Effect of the Luminosity Spectrum of the 380 GeV Machine on a Top Threshold Scan

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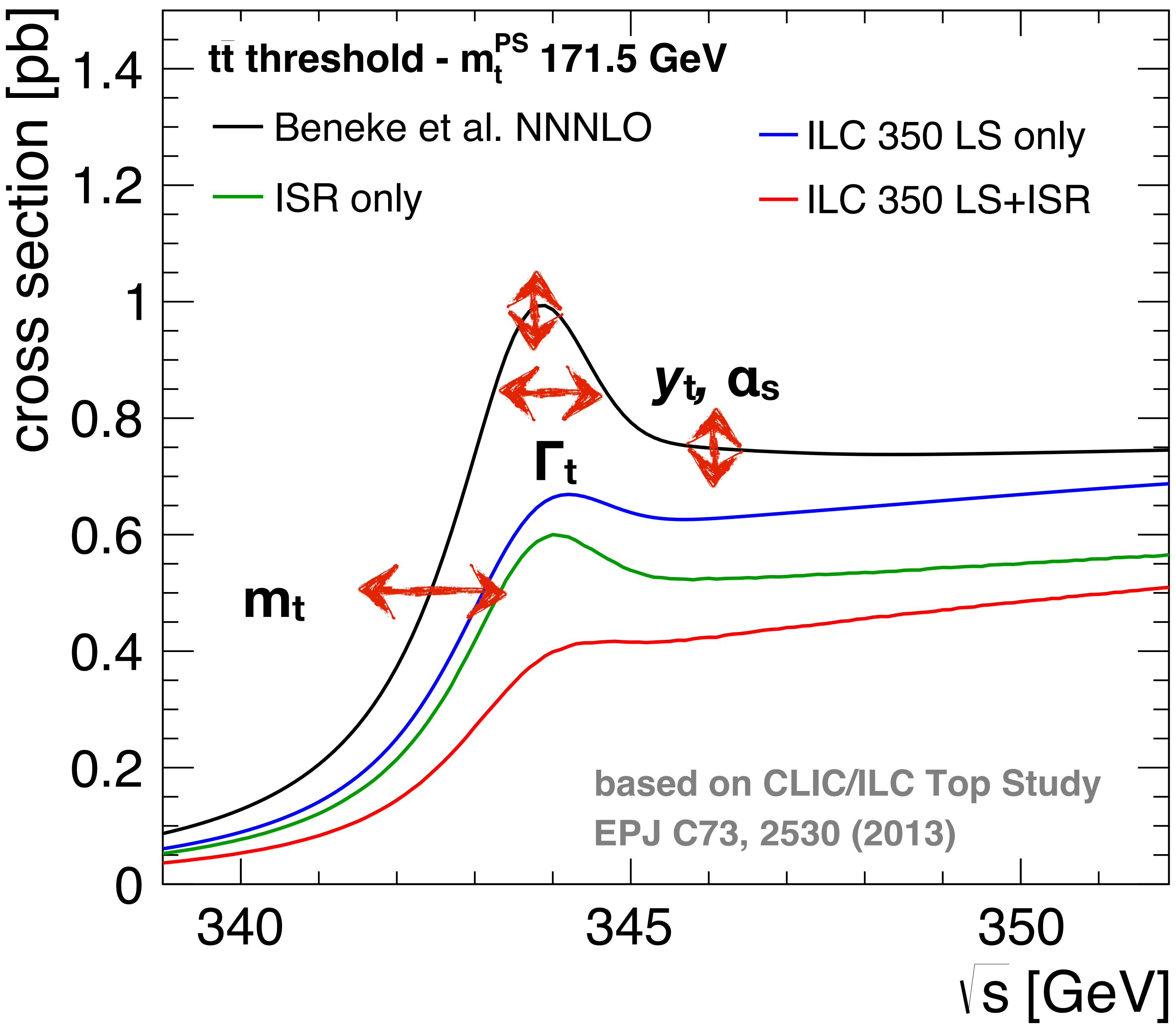
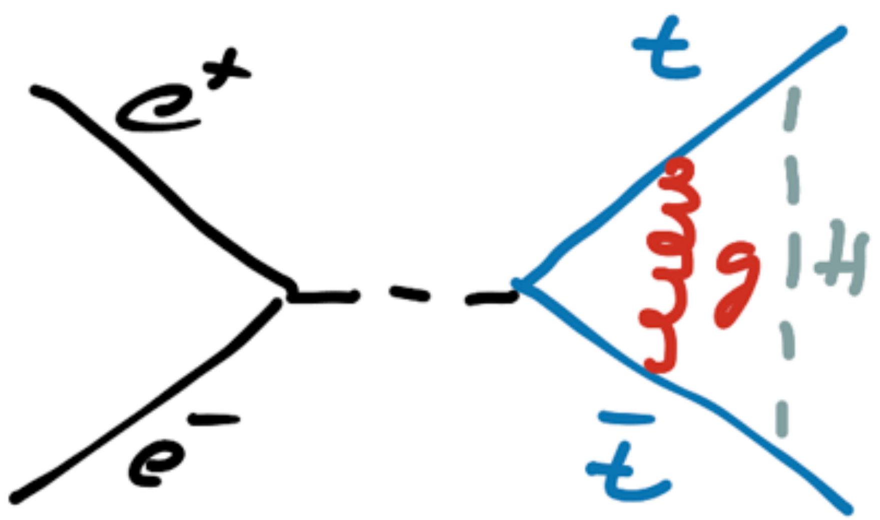
Outline

- Brief Motivation
- The CLIC Luminosity Spectrum at the Top Threshold
- Projected Uncertainties on
  - Mass
  - 2D Extraction of Mass & With, Mass & Yukawa Coupling
- Theory Systematics & Parametric Uncertainties
- Summary

Introduction: Top Threshold Scan



- The cross-section around the threshold is affected by several properties of the top quark and by QCD
  - Top mass, width, Yukawa coupling
  - Strong coupling constant



- Effects of some parameters are correlated; dependence on Yukawa coupling rather weak - precise external α_s helps

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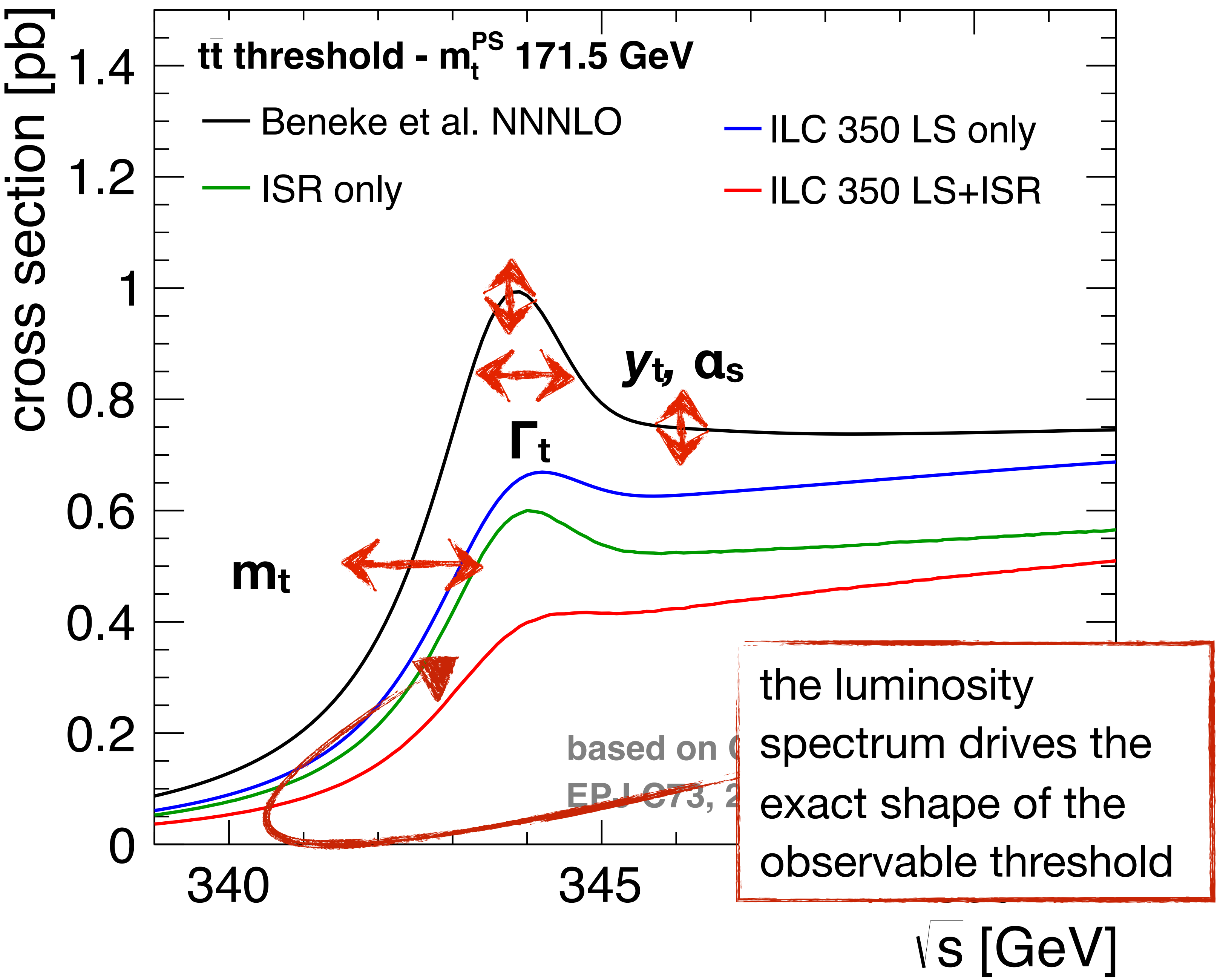

