The Top Threshold at CLIC

Thoughts on Lumi Spectra & Scan Range

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Max-Planck-Institut für Physik
(Werner-Heisenberg-Institut)

Outline

- Introduction: Measuring top quark properties in a threshold scan
- Optimising energy points
  - The role of systematic uncertainties
- An ad-hoc optimised scanning scenario
- The influence of the luminosity spectrum
- Summary

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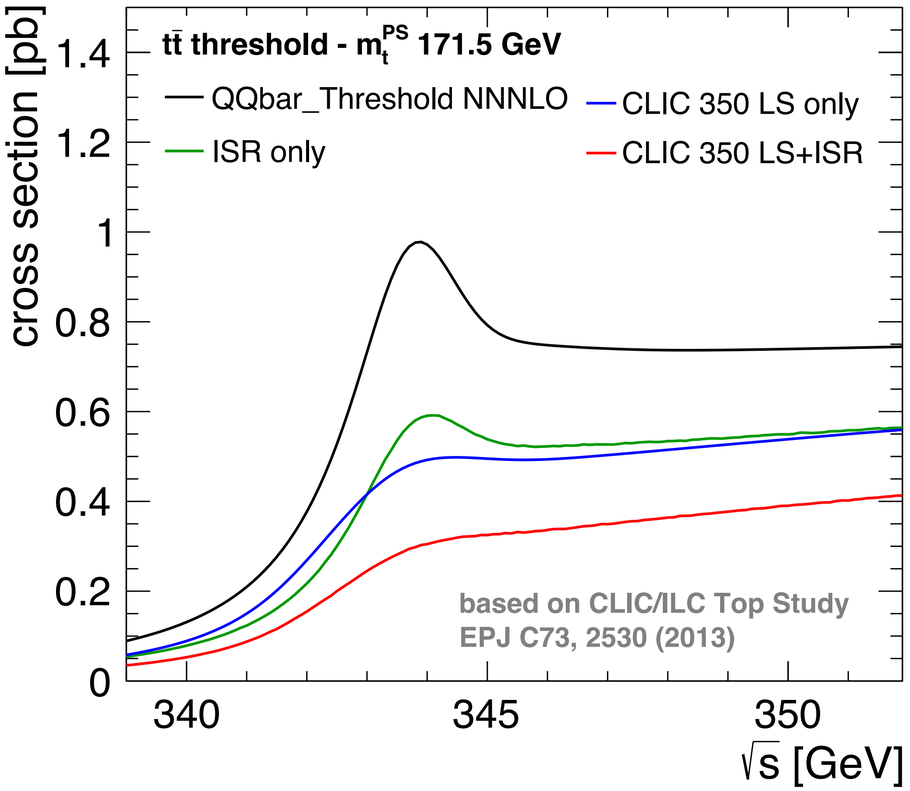
A word on numbers:
All studies shown here use the ***PS mass scheme*** for the top quark, one of the mass schemes well suited for the threshold problem. Assuming here:
$m_t^{PS} = 171.5$ ***GeV***
this corresponds to a ***top quark pole mass of 173.3 GeV***, consistent with the current WA (assuming this is numerically close to the pole mass, which is a reasonable assumption)

Introduction

Precision Top Physics at the Threshold

- The top quark is the only quark that has so far escaped the scrutiny of e^+e^- colliders - at the same time it may be particularly sensitive to New Physics
- Precise measurements, coupled with precise theoretical calculations, provide excellent discovery potential

- 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 - and can be calculated with high precision



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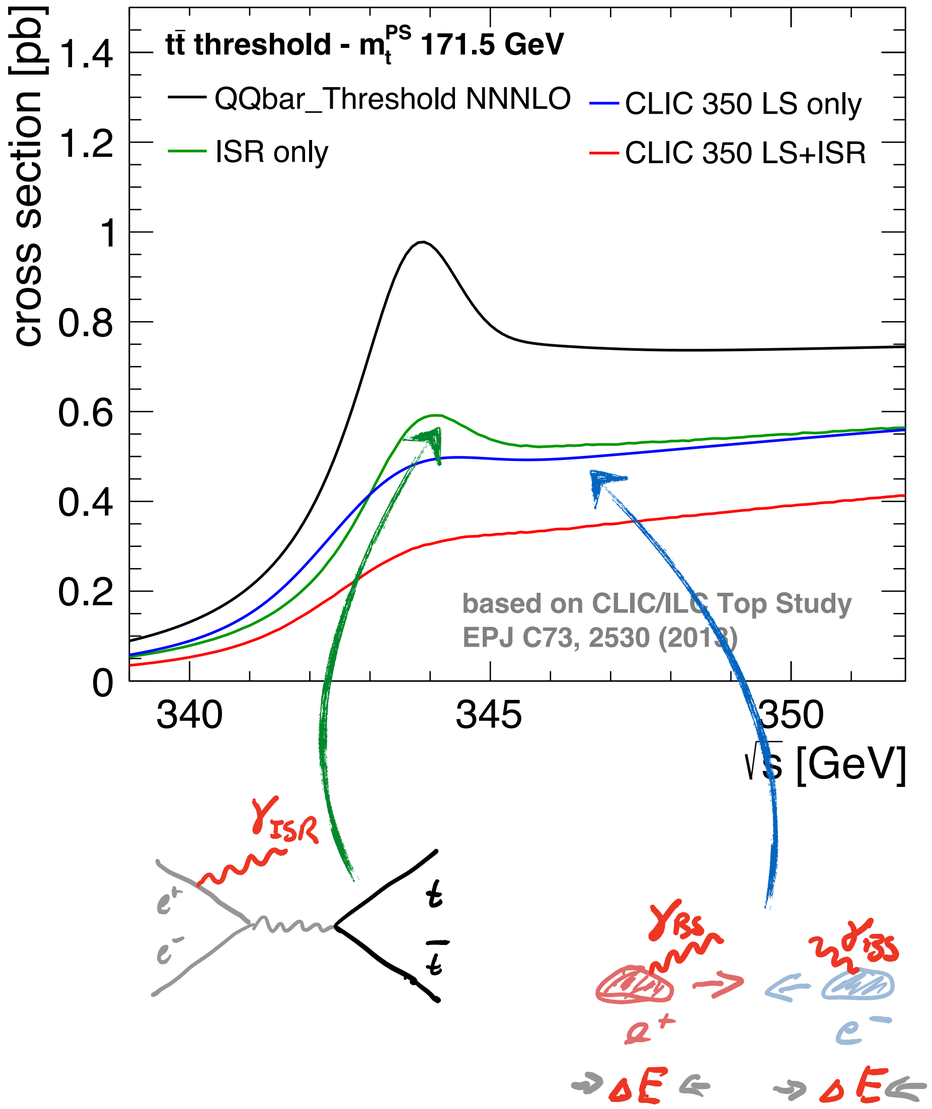
  - also depends on accelerator features
    Here: Considering two scenarios for the CLIC Luminosity Spectrum



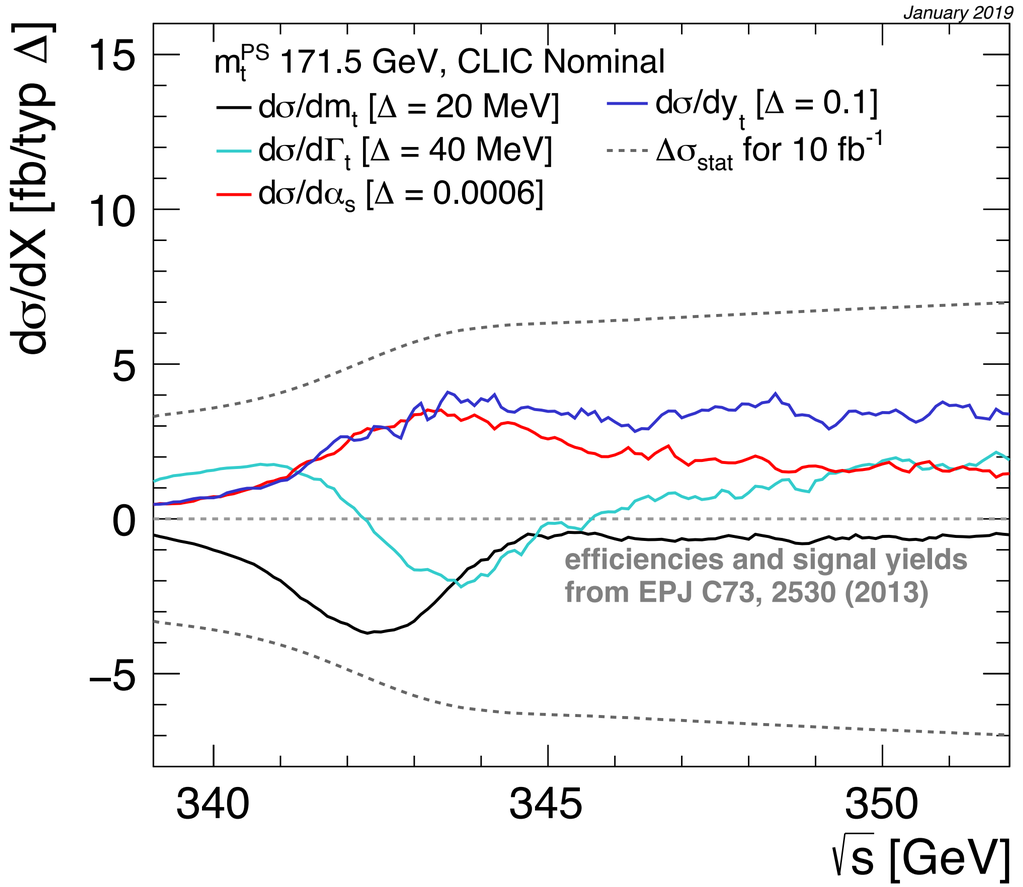
Optimising Threshold Scans

Measuring at the right energies

- Default assumption: 10 points spaced by 1 GeV, each with equal integrated luminosity
  Obvious question: **Can we do better?**

➪ The optimal way to distribute the integrated luminosity in the threshold region depends on the quantities you want to measure

Plot shows the derivative of the cross section for various parameters - to make this understandable this is normalised to typical changes of these parameters



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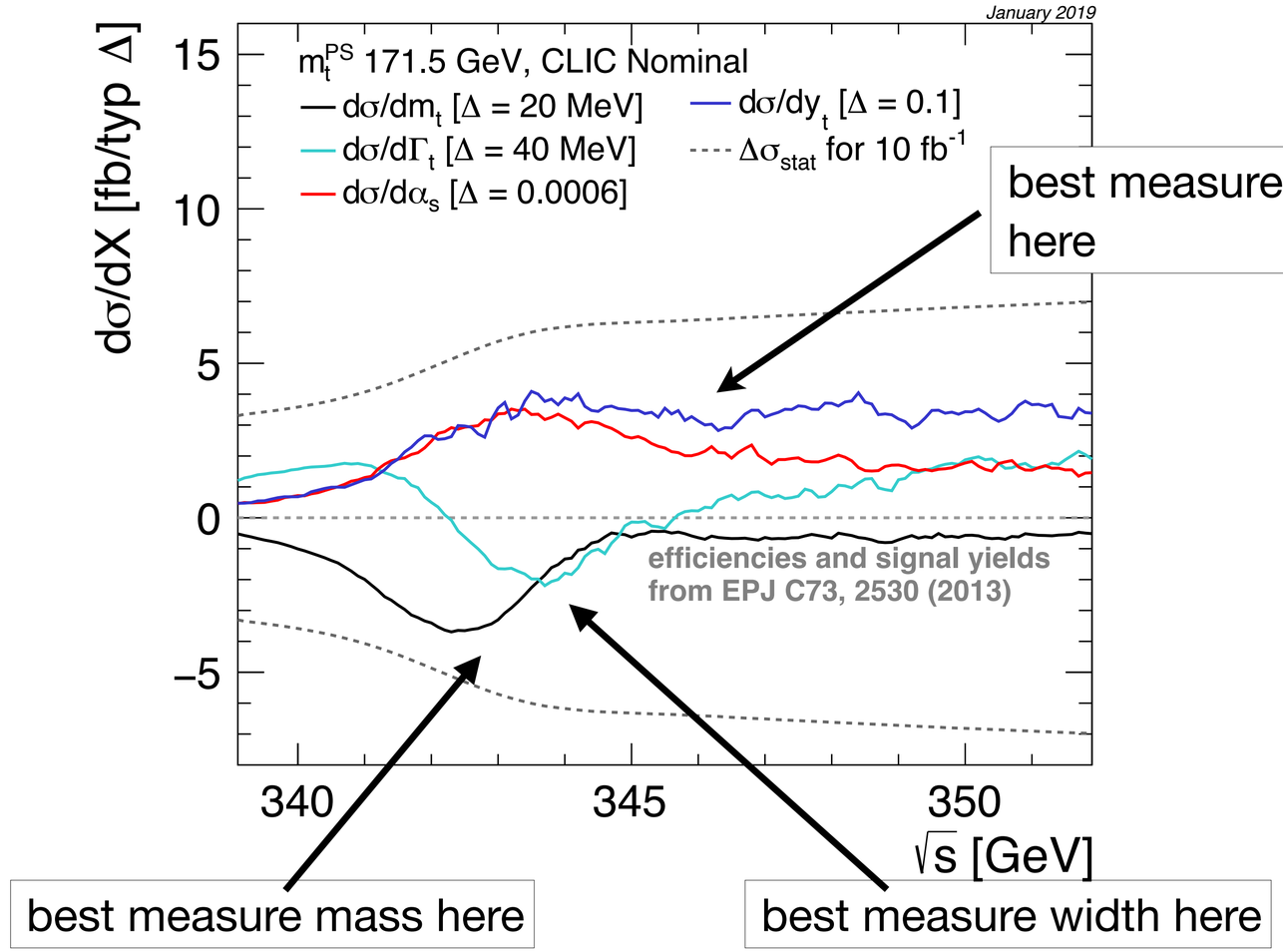
For each of the quantities there is an optimum - if you concentrate your integrated luminosity there you get the best statistical precision



