CEPC Higgs combination

ZhangKaili

IHEP

2017-08-14

Outline

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

Combination measurement

- Uniformed, simultaneous fit framework
- Can easily include necessary correlations/uncertainties
- Extensibility for making different assumptions
- Currently, with MC sample,
  - fit Asimov data to get
  - estimated precisions of $\sigma * Br$, Br, and κ of CEPC.

Fit techniques

- Workspace: container of likelihood model and data.
- Input: Higgs 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

For $\Delta\sigma = 0.5\%$

The response function is 1+0.005ε,

$\varepsilon(-5,5),\ \sim\text{N}(\mu,1),\ and\ \mu(-5,5)$

And convolute it to whole model.

The fit determines the value of ε and μ.

So not always $\Delta\sigma = 0.5\%$.

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 Tot=N_{bb}*Pdf+N_{cc}*Pdf_{cc}+……+N_{bkg}*Pdf_{bkg}
  - Add μs on evnets number N_{bb}, could be:
    - When measure $\sigma * Br$, $N_{bb} = N_{bb\_SM} * \mu_{bb}$
    - When measure Br, $N_{bb} = N_{bb\_SM} * \frac{Br_{bb}}{Br_{bbSM}} * \frac{\sigma(ZH)}{\sigma(ZH)_{SM}}$
    - When measure κ, $N_{bb} = N_{bb\_SM} * \kappa_z^2 * \kappa_b^2$
    - Different channel share the same μs. eebb, mmbb, qqbb, vvbb……
  - Use Combine pdf to make Asimov data 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 39)

*H->ee/eμ not listed due to no certain ratio.
*nn/qq+ττ without bkg.
*H->zz->νννν is tagged H->invisible.

Signal Z	Signal H	Observed Events	Who takes charge	Last update
H->qq				
ee	bb	7655	Baiyu	2017.7
	cc	351		
	gg	1058		
μμ	bb	10575		
	cc	538		
	gg	1556		
qq	bb	176542		
	cc	8272		
	gg	25293		
νν	bb	70608		
	cc	3061		
	gg	9633		
H->γγ				
ll	γγ	93	Feng	2015
νν		309		
qq		822	Yitian	2017.4
H->Invisible				
qq	νννν	202	MoXin	2017.7
ee		8		
μμ		18		

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

Signal Z	Signal H	Observed Events	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	200		
ee	ννjj	69		
H->ll				
μμ	ττ	2068	Dan	2017.7*
qq		36023		
νν		12456		
qq	μμ	71	Zhenwei	2017.8
ee		1		
μμ		4		
νν		14		

Individual analysis intro

$bb/cc/gg$

- Higgs ~70% to dijets bb/cc/gg
  - Flavor tagging algorithm
- Pre_CDR
  - bb/cc/gg separated (not reasonable)
  - $v\bar{v}H$, $\bar{q}qH$ results are extrapolated from ILC studies.
  - Bkg estimation optimistic
- Baiyu, Liboyang's template fit
  - $Z \rightarrow ee\ \mu\mu\ qq\ vv$, $\mathrm{H} \rightarrow bb/cc/gg$ are studies.
  - 2D fit, with dijets' b/c likeness
  - In $Z \rightarrow ee\ \mu\mu\ qq\ vv$, Tot=bb+cc+gg+$bkg_{zh}$+$bkg_{sm}$.
  - Build individual pdf by MC, then fit to determine fraction.
  - the shape of bkg is fixed.
    - Which means we have a wonderful understanding with bkg,
    - may be more suitable for CEPC.
  - toyMC to measure the precision
- Repeat their template in my model
  - Result is consistent.

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

Pre_CDR	μ_bb	μ_cc	μ_gg
eeH	1.1%	14.6%	5.6%
mmH	0.9%	12.6%	3.8%
qqH	0.4%	3.0%	2.6%
vvH	0.45%	3.2%	2.8%
Combined	0.28%	2.2%	1.6%

Baiyu's	μ_bb	μ_cc	μ_gg
eeH	1.2%	14.4%	7.8%
mmH	1.1%	12.8%	6.9%
qqH	0.4%	8.0%	5.2%
vvH	0.4%	3.8%	1.6%
Combined	0.3%	3.2%	1.6%

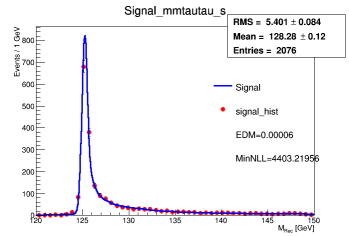
Mine	μ_bb	μ_cc	μ_gg
eeH	1.26%	14.96%	7.16%
mmH	1.04%	14.36%	5.28%
qqH	0.47%	8.08%	6.76%
vvH	0.40%	3.80%	1.54%
Combined	0.27%	3.39%	1.42%

