Higgs combination toward CDR

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Outline

- Motivation
- Model introduction
- Brief look of individual analysis
- Fit Result of $\Delta(Br * \sigma)$ and κ

Combination: motivation

- Old individual analysis
  - Correlations between channels not taken into account
  - Treat ZH backgrounds wrongly
    - One channel's ZH bkg is another channel's signal, should combine together.
  - Systematic uncertainties are difficult to address
- Combination measurement
  - Uniformed, simultaneous fit framework
  - Can easily include necessary correlations/uncertainties
  - Extensibility for making different assumptions

Fit techniques

- Workspace: container of likelihood model and data.
- Input: invariant/recoil mass spectrum, b/c/g template
- POI(parameter of interest): $\sigma * Br$, Higgs coupling κ
- NP(nuisance parameter): function & constrains in model besides POI
  - represents uncertainties
  - correlated NP share the same name
  - currently set $\Delta\sigma = 0.5\%, \Delta\text{Lumi} = 0.1\%$
  - more NP can be introduced in the future.
- PDF for fit:
  - signal: CB ball + Gaussian;
  - bkg: 2rd poly exp
- Algorithm:
  - Minuit2 + Minimize

Currently, with MC sample,
we can fit Asimov data to get
estimated precisions of
$\sigma * Br$, Br, and κ of CEPC.

All the result are consistent with
pre_CDR's result.

In the future with real data,
we can directly use this framework
to get these pois' value and
uncertainties.

Fit techniques

pdf shape is fixed all the time.

- For each channel (like eeqq, $\mu\mu\tau\tau$)
  - Input observables from MC sample.
  - Build Combine S+B Pdf $\quad$ $Tot=N_{bb}*Pdf+N_{cc}*Pdf_{cc}+......+N_{bkg}*Pdf_{bkg}$
  - Add μs on evnets number N_{bb}, could be:
    - When measure $\sigma * Br$, $\quad$ $N_{bb}= N_{bb\_SM}* \mu_{bb}$
    - When measure Br, $\quad$ $N_{bb}= N_{bb\_SM}* \mu_{bb} *\sigma(ZH)(0.5\%)$
    - When measure κ, $\quad$ $N_{bb}= N_{bb\_SM}* \kappa_{z}^{2} * \kappa_{b}^{2}$
    - Different channel share the same μs. $\quad$ eebb, mmbb, qqbb, vvbb......
  - Use Combine pdf to make Asimov data $\quad$ No fluctuation made (Unlike ToyMC test)
  - Simultaneous fit combine pdf to Asimov Data with different asumptions.

ZH bkg events, like ZZ events in WW channel, will contribute to μ_{ZZ}.
If no specific channels known, will only contribute to μ_{global} or κ_z

Channels Table (now 36)

*H->ee/$e\mu$ not listed due to no certain ratio.
*nn/qq+$\tau\tau$ without bkg.
*H->zz->νννν is tagged H->invisible.

Signal Z	Signal H	Observed	Who takes charge	Last update
H->qq				
ee	bb	7466	Baiyu	2017.7
	cc	343		
	gg	1039		
μμ	bb	10575		
	cc	538		
	gg	1556		
qq	bb	176734		
	cc	8268		
	gg	25279		
νν	bb	70443		
	cc	3054		
	gg	9585		
H→γγ				
ll	γγ	93	Feng	2015
νν		309		
qq		822	Yitian	2017.4
H→ll				
μμ	ττ	2067	Dan	2017.7
qq		36024		
nn		12478		
Inc.	μμ	47	Zhenwei	2016.8

Signal Z	Signal H	Observed	Who takes charge	Last update
H->WW				
μμ	μνμν	52	Libo	2017.4
	eνeν	36		
	eνμν	105		
	eνqq	663		
	μνqq	717		
ee	μνμν	44		
	eνeν	22		
	eνμν	81		
	eνqq	612		
	μνqq	684		
νν	qqqq	9022		

H->ZZ				
νν	μμjj	190	Yuqian	2016.9
μμ	ννjj	209		
ee	ννjj	72		
H->Invisible				
qq	νννν	202	MoXin	2017.7
ee		12		
μμ		22		

Observed=tagged signal after cutflow and in asimov fit range.
All events are normalized to $5ab^{-1}$.

