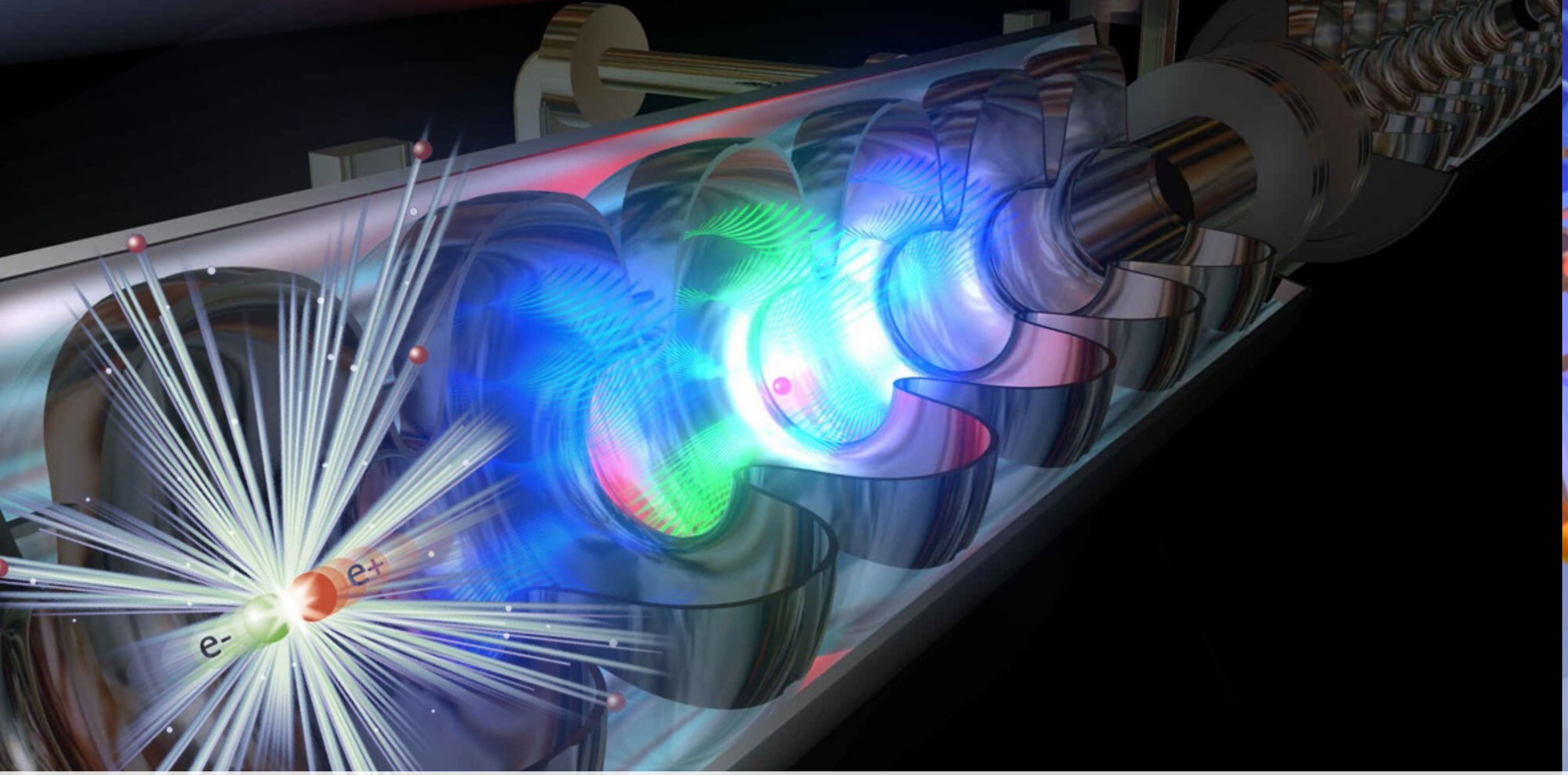
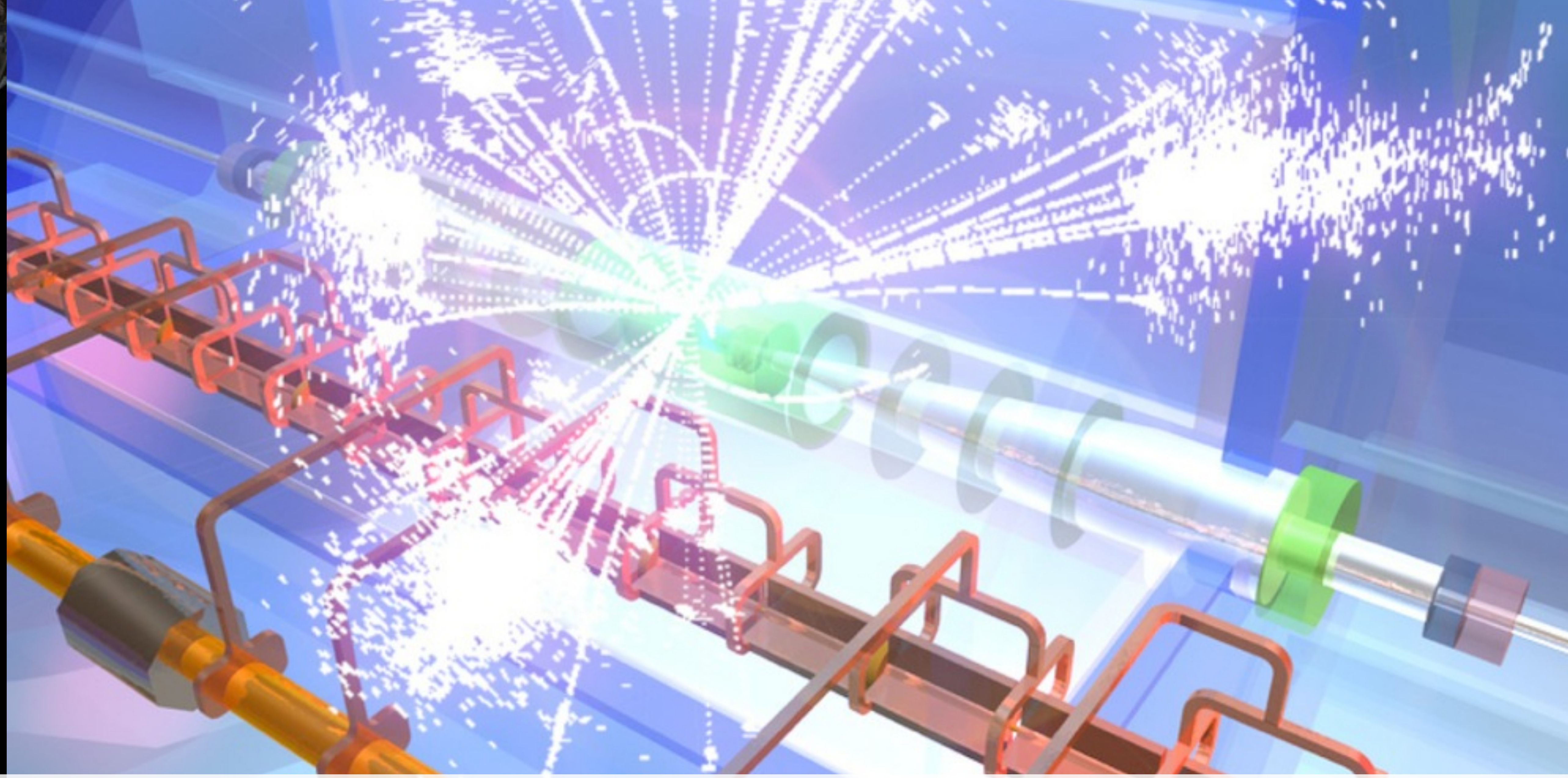




Experimental Physics at Lepton Colliders

Frank Simon

@ Summer Student Lectures
CERN/Zoom - July 2022

MAX-PLANCK-INSTITUT
FÜR PHYSIK

Part II

Overview

A two-part story

- Part 1:
  - Scientific motivation
  - Future e^+e^- colliders in broad strokes
  - Detectors at future e^+e^- and $\mu^+\mu^-$ colliders
- **Part 2:**
  - Higgs physics
  - Electroweak precision
  - Top quark physics
  - Into the unknown

Disclaimer

- The point of the following discussions is not to compare projects in the sense of drawing conclusions which one should be built - that is a multi-facetted question which extends beyond performance projections shown here.
- The numerical results may not always be perfectly up-to-date - again, the goal is not to compare, but to illustrate certain features of measurements and facilities

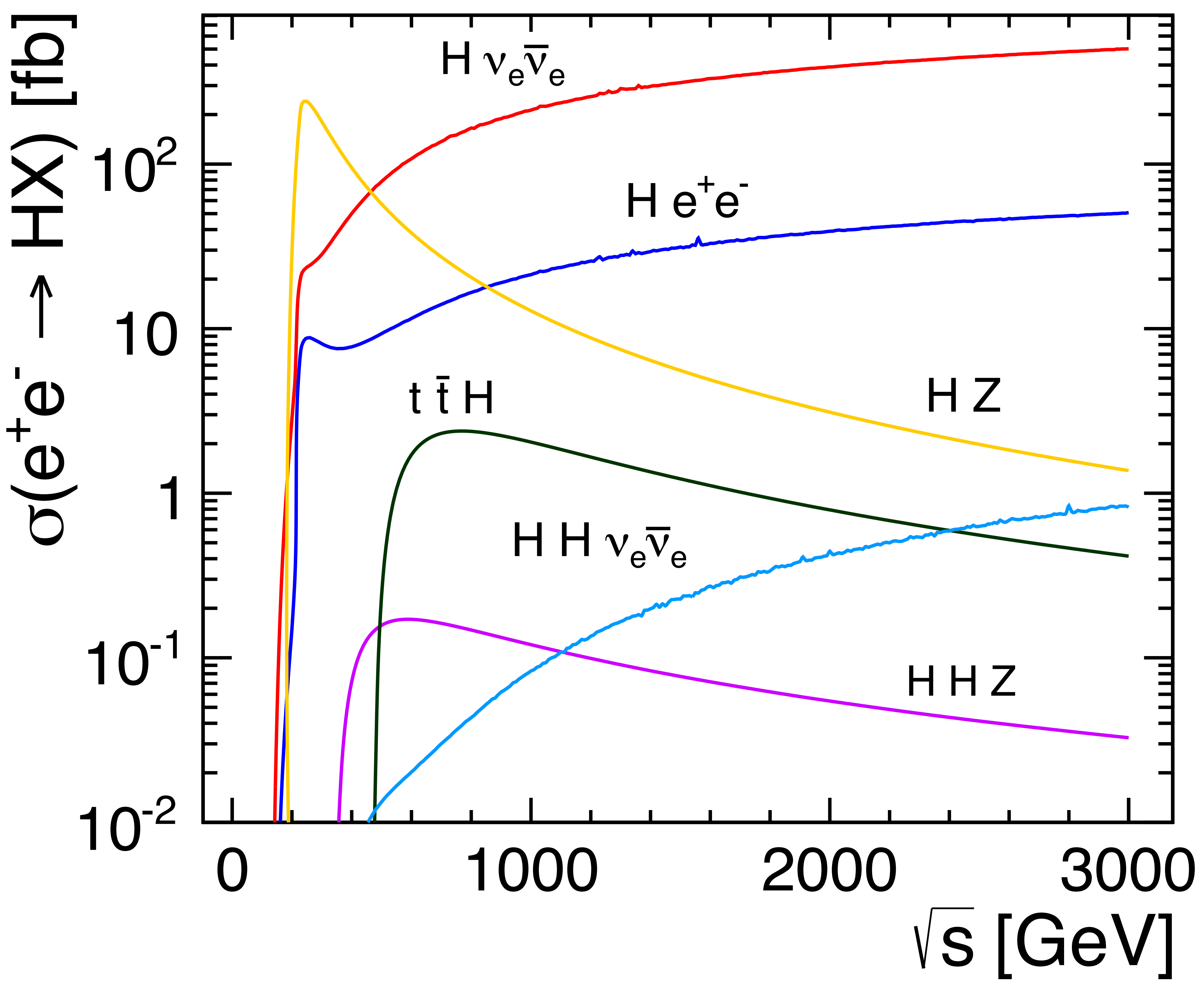
- I am focussing on e^+e^- colliders, only few remarks about $\mu^+\mu^-$

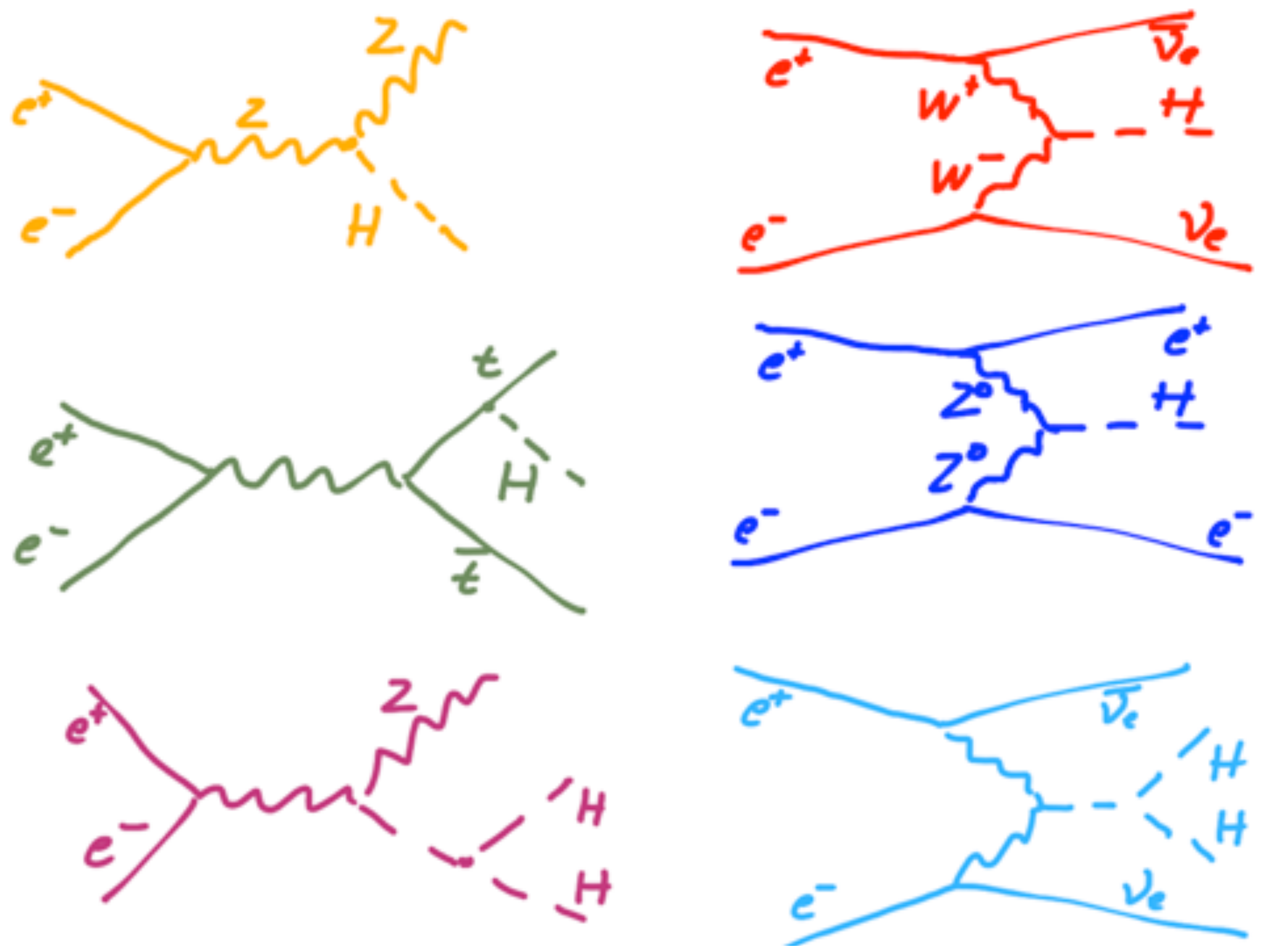
Precision Higgs Measurements

Higgs Factories and beyond

Higgs Boson Production in e^+e^-

A rich field to explore





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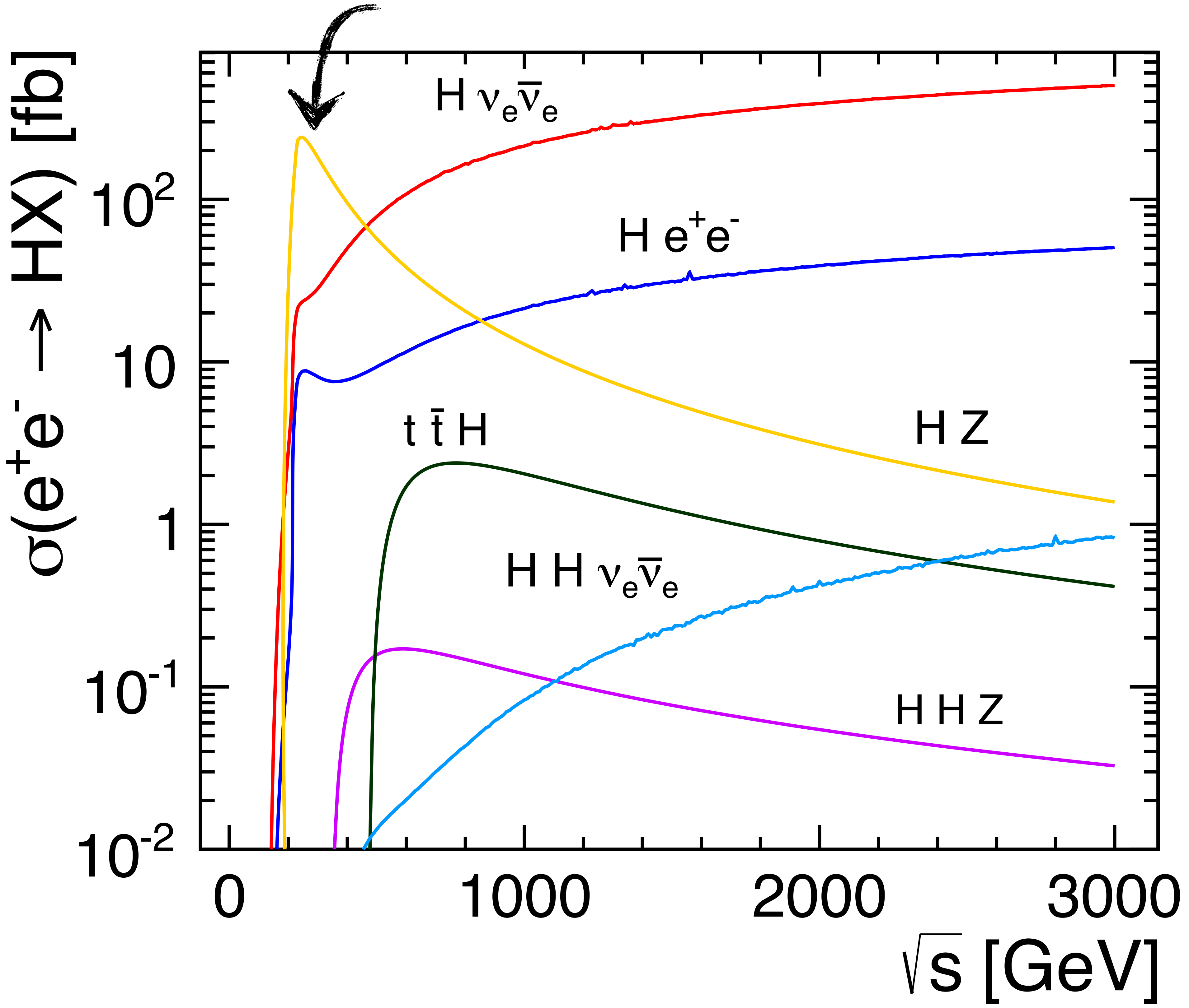

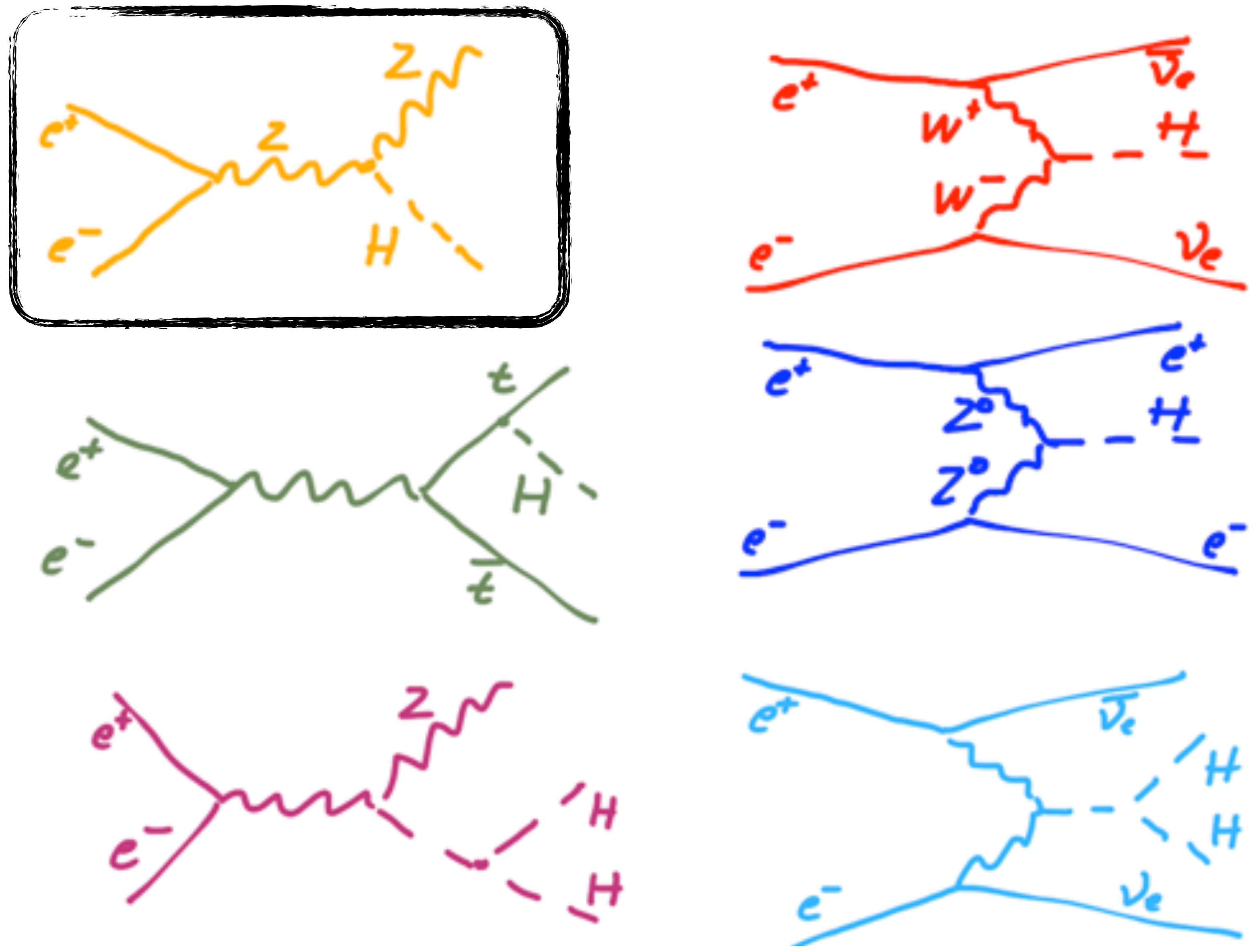

250 GeV:

Maximum of ZH production

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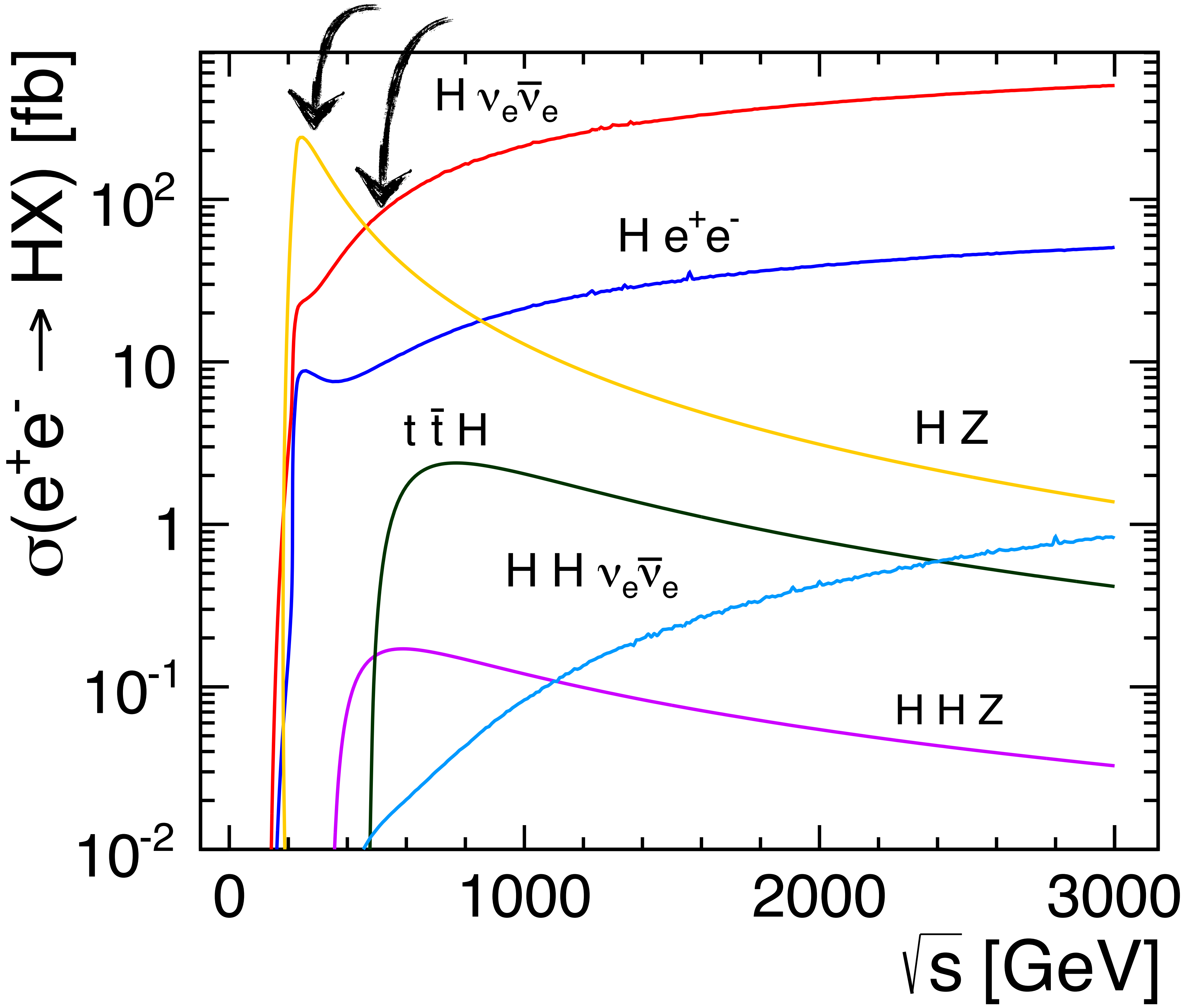

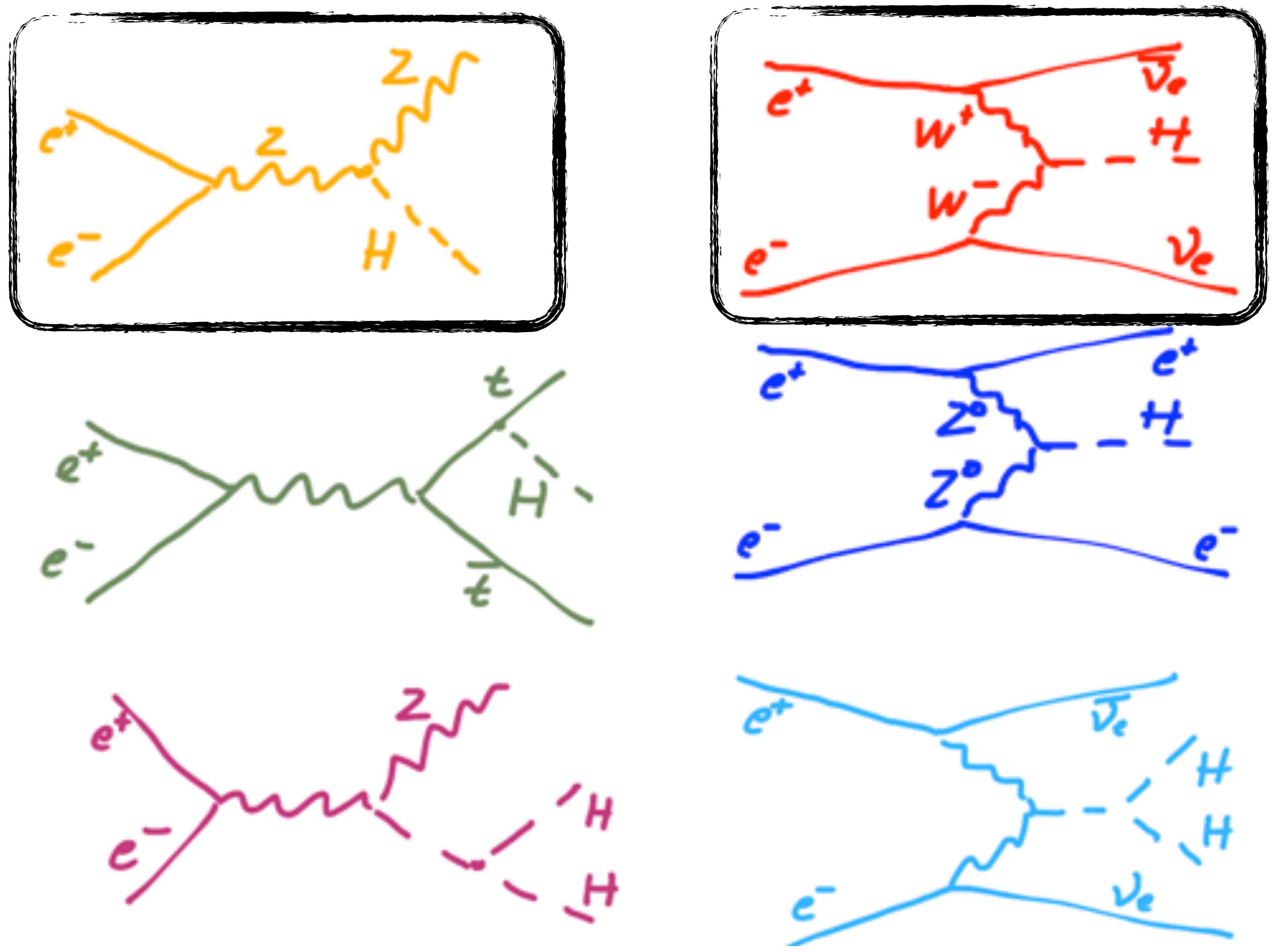

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WW fusion kicks in
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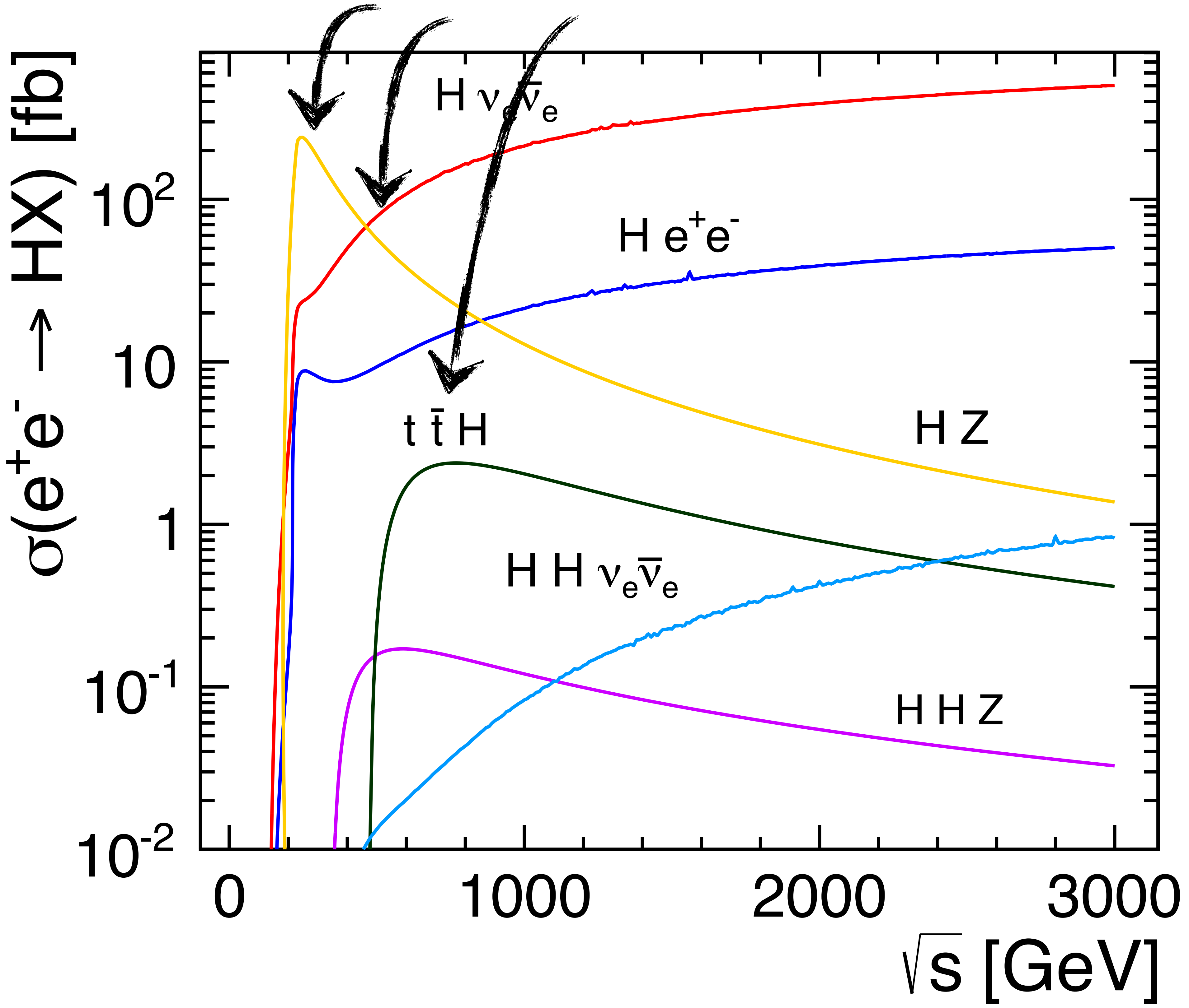

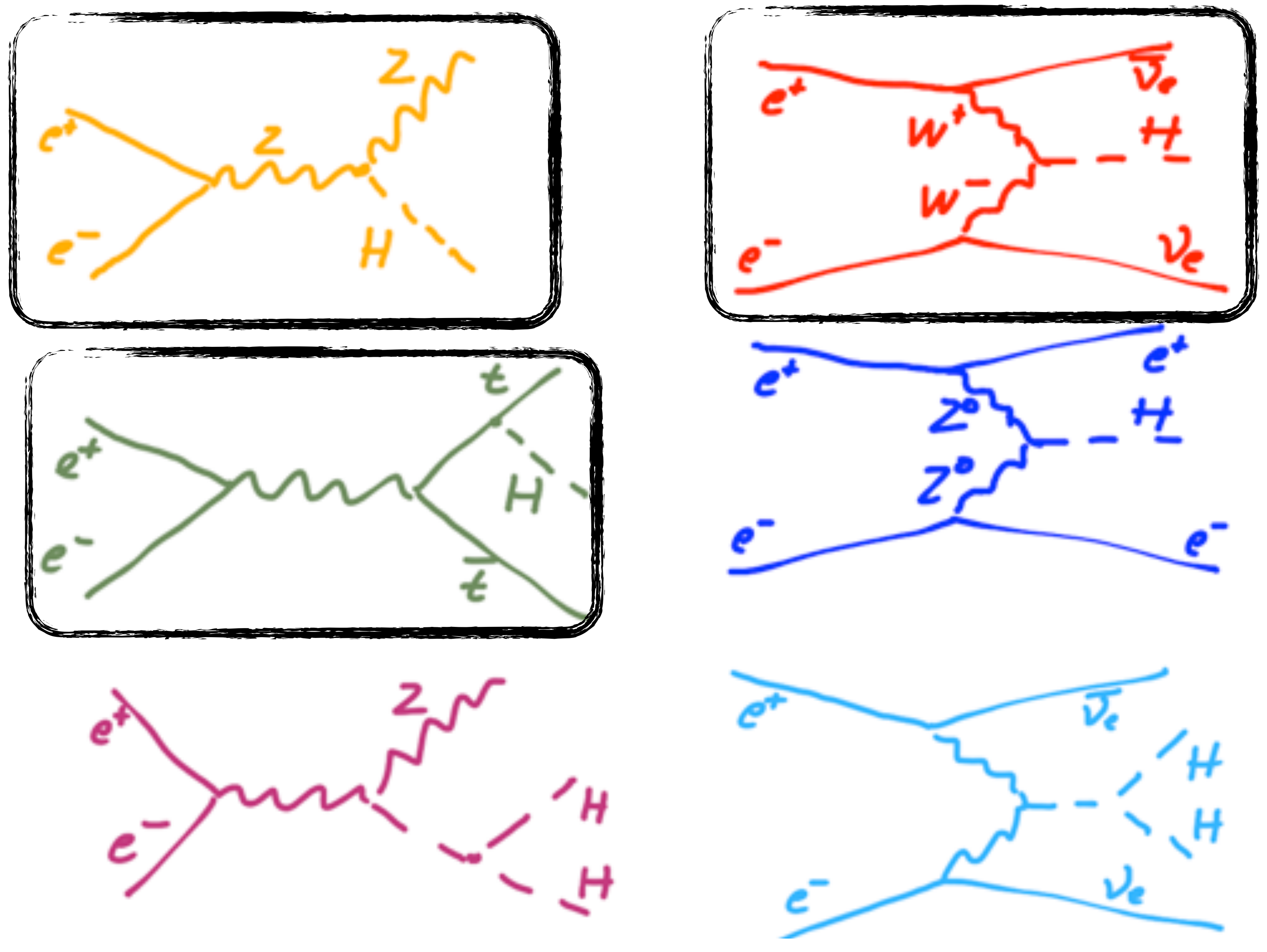

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ttH: direct access to top Yukawa coupling

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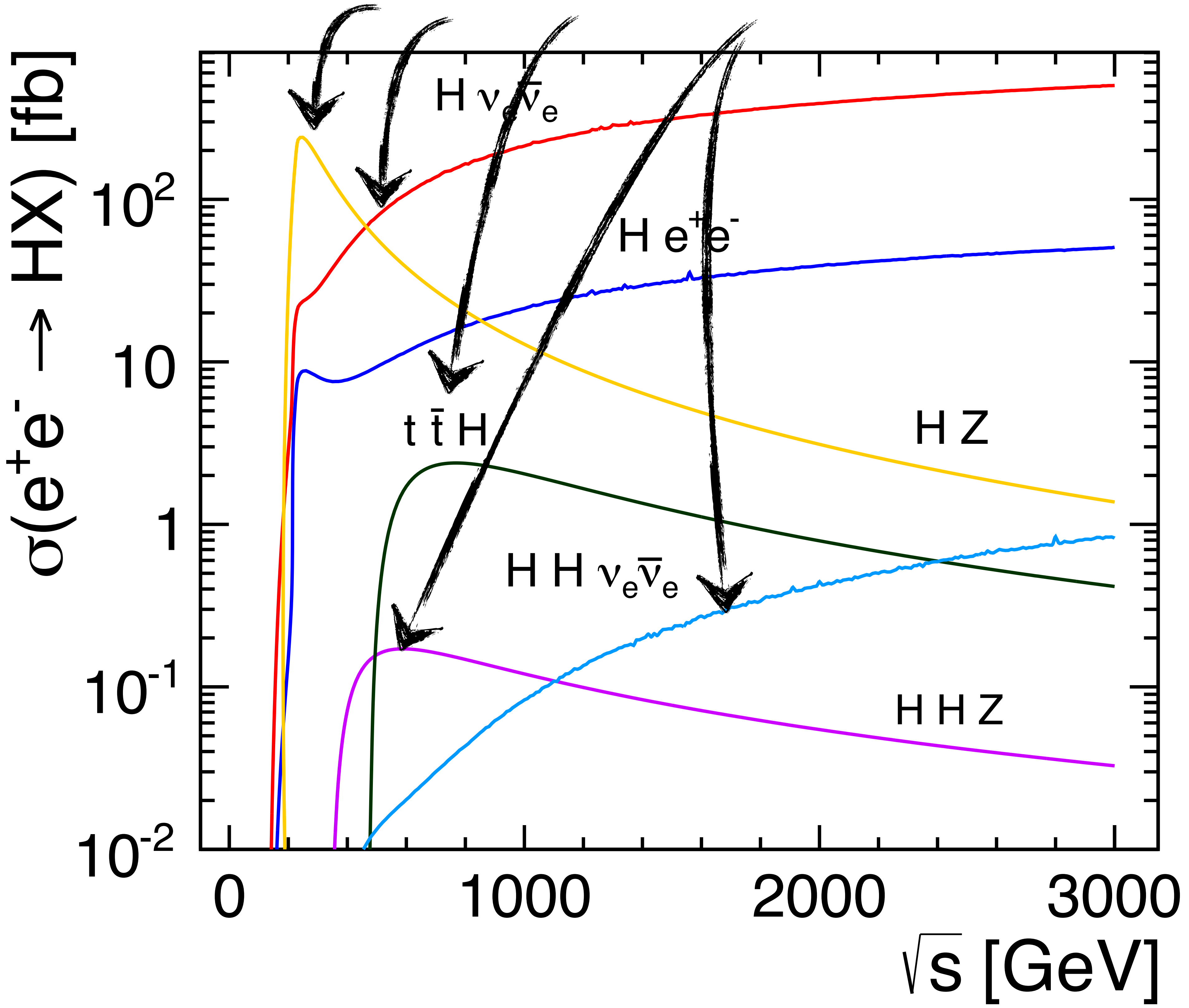

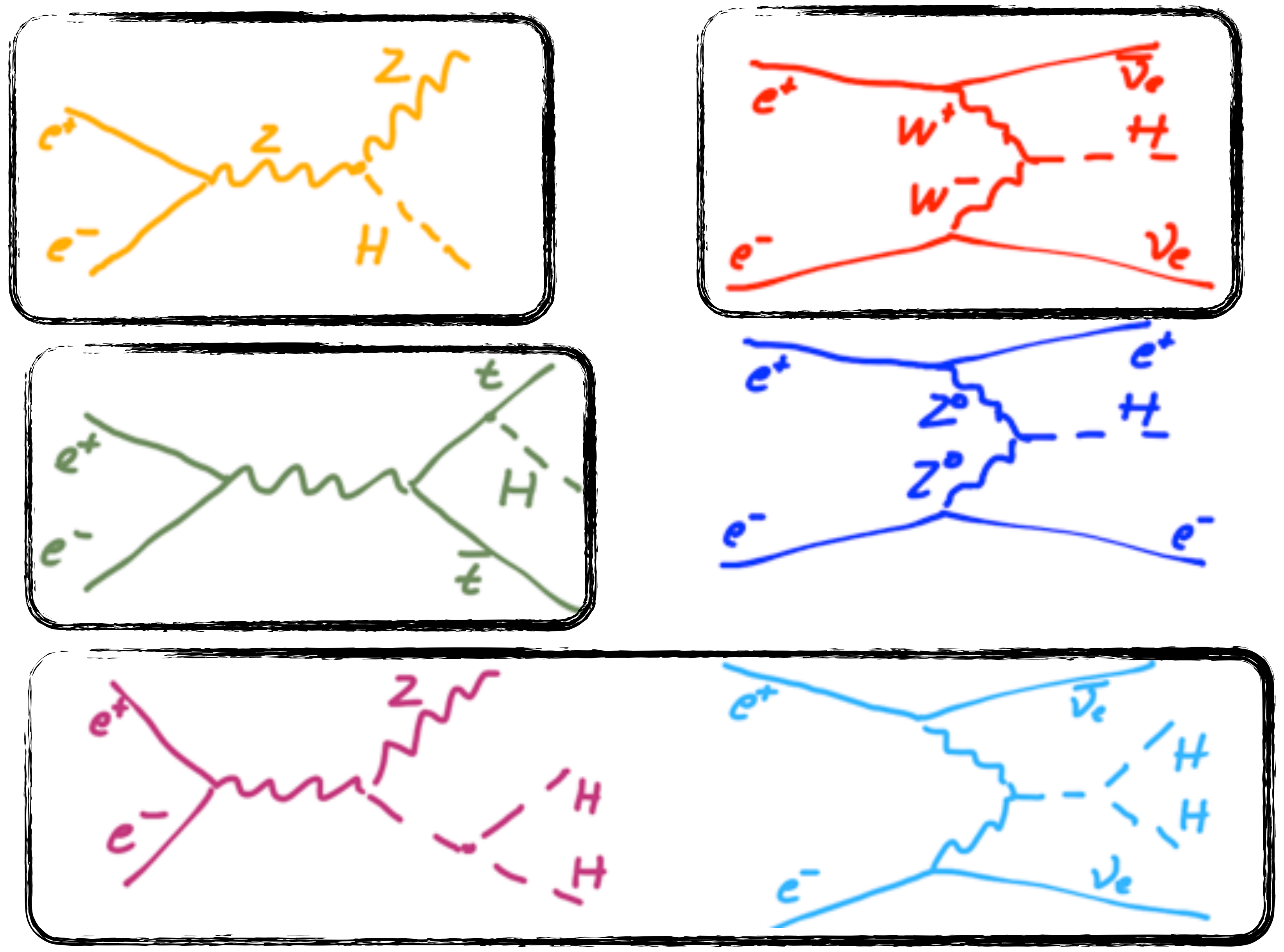

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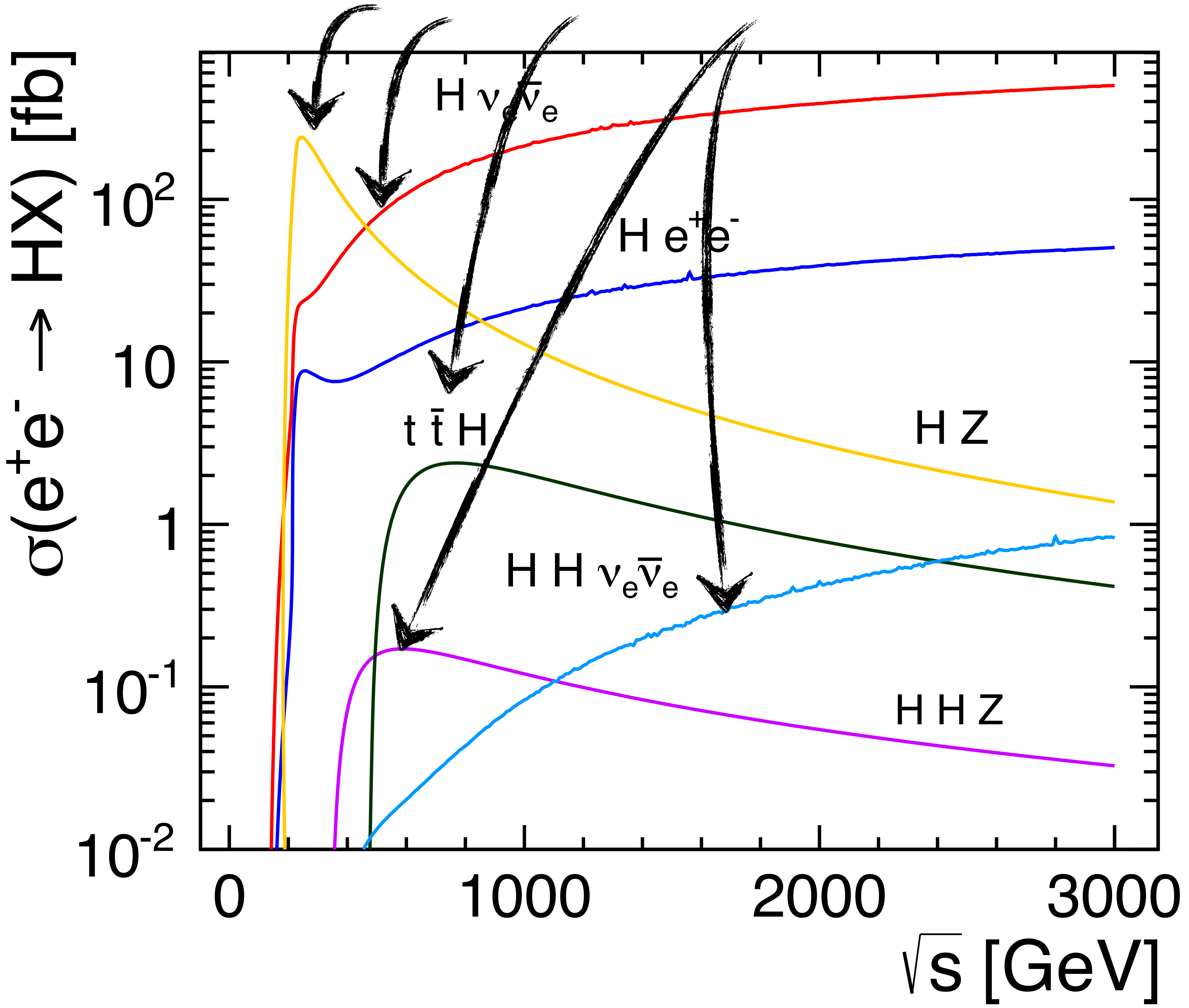

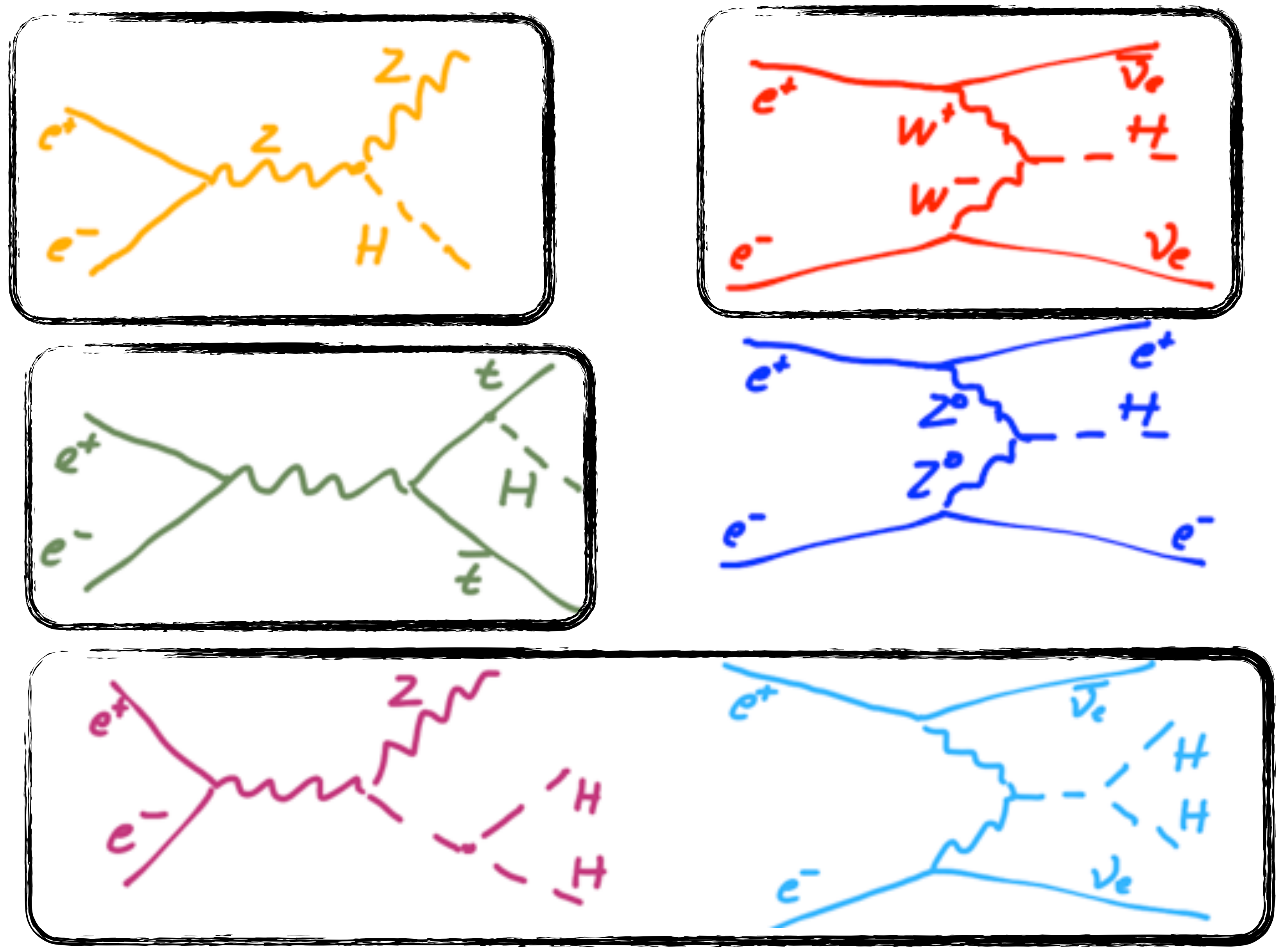

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500 GeV; 1+ TeV:
Higgs self-coupling

- 240 - 250 GeV: the minimum energy for a Higgs factory
- ~ 350 GeV: Additional production mode, also still access to ZH
- Higher energies: More processes
- 125 GeV, and extreme luminosity: A possibility to measure electron Yukawa coupling

Model Independence: The Pillar of Higgs Physics in e+e-

The ZH Higgsstrahlung process

- What model independence means: Measure the coupling of the Higgs Bosons to elementary particles free from model assumptions (e.g. how it decays)
  - Requires: The “tagging” of Higgs production without observing the particle directly
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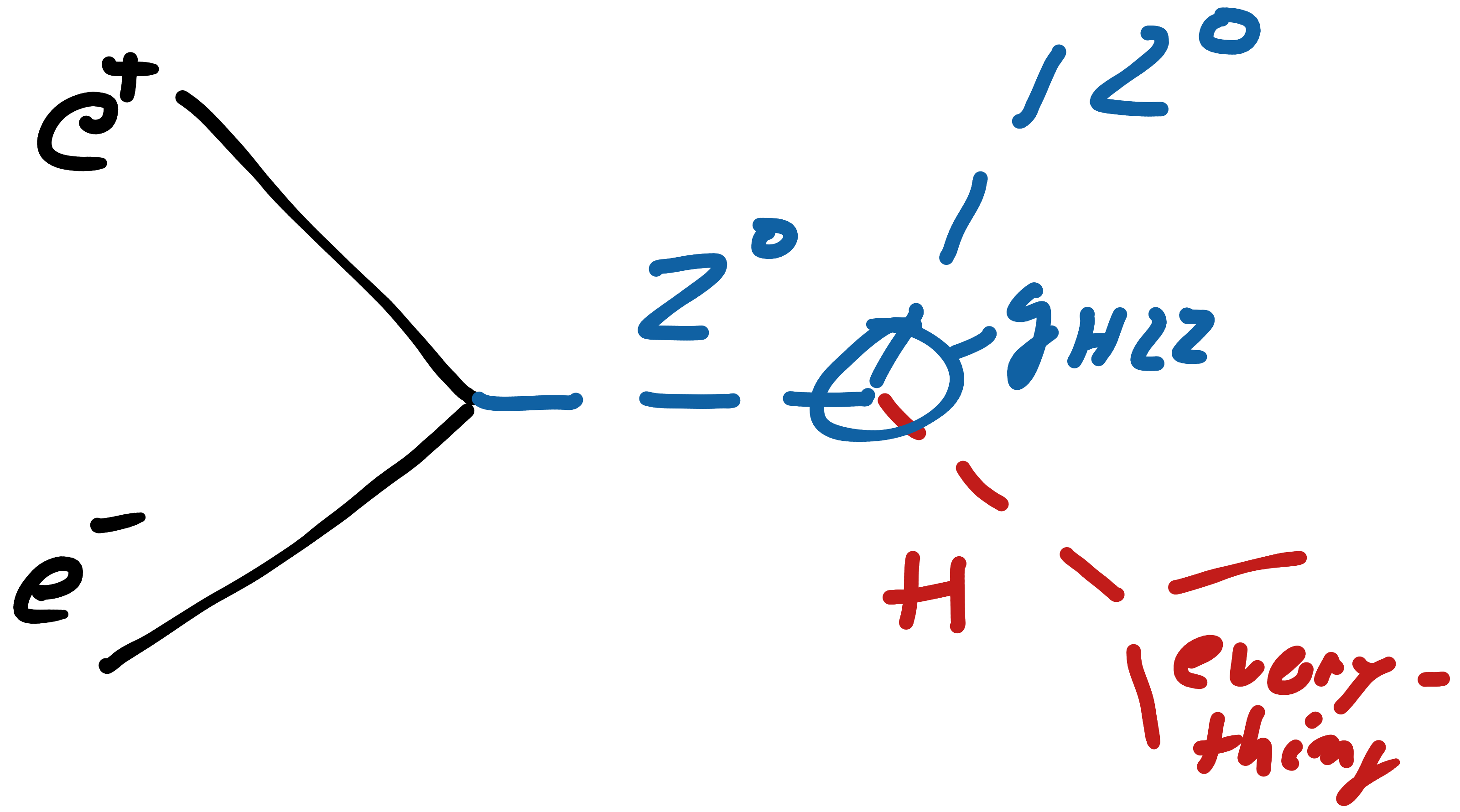

