Top mass measurements at CEPC

Zhan Li on behalf of

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CEPC Physics and Detector Plenary Meeting

2021.8.25

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Motivation

- Top mass is a fundamental factor in the Standard Model, also a stringent check of internal consistency of SM.
- Top mass is measured using top reconstruction at hadron colliders. But it is difficult to further improve the precision given dominant systematic uncertainties at hadron colliders.
- e^+e^- colliders can provide not only the top reconstruction method but also the ttbar threshold scan.

Motivation

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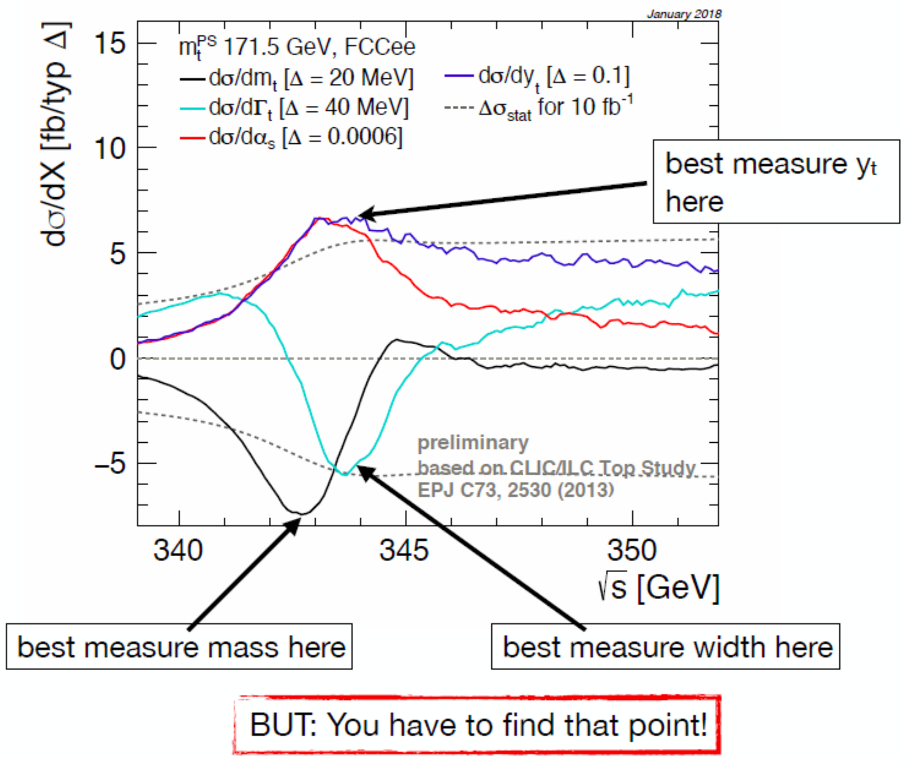
- ttbar threshold scan is made against $\sqrt{s}$ and cross section, which is direct observable.
- It brings measurements of such parameters:
  - **Top mass**
  - Top width
  - Top Yukawa coupling
  - α_s (strong coupling)



Our setup

- Use the package “QQbar_threshold” to calculate cross section near threshold in ee-colliders at N3LO in resummed non-relativistic perturbation theory
    - *Coulomb interactions between the quark and the antiquark leading to a strong enhancement of the cross section is included*
    - Initial state radiation (ISR) effects are also included in the package
- We incorporate Luminosity Spectrum(LS) by a simple Gaussian function with 1 GeV as the energy resolution at the moment
    - We will update to CEPC LS (~0.5GeV) provided by Yiwei Wang.

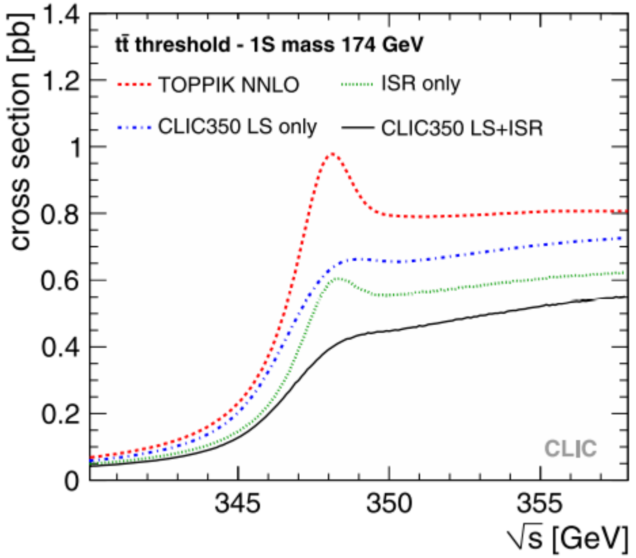


Fig. 4 Top pair production cross section from theory calculations, with the luminosity spectrum (LS) of CLIC at 350 GeV and ISR as well as for all effects combined

Method: $\sqrt{s}$ scan

- Since we are interested in the precise measurement of top mass by using threshold scan, we can try to fit the calculated models to experiment data.
- We can construct our likelihood function with 1 energy point in the following way:

$$L = P\left(D \middle| E\left(\sigma\left(m_{\mathrm{top}}, \Gamma_{\mathrm{top}}, \alpha_s, \sqrt{s}\right)\right), \mathcal{L}, \theta\right)$$

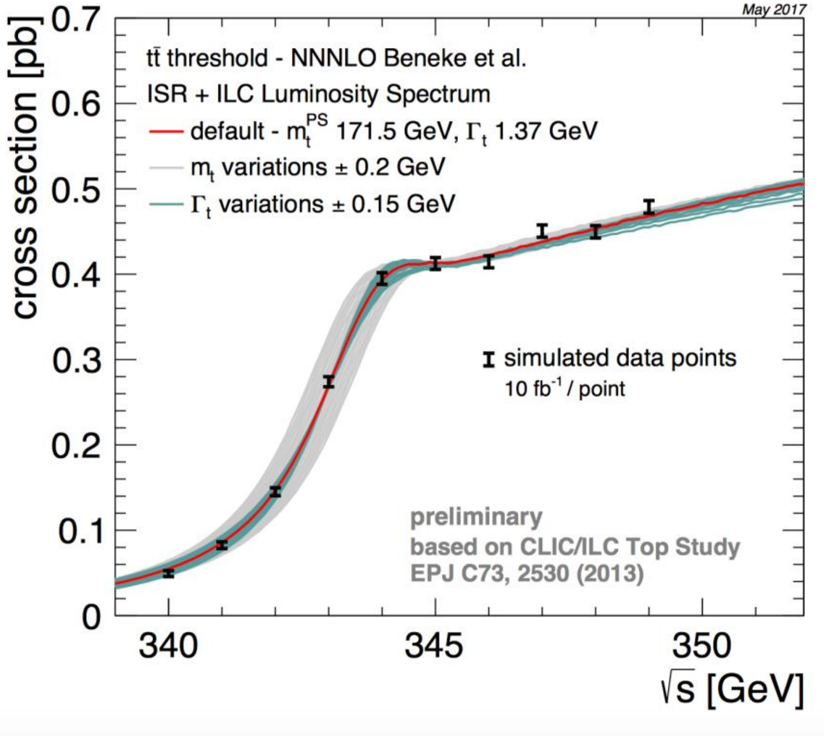
- Since we do not have real experiment data, we use QQbar_threshold to generate pseudo data instead.
  - In this set of pseudo data, top mass is set to be 171.5 GeV.