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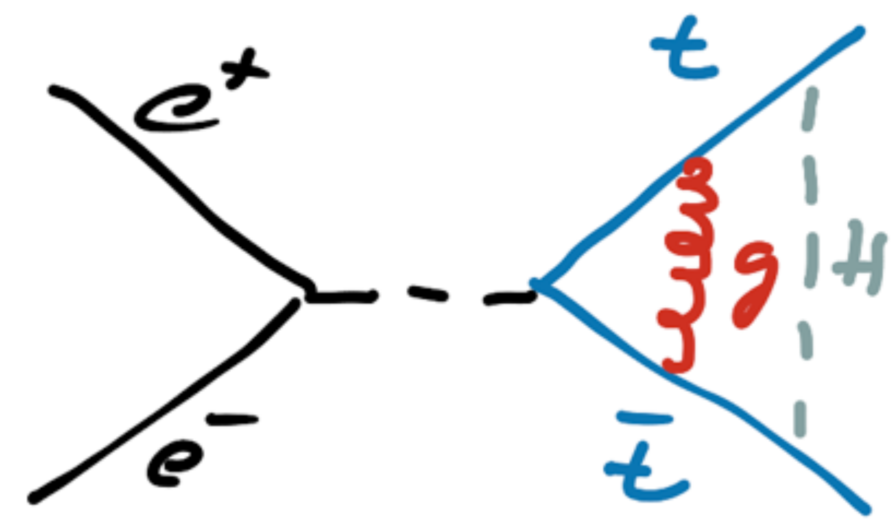

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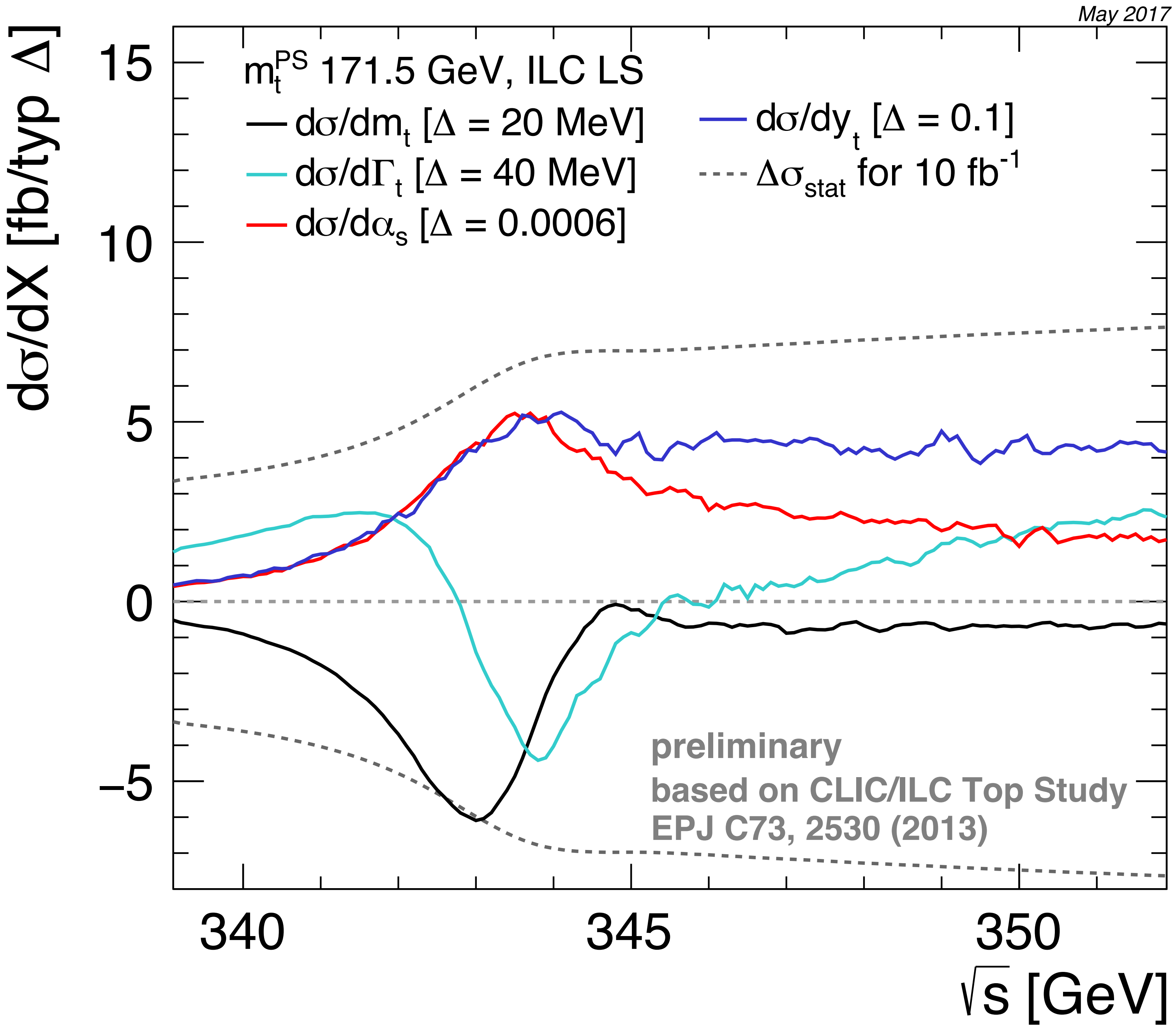

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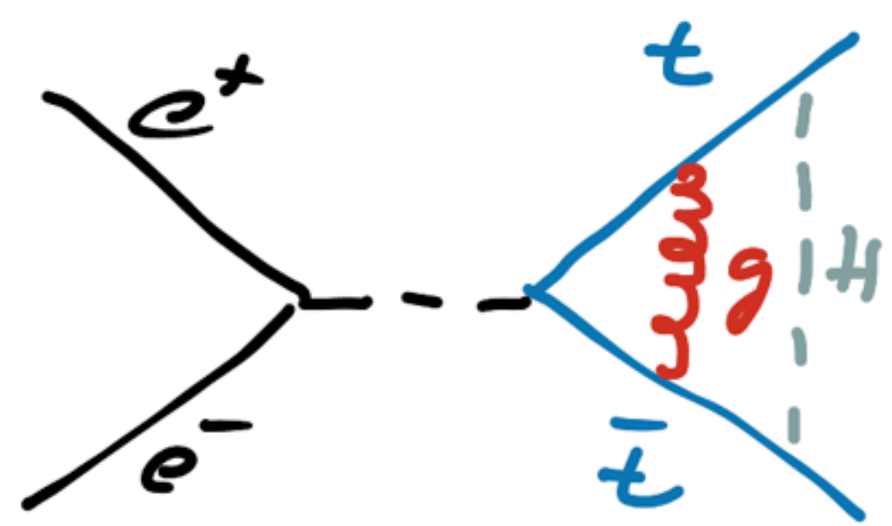

