BSM @ AT FUTURE COLLIDERS

<u>OUTLINE</u>

- The questions
- The colliders
- The physics

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CERN & INFN Genova

Seoul - 07 July 2018

The questions

The open questions

- Origin of Dark Matter/Energy
- Inflation (or why is our universe so homogeneous and isotropic)
- Gravity (quantum gravity, string theory)
- Unification of forces
- Origin of matter/anti-matter asymmetry
- Origin of EWSB
- Hierarchy problem
- Origin of flavour (flavor violation, g-2, EDMs, etc.)
- Neutrino masses
- Strong CP problem (axions, etc.)

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Have or may have a relation with physics at the weak scale

↓

Future Colliders

The colliders

The spectrum of Future Colliders

Starting point

HiLumi HL-LHC PROJECT

Lepton Collider at highest possible energy

CLIC

Hadron Collider at highest possible energy

HE-LHC

SppC

FCC hh ee he

Lepton Collider at threshold

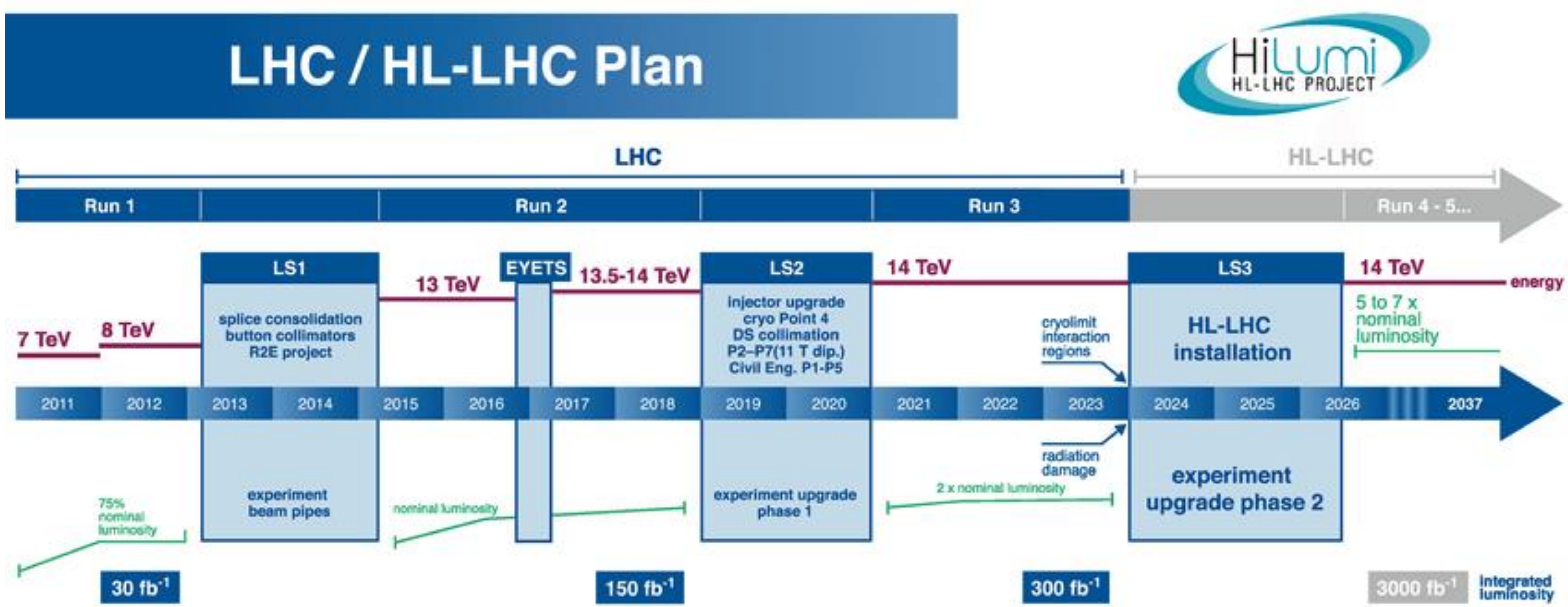
ILC

CEPC

FCC hh ee he

HL-LHC and HE-LHC

- Big effort (exp+th) to assess the physics opportunities
- Ongoing “Workshop on the physics of HL-LHC, and perspectives at HE-LHC”
- Yellow report will be completed by the end of this year -> input to the next Update of the European Strategy for Particle Physics (2019)
- HE-LHC benchmarks: 27 TeV of c.o.m. energy and 15/ab of integrated luminosity



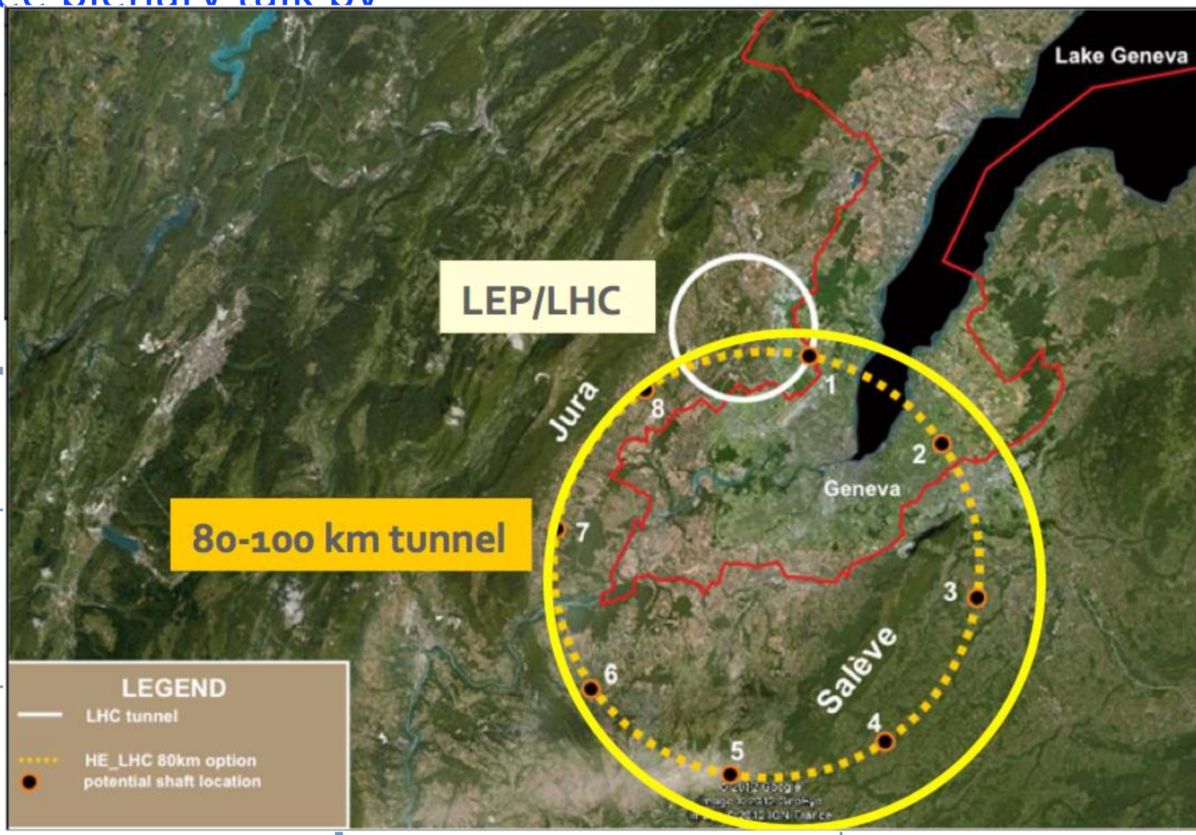
Future Lepton Colliders

see plenary talk by X. Lou

	Triple LEP (see FCC)	Circular Electron Proton Collider	International Linear Collider	Compact Linear Collider
design	circular		linear	
$\sqrt{s}$	350 GeV	240 GeV	500 GeV	3000 GeV
acceleration gradient	20 MV/m	20 MV/m	31.5 MV/m	100 MV/m
length	80 - 100 km	50 - 70 km	31 km	48.4 km
feasibility	mostly existing technology	mostly existing technology	mostly existing technology	new technology
cost* * large uncertainties	2.5/4.5 billion CHF (tunnel) 2/3 billion CHF (rest, most RF)	?	7.8 billion CHF	8-20 billion CHF
reference	FCC (also see talk by E. Levichev)	CEPC/SppC (also see talk by J. Gao)	LCC	LCC (also see talk by D. Shulte)

