Measurement of the Higgs Self-Coupling with the HL-LHC

Valère Lambert, Da An, Si Xie

California Institute of Technology

Motivation

Goal: Measure the self-coupling constant of the Higgs boson and infer the Higgs potential

- Infer the size and structure of the Higgs self-coupling from the cross section of the diHiggs production.
- Require higher luminosity to measure the small cross section for diHiggs production

Looking at the Phase II Upgrades for 2020 with the High Luminosity LHC with 3000 fb-1 at 14 TeV

Overview:

Produce Madgraph samples for HH → bbγγ signal and backgrounds

Calculate the signal and background event yields

Examine methods for improving the measurement of the diHiggs cross section

Irreducible Backgrounds:

QCD (bbγγ)

(H->γγ)bb

(Z->bb)(H->γγ)

ttbar(H->γγ)

Reducible backgrounds:

jjγγ

ccγγ

bbjj

ccjj

jjjj

bbjγ

ccjγ

jjjγ

Tagging Efficiencies

Study involves reducible bbγγ backgrounds from fake photons and bjets
Produce background samples with generator level objects weighted with tagging efficiencies for reconstruction

Efficiencies calculated with: **numerator:** real reconstructed objects passing ID cuts
denominator: fakeable gen-level objects

Tagging Efficiencies

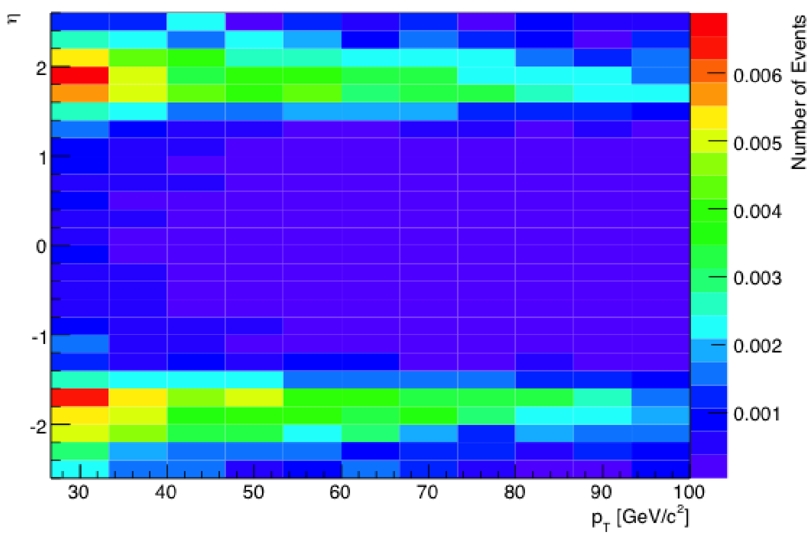
- Photon Tagging
- B Tagging

Mistagging Efficiencies

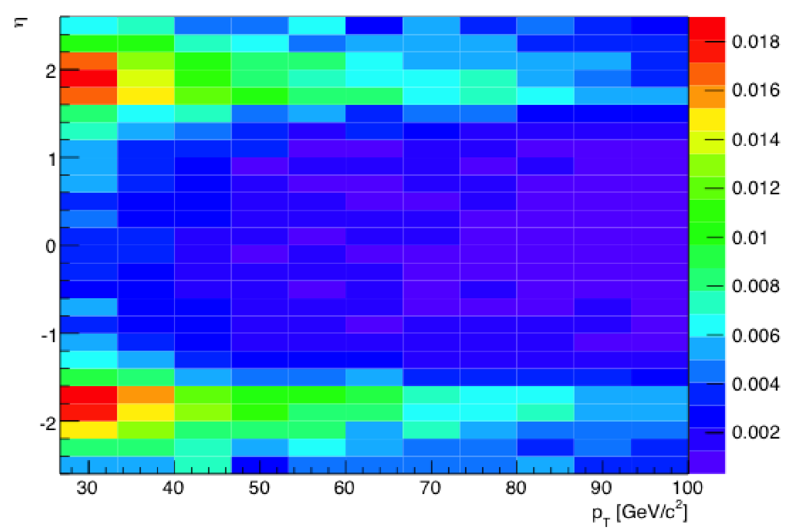
Photon Mistags:
- gluon jets faking photons
- quark jets faking photons

