Probing a degenerate-scalar scenario in a pseudoscalar dark-matter model

[arXiv:2101.04887]

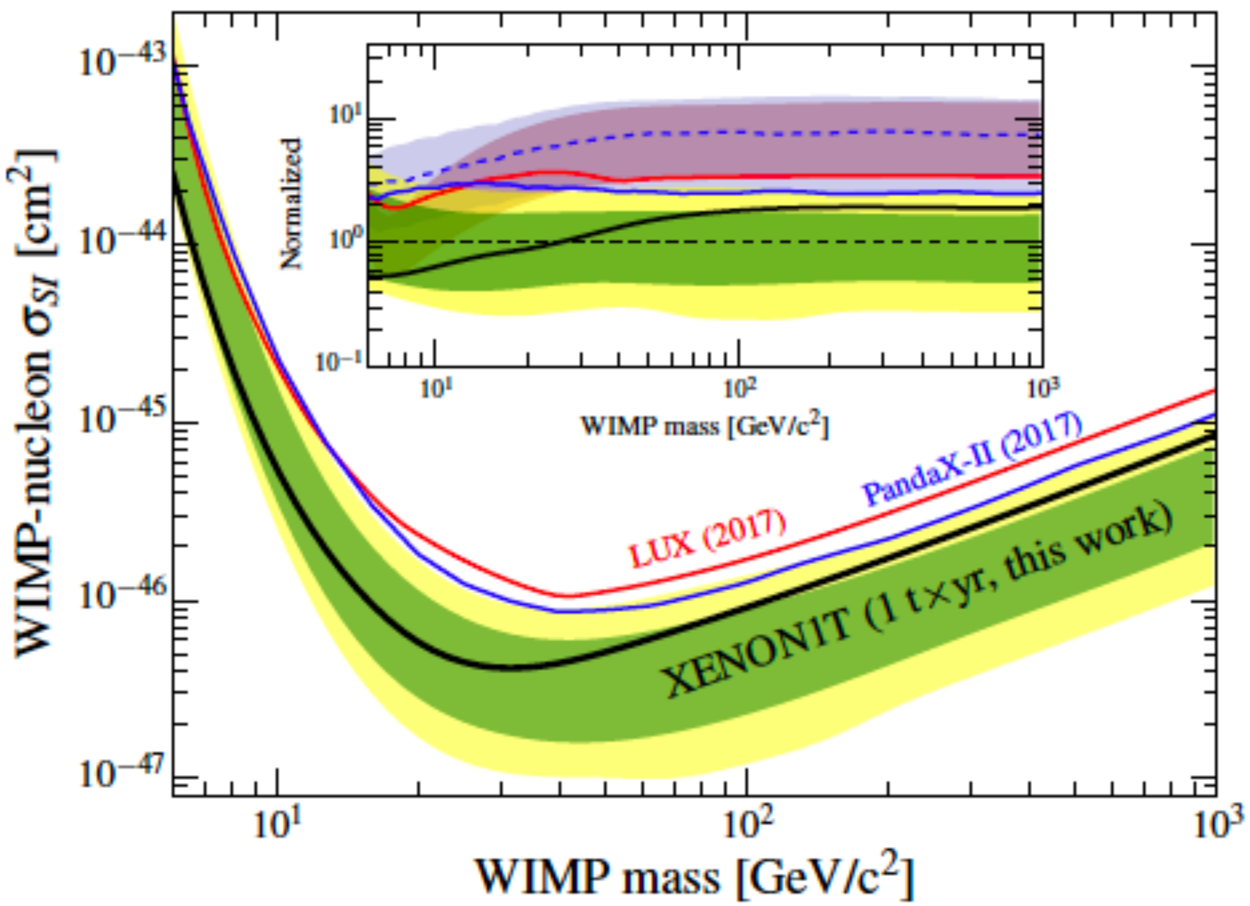
Kentarou Mawatari

Iwate University 岩手大学

in collaboration with
G-C. Cho and S. Abe
(Ochanomizu U.)

Strong constraints from DM direct detection experiments

XENON1T [1805.12562]



How can we avoid such strong constraints ?

Motivation

PRL **119,** 191801 (2017) PHYSICAL REVIEW LETTERS week ending 10 NOVEMBER 2017

Cancellation Mechanism for Dark-Matter–Nucleon Interaction

Christian Gross,[1] Oleg Lebedev,[1] and Takashi Toma[2]
[1] *Department of Physics and Helsinki Institute of Physics, Gustaf Hällströmin katu 2, FI-00014 Helsinki, Finland*
[2] *Physik-Department T30d, Technische Universität München, James-Franck-Straße, D-85748 Garching, Germany*
(Received 14 August 2017; published 7 November 2017)

We consider a simple Higgs portal dark-matter model, where the standard model is supplemented with a complex scalar whose imaginary part plays the role of weakly interacting massive particle dark matter (DM). We show that the direct DM detection cross section vanishes at the tree level and zero momentum transfer due to a cancellation by virtue of a softly broken symmetry. This cancellation is operative for any mediator masses. As a result, our electroweak-scale dark matter satisfies all of the phenomenological constraints quite naturally.

Model

- CxSM : A complex singlet extension of the SM with a softly broken U(1) symmetry

$$V = \frac{m^2}{2}|H|^2 + \frac{\lambda}{4}|H|^4 + \frac{\delta_2}{2}|H|^2|S|^2 + \frac{b_2}{2}|S|^2 + \frac{d_2}{4}|S|^4 + \left(a_1 S + \frac{b_1}{4}S^2 + \text{c.c.}\right)$$

$$H = \frac{1}{\sqrt{2}}\begin{pmatrix} 0 \\ v+h \end{pmatrix}, \quad S = \frac{1}{\sqrt{2}}(v_S + s + i\chi)$$

