WG1-SRCH

SRCH subgroup report/plans

Roberto Franceschini (Roma Tre U. and INFN) - Oct. 11th 2024

Rebeca Gonzalez Suarez, Aleksander Filip Zarnecki

Outline

- EXtt focus topic
  - Update of top quark FCNC upper bound from new physics models
  - New search for generic scalar $t \to \phi c \to cb\bar{b}$
- Other WG1-SRCH activities not covered by LLP and Exotic scalar plenary talks on Wed., mostly summarizing some results appeared in the parallels of Wed. and Thu.
  - Dark Matter ($\supset$ SUSY) some Z’

EXtt focus topics

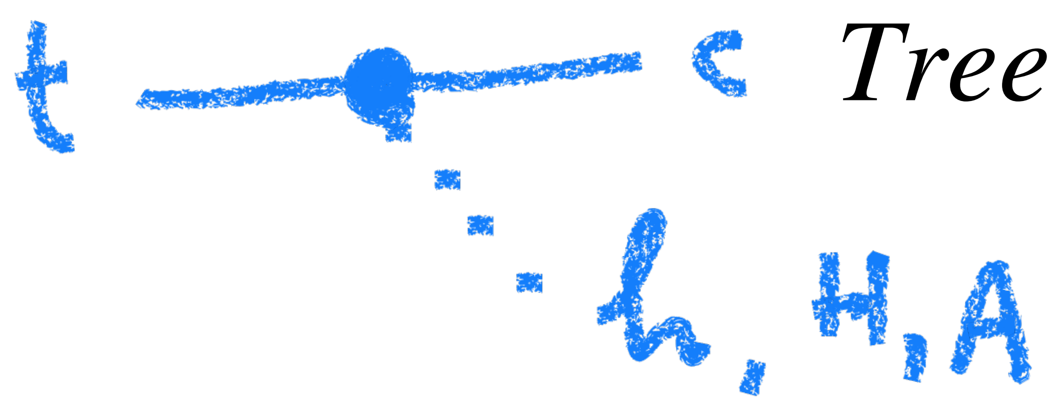
Top Exotic decays and Flavor Changing Neutral Currents at the top factory

Patrizia Azzi, Nuño Castro, Marina Cobal, Gauthier Durieux, RF, María Teresa Núñez Pardo de Vera, Kirill Skovpen, Marcel Vos

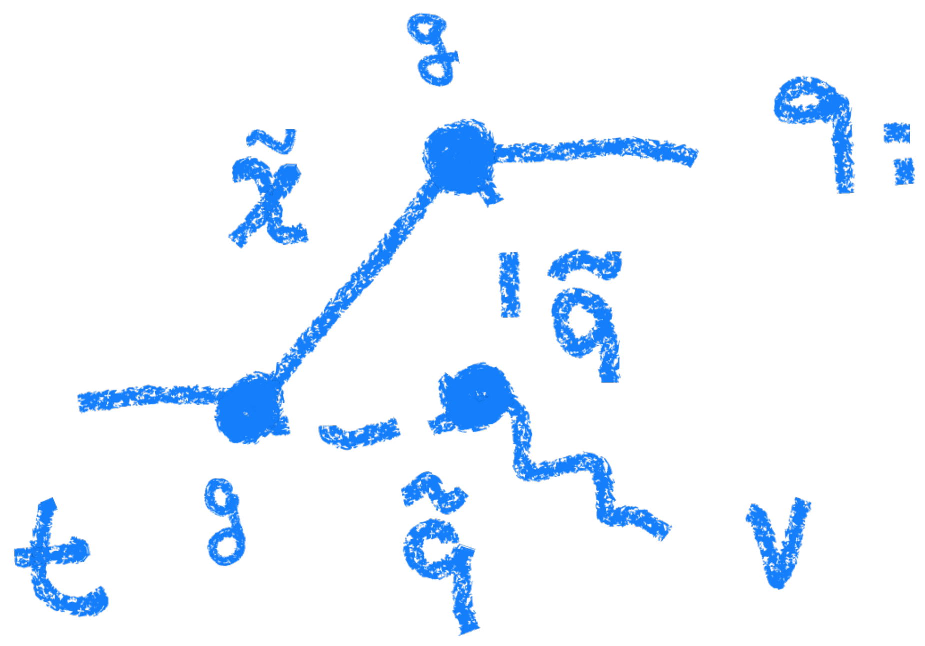
Contributions: Sagar Airen, Miriam Bulliri, Didar Dobur, Federico Mescia, Kevin Mota

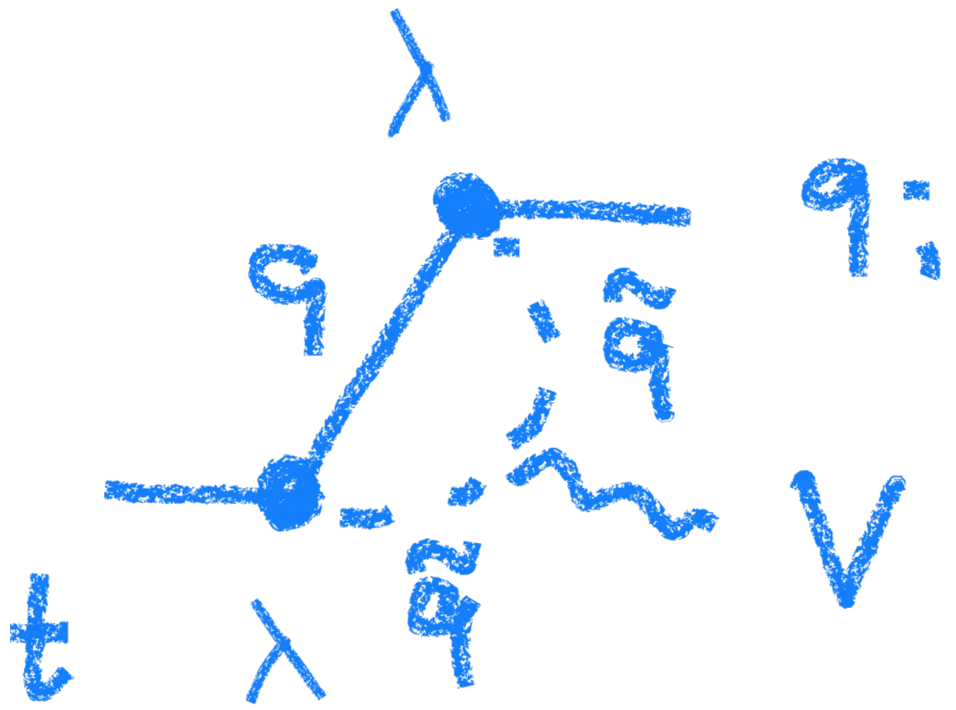
Top quark decay at the Top Factory

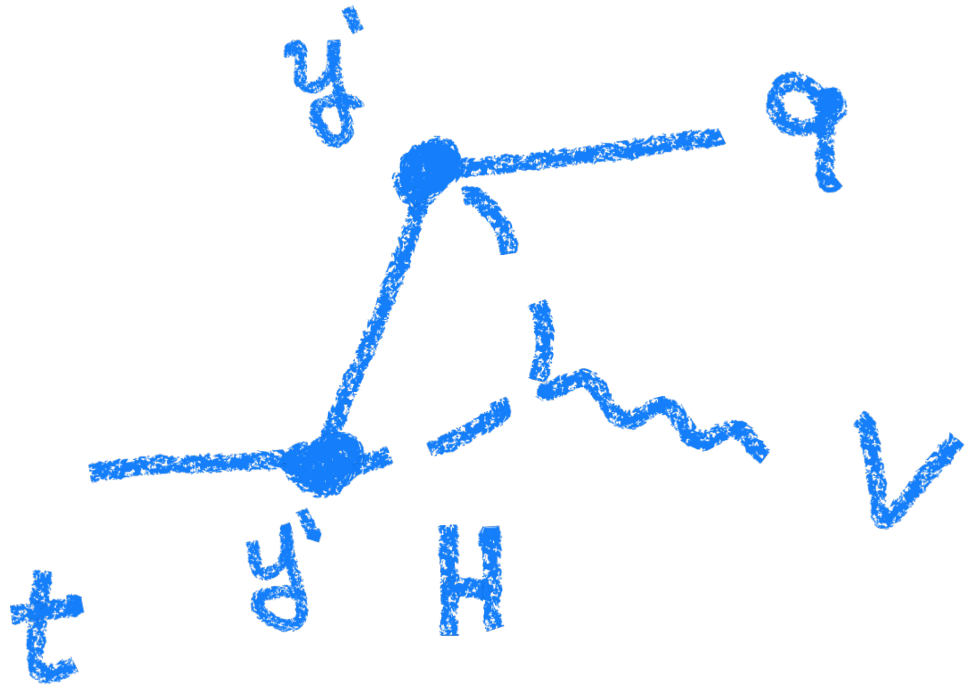
$t \to BSM$

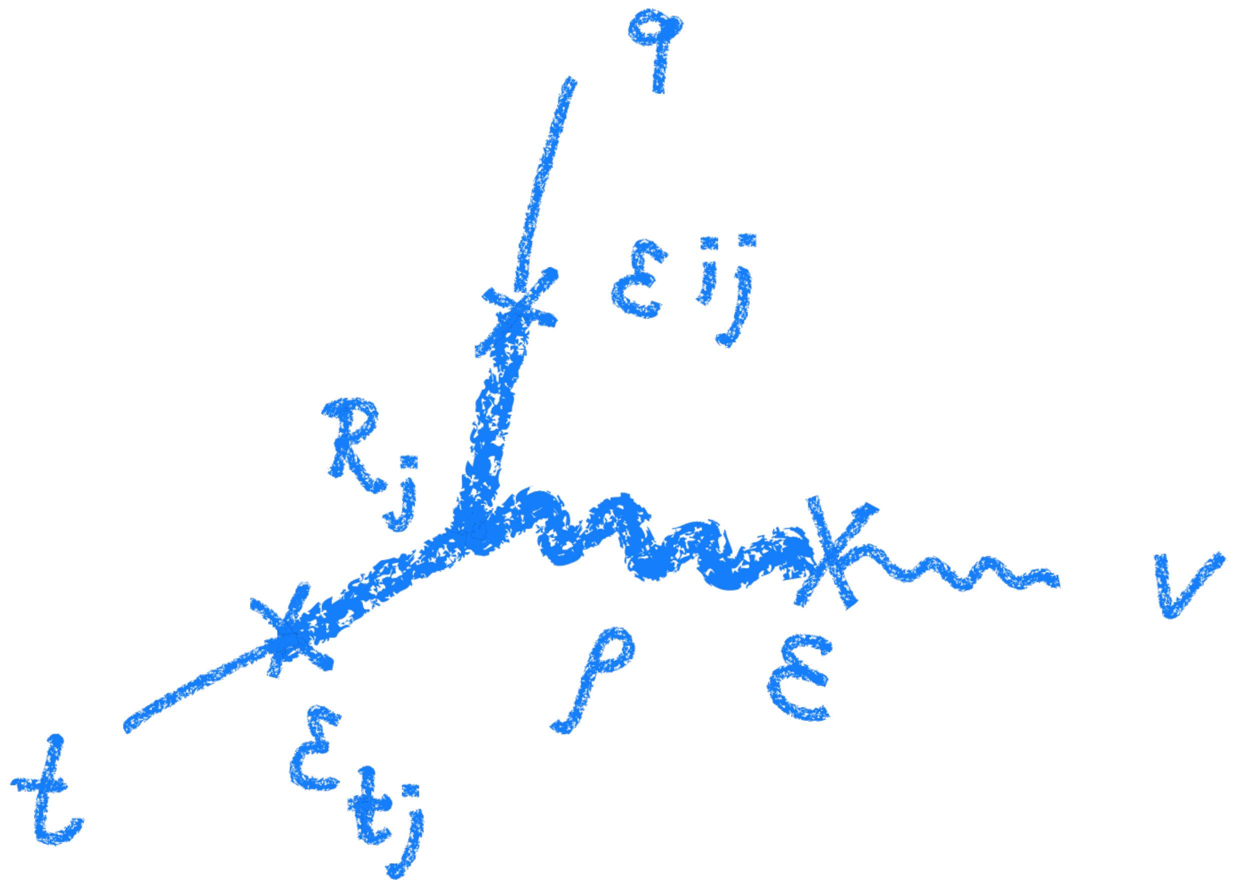


Tree – Level





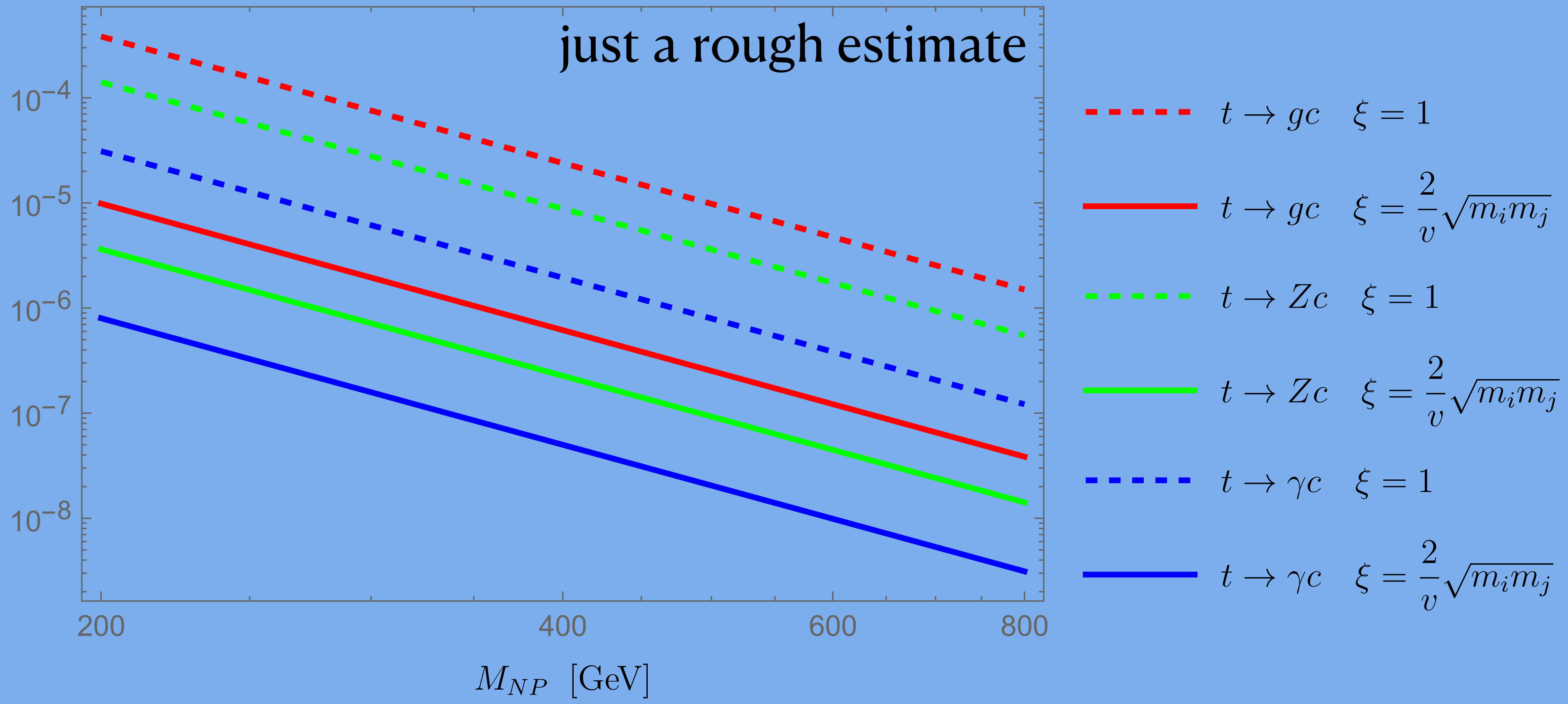




$$BR^{i\to k}_{loop} \propto \left(g_{SM} \frac{\xi_{ij}\xi_{jk}}{16\pi^2} \right)^2 \left(\frac{m_t}{M_{NP}} \right)^4 = 4 \cdot 10^{-5} \cdot g_{SM}^2 \cdot \left(\frac{m_t}{M_{NP}} \right)^4 \cdot (\xi_{ij}\xi_{jk})^2$$

Even a mere factor 2 stronger bounds on the particles originating flavor violation makes a factor 16 in the FCNC BR. This can take a “border-line observable at top factory” BR=10^{-5} down to 10^{-6} and ruin the party.

Top quark decay at the Top Factory



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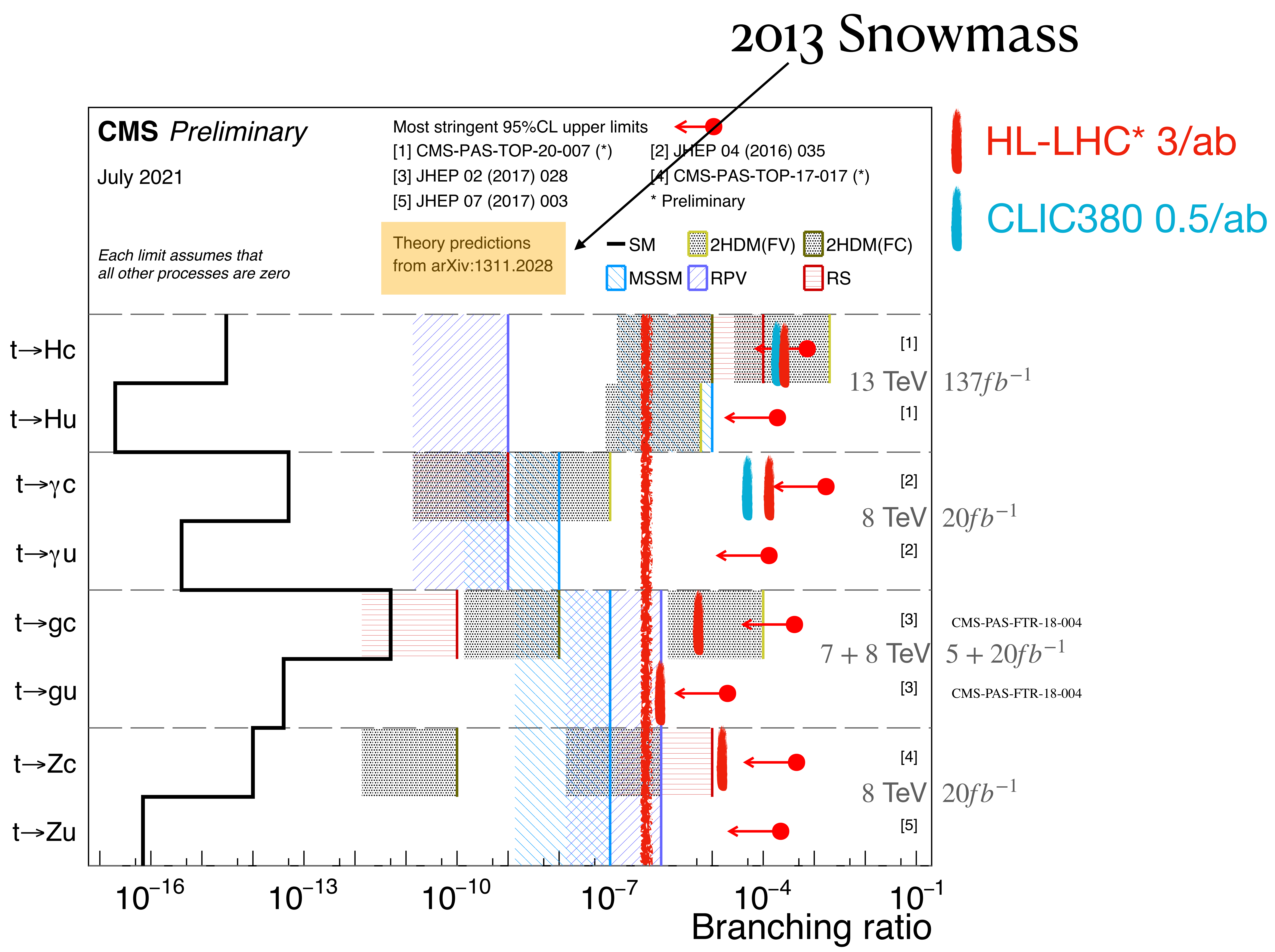


- **Last refresh of BSM benchmarks is quite old**
- Regardless of the focus topics a refresh seems needed for the final report
- Relation to EFT to be investigated further

Staus for Snowmass 2013

arXiv:1311.2028

Table 1-7. *SM and new physics model predictions for branching ratios of top FCNC decays. The SM predictions are taken from [119], on 2HDM with flavor violating Yukawa couplings [119, 120] (2HDM (FV) column), the 2HDM flavor conserving (FC) case from [121], the MSSM with 1TeV squarks and gluinos from [122], the MSSM for the R-parity violating case from [123, 124], and warped extra dimensions (RS) from [125, 126] .*

Model – III (2HDM(FV)); max(*Model – I*, *Model – II*) (2HDM(FC))

Process	SM	2HDM(FV)	2HDM(FC)	MSSM	RPV	RS
$t \to Zu$	7×10^{-17}	–	–	$\leq 10^{-7}$	$\leq 10^{-6}$	–
$t \to Zc$	1×10^{-14}	$\leq 10^{-6}$	$\leq 10^{-10}$	$\leq 10^{-7}$	$\leq 10^{-6}$	$\leq 10^{-5}$
$t \to gu$	4×10^{-14}	–	–	$\leq 10^{-7}$	$\leq 10^{-6}$	–
$t \to gc$	5×10^{-12}	$\leq 10^{-4}$	$\leq 10^{-8}$	$\leq 10^{-7}$	$\leq 10^{-6}$	$\leq 10^{-10}$
$t \to \gamma u$	4×10^{-16}	–	–	$\leq 10^{-8}$	$\leq 10^{-9}$	–
$t \to \gamma c$	5×10^{-14}	$\leq 10^{-7}$	$\leq 10^{-9}$	$\leq 10^{-8}$	$\leq 10^{-9}$	$\leq 10^{-9}$
$t \to hu$	2×10^{-17}	6×10^{-6}	–	$\leq 10^{-5}$	$\leq 10^{-9}$	–
$t \to hc$	3×10^{-15}	2×10^{-3}	$\leq 10^{-5}$	$\leq 10^{-5}$	$\leq 10^{-9}$	$\leq 10^{-4}$

Sagar Airen (U. of Maryland)

Miriam Bulliri (Roma1 “Sapienza”)

observable at top factory

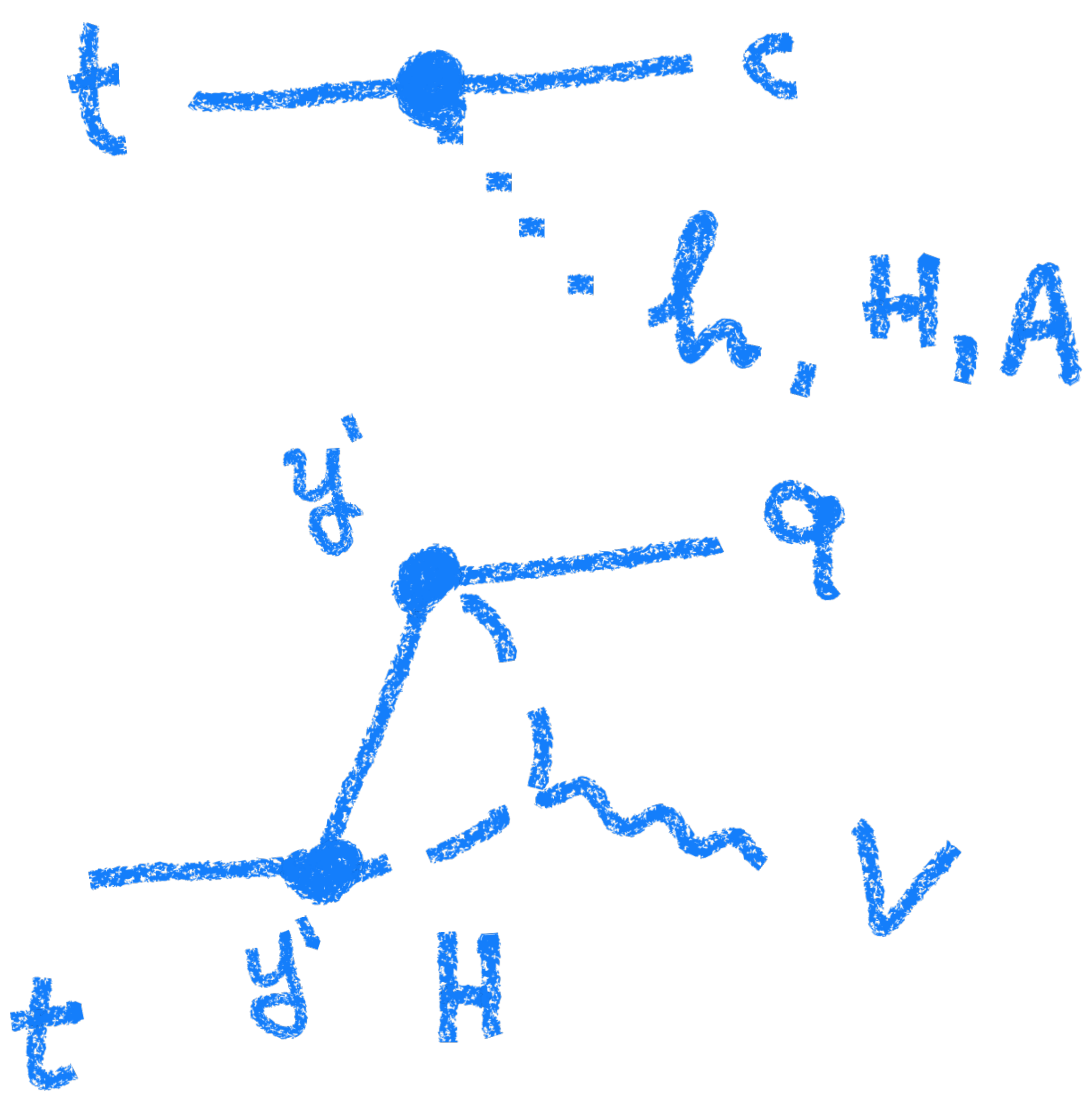
not observable at top factory

Use MSSM instead

2HDM-FV

Miriam Bulliri (U. of Rome "Sapienza") Federico Mescia (LNF Frascati)

$t \to cV$ in 2HDM-FV



htc coupling tuned away by "alignment" making *h* SM-like (flavor conserving and SM strength as LHC measurements suggest quite strongly)

$$g_{hVV} = \sin(\beta - \alpha) \simeq 1 - \frac{1}{2}\cos^2(\beta - \alpha) + \ldots$$

FV coupling of *h*

$m_{H,A,H^+} > m_t$ so that they do not have a tree-level decay

$$\mathcal{L}_{\rm Y} = \mathcal{L}_{\rm Y,\,SM} + \frac{1}{\sqrt{2}}\,\bar{d}\xi^d dH + \frac{1}{\sqrt{2}}\,\bar{u}\xi^u uH + \frac{1}{\sqrt{2}}\,\bar{\ell}\xi^\ell \ell H - \frac{i}{\sqrt{2}}\,\bar{d}\gamma_5\xi^d dA - \frac{i}{\sqrt{2}}\,\bar{u}\gamma_5\xi^u uA$$
$$-\frac{i}{\sqrt{2}}\,\bar{\ell}\gamma_5\xi^\ell \ell A + \left[\bar{u}\left(\xi^u V_{\rm CKM} P_L - V_{\rm CKM}\xi^d P_R\right) dH^+ - \bar{\nu}\xi^\ell P_R \ell H^+ + {\rm h.c.}\right],$$

both the doublets couple to all the quarks and leptons, but flavor violation is only in the doublet that does not take a VEV

$t \to cg$ in 2HDM-FV

Atwood et al 1996

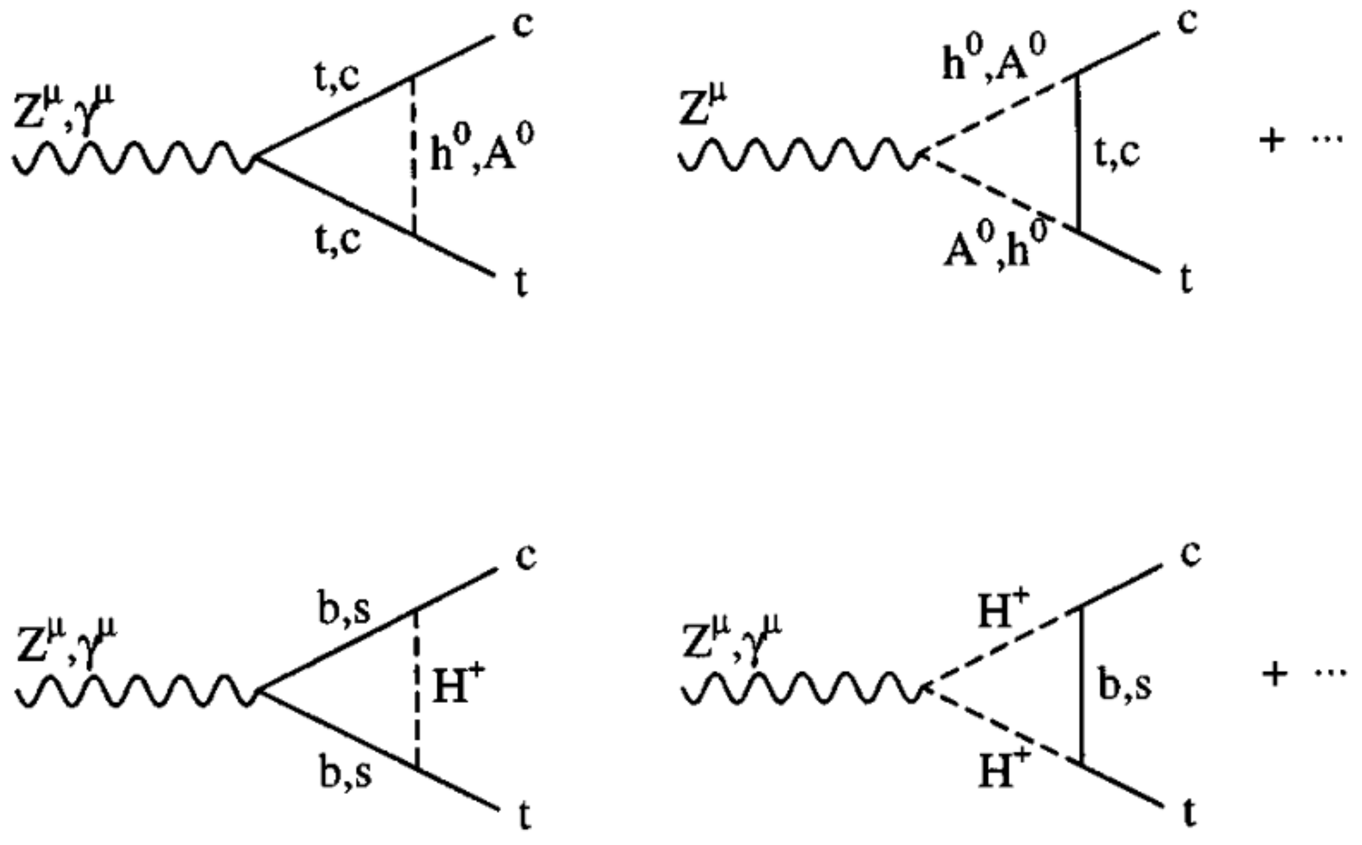


TABLE I. Values of $B(t \to c\gamma)$, $B(t \to cZ)$, and $B(t \to cg)$ for $m_t \simeq 180$ GeV, in the SM and in the 2HDM's denoted as model I, model II, and model III. Each range is obtained by varying m_c, m_h, m_A, $\tan\beta$, ... over a broad region of t[…] space of the corresponding model, as explained in […] model III, we have fixed $\lambda_{ij} \simeq \lambda = 1$ in the FC coupli[…]

what went in the snowmass 2013

Decay	SM	"up-specifc" Model I NFC – Type II	Inert Model II NFC – Type I	Model III FV
$t \to c\gamma$	$\sim 5 \times 10^{-12}$	10^{-13}–10^{-11}	10^{-13}–10^{-9}	10^{-12}–10^{-7}
$t \to cZ$	$\sim 10^{-13}$	10^{-13}–10^{-11}	10^{-13}–10^{-10}	10^{-8}–10^{-6}
$t \to cg$	$\sim 5 \times 10^{-11}$	10^{-11}–10^{-9}	10^{-11}–10^{-8}	10^{-8}–10^{-4}

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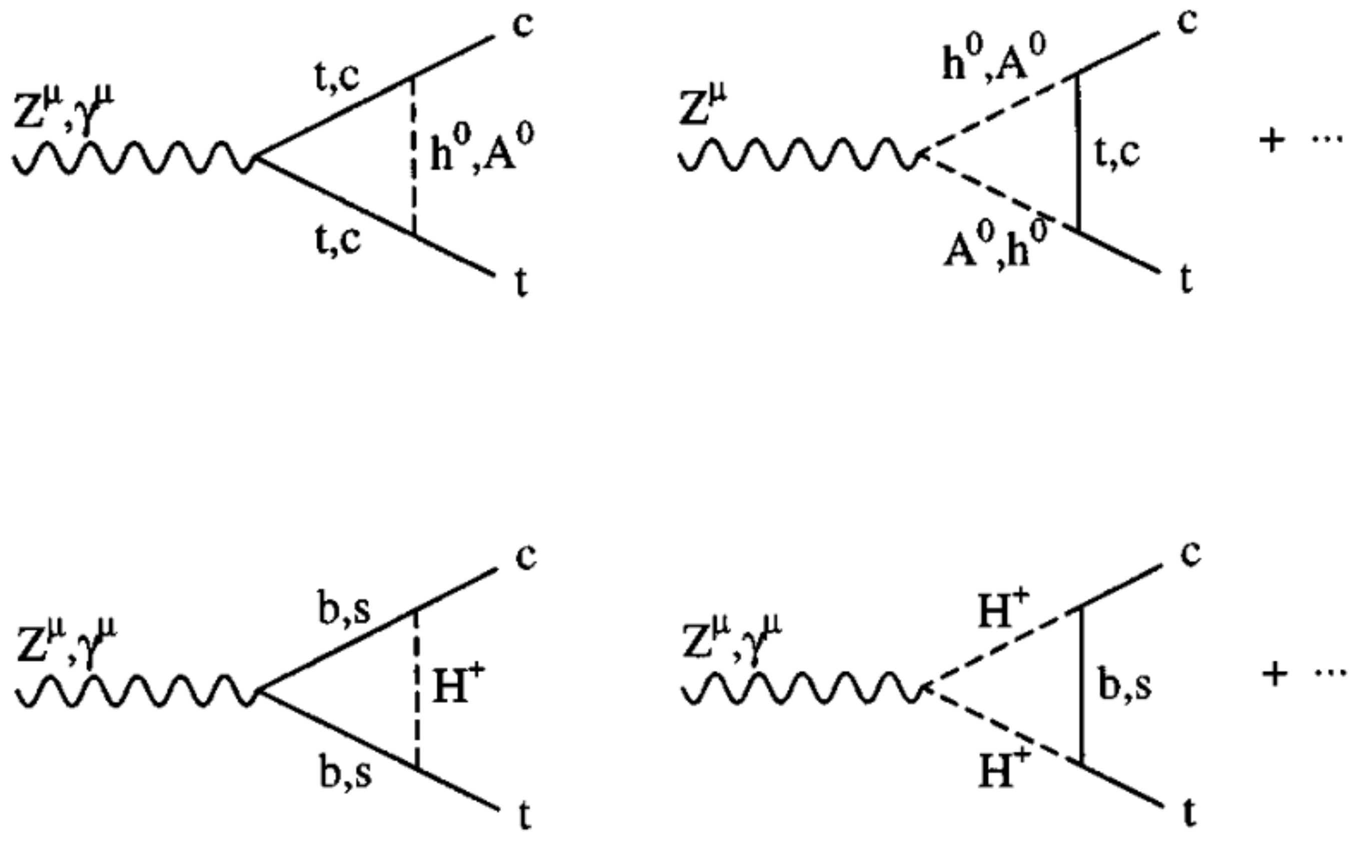

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above 10^{-6}

(largest rate)

$t \to cg$ in 2HDM-FV

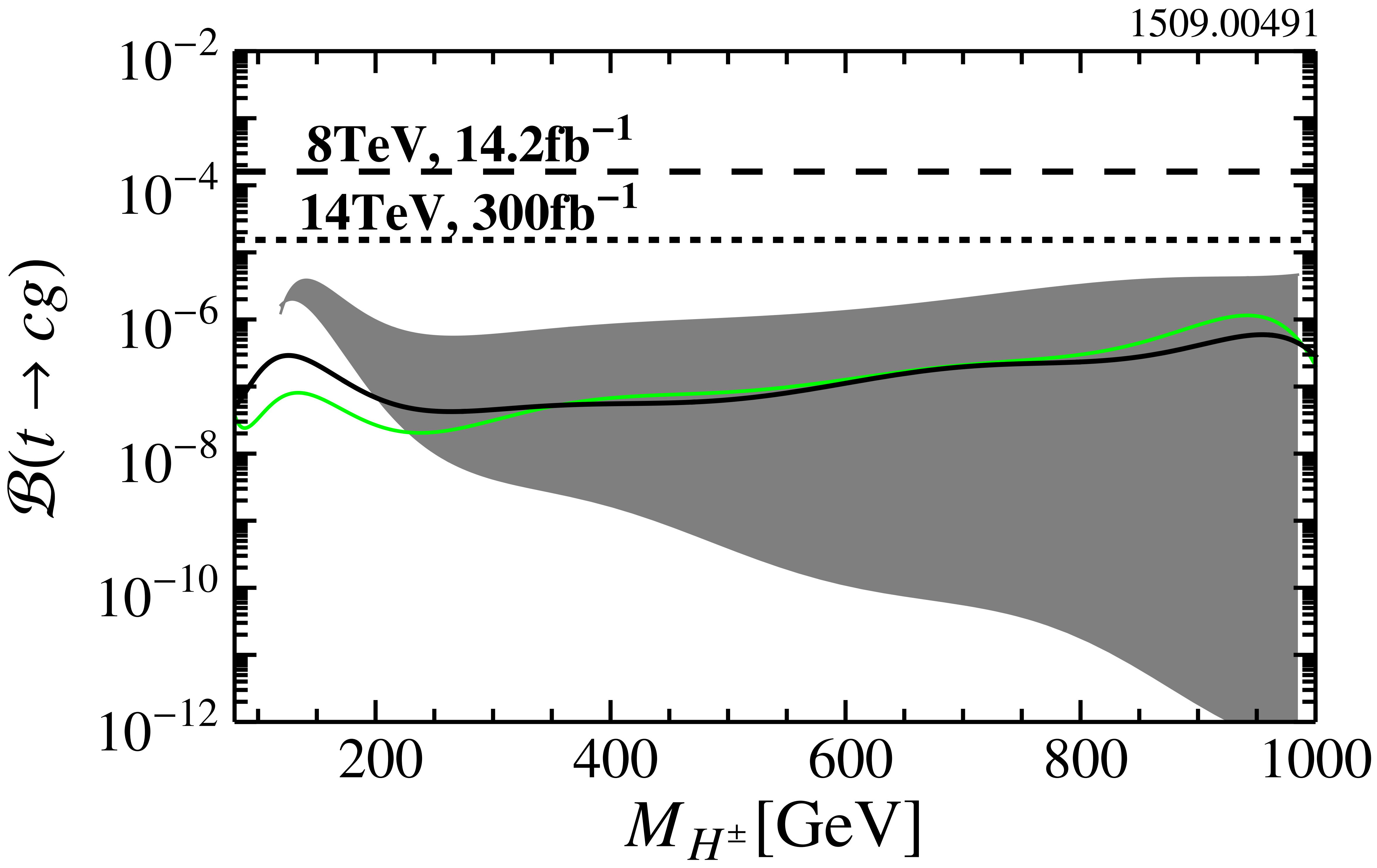
Kim et al, 1509.00491 2015

observable	SM	EXP
$\mathcal{B}(B \to \tau\nu) \cdot 10^4$	0.85 ± 0.14	1.14 ± 0.22
$R(D)$	0.297 ± 0.017	$0.391 \pm 0.041 \pm 0.028$
$R(D^*)$	0.252 ± 0.003	$0.322 \pm 0.018 \pm 0.012$
$\Delta m_d[\text{ps}^{-1}]$	0.51 ± 0.06	0.510 ± 0.003
$\Delta m_s[\text{ps}^{-1}]$	16.93 ± 1.16	17.757 ± 0.021
$\mathcal{B}(B \to X_s\gamma) \cdot 10^4$	3.36 ± 0.23	$3.43 \pm$ 0.22 was 0.66
$\mathcal{B}(t \to cg)$	$< 10^{-10}$	$< 1.6 \times 10^{-4}$ (95% CL)
$\sigma(pp \to tt)$	-	< 62 fb (95% CL)
R_b	0.21576 ± 0.00003	0.21629 ± 0.00066
ρ_0	1	$1.00040 \pm$ 0.00024 was 0.0025

