Precision Higgs studies at the linear colliders

Stefania Gori
Perimeter Institute for Theoretical Physics

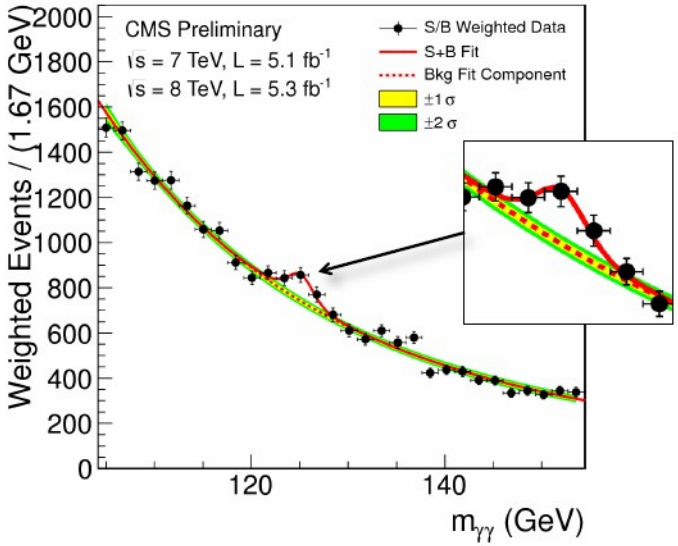
LCWS15

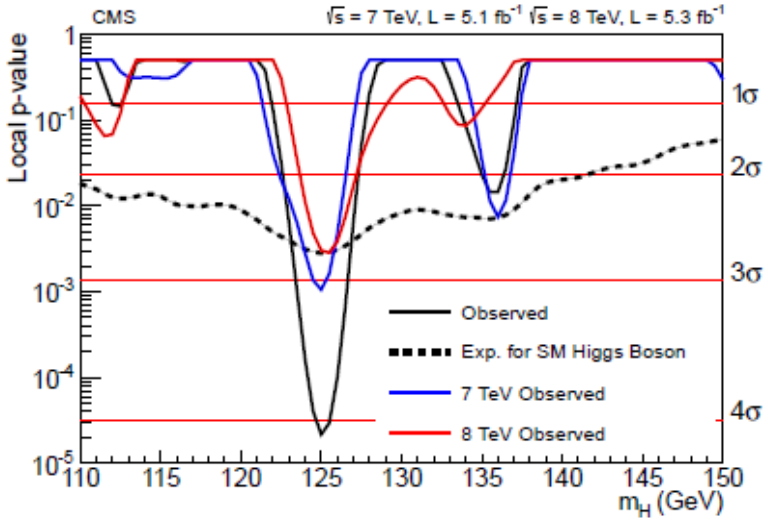
Whistler,
November 2nd 2015

We have the Higgs!

A new particle annouced in July 2012

1207.7214





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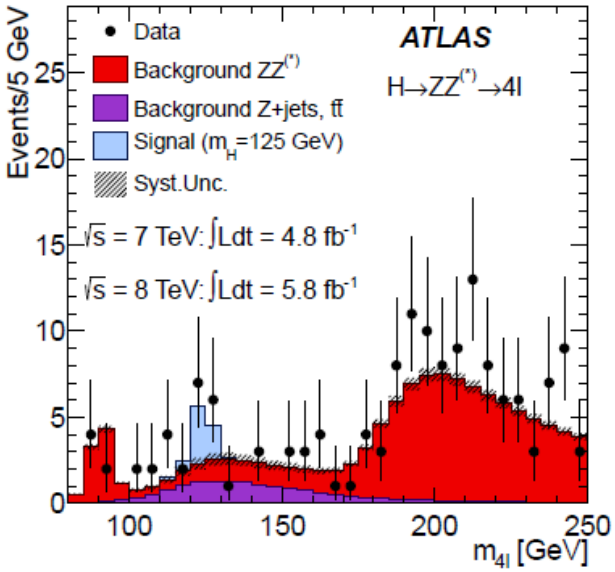
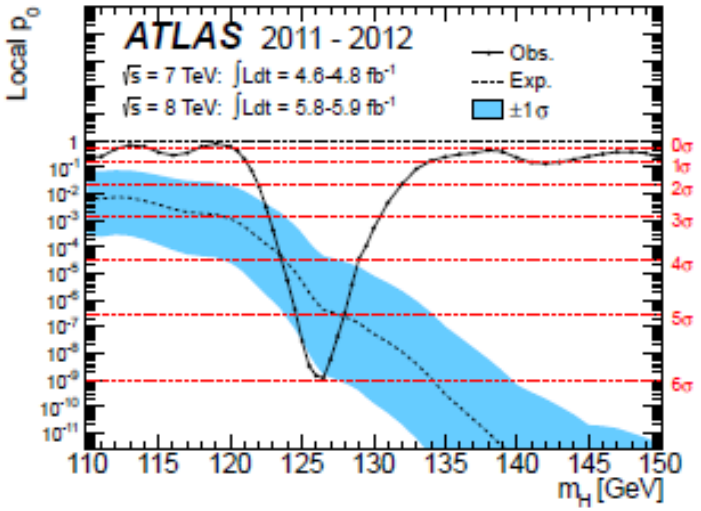
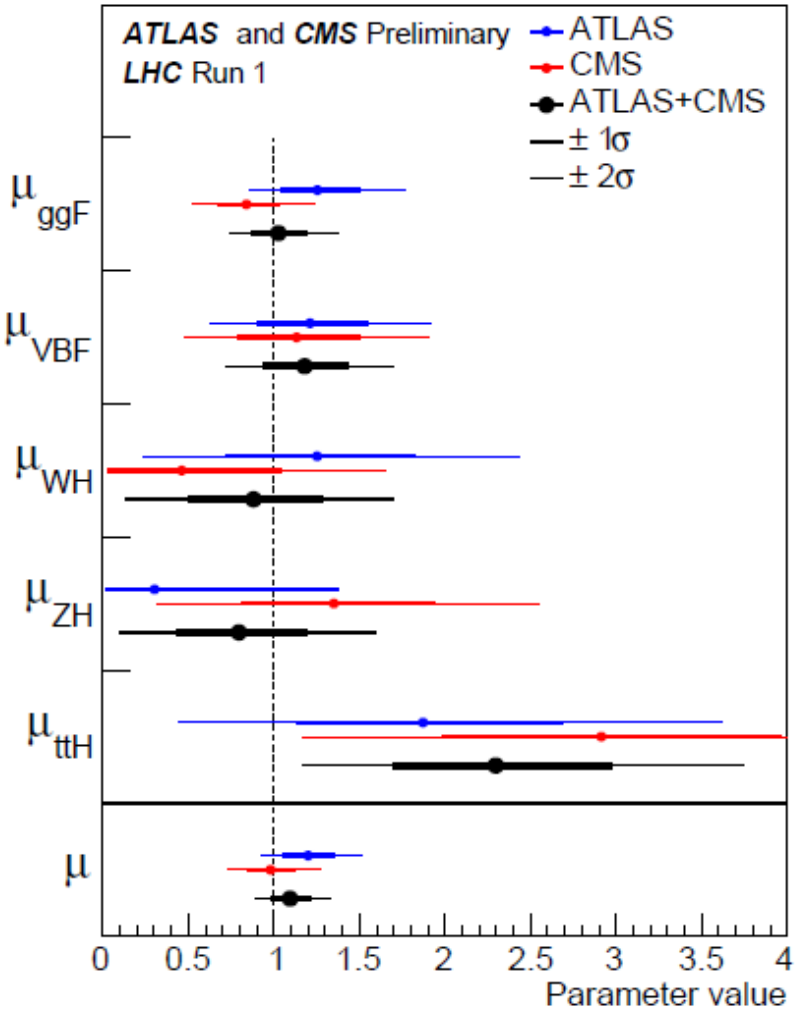


