2019 IBS-Busan Joint workshop
on Physics beyond the SM

Inert Doublet Model with U(1) symmetry

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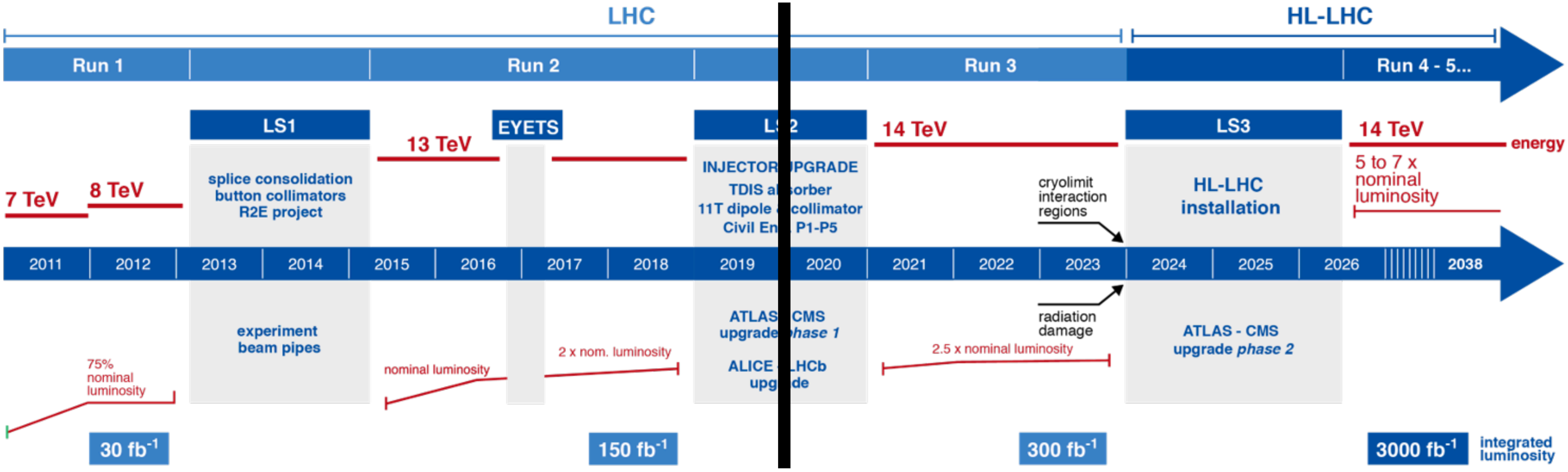
w/ Jin Heung Kim, Soojin Lee, So Young Shim

Paradise Hotel Busan, 2019. 12. 6.

1. Motivation: Where are we?
2. Inert Doublet Model with Z_2 parity
3. Inert Doublet Model with U(1) symmetry
4. Constraints on the IDM with U(1)
5. LHC phenomenology of the IDM with U(1)
6. Conclusions

1. Motivation: Where are we?

LHC/ HL-LHC plan



LHC

HL-LHC

Run 1

Run 2

Run 3

Run 4 - 5...

LS1

EYETS

LS2

LS3

7 TeV

8 TeV

13 TeV

14 TeV

14 TeV

energy

splice consolidation
button collimators
R2E project

INJECTOR UPGRADE
TDIS absorber
11T dipole & collimator
Civil En. P1-P5

HL-LHC
installation

5 to 7 x
nominal
luminosity

cryolimit
interaction
regions

2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 | 2022 | 2023 | 2024 | 2025 | 2026 | 2038

