Four-Lepton Signatures

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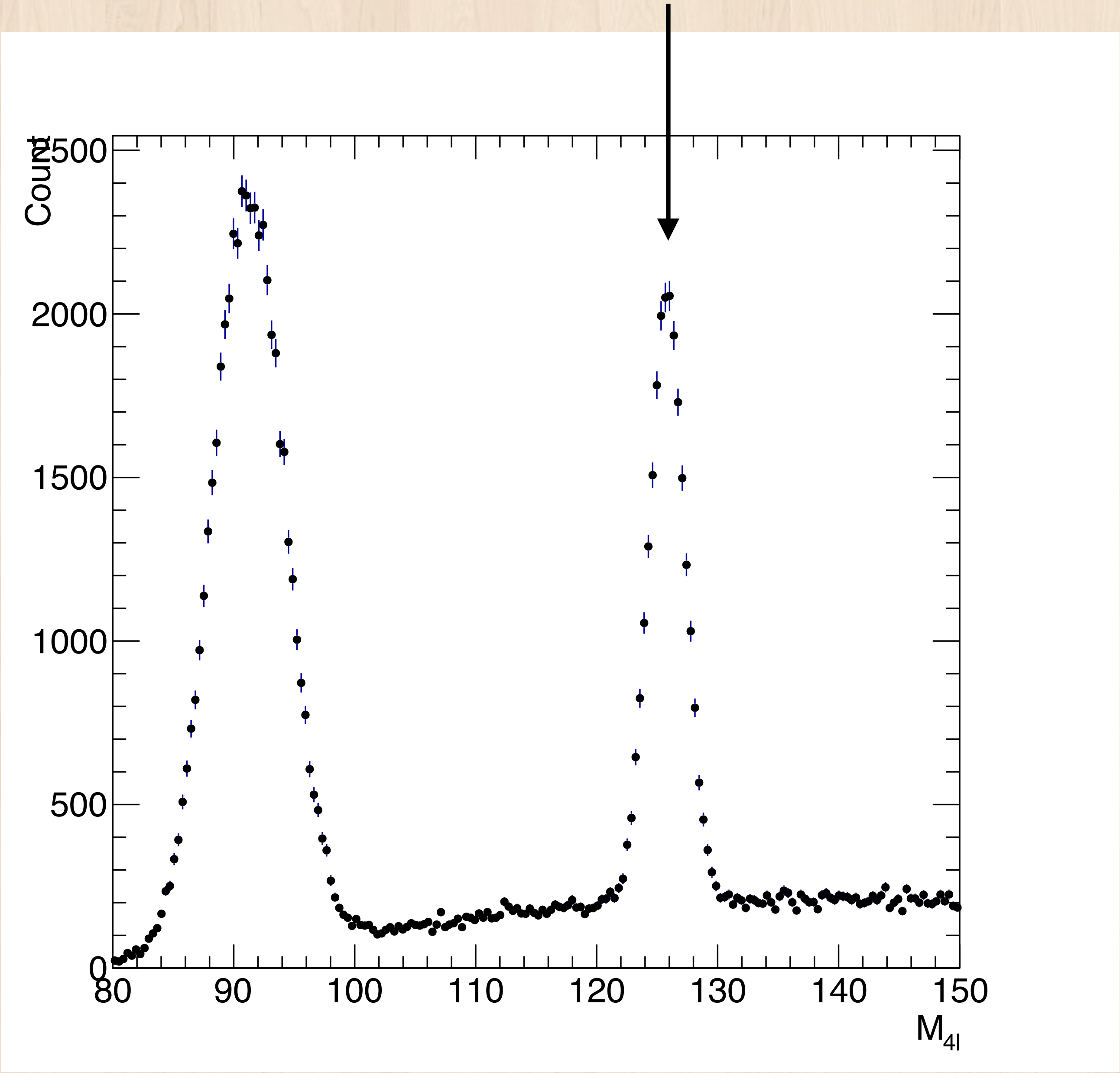
Based on 1310.2893, 1404.1336, 1503.05855, 1505.01168, 1608.02159
in collaboration with Roni Harnik, Joseph Lykken, Maria Spiropulu,
Daniel Stolarski and Roberto Vega-Morales

The 4l Channel

What can we learn from on-shell 4l decay?

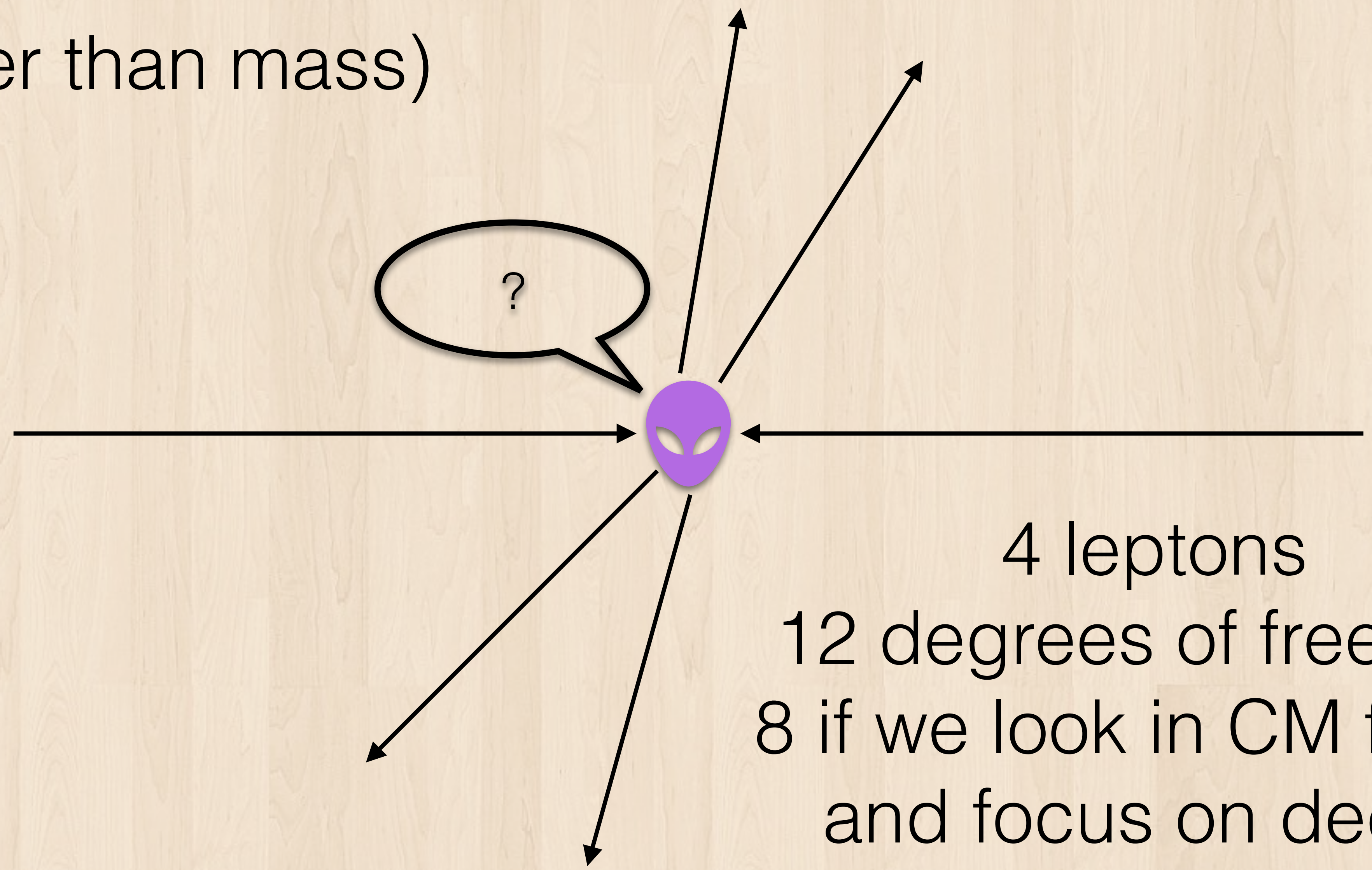


$N_S = 20000$

The 4l Channel

What can we learn from on-shell 4l decay?