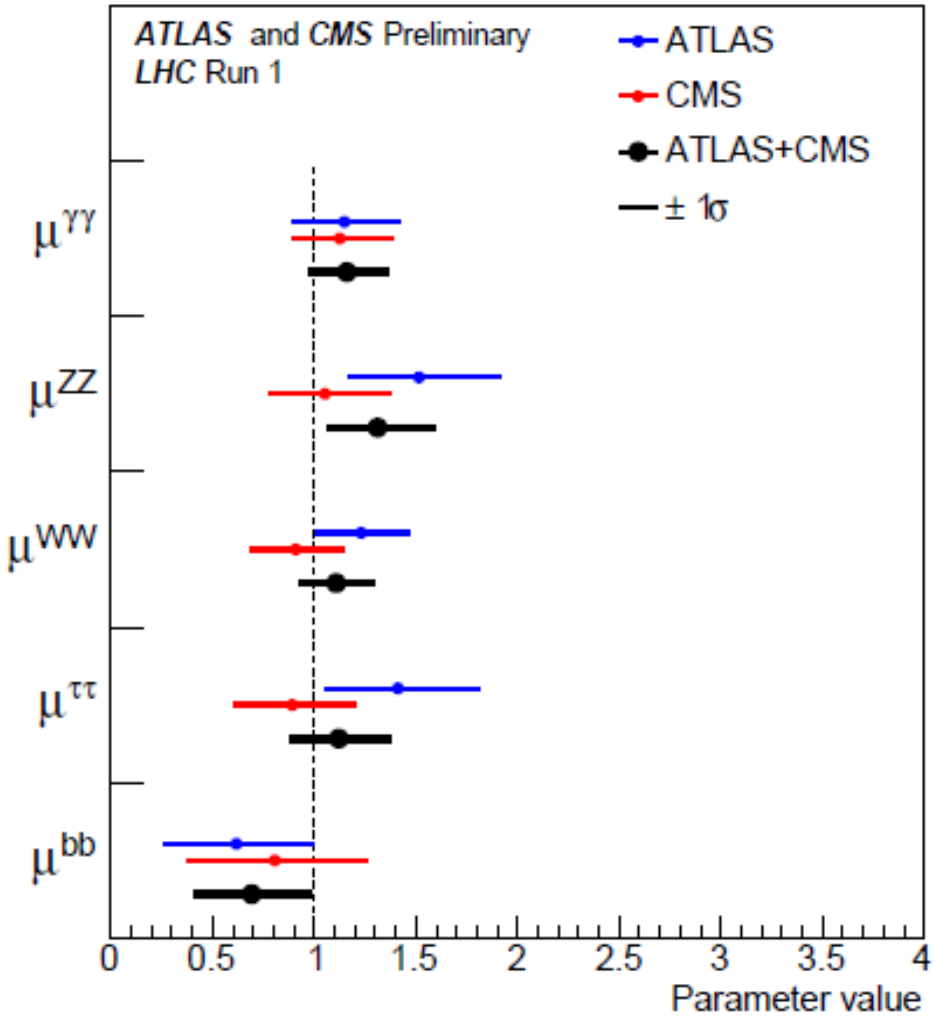


Higgs rates at Run I LHC

Recently ATLAS and CMS have combined their results for the Higgs rates

ATLAS-CONF-2015-044
CMS-PAS-HIG-15-002





Self-consistency of the Standard Model

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Why is it so important? What do we learn?

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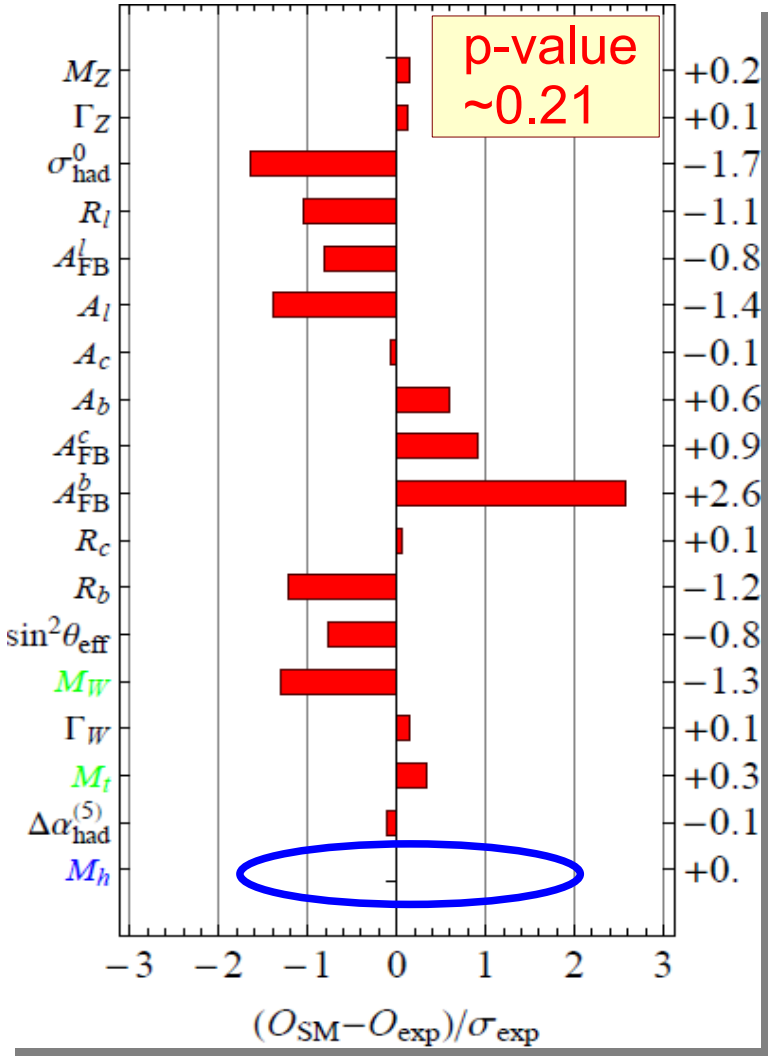

Update from Batell, SG, Wang, 1209.6382

If the Higgs is the one of the SM...

For the first time in the history of physics, we have a self-consistent picture for the electro-weak sector

Self-consistency of the Standard Model

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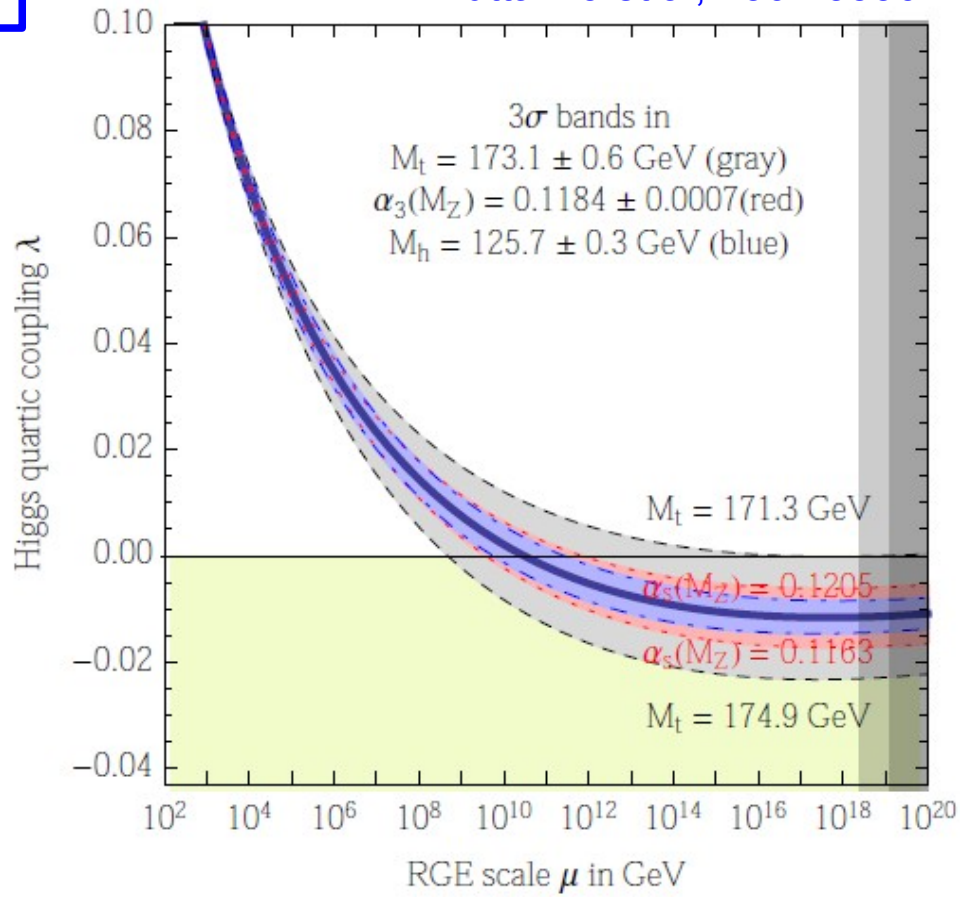
2.

Buttazzo et al, 1307.3536



It is not clear that this instability shoud be considered a problem of the SM

What about the Higgs couplings?

In the gauge sector of the Standard Model, all couplings are determined by the SU(3)xSU(2)xU(1) symmetry

In the Higgs sector, there is no such an organizing principle.

We need to measure the Higgs couplings
(as precisely as possible)

Why is this physics program crucial?