Method: $\sqrt{s}$ scan

- For different top masses, we select multiple center mass energy points. To combine the statistical power of all scan points, we can multiply 1-point likelihood functions together:

$$L = \prod_i P\left(D_i \middle| E_i(\sigma\left(m_{\text{top}}, \Gamma_{\text{top}}, \alpha_s, \sqrt{s}\right)), \mathcal{L}_i, \theta\right)$$

  - i corresponds to the i-th scan point



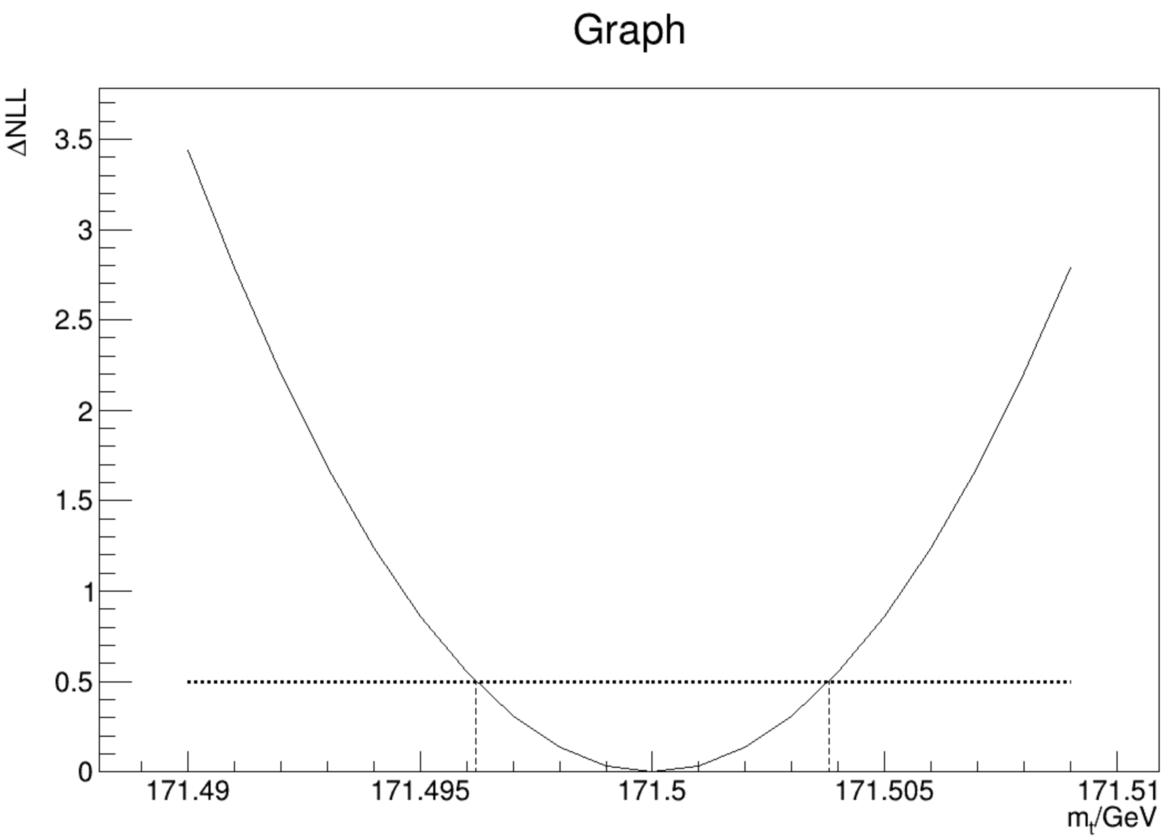
Reminder: last status at Yangzhou Workshop

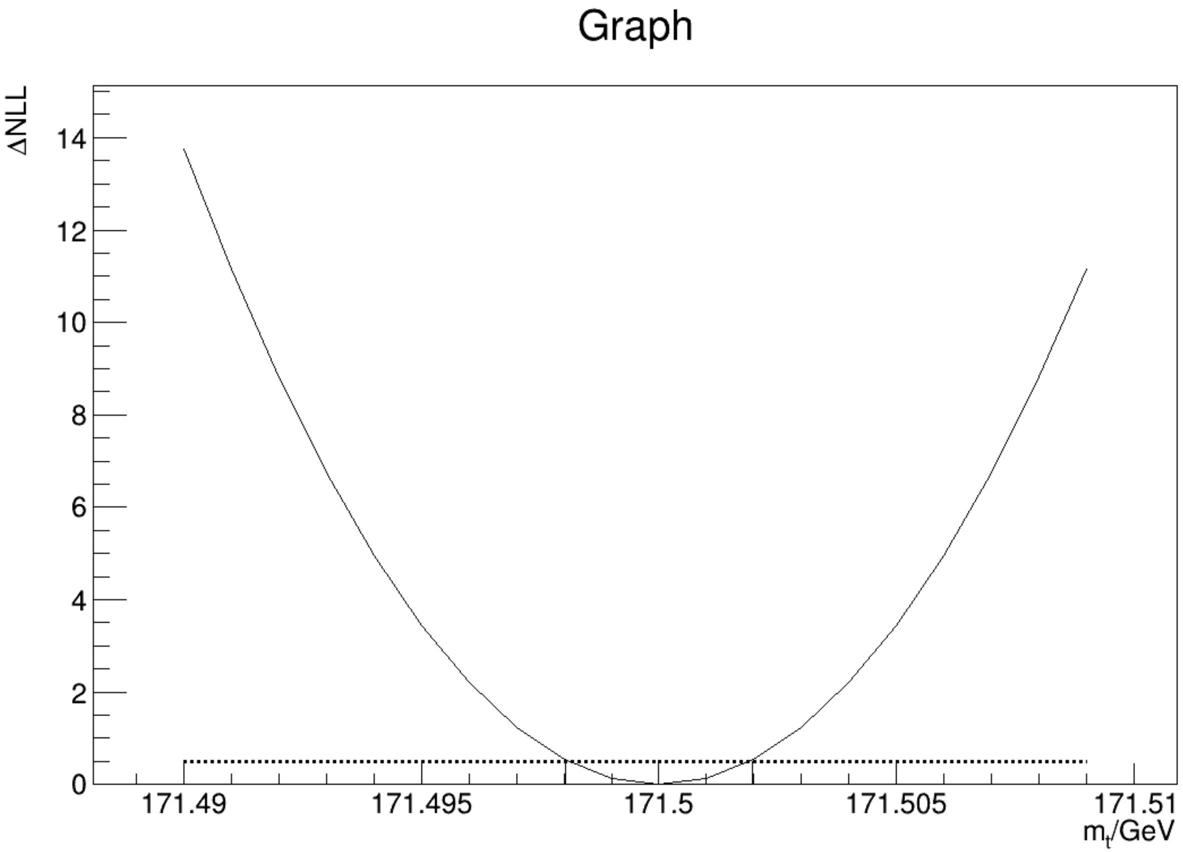
- We use these setup:
  - The acceptance and selection efficiency are assumed to be 100%.
  - Background events are not considered.
  - ISR is considered, but LS is not included.
  - Luminosity per scan point is assumed to range from 25fb^{-1} to 100fb^{-1}.
  - Systematic uncertainties are not considered.

