

Top quark properties measurements at CEPC

Zhan Li on behalf of

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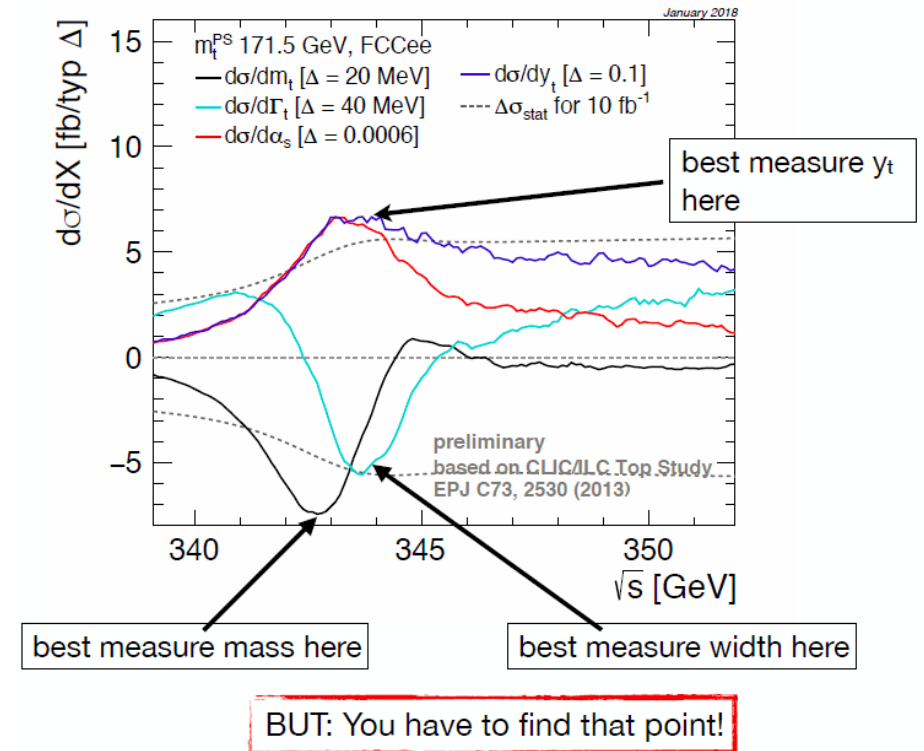
Motivation

- Top quark properties are fundamental factors in the Standard Model, also a stringent check of internal consistency of SM.
- Top quark properties are 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 $t\bar{t}$ threshold scan.

Motivation

- $t\bar{t}$ 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)

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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 CEPC LS setup ($\sim 0.5\text{GeV}$) as the energy resolution at the moment.

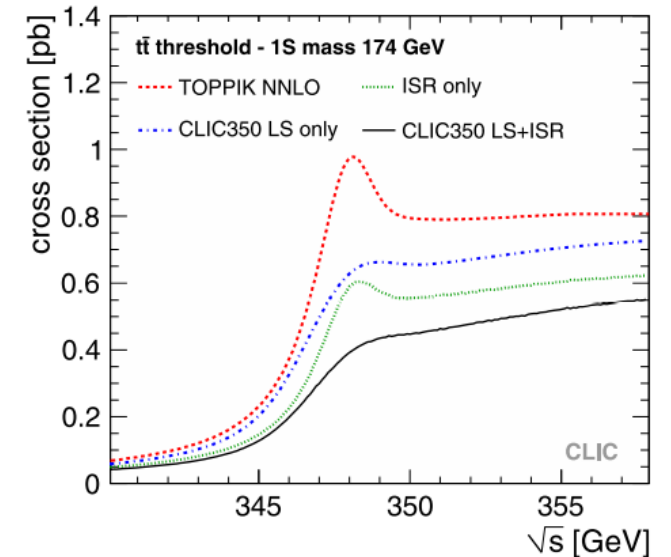


Fig. 4 Top pair production cross section from theory calculations, with the luminosity spectrum (LS) of CLIC at 350 GeV and ISR as well as for all effects combined

Method: \sqrt{s} scan

- Since we are interested in the precise measurement of top properties 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:

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

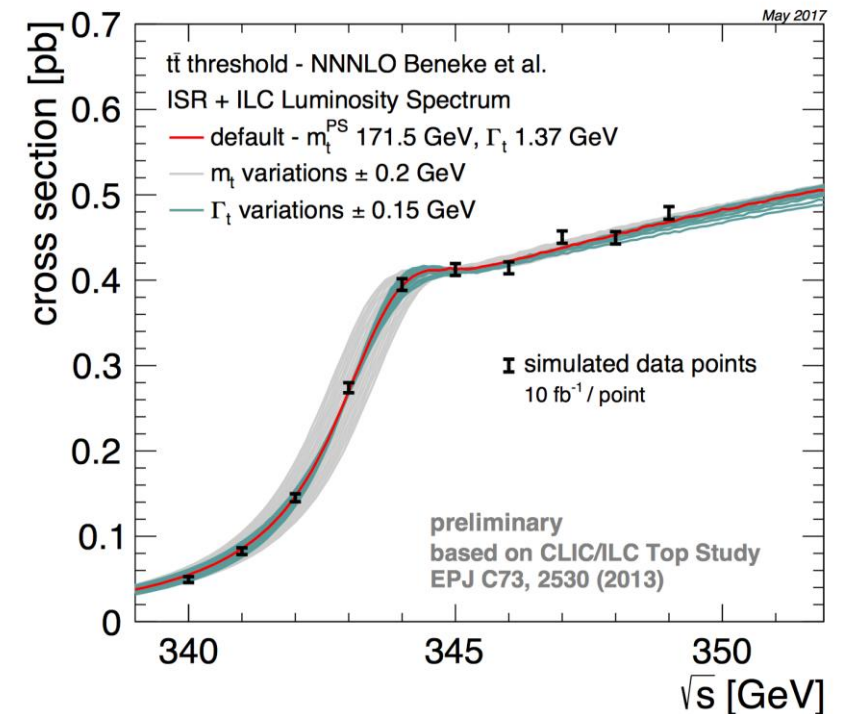
- Since we do not have real experiment data, we use `QQbar_threshold` to generate pseudo data instead.