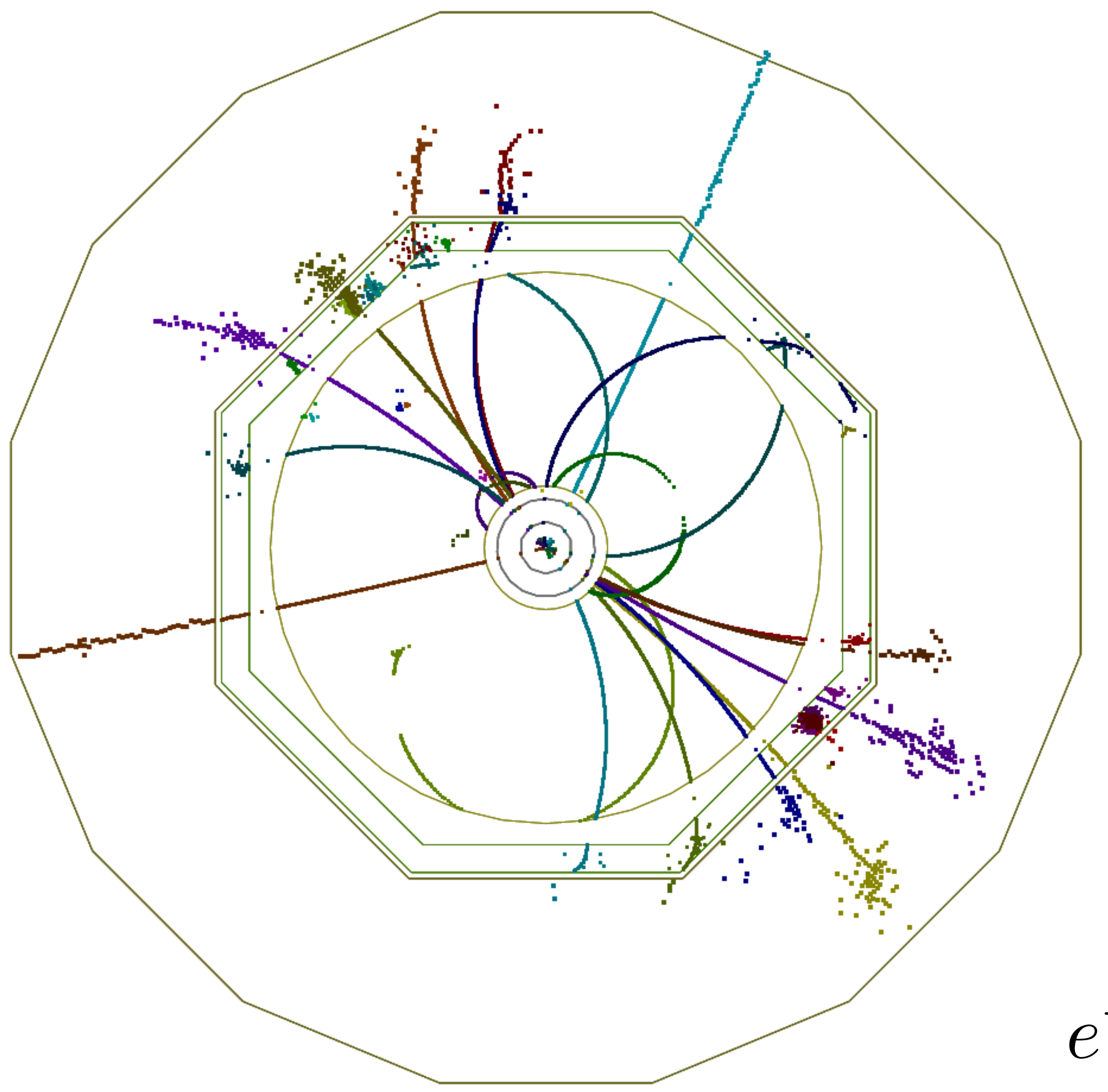

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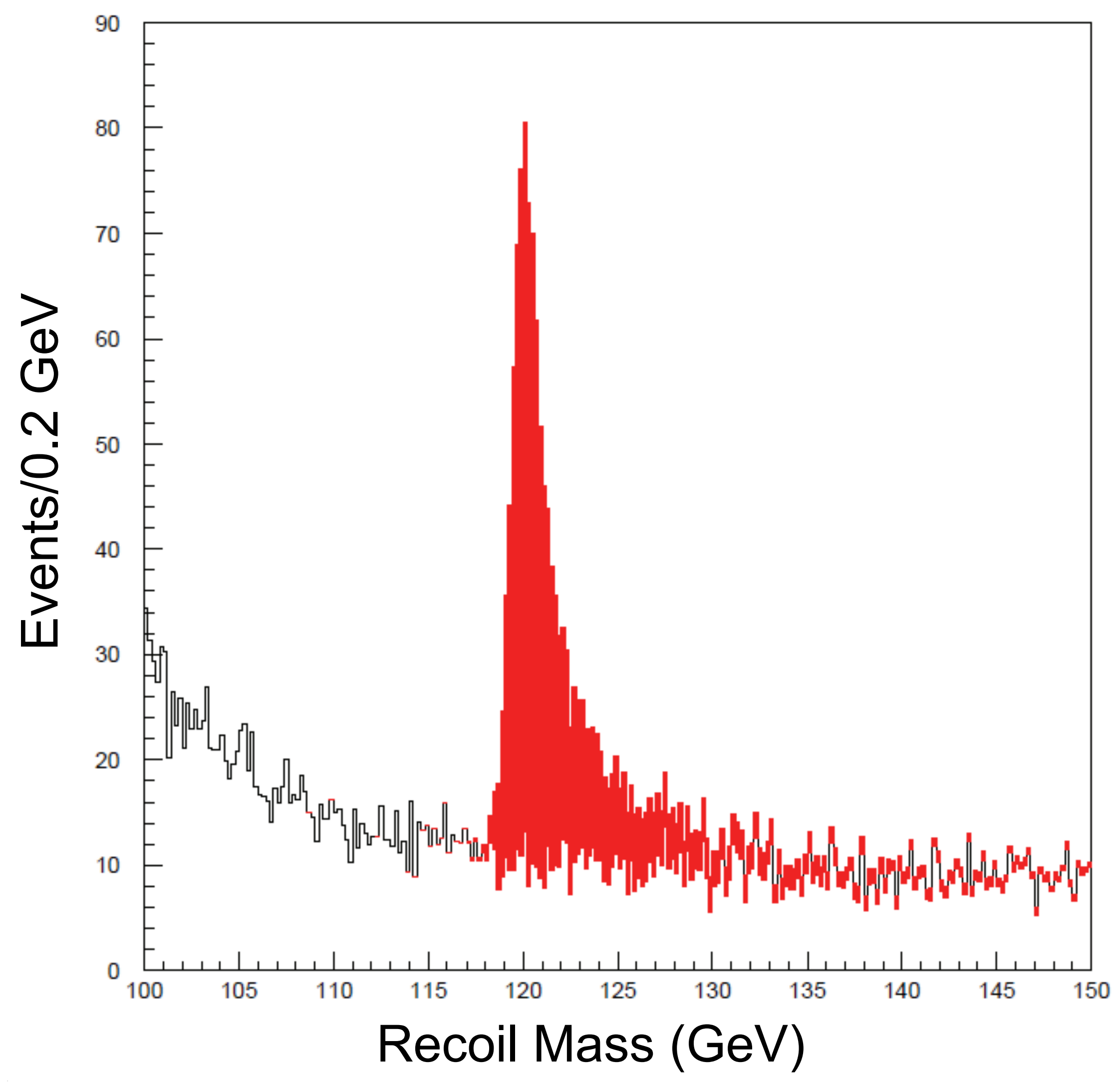
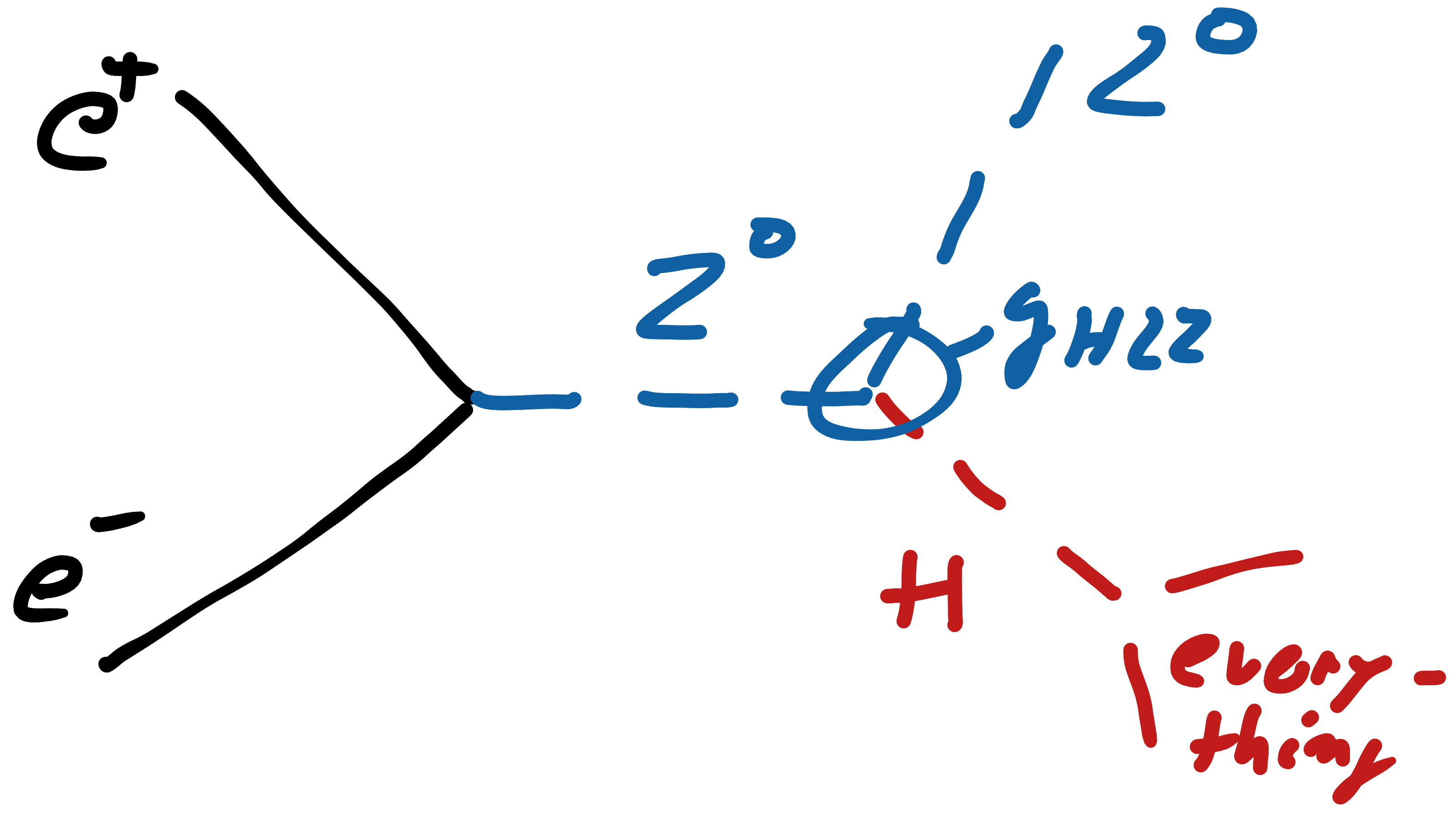
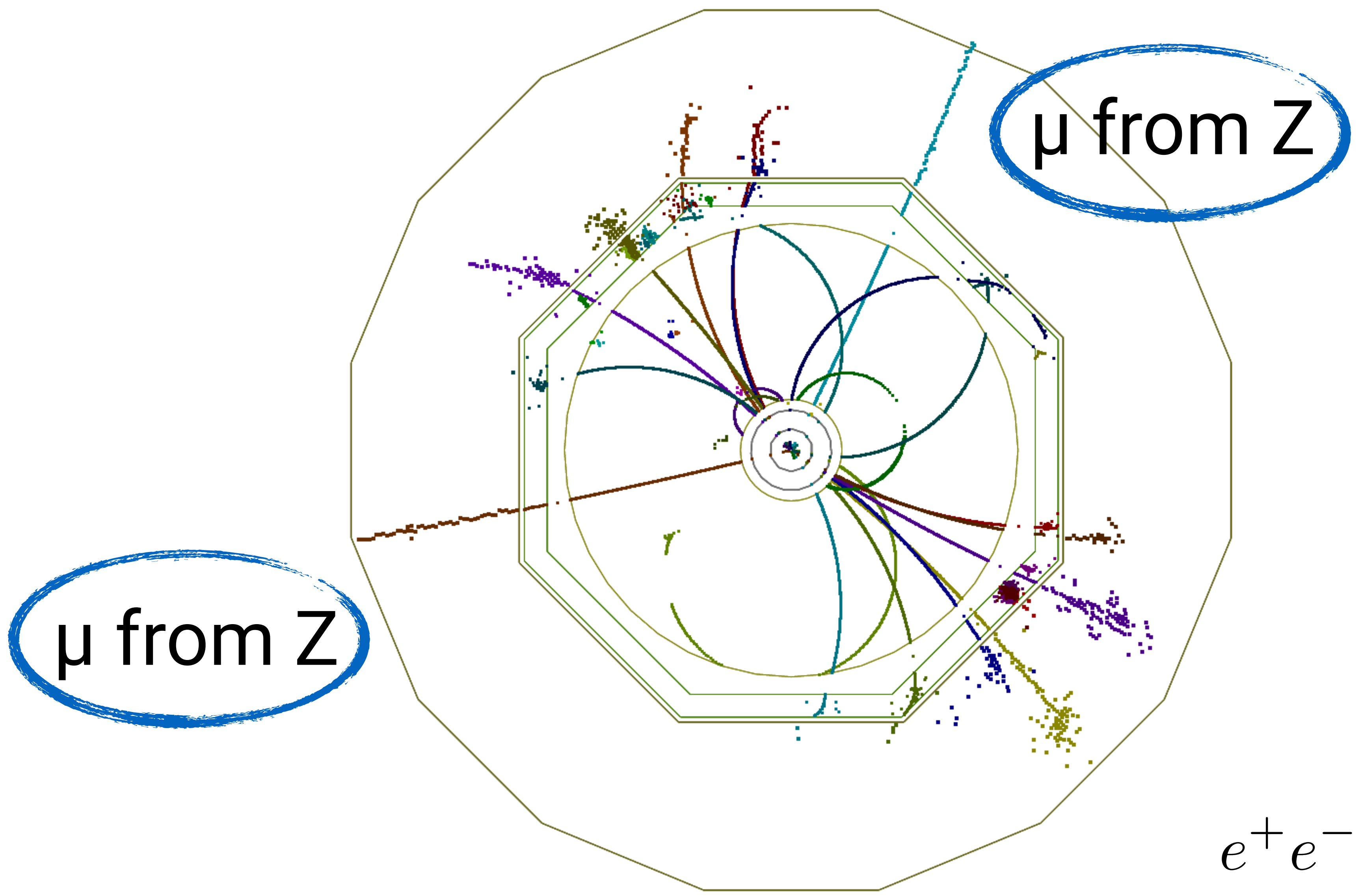
recoil mass: measure only the Z!

$$m_{rec}^2 = s + m_Z^2 - 2E_Z\sqrt{s}$$







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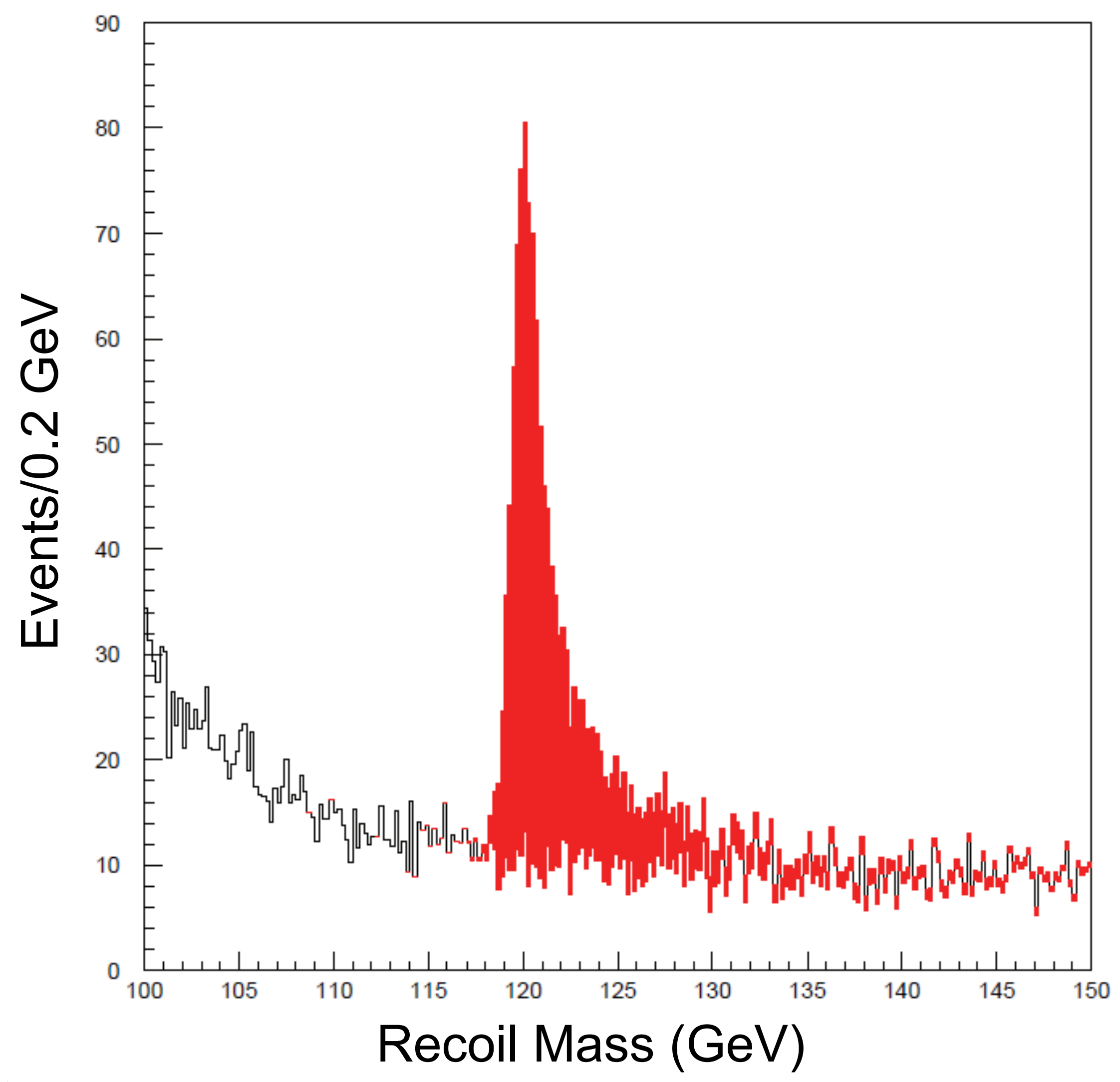

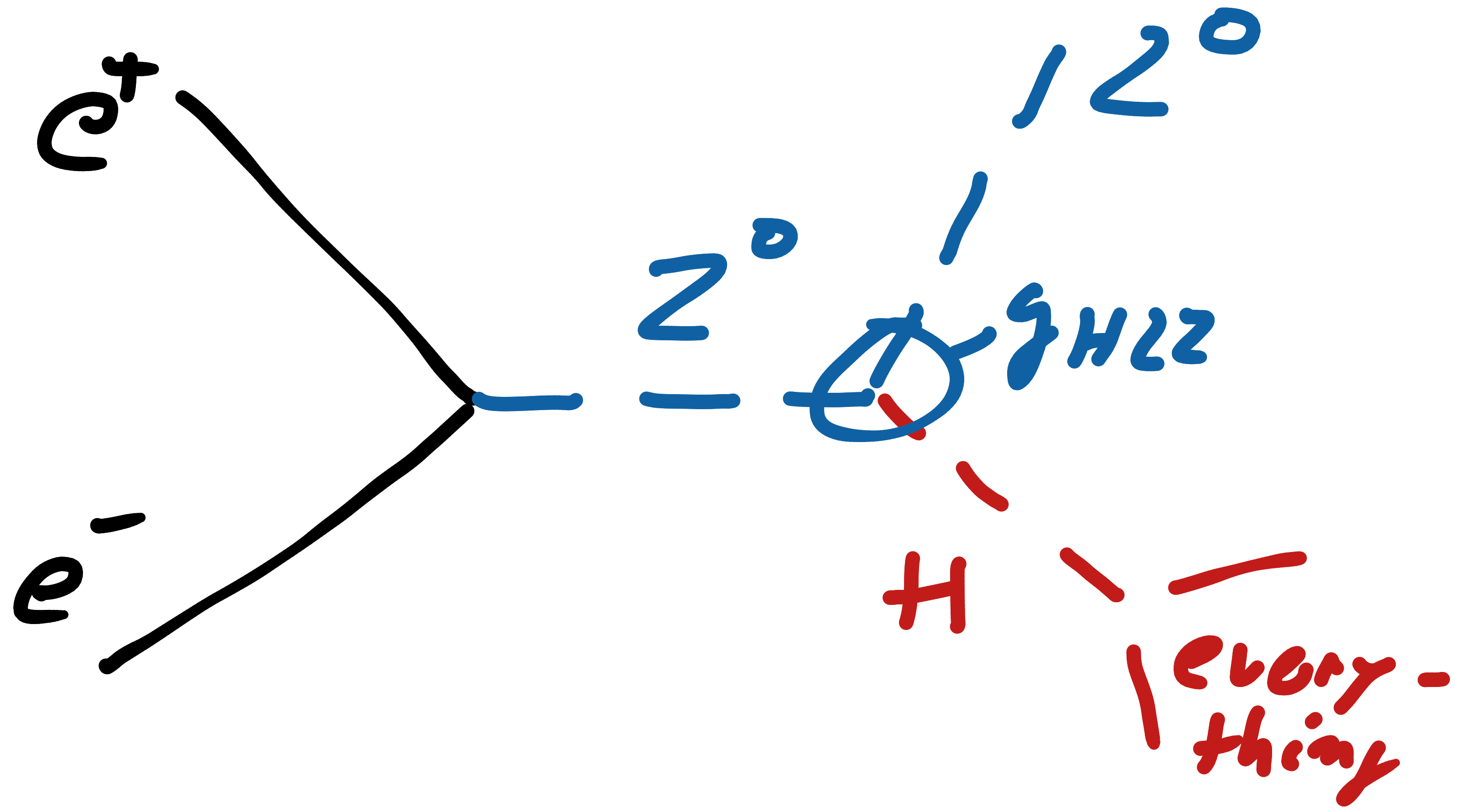

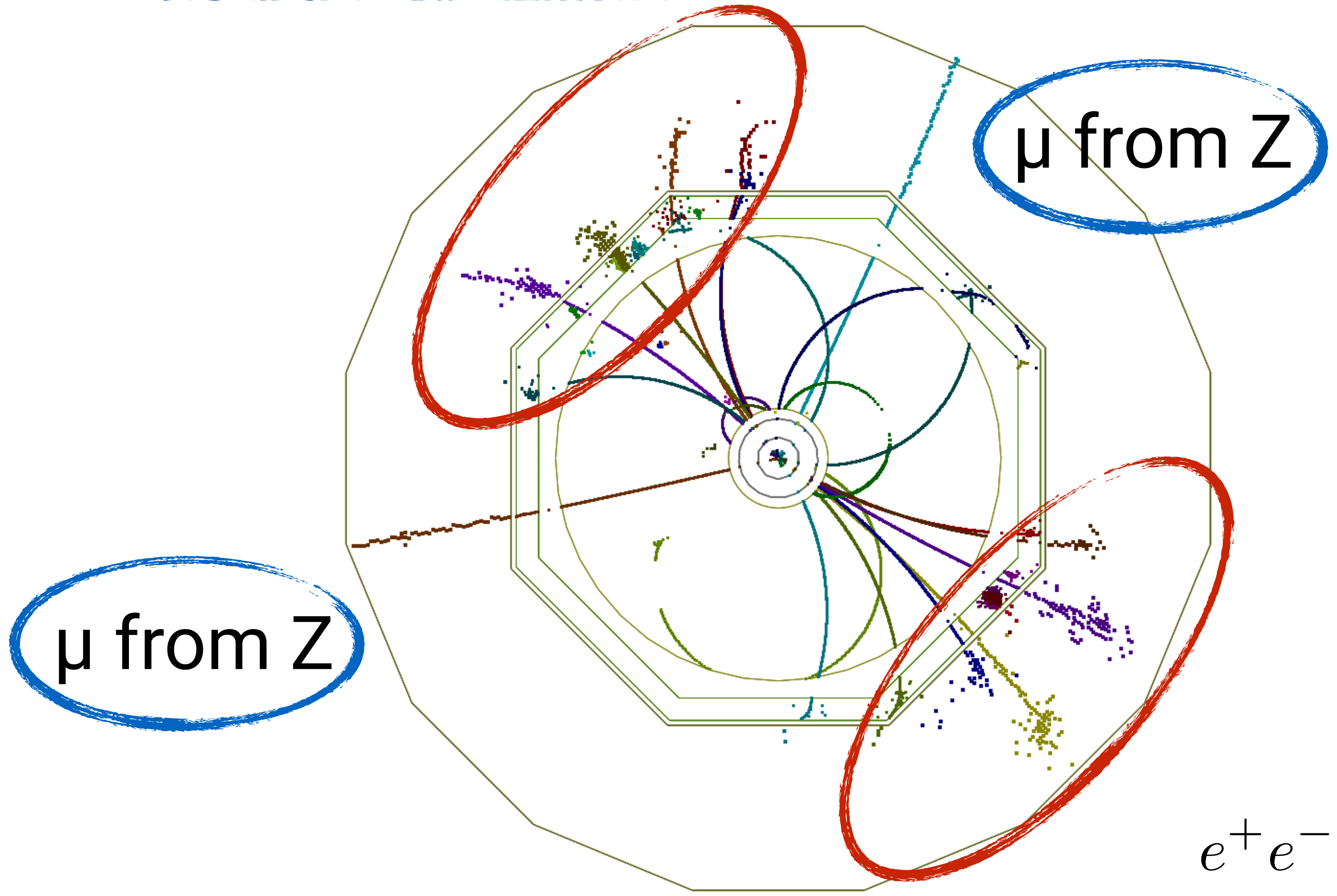

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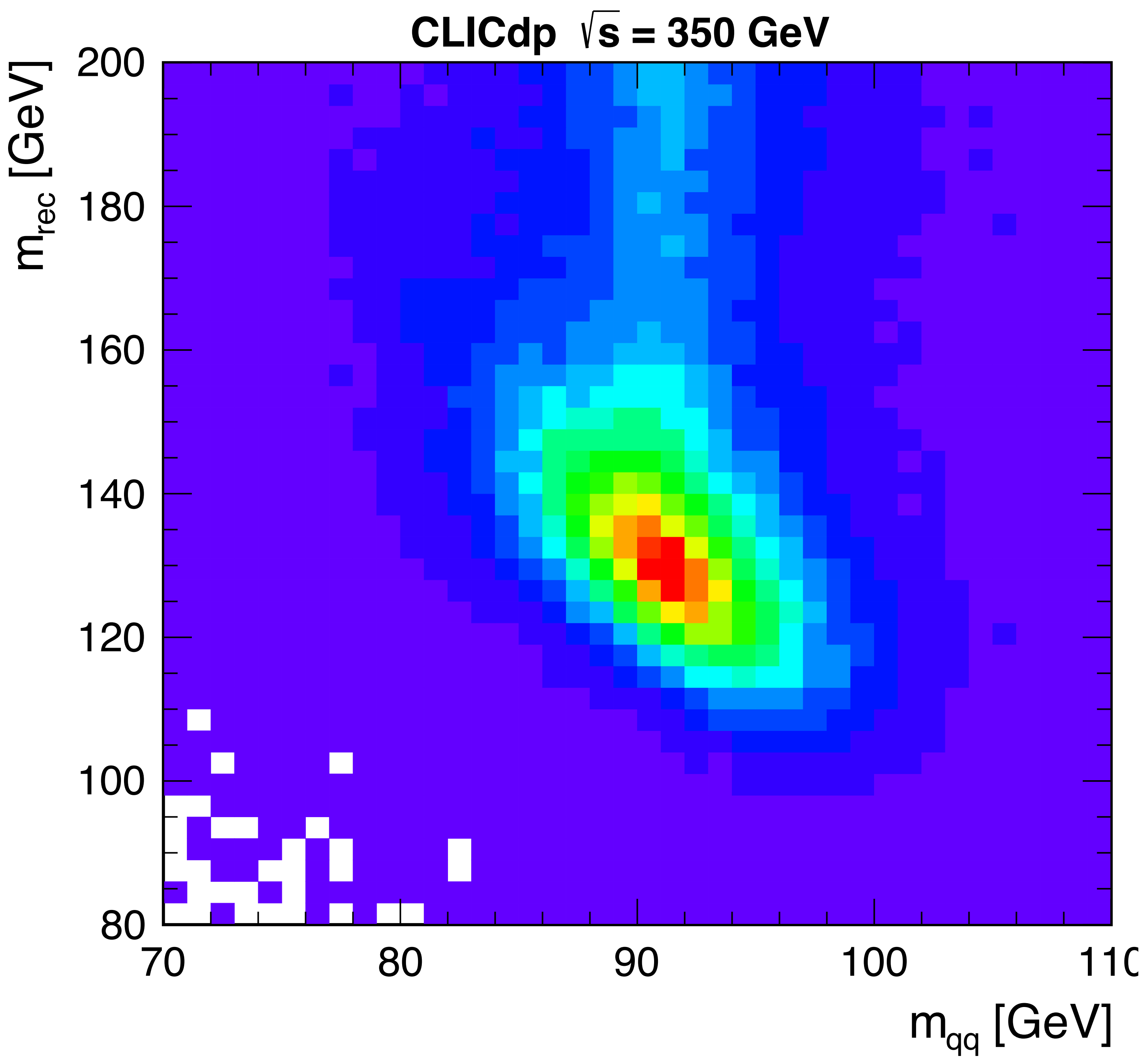
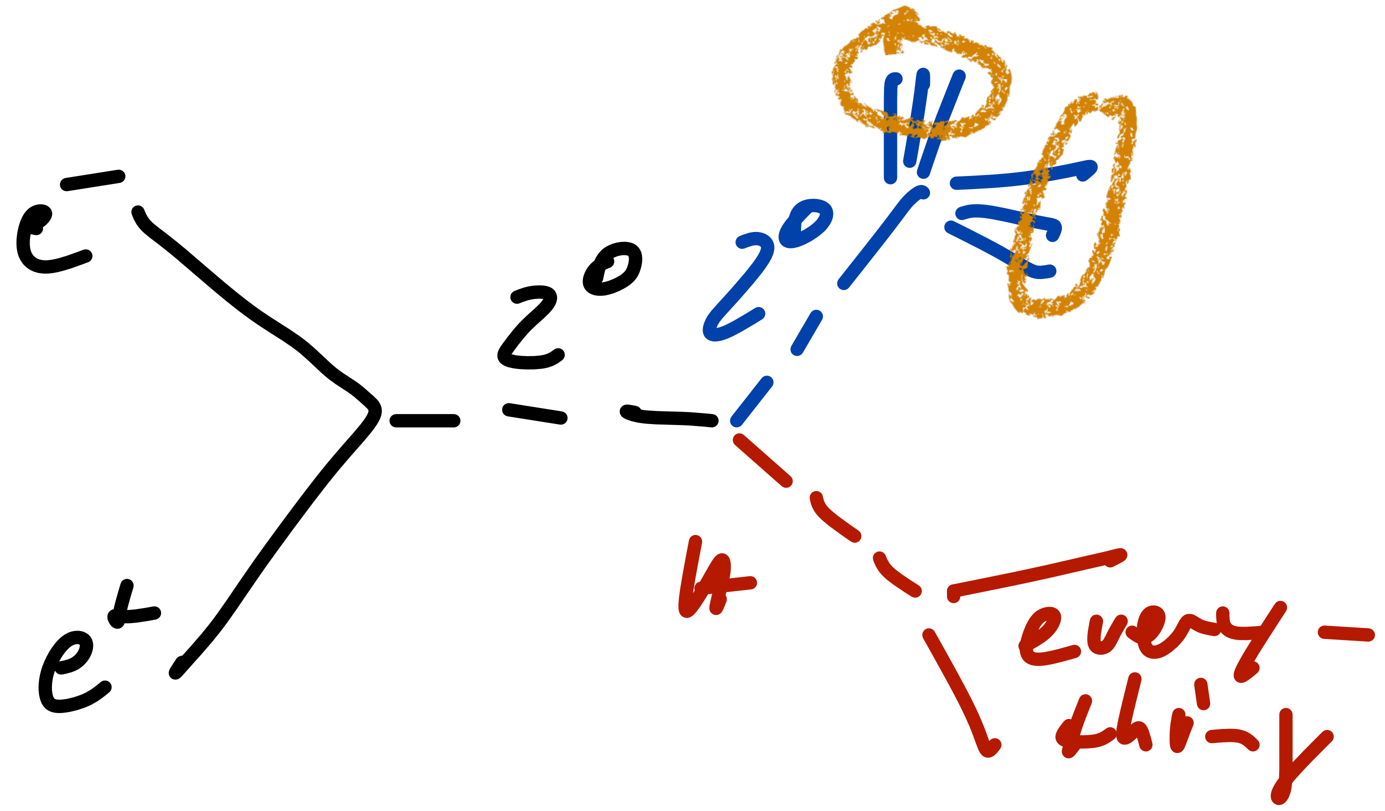
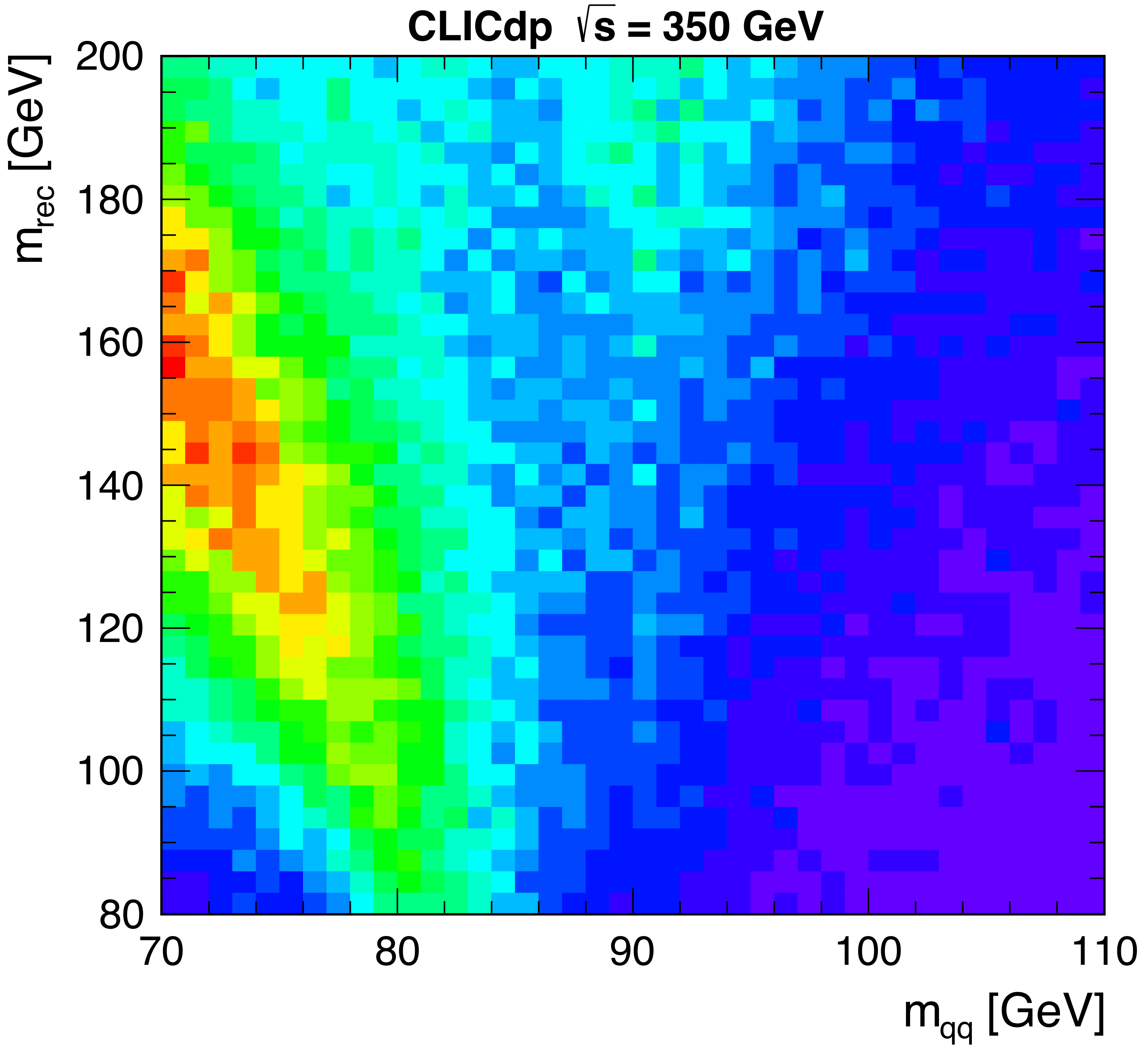
Hadronic Recoils & Invisible Decays

Fully exploiting Higgsstrahlung



- Significantly extending the HZ sample: Using hadronic Higgs decays - adds x4 in statistical sensitivity
  - requires careful analysis setup to ensure model independence





example from CLIC

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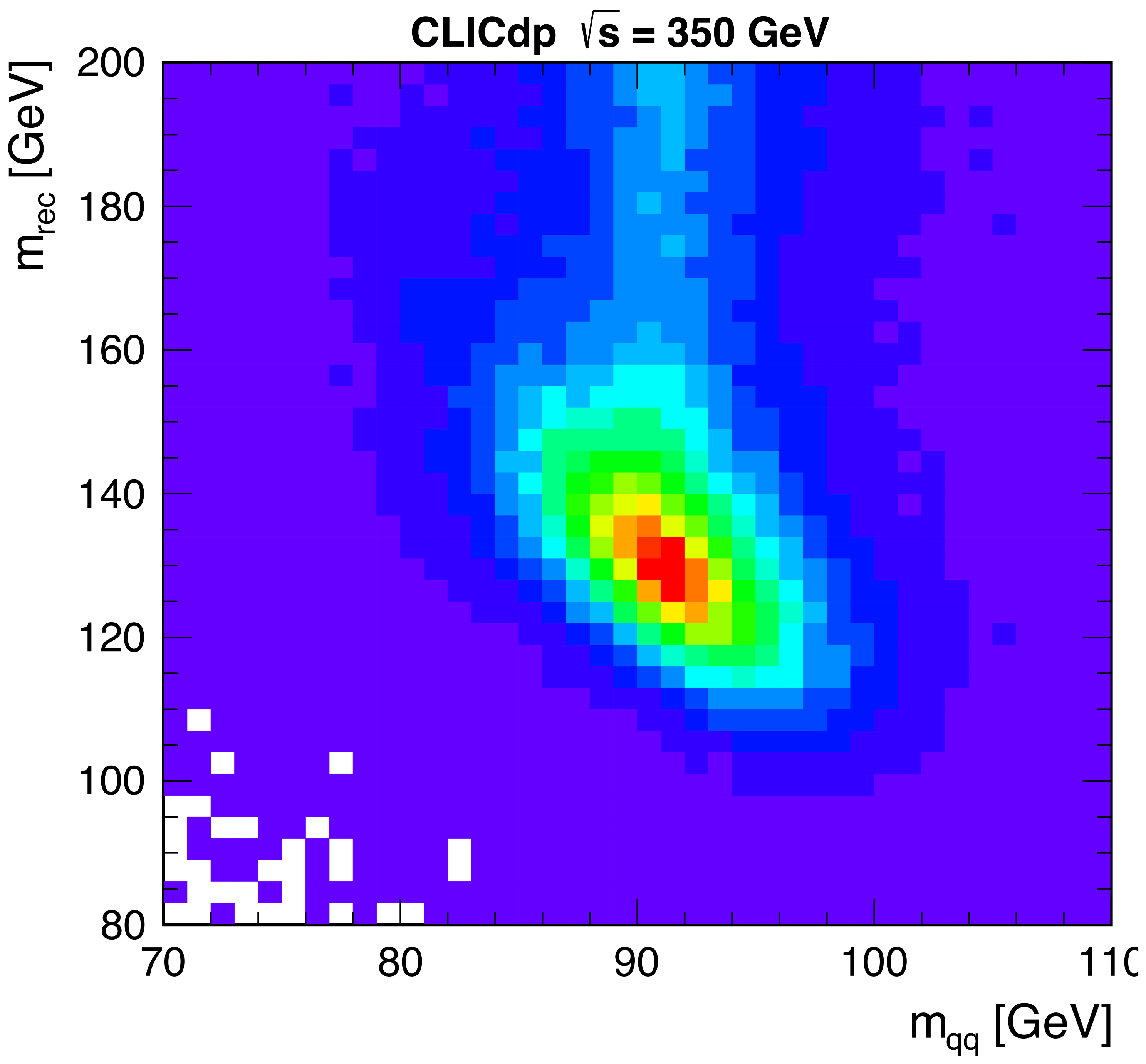

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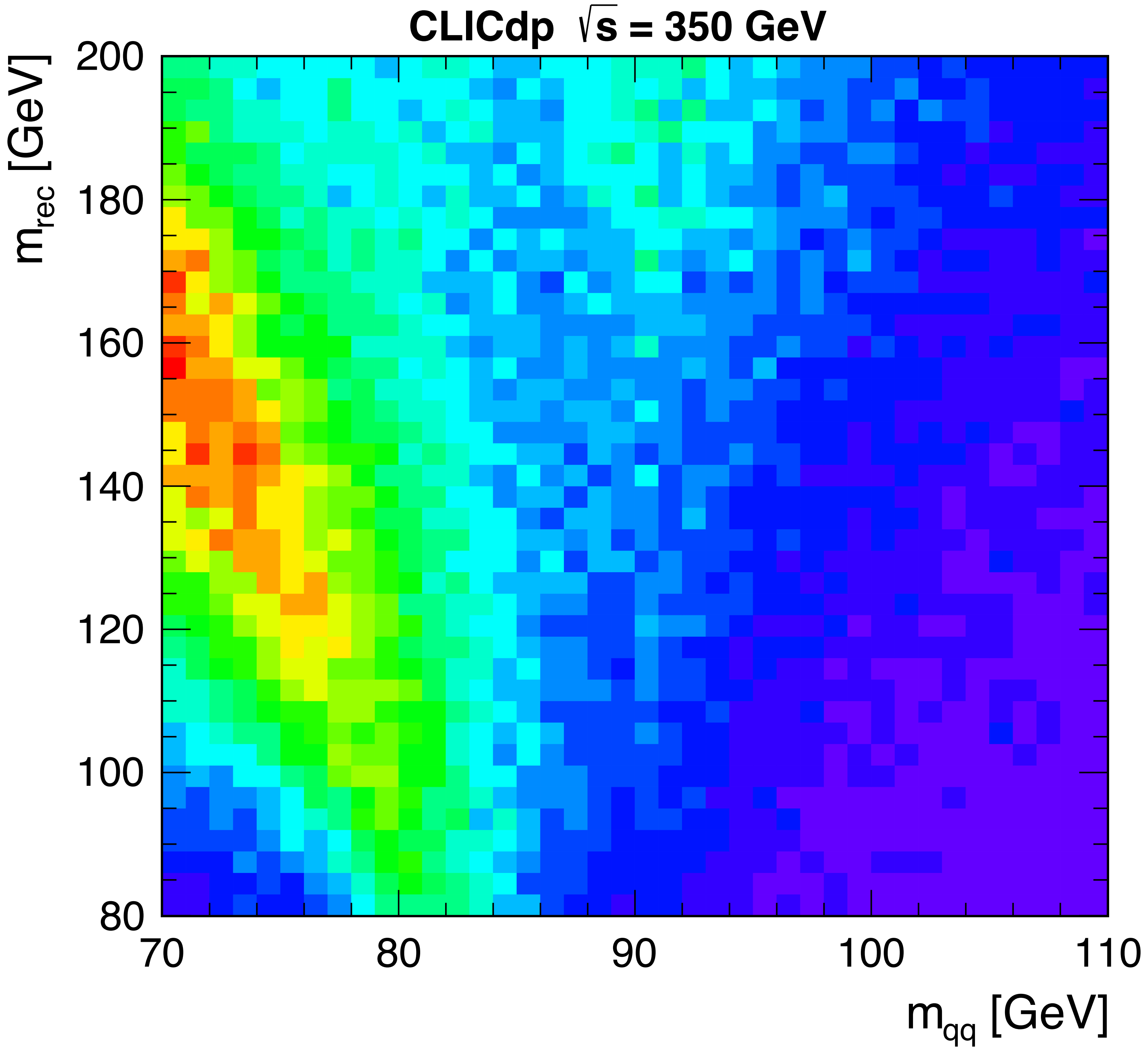
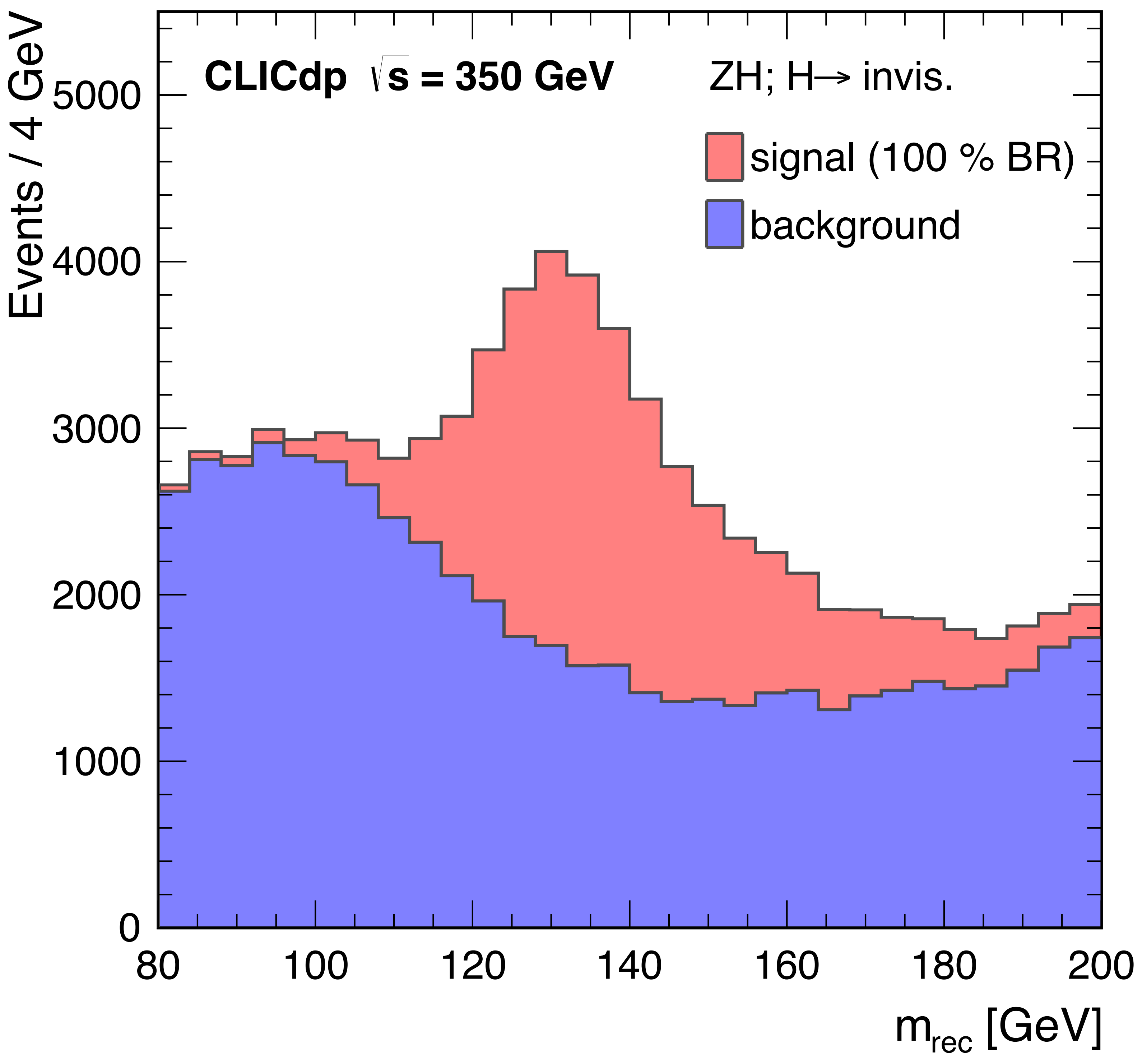
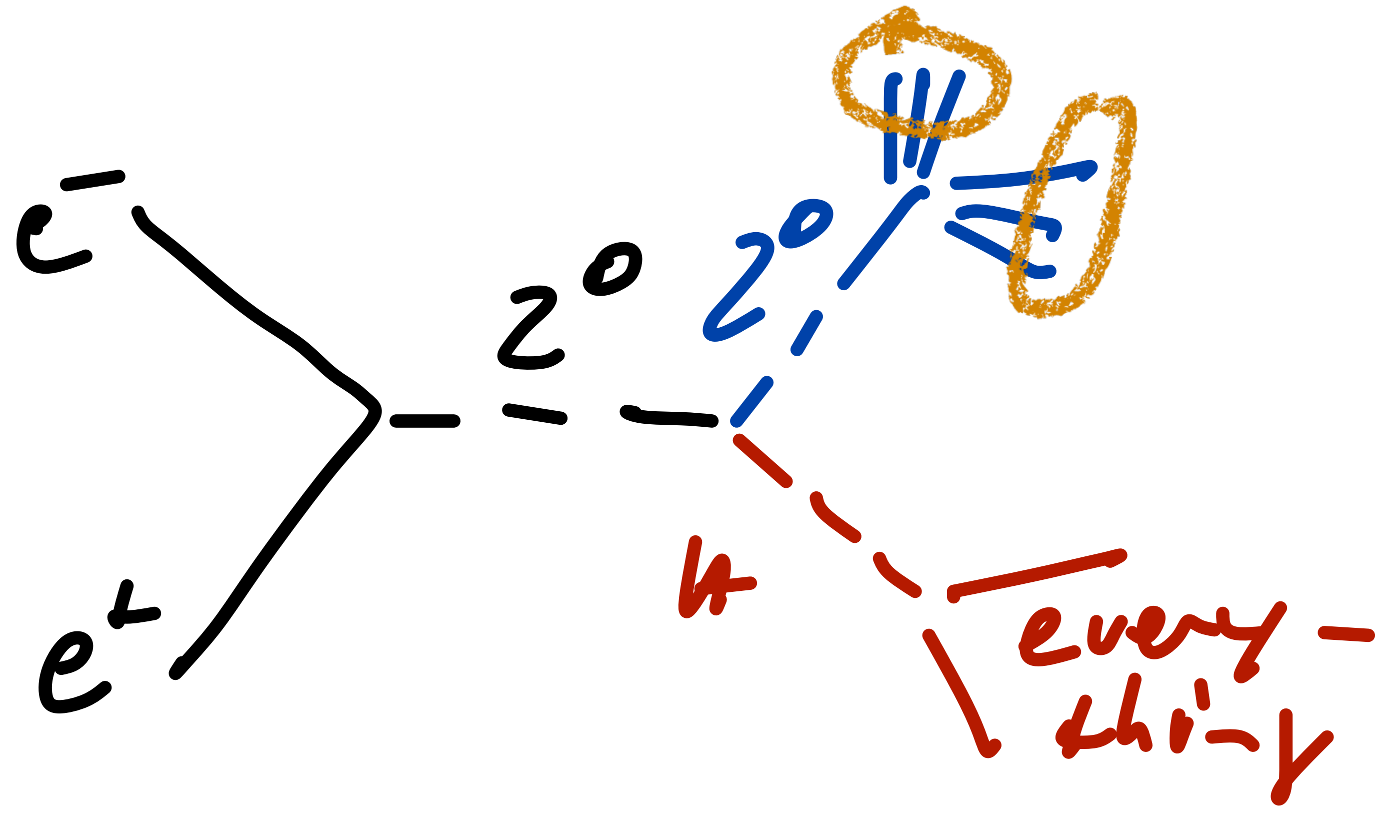






- HZ events can be used to constrain invisible Higgs decays: Limits on the few per mille level

example from CLIC

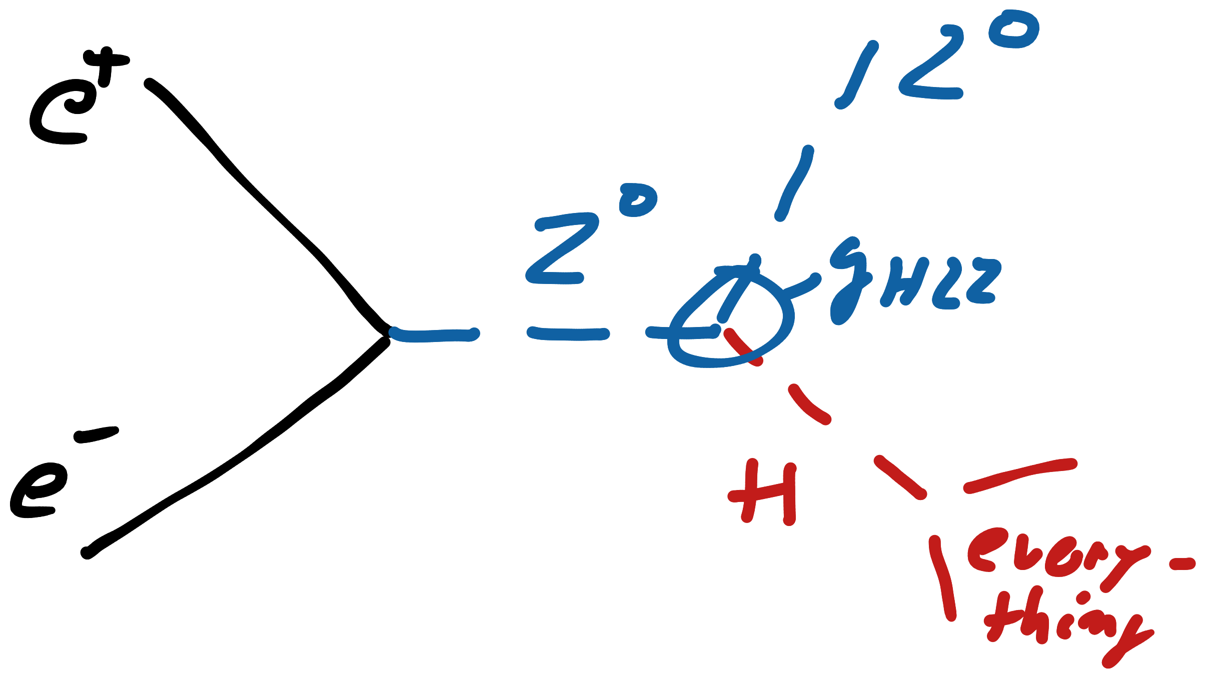
Precision Measurements of Couplings

Exploring the Higgs Sector

- The main measurements to make:

  σ for Z recoil measurements

$$\sigma_{\mathrm{recoil}} \propto g^2_{\mathrm{HZZ}}$$



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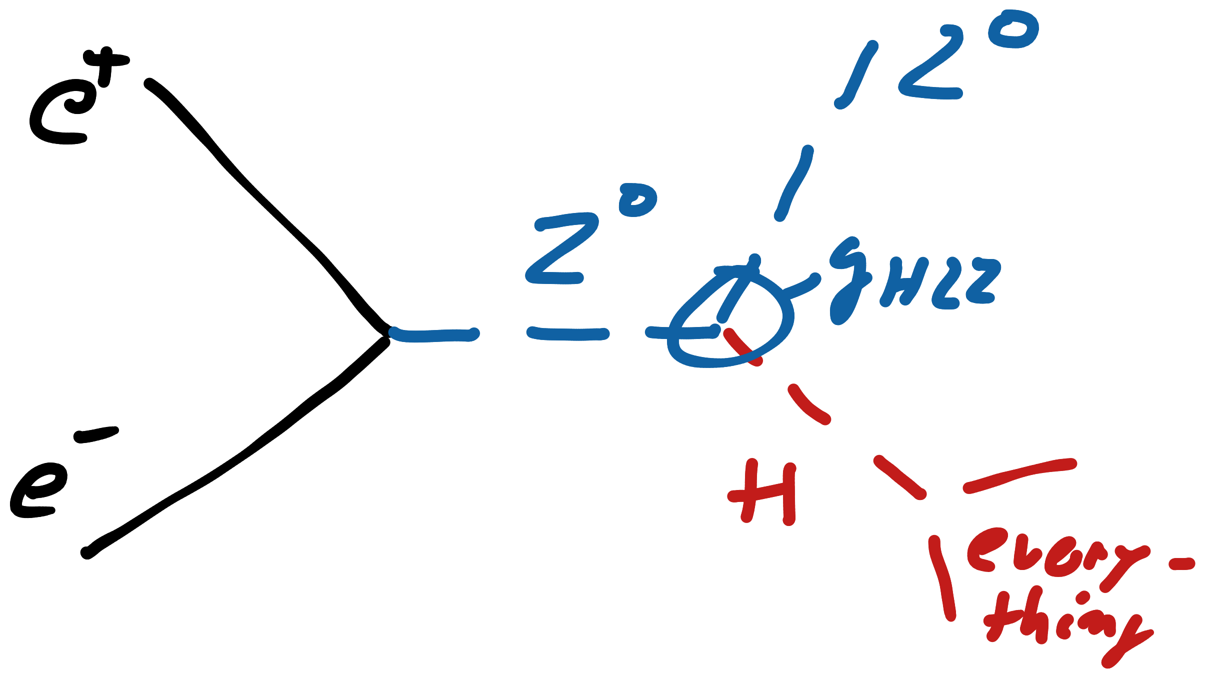

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  σ x BR for specific Higgs decays - here the mass of 125 GeV is giving us many possibilites

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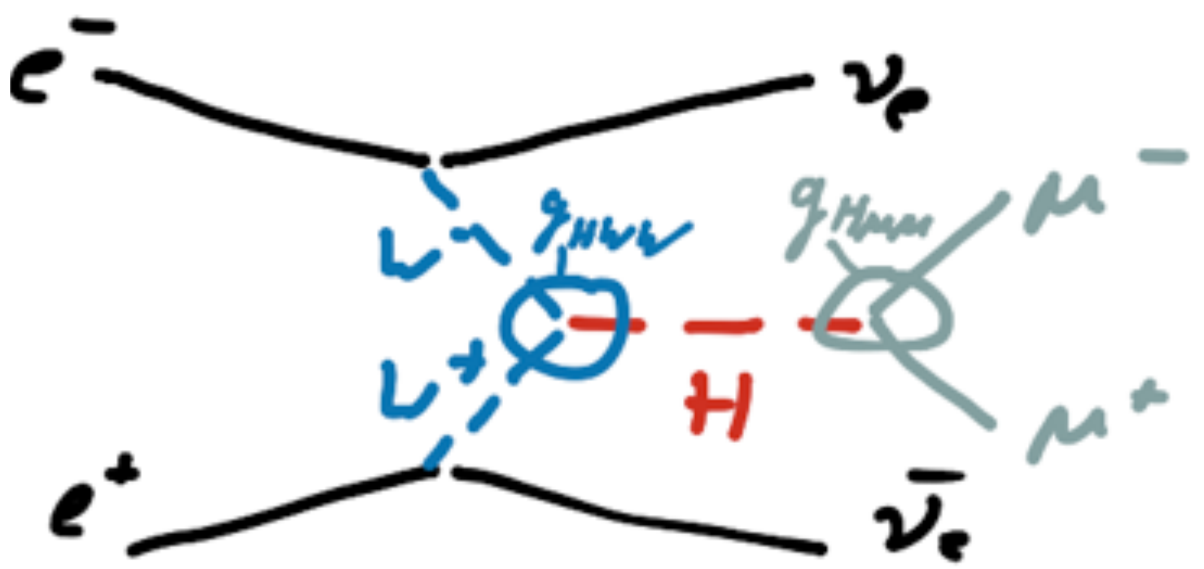

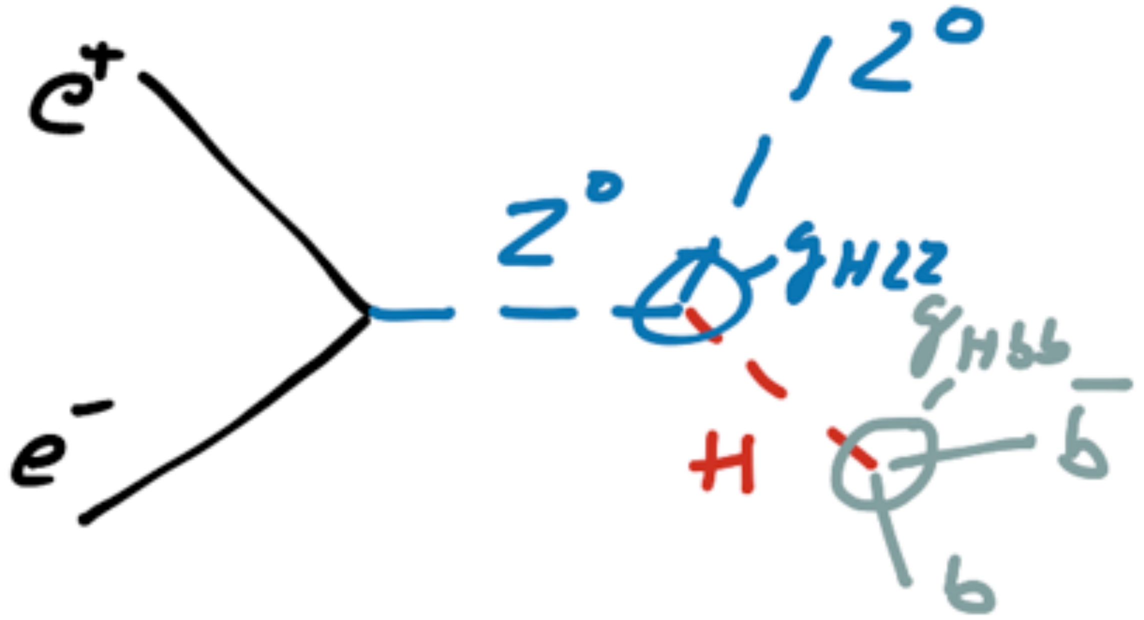

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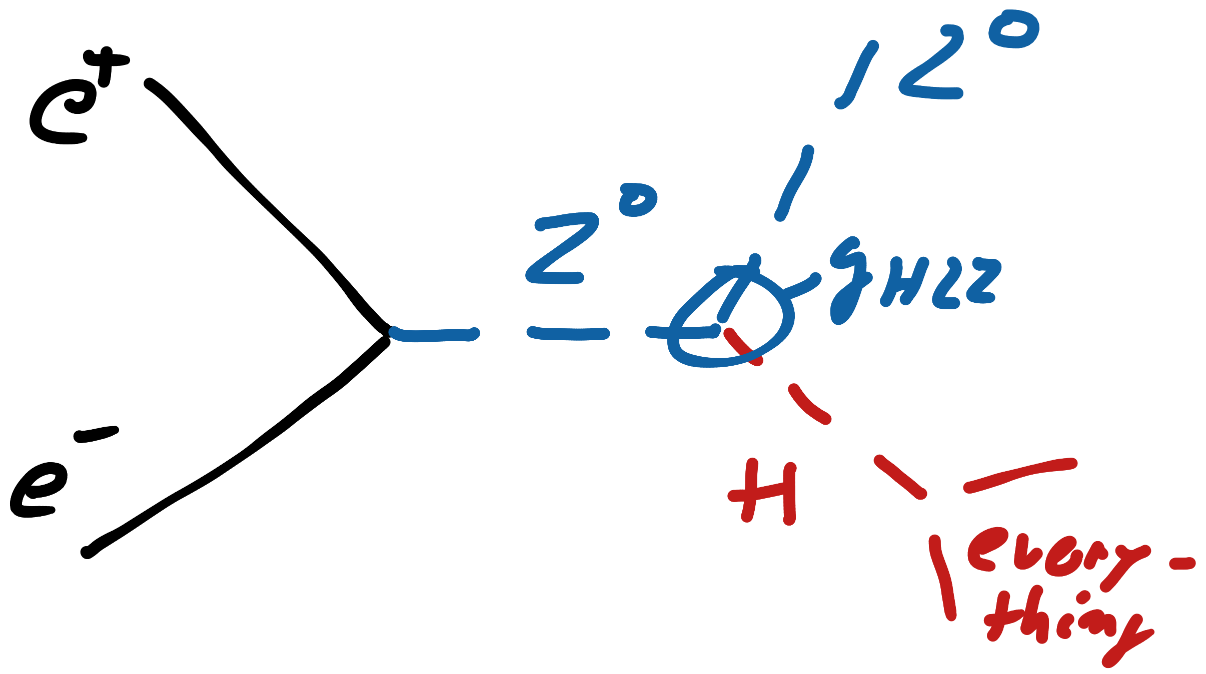

