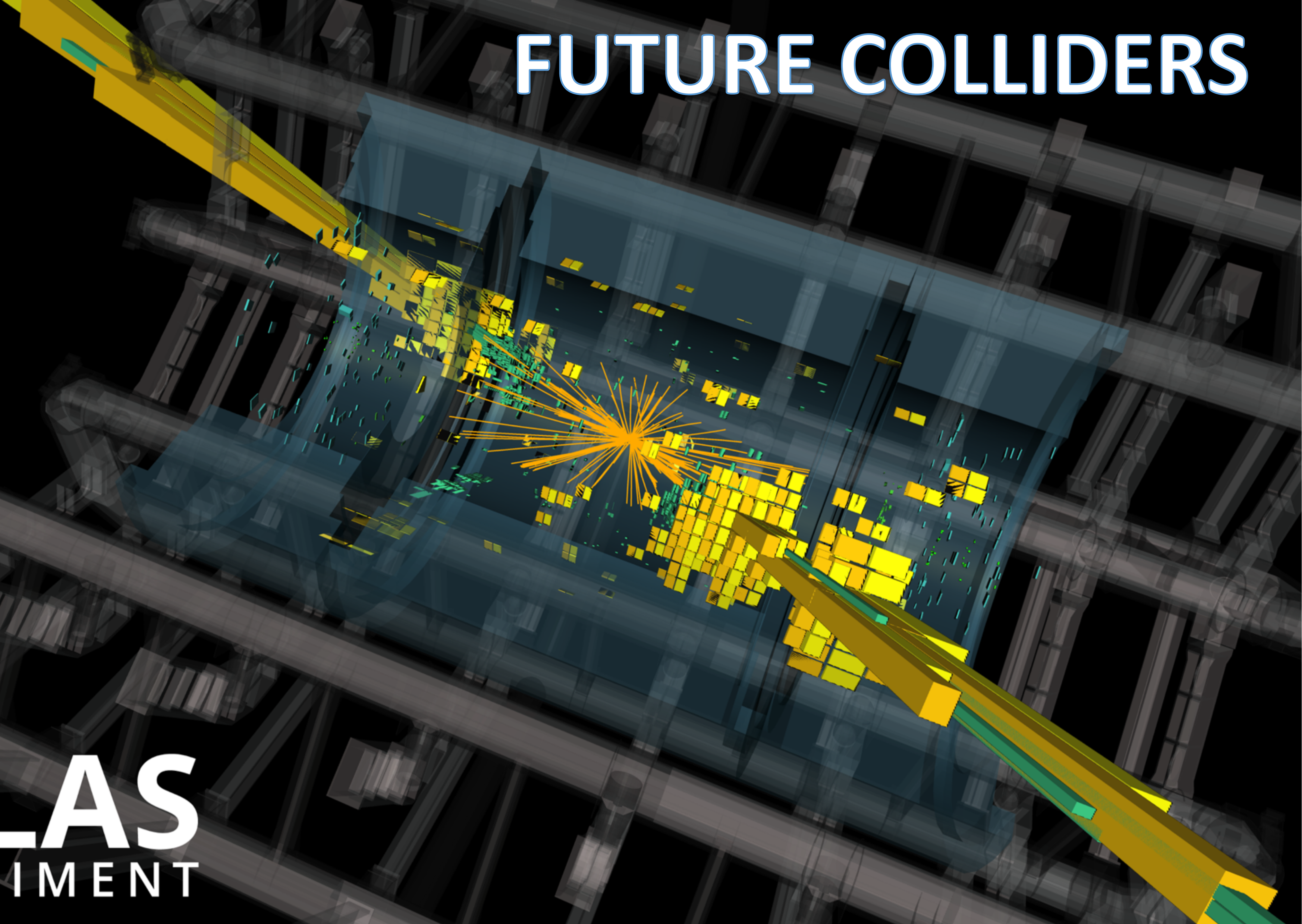
FUTURE COLLIDERS

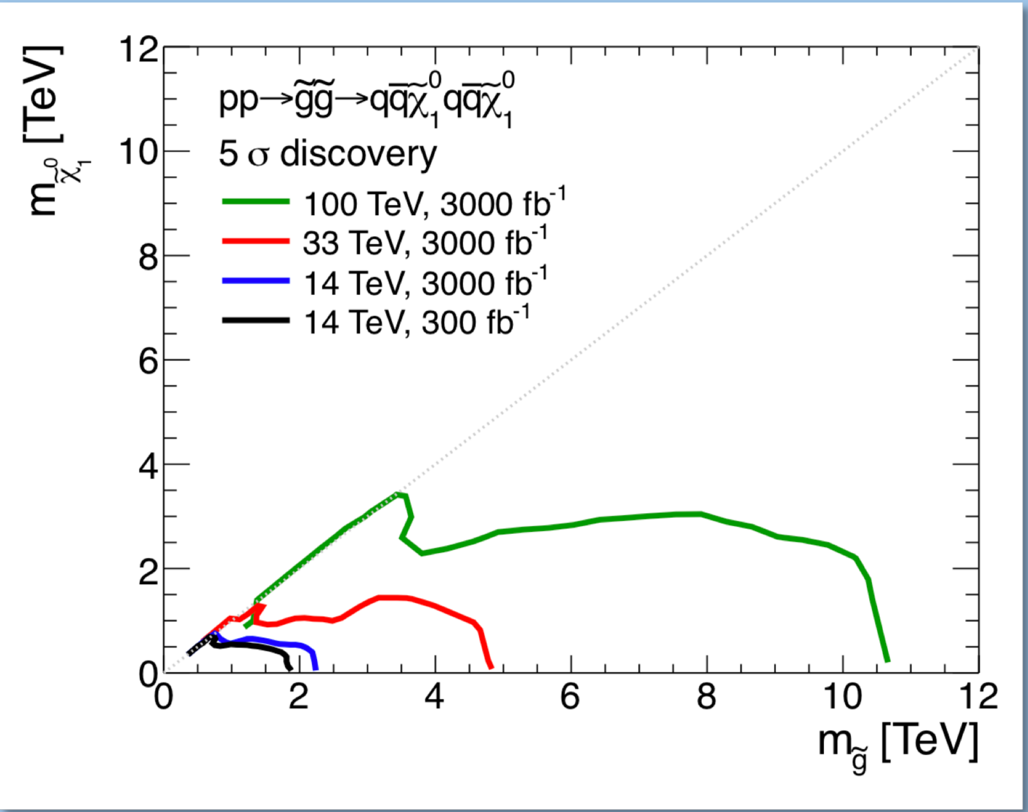
ESPP discussion
Energy frontier
Frank & Tristan
Nikhef, 5 October 2018