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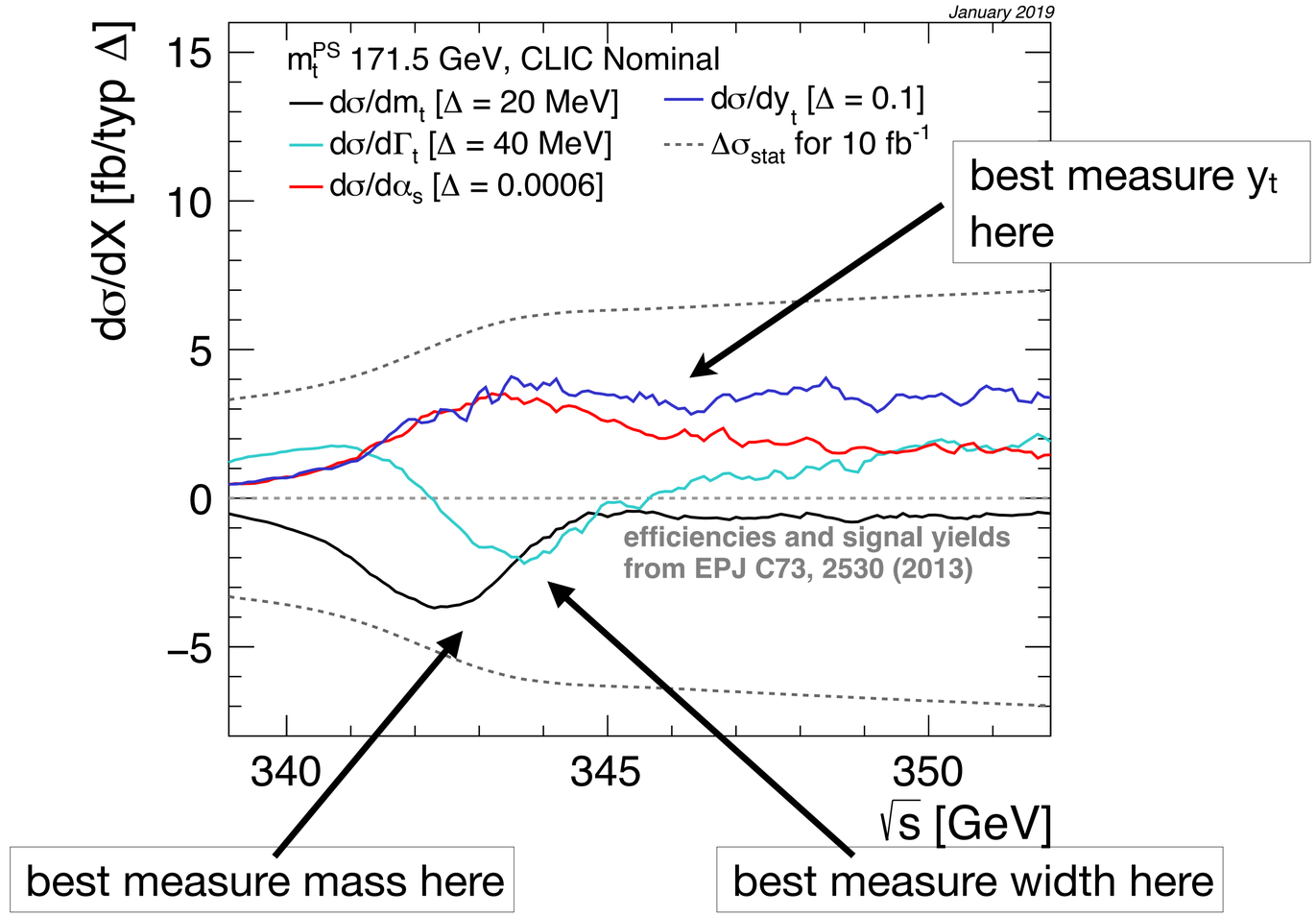
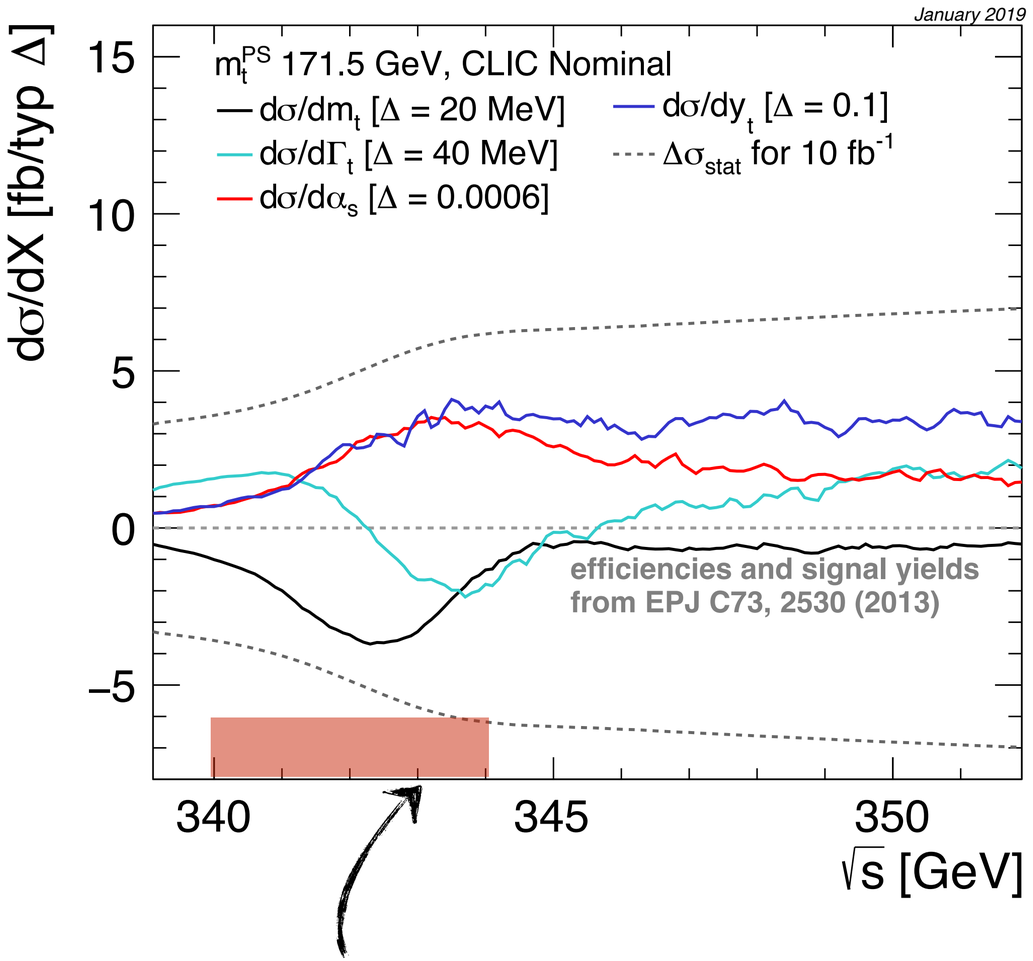


BUT: You have to find that point - and consider systematics!

Optimising Threshold Scans

Pinning down the position of the threshold

- Assuming you know the PS mass with 1 GeV precision from LHC (N.B. here you have to include all theory uncertainties - so *today* +- 1 GeV is realistic):
  The position of the optimum for the mass measurement is uncertain by **+- 2 GeV** (threshold = 2 x m_t)
  - In principle you can determine m_t with a **single measurement of ~ 5 - 10 fb^{-1}** to ~ 100 MeV -
    you need a 4 GeV wide window where this works to be safe given the LHC input -



sensitivity to mass provided over whole range

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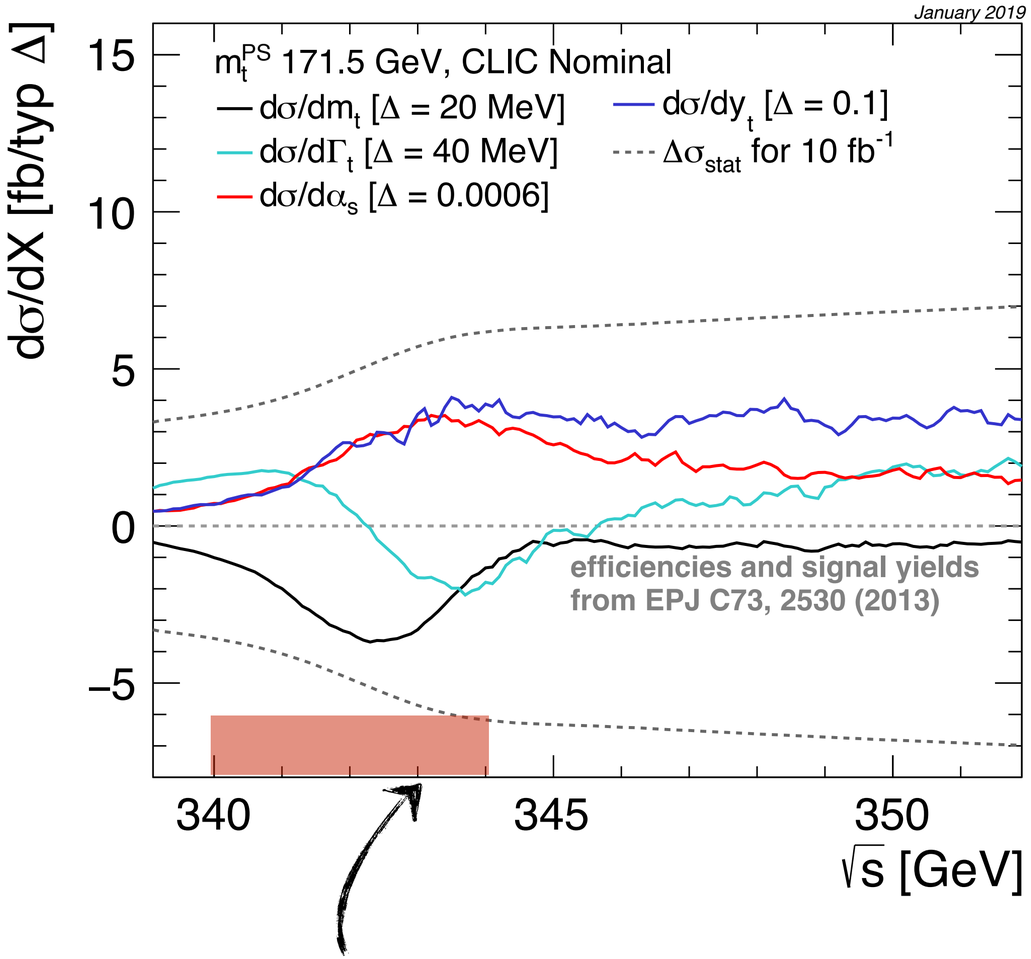


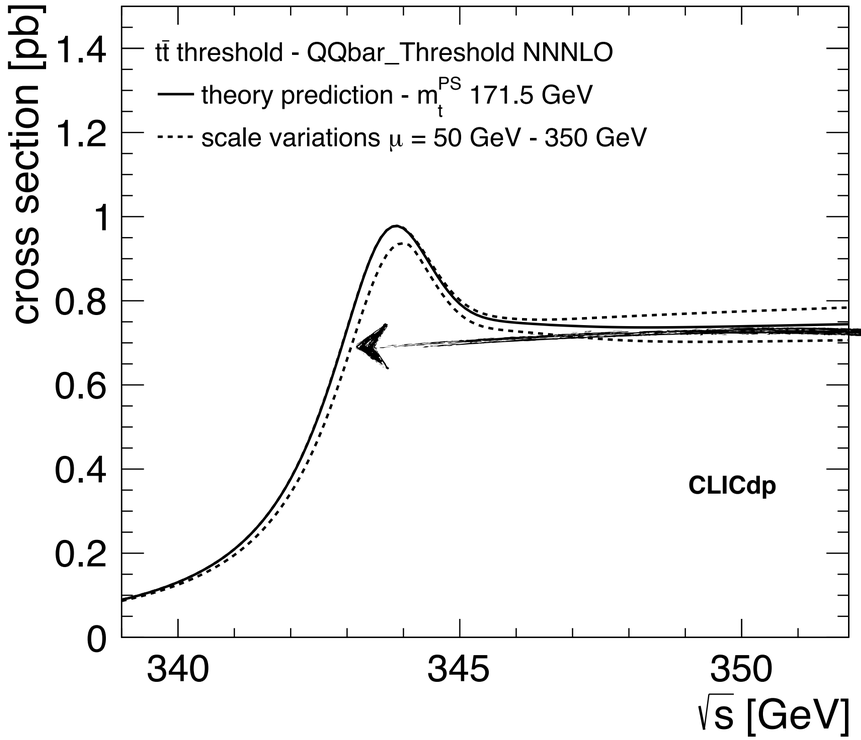
sensitivity to mass provided over whole range

N.B.: It is not unrealistic to assume we will know the mass with ~ 200 MeV precision (or even better) by the time a threshold scan would be done:

- Improved theoretical understanding of LHC mass definition
- Measurements at higher energy in e^+e^- -> $tt\gamma_{ISR}$

