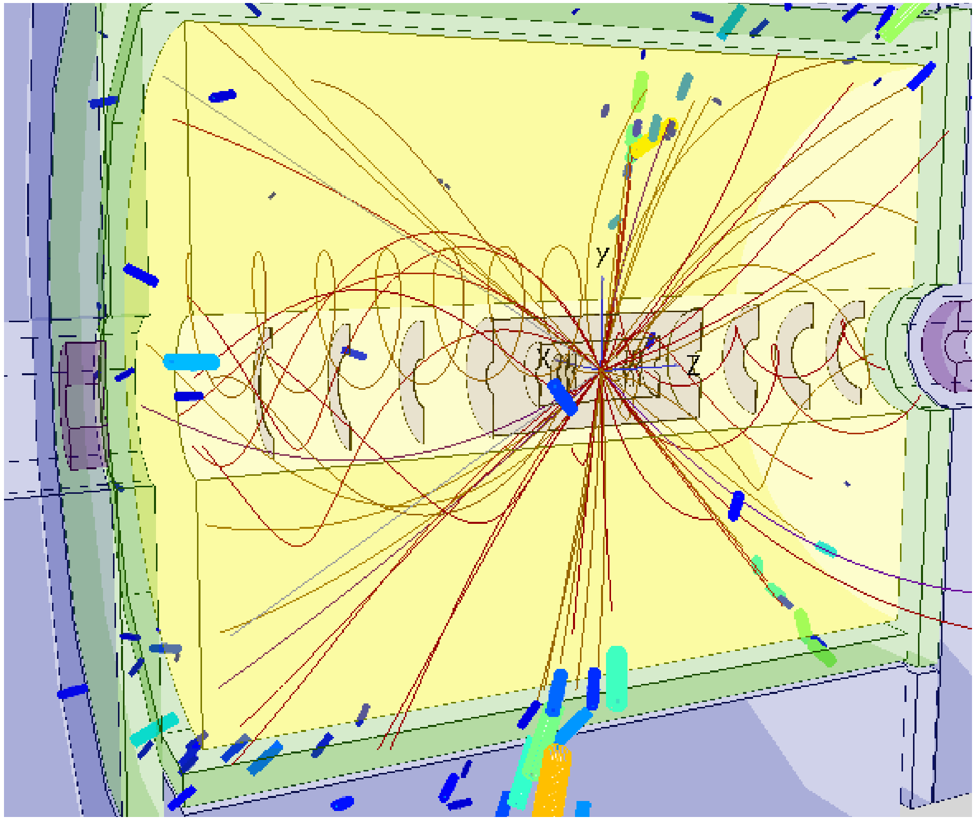
Extracting top-quark mass and Yukawa coupling from the threshold scan

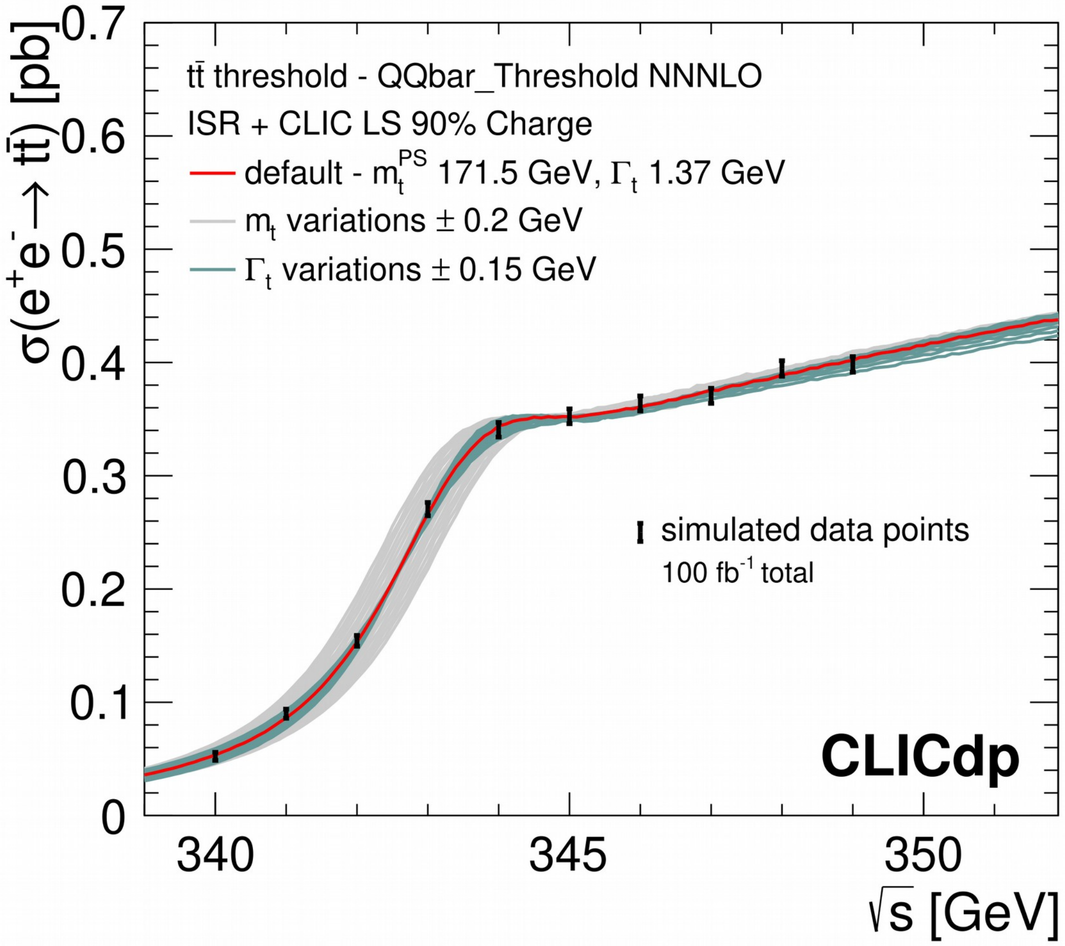


Kacper Nowak, Aleksander Filip Żarnecki

FACULTY OF PHYSICS UW

Motivation

Motivation

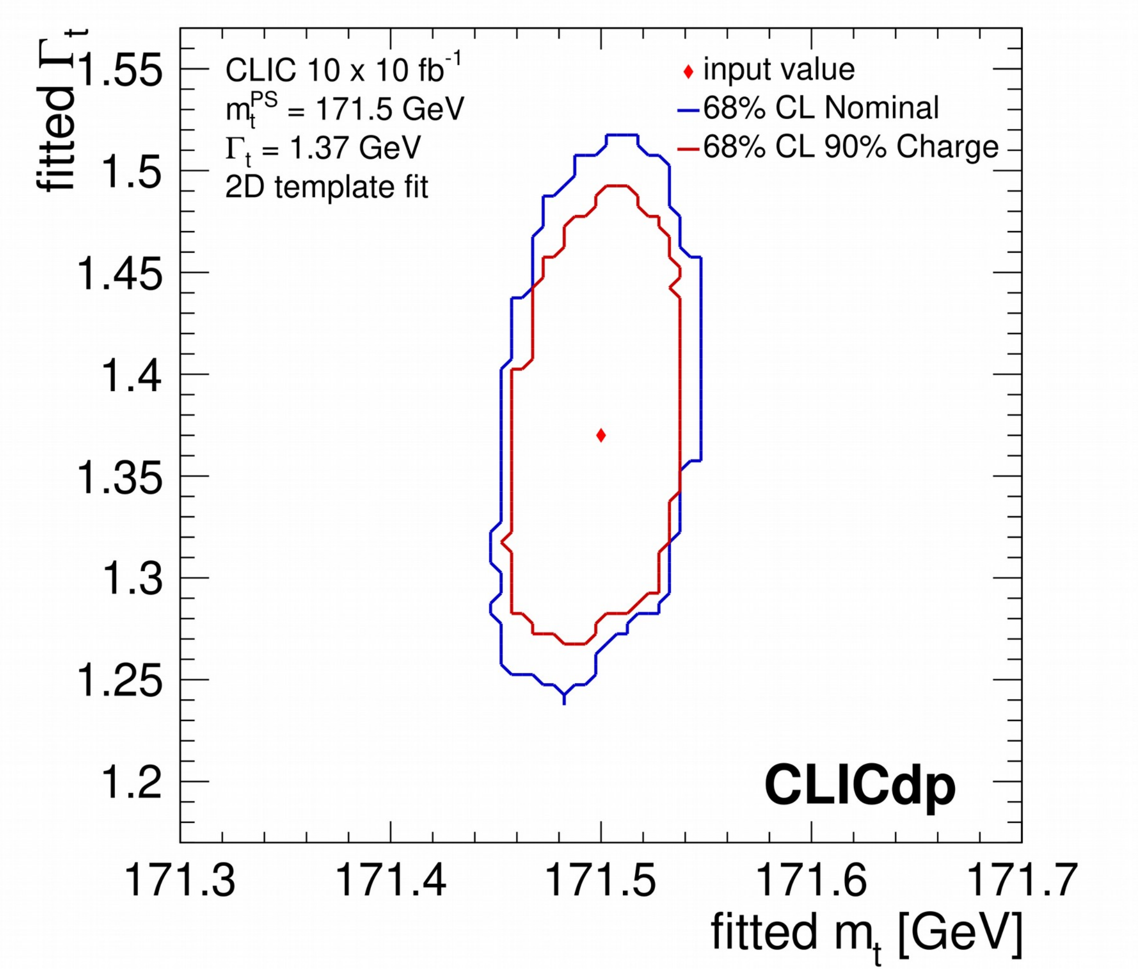


Threshold scan is assumed to be the most precise method to determine the top quark mass.

Baseline scenario assumes 10 scan points with 10 fb^{-1} each

H.Abramowicz et al. (CLICdp Collaboration), *Top-Quark Physics at the CLIC Electron-Positron Linear Collider*, **arXiv:1807.02441**, accepted for publication in JHEP

Motivation

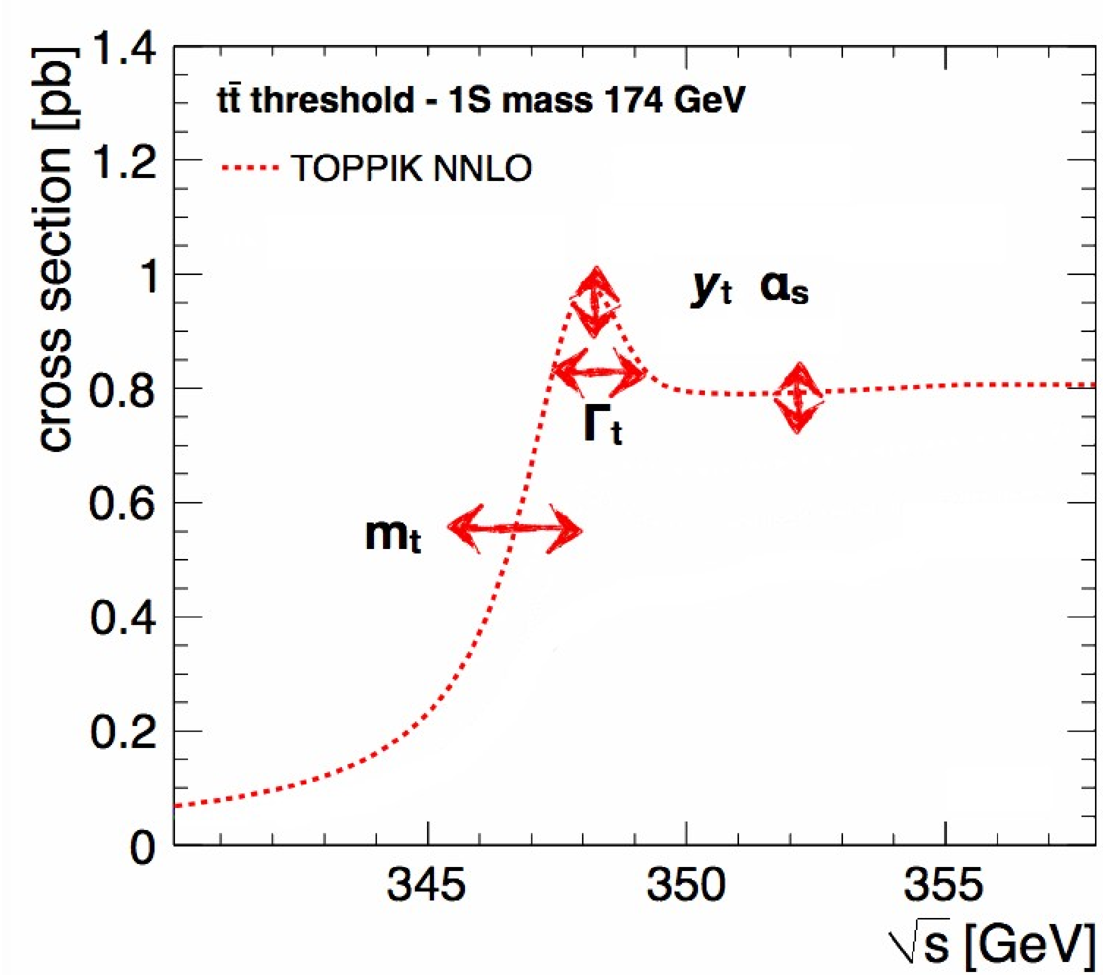


Dedicated study for CLIC indicates that the statistical precision of the measurement is around 20 MeV

However, this is based on a 2-D mass-width fit...