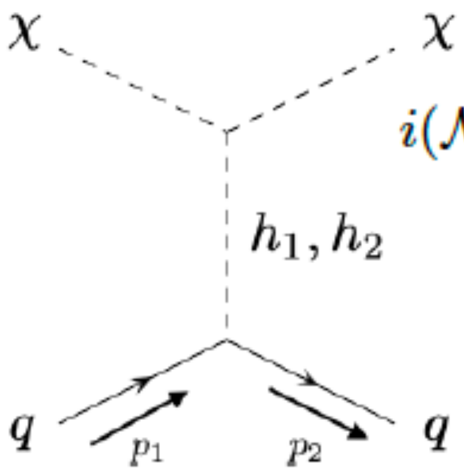
h_1, h_2 DM

125GeV SM-like Higgs boson

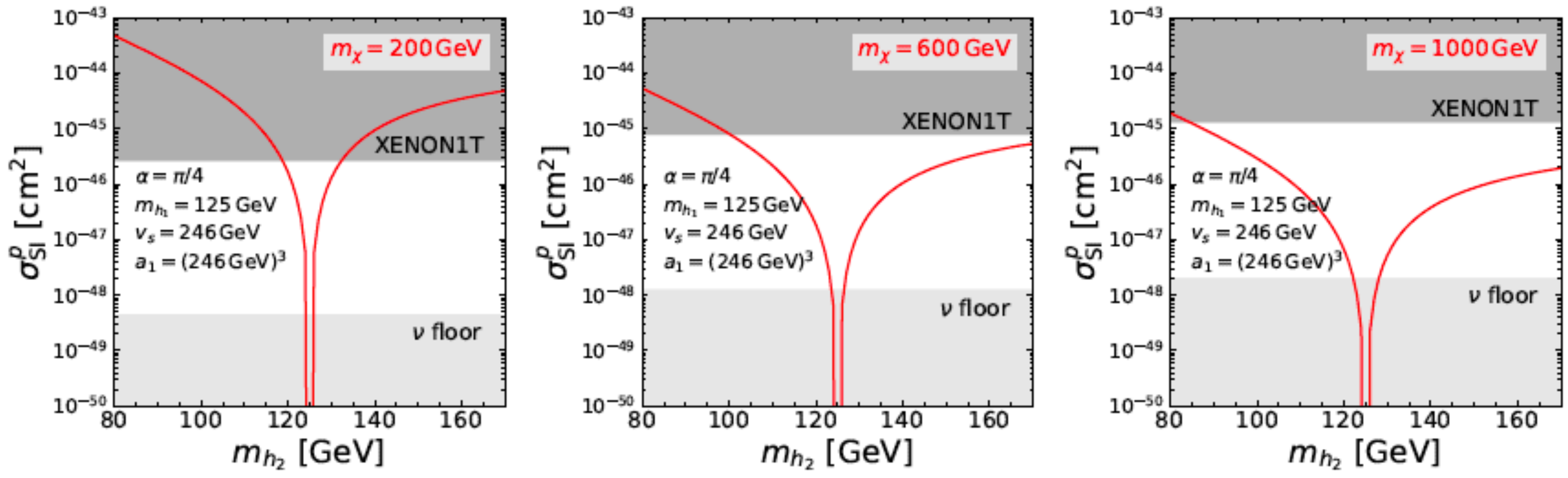
5 free parameters

$m_{h_2},\ m_\chi,\ \alpha,\ a_1,\ v_S$

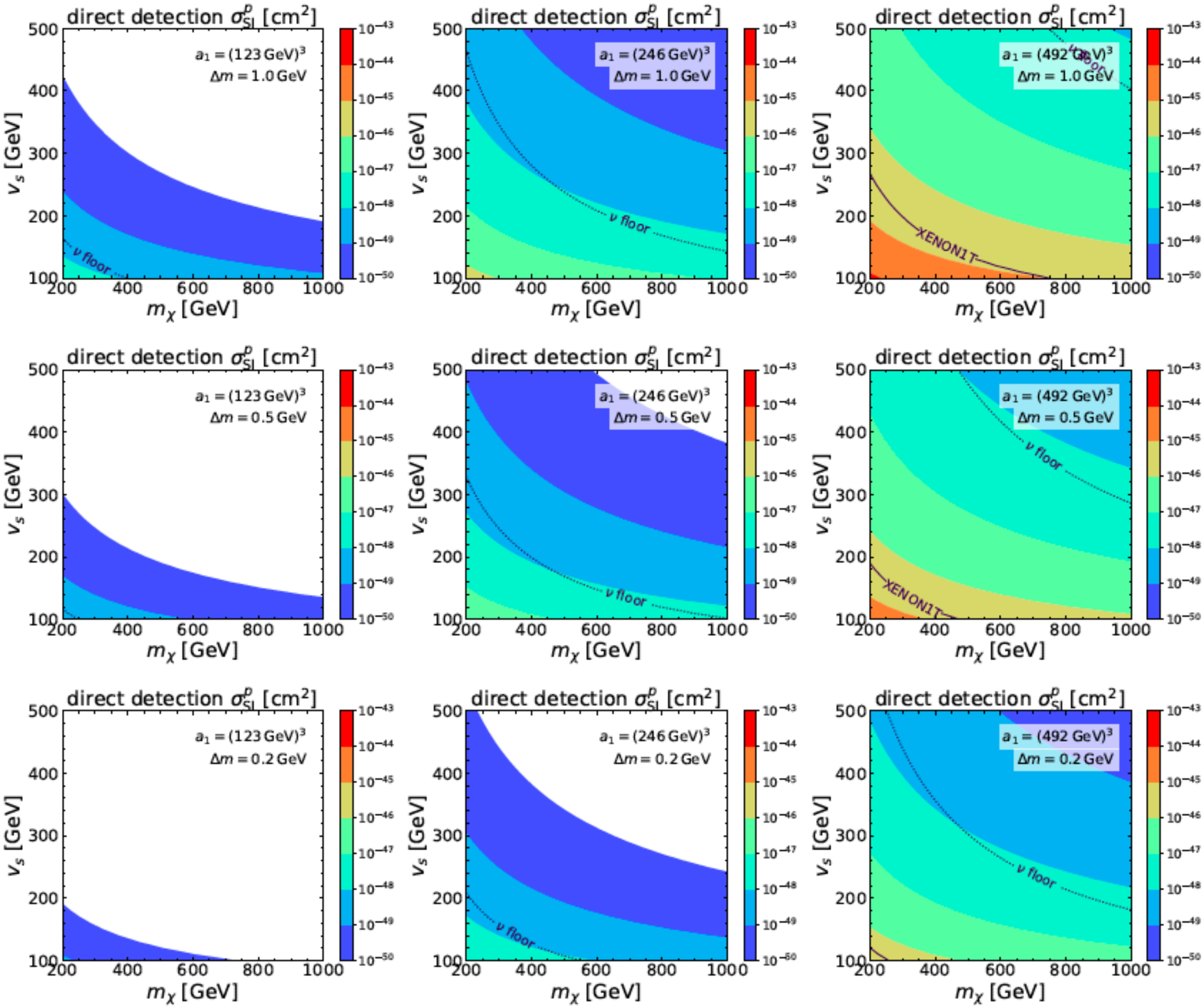
Suppression of the DM-quark scattering amplitudes

