Highlights of

Searches and Flavor studies for the “ECFA HET Factory study”

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FLAV: Stephane Monteil, David Marzocca, Pablo Goldenzweig

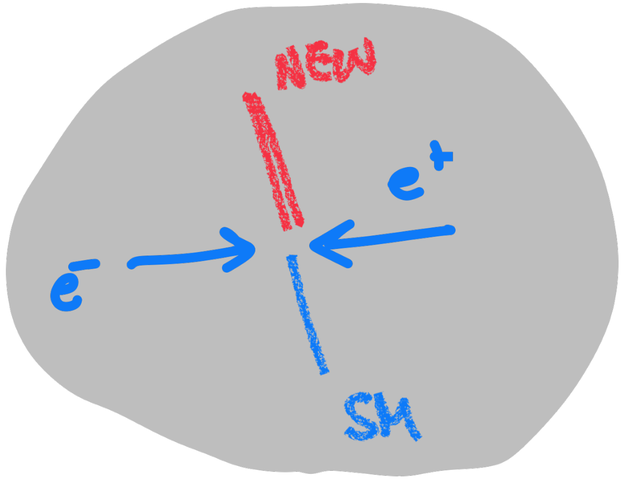
THX: Giuseppe Gagliardi, Antonio Passeri, Francesco Sanfilippo

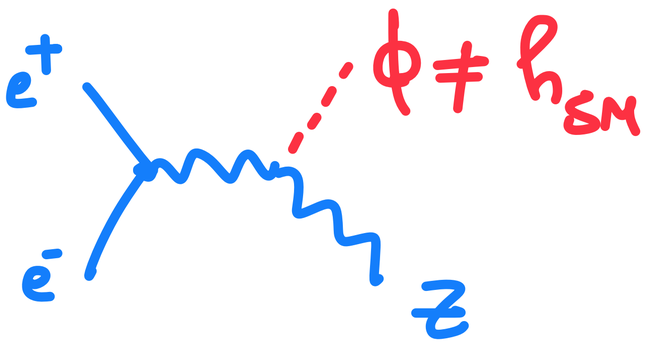
115th ECFA meeting - https://indico.cern.ch/event/1361604/ - Nov. 15th 2024

Outline

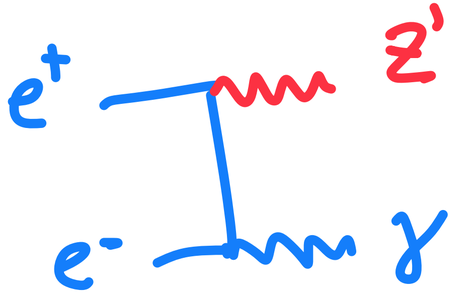
SRCH stands for "Searches"

- Group tasked to study potential for direct discovery of new physics at the HTE factory.

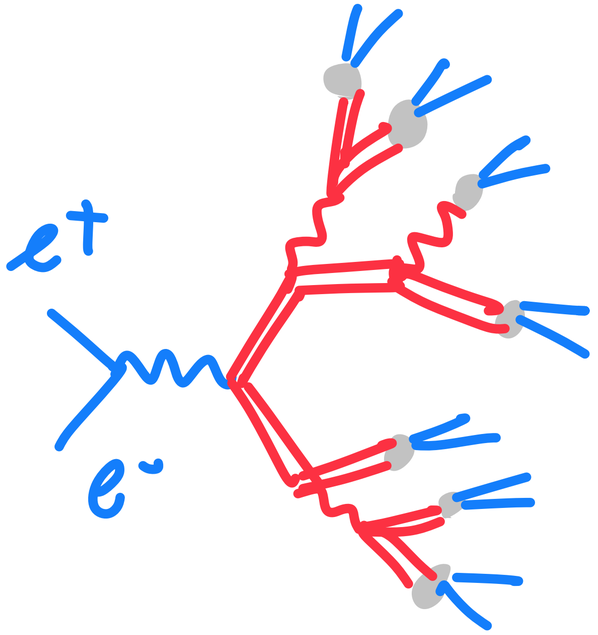




new scalars



new gauge bosons

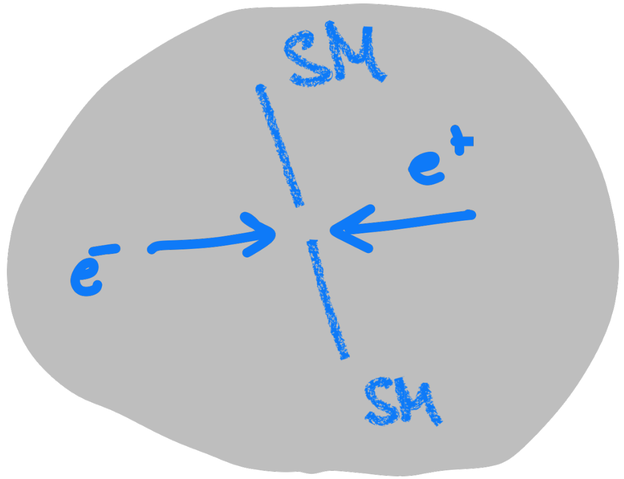


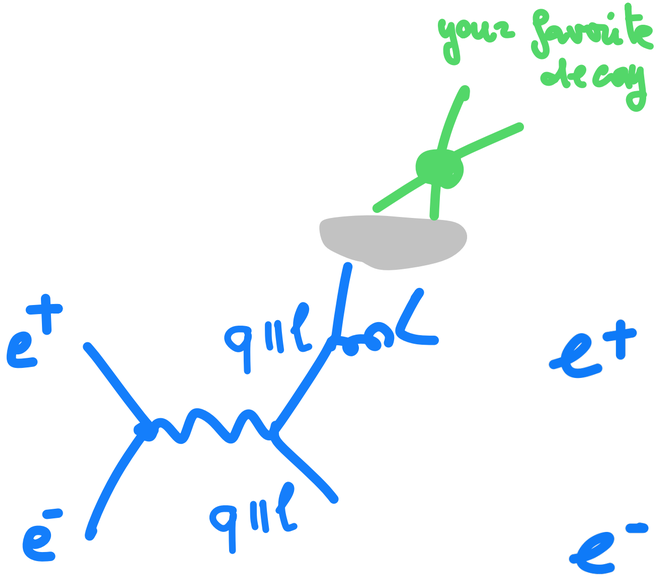
new (hidden) sector of particles!

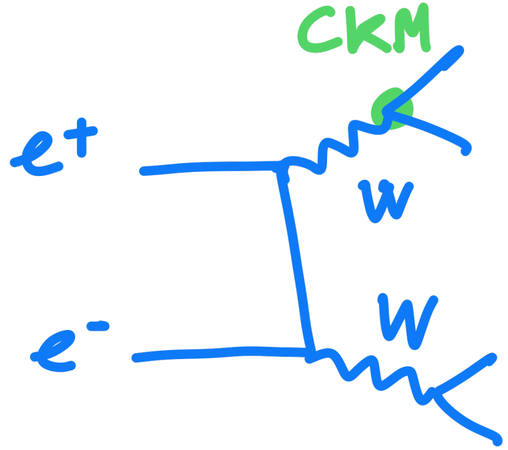
Outline

FLAV stands for “Flavor”

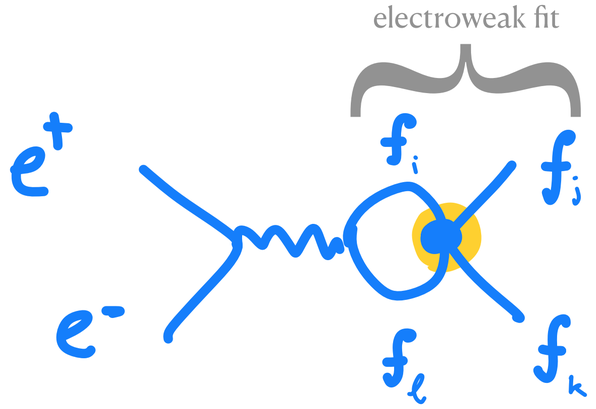
- Group tasked to study potential for direct and indirect observation flavor related observables at the HTE factory.

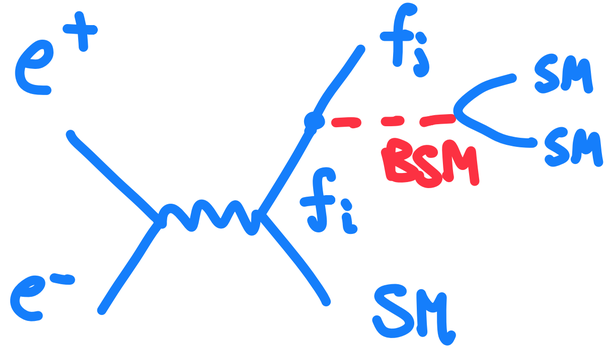






new decay modes and new probes





new contact interactions and new flavored particles

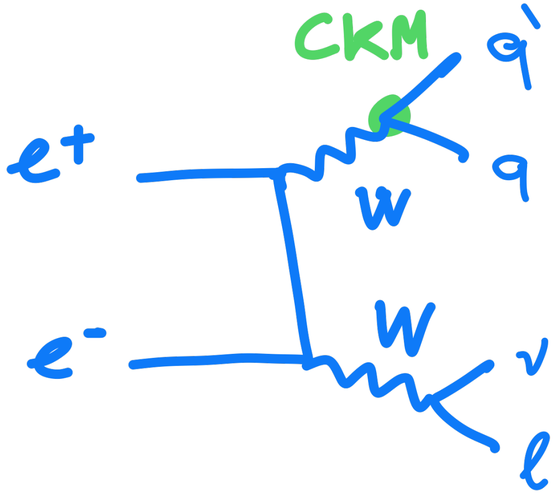
in the Report

HTE factory Flavor topics

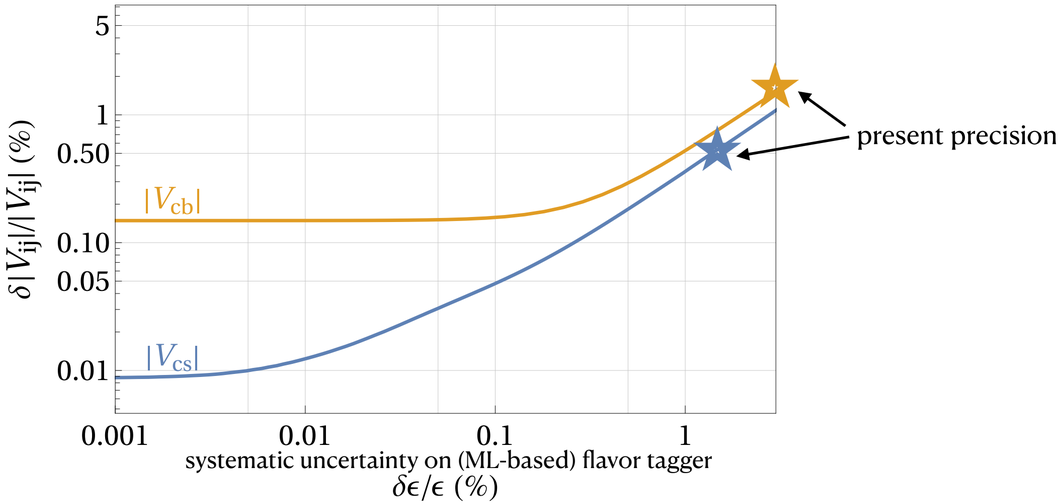
- $Z \to f\bar{f}$ source of boosted flavored objects, inclusive production of hadronic species ($\neq \Upsilon(4S)$) with low background (≠LHC*b*)
- *B* meson studies (some stat-limited from Belle II, some not accessible at LHC*b*)
- also *D* and τ (some in backup)
- new approach to CKM: direct observation of $W \to qq'$ (V_{cb}, V_{cs}) and $t \to Ws$ (V_{ts})
- several detector performances investigated (e.g. flavor tagging, particle ID, ...)

Flavor

CKM from W decays



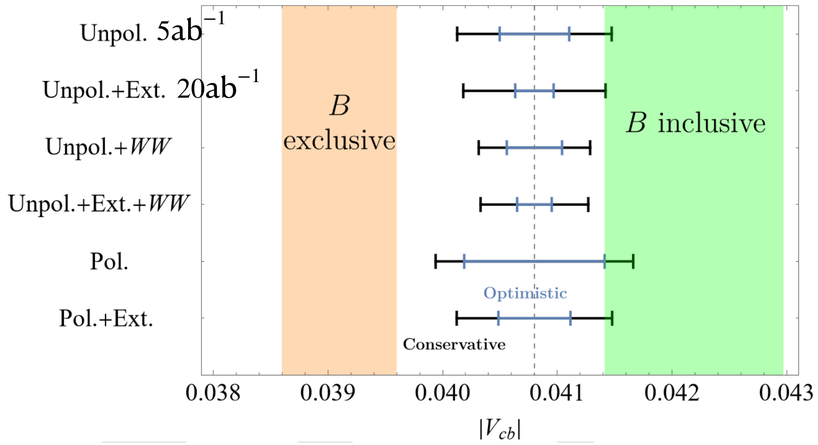
result depends crucially flavor tagging performance (especially systematic uncertainty)

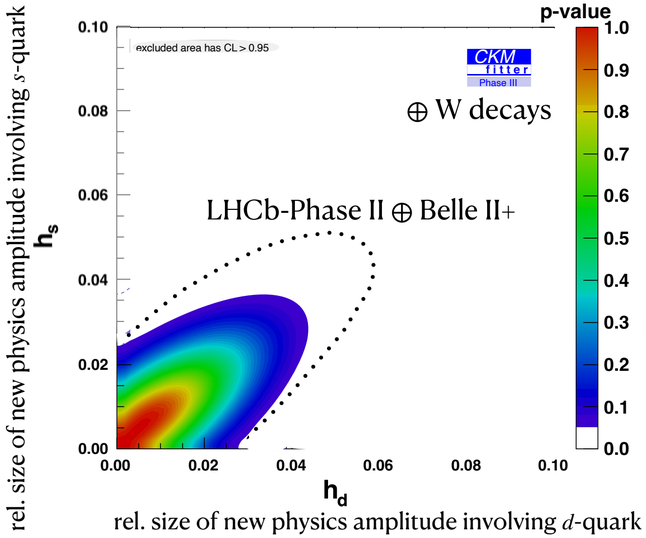


Independent determination from that from (currently in tension) B decays

important to have a Z pole run to calibrate the taggers with high-precision ~0.1%

