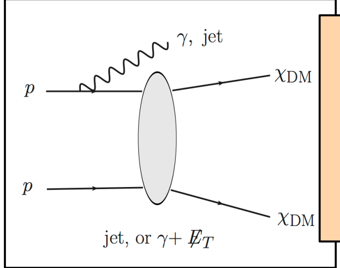
From relic abundance:

$$M_{\rm DM} \lesssim 1.8\ \text{TeV} \left(\frac{g_{\rm eff}^2}{0.3}\right)$$



Low, Wang
arXiv:1404.0682v2

DM candidates from generic EW multiplets (direct pair production or from 1-step decays of nearly-degenerate heavier states)



Note: challenging experimental signatures (mainly based on ISR mono-object)

... and of course exploration of unknown territory ...

Conclusions

The full exploitation of the LHC, as well as future high-energy/intensity colliders, are necessary to advance our knowledge of fundamental physics

↓

Motivations:
- ❑ Conclusive exploration of EWSB, highest-precision studies of the H boson, investigation of related issues: vacuum stability (the fate of the universe !), EW baryogenesis, …
- ❑ Addressing outstanding questions (the "known unknowns"): dark matter, flavour problem, matter-antimatter asymmetry, naturalness, etc.
- ❑ Exploration, via direct and indirect probes, of uncharted territory (the highest E-scales and smallest couplings) to look for "unknown unknowns" and manifestations of the new physics that we know MUST be somewhere

Future LHC results (Run-2 and beyond) will hopefully (!!) provide some of the answers and indications of the future path: e.g if new (heavy) physics is discovered → completion of spectrum and more detailed measurements of new physics likely require multi-TeV energies

Regardless of the detailed scenario, and even in the absence of theoretical/experimental preference for a specific E scale, the main lines are clear:
- ❑ highest precision → to probe the highest E-scales indirectly and the smallest couplings
- ❑ highest E → to explore directly new energies and interpret results from indirect probes

N.B. historically, accelerators have been our most powerful tool for particle physics exploration

Thanks also to great technological progress, many scientifically strong opportunities for high-intensity/high-energy future colliders are available → decision on how to proceed, and the time profile of the projects, depends on science (e.g. LHC results), maturity of technology, cost and availability of funding, worldwide perspective.

None of these opportunities is easy, none is cheap.

HOWEVER

1) The extraordinary success of the LHC (result of ingenuity, vision and perseverance of the worldwide HEP community and > 20 years of talented, dedicated work) demonstrates the strength of the community (accelerators, experiments, theory) → asset in view of future, even more ambitious, projects.

2) The correct approach, as scientists, is not to abandon our exploratory spirit, nor give up due to financial and technical challenges. The correct approach is to use our creativity to develop the technologies needed to make future projects financially and technically affordable