(other than mass)



4 leptons
12 degrees of freedom
8 if we look in CM frame
and focus on decay

Experimental Advantage

Leptons are clean and well-measured

We have analytical differential cross section

Possible to build full detector-level likelihood without the need of huge simulation samples

Many well-established analysis techniques

Many studies available

Godbole, Miller, Muhlleitner, 0708.0458

Cao, Jackson, Keung, Low, 0911.3398

Gao, Gritsan, Guo, Melnikov, Schulze et al, 1001.3396

De Rujula, Lykken, Pierini, Rogan, Spiropulu, 1001.5300

Gainer, Kumar, Low, Vega-Morales, 1108.2274

Bolognesi, Gao, Gritsan, Melnikov et al, 1208.4018

Boughezal, LeCompte, Petriello, 1208.4311

Avery, Bourilkov, Chen, Cheng, Drozdetskiy et al, 1210.0896

Cambell, Giele, Williams, 1205.3434

Cambell, Giele, Williams, 1204.4424

Gainer, Lykken et al, 1304.4936

Artoisenet, de Aquino, Demartin, Maltoni et al, 1306.6464

Sun, Wang, Gao, 1309.4171

Anderson, Bolognesi, Caola, Gao, Gritsan et al, 1309.4819

Chen, Gainer et al, 1310.1397

Gonzales-Alonso, Isidori, 1403.2648

Gainer, Lykken, Matchev, Mrenna, Park, 1403.4951

Beneke, Boito, Wang, 1406.1361

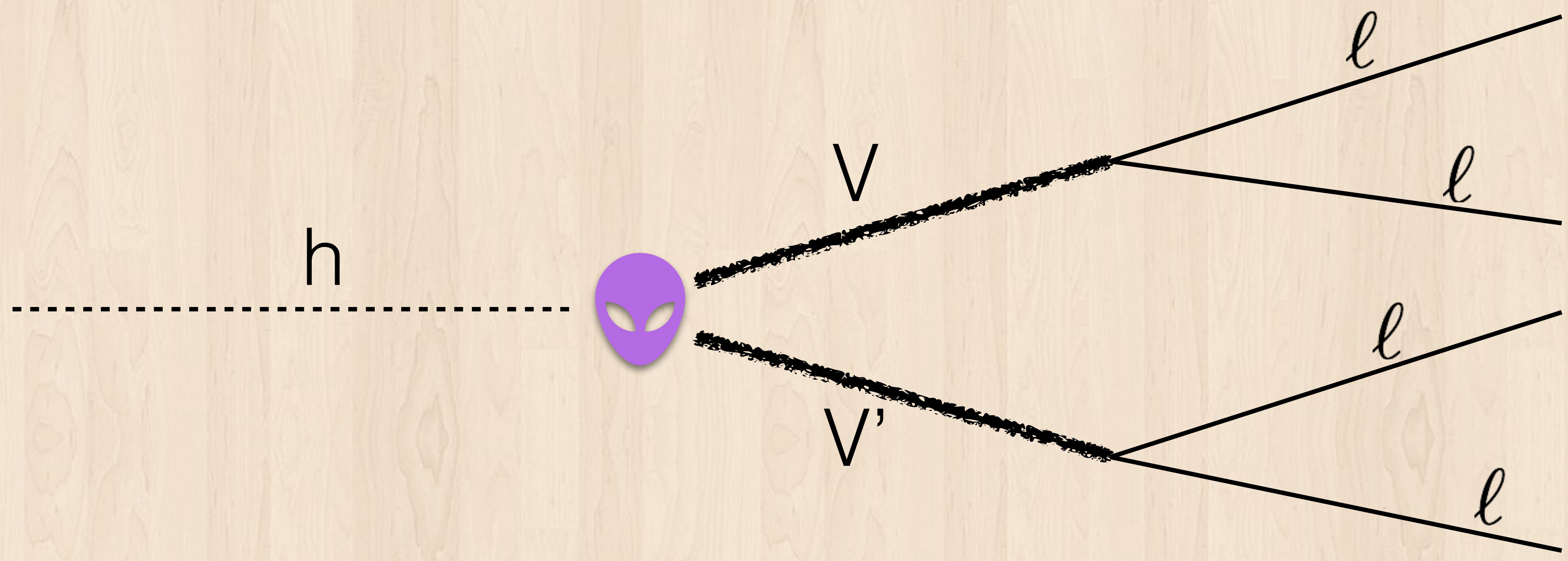
Gonzales-Alonso, Greljo, Isidori, Marzocca, 1412.6038

Gonzales-Alonso, Greljo, Isidori, Marzocca, 1504.04018

Bordone, Greljo, Isidori, Marzocca, Pattori, 1507.02555

As well as many other studies, including studies from the LHC experiments

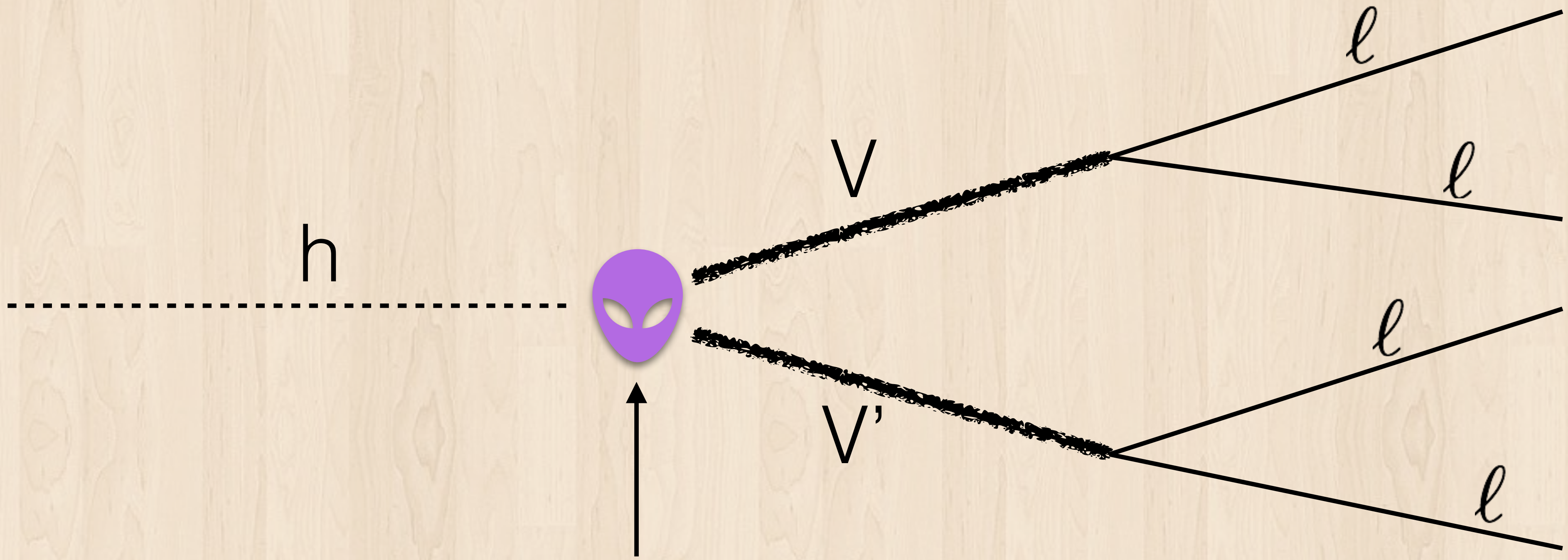
Intermediate Boson



The intermediate boson can be Z or photon in SM

How sensitive are we to (effective) coupling involving photons?

Intermediate Boson



Parameterization used in this talk:

$$L \supset \frac{h}{4v}\left(2A_1^{ZZ} m_Z^2 Z^\mu Z_\mu + A_2^{ZZ} Z^{\mu\nu} Z_{\mu\nu} + A_3^{ZZ} Z^{\mu\nu} \tilde{Z}_{\mu\nu} + A_2^{Z\gamma} Z^{\mu\nu} F_{\mu\nu} + A_3^{Z\gamma} Z^{\mu\nu} \tilde{F}_{\mu\nu} + A_2^{\gamma\gamma} F^{\mu\nu} F_{\mu\nu} + A_3^{\gamma\gamma} F^{\mu\nu} \tilde{F}_{\mu\nu}\right)$$

