

Top Pair Threshold Production at a Linear Collider with WHIZARD

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with A. Hoang and M. Stahlhofen

DESY Hamburg

2nd Intl. WHIZARD Forum, Würzburg, 2015/03/17

Outline

1. Motivation
2. **WHIZARD** teaser
3. The **WHIZARD** implementation
4. **WHIZARD** release v2.2.3+
5. **WHIZARD** release v2.2.6 (?) preview:
NLO continuum matching & new features

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NLO continuum matching & new features

Non-Relativistic QCD framework (NRQCD)

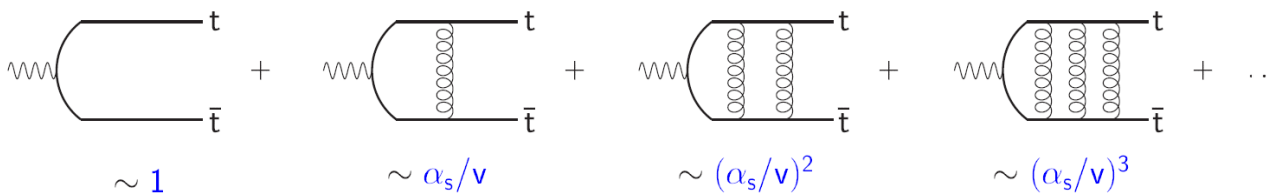
- > close to $t\bar{t}$ threshold: top velocity $v \sim \alpha_s \ll 1$
- > resummation of singular terms close to threshold ($v = 0$) [e.g. Hoang et al. '01]:

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phase space of two massive particles

low energy effective theory w/ matching conditions:
renormalization group improved framework v NRQCD

Coulomb potential gluon ladder resummation:



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tree level γ/Z exchange:
“what WHIZARD does”

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p -wave $\sim v^2 \rightarrow$ NNLL

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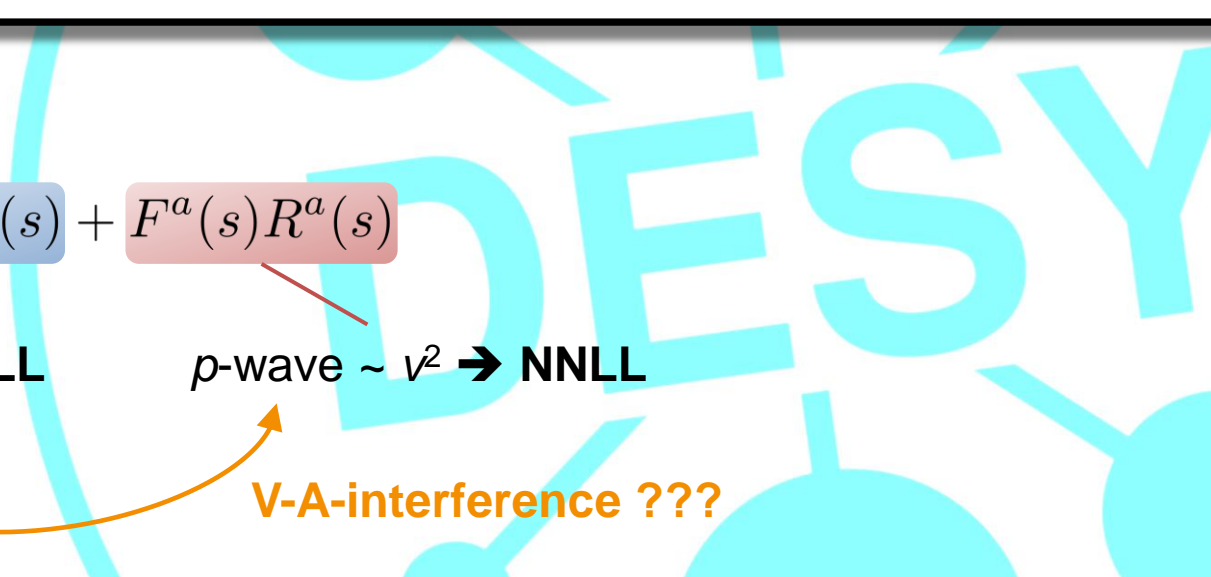
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V-A-interference ???



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V-A-interference: $\sim \cos \theta_t \rightarrow 0$ in R

\rightarrow but contributes differentially \sim NLL

Non-Relativistic QCD framework (NRQCD)

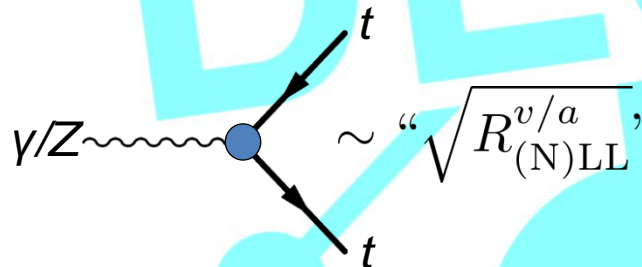
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can be mapped onto **effective $t\bar{t}V$ vertex:**



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$$\sim \mathcal{G}_{(N)LL}^{v/a} \left(\alpha_s, m_t^{\text{pole}}, \sqrt{s}, |\vec{p}_t|, \Gamma_t \right)$$

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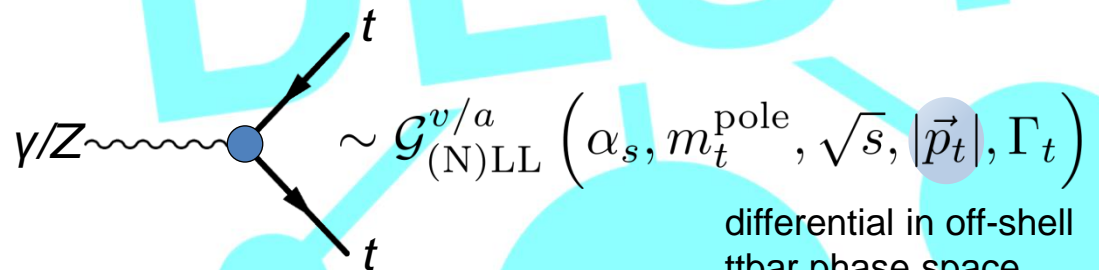
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differential in off-shell $t\bar{t}$ phase space

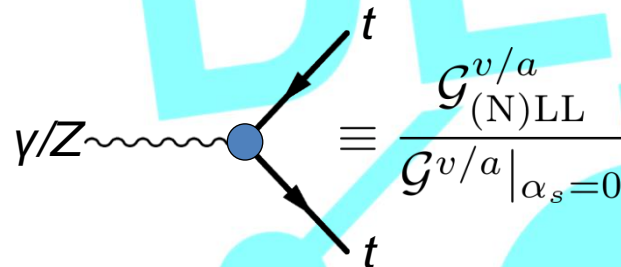
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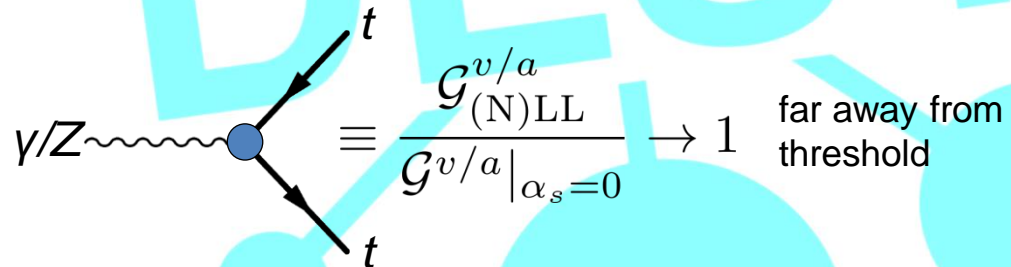
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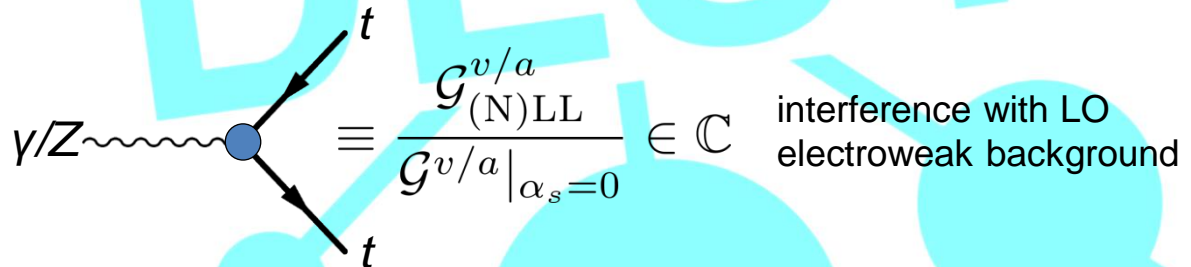
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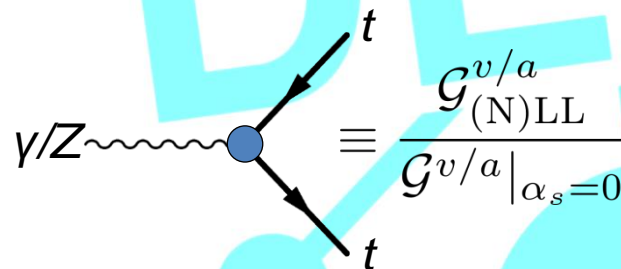
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WHIZARD approach

WHIZARD $t\bar{t}$ threshold implementation (v2.2.3 release)

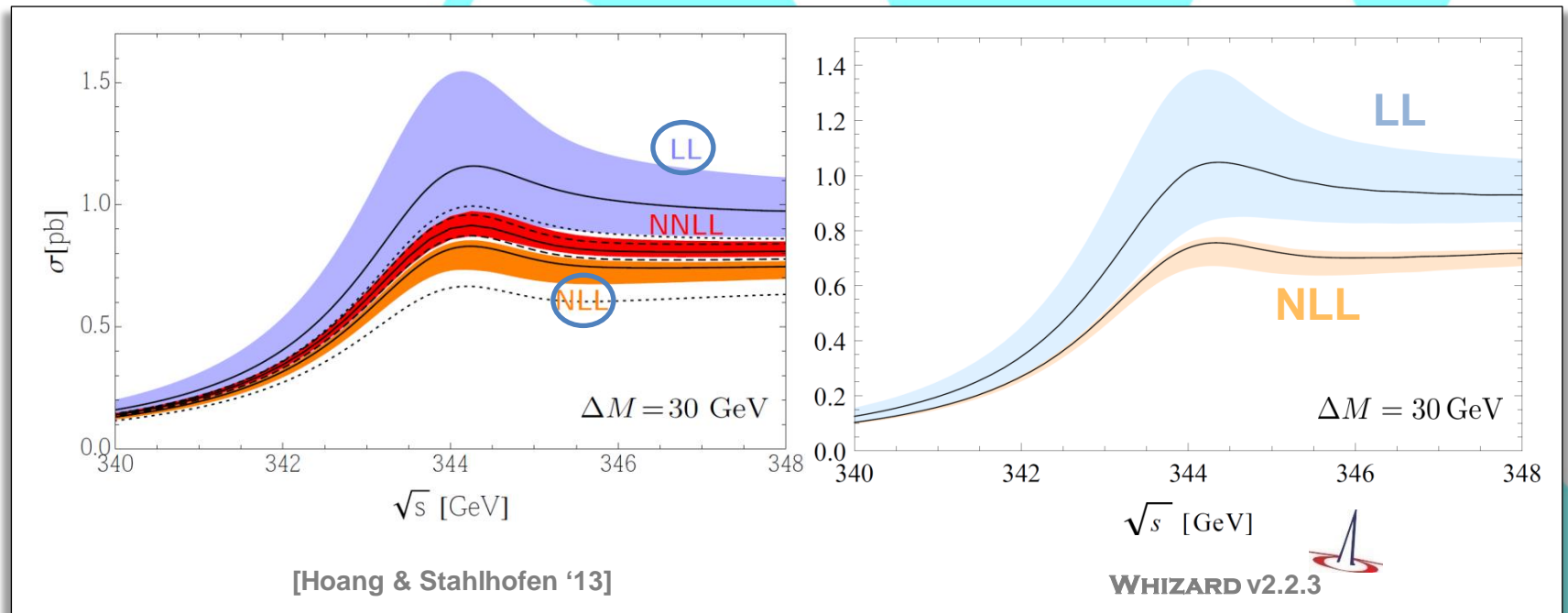
- > compare WHIZARD implementation with NRQCD calculation
- > LL/NLL $t\bar{t}V$ form factor implemented using TOPPIK [Hoang & Teubner '99]

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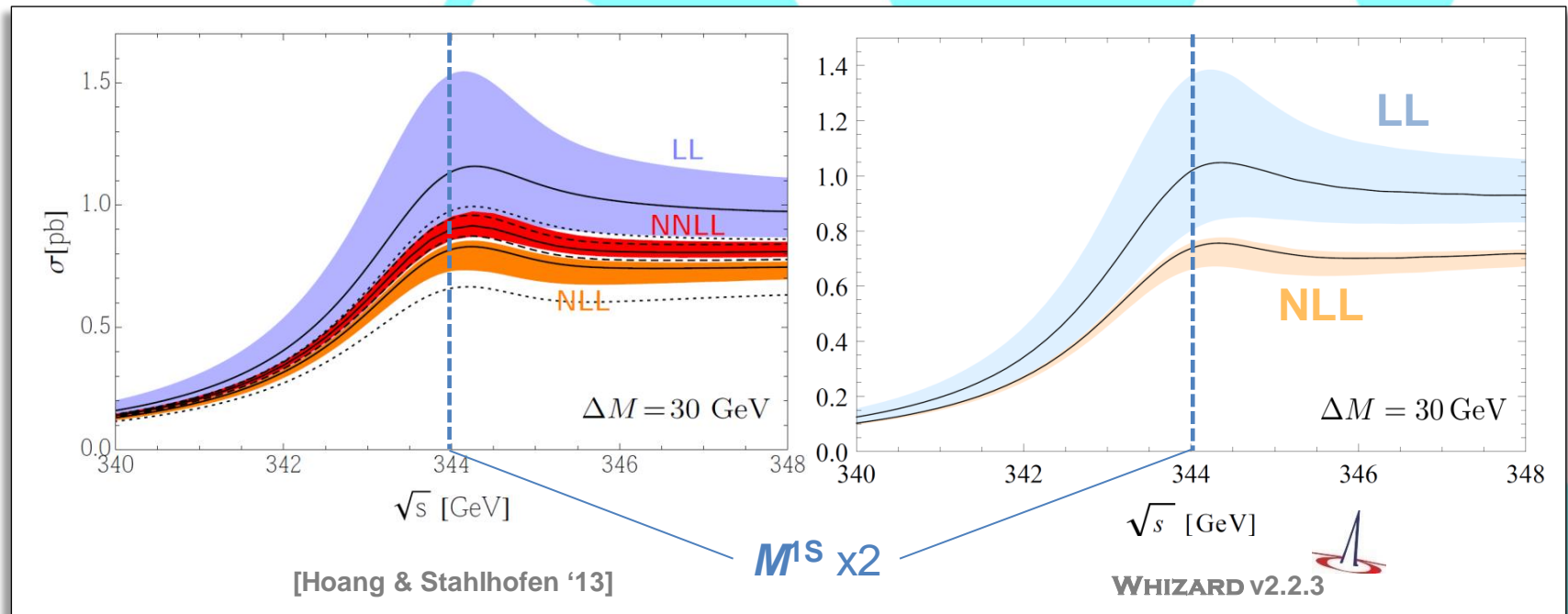
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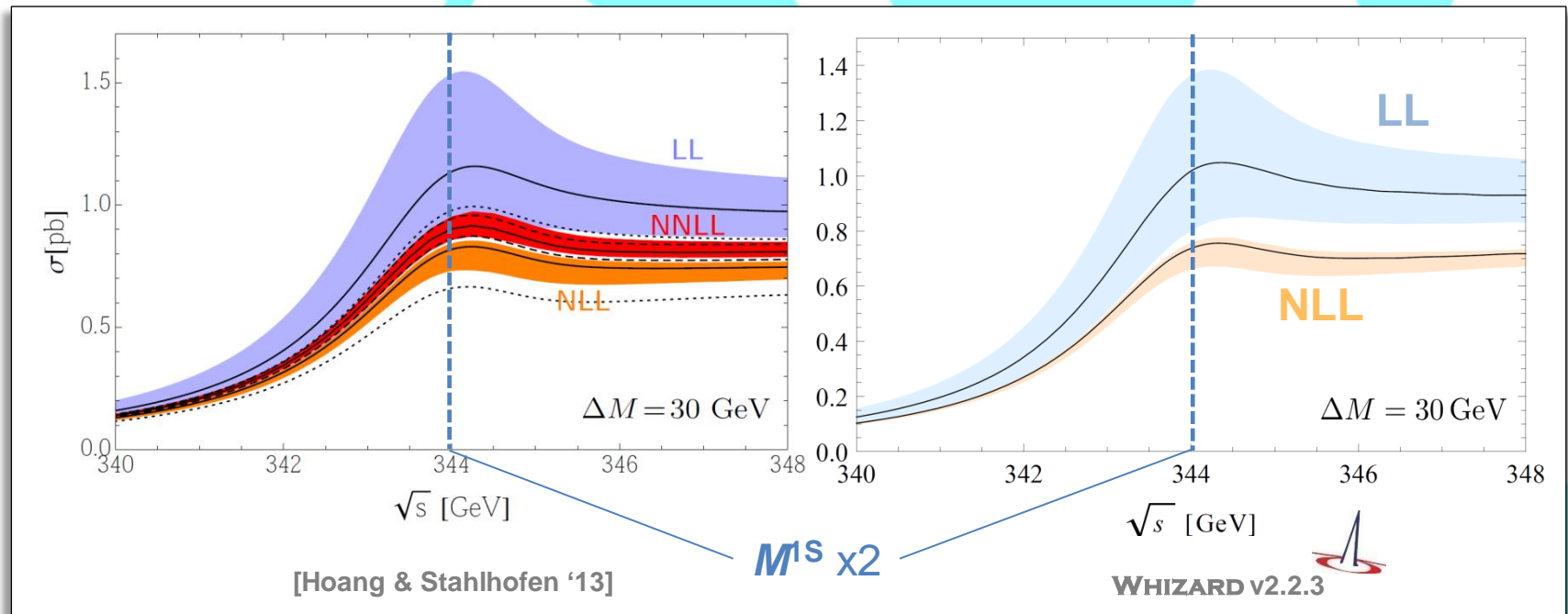
$$M^{1S} = m_t^{\text{pole}} \left(1 - \Delta^{\text{LL/NLL}} \right)$$



