Measurements of the top quark mass at the ILC

Snowmass EF04 meeting November 20th 2020

Esteban Fullana @ IFIC-Valencia (UVEG-CSIC) presenting the work of the Valencia group, Frank Simon studies and Kacper Nowak's work

Top Mass Measurements in e+e- Colliders

Overview

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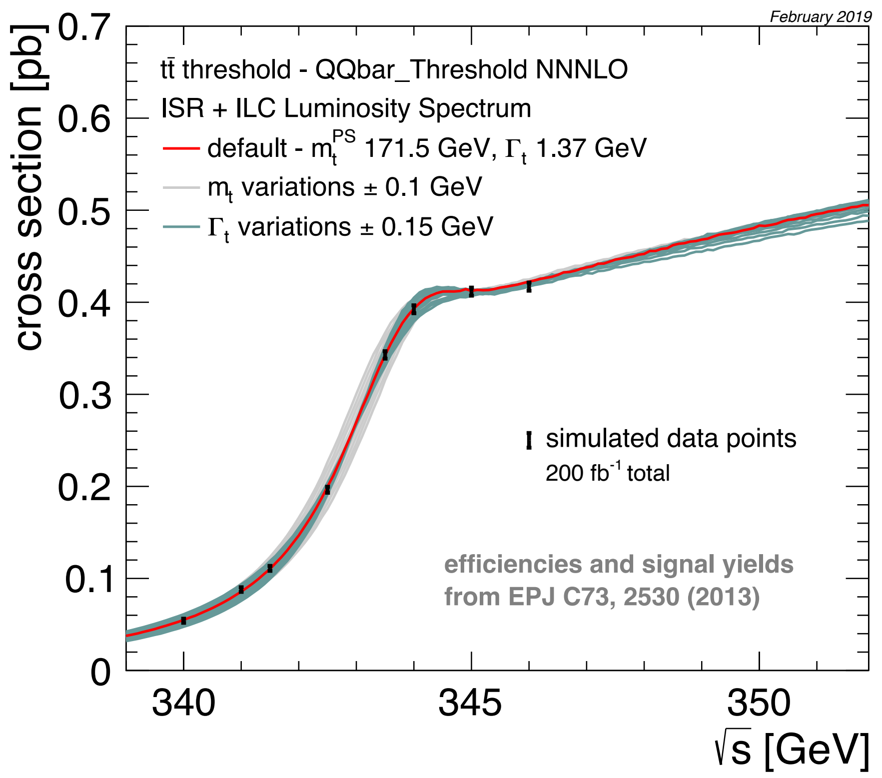
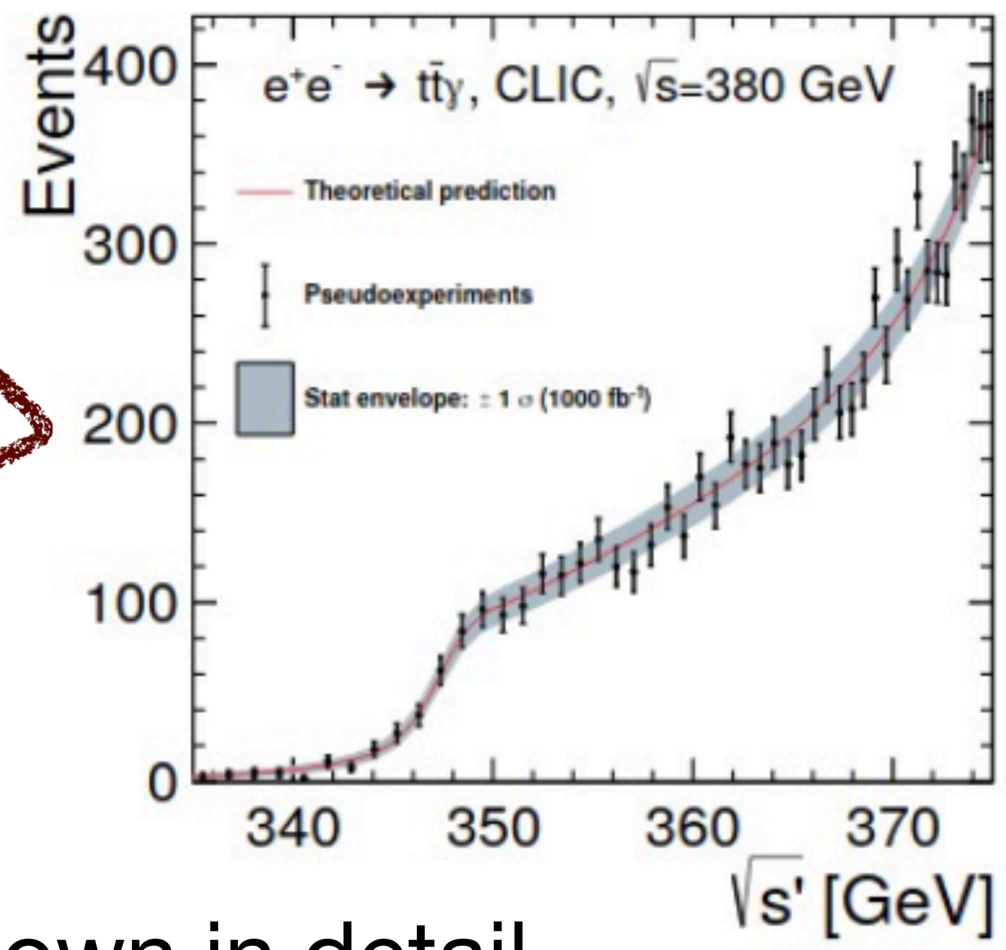
- The accelerator side: Requires sufficient collision energy for top pair production
  - So far thoroughly studied for ILC, CLIC, some derivative studies for FCCee

Three approaches to the top mass

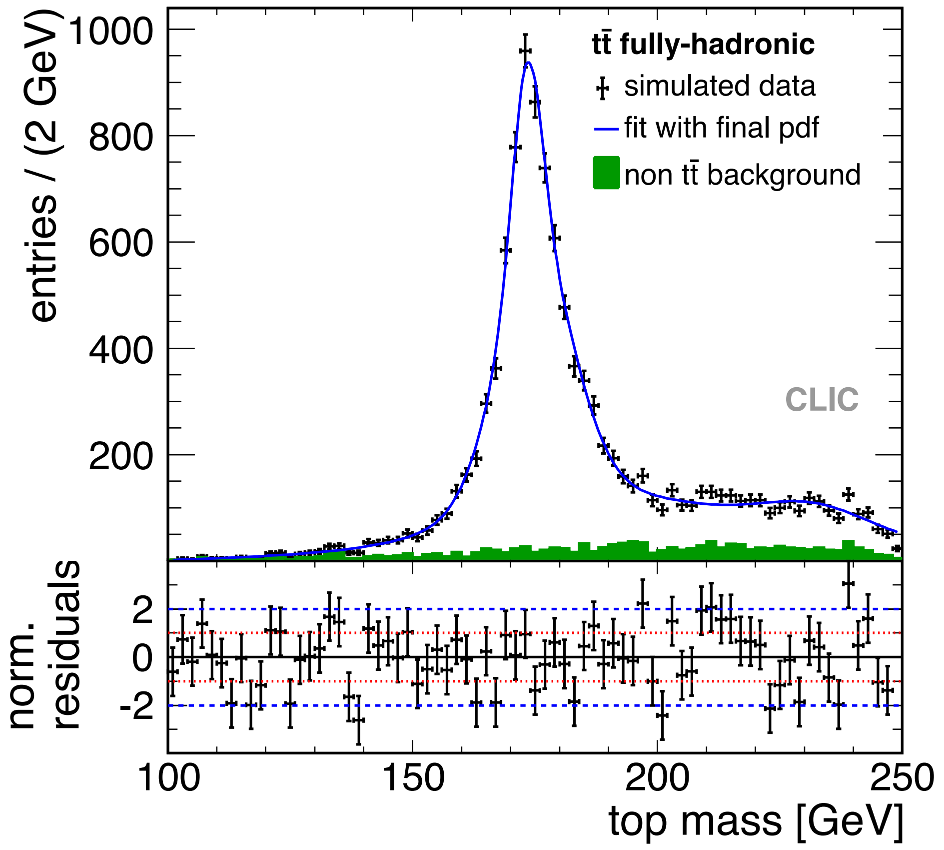
The threshold scan around 350 GeV



The top mass from radiative events



Direct kinematic reconstruction



not shown in detail, stat: ~ 20 - 40 MeV

Key references:

EPJ C73, 2530 (2013)
(CLIC, (ILC): Threshold, direct)

JHEP 11, 003 (2019)
(CLIC: Threshold, radiative, direct)

PLB 804,135353 (2020)
(ILC, CLIC: radiative)

+ a rich set of reports and conference proceedings on arXiv

This talk includes material from the following people:

IFIC CSIC Universitat de València

Top Mass from Radiative Events

PhD Thesis of M. Boronat and P. Gomis

Together with J.Fuster, M. Perello, M. Vos, E. Fullana from Valencia group

Theoretical framework: A. H. Hoang, V. Mateu, A. Widl,

Physics Letters B 804 (2020) 135353

Contents lists available at ScienceDirect

Physics Letters B

www.elsevier.com/locate/physletb

ELSEVIER

Top quark mass measurement in radiative events at electron-positron colliders

M. Boronat [a], E. Fullana [a], J. Fuster [a], P. Gomis [a,*], A.H. Hoang [b,c], A. Widl [b], V. Mateu [d,e], M. Vos [a]

[a] Institut de Física Corpuscular (Universitat de València/CSIC), c./ Catedrático J. Beltran, 46980 Paterna, Valencia, Spain
[b] University of Vienna, Faculty of Physics, Boltzmanngasse 5, 1090 Vienna, Austria
[c] Erwin Schrödinger International Institute for Mathematical Physics, Austria
[d] Departamento de Física Fundamental e IUFFyM, Universidad de Salamanca, Plaza de la Merced S/N, 37008 Salamanca, Spain
[e] Instituto de Física Teórica UAM-CSIC, Spain

arXiv:1902.07246v2 [hep-ex] 22 May 2020

Scanning Strategies at the Top Threshold at ILC

Frank Simon

Max-Planck-Institut für Physik, Munich, Germany

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ABSTRACT: A scan of the top quark pair production threshold at a future electron-positron collider provides the possibility for high-precision measurements of the top quark mass, and, when using two dimensional fits of the measured cross sections, also of other properties such as the width and the Yukawa coupling. The energy range of the scan and the distribution of the integrated luminosity can be optimized depending on the main goals of the threshold program. This contribution examines the possibility to determine the top quark mass in fast exploratory measurements with an adequate precision to enable such an optimization, and studies a scanning program with a reduced energy range of 6 GeV for the measurement of the mass, width and the Yukawa coupling, taking theoretical uncertainties from QCD scale variations and parametric uncertainties from the strong coupling constant into account.