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:

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

- i corresponds to the i -th scan point



Review

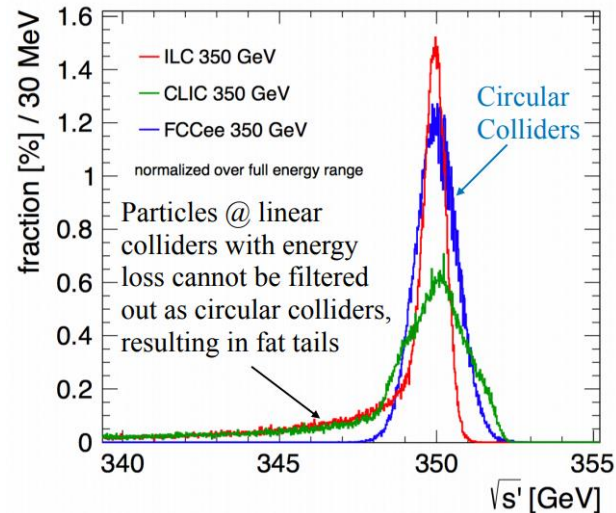
- The uncertainty of this method is tightly related to our points selection scheme.
- 1-point scheme has the best performance at its best point.
- At present we use Fisher information to crosscheck the best point.
- We proposed to scan the point with low luminosity to identify the best point.
- Only mass results were given last time.

Setup

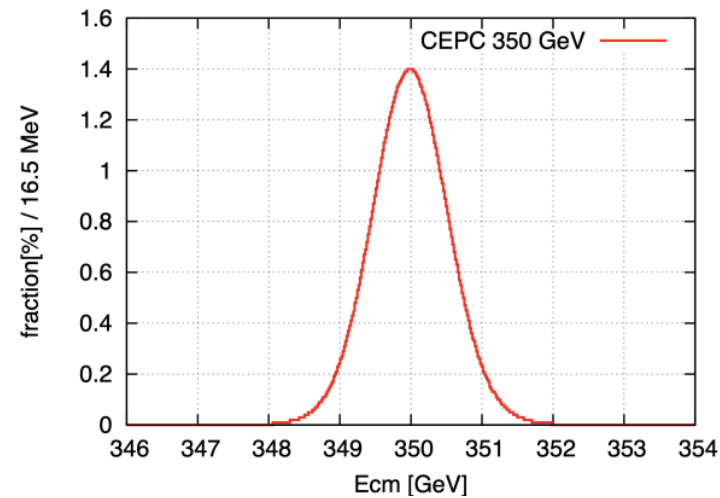
- Top properties:
 - The mass of the top quark is set to be 171.5 GeV.
 - The width of the top quark is set to be 1.33 GeV.
 - The α_s of the top quark is set to be 0.1184.
- Background:
 - It is assumed that the nominal background contribution is well known both from theory and from measurements below threshold, so that the nominal number of background events can be subtracted from the signal.
 - Only signal events included.

Setup

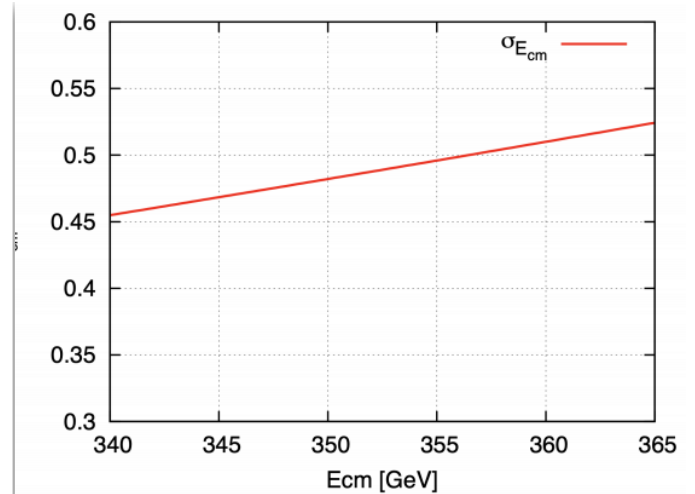
- Channels: Semi-leptonic channel and full-hadronic channel are considered.
- The LS of CEPC compared to others.