- The hierarchy problem generically implies the presence of light/not too heavy New Physics (NP) particles that interact with the Higgs
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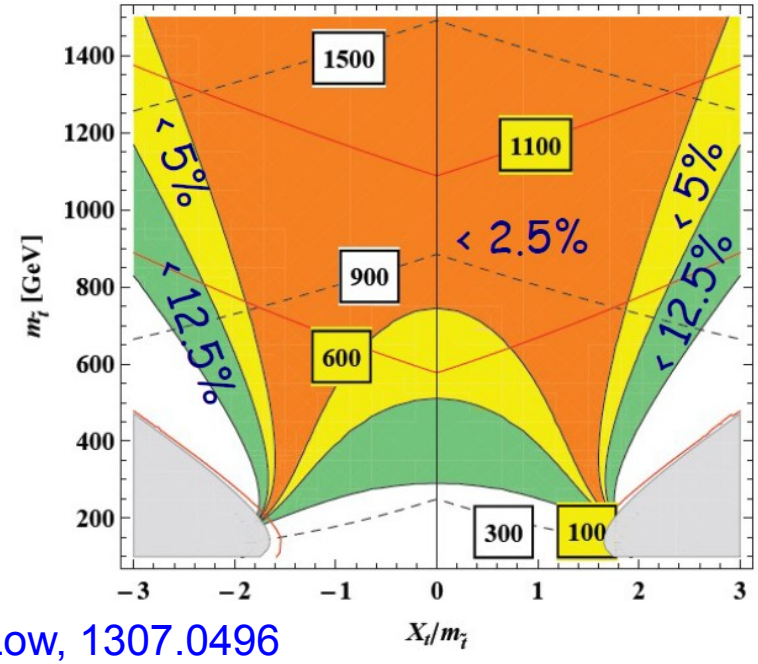
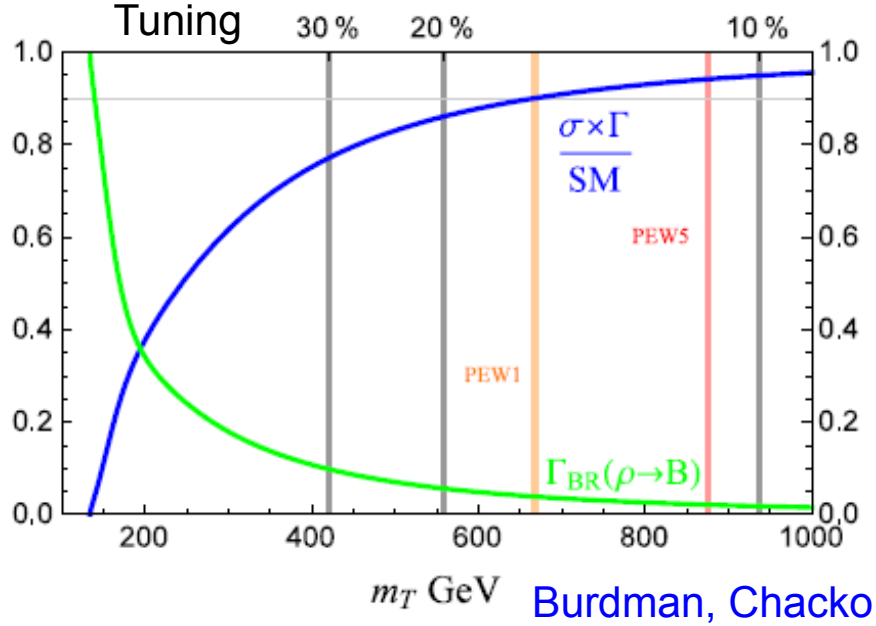
Stops in Supersymmetry



SG, Low, 1307.0496

Top partners in Twin Higgs models



Burdman, Chacko, Harnik, De Lima, Verhaaren, 1411.3310

NP contributions to the Higgs couplings scale as $\mathcal{O}\left(\frac{v^2}{m_{\rm NP}^2}\right) \sim 5\%$

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The discovery of some deviation in the Higgs couplings to SM particles would give us the hint for a NP mass scale, that could be probed directly by the LHC/next generation colliders

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LHC extraction of the Higgs couplings

- Higgs couplings can be extracted from a global fit of the Higgs rates:

Example: $$\mu_Z = \frac{\sigma(pp \to h)}{\sigma(pp \to h)_{\rm SM}} \times \frac{\Gamma(h \to ZZ^*)}{\Gamma_{\rm tot}} \frac{\Gamma_{\rm tot,SM}}{\Gamma(h \to ZZ^*)_{\rm SM}} = \frac{\kappa_g^2 \kappa_Z^2}{\Gamma_{\rm tot}/\Gamma_{\rm tot,SM}}$$

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- At hadron colliders, measurements of the Higgs total width have some model dependence: the Higgs total width can be extracted from

- ✔ the fit of Higgs rates, with some assumption.
  for example $\kappa_Z \leq 1$
- ✔ on-shell/off-shell measurements of $pp \longrightarrow h^{(*)} \longrightarrow ZZ$
- ✔ study of the interference between
  $gg \longrightarrow \gamma\gamma$ and $gg \longrightarrow h \longrightarrow \gamma\gamma$
  $\Gamma_h \leq 15 \times \Gamma_{SM}$ (prospects for the HL-LHC)
  Dixon, Li, 1305.3854
- ✔ ...

$\Gamma_H < 4.2\ \Gamma_{H,SM}$
$< (4.8 – 7.7)\ \Gamma_{H,SM}$
CMS-PAS-HIG-14-002
ATLAS-CONF-2014-042

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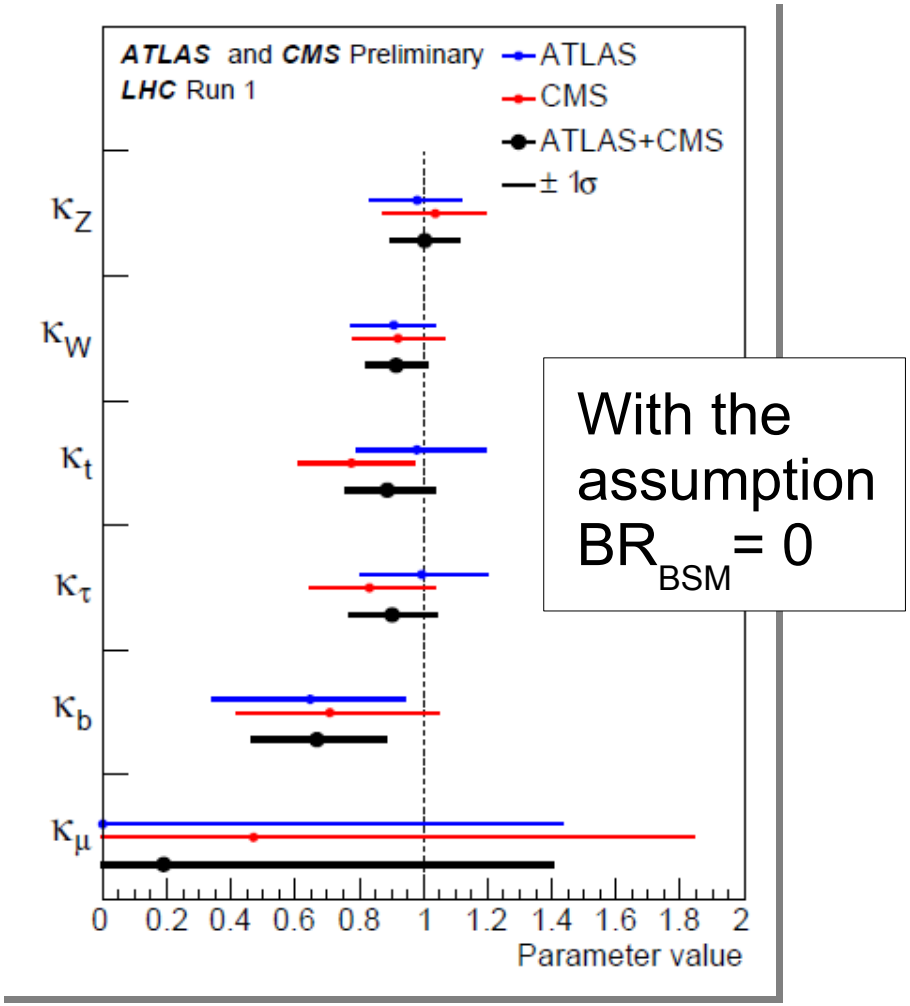

With the assumption $BR_{BSM} = 0$

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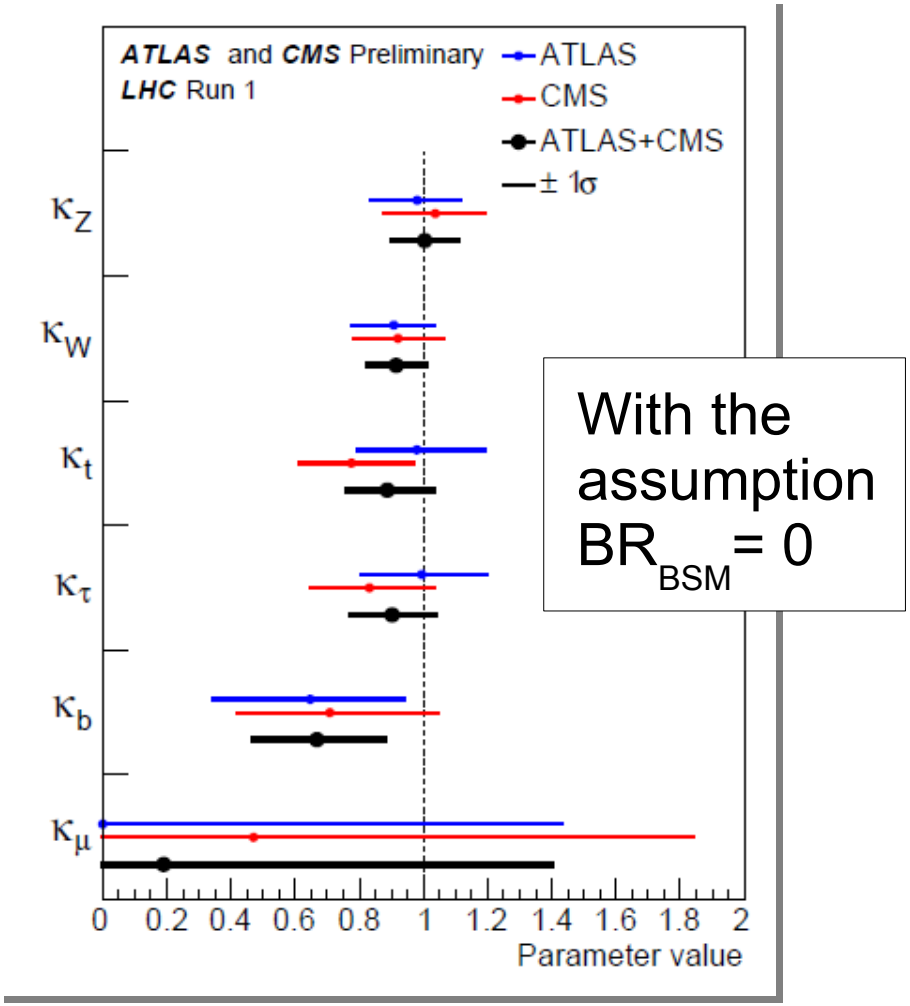