ATLAS EXPERIMENT

A NEW COLLIDER

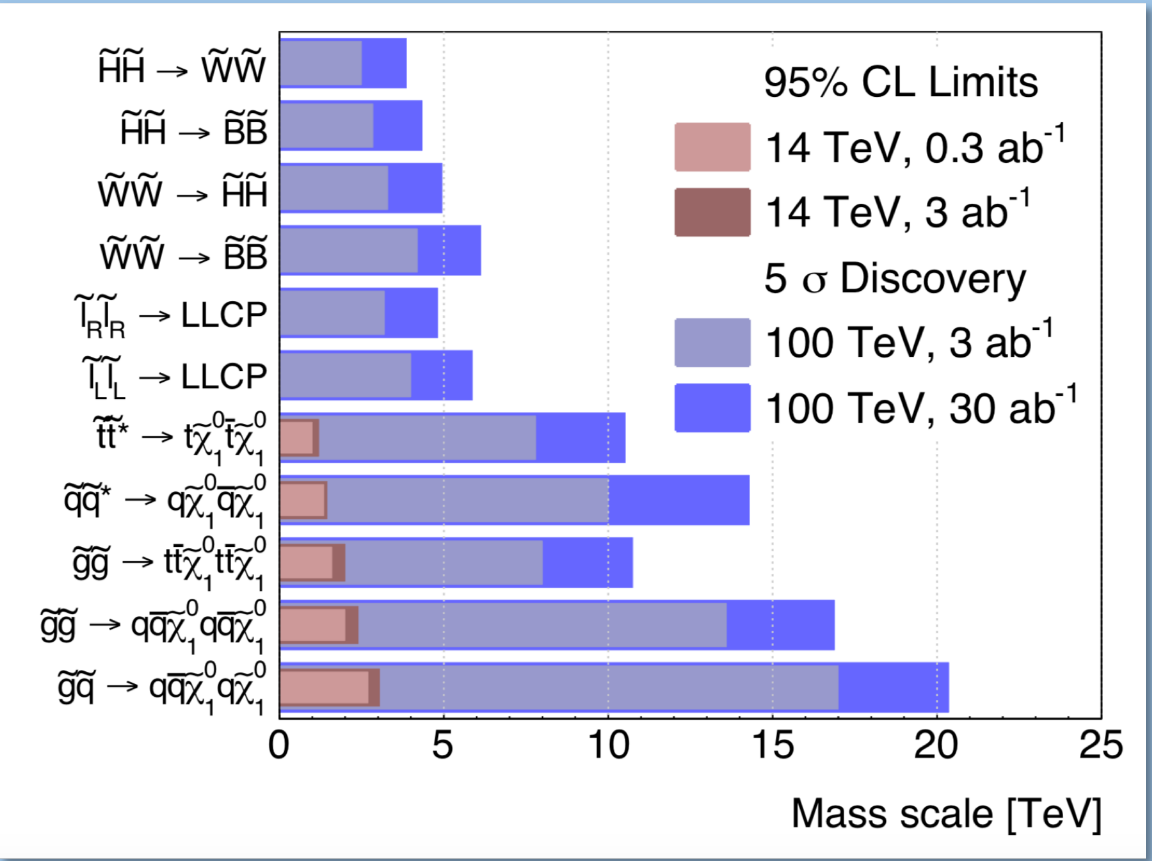
- **Discovery of SUSY?**



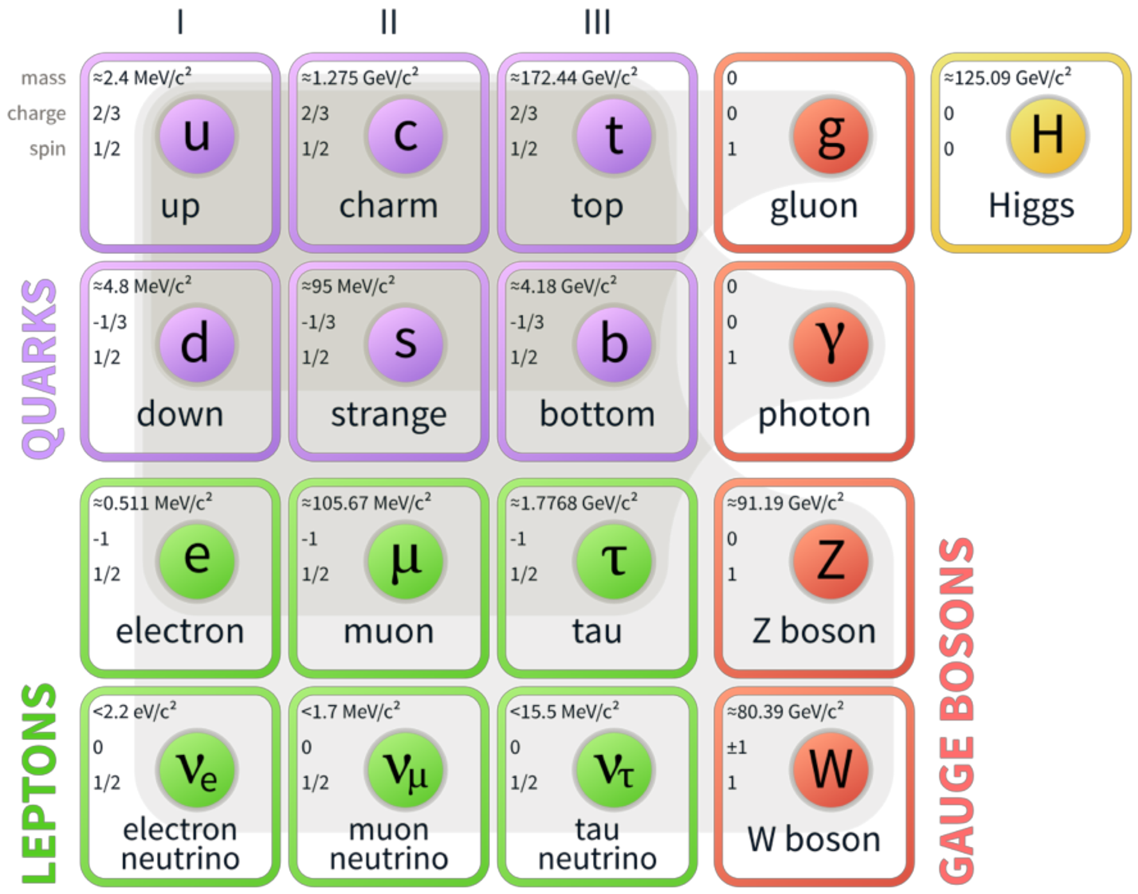
A NEW COLLIDER

TdP et al
BSM @ FCC-hh
arXiv/1606.00947

- **Discoveries?**

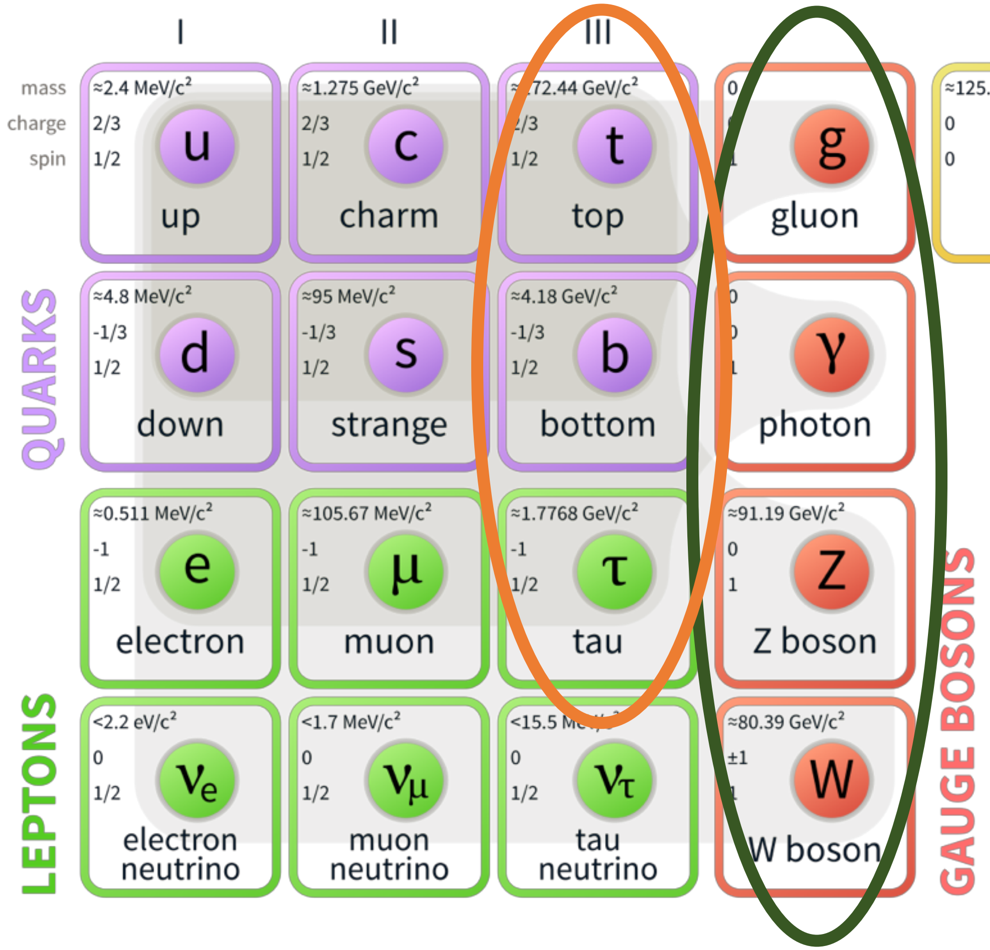


MOTIVATION



Wikipedia user MissMJ

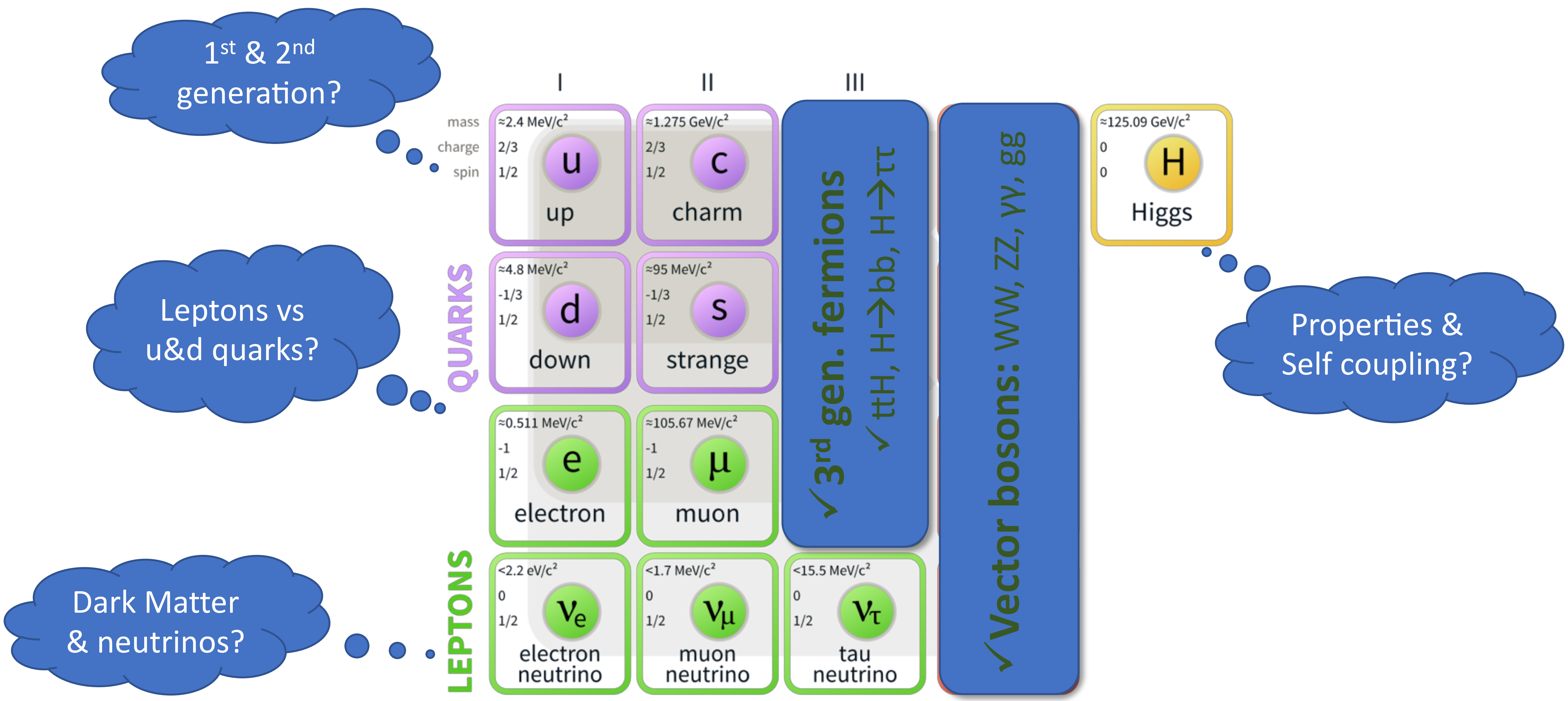
HIGGS: DONE



✓**Gauge bosons**
- ✓WW, ZZ, γγ, gg

✓**3rd generation fermions**
- ✓ttH, H→bb, H→ττ