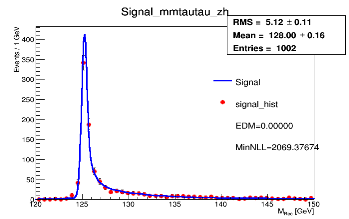
$\tau\tau$

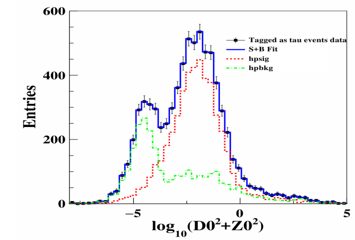
	CDR	Currently
$\tau\tau$	1.2%	0.53% (overestimated)

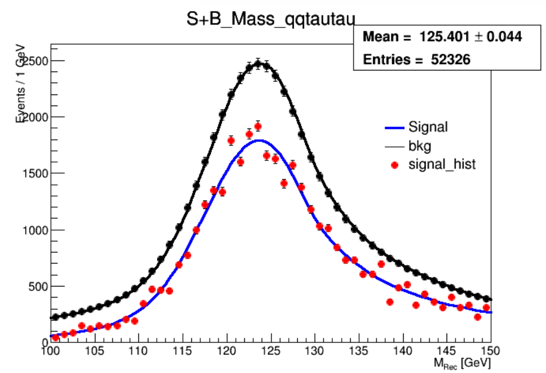
- Pre_CDR concludes the precision result but no description.
- Signal and ZH events(Main WW) share the same shape
  - Dan use $\log_{10}(D_0^2 + Z_0^2)$ fit to separate signal
    - Distance from beam spot
  - Determine the ratio, then use ratio to produce signal sample.
- Currently,
  - qq$\tau\tau$ and νν$\tau\tau$'s bkg not ready; only signal.
  - So this 0.53% can be overestimated.
  - （only considering mm$\tau\tau$, precision is 2.71%）

Dan's result	mm	νν	qq
$\tau\tau$	2.68%	1.86%	0.76%









WW

	CDR	Mine
WW	1.5%	**1.26%**

- 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

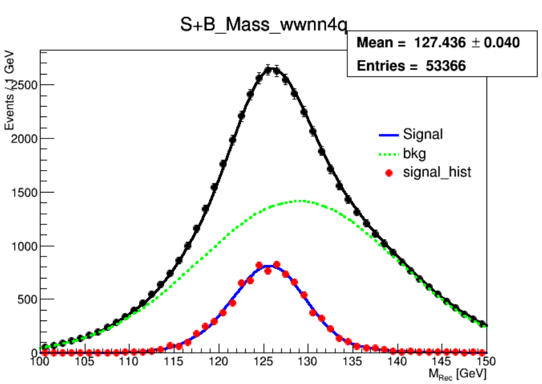
Done

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

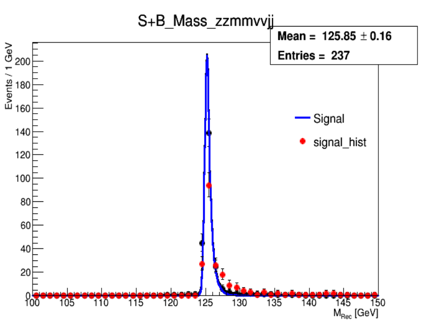
Category	Signal	Relative uncertainty	Efficiency of se
$Z \to e^+e^-; H \to WW^* \to e\nu e\nu$	20±7	35%	25.0%
$Z \to e^+e^-; H \to WW^* \to \mu\nu\mu\nu$	44±8	18.2%	43.1%
$Z \to e^+e^-; H \to WW^* \to e\nu\mu\nu$	53±8	15.1%	27.6%
$Z \to e^+e^-; H \to WW^* \to e\nu qq$	435±23	5.3%	37.0%
$Z \to e^+e^-; H \to WW^* \to \mu\nu qq$	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

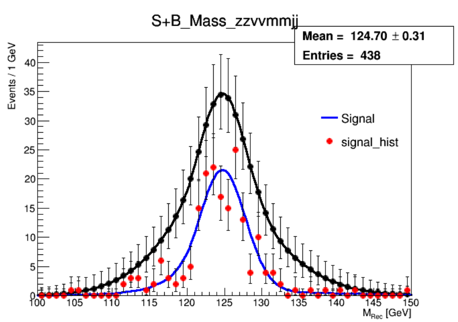
	CDR	Mine
ZZ	4.3%	5.57%

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]