Individual analysis intro

$bb/cc/gg$

$$B_{likeness} = \frac{b_{j1} b_{j2}}{b_{j1} b_{j2} + (1 - b_{j1})(1 - b_{j2})}$$

- Higgs ~70% to dijets bb/cc/gg
  - Flavor tagging algorithm
- Baiyu, Liboyang's template fit
  - $Z \to ee\ \mu\mu\ qq\ \nu\nu, \mathrm{H} \to bb/cc/gg$ are studies.
  - 2D fit, with dijets' b/c likeness
  - In $Z \to ee\ \mu\mu\ qq\ \nu\nu,$ Tot=bb+cc+gg+bkg_{zh}+bkg_{sm}.
  - Build individual pdf by MC, then fit to determine fraction.

In Baiyu's result, also, the shape of bkg is fixed.
Which means we have a wonderful understanding with bkg, which may be more suitable for CEPC.

Baiyu's	μ_bb	μ_cc	μ_gg	Pre_CDR	μ_bb	μ_cc	μ_gg
eeH	1.2%	14.4%	7.8%	eeH	1.1%	14.6%	5.6%
mmH	1.1%	12.8%	6.9%	mmH	0.9%	12.6%	3.8%
qqH	0.4%	8.0%	5.2%	qqH	0.4%	3.0%	2.6%
vvH	0.4%	3.8%	1.6%	vvH	0.45%	3.2%	2.8%
Combined	0.3%	3.2%	1.6%	Combined	0.28%	2.2%	1.6%

Pre_CDR, $\nu\bar{\nu}H$, $\bar{q}qH$ results are extrapolated from ILC studies.
It seems Pre_CDR's result too optimistic.

A cut flow on qqqq

筛选条件	四喷注组合并去除轻子	可见能量 >206GeV	y_{34} > 0.007	喷注粒子数>9	$\Delta\theta > 0.92$	X>0.21	BDT>-0.19
所有信号	493947	459972	393979	371240	318163	236652	211281
信号－$b\bar{b}$	413299	381470	325137	305982	261808	197510	177447
信号－$c\bar{c}$	19362	18690	15976	14903	12610	9562	8324
信号－gg	61286	59812	52866	50355	43745	29580	25510
所有背景	75M	50.6M	26.4M	21.4M	13.55M	3.15M	1.52M
希格斯背景	299534	109529	100813	82281	71987	38579	32653
四费米子强子衰变	36.83M	28.19M	21.32M	18.78M	12.16M	2.2M	1.08M
两夸克	23.86M（250M）	20.37M	5.207M	2.601M	1.315M	907188	405567
四费米子半轻子衰变	14.72M	1.967M	218394	27487	4745	3012	580

	信号－$b\bar{b}$	信号－$c\bar{c}$	信号－gg	背景
筛选前	413299	19362	61286	560M
筛选后	177447	8324	25510	1.52M
筛选效率	42.9%	43.0%	41.9%	0.27%

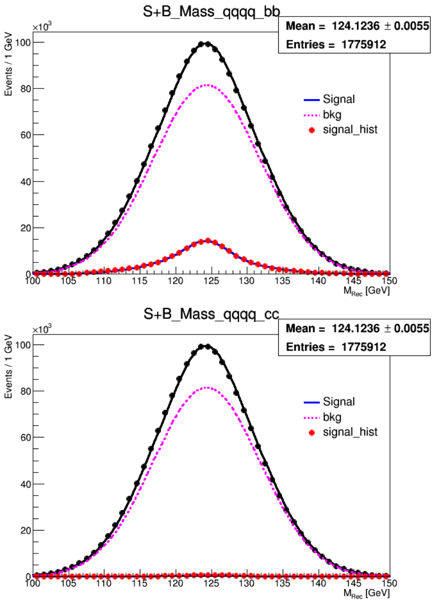
huge bkg events (1520000) will reduce the performance.

