Higgs exotic decays

Stefania Gori

Perimeter Institute for Theoretical Physics

2nd CFHEP symposium on circular collider physics

Beijing, August 11st 2014

(Exotic Higgs) decays

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Introduction

What do we want to know about the Higgs in the next n-years?

1. Higgs SM-couplings
• LHC will measure 3rd generation couplings to ~5% level
• How well can HL-LHC measure 2nd generation couplings?

2. Higgs spin/parity
• Higgs is spin 0
• What about CP-admixtures?

3. Are there more Higgs particles?
• LHC will typically probe 1 TeV scale

4. Are there new ways to produce the Higgs?
• Sparticle decays into Higgs bosons?

5. Are there rare/exotic Higgs decays?
• Are there flavor changing Higgs decays?

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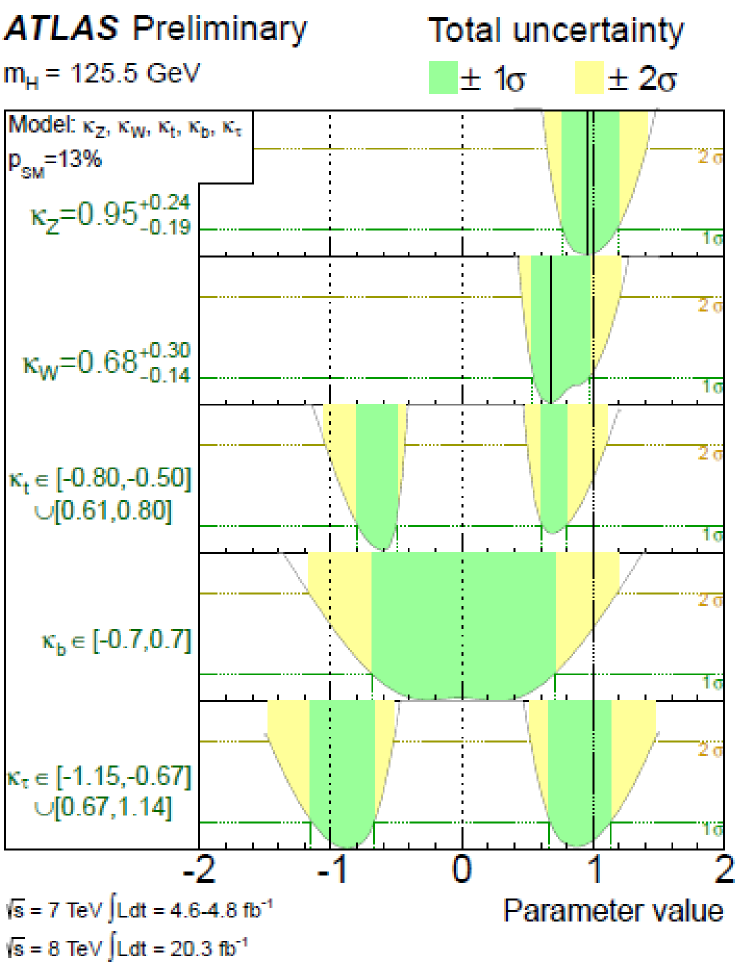
My focus:
Looking for electroweak particles through the Higgs properties
(staus, additional Higgs bosons, Z')

Higgs couplings: present and future

NOW

The Higgs couplings are determined at the level of 30%



ATLAS-CONF-2014-009

FUTURE

LHC:

κ values	300 fb^{-1} here	3000 fb^{-1} here
γ	[5.7 , 9.0]	[2.9 , 6.5]
W	[4.2 , 5.4]	[1.6 , 3.3]
Z	[5.7 , 8.5]	[2.8 , 6.3]
g	[4.9 , 6.9]	[2.3 , 4.8]
b	[11.4 , 14.9]	[4.2 , 8.5]
t	[17.3 , 20.5]	[5.7 , 12.9]
τ	[5.8 , 9.5]	[2.7 , 6.5]
inv.	[6.3 , 8.0]	[2.0 , 4.0]

7-parameter fit

ILC:

	250	500	500up	1000	1000up
W	4.6	0.46	0.22	0.19	0.15
Z	0.78	0.50	0.23	0.22	0.22
g	6.1	2.0	0.96	0.79	0.60
γ	18.8	8.6	4.0	2.9	1.9
b	4.7	0.97	0.46	0.39	0.32
c	6.4	2.6	1.2	0.98	0.72
τ	5.2	2.0	0.89	0.79	0.65
invis.	0.54	0.52	0.22	0.22	0.21

Peskin, 1312.4974

$$\kappa_A \equiv \frac{g(hAA)}{g(hAA)_{SM}}$$

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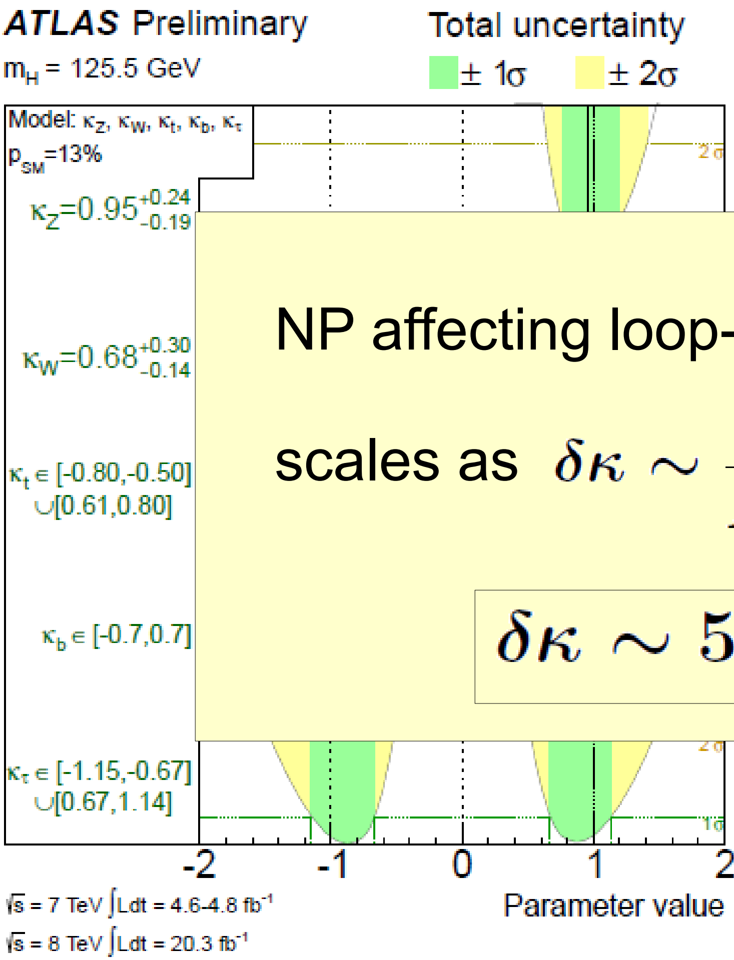

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NP affecting loop-induced and tree level couplings

scales as $\delta\kappa \sim \dfrac{v^2}{\Lambda_{NP}^2}$

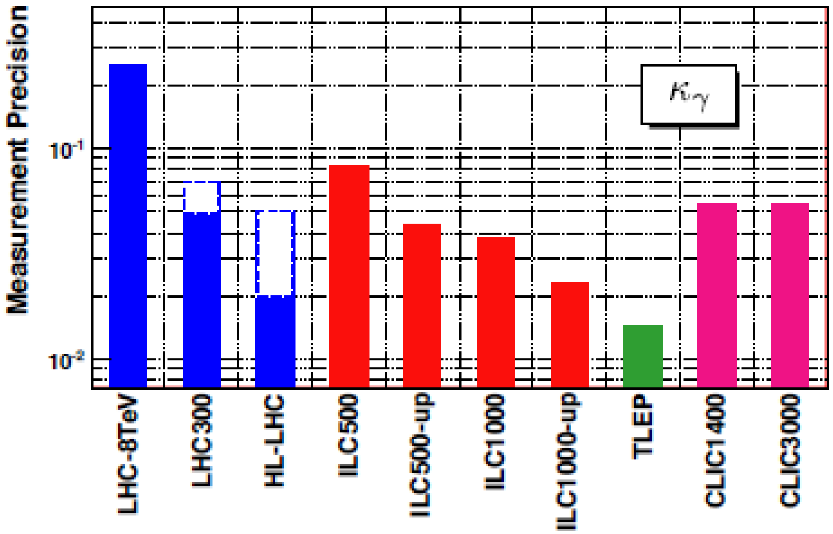
$$\delta\kappa \sim 5\% \Rightarrow \Lambda_{NP} \sim 1\,\mathrm{TeV}$$

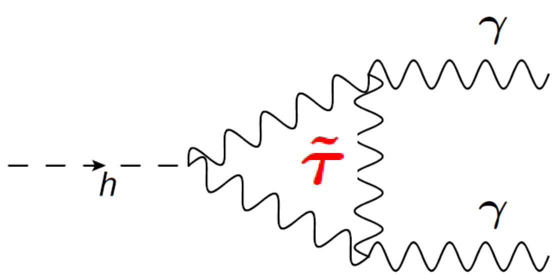
$$\kappa_A \equiv \frac{g(hAA)}{g(hAA)_{SM}}$$

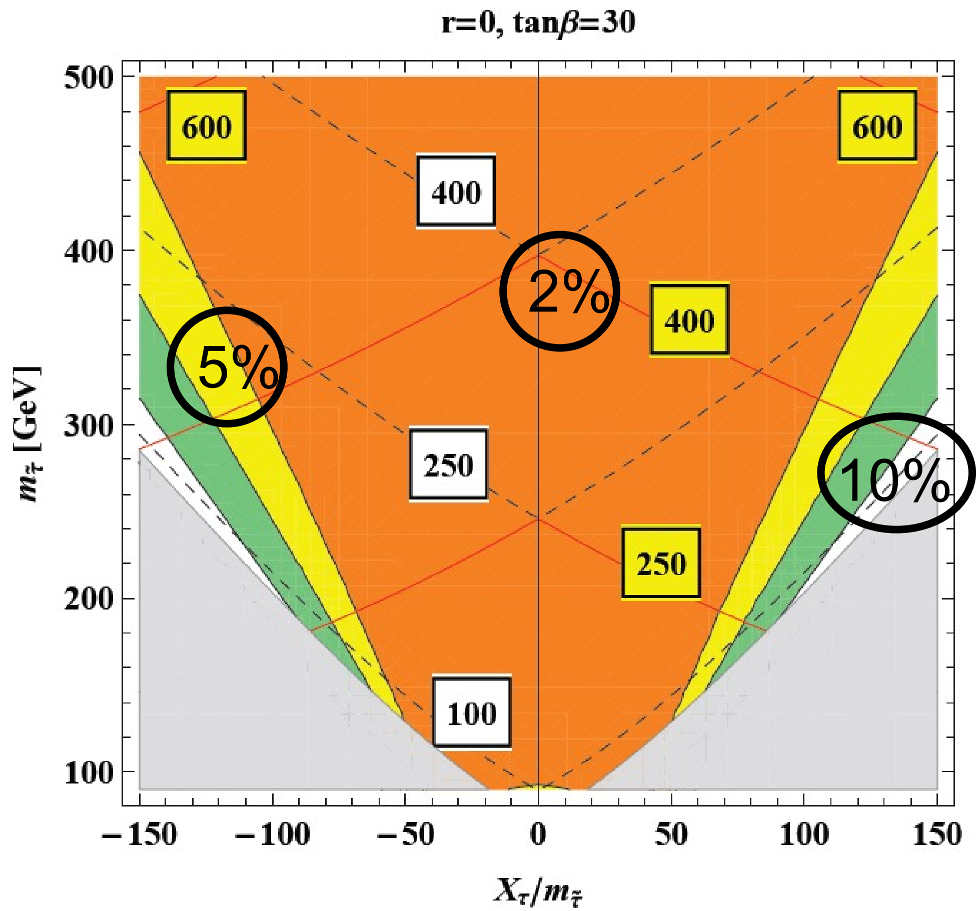
Peskin, 1312.4974

A few remarkable examples (1)

