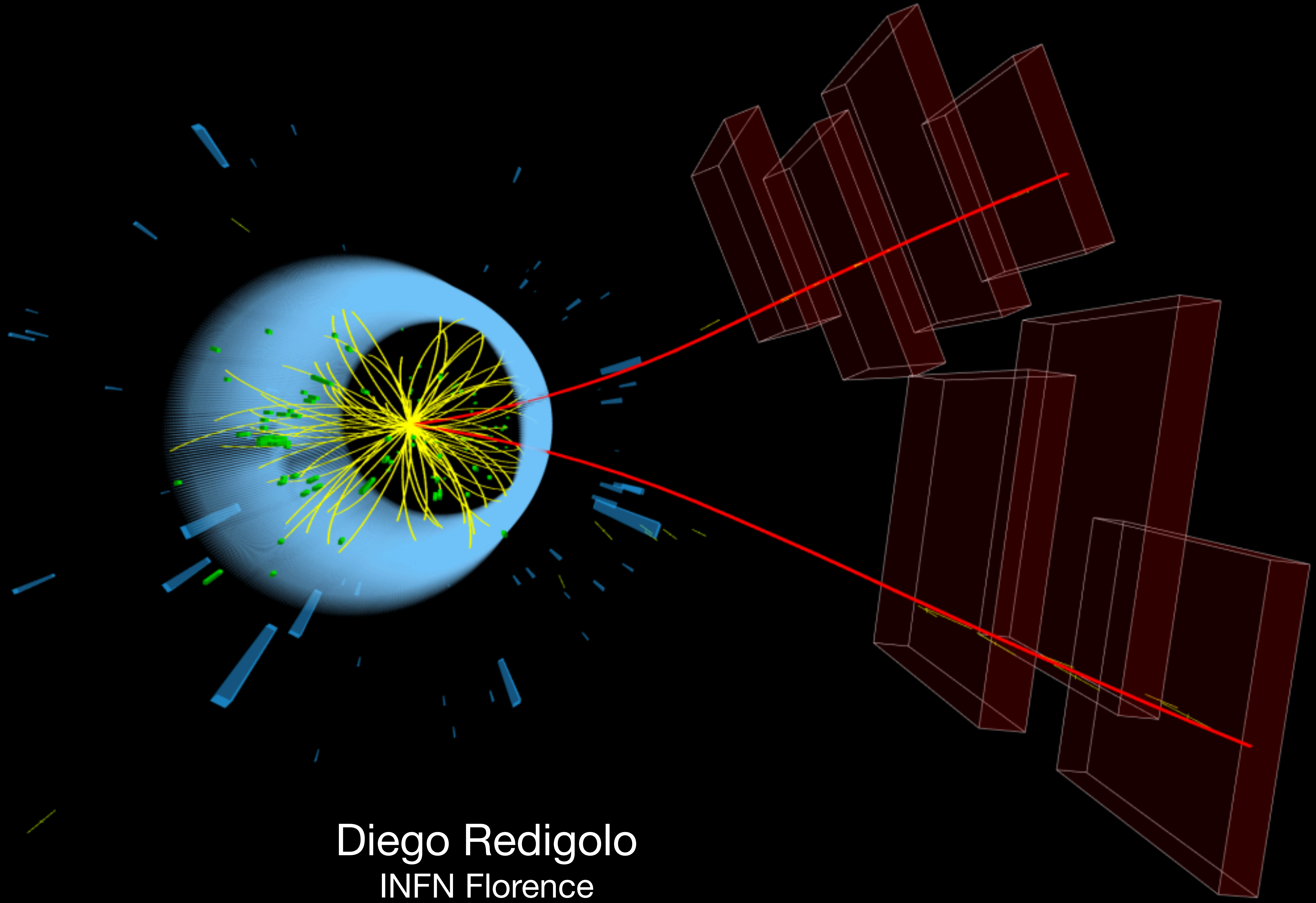
LHC and flavor experiments at the intensity frontier



Diego Redigolo
INFN Florence

Keyword

TRIGGERING

Finite band width make experiments theory biased

We will loose important data if we do not ASK to look for it

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TRIGGERING

Finite band width make experiments theory biased

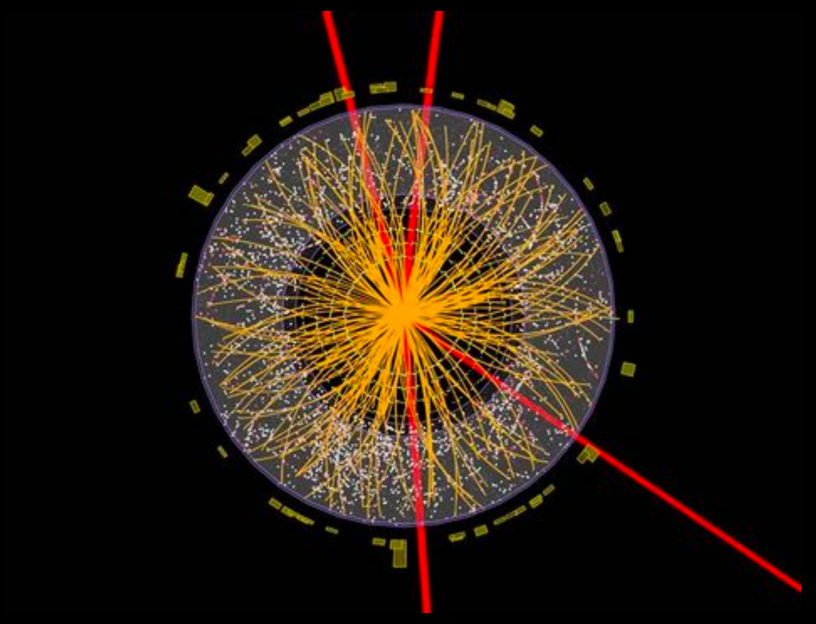
We will loose important data if we do not ASK to look for it

@ LHC

ATLAS EXPERIMENT

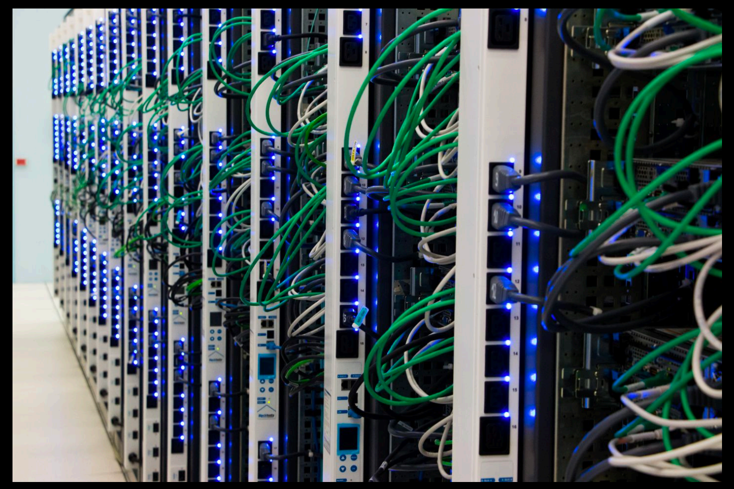
CMS

LHC Trigger basics



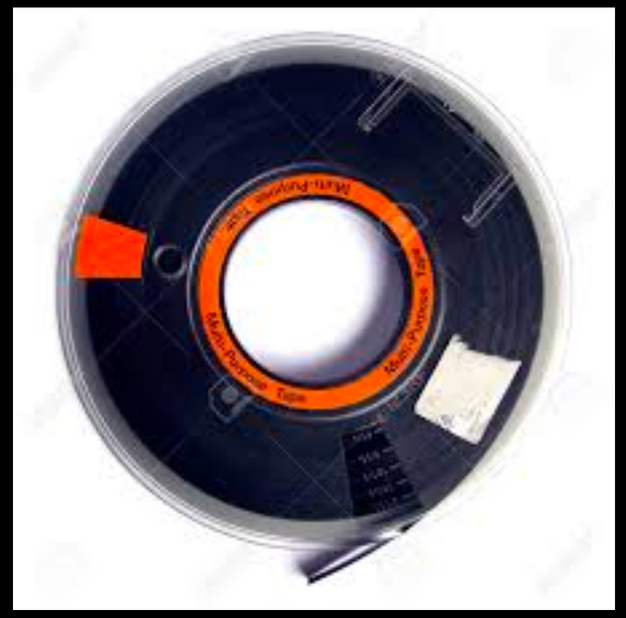
40 MHz

Level 1 (L1)



100 kHz

High level (HLT)



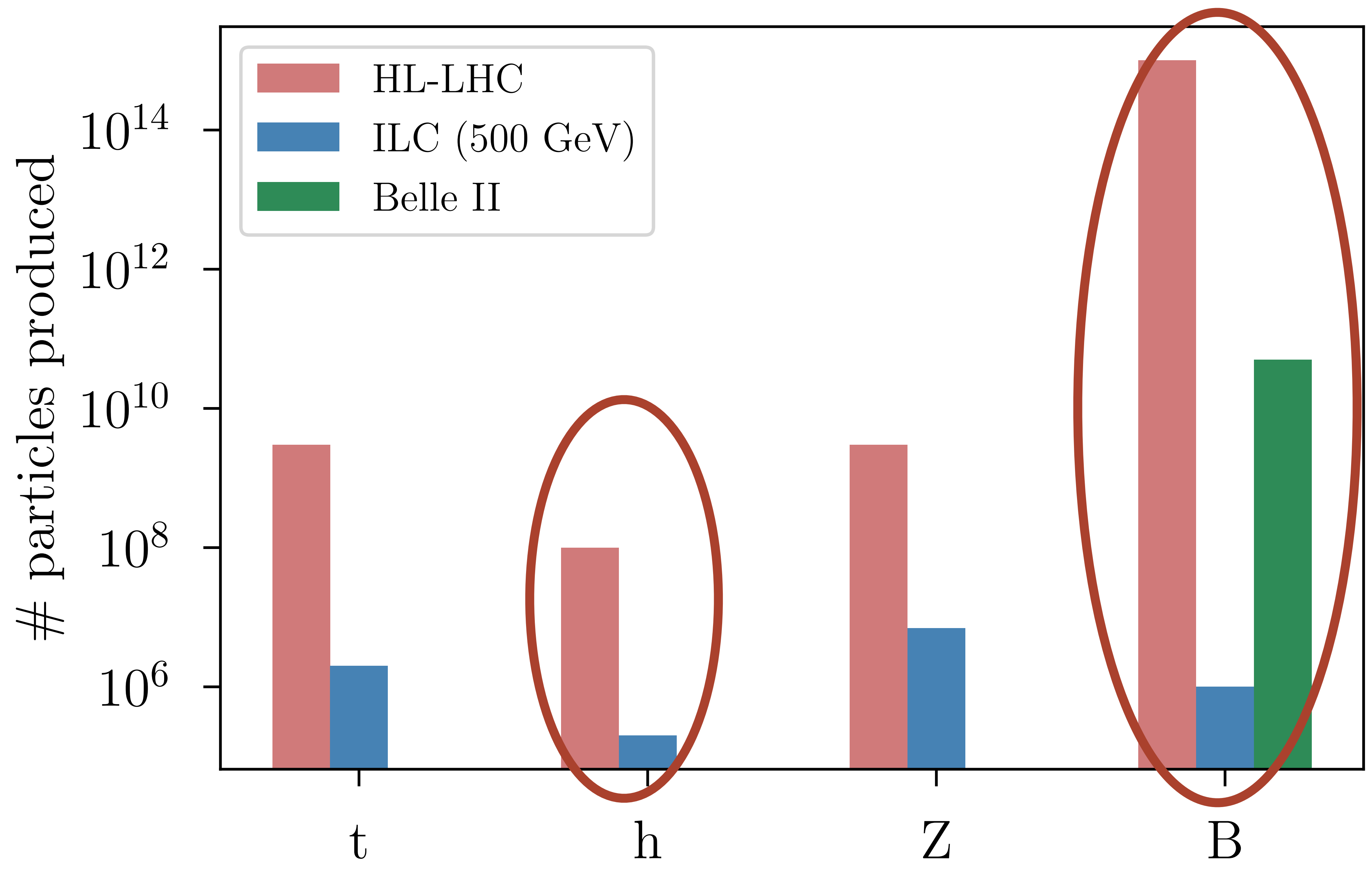
1 kHz

Only 0.0025 % of all collisions get recorded 😨

→ Triggers are critical to the experimental programs at ATLAS, CMS and LHCb!

Currently only tracking at HLT step

LHC at the intensity frontier



Yield for exotic decay modes:

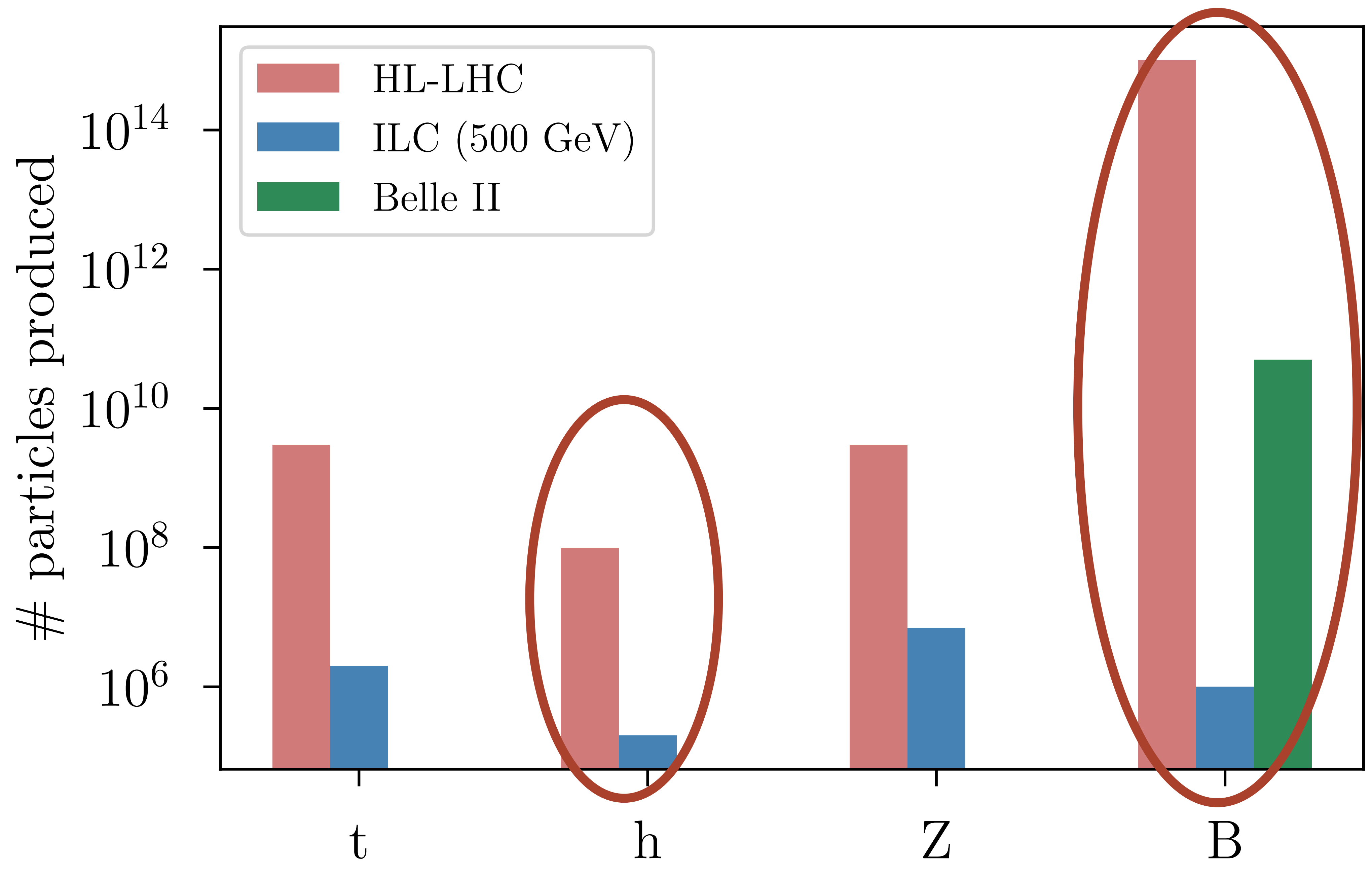
$$\# = \text{Luminosity} \times \sigma_{B\bar{B}} \times \frac{\Gamma_{\text{exotic}}}{\Gamma_B}$$

~ 0.5 mbn

~ 0.4 meV

Sensitive to tiny couplings!

LHC at the intensity frontier



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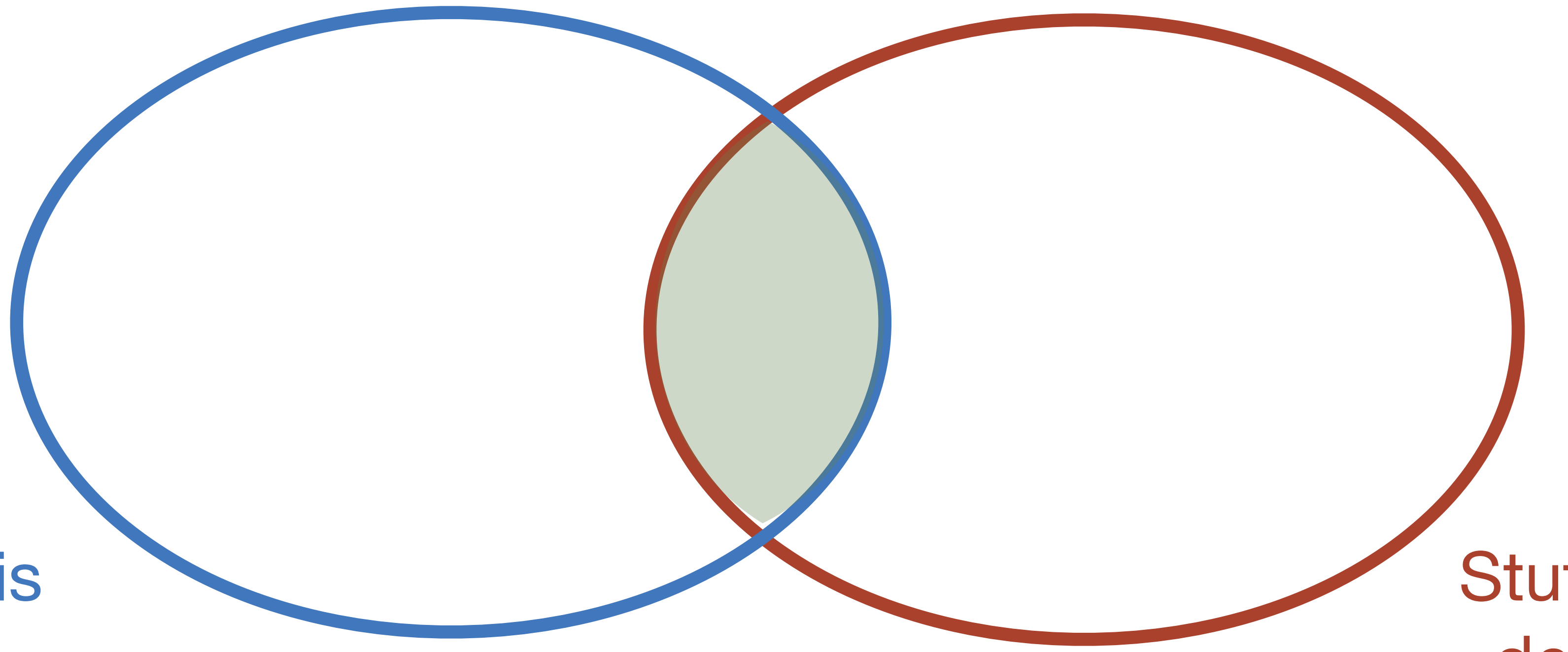
Complementary sensitivity for signals with

- Low rates
- Relatively low backgrounds (online + offline)

Things to do with the phase II upgrade

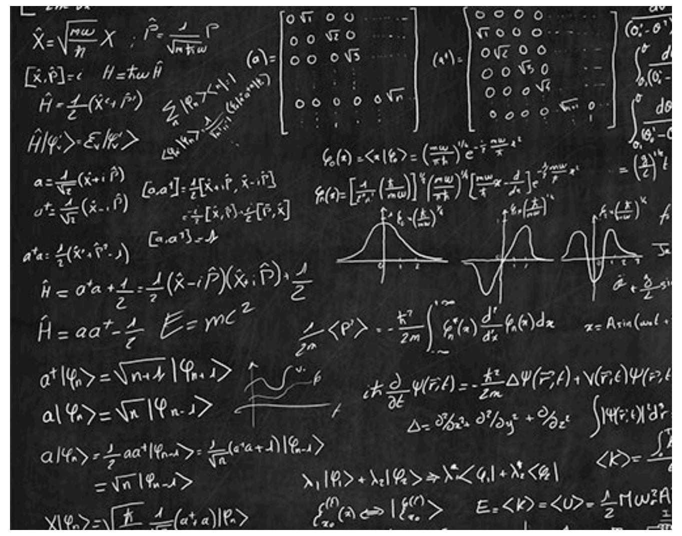
Experimental physics

Stuff that is feasible



Stuff that is desirable

Stuff that we should try to do



Theoretical physics

Two examples:

Things to do with the phase II upgrade

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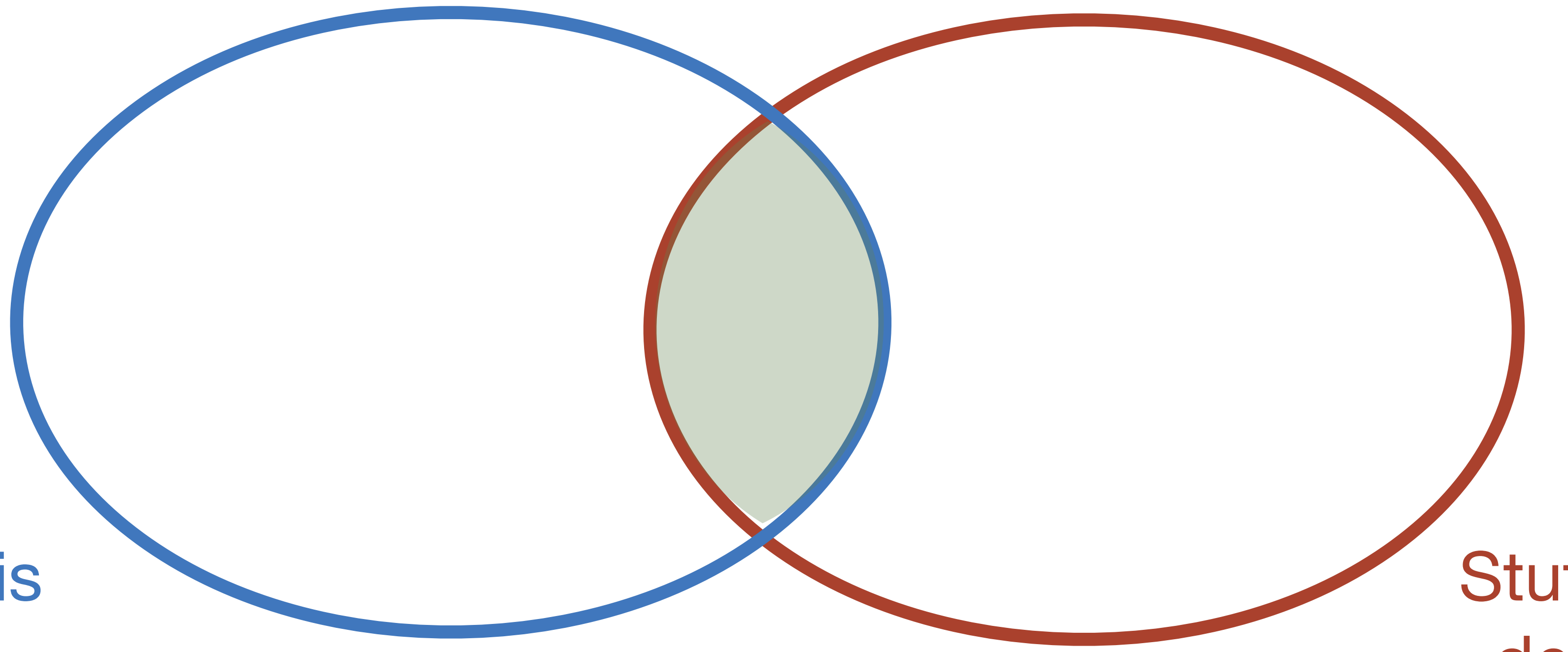

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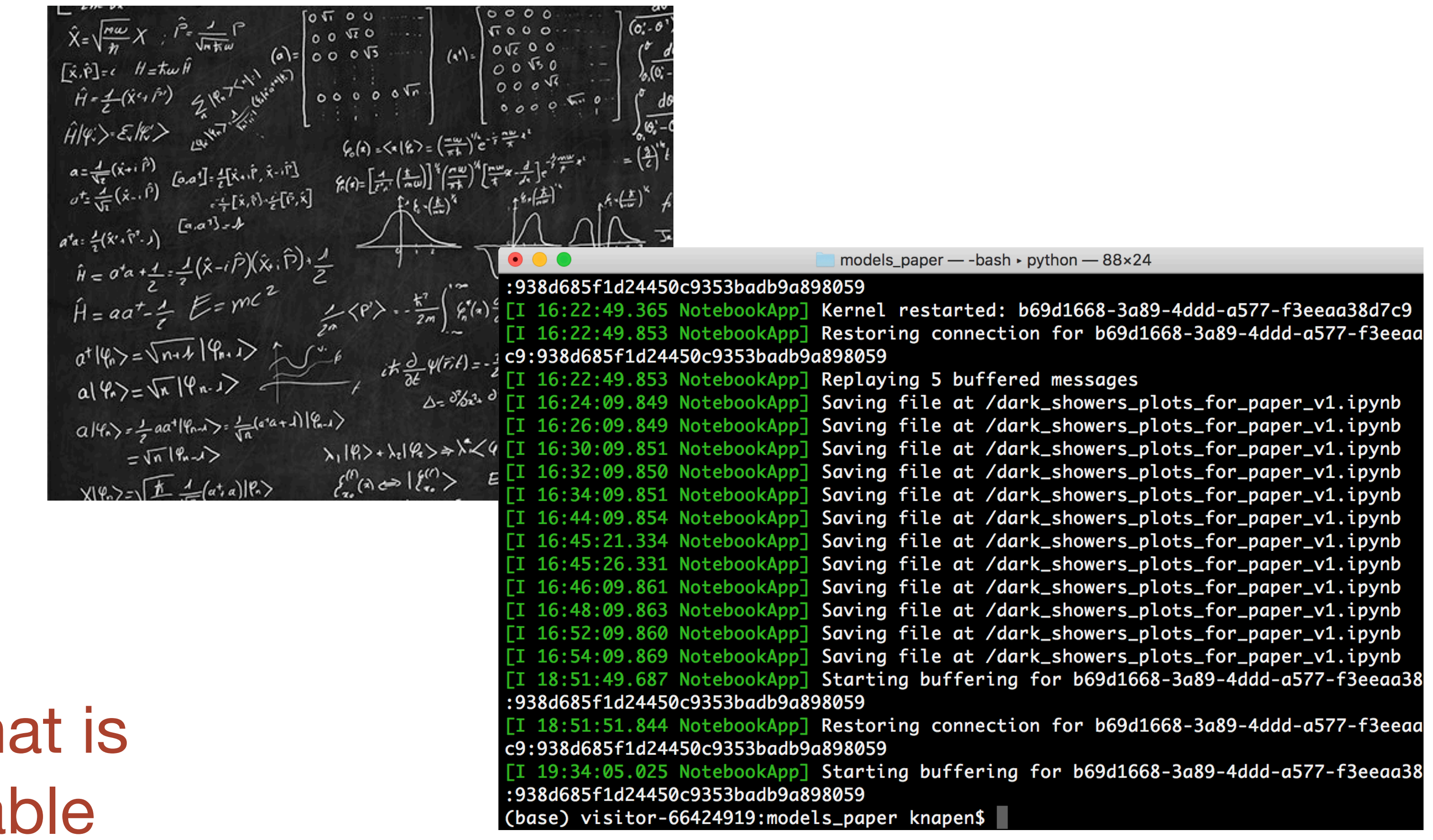