if bkg is float, the precision can be worse in qqqq: (0.96%, 12.1%, 18.9%)

My attempt, $bb/cc/gg$

	CDR	Old sample	Current	Baiyu's
bb	0.28%	0.25%	1.53%	0.3%
cc	2.2%	2.70%	38.0%	3.2%
gg	1.6%	1.17%	7.9%	1.6%

- Now, we can use either mass spectrum or template as observables.
- In old sample, bb/cc/gg is separated(which is not realistic.) and bkg is not complete.
- Now in a single channel, as bb/bkg large, cc/gg events limited,
  - qqbb 170000, qqcc 8000, and bkg ~1520000.
  - the fit is unstable/ performance is vary poor now.
  - Fixing……
  - Other channels not influenced.
  - In theory this result is all the same with Baiyu's result.

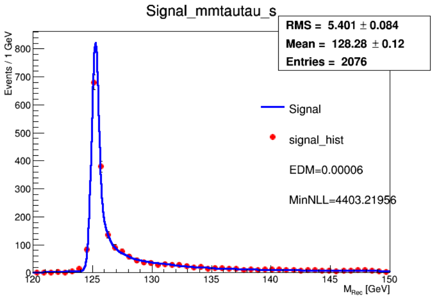


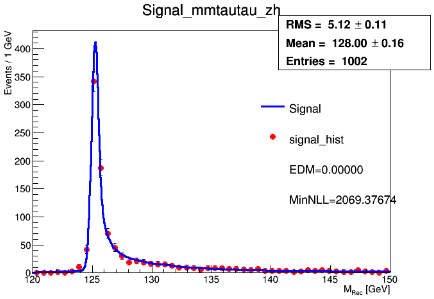
Black line&dot: Asimov s+b pdf&data
Blue line: signal pdf
Red dot: signal mc sample
Ping dash: SM bkg

$\tau\tau$

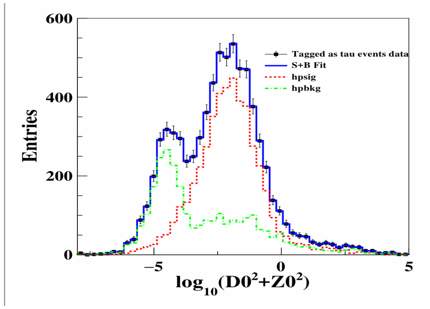
	CDR	Currently
$\tau\tau$	1.2%	0.74% (overestimated)

- Pre_CDR concludes the precision result but no description.
- Signal and ZH events(Main WW) share the same shape
    - Dan use $\log_{10}(D_0^2 + Z_0^2)$ fit to separate signal
    - Distance from beam spot
    - Determine the ratio, then use ratio to produce signal sample.





- Currently,
    - qqtt channel's bkg not ready and some bugs in vvtt's bkg.
    - So bkg not included; this 0.74% can be overestimated.



WW

	CDR	Manqi's	Mine
WW	1.5%	1.0%	**1.24%**

- Pre_CDR's result contains:

Channel	Precision	Comment
$Z \to \mu\mu, H \to WW^* \to \ell\nu qq, \ell\ell\nu\nu$	4.9%	CEPC Full Simulation
$Z \to ee, H \to WW^* \to \ell\nu qq, \ \ell\ell\nu\nu$	7.0%	Scaled from $\mu^+\mu^-$ channel
$Z \to \nu\bar{\nu}, H \to WW^* \to qqqq$	2.3%	Extrapolated from ILC result
$Z \to qq, H \to WW^* \to \ell\nu qq$	2.2%	Extrapolated from ILC result
Combined	1.5%	