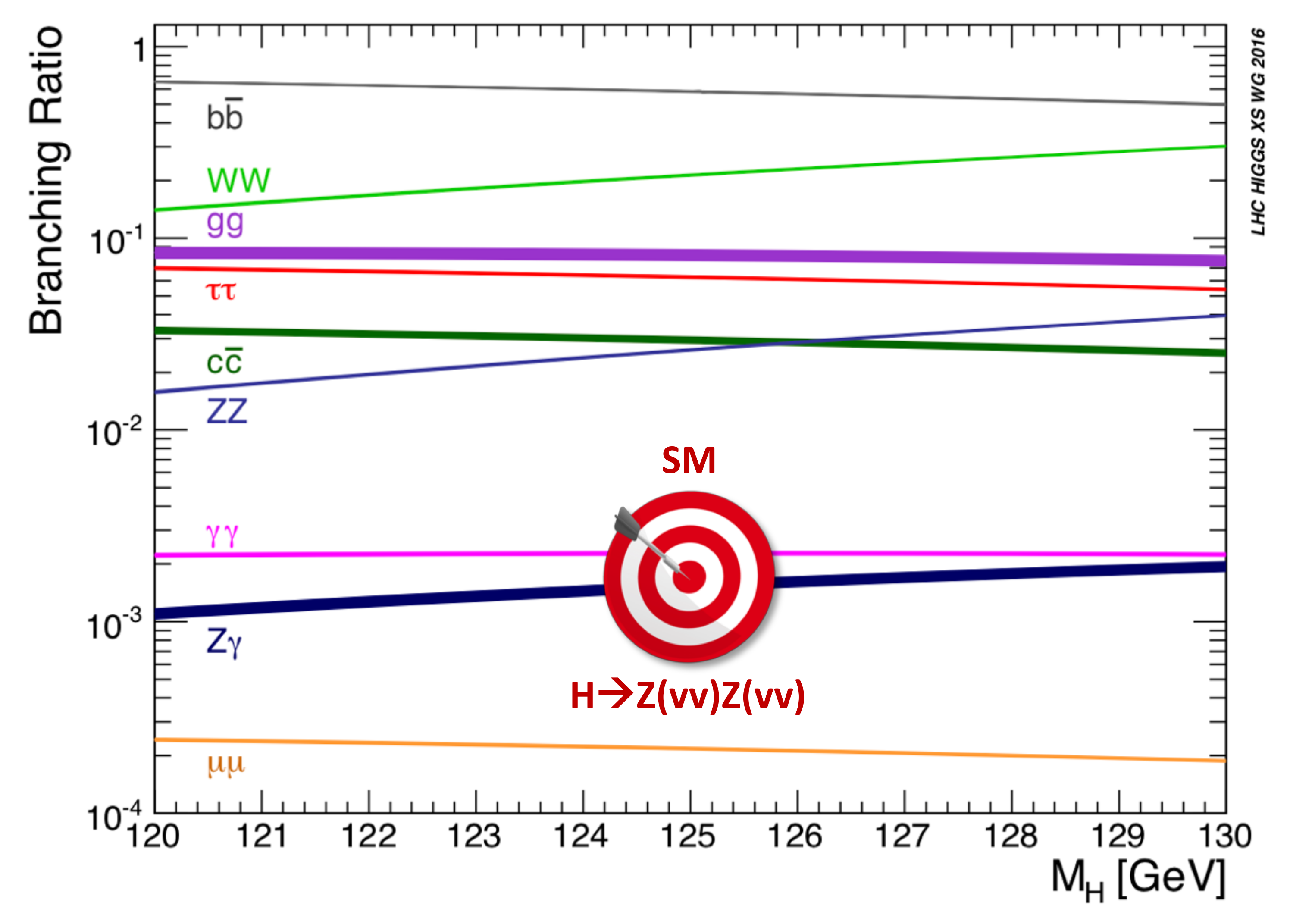
TO DO


1st & 2nd generation?
Leptons vs u&d quarks?
Dark Matter & neutrinos?
Properties & Self coupling?
I
II
III
mass
charge
spin
≈2.4 MeV/c²
2/3
1/2
u
up
≈1.275 GeV/c²
2/3
1/2
c
charm
≈4.8 MeV/c²
-1/3
1/2
d
down
≈95 MeV/c²
-1/3
1/2
s
strange
≈0.511 MeV/c²
-1
1/2
e
electron
≈105.67 MeV/c²
-1
1/2
μ
muon
<2.2 eV/c²
0
1/2
electron neutrino
<1.7 MeV/c²
0
1/2
muon neutrino
<15.5 MeV/c²
0
1/2
tau neutrino
