

HH HE LHC Projections

HE LHC

- $\sqrt{s} = 27 \text{ TeV}$
- $L = 15 \text{ ab}^{-1}$
- Increase in HH cross section by ~ 4 w.r.t. $\sqrt{s} = 14 \text{ TeV}$

ATLAS projections for

- $HH \rightarrow bb\gamma\gamma$
- $HH \rightarrow bb\tau\tau$

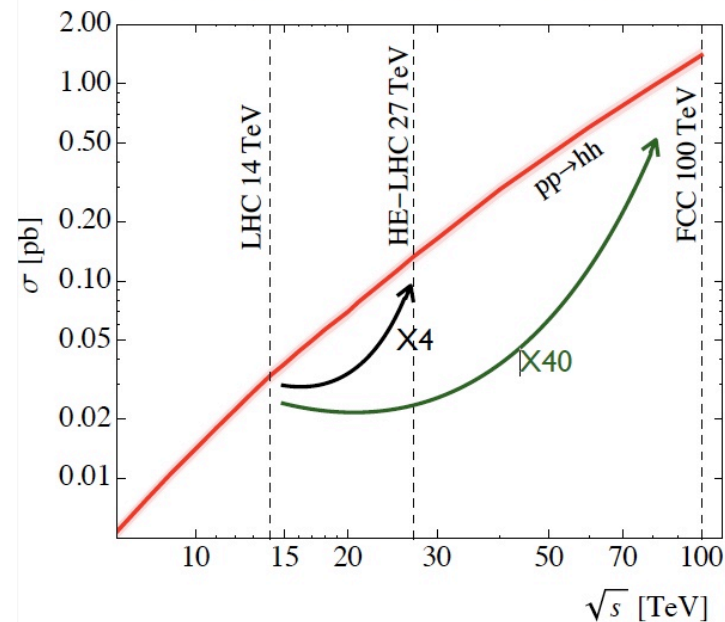
Higgs Trilinear Coupling at an HE-LHC (Samuel Homiller, Patrick Meade)

- Talk and Yellow Report writeup

Double Higgs production HE LHC prospects (Dorival Gonçalves, Tao Han, Felix Kling, Tilman Plehn and Michihisa Takeuchi)

- Double Higgs Production and Yellow Report writeup

DG, Han, Kling, Plehn, Takeuchi (2018)



ATLAS $HH \rightarrow bb\gamma\gamma$ and $HH \rightarrow bb\tau\tau$

• Idea:

- Extrapolate event yields from HL LHC to HE LHC assuming same detector performances as ATLAS at HL LHC (no Delphes)
 - Scale according to cross section and luminosity
 - Requires acceptance \times efficiency very similar to $\sqrt{s} = 14$ TeV