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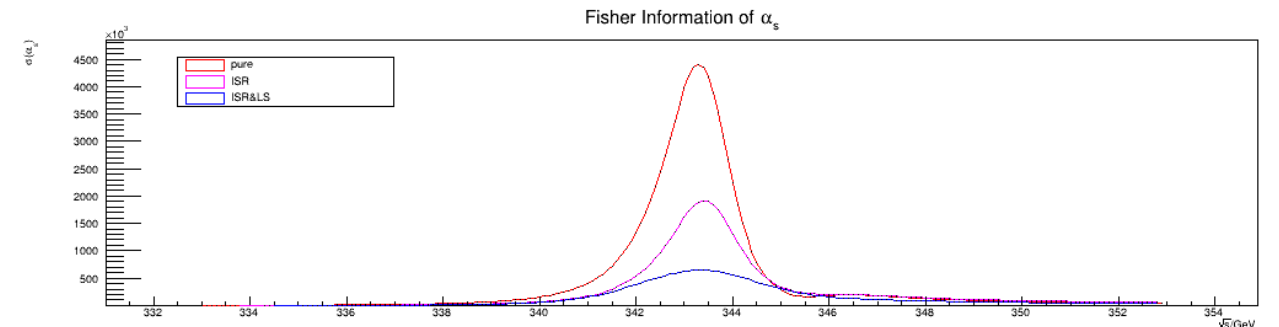
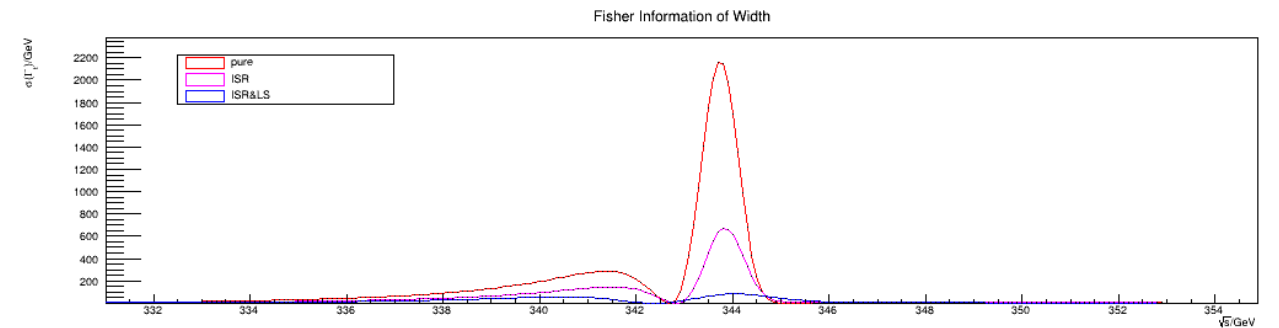
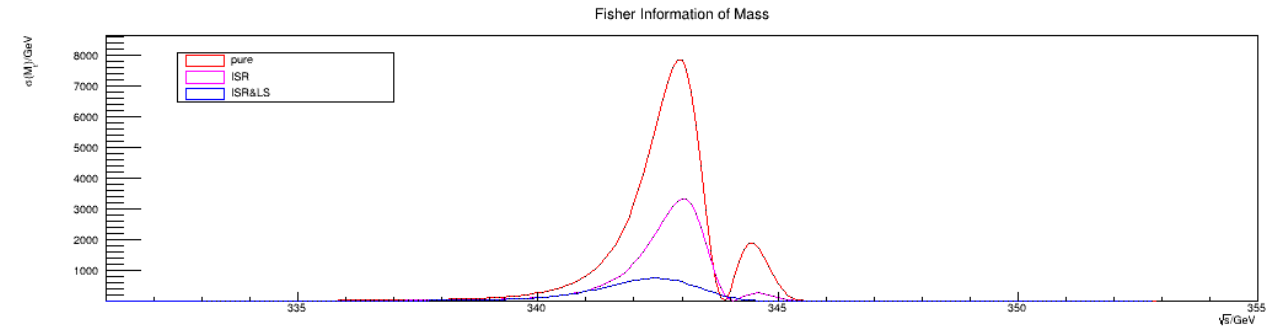
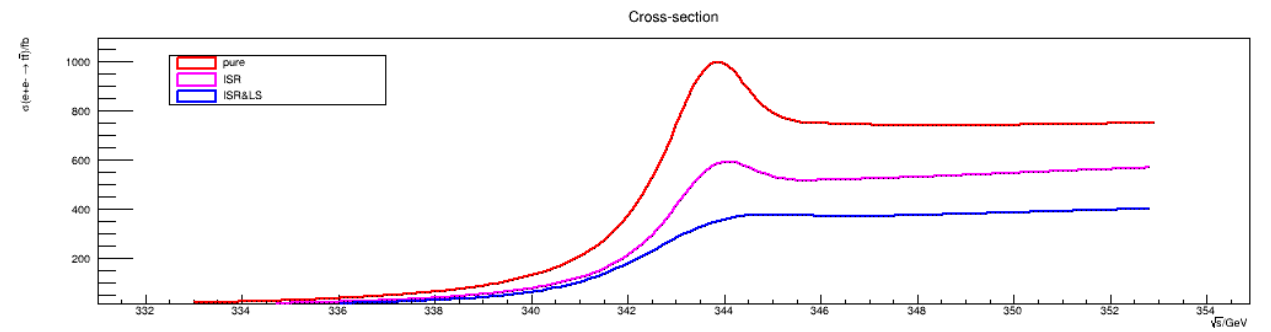


