Tuning of the CLIC Luminosity Spectrum for a Top Threshold Scan

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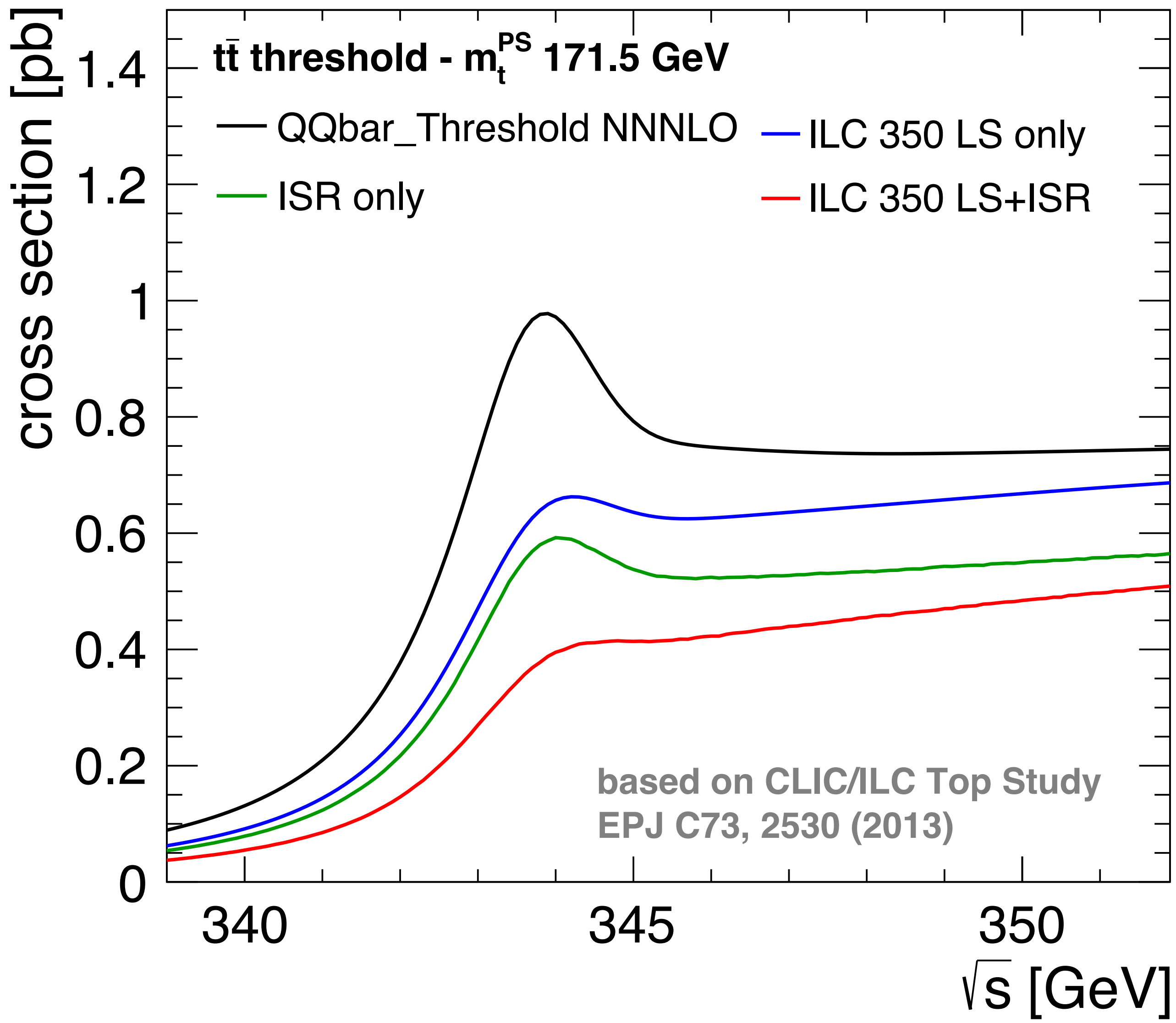
Outline

- 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

Parameters affecting the Top Threshold

- The cross section for top quark pair production in the threshold region is highly sensitive to the top quark mass and other top quark properties



The shape of the threshold curve influences the "statistical power" of measurements - with a particularly strong impact on multi-parameter studies

⇨ A special "top threshold tune" of the accelerator may be beneficial for the program!

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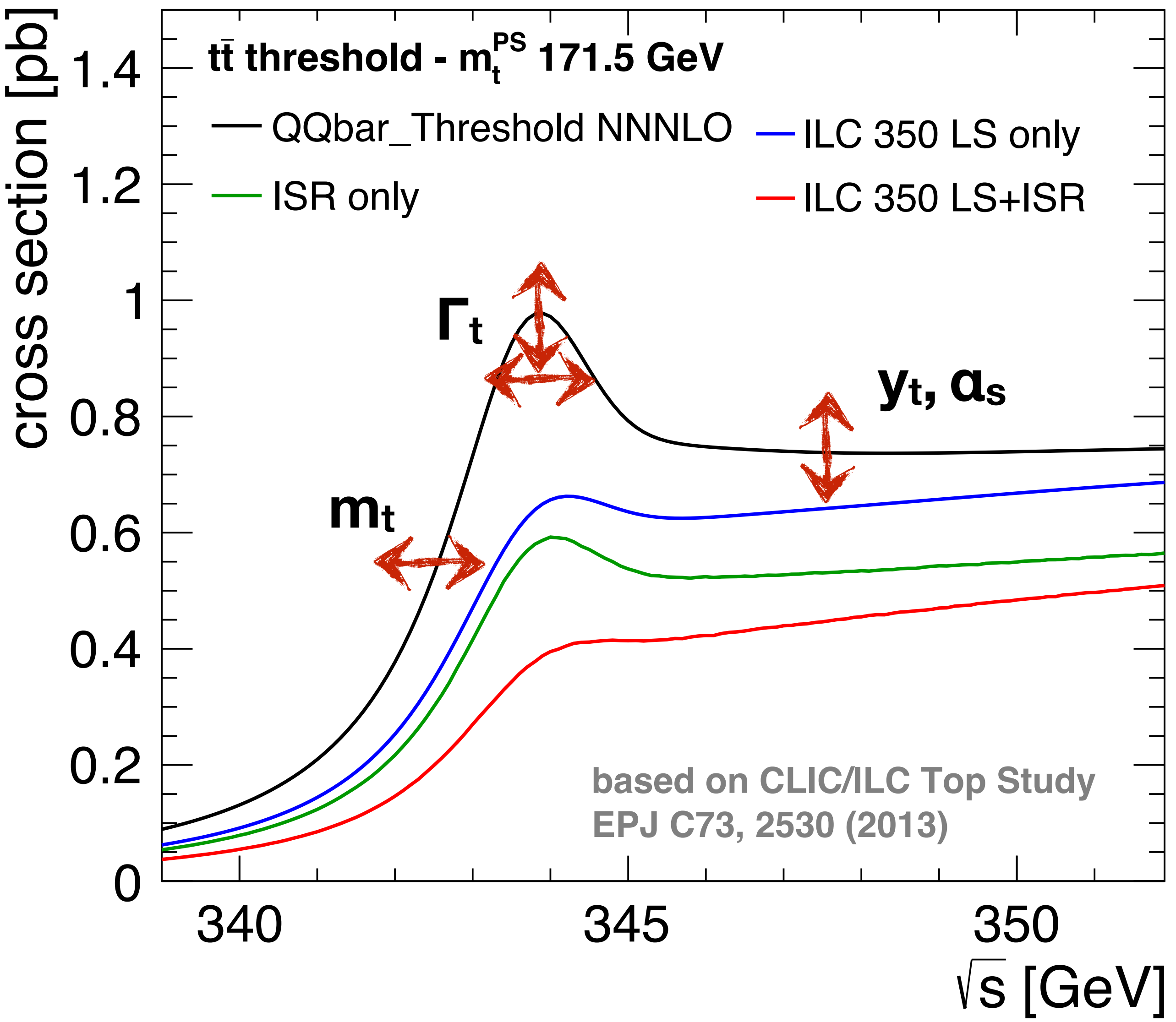