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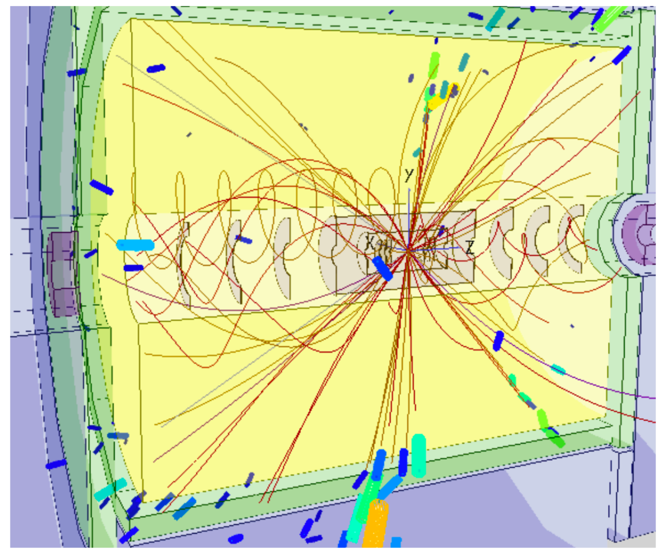
Optimising top-quark pair-production threshold scan at future e+e- colliders



ILD Top/HF group meeting, November 13, 2020

Kacper Nowak, Aleksander Filip Żarnecki

FACULTY OF PHYSICS UW

Eur. Phys. J. C (2013) 73:2530
DOI 10.1140/epjc/s10052-013-2530-7

THE EUROPEAN PHYSICAL JOURNAL C

Special Article - Tools for Experiment and Theory

Top quark mass measurements at and above threshold at CLIC

Katja Seidel[1], Frank Simon[1,a], Michal Tesař[1], Stephane Poss[2]

[1] Max-Planck-Institut für Physik, Föhringer Ring 6, 80805 Munich, Germany
[2] CERN, 1211 Geneva, Switzerland

Received: 15 March 2013 / Revised: 26 July 2013 / Published online: 20 August 2013

Plus the following papers :

(https://arxiv.org/pdf/hep-ph/0207315, https://arxiv.org/pdf/1310.0563, https://arxiv.org/pdf/1604.08122)

Let’s start with:

IFIC INSTITUT DE FÍSICA CORPUSCULAR

CSIC

VNIVERSITAT DE VALÈNCIA

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PHYSICS LETTERS B

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Check for updates

M. Boronat [a], E. Fullana [a], J. Fuster [a], P. Gomis [a,*], A.H. Hoang [b,c], A. Widl [b], V. Mateu [d,e], M. Vos [a]

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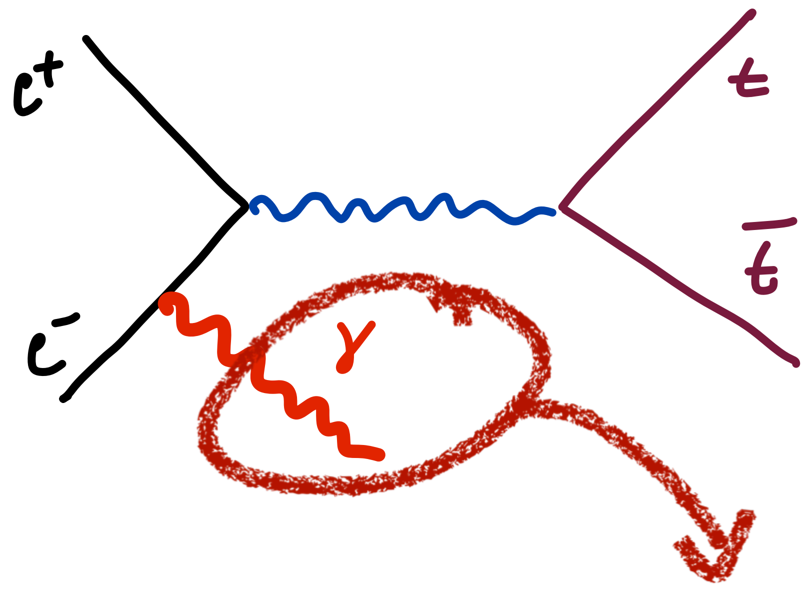
…because also in the lifetime of the ILC would be convenient to start with this measurement of the top-quark mass

Mass from Radiative Events

At CLIC, ILC - 380 and 500 GeV

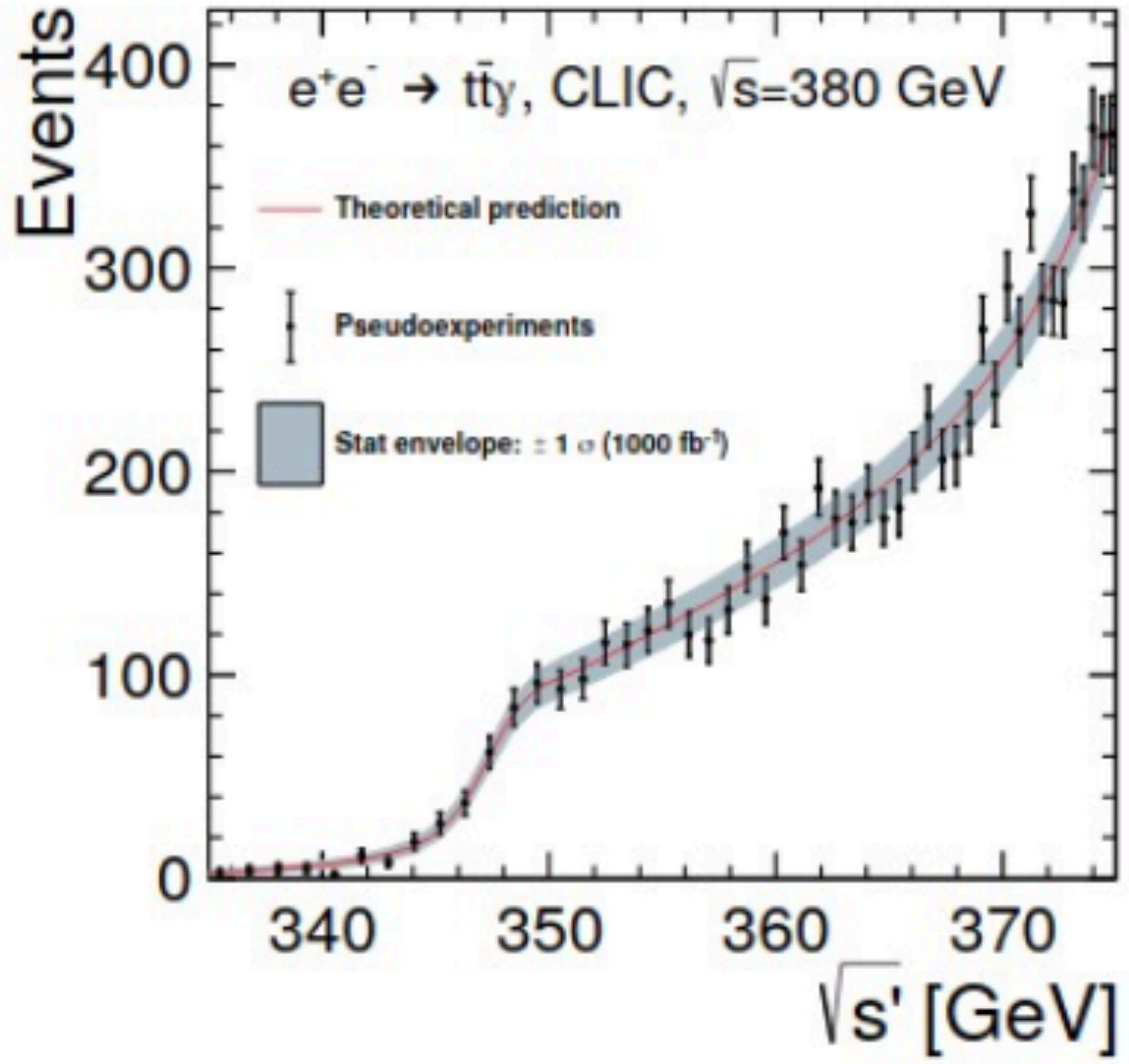
- A new(er) idea to measure the top mass in a theoretically well-defined scheme in high-energy running above the threshold

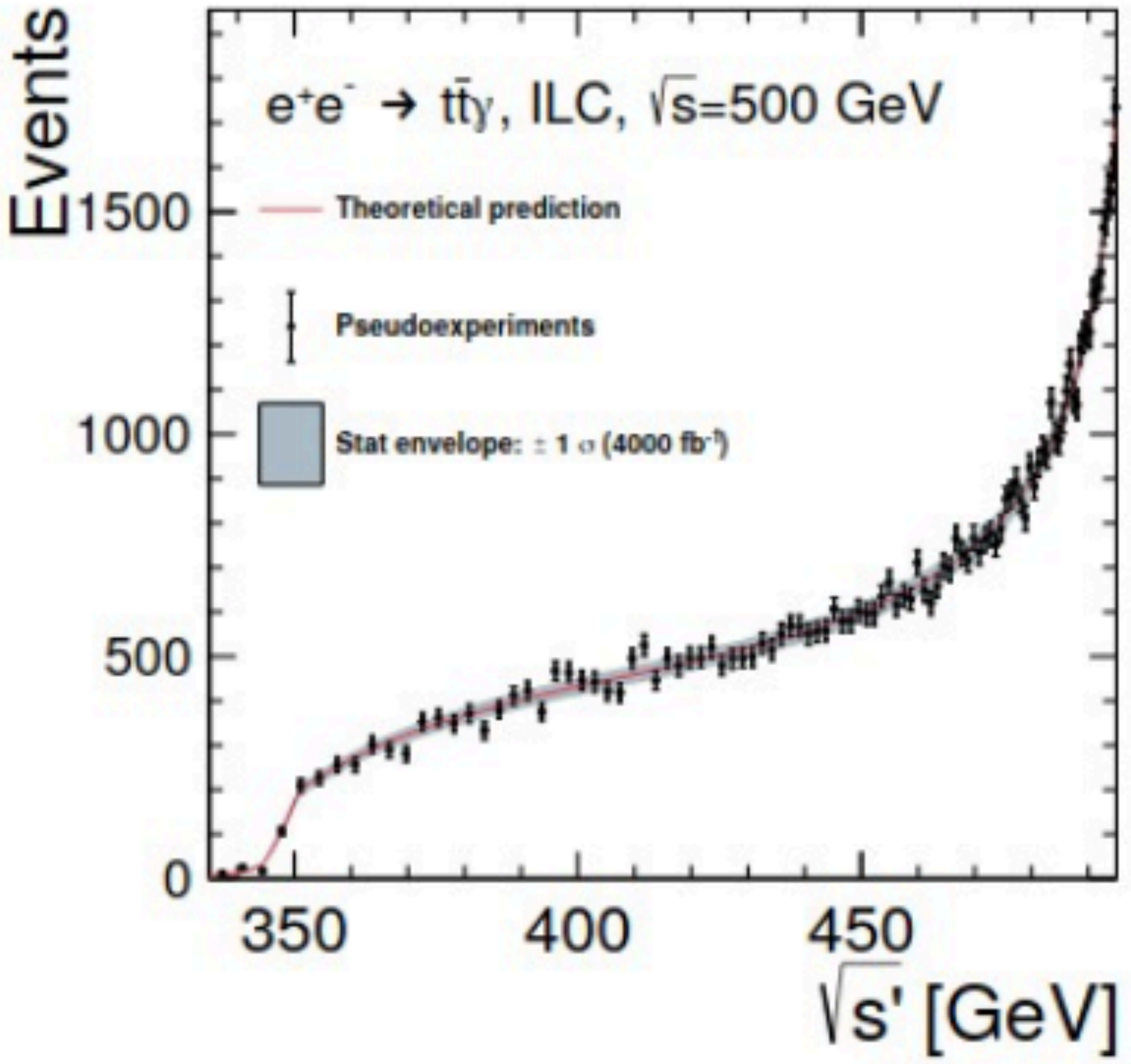


matched NNLO + NNLL calculation, luminosity spectrum folded in explicitly; Extraction of short distance MSR mass