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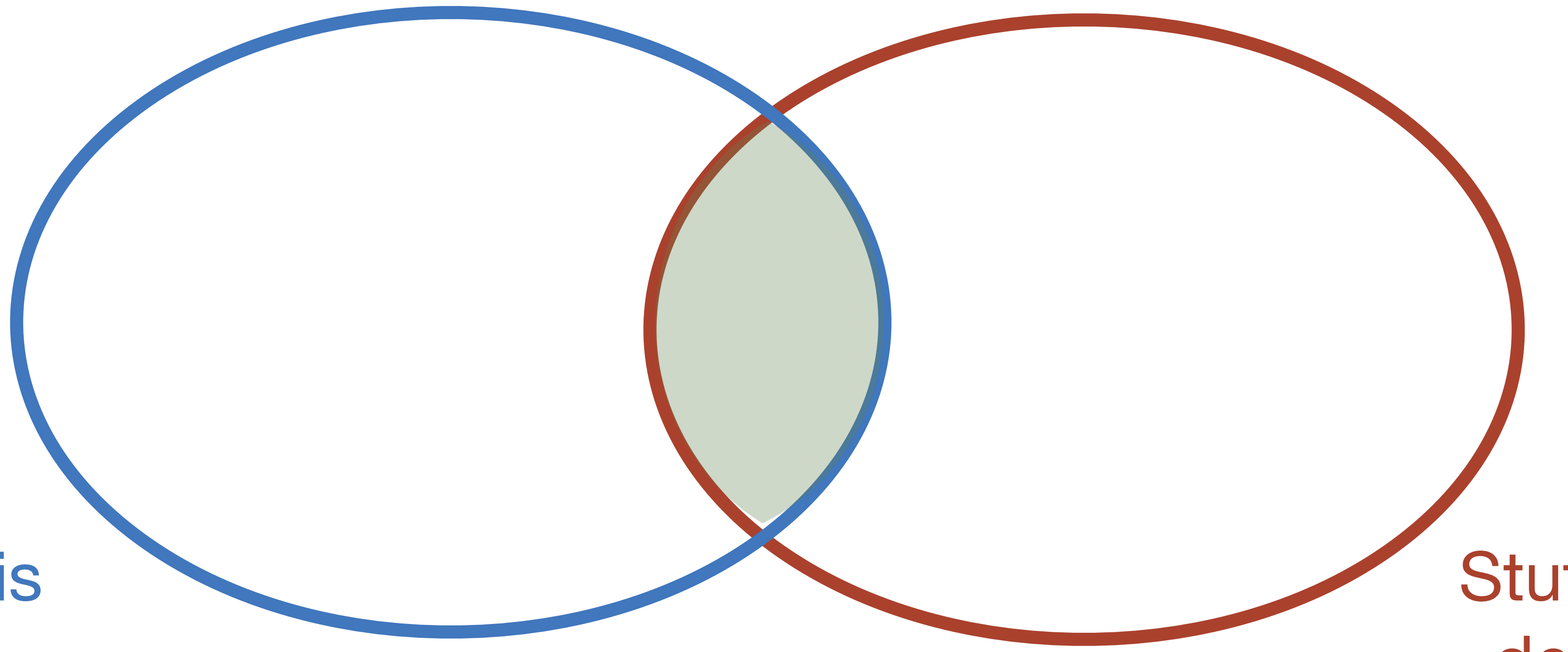

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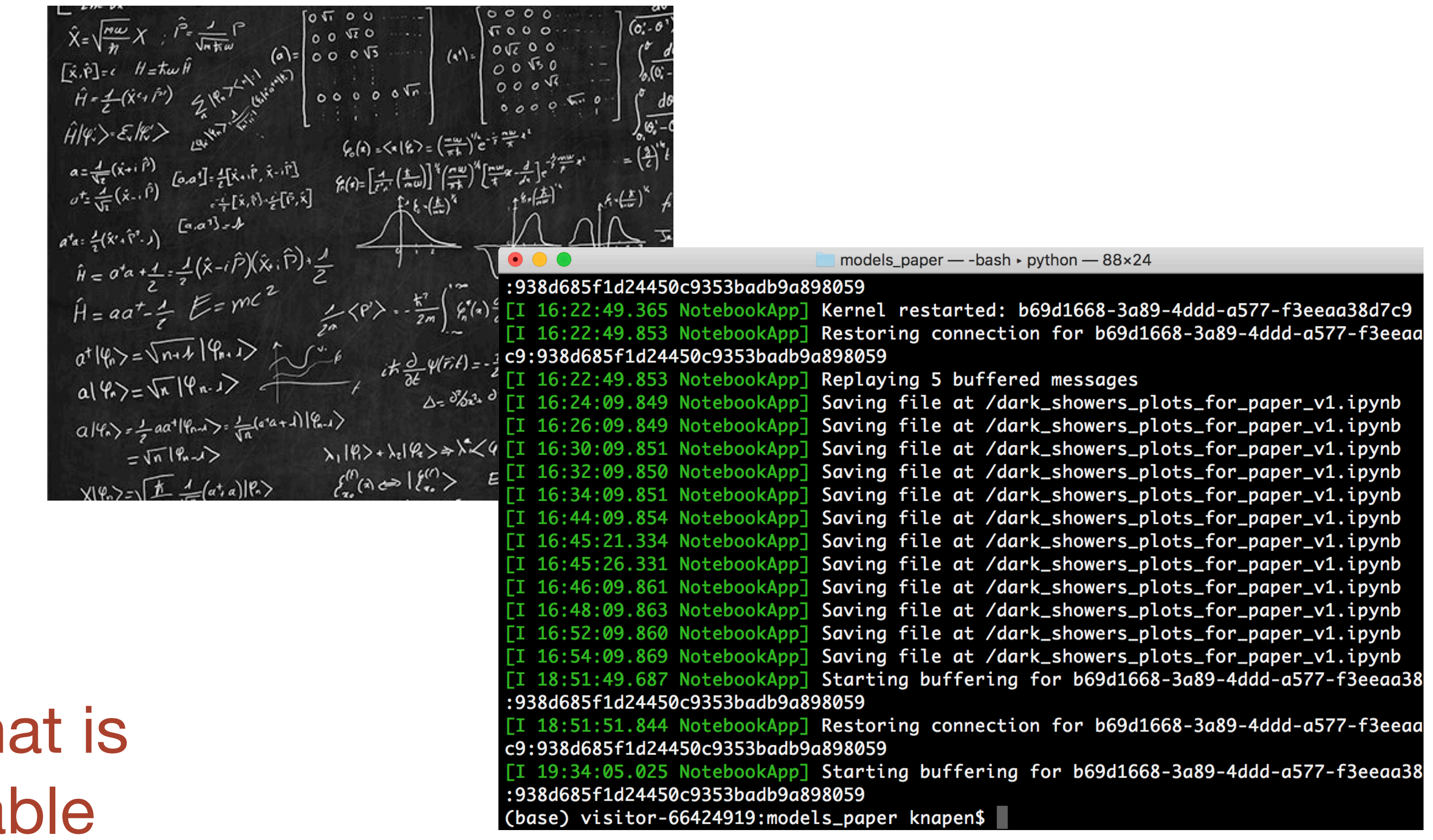


Theoretical physics

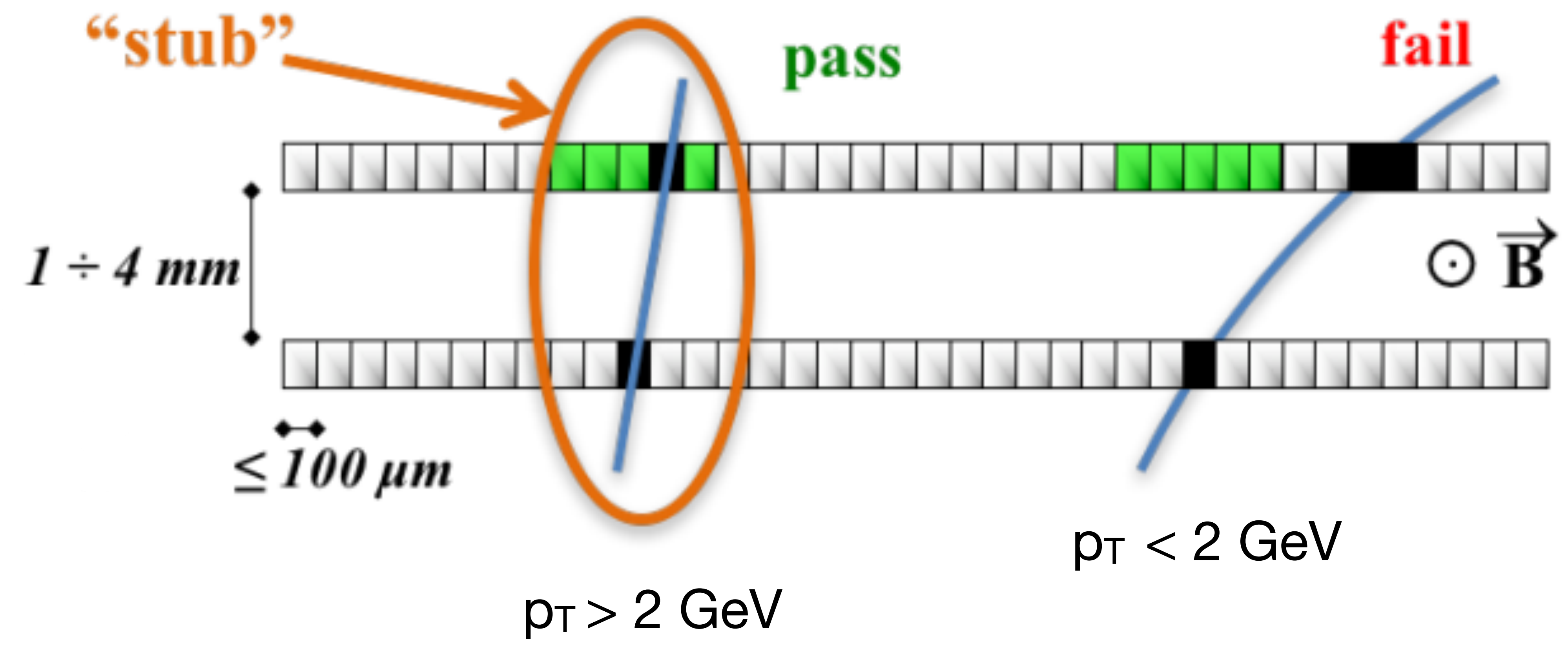
Two examples:

Displaced vertex triggers (Exotic Higgs & B decays)

Data scouting (Light diphoton resonances)

Experimental opportunities with the LHC upgrade

CMS L1 track trigger $\eta < 2.4$



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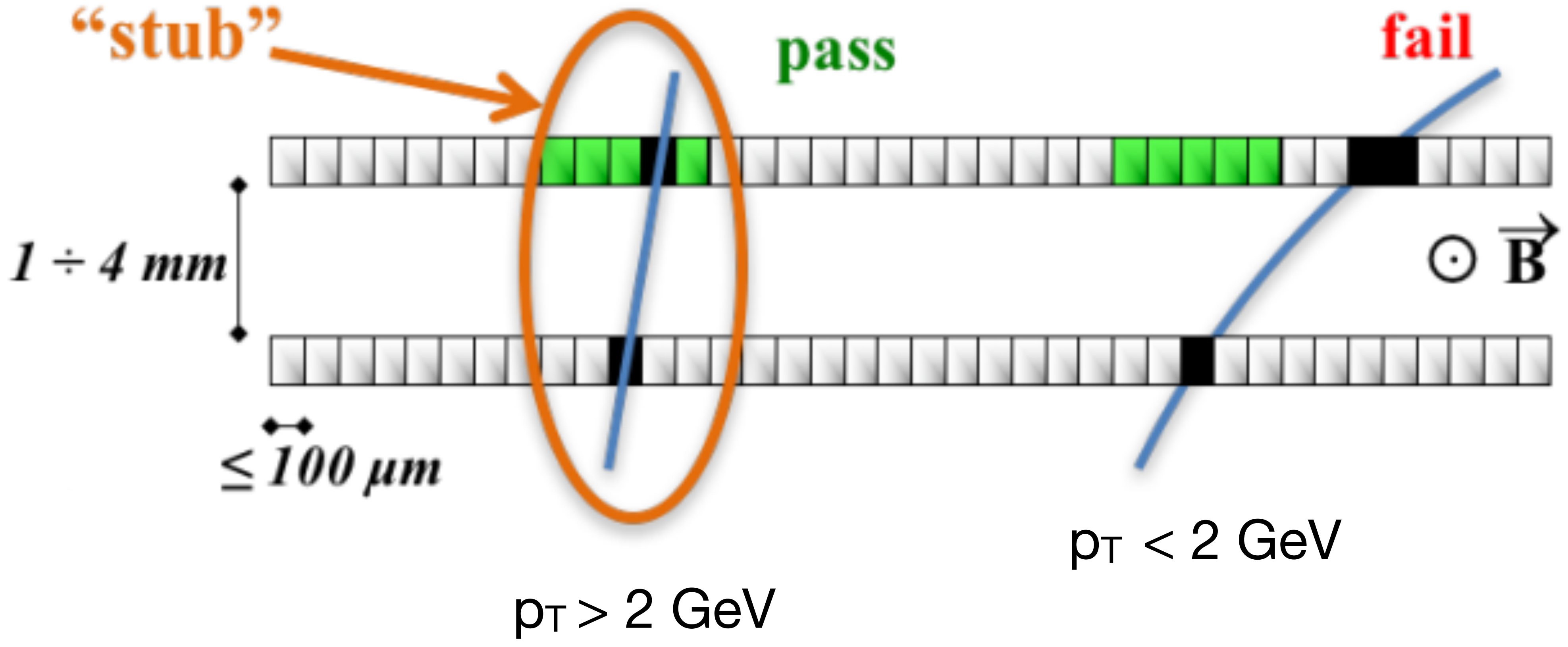

Each module independently measures the p_T of the stubs

↓

Only stubs with $p_T > 2$ GeV are used in track reconstruction

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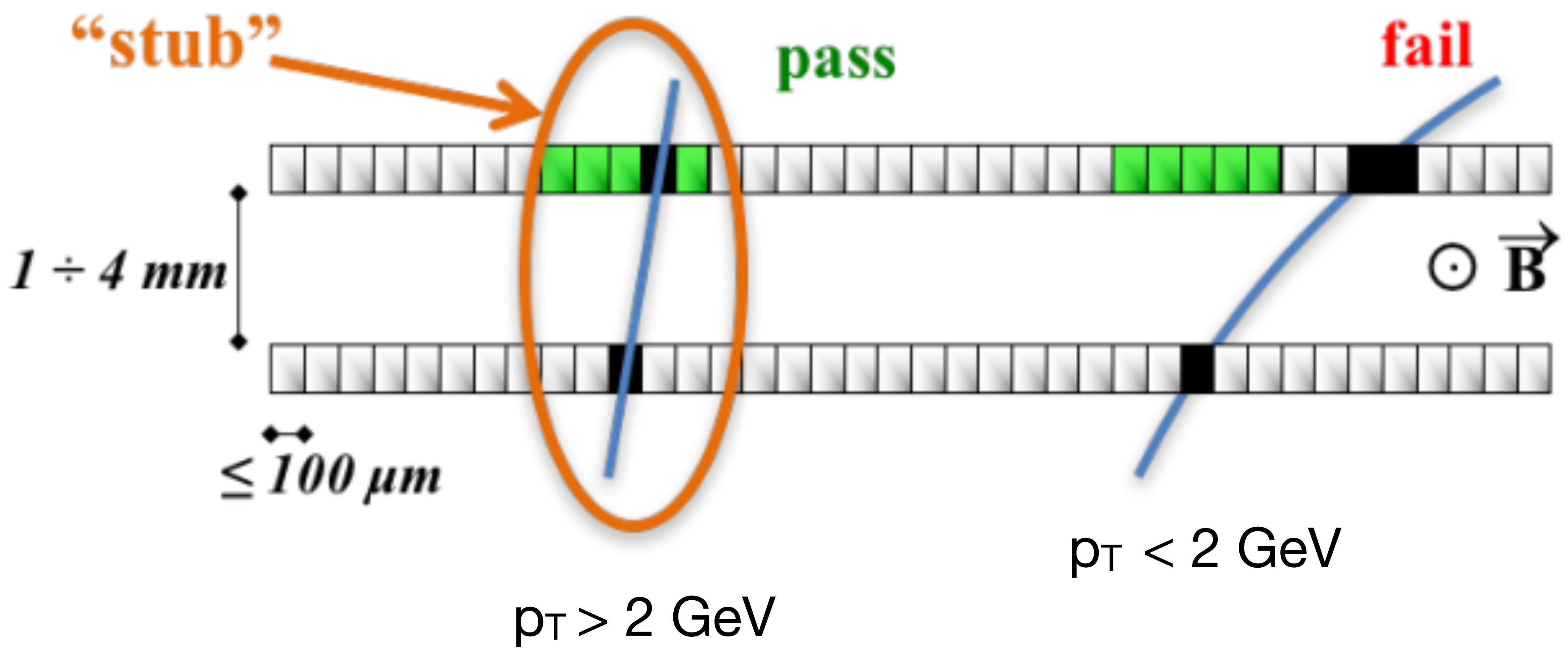

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↓

Only stubs with $p_T > 2$ GeV are used in track reconstruction

Key point: For moderate displacements, stubs are still reconstructed

↓

In principle, track trigger could find displaced tracks

Y. Gershtein: arXiv 1705.04321
CMS PAS FTR-18-018

Experimental challenge

There are A LOT of displaced tracks!

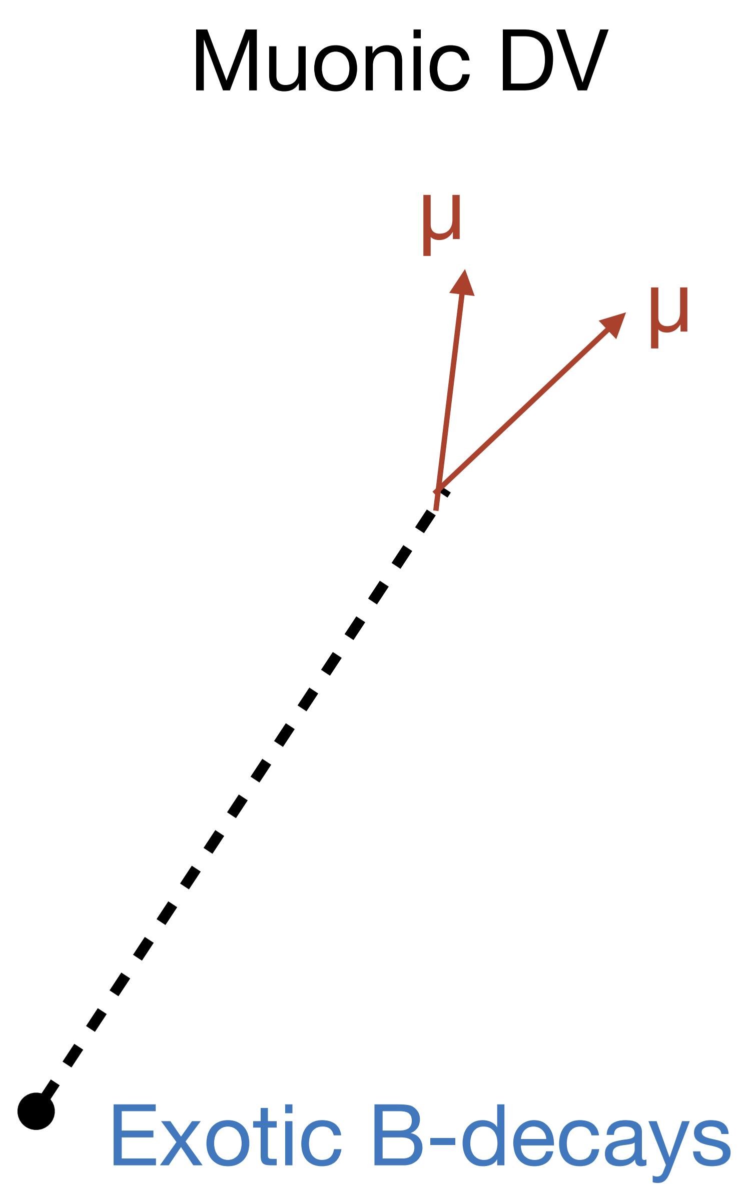
The TRIGGER DESIGN should keep a decent signal efficiency while bringing down the bandwidth to ~1 kHz

Which signal?

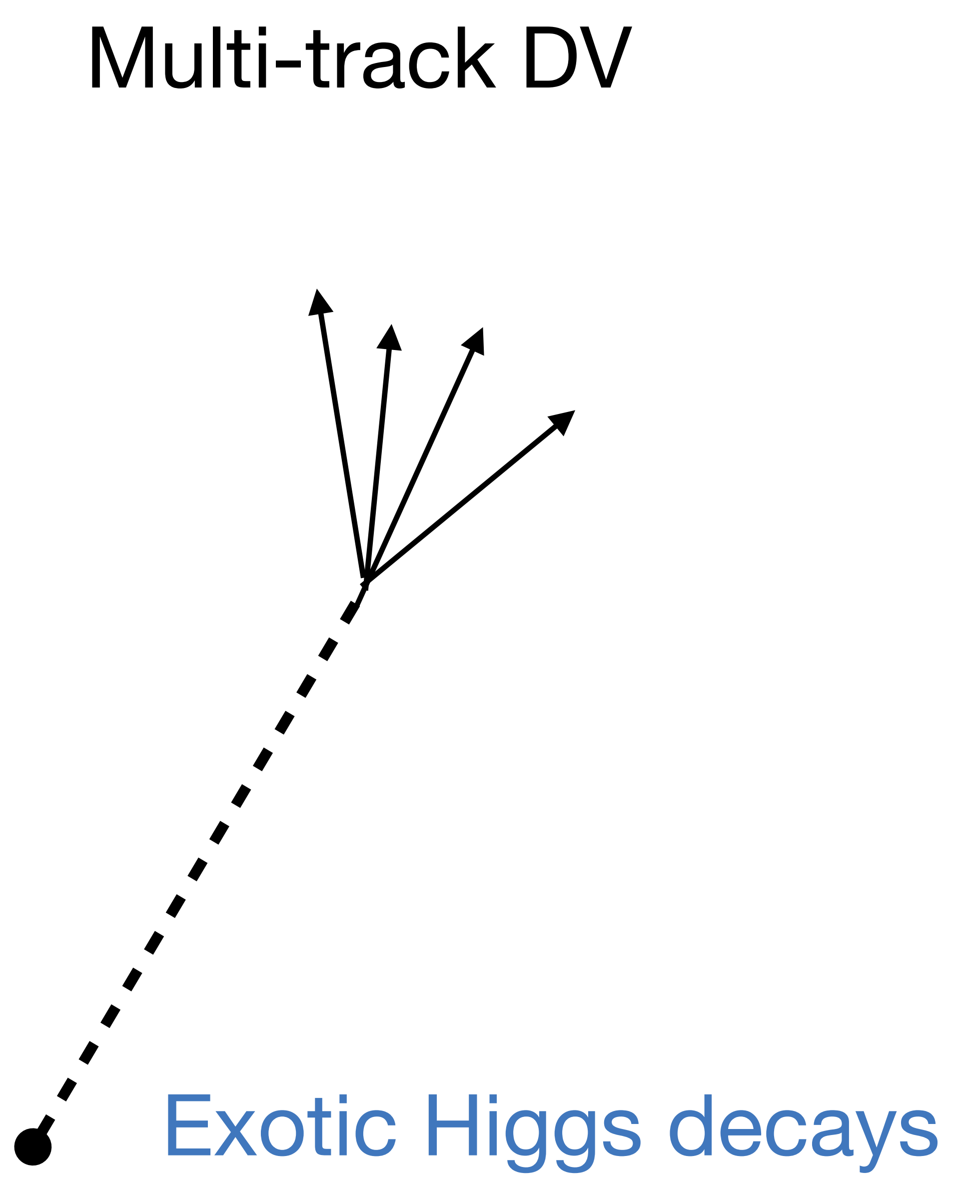
Light new physics is a perfect opportunity

1) Naturally lead to displaced signatures $\Gamma \simeq \frac{\lambda}{8\pi} m$

2) Raising the pT threshold to meet the bandwidth requirements kills the signal efficiency



Y. Gerhstein, S. Knapen
arXiv 1907.00007



Y. Gerhstein, S. Knapen, D.R.
arXiv 2012.07864

Other?