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Parameters affecting the Top Threshold

- The cross section for top quark pair production in the threshold region is highly sensitive to the top quark mass and other top quark properties
  - also depends on accelerator features

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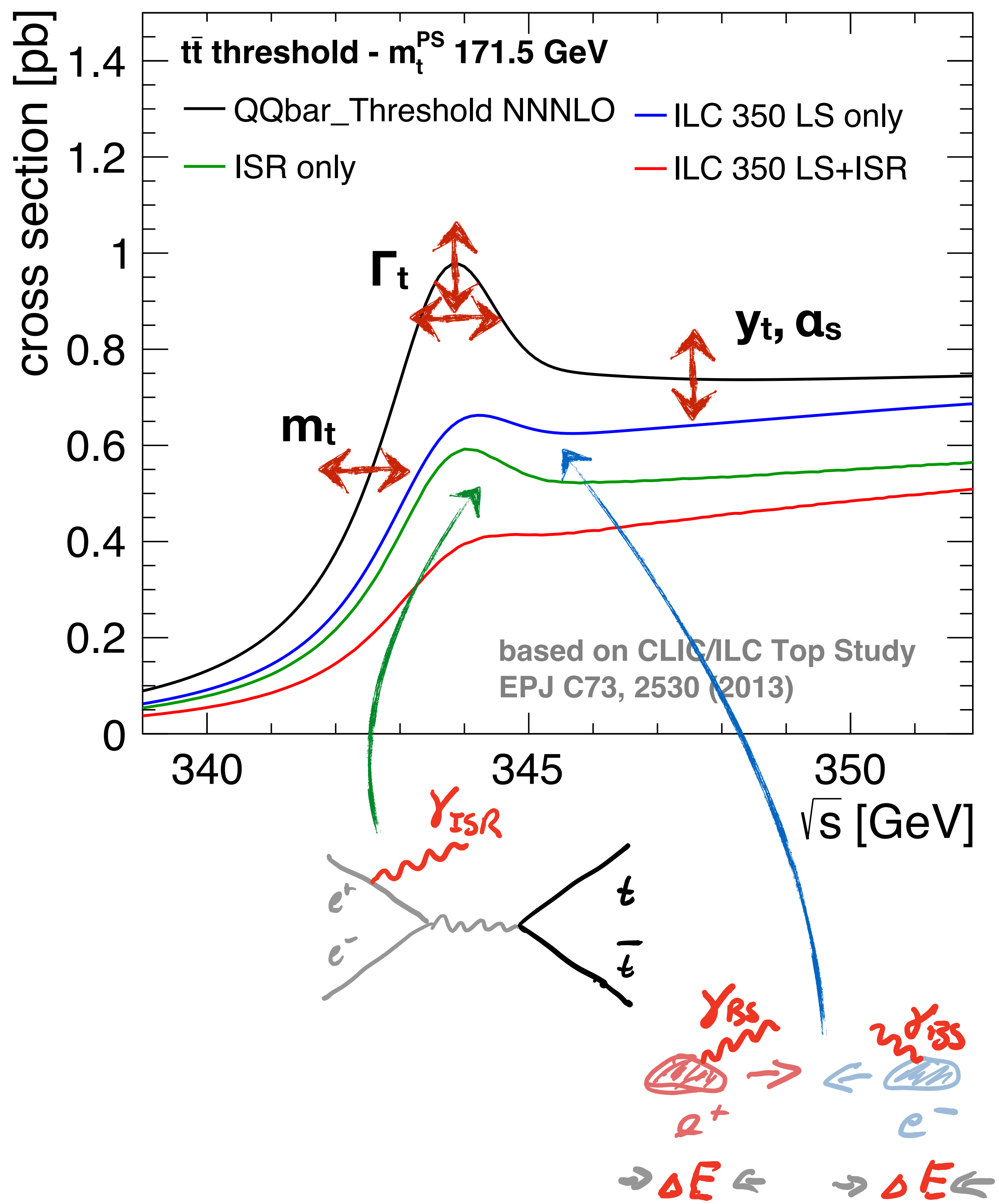
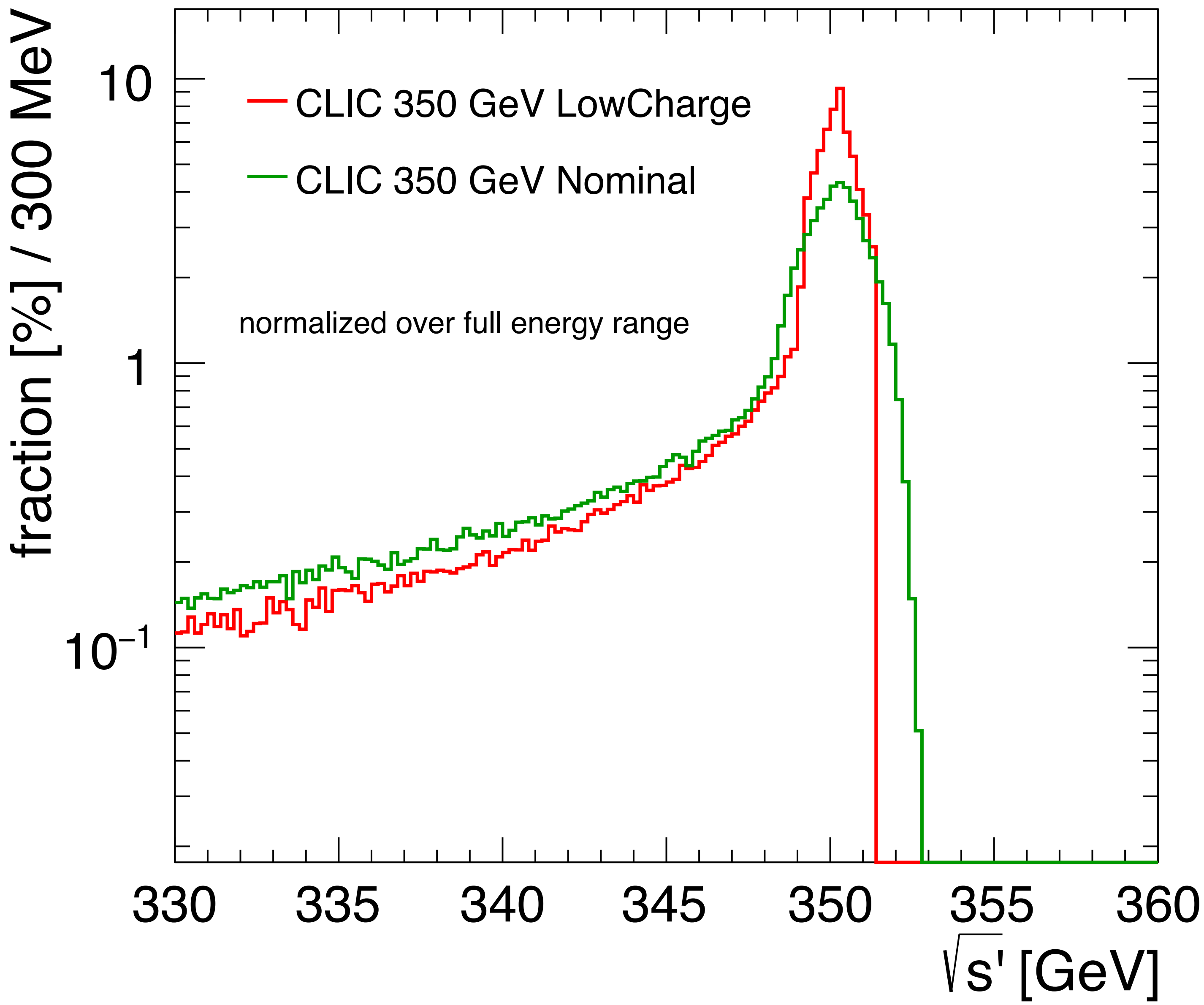


