

# *Focus topic meeting “ $t\bar{t}$ bar threshold”*

**Marcel Vos, IFIC, CSIC/UV, Valencia, Spain**

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R. Franceschini, A. Irlles J. de Blas (related focus topics), P. Azzi (liaison FCCee)



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# Practical

The ECFA focus topics document is out:

<https://arxiv.org/abs/2401.07564>

There is a mailing list for this group:

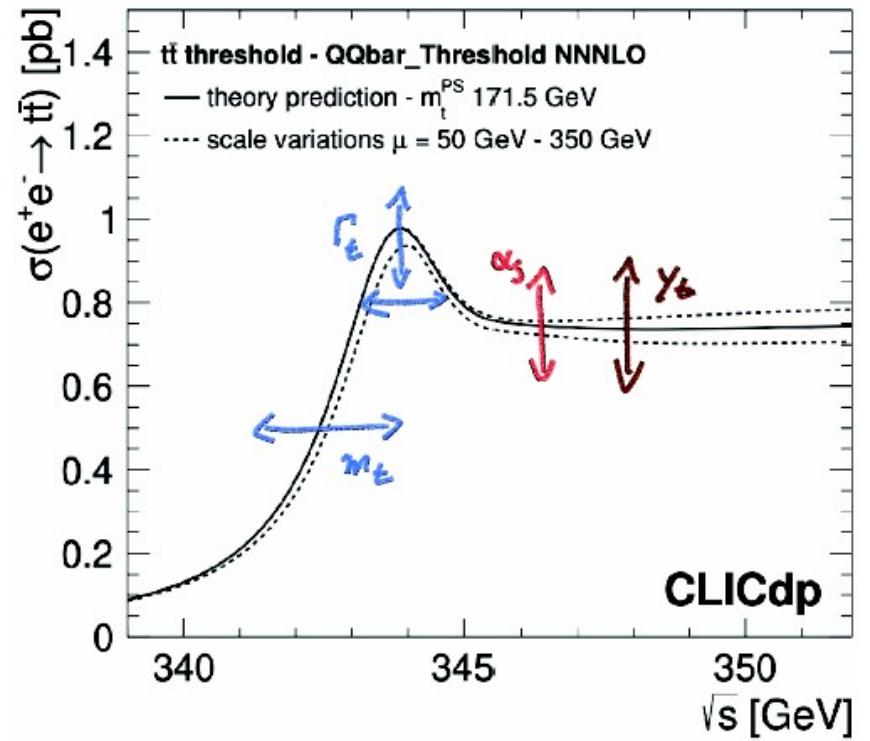
<https://gitlab.in2p3.fr/ecfa-study/ECFA-HiggsTopEW-Factories/-/wikis/FocusTopics/TTthresh>

You may have received the announcement twice, because not everyone was on the list yet

## Focus topics for the ECFA study on Higgs / Top / EW factories

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# The $t\bar{t}$ threshold scan