Future Lepton Colliders

see plenary talk by X



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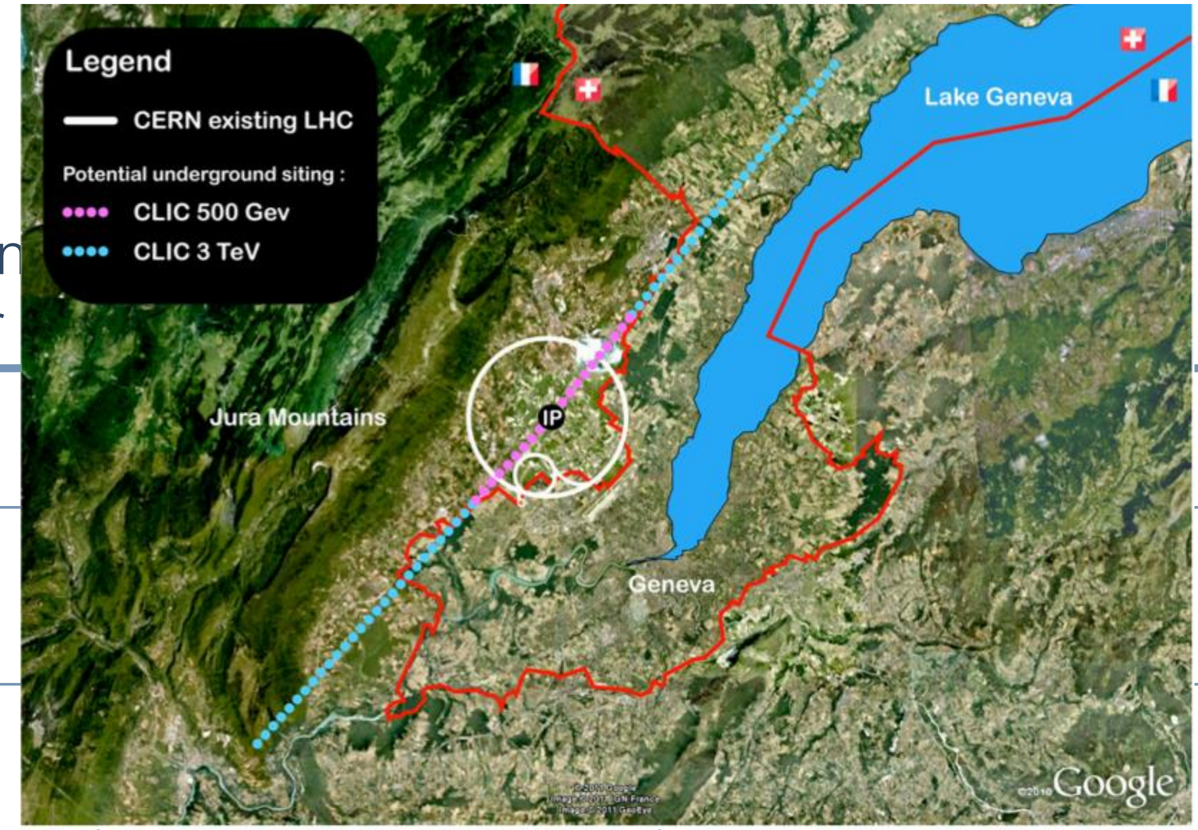

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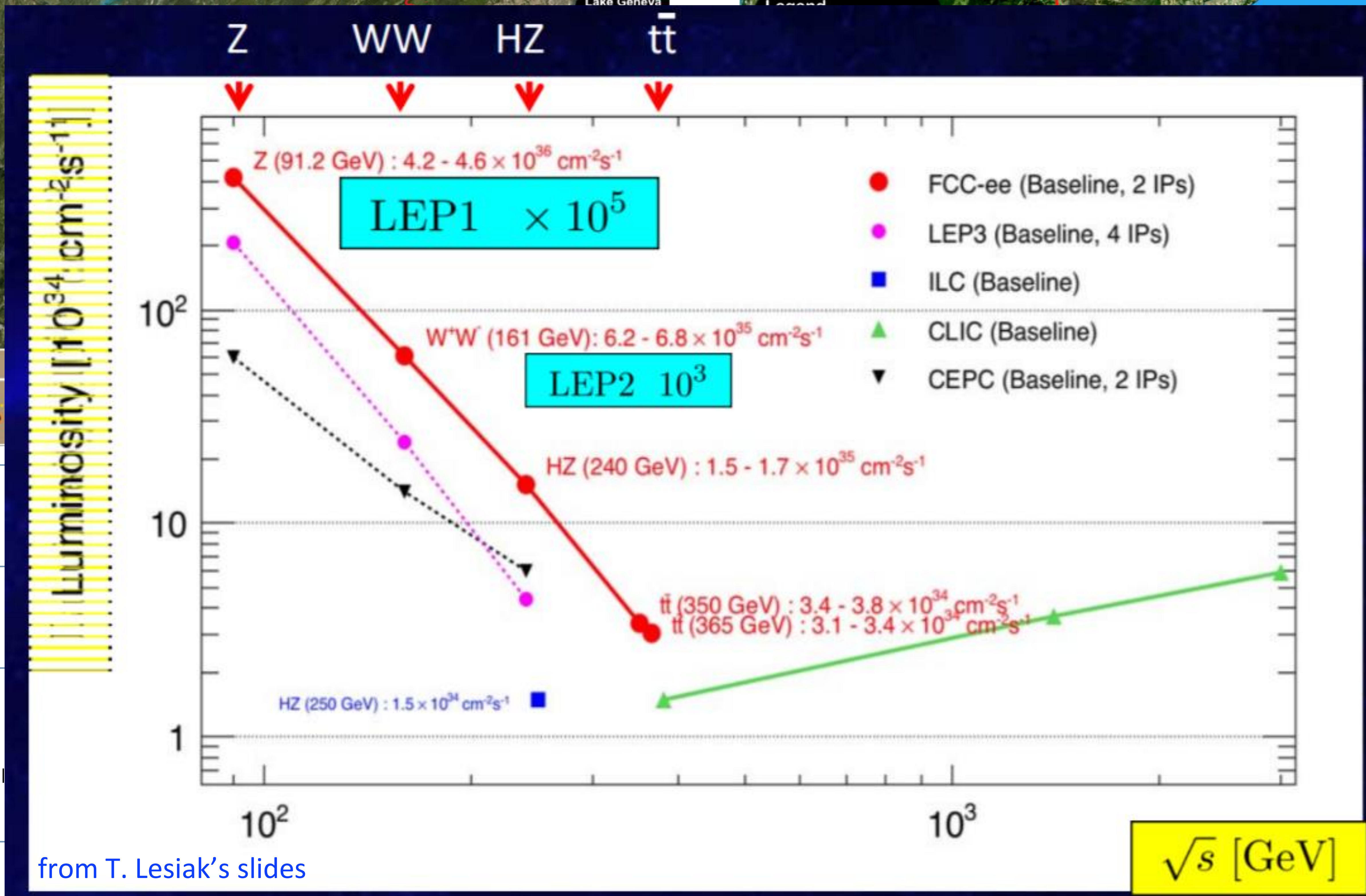