The Luminosity Spectrum at CLIC 380

- The situation at the top threshold changed with the introduction of the 380 GeV machine: Now the threshold scan is close to the (lumi-optimised) default operation conditions: Substantially increased beamstrahlung (but also higher luminosity!)



considering two options:

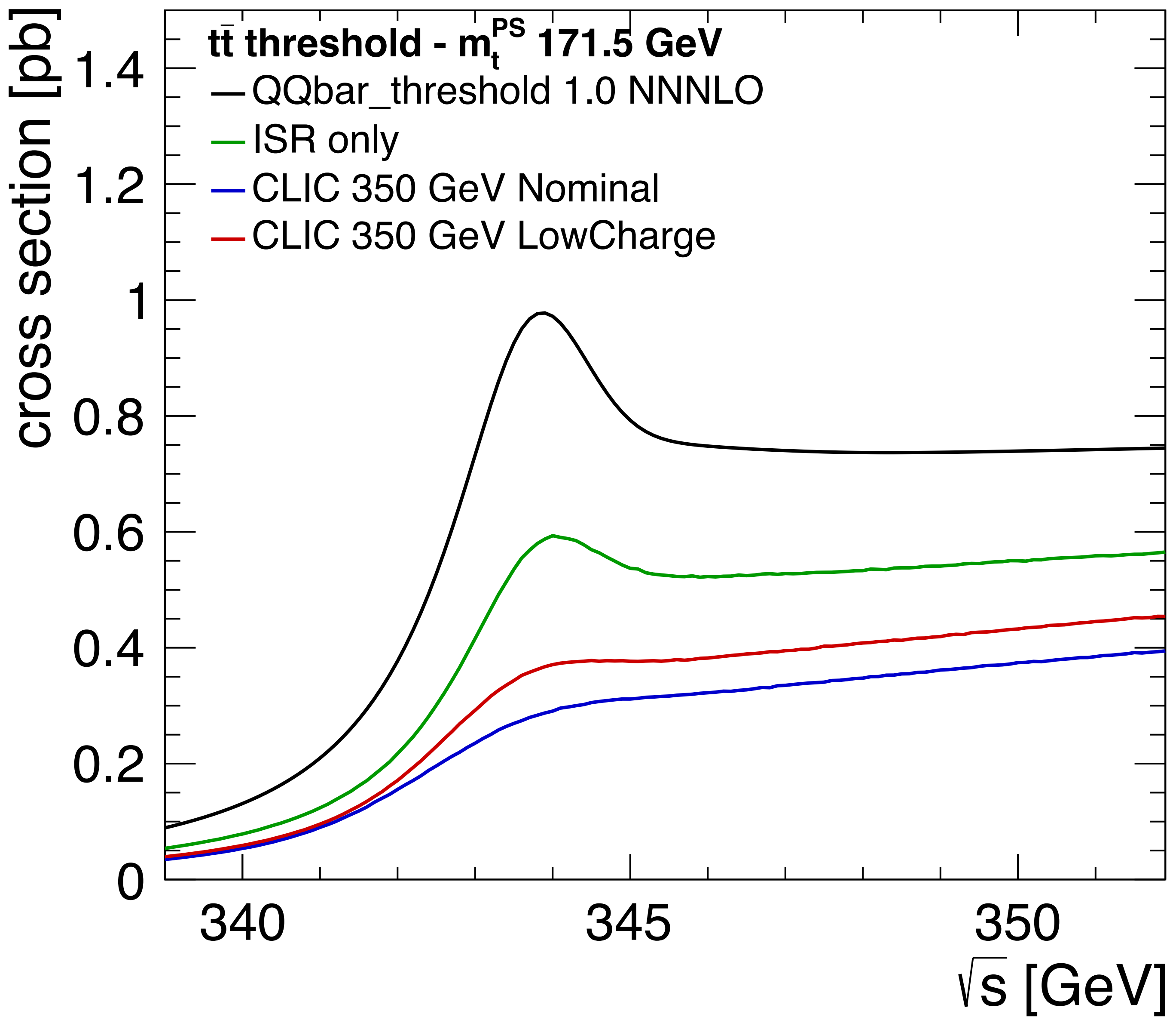
nominal:

- L = 1.29 x 10^{34} $cm^{-2}s^{-1}$
- 59.6% at E > 0.99 $E_{nominal}$
- 88.4% at E > 0.99 $E_{nominal}$

LowCharge:

- L = 0.64 x 10^{34} $cm^{-2}s^{-1}$
- 71.4% at E > 0.99 $E_{nominal}$
- 94.2% at E > 0.99 $E_{nominal}$