arXiv:1807.02441

Motivation



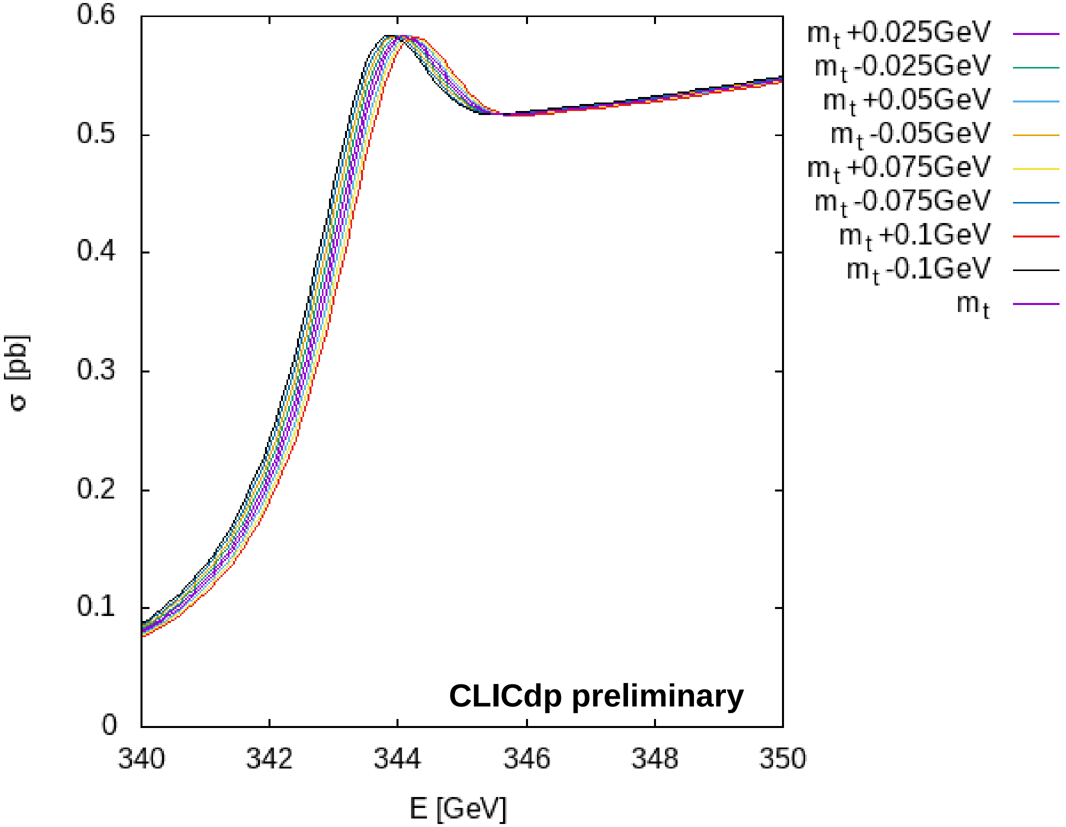
Threshold cross section depends on other model parameters as well…

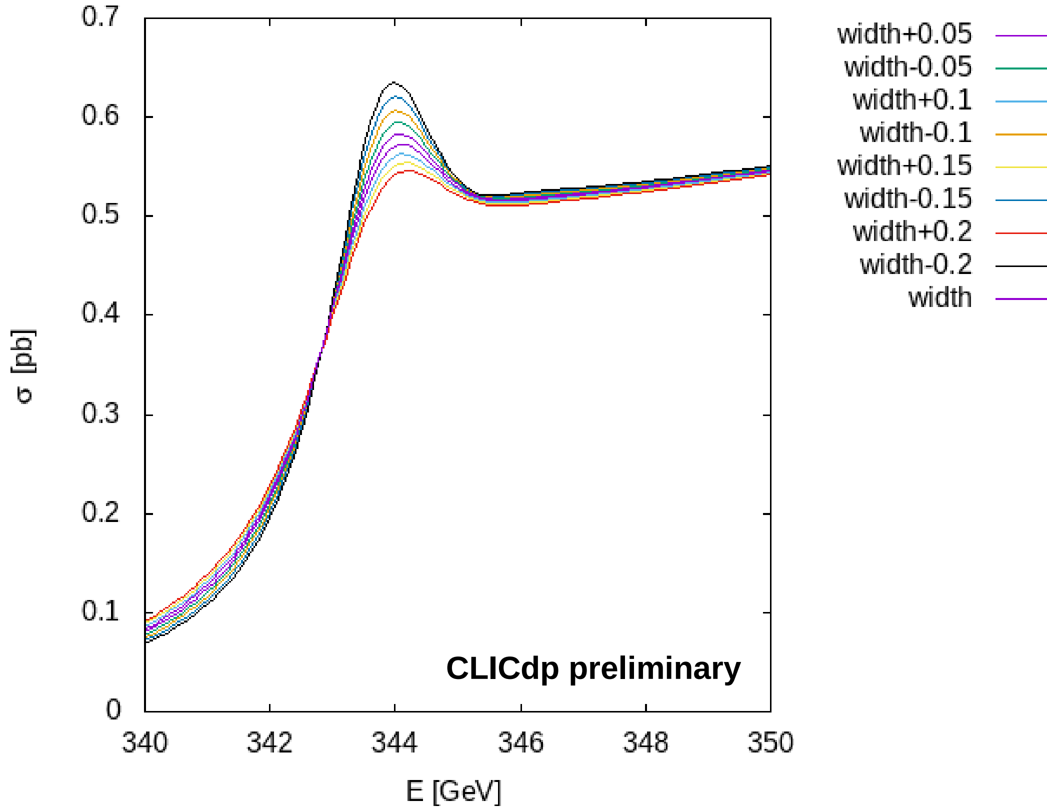
Does it influence m_t determination precision?

Can the scan procedure be optimized?

Fit method

Cross-section templates

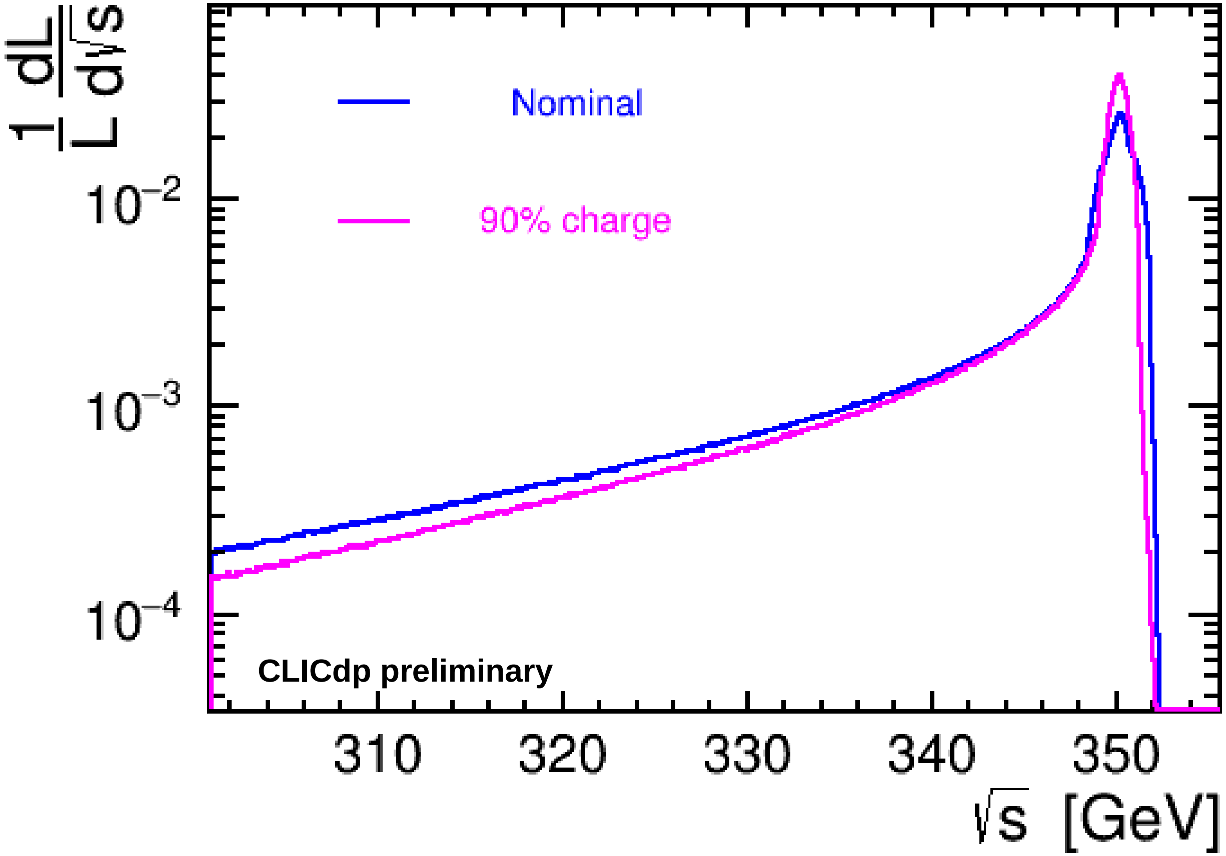




Templates generated with **Qqbar_threshold**

Beneke, M. et al. "Near-threshold production of heavy quarks with QQbar_threshold," Comput. Phys. Commun. 209, 96–115 (2016).

Luminosity spectra



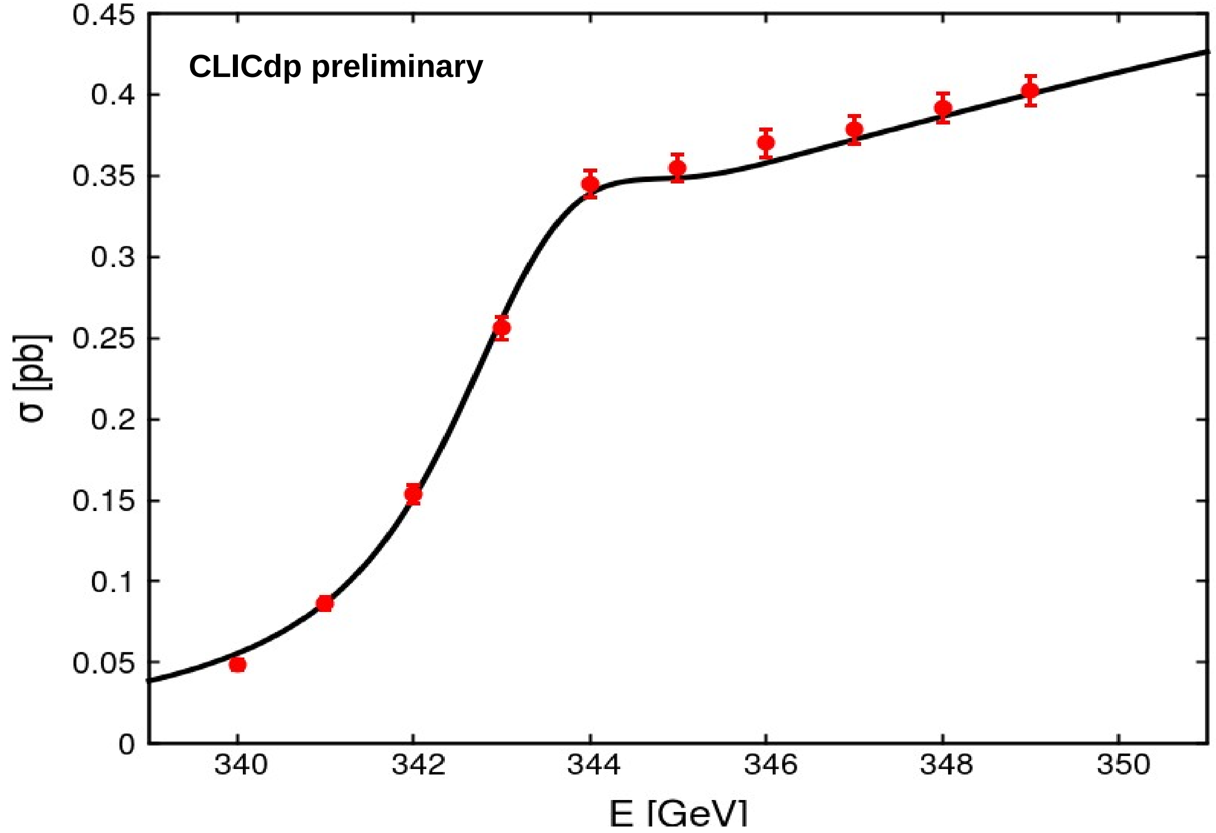
Theoretical cross section templates are convoluted with luminosity spectra

New CLIC spectra for 350 GeV is scaled for different values of $\sqrt{s}$

90% charge spectra used for presented results

Benchmark scenario

Assume 10 measurements at the threshold, with 1 GeV step in energy, with 10 fb^{-1} taken at each energy point (100 fb^{-1} total).