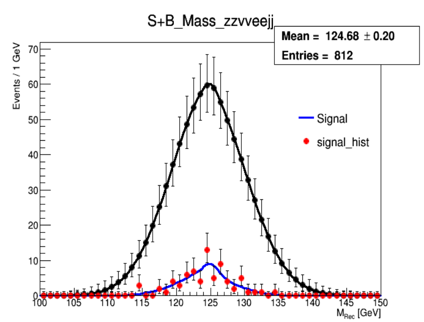
- 3 final Z, one off-shell.
- Pre_CDR's result from extrapolating the FCC-ee.
- Now has 3 channels clear and easy to study
    - Others are rather difficult; undergoing by Yuqian.



μμ	vvjj



vv	μμjj



ee	vvjj

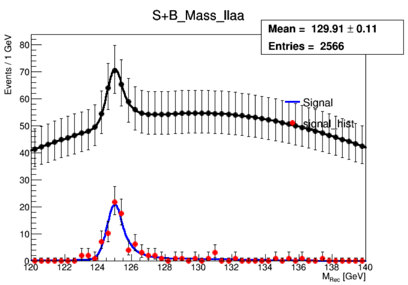
$\gamma\gamma$

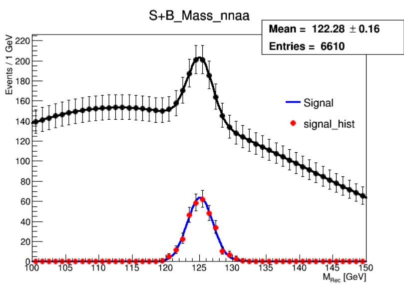
	CDR	Mine
ZZ	9.0%	7.31%

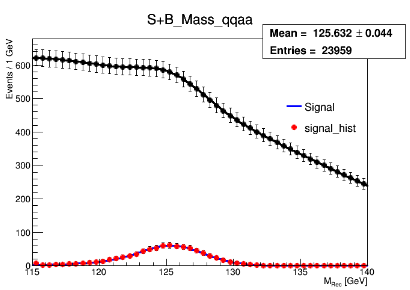
Z	H	Mine	CDR
ll	γγ	90	62+56
vv		328	339
qq		828	582

Signal events comparison

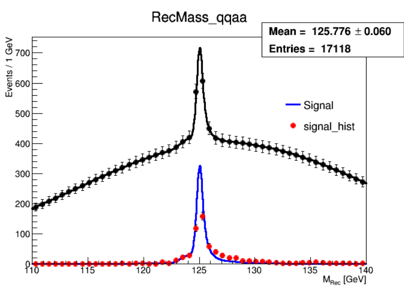
- 3 channels of $\gamma\gamma$ ($ll, vv, qq + \gamma\gamma$, lepton=$\mu, \tau$)
- Pre_CDR assume ECAL's resolution $\sim \frac{16\%}{\sqrt{E}} \oplus 1\,\%$, then to 9%.
- llrr, vvrr are fast simulated by Feng in 2015, and now outdated.
- qqrr updated by Yitian in 2017.4.
- Awaiting update.







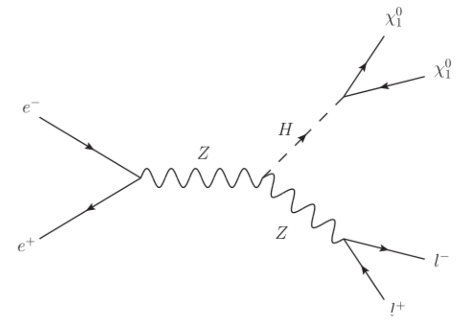
New plot for qqrr



Old plot for qqrr, totally different.

$H \rightarrow invisible$

	CDR	Mine
invisible	0.14%	\



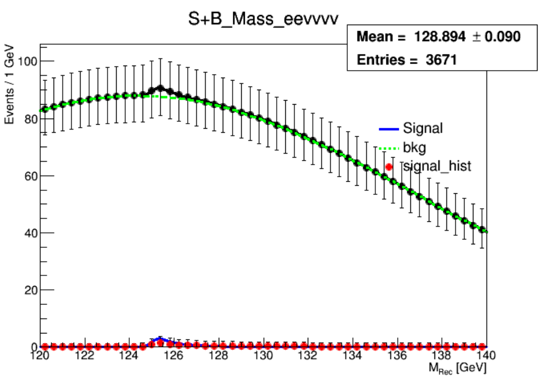
- In pre_CDR, plan to search exotic decay
  - SUSY $H \rightarrow \chi_1 \chi_1$ assume σ =200 fb.