Excepted signal events of each type

W boson decay \ Z boson decay	ee	$\mu\mu$	$\tau\tau$	$\nu\nu$	qq
$WW^* \to e\nu e\nu$	88	88	88	525	1836
$WW^* \to \mu\nu\mu\nu$	87	87	87	517	1808
$WW^* \to e\nu\mu\nu$	175	175	175	1052	3644
$WW^* \to e\nu\tau\nu$	187	187	188	1116	3901
$WW^* \to \mu\nu\tau\nu$	186	186	186	1107	3872
$WW^* \to \tau\nu\tau\nu$	99	99	99	593	2072
$WW^* \to e\nu qq$	1111	1112	1114	6612	23112
$WW^* \to \mu\nu qq$	1103	1104	1105	6562	22939
$WW^* \to \tau\nu qq$	1181	1182	1183	7025	24558
$WW^* \to qqqq$	3498	3502	3506	20808	72735

Done

To do

Wei Yuqian's work

Mila

- Currently have 11 channels of WW (with box)
  - Data entry is different with Pre_CDRs'.
  - Others are undergoing

Libo's summary

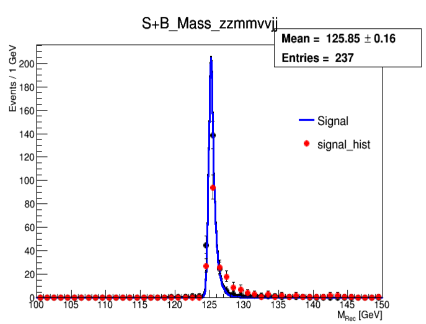
Category	Signal	Relative uncertainty	Efficiency of se
$Z \to e^+e^-; H \to WW^* \to e\nu e\nu$	20±7	35%	25.0%
$Z \to e^+e^-; H \to WW^* \to \mu\nu\mu\nu$	44±8	18.2%	43.1%
$Z \to e^+e^-; H \to WW^* \to e\nu\mu\nu$	53±8	15.1%	27.6%
$Z \to e^+e^-; H \to WW^* \to e\nu qq$	435±23	5.3%	37.0%
$Z \to e^+e^-; H \to WW^* \to \mu\nu qq$	551±24	4.5%	48.0%
$Z \to \mu^+\mu^-; H \to WW^* \to e\nu e\nu$	23±5	21.7%	25.8%
$Z \to \mu^+\mu^-; H \to WW^* \to \mu\nu\mu\nu$	39±7	18%	44.8%
$Z \to \mu^+\mu^-; H \to WW^* \to e\nu\mu\nu$	93±10	11%	54.1%
$Z \to \mu^+\mu^-; H \to WW^* \to e\nu qq$	573±25	4.0%	51.7%
$Z \to \mu^+\mu^-; H \to WW^* \to \mu\nu qq$	756±30	4.4%	68.4%
$Z \to \nu\bar{\nu}; H \to WW^* \to qqqq$	8403±202	2.4%	34.7%
$Z \to \mu^+\mu^-; H \to WW^* \to qqqq$	±	2.93%	

ZZ

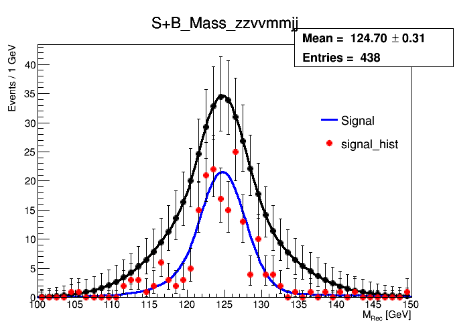
	CDR	Mine
ZZ	4.3%	5.41%

Channel	Precision	Comment
$\sigma(Z(\nu\bar{\nu})H + \nu\bar{\nu}H) \times \mathrm{BR}(H \to ZZ)$	6.9%	CEPC Fast Simulation
$\mathrm{BR}(H \to ZZ^*)$	4.3%	Extrapolation from FCC-ee [36]

