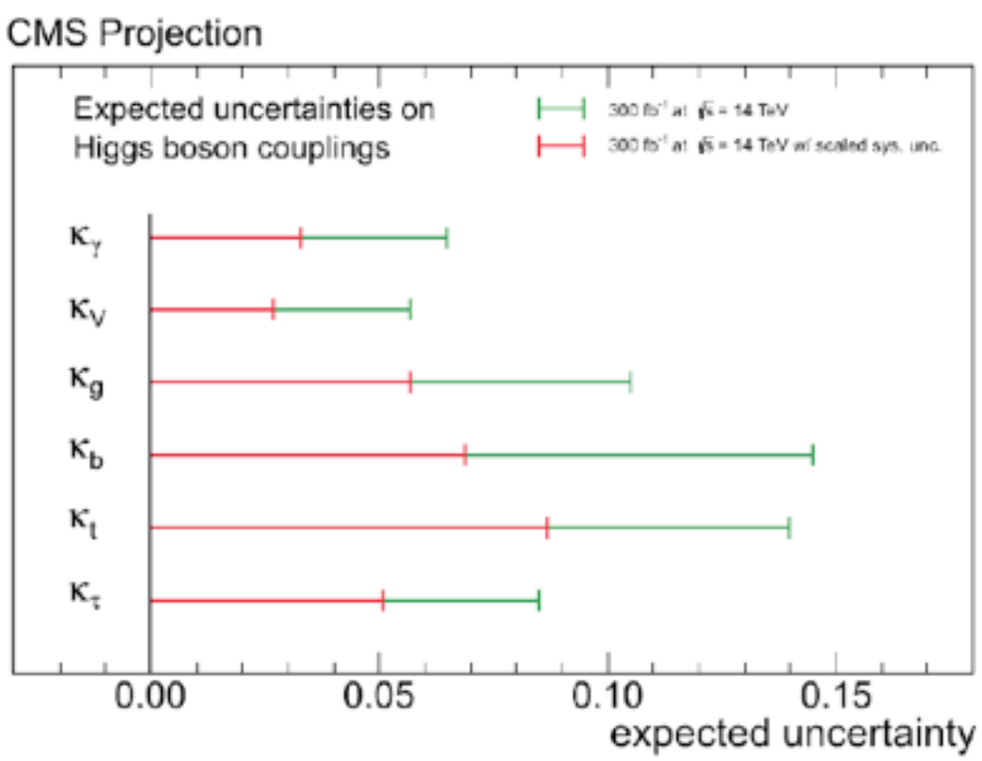
CMS sensitivity of Higgs coupling: projections for LHC and HL-LHC

Michele de Gruttola (U of Florida)

on behalf of CMS collaboration

Introduction

- Goal is to update the Higgs coupling projections for the completion of LHC(300 fb^{-1}) and HL-LHC(3000 fb^{-1}) presented first time at European Strategy for Particle Physics
  - http://cds.cern.ch/record/1494600/files/NOTE2012_006.pdf



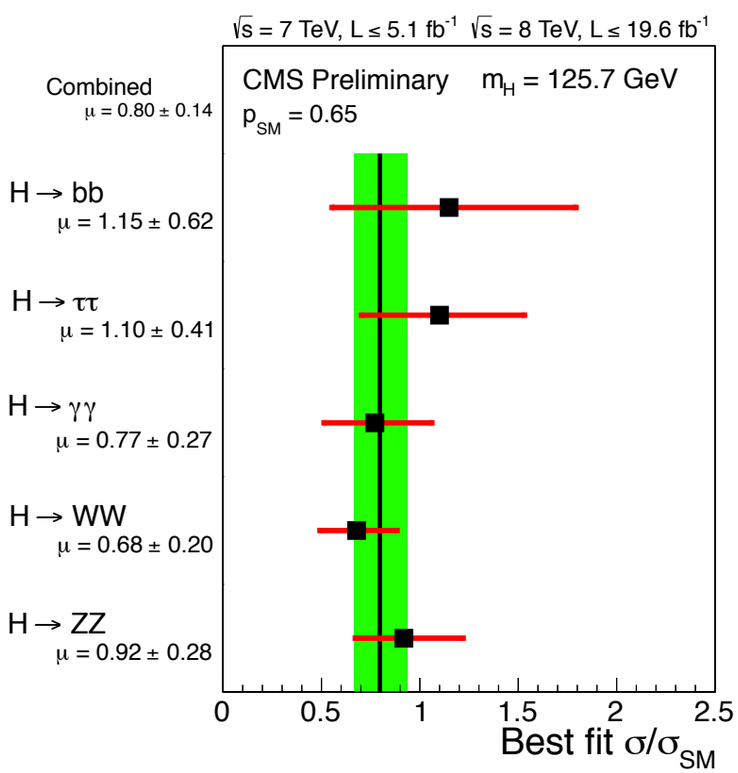
Coupling	Uncertainty (%)			
	300 fb^{-1}		3000 fb^{-1}	
	Scenario 1	Scenario 2	Scenario 1	Scenario 2
κ_γ	6.5	5.1	5.4	1.5
κ_V	5.7	2.7	4.5	1.0
κ_g	11	5.7	7.5	2.7
κ_b	15	6.9	11	2.7
κ_t	14	8.7	8.0	3.9
κ_τ	8.5	5.1	5.4	2.0

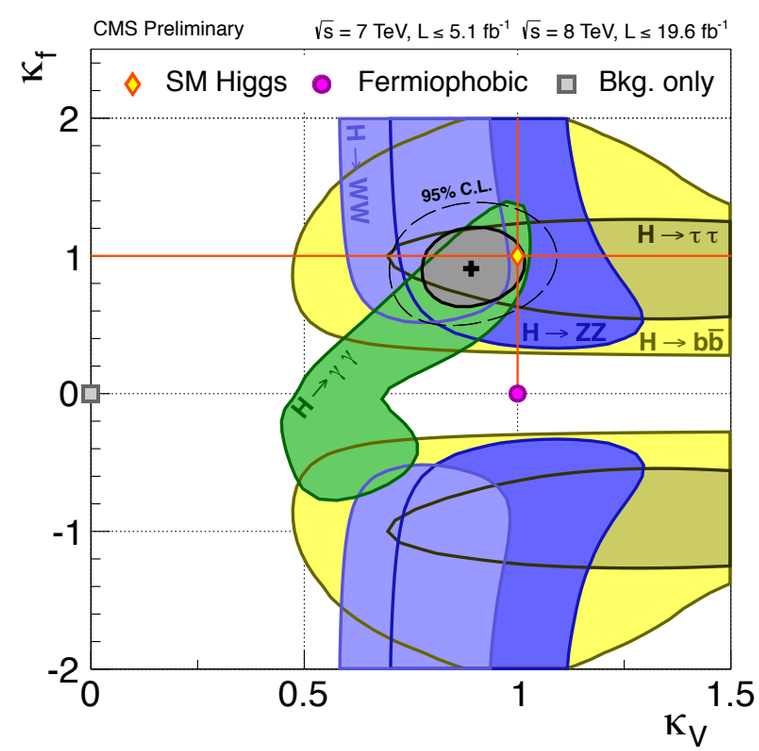
- we'll show here preliminary update on couplings for the so called scenario 1 and 2
- more to come for Minneapolis and white paper submission