from T. Lesiak's slides

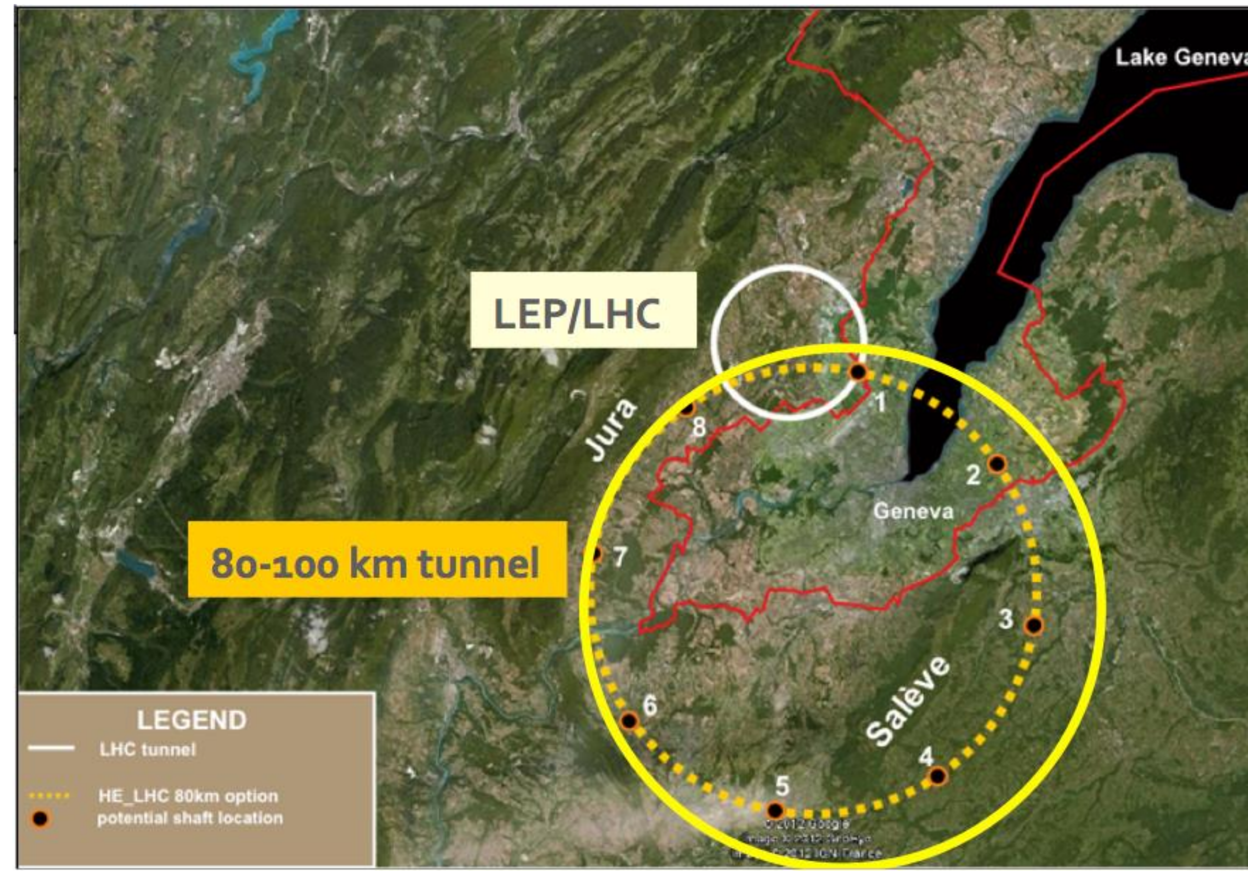
reference

FCC

LCC

Future Hadron Colliders

	Future Circular Collider FCC-hh
design	circular
$\sqrt{s}$	80 - 100 TeV
final luminosity	> 3-10/ab
length	80 - 100 km
feasibility	new technology
cost	?
reference	FCC (also see talk by D. Schulte)



	SppC
design	circular
$\sqrt{s}$	50/70 TeV (pp)
final luminosity	> 3-10/ab
length	50 - 70 km
feasibility	new technology
cost	?
reference	CEPC/SppC (also see talk by Q. Xu)

The physics

Higgs

Precision Higgs physics is crucial, lepton colliders (at threshold) usually the best probe

Result of the coupling (a.k.a. κ) fit

- Comparison(*) with other lepton colliders at the EW scale (up to 380 GeV)

13	μ Coll$_{125}$	ILC$_{250}$	CLIC$_{380}$	LEP3$_{240}$	CEPC$_{250}$	FCC-ee$_{240}$	FCC-ee$_{365}$
Years	6	15	5	6	7	3	+4
Lumi (ab^{-1})	0.005	2	0.5	3	5	5	+1.5
δm_H (MeV)	0.1	t.b.a.	110	10	5	7	6
$\delta\Gamma_H / \Gamma_H$(%)	6.1	3.8	6.3	3.7	2.6	2.8	1.6
$\delta g_{Hb} / g_{Hb}$ (%)	3.8	1.8	2.8	1.8	1.3	1.4	0.70
$\delta g_{HW} / g_{HW}$ (%)	3.9	1.7	1.3	1.7	1.2	1.3	0.47
$\delta g_{H\tau} / g_{H\tau}$(%)	6.2	1.9	4.2	1.9	1.4	1.4	0.82
$\delta g_{H\gamma} / g_{H\gamma}$ (%)	n.a.	6.4	n.a.	6.1	4.7	4.7	4.2
$\delta g_{H\mu} / g_{H\mu}$ (%)	3.6	13	n.a.	12	6.2	9.6	8.6
$\delta g_{HZ} / g_{HZ}$ (%)	n.a.	0.35	0.80	0.32	0.25	0.25	0.22
$\delta g_{Hc} / g_{Hc}$ (%)	n.a.	2.3	6.8	2.3	1.8	1.8	1.2
$\delta g_{Hg} / g_{Hg}$ (%)	n.a.	2.2	3.8	2.1	1.4	1.7	1.0
Br_{invis} (%)$_{95\%CL}$	SM	<0.3	<0.6	<0.5	<0.15	<0.3	<0.25
BR_{EXO} (%)$_{95\%CL}$	–	<1.8	<3.0	<1.6	<1.2	<1.2	<1.1

Patrick Janot — Higgs properties @ Circular Lepton Colliders, 1 June 2018 — 12

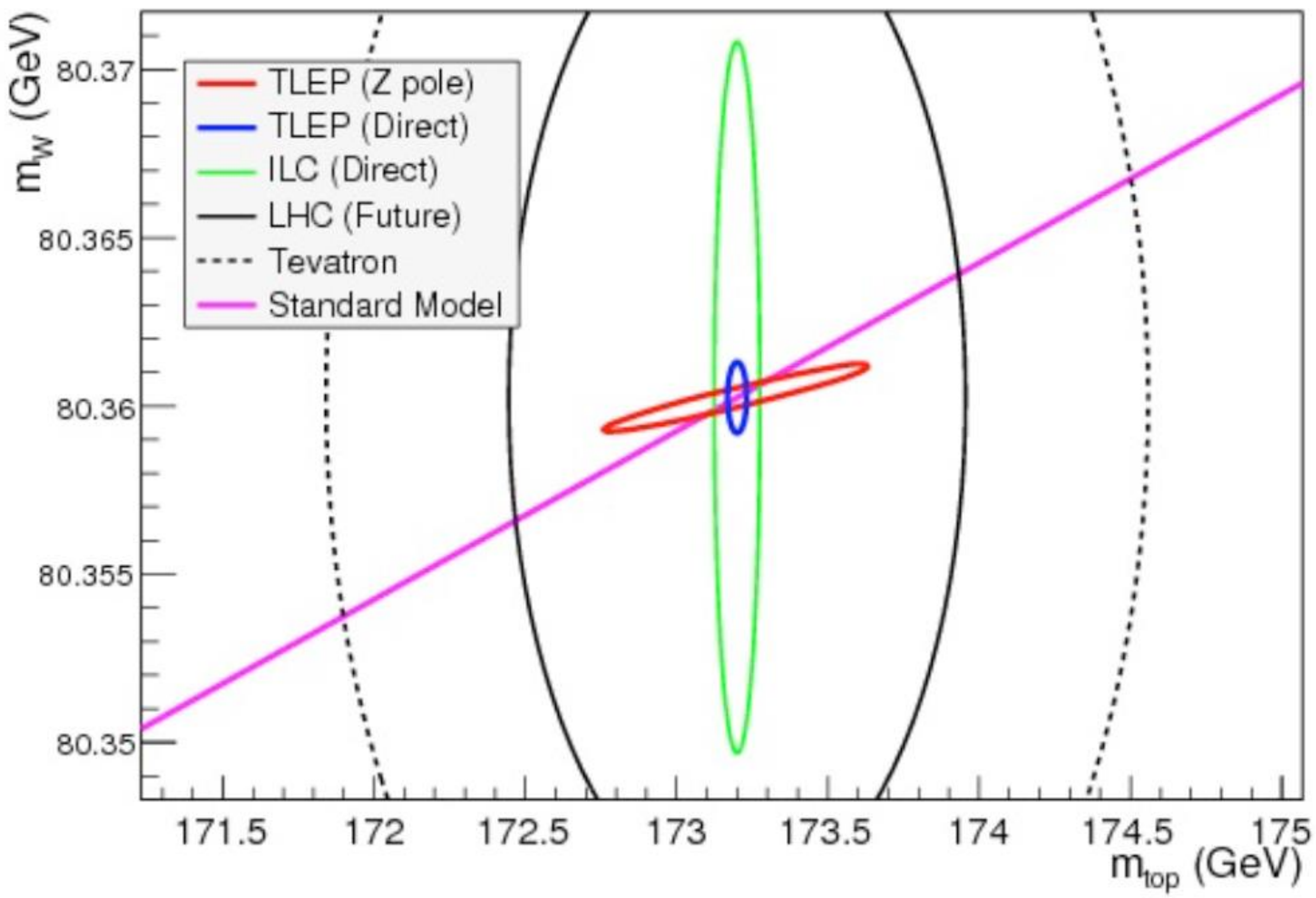
(*) Green = best, Red = worst

see talks by A. Blondel, T. Ogawa, M. Selvaggi, R. Franceschini, M. A. Weber

Precision observables

For the W mass determination a big improvement over Tevatron&LHC (and HL-LHC) is expected, of the order of 10 (ILC) to 20 (TLEP)

