SM

INTRODUCTION TO DARK SECTORS, LLPS AND DISCOVERY PHYSICS

ROBERTO FRANCESCHINI, SEPT. 12th 2022
EEFACT WORKSHOP (LNF FRASCATI)

ROMA TRE UNIVERSITÀ DEGLI STUDI

INFN Roma3

DARK

https://agenda.infn.it/event/21199/

Outline

- Ideology of BSM in the 2020s
- What can we probe at e^+e^-
- high-lumi direct probes

Open questions and shortcomings of the SM

- ? Need new matter (or even bigger modifications to the SM)
- Adjusting one SM parameter might do
- Adjusting several SM parameters might do
- EFT Separation of scales as an organizing principle might fail

- ? what is the dark matter in the Universe?
- why QCD does not violate CP?
- how have baryons originated in the early Universe?
- what originates flavor mixing and fermions masses?
- what gives mass to neutrinos?
- EFT why gravity and weak interactions are so different?
- EFT what fixes the cosmological constant?

EACH of these issues one day will teach us a lesson

Open questions and shortcomings of the SM

- ? Need new matter (or even bigger modifications to the SM)
- Adjusting one SM parameter might do
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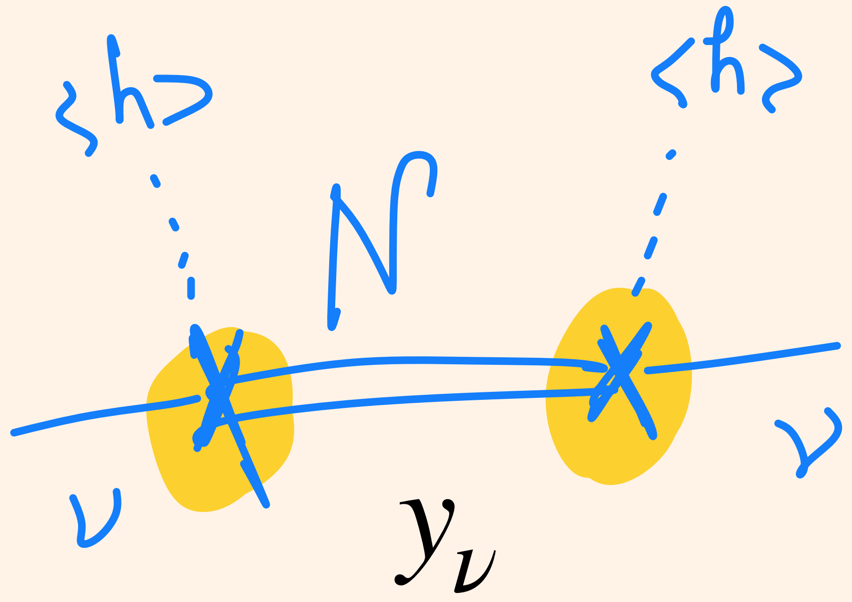
- ~~EFT~~ Separation of scales as an organizing principle might fail

- what is the dark matter in the Universe?
- why QCD does not violate CP?
- how have baryons originated in the early Universe?
- what originates flavor mixing and fermions masses?
- what gives mass to neutrinos? → very small mass!
- ~~EFT~~ why gravity and weak interactions are so different?
- ~~EFT~~ what fixes the cosmological constant?

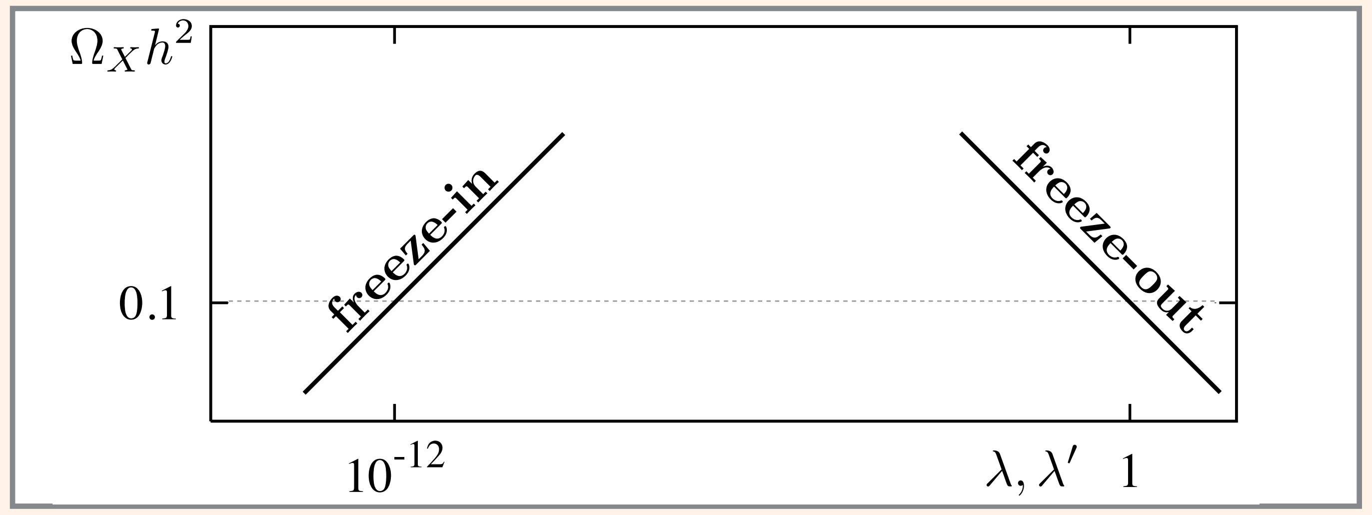
Solutions involve either a small coupling or very high scale, or both.

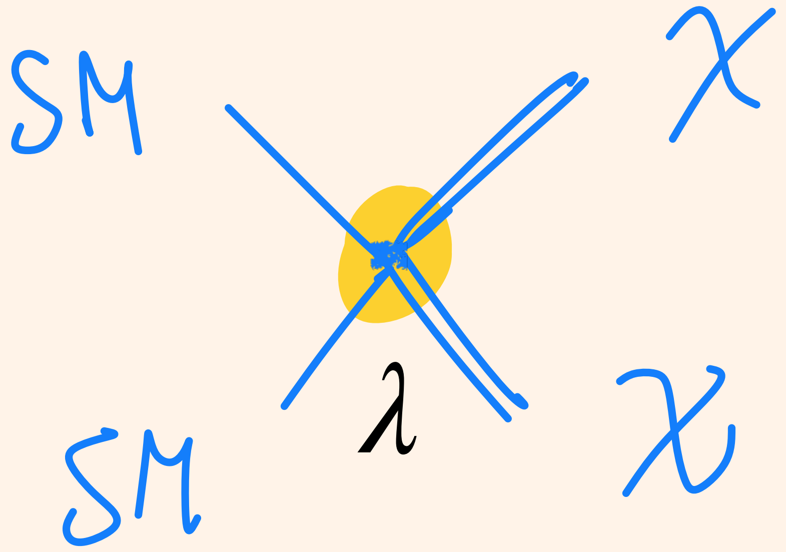
Tiny couplings are often needed in models of New Physics

$$m_\nu \simeq \frac{y_\nu^2 v^2}{M}$$



TYPE 1 SEE-SAW





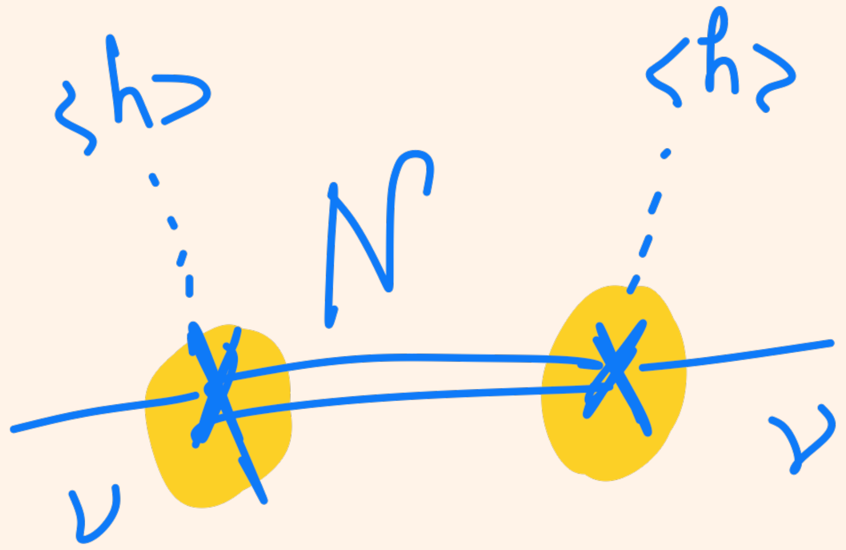
FREEZE-IN DM

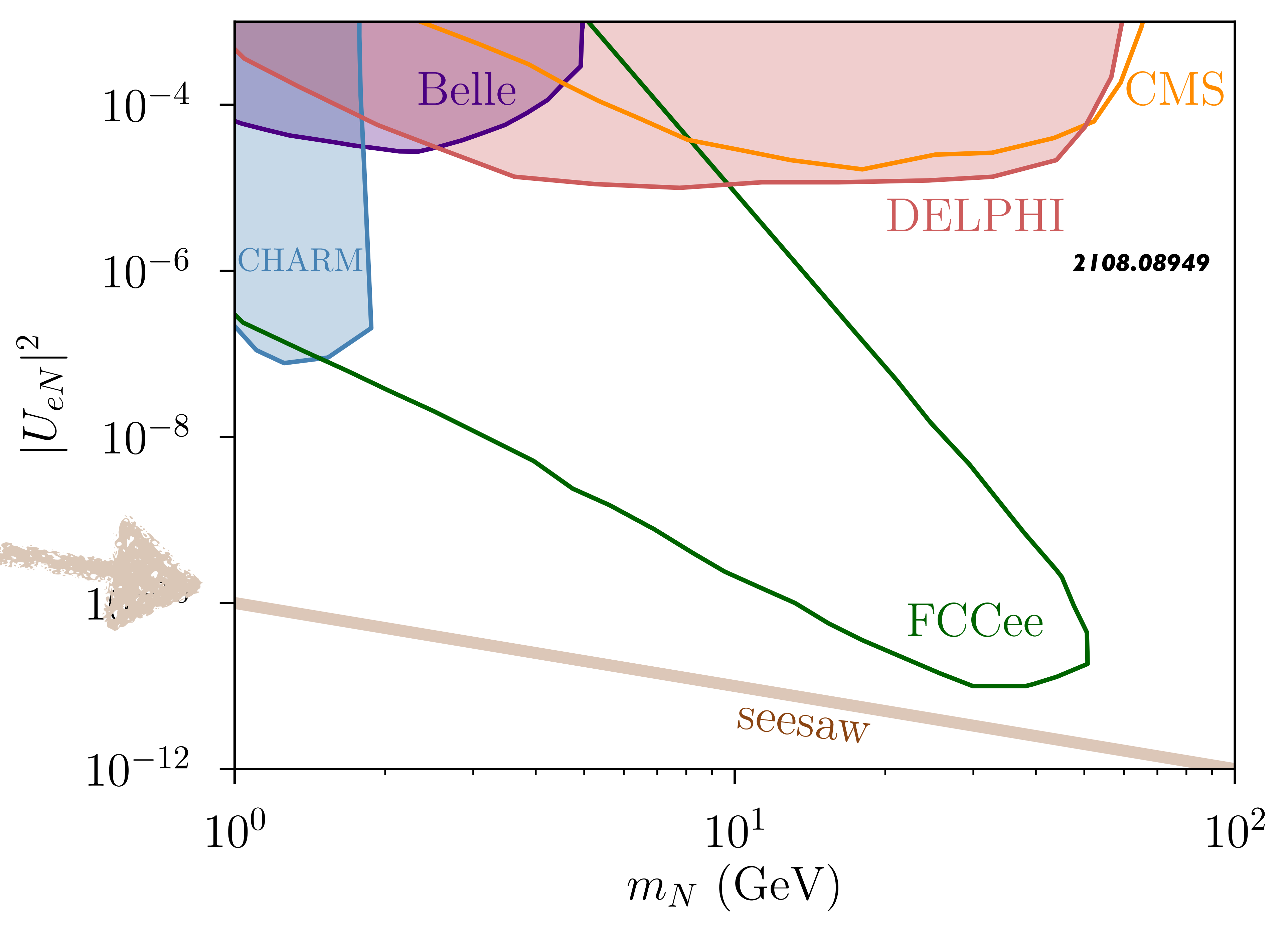
...