Provided by Yiwei Wang



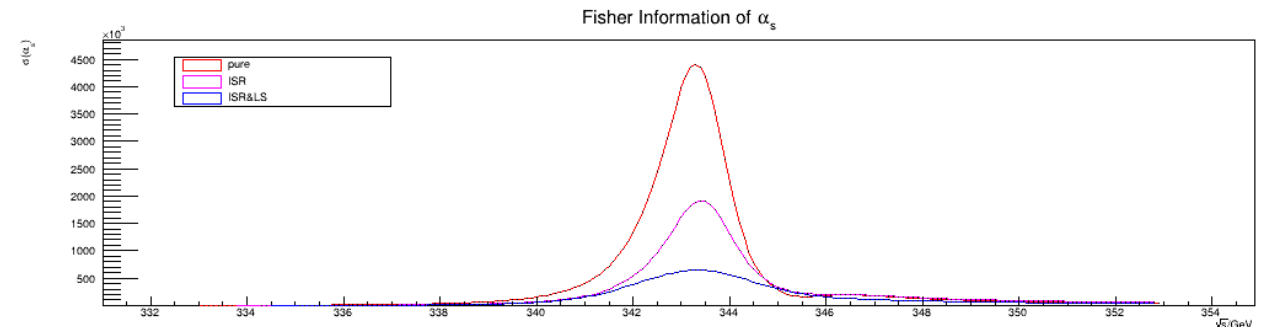
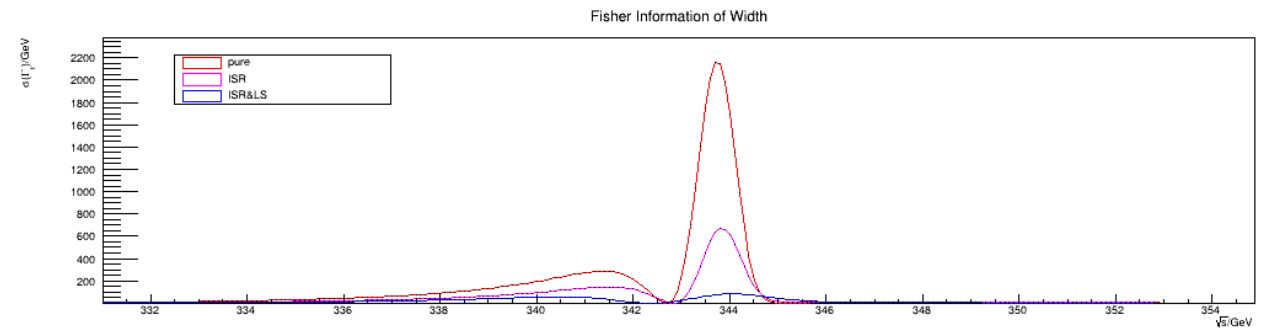
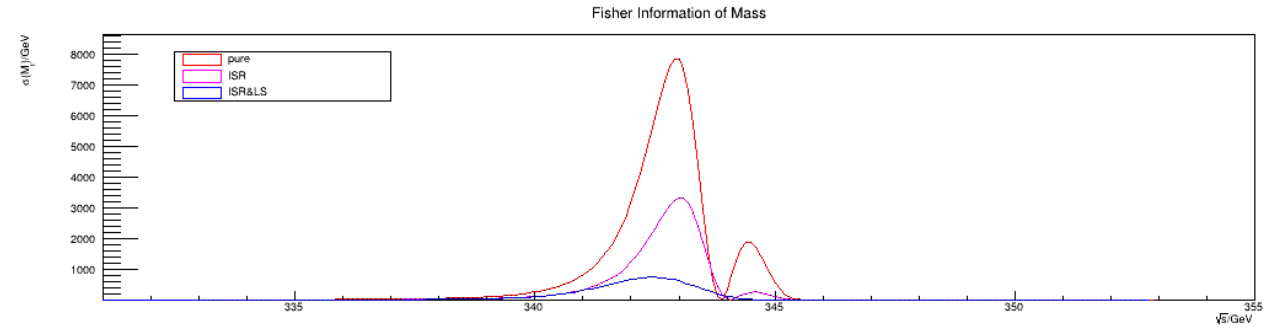
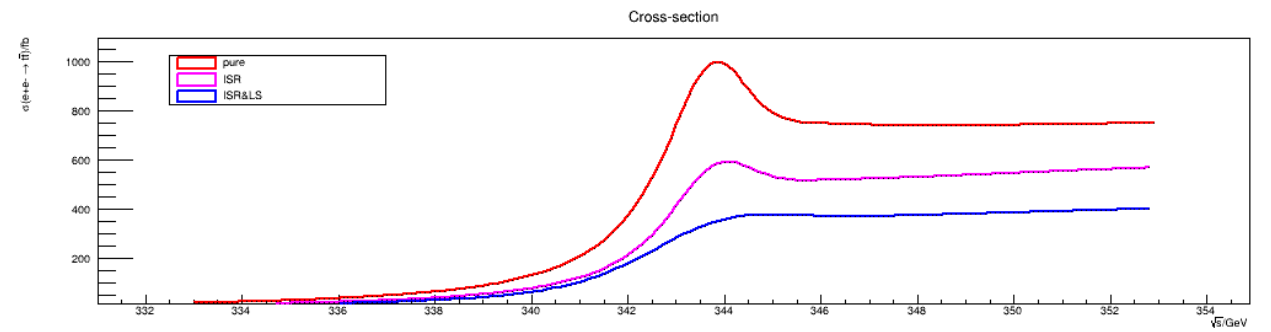
Fisher Information

- Calculating fisher information is concerned with its first derivative.
- Larger amplitudes implies richer information and higher sensitivities.



Fisher Information

- Best mass point: 342.75 GeV
- Best width point: 344.00 GeV
- Best α_s point: 343.5 GeV



Expected precision

- With the CEPC setup, limited to the total luminosity of 100 fb^{-1} , top quark mass, width and α_s are measured individually at their optimal energy points.