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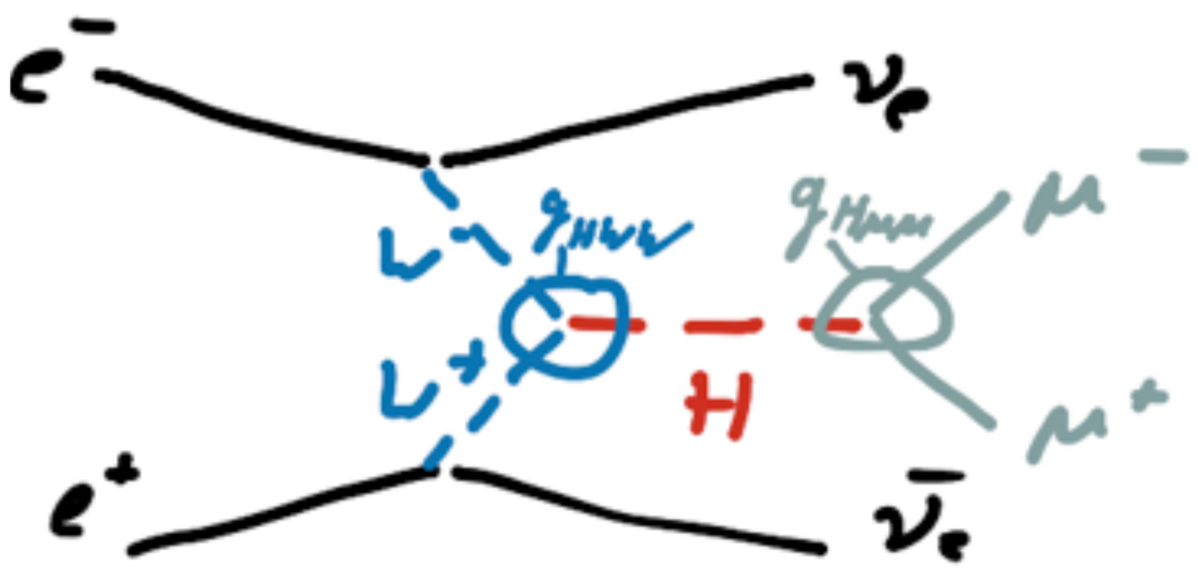
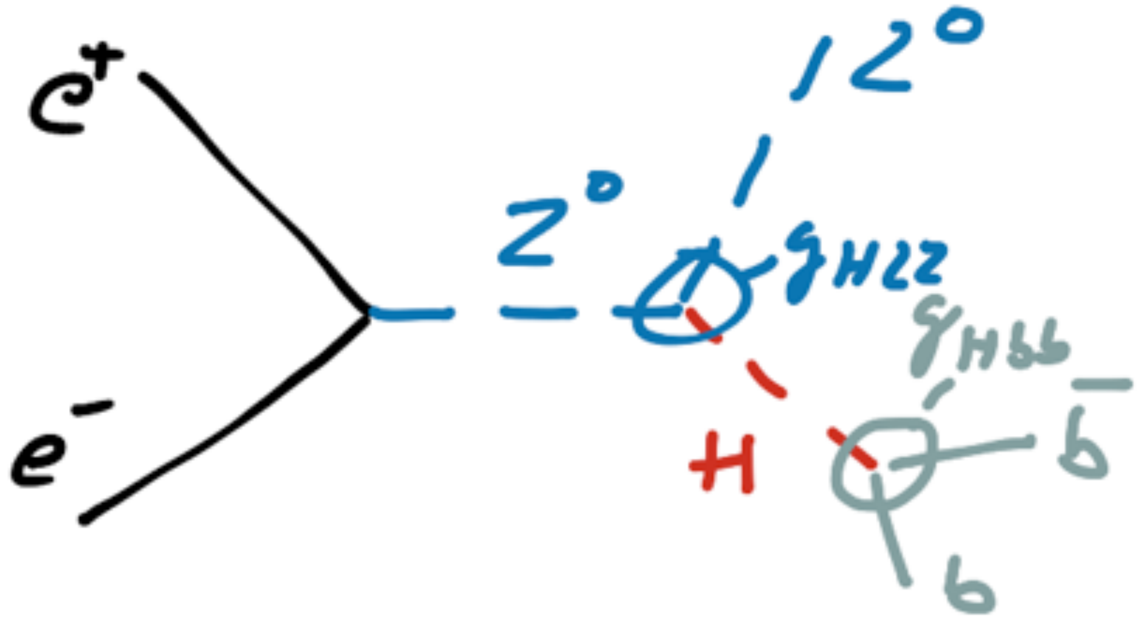




measure couplings to fermions and bosons using production and decay

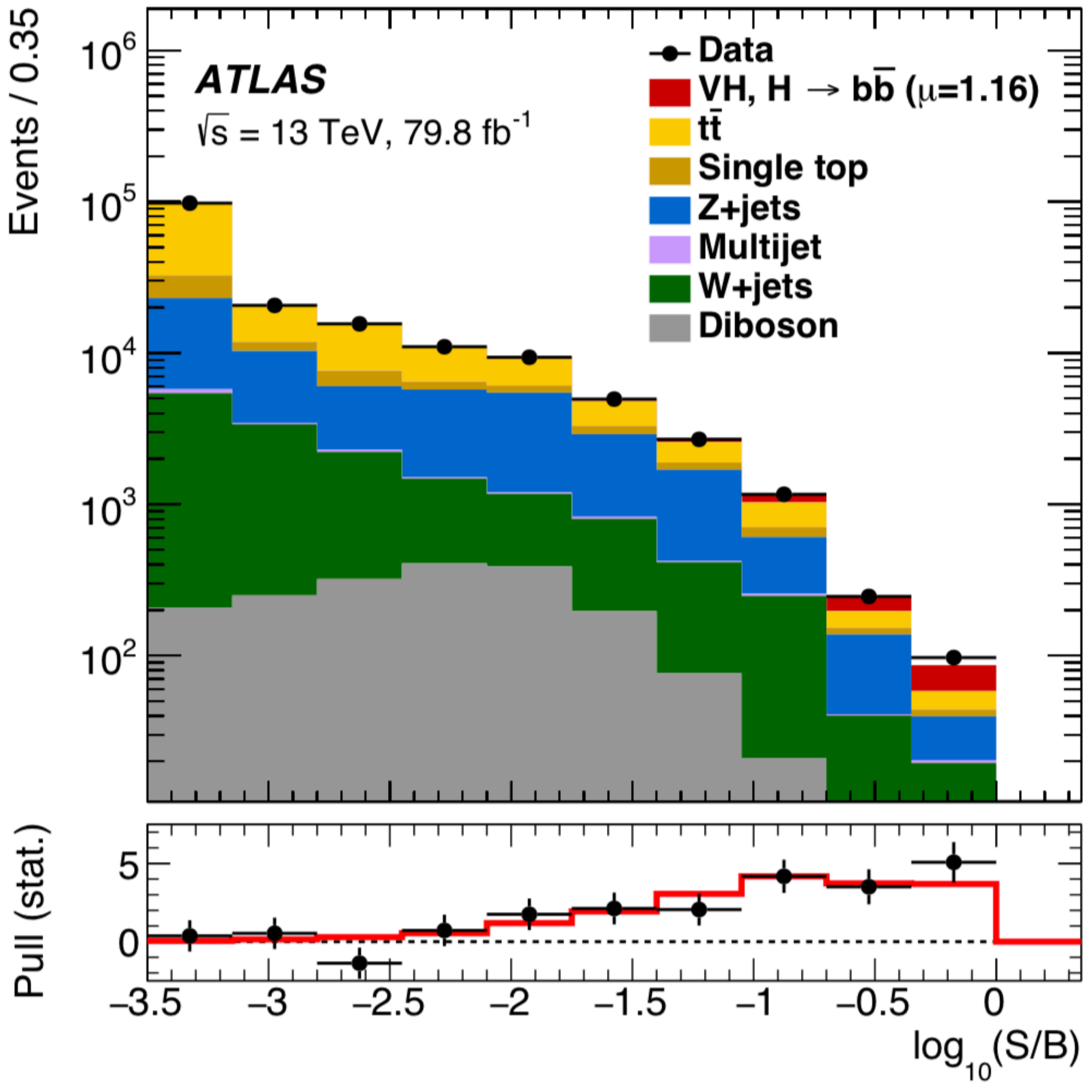
➯ can be made model-independent in combination with the measurement of the HZ coupling in recoil

Unique Measurements at Lepton Colliders

Enabled by the clean environment

- H->bb: A difficult channel at LHC, a "simple" measurement in e+e-

at LHC



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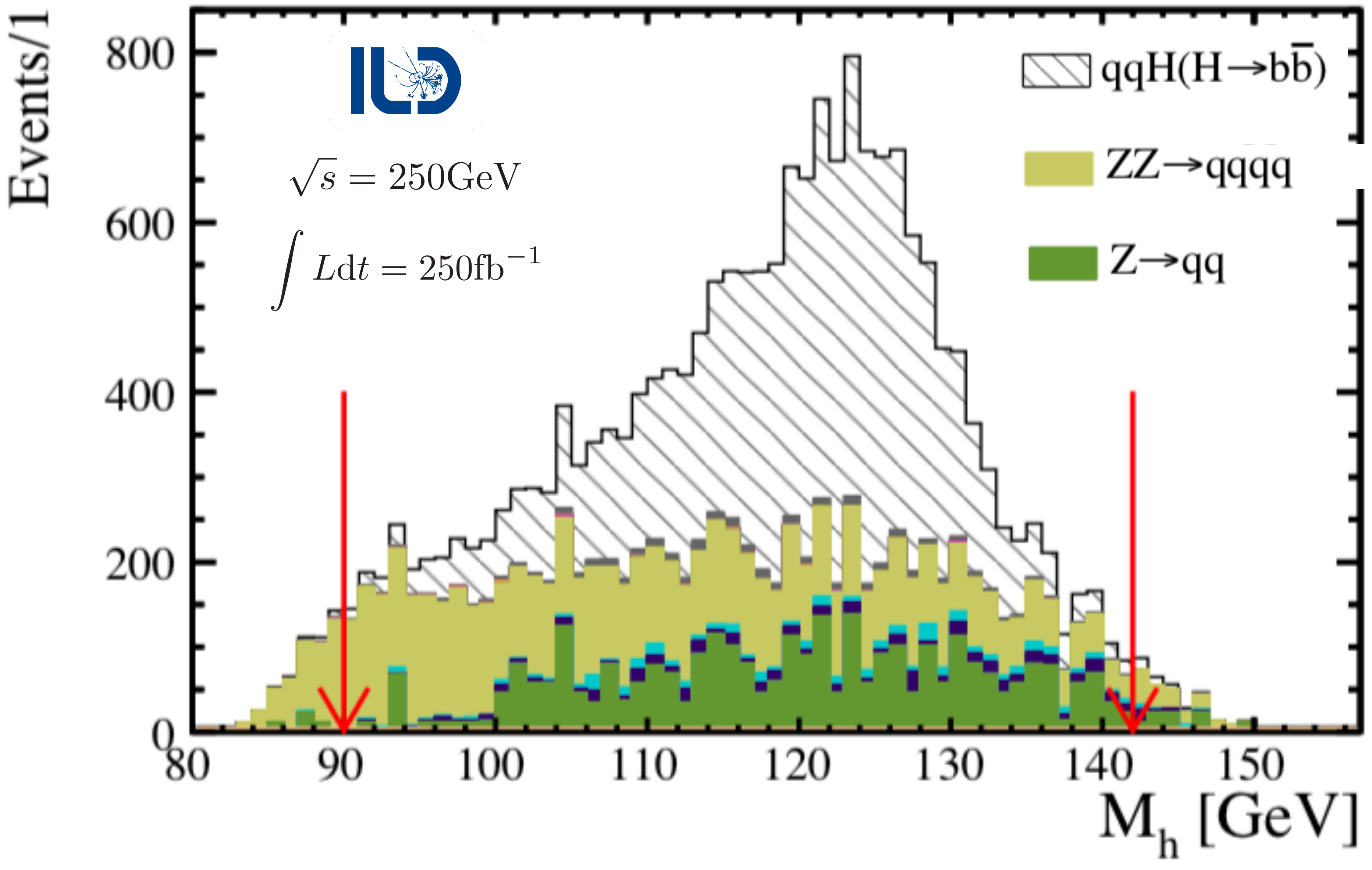

with 1.3 fb⁻¹ data ~ 2 days running

- Low backgrounds, and highly capable detectors enable observations of final states that are hard or impossible at LHC

	at LHC	at e+e-
# of Higgs produced:	~4,000,000	~400
significance:	5.4σ	5.2σ

J. Tiang, LCWS 2018

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  Measurement of H->bb, cc, gg
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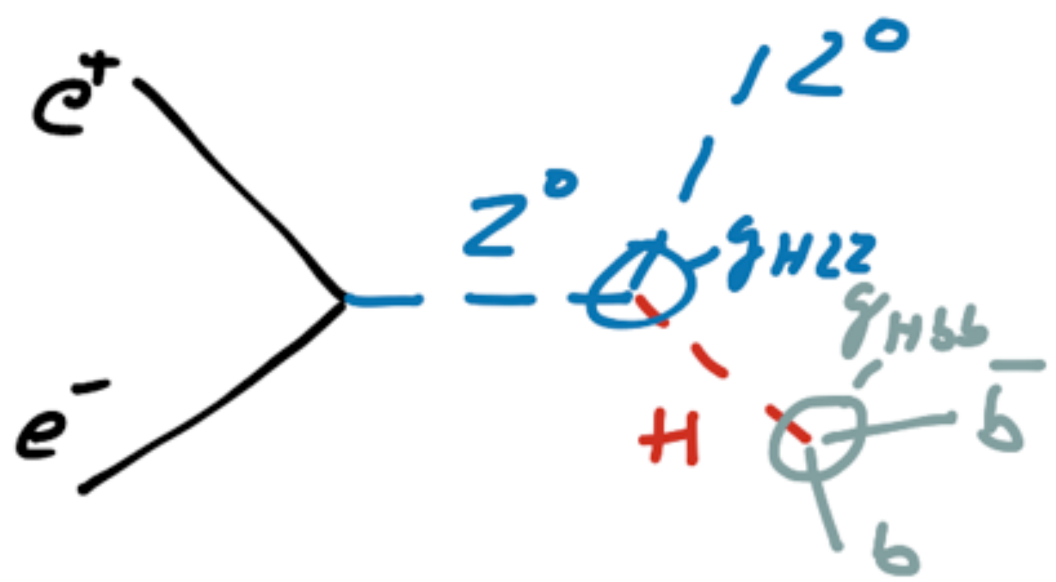

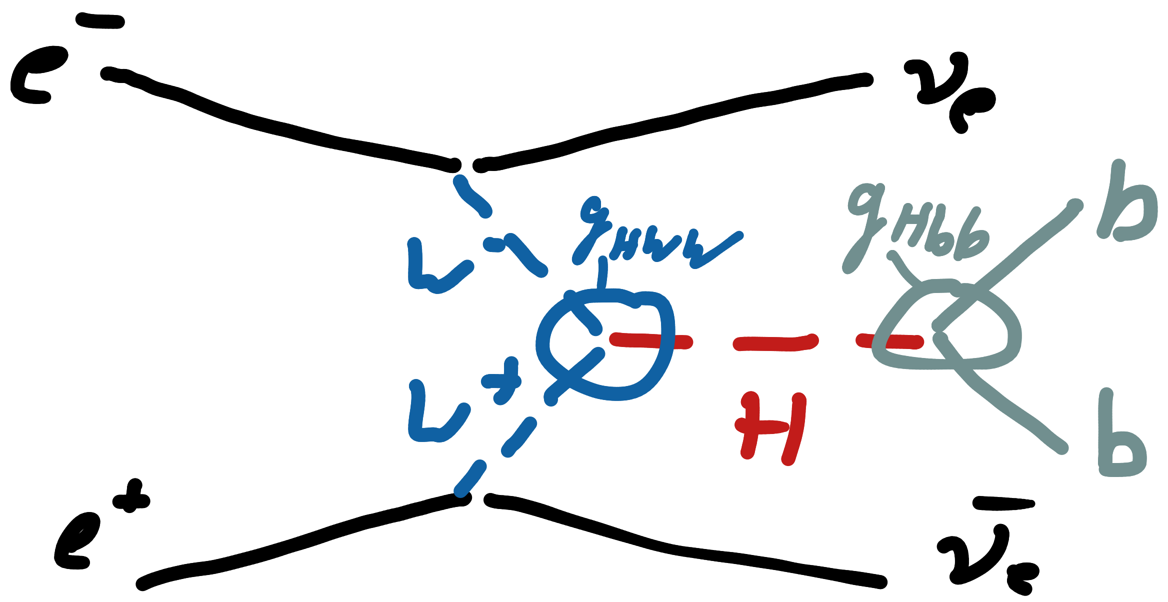

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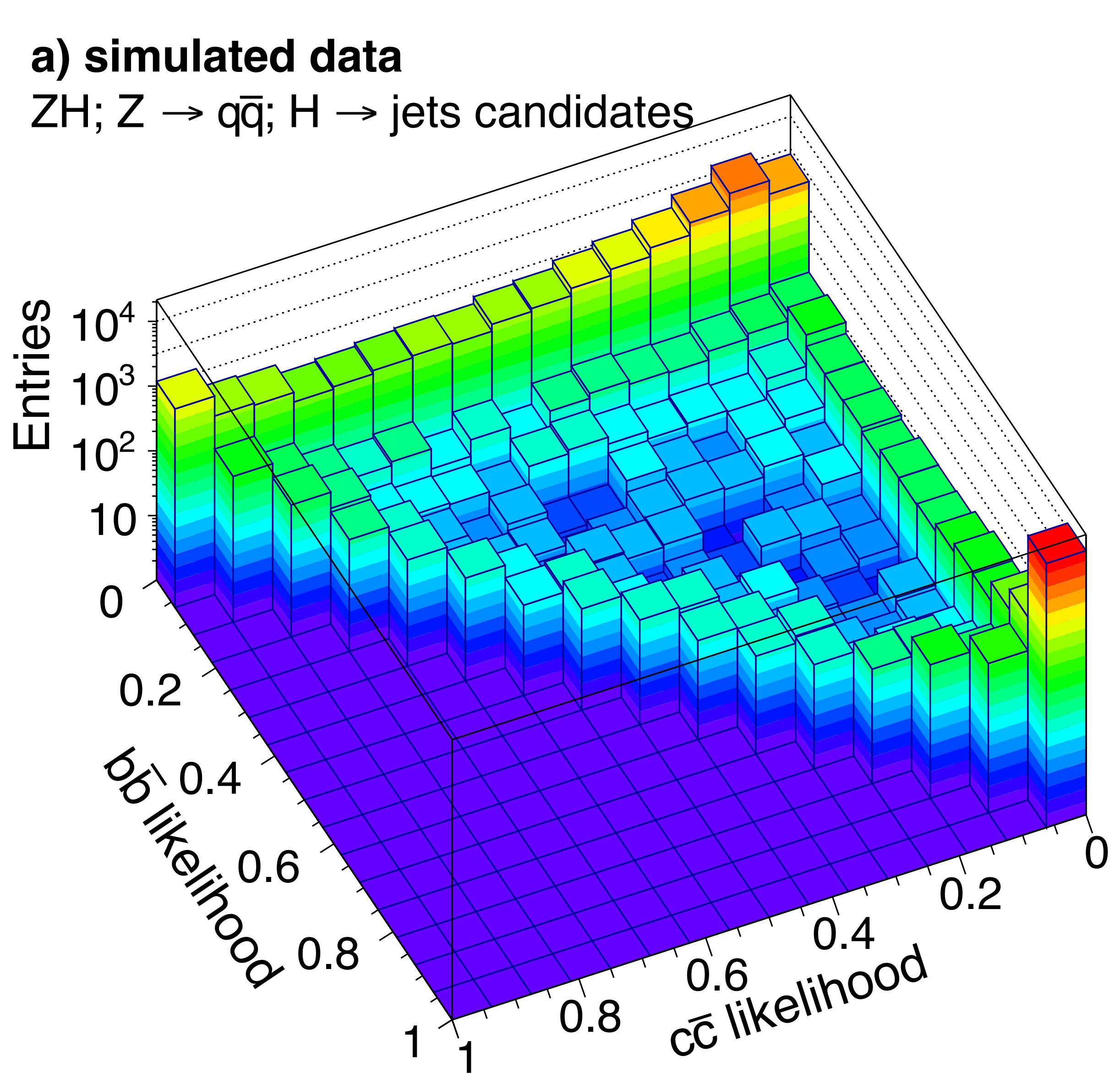

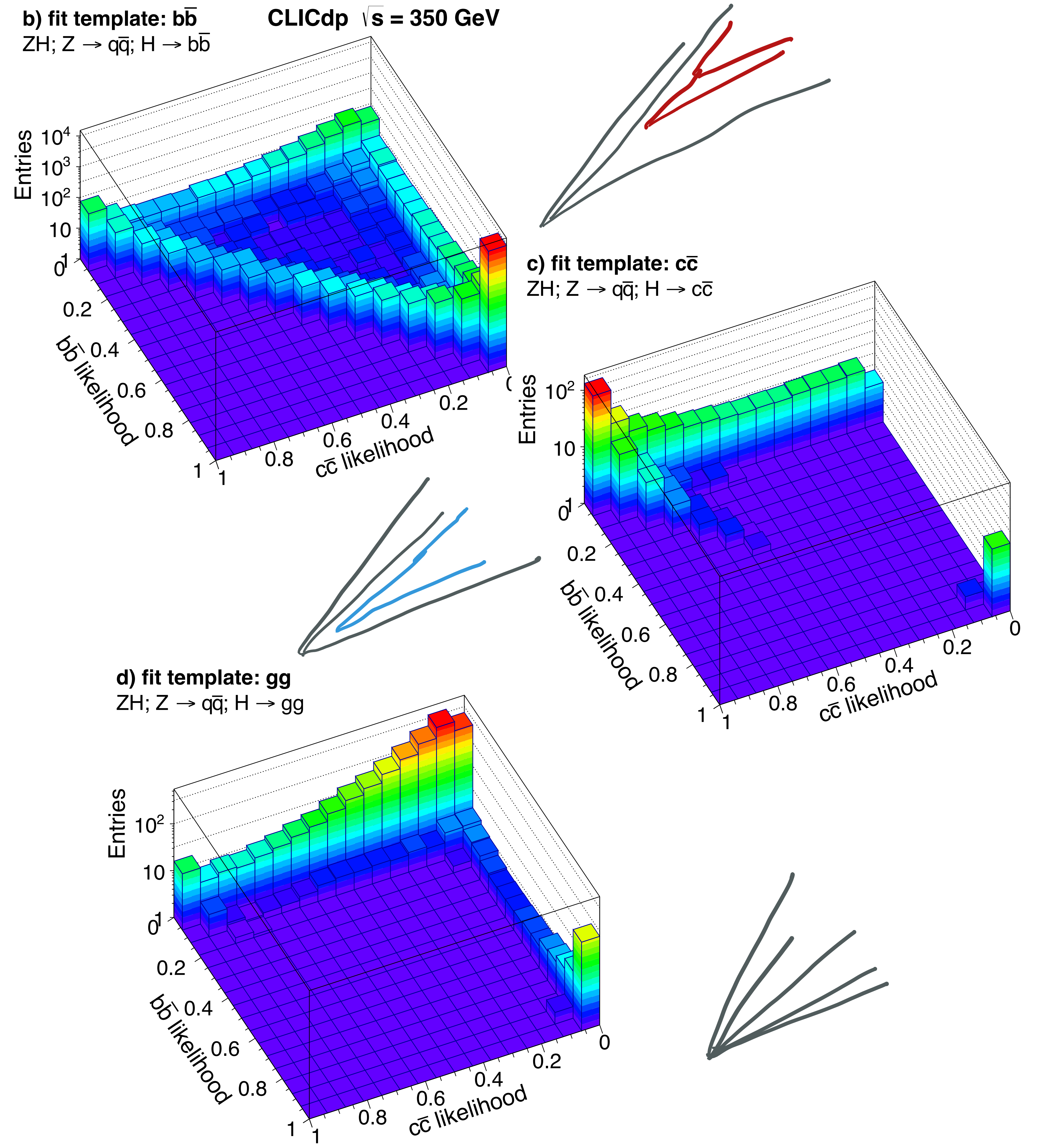

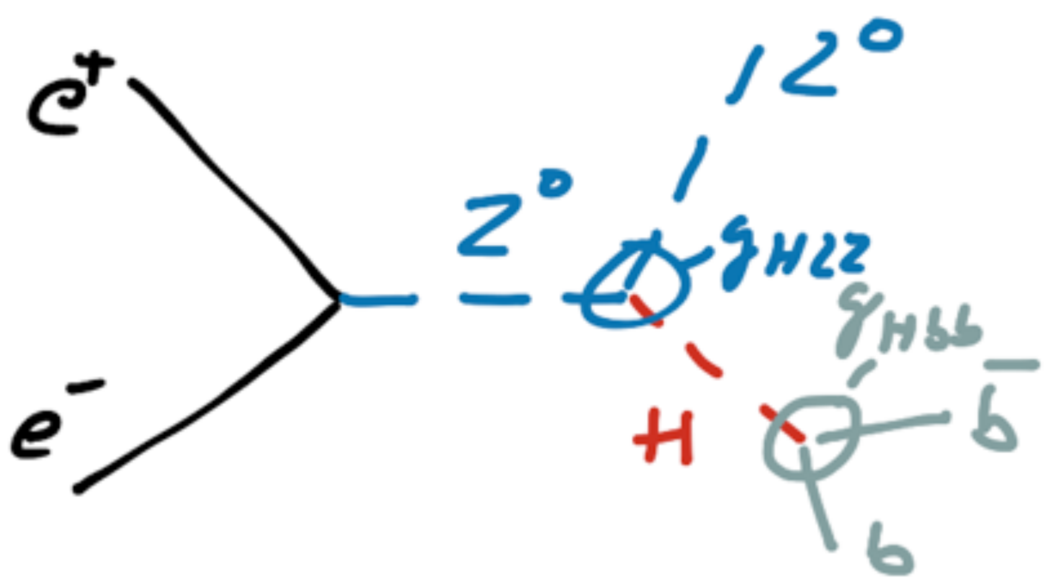

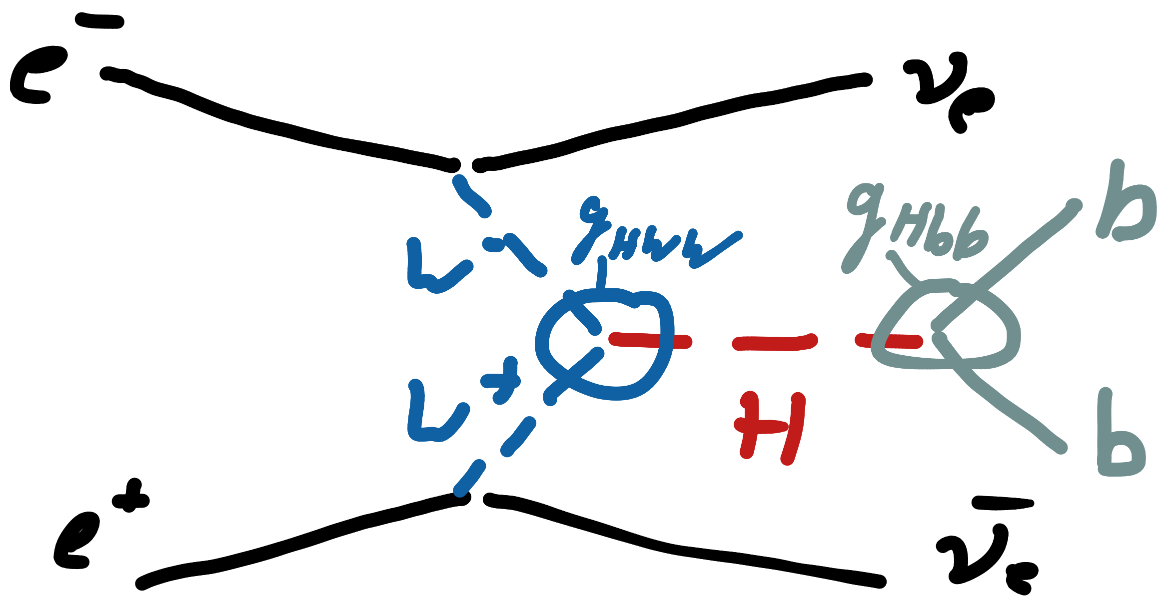

Interpreting Higgs Measurements

A Word on Fits

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- The Higgs coupling measurements at any present and future collider unfold their full potential in global fits of all observables - possibly beyond Higgs measurements alone
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Typical fits used in this context:

- **“Model-independent” fit**

minimize a χ^2 with all measurements:

$$\chi^2 = \sum_i \frac{(C_i - 1)^2}{\Delta F_i^2}$$

$$C_{\mathrm{ZH}} = g^2_{\mathrm{HZZ}}$$

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total width as a free parameter: no constraints imposed on BSM decays

N.B.: Not fully model independent, does not account for certain possible BSM features of HV couplings

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- **"Model-independent EFT" fit**

  A global fit of Higgs and other EW observables parametrizing deviations from the SM by various operators - allows for couplings not included in κ fit, includes connections between W and Z couplings

Extracting the Total Width

Model independent measurement at high precision

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➯ The low BR of H->ZZ and correspondingly large uncertainties make this determination relatively imprecise

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➯ The low BR of H->ZZ and correspondingly large uncertainties make this determination relatively imprecise

➯ Profits substantially from higher energy, where WW fusion becomes relevant:

$$\sigma(\mathrm{H}\nu_e\nu_e) \times \mathrm{BR}(\mathrm{H} \to \mathrm{WW}^*) \propto \frac{g^4_{\mathrm{HWW}}}{\Gamma_{\mathrm{tot}}}$$

$$\frac{\sigma(e^+e^- \to \mathrm{ZH}) \times \mathrm{BR}(\mathrm{H} \to b\bar{b})}{\sigma(e^+e^- \to \mathrm{H}\nu_e\nu_e) \times \mathrm{BR}(\mathrm{H} \to b\bar{b})} \propto \frac{g^2_{\mathrm{HZZ}}}{g^2_{\mathrm{HWW}}}$$

need the "model-independent anchor" of the ZH measurement

Extracting the Total Width

Model independent measurement at high precision

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- e^+e^- colliders provide the possibility for a model-independent measurement of the total width at the level of a few %:

- In the "model-independent fit" framework the total width is obtained from production and decay of the Higgs:

$$\sigma(\mathrm{ZH}) \times \mathrm{BR}(\mathrm{H} \to \mathrm{ZZ}) \propto \frac{g_{HZZ}^4}{\Gamma_{\mathrm{tot}}} \quad \text{and} \quad \sigma(\mathrm{ZH}) \propto g_{HZZ}^2$$

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$$\sigma(\mathrm{H}\nu_e\nu_e) \times \mathrm{BR}(\mathrm{H} \to \mathrm{WW}^*) \propto \frac{g_{\mathrm{HWW}}^4}{\Gamma_{\mathrm{tot}}}$$

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need the "model-independent anchor" of the ZH measurement

➩ Higher energies important for width measurements

➩ In EFT fits W and Z are connected, there the width can be well constrained also without WW fusion

Perspectives on Precision

Interplay of Measurements, Energy Stages

- Comparisons of the potential of different colliders are non-straightforward: The projections are based on different levels of realism / pessimism / optimism in detector modeling, analysis techniques, systematic uncertainties and machine parameters / running scenarios,…

  Here: Taking the “model independent” fit results - combine the projected uncertainties on σxBR to illustrate interplay of measurements, not to compare facilities. Results from European Strategy 2019

	ILC 250	ILC 500	CLIC 380	CLIC 3 TeV	CEPC	FCCee 240	FCCee 365
$\delta g_{HZZ}/g_{HZZ}$	0,38	0,30	0,6	0,6	0,25	0,21	0,18
$\delta g_{HWW}/g_{HWW}$	1,8	0,40	1,0	0,6	1,4	1,3	0,44
$\delta g_{Hbb}/g_{Hbb}$	1,8	0,60	2,1	0,7	1,3	1,3	0,69
$\delta g_{Hcc}/g_{Hcc}$	2,4	1,2	4,4	1,4	2,2	1,8	1,3
$\delta g_{Hgg}/g_{Hgg}$	2,2	0,97	2,6	1,0	1,5	1,7	1,0
$\delta g_{H\tau\tau}/g_{H\tau\tau}$	1,9	0,80	3,1	1,0	1,5	1,4	0,74
$\delta g_{H\mu\mu}/g_{H\mu\mu}$	5,6	5,1		5,7	8,7	10.0	8,9
$\delta g_{H\gamma\gamma}/g_{H\gamma\gamma}$	1,1	1,0		2,3	3,7	4,8	3,9
$\delta g_{Htt}/g_{Htt}$	-	6,7	-	3,0	-	-	-
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ILC 250: 2 ab^{-1} @ 250 GeV

ILC 500: +0.2 ab^{-1} @ 350 GeV
+ 4 ab^{-1} @ 500 GeV

CLIC 380: 1 ab^{-1} @ 380 GeV

CLIC 3 TeV: + 2.5 ab^{-1} @ 1.5 TeV
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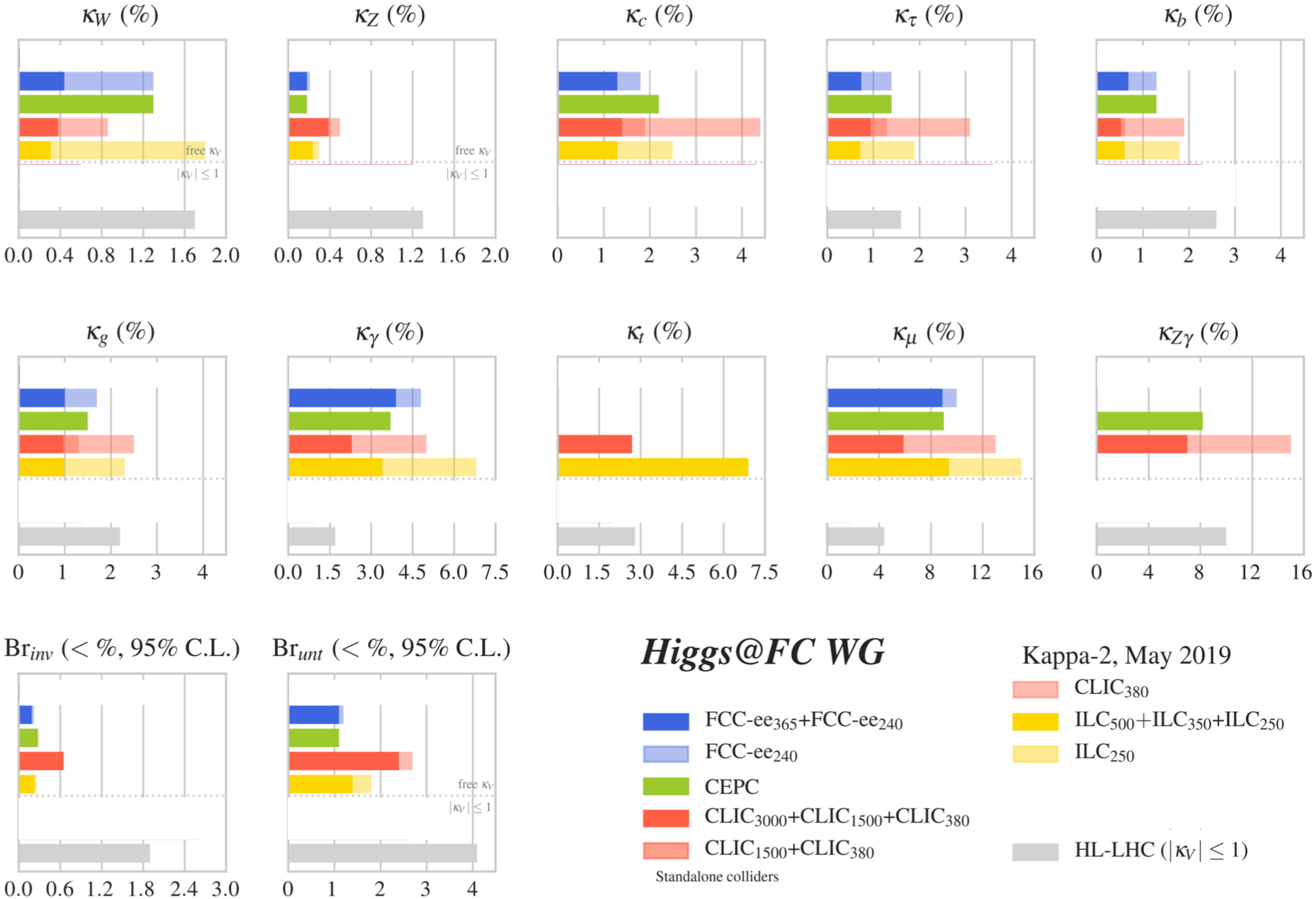
Perspectives on Precision

Illustrating Interplay and Reach

Scenario	BR_{inv}	BR_{unt}	include HL-LHC
kappa-2	measured	measured	no

hadron collider cannot measure width
need an assumption to close the fit
e.g. κ_V<1

e^+e^- standalone



not showing HE-LHC, LHeC, FCC-hh

Perspectives on Precision

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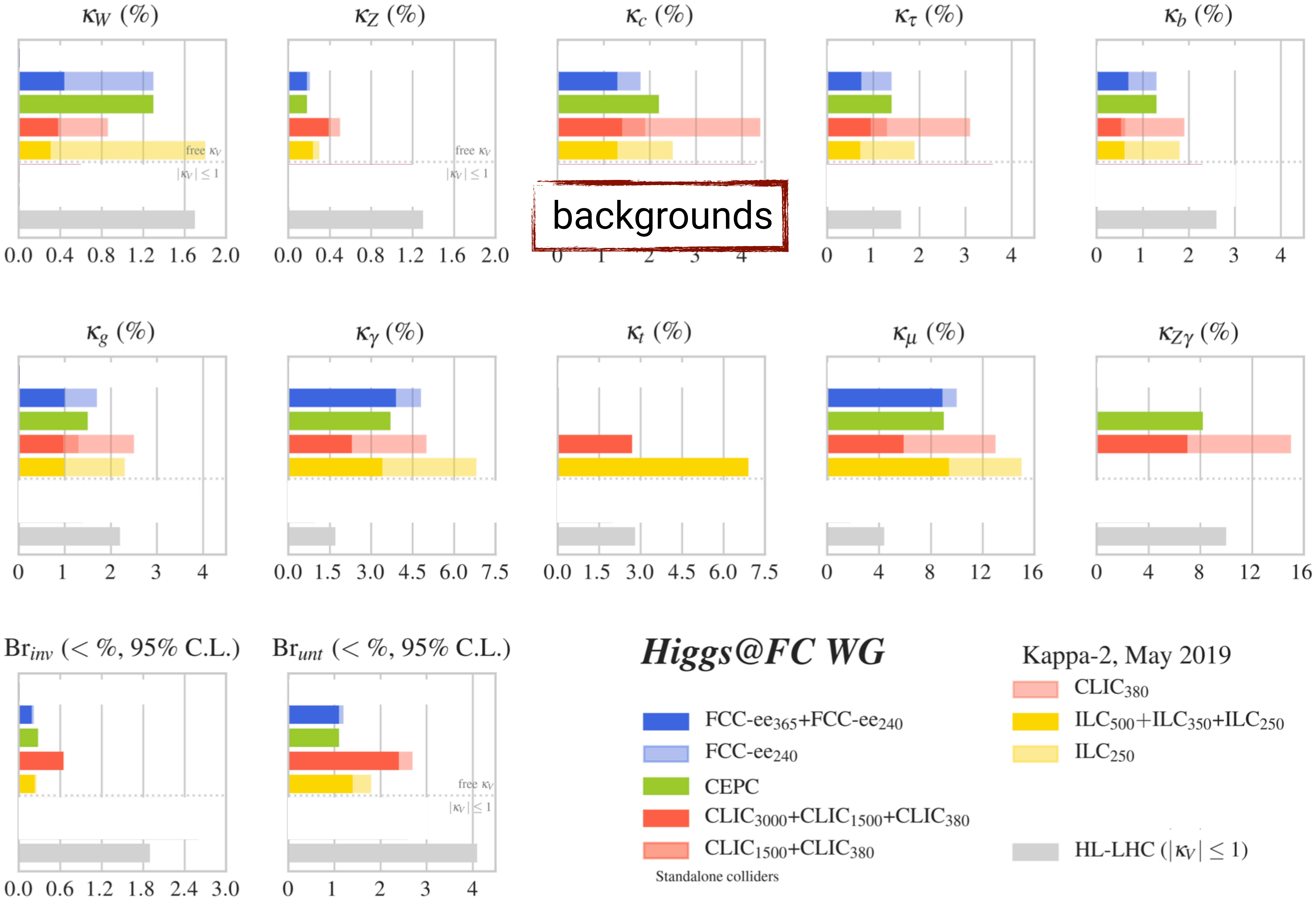

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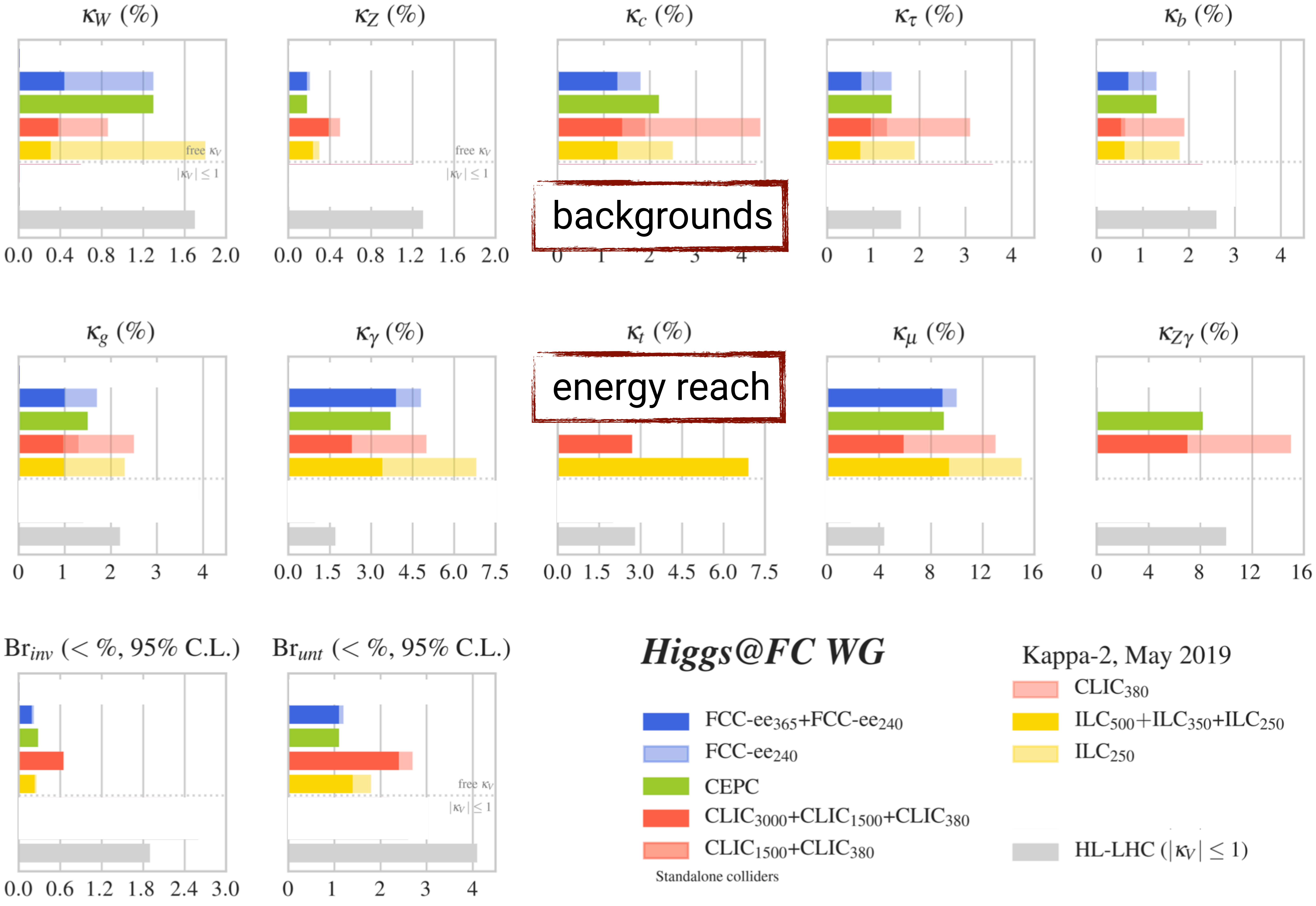

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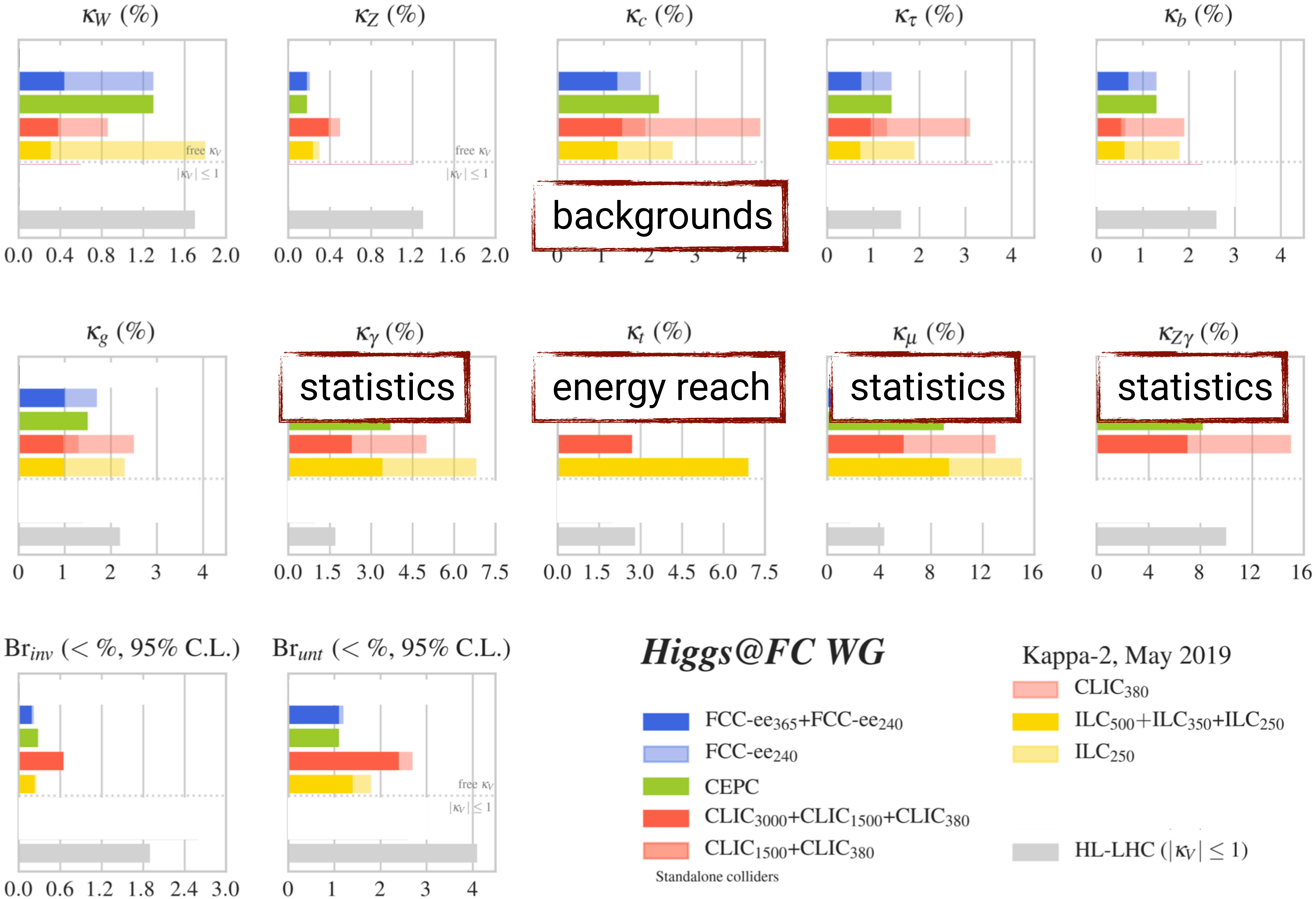
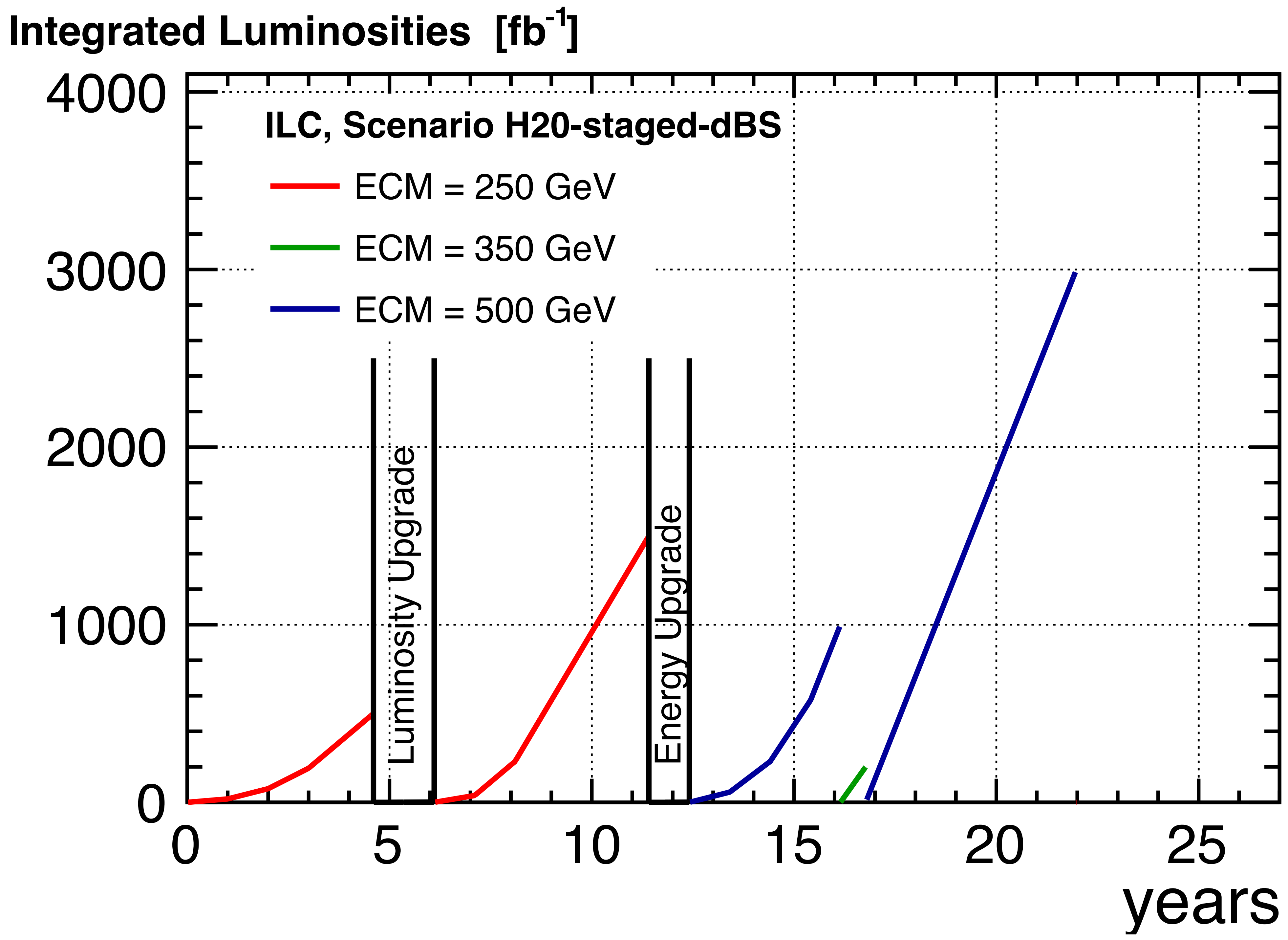


The Relevance of Higgs Coupling Measurements

One EFT Example for ILC



- Precision measurements of couplings may show deviations from the Standard Model
  - "Fingerprinting" of deviation pattern reveals underlying mechanisms

The Relevance of Higgs Coupling Measurements

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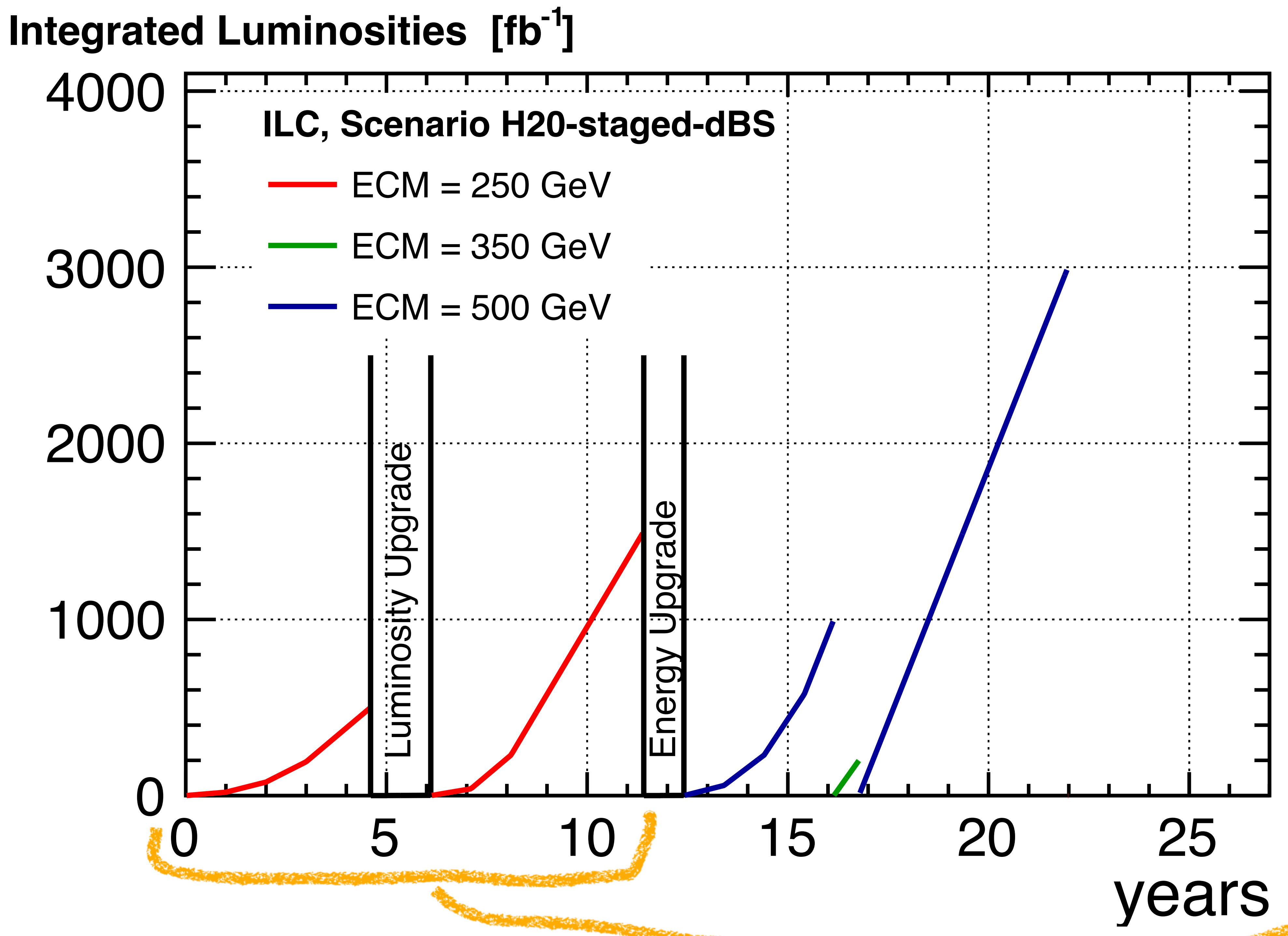

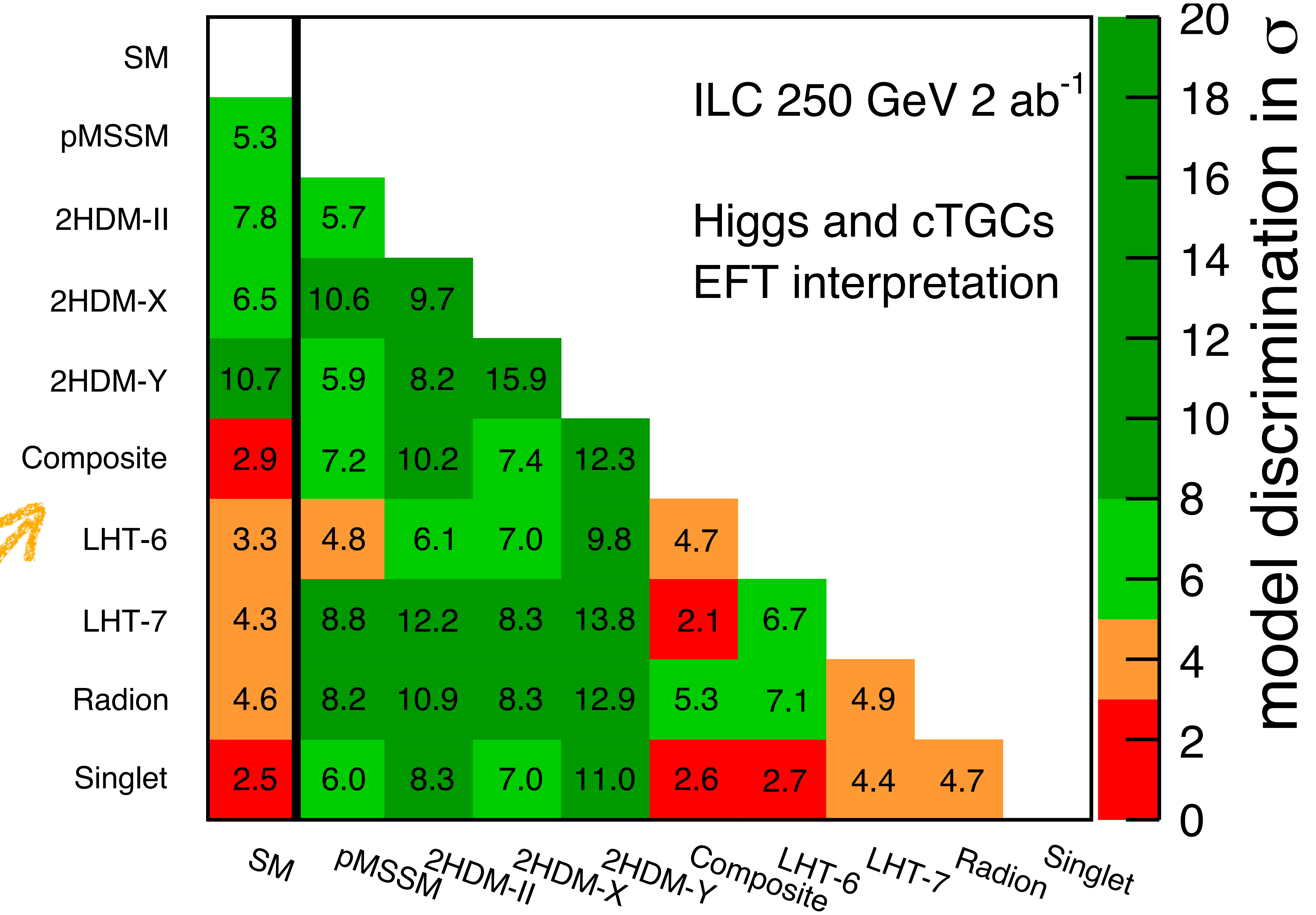

- Precision measurements of couplings may show deviations from the Standard Model
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- Discrimination power between models illustrated with EFT fit of ILC projections

arXiv:1708.08912
arXiv:1710.07621

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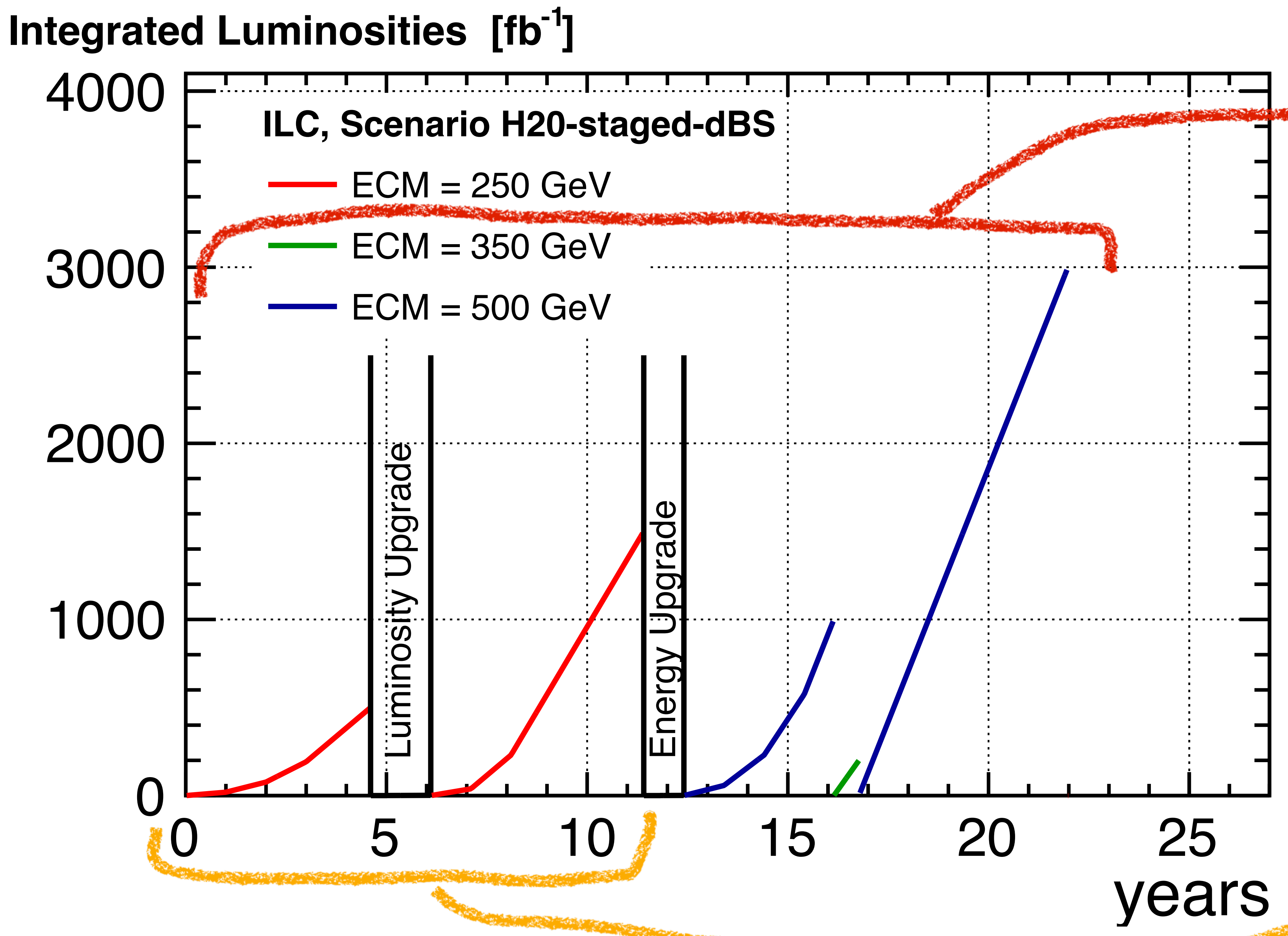

