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# *Bounding exotic top decays inclusively at FCC-ee (via ~10 $^6$ t tbar)*

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mainly a few thoughts
not an exhaustive discussion !

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# heavy top mass allows decays into new BSM states

just few examples:

$$t \to H^+ b \to \tau \nu b$$

$$t \to H^+ s \to c \bar{s} s$$

still allowed beyond 2HDM type II

$t \to Z' c, Z' u$ (light neutral gauge bosons)

$t \to \chi\chi c, \quad \chi\chi u$ (dark matter)

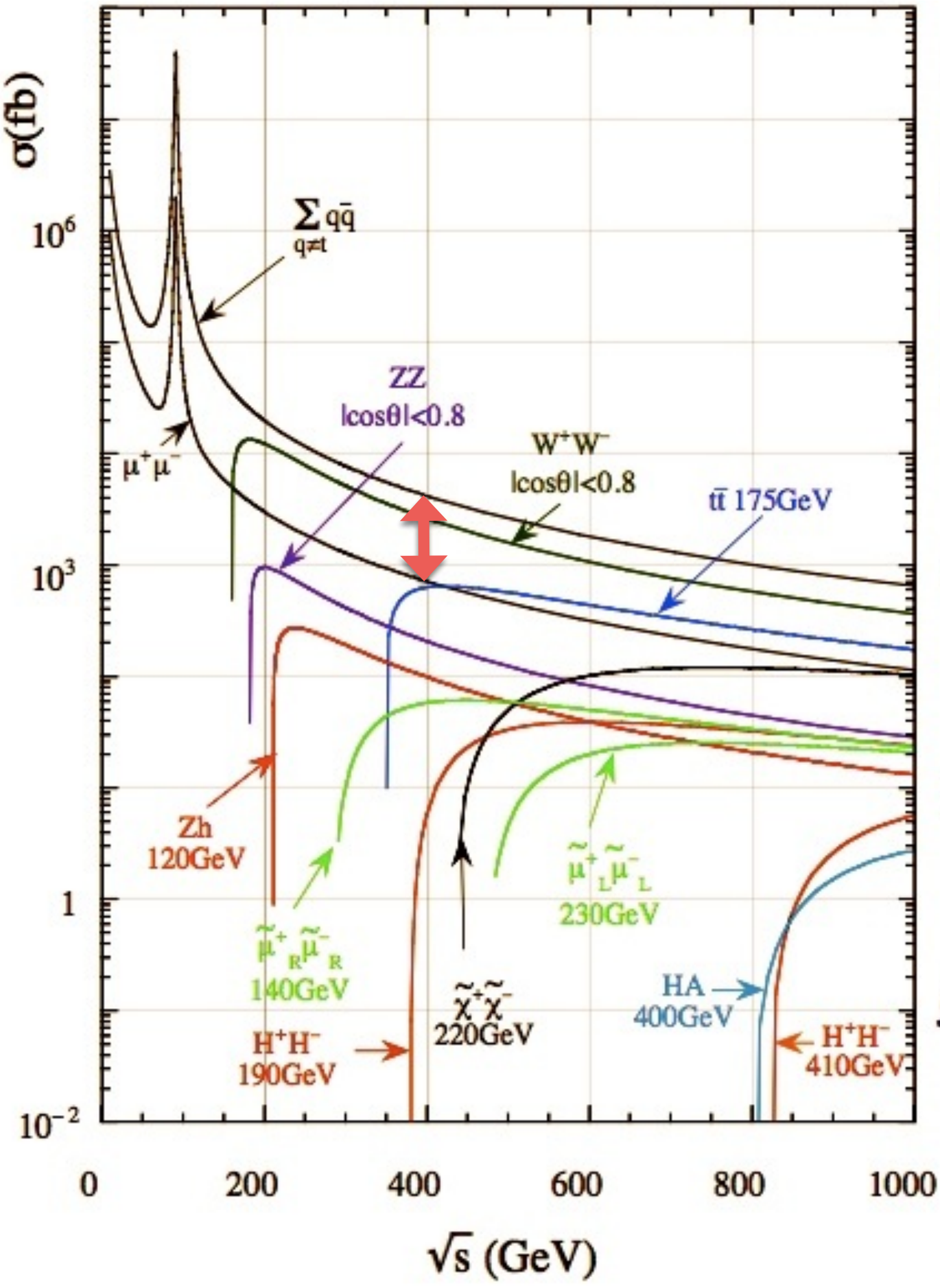
$t \to n\ jets \neq bW \to bjj$ (???)