- We use these 3 following schemes:

  4 points scheme, 6 points scheme, and 8 points scheme.

6 $\sqrt{s}$ scheme={341,342,342.5,343,343.5,344.5}



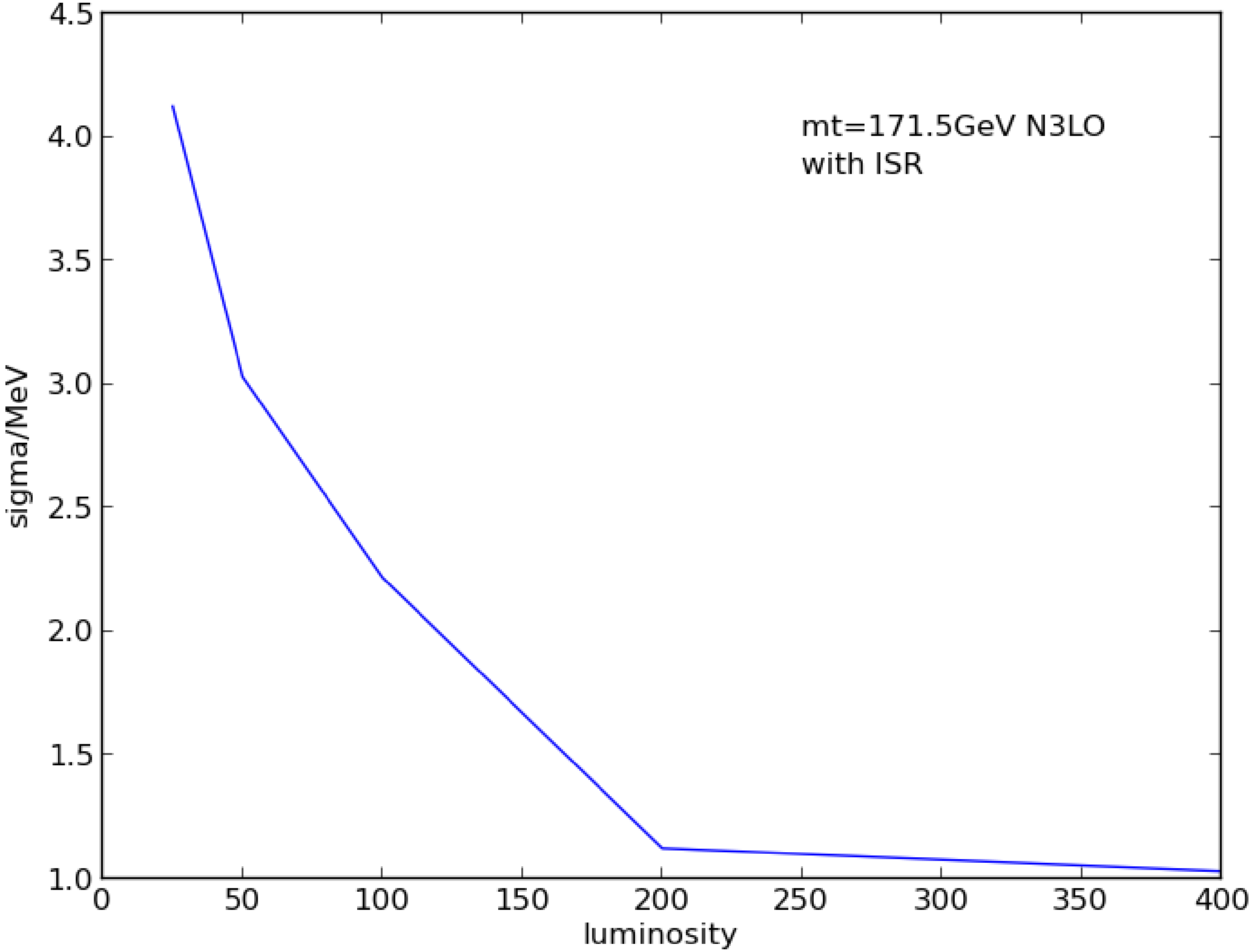


25fb^{-1} sigma: -0.004125 +0.004125

100fb^{-1} sigma: -0.002189 +0.002189

$\sqrt{s}$ NLL scan

- We pick the 6- $\sqrt{s}$ scheme for its better performance.
- And we tested more luminosity assumptions.
- The curve is consistent with our expectation.

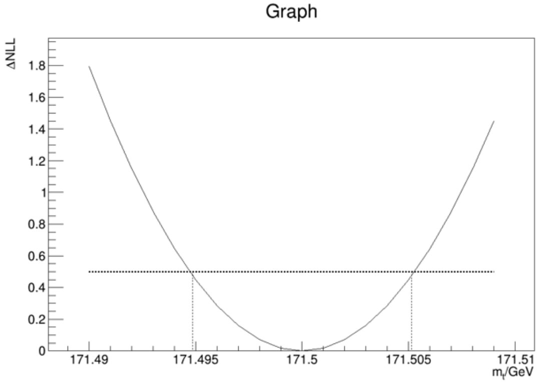


Summary of Previous Results

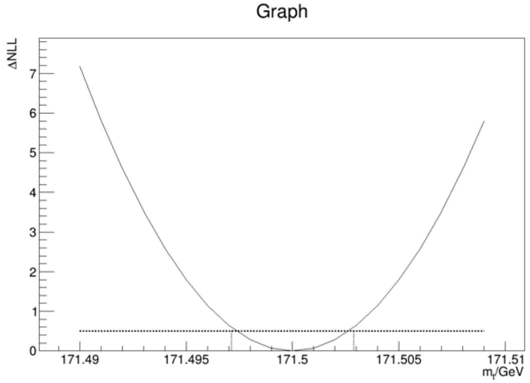
scheme	4 points	6 points	8 points
$\sigma(m_t)$/MeV $100fb^{-1}$	2.9	2.2	2.2
$\sigma(m_t)$/MeV $25fb^{-1}$	5.1	4.1	4.1

- Build up the machinery of this $\sqrt{s}$ scan to estimate measurement uncertainties.
- Test with a few set of parameters and schemes.
- The way of selecting points is crucial if we want lower error.

