Institute of High Energy Physics Chinese Academy of Sciences

PEKING UNIVERSITY

Top mass measurements at CEPC

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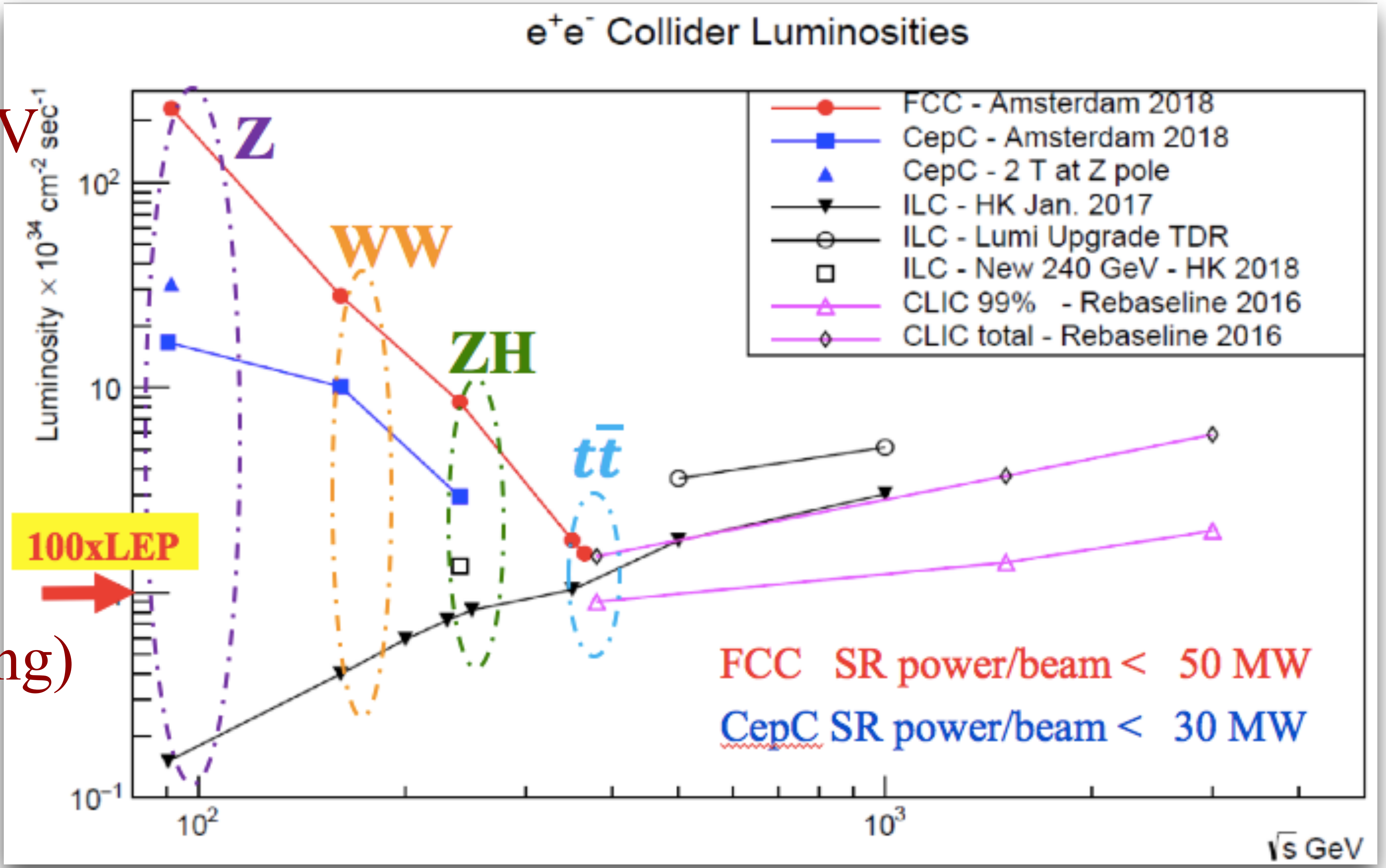
孙小虎 Xiaohu SUN
on behalf of
Gang LI, Zhan LI, Zhijun LIANG, Yaquan FANG, Shudong WANG, Yiwei WANG, Shuiting XIN, Hao ZHANG

Introduction

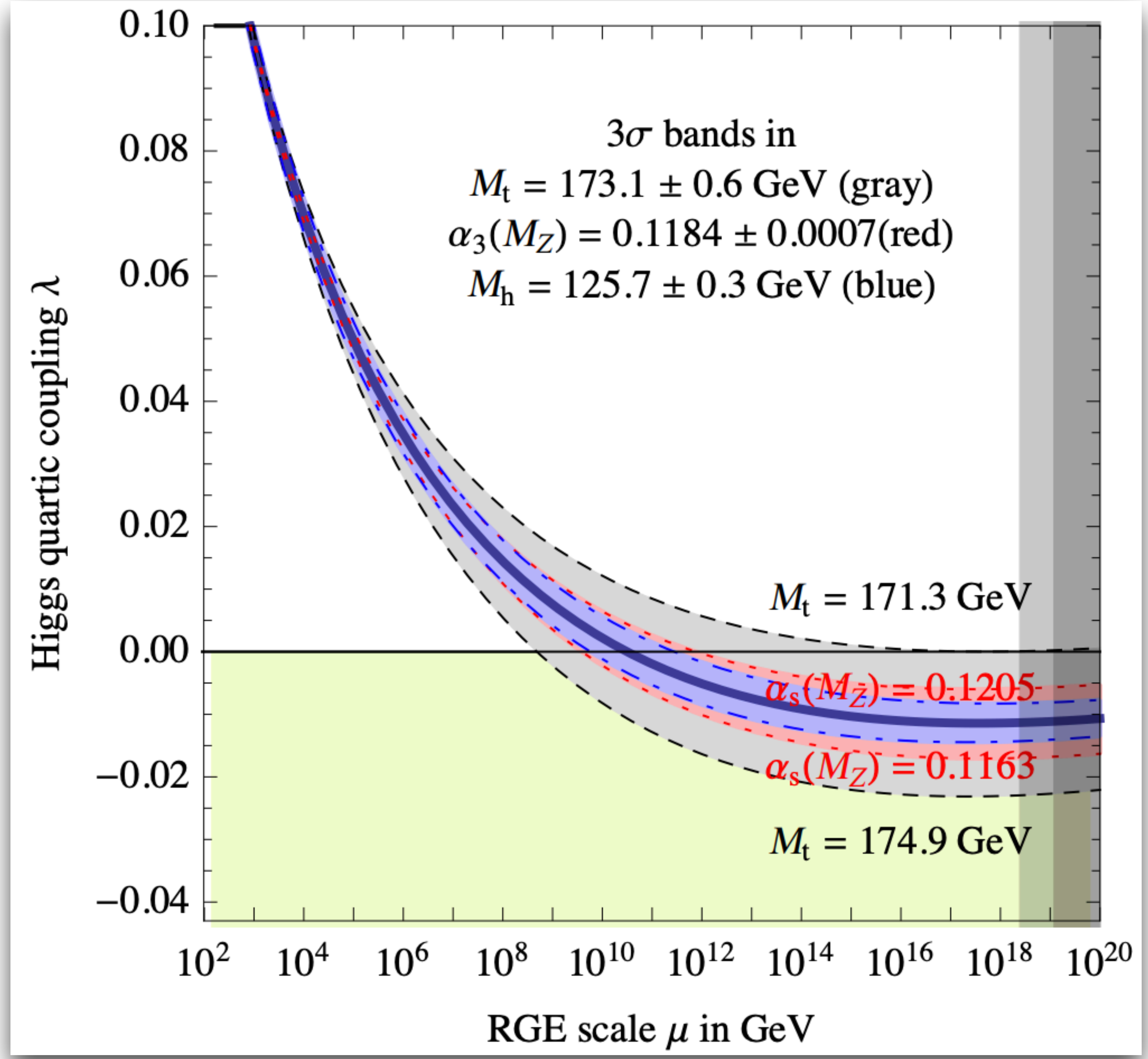
- CEPC will be a versatile machine with many opportunities
  - Higgs factory @~240 GeV
  - Diboson factory @~160 GeV
  - Z factory @~90 GeV
- Can it also be a tt factory?
  - Beam @ tt runs (Yiwei)
  - Top coupling (Zhen)
  - Top for new physics (Shufang)
  - Top mass (this talk)
  - Higgs @ tt runs (Kaili)



F. Bedeschi

Why top mass?