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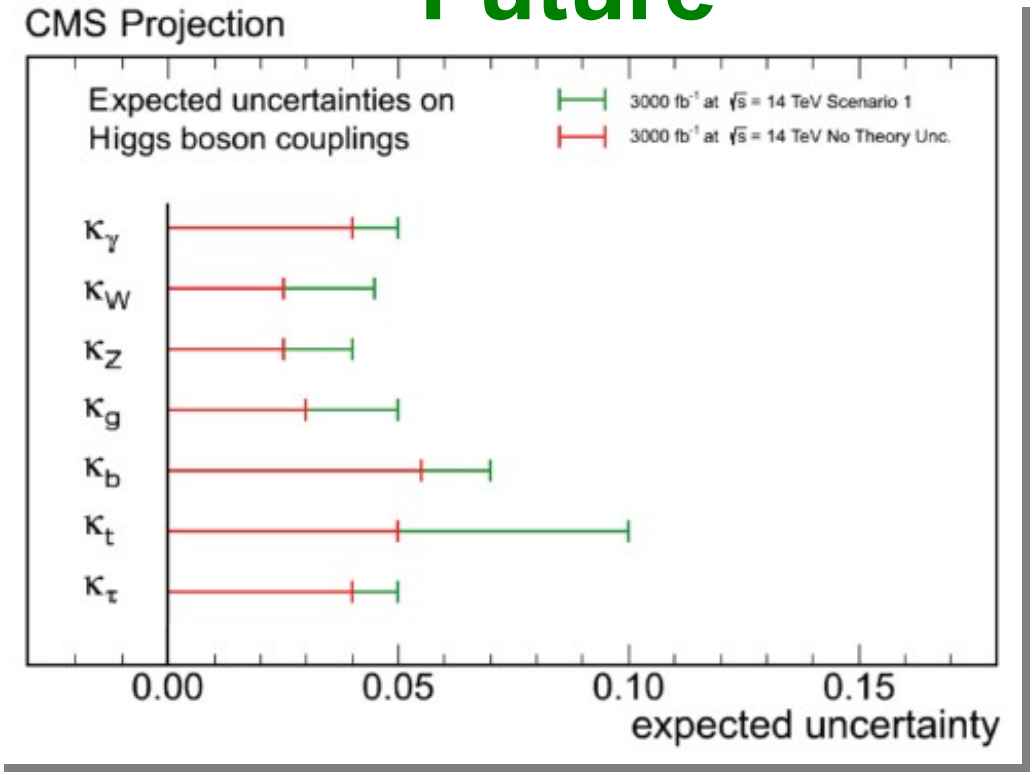
Future



CMS-NOTE-13-002

Challenging measurements at the LHC

- Some Higgs decay modes are background limited at the LHC

Examples: $h \longrightarrow gg$ (BR = 8.6%)
$h \longrightarrow cc$ (BR = 2.9%)

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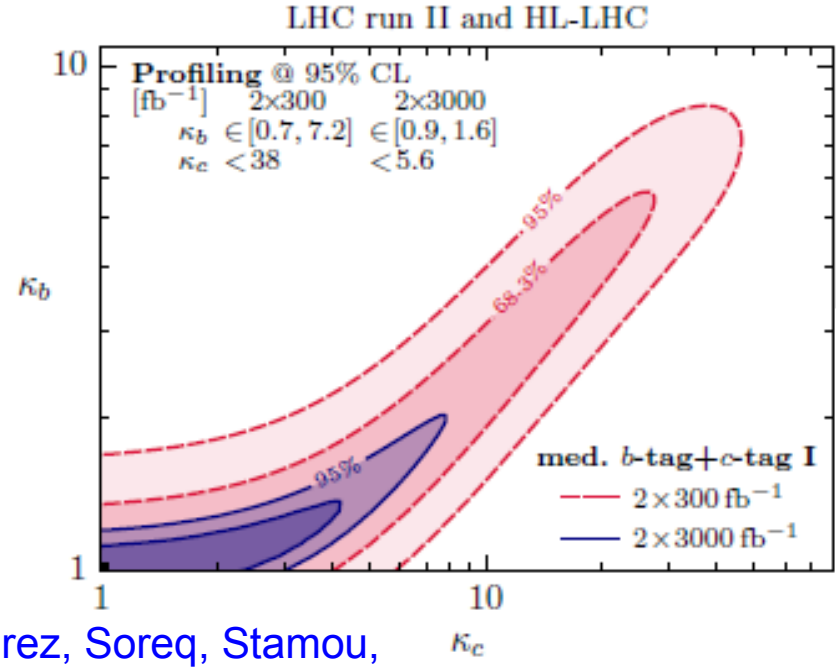
In particular, for the Higgs-charm coupling:

1. Inclusive determination:

Studying the signal strenght of h⟶bb:



Perez, Soreq, Stamou, Tobioka, 1505.06689

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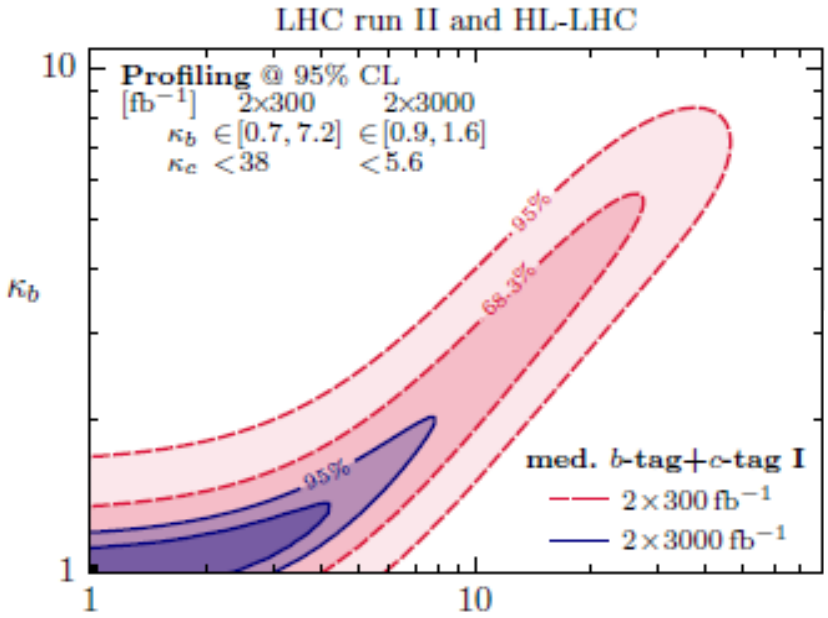
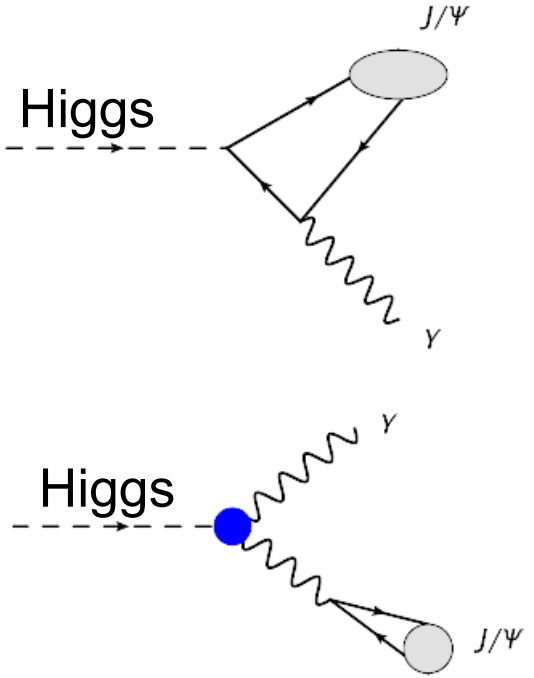


Perez, Soreq, Stamou, Tobioka, 1505.06689

2. Exclusive determination:

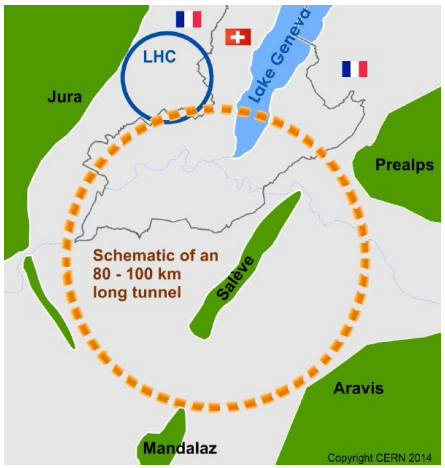
Quarkonium interferometry



At RunI:

$$\kappa_c \leq 220$$

What can a e^+e^- collider tell us?



Measurements at e^+e^- colliders

In all generality...

