CEPC-SPPC WORKSHOP

H->bb/cc/gg Branch Ratio Measurement in CEPC

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On Behalf of CEPC Physics-Software Working Group

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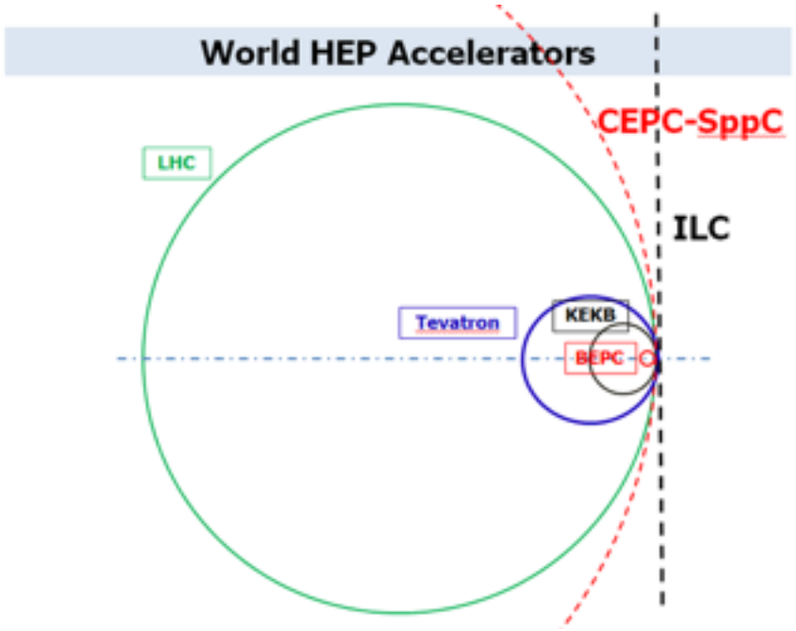


Outline

- Introduction
- H->bb/cc/gg *br.* measurement in μμ+jj channels
- H->bb/cc/gg *br.* measurement in νν+jj channels
- H->bb/cc/gg *br.* measurements in multi-jets channel
- Summary

Introduction: *Physics* Overview

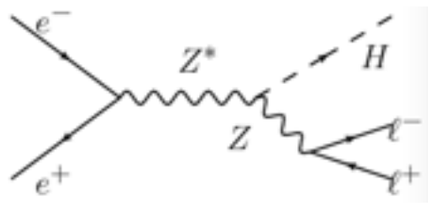
- Higgs decay branch ratio measurements with high precision are crucial to understand the electroweak mechanism, and are one of the most significant goal in the future collider experiment in frontier.
  - Reason of fermions mass
  - Is there only one higgs boson?
  - Higgs width
- CEPC is suitable for precise measurement of Higgs decay branch ratio
  - Much lower background (than hadron collider)
  - Utility of recoil mass, free of higgs decay channel
  - Excellent energy/momentum resolution
  - High luminosity

Introduction: Signal Process

√s = 250 GeV

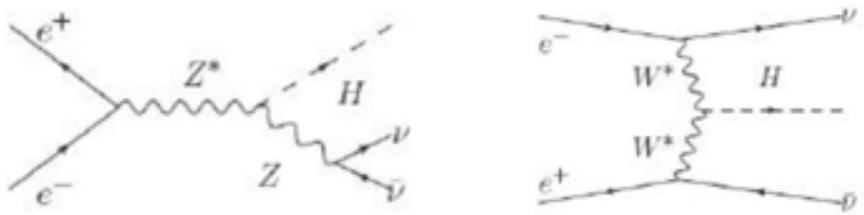
- **ZH->μμ+jj**
  - ZH production with Z decay to muon pair, H decay to bb/cc quark or gluon pair
  - Very clean signal in muon pair invariant mass and recoil mass

ZH->μμ+jj



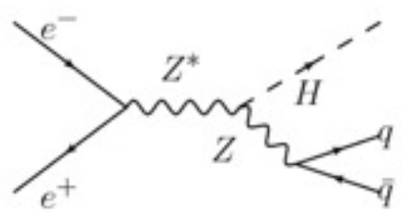
- **ZH->νν+jj**
  - Via ZH(~86%) or WW fusion(~14%)
  - Clean background

ZH->νν+jj



- **ZH->Multi-jet**
  - Both Z and Higgs decay hadronically
  - Much larger cross section than semi-leptonic channel

ZH->multi-jets



Integral luminosity of 5000 fb^{-1} is assumed in these study, corresponding to that of a few years of CEPC running

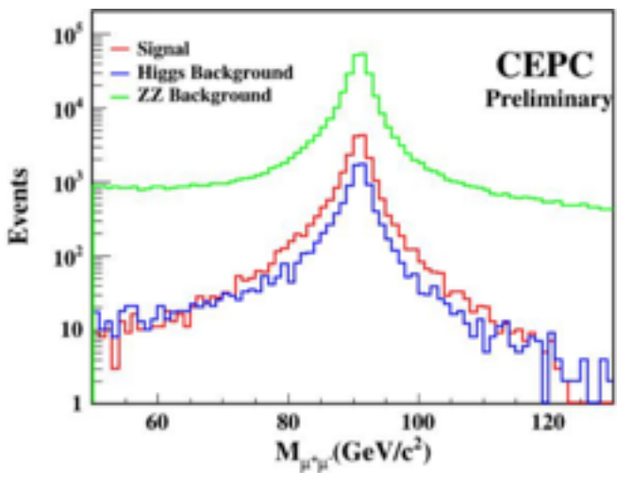
ZH->ll+jj Channel

Final states, 2 muons + 2 jets.