4 $\sqrt{s}$ scheme={341.5,342.5,343,344.5}

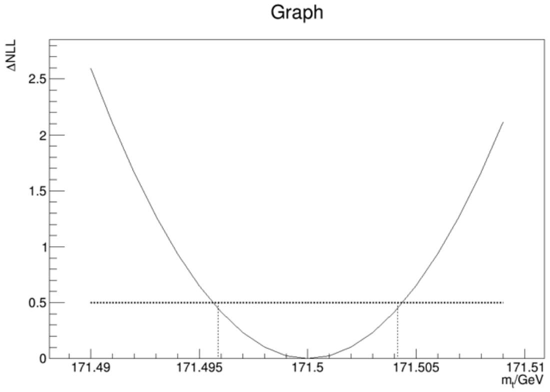


$25fb^{-1}$ sigma: -0.005125 +0.005125

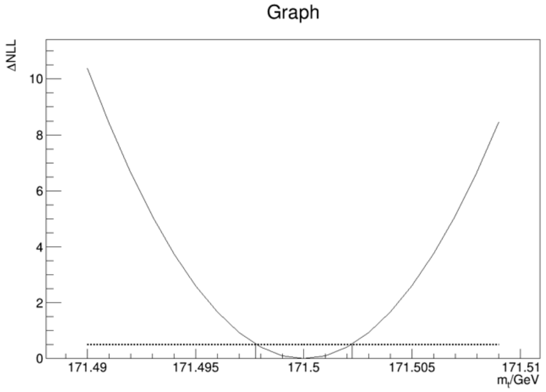


$100fb^{-1}$ sigma: -0.002875 +0.002875

8 $\sqrt{s}$ scheme ={340,341,342,342.5,343,343.5,344.5,345}

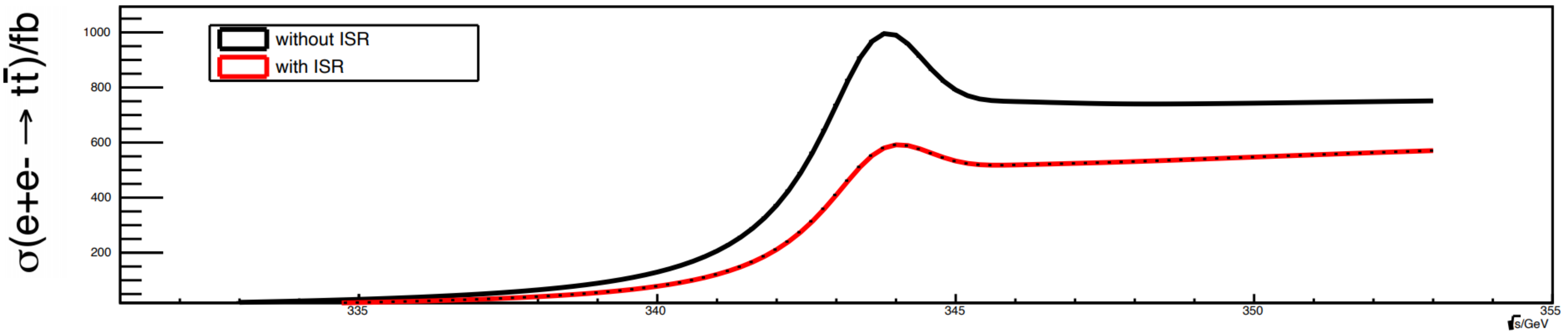


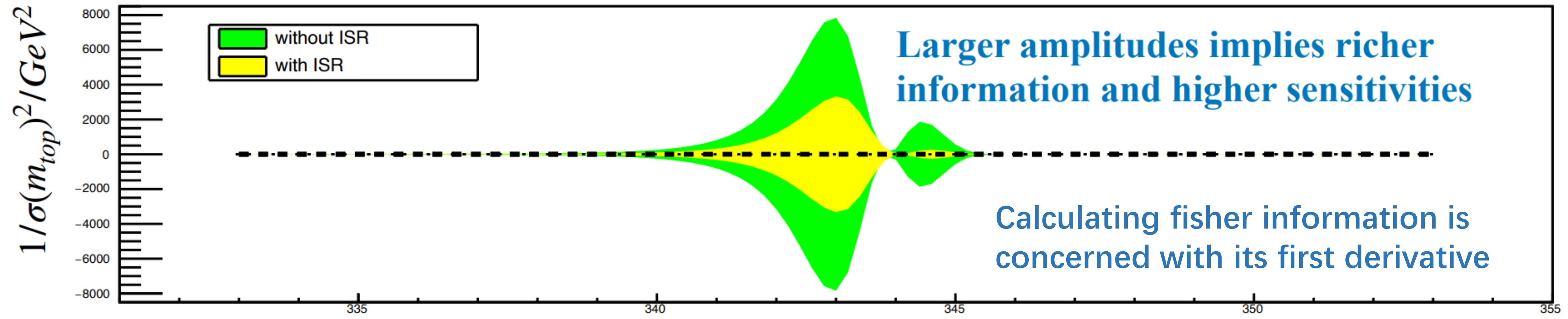
$25fb^{-1}$sigma: -0.004125 +0.004125



$100fb^{-1}$ sigma: -0.002219 +0.002219

Fisher information





Setup for this presentation

- ISR and LS are considered. Systematic uncertainties are not taken into account.
- Acceptance and selection efficiency are added.
- Background events are included.
- We only consider these 2 channels: semi-leptonic and fully-hadronic.
- Luminosity are adjusted.

Acceptance and selection efficiency for signal

- The number read from CLIC Eur. Phys. J. C (2013) 73:2530
- semi-leptonic :
  - Data: 8296, Bkg: 643, extracted signal: 7653, acceptance*selection efficiency = 48.13%, Branch ratio=30%
- Full-hadronic
  - Data: 11396, Bkg: 1393, extracted signal: 10003, acceptance*selection efficiency = 41.0%, Branch ratio=46%
- These parameters are under 500 GeV situation. At the moment we assume that acceptance and selection efficiency will not change under 352 GeV situation.
- The signal yields of our pseudo data: at 343GeV, 100 fb^{-1}
  - semi leptonic 4009.14
  - fully hadronic 5236.67

Background events

- Background events are directly scaled from 500GeV to 352GeV, according to their cross section estimated by CLIC paper.
  - For CLIC's 500GeV situation, the luminosity is 100 fb^{-1}
  - Because there is no information about background yields under 352GeV in the paper of CLIC.

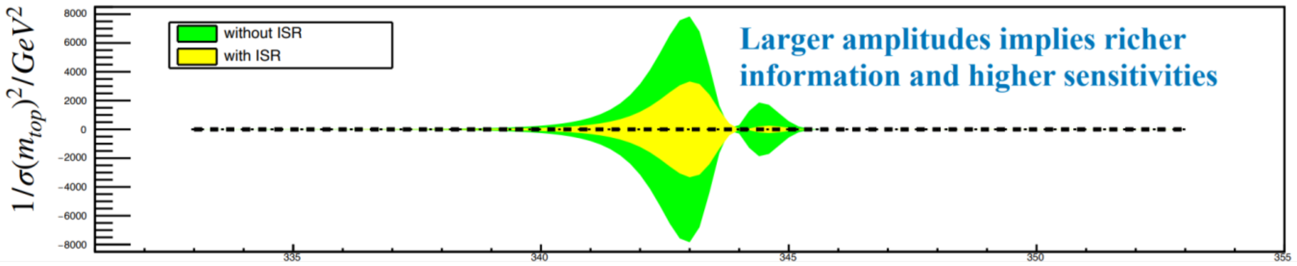
Table 1 Signal and considered physics background processes, with their approximate cross section calculated for CLIC at 500 GeV and at 352 GeV