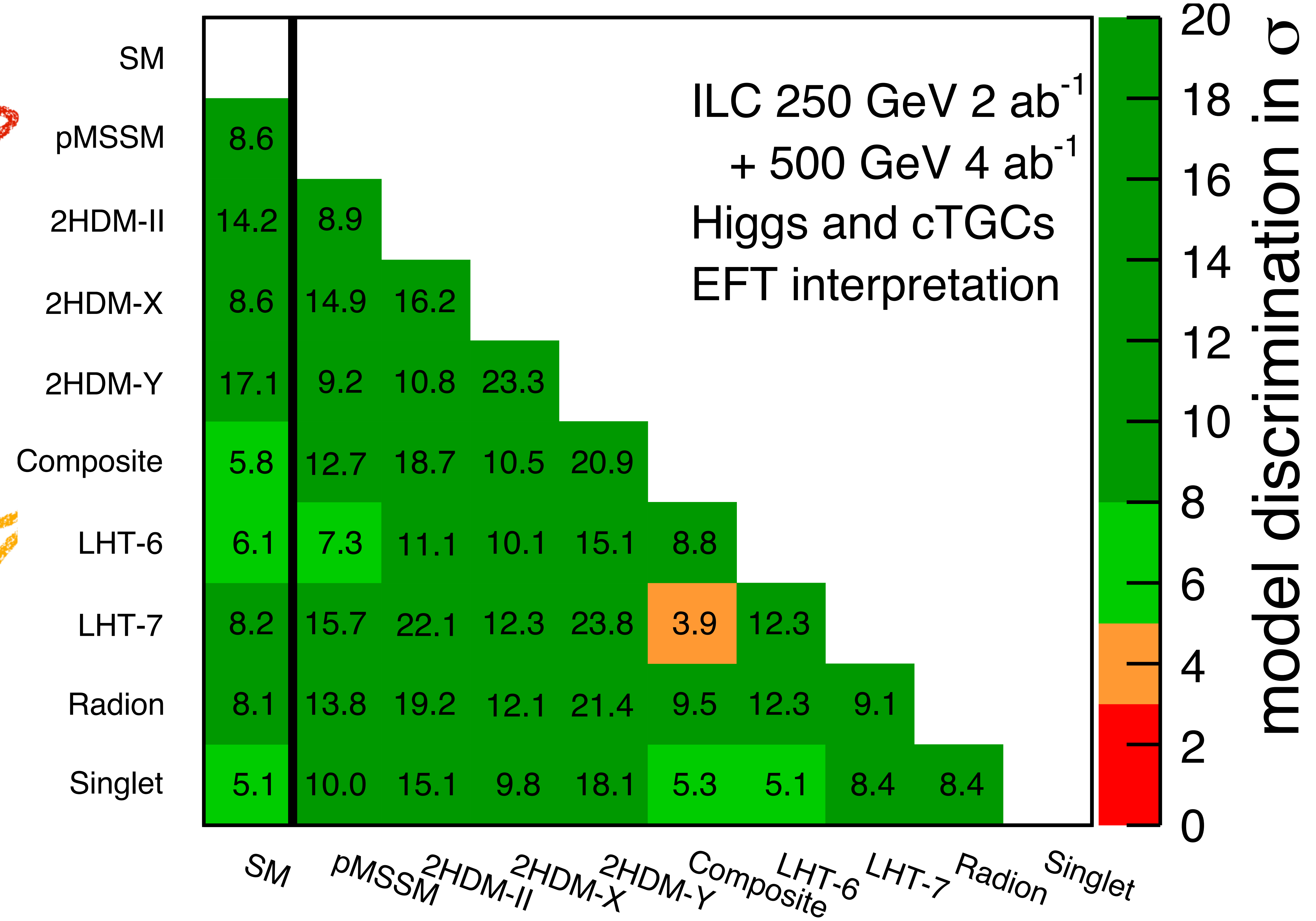

- Precision measurements of couplings may show deviations from the Standard Model
  - "Fingerprinting" of deviation pattern reveals underlying mechanisms
- Discrimination power between models illustrated with EFT fit of ILC projections
  - higher energy may be decisive

arXiv:1708.08912
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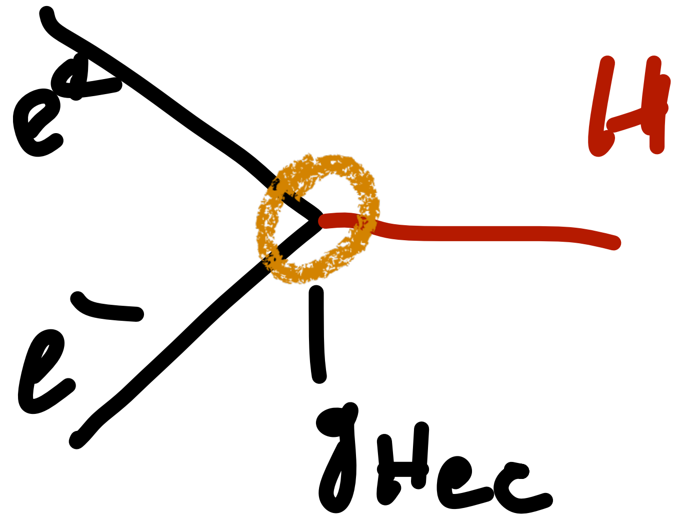
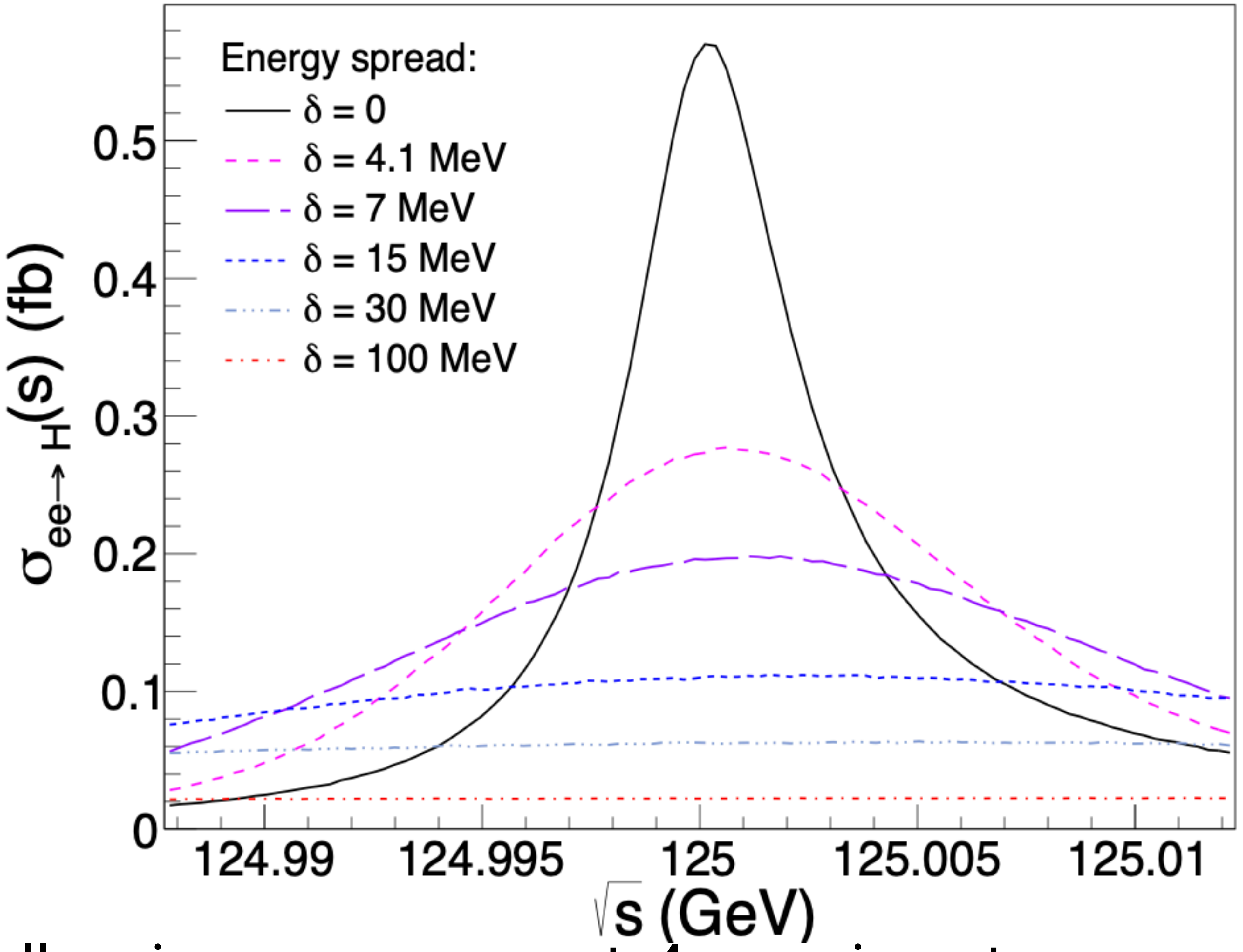
Accessing the Couplings to First Generation Leptons

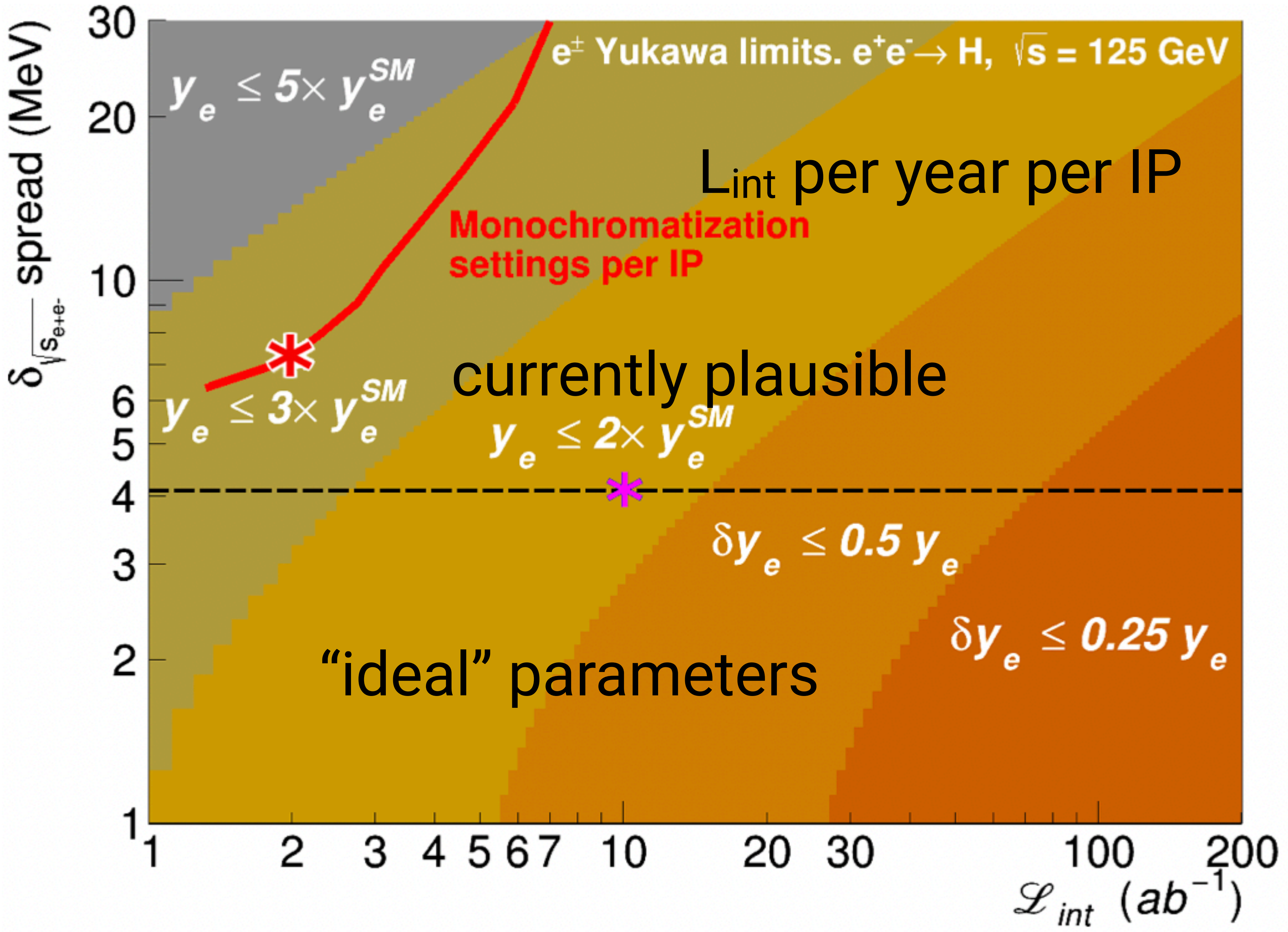
Requiring extreme luminosities of circular colliders

- The only chance to access couplings to first generation: Study of s-channel Higgs production in e^+e^- collisions
  - Requires high luminosities and very small energy spread at 125.1 GeV





Requires special monochromatization to reduce energy spread

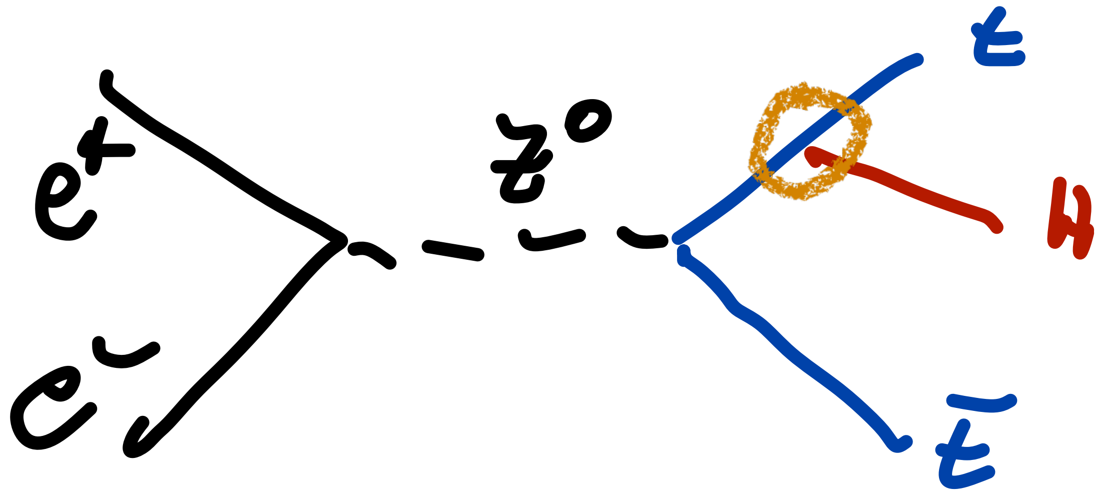


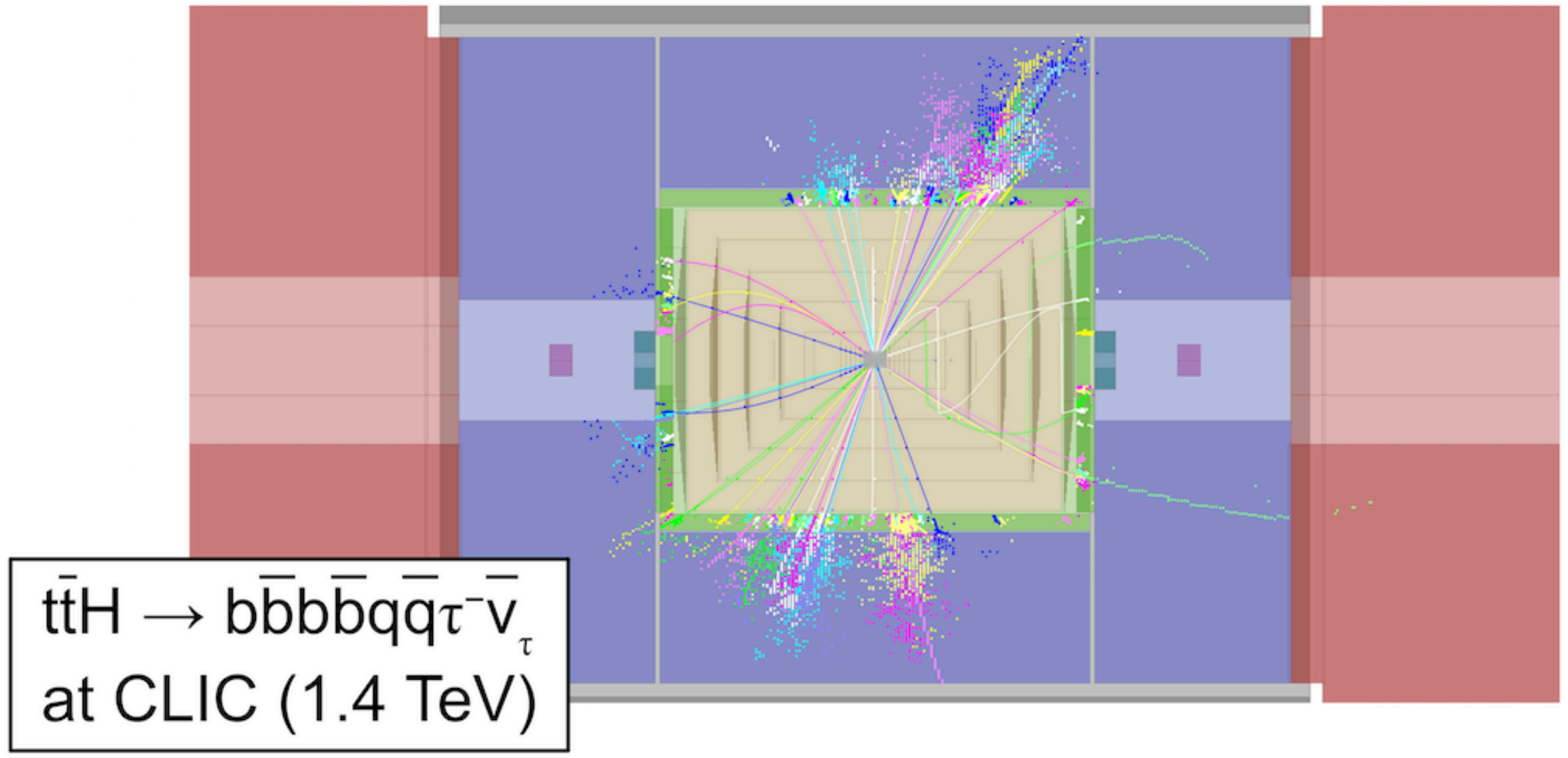
➯ A very challenging measurement, 4 experiments and 3 years may reach a result

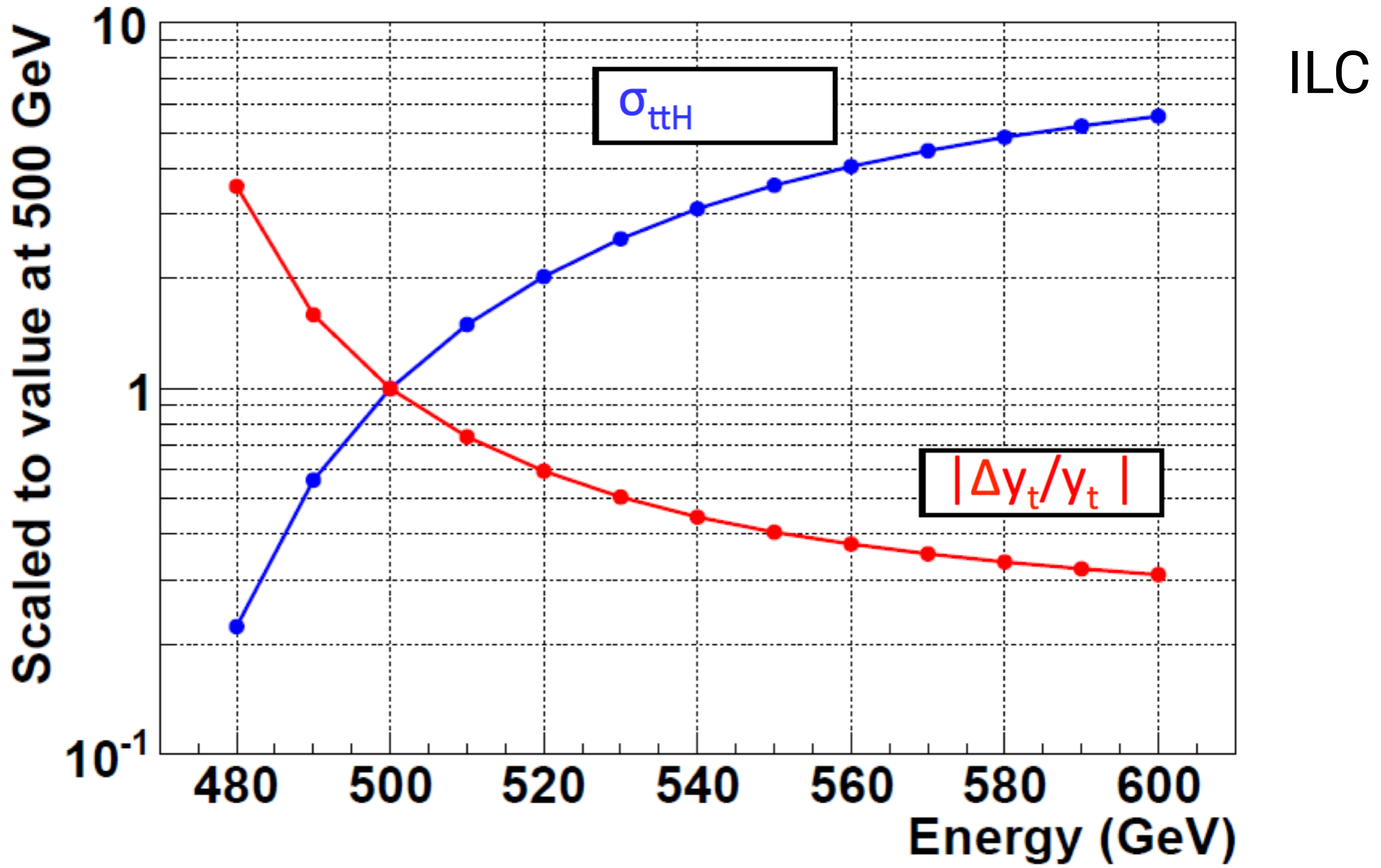
Directly measuring the Coupling to the Top Quark

A higher-energy exclusive

- Direct access to the top Yukawa coupling provided by ttH final state: requires energy ≥ 500 GeV (ideal ~ 550 GeV - 1.5 TeV)







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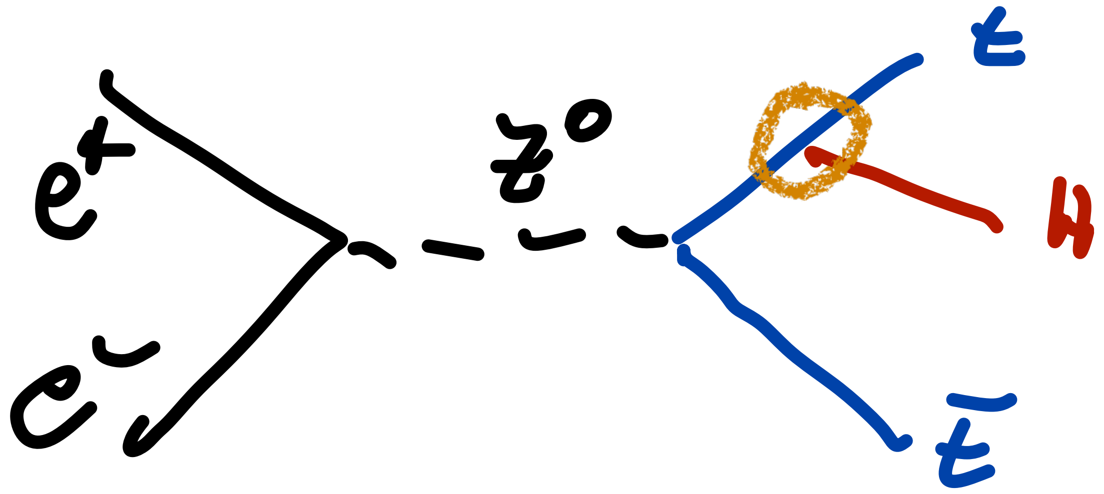

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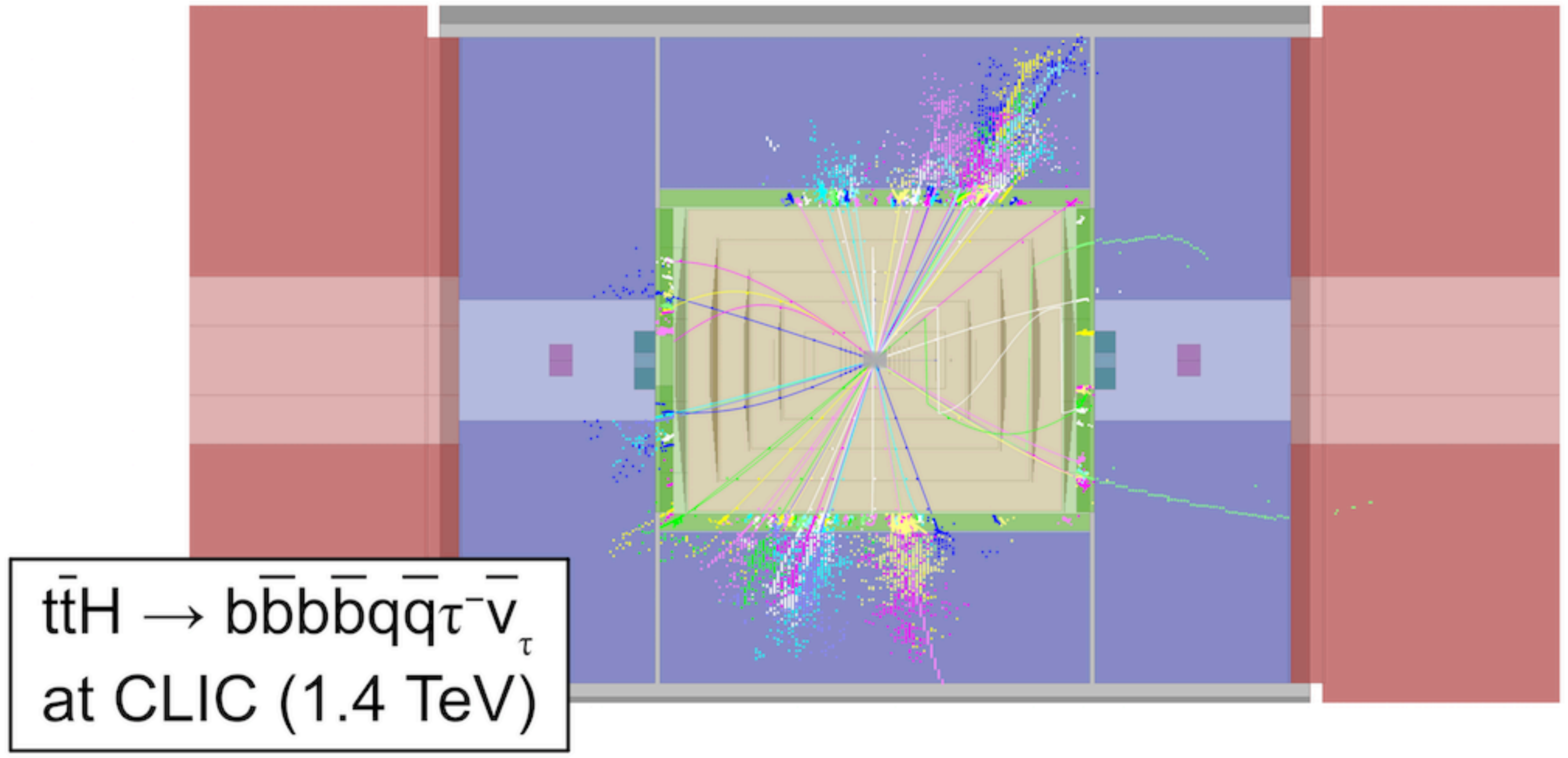
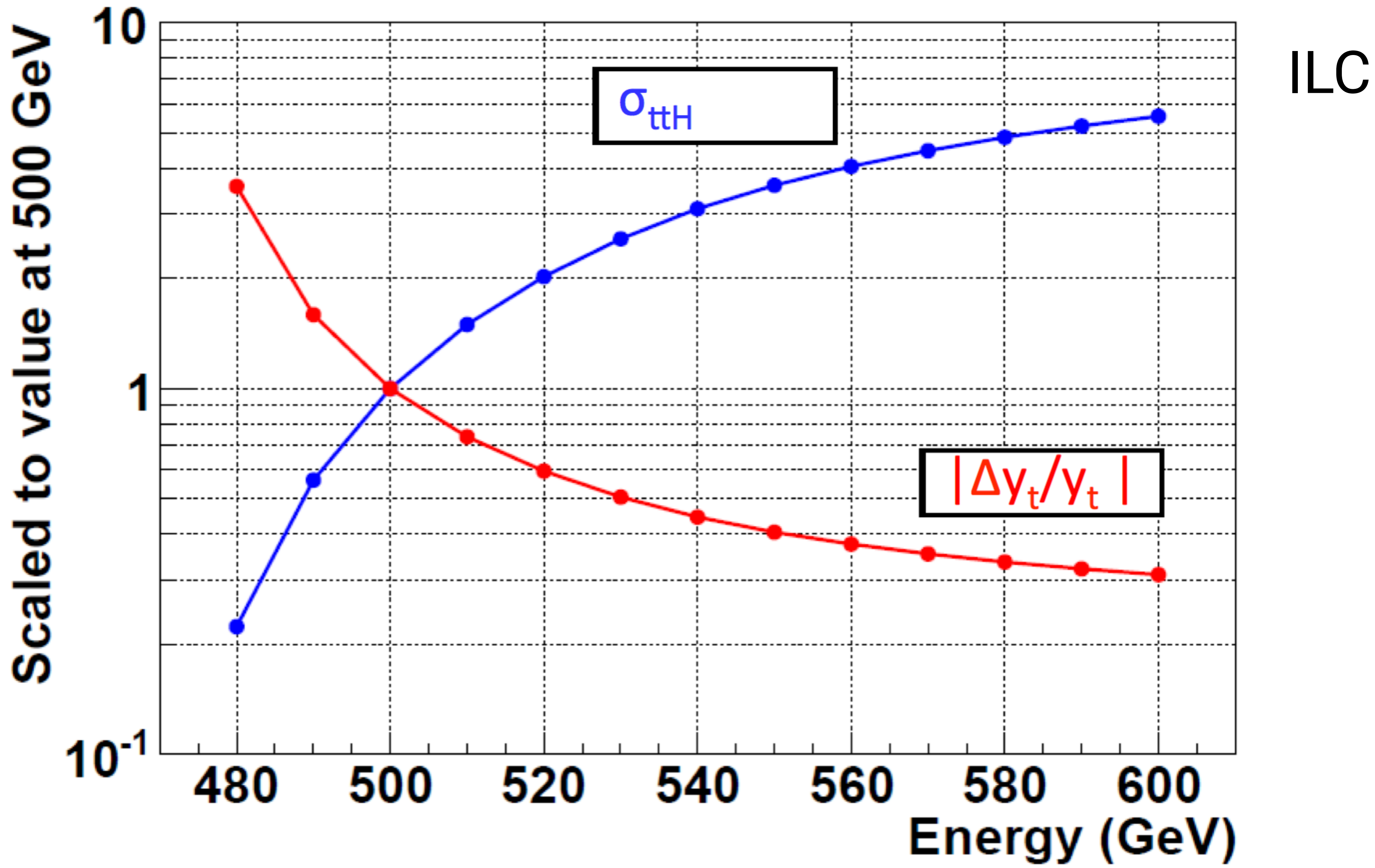




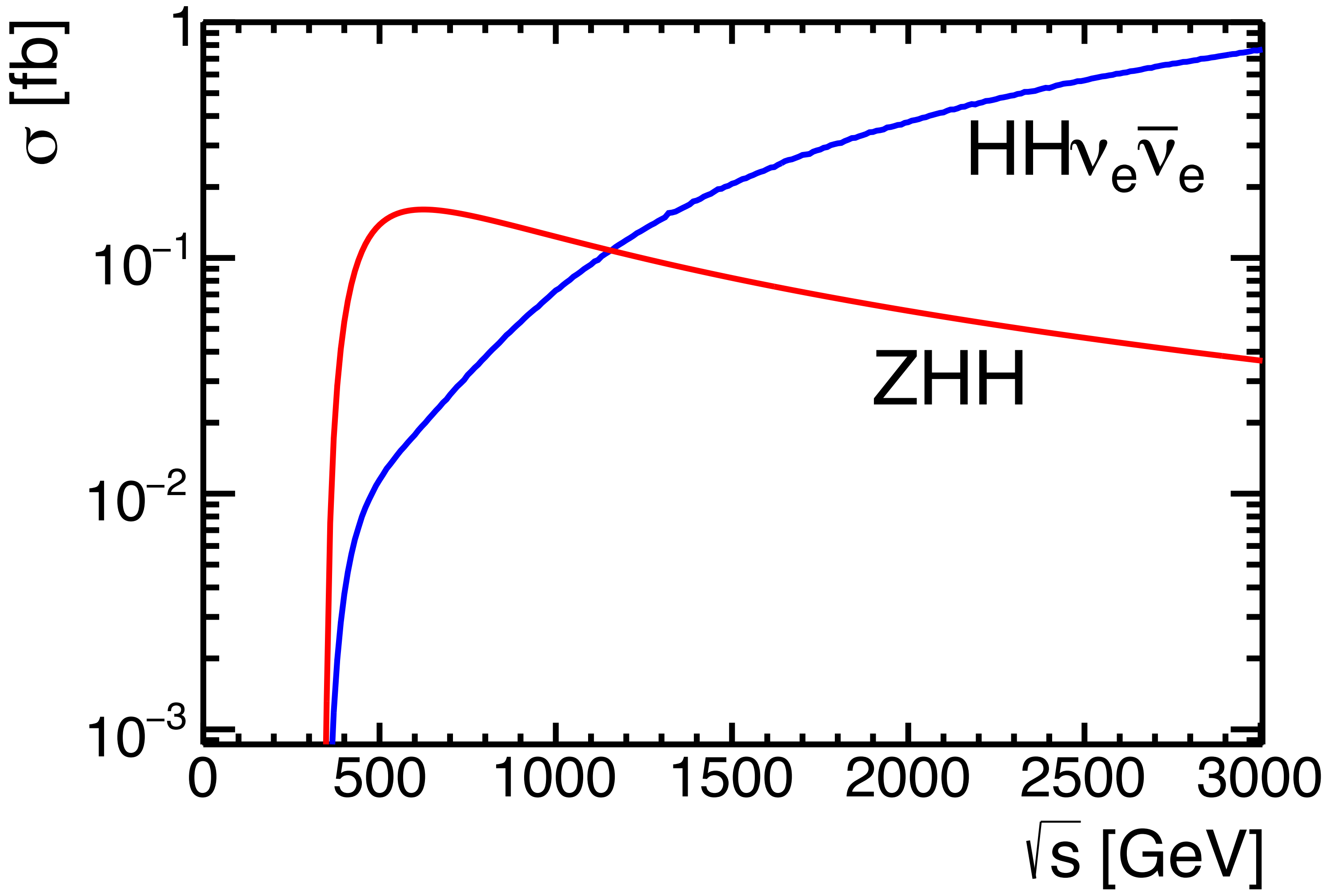
ILC: $\Delta g_{ttH}/g_{ttH}$ ~ 6.3% with 4 ab^{-1} @ 500 GeV
would be ~ 3% @ 550 GeV
(and ~ 13% @ 485 GeV: achieving design energy critical!)

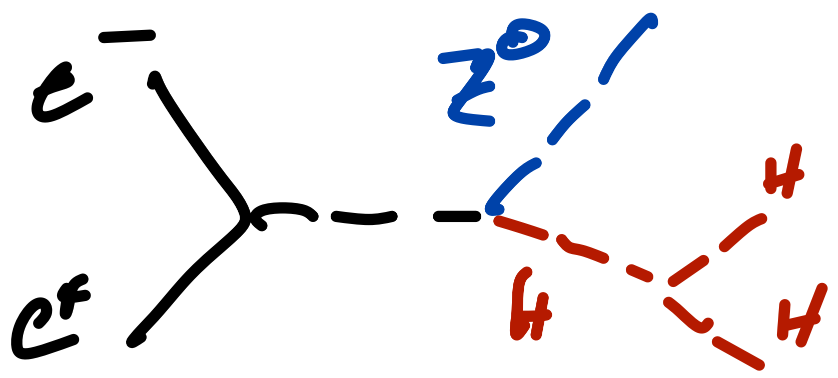
CLIC: $\Delta g_{ttH}/g_{ttH}$ ~ 2.9% with 2.5 ab^{-1} @ 1.4 TeV

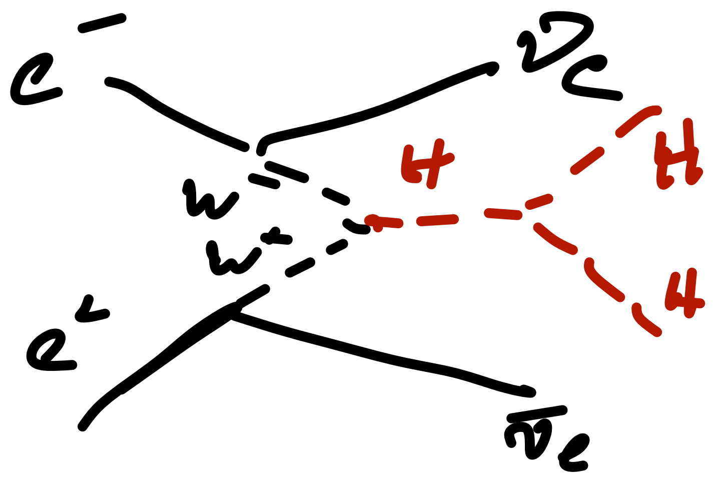
The Higgs Self-Coupling

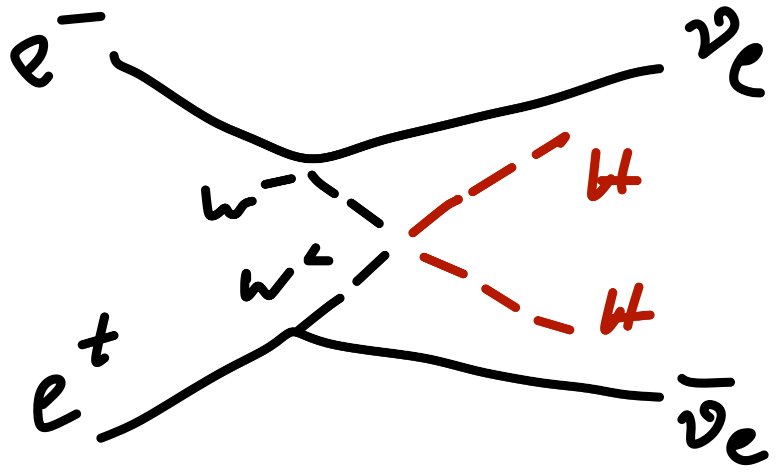
Requires higher energy - one of the key challenges of HEP

- Two processes with sensitivity at e^+e^- colliders:









the final state also receives contributions from the quartic coupling

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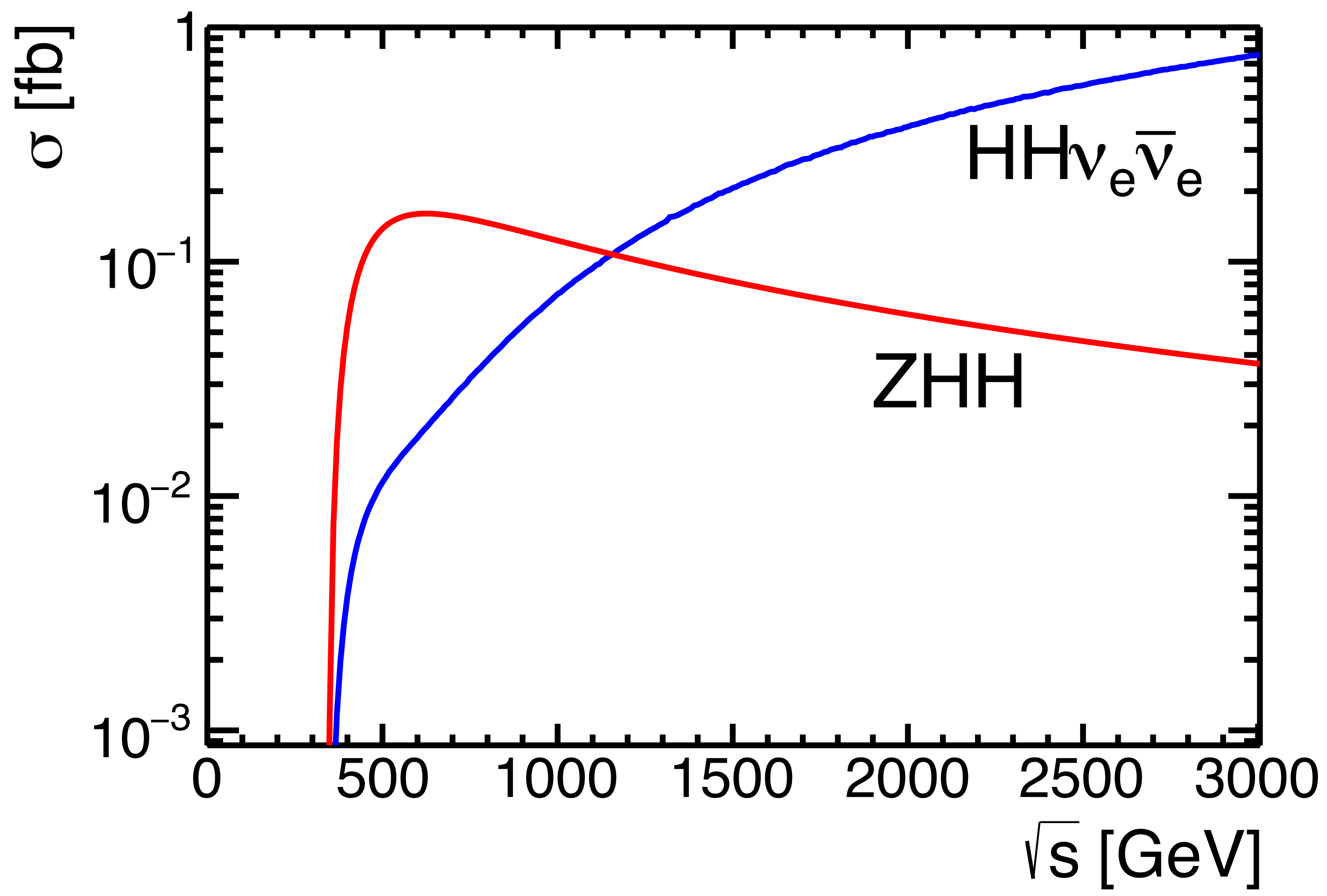
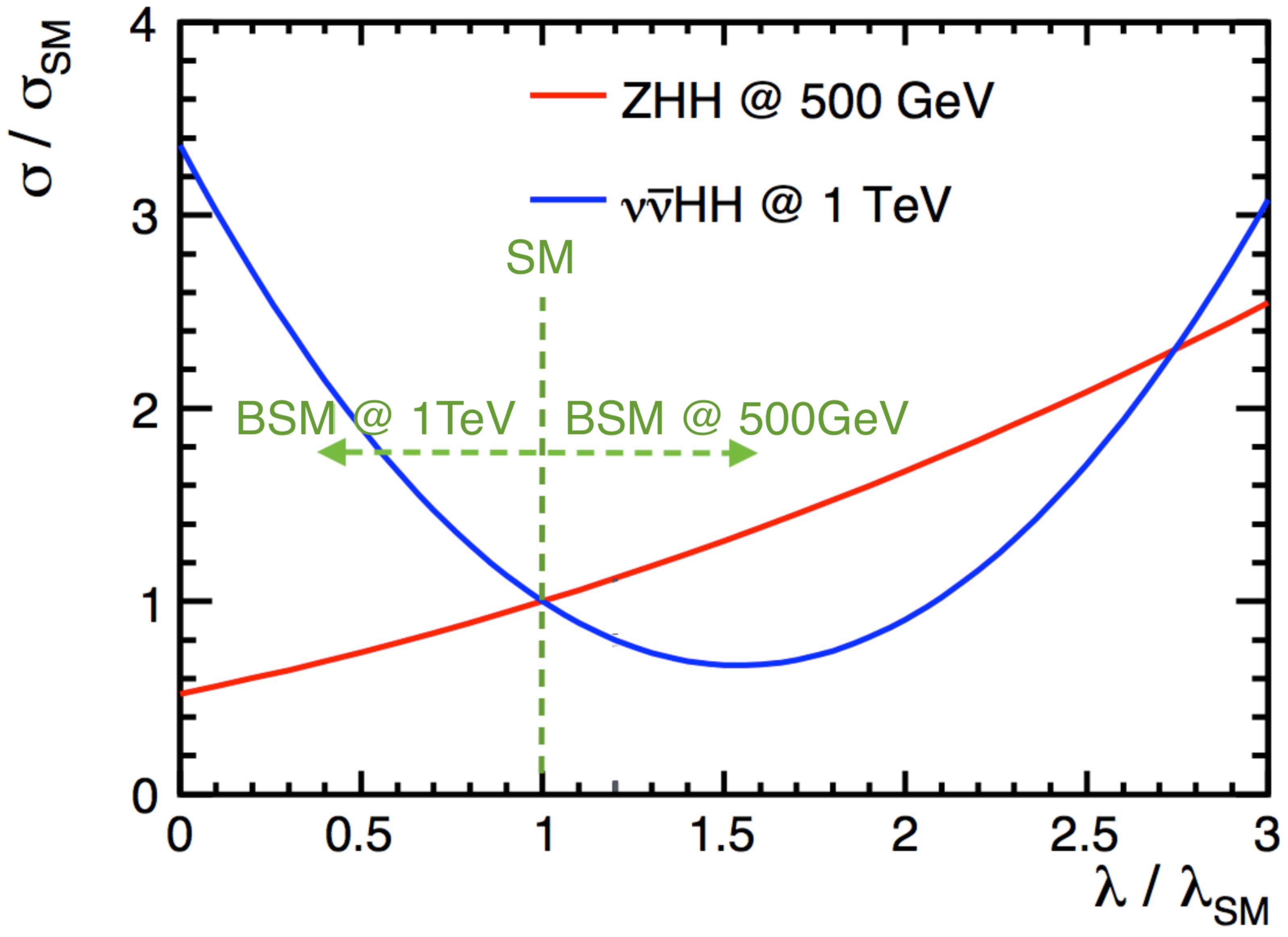
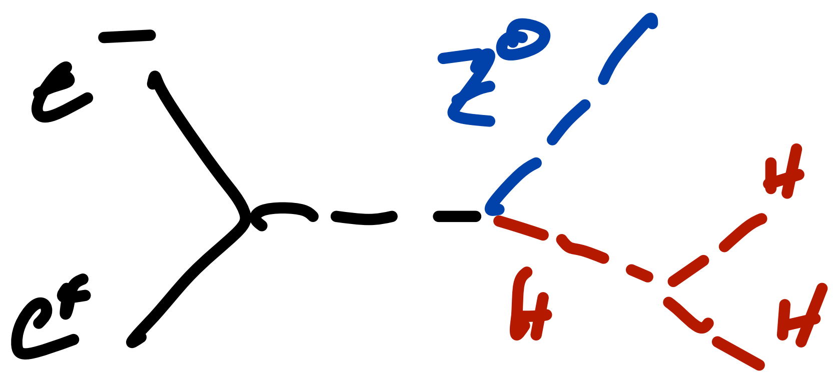
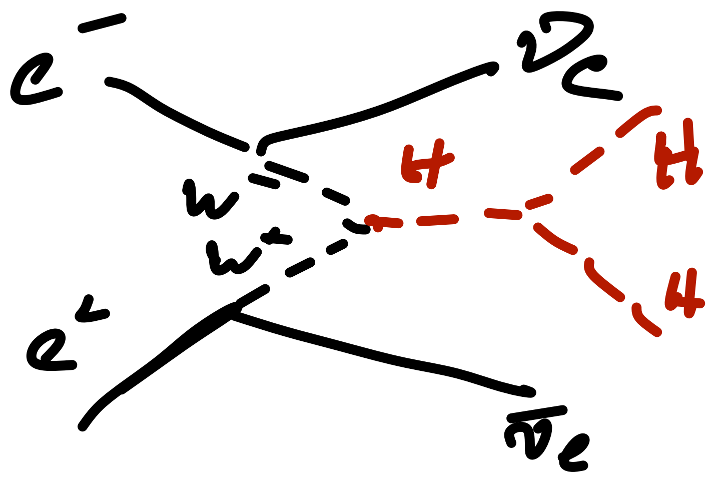
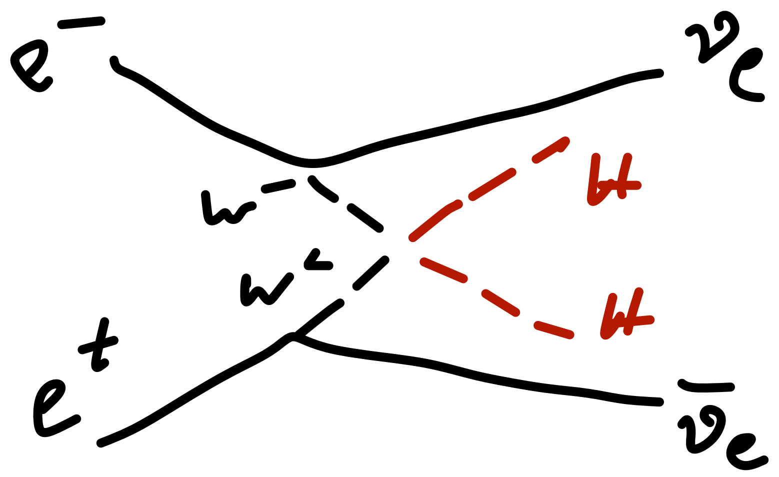


cross section depends non-linearly on λ, measurements at different energies / of different processes lift degeneracies









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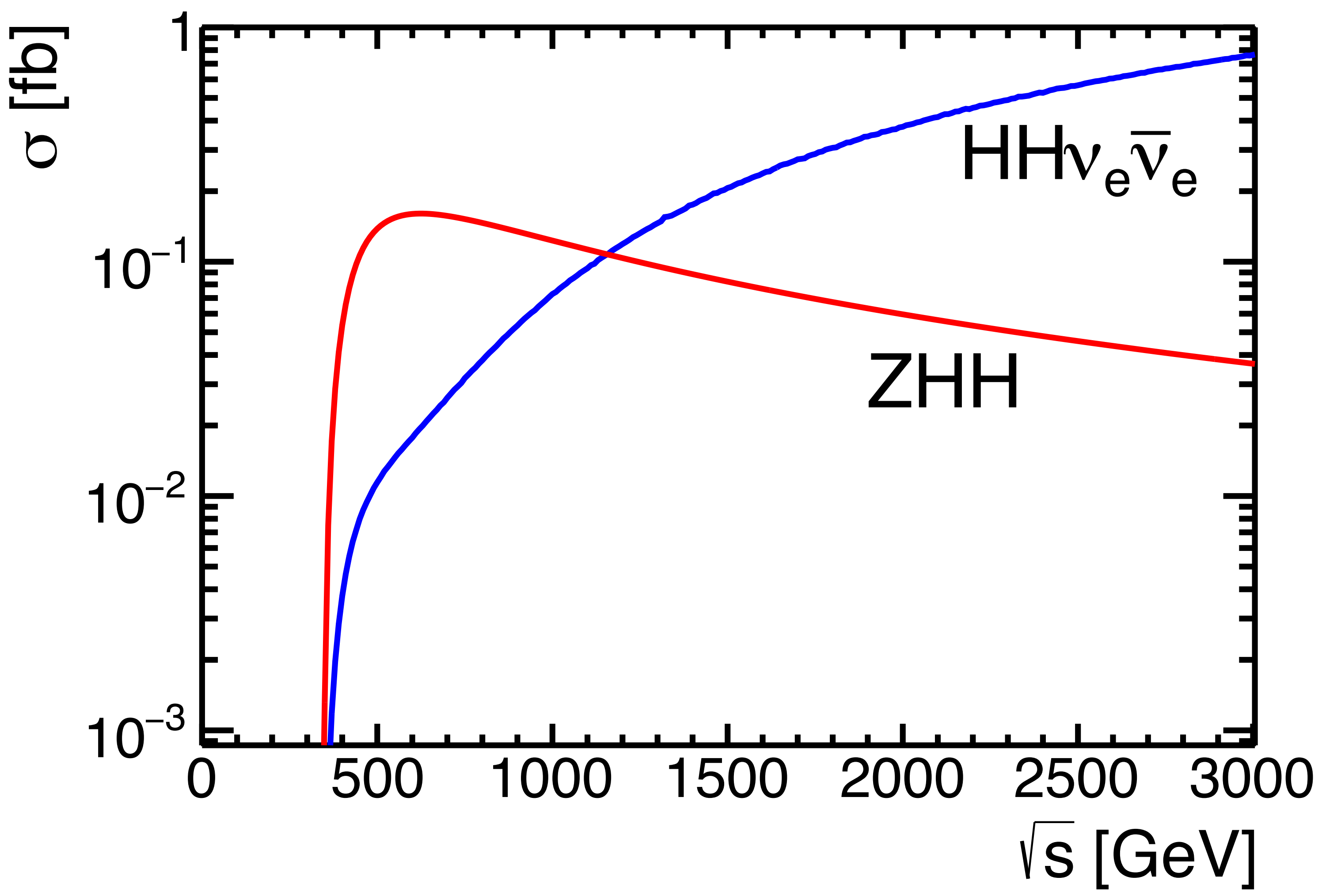

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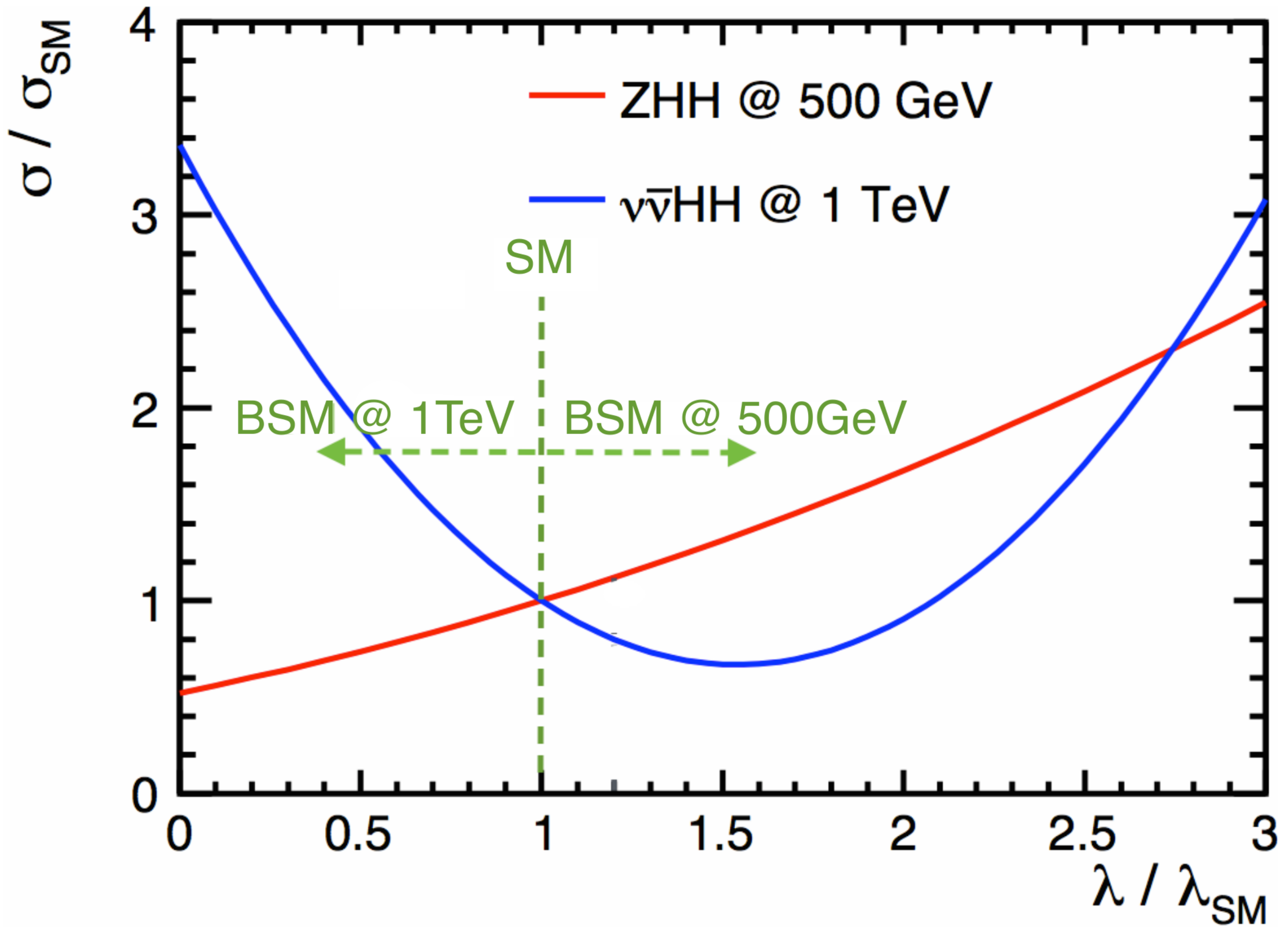

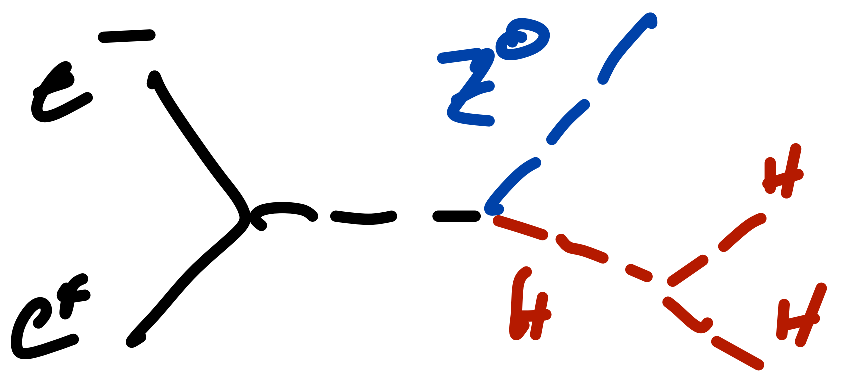

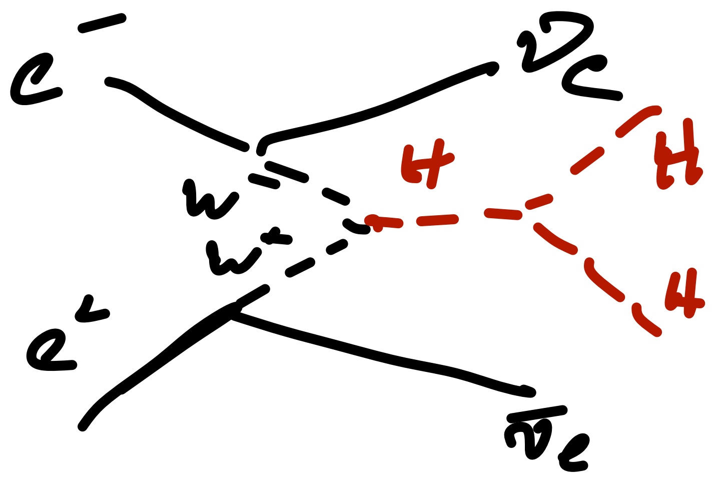

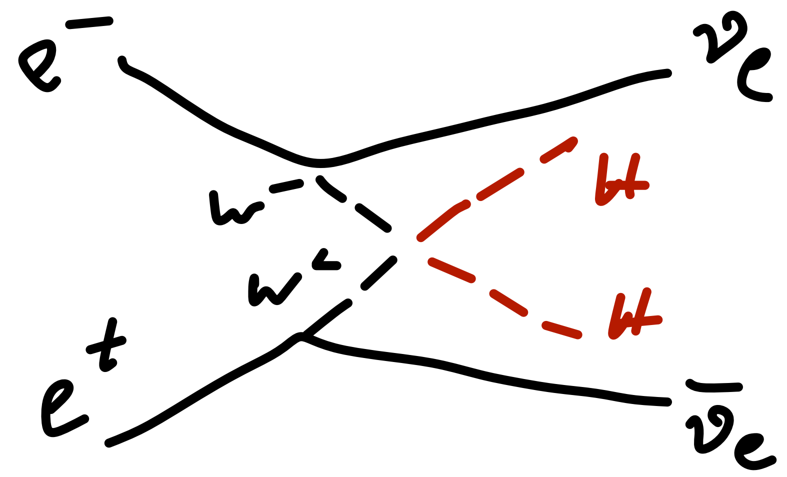

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Full potential unfolds in the multi-TeV region through growing σ of VBF process:

➯ 10% measurement feasible

➯ Significant observation also of ZHH channel in lower-energy running (up to ~ 1.5 TeV)

Indirect Measurement of the Self Coupling

Accessible via particle loops

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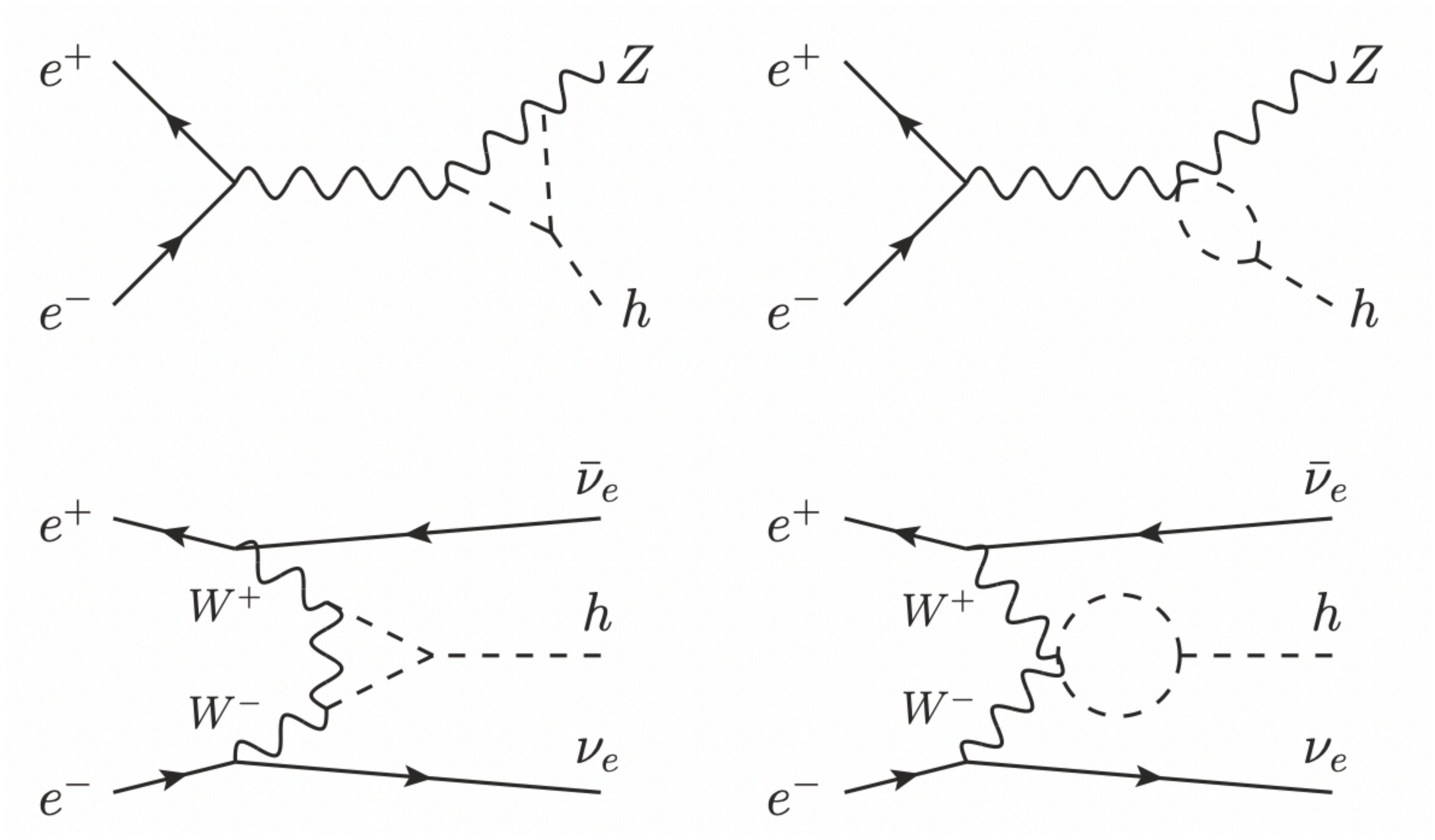
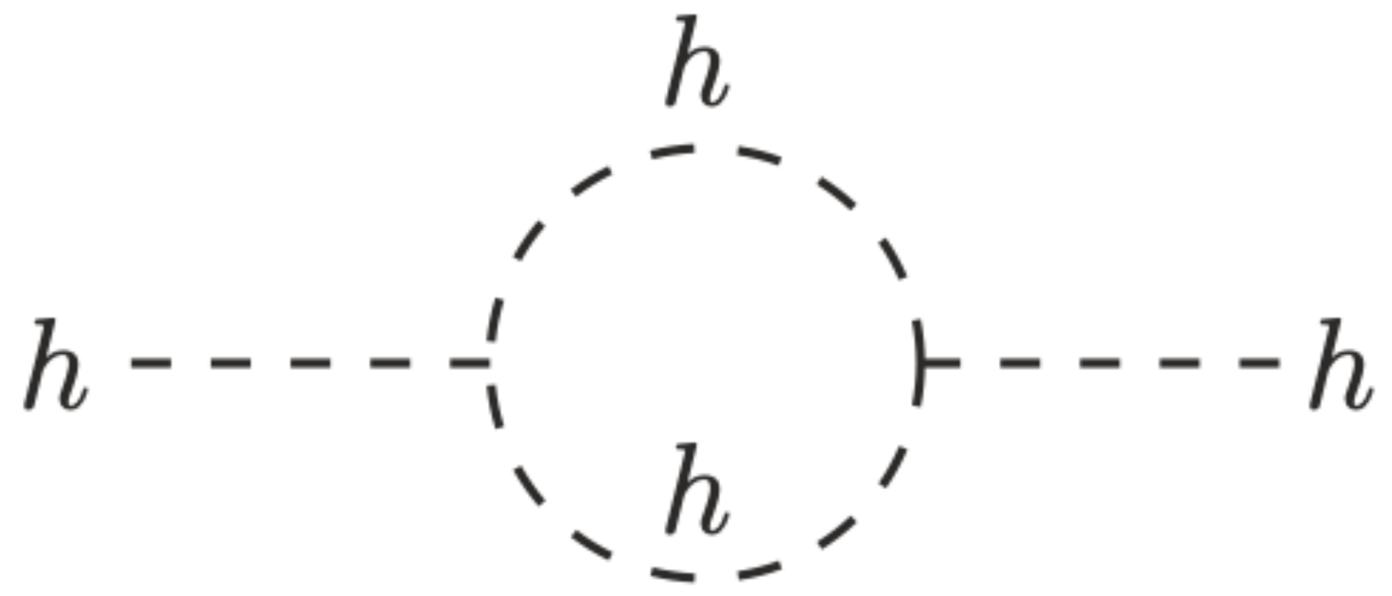
- The self-coupling also influences single Higgs production:

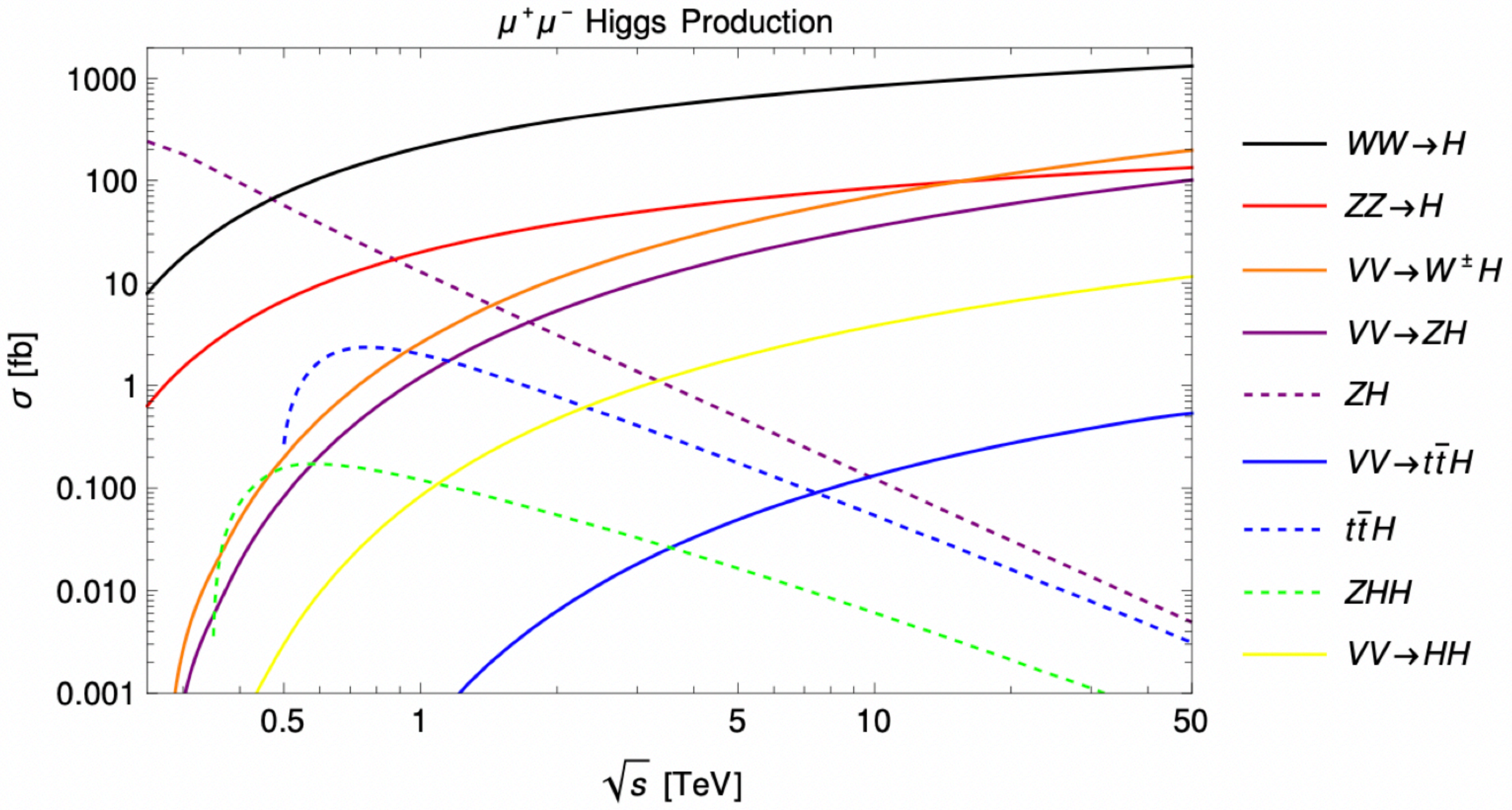




Model-dependent: assumptions required for interpretation!

Overall precision limited, ~ 33% at FCC-ee combined with HL-LHC (which provides ~ 50%)

- In general the same processes as for e^+e^-, but with the backdrop of a much larger background, and reduced acceptance at small angles (which has an impact on WW fusion processes in particular). Here (much) higher energy can compensate!



Higgs Physics at Muon Colliders

Brief overview

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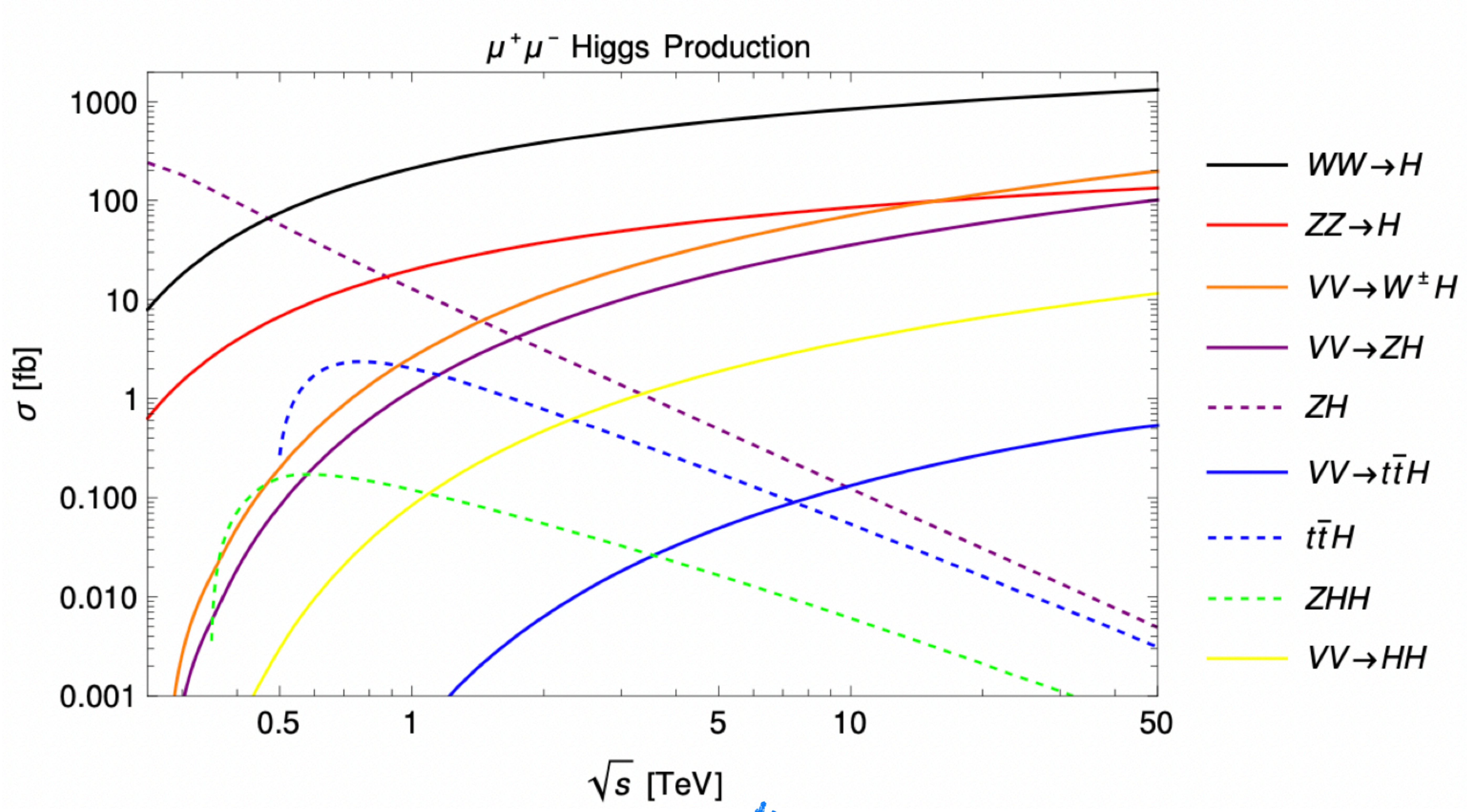

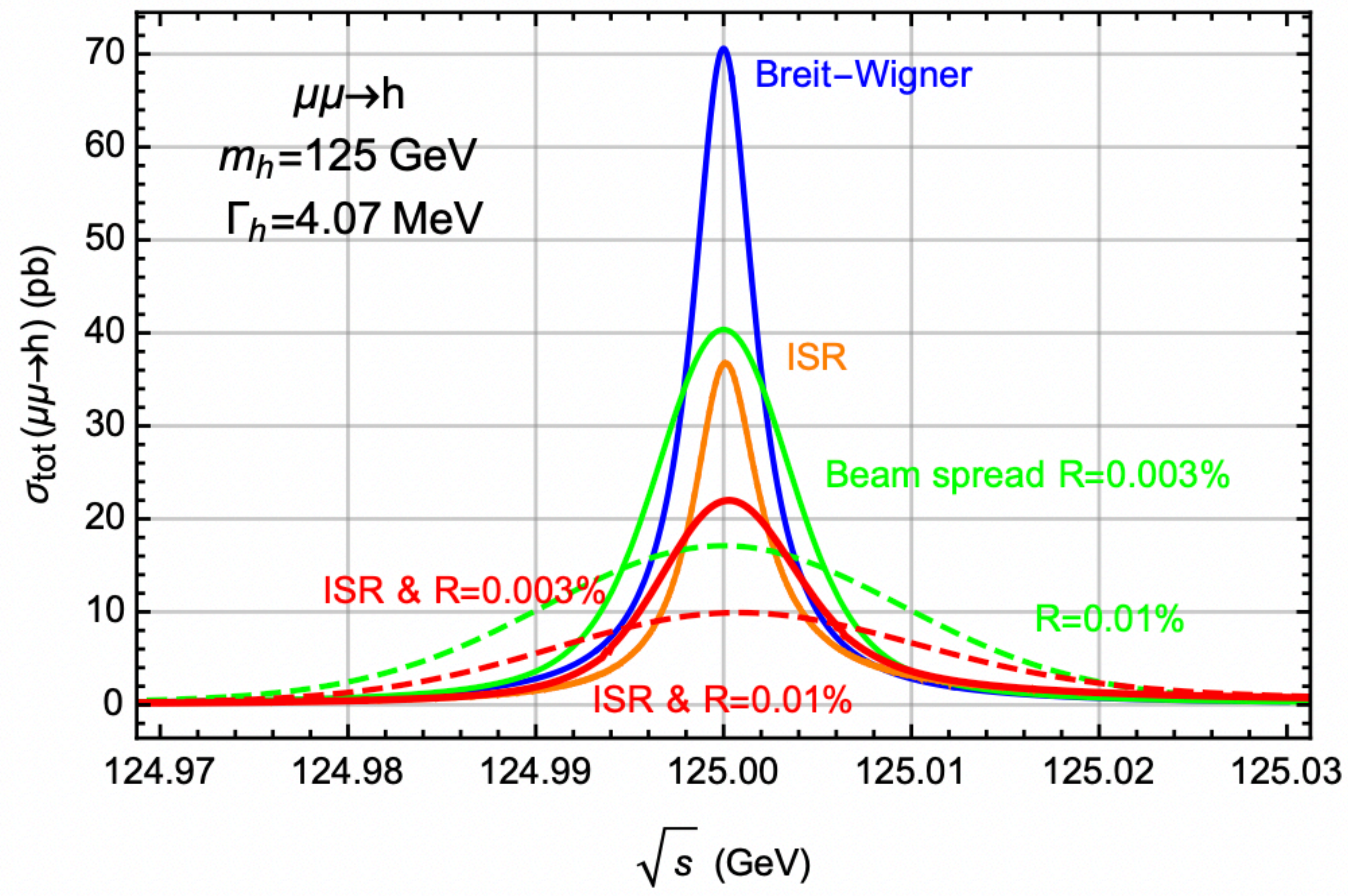

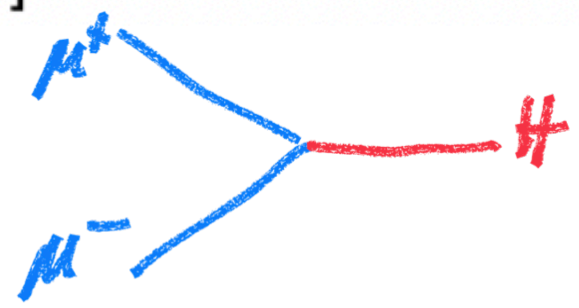

s-channel production at 125 GeV:

Cross section ~10^5 x e^+e^-: Coupling, + reduced ISR smearing for μ

Overall Precision Perspective

Including muon colliders

- An EFT fit, performed for Snowmass - hot of the press from earlier this week!

Electroweak Precision

A Playground for Circular Colliders

The FCC-ee Program at Z and WW

The ultimate electroweak program

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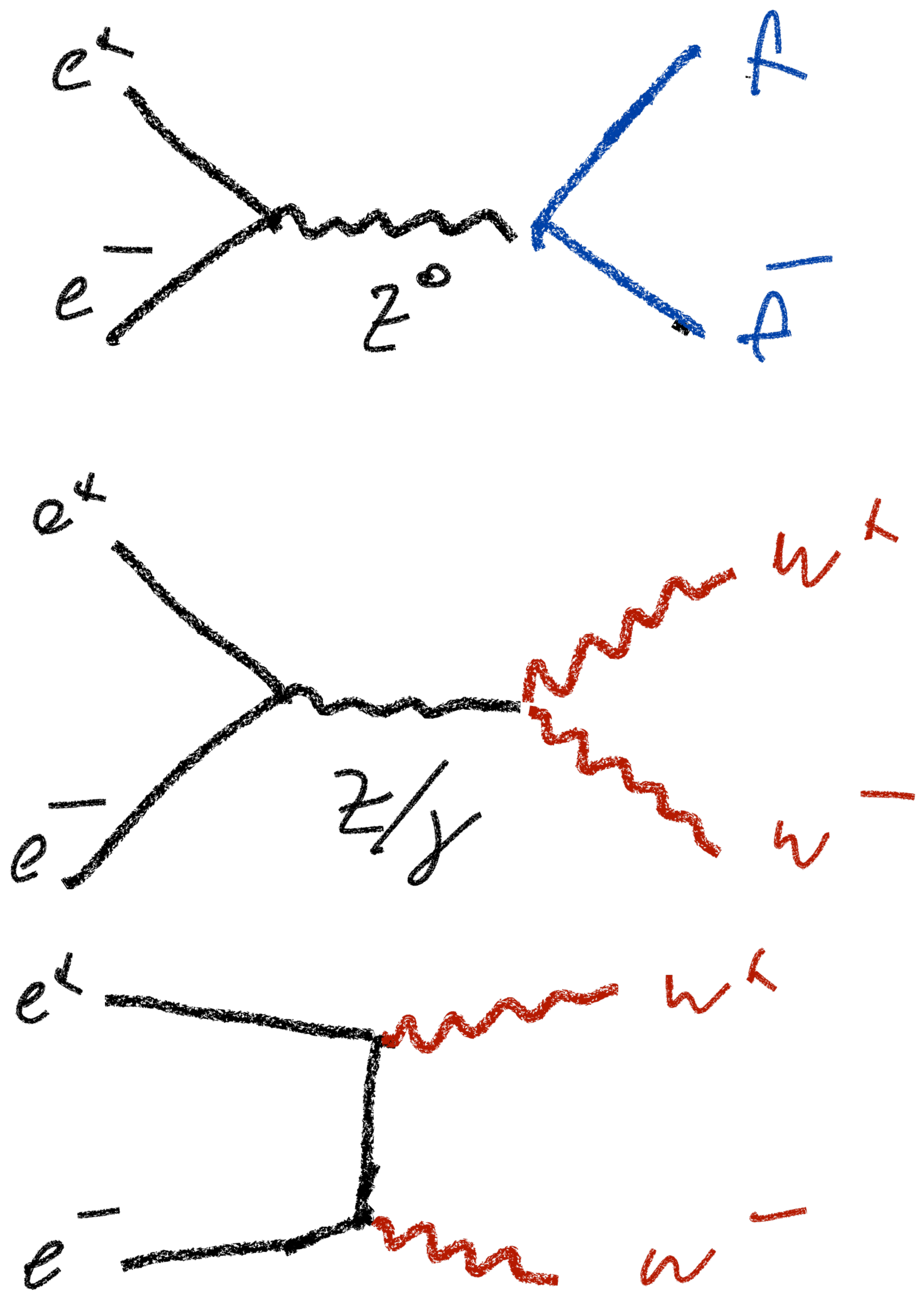

- Building on the success of LEP & LEP II
  - High-statistics program at the Z - pole
  - W pair production - mass measurement and beyond

with 2 IPs:

$5x10^{12}$ Zs (10^5 x LEP)

10^8 W pairs ($2x10^3$ x LEP)

N.B.: Measurements also possible at linear colliders, but the statistics will be orders of magnitude smaller due to their lower luminosity at low energy.

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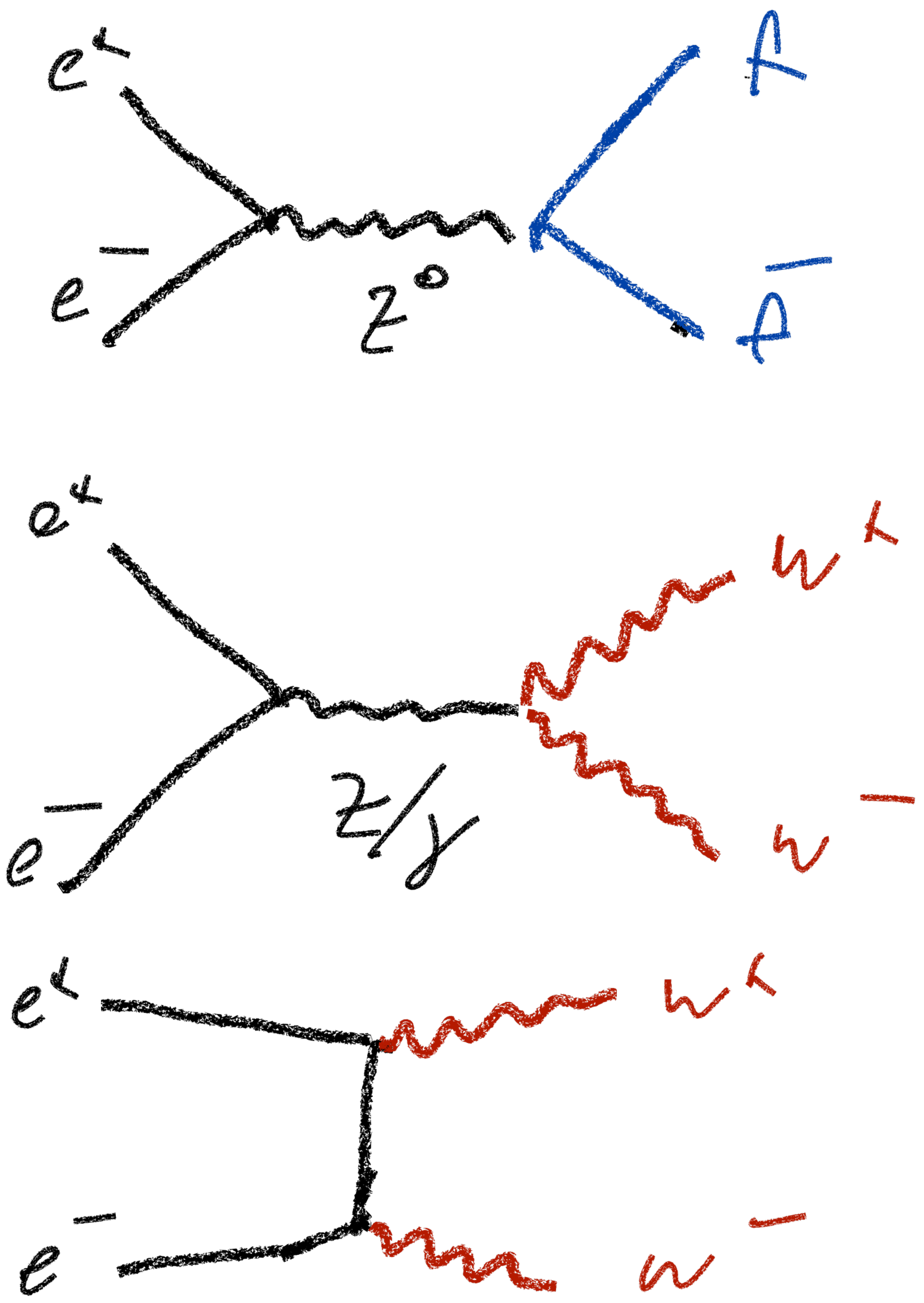

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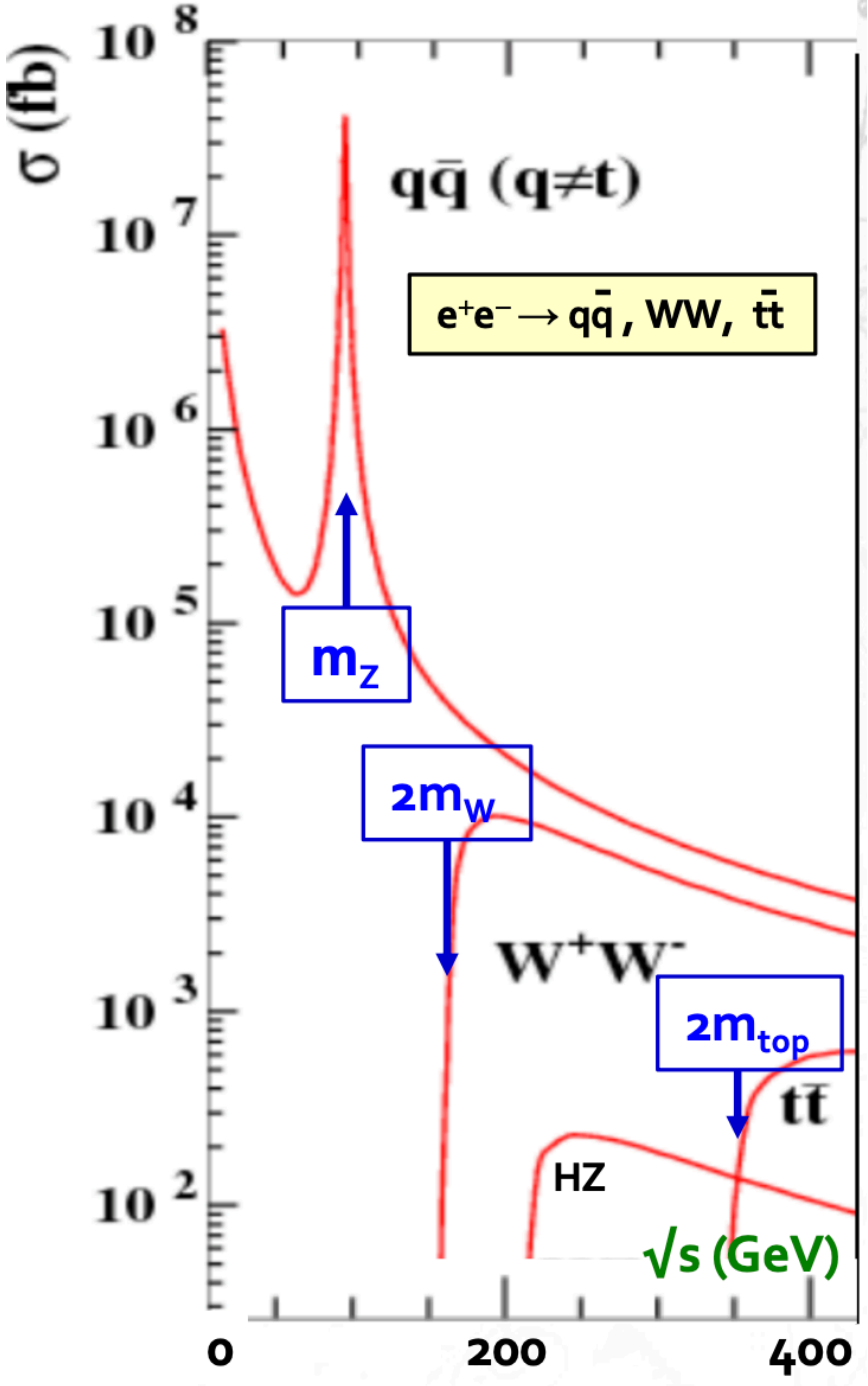
⇨ Improving electroweak precision observables, enter into global fits

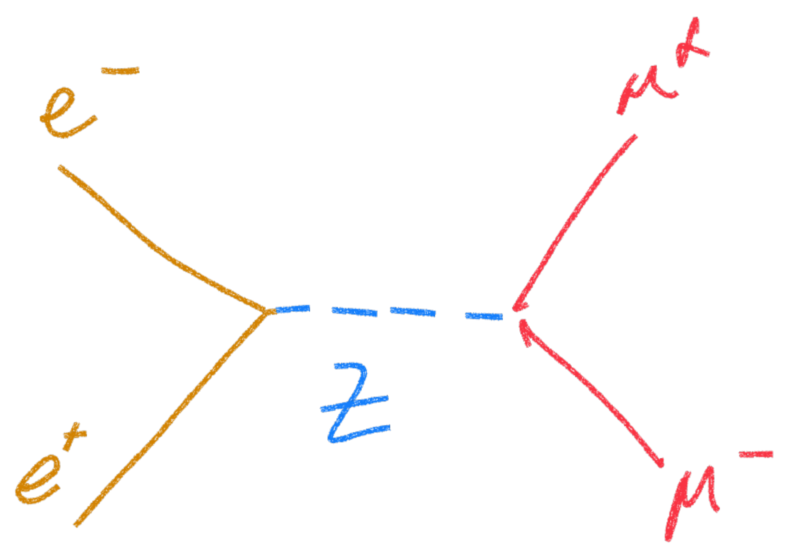
⇨ Indirect searches for New Physics

N.B.: Measurements also possible at linear colliders, but the statistics will be orders of magnitude smaller due to their lower luminosity at low energy.

Electroweak Measurements

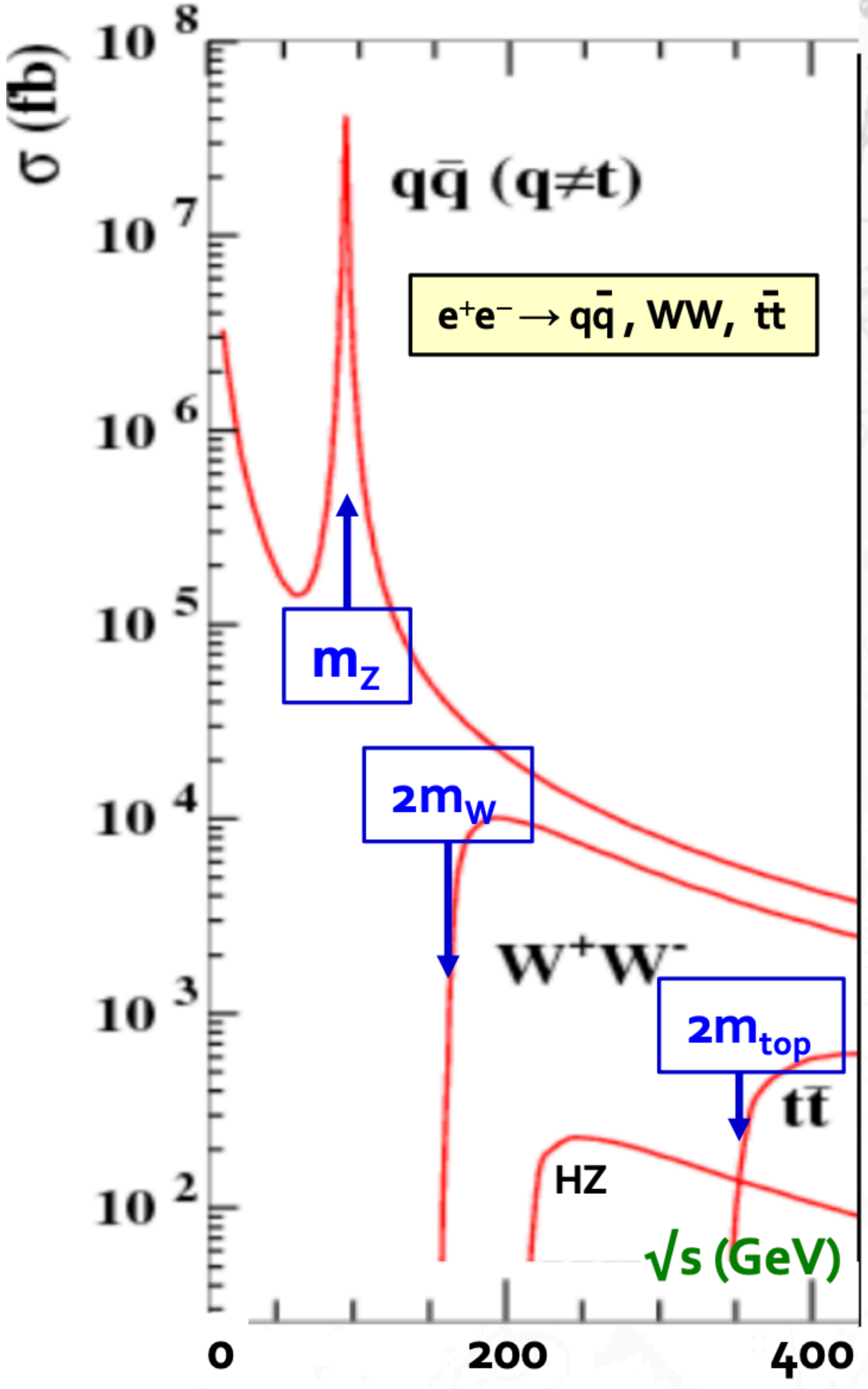
Cross sections and asymmetries

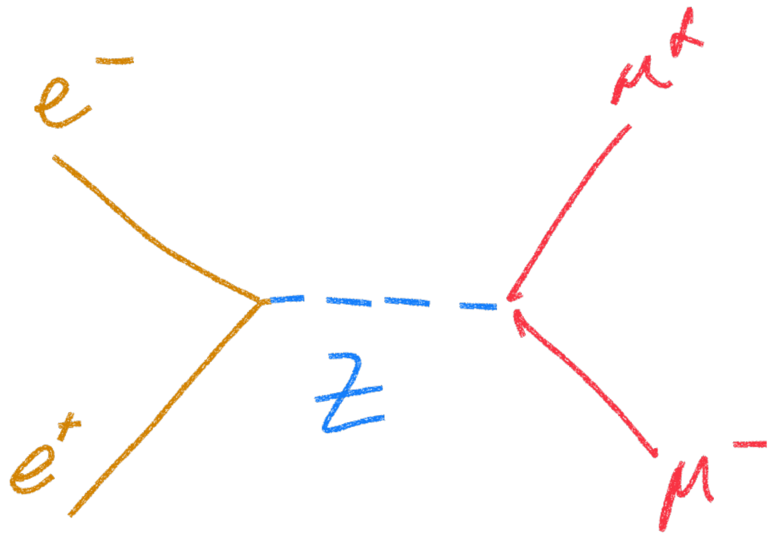


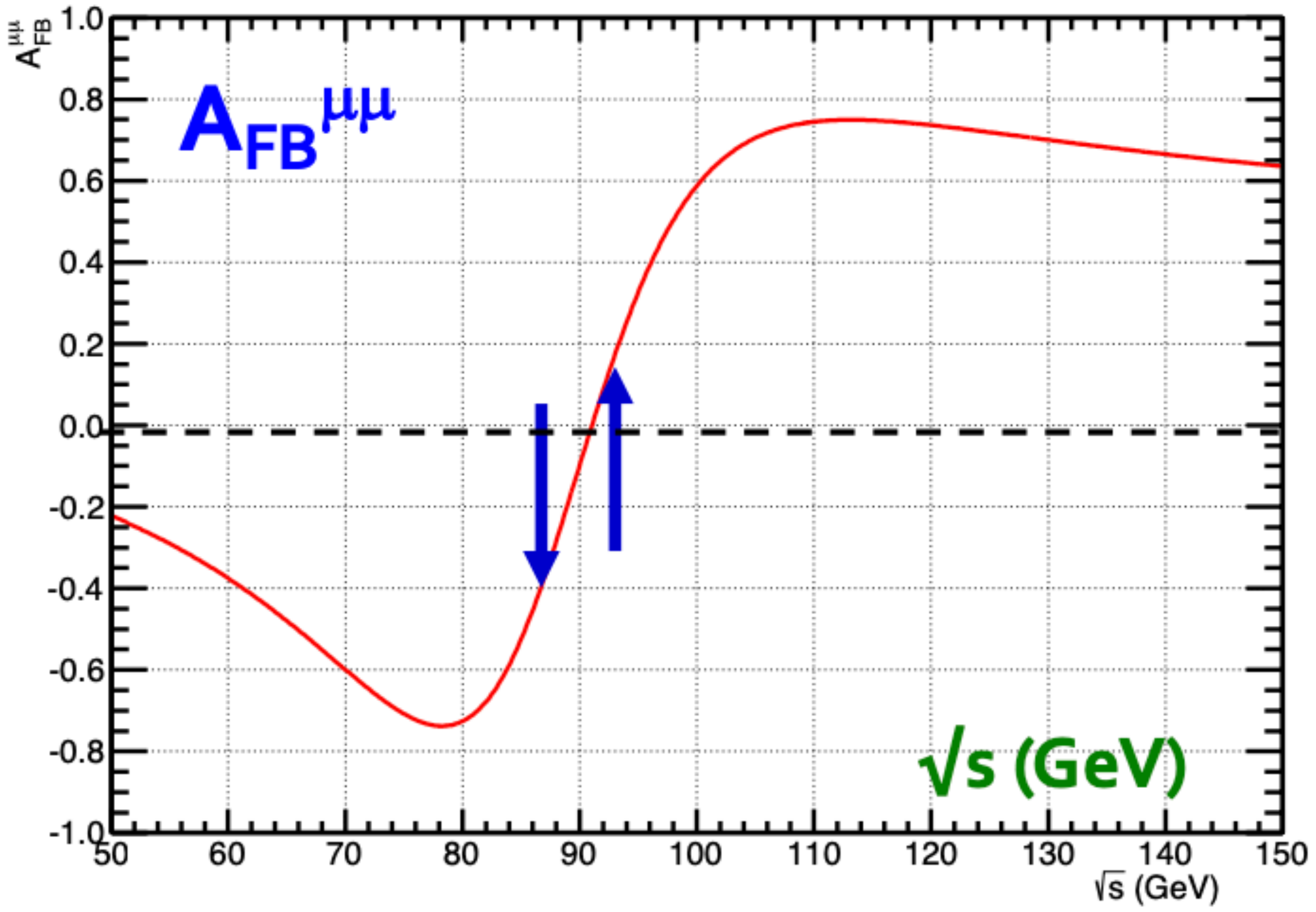


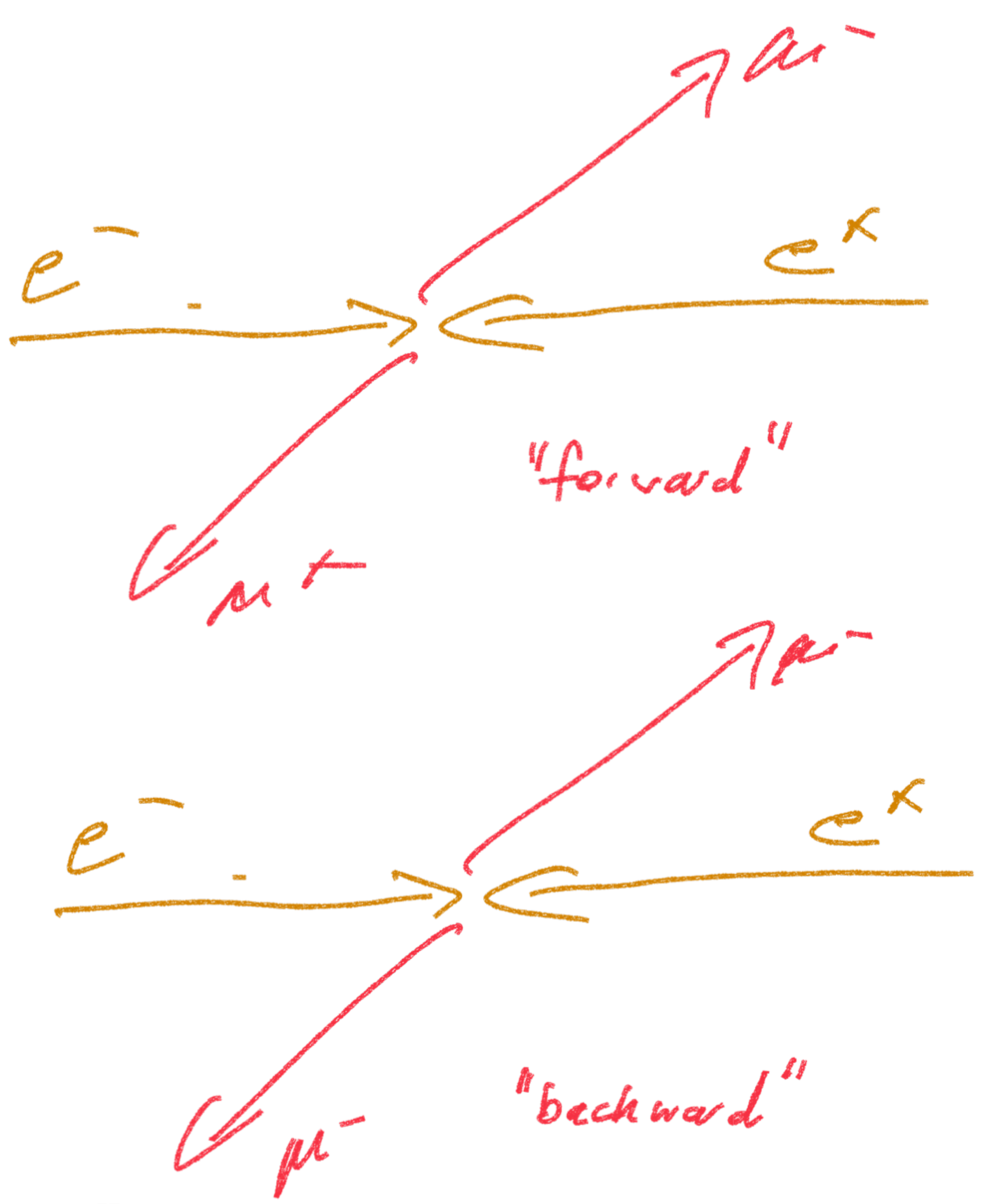
Electroweak Measurements

Cross sections and asymmetries







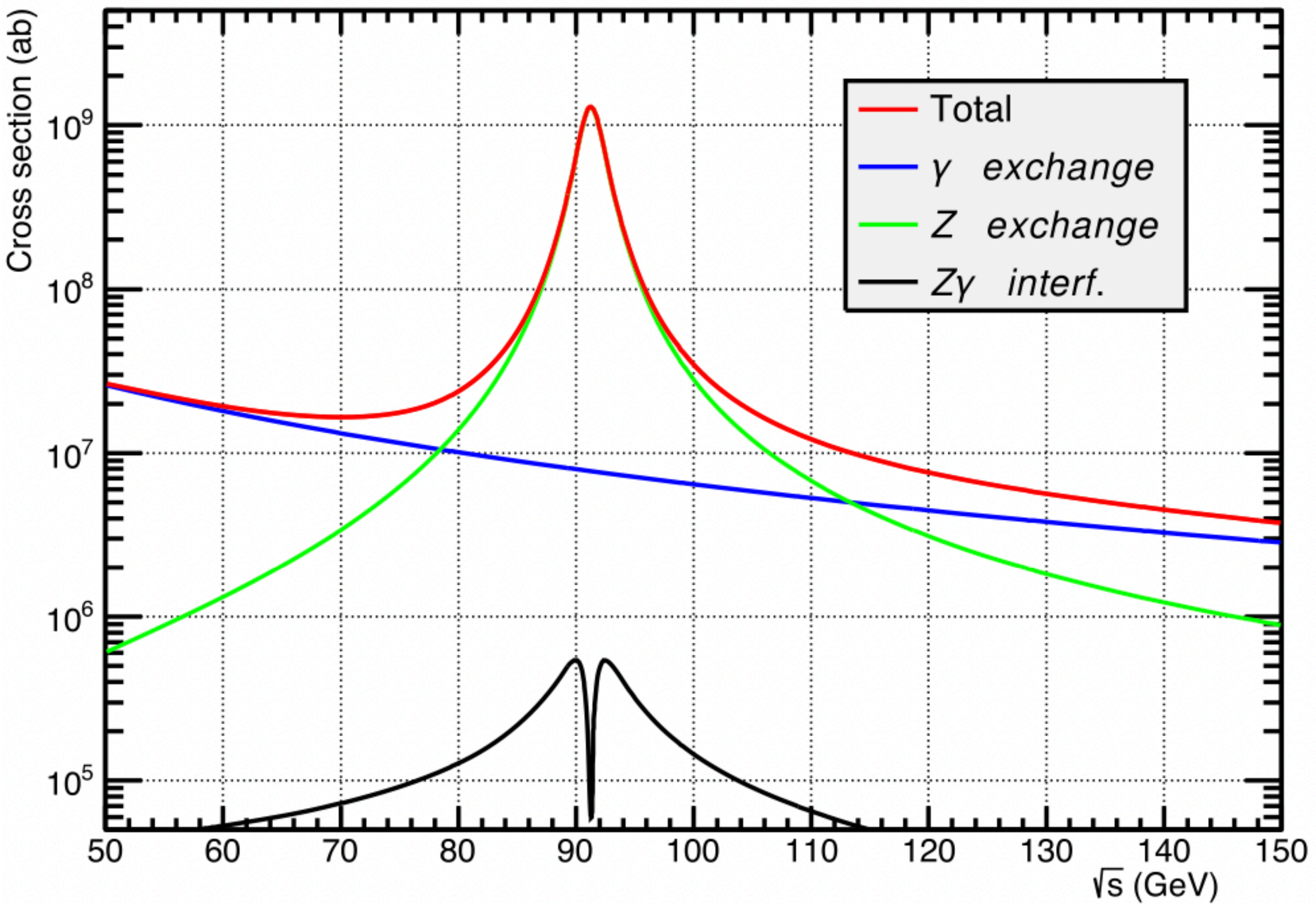


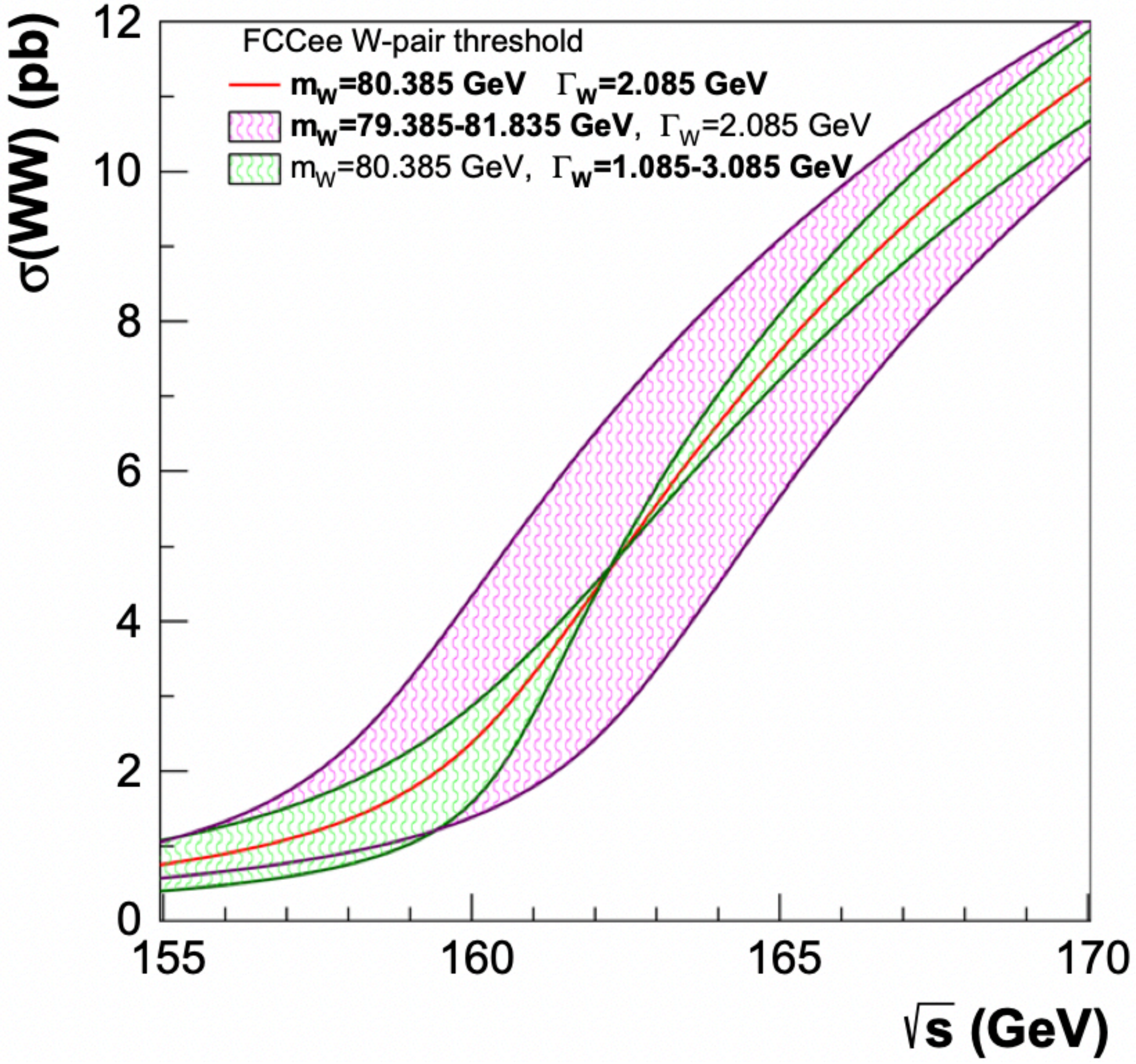
$$A_{FB}^{\mu\mu} = \frac{N_F^{\mu+} - N_B^{\mu+}}{N_F^{\mu+} + N_B^{\mu+}} \approx f(\sin^2 \vartheta_W^{eff}) + \alpha_{QED}(s)\frac{s - m_Z^2}{2s} g(\sin^2 \vartheta_W^{eff})$$

- Measure $\sin^2\Theta_W$ via A_{FB} at $\sqrt{s} = m_Z$
- Measure $\alpha_{QED}(m_Z)$ via A_{FB} slightly below and above resonance

Lineshapes and Thresholds

The things to explore





- Lineshapes, cross sections, asymmetries provide access to a wide range of electroweak precision measurements, putting the Standard Model to extremely stringent tests

FCC-ee Electroweak Projections

Summary

Observable	Present value ± error	FCC-ee Stat.	FCC-ee Syst.	Comment and dominant exp. error
m_Z (keV)	$91,186,700 \pm 2200$	4	100	From Z lineshape scan; beam energy calibration
Γ_Z (keV)	$2,495,200 \pm 2300$	4	25	From Z lineshape scan; beam energy calibration
R_ℓ^Z ($\times 10^3$)	$20,767 \pm 25$	0.06	0.2 – 1.0	Ratio of hadrons to leptons; acceptance for leptons
$\alpha_S(m_Z^2)$ ($\times 10^4$)	$1,196 \pm 30$	0.1	0.4 – 1.6	From R_ℓ^Z above
R_b ($\times 10^6$)	$216,290 \pm 660$	0.3	< 60	Ratio of $b\bar{b}$ to hadrons; stat. extrapol. from SLD
$\sigma^0_{\rm had}$ ($\times 10^3$) (nb)	$41,541 \pm 37$	0.1	4	Peak hadronic cross section; luminosity measurement
N_ν ($\times 10^3$)	$2,996 \pm 7$	0.005	1	Z peak cross sections; luminosity measurement
$\sin^2\theta_W^{\rm eff}$ ($\times 10^6$)	$231,480 \pm 160$	1.4	1.4	From $A_{FB}^{\mu\mu}$ at Z peak; beam energy calibration
$1/\alpha_{\rm QED}(m_Z^2)$ ($\times 10^3$)	$128,952 \pm 14$	3.8	1.2	From $A_{FB}^{\mu\mu}$ off peak
$A_{FB}^{b,0}$ ($\times 10^4$)	992 ± 16	0.02	1.3	b-quark asymmetry at Z pole; from jet charge
A_e ($\times 10^4$)	$1,498 \pm 49$	0.07	0.2	from $A_{FB}^{{\rm pol},\tau}$; systematics from non-τ backgrounds
m_W (MeV)	$80,350 \pm 15$	0.25	0.3	From WW threshold scan; beam energy calibration
Γ_W (MeV)	$2,085 \pm 42$	1.2	0.3	From WW threshold scan; beam energy calibration
N_ν ($\times 10^3$)	$2,920 \pm 50$	0.8	Small	Ratio of invis. to leptonic in radiative Z returns
$\alpha_S(m_W^2)$ ($\times 10^4$)	$1,170 \pm 420$	3	Small	From R_ℓ^W

Flavour Physics

Increasing interest

- An e^+e^- collider running at the Z pole is also an excellent flavour factory!
  The 5 x 10^{12} Zs at FCC-ee will provide: 10^{12} bb events, 1.7 x 10^{11} $\tau^+\tau^-$ events
  An excellent testing ground of universality, rare decays; precision measurements of masses and lifetimes

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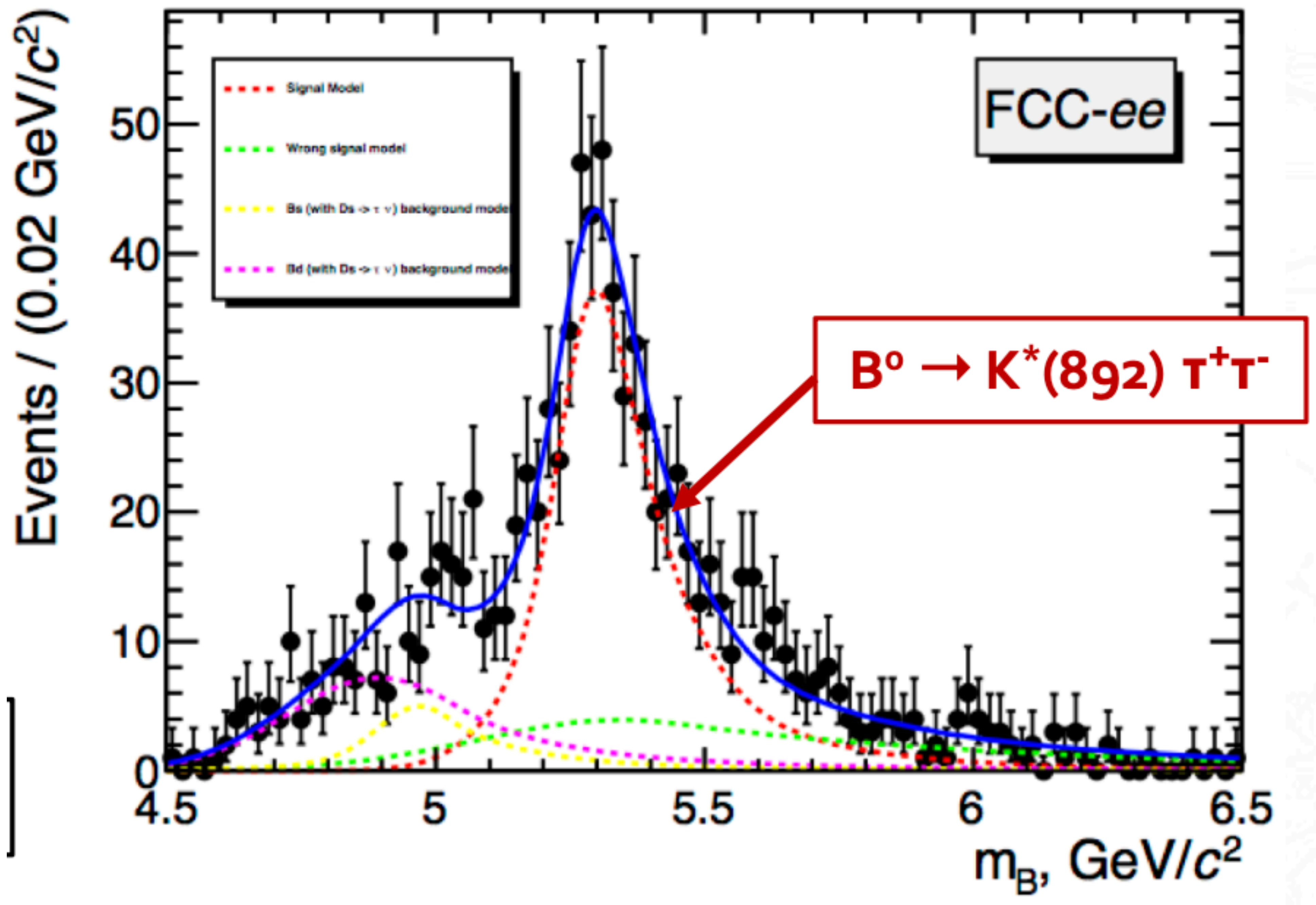
High-statistics measurements to follow up on hints for Lepton Flavour non-universality seen in b->sll transitions



