

$H \rightarrow bb/cc/gg$ at 350 GeV at CLIC

LCWS15 - 04 Nov 2015

Marco Szalay for the CLICdp collaboration



Outline

- Introduction
- Event selection
- Template Fit
- Conclusions

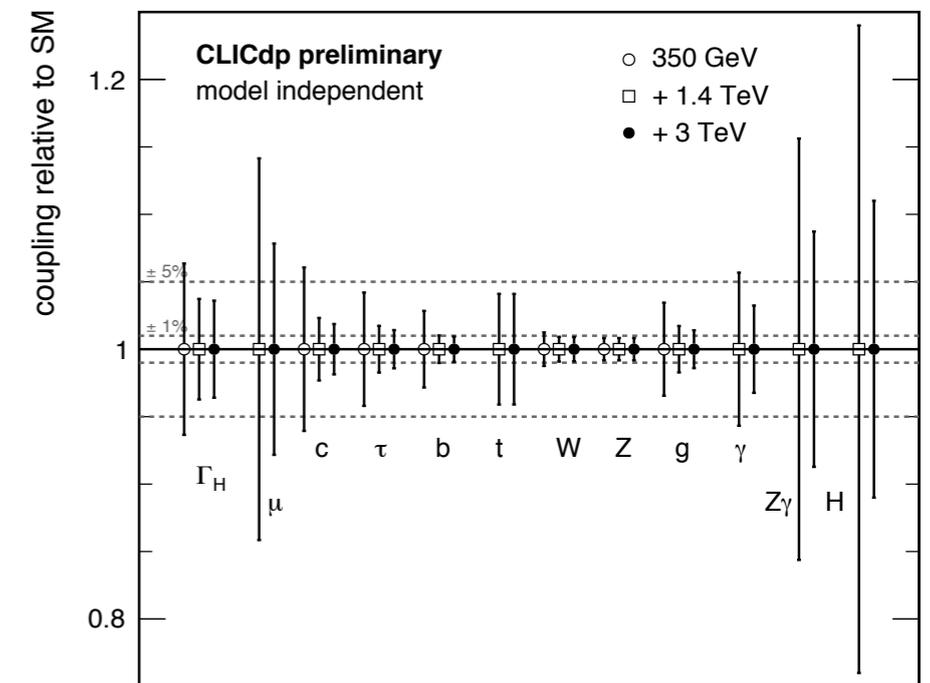
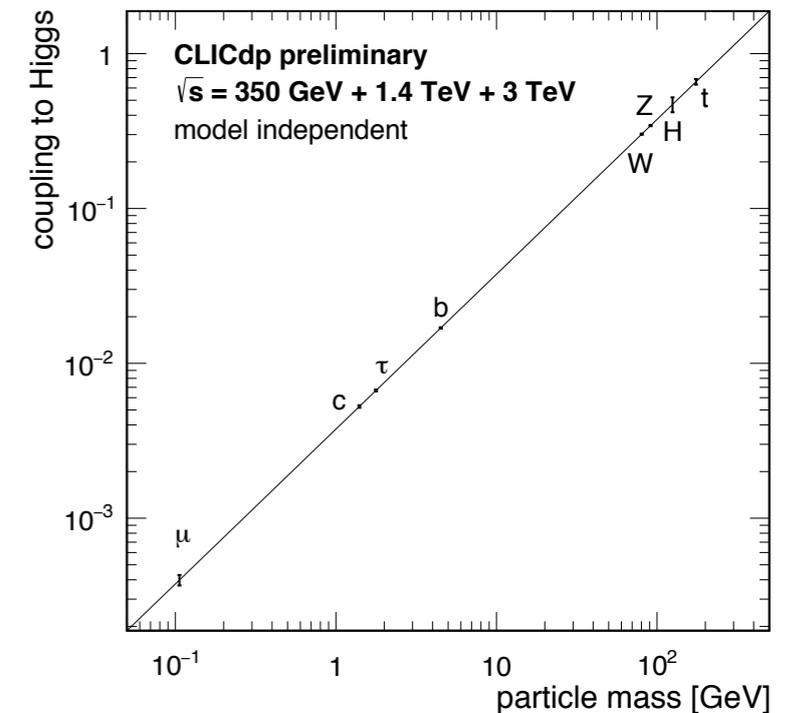
Global Fit

- Higgs couplings can be calculated from $\sigma \times \text{BR}$ and total width Γ_H
- Γ_H can be determined via a global fit with high precision from VBF and ZH for $H \rightarrow bb$

$$\frac{g_{HWW}^2 g_{Hbb}^2}{\Gamma}$$

$$\frac{g_{HZZ}^2 g_{Hbb}^2}{\Gamma}$$

- The simultaneous measurement of both can be performed only around this CMS energy range



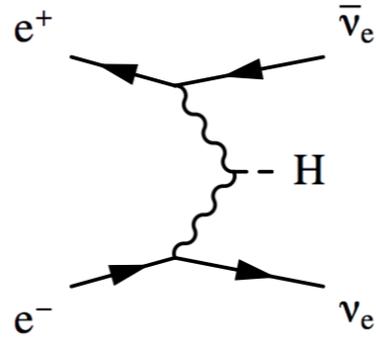
Higgs production in e^+e^- collisions

Main H production channels at 350 GeV:

- Vector Boson Fusion

signatures:

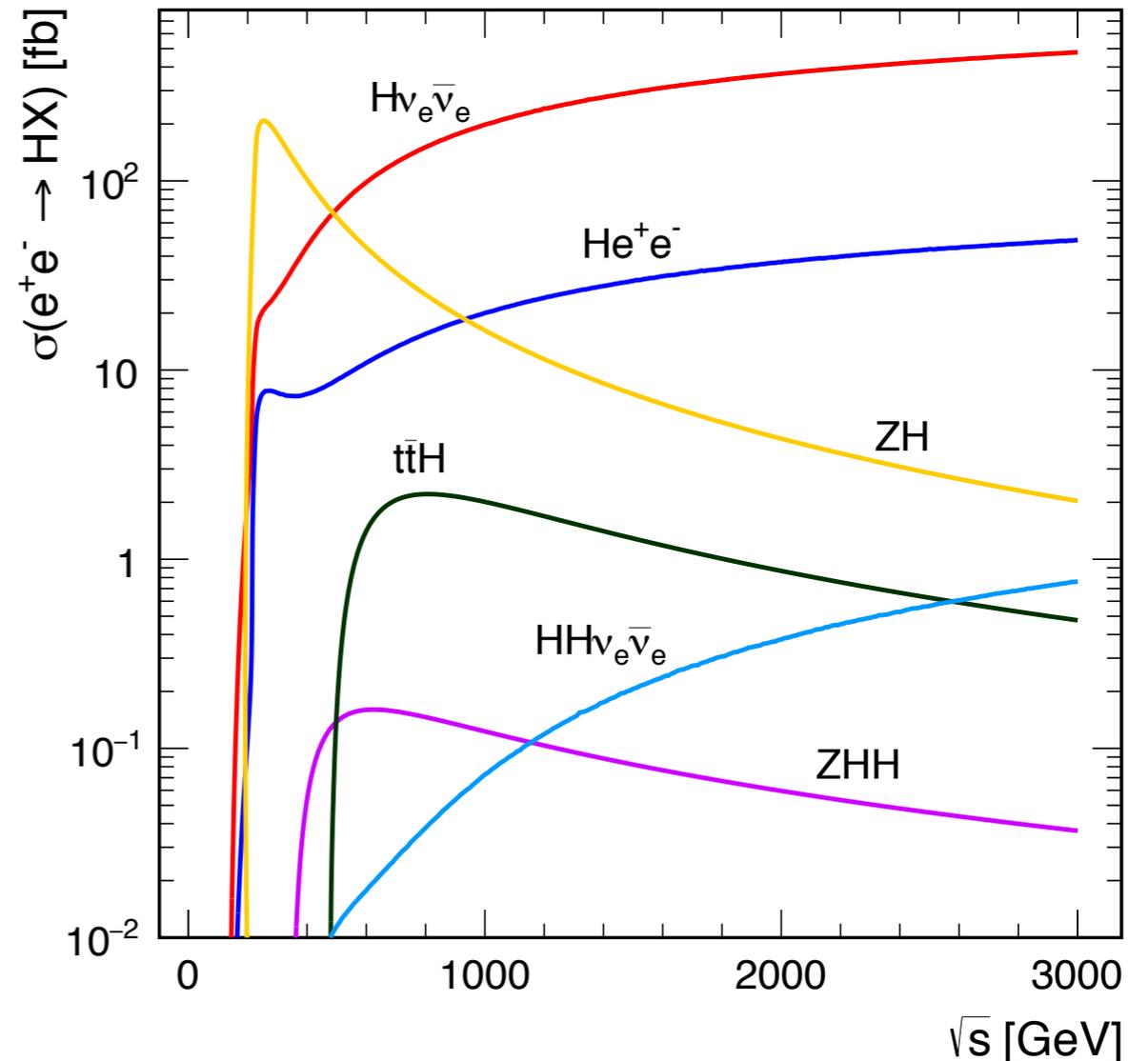
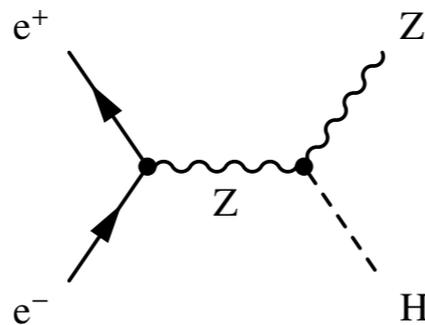
- 2 jets + missing mass & low H_{Pt}



- Higgs strahlung

signatures:

- 2 jets + missing mass
- 2 jets + 2 leptons
- 4 jets

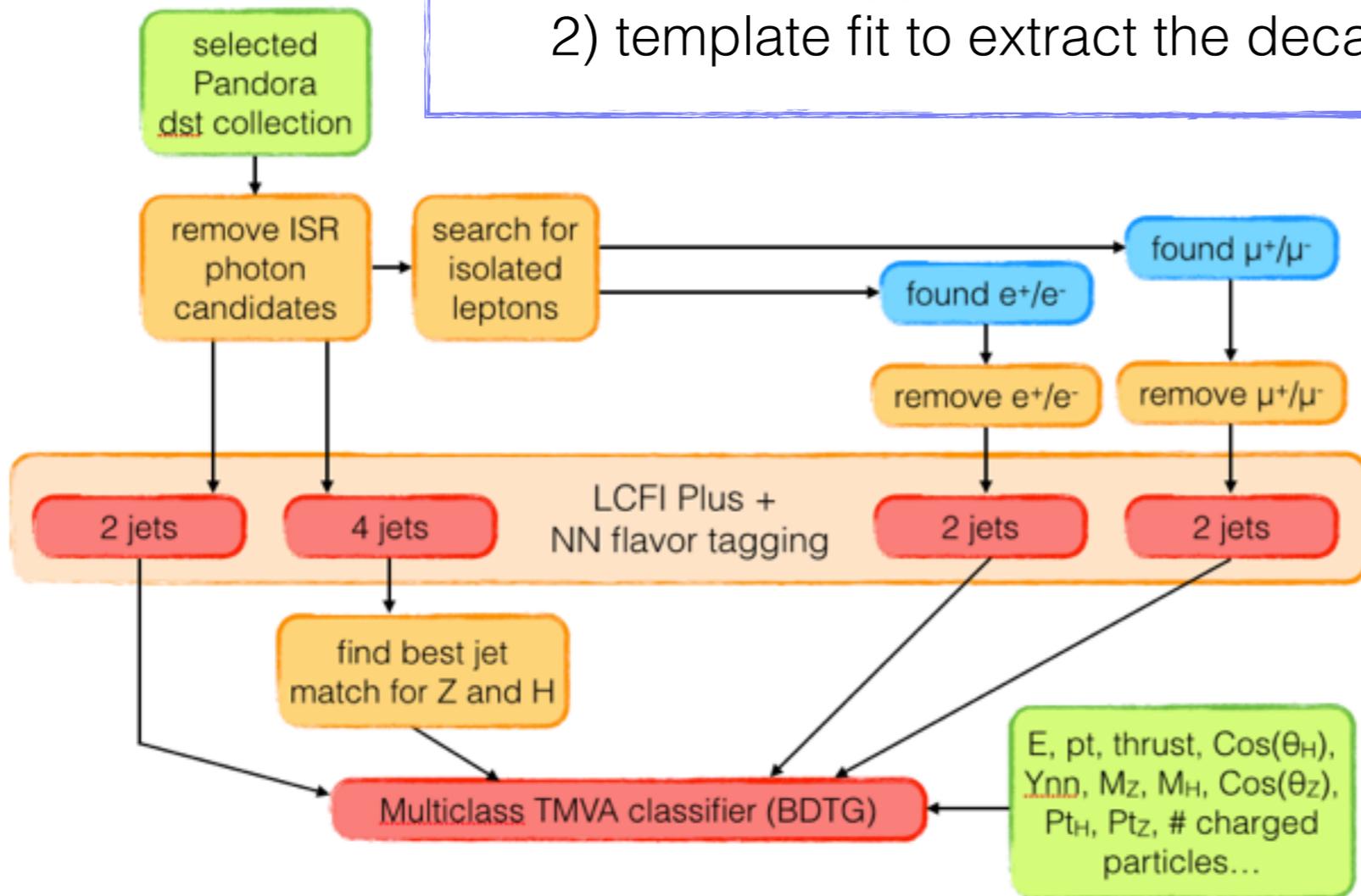


Diagrams have overlapping $H\nu\nu$ final state, when $Z \rightarrow \nu\nu$

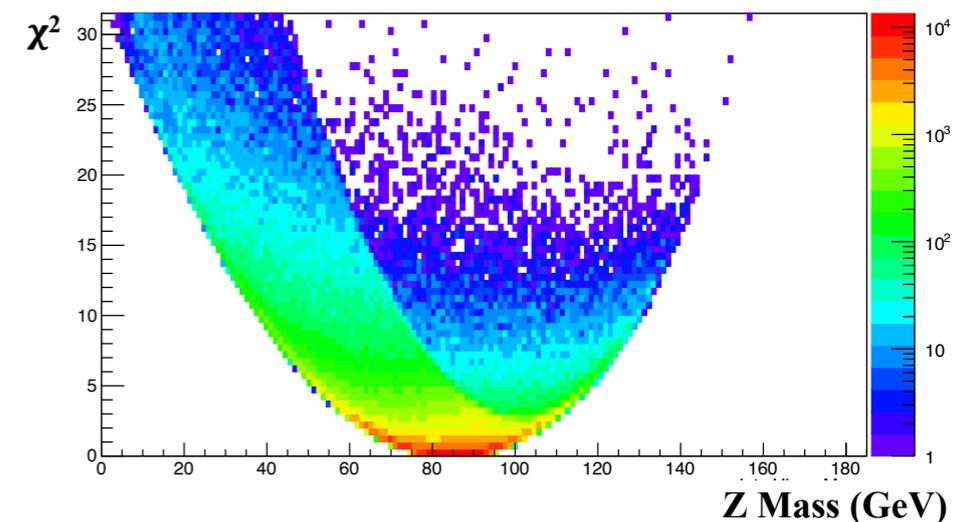
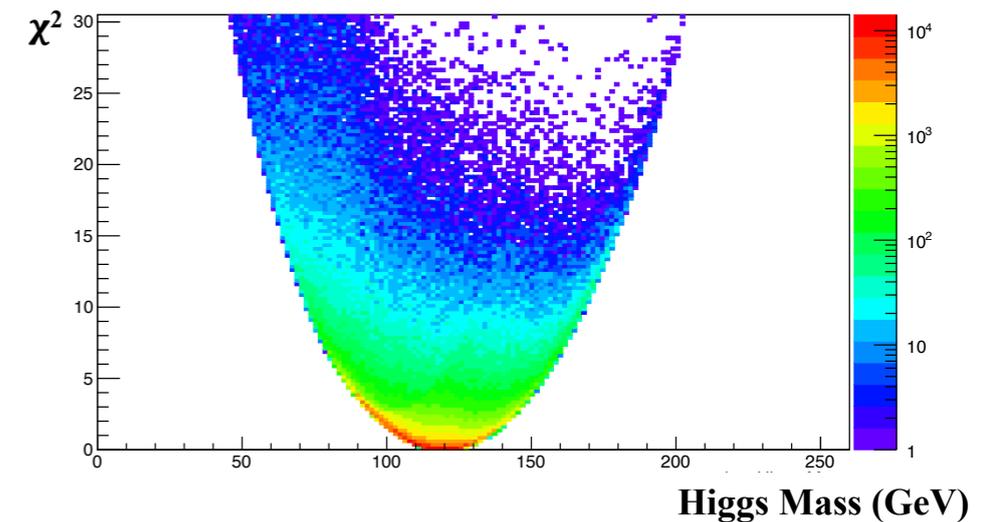
Event Selection

2-step analysis:

- 1) extract Higgs events from SM background
- 2) template fit to extract the decay fraction of the Higgs boson