Interference Sizes

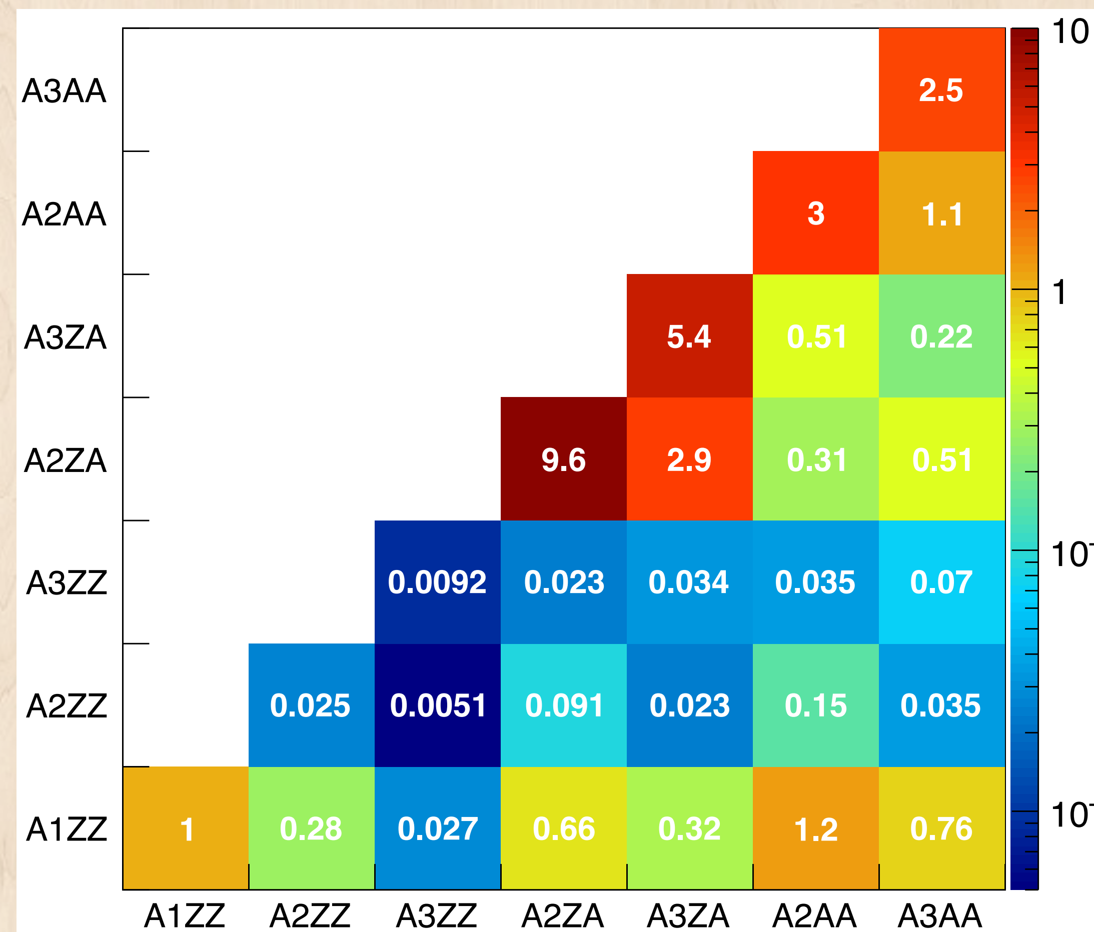
Differential Cross Section

$$\frac{d\Gamma}{d\Omega} \sim \sum A_n^i A_m^{j*} \times \frac{d\Gamma_{nm}^{ij}}{d\Omega}$$

Integrated Magnitude

$$\Pi_{nm}^{ij} = \int \left| \frac{d\Gamma_{nm}^{ij}}{d\Omega} \right| d\Omega$$

O(1) coupling



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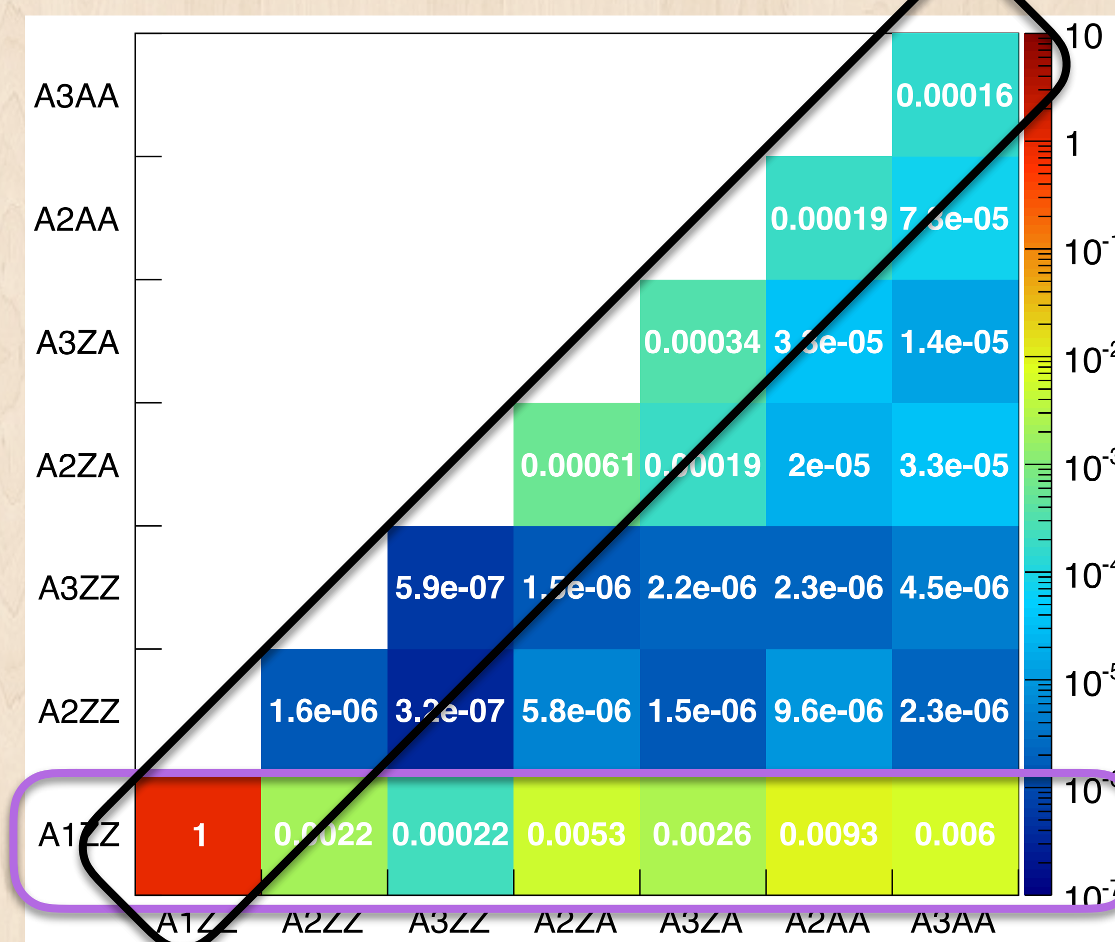
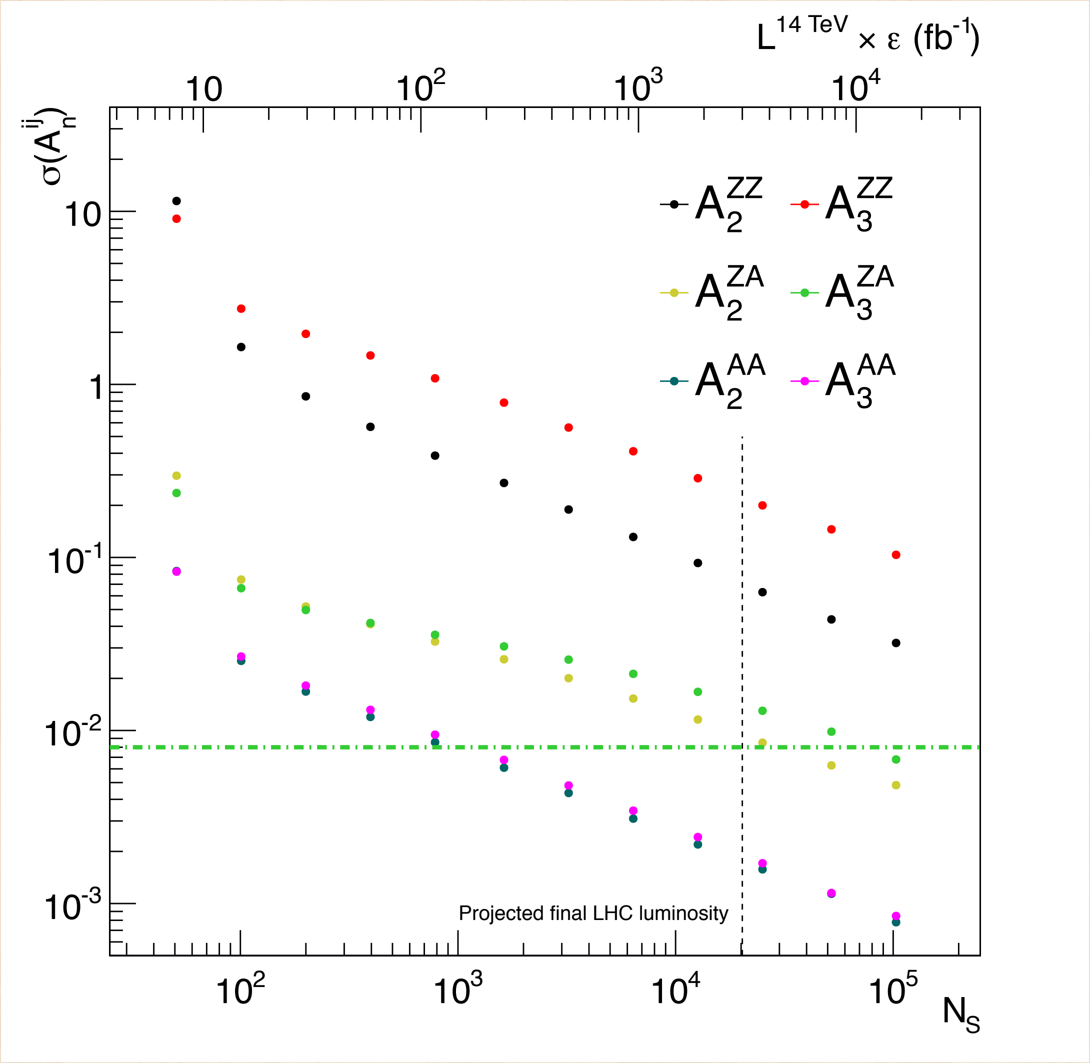
SM-like coupling O(%)