Type	Final state	σ 500 GeV	σ 352 GeV
Signal ($m_{top} = 174$ GeV)	$t\bar{t}$	530 fb	450 fb
Background	WW	7.1 pb	11.5 pb
Background	ZZ	410 fb	865 fb
Background	$q\bar{q}$	2.6 pb	25.2 pb
Background	WWZ	40 fb	10 fb

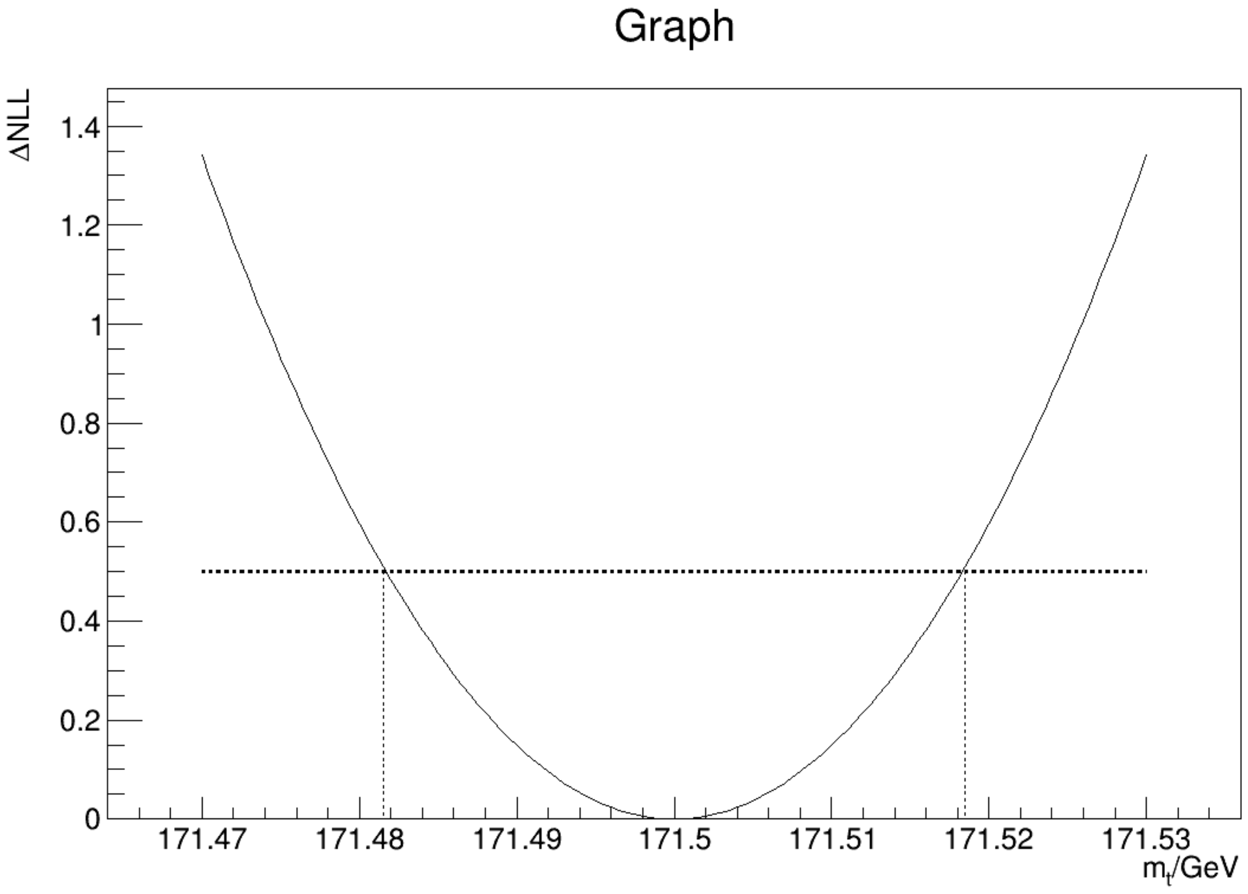
- Result:
  - semi leptonic bkg event number:2380
  - fully hadronic bkg event number:5156

Luminosity and scan $\sqrt{s}$ range

- In last work, the luminosity for every point is $100\mathrm{fb}^{-1}$.
- In this work, the luminosity of each point is the same. Total luminosity will be $100\mathrm{fb}^{-1}$.
  - We would like to compare our results with CLIC, so we are trying to keep these parameters close to CLIC's.
- $\sqrt{s}$ scan ranges from 340GeV to 345GeV.
  - Drop less sensitive points step by step from 8 points to 1 points.



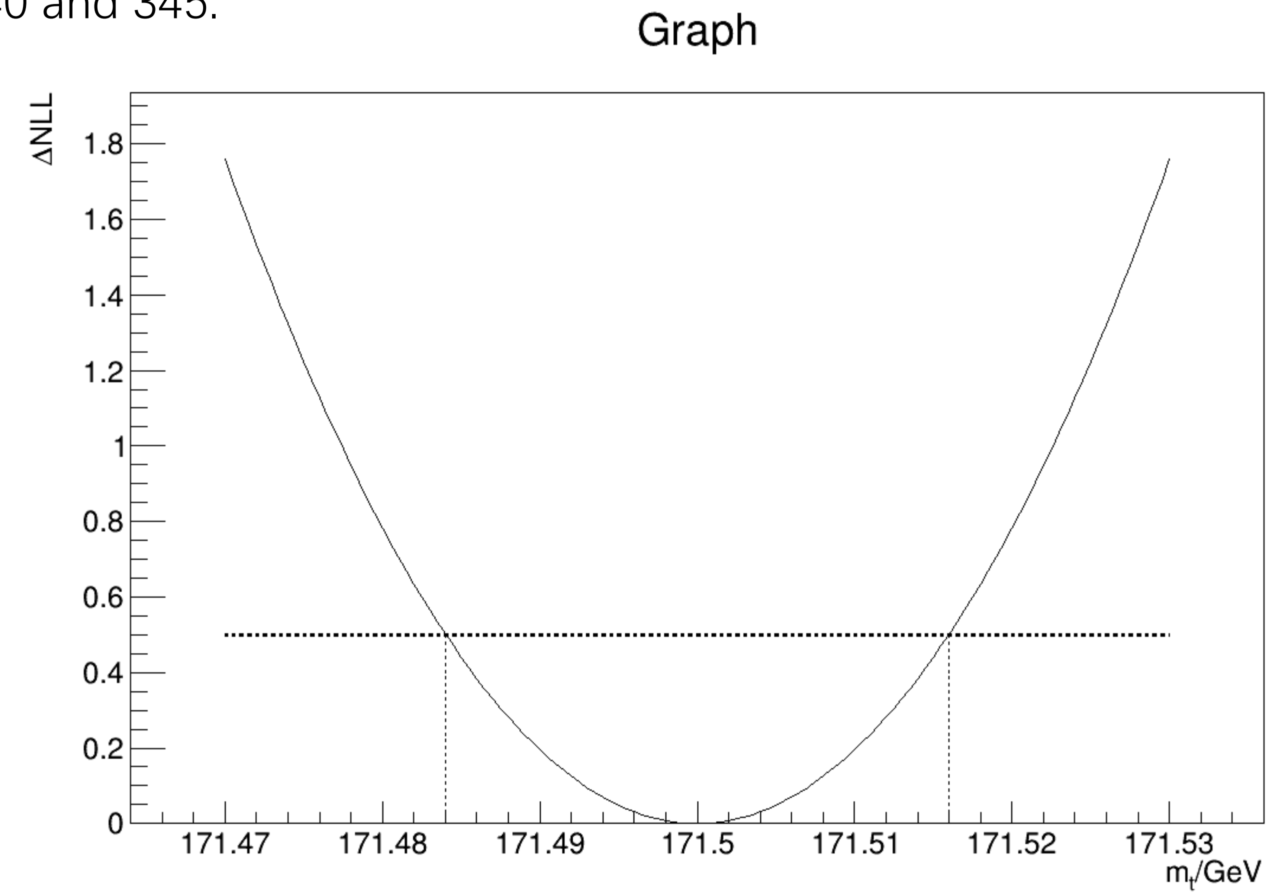
8 $\sqrt{s}$ scheme ={340,341,342,342.5,343,343.5,344.5,345}