Generate statistical fluctuation assuming 70.2% event reconstruction efficiency and background level (remaining after cuts) corresponding to the 73 fb

K. Seidel et al., Eur. Phys. J. C 73 (2013) 2530 [arXiv:1303.3758]

Fit procedure

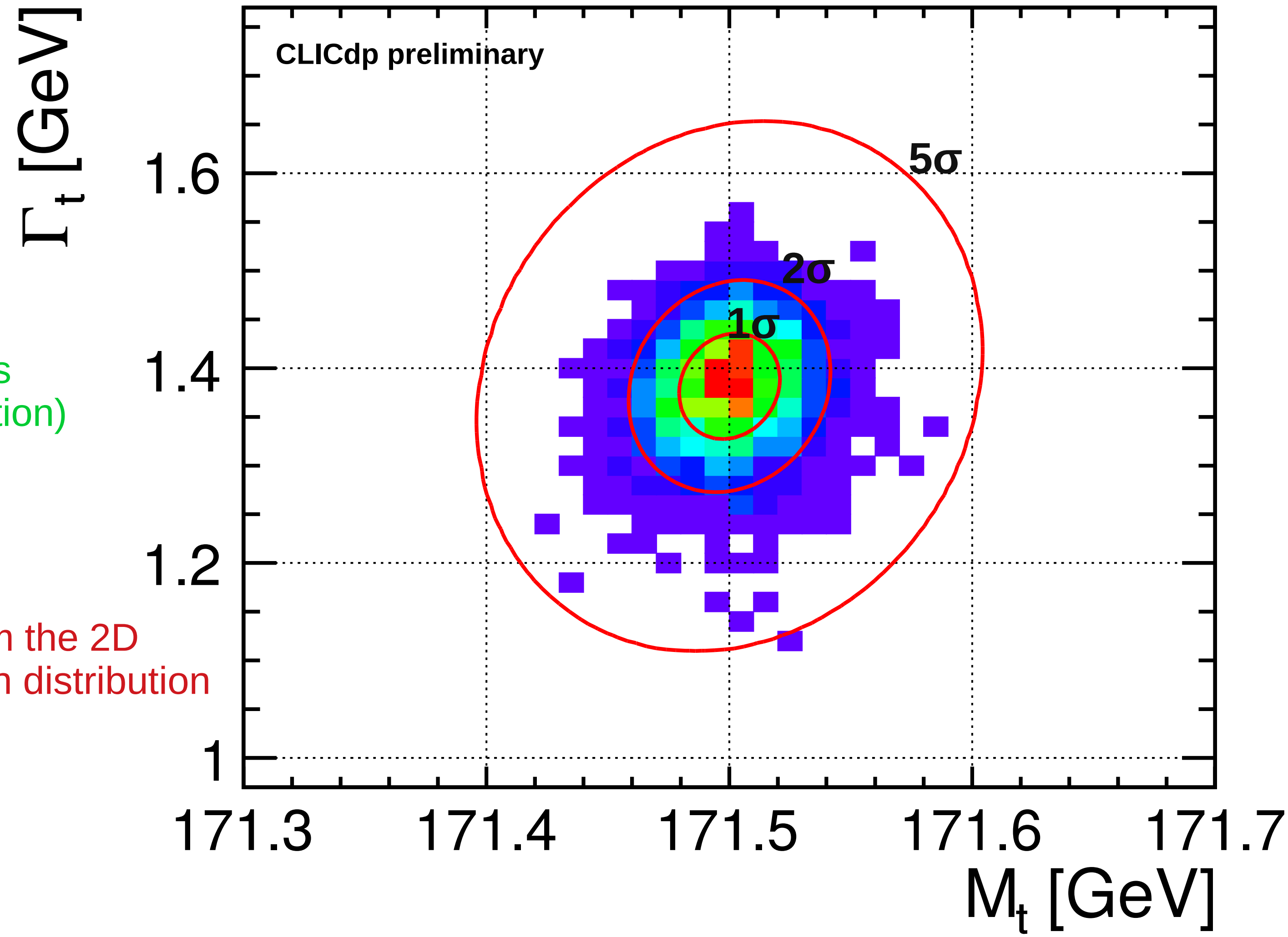
For each generated data set (pseudo-experiment) χ^2 value is calculated for different parameter values (different templates)

Quadratic dependence of the χ^2 value on the model parameters is fitted to find the best fit parameter values and the estimated uncertainty (corresponding to $\Delta\chi=1$)

Fits resulting in the parameter values outside the range used to generate templates are ignored.

Example of fit results

Fit with two free parameters (**2D**): mass vs width



Other parameters (α_s, y_t, normalization) fixed

Error elipses from the 2D fit of the gaussian distribution

σ_m = 21 MeV

σ_Γ = 54 MeV

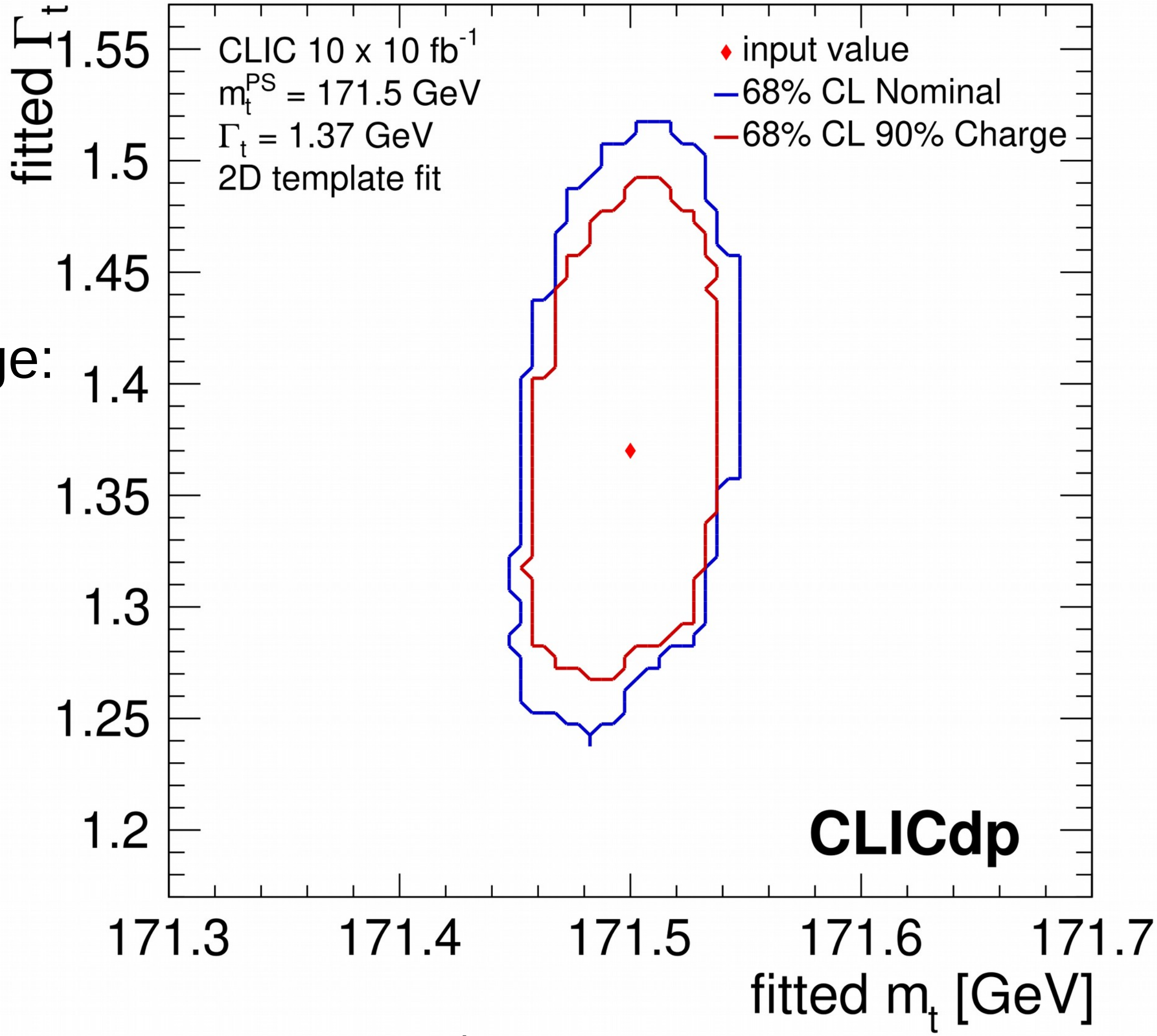
Previous results

Our results are consistent with previous study

Expected results with reduced charge:

σ_m = 21 MeV

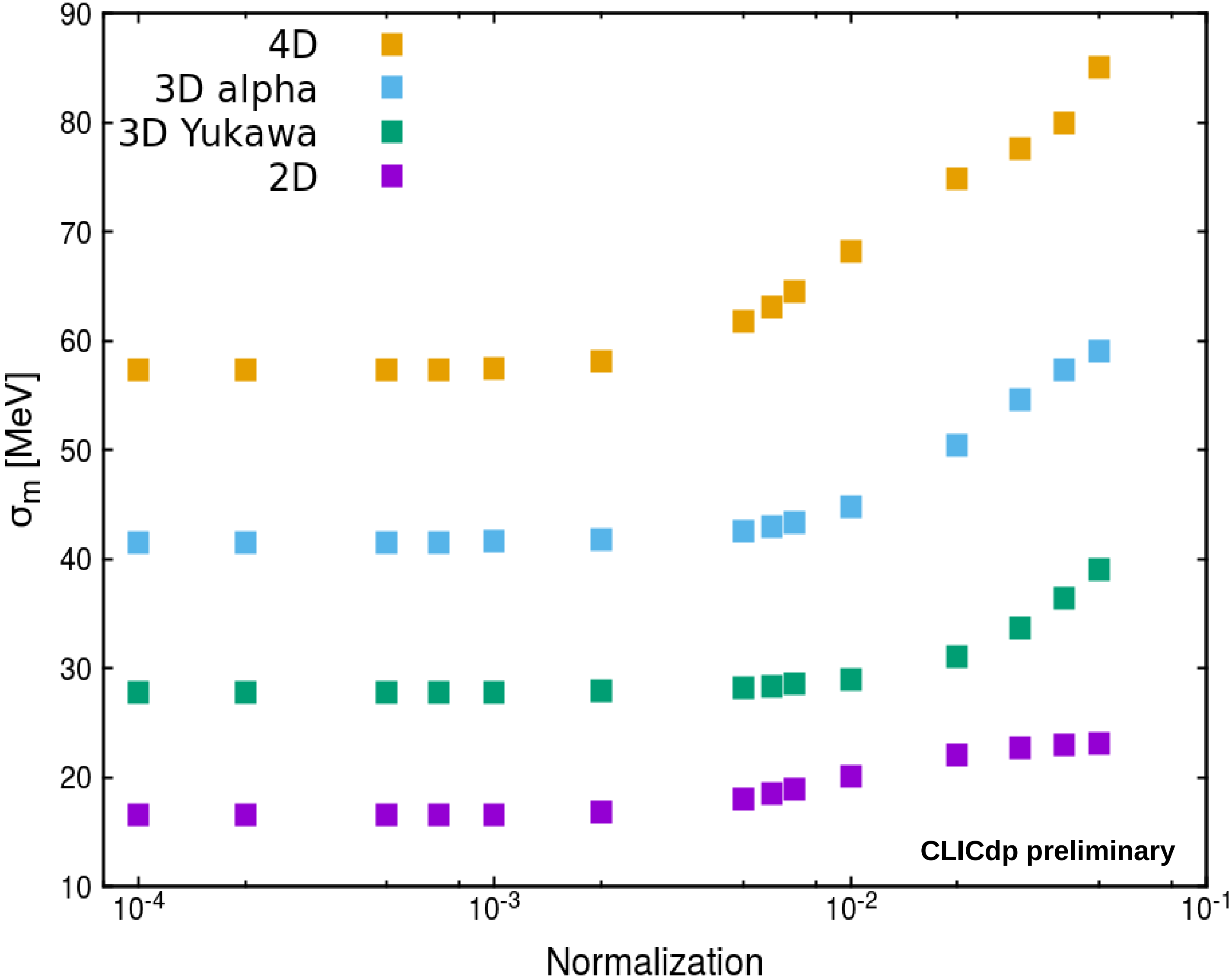
σ_Γ = 51 MeV



arXiv:1807.02441

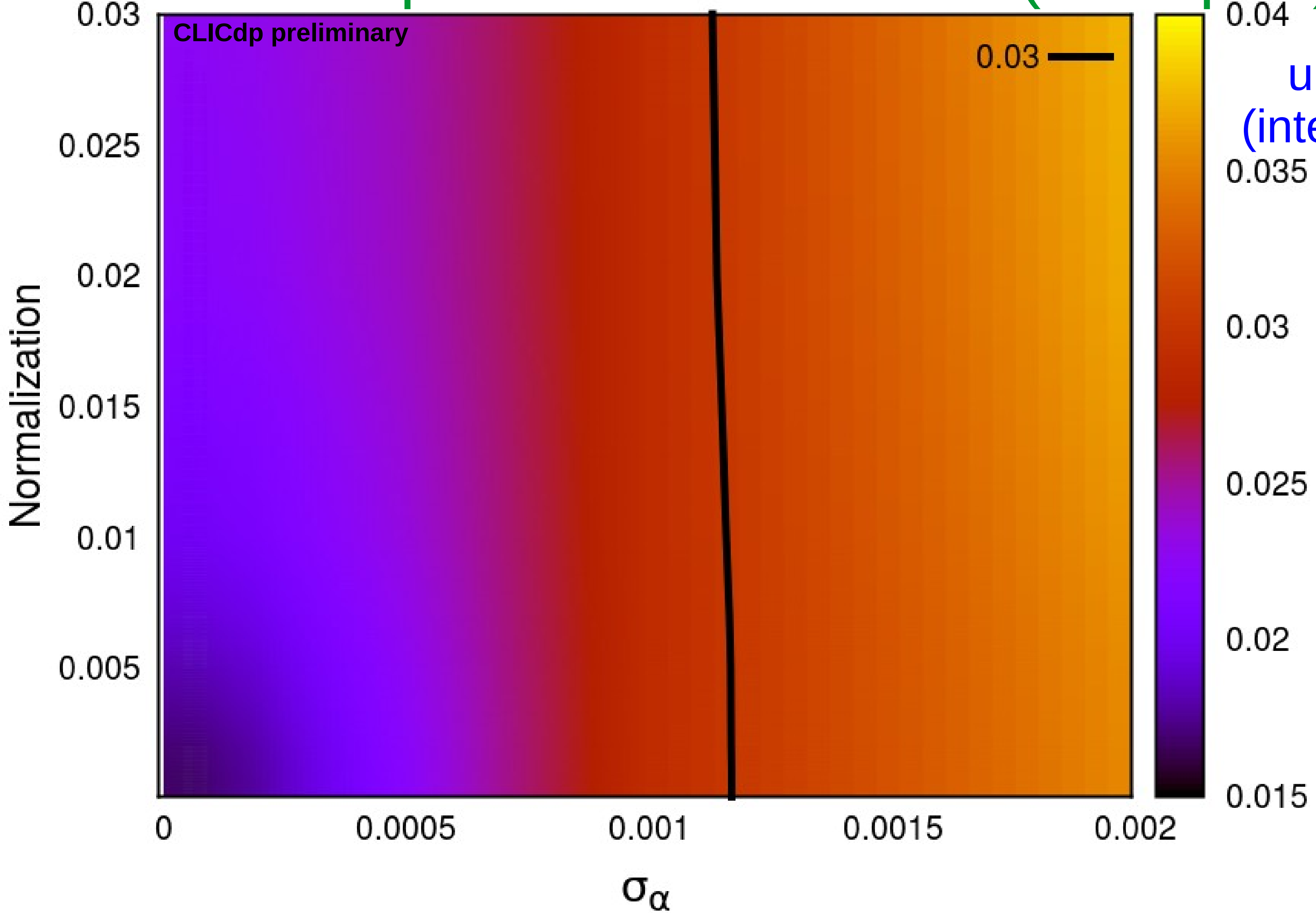
Fit results

Fit configuration



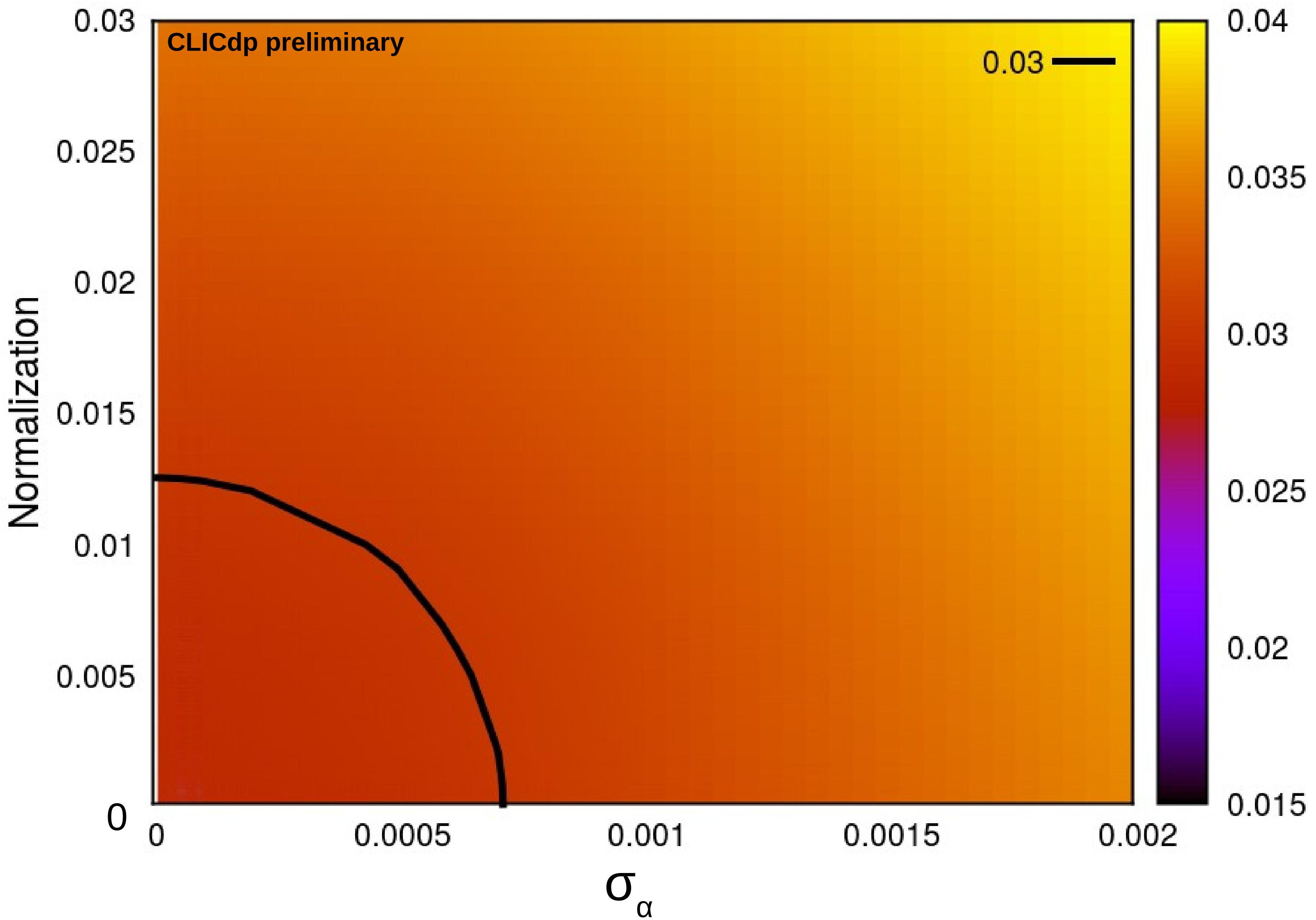
Consider overall normalization uncertainty and uncertainty of strong coupling constant

one more parameters in the fit (3D alpha)



Mass uncertainty (interpolated)

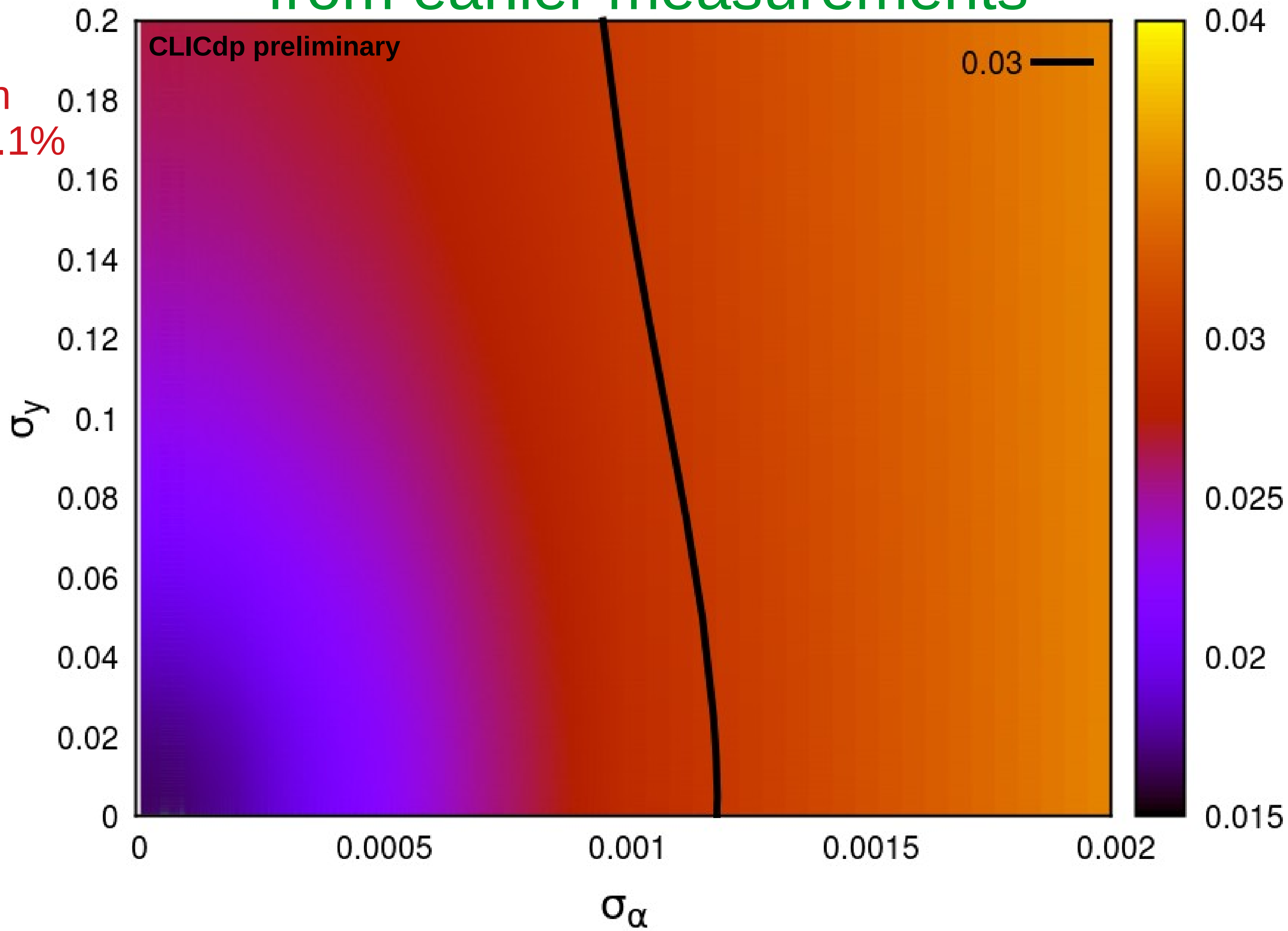
Consider top Yukawa coupling as additional free fit parameter (4D fit)



Statistical uncertainty on top-quark mass vs Yukawa and strong coupling uncertainties