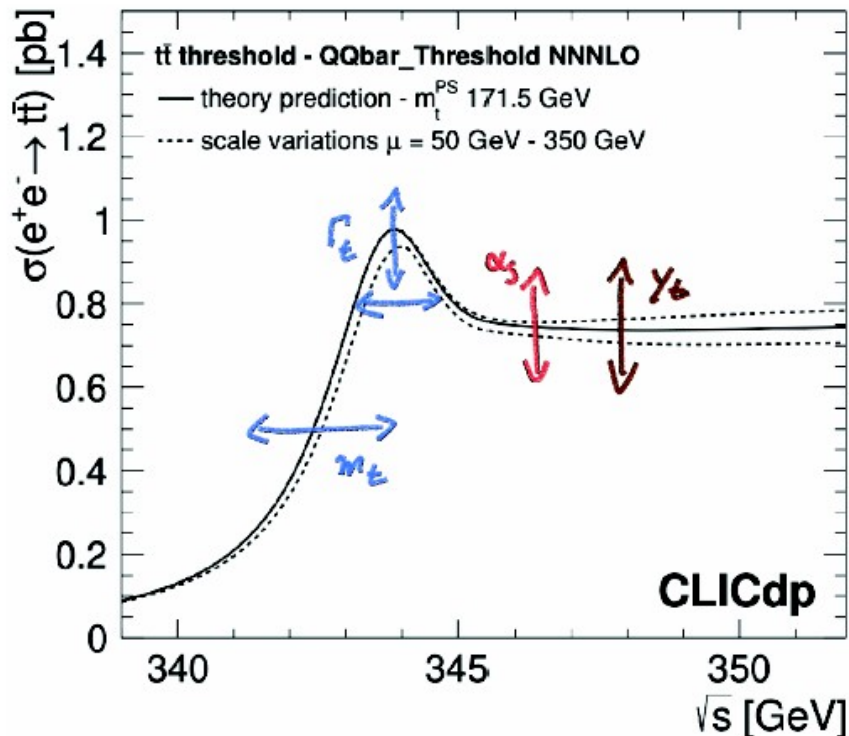


## e+e- threshold scan

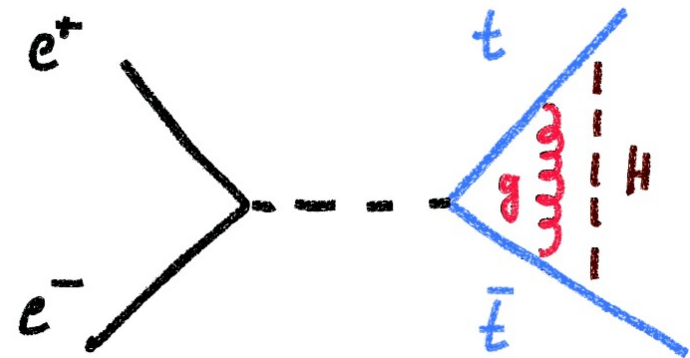
A scan of the  $e^+e^-$  center-of-mass energy through the pair production threshold allows for the ultimate mass measurement (*Gusken & Kuhn '85, Peskin & Strassler '91*)

Experimental studies: Martinez & Miquel, hep-ph/020735, Seidel et al., arXiv:1303.3758

**Part of the operation plan for all e+e- collider projects: Higgs & top factory!**



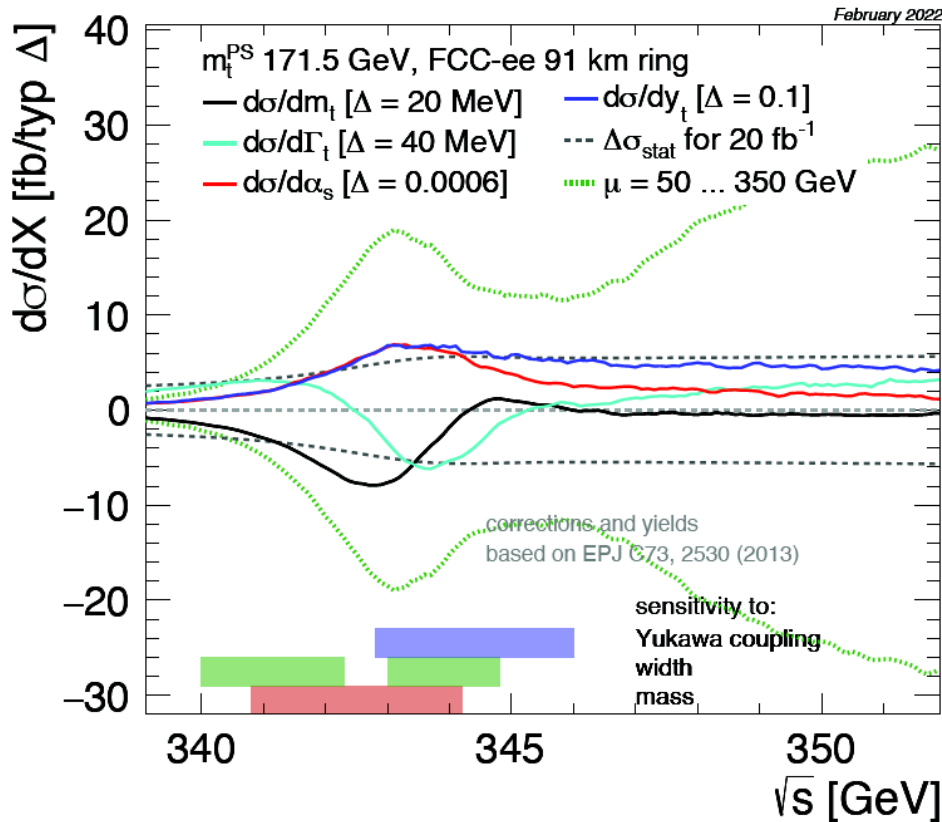
Art-work: Frank Simon



The threshold position is sensitive to the top quark mass, the shape to the width  
 The normalization is sensitive to strong coupling and top quark Yukawa coupling  
 Just measure the cross section vs.  $\sqrt{s}$  shape and derive all parameters

# Top quark mass

Frank Simon's seminar  
Snowmass top physics report



Statistical uncertainty - - - can be made small with 1-2 years of operation

Theory uncertainty ..... requires calculation beyond NNNLO (QCD) + NNLO (EW). Resummation is available and can be added.