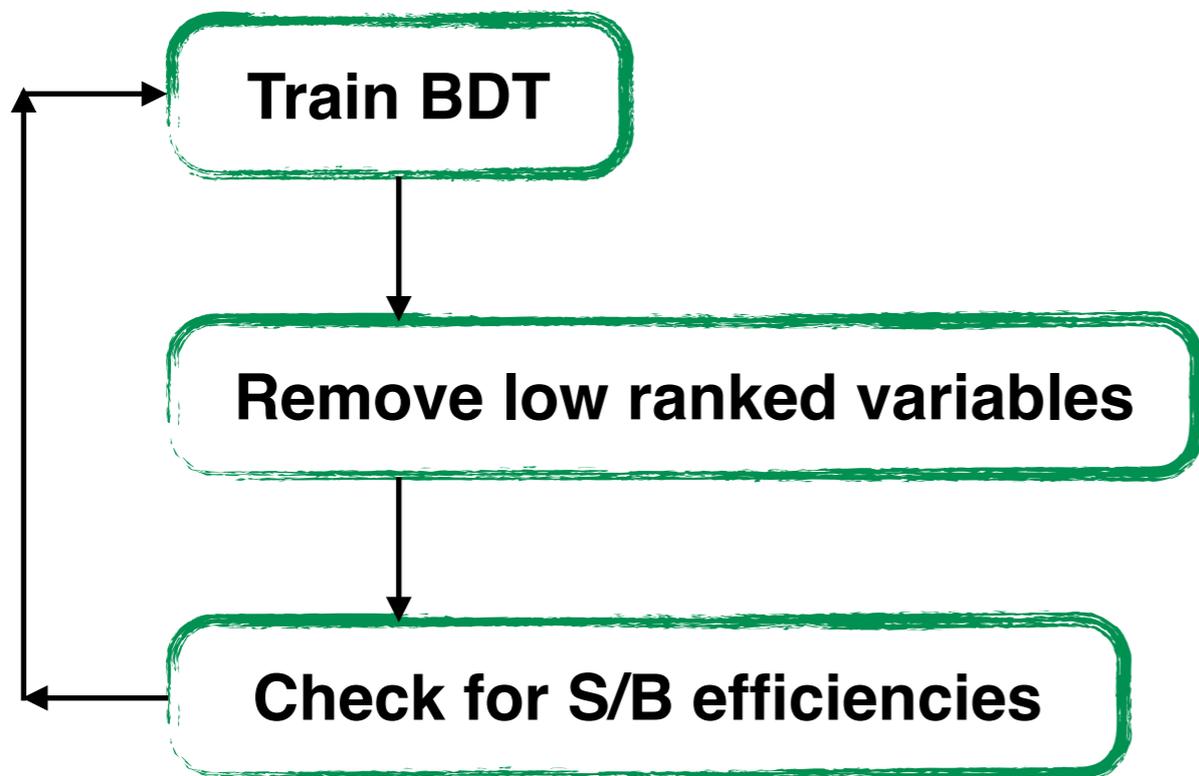


No Higgs jets flavor tagging information is used in the BDT

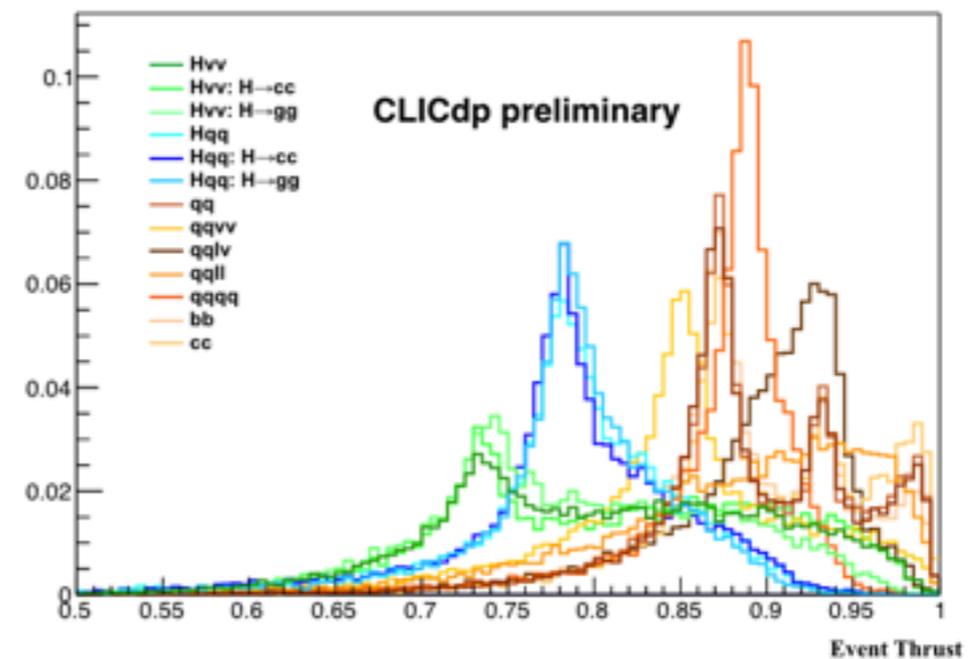
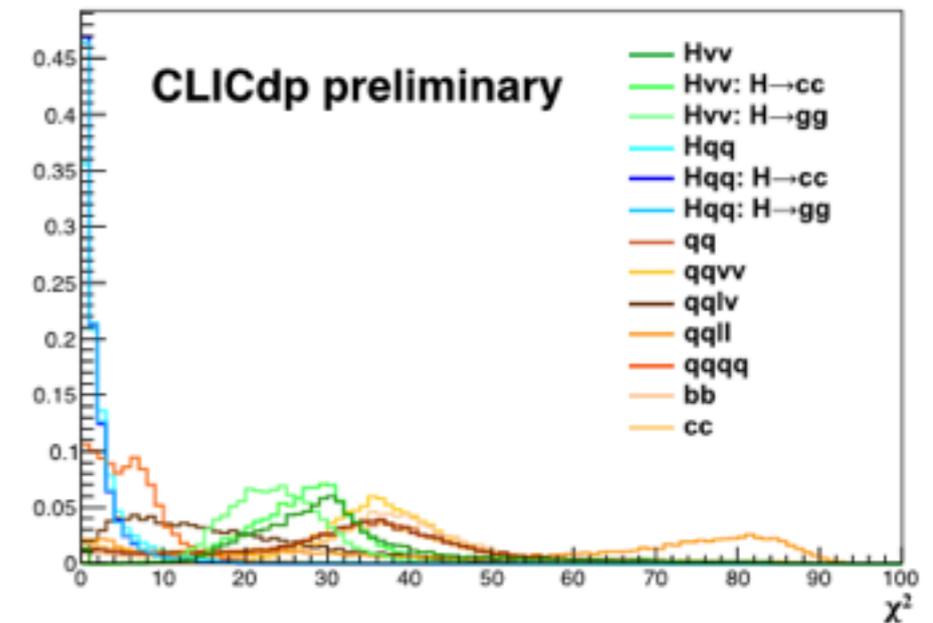


Event Selection

Initially, 150+ training variables, iterative method to reduce the MVA space (down to ~50 vars per analysis):



See backup for more variables distributions



Efficiencies

BDT cut optimized for best combined signal significance

VBF and ZH:Z \rightarrow $\nu\nu$

ZH:Z \rightarrow qq

| H $\nu\nu$ cutflow | nocuts | BDT (H $\nu\nu$) > 0.16 | Total Efficiencies |
|------------------------|---------------------|--------------------------|--------------------|
| H \rightarrow bb | 14456 | 8375 | 58% |
| H \rightarrow cc | 729 | 380 | 52% |
| H \rightarrow gg | 2185 | 1373 | 63% |
| H \rightarrow others | 8398 | 599 | 7% |
| qq | 12x10 ⁶ | 1092 | 0.009% |
| qqlv | 2.9x10 ⁶ | 2805 | 0.09% |
| qqvv | 16x10 ⁴ | 2357 | 1.5% |
| qqqq | 2.8x10 ⁶ | < 100 | < 0.001% |

| Hqq cutflow | nocuts | BDT (Hqq) > 0.16 | Total Efficiencies |
|------------------------|---------------------|------------------|--------------------|
| H \rightarrow bb | 26209 | 10563 | 40% |
| H \rightarrow cc | 1322 | 407 | 31% |
| H \rightarrow gg | 3961 | 1340 | 34% |
| H \rightarrow others | 15226 | 1706 | 11% |
| qq | 12x10 ⁶ | 8270 | 0.06% |
| qqlv | 2.9x10 ⁶ | < 100 | < 0.001% |
| qqvv | 16x10 ⁴ | < 10 | < 0.001% |
| qqqq | 2.8x10 ⁶ | 9899 | 0.35% |

Flavor Space Template Fit

- Binned maximum likelihood fit on multi-dimensional space: b and c likelihoods and H_{Pt}
- Assume Poissonian fluctuation for each data bin:

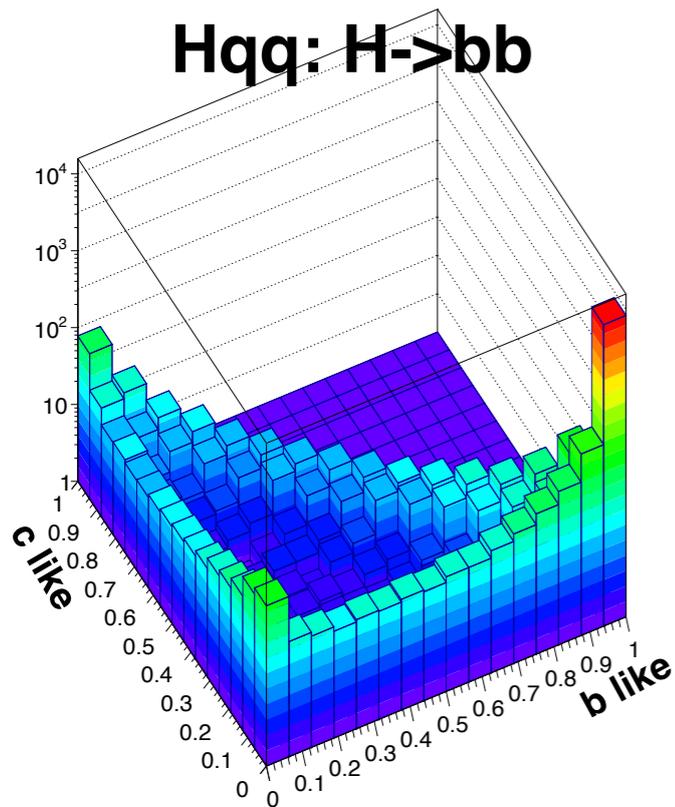
$$P_{ijk} = \frac{\mu^n e^{-\mu}}{n!}$$

with n = number of data entries in bin ijk
and $\mu = \sum w_m T_m$ for the same bin, with w_m being the weights and T_m the templates

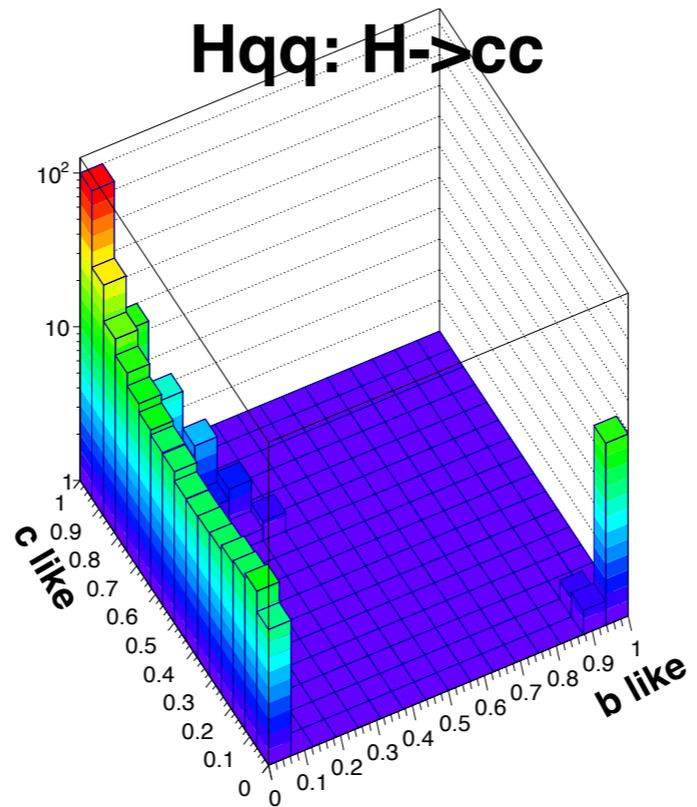
- Then the Likelihood is the product of P_{ijk} in all bins
- Find the w_m that maximize this value
- Repeat the procedure few thousand times in a toy MC setup, drawing data-like distribution from templates
- Fitting procedure performed fixing the SM background and $H \rightarrow$ others templates for improved stability

Templates

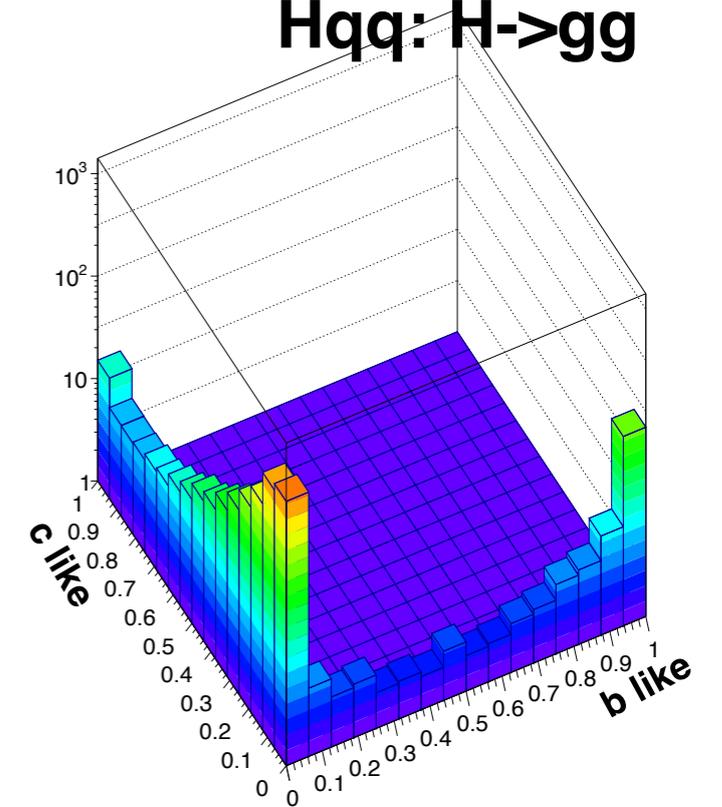
Hqq: H->bb



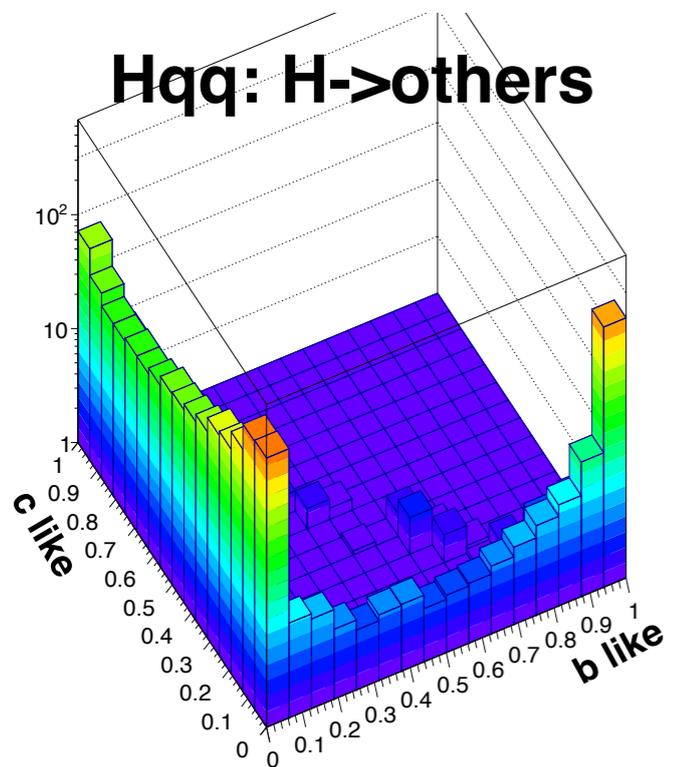
Hqq: H->cc



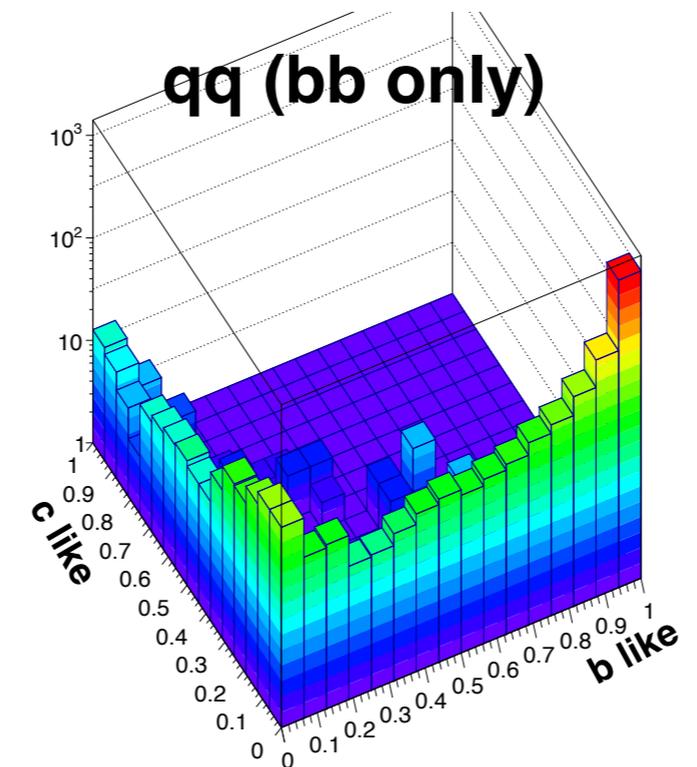
Hqq: H->gg



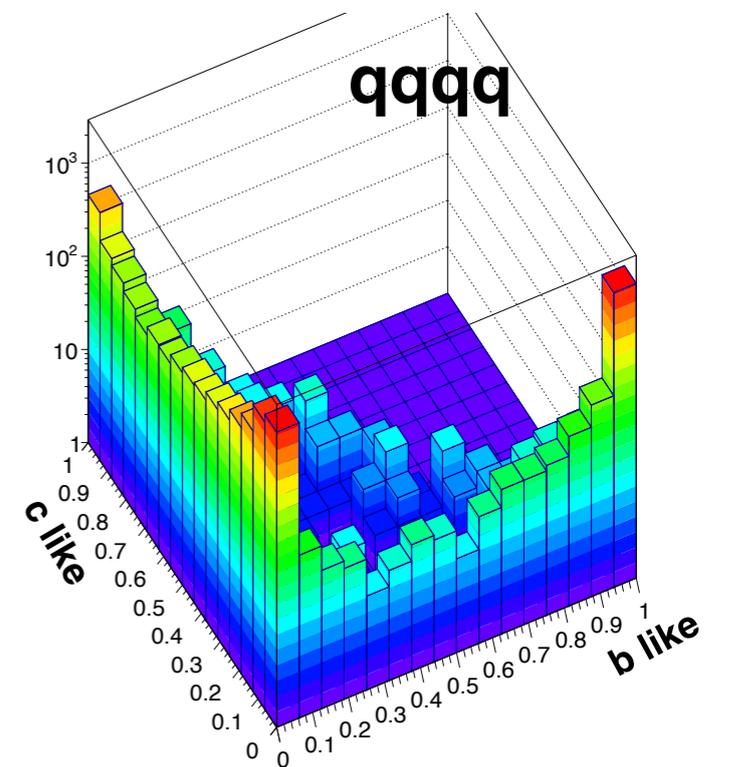
Hqq: H->others



qq (bb only)