Present

	Significance (m_H = 125.7 GeV)		
Combination	**Expected (pre-fit)**	**Expected (post-fit)**	**Observed**
H→ZZ	7.1 σ	7.1 σ	6.7 σ
H→γγ	4.2 σ	3.9 σ	3.2 σ
H→WW	5.6 σ	5.3 σ	3.9 σ
H→bb	2.1 σ	2.2 σ	2.0 σ
H→ττ	2.7 σ	2.6 σ	2.8 σ
H→ττ and H→bb	3.5 σ	3.4 σ	3.4 σ

>3 σ evidence for fermions decay





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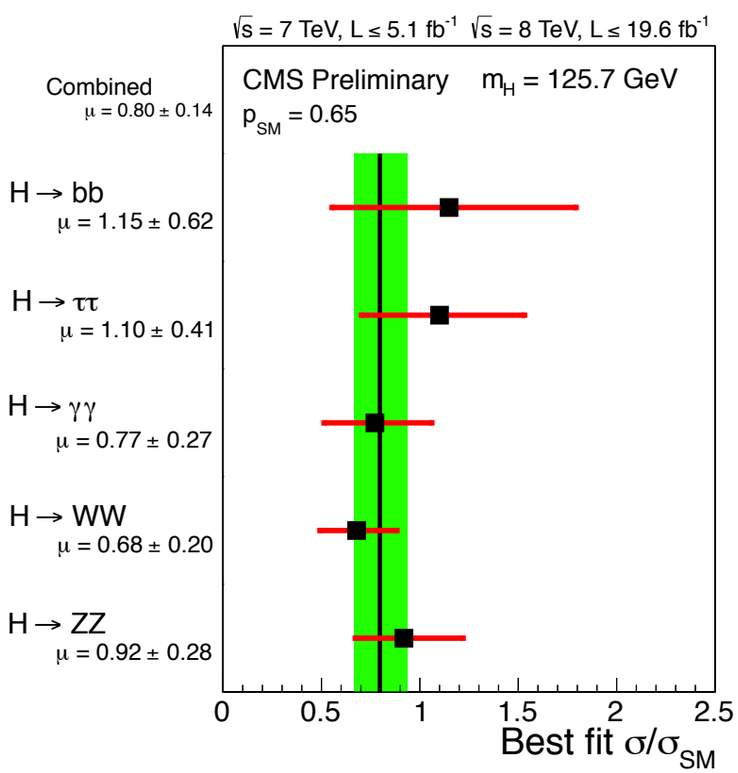
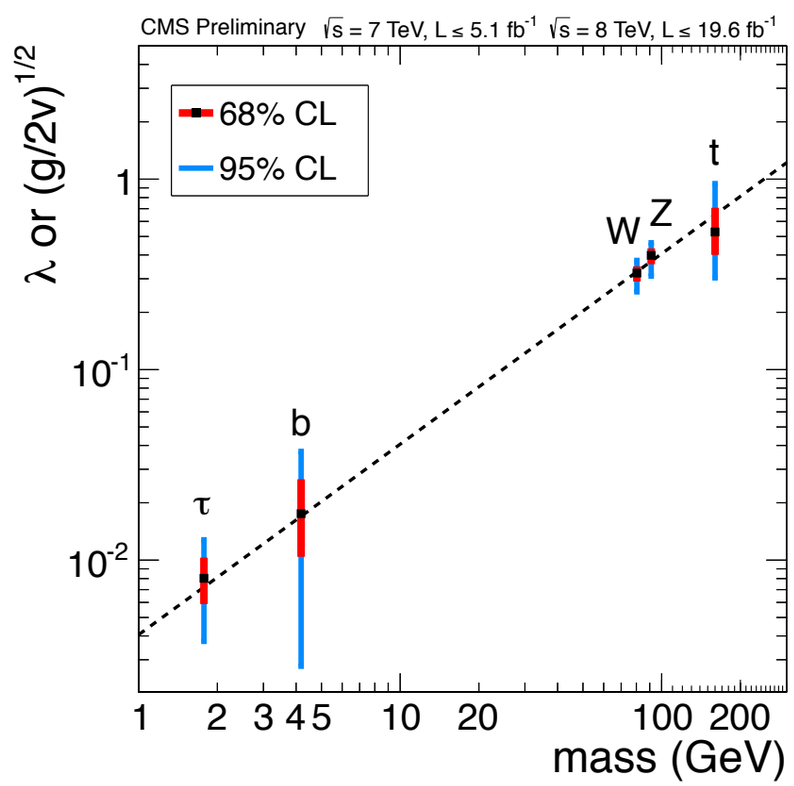