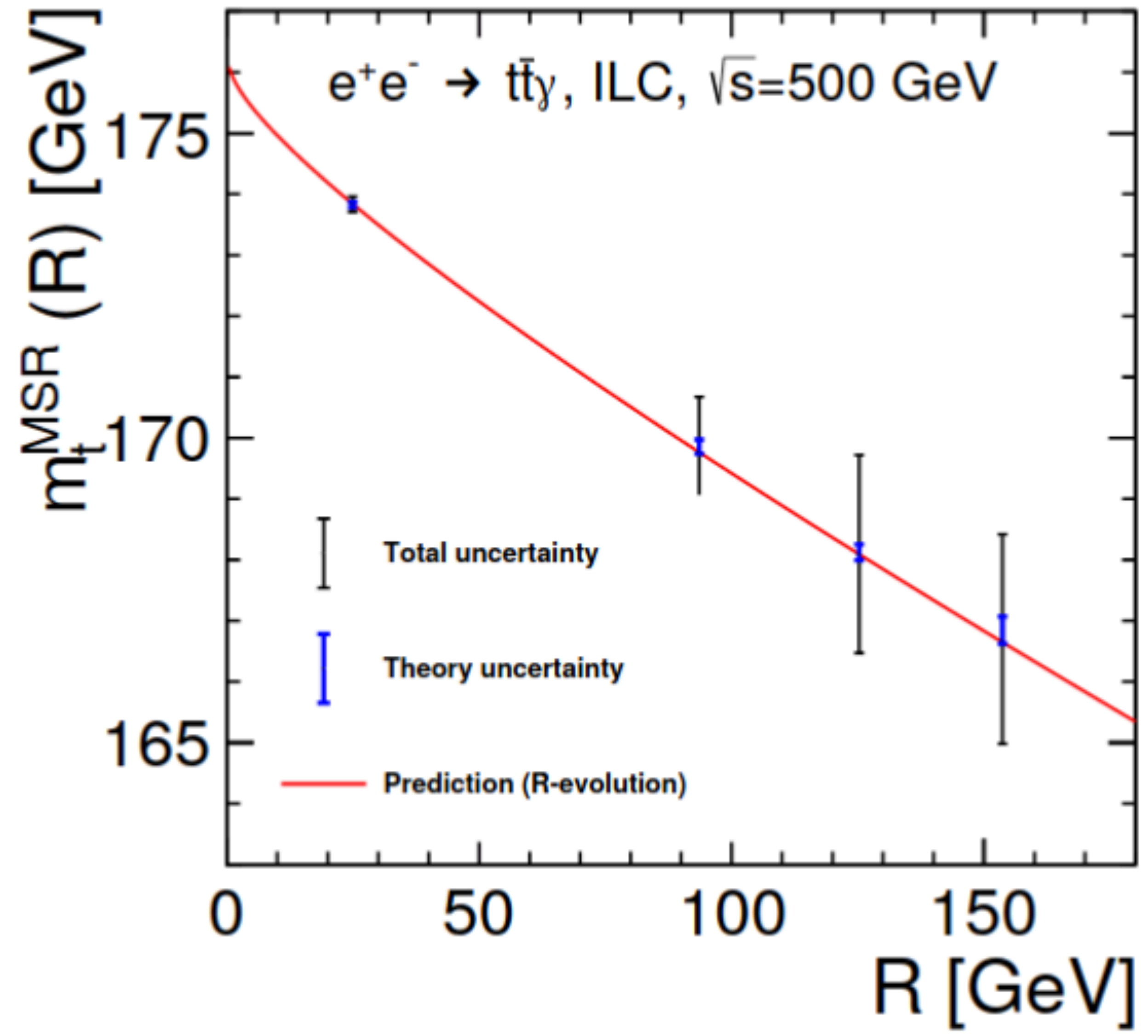
The expected uncertainty on the top $\overline{\text{MS}}$ mass

cms energy	CLIC, $\sqrt{s} = 380$ GeV		ILC, $\sqrt{s} = 500$ GeV	
luminosity [fb^{-1}]	500	1000	500	4000
statistical	140 MeV	90 MeV	350 MeV	110 MeV
theory	46 MeV		55 MeV	
lum. spectrum	20 MeV		20 MeV	
photon response	16 MeV		85 MeV	
total	150 MeV	110 MeV	360 MeV	150 MeV





can provide 5σ evidence for scale evolution ("running") of the top quark MSR mass from ILC500 data alone



… and now that we have the top-quark mass in the ~100MeV ballpark we can move to

Scanning Strategies at the Top Threshold at ILC

Frank Simon
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MAX-PLANCK-INSTITUT FÜR PHYSIK

ABSTRACT: A scan of the top quark pair production threshold at a future electron-positron collider provides the possibility for high-precision measurements of the top quark mass, and, when using two dimensional fits of the measured cross sections, also of other properties such as the width and the Yukawa coupling. The energy range of the scan and the distribution of the integrated luminosity can be optimized depending on the main goals of the threshold program. This contribution examines the possibility to determine the top quark mass in fast exploratory measurements with an adequate precision to enable such an optimization, and studies a scanning program with a reduced energy range of 6 GeV for the measurement of the mass, width and the Yukawa coupling, taking theoretical uncertainties from QCD scale variations and parametric uncertainties from the strong coupling constant into account.

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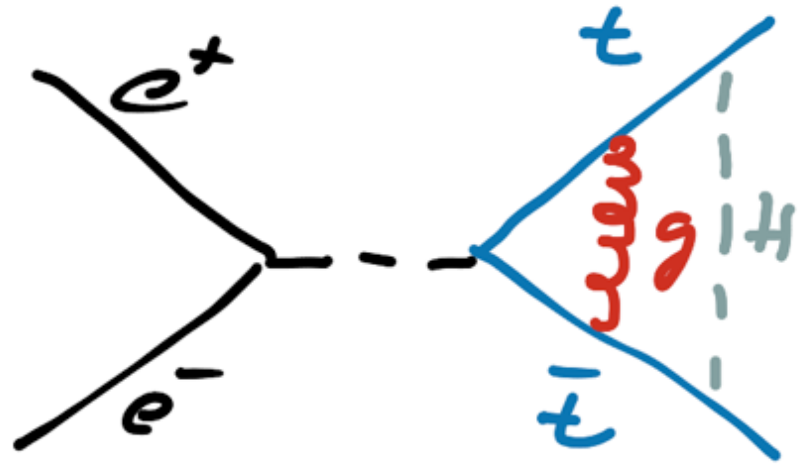
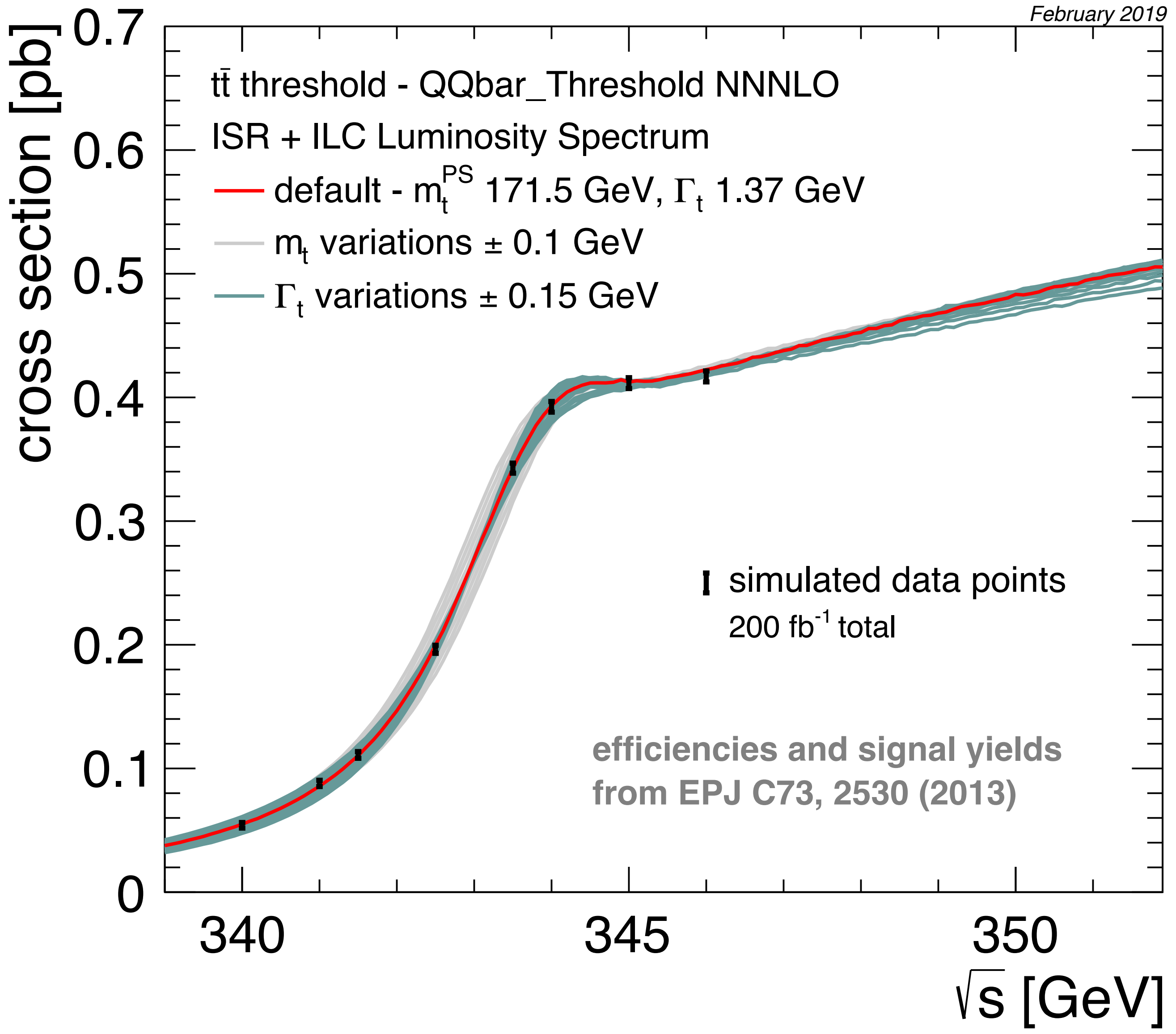
Mass at the Threshold

At CLIC, ILC, FCCee

- The top threshold provides excellent sensitivity to the mass and other top quark properties
  - Measurement of the top quark mass in theoretically well-defined mass schemes





- Assuming an integrated luminosity of 200 fb^{-1} (default for ILC, FCCee, x2 of CLIC standard scenario - 10 points spaced by 1 GeV)

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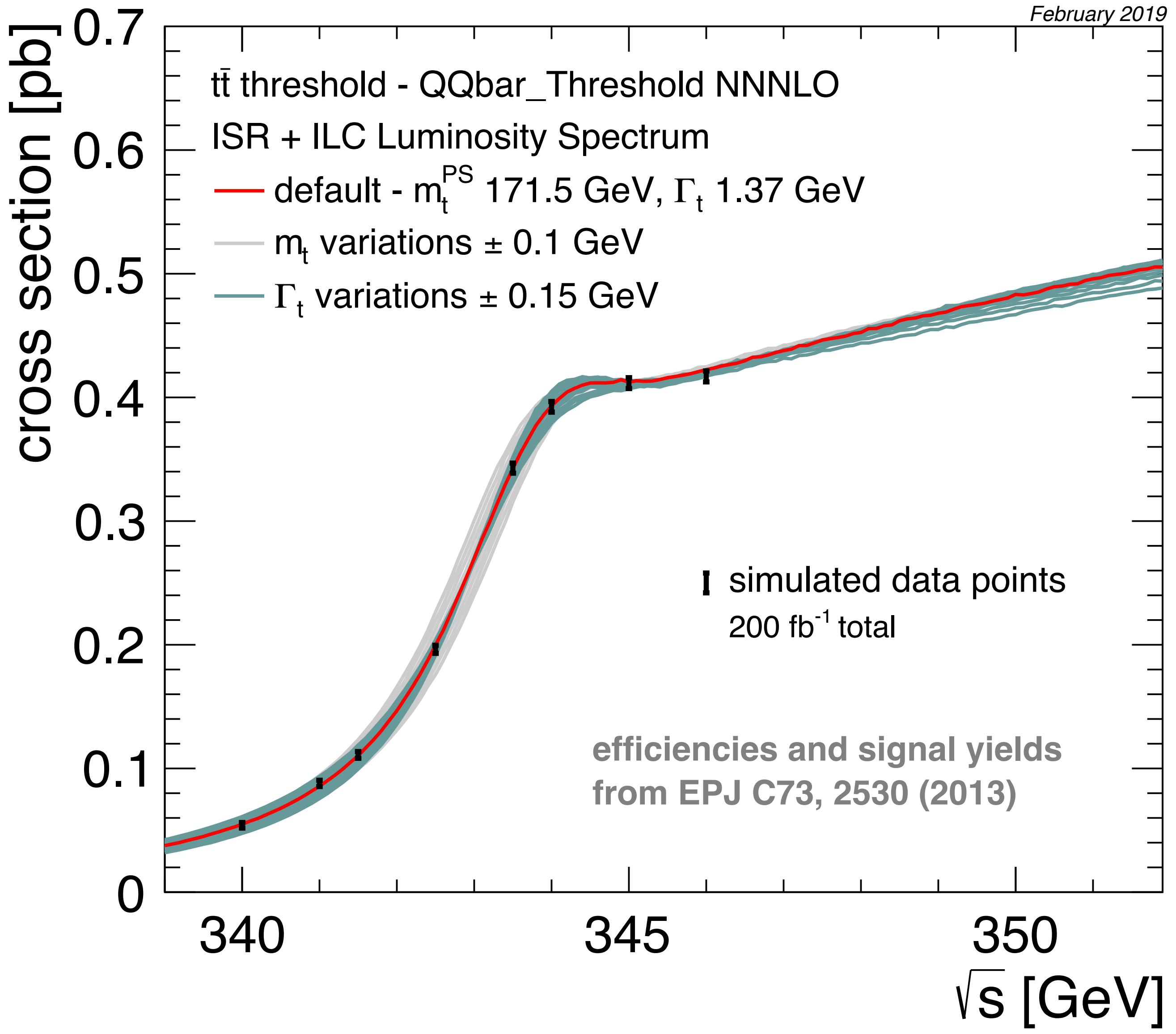