Bjet Mistags:
- charm jets faking B jets
- Light jets faking B jets

Fake Photon Efficiencies: Gluons



Fake Photon Efficiencies: Quarks



Background Selections

Generate Madgraph samples for HH->bbγγ background at 14 TeV with 3000 fb-1

Cuts in sample generation: pT > 20 GeV on photons and b's, M(*γ, γ) ∈ [60, 200] GeV and M(b, b) ∈ [60, 200] GeV*

bbjj: 2 real bjets + 2 fake photons:

- Veto events with real photons and without real bjets (pT > 30 and |η| < 2.4) using PDG identification
- Take remaining non-bjets and create all potential unique pairs in which jets passing cuts of pT > 20 and |η| < 2.5 are promoted to photons
- Weight the event with efficiencies corresponding to each fake photon and real bjet reconstruction.

Similar process for jjgg, ccjj, jjjj, jjjg, ccjg, and bbjg backgrounds

Estimate the number of expected background events by:

-Normalizing the sample by its respective production cross section

-Integrating over the weighted sample distributions

Backgrounds:	Cross Sections (fb):
bbjj : b jets + fake photons	214,000,000
ccjj :charm mistagging + fake photons	214,400,000
jjjj : light jet mistagging + fake photons	20,440,000,00

Sample Event Yields

$$\text{Sig/Bkgd Ratio} = \frac{\text{Events}_{sig}}{\text{Events}_{bkgd}}$$

$$\text{Significance} = \frac{\text{Events}_{sig}}{\sqrt{\text{Events}_{bkgd}}}$$

Scheme 0

$\Delta R_{gg} < 2.0$ and $\min \Delta R_{gb} > 1.0$

Scheme 0	
Sample Type	Expected Events
jjjj	0.14
ccjj	0.0002
bbjj	0.06
** jjgg	16.0
** bbgg	15.3
ttbar	0.8
ZH $\rightarrow$ bbγγ	3.6
ttH, H $\rightarrow$ γγ	2.9
* HH $\rightarrow$ bbγγ	13.6
Sig/Bkgd Ratio	0.4
Significance	2.20