Interference > diagonal

Sensitivity



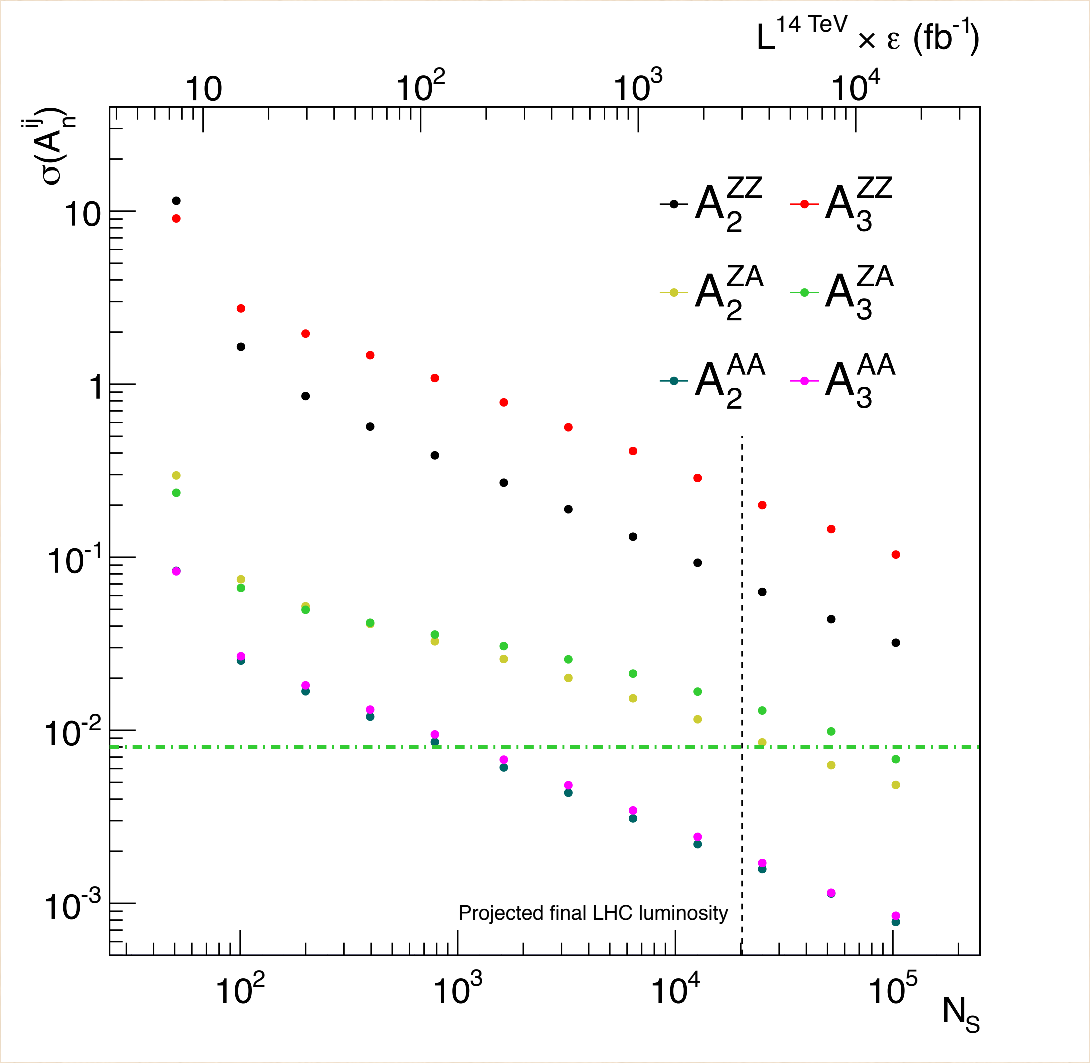
CMS Run I like cut

Parameter extraction with pseudo-experiments

Perform a fit to the differential cross section

Background assumed to be dominated by qq->4l

Sensitivity



CMS Run I like cut

Most sensitive to diphoton

Reaches SM prediction with O(1000) signal events

Can be improved by lowering di-lepton mass cut

ZA is hard (beyond 3ab^{-1})

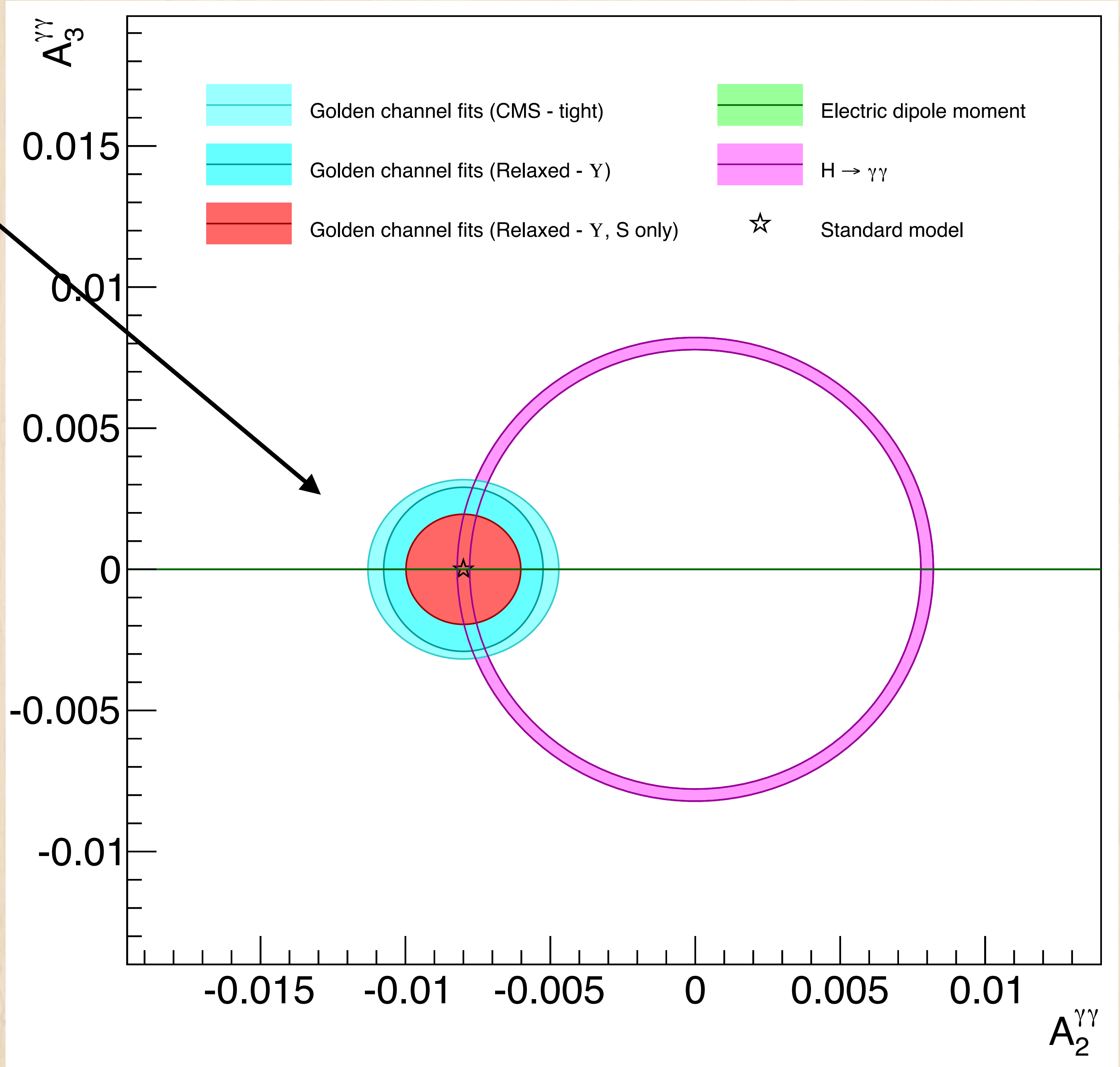
ZZ is hard^2 (beyond 3ab^{-1})

Projection to a few ab^{-1}

68% contour

Different selections investigated:

- CMS Run I-like
- Relaxed M_{ll} cut (M_{ll} > 4 GeV, and not close to M_{Υ})