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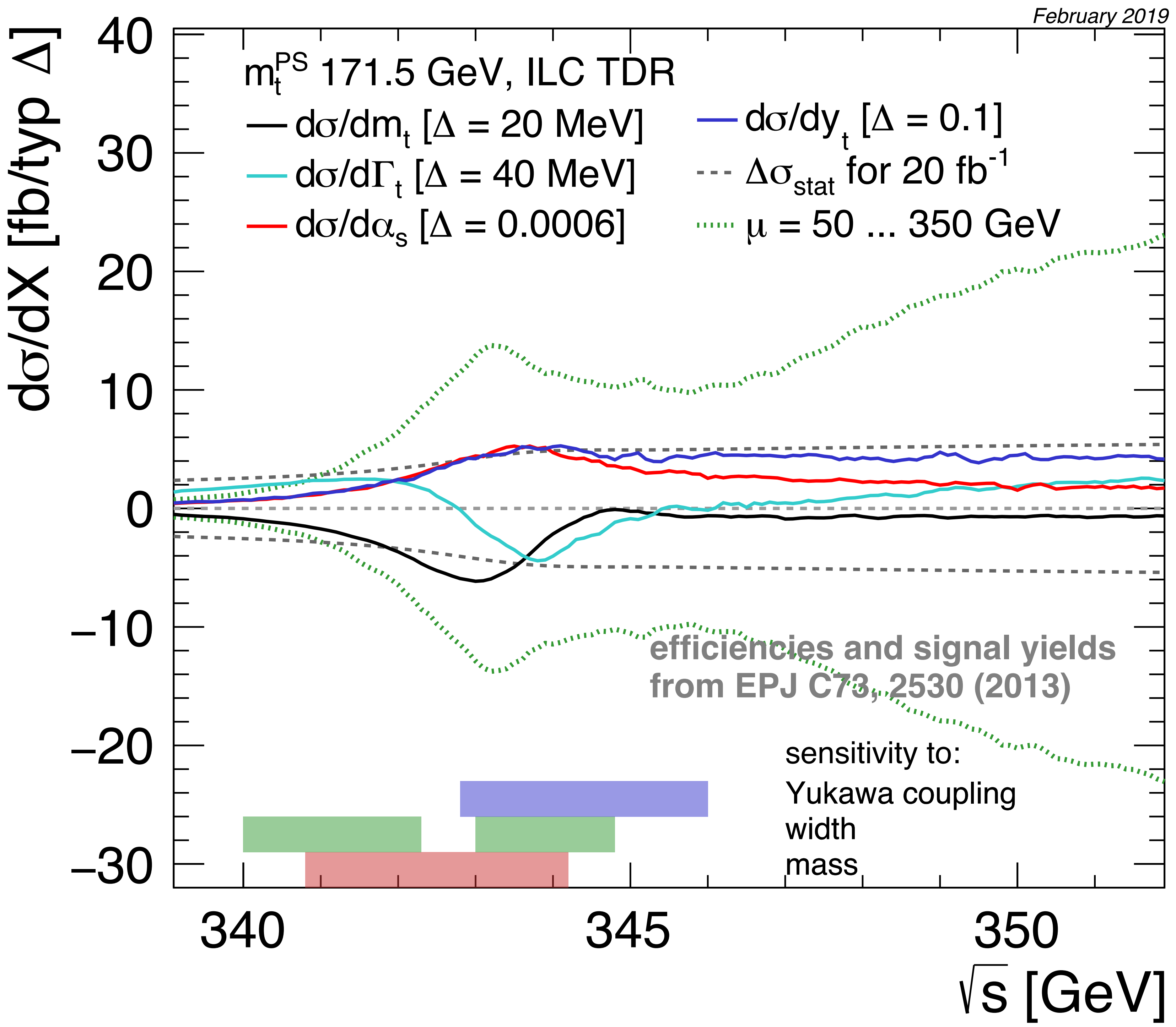

- Sensitivity to :
  - Top-quark mass
  - Top-quark width
  - Yukawa coupling
  - Strong coupling constant

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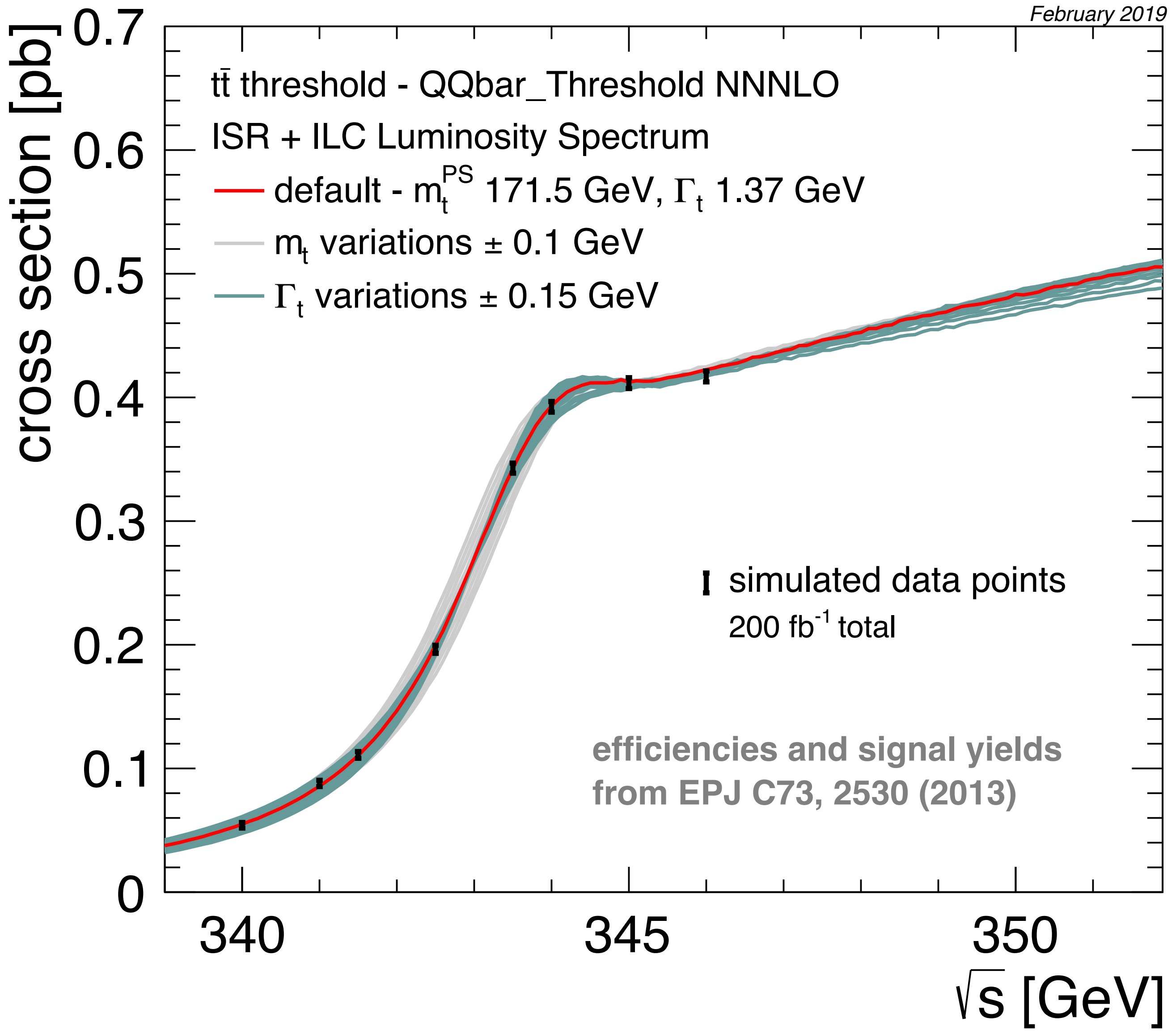

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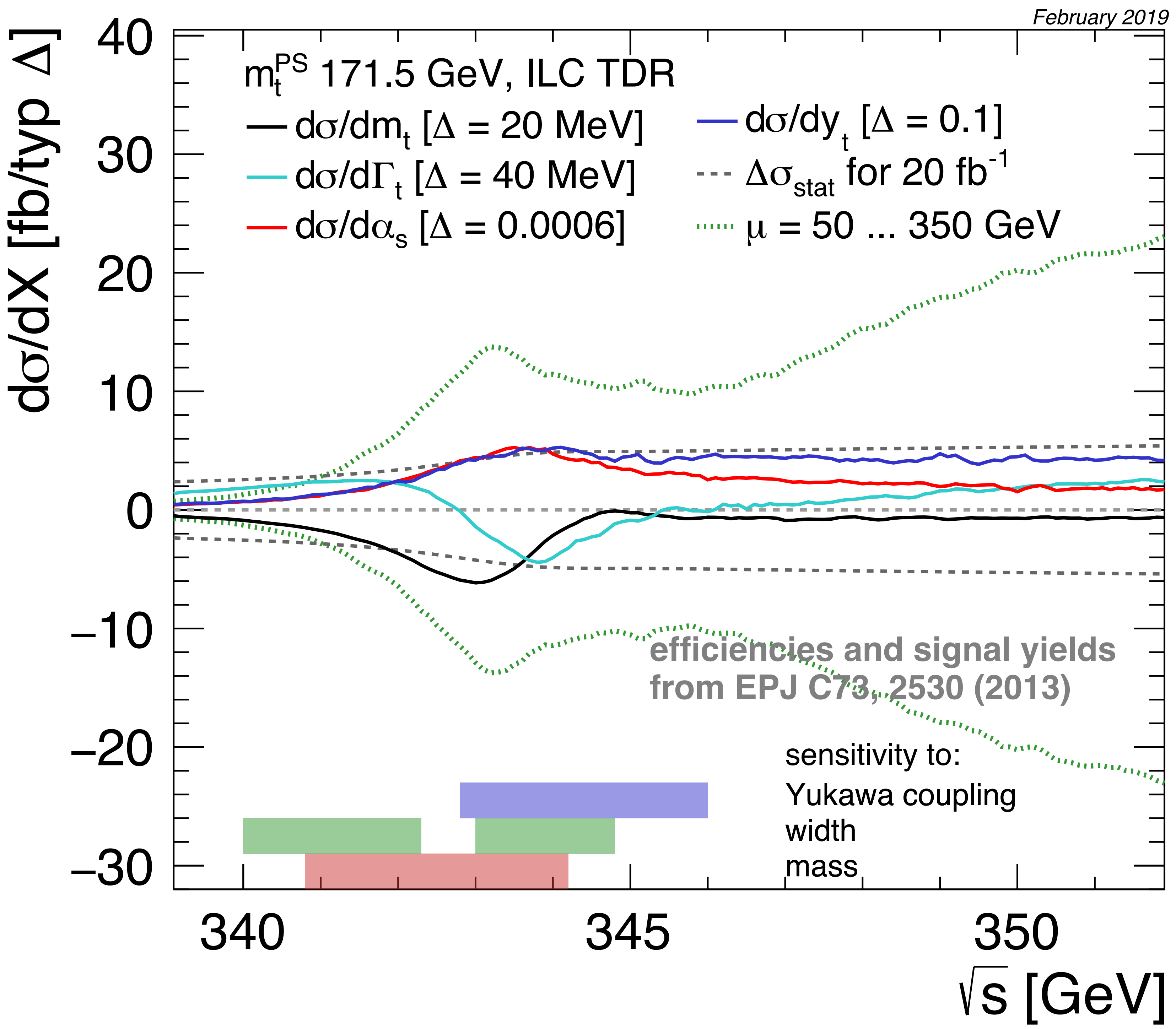


- Sensitivity to :
  - Top-quark mass
  - Top-quark width
  - Yukawa coupling
  - Strong coupling constant