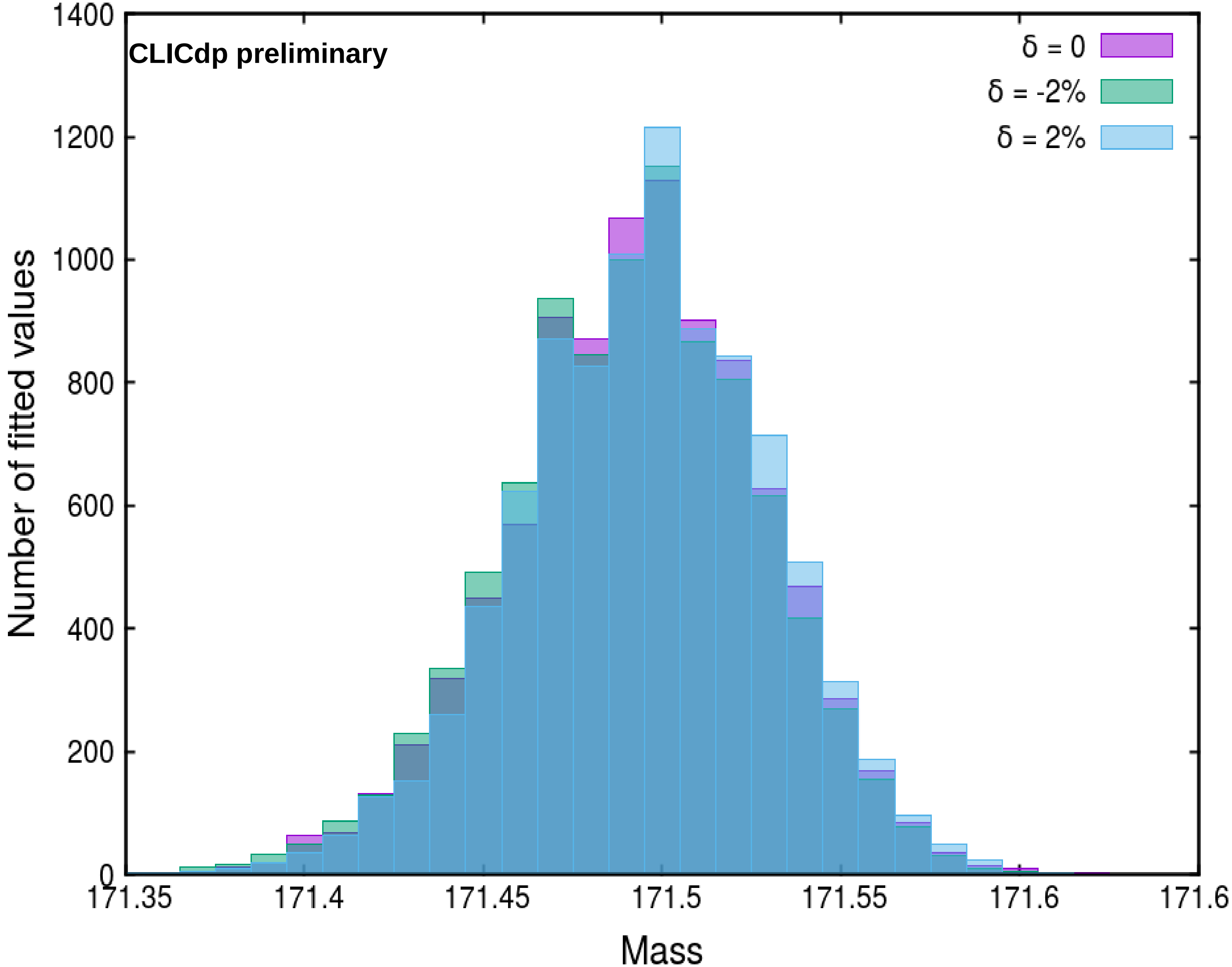
from earlier measurements

Normalization uncertainty 0.1%



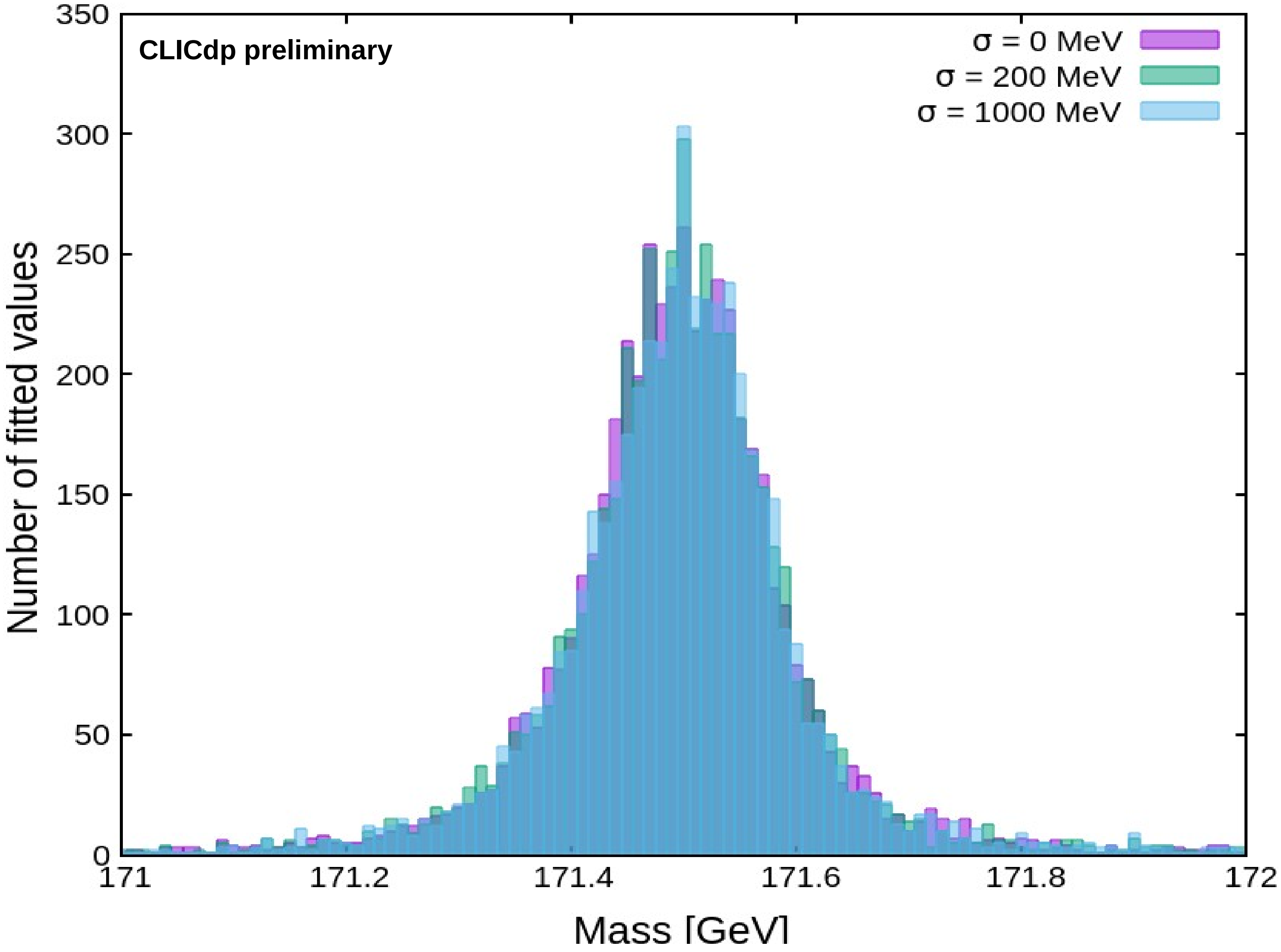
Background level uncertainty

Change background normalization in pseudo-experiment generation by ±2%



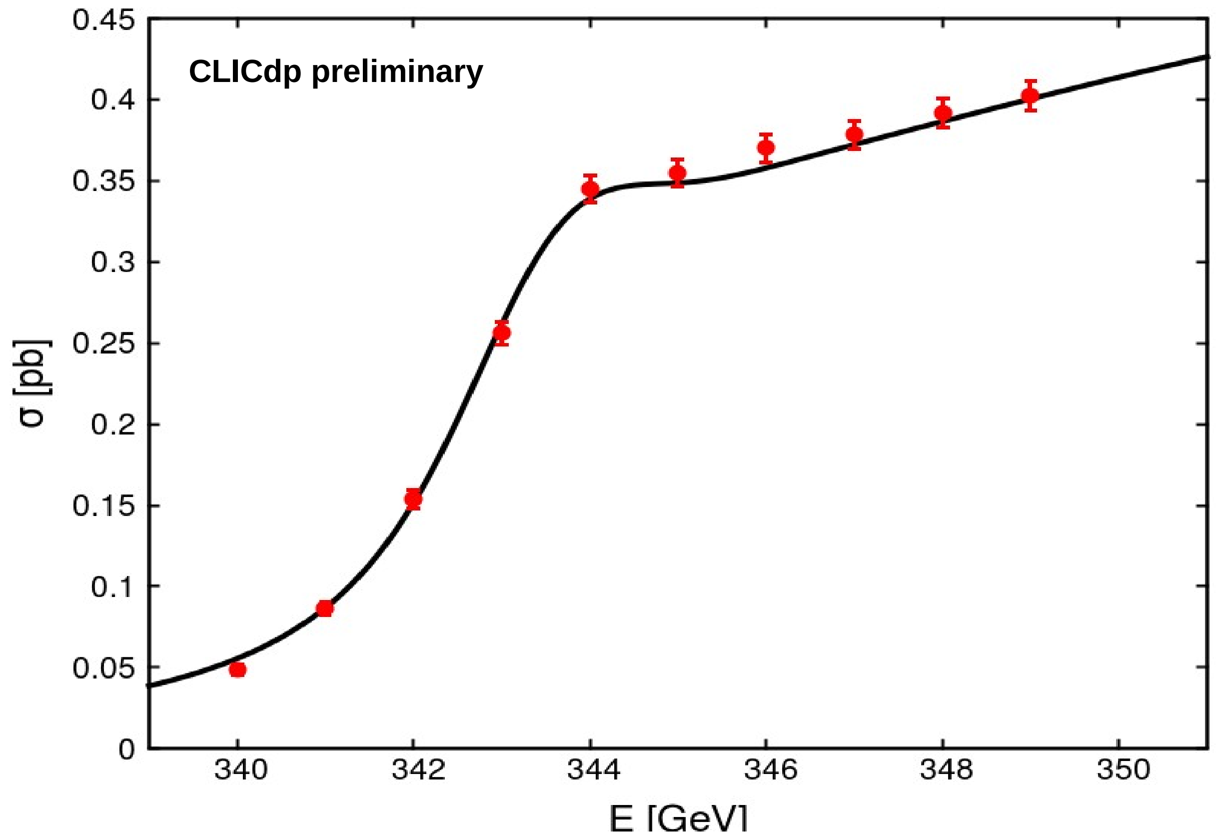
(Initial) mass uncertainty

Assumed true mass value from normal distribution



Benchmark scenario

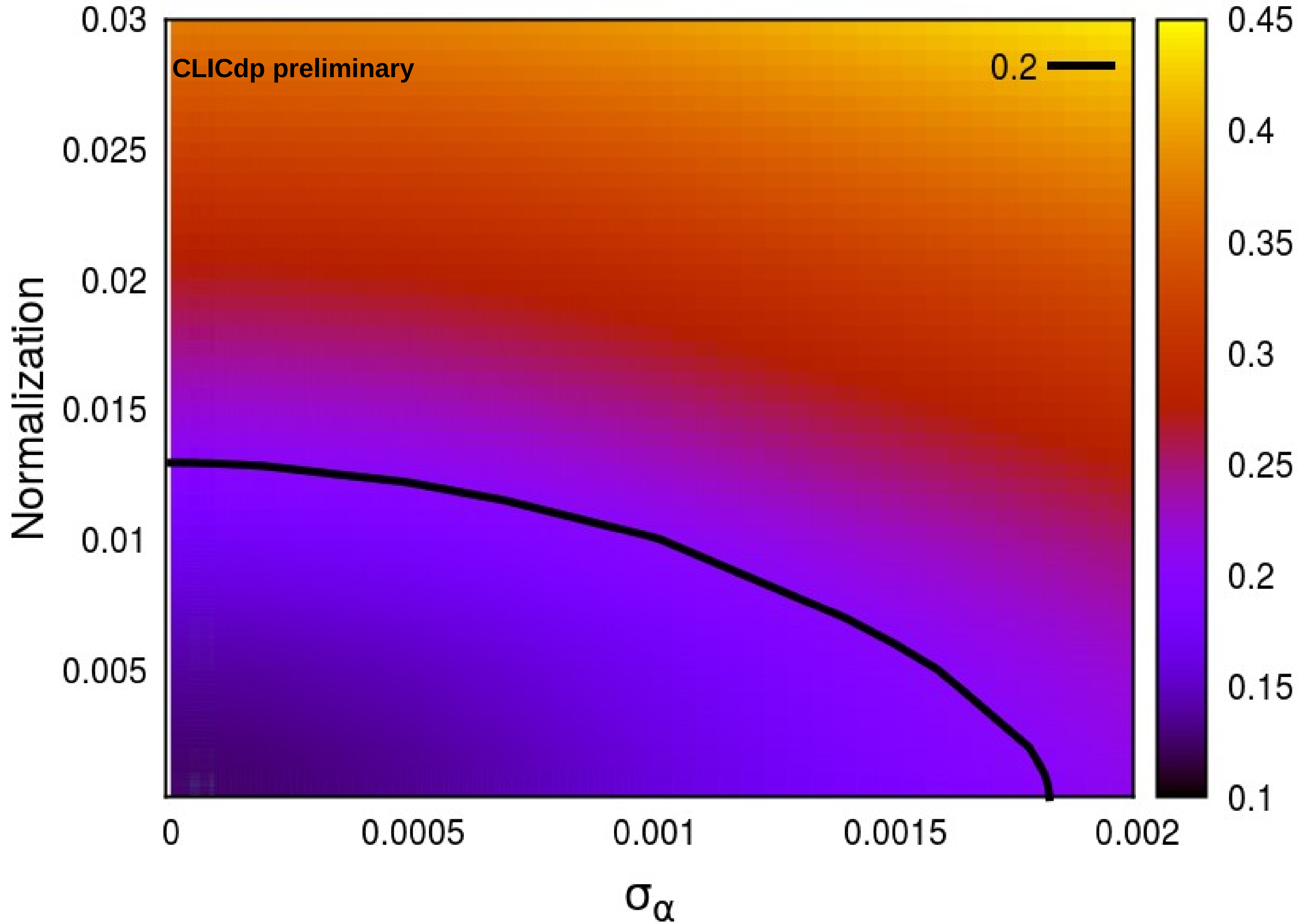
Assume 10 measurements at the threshold, with 1 GeV step in energy, with 10 fb^{-1} taken at each energy point (100 fb^{-1} total).



Generate statistical fluctuation assuming 70.2% event reconstruction efficiency and background level (remaining after cuts) corresponding to the 73 fb