12.5fb^{-1} per point $\sigma(m_t)$:-0.01844 +0.01844

6 $\sqrt{s}$ scheme={341,342,342.5,343,343.5,344.5}

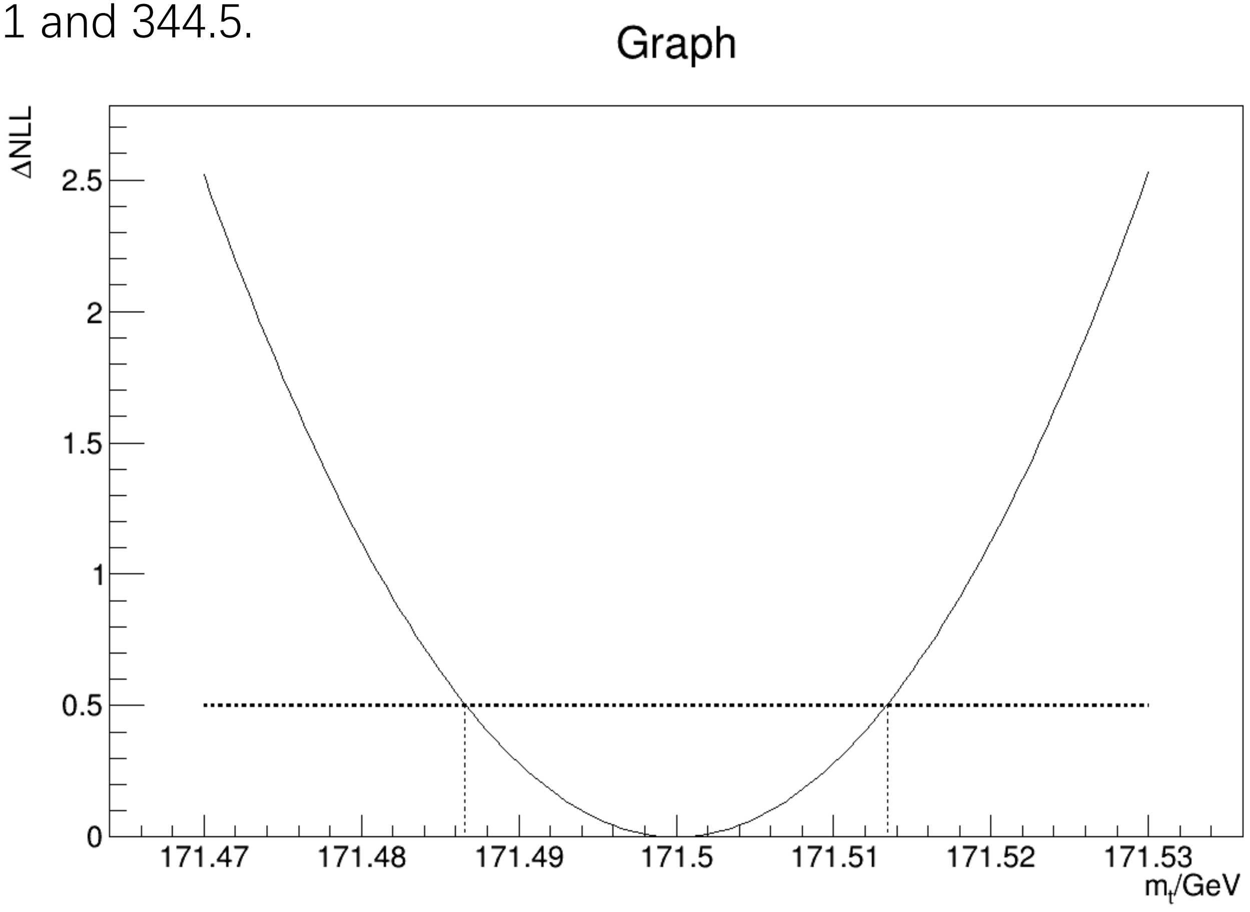
We dropped 340 and 345.



16.7 fb^{-1} per point $\sigma(m_t)$: -0.01597 +0.01597

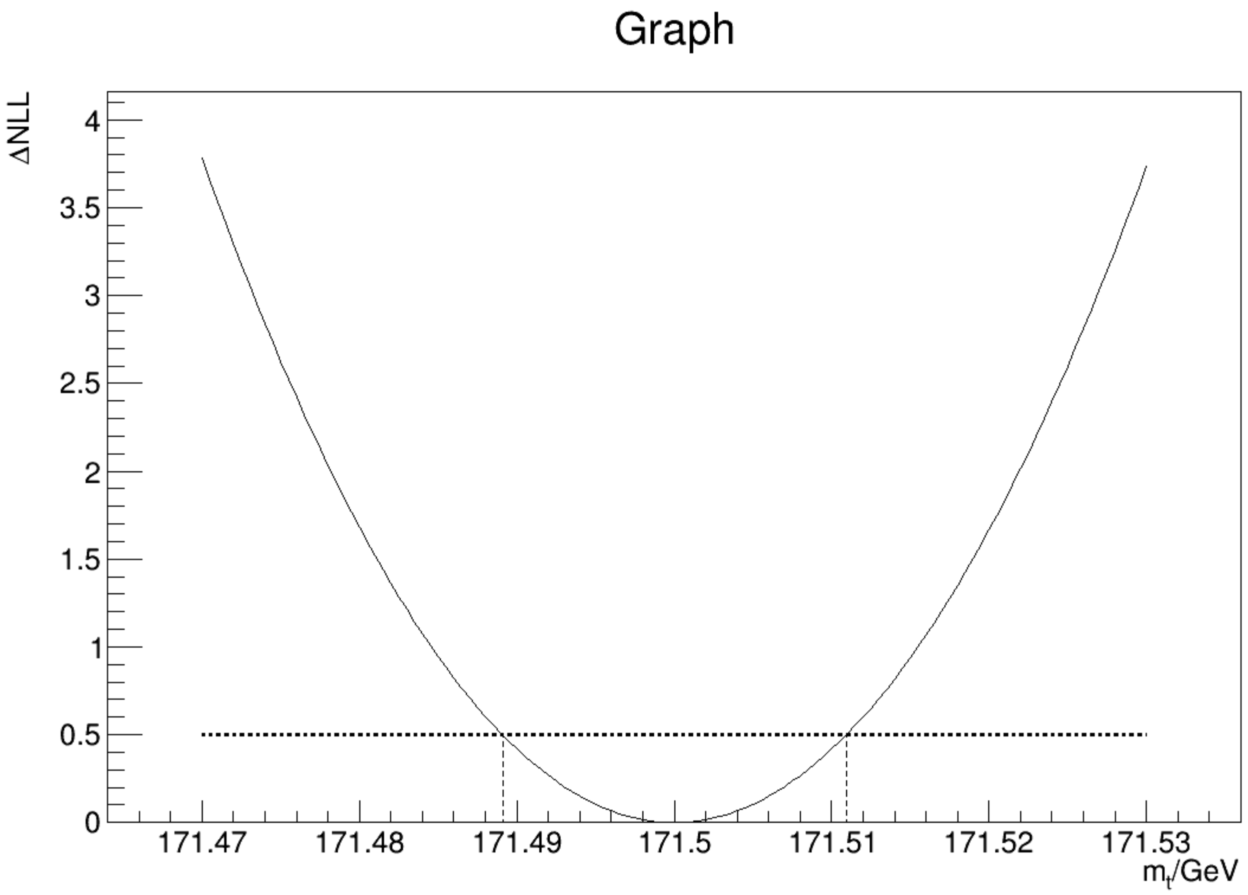
4 $\sqrt{s}$ scheme={342,342.5,343,343.5}