Reach on type-1 see-saw models

Very high-lumi Z-pole

$$m_\nu \simeq \frac{y_\nu^2 v^2}{M}$$





Long-lived signature

Prototypical:

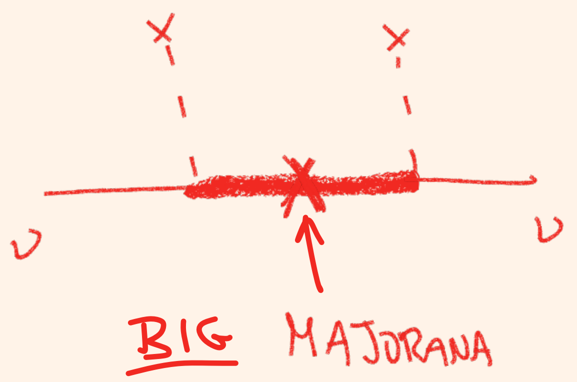
- depends crucially on lumi (within the mass range that can be probed by the machine)
- suggests a new signature (•‿•)
- there are alternative theoretical models (most of which cannot be probed at the same machine) ¯_(ツ)_/¯

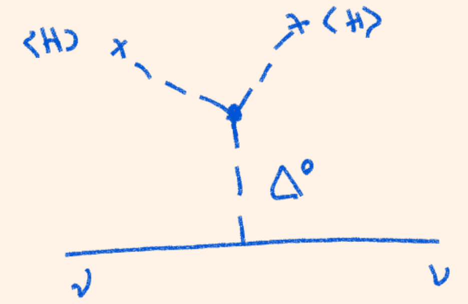
A chart of neutrino mass generation mechanisms

The breaking of lepton number

L – violation

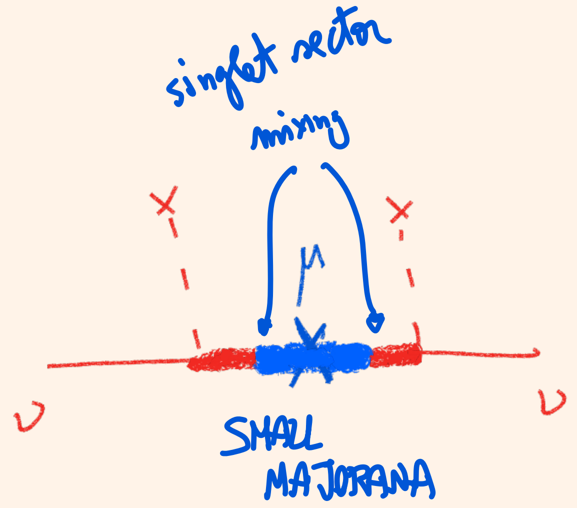
(1,1,0) (at least 2)

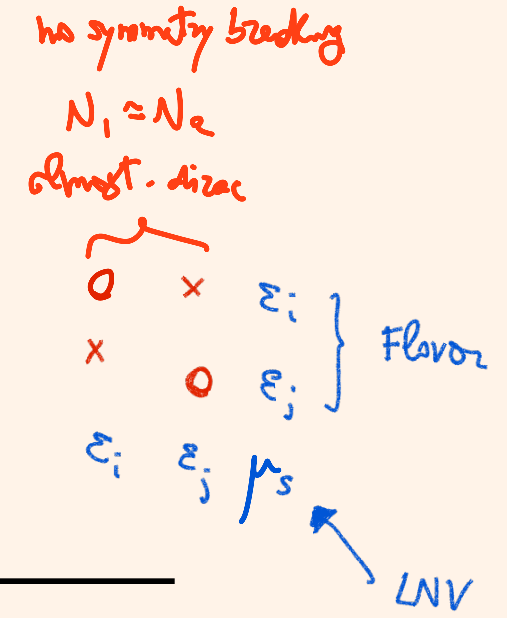




(1,3,1) (1 is enough)

(1,1,0) (at least 2+1)



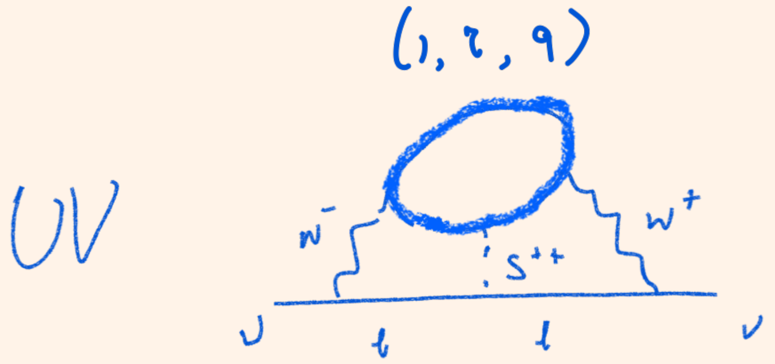


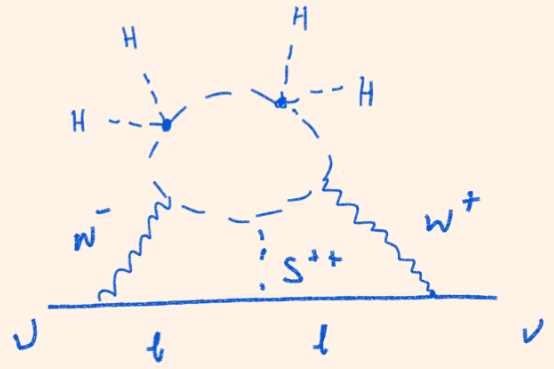
L – not accidental

new physics before 2012

$d = 5 \quad (1,2,1/2) \qquad \frac{(LH)^2}{\Lambda}$

$d = 7 \quad (1,1,2) \qquad \frac{\left(DH\sigma_2 H\right)^2 S^{--}}{\Lambda^3}$





L – gauged, SSB

$SU(3) \otimes SU(2)_L \otimes SU(2)_L \otimes U(1)_{B-L}$

$(1,2,1,1), (1,1,2,1), (1,2,2,1), (1,1,1,2),$

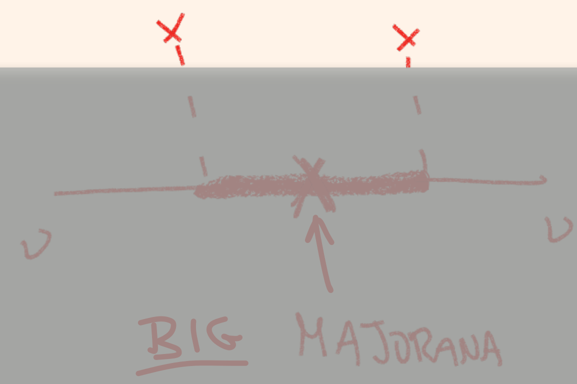
A chart of neutrino mass generation mechanisms

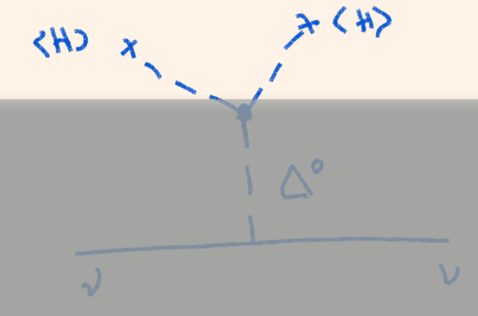
The breaking of lepton number

Unlike the situation with SM Higgs boson, which stood apart from other solutions for EWSB, and even had a “no loose theorem” at LHC, we are now in a mode of scientific exploration that is truly exploratory: there is no such thing as “the” model of new physics.

$L -$ violation

(1,1,0) (at least 2)





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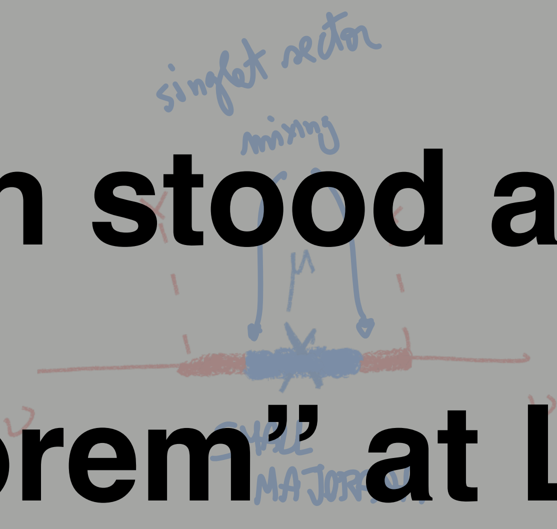

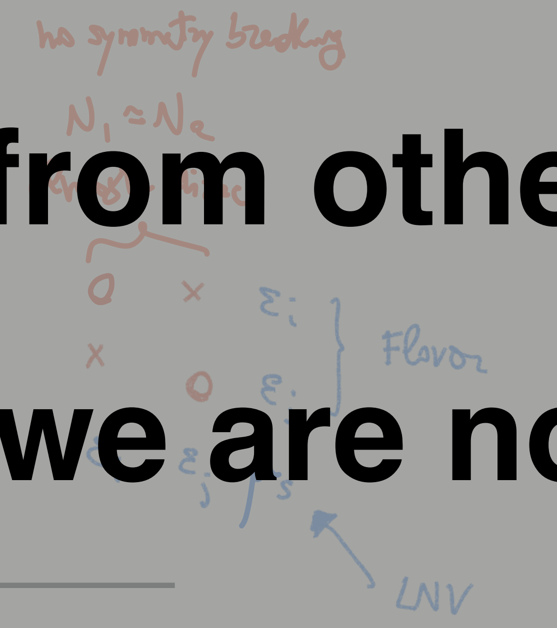

$L -$ not accidental

$d = 5$ (1,2,1/2) $\frac{(LH)^2}{\Lambda}$ UV

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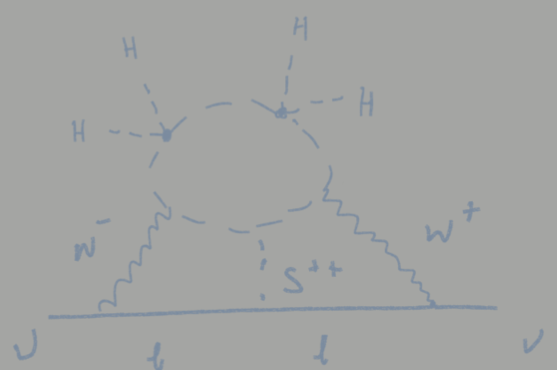