Parameter of interest	Statistical uncertainty
m_t	9.06 MeV
Γ_t	25.86 MeV
α_s	0.000394

CLIC results:

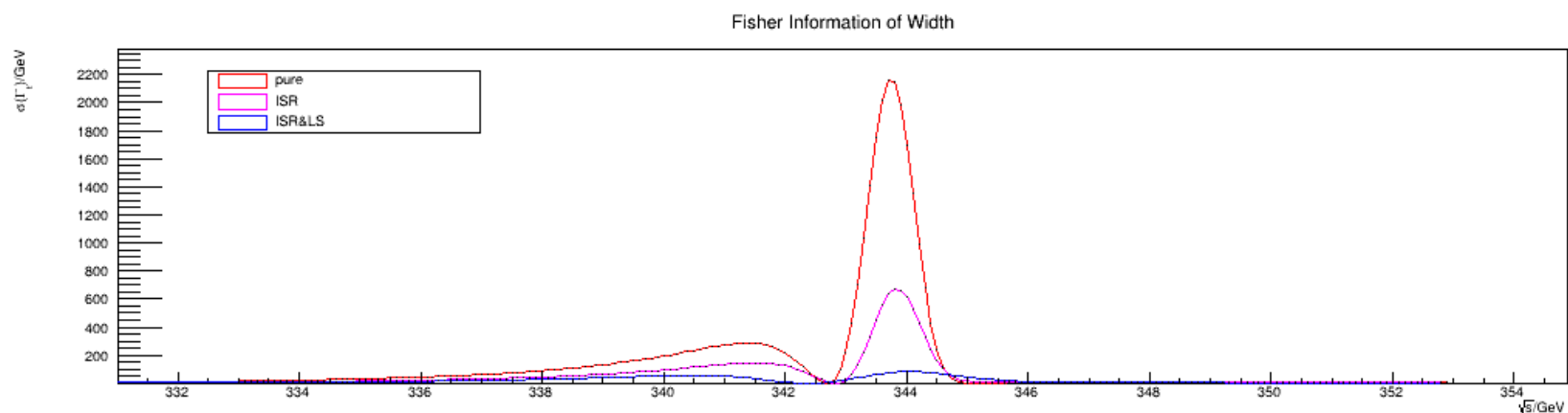
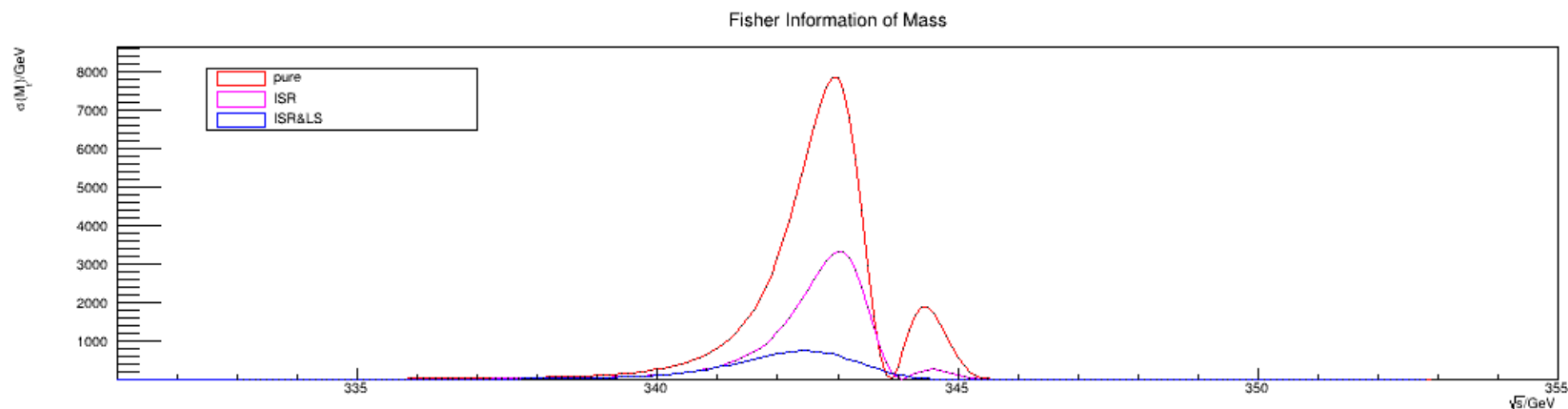
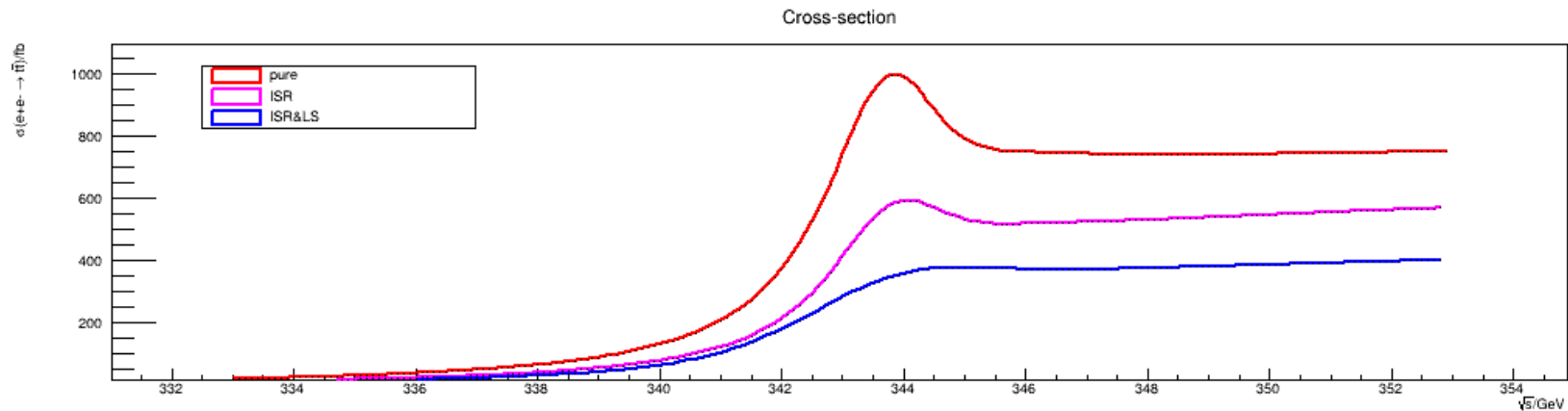
POI	Stat. uncertainty
m_t	34 MeV
Γ_t	
α_s	0.0009