Determination without lattice inputs



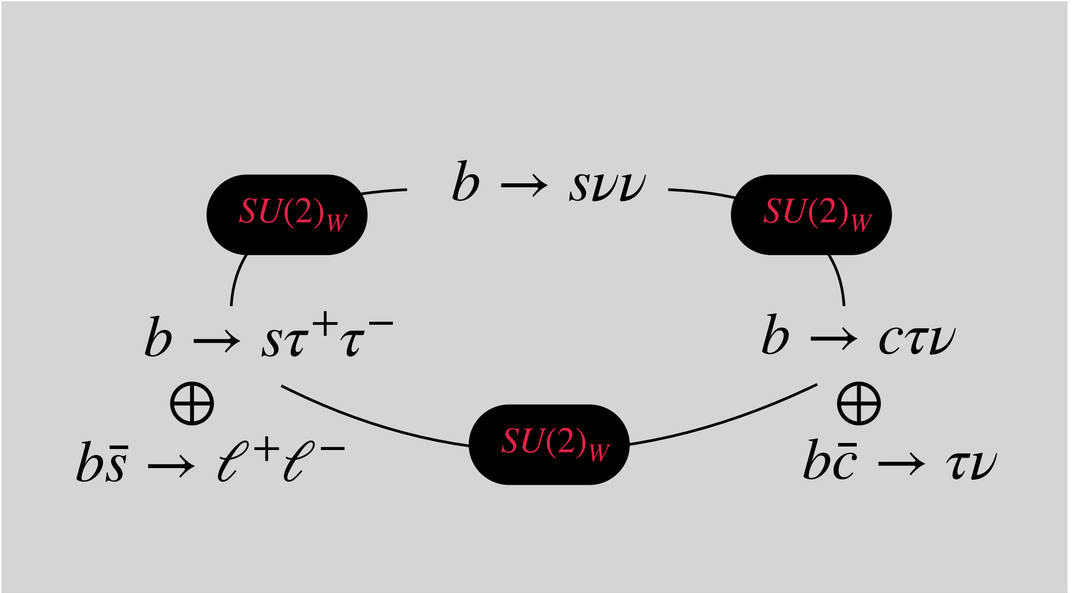


B meson studies

Attribute	$\Upsilon(4S)$	pp	Z^0
All hadron species		✓	✓
High boost		✓	✓
Enormous production cross-section		✓	
Negligible trigger losses	✓		✓
Low backgrounds	✓		✓
Initial energy constraint	✓		(✓)

improvements expected on the on a large set of flavor observables

transitions involving 3rd matter



$b \to s\nu\nu$ first indications in 2023 at Belle II

$B_s^0 \to \phi\nu\nu$

$B^0 \to K^*\nu\nu$

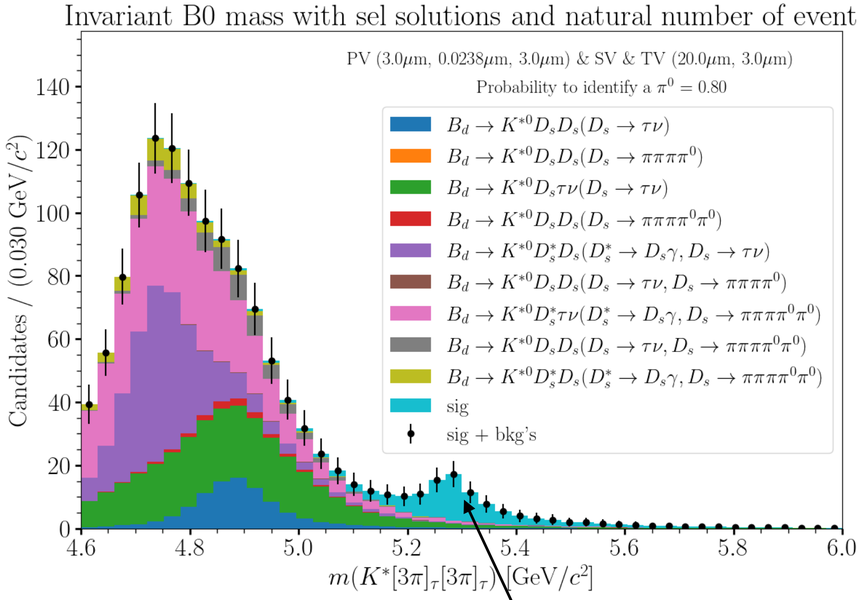
$B^0 \to K_S\nu\nu$

sensitivity at 1.2% on $BR \sim 10^{-5}$

important to separate K from π

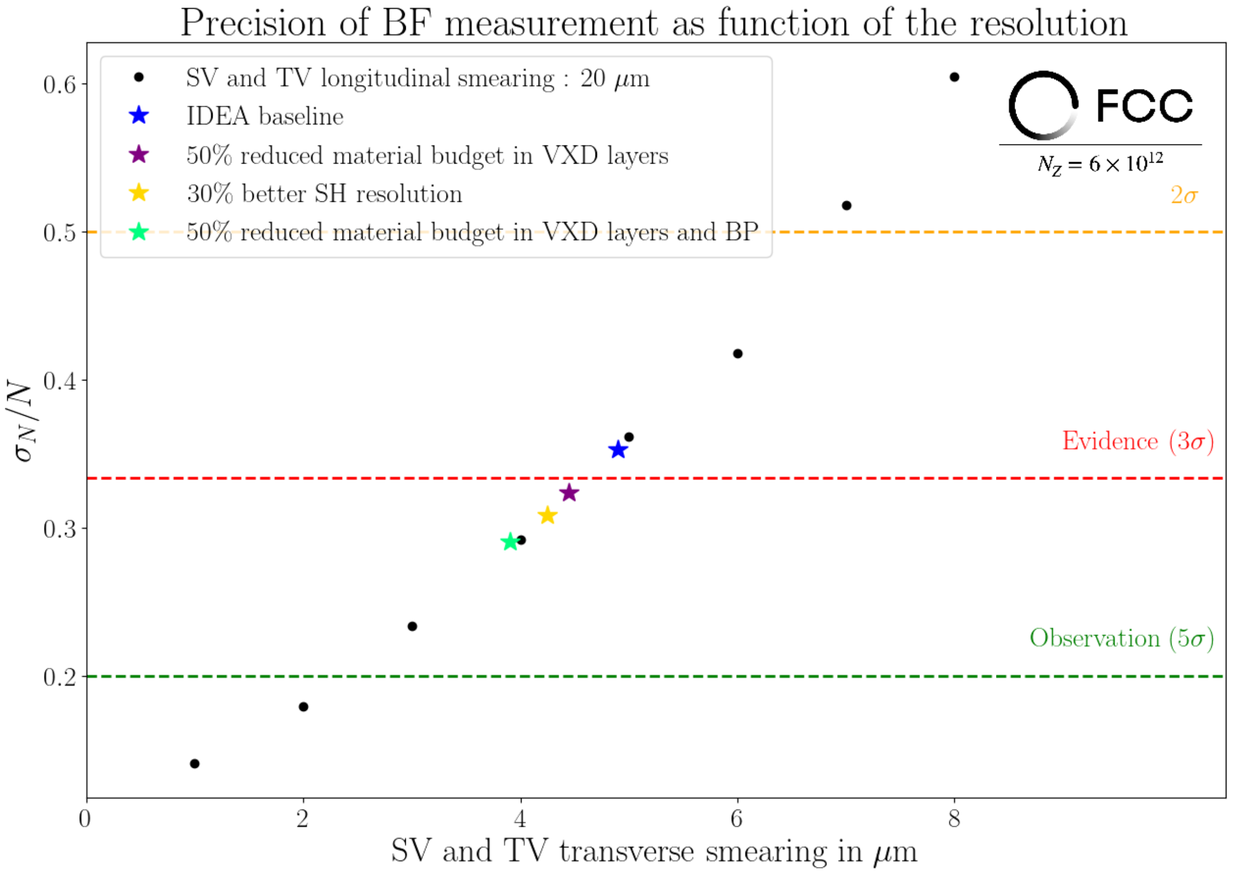
$B^0 \to K^{0*}\tau^+\tau^- \to (K\pi)(3\pi)_\tau(3\pi)_\tau$

whole final state made of charged tracks



tiny signal detection enable by large statistics of HTE factory

benchmark for the vertex detector performance



measurement limited by material budget (especially around the beam pipe)

in the Report

HTE factory Searches topics

new physics with elusive signal can escape at HL-LHC (hadronic, too light, ...)

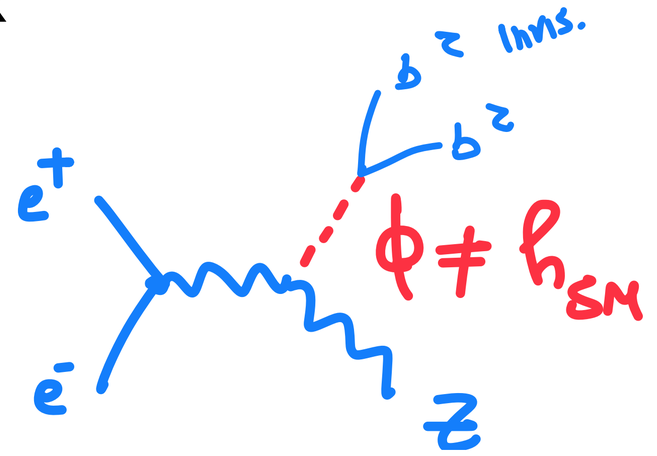
- new scalars
- new gauge bosons
- new electroweak states (including SUSY)
- dark matter
- exotic signals from (hidden/dark) sectors
- “portals” to new physics

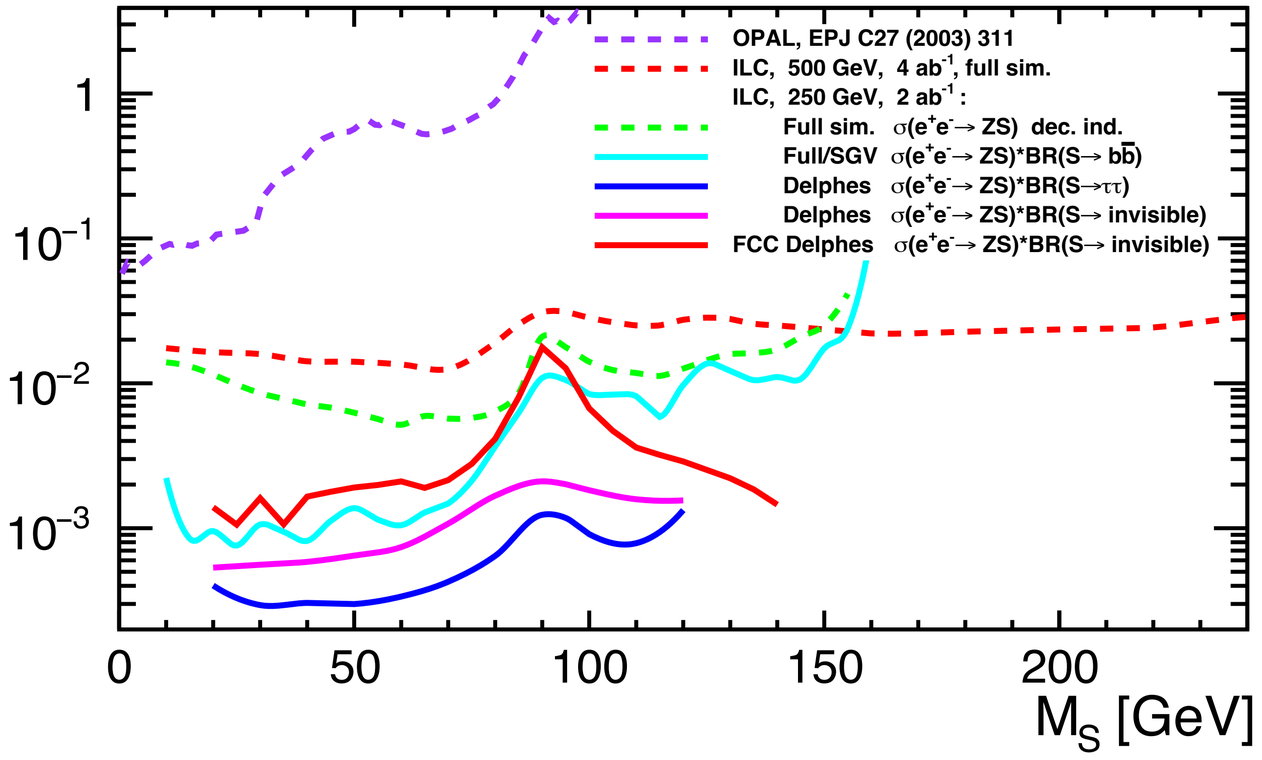
New scalars

New scalars

related to Higgs and electroweak

- The SM Higgs boson may not be the only one!
- Difficult to imagine new scalars to not be related to the SM Higgs or electroweak boson or both
- Lots of possible scenarios in which HTE factory can do very well, expanding significantly searches at the HL-LHC
  - new scalar heavier than 125 GeV
  - new scalar lighter than 125 GeV





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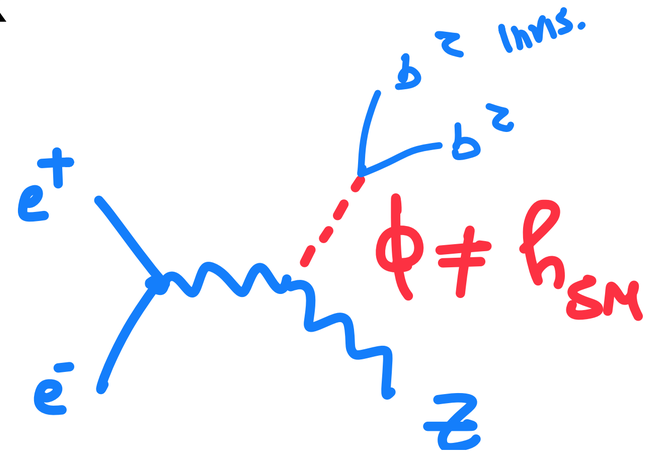