see talks by T. Lesiak and Z. Liang



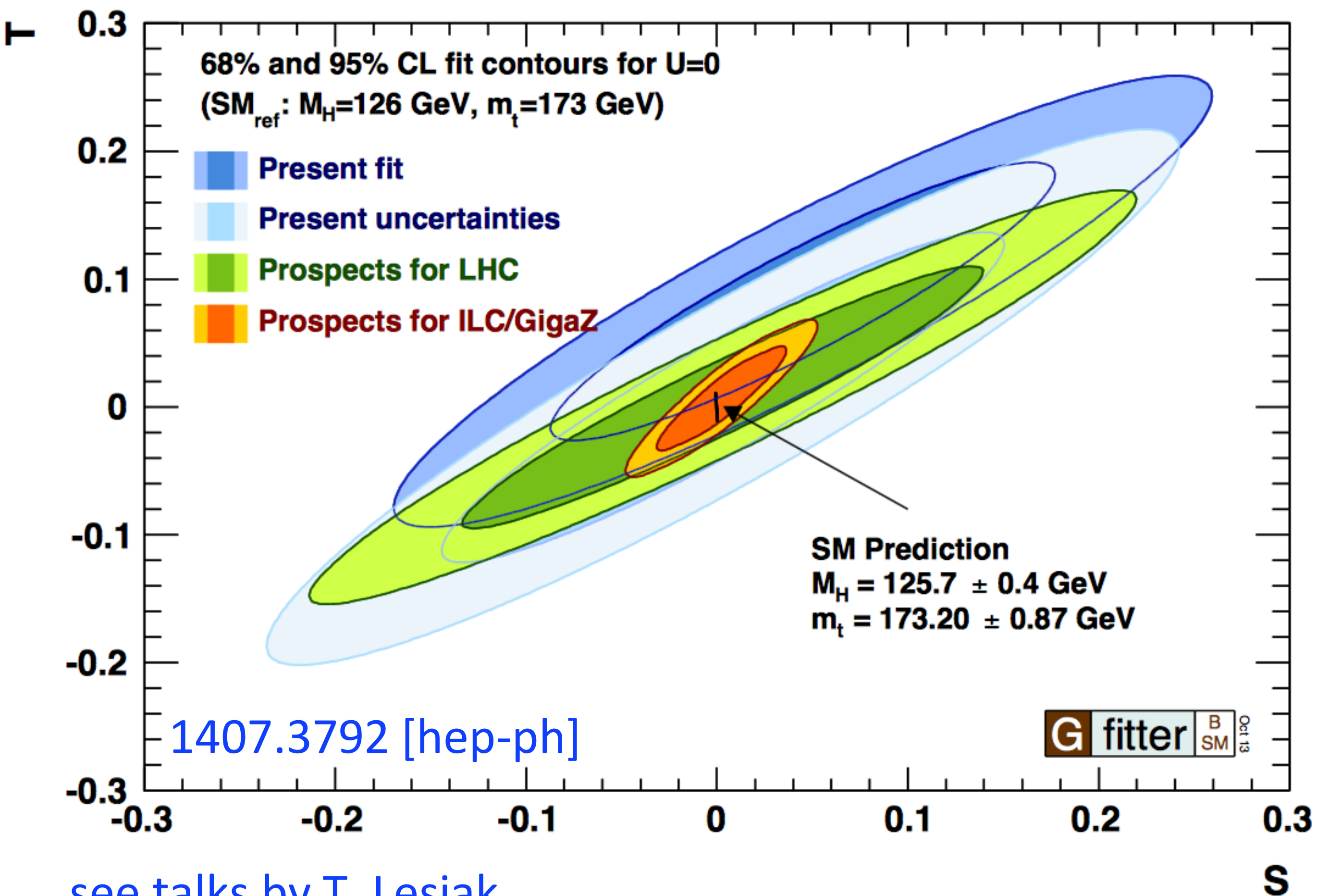
TLEP report
Snowmass report

	LHC	LHC	ILC/GigaZ	ILC	ILC	ILC	TLEP	SM prediction
$\sqrt{s}$ [TeV]	14	14	0.091	0.161	0.161	0.250	0.161	-
$\mathcal{L}[\text{fb}^{-1}]$	300	3000		100	480	500	3000×4	-
ΔM_W [MeV]	8	5	-	4.1-4.5	2.3-2.9	3.6	1.2	4.2(3.0)
$\Delta \sin^2\theta^{\ell}_{\text{eff}}$ [10^{-5}]	36	21	1.3	-	-	-	0.3	3.0(2.6)

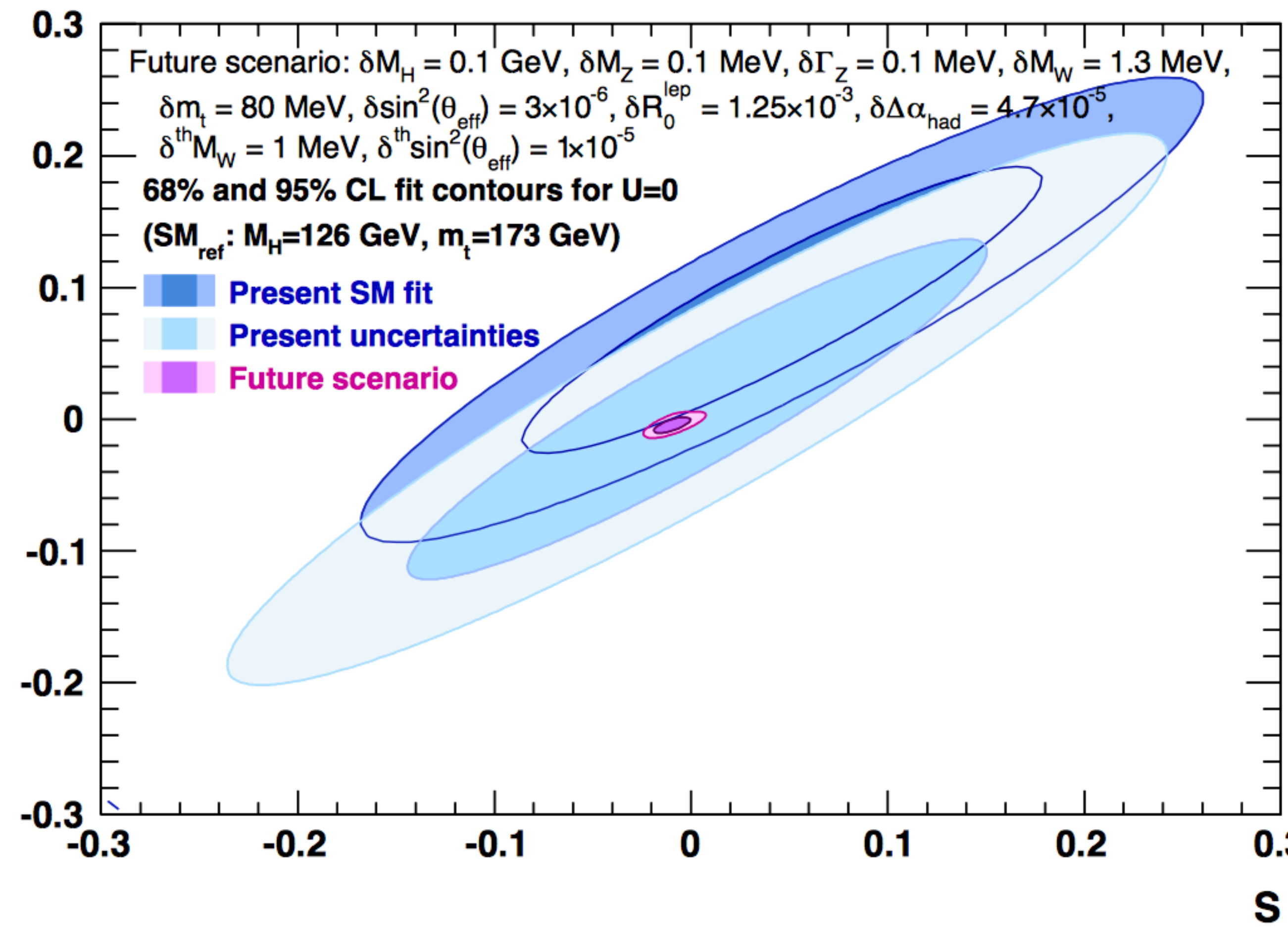
Oblique parameters (on-shell)