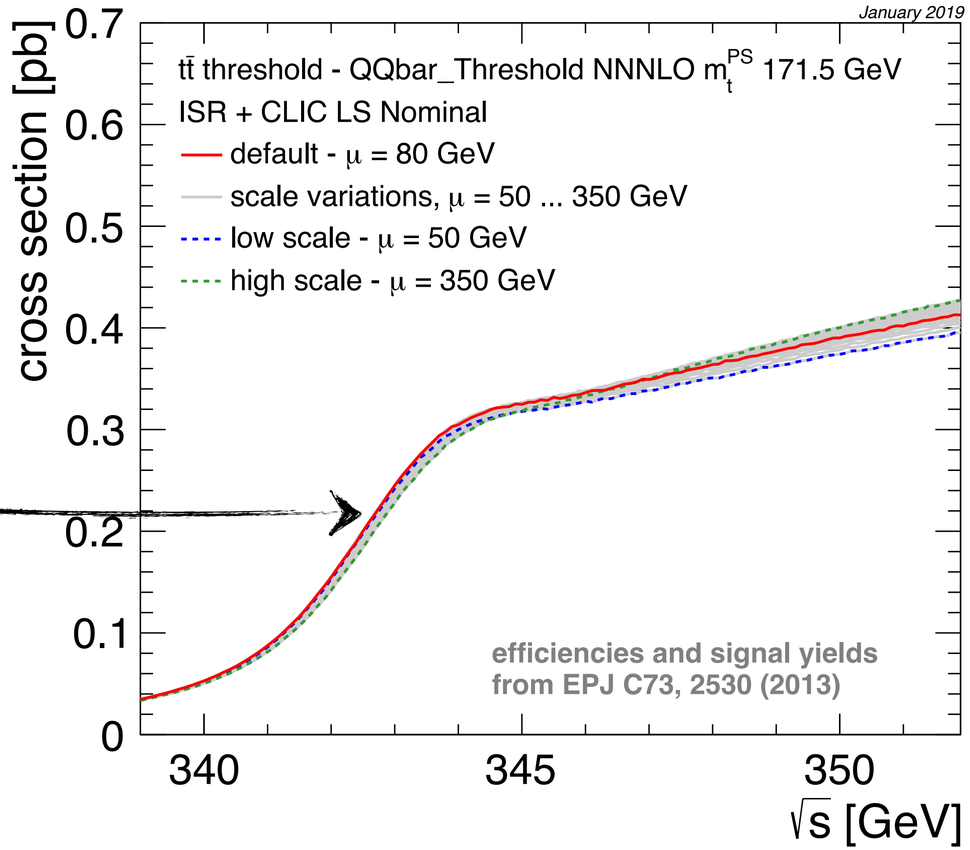
Optimising Threshold Scans

The Role of Theoretical Uncertainties



- Theory calculations available at NNNLO / NNLO + NNLL from two different groups: Remaining uncertainty around 3% (but energy - dependent): Given by scale variations

scale uncertainties
(N.B.: not symmetric, default scale results in maximal cross section in threshold region)



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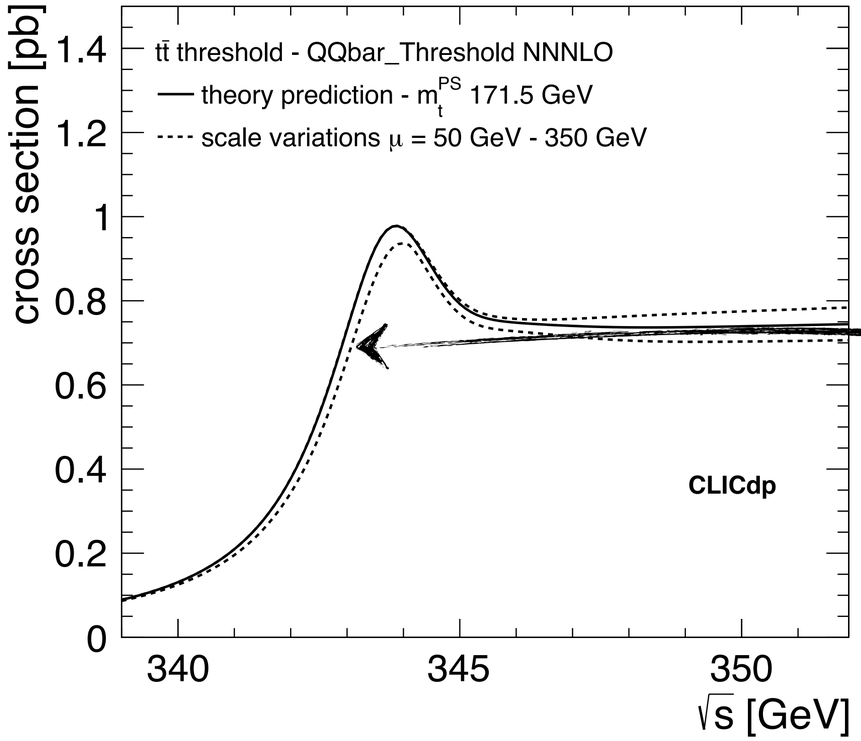

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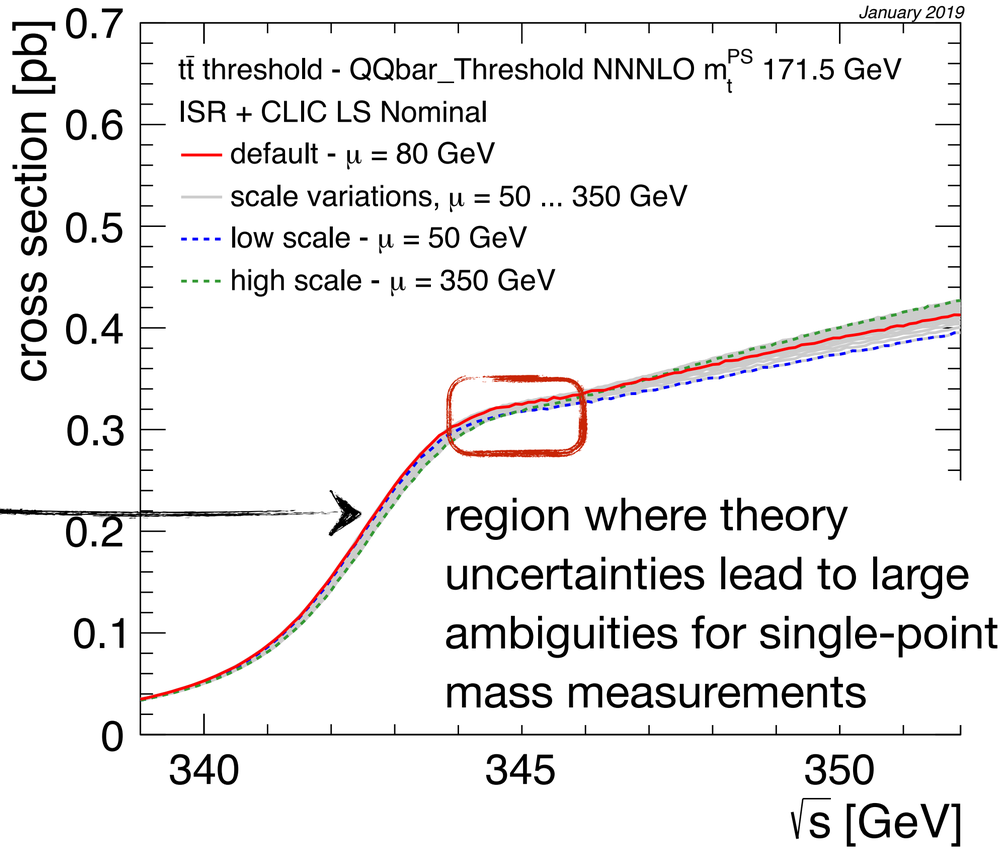

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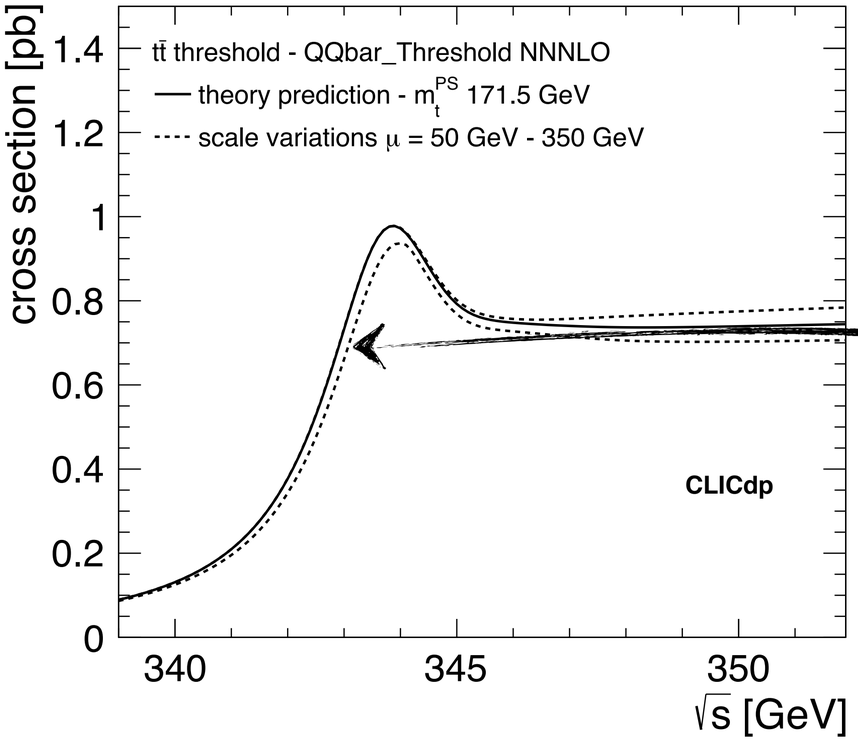

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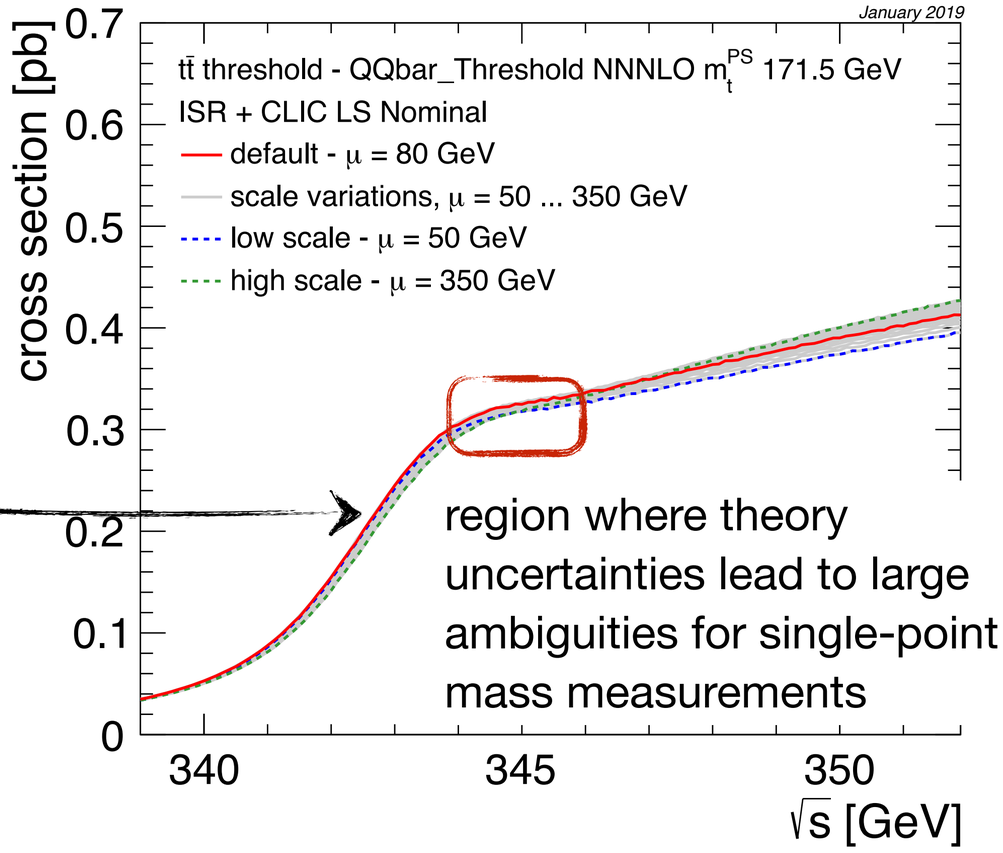
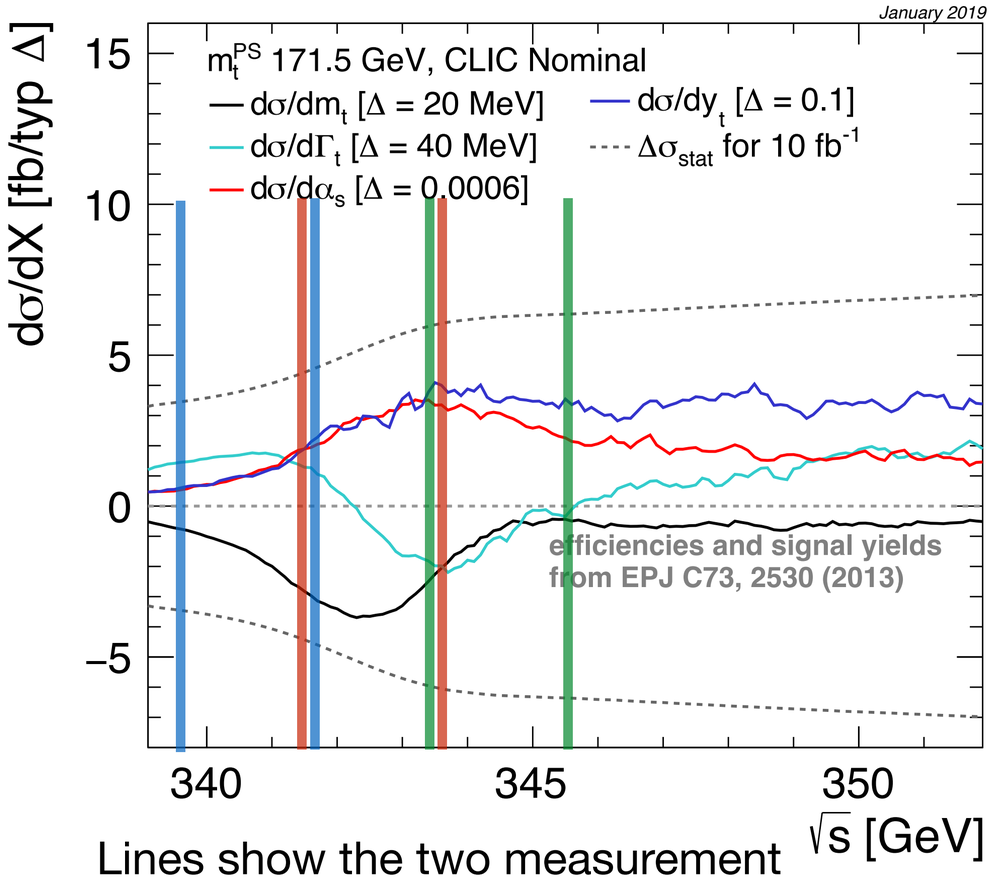