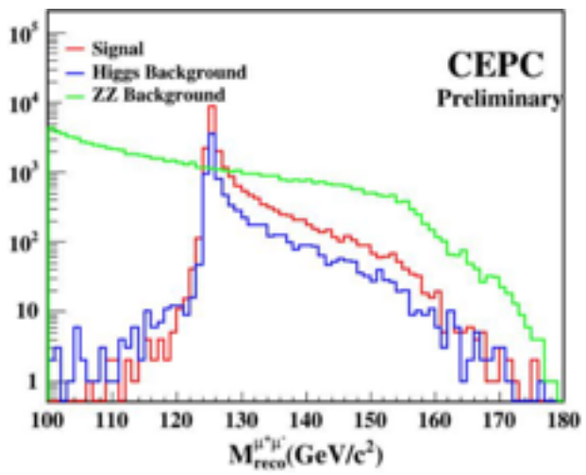
Using invariant mass of muon pair, jet pair, and the recoil mass of muon pair

Recoil mass study see: http://indico.ihep.ac.cn/event/5592/contribution/7/material/slides/0.pdf

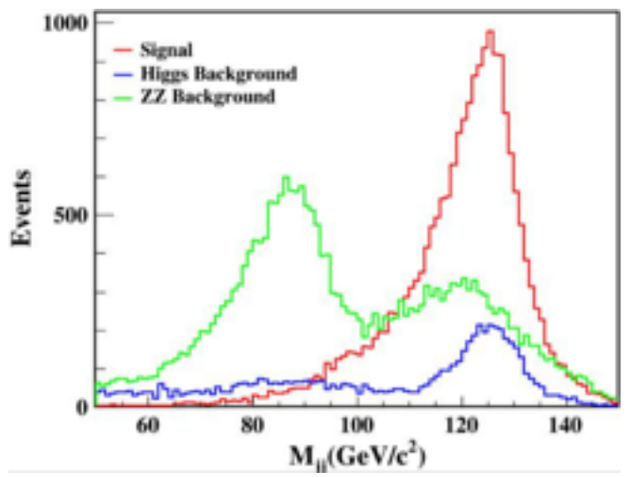
muon pair invariant mass between 70 - 105 GeV