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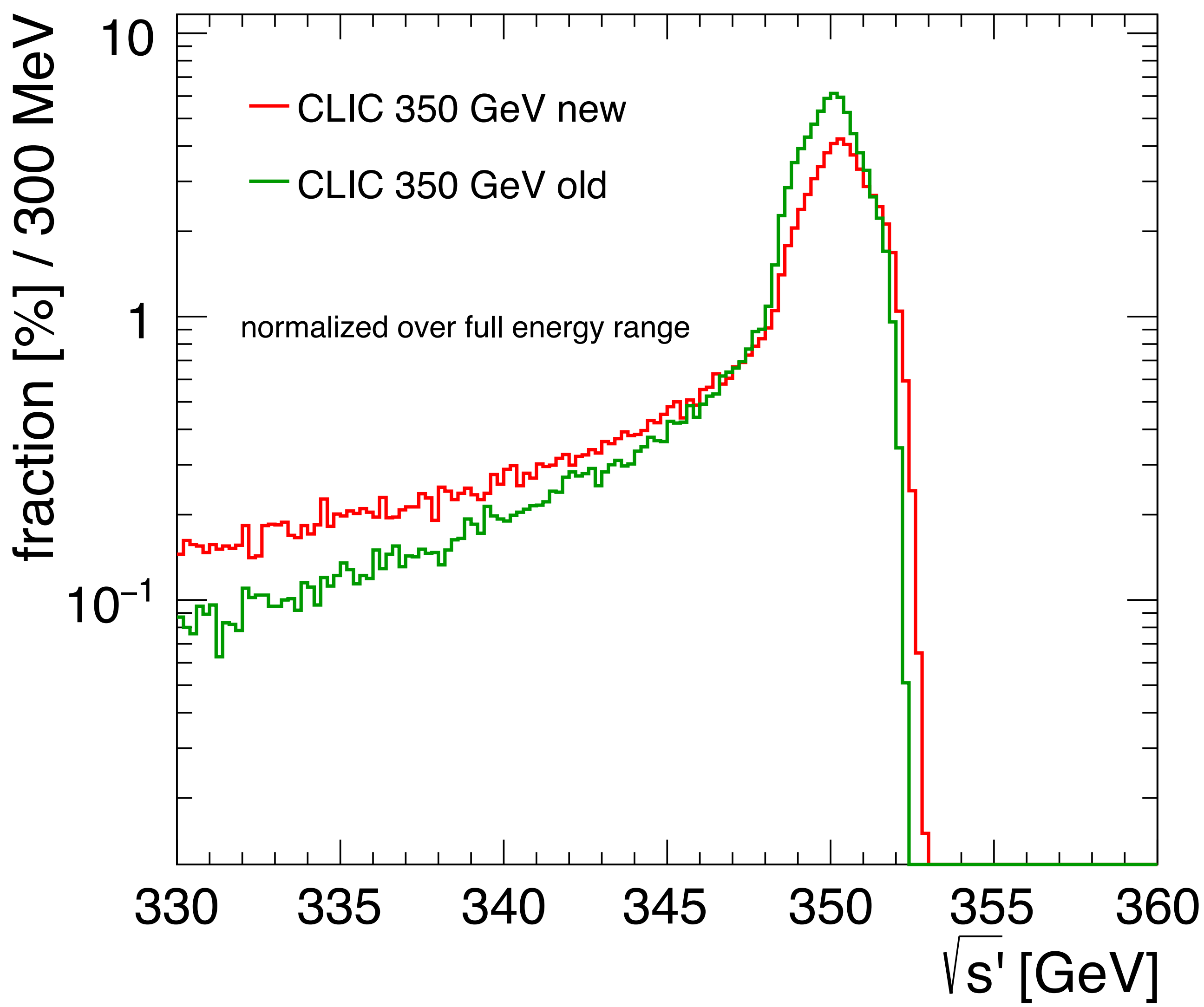
The “new” Luminosity Spectrum

- With the new CLIC stage 1 baseline at 380 GeV the luminosity spectrum for a threshold scan also changes:
  - Machine optimised for luminosity at 380 GeV - (essentially) the same level of beamstrahlung at 350 GeV, compared to much reduced beamstrahlung when running a 500 GeV machine at 350 GeV



For a nominal energy of 350 GeV:

- 76.1% of all events are above 347 GeV for the 500 GeV Machine
- 59.4% of all events are above 347 GeV for the 380 GeV Machine

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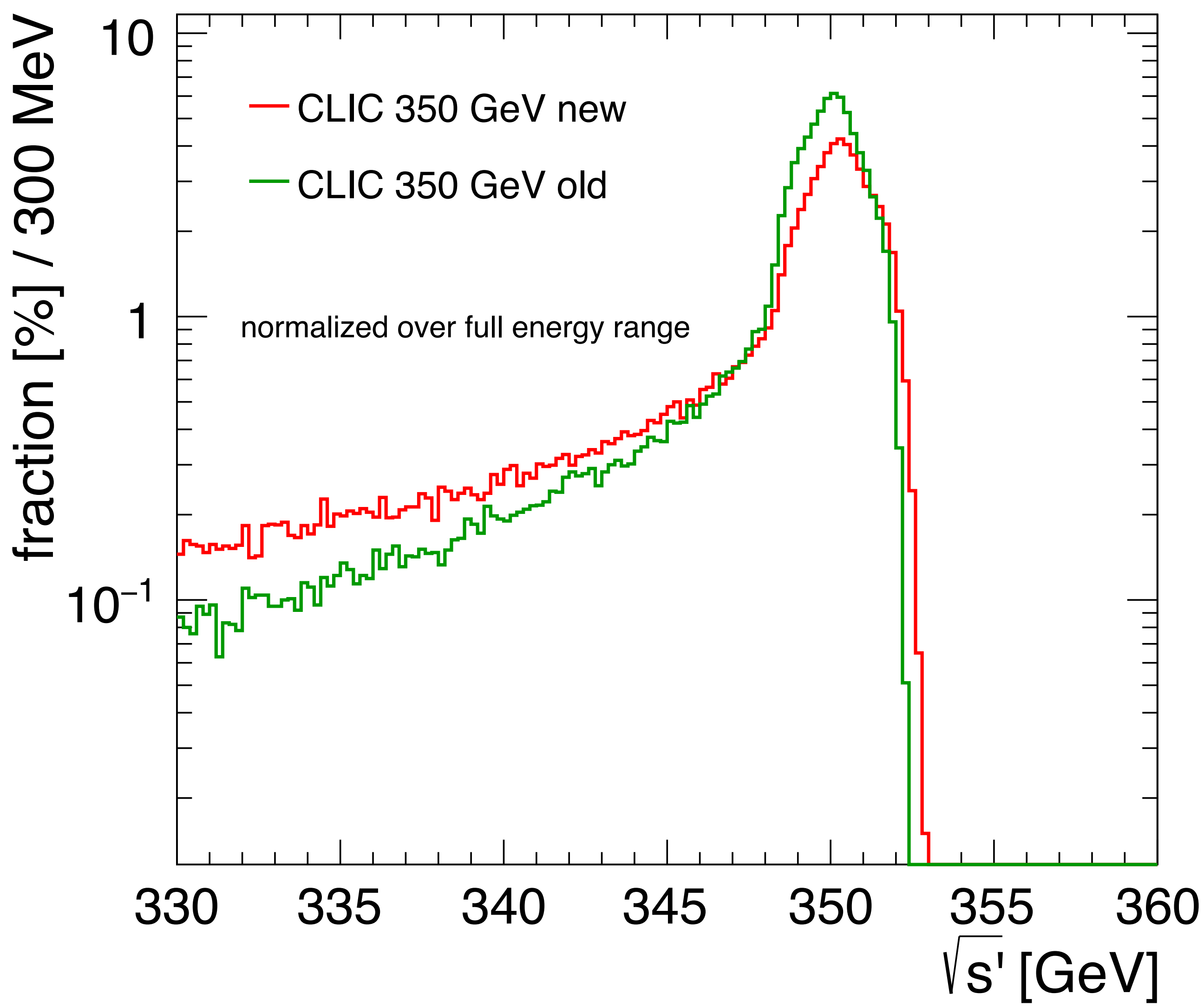