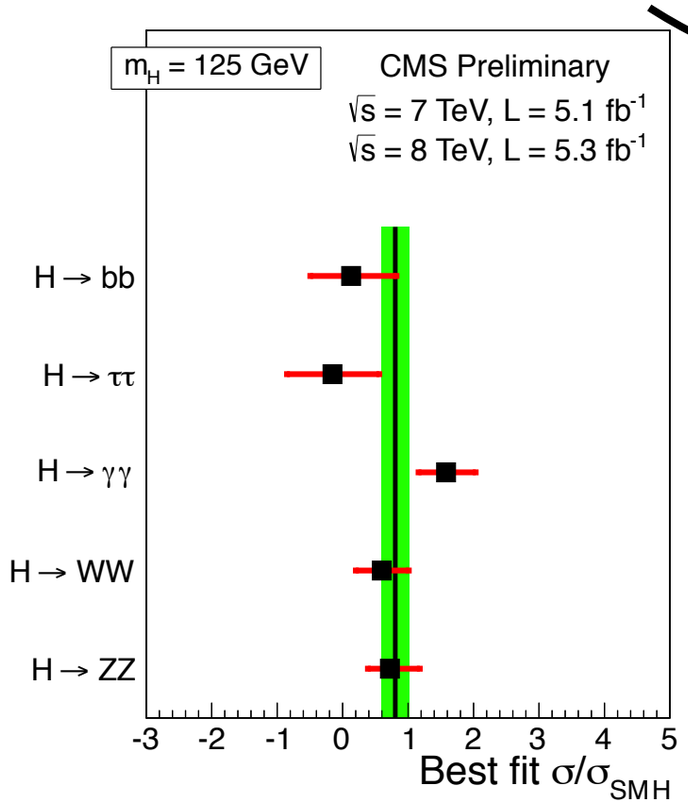
Inputs compared to previous projections

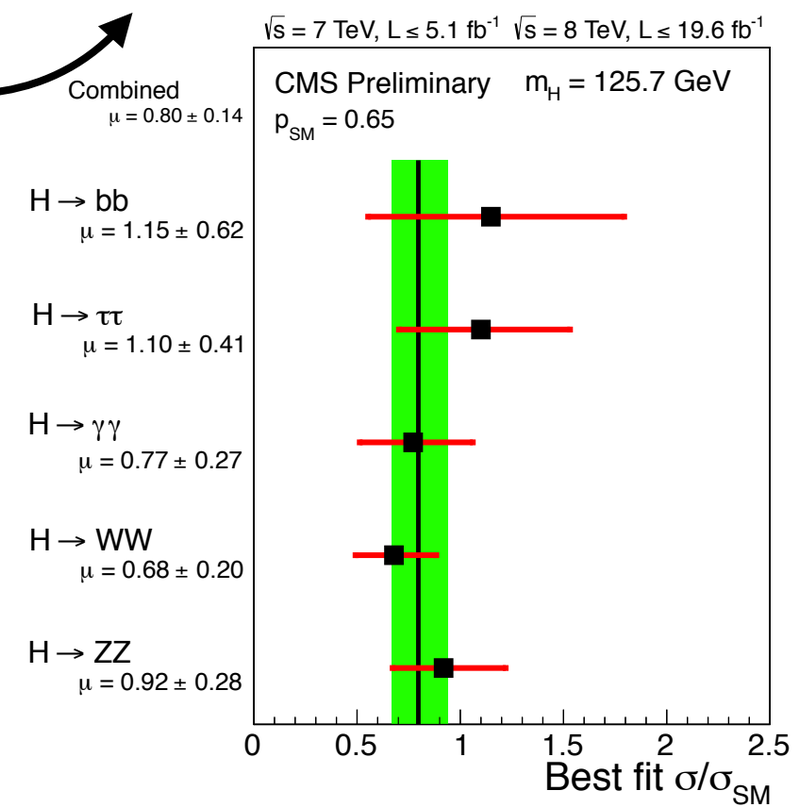
- CMS has made significant progress from the Higgs discovery phase

ichep12: 4th July revolution (inputs for ESPG)

One year later, preliminary results on all 2012 stat (input for this)

0.80 ± 0.22 → 0.80 ± 0.14





- it looks even more like a Higgs boson!
- more important here: the uncertainty scale amazingly according to the expectation
  - some changes in the sub-channels in the interplay of syst and theory uncertainty

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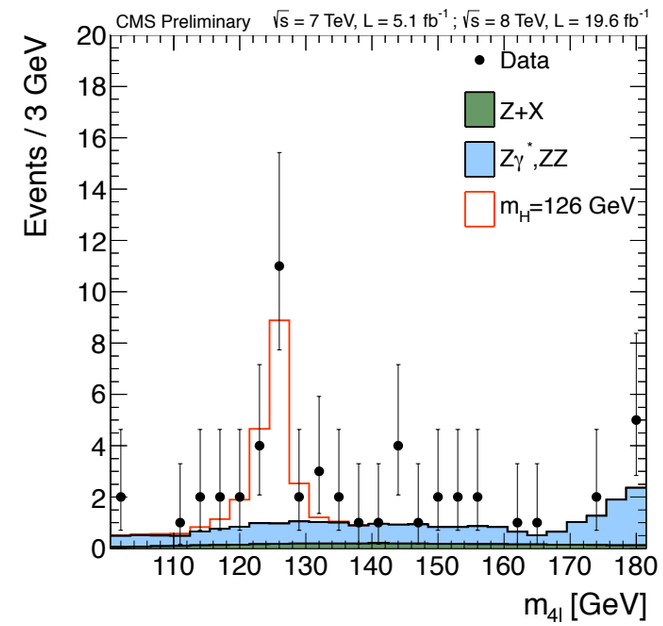
HZZ,Hγγ