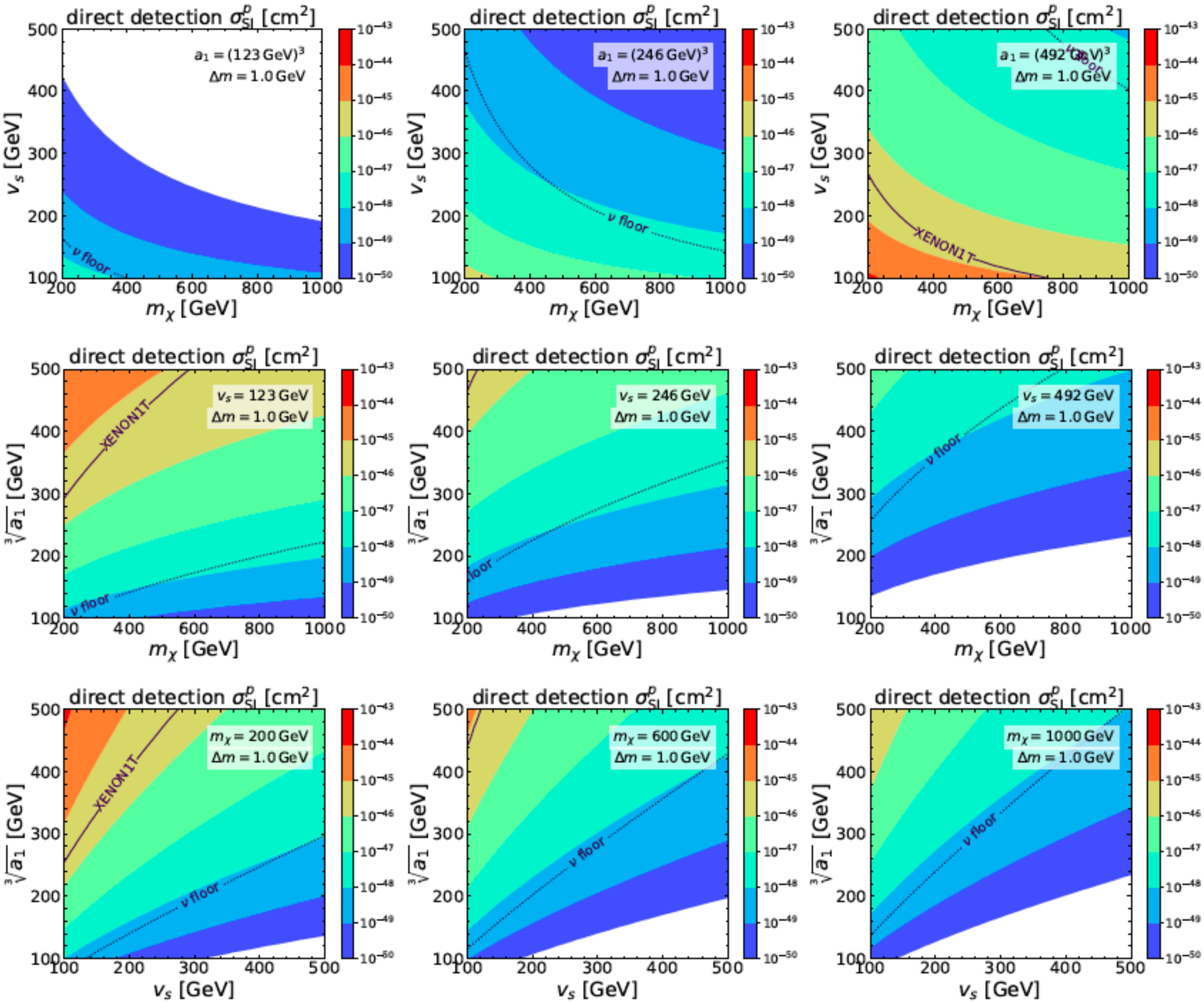


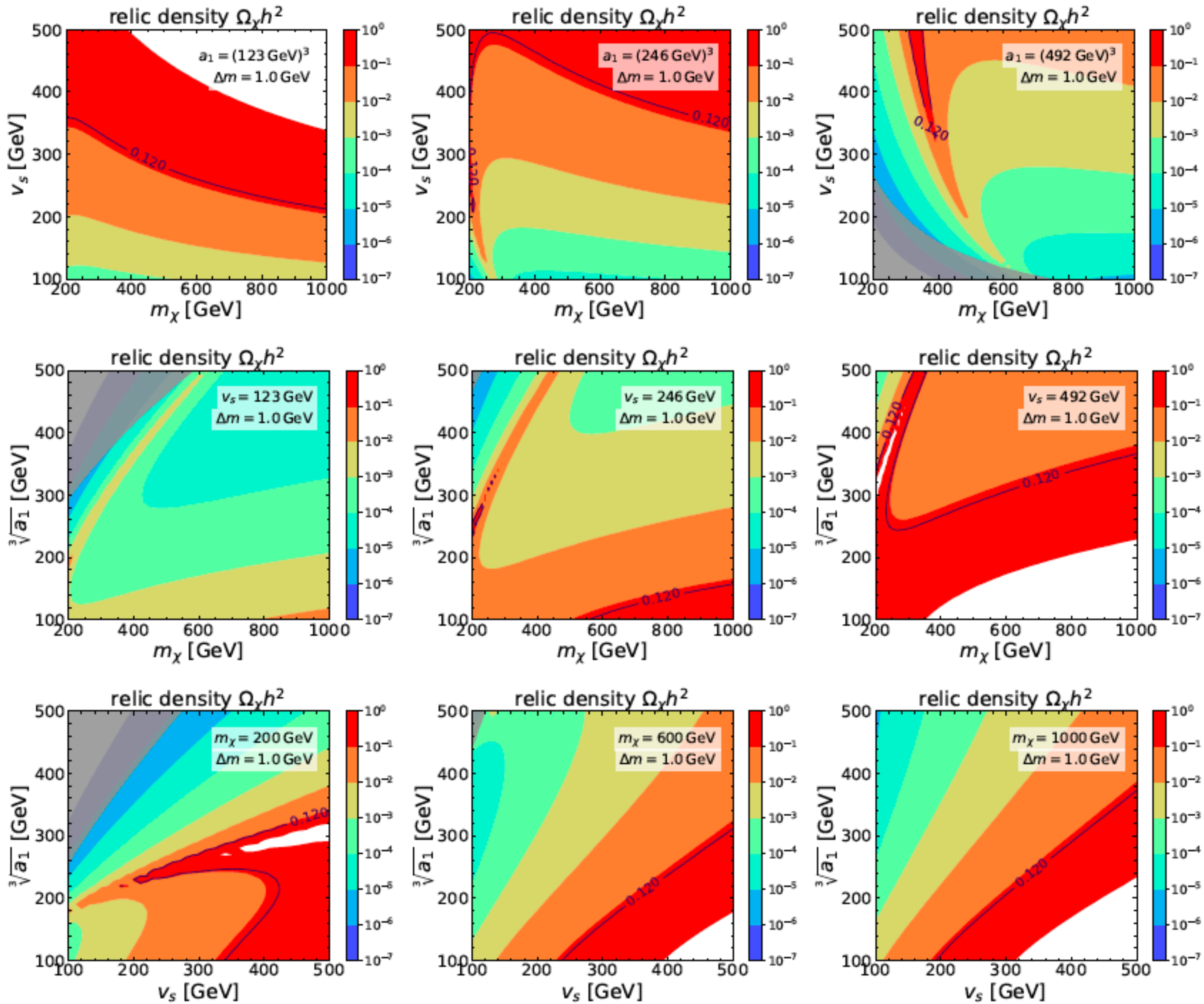
$$i(\mathcal{M}_{h_1}+\mathcal{M}_{h_2}) \simeq i\frac{m_q}{v v_S}\sin\alpha\cos\alpha\,\bar{u}(p_2)u(p_1)$$
$$\times\frac{1}{m_{h_1}^2 m_{h_2}^2}\left\{\left(m_{h_2}^2-m_{h_1}^2+\frac{\sqrt{2}a_1}{v_S}\frac{m_{h_2}^4-m_{h_1}^4}{m_{h_1}^2 m_{h_2}^2}\right)t+\frac{\sqrt{2}a_1}{v_S}\left(m_{h_2}^2-m_{h_1}^2\right)\right\}$$