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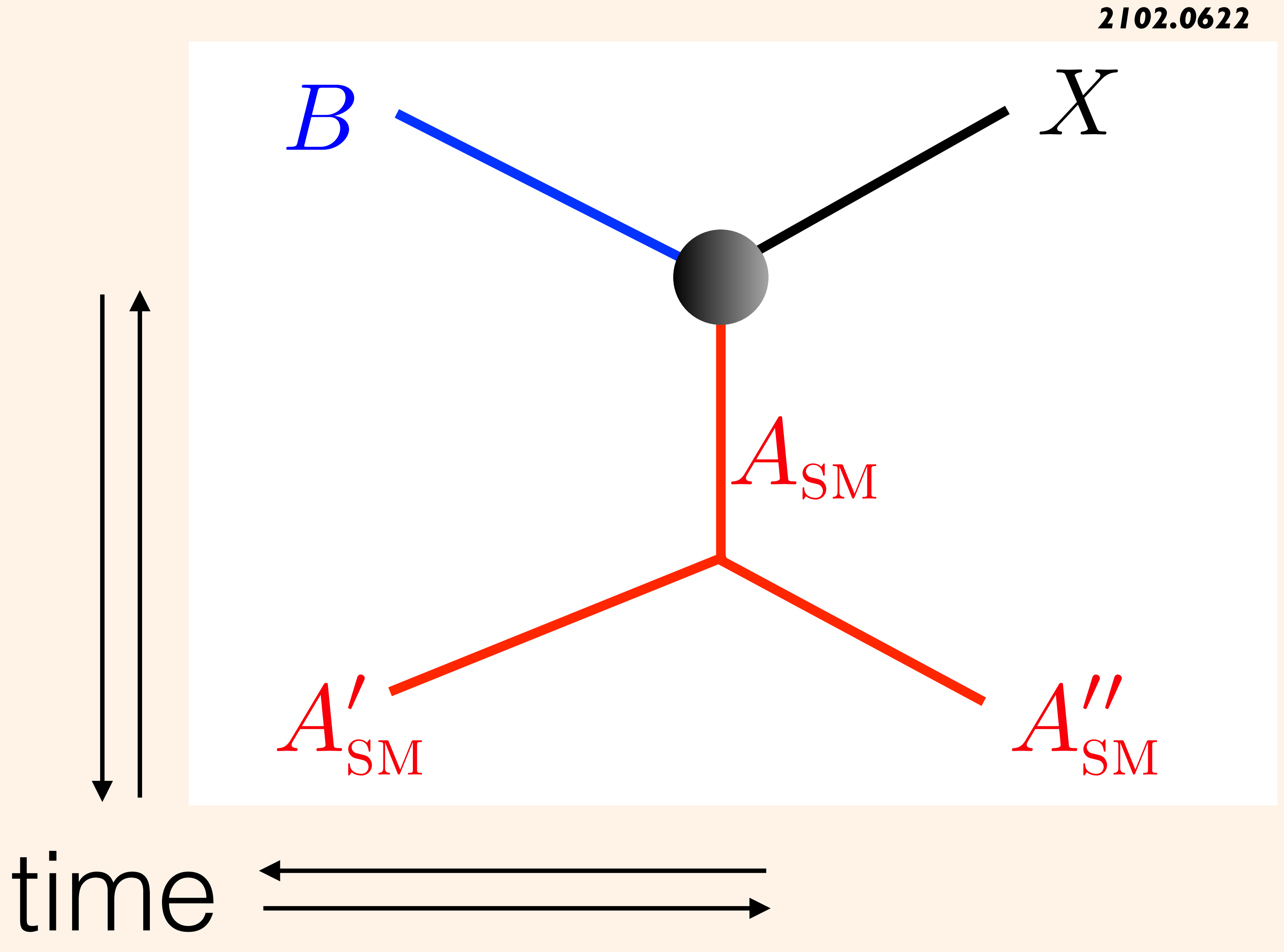
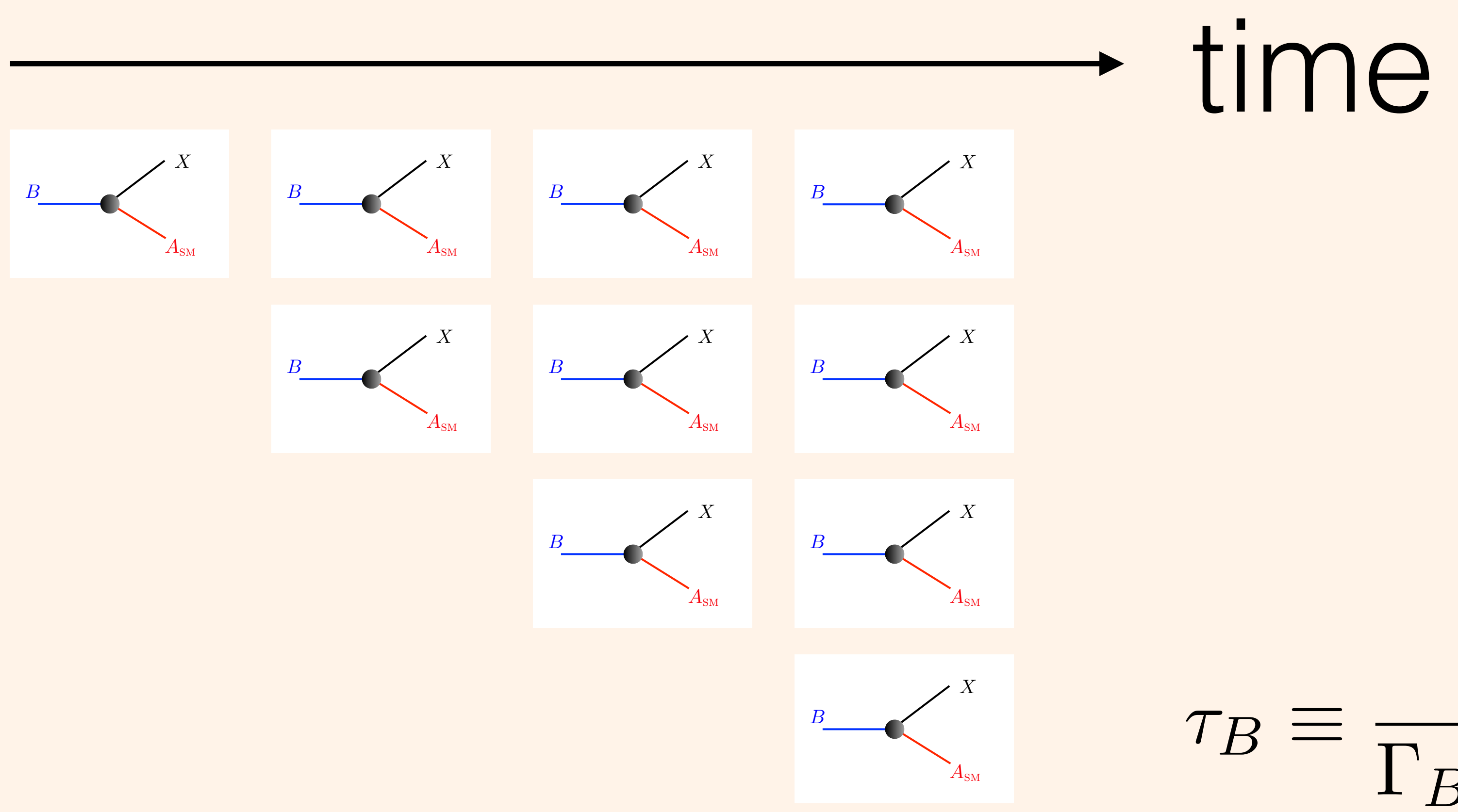
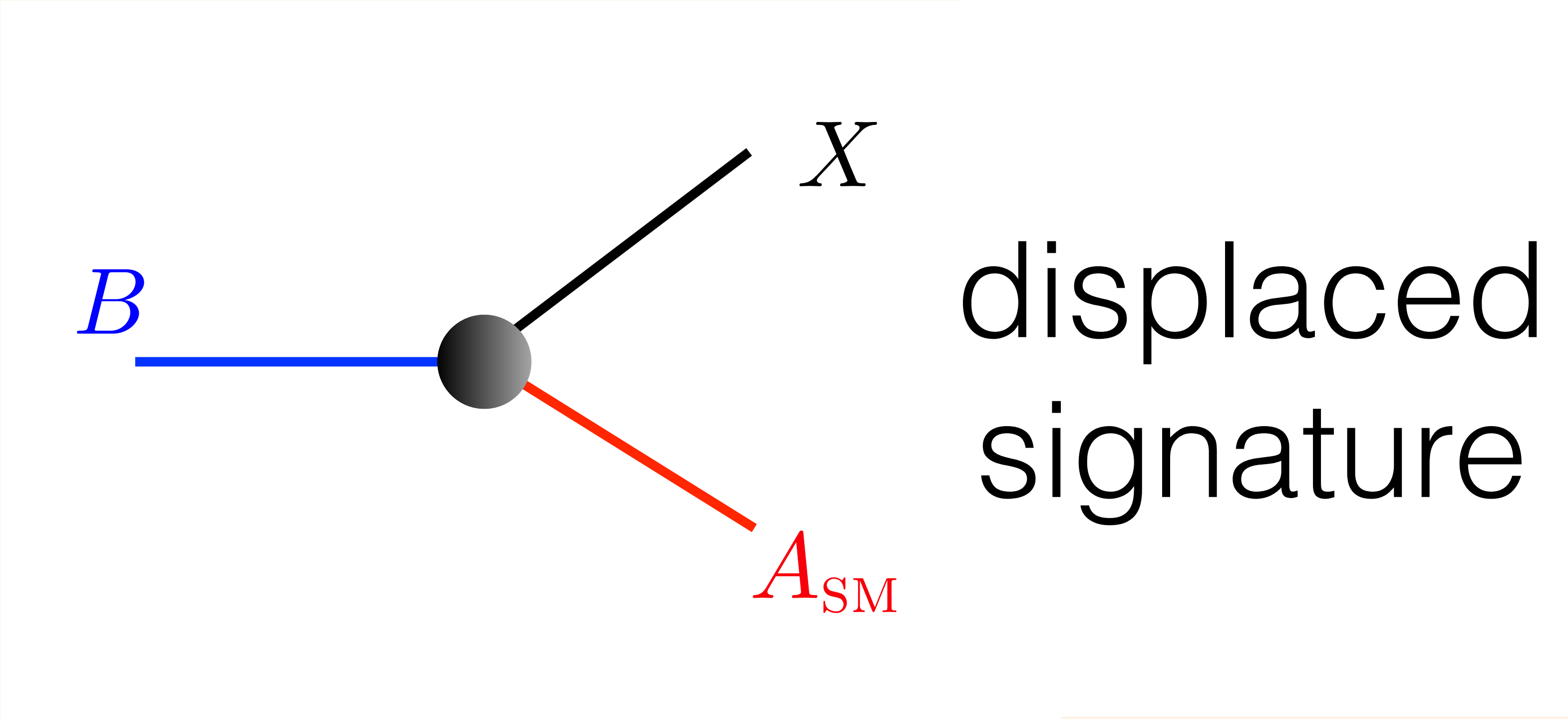
Freeze-in Dark Matter candidates

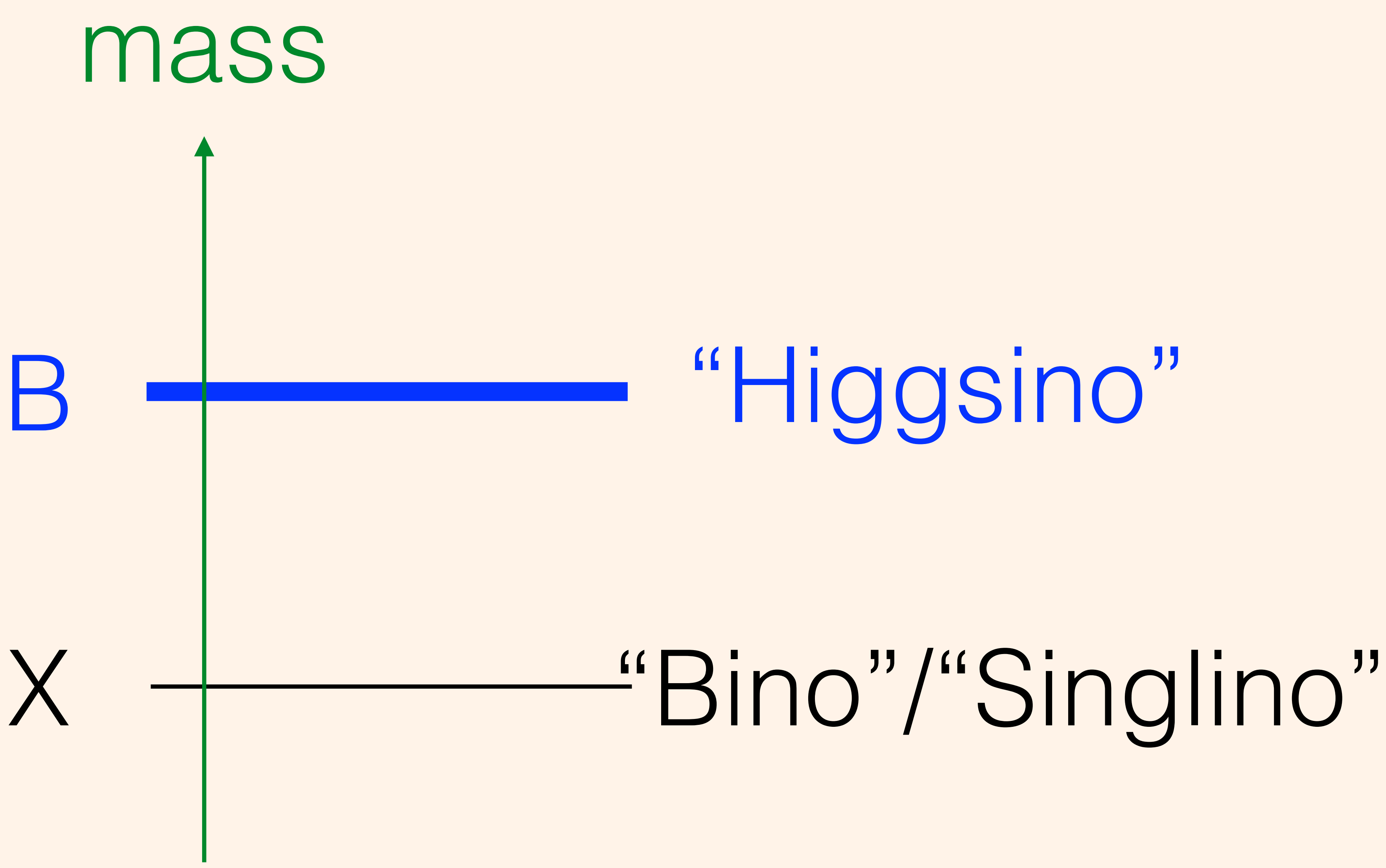




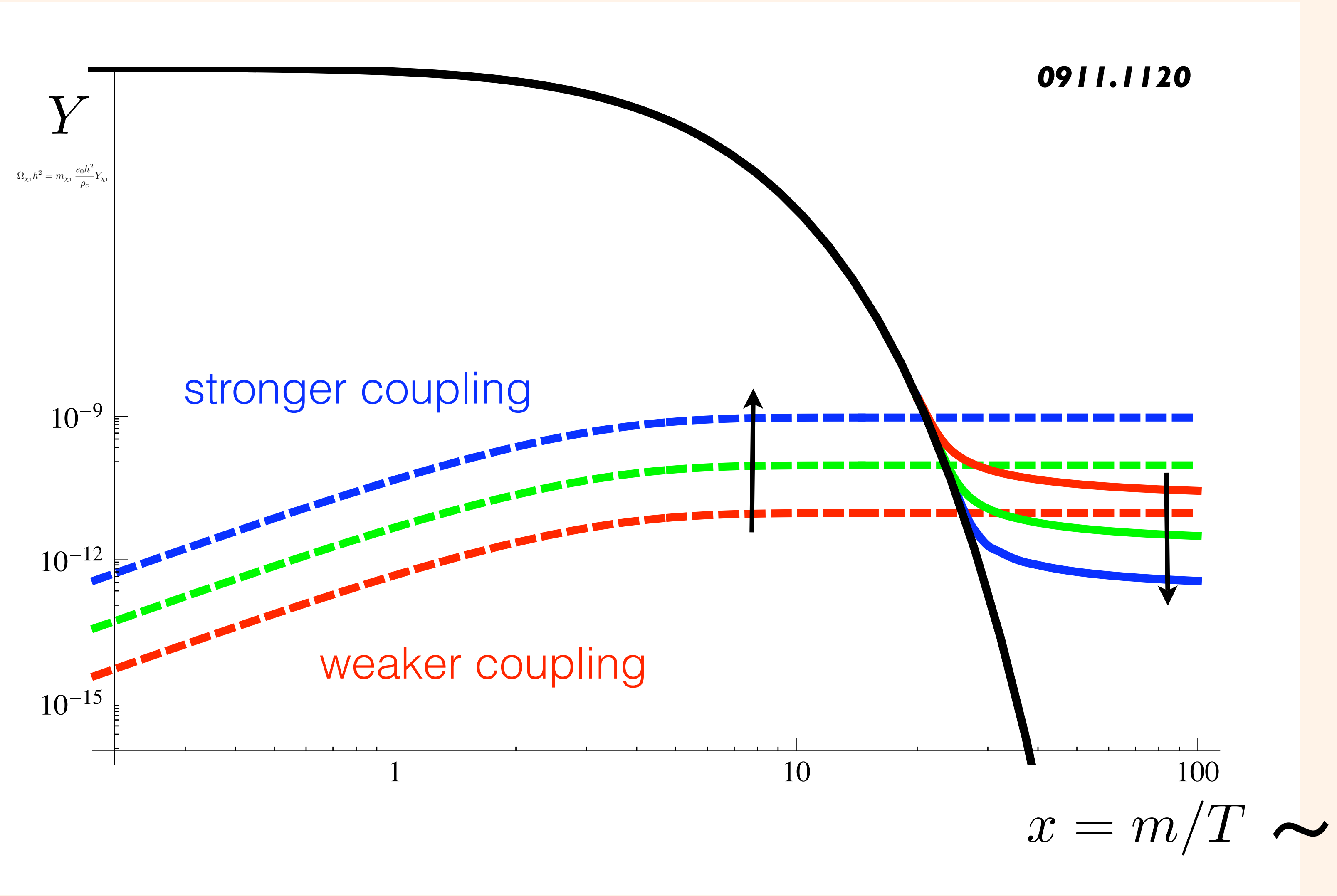


$$\tau_B \equiv \frac{1}{\Gamma_{B\to A_{SM}X}} \simeq 3.3\times 10^3\,\mathrm{m}\left(\frac{g_B}{2}\right)\left(\frac{m_X}{1\,\mathrm{GeV}}\right)\left(\frac{1\mathrm{TeV}}{m_B}\right)^2$$

$$\Omega_{\chi_1}h^2 = 0.1\left(\frac{105}{g_*}\right)^{3/2}\left(\frac{m_{\chi_1}}{10\text{ keV}}\right)\left(\frac{1\text{ TeV}}{\mu}\right)^2\left(\frac{\sum_{ij} g_{A_i}\Gamma_{ij}}{5\times 10^{-15}\text{ GeV}}\right)$$

