A quick look at CEPC 360GeV $t\bar{t}$ run

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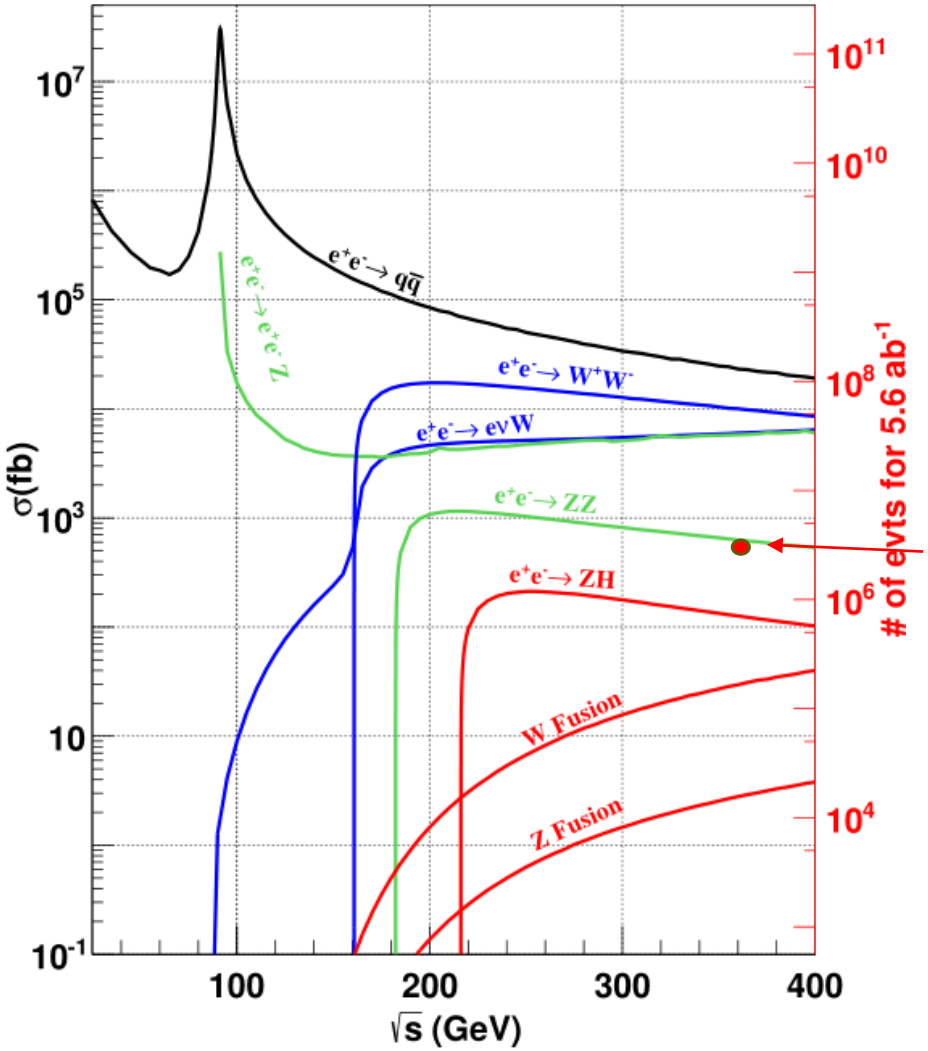
Outline

- Physics overview
- Practice from Fcc-ee
  - $t\bar{t}$ threshold scan + $t\bar{t}$ run
  - $t\bar{t}$ cross section
- CEPC current estimation
  - Higgs extrapolation
  - Top decays