- Small backgrounds: all background is electroweak. S/B~1

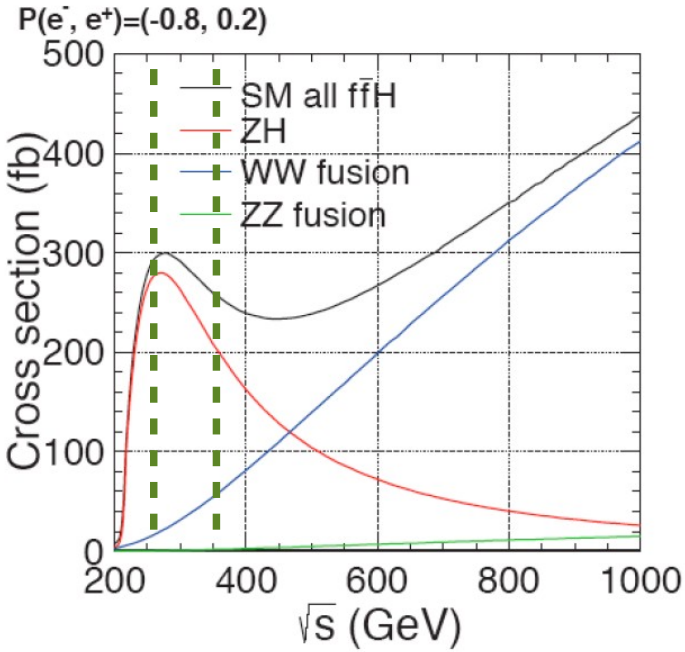
Great for the measurement of the LHC Higgs background limited decays (gg, cc, ...)

- The Higgs recoil measurement of $\sigma(e^+e^- \longrightarrow Zh)$ provides a model independent measurement of all BRs and of the Higgs width,

without reconstructing decays of the Higgs boson.
The uncertainty of the measurement of the cross section is less than ~2%

At the several energies...

- 250 GeV
  - ✔ Measure the Higgs mass and κ_Z precisely.
  - ✔ Measure invisible and exotic decay modes.
- 350 GeV
  - ✔ Better measure the total width, through the WW fusion process.



At the several energies...

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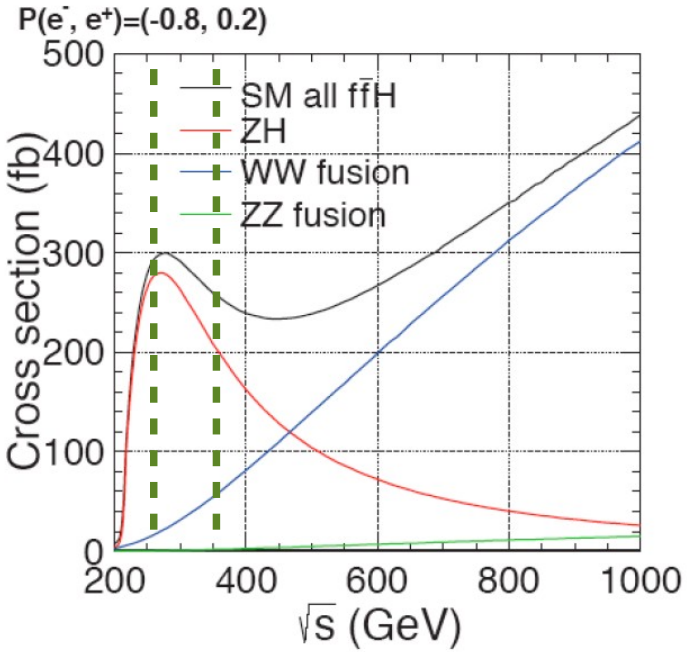
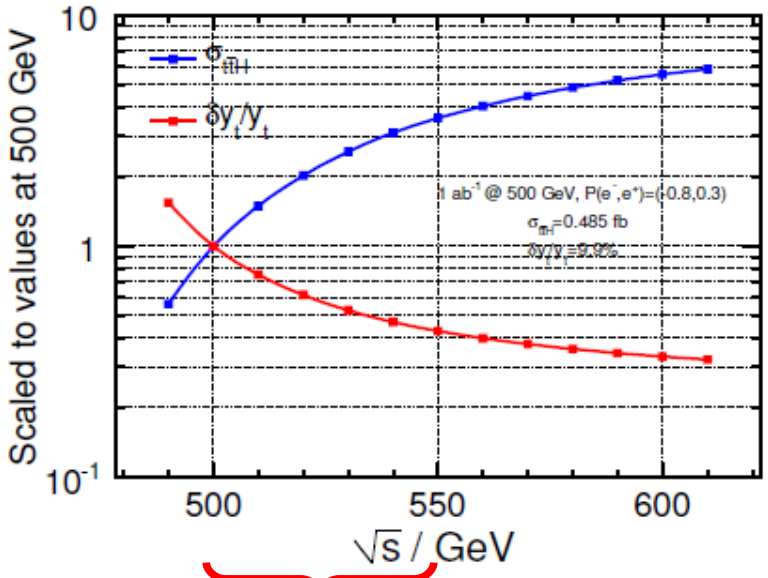
- 500 GeV
  - Measure κ_W precisely using WW fusion.
  - At around this energy, σ(tth) increases very quickly.





Factor of ~3 better precision

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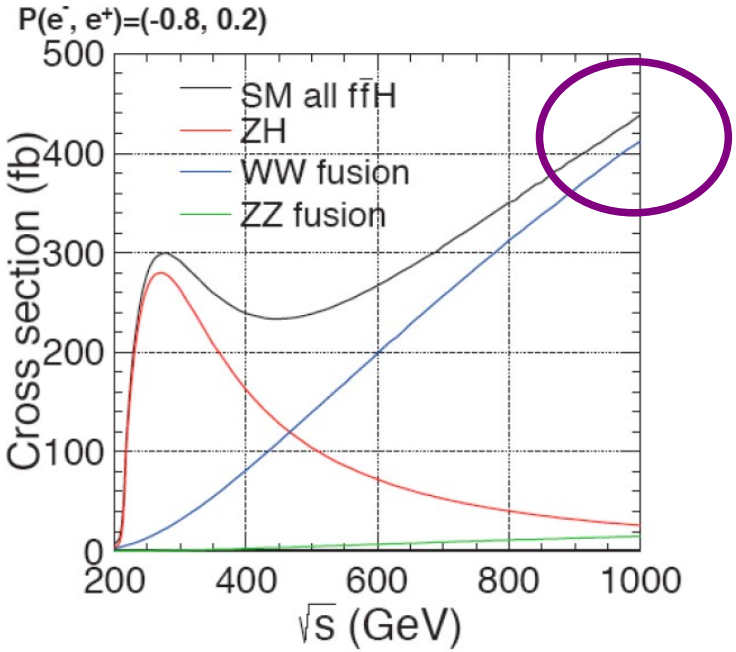
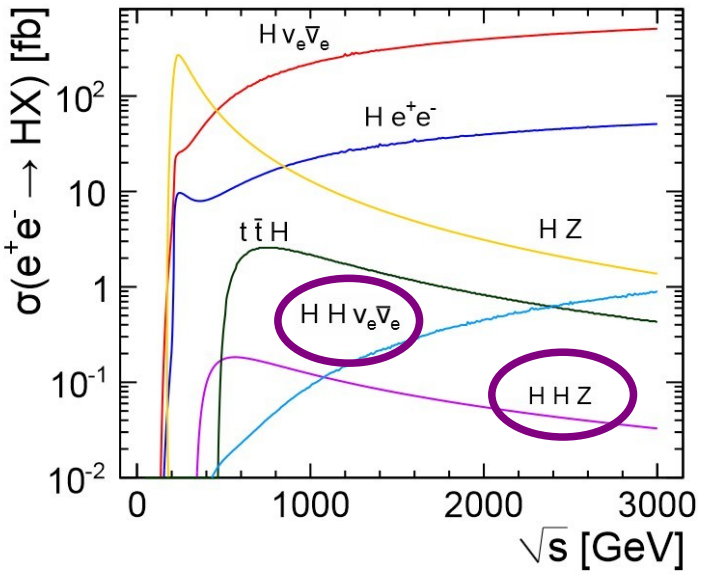
  - Measure κ_W precisely using WW fusion..
  - At around this energy, σ(tth) increases very quickly.
- ≥ 1 TeV
  - Higgs factory.
  - Accumulate more statistics for κ_τ, κ_γ.
  - Measure κ_μ, Higgs self coupling.