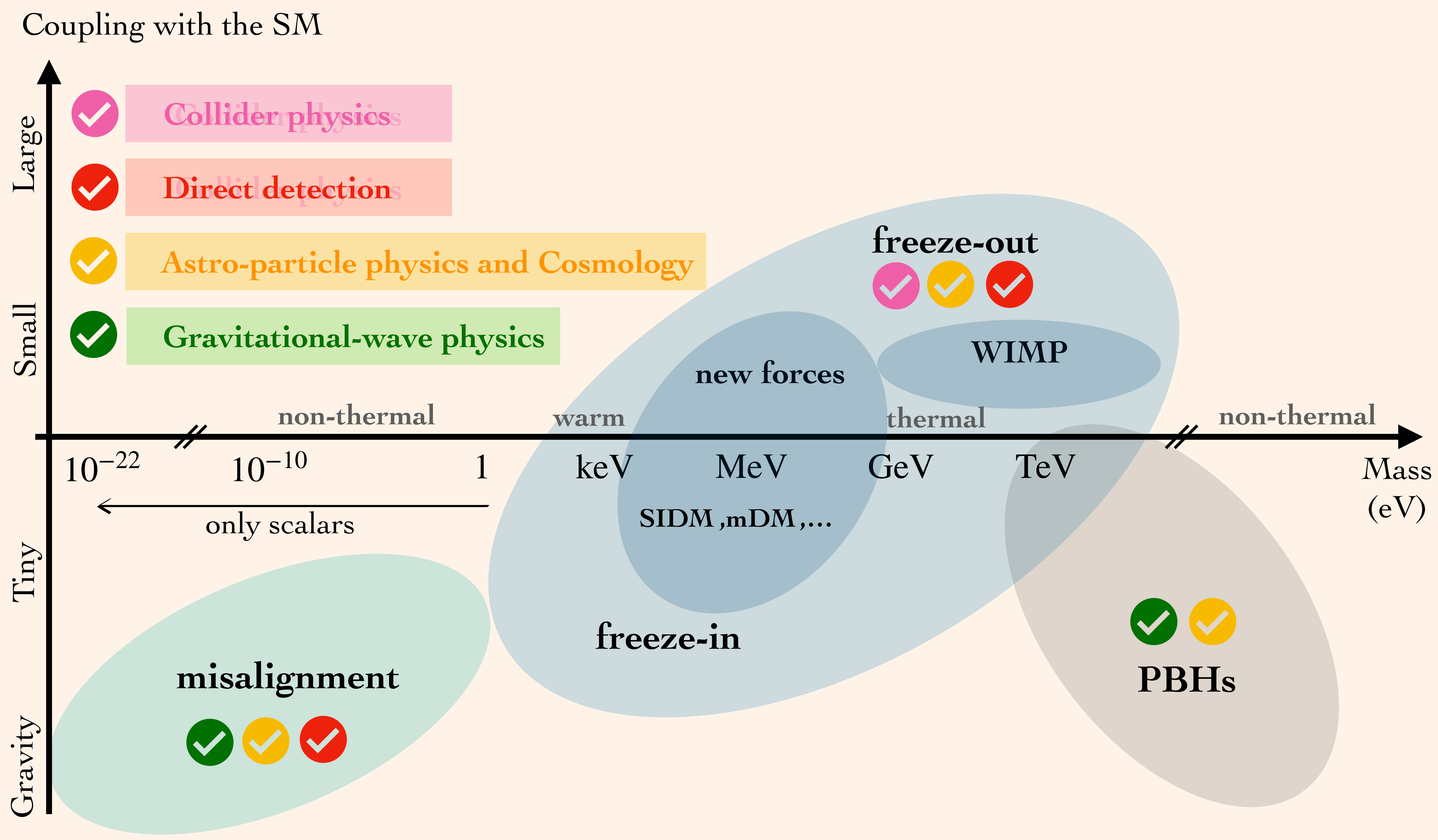


Abundance~



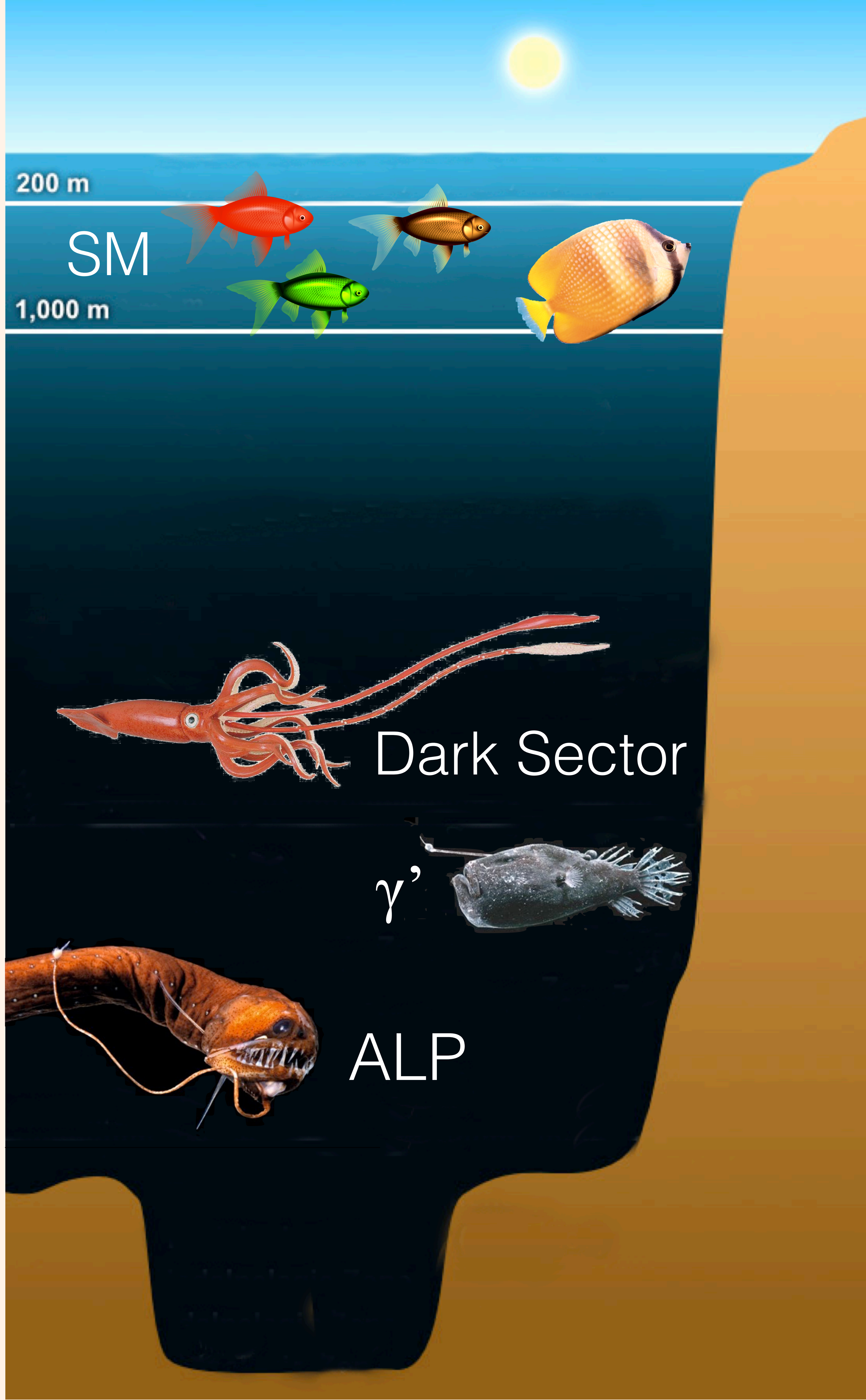
~time

A chart of Dark Matter candidates



we need to keep the search broad and on multiple fronts

The deeper you look …
the larger lumi you need



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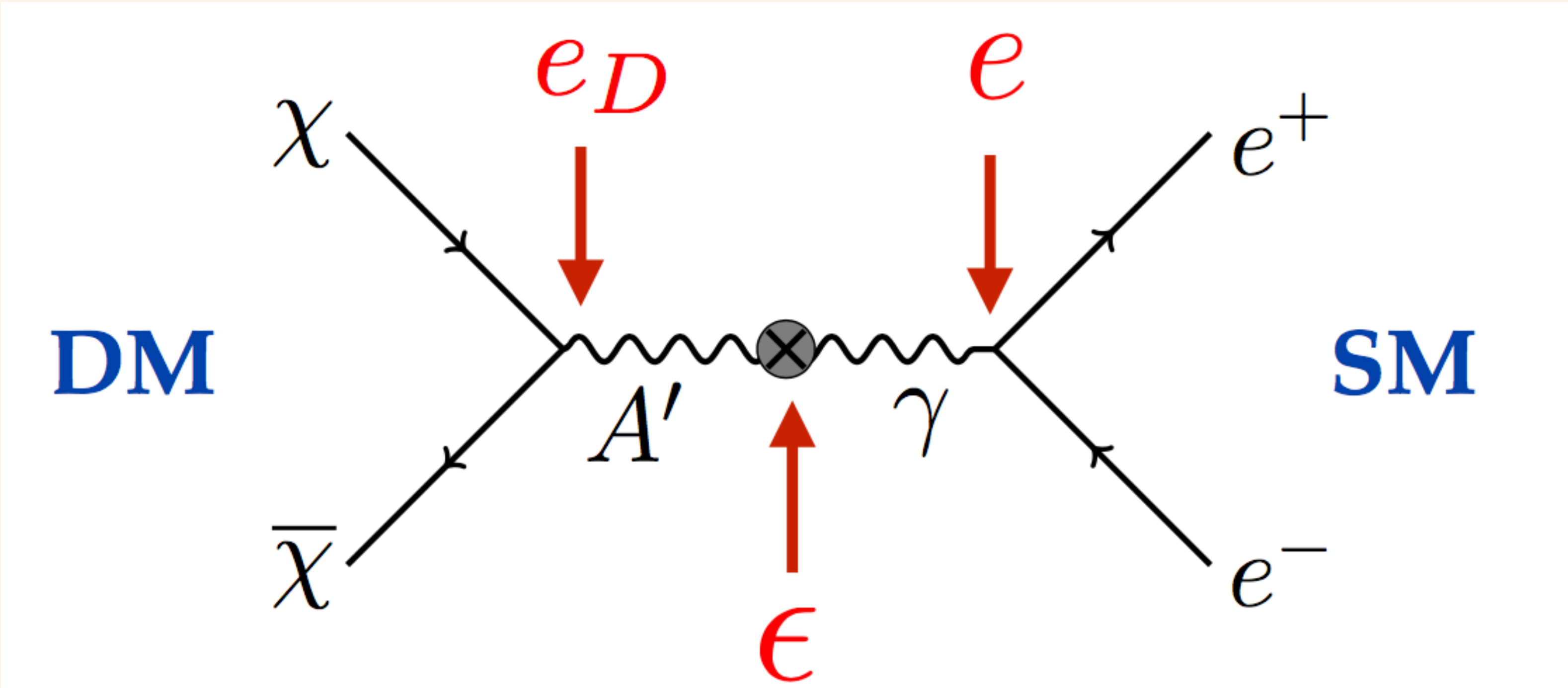
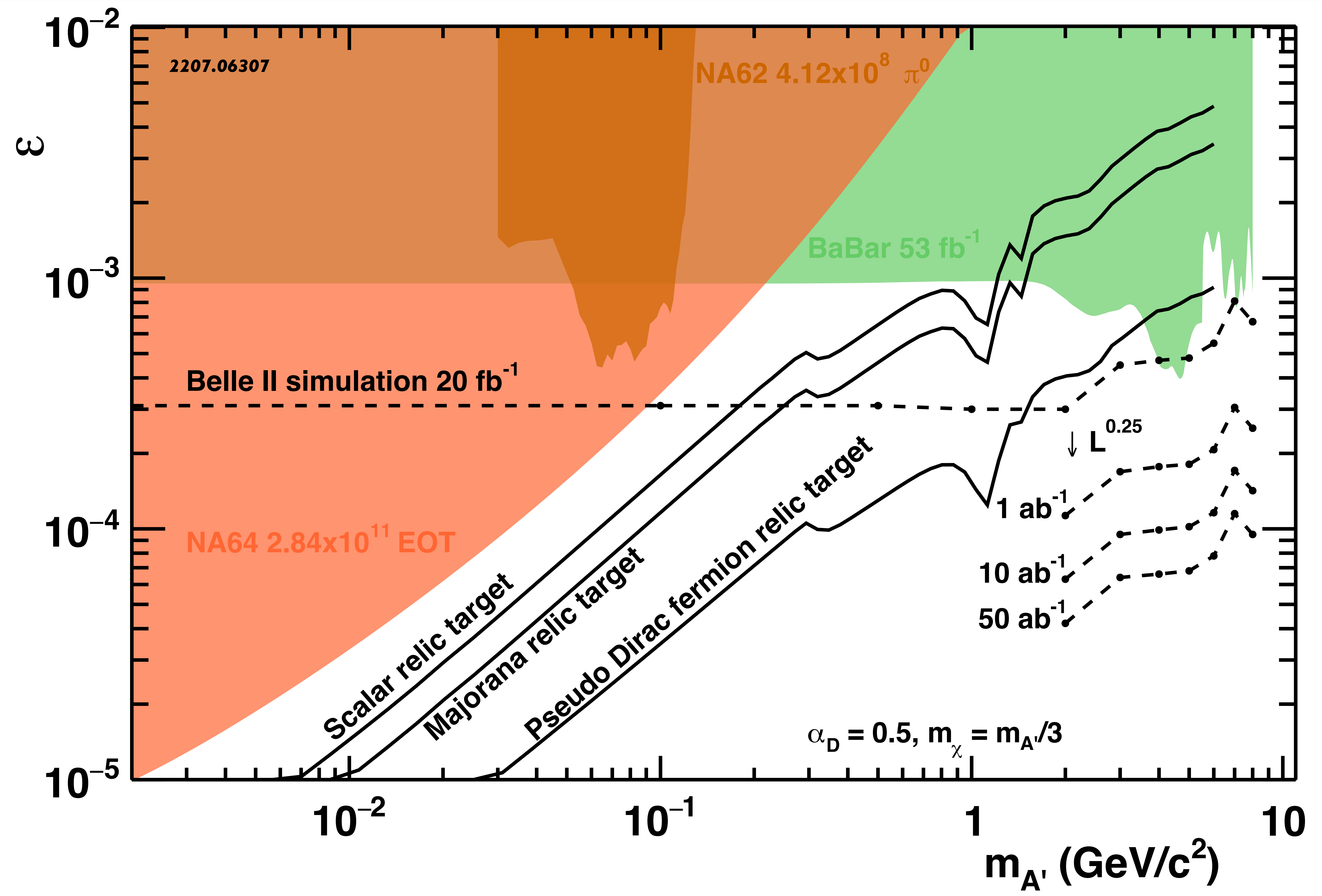
invisible final states

new gauge interactions for thermal equilibrium of sub-GeV dark matter



- p-wave annihilation allowed by CMB
- direct detection limits drop below few GeV
- sub-MeV more conflicts with cosmology