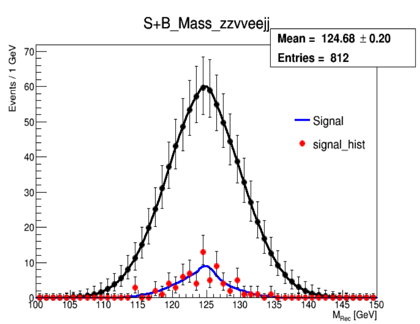
- 3 final Z, one off-shell.
- Pre_CDR's result from extrapolating the FCC-ee.
- Now has 3 channels clear and easy to study
  - Others are rather difficult; undergoing by Yuqian.



μμ	vvjj



vv	μμjj



ee	vvjj

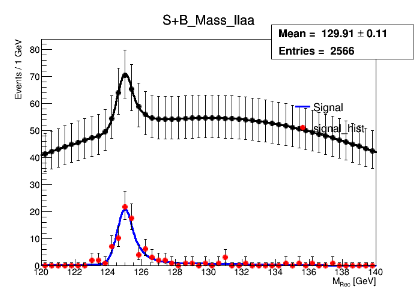
$\gamma\gamma$

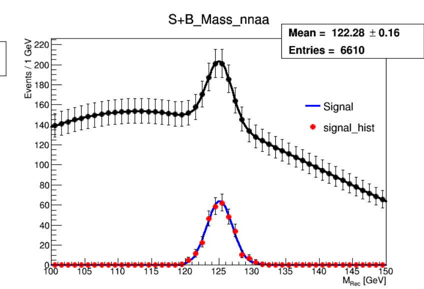
	CDR	Mine
ZZ	9.0%	7.38%

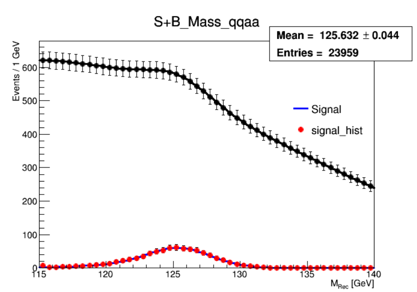
Z	H	Mine	CDR
ll		90	62+56
vv	γγ	328	339
qq		828	582

Signal events comparison

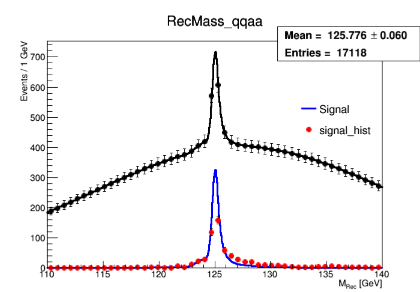
- 3 channels of $\gamma\gamma$ ($ll, vv, qq + \gamma\gamma$, lepton=$\mu, \tau$)
- Pre_CDR assume ECAL's resolution $\sim \frac{16\%}{\sqrt{E}} \oplus 1\ \%$, then to 9%.
- llrr, vvrr are fast simulated by Feng in 2015, and now outdated.
- qqrr updated by Yitian in 2017.4.
- Awaiting update.







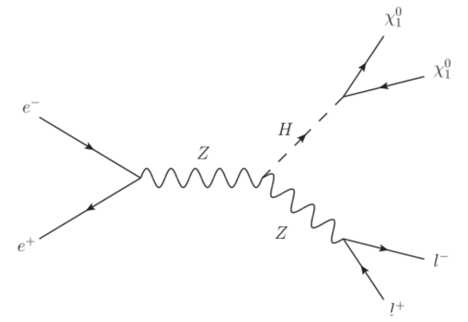
New plot for qqrr



Old plot for qqrr, totally different.