- In combination with luminosity spectrum a relatively wide region of energies would provide inconclusive results for a single measurement

Optimising Threshold Scans

Pinning down the position of the threshold - accounting for uncertainties



Lines show the two measurement points for three scenarios:

- LHC spot-on
- LHC 1 GeV low
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- When considering theory uncertainties, you need two measurement points with 5 fb^{-1} each to get a guaranteed top mass measurement with a precision of ~ 100 MeV (stat+theo - other systematics don't matter here)

The recipe: Measure at
2 x m_t^{PS},LHC - 1.5 GeV
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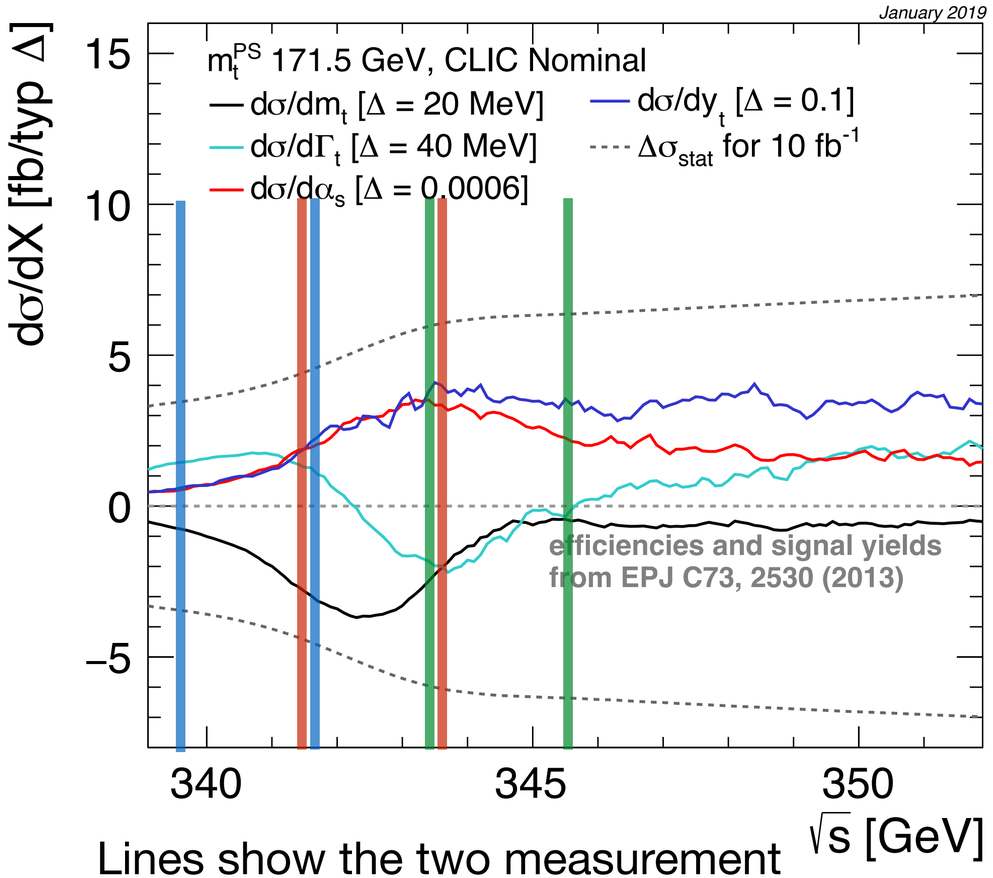

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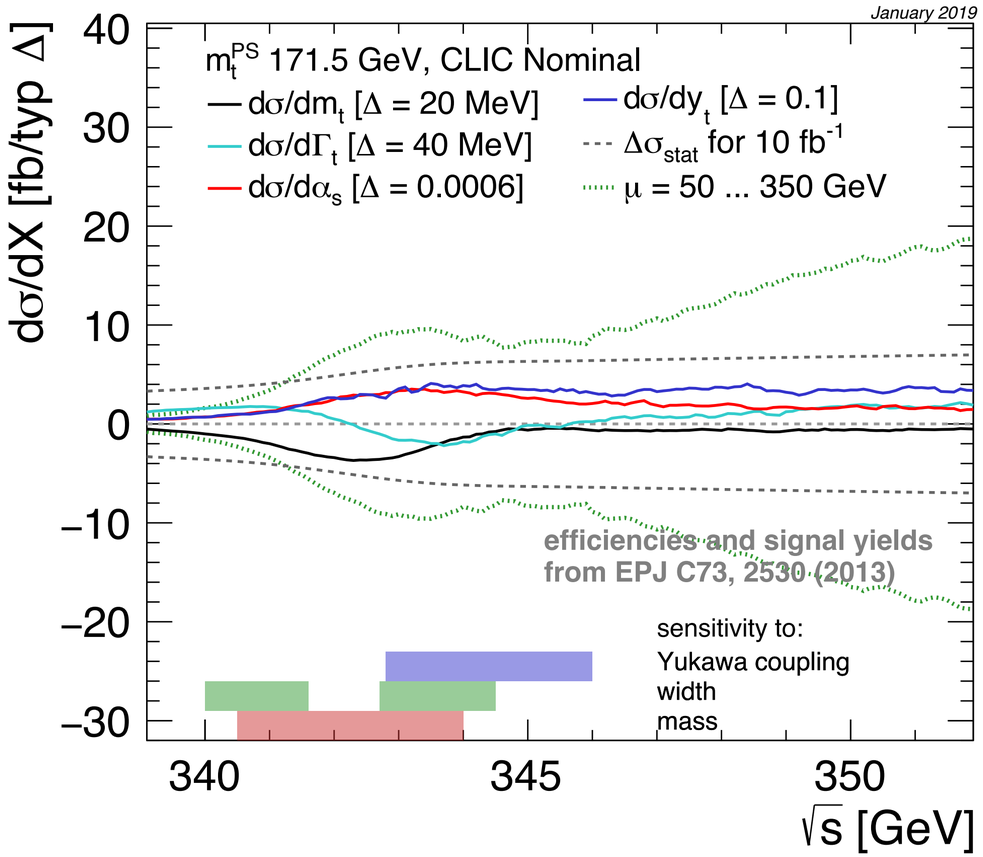
The threshold scan strategy:
Exploratory measurement of 2 x 5 fb^{-1}
to define measurement range
then regular threshold scan
N.B.: Also need one additional measurement **below threshold** to pin down backgrounds, single top, …

A New Scanning Scenario

Considering Mass, Width and Yukawa Coupling



- Different regions of the threshold sensitive to different parameters: Distribute luminosity over a range of regions
  - Going to very high energies, which in principle helps for y_t, does not make much sense: Growing theory systematics

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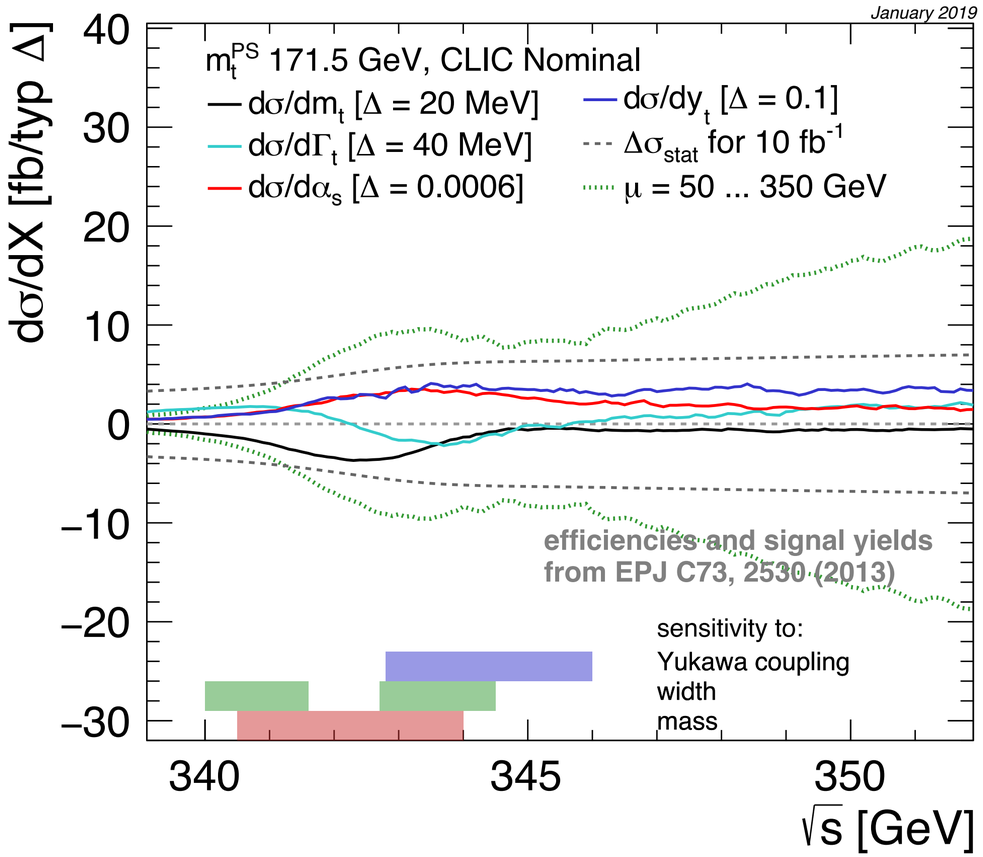

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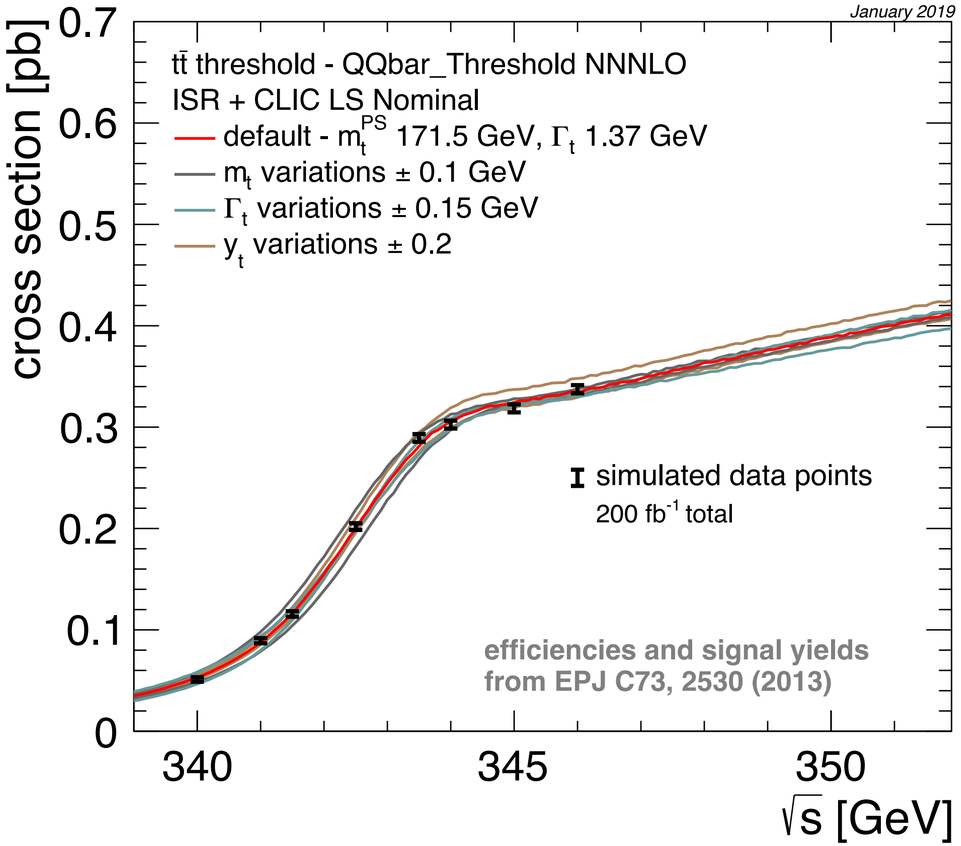


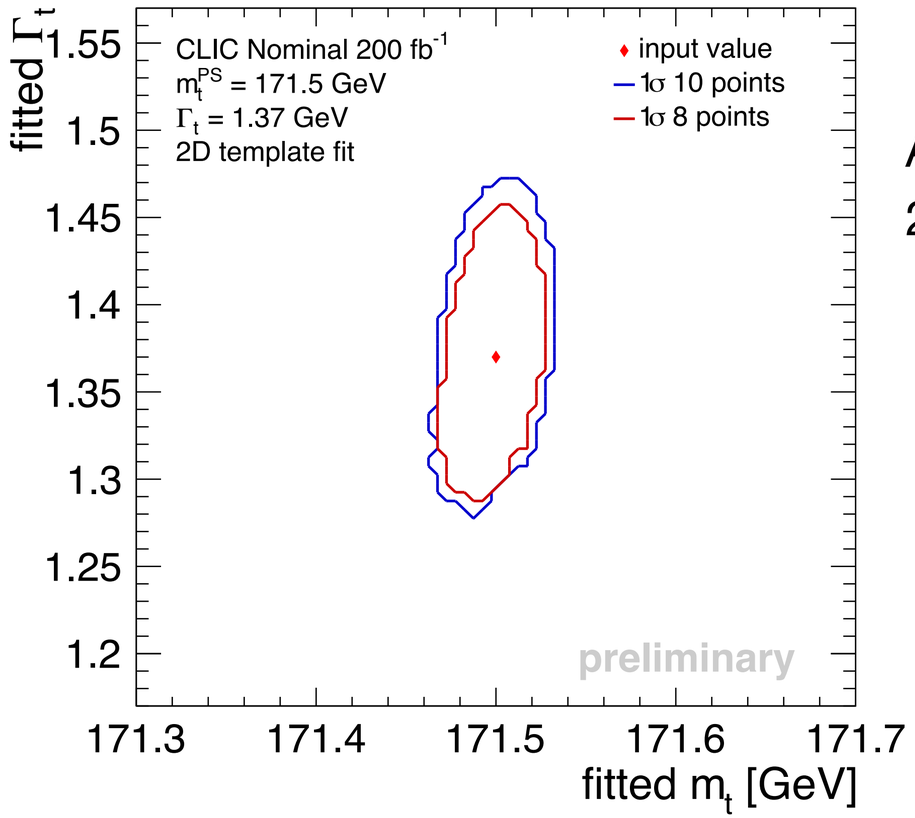
➪ As a (reasonable) guess: An **8-point scan** spanning 6 GeV