3x better

10x better

0.0018



Hardly tenable to consider $BR > 10^{-6}$

Bulliri et al. Work in progress to remove effect from R(D) and R(D*) in 1509.00491 and update limits from ρ and $b \to X_s\gamma$

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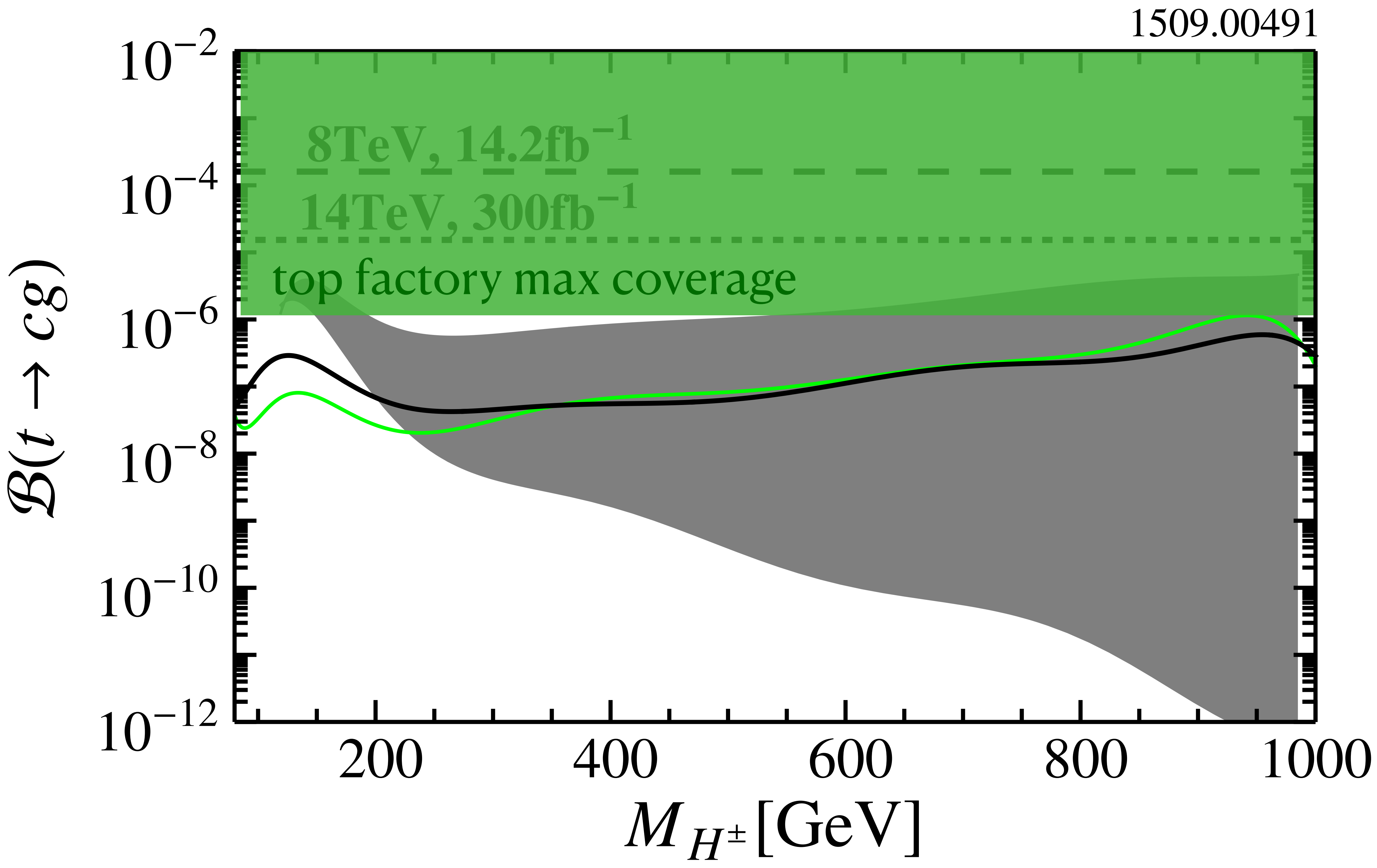

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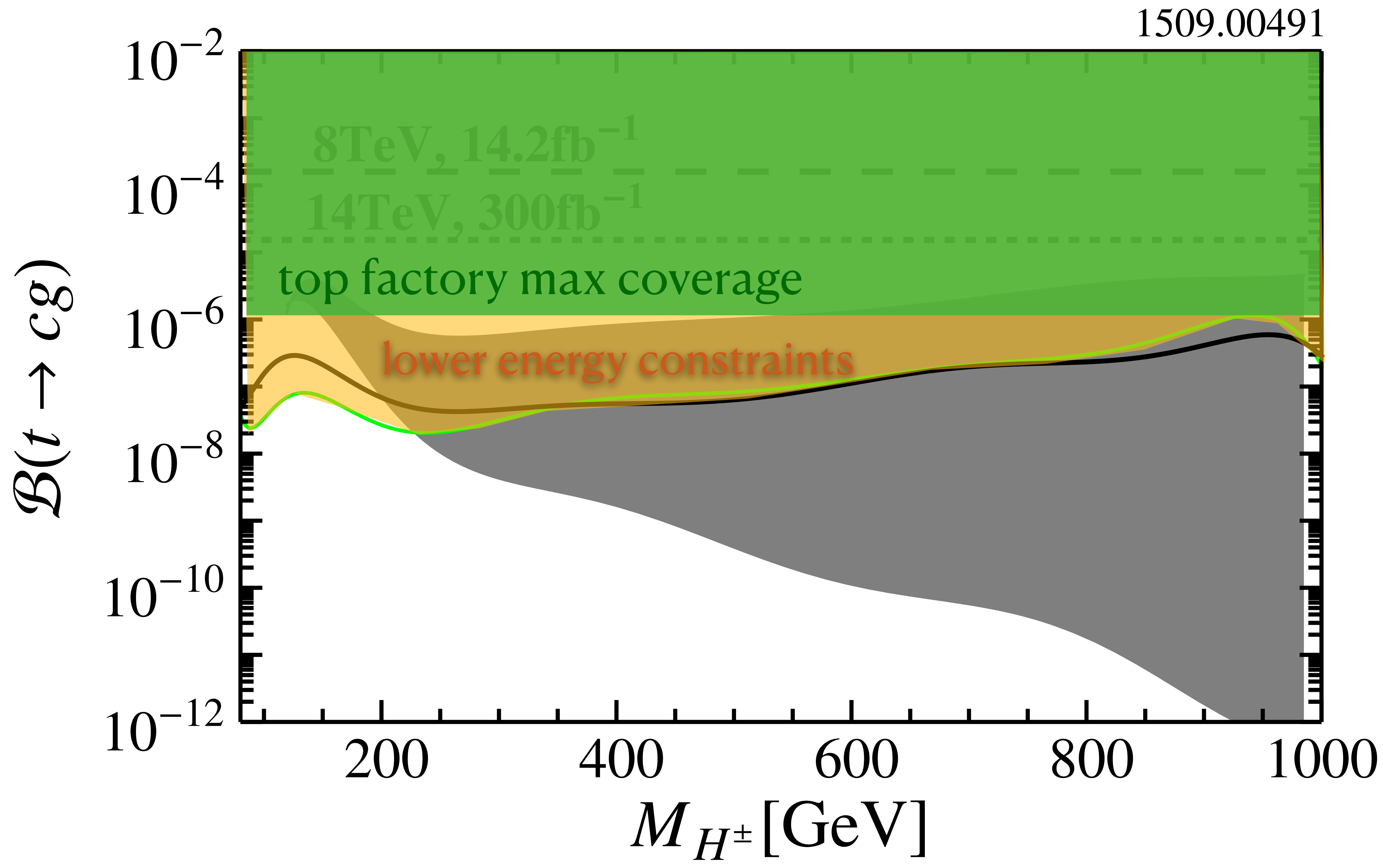

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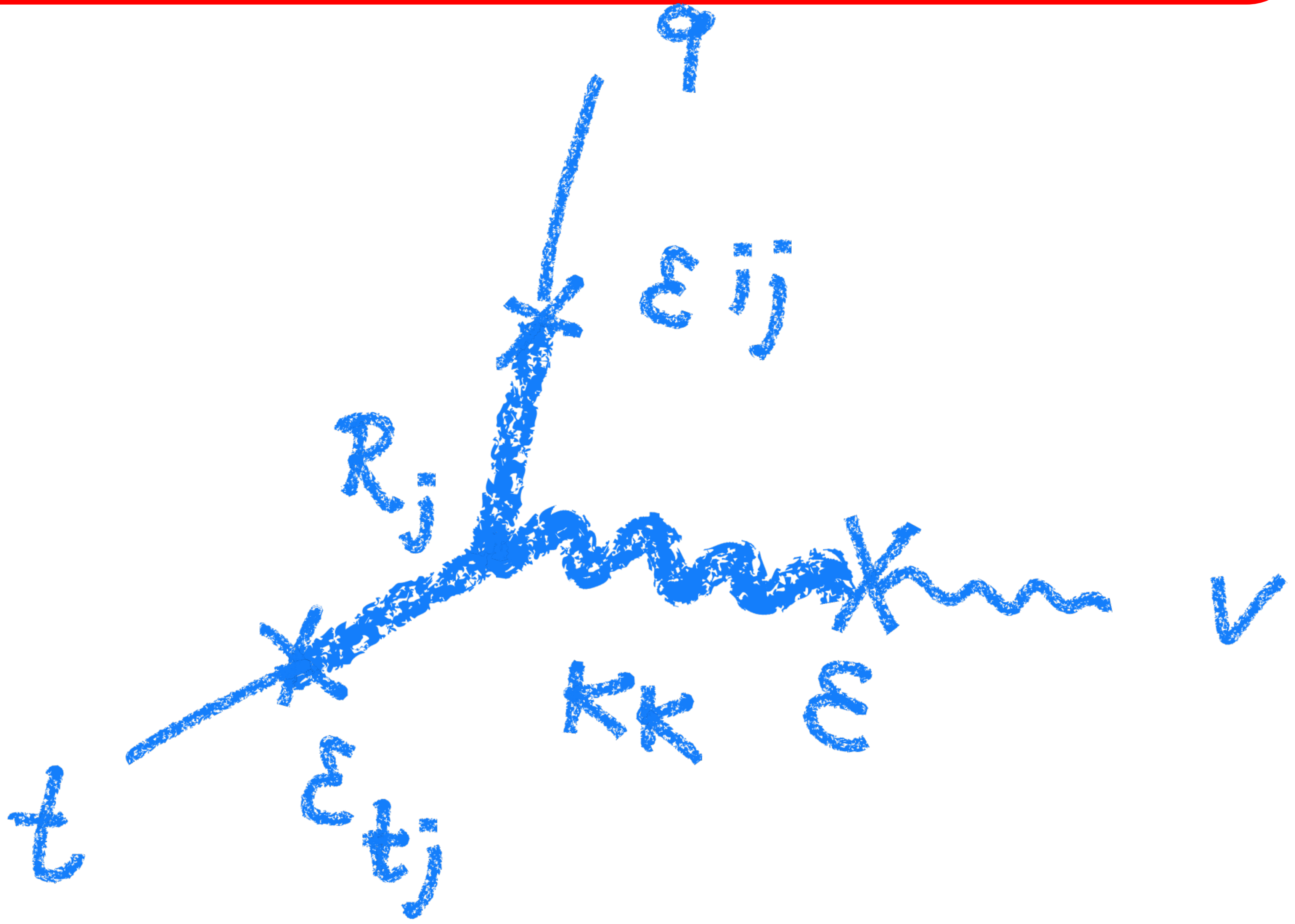
Randall Sundrum

Sagar Airen (U. of Maryland)

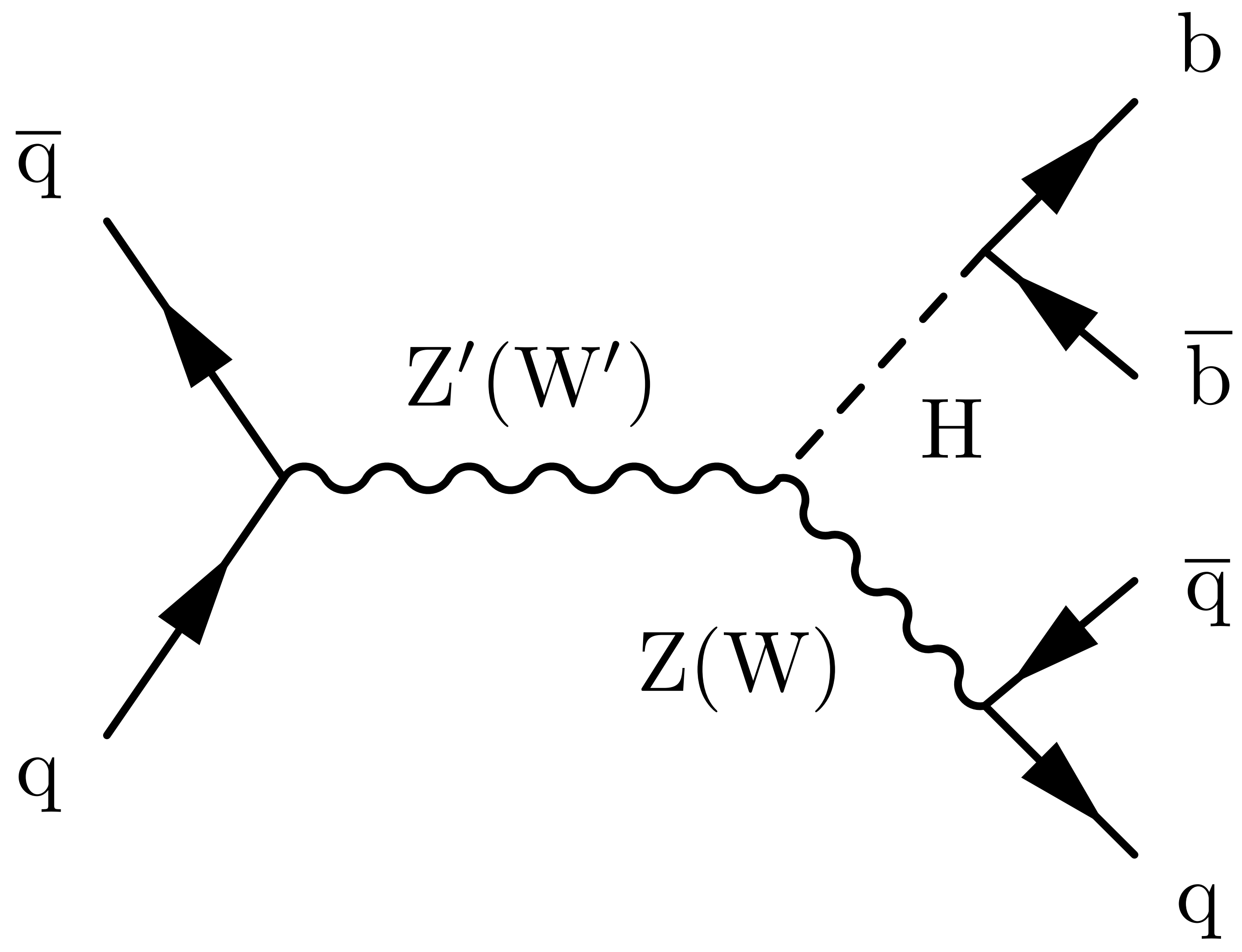
RS predictions and recast of LHC searches

HVT ↔ Randall Sundrum

$$\mathrm{BR}\,(t \to cZ) \;\sim\; 10^{-5}\left(\frac{3\ \mathrm{TeV}}{m_{KK}}\right)^4\left(\frac{(U_R)_{23}}{0.1}\right)^2 .$$



$$U_R^{23} \sim \frac{m_c}{m_t \lambda_{CKM}^2}$$



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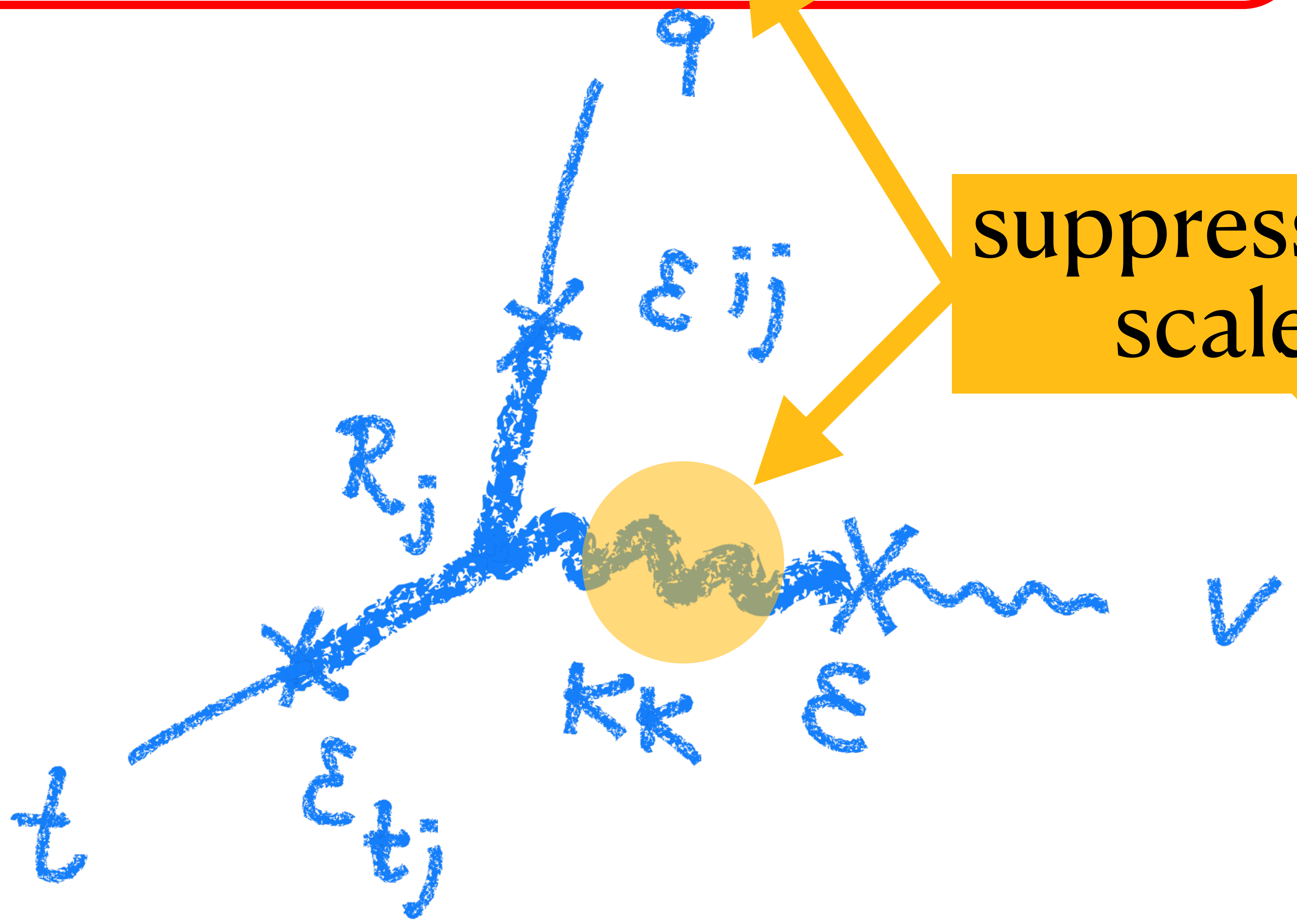
suppression scale



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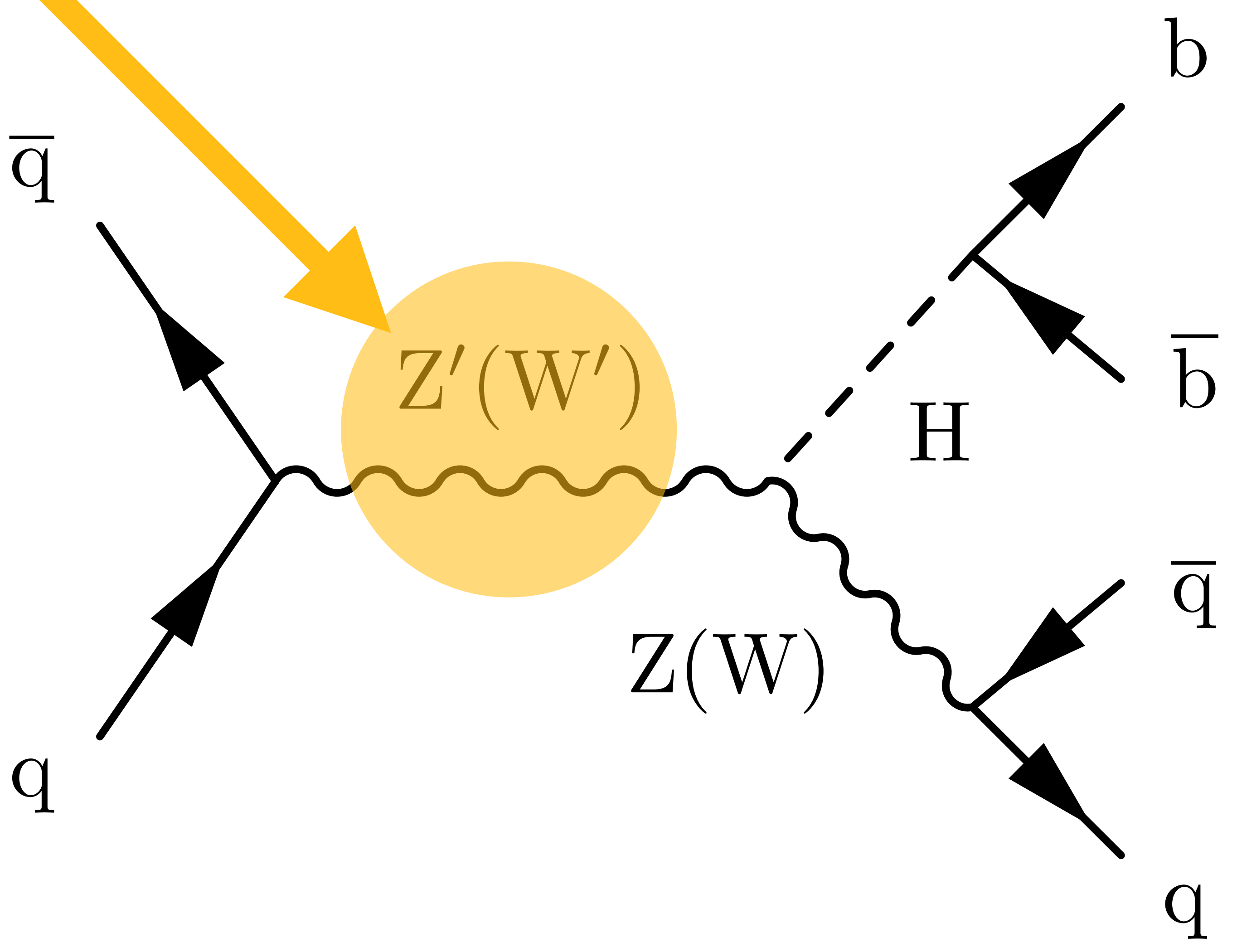

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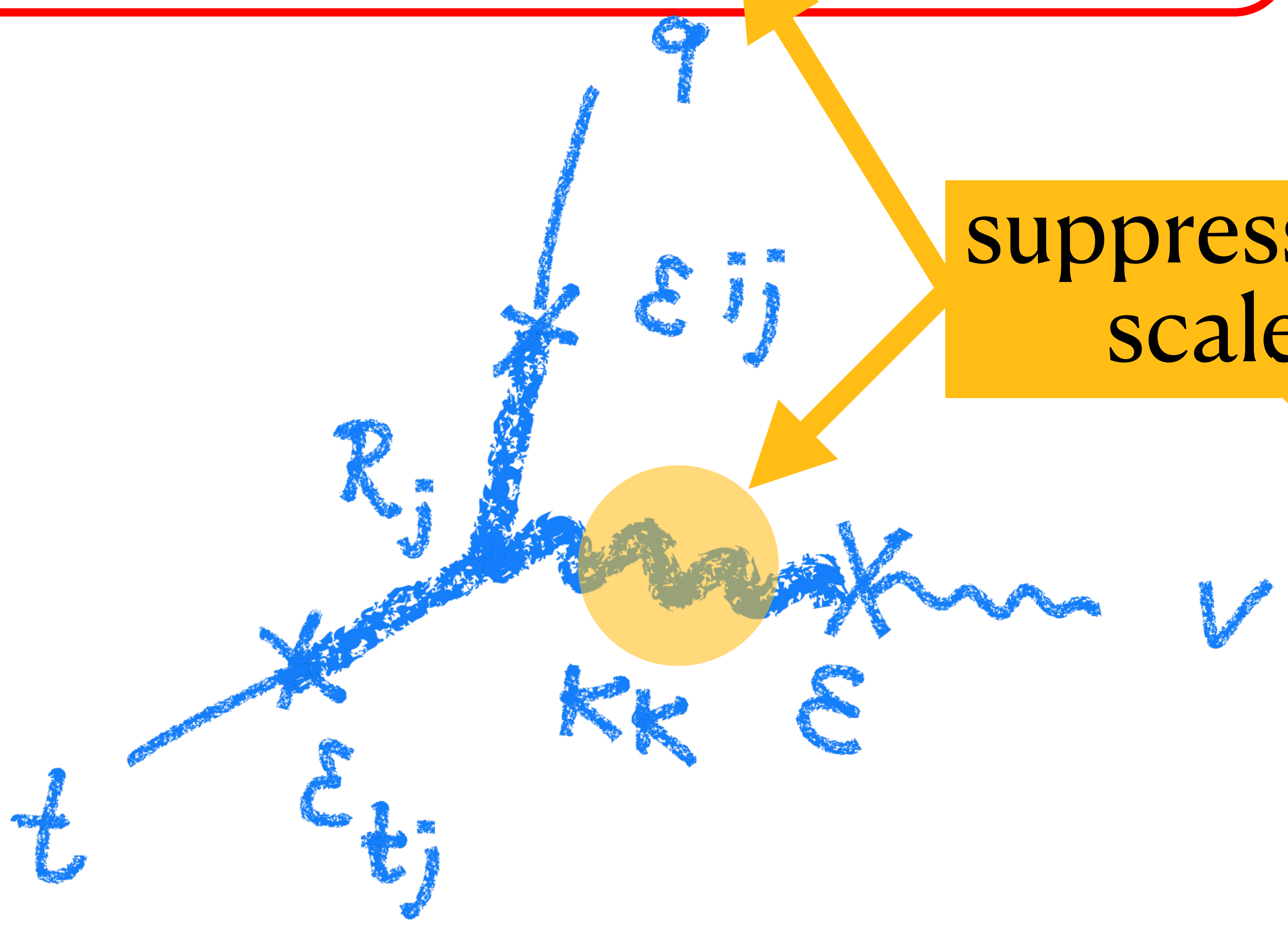
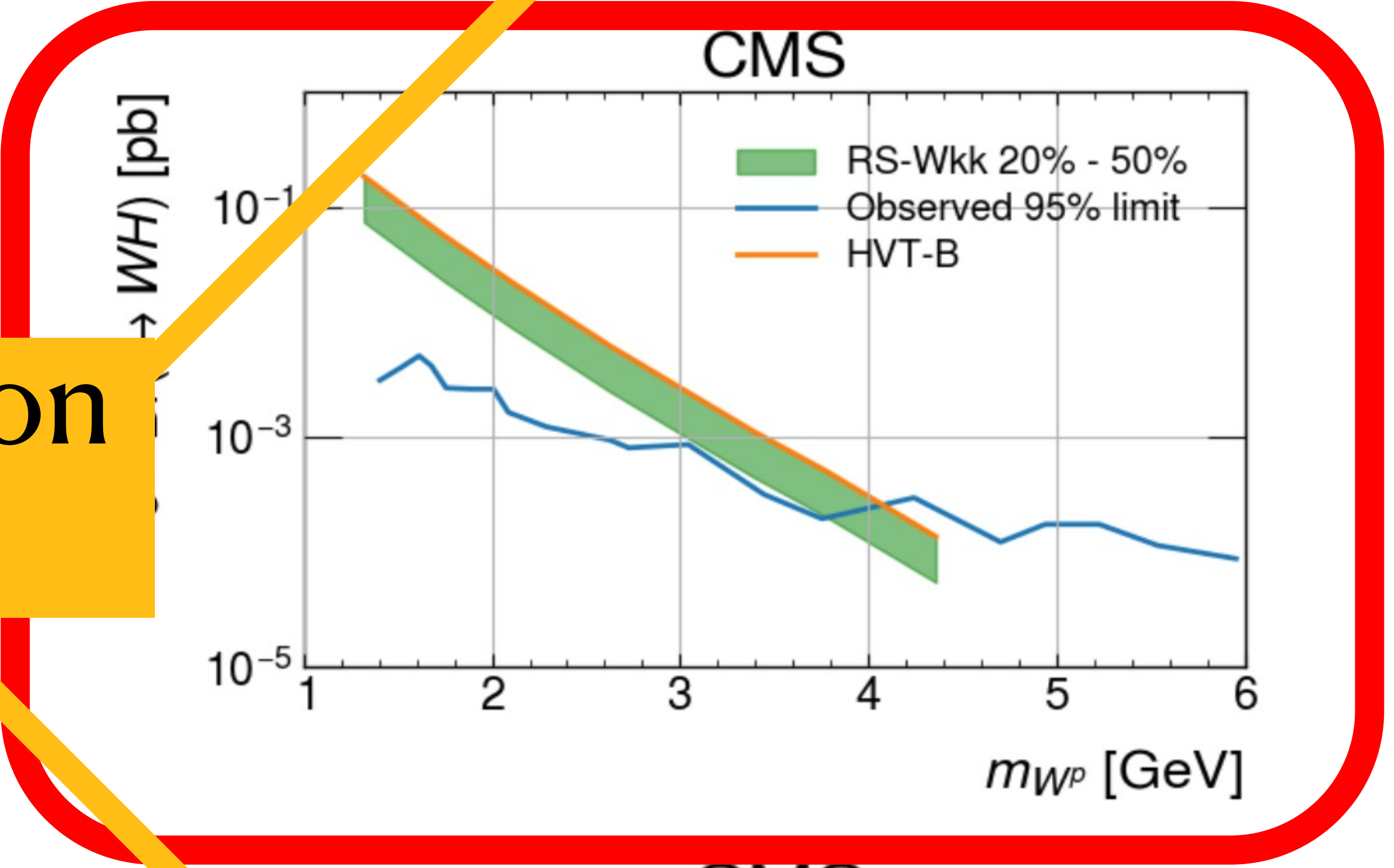
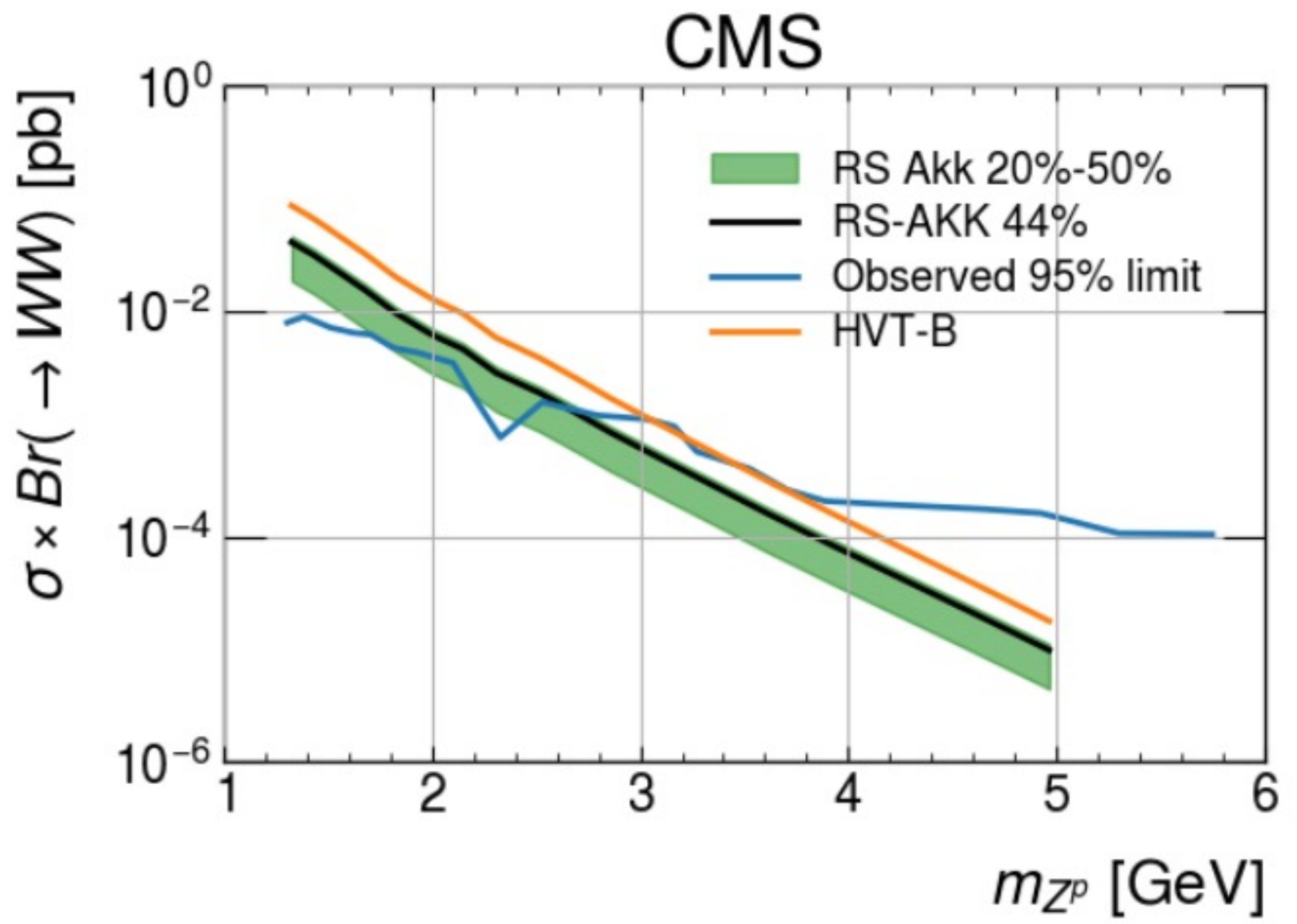
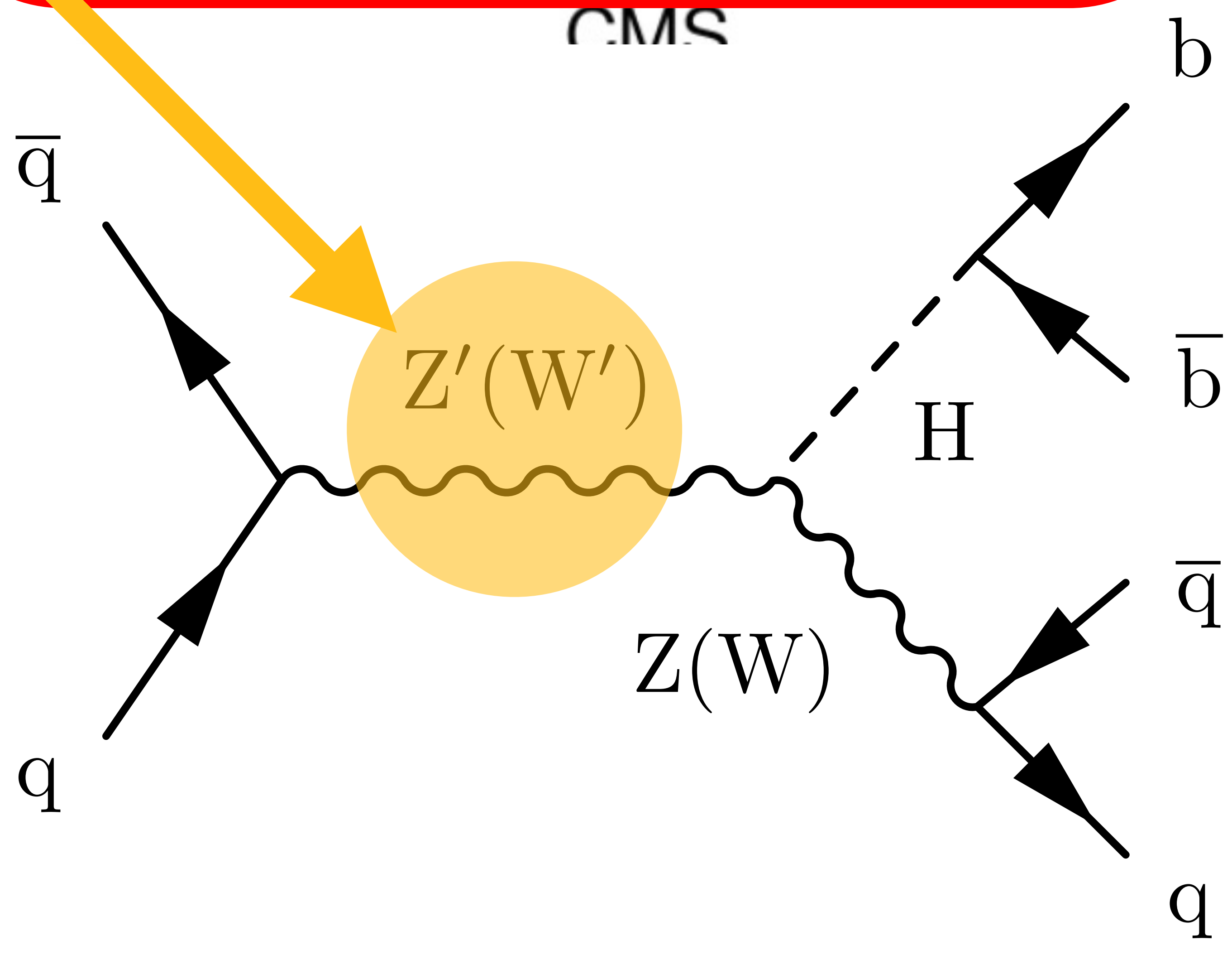
- Recast $m_{EW_{KK}} > 3.7\ TeV$ with 138 fb^{-1} 13 TeV data
- Channels ZH, WW, WH, ZW, ttbar