We dropped 341 and 344.5.



25fb^{-1} per point $\sigma(m_t)$: -0.01344 +0.01344

1 $\sqrt{s}$ scheme={343}

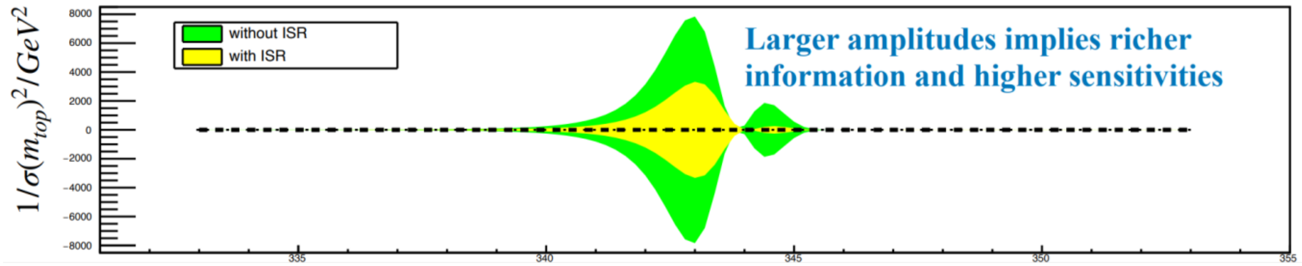


$100fb^{-1}$ per point $\sigma(m_t)$:-0.01089 +0.01098

Results

scheme	8 points	6 points	4 points	1 point
$\sigma(m_t)$/MeV	18.44	15.97	13.44	10.93

- For 171.5GeV top mass, 343 GeV center mass energy is the best point, given the total luminosity 100 fb^{-1} .
- Top mass is known as 171.5GeV, so we can get the best point through its known fisher information. But for unknown top mass, we need to first locate a proper range.



Compare with CLIC and FCC-ee

scheme	8 points	6 points	4 points	1 point
$\sigma(m_t)$ /MeV	18.44	15.97	13.44	10.98

- The estimation of FCC-ee:
  - ~17 MeV for top mass (stat. uncert.)
  - ~45 MeV for top width (stat. uncert.)
  - with 25 fb^{-1} taken at each of the 8 centre-of-mass energy points N3LO cross-section calculation brings 40 MeV uncertainty additionally

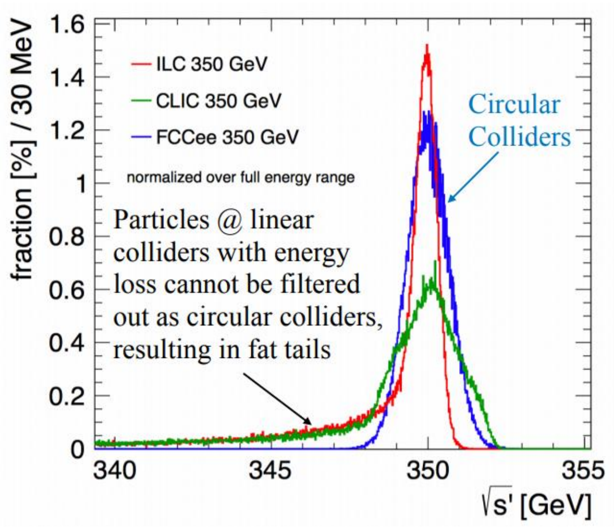
2d fit results of CLIC Eur. Phys. J. C (2013) 73:2530

Table 4 Summary of the 2D simultaneous top mass and α_s determination with a threshold scan at ILC for 10 points with a total integrated luminosity of 100 fb^{-1}. Event selection and background rejection from CLIC_ILD is used

1S top mass and α_s combined 2D fit	
m_t stat. error	27 MeV
m_t theory syst. (1 %/3 %)	5 MeV/9 MeV
α_s stat. error	0.0008
α_s theory syst. (1 %/3 %)	0.0007/0.0022

Conditions of our setup

- Systematic uncertainties are not considered.
- We use the bkg yields of 352 GeV. But the energy that we use ranges from 340 to 346 GeV, where there will be more background events than 352GeV.
- The LS of CEPC is better than others.



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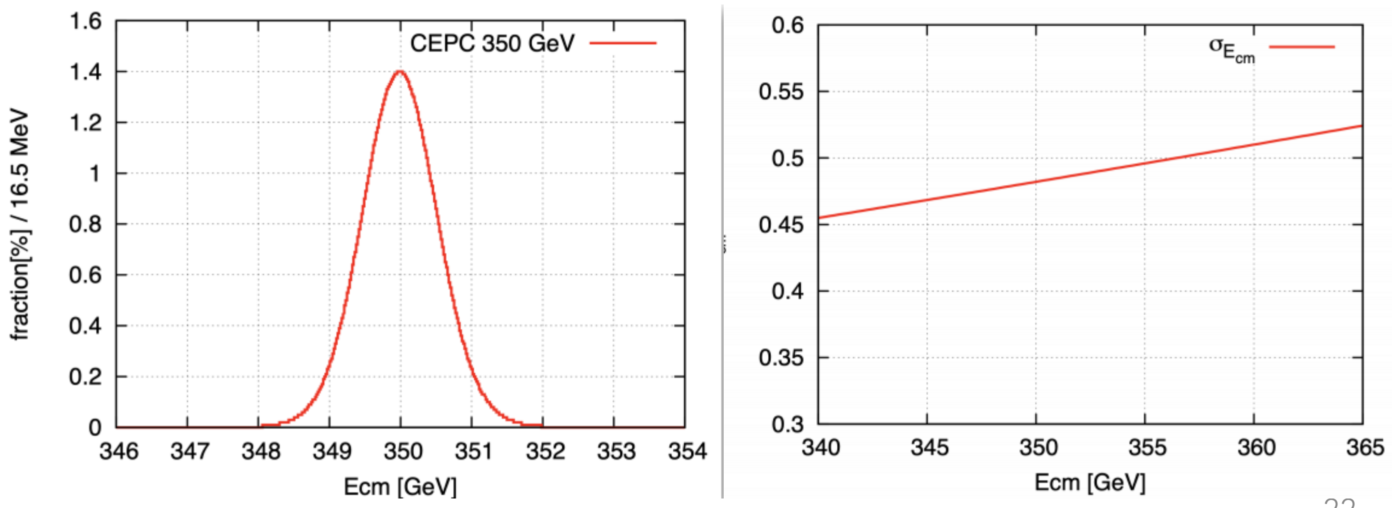