[340, 341, 341.5, 342.5, 343.5, 344, 345, 346]

A New Scanning Scenario: Results

For the Nominal Spectrum, for 200 fb^{-1}

- Mass: **13.3 MeV** (stat), **-30.4 MeV** (α_s [10^{-3}]), **45.8** (scale)
- 2D extraction of mass and width



Area of 1σ contour:
25% smaller

[*10 point scan:*
16.0 MeV (stat), -30.5 MeV (α_s [10^{-3}]), 42.2 ([scale)]

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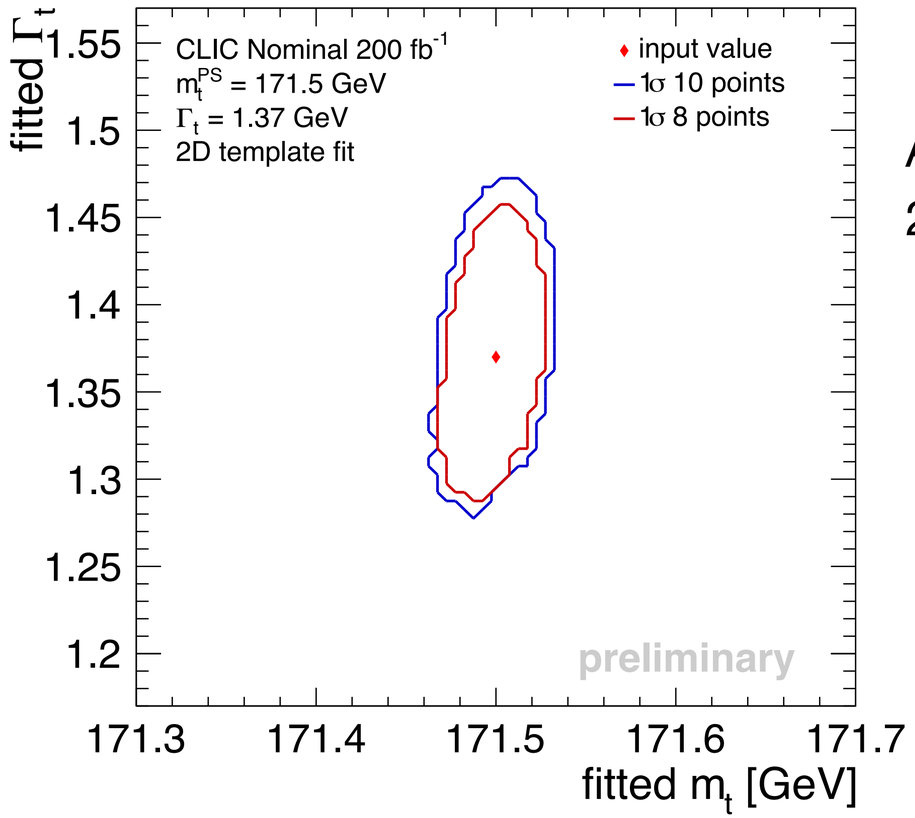

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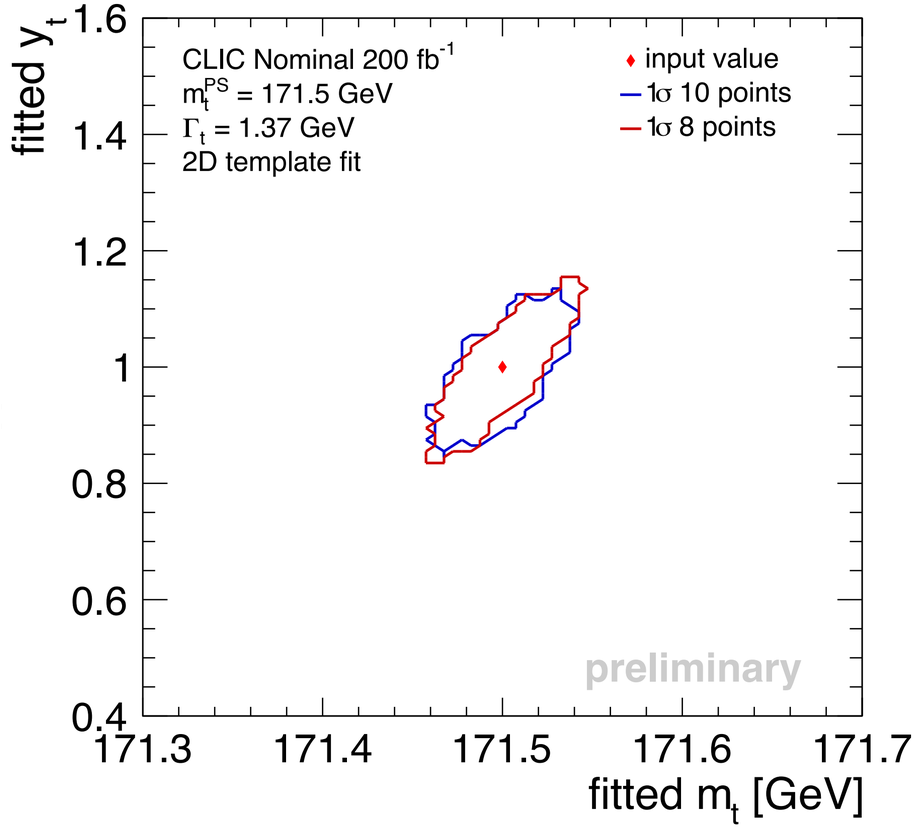

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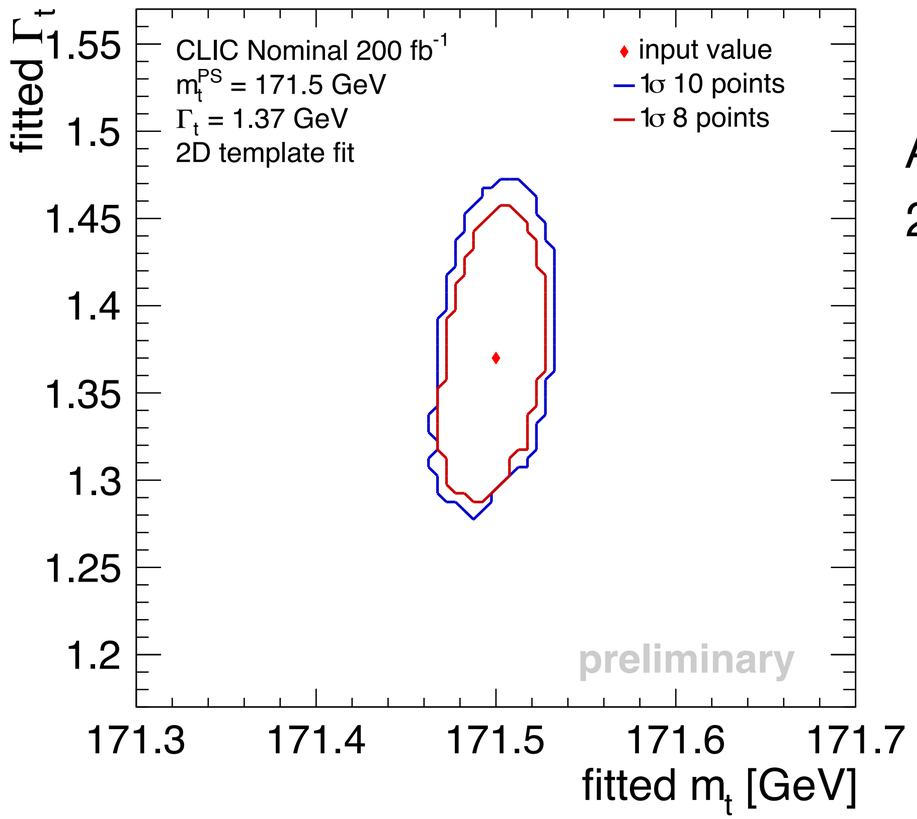

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Main benefit for mass and width, slightly negative for Yukawa coupling

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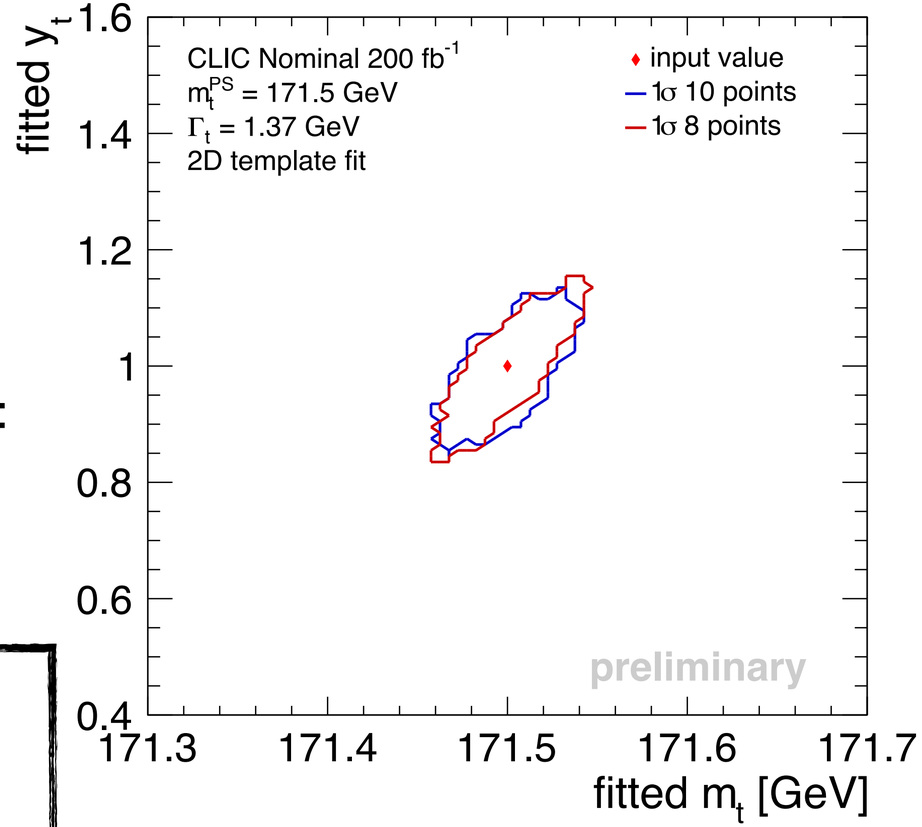

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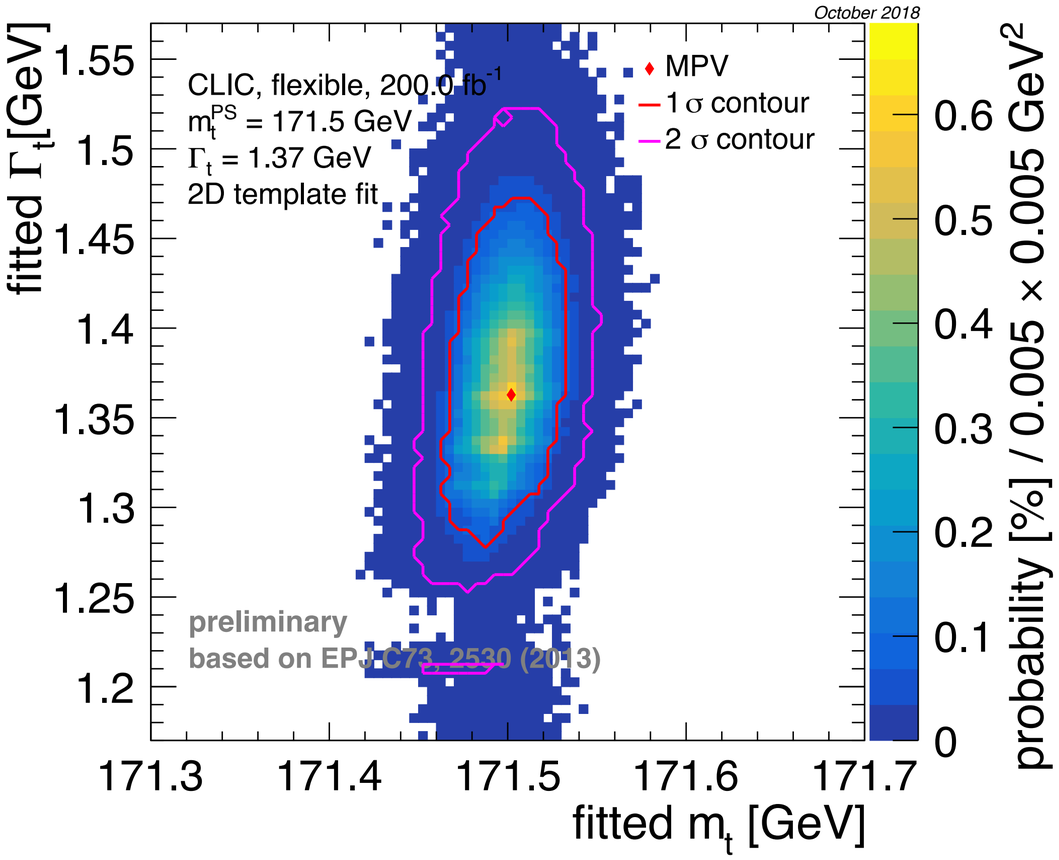
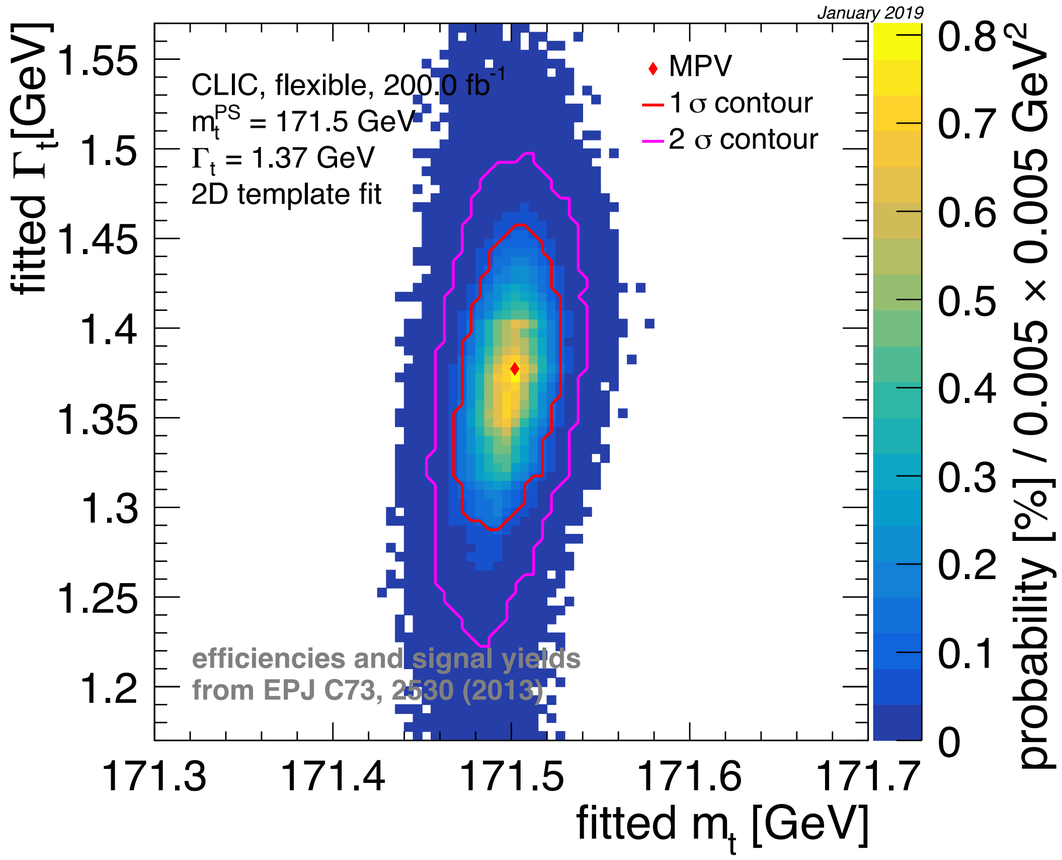
For the Nominal Spectrum, for 200 fb^{-1} - with a closer look at the 2D fits