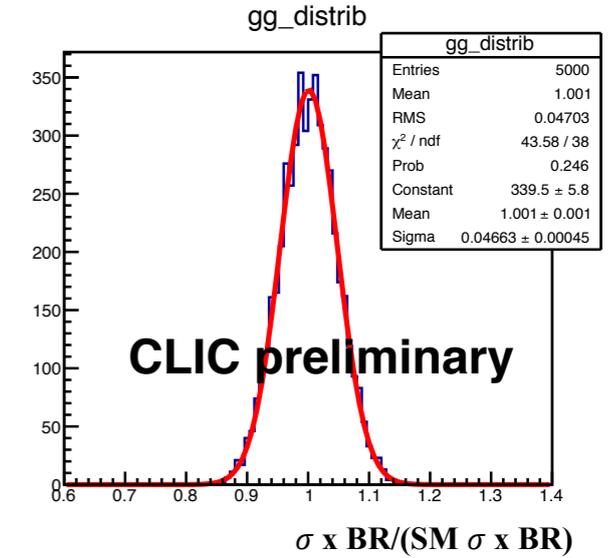
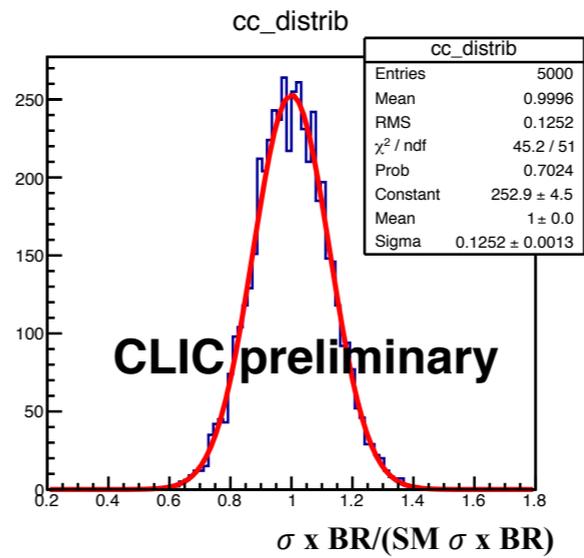
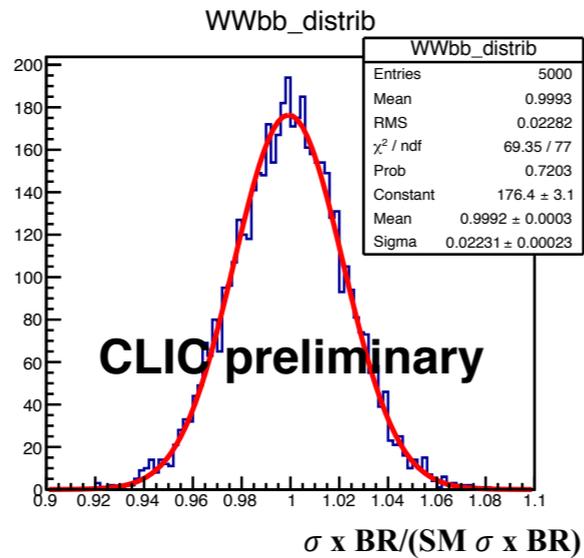
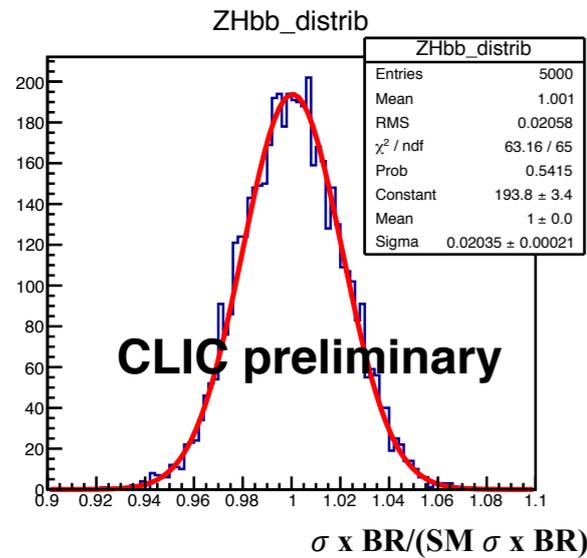


qqqq



Fit Results (Improved MC statistics)

Hvv Fit



Uncertainties

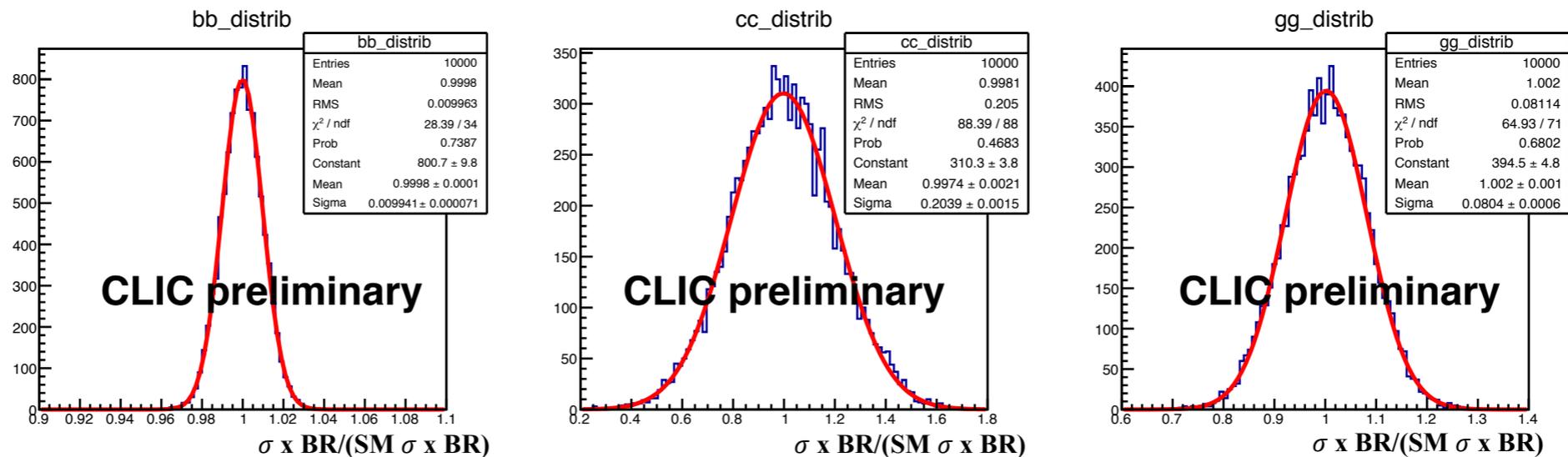
| | |
|---------------------|-------|
| Δ_{bb} (VBF) | 2.2% |
| Δ_{bb} (ZH) | 2.0% |
| Δ_{cc} | 12.5% |
| Δ_{gg} | 4.7% |

Correlations

| | Δ_{bb} (VBF) | Δ_{bb} (ZH) | Δ_{cc} | Δ_{gg} |
|---------------------|------------------------|-----------------------|---------------|---------------|
| Δ_{bb} (VBF) | 1 | -0.47 | -0.035 | -0.014 |
| Δ_{bb} (ZH) | | 1 | -0.04 | -0.02 |
| Δ_{cc} | | | 1 | -0.18 |
| Δ_{gg} | | | | 1 |

Fit Results (Improved MC statistics)

Hqq Fit



Uncertainties

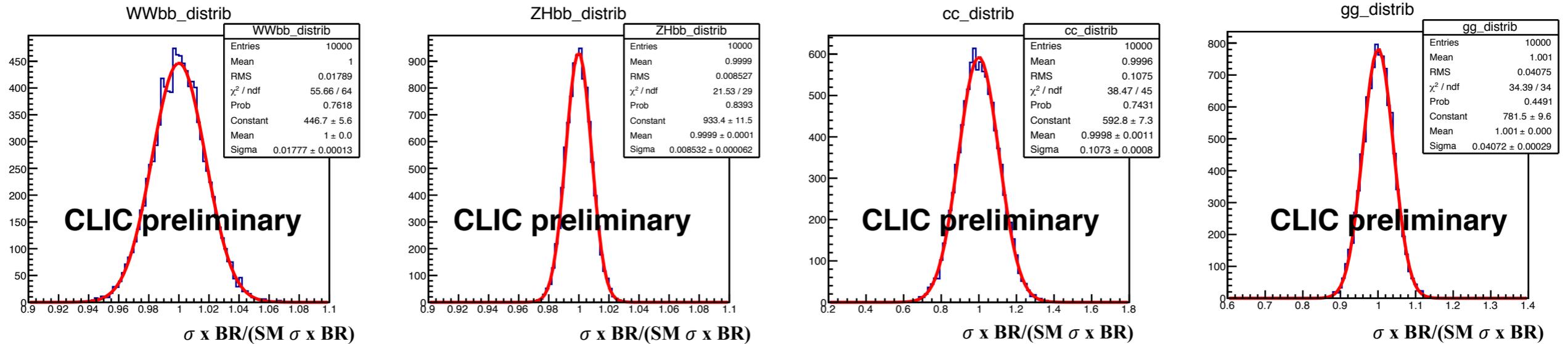
| | |
|--------------------|-------|
| Δ_{bb} (ZH) | 0.99% |
| Δ_{cc} | 20.4% |
| Δ_{gg} | 6.0% |

Correlations

| | Δ_{bb} (ZH) | Δ_{cc} | Δ_{gg} |
|--------------------|-----------------------|---------------|---------------|
| Δ_{bb} (ZH) | 1 | -0.099 | -0.12 |
| Δ_{cc} | | 1 | -0.20 |
| Δ_{gg} | | | 1 |

Fit Results (Improved MC statistics)

Combined Fit



Uncertainties

| | |
|---------------------|-------|
| Δ_{bb} (VBF) | 1.8% |
| Δ_{bb} (ZH) | 0.85% |
| Δ_{cc} | 10.7% |
| Δ_{gg} | 4.07% |

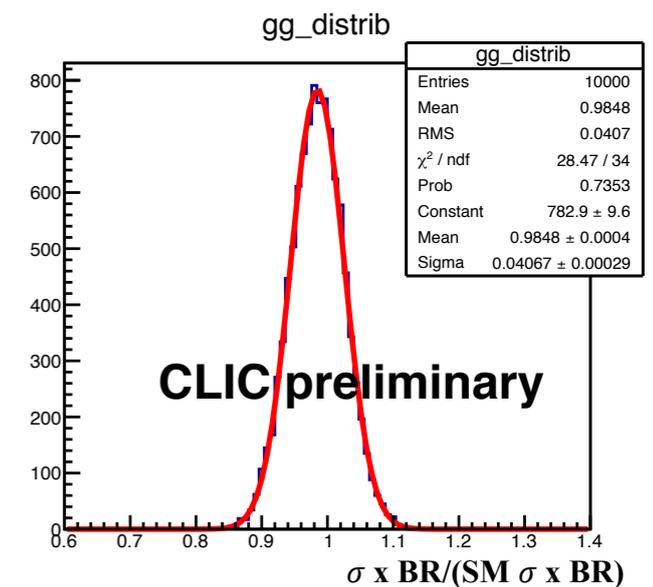
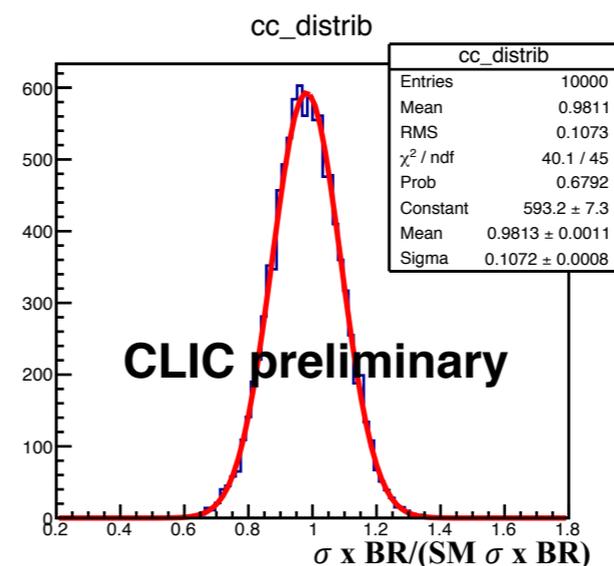
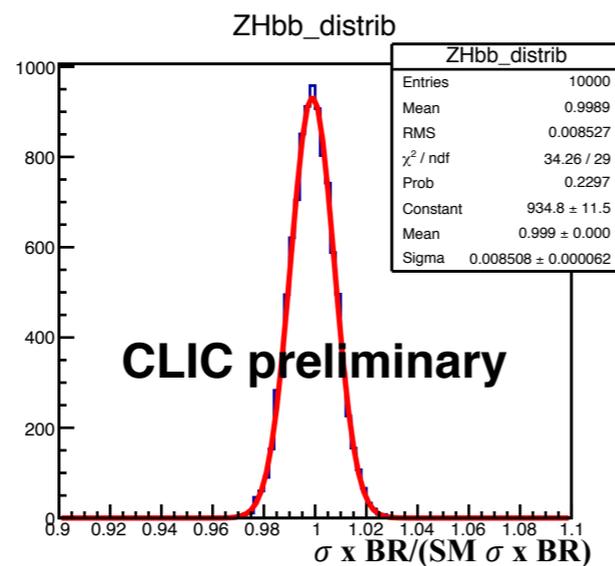
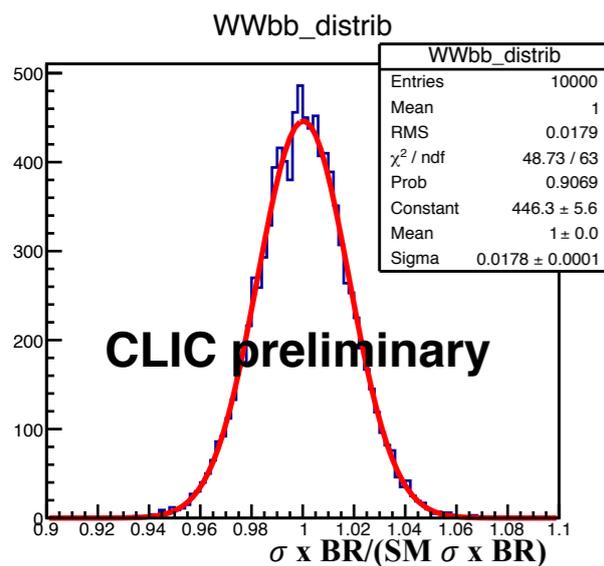
Correlations

| | Δ_{bb} (VBF) | Δ_{bb} (ZH) | Δ_{cc} | Δ_{gg} |
|---------------------|------------------------|-----------------------|---------------|---------------|
| Δ_{bb} (VBF) | 1 | -0.25 | -0.034 | -0.009 |
| Δ_{bb} (ZH) | | 1 | -0.06 | -0.06 |
| Δ_{cc} | | | 1 | -0.05 |
| Δ_{gg} | | | | 1 |

Fit Results - Systematics

Repeat the toyMC fitting procedure accounting for 3% error in combined $H \rightarrow \text{other}$ template and 1% for SM background

$H \rightarrow \text{other} + 3\%$,
SM background $+ 1\%$



WW \rightarrow H \rightarrow bb and ZH: H \rightarrow bb unaffected,
2% in H \rightarrow cc, 1.5% in H \rightarrow gg

All systematic error are well below statistical uncertainty

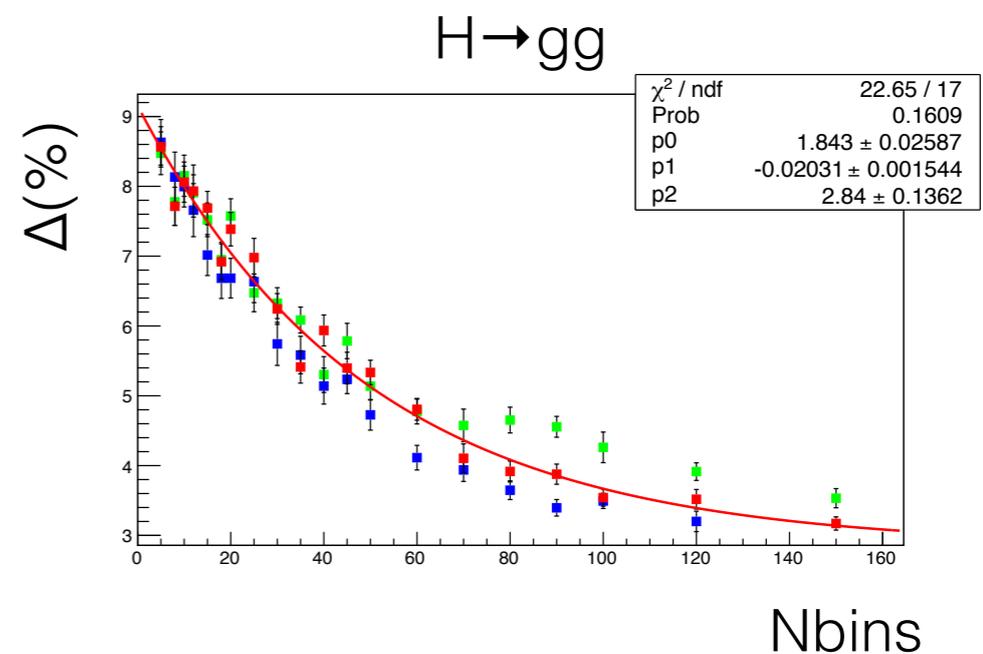
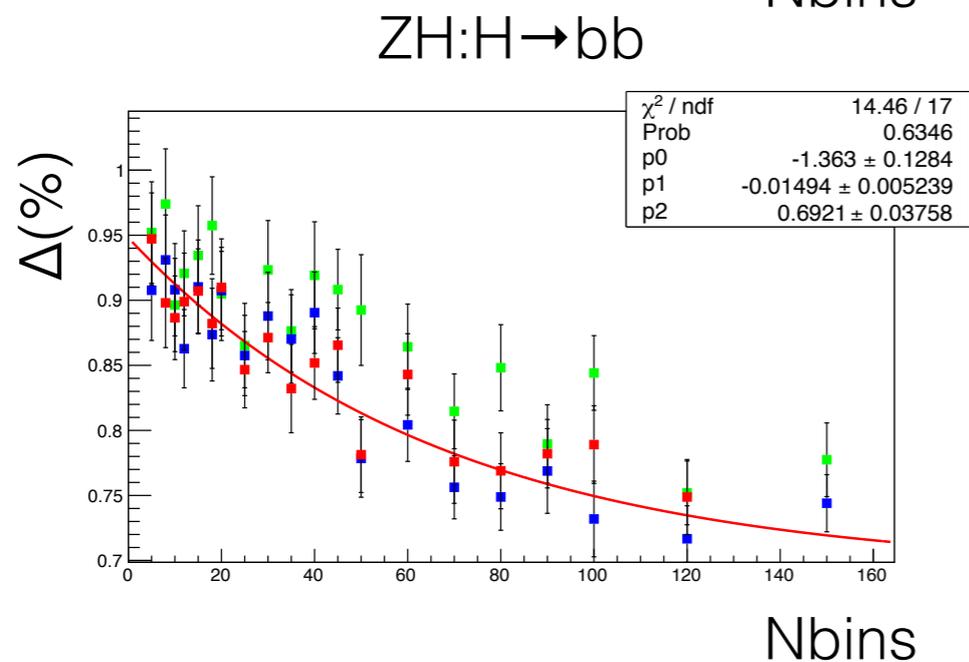
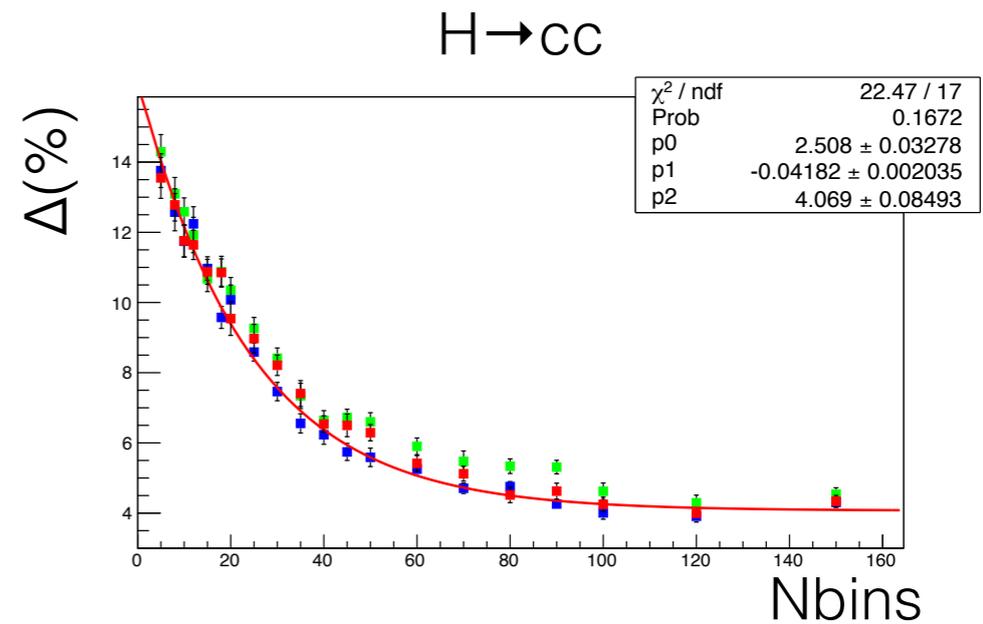
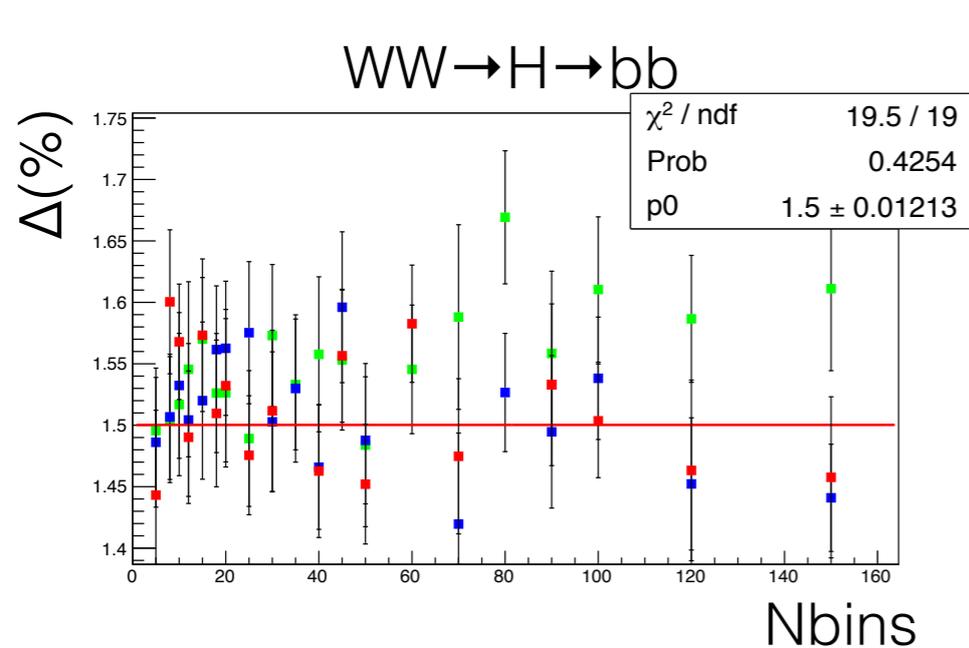
Conclusions