K. Seidel et al., Eur. Phys. J. C 73 (2013) 2530 [arXiv:1303.3758]

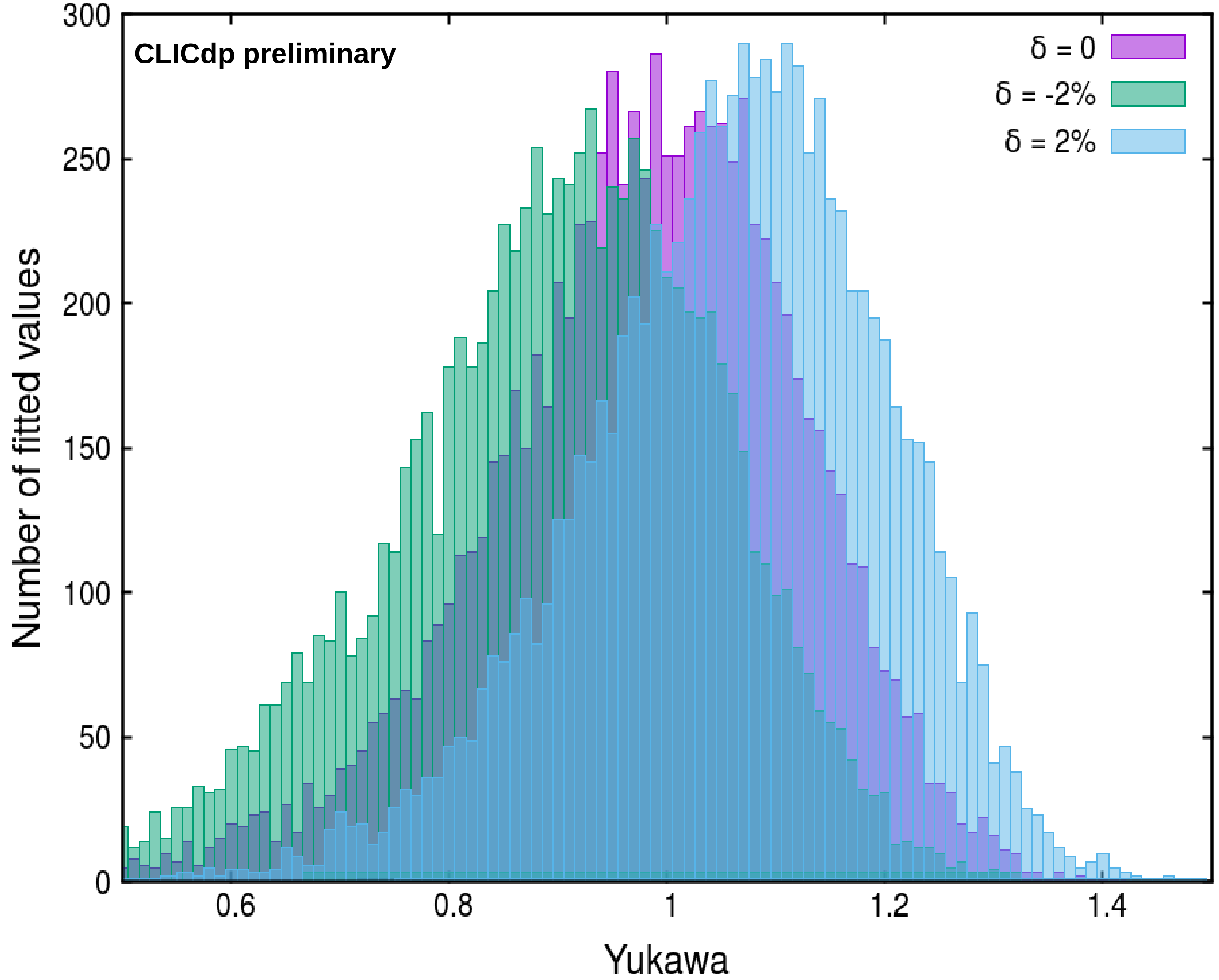
Yukawa uncertainty
from 4D fit



Background level uncertainty

Change background normalization in pseudo-experiment generation by ±2%

Influence on Yukawa coupling determination

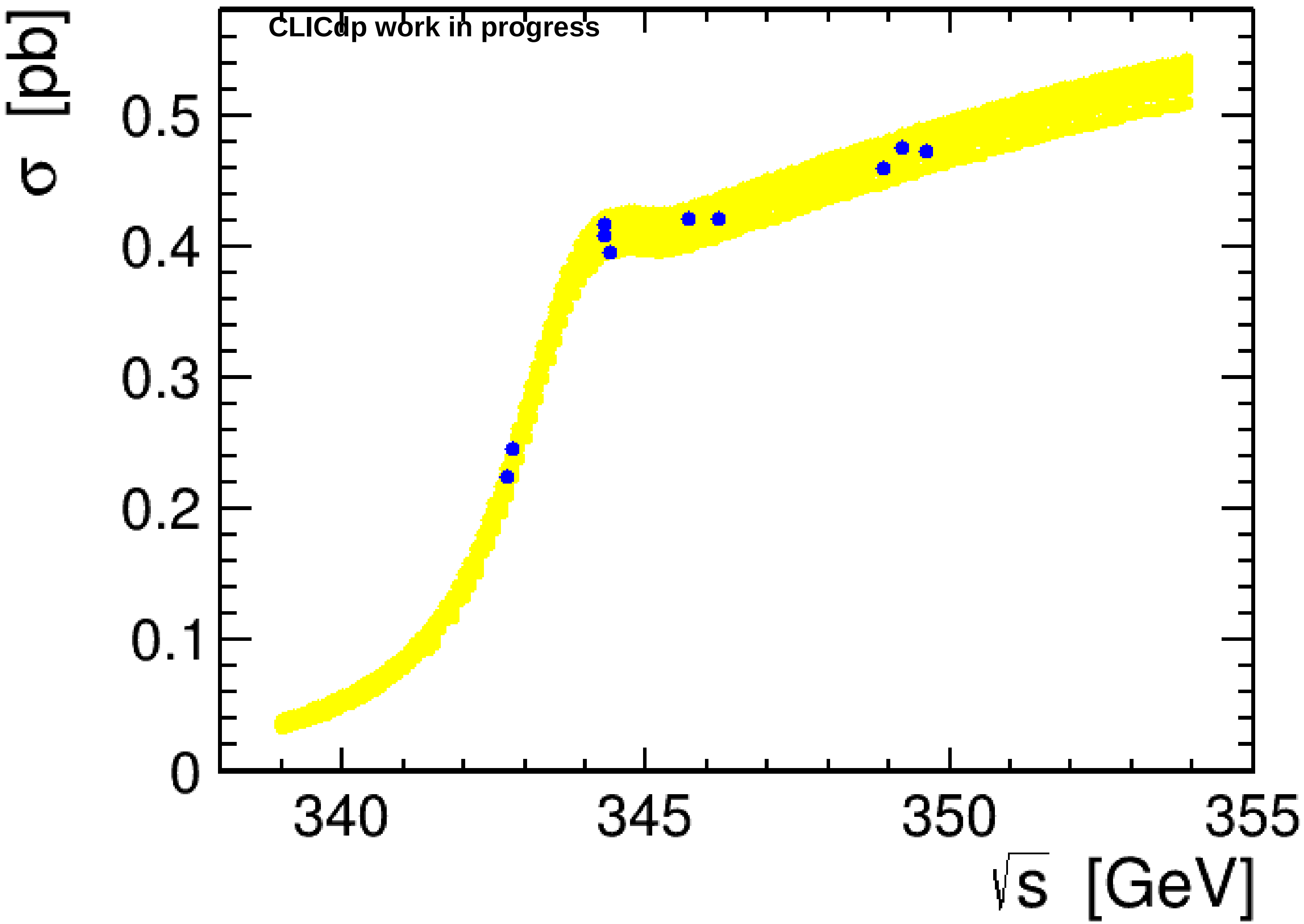


Scan optimization

(For fit including all parameters)

Looking for a better way

We generate random scan sequences (10 x 10 fb^{-1})



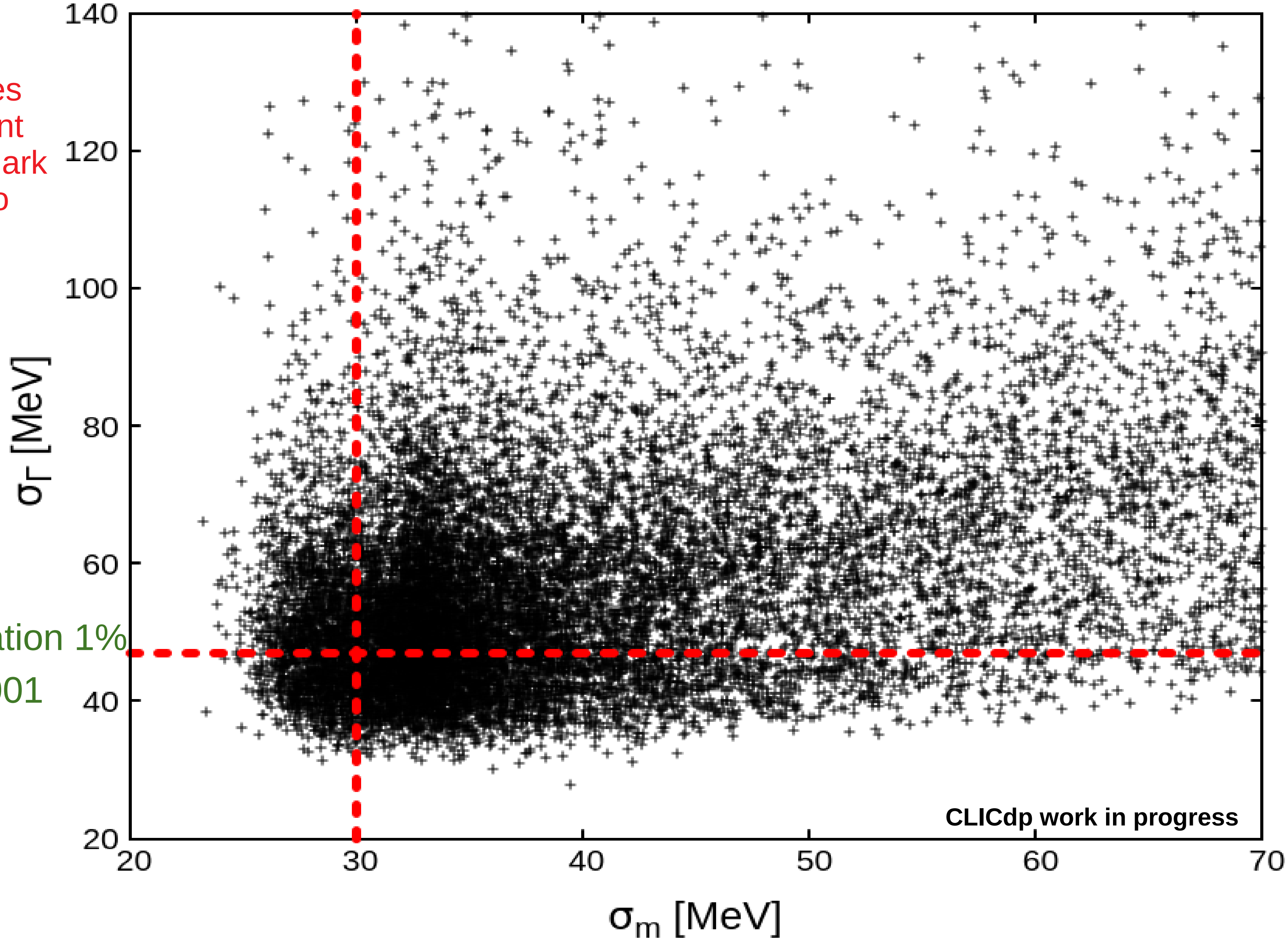
Is there room for improvement?

