Possible items for discussion on Higgs couplings and spin

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Theory uncertainties & couplings

- Impact of theory uncertainties was so far quite small for exclusions and discovery.
- Becoming visible now in some measurements (e.g. overall μ or μ_{ggH} from full combination),
  - **and will be very important at high luminosity!**
- Discussion ongoing in the LHC Higgs XS WG for an updated prescription, with a different confidence profile ("approximately flat up to $\pm 1\sigma$, plus tails")
  - Explored by ATLAS using double Fermi-Dirac pdf.
  - Outside the Gaussian limit, results also become sensitive to the choice of the statistical treatment of this uncertainty

Probing interference terms

- Processes where the SM yields are suppressed by destructive interference very interesting to probe for possible new physics.
- **H → γγ:** if the W-t interference were to be constructive, the yield would be 2.3*SM. **Disfavoured at 1σ & 2.7σ by ATLAS & CMS**
- **t H:** constructive interference would result in yields O(10*SM), perhaps potentially accessible already with the current data (SM rate is not) **No result from ATLAS & CMS yet on this.**

Probing BSM Higgs Decays

Complementary approaches by both ATLAS & CMS:

- Searches in specific topologies (e.g. H→invis.)
- Indirect limits on total width from coupling fits with some constraint to break the degeneracy from the overall scaling $\kappa \rightarrow x\,\kappa$, $\Gamma_{tot} \rightarrow x^2\,\Gamma_{tot}$
  - SM-like tree-level couplings (at least to W/Z)
  - $\kappa_V \leq 1$ (true for a large class of EWSB models)
- A combination of the two approaches possible in the context of some scenarios (e.g. when H→invis is the only BSM decay mode), but not yet done.

EFT approach to coupling fits

Current coupling fits very phenomenological:

- The coupling modifiers “κ_x” are not parameters of any plausible BSM theory
  - Can be used only to compare with SM (κ=1) or with the expected κ_x for a given BSM theory (e.g. MSSM)
  - Hard to combine e.g. with EW precision data
- A more well-sounded approach being defined: instead of deviations, measure the coefficients of operators in an Effective Field Theory (universal limit for any BSM theory with no other light particles)
  - Gives a physics meaning also to $\kappa \neq 1$ values
  - Challenge: get accurate predictions in such a theory.

Double-ratios

- The double ratio of production modes and decay modes can be used to evaluate the consistency of the data with the hypothesis of a single boson.

$$R^{XX/YY}_{VBF/ggH} = \frac{[\mu_{VBF} / \mu_{ggH}]_{H\text{->}XX}}{[\mu_{VBF} / \mu_{ggH}]_{H\text{->}YY}}$$

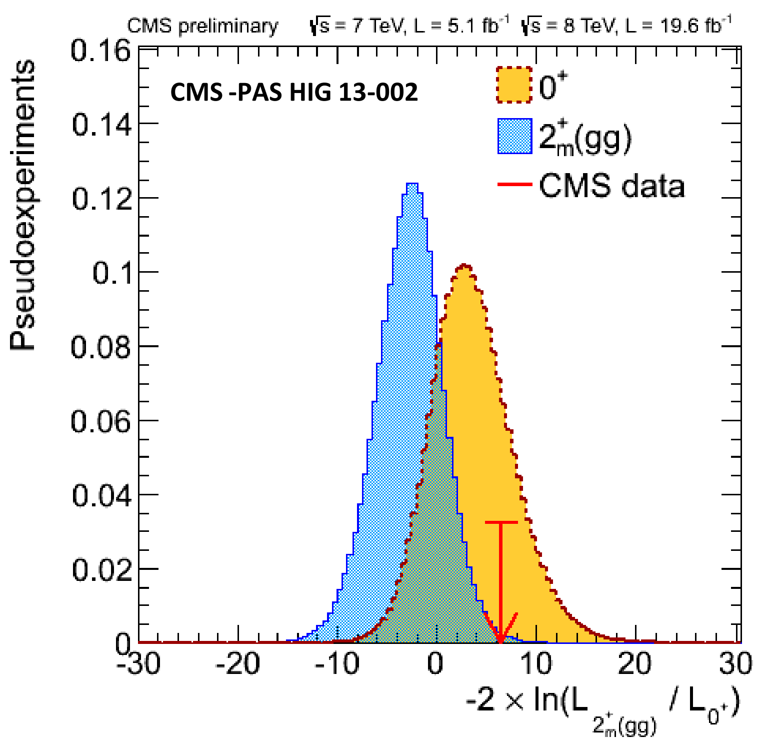
- Potentially more interesting at higher luminosity, where more exclusive modes will be accessible, and with higher precision.