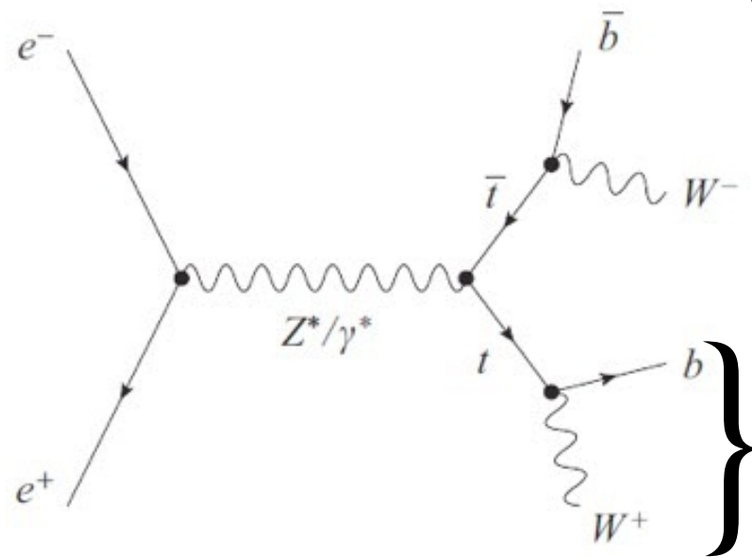
could have many different "unexpected" final states with unexpected kinematical features ...
can't find them at LHC [unless you make assumptions on what you are looking for] !

# what about $e^+e^-$ collider ?

## what makes unique $e^+e^-$ environment wrt (larger $N_{ev}$) had. collisions :

- democracy in σ's (all EW σ's !)
- accurate TH predictions
- clean EXP environment
- untriggered operation
- can detect and reconstruct "any" hadronic final state
- can detect what is invisible at LHC just because we do not know what to trigger on …