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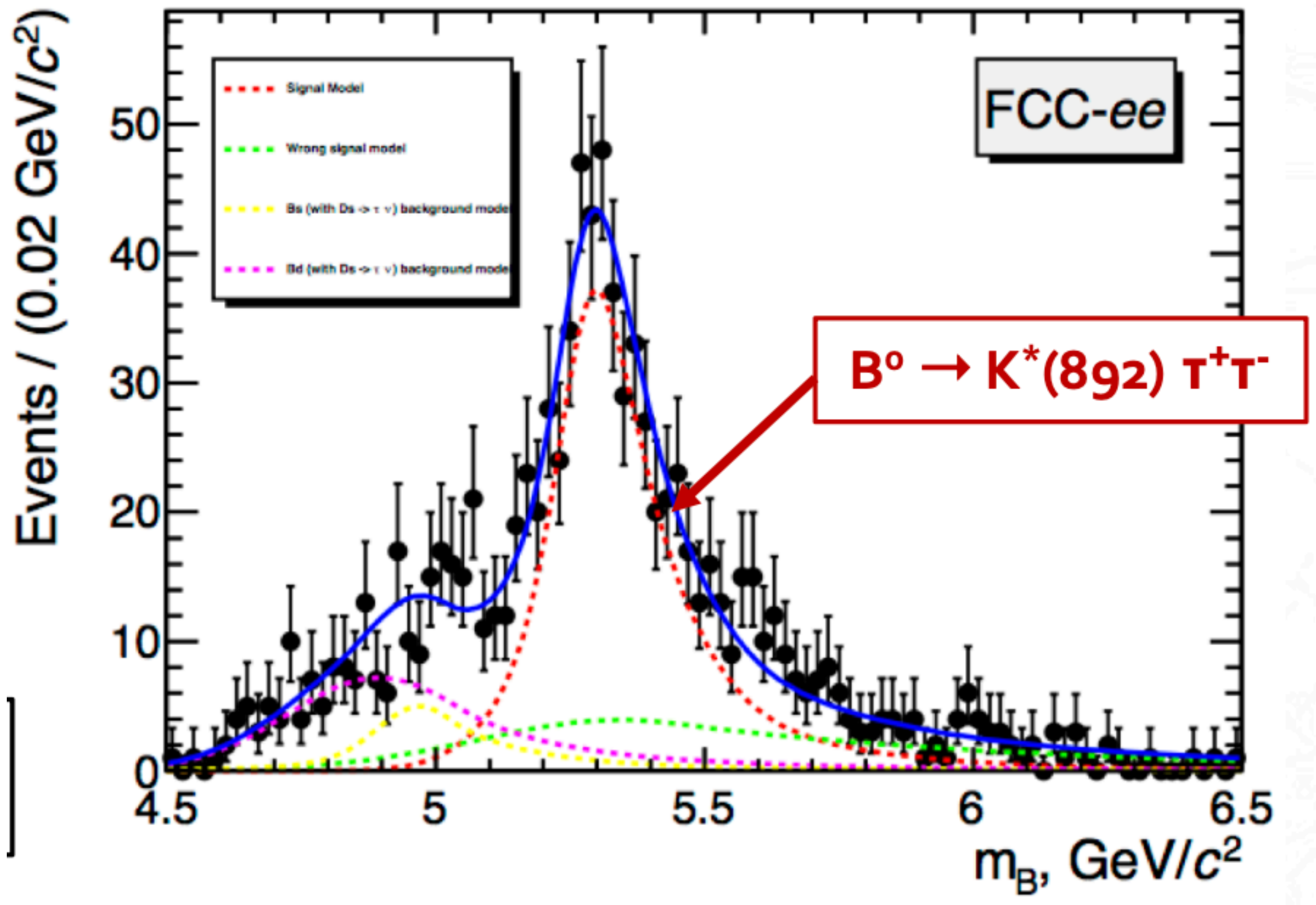
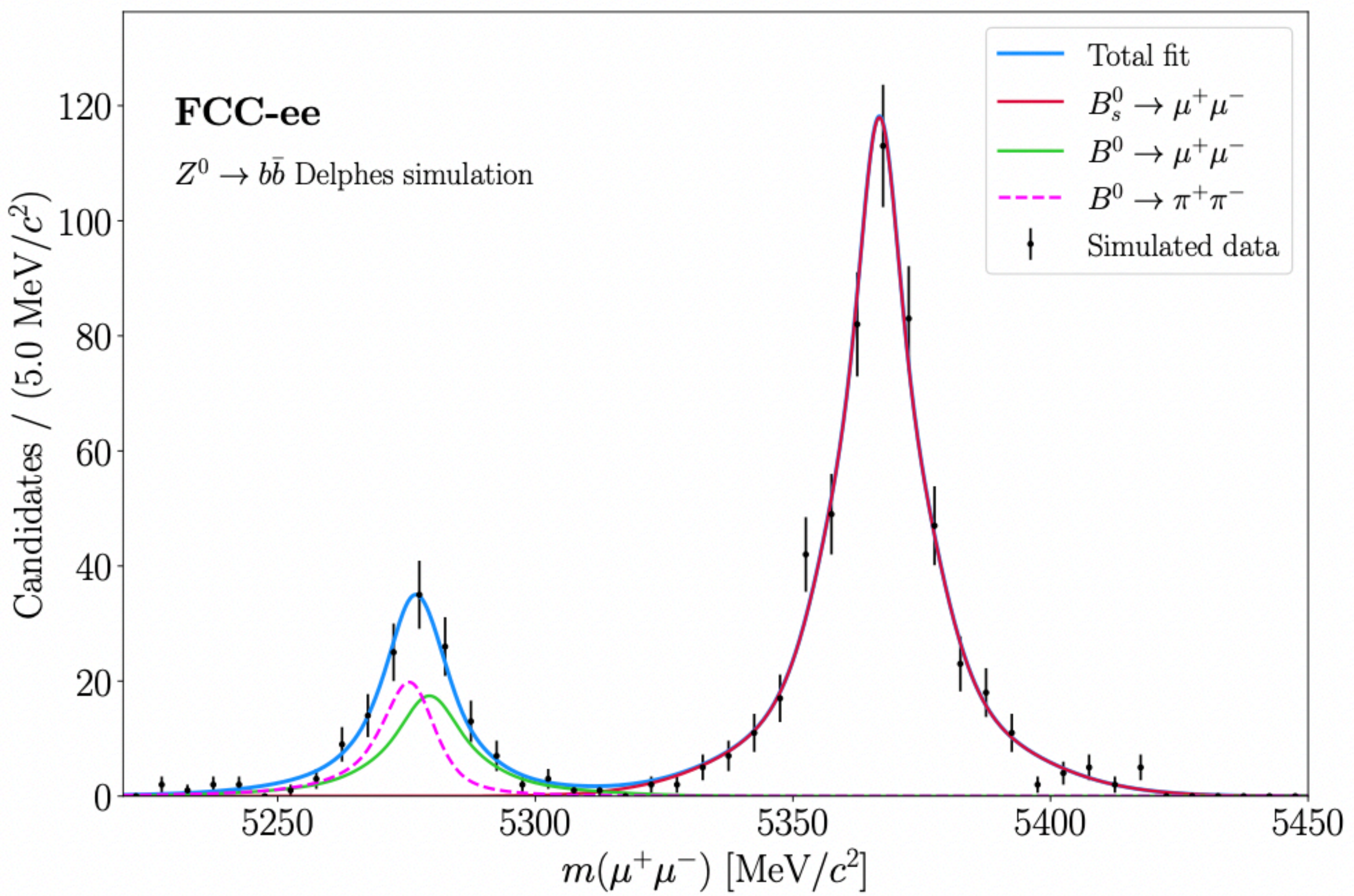


Explore rare be decays with unprecedented precision.
Study of CP violation, the CKM matrix, …



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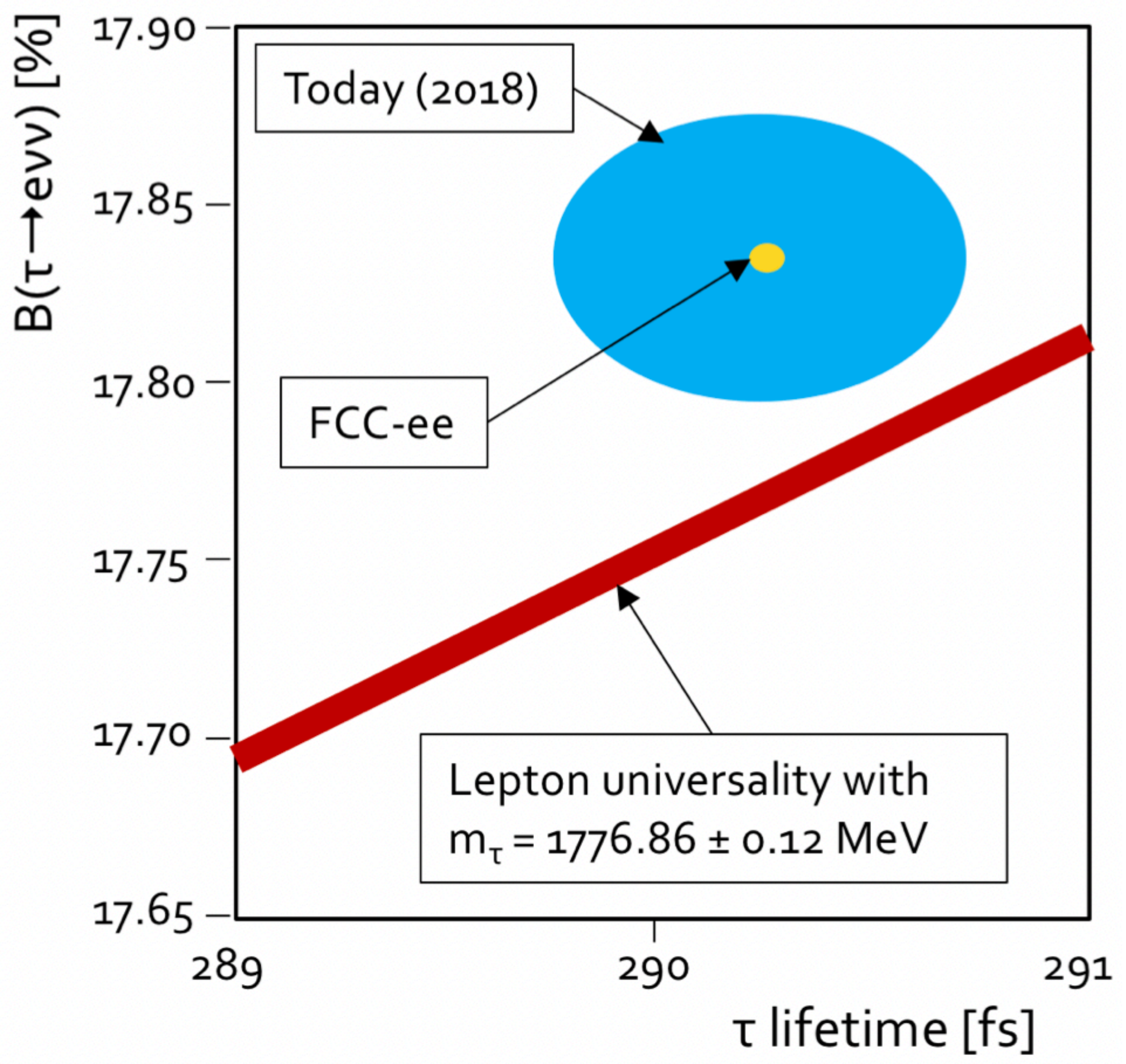

A precise study of the τ - extending beyond Belle II now beginning

Observable	Current precision	FCC-ee stat.	Possible syst.
m_τ [MeV]	1776.86 ± 0.12	0.004	0.1
τ_τ [fs]	290.3 ± 0.5 fs	0.001	0.04
$B(\tau\rightarrow e\nu\nu)$ [%]	17.82 ± 0.05	0.0001	0.003
$B(\tau\rightarrow \mu\nu\nu)$ [%]	17.39 ± 0.05		

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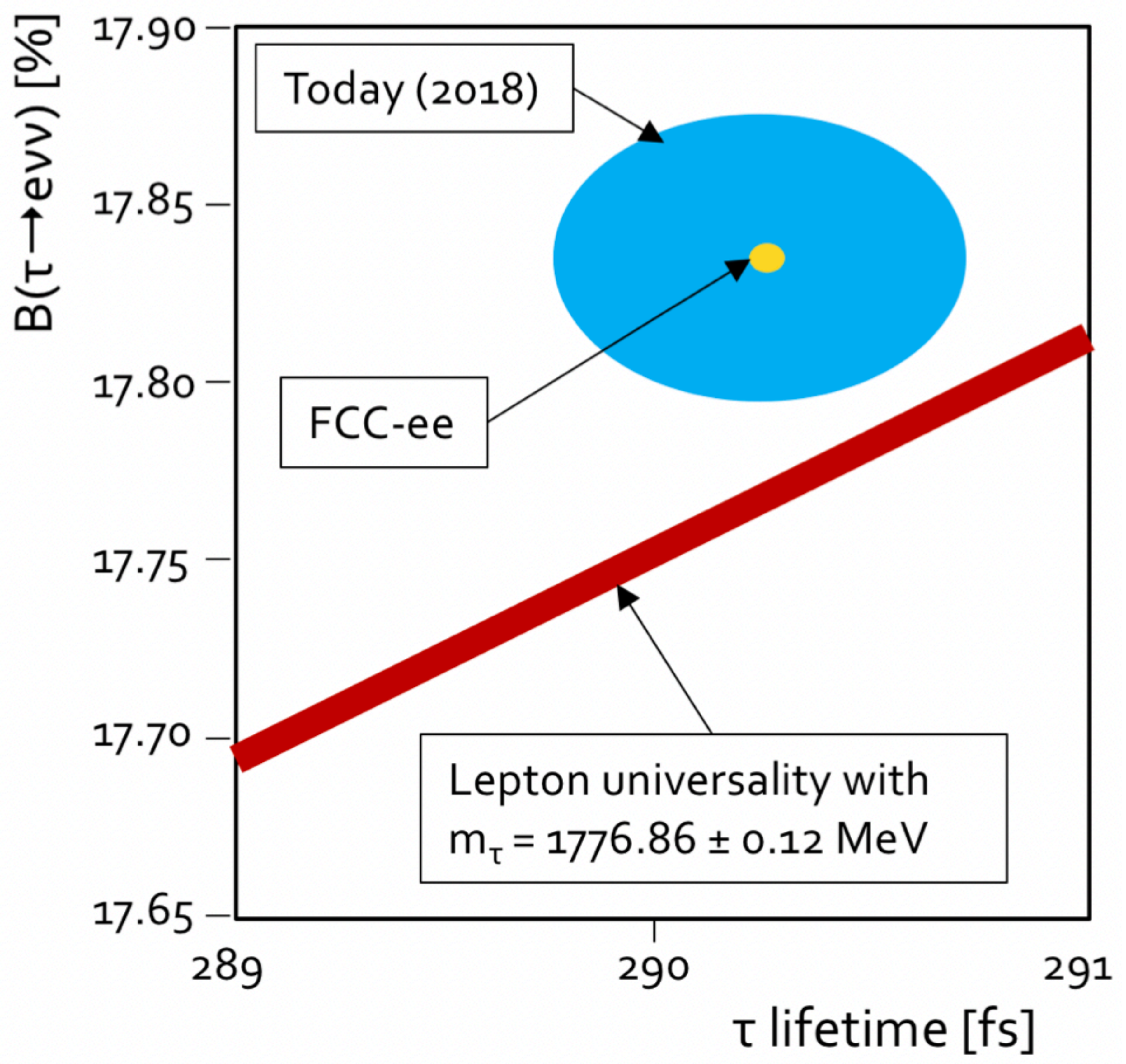

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B(τ→μνν) [%]	17.39 **± 0.05**		

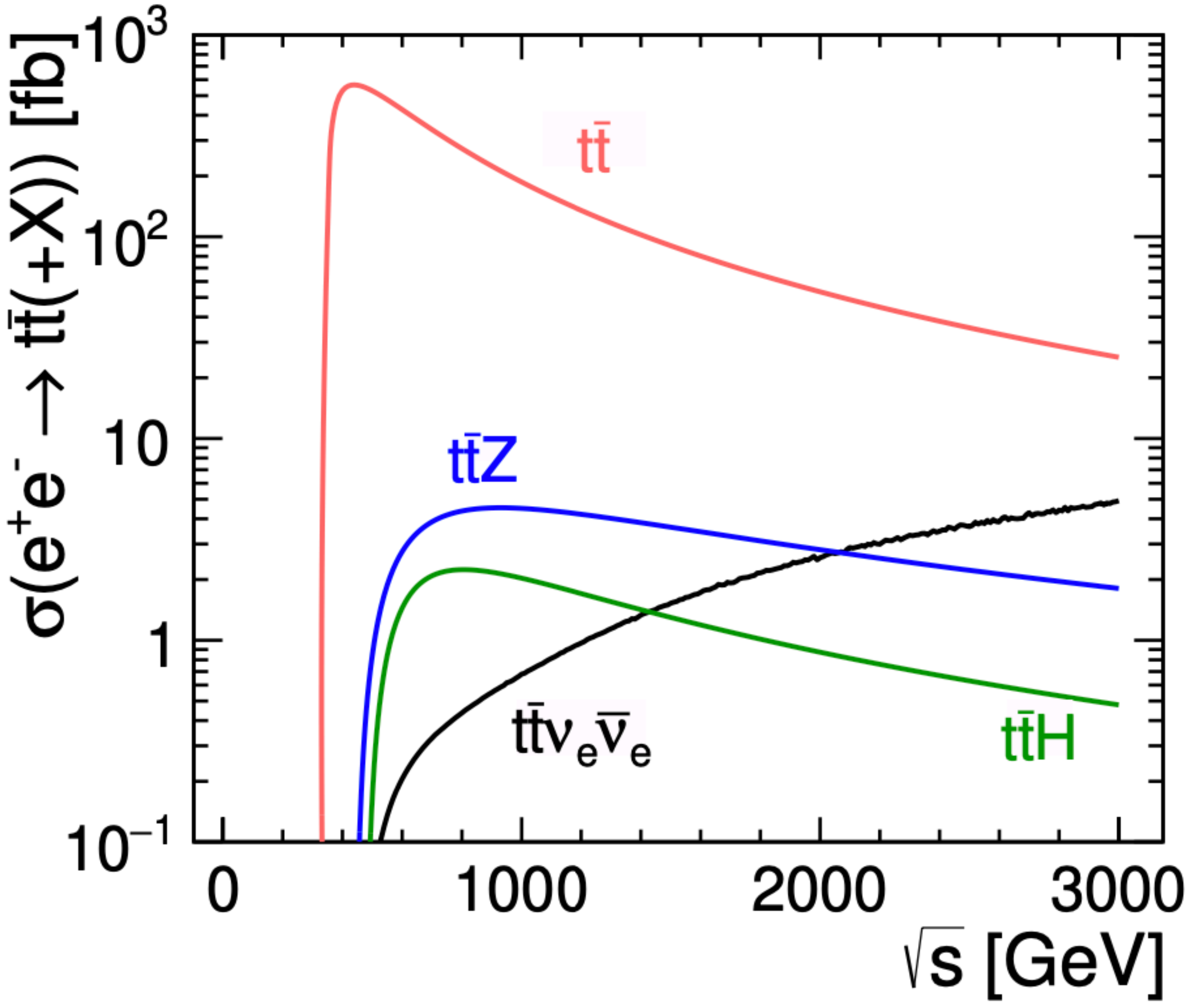
N.B.: Flavour physics introduces specific detector requirements such as PID, typically not front-and-center in Higgs Factory detector designs

The Top Quark

A new arena at 350 GeV and above

Overview: Top Physics at e+e- Colliders

Understanding the Top, using the Top



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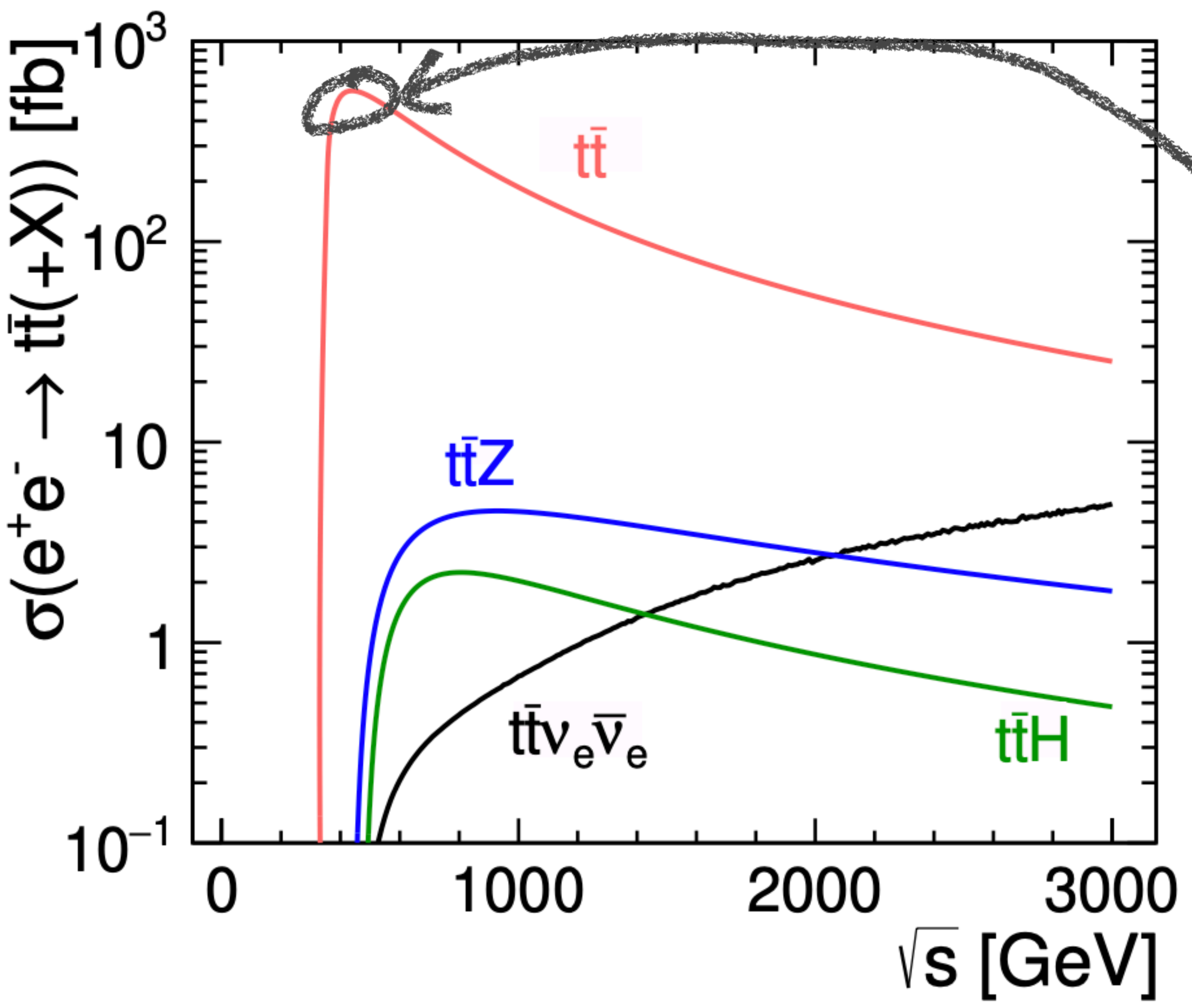

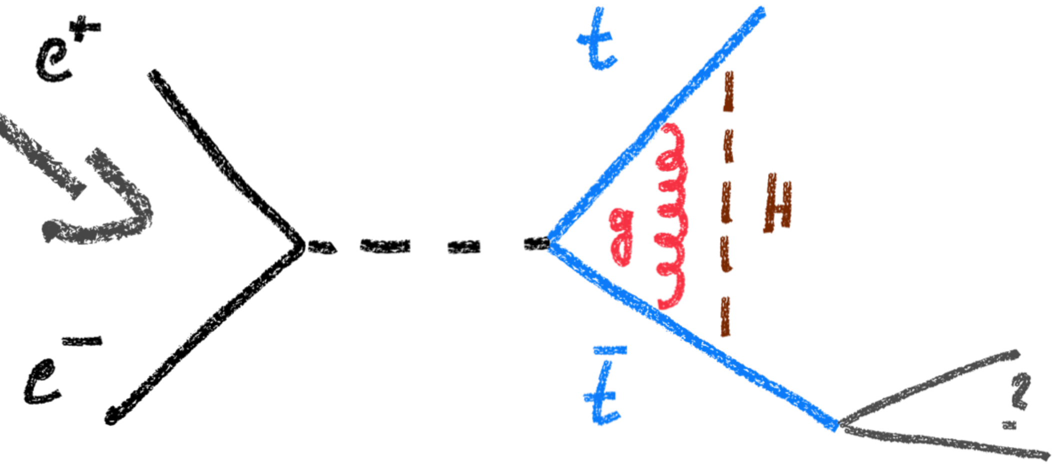

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- Search for BSM decays in clean environment

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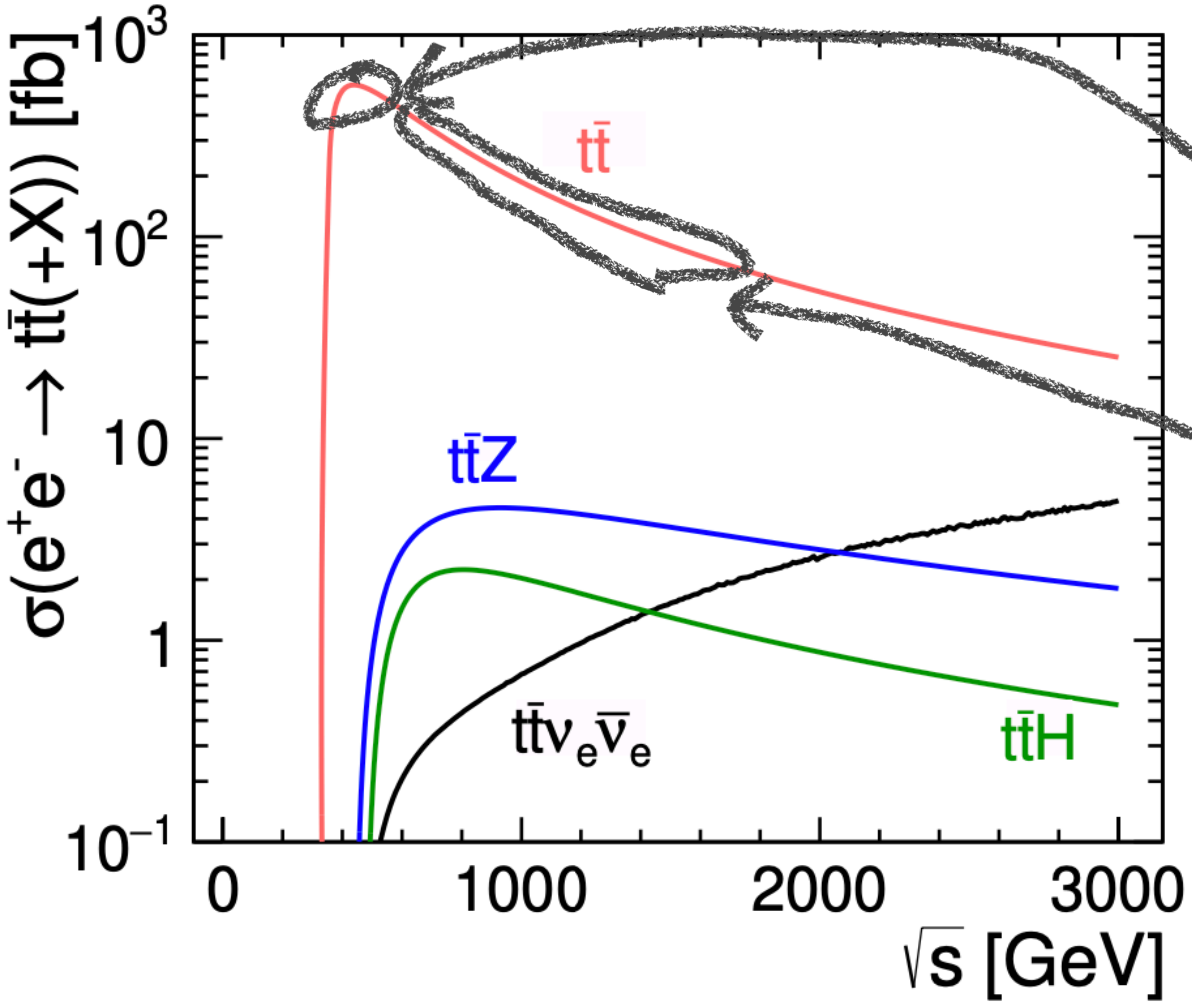

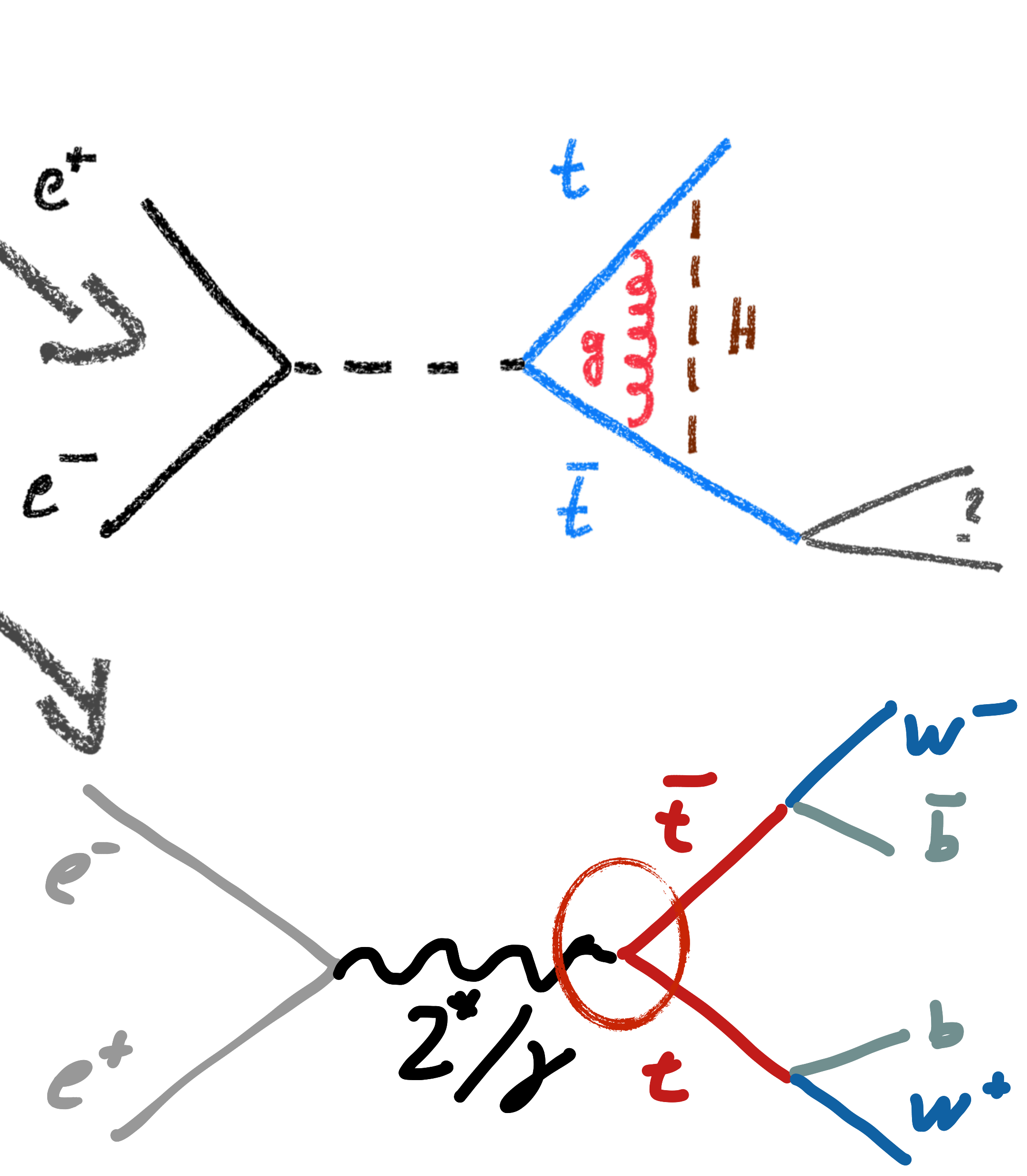

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Overview: Top Physics at e⁺e⁻ Colliders

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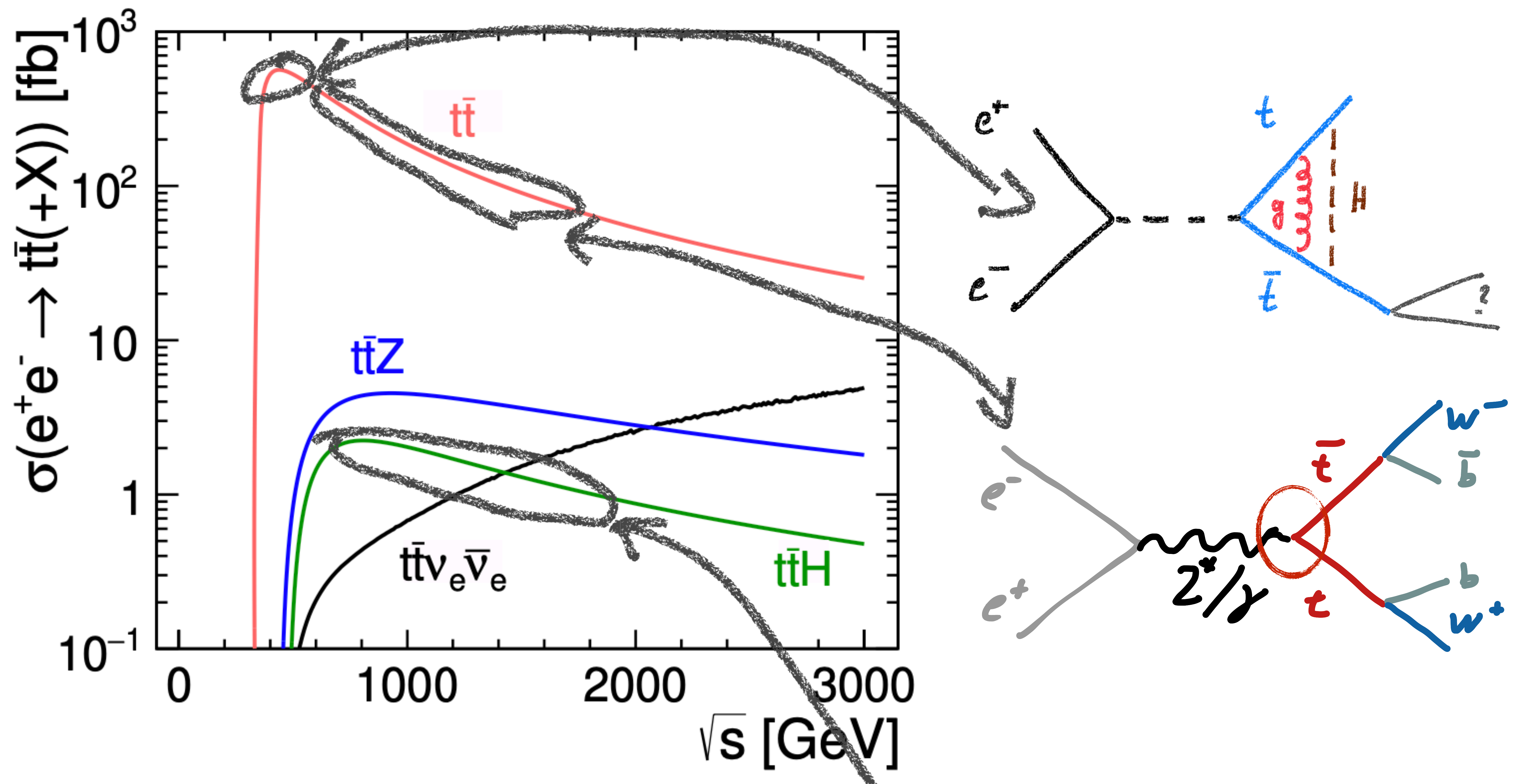

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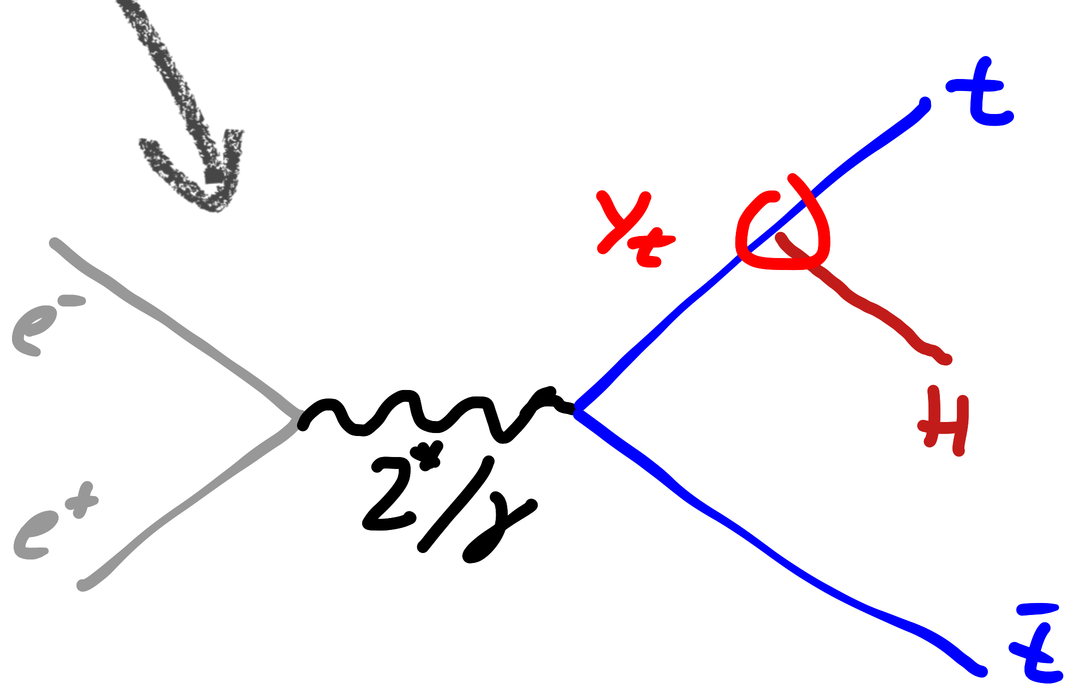


- Direct measurement of the top Yukawa coupling, ultimate potential of 2%
  [requires > 500 GeV, full scope assumes ~ 1 TeV]

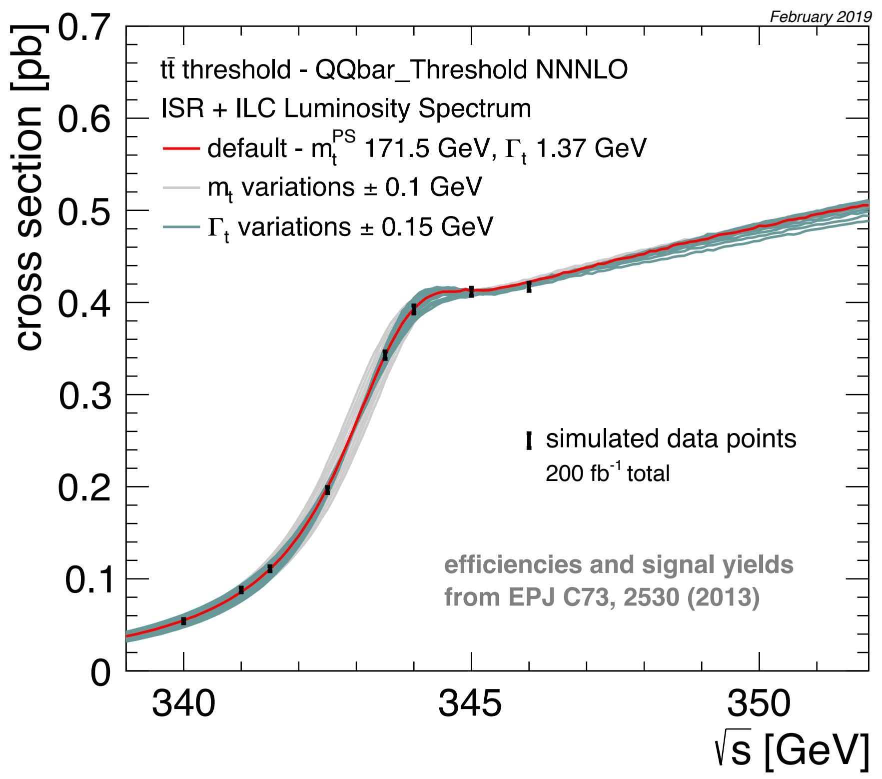
The Top Quark Mass (and other parameters)

Possibilities & Precision

- The accelerator side: Requires sufficient collision energy for top pair production
  - So far thoroughly studied for ILC, CLIC, threshold studies common for CLIC, FCC-ee, ILC

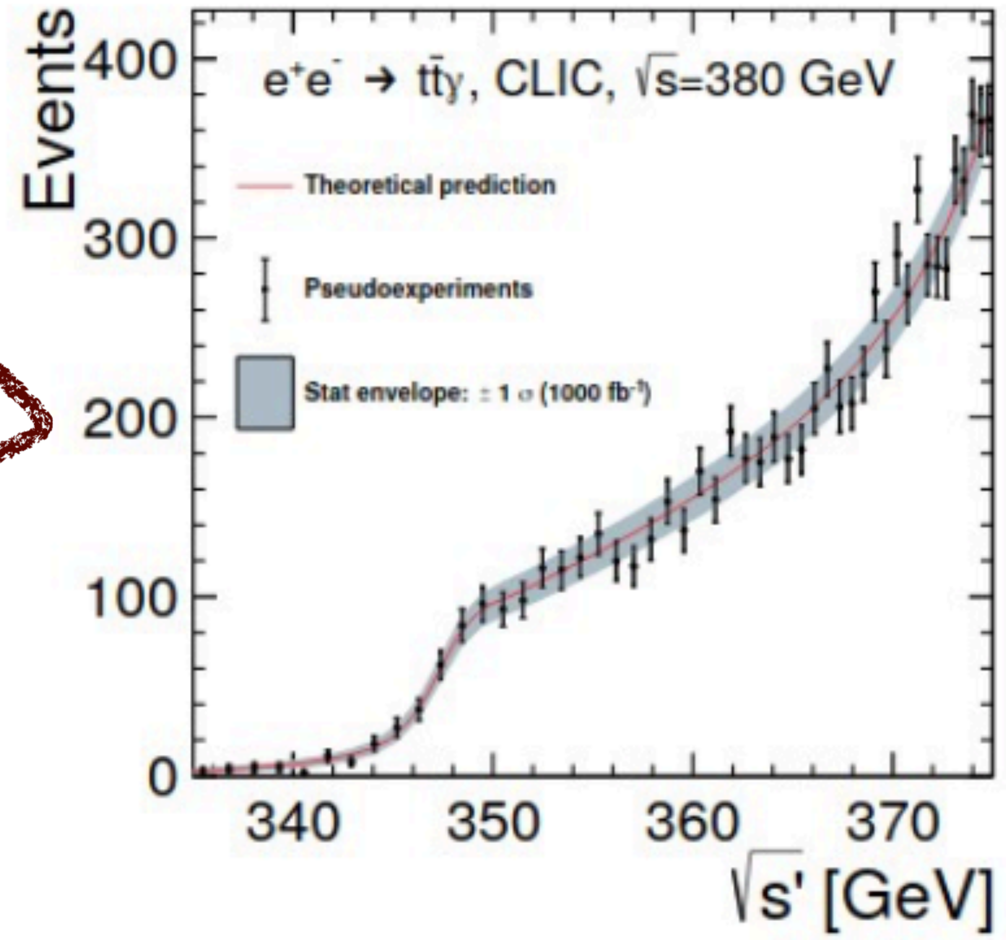
Three approaches to the top mass

The threshold scan around 350 GeV

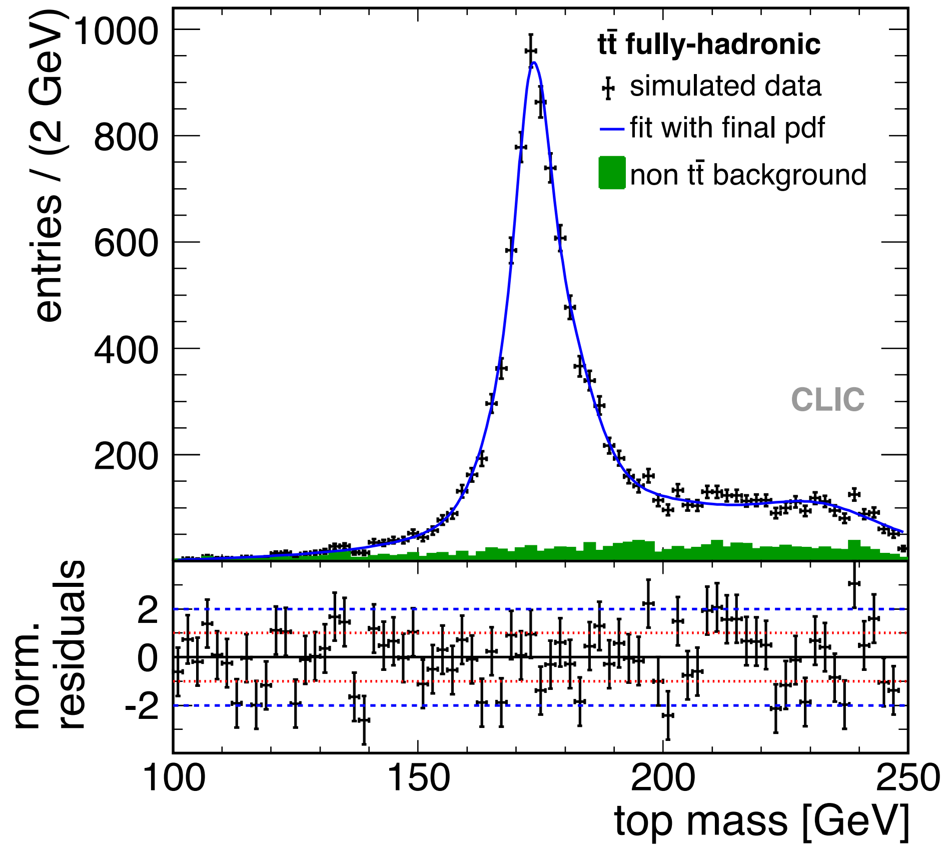


Extraction of the mass in theoretically well-defined mass definition (1S, PS): can directly be used in precision calculations, minimal conversion uncertainties to MSbar mass etc.

The top mass from radiative events



Direct kinematic reconstruction



measurement of a "MC mass": Interpretation uncertainties of several 100 MeV

The Top Quark Mass

Ultimate precision at the threshold

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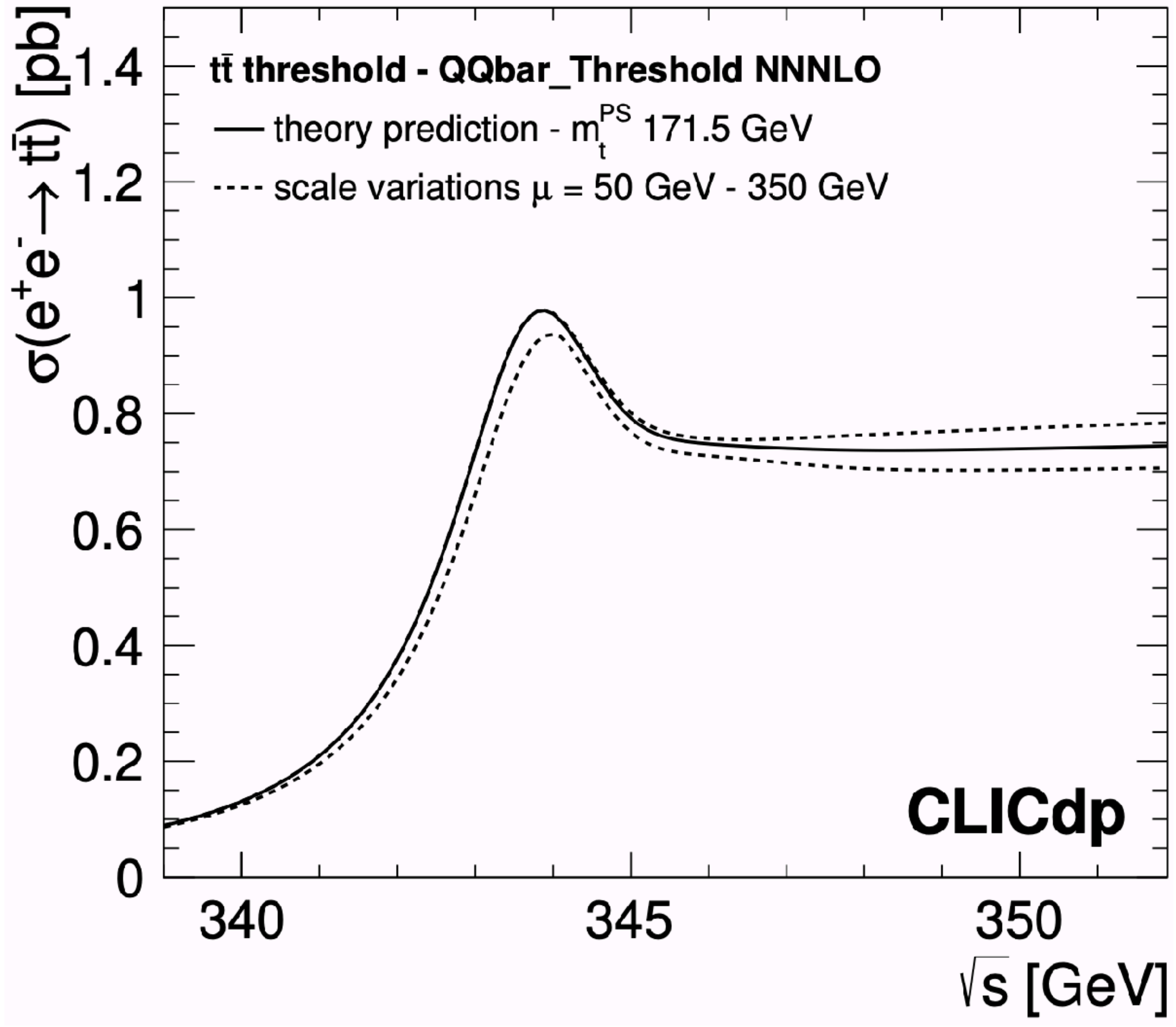

- Exploit precise theoretical calculations of cross section in the threshold region, in well-defined mass schemes (m_t^{PS}, m_t^{1S}…) -> Can be converted directly into MSbar mass.

The Top Quark Mass

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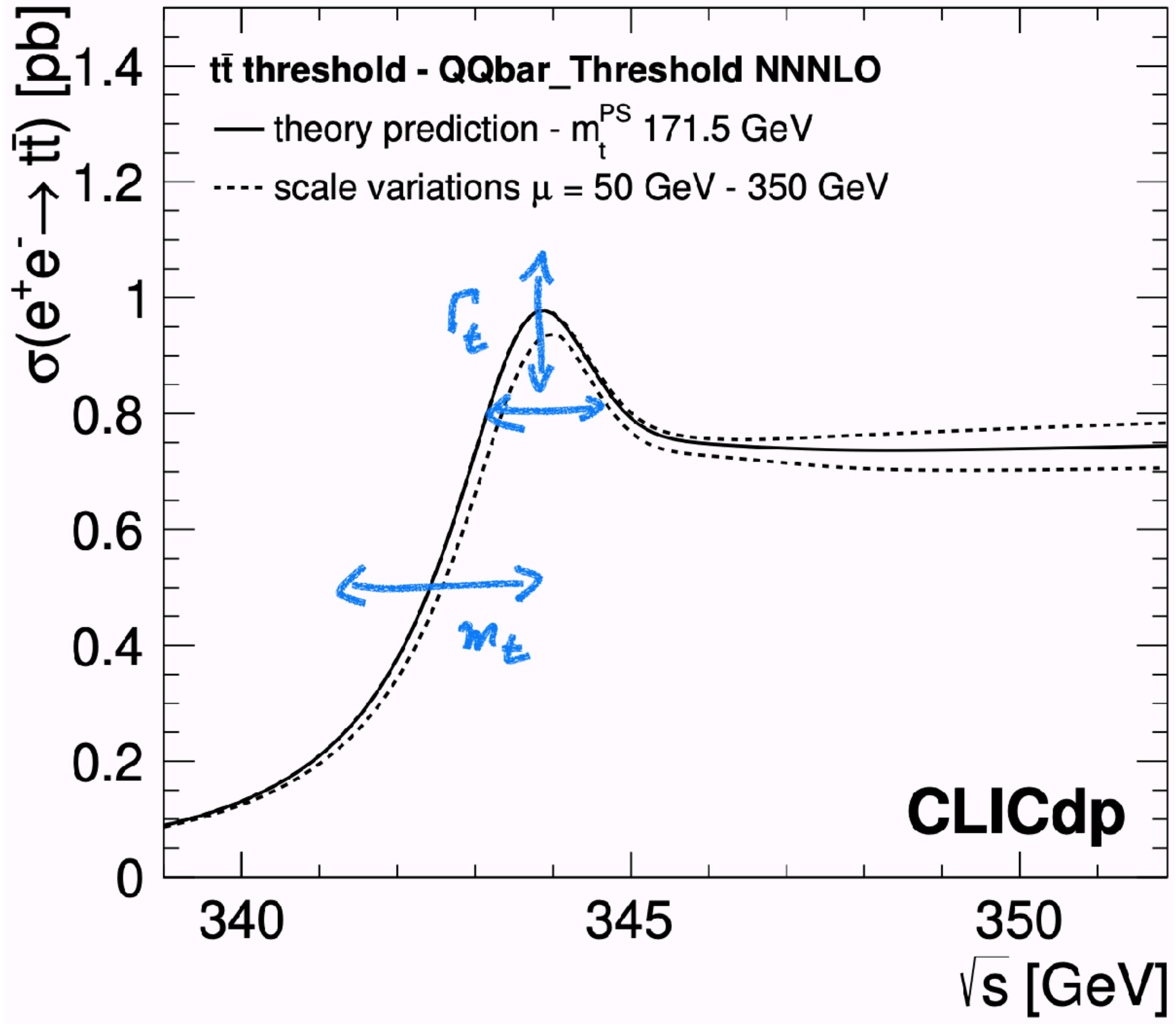

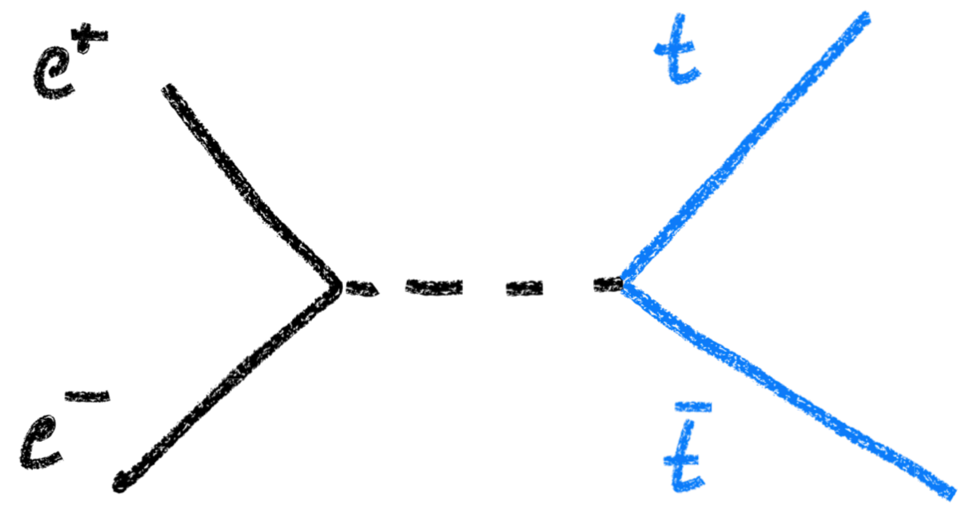

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The threshold is sensitive to top quark properties

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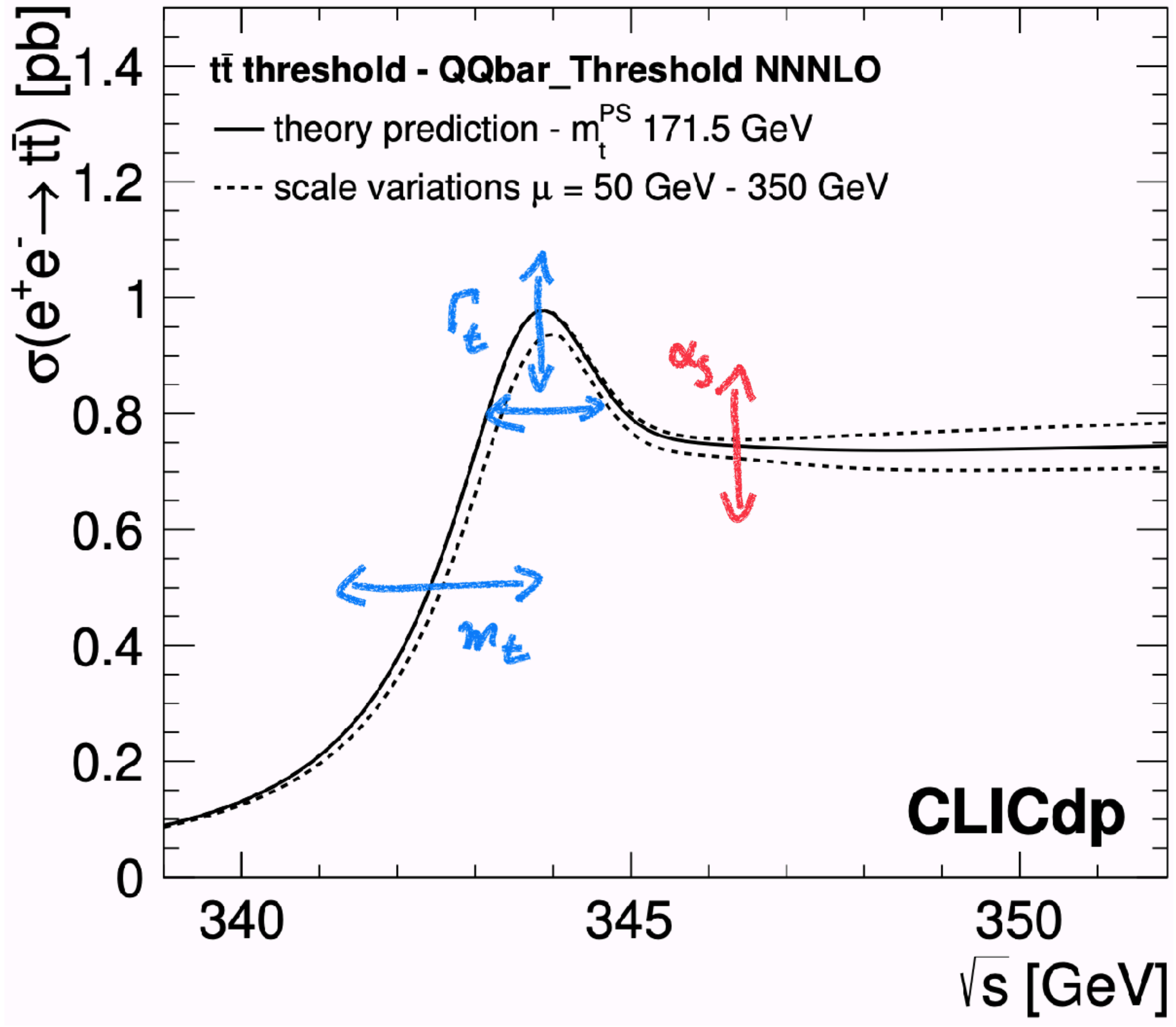

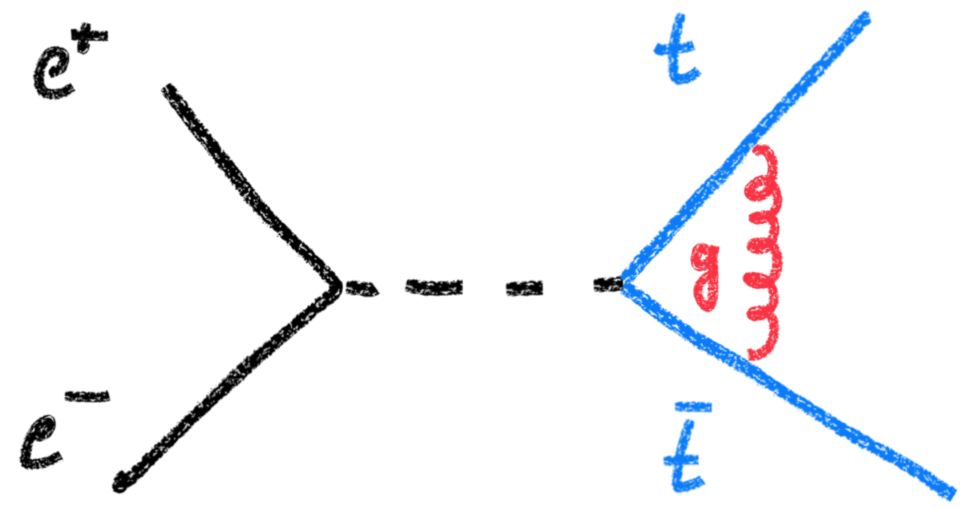

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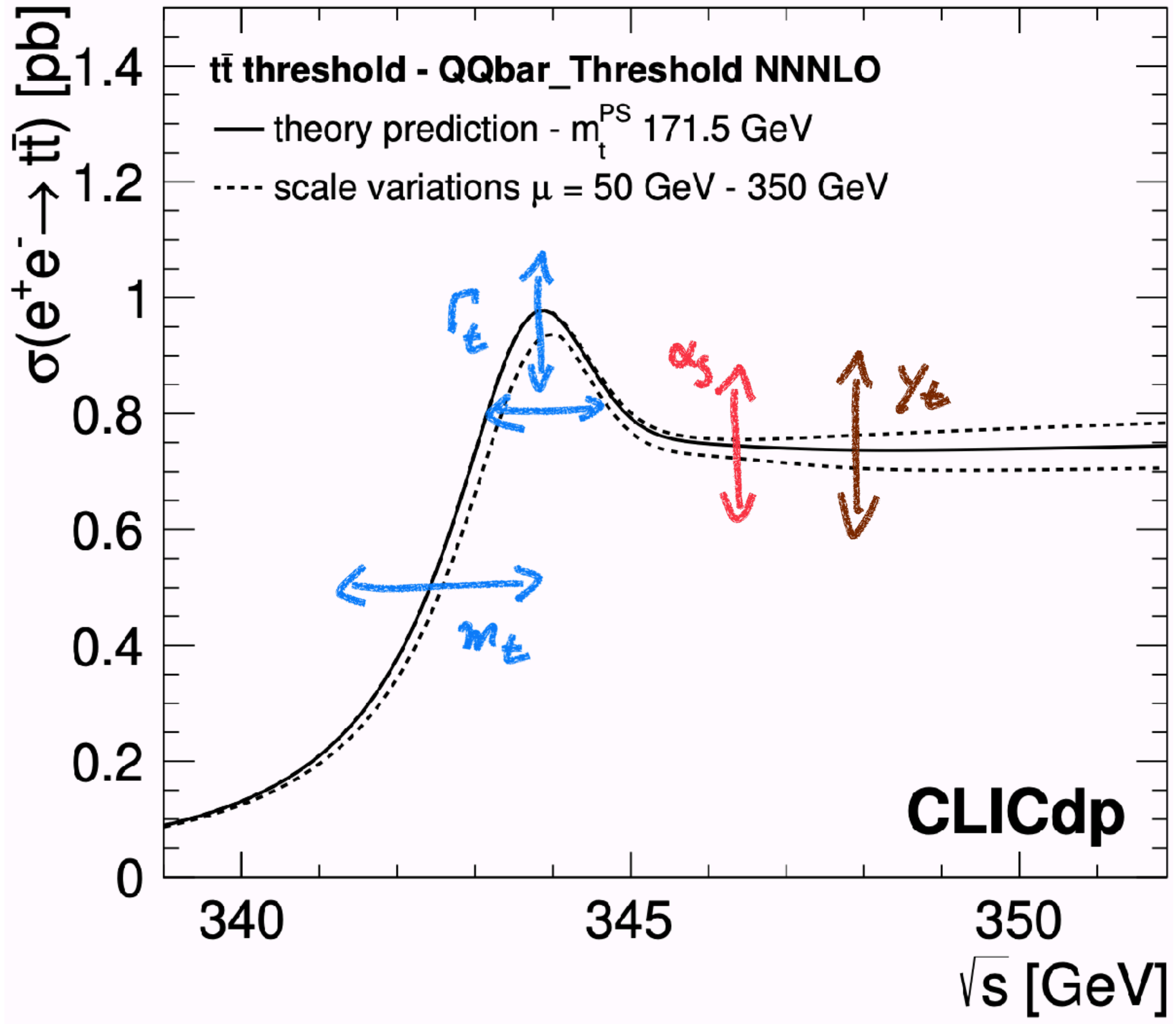