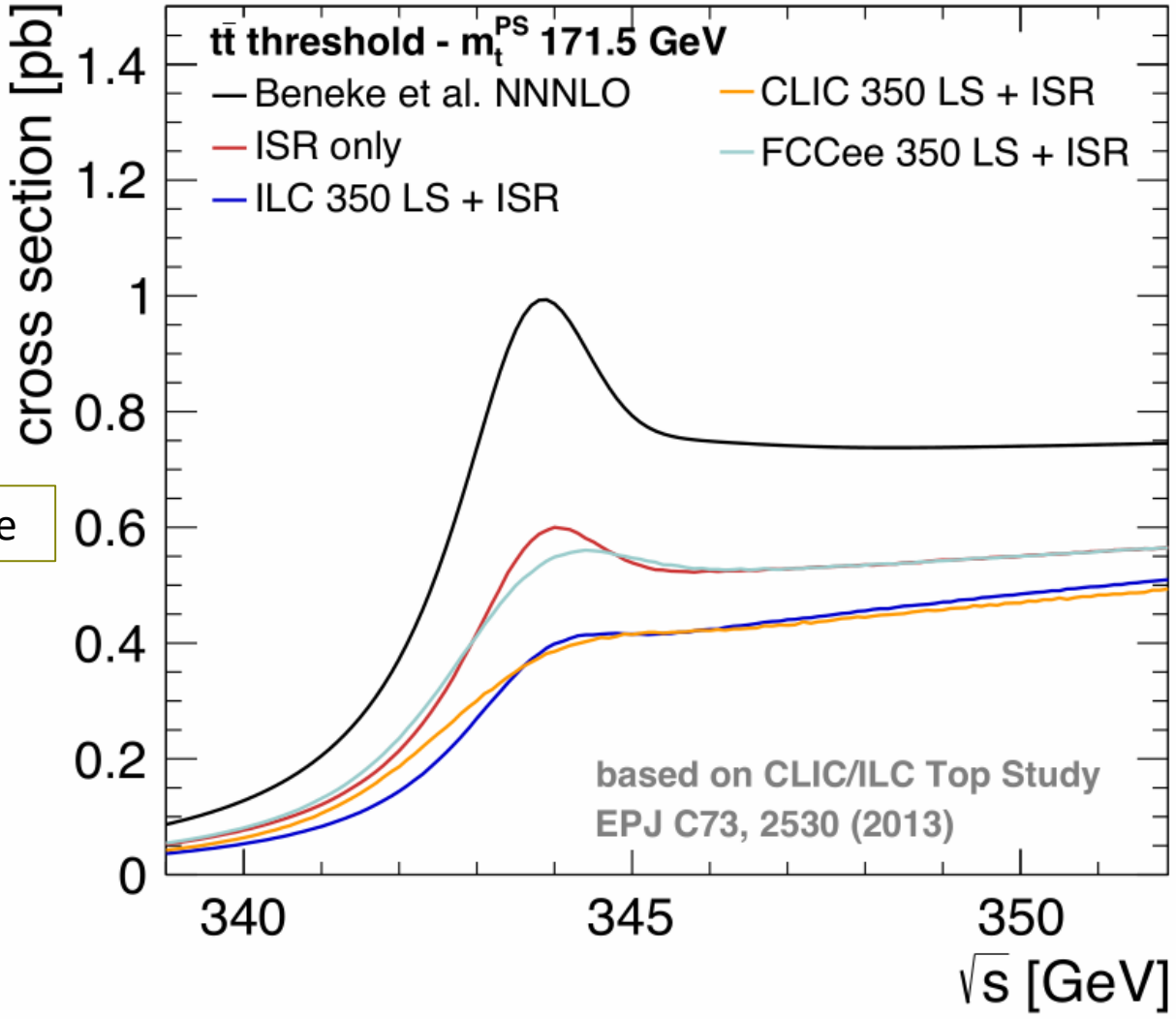
Processes at $t\bar{t}$ threshold

In CEPC CDR:



$t\bar{t}$: here

Fcc CDR and 2017 Top Physics WS, based on EPJ C73 2530(2013) arXiv:1303.3758



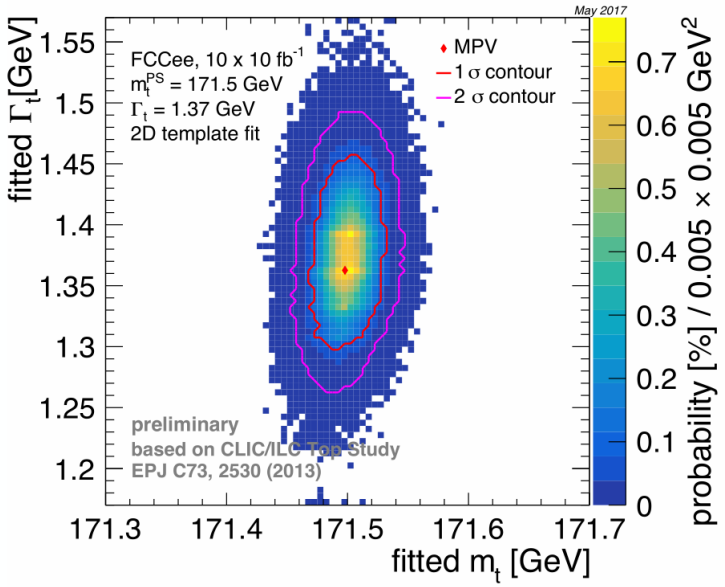
Practice from Fcc-ee

- Fcc-ee did a comprehensive study on threshold scan and 365GeV run, and how they helps the Top Physics, Coupling, EFT and so on.
  - Their CDR, Their theory report arXiv:1905.05078v2, and so on;
  - We could roughly refer to. Since our performance could be comparable.
- 0.2iab for threshold scan
  - 8 points between 340 to 345GeV, each 25ifb.
- 1.5iab for 365GeV
    - 365GeV is chosen to optimally measure the top-quark electroweak couplings, without the need of incoming beam polarization: arXiv:1503.01325

Fcc-ee Precision

Luminosity spectrum is assumed to be a gaussian with a σ of 0.19%

- Top:
  - Top Mass: $\pm 17\mathrm{MeV}$ (stats)
    - $\pm 10\mathrm{MeV}$ (stats, fixed to SM prediction)
  - Top Width: $\pm 45\mathrm{MeV}$ (stats)
  - Current QCD theoretical uncertainty: ~40MeV. To be suppressed to 10MeV.



- Higgs

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

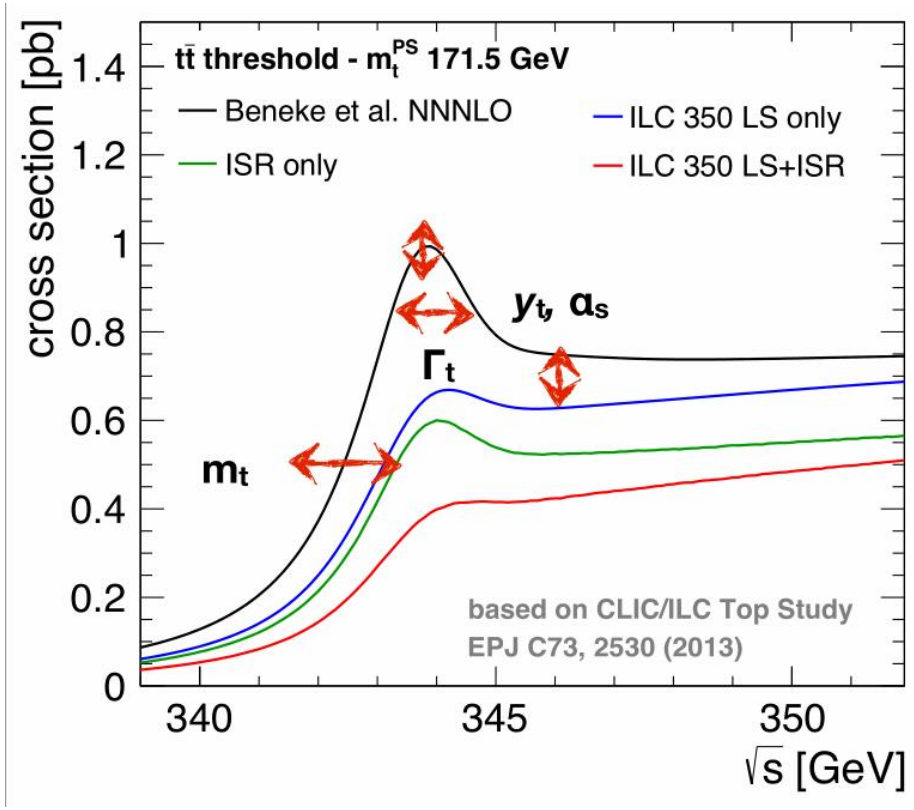
- Width could be measured at 1.3%.