QUARKS
LEPTONS
✓3rd gen. fermions
✓ttH, H→bb, H→ττ
✓Vector bosons: WW, ZZ, γγ, gg
≈125.09 GeV/c²
0
0
H
Higgs

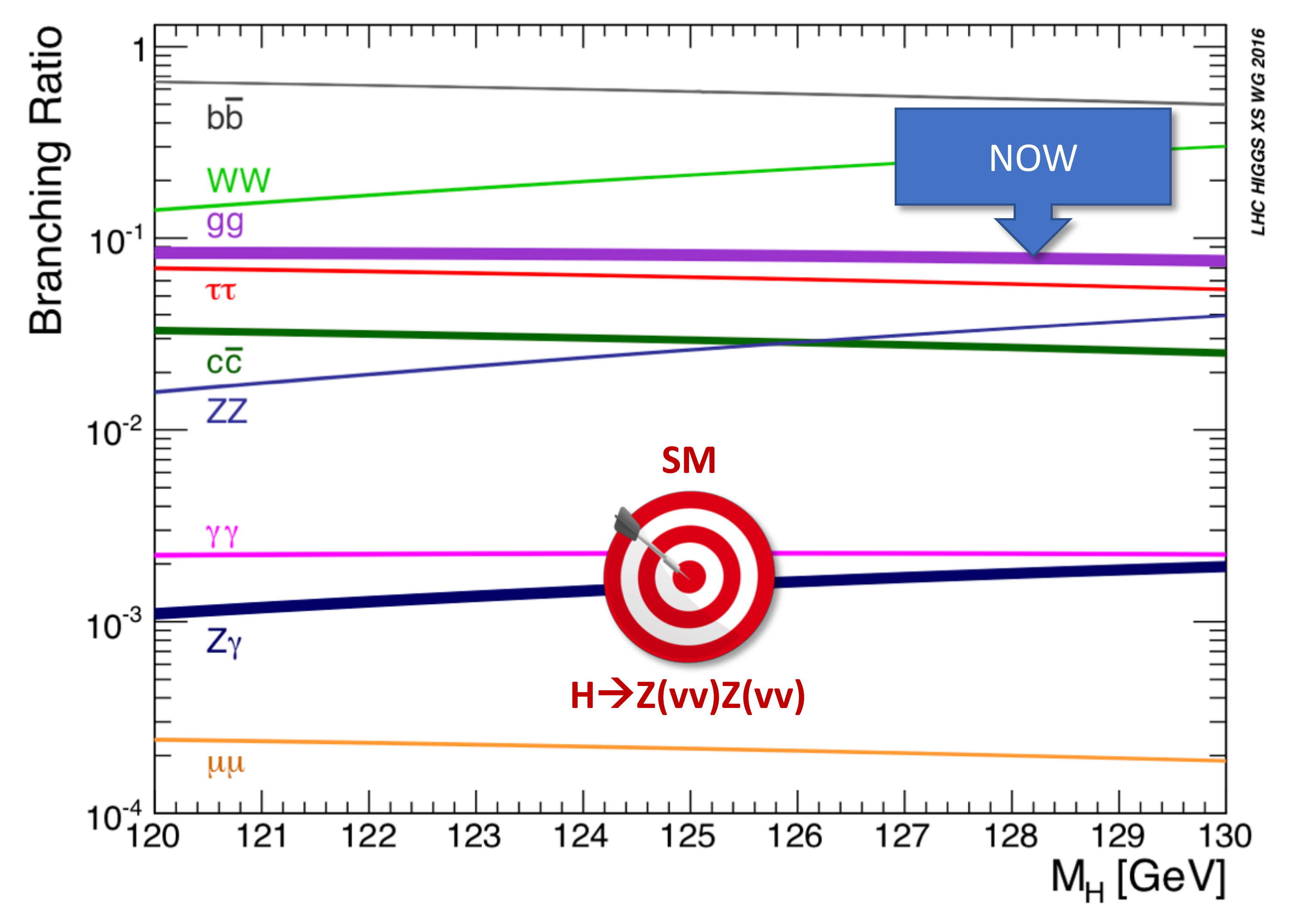
EXAMPLE 1: DARK HIGGS

H→invisible: Coupling of Higgs to **Dark Matter** and/or **neutrinos**?

PROSPECTS


Branching Ratio
1
10^{-1}
10^{-2}
10^{-3}
10^{-4}
$b\bar{b}$
WW
gg
ττ
$c\bar{c}$
ZZ
γγ
Zγ
μμ
SM
H→Z(νν)Z(νν)
LHC HIGGS XS WG 2016
120 121 122 123 124 125 126 127 128 129 130
M_H [GeV]