• Cross sections at $\sqrt{s} = 27$ TeV

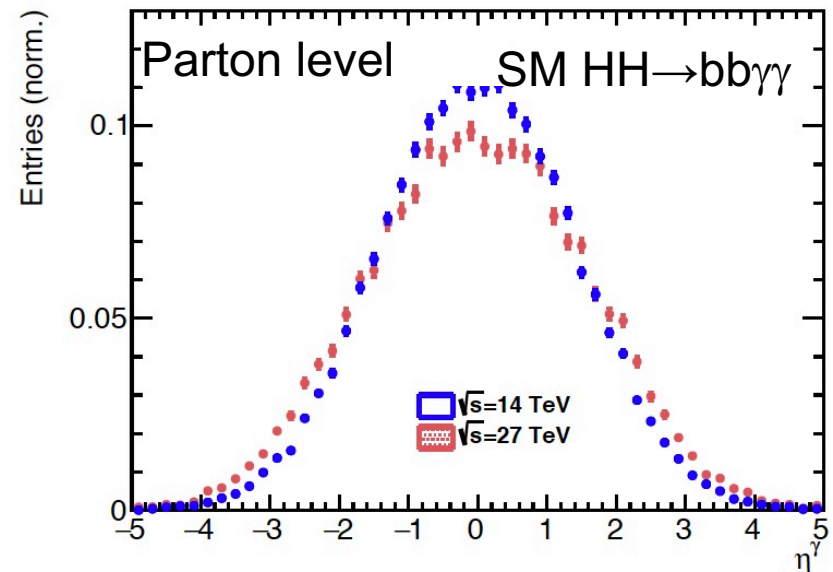
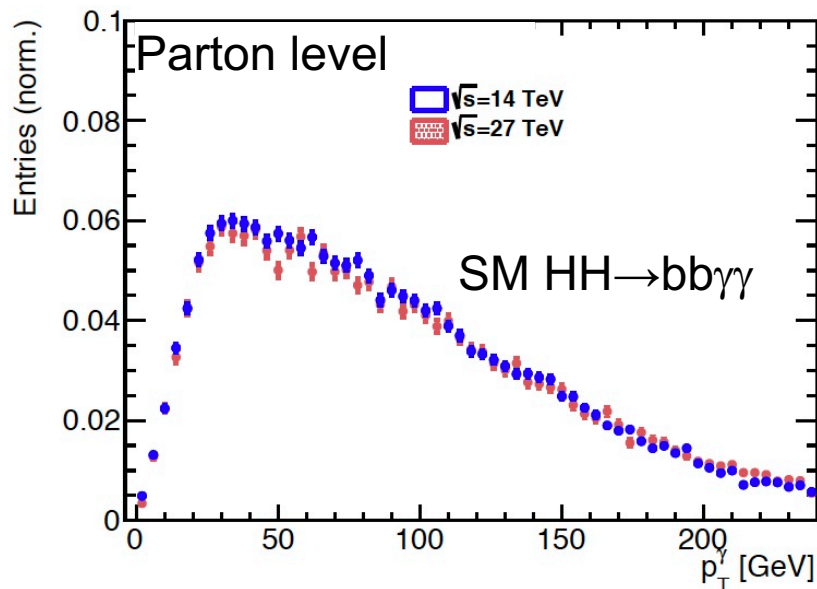
- SM HH: normalise to $\sigma = 139.9$ fb (Higgs LHC WG)
- Use MC generator cross sections and normalise to include higher order(s) (if available) using $\sqrt{s} = 14$ TeV k factors

ATLAS $HH \rightarrow bb\gamma\gamma$ and $HH \rightarrow bb\tau\tau$

Acceptance \times efficiency

Comparisons of parton level distributions (p_T , η , $m_{\gamma\gamma}$, m_{bb} , $m_{bb\gamma\gamma}$, $\Delta R(\gamma\gamma)$ etc) showed very similar behaviour for signal and background distributions

Largest differences found for rapidity distribution of Higgs decay products



ATLAS $HH \rightarrow bb\gamma\gamma$ and $HH \rightarrow bb\tau\tau$

• Acceptance \times efficiency

- Similar distributions found for acceptance \times efficiency as a function of m_{HH} for $\sqrt{s} = 14$ TeV and $\sqrt{s} = 27$ TeV hh signal samples
- BDT selections optimised for $\sqrt{s} = 14$ TeV will work well also at $\sqrt{s} = 27$ TeV

ATLAS $HH \rightarrow bb\gamma\gamma$ and $HH \rightarrow bb\tau\tau$ Results

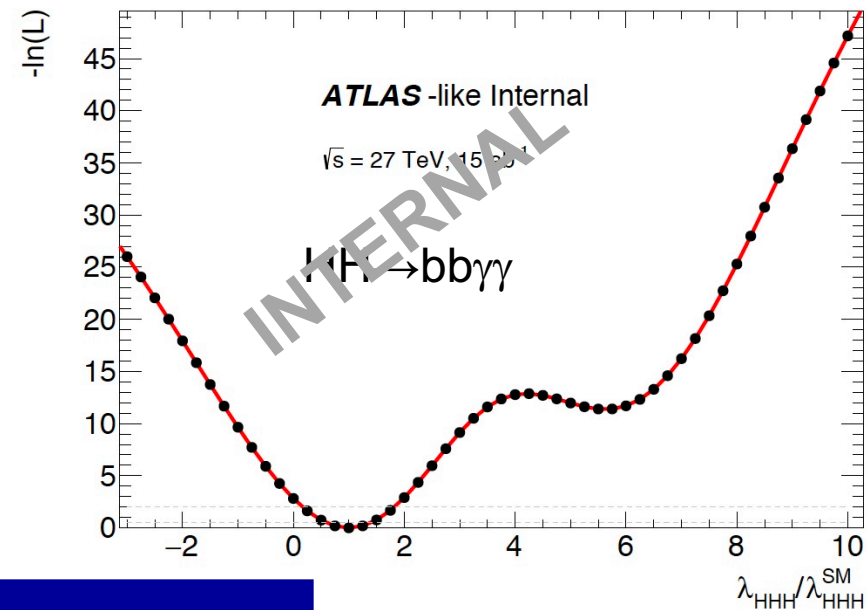
- Significance to observe SM HH production (no systematic uncertainties applied as not yet known):

channel	Significance
$HH \rightarrow bb\gamma\gamma$	8.2σ
$HH \rightarrow bb\tau\tau$	10.7σ