Prospective for spin and parity measurements of the Higgs

- Two approaches to study the J^P of the Higgs
  - Hypothesis testing with spin >0
    - Effort already started from the Higgs discovery
    - Set of models already studied/excluded
      - Actually probed HZZ,HWW,H$\gamma\gamma$ vertices
    - Identify additional theoretical motivated benchmark models
    - model independent approach?
    - With high integrated luminosity: VBF topologies, H$\tau\tau$
  - CP-violation in the Higgs sector (spin0)
    - f_{a3} measurement (adding f_{a2}?)
    - fitting individual constants or ratios within specific model

Pure Hypothesis testing: projection

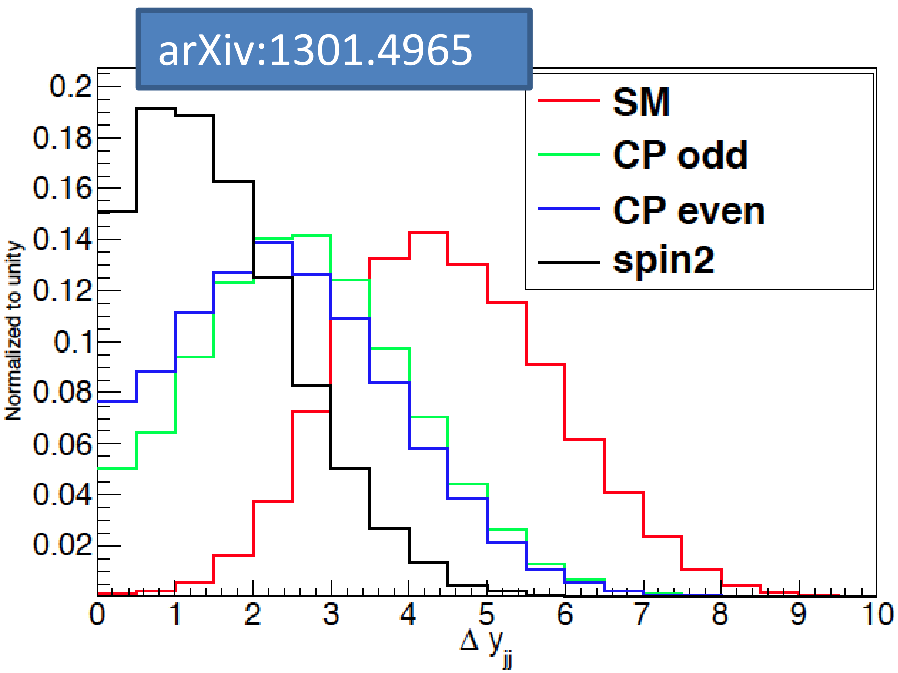
- Exclusion of benchmark models at >5σ level possible in single channels with 100/fb



- E.g. spin 2^+_m exclusion with HZZ alone
  - CMS expected exclusion of 1.9σ scales to ~6σ with 100/fb
  - ATLAS expected exclusion of 1.5σ scales to ~5σ with 100/fb

Spin and parity in VBF topologies

- Kinematics of the tagging jets in Higgs VBF production to test the tensor structure of the Higgs-vector boson HVV interaction
  - spin and CP properties



- Anomalous HVV vertex, affects the rapidity between the two scattered quarks and their transverse momenta
  - Changes in the acceptance of VBF topology

CP mixing - projections

- Limits on f_{a3} parameter (CMS):
  - Actual expected limits: $f_{a3} > 0.78$ excluded at 2σ level
  - 100/fb projection: $f_{a3} > 0.23$ excluded at 2σ level
- ATLAS extrapolations (ATL-PHYS-PUB-2012-004)