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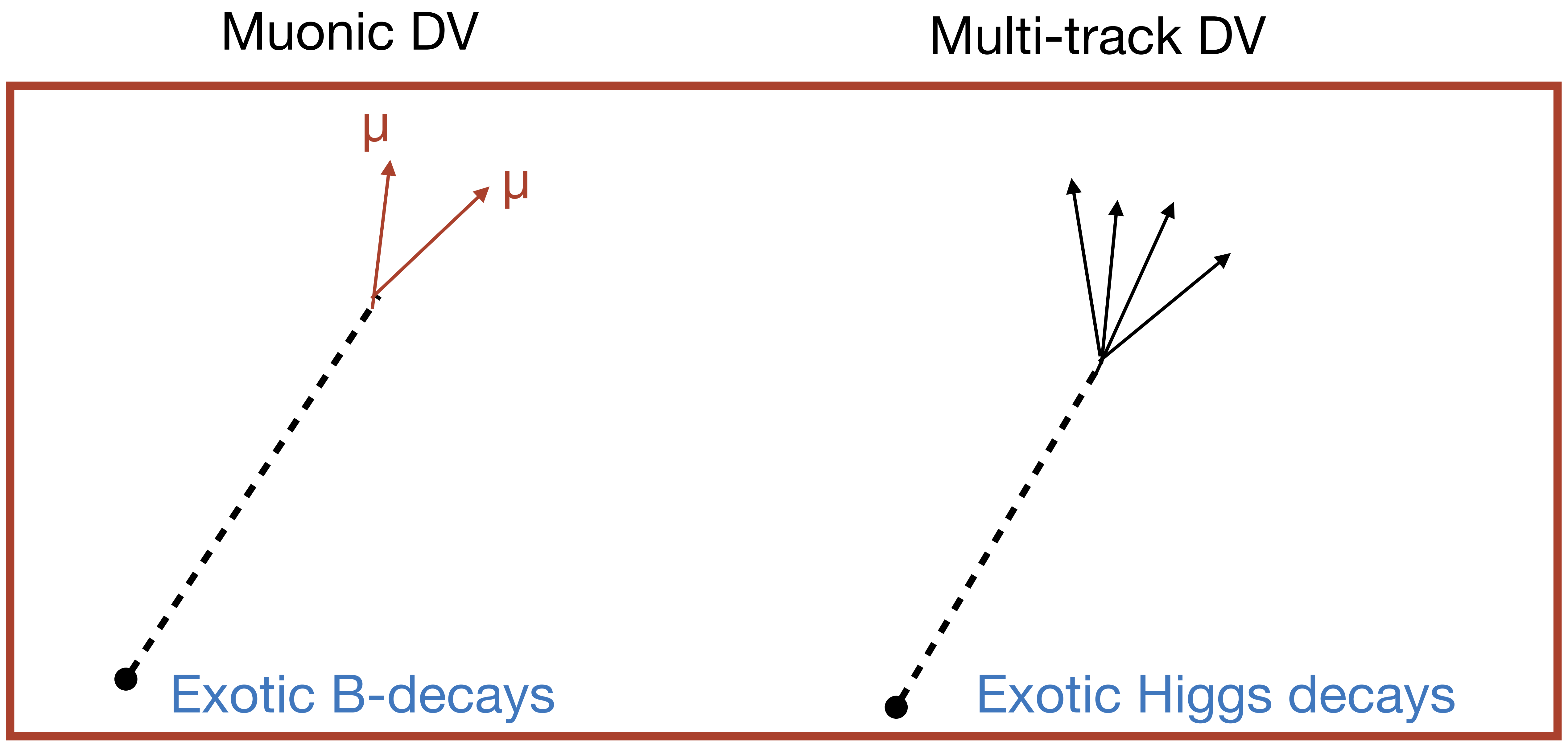

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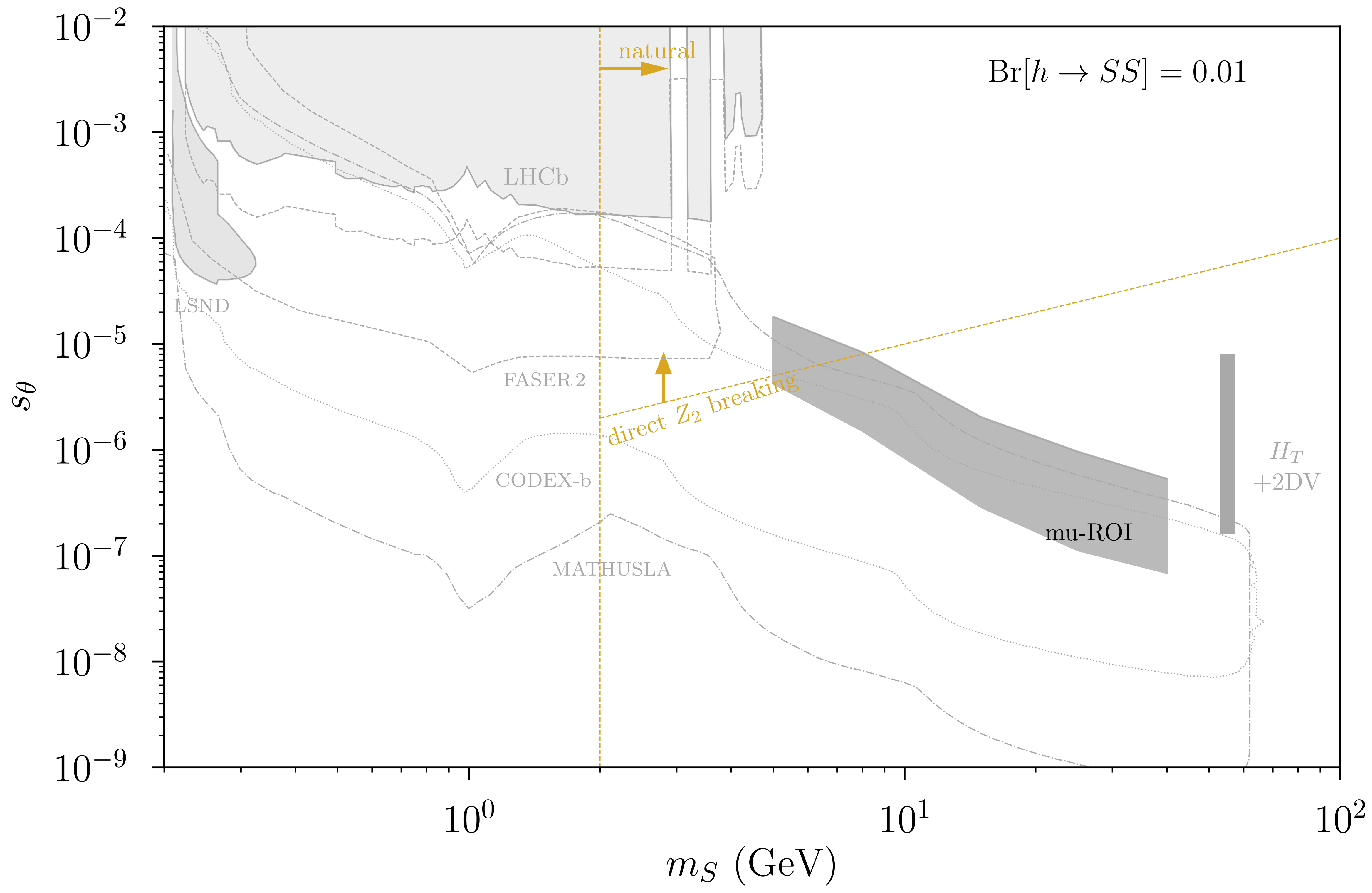
Which model?

Light singlet mixed with the Higgs

$$\mathcal{L}_{\rm S} \supset -\frac{1}{2}\tilde{m}_S^2 S^2 - \mu S H^\dagger H - \frac{1}{2}\lambda_{SH} S^2 H^\dagger H - V_{\rm int}(S)$$



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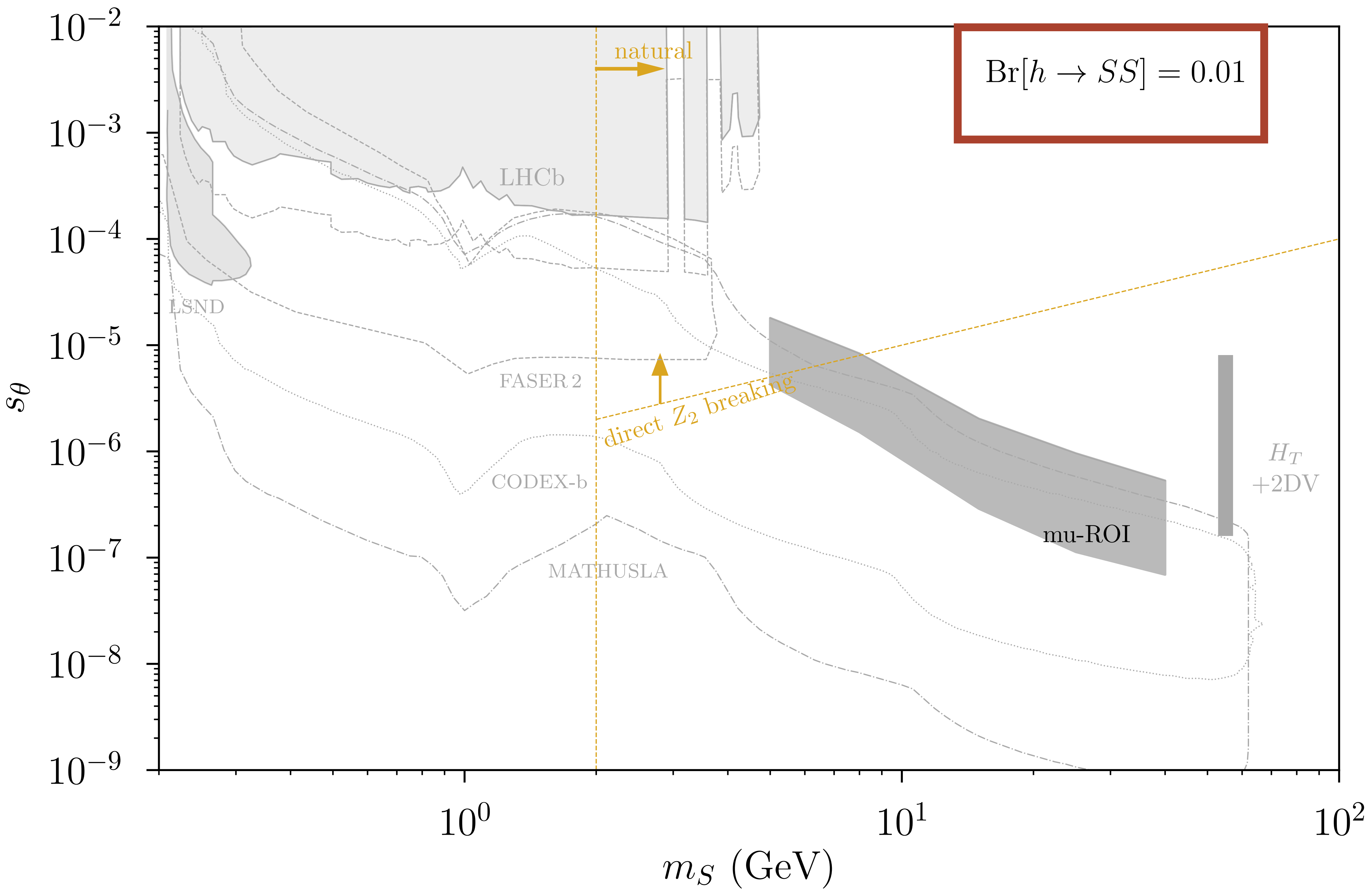

$$\mathrm{Br}[h \to SS] \approx \frac{\Gamma_{h\to SS}}{\Gamma_{h\to b\bar{b}}} \approx \frac{\lambda_{SH}^2}{6y_b^2\lambda_H}$$

The Higgs is narrow!

$\lambda_{SH} = 1.7 \times 10^{-3} \leftrightarrow \mathrm{BR}(h \to SS) = 0.01$

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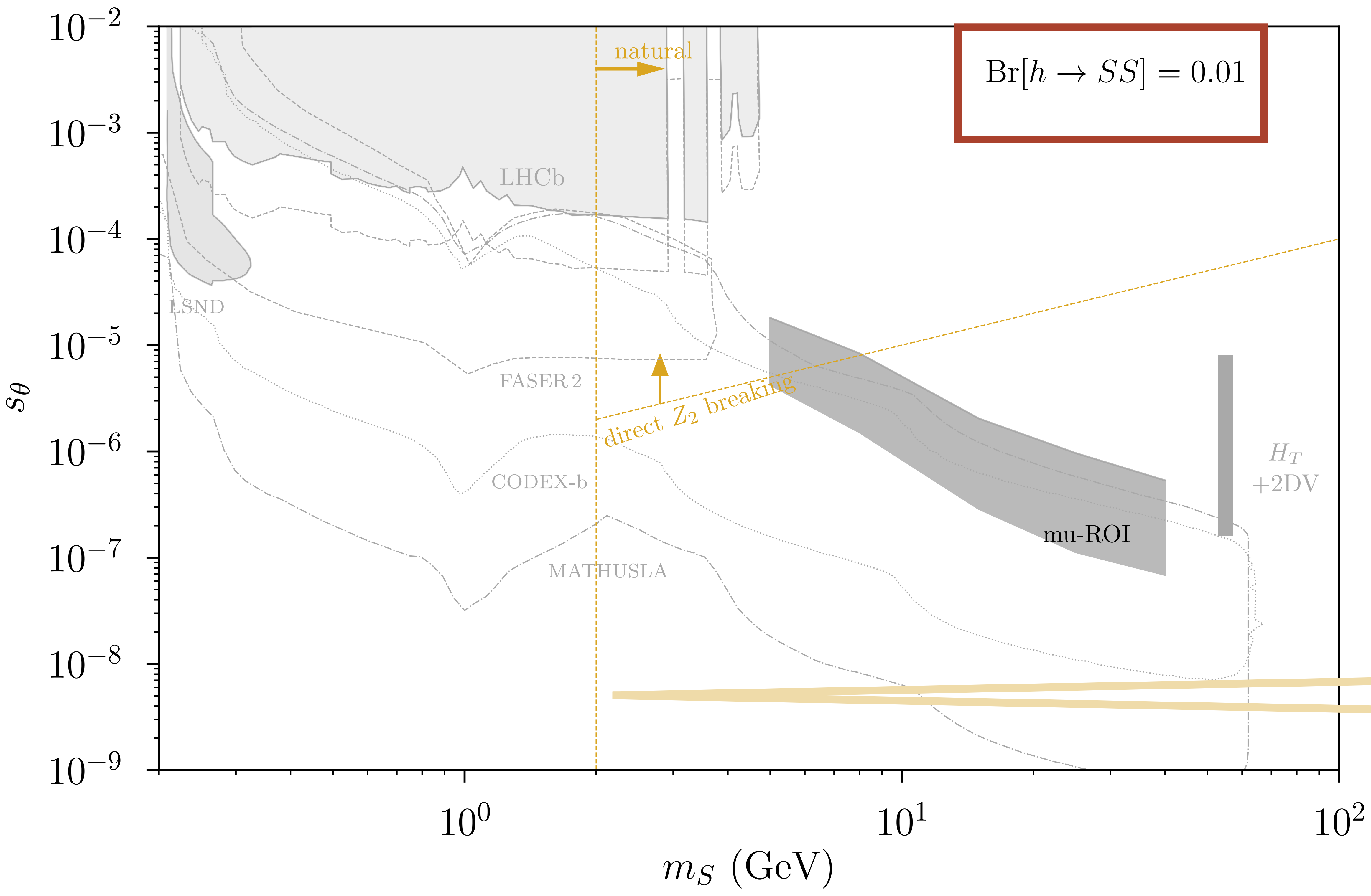

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$$m_S^2 = \tilde{m}_S^2 + \frac{1}{2}\lambda_{SH} v^2$$

S can't be too light!

$$m_S \approx 2\ \text{GeV} \times \left(\frac{\text{Br}[h\to SS]}{0.01}\right)^{1/4} \times \left(\frac{\Delta}{0.1}\right)^{1/2}$$

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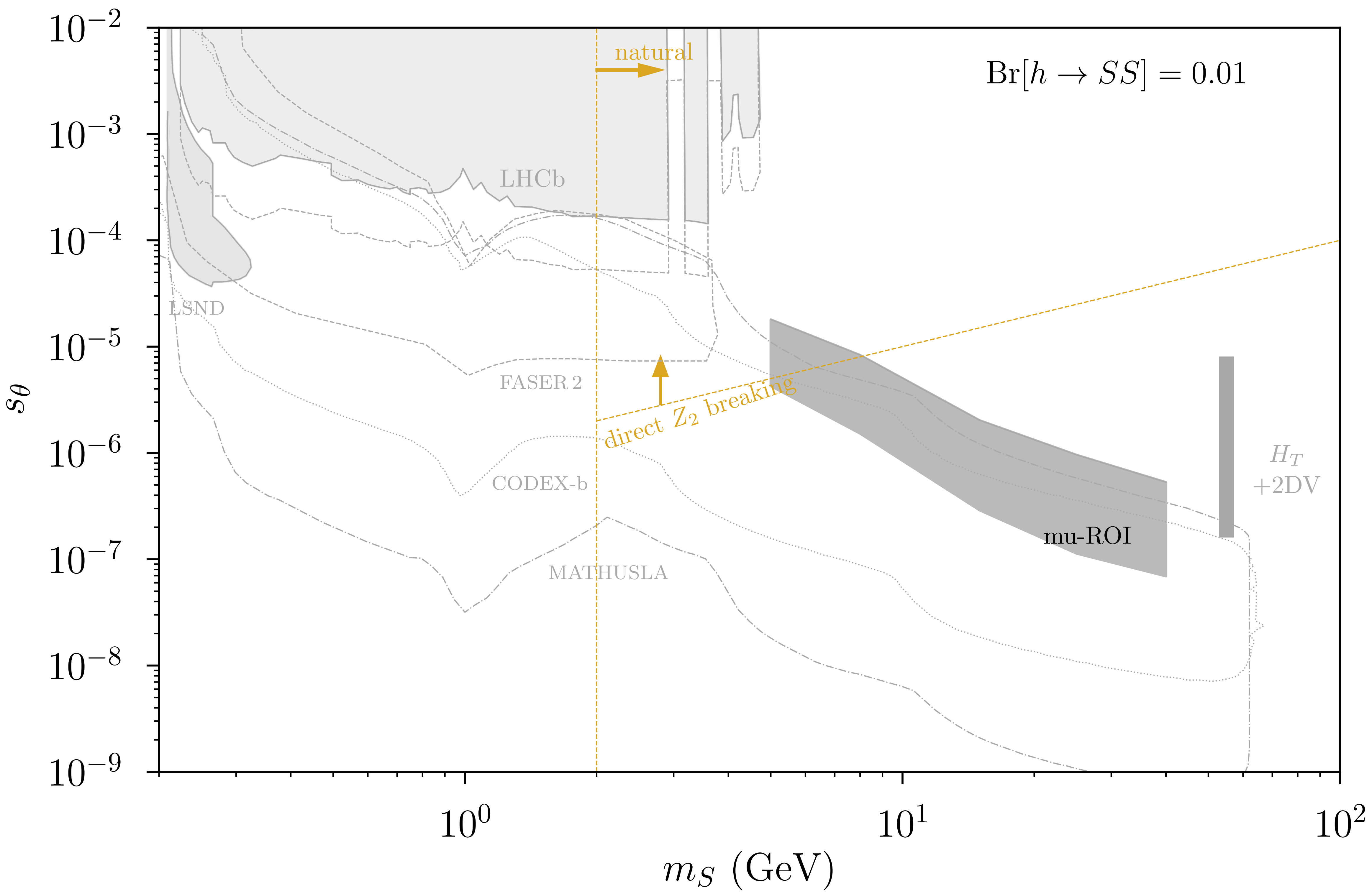

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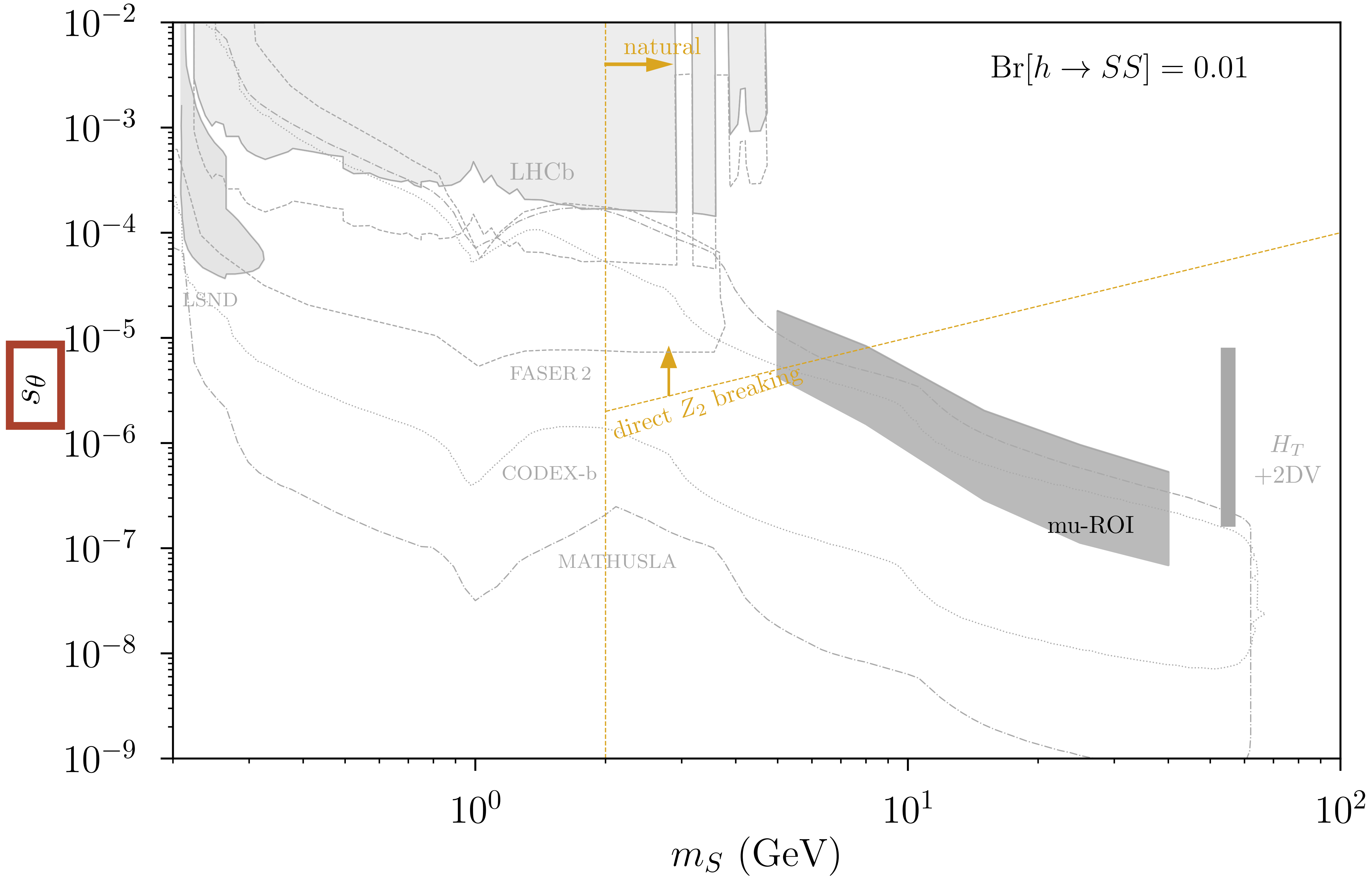

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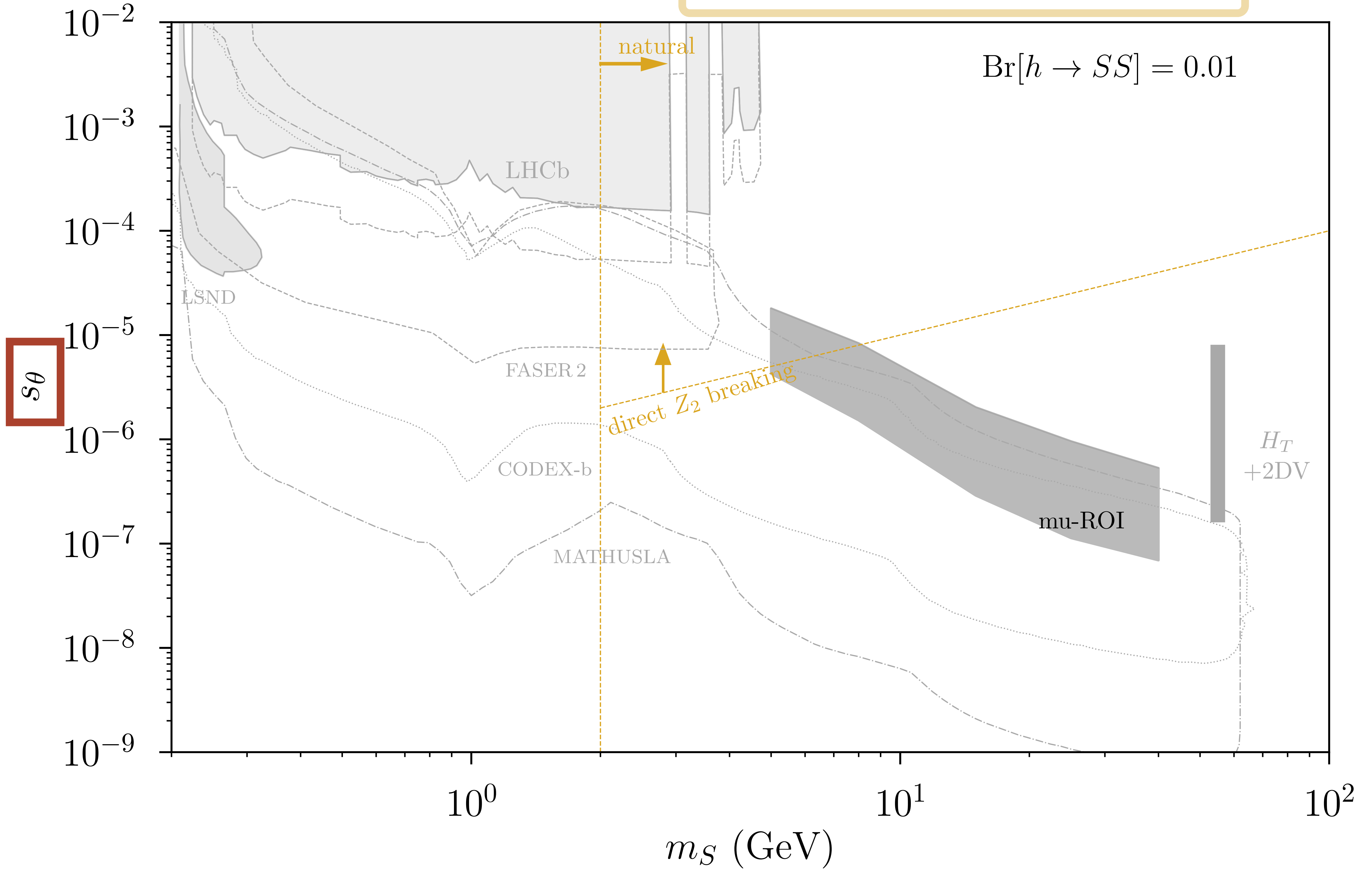

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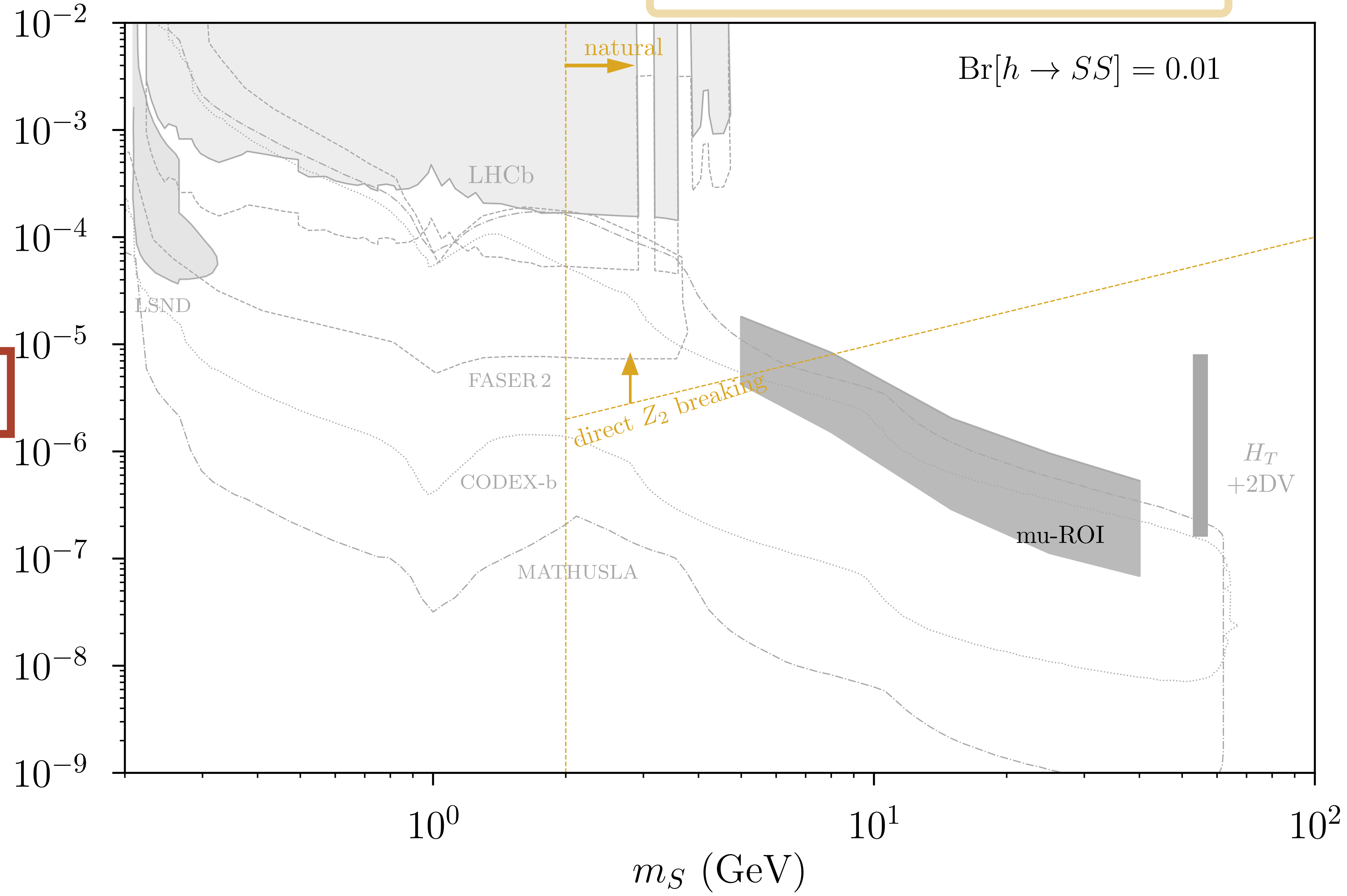