Red lines represent benchmark scenario

Normalization 1%

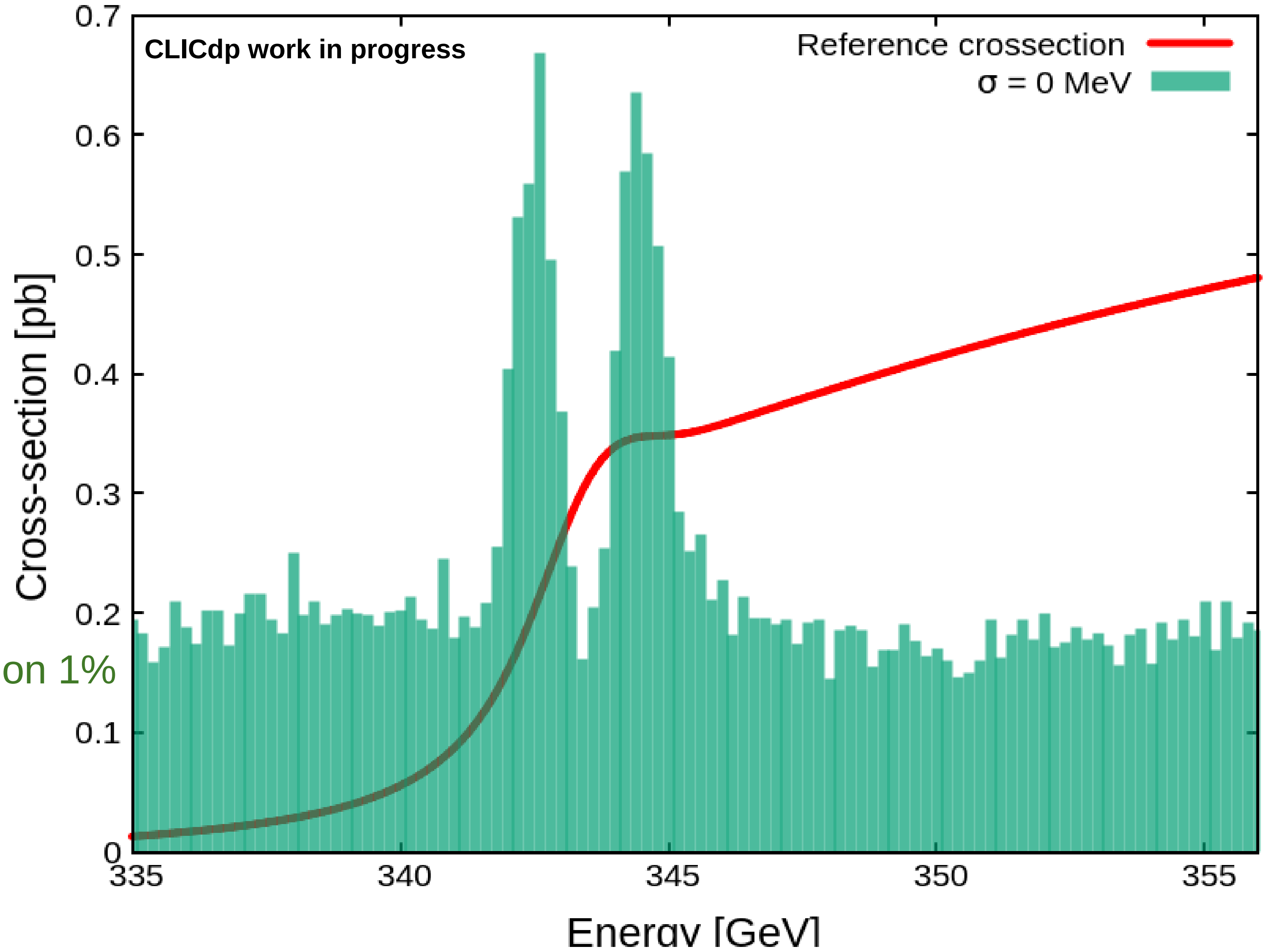
$\sigma_\alpha = 0.001$

$\sigma_y = 0.1$



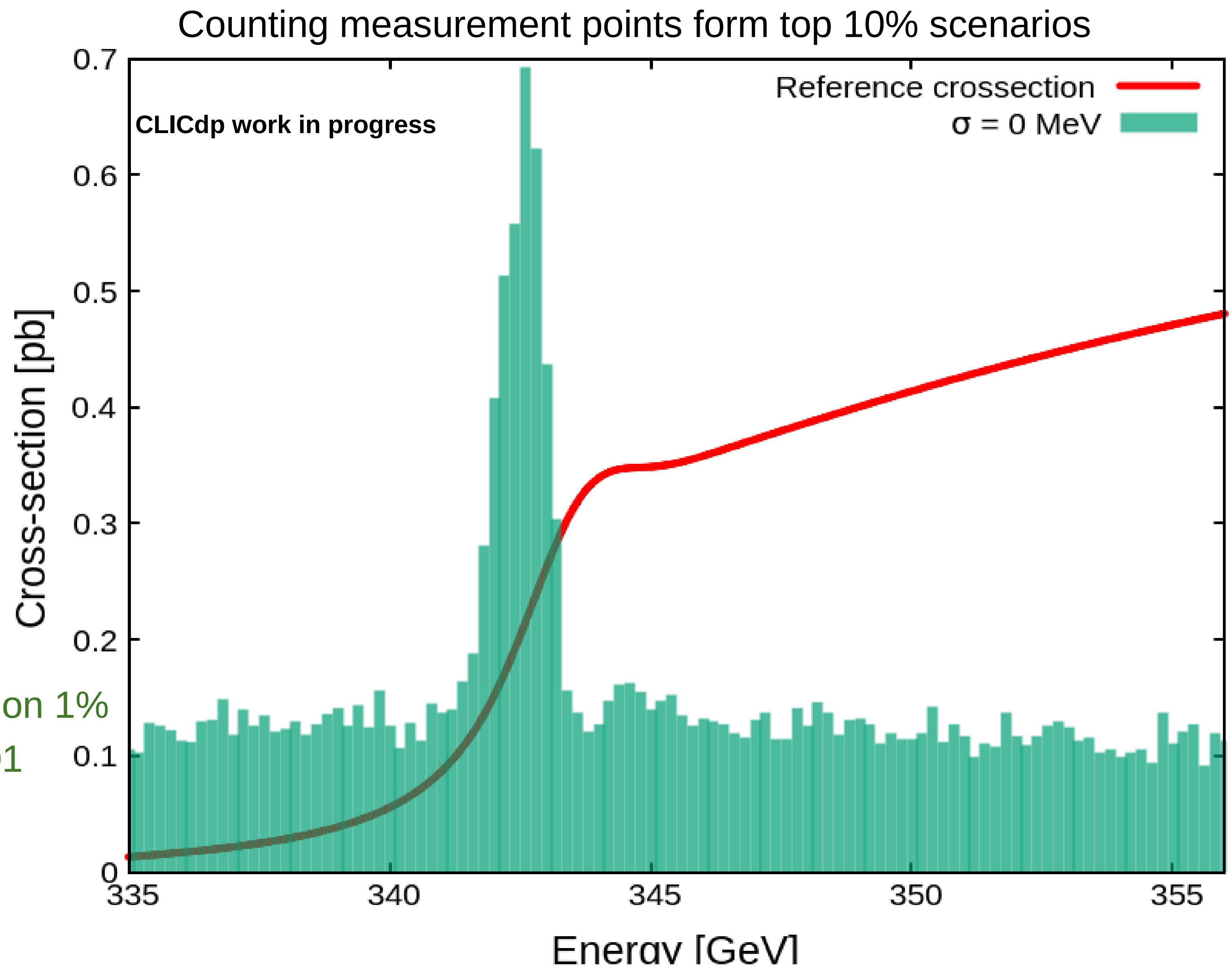
Optimizing mass measurement

Counting measurement points form top 10% scenarios



Normalization 1%

Optimizing mass measurement



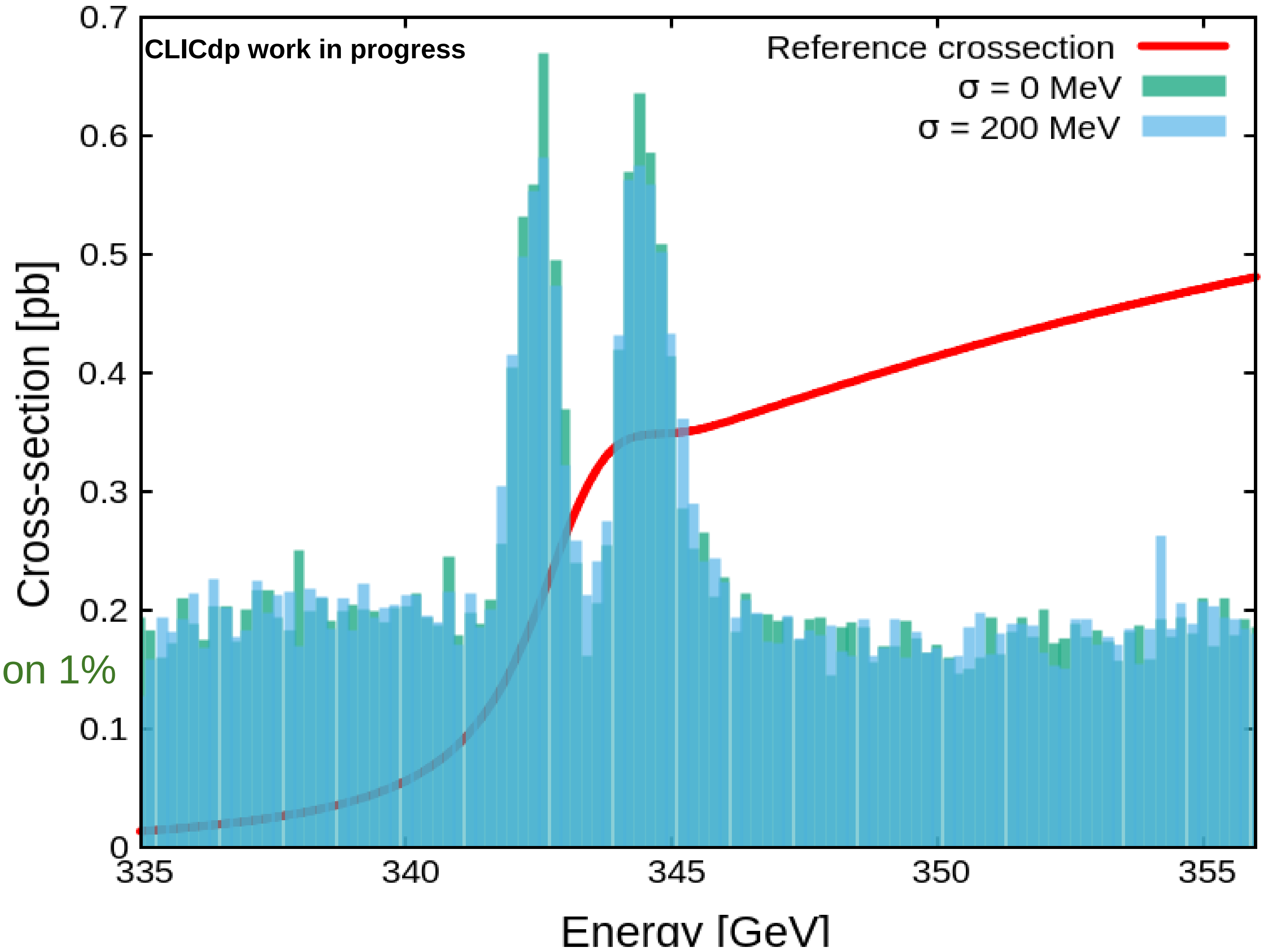
Normalization 1%

$\sigma_\alpha = 0.001$

$\sigma_y = 0.1$

Optimizing mass measurement

Counting measurement points form top 10% scenarios

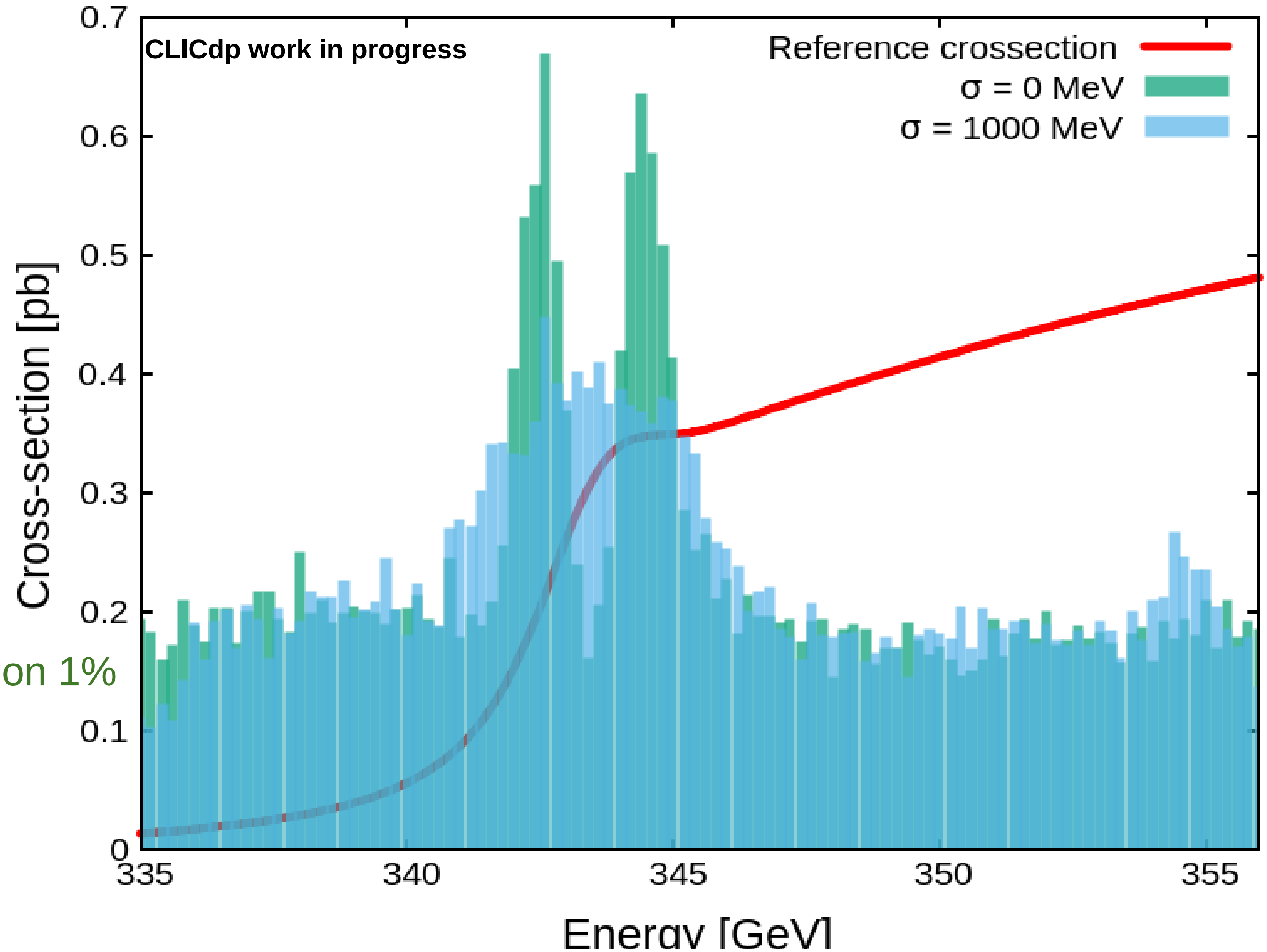


Normalization 1%

Optimizing mass measurement

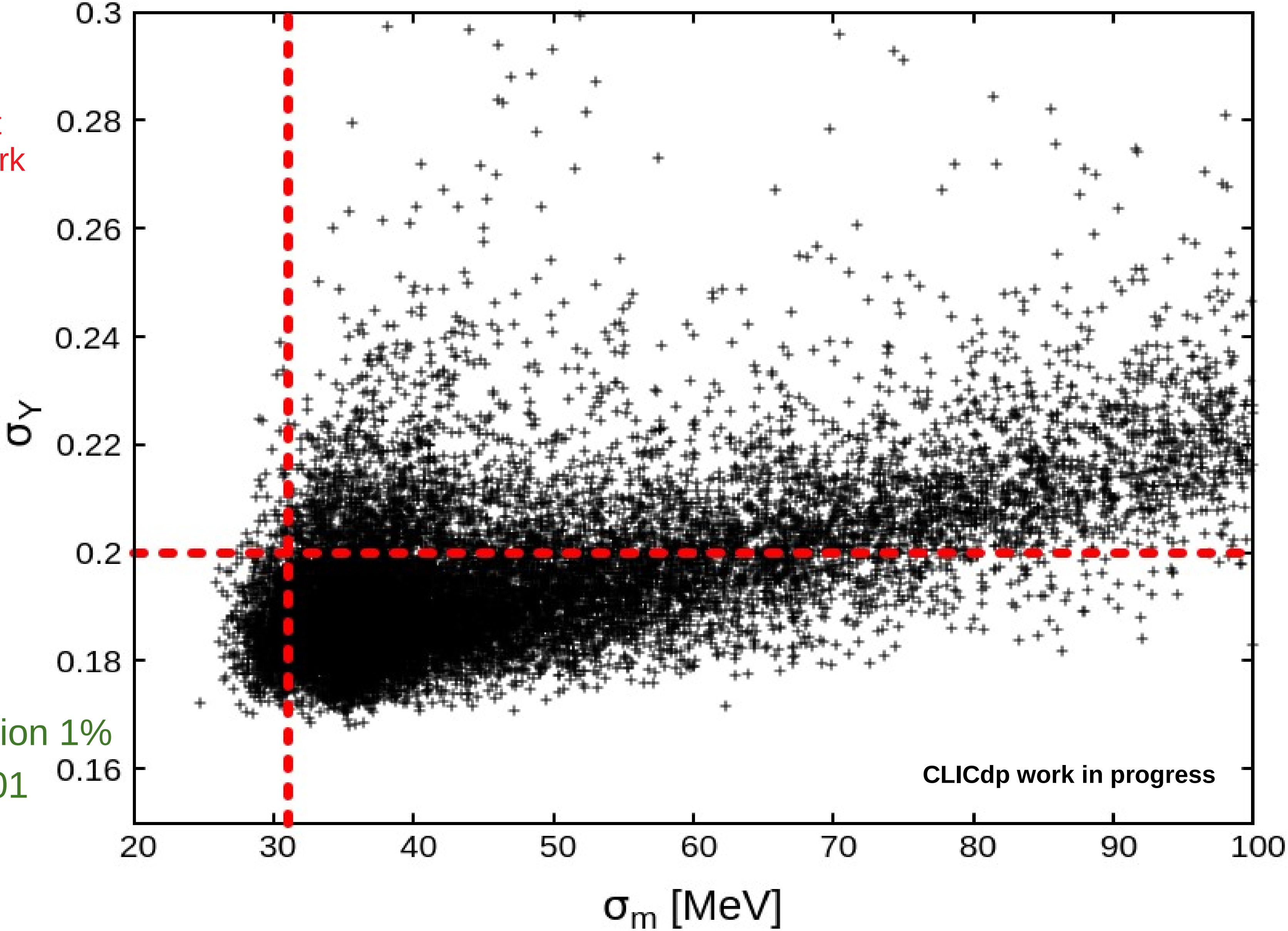
Counting measurement points form top 10% scenarios