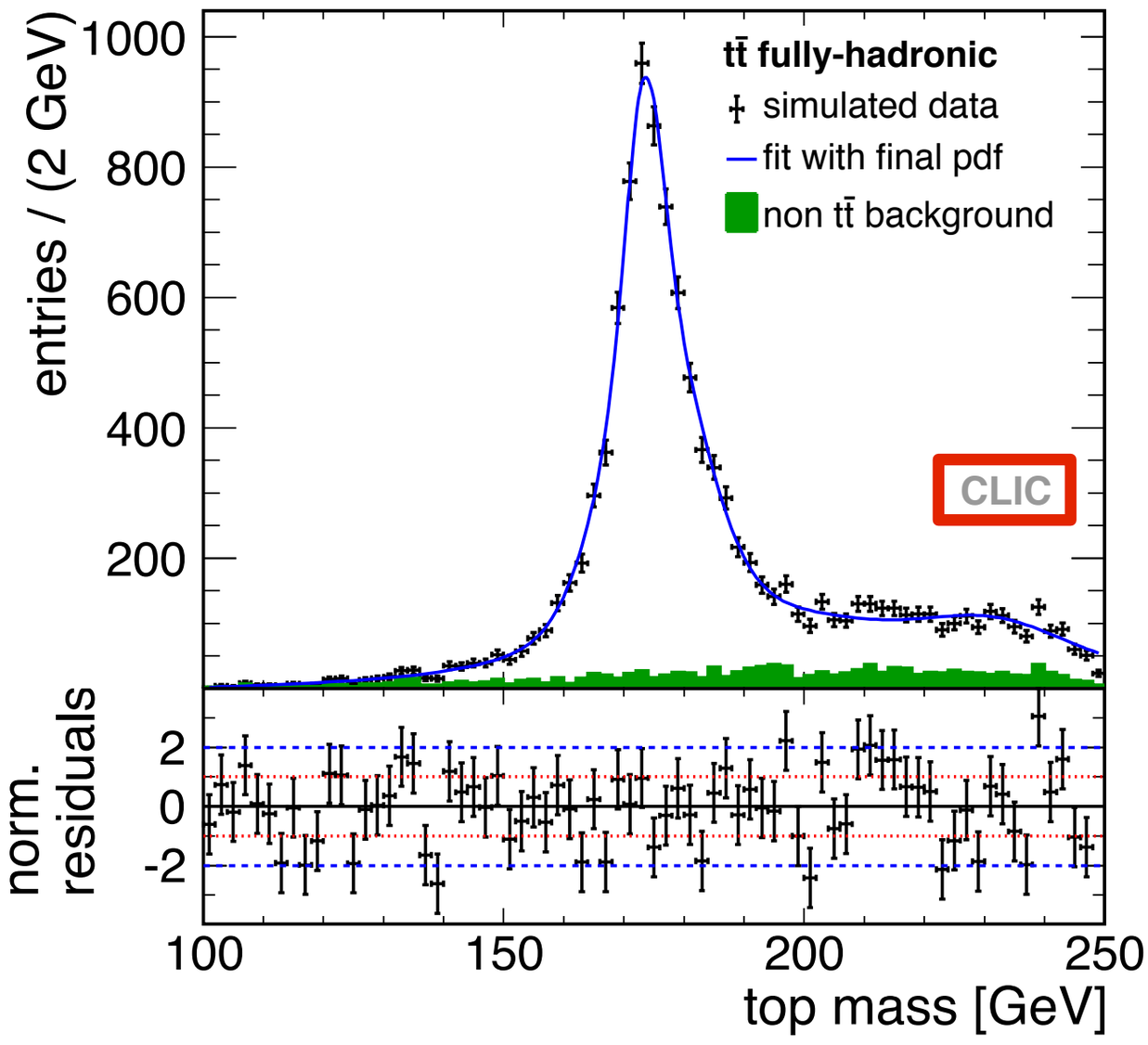


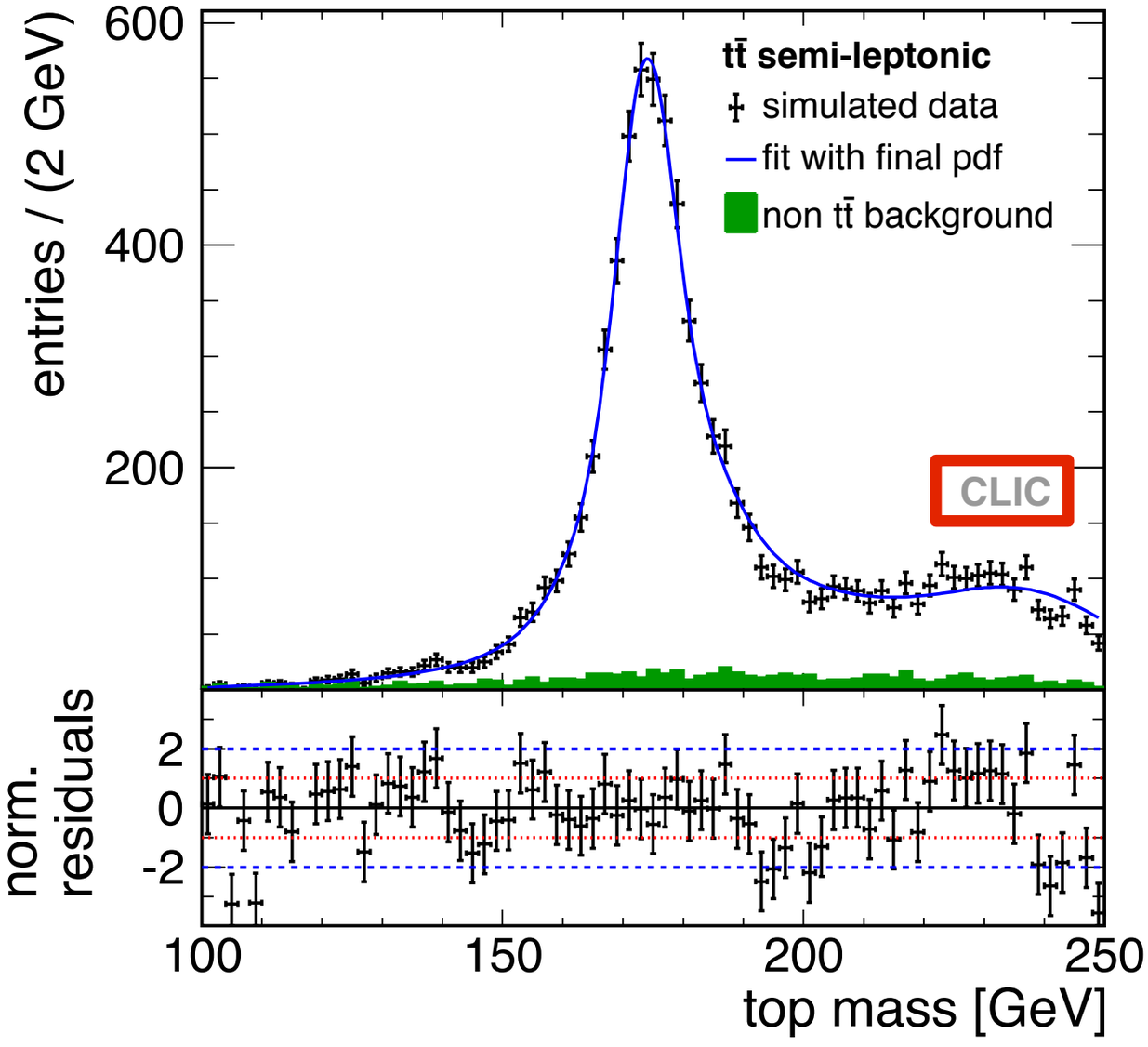



# ttbar physics cleanness in $e^+e^-$ collisions well represented by plots below (**green is background !**)

**fully hadronic and semi-leptonic top mass reconstruction**

Seidel et al. 1303.3758



# two different approaches to rare top decays

**"exclusive" approach** **(two examples)**

@ "measurable" SM rare top decays ➜ $t \to s\,W$

**(BR ~ $10^{-3}$)**

@ rare top decays **measurable only in BSM**

➜ $t \to c\,\gamma\,(Z, g, H)$ **($BR_{SM} < 10^{-12}$)**

**"inclusive" approach to (exotic) decays**

**a)** excess in **top total width**

**b)** study of ***top recoil system*** in top pairs

proposal for $e^+e^-$ collisions

➜ hard to conceive at hadron colliders !

here we focus on :

**inclusive approaches to exotic top decays**

# inclusive approach (a) →→ THEORY

[excess in top total width: $\Gamma_{top}$-$\Gamma_{top}^{(SM)}$]

**bounds on $\delta\,\Gamma_{top}$ can bound exotic decay widths**

**SM:**

$$\Gamma_t = \frac{G_F m_t^3}{8\pi\sqrt{2}}|V_{tb}|^2\left(1-\frac{m_W^2}{m_t^2}\right)^2\left(1+2\frac{m_W^2}{m_t^2}\right)\left[1-\frac{2\alpha_s}{3\pi}\left(\frac{2\pi^2}{3}-\frac{5}{2}\right)\right]$$