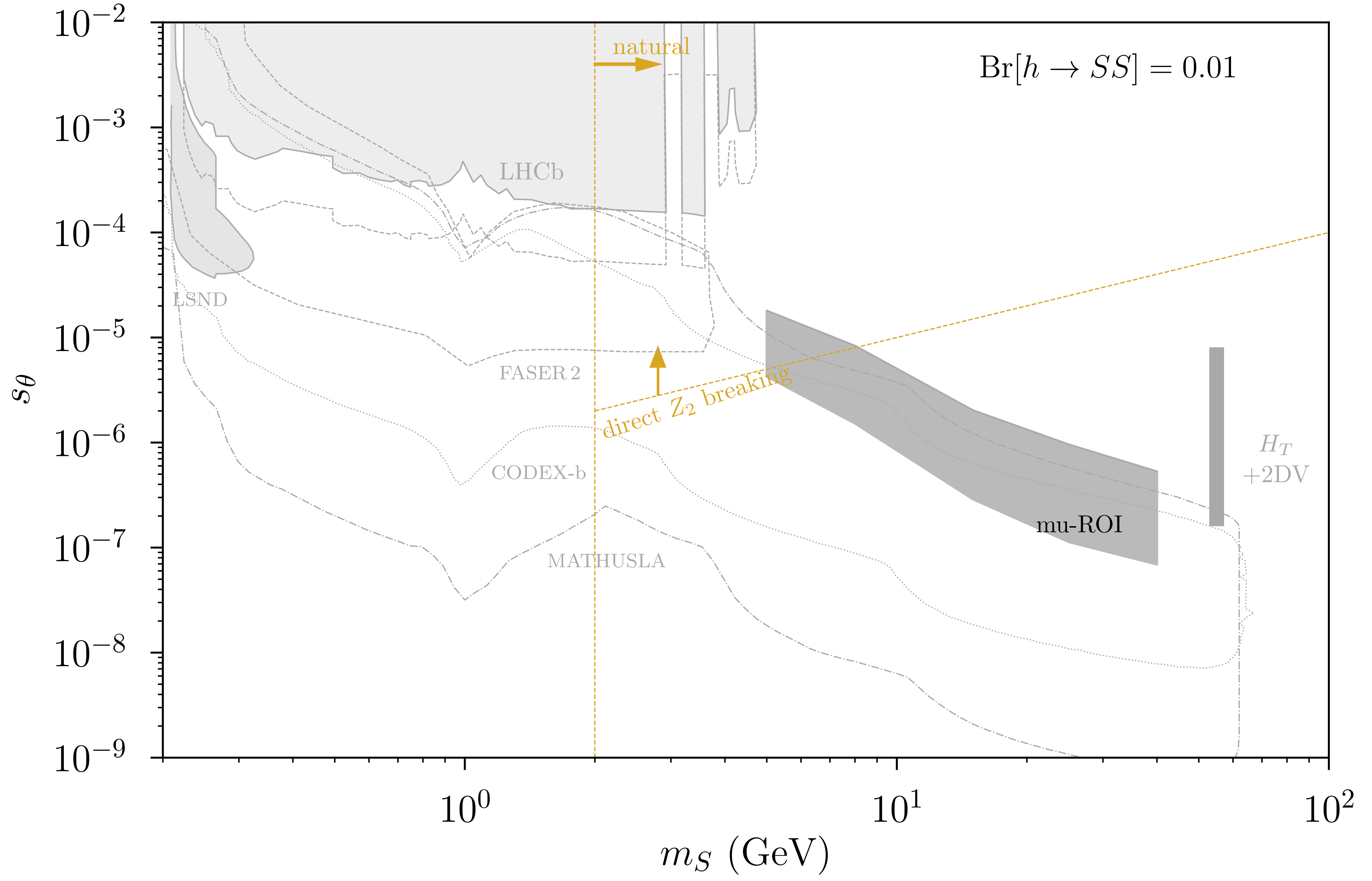
$\text{direct} - \not{\mathbb{Z}}_2$

$$s_\theta \gtrsim 10^{-6} \times \left(\frac{m_S}{1\text{ GeV}}\right) \times \left(\frac{4\pi}{\sqrt{\lambda_S}}\right)$$

S can't be too narrow

(caveat dark showers)

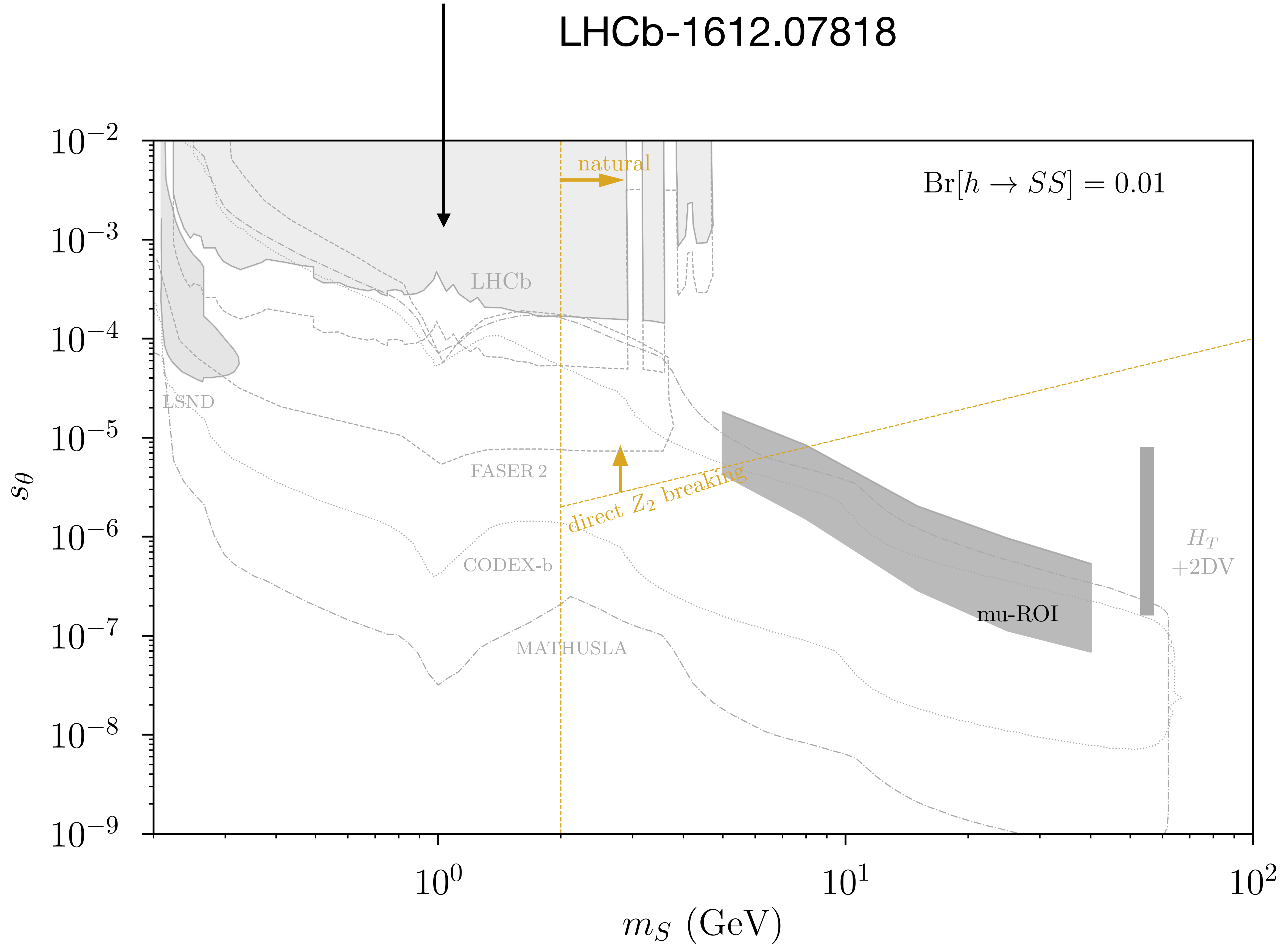
EXPERIMENTAL STATUS of the light singlet



EXPERIMENTAL STATUS of the light singlet

prompt decay: $B^+ \to K^+ S(2\mu)$

LHCb-1612.07818



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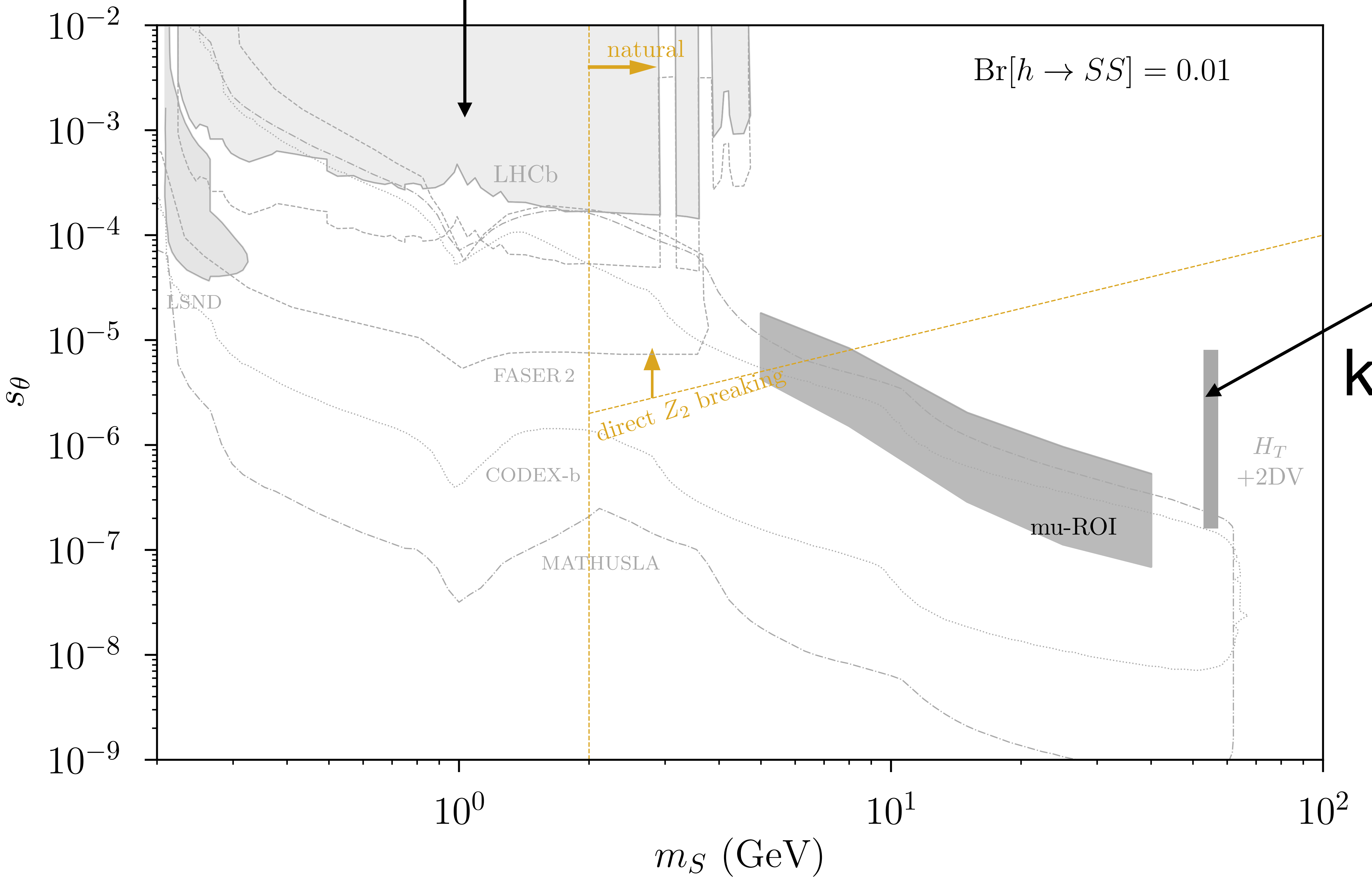

H_T-trigger

kills the signal at low masses

CMS-2012.01581

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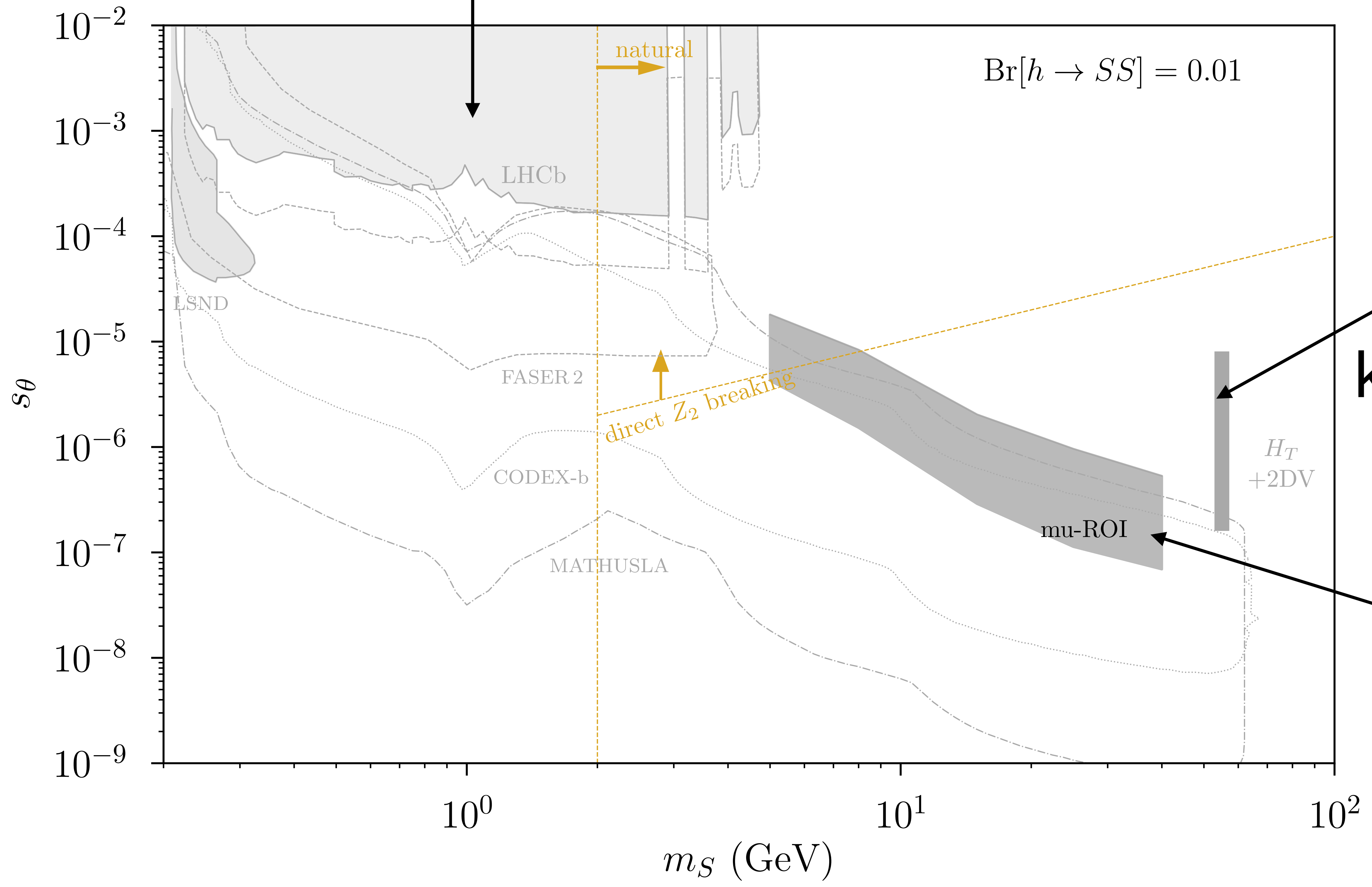

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Muon RoI Cluster trigger

ATLAS-1811.07370

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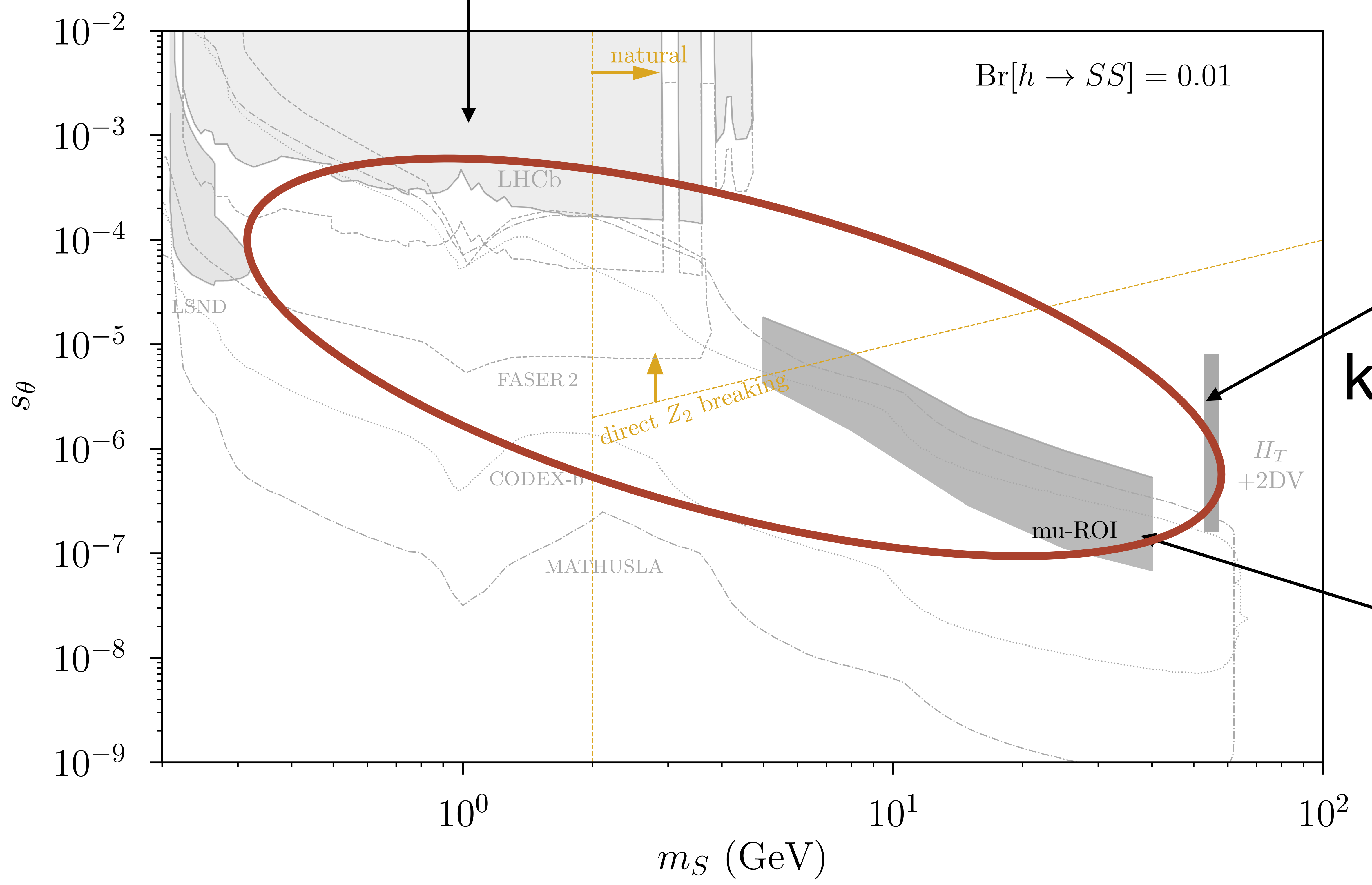

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OPPORTUNITY FOR Muonic DV + Multitrack DV

EXPERIMENTAL STATUS of the light singlet

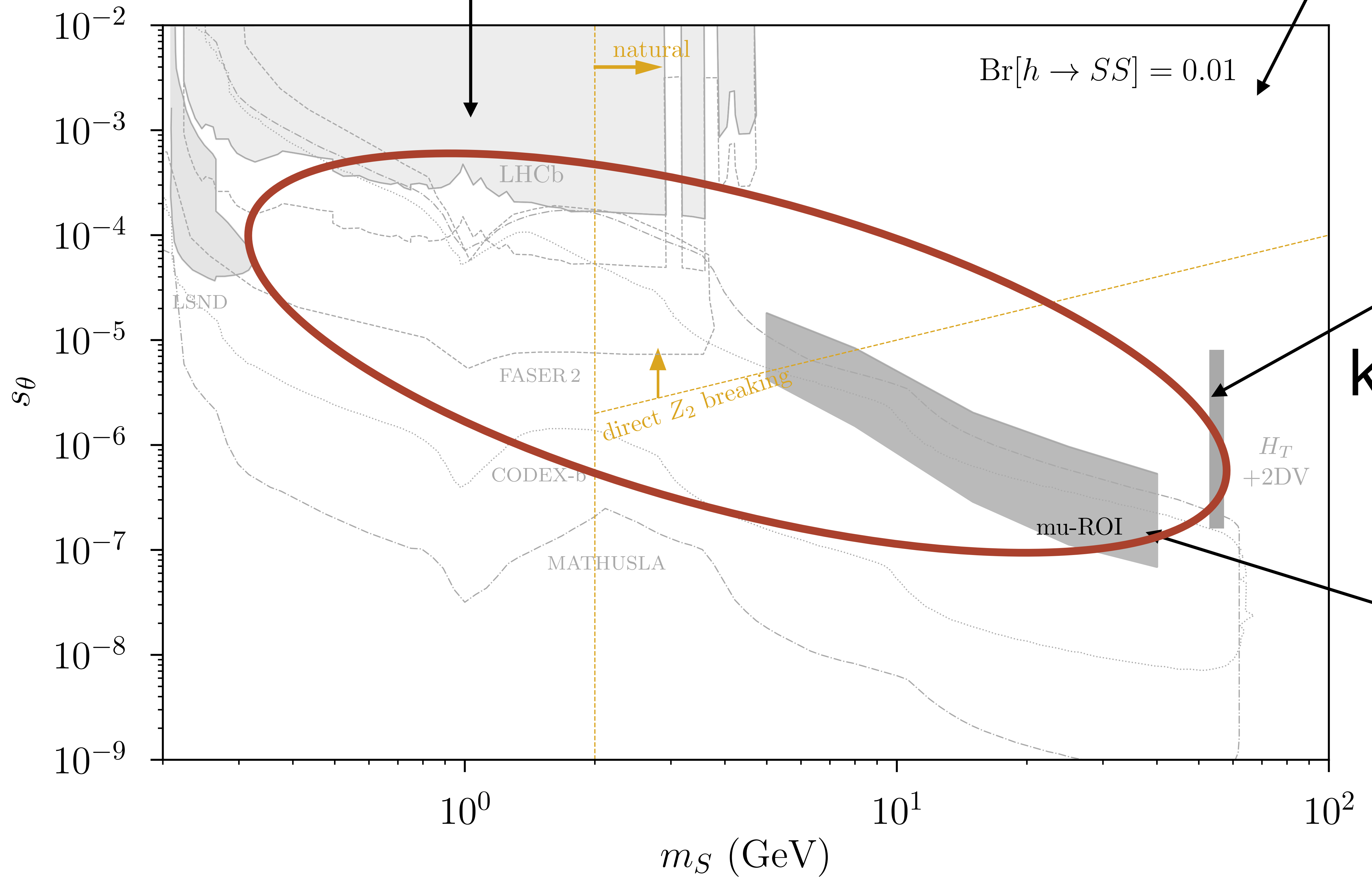
prompt decay: $B^+ \to K^+ S(2\mu)$

LHCb-1612.07818

no bounds in the prompt region from $h \to SS$

for ex. $h \to 2b2\mu$

ATLAS-1807.00539



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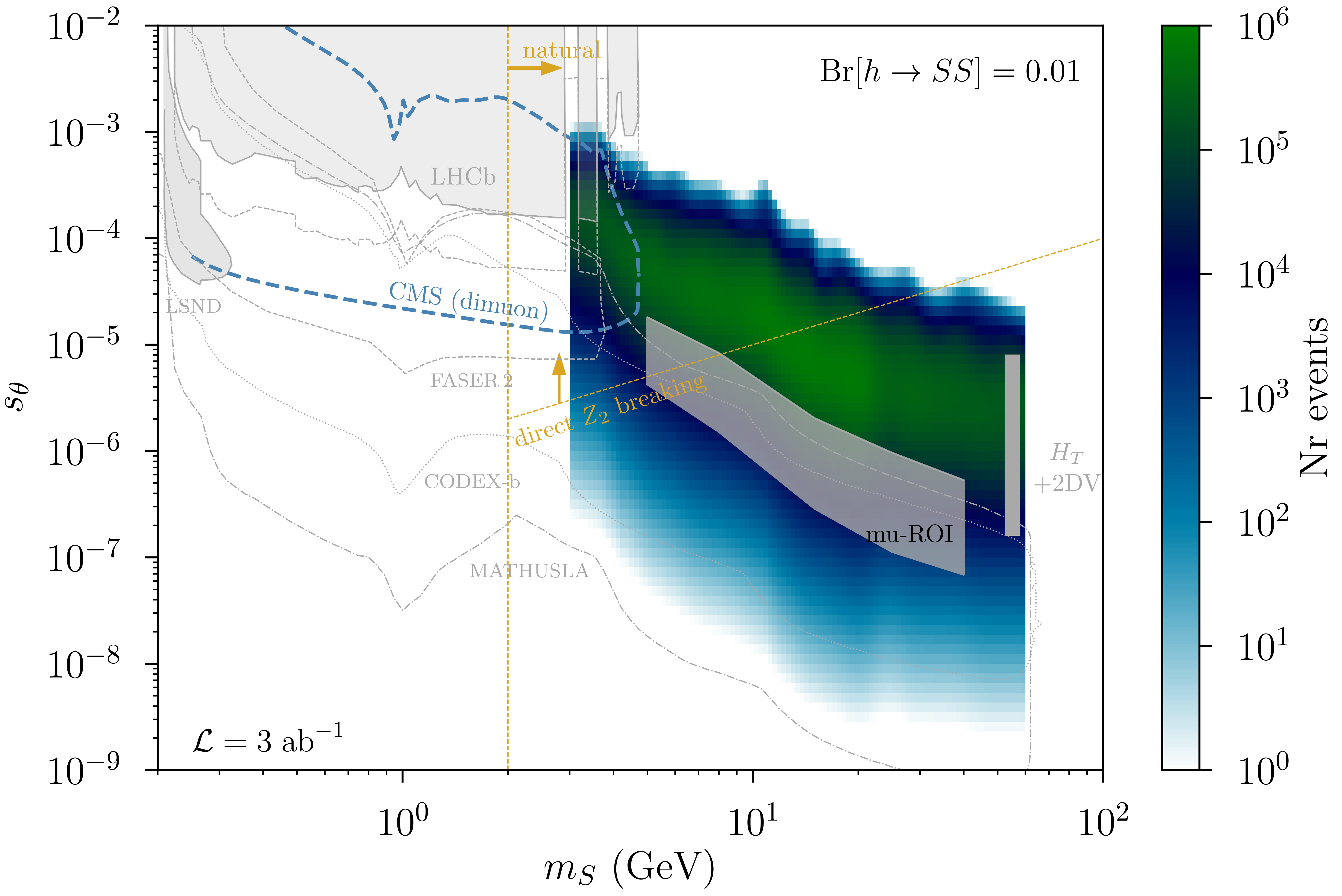
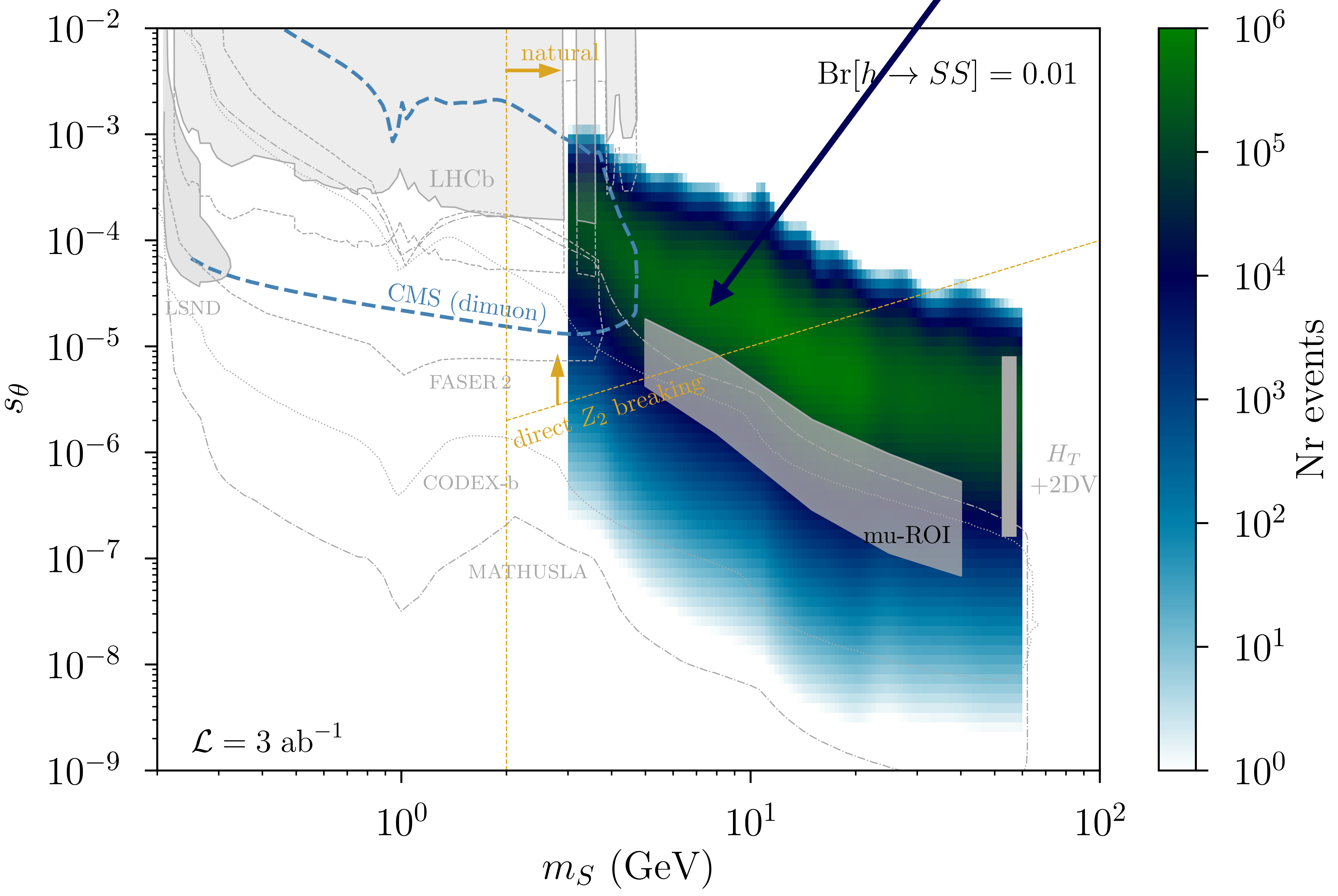
FUTURE of the light singlet