Two Scenarios: Impact on the Threshold



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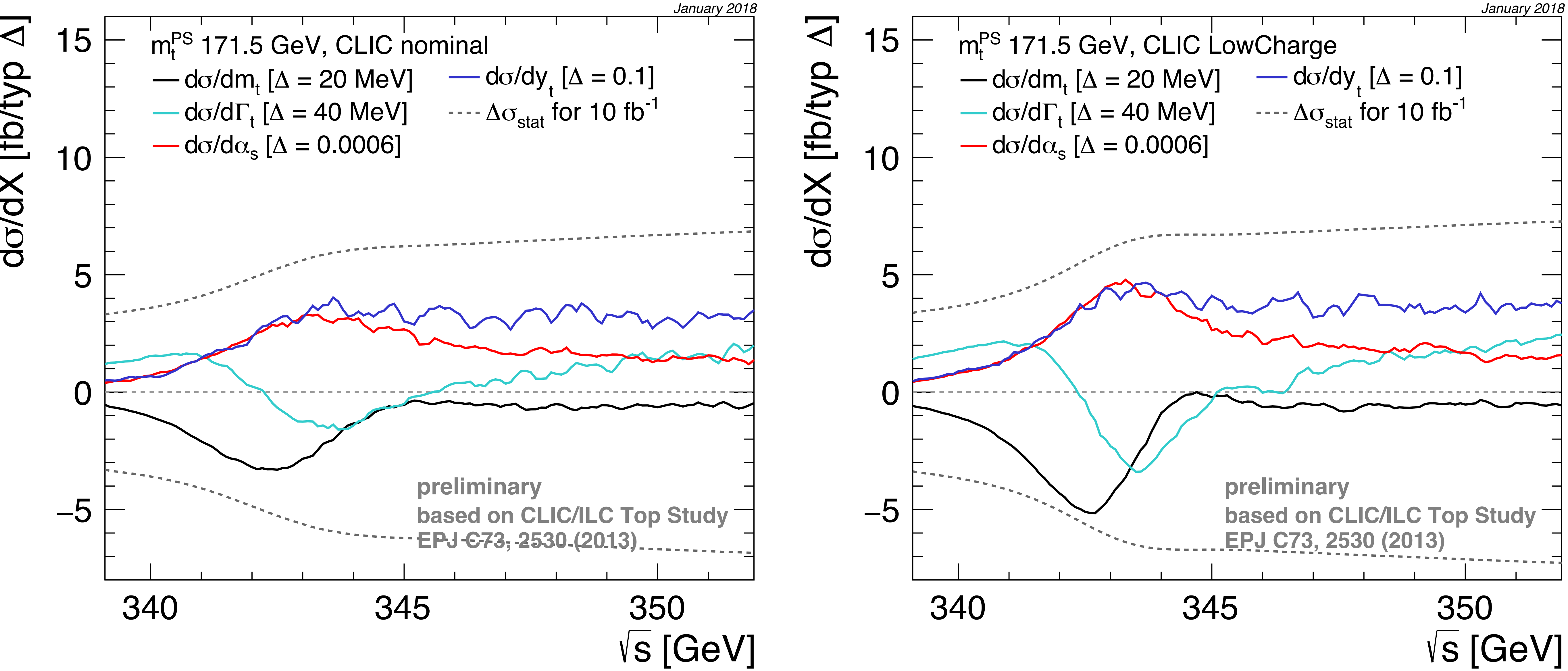
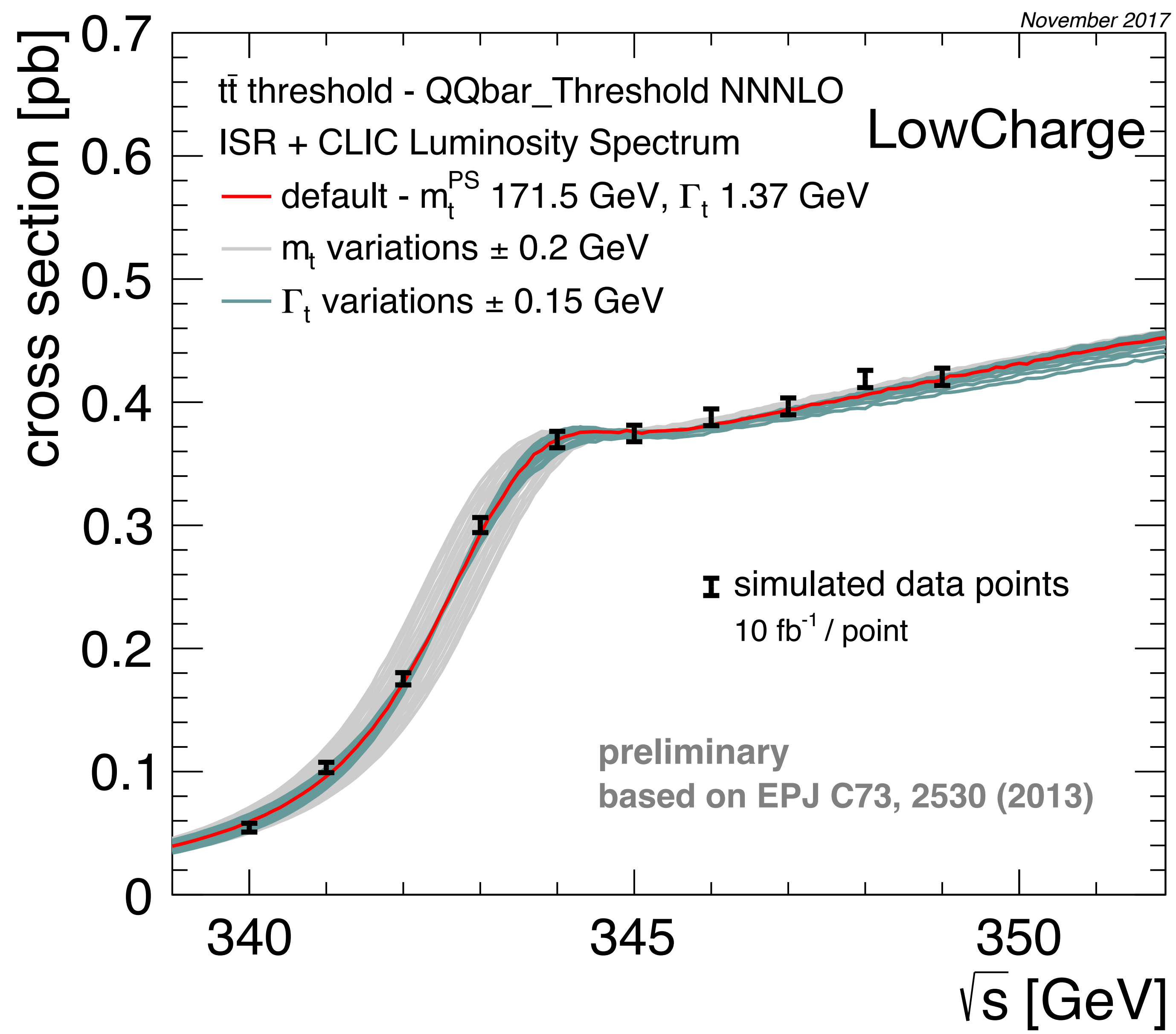


- Significance of top parameter variations substantially improved with LowCharge option
- Better decoupling of different effects - most notably for mass and width

Impact on the Mass Measurement

- The default analysis: a threshold scan of 100 fb^{-1}

Δm_t **(stat)**		*[equal lumi]*
23.3 MeV	=>	18.8 MeV
(nominal)		(LowCharge)