1401.6081 Report of the 2013 community summer study: energy frontier







SG, Low, 1307.0496

A few remarkable examples (2)

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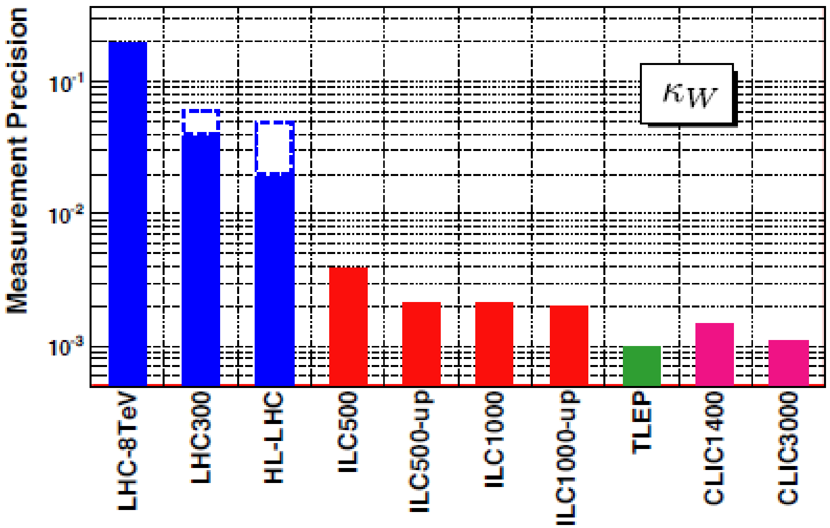
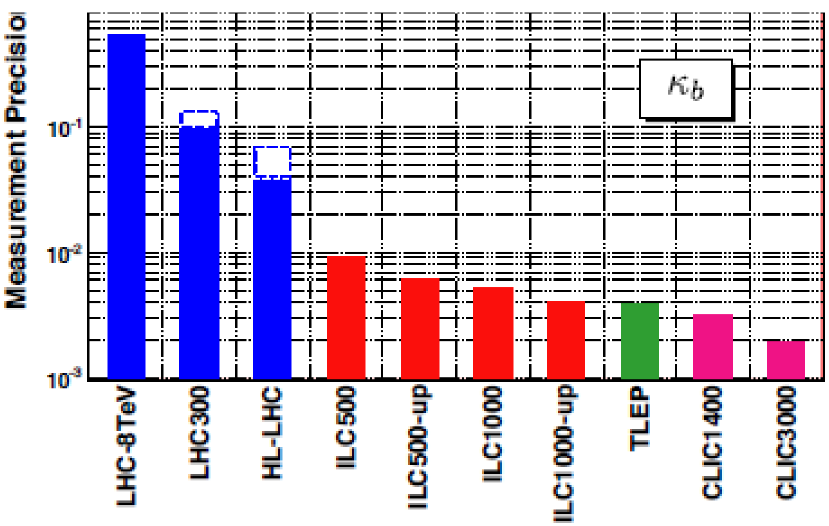
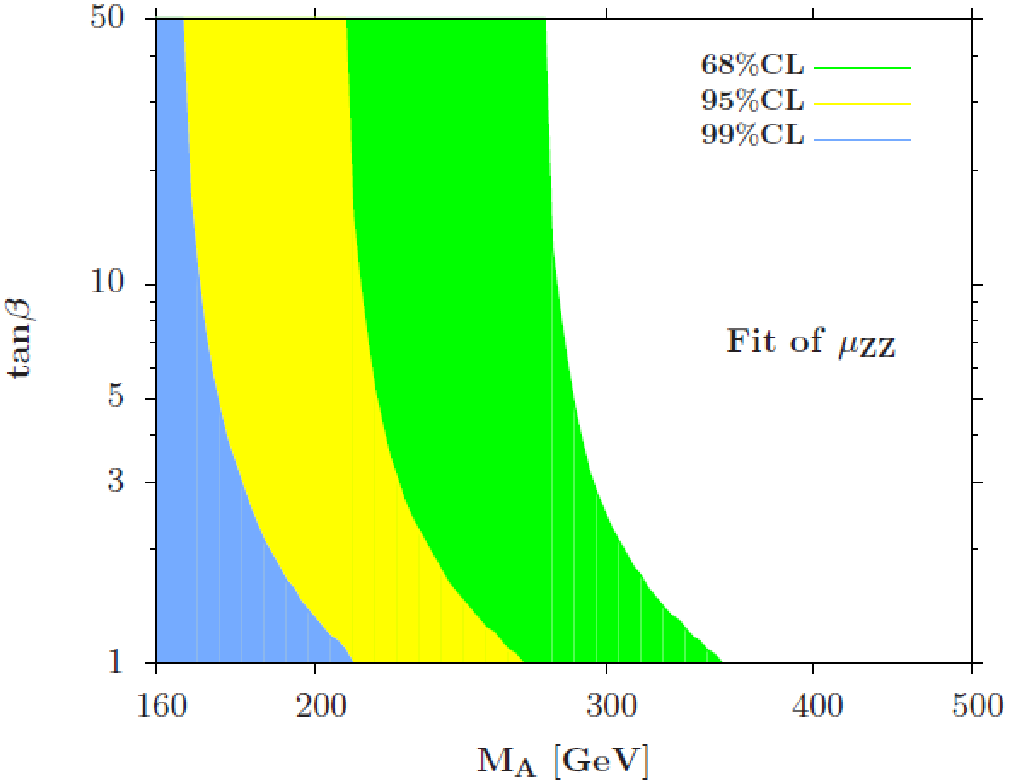




Present exclusion

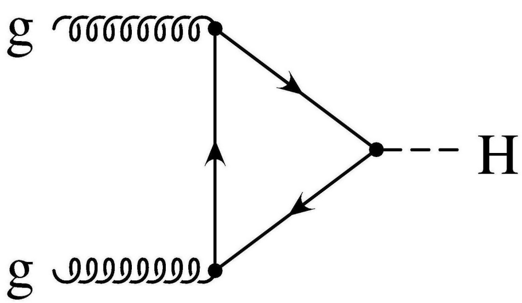


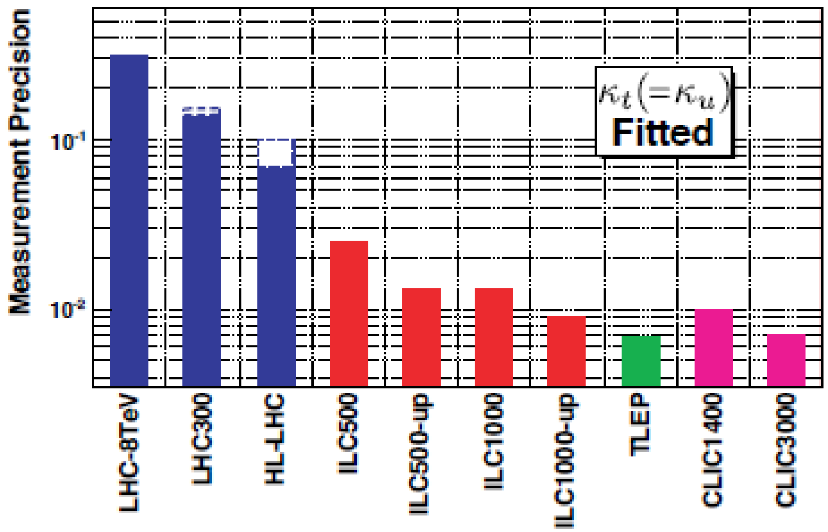
Djouadi, Quevillon, 1304.1787

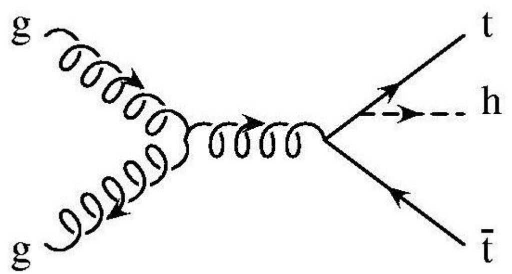
With 3000 fb^{-1} LHC14 data all this plane will be covered ($m_A \leq 500$GeV)

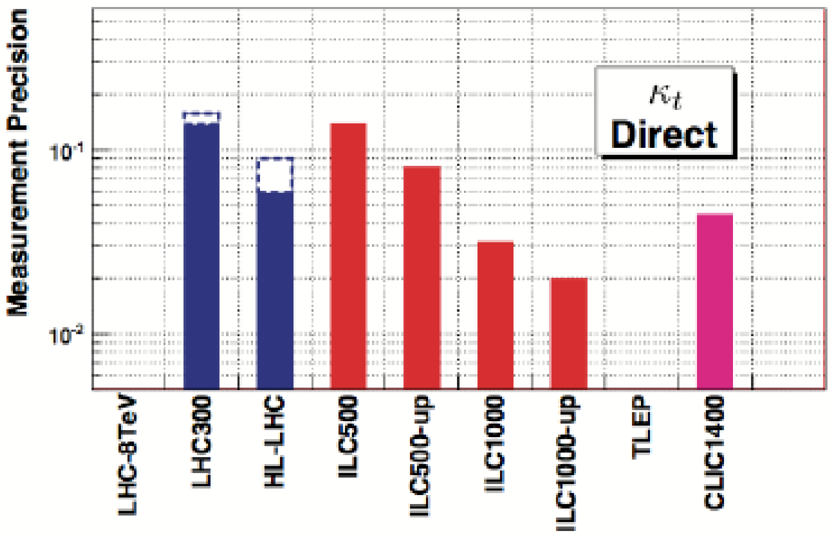
1401.6081 Report of the 2013 community summer study: energy frontier

Top Yukawa particularly interesting









A few remarkable examples (3)

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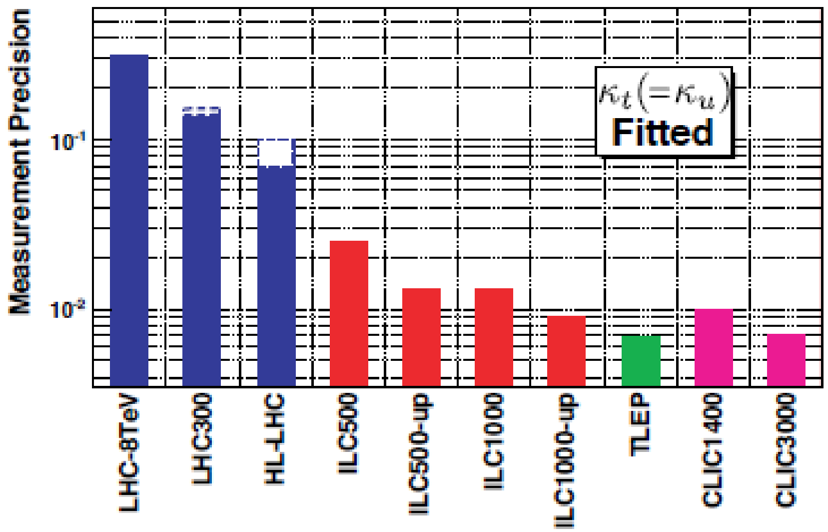
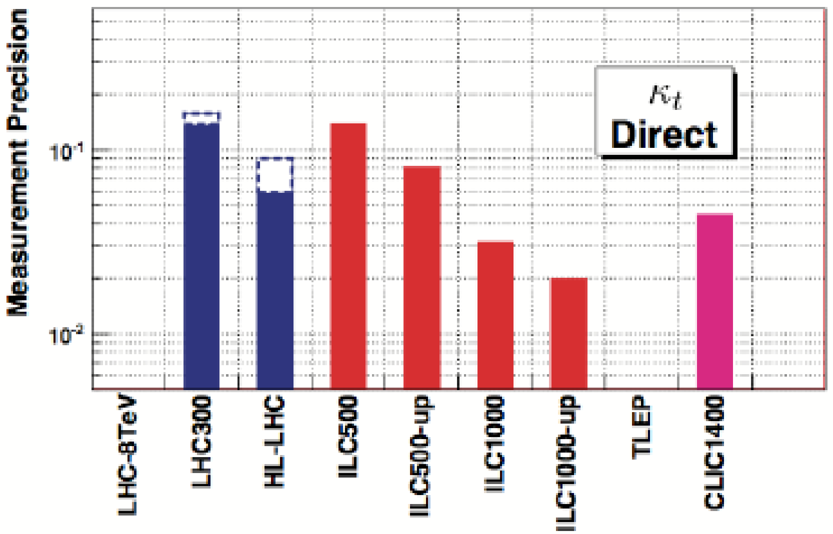
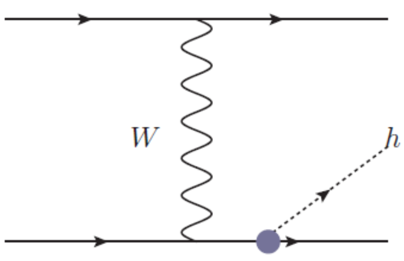