FUTURE of the light singlet

Large signal yield
with moderate displacement
for multitrack DV S. Knapen, et al. [arXiv 2012.07864]



FUTURE of the light singlet

projection of CMS Muonic DV

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CMS PAS EXO-20-014

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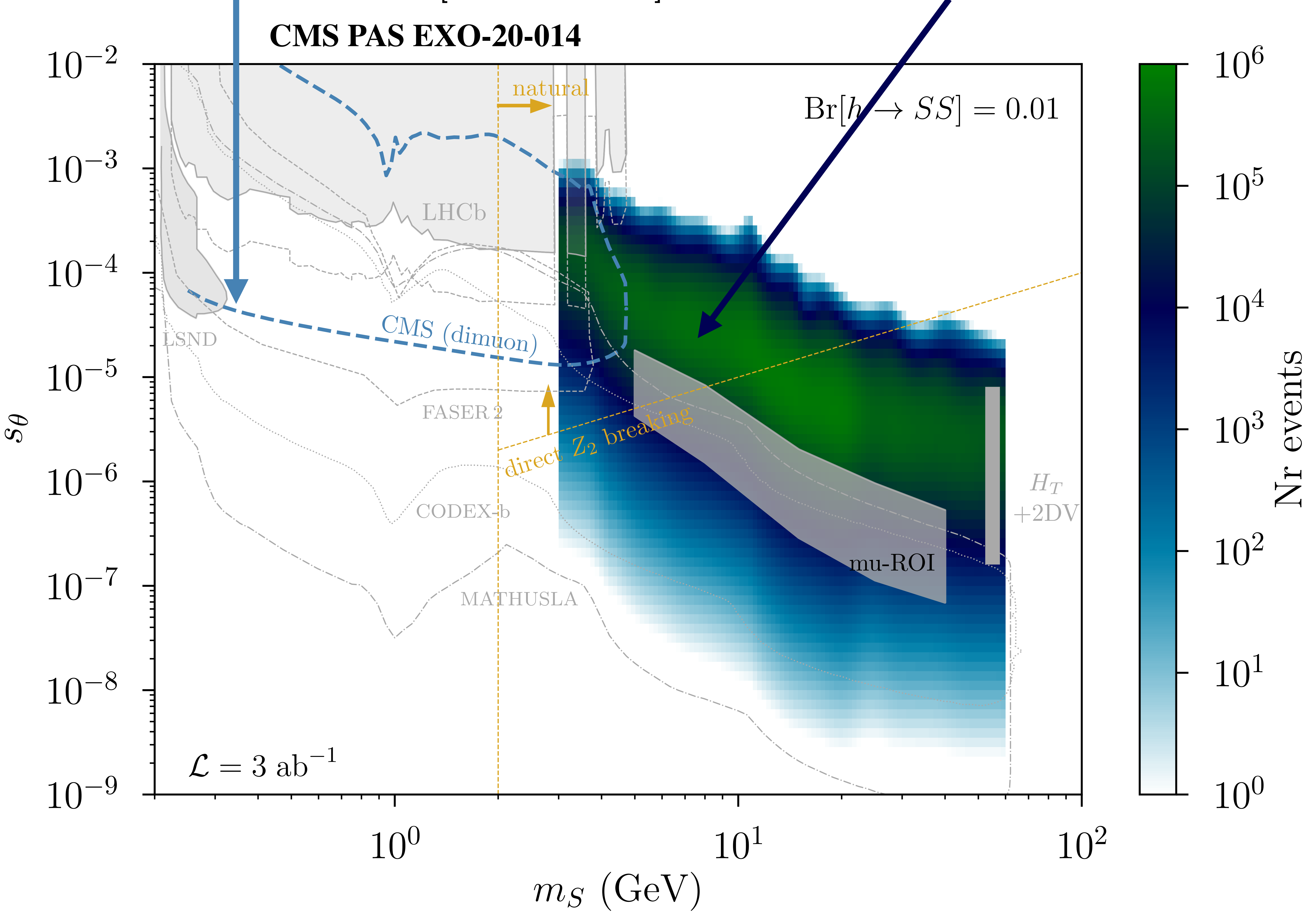

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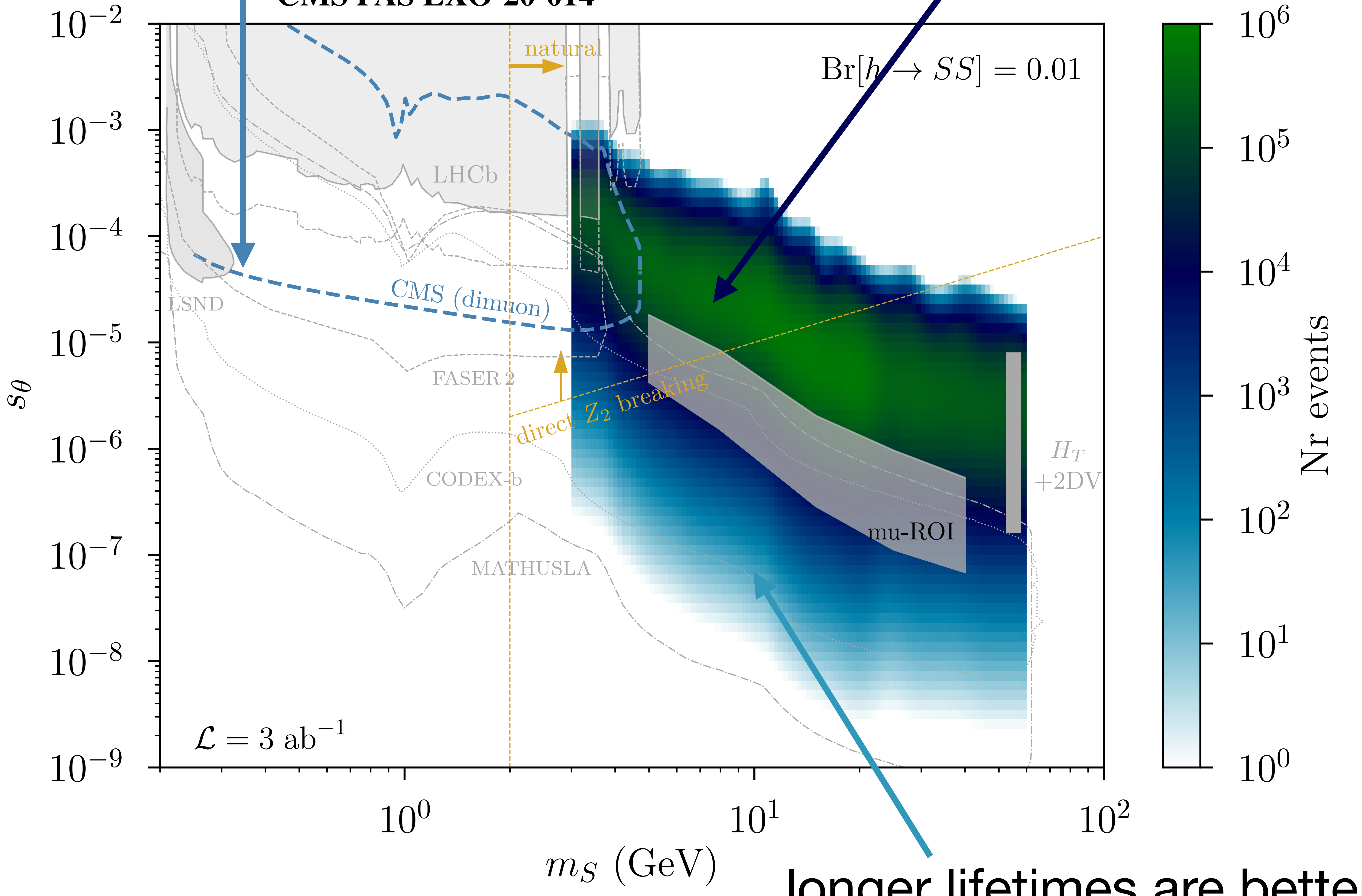

longer lifetimes are better probed by CODEX-b + MATHUSLA

EXPERIMENTAL STATUS model independently

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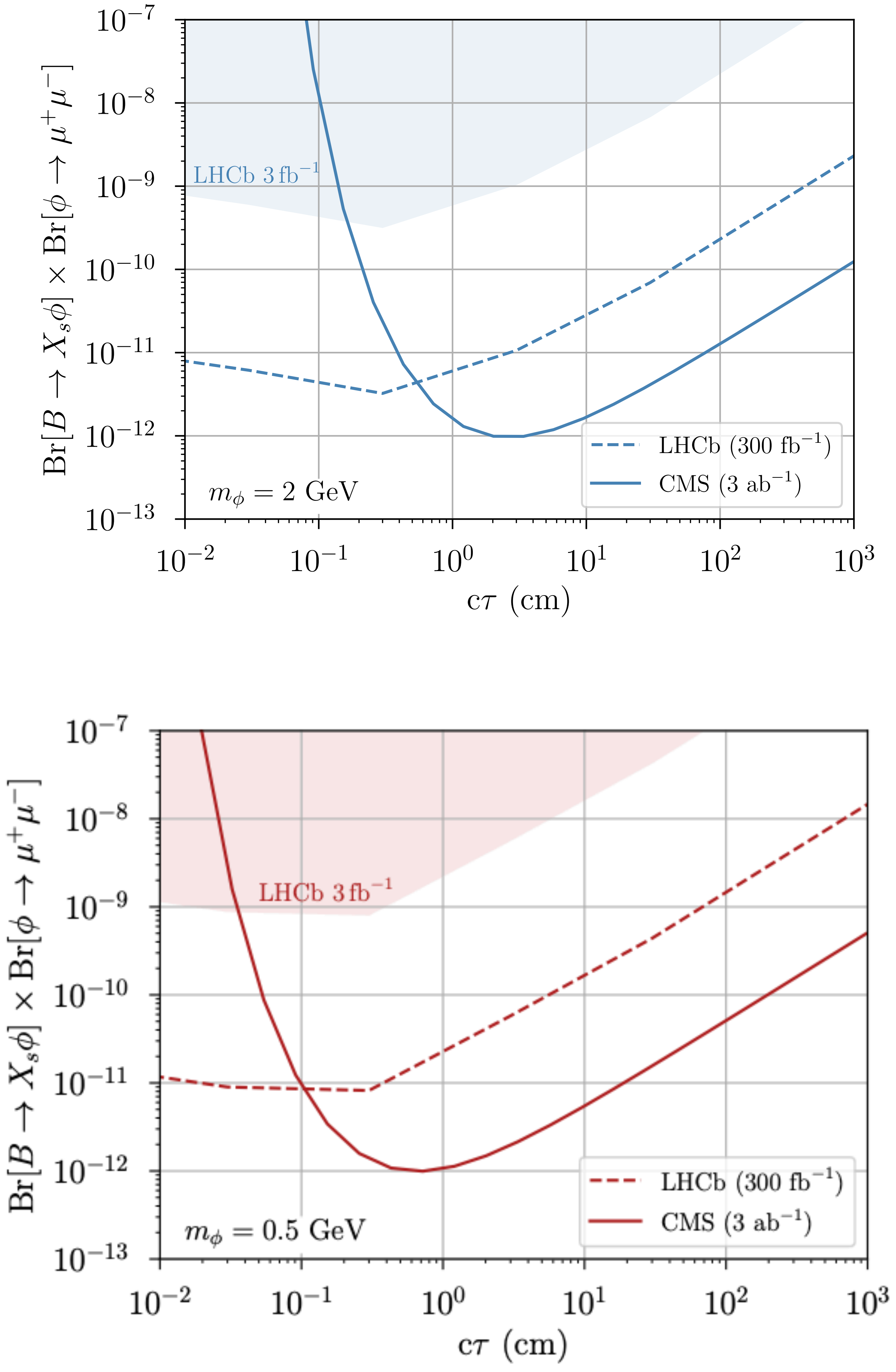

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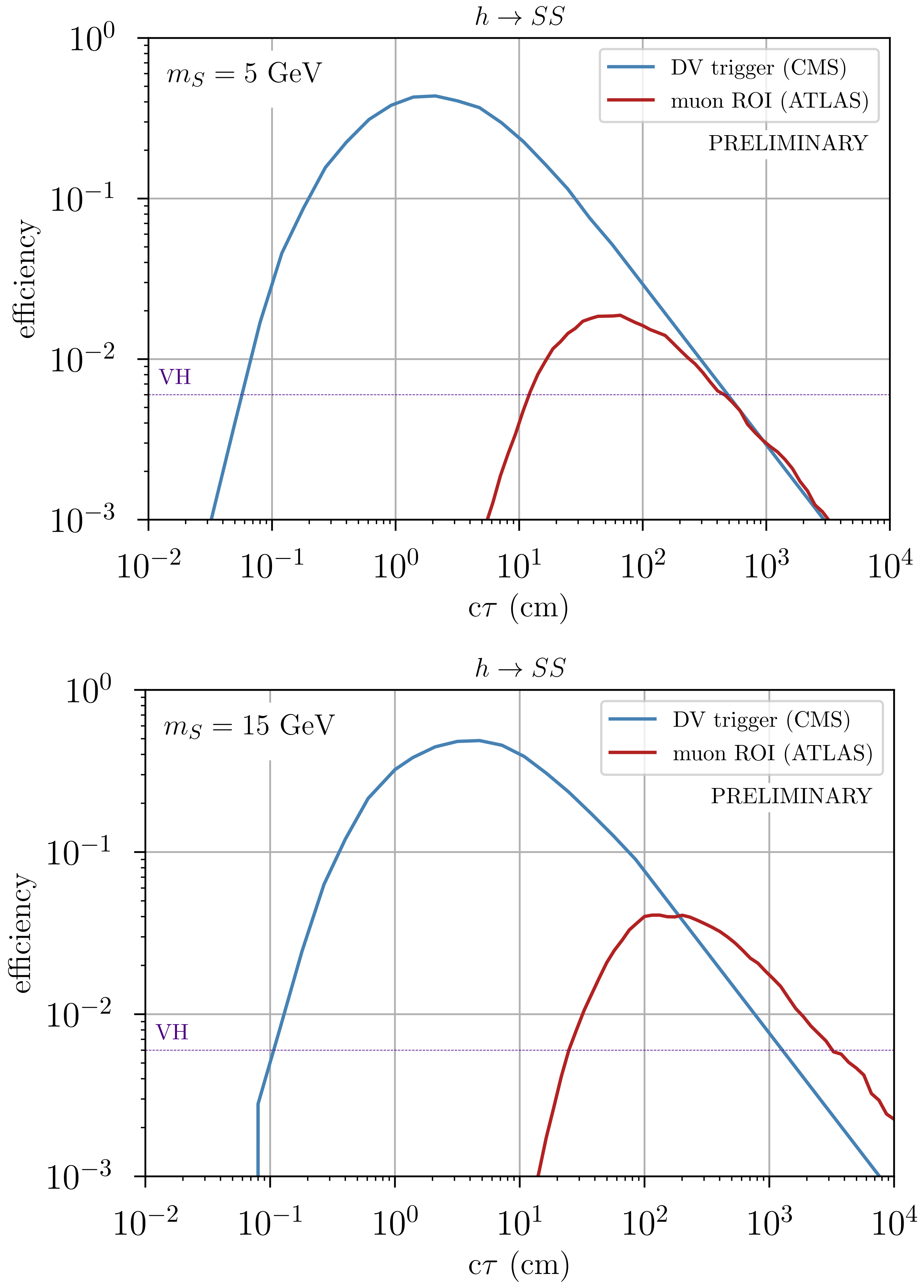
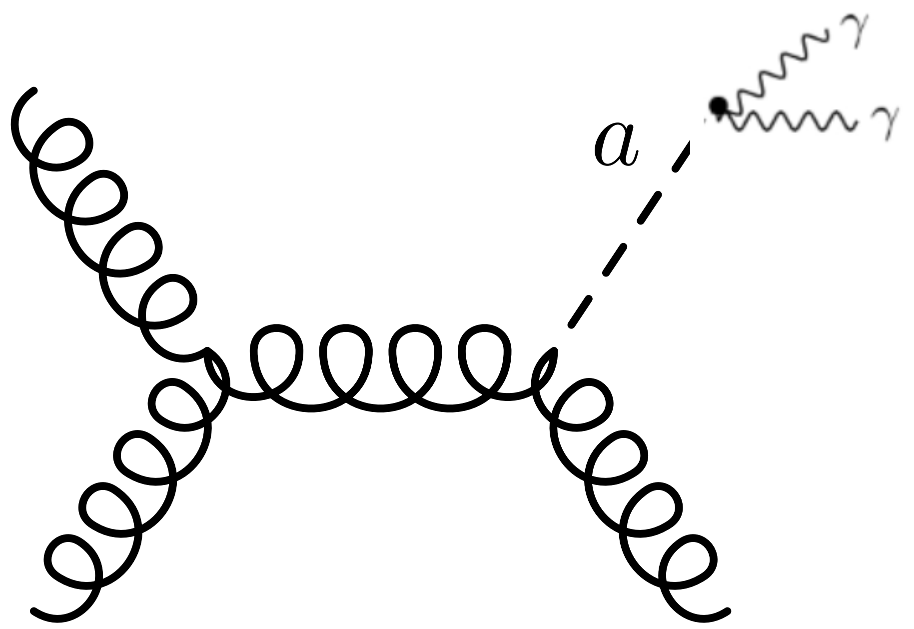


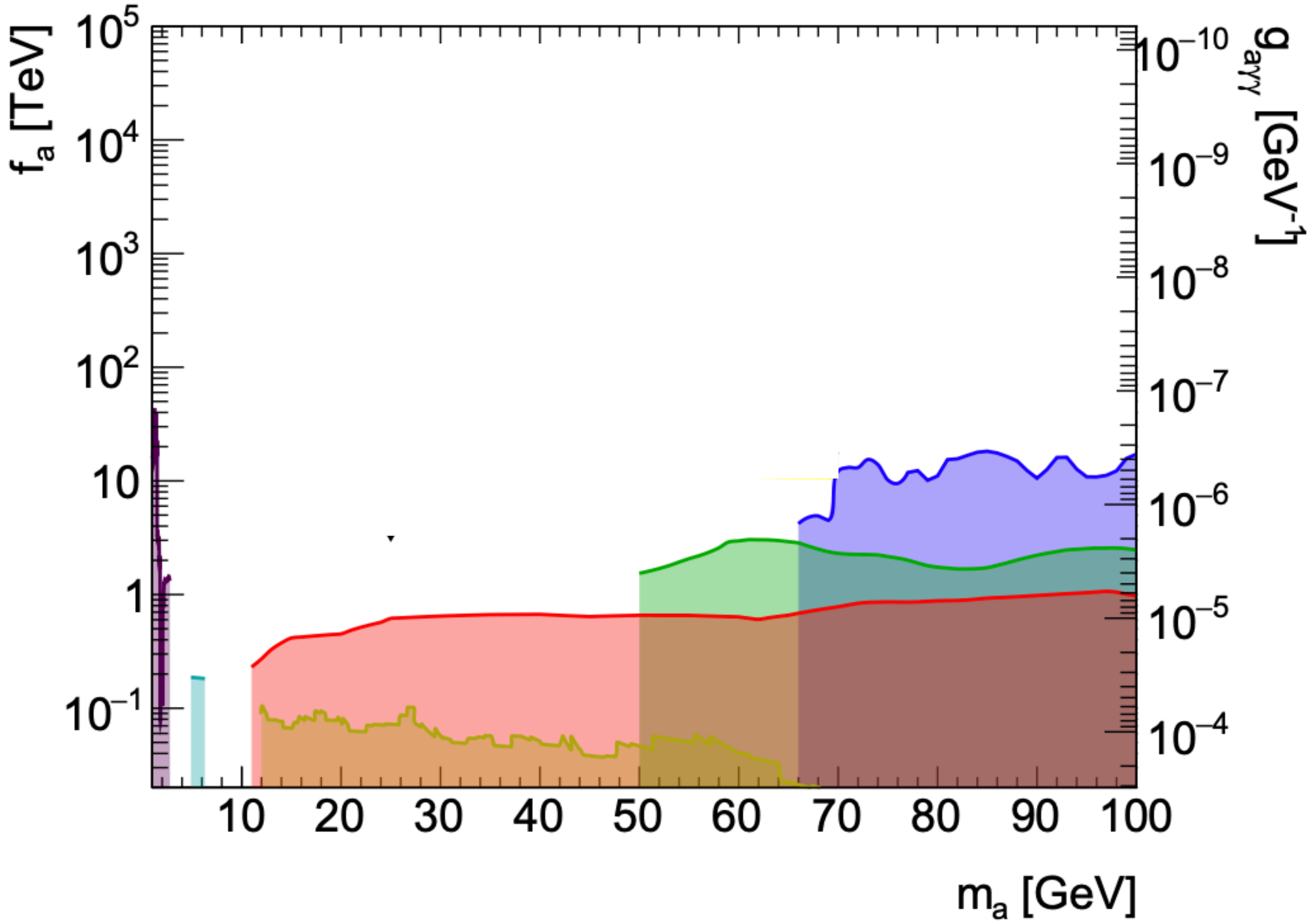
Difficult triggers
but worth doing!