  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 ~10%.
  - The Br precision is 0.18% (in pre_CDR it's 0.28%)

Table 11: Branching ratio measurement and upper limit

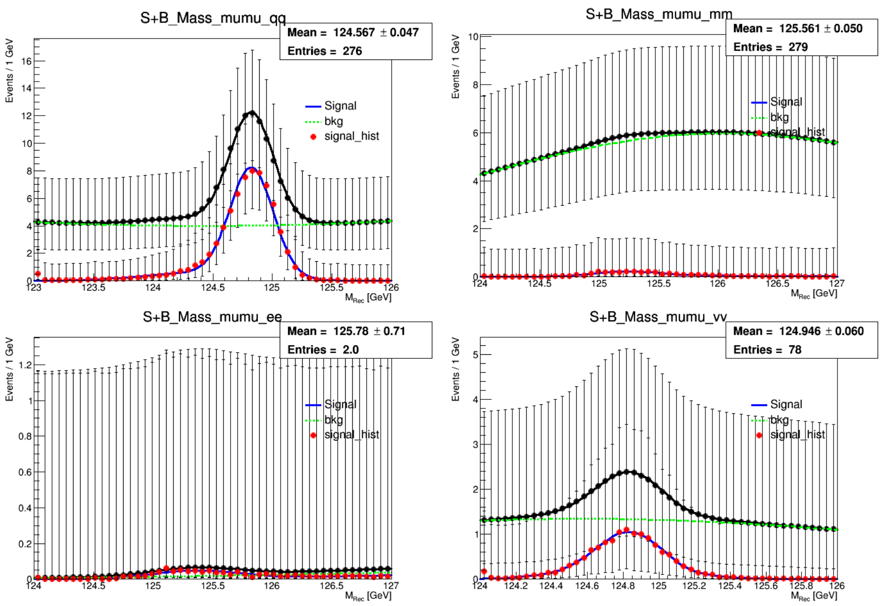
	e^+e^-h	$\mu^+\mu^-h$	$q\bar{q}h$
Br	0.11 ± 0.49%	0.18% ± 0.27%	0.06% ± 0.34%
CL 95% upper limit	1.06%	0.69%	0.42%
Combination	Br 0.18% ± 0.18%, CL 95% upper limit 0.50%		



$\mu\mu$ and other rare decays

	CDR	Mine
$\mu\mu$	17%	15.0%

- $\mu\mu$ process
  - Pre_CDR's 17% not reliable;
  - Zhen Wei separate Z->ee,mm, vv and qq
  - Small signal window;
  - After cut 90 signals left.



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

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

	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%	0.20%		
$\sigma(ZH) * \mathrm{Br}(\mathrm{H} \to \mathrm{bb})$	0.28%	**0.27%**	0.57%	0.57%
$\sigma(ZH) * \mathrm{Br}(\mathrm{H} \to \mathrm{cc})$	2.2%	**3.39%**	2.3%	3.43%
$\sigma(ZH) * \mathrm{Br}(\mathrm{H} \to \mathrm{gg})$	1.6%	**1.42%**	1.7%	1.51%
$\sigma(ZH) * \mathrm{Br}(\mathrm{H} \to \mathrm{WW})$	1.5%	**1.26%**	1.6%	1.36%
$\sigma(ZH) * \mathrm{Br}(\mathrm{H} \to \mathrm{ZZ})$	4.3%	**5.57%**	4.3%	5.59%
$\sigma(ZH) * \mathrm{Br}(\mathrm{H} \to \tau\tau)$	1.2%	**0.53%***	1.3%	0.73%*
$\sigma(ZH) * \mathrm{Br}(\mathrm{H} \to \gamma\gamma)$	9.0%	**7.31%**	9.0%	7.33%
$\sigma(ZH) * \mathrm{Br}(\mathrm{H} \to \mu\mu)$	17%	**15.00%**	17%	15.00%
$\mathrm{Br}(\mathrm{H} \to \mathrm{inv.})$	\	\	0.28%	0.18%(Moxin)

In general, fit result is consistent with results of Pre_CDR and Individual studies.