Integrated Luminosity	Signal (S) and Background (B)	a_3 values: $6+6i$ (f_{a3}>0.63)	$6i$ (f_{a3}>0.46)	$4+4i$ (f_{a3}>0.43)
100 fb^{-1}	$S = 158; B = 110$	3.0σ	2.4σ	2.2σ
200 fb^{-1}	$S = 316; B = 220$	4.2σ	3.3σ	3.1σ
300 fb^{-1}	$S = 474; B = 330$	5.2σ	4.1σ	3.8σ

  - Expected 2σ exclusion of $f_{a3} > 0.3 - 0.4$
- Consider additional channels with lower sensitivity?
  - e.g. HWW

Generators for CP-violation studies

$$A(X \to VV) \sim (\underbrace{a_1 M_X^2 g_{\mu\nu} + a_2 (q_1+q_2)_\mu (q_1+q_2)_\nu}_{\text{CP-even}} + \underbrace{a_3 \varepsilon_{\mu\nu\alpha\beta} q_1^\alpha q_2^\beta}_{\text{CP-odd}}) \varepsilon_1^{*\mu} \varepsilon_2^{*\nu}$$

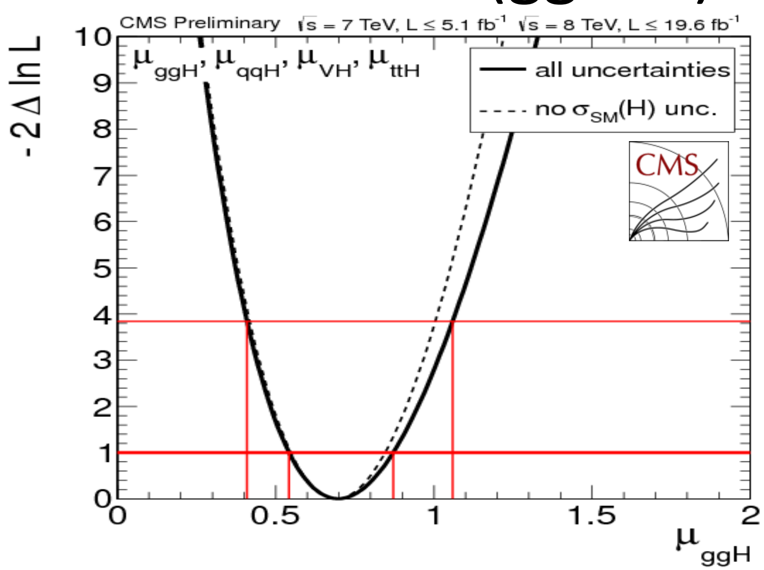
- JHU (LO generator):
  - a1,a2,a3 can be varied independently
- MG5+aMC@NLO:
  - NLO prediction, 1 mixing angle (a1 and a3 considered)

Extra-material

Theory uncertainties & couplings

CMS fit for μ_{ggH}

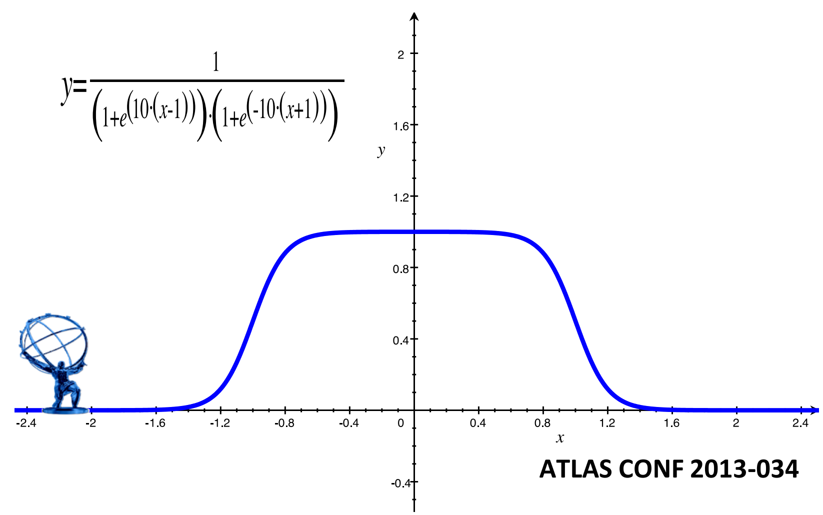
- Split out contribution of the overall uncertainty on inclusive σ(gg→H)



$$\mu_{ggH} = 0.69 \begin{smallmatrix}+0.15 & +0.09 \\ -0.14 & -0.05\end{smallmatrix}$$