- H->4l channels already at iCHEP12 had a very sophisticated analysis

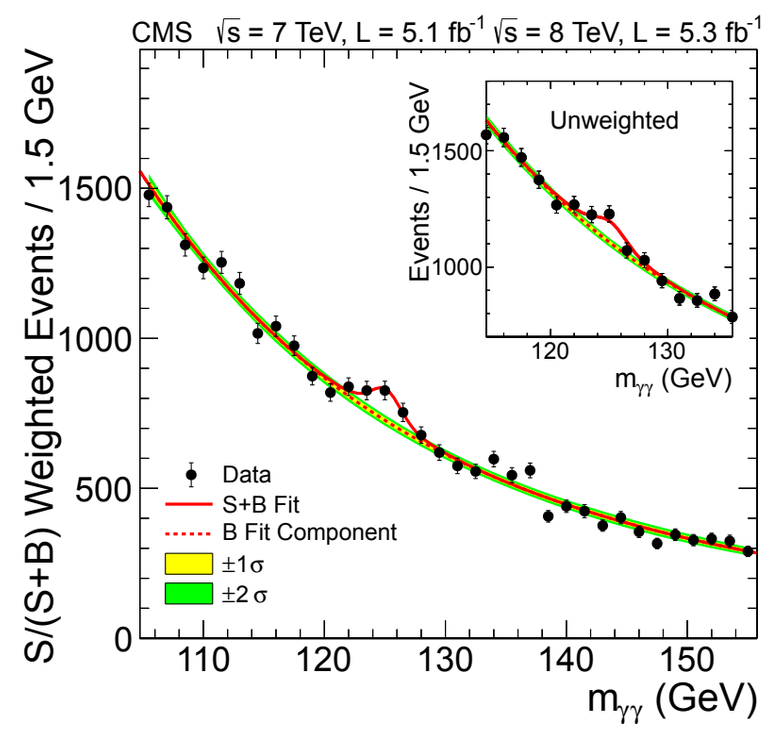
HIG-13-002

  - added VH and VBF category
  - added JPC study.... not the content on this talk



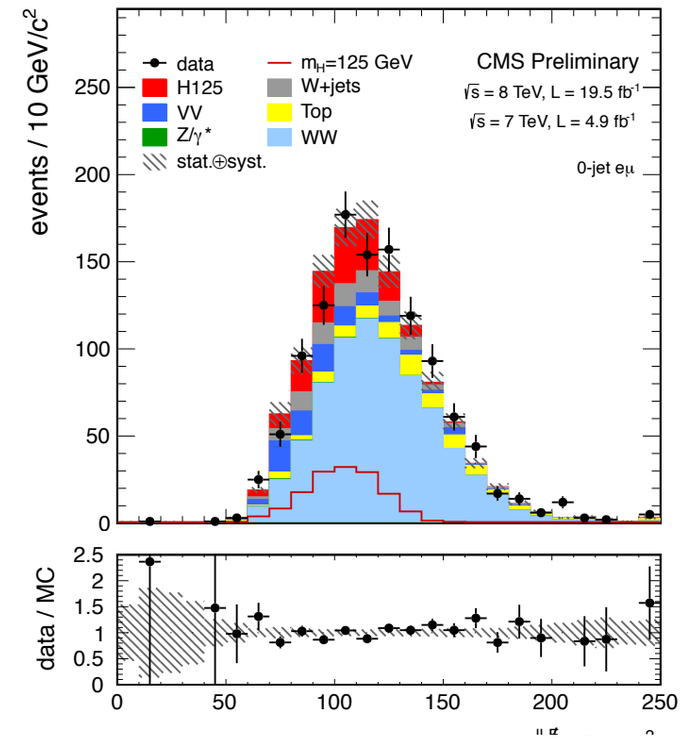
- H->2γ
  - Analysis consolidated since last year
    - added VH, ttH topology!

HIG-13-001



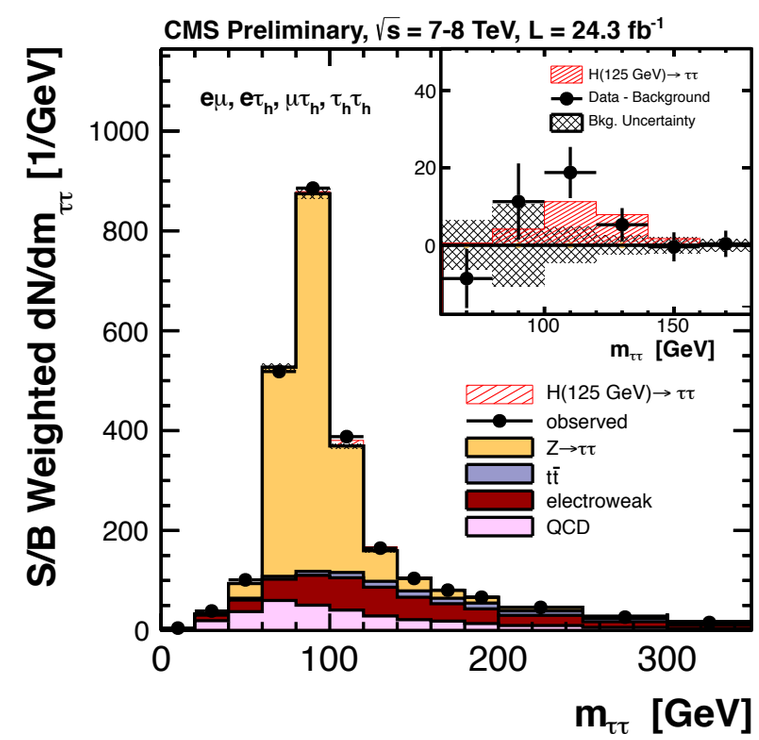
HWW,Hττ

- HWW: analysis managed to improve slightly
  - 2l2v: from MVA + CC (m_{ll}) to 2D-fit (m_{ll}, m_T)
    - observation also in WW now! HIG-13-003
  - 2l2q, 3l3v, include WH and VBF



- Hττ: analysis strategy unchanged
  - further optimization, improved MET resulting in improved analysis

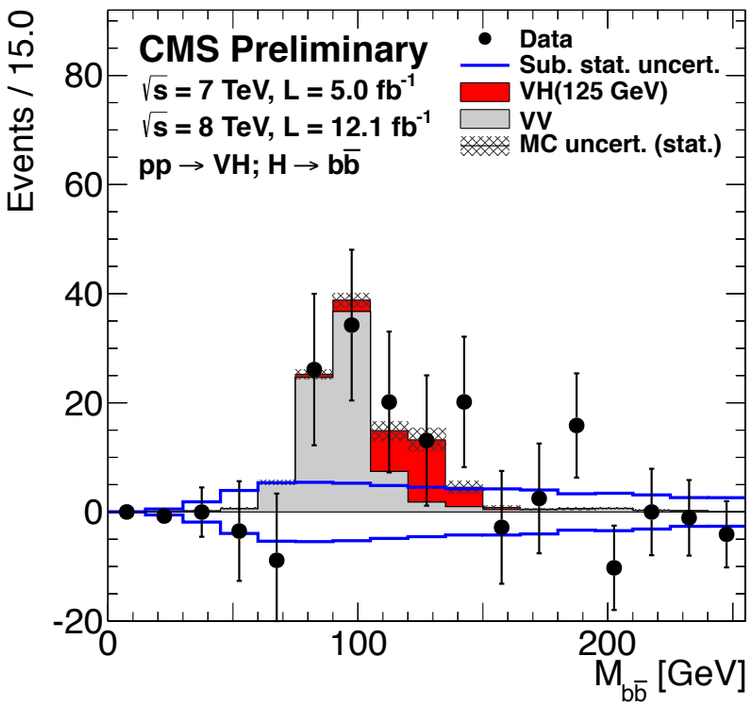
    HIG-13-004
    - add VH
    - strong indication here!