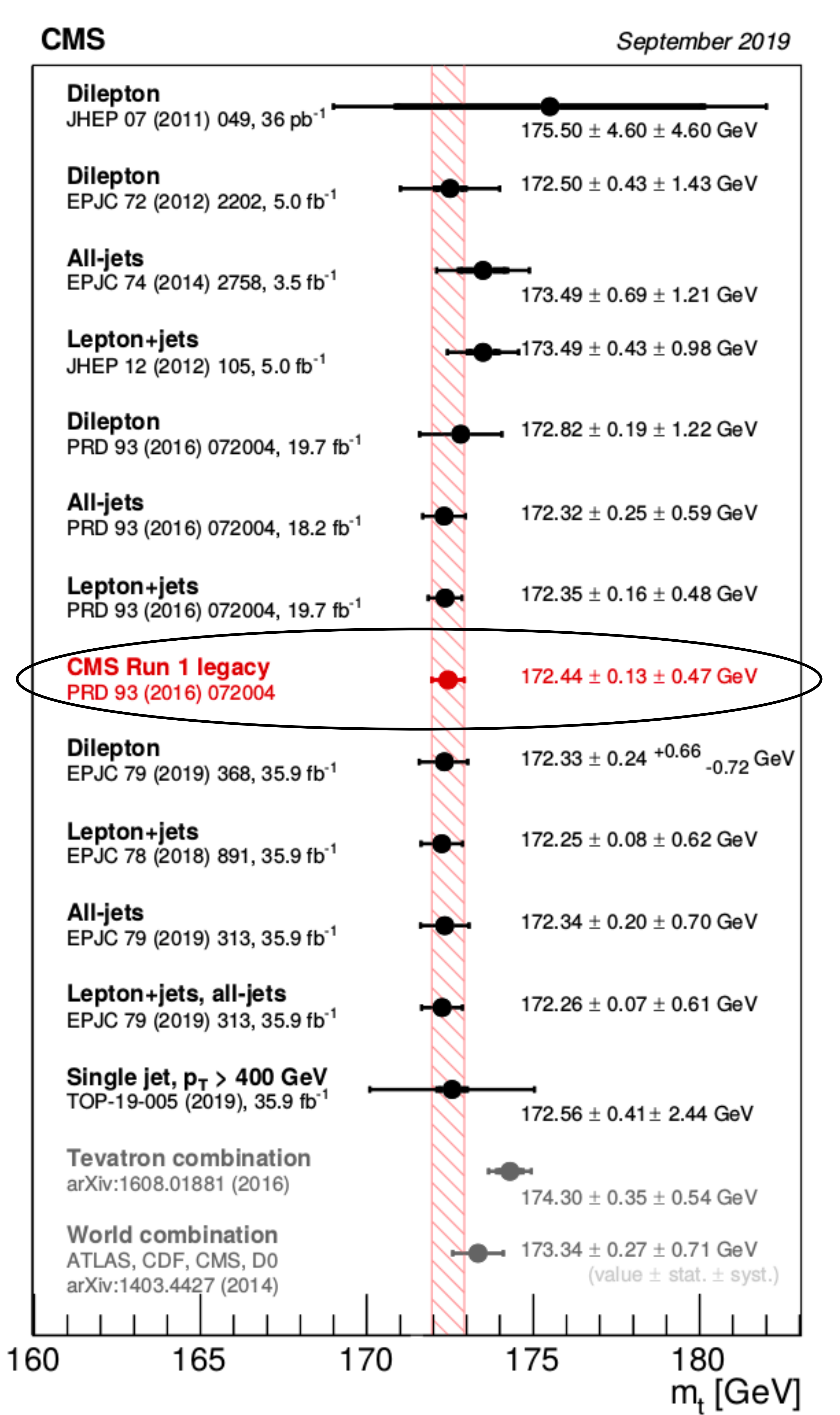
- A fundamental parameter in SM
- A stringent check of the internal consistency of SM
- Required in the evolution of Higgs quartic coupling affecting the Higgs potential stability at high energy scale
- Of course, the top mass is the heaviest particle "so far", why?



JHEP08(2012)098

Top mass measurements

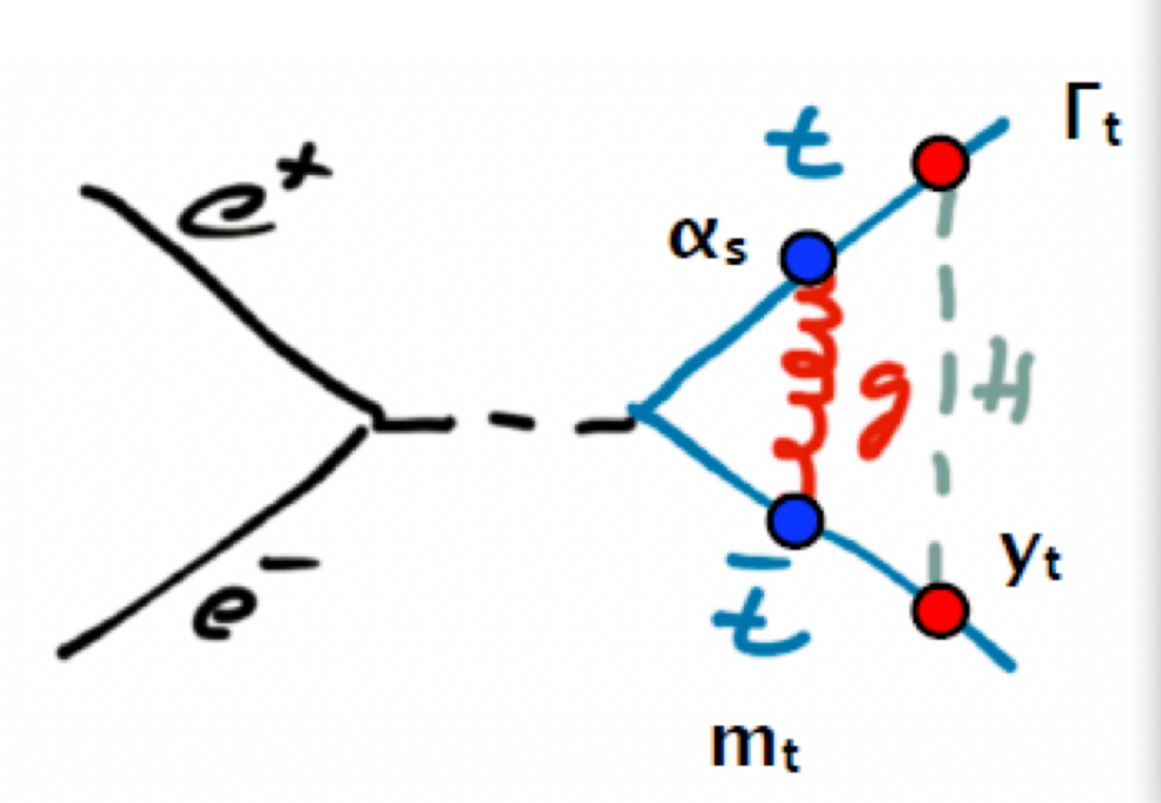
- The top mass is measured using top reconstruction at hadron colliders
  - Heavily relies on the solution of the neutrino and jet energy scale/resolution uncertainties
- CMS Run1 combined uncertainty reached ~500 MeV dominated by systematic uncertainties
- Very difficult to further improve the precision given dominant systematic uncertainties at hadron colliders

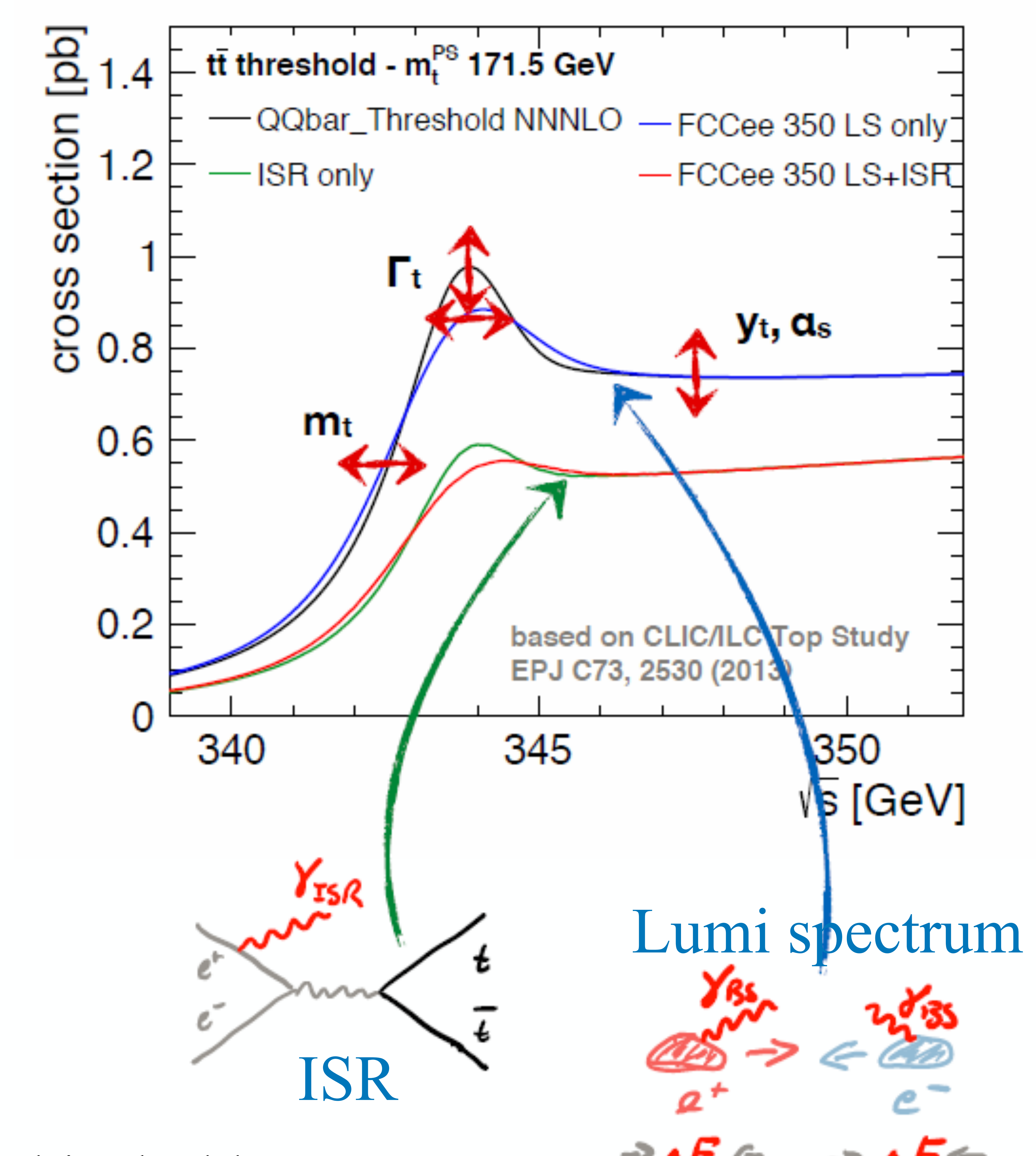


tt threshold scan

- ee-colliders provide not only the top reconstruction method but also the tt threshold scan
- The scan is made against $\sqrt{s}$ and cross-section is the direct observable
- This brings measurements of top mass and a bunch of other parameters
  - Top width
  - Top Yukawa coupling
  - α_S