radiation
damage

experiment
beam pipes

ATLAS CMS
upgrade phase 1

ALICE - LHCb
upg de

ATLAS - CMS
upgrade *phase 2*

75%
nominal
luminosity

nominal luminosity

2 x nom. luminosity

2.5 x nominal luminosity

30 fb^{-1}

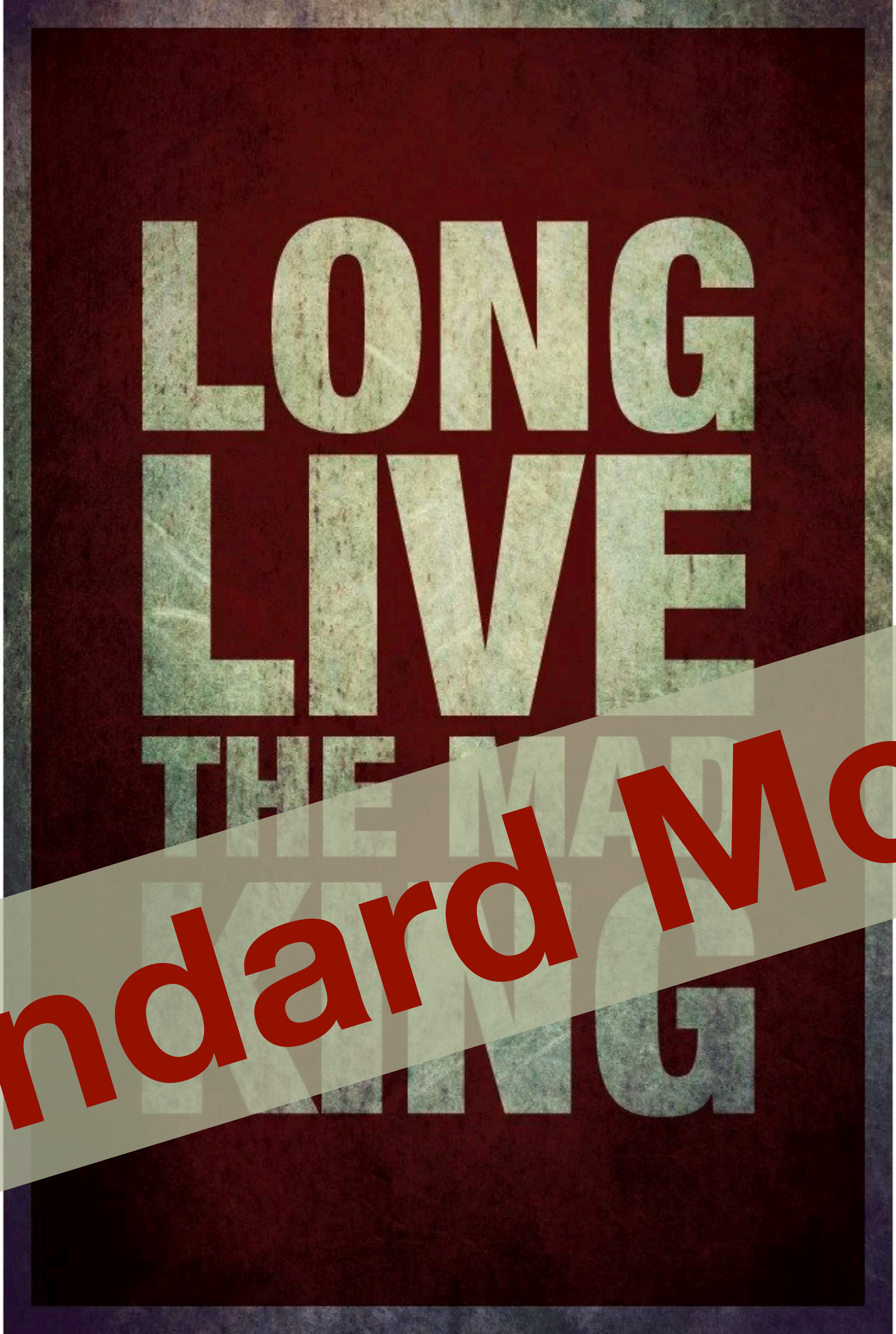
150 fb^{-1}

300 fb^{-1}