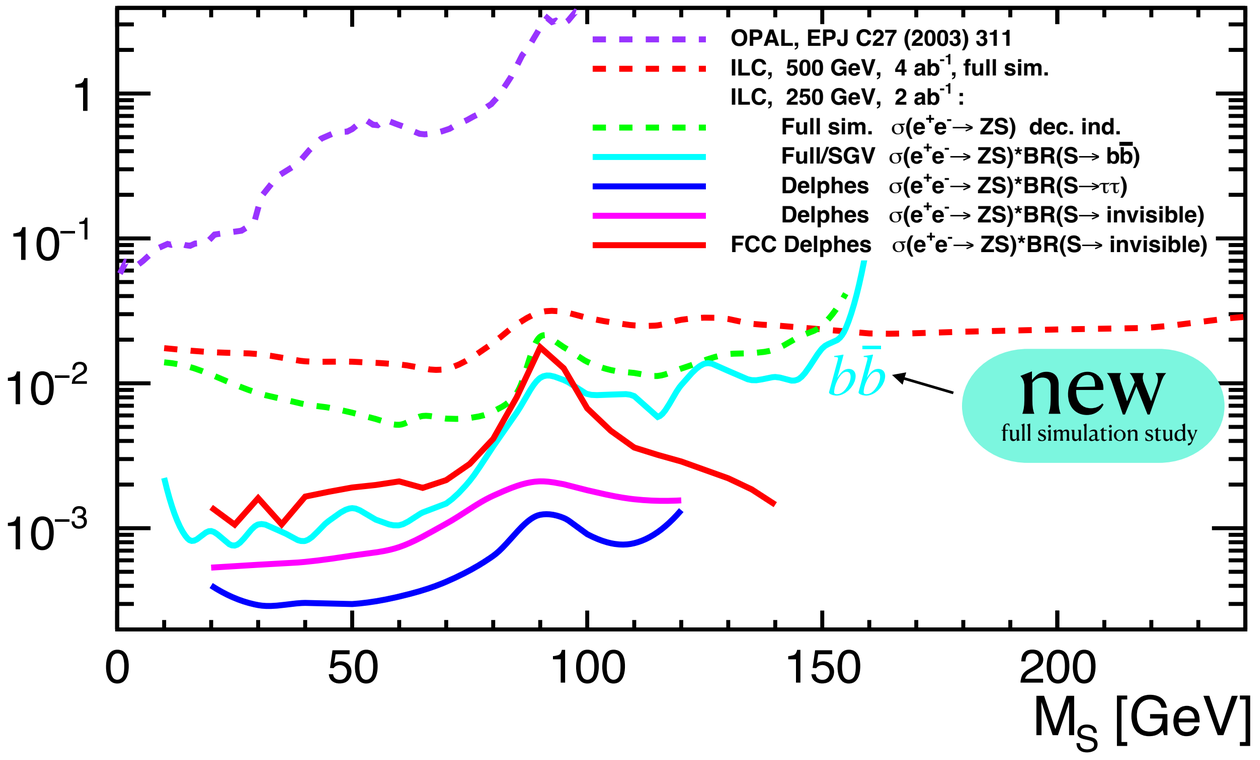

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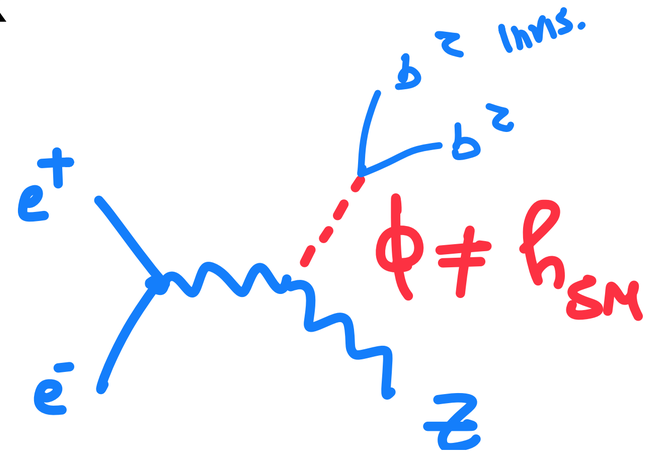

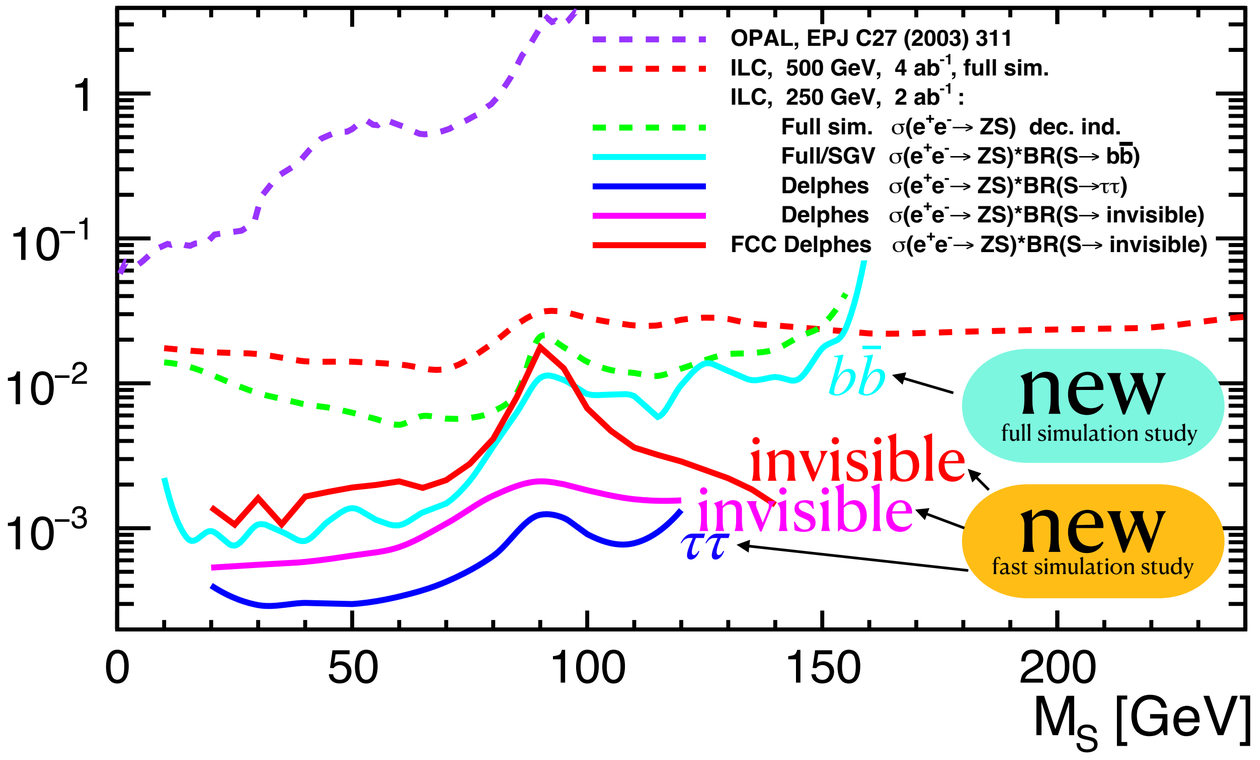

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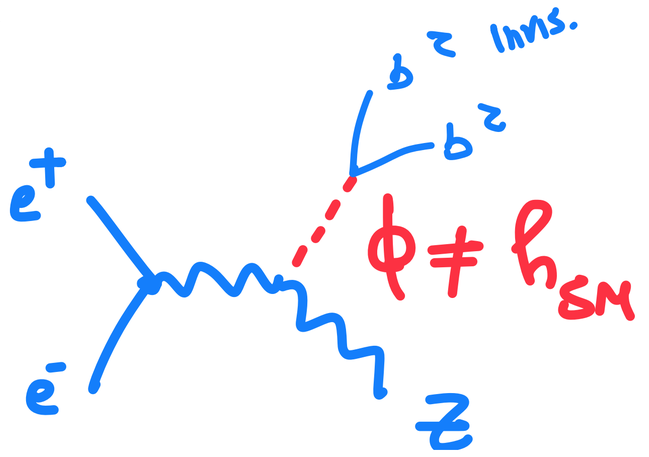

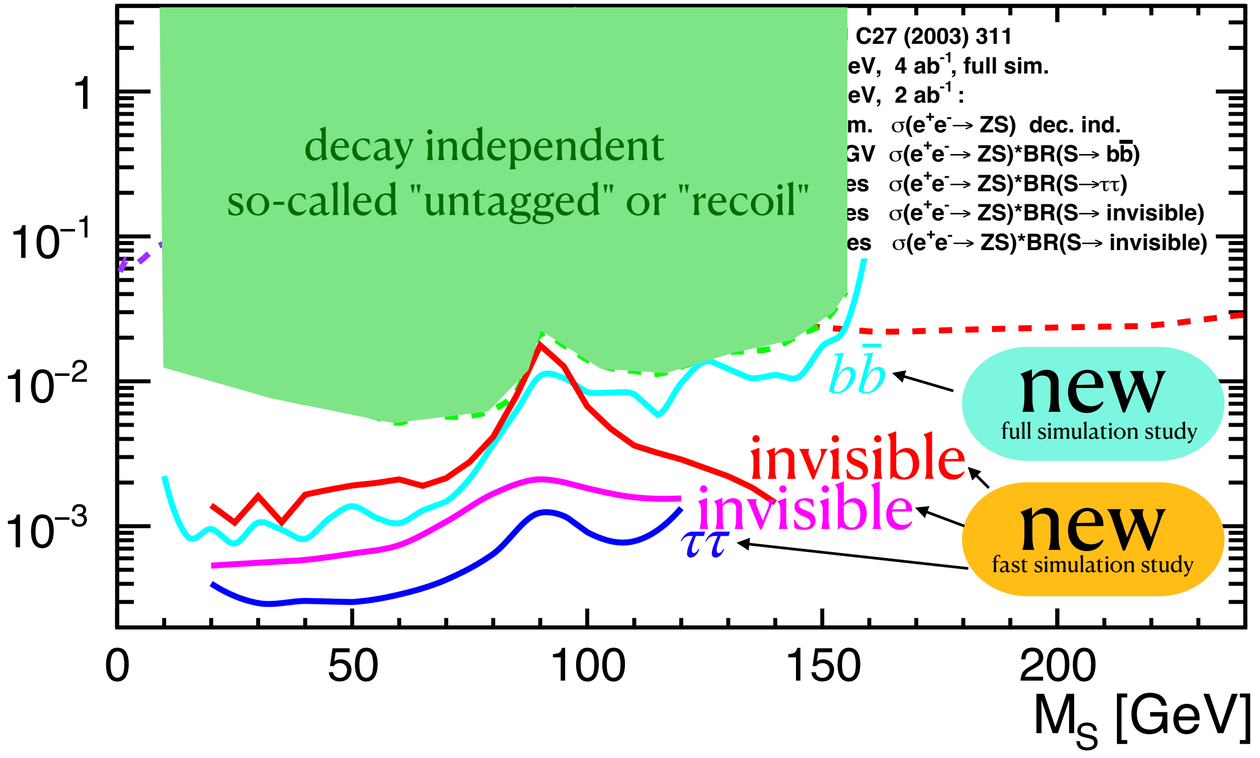

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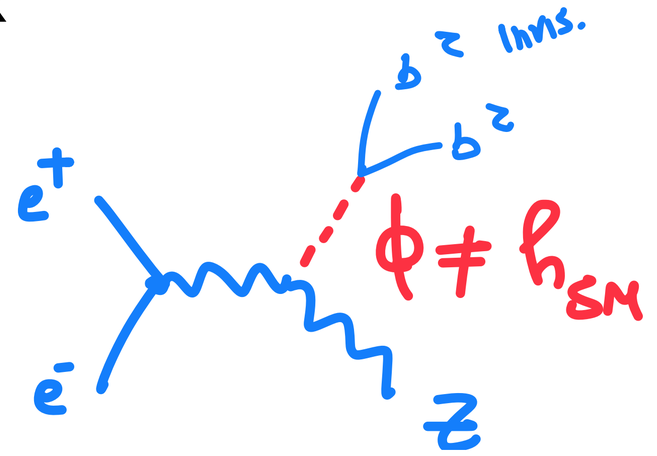