MANY THANKS TO …

THE ORGANISERS

and

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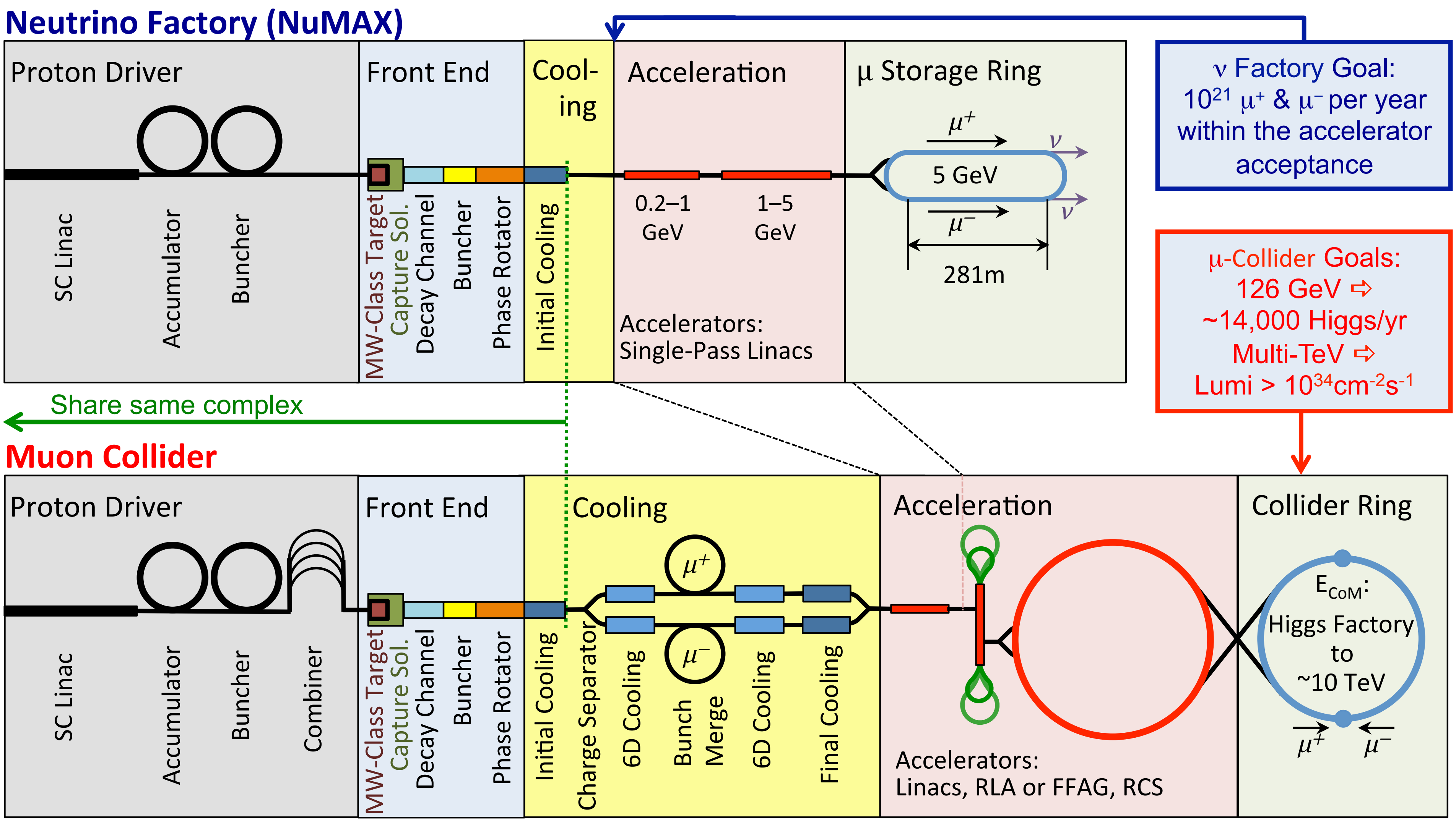
EXTRAS

Neutrino Factory & Muon Collider



Hard, challenging work for everybody to make the "impossible" possible !

Accelerator R&D (few examples …):

- High-field, accelerator-quality Nb_3Sn superconducting magnets ready for massive industrial production starting mid-end next decade. Continue to push HTS for farther-term future.
- Normal- and super-conducting high-Q RF cavities reaching higher field at lower cost (great progress recently in SCRF)
- Higher-efficiency RF sources
- Novel ideas to reach GV/m acceleration gradients, allowing factor ~10 shorter Linacs: e.g. laser- and beam-driven plasma wakefield acceleration (FACET@SLAC, BELLA@LBNL, AWAKE@CERN, LAOLA@DESY, FLAME@LNF)
- MW-class proton sources and high-power targets for longer-term opportunities (muon colliders, …)

Detectors (few examples …):

- ultra-light, ultra-fast, ultra-granular, rad-hard, low-power Si trackers
- 10^8 channel imaging calorimeters (power consumption and cooling at high-rate machines,..)
- big-volume 5-6 T magnets (~2 x magnetic length and bore of ATLAS and CMS, ~50 GJ stored energy) to reach momentum resolutions of ~10% for p~20 TeV muons

Theory: improved theoretical calculations (higher-order EW and QCD corrections) needed to match present and future experimental precision on EW observables, Higgs mass and branching ratios. Work together with experiments on model-independent analyses in framework of Effective Field Theory

Some typical energy points

	Size km	$\sqrt{s}$ GeV	RF MV/m	L per IP 10^{34}	Bunch/train x-ing rate(Hz)	σ_x µm	σ_y nm	Lumi within 1% of $\sqrt{s}$	Long. polarisation e^-/e^+
CEPC	54	240	15	2	3×10^5	70	150	>99%	considered
FCC-ee	100	240	9	6	4×10^6	22	40	>99%	considered
ILC	31	250	14.7	1.5	10	0.7	7.7	87%	80%/30%
ILC	31	500	31.5	1.8	5	0.5	5.9	58%	80%/30%
CLIC	15	380	72	1.5	50	0.14	3	60%	80%/considered
CLIC	48	3000	100	6	50	0.04	1	33%	80%/considered