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$$M^{1S} = m_t^{\text{pole}} \left(1 - \Delta^{\text{LL/NLL}} \right) \sim \text{Coulomb potential}$$

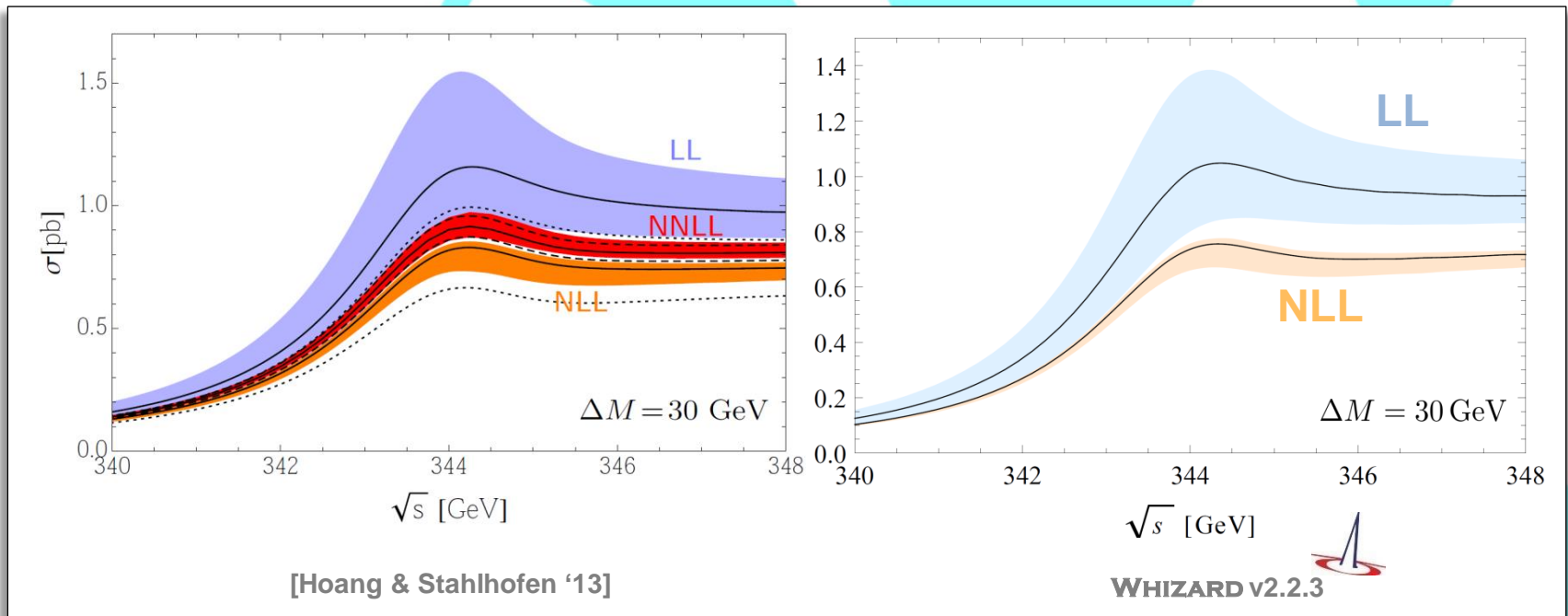


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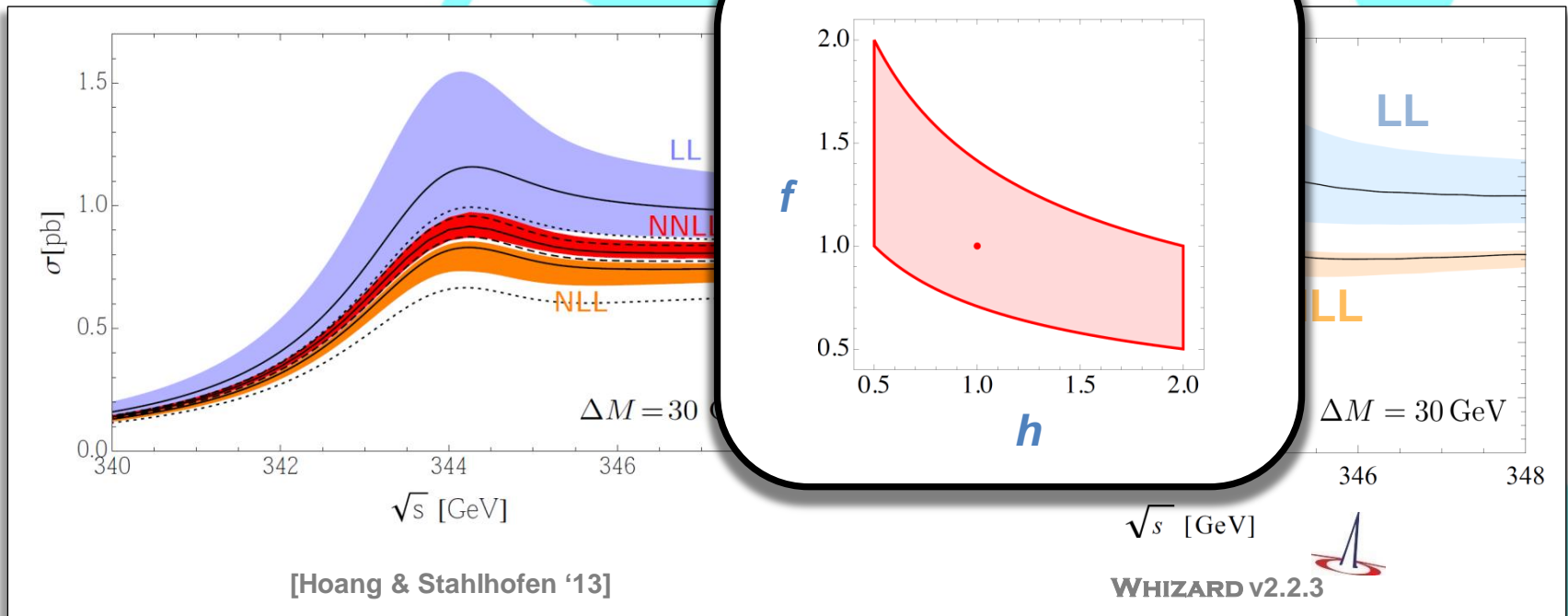
→ minimal consistent width in $2 \rightarrow 4$ process: $\Gamma_t \geq \Gamma(t \rightarrow bW)$

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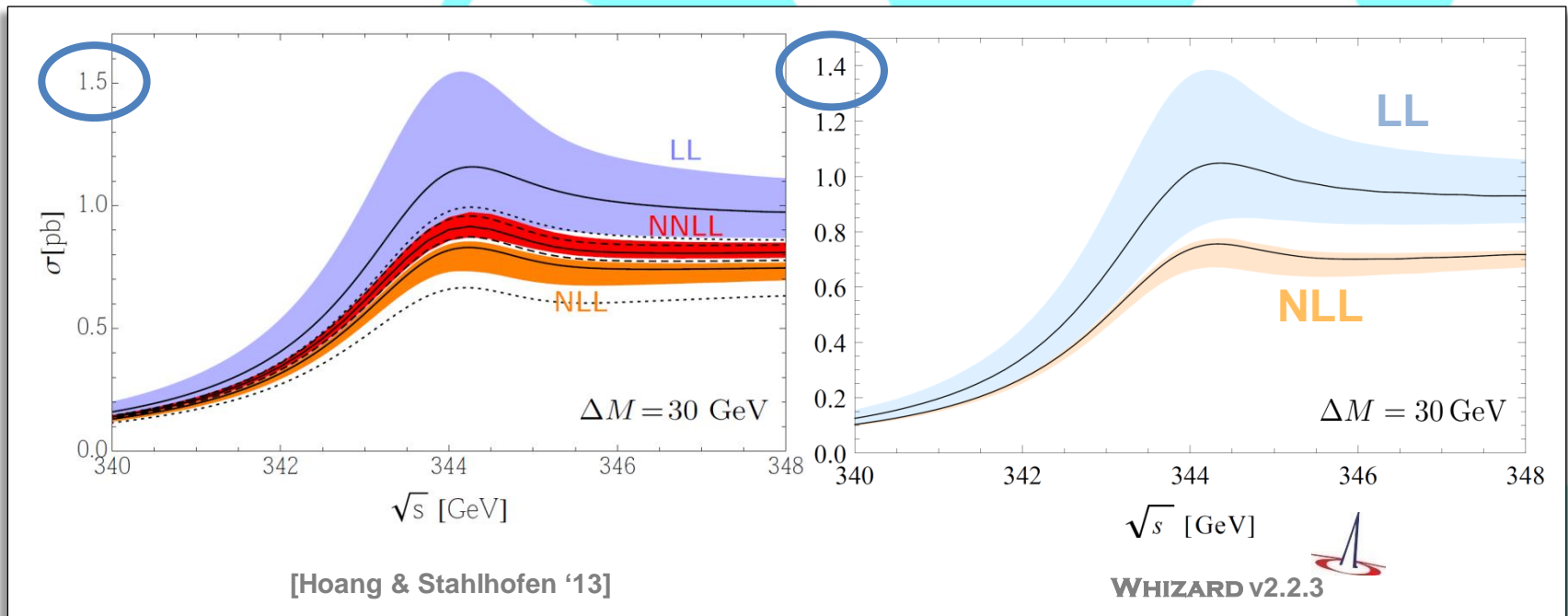
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 - > note the normalization difference!



WHIZARD $t\bar{t}b\bar{b}$ threshold implementation (v2.2.3 release)

> compare WHIZARD NLL calculation with NRQCD calculation

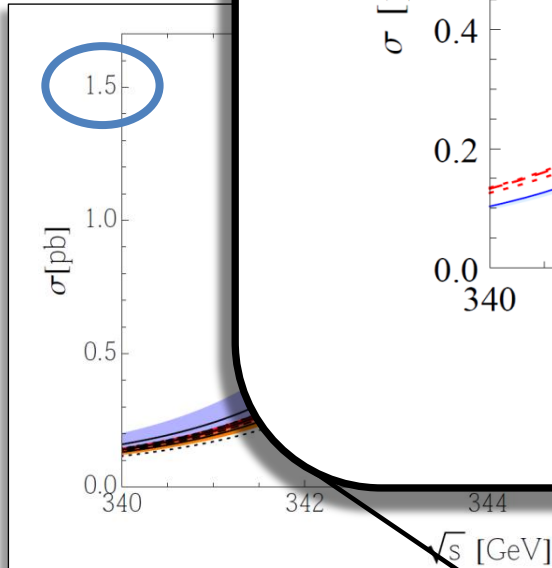
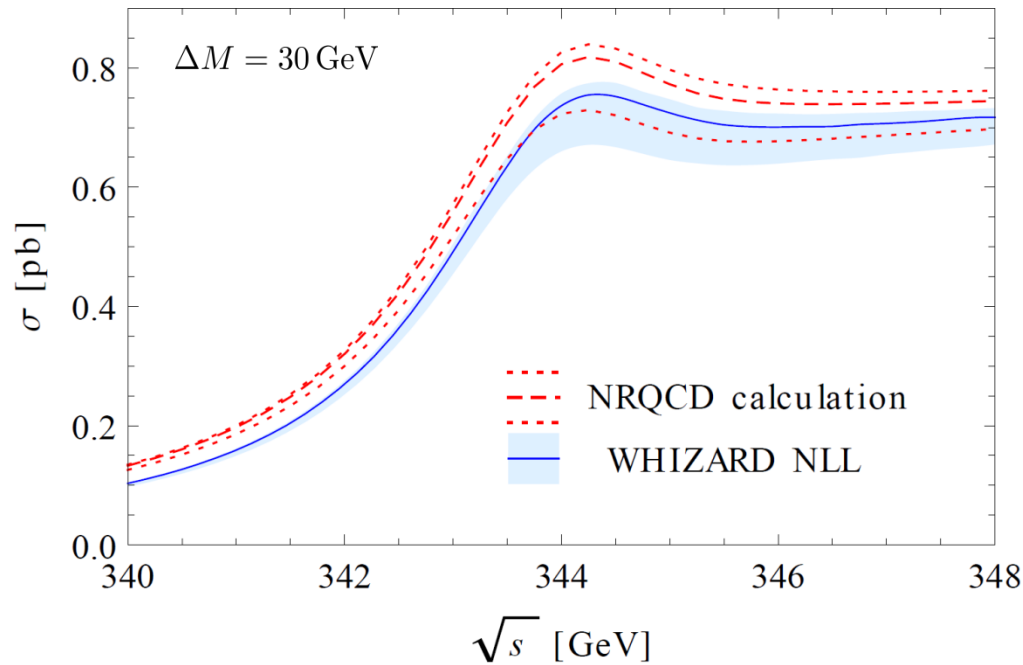
> LL/NLL

> def

> the

> not

direct comparison @ NLL:



[Hoang & Stahlhofen '13]

WHIZARD v2.2.3



B
 $= f \cdot m_t v$

$\Delta M = 30 \text{ GeV}$

WHIZARD $t\bar{t}$ threshold implementation (v2.2.3 release)

> compare WHIZARD NLL with NLO and NNLO

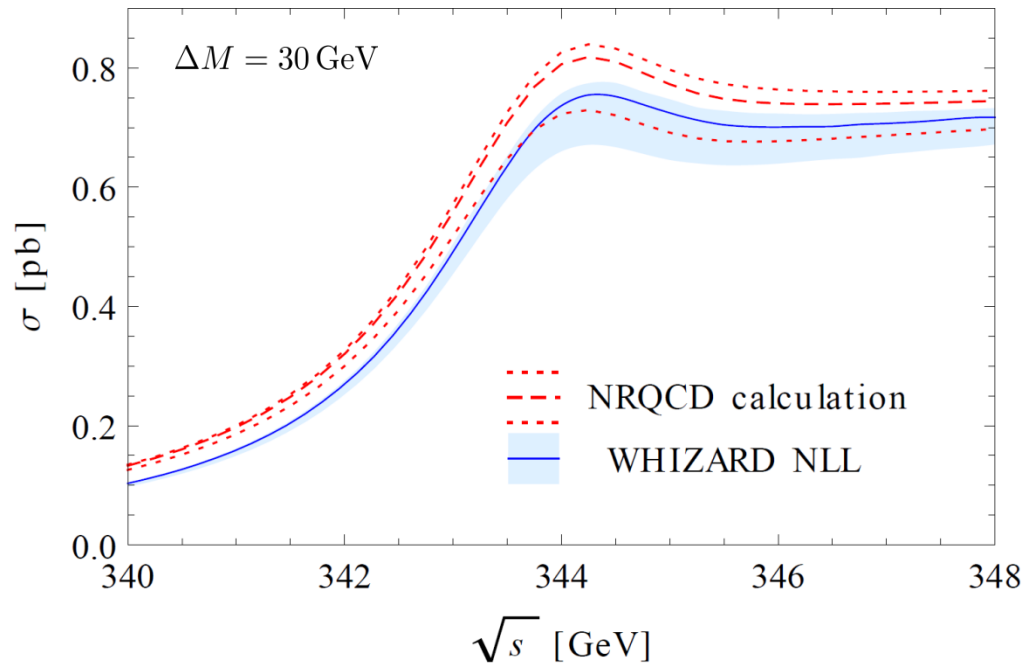
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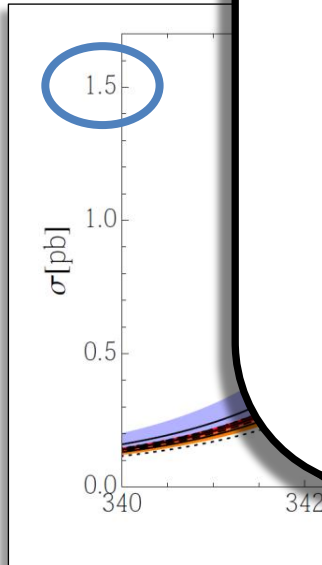
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cross-check with $\alpha_s \rightarrow 0$ ✓



[Hoang & Stahlhofen '13]

WHIZARD v2.2.3



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$= 30 \text{ GeV}$

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> compare WHIZARD NLL with NLO+NRQCD