- The Γ_H needs high precision measurements on Higgs hadronic decays, in particular $H \rightarrow bb$
- With this study we can investigate $\sigma \times \text{BR}$ for ZH: $H \rightarrow bb$ and $WW \rightarrow H \rightarrow bb$. With 500fb^{-1} of data we get to and get sub-percent precision and 1.8% precision respectively
- $H \rightarrow gg$ can be measured at the 4% level
- $H \rightarrow cc$, due to the low branching fraction, can be measured with a precision of $\sim 10.5\%$
- The correlation matrix can be used in the global fit to improve the measurement of Γ_H
- Systematic uncertainties for SM background and other Higgs branching fractions are well below statistical uncertainties in all Higgs hadronic channels

BACKUP

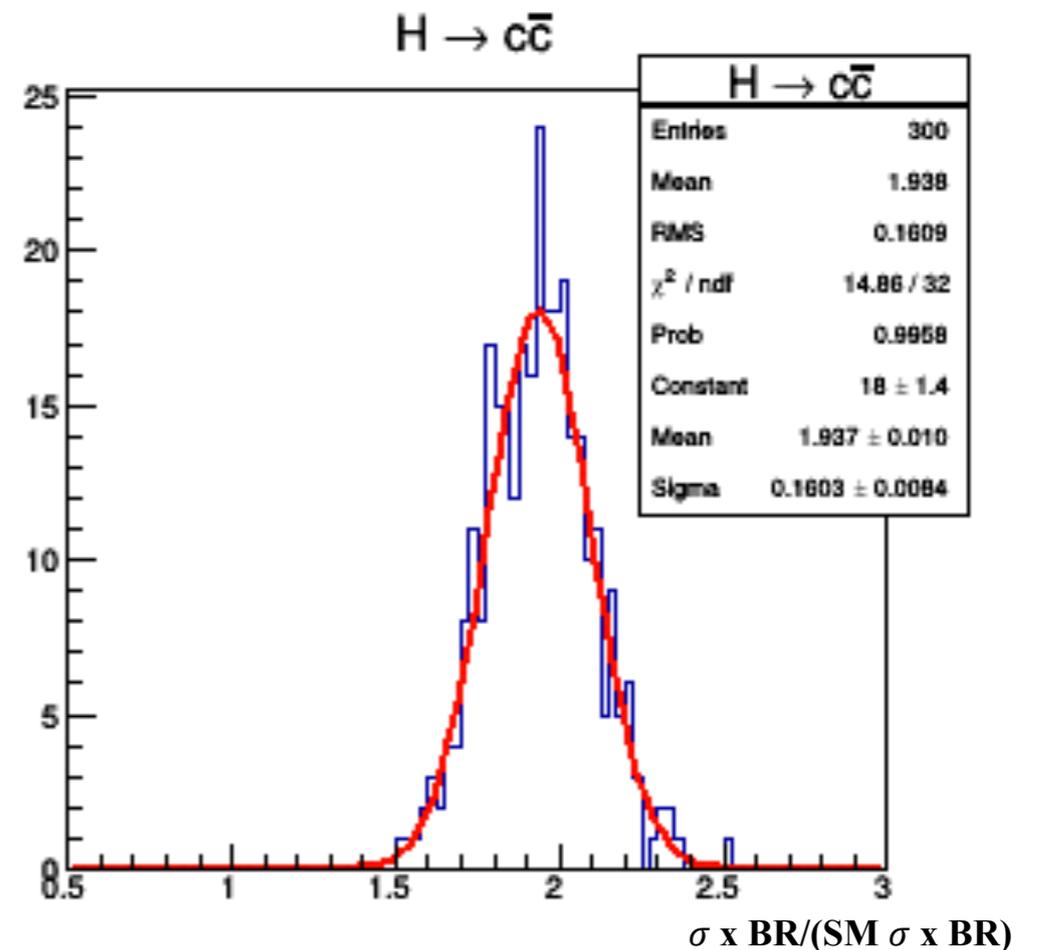
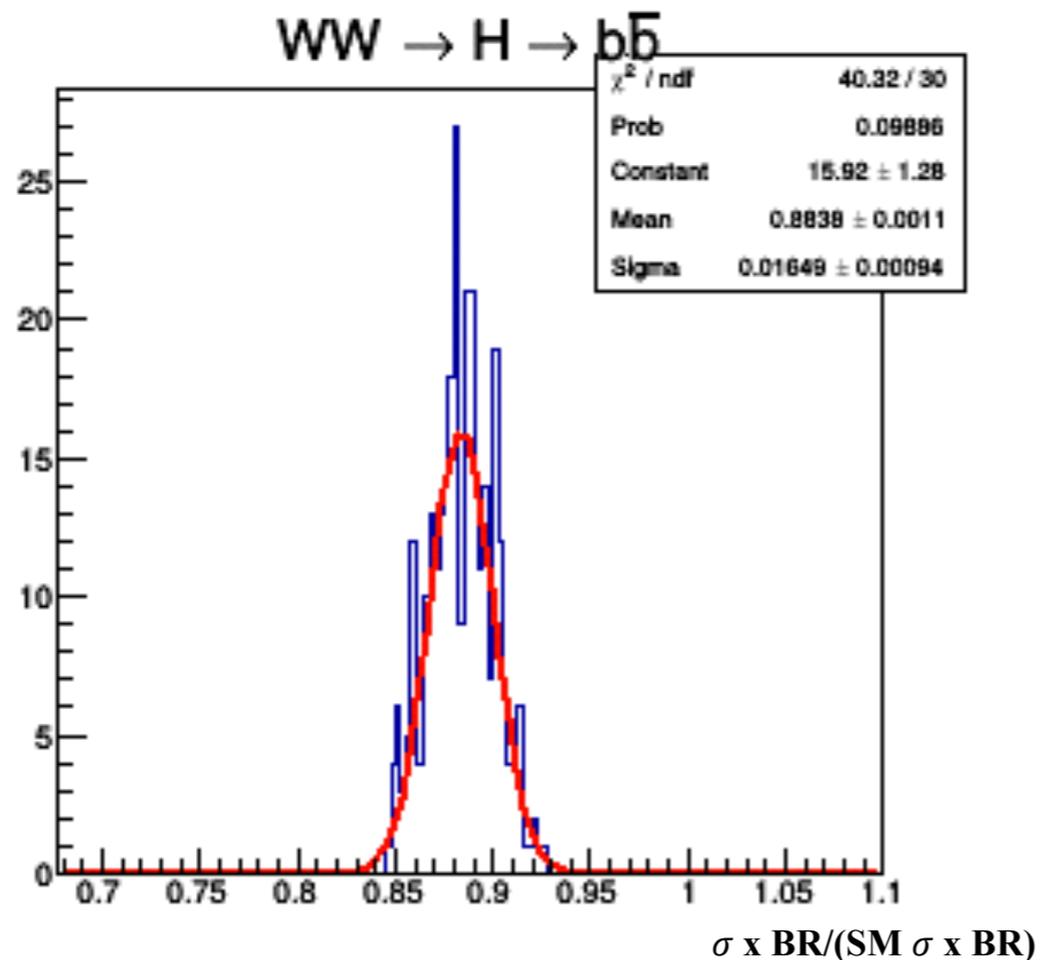


Template Fit (with limited MC statistics)



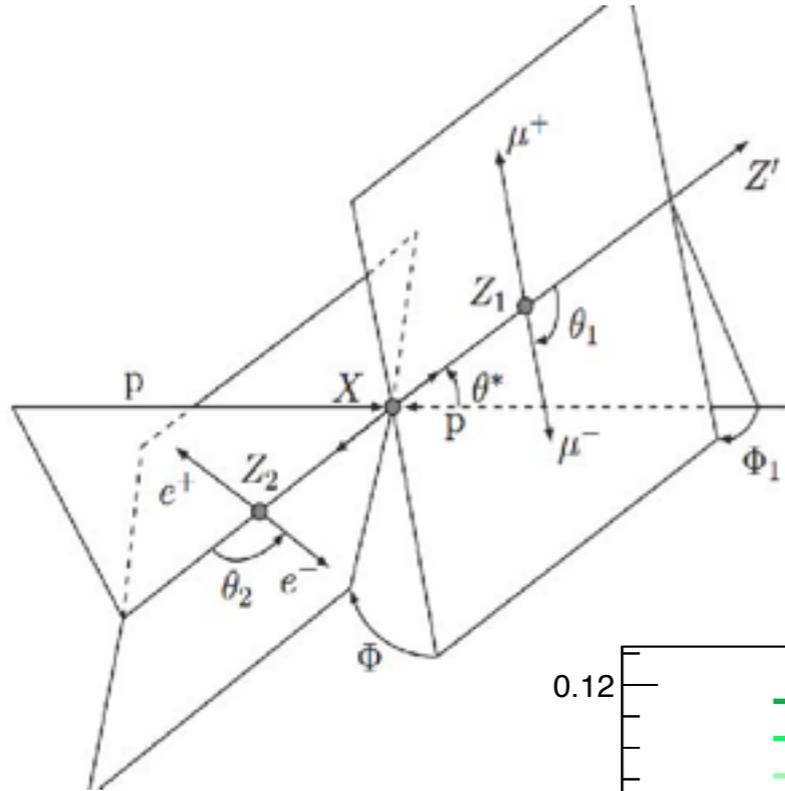
At first it seems that a finer binning in every dimension dramatically improves fit resolution

Template Fit (with limited MC statistics)

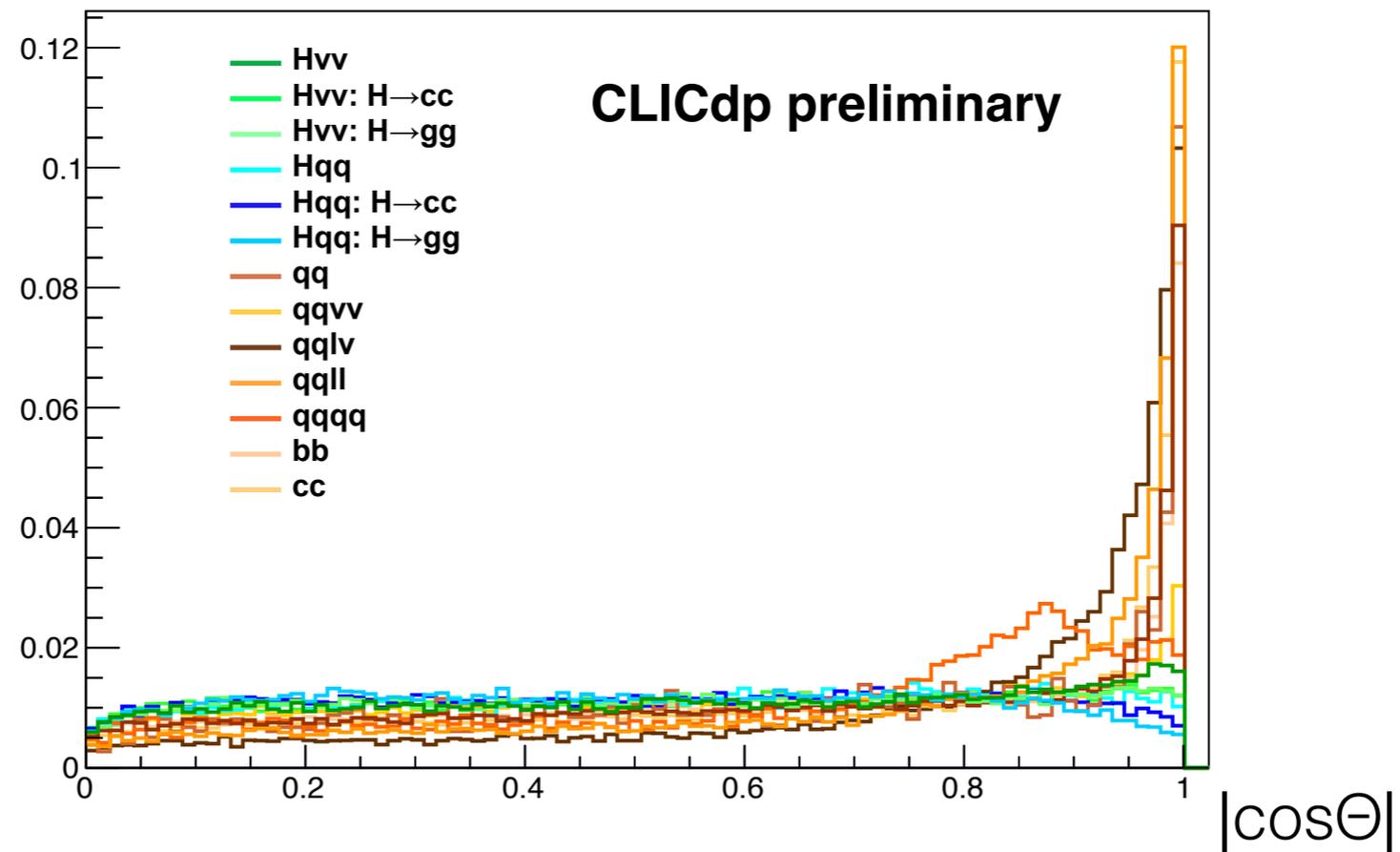


Repeating the procedure with independent distributions for templates and data
→ enormous discrepancies in fit results
→ asymptotic resolution improvement is unphysical
(driven by artifacts in the fitted templates, generated by the limited MC statistics)

Spin Analysis

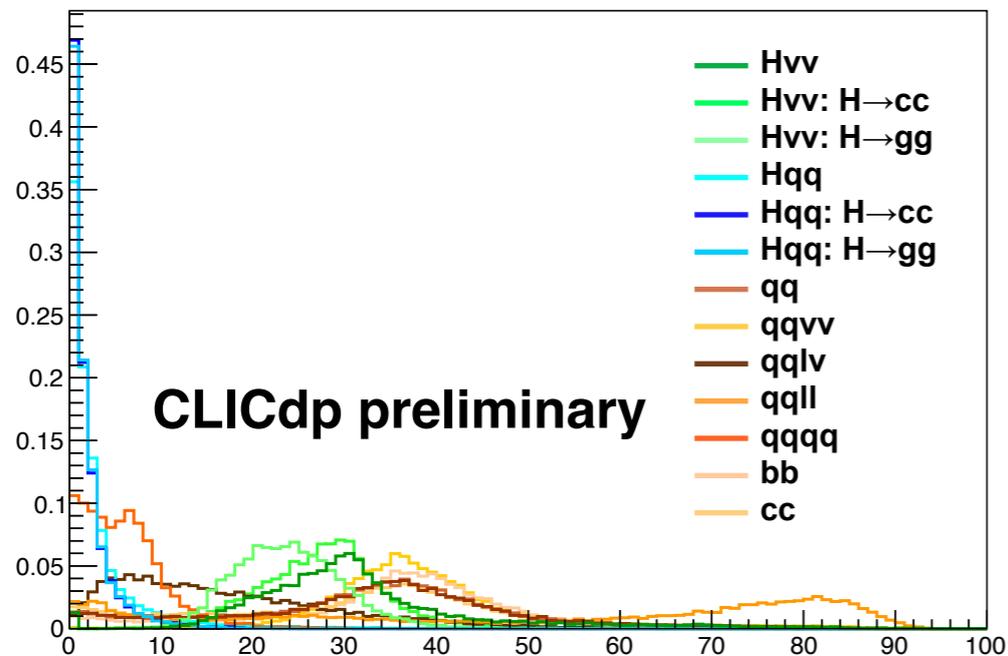


Angle between leading energy jet and flight direction of the Higgs in the Higgs frame of reference