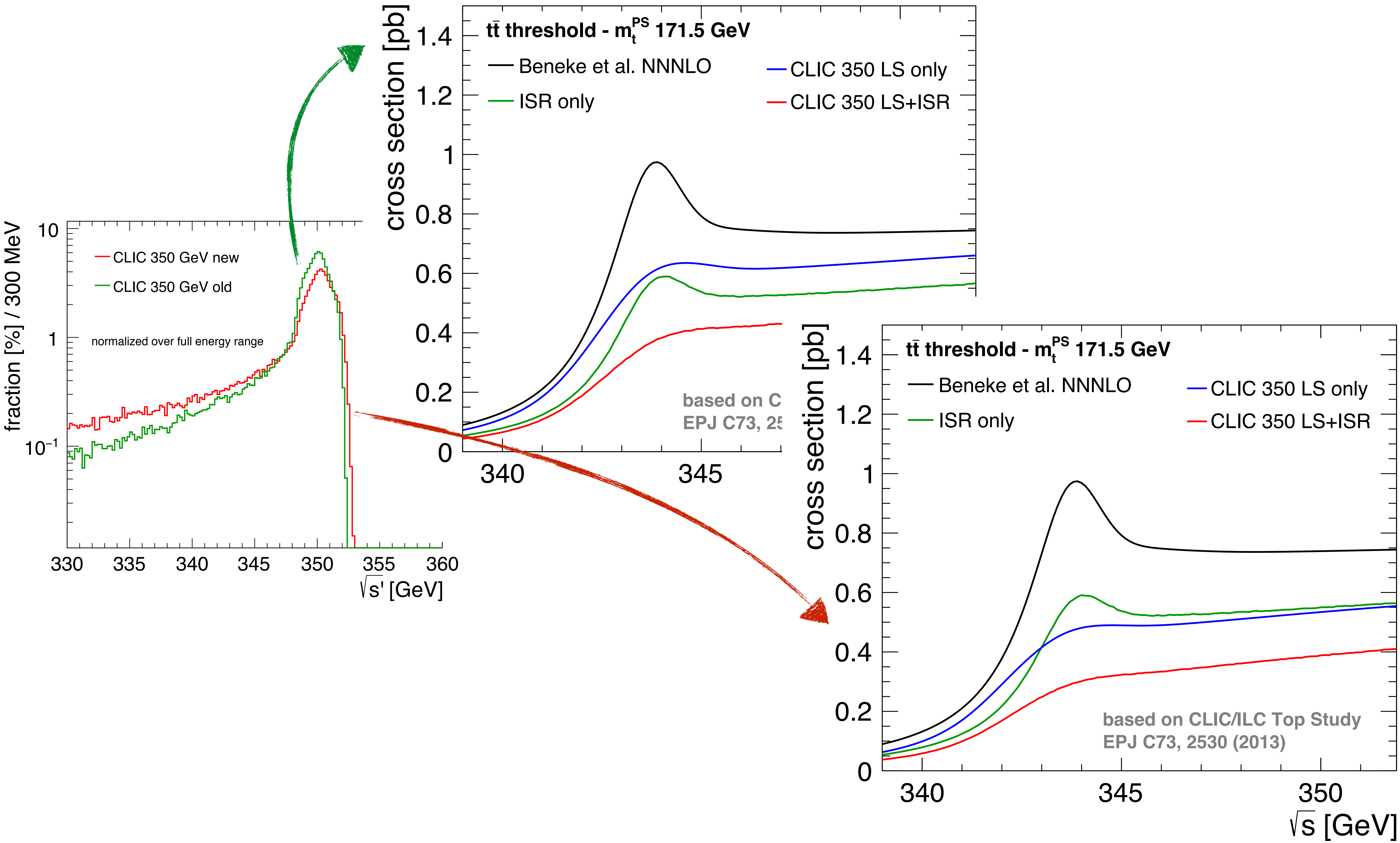
For a nominal energy of 350 GeV:

- 76.1% of all events are above 347 GeV for the 500 GeV Machine
- 59.4% of all events are above 347 GeV for the 380 GeV Machine

➪ ~ 20% less “effective” luminosity in a threshold scan

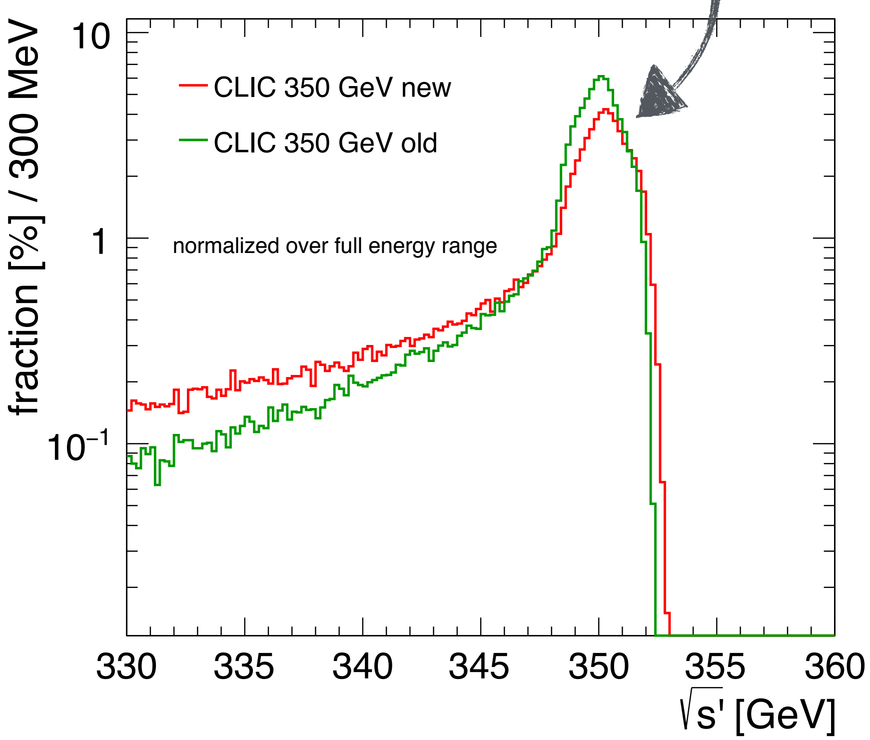
➪ more pronounced smearing of the threshold curve