Light diphoton resonances



ALPs produced in gluon fusion

$$\mathcal{L}_a \supset -\frac{1}{2}m_a^2 a^2 - \frac{\alpha_s}{8\pi}\frac{a}{f_a}G\tilde{G} + \frac{E}{N}\frac{\alpha_{em}}{8\pi}\frac{a}{f_a}F\tilde{F}\,.$$



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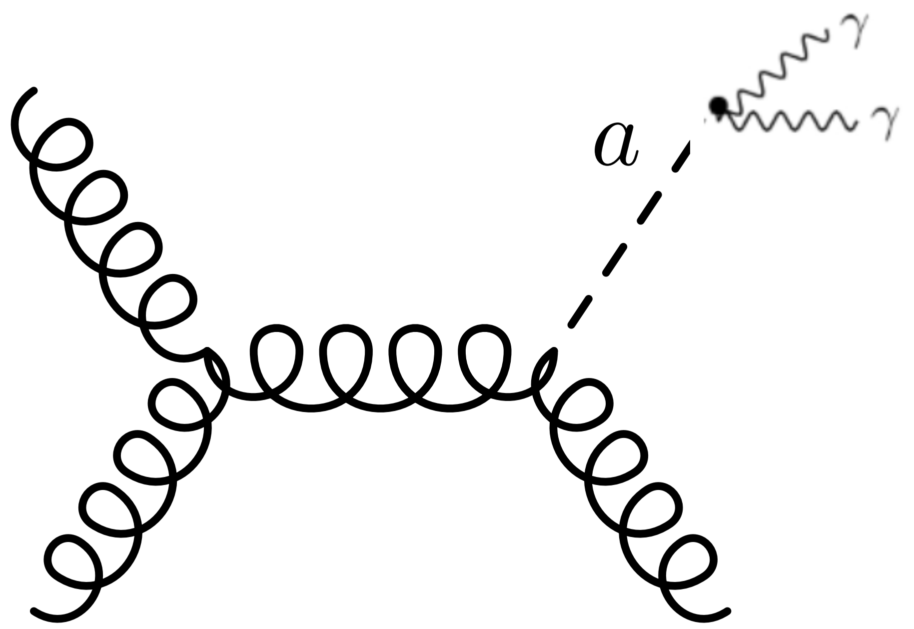

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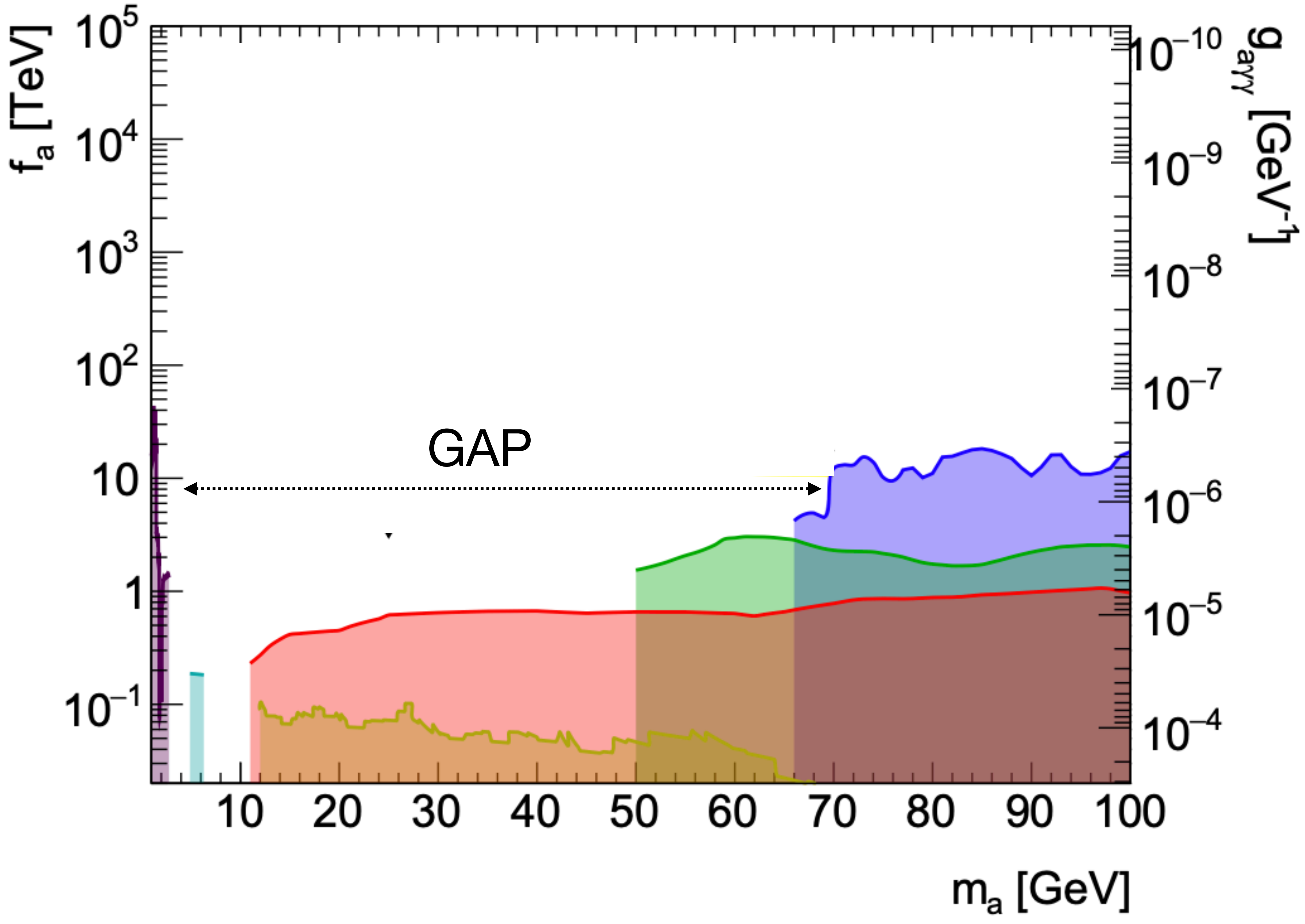
Filling the gap between 5-70 GeV



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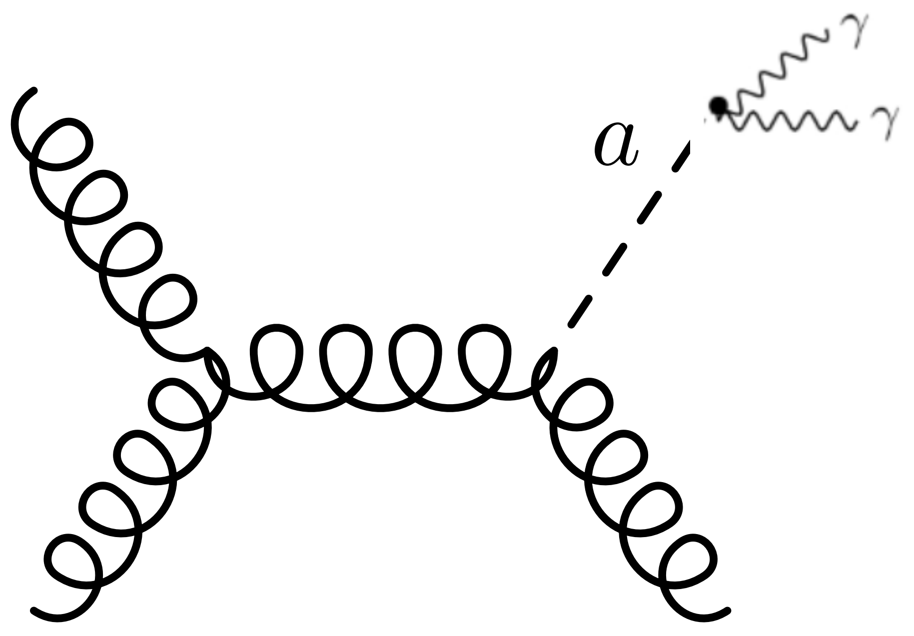

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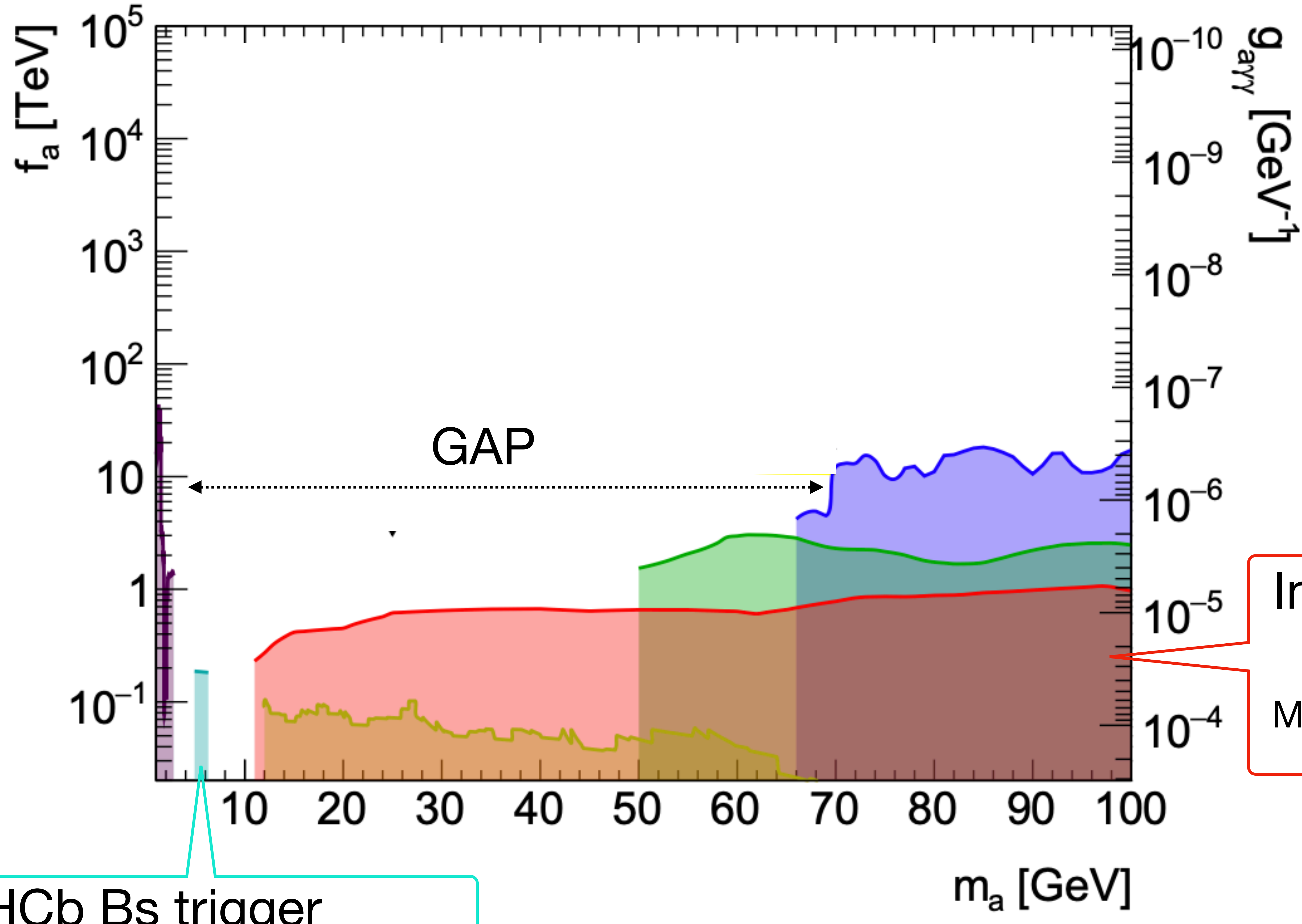


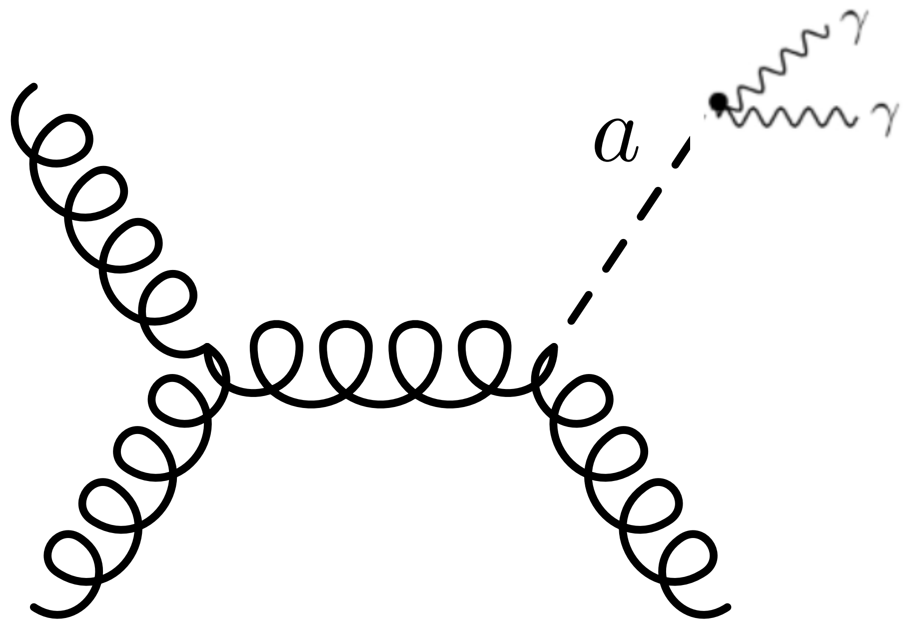
Inclusive cross section measurements

Mariotti, D.R. et al. arXiv 1710.01743

LHCb Bs trigger

Cid Vidal, D.R. et al. arXiv 1810.09452

Light diphoton resonances



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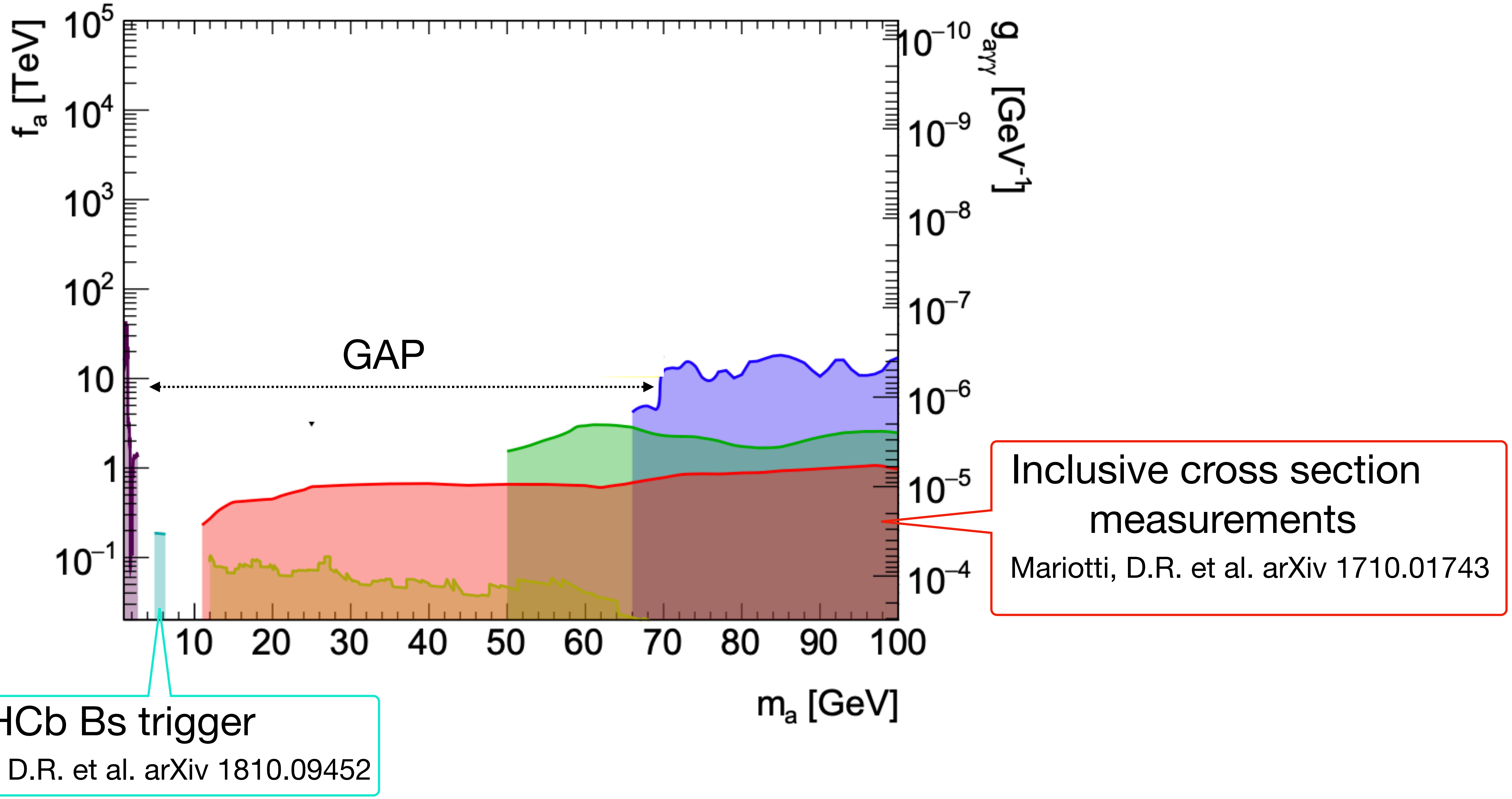
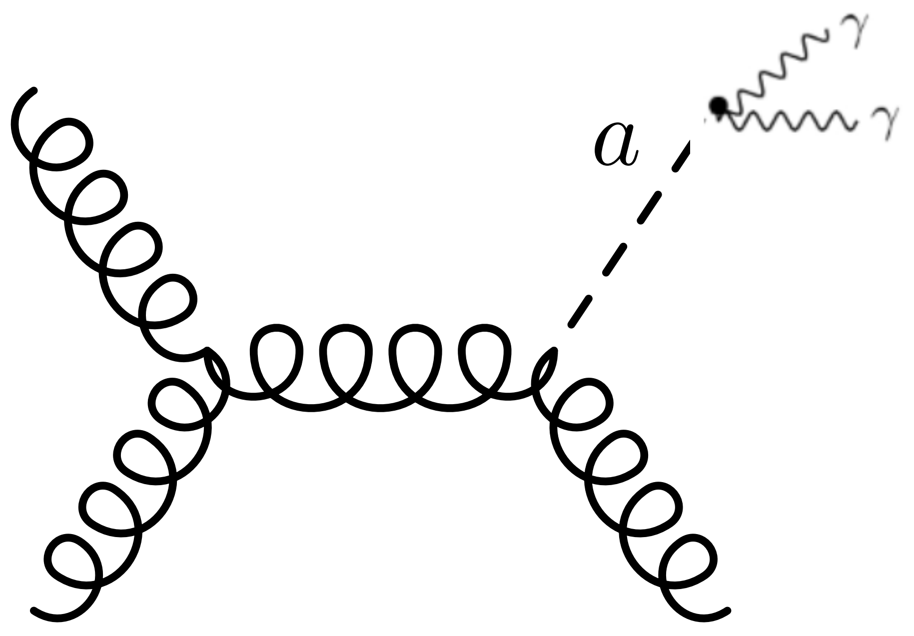


$$m_{\gamma\gamma} \simeq \sqrt{p_{T_1}^{\gamma} p_{T_2}^{\gamma}} \times \Delta R_{\gamma\gamma}$$

is constrained by trigger requirements on photons pT and isolation (ISO)

ATLAS search to fill the gap



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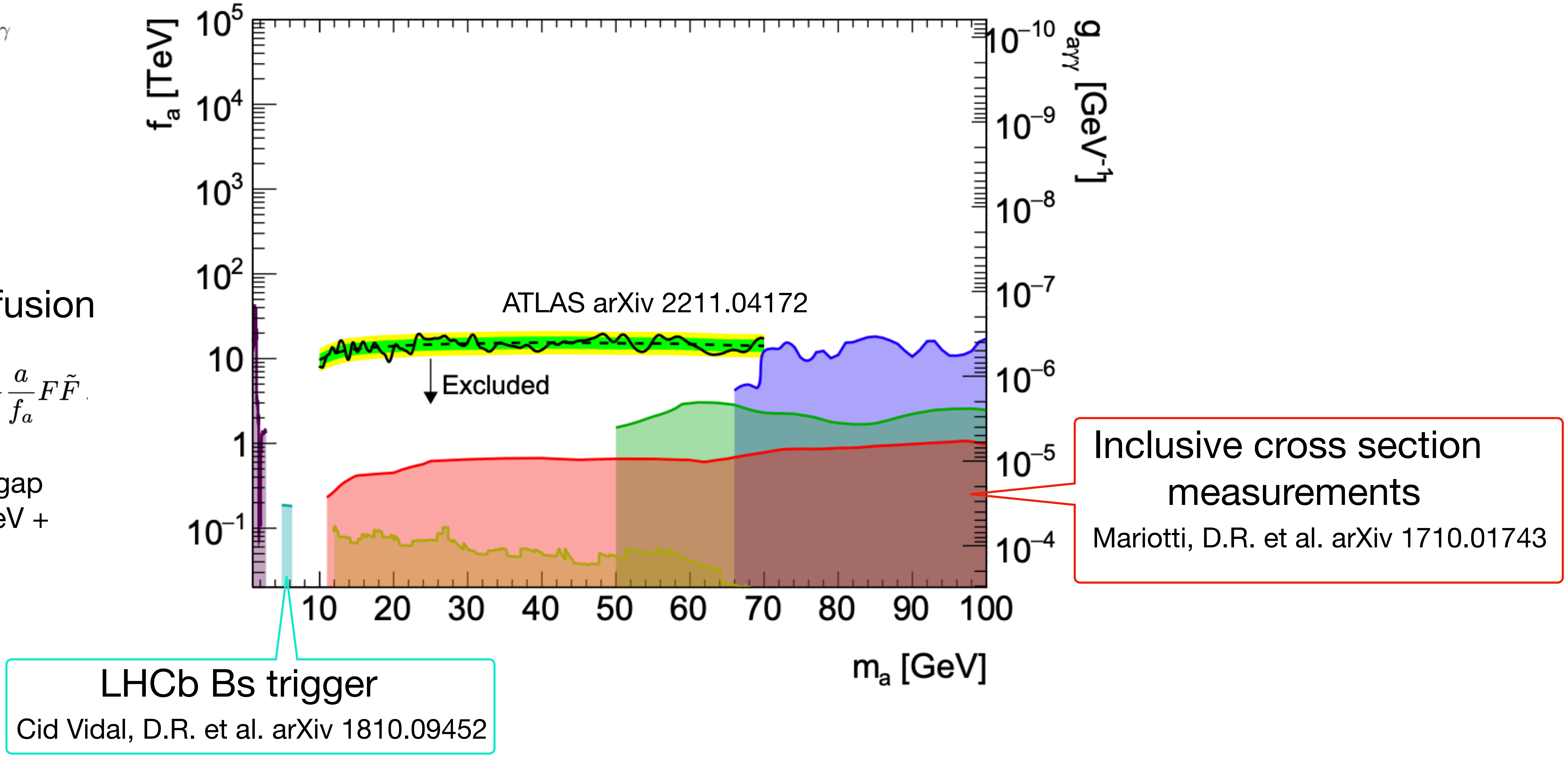
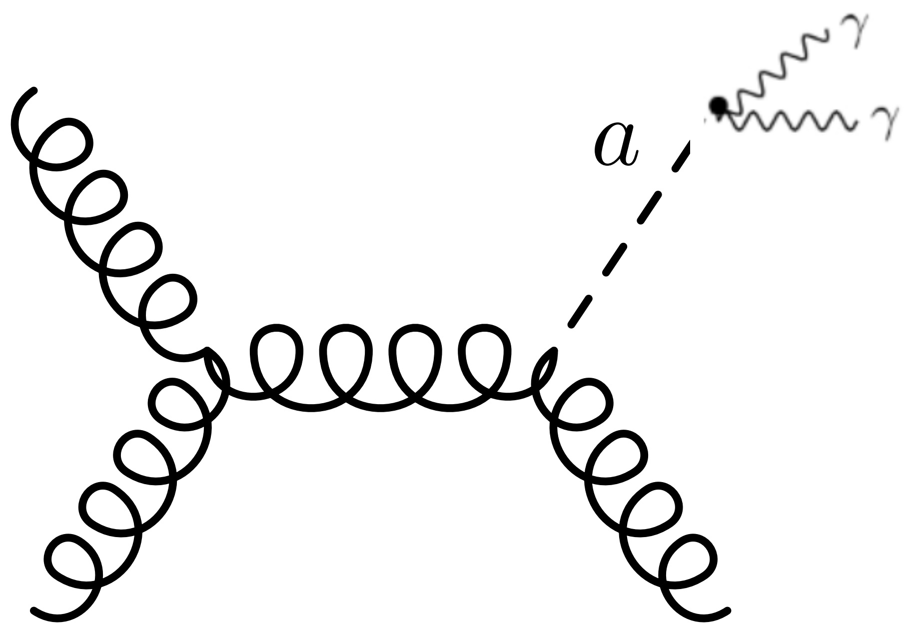
$$\mathcal{L}_a \supset -\frac{1}{2}m_a^2 a^2 - \frac{\alpha_s}{8\pi}\frac{a}{f_a}G\tilde{G} + \frac{E}{N}\frac{\alpha_{\rm em}}{8\pi}\frac{a}{f_a}F\tilde{F}$$

ATLAS recently filled most of the gap with data based on a pT-20/22 GeV + loose ISO photon trigger



$m_{\gamma\gamma} \simeq \sqrt{p_{T_1}^{\gamma} p_{T_2}^{\gamma}} \times \Delta R_{\gamma\gamma}$ is constrained by trigger requirements on photons pT and isolation (ISO)

ATLAS search to fill the gap



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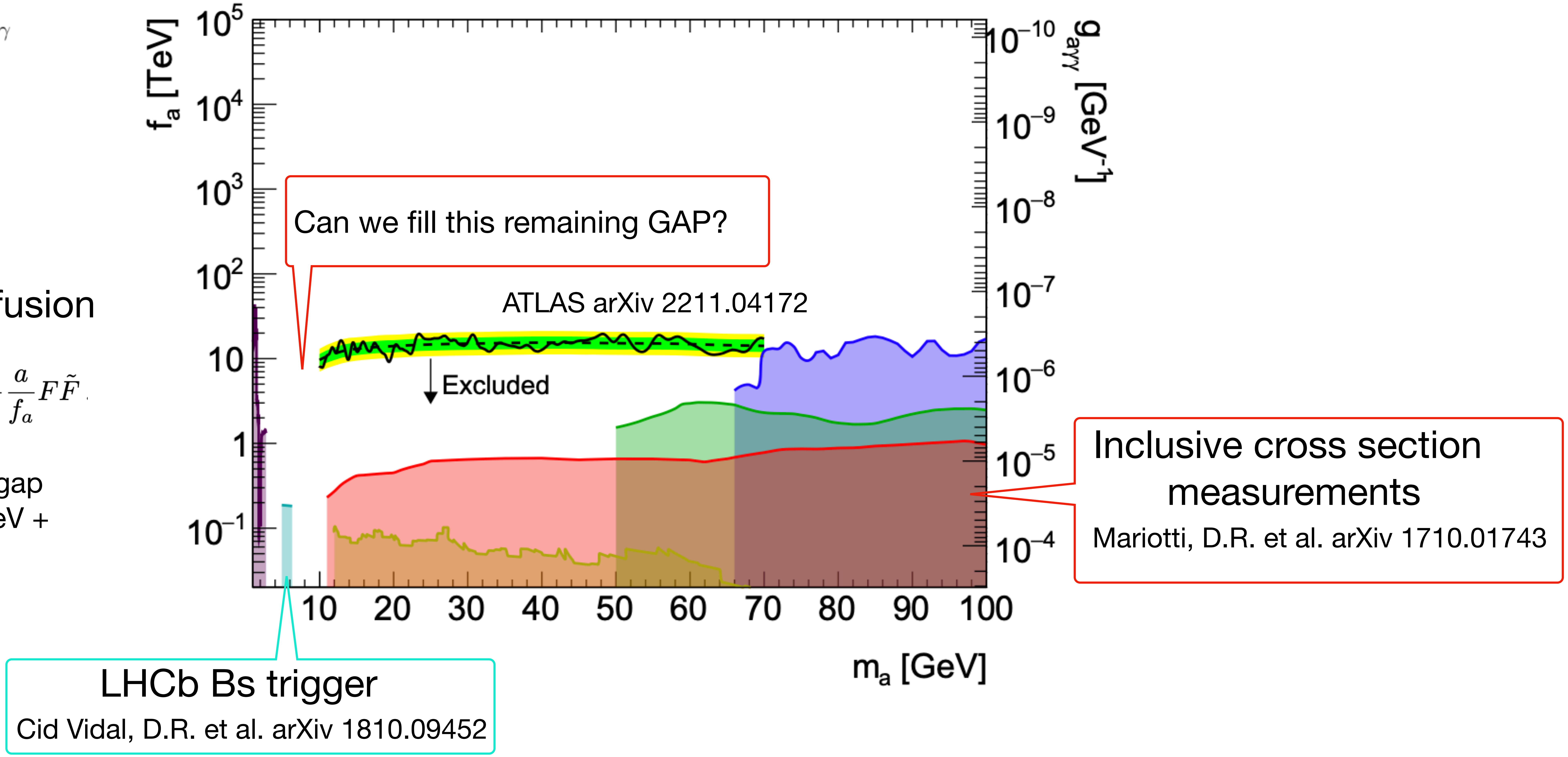

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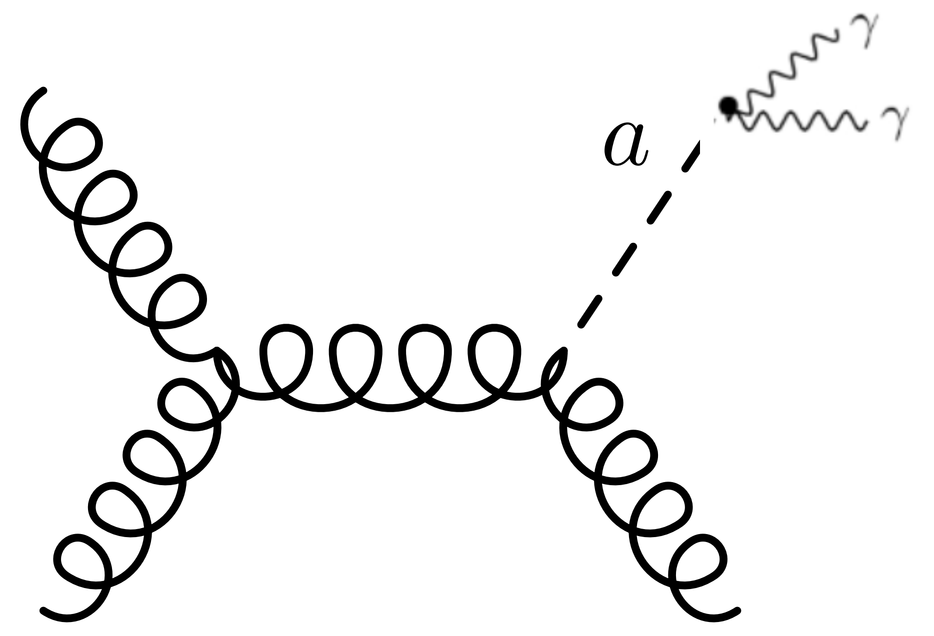
is constrained by trigger requirements on photons pT and isolation (ISO)