- Allowed range for $\lambda_{HHH}/\lambda_{SM}^{HHH}$ (no syst. uncertainties)

	$bb\gamma\gamma$	$bb\tau\tau$
1σ	$0.6 < \lambda_{HHH}/\lambda_{SM}^{HHH} < 1.4$	$0.8 < \lambda_{HHH}/\lambda_{SM}^{HHH} < 1.2$
2σ	$0.2 < \lambda_{HHH}/\lambda_{SM}^{HHH} < 1.8$	$0.6 < \lambda_{HHH}/\lambda_{SM}^{HHH} < 1.4$

- Measure λ_{HHH} with 40% (20%) precision in $bb\gamma\gamma$ ($bb\tau\tau$) (stat. only)
- This is a first projection, quite some room for improvements



Higgs Trilinear Coupling at an HE-LHC

- Talk at Fermilab WS, show updated results here from write-up in YR
- Study of measuring λ_{HHH} (λ_3) in $bb\gamma\gamma$ channel
- Signal and backgrounds produced at $\sqrt{s} = 27$ TeV
 - Consider same background processes as done in ATLAS analysis
- Use HE LHC Delphes detector emulation
 - But improved Ecal resolution and photon efficiencies, and degraded dijet mass resolution

• Selections

- At least 2 isolated photons and b-tagged jets with leading $p_T > 60$ GeV and sub-leading $p_T > 35$ GeV, all with $|\eta_{\gamma,b}| < 2.5$.
- $p_{T,\gamma\gamma}, p_{T,b\bar{b}} > 125$ GeV.
- $\Delta R_{b\bar{b}}, \Delta R_{\gamma\gamma} < 3.5$.
- $|m_{\gamma\gamma} - 125.0 \text{ GeV}| < 4.0 \text{ GeV}$.
- $|m_{b\bar{b}} - 125.0 \text{ GeV}| < 25 \text{ GeV}$.
- $n_{\text{jets}} < 6$ for jets with $p_T > 30$ GeV, $|\eta| < 2.5$.
- No isolated leptons with $p_T > 25$ GeV.
- $|\cos \theta_{hh}| < 0.8$.