Post – Object Selection Cuts

$Pt_{bjet1}, Pt_{bjet2}, Pt_{pho1}, Pt_{pho2} > 25$

$\max(Pt_{pho1}, Pt_{pho2}) > 40$

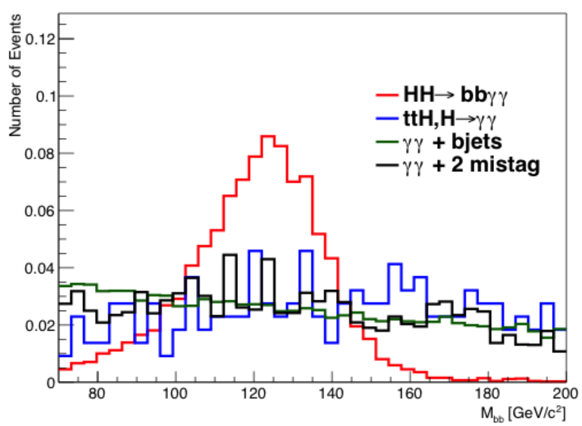
number of central jets ≤ 3

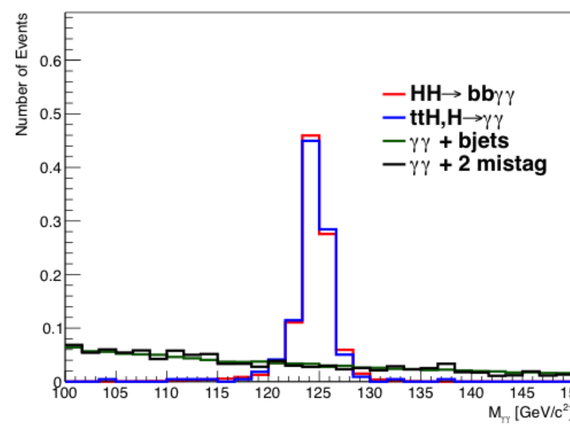
number of leptons ≤ 0

Integrate distributions for Expected Events within Mass Windows

$120 < M_{\gamma\gamma} < 130$

$105 < M_{bb} < 145$





Signal to Background Optimization

Scheme 1

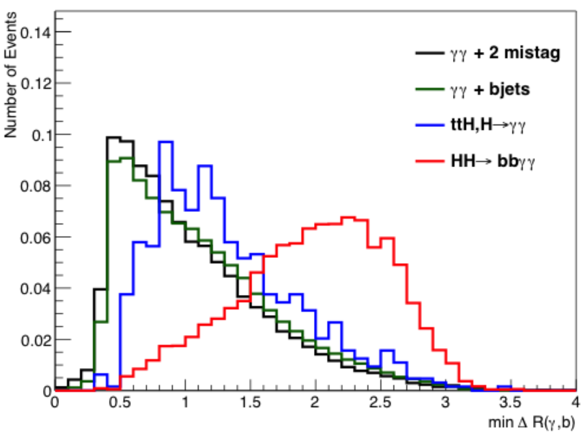
$\Delta R_{gg} < 2.0$, $\Delta R_{bb} < 2.0$ and min $\Delta R_{gb} > 1.5$

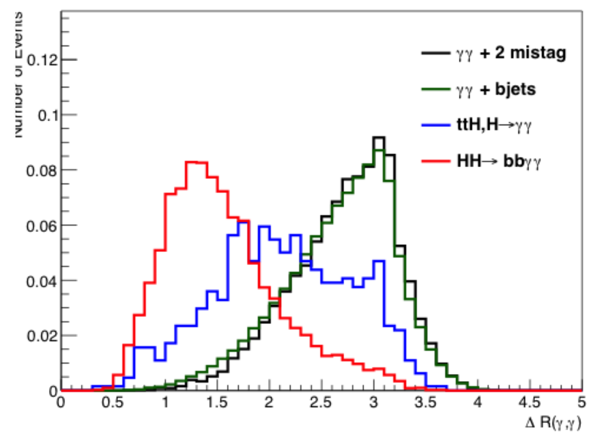
Scheme 1	
Sample Type	Expected Events
jjgg	8.0
bbgg	9.6
ttH, H $\rightarrow$ γγ	1.7
HH $\rightarrow$ bbγγ	12.0
Sig/Bkgd Ratio	0.5
Significance	2.5

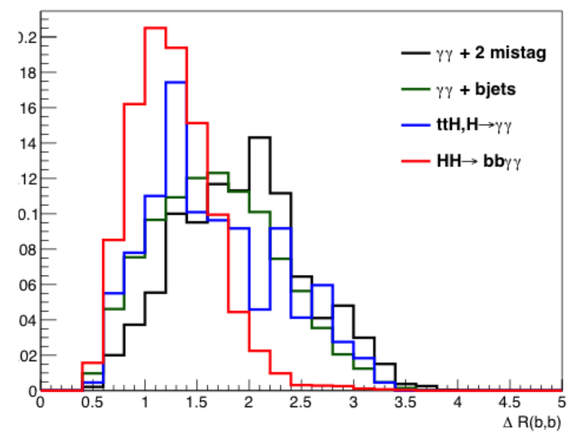
Scheme 1 Tight

$\Delta R_{gg} < 1.6$, $\Delta R_{bb} < 1.6$ and min $\Delta R_{gb} > 1.5$

Scheme 1 Tight	
Sample Type	Expected Events
jjgg	2.7
bbgg	3.7
ttH, H $\rightarrow$ γγ	1.1
HH $\rightarrow$ bbγγ	9.0
Sig/Bkgd Ratio	1.0
Significance	2.9