DM in MeV-GeV range (in this class of models)



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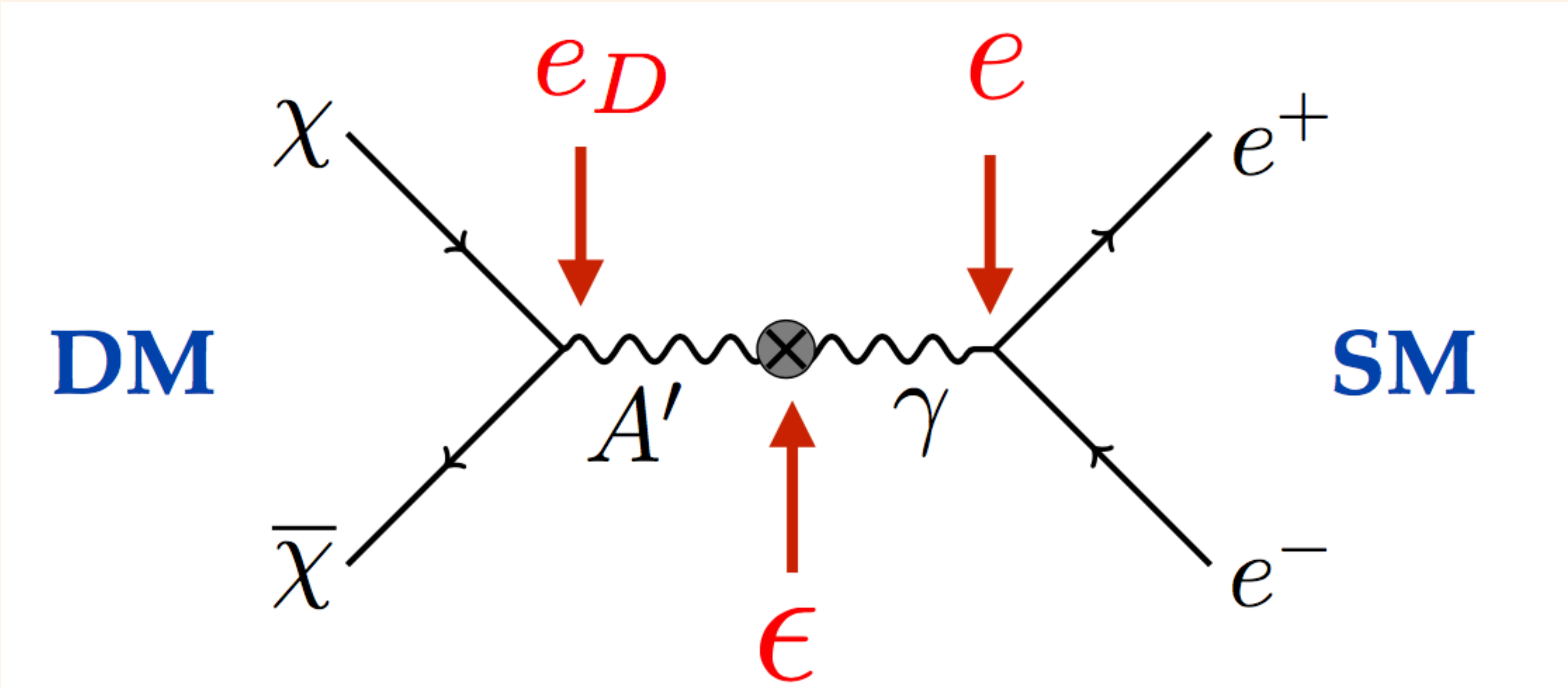

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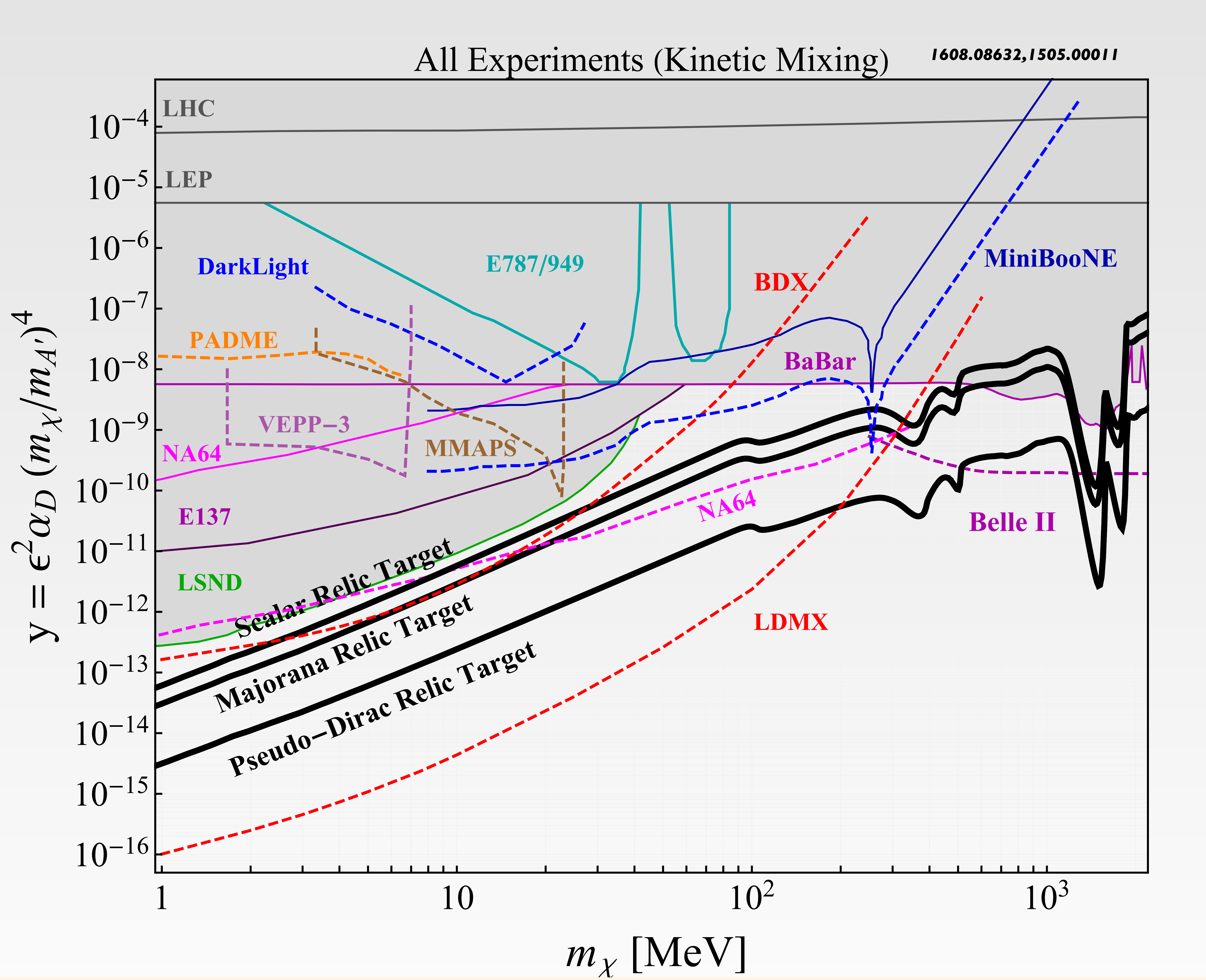

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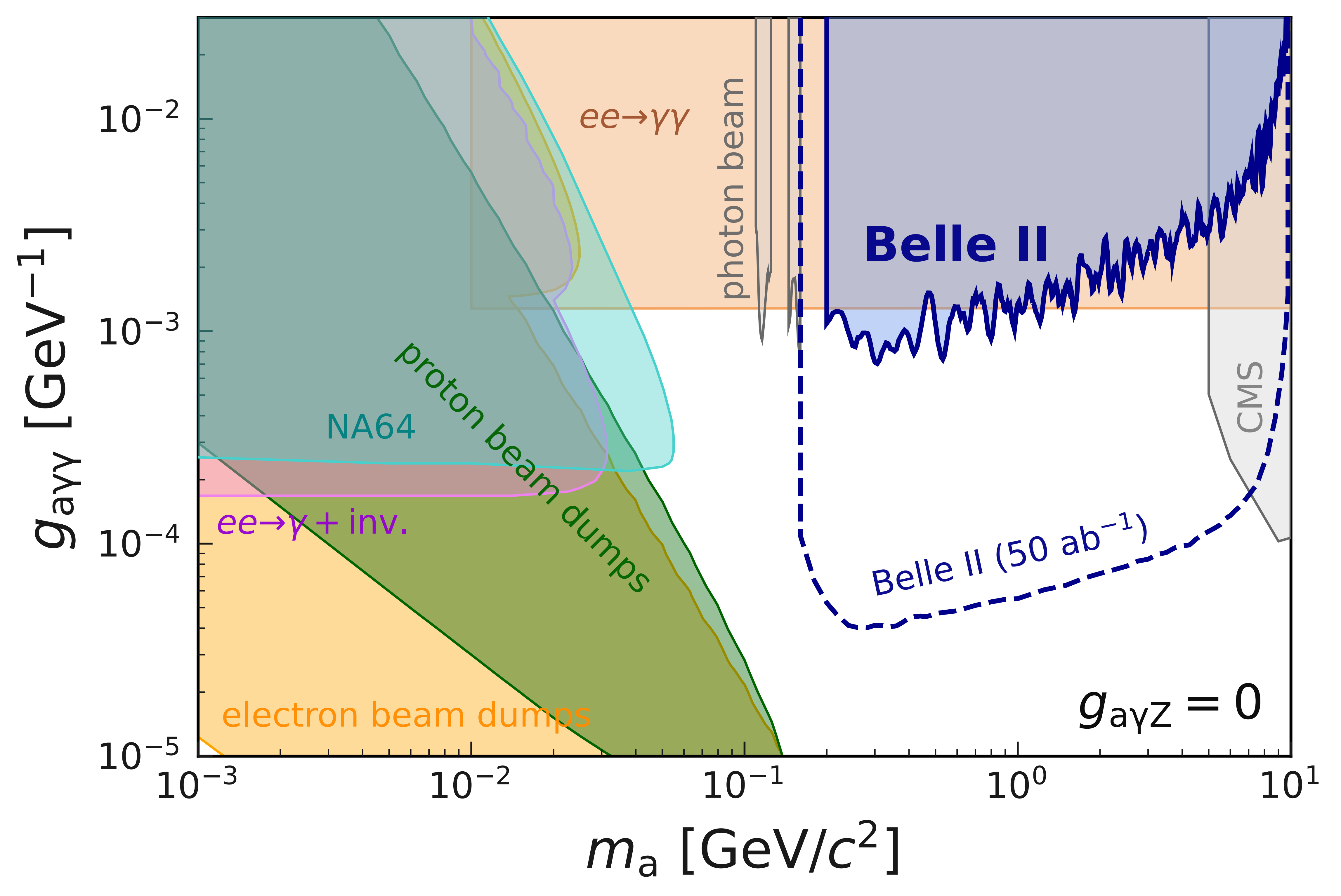
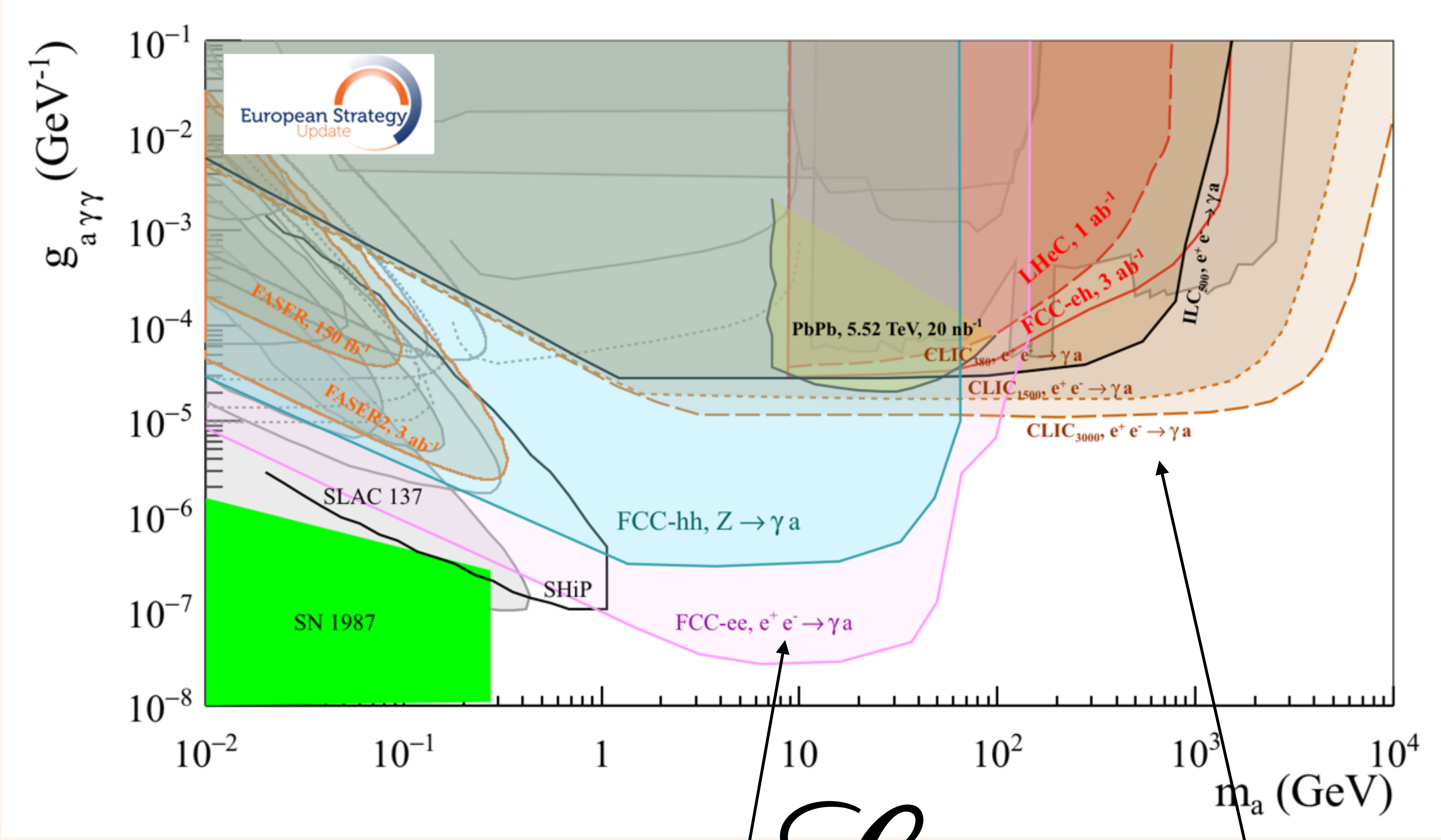
prompt(ish) visible final states $e^+e^- \to \gamma + \gamma\gamma$