The result on width

- In reality it is hard to always achieve the best point.
- To estimate the expected precision of width, we consider such situation: we give luminosity to both the best mass point and the best width point, {342.75, 344.00}. The results are listed below.

Luminosity/fb ⁻¹	Mass precision/MeV	Width precision/MeV
{100, 0}	9.06	342.734
{80, 20}	10.25	57.2656
{50, 50}	12.75	35.918
{20, 80}	19.23	29.6094
{0, 100}	>50	25.8594

- This way we are sacrificing the precision on mass for the precision on width.
- On the FI figure we can see that 344.00 can be the worst point for mass.



The result on α_s

- Then we do the same thing on α_s . The centre-of-mass energies are {342.75, 343.5}.

Luminosity/fb ⁻¹	Mass precision/MeV	α_s precision
{100, 0}	9.06	0.000402
{80, 20}	9.94	0.000401
{50, 50}	10.94	0.000399
{20, 80}	12.71	0.000394
{0, 100}	14.32	0.000389

Effect from Luminosity Spectrum

- To improve the precision of top properties measurement, the effect from luminosity spectrum need to be investigated.
- To gain the direct-viewing influence of luminosity spectrum, the energy width is decreased by 20% and 50%. The results are listed below.

	Error/MeV
Keep total CEPC LS	9.06
Reduce 20% of the LS	8.94
Reduce 50% of the LS	8.40

Uncertainty from Beam

- In CEPC, the beam can cause the shift in centre-of-mass energy.
- In tt scan, the shift can be $1.8 * \sqrt{2} = 2.55$ MeV.
- The shift can contribute to the change of the median value of top mass.

	Higgs mode	Z mode	WW scan	tt scan
E_{beam}/GeV	120	45	80	175
X_{edge}/m	6.163 52	9.296 86	7.103 43	5.572 76
X_{beam}/m	1.879 35	5.011 78	2.819 03	1.288 68
$\delta X_{edge}/\text{m}$		2.6×10^{-5}		
$\delta X_{beam}/\text{m}$		6×10^{-8}		
$\delta E_{beam}/\text{MeV}$	1.0	0.3	0.6	1.8

G.Y. Tang et al, Rev. Sci. Instrum. 91, 033109 (2020)

	Median Value	Delta
plus	171.4980 GeV	-2 MeV
minus	171.5010 GeV	+1 MeV

Uncertainty from Theory

- The theory uncertainty of the overall normalization of the cross section is in that case fully absorbed by an uncertainty of the top mass. The results are listed below.

Cross-section uncertainty	Error
+1%	+5 MeV
-1%	-9 MeV
+3%	+24 MeV
-3%	-26 MeV

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When assuming a 1 % and a 3 % uncertainty, the uncertainty of top mass is 18 MeV and 56 MeV.