Filling the GAP with data scouting



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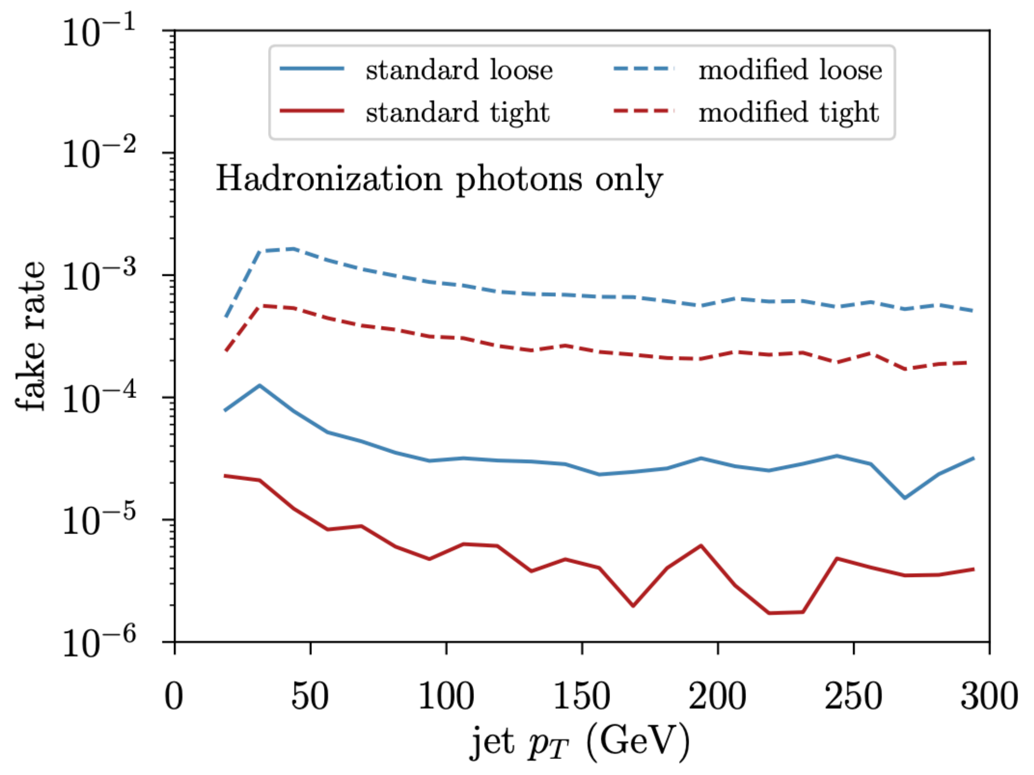
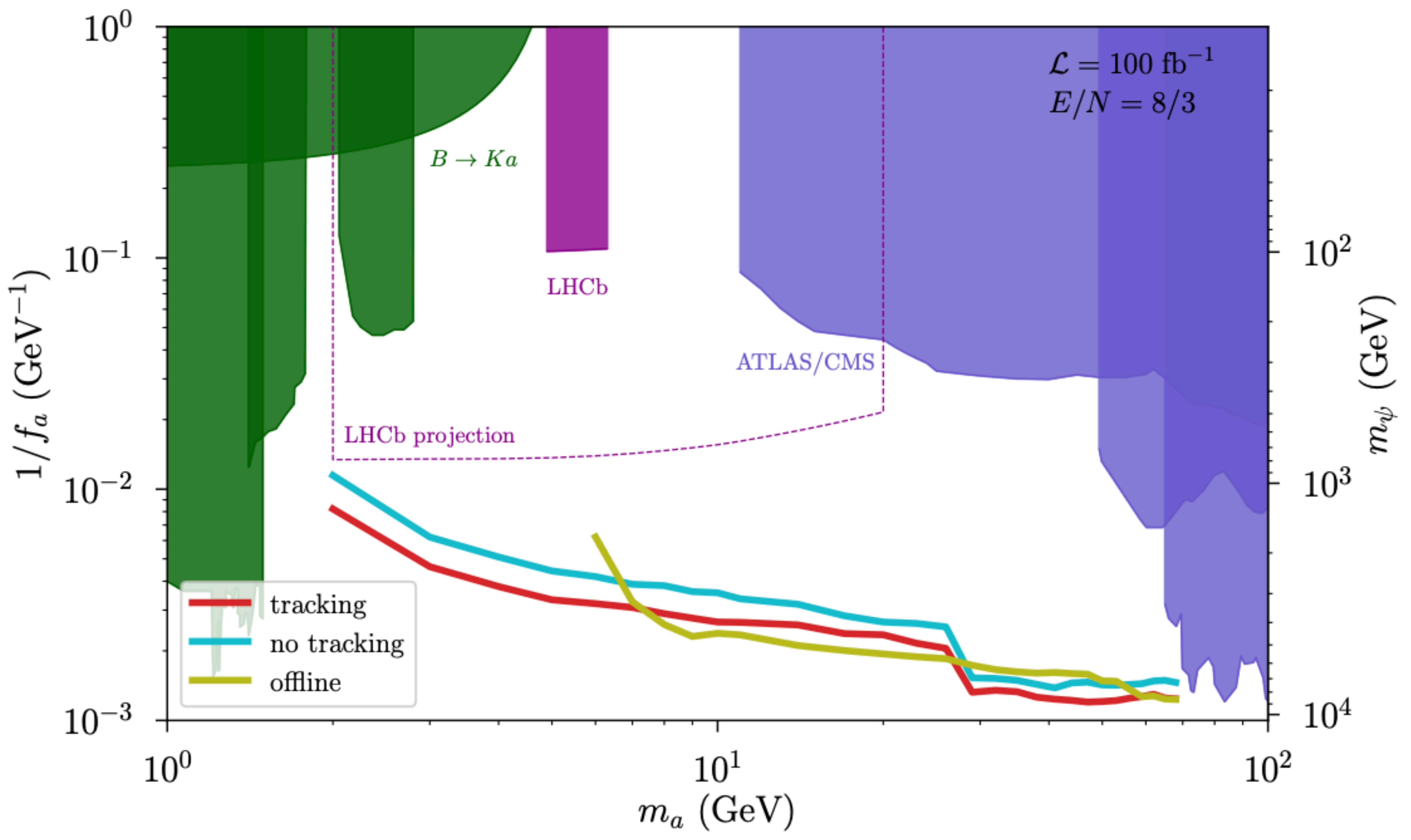
15 no ISO at L1 with/without tracking

Knapen, Kumar, D.R. 2112.07720

Modified ISO to keep the boosted resonance





It looks like the GAP can be completely closed!

Keyword

TRIGGERING

Finite band width make experiments theory biased

We will loose important data if we do not ASK to look for it

...

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@ FLAVOR EXPERIMENTS

NA62

MEG II

Belle II

…

Flavor at the intensity frontier

Kaon, B and muon factories benefit from enormous luminosities but have exclusive triggers

Focus on SM rare decays + SM predictions

For a complete review of the missing opportunities
in Kaon physics see arXiv 2201.07805

New Physics Searches at Kaon and Hyperon Factories

Editors: Evgueni Goudzovski[1], Diego Redigolo[2,3], Kohsaku Tobioka[4,5], Jure Zupan[6]

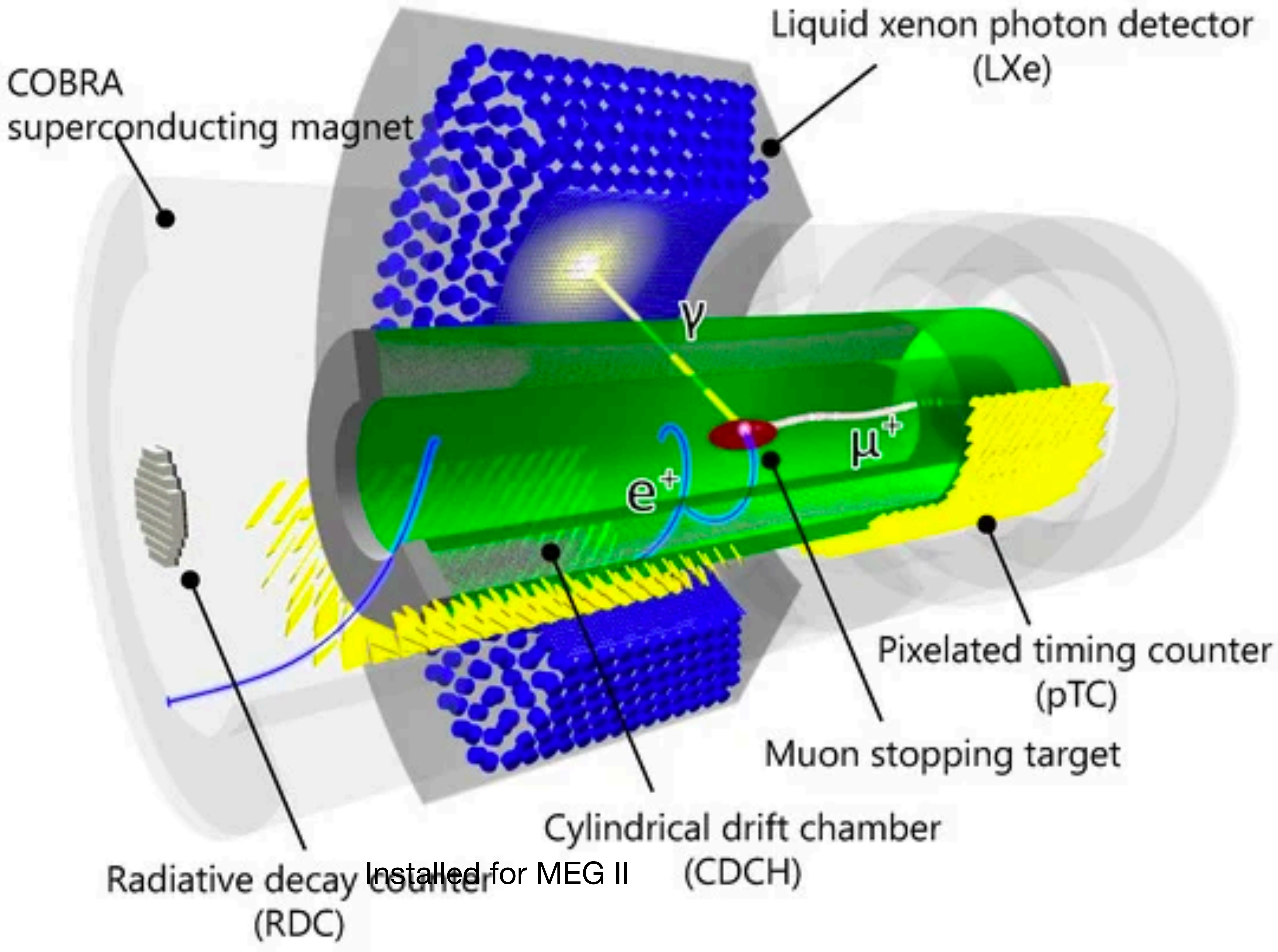
Authors: Gonzalo Alonso-Álvarez[7], Daniele S. M. Alves[8], Saurabh Bansal[6], Martin Bauer[9], Joachim Brod[6], Veronika Chobanova[10], Giancarlo D'Ambrosio[11], Alakabha Datta[12], Avital Dery[13], Francesco Dettori[14], Bogdan A. Dobrescu[15], Babette Döbrich[16], Daniel Egana-Ugrinovic[17], Gilly Elor[18], Miguel Escudero[19], Marco Fabbrichesi[20], Bartosz Fornal[21], Patrick J. Fox[15], Emidio Gabrielli[20,22,23], Li-Sheng Geng[24], Vladimir V. Gligorov[25], Martin Gorbahn[26], Stefania Gori[27], Benjamín Grinstein[28], Yuval Grossman[13], Diego Guadagnoli[29], Samuel Homiller[30], Matheus Hostert[17,31,32], Kevin J. Kelly[2,15], Teppei Kitahara[33], Simon Knapen[2,34,35], Gordan Krnjaic[36,37,38], Andrzej Kupsc[39,40], Sandra Kvedaraitė[6], Gaia Lanfranchi[41], Danny Marfatia[42], Jorge Martin Camalich[43,44], Diego Martínez Santos[10], Karim Massri[16], Patrick Meade[45], Matthew Moulson[41], Hajime Nanjo[46], Matthias Neubert[18], Maxim Pospelov[31,32], Sophie Renner[2], Stefan Schacht[47], Marvin Schnubel[18], Rui-Xiang Shi[25,48], Brian Shuve[49], Tommaso Spadaro[41], Yotam Soreq[50], Emmanuel Stamou[51], Olcyr Sumensari[52], Michele Tammaro[53], Jorge Terol-Calvo[43,44], Andrea Thamm[54], Yu-Chen Tung[55], Dayong Wang[56], Kei Yamamoto[57], Robert Ziegler[58]

Probably the most interesting is $K \to \mu\nu\gamma'(e^+e^-, \mu^+\mu^-)$

Here I am going to focus on MEG II to make an example ...

MEG II

$\mathrm{BR}(\mu \to e\gamma) < 4.2 \times 10^{-13}$ MEG 2016



Trigger level info:

1) Photon energy by liquid Xenon scintillator

2) hit on the timing counter

Offline:

3) full mesure of the positron momentum

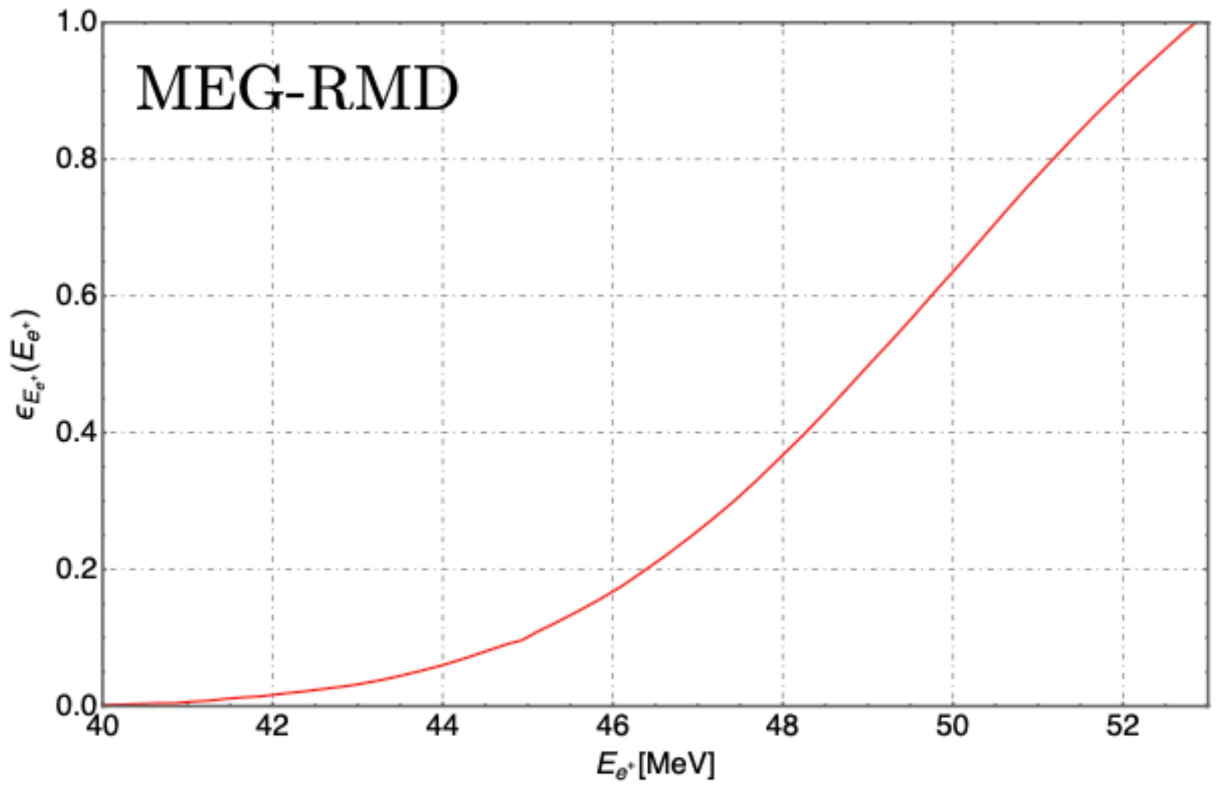
Trigger Selection

$\mathrm{BR}(\mu \to e\gamma) < 4.2 \times 10^{-13}$ MEG 2016 $\longleftrightarrow$ 1) very high intensity
2) very exclusive trigger targeted at $\mu \to e\gamma$

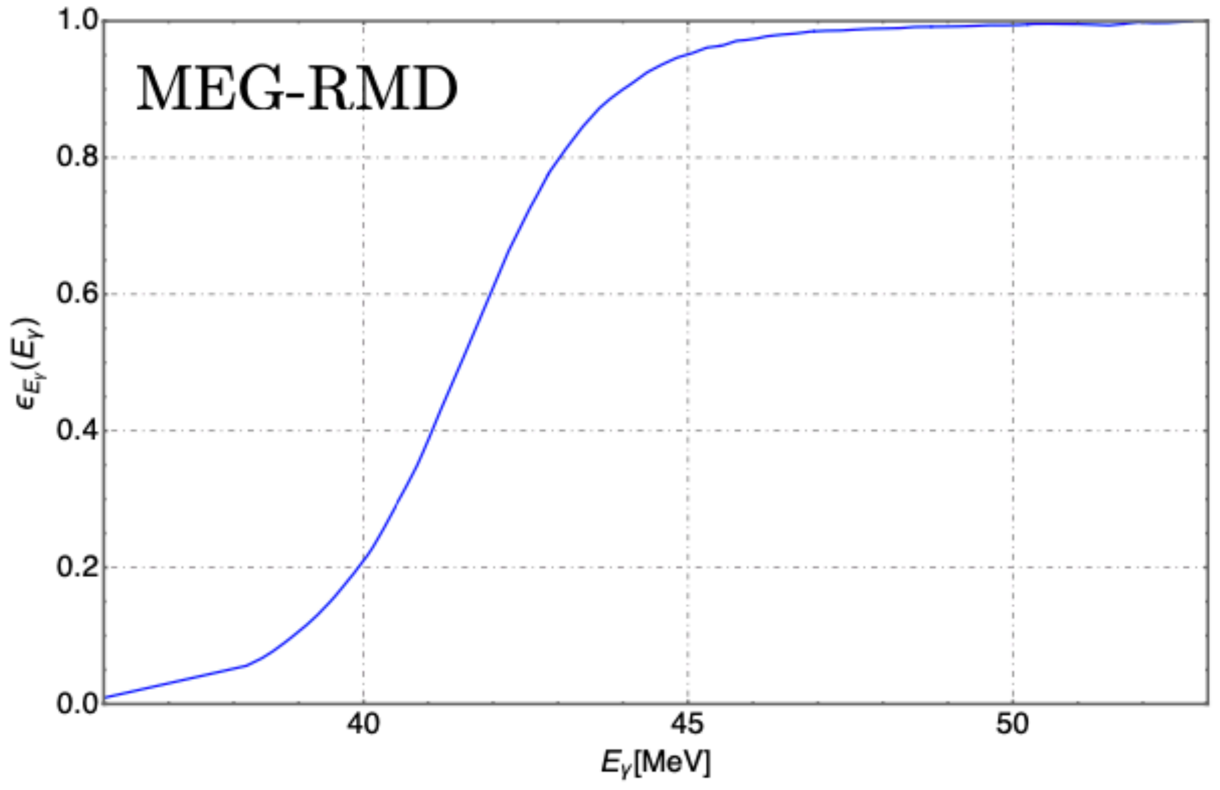
The trigger maximize the efficiency to back to back positron-photon of $E = m_\mu/2$

See Galli et al. *JINST 9 (2014)*

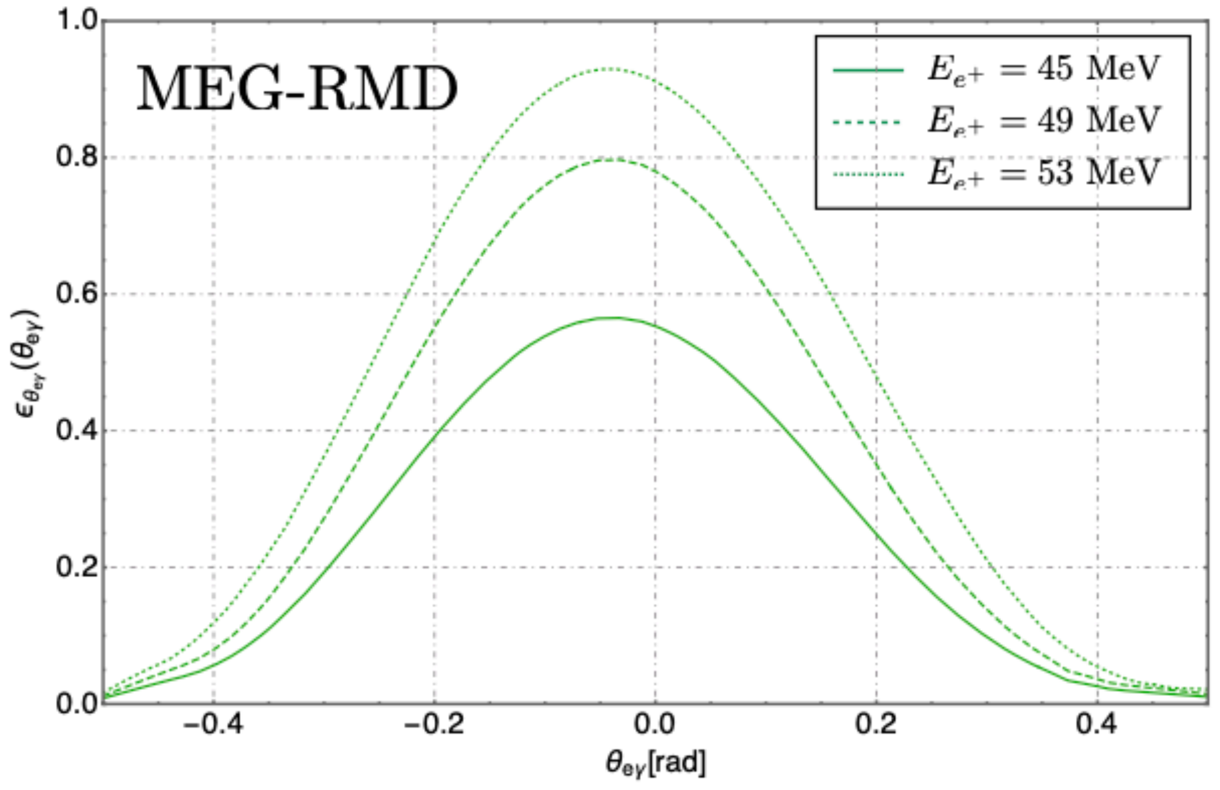
Positron energy >45 MeV hardware



Photon >45 MeV @ trigger level



back to back topology @ trigger level



Taken from *MEG-RMD measurement 1312.3217*

In numbers…

Besides $R_{\mu^+}^{\rm MEG} = 3 \times 10^7 \mu^+/{\rm sec}$ intensity

Very little data can be saved on disk or analysed offline at MEG II

At MEG 10 Hz is the maximal allowed stream

Online the trigger should select 1 “interesting” muon event out of 10^7

In numbers…

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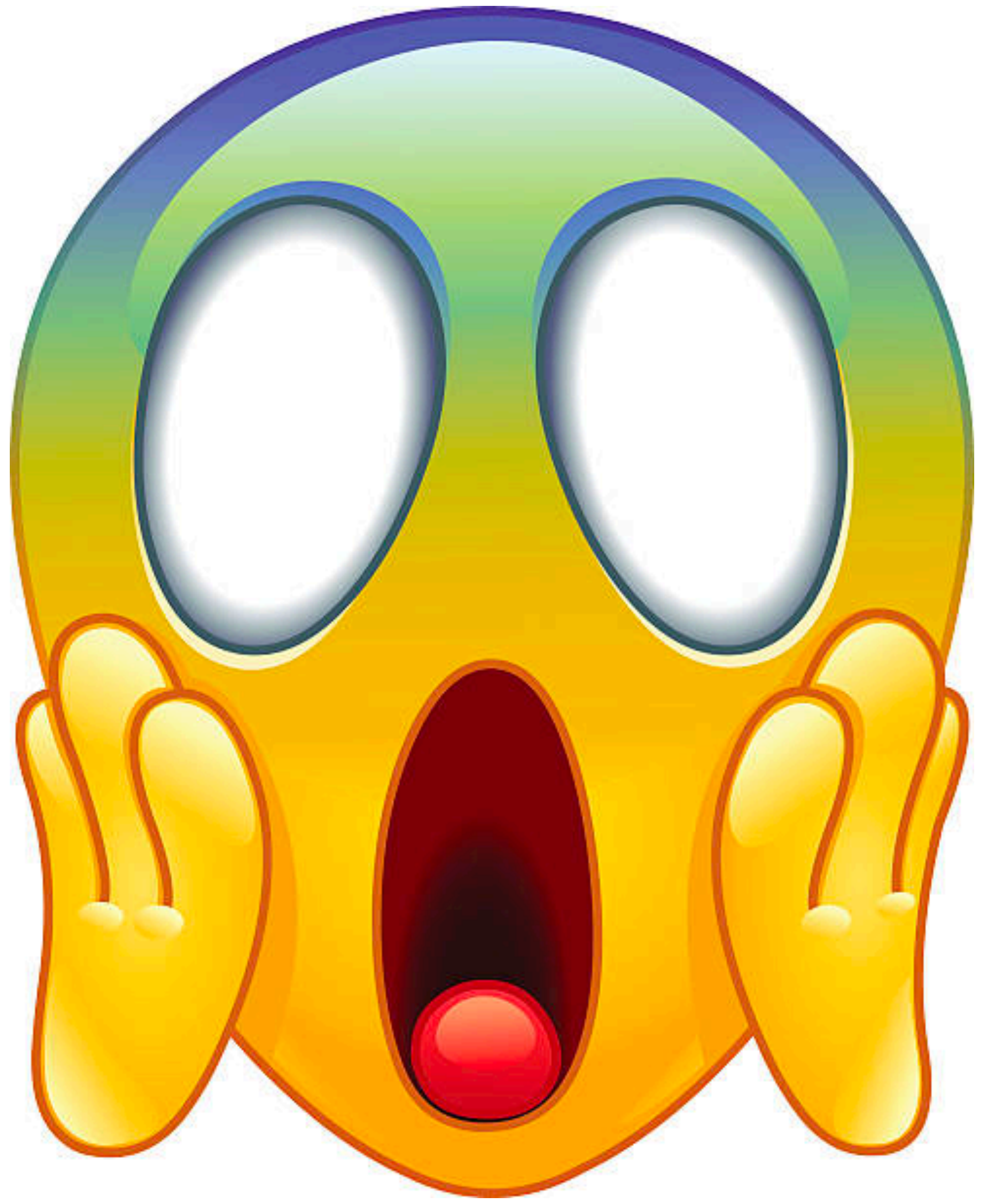
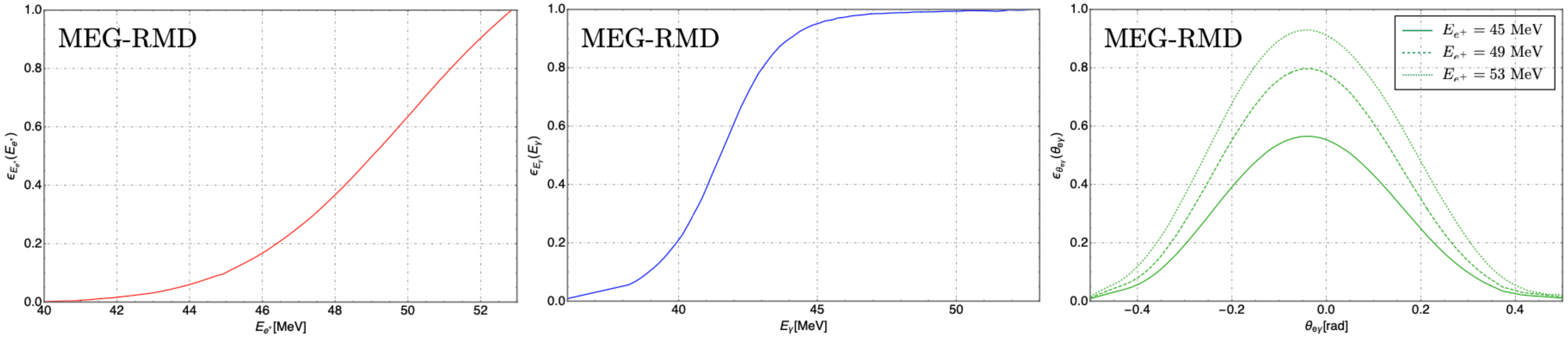
All the rest of the data is lost!