+ (b → s,d)

$$\Gamma_t = 1.33\ \text{GeV} \qquad (m_t = 172.5\text{GeV})$$

**top width most recent N³LO QCD determination (SM):**

$$\Gamma_t^{\text{tot}} = 1.3120^{+0.0194}_{-0.0192}\ \text{GeV}$$ (2404.11133)

$\Delta\Gamma_{top}$ (TH) ~ 1.5 %

# inclusive approach (a) →→ MEASUREMENTS

**PRESENT → top width measurement at hadron colliders :**

**assuming SM** ( $\sum_q \mathcal{B}(t \to Wq) = 1$ )

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***t*-quark DECAY WIDTH** [PDG 2024]

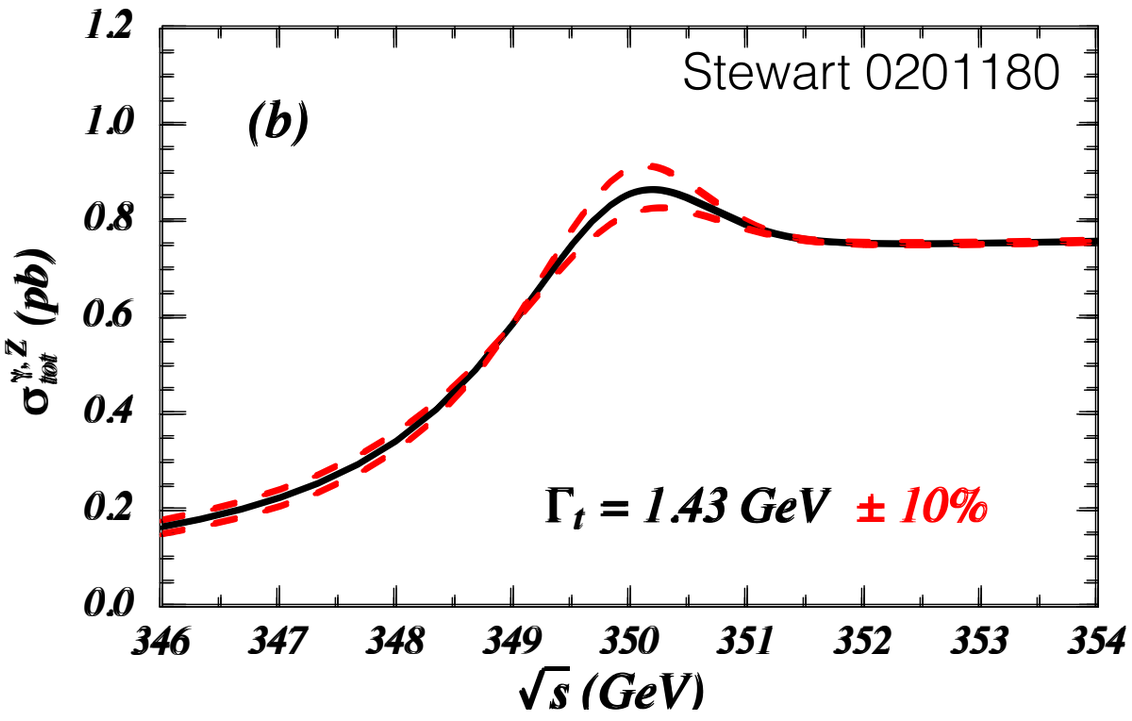
| *VALUE* (GeV) | *CL%* | *DOCUMENT ID* | | *TECN* | *COMMENT* |
|---|---|---|---|---|---|
| → **$1.42^{+0.19}_{-0.15}$ OUR AVERAGE** | | Error includes scale factor of 1.4. | | | |
| $1.76 \pm 0.33^{+0.79}_{-0.68}$ | | [1] AABOUD | 18AZ | ATLS | $\ell + \not{E}_T + \geq 4$j ( $\geq 1$ $b$) |
| $1.36 \pm 0.02^{+0.14}_{-0.11}$ | | [2] KHACHATRY... | 14E | CMS | $\ell\ell + \not{E}_T$ +2-4jets (0-2$b$-tag) |
| $2.00^{+0.47}_{-0.43}$ | | [3] ABAZOV | 12T | D0 | $\Gamma(t \to bW)/\mathrm{B}(t \to bW)$ |