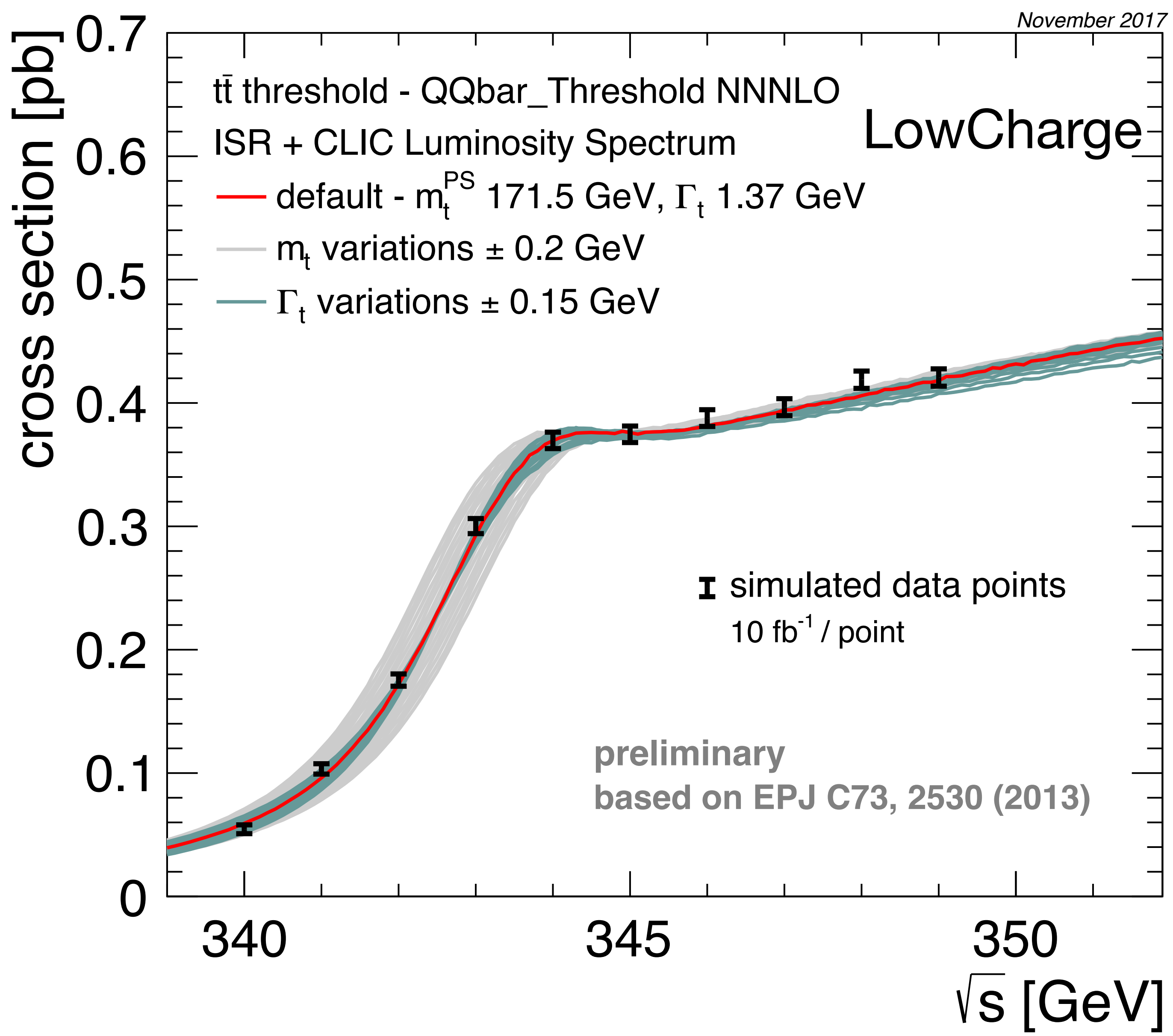
Impact on the Mass Measurement

- The default analysis: a threshold scan of 100 fb^{-1}

Δm_t (stat)		*[equal lumi]*
23.3 MeV	=>	18.8 MeV
(nominal)		(LowCharge)

But: The instantaneous luminosity in the nominal scenario is 2 x that in LowCharge

Δm_t (stat)		*[equal time]*
17.0 MeV	=>	18.8 MeV
