360GeV Extrapolation @ CEPC Higgs Combination

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CEPC Physics Workshop

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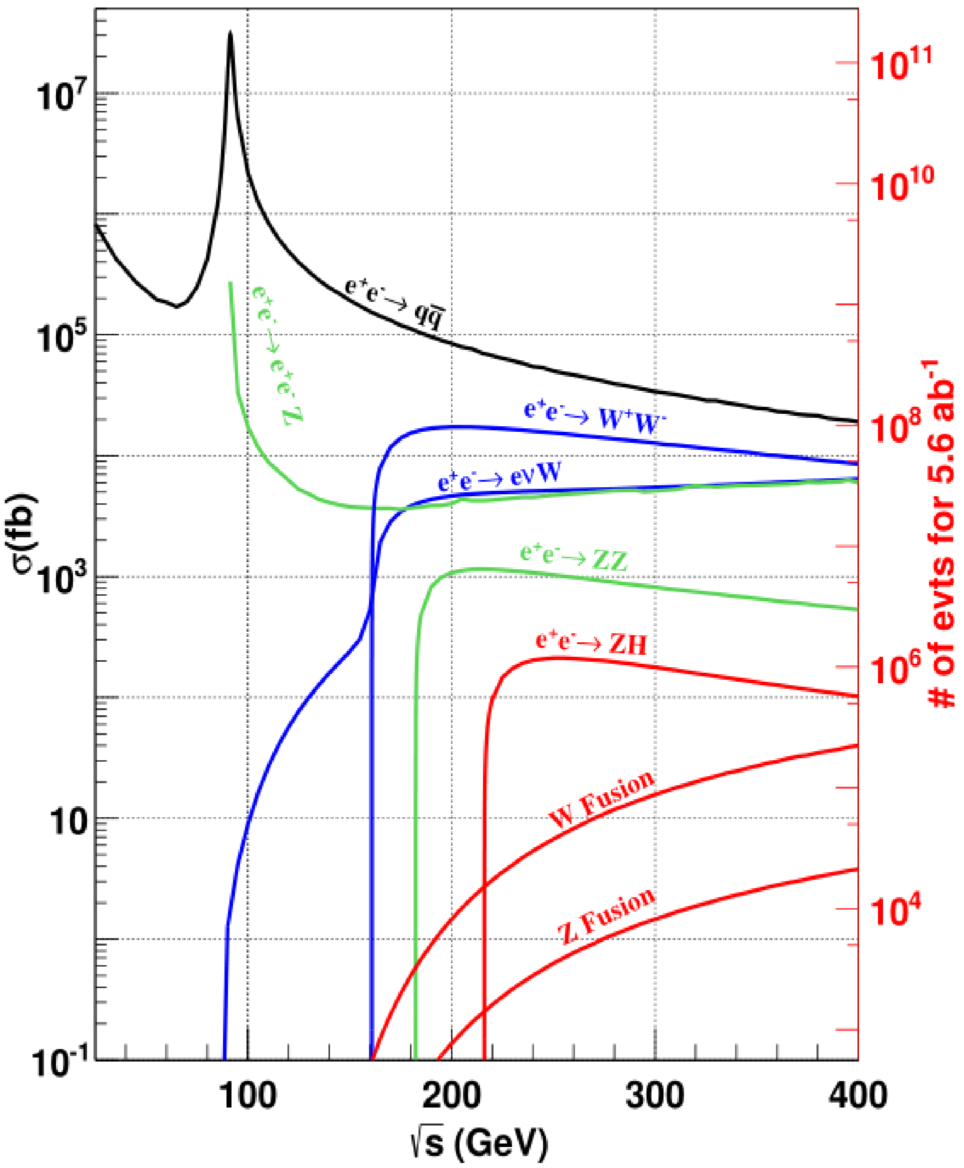
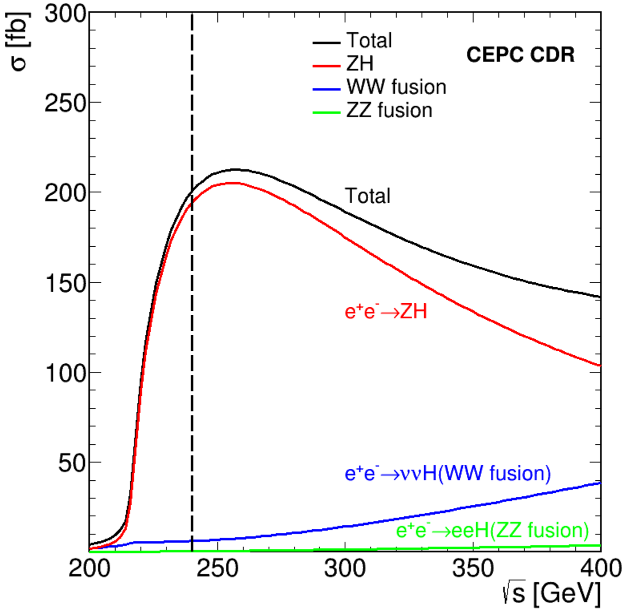
Higgs Physics @ CEPC

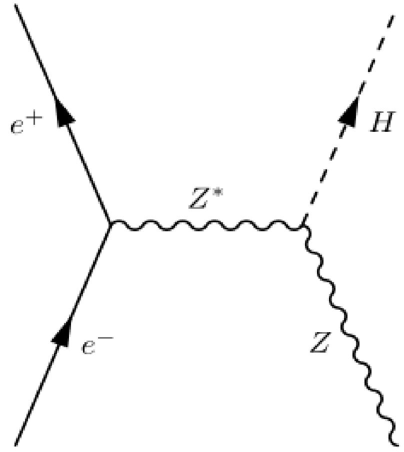




CEPC CDR: arxiv:1811.10545

White Paper: arxiv:1810.09037

Combination Report in Oxford;



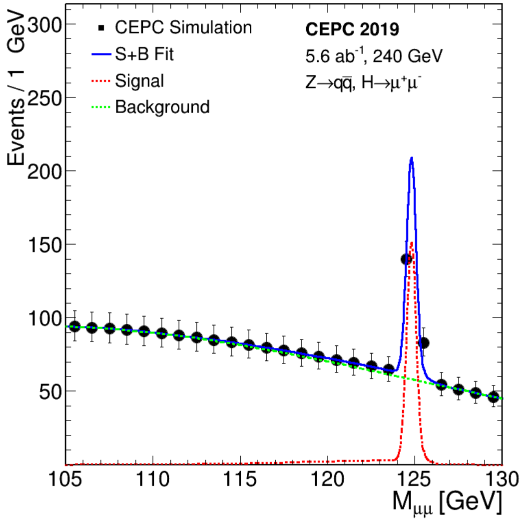
CDR: 1M Higgs in 240GeV, 5.6ab^{-1}

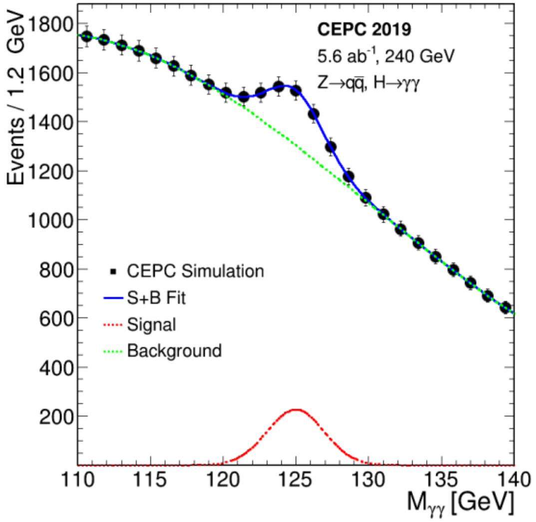
Process	Cross section	Events in 5.6 ab^{-1}
Higgs boson production, cross section in fb		
$e^+e^- \to ZH$	196.2	1.10×10^6
$e^+e^- \to \nu_e\bar{\nu}_e H$	6.19	3.47×10^4
$e^+e^- \to e^+e^- H$	0.28	1.57×10^3
Total	203.7	1.14×10^6