<u>Top Yukawa particularly interesting</u>

A 100TeV pp collider could perform a qualitatively different type of measurement: Htj

Htj a golden channel to determine the sign of y_t (Farina et al. 1211.3736)

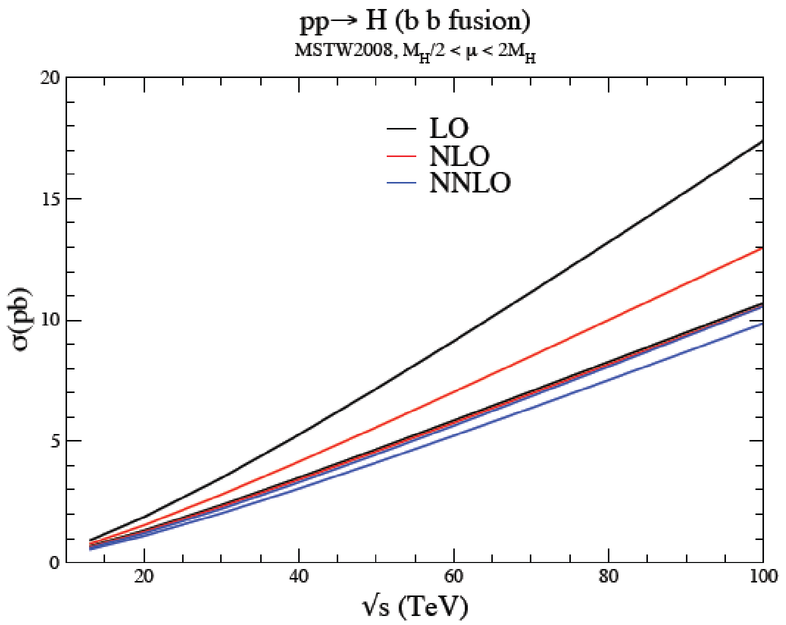


<u>LHC14</u> with 300 fb^{-1} not yet sensitive (Chang et al. 1403.2053). Best achieved for semileptonic t, and for H→bb and H→γγ, but only O(20) SM H(→γγ)tj events expected without cuts (see also CMS PAS HIG-14-001)

At <u>100 TeV</u> with 3 ab^{-1} O(10000) SM H(→γγ)tj events expected without cuts.

Higgs production

1. bbh: available production mode also for the SM-Higgs at the 100TeV collider
(not only for Higgs bosons with tanβ enhanced coupling to bottoms)



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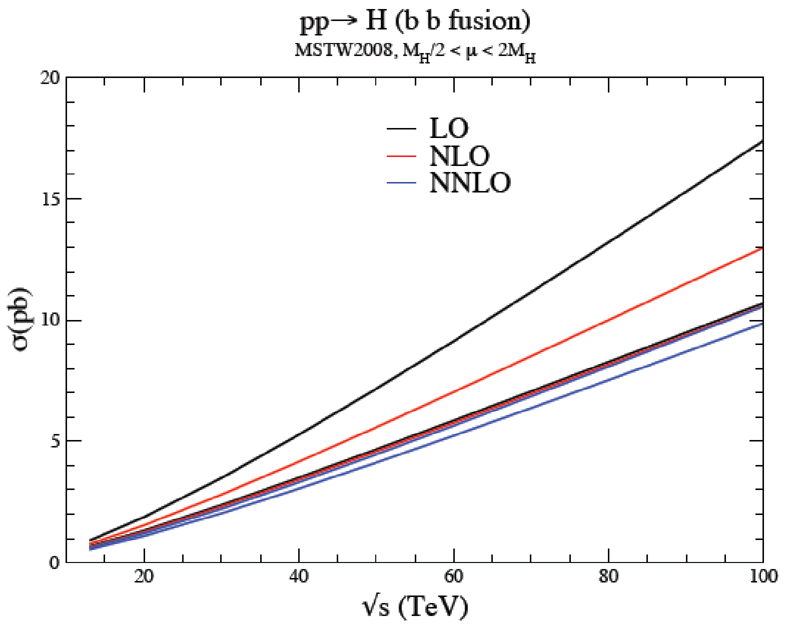
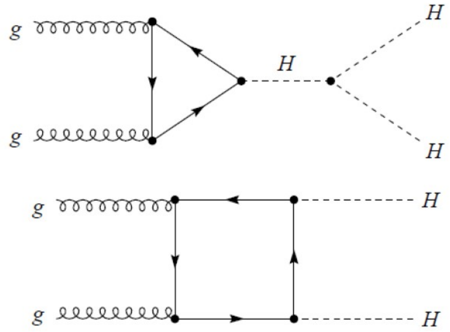


2. Double Higgs production:
Sensitive to the HHH coupling
bbγγ channel is the most promising but small rates at the LHC14



probe the completeness of the SM scalar potential

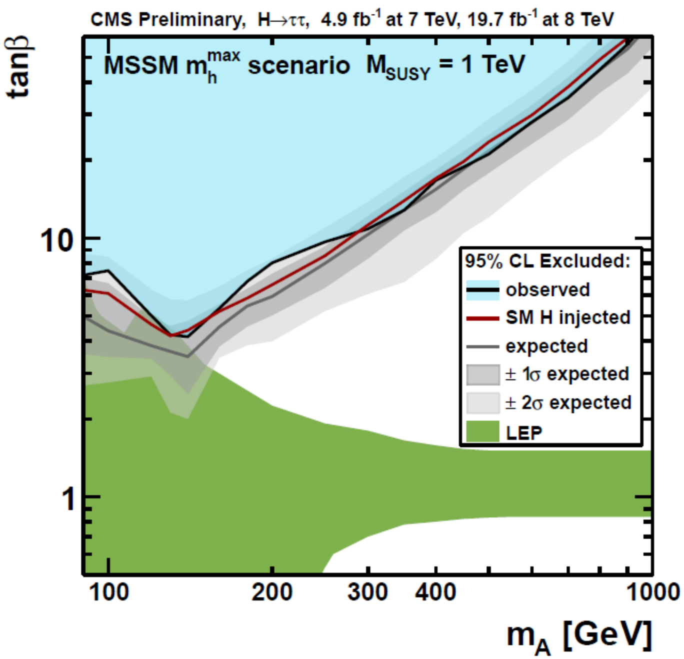
$$V = \frac{m_H^2}{2} H^2 + \frac{M_H^2}{2v} H^3 + \frac{M_H^2}{8v^2} H^4$$

Yao, 1308.6302

With 3 ab^{-1} data, it is possible to measure the Higgs self-coupling at the level of 50% at the LHC14, at the level of 8% at 100TeV collider

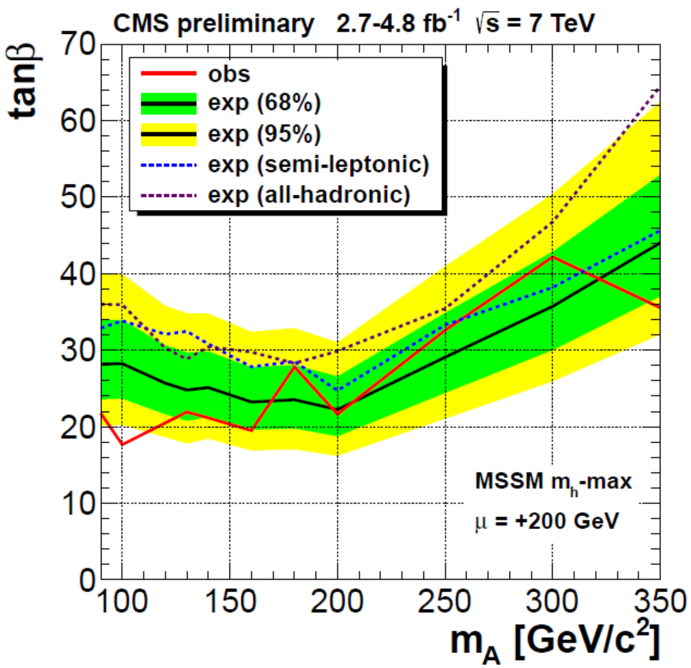
Additional Higgs bosons often arise in natural theories of EWSB
(Higgs sector of the MSSM/NMSSM, Twin Higgs models and their variants, (some) composite Higgs models)

CMS-PAS-HIG-13-021



$$pp \to H, A \to \tau\tau$$

CMS-PAS-HIG-12-033



$$pp \to b(H, A) \to b(bb)$$

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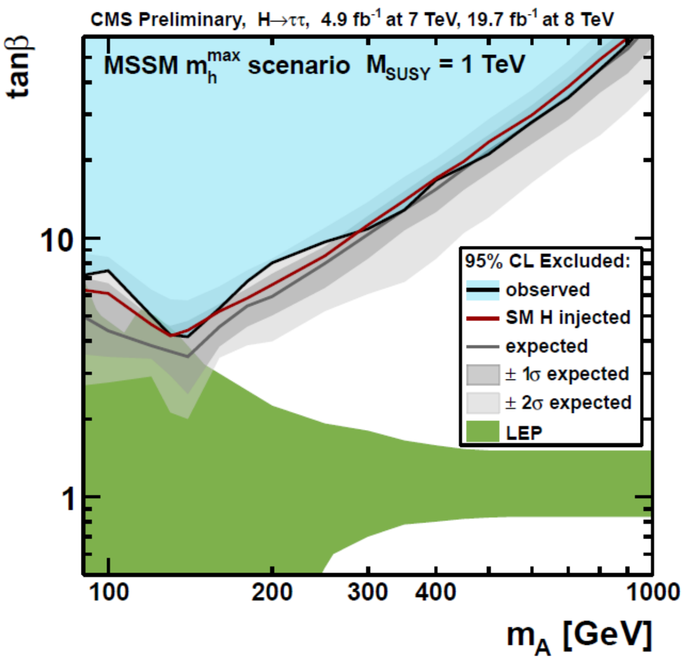

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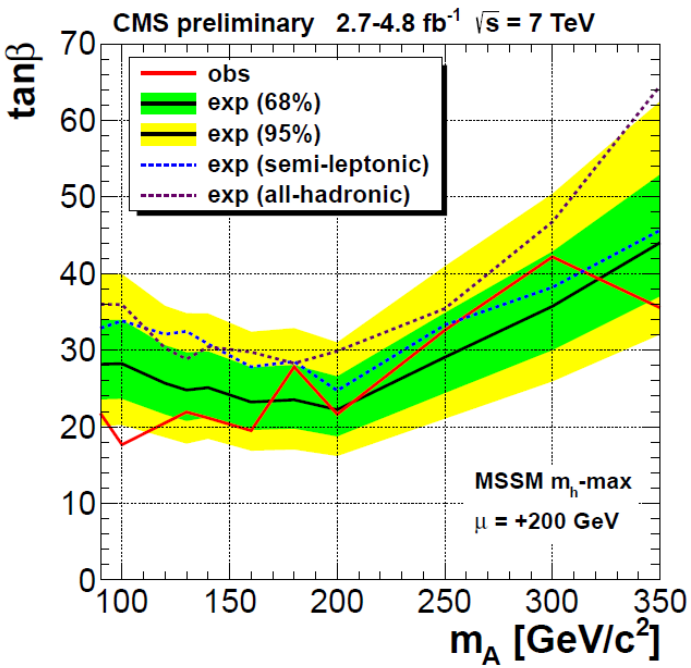