(nominal)		(LowCharge)



Impact on the Mass Measurement

- Looking beyond statistical uncertainties:

Parametric: α_s -30 MeV /0.001 => -27 MeV / 0.001

(nominal) (LowCharge)

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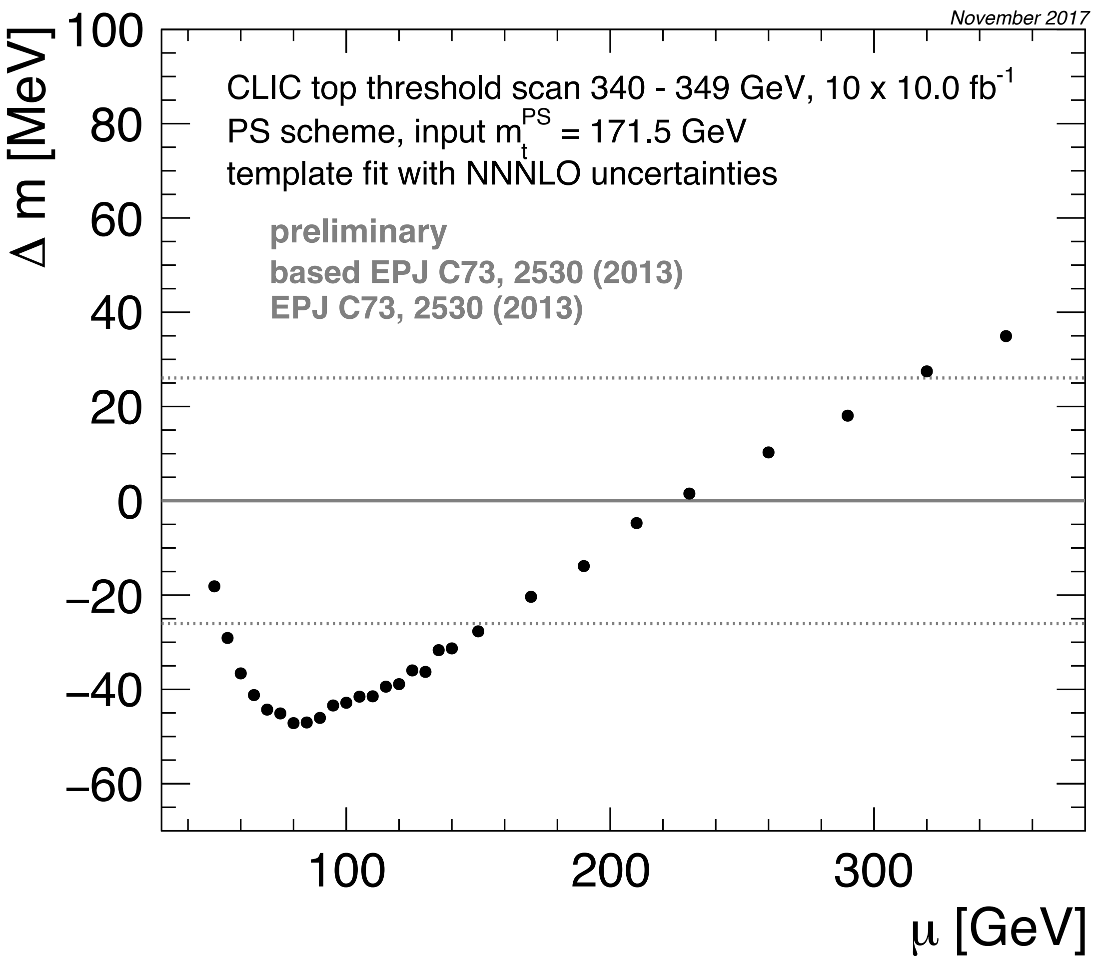
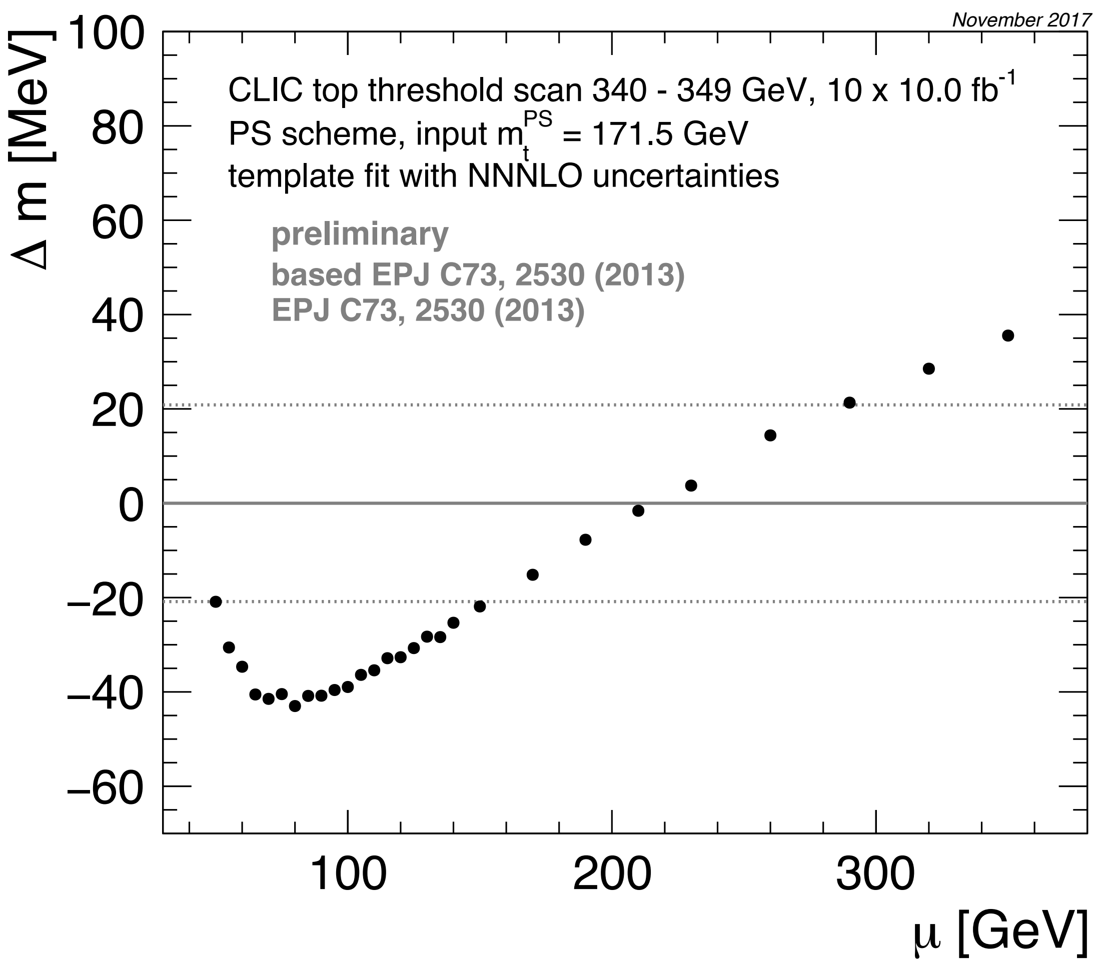
Theory systematics: scale variations