EPJC 73,(2013)2530

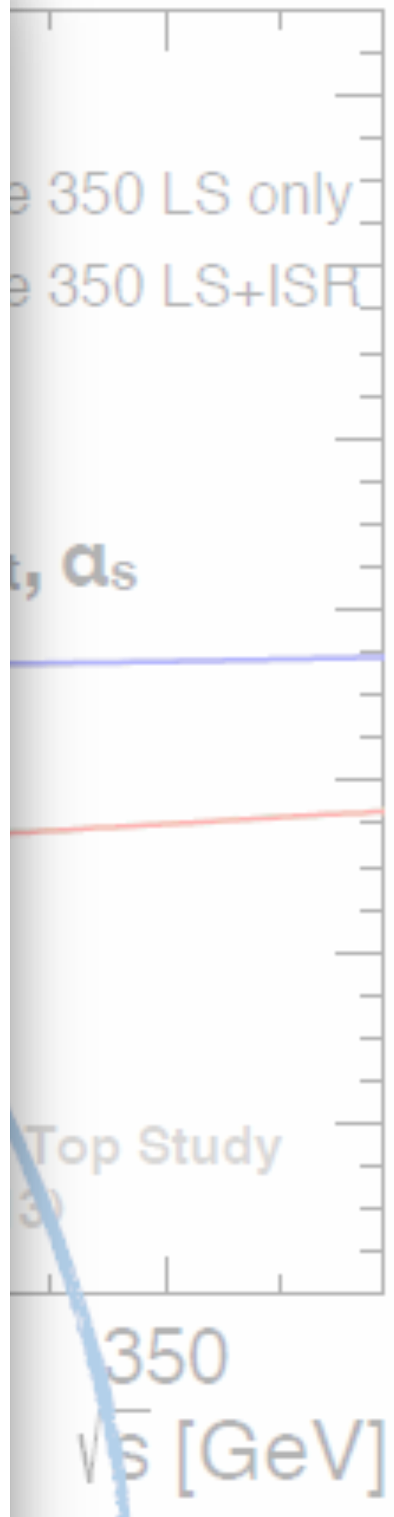




Alain Blondel

tt threshold scan

EPJC 73,(2013)2530



It is expected to measure the top properties using the tt threshold scan with ee-colliders at a precision level of

- ~17 MeV for top mass (stat. uncert.)
- ~45 MeV for top width (stat. uncert.)

Estimated by FCC-ee with 25fb^{-1} taken at each of the 8 centre-of-mass energy points

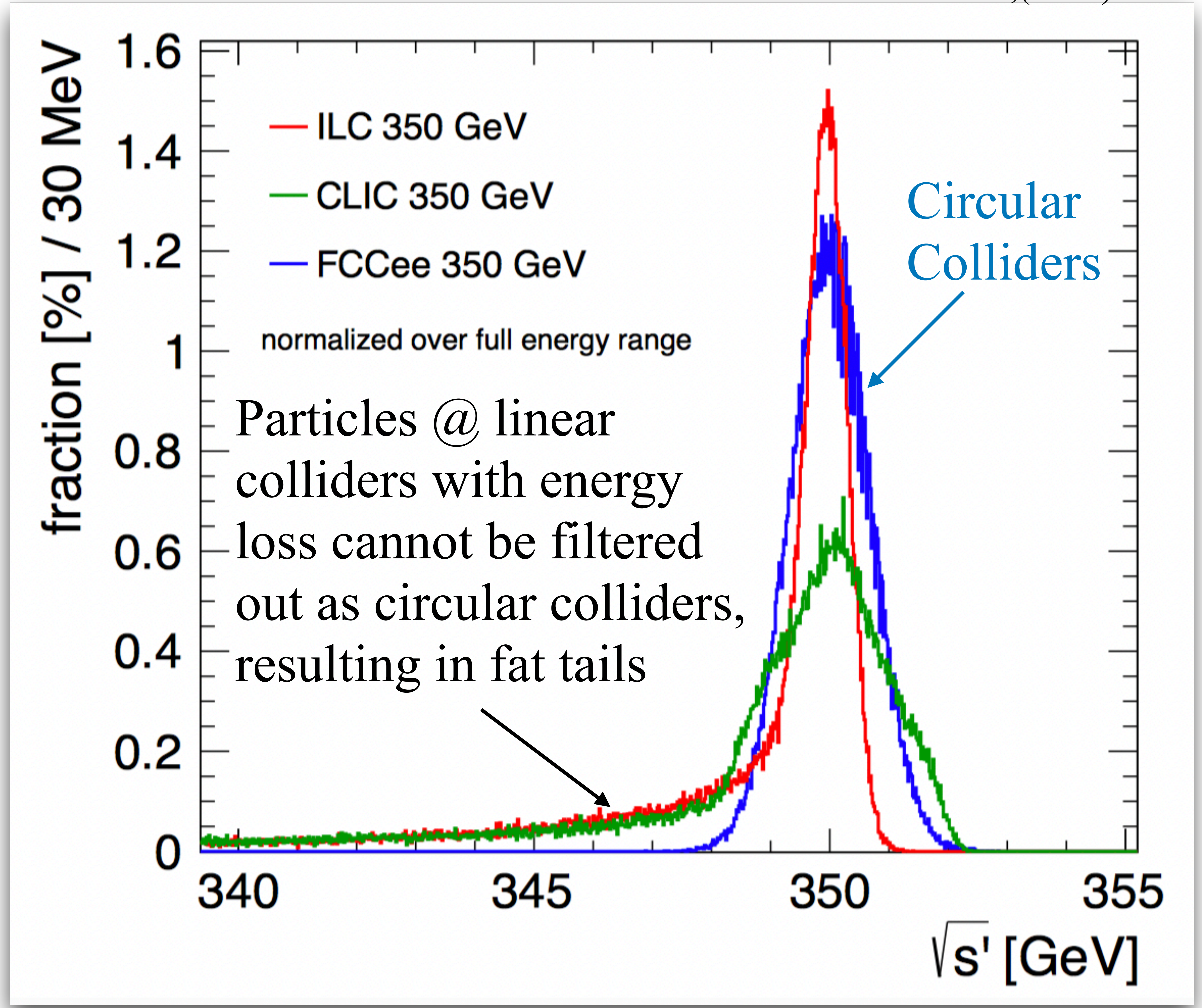
N^3LO cross-section calculation brings 40 MeV uncertainty additionally

Advantages from circular colliders

- The luminosity spectrum at linear colliders is obviously worse than circular colliders given the particles with energy loss not being removed by the bending magnets

- This can substantially change the cross-section curve at around the tt threshold