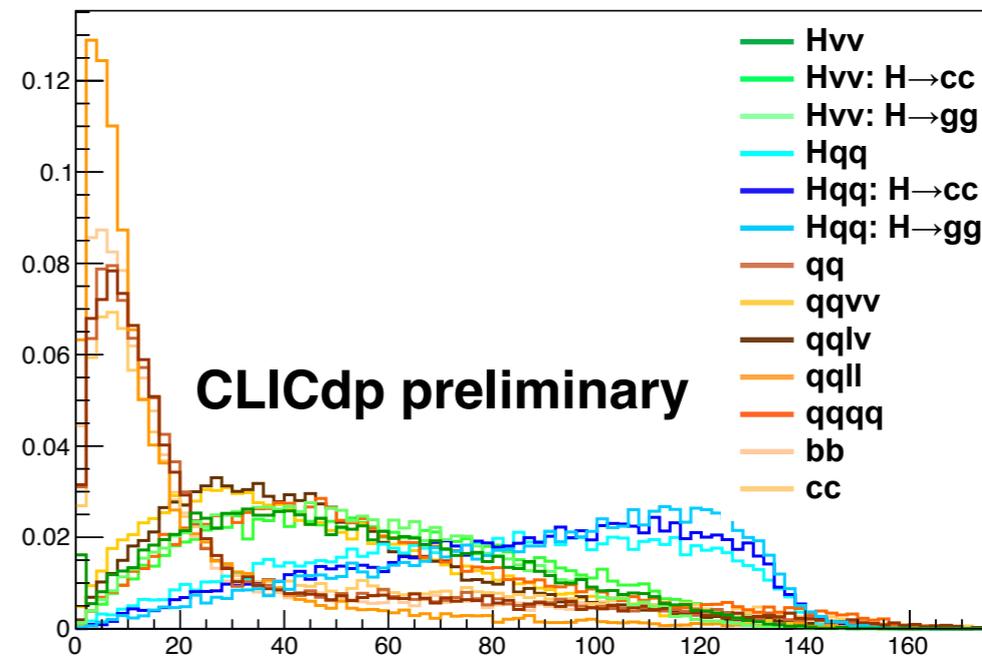


BDT input variables

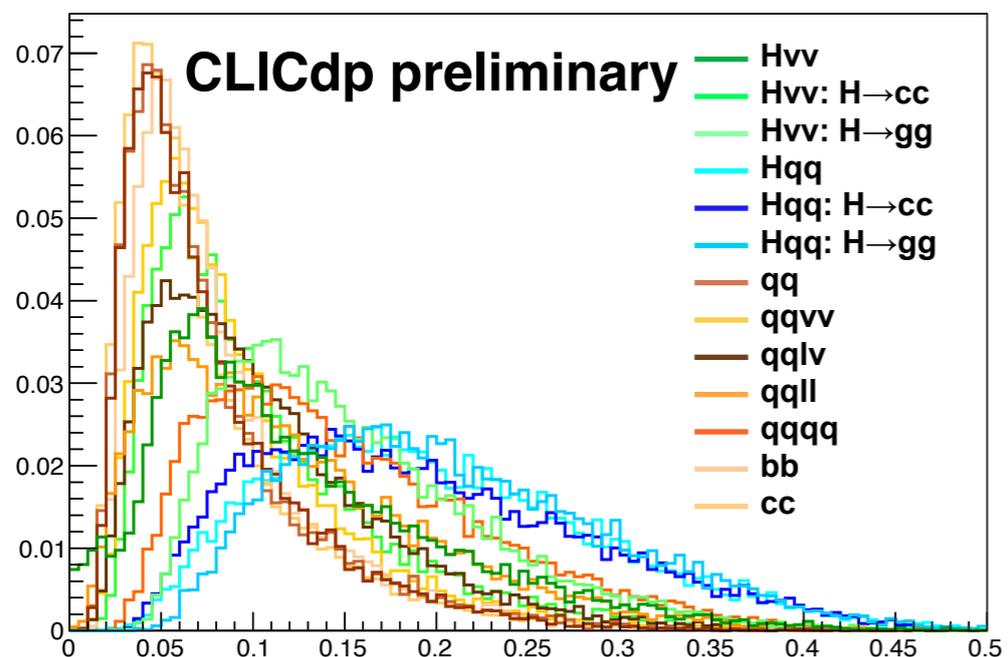
Chi2



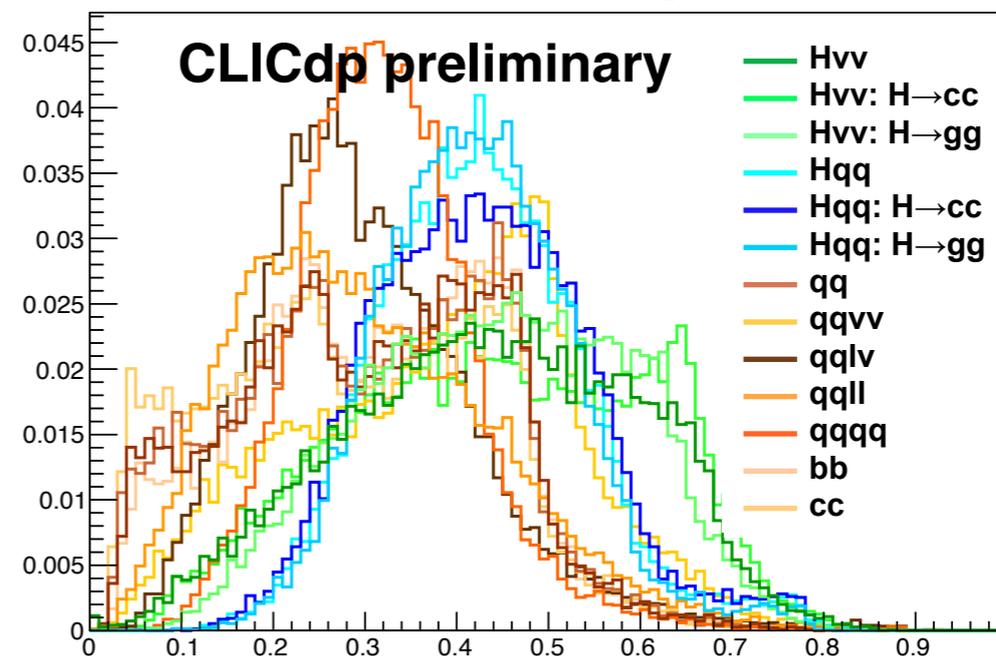
Higgs Pt



Thrust Minor

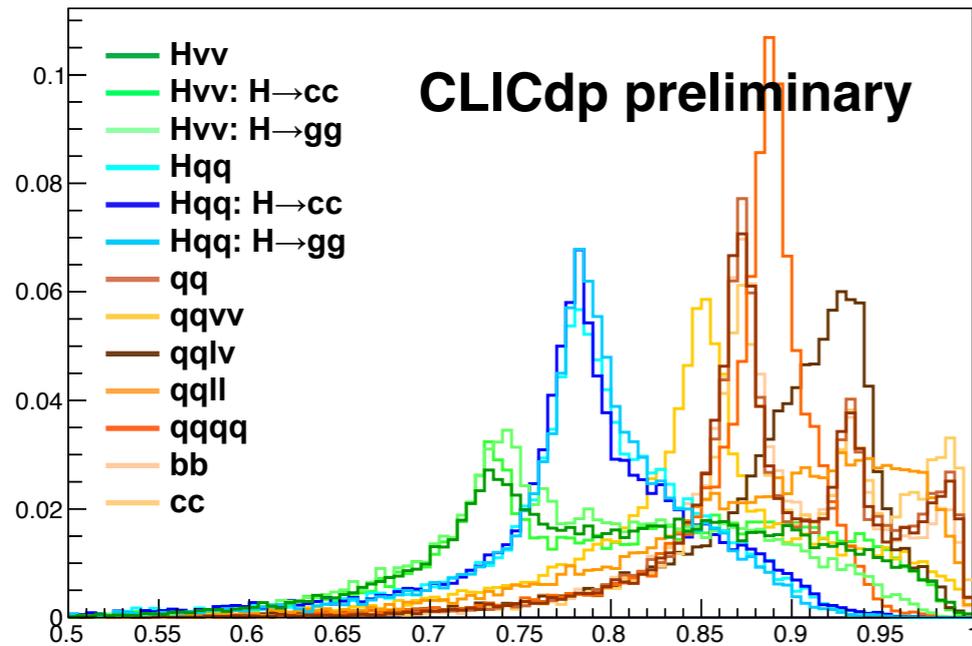


Thrust Major

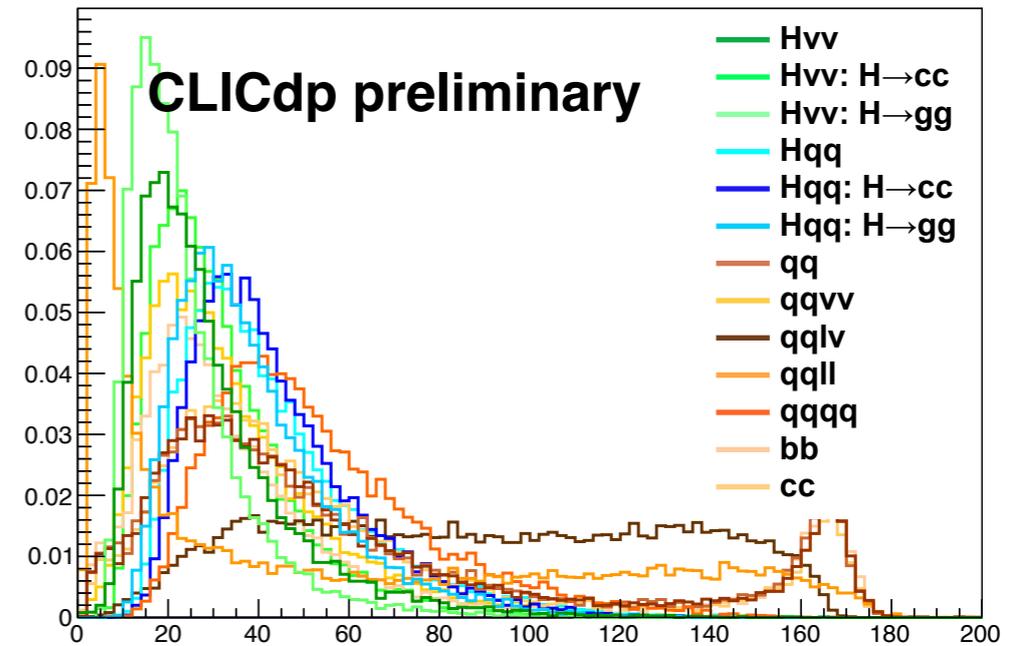


BDT input variables

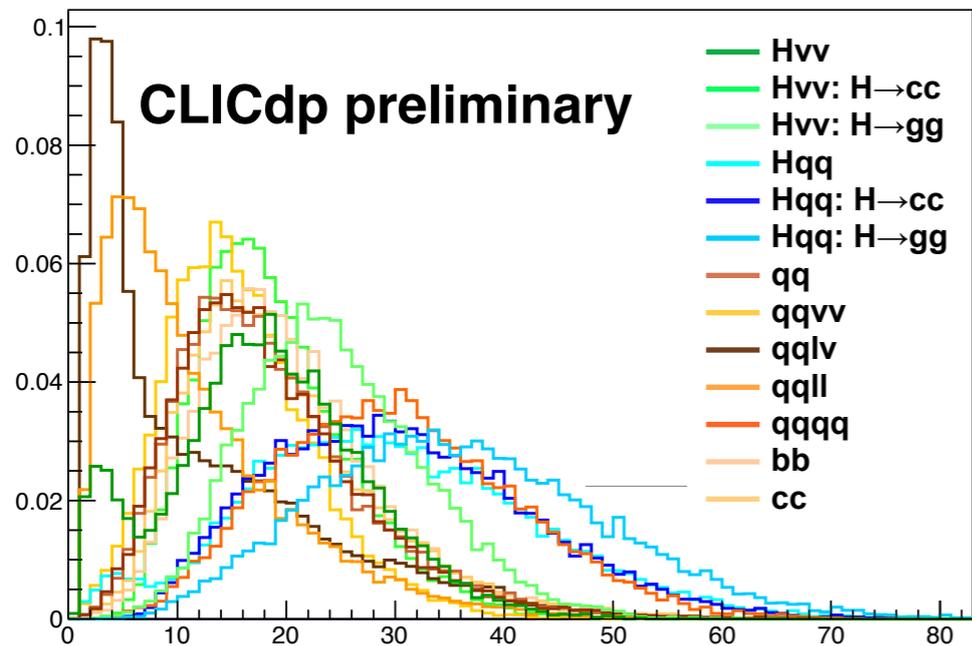
Thrust



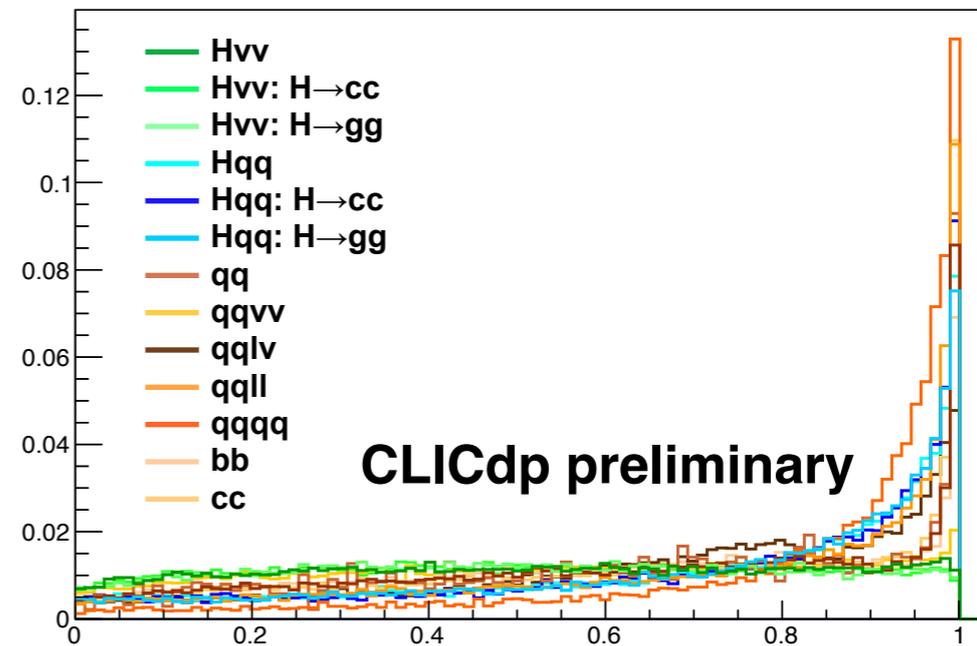
Highest momentum track



of tracks in Higgs jet 2



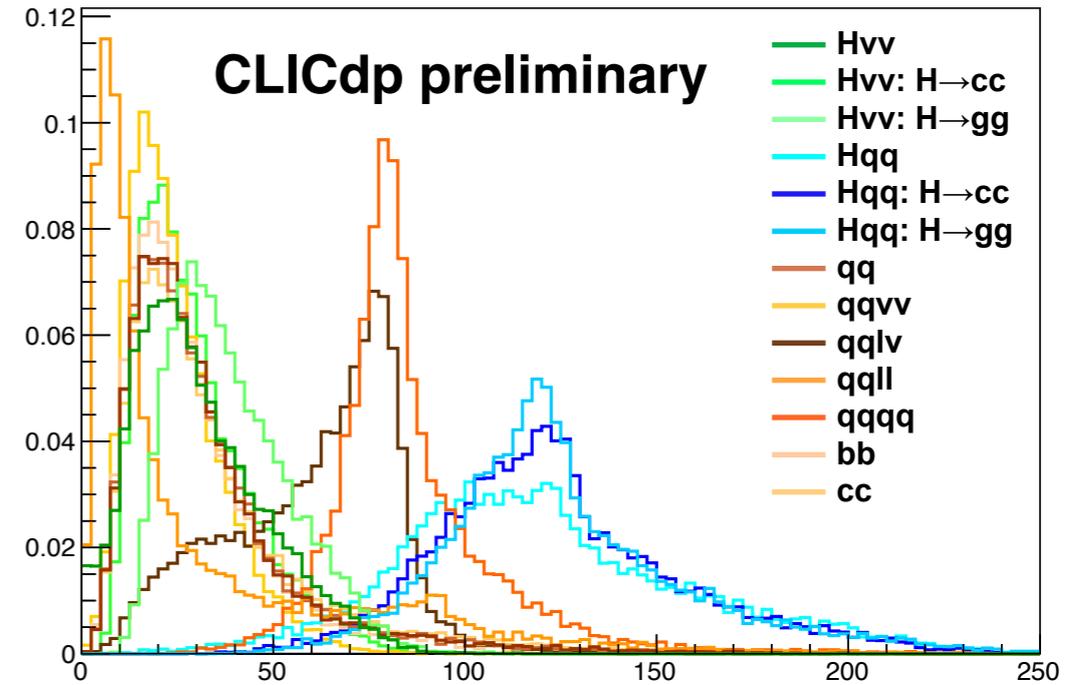
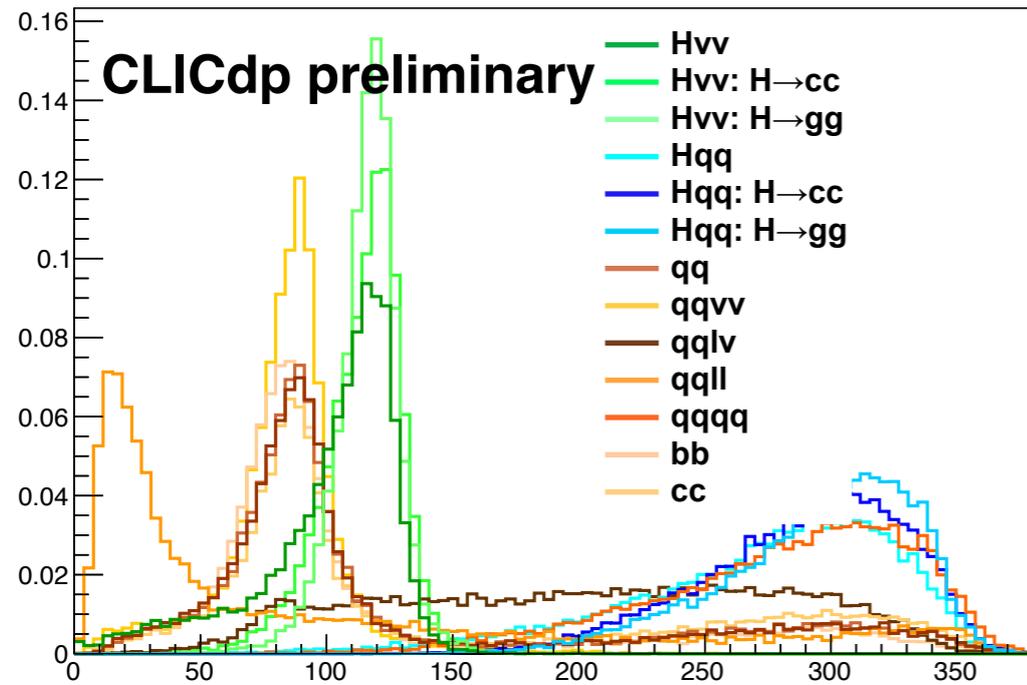
Higgs candidate spin