- Improved sensitivity on mass / width by concentrating data in regions sensitive to those parameters

Effect of the Luminosity Spectrum

Nominal vs 90% Charge Options

- CLIC is flexible: By changing parameters, the luminosity spectrum can be changed
  - Possibility for a “cleaner” spectrum - at the price of reduced luminosity

The latest scenario (10/2018):

3 options: Nominal, reduced charge (90%), low charge (70%)

- With improved tuning of higher-charge options, low charge became uninteresting: No significant advantage over the 90% charge option, but almost x2 luminosity penalty

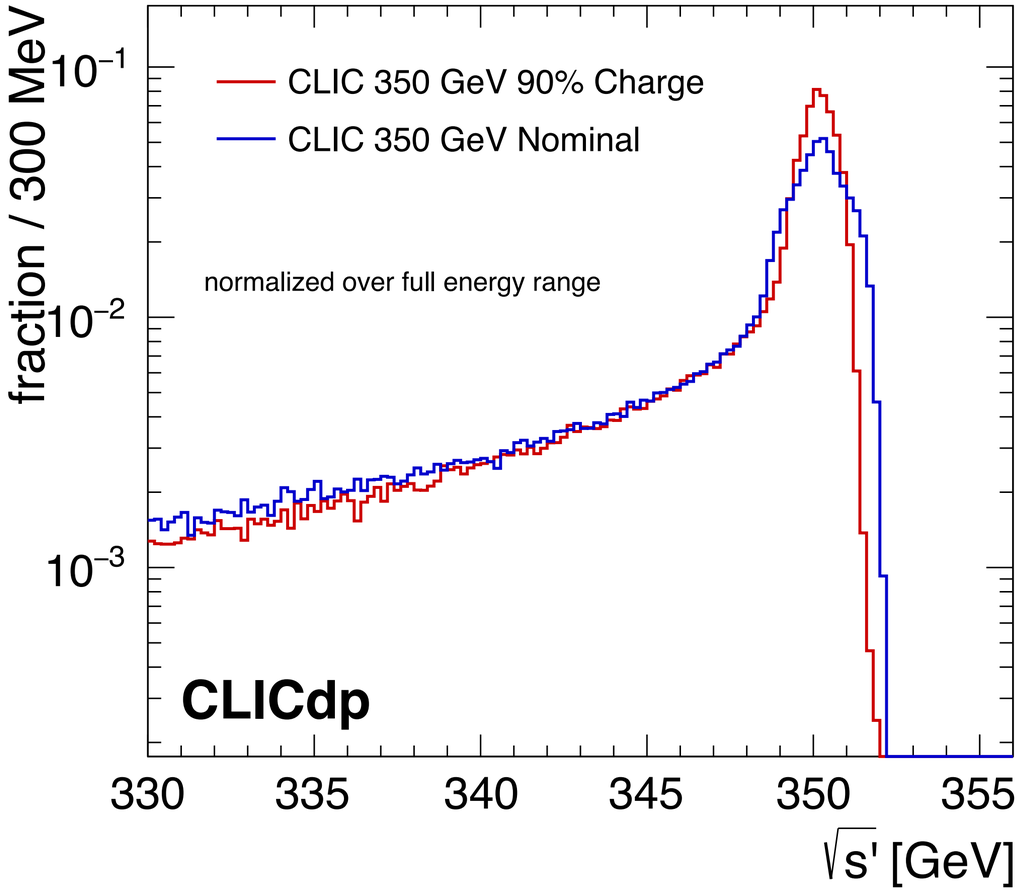
Luminosities:

Nominal: 1.47 x 10^{34}

90% Charge: 1.12 x 10^{34}

30% longer running time for the 90% charge option to achieve the same L_{int}

➪ Break-even if 90% Charge provides ~ 15% smaller uncertainties for the same L_{int}

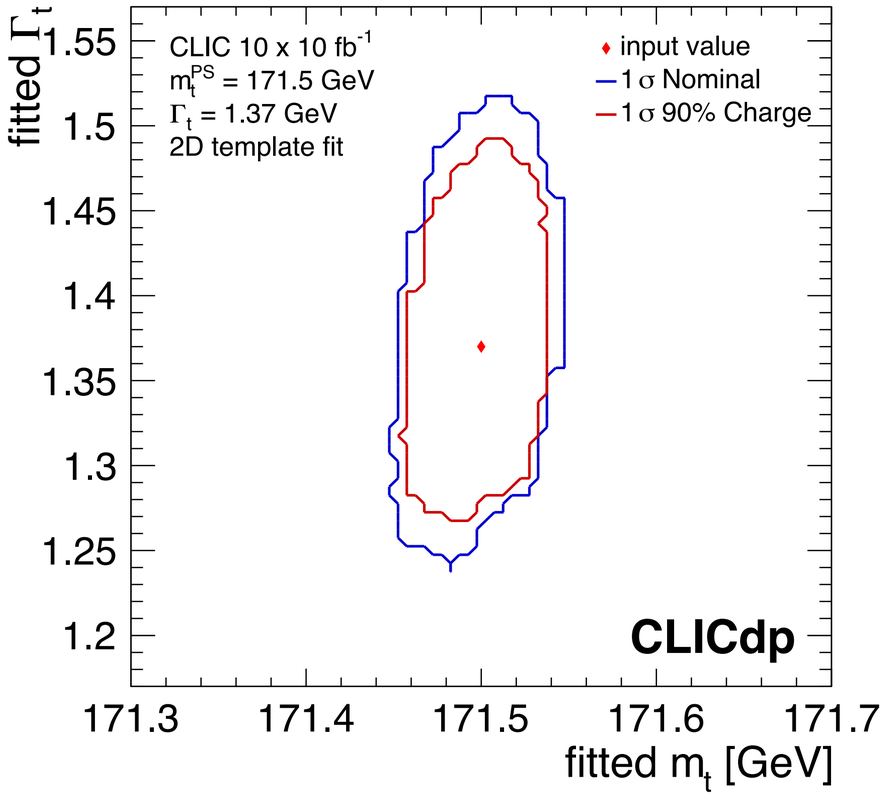


Effect of the Luminosity Spectrum

In the Top Paper: With a 10 point scan

N.B.: 100 fb^{-1}

- Mass: 22.4 MeV (stat) -> 20 MeV (stat):
  10% improvement with 90% Charge spectrum



Extent of 1σ contour along width axis:

275 MeV -> 225 MeV: ***~ 22% improvement***

⇨ 90% charge yields smaller uncertainty for same running time

on the mass axis:

~ 16% improvement -

at the break-even point

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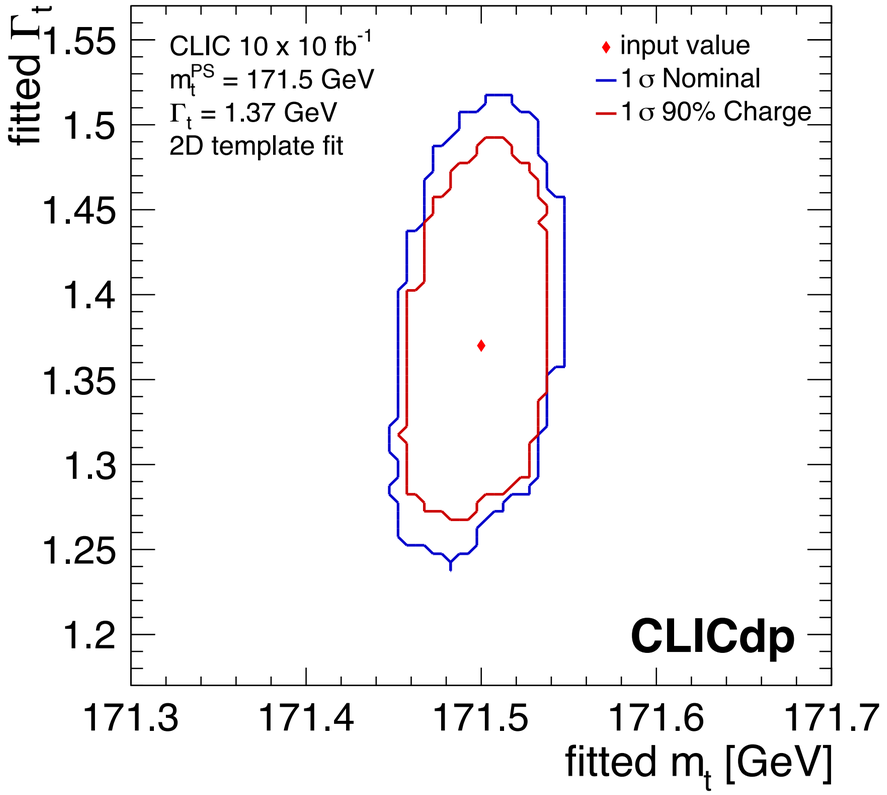

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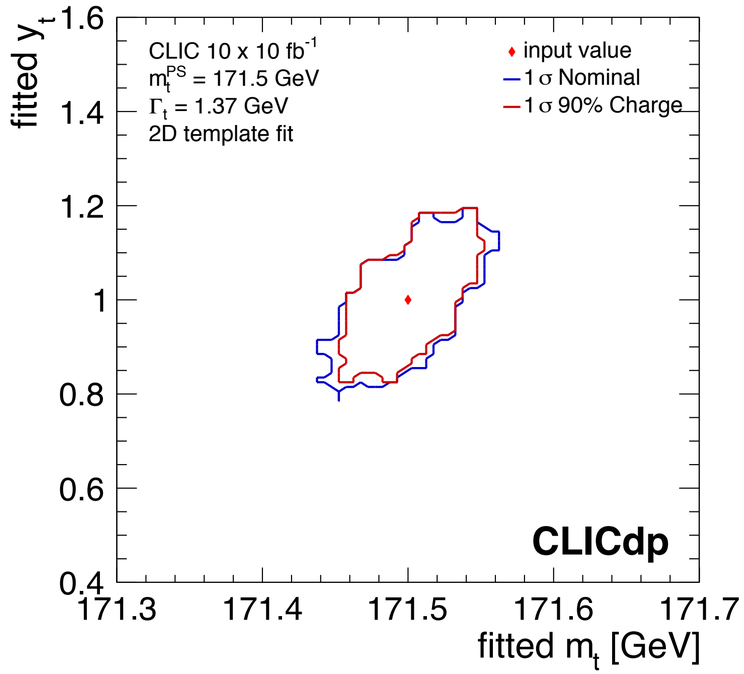
For the Yukawa coupling: Only very little advantage with 90% Charge spectrum: sensitivity primarily from region above the threshold