$t\bar{t}$ threshold scan

- pp collider can not measure Top mass better than 1GeV. Large uncertainties.
  - Top physics require a scan near the threshold first. To measure Top mass and width.

- For Higgs Physics
  - Sensitive to total integrated luminosity.
  - 340/345/360/365 do not have huge difference.

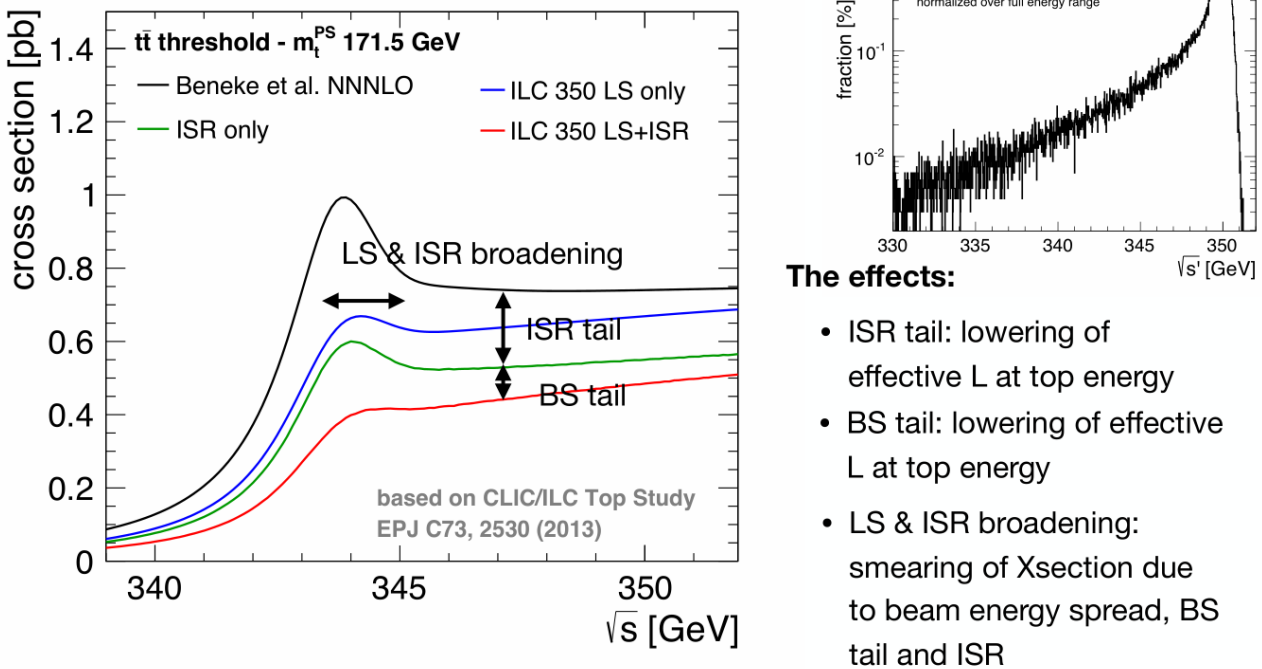
- CEPC also need a similar plan for scan.



$t\bar{t}$ cross section

Many effects,
beamstrahlung, beam spread, ISR……

- What the luminosity spectrum does to the threshold:

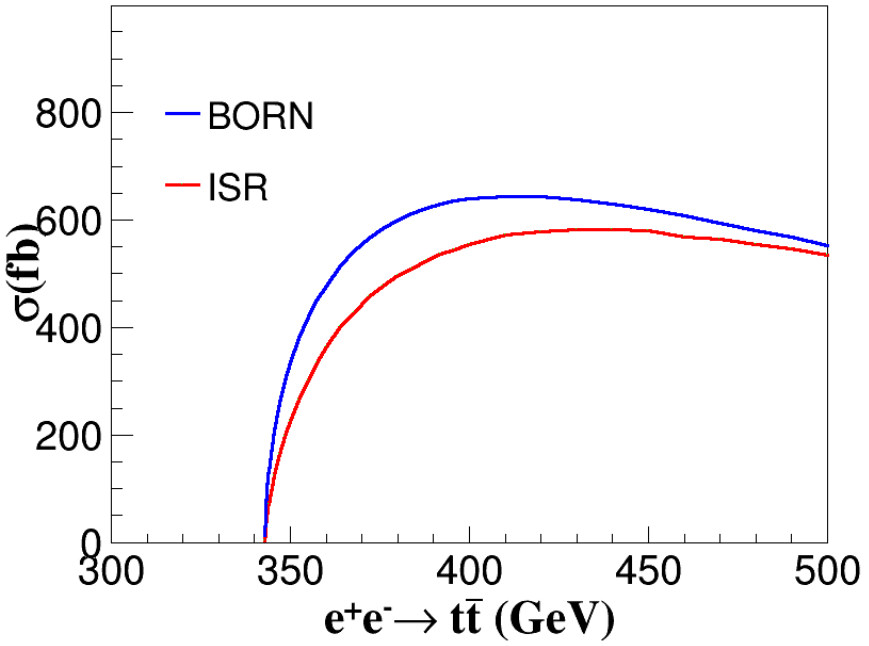


The effects:

- ISR tail: lowering of effective L at top energy
- BS tail: lowering of effective L at top energy
- LS & ISR broadening: smearing of Xsection due to beam energy spread, BS tail and ISR

Also the bump ~344GeV is one interesting target for scan.

Calculation by Gang, whizard2, no top width:



Results are much smaller than ILC/Fcc did.
Need further check.

For convenience, in the following we take $t\bar{t}$ cross section for
350GeV: 0.49pb; 360GeV: 0.60pb; 365GeV: 0.65pb;

CEPC $t\bar{t}$ run

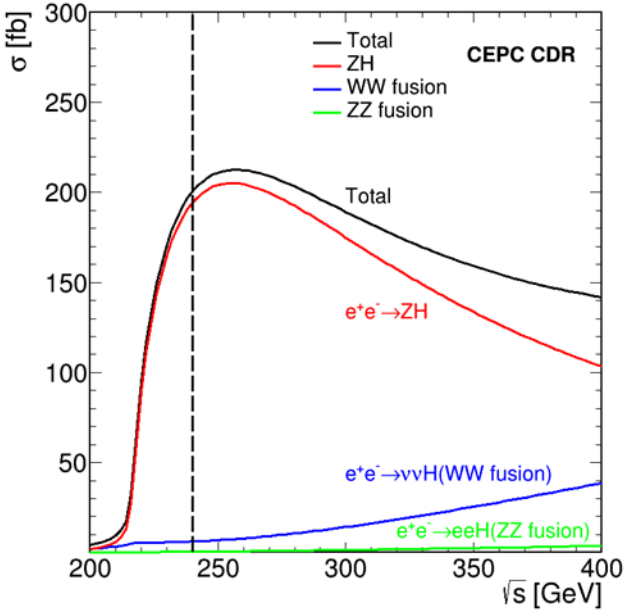
- ttbar run would mostly benefit the physics like EW and Top.
- For Higgs, it improves width precision best.
  - Dominated by vvH->bb measurement.
- Temporary benchmark: 2 iab @ 365GeV
  - ~~Why 360? It saves 10% energy with respect to 365 GeV~~
  - Main reason for 365GeV could refer to arXiv:1503.01325
    - Best precision for top-quark electroweak couplings
    - Also could note that, 350GeV run also has decent precision.
    - Need suggestion from Accelerator/Detector part.

2iab is also one temporary value. It would take about 5 years to take.

Major Processes

fb	240	350	360	365	365/240
ZH	196.9	133.3	126.6	123.0	-38%
WW fusion	6.2	26.7	29.61	31.1	+401%
ZZ fusion	0.5	2.55	2.80	2.91	+482%
Total	203.6			157.0	
Total Events	1.14M			0.31M	