EPJC 73,(2013)2530



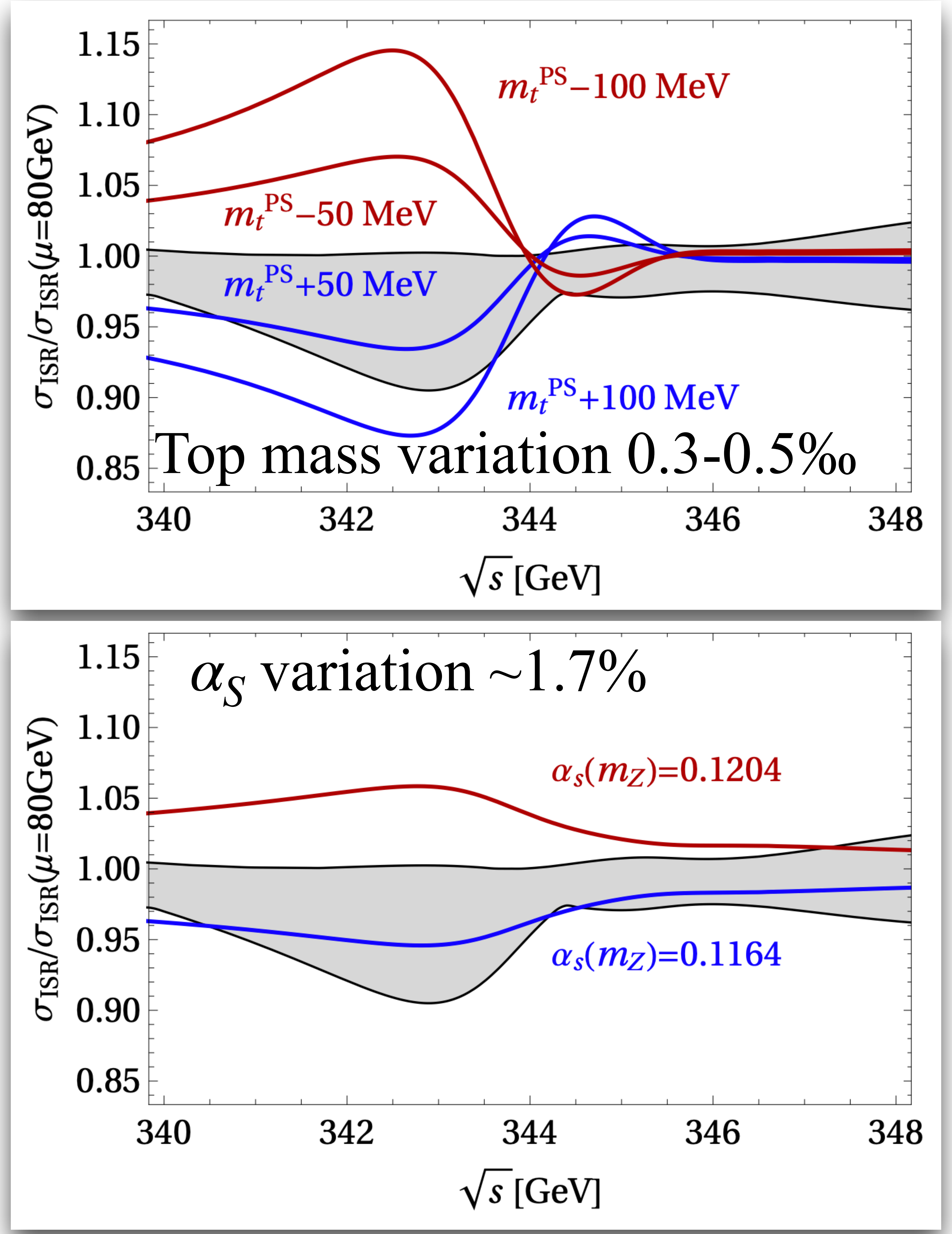
Our setup

Comput. Phys. Commun. 209 (2016) 96-115
JHEP 1802 (2018) 125

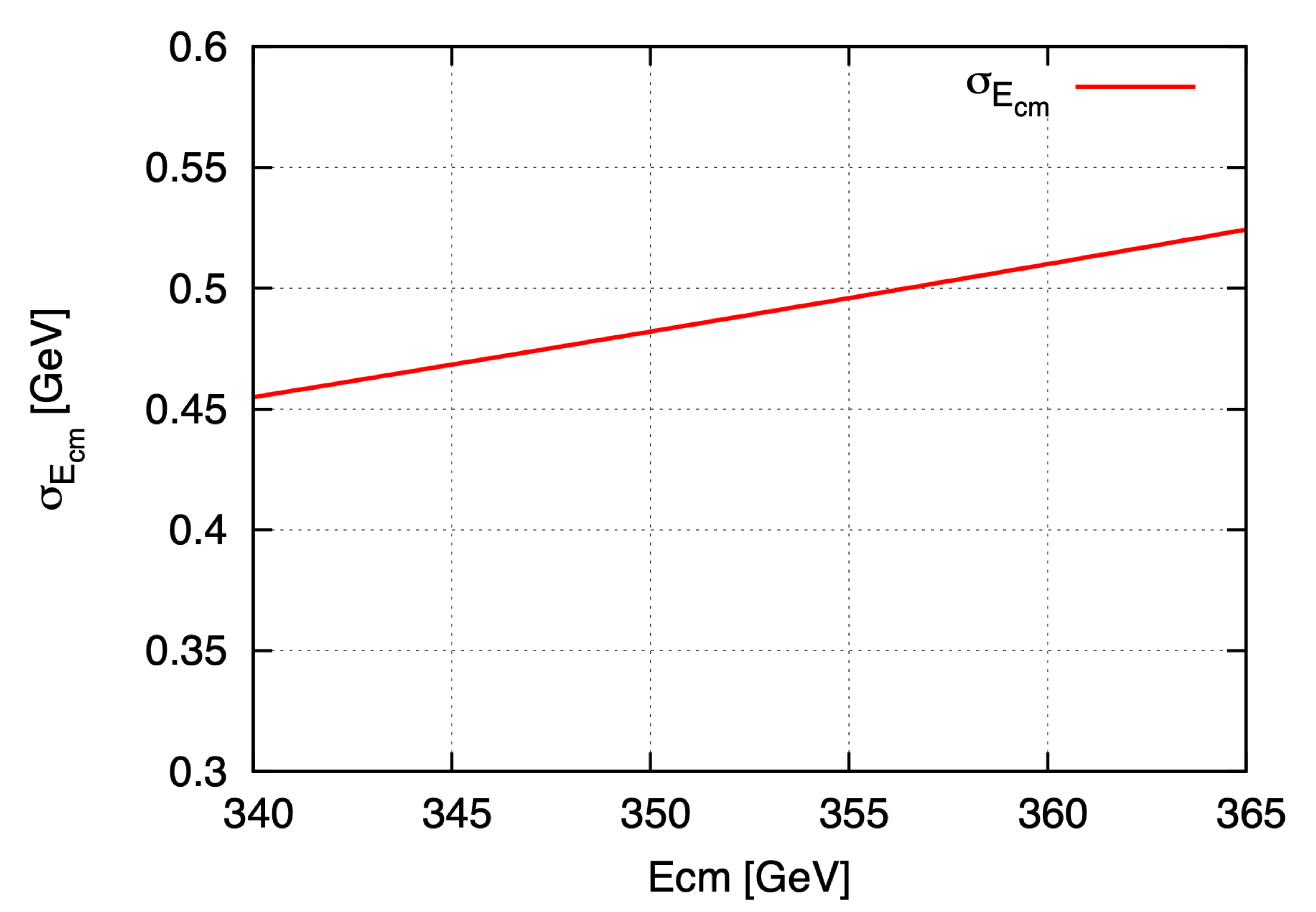
- Use the package "QQbar_threshold" to calculate cross-section near threshold in ee-colliders at N^{3}LO in resummed non-relativistic perturbation theory
  - Coulomb interactions between the quark and the antiquark leading to a strong enhancement of the cross section is included
- To avoid IR renormalon ambiguities, the PS shift (PSS) mass scheme is applied by default in the package

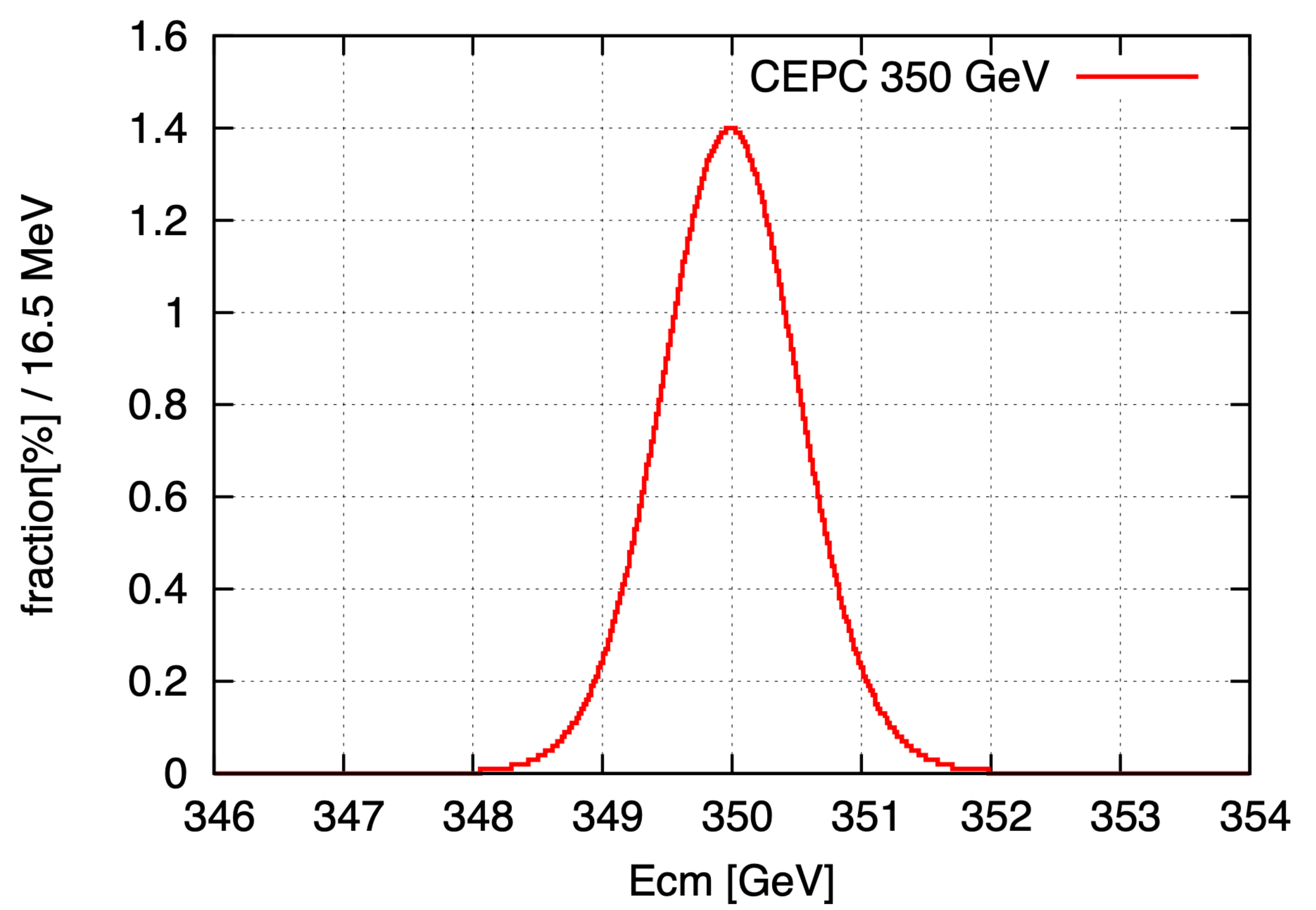
$$m_t^{\mathrm{PS}} = 171.5\,\mathrm{GeV}, \qquad \alpha_s(m_Z) = 0.1184$$

- ISR effects are also included in the package
- We incorporate luminosity spectrum by a simple Gaussian function with 1 GeV as the energy resolution at the moment