For the oblique precision observables S and T (and possibly U) a factor of 3 improvements at ILC and a factor of 10 improvements at TLEP

Present / LHC / ILC



Future scenario



see talks by T. Lesiak and Z. Liang

GFitter

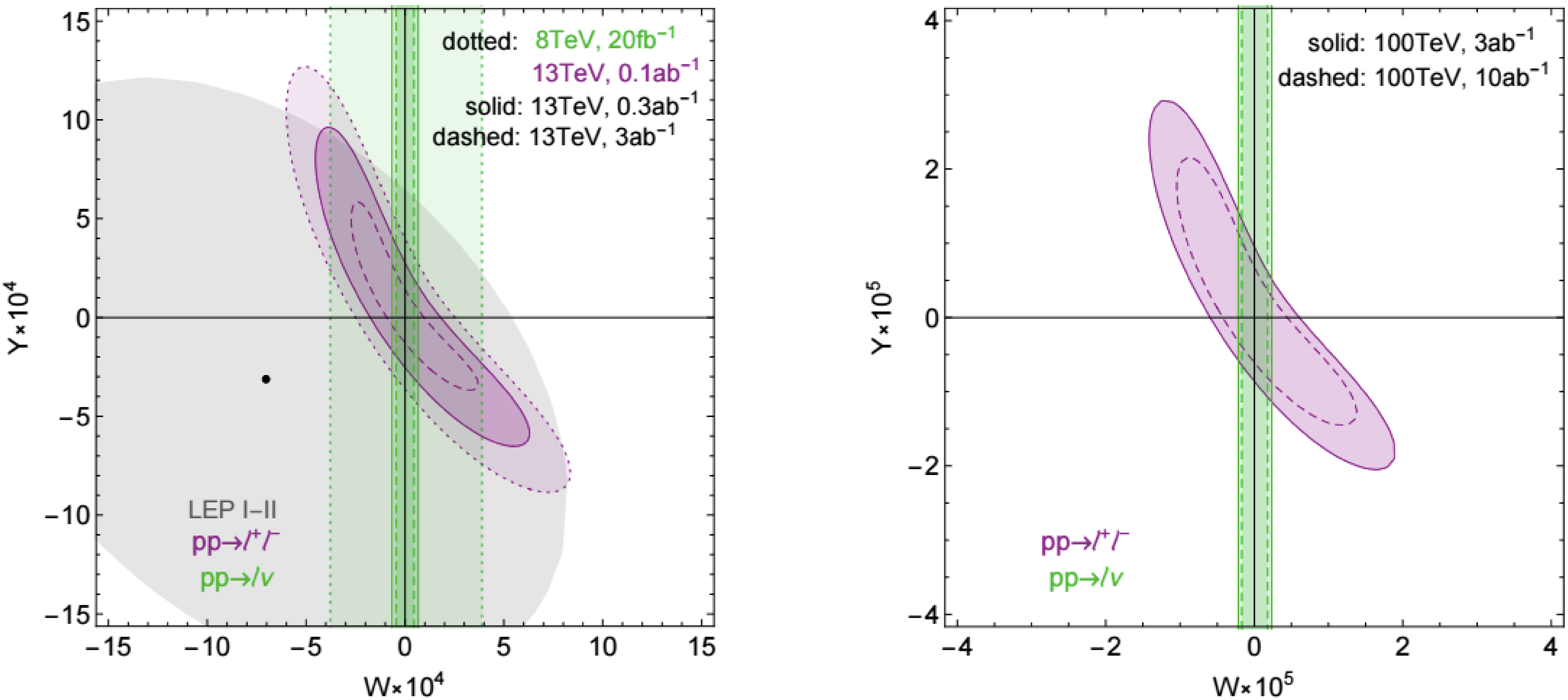
Important to assess the precision possibilities of high energy hadron colliders

Less clean environment, but enhancement of the higher order observables (W, Y, V, X) with the energy

This could lead to important constraints complementary to the S,T,U ones

Oblique parameters (off-shell)