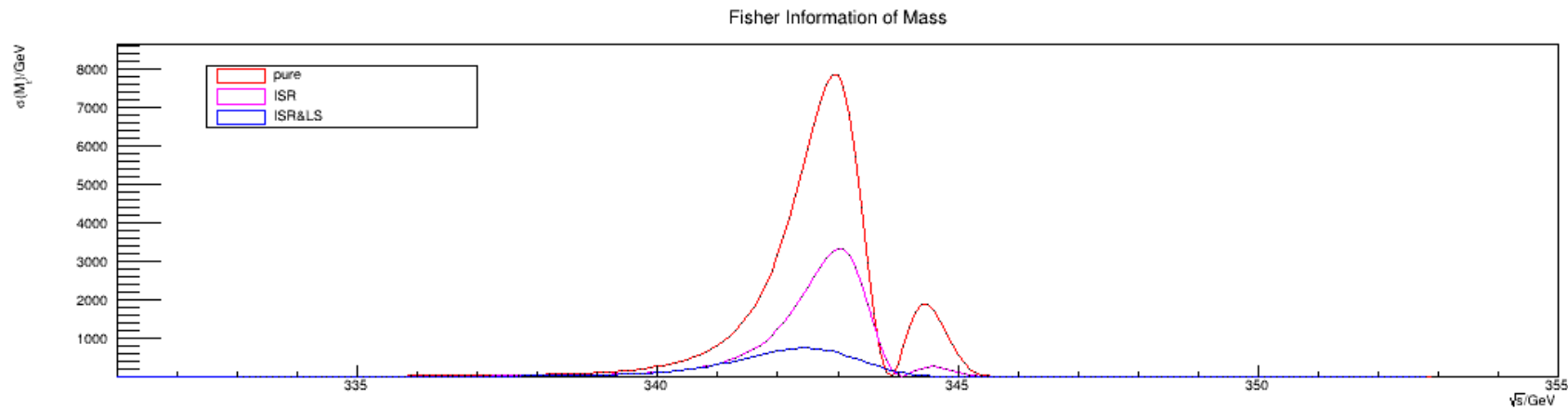
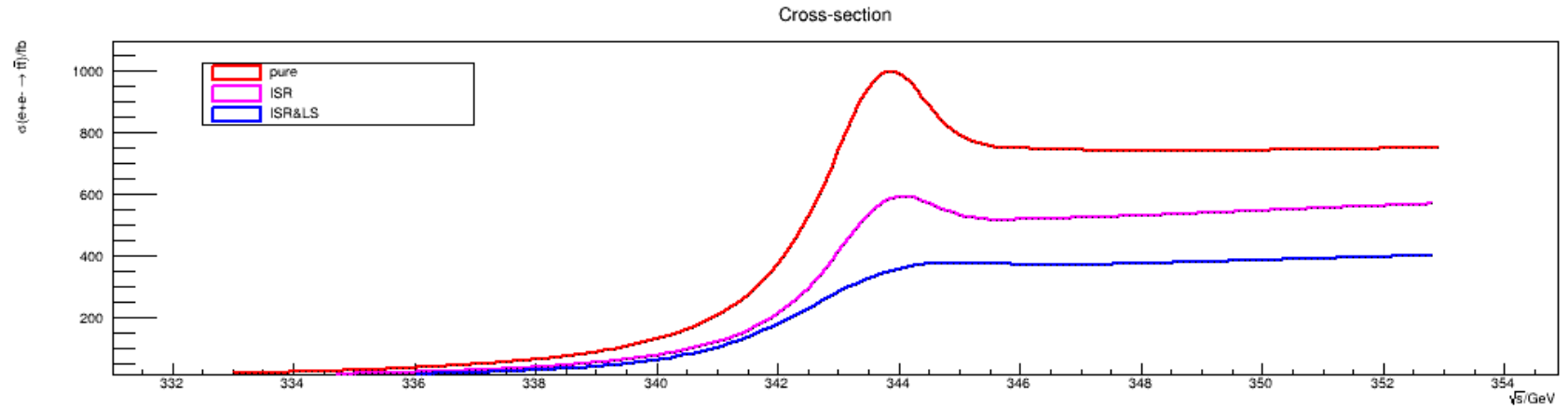
Summary & Next

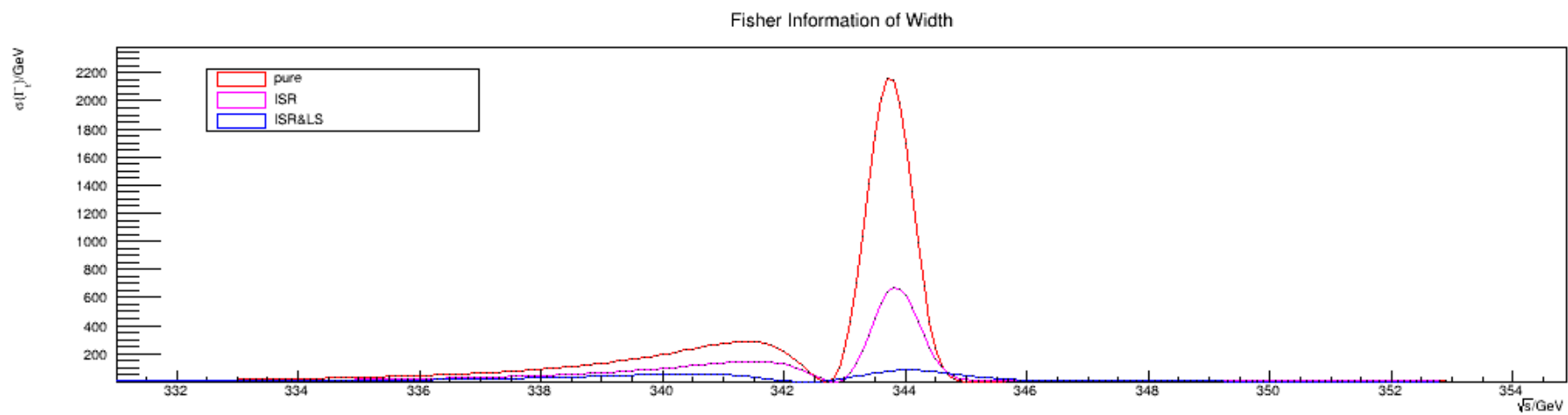
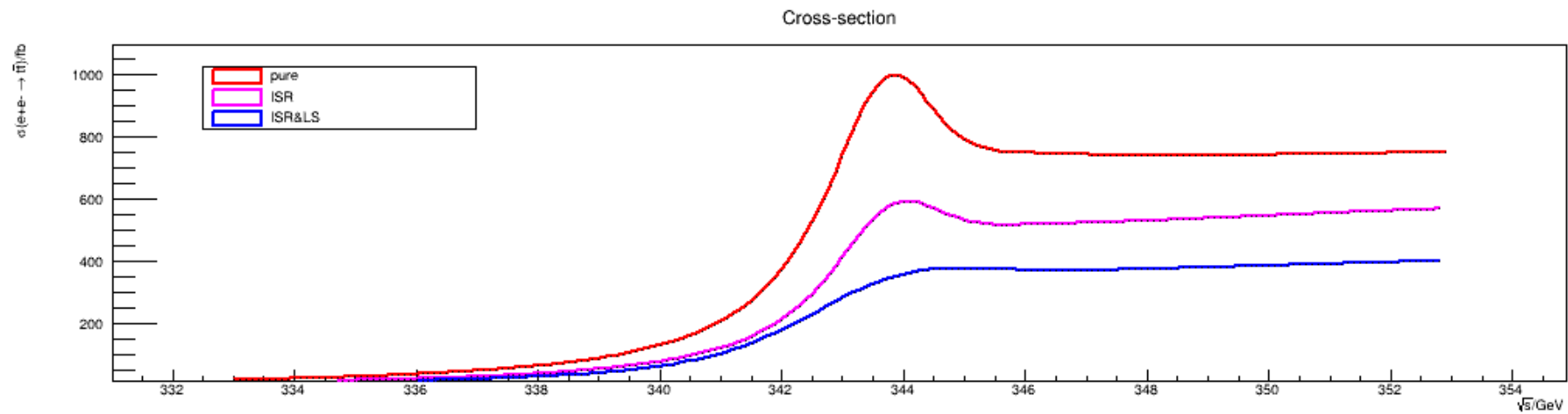
- Summary:
 - The statistic uncertainties of top mass, width and α_s are given.
 - The reduction of LS can only do little on improving the performance of top mass precision.
 - Beam uncertainty and theoretical uncertainty are considered on top mass.
 - 3% fluctuation on theory can make great contribution to the uncertainty.
- Next:
 - Our paper will be uploaded to arXiv soon after wrapping up a few systematic uncertainties.
 - The systematic uncertainty of width and α_s should be added.
 - The uncertainty of the background and luminosity spectrum will be considered.