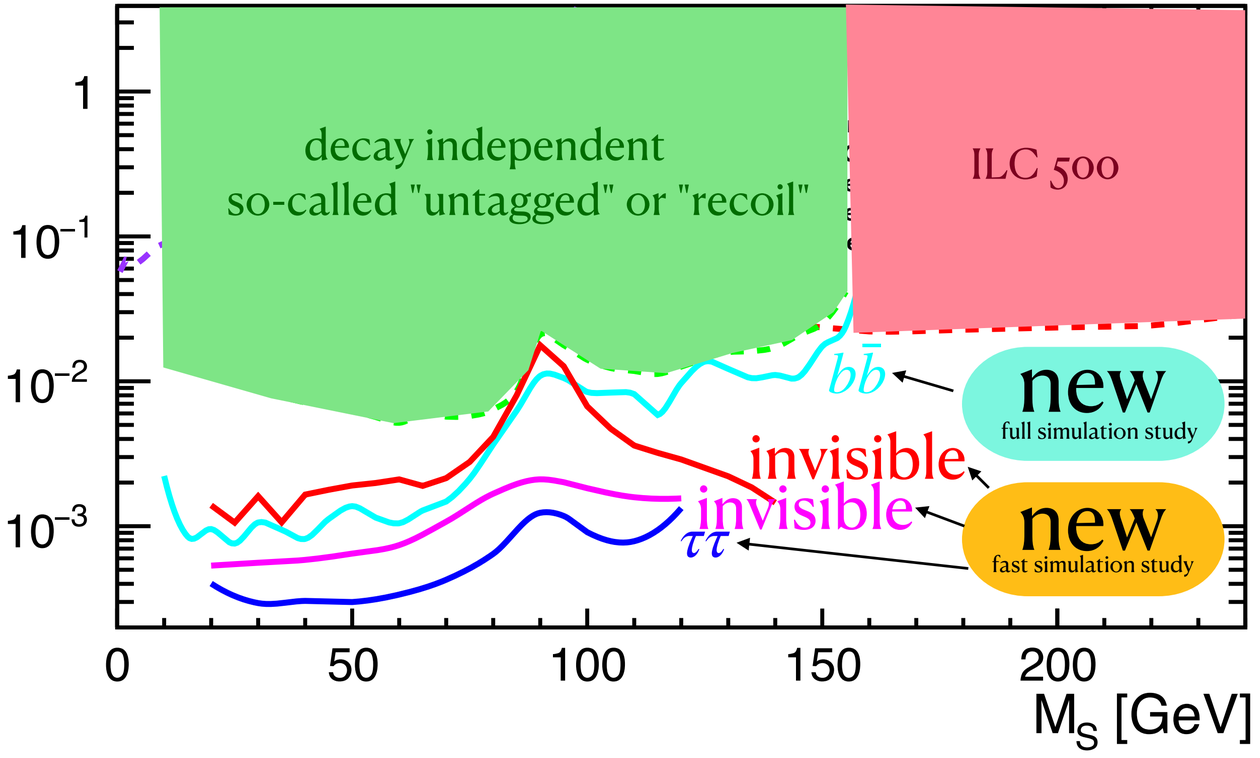

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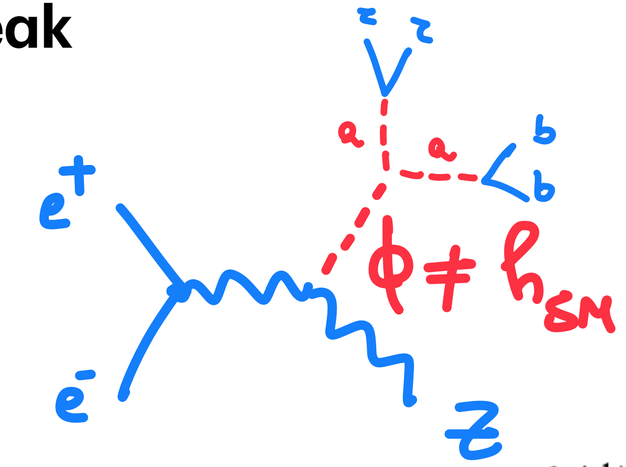
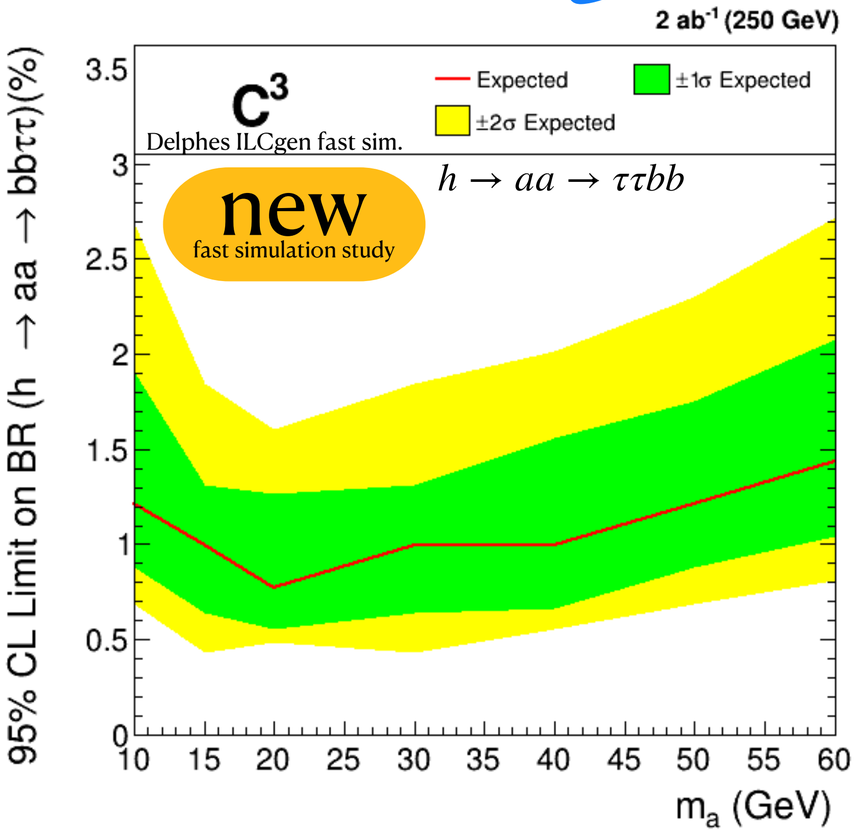
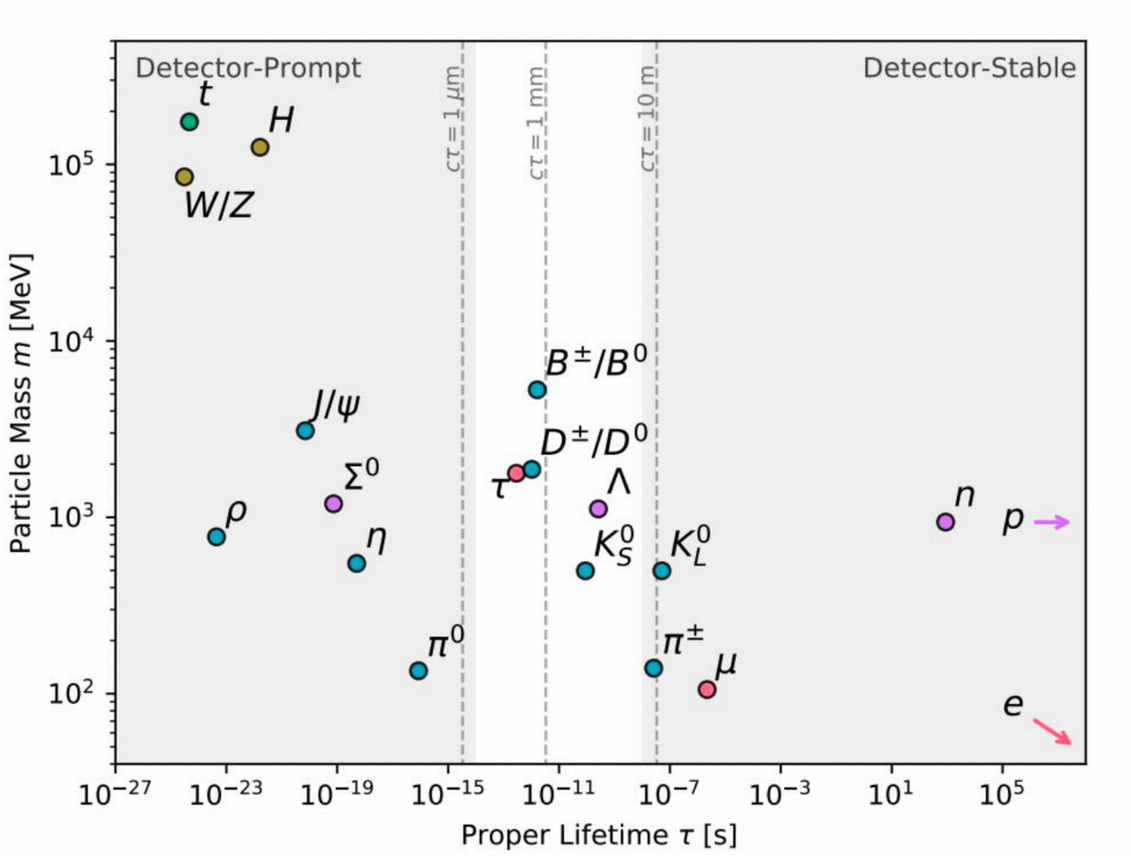




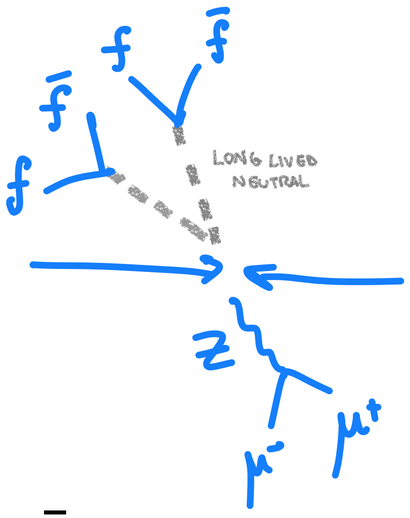
Long Lived Particles

New phenomena with non-prompt signatures

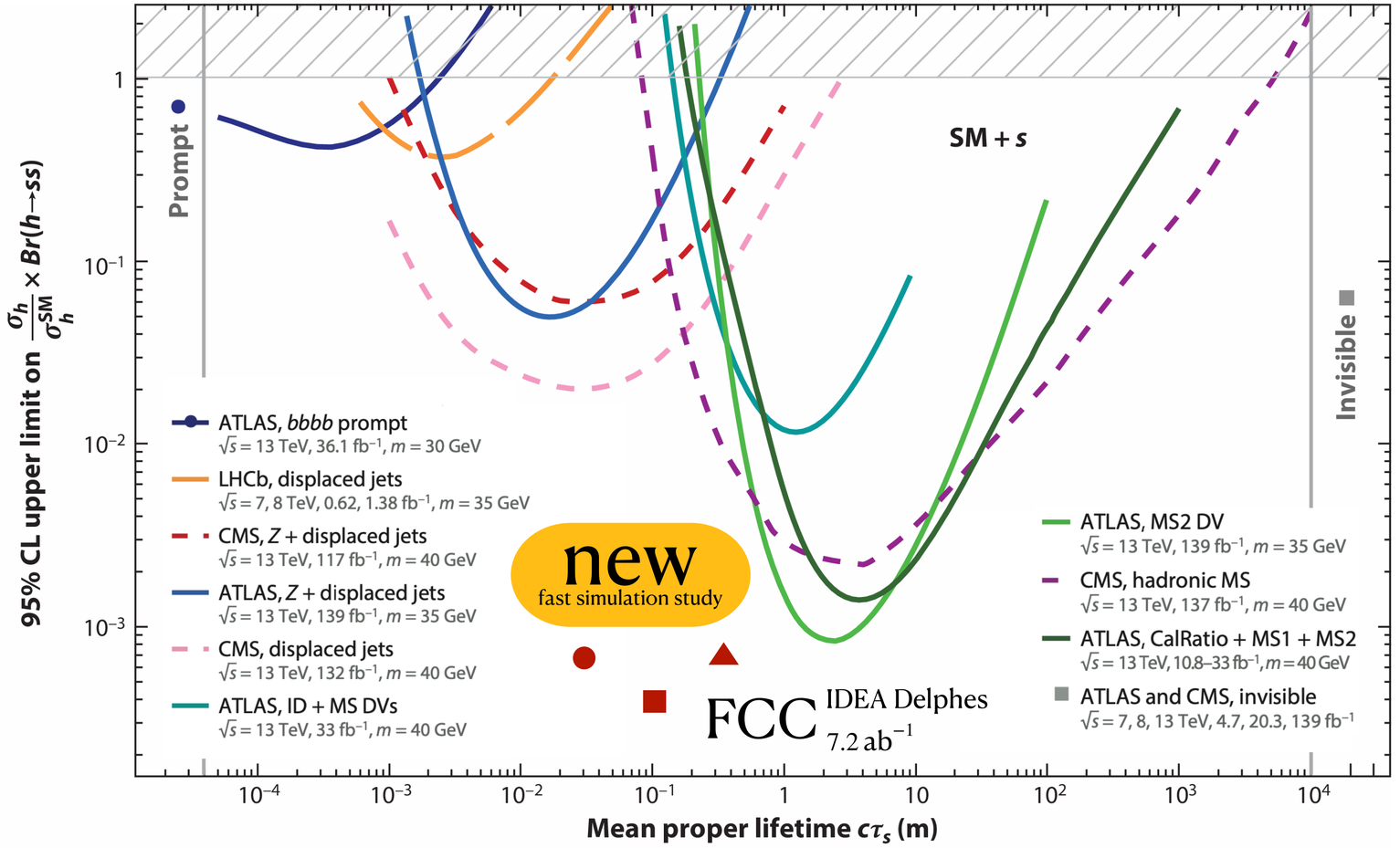
- Non-prompt happens in the SM quite a lot! Also in new physics?
- Significant benchmarks for detector design (hermetic, dE/dx, ToF, vertex, timing ...) while still on the design board!
- Lots of possible scenarios in which HTE factory can do very well, expanding significantly searches at the HL-LHC



$e^+e^- \to Zh \to \ell\ell + SS$

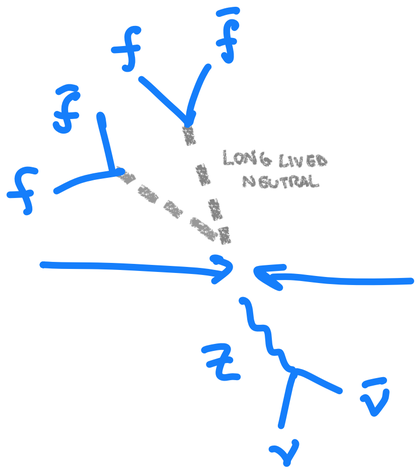


- $S \to f\bar{f}$ via Higgs-S mixing
- Displaced vertex counting
- more Z decay modes can be added



- ● m_S=20 GeV, sinθ=3·10^{-6} Event yield: 3.3
- ■ m_S=50 GeV, sinθ=1·10^{-7} Event yield: 5.6
- ▲ m_S=20 GeV, sinθ=1·10^{-6} Event yield: 10.7

$e^+e^- \to Zh \to \nu\nu + SS$



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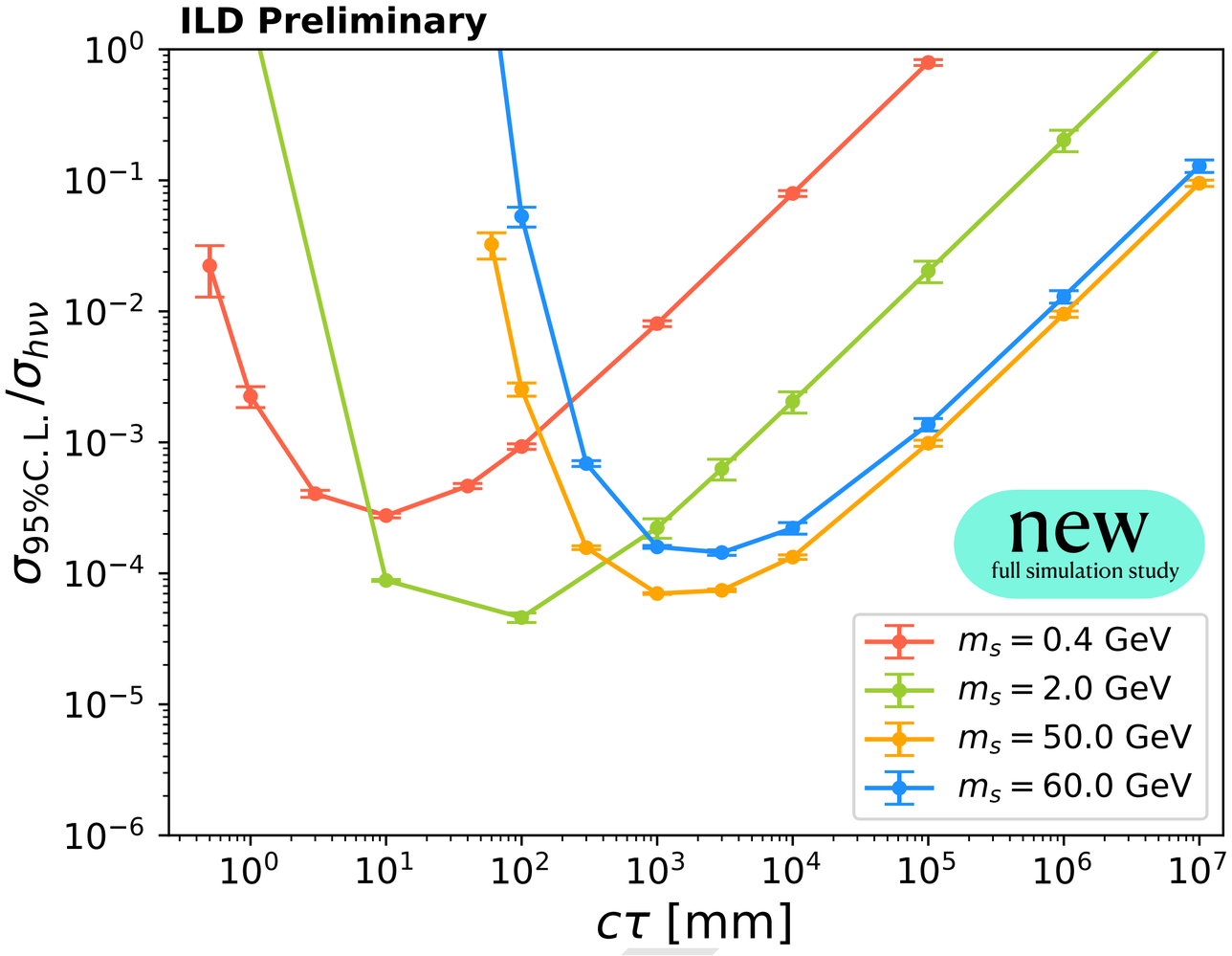
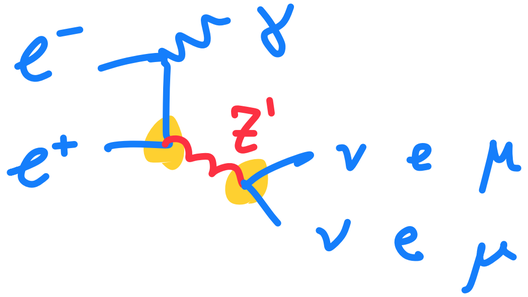
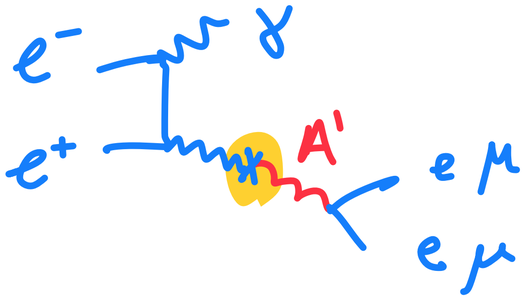