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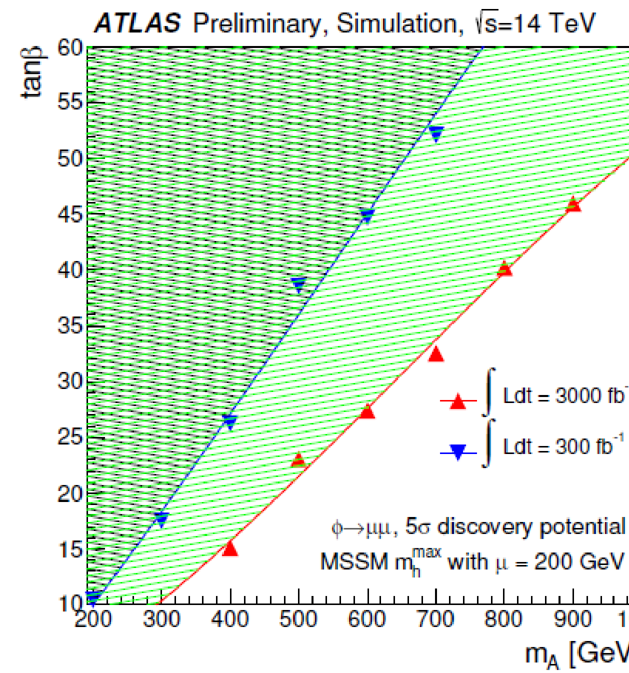
ATLAS-PHYS-PUB-2013-016



5σ discovery

$$pp \to H, A \to \mu\mu$$

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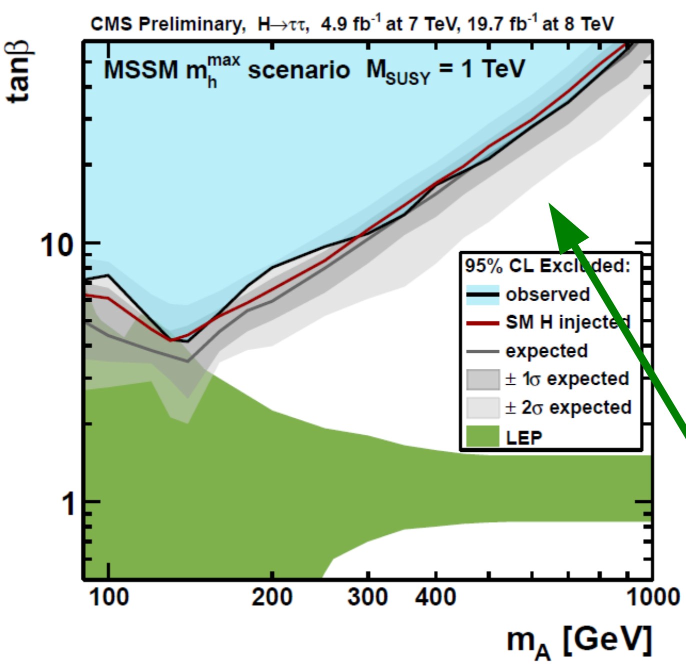

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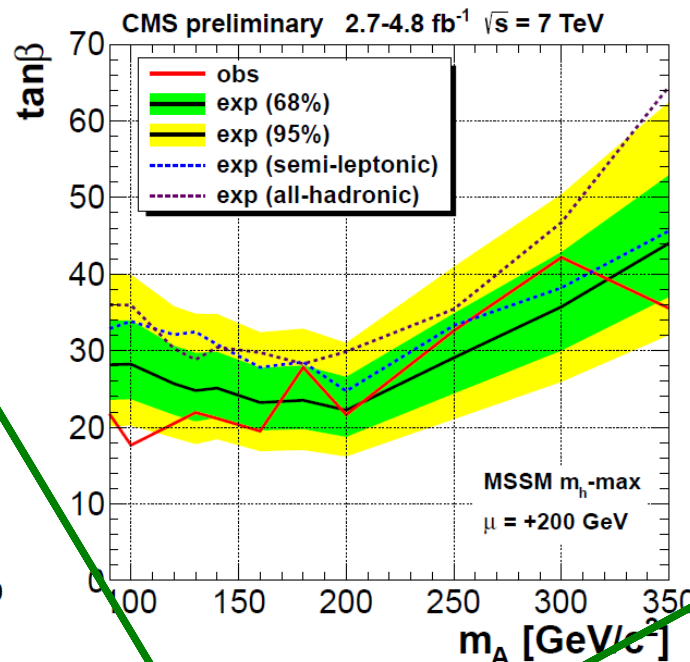
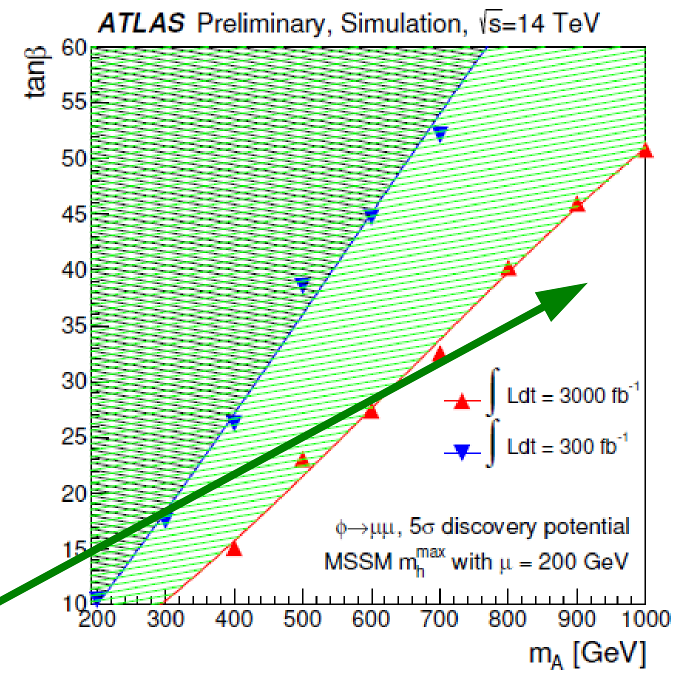


$$pp \to b(H, A) \to b(bb)$$

ATLAS-PHYS-PUB-2013-016



5σ discovery
$$pp \to H, A \to \mu\mu$$

The 100 TeV region

Additional opportunities at the 100TeV collider?

Additional Higgs bosons

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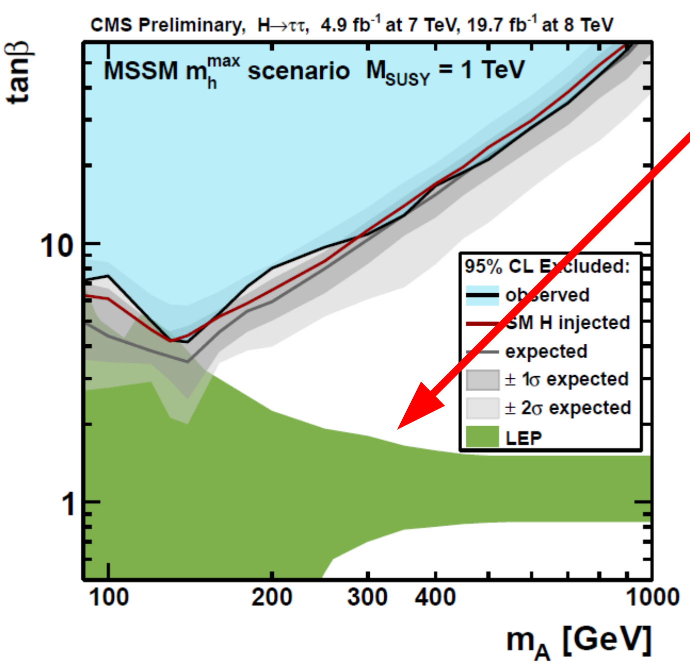

At low tanβ main decay into tops

Present tt resonance searches put only very weak bounds on this scenario pp→H,A→tt.
What about 14 TeV?

Another possibility:
4 top signature pp→tt(H,A→tt).

	$m_A = 500\,\mathrm{GeV}$	$m_A = 1000\,\mathrm{GeV}$
14 TeV	4 fb	0.4 fb
100 TeV	1 pb	0.2 pb

tanβ=2

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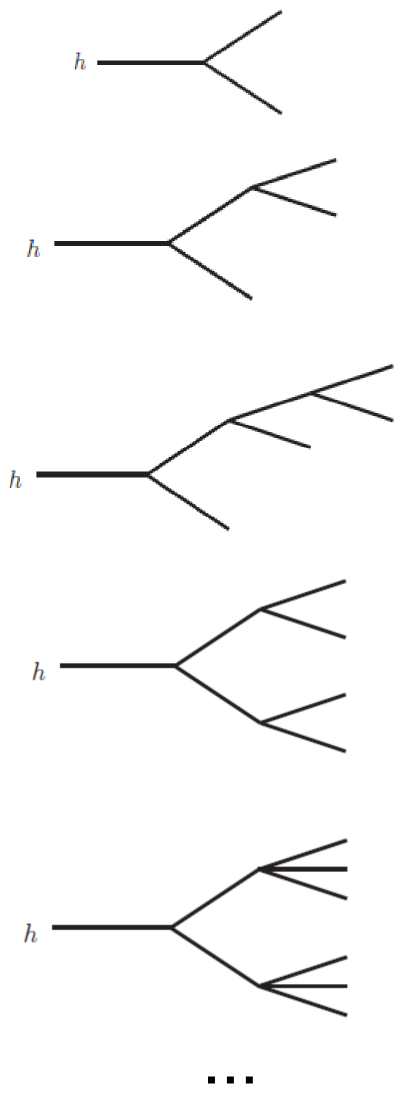
Higgs exotic decays and light new particles

The role of 100 TeV is to find Heavy New Particles

What is its role in looking for (missed) light (≤100GeV) „electroweak“ NP particles?
What about Higgs decaying to light particles?

- experiment: a huge amount of signatures could arise.



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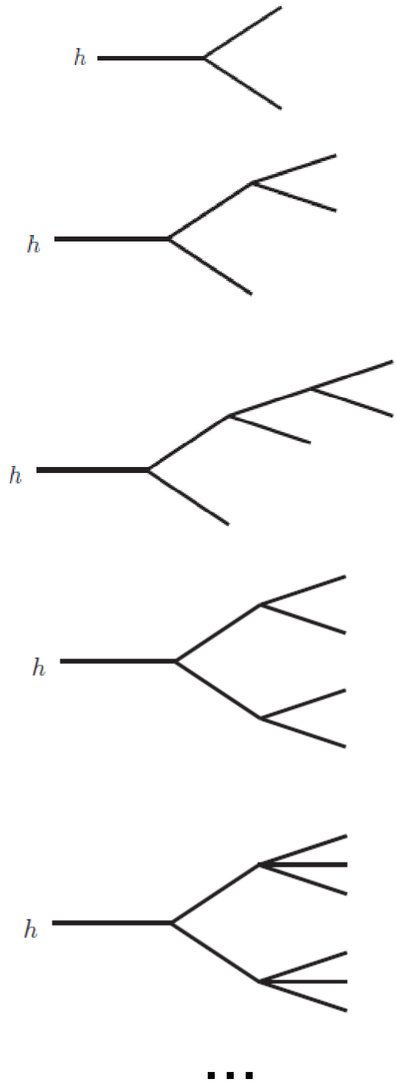


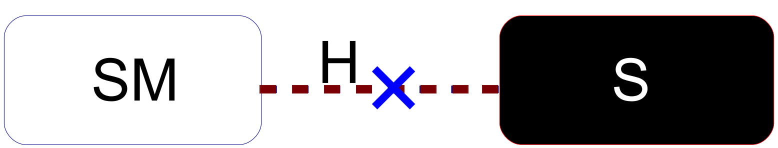
- experiment: a huge amount of signatures could arise.