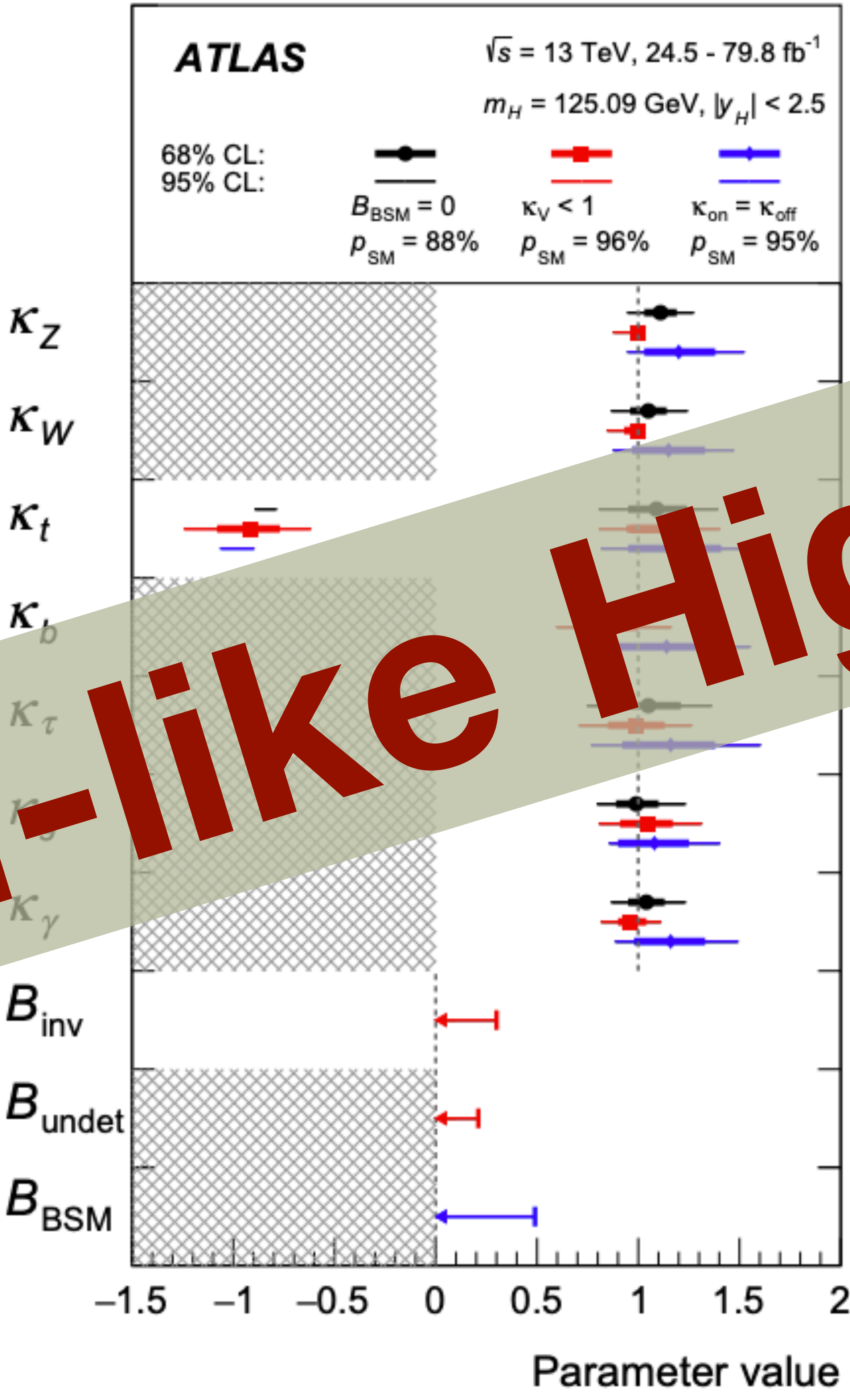
3000 fb^{-1}

integrated
luminosity

LONG
LIVE
THE MAD
KING



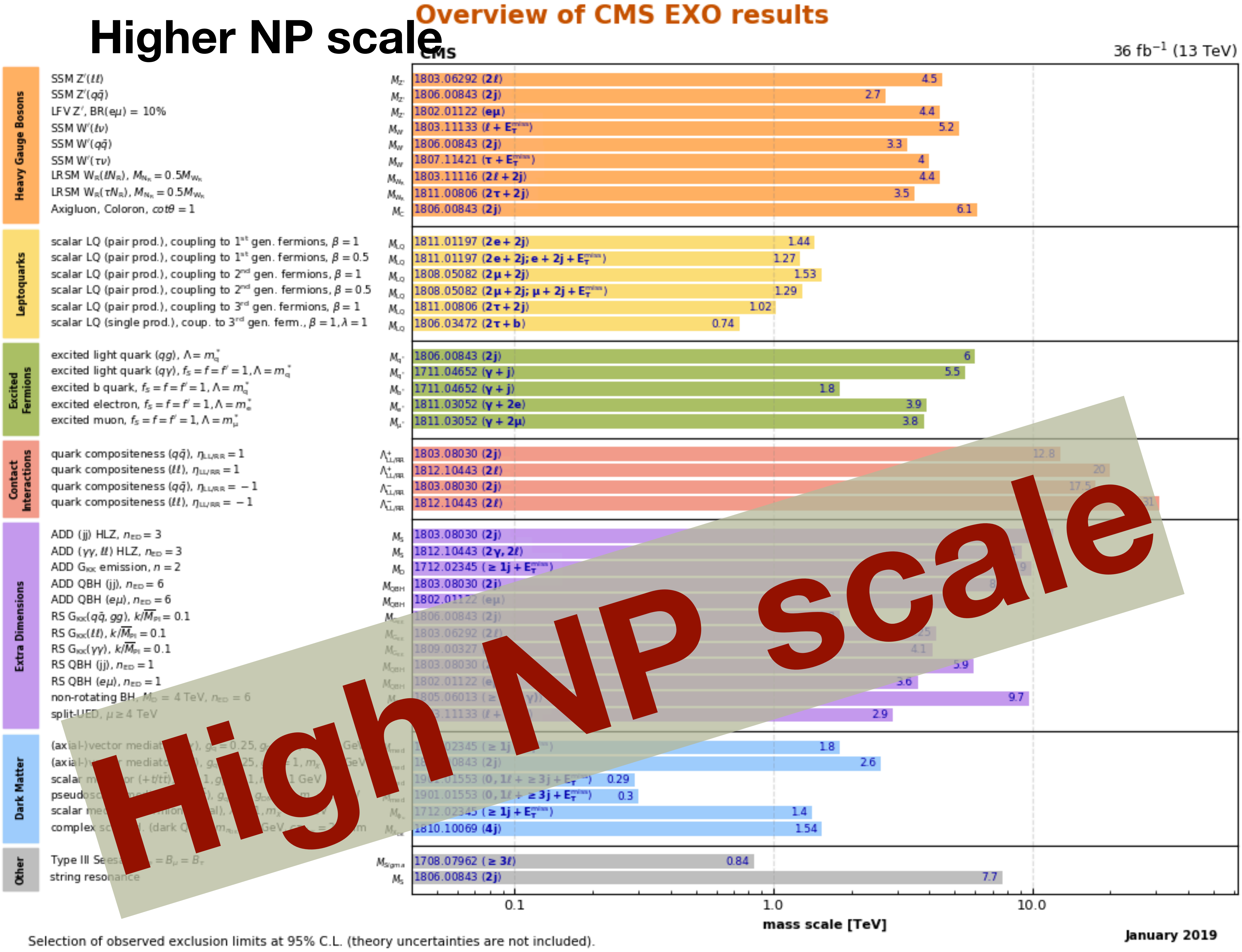
Standard Model



SM-like Higgs

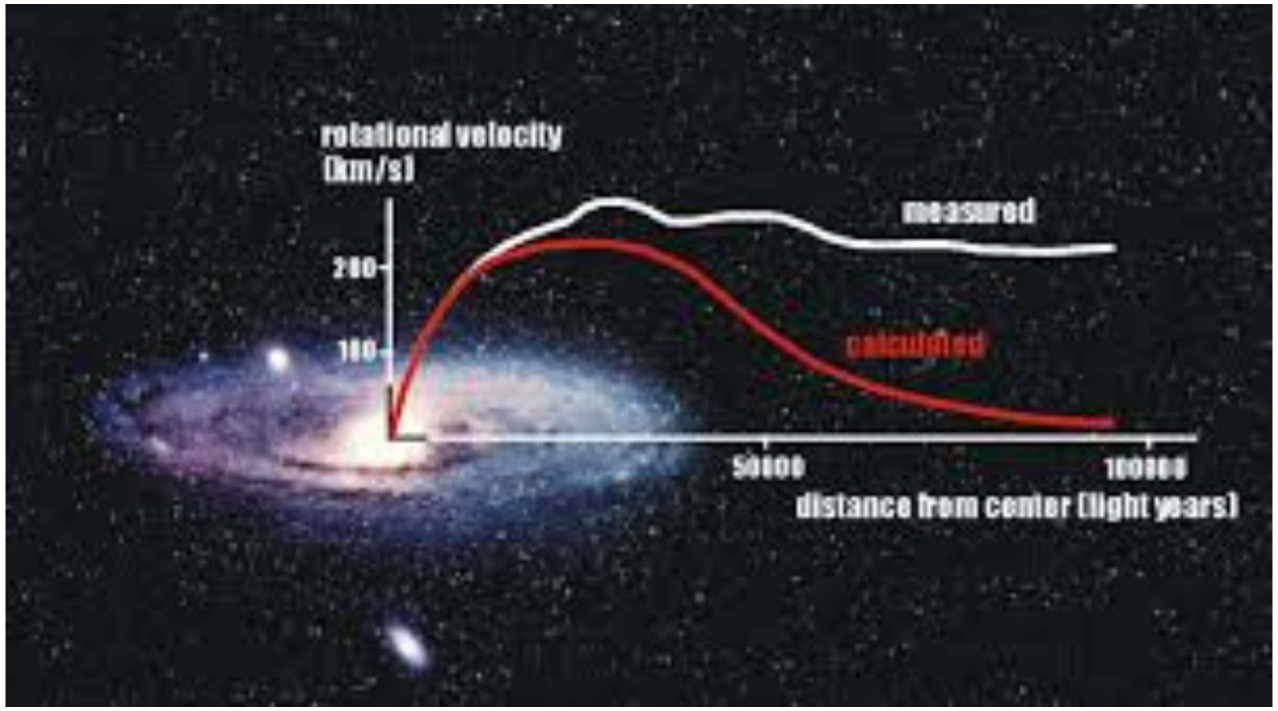
1909.02845

Higher NP scale

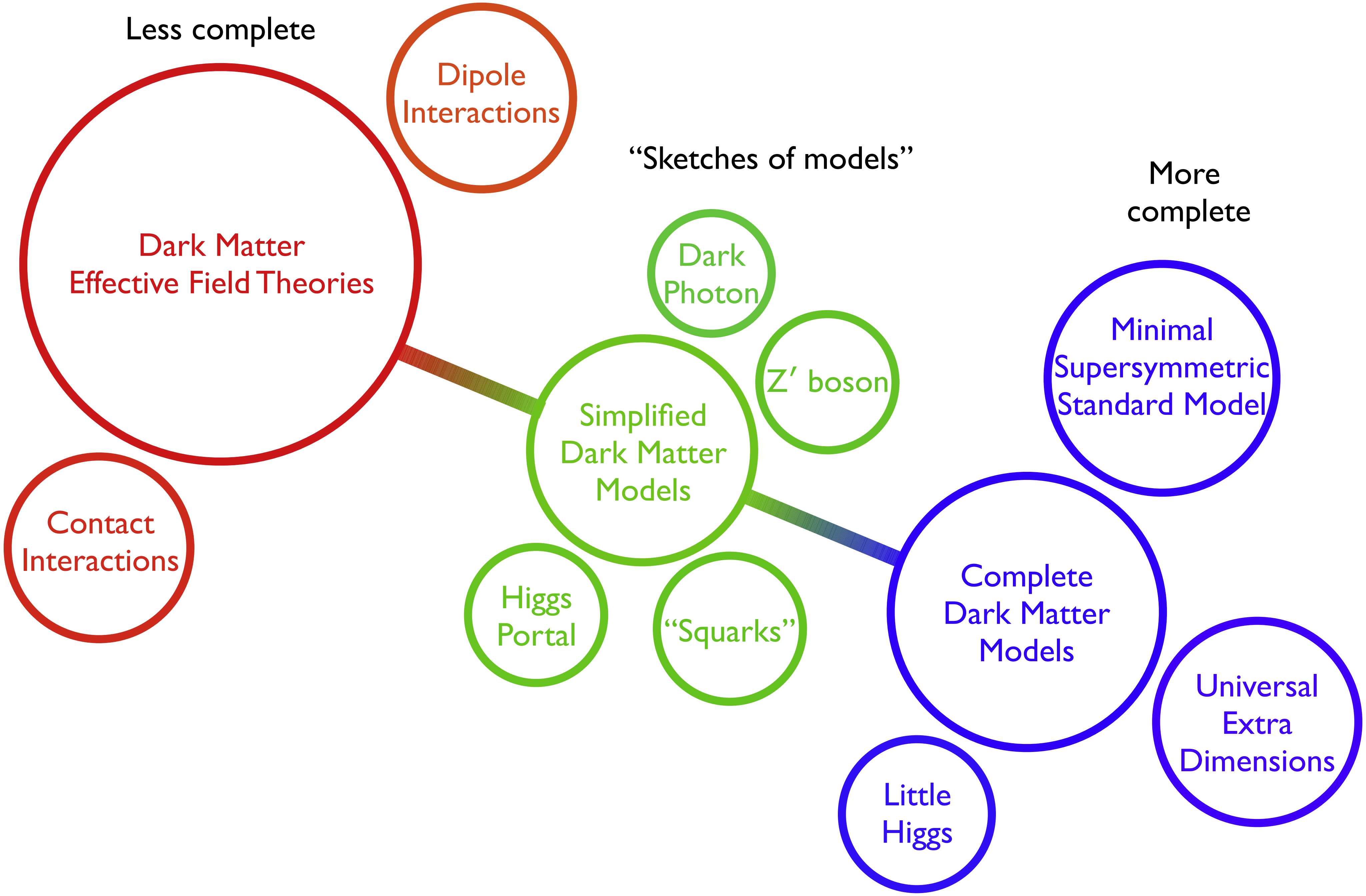


High NP scale

Dark Matter


rotational velocity
(km/s)
200
100
measured
calculated
50000
100000
distance from center (light years)

3 approaches



Less complete

Dark Matter
Effective Field Theories

Dipole
Interactions

Contact
Interactions

"Sketches of models"

Simplified
Dark Matter
Models

Dark
Photon

Z′ boson

Higgs
Portal

"Squarks"