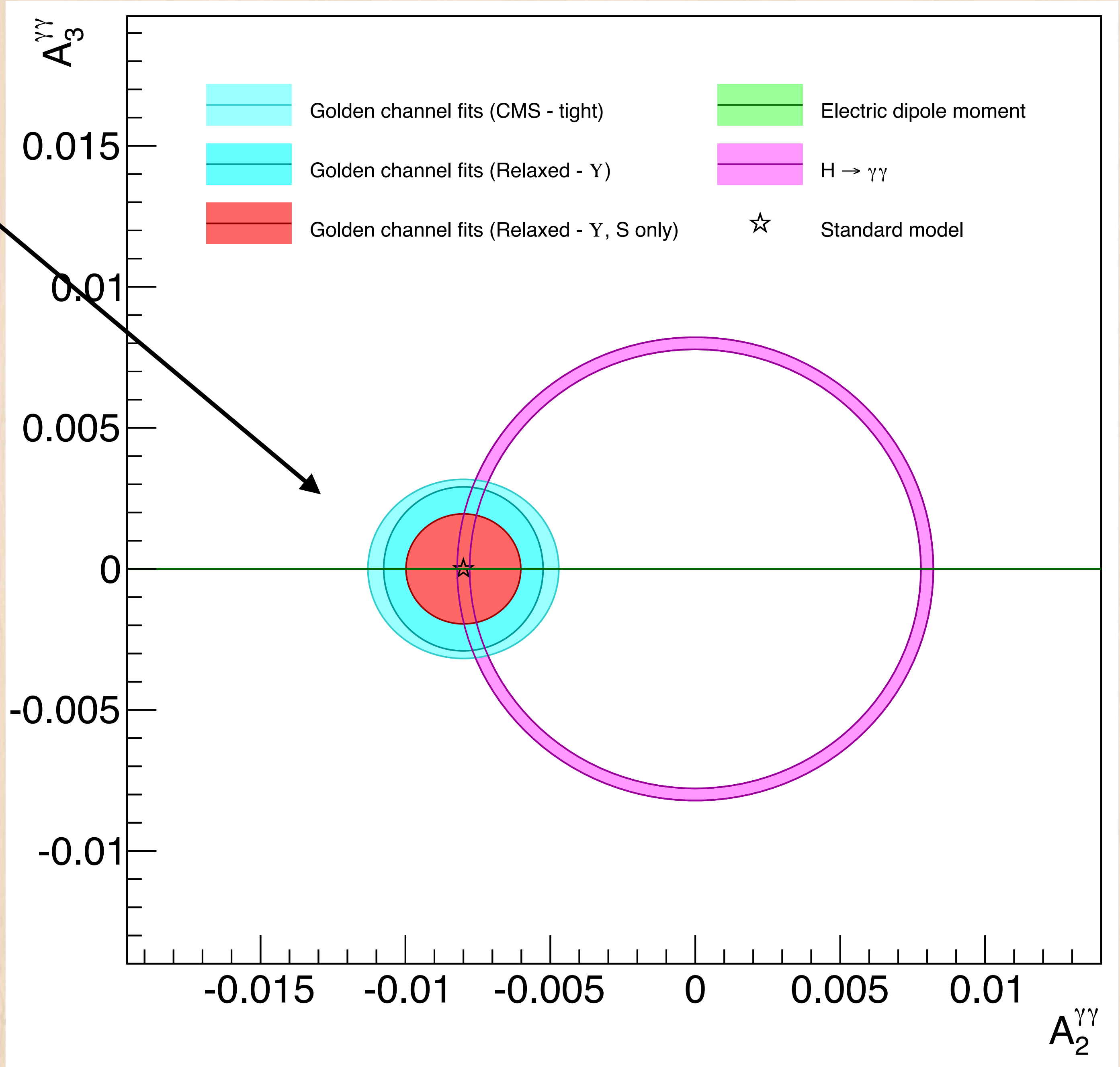


Projection to a few ab^{-1}

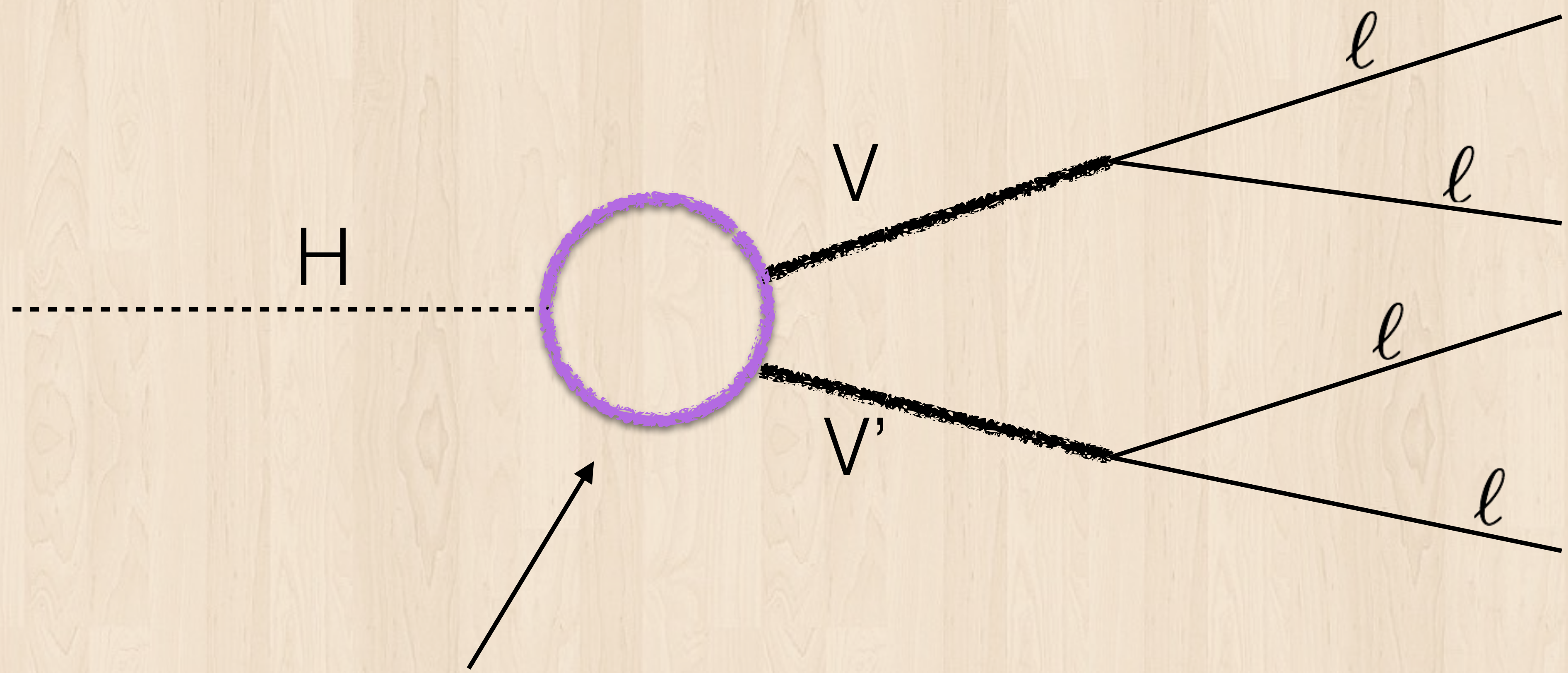
68% contour

Direct measurement size of coupling better

4-lepton channel can obtain sign and CP properties



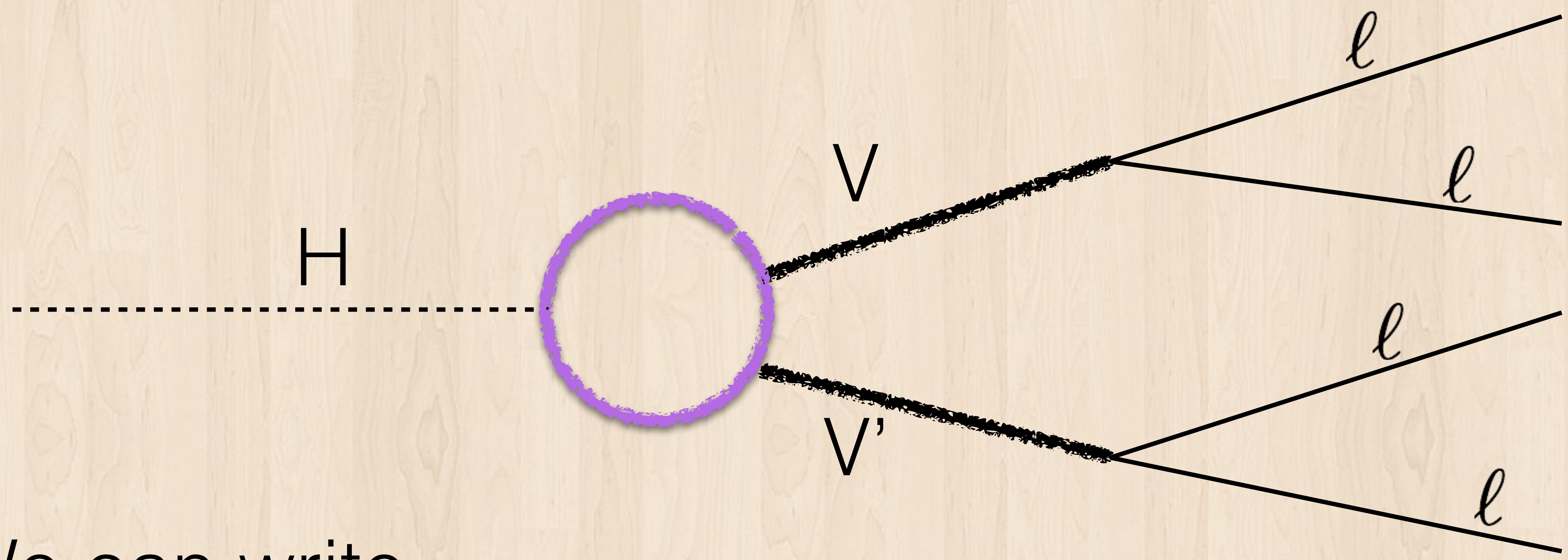
Resolving 1-Loop



When V/V' contains photon, there are two major contributions to the loop: W and top quark

Loops containing Higgs contribute to ZZ case

Resolving 1-Loop



We can write

$$A_i^{VV'} = A_i^{VV'}(y_t, \tilde{y}_t, g_{WW}, \ldots)$$

Htt coupling CP-odd version HWW coupling

Substitute them into the differential cross section,
and try to estimate the sensitivity