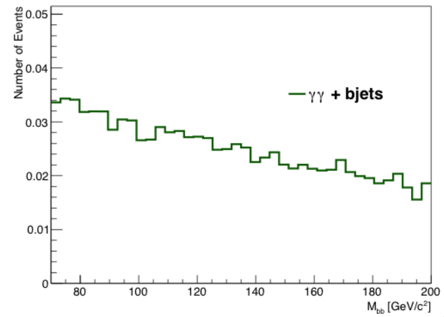


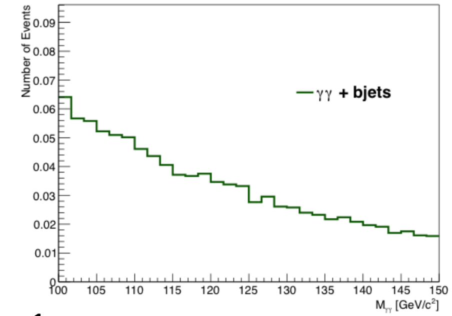
Mass Fitting

- Confirm that the optimizations do not skew the shape of the diphoton and dibjet masses for fitting

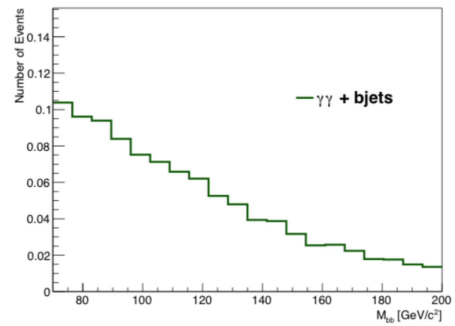
- Float the signal and background event yields and perform maximum likelihood fits on the masses to extract the signal and its cross section

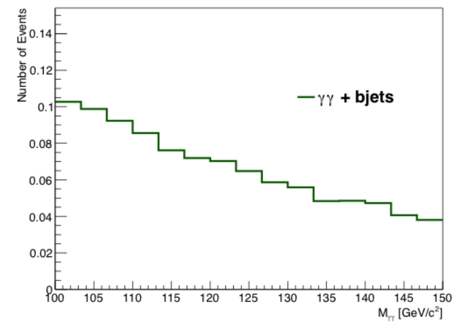
Scheme 0



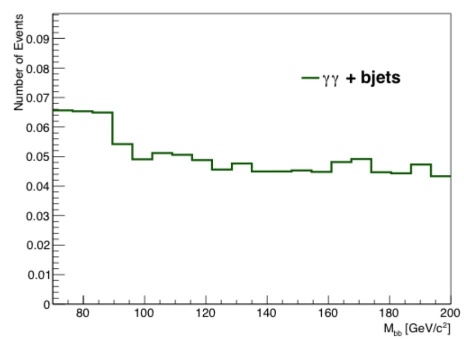


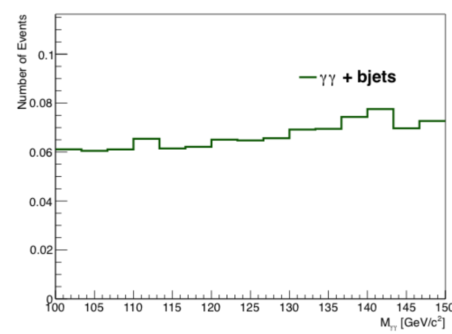
Scheme 1





Scheme 2: Alternative pT Cuts





Conclusions

The reducible backgrounds from fake photons are under control and the dominant background sources appear to be QCD ($bb\gamma\gamma$) and the mistagged bjets ($jj\gamma\gamma$).

These backgrounds may be reduced with stricter angular cuts on the photons and b quarks to increase the signal to background ratio.

In progress and for the future:

- We are fitting the diphoton and dibjet Higgs invariant masses to attempt to extract the cross section for the diHiggs production

- Will prepare various scenario studies to examine these results under differing detector conditions (pile up, improved bjet resolution, degraded photon resolution, etc.)