The 8 Point Scan with reduced Charge: Results

For 200 fb^{-1}

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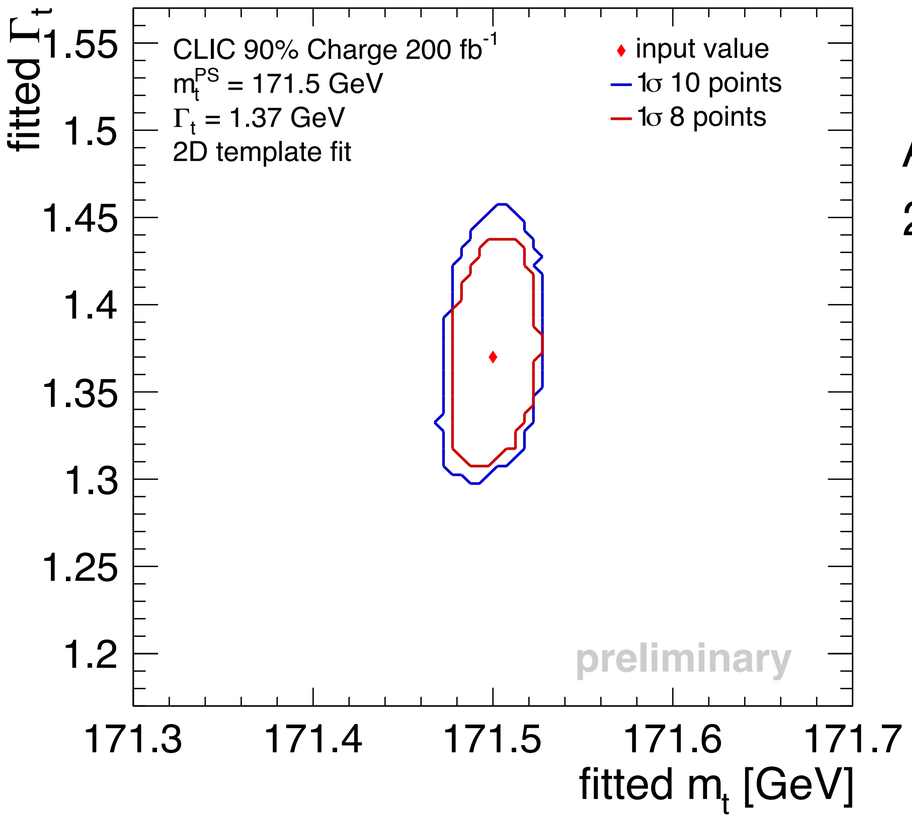
- 2D extraction of mass and width



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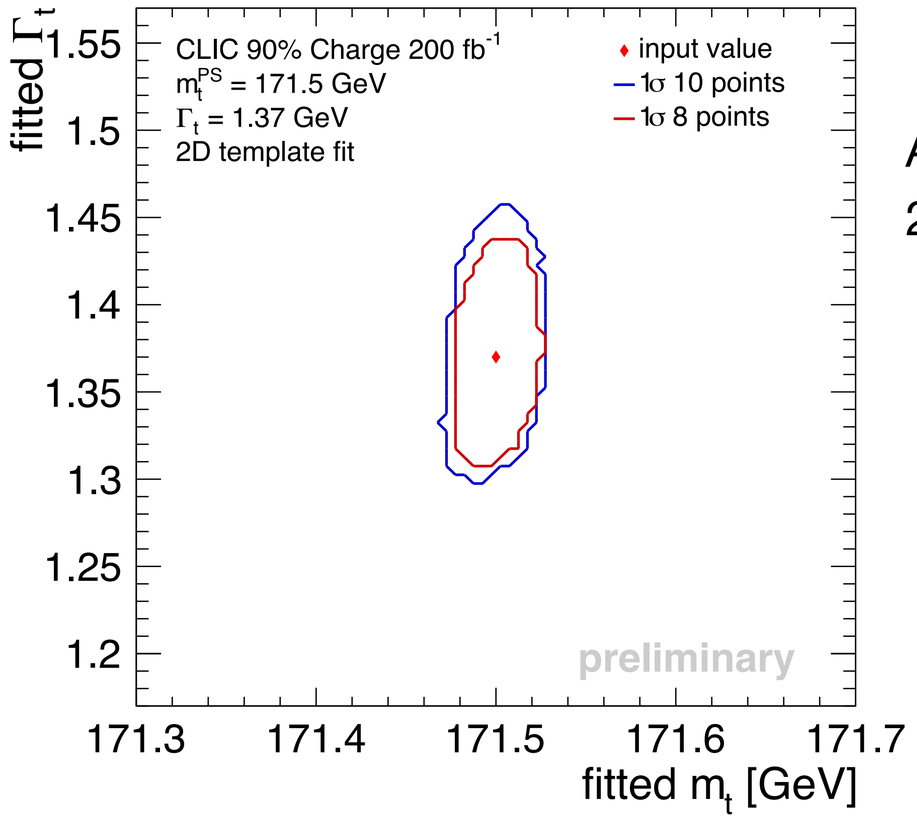

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Area of 1σ contour:
2% larger

Main benefit for mass and width, slightly negative for Yukawa coupling

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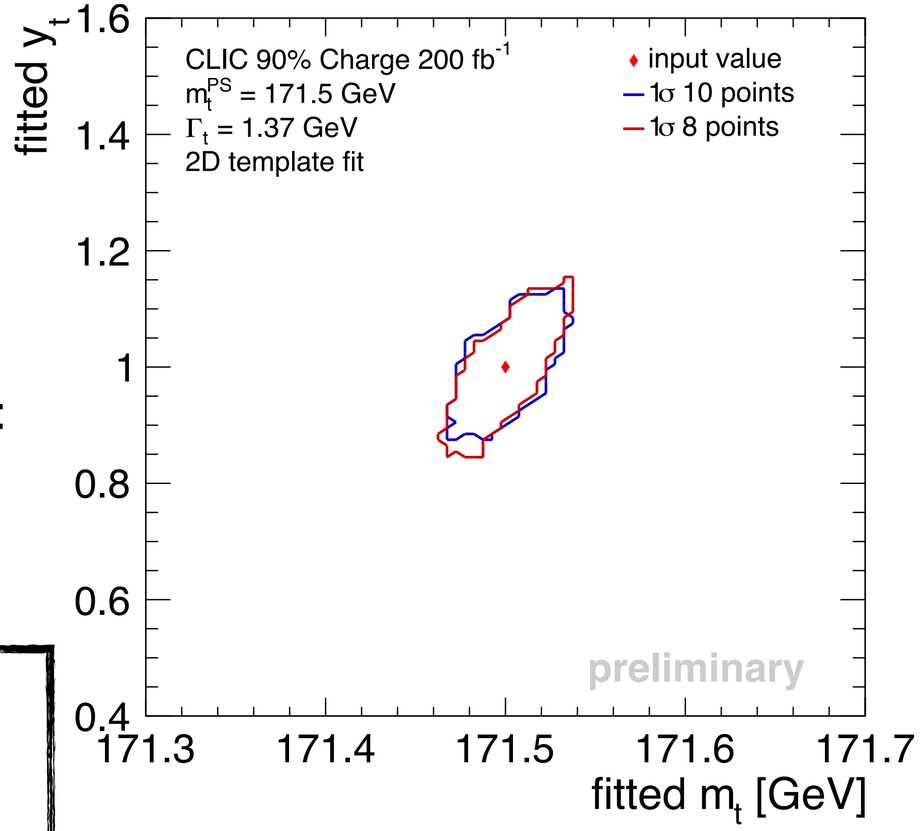
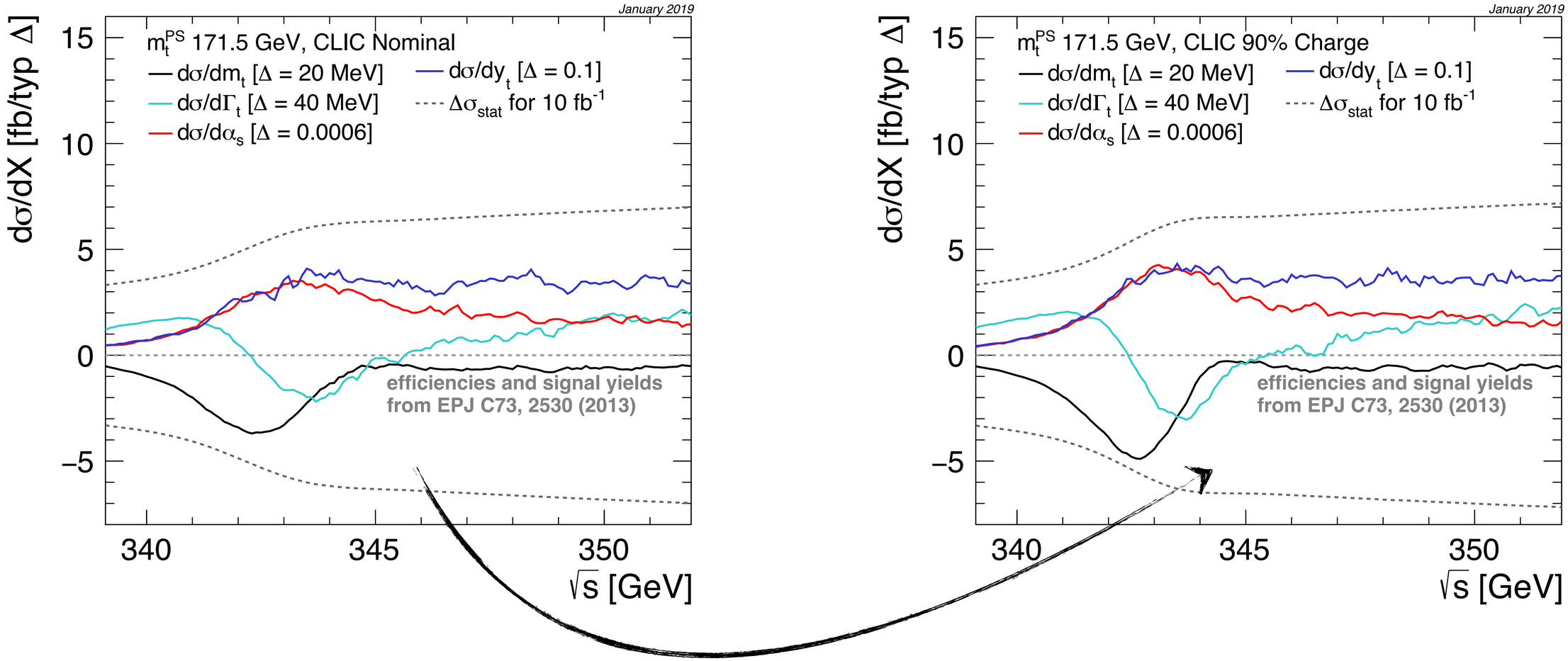


The Impact of the Luminosity Spectrum

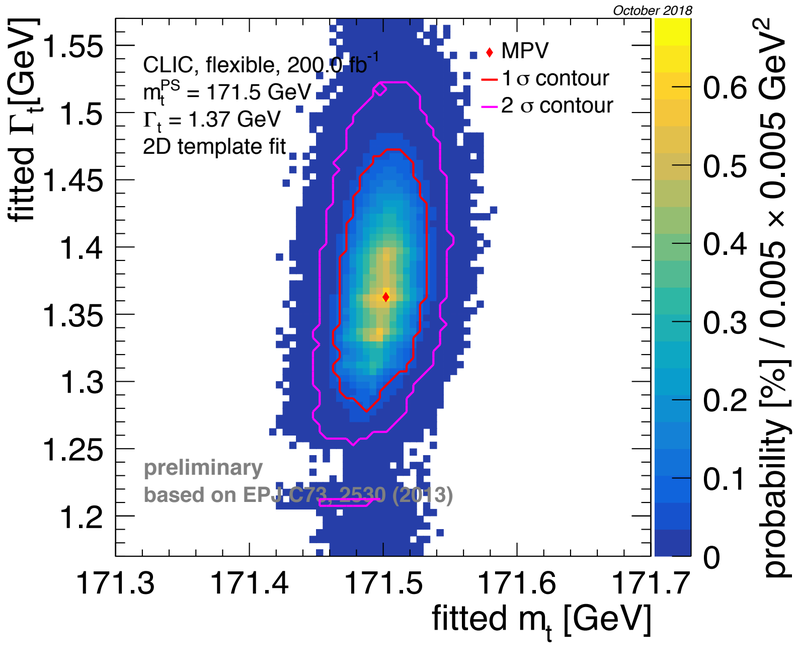
A Closer Look



- "Sharper" luminosity spectrum improves separation of mass and width effects, increases statistical sensitivity

The Impact of the Luminosity Spectrum and Scan Range

Illustrated for 2D Fits of Mass & Width



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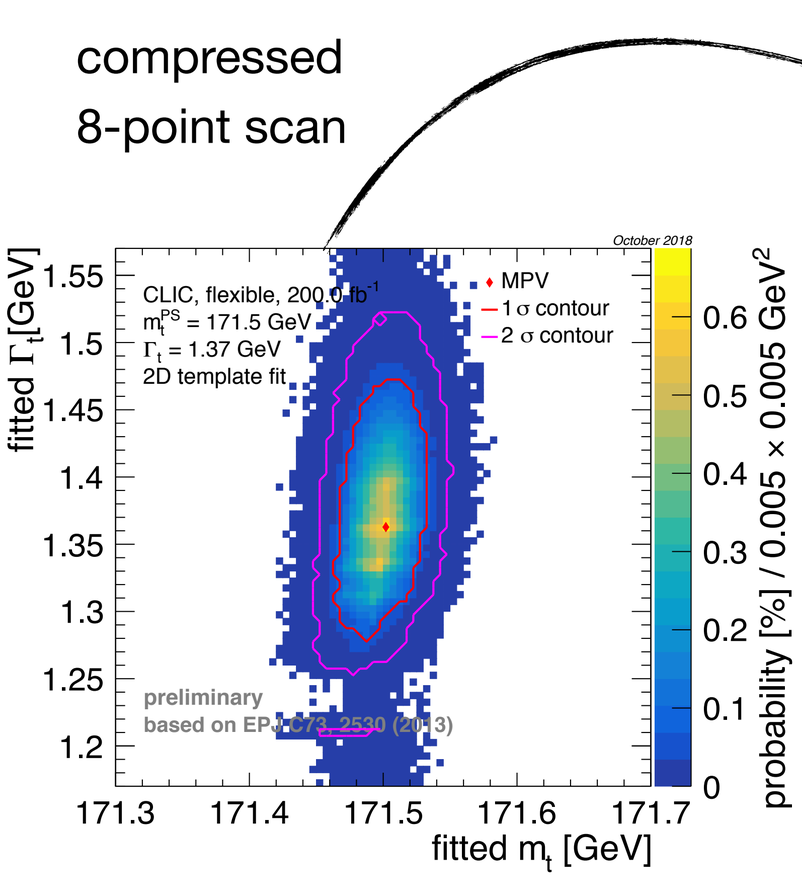
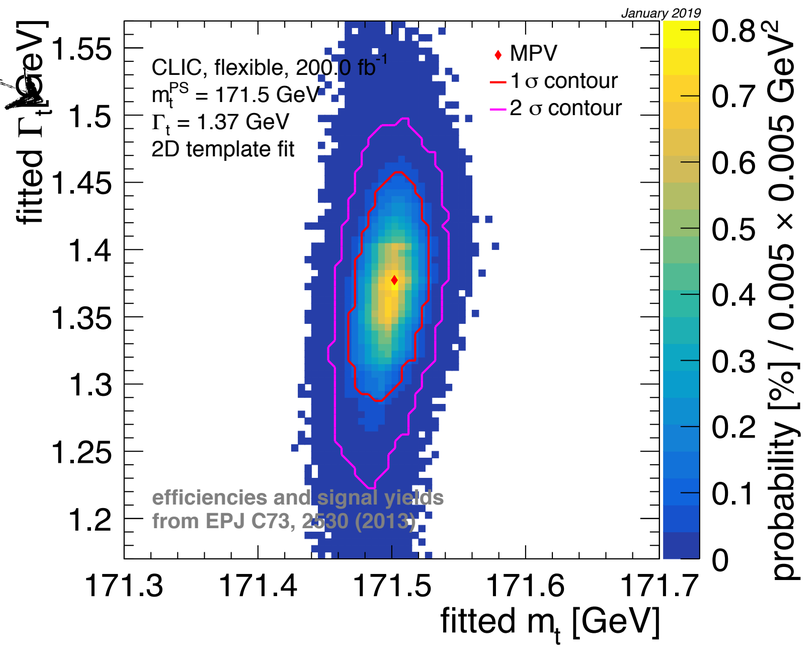
compressed
8-point scan