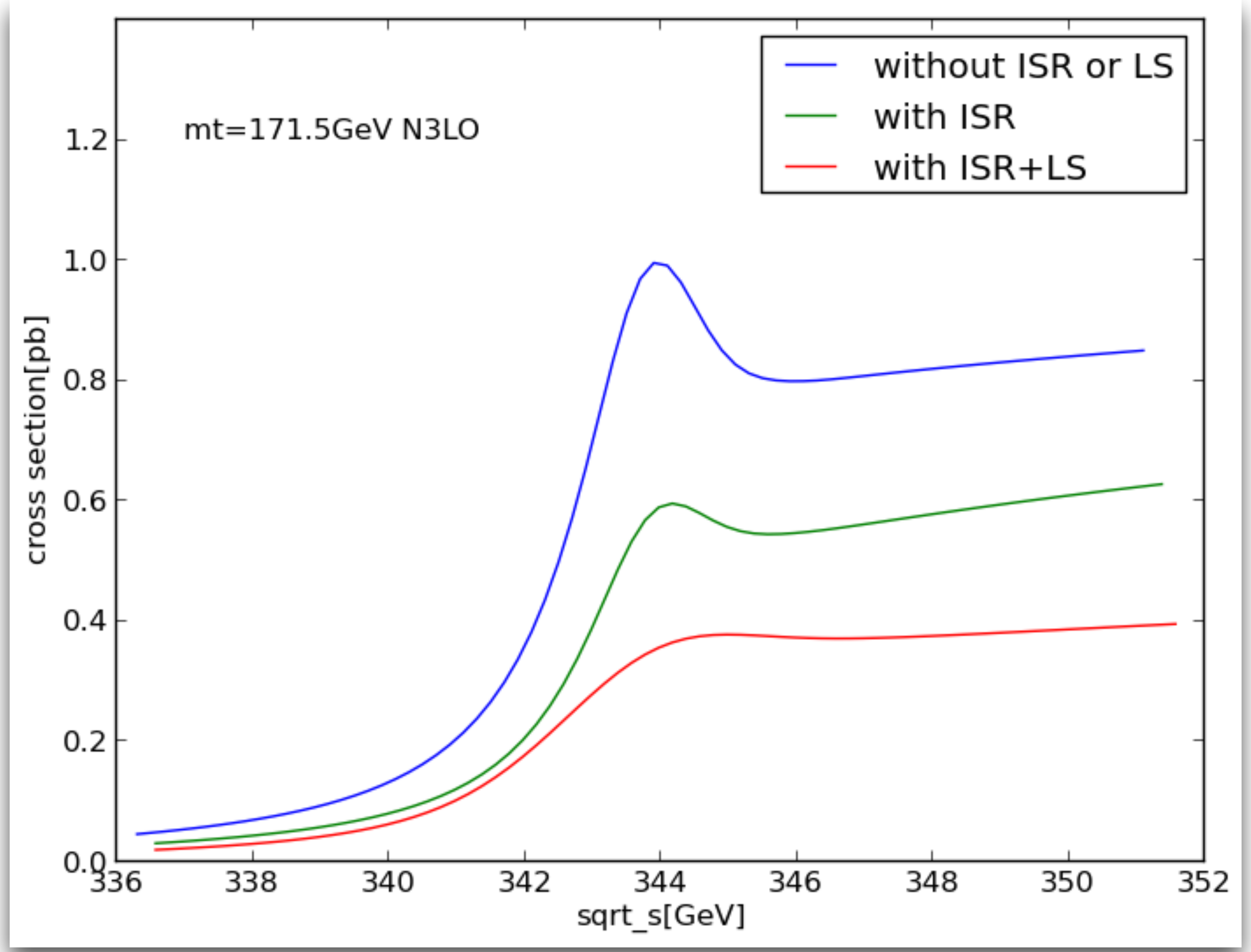
Luminosity spectrum @ CEPC





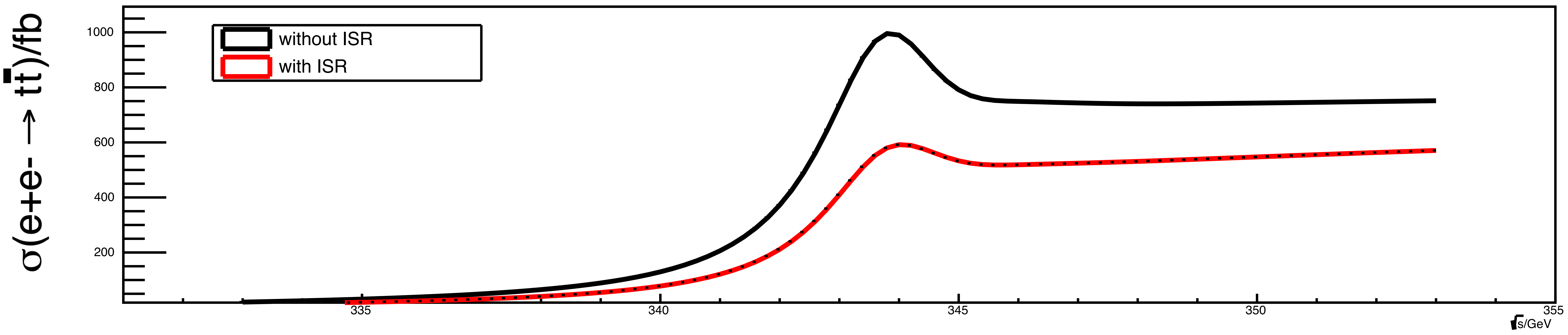
- The beam energy resolution increases as a function of $\sqrt{s}$
- The luminosity spectrum is shown for $\sqrt{s} = 350$ GeV with a width of ~480 MeV

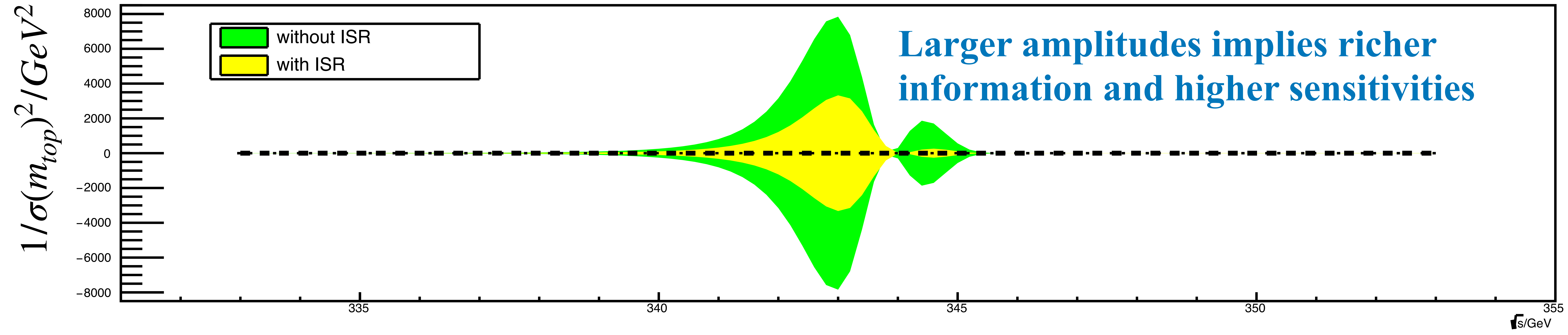
ISR and LS effects



- The cross section as a function of centre-of-mass energy
  - A clear peak of production can be seen at around the tt threshold
  - Adding ISR and LS (1 GeV width), the position of peak is hardly affected, but the sharpness is weakened and the total rate is suppressed in this region