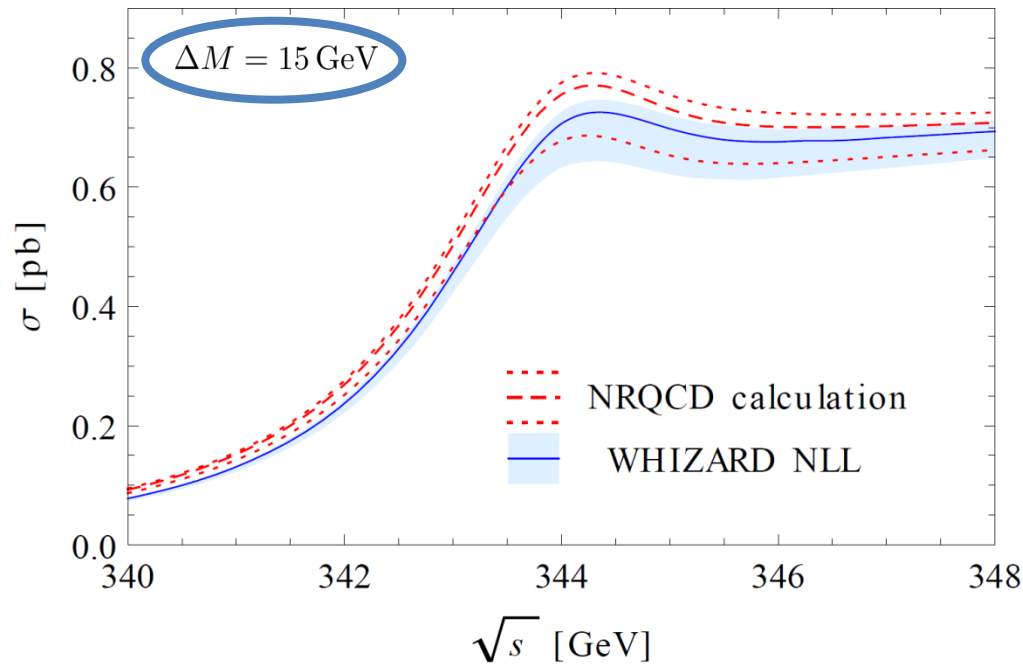
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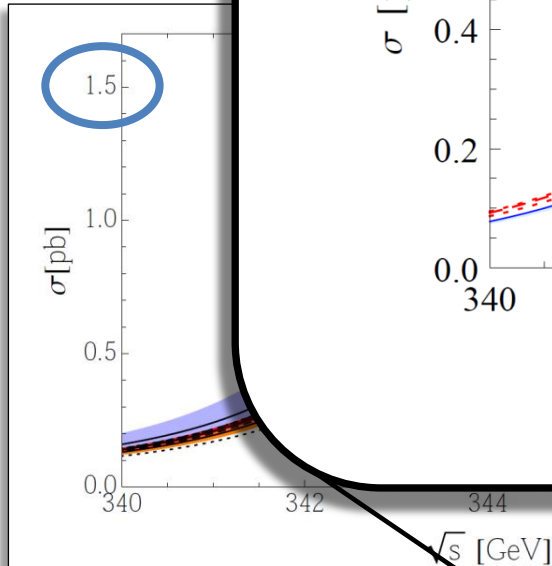
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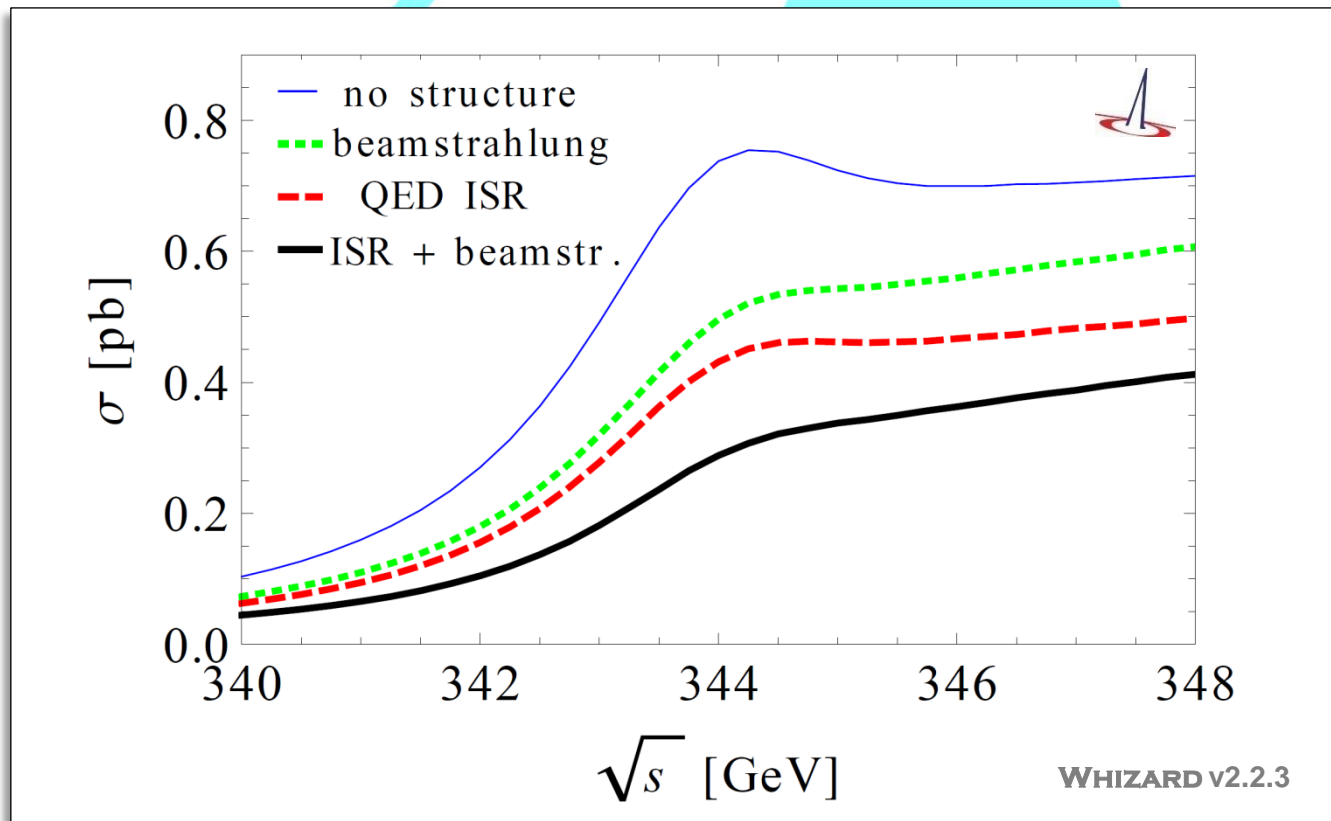
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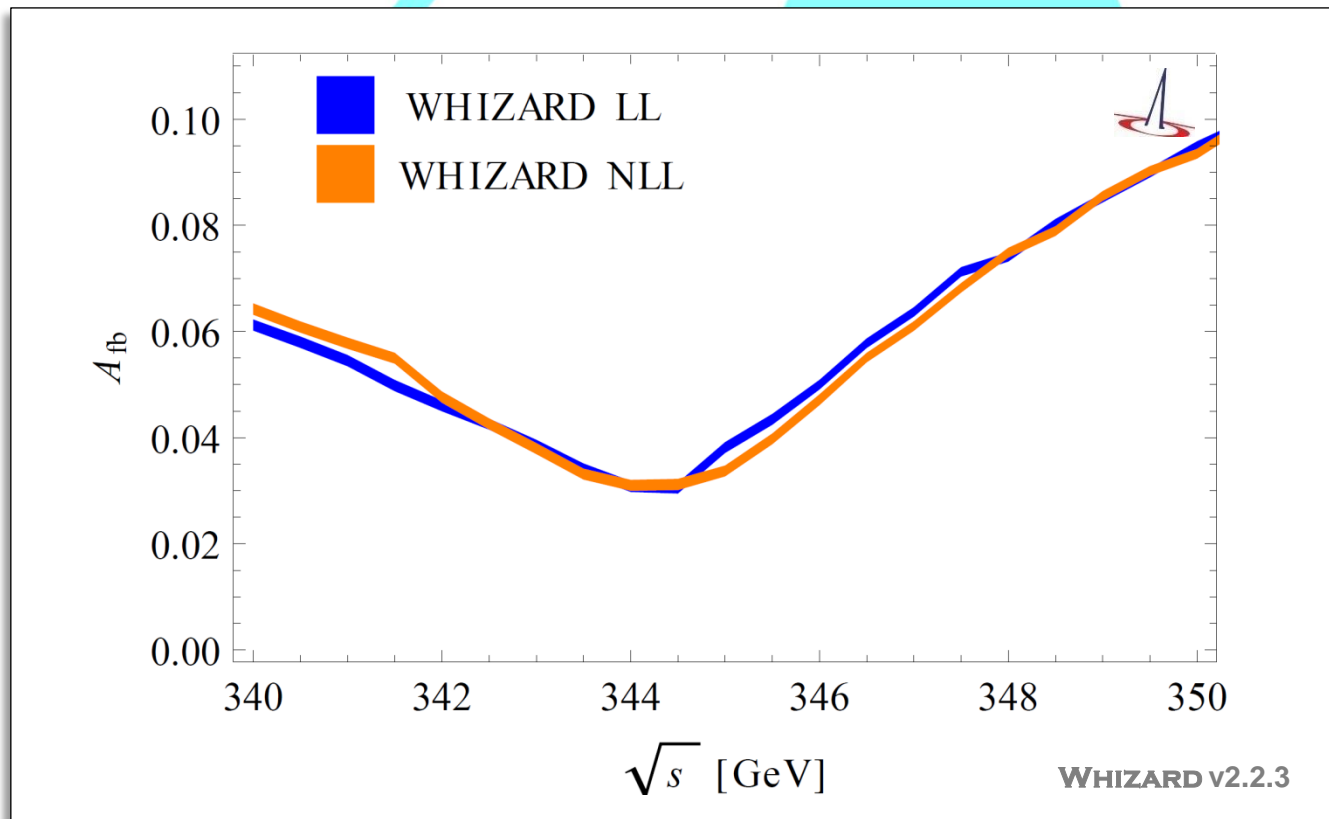
WHIZARD ttbar threshold implementation (v2.2.3 release)

- > new features/possibilities with **WHIZARD** implementation:
 - > include the **beam structure**



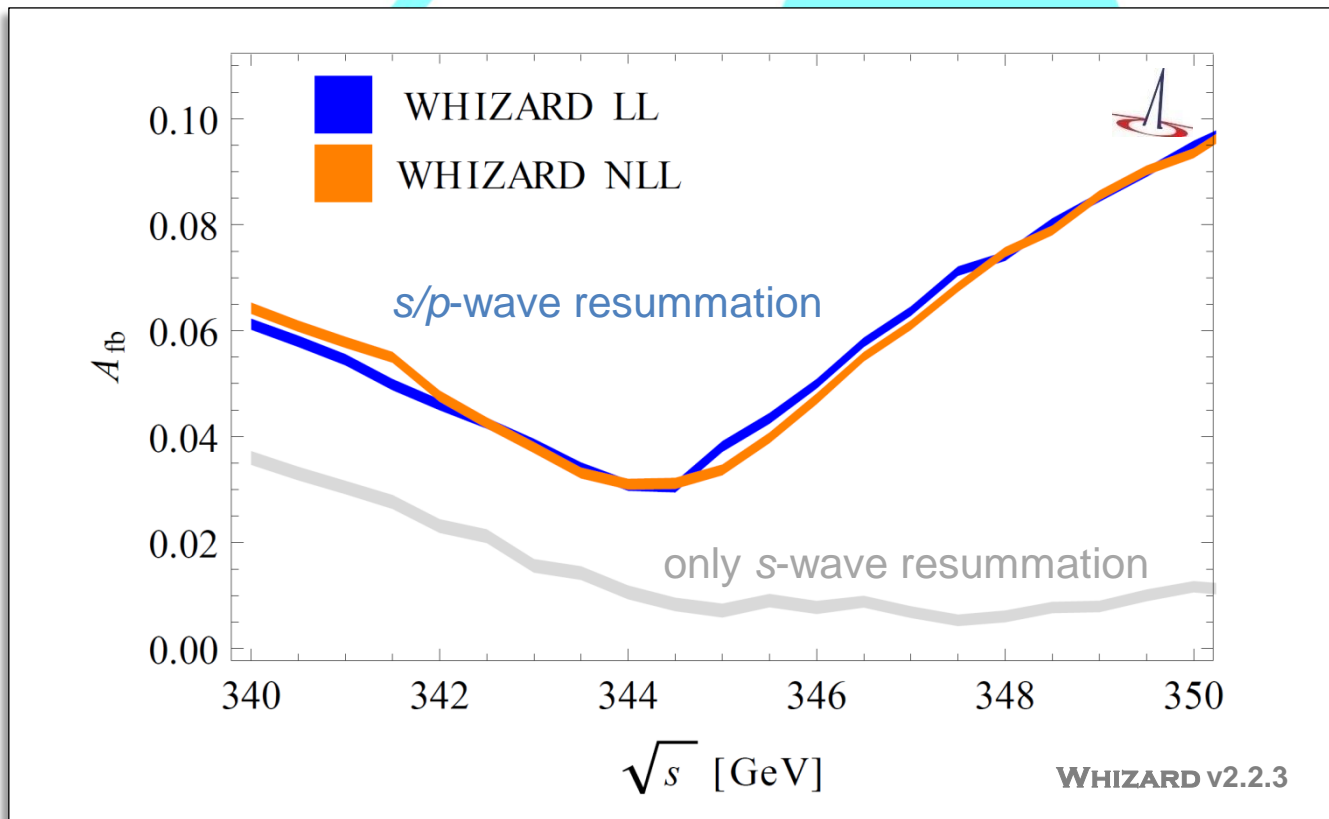
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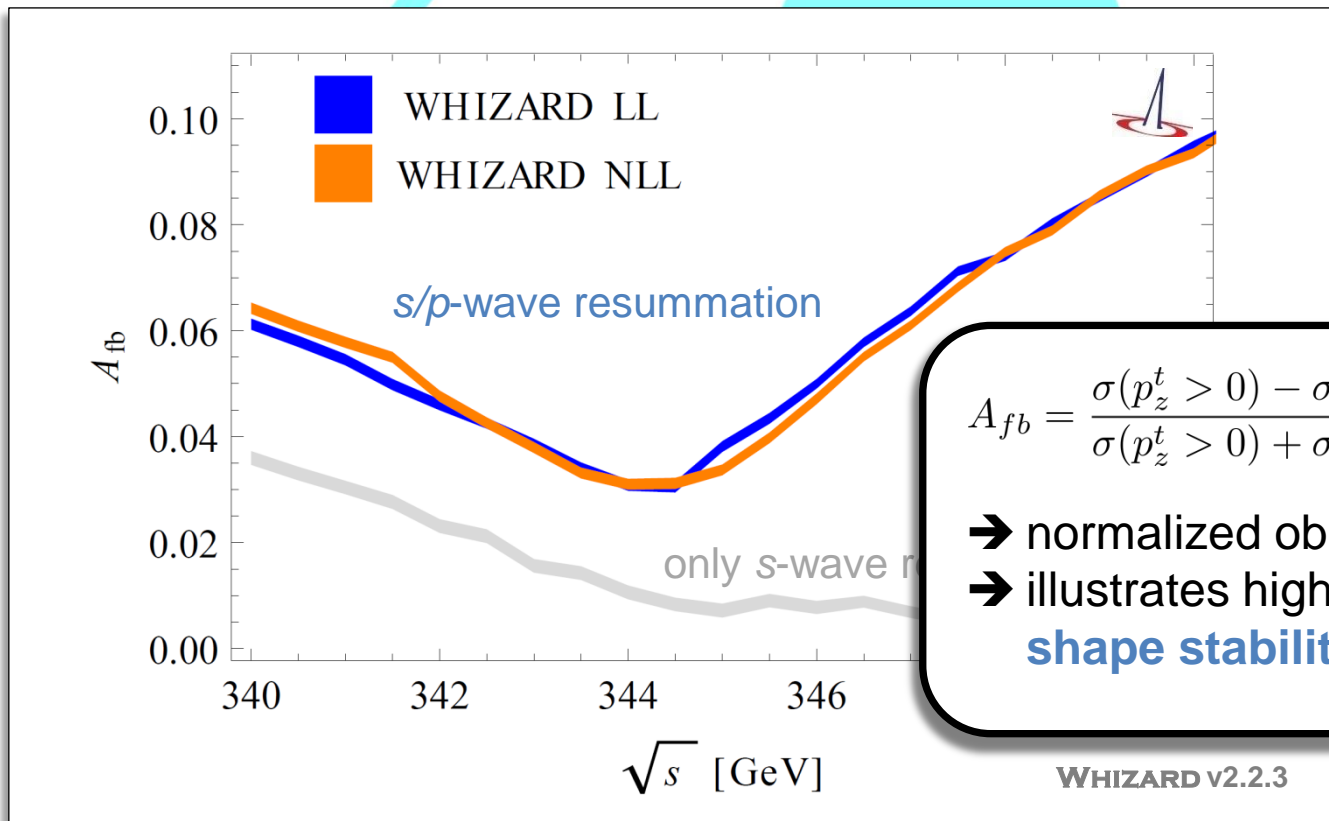
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WHIZARD ttbar threshold model & parameters

- > ttbar LC threshold model **officially released in v2.2.3**
- > current status of **model layout & parameter setup**:
 - > model name:
`SM_tt_threshold`

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WHIZARD ttbar threshold model & parameters

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> model name:

SM_tt_threshold

> model parameters & default values:

alpha_em_i = 125.924

m1S = 172.

wtop = 1.54

nloop = 1

sh = 1.

sf = 1.