So we are going to assume three scenarios

Scenario 1 : We fit all

float top quark mass, width, Yukawa coupling and alpha_s

arXiv:hep-ph/0207315v2 23 Oct 2002

Multi-parameter fits to the $t\bar{t}$ threshold observables at a future e^+e^- linear collider

Manel Martinez[a], Ramon Miquel[b]

[a] *Institut de Física d'Altes Energies, Univ. Aut. de Barcelona E-08390 Bellaterra (Barcelona) Spain*

[b] *Lawrence Berkeley National Laboratory, Physics Division 1 Cyclotron Road, Berkeley, CA 94720, USA*

November 1, 2018

- Assumes an integrated luminosity of 300 fb^{-1} (10 points)
- Assumes M(Higgs) = 120GeV
- TESLA beam conditions
- Theoretical error normalisation ~1%
- 3 observables : XS, momentum distribution and F-B asym.
  - But XS is dominant

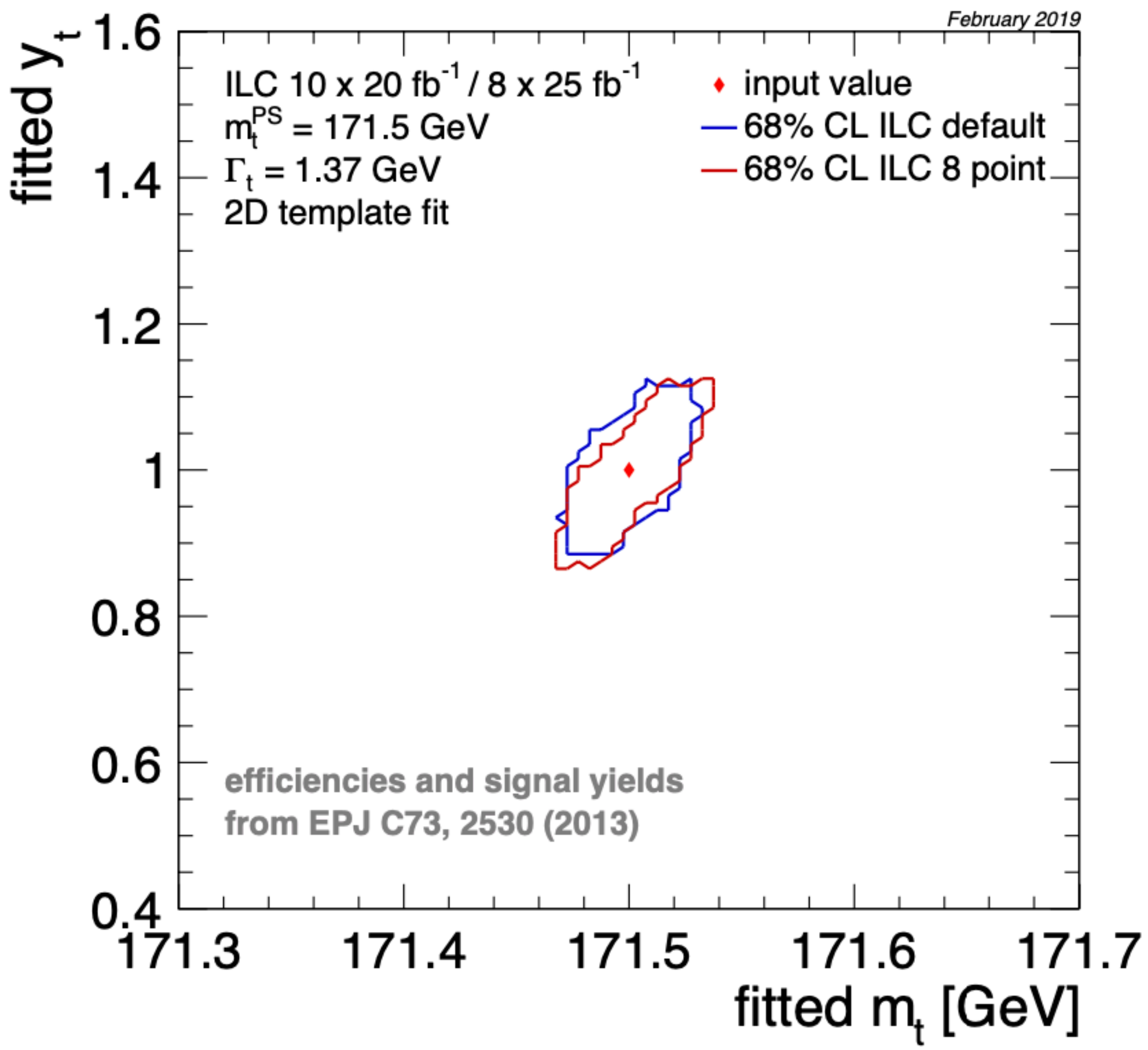
$$\Delta m_t = 31 \text{ MeV} \qquad \Delta\alpha_s = 0.001 \text{ (constraint)}$$

$$\Delta\Gamma_t = 34 \text{ MeV} \qquad \frac{\Delta\lambda_t}{\lambda_t} = {}^{+0.35}_{-0.65} \; .$$

This scenario will be revisited in the last part of the talk

Scenario 2 : We fit the mass and the coupling

fit the Yukawa coupling, floating the mass, but not the width. Vary alpha_s within some uncertainty.



parameter	8 point scan		10 point scan	
2D fit m_t and y_t		marg.		marg.
m_t	$(\pm 35_{(stat)} \pm 45_{(theo)})$ MeV	17.0 MeV	$(^{+34}_{-31}{}_{(stat)} \pm 42_{(theo)})$ MeV	15.2 MeV
y_t	$^{+0.120}_{-0.140}{}_{(stat)} \pm 0.09_{(theo)}$	0.055	$^{+0.128}_{-0.112}{}_{(stat)} \pm 0.132_{(theo)}$	0.047

Yukawa coupling current (pdg) value(*) : 1.07+0.34-0.43

Prospects after the ILC@500GeV run (1ab^{-1}) set at the 10% ballpark.

(*) ratio wrt the SM predicted value

Scenario 3 : We fit only the mass

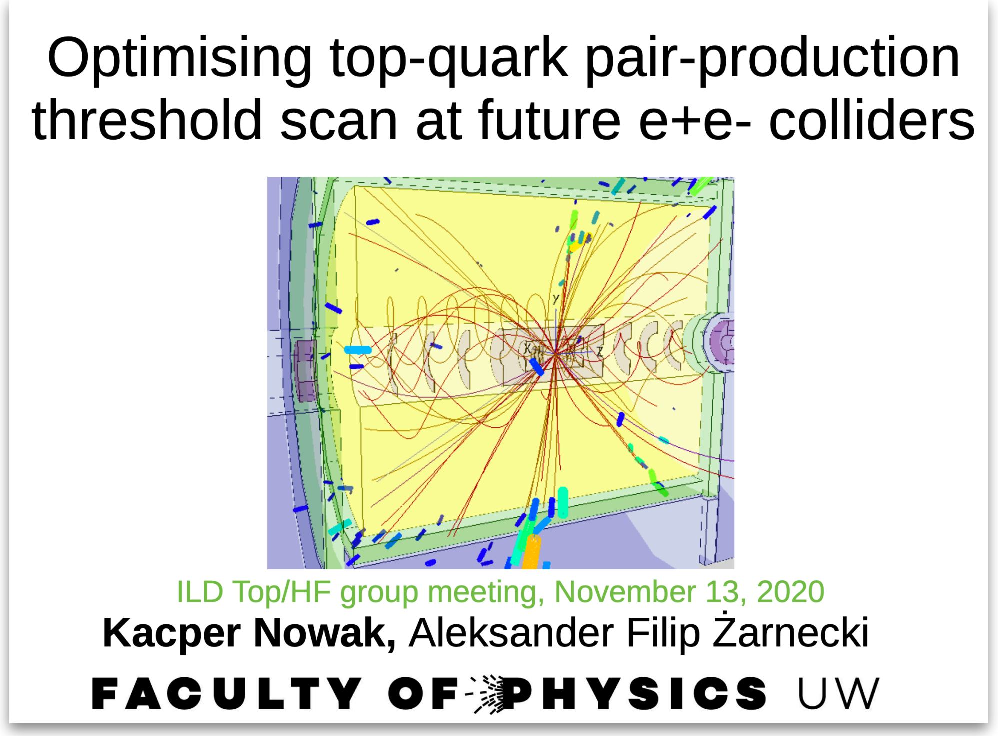
extraction of the top mass assuming the SM: fix width to SM prediction, fix y_t = 1. Vary alpha_s within some uncertainty.

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

- Detailed evaluation of systematic uncertainties
- 8 points configuration for this uncertainty
- Theory dominated (~40MeV vs ~10MeV); assuming a N4LO available for 2040 expect further reductions

For other configurations of the scan points :

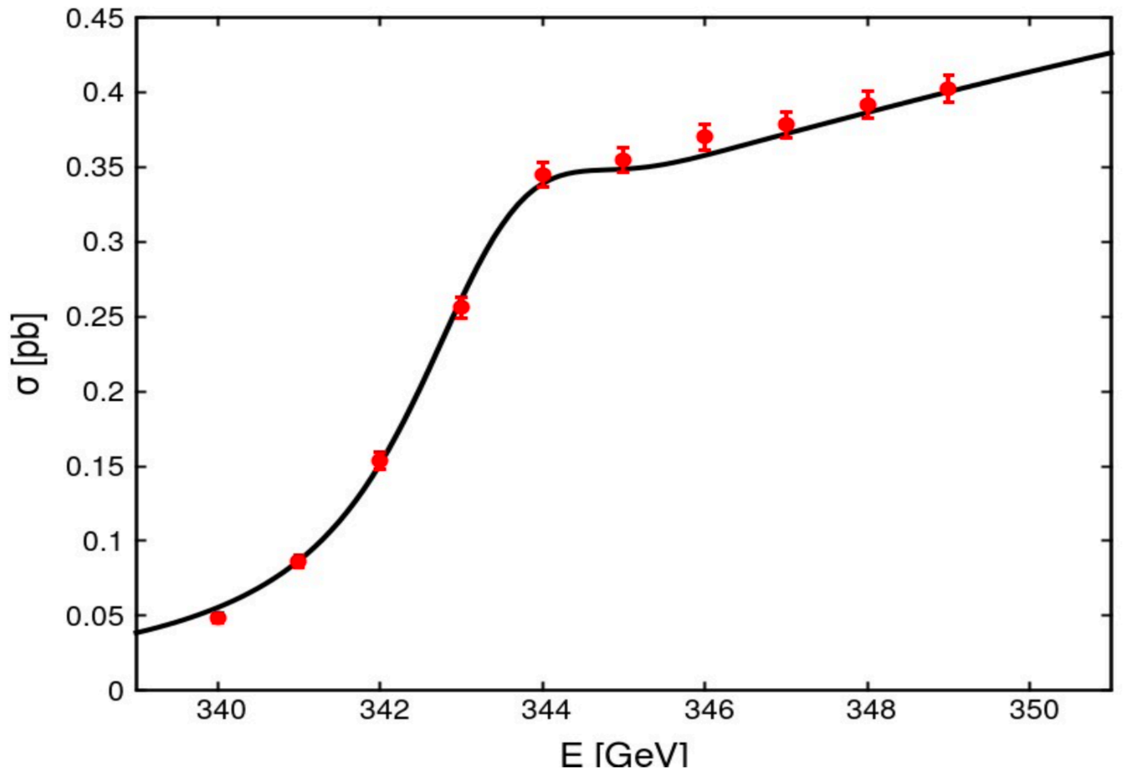
parameter	8 point scan	10 point scan
1D fit		
m_t	$(\pm 10.3_{(stat)} \pm 44_{(theo)})$ MeV	$(12.2_{(stat)} \pm 40_{(theo)})$ MeV