- theory: easy to have a „sizable" branching ratio into exotics.

Portals to a dark sector

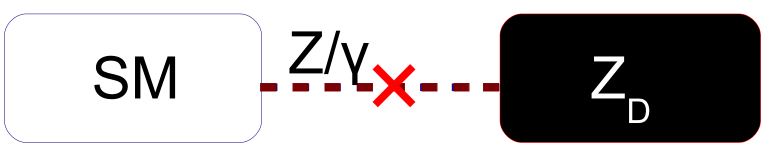
- Scalar portal

$$V(H,S) \supset \zeta |S|^2 |H|^2$$



- Vector portal

$$\mathcal{L} \supset \frac{\epsilon}{2\cos\theta} \hat{B}_{\mu\nu} \hat{Z}_D^{\mu\nu}$$



Recommendation: not to leave any loophole in the search for light particles!

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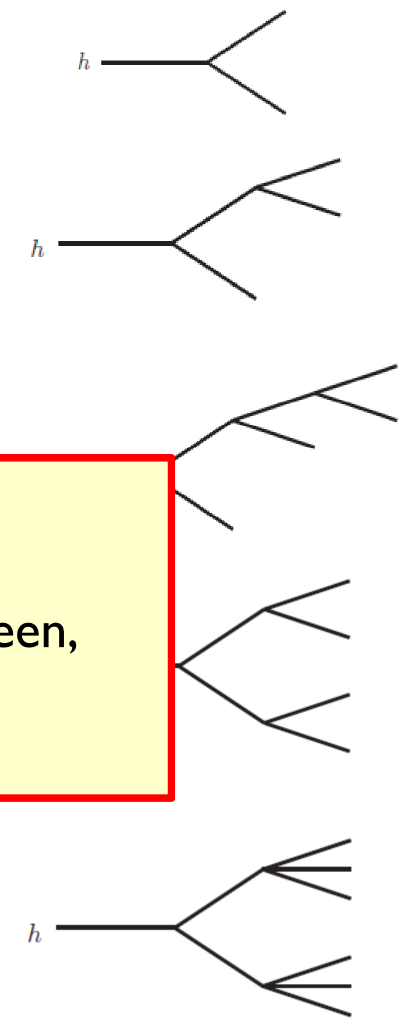

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Exotic Decays of the 125 GeV Higgs Boson, 1312.4992

D. Curtin, R. Essig, SG, P. Jaiswal, A. Katz, T. Liu, Z. Liu, D. McKeen, J.Shelton, M. Strassler, Z. Surujon, B. Tweedie, Y-M. Zhong

- Scalar p

$V(H, S) \supset \varsigma |S|^2 |H|^2$

$2 \cos\theta \quad D_{\mu\nu} Z_D$

SM --H-- × -- S

SM --Z/γ-- × -- Z_D

Recommendation: not to leave any loophole in the search for light particles!

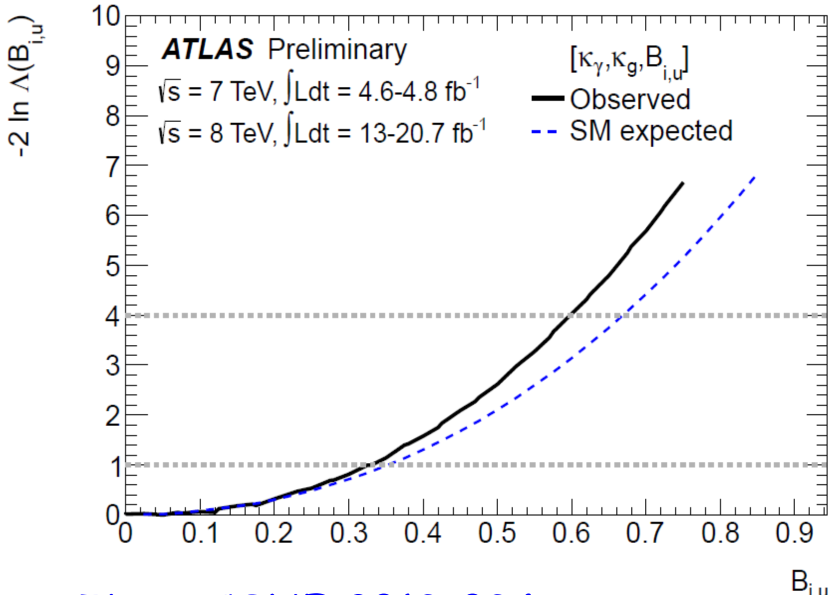
Higgs width, now and future

$$\Gamma_h^{SM}(125\ \text{GeV}) \sim 4.1\ \text{MeV}$$

Too small to be measured directly, except at a muon collider where the Higgs can be produced as a resonance

What bound can we learn?

Now



ATLAS-CONF-2013-034

Future

In general the extraction of the Higgs width at hadron colliders is difficult.
It has to rely on some assumption (e.g $\kappa_Z, \kappa_W < 1$)
Typically ~10% at 300 fb^{-1}, ~5% at 3000 fb^{-1} LHC

ILC: The Higgs width can be bounded in a model-independent way.
Bound at the level of O(5%) for BR_{exotic} at ILC

Small branching ratios are difficult to discover in this way
Importance of looking directly for Higgs exotic decays

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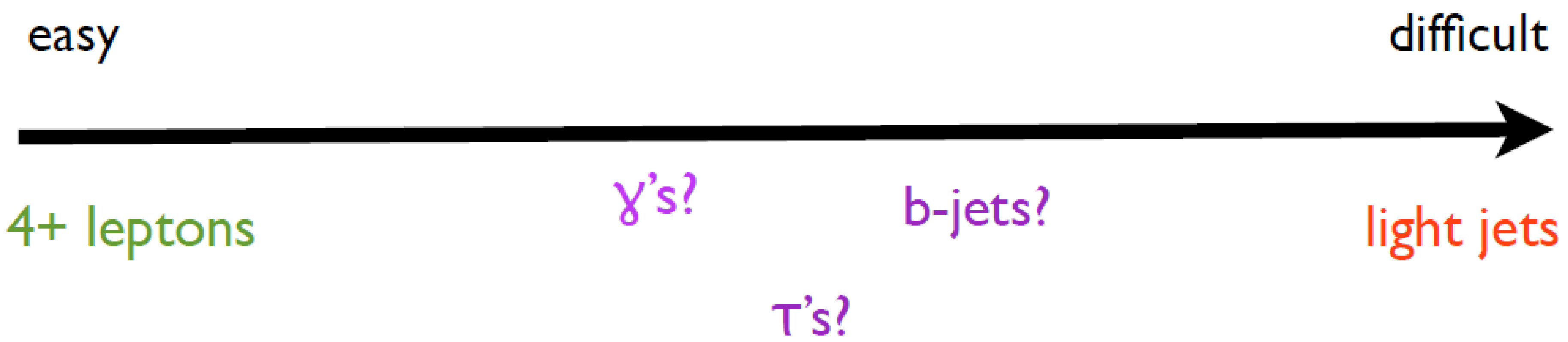
What exotic decay?

The reach of a hadron colliders depends very sensitively on the kind of exotic higgs decay mode



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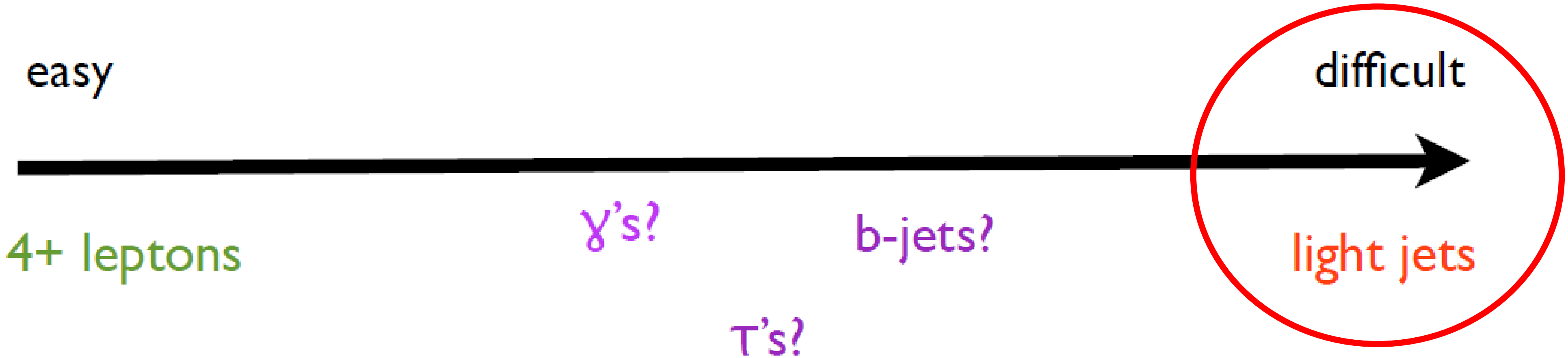
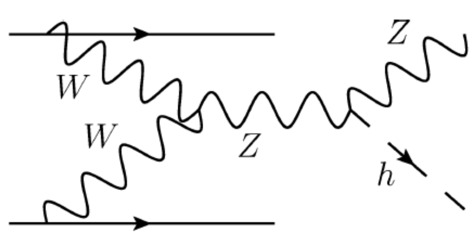


Background limited

It helps having extra handles:

New production modes for the Higgs



Example: VBF production of ZH, H→jj

σ ~1pb at 100 TeV

Preliminary analysis: 100TeV collider might probe BR(H→jj)~10^{-2}

D.Curtin, in progress

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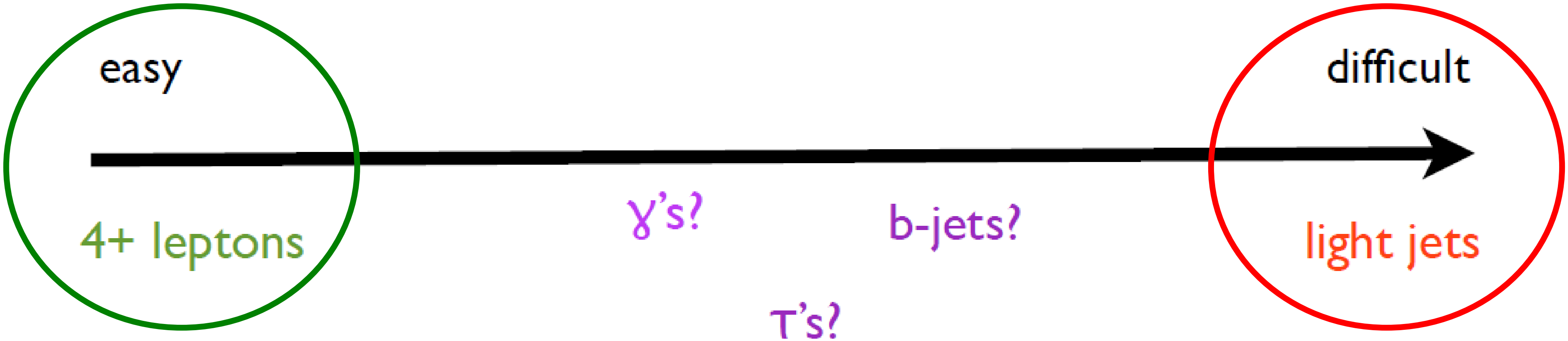
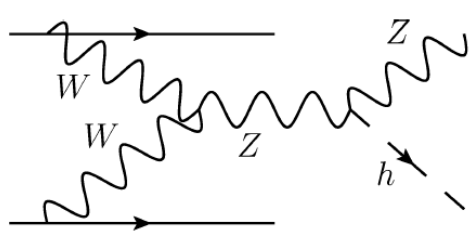