PROSPECTS


Branching Ratio
1
10^-1
10^-2
10^-3
10^-4
bb̄
WW
gg
ττ
cc̄
ZZ
γγ
Zγ
μμ
NOW
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H→Z(νν)Z(νν)
120
121
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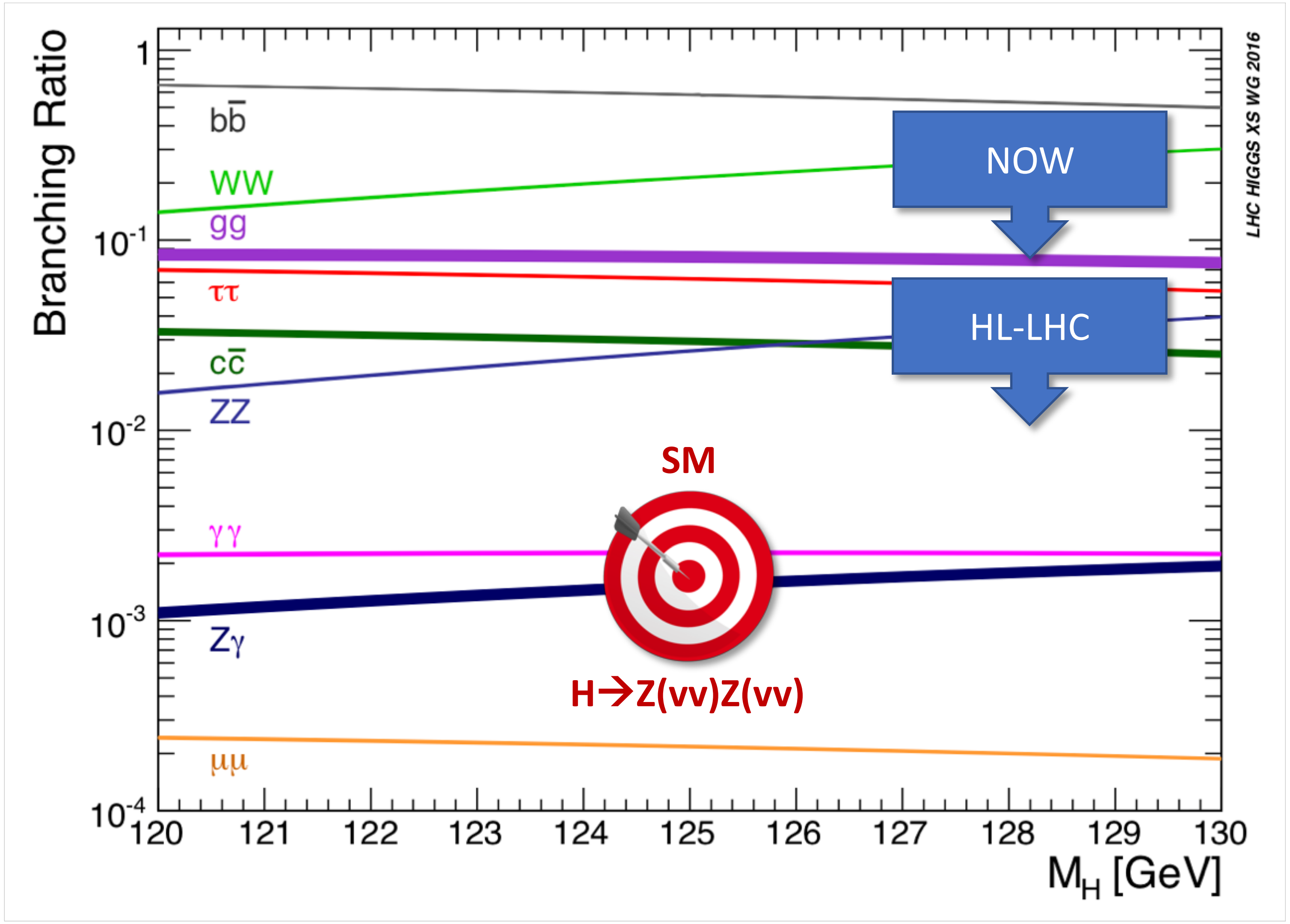
M_H [GeV]
LHC HIGGS XS WG 2016

PROSPECTS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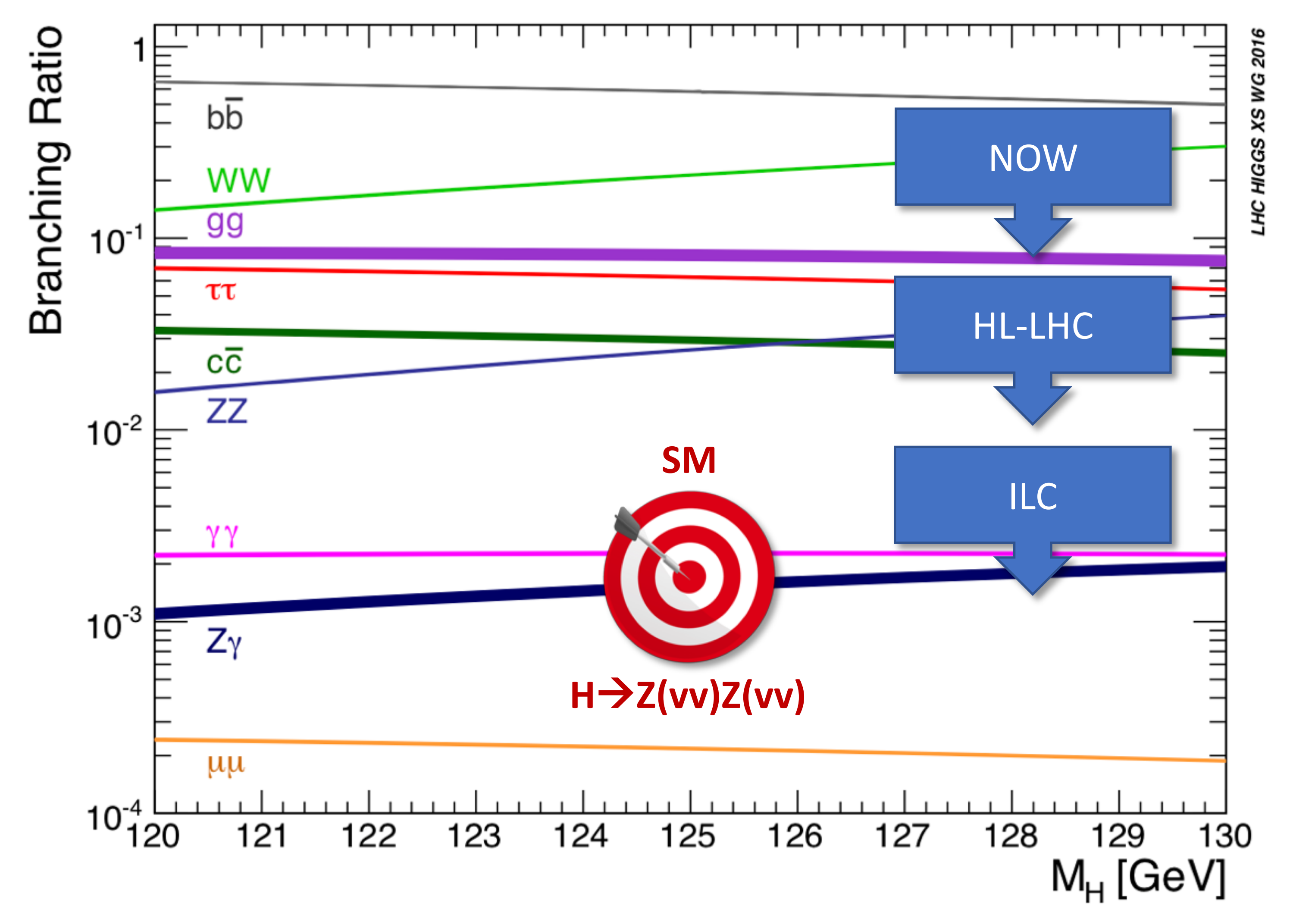
120 121 122 123 124 125 126 127 128 129 130
M_H [GeV]
LHC HIGGS XS WG 2016
NOW
HL-LHC
SM
H→Z(νν)Z(νν)