muon pair recoil mass between 120 - 150 GeV



jet pair recoil mass between 105 - 135 GeV



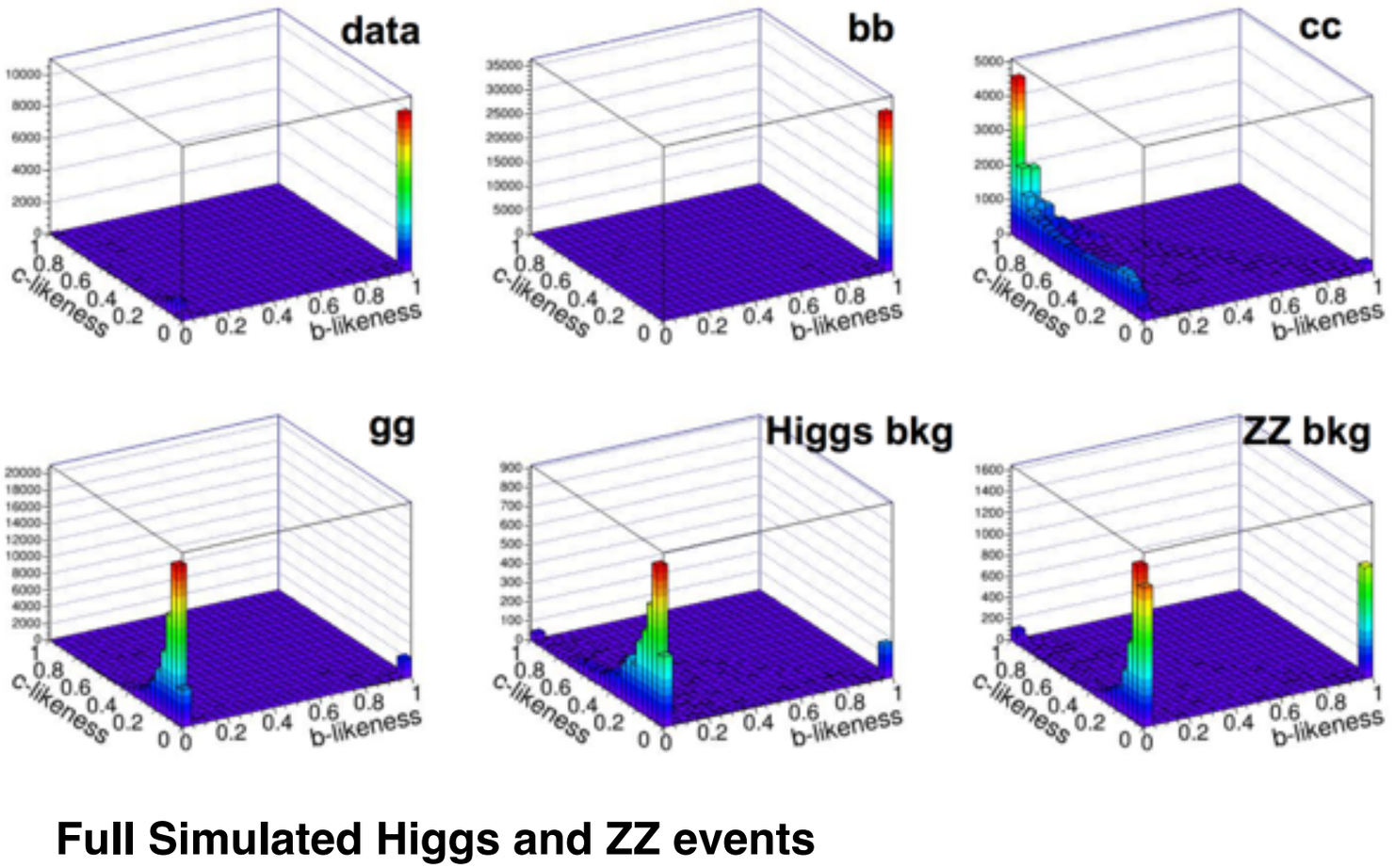
Template Fit in ll+jj Channel

Templates and data

Category	*Signal*	*ZH*	*ZZ*
Pre-selection	21300	9486	381678
$120GeV < M^{\mu^+\mu^-}_{recoil} < 150GeV$	20582	8678	35305
$70GeV < M_{\mu^+\mu^-} < 105GeV$	20121	8340	26525
$105GeV < M_{jj} < 135GeV$	16479	3336	7732