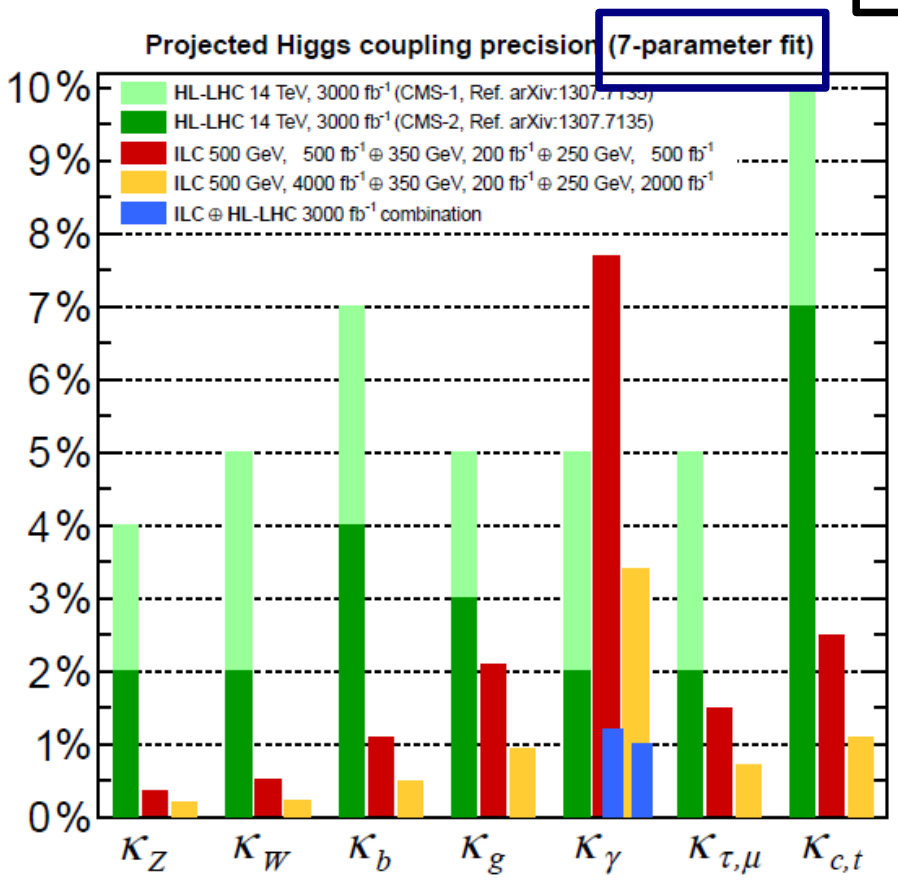


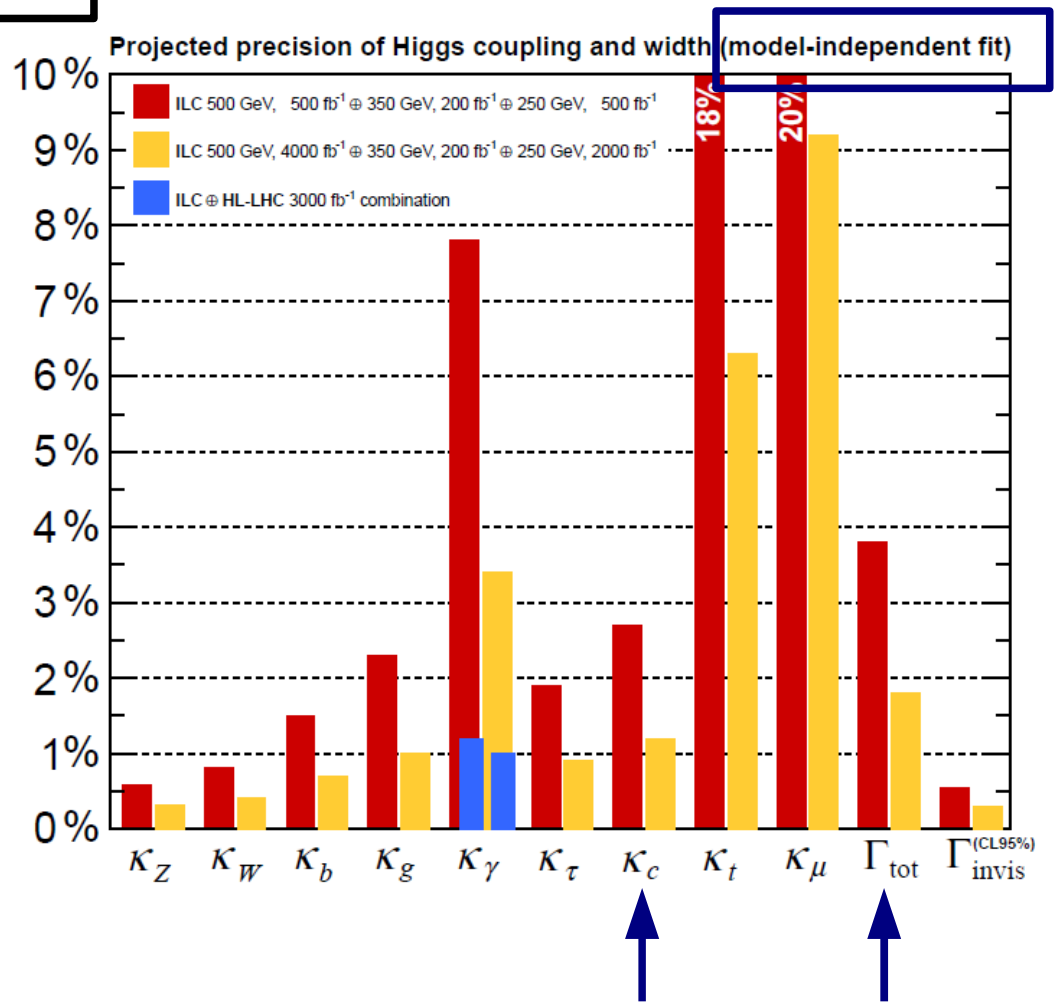


Higgs coupling measurements at e^+e^-

Fujii, et al,
1506.05992

ILC





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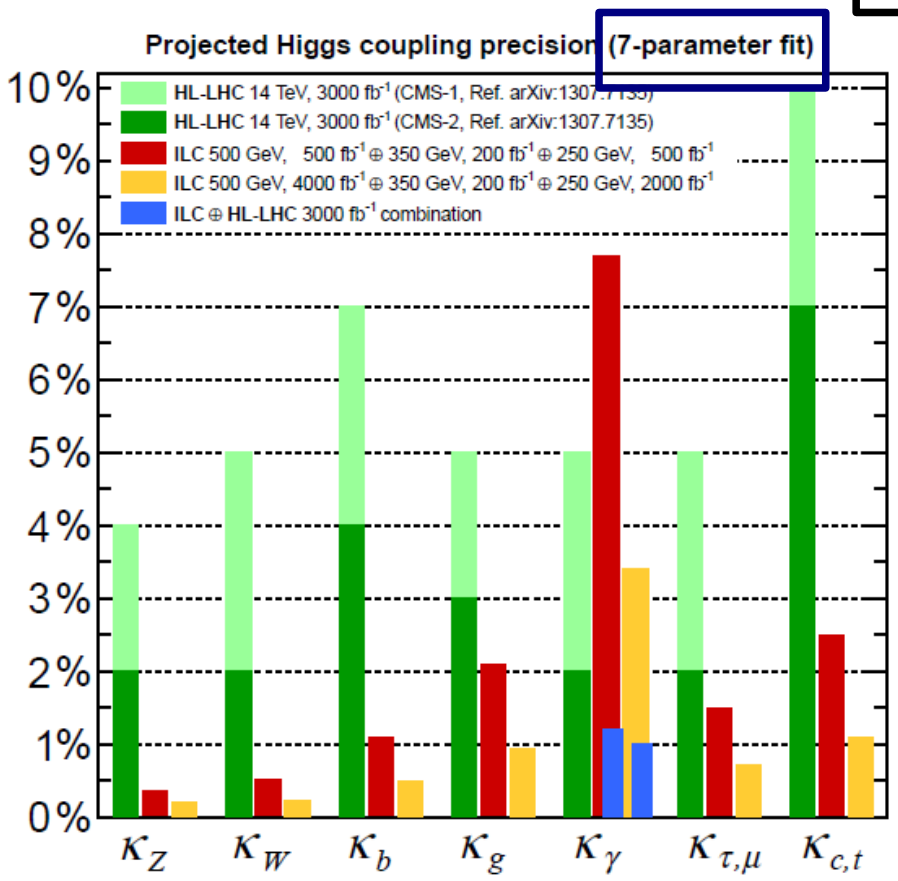
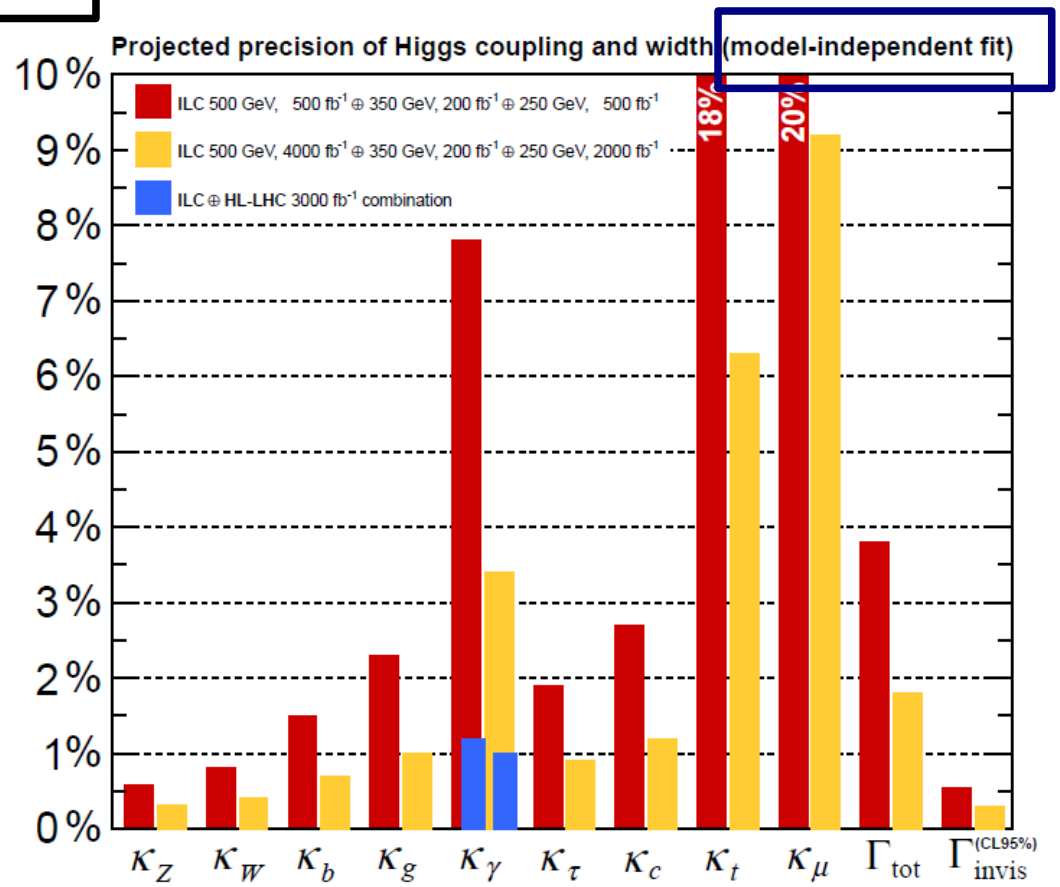