More
complete

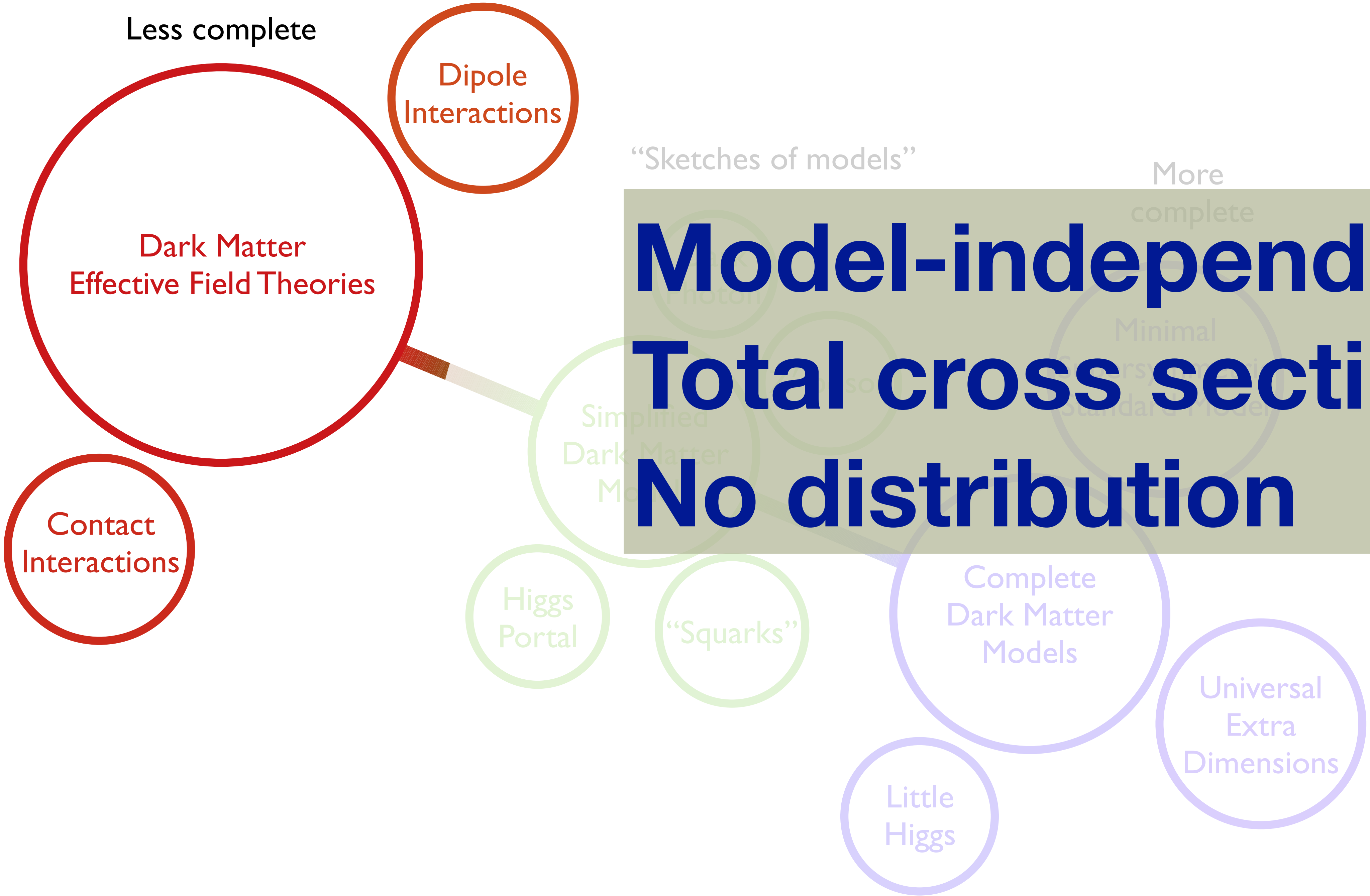
Complete
Dark Matter
Models

Minimal
Supersymmetric
Standard Model

Universal
Extra
Dimensions

Little
Higgs

Physics of the Dark Universe 9–10 (2015) 8–23


Less complete

Dipole Interactions

Dark Matter Effective Field Theories

Contact Interactions

“Sketches of models”

More complete

Simplified Dark Matter Models

Minimal Supersymmetric Standard Model

Higgs Portal

“Squarks”