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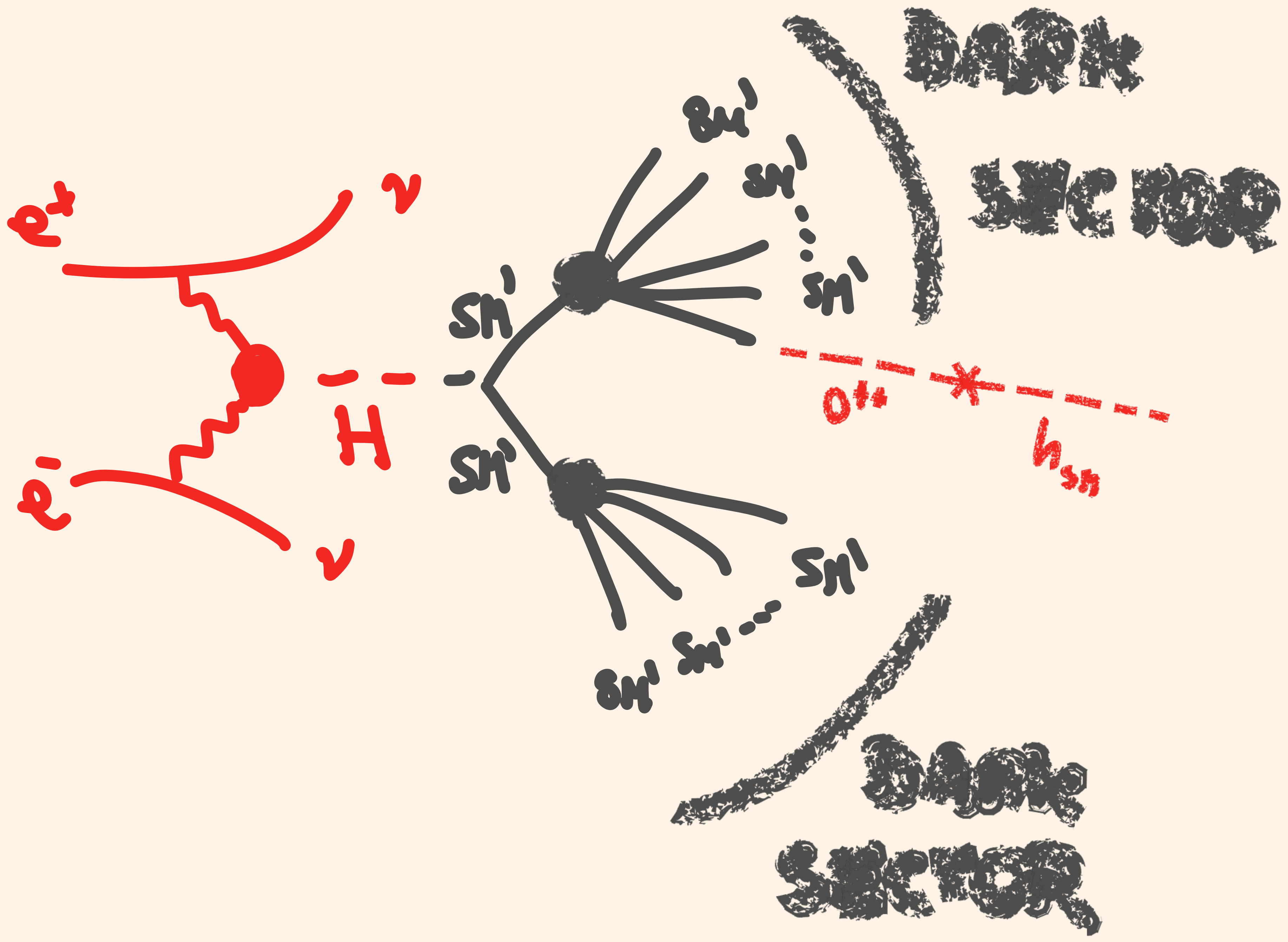
long-lived visible signatures

A whole sector “mirrors” the SM in order to explain (at least in part) the lightness of Higgs boson.

The coupling between the SM and the mirror sector needs to be somewhat suppressed to accomplish the task (e.g. stabilize the weak scale)

$e^+e^- \to H\,\nu\nu$ | $H \to LLP\,LLP$ ……$c\beta\gamma\tau_0$…… $LLP \to bb$

“Neutral Naturalness” scenarios: Folded SUSY, fraternal Twin Higgs, …



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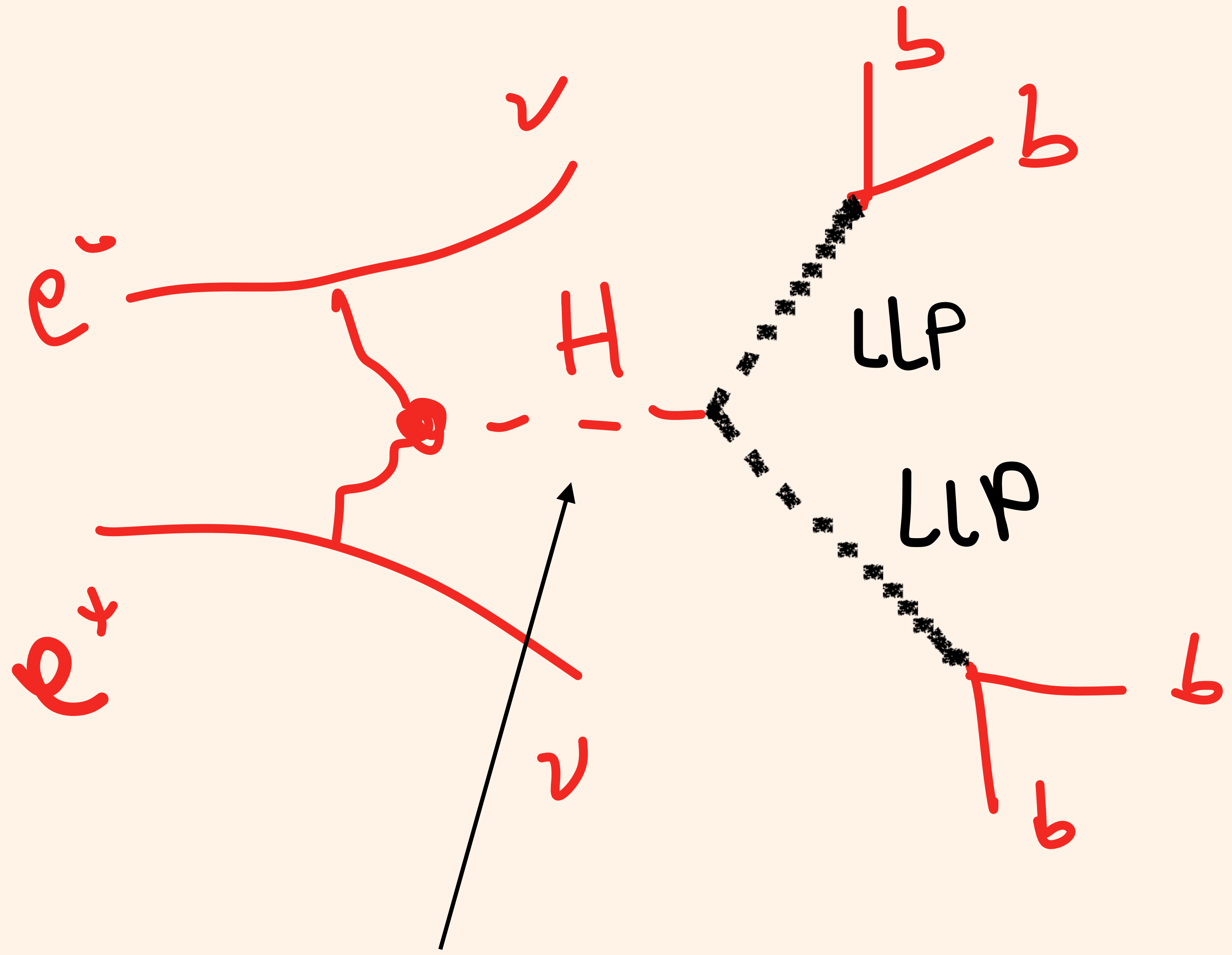
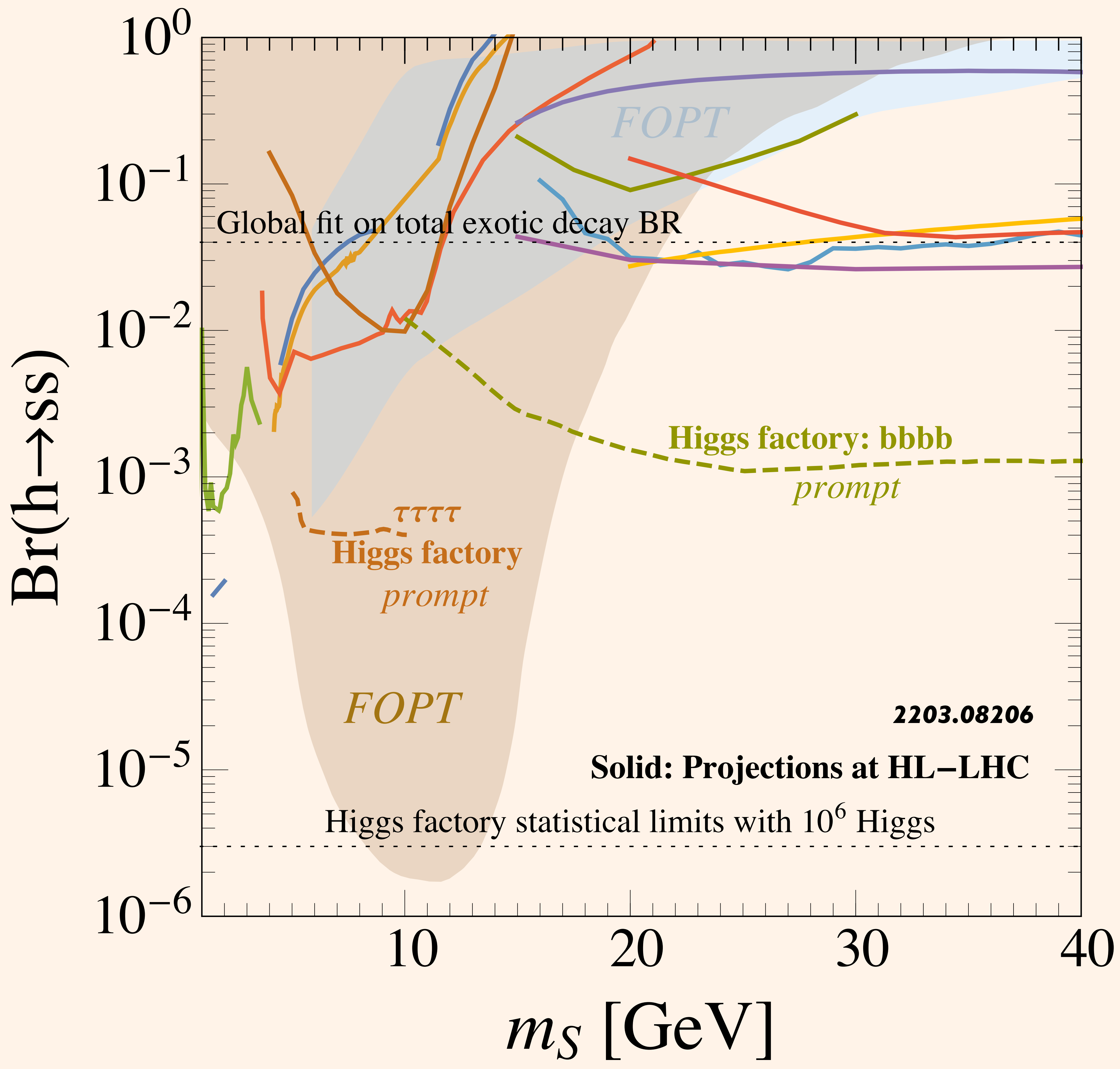