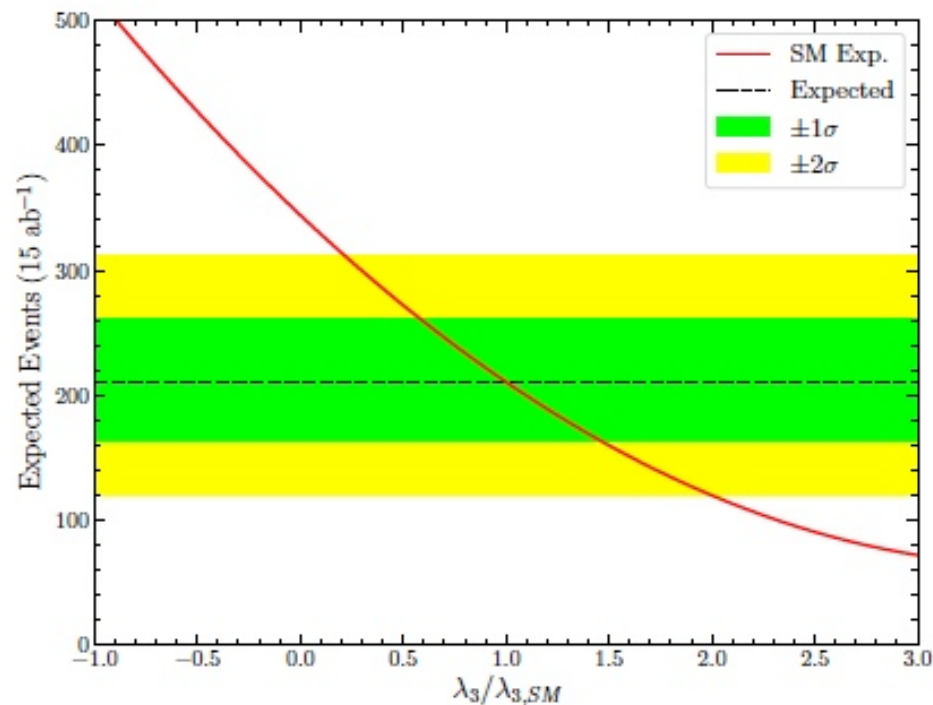
Higgs Trilinear Coupling at an HE-LHC

Event yields

Process	Expected Events (27 TeV, 15 ab ⁻¹)	
$h(b\bar{b})h(\gamma\gamma)$	209.6	± 0.2
$t\bar{t}h(\gamma\gamma)$	286.8	± 1.6
$Zh(\gamma\gamma)$	67.1	± 0.7
$b\bar{b}h(\gamma\gamma)$	2.3	± 0.1
$ggF(\gamma\gamma)$	349.7	± 9.5
$b\bar{b}\gamma\gamma$	414.6	± 10.3
$c\bar{c}\gamma\gamma$	185.7	± 4.2
$j\bar{j}\gamma\gamma$	63.3	± 3.8
$b\bar{b}j\gamma$	199.6	± 9.4
$c\bar{c}j\gamma$	125.3	± 3.0
$b\bar{b}jj$	155.4	± 8.2
$Z(b\bar{b})\gamma\gamma$	21.5	± 0.4
$t\bar{t}$	11.6	± 3.3
$t\bar{t}\gamma$	145.0	± 10.3

- Significance: $4.77 \pm 0.14\sigma$ to be compared to 8.2σ with ATLAS analysis (using BDT)

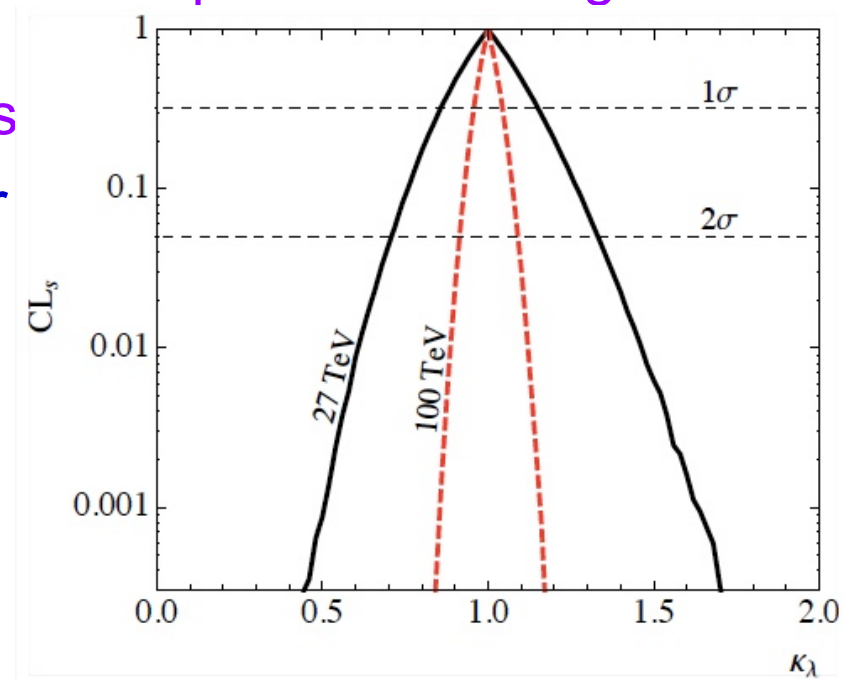
Sensitivity to λ_3



- Estimated precision on SM coupling $\lambda_3 \sim 45\%$

Double Higgs production

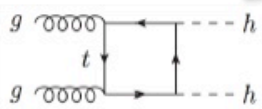
- From Talk at June HL(HE) LHC WS + YR write-up
- Detector level analysis (ATLAS performance assumed) for $HH \rightarrow bb\gamma\gamma$ based on simulated signal + background samples merged up to one jet
 - Easy to produce extra hard jets at HE LHC \Rightarrow do not only consider two highest p_T jets in event
 - Excellent photon and b-jet resolution important for design of detector \Rightarrow affects directly how fast we can discover HH process
- Binned log-likelihood analysis for m_{hh} distribution for $HH \rightarrow bb\gamma\gamma$
 - HE-LHC:
 - $\kappa_\lambda \approx 1 \pm 15\%$ (1σ), 30% (2σ)
 - FCC-100TeV:
 - $\kappa_\lambda \approx 1 \pm 5\%$ (1σ), 10% (2σ)