Complete Dark Matter Models

Universal Extra Dimensions

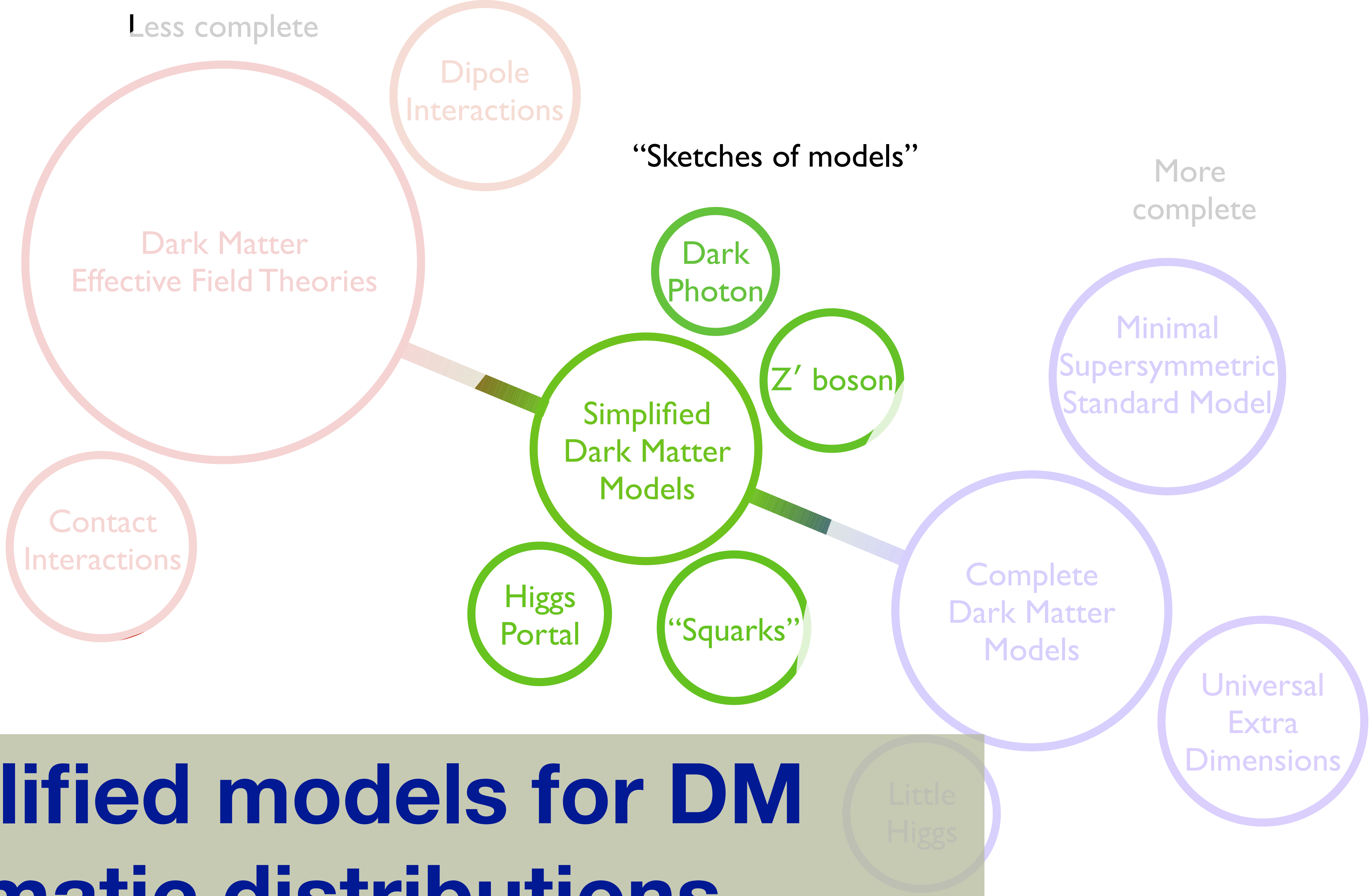
Little Higgs

Model-independent

Total cross section

No distribution

Physics of the Dark Universe 9–10 (2015) 8–23



Less complete

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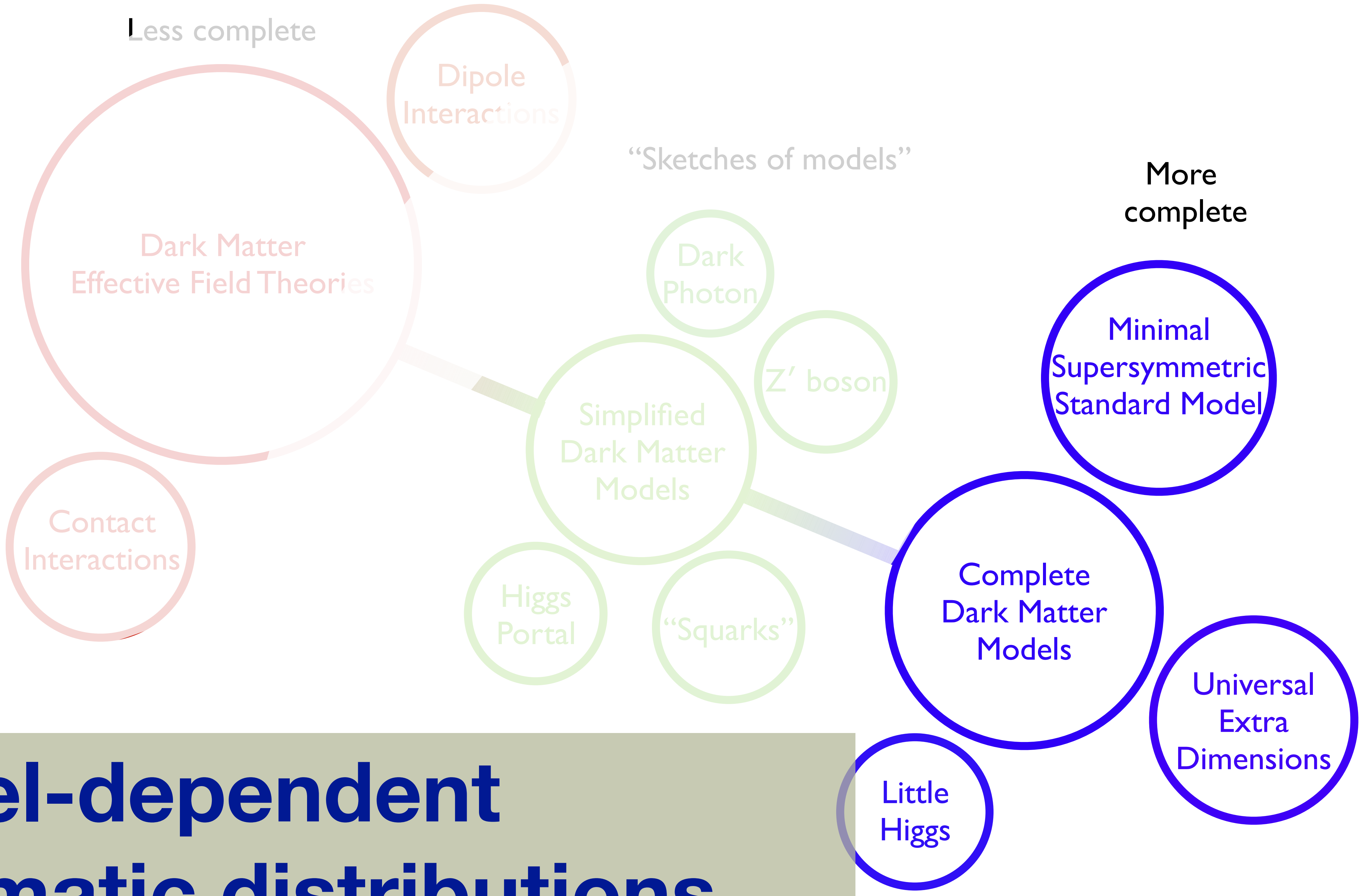
Simplified models for DM

Kinematic distributions

No correlation b/w processes

Physics of the Dark Universe 9–10 (2015) 8–23



Less complete

Dipole
Interactions

Dark Matter
Effective Field Theories

Contact
Interactions

"Sketches of models"