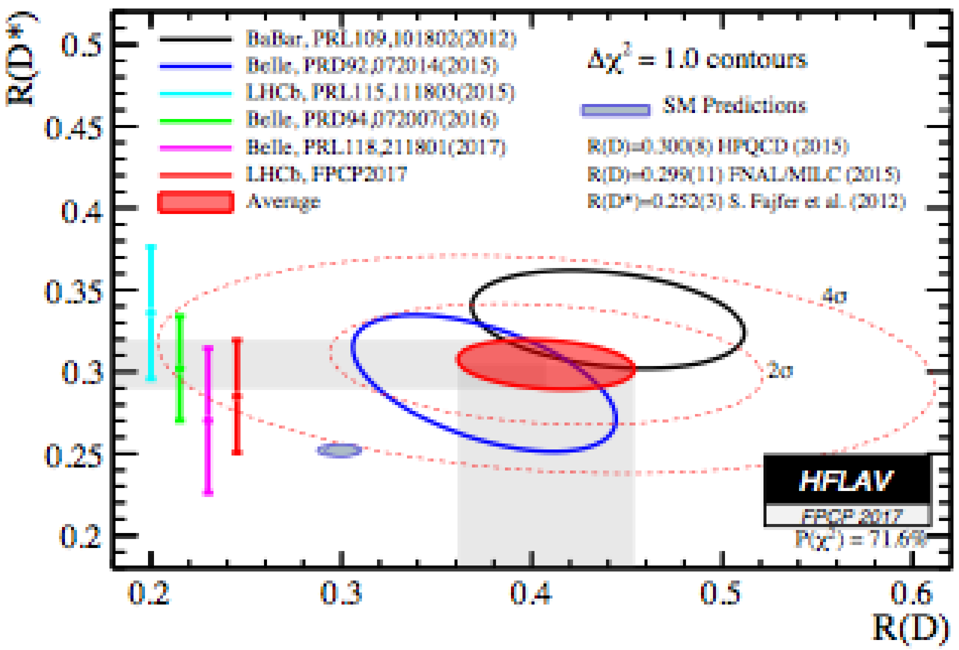
Farina et al., 1609.08157



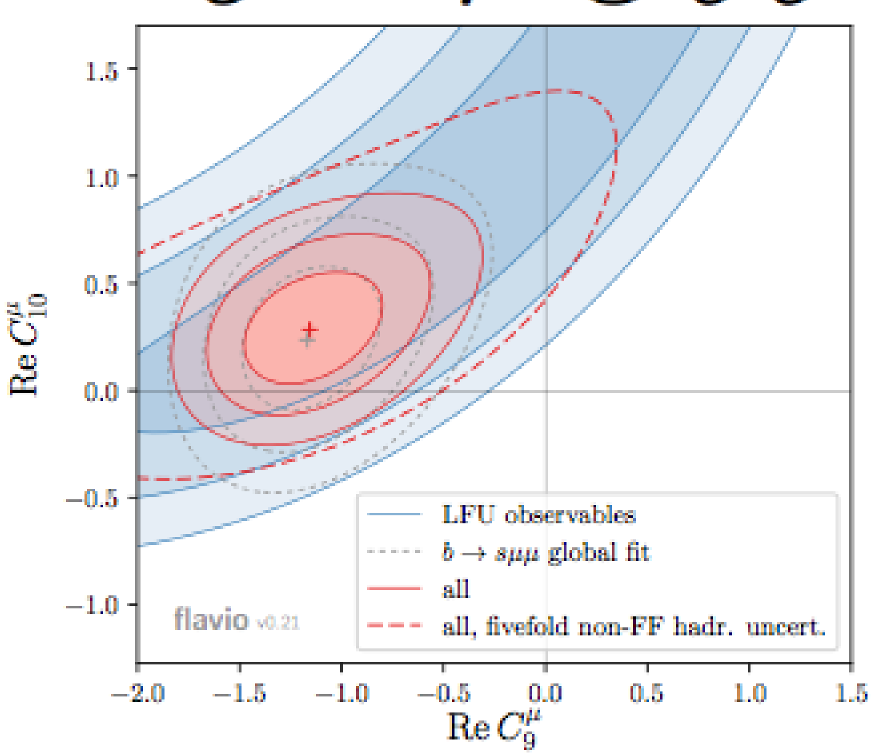
		LEP	ATLAS 8	CMS 8	LHC 13		100 TeV	ILC	TLEP	ILC 500 GeV
luminosity		$2\times10^7\,Z$	$19.7\,\mathrm{fb}^{-1}$	$20.3\,\mathrm{fb}^{-1}$	$0.3\,\mathrm{ab}^{-1}$	$3\,\mathrm{ab}^{-1}$	$10\,\mathrm{ab}^{-1}$	$10^9\,Z$	$10^{12}\,Z$	$3\,\mathrm{ab}^{-1}$
NC	$W\times10^4$	$[-19, 3]$	$[-3, 15]$	$[-5, 22]$	±1.5	±0.8	±0.04	±3	±0.7	±0.3
	$Y\times10^4$	$[-17, 4]$	$[-4, 24]$	$[-7, 41]$	±2.3	±1.2	±0.06	±4	±1	±0.2
CC	$W\times10^4$	—	±3.9		±0.7	±0.45	±0.02	—	—	—

Flavor anomalies

$$b \to c\ell\bar{\nu}$$



$$b \to s\ell\ell$$



M_{NP} < 9TeV [pert.unitarity]

Candidates:

- W', Z'
- EW scalars
- Leptoquarks

Combined explanation by "Natural" μ suppression

see e.g. talk by Greljo @ 2nd FCC Physics Workshop

see talk by M. Klute

Flavor anomalies

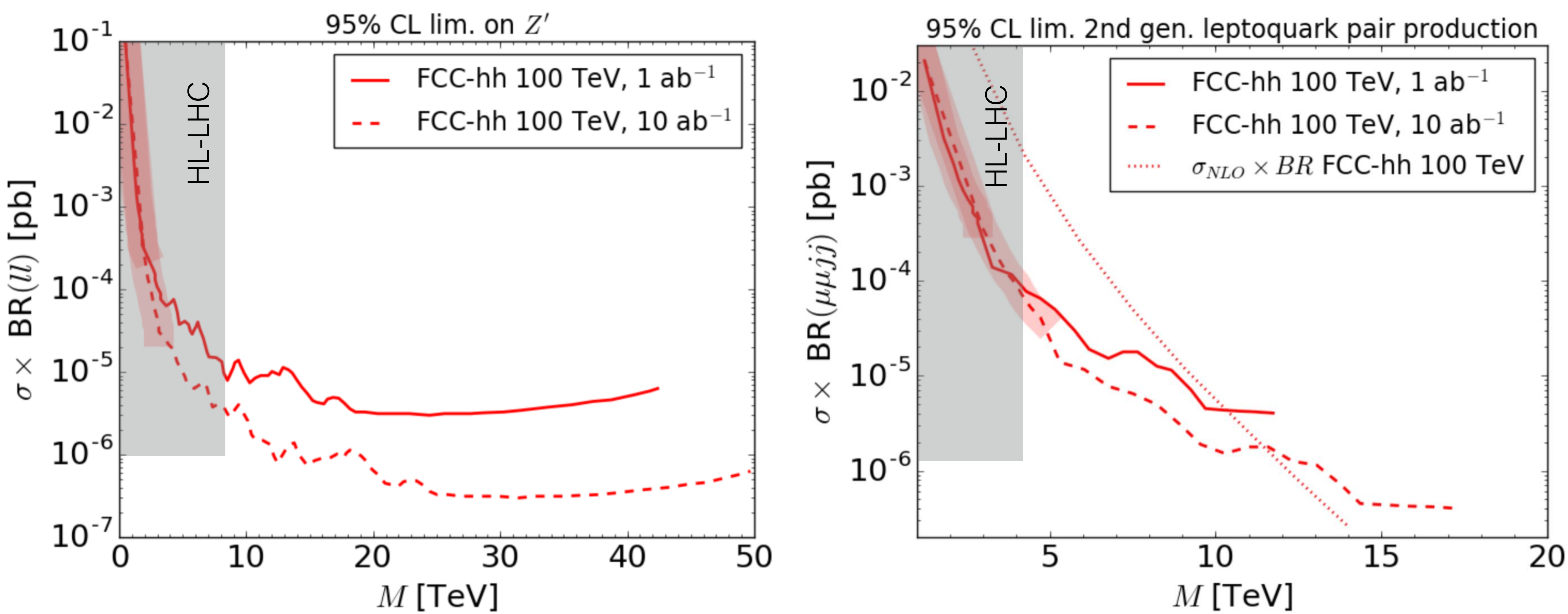
Several ongoing studies

Final states with τ, and b pose challenges

Indirect FCC-ee potential also under investigation

Some prospects for high-pt searches already available

Allanach et al., 1710.06363

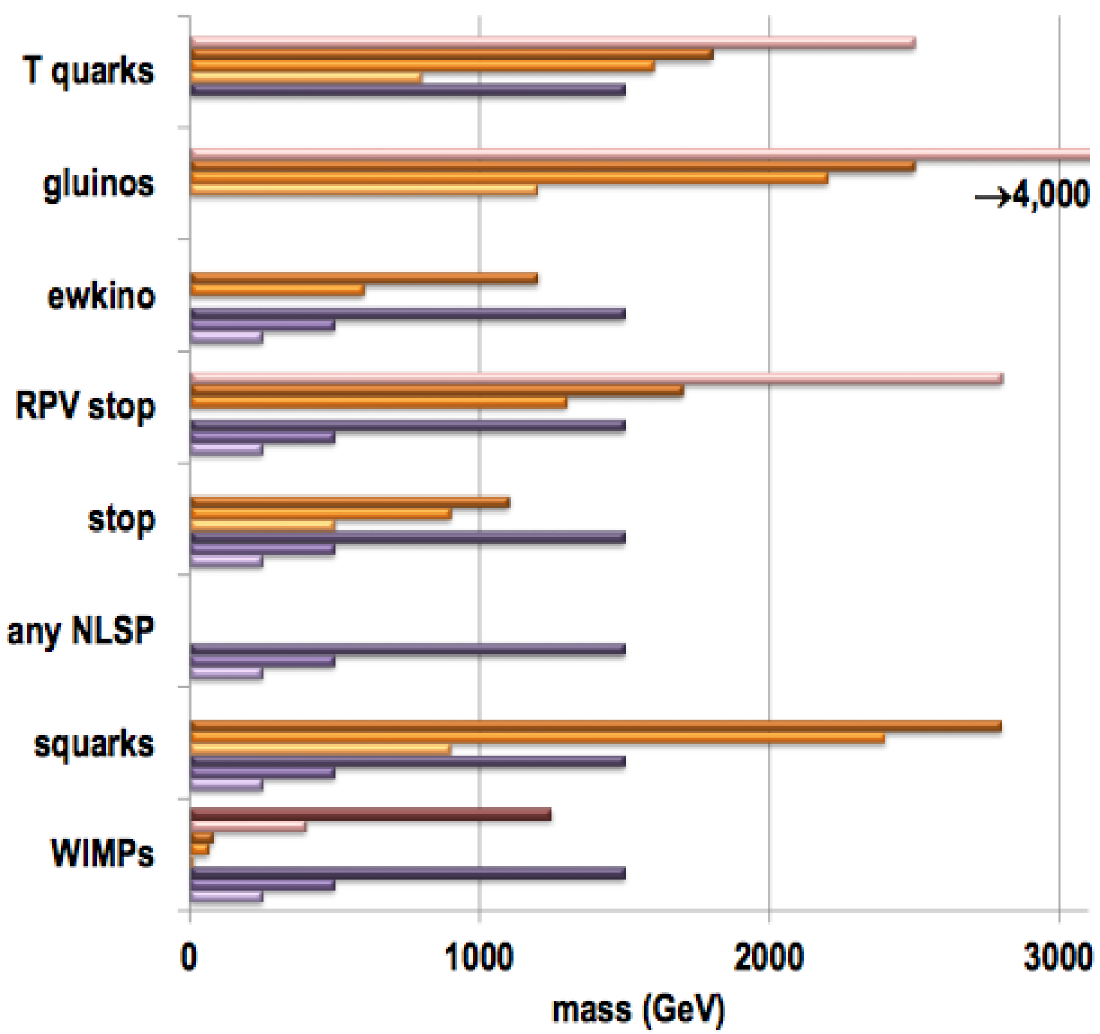


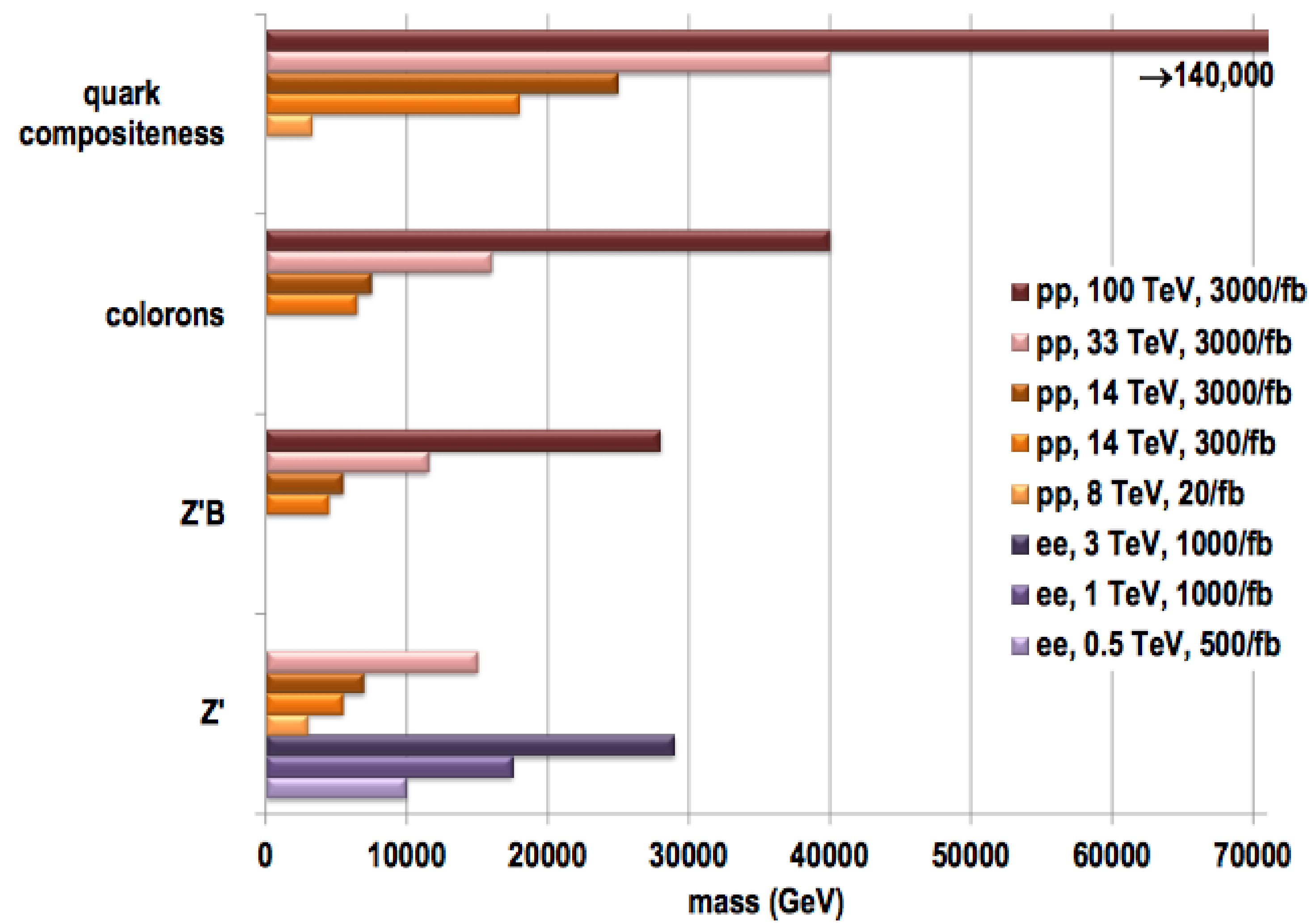
Direct searches and reach

Direct searches at high mass are a priority of high energy colliders

The reach on SUSY particles extends well above TeV

For s-channel resonances several tens of TeV possible



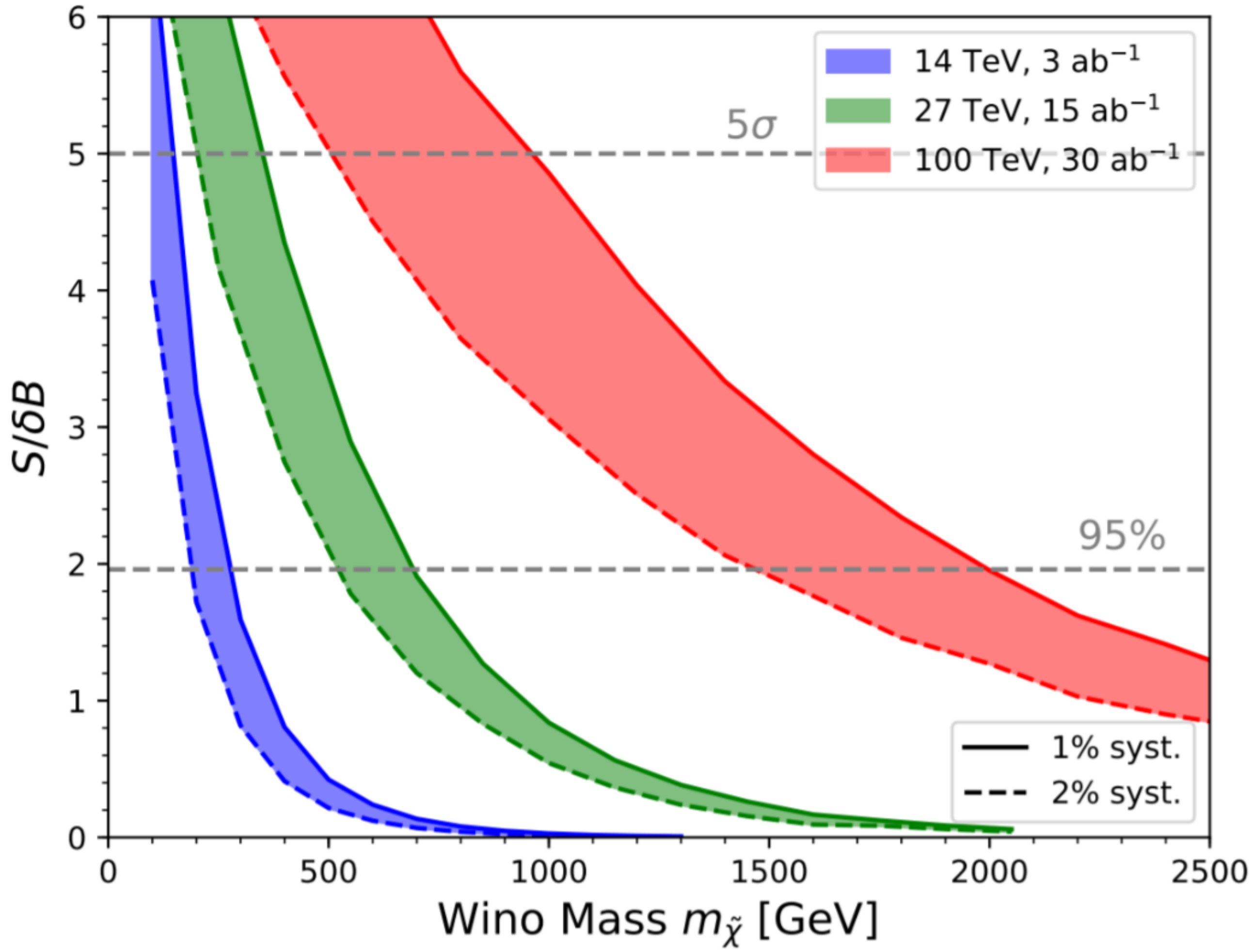


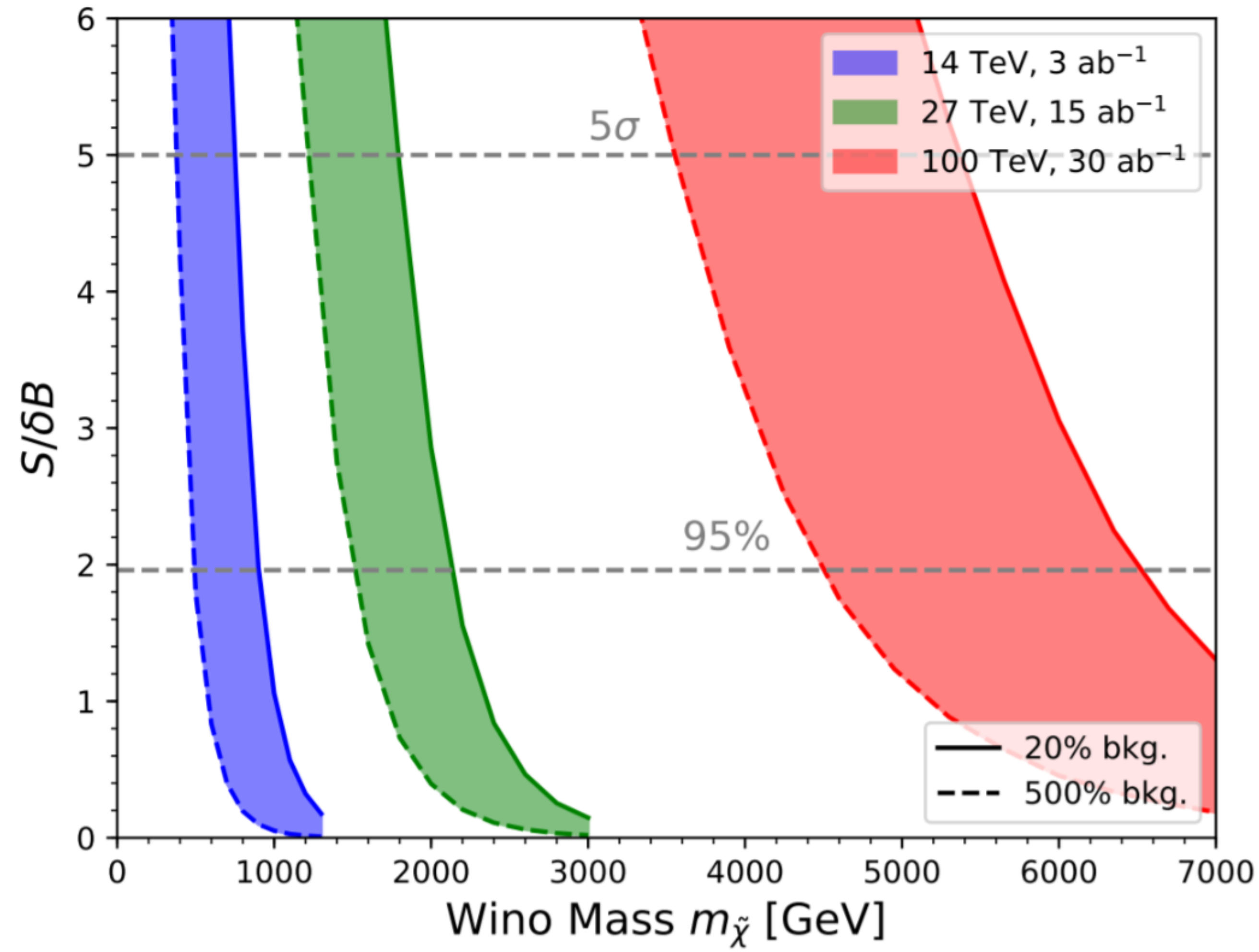
Snowmass Report, 1311.0299
also see BSM FCC-hh report

see talk by C. Helsen

Dark Matter