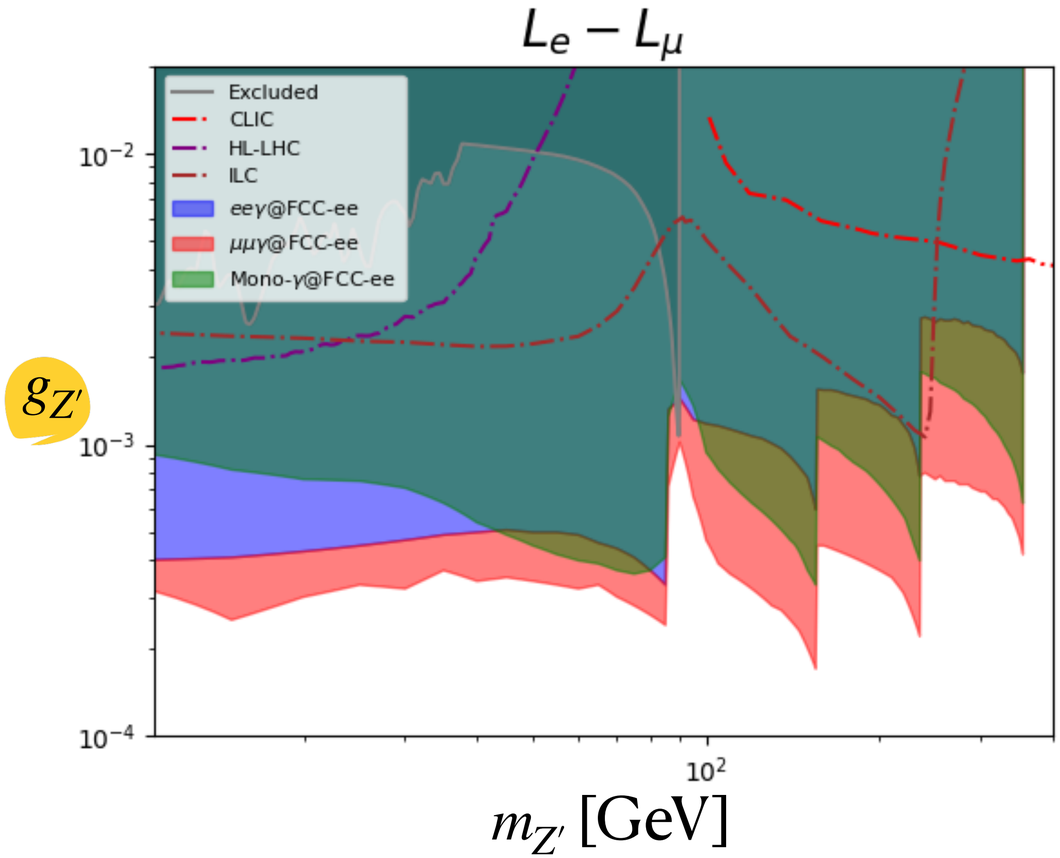
New Gauge Bosons

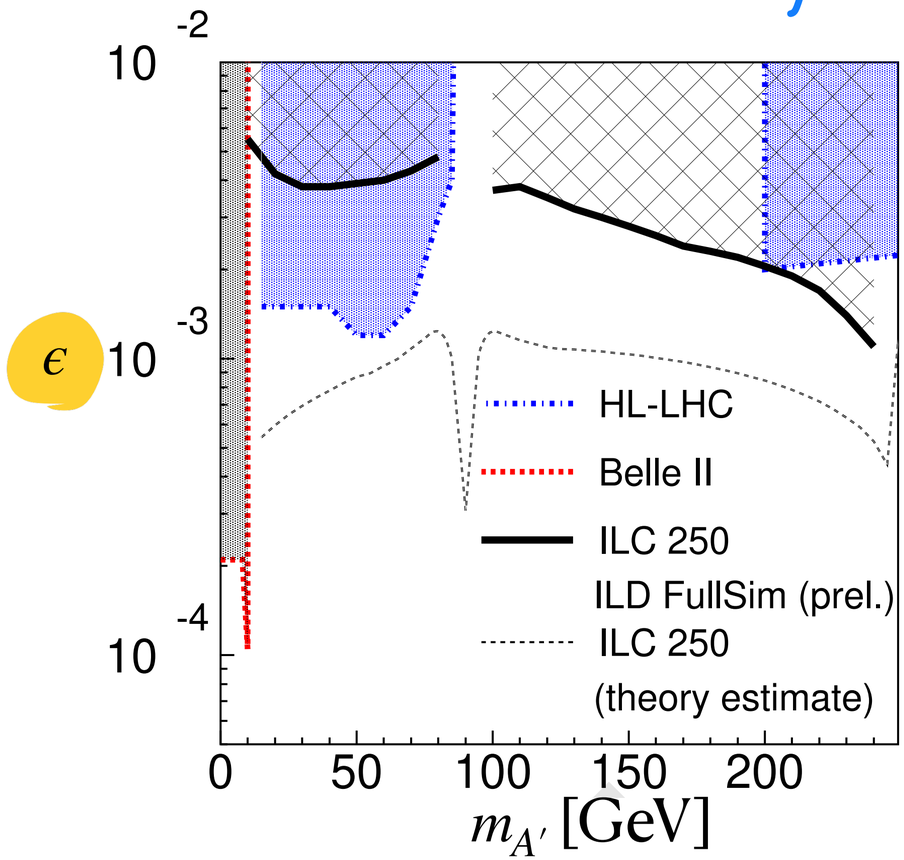
Gauge bosons

gauged $L_e - L_\mu$ and photon-new gauge boson mixing models









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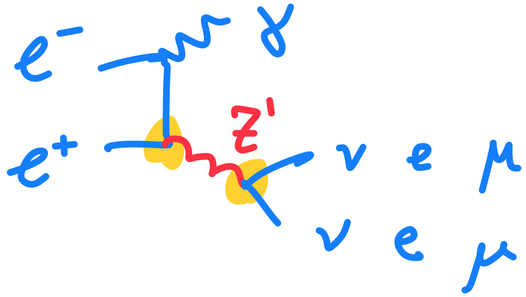

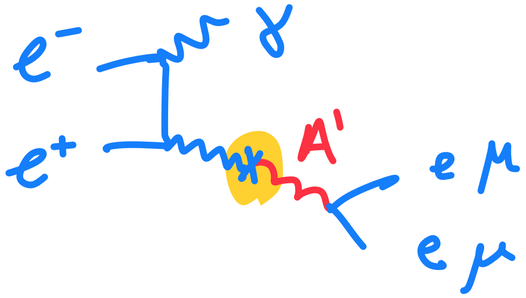

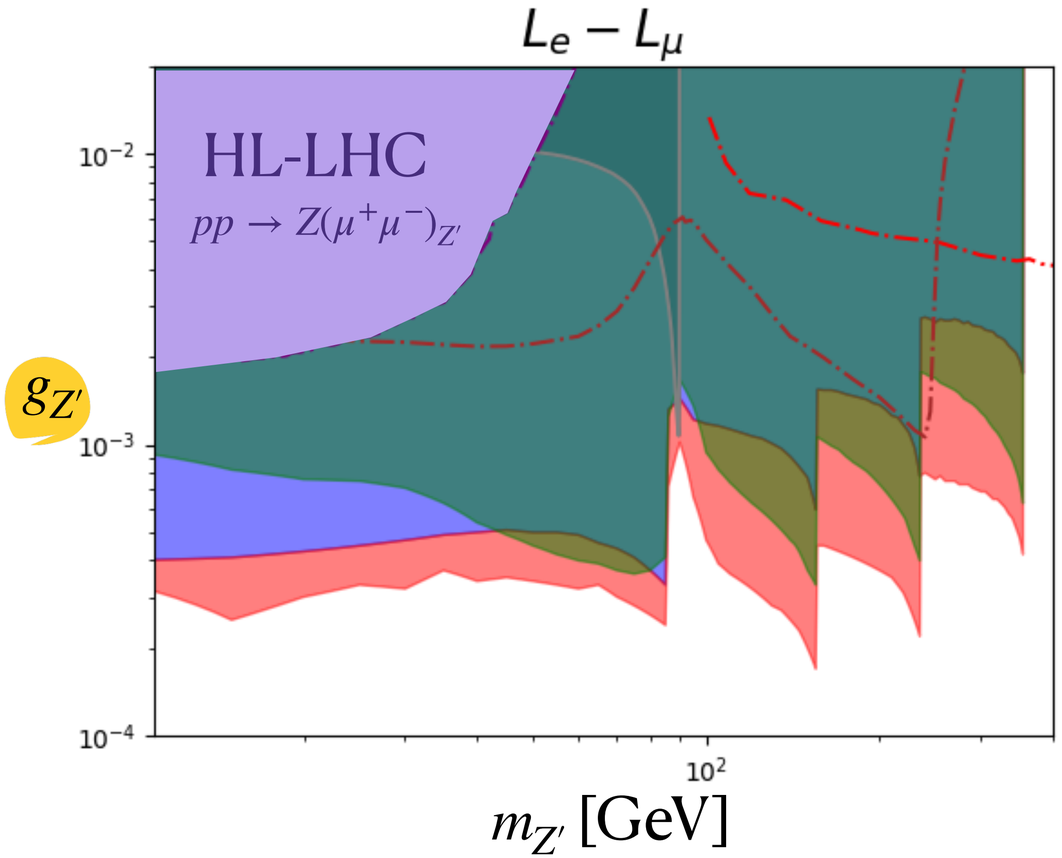

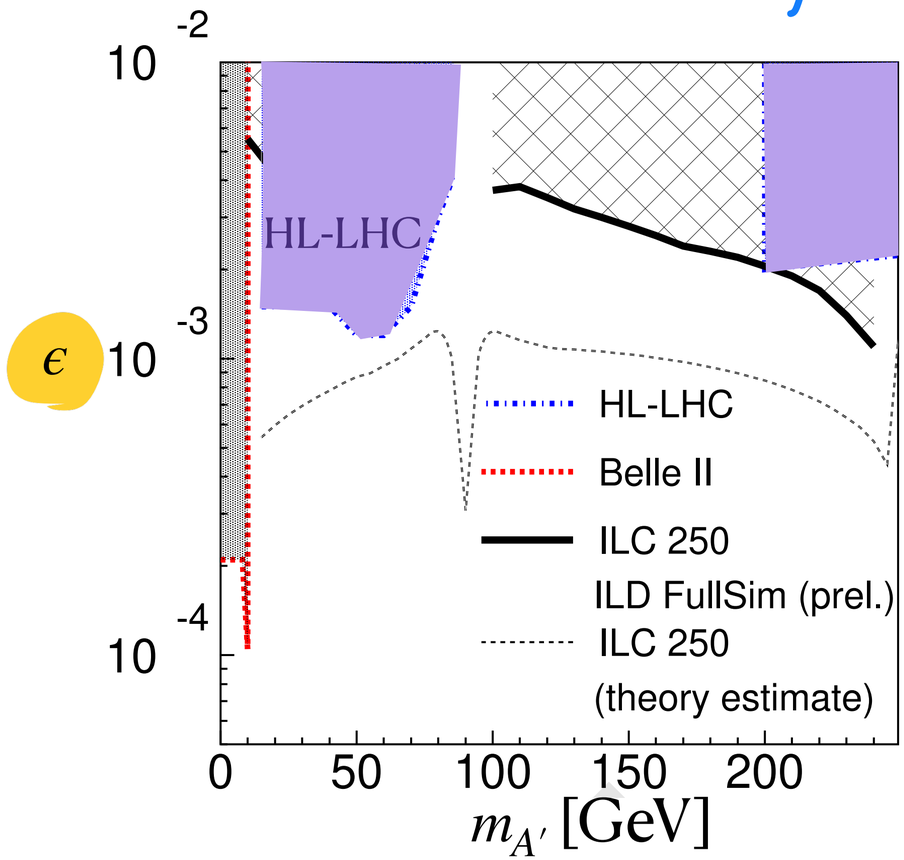

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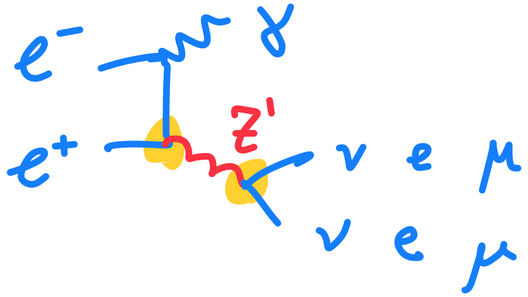