Scenario 1 revisited

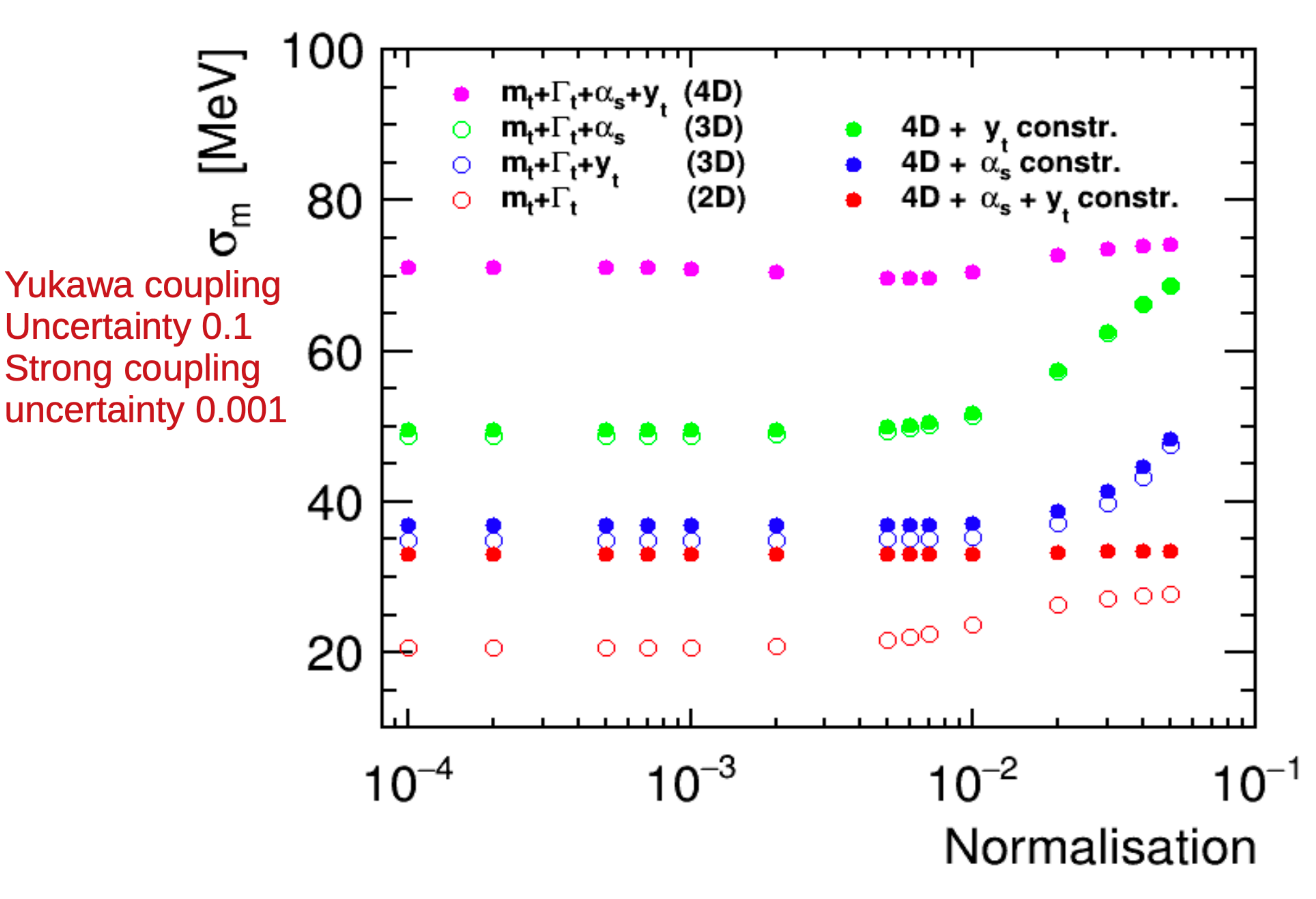
Studies done by Kacper Nowak and Filip Zarnecki

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

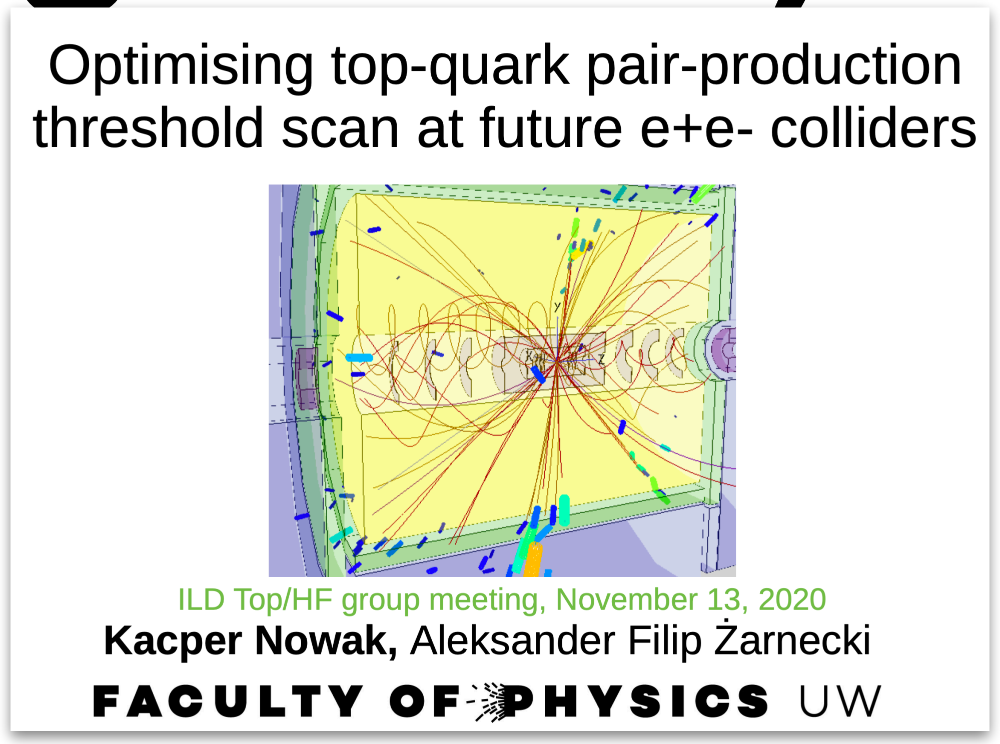
results for the benchmark scenario

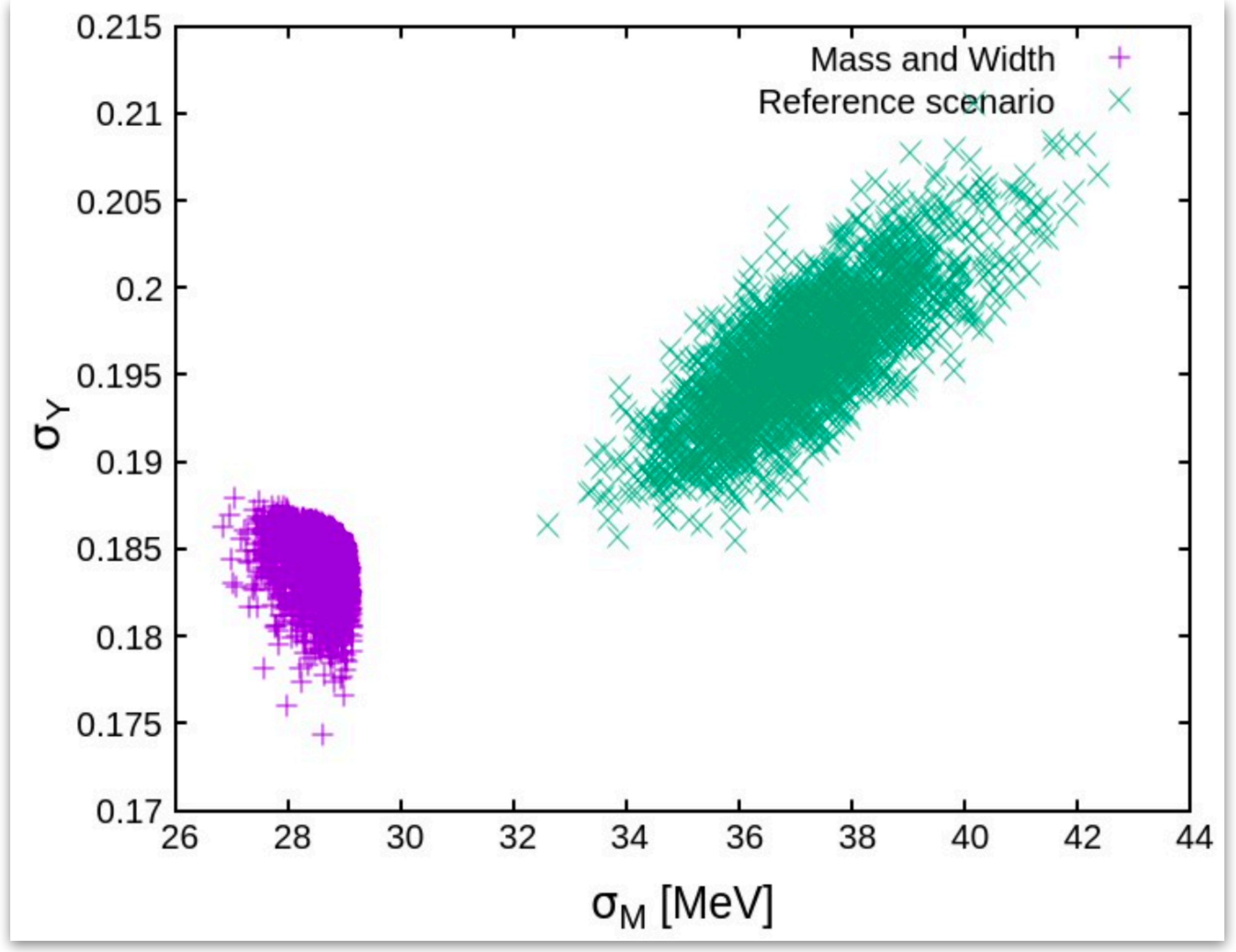


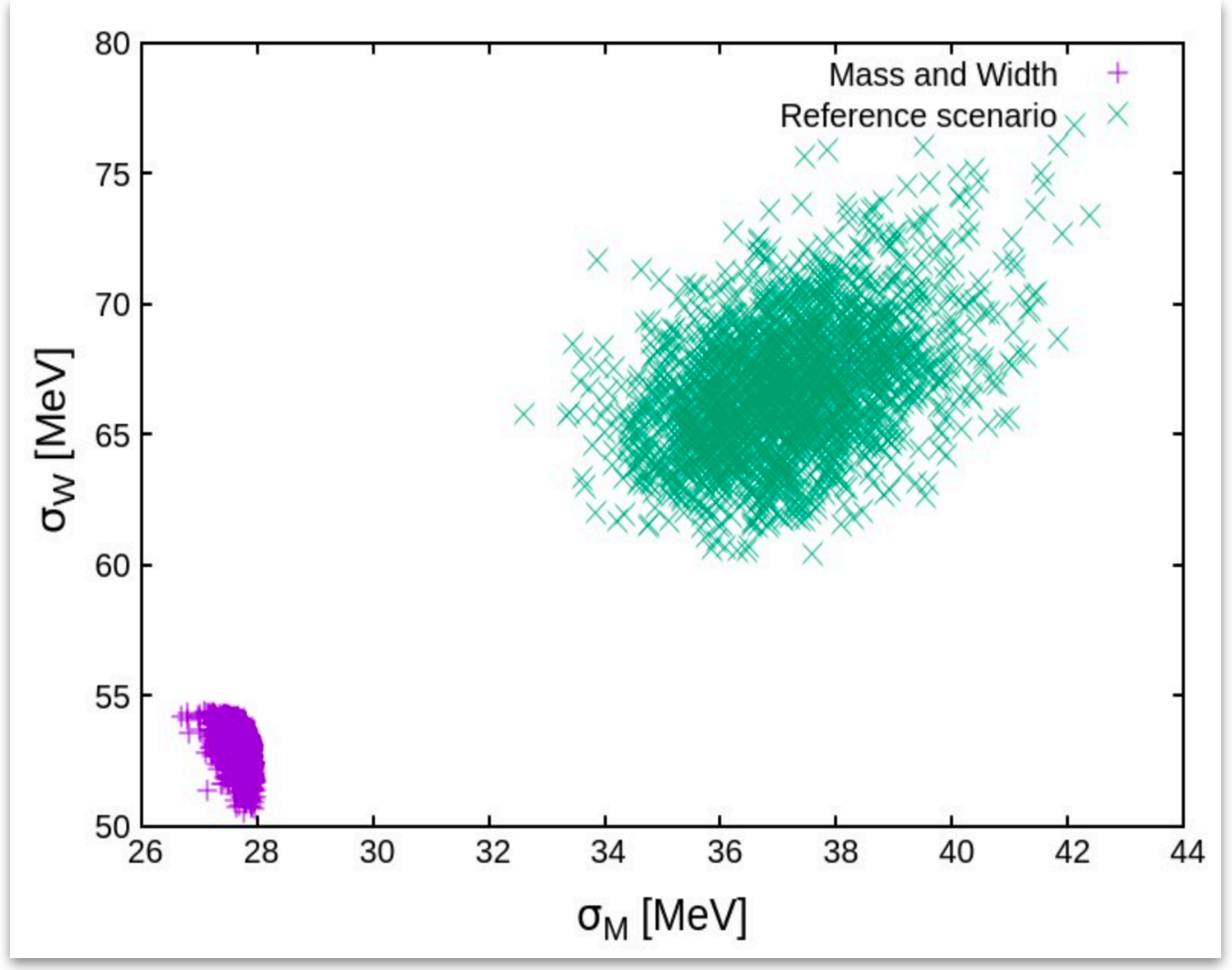
See Kacper Thesis CERN-THESIS-2020-099 for more details