$H \to invisible$

	CDR	Mine
$invisible$	0.14%	\



- In pre_CDR, plan to search exotic decay
  - SUSY $H \to \chi_1 \chi_1$ assume σ =200 fb.

  In this case, extrapolated from ILC studies, precision is 0.14%

- Here, treat H->ZZ->vvvv as invisible.
  - 3 channels analyzed by Moxin, Z->ee/mumu/qq
  - As large bkg, my precision of μ is ~14.5%.
  - The Br precision is 0.18% (in pre_CDR it's 0.28%)

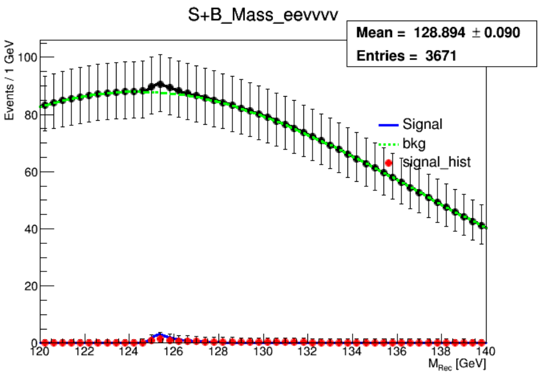


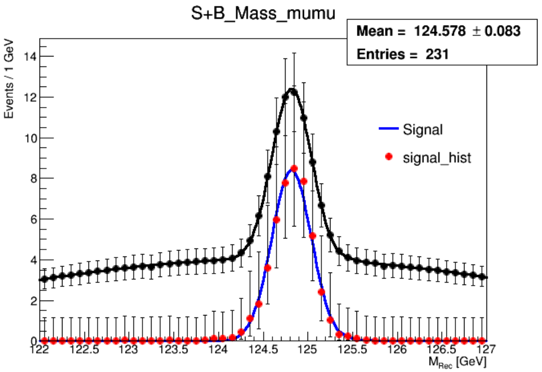
Table 11: Branching ratio measurement and upper limit

	e^+e^-h	$\mu^+\mu^-h$	$q\bar{q}h$
Br	0.11 ± 0.49%	0.18% ± 0.27%	0.06% ± 0.34%
CL 95% upper limit	1.06%	0.69%	0.42%
Combination	Br 0.18% ± 0.18%, CL 95% upper limit 0.50%		

$\mu\mu$ and other rare decays

	CDR	Mine
$\mu\mu$	17%	14.50%

- $\mu\mu$ process, the Z decay is inclusive
  - performance benchmark for the tracking system design



- $Z\gamma, e\mu, ee$ process are studied.
  - Since low stats and no clear ratio, not taken into fit model.

$\Delta(Br * \sigma)$ fit Result

bb/cc/gg use Baiyu's result

	PreCDR	$\sigma(ZH) * \mathrm{Br}$	**PreCDR for ΔBr**	**Fit result for ΔBr**
$\sigma(ZH)$	0.51%	set to 0.50%		
$\Delta(Br * \sigma)$	0.28%	0.17%		0.54%
$\sigma(ZH) * \mathrm{Br}(\mathrm{H} \to \mathrm{bb})$	0.28%	**0.30%**	0.57%	0.57%
$\sigma(ZH) * \mathrm{Br}(\mathrm{H} \to \mathrm{cc})$	2.2%	**3.20%**	2.3%	1.80%
$\sigma(ZH) * \mathrm{Br}(\mathrm{H} \to \mathrm{gg})$	1.6%	**1.60%**	1.7%	1.06%
$\sigma(ZH) * \mathrm{Br}(\mathrm{H} \to \mathrm{WW})$	1.5%	**1.24%**	1.6%	1.35%
$\sigma(ZH) * \mathrm{Br}(\mathrm{H} \to \mathrm{ZZ})$	4.3%	**5.41%**	4.3%	5.42%
$\sigma(ZH) * \mathrm{Br}(\mathrm{H} \to \tau\tau)$	1.2%	**0.74%**	1.3%	1.00%
$\sigma(ZH) * \mathrm{Br}(\mathrm{H} \to \gamma\gamma)$	9.0%	**7.38%**	9.0%	7.38%
$\sigma(ZH) * \mathrm{Br}(\mathrm{H} \to \mu\mu)$	17%	**14.65%**	17%	14.65%
$\mathrm{Br}(\mathrm{H} \to \mathrm{inv.})$	\	\	0.28%	0.18%