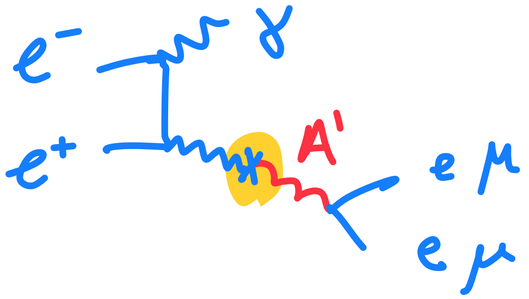

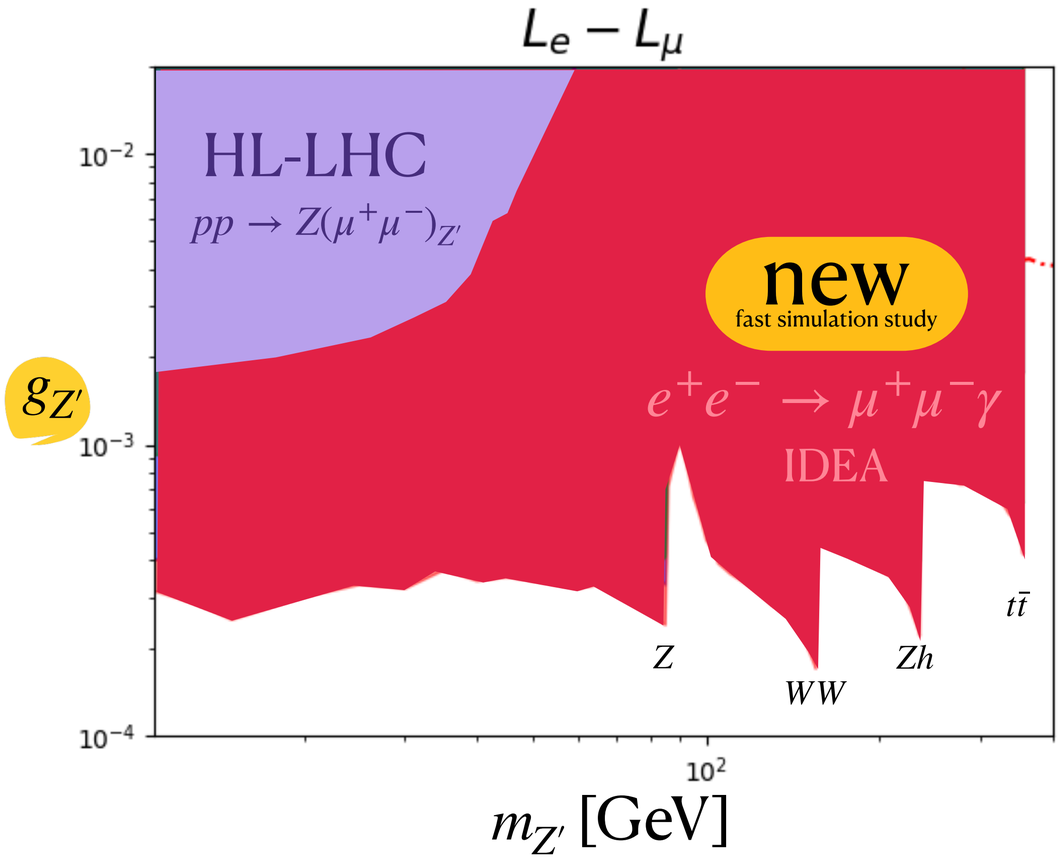

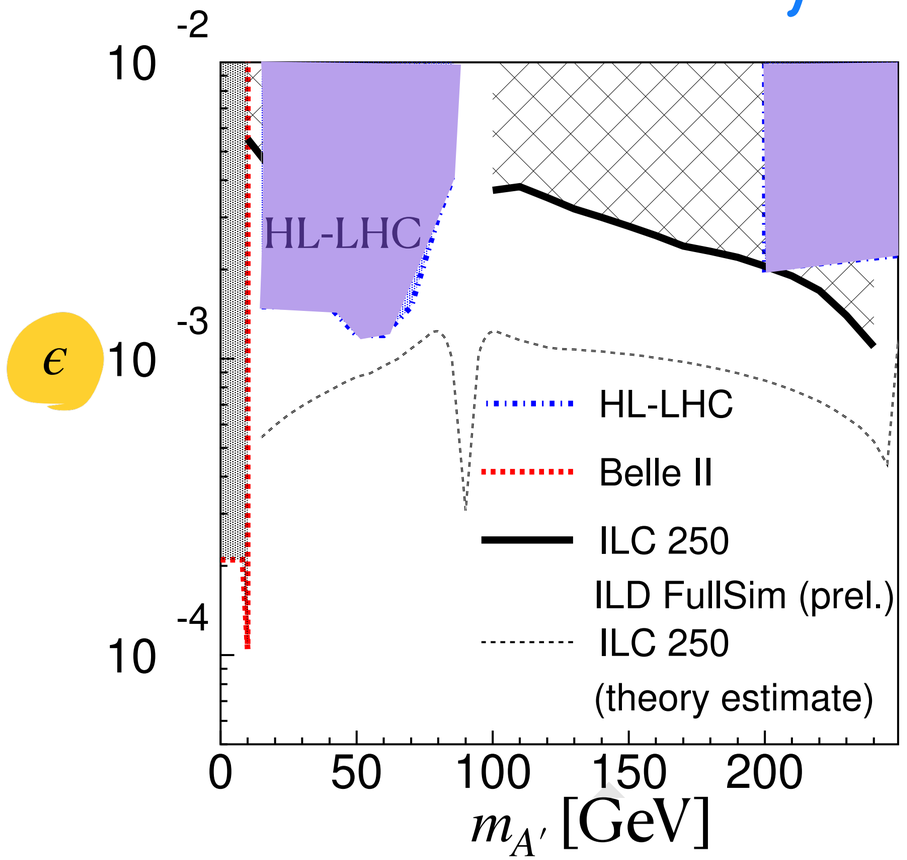

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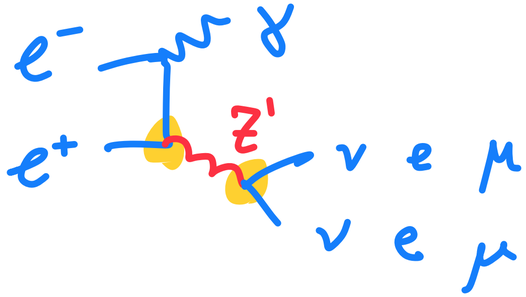
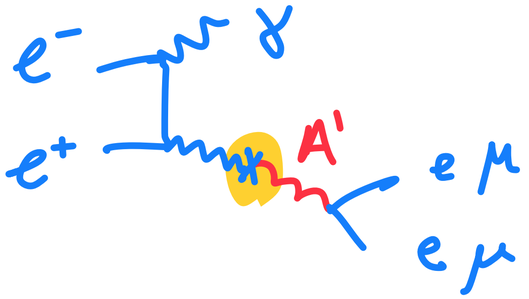
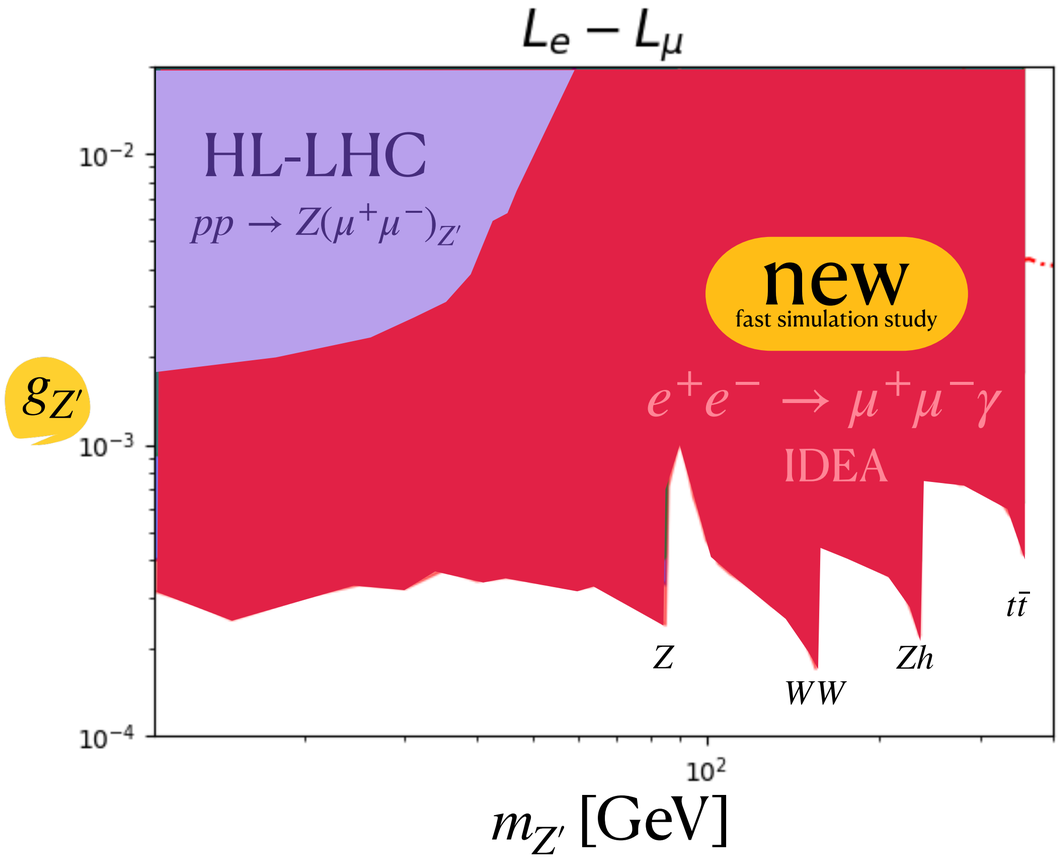
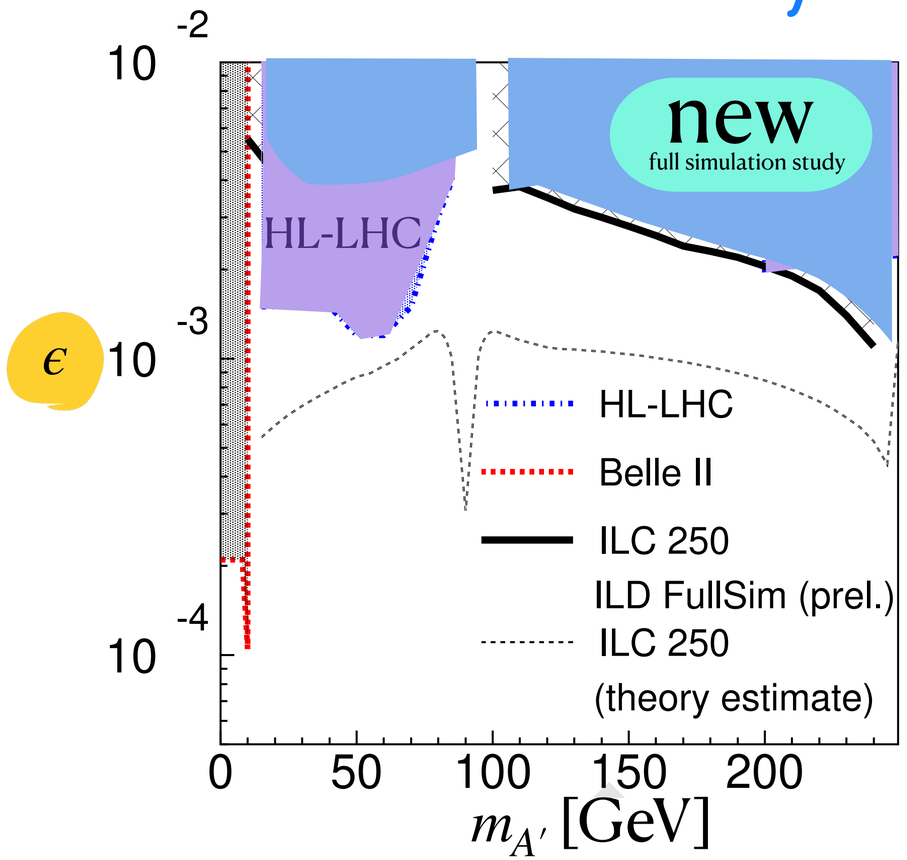








New physics in top quark decay

BSM decays of top quark

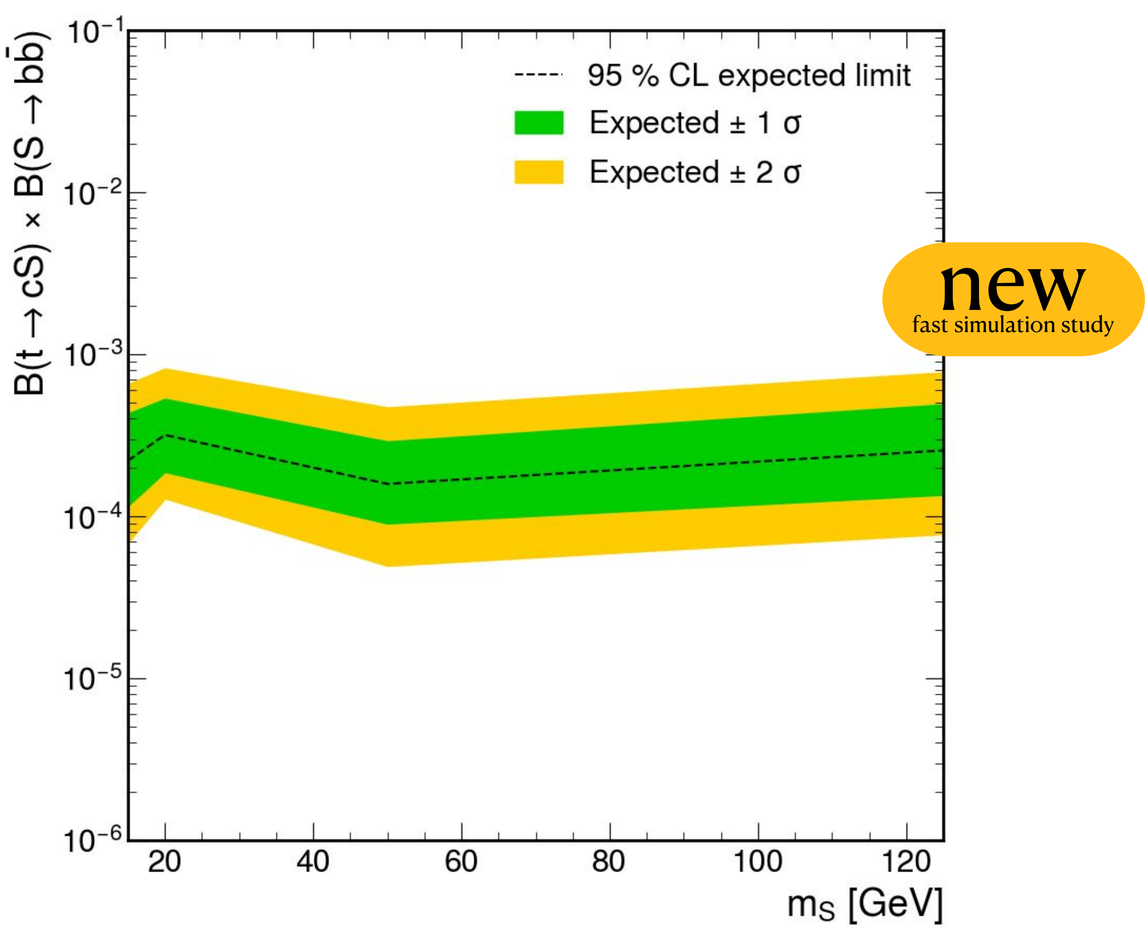
Process	SM	2HDM(FV)	2HDM(FC)	MSSM	RPV	RS
$t \to Zu$	7×10^{-17}	–	–	$\leq 10^{-7}$	$\leq 10^{-6}$	–
$t \to Zc$	1×10^{-14}	$\leq 10^{-6}$	$\leq 10^{-10}$	$\leq 10^{-7}$	$\leq 10^{-6}$	$\leq 10^{-5}$
$t \to gu$	4×10^{-14}	–	–	$\leq 10^{-7}$	$\leq 10^{-6}$	–
$t \to gc$	5×10^{-12}	$\leq 10^{-4}$	$\leq 10^{-8}$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

observable at top factory

not observable at top factory

Use MSSM instead

- **So far $BR(t \to hc)$ remains above 10^{-6}**
- **New study $t \to c\phi, \phi \to b\bar{b}$ with $\phi \neq h$**