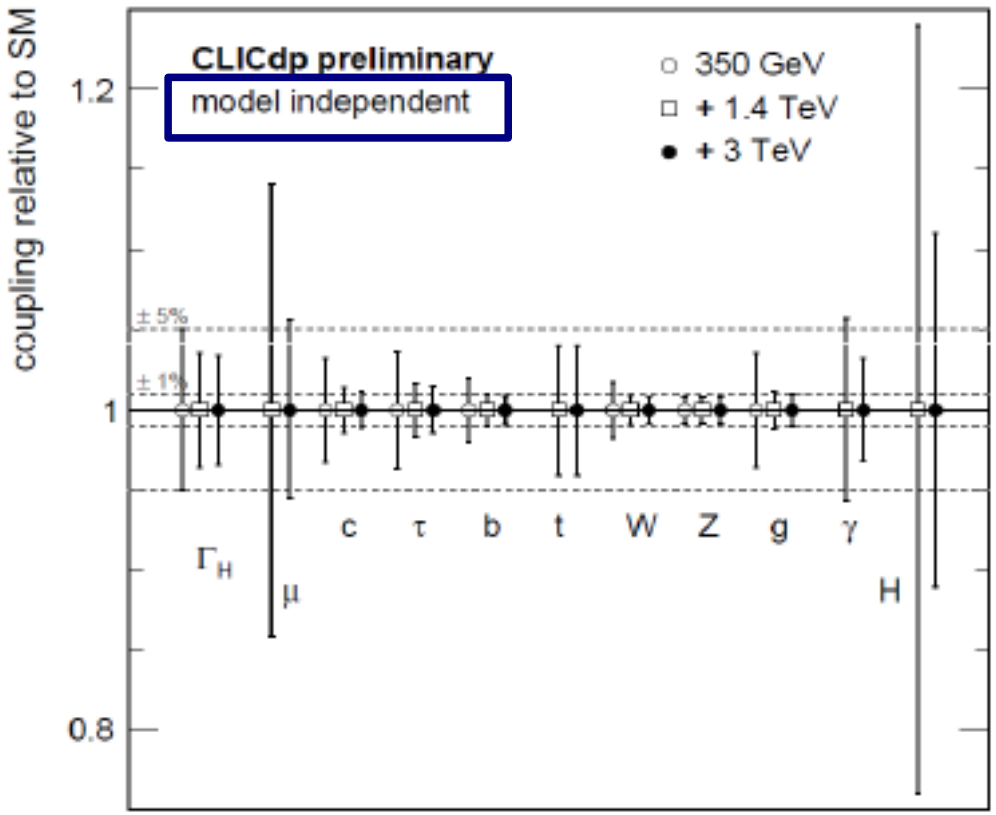
The measurement of κ_γ is statistics limited at the ILC.

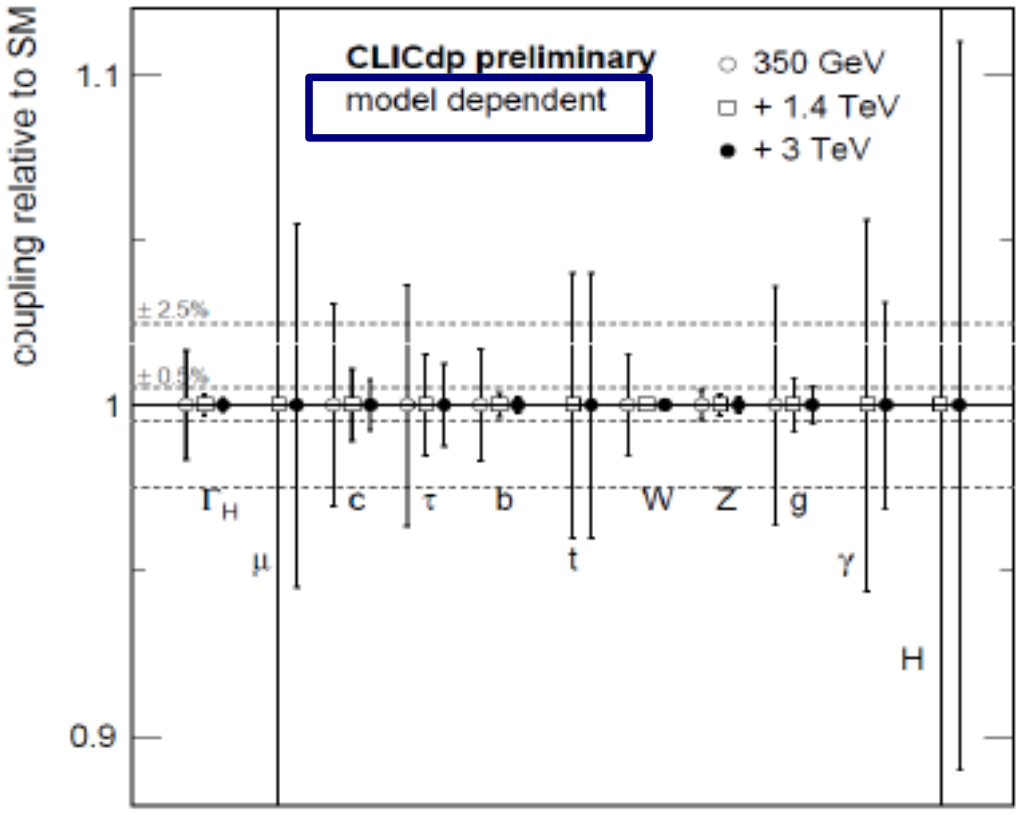
However, LHC can very well measure BR(h⟶γγ)/BR(h⟶ZZ) (~2% precision).
Combination with the κ_Z measurement from the ILC
will allow to reach a 1% level precision for κ_γ

Peskin, 1312.4974

Higgs coupling measurements at e^+e^-

CLIC





From Pandurović talk @
The XIII-th international school-conference
"The actual problems of microworld physics", August 2015

Beyond the SM Higgs couplings...

- The Higgs can easily couple to NP particles:
  since $|H|^2$ is a singlet with respect to the SM gauge group, the Higgs can couple to NP that are neutral w.r.t the SM (e.g. hidden valleys)

- If these NP particles are light ($m_{NP} < m_H/2$),
  the Higgs will have new decay modes: H ⟶ NP particles

Models for DM, neutral naturalness, baryogenesis, ...

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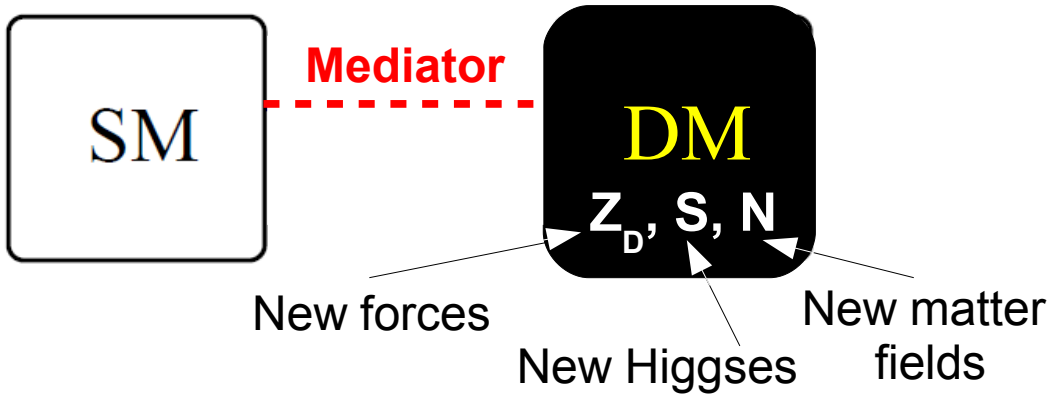