κ framework

- Define as the ratio of the coupling to SM expects.

$$\kappa_f = \frac{g(hff)}{g(hff;\mathrm{SM})},\ \kappa_V = \frac{g(hVV)}{g(hVV;\mathrm{SM})}$$

- In CEPC, κ occurs on three places:
  - For Production, as now only ZH sample, κ_Z^2;
  - For Partial decay, no top quark κ_t like: $\kappa_Z^2, \kappa_W^2, \kappa_b^2, \kappa_c^2, \kappa_g^2, \kappa_\tau^2, \kappa_\gamma^2, \kappa_\mu^2, \kappa_{Inv}^2$ … …
  - For Total width Γ_H. $\Gamma_H = \Gamma_{SM} + \Gamma_{BSM}$ for exotic decays.
- κ framework varies for different assumptions.
- Here our fit, as sample limited, we set:
  - $\Gamma_{BSM} = 0$
  - Assume Γ_H constant currently
  - So set 9 κ: $\kappa_Z^2, \kappa_W^2, \kappa_b^2, \kappa_c^2, \kappa_g^2, \kappa_\tau^2, \kappa_\gamma^2, \kappa_\mu^2, \kappa_{Inv}^2$

κ: current precision result

κ	9	8	7
κ_{b}	1.22%	1.22%	1.22%
κ_{c}	1.77%	1.77%	1.77%
κ_{g}	1.29%	1.29%	1.29%
κ_{γ}	4.01%	4.02%	4.00%
κ_{τ}	1.28%	1.28%	1.16%
κ_{μ}	8.11%	8.11%	
$\kappa_{inv(H\to vvvv)}$	12.99%		
κ_{Z}	0.93%	0.93%	0.90%
κ_{W}	1.13%	1.14%	1.10%

9: Assume Γ_H constant.

8: Assume no invisible decay. set $\kappa_{inv} = 1$

7: Assume lepton universality $\kappa_l = \kappa_\tau = \kappa_\mu$

These simplification little affect the precision.

κ: comparison to pre_CDR

10 κ	**My fit**	**Pre_CDR**	**7 κ**	**My fit**	**Pre_CDR**
κ_b	1.22%	1.3%	κ_b	1.22%	1.2%
κ_c	1.77%	1.7%	κ_c	1.77%	1.6%
κ_g	1.29%	1.5%	κ_g	1.29%	1.5%
κ_γ	4.01%	4.7%	κ_γ	4.00%	4.7%
κ_τ	1.28%	1.4%	κ_μ=κ_τ	1.16%	1.3%
κ_μ	8.11%	8.6%			
Br_{inv}	12.99%				
κ_Z	0.93%	0.26%	κ_Z	0.90%	0.16%
κ_W	1.13%	1.2%	κ_W	1.10%	1.2%
Γ_H	/	2.8%			

Pre_CDR's result from Michael Peskin's codes, totally theoretic calculation. (most stats. dependent)

Mine from MC sample.

The fit didn't consider $\Delta\sigma(ZH) = 0.5\%$, which contributes a lot to κ_Z.
(and only κ_Z, so others are consistent.)

So there are a big gap.