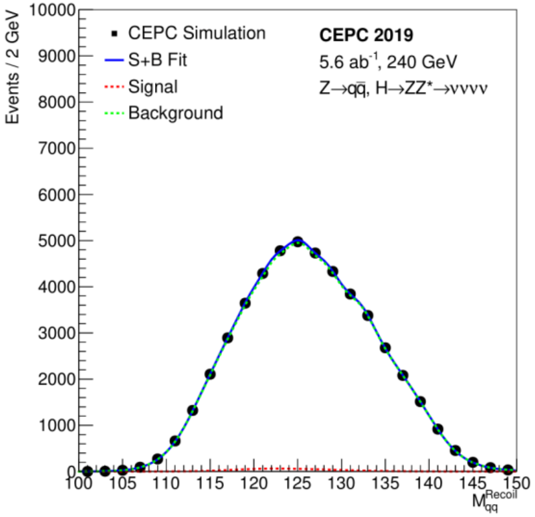
Existing results:240GeV, 5.6iab

$(240GeV,5.6ab^{-1})$	CDR	2019.07	Related Report
$\sigma(ZH)$	**0.50%**		
$\sigma(ZH)*\mathrm{Br}(\mathrm{H}\to \mathrm{bb})$	**0.27%**		
$\sigma(ZH)*\mathrm{Br}(\mathrm{H}\to \mathrm{cc})$	**3.3%**		**Yu Bai**
$\sigma(ZH)*\mathrm{Br}(\mathrm{H}\to \mathrm{gg})$	**1.3%**		
$\sigma(ZH)*\mathrm{Br}(\mathrm{H}\to \mathrm{WW})$	**1.0%**		
$\sigma(ZH)*\mathrm{Br}(\mathrm{H}\to \mathrm{ZZ})$	**5.1%**		**Kiuchi**
$\sigma(ZH)*\mathrm{Br}(\mathrm{H}\to \tau\tau)$	**0.8%**		**Dan Yu**
$\sigma(ZH)*\mathrm{Br}(\mathrm{H}\to \gamma\gamma)$	**6.8%**	**5.4%**	**Fangyi Guo**
$\sigma(ZH)*\mathrm{Br}(\mathrm{H}\to \mu\mu)$	**17%**	**12%**	**Kunlin RAN**
$\sigma(\mathrm{vv}H)*\mathrm{Br}(\mathrm{H}\to \mathrm{bb})$	**3.0%**		**Hao Liang**
$\mathrm{Br}_{\mathrm{upper}}(\mathrm{H}\to \mathrm{inv.})$	**0.41%**	**0.2%**	**Yuhang Tan**
$\sigma(ZH)*\mathrm{Br}(\mathrm{H}\to Z\gamma)$	**16%**		
Width	**2.8%**		

Several channels are improved since last November.







Invisible and $\mu\mu$: Redo the analysis.
$\gamma\gamma$: Applied MVA in qqyy channel.

See more details in their slides!

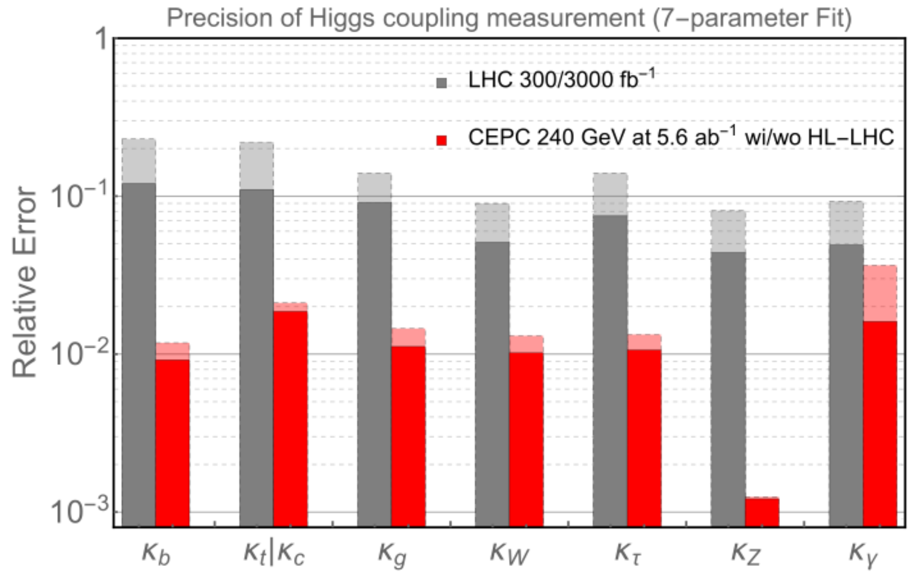
κ Framework result

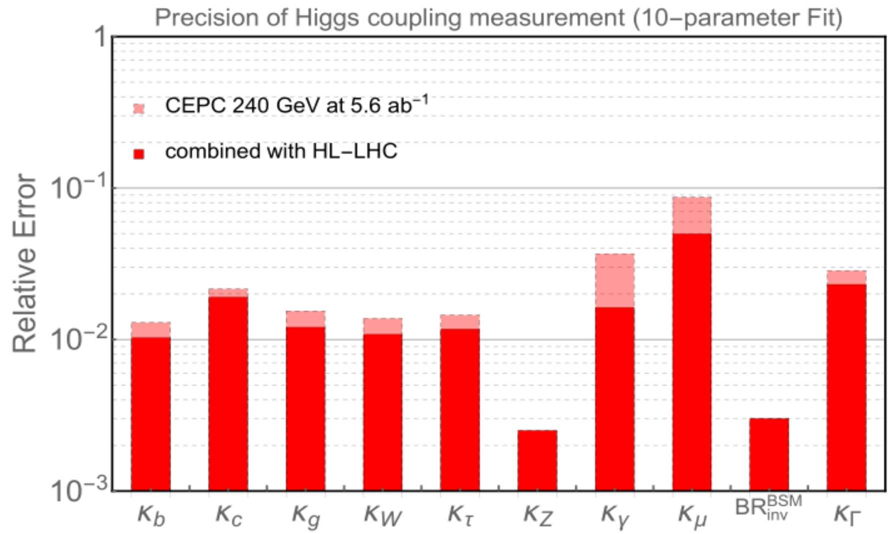
$Z \to \mu\mu, H \to \tau\tau$ channel, the signal will be $\kappa_Z^2 \kappa_\tau^2 / \Gamma_H$;
For $\nu\nu H \to bb$, it's $\kappa_W^2 \kappa_b^2 / \Gamma_H$

See more in Zhen's report!