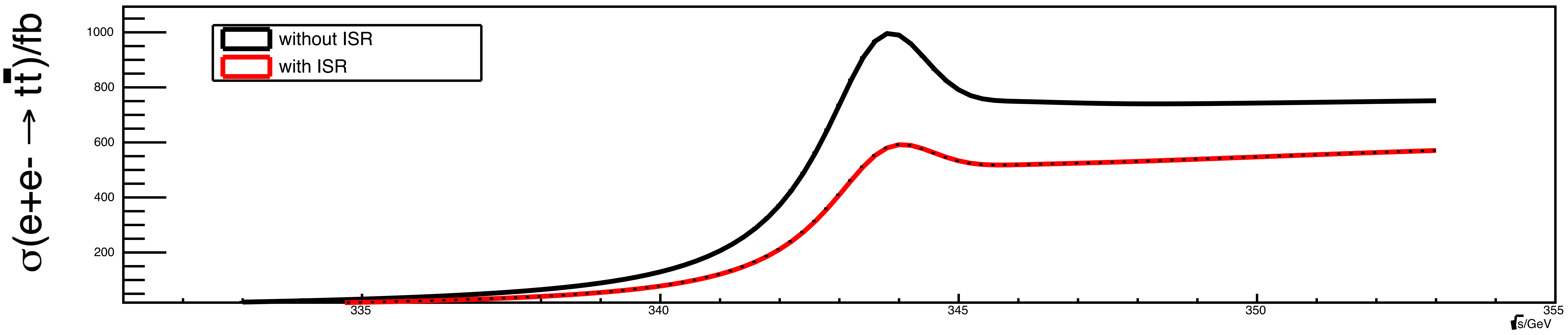
Fisher information

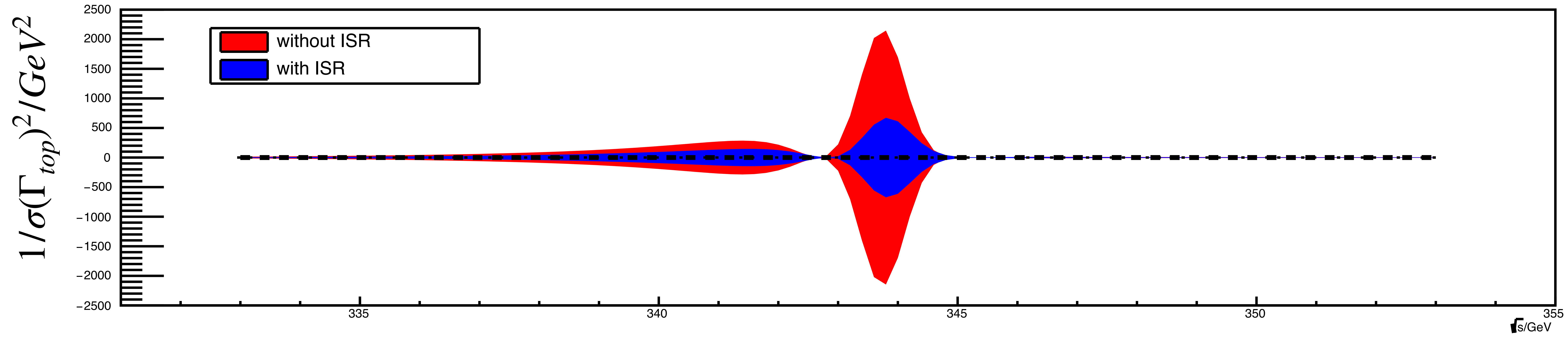




Larger amplitudes implies richer information and higher sensitivities

Fisher information





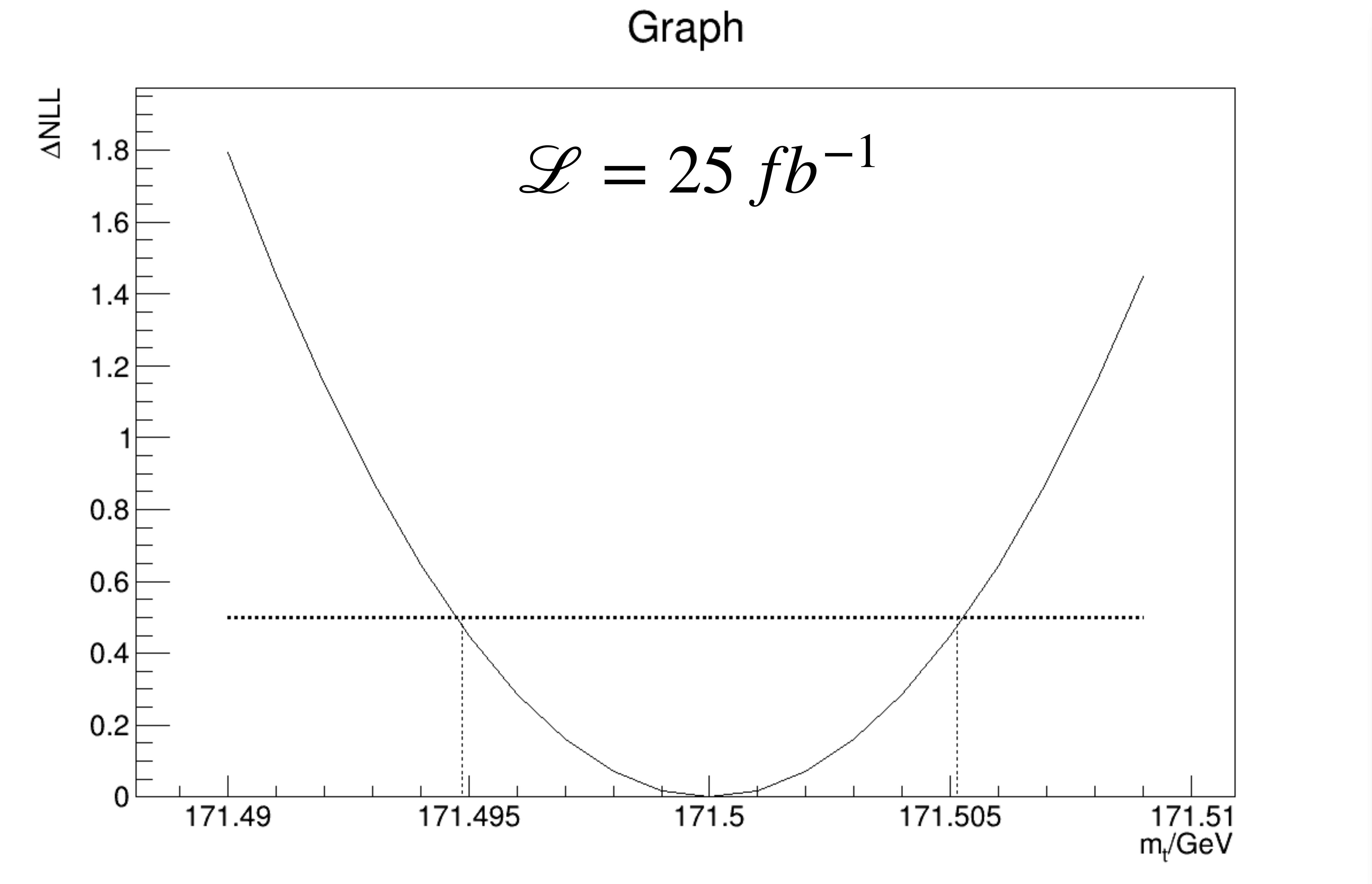
$\sqrt{s}$ scans

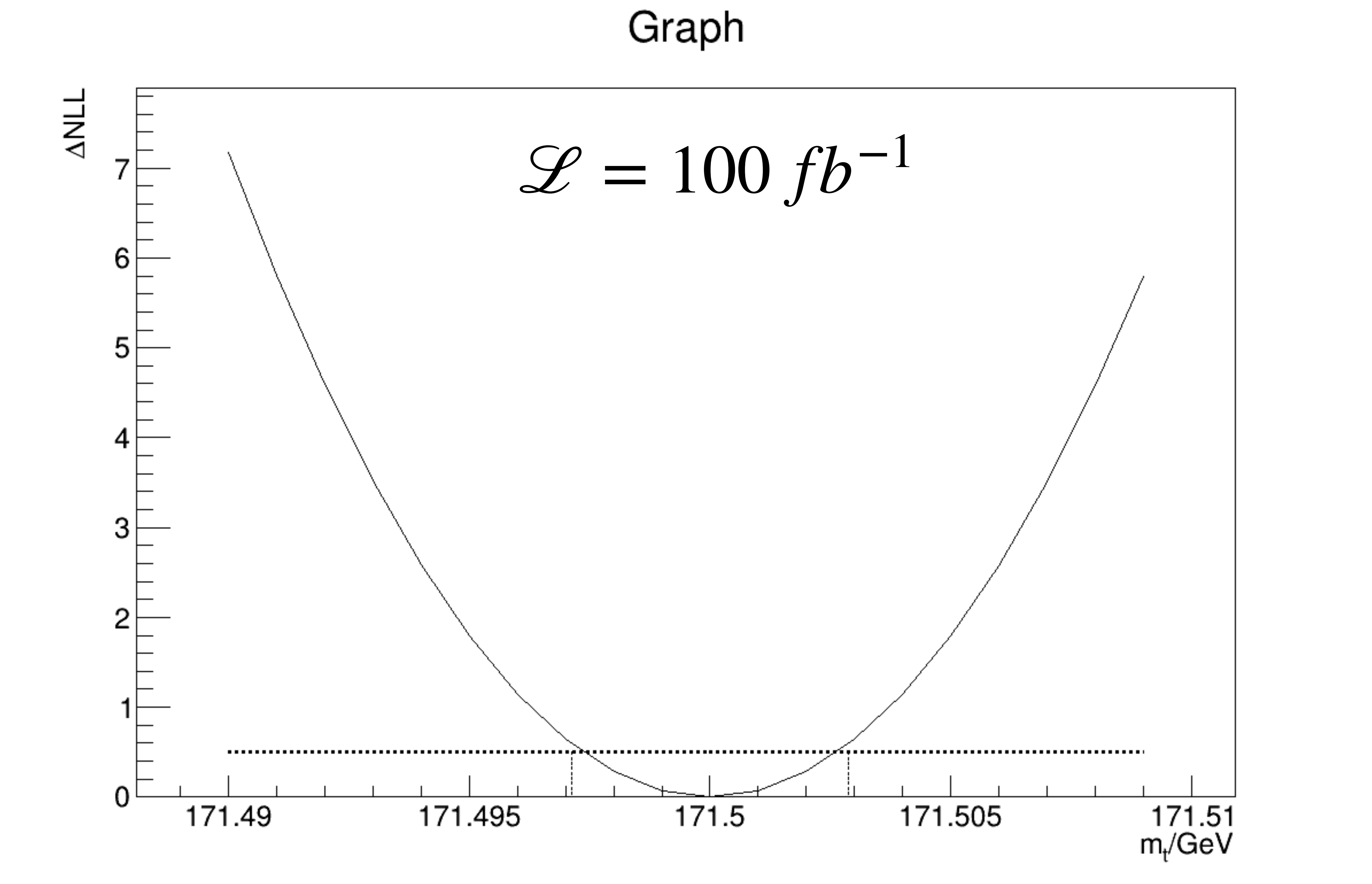
- Test with a series of centre-of-mass energy grids
  - 4-$\sqrt{s}$ scheme = {341.5,342.5,343,344.5} GeV
  - 6-$\sqrt{s}$ scheme = {341,342,342.5,343,343.5,344.5} GeV
  - 8-$\sqrt{s}$ scheme = {340,341,342,342.5,343,343.5,344.5,345} GeV
- Top mass is assumed as 171.5 GeV; the acceptance and efficiency is assumed to be 100% at the moment; ISR is considered; but LS is yet to be included
- Luminosity per scan point is assumed to range from 25/fb to 100/fb
- A likelihood is constructed to combine the statistical power of all scan points

$$L = \prod_i P(\vec{D}_i \mid \vec{E}_i(\sigma(m_{top}, \Gamma_{top}, \alpha_S, \sqrt{s}), \mathscr{L}_i, \vec{\theta}))$$