ATLAS compatibility p-value for μ=1 hypothesis:

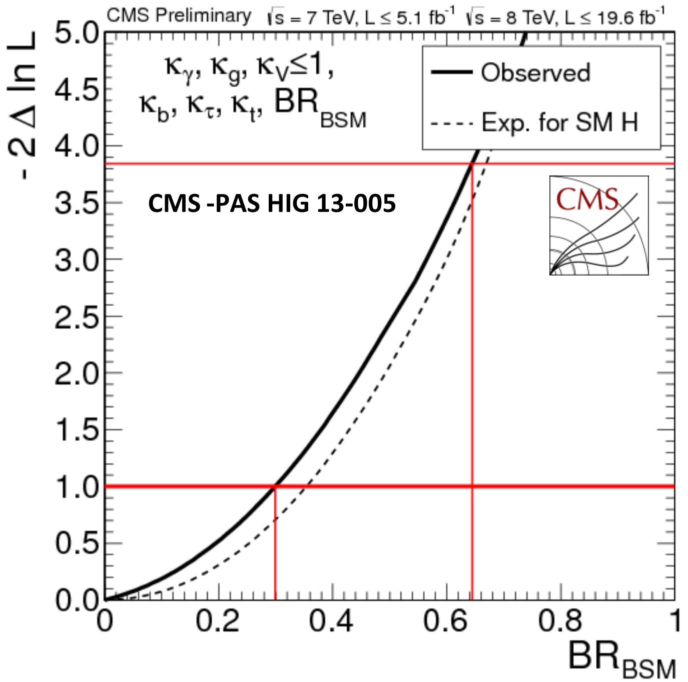
- 9% when using a log-normal pdfs for THU
- 40% when using a double-Fermi Dirac pdf.