Relative coupling measurement precision and the 95% CL upper limit on BR_{inv}^{BSM}

Quantity	10-parameter fit		7-parameter fit	
	CEPC	CEPC+HL-LHC	CEPC	CEPC+HL-LHC
κ_b	1.3%	1.0%	1.2%	0.9%
κ_c	2.2%	1.9%	2.1%	1.9%
κ_g	1.5%	1.2%	1.5%	1.1%
κ_W	1.4%	1.1%	1.3%	1.0%
κ_τ	1.5%	1.2%	1.3%	1.1%
κ_Z	0.25%	0.25%	0.13%	0.12%
κ_γ	3.7%	1.6%	3.7%	1.6%
κ_μ	8.7%	5.0%	–	–
BR_{inv}^{BSM}	$<0.30\%$	$<0.30\%$	–	–
Γ_H	2.8%	2.3%	–	–





$\sigma(ZH)0.5\%$, $\kappa_Z 0.25\%$;
Except κ_Z, all the coupling are constrained by Higgs width;
Could not be better than half width(1.4%).

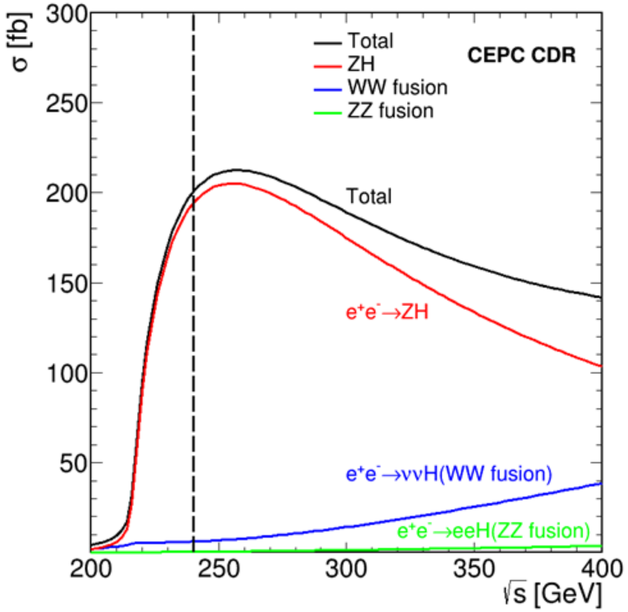
Higher Energy Run

- 350~365GeV Run: worthwhile
  - Over top threshold, EW/EFT/Theoretical part benefits;
  - Larger vvH cross section; Benefit width measurement
    - All constrained by width(2.8%), in current CEPC 240GeV run, Higgs coupling suffered;
  - Fcc-ee/ILC/CLIC all have similar plan
- Temporary benchmark: 2 iab @ 360GeV
  - Test the impact to Higgs measurement
  - 360 saves 10% energy with respect to 365 GeV
  - Not determined yet

The Plan for Fcc-ee (CERN-ACC-2018-0057) :
0.2iab 350GeV + 1.5iab 365GeV

Signal Cross Sections

- 240GeV:
  - ZH: 196.9; vvH: 6.2; interference: ~10% of vvH; about 318:10:1; (Z->vv : vvH = 6.4:1)
  - interference are ignored in the following extrapolation.
- 350GeV: (vvH ~ 100% Z->vv), (eeH ~ 60% Z->ee)
- 360GeV: (vvH ~ 117% Z->vv), (eeH ~ 67% Z->ee)
- 365GeV: (vvH ~ 126% Z->vv), (eeH ~ 71% Z->ee)

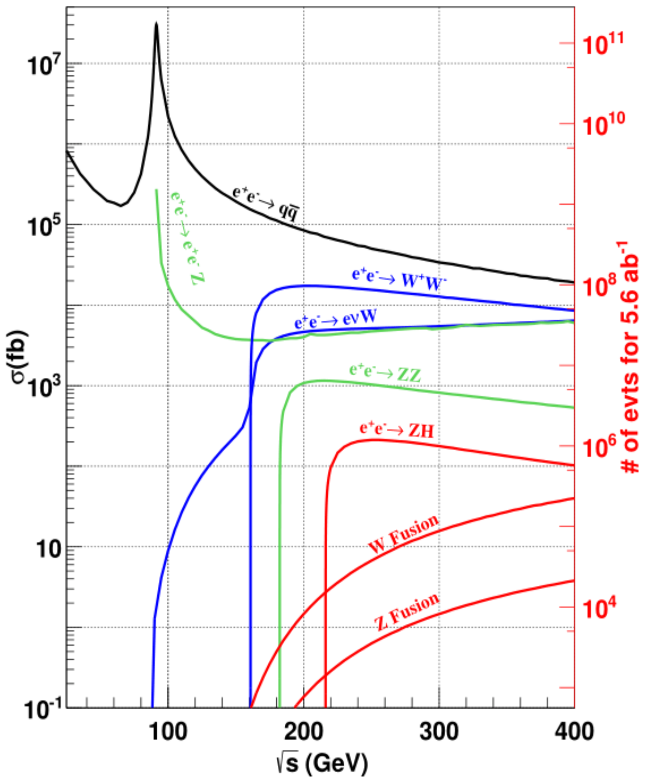


fb	240	350	360	365	360/240
ZH	196.9	133.3	126.6	123.0	-36%
WW fusion	6.2	26.7	29.61	31.1	+377%
ZZ fusion	0.5	2.55	2.80	2.91	+460%
Tot	203.6		159.0		
Tot Events	1.14M		0.32M		

ZZ fusion (2%) also cannot be ignored.

Major background cross sections

pb	240	350	360	365	365/240
$ee(\gamma)$	930	336	325	319	-66%
$\mu\mu(\gamma)$	5.3	2.2	2.1	2.1	-60%
$qq(\gamma)$	54.1	24.7	23.2	22.8	-58%
WW	16.7	10.4	10.0	9.81	-41%
ZZ	1.1	0.66	0.63	0.62	-44%
tt	\	0.155	0.317	0.369	
sZ	4.54	5.72	5.78	5.83	+28%
sW	5.09	5.89	6.00	6.04	+19%



In 240GeV, most channels are 4f bkg dominant, usually ZZ.

$ee \to t\bar{t} \to WW^*b\bar{b}$ would be 6 jets/ llvv+2jets.
Would challenging for jet clustering.

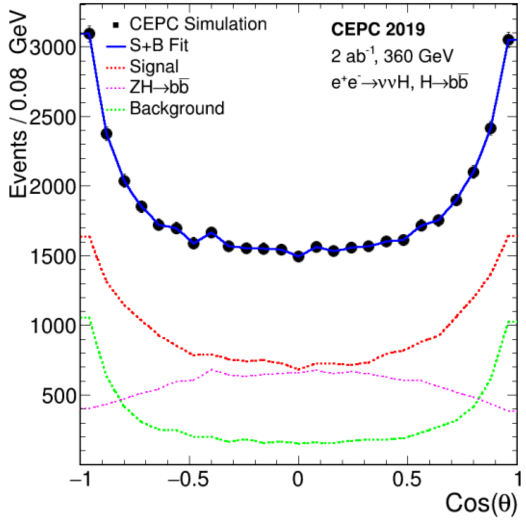
Need further work to validate the performance.