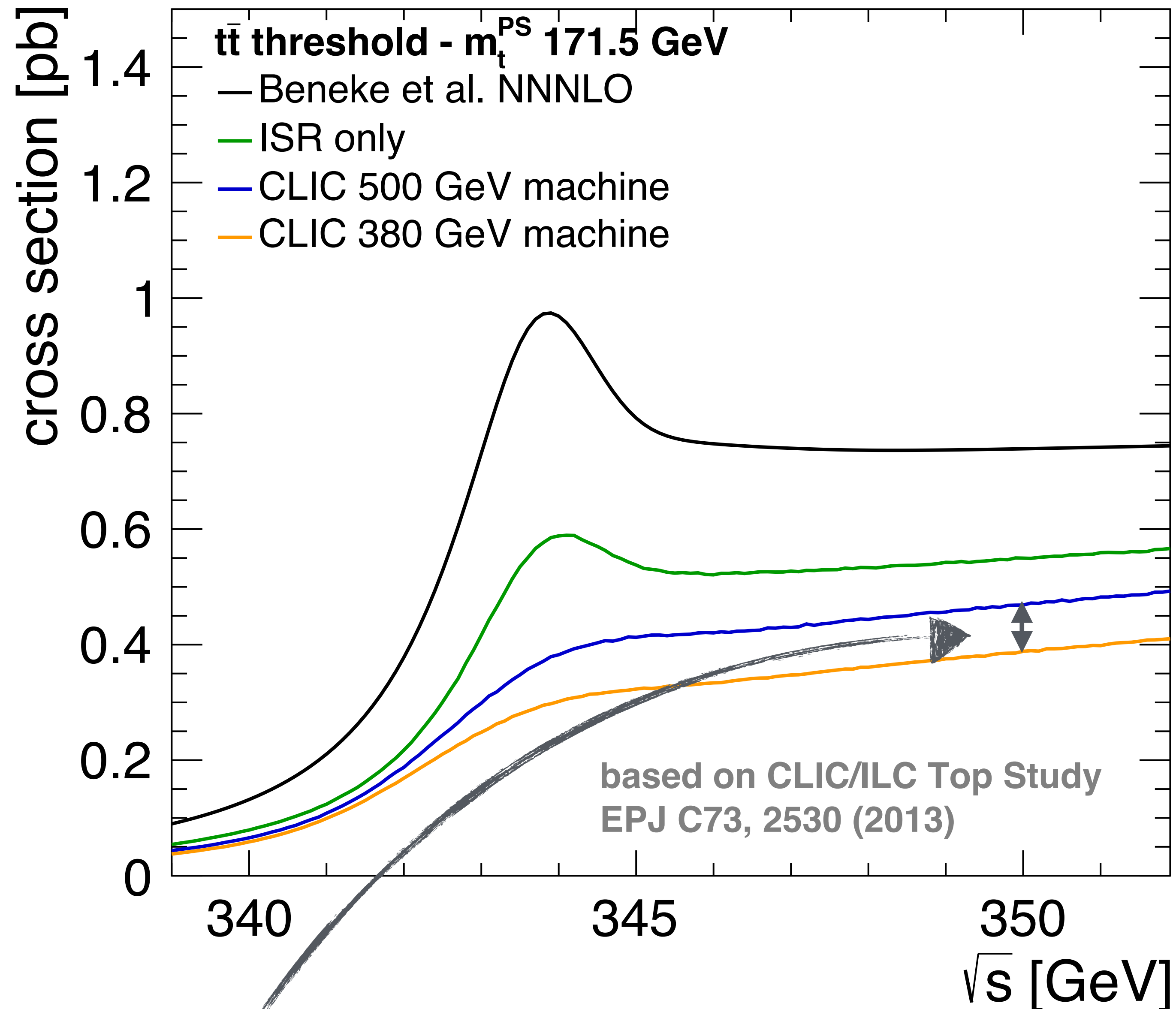
Effect on Top Production at Threshold



Effect on Top Production at Threshold

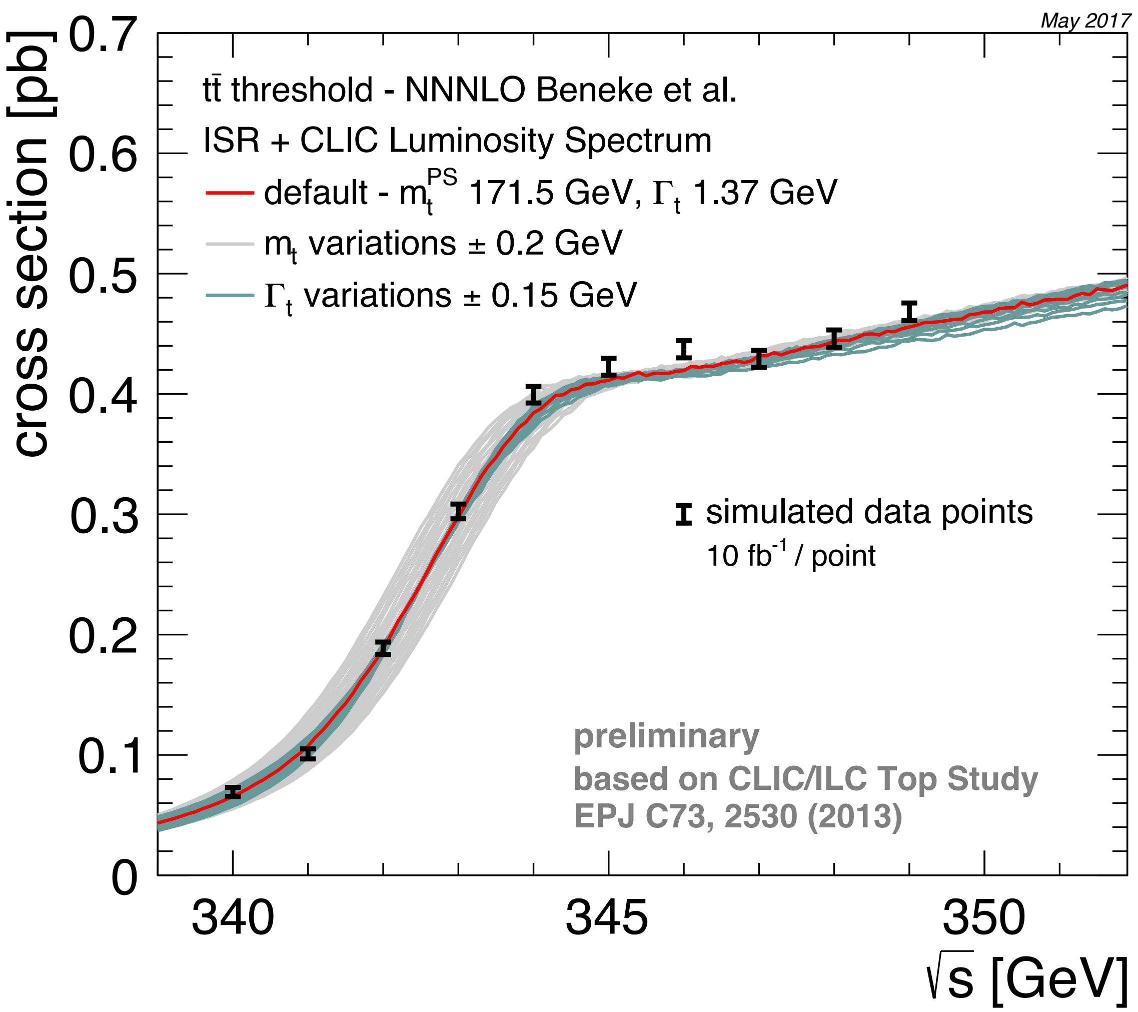
~ 20% less luminosity in peak region

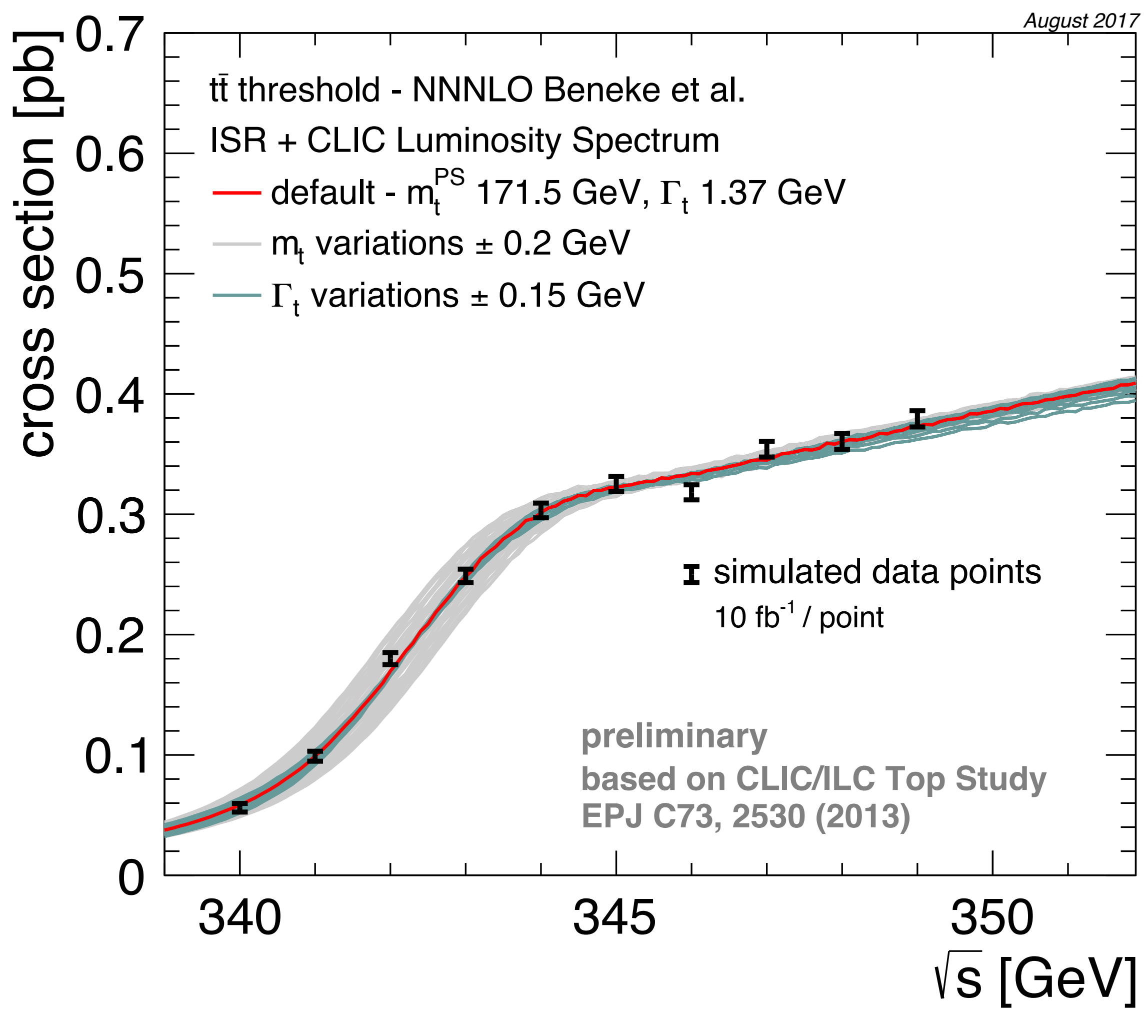




~ 20% reduction of effective ttbar cross section

Consequences for the Mass Measurement





- With the 500 GeV Machine:
  - Δm_t^{PS} = 19.4 MeV (stat)
- With the 380 GeV Machine:
  - Δm_t^{PS} = 23.8 MeV (stat)