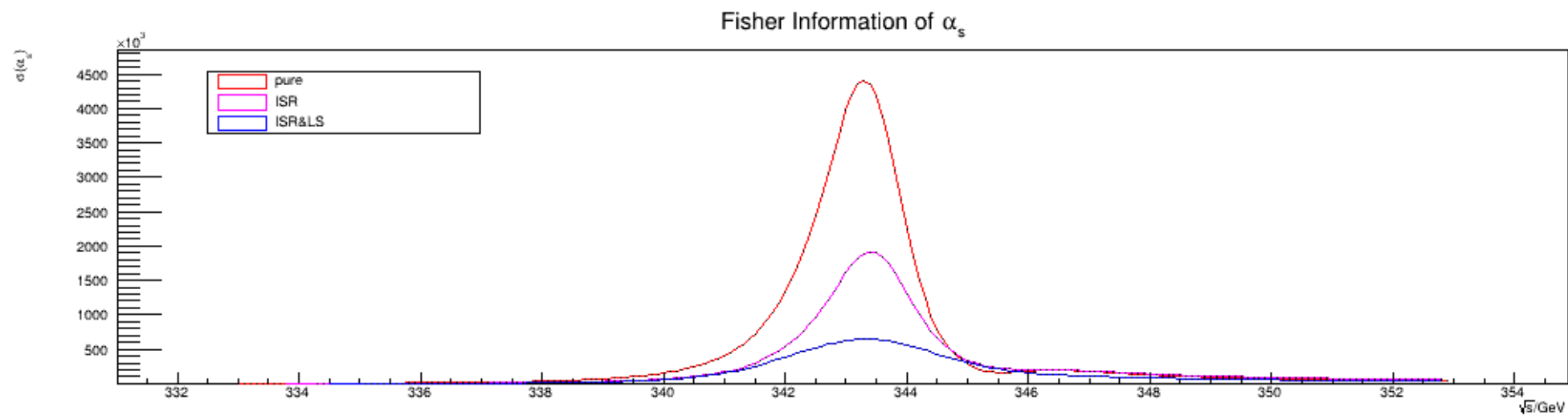
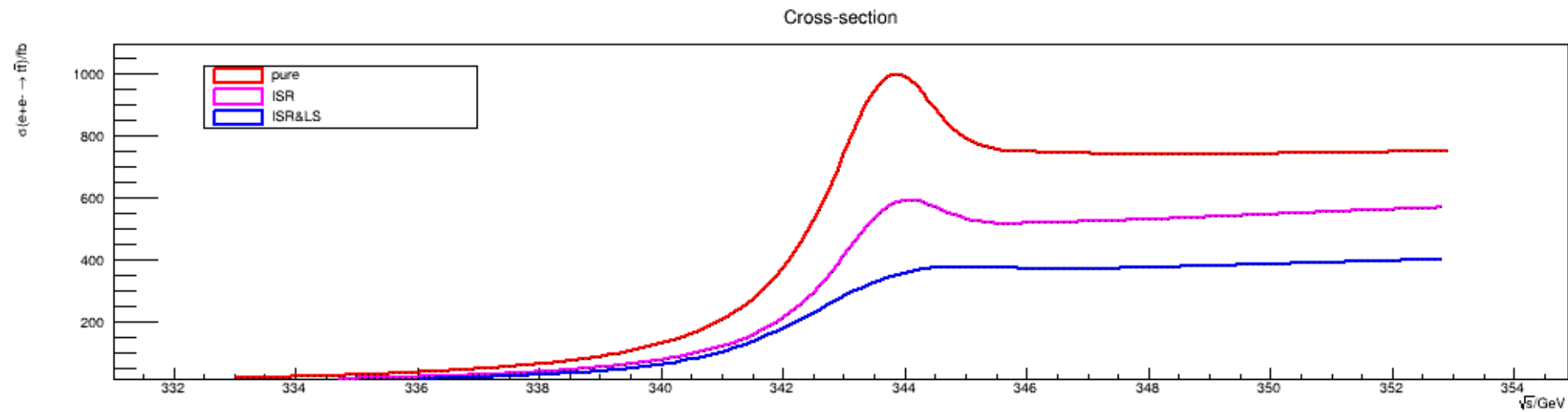
Thank you!

Back-up

Fisher Information of mass







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