Yes, if the two scalars are nearly degenerate.

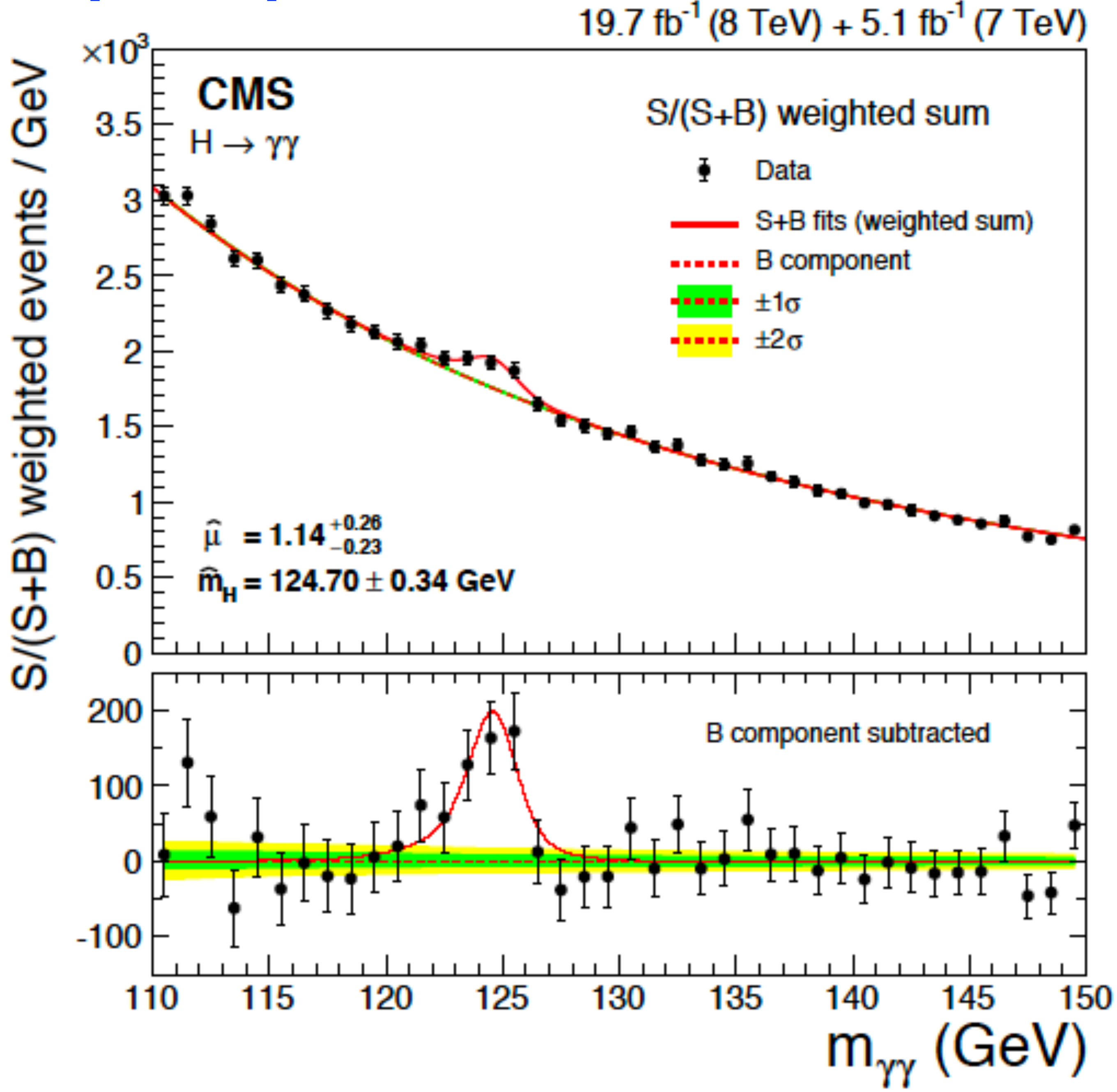

direct detection σ^p_{SI} [cm^2]
$a_1 = (123\,\mathrm{GeV})^3$
$\Delta m = 1.0\,\mathrm{GeV}$
ν floor
direct detection σ^p_{SI} [cm^2]
$a_1 = (246\,\mathrm{GeV})^3$
$\Delta m = 1.0\,\mathrm{GeV}$
ν floor
direct detection σ^p_{SI} [cm^2]
$a_1 = (492\,\mathrm{GeV})^3$
$\Delta m = 1.0\,\mathrm{GeV}$
XENON1T
direct detection σ^p_{SI} [cm^2]
$a_1 = (123\,\mathrm{GeV})^3$
$\Delta m = 0.5\,\mathrm{GeV}$
direct detection σ^p_{SI} [cm^2]
$a_1 = (246\,\mathrm{GeV})^3$
$\Delta m = 0.5\,\mathrm{GeV}$
ν floor
direct detection σ^p_{SI} [cm^2]
$a_1 = (492\,\mathrm{GeV})^3$
$\Delta m = 0.5\,\mathrm{GeV}$
ν floor
XENON1T
direct detection σ^p_{SI} [cm^2]
$a_1 = (123\,\mathrm{GeV})^3$
$\Delta m = 0.2\,\mathrm{GeV}$
direct detection σ^p_{SI} [cm^2]
$a_1 = (246\,\mathrm{GeV})^3$
$\Delta m = 0.2\,\mathrm{GeV}$
ν floor
direct detection σ^p_{SI} [cm^2]
$a_1 = (492\,\mathrm{GeV})^3$
$\Delta m = 0.2\,\mathrm{GeV}$
ν floor
v_s [GeV]
m_χ [GeV]
100 200 300 400 500
200 400 600 800 1000
10^{-43} 10^{-44} 10^{-45} 10^{-46} 10^{-47} 10^{-48} 10^{-49} 10^{-50}