i corresponds to the i-th $\sqrt{s}$ scan point

4-$\sqrt{s}$ scheme

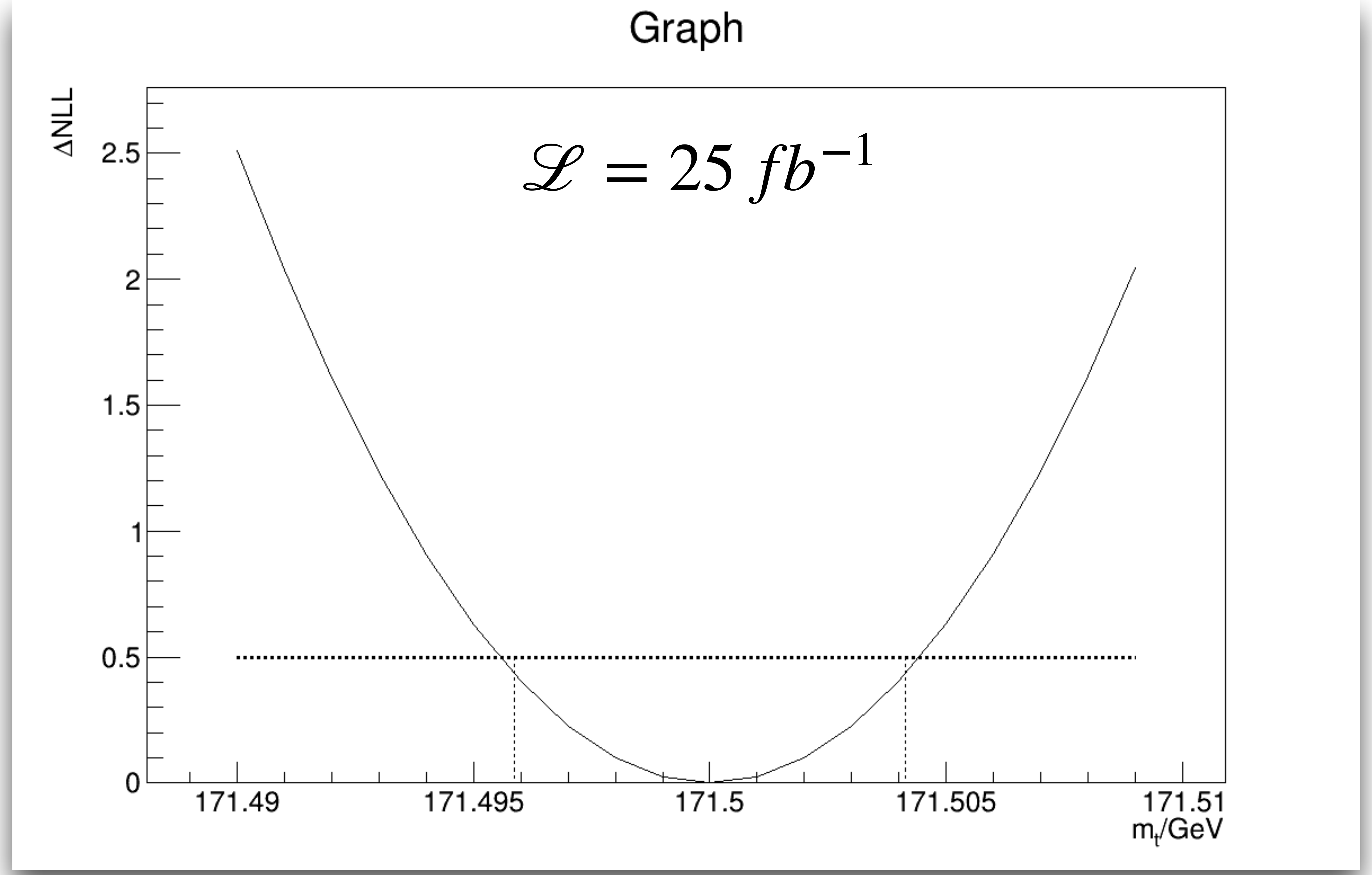


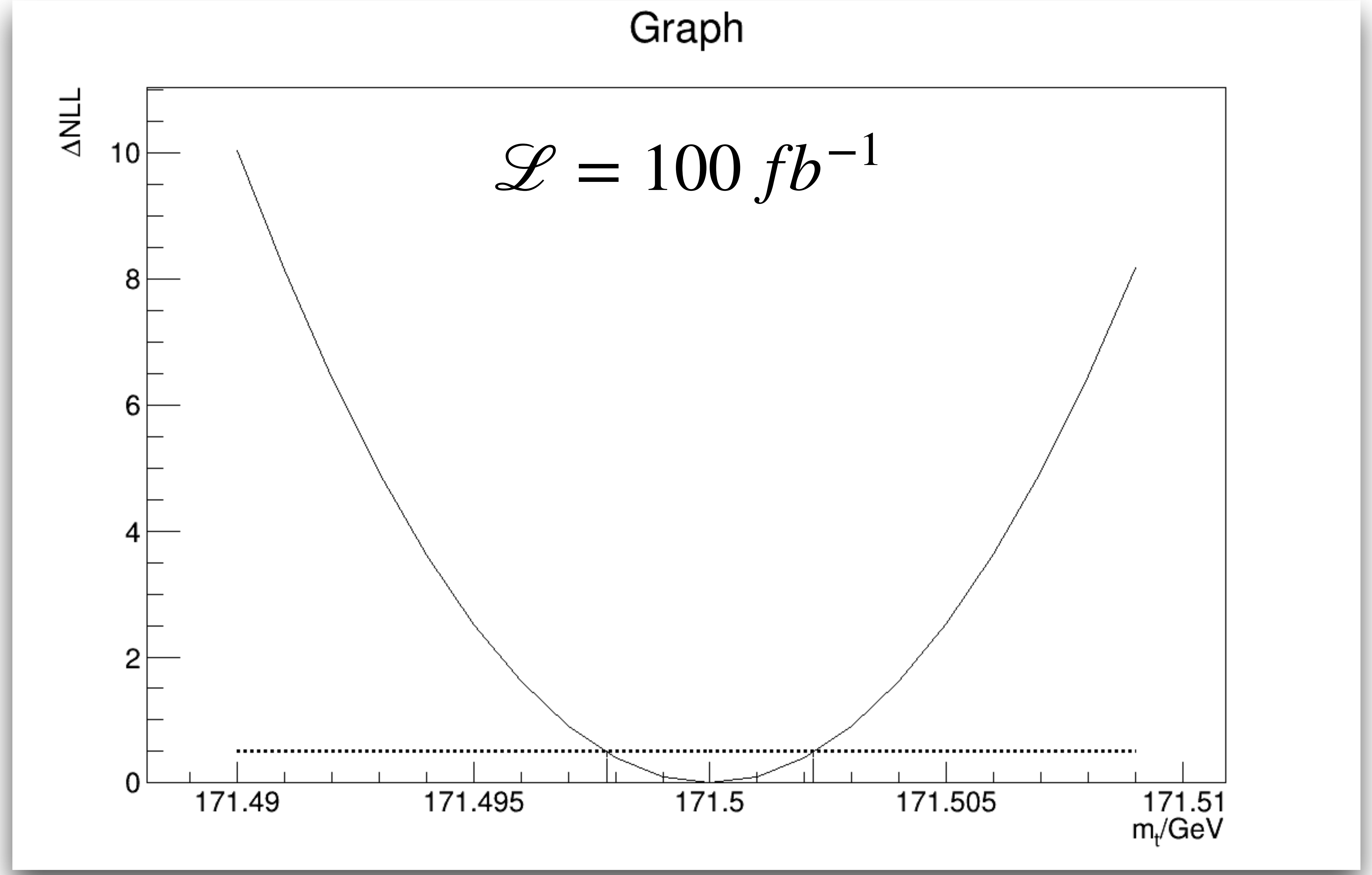


$\sigma(m_{top}) = 5.1$ MeV

$\sigma(m_{top}) = 2.9$ MeV

6-$\sqrt{s}$ scheme

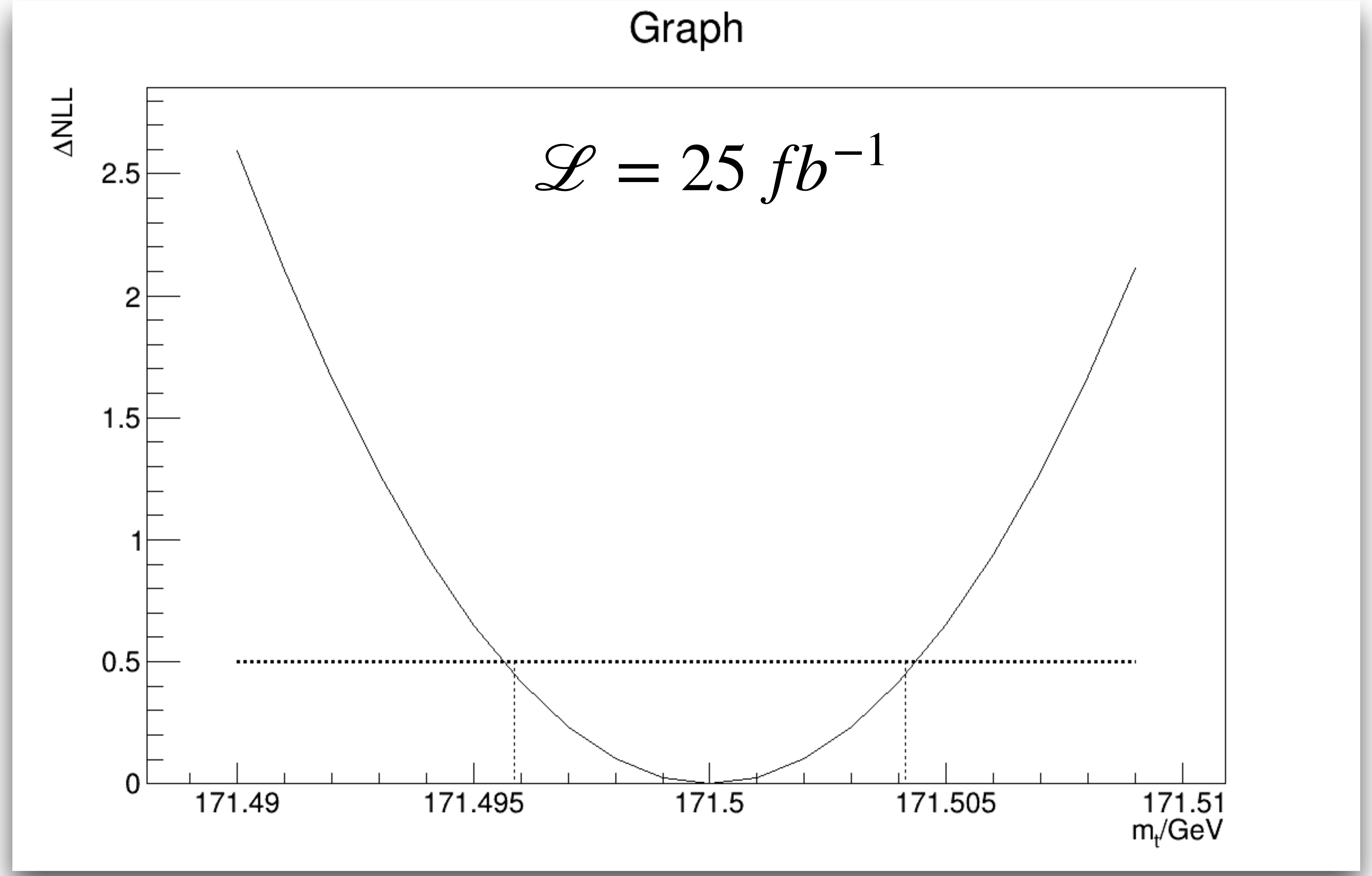


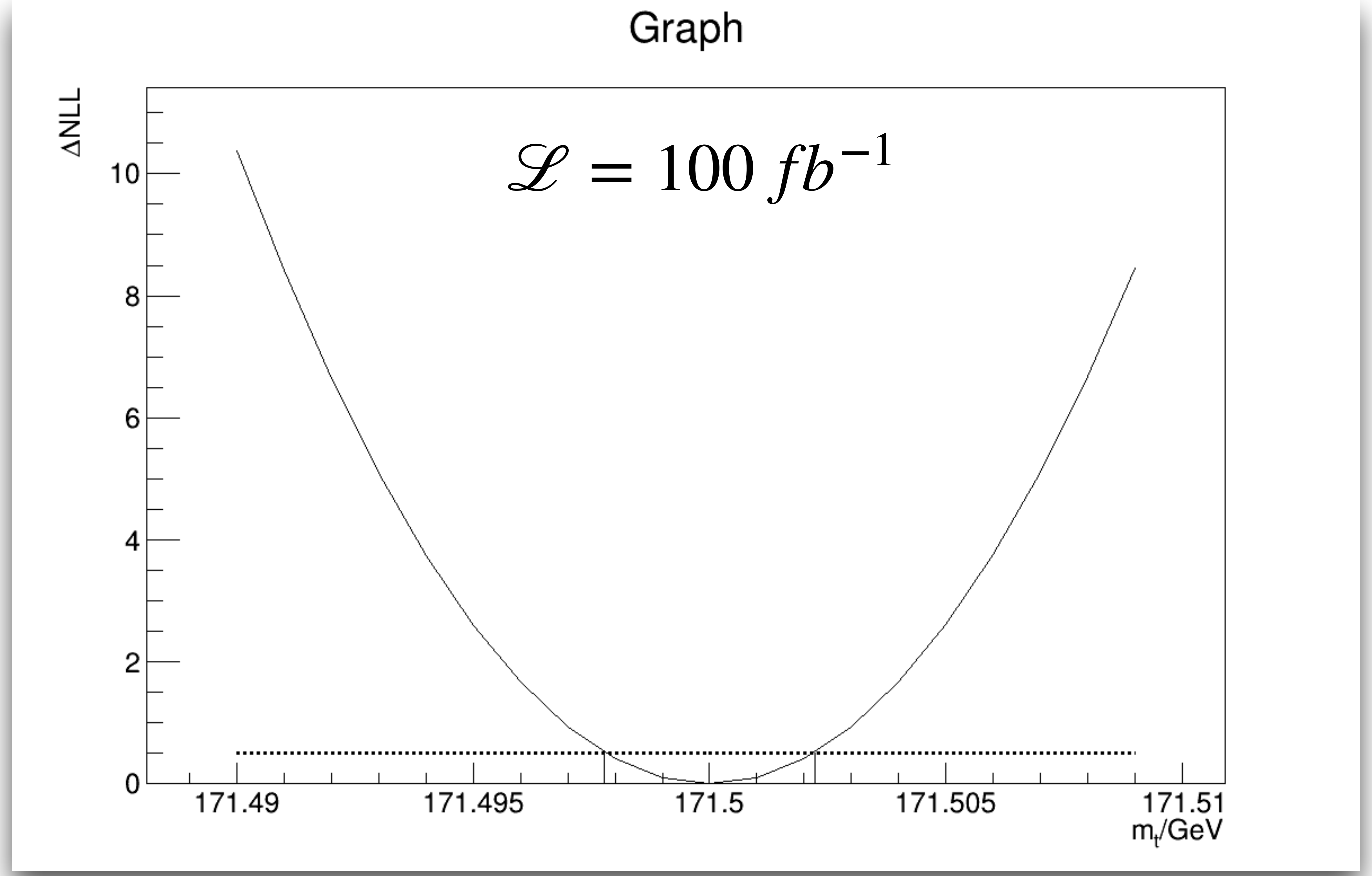


$\sigma(m_{top}) = 4.1$ MeV

$\sigma(m_{top}) = 2.2$ MeV

8-$\sqrt{s}$ scheme



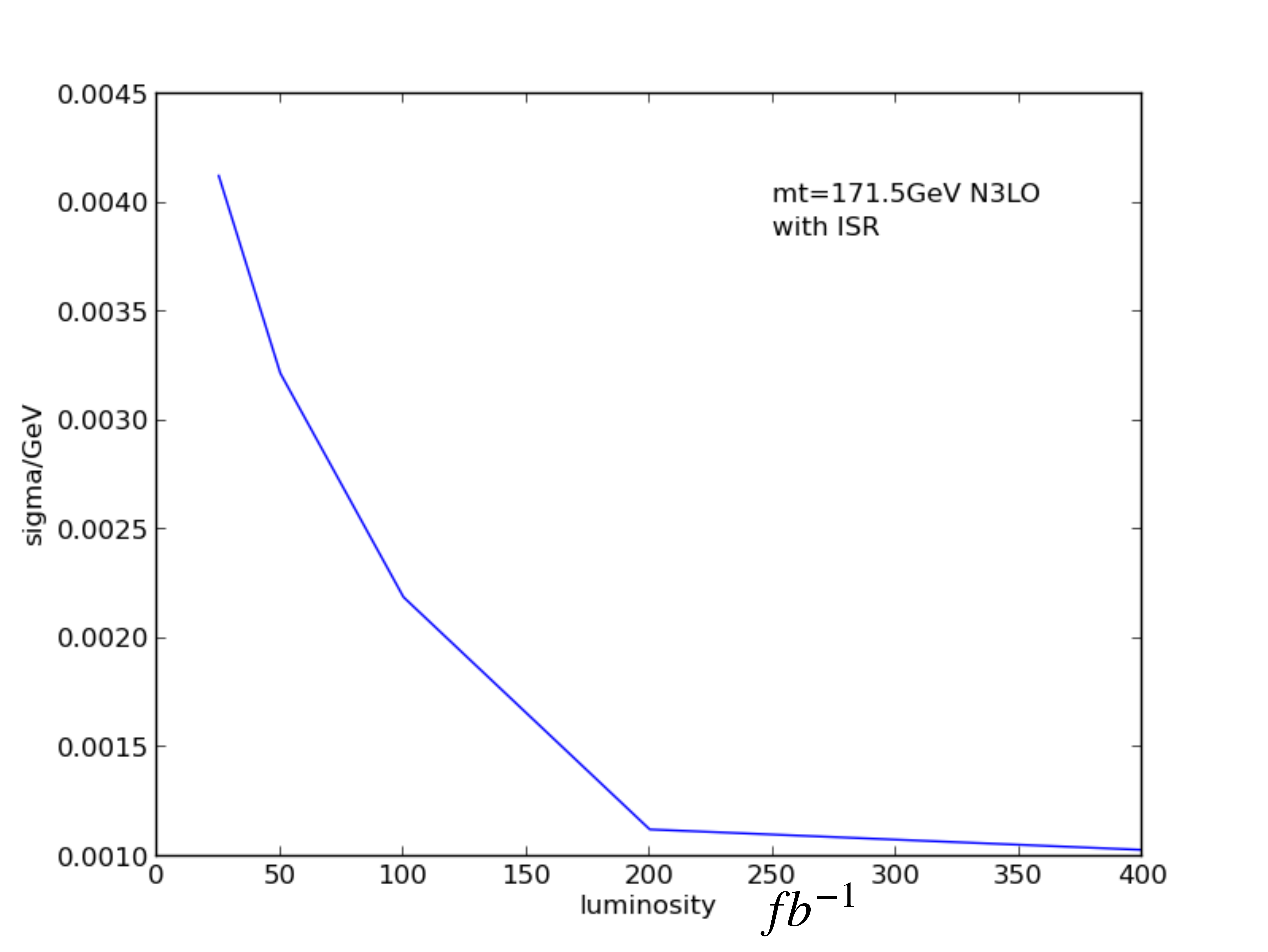


$\sigma(m_{top}) = 4.1$ MeV

$\sigma(m_{top}) = 2.2$ MeV

More lumi

- 6-$\sqrt{s}$ scheme performs better than 4-$\sqrt{s}$ and 8-$\sqrt{s}$ does not improve significantly
  - So pick 6-$\sqrt{s}$ scheme ⟶
- More luminosity assumptions are tested with this scheme
- Keep in mind, there are several ideal assumptions: no LS, ideal acceptance, and no systematics yet
- But relatively one can learn the gain in the top mass uncertainty as lumi increases



Summary

- Many opportunities of top property measurements @ CEPC
- Top mass can be measured with a precision 1 order of magnitude better than hadron colliders at the moment
- Top width, α_S can also be simultaneously measured
- This talk summarizes the **recent progresses of the CEPC top mass team**
  - Extract information in the cross-section curve at the tt threshold
  - Construct 1D likelihood to make scan to estimate measurement uncertainties