To compare: ILC: ~ 18 MeV, FCCee ~ 16 MeV

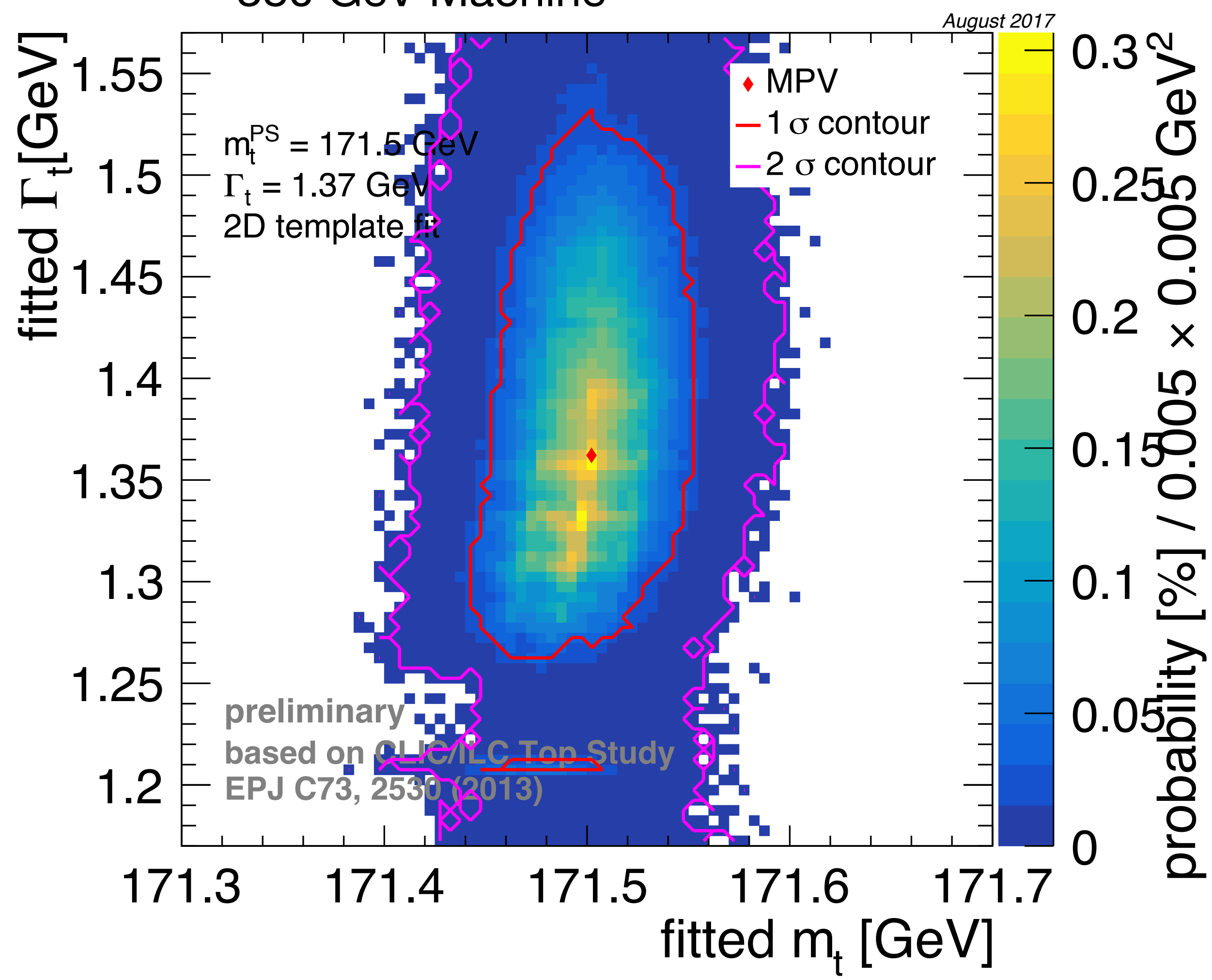
➯ The luminosity spectrum of the 380 GeV machine has a substantial impact: The statistical uncertainties of CLIC are now much bigger - a 10% - 20% effect turned into a 30% - 40% effect

Loosing Sensitivity when adding Dimensions

- 2D fits: Mass and width

500 GeV Machine

380 GeV Machine



- Softening of “edge” of cross-section turn-on makes simultaneous extraction of mass and width more difficult from cross-section alone
  - 1D width fit uncertainty from 51 MeV -> 66 MeV

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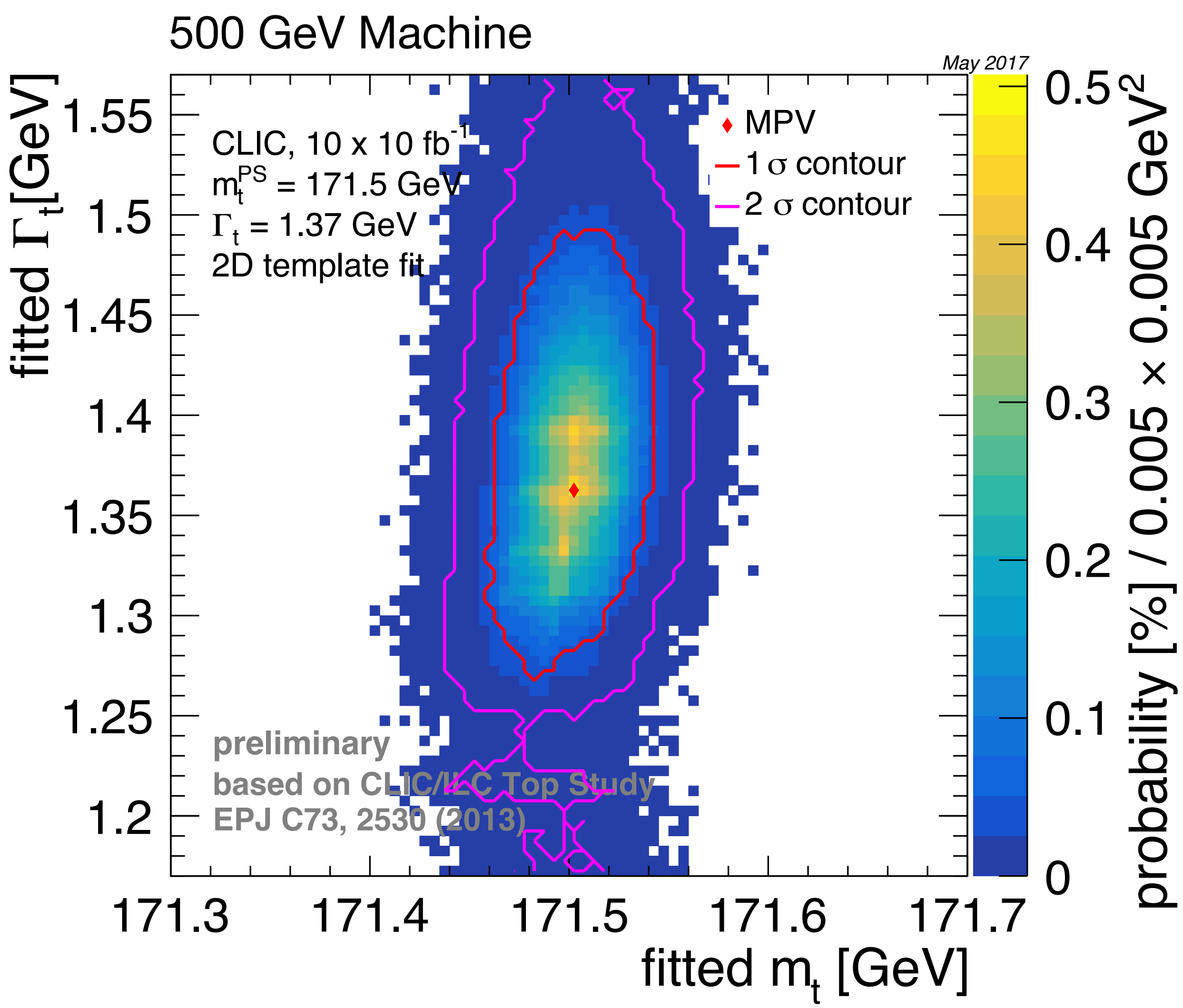