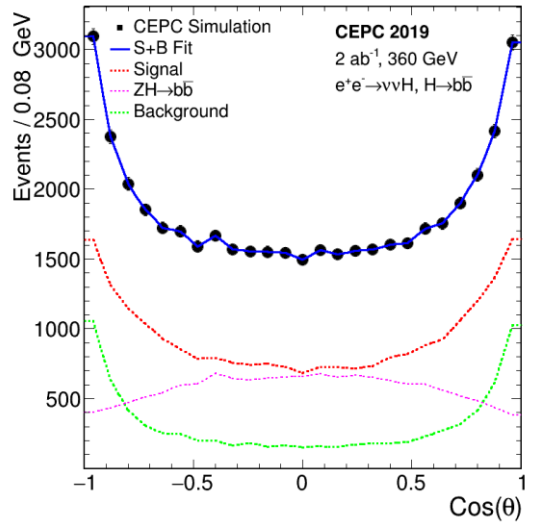
pb	240	350	360	365	365/240
ee(γ)	930	336	325	319	-65%
$\mu\mu(\gamma)$	5.3	2.2	2.1	2.1	-60%
qq(γ)	54.1	24.7	23.2	22.8	-57%
WW	16.7	10.4	10.0	9.81	-40%
ZZ	1.1	0.66	0.63	0.62	-43%
tt	\	0.49	0.60	0.65	+
sZ	4.54	5.72	5.78	5.83	+27%
sW	5.09	5.89	6.00	6.04	+18%

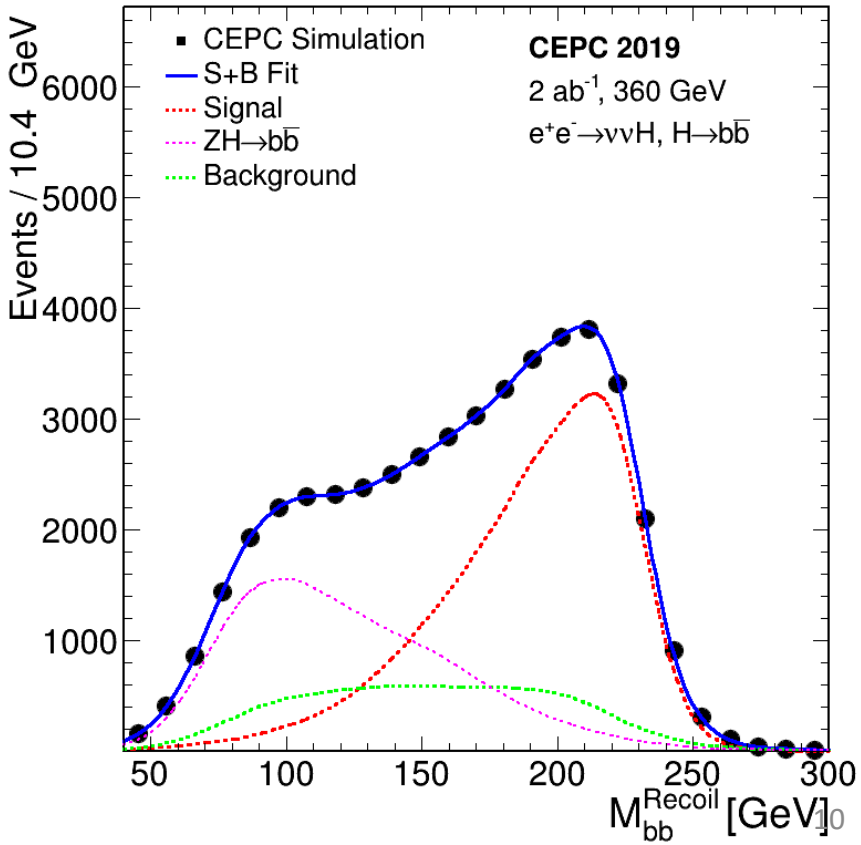


In total ~1.45M Higgs would be collected in CEPC 240+365GeV.
Correlation between ZH and vvH considered.
For back ground processes, major 2f are reduced.
ttbar cross section would be close to ZZ 4f process.

vvH->bb, full simulation

- 2d Recoil qq + Cos θ_{qq} Fit
- Clear separation between ZH and vvH.
- Constrain from other ZH->bb($ee, \mu\mu, qq$) considered
  - $\sigma(\mathrm{vv}H) * \mathrm{Br}(\mathrm{H} \to \mathrm{bb})$:0.76%
  - $\sigma(\mathrm{Z}H) * \mathrm{Br}(\mathrm{H} \to \mathrm{bb})$: 0.63%
  - share the anti-correlation -15.8%.





Higgs width

- Now CEPC Higgs width is fitted in the 10- κ framework.