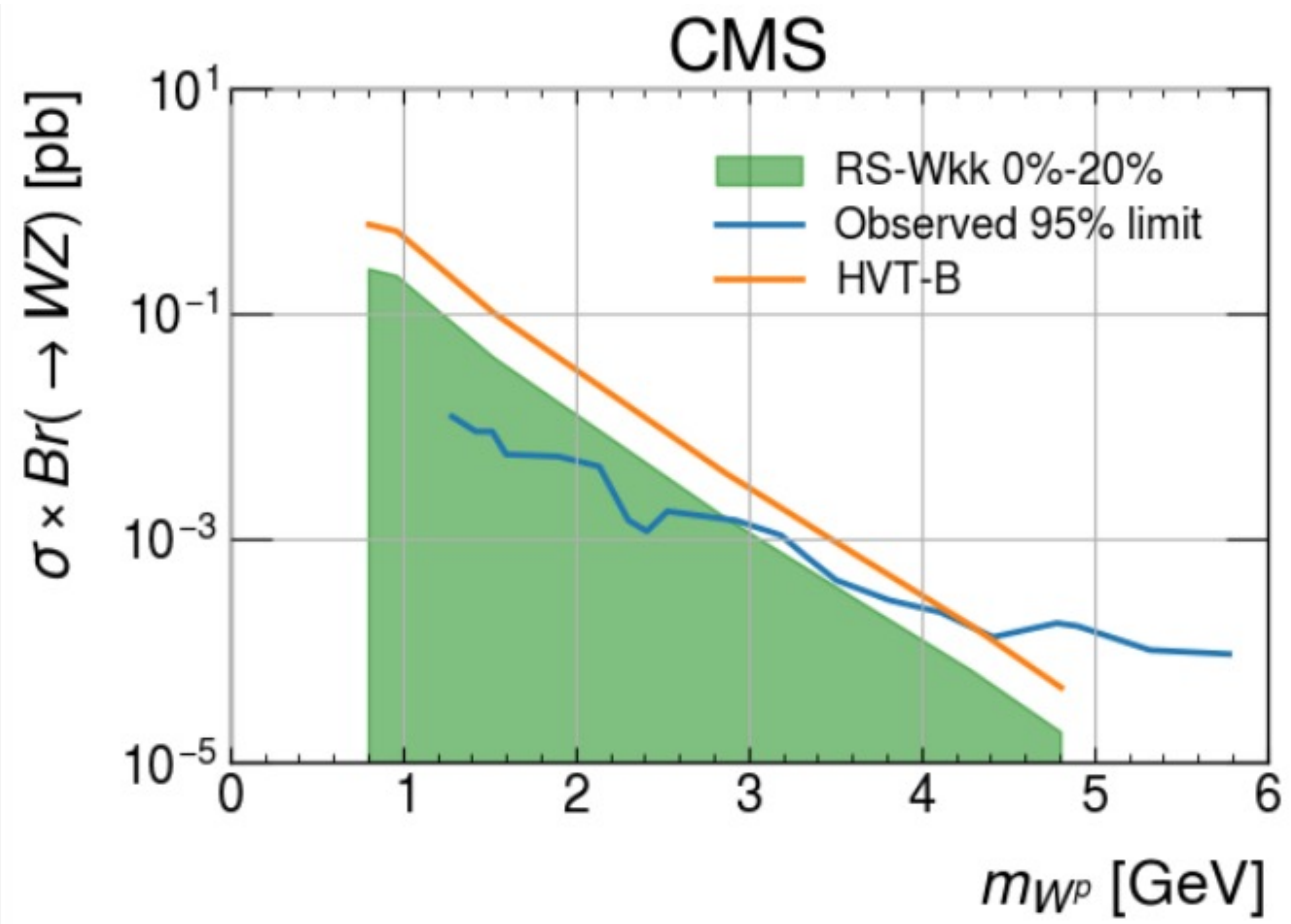
suppression scale











$$U_R^{23} \sim \frac{m_c}{m_t \lambda_{CKM}^2}$$

RS predictions and recast of LHC searches

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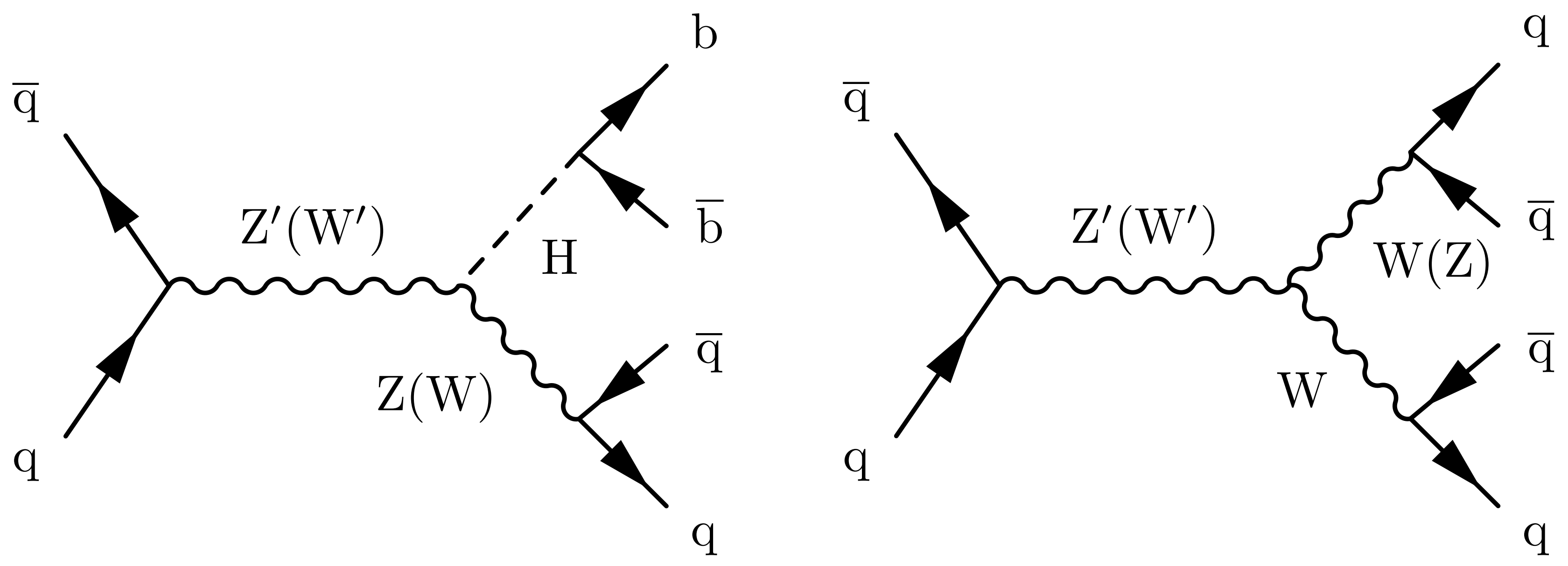
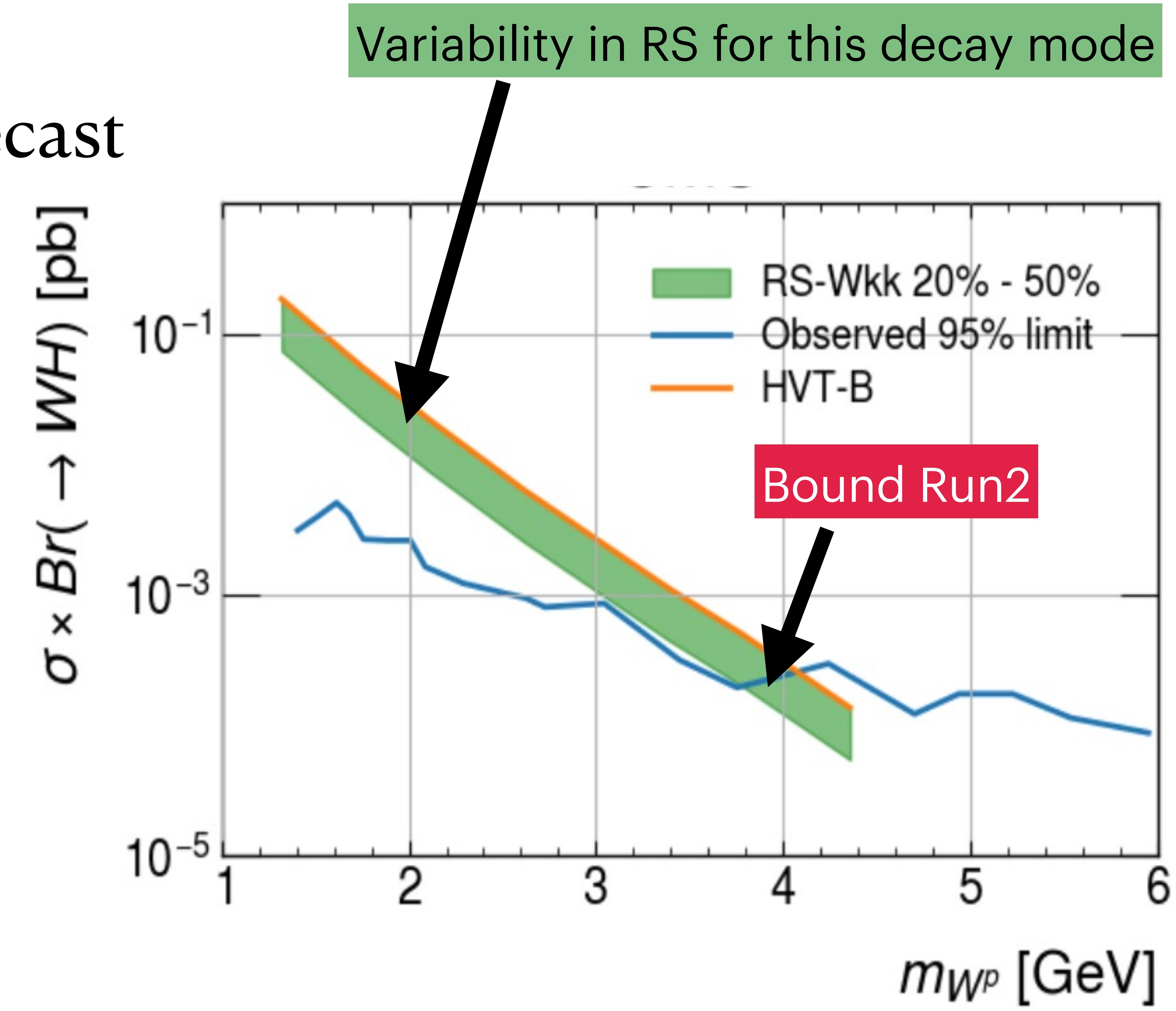
HVT recast to RS uses W' and Z'

KK gluon is model dependent and ignored in the recast





- Current bound $m_{KK} > 3.7\ TeV$
- At HL-LHC 3 ab^{-1} we expect it to go to roughly 5 TeV. $\Rightarrow Br(t \to cZ) \approx 1.2 \times 10^{-6}$

RS-like New Physics that can source $BR(t \to Zc) > 10^{-6}$ will be probed at HL-LHC

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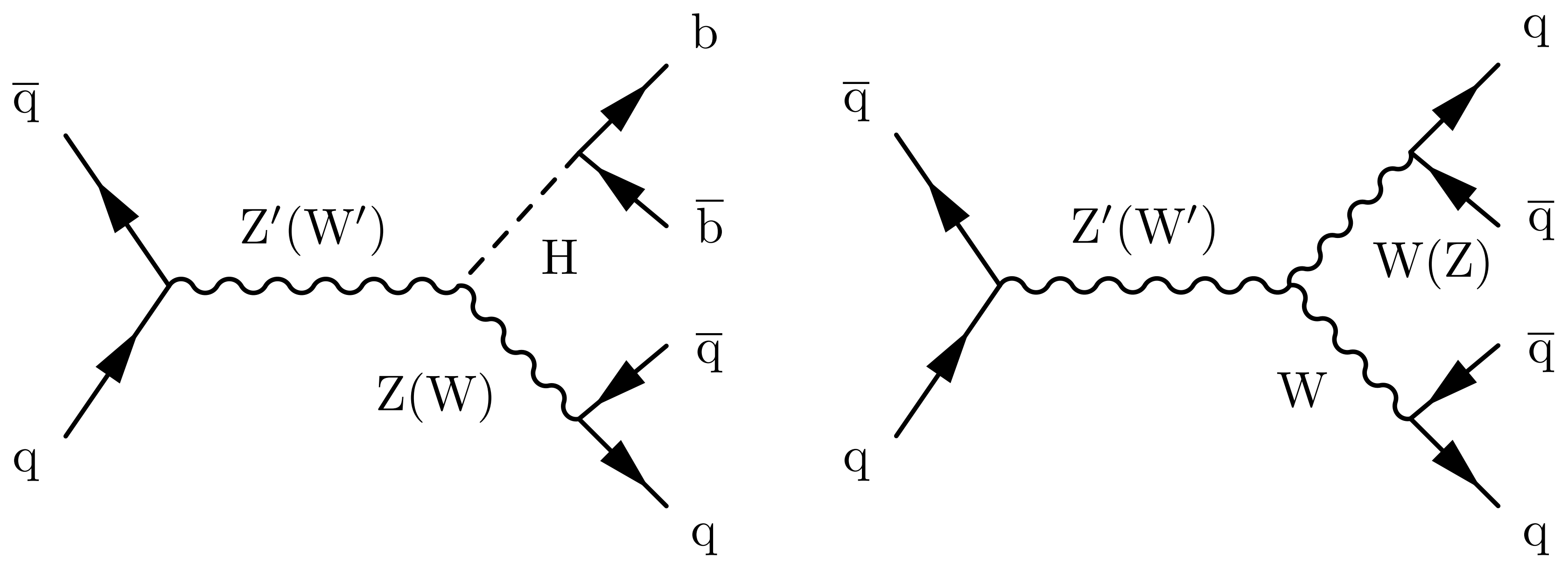

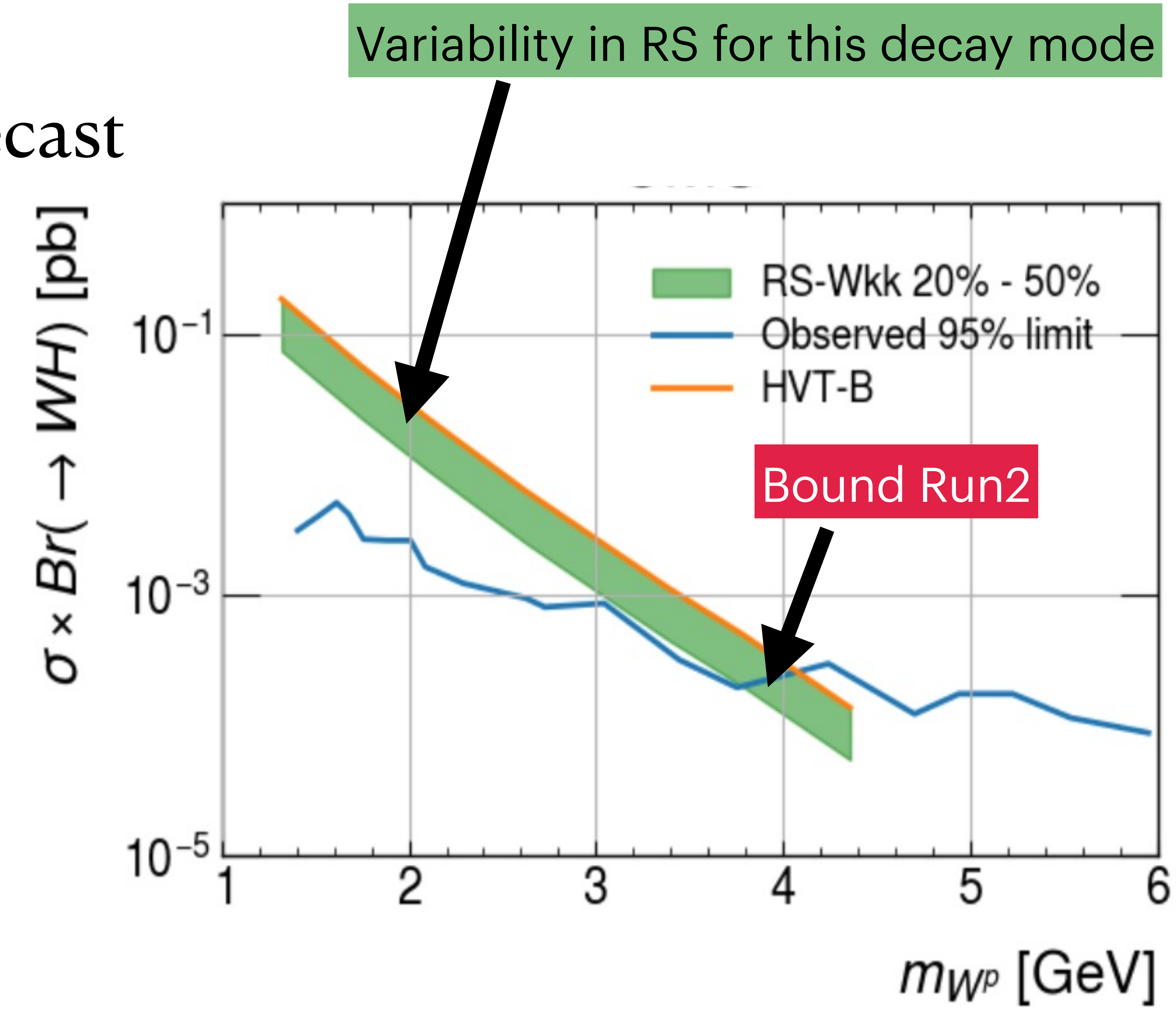

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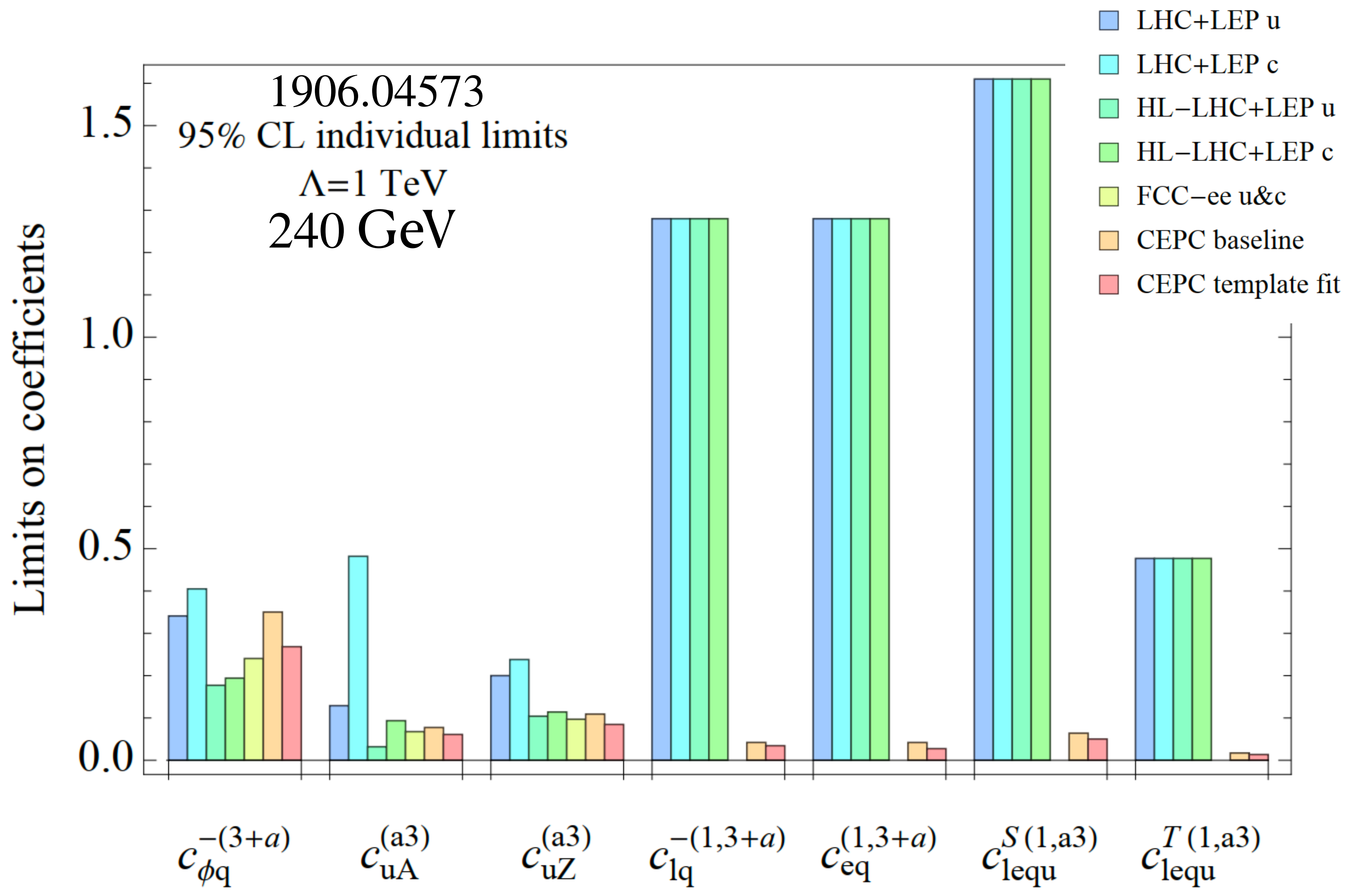
Single top $e^+e^- \to tc$

Sagar Airen (U. of Maryland)

Before the $t\bar{t}$ stage

$e^+e^- \to (Z,\gamma)^* \to tc$ **and** $e^+e^- \to Z$

- $e^+e^- \to (Z,\gamma)^* \to tc$ at 240 GeV turns out to be a stronger probe of the Ztc coupling than direct observation of the decay $t \to Zc$ (see e.g. 1906.04573 for CEPC).
- Probing power of single top production holds pretty independently of the analysis details, and can even be attained at energies somewhat lower than 240 GeV (if $\mathscr{L} \sim E^4_{e^+e^-}$)
- EWfit at LEP sensitive to 3 TeV RS mass scale. Expected to improve significantly with the Z factory data. Potentially sensitive to $BR(t \to Zc) \lll 10^{-6}$.



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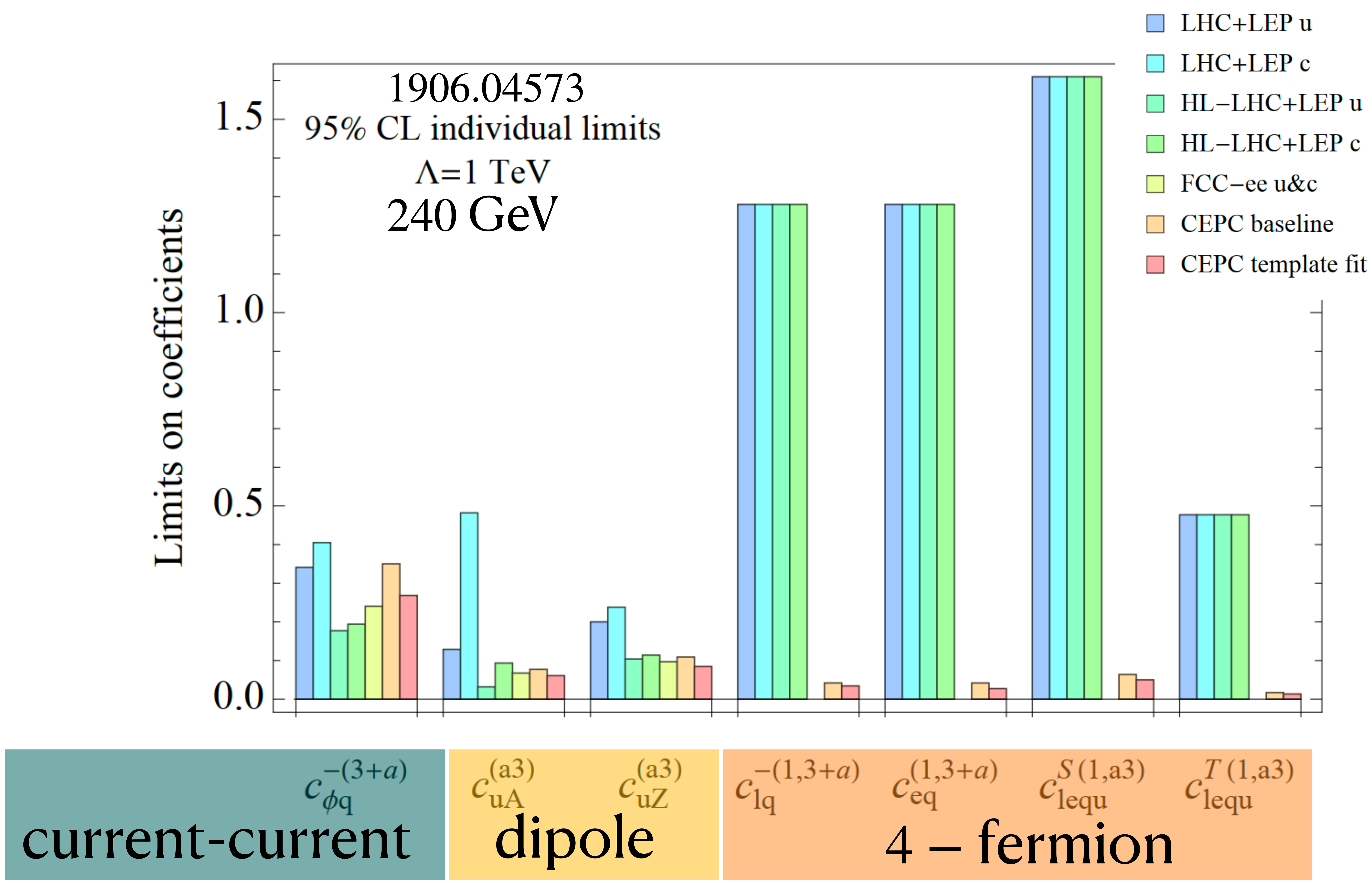

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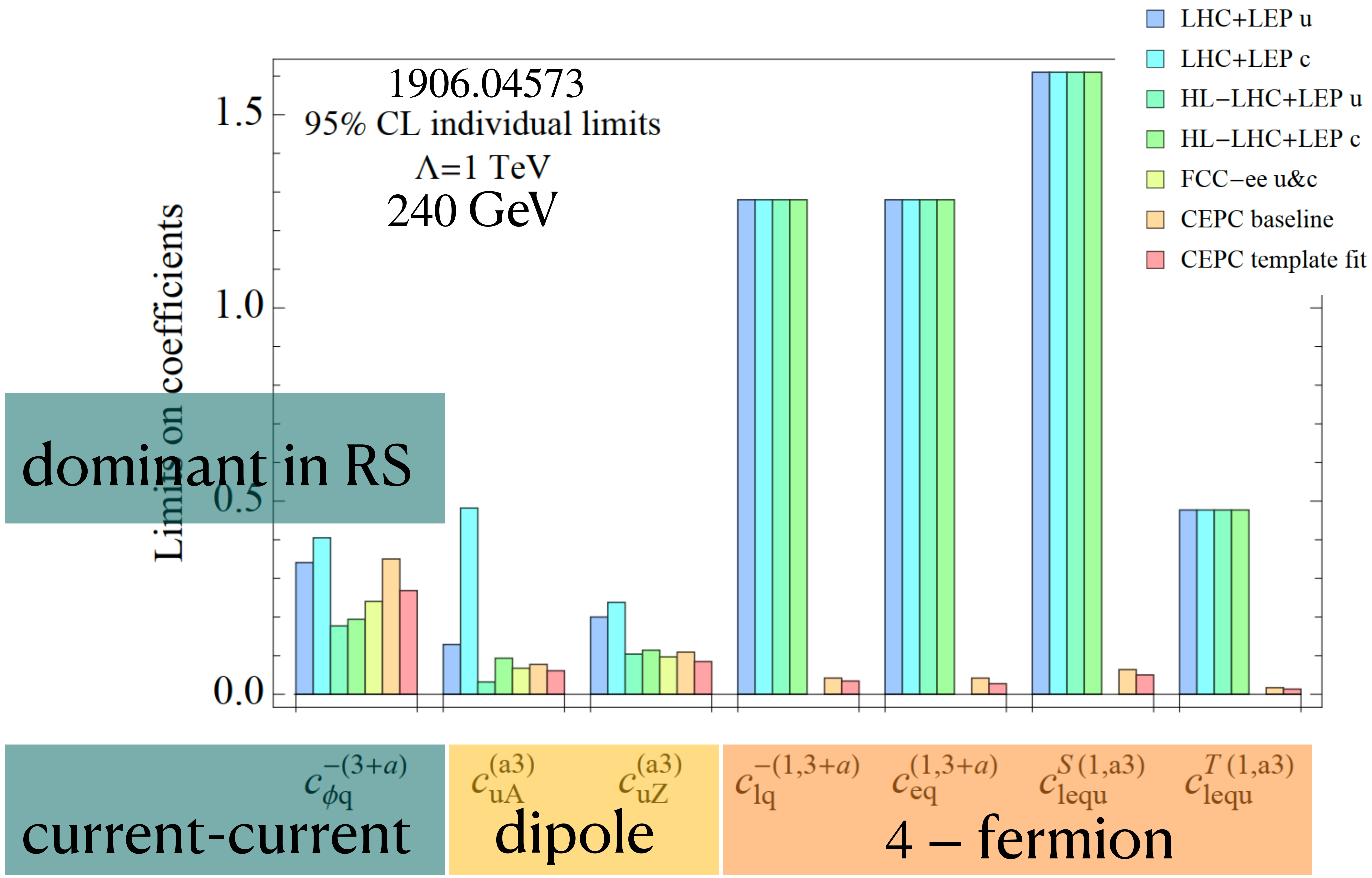


Interim Summary from FCNC update

- Ztc **coupling is best probed at 240 GeV via single-top production at** e^+e^-
- **No model* of the Snowmass 2013 able to generate a** $BR > 10^{-6}$
- gtc **coupling is best probed at the LHC via single top production**
- **No model* of the Snowmass 2013 able to generate a** $BR > 10^{-6}$

  - No update so far for htc coupling
  - Will go down compared to Snowmass 2013, but safe to say some model will stay above $BR > 10^{-6}$
  - Motivates pursuing also ϕtc couplings with a general BSM scalar ϕ

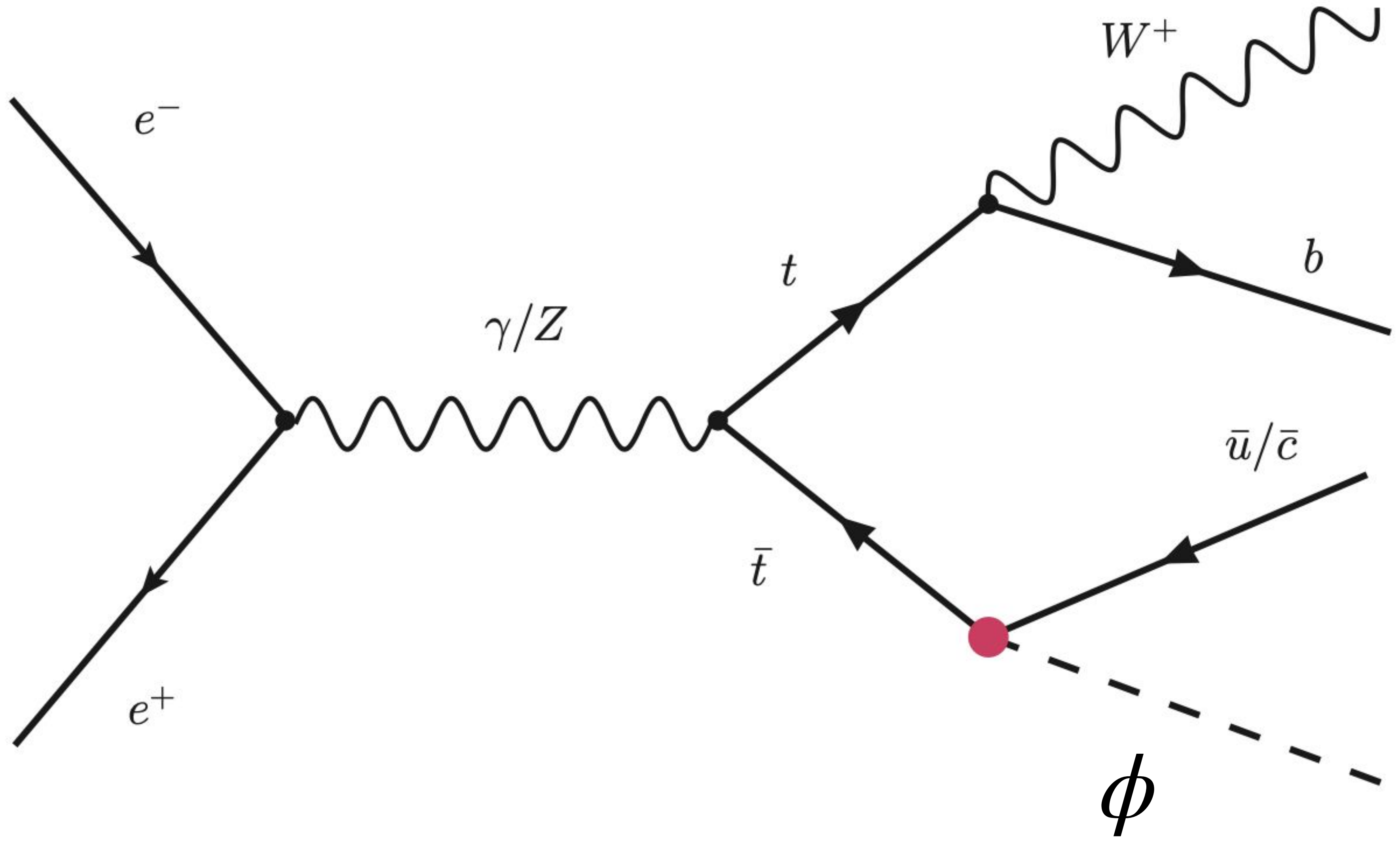
*** does not mean one cannot make new ad-hoc models!**

$t \to \phi c$ in IDEA

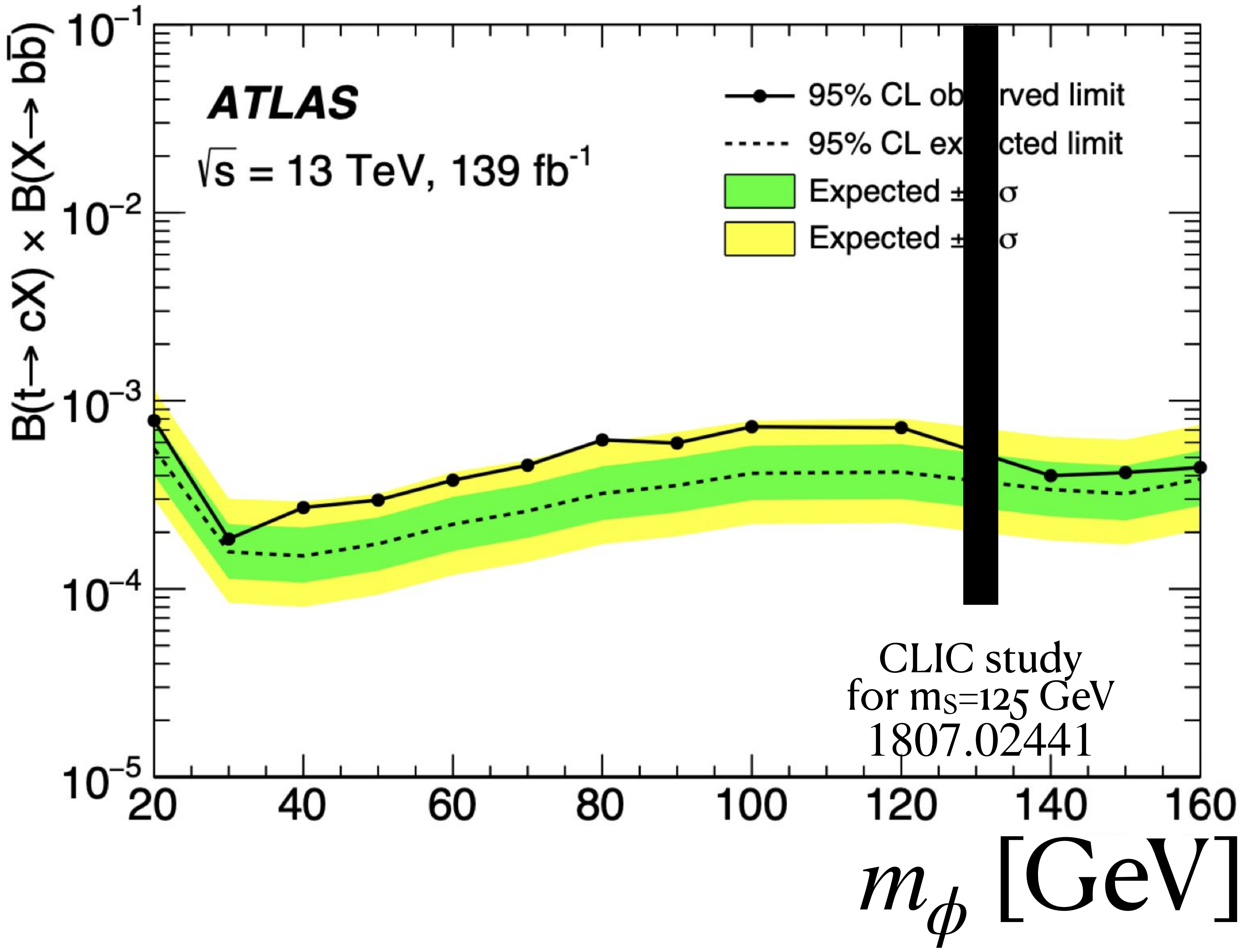
Didar Dobur, Kevin Mota, Kirill Skovpen (Gent U.)

BSM decays of top quark

$$t \to c\phi$$



studied for $m_\phi = 15,20,50,120$ GeV



New bounds

$t \to c\phi, \phi \to b\bar{b}$

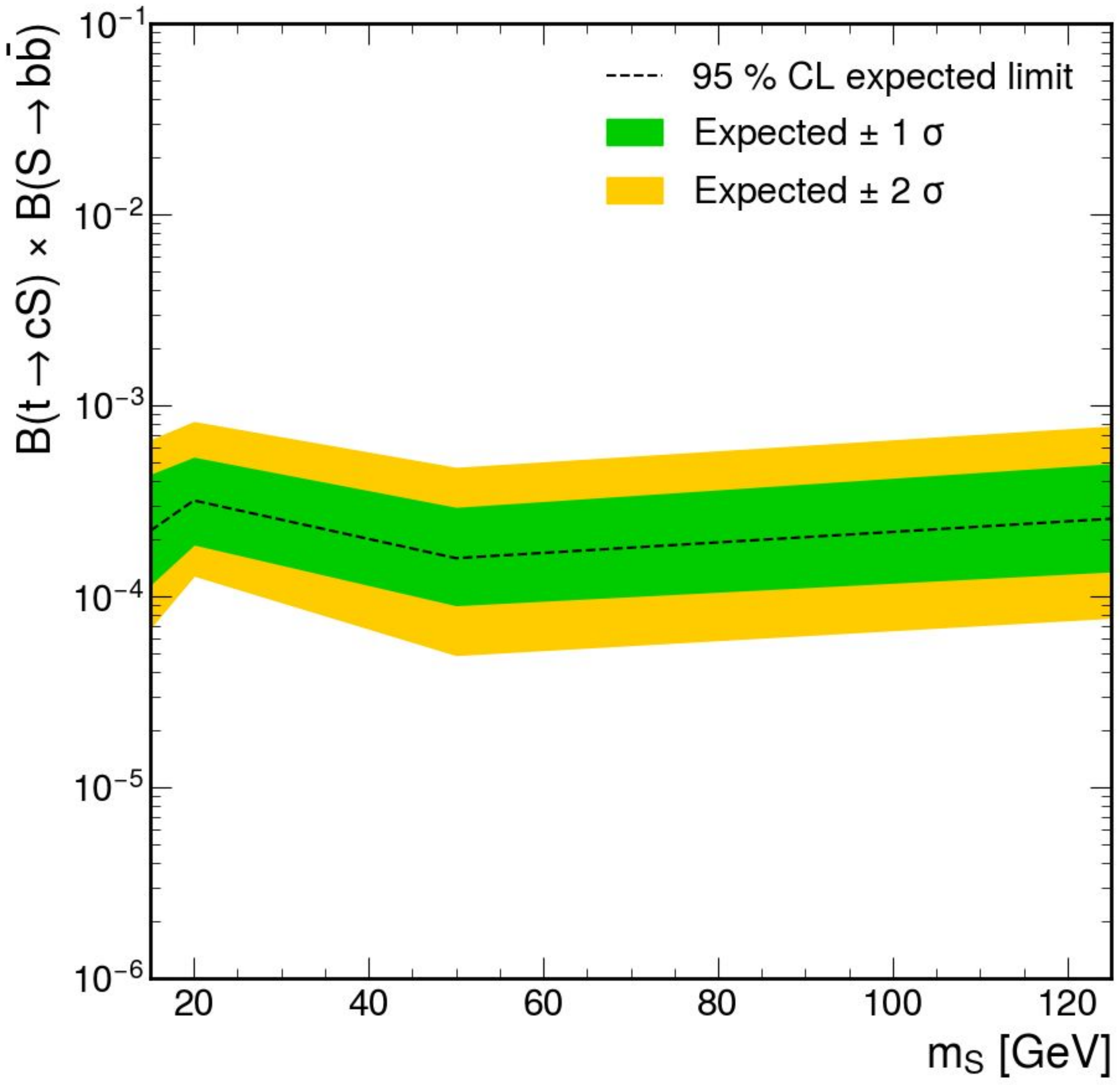
background $tt + jet$

Key4Hep production chain with Delphes

- At least one isolated lepton: p > 5 GeV, |η| < 2.9, relative isolation ΔR < 0.5
- 4-jets exclusive clustering with algo Durham, at least two of which are b-tagged (ParticleTransformer, trained on Higgs samples, training: wc_pt_13_01_2022, WP > 0.5) and at least one that is c-tagged (WP > 0.5)
- Flavour tagging performance is crucial for this analysis.
- Jets are combined in order to get the best combination for the S -> bb and t -> cS

BDT to discriminate signal to background

- With good performance for high working point (0.97).