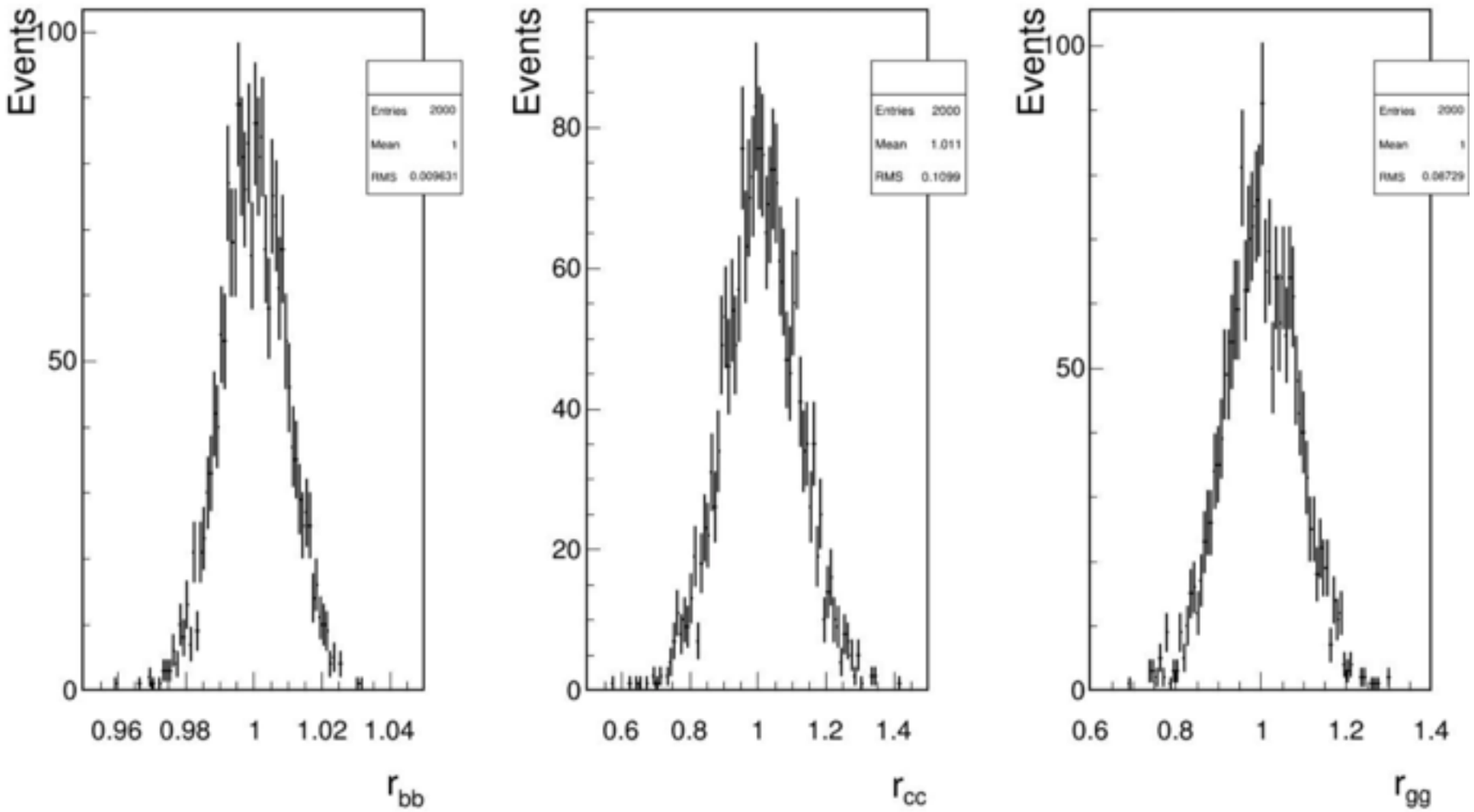
Fit target

$$L_{qq} = \frac{qq\ pair}{qq\ pair\ +\ neither\ is\ q} = \frac{x_q^1\, x_q^2}{x_q^1 x_q^2 + (1-x_q^1)(1-x_q^1)}\ (qq = bb, cc)$$



Full Simulated Higgs and ZZ events

Template Fit in ll+jj Channel: Toy MC Check



bb: 0.96% cc: 10.99% gg: 8.73%

Fit works stable

$\nu\nu$+jj Channel, Datasets and Event Pre-selection

Datsets:

Name	Statistics	weight	Note
$\nu\nu H$	5000fb^{-1}	1	Full simulation
$(qq, e^+e^-, \mu^+\mu^-)H$	5000fb^{-1}	1	Full simulation
$\tau^-\tau^+H$	0	0	Not available
2fermions/4fermions	500fb^{-1}	10	Fast simulation

Generator: Whizard, Simulation arbor
Major SM background are with qqln, qqnn and qq events

Event Pre-selection:

- Number of particles(PFO) >=20
- Visible Energy between 110 and 150 Ge
- Isolated electron and isolated muon veto
- y_{12} between 0.15 and 1.0, y_{23}<0.06, y_{34}<0.008
- cos θ between -0.98 and -0.4,
- BDT Cut

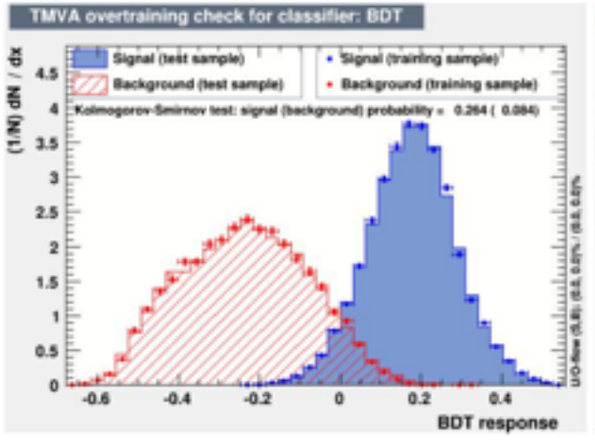
Event yields after Cut flow

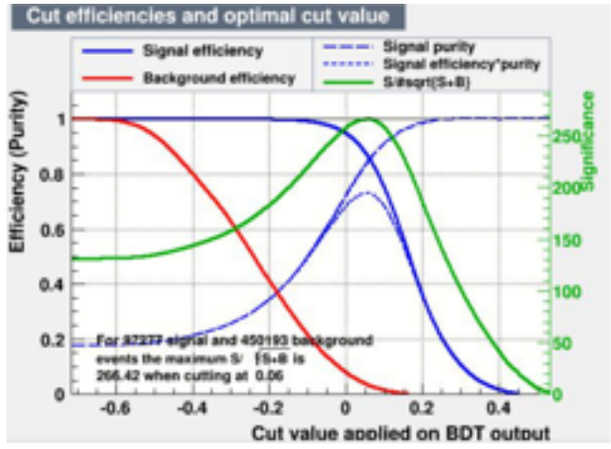
Cut Definition	*Sig.*	*qq*	*qqnn*	*qqln*	*nnh*
Generated	16260	25M	183K	3681K	
FSClasser output	16768	25M	183K	3681K	7485
$N_{\mathrm{PFO}(E>0.4\mathrm{GeV})} > 20$	16748	23M	163K	3439K	4889
$110 < E_{\mathrm{total}} < 150$	14689	10M	126K	705K	3311
$P_T > 19$	13687	34K	116K	627K	3101
Isolation lepton veto	13429	33775	115K	327K	2537
$100 < M_{\mathrm{inv}} < 135$	12827	9506	10420	162K	2269
$70 < M_{\mathrm{rec}} < 125$	12166	7521	10045	110K	2260
$0.15 < y_{12} < 1$	12093	7405	9702	101K	2211
$y_{23} < 0.06$	10902	6644	8456	69313	1220
$y_{34} < 0.008$	10377	6504	7878	58532	519
$-0.98 < \cos(\theta^{(2\mathrm{jets})}_{\mathrm{included}}) < -0.4$	10284	5766	5454	34823	485
$BDT > 0.04$	8705	381	465	267	230
Significance	**84.92**				
Efficiency	**53.5%**				