CepC-SppC pre-CDR

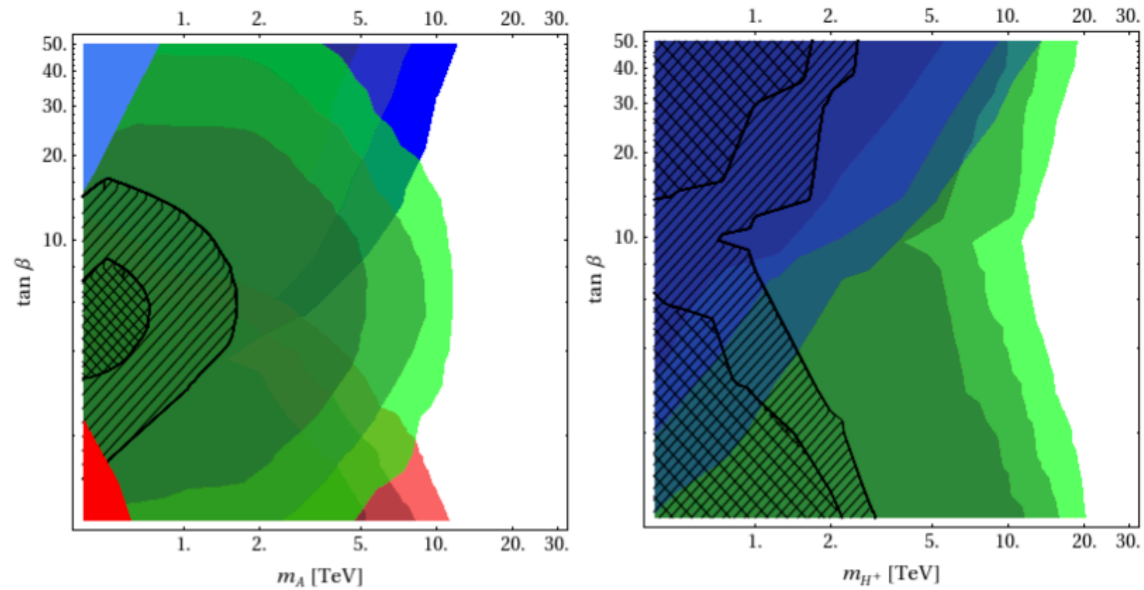
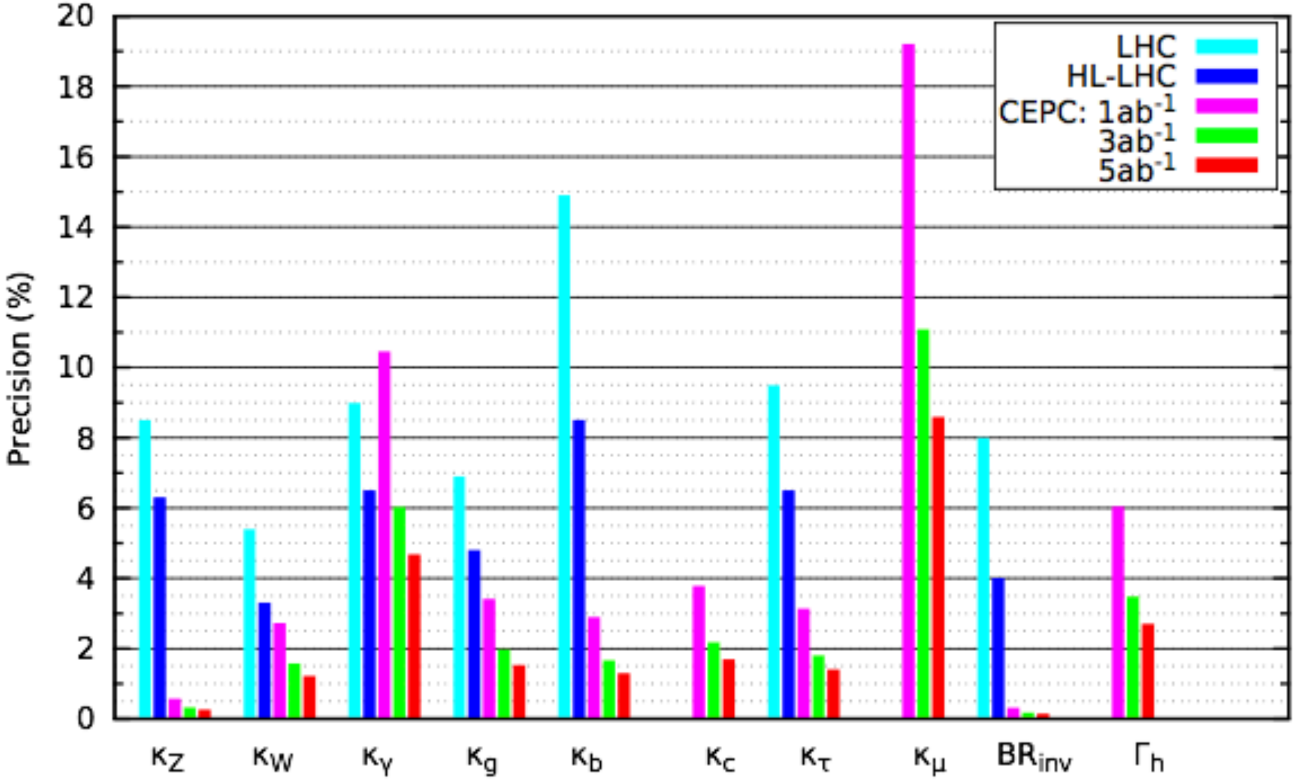