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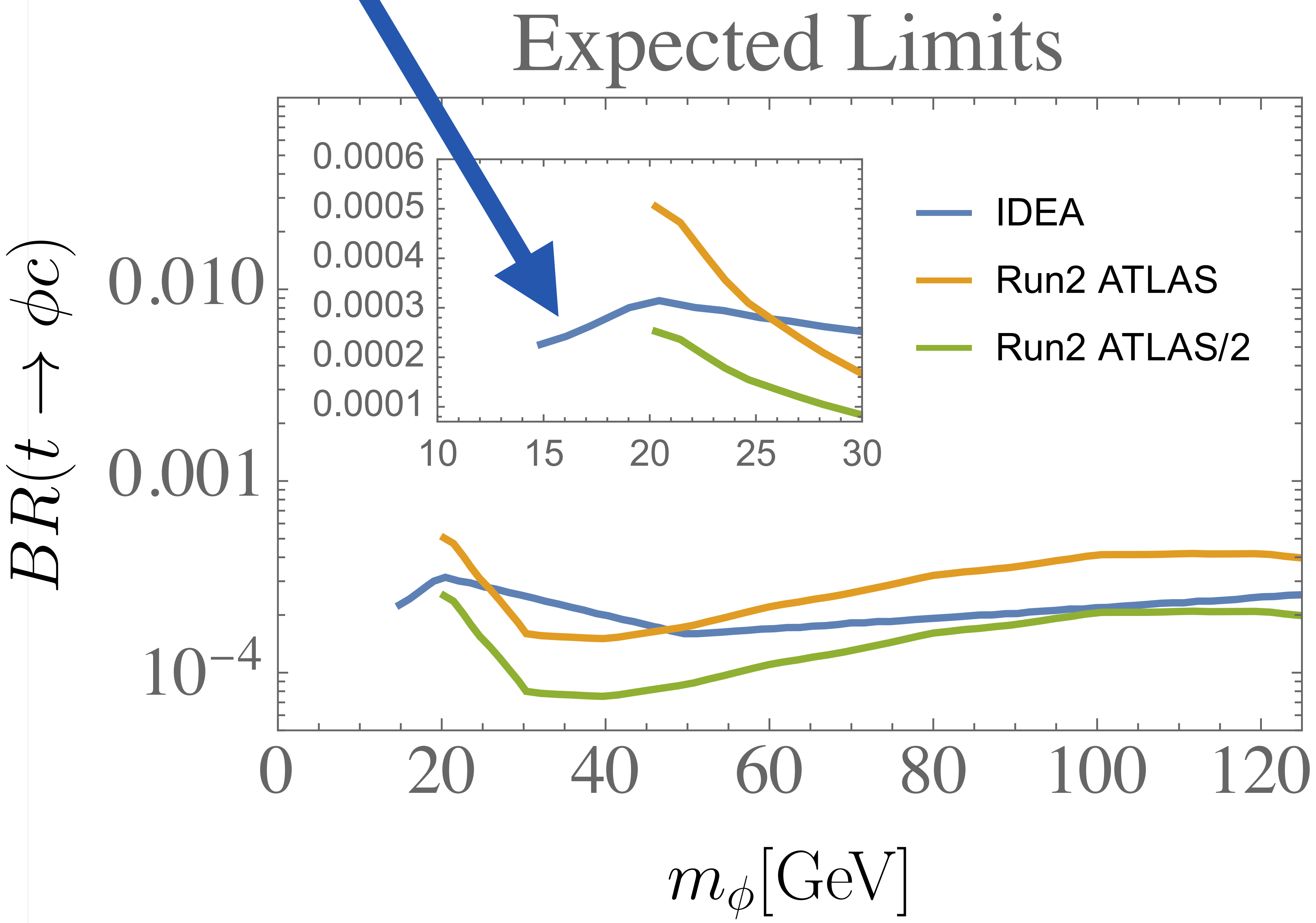
BDT to discriminate signal to background

- With good performance for high working point (0.97).

Demonstrated sensitivity to light scalar below range probed at LHC



Paris SRCH parallels

Dark Matter

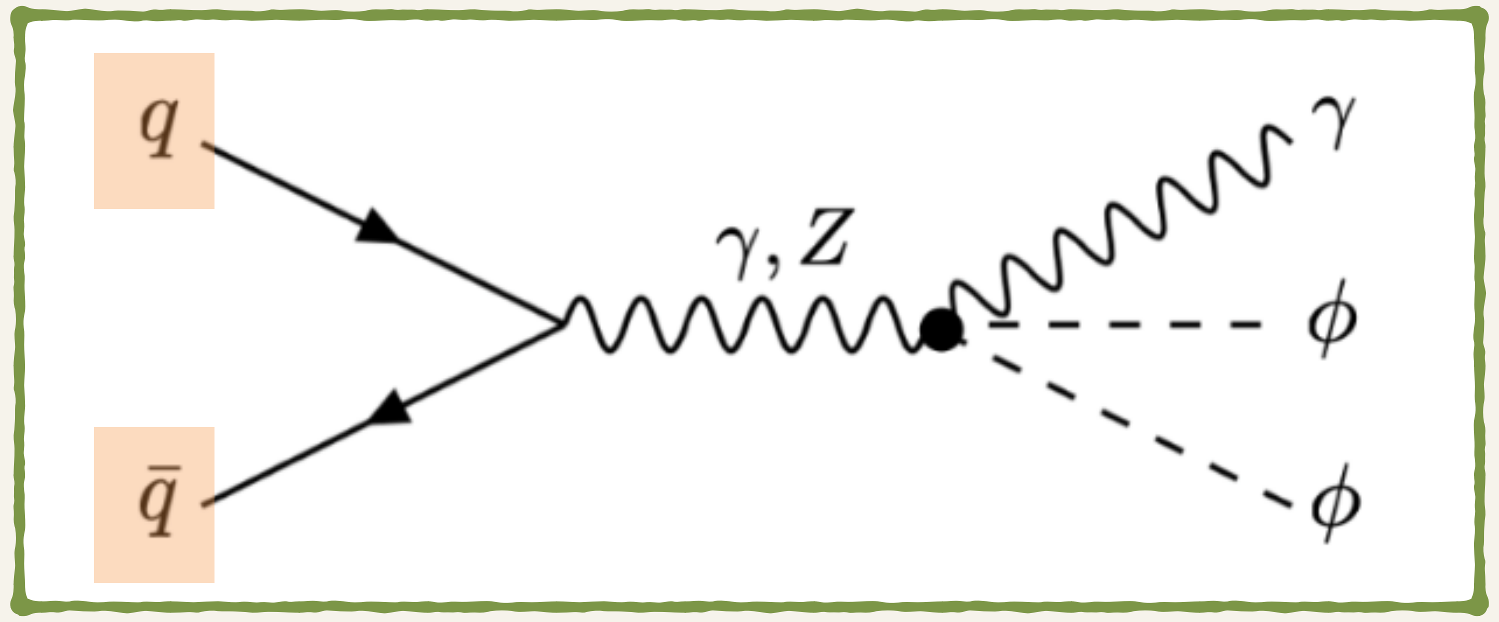
“Pair-coupled” Dark Matter

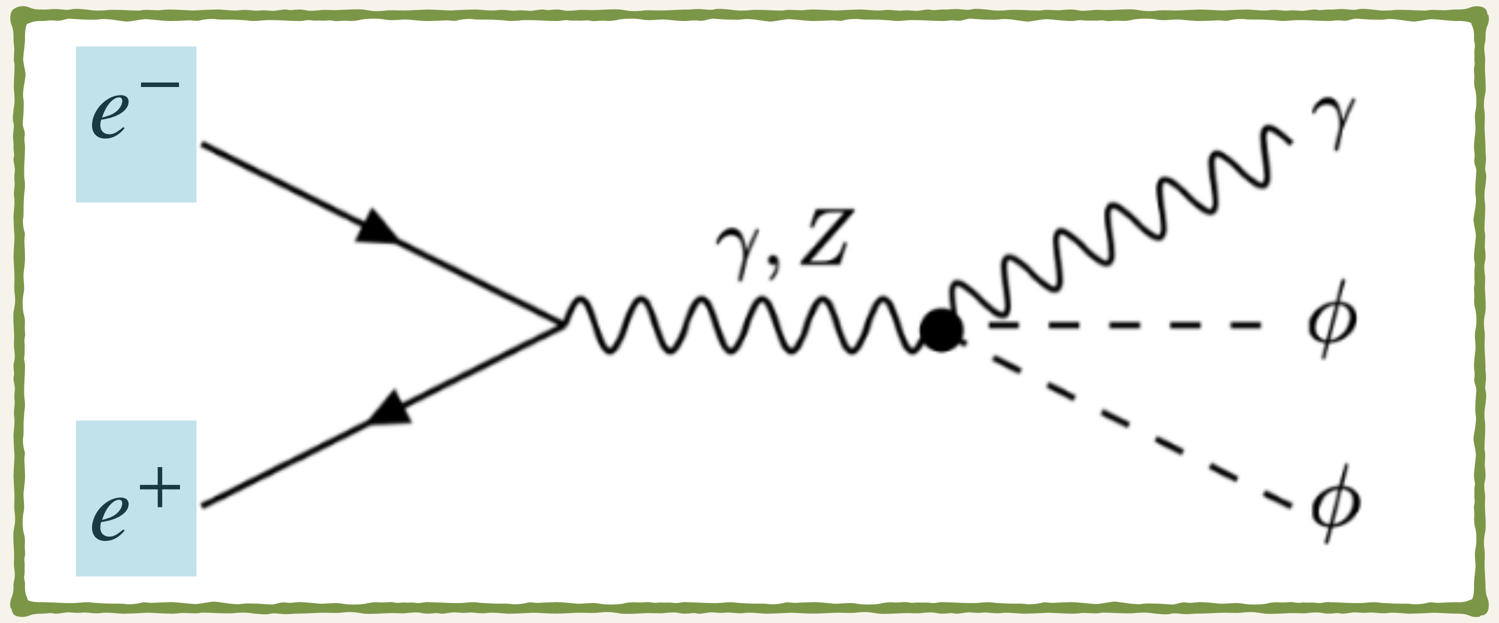
LHC and HTE factory

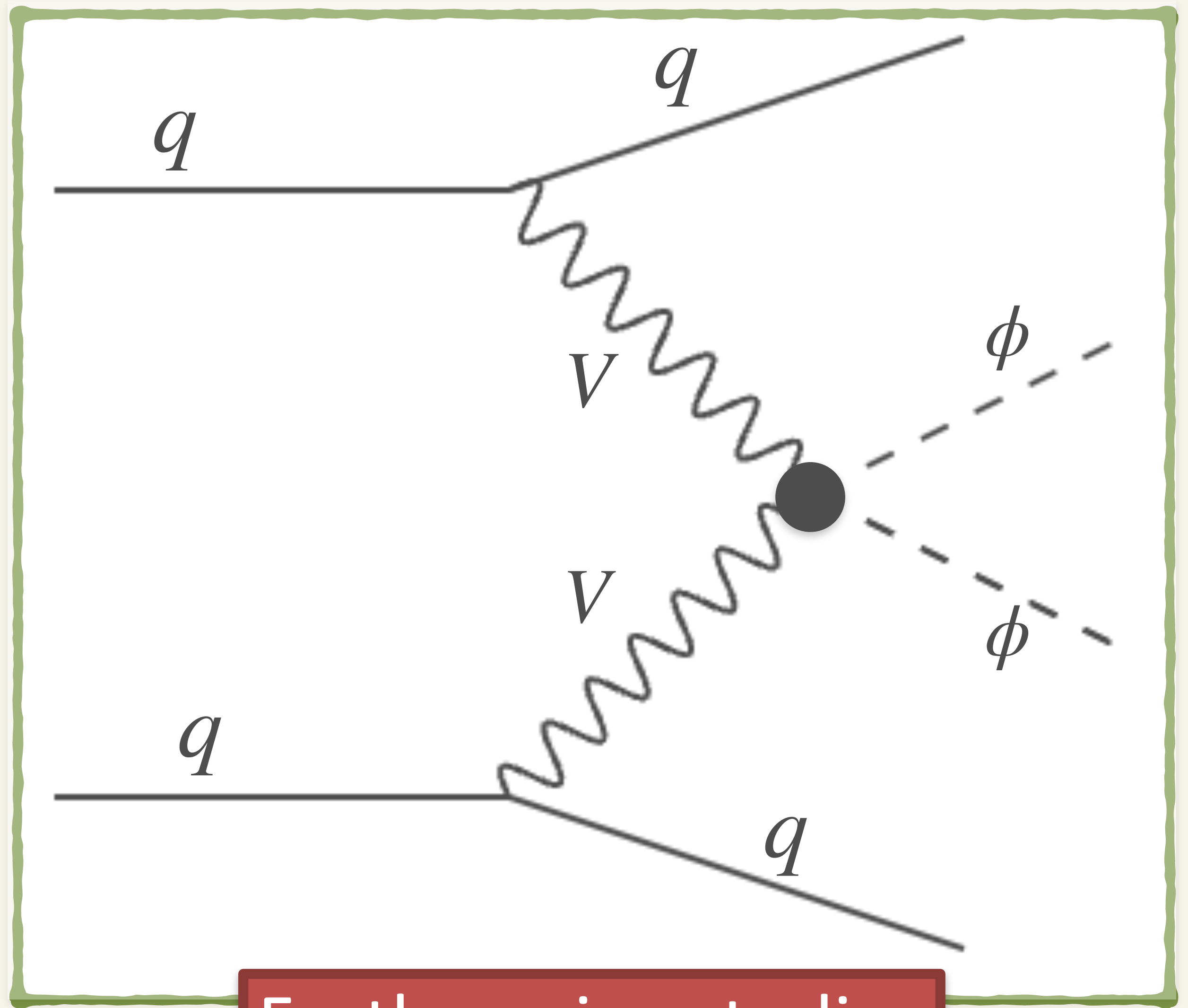
5

ECFA | 2024

Drell-Yan processes + Fusion TBD







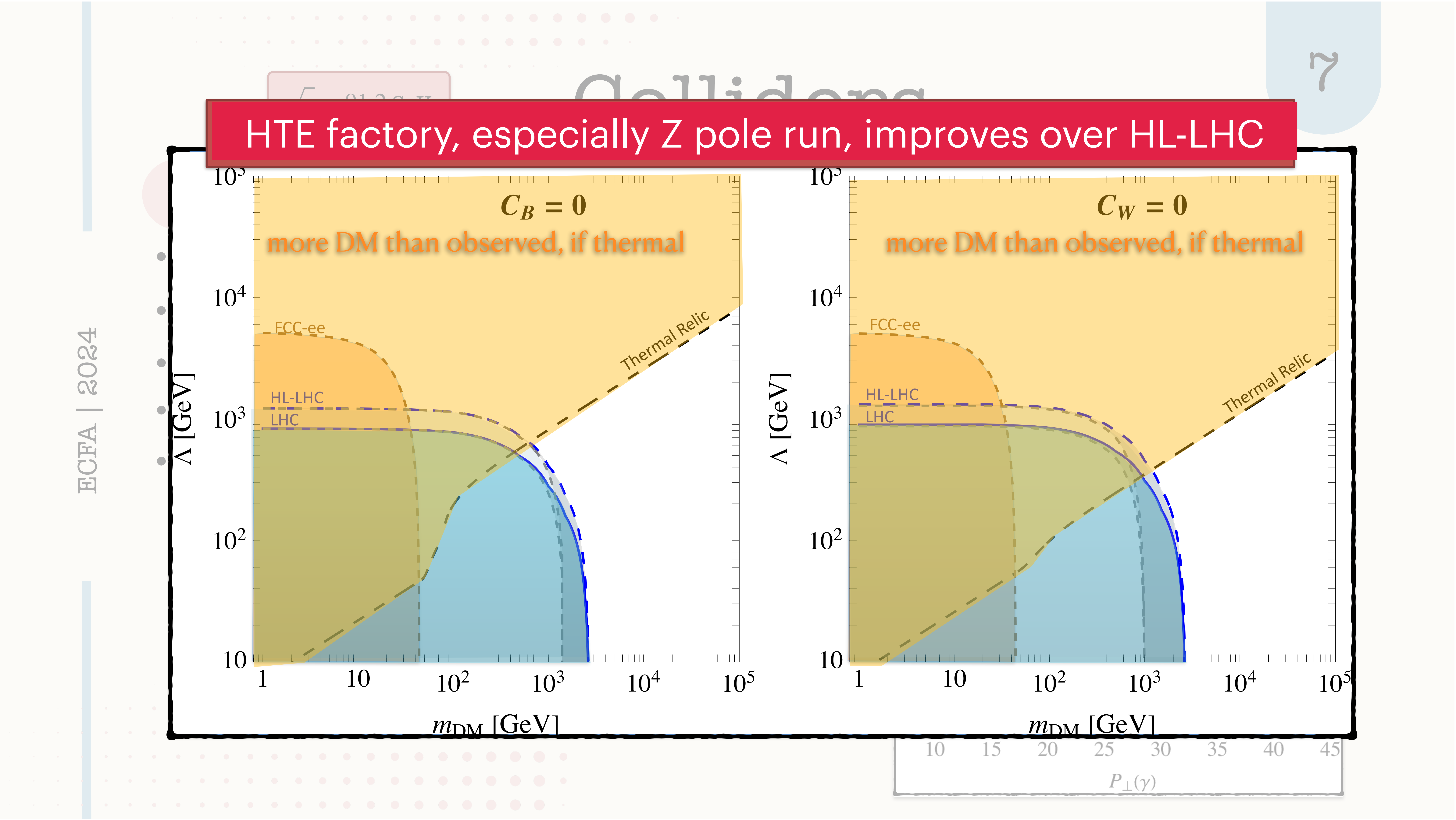
Forthcoming studies

Giulio Marino

“Pair-coupled” Dark Matter

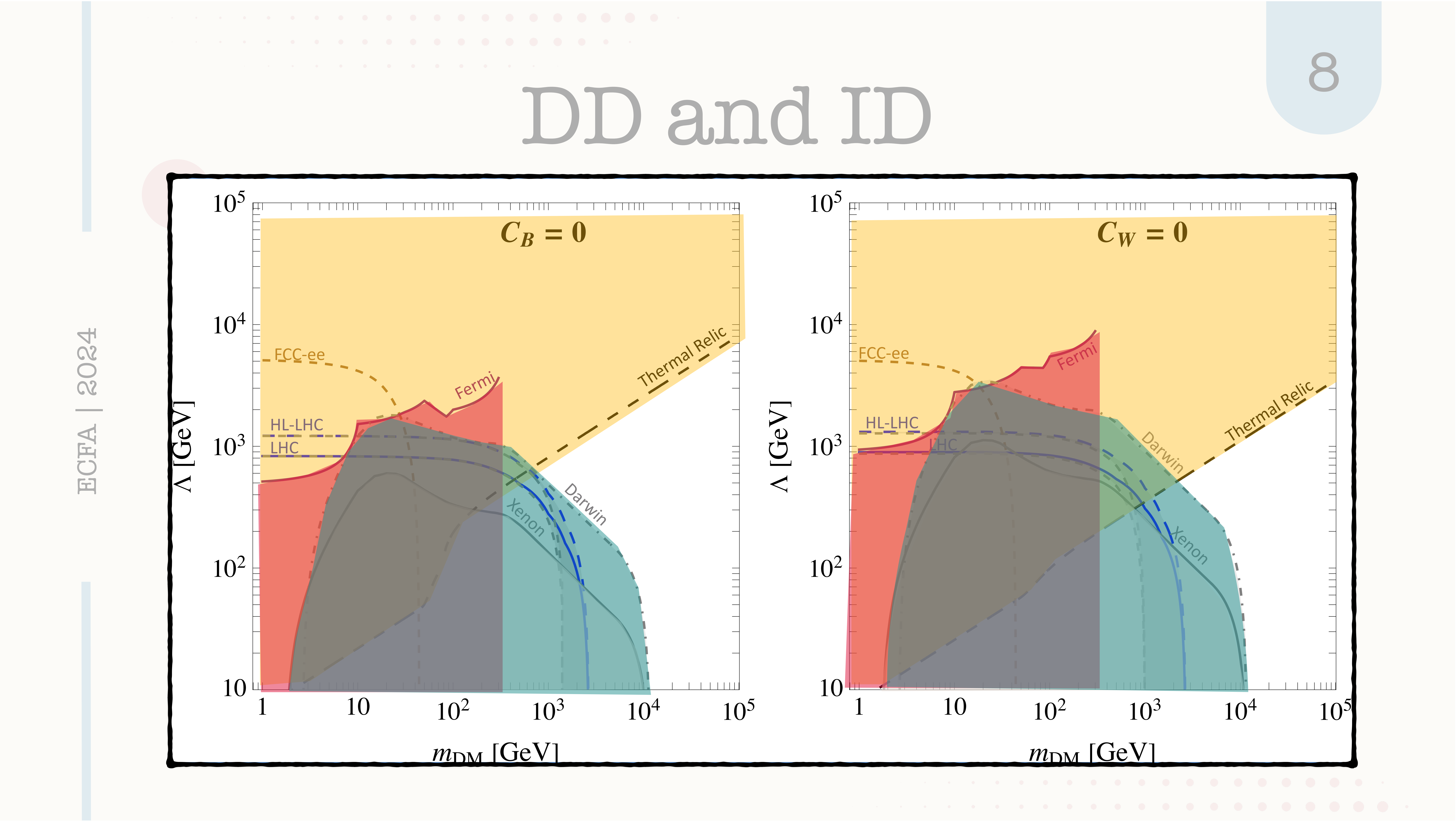
improved sensitivity for light DM candidates

HTE factory, especially Z pole run, improves over HL-LHC



“Pair-coupled” Dark Matter

improved sensitivity for light DM candidates



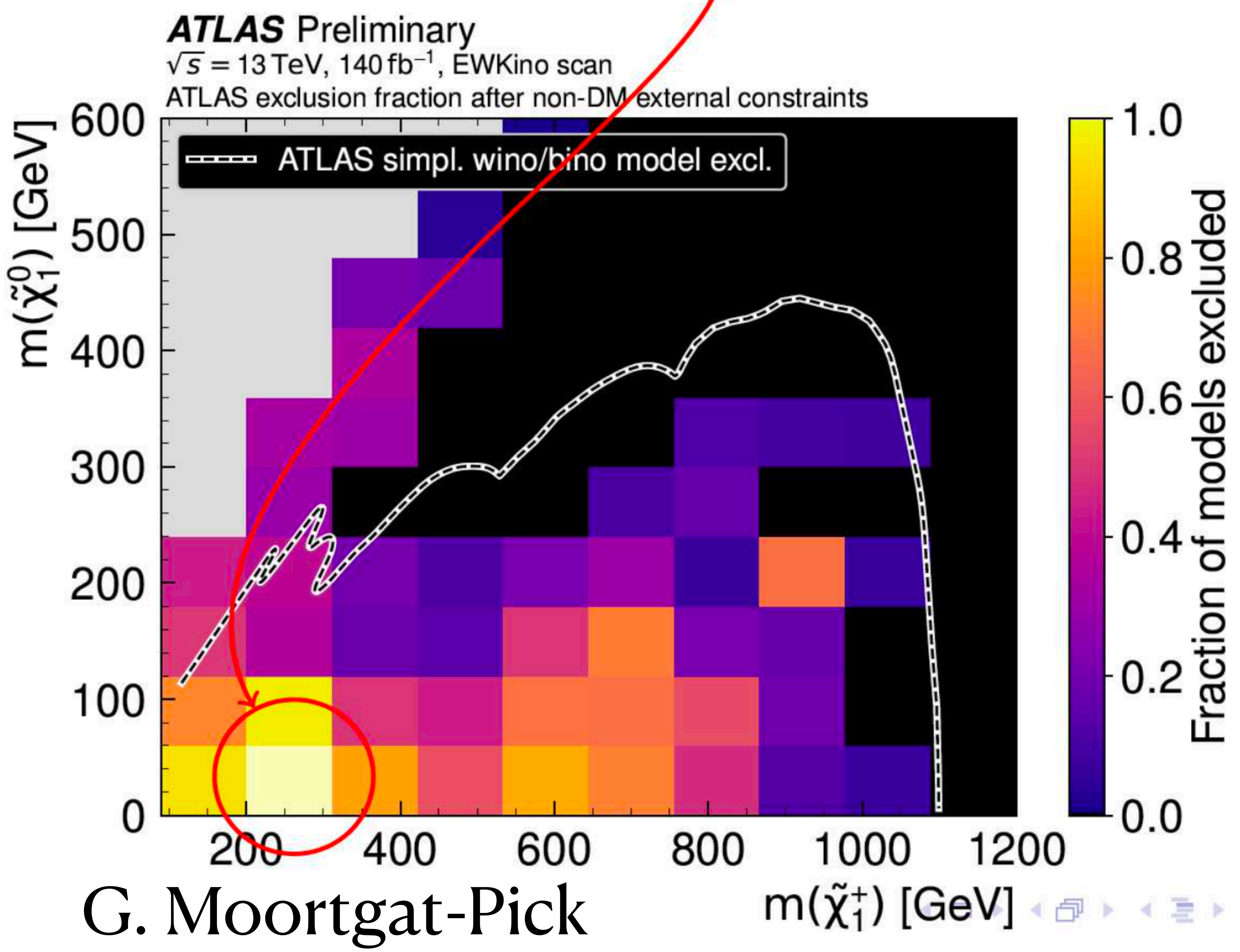
Light chargino-neutralino

starting to appear in the LHC data?

Impact from LHC SUSY searches limits

taken from M. Berggren 2023

Only this one is actually excluded !



G. Moortgat-Pick

Focus on two scenarios: wino/bino vs higgsino

A) Wino/bino DM with chargino co-annihilation

Parameter scan:

M. Chakraborti, S. Heinemeyer, I. Saha 24

$$100\text{ GeV} \le |M_1| \le 400\text{ GeV},$$
$$|M_1| \le M_2 \le 1.1|M_1|,$$
$$1.1|M_1| \le \mu \le 10|M_1|,$$
$$2 \le \tan\beta \le 60,$$
$$100\text{ GeV} \le m_{\tilde{L}} \le 1.5\text{ TeV},$$
$$m_{\tilde{R}} = m_{\tilde{L}}.$$

(latter condition only to make the analysis simpler, no relevant effect)

wino/bino(+): $M_1 \times \mu > 0$
wino/bino(−): $M_1 \times \mu < 0$

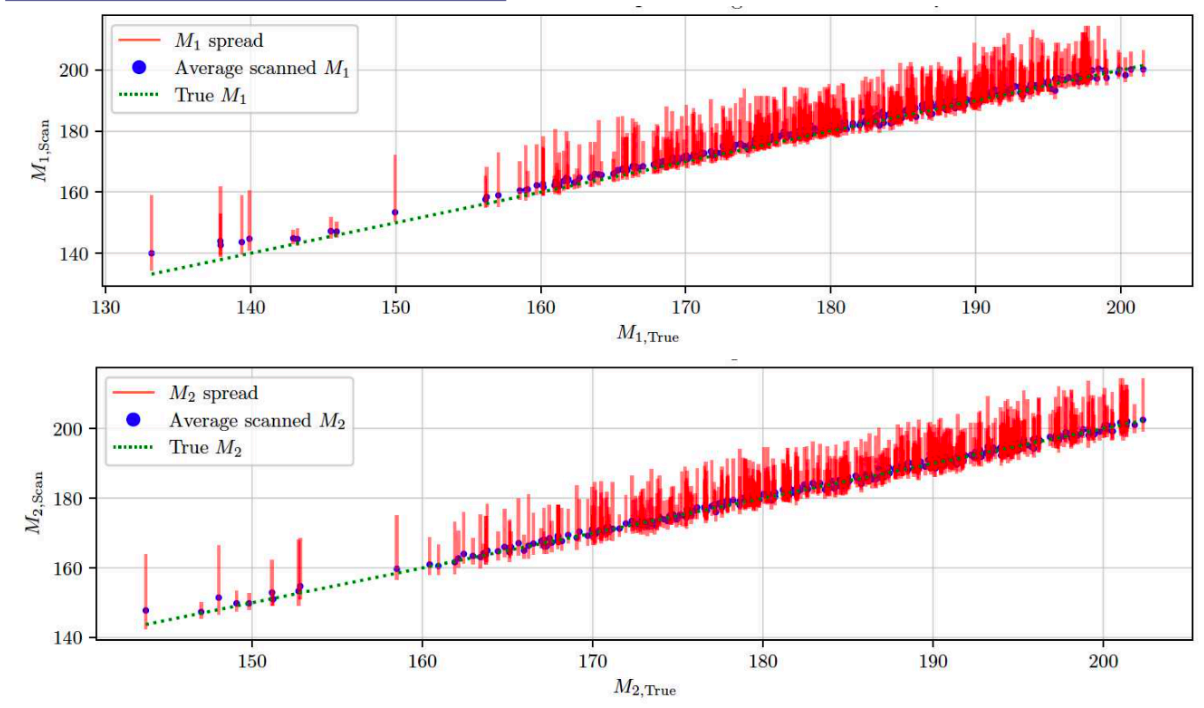
relic DM density can be 100% fulfilled
$\Rightarrow m_{(N)LSP} \lesssim 600(650)$ GeV
(original scan assuming a 5 σ deviation in $(g-2)_\mu$)

Light chargino-neutralino

starting to appear in the LHC data?

Reconstruction of parameters

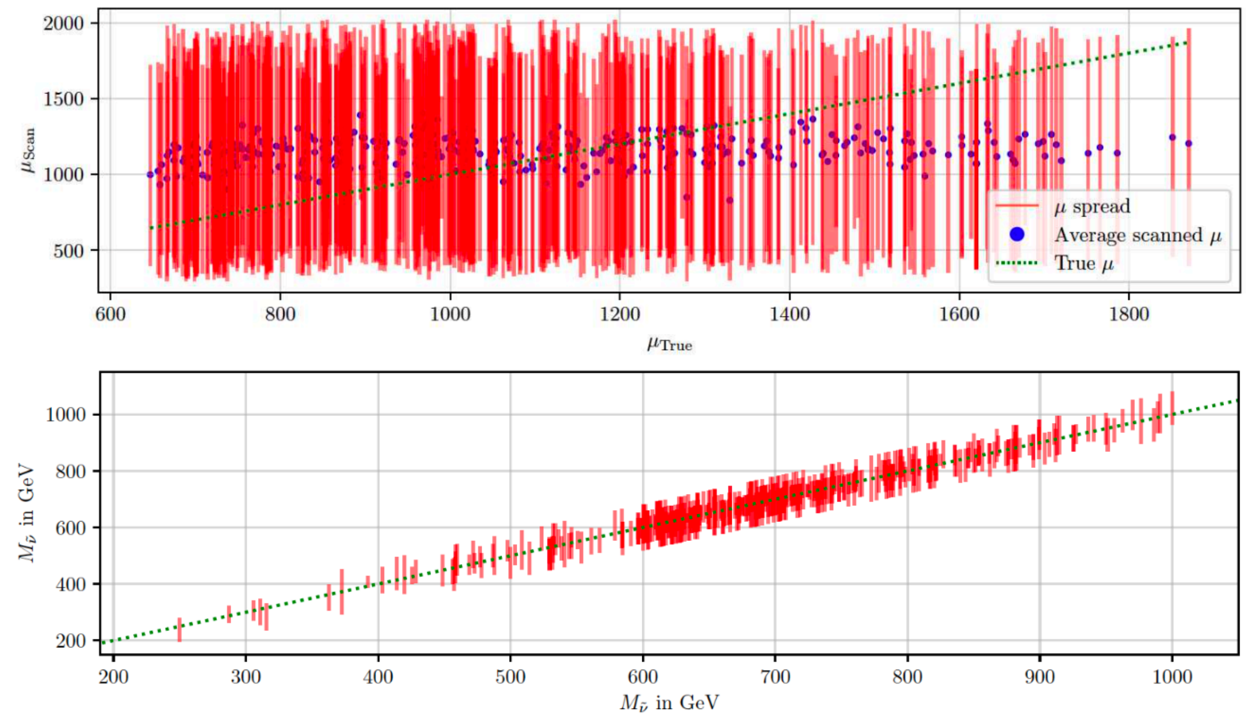
Reconstruction of M_1 and M_2:



$\Rightarrow$ good reconstructions possible

Reconstruction of parameters

Reconstruction of μ and $m_{\tilde{\nu}_e}$:

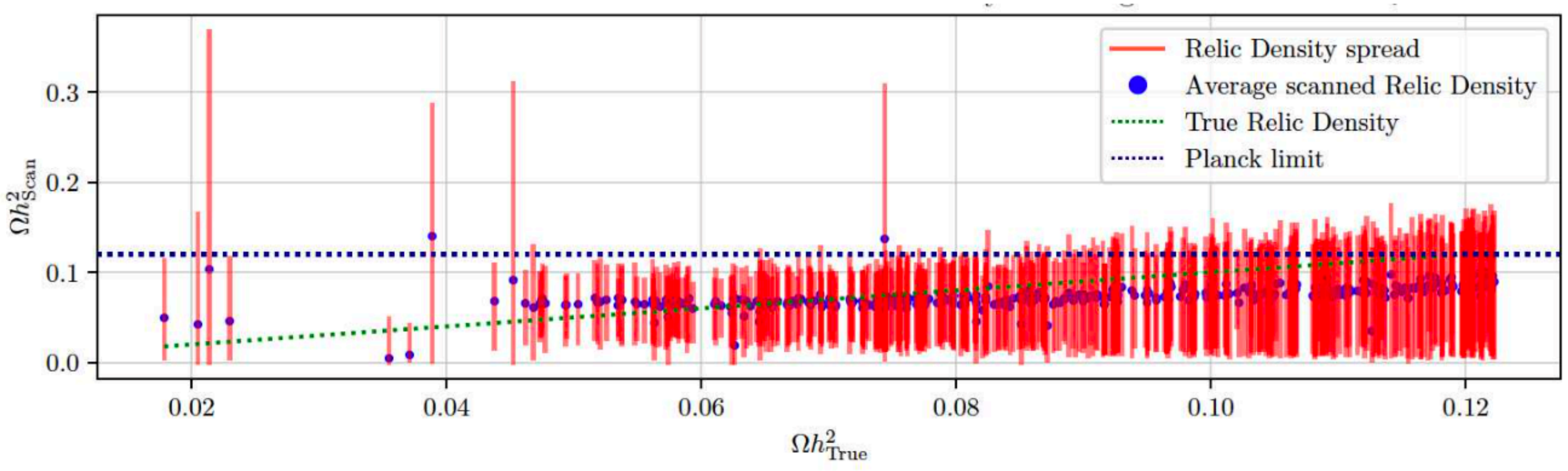


$\Rightarrow$ bad reconstruction of μ, good reconstruction of $m_{\tilde{\nu}_e}$

$\Rightarrow$ no problem, since μ is not very relevant in this scenario

Relic density

Reconstruction of $\Omega_\chi h^2$:



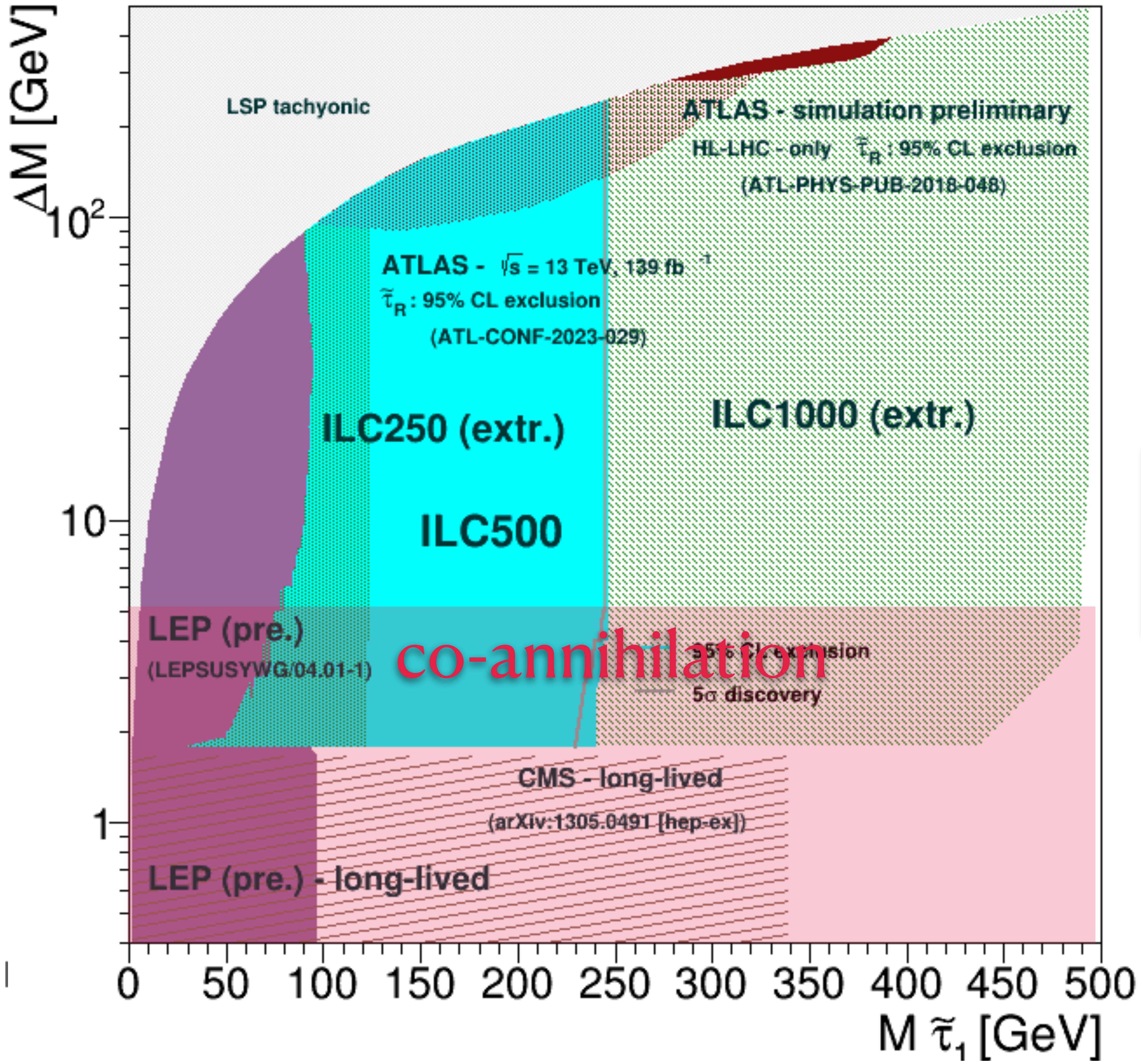
$\Rightarrow$ often large uncertainties - but not too bad either