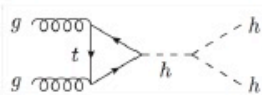
Double Higgs production in EFT

Dim-6 Lagrangian relevant to HH production:

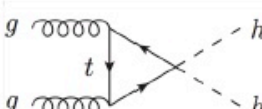
$$\mathcal{L}_{non-lin} \supset -m_t \bar{t}t \left(c_t \frac{h}{v} + c_{2t} \frac{h^2}{v^2} \right) - c_3 \frac{m_h^2}{2v} h^3 + \frac{g_s^2}{4\pi^2} \left(c_g \frac{h}{v} + c_{2g} \frac{h^2}{2v^2} \right) G_{\mu\nu}^a G^{a\mu\nu}$$



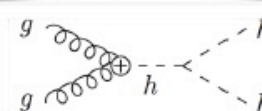
$$\sim c_t^2 \frac{\alpha_s}{4\pi} y_t^2$$



$$\sim c_t c_3 \frac{\alpha_s}{4\pi} y_t^2 \frac{m_h^2}{\hat{s}} \left(\log \frac{m_t^2}{\hat{s}} + i\pi \right)^2$$



$$\sim c_{2t} \frac{\alpha_s}{4\pi} y_t^2 \left(\log \frac{m_t^2}{\hat{s}} + i\pi \right)^2$$

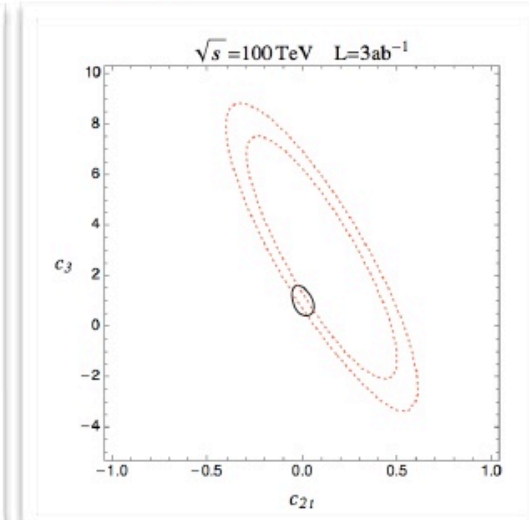
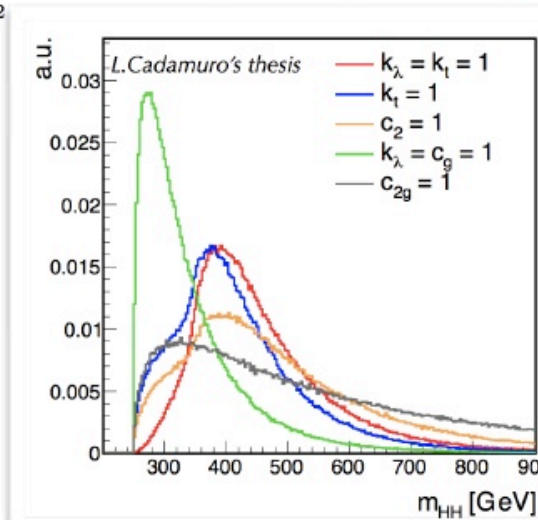


$$\sim c_g c_3 \frac{\alpha_s}{4\pi} \frac{m_h^2}{v^2}$$



$$\sim c_{2g} \frac{\alpha_s}{4\pi} \frac{\hat{s}}{v^2}$$

→ Shape analysis can significantly improve the fits:



Azatov, Contino, Panico, Son (2015)

Conclusions and outlook

• ATLAS results

- No text yet for YR, will be written by the deadline, with numerical results to be added as soon as the PUB note is public

• Theory results

- Already in the YR draft, sections to be harmonised