Note: interpretation unambiguous, translation to  $\overline{MS}$  scheme with  $O(10 \text{ MeV})$  QCD scale uncertainty, parametric uncertainty from  $\alpha_s$  requires care, as well as EW corrections

Top quark mass to **approx. 50 MeV**, limited by theory uncertainty and to first order independent of collider design (luminosity spectrum has 2nd order effect)

Top quark width to 45 MeV → bounds on invisible decays+SMEFT arXiv:1907.00997  
Precision for  $\alpha_s \sim 0.001$  and  $y_t \sim 12\%$  not competitive, but good cross-checks

# Future directions

Exp: Full-simulation study to revisit and harmonize experimental systematic uncertainties

Theo: Fully differential predictions at adequate precision

Specify procedure for comparison of data and theory (i.e. treatment of ISR?)

Study width prospects in more detail (i.e. comparison LHC, interpretation in NP scenarios)

Embed top mass prospect in global EW fit environment

Find a way to make top Yukawa and strong coupling results more competitive

## Theoretical and phenomenological targets

- Complete and harmonised assessment of systematic uncertainties on SM parameters extracted from the threshold scan.
- Degeneracies in a EFT analysis including only “one” energy point. How to disentangle effects combining with other (non-top-quark) measurements. Indirect constraints on top Yukawa.

## MC samples needed

Basic samples available as listed in the Motivation Section, dedicated samples for threshold scan are needed.

## Existing tools / examples

- ILD  $t\bar{t}$  analysis [https://github.com/ILDAnaSoft/ILDbench\\_QQbar](https://github.com/ILDAnaSoft/ILDbench_QQbar)

## Contact & Further Information

- Gitlab wiki: <https://gitlab.in2p3.fr/ecfa-study/ECFA-HiggsTopEW-Factories/-/wikis/FocusTopics/TTthresh>
- Sign up for egroup: ECFA-WHF-FT-TTthres@cern.ch via <http://simba3.web.cern.ch/simba3/SelfSubscription.aspx?groupName=ecfa-whf-ft-ttthres>
- and/or email the conveners of ECFA WG1 GLOBal group: <mailto:ecfa-whf-wg1-glob-conveners@cern.ch>

# Towards a standard sample

WHIZARD sample in preparation by M.V. (with help from J. Reuter, J. Tian)

$e^+e^- \rightarrow 6$  fermions ( $b\bar{b}$ , 2 charged leptons, 2 neutrinos)

- Mostly  $e^+e^- \rightarrow t\bar{t} \rightarrow WbWb$ , with all W decays, but see next slide
- Using SM\_CKM (leading order, no threshold enhancement)