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: $\kappa_Z^2, \kappa_W^2, \kappa_b^2, \kappa_c^2, \kappa_g^2, \kappa_\tau^2, \kappa_\gamma^2, \kappa_\mu^2, \kappa_{Inv}^2$

Currently the model can't fit out the Higgs width, need to import from outside. (in Pre_CDR 2.8%)

- $N_{bb} = N_{bb\_SM} * \kappa_z^2 * \kappa_b^2$ Fit principle is all the same with $\Delta(Br * \sigma)$. (replace μ_{bb} to $\kappa_z^2 \kappa_b^2$)

κ: current precision result

κ	7	8	9
κ_{b}	0.54%	0.54%	0.54%
κ_{c}	1.82%	1.82%	1.82%
κ_{g}	0.95%	0.95%	0.95%
κ_{γ}	4.01%	4.04%	4.04%
κ_{τ}	0.76%*	0.77%	0.77%
κ_{μ}		6.95%	6.95%
$\kappa_{inv(H\to\nu\nu\nu\nu)}$			10.78%
κ_{Z}	0.51%	0.52%	0.52%
κ_{W}	0.82%	0.83%	0.83%

9: Assume Γ_H constant.

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

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

These assumptions are also used in Pre_CDR.

*result of κ_τ is overestimated.

These simplification little affect the precision.

κ: comparison to pre_CDR

7 κ	My fit	Pre_CDR
κ_b	0.54%	1.2%
κ_c	1.82%	1.6%
κ_g	0.95%	1.5%
κ_γ	4.01%	4.7%
κ_μ=κ_τ	0.76%	1.3%
κ_Z	0.51%	0.16%
κ_W	0.82%	1.2%

Pre_CDR's result from Michael Peskin's codes, totally theoretic calculation.

Mine from MC sample.

As current no inclusive data,
My data don't contain $\Delta(ZH) = 0.5\%$
which is a strong constrain to κ_Z.

Still, Except κ_Z, this fit result is much better than the Pre_CDR.

Undergoing……

Add pseudo data

- If we reuse some MC sample
  - Ensure out total $\sigma(ZH) = 0.5\%$
  - This new channel only contribute to κ_z
  - Then κ_z could be 0.12%
  - And all other kappa improved.
  - (all constrained by κ_Z's precision)

Why this kappa result so good?

(Meanwhile $\Delta(Br * \sigma)$ result consistent?)

Under check.

7 κ	**With pseudo**	**Wo pseudo**	**Pre_CDR**
κ_b	0.18%	0.54%	1.2%
κ_c	1.72%	1.82%	1.6%
κ_g	0.72%	0.95%	1.5%
κ_γ	4.02%	4.01%	4.7%
κ_μ=κ_τ	0.31%	0.76%	1.3%
κ_Z	0.12%	0.51%	0.16%
κ_W	0.64%	0.82%	1.2%

Other assumptions (with pseudo)

Let $\kappa_b = \kappa_c = \kappa_g$	
5 κ	My fit
κ_q	**0.175%**
κ_l	**0.310%**
κ_γ	**4.025%**
κ_Z	**0.118%**
κ_W	**0.635%**

Only differ Boson and Fermi	
2 κ	My fit
κ_V	**0.107%**
κ_f	**0.162%**

Combine bb/cc/gg	$\sigma(ZH) * \mathrm{Br}$	ΔBr
$\sigma(ZH) * \mathrm{Br}(H \to qq)$	0.25%	0.56%
$\sigma(ZH) * \mathrm{Br}(H \to WW)$	**1.25%**	1.35%
$\sigma(ZH) * \mathrm{Br}(H \to ZZ)$	**5.57%**	5.59%
$\sigma(ZH) * \mathrm{Br}(H \to \tau\tau)$	**0.52%**	0.72%
$\sigma(ZH) * \mathrm{Br}(H \to \gamma\gamma)$	**7.31%**	7.33%
$\sigma(ZH) * \mathrm{Br}(H \to \mu\mu)$	**14.99%**	15.00%

Classified by Z decay （will comparible with inclusive data）	$\sigma(ZH) * \mathrm{Br}$	ΔBr
$\sigma(ZH) * \mathrm{Br}(Z \to ee)$	**1.11%**	1.22%
$\sigma(ZH) * \mathrm{Br}(Z \to \mu\mu)$	**0.87%**	1.00%
$\sigma(ZH) * \mathrm{Br}(Z \to qq)$	**0.32%**	0.59%
$\sigma(ZH) * \mathrm{Br}(Z \to \nu\nu)$	**0.34%**	0.60%

To dos

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

- Wait inclusive data sample
- Study κ framework
- Add Higgs width to model
- Profile likelihood ratio, 2-D Contour, ……

Thanks for your attention!