Towards a new data taking strategy

Logic: the trigger requirements are killing the ALP signal



*

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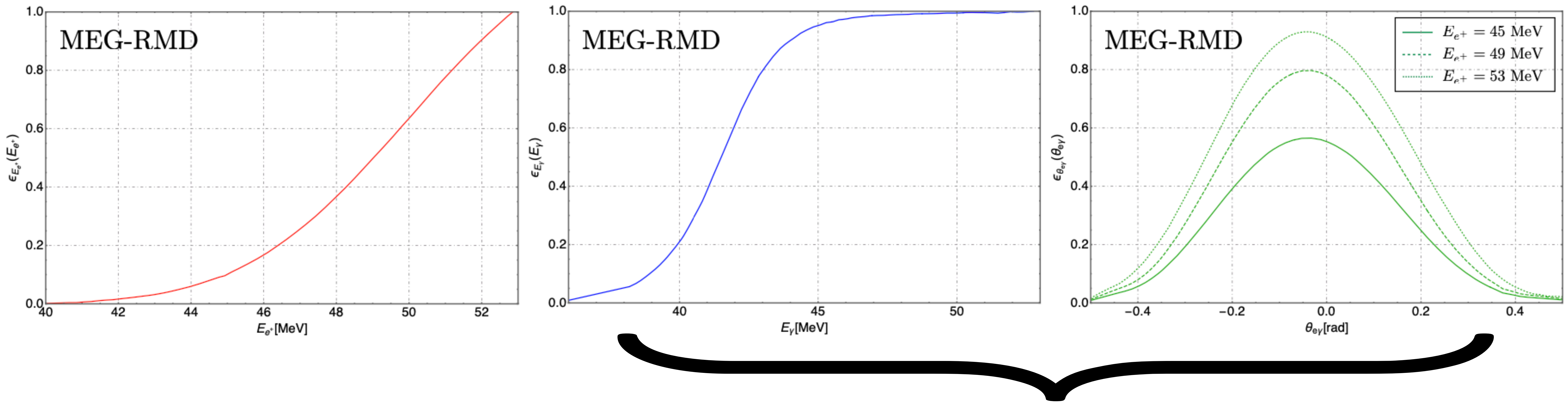

1) Eliminating the matching of the TC hit which assumes back to back topology

2) Lowering the photon trigger threshold reducing the beam intensity

*

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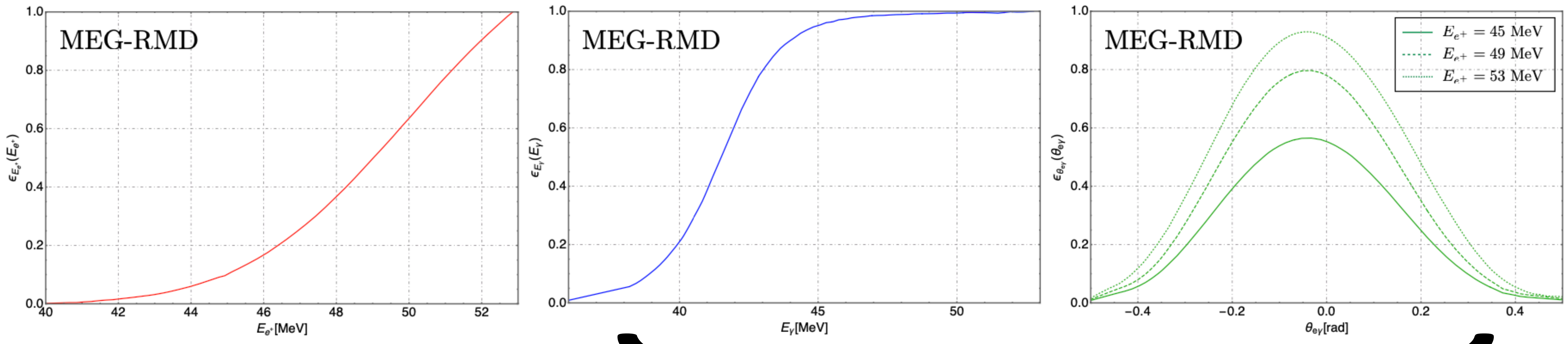

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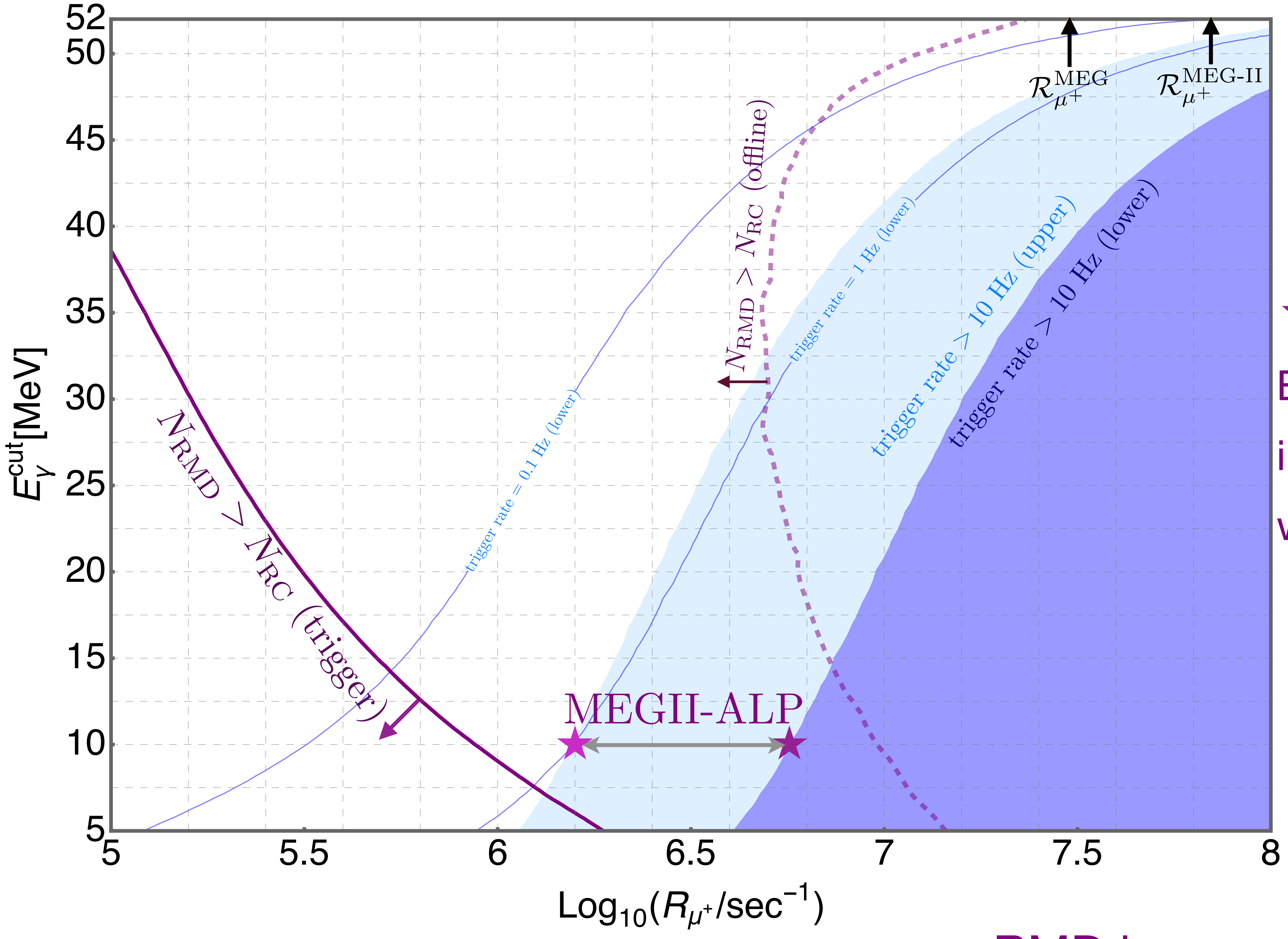
The RC dominates the trigger rate but it can be suppressed by reducing R_μ* the intensity

$$\mathrm{RC} \sim R_\mu^2 \quad \mathrm{RMD} \sim R_\mu$$

*many thanks to Luca Galli for teaching us all this!

Towards a new data taking strategy



★ Benchmark set to the highest intensity for photons of 10 MeV with our estimate of the trigger rate

Max trigger rate 10 Hz

fixes the intensity vs photon cut

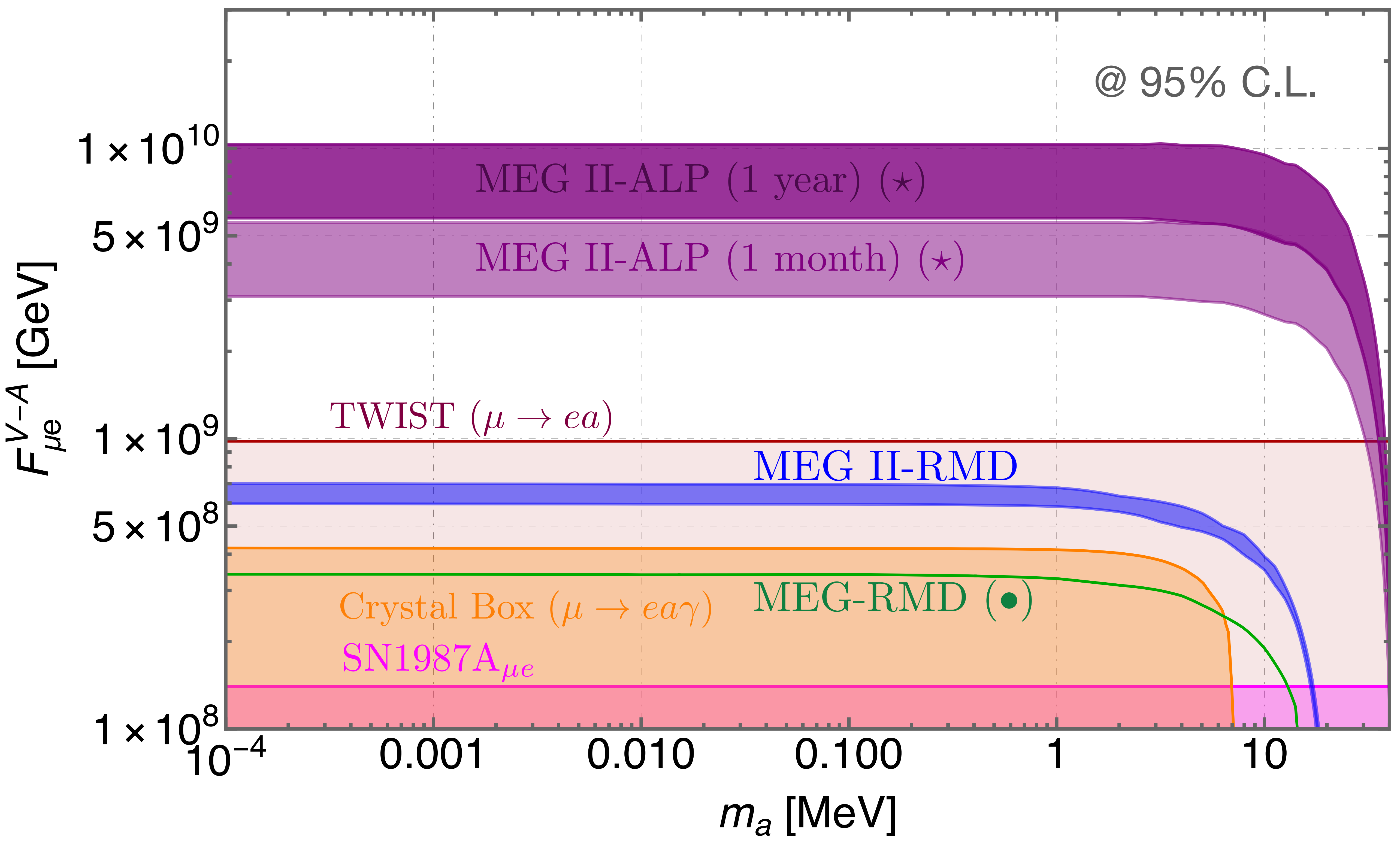
RMD becomes the dominant bkd

below a certain intensity

(harder to suppress RMD online)

What can we test?

Jho, Knapen, D.R. 2112.07720



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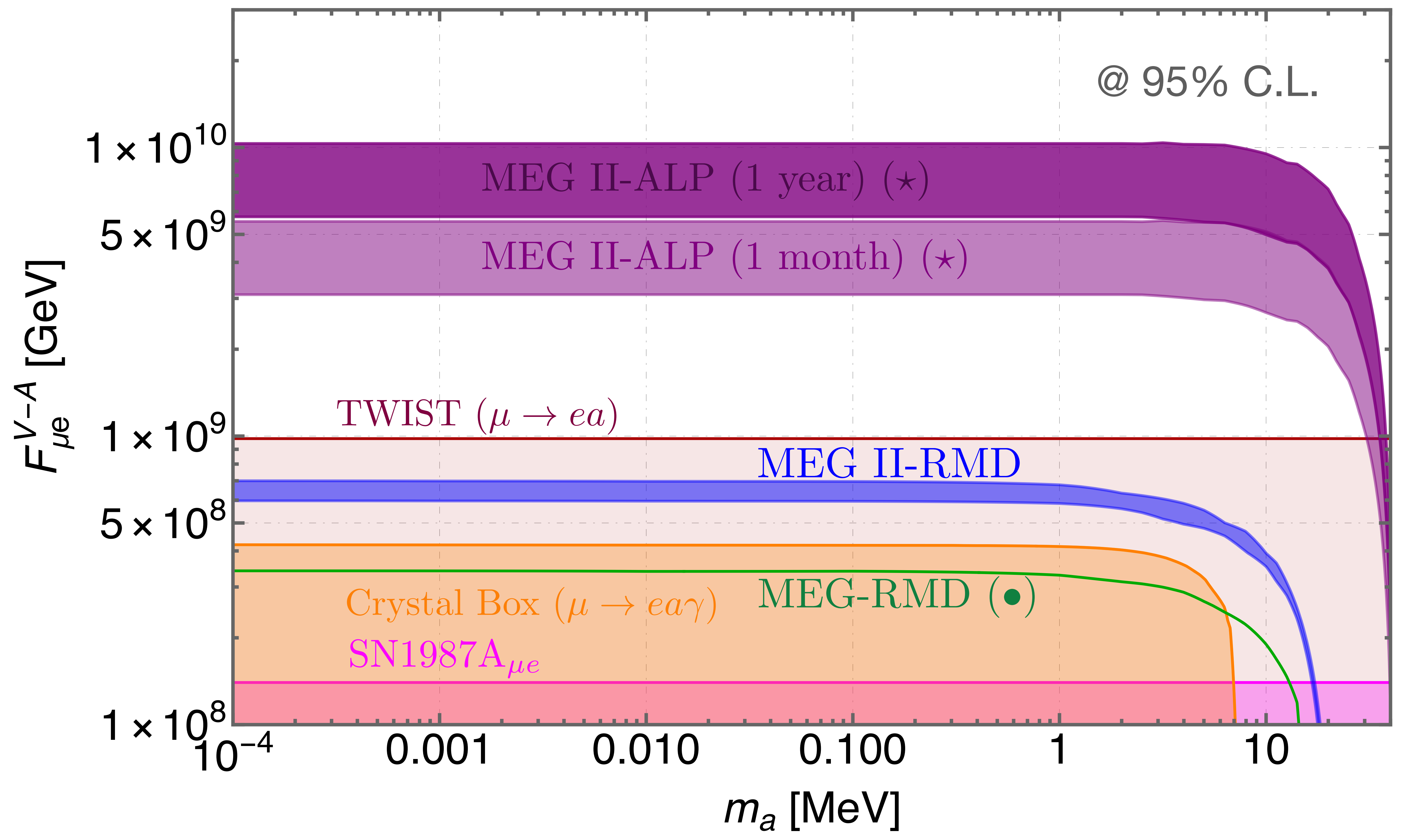
Jho, Knapen, D.R. 2112.07720



MEG II-ALP can improve on TWIST with only 1 month of data taking*

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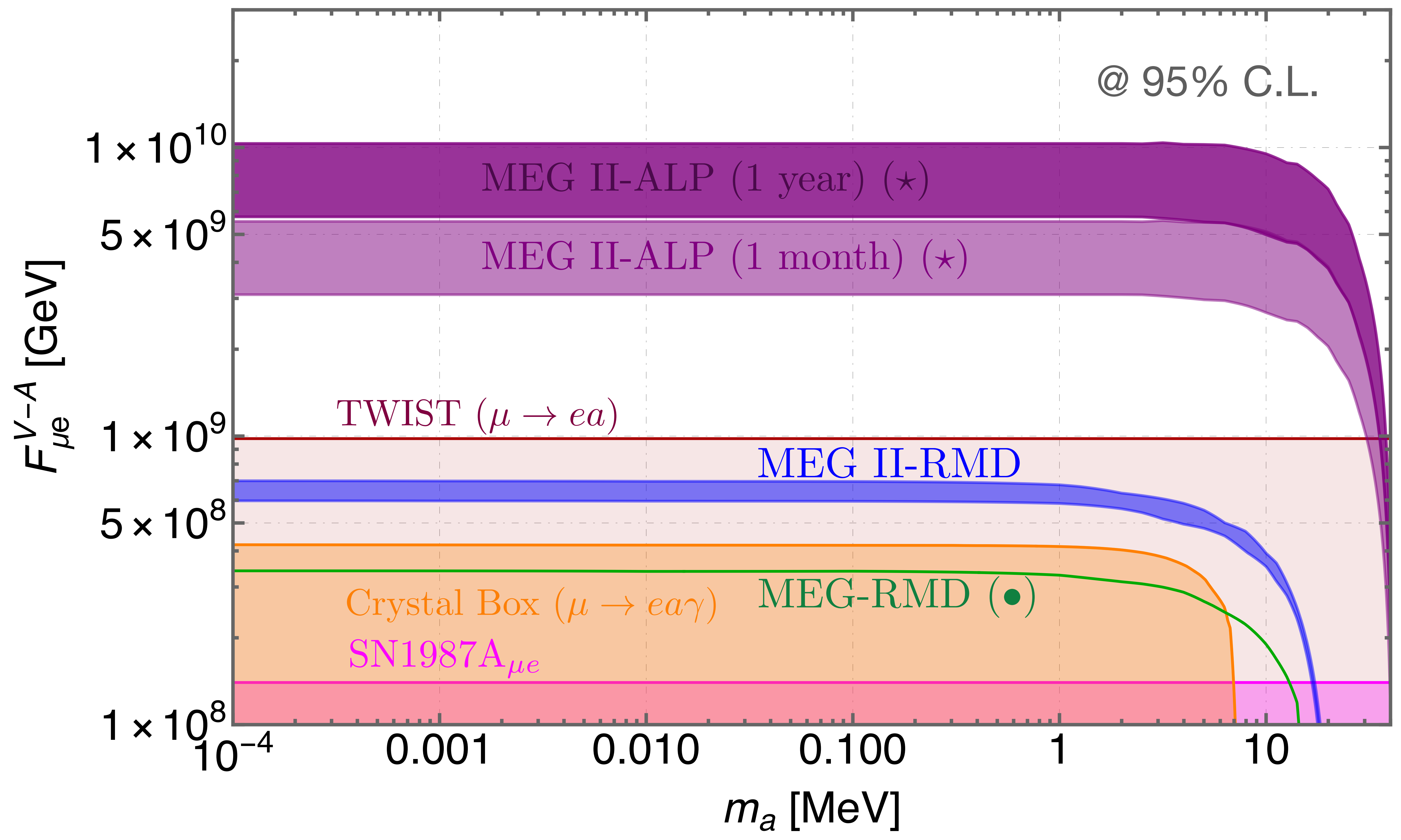
Jho, Knapen, D.R. 2112.07720



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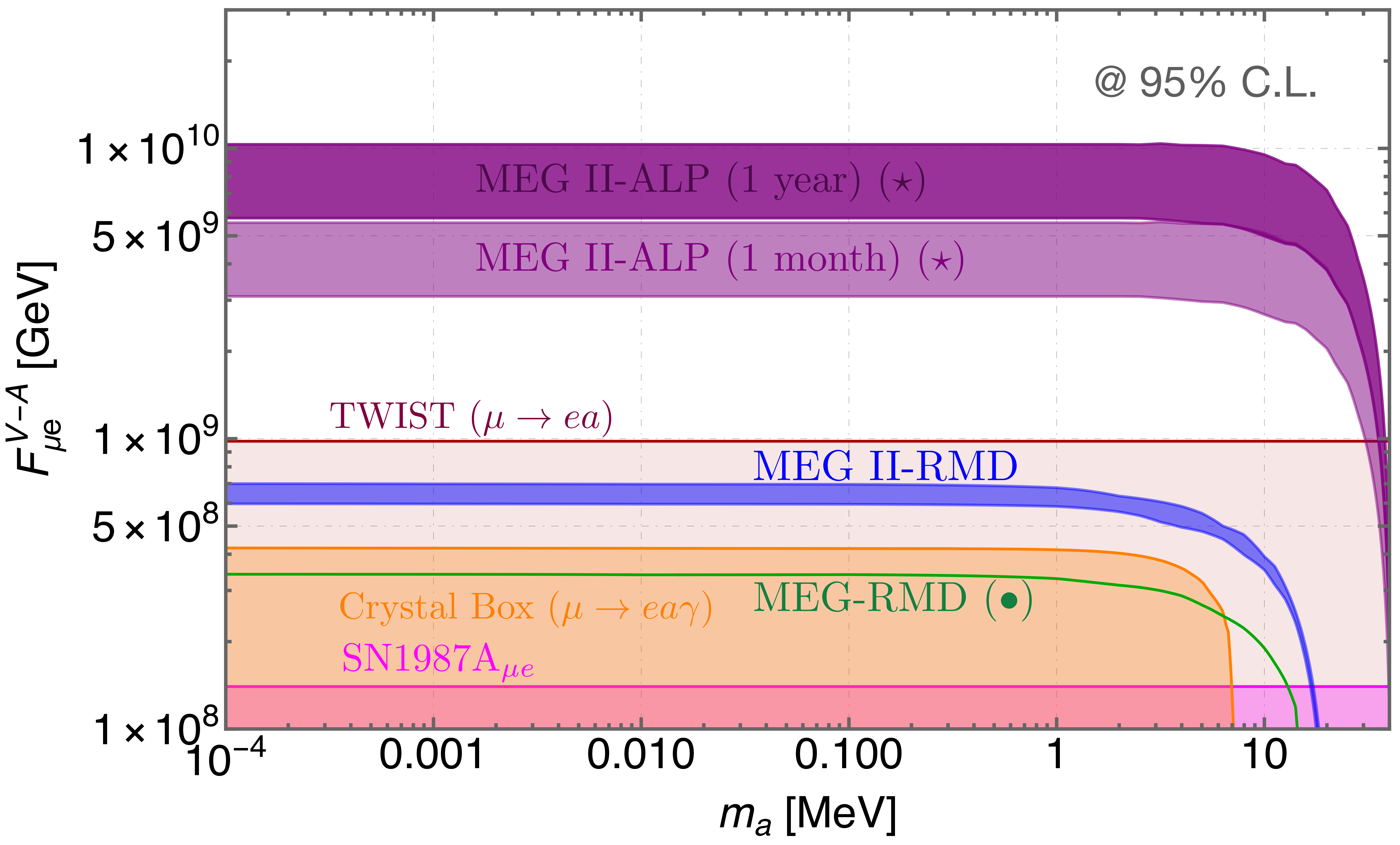

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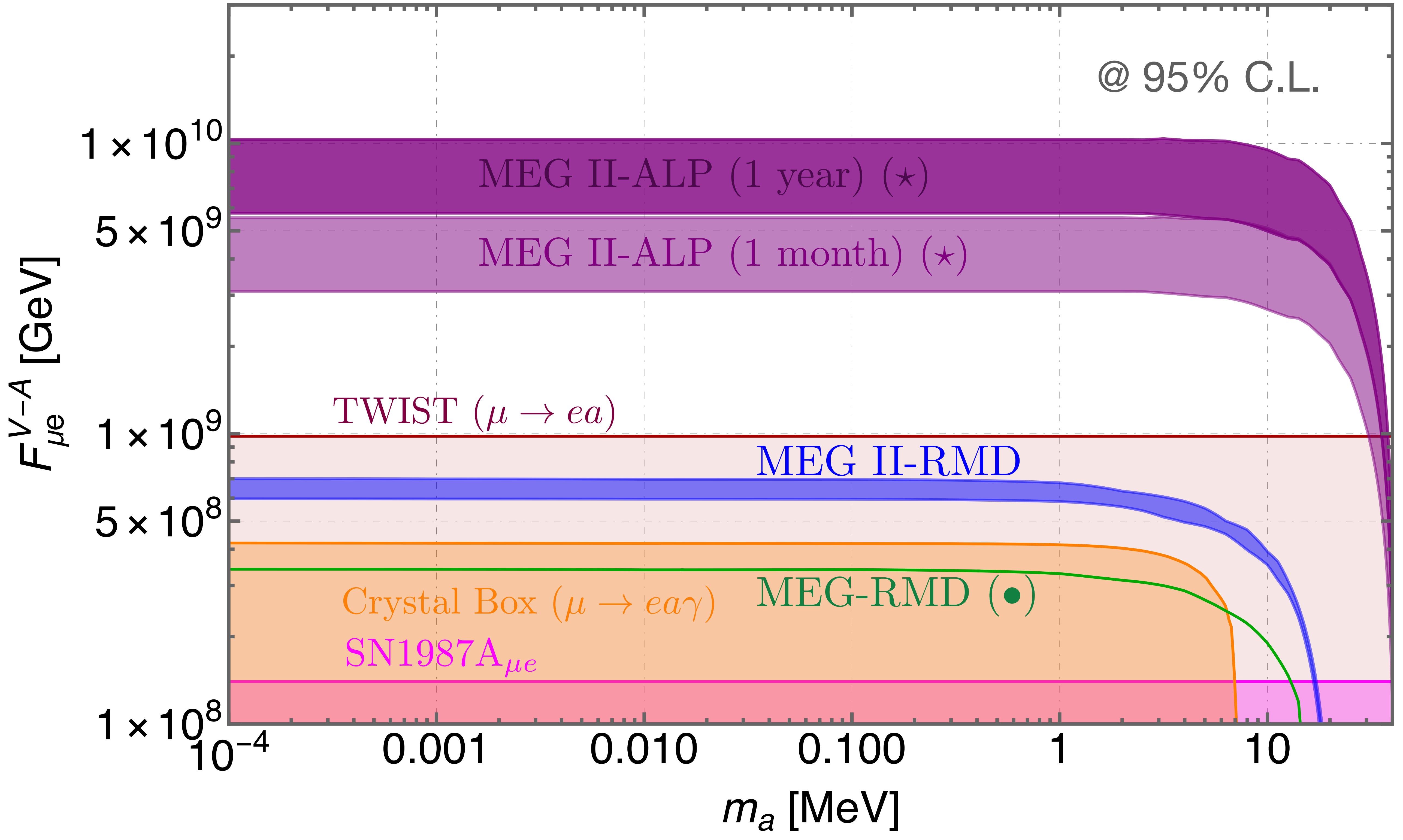
Jho, Knapen, D.R. 2112.07720



MEG II-ALP can improve on TWIST with only 1 month of data taking*

* the band in the reach is due to the uncertainty into our estimate of the trigger rate

* we cut photon below 10 MeV, maybe MEG II detector can do better

* no systematic uncertainties have been accounted for in this reach

New Opportunities to hunt for new physics with current experiments

TRIGGERING

...

New Opportunities to hunt for new physics with current experiments

TRIGGERING

@ LHC

@ FLAVOR EXPERIMENTS

…