Normalization 1%



Optimizing Yukawa measurement

Red lines represent benchmark scenario

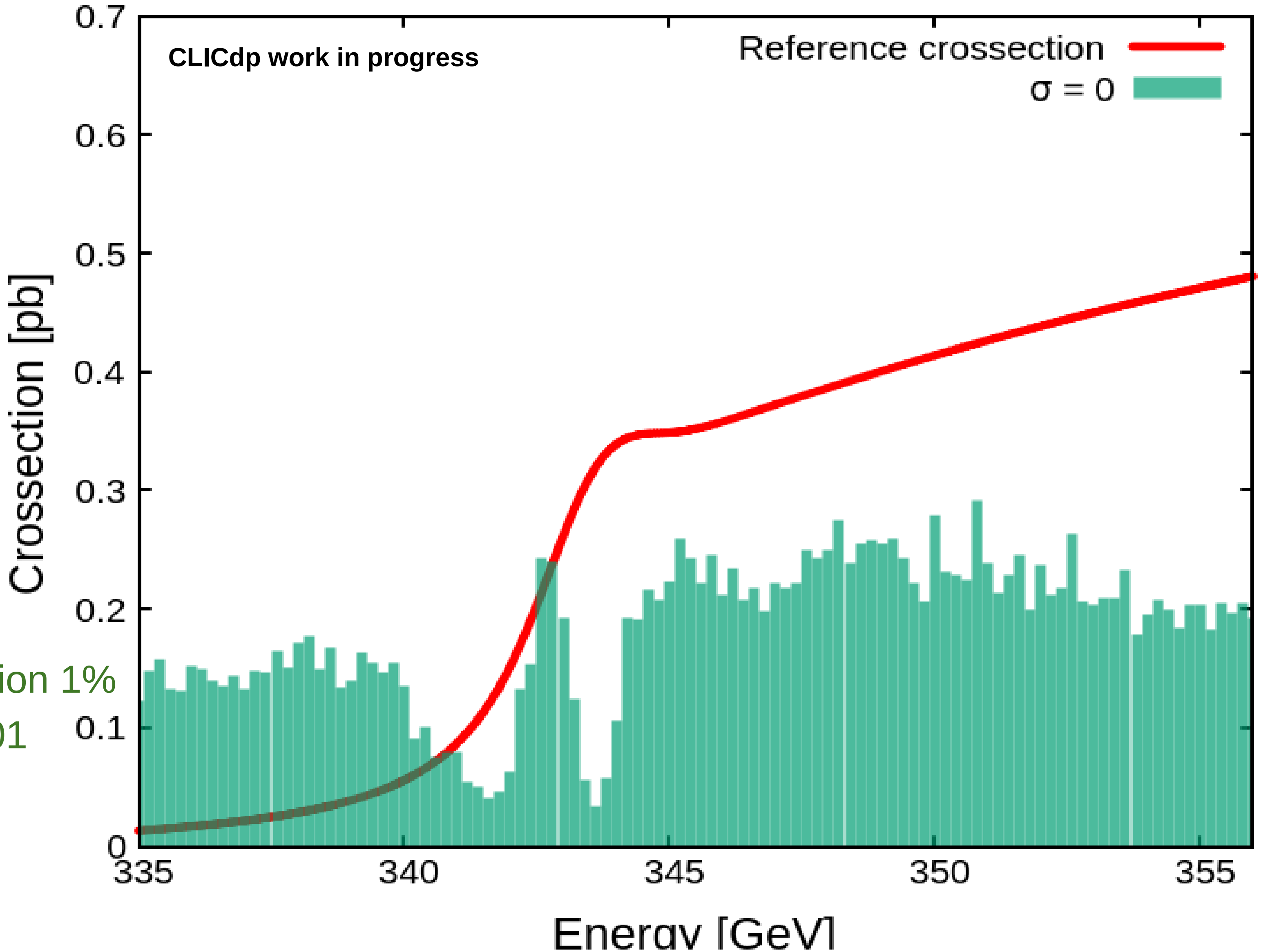


Normalization 1%

$\sigma_\alpha = 0.001$

Optimizing Yukawa measurement

Counting measurement points form top 10% scenarios



Normalization 1%

$\sigma_{\alpha} = 0.001$

Conclusions

Top-quark mass

can be extracted with ~20 MeV statistical uncertainty, provided σ_α<0.0004, σ_y < 0.06 and normalization ~1%.

Top-quark Yukawa coupling

Contribution to the top pair-production can be observed with significance > 5σ

Systematic uncertainties very important for Yukawa determination.

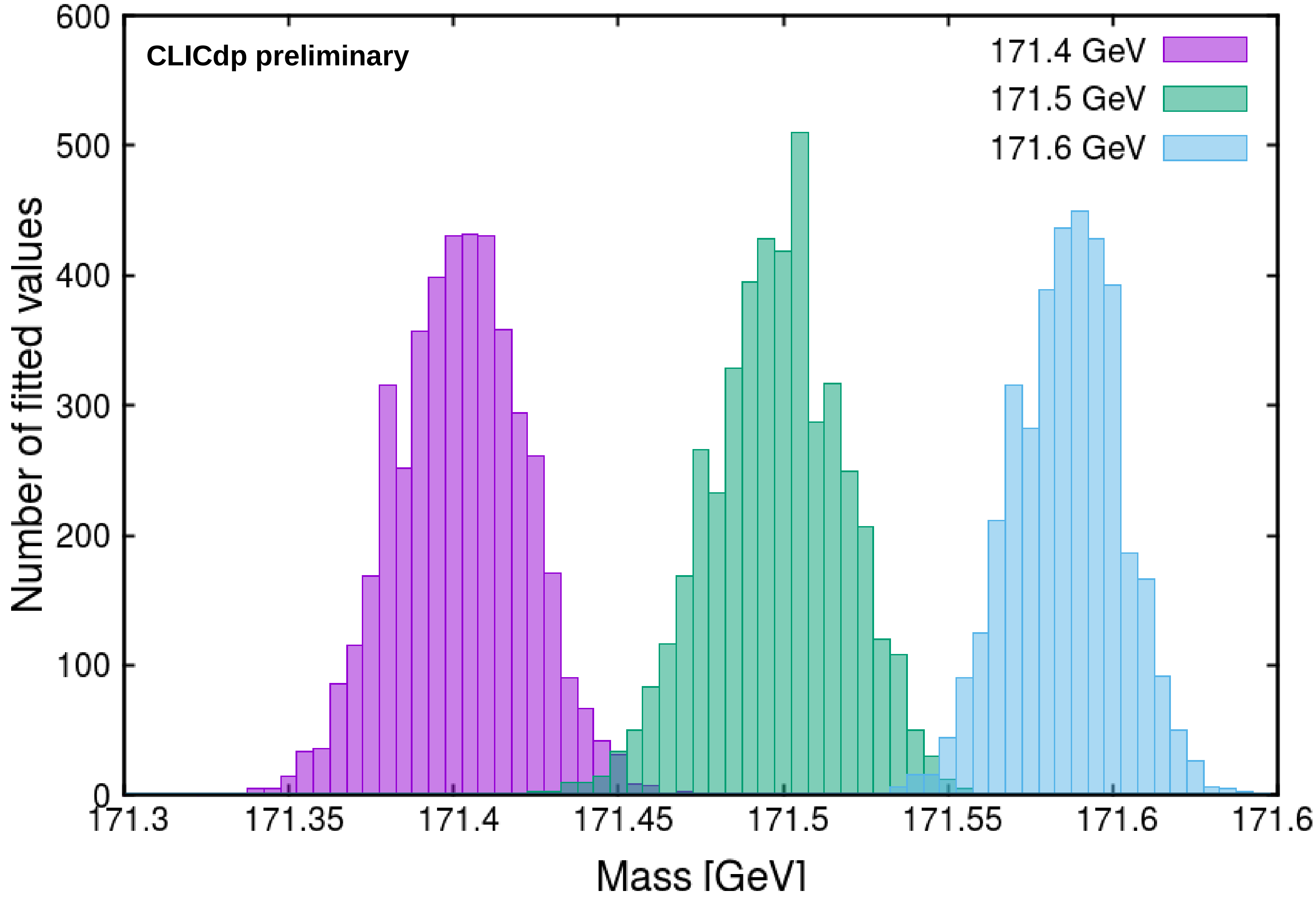
Scan optimisation

Statistical uncertainty of the extracted top-quark mass can be significantly reduced if the scan procedure is optimised.

The optimal scenario depends on the asumptions made. The study is ongoing...

Validation

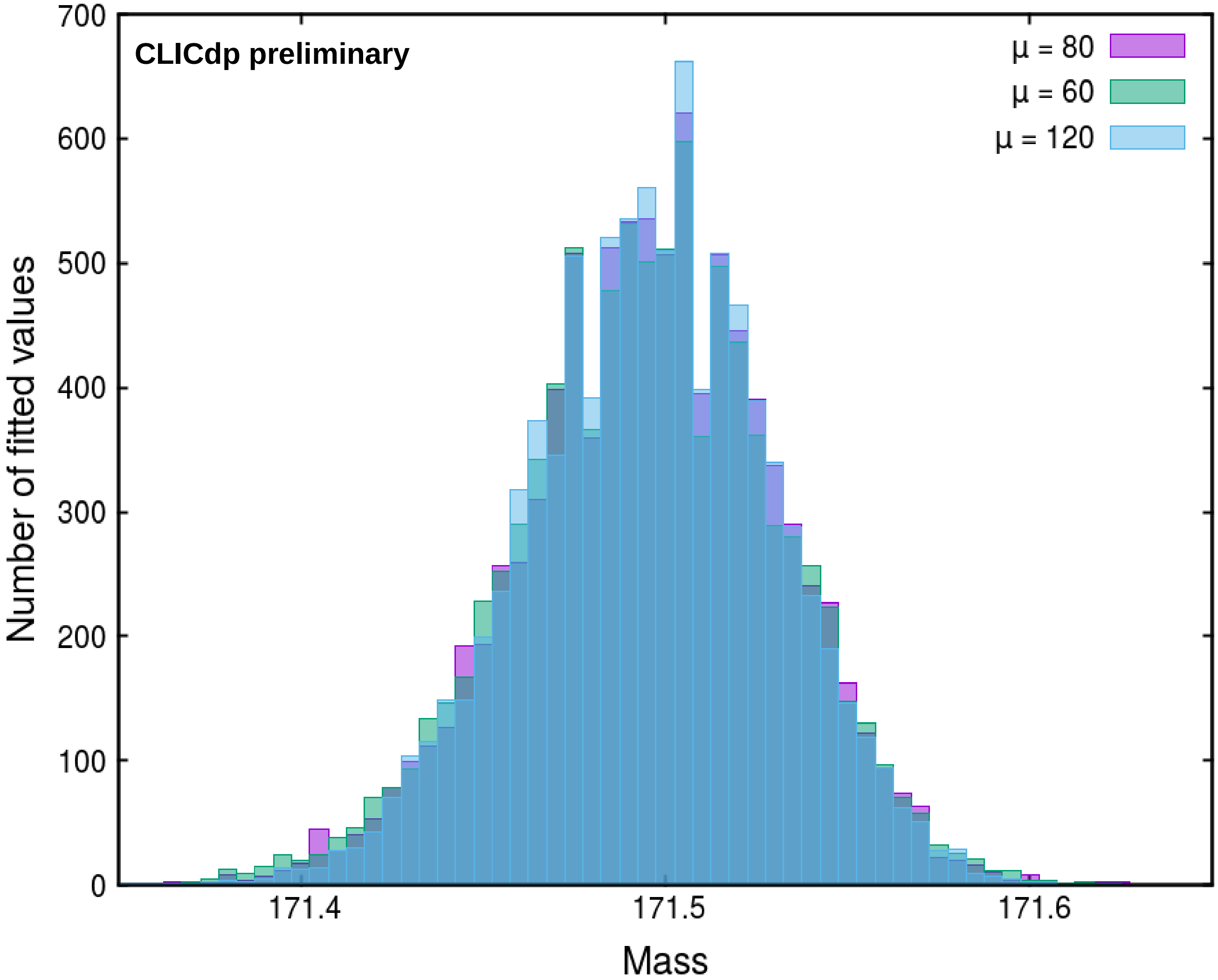
Fit results for different choices of template for pseudo-experiment generation



Estimate of theoretical error

Vary scale μ = 60 – 120 GeV in pseudo-experiment generation.

Templates generated with nominal value (μ = 80 GeV) used in the fitting procedure.



Estimate of theoretical error

Vary scale μ = 60 – 120 GeV in pseudo-experiment generation.

Templates generated with nominal value (μ = 80 GeV) used in the fitting procedure.