With luminosity spectrum and ISR

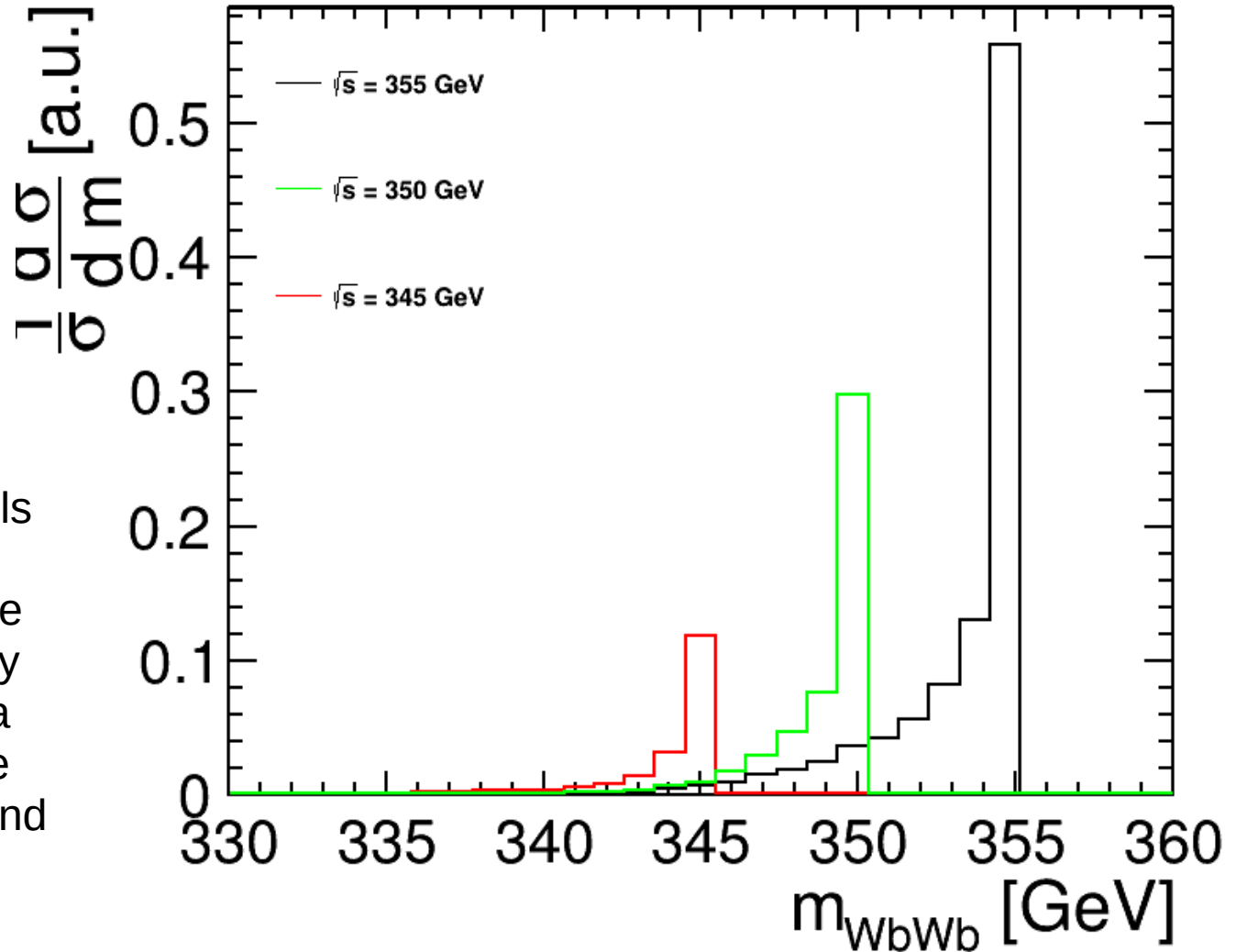
- ILC 350, also FCCee is possible
- Polarization is possible?

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```

Hadronization handled by Pythia (volunteers for Pythia variations?)

Simulation to be requested in ILD, FCC concepts, etc.

# Threshold scan MC samples



Note: ISR and luminosity spectrum lead to low- $\sqrt{s}$  tails

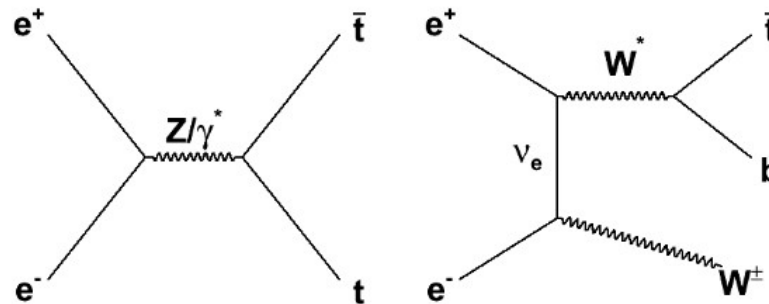
Note: to normalize the cross section properly we need to assume a relation between pole mass (used in MC) and PS mass (in calculation)



# Signal vs. background

We need a working definition of **signal** and **background** between experiment and theory

Single top

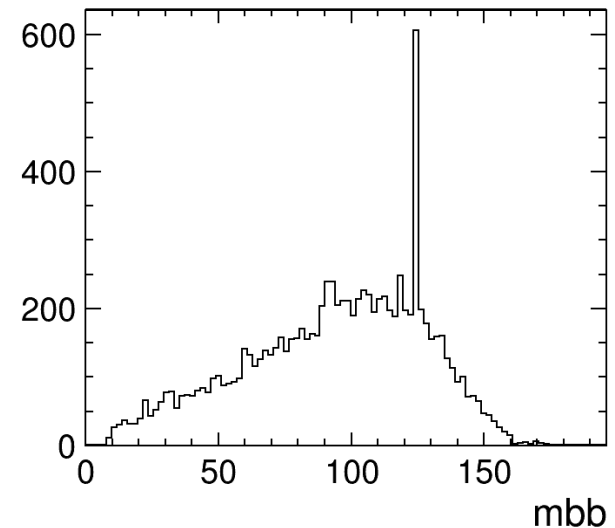


(note: single top is considered signal in  $WbWb$  calculations)

Also  $e^+e^- \rightarrow ZH, Z \rightarrow W^+W^-, H \rightarrow bb$  (or vice versa) is part of  $e^+e^- \rightarrow WbWb$

Clear backgrounds: 6f without b-jets and 2f & 4f backgrounds

See: Martin Beneke, this meeting, for what's included in the prediction:



# Experimental systematic uncertainties

Is the acceptance constant vs.  $\sqrt{s}$  over the range of the threshold scan?