$\Rightarrow$ reason: experimental uncertainties in M_1 and M_2

$\Rightarrow$ possible improvement: optimized $\sqrt{s}$

$\tilde{\tau}$ co-annihilation dark matter

close to the degenerate LSP-NLSP



At ILC discovery and exclusion are almost the same and close to the kinematic limit

arXiv:2105.08616

Teresa Núñez

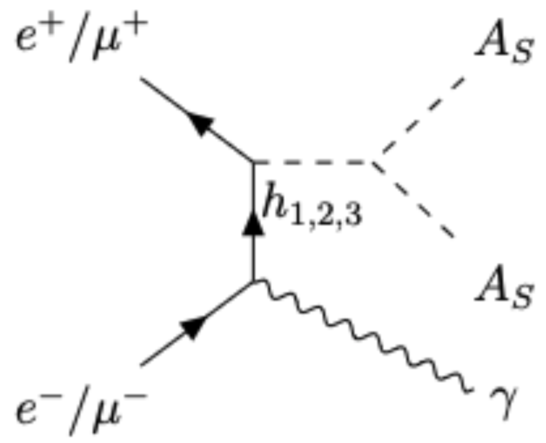
Dark matter from 2HDM+Singlet

more structure signals of DM

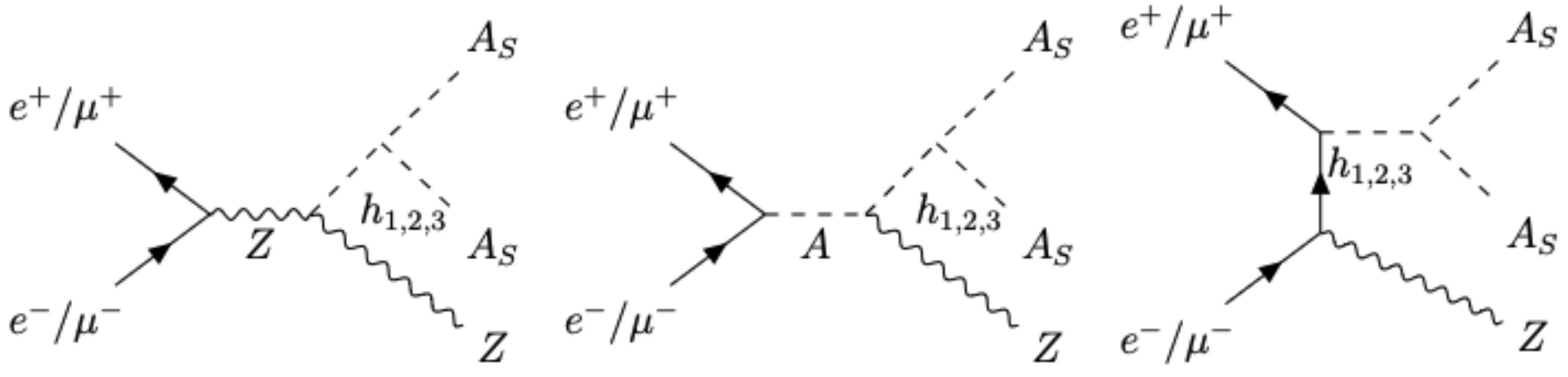
$$
\begin{aligned}
\not{M} &= E_{inv}^2 - |\vec{p_{inv}}|^2 \\
&= (\sqrt{s} - E_Z)^2 - |\vec{p_Z}|^2 \\
&= (\sqrt{s} - E_Z)^2 - (E_Z^2 - m_Z^2) \\
&= s - 2\sqrt{s}E_Z + m_Z^2
\end{aligned}
$$

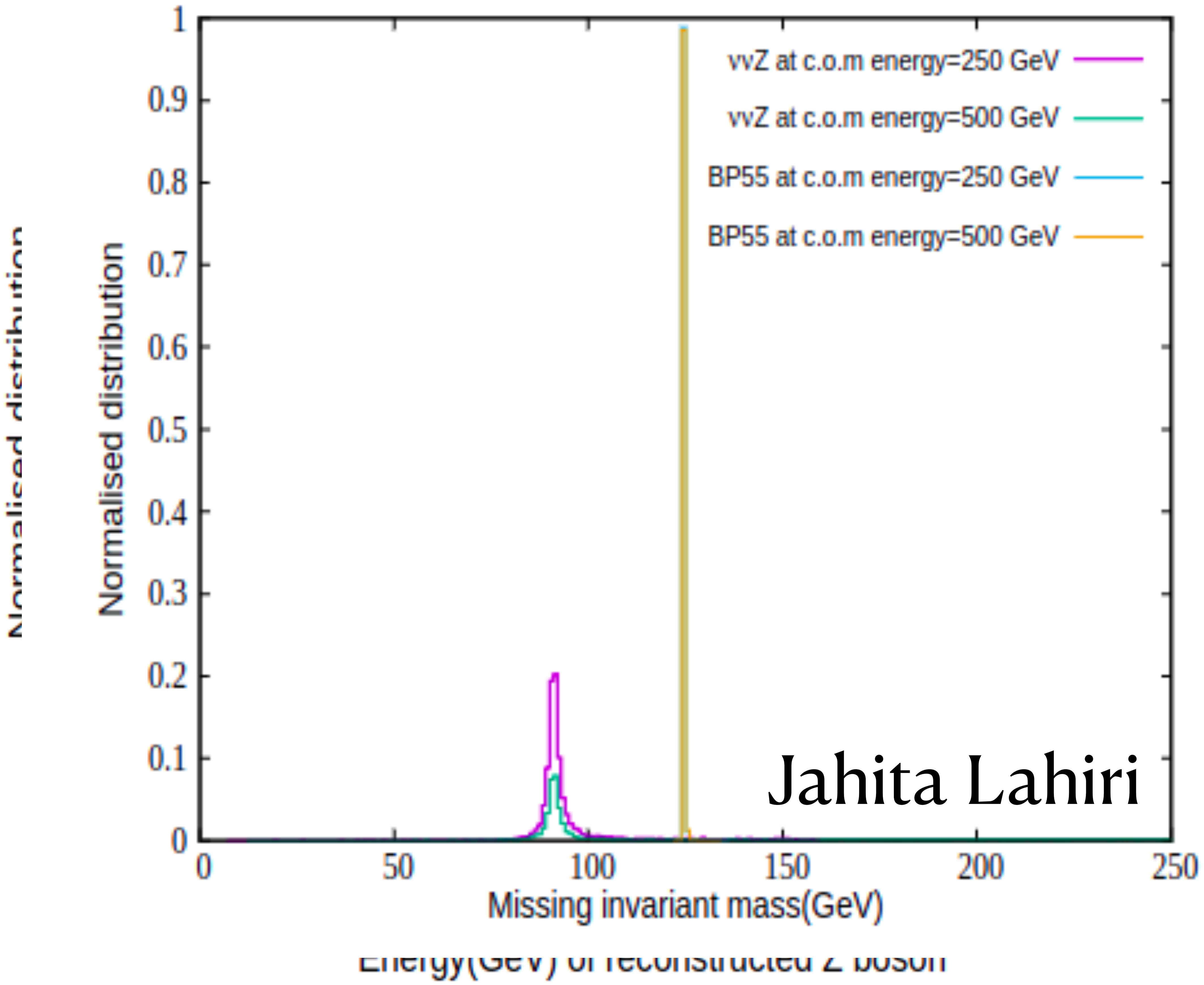
Dark matter search at lepton colliders

Mono-γ



Mono-Z

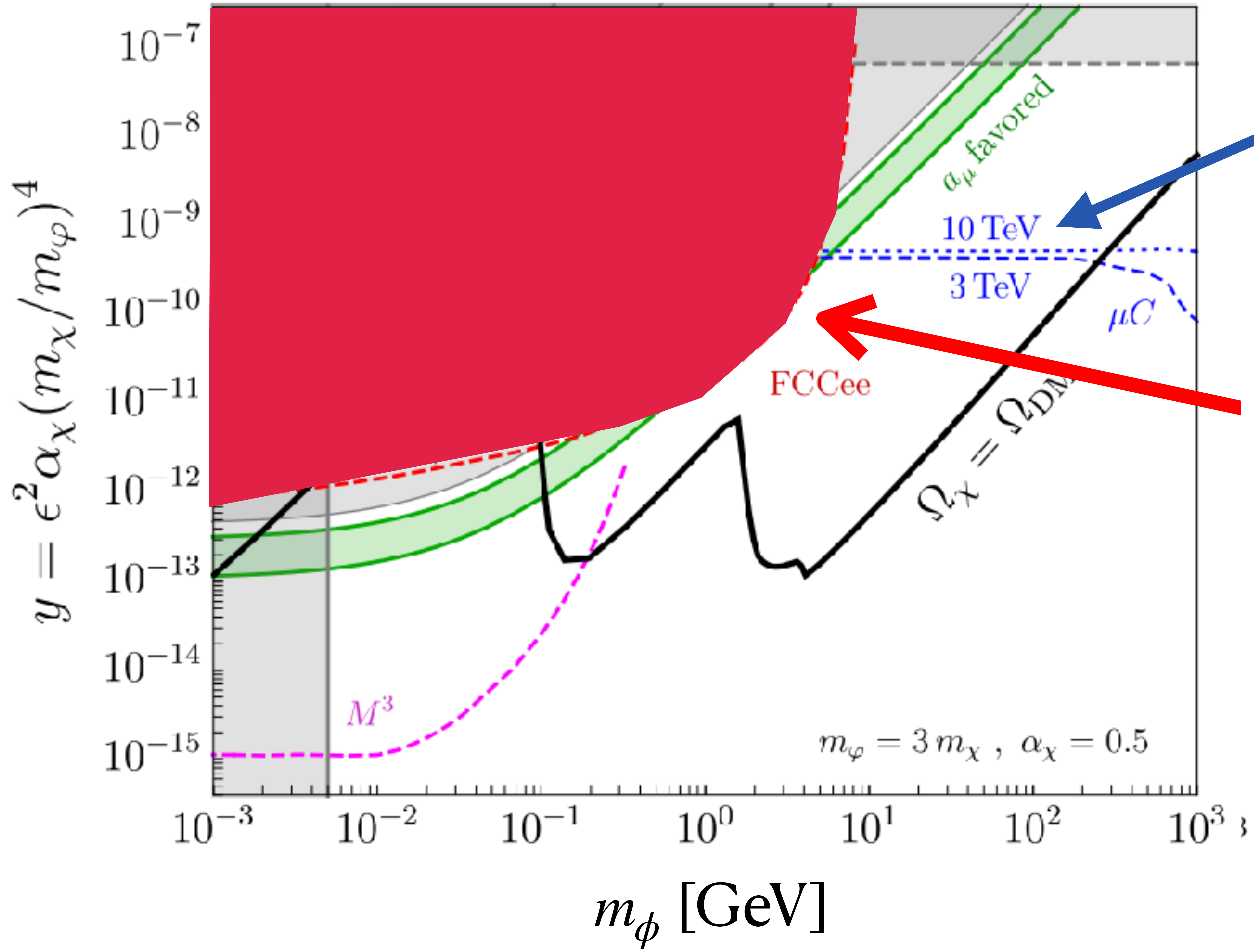




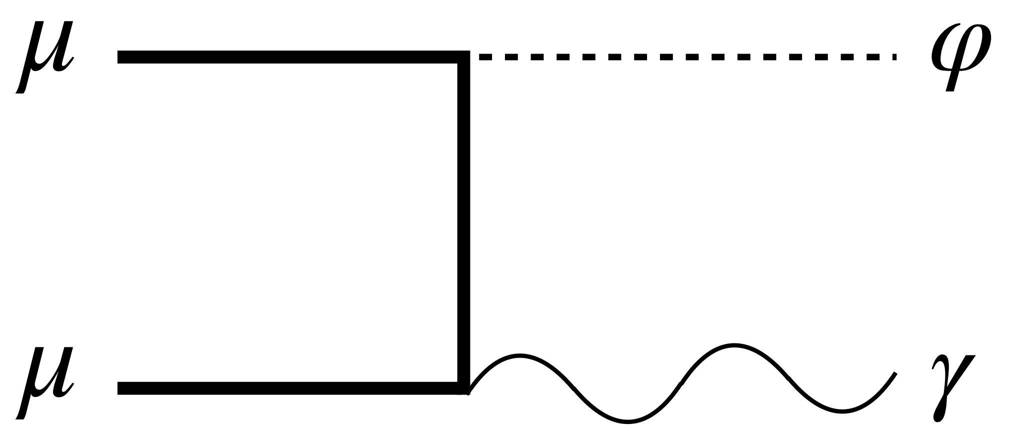
lepto-philic dark matter

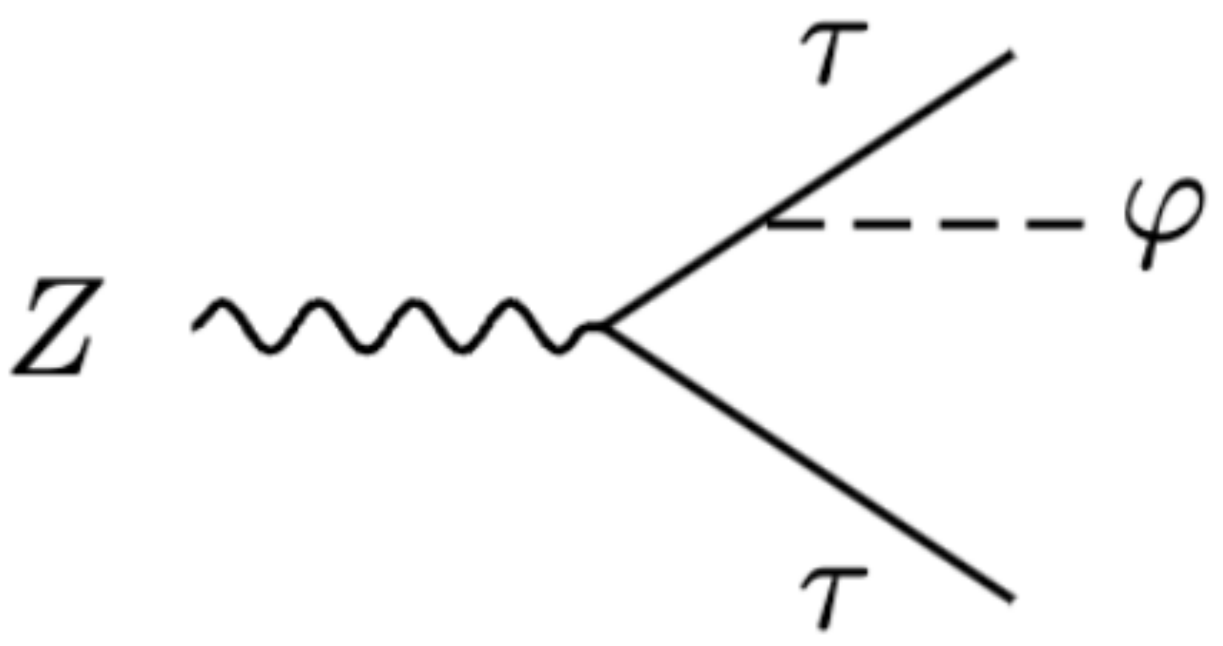
1 singlet, 2 doublets (one only couples to leptons)

$$H_1 \sim (1,2)_{1/2} \qquad +S \sim (1,1)_0$$
$$H_2 \sim (1,2)_{-1/2}$$



$$\mu^+\mu^- \to \varphi\gamma$$
$$E_\gamma \sim \sqrt{s}/2$$





$$\Gamma(Z \to \tau\tau)$$

Cari Cesarotti

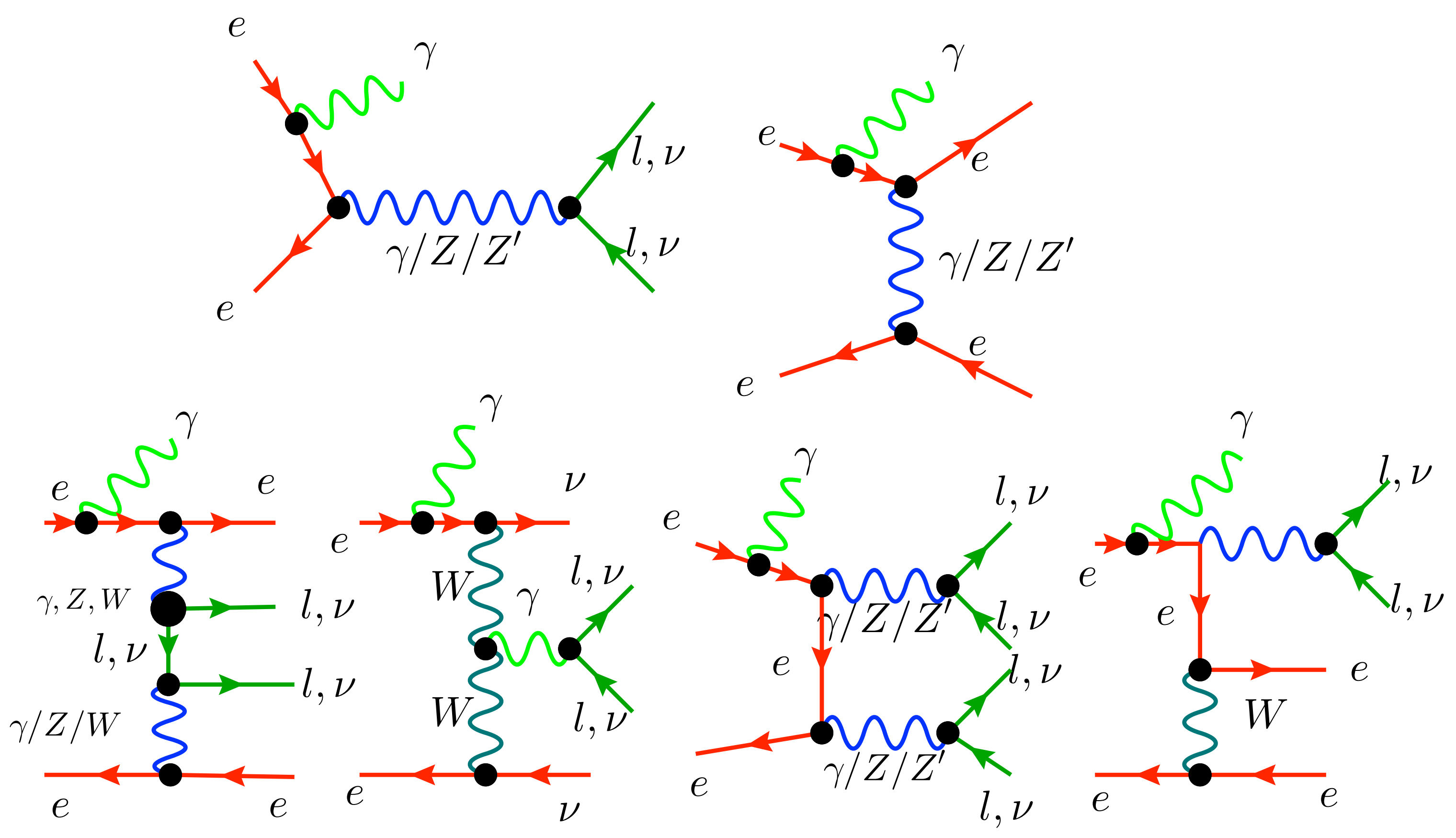
Paris SRCH parallels

Z’

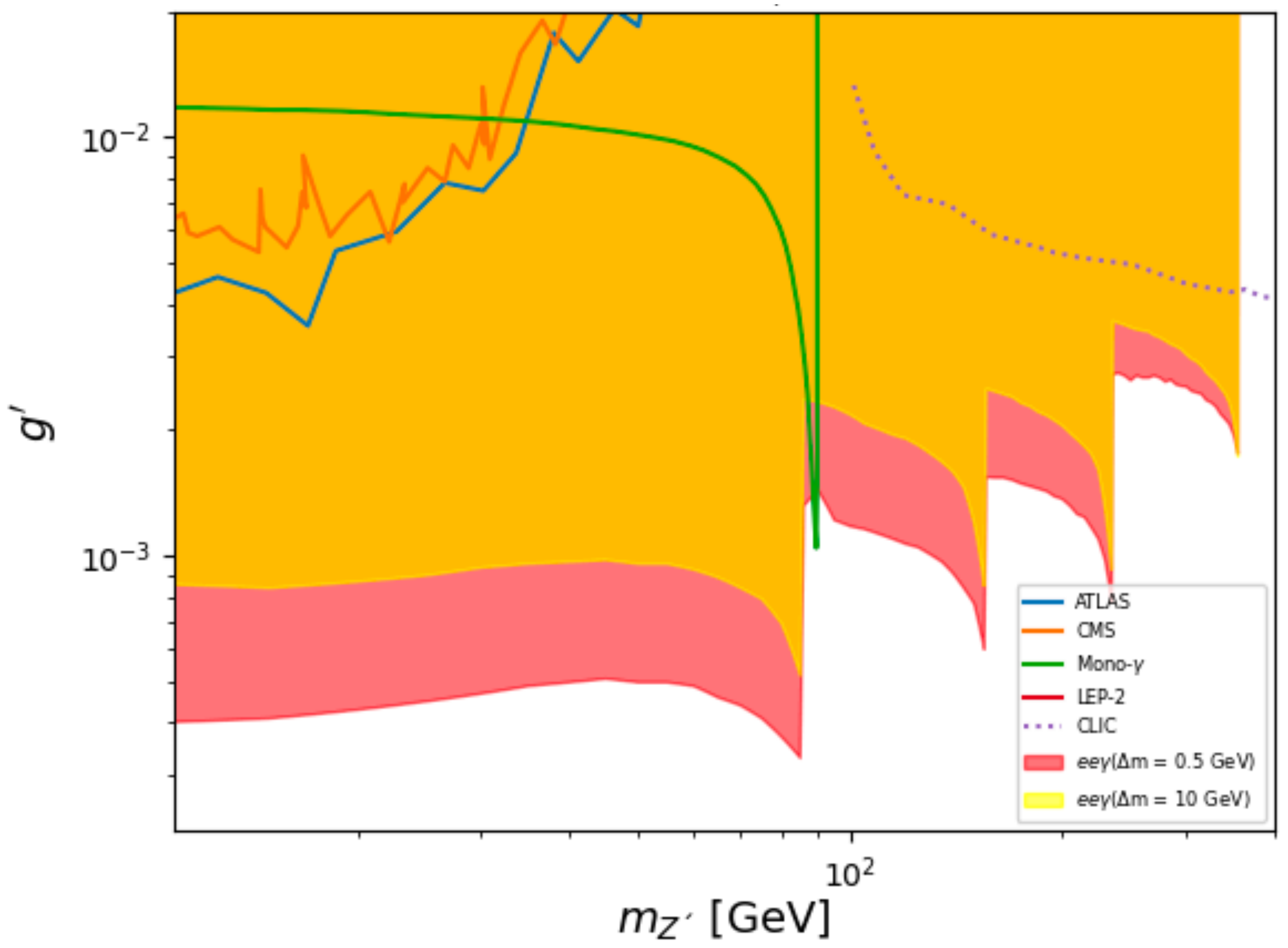
New vector states

flavor-aware gauge bosons in IDEA

- Signal: $e^+e^- \to \gamma X$ with $X = l^+l^-, \nu\nu$
  - Selection cuts (aligned with IDEA thresholds)
    - $e, \mu : p_T > 0.5$ GeV, $|\eta| \leq 2.5$, $\Delta R(l, X) > 0.5$.
    - $\gamma : E > 2$GeV, $p_T > 0.5$ GeV, $|\eta| \leq 3.0$, $\Delta R(\gamma, X) > 0.5$.
    - $\tau : p_T > 1$ GeV, $|\eta| \leq 3.0$, $\Delta R(\tau, X) > 0.5$,
  - Object efficiencies (from IDEA card): $\epsilon_{e,\mu,\gamma} = 0.99, \epsilon_\tau = 0.6$



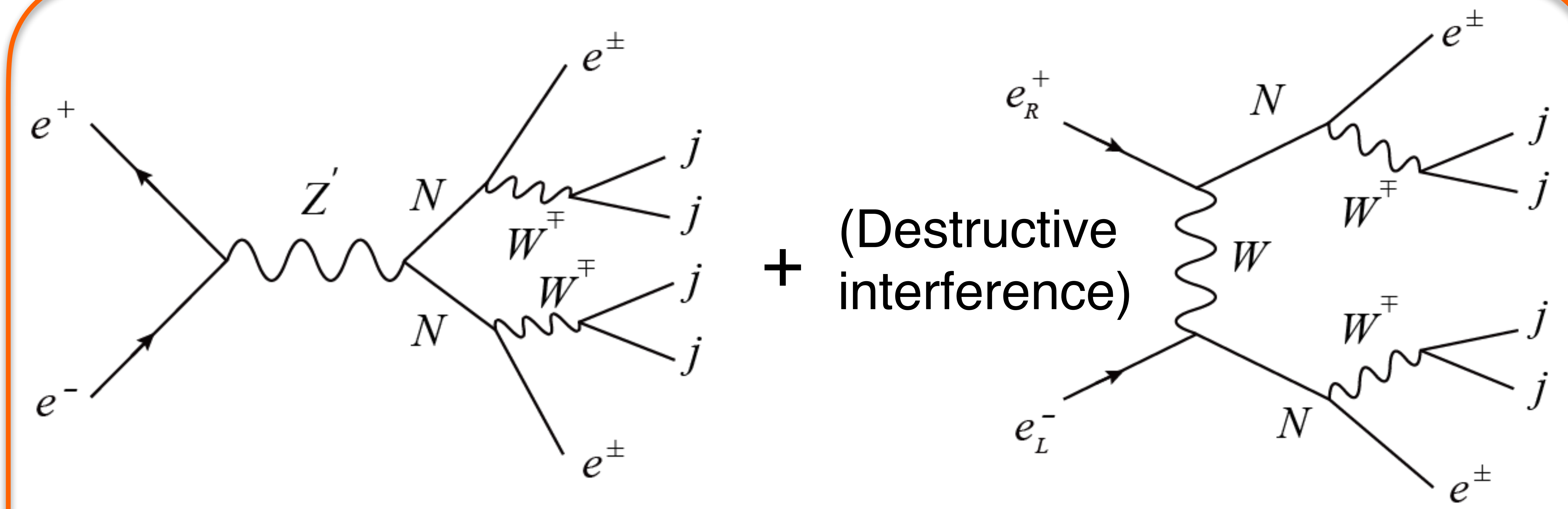
$L_e - L_\tau$ gauge boson



Jose Zurita

New vector states

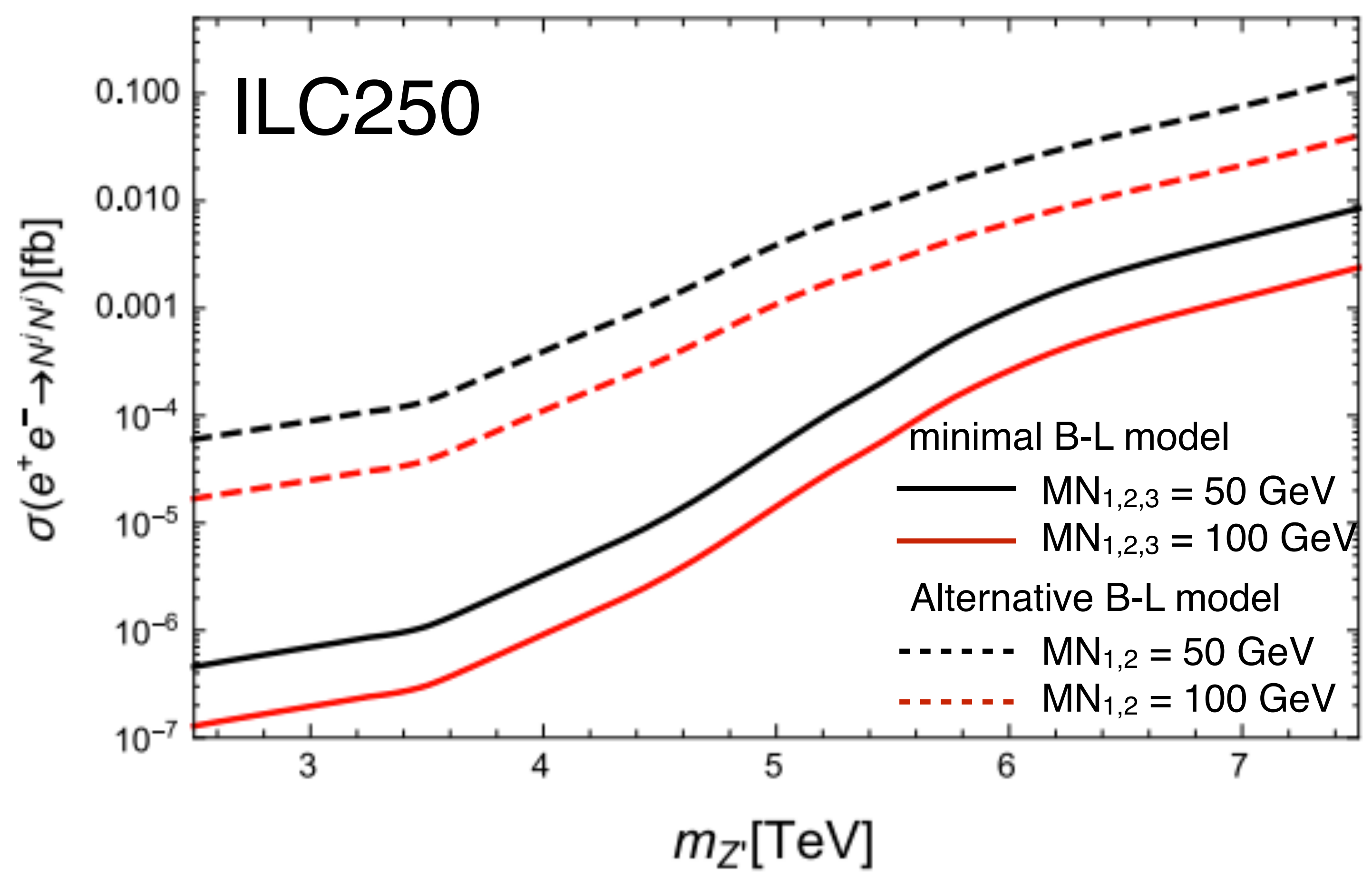
HNL gauge bosons in ILD



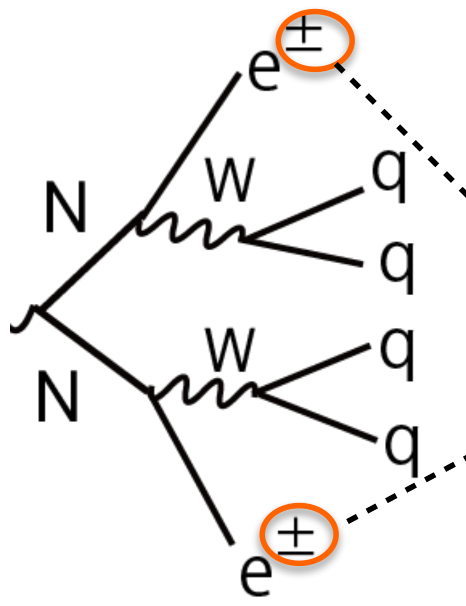
s-channel via Z'

t-channel via W (only e_L)

RHN pair production crosssection at ILC250 for expected HL-LHC limits on $M_{Z'}/g'$



arXiV[1812.11931]



Lepton # violation is possible!

↓

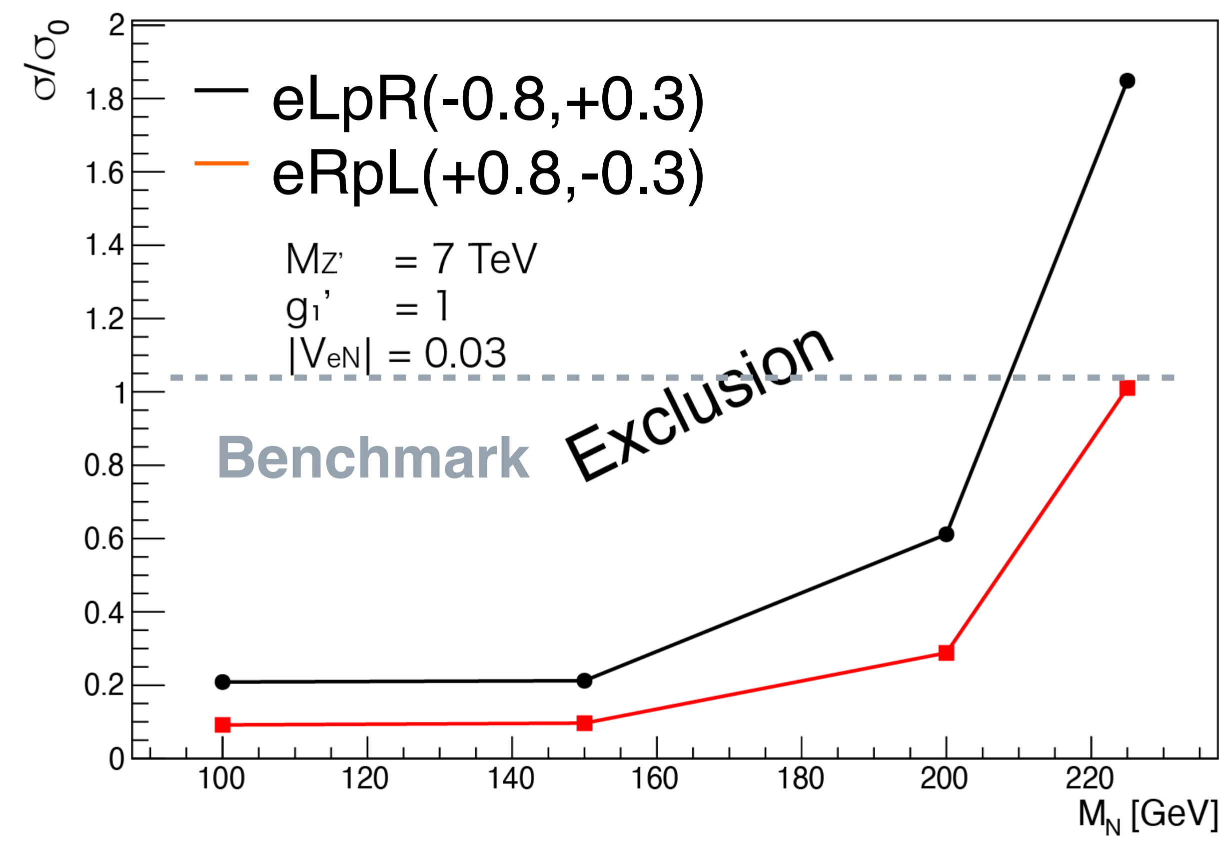
Same sign leptons possible

↓

Very small SM BG!

Calculate 95% UL on σ/σ_0

σ_0 : benchmark cross-section



Strongly limited by eRpL case and lighter RHN masses

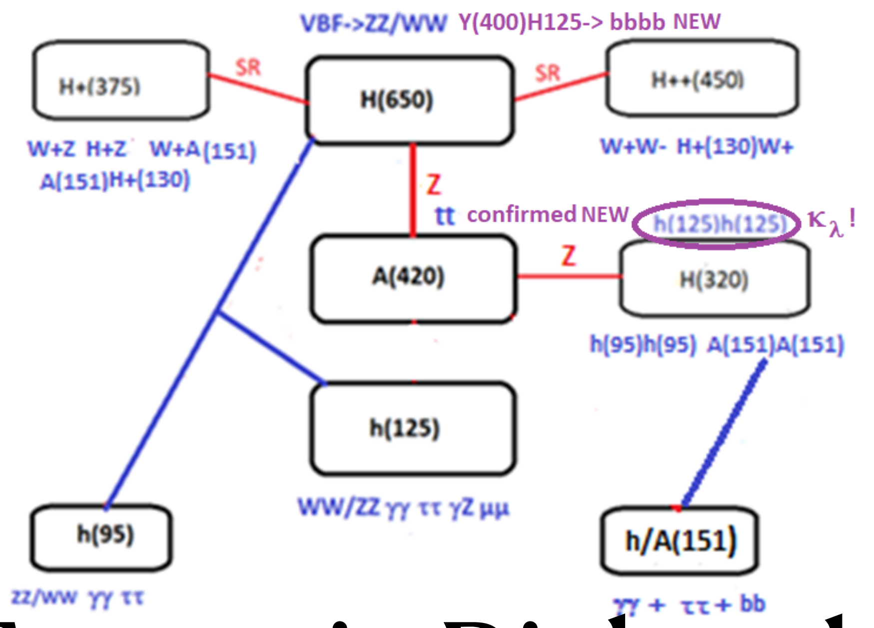
Jurina Nakajima

New vector and (tensor?) states

puzzles from the LHC keep showing up …

Should the LHC experiment start to publish the "trial factor"? How many independent signal regions have been looked at? Is 3σ the new 1σ? Helpful to take into account properly the LHC results in our study.

SUMMARY OF BSM SCALAR CANDIDATES



François Richard

- We should not ignore the possibility of tensor candidates in searches for BSM scalar resonances
- To select T(650)->ZZ, it is therefore important to apply a genuine **cut based** method to CMS data, separating VBF from ggF
- The RS scenario seems able to accommodate the tensor T(650) candidate but also implies **Kaluza Klein heavy vectors** which require our attention
- **T(650)** is a fascinating object which can be fully elucidated with an e+e- machine reaching 1 TeV
- This could also be true for the **fiveplet** comprising **T(450)++**
- We await with great hopes a reanalysis of X(650)->ZZ and conclusive results from RUN3, **3.5 sd true signals could then become 5 sd**

Thank you!

if you missed our parallels please check the backup slides

Nomenclature for 2HDMs (no pretense to be complete)

Table 1. The most familiar 2HDMs.

2207.06771

	Model	u_R^i	d_R^i	e_R^i	
$\phi_1 \to -\phi_1$	Type I	Φ_2	Φ_2	Φ_2	a.k.a. *NFC – Type I* or *Inert*
$\phi_2 \to -\phi_2, u_R \to -u_R$	Type II	Φ_2	Φ_1	Φ_1	a.k.a. "up-specifc" or *NFC – Type II*
$\phi_1 \to -\phi_1, e_R \to -e_R$	Lepton-specific	Φ_2	Φ_2	Φ_1	a.k.a. "lepton-specifc"
$\phi_1 \to -\phi_1, d_R \to -d_R$	Flipped	Φ_2	Φ_1	Φ_2	a.k.a. "down-specifc"

NFC=Natural Flavor Conservation

Symmetries can be advocated to fix which Higgs doublet interacts with which kind of fermions.