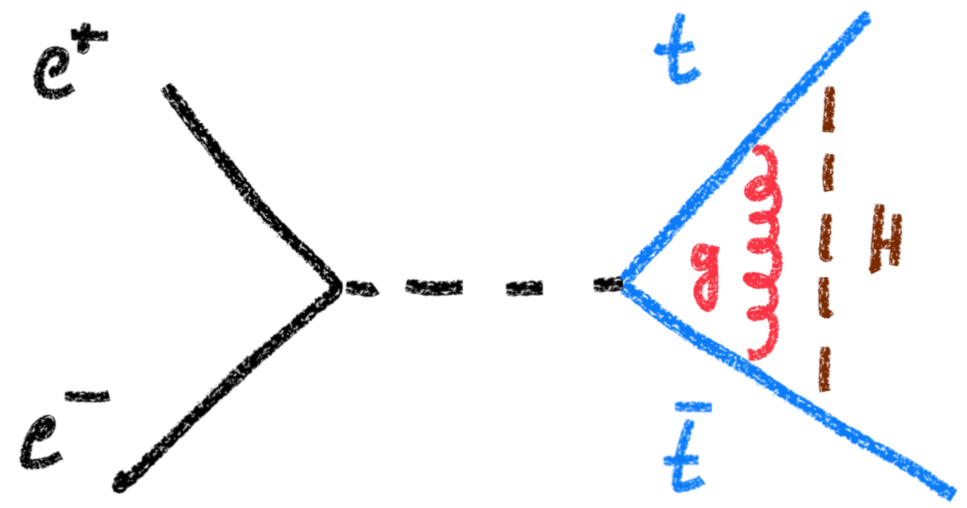

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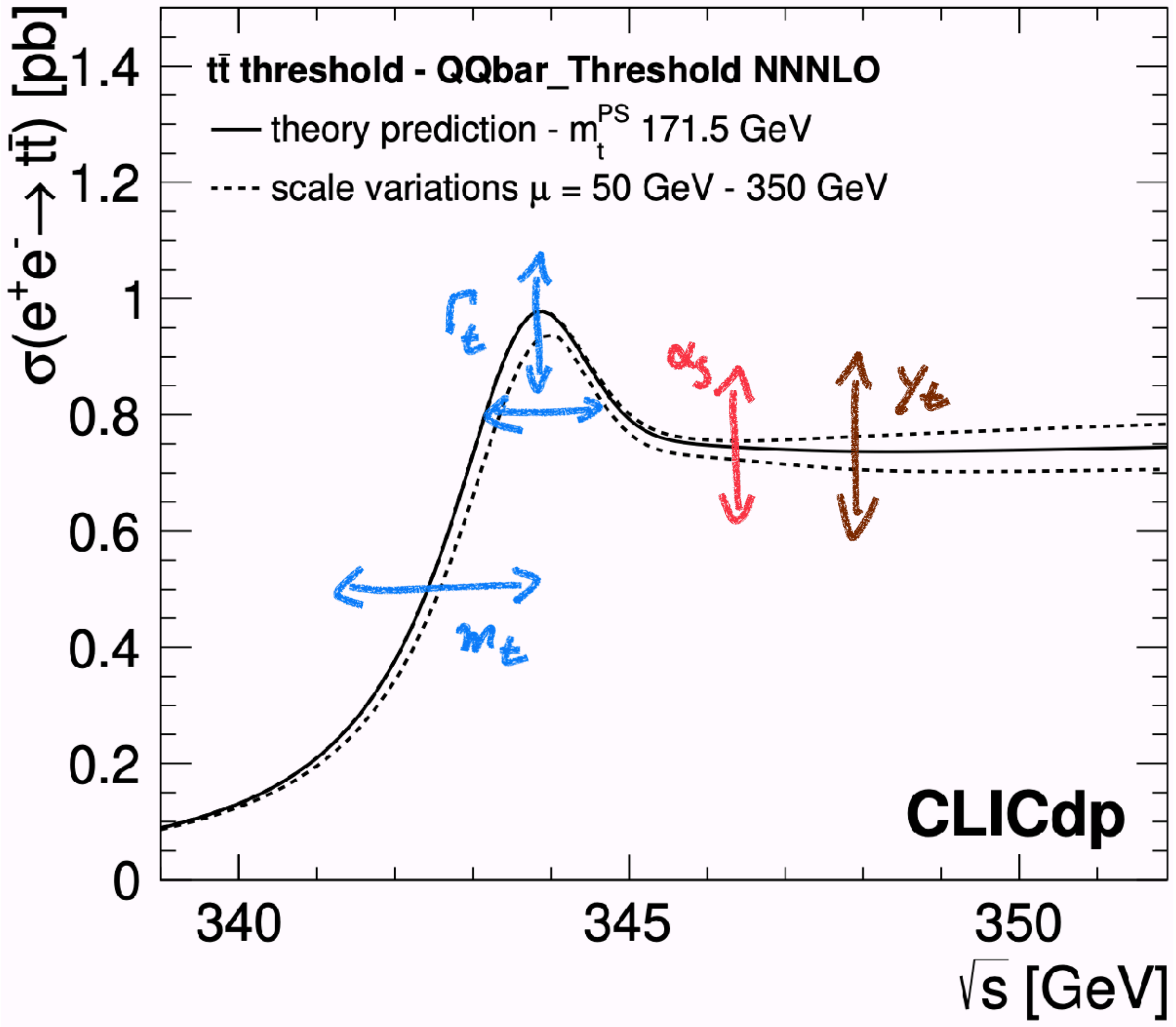

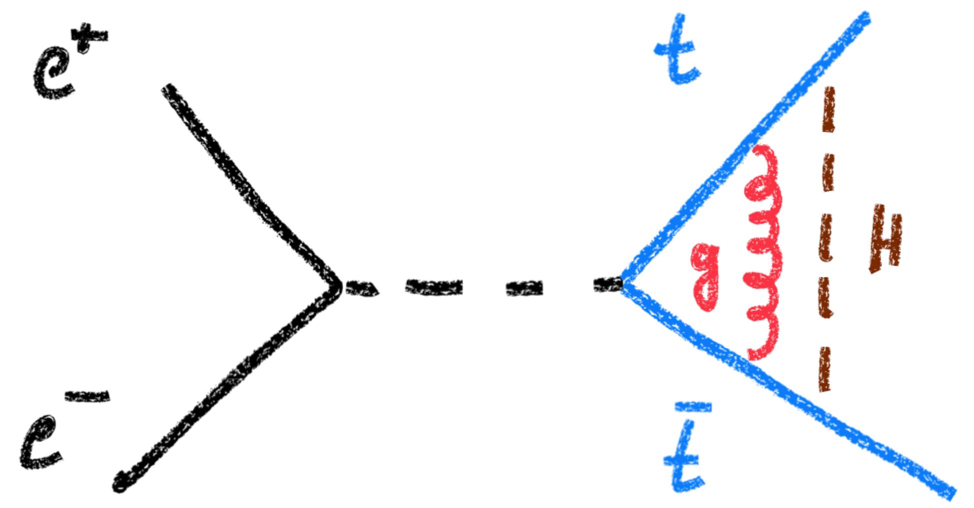

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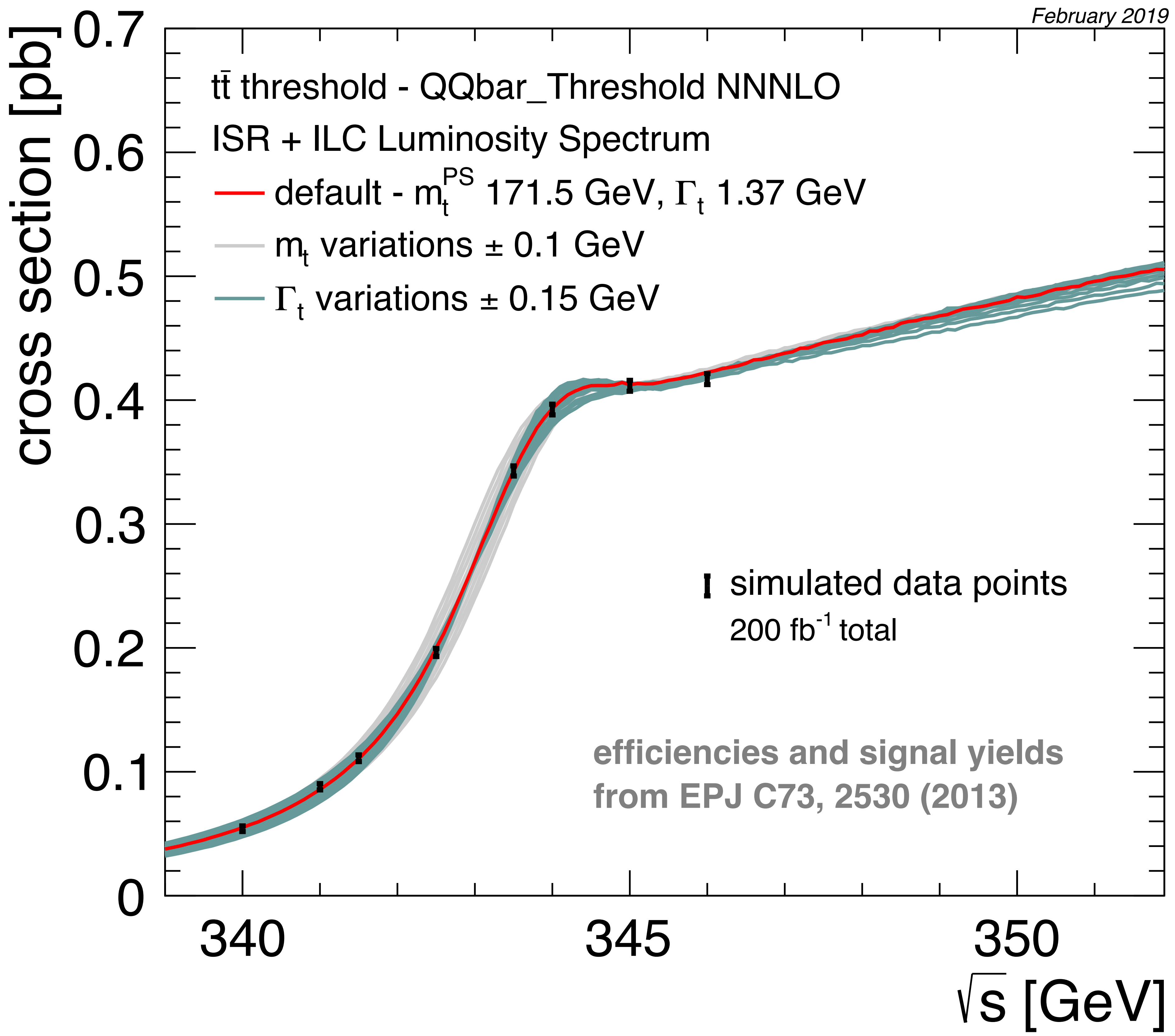
ISR, luminosity spectrum, reconstruction

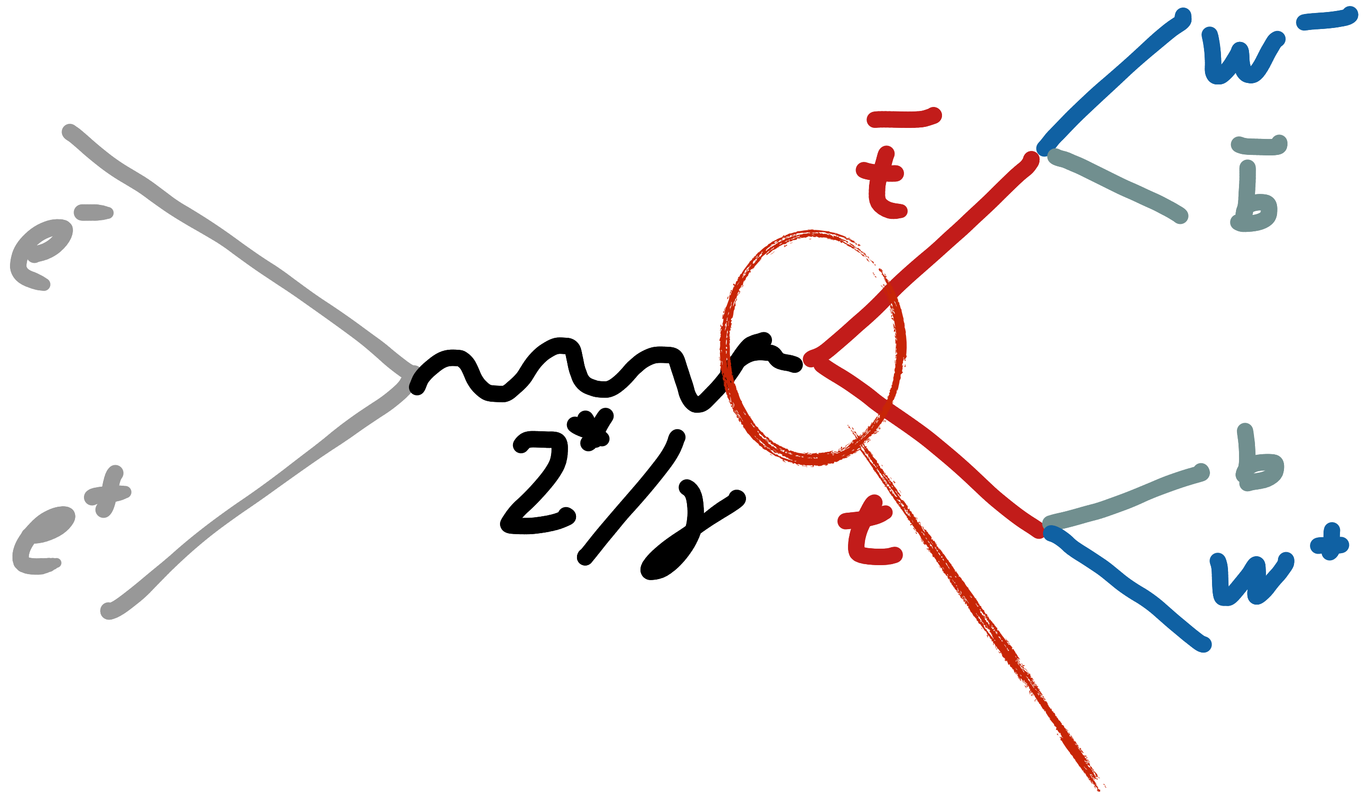
The potential for a measurement of the mass with < 50 MeV tota uncertainty (dominated by theory) - stat. precision ~ 10 MeV



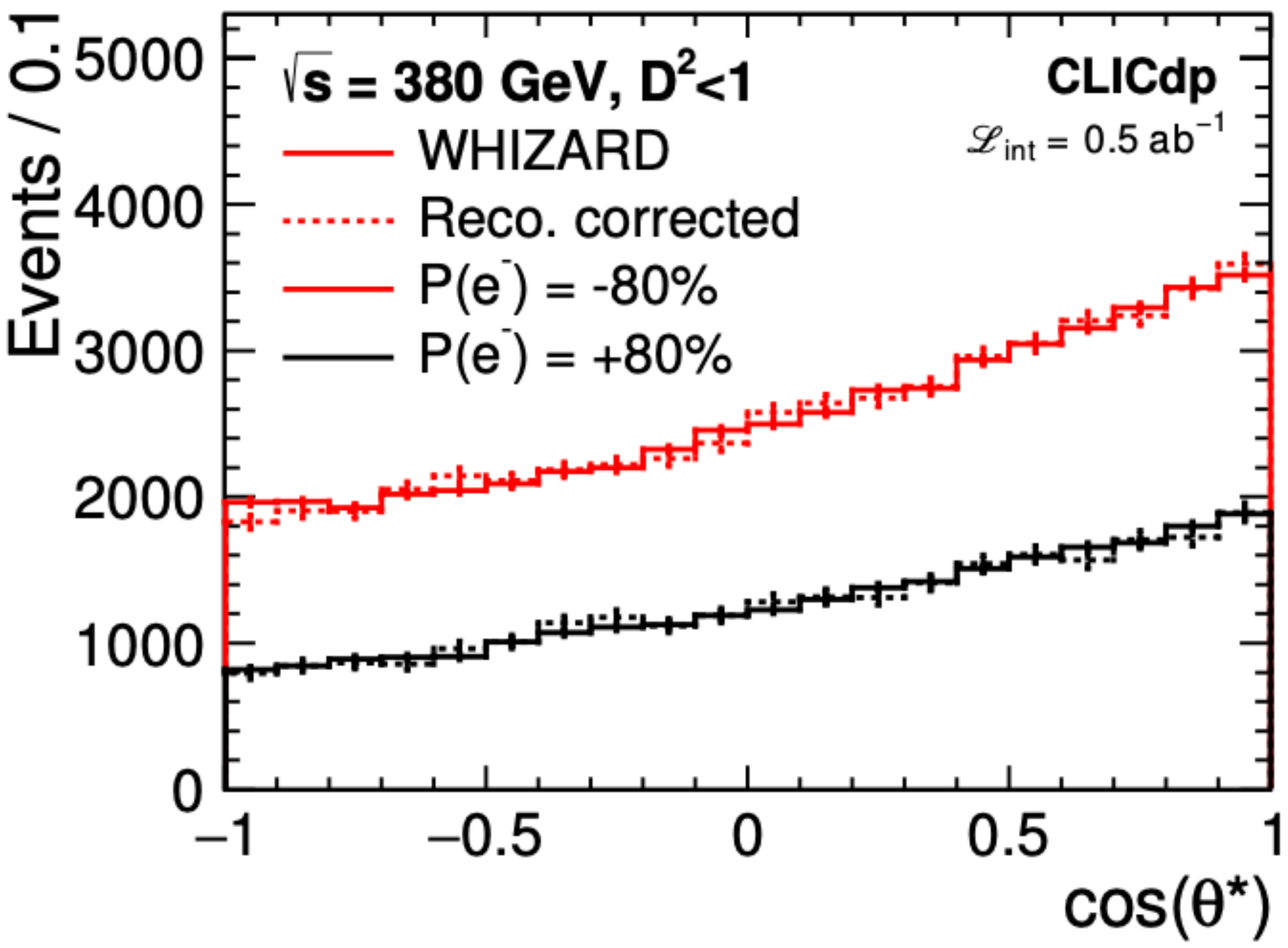
The threshold is sensitive to top quark properties

Electroweak Couplings of the Top Quark

Access via cross section and asymmetries



Accessing electroweak couplings in ttbar



- At Linear Colliders:
  - Using different beam polarisations
  - Measuring cross section, A_{FB}, and helicity angle (some studies)
  - Particularly powerful with two (or more) energy points

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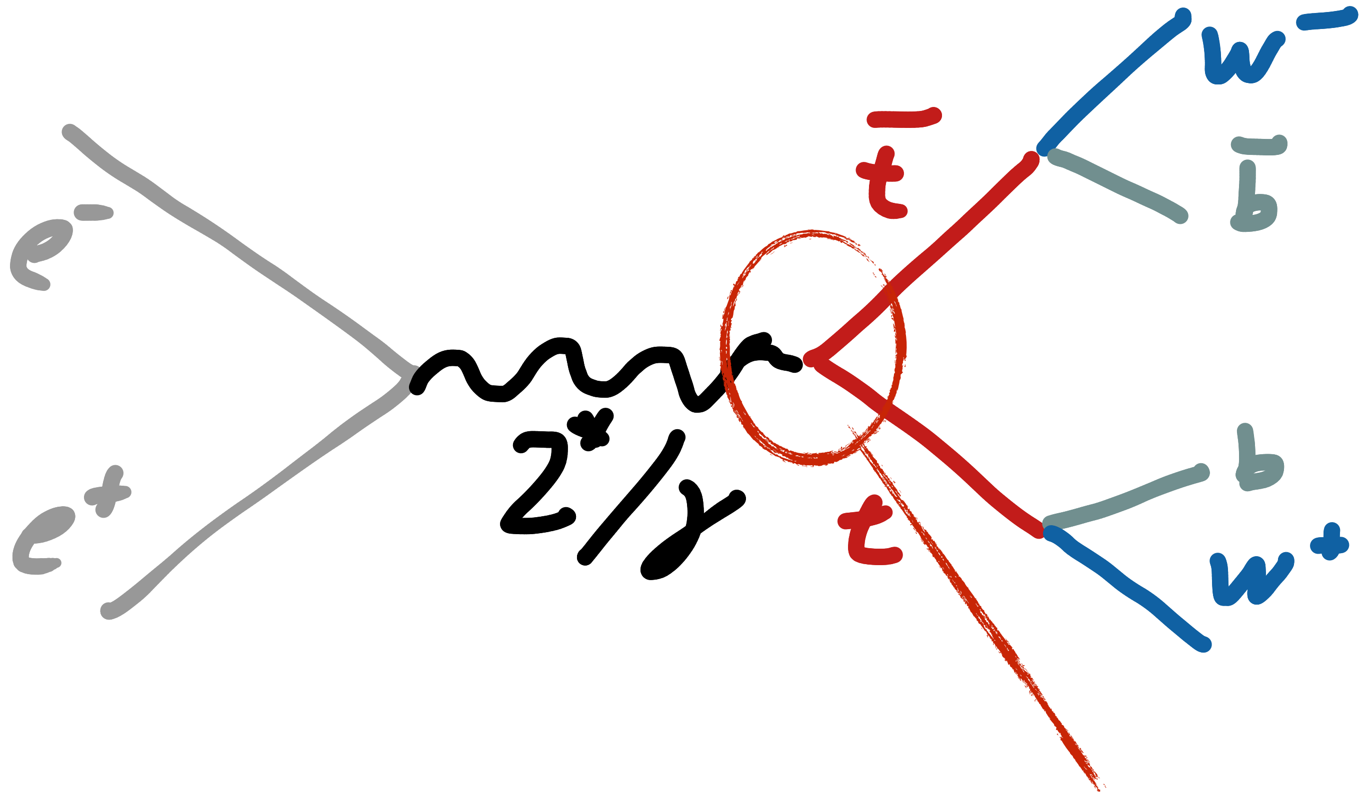

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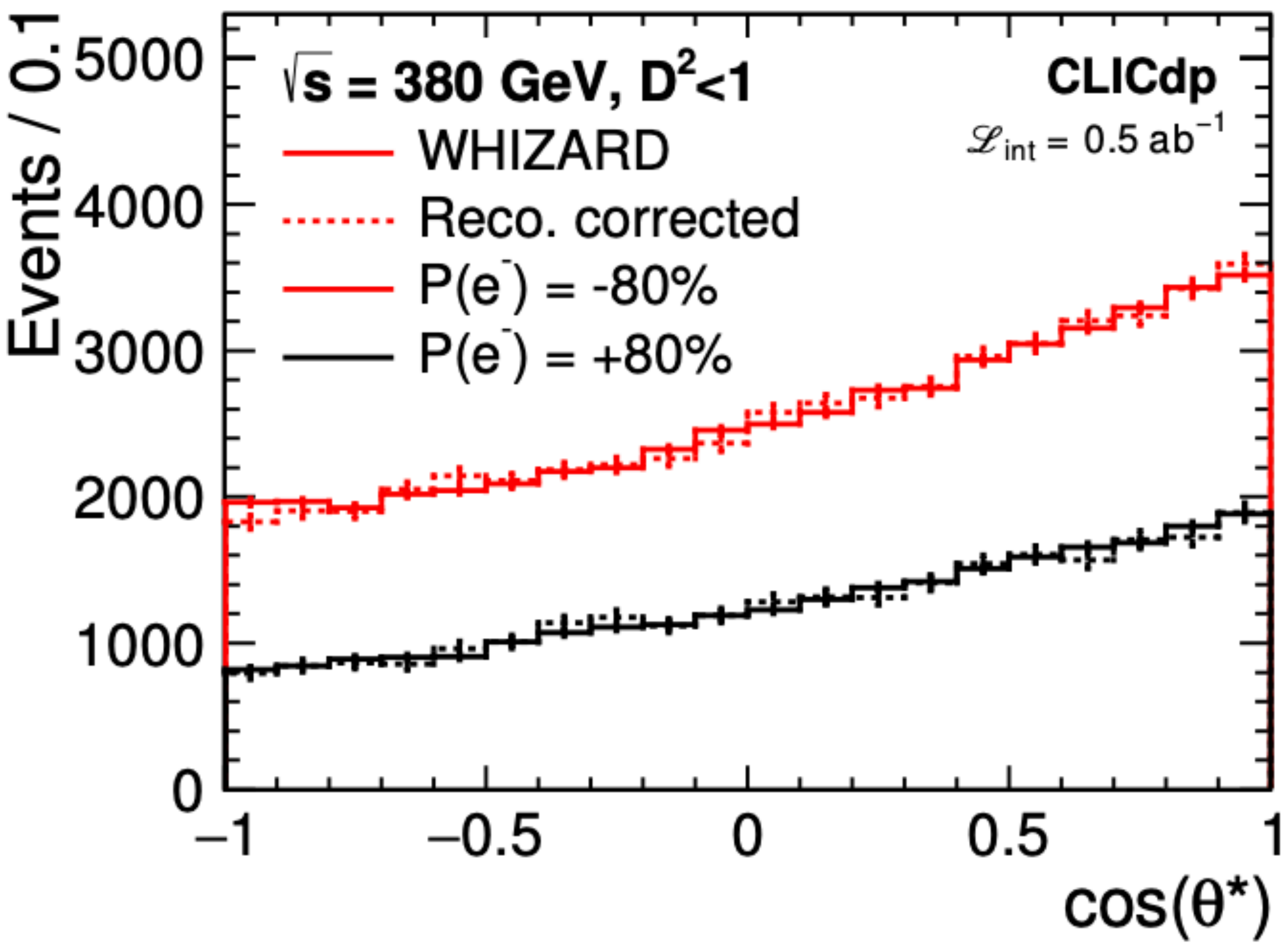
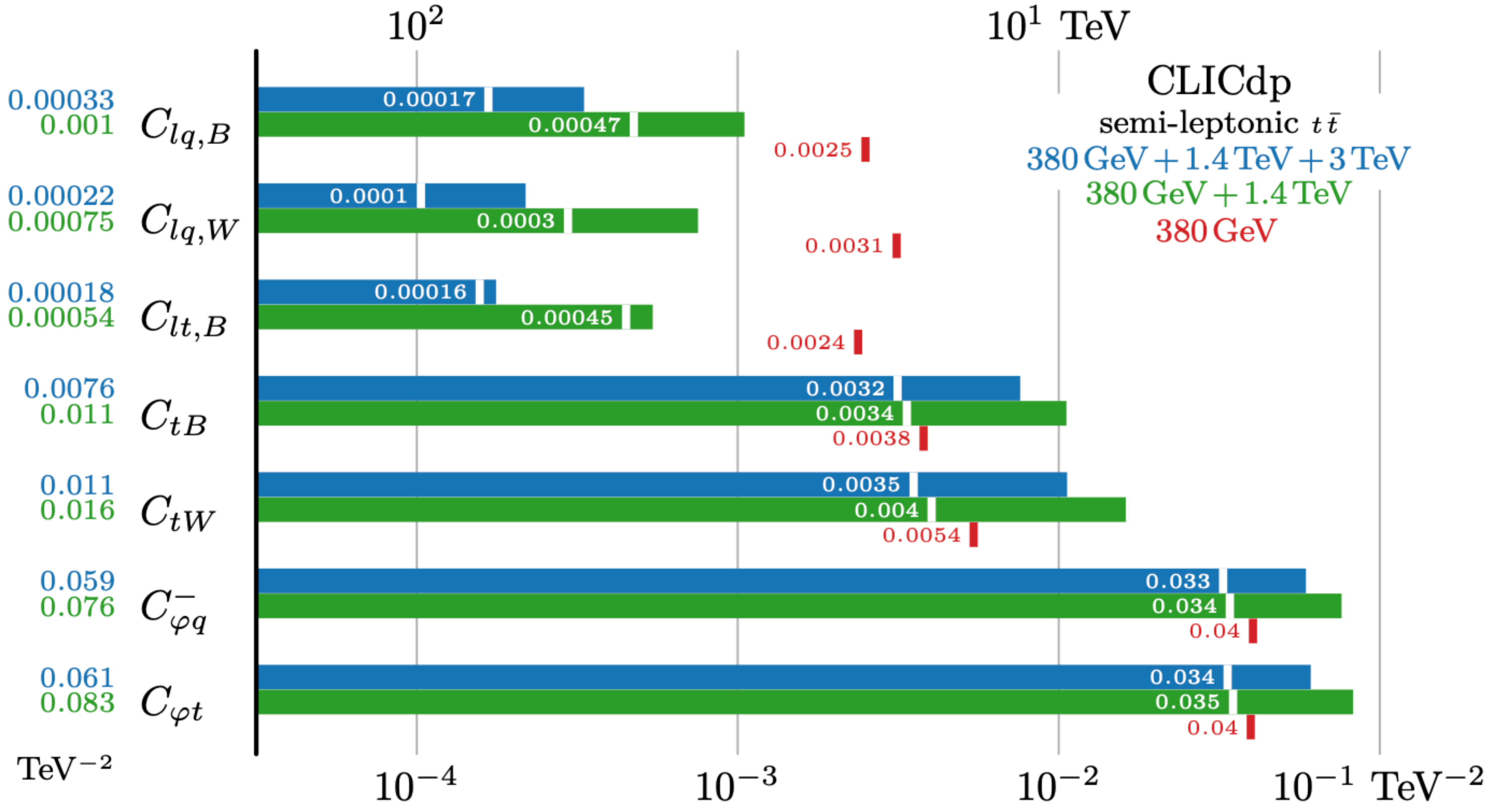


As an example: CLIC EFT-interpretation -> Reach up to 100 TeV

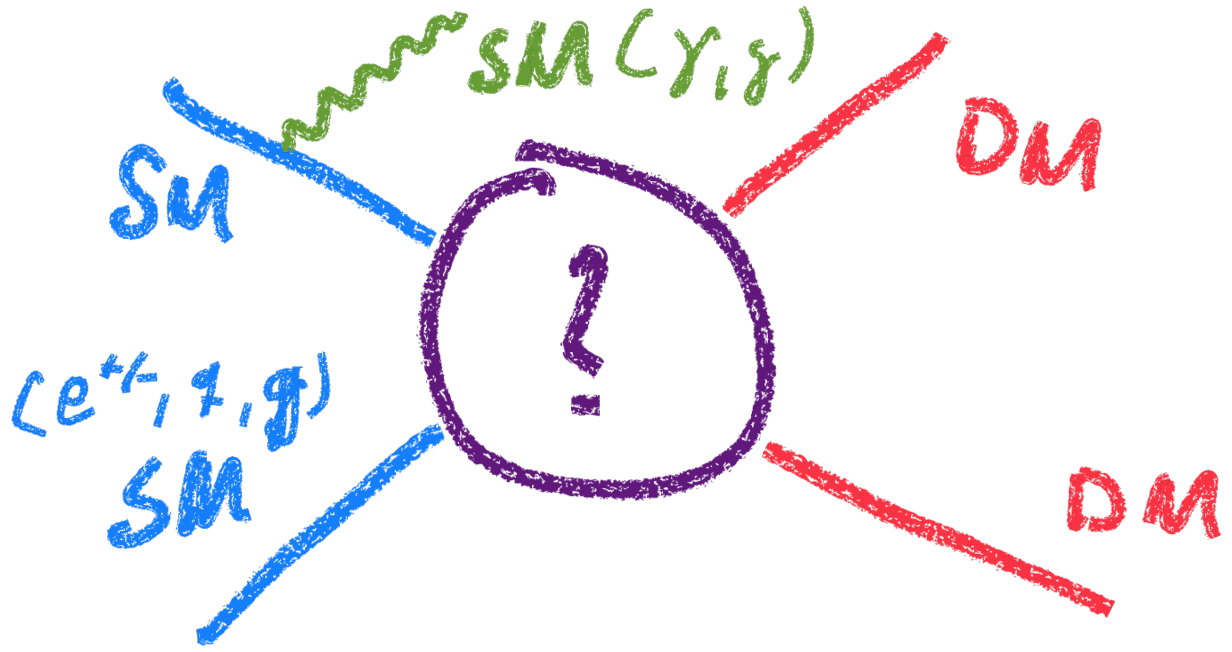


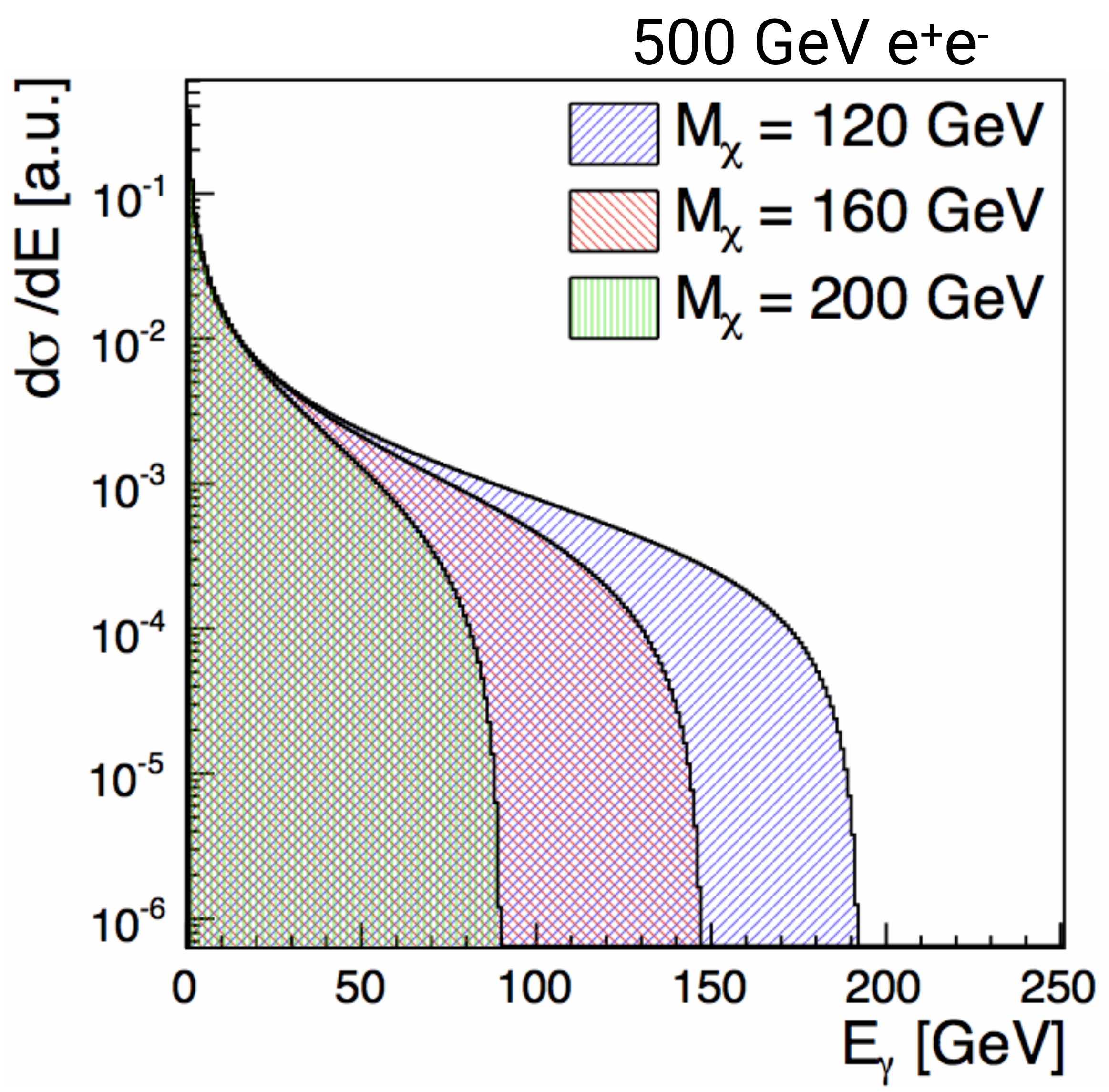
Into the Unknown

Searching for New Physics

- A (very) wide range of possibilities - a few obvious examples:

Search for Dark Matter





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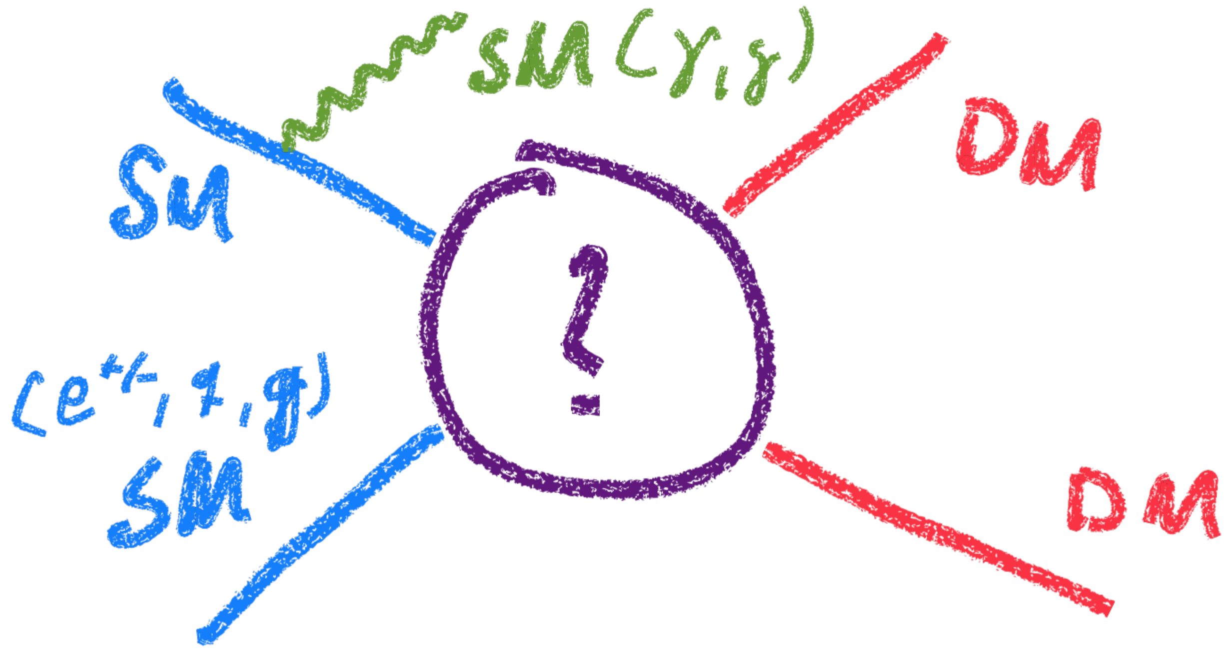

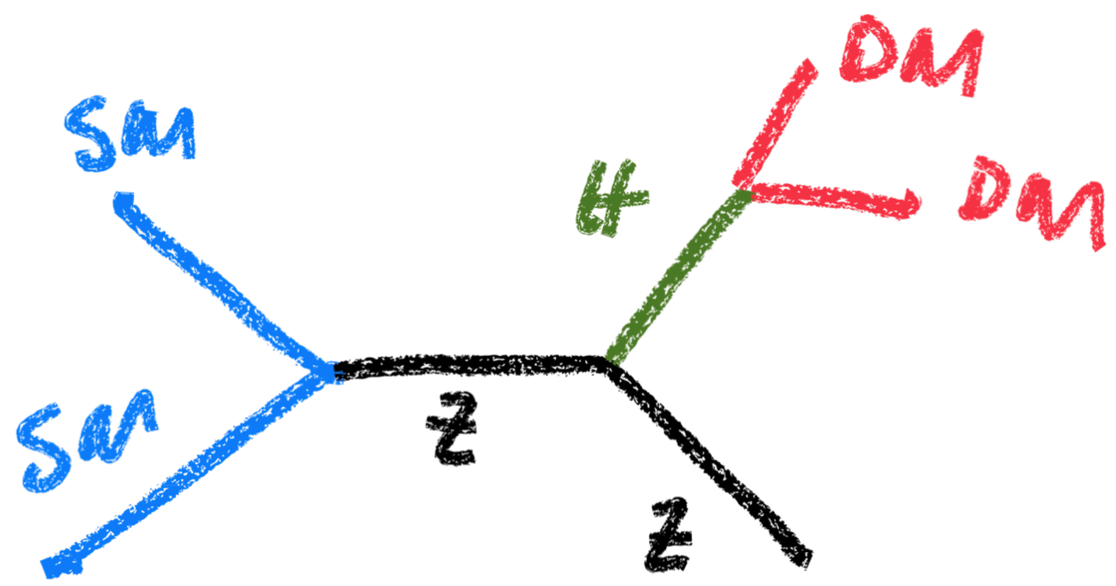

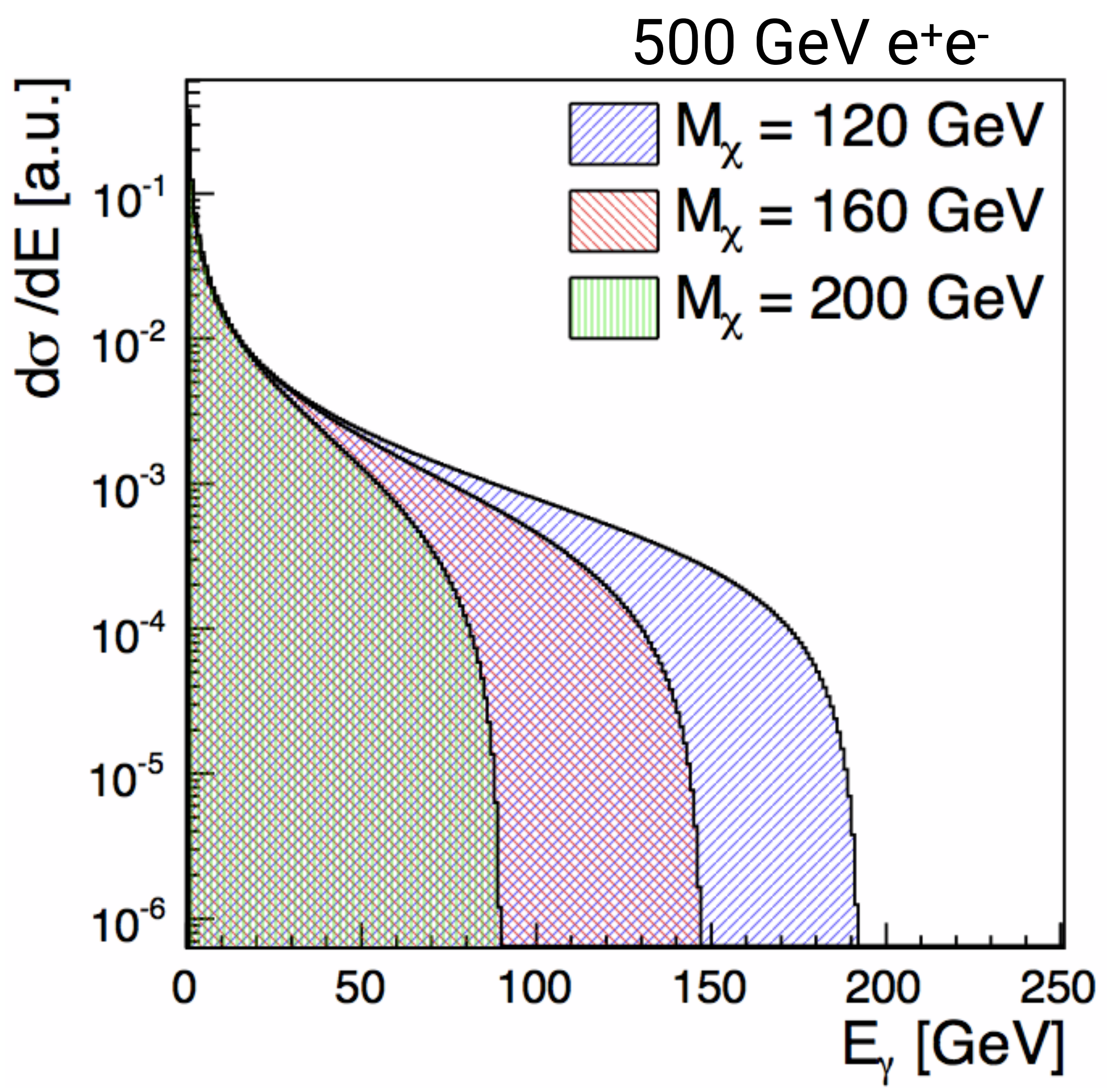

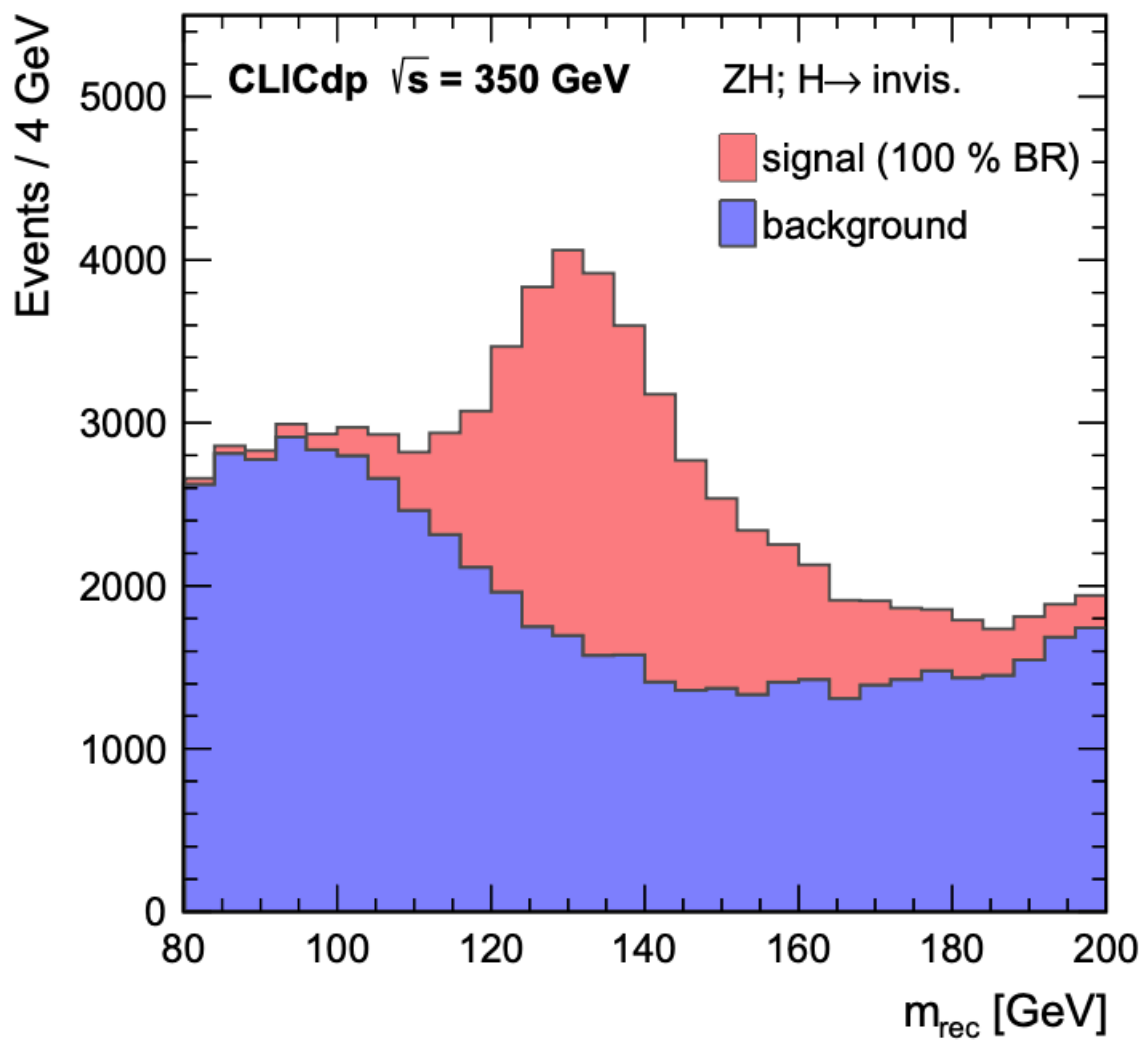

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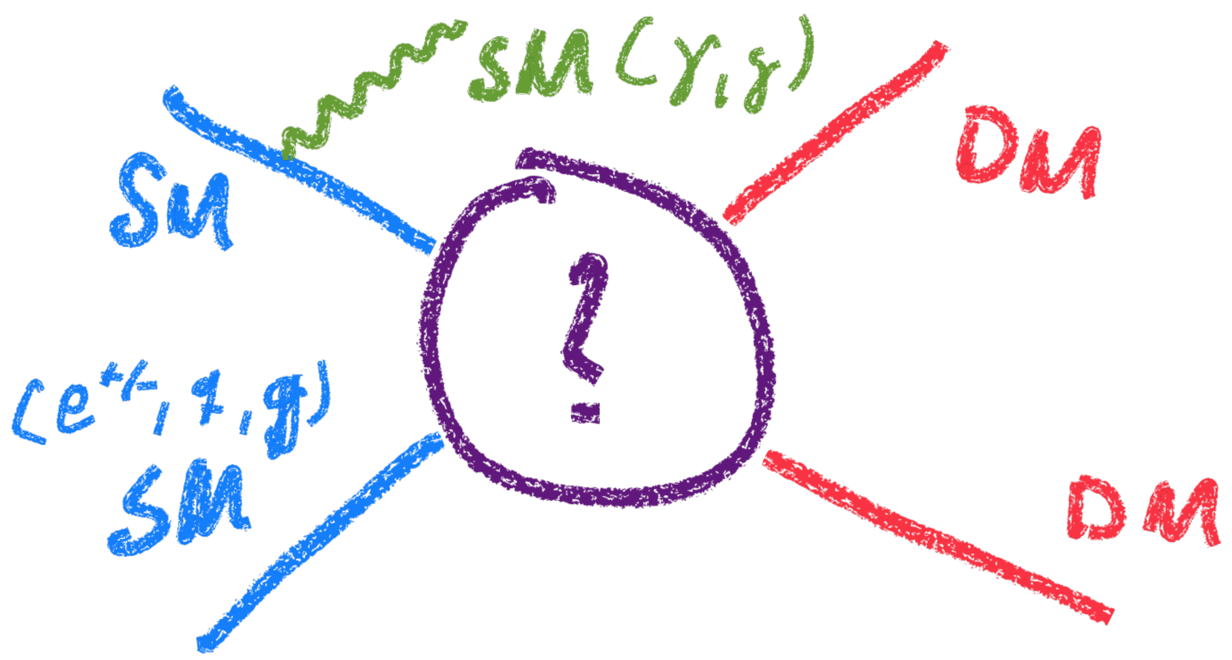
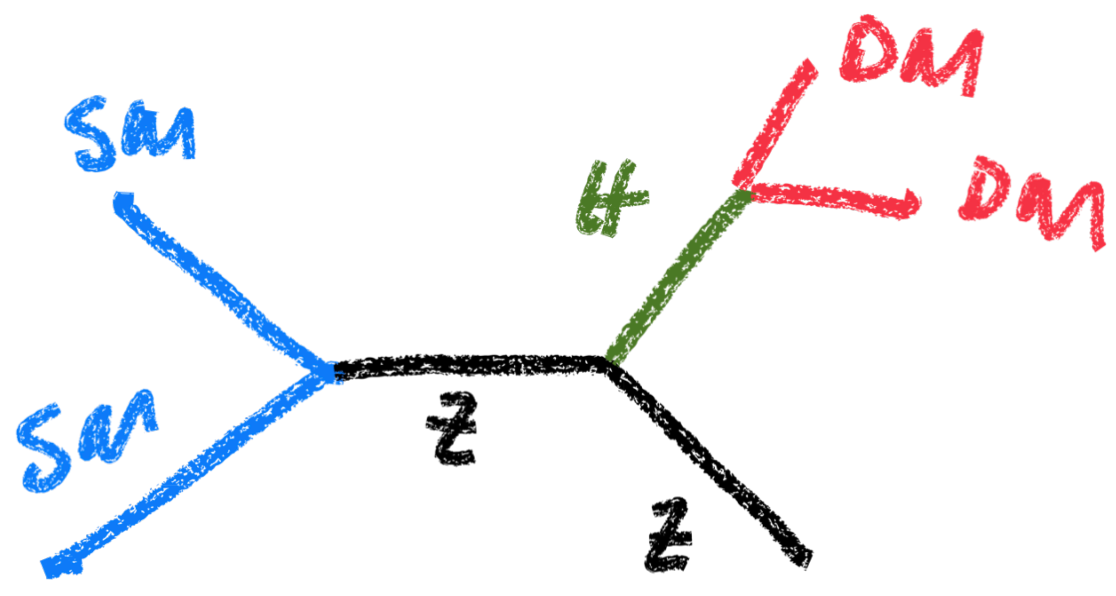
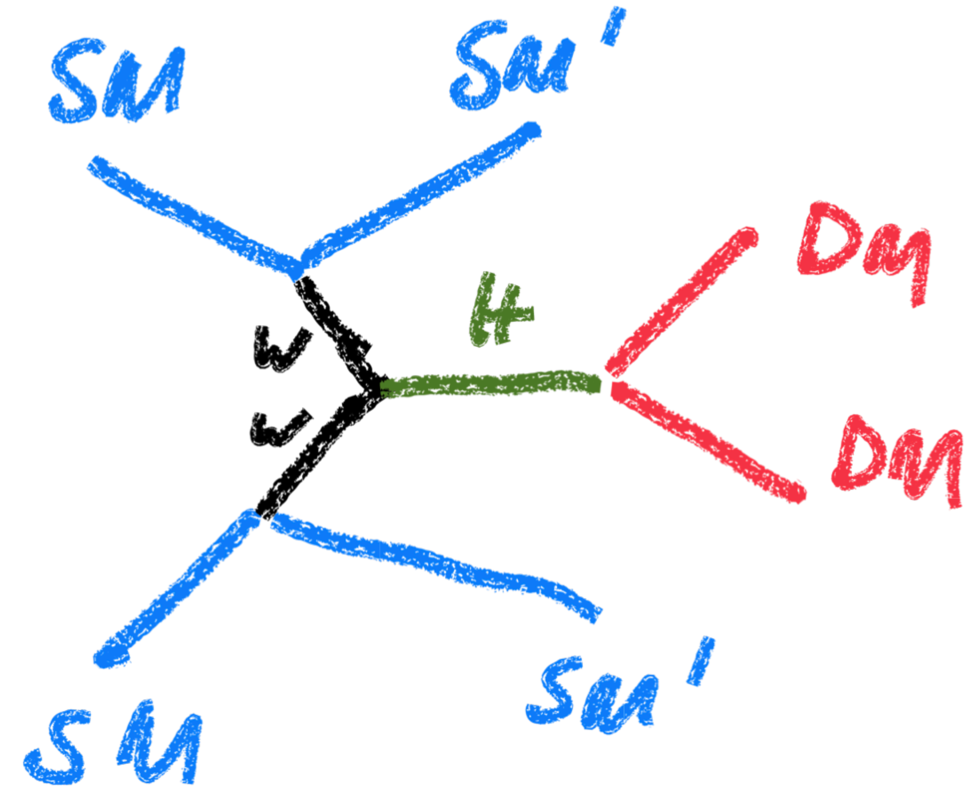
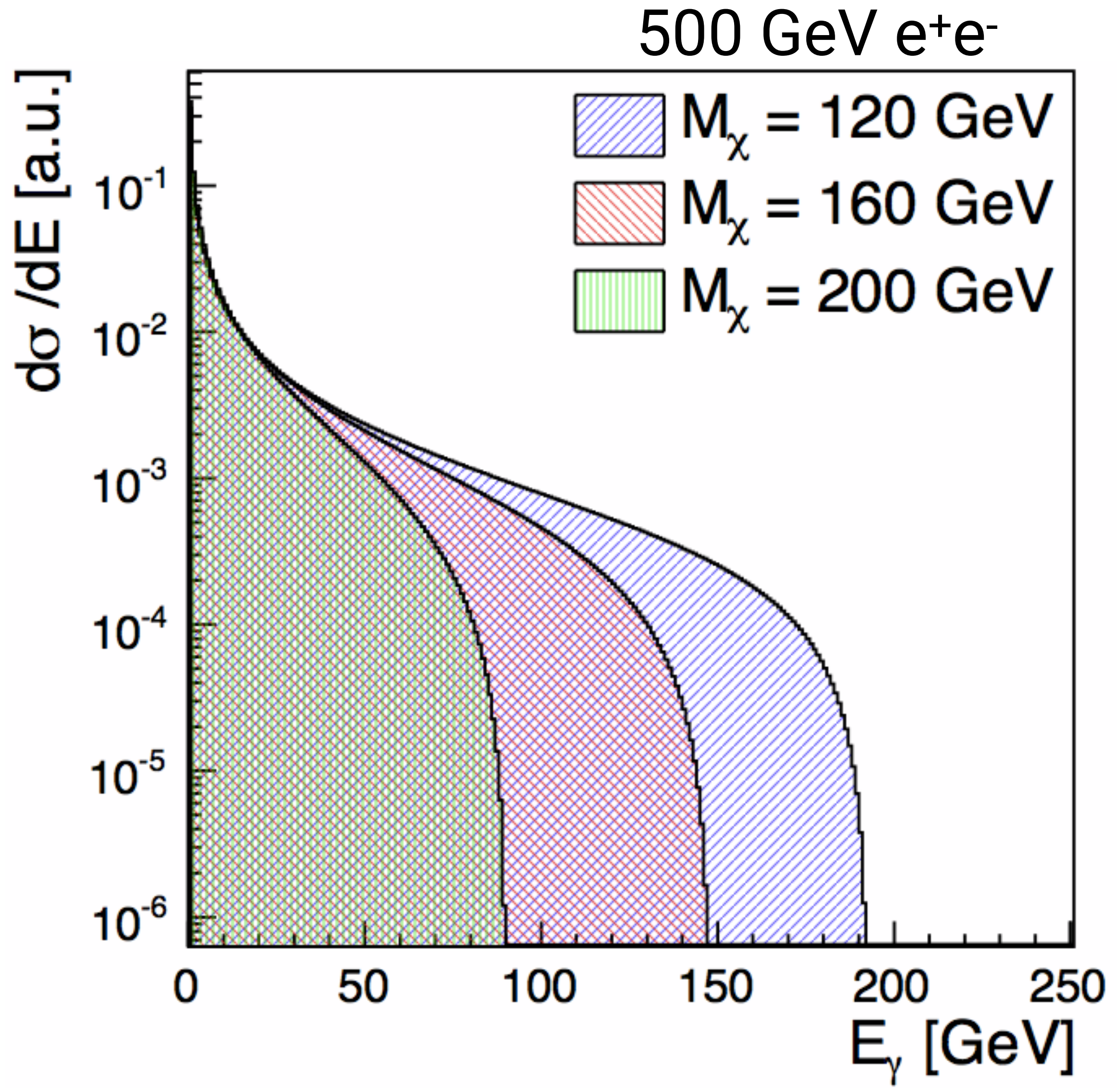
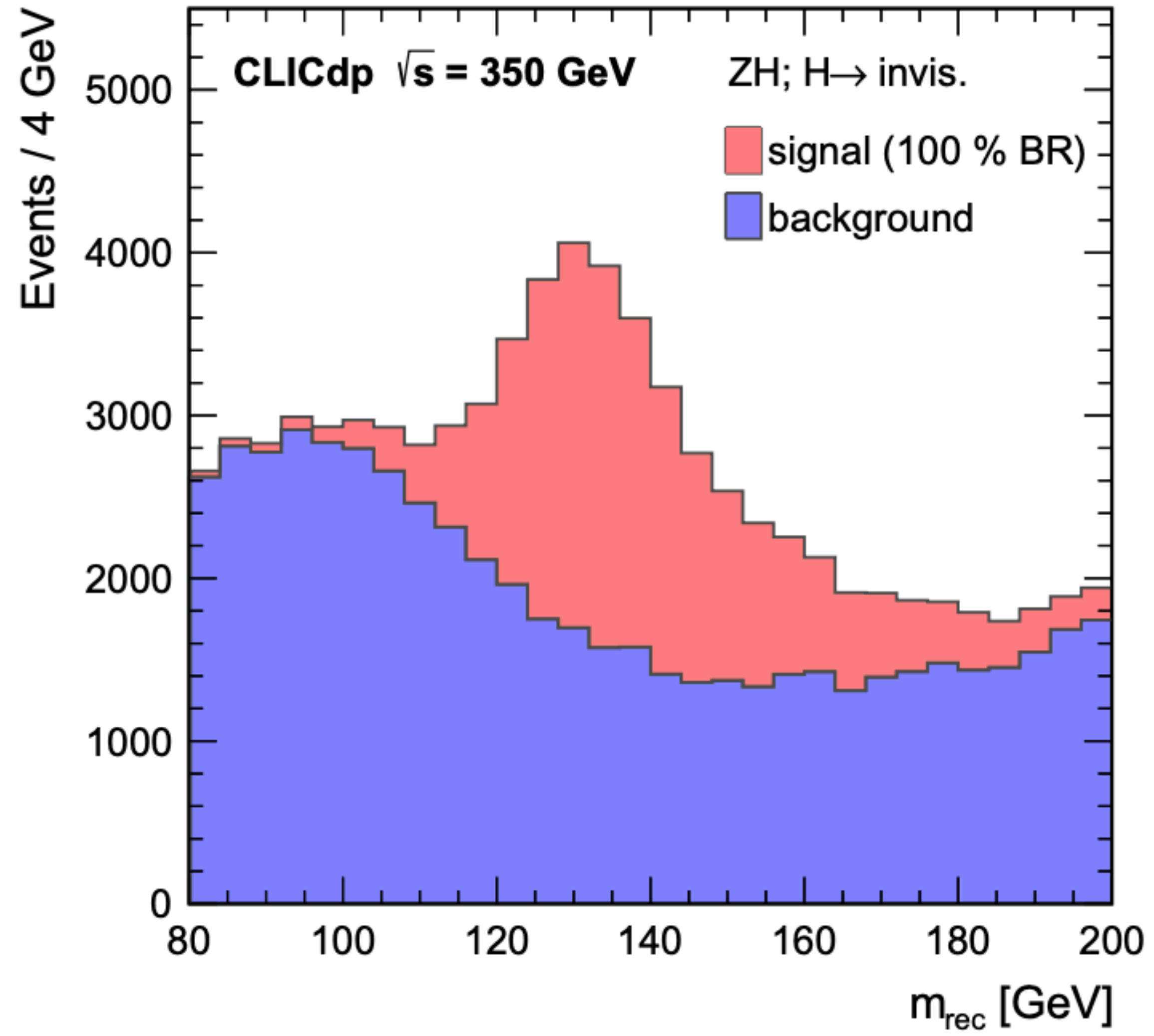