Figure 7.35 95% C. L. Exclusion limits for the MSSM Higgs bosons at a 100 TeV pp collider [299]. The three regions with the same color and different opacities are excluded by assuming a luminosity of 0.3 ab^{-1}, 3 ab^{-1}, and 30 ab^{-1}, respectively. Left: neutral Higgs bosons (H/A). The blue, green and red regions are excluded by the channels $pp \to bbH/A \to bb\tau_h\tau_l$, $pp \to bbH/A \to bbt_ht_l$ and $pp \to H/A \to t_ht_l$, respectively. The blue and red regions in the upper left and lower left corners are the current exclusion limits of $pp \to bbH/A \to bb\tau_h\tau_l$ and $pp \to H/A \to t_ht_l$ at the LHC. Right: charged Higgs bosons ($H^\pm$). The blue and green regions are excluded by the channels $pp \to tbH^\pm \to tb\tau_h\nu_\tau$ and $pp \to tbH^\pm \to t_hbt_lb$, respectively. The cross-hatched and backward diagonal hatched regions are the predicted exclusion contours for associated Higgs production at the LHC for 0.3 ab^{-1}, and 3 ab^{-1} of data, respectively.



Precision (%)
20
18
16
14
12
10
8
6
4
2
0
LHC
HL-LHC
CEPC: 1ab-1
3ab-1
5ab-1
κZ
κW
κγ
κg
κb
κc
κτ
κμ
BRinv
Γh