Dark
Photon

Z′ boson

Simplified
Dark Matter
Models

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More
complete

Minimal
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Standard Model

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Models

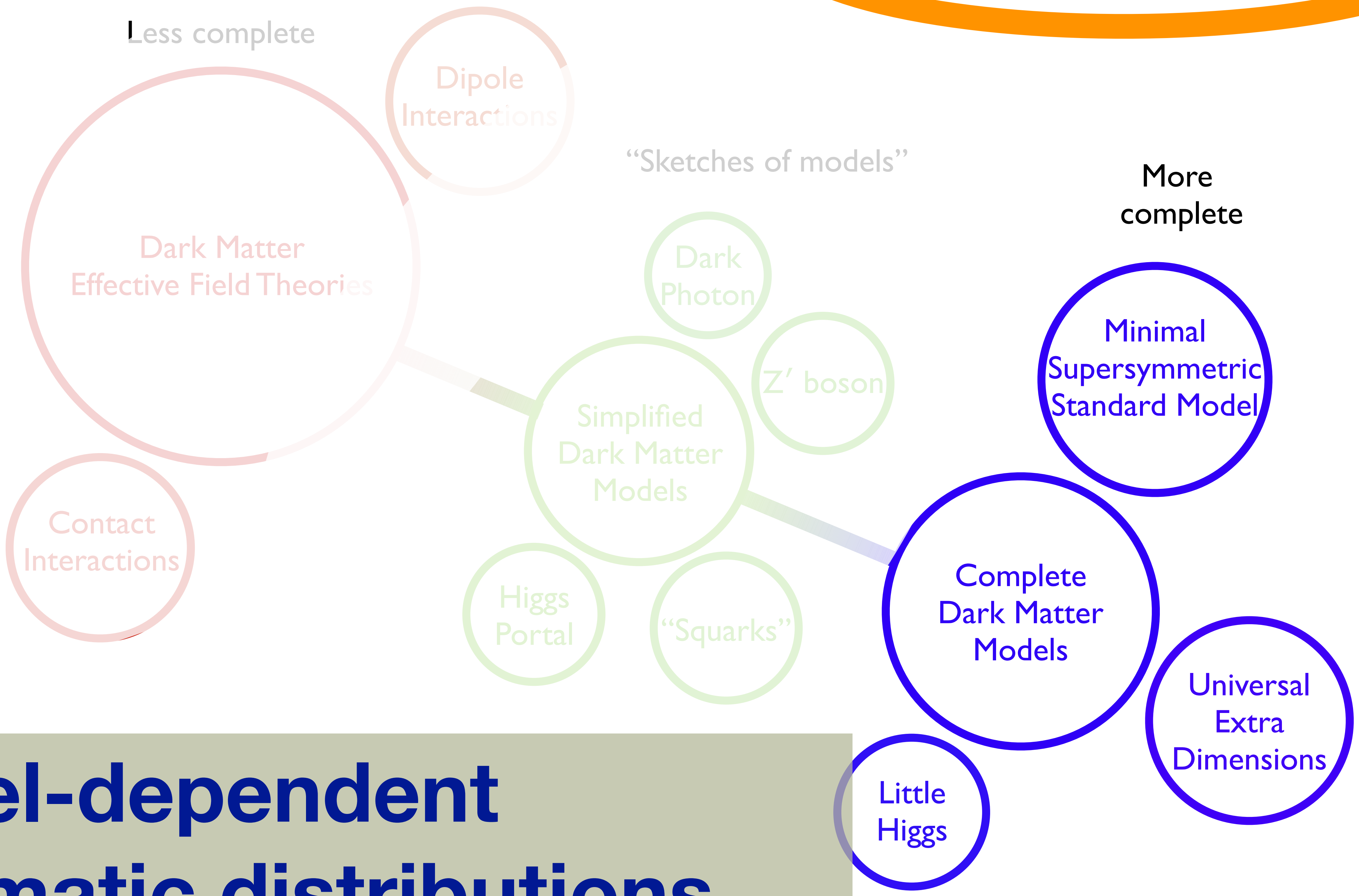
Universal
Extra
Dimensions

Little
Higgs

Model-dependent
Kinematic distributions
Correlation b/w processes

Physics of the Dark Universe 9–10 (2015) 8–23

Inert Doublet Model



Less complete

Dipole Interactions

Dark Matter Effective Field Theories

Contact Interactions

"Sketches of models"

Dark Photon

Z′ boson

Simplified Dark Matter Models

Higgs Portal

"Squarks"

More complete

Minimal Supersymmetric Standard Model

Complete Dark Matter Models

Universal Extra Dimensions

Little Higgs

Model-dependent

Kinematic distributions

Correlation b/w processes

of the Dark Universe 9–10 (2015) 8–23

2. Inert Doublet Model with discrete Z_2 parity

SM Higgs boson ϕ_1 & another Higgs doublet ϕ_2

$$\phi_1 = \frac{1}{\sqrt{2}} \begin{pmatrix} 0 \\ v + H \end{pmatrix}$$

$\boxed{Z_2\text{-even}}$ **All the SM particles**

$$\phi_2 = \frac{1}{\sqrt{2}} \begin{pmatrix} \sqrt{2} h^+ \\ h_1 + i h_2 \end{pmatrix}$$

$\boxed{Z_2\text{-odd}}$

New scalar bosons

Two neutral scalar: h_1 & h_2

charged scalars: $H^{\pm}$

New scalar bosons

Two neutral scalar: h_1 & h_2

charged scalars: $H^\pm$

- h_1 & h_2: opposite CP parities
- Impossible to tell which is CP-even.
- Under CP transformation

  $h_1 \to h_1, \quad h_2 \to -h_2$

New scalar bosons

Under the rephasing $\phi_2 \to i\phi_2$

- h_1 & h_2: opposite CP parities
- Impossible to tell which is CP-even.
- Under CP transformation

~~$h_1 \to h_1, \quad h_2 \to -h_2$~~

$$h_1 \to -h_1, \quad h_2 \to h_2$$

The scalar potential allowed by Z₂ symmetry

$$
\begin{aligned}
V = & -m_1^2(\phi_1^\dagger\phi_1) - m_2^2(\phi_2^\dagger\phi_2) + \lambda_1(\phi_1^\dagger\phi_1)^2 + \lambda_2(\phi_2^\dagger\phi_2)^2 \\
& + \lambda_3(\phi_1^\dagger\phi_1)(\phi_2^\dagger\phi_2) + \lambda_4(\phi_2^\dagger\phi_1)(\phi_1^\dagger\phi_2) \\
& + \frac{\lambda_5}{2}[(\phi_1^\dagger\phi_2)^2 + (\phi_2^\dagger\phi_1)^2].
\end{aligned}
$$

- No mixing b/w H and $h_{1,2}$
- No Yukawa coupling b/w new scalars & SM fermions

Inert

Masses of the new scalars

$$M_H^2 = 2\lambda_1 v^2 = 2m_1^2, \qquad M_{h^+}^2 = \frac{1}{2}\lambda_3 v^2 - m_2^2,$$

$$M_{h_1}^2 = \frac{1}{2}(\lambda_3 + \lambda_4 - |\lambda_5|)v^2 - m_2^2,$$

$$M_{h_2}^2 = \frac{1}{2}(\lambda_3 + \lambda_4 + |\lambda_5|)v^2 - m_2^2 > M_{h_1}^2.$$

3. Inert Doublet Model with U(1)

continuous $U(1)$ symmetry,
not spontaneously broken by the vacuum.