PROSPECTS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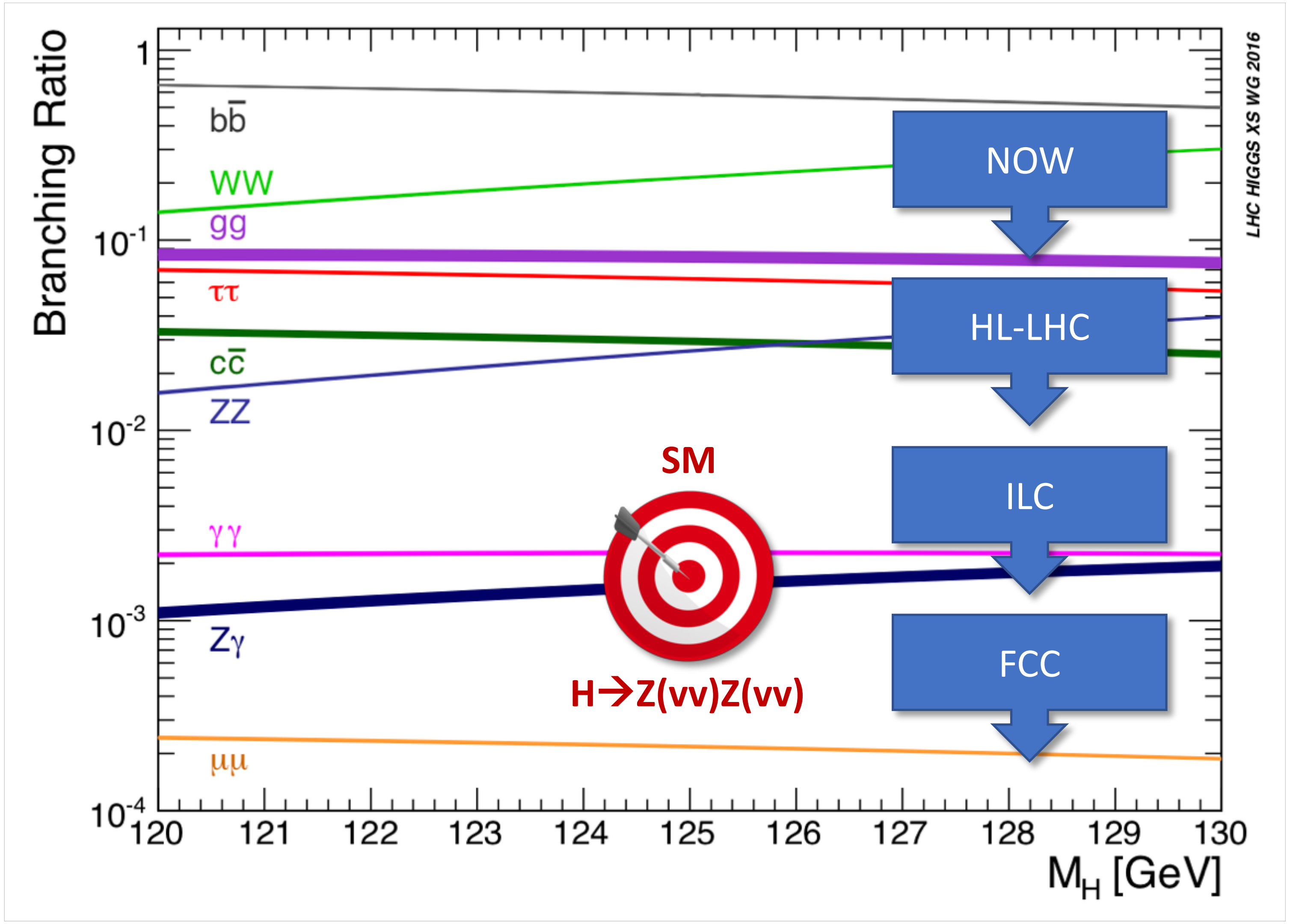
γγ
Zγ
μμ
120 121 122 123 124 125 126 127 128 129 130
M_H [GeV]
LHC HIGGS XS WG 2016
NOW
HL-LHC
ILC
SM
H→Z(νν)Z(νν)

PROSPECTS



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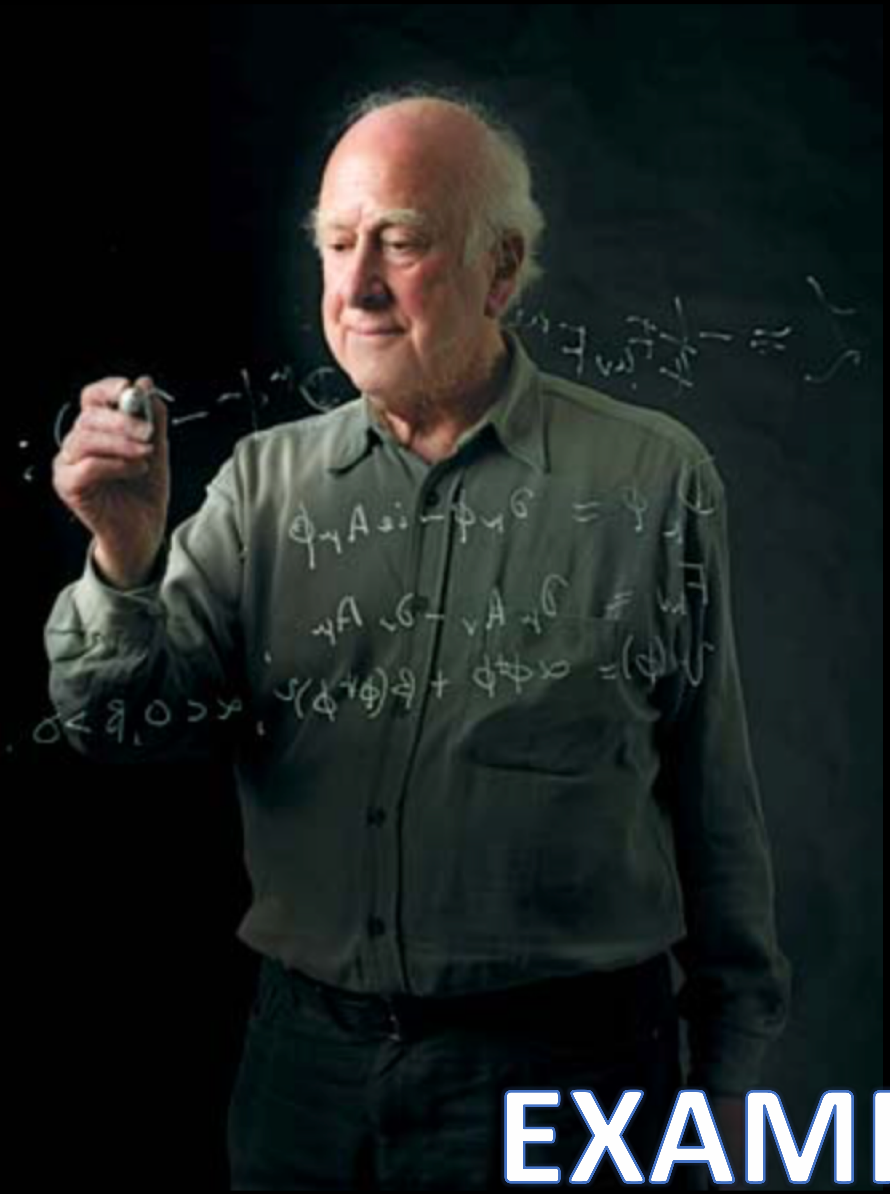
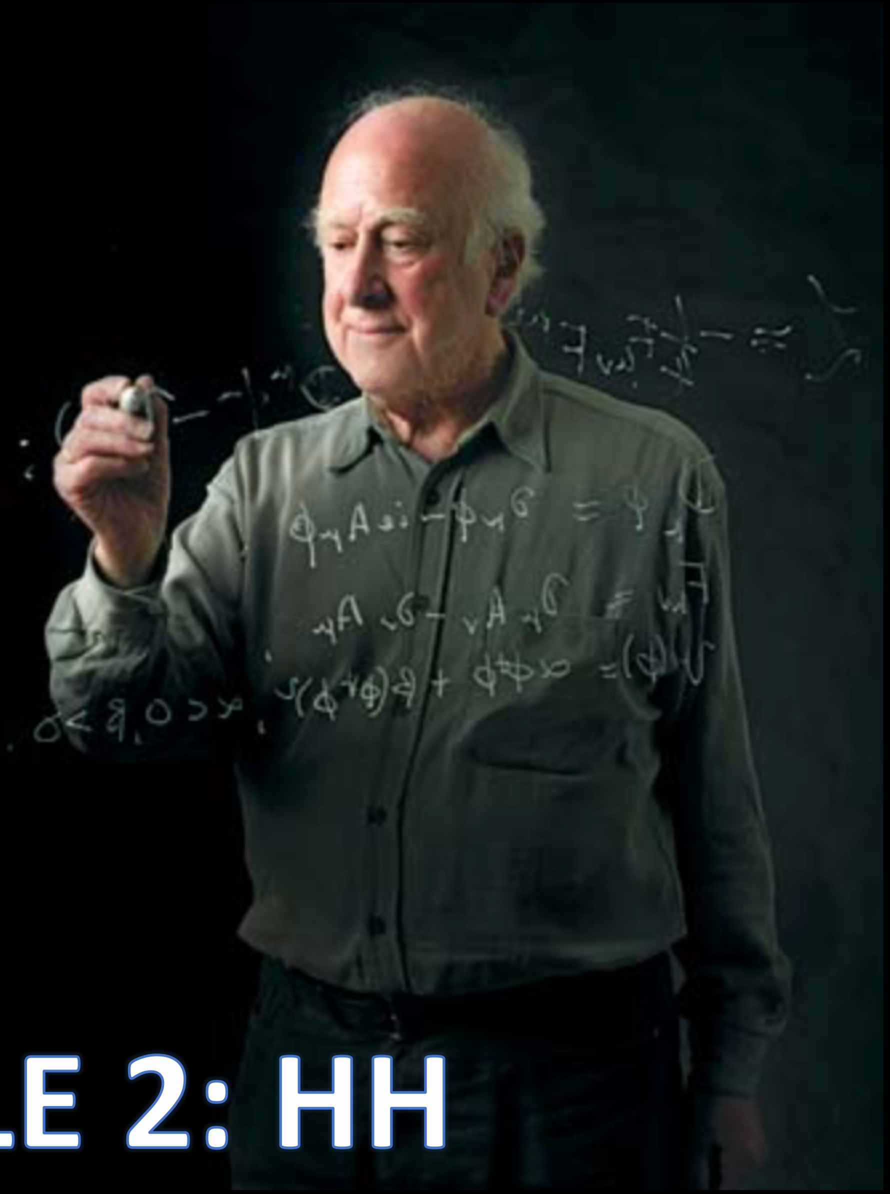