ATLAS CONF 2013-034

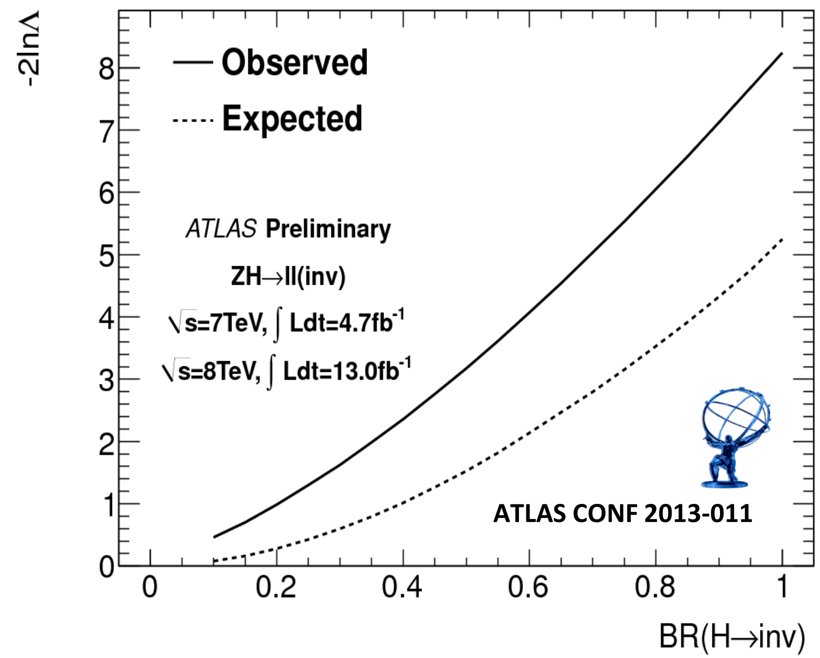
Probing BSM Higgs Decays

CMS: indirect limit on BR_{BSM}



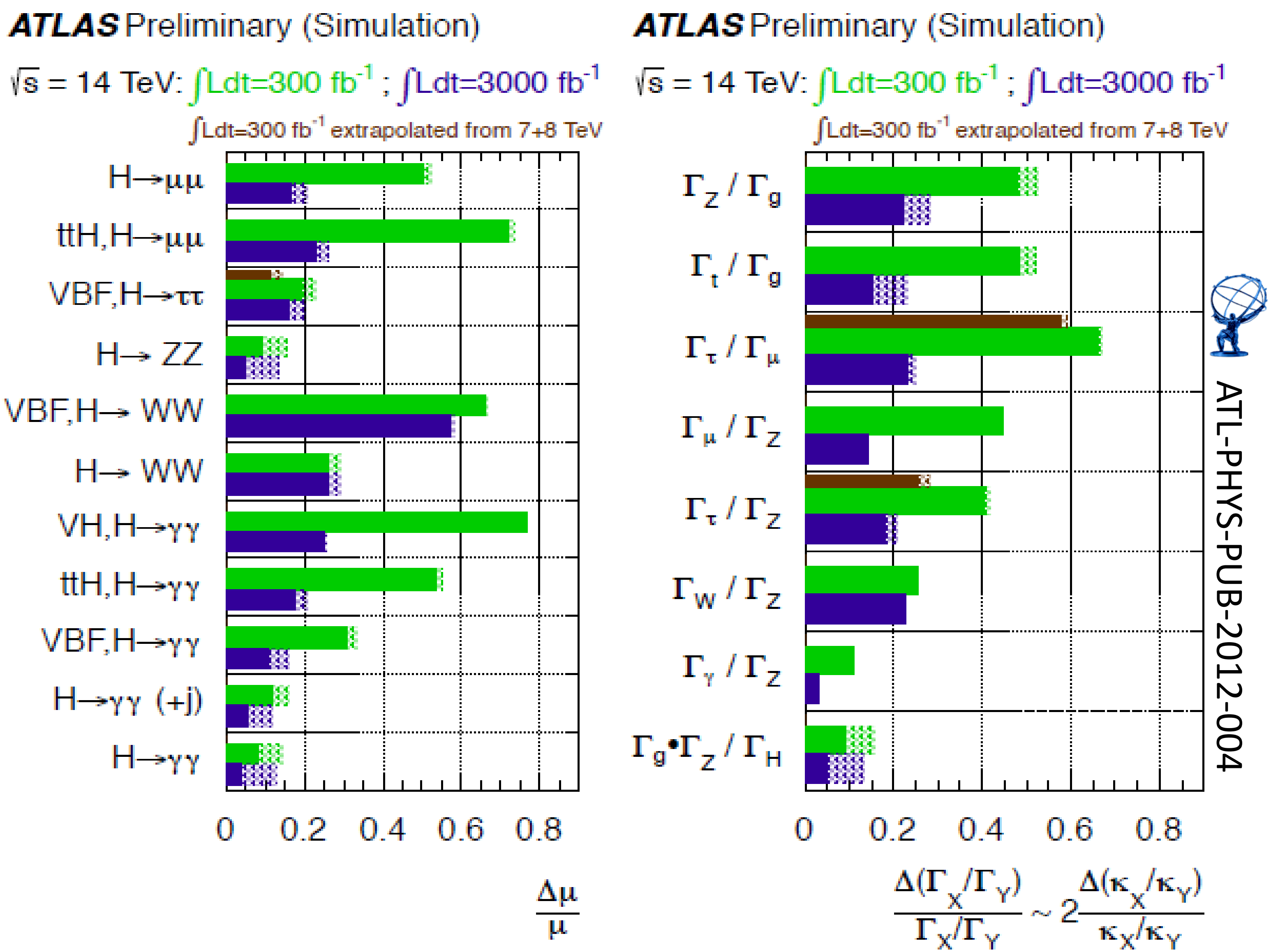
(Similar ATLAS & CMS results also fixing tree-level κ's to 1)