Custodial Symmetry

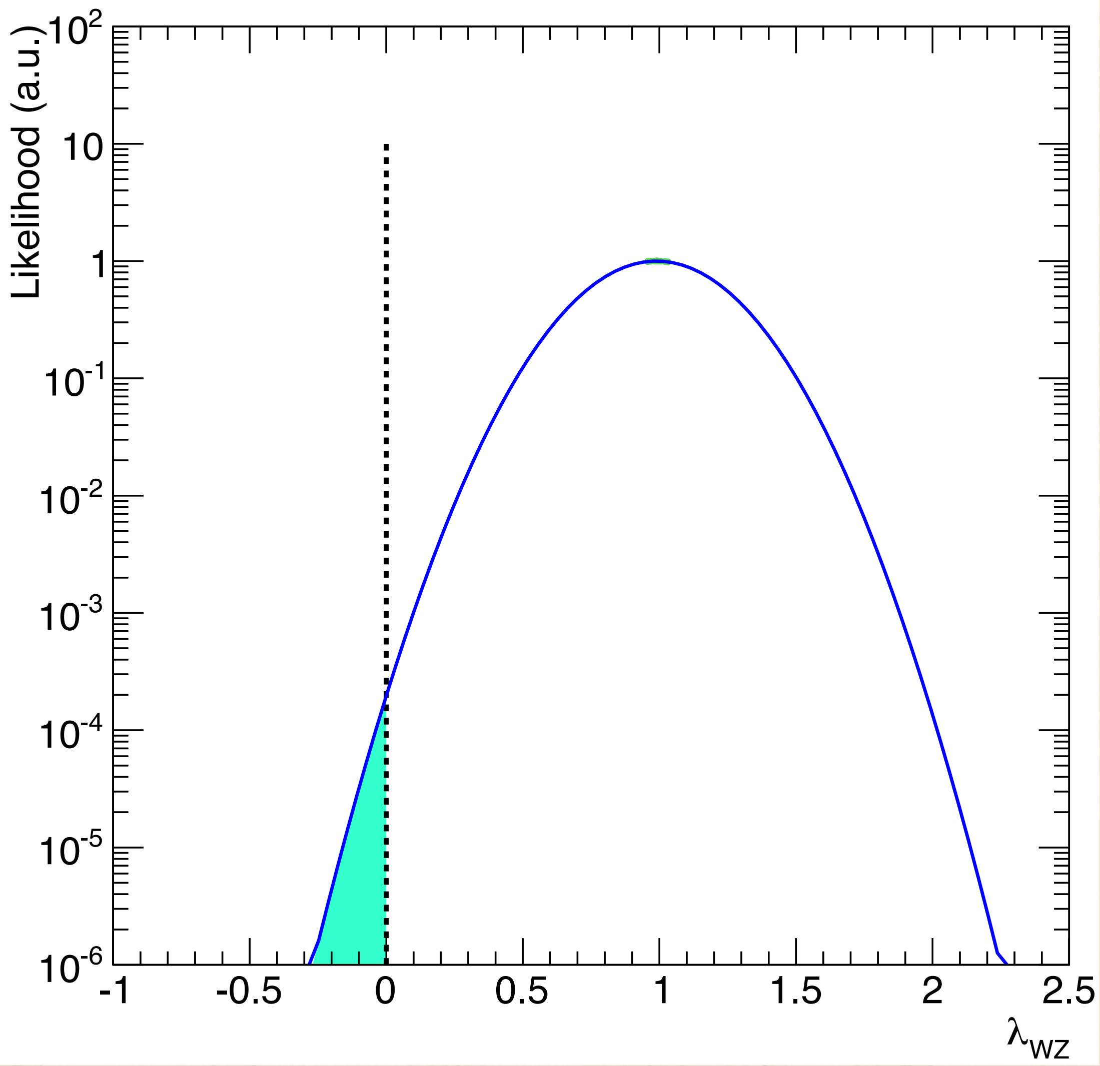
Here we investigate two different models to demonstrate the sensitivity to sign of the g_{WW} (relative to g_{ZZ})

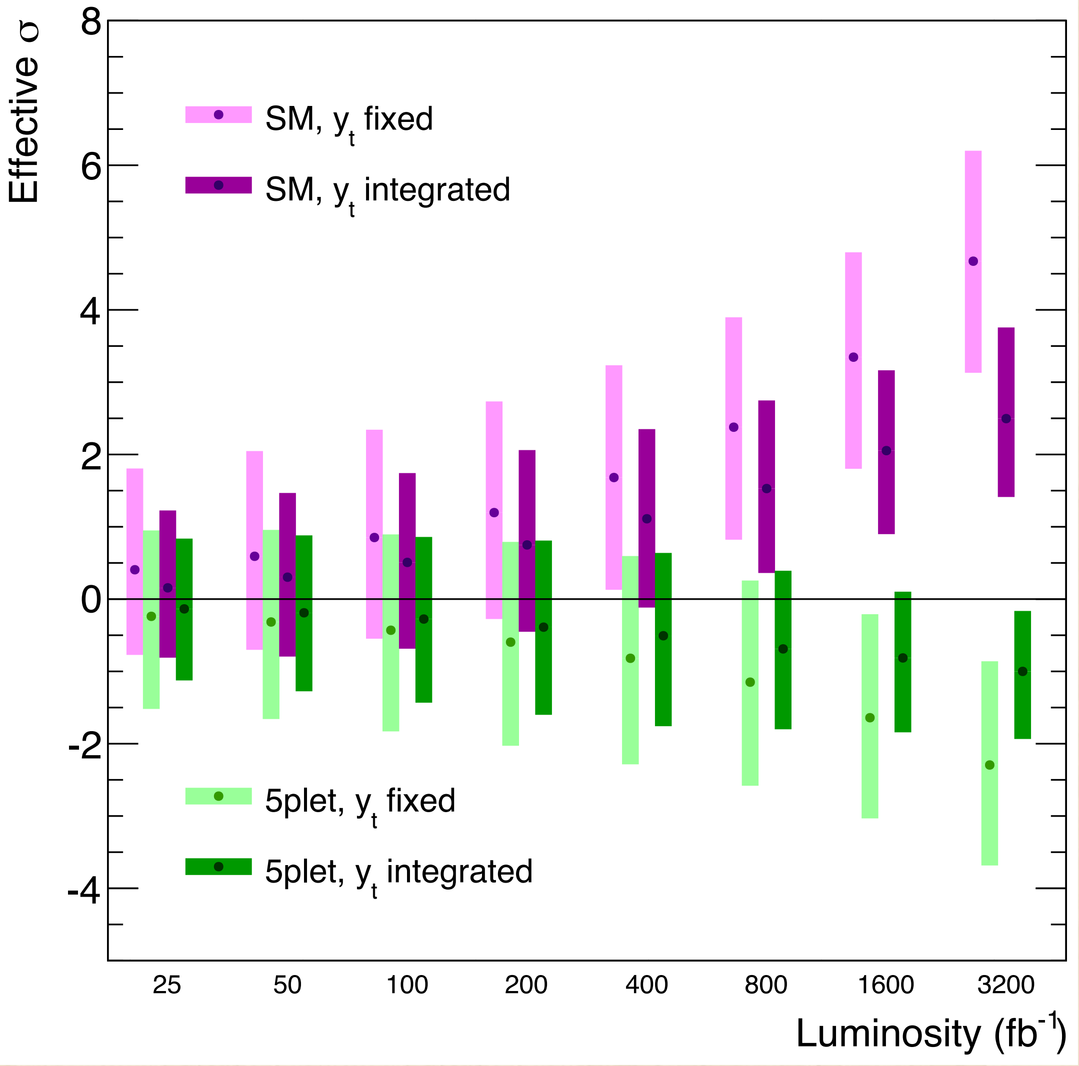
$\lambda_{WZ} = g_{WW} / g_{ZZ} = +1$ (SM), $-1/2$ (5plet)

We consider two cases: fixing top Yukawa coupling to the SM value, or integrate it out during the model comparison