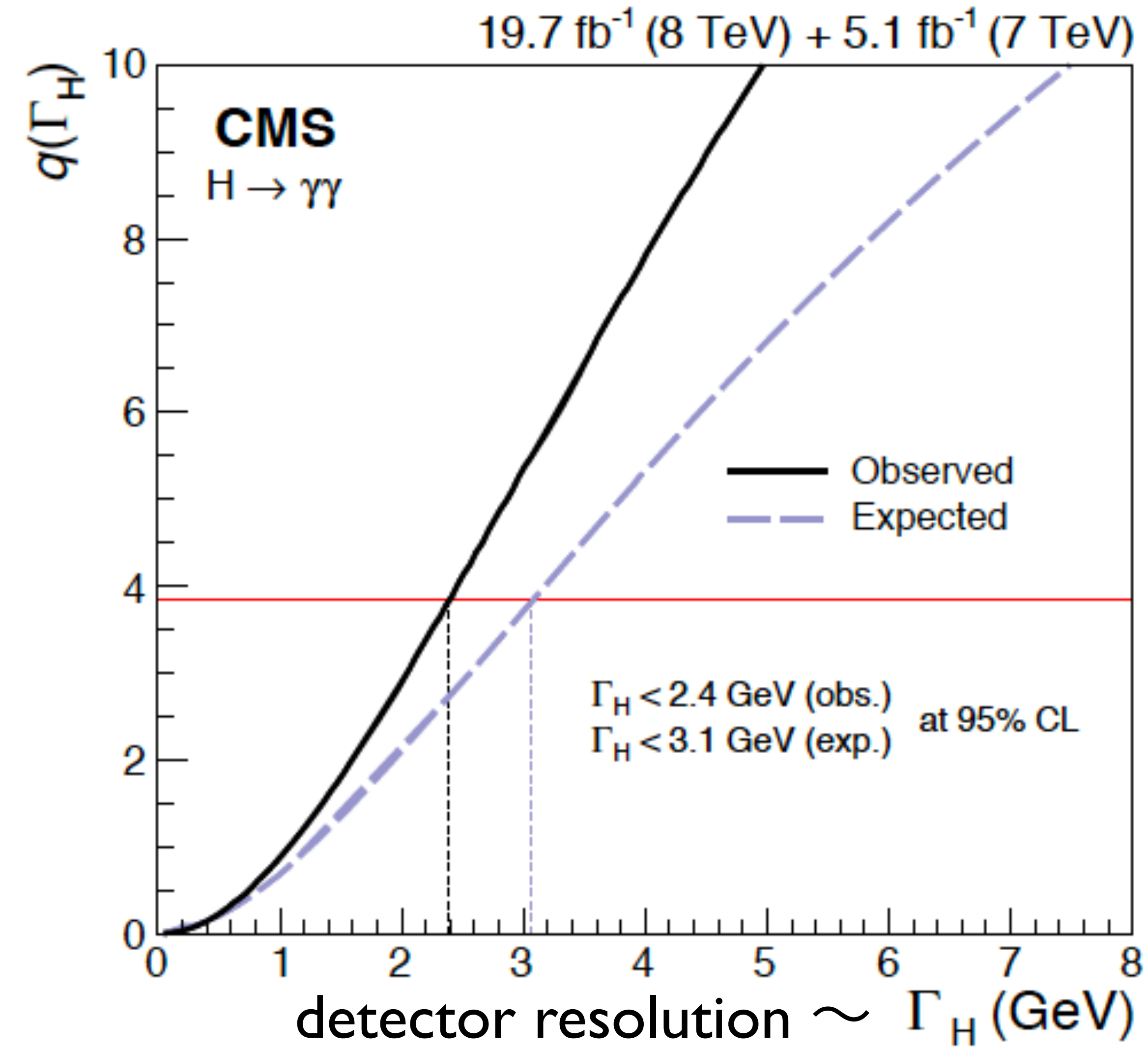

direct detection σ^p_{SI} [cm^2]
$a_1 = (123\,\text{GeV})^3$
$\Delta m = 1.0\,\text{GeV}$
ν floor
$a_1 = (246\,\text{GeV})^3$
$a_1 = (492\,\text{GeV})^3$
XENON1T
$v_s = 123\,\text{GeV}$
$v_s = 246\,\text{GeV}$
$v_s = 492\,\text{GeV}$
$m_\chi = 200\,\text{GeV}$
$m_\chi = 600\,\text{GeV}$
$m_\chi = 1000\,\text{GeV}$
v_s [GeV]
m_χ [GeV]
$\sqrt[3]{a_1}$ [GeV]


relic density $\Omega_\chi h^2$
$a_1 = (123\,\mathrm{GeV})^3$
$\Delta m = 1.0\,\mathrm{GeV}$
$a_1 = (246\,\mathrm{GeV})^3$
$\Delta m = 1.0\,\mathrm{GeV}$
$a_1 = (492\,\mathrm{GeV})^3$
$\Delta m = 1.0\,\mathrm{GeV}$
$v_s = 123\,\mathrm{GeV}$
$\Delta m = 1.0\,\mathrm{GeV}$
$v_s = 246\,\mathrm{GeV}$
$\Delta m = 1.0\,\mathrm{GeV}$
$v_s = 492\,\mathrm{GeV}$
$\Delta m = 1.0\,\mathrm{GeV}$
$m_\chi = 200\,\mathrm{GeV}$
$\Delta m = 1.0\,\mathrm{GeV}$
$m_\chi = 600\,\mathrm{GeV}$
$\Delta m = 1.0\,\mathrm{GeV}$
$m_\chi = 1000\,\mathrm{GeV}$
$\Delta m = 1.0\,\mathrm{GeV}$
0.120
m_χ [GeV]
v_s [GeV]
$\sqrt[3]{a_1}$ [GeV]