As an example consider pure-wino Minimal Dark Matter



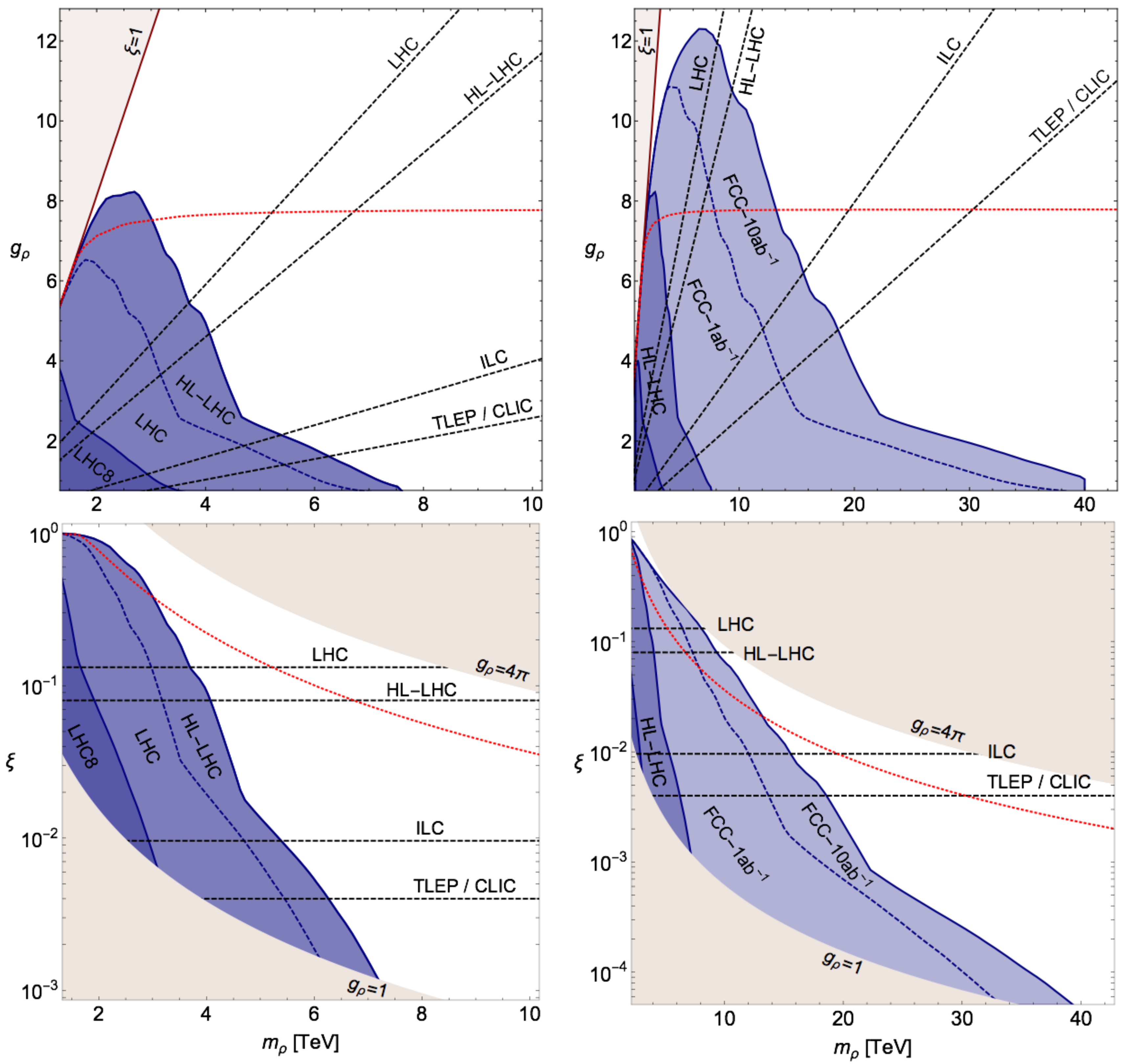


HL/HE LHC Yellow Report, to appear

Compositeness

Thamm et al., 1502.01701

In motivated and predictive scenarios one can study interplay



Conclusions

- While the LHC is running the community is working hard to plan the future of Collider Physics (joint accelerator/detector/experimental/theory effort)
- It is important to asses the capabilities of different colliders both at the level of direct and indirect tests of SM and BSM physics
- First physics studies devoted to the understanding of the necessary machine and detector requirements to get the best out of new machines
- Lots of ideas from the theory community for new tests of the SM and of New Physics
- Several studies completed or in completion by this year as input to the forthcoming update of the European Strategy for Particle Physics (2019)

Thank you