Provided by Yiwei Wang

Investigate on ‘Best Point’

- There exists a ‘best point’ for this method.
- 2 problems:
  - We should validate if 1 point scheme has the smallest error.
  - And how can we use this method to determine our scheme?

Exhaustion on 4 sqrts scheme

- Total lumi = 100
- $\sqrt{s}$ ={342,342.5,343,343.5}
- Calculate the error of all possible lumi ratio and sequence them
- 286 lumi combinations in total
    - List from low error to high error
    - Top 30 are listed
- Conclusion: 343GeV is the best point.

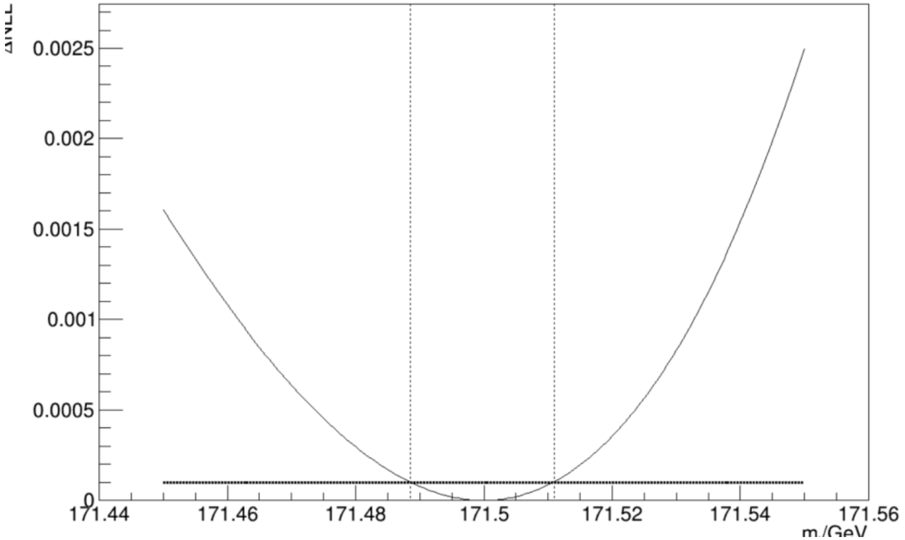
```
lumi ratio= {0, 0, 100, 0},       err= 0.0109375
lumi ratio= {0, 10, 90, 0},       err= 0.0110801
lumi ratio= {0, 0, 90, 10},       err= 0.0110962
lumi ratio= {0, 0, 80, 20},       err= 0.0114375
lumi ratio= {0, 10, 80, 10},      err= 0.0114375
lumi ratio= {0, 20, 80, 0},       err= 0.0114375
lumi ratio= {10, 0, 90, 0},       err= 0.0114375
lumi ratio= {0, 0, 70, 30},       err= 0.0114902
lumi ratio= {0, 10, 70, 20},      err= 0.0114979
lumi ratio= {10, 0, 80, 10},      err= 0.0115028
lumi ratio= {10, 10, 80, 0},      err= 0.0115098
lumi ratio= {0, 20, 70, 10},      err= 0.0115167
lumi ratio= {0, 10, 60, 30},      err= 0.0115625
lumi ratio= {0, 20, 60, 20},      err= 0.0115625
lumi ratio= {10, 0, 70, 20},      err= 0.0115625
lumi ratio= {10, 10, 70, 10},     err= 0.0115625
lumi ratio= {0, 30, 70, 0},       err= 0.0115684
lumi ratio= {0, 0, 60, 40},       err= 0.0115903
lumi ratio= {0, 30, 60, 10},      err= 0.01175
lumi ratio= {0, 40, 60, 0},       err= 0.01175
lumi ratio= {10, 20, 70, 0},      err= 0.01175
lumi ratio= {20, 0, 80, 0},       err= 0.01175
lumi ratio= {10, 0, 60, 30},      err= 0.0118866
lumi ratio= {0, 0, 50, 50},       err= 0.0119141
lumi ratio= {0, 10, 50, 40},      err= 0.0119141
lumi ratio= {0, 20, 50, 30},      err= 0.0119375
lumi ratio= {10, 10, 60, 20},     err= 0.0119375
lumi ratio= {0, 30, 50, 20},      err= 0.0119844
lumi ratio= {20, 0, 70, 10},      err= 0.0119844
lumi ratio= {0, 40, 50, 10},      err= 0.0119873
lumi ratio= {10, 20, 60, 10},     err= 0.0119902
```

Proposal to find the Best Point

- Running at a low luminosity ($1\,fb^{-1}$)
- The discriminant value is much smaller than the one used for deriving $\sigma(m_t)$

```
sqrts = {340, 341, 342, 342.5, 343, 343.5, 344.5, 345}
lum= 1, discriminant value = 1e-4
lumi ratio= {0, 0, 0, 0, 1, 0, 0, 0},   err= 0.00151562
lumi ratio= {0, 0, 0, 1, 0, 0, 0, 0},   err= 0.00190234
lumi ratio= {0, 0, 0, 0, 0, 1, 0, 0},   err= 0.0019375
lumi ratio= {0, 0, 1, 0, 0, 0, 0, 0},   err= 0.0025625
lumi ratio= {0, 1, 0, 0, 0, 0, 0, 0},   err= 0.0054375
lumi ratio= {0, 0, 0, 0, 0, 0, 1, 0},   err= 0.00796094
lumi ratio= {1, 0, 0, 0, 0, 0, 0, 0},   err= 0.00958594
lumi ratio= {0, 0, 0, 0, 0, 0, 0, 1},   err= 0.0111875
```

- This figure is for {345}
- LS energy width=1GeV



Summary & Next

- Summary:
  - The uncertainty of this method is tightly related to our points selection scheme.
  - 1-point scheme has the best performance, if we have already found the best point.
  - We proposed to scan the point with low luminosity to identify the best point.
    - the method should be further investigated, considering the effects of systematics, etc.
  - We can scan some points in non-sensitive area (e.g. 320GeV) to do background study.
- Next:
  - 1. Width, α_s , and Yukawa coupling factor should be considered in the measurements.
  - 2. Theory uncertainty should be added.