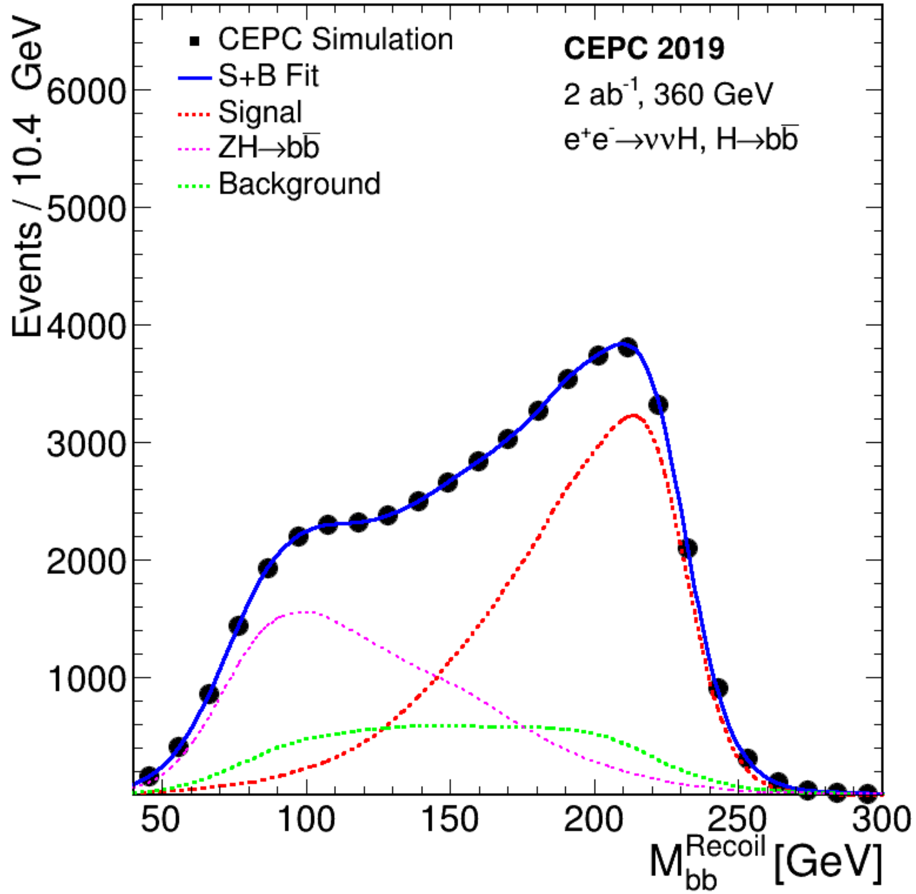
Extrapolation strategy

- Yields: scale by cross section;
- Resolution:
  - Pick 2 benchmark channels to check the impact
  - dimuon: worse resolution; from ~0.3GeV to 1GeV;
  - diphoton: better resolution; from ~2.5GeV to 2GeV;
- Mass spectrum:
  - Z/H system would stay the same;
  - Try scale factors to describe the phase space shift, like $\frac{2}{3}$ (240/360).

vvH->bb, Full simulation

- See Hao's slides for further information
  - vvH Eff 60+%;
  - Bkg: 4f bkg full simulation, qq scaled from 240 case
    - tt MC not ready; Consider qq +20%;
  - 2d Recoil qq + Cos θ_{qq} Fit
  - Considering ZH constrain:
    - $\sigma(\mathrm{vv}H) * \mathrm{Br}(\mathrm{H} \rightarrow \mathrm{bb})$:0.79%
    - 240GeV: 3%; big improvement;
  - ZH->bb (0.63%) share the anti-correlation -45%.





Results

	$5.6ab^{-1}$, 240	$2ab^{-1}$, 360	$1.5ab^{-1}$, 360
$\sigma(ZH)$	**0.50%**	**1% ?**	
$\sigma(ZH) * \mathrm{Br}(\mathrm{H} \to \mathrm{bb})$	**0.27%**	**0.63%**	**0.71%**
$\sigma(ZH) * \mathrm{Br}(\mathrm{H} \to \mathrm{cc})$	**3.3%**	**6.2%**	**7.2%**
$\sigma(ZH) * \mathrm{Br}(\mathrm{H} \to \mathrm{gg})$	**1.3%**	**2.4%**	**2.7%**
$\sigma(ZH) * \mathrm{Br}(\mathrm{H} \to \mathrm{WW})$	**1.0%**	**2.0%**	**2.3%**
$\sigma(ZH) * \mathrm{Br}(\mathrm{H} \to \mathrm{ZZ})$	**5.1%**	**12%**	**14%**
$\sigma(ZH) * \mathrm{Br}(\mathrm{H} \to \tau\tau)$	**0.8%**	**1.5%**	**1.7%**
$\sigma(ZH) * \mathrm{Br}(\mathrm{H} \to \gamma\gamma)$	**5.4%**	**8%**	**9.2%**
$\sigma(ZH) * \mathrm{Br}(\mathrm{H} \to \mu\mu)$	**12%**	**29%**	**33%**
$\sigma(\mathrm{vv}H) * \mathrm{Br}(\mathrm{H} \to \mathrm{bb})$	**3%**	**0.79%**	**0.91%**
$\mathrm{Br}_{\mathrm{upper}}(\mathrm{H} \to \mathrm{inv.})$	**0.2%**	****	****
$\sigma(ZH) * \mathrm{Br}(\mathrm{H} \to Z\gamma)$	**16%**	**25%**	**29%**
Width	**2.8%**	**~0.8%**	

*: $\sigma(ZH)$ estimated as 1%.

Fcc:

$\sqrt{s}$ (GeV)	240		365	
Luminosity (ab^{-1})	5		1.5	
$\delta(\sigma BR)/\sigma BR$ (%)	HZ	$\nu\bar{\nu}$ H	HZ	$\nu\bar{\nu}$ H
$H \to$ any	± 0.5		± 0.9	
$H \to b\bar{b}$	± 0.3	± 3.1	± 0.5	± 0.9
$H \to c\bar{c}$	± 2.2		± 6.5	± 10
$H \to gg$	± 1.9		± 3.5	± 4.5
$H \to W^+W^-$	± 1.2		± 2.6	± 3.0
$H \to ZZ$	± 4.4		± 12	± 10
$H \to \tau\tau$	± 0.9		± 1.8	± 8
$H \to \gamma\gamma$	± 9.0		± 18	± 22
$H \to \mu^+\mu^-$	± 19		± 40	
$H \to$ invisible	< 0.3		< 0.6	

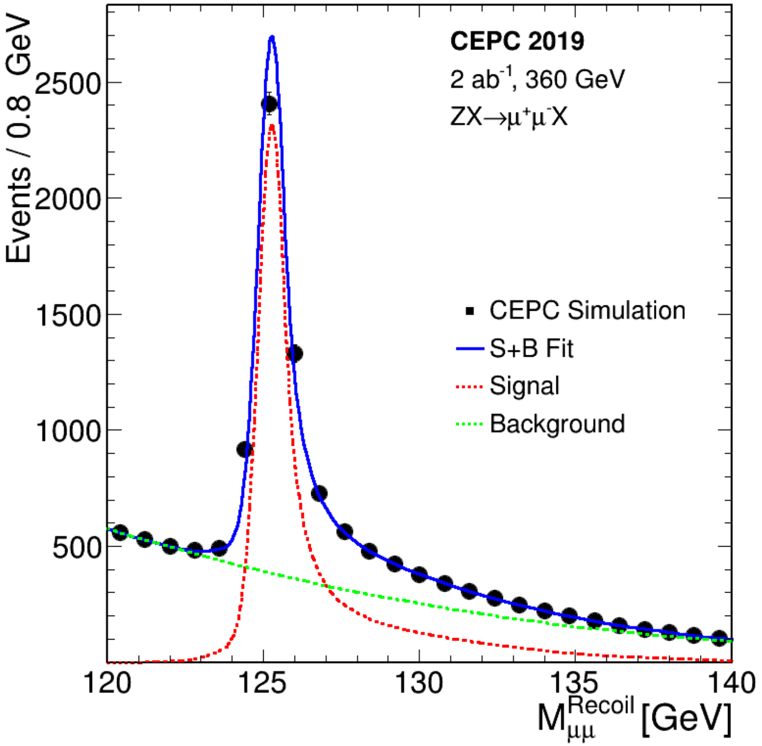
Generally, since the extrapolation is not so accurate, results are comparable.