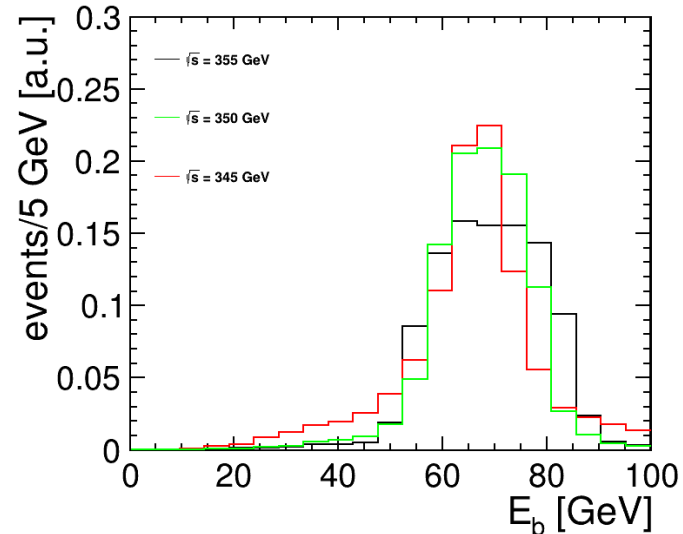
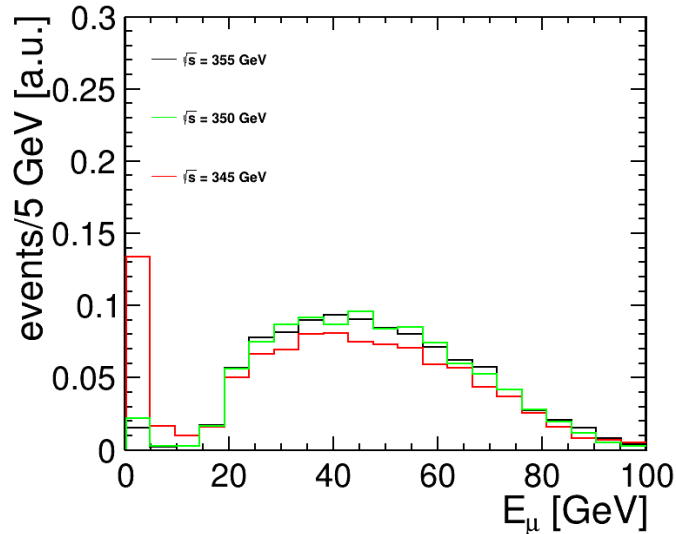
- Realistic selection requires one/two b-tags and isolated leptons, with “near-complete polar angle coverage” (<https://arxiv.org/pdf/1307.8102.pdf> + CLIC 380 <https://arxiv.org/pdf/1807.02441.pdf>)

Is the b-tagging efficiency constant? Or can we calibrate it in-situ?

- Double-tag method, ATLAS (<https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PAPERS/TOPQ-2023-21/>), LEP (<https://arxiv.org/abs/hep-ex/0509008>), or ILD (<https://arxiv.org/pdf/2306.11413.pdf>)

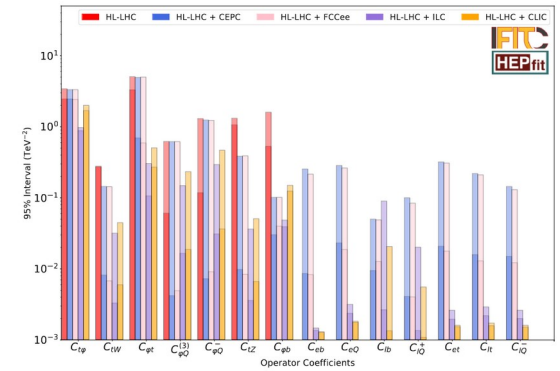
No reconstruction?

- Required by measurement of  $A_{FB}$ , but not needed (or desirable) for cross section



# Above the threshold: a broad precision programme

To be discussed in another meeting



# Summary

## **Threshold scan signal MC samples are in development:**

- WHIZARD six-fermion (with single top, Higgs, etc.) pure leading order in pole mass scheme
- Samples with more advanced model, including threshold enhancement, could be produced in the future

We need volunteers to analyze these

Plenty of related activities are still looking for personpower

## **Practical:**

Register on the mailing list if you haven't done so yet.

Step up the frequency of these meetings (and possibly move to another day)