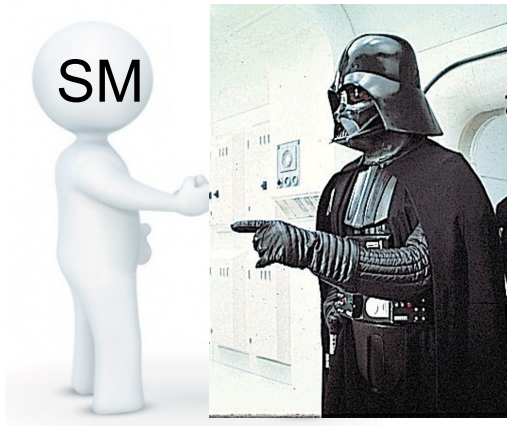

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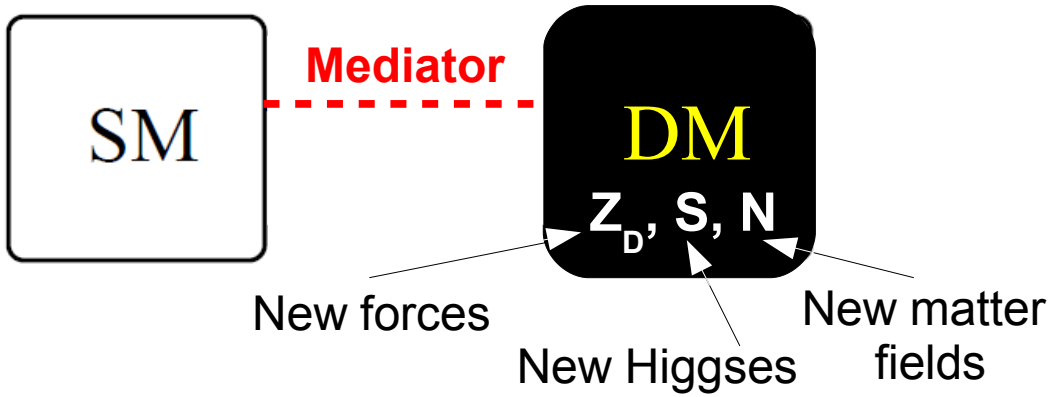

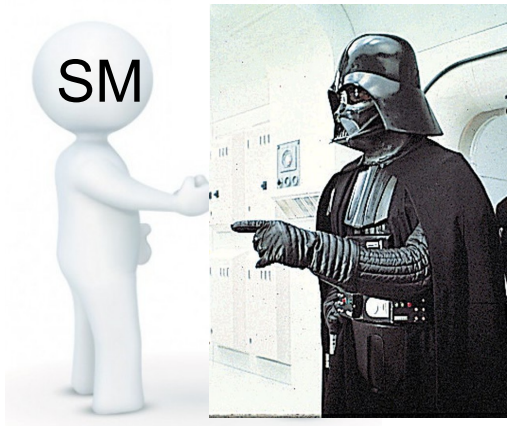

The interactions can be mediated by a (small set of) renormalizable "portals":

$Z_{\mu\nu} Z_D^{\mu\nu}$ $\quad$ $|H|^2 |S|^2$ $\quad$ HLN

$H \to Z Z_D$ $\quad$ $H \to ss$ $\quad$ $H \to LN$

Higgs (rare) exotic decays

Possibility to discover Higgs branching ratios to NP particles below 2%?

Looking "directly" for rare new decays of the Higgs:

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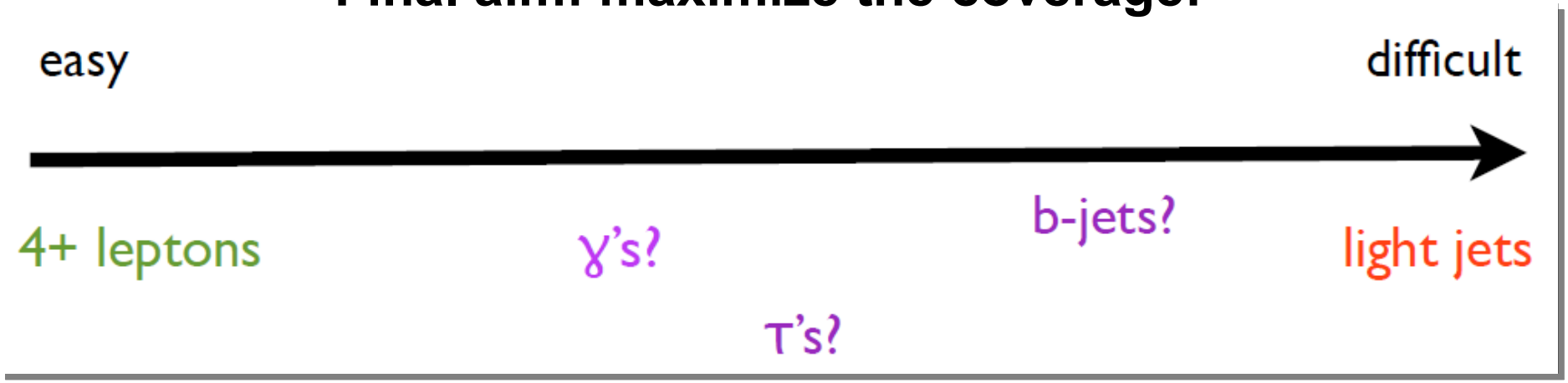

For a review:

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

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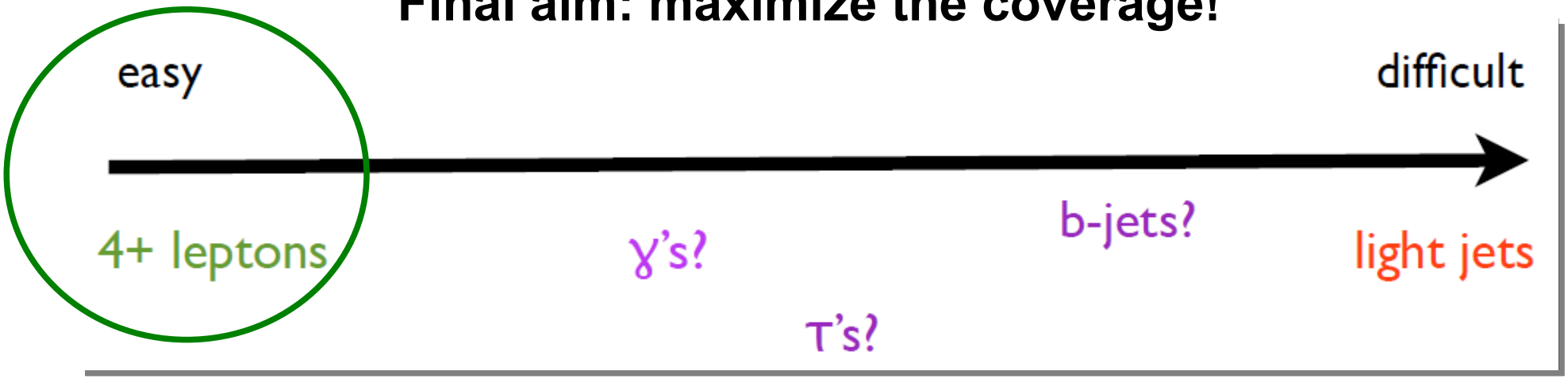

Example:
$h \longrightarrow ZZ_D \longrightarrow 4l$

These can be seen by the LHC pretty easily:
BRs ~ 10^{-6} – 10^{-7} can be probed by the HL-LHC

Curtin, Essig, SG, Shelton 1412.0018

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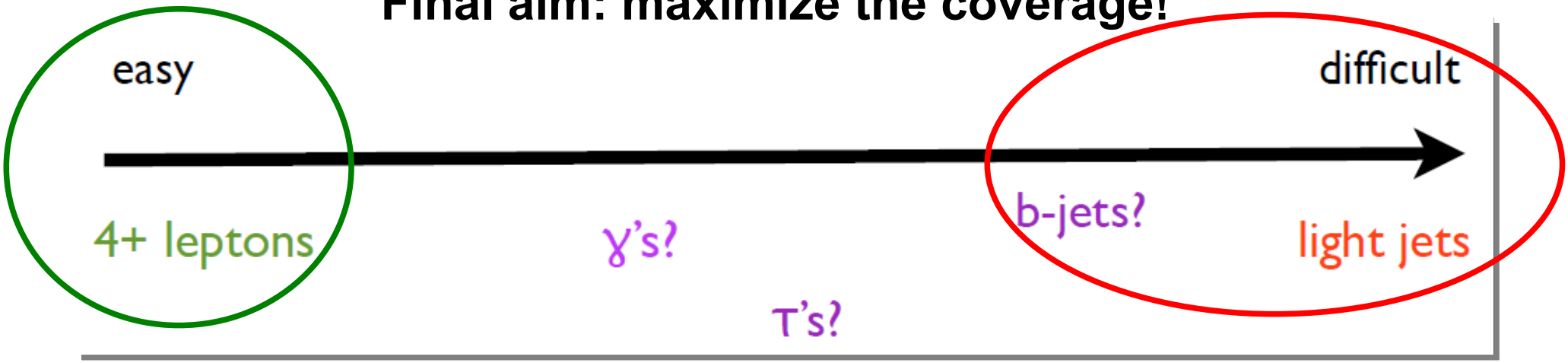

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Curtin, Essig, SG, Shelton 1412.0018

See Liu, Potter, 1309.0021 for a ILC
$h \longrightarrow 4\tau$ analysis

Example: (as in the NMSSM)
$h \longrightarrow ss \longrightarrow 4b$

Background limited at the LHC.
Theory studies show that BRs ~ 0.1 might be reached Cao et al, 1309.4939

What can e^+e^- colliders say about these difficult decay modes?

Conclusions

Program for Higgs characterization

- Due to their unique experimental environment, e^+e^- linear colliders provide a significant step in the precision study of Higgs boson properties.

Model independent measurements of the Higgs couplings.

- e^+e^- machines offer impressive opportunities to probe couplings that are difficult for the LHC (e.g. cc, gg, …)

- Very important physics program to be pursued at at the LHC and at e^+e^-colliders: direct search for Higgs exotic decays. Interplay between LHC and e^+e^- measurements