$\Delta\Gamma_{top}$ (exp) ~ 200 MeV ~ 13%

# inclusive approach (a) →→ FCC-ee

**(model independent) $\Gamma_{top}$ measurement at ~3% at FCC-ee**

resonance cross section at threshold very sensitive to $\alpha_s,\ m_t,\ \Gamma_t$ ;
peak at $\sigma_{\rm res} \sim \alpha_s^3/(m_t\Gamma_t)$




**$\Delta\Gamma_{top}$ ~ 45 MeV at FCC-ee**

**[by 0.2 ab$^{-1}$ around tt threshold]**

- FCC CDR, vol. 2

**bounds on $\delta\,\Gamma_{top}$ can probe inclusively rare decays with $BR_{exotic} \geq$ few % at FCC-ee**

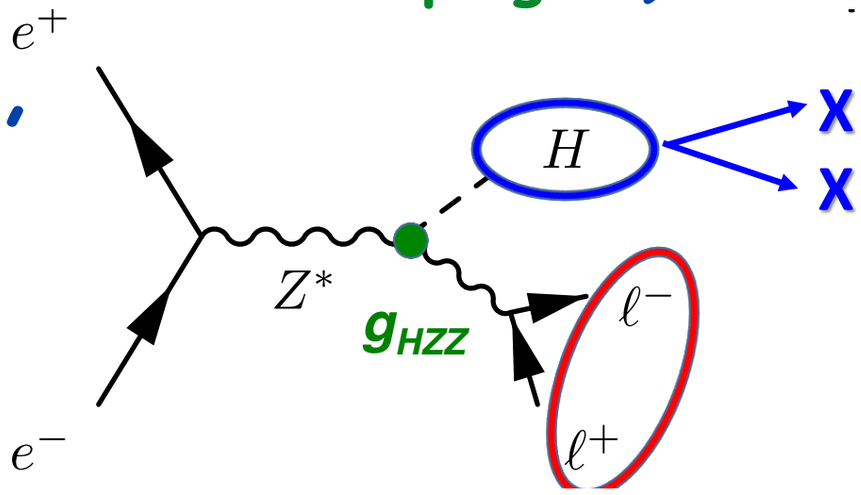
# one further inclusive approach

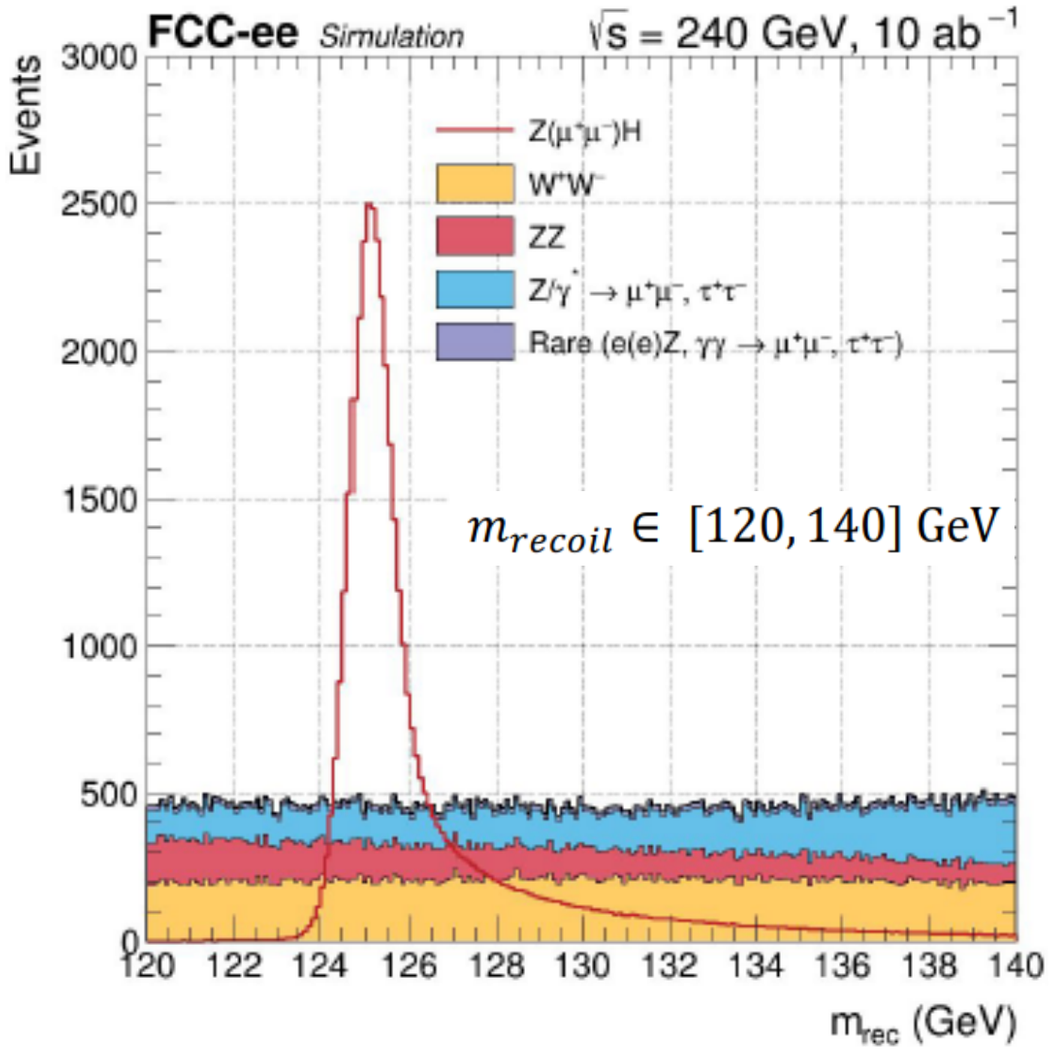
# inclusive Higgs studies through Z recoil system [LHC]

- HZ selected by just identifying Z decay products

  (→ absolute $\sigma_{tot}$ (~$g_{HZZ}^2$) measurement → model indep. $g_{HZZ}$)

- → direct access to invisible H decays, and invisible-at-LHC decays (H → cc, ss H → gg)