Paris SRCH parallels

Already? discussed in plenary

(Heavy) Neutrinos

Heavy Neutral Lepton

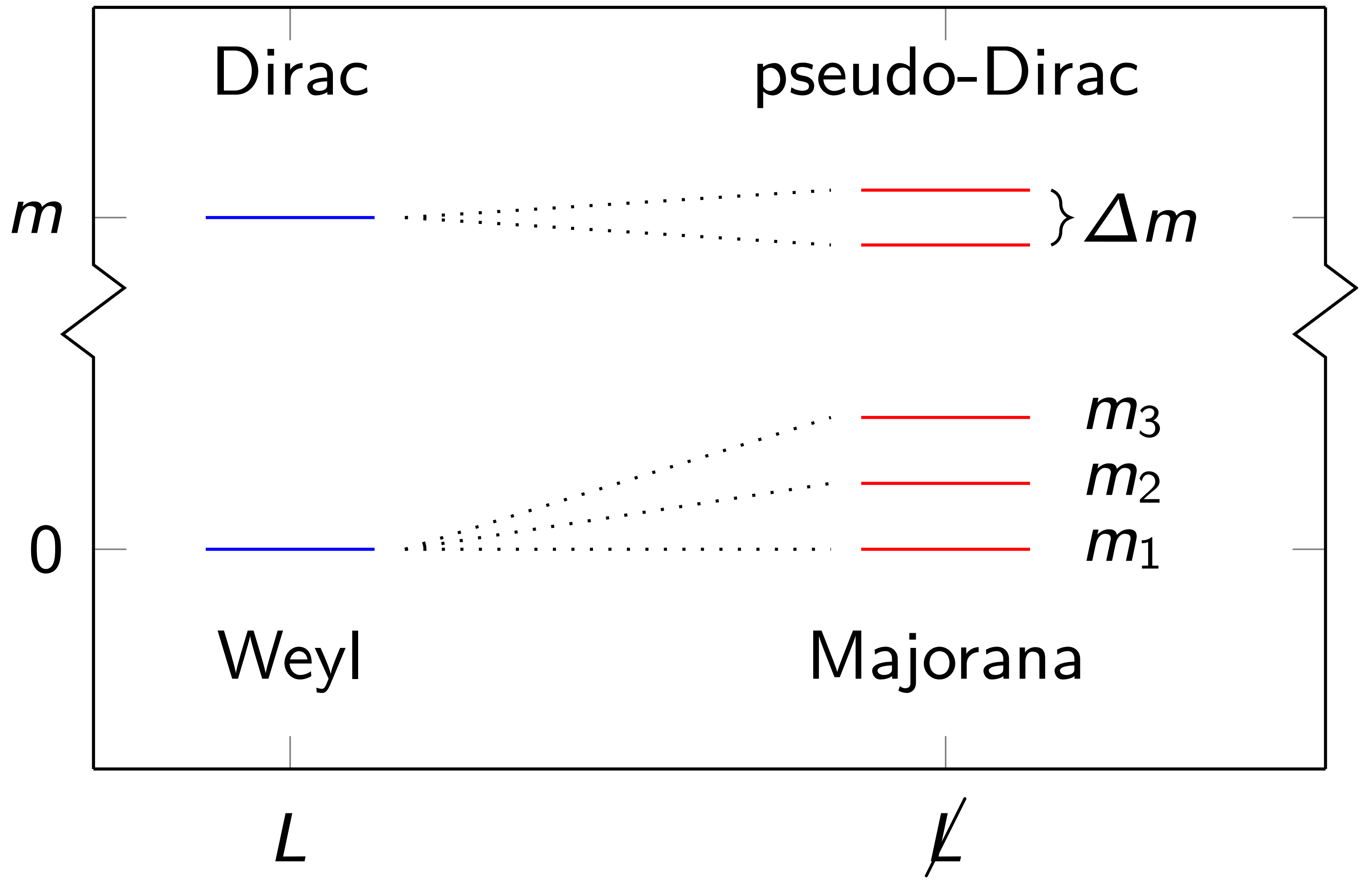
characterization

Symmetry-protected low-scale seesaw

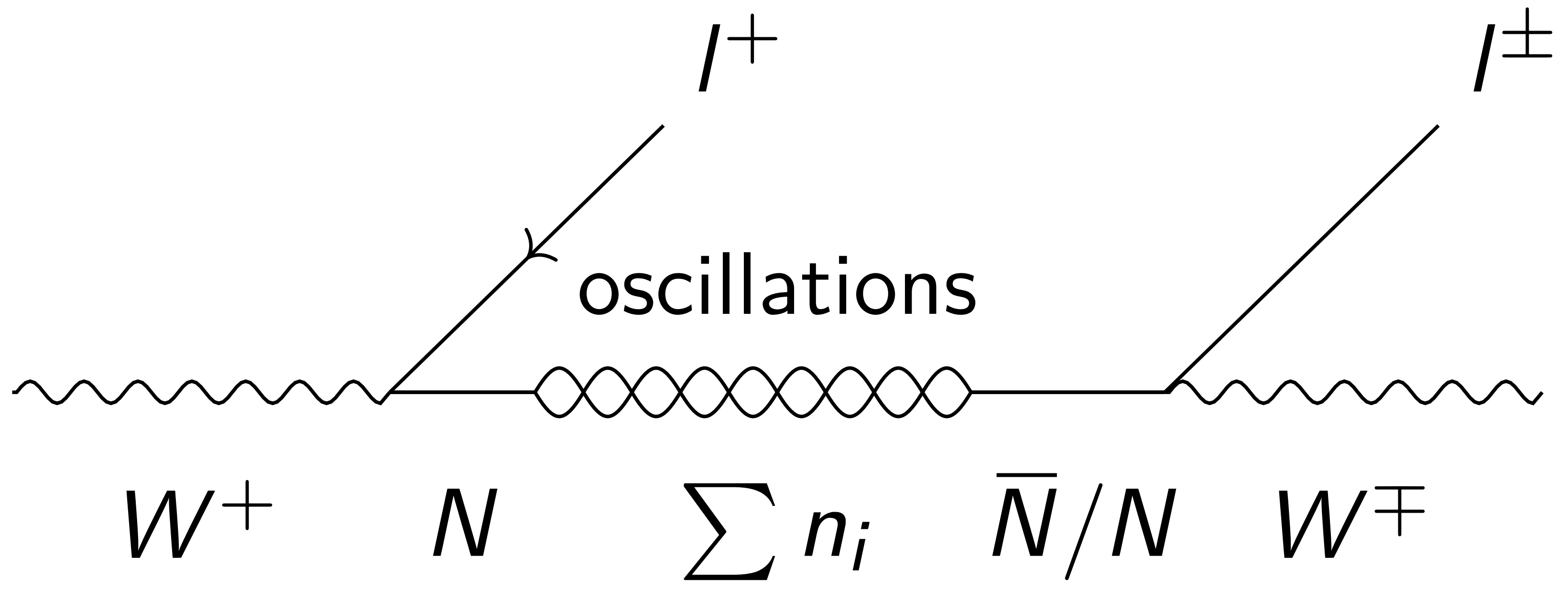
Small symmetry breaking $\not{L}$

- Light neutrino masses $m_\nu \propto \not{L}$
- Heavy neutrino mass splitting $\Delta m \propto \not{L}$

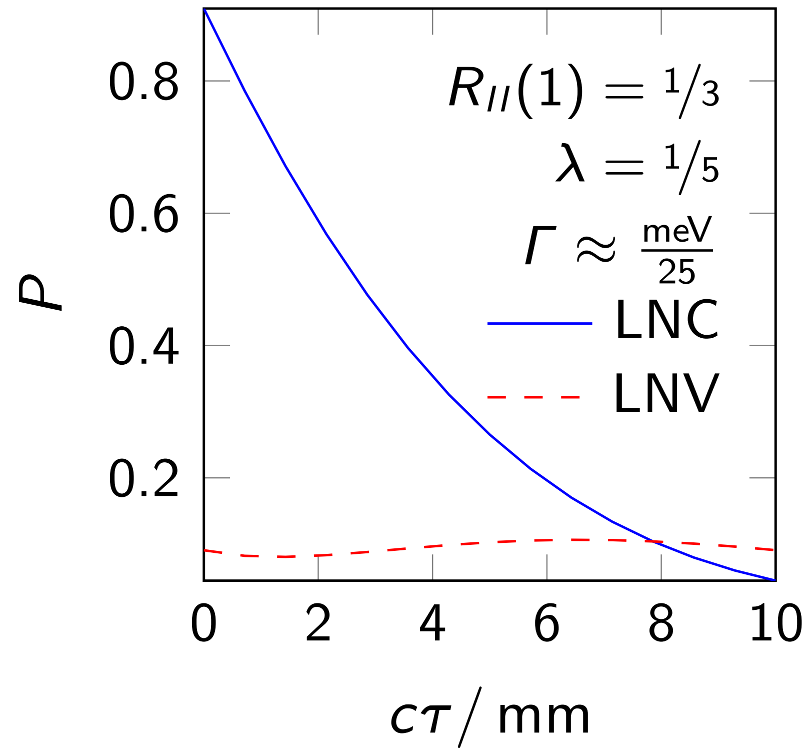
Breaking induced neutrino mass splitting



Oscillating mass eigenstates n_i

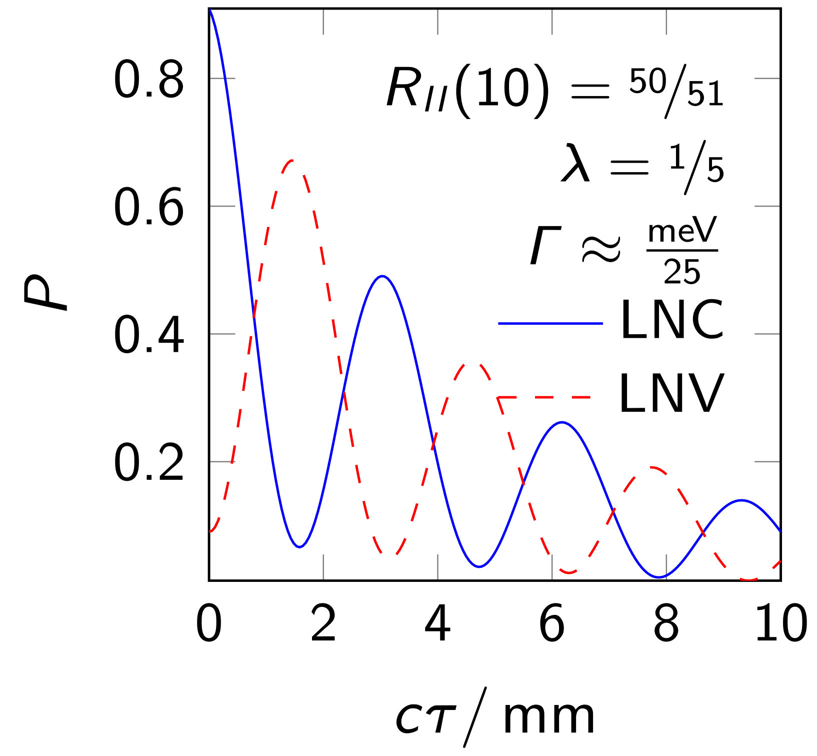


Almost Dirac limit



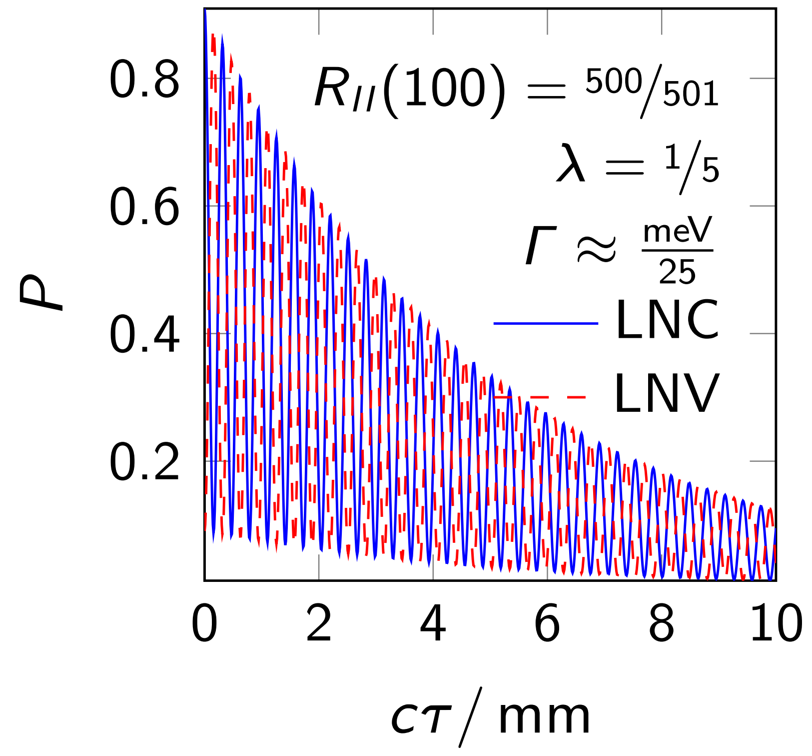
- Mostly LNC

Archetypical pseudo-Dirac



- Potentially resolvable

Double-Majorana limit

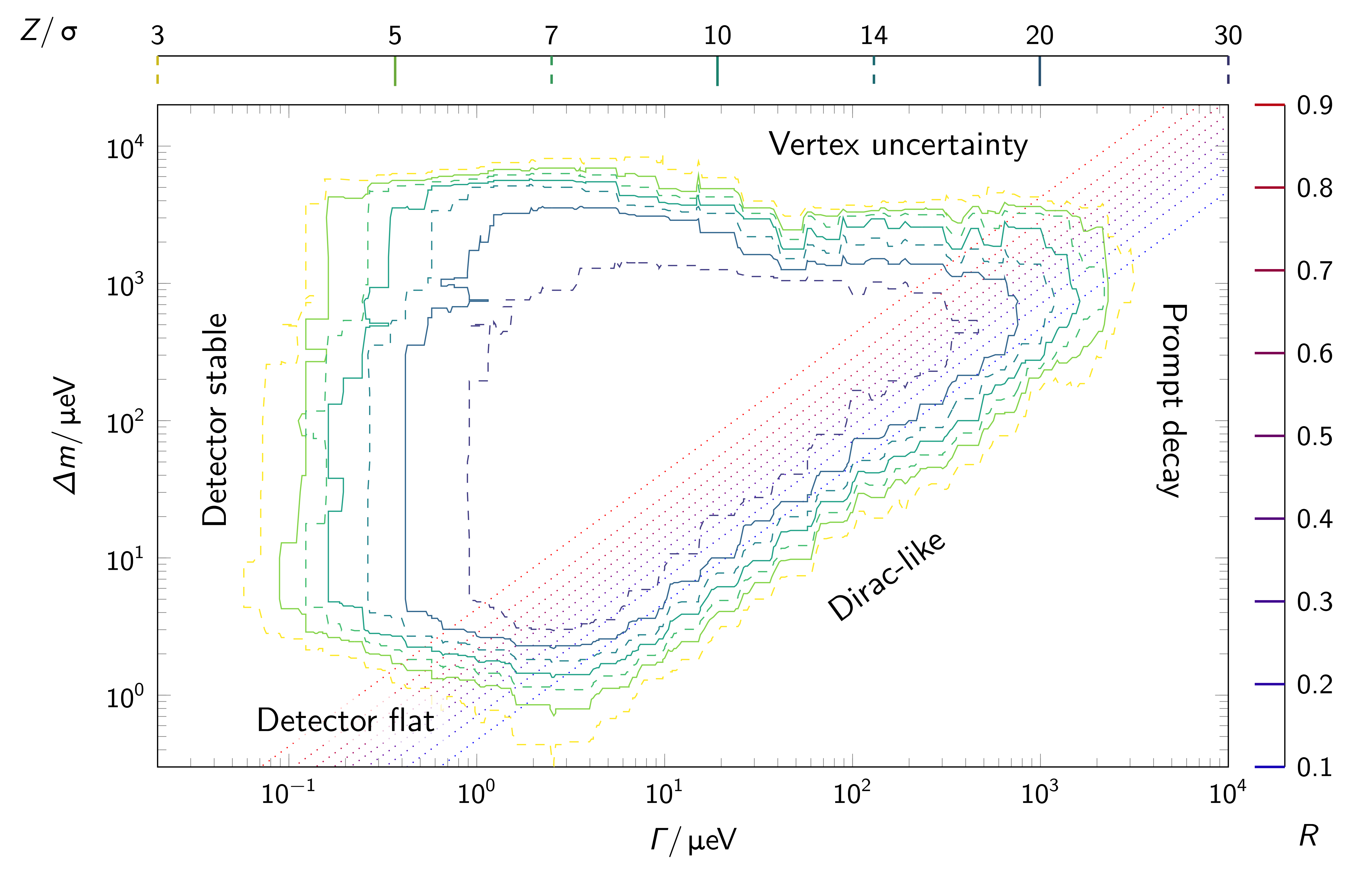


- Unresolvable
- LNV as frequent as LNC

Heavy Neutral Lepton

characterization

Maximal significance of the FCC-*ee*

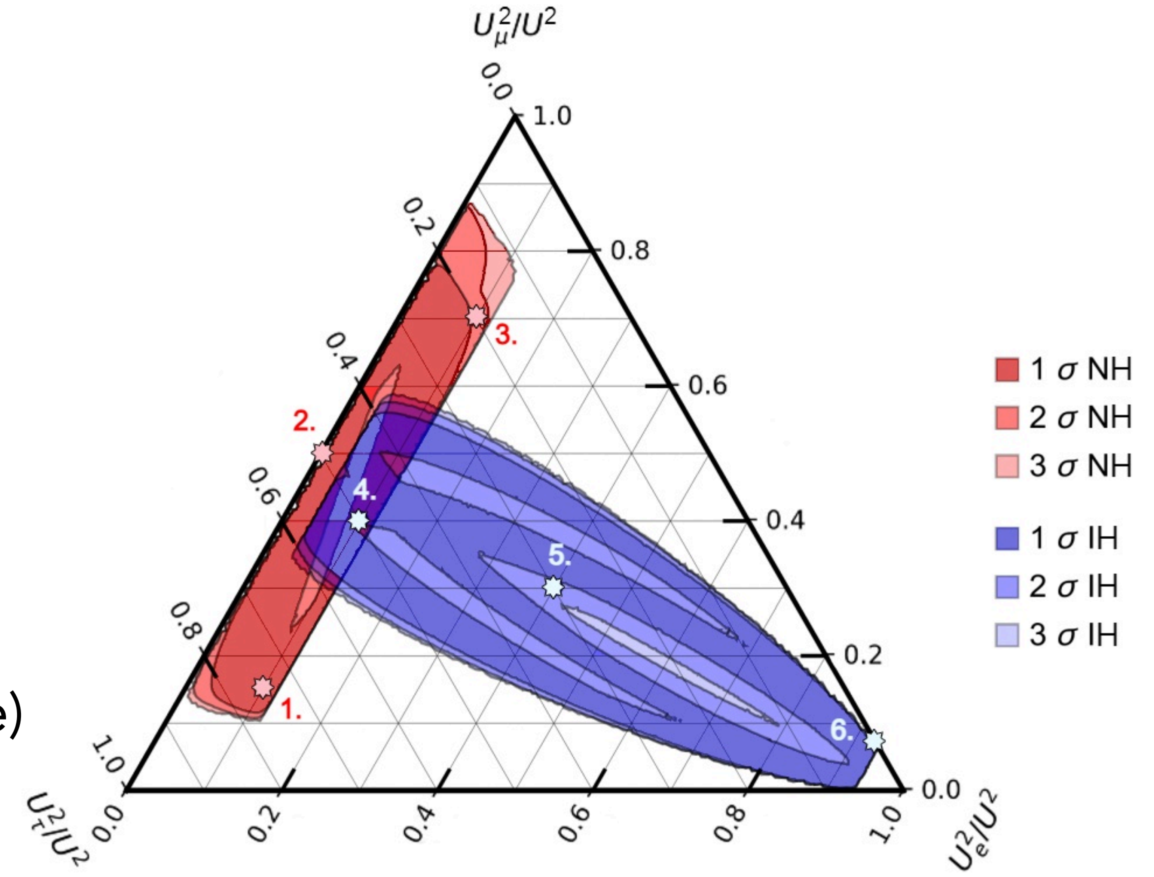


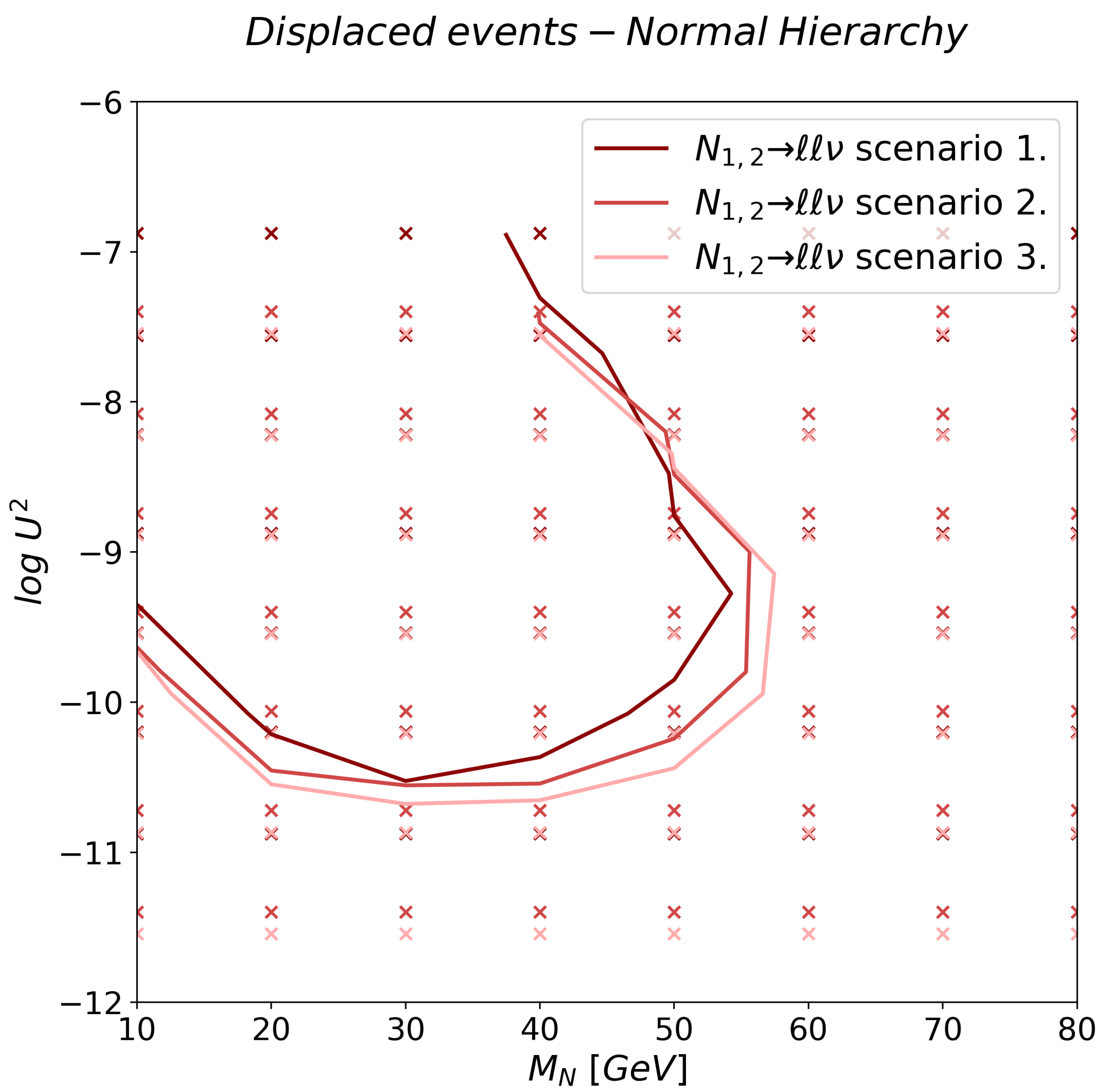
Discover reach is limited by detector geometry and interplay between oscillations and decay

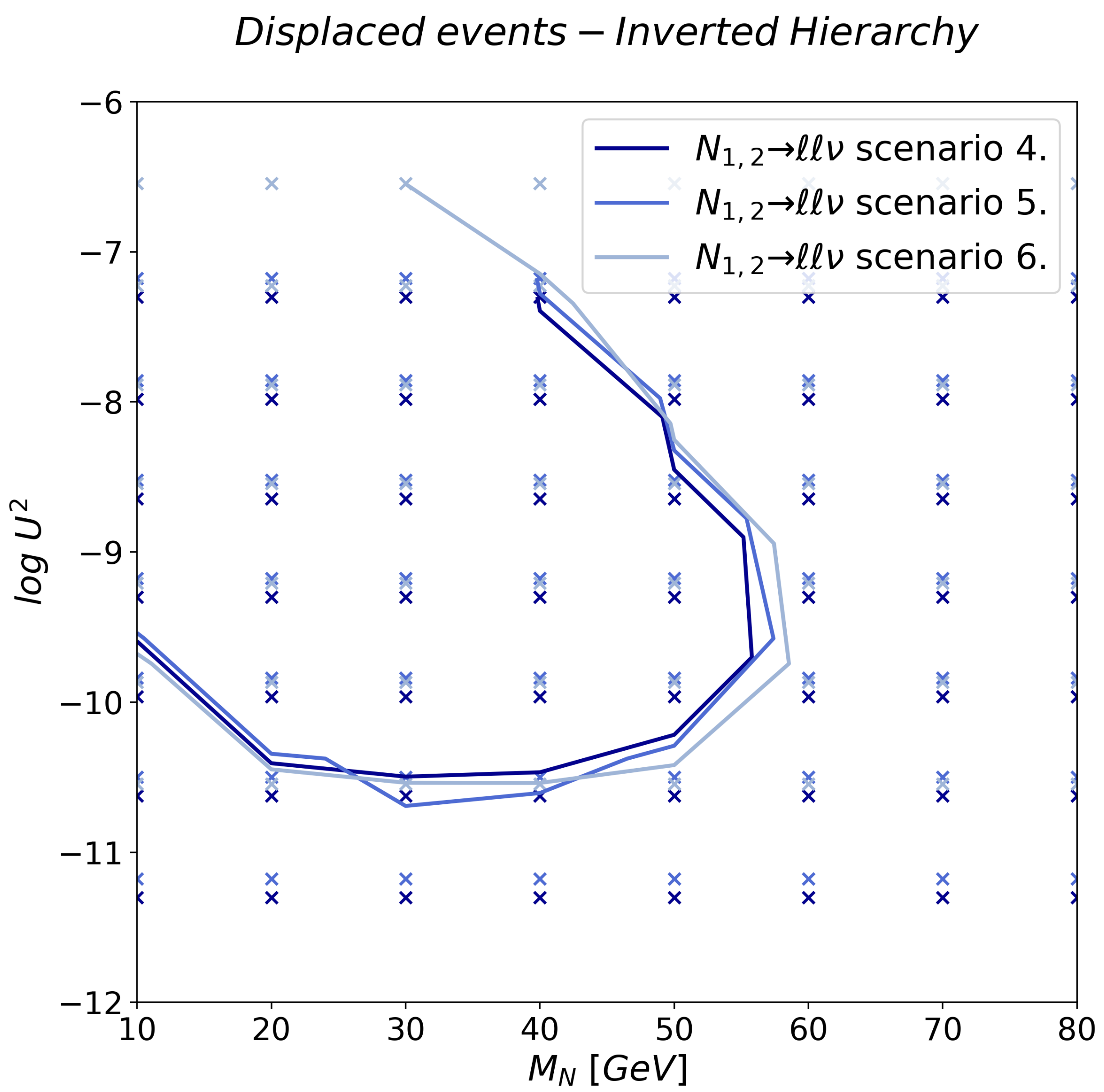
Heavy Neutral Lepton

leptogenesis

- Parameters are chosen in agreement with leptogenesis Phys. Rev. D 108 (2023) L101302 and oscillation data JHEP 09 (2020) 178:
  - $\Delta M = |M_1 - M_2| = 1 \cdot 10^{-5}$ GeV
  - $M_N = M_1 \in [10, 80]$ GeV
- Unitarity of the mixing matrix $U_e^2/U^2 + U_\mu^2/U^2 + U_\tau^2/U^2 = 1$ to set:
  - $|U_{\mu\ 1,2}| \in [1 \cdot 10^{-6}, 1 \cdot 10^{-4}]$
- Six benchmarks selected (shown in the picture)





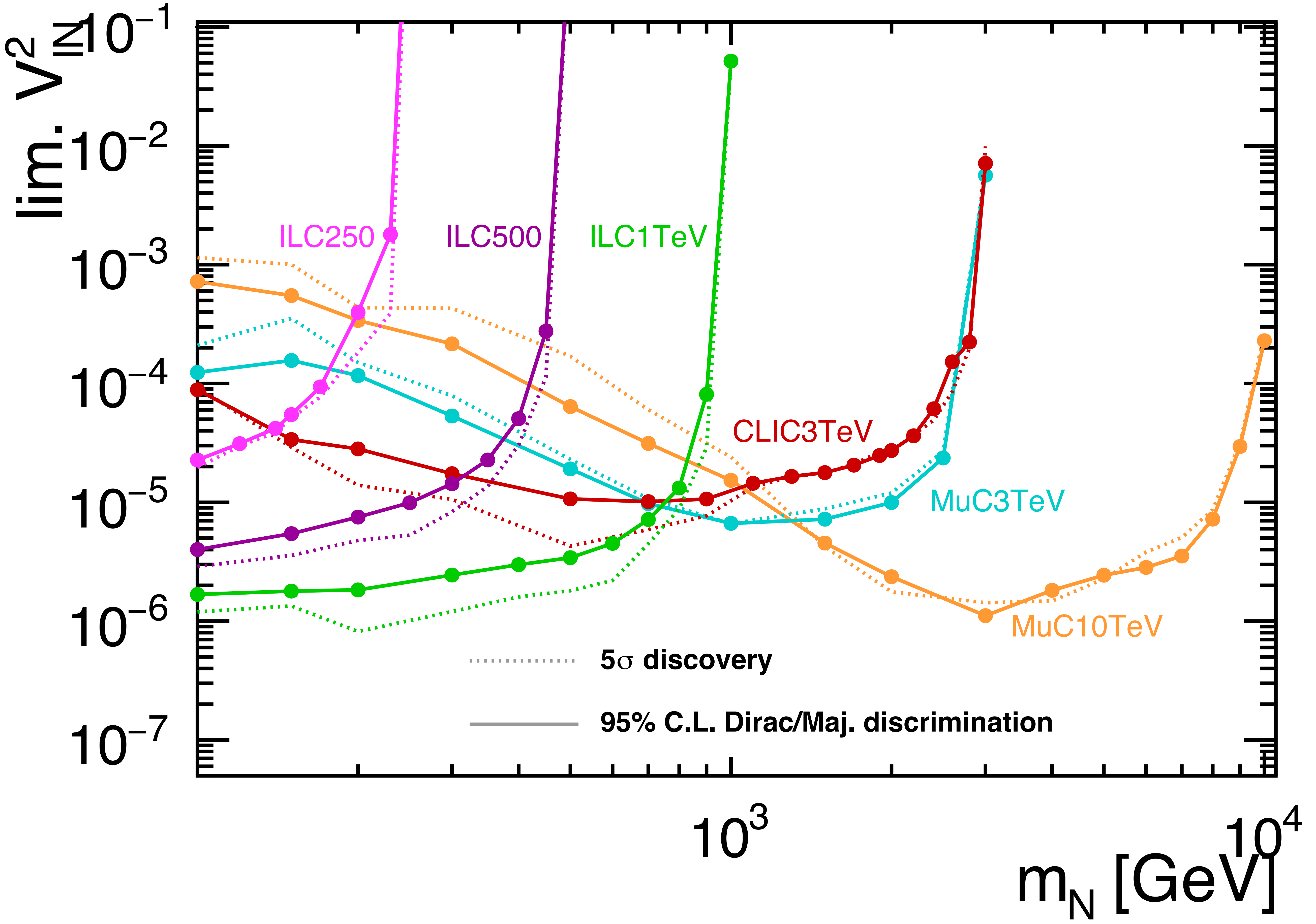


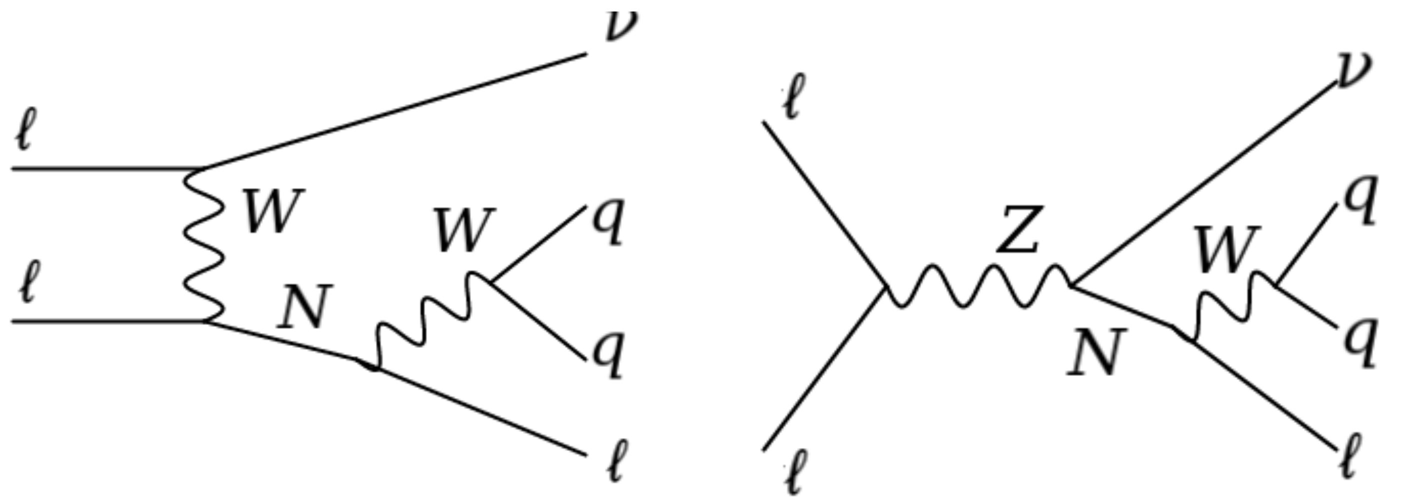
Selection:
Two leptons, no photons $p_{T,miss} > 5\ GeV,\ p_{T,\ell} > 1\ GeV,\ E_\ell > 2\ GeV$
No other track and no neutral hadron
$p_{T,miss} > 10\ GeV$
$cos\theta_{ll} > -0.8$
$M(l, l') < 80\ GeV$
$\chi^2 < 10$
$\vert d_0\vert > 0.64\ mm$