For $\mathrm{H} \to \gamma\gamma$ and $\mathrm{H} \to \mu\mu$, resolution changes considered.
Keep diphoton resolution ~(2.5GeV) : 10.2%
2.5GeV to 2GeV: 9.2%

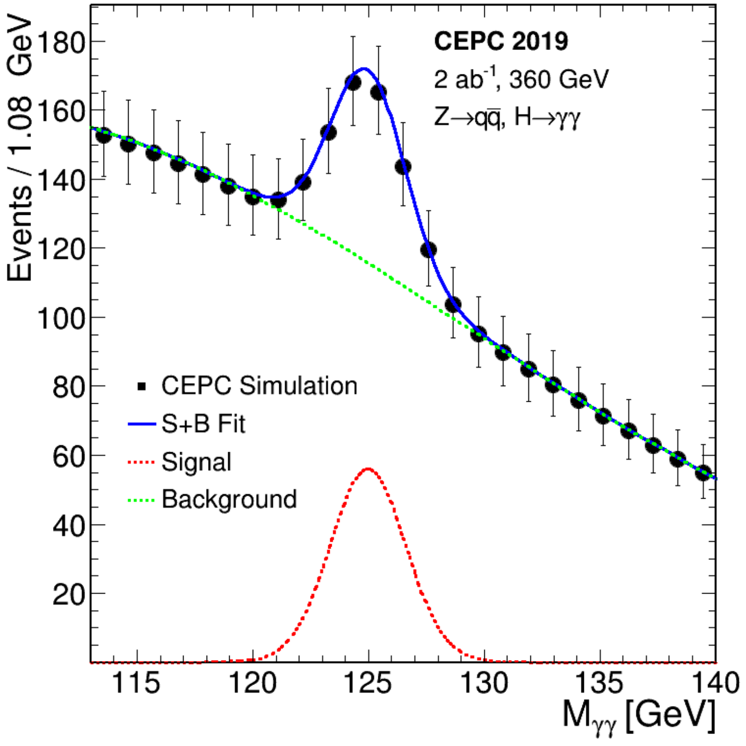
Keep dimuon resolution ~(0.3GeV): 23%
0.3GeV to 1GeV: 29%

360 GeV Plots

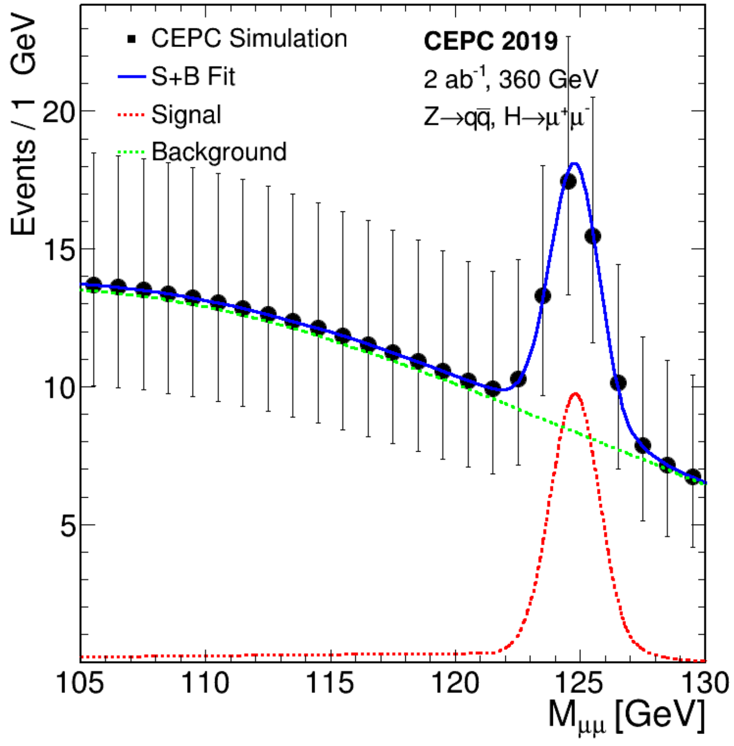
Inclusive: 0.92% -> 1.72%



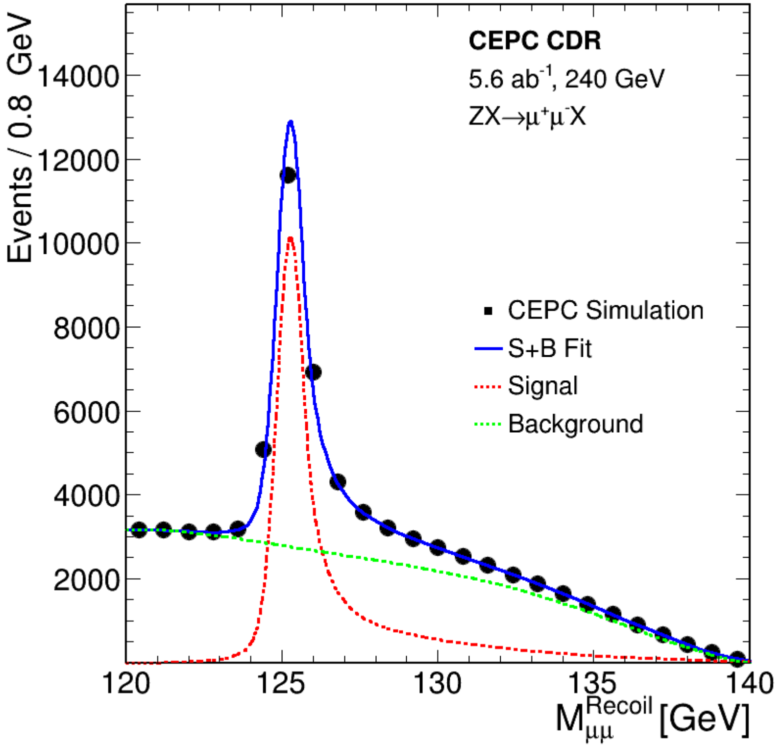
Resolution: 2GeV;