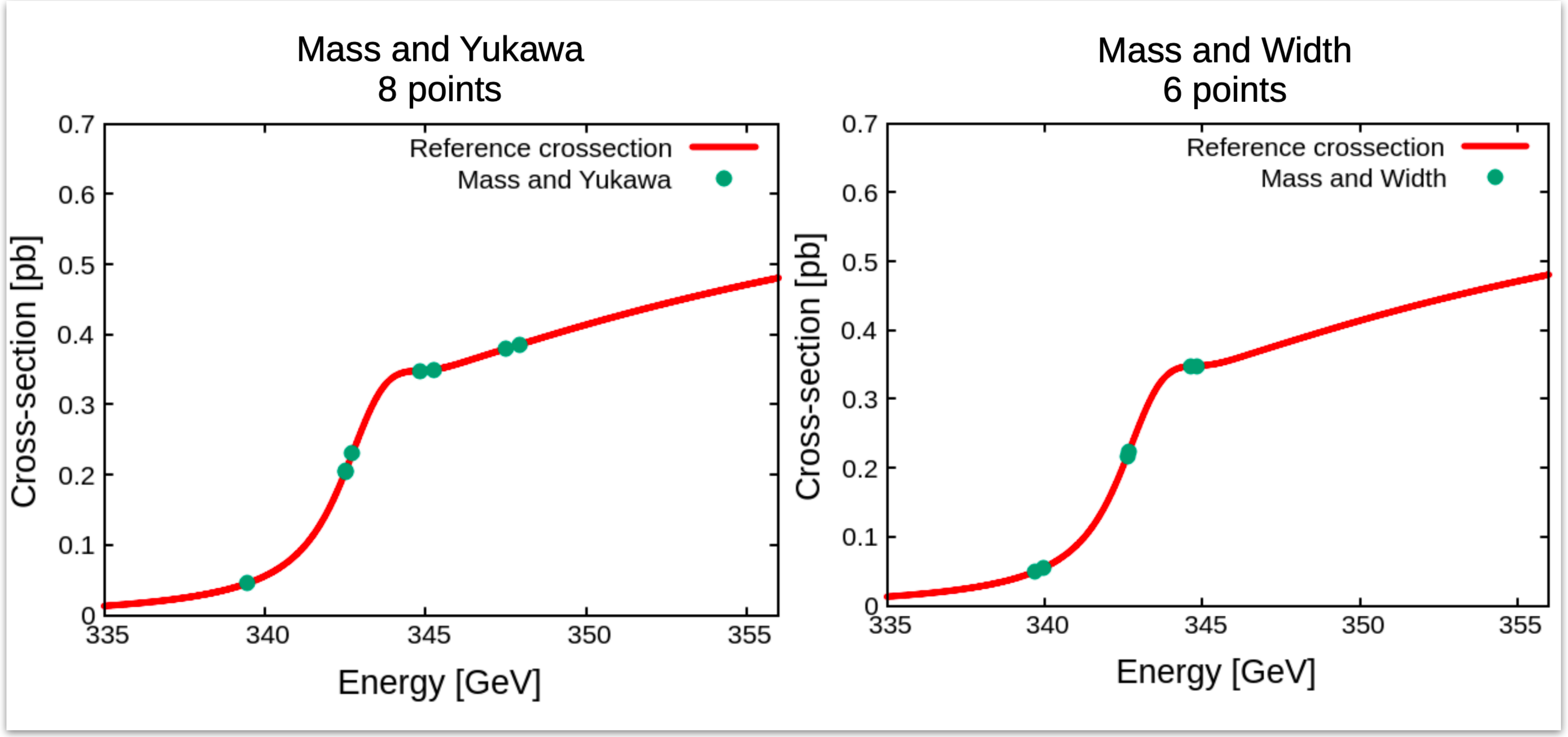
Optimisations (based on the genetic algorithm)

Studies done by Kacper Nowak and Filip Zarnecki









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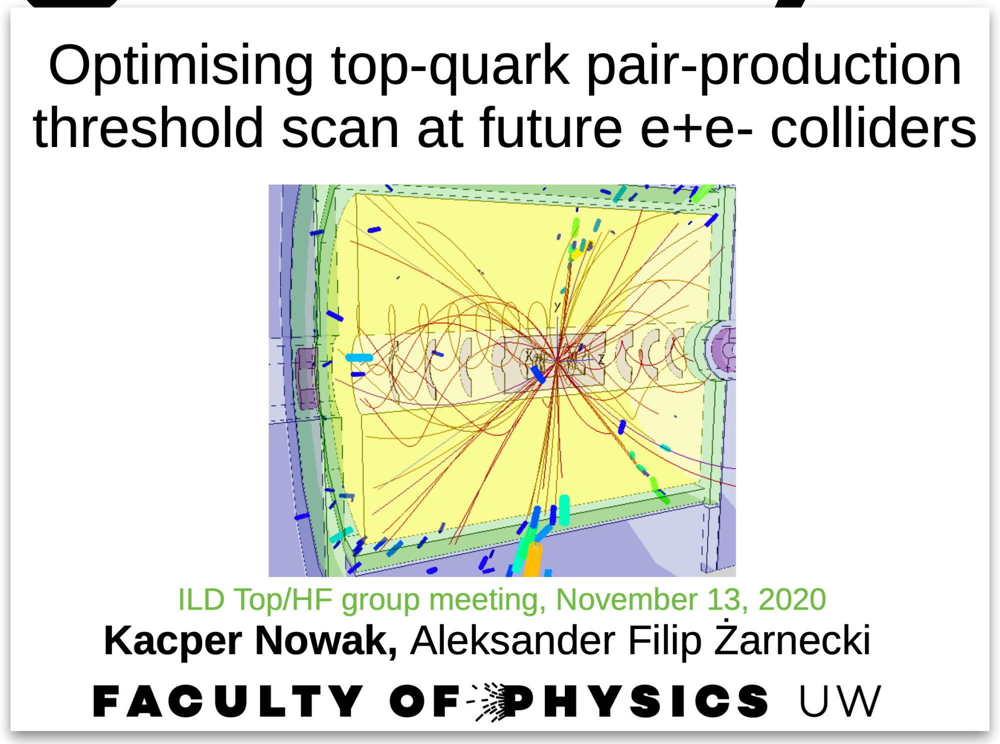
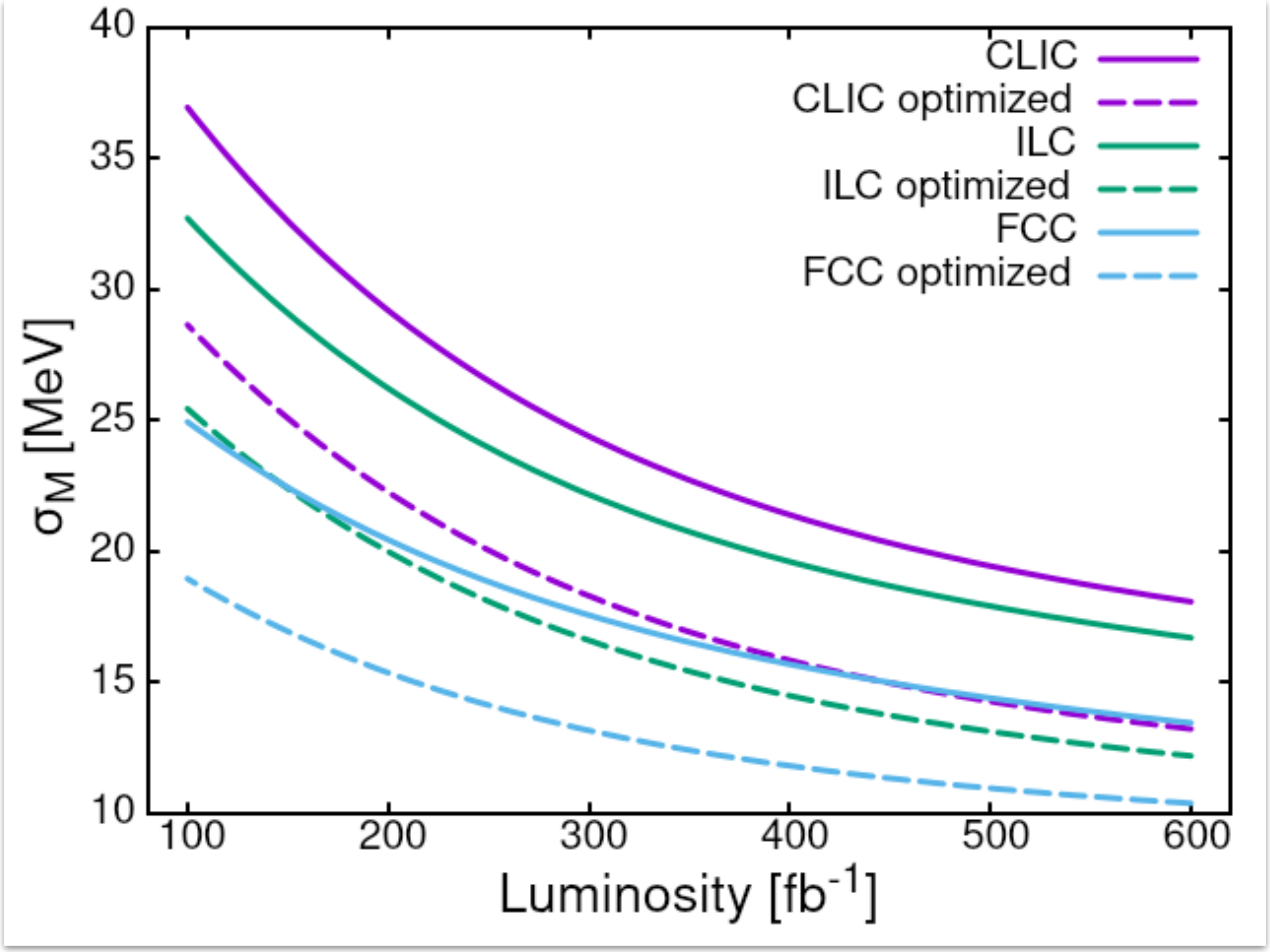




Statistical uncertainty of the extracted top-quark mass can be reduced by ~25%, without losing precision in width or Yukawa determination