125GeV resonance

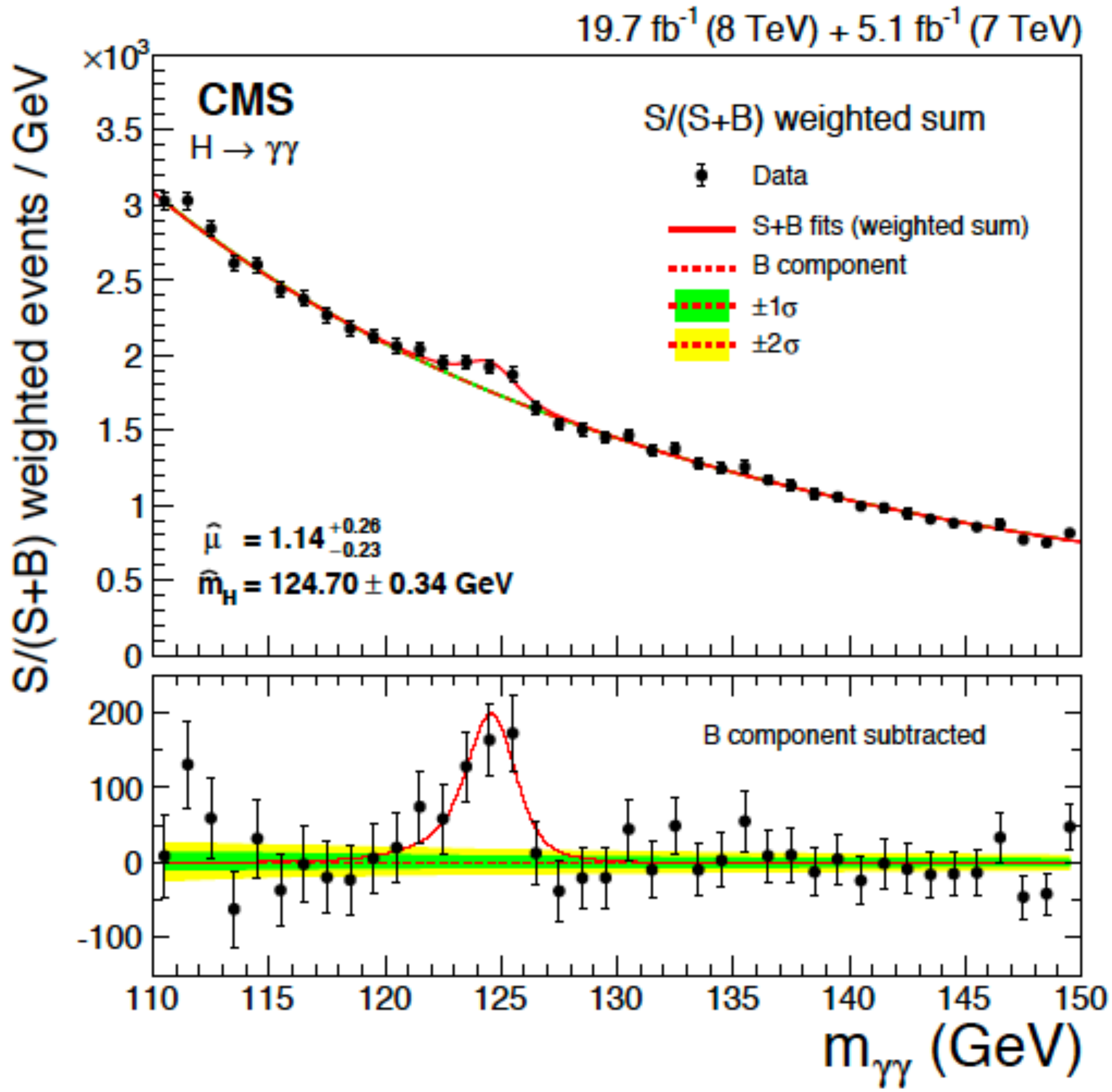
CMS [1407.0558]

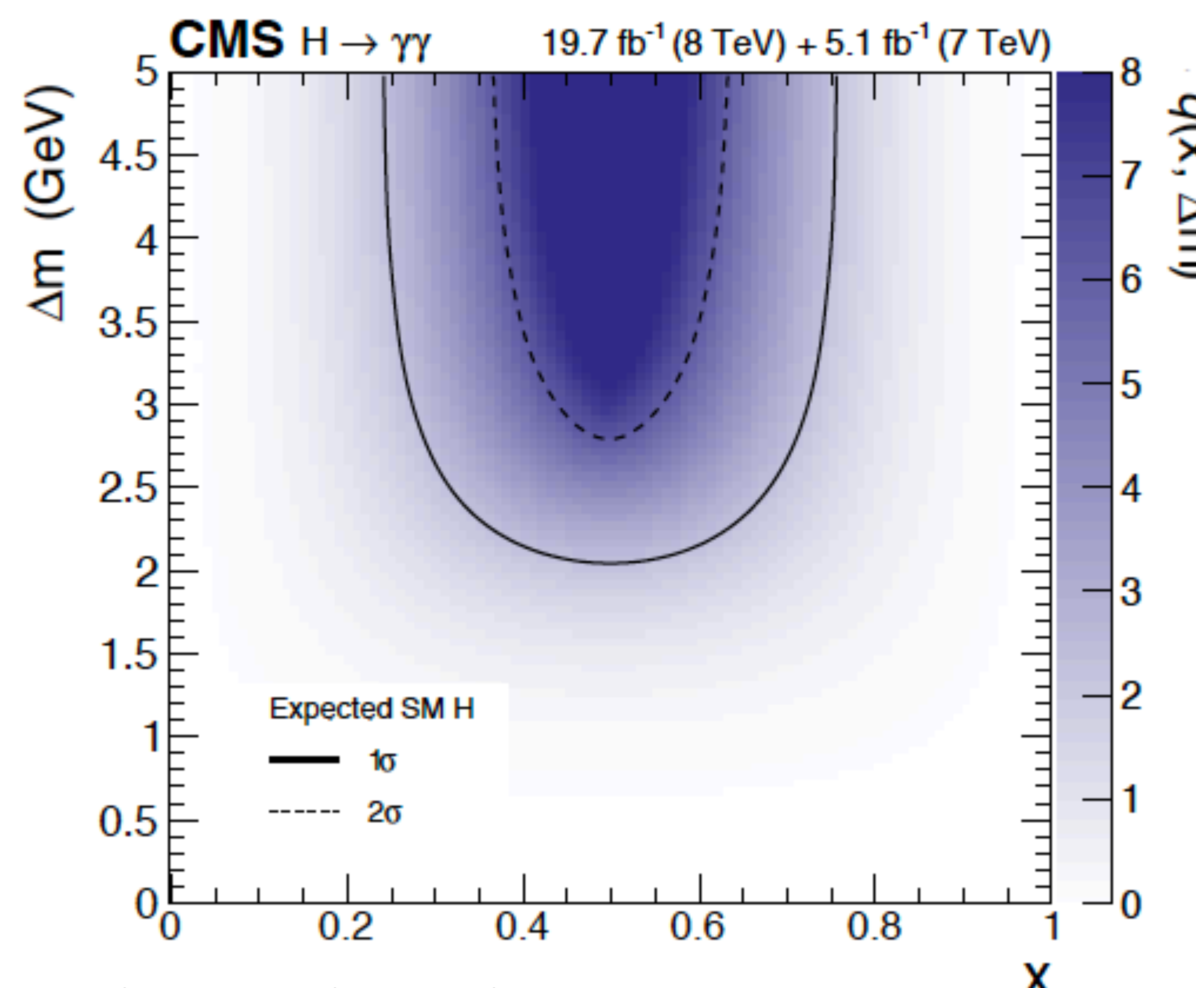




cf. Γ_H (SM) ∼ 4 MeV

Single H or 2 near mass-degenerate H ?