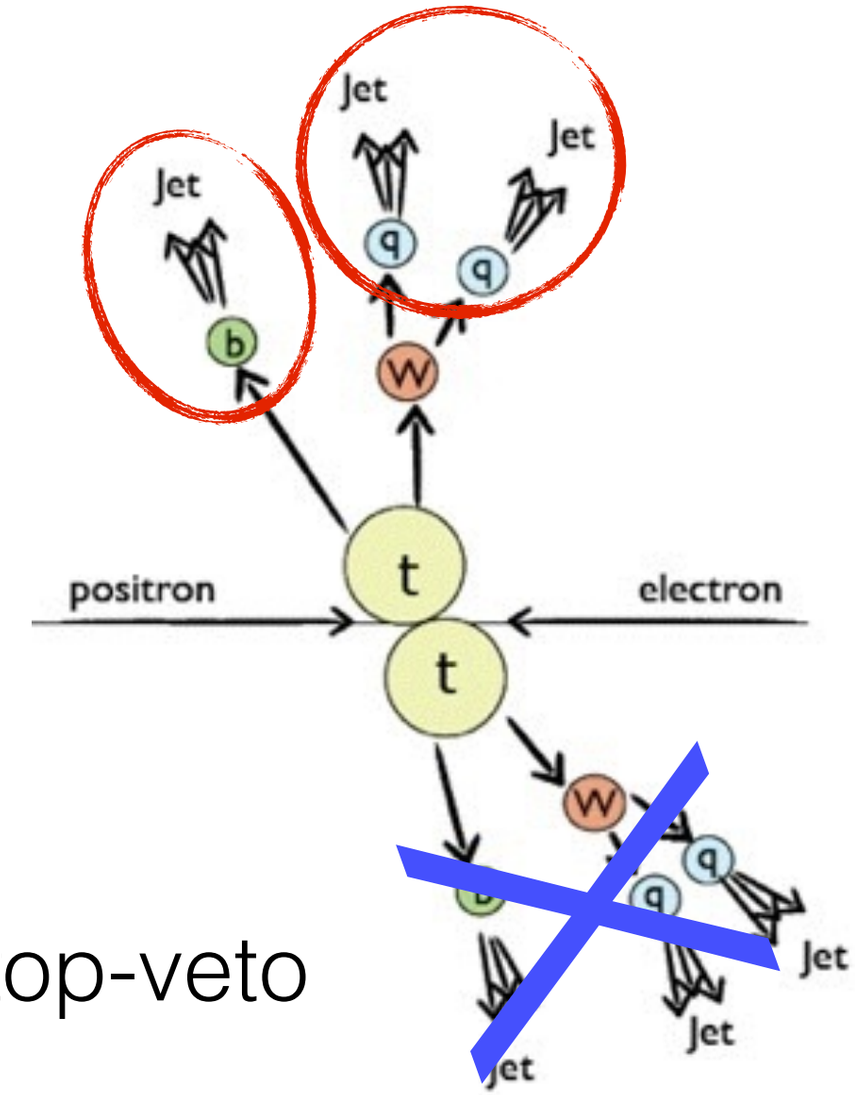



could we extend this technique to top pairs in $e^+e^- \to t\bar{t}$ and make inclusive searches for exotic top final states by looking at top recoil system ???

# inclusive searches for exotic t decays through recoil system ($e^+e^-$)

large variety
of possible final states
➜ global analysis of the
recoil system with a top-veto




top-veto

- $E_{cm}$ > 350 GeV

a) define criteria to tag
a Wb/Wj system
as a (SM) top quark

b) look for events containing
one top-system with
a veto on a 2nd tagged top
(i.e. recoil system does not
pass the SM top-system
criteria)

c) full simulation needed to
assess sensitivity ( <% σ ?)

d) get model independent
bounds on $BR(top)_{exotica}$ !

how good can be this strategy depends on
how efficiently we are able to simulate
the real SM top pair production !

any SM tt event badly reconstructed
(where only one top passes the tagging request)
contributes in principle to a fake "exotic top width"

actual strategy ???

- take a SM tt fully simulated sample
- require kinematically robust (→ hadronic) tag for first top
- put a veto on had+lep tag on second top
- measure how much is left out of the SM tt sample
- sensitivity to $\Gamma_{top}$ excess is connected to that !

*[ongoing analysis…]*

a comment :

**events are in general so clean**
**that it would be feasible in the real exp sample**
**to look into the "unrecognized" tt events**
**and scrutinize what is inside the second top**
**➜ going beyond inclusive approach…**

**"unrecognized" tt** ➜ only single tag passed

# Outlook

- ever since its discovery, the top quark has never been produced and studied in such a clean environment as the one expected in $e^+e^-$ collisions

- $e^+e^-$ collisions will almost allow to trace back top-quark final states on an event-by-event basis

- this will open the opportunity to look at details of top production and kinematics that is unthinkable in hadron collisions (relevant strategies mostly still to be developed …)

- rare top decays is one of the (many) top physics chapters that would widely benefit from such spectacularly clean environment