Add pseudo data

- Since now data incomplete, bad result for κ_z

- If we reuse some MC sample
  - Ensure out total $\sigma(ZH) = 0.5\%$
  - Contribute to κ_z and μ_{global}
  - Then κ_z could be 0.12%
  - $\mu_{global} = 0.11\%$, other unchanged;

κ: other assumptions

κ	**2**
κ_{V}	0.11%
κ_f	0.18%

- κ, only κ_V Boson and κ_f Fermi:
  - Means the ratio $\frac{g}{g_{SM}}$ for each Boson/Fermi are equal.
- Introducing other colliders' results in
  - Resolutions like $\kappa_\gamma^2 = 1.59\kappa_W^2 + 0.07\kappa_t^2 - 0.66\kappa_W\kappa_t$ can be added;

To dos

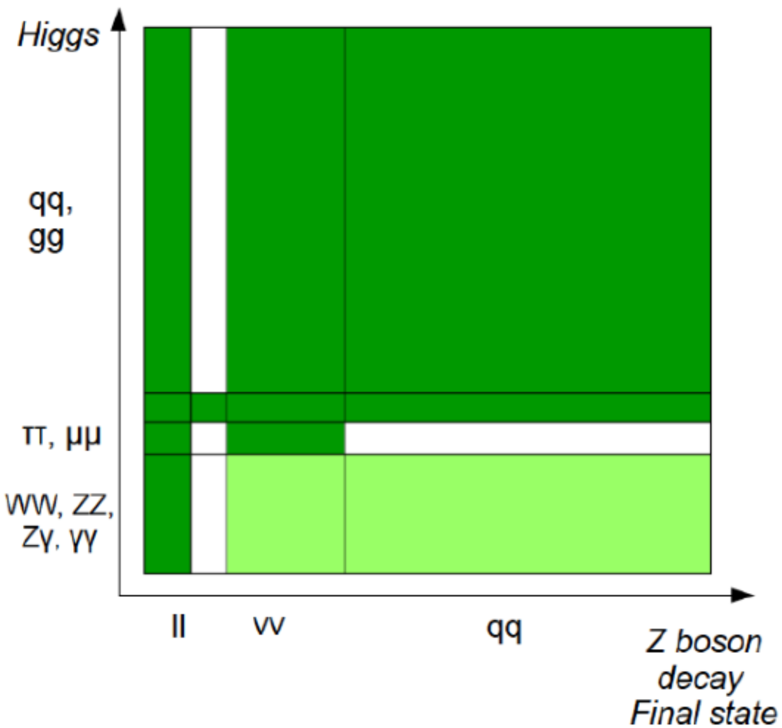
Can do a lot to improve this model in the future:

- Fix template issues.
- Use different assumptions to complete κ.
- Introduce NPs to describe uncertainties.
- Profile likelihood ratio? 2-D Contour? ……

Thanks for your attention!

Manqi's summary on LHEP 2017

CEPC: Simulation Studies



	PreCDR (Jan 2015)	Now (Aug 2016)
σ(ZH)	0.51%	0.50%
σ(ZH)*Br(H→bb)	0.28%	0.21%
σ(ZH)*Br(H→cc)	2.1%	2.5%
σ(ZH)*Br(H→gg)	1.6%	1.3%
σ(ZH)*Br(H→WW)	1.5%	1.0%
σ(ZH)*Br(H→ZZ)	4.3%	4.3%
σ(ZH)*Br(H→ττ)	1.2%	1.0%
σ(ZH)*Br(H→γγ)	9.0%	9.0%
σ(ZH)*Br(H→Zγ)	-	~4 σ
σ(ZH)*Br(H→μμ)	17%	17%
σ(ννH)*Br(H→bb)	2.8%	2.8%
Higgs Mass/MeV	5.9	5.0
σ(ZH)*Br(H→inv)	95%. CL = 1.4e-3	1.4e-3
Br(H→ee/emu)	-	1.7e-4/1.2e-4
Br(H→bbχχ)	$<10^{-3}$	3.0e-4