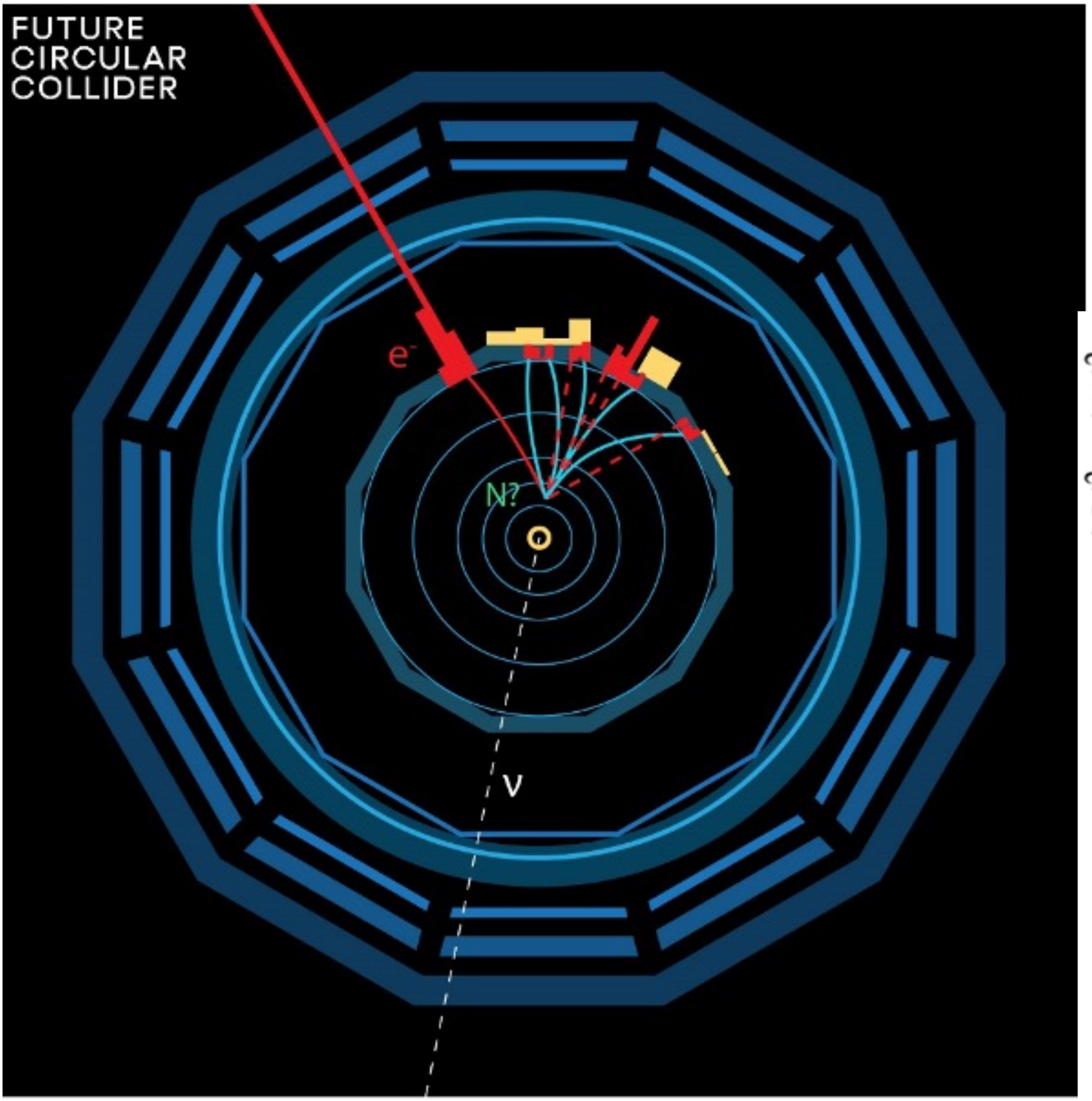




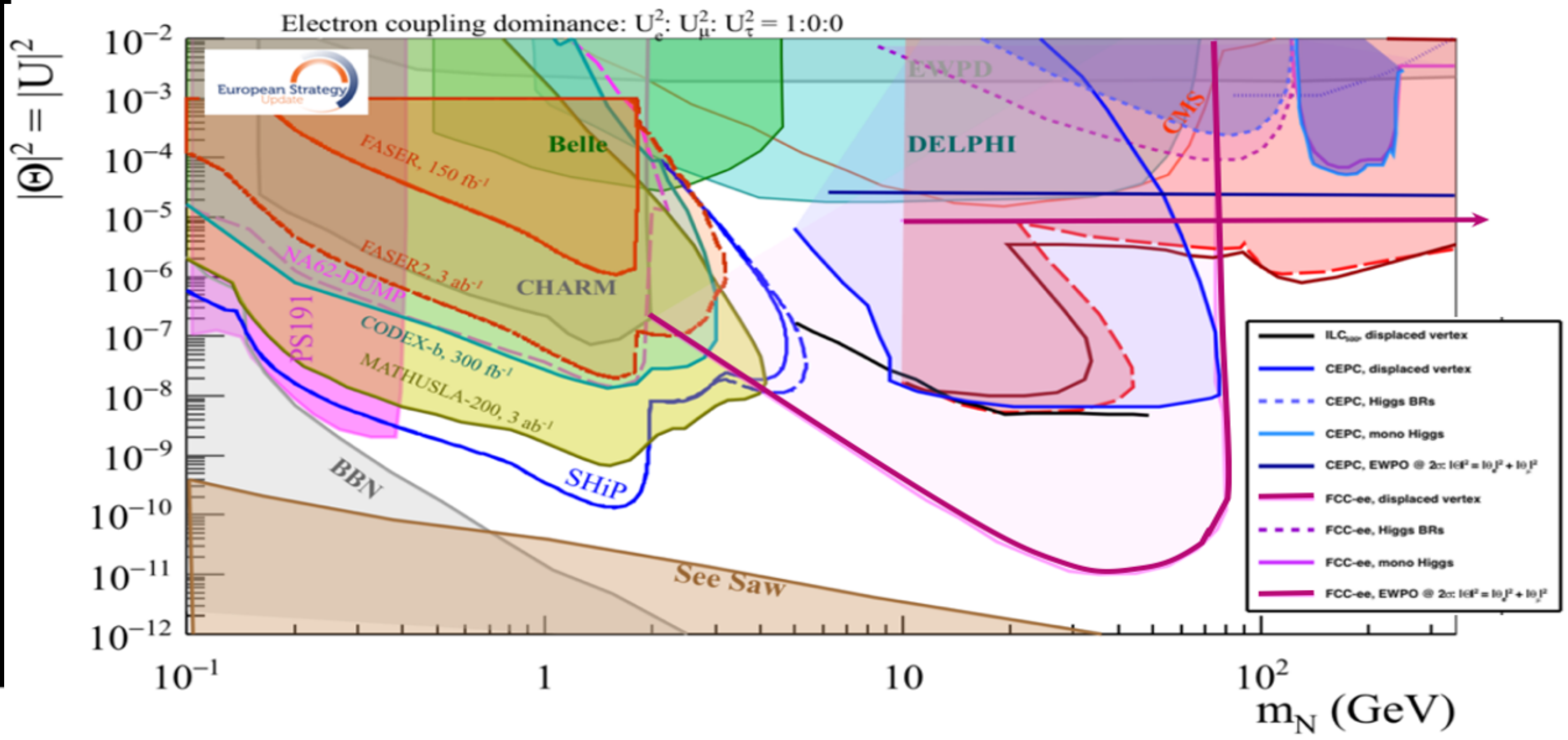


Sensitivity depends on

- Energy reach -> Mass coverage
- Background levels: Sensitivity to small couplings



- Exploiting extreme statistics to search for heavy neutral leptons (right-handed sterile neutrinos, …): Z-> ν+HNL



mass vs mixing² - unique phase space covered by FCC-ee

Into the Unknown

Indirect and direct exploration of the highest energy scales

MAX-PLANCK-INSTITUT
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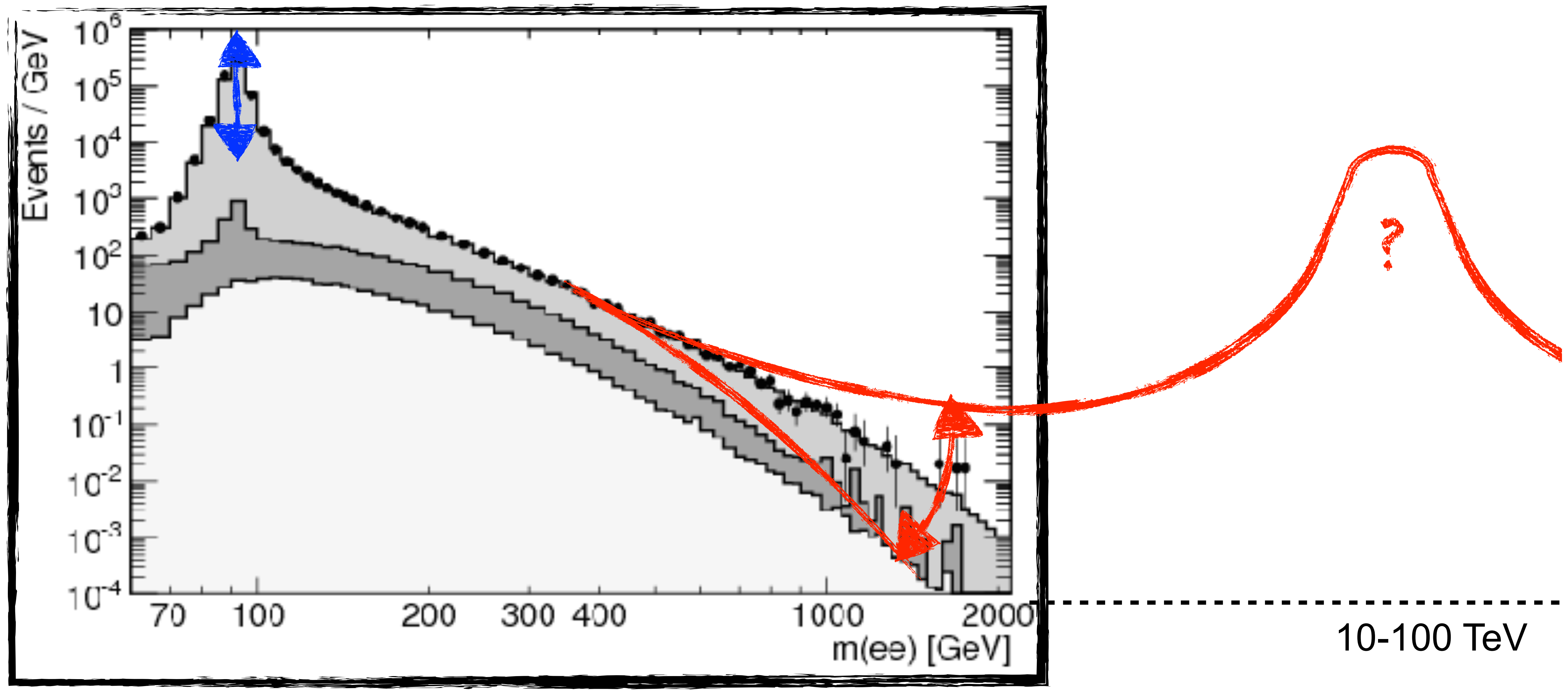
- Indirect probes with lepton colliders



For many generic models & new interactions:

Corrections to SM suppressed by 1/(mass scale)^2

➯ Sensitivity grows with s

Into the Unknown

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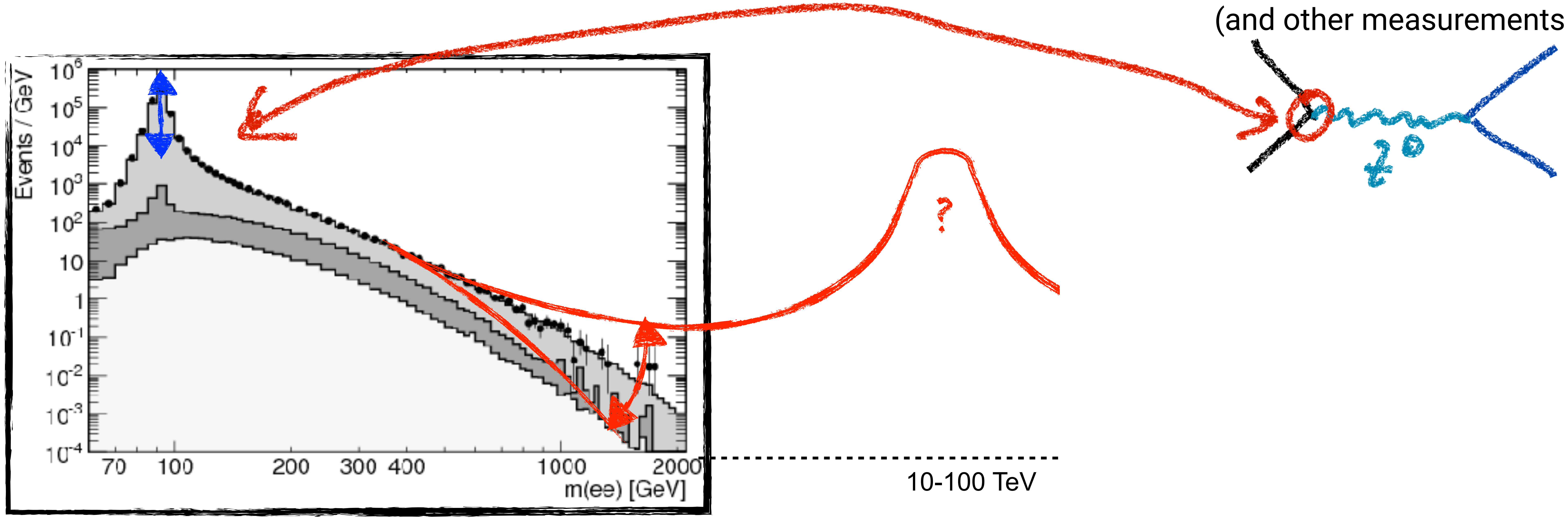
extreme precision with Z-pole programs

(and other measurements we talked about)



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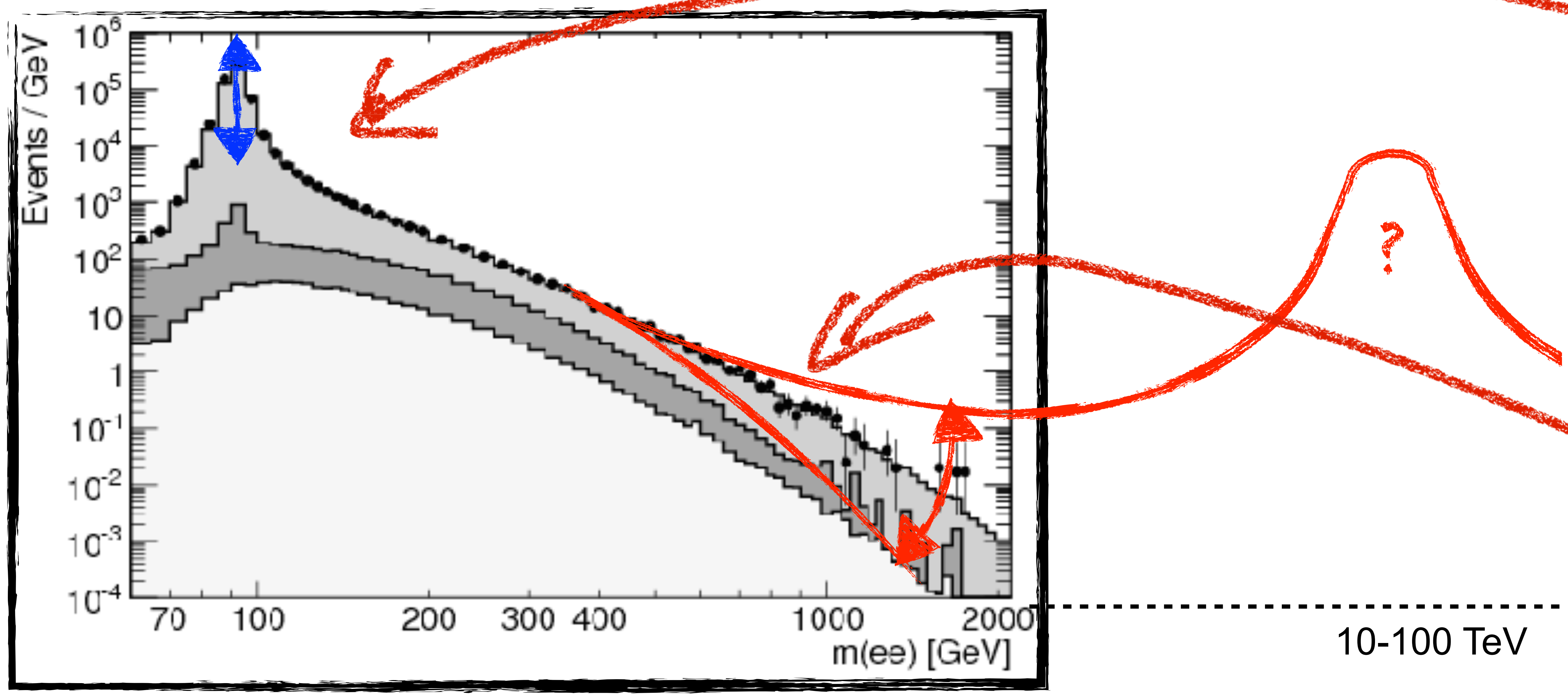

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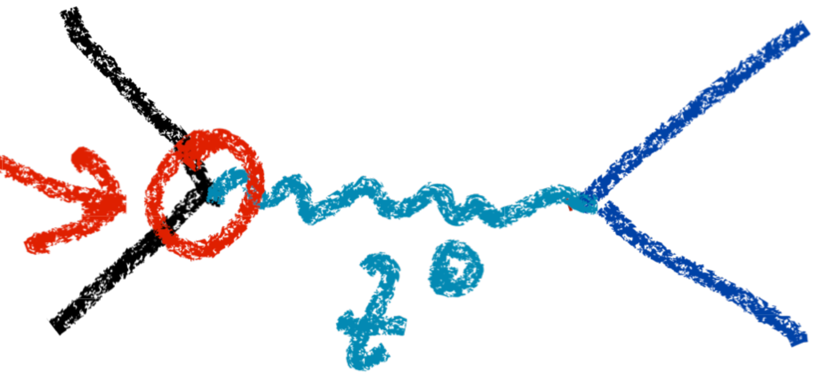
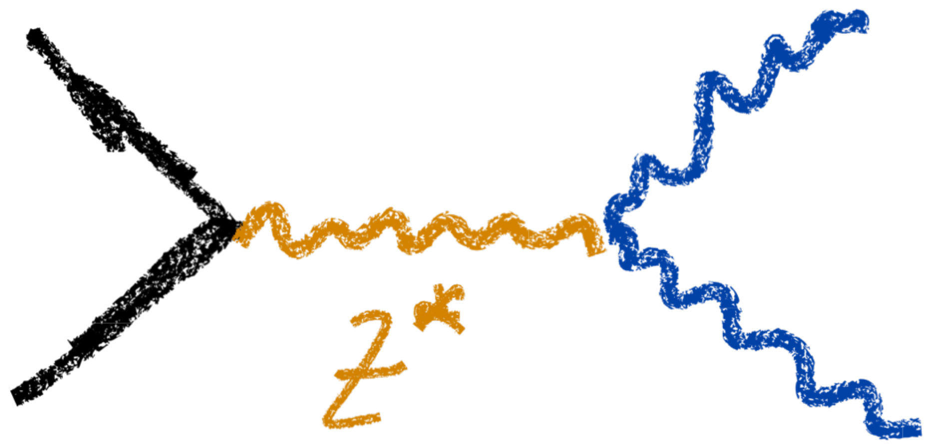


larger effects at higher energies



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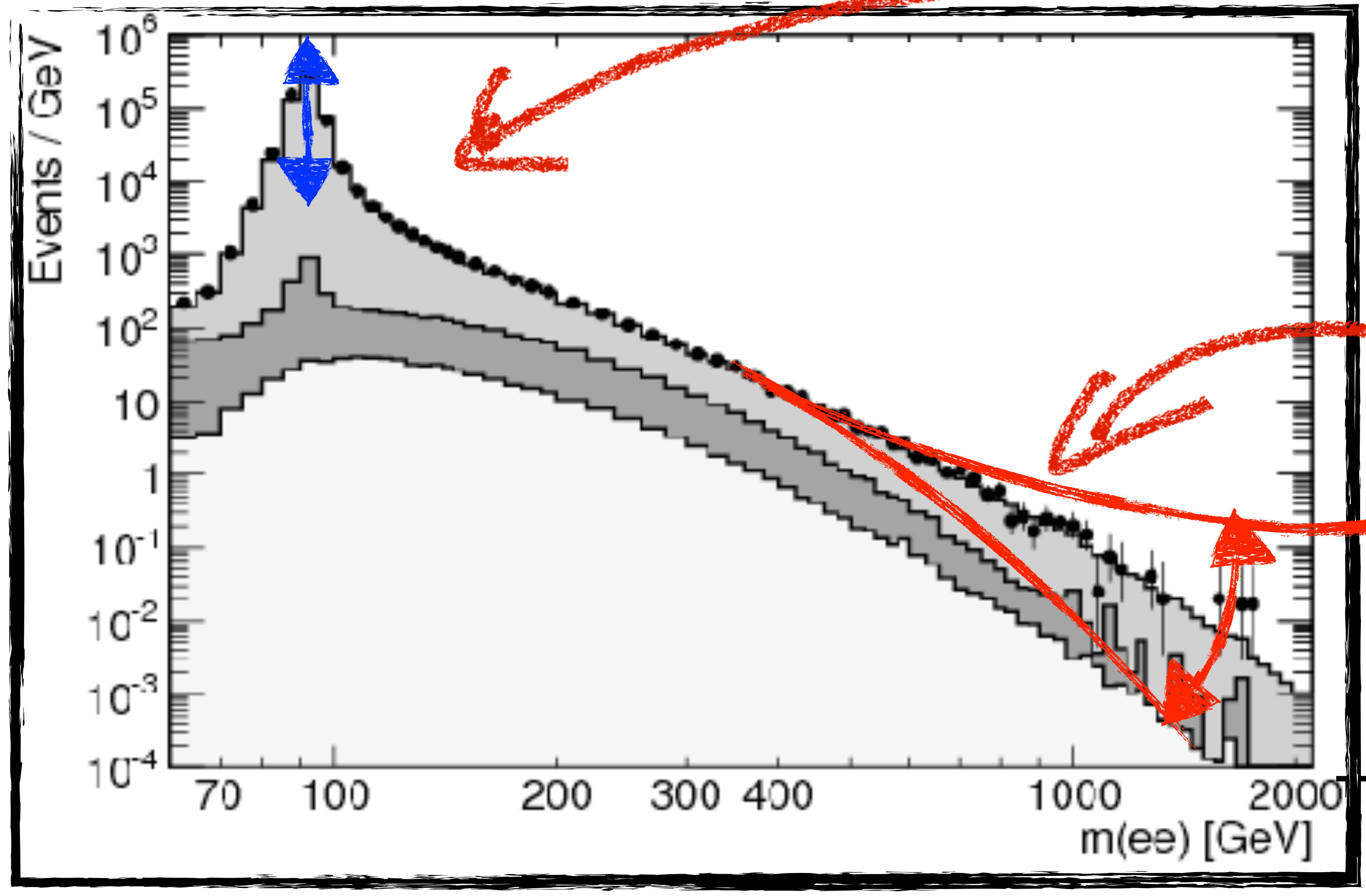

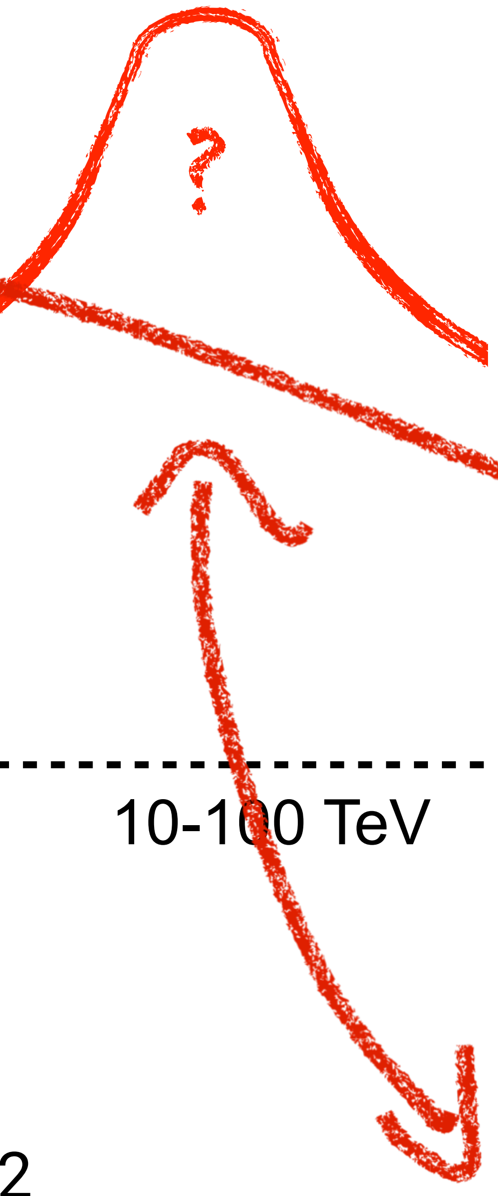

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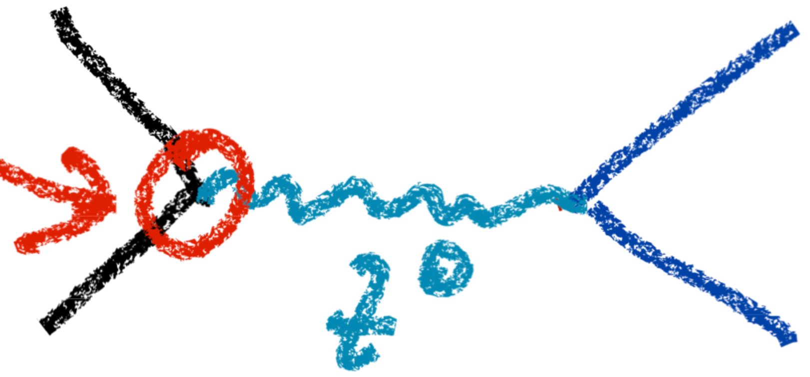

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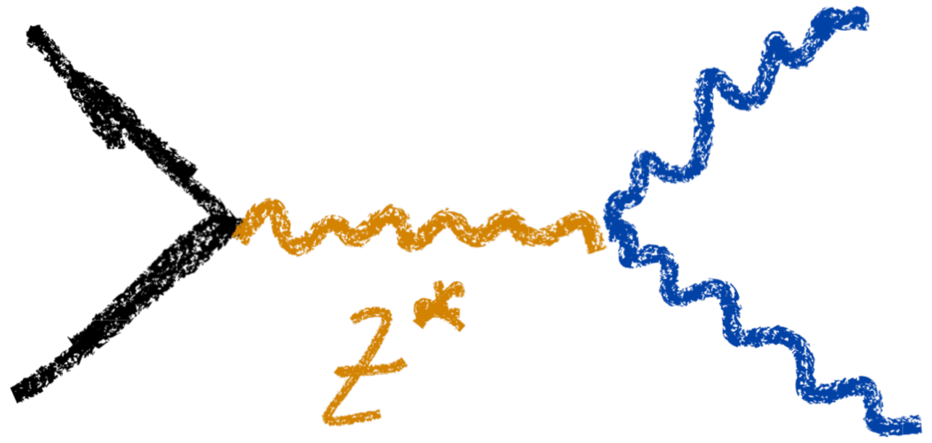

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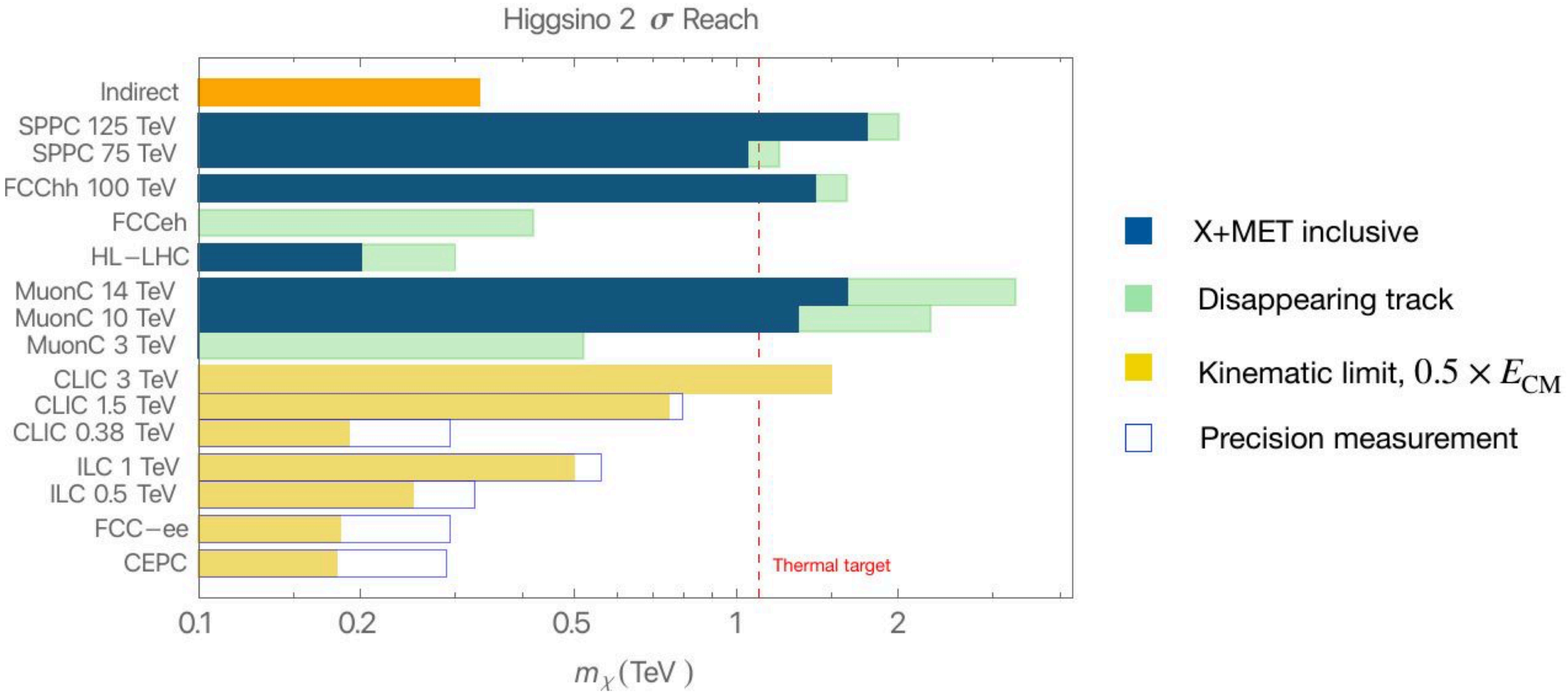
Potential for direct production at highest energies - primarily hadron colliders, or 10+ TeV muon colliders

Sensitivity to High Scales

The Strength of CLIC and Muon Colliders

- Pushing limits on dark matter



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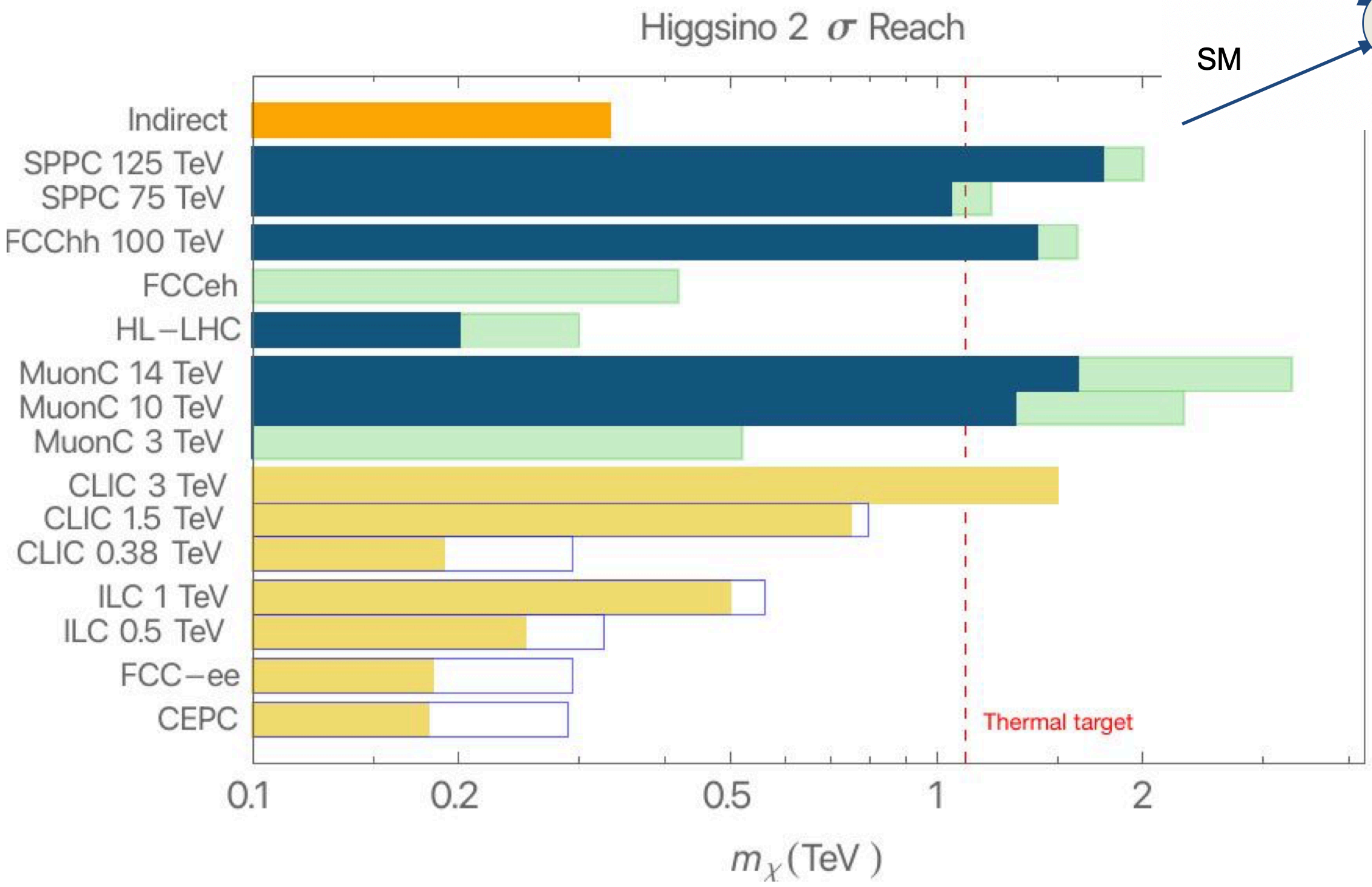

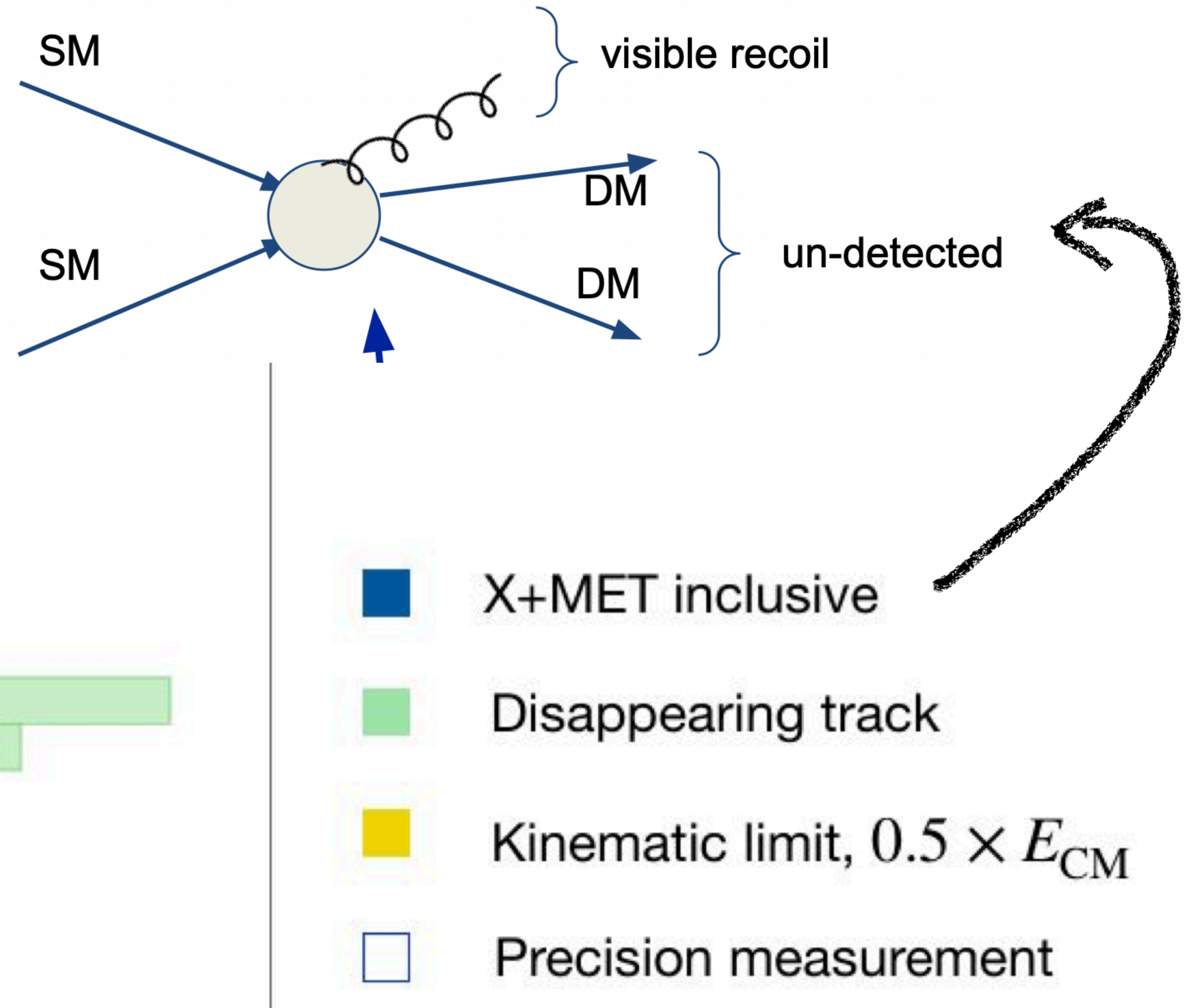

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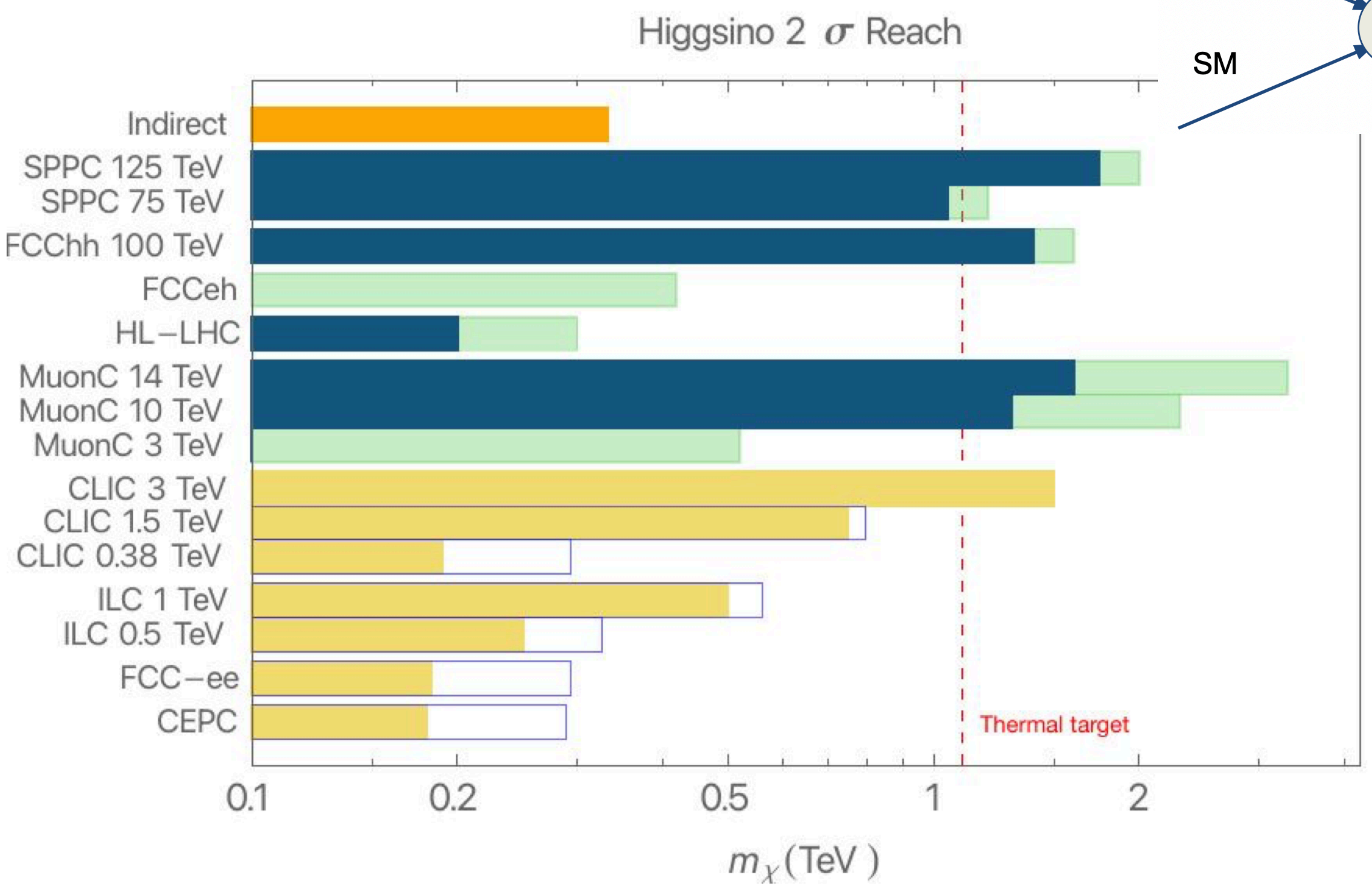

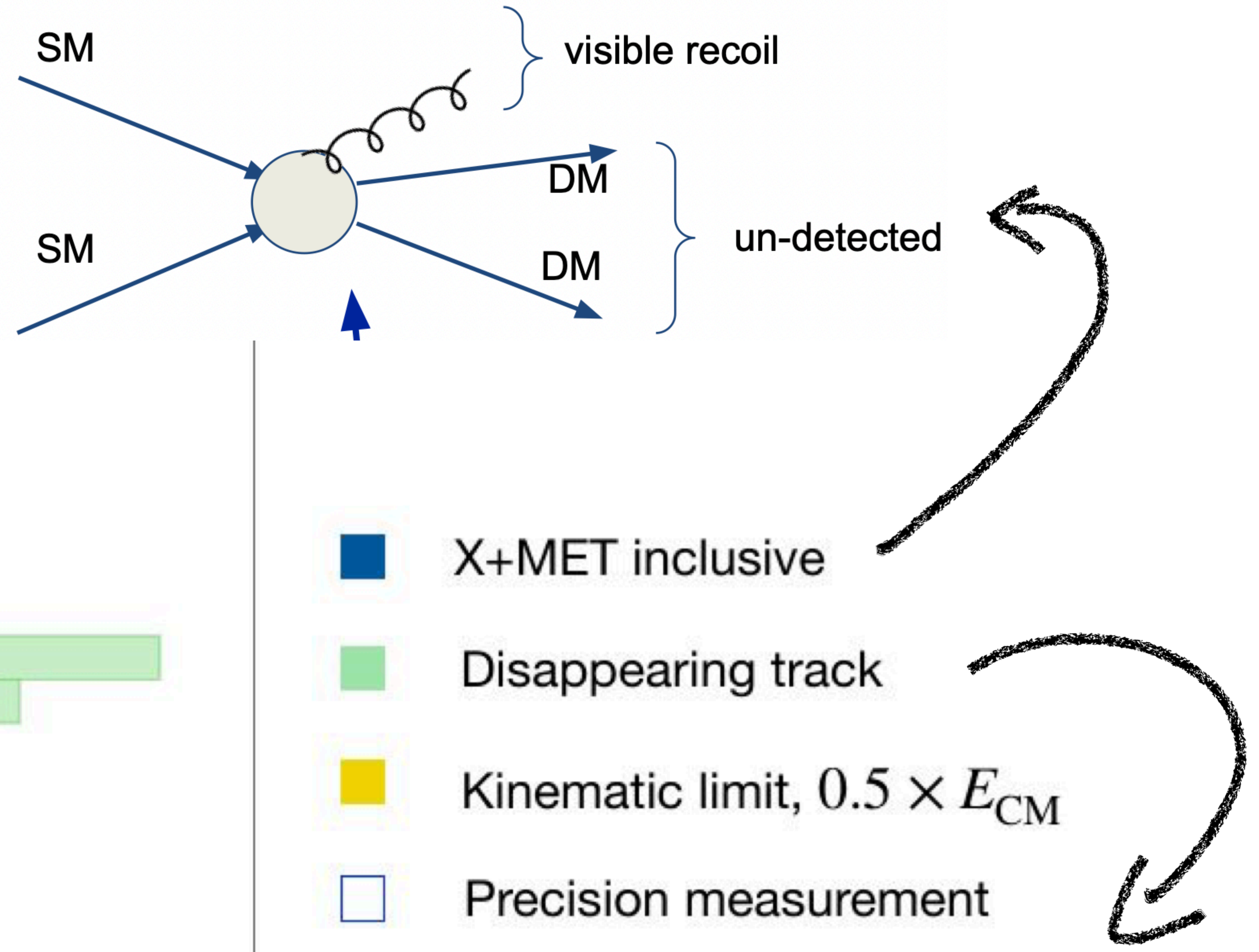

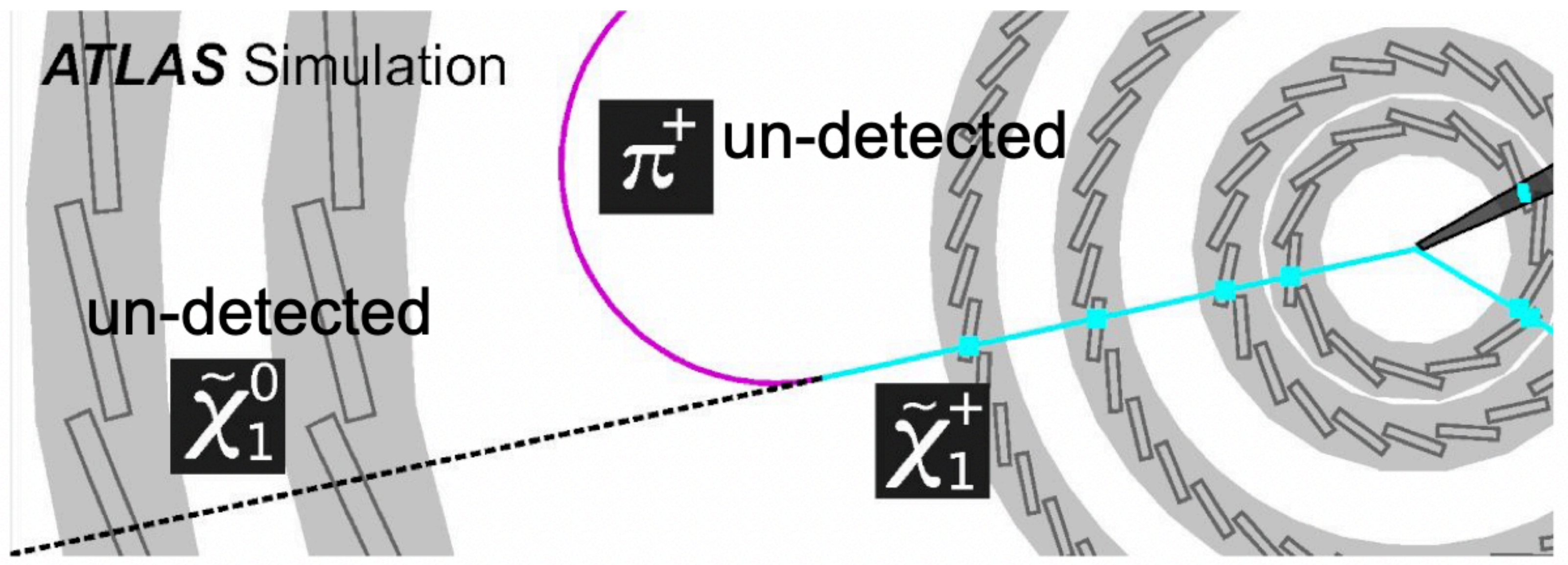

- Discovery potential for new particles - SUSY as an example

Lepton colliders: Full collision energy available for new particles -> Sensitivity up to kinematic limit.

Conclusions

Wrapping up

Compelling Scientific Opportunities

- An e^+e^- collider operating around 250 - 380 GeV will provide a model-independent, precise investigation of the Higgs sector, and studies of unprecedented precision of the top quark
- A revisit to the Z pole with much higher luminosity than LEP will enable to electroweak precision tests of the Standard Model at completely new levels. At the same time, this will also be a high-statistics flavour physics program.

- Scales in the TeV region and above can directly be probed by high-energy lepton colliders - CLIC, a (multi-)TeV ILC, and a muon collider. This also includes the measurement of the self-coupling of the Higgs.

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CERN is currently studying the feasibility of the **Future Circular Collider**:

- An e^+e^- machine running from the Z-pole up to 365 GeV - precision Higgs, Top, Electroweak.
- Followed by a ~ 100 TeV hadron collider - exploration of the highest energy scales, measurement of the self-coupling of the Higgs.

- **CLIC** is studied as “Option B” in case FCC cannot go forward.

The Way Forward

Strategies and Timescales - taken from this week's Snowmass Meeting

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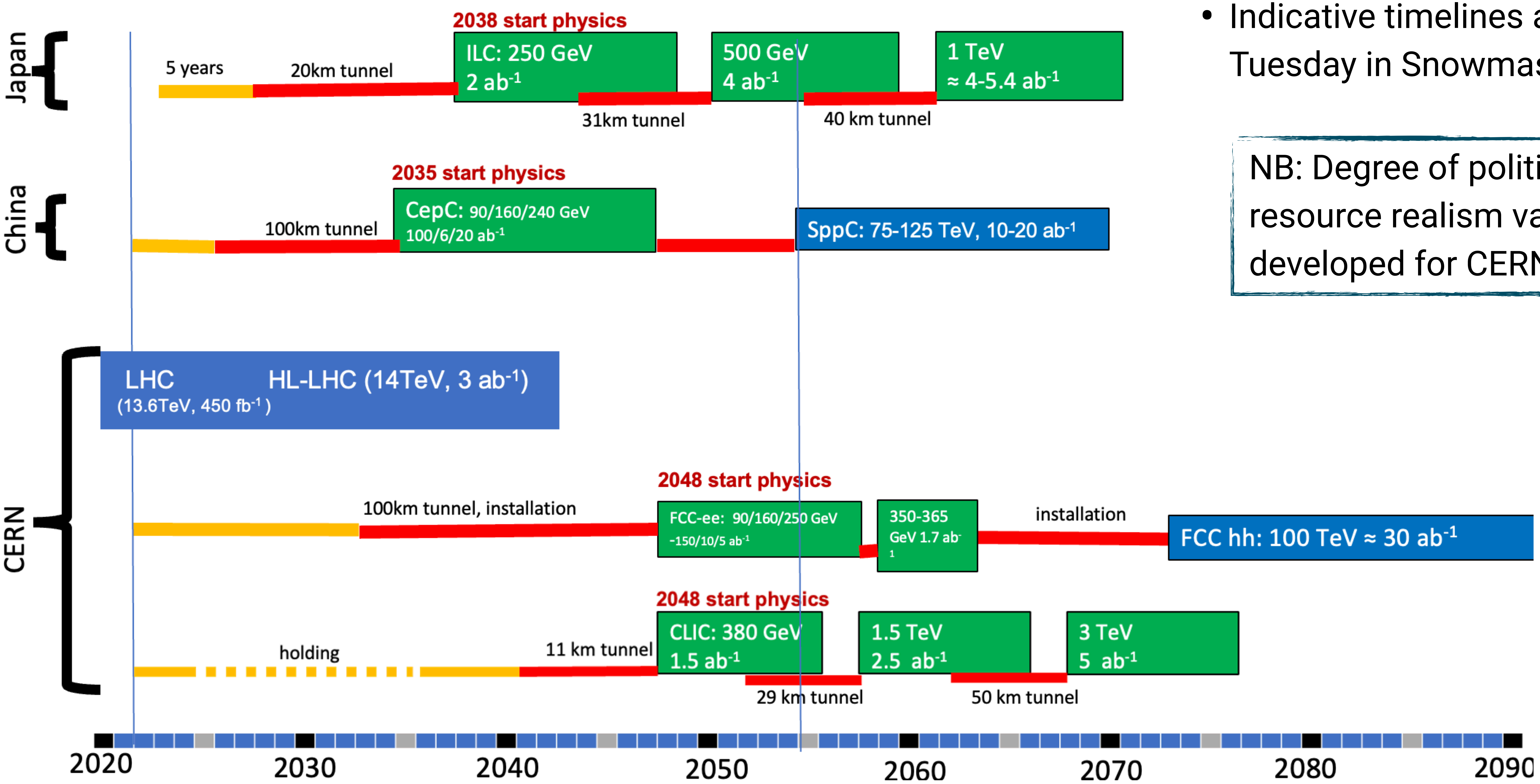

- Indicative timelines as discussed on Tuesday in Snowmass @ Seattle

> NB: Degree of political and resource realism varies - most developed for CERN projects

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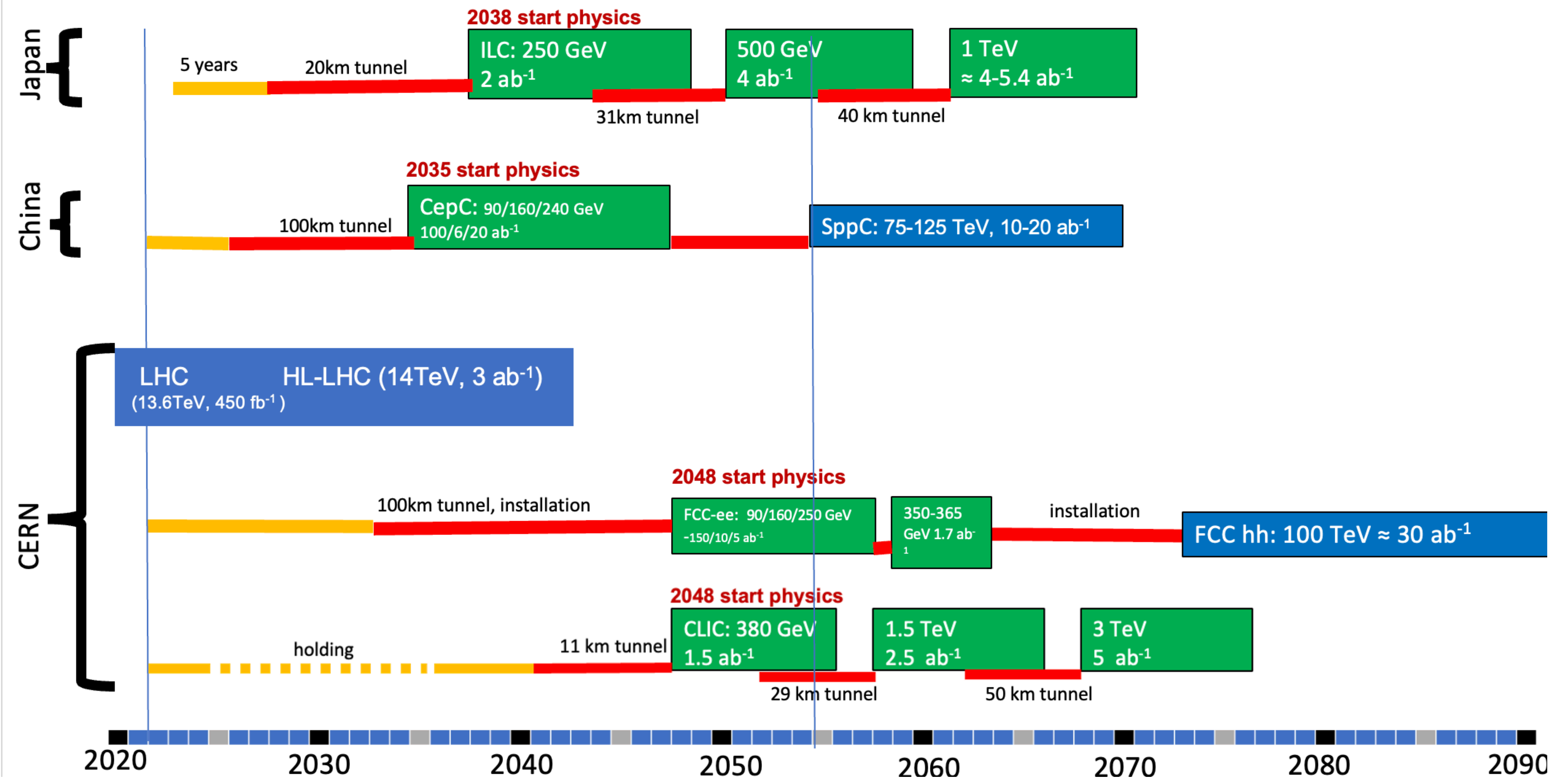

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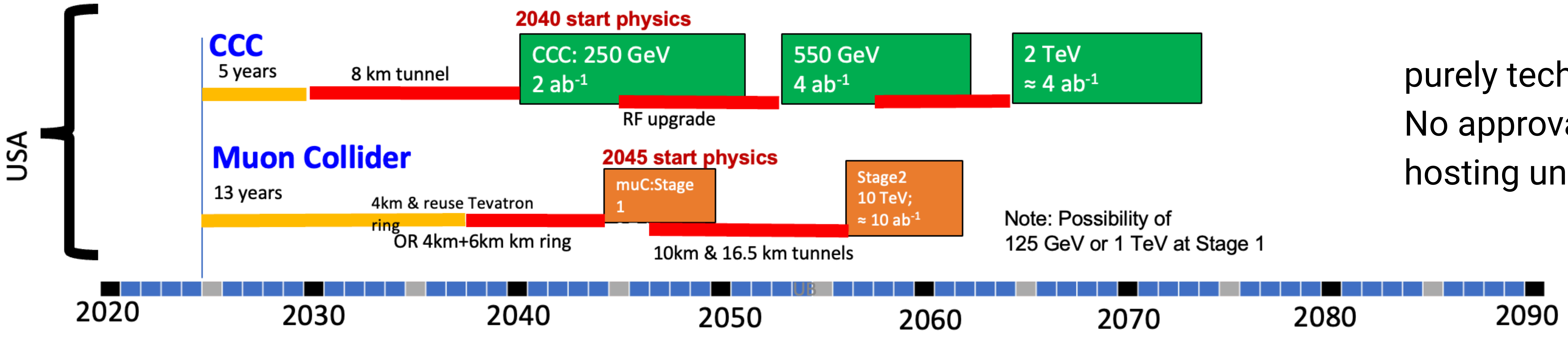
Proposals emerging from this Snowmass for a US based collider



purely technical!
No approval process yet, hosting unclear

Final Words

There are very exciting questions in high energy physics - a new e^+e^- collider may answer some of them!

Global large projects = long time scales - but contributions are needed now to make them happen.

This will be *your* HEP facility!