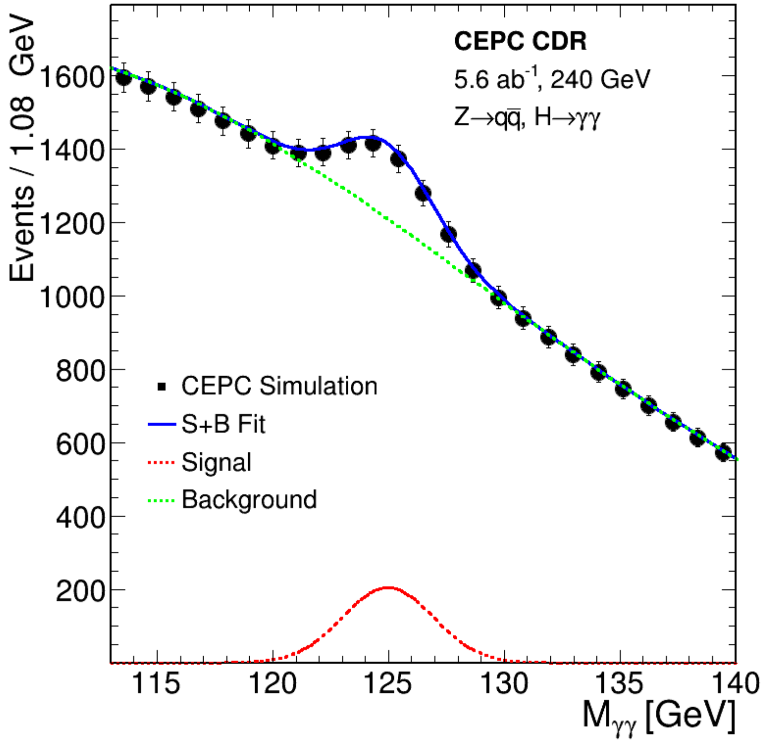


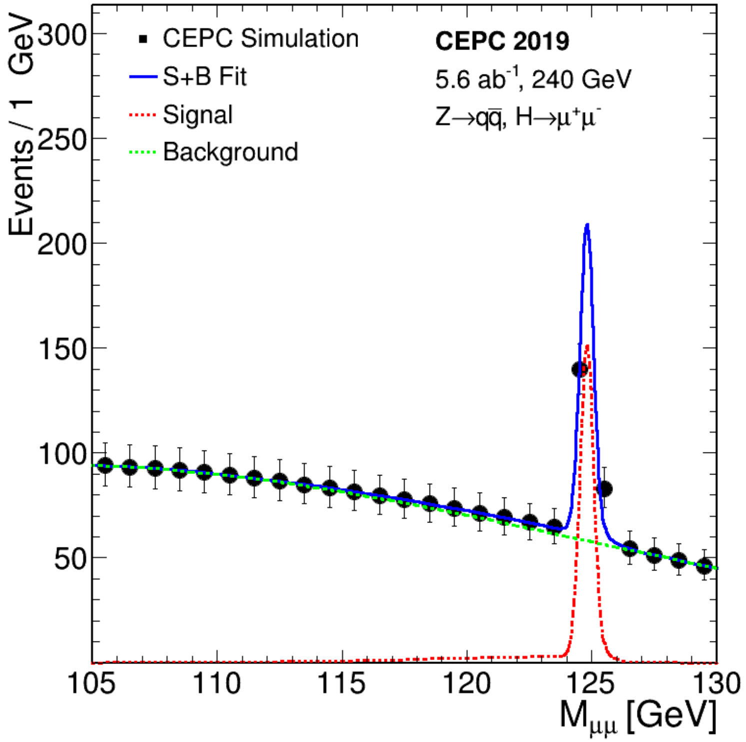
Resolution: 1GeV;