Statistics limited

It helps having
- large rates
- New detectors for better acceptance



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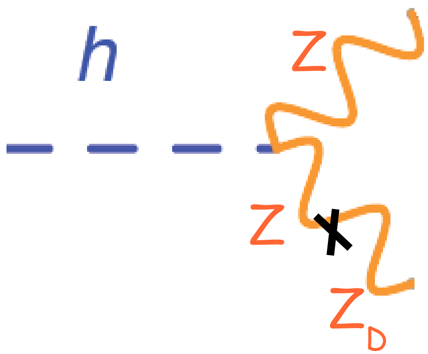
Statistically limited decay modes

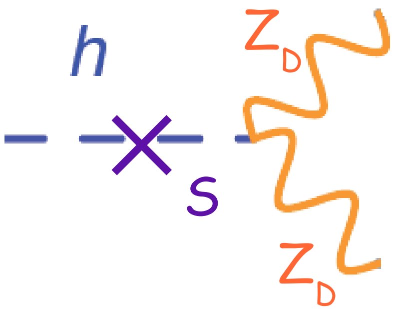
Theories with an additional (dark) Z boson that communicates to the SM sector only through the kinetic mixing operator

$$\mathcal{L} \supset \frac{\epsilon}{2\cos\theta}\hat{B}_{\mu\nu}\hat{Z}_D^{\mu\nu}$$



Additional scalar S to break the U(1)' symmetry

$$V(H,S) \supset \zeta |S|^2 |H|^2$$



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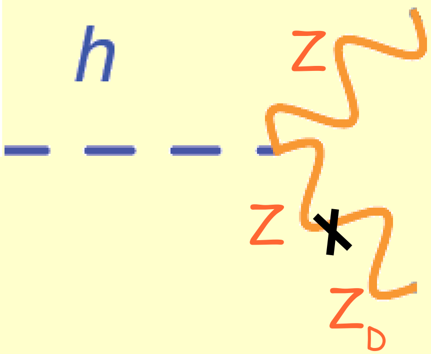

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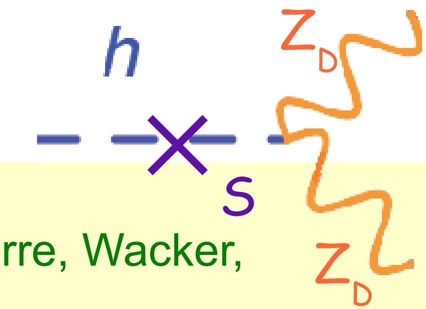
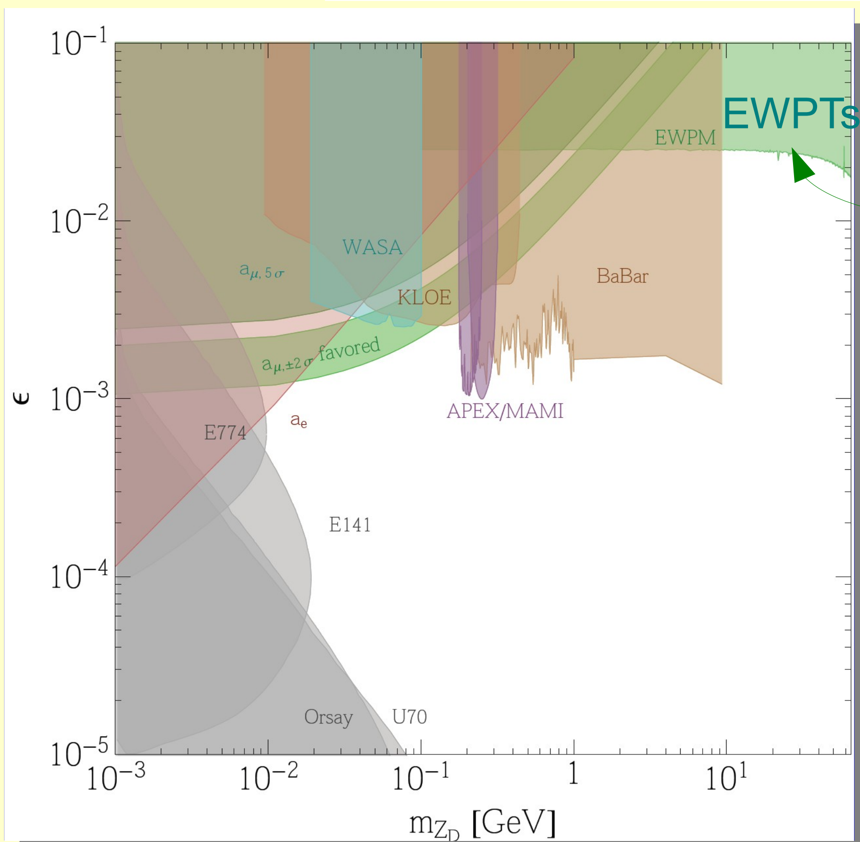
$$V(H,S) \supset \zeta |S|^2 |H|^2$$



Present constraints on the minimal model



EWPTs

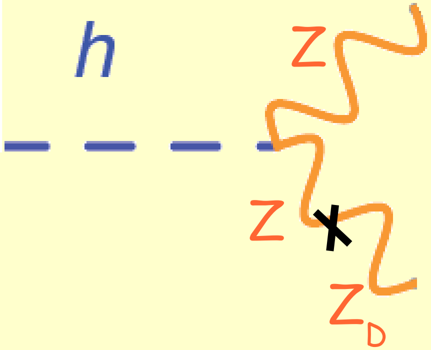
Hook, Izaguirre, Wacker, 1006.0973

 S.Gori

Statistically limited decay modes

Theories with an additional (dark) Z boson that communicates to the SM sector only through the kinetic mixing operator

$$\mathcal{L} \supset \frac{\epsilon}{2\cos\theta}\hat{B}_{\mu\nu}\hat{Z}_D^{\mu\nu}$$



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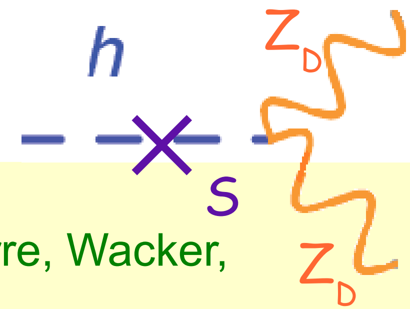

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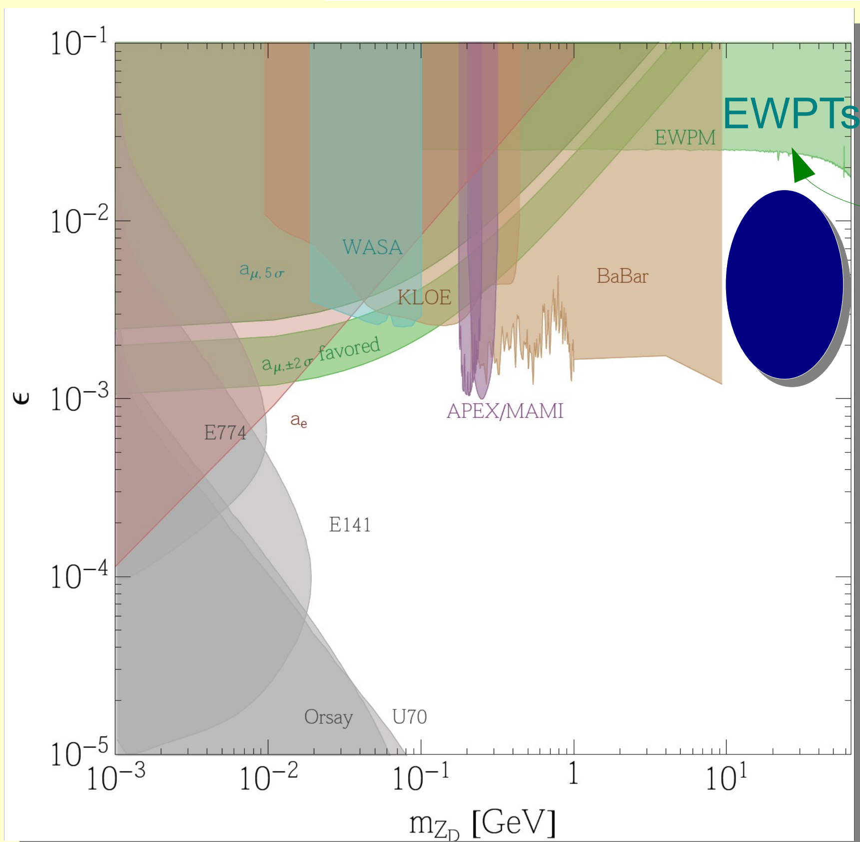
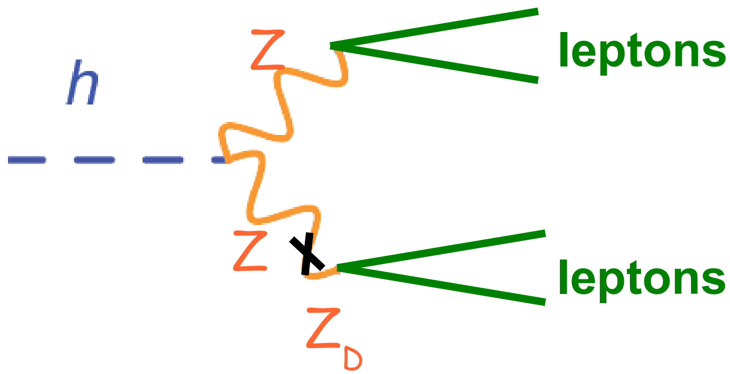


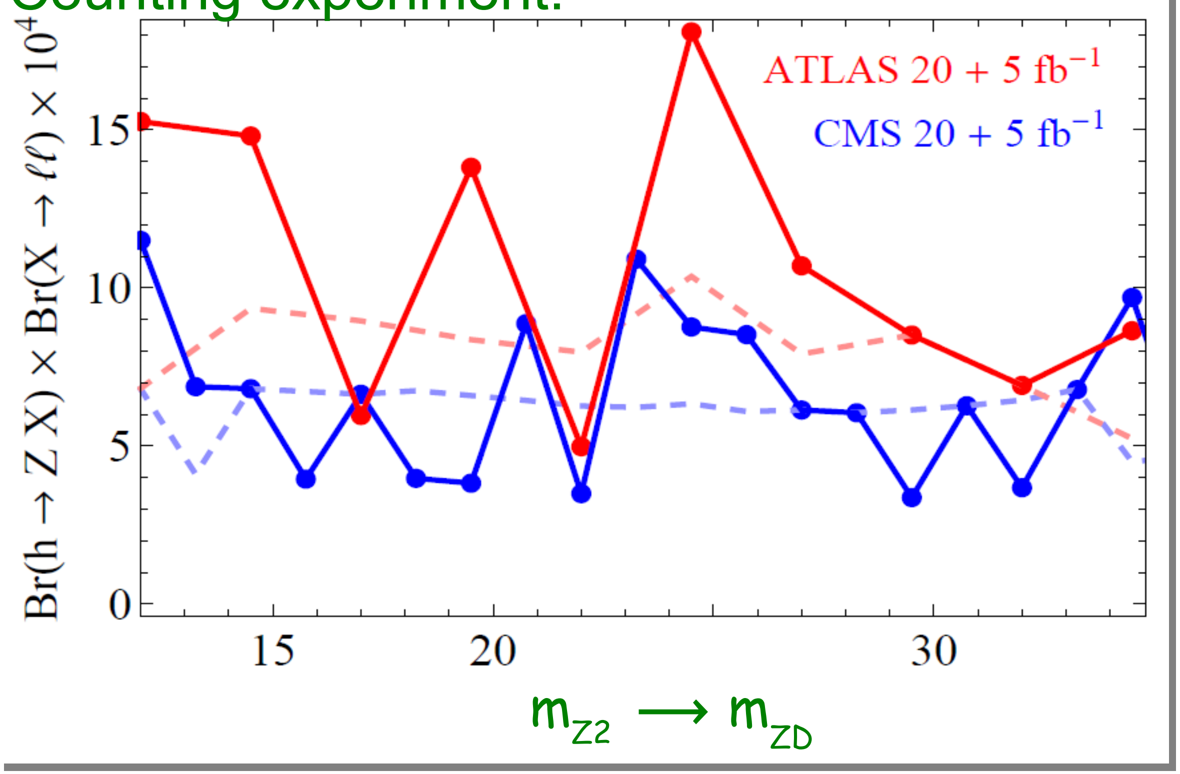
Hook, Izaguirre, Wacker, 1006.0973

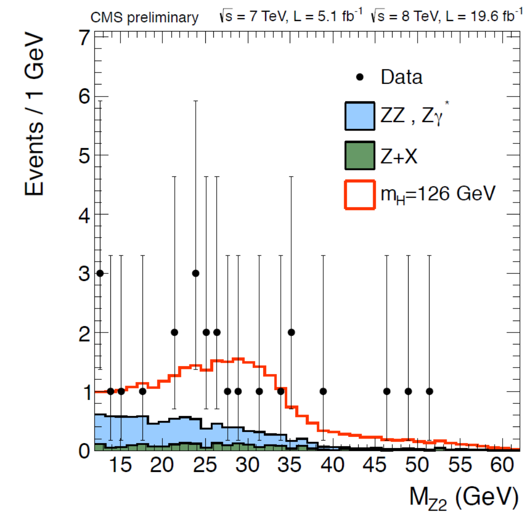
What is the role of the Higgs in probing these models? Can this Z_D be discovered at the LHC/ Future colliders using Higgs decays?