  - Preliminary tests with a few proposals of luminosities and energies

Backup

	δm_t^{hyb} [GeV]		
	all-jets	ℓ+jets	combination
Experimental uncertainties			
Method calibration	0.06	0.05	0.03
JEC (quad. sum)	0.15	0.18	0.17
– Intercalibration	−0.04	+0.04	+0.04
– MPFInSitu	+0.08	+0.07	+0.07
– Uncorrelated	+0.12	+0.16	+0.15
Jet energy resolution	−0.04	−0.12	−0.10
b tagging	0.02	0.03	0.02
Pileup	−0.04	−0.05	−0.05
All-jets background	0.07	–	0.01
All-jets trigger	+0.02	–	+0.01
ℓ+jets background	–	+0.02	−0.01
Modeling uncertainties			
JEC flavor (linear sum)	−0.34	−0.39	−0.37
– light quarks (uds)	+0.07	+0.06	+0.07
– charm	+0.02	+0.01	+0.02
– bottom	−0.29	−0.32	−0.31
– gluon	−0.13	−0.15	−0.15
b jet modeling (quad. sum)	0.09	0.12	0.06
– b frag. Bowler–Lund	−0.07	−0.05	−0.05
– b frag. Peterson	−0.05	+0.04	−0.02
– semileptonic b hadron decays	−0.03	+0.10	−0.04
PDF	0.01	0.02	0.01
Ren. and fact. scales	0.04	0.01	0.01
ME/PS matching	+0.24	−0.07	+0.07
ME generator	–	+0.20	+0.21
ISR PS scale	+0.14	+0.07	+0.07
FSR PS scale	+0.18	+0.13	+0.12
Top quark p_T	+0.03	−0.01	−0.01
Underlying event	+0.17	−0.07	−0.06
Early resonance decays	+0.24	−0.07	−0.07
CR modeling (max. shift)	−0.36	+0.31	+0.33
– "gluon move" (ERD on)	+0.32	+0.31	+0.33
– "QCD inspired" (ERD on)	−0.36	−0.13	−0.14
Total systematic	0.70	0.62	0.61
Statistical (expected)	0.20	0.08	0.07
Total (expected)	0.72	0.63	0.61

CMS top mass
Eur. Phys. J. C 79 (2019) 313