Heavy Neutral Lepton

up to bigger masses, probing Dirac vs. Majorana

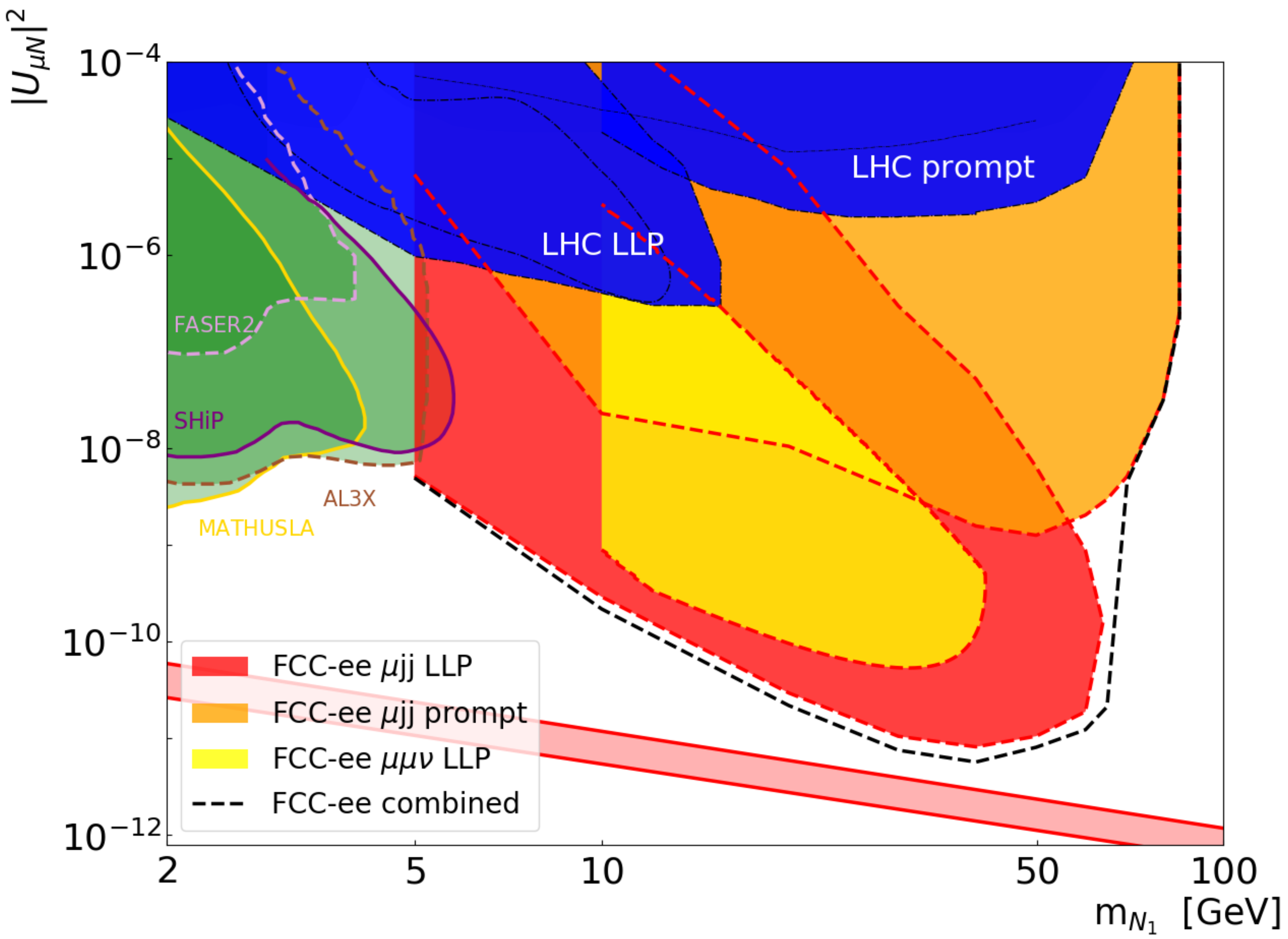
Dirac vs. Majorana – results

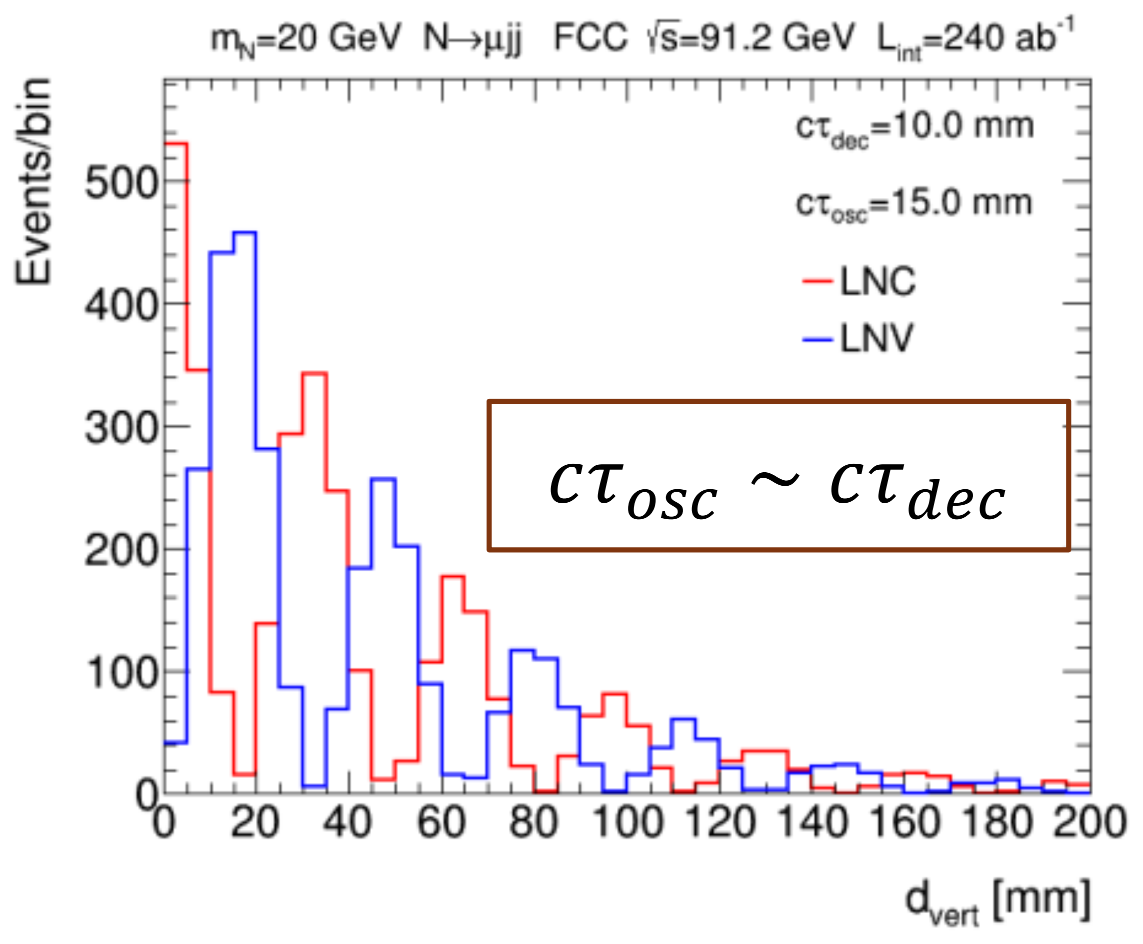


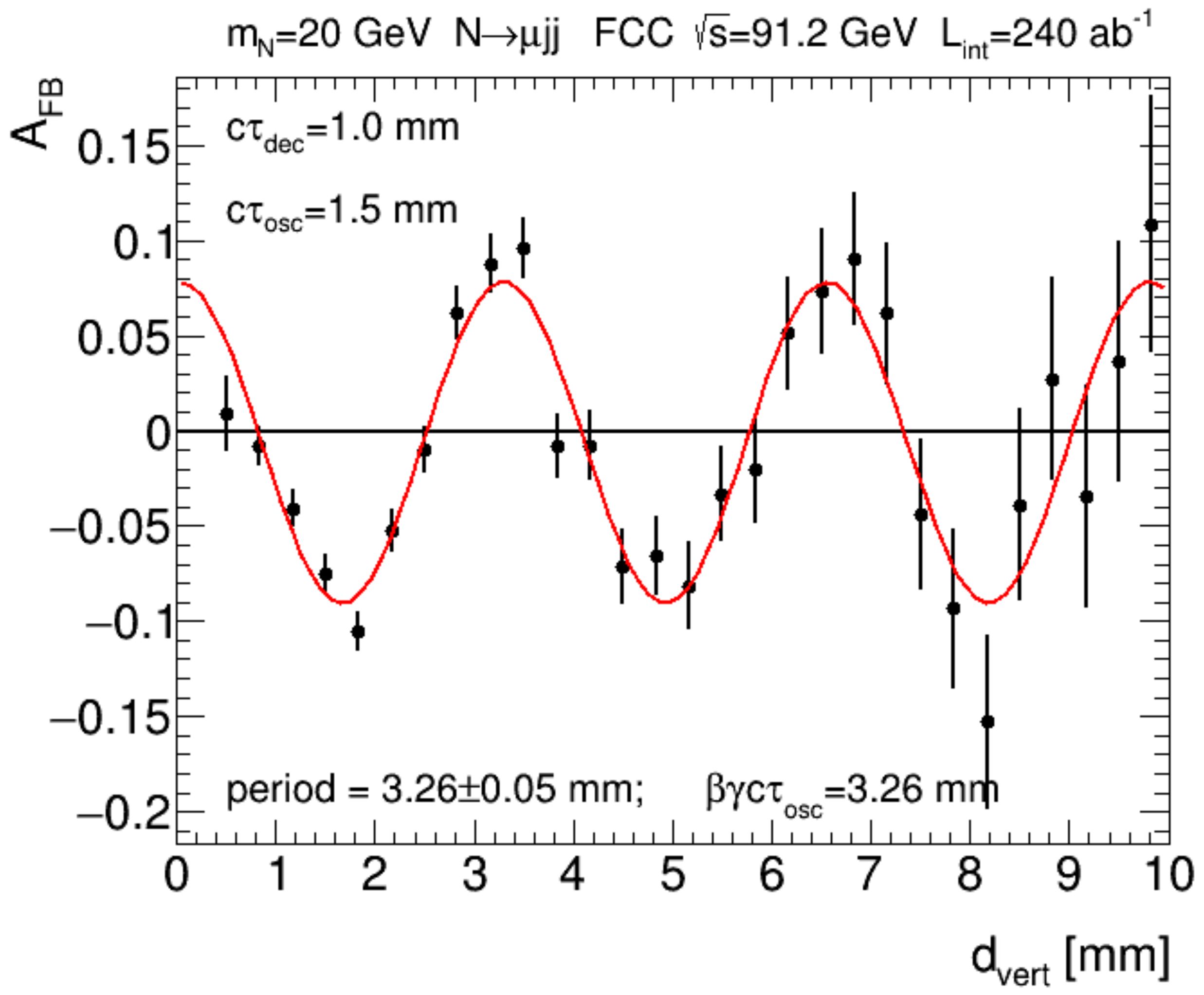


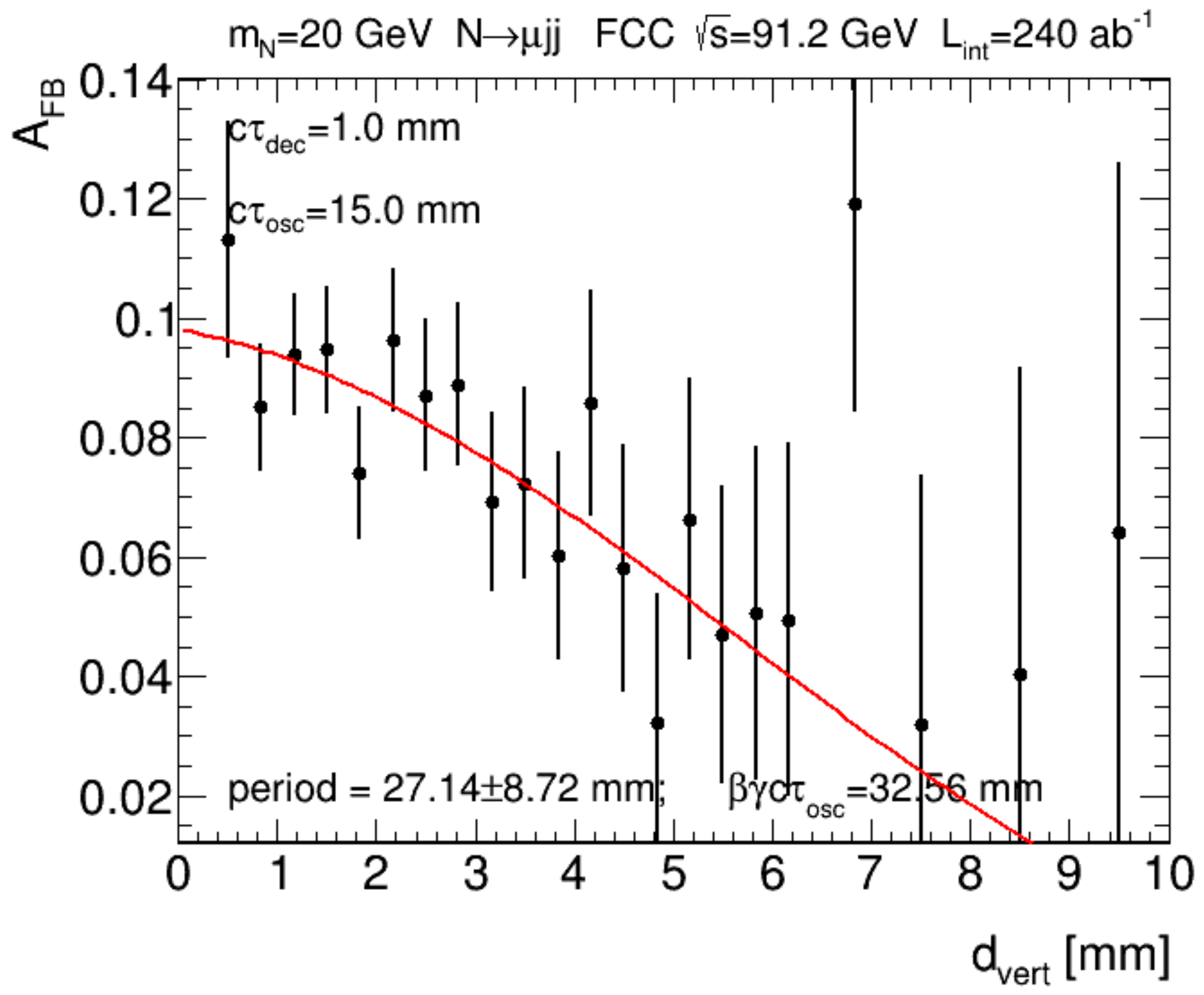
Heavy Neutral Lepton

fully reconstructible LLP and prompt with IDEA



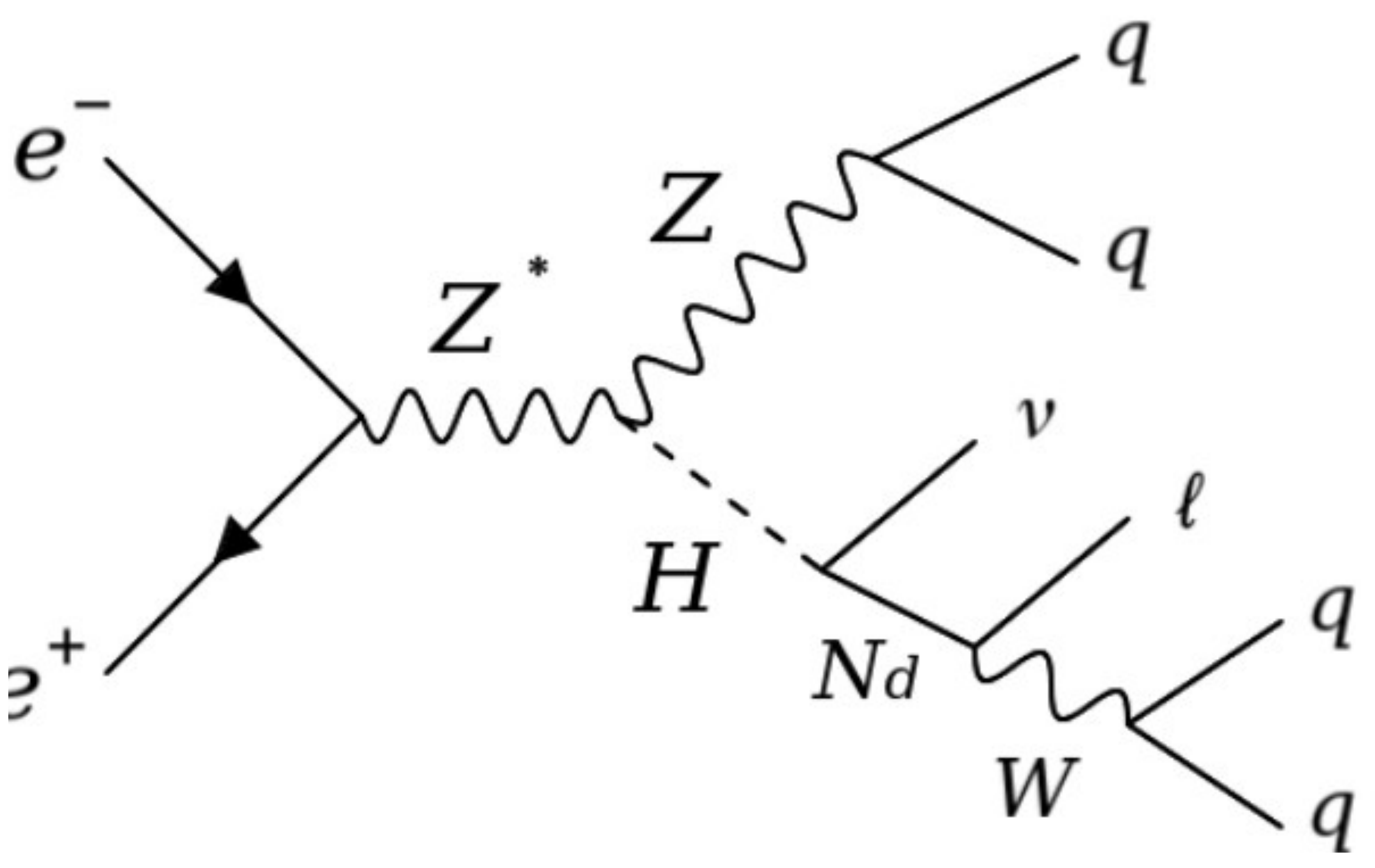


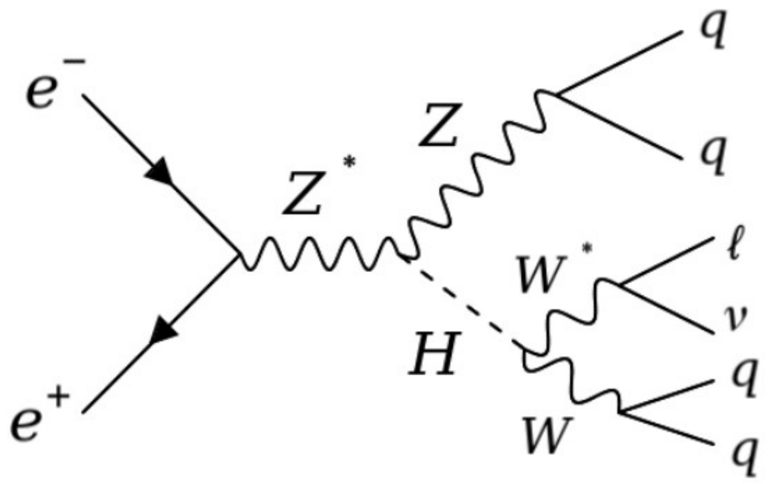


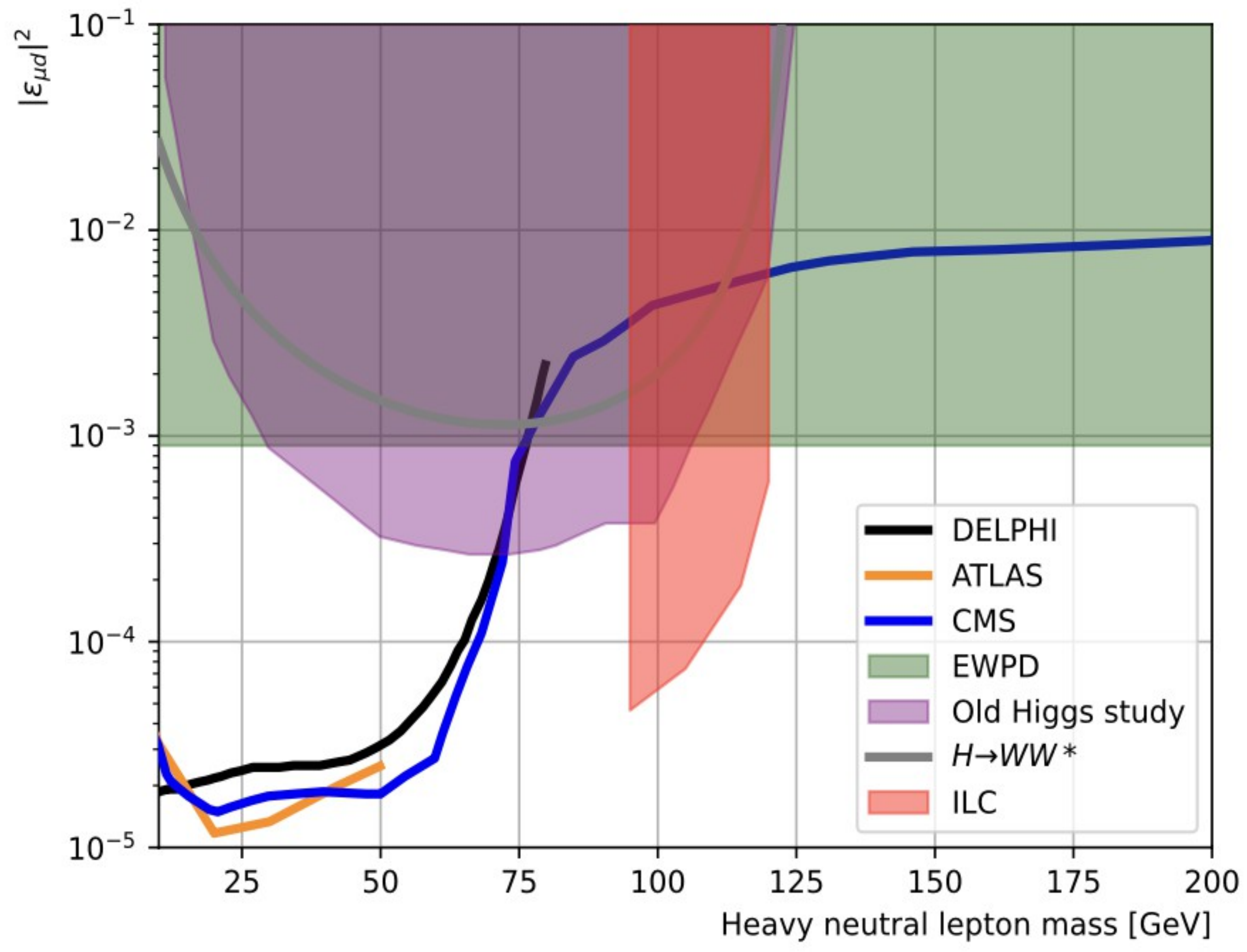


Heavy Neutral Lepton

ML-powered studies







17

- Constrain BR($H\rightarrow\nu N_d$)BR($N_d\rightarrow lW$) to **0.1%** (at 2σ)
- 25x higher significance compared to HL-LHC
  - **ILC allows for high precision measurements!**

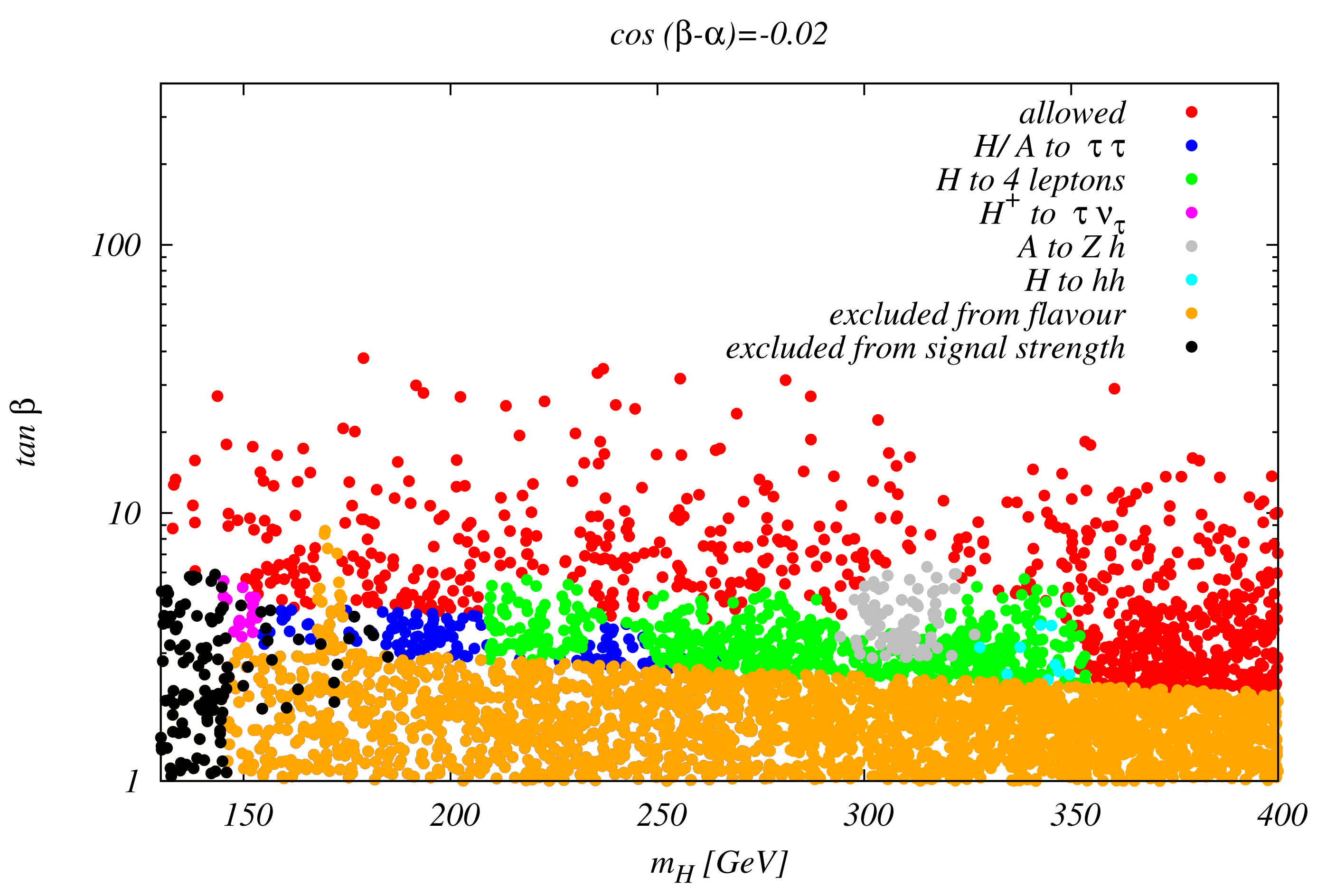
Scalars

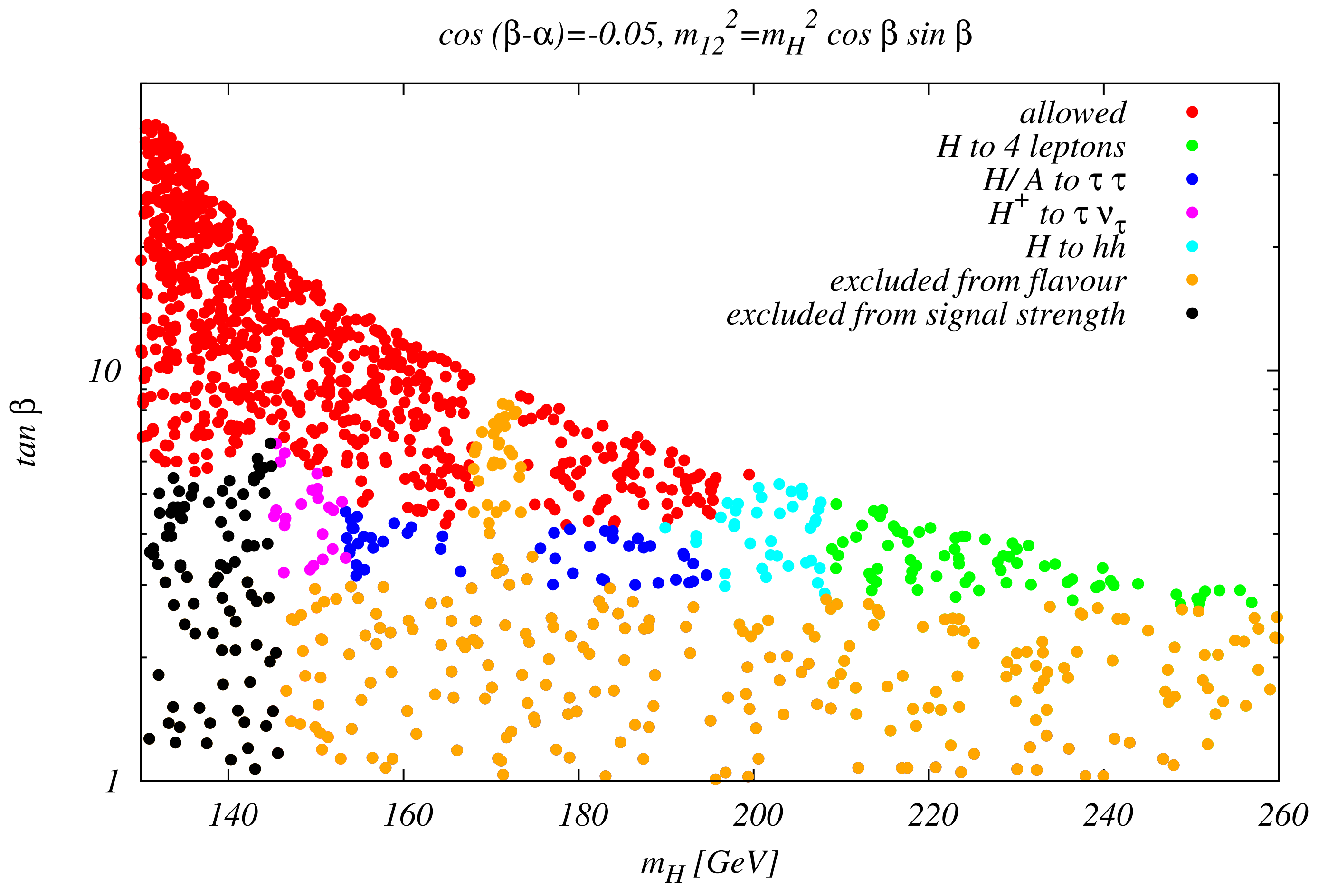
Type-1 "Inert-like"

can be light!

2HDM parameter space for fixed $\cos(\beta - \alpha)$, Type I

TR, ArXiv:2409.19657





$$m_H = m_A = m_{H^\pm}$$

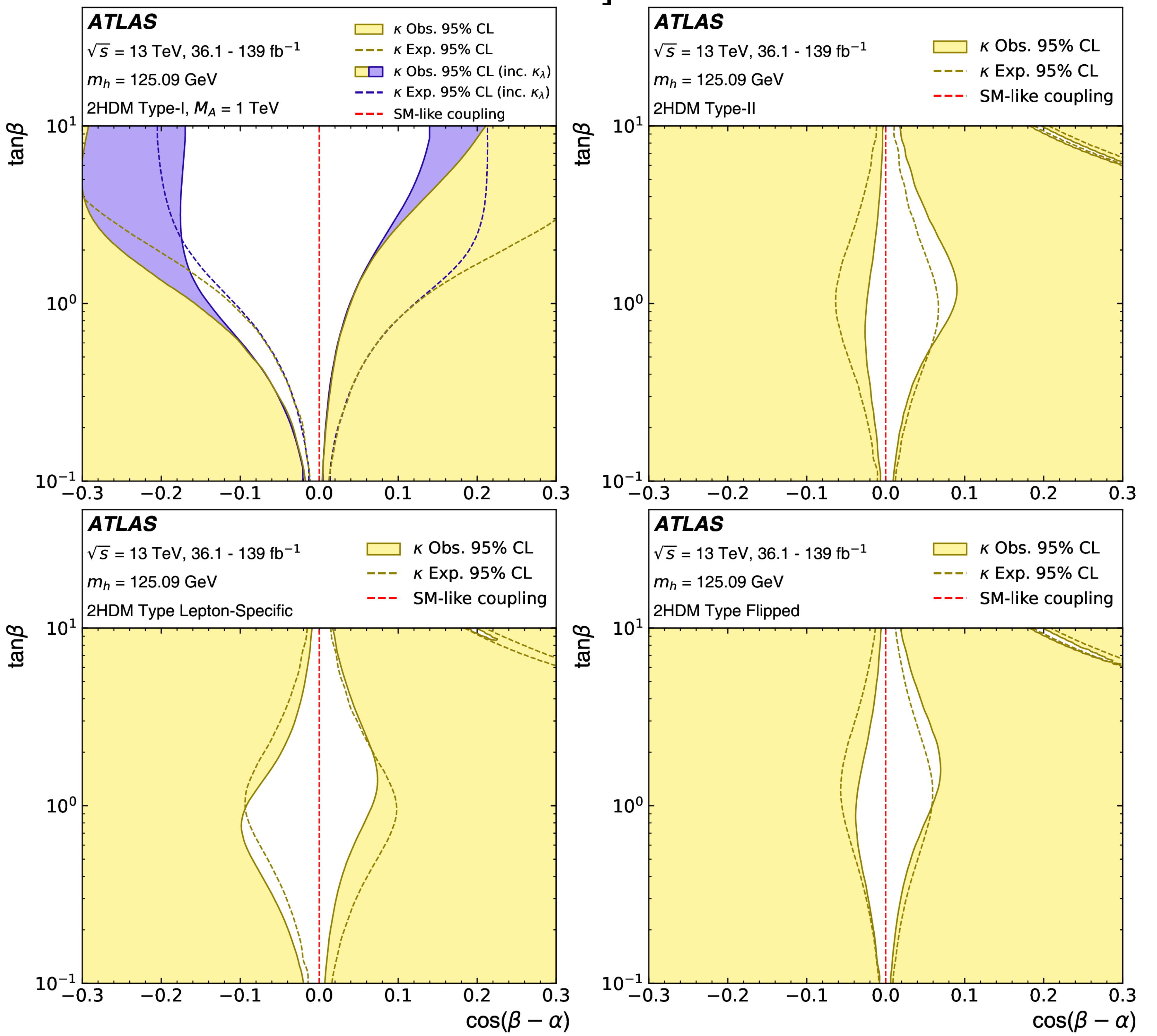
[using thdmTools, Biekoetter ea, JHEP 01 (2024) 107]

Type-1 "Inert-like"

can be light!

Current constraints on alignment in 2HDMs

[arXiv:2402.05742, ATLAS Full Run II]



Fully inert

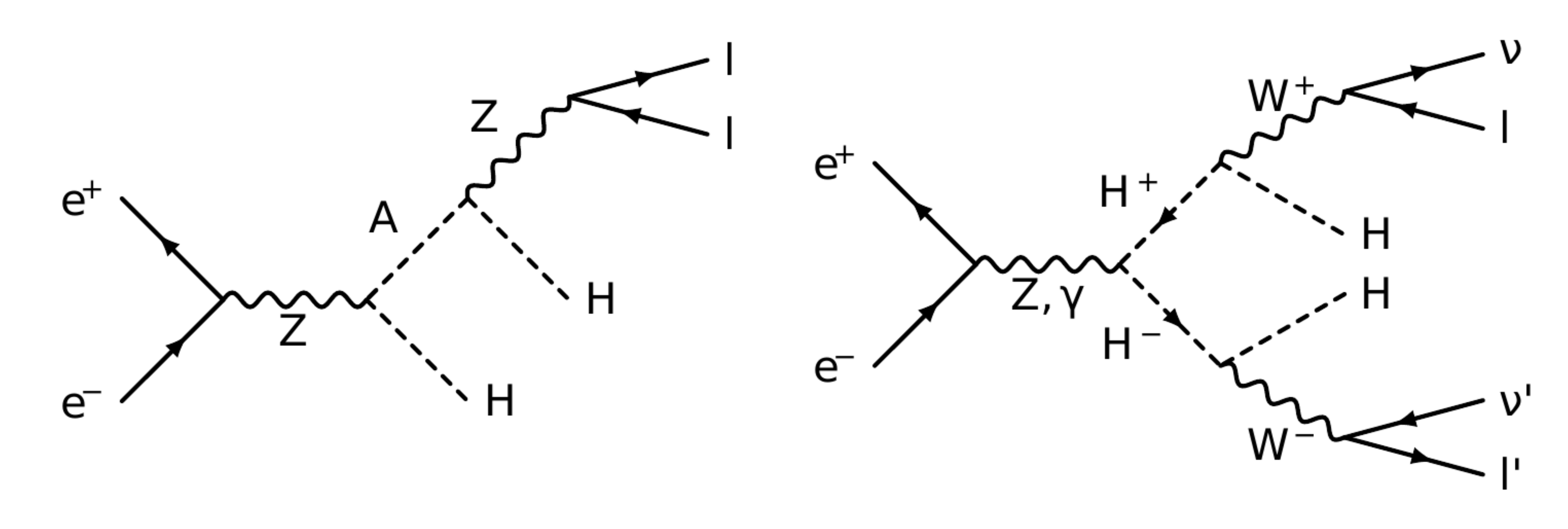
can be light!

The Inert Two-Higgs-Doublet model (IDM)

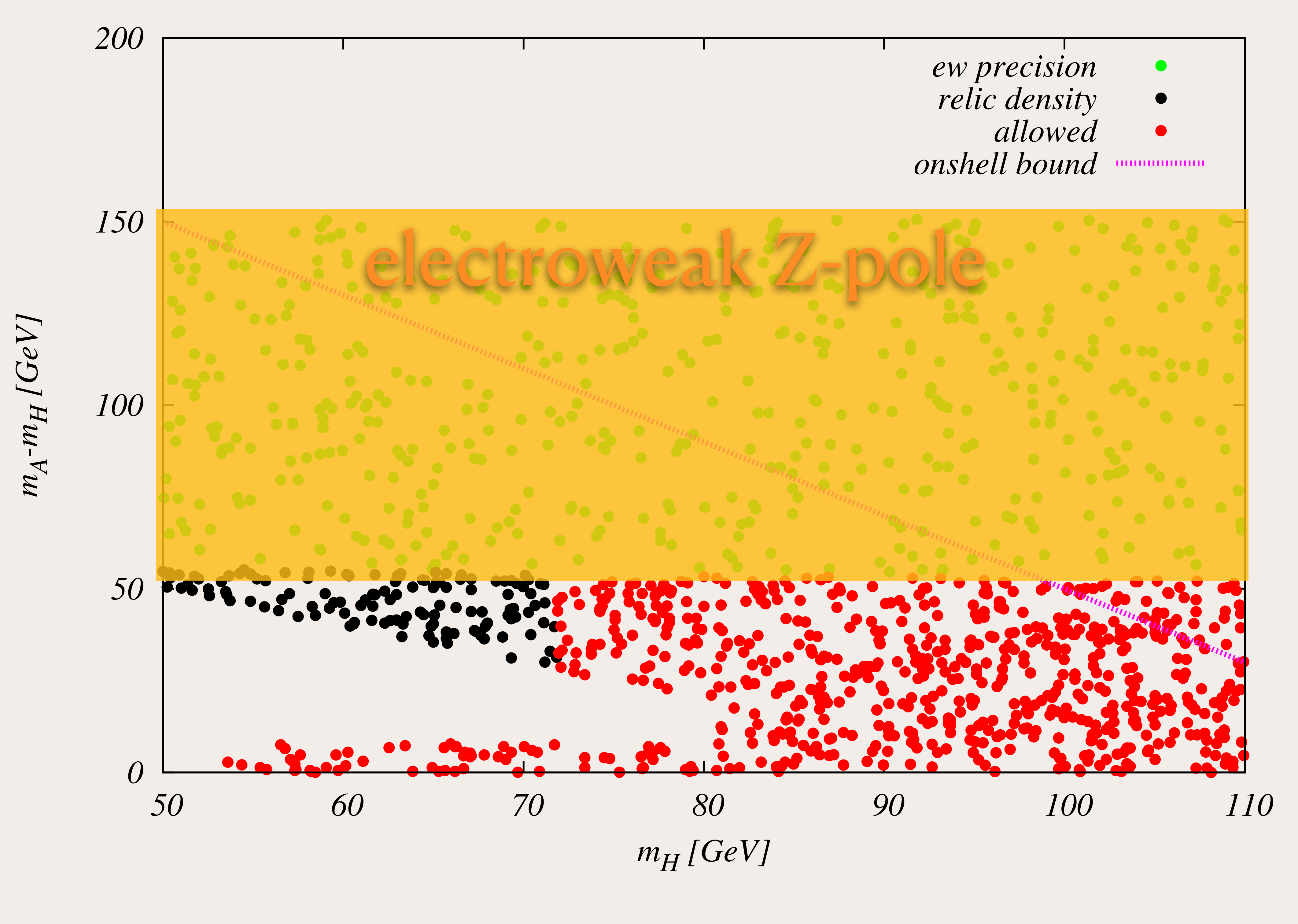
IMPERIAL Ruđer Bošković Institute FCC

- Two Higgs-Doublet model: 5 scalars, h, H, A, H+, H-.
- h is the SM Higgs with constraints from SM measurements.
- Add Z2 symmetry: $\phi_D \to -\phi_D$, $\phi_S \to \phi_S$, SM $\to$ SM.
- New scalars do not couple to fermions and are pair-produced.
- Dark Matter candidate(s): choose H.
- Five free parameters: m_H, m_A, $m_{H\pm}$, λ_{345}, λ_2.

Final state considered: 2ℓ(=e or μ) + HH, mainly produced through AH and H^+H^-



ee→ llHH and ee→ llννHH.



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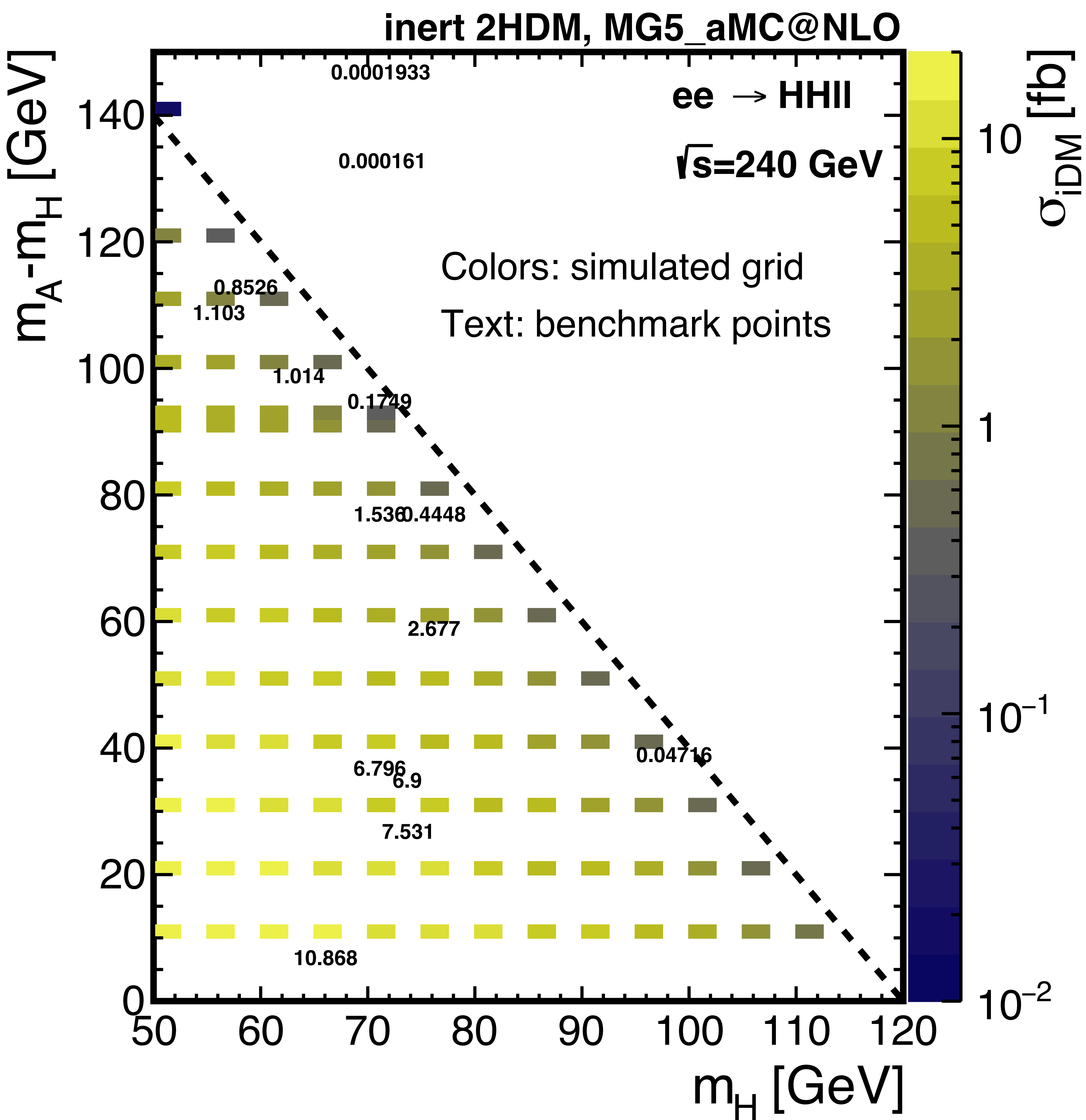
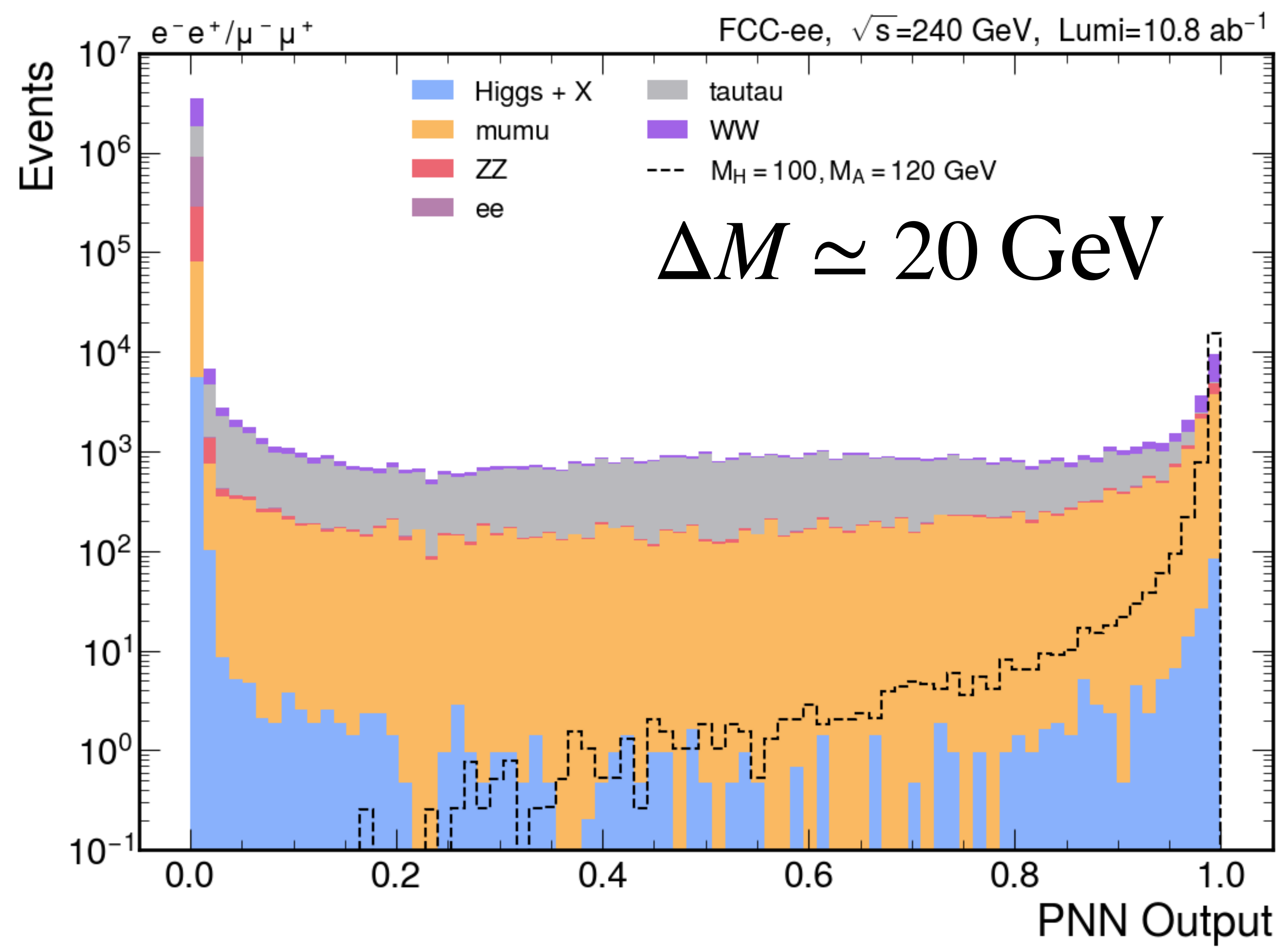




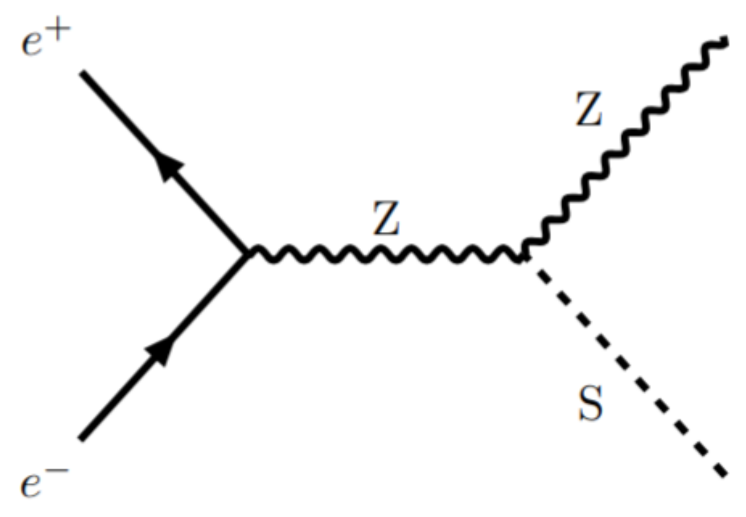
$\Delta M \simeq 20$ GeV

Invisible

can be light!