240 GeV Plots





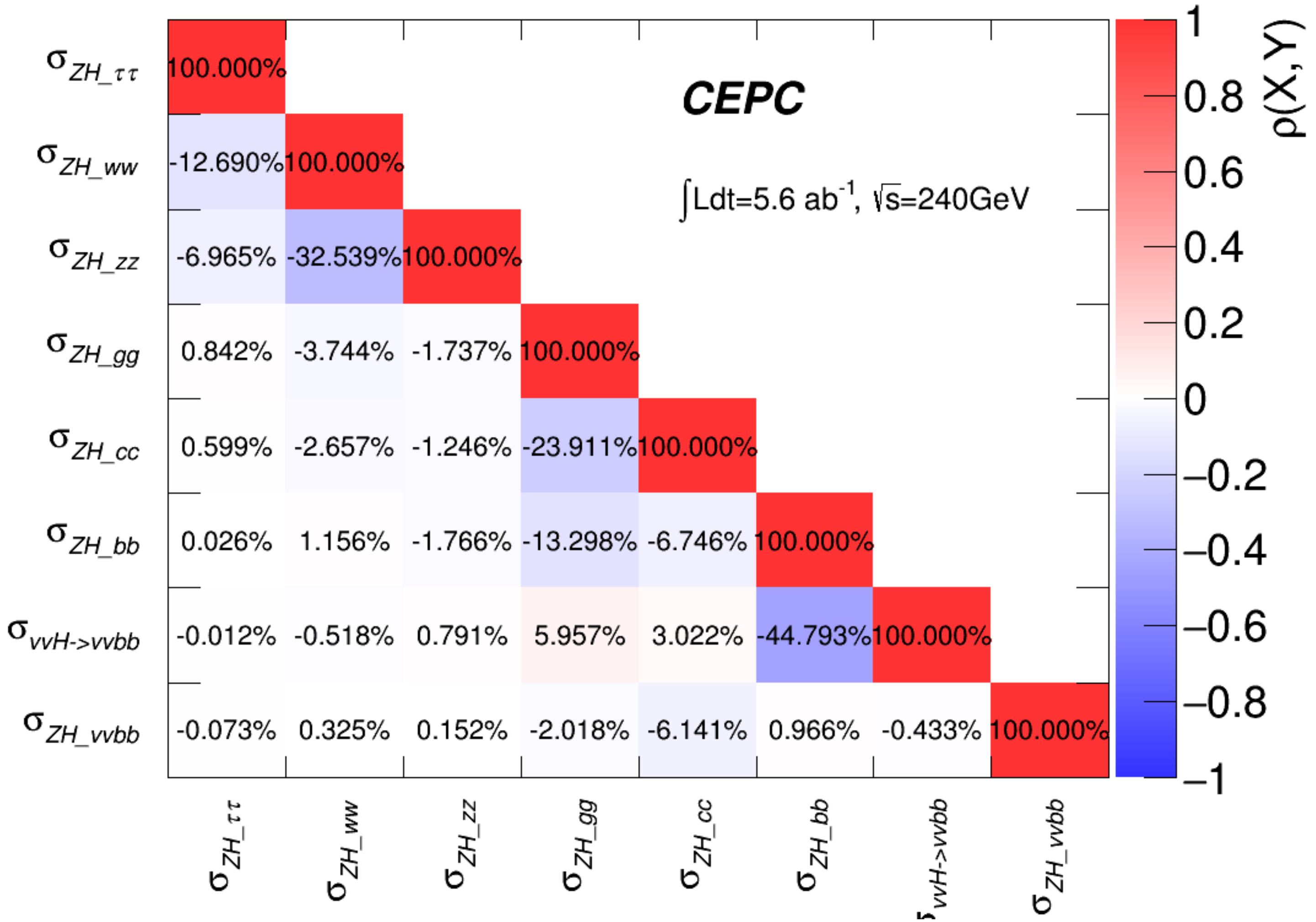


Discussion

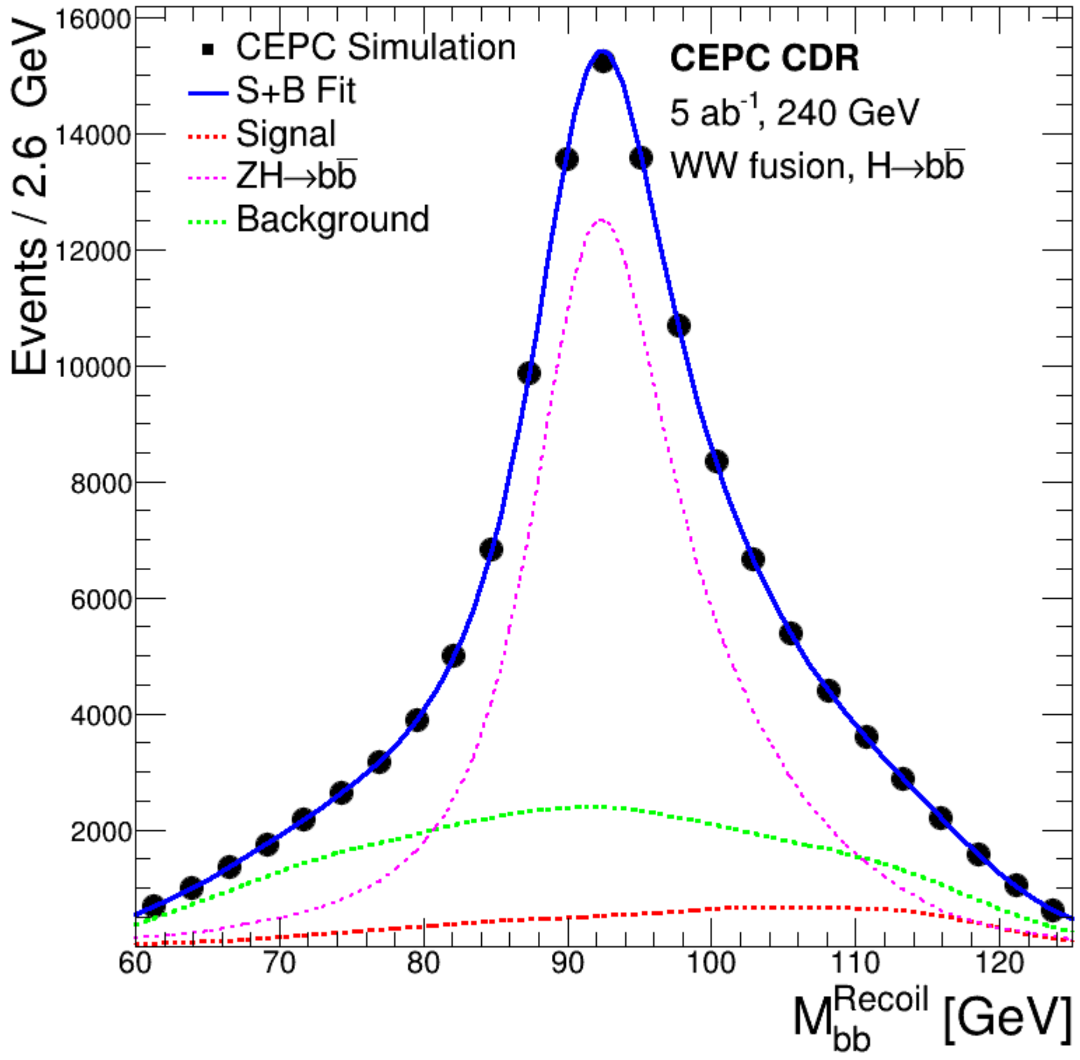
- Current extrapolation
  - Mainly scale yields
    - bkg could be even lower if correct analysis strategies are applied.
  - Can not deal with W/Z fusion related channels and $\sigma(ZH)$
    - several channels are studied with m_{ee}^{recoil} and $m_{missing}$ would suffer;
  - Preliminary estimation, need further work

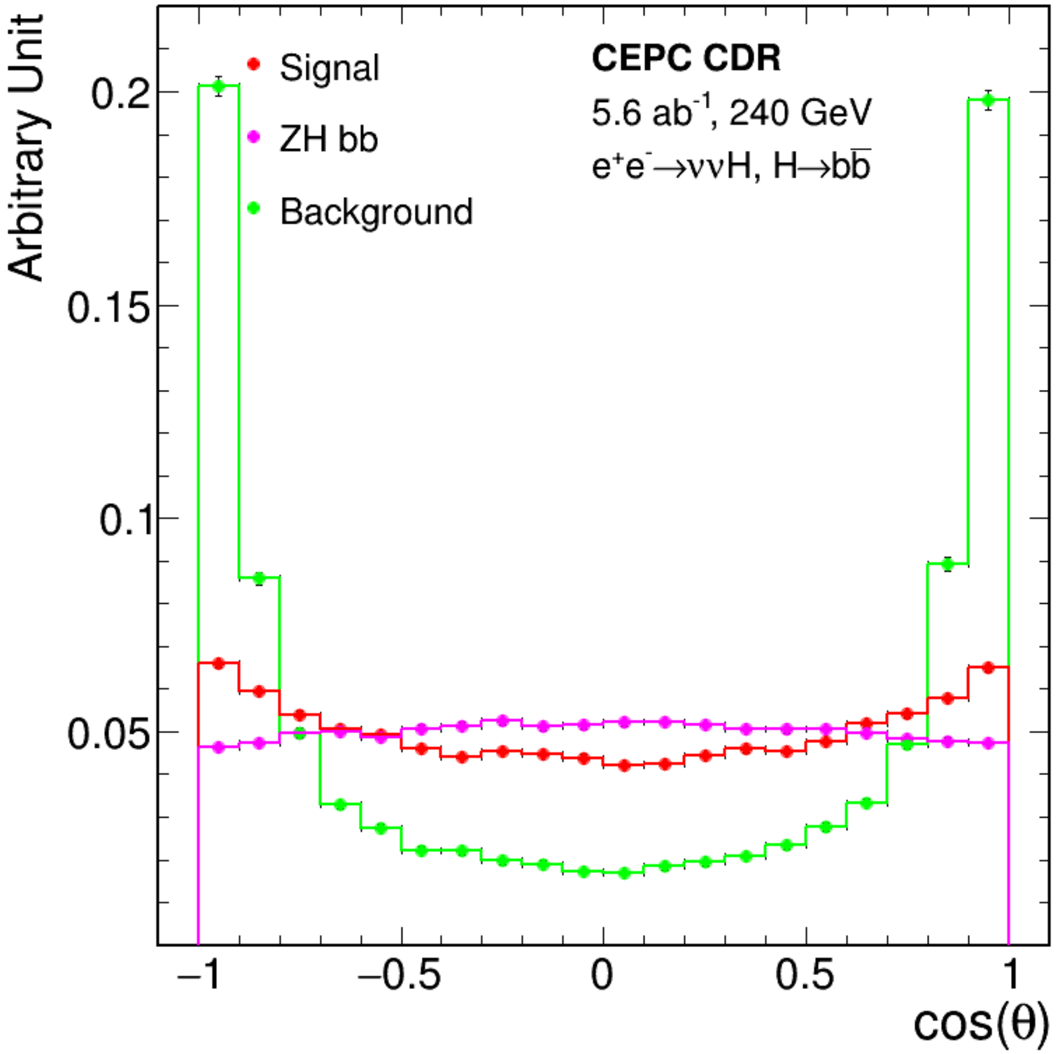
backup

Correlation matrix



vvH->bb 240GeV





Higgs width

- Absolute width measurement by 2 dominant channels:

$$\Gamma_H = \frac{\Gamma_{H\to ZZ}}{Br(H\to ZZ)} \propto \frac{\sigma(ZH)}{Br(H\to ZZ)} \text{ and } \Gamma_H = \frac{\Gamma_{H\to bb}}{Br(H\to bb)} \propto \frac{\sigma(\nu\nu H\to \nu\nu bb)}{Br(H\to bb)Br(H\to WW)}$$

- Since $\sigma(\mathrm{vv}H) * \mathrm{Br(H \to bb)}$: 0.79%

- But width correlated with all channels

  - $\nu\nu H \to \nu\nu bb$ and $\mathrm{Z}H \to bb$ -45%   -> would worse the result