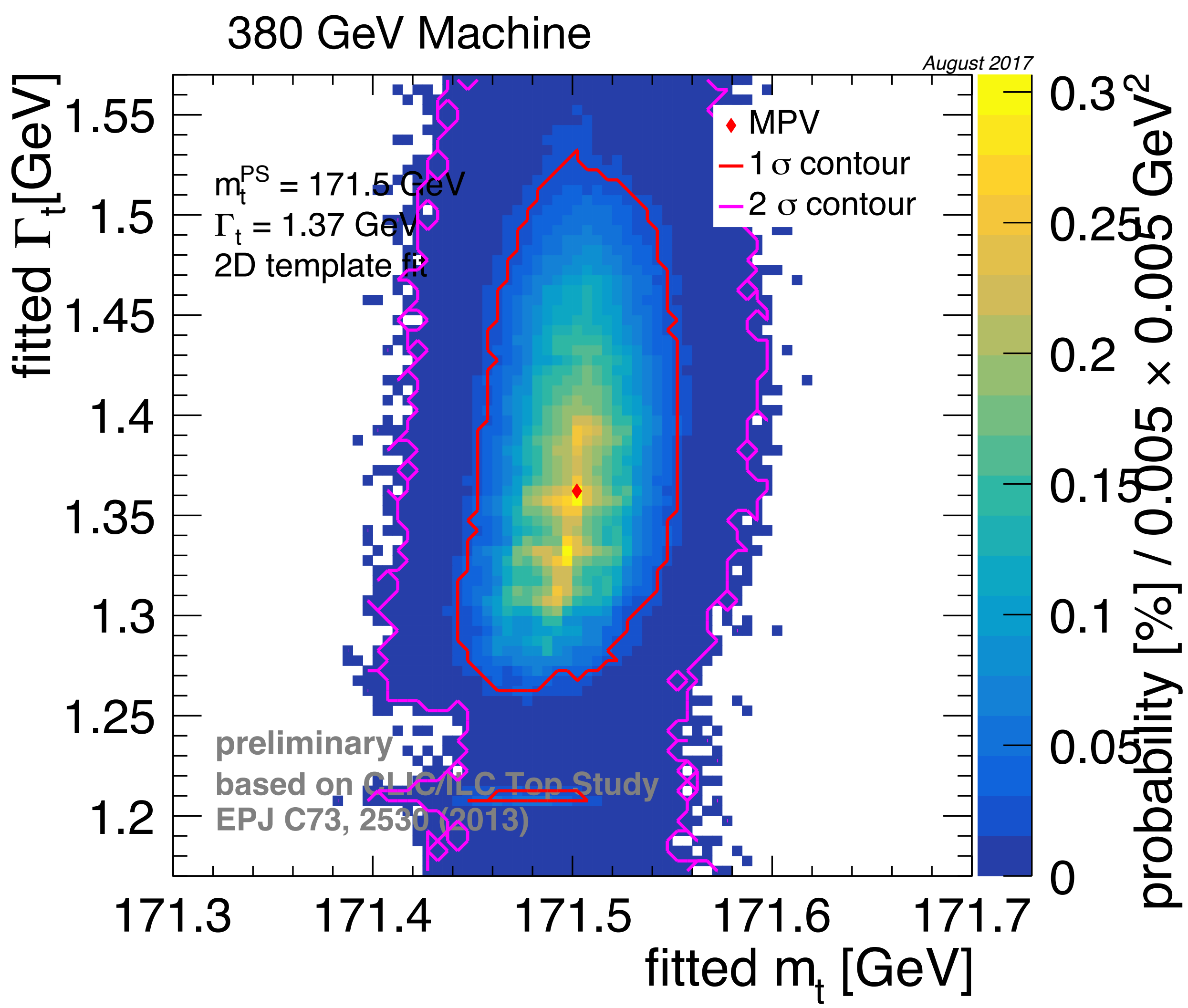

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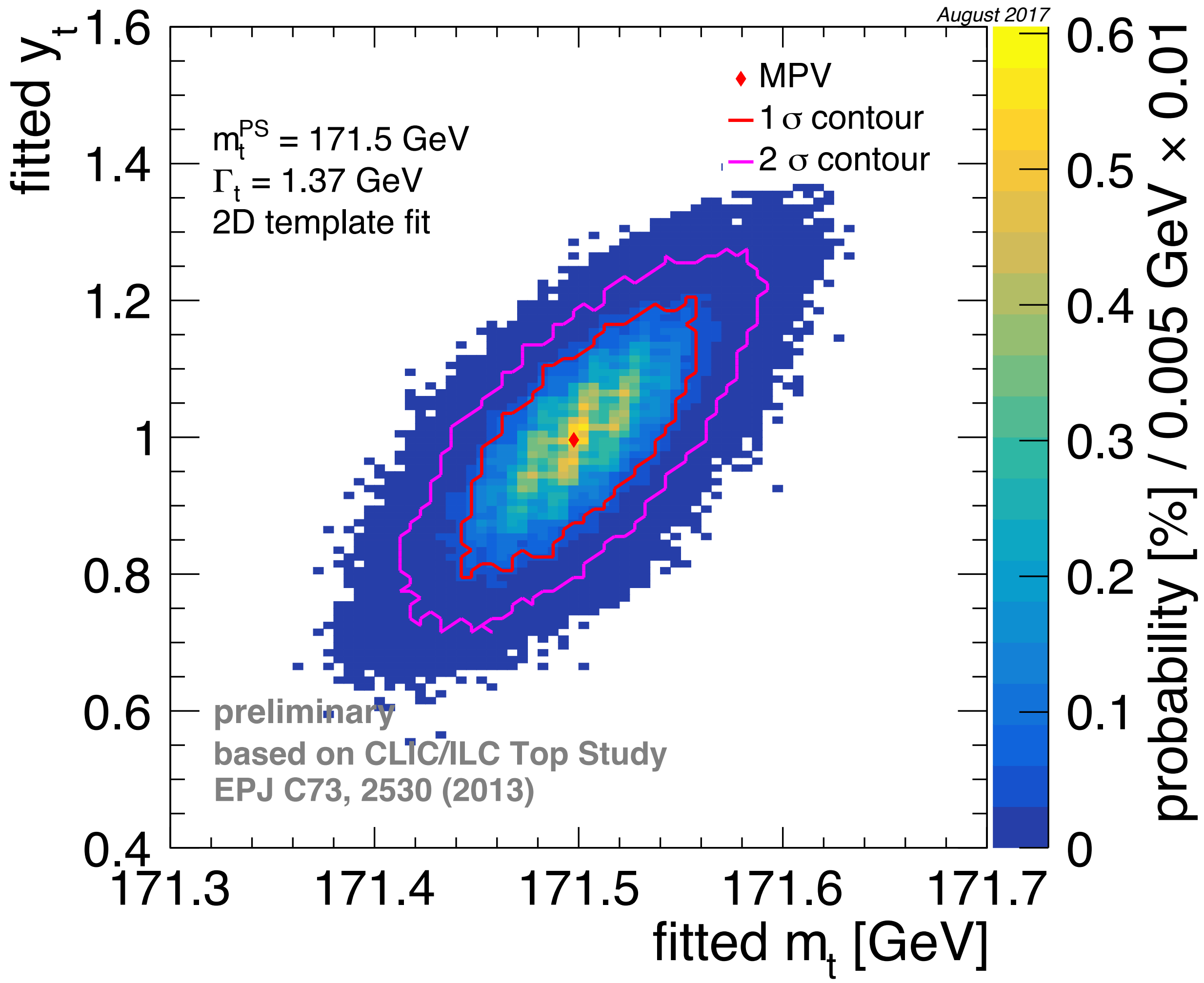
Loosing Sensitivity when adding Dimensions

- 2D fits: Mass and Yukawa Coupling

500 GeV Machine

380 GeV Machine



- Effect on Yukawa coupling less dramatic: Sensitivity driven by region above the threshold, here a “simple” statistics effect
  - 1D width fit uncertainty from 0.067 MeV -> 0.074 MeV