m_H=125, 200, 400, 600, 800, 1000 GeV

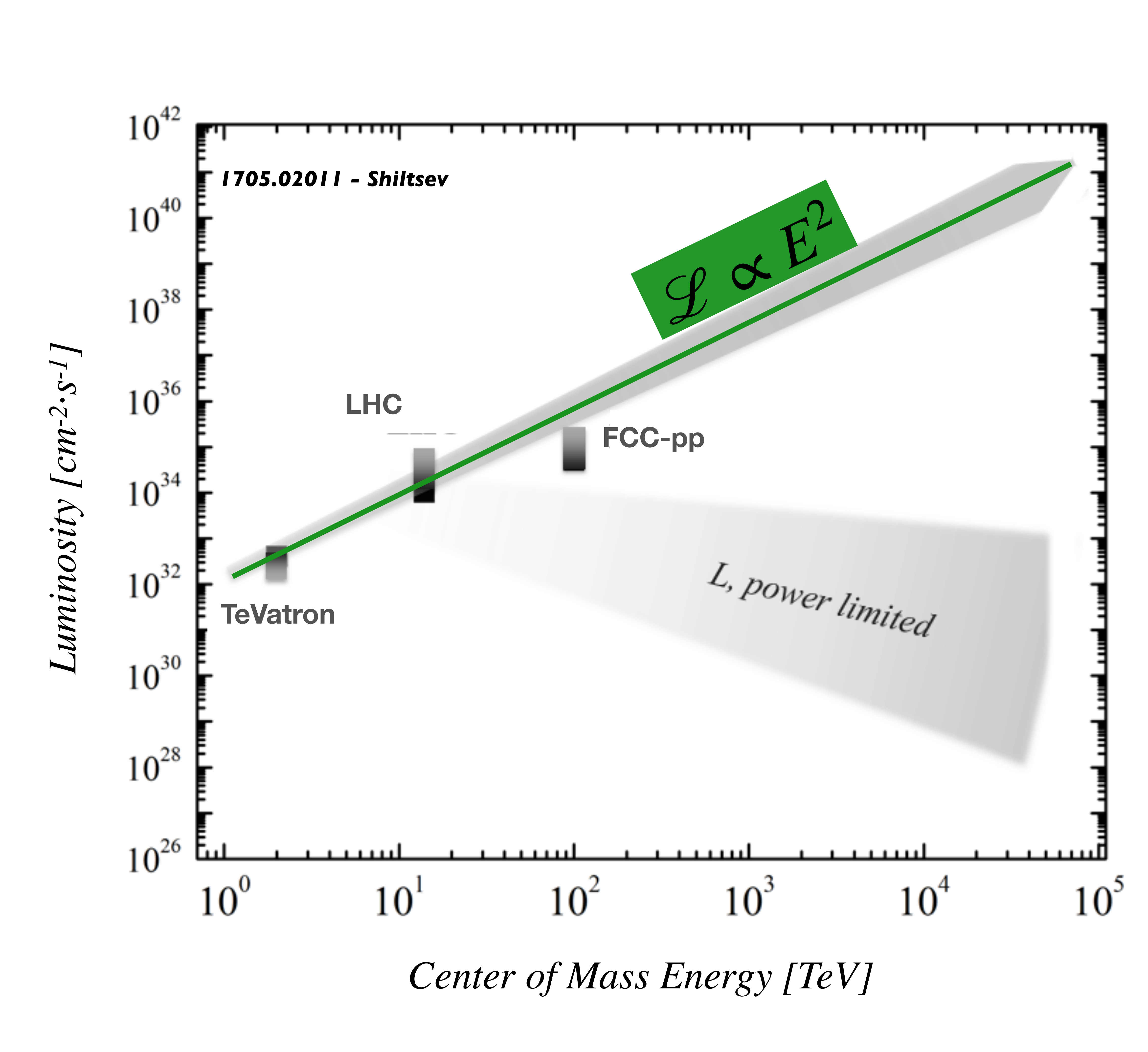
The deeper you look …
the larger lumi you need

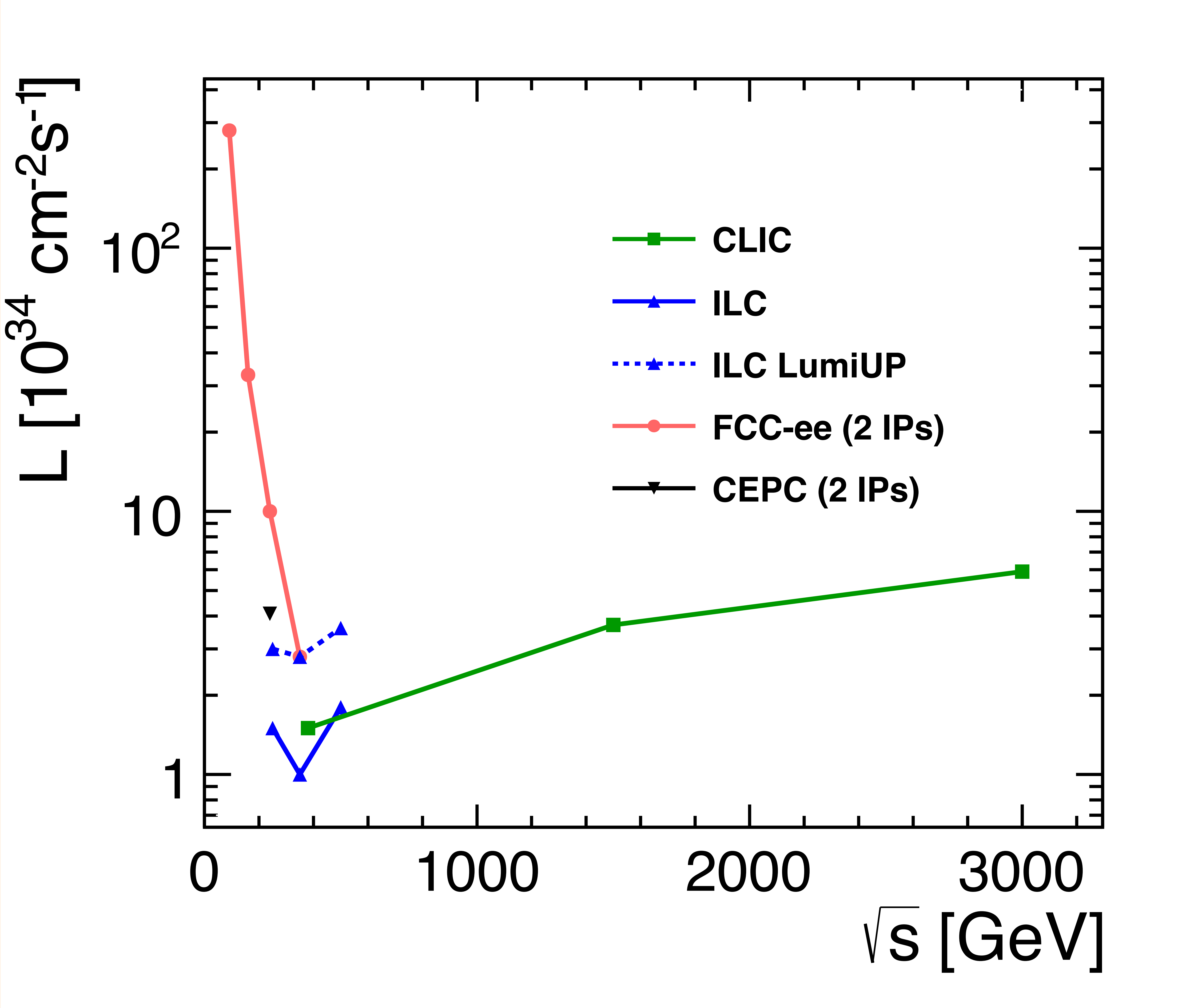
other possible LLP origins may include the realization of one Sakharov condition for baryogensis: an out-of-equilibrium phase of the Universe during a 1st order Phase Transition at the weak scale