Custodial Symmetry

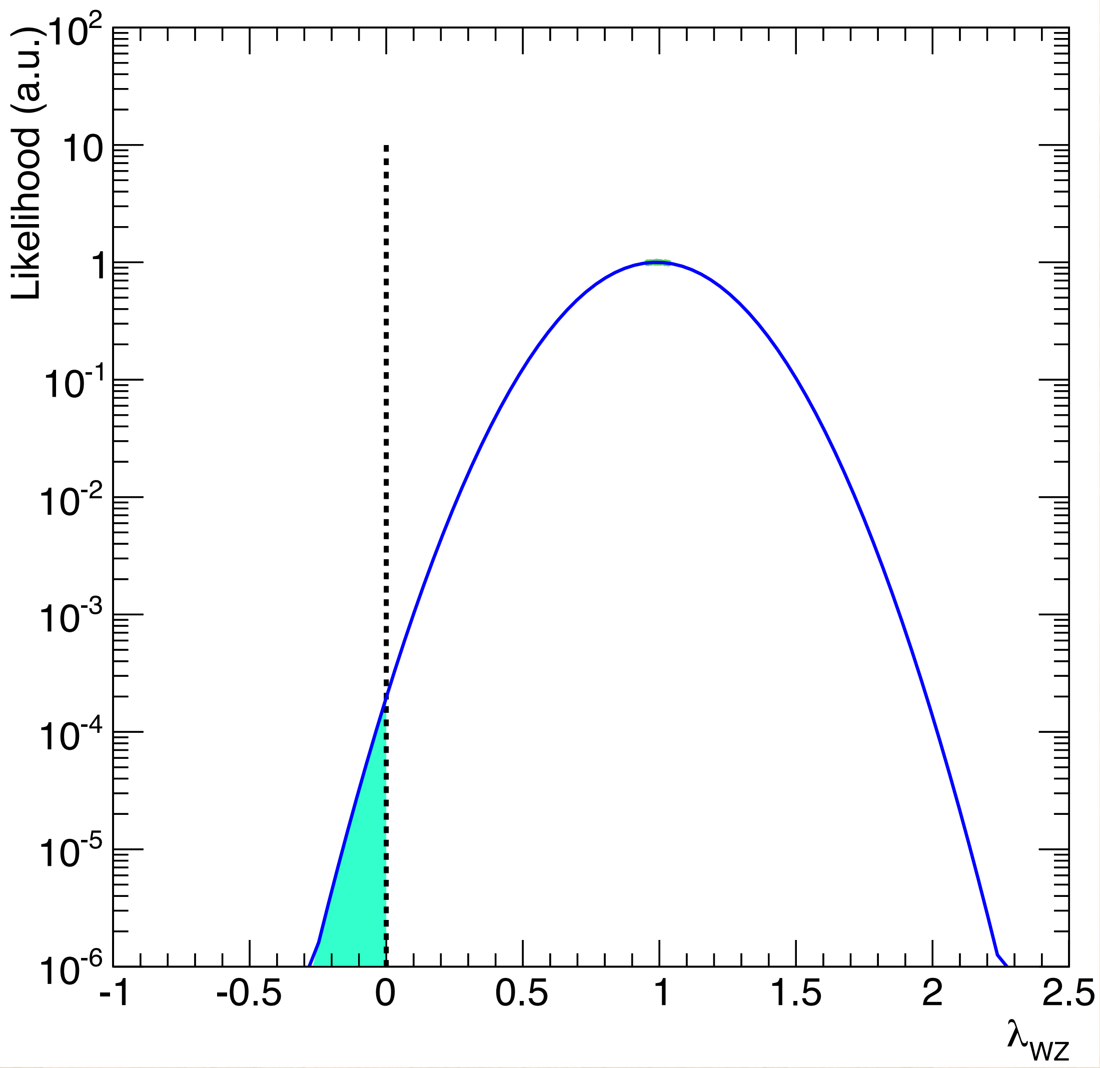
For each model, we generate pseudo-data and evaluate the likelihood of having a negative λ_{WZ}.