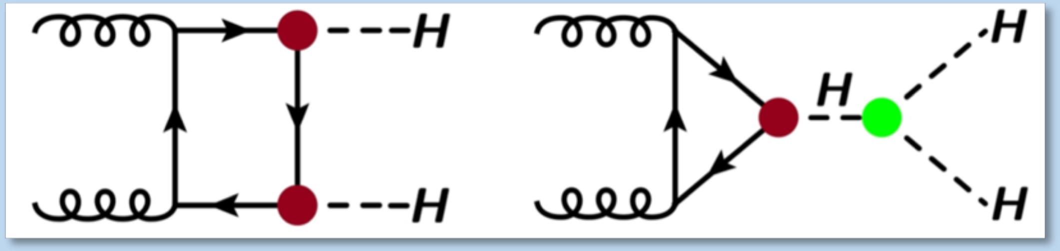


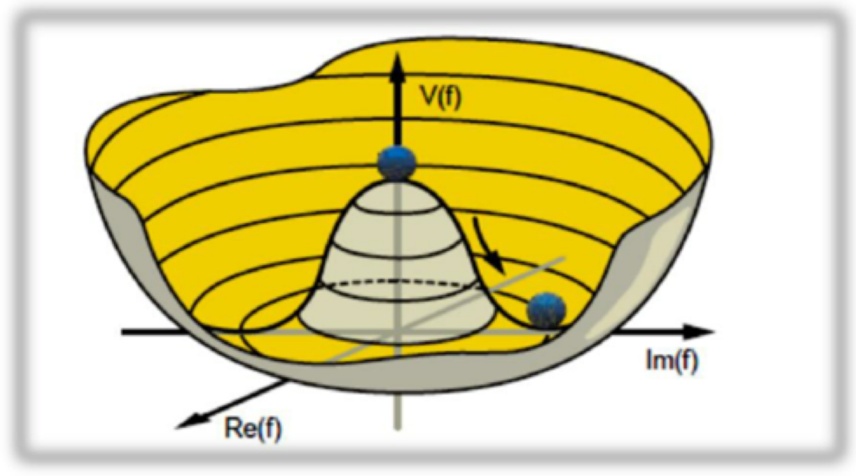
EXAMPLE 2: HH

Double Higgs: Self coupling, Higgs potential, Baryogenesis?

SELF COUPLING

- **HH production challenging**
  - For LHC: **σ(13 TeV) = 33 fb**
  - Destructive interference





Sensitivity

- Current @ ATLAS: **10 x SM**
- Projections for HL-LHC:
  >3 σ per experiment

SENSITIVITIES

- **Self coupling**

Collider	Method	Sensitivity
LHC (pp)	Di-Higgs	⭐
FCC-ee	Loops (indirect)	⭐⭐
HE-LHC (pp)	Di-Higgs	⭐⭐⭐
CLIC	Di-Higgs (no interference)	⭐⭐⭐⭐
FCC-pp (pp)	Di-Higgs	⭐⭐⭐⭐⭐

SENSITIVITIES

➢**pp & ee colliders: a complementary program!**

Self coupling
2nd gen. **quarks**
2nd gen. **leptons**
Invisible decays

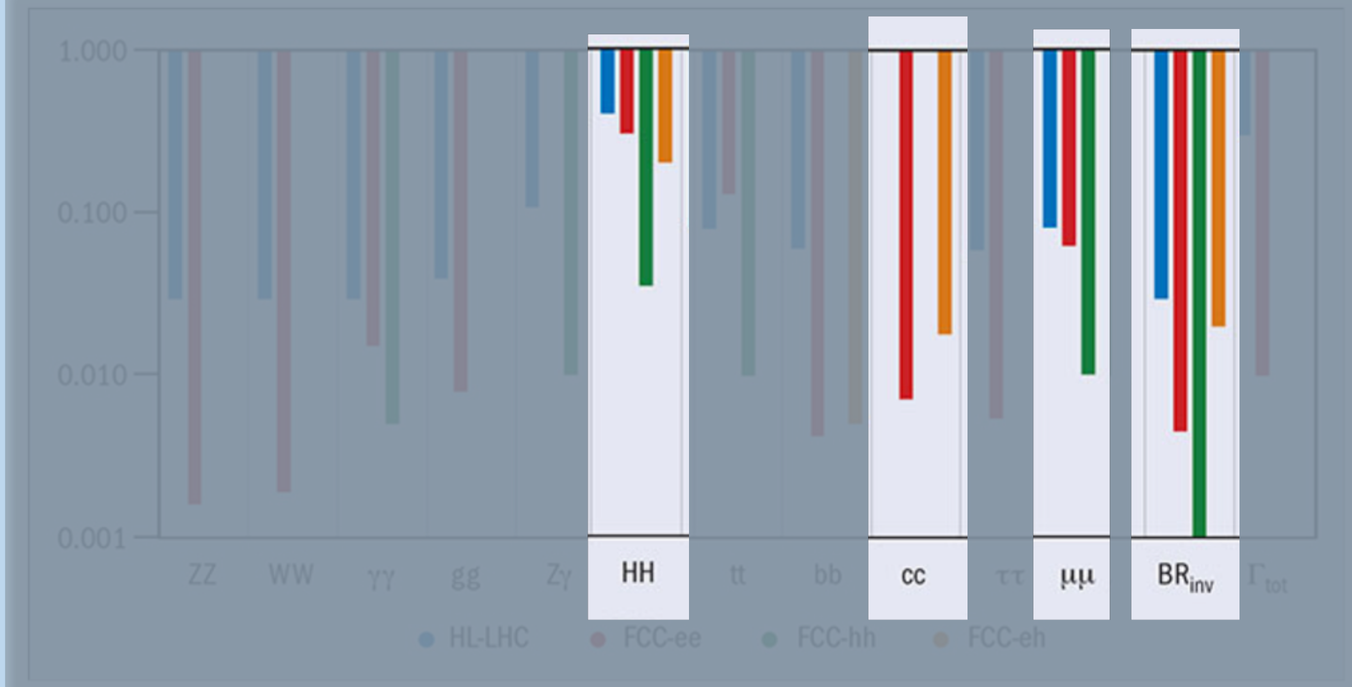


Fig. 1. Together, FCC-ee, hh and eh can provide detailed measurements on the Higgs properties. The figure shows indicative precision in the determination of couplings to gauge bosons, quarks and leptons, as well as of the Higgs self-coupling, of its total width and of the invisible decay rate. Firmer estimates will appear in the CDR.