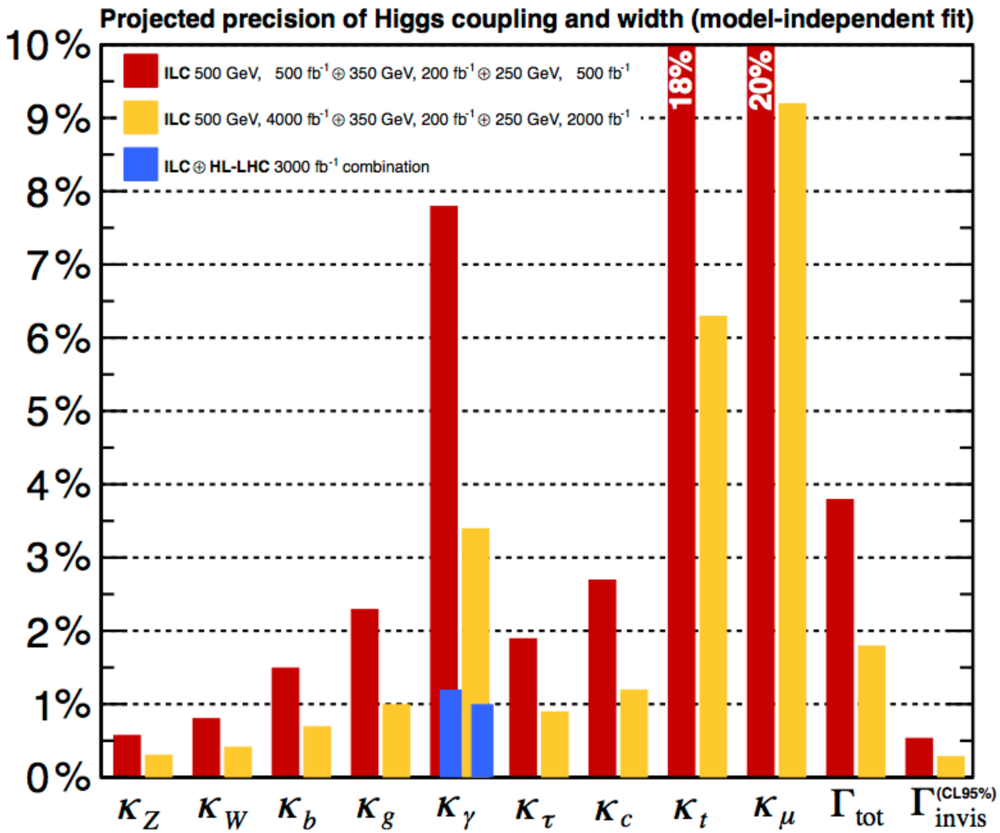
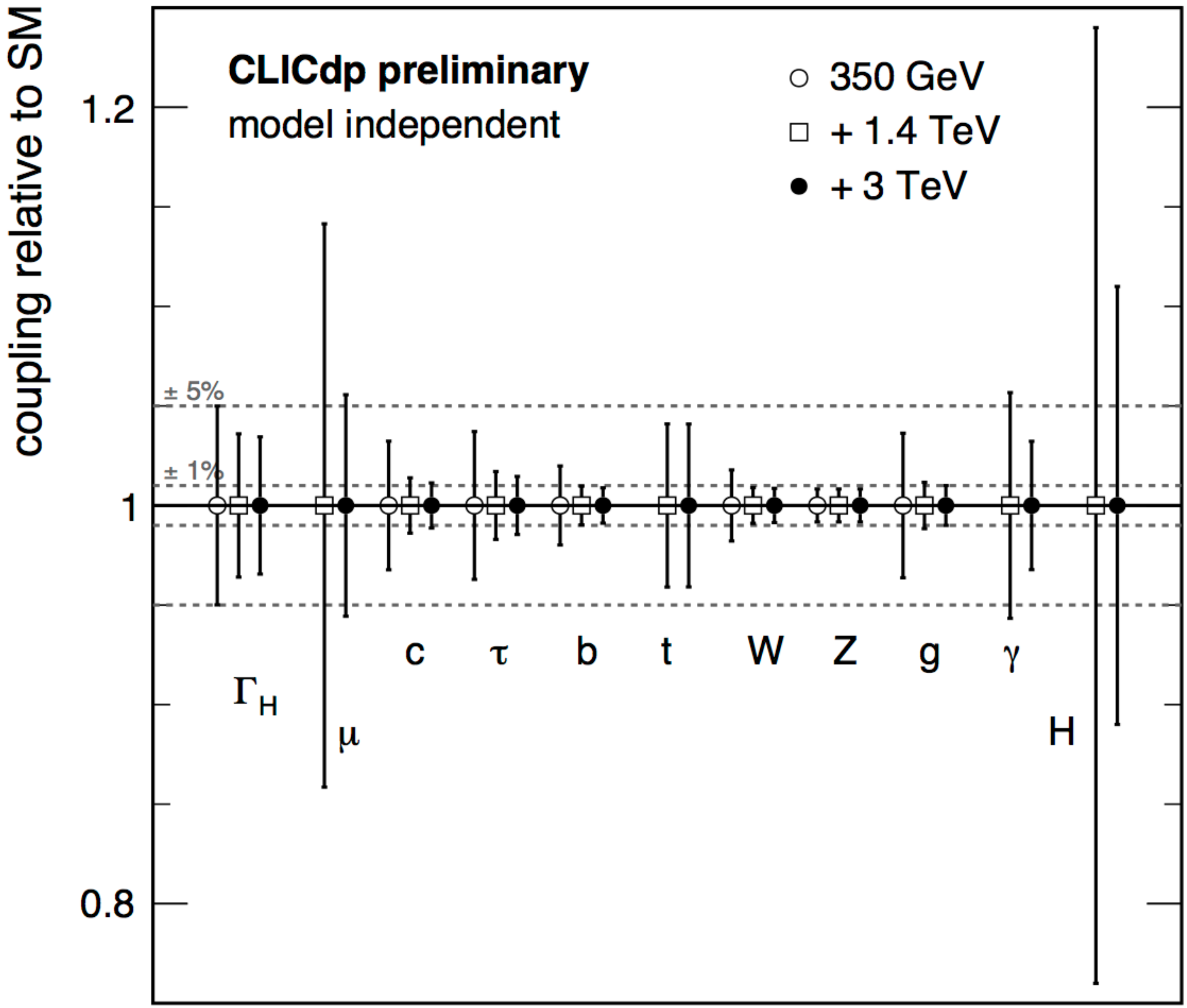


Figure 5: Relative precisions for the various Higgs couplings extracted from a model-independent fit to expected data from the ILC. The notation is as in Fig. 4.



CLICdp preliminary
model independent
350 GeV
+ 1.4 TeV
+ 3 TeV
coupling relative to SM
1.2
1
0.8
± 5%
± 1%
Γ_H
μ
c
τ
b
t
W
Z
g
γ
H