ATLAS: direct search for BR_{Invis}



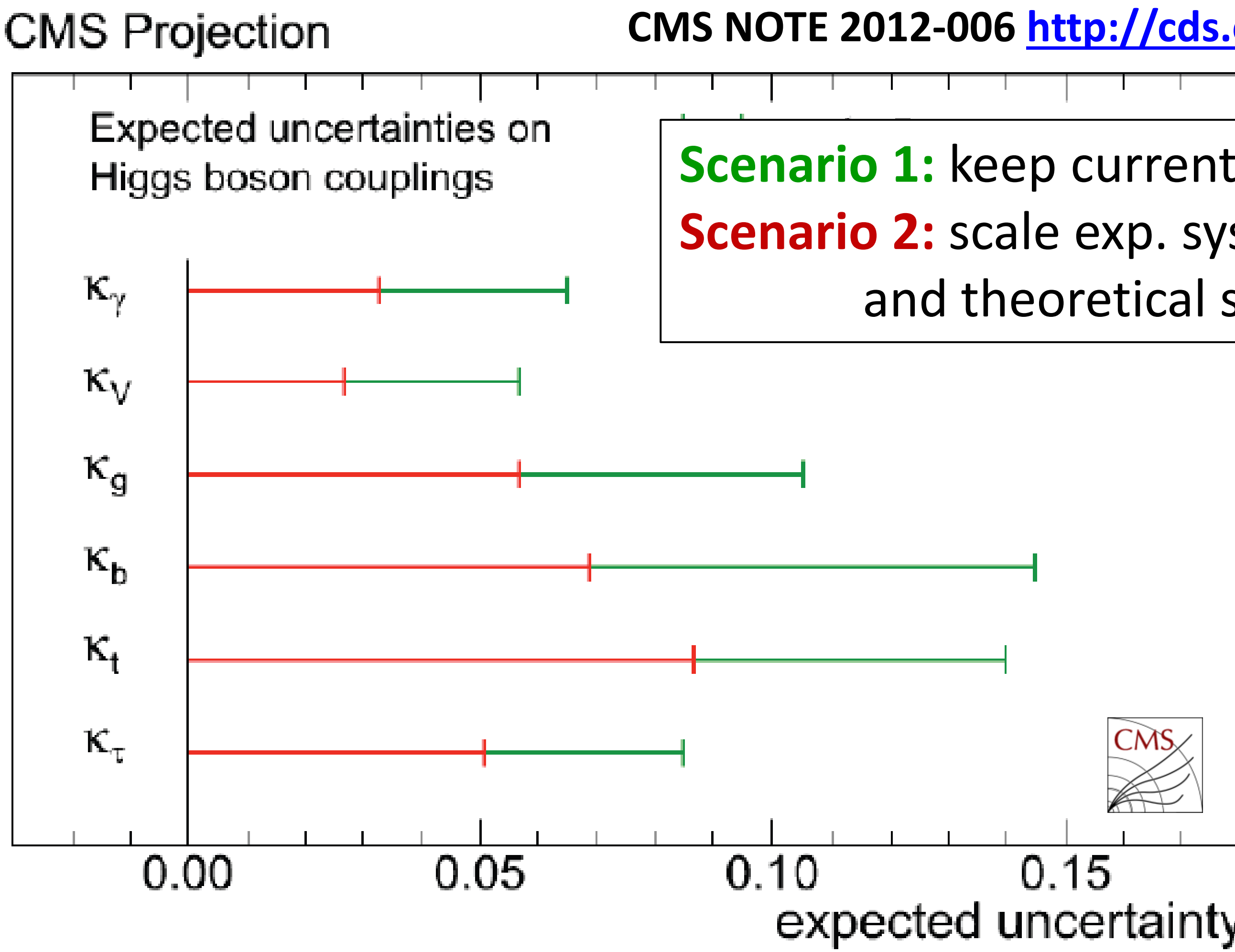
(Being explored at CMS too, stay tuned for new results)

Projections on couplings (300 fb^{-1})



Projections on couplings (300 fb)

CMS NOTE 2012-006 http://cds.cern.ch/record/1494600



Scenario 1: keep current systematics

Scenario 2: scale exp. systematics by 1/√L and theoretical systematics by 1/2

Projections on couplings (300 fb)

Table 1: Ultimate achievable precision on the measurements of κ_γ, κ_V, κ_g, κ_b, κ_t, and κ_τ. These values are obtained at $\sqrt{s} = 14$ TeV using an integrated dataset of 300 and 3000 fb^{-1}. The results are shown for two uncertainty scenarios. In the first one (Scenario 1) all systematic uncertainties are kept unchanged. In the second one (Scenario 2) the theoretical uncertainties are scaled by a factor of 1/2, while other systematical uncertainties are scaled by the square root of the integrated luminosity.