Motivation

- $e^+e^- \to Z\ S$ (scalar-strahlung) process could be used to probe new low mass scalar using Recoil Mass analysis technique.



- One can use the decay products of Z boson to probe this process.
- Light exotic scalar states at low masses are not excluded by existing data.
- We have considered hadronic decay of the Z boson which has a $Br(Z \to q\bar{q}) \simeq 70\%$ and invisible decay of new scalar - $S \to inv$ (which may include Dark Matter).
- This study considers the center of mass energy as 240 GeV.
- Previously, this was studied for CLIC at 380 GeV. Eur. Phys. J. Plus 136, 160 (2021)

$H \to ZZ \to \nu\bar{\nu}\nu\bar{\nu}$

Background Event Samples

- All background samples have been generated using the same chain of tools as for signal.
- Background consists of a combination of jets, leptons, and neutrinos.
- We have considered the final states consisting of two jets, four jets, two jets + two leptons, two jets + neutrinos, two jets + lepton + neutrino.

Invisible

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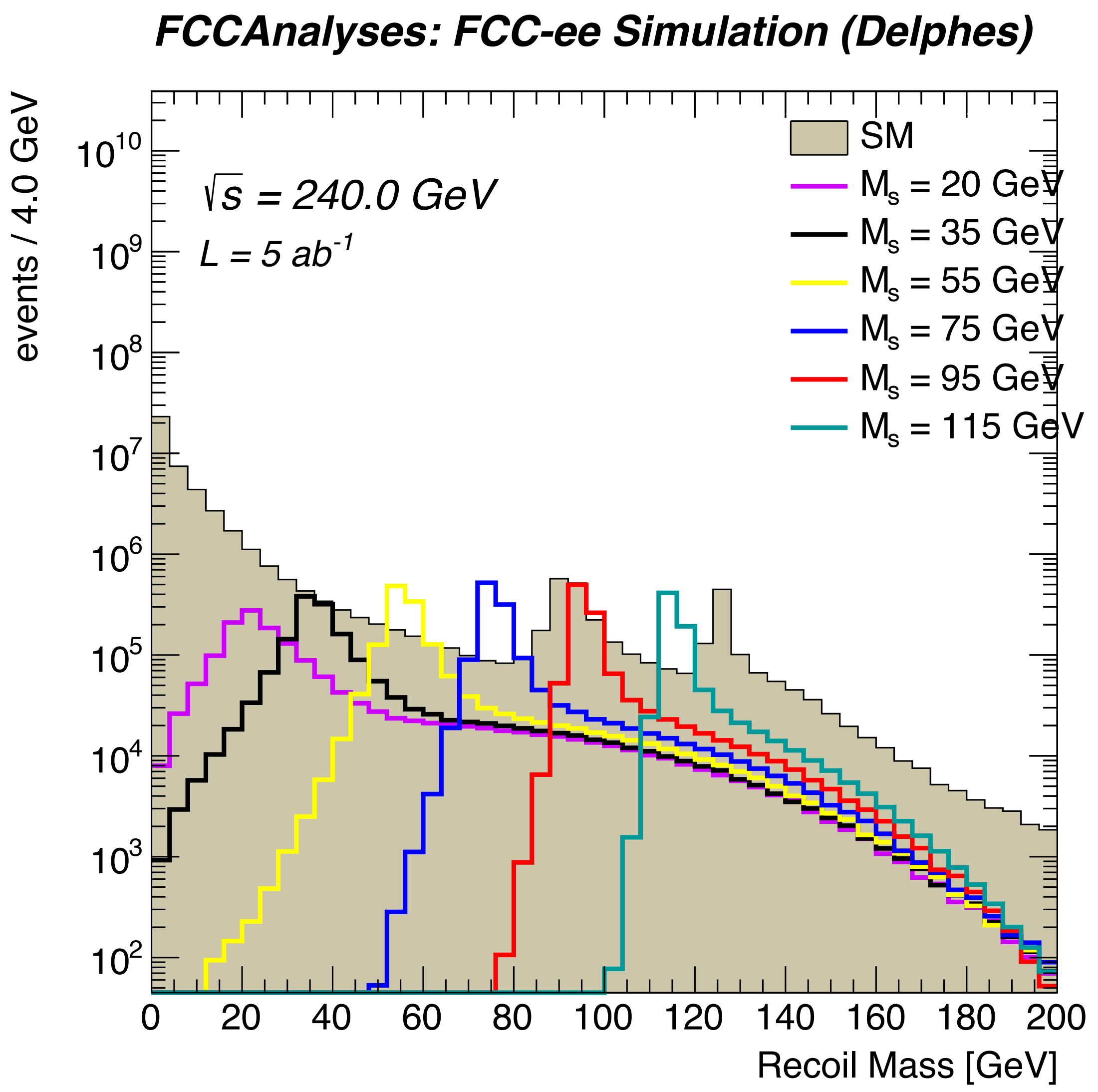
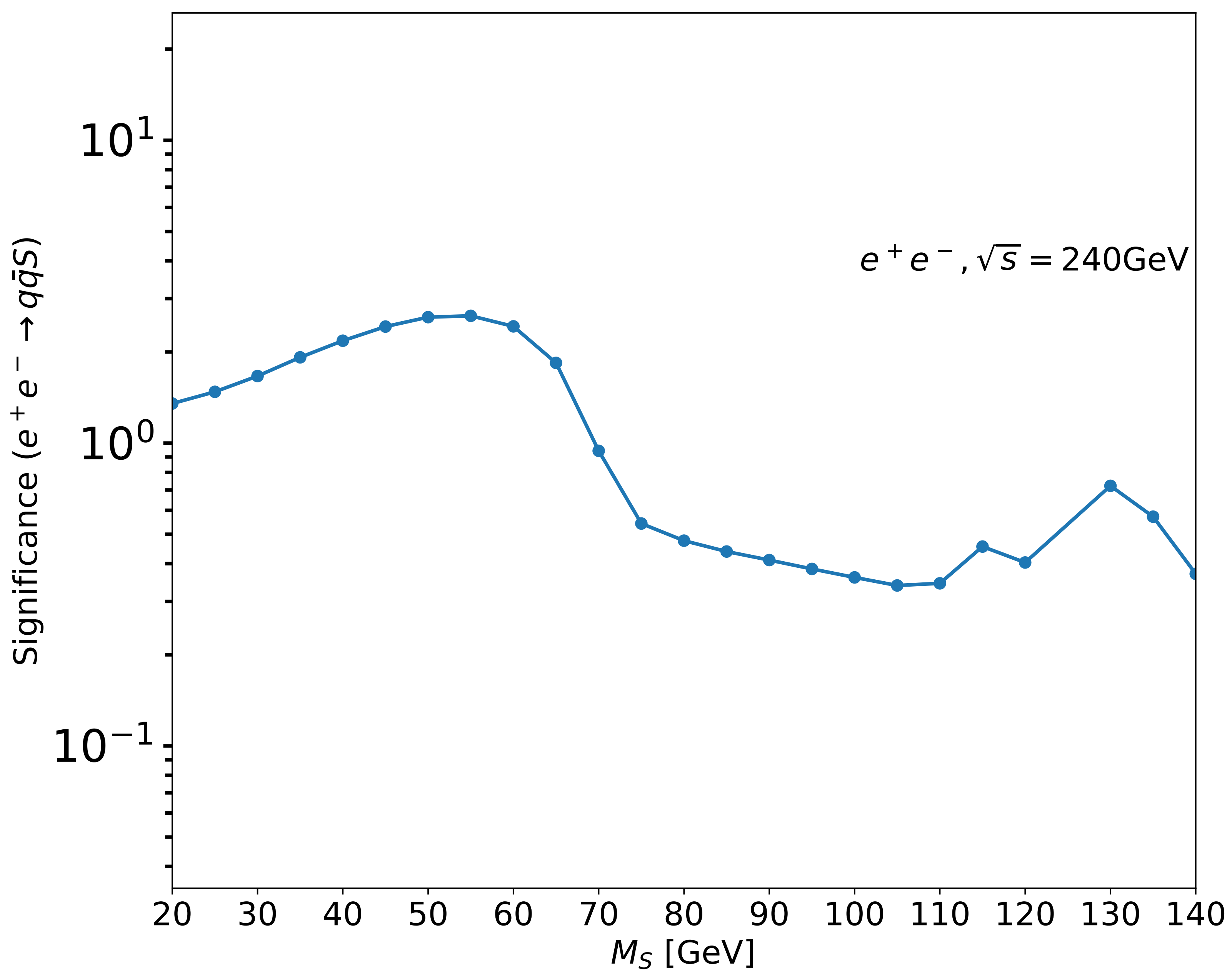
Recoil Mass Reconstruction



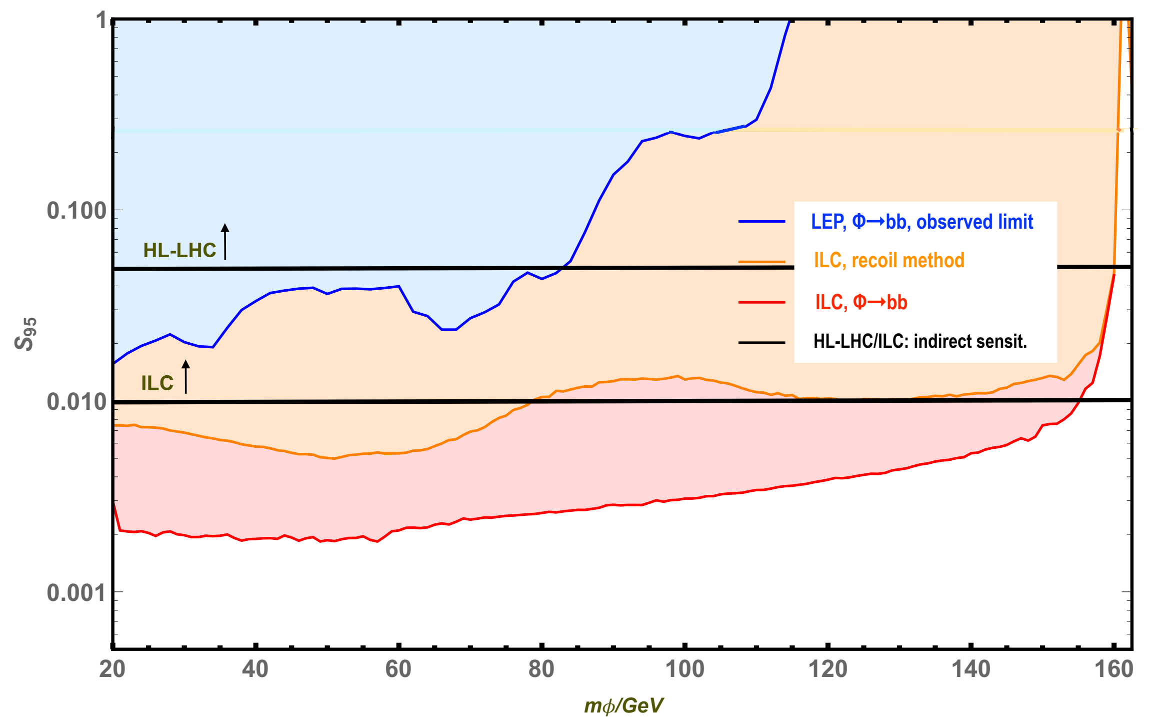
"typical" suppression with $\sin\theta \sim 0.24$ for signal



- Recoil mass is given by: $M_{\mathrm{Recoil}} = s + m_Z^2 - 2E_z\sqrt{s}$
- A variable cut on M_{Recoil} is applied in a window of a given $M_S \pm 20$ GeV.
- Peaks seen in SM distribution are from ZZ (at 90 GeV) and ZH events (at 125 GeV).

Multiple final state

digging deeper



Target I Search for light exotic scalars in the process:

$$e^+e^- \to Z\,S$$

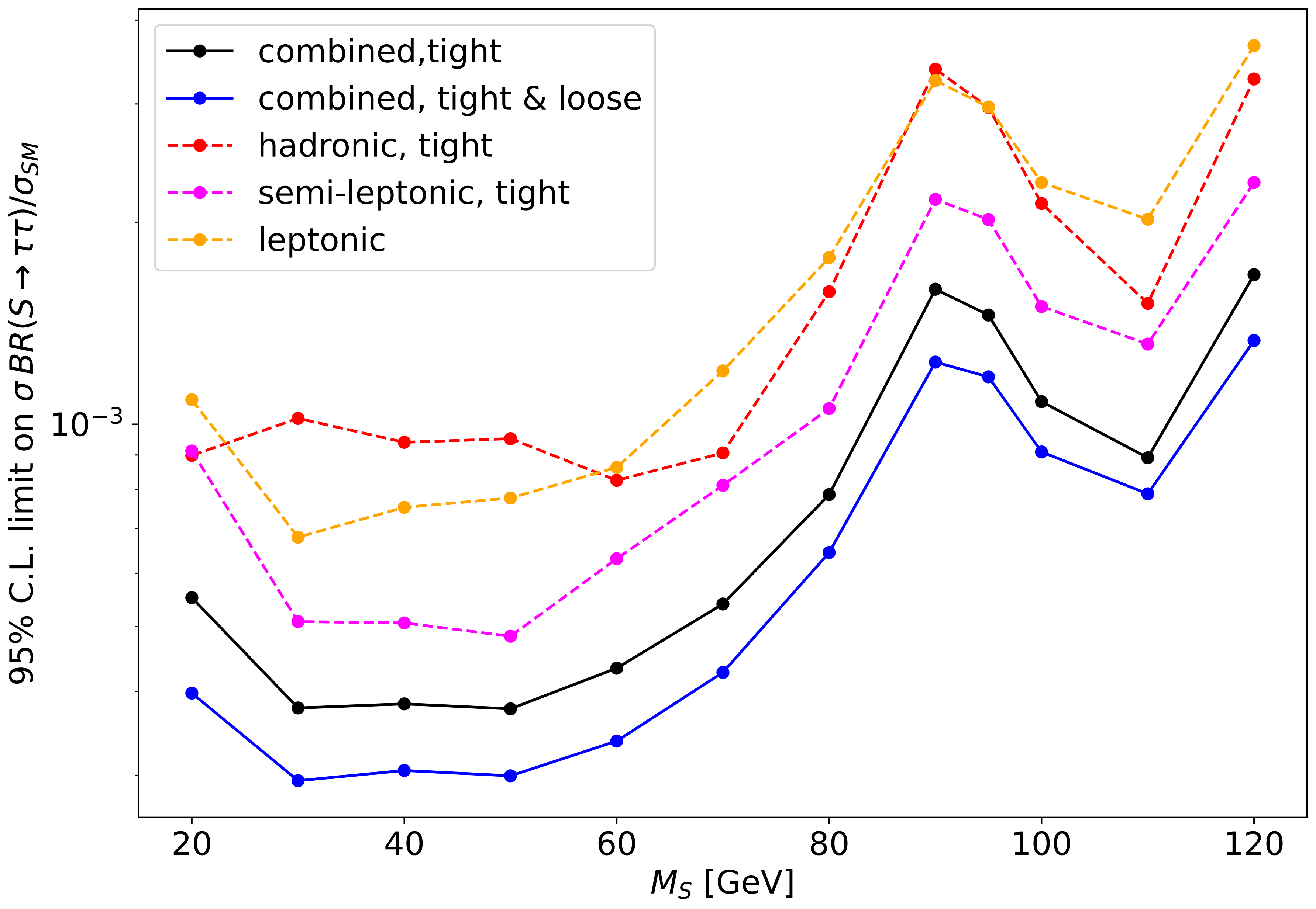
Production of new scalars can be tagged, independent of their decay, based on the recoil mass.

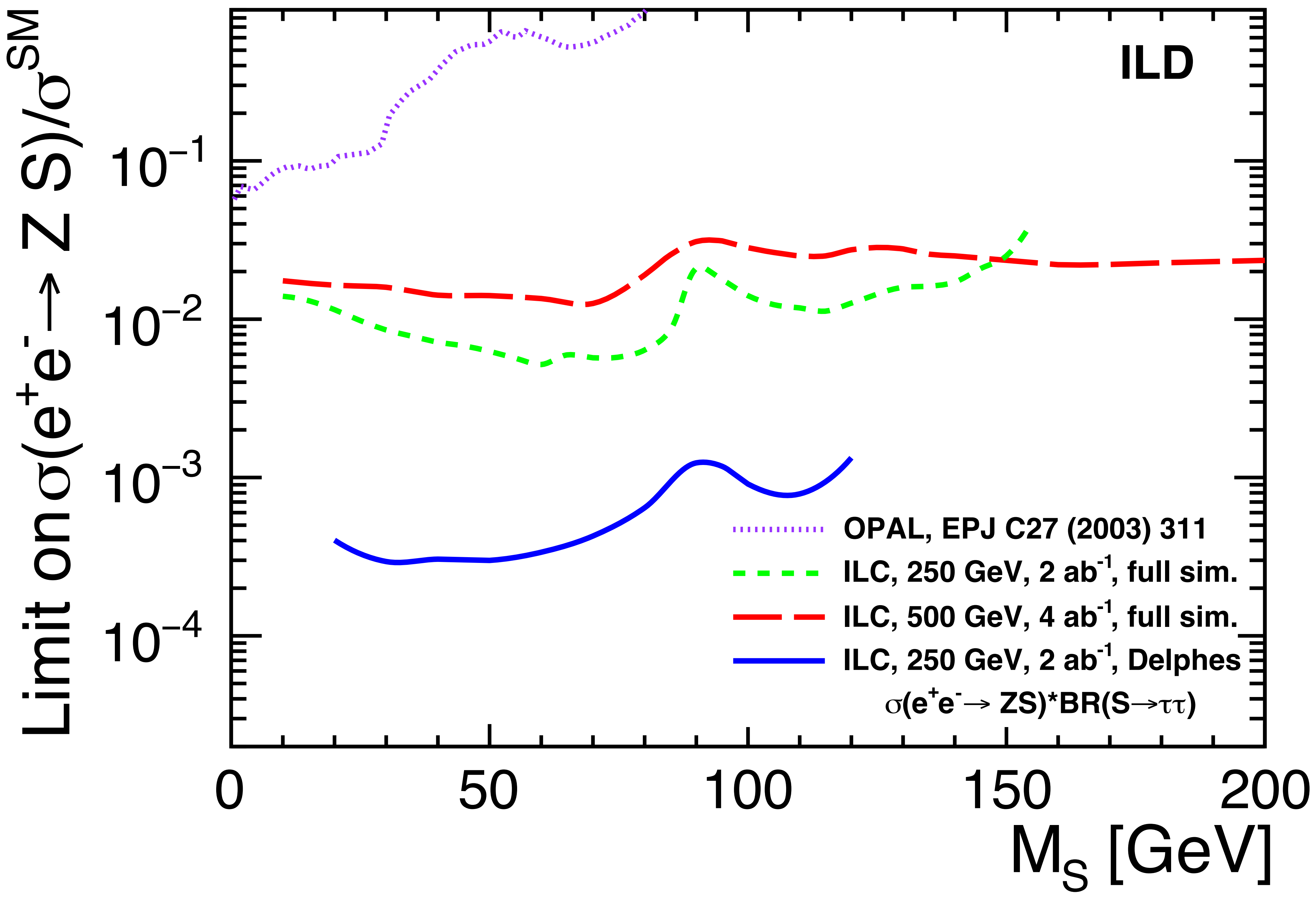
Different scalar decay channels e.g. $b\bar{b}$, $W^{+(*)}W^{-(*)}$, $\tau^+\tau^-$ or invisible should be considered.

Non-standard decays channels of the new scalar can also be looked for.

Cross section limits for $\sigma(e^+e^- \to Z\,S)\cdot BR(S\to\tau\tau)$

for different event categories and combined analysis





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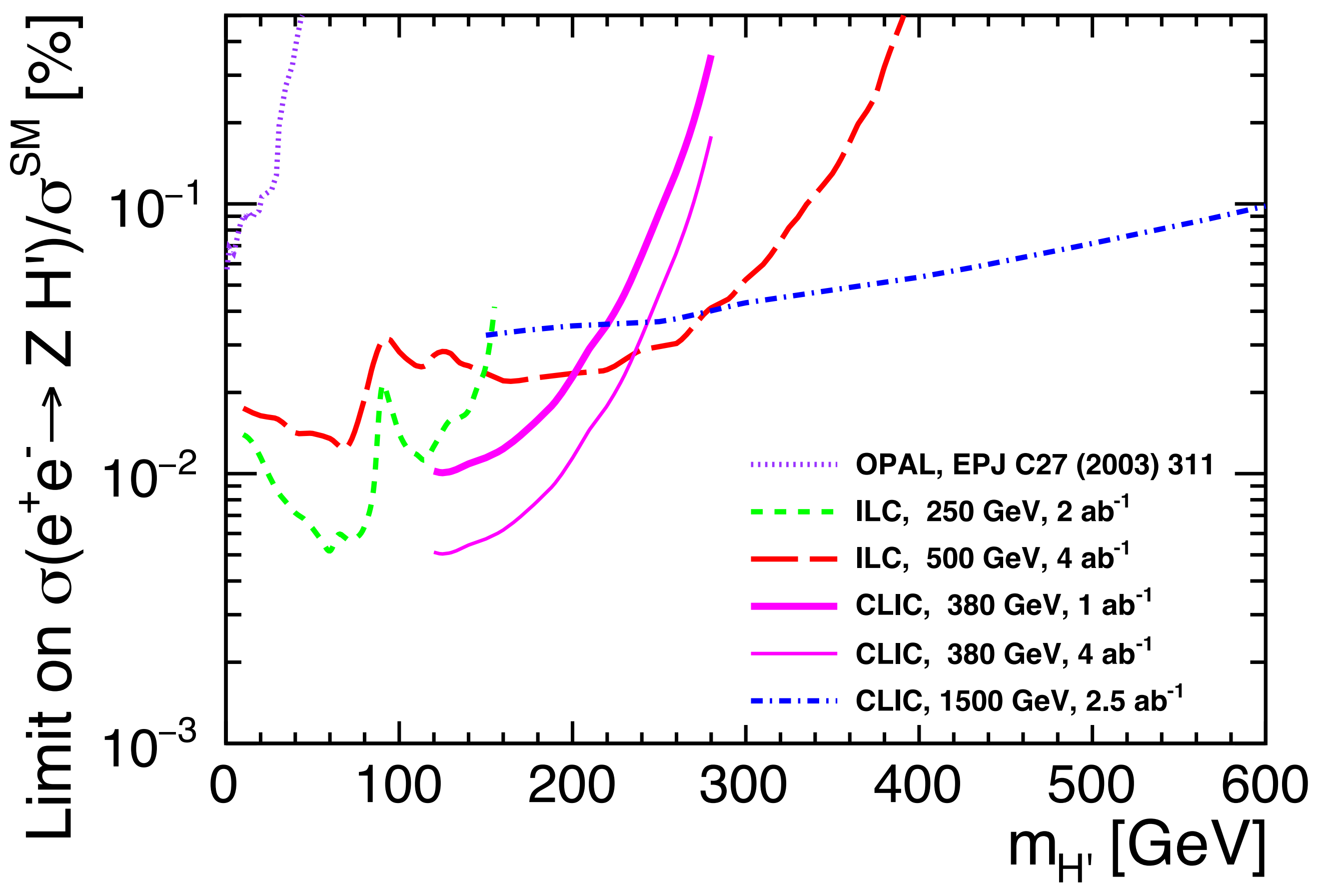
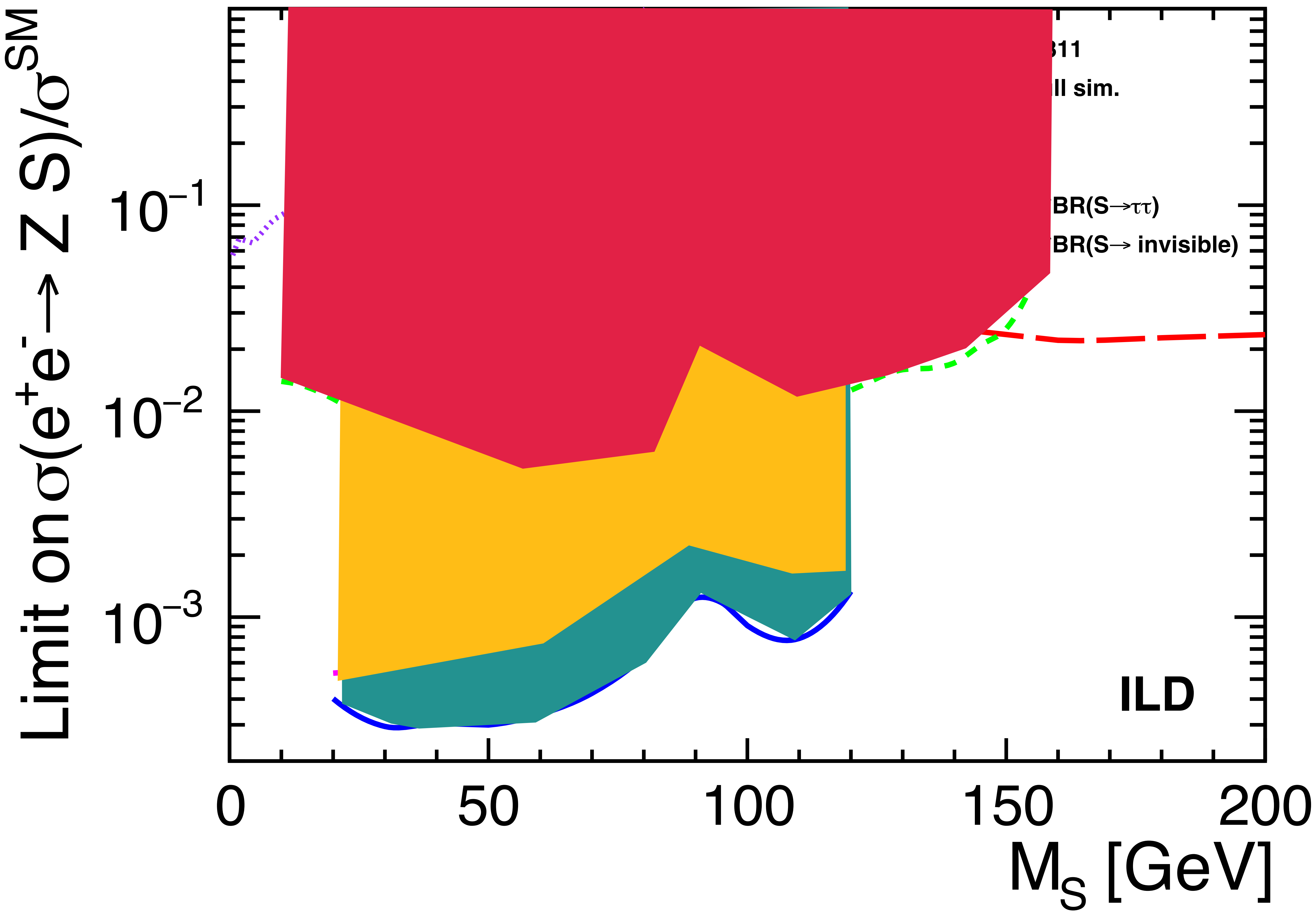
arXiv:2002.06034 arXiv:2107.13903

Expected sensitivities of CLIC @ 380 GeV and 1.5 TeV



compared with decay independent limits from LEP and ILC



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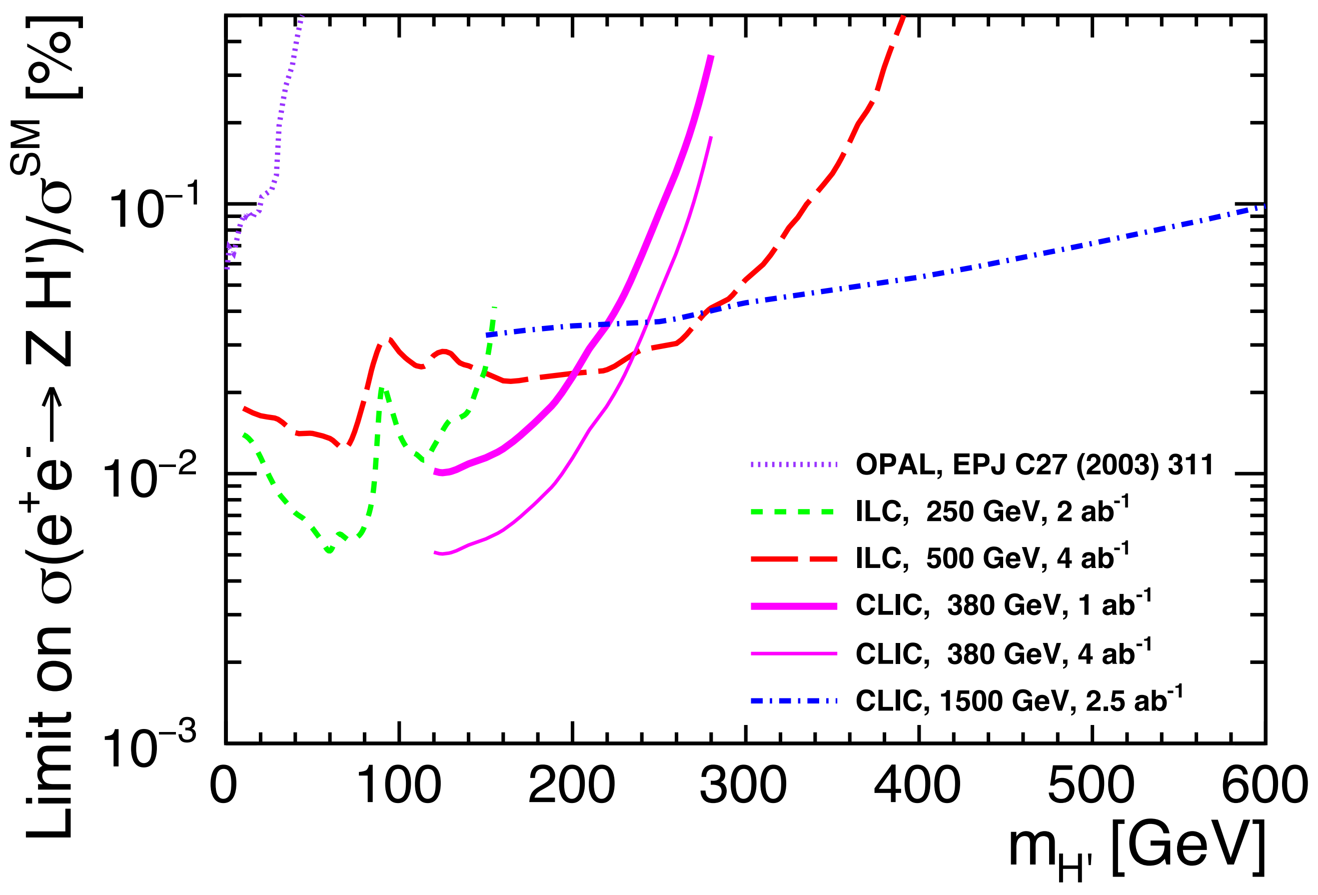

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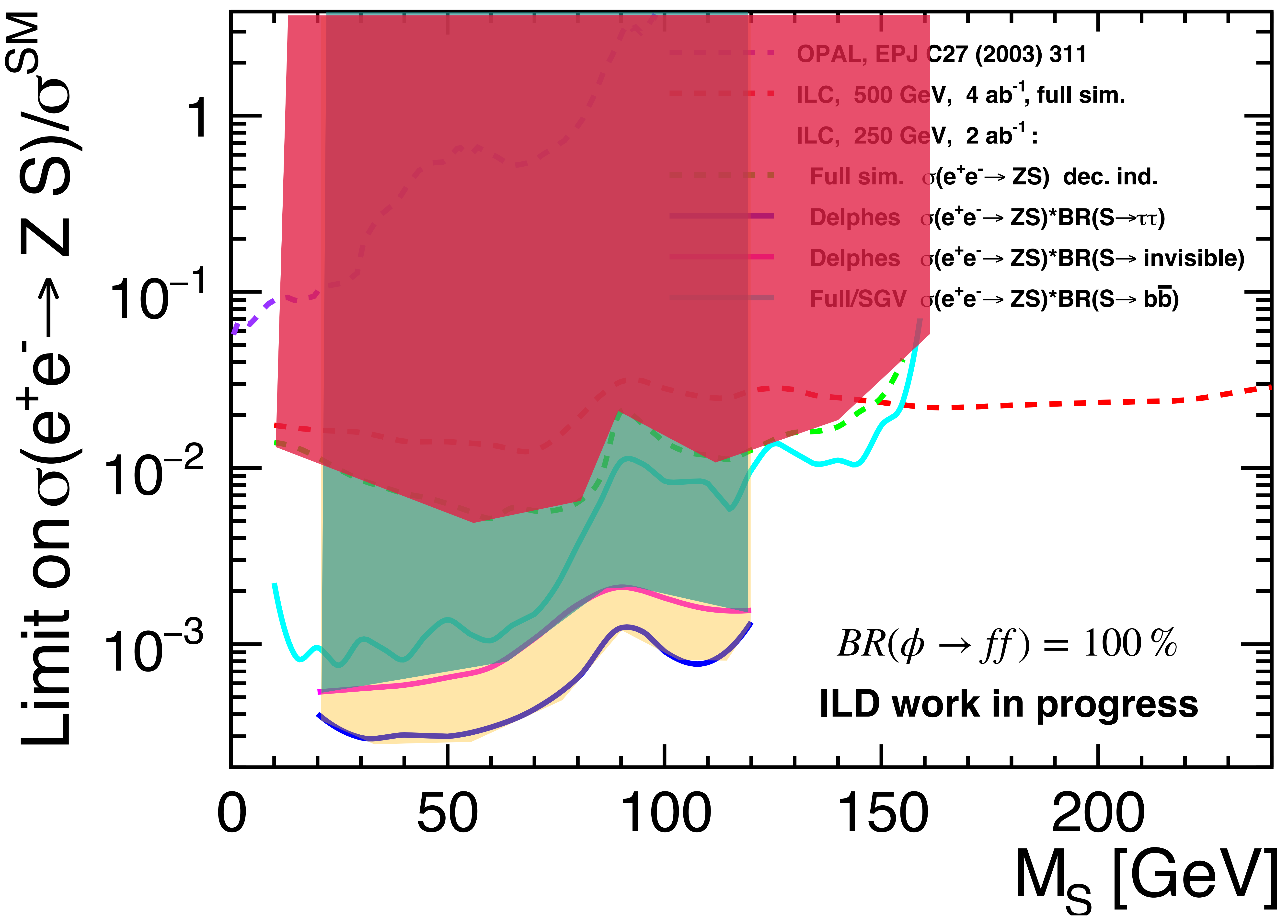

The decay mode independent search

broad sensitivity

Motivation and conditions current studies

Reimplementation of previous analysis with current experimental conditions and full simulation software

Full detector simulation and reconstruction procedures of the ILD at the ILC for $\sqrt{s}$ = 250 GeV

Different Z decays modes want to be covered

Samples:

- Background using new SM 250 GeV samples generated with Whizard v.2.8.5, the SetA beam-spectrum, simulation and reconstruction with the ILD_l5_o2_v02 model, and ILCSoft v02-02-01
- Signal generated with Whizard v.2.8.5, the SetA beam-spectrum, detector simulation done by

Calculation of the limits is going on

Hints of light new particles

requires HTE-level of $h \to \gamma\gamma$

Explanation in 2HDM

Analysis

- Dominant decay modes of $H^{\pm}$: $\tau\nu$, tb
- Considered Benchmark Point:

$$m_H = 152\ \text{GeV}, m_{H\pm} = 130\ \text{GeV}, \alpha - \beta \approx \pi/2$$
$$m_A = 200\ \text{GeV}, \tan\beta = 20, m_{12}^2 = 1100\ \text{GeV}$$

- $\text{Br}(H \to \gamma\gamma)$ required at the percent level
- Possible in Aligned 2HDM without Z_2 symmetry