H->bb, ttH

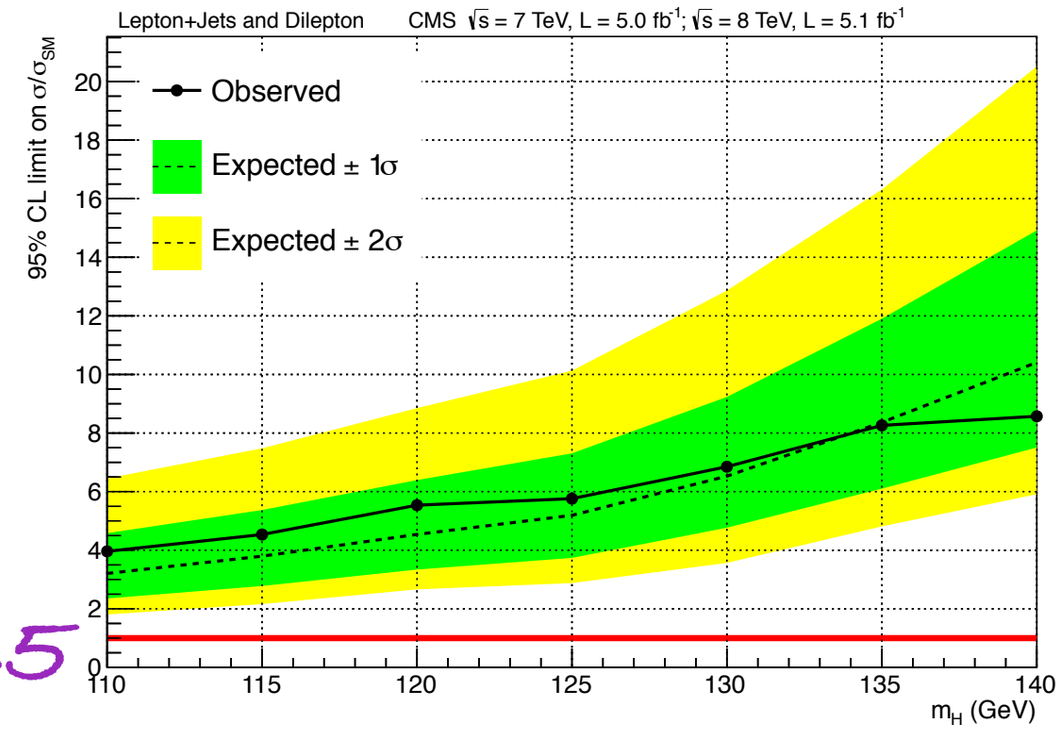
- H->bb:
  - VHbb: strategy not changed (boost)
  - reduction of bkg systematics
  - new boost theory corrections with ~10% uncertainty
    - http://arxiv.org/pdf/1112.5142v1.pdf

HIG-13-012



- ttH:
  - ttHbb: new results includes full systematics treatment
    - fully MVA, more conservative uncertainties resulting in lower sensitivity
    - S/B worse at 8TeV due to ttbar increasing more than signal
  - ttHgg: new addendum in CMS, less sensitivity wrt bb

HIG-12-035



Scenarios

- Signal and background are scaled to 14 TeV and to L=300(3000)fb^{-1}
- We "assume" CMS triggers and reconstructs with same efficiency/thresholds
  - CMS L1 TDR: https://cds.cern.ch/record/1556311
- Use the most recent CMS results (more information wrt to ESPG)
  - scenario 1:
    - do not touch the experimental and theory uncertainties

  - scenario 2:
    - scale experimental systematics uncertainties byt 1/sqrt(L)
    - reduce by 50% the theoretical uncertainty

The goal for CMS is to do something close to scenario 2 with the future upgrades!

Maquillage

current Phase1 Phase2

- See J.Olsen talk for details on how CMS will look better in the future

Physics model

- Usual set of signal strength (single fit parameter) grouping decay modes

- Same model used by CMS current results and recommended by LHC XS WG (arXiv:1209.0040)

$$\sigma \cdot BR(ii \rightarrow H \rightarrow ff) = \sigma_{SM} \cdot BR_{SM} \frac{\kappa_i^2 \cdot \kappa_f^2}{\kappa_H^2}$$

  - 6 parameters: Higgs couplings to g, γ,V(W,Z),t,b,τ
  - measurements:
    - GF : H -> ZZ,WW,γγ
    - VBF : H->ZZ,WW, γγ, ττ
    - VH : H -> bb, H->ττ, γγ
    - ttH : H->bb, H->γγ
  - loops not resolved (modified scaling effective coupling to γ and gluons)
  - LO parametrization, don't aim at o(1%) precision...
  - all k's are correlated to total width, k_b dominates

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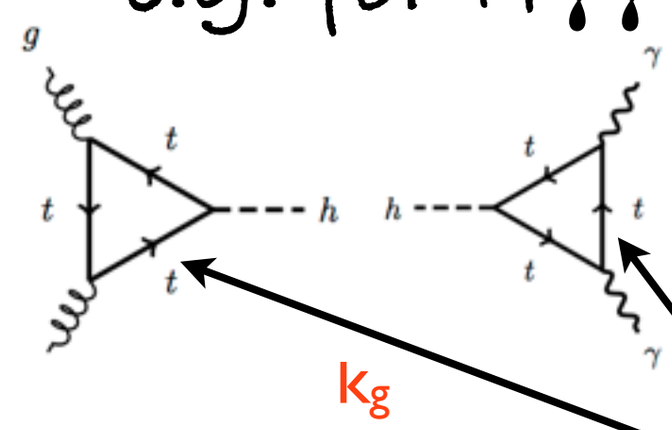
e.g. for Hγγ



$$(\sigma \cdot BR)(gg \rightarrow H \rightarrow \gamma\gamma) = \sigma_{SM}(gg \rightarrow H) \cdot BR_{SM}(H \rightarrow \gamma\gamma) \cdot \frac{\kappa_g^2 \cdot \kappa_\gamma^2}{\kappa_H^2}$$