inverse QED coupling @ threshold

M^S mass

top width

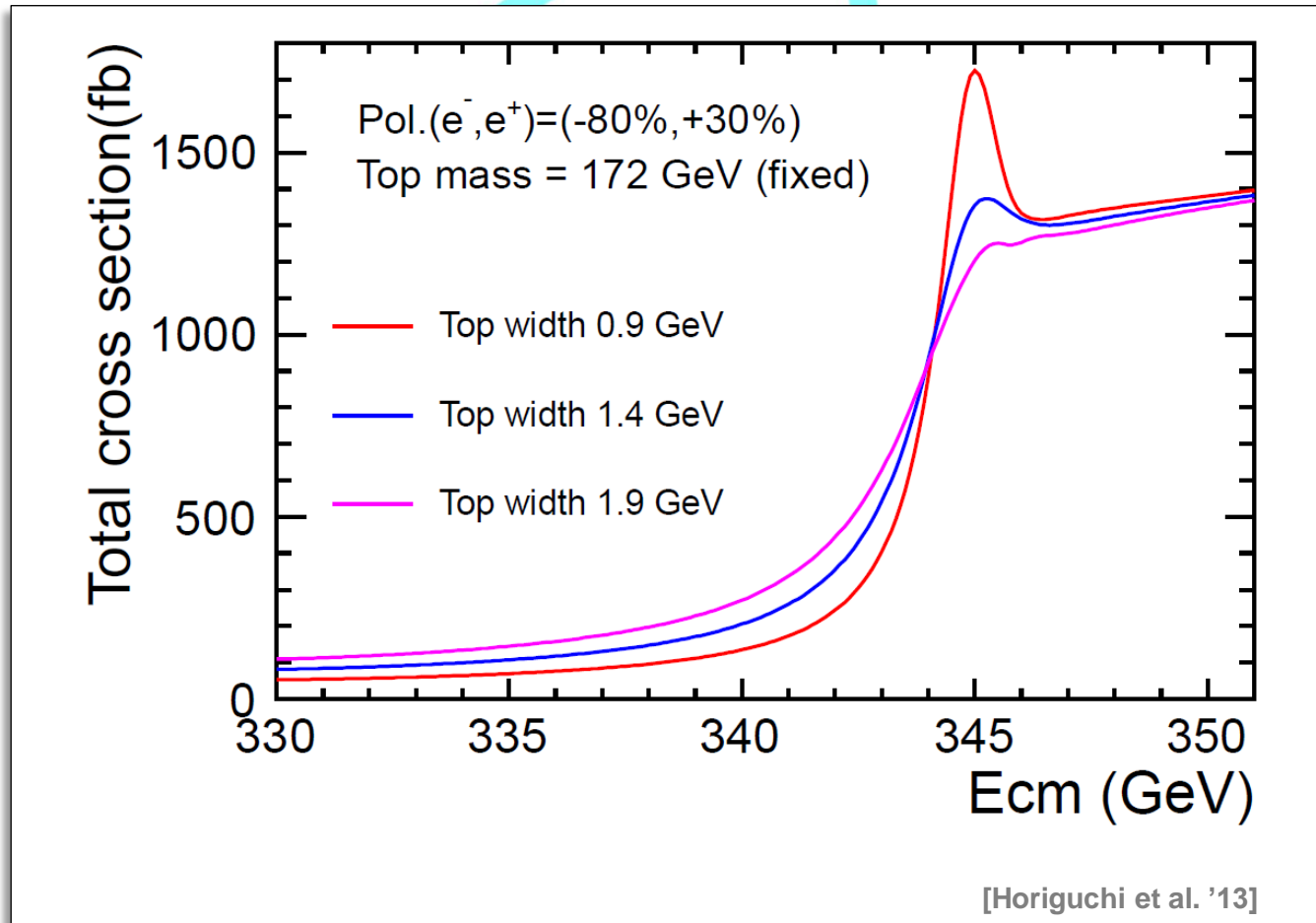
NRQCD order: 0: LL, 1: NLL

hard matching scale h

soft renormalization scale f

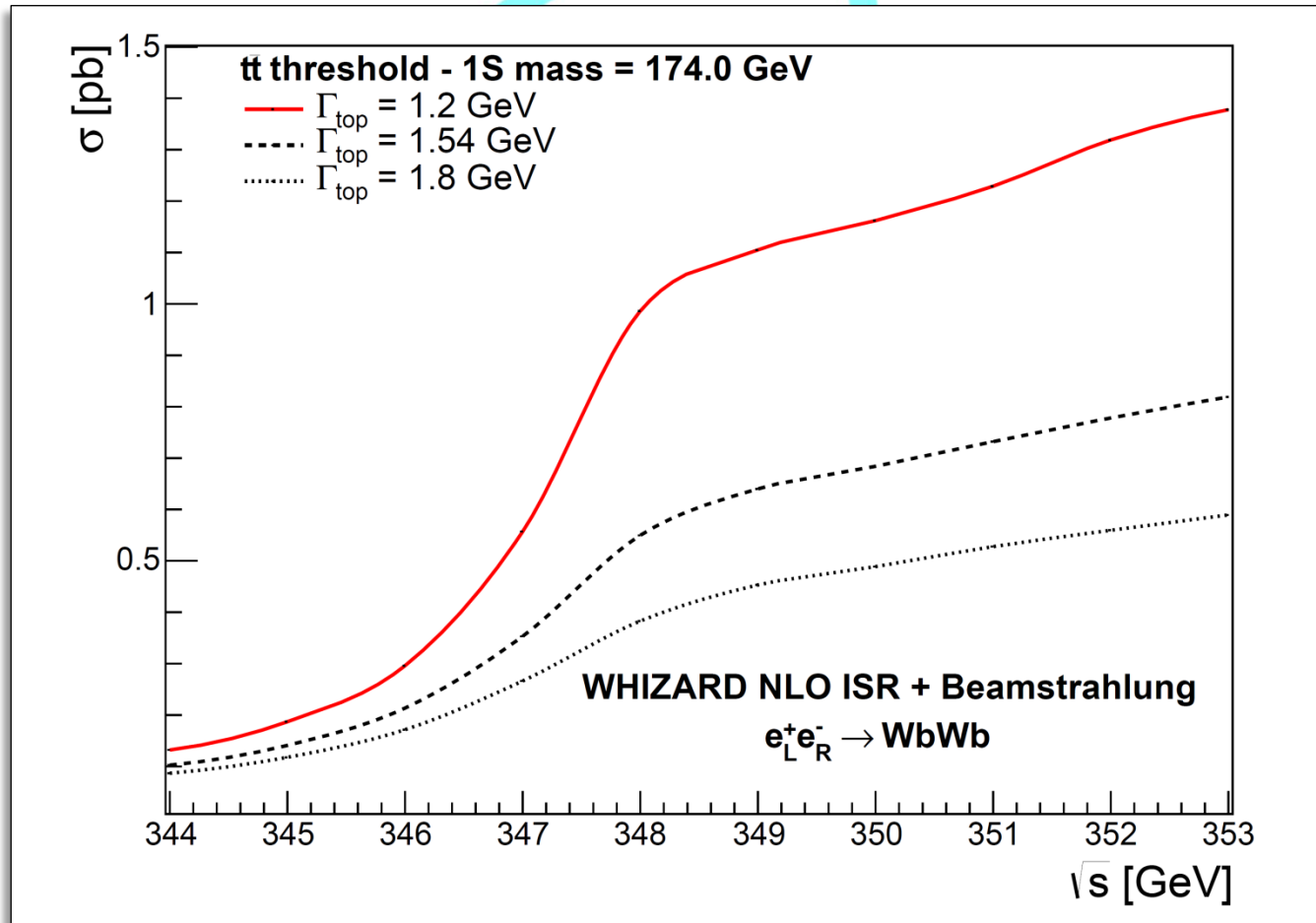
Some comments on the top width

- try to assess the sensitivity to Γ_t at the threshold:



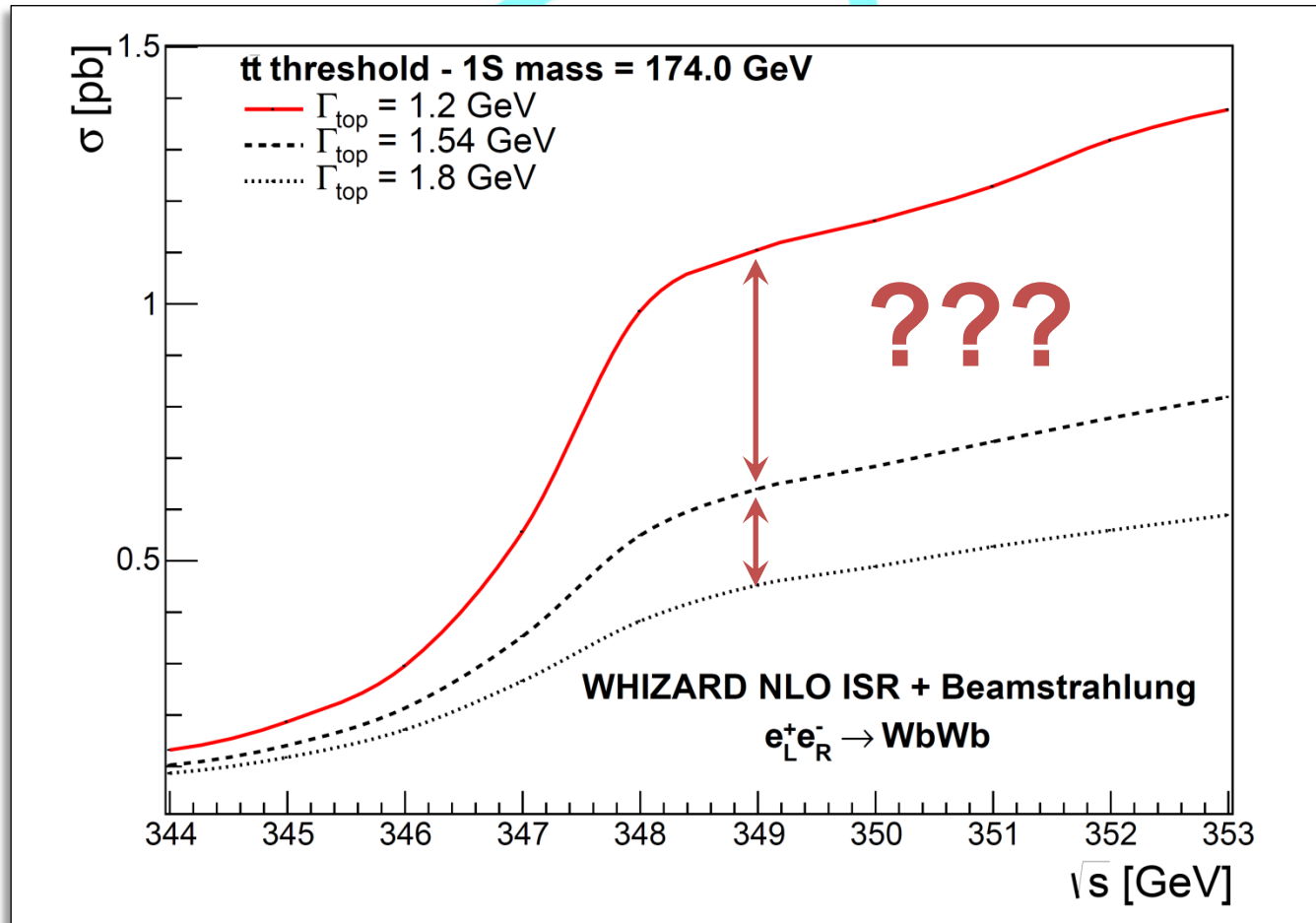
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> this is what happens with **WHIZARD**:



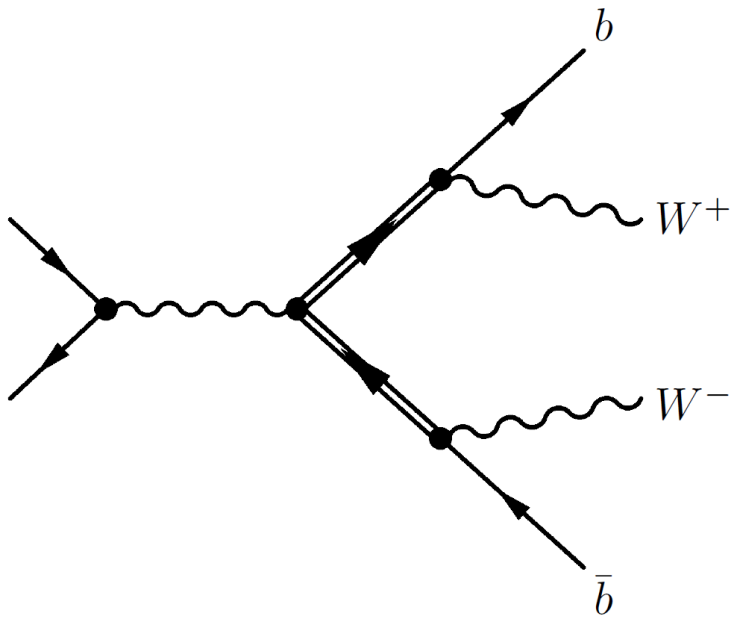
Some comments on the top width

> this is what happens with **WHIZARD**:



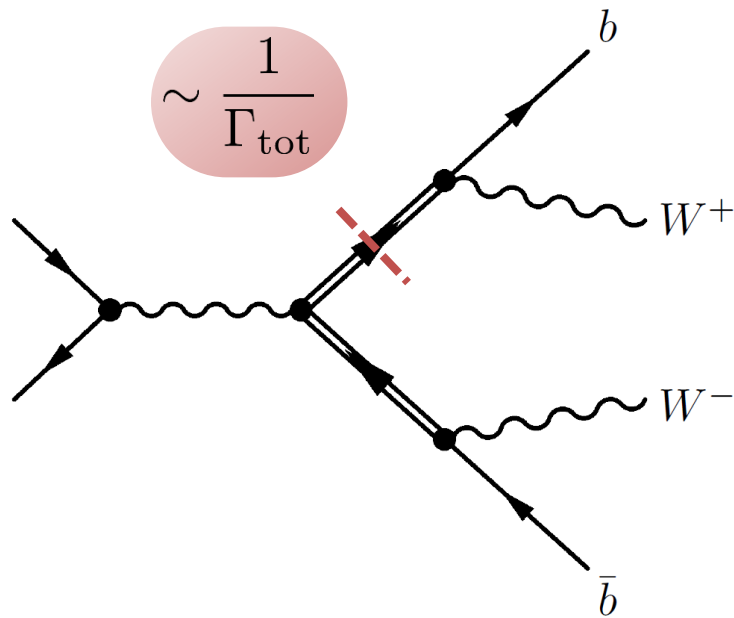
Some comments on the top width

- a closer look at the $2 \rightarrow 4$ process $e^+e^- \rightarrow bbW^+W^-$ with off-shell tops:



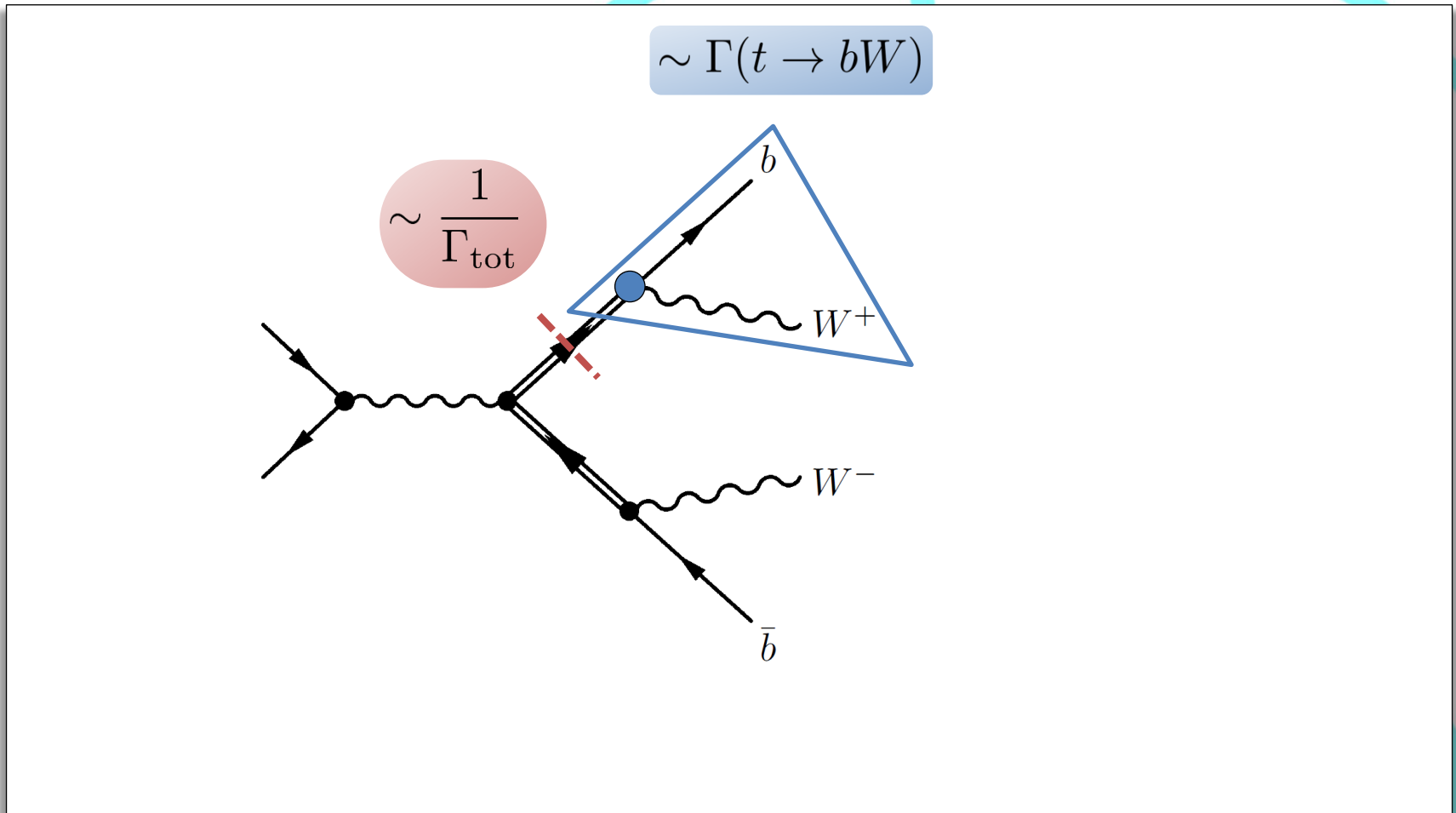
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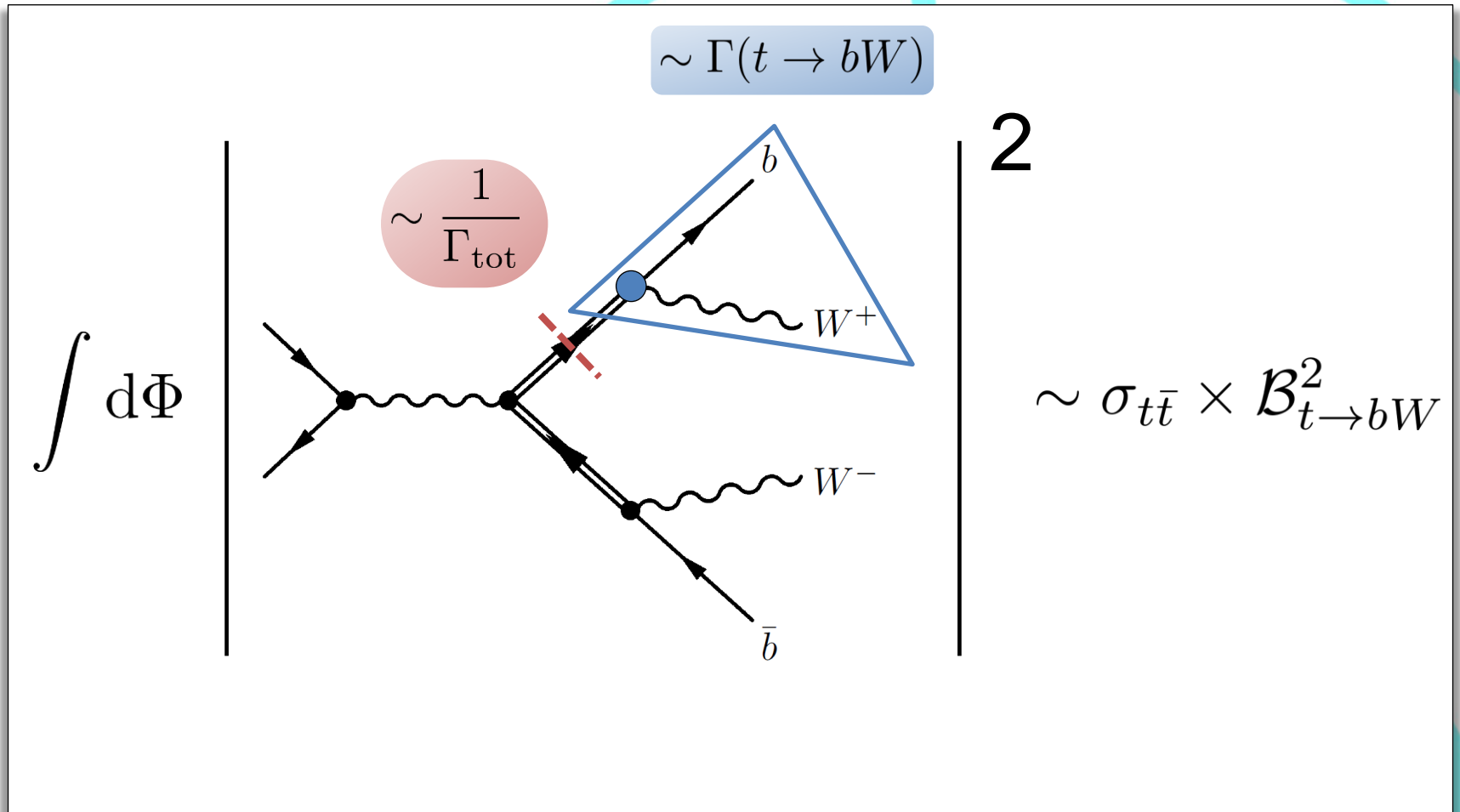
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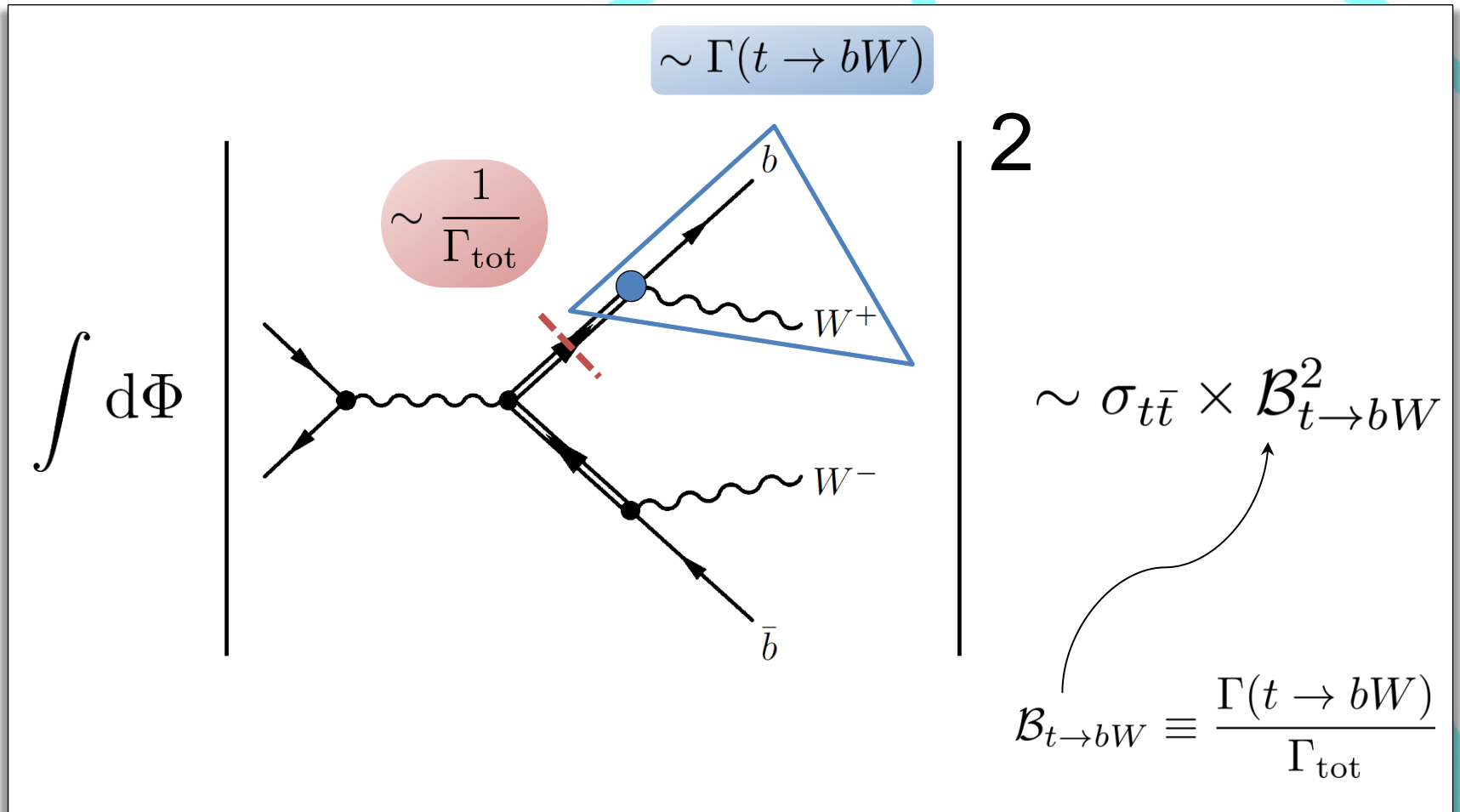
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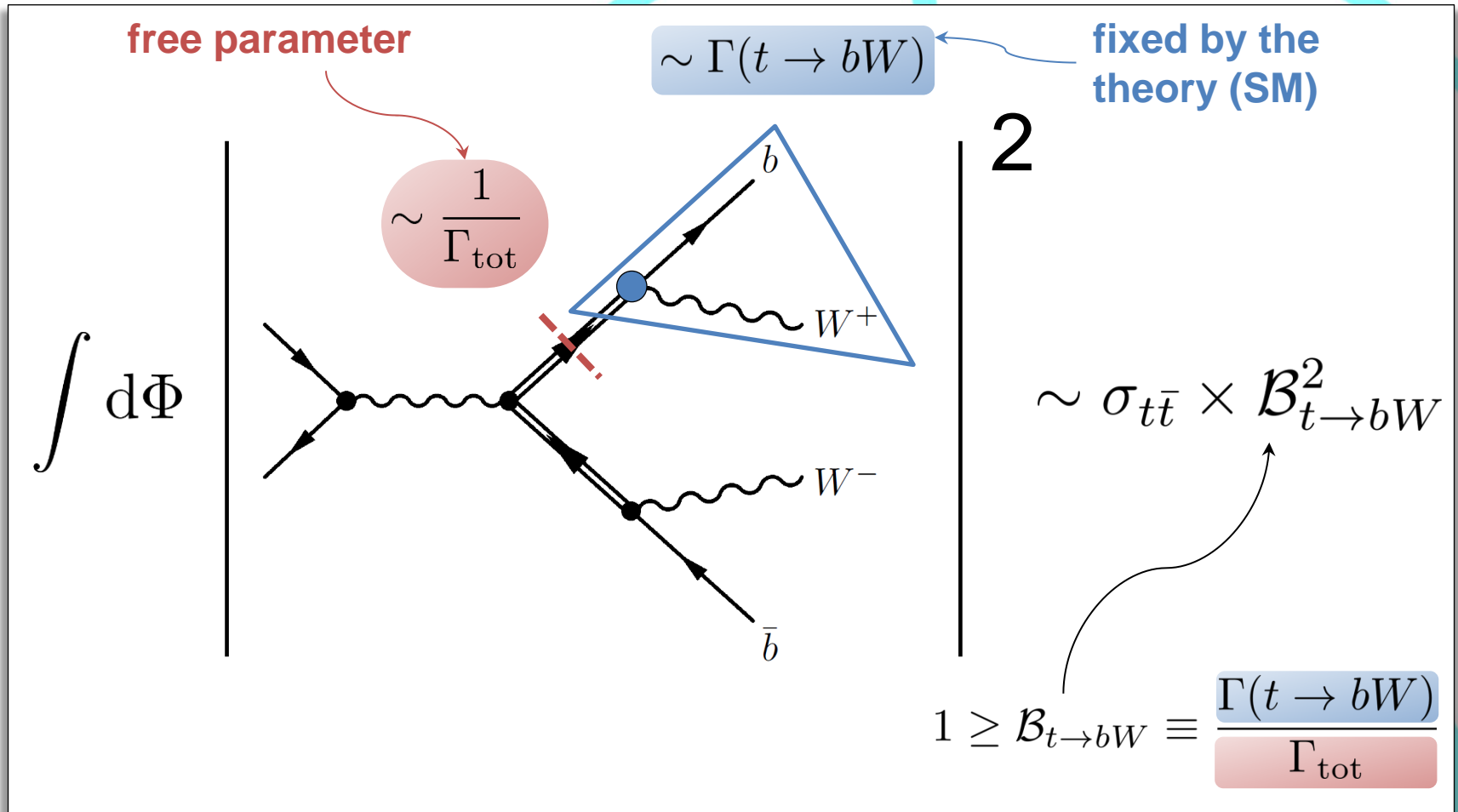
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Some comments on the top width

- a closer look at the $2 \rightarrow 4$ process $e^+e^- \rightarrow bbW^+W^-$ with off-shell tops:

free parameter ???

$\sim \frac{1}{\Gamma_{\text{tot}}}$

fixed by the theory (SM)

$\sim \Gamma(t \rightarrow bW)$

2

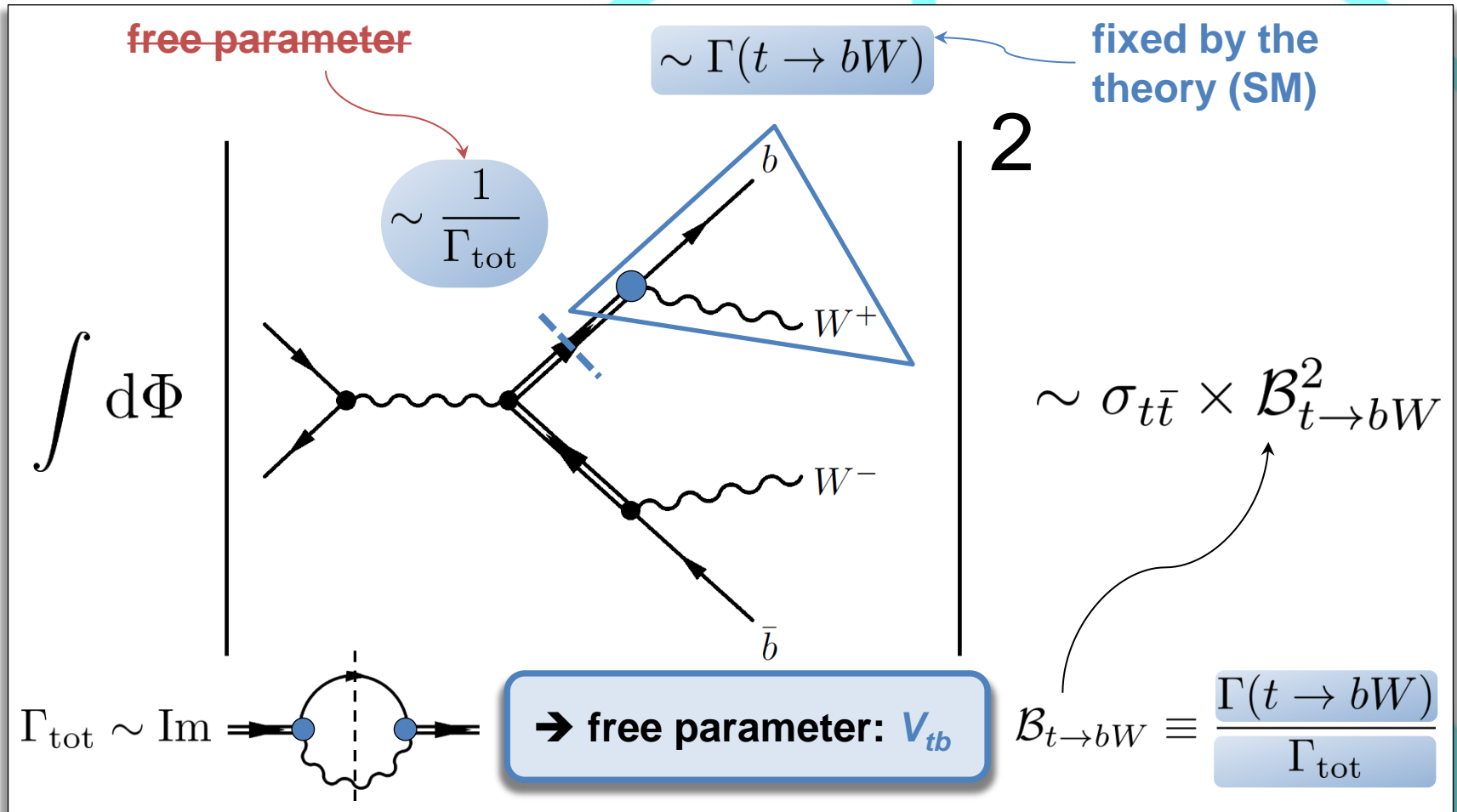
$\sim \sigma_{t\bar{t}} \times \mathcal{B}_{t \rightarrow bW}^2$

$\Gamma_{\text{tot}} \sim \text{Im} \Rightarrow$

$1 \geq \mathcal{B}_{t \rightarrow bW} \equiv \frac{\Gamma(t \rightarrow bW)}{\Gamma_{\text{tot}}}$

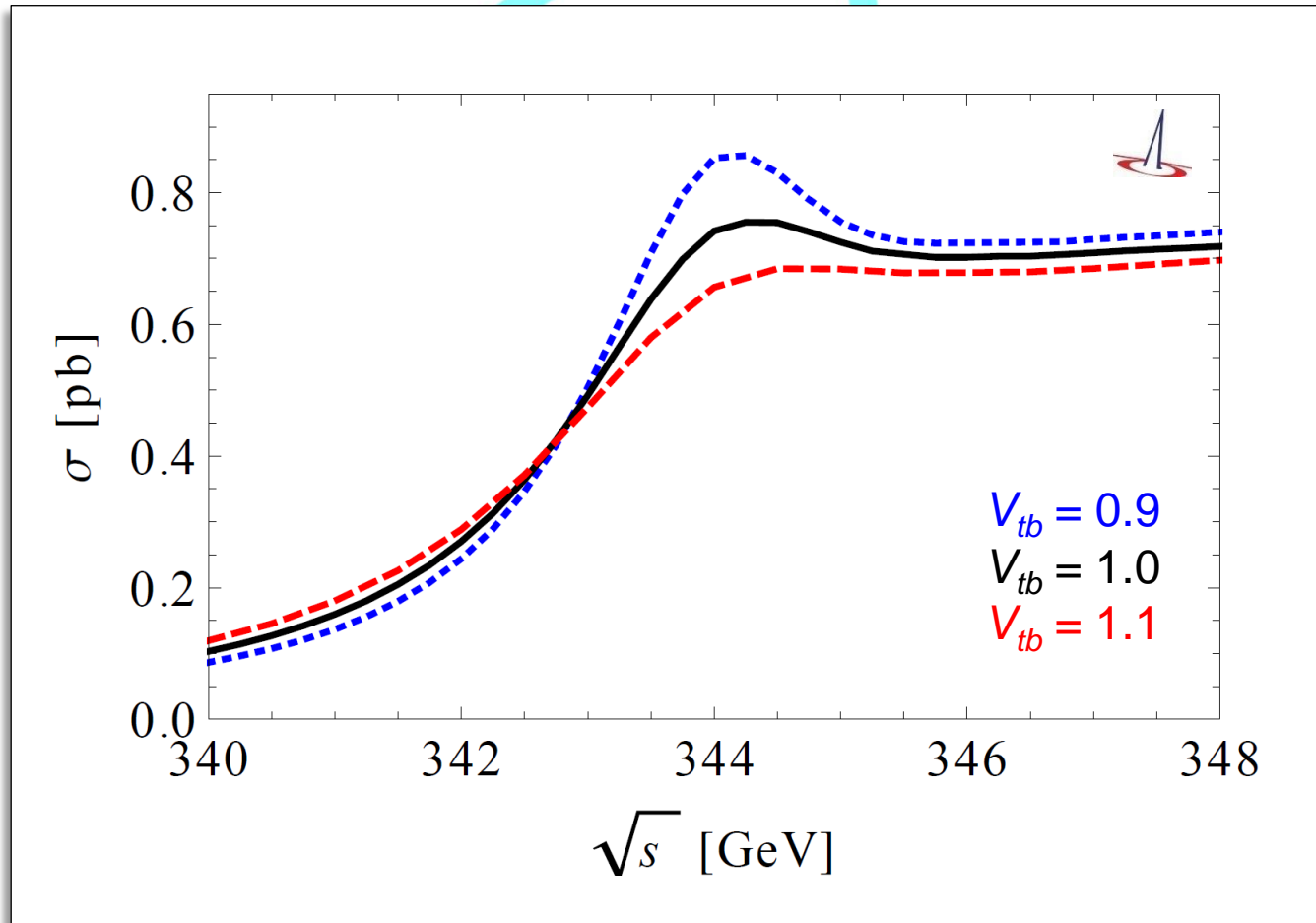
Some comments on the top width

➤ a closer look at the $2 \rightarrow 4$ process $e^+e^- \rightarrow bbW^+W^-$ with off-shell tops:



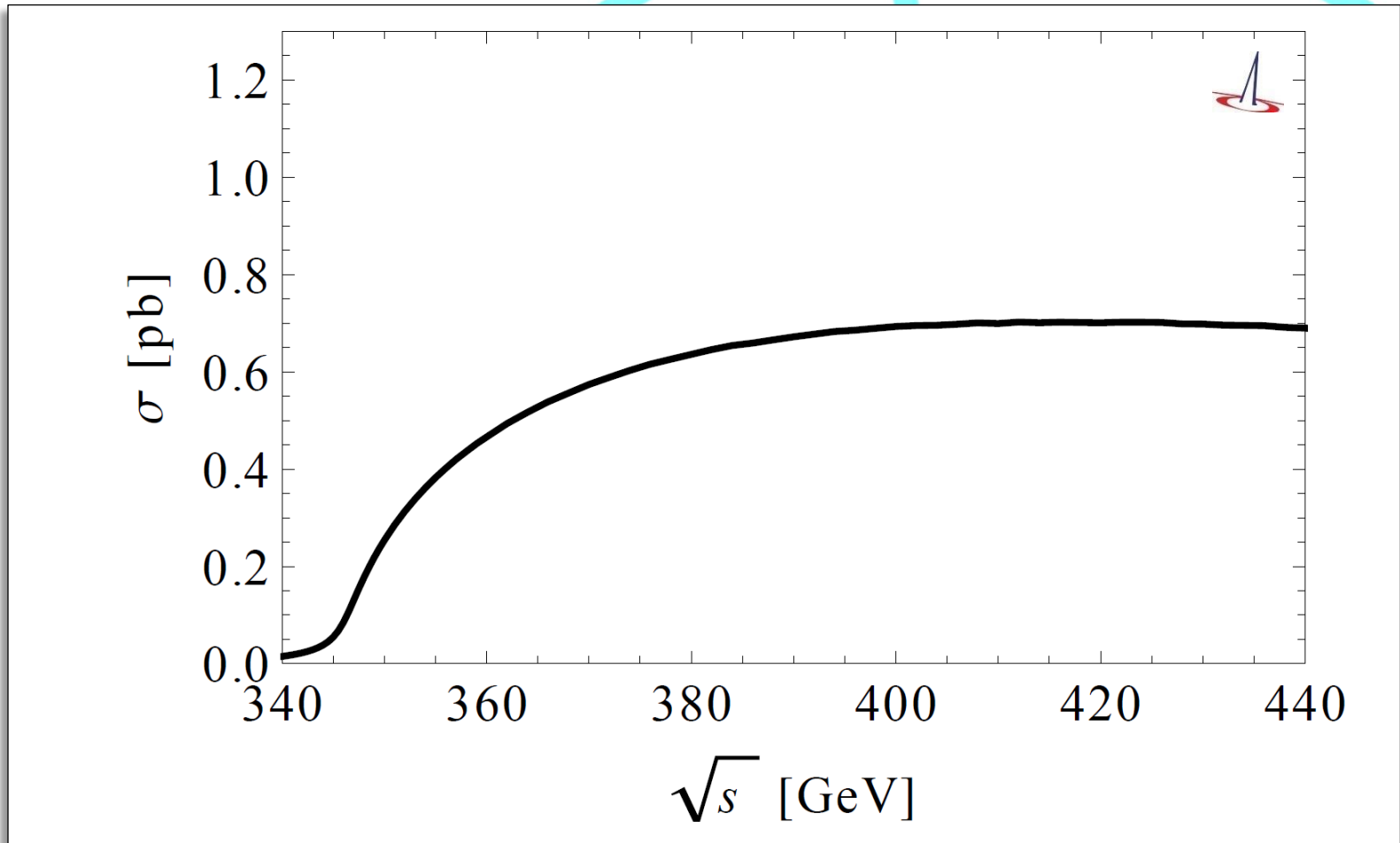
Some comments on the top width

> vary V_{tb} with WHIZARD:



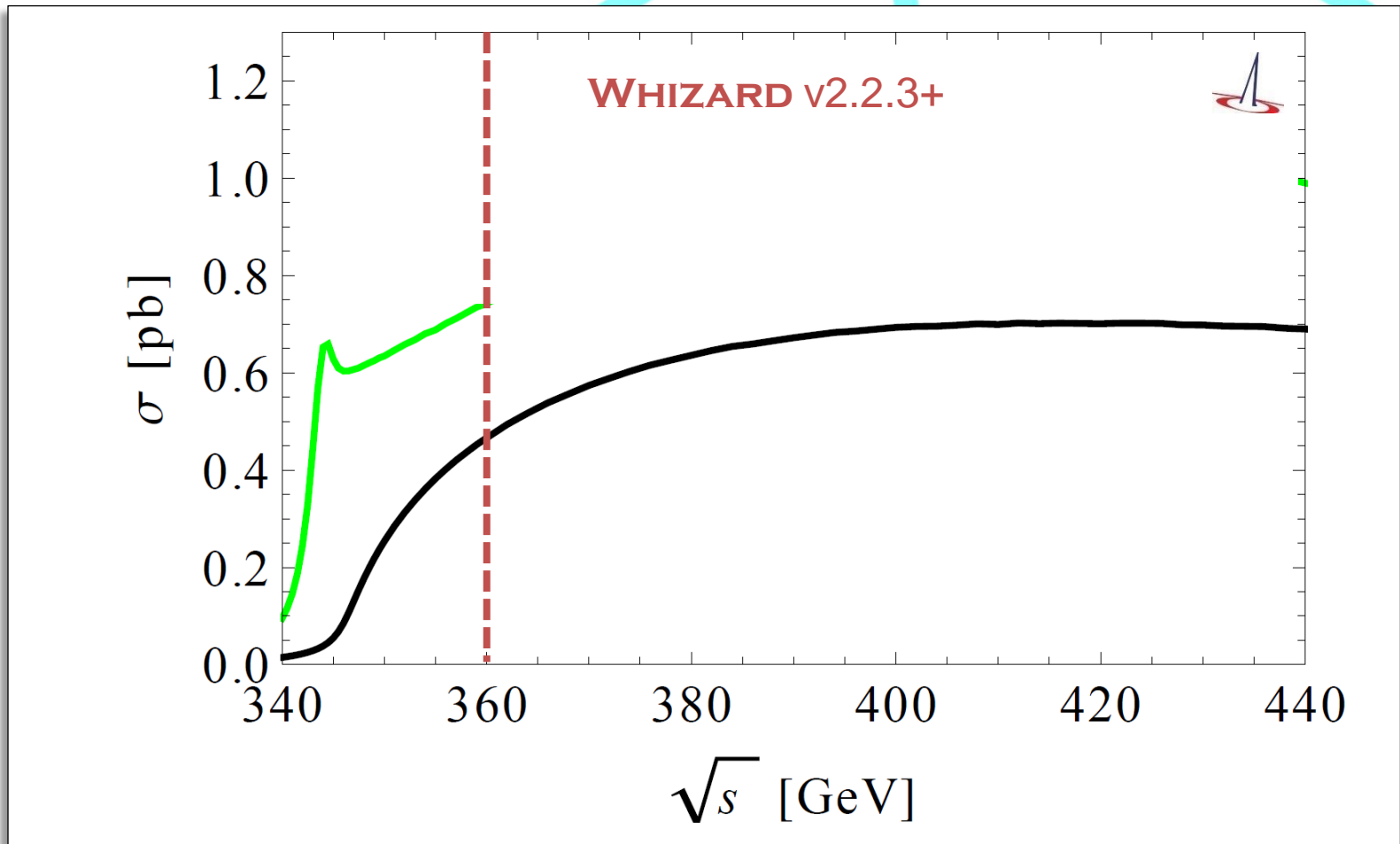
Match NLL threshold resummation to relativistic NLO continuum

> tree level



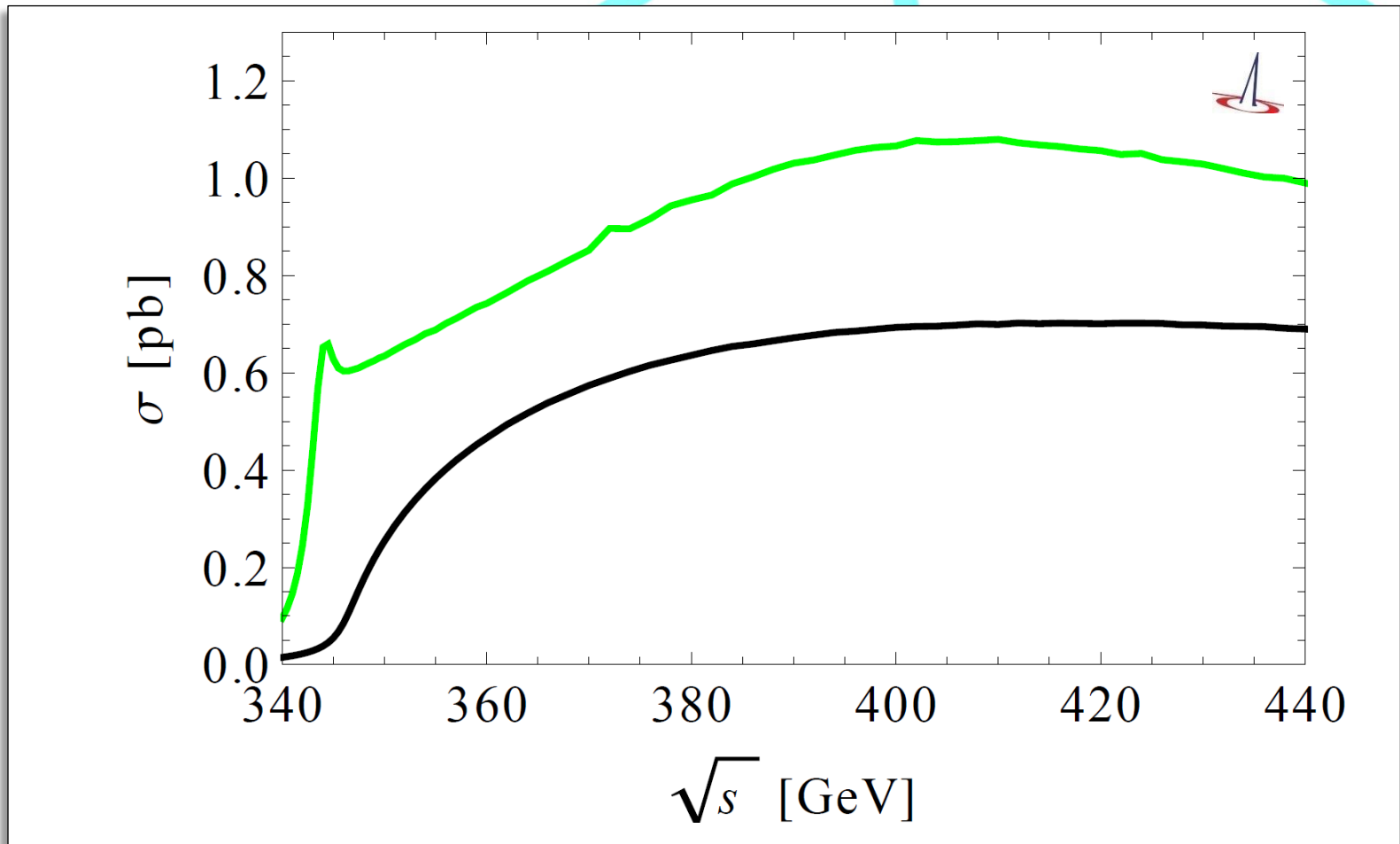
Match NLL threshold resummation to relativistic NLO continuum

- > nonrelativistic NLL threshold resummation using **TOPPIK** [Hoang & Teubner '99]



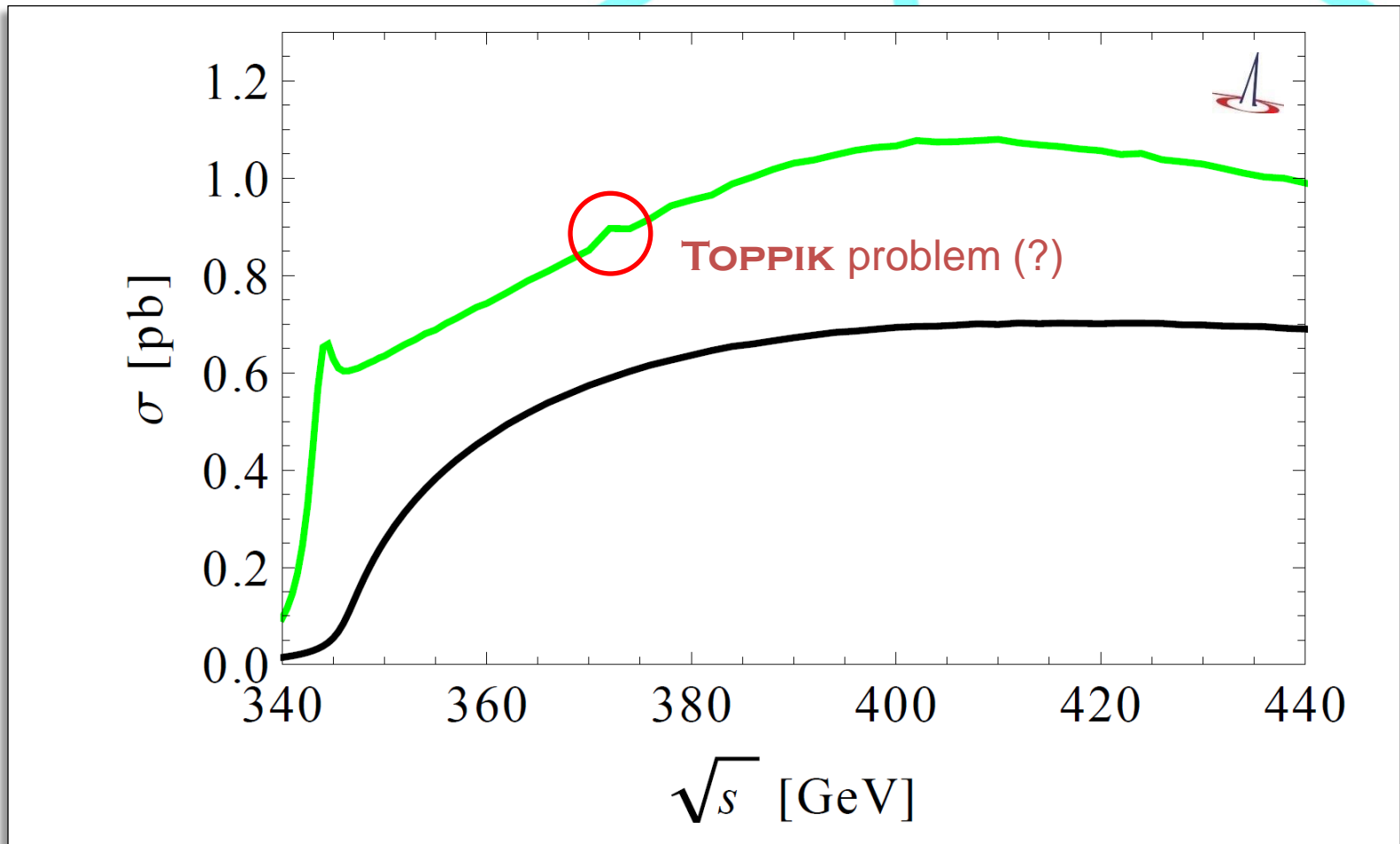
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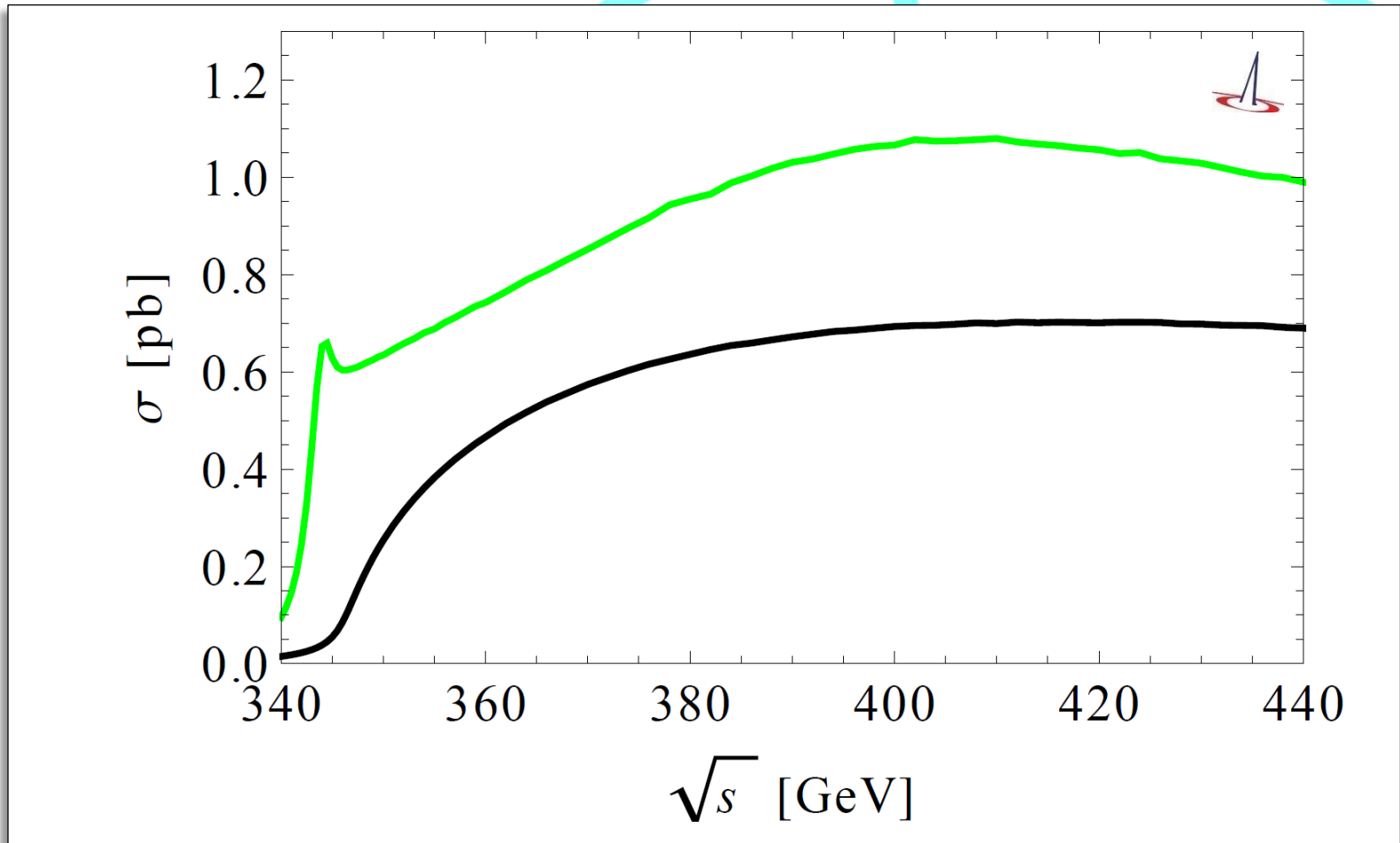
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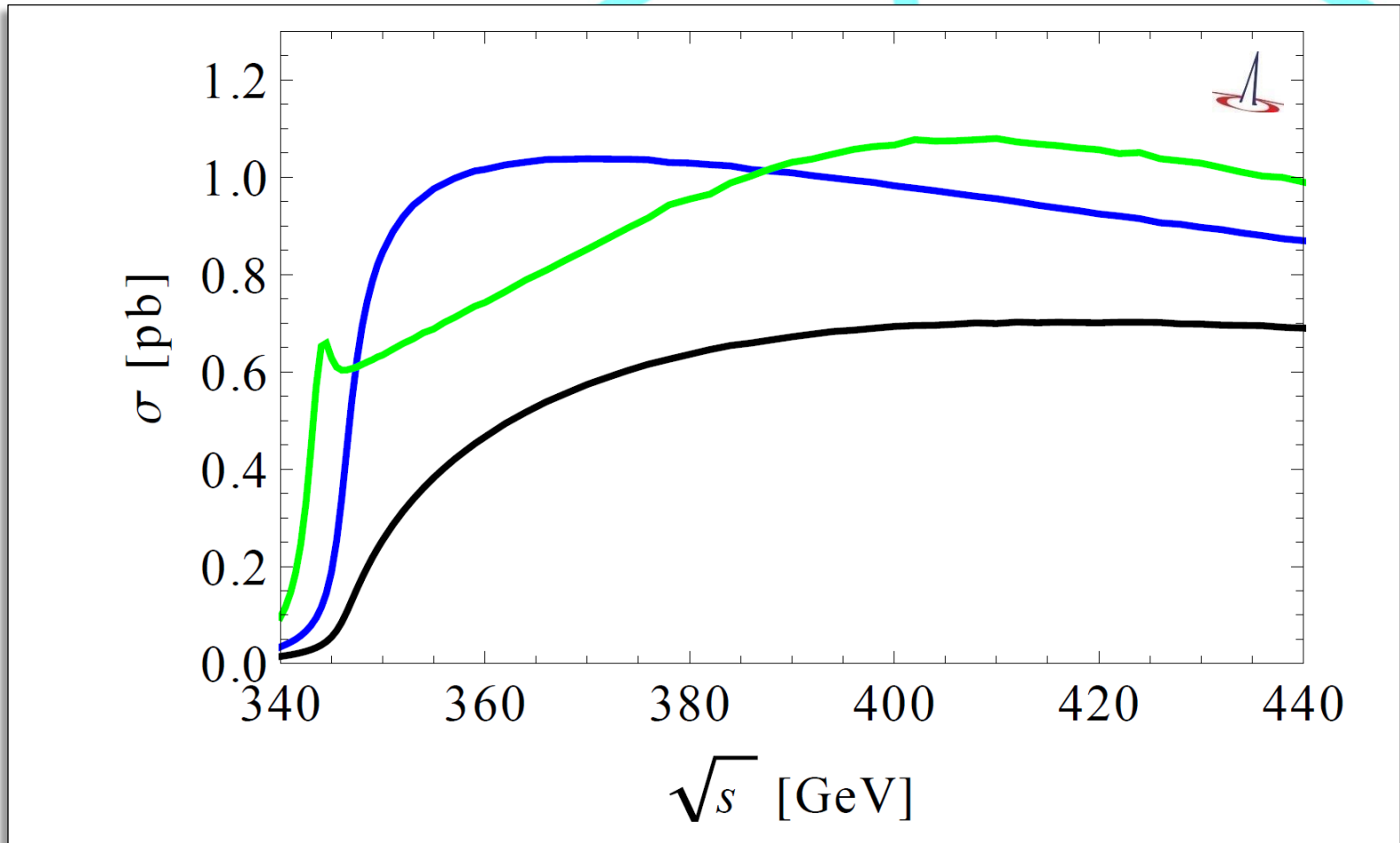
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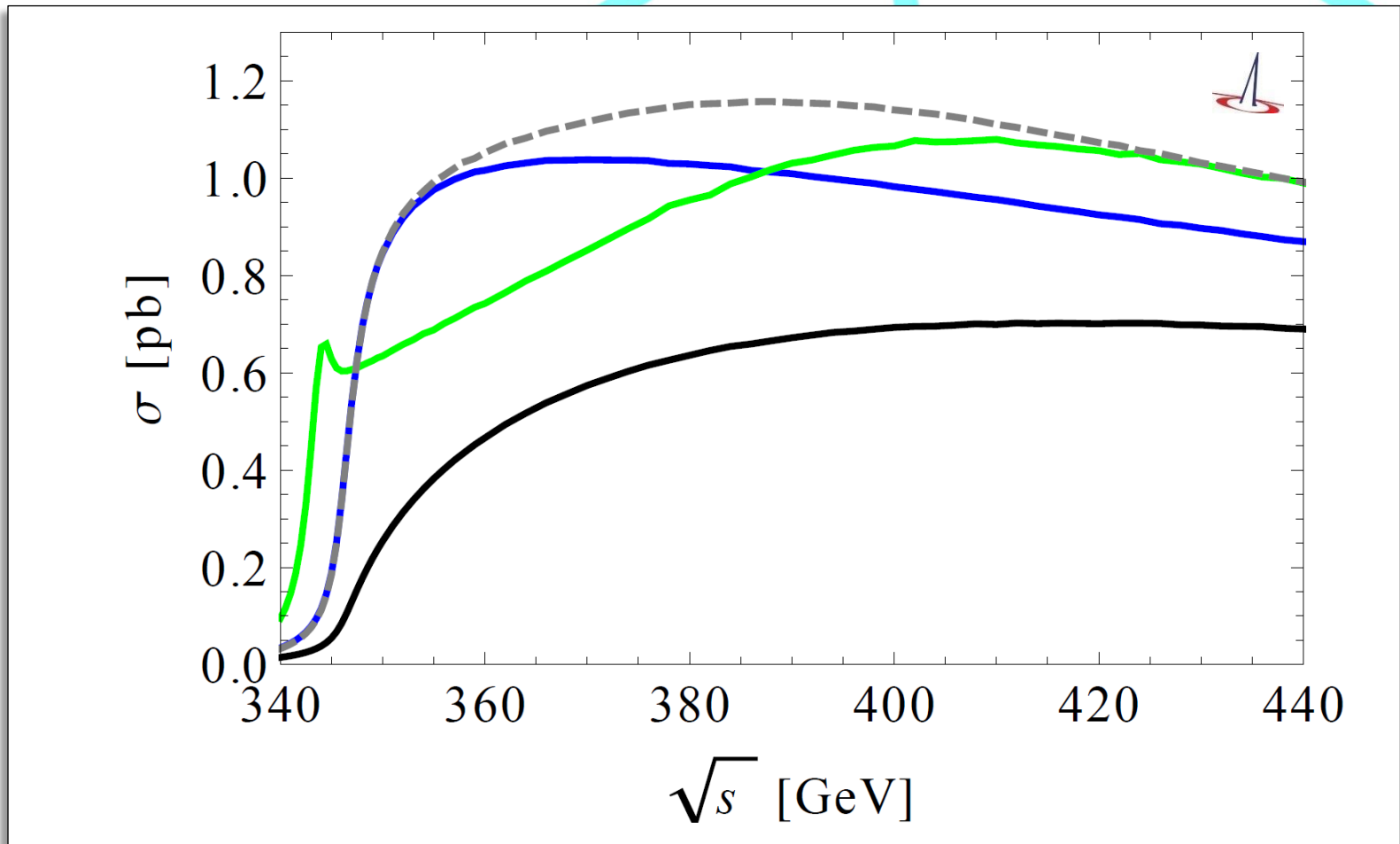
Match NLL threshold resummation to relativistic NLO continuum