BDT input variables

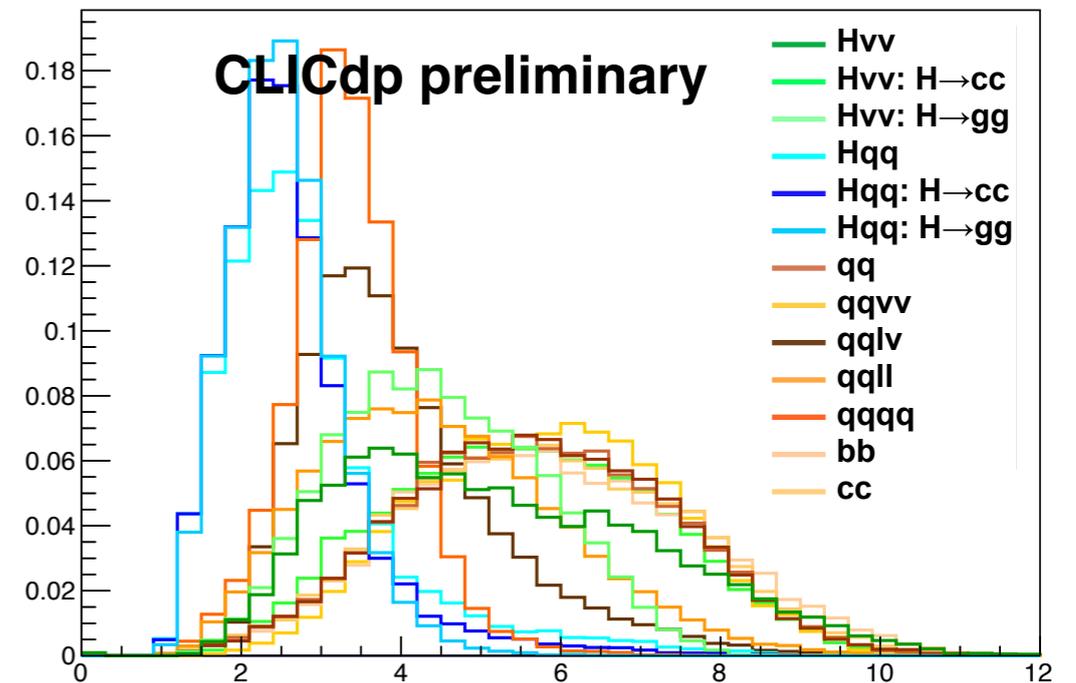
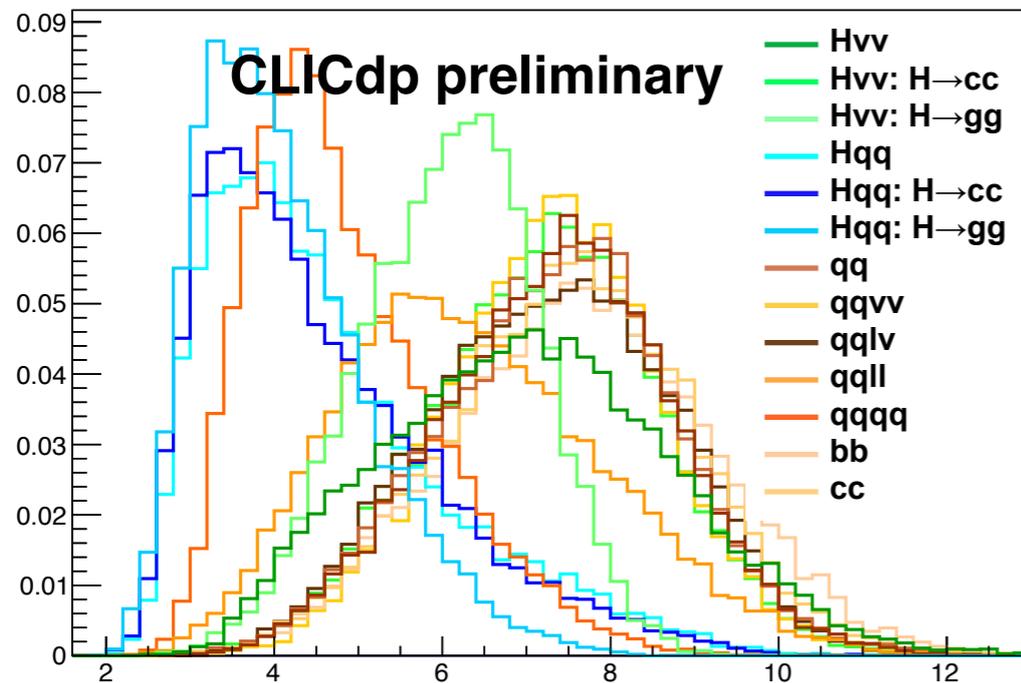
2 jets invariant mass

Higgs jet highest mass



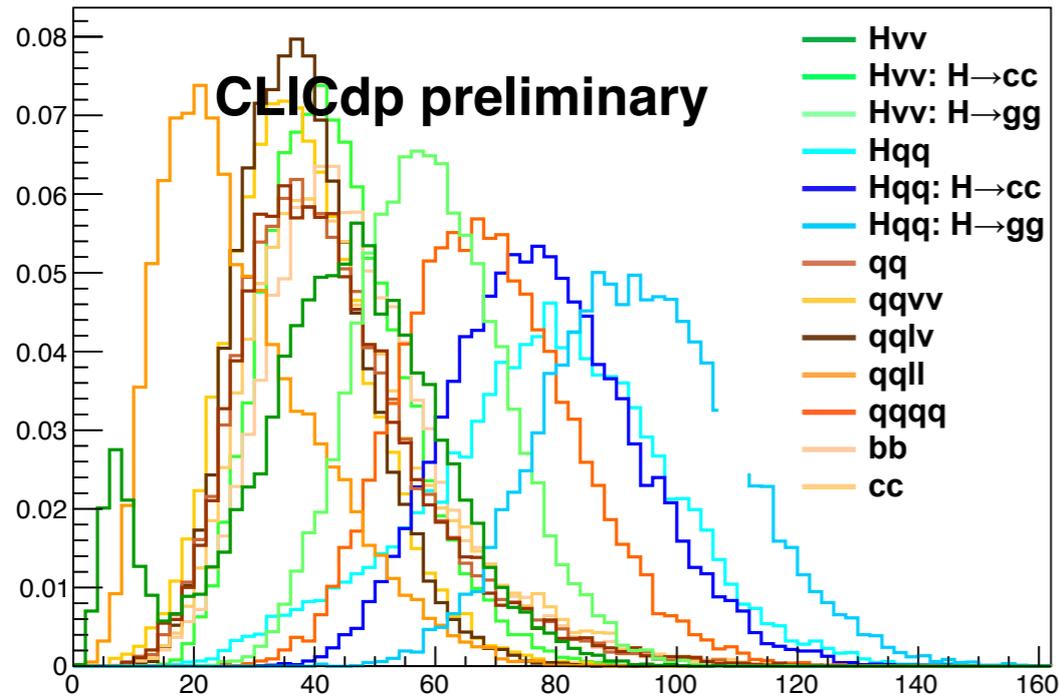
-Log(Y34)

-Log(Y23)

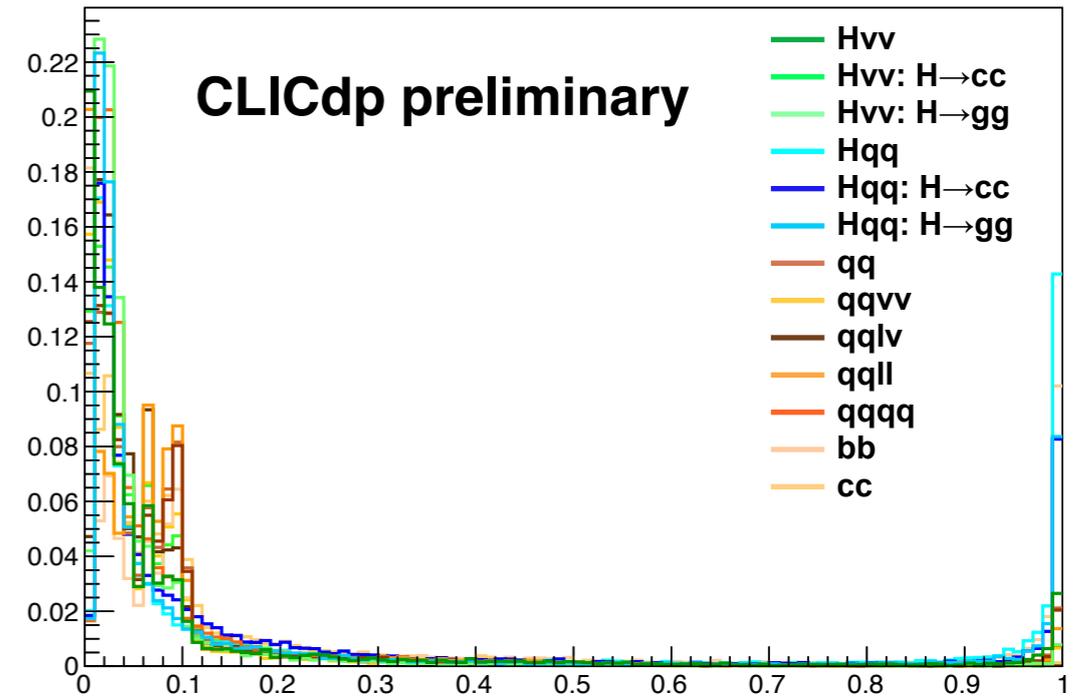


BDT input variables

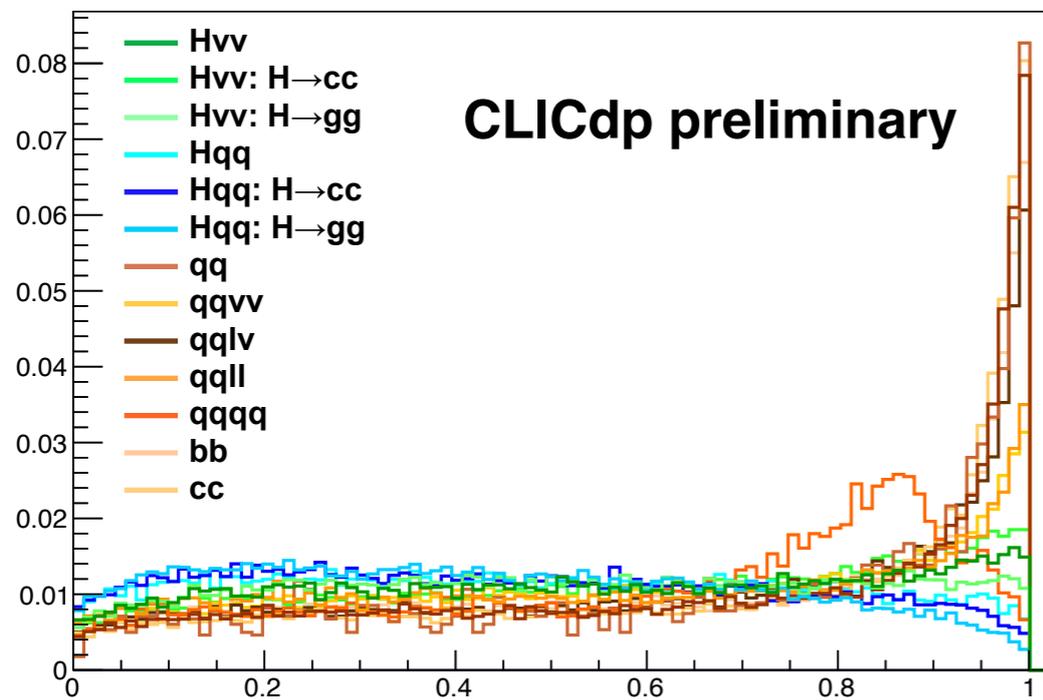
of tracks



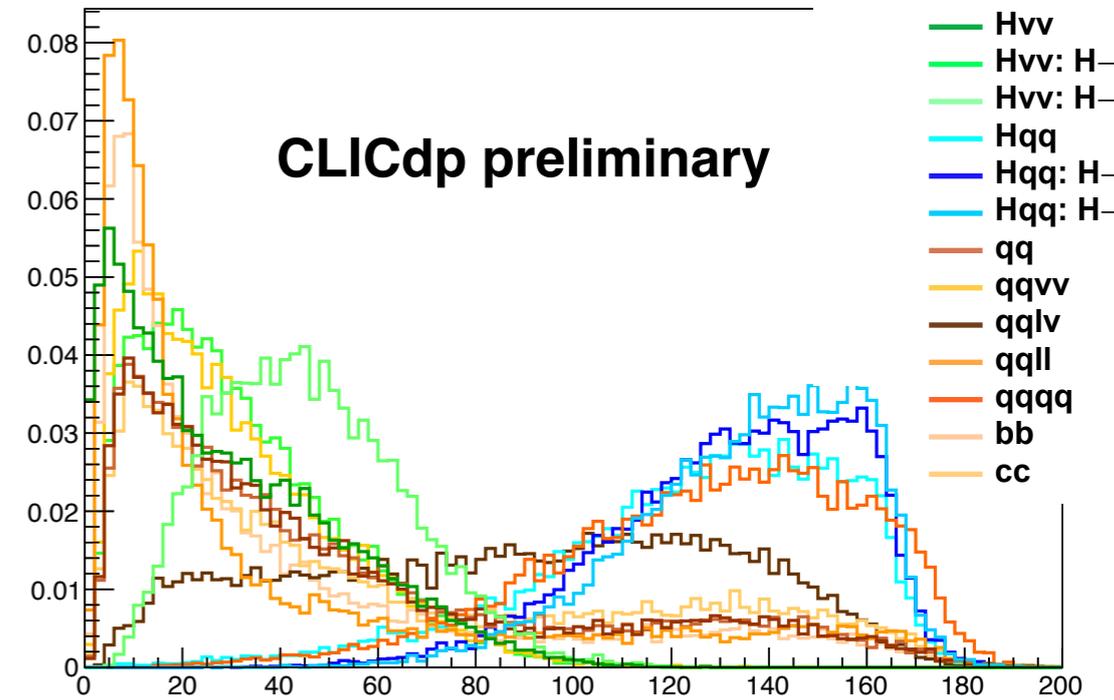
Z boson candidate B tag



Z boson candidate spin



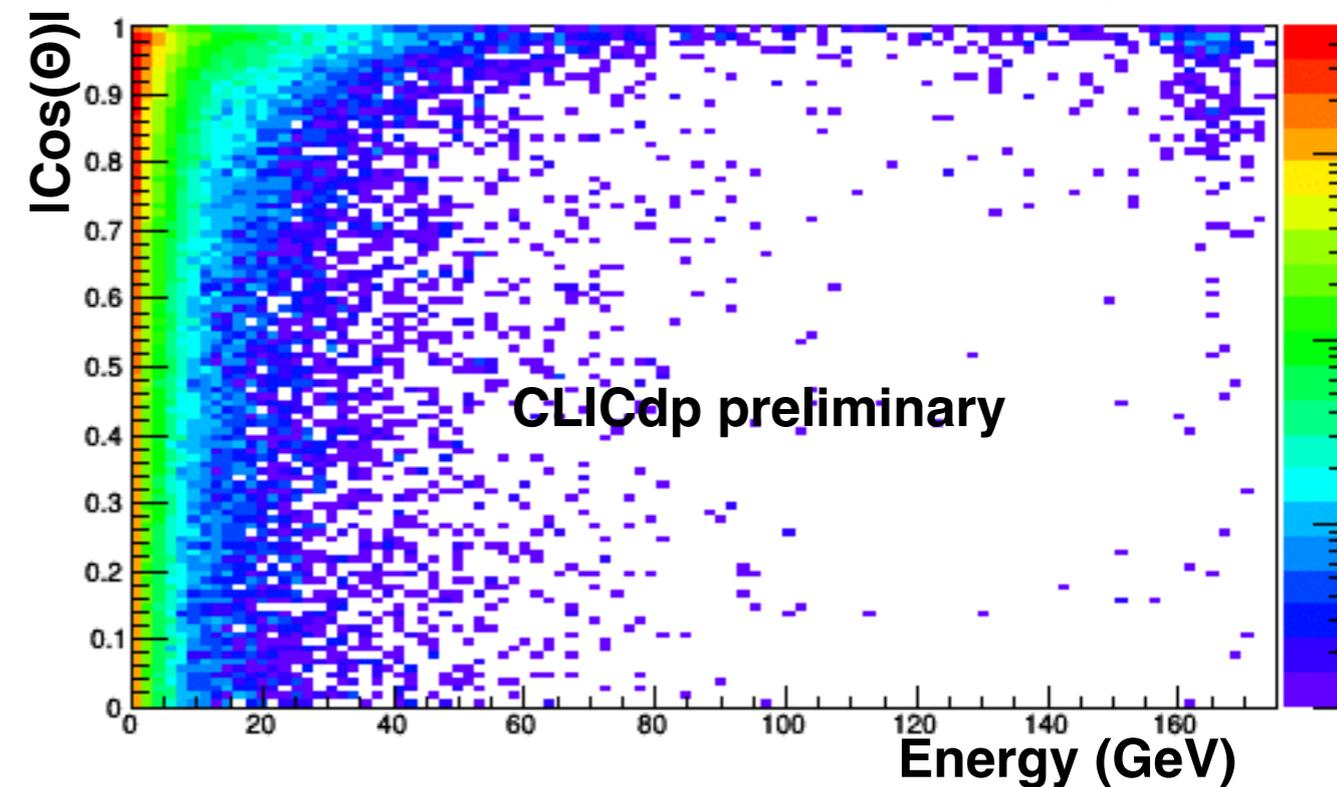
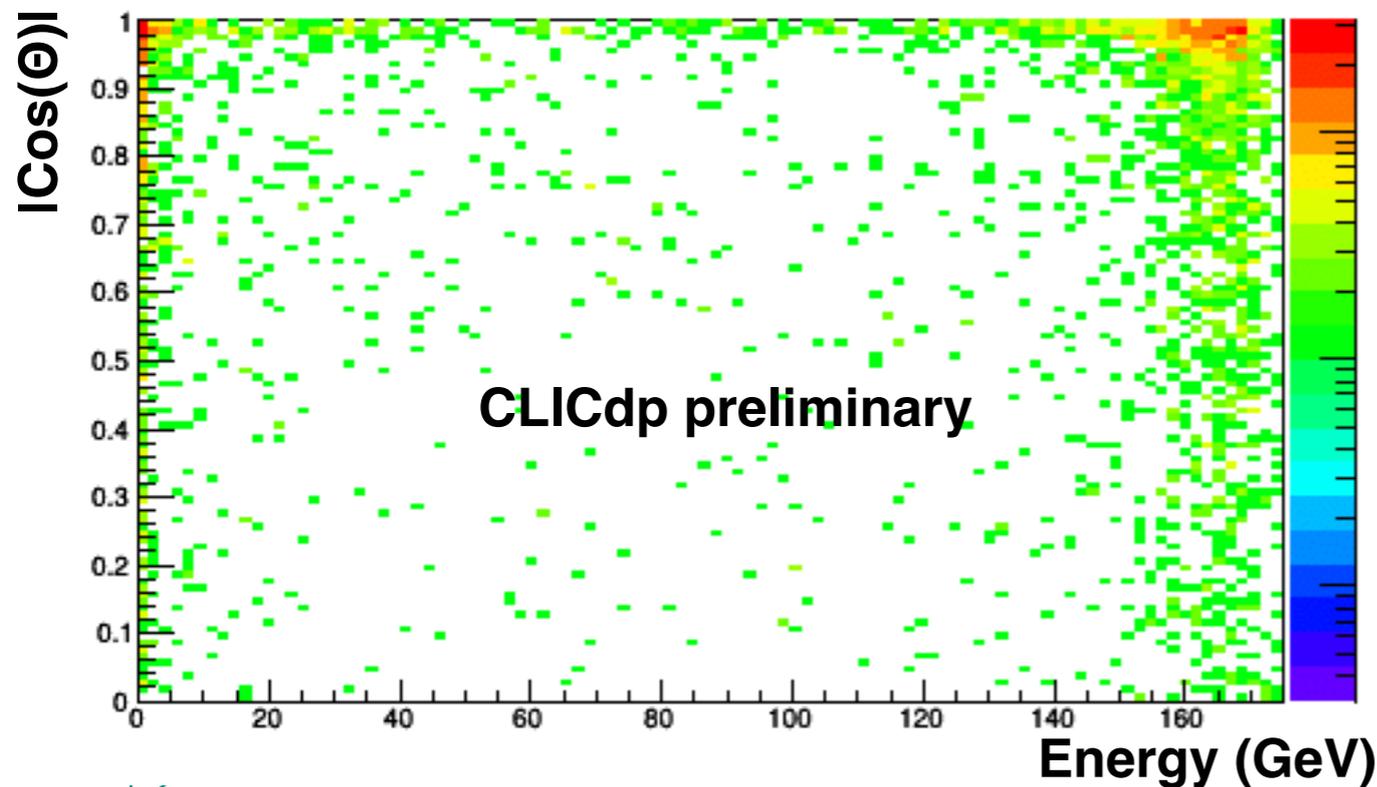
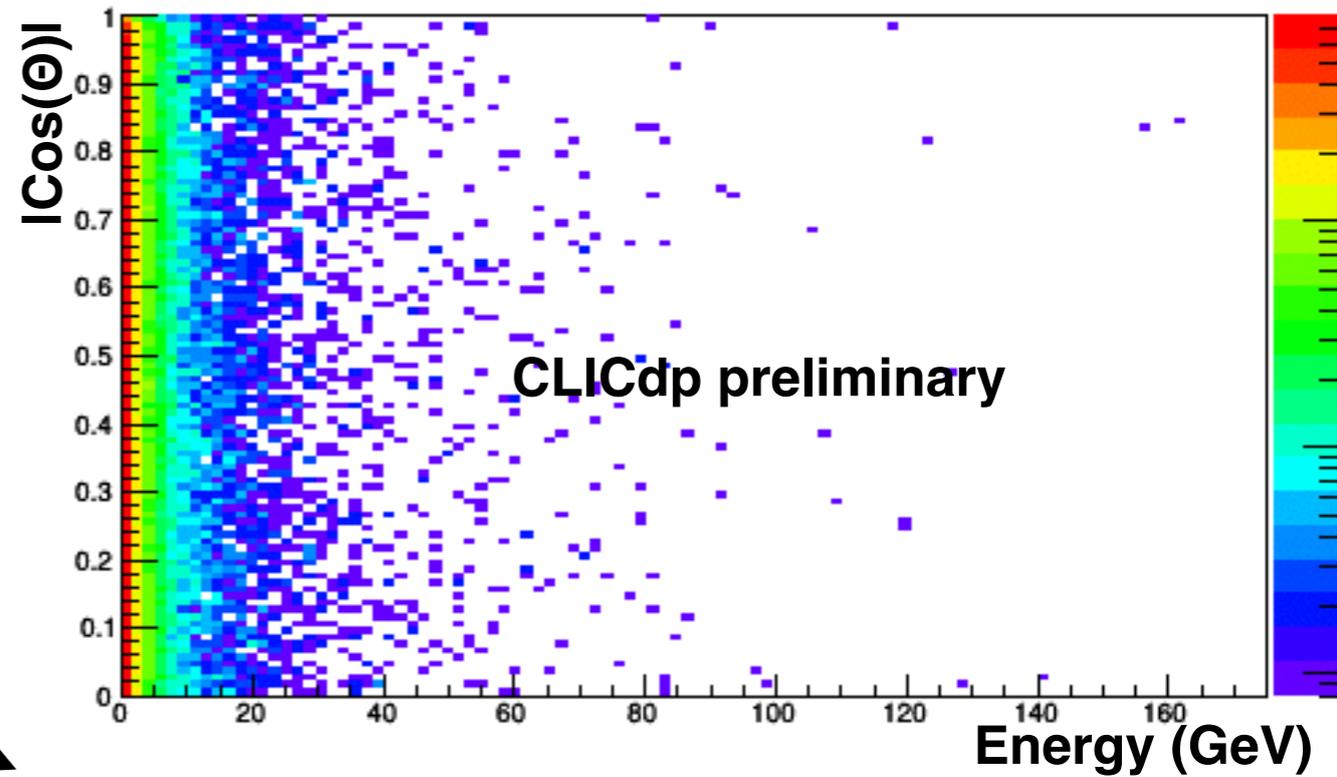
Z boson candidate energy