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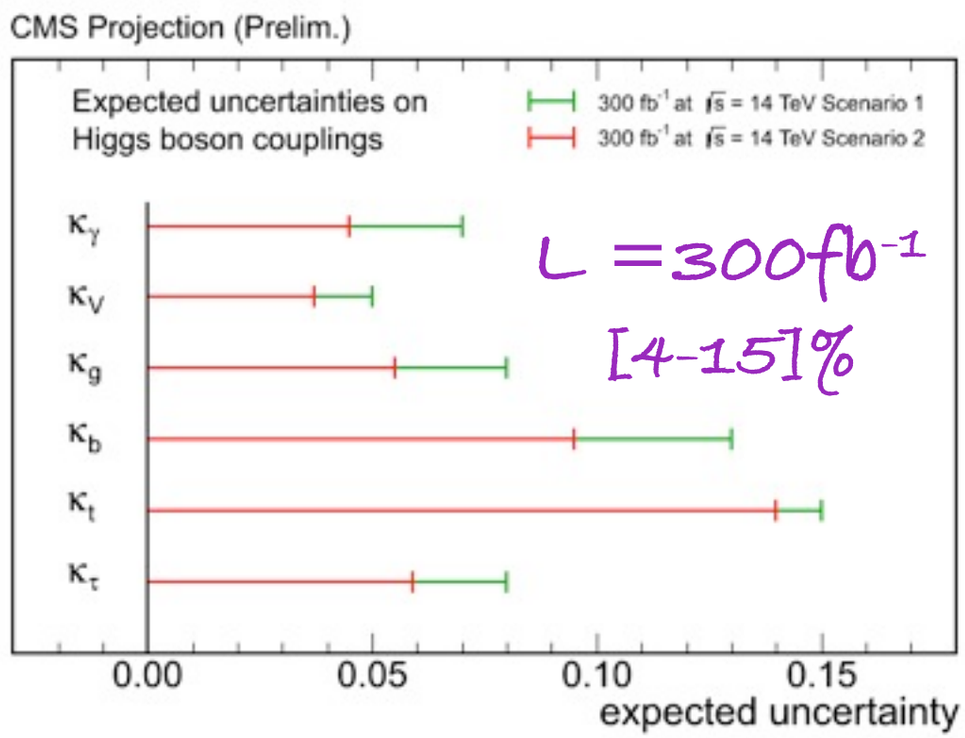
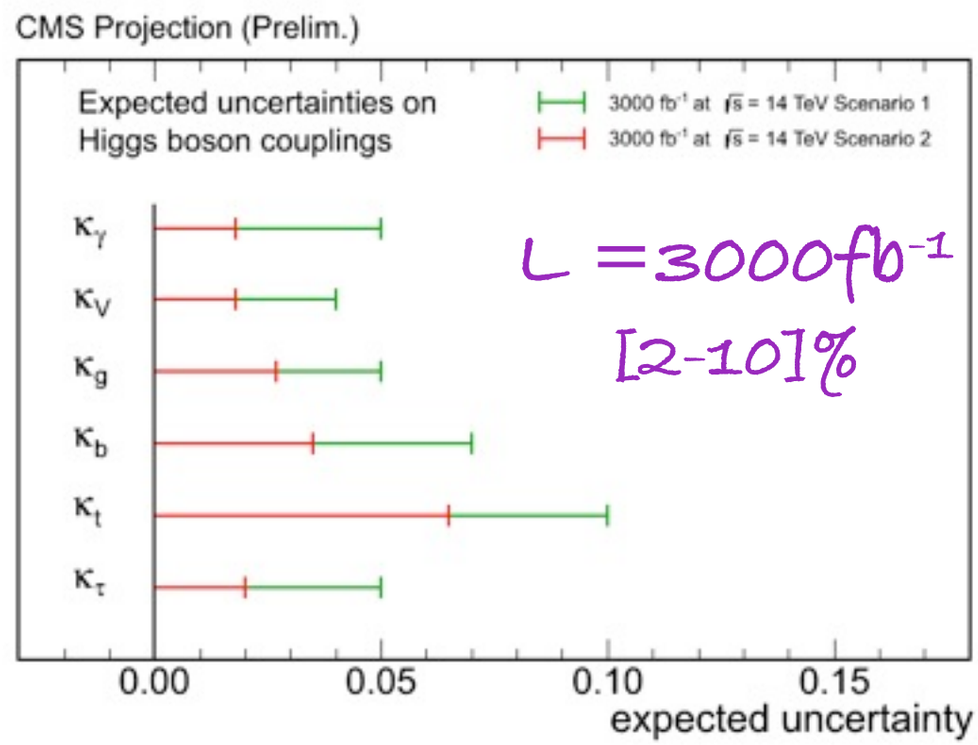
Results





Numbers in brackets are % uncertainties on coupling deviations for [scenario 2, scenario 1]

L (fb^{-1})	κ_γ	κ_V	κ_g	κ_b	κ_t	κ_τ
300	[5, 7]	[4, 5]	[6, 8]	[10, 13]	[14, 15]	[6, 8]
3000	[2, 5]	[2, 3]	[3, 5]	[4, 7]	[7, 10]	[2, 5]

Goal: ultimate precision of ~5% or better

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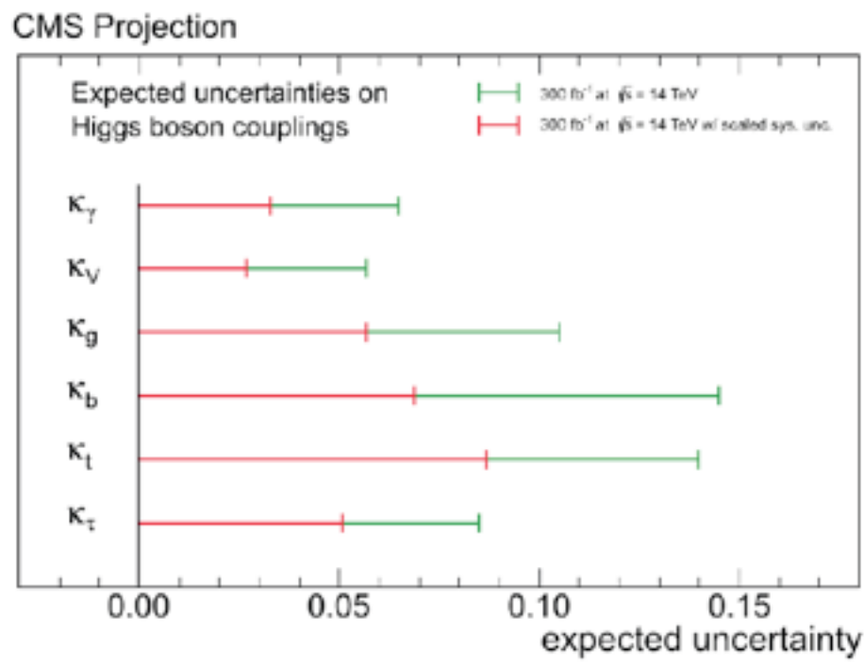
Explain the changes wrt ESPG