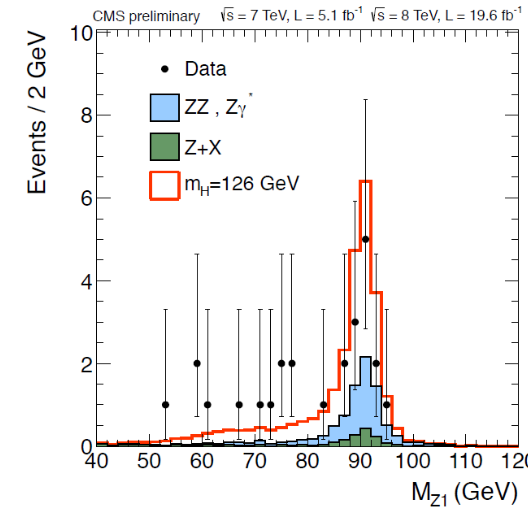
A 4 lepton signature, present bound



Counting experiment:



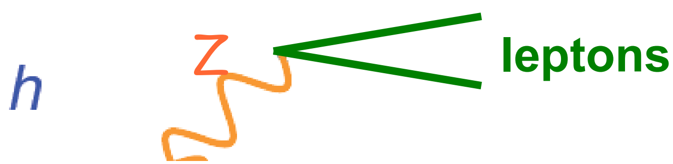


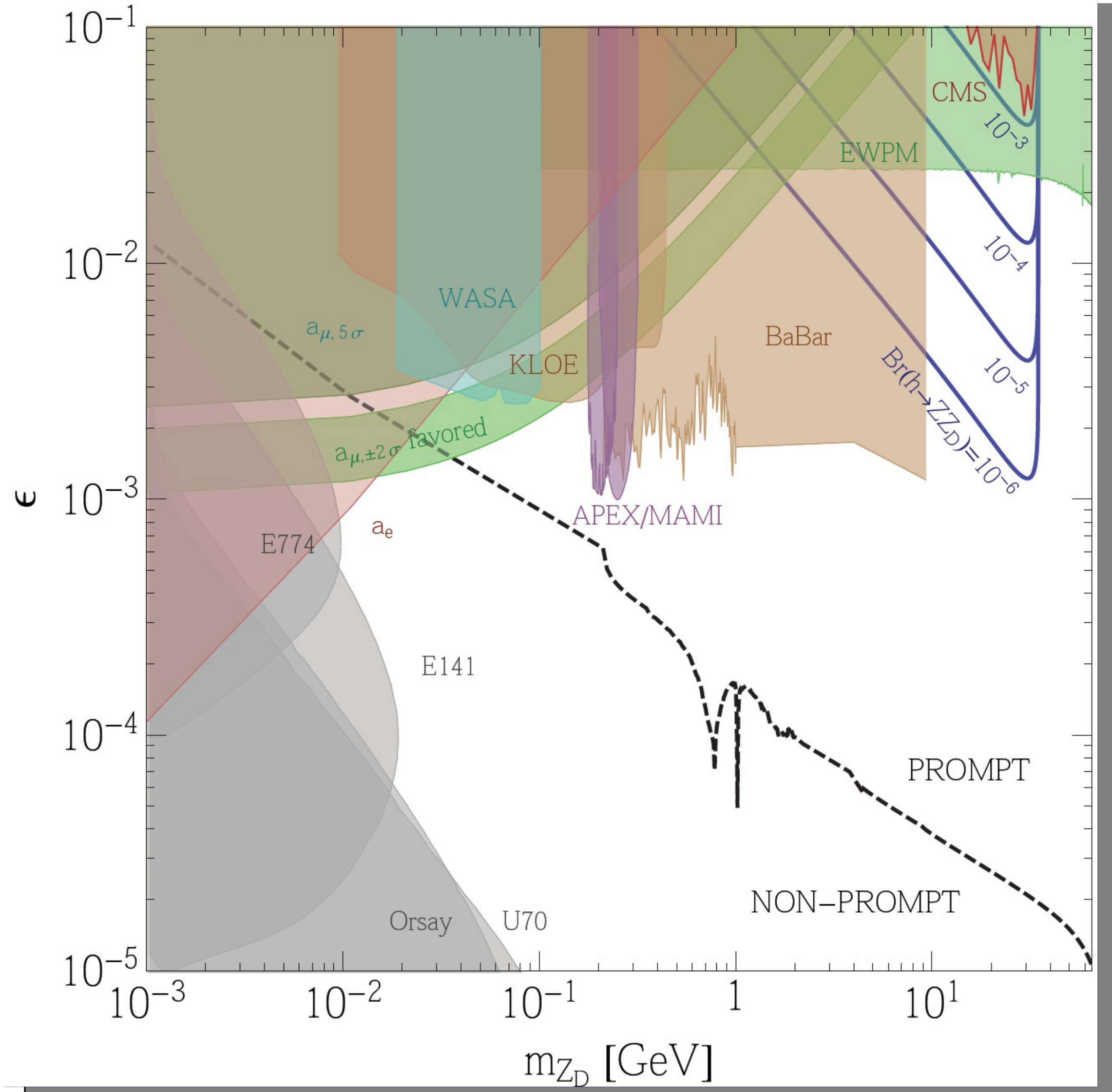


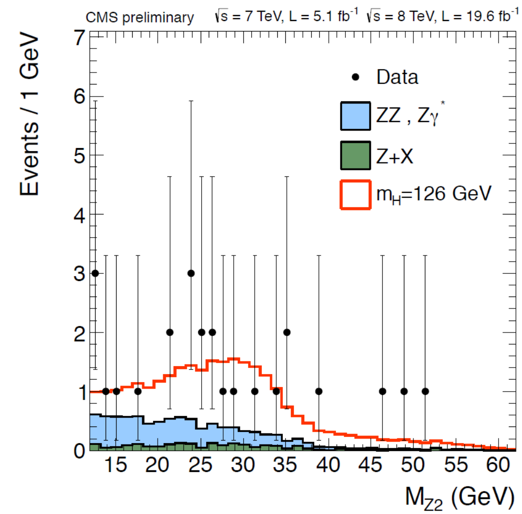
Bound from the CMS, ATLAS h⟶ZZ* analysis

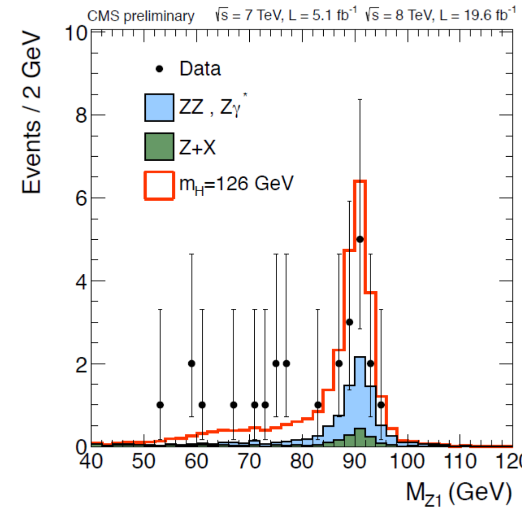
$BR(h \longrightarrow ZZ_D) \sim 10^{-3}$ are already probed with the present (un-dedicated) (7+8) TeV LHC searches

A 4 lepton signature, present bound









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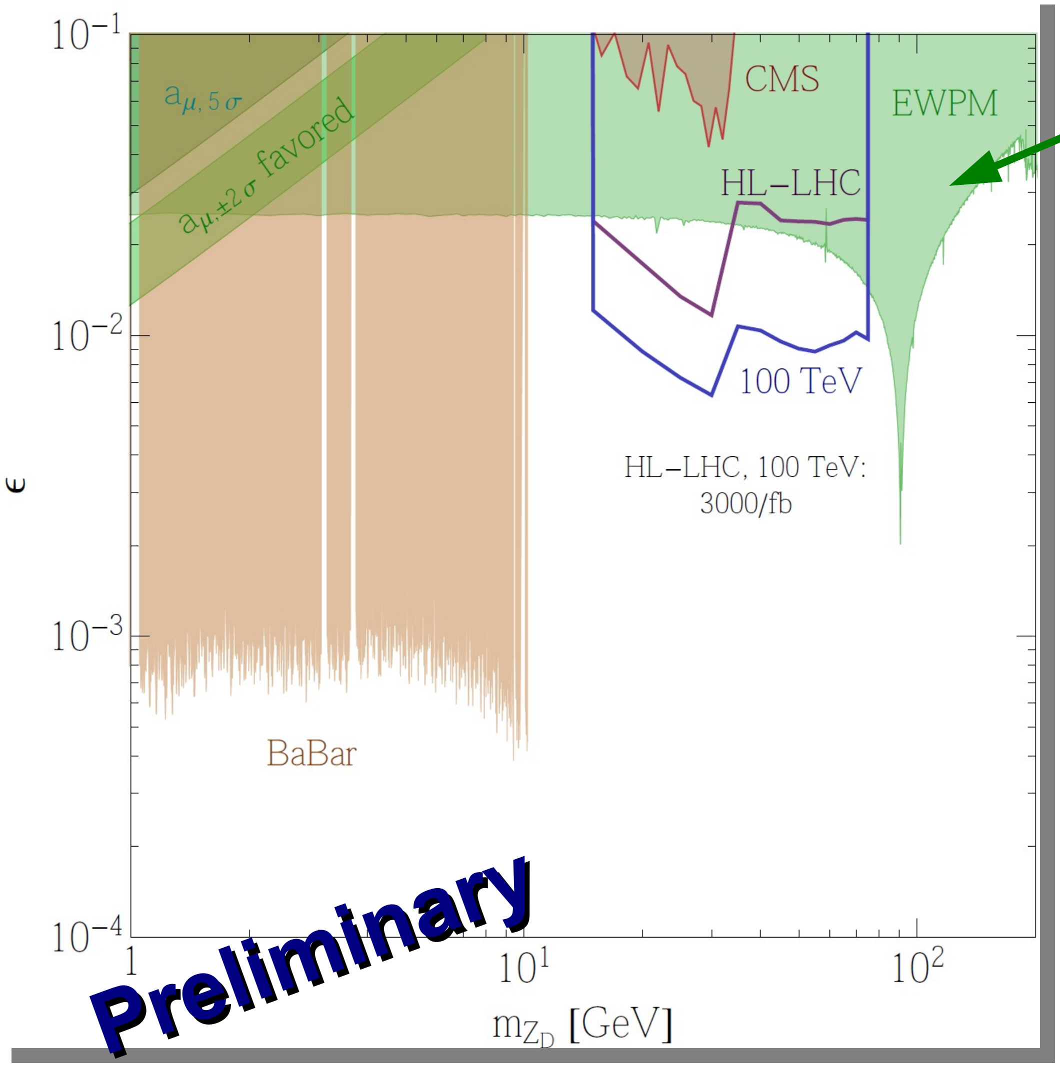
Where we can stand in the future



Curtin, Essig, S.G., Shelton, in preparation

Z-factories will improve this bound too

BR(h⟶ZZ_D)~10^{-4}
can be reached by HL-LHC

BR(h⟶ZZ_D)~10^{-5}
can be reached by a 100TeV collider

- possible improvements:

<u>Larger eta coverage</u>

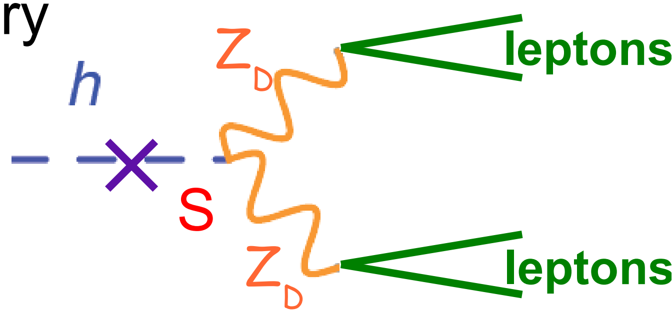
We demand |η|<2.5
as in the CMS/ATLAS analysis.
Relaxing this requirement:
|η|<5 would give us a improvement by a factor of ~2 in the branching ratio

A much more hidden dark sector...