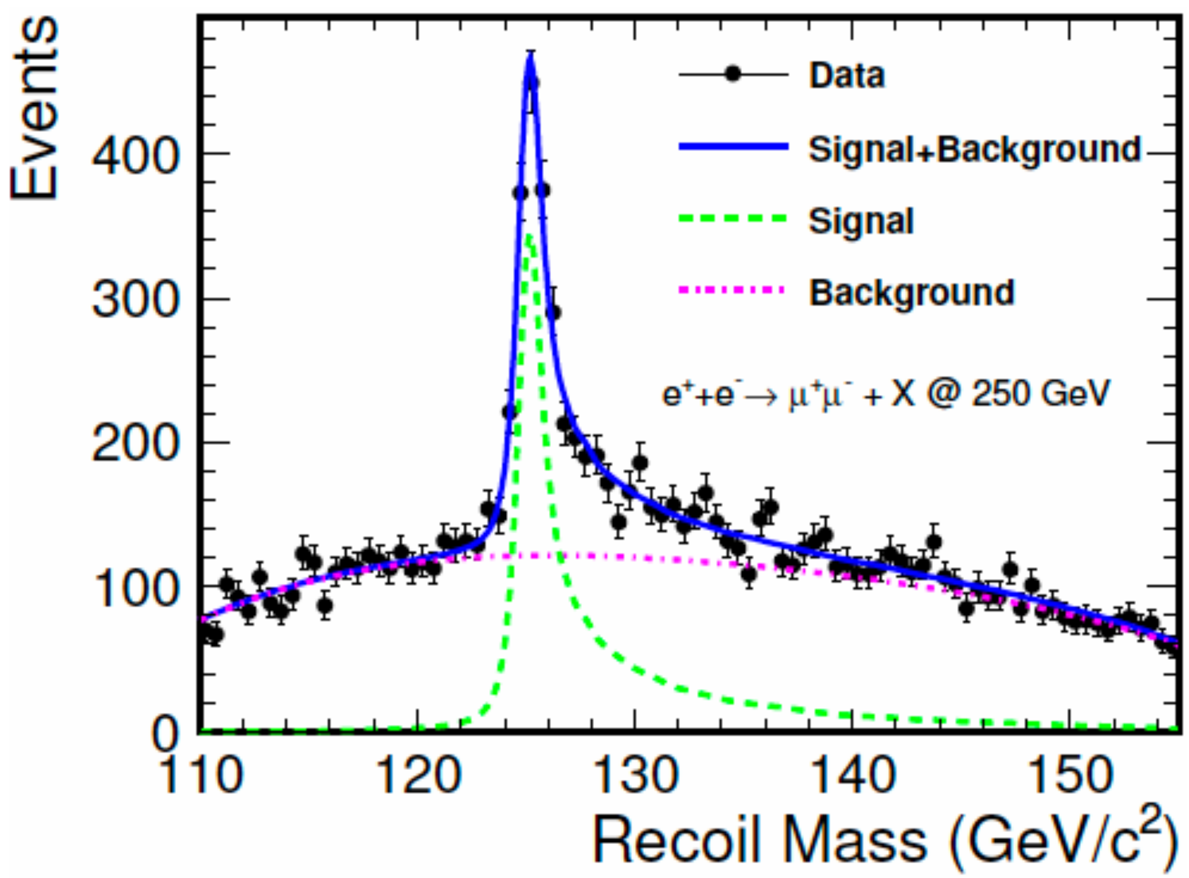
the fraction of signal for the lower mass state

At the LHC, two near mass-degenerate Higgs bosons with Δm<3GeV can not be distinguished from the single-state Higgs boson (SM).

How about at the ILC?

Recoil mass at the ILC

m_h Fujii et al. [1604.07524]