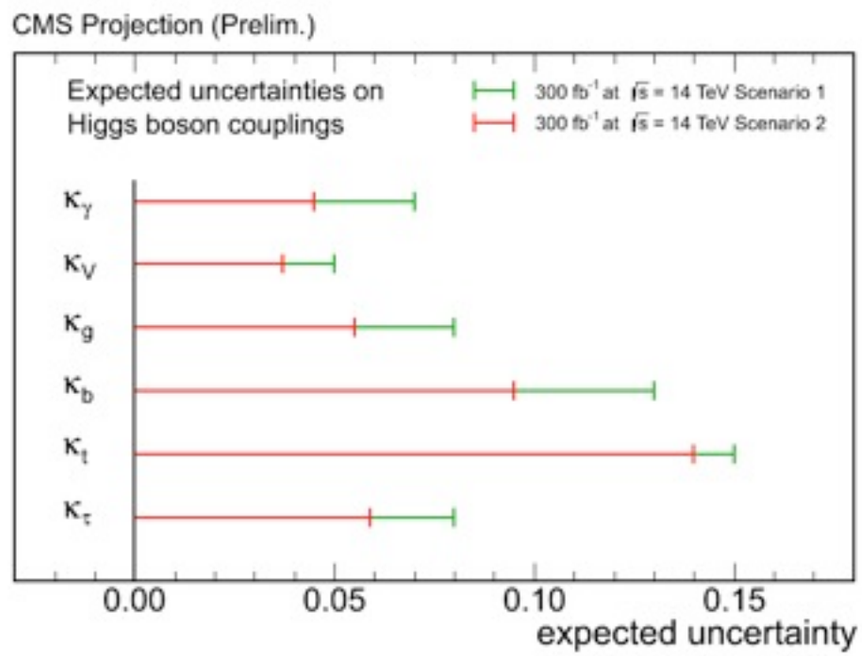
ESPG

$L = 300 fb^{-1}$

[4-15]%

- k_t: uncertainty now bigger due to the change in the preliminary results for ttHbb at iCHEP (5 fb^{-1} 7 TeV) used for ESPG to published results (5fb^{-1} 7TeV + 5fb^{-1} 8TeV)
  - fork closer for L=300: because it is still stat dominated
- k_b: change in VHbb
  - higher theoretical uncertainty: this explain why scenario 2 is slightly worse (also considering the precision)
  - lower experimental uncertainty: this explain why scenario 1 is better now
- all ks are correlated through the total width
  - change in kb influence all the others

Explain the changes wrt ESPG



Snowmass

$L = 300 fb^{-1}$

[3-15]%

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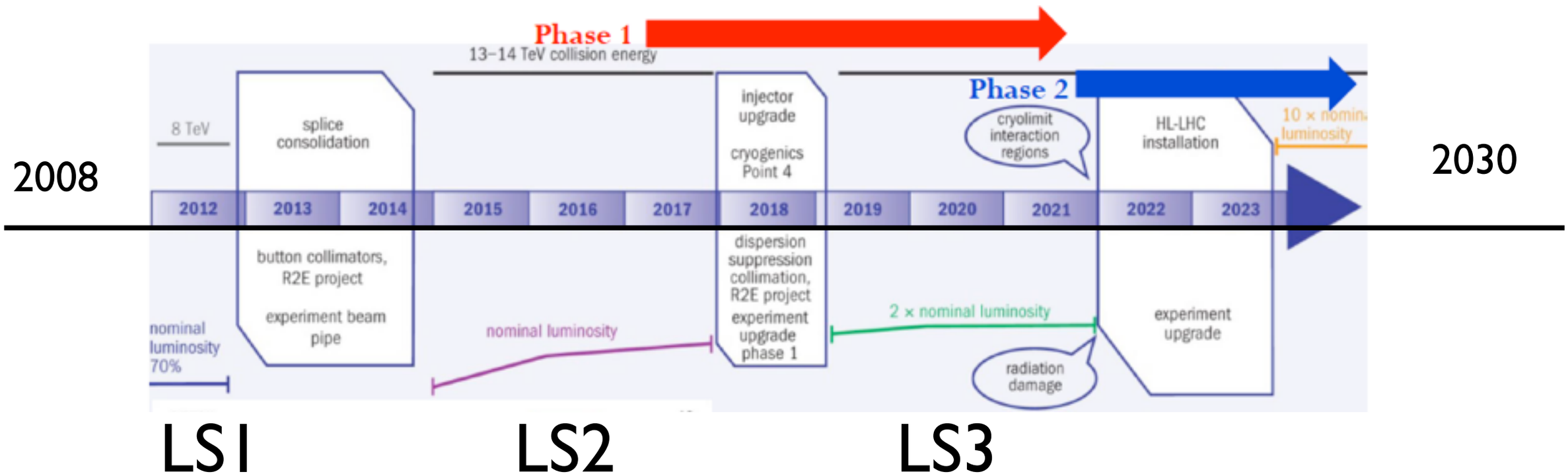
Conclusions