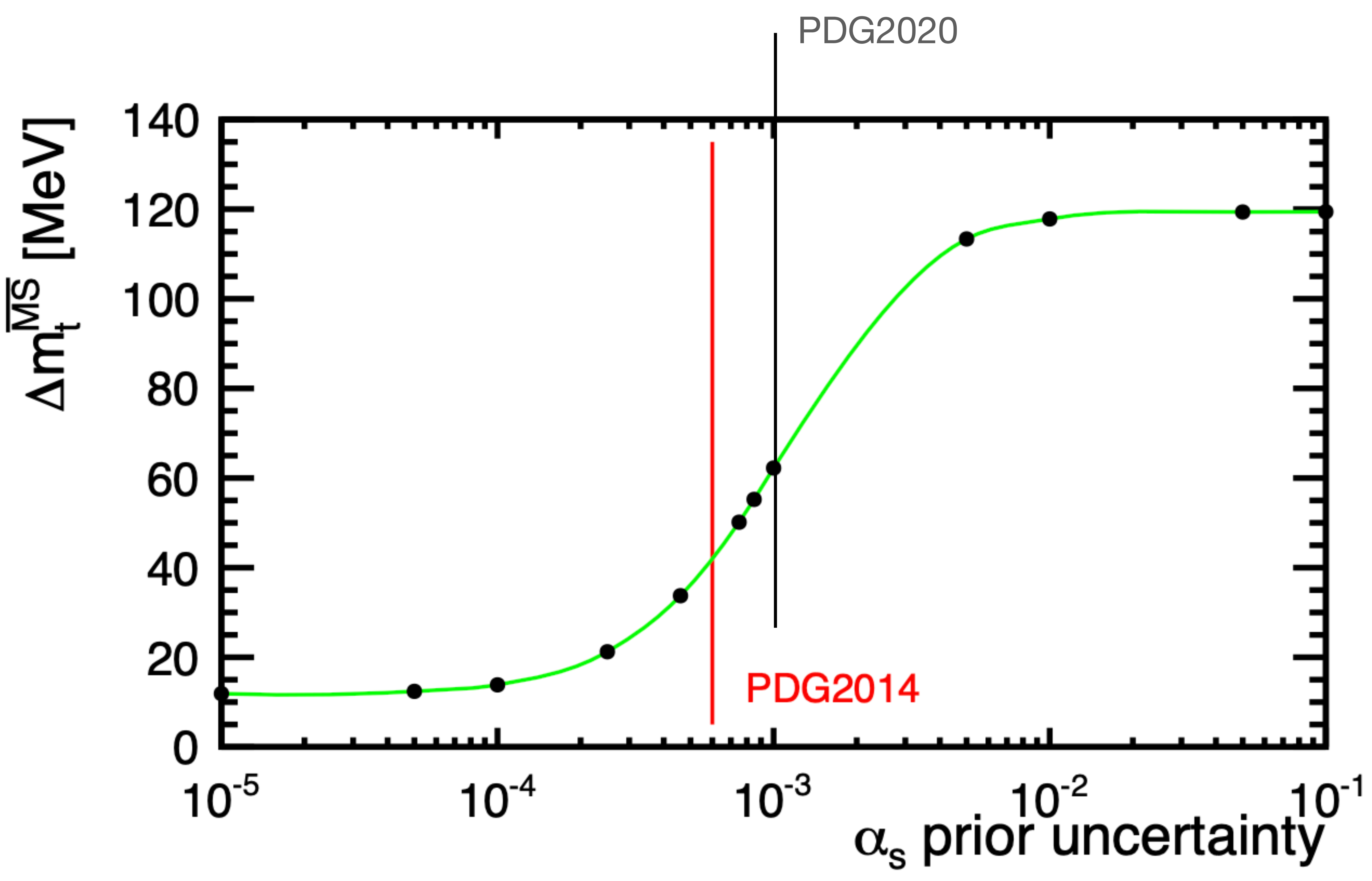
Summary

- Current precision ~50MeV dominated by theoretical uncertainty
- Possibility to measure other parameters : width, strong coupling and Yukawa
  - To be decided after the ILC@500GeV run
- Room for optimisation and the optimisation depends on the parameters we want to aim

the end

Dependency with Alpha_s

Taken from arXiv:1604.08122v1 [hep-ex]



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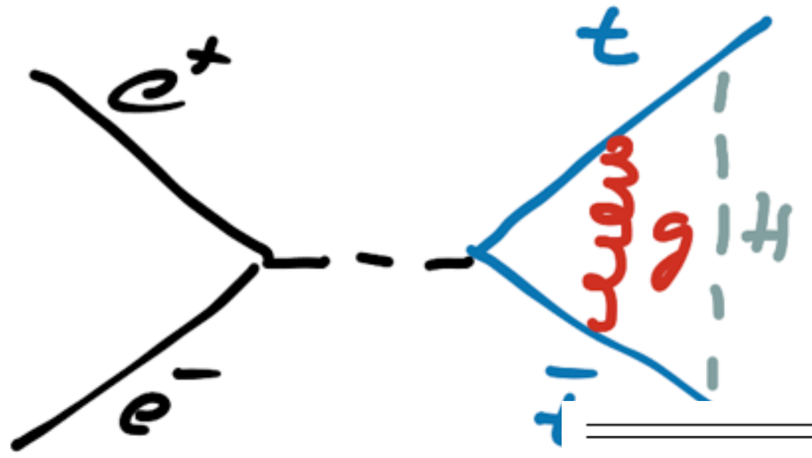
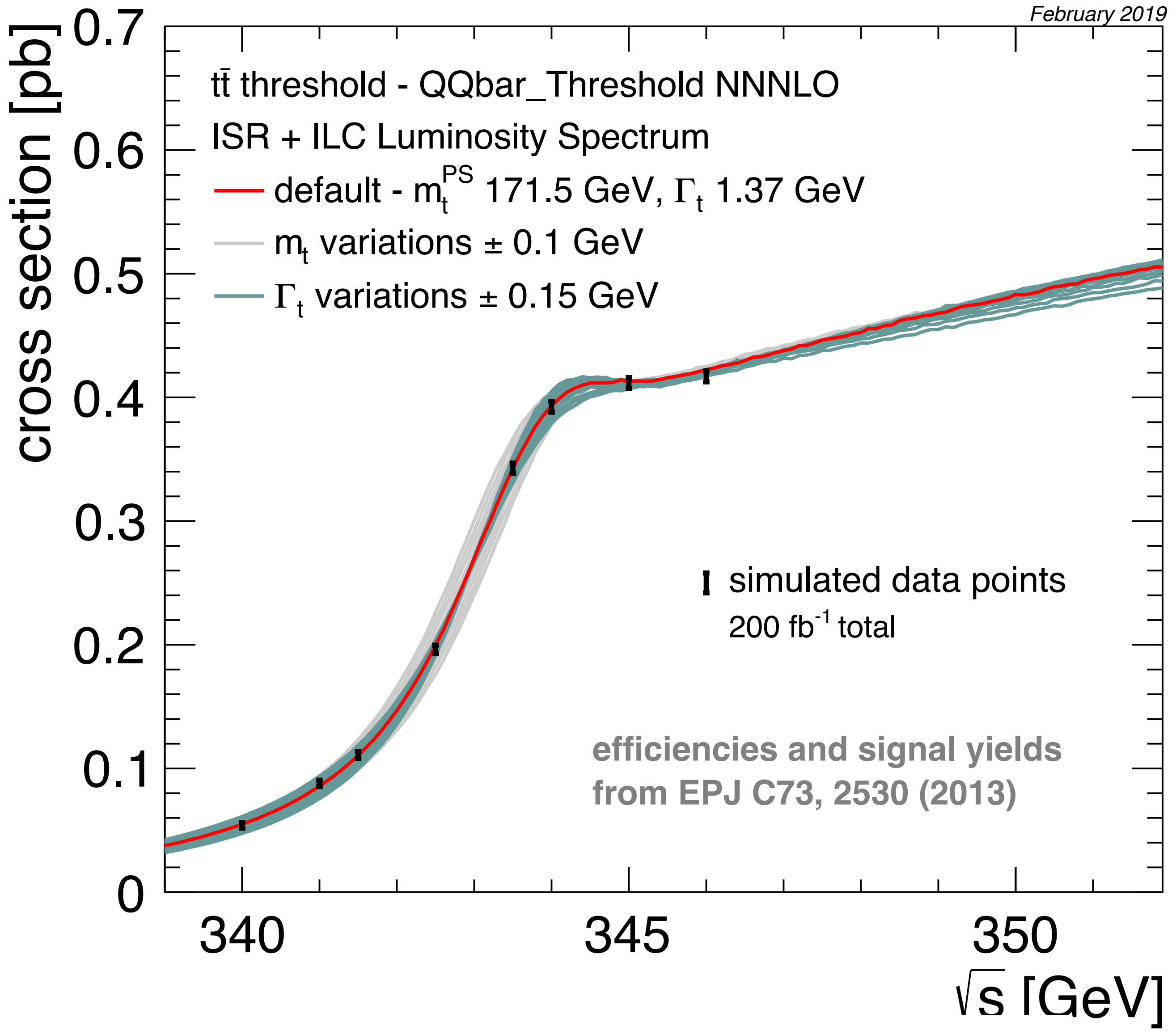
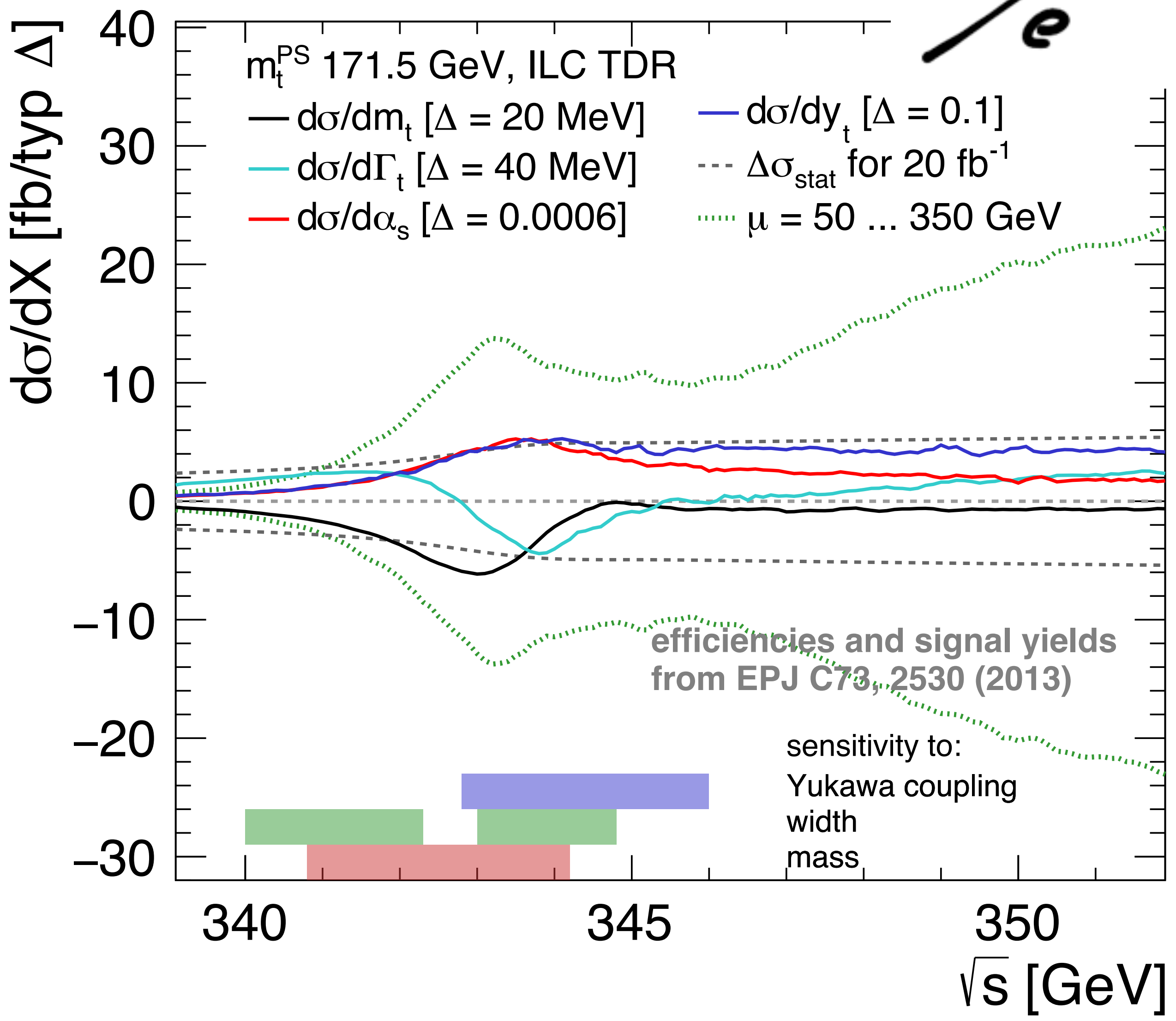




- Assuming an integrated luminosity of 200 fb^{-1} (default for ILC, FCCee, x2 of CLIC standard scenario - 10 points spaced by 1 GeV)
- Standard fit of mass only:
  ILC 12.2 MeV [stat]
  CLIC 13.3 MeV [stat]
  FCCee 10.0 MeV [stat]



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- Detailed evaluation of systematic uncertainties
- Multi-parameter fits (mass, width, α_s, y_t), scan optimization…