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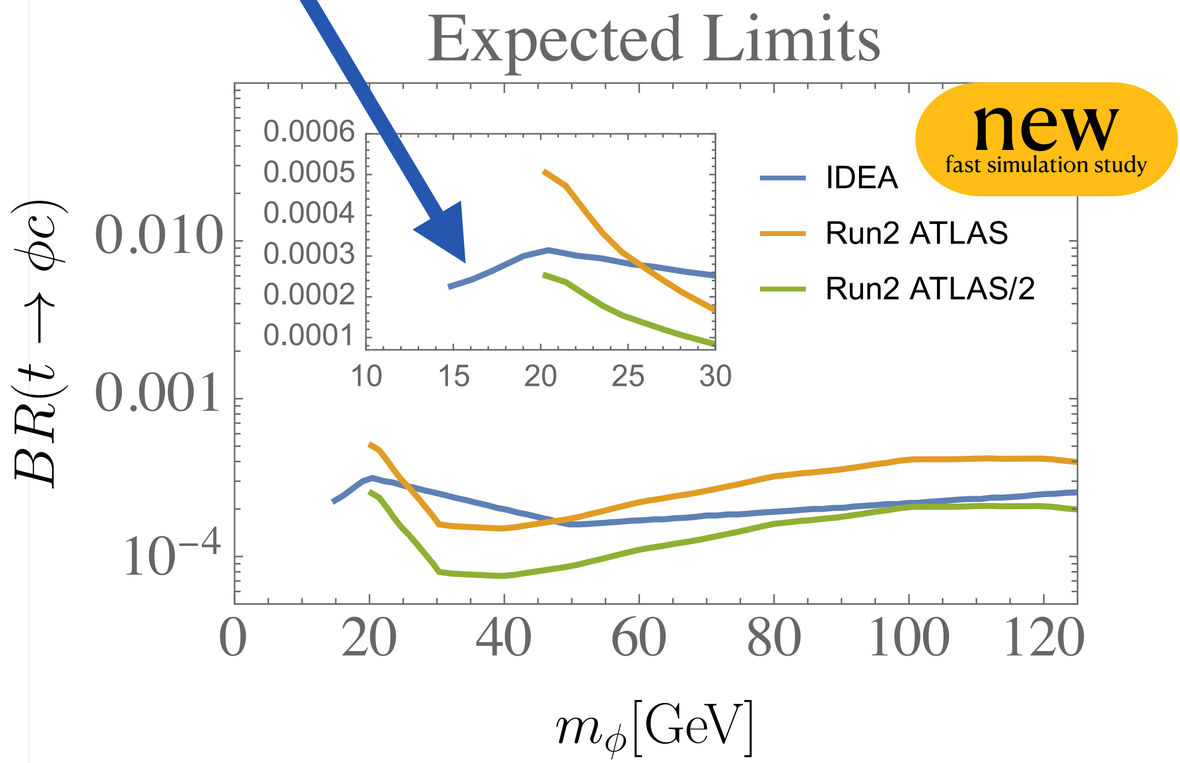

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BSM decays of top quark

Update on Snowmass 2013 top quark FCNC

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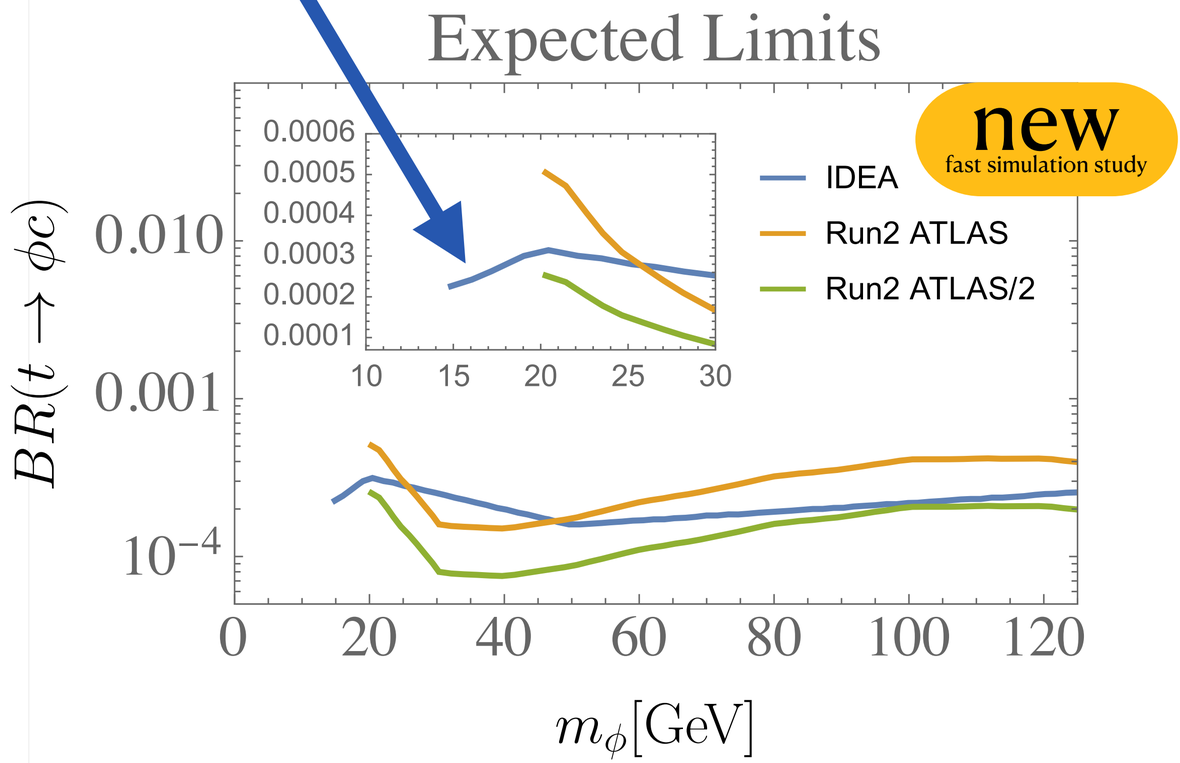

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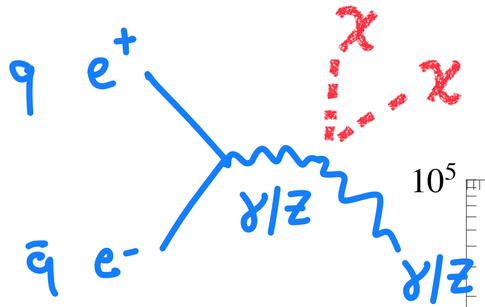
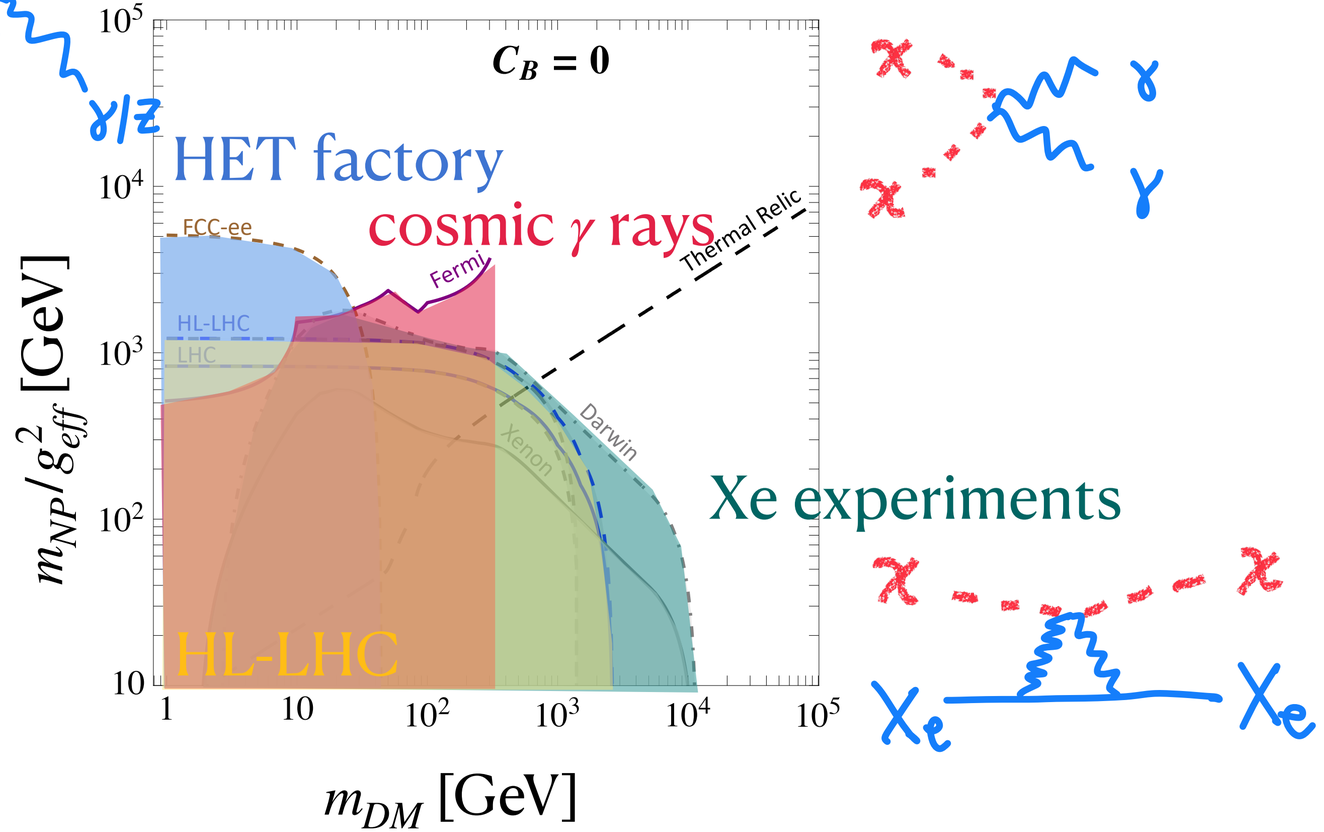
Dark matter

Dark Matter

Dark Matter couples only to pairs of gauge bosons

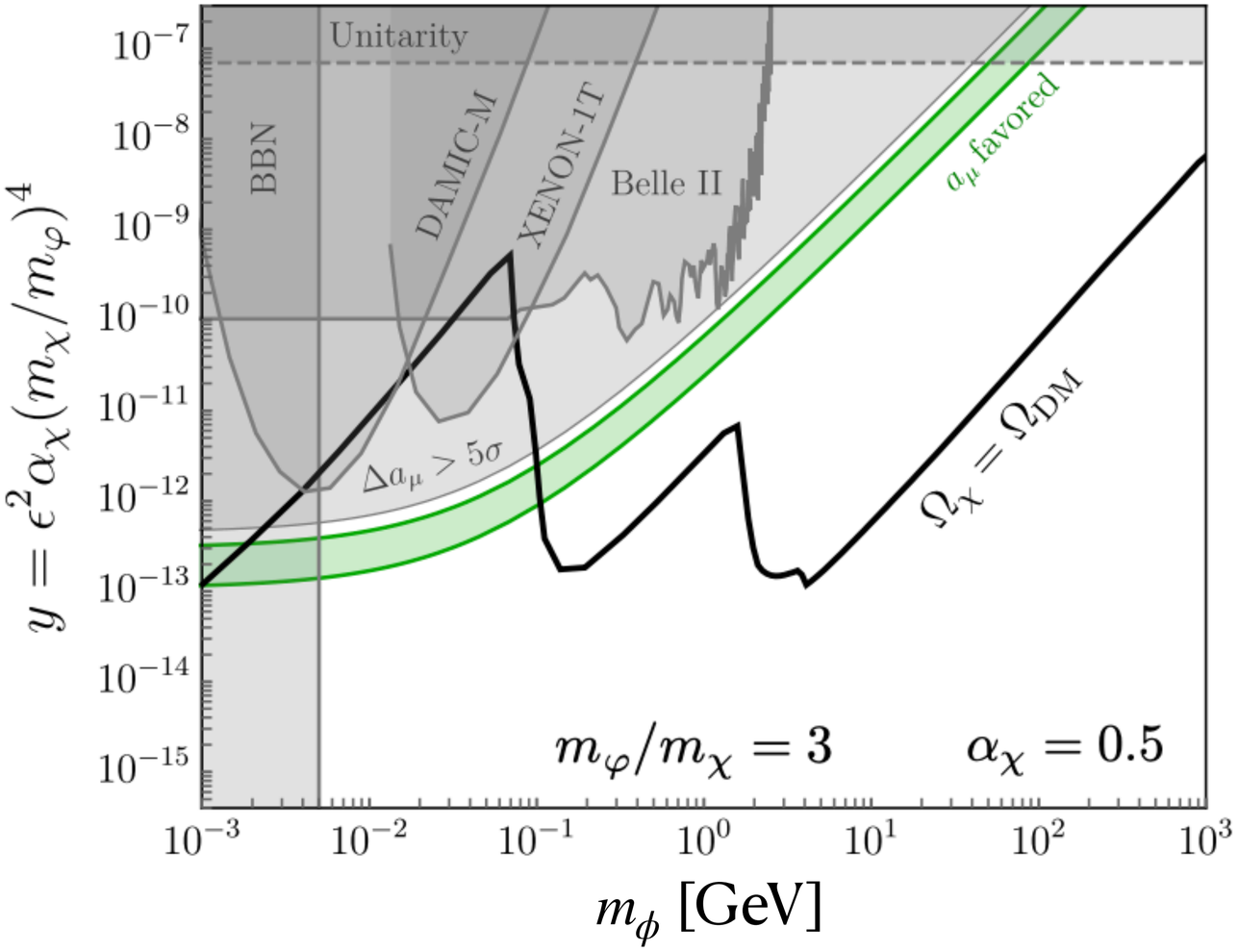
- Dark Matter candidates spanning many many orders of magnitude in mass)
- Very synergetic effort needed to hunt dark matter from all possible angles





lepto-philic dark matter

Dark Matter only couples to leptons, the heavier the lepton the better



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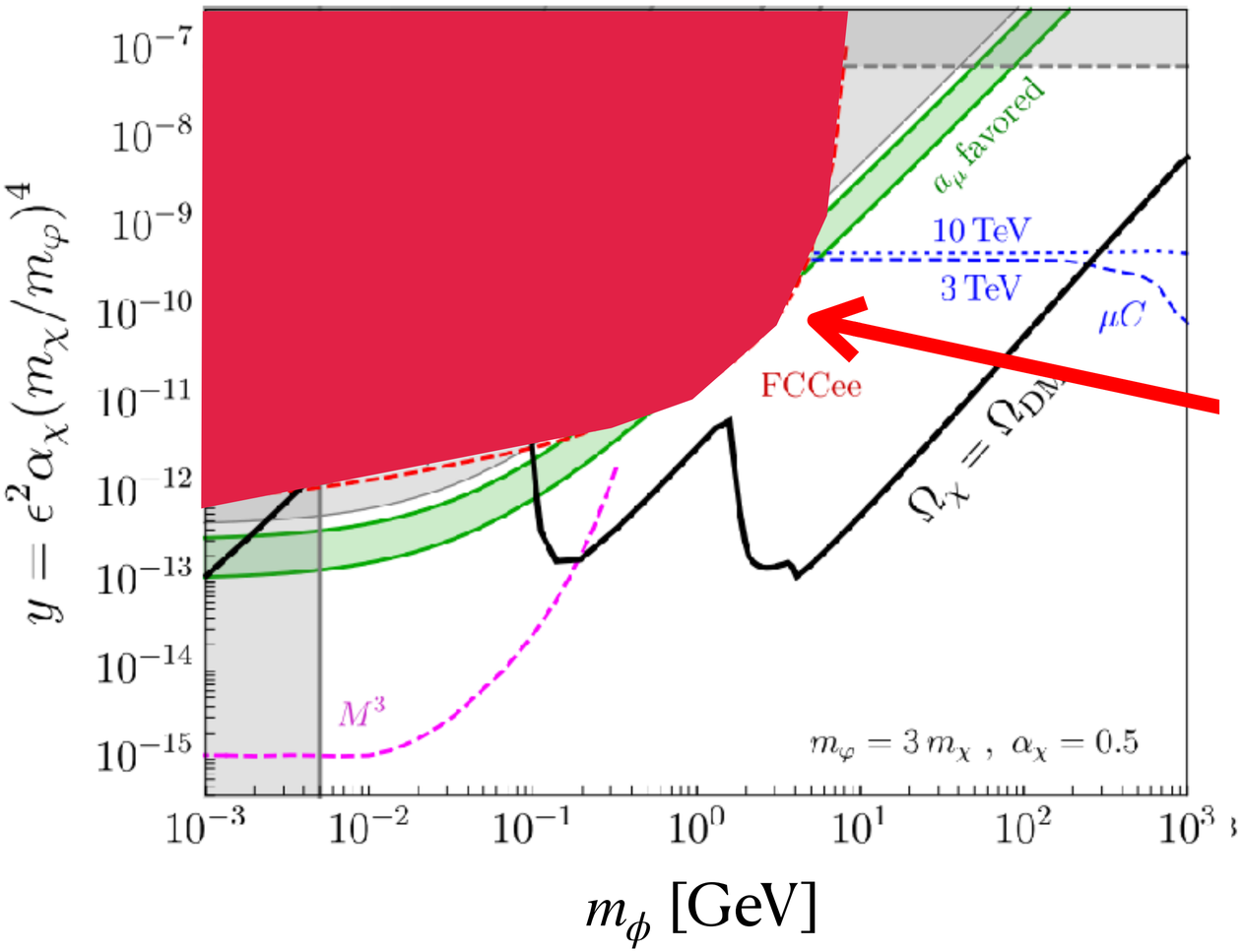
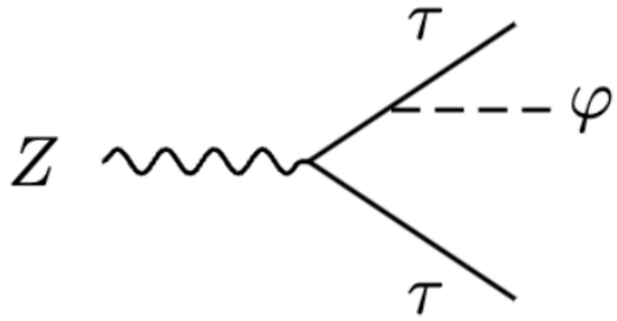