Coupling	Uncertainty (%)			
	300 fb^{-1}		3000 fb^{-1}	
	Scenario 1	Scenario 2	Scenario 1	Scenario 2
κ_γ	6.5	5.1	5.4	1.5
κ_V	5.7	2.7	4.5	1.0
κ_g	11	5.7	7.5	2.7
κ_b	15	6.9	11	2.7
κ_t	14	8.7	8.0	3.9
κ_τ	8.5	5.1	5.4	2.0

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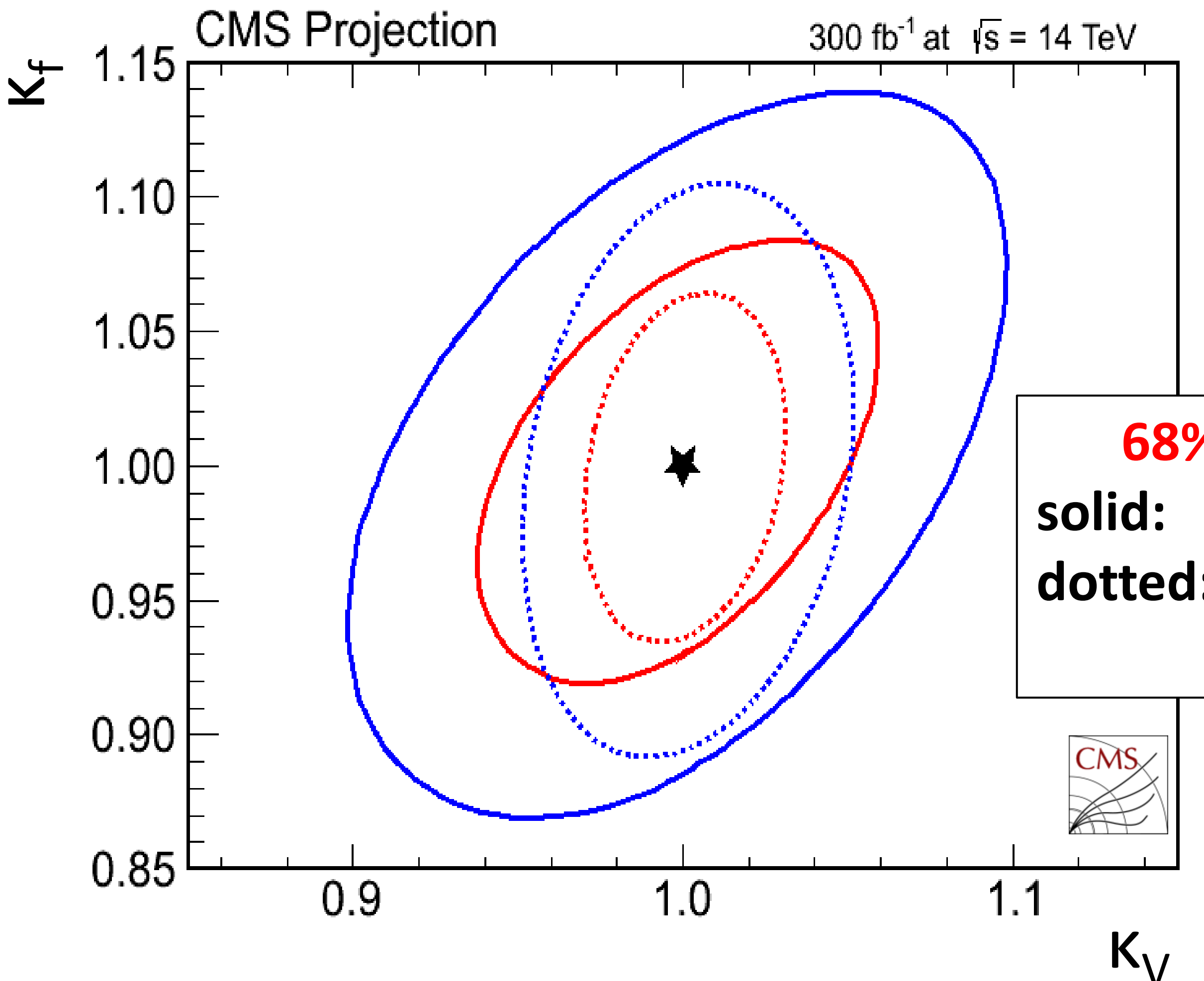
Projections on couplings (300 fb)



68% and **95%** CL contours

solid: current systematics

dotted: no theory systematics, exp. syst scaled as $1/\sqrt{L}$

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