The Impact of the Luminosity Spectrum and Scan Range

Illustrated for 2D Fits of Mass & Width

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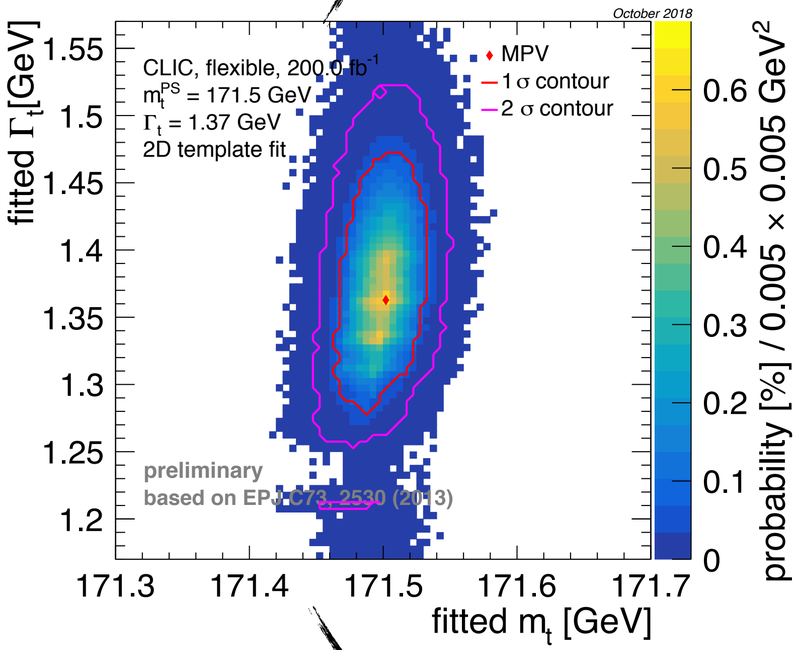
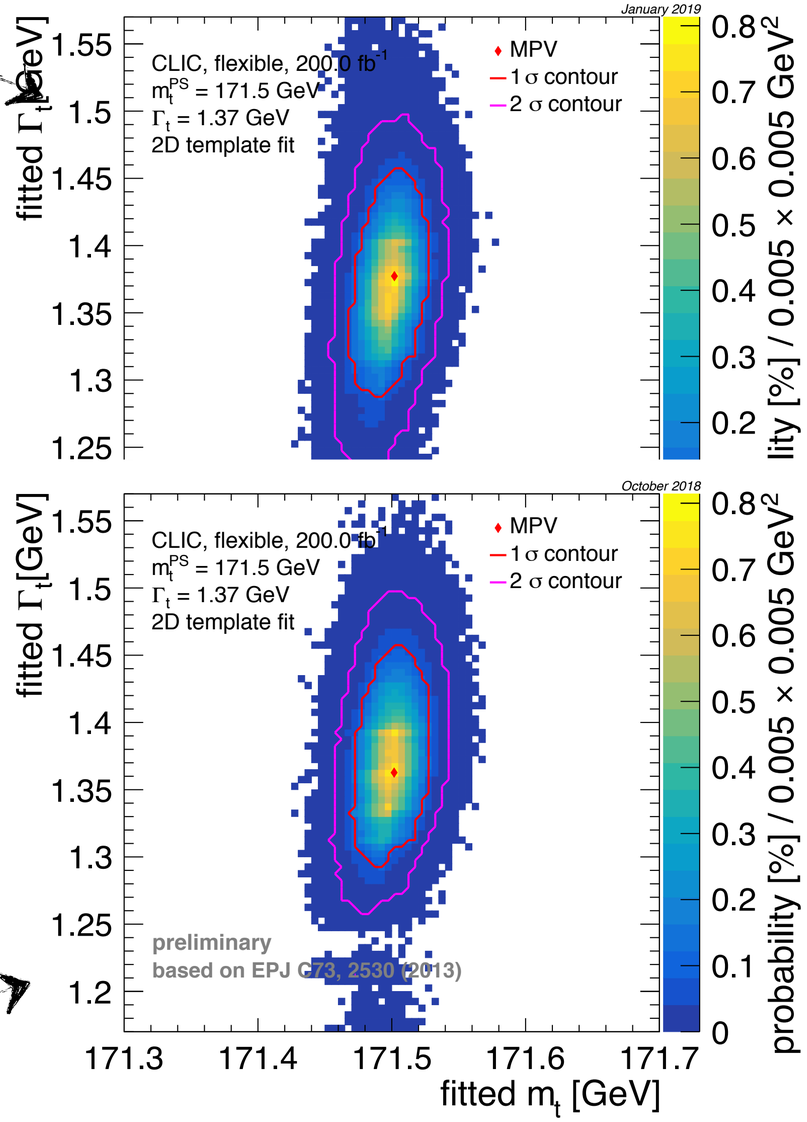
8-point scan





"sharper"
lumi spectrum

Frank Simon (fsimon@mpp.mpg.de)

The Impact of the Luminosity Spectrum and Scan Range

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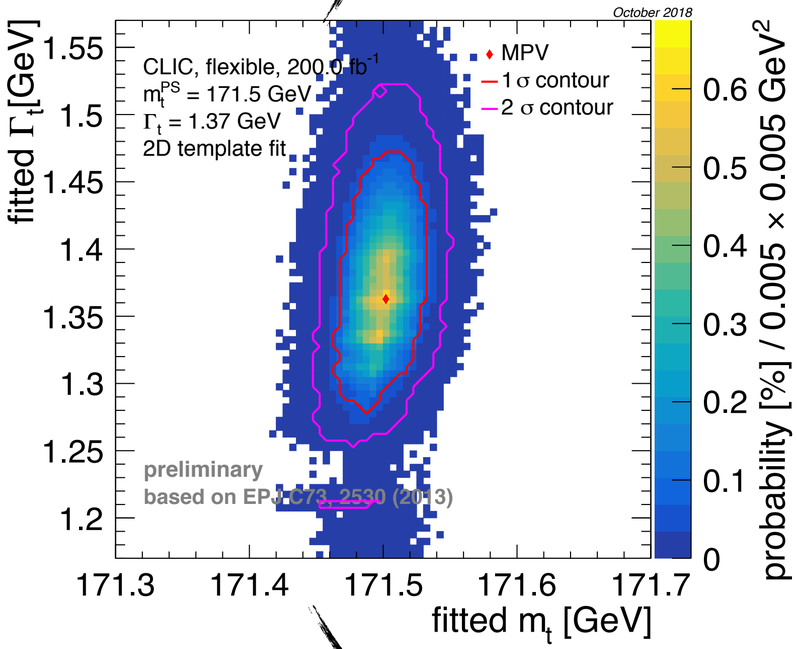

“sharper”
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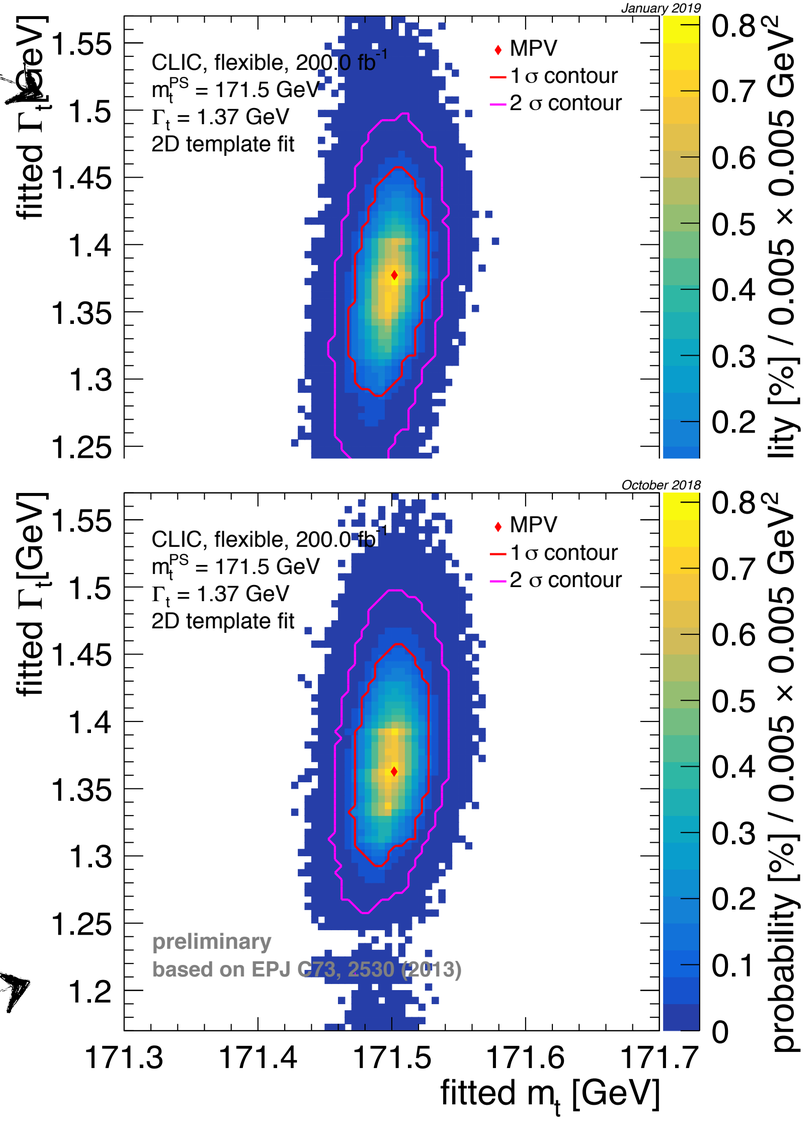

“sharper”
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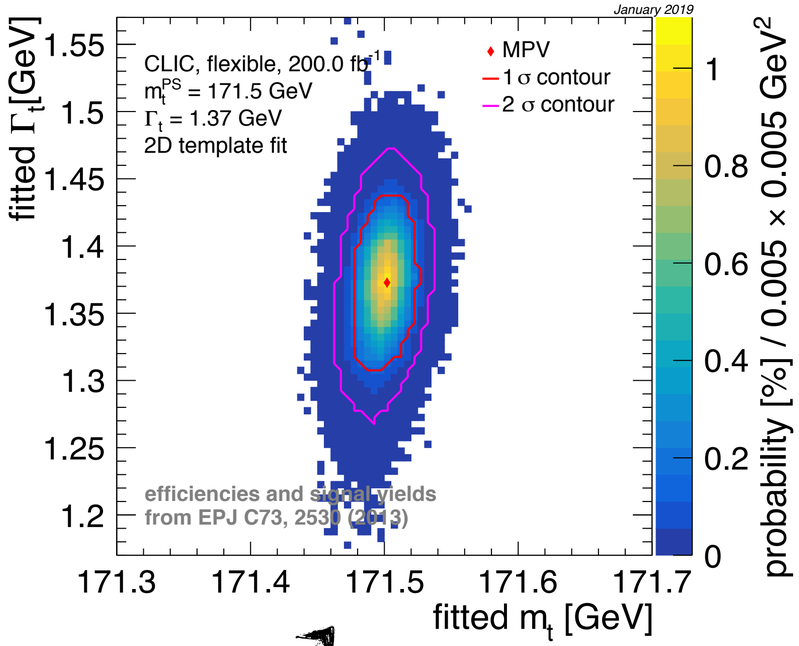

compressed
8-point scan

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Summary

- A threshold scan can be used for more than just the mass
  - Measurement of width to a level of ~ 100 MeV including theory uncertainty appears feasible in a combined fit together with the top quark mass
  - In principle also a measurement of the Yukawa coupling - but reduced sensitivity due to sizeable correlation with mass in 2D fit, large theory uncertainties: ~ 13% from scale variations, 10% from α_s with present WA
- The scan range can be optimised to better use the available total integrated luminosity
  - Needs a knowledge of the mass on the 100 MeV - level: Possible with 2 x 5 fb^{-1} if placed right
- The luminosity spectrum affects the power of 2D fits - a reduced charge option with 90% of the nominal bunch charge increases the sensitivity for mass and width - improvements outweigh the luminosity penalty in particular for the width measurement

Extras