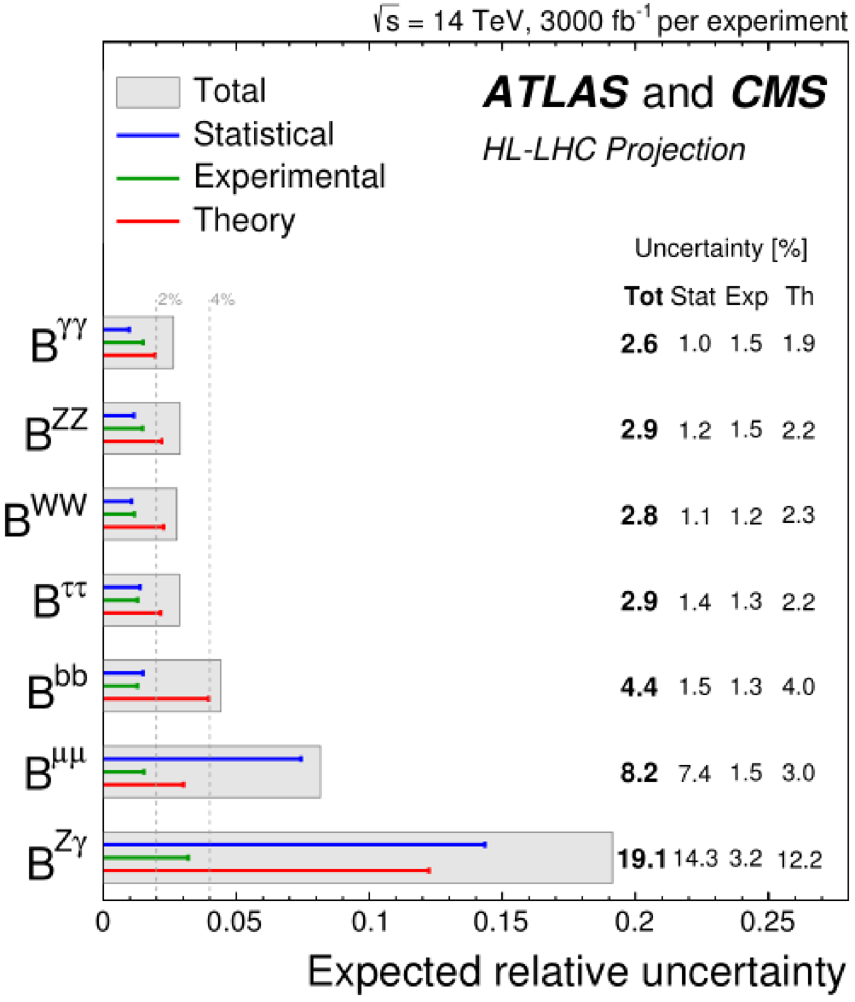
- Combined fit in 10κ framework:

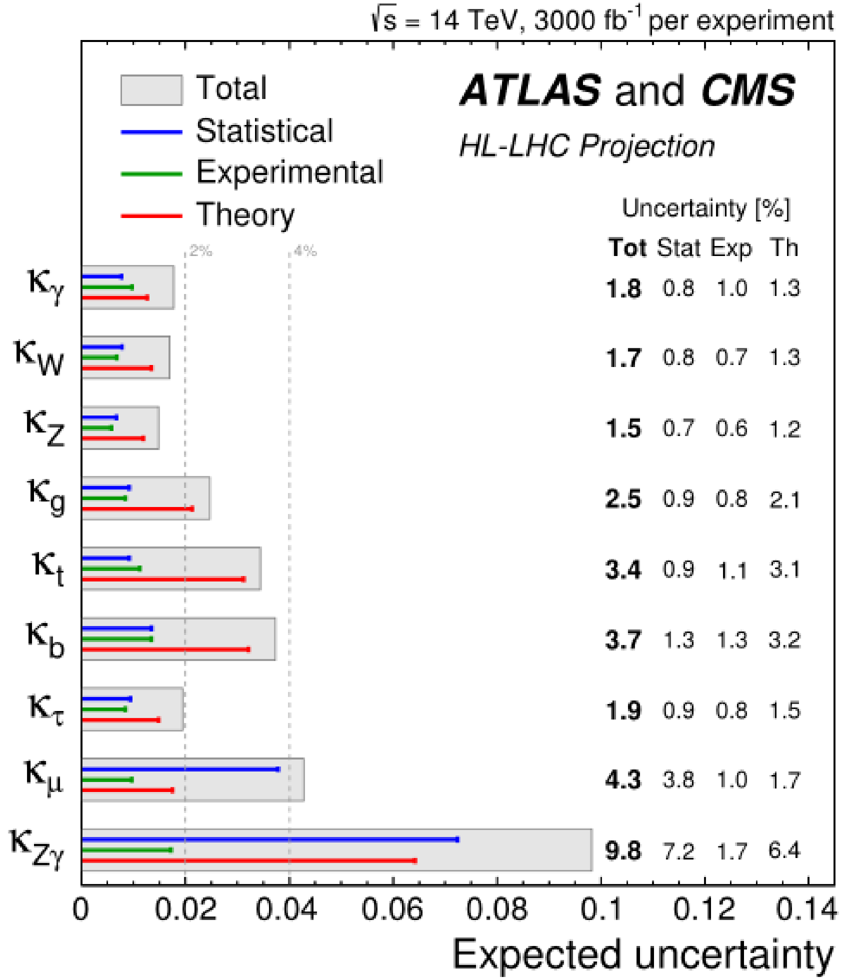
$$\Delta(\Gamma_H) \approx 0.8\%$$

Synergy of HL-LHC

Arxiv:1902.00134

- HL-LHC S2 estimation; has wonderful prediction on such channels like $\gamma\gamma$.





$B_{\gamma\gamma}: \sigma * Br(H \to \gamma\gamma);$

Kappa Synergy

Collider	HL-LHC	ILC_{250}	$CLIC_{380}$	$LEP3_{240}$	$CEPC_{250}$	$FCC\text{-}ee_{240+365}$		
Lumi (ab^{-1})	3	2	1	3	5	5_{240}	$+1.5_{365}$	+ HL-LHC
Years	25	15	8	6	7	3	+4	
$\delta\Gamma_H/\Gamma_H$ (%)	SM	3.6	4.7	3.6	2.8	2.7	**1.3**	1.1
$\delta g_{HZZ}/g_{HZZ}$ (%)	1.5	0.3	0.60	0.32	0.25	0.2	**0.17**	0.16
$\delta g_{HWW}/g_{HWW}$ (%)	1.7	1.7	1.0	1.7	1.4	1.3	**0.43**	0.40
$\delta g_{Hbb}/g_{Hbb}$ (%)	3.7	1.7	2.1	1.8	1.3	1.3	**0.61**	0.56
$\delta g_{Hcc}/g_{Hcc}$ (%)	SM	2.3	4.4	2.3	2.2	1.7	**1.21**	1.18
$\delta g_{Hgg}/g_{Hgg}$ (%)	2.5	2.2	2.6	2.1	1.5	1.6	**1.01**	0.90
$\delta g_{H\tau\tau}/g_{H\tau\tau}$ (%)	1.9	1.9	3.1	1.9	1.5	1.4	**0.74**	0.67
$\delta g_{H\mu\mu}/g_{H\mu\mu}$ (%)	4.3	14.1	n.a.	12	8.7	10.1	**9.0**	3.8
$\delta g_{H\gamma\gamma}/g_{H\gamma\gamma}$ (%)	1.8	6.4	n.a.	6.1	3.7	4.8	**3.9**	1.3
$\delta g_{Htt}/g_{Htt}$ (%)	3.4	–	–	–	–	–	–	3.1
BR_{EXO} (%)	SM	< 1.7	< 2.1	< 1.6	< 1.2	< 1.2	$<$ **1.0**	$<$ **1.0**