- > relativistic NLO ($t\bar{t}V$ off-shell vertex @ NLO [Kızılersü et al. '95; Davydychev et al. '00])



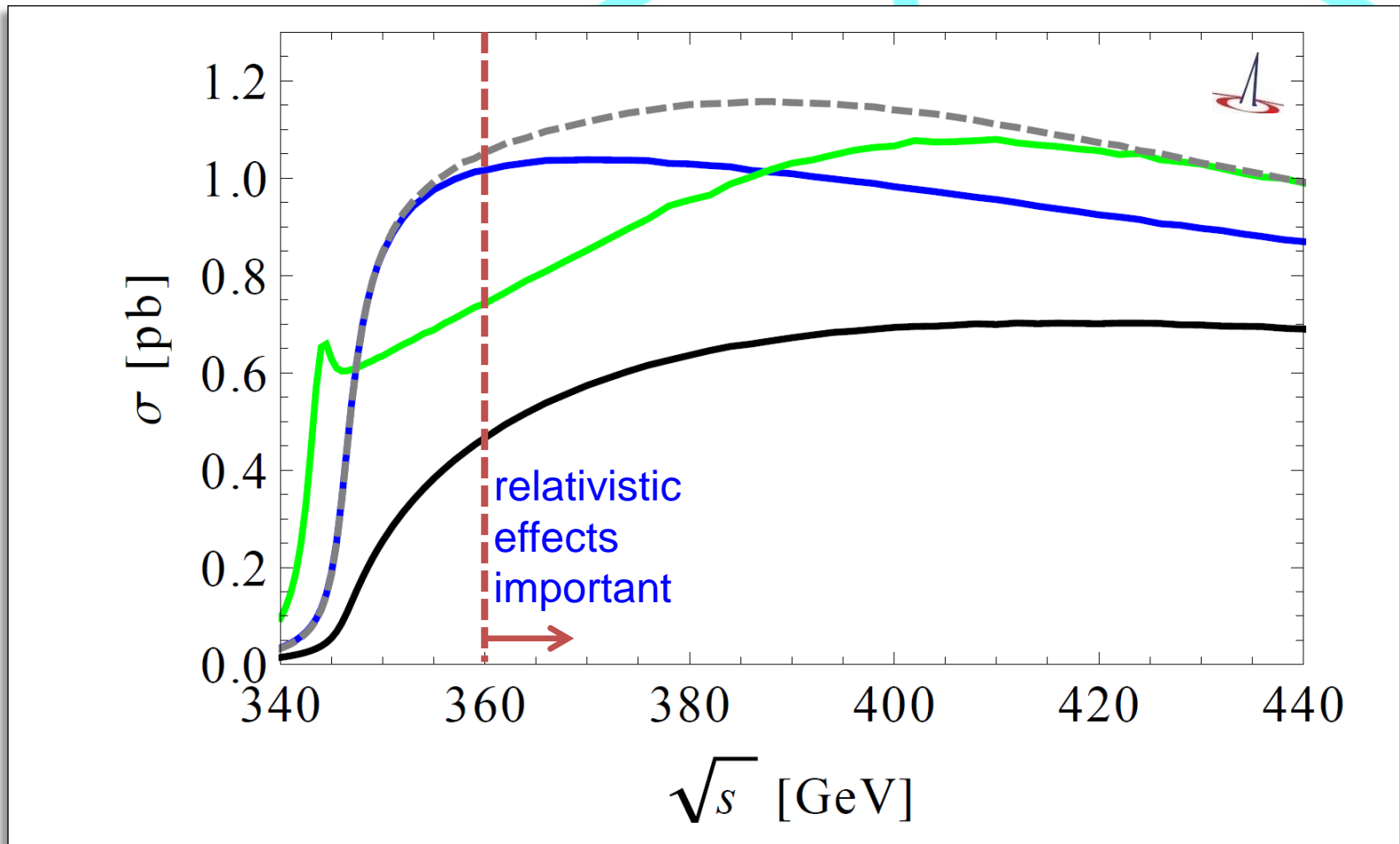
Match NLL threshold resummation to relativistic NLO continuum

- nonrelativistic $O(\alpha_s)$ expansion



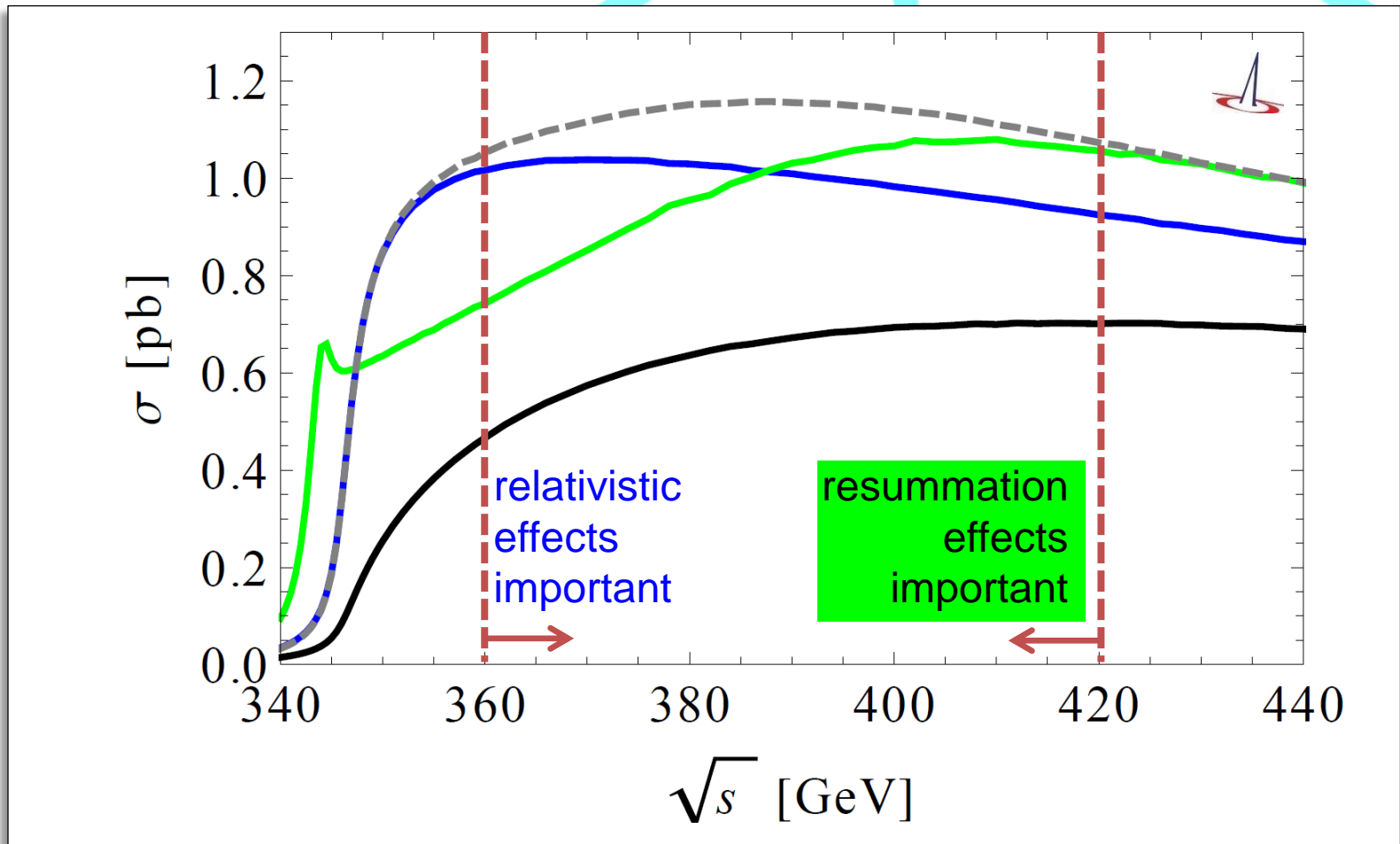
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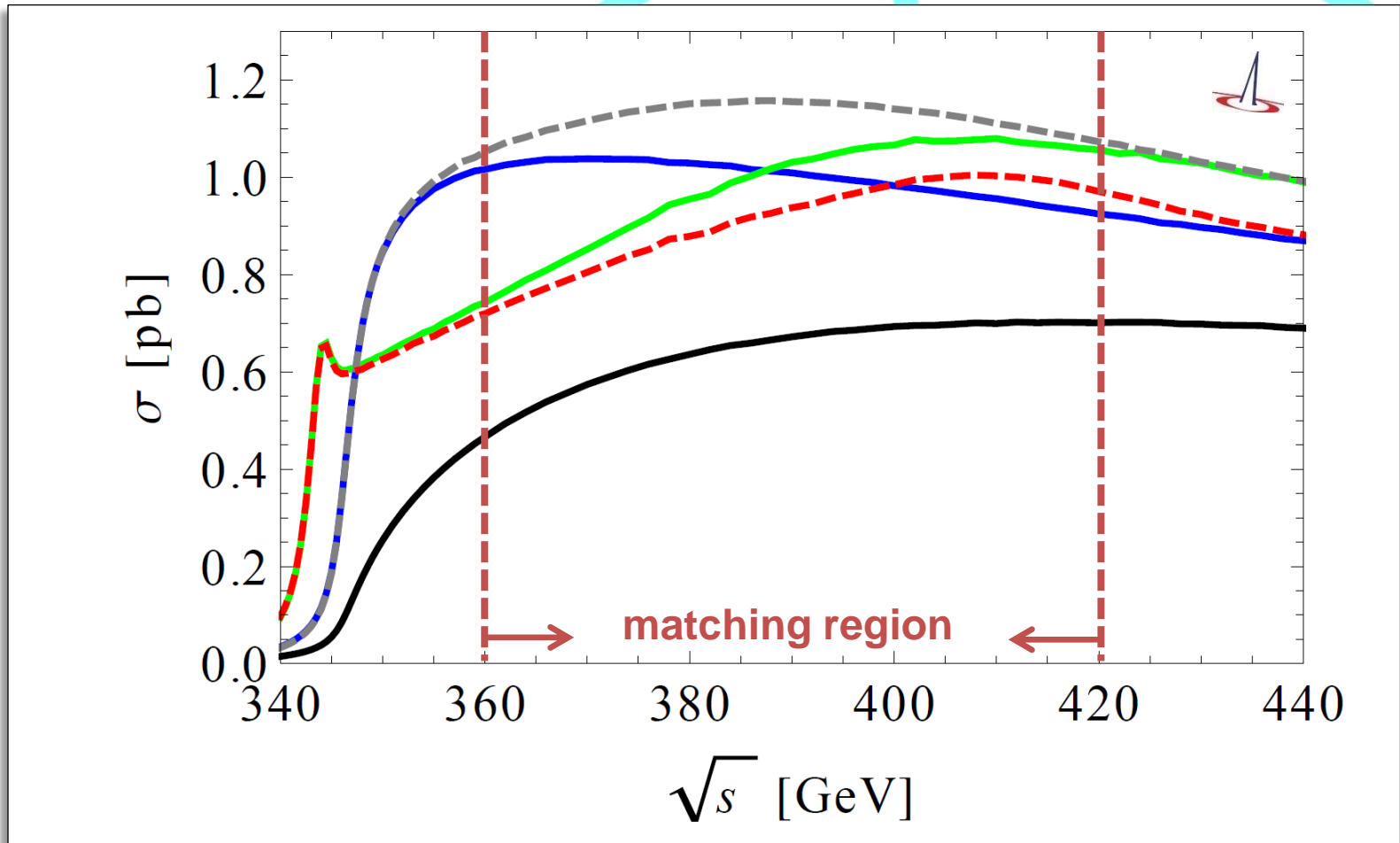
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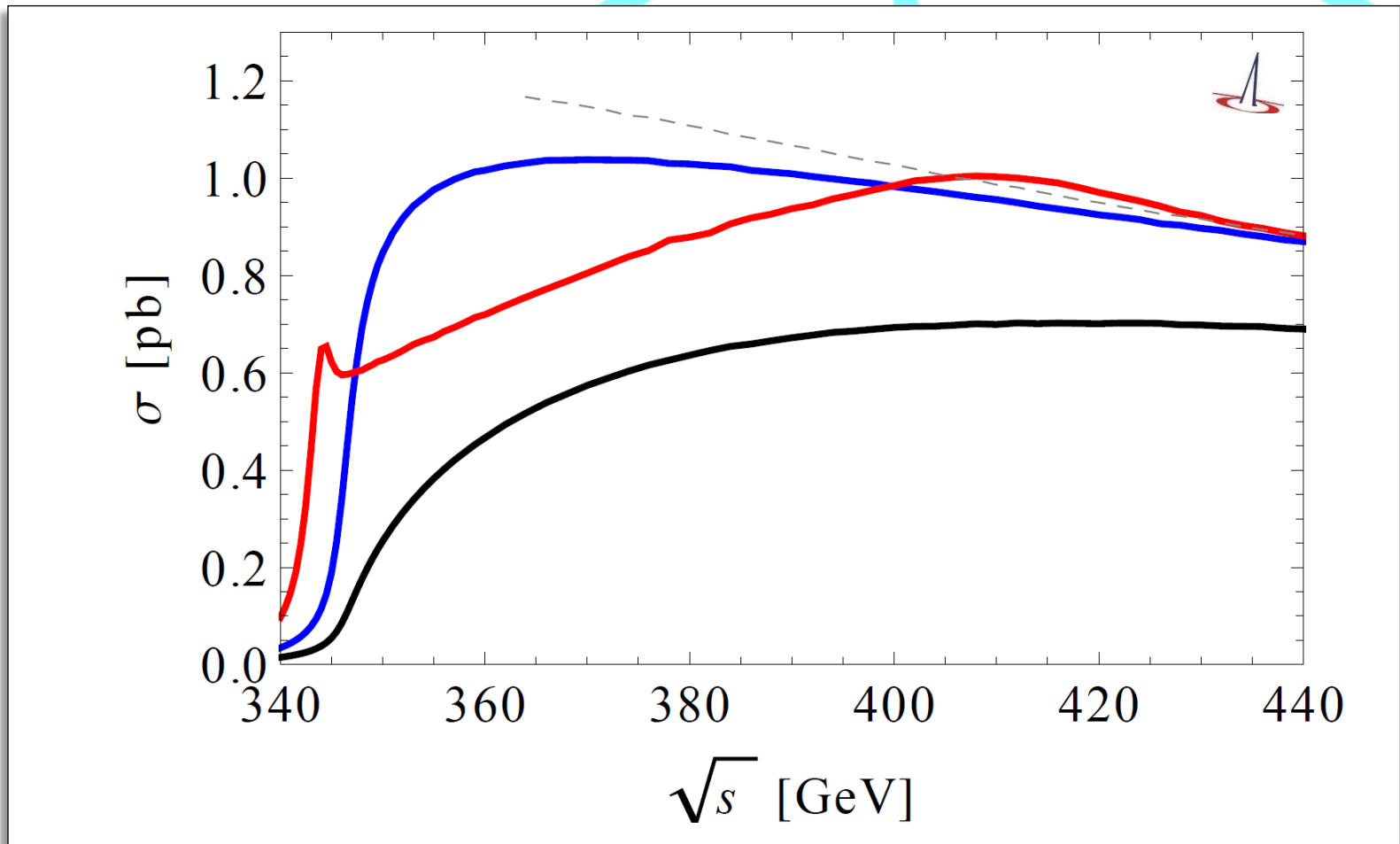
Match NLL threshold resummation to relativistic NLO continuum