10% deterioration consistent with 20% reduction in effective *L*

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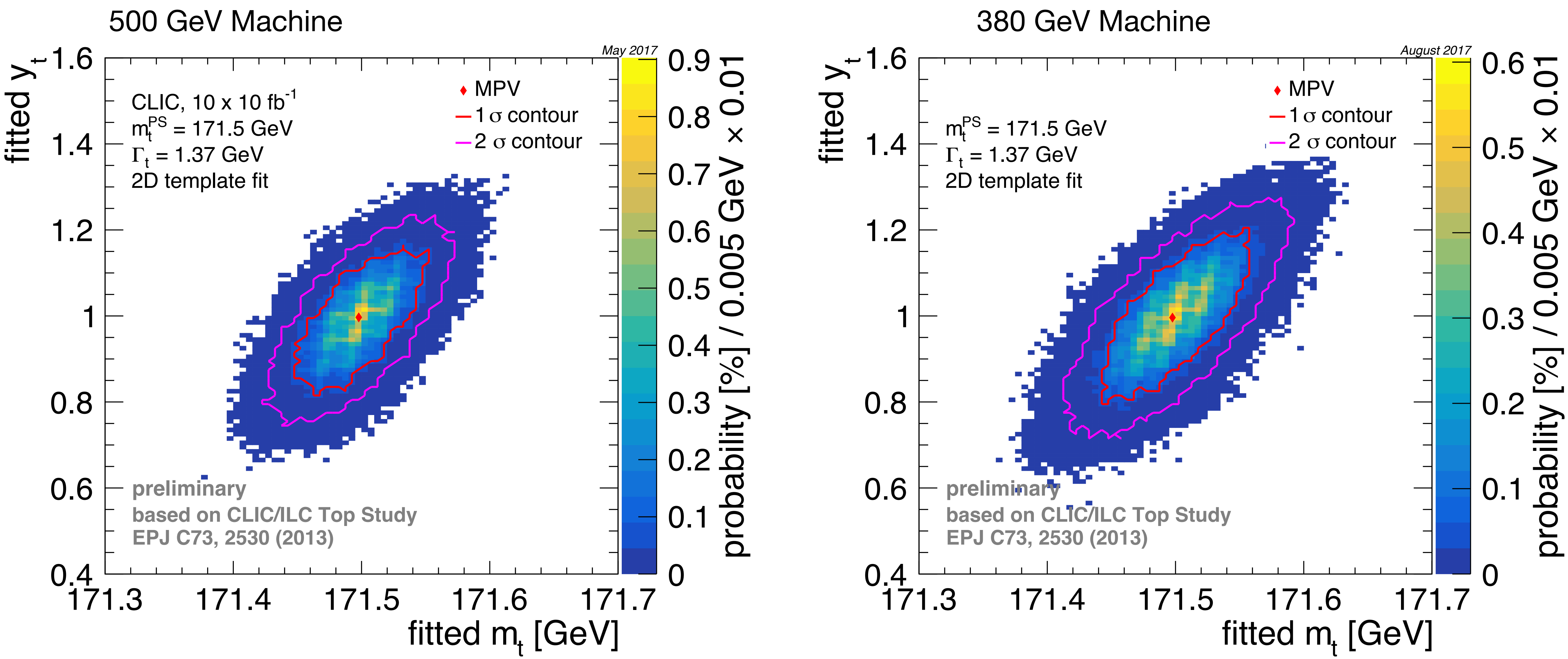

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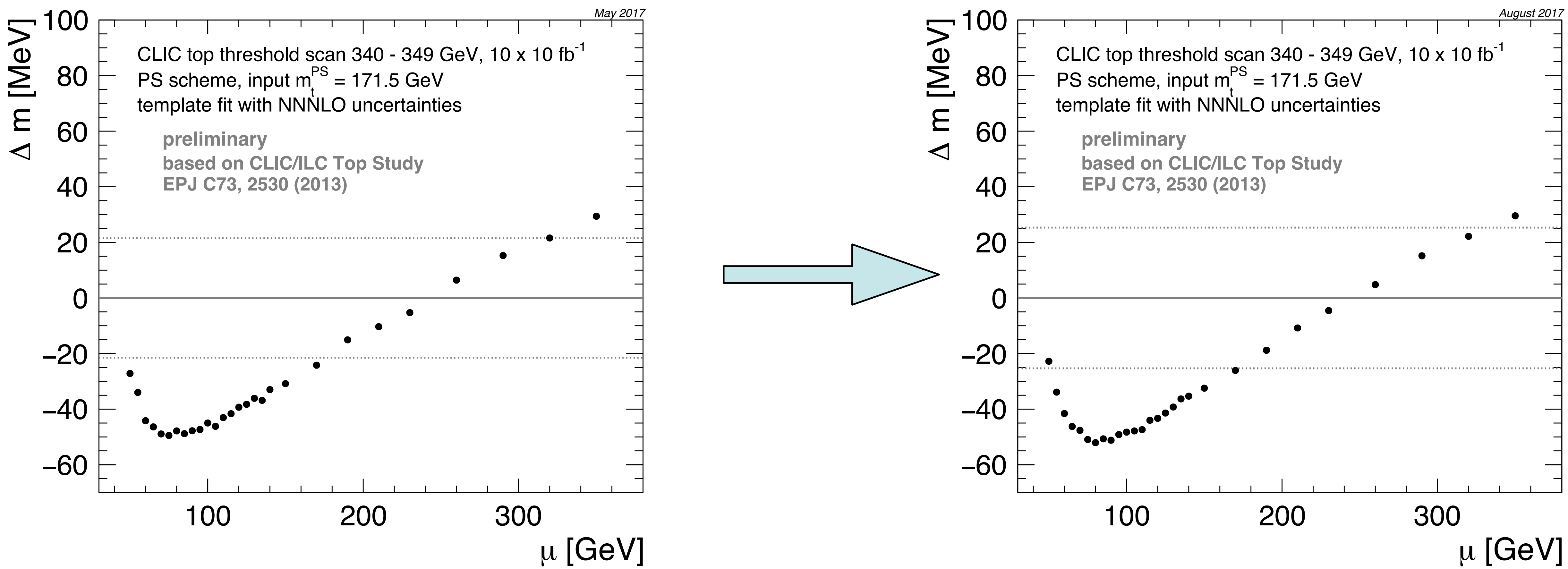
Parametric Uncertainties & Theory Uncertainties

- The increased “tilt” of the cross section above the threshold also leads to a mild increase in the parametric uncertainties on α_s on the top quark mass:

  - 29 MeV / 0.001 change in α_s, up from -27 MeV / 0.001

- (Almost) no effect on impact on scale variations: ~ 42 MeV remains valid



Conclusions

- The luminosity spectrum of the 380 GeV machine is characterized by a more pronounced beamstrahlungs-tail than the 500 GeV machine when operated at the top threshold

- Strong negative impact on top mass measurements and 2D fits of the threshold cross-section
  - 20% deterioration of statistical uncertainty for mass, 30% impact on width measurements

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- Mild increase in α_s dependence - less than a 10% effect

- Theory uncertainties essentially unaffected

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➯ Is a “low beamstrahlung” run conceivable at the top threshold?

Backup

Top Mass Uncertainties - Status

- A number of studies in Tesla, ILC, CLIC contexts: Expected statistical uncertainty **20 - 30 MeV** (for 100 fb^{-1})

error source	Δm_t^{PS} [MeV]
stat. error (200 fb^{-1})	13
theory (NNNLO scale variations, PS scheme)	40
parametric (α_s, current WA)	35
non-resonant contributions (such as single top)	< 40
residual background / selection efficiency	10 – 20
luminosity spectrum uncertainty	< 10
beam energy uncertainty	< 17
combined theory & parametric	30 – 50
combined experimental & backgrounds	25 - 50
total (stat. + syst.)	40 – 75

- Summary of status for ILC “New Particles” Report arXiv:1702.05333

Study Basics

- Experimental details:
  - Based on CLIC / ILC top threshold study (EPJ C73, 2530 (2013)):
    - CLIC_ILD Detector model
    - Threshold simulated using efficiency & backgrounds from full simulations, signal scaled according to theory input
    - Assuming ILC TDR luminosity spectrum
- Theory input:
  - NNNLO QCD Theory calculations, using QQbar_threshold (arXiv:1605.03010)
    - M. Beneke, Y. Kiyo, P. Marquard, A. Penin, J. Piclum, M. Steinhauser, Phys. Rev. Lett. 115, 192001 (2015)
    - Including NNNLO Higgs effects, NLO non-resonant EW contributions, NLO QED
      - M. Beneke, A. Maier, J. Piclum, T. Rauh, Nucl. Phys. B899, 180 (2015)
  - Using the ***PS Mass Scheme*** as the “native” scheme of the calculation, also using MSbar and 1S schemes to explore scheme dependence

Thanks to Martin Beneke, Andreas Meyer, Jan Piclum for help and fruitful discussions!