DREAM BIG !


martijn v calmthout
@vancalmthout
Following
Dubbele Higgs productie. Sommige experimentatoren dromen ervan. Omdat je daar ziet hoe higgs iets van zichzelf voelt. Tot zover de berichten uit de kroeg. #sciencepark
Translate Tweet
6:28 PM - 4 Oct 2018
10 Likes
2
10

“Energy Frontier” intro

Tristan, Frank

Charge

From Pamela's slides as shown on September 6:

FUTURE ACCELERATION

- Support an ambitious future accelerator programme at CERN.
- Exploit the unique opportunity opened by the next generation of pp accelerators at CERN (HE_LHC, FCC-pp) to explore the physics processes of the extremely early universe.
- muon collider : no input from strategy document.
- SppC: no input from strategy document.

Per the above, will discuss HE-LHC, Fcc-pp, SppC, Muon Collider

Assumed boundary conditions:

- current data do not provide clear hints about the scale of BSM physics
  ➠ should aim for accessing the highest possible energy scale
- continued role of CERN (see previous discussion)
- requires a major project at/near CERN starting data taking not (significantly?) later than 2045

FCC-pp & HE-HLC

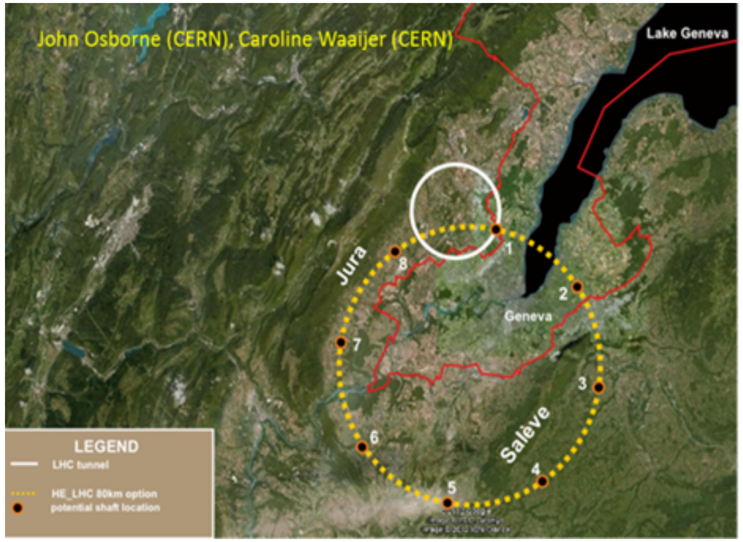


Table source: Daniel Schulte (CERN), 2017

- comparable (identical?) technologies (e.g. dipoles) except CM energy (due to larger circumference of FCC-pp)
- increase from 13 TeV (now) to 27 TeV (by ~ 2045) not sufficiently interesting
  ➠ strong preference for FCC-pp
  - long lead time for (mass) production of 16 T magnets (Nb_3Sn)?

	FCC-pp	HE-LHC
E_{CM} [TeV]	100	27
Luminosity [10^{34} cm^{-2} s^{-1}]	< 30	25
dipole field strength [T]	16	16
bunch spacing [ns]	25 (5)	25 (5)
interactions / crossing	< 1000 (< 200)	800 (160)

Super proton-proton Collider (SppC)

To be housed in same (100 km?) tunnel as CepC

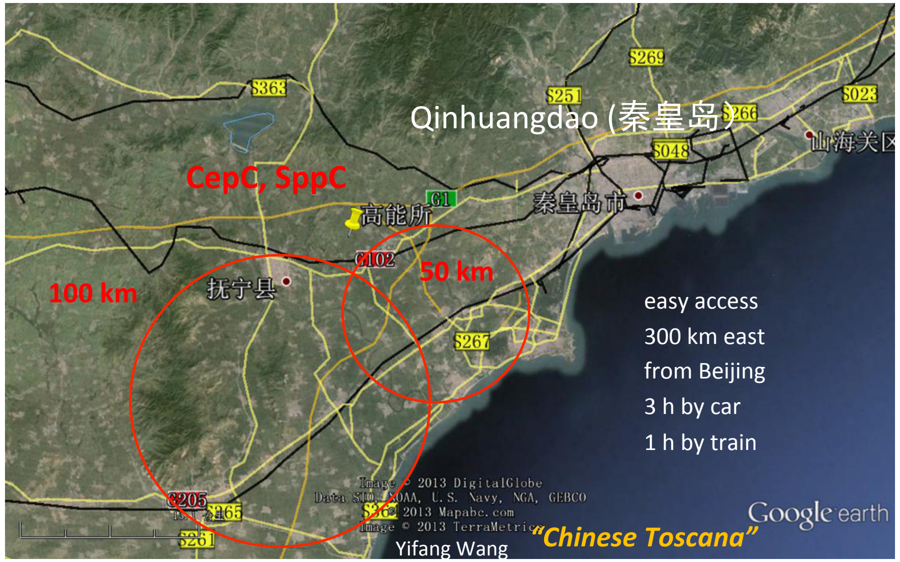
- most effort on CepC & 54 km?

Timescale (2050) & design parameters very similar to those for FCC-pp

- but aim for ultimate E_{CM} = 150 TeV
  - not obvious how this is to be achieved

Direct competition for FCC-pp

- not interesting (for Nikhef / Europe) if FCC-pp will be built



Muon Collider

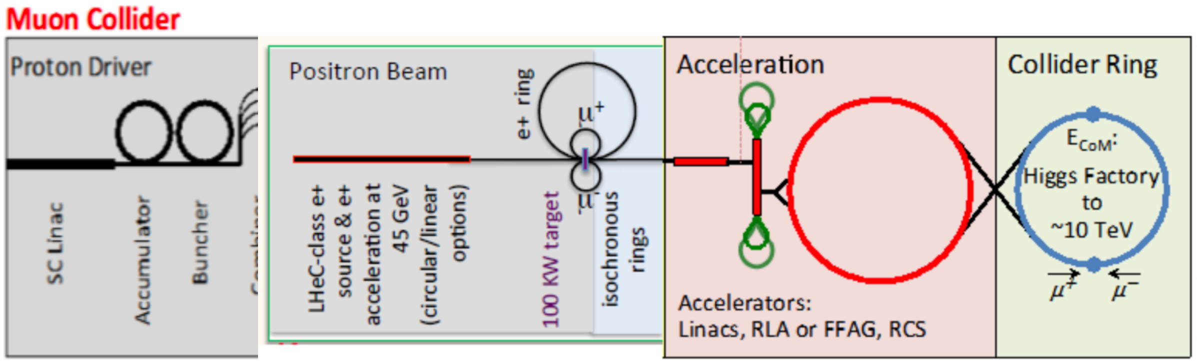
information:
Muon Collider WS

Leptons (i.e., elementary), but $m_\mu \approx 200\ m_e$

- greatly reduced synchrotron radiation ($\sim \gamma^4/R$ per turn)

Challenges: produce copiously, cool (6D: $\sim 10^6$) sufficiently rapidly

- long-standing R&D programme (MAP; MICE)
- novel production (LEMMA) & cooling (PIC) schemes



Beam decay consequences:

- heat load on IR quadrupoles ➠ special magnet design (tungsten "lining")
- significant bg in detector ("comparable to LHC" after use of shielding & timing)
- high E: off-site ν radiation dose in decay cone ~ E^2/D (depth), limit to E < 10 TeV?

Significant development effort needed, but no clear show-stoppers

Muon Collider (2)

Achievable luminosity grows with E_{CM} (Liouville)

Significant (collider) cost reduction possible by using existing infrastructure

- LHC: 14 TeV — energy scale equivalent to ~ 100 TeV pp machine
- FCC-pp: 100 TeV — energy scale equivalent to multi-100 TeV pp

Development path appears long but holds great promise

- if a firm commitment is not opportune yet, it is in Europe's interest to increase R&D effort
  (true also for wakefield acceleration)