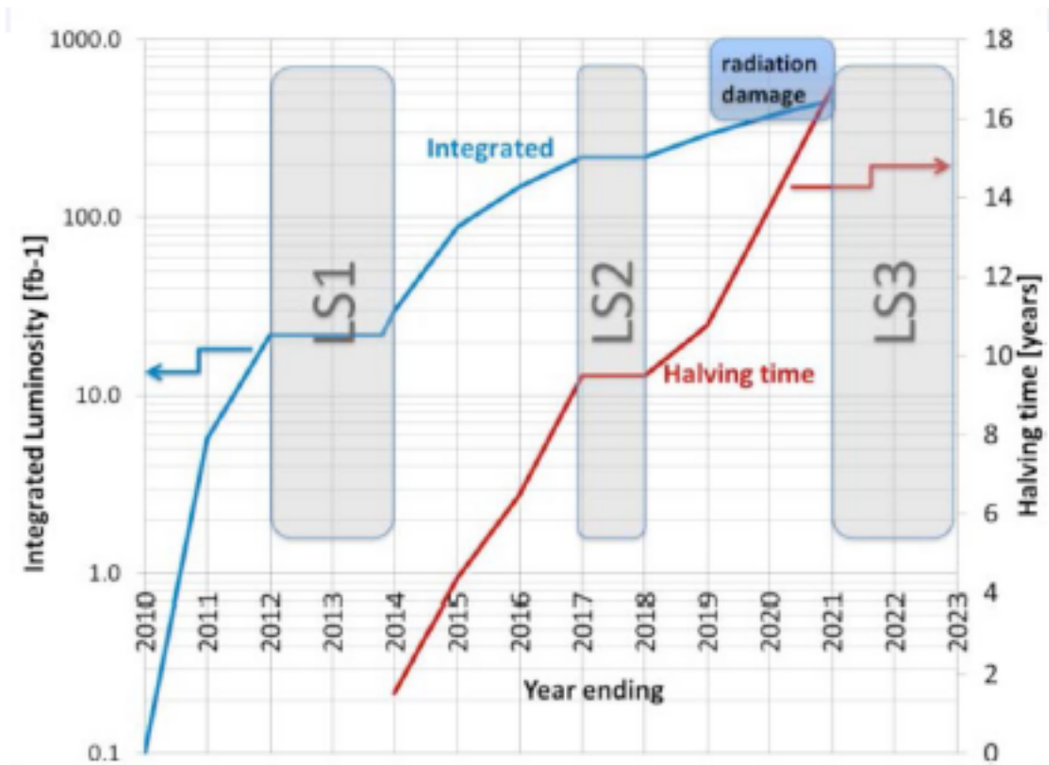
- CMS experiment plans to cope with <50> PU and <140>PU thought LHC and HL-LHC life
- We show the preliminary updated of Higgs coupling projections
- we can achieve for all the Higgs coupling constants an uncertainty of 5% or better
  - fork between pessimistic and optimistic scenario reduced
    - central values basically the same even thought many inputs have significantly changed!
  - theory uncertainty scaled by 50% in scenario 2
    - could we do better in 10 ys from now? (e.g. on boost VH?)

BACK-UP

Future



- Phase 1: 2015- 2021
  - reach design luminosity by LS2, 2x design by LS3 (will require an already planned more intense upgrade program)
  - integrate 300 fb^{-1} by 2022 (PU = 50-100)
- Phase 2: 2024 - early 2030s
  - 5x design lumi
  - integrate 3000 fb^{-1} (PU=140)



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Upgrade

- Details in Jim Olsen talk

Channel	Key Features	Upgrades addressing future challenge:
$H \rightarrow \gamma\gamma$	di-photon mass	Tracker, trigger, forward calo, precision timing
$H \rightarrow ZZ$	Lepton reco/iso	Tracker, trigger, muon, calorimetry
$H \rightarrow WW$	Lepton reco/iso, MET	Tracker, trigger, muon, HCAL, forward calo
$H \rightarrow \tau\tau$	di-tau mass, VBF tag	Tracker, trigger, HCAL, forward calo
$H \rightarrow bb$	b-tagging, di-jet mass	Tracker, trigger, HCAL

Upgrades will specifically address dominant systematic uncertainties impacting Higgs precision measurements and searches for additional Higgs bosons

Explain the changes wrt ESPG

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- K_t: uncertainty now bigger due to the change in the preliminary results for ttHbb at iCHEP (5 fb^{-1} 7 TeV) used for ESPG to published results (5fb^{-1} 7TeV + 5fb^{-1} 8TeV)
  - [1] 95% CL limit: 3.8 obs(4.9 exp) https://twiki.cern.ch/twiki/bin/view/CMSPublic/Hig12025TWiki
  - [2] 95% CL limit: 5.8 obs(5.2 exp) https://twiki.cern.ch/twiki/bin/view/CMSPublic/Hig12035TWiki
  - fork closer in scenario 1: because it is still stat dominated
  - the addition of ttHgg is minimal
  - it will get better when we'll add the ttH multi-lepton final states
- K_b: change in VHbb (demonstrated by running the new cards with ESPG nuisance setting)
  - more extensive use of shapes wrt to lnN uncertainties: this explain why scenario 2 is slightly worse (also considering the precision)
  - reduced bkg and lnN signal uncertainties in general, but higher shapes theory uncertainties: this explain why scenario 1 is better now
- the change in K_b also explain the increase for scenario 2 for all Ks and decrease for scenario 1
  - all Ki are correlated trough the total width

EFT

Probing loops while allowing other couplings to float assuming no invisible or undetectable widths

Free parameters: $\kappa_g, \kappa_\gamma, \kappa_V (= \kappa_W = \kappa_Z), \kappa_f (= \kappa_t = \kappa_b = \kappa_\tau)$.

	$H \to \gamma\gamma$	$H \to ZZ^{(*)}$	$H \to WW^{(*)}$	$H \to b\bar{b}$	$H \to \tau^-\tau^+$
ggH	$\frac{\kappa_g^2 \cdot \kappa_\gamma^2}{\kappa_H^2(\kappa_i)}$	$\frac{\kappa_g^2 \cdot \kappa_V^2}{\kappa_H^2(\kappa_i)}$		$\frac{\kappa_g^2 \cdot \kappa_f^2}{\kappa_H^2(\kappa_i)}$	
$t\bar{t}H$	$\frac{\kappa_f^2 \cdot \kappa_\gamma^2}{\kappa_H^2(\kappa_i)}$	$\frac{\kappa_f^2 \cdot \kappa_V^2}{\kappa_H^2(\kappa_i)}$		$\frac{\kappa_f^2 \cdot \kappa_f^2}{\kappa_H^2(\kappa_i)}$	
VBF WH ZH	$\frac{\kappa_V^2 \cdot \kappa_\gamma^2}{\kappa_H^2(\kappa_i)}$	$\frac{\kappa_V^2 \cdot \kappa_V^2}{\kappa_H^2(\kappa_i)}$		$\frac{\kappa_V^2 \cdot \kappa_f^2}{\kappa_H^2(\kappa_i)}$	