Very high signal/background ratio

BDT in $\nu\nu$+jj Channel

- Input variables: N_{PFO}, $P_{T,total}$, M_{inv}, M_{reco}, y_{12}, y_{23} , y_{34}, θ_{2jets}. (E_{total} was not included to reduce the overfitting.)
- Optimization: maximize the statistics significance (= $S/\sqrt{S+B}$).



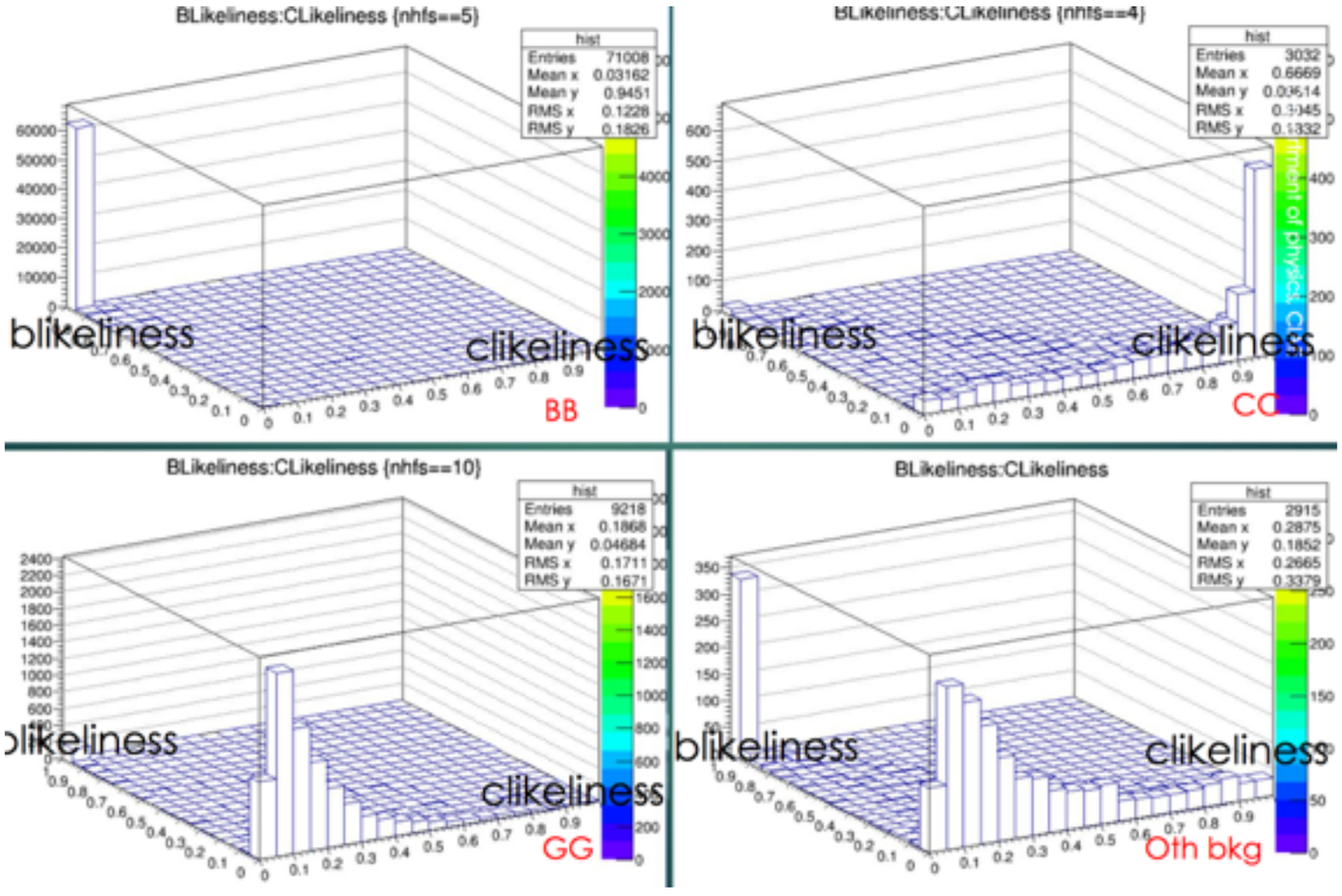


Number	bb	cc	gg	Oth higgs	SM
before	125725	5853	17377	Didn't cal.	Didn't cal.
Efficiency	59.0%	55.8%	55.9%	Didn't cal.	Didn't cal.
Left	74191	3266	9710	3299	1556*10

Overall signal efficiency 58.5%. 266 statistic significance.