Initial state radiation cut

H $\nu\nu$ signal FSR
photon distribution

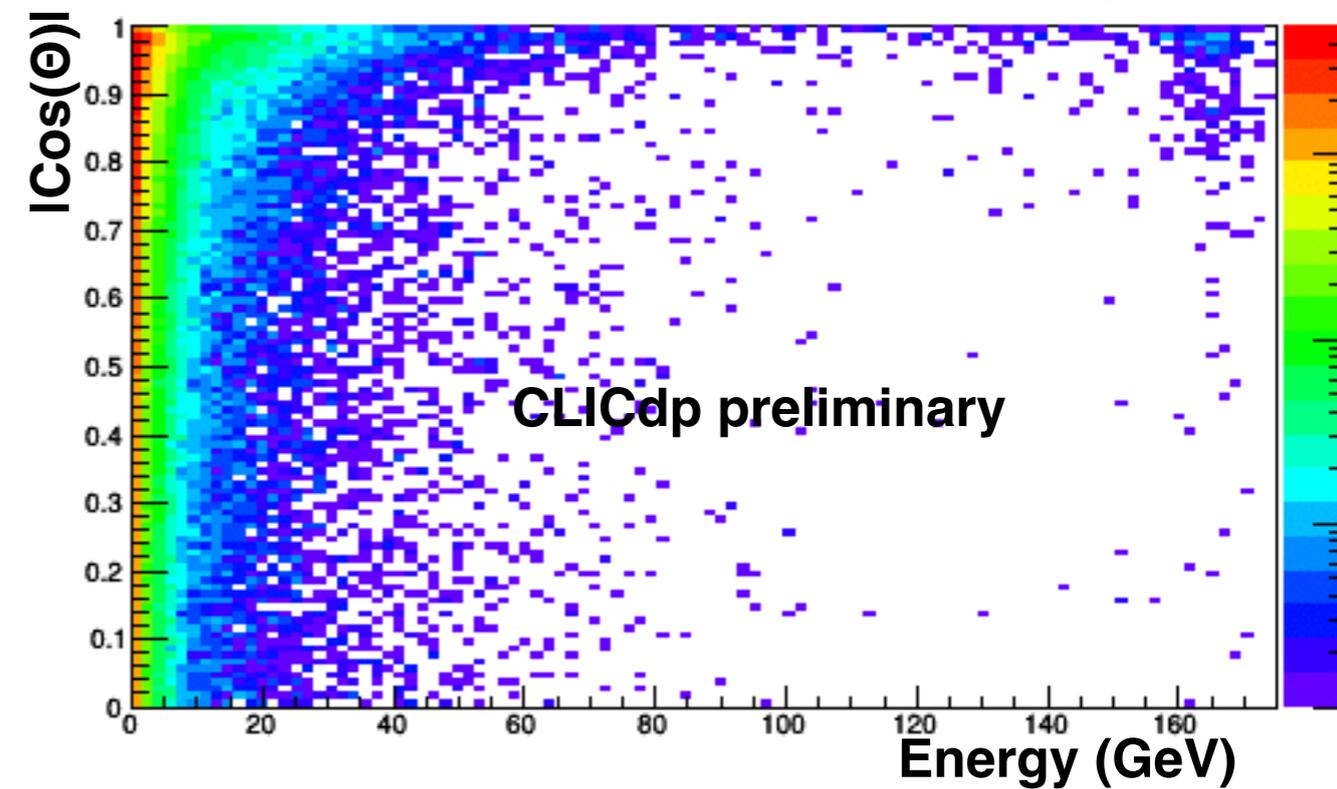
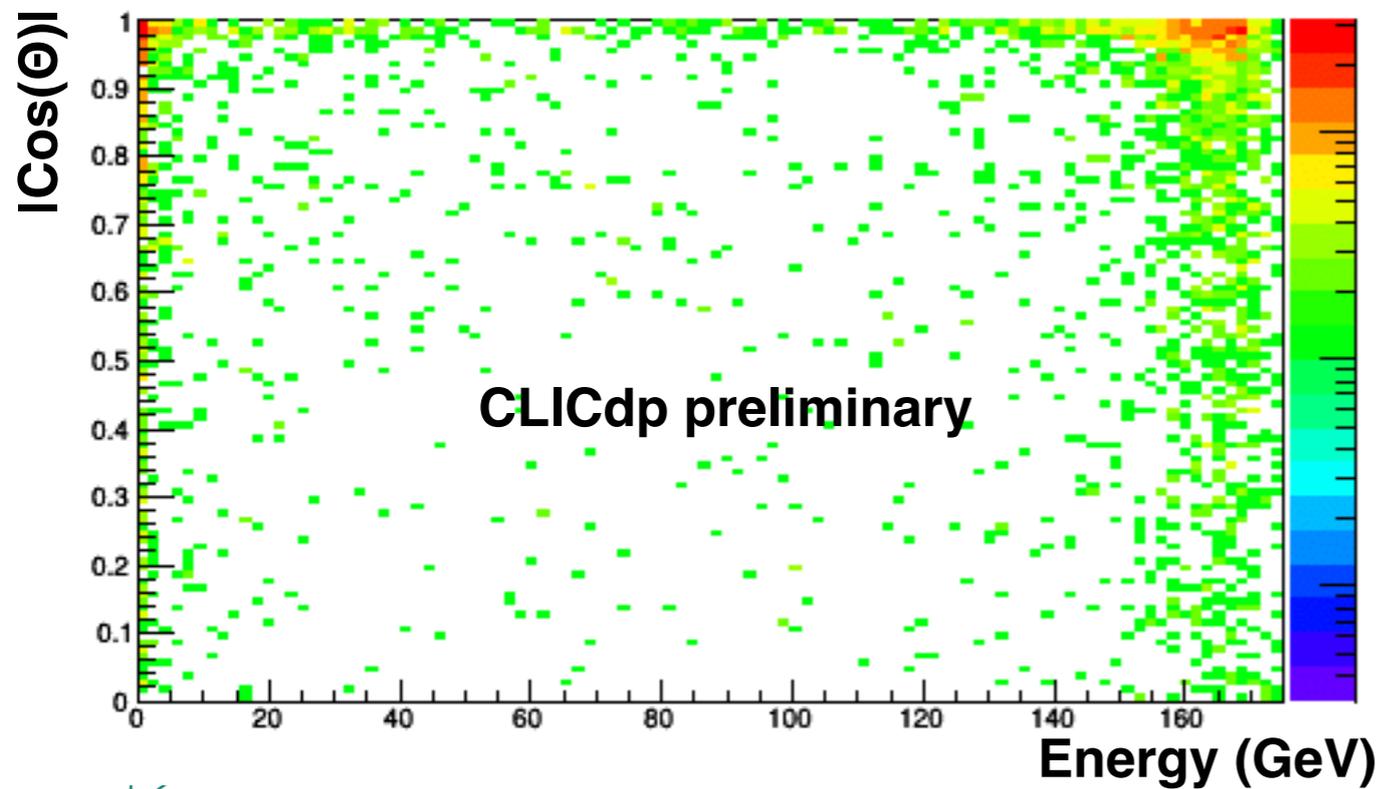
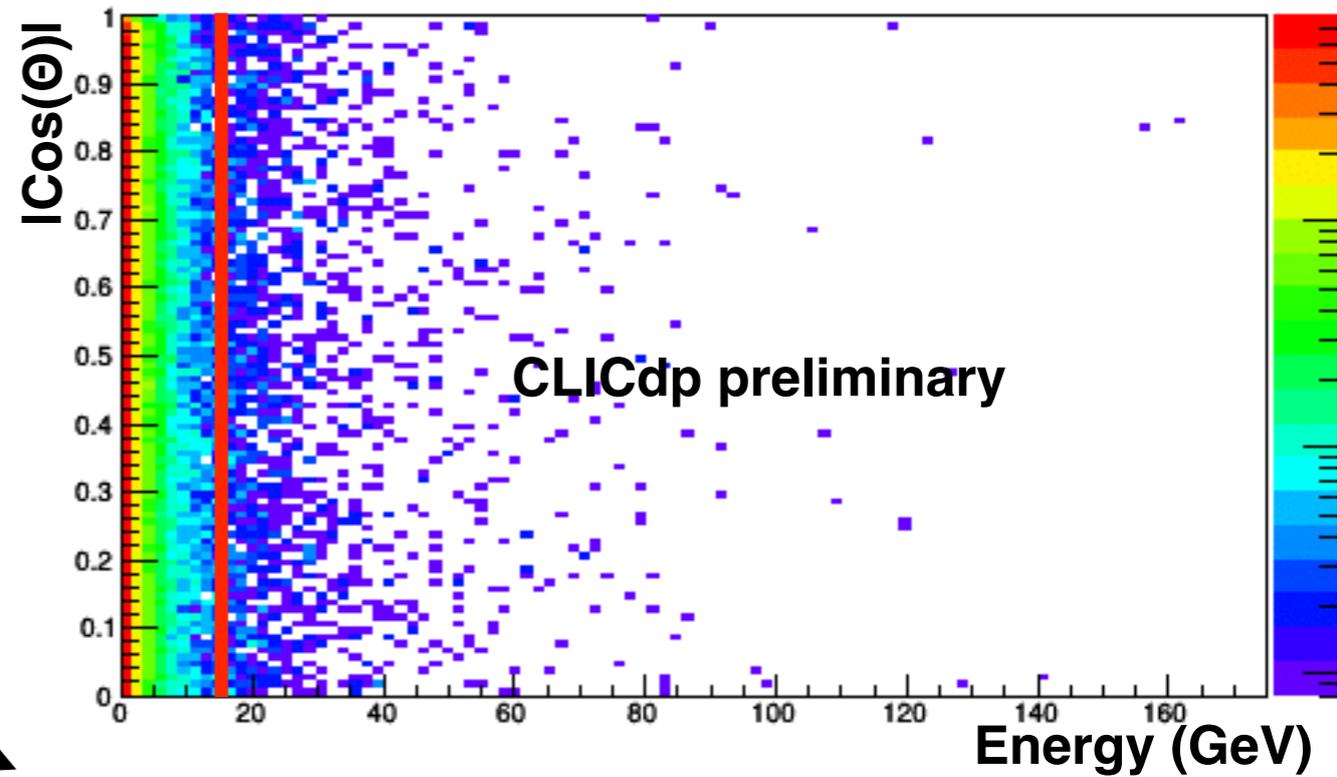
qq background
ISR and FSR



Initial state radiation cut

H $\nu\nu$ signal FSR
photon distribution

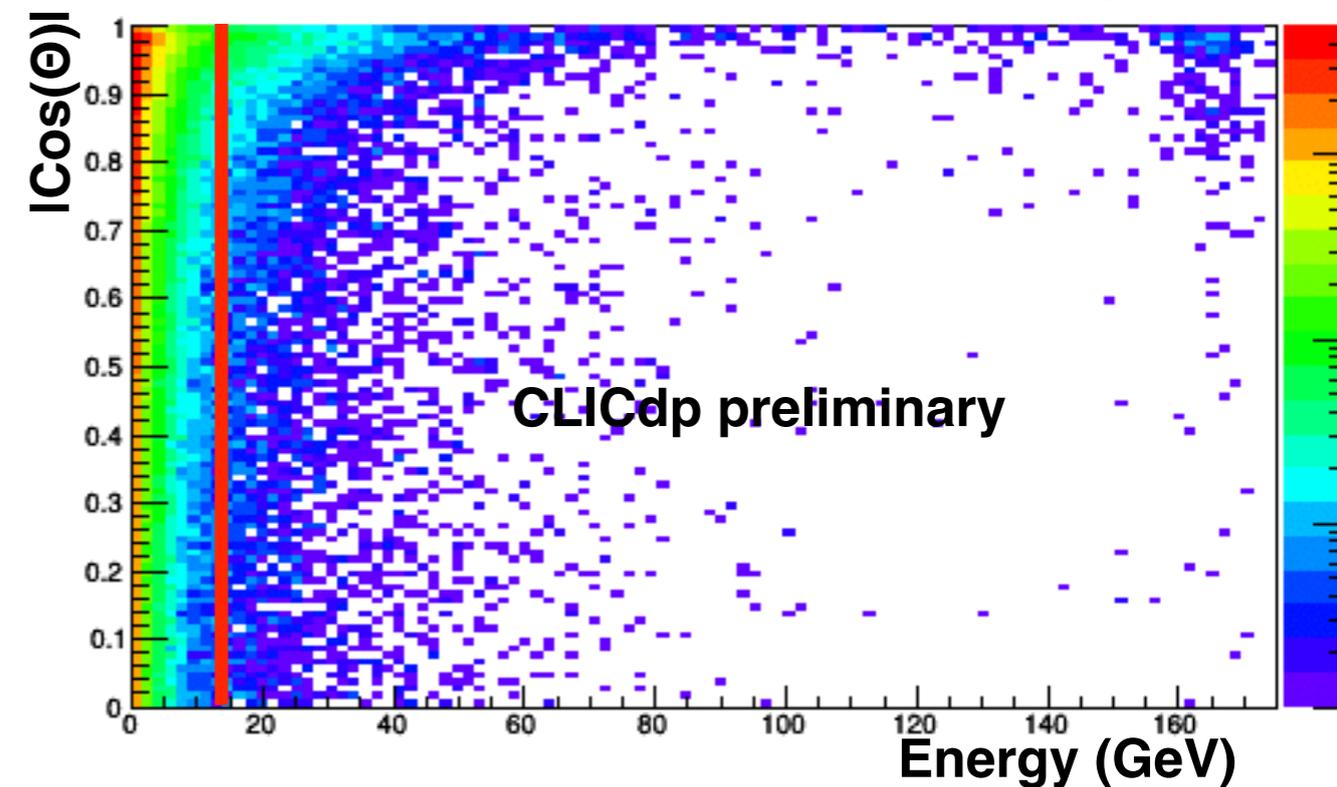
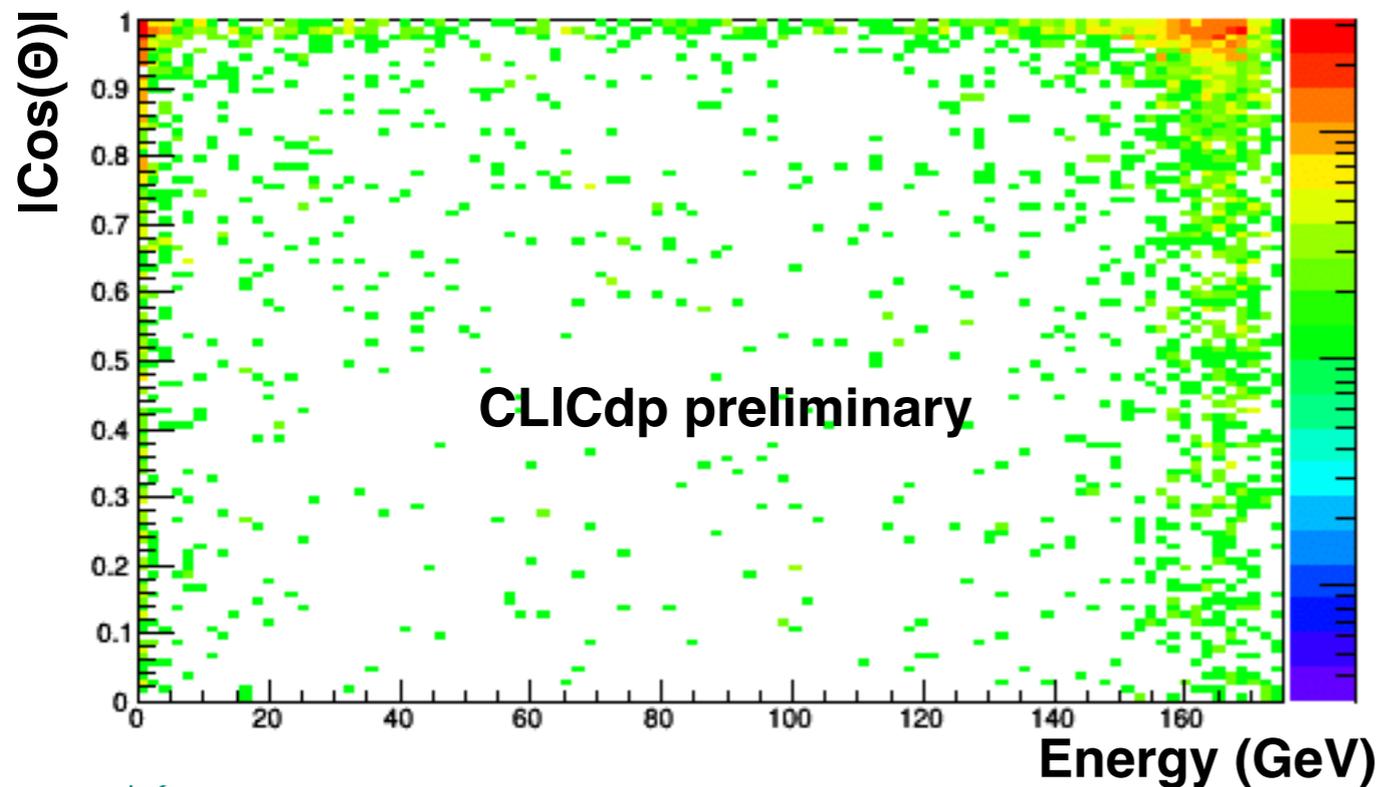
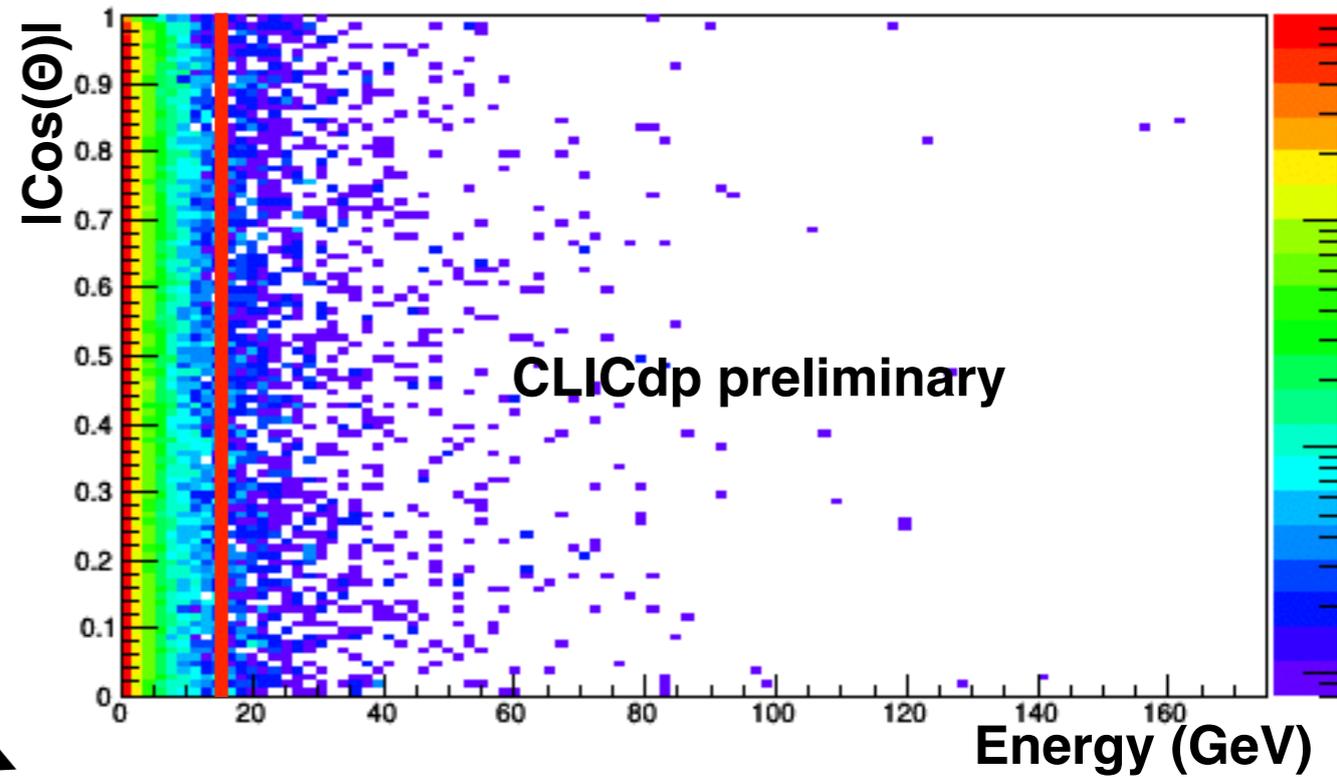
qq background
ISR and FSR