...with the same signature

Additional Higgs bosons S to break the U(1)' symmetry

$$V(H,S) \supset \zeta |S|^2 |H|^2$$



Only small mixings are needed:

$$\zeta \sim 10^{-3}$$

for BR($h \longrightarrow Z_D Z_D$) ~ 1%

Not able to probe it through the measurement of SM-Higgs couplings

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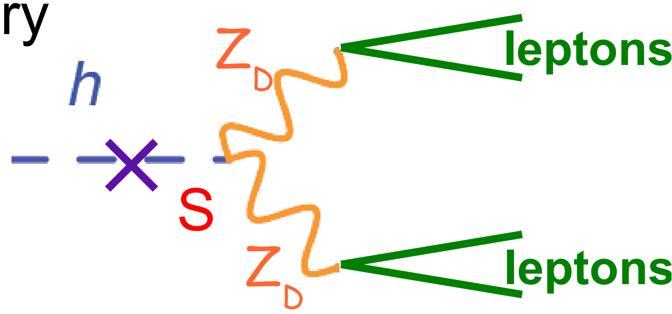
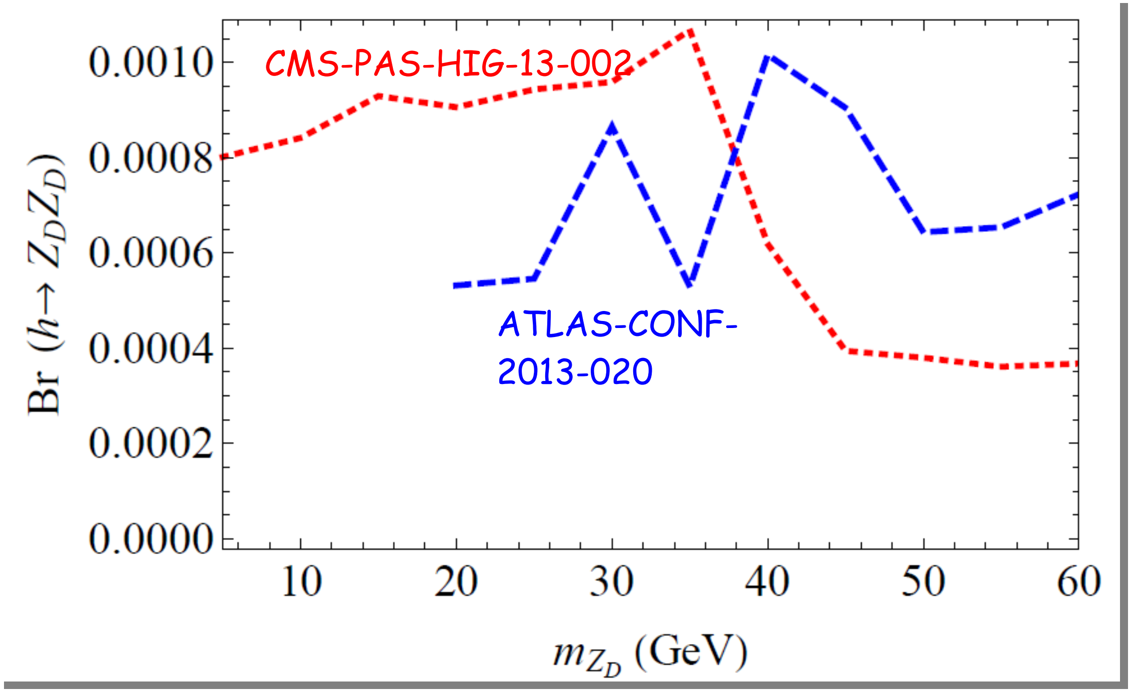


Much smaller background than for ZZ_D

Very much statistically limited measurement



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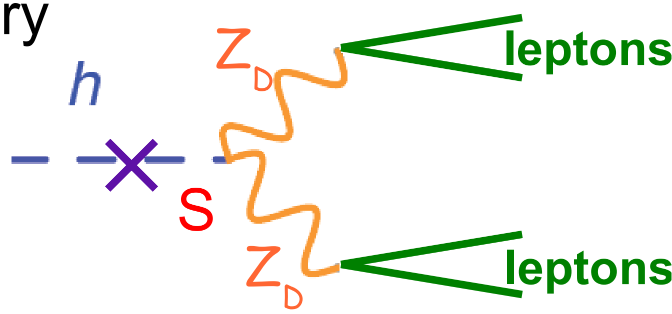

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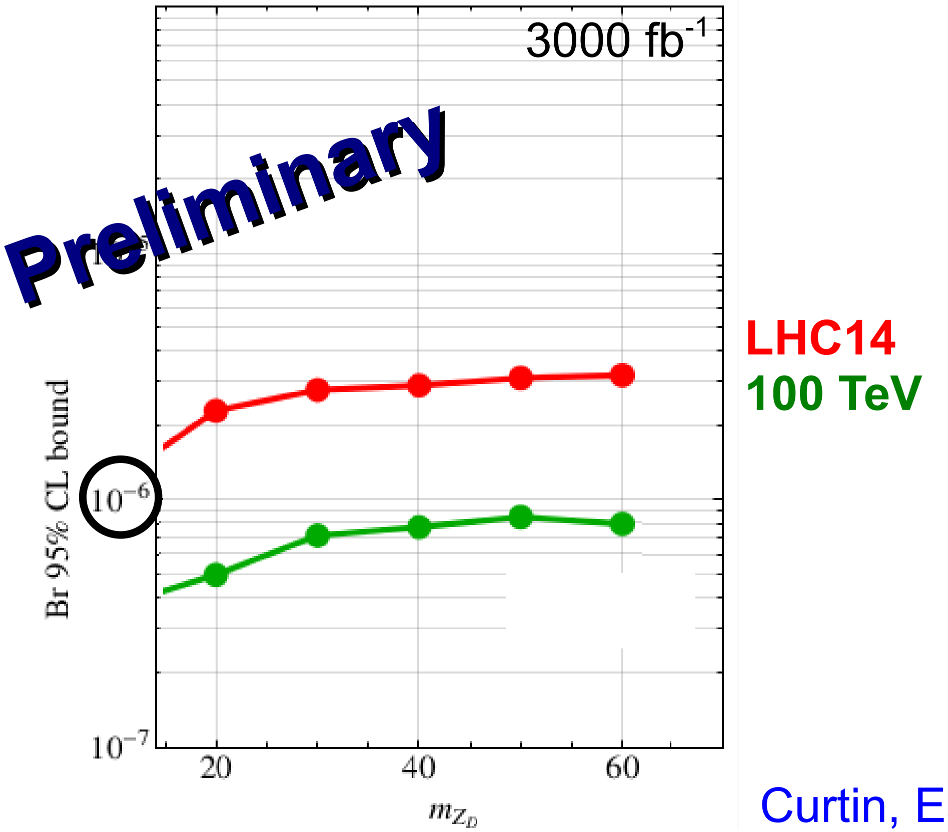

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Curtin, Essig, S.G., Shelton, in preparation

General lessons and thoughts

With the discovery of the Higgs, the hierarchy problem is more pressing than ever → Need for New Physics

$\Lambda_{NP} \sim 1$ TeV

New Physics particles required by naturalness easily affect the Higgs SM-couplings → Program of Higgs coupling precision measurement is crucial

Going to higher energy will buy us rate → New Higgs channels open

Dark matter is still a mystery. It can live in a „dark sector“ that communicates with us through portals

$\Lambda_{NP} \sim 100$ GeV?

Great opportunity to probe this type of NP: Higgs exotic decays

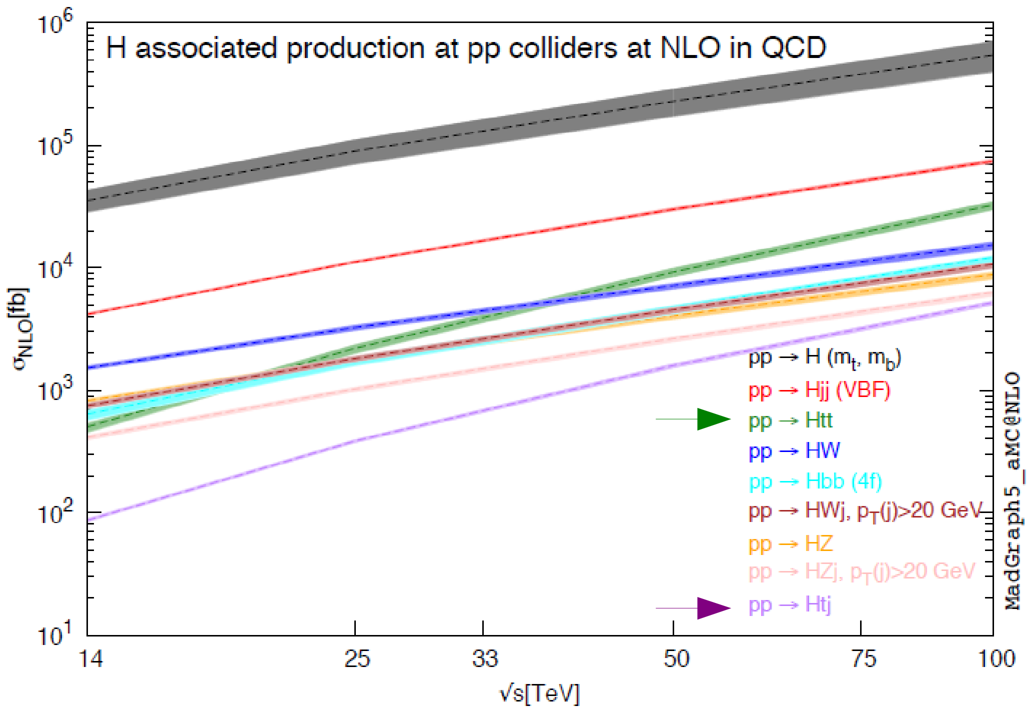
Gain at future higher energy colliders

1. Huge rates

	√S=14 TeV	√S=33 TeV	√S=100 TeV
ggF	50.4 pb	178 pb	740 pb
VBF	4.4 pb	17 pb	82 pb
WH	1.6 pb	4.7 pb	16 pb
ttH	.62 pb	4.6 pb	38 pb
HH	.034 pb	.2 pb	1 pb

Higgs cross section working group

Quantity



2. Futuristic detectors

Quality