- Adding one mass point would significantly improve the constrain.

  - Much more vvH event and better separation. Significantly improve the constrain.

  - Standalone 240GeV gives 2.9%, while 360GeV alone gives 2.8%.

  - Combined fit

$$\Delta(\Gamma_H) \approx 1.4\%$$

*: Fcc-ee assumes that exotic Br can not smaller than 0. This assumption lower the negative side, Like (-1.2%, 1.4%). Then Fcc use median 1.3%,

We didn't take this assumption. The results are comparable.

Higgs measurement results

	240GeV, 5.6ab^{-1}	360GeV, 2ab^{-1}	
	ZH	ZH	vvH
any	**0.50%**	**1%**	****
H → bb	**0.27%**	**0.63%**	**0.76%**
H → cc	**3.3%**	**6.2%**	**11%**
H → gg	**1.3%**	**2.4%**	**3.2%**
H → WW	**1.0%**	**2.0%**	**3.1%**
H → ZZ	**5.1%**	**12%**	**13%**
H → $\tau\tau$	**0.8%**	**1.5%**	**3%**
H → $\gamma\gamma$	**5.4%**	**8%**	**11%**
H → $\mu\mu$	**12%**	**29%**	**40%**
$\mathrm{Br}_{\mathrm{upper}}(\mathrm{H} \to \mathrm{inv.})$	**0.2%**	****	****
$\sigma(ZH) * \mathrm{Br}(\mathrm{H} \to Z\gamma)$	**16%**	**25%**	****
Width	**2.9%**	**1.4%**	

Generally, since the extrapolation is not so accurate, results are comparable.
For Higgs coupling, also similar performance could be expected.
Higgs Performance would not have huge deviation for 360 and 365GeV.

Fcc:

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See previous talk @CEPC day;

$t\bar{t}$ samples at CEPC

- From Gang: Now Whizard2 could generate the sample correctly.
  - Ready to request $t\bar{t}$ samples.
  - First need to discuss about the strategy.
- $t\bar{t} \to WW^*\bar{b}b$:
  - A brief estimation from Manqi:
    - *qqqq+bb:* *Eff*Purity≈50%*
    - *lvqq+bb:* *Eff*Purity≈75%* *One optimal-observable study in this channel described in* arXiv:1503.01325
    - *lvlv+bb:* *Eff*Purity≈90%*
  - In total we would have ~1.3Million $t\bar{t}$ events.
    - ~62% of them would be easy to tag. -> 800k.
  - Strict requirement for our jet performance.
    - 2/4/6 Jet separation, b-tagging and BMR?
  - Others: Kinematic Fitting? Boosted Top quark?

$$\chi^2 = \frac{(m^2_{\ell\nu b} - m_t)^2}{\sigma^2_{m_t,\mathrm{lep}}} + \frac{(m^2_{jj} - m_W)^2}{\sigma^2_{m_W,\mathrm{had}}} + \frac{(m^2_{jjj} - m_t)^2}{\sigma^2_{m_t,\mathrm{had}}}.$$

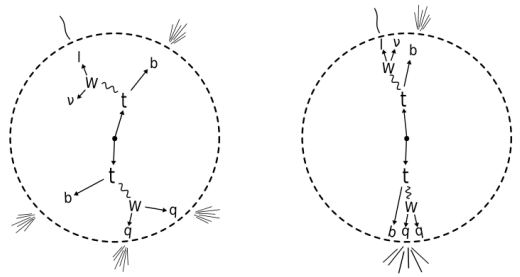

Figure 4: Illustration of resolved (left) and boosted (right) event topologies in single-lepton $t\bar{t}$ decays. Picture courtesy of Shawn Williamson.

Summary

- A brief look at top and higgs physics at $t\bar{t}$ run for CEPC
  - For Top, need a threshold scan for Top mass and width
    - From Fcc-ee result, Top Mass(Width): $\pm 17\mathrm{MeV}(\pm 45\mathrm{MeV})$
  - For Higgs, need a ~365GeV run for vvH to constrain Higgs width
    - 2 different energy points would help for width and also triple Higgs coupling and so on.
  - Need to set a benchmark for CEPC run.
    - Fcc-ee use 0.2iab Scan + 1.5iab 365GeV. Our value?