Initial state radiation cut

H $\nu\nu$ signal FSR
photon distribution

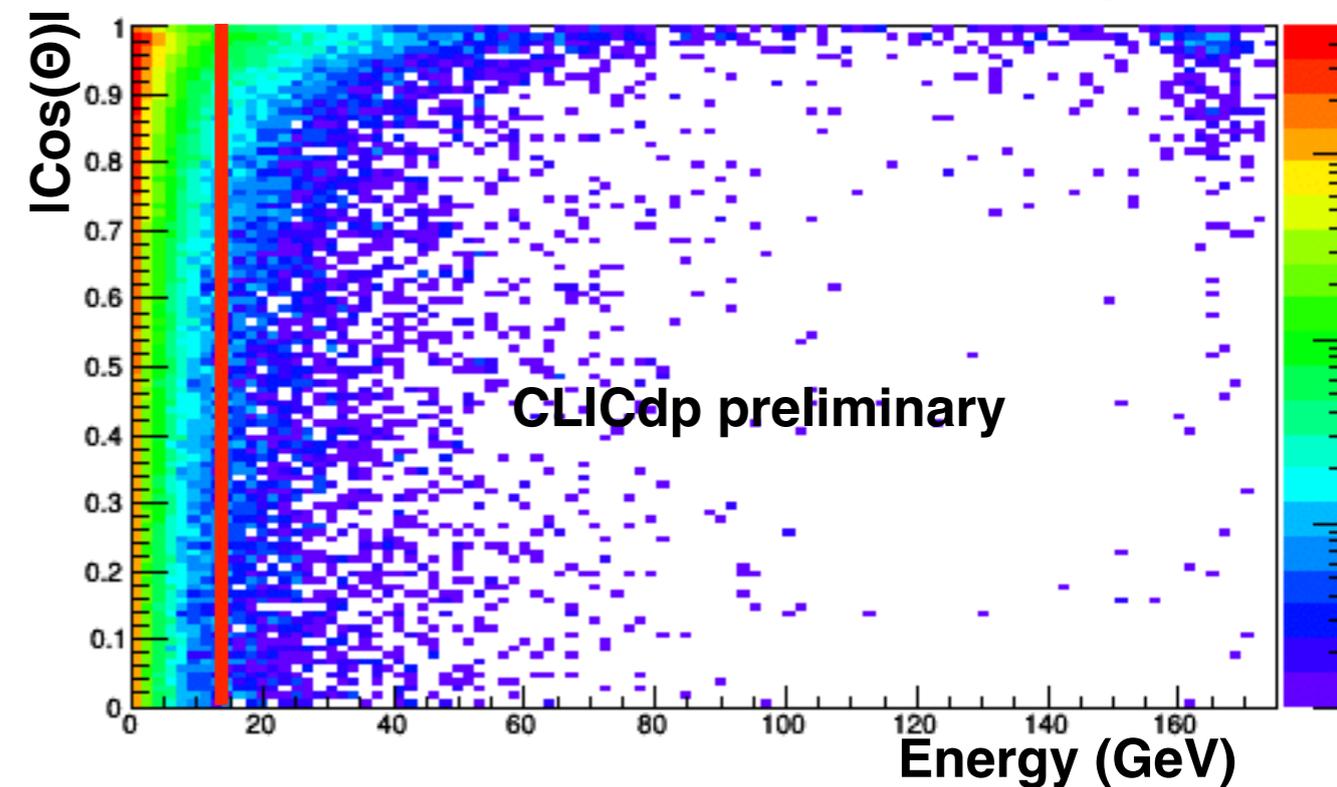
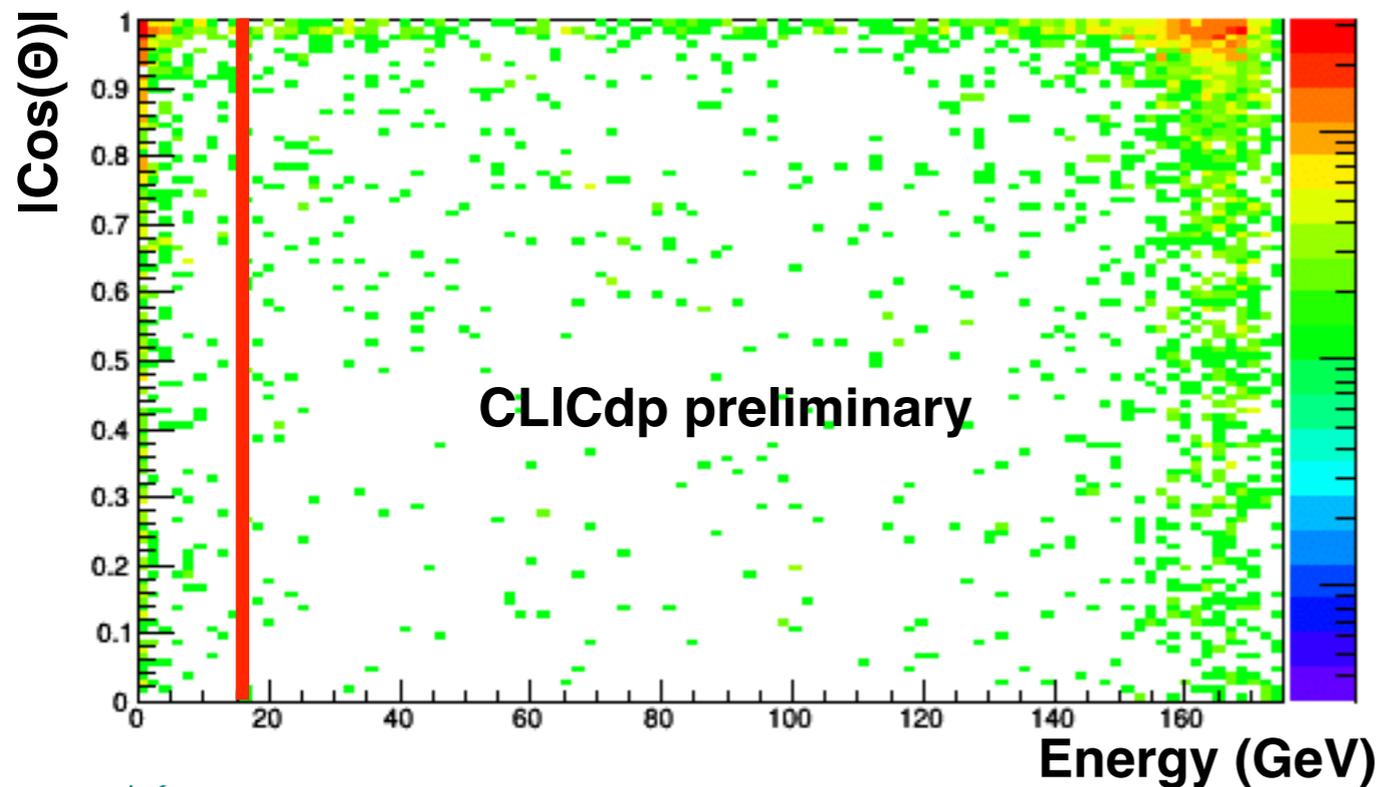
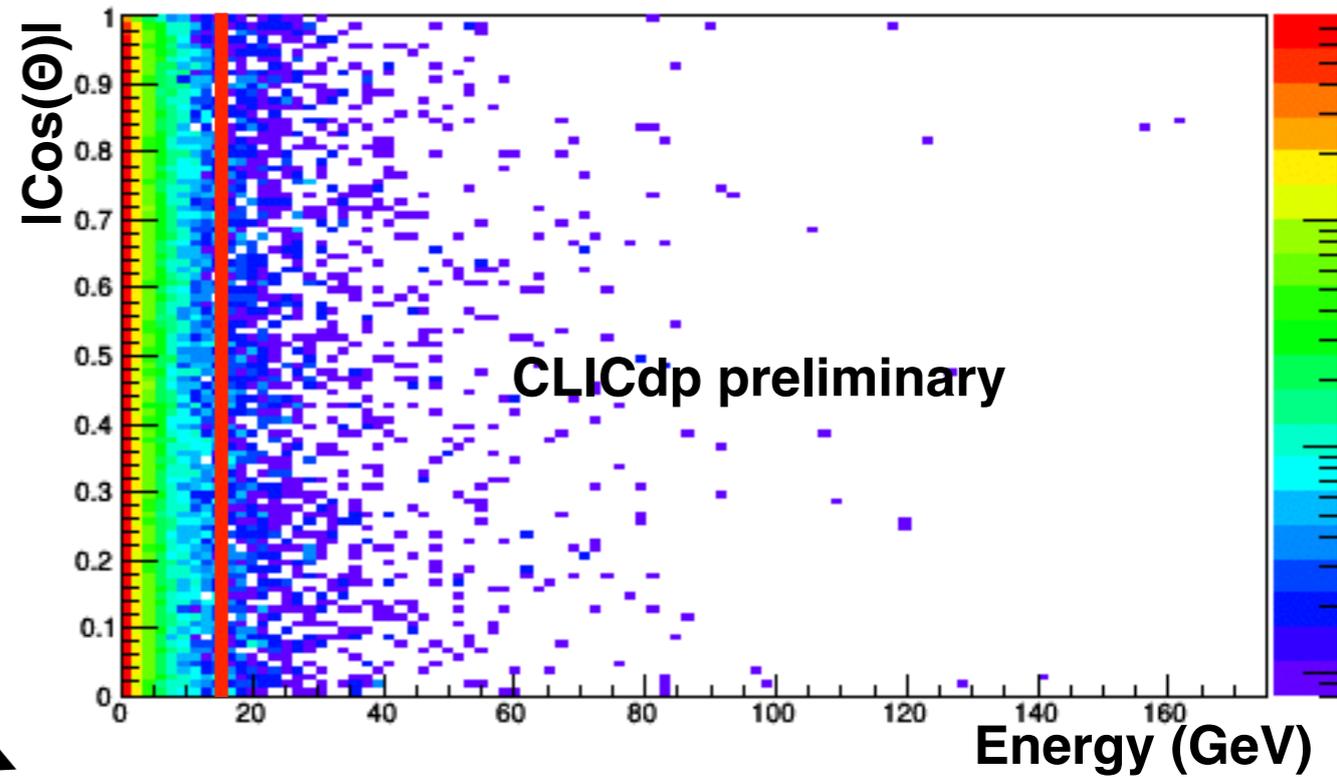
qq background
ISR and FSR



Initial state radiation cut

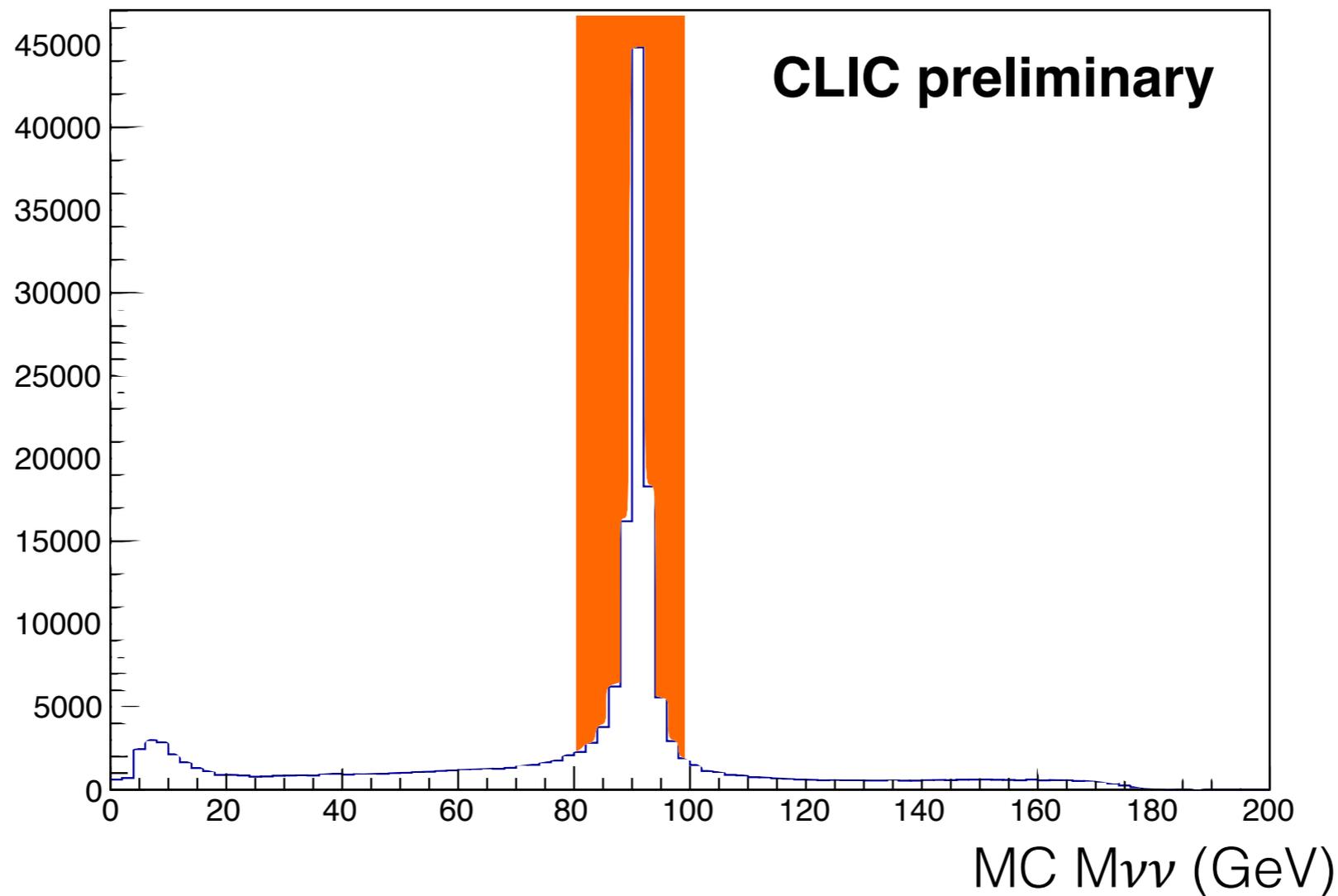
H $\nu\nu$ signal FSR
photon distribution

qq background
ISR and FSR



Separation of VBF and ZH: $Z \rightarrow \nu\nu$ at generator level

From an $H\nu\nu$ inclusive sample



if $86 < M_{\nu\nu} < 96 \rightarrow Z$ strahlung event ($Z \rightarrow \nu\nu$)