± 41.5 MeV (symmetrized) => ± 40 MeV (symmetrized)

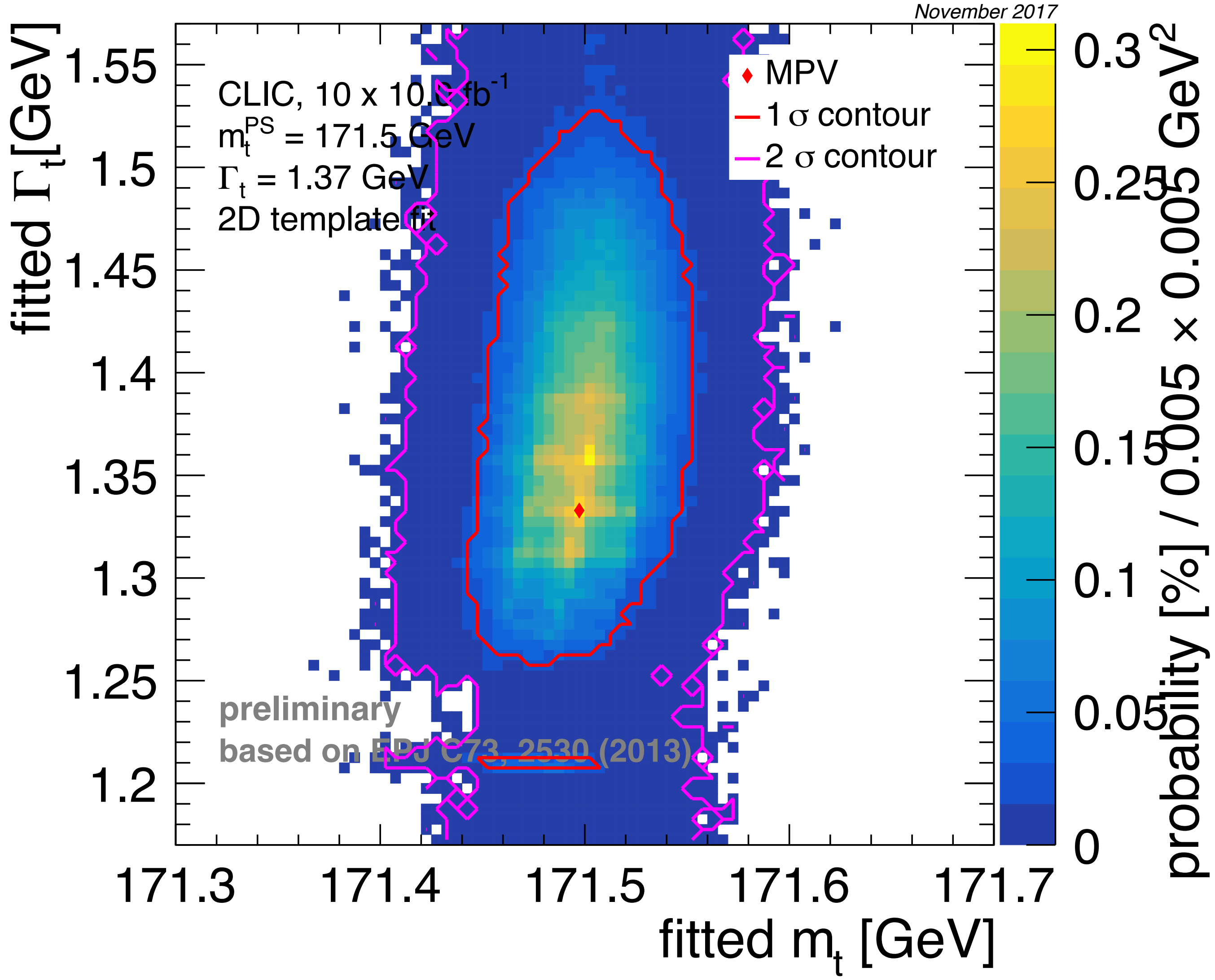


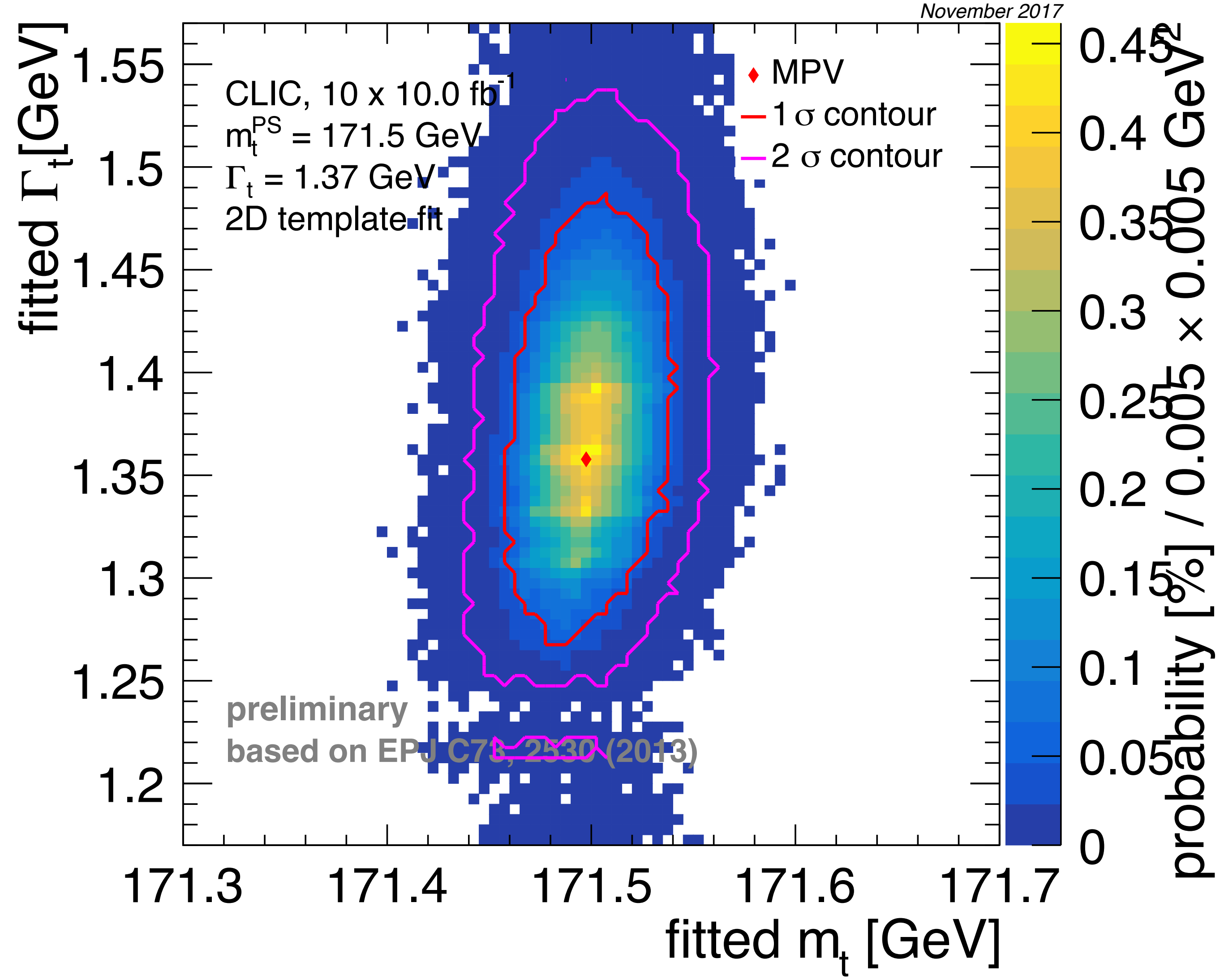


Beyond the Mass: Mass & Width

- 2D Fits of Mass & Width:

(nominal) *[equal lumi]* (LowCharge)





2D fits with 100 fb^{-1} in the nominal configuration are a challenge…

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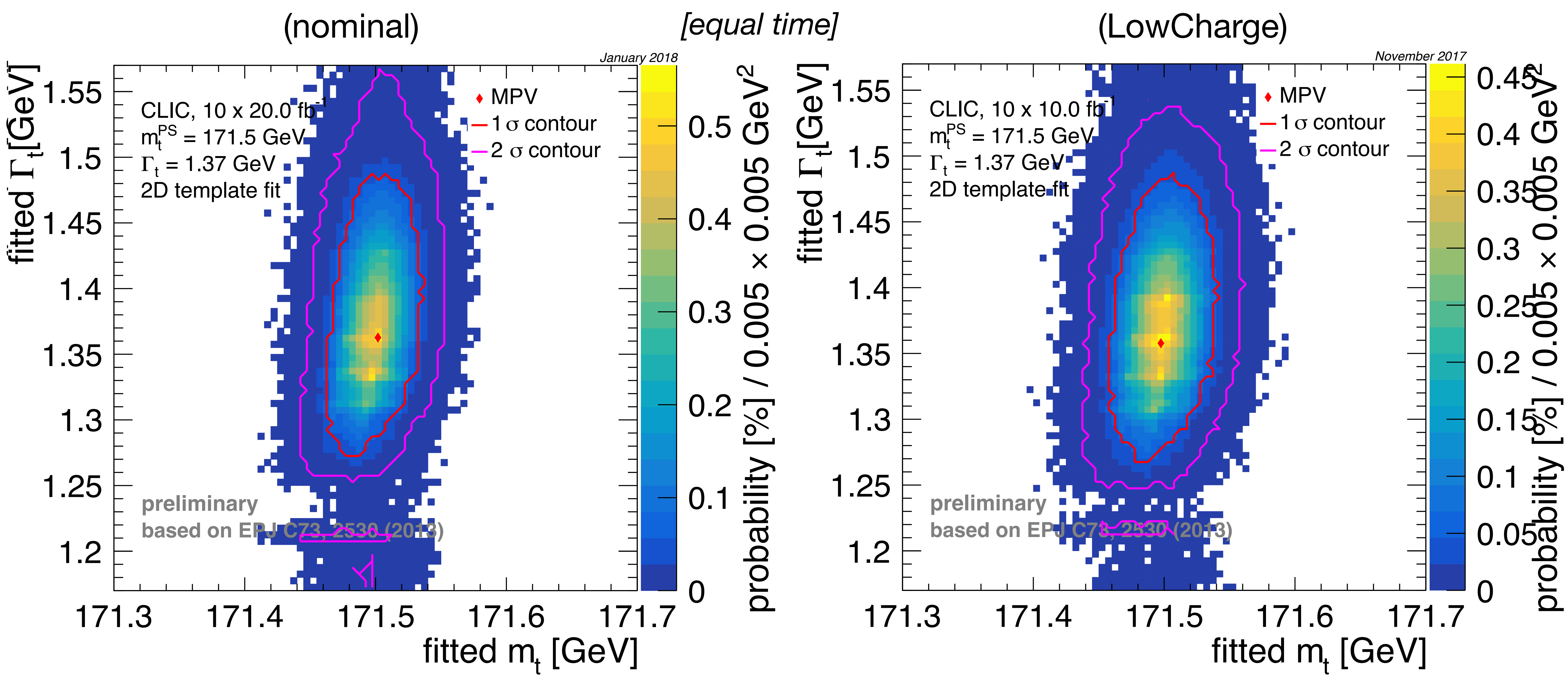