BDT in $\nu\nu$+jj Channel Template Fit

Template and data



Only Higgs background are included

Fix the vvH background in the fitting

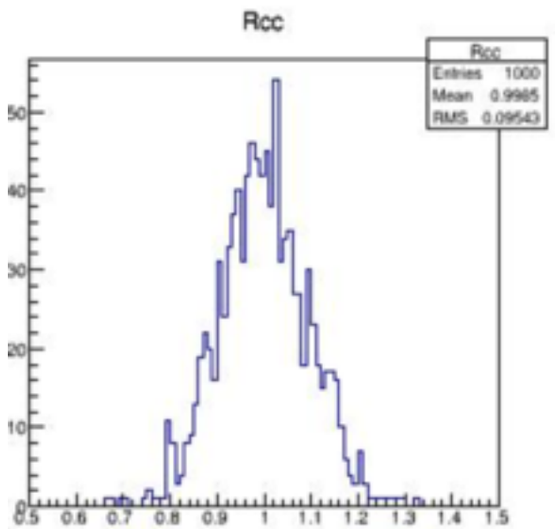
BDT in $\nu\nu$+jj Channel Template Fit : Result and ToyMC

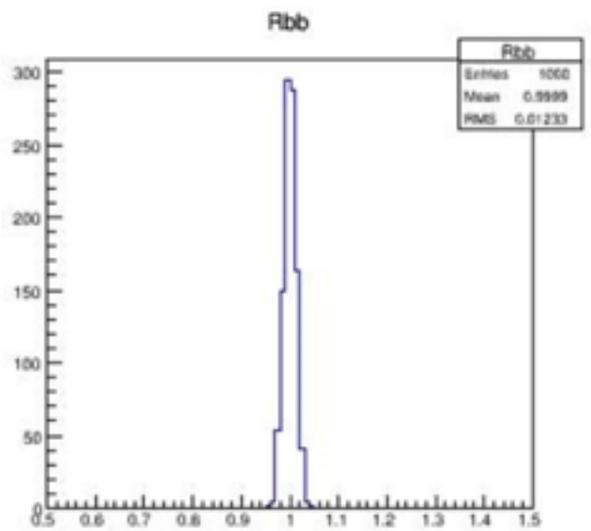
Channel	bb	cc	gg	Oth Higgs
Truth	7419.1	326.6	971.0	329.9
Mean	7419.0	325.0	969.4	330.0
RMS (fitTo)	88.1	28.4	38.8	-
RMS (ToyMC)	87.1	30.1	39.6	-
Relative error	1.23%	9.3%	4.2%	-
1/sqrt(Truth)	1.16%	5.5%	3.2%	-