$$\Gamma(Z \to \tau\tau)$$

Conclusions

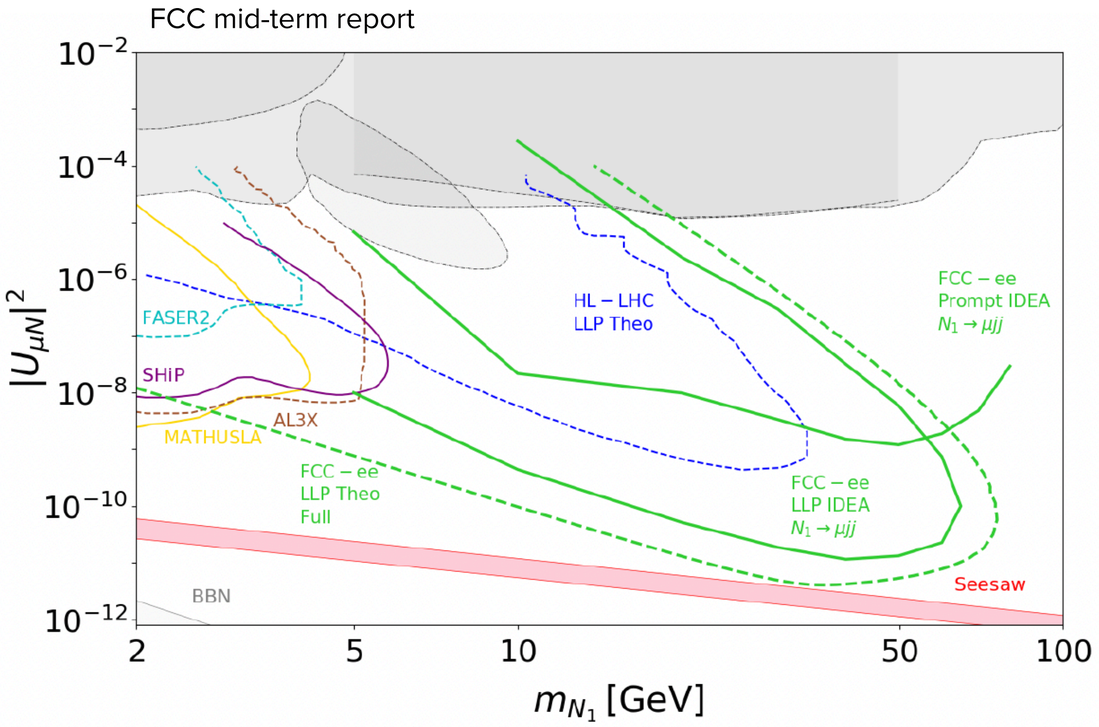
Lots of new studies delivered for the Report triggered by the HTE factory study.

- FLAV
  - improvements and complementarity “all-round” with respect to Belle II and LHC*b*
  - specific detector requirements (well understood syst. unc. flavor tagger, particle ID, ...)
  - new methods to access SM flavor parameters (e.g. CKM from high energy decay/scattering)
- SRCH
  - HTE can access new physics that escapes LHC (too faint signal, too light to trigger, ...)
  - sensitivity to models motivated from the bottom-up as well as top-down models
  - potential to probe new parameter space of new scalars and new gauge boson
  - potential to contribute to the great chase for dark matter

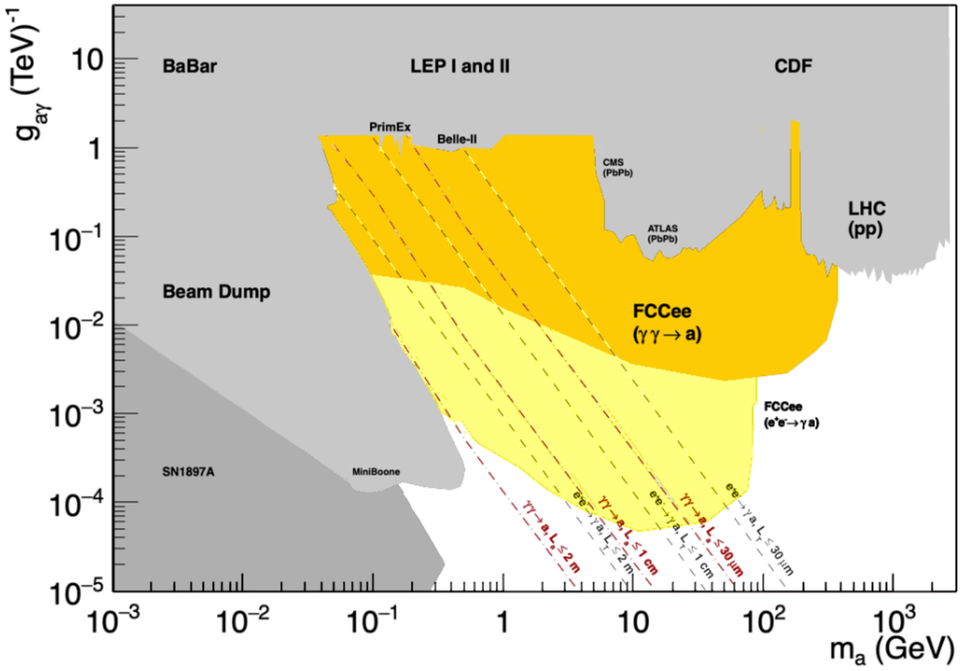
Thank you!

more LLPs

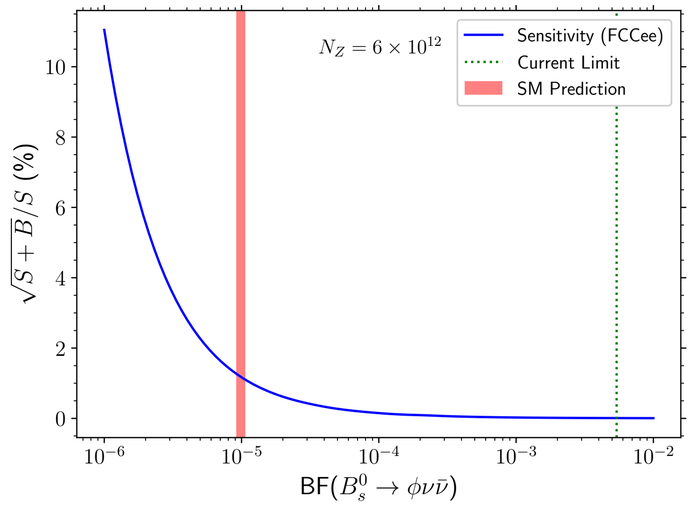
Heavy neutral lepton LLP

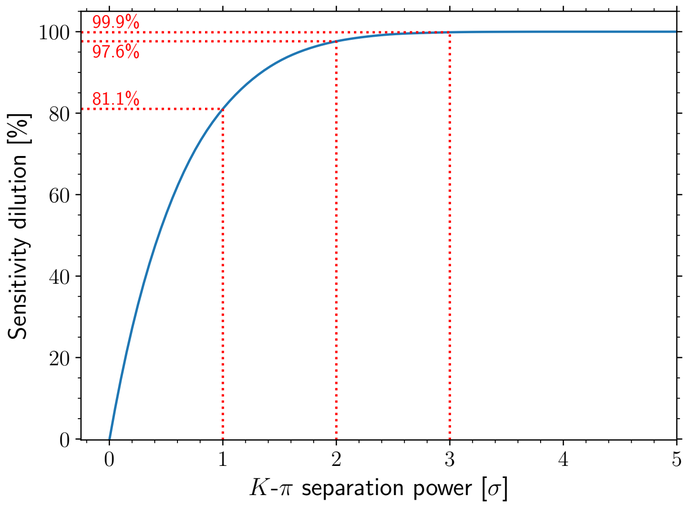


Di-photon LLP (axion-like particle)



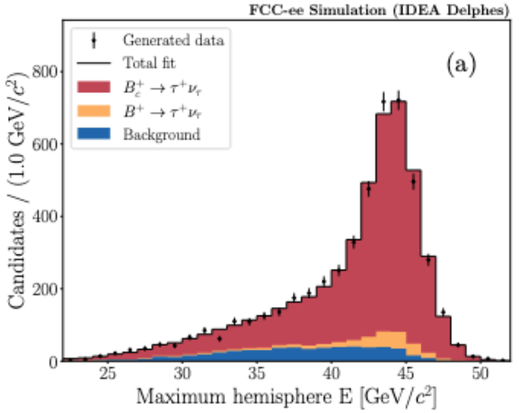
more *B* meson studies

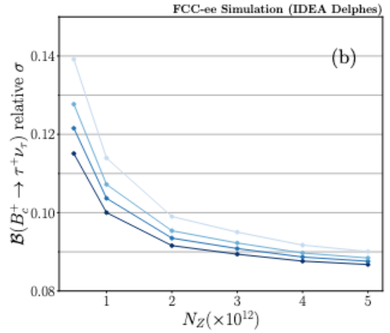




2) Flashing few studies — Leptonic decays

- *$B_c \to \tau^+\nu$:* another fundamental test of third generation couplings. Lepton universality in quark transitions. Counterpart of R_{D,D^*}. Reference here [2105.13330, see also 2007.08234]





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Bottomline: few percent precision mostly limited yet by the knowledge of the normalising BF(J/$\psi\mu\nu$).

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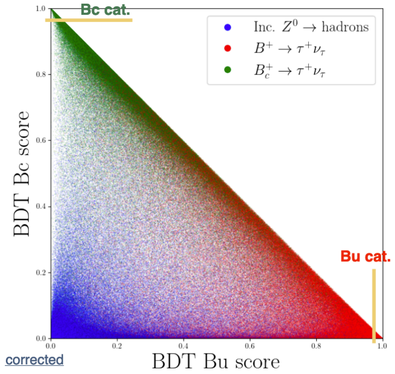
Bottomline: *2305.02998* makes the synthesis of both analyses.



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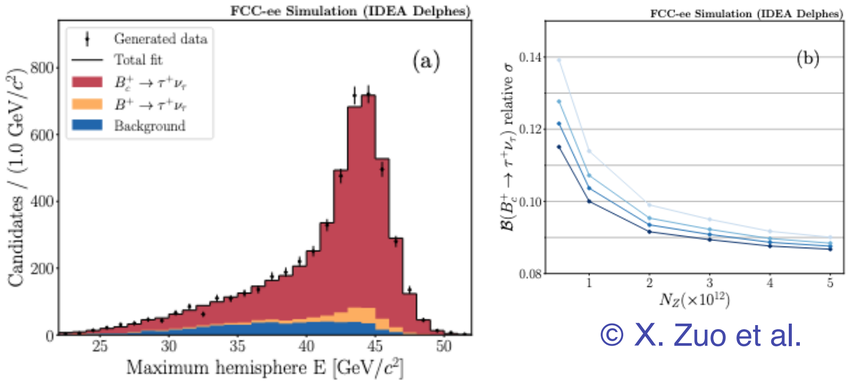

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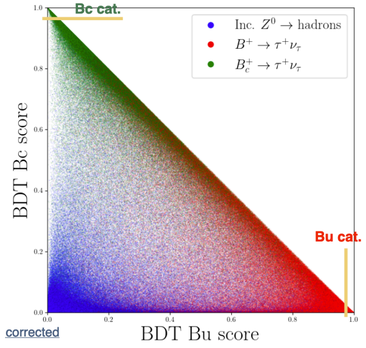

τ studies

2) Flashing few studies — Tau physics

- Tau Physics: Lepton Flavour Universality

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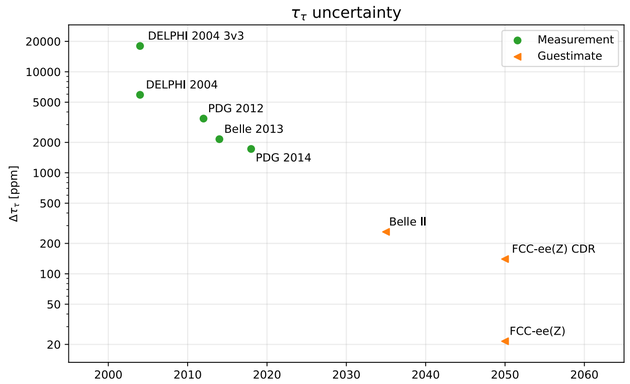

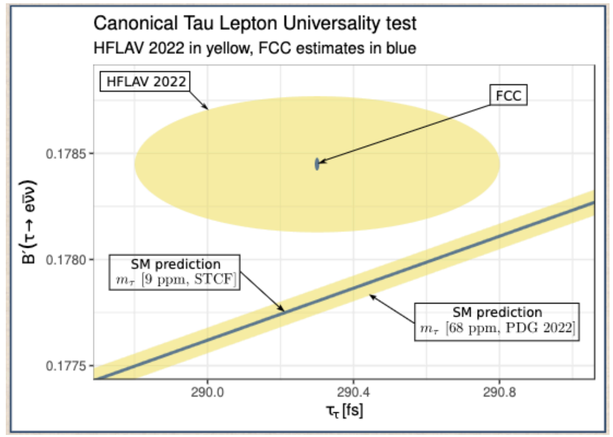

Comment: B-factories did not improve LEP measurements (Belle II did). FCC-ee has better experimental conditions than LEP and about 5× the nominal Belle II tau pairs (and boosted).

Bottomline: lifetime resolution obtained with three-prongs decays. Orders of magnitude improvements w.r.t. the stator the art. Same is true for Lepton-Flavour violating tau decays.

Thank you!

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