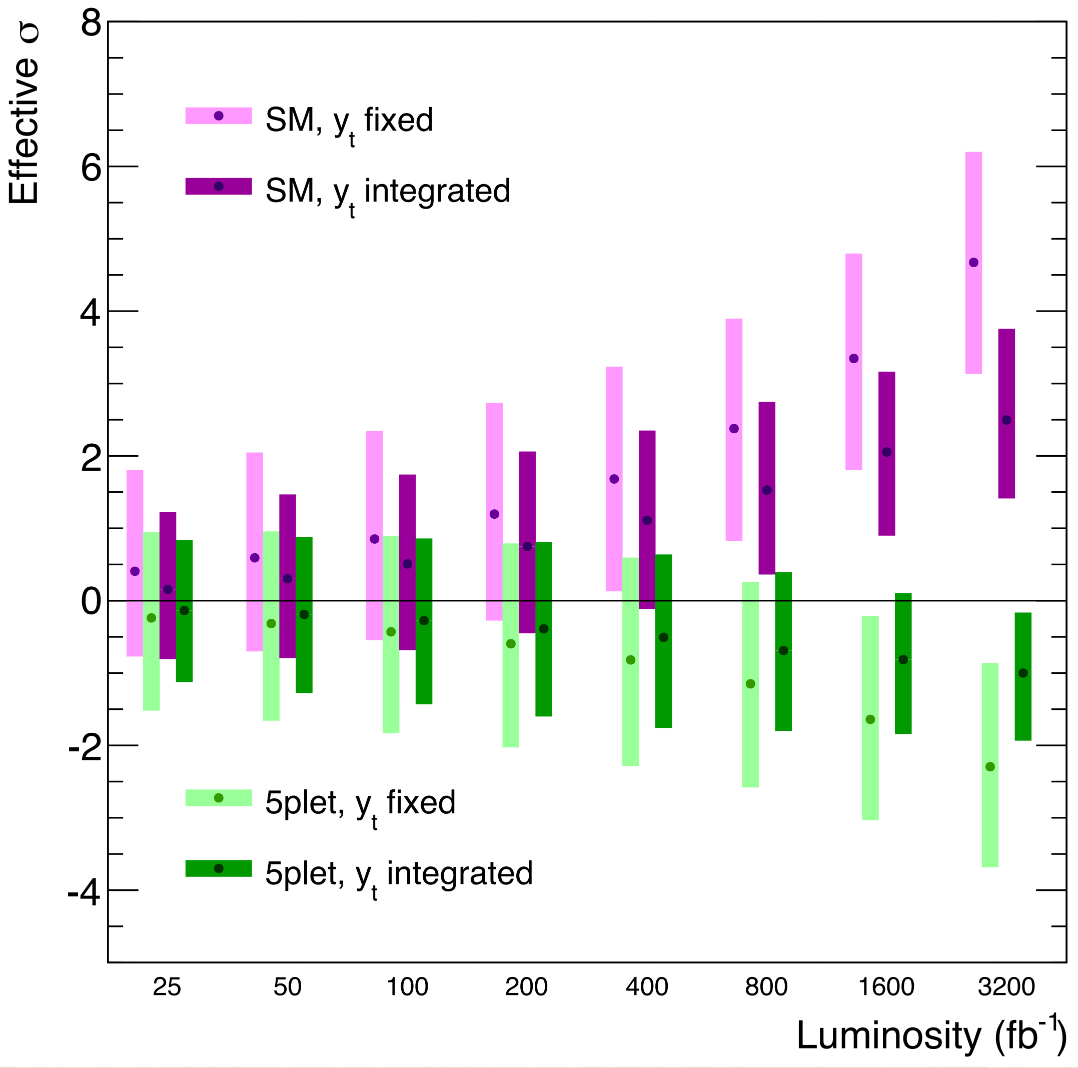




Custodial Symmetry

…and express the p-value in terms of effective sigma



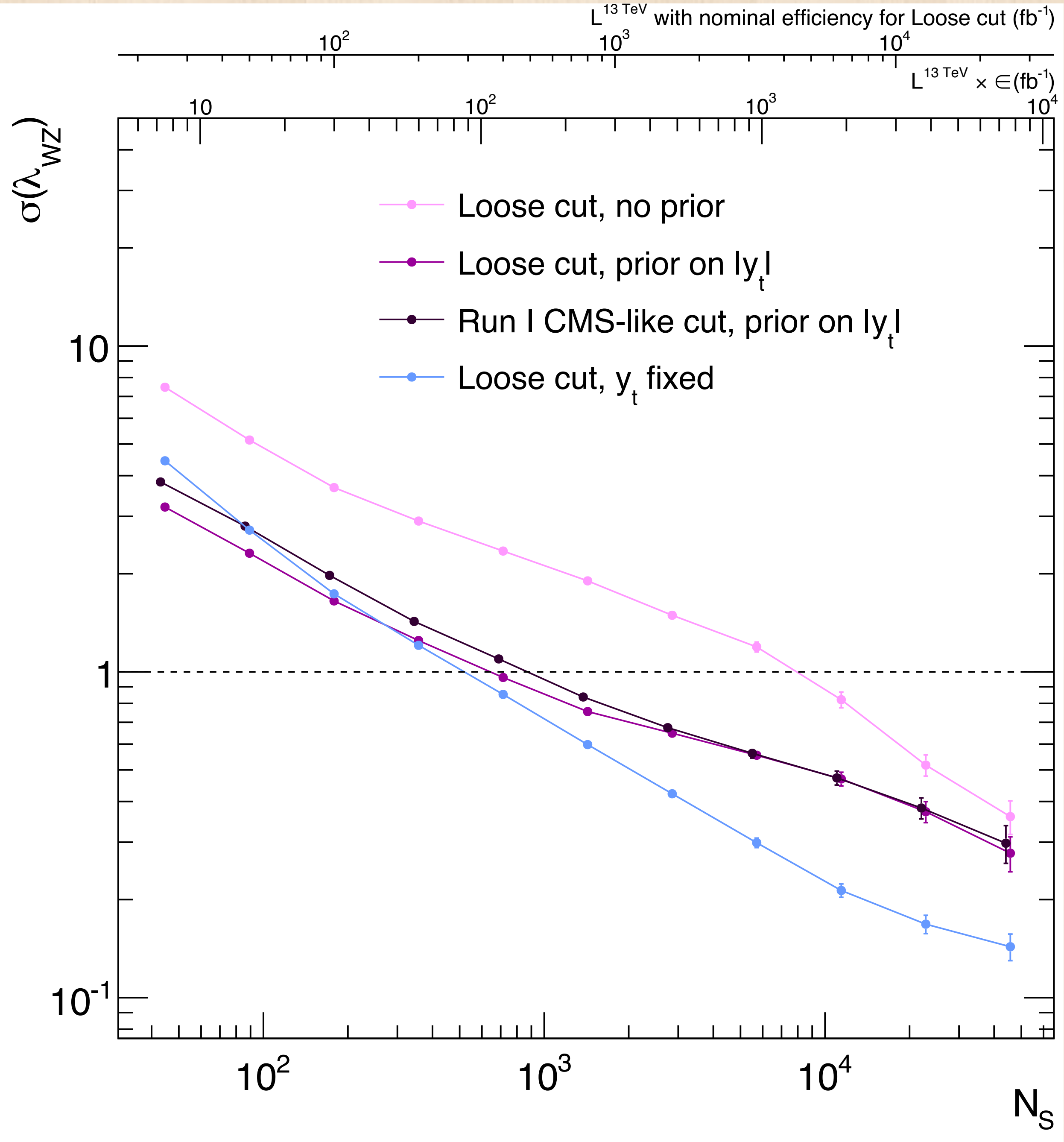


Custodial Symmetry

Assuming true model is SM, sensitivity on ratio between W and Z

Prior on y_t ~ restricting range between -3 – 3, free floating within 2

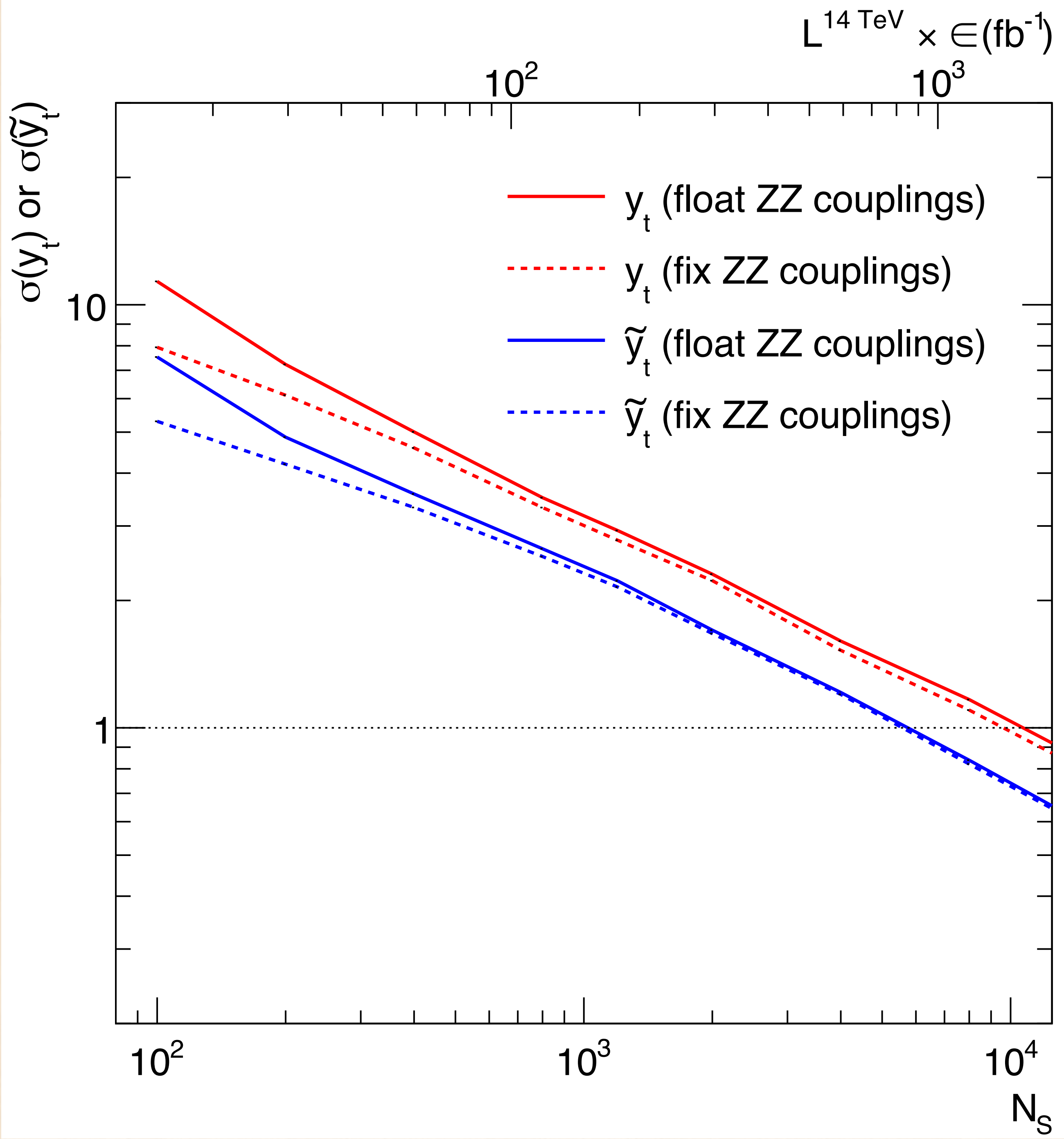
Restricting range on y_t helps the sensitivity a lot



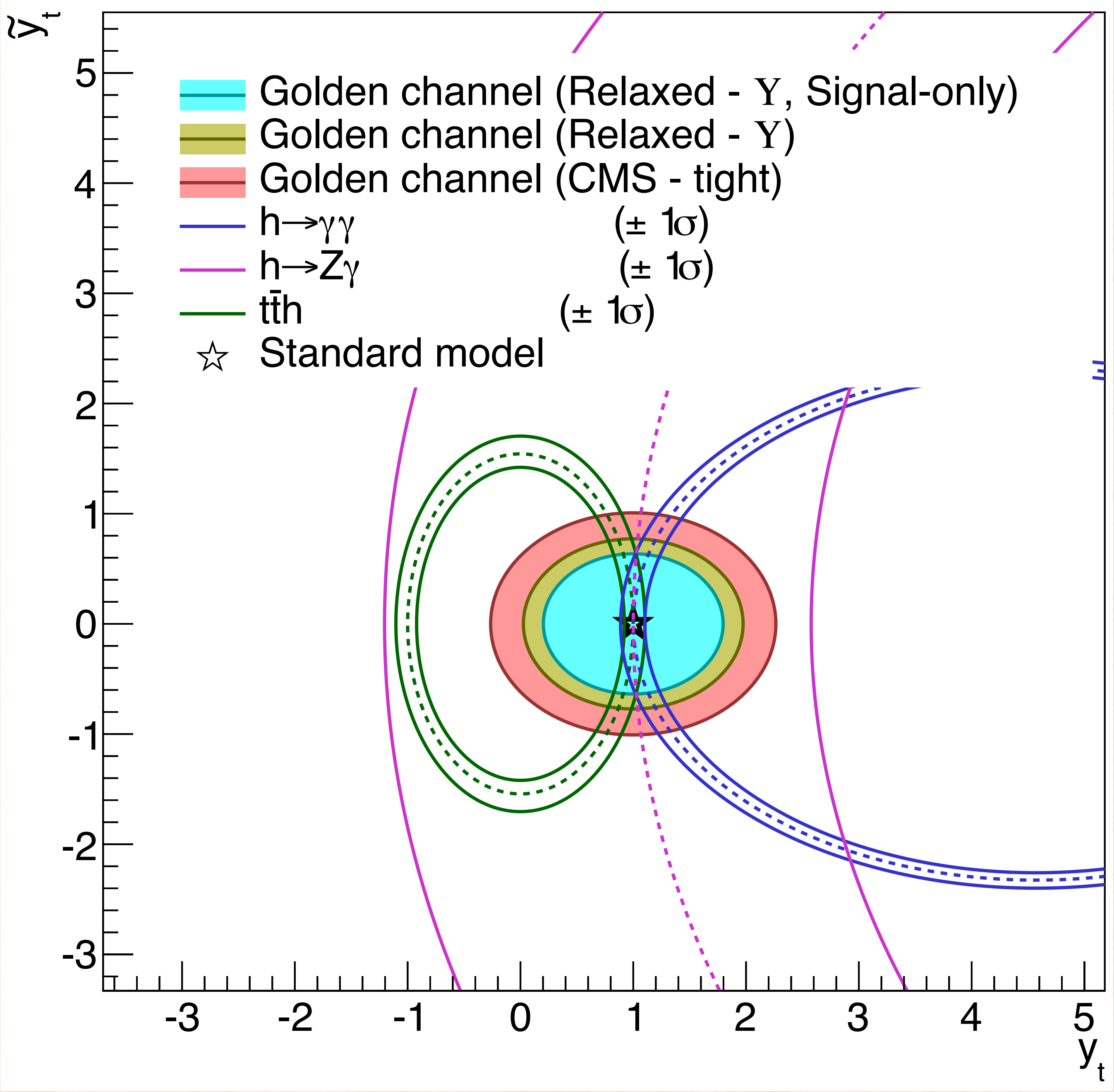
Top Coupling

Here we investigate sensitivity to y_t

We only reach 1 sigma with a few ab^{-1} assuming true model is SM



Top Coupling



Projection to end of HL-HLC

Direct measurement can pin down the value quite well

4l channel would be independent confirmation

Concluding Remarks

- The 4l channel provides a unique opportunity to measure the sign of couplings due to interference effects
- It complements direct cross section measurement from other channels

Backup Slides Ahead

y_t prior in λ_{WZ} analysis