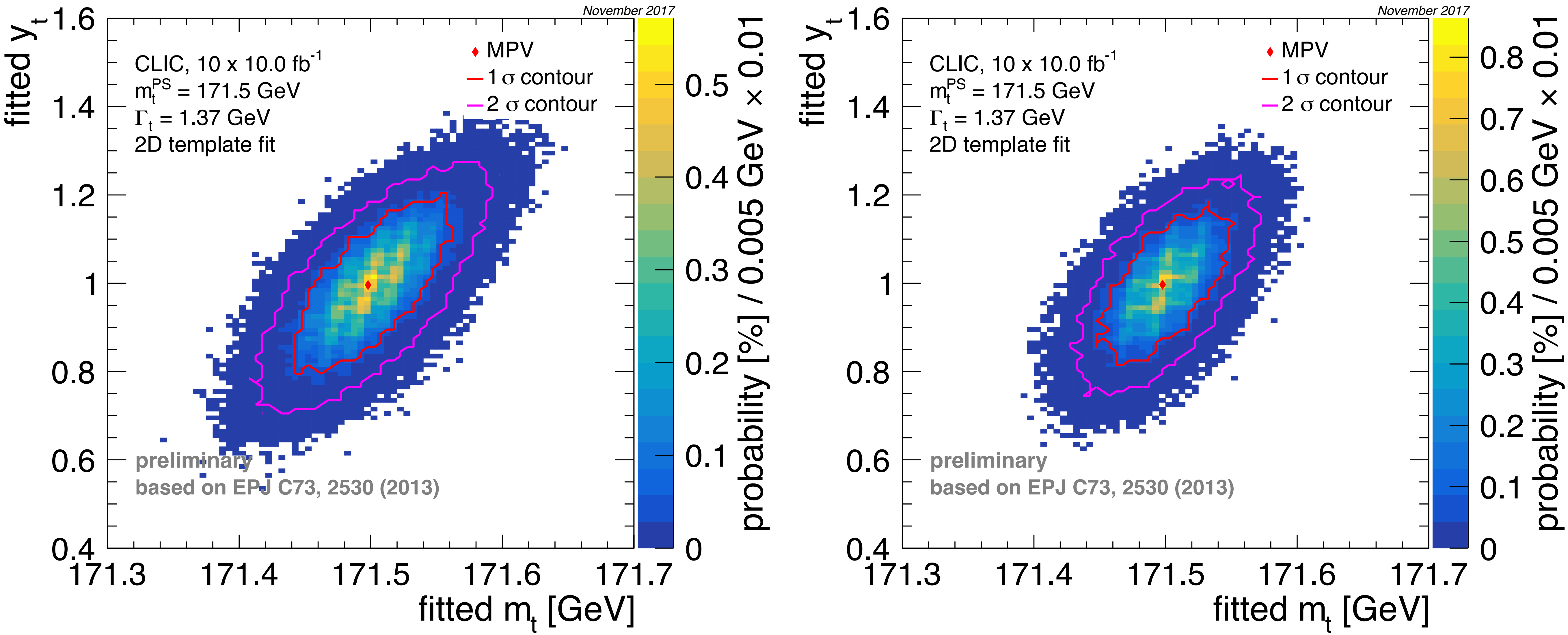
2D fits with 100 fb^{-1} in the nominal configuration are a challenge…

For equal running time, the mass gets slightly better for nominal, 1σ width ~ equal, but longer tails in the 2σ contour

Beyond the Mass: Mass & Yukawa coupling

- 2D Fits of Mass & Yukawa coupling:

(nominal) *[equal lumi]* (LowCharge)



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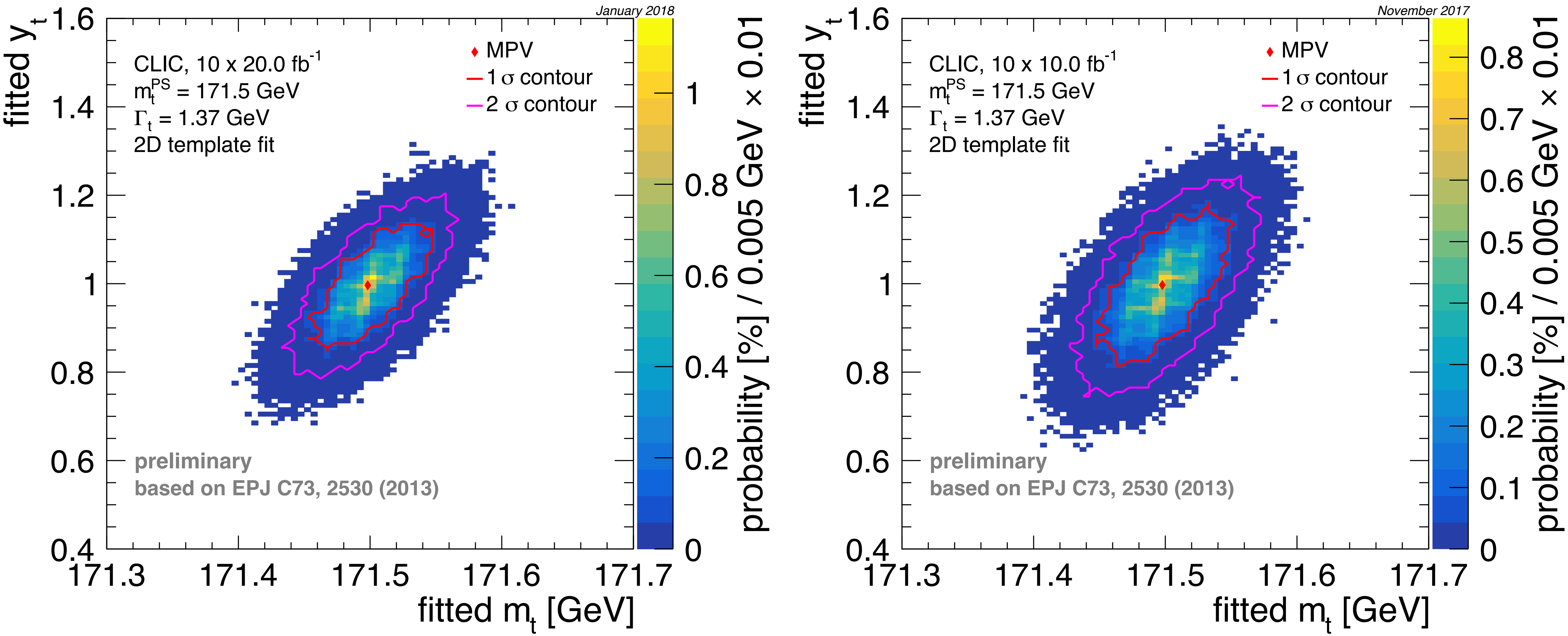

2D fits with 100 fb^{-1} in the nominal configuration are substantially less precise…

For equal running time, the nominal scenario does substantially better than low charge - due to fairly decent decoupling of mass & Yukawa in both scenarios

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
  - ➯ Leads to a “visible gap” in performance between CLIC and other e^+e^- colliders
- A low beamstrahlung option for running at 350 GeV has been developed: achieved primarily by reducing the bunch charge
  - Results in a x2 reduction of luminosity

➯ Recovers performance when assuming the “canonical” 100 fb^{-1} - but when considering equal running time the nominal scenario wins - with a small margin also for 2D fits assuming there are no unaccounted-for uncertainties that grow for the nominal scenario

Extras

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!