$$h \to s_{LLP}\, s_{LLP}$$



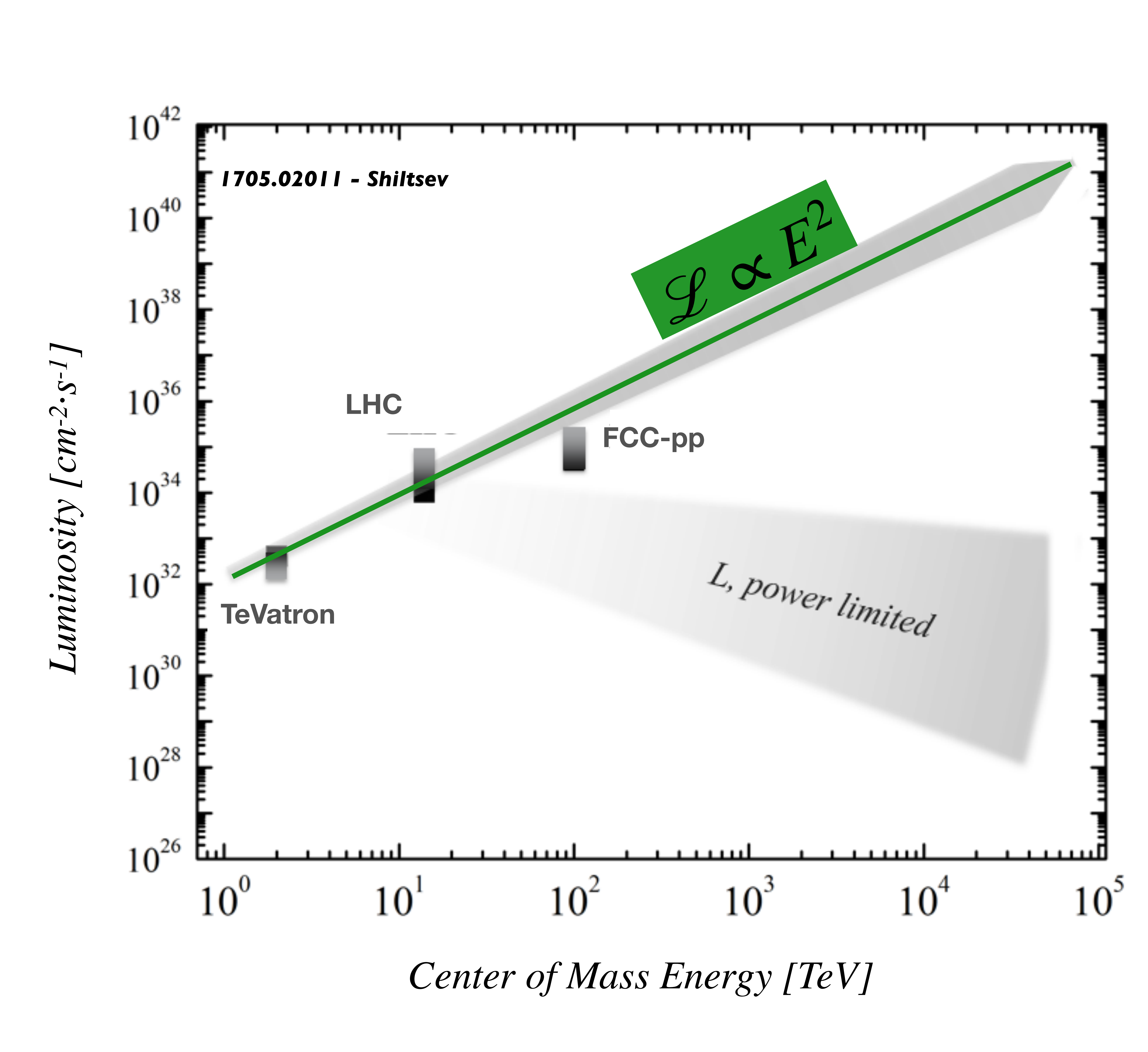
The larger lumi you need

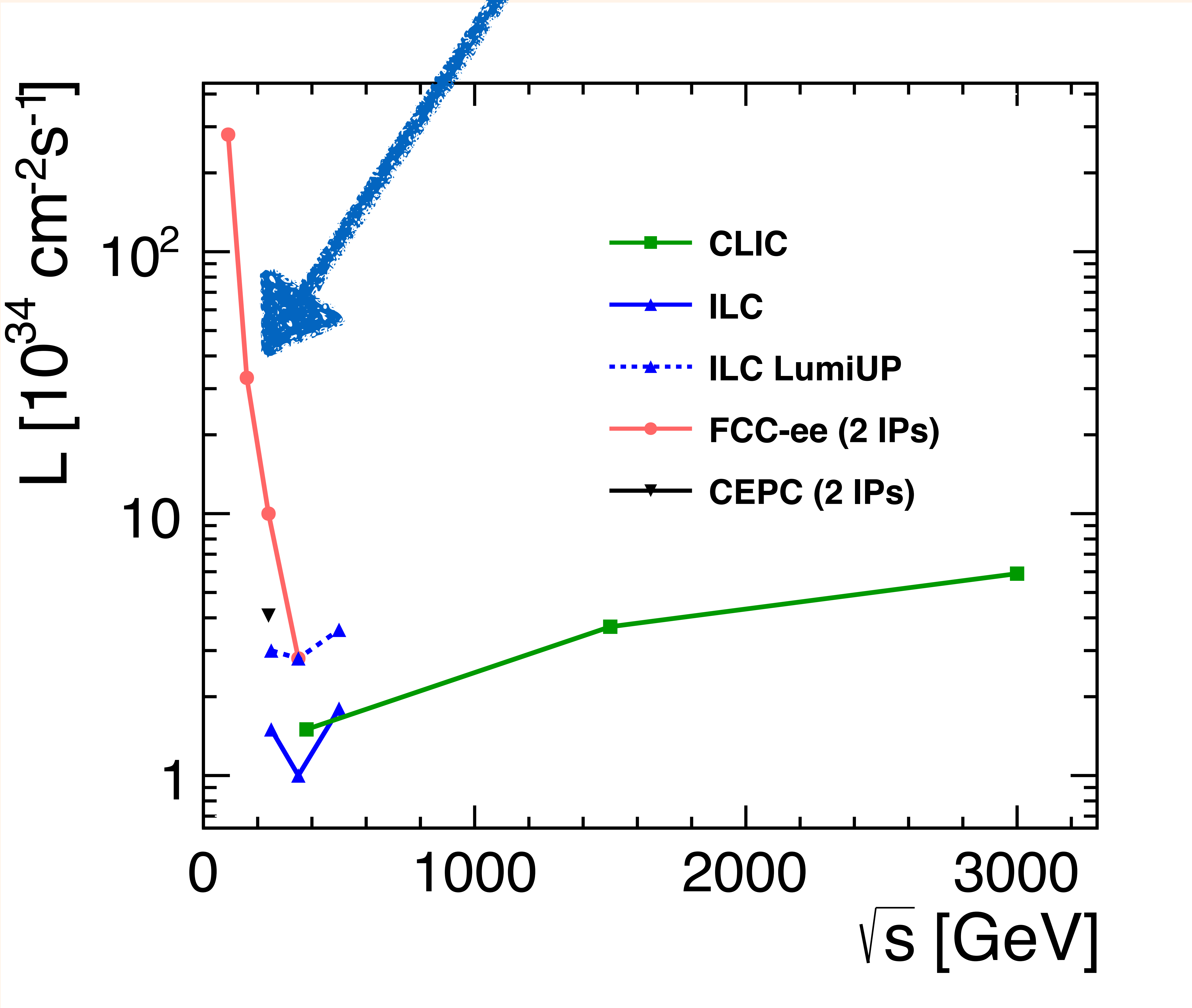




The larger lumi you need

Luminosity falls too fast





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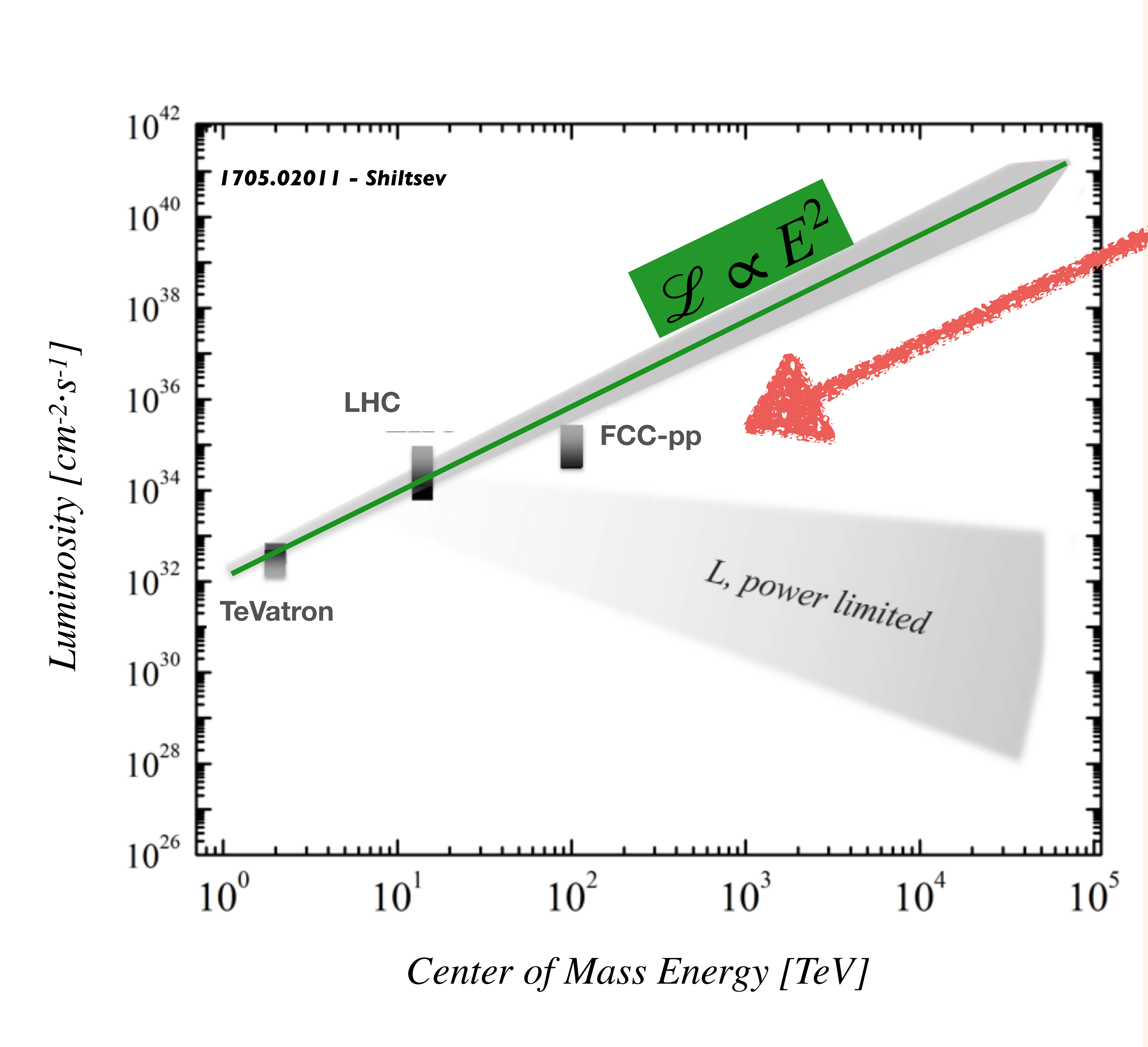
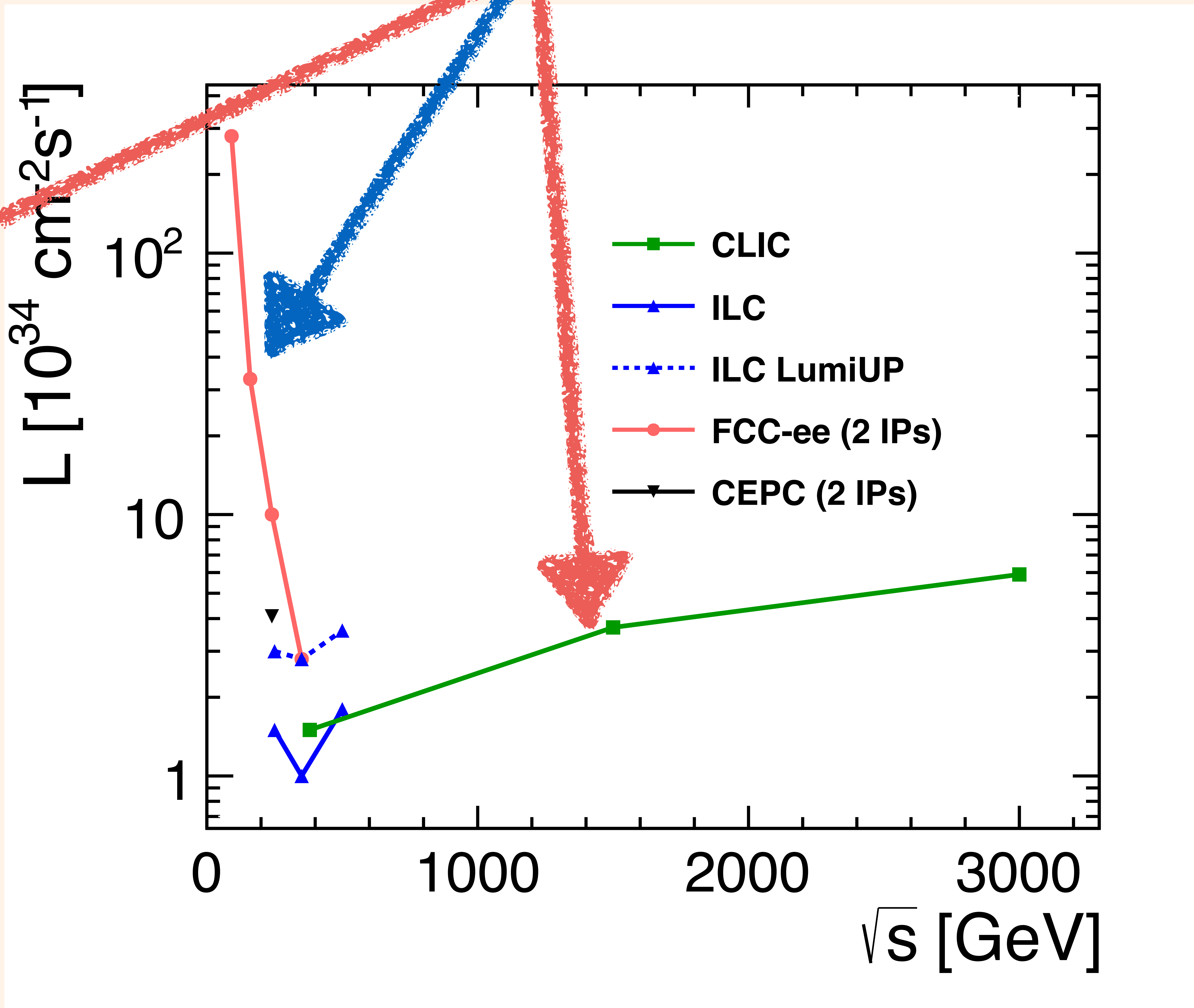
Luminosity is not growing fast enough



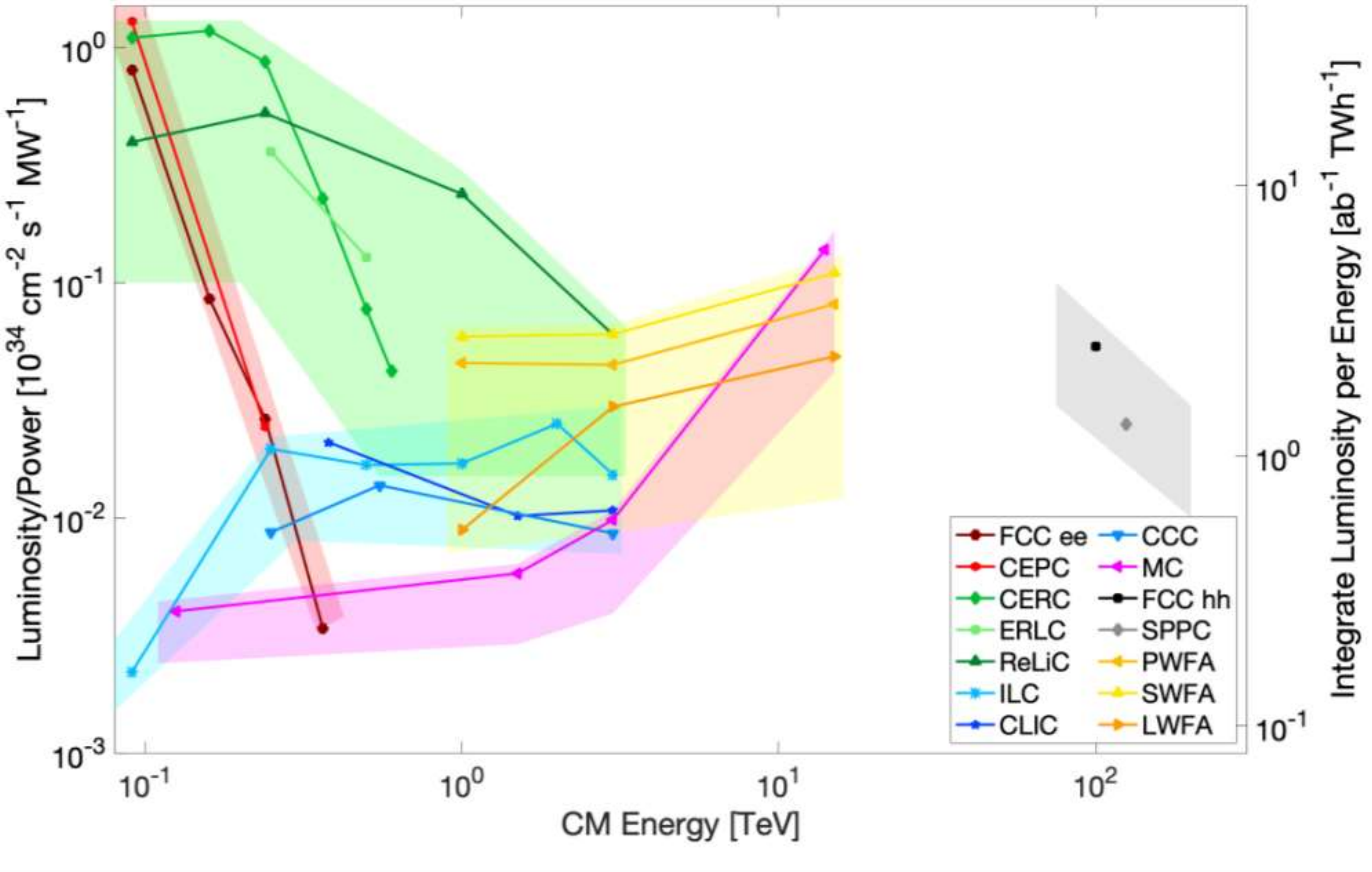


Luminosity per Power

Shiltsev@eeFACT22

Circular *ee*	ERL based *ee*	Linear *ee*	Muon coll	Wakefield	Hadron *pp*

- Figure-of-merit Peak Luminosity (per IP) per Input Power and Integrated Luminosity per TWh.
- Integrated luminosity assumes 10^7 seconds per year.
- The luminosity is per IP.
- Data points are provided to the ITF by proponents of the respective machines.
- The bands around the data points reflect approximate power consumption uncertainty for the different collider concepts.



Once again: luminosity and power consumption values have not been reviewed by ITF - we used proponents' numbers.

Fermilab

ITF Report – T.Roser, et al, arXiv:2208.06030

Conclusions

- lots of motivations for BSM out there!
- Dark Matter suggests a whole dark sector may exist
- other issues may find a solution in scenario featuring a somewhat secluded sector $\Rightarrow$suggestive of small couplings (for baryogenesis, Higgs and weak scale, neutrino and flavor patterns …)
- luminosity is a key parameter to gain sensitivity to these scenarios at e^+e^- machines

Thank you!