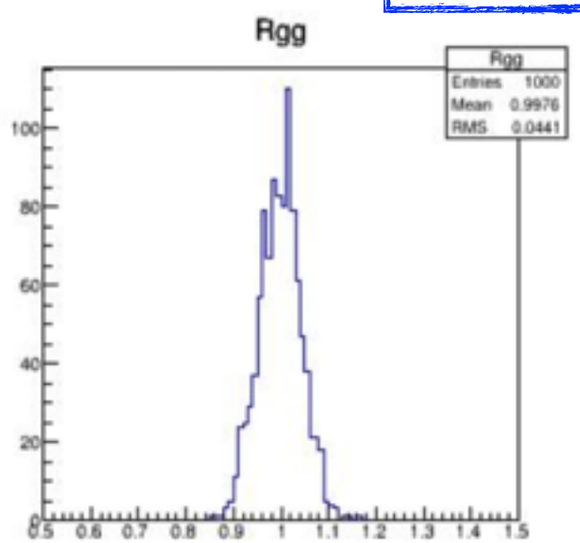
No Significant bias found

Results from 1000 fitting

Looks Stable

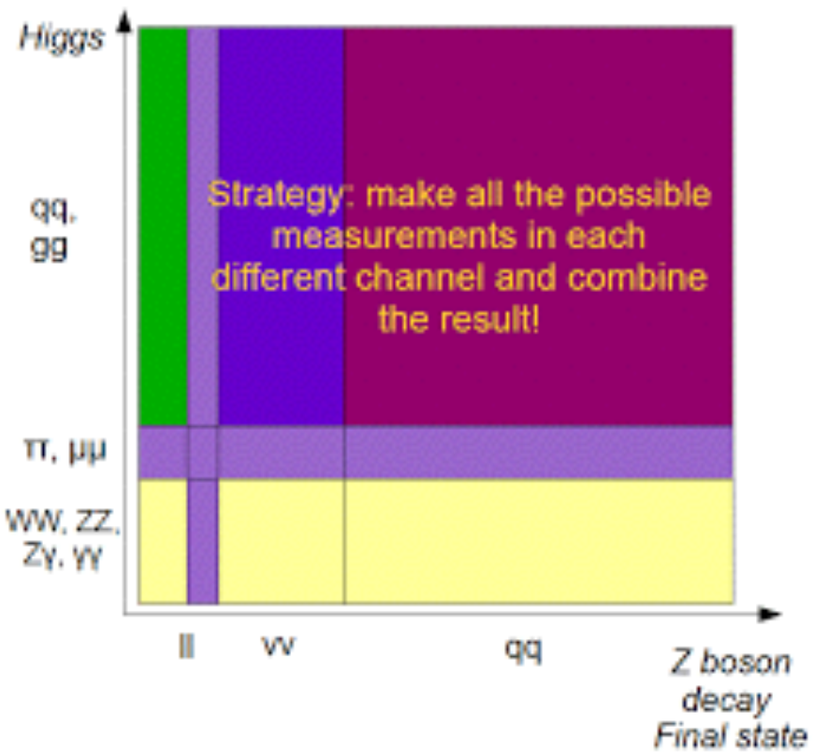






Multi-jets Channel

Majority decay FS in HZ production
Large Statistics



Datasets:

- **Main background: Irreducible background from WW/ZZ and quark pair process**
- **Full simulation of Higgs production and hadronic channel in WW/ZZ, fast simulation for the others**
- **Quark pair sample are filtered due to its huge cross section and low rate to passing the event selection**
  - **Veto events without gluon radiation or gluon splitting**
  - **Veto events without radiation return**
  - **Efficiency ~10%, contain over 90% of event survive selection**

Event Selection and Cut flow

	Signal	Other qqH	ffH	qq(filtered)	ll	qqqq	llqq	lvqq/vvqq	pure leptonic
Original	717k		354k	246.9M(unfiltered	271.7	~40M		36.8M	
Final state 4J	716k		343k	22.6M	20.5M	40.8M	3.16M	37.1M	2.11M
Jet Qualification	358.5k	89.0k	8.5k	4.65M	0	18.47M	4.0k	11.6k	0
Missing E < 58 GeV	354.2k	83.3k	2.95k	4.44M	0	16.94M	3.54k	3.57k	0
y34 > 0.204	214.6k	58.8k	1.50k	530k	0	12.22M	662	269	0
Invariant Mass Window	21.4k	3.5k	28.2k	23.6k	-	92.8k	-	-	-

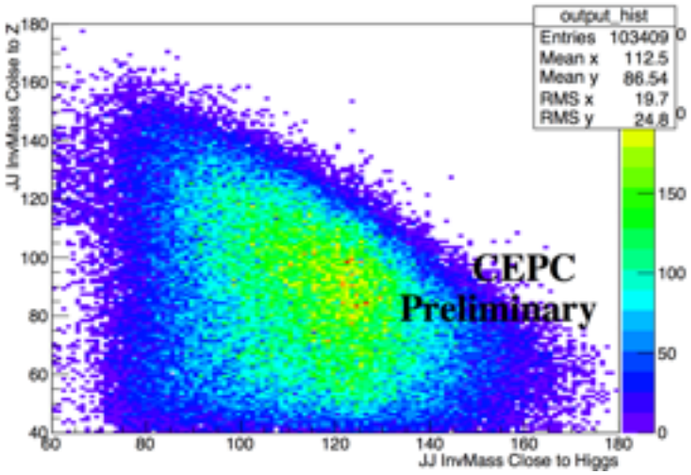
Energy > 25 GeV, $|\eta|<2.1$
At least 10 PFOs.

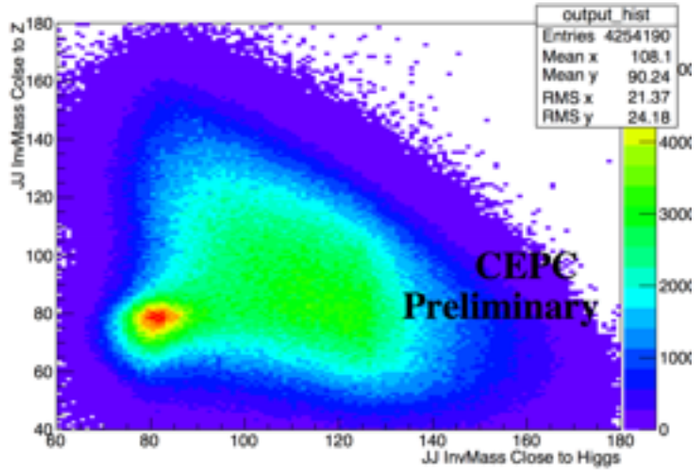
Jet paring and Invariant Mass:

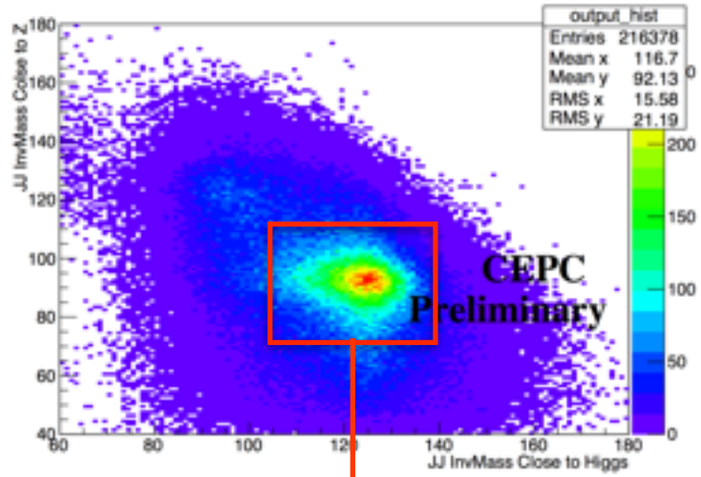
- HZ paring: find the jet pair mass closet to Higgs Mass
- WW paring: the sum of the square of difference between jet pair mass and W mass get minimized
- ZZ paring: find the jet pair mass closet to Z mass

Invariant Mass of Jet Pair

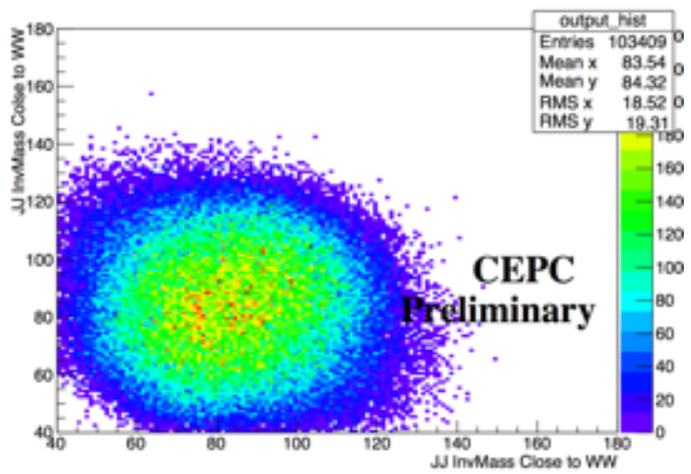
HZ Assumption

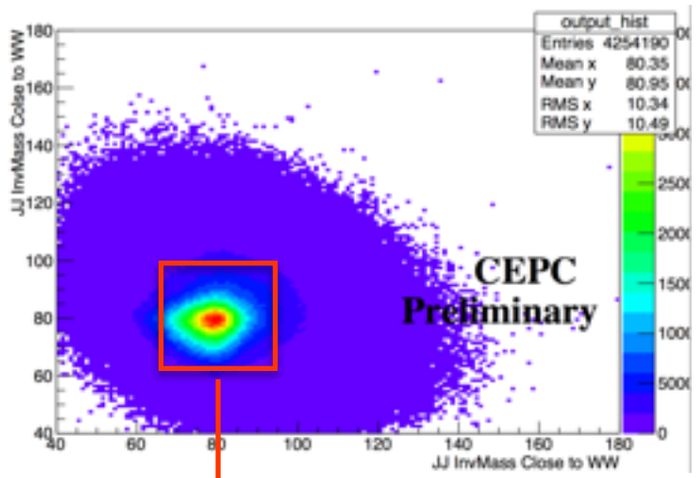




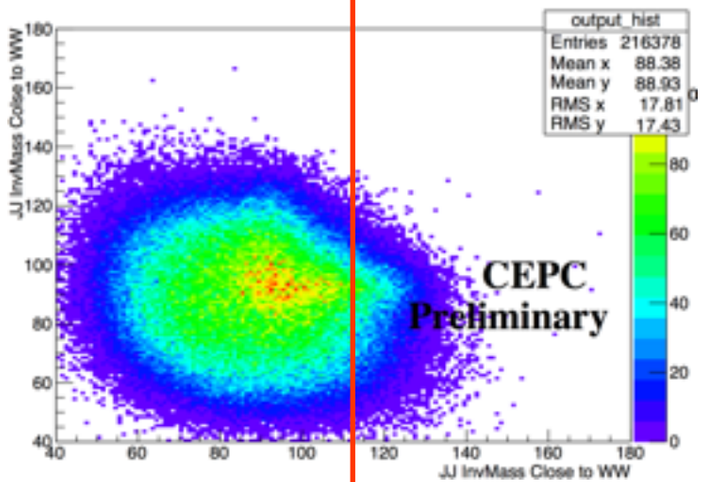


WW Assumption





Reject



Accept

Flavor tagging in Multi-jet Channel

- We also tried template fit for multi-jet channel
- The bb/cc fraction are fitted relatively better than gg branch ratio. May due to the resemblance between background from higgs process and H->gg+qq events — H->gg can be fixed(similar to vv+jj channel)
- We are also trying other method

Summary

- We enumerate in various type of final states to measure higgs->bb/cc/gg branch ratio
- ZH->ll+jj is a clean channel and looks very promising
    - As a very clean channel, we can consider sys. issues: like recoil mass study, sys. from flavor tagging etc.
- Background in vvjj channel is clean and the results from fit looks quite stable.
- ZH->multijets is ongoing. Results from full simulated irreducible background shows
- There are some limits in using template fit now, need to solve
- More and more full simulated sample come out. Can be used in analysis.