- NLL resummed threshold → relativistic NLO continuum matching



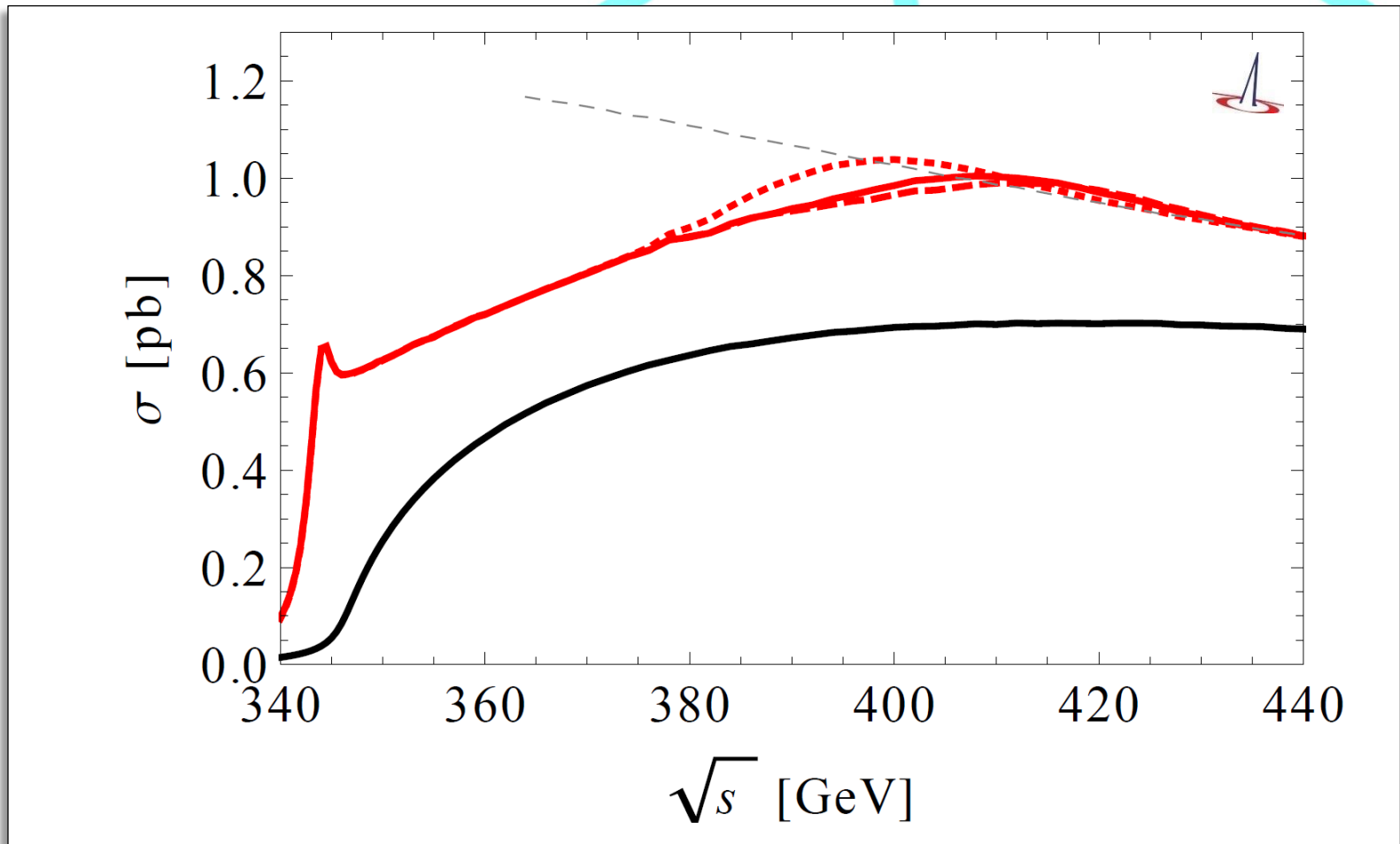
Match NLL threshold resummation to relativistic NLO continuum

- soft nonrelativistic $O(\alpha_s)$ corrections vanishing as $\log(v)$ with $v \rightarrow 1$



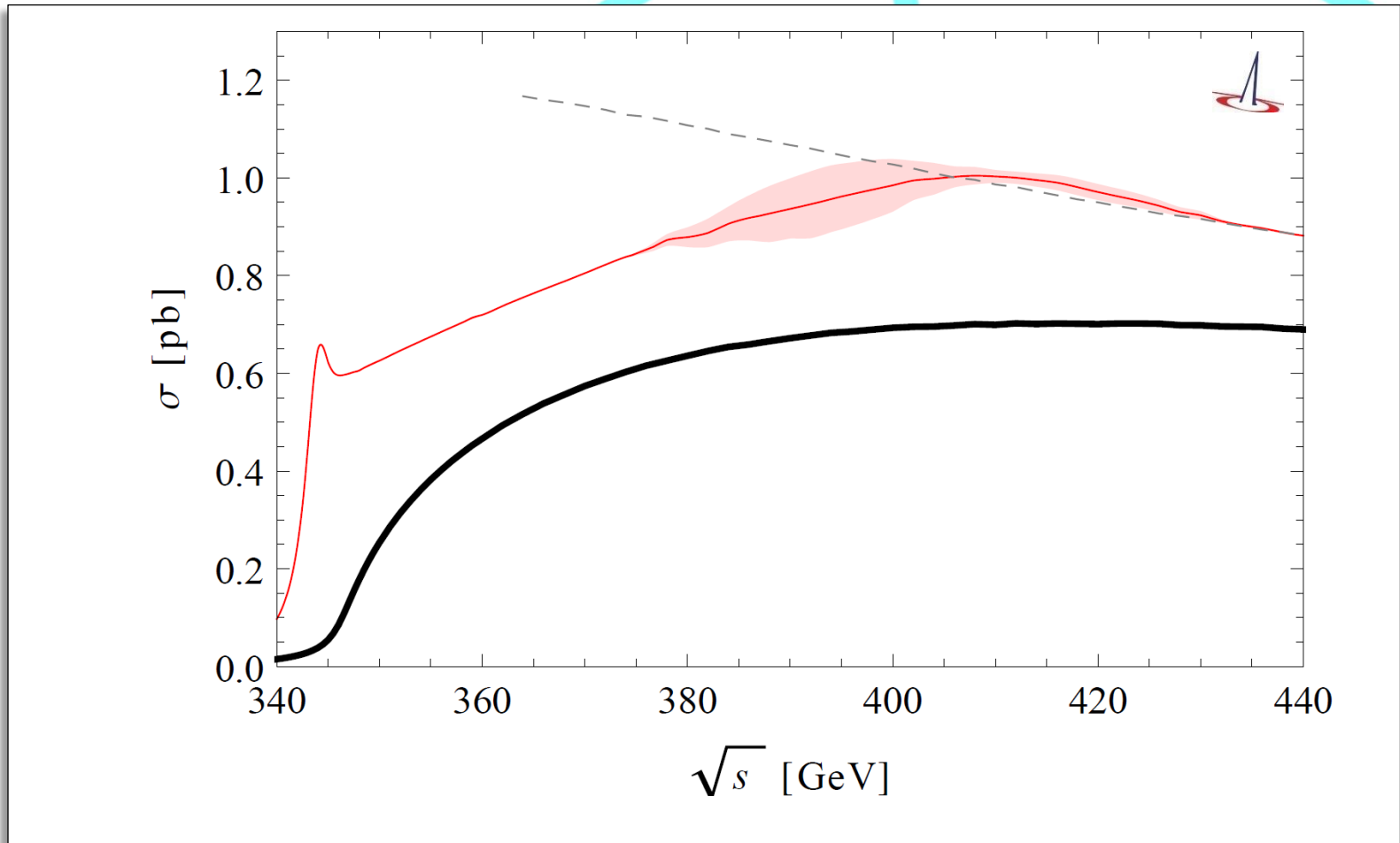
Match NLL threshold resummation to relativistic NLO continuum

> details of the matching procedure:



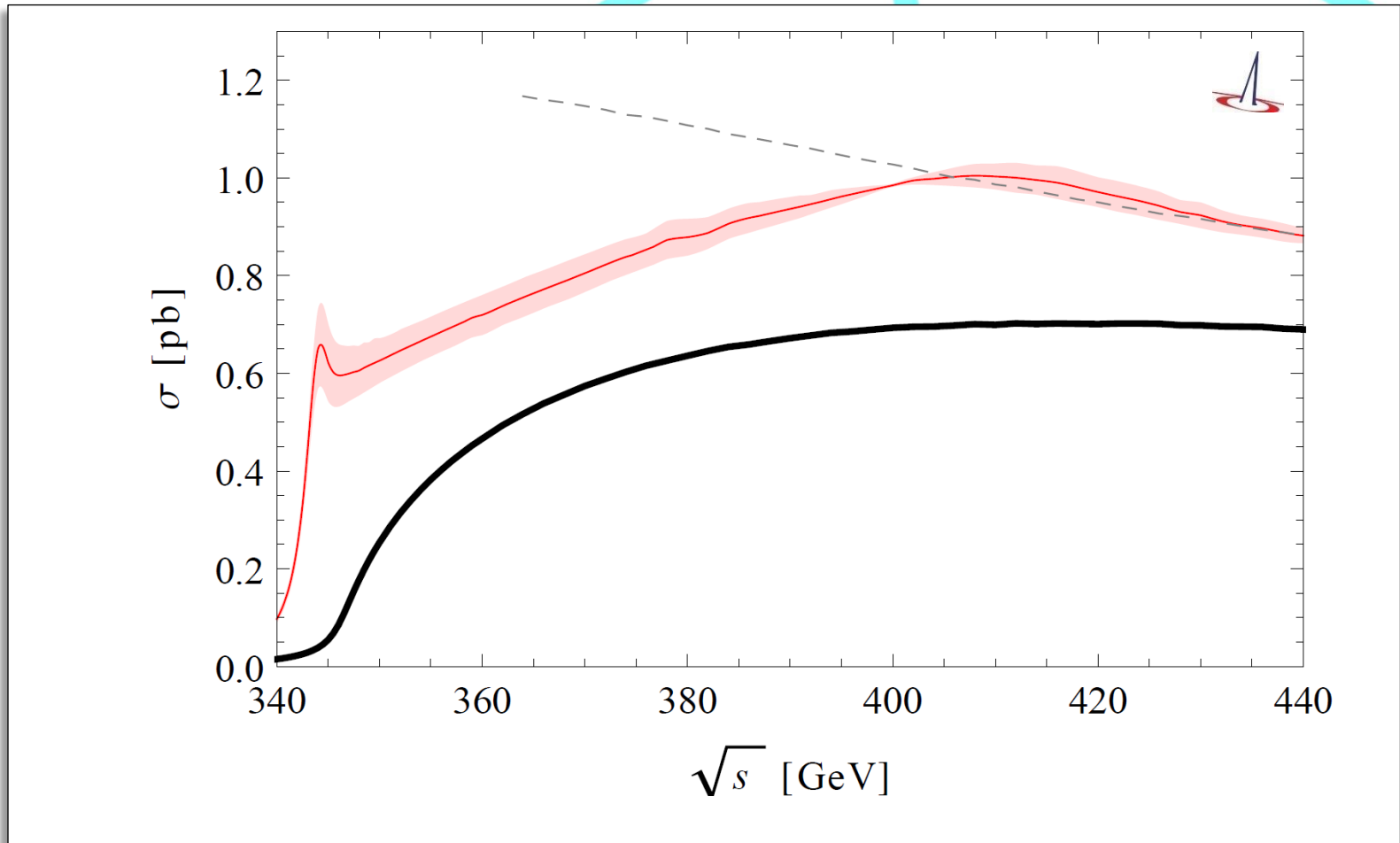
Match NLL threshold resummation to relativistic NLO continuum

- details of the matching procedure: **matching variation band**



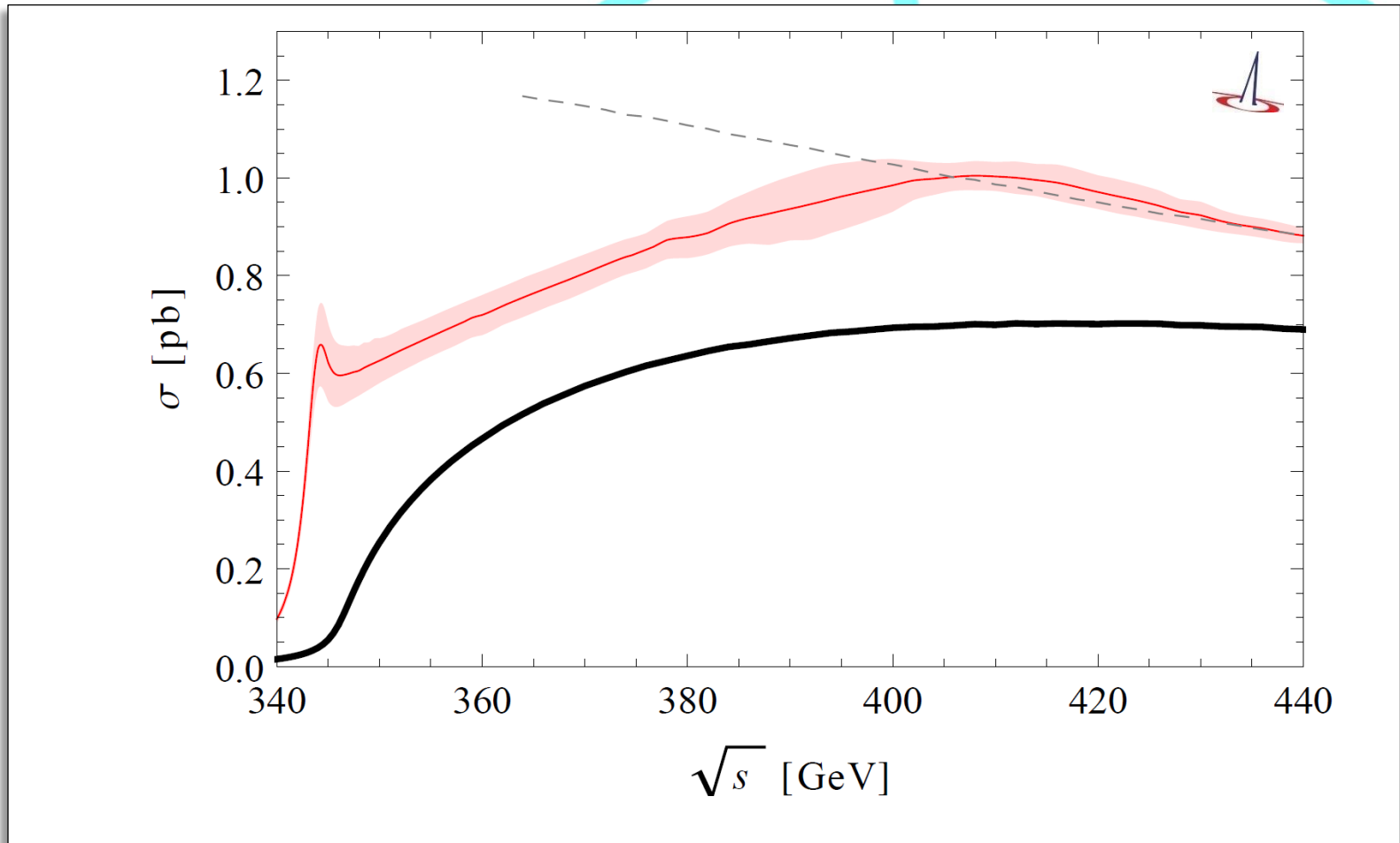
Match NLL threshold resummation to relativistic NLO continuum

> usual scale variations: ***h-f* variation band**



Match NLL threshold resummation to relativistic NLO continuum

- Total uncertainty: **combined matching & h - f variation band**





WHIZARD v2.2.6 ttbar threshold model & parameters !!! DRAFT !!!

> ttbar LC threshold model **revised and extended in v2.2.6**

> planned **model layout & parameter setup:**

> model name:

SM_tt_threshold

> model parameters & default values:

alpha_em_i = 125.924

inverse QED coupling @ threshold
 M^S mass

m1S = 172.

Vtb = 1.

CKM matrix element V_{tb}

wt_inv = 0.

invisible top width (BSM scenarios)

nloop = 1

NRQCD order: 0: LL, 1: NLL

sh = 1.

hard matching scale h

sf = 1.

soft renormalization scale f

> top quark pole mass and width (single particle resonance at LO)

mtpole ---

fixed by parameters!

wtop ---

fixed by parameters!



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