$\Delta m_H \sim 0.04$GeV

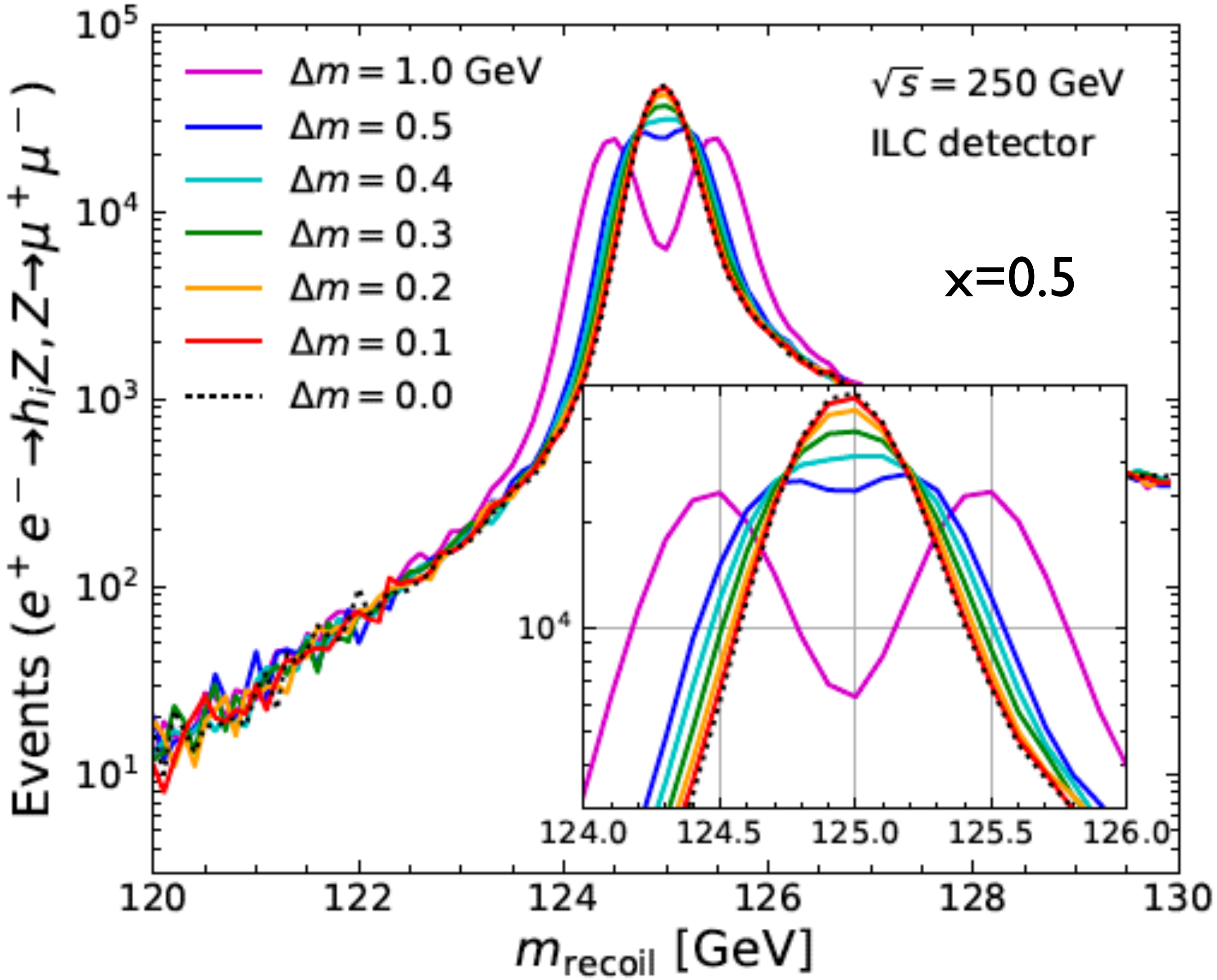
@250/fb

$$M_{\rm rec}^2 = \left(\sqrt{s} - E_{l^+l^-}\right)^2 - |\vec{p}_{l^+l^-}|^2$$

Precise measurement of the Higgs boson mass

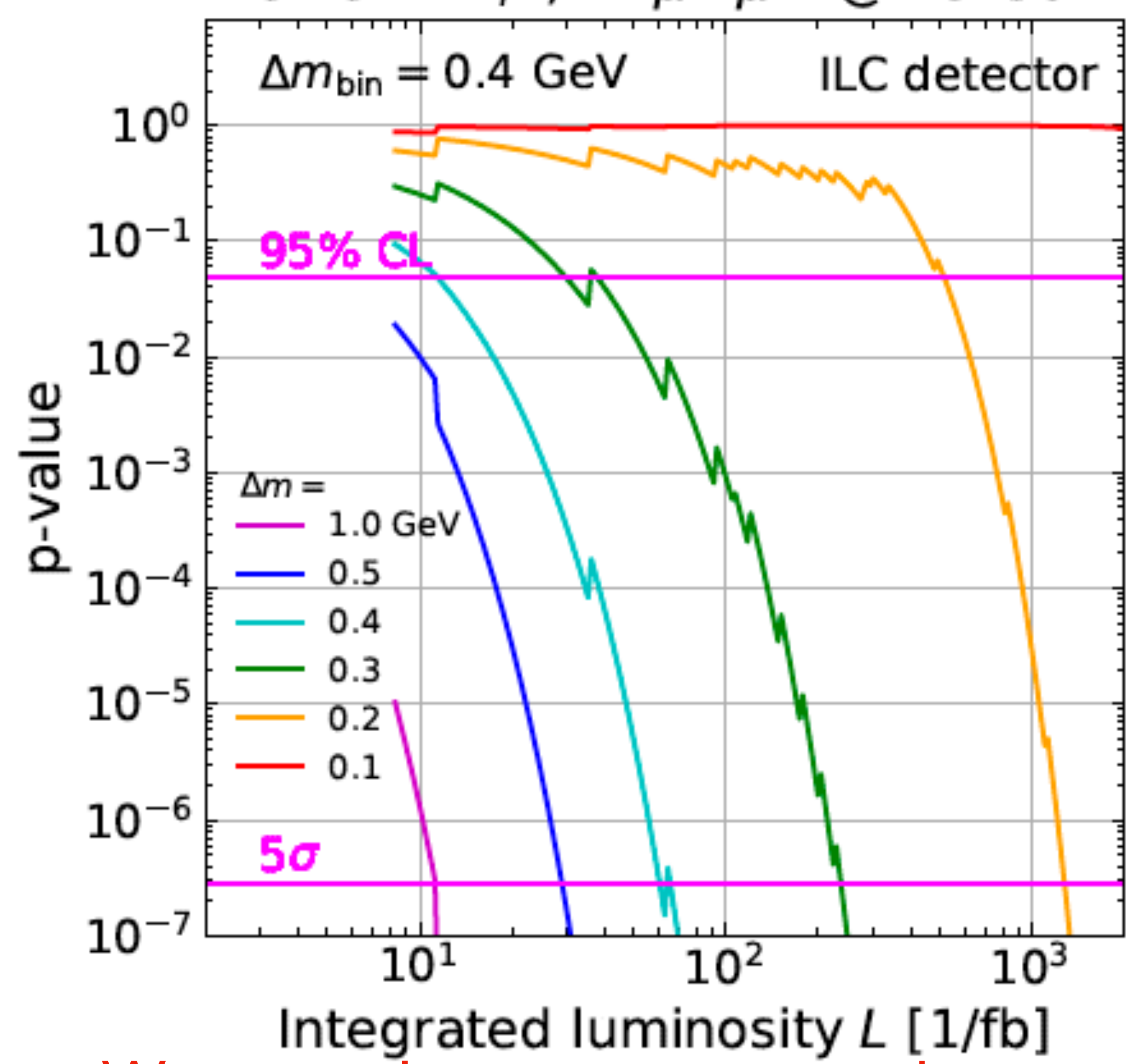
2 near mass-degenerate Higgs bosons

$$m_{h_1,h_2} = \left(125 \pm \frac{\Delta m}{2}\right)\ \mathrm{GeV}$$



$$\chi^2 = \sum_{i=1}^{N} \frac{(n^i - n^i_{\mathrm{SM}})^2}{n^i_{\mathrm{SM}}}$$

$e^+e^- \to h_i Z, Z \to \mu^+\mu^-$ @ILC250



We can explore two near mass-degenerate Higgs boson at the ILC if Δm>0.2GeV.

Summary

- CxSM is one of the simplest extensions of the SM, which contains an additional Higgs boson and a DM candidate.
- If $m_{h1} \sim m_{h2}$, we can avoid strong constraints from DM direct detection experiments due to the suppression of the DM-nucleon scattering amplitudes.
- Such a degenerate-scalar scenario can be tested at the ILC by using the recoil mass technique.