$$\phi_1 \to \phi_1, \quad \phi_2 \to e^{i\theta}\phi_2$$

ArXiv ePrint: 1808.08629

The scalar potential allowed by U(1) symmetry

$$\boxed{\phi_1 \to \phi_1, \qquad \phi_2 \to e^{i\theta}\phi_2}$$

$$\begin{aligned} V = & -m_1^2(\phi_1^\dagger\phi_1) - m_2^2(\phi_2^\dagger\phi_2) + \lambda_1(\phi_1^\dagger\phi_1)^2 + \lambda_2(\phi_2^\dagger\phi_2)^2 \\ & + \lambda_3(\phi_1^\dagger\phi_1)(\phi_2^\dagger\phi_2) + \lambda_4(\phi_2^\dagger\phi_1)(\phi_1^\dagger\phi_2) \\ & \xcancel{+ \frac{\lambda_5}{2}[(\phi_1^\dagger\phi_2)^2 + (\phi_2^\dagger\phi_1)^2].} \end{aligned}$$

$$\boxed{\lambda_5 = 0}$$

The scalar potential allowed by U(1) symmetry

$$\boxed{\phi_1 \to \phi_1, \qquad \phi_2 \to e^{i\theta}\phi_2}$$

$$\begin{aligned} V = &-m_1^2(\phi_1^\dagger\phi_1) - m_2^2(\phi_2^\dagger\phi_2) + \lambda_1(\phi_1^\dagger\phi_1)^2 + \lambda_2(\phi_2^\dagger\phi_2)^2 \\ &+ \lambda_3(\phi_1^\dagger\phi_1)(\phi_2^\dagger\phi_2) + \lambda_4(\phi_2^\dagger\phi_1)(\phi_1^\dagger\phi_2) \\ &\xcancel{+ \frac{\lambda_5}{2}[(\phi_1^\dagger\phi_2)^2 + (\phi_2^\dagger\phi_1)^2].} \end{aligned}$$

$$\boxed{\lambda_5 = 0}$$

$$\begin{aligned} M_{h_1}^2 &= \frac{1}{2}(\lambda_3 + \lambda_4 - \xcancel{|\lambda_5|})v^2 - m_2^2, \\ M_{h_2}^2 &= \frac{1}{2}(\lambda_3 + \lambda_4 + \xcancel{|\lambda_5|})v^2 - m_2^2 \end{aligned}$$

$$\boxed{M_{h_1} = M_{h_2} \text{ by } U(1) \text{ symmetry}}$$

The mass degeneracy is protected even at loop level.

Q. Phenomenological characteristics of $\mathrm{IDM}_{U(1)}$?

Inert Higgs couplings

$$\begin{aligned}
\mathscr{L}_{VHH} = {}& \frac{1}{2} g_Z Z^\mu \boxed{h_2 \overleftrightarrow{\partial}_\mu h_1} - \frac{g}{2}\left[i W^+ \boxed{H^- \overleftrightarrow{\partial}_\mu (h_1 + i h_2)} + \text{H.c.} \right] \\
& \left[i e A^\mu + i g_Z \left(\frac{1}{2} - s_W^2 \right) Z^\mu \right] \boxed{H^+ \overleftrightarrow{\partial}_\mu H^-},
\end{aligned}$$

$$\begin{aligned}
\mathscr{L}_{VVHH} = {}& \left(\frac{1}{4} g^2 W_\mu^+ W^{-\mu} + \frac{1}{8} g_Z^2 Z_\mu Z^\mu \right) (h_1^2 + h_2^2) \\
& + \left[\frac{1}{2} g^2 W_\mu^+ W^{-\mu} + e^2 A_\mu A^\mu + g_Z^2 \left(\frac{1}{2} - s_W^2 \right)^2 Z_\mu Z^\mu \right. \\
& \qquad \left. + 2 g_Z e \left(\frac{1}{2} - s_W^2 \right) A_\mu Z^\mu \right] H^+ H^- \\
& + \left[\left(\frac{1}{2} e g A^\mu W_\mu^+ - \frac{1}{2} g_Z^2 s_W^2 Z^\mu W_\mu^+ \right) H^- (h_1 + i h_2) + h.c. \right],
\end{aligned}$$

w/ two inert scalars

Inert Higgs couplings

$$
\begin{aligned}
\mathscr{L}_{3h} &= -\frac{1}{2}\lambda_{34} v H \boxed{(h_1^2 + h_2^2)} - \lambda_3 v H \boxed{H^+ H^-}, \\
\mathscr{L}_{4h} &= -\frac{\lambda_{34}}{4} H^2 (h_1^2 + h_2^2) - \frac{\lambda_3}{2} H^2 H^+ H^- \\
&\quad - \frac{\lambda_2}{4} (h_1^2 + h_2^2)^2 - \lambda_2 H^+ H^- (h_1^2 + h_2^2 + H^+ H^-).
\end{aligned}
$$

$$\boxed{\lambda_{34} = \lambda_3 + \lambda_4}$$

Inert Higgs couplings

$$
\begin{aligned}
\mathscr{L}_{3h} &= -\frac{1}{2}\boxed{\lambda_{34}}vH(h_1^2+h_2^2)-\boxed{\lambda_3}vHH^+H^-,\\
\mathscr{L}_{4h} &= -\frac{\boxed{\lambda_{34}}}{4}H^2(h_1^2+h_2^2)-\frac{\boxed{\lambda_3}}{2}H^2H^+H^-\\
&\quad -\frac{\lambda_2}{4}(h_1^2+h_2^2)^2-\lambda_2H^+H^-(h_1^2+h_2^2+H^+H^-).
\end{aligned}
$$

- λ_{34}, λ_3: couplings with the Higgs boson.
- λ_2: couplings among inert scalars.

$$\boxed{\lambda_2 = 0}$$

Three model parameters

$$\{M_S, M_{H^\pm}, \lambda_{34}\}$$

$$\Downarrow$$

$$\begin{aligned}
\lambda_1 &= \frac{m_H^2}{2v^2}, \\
\lambda_3 &= \lambda_{34} + \frac{2}{v^2}\left(M_{H^\pm}^2 - M_S^2\right), \\
\lambda_4 &= -\frac{2}{v^2}\left(M_{H^\pm}^2 - M_S^2\right) < 0, \\
M_{h_1} &= M_{h_2} = M_S .
\end{aligned}$$

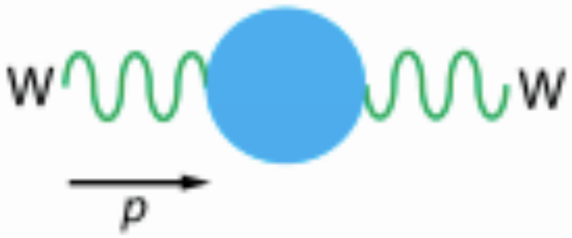
Decays of inert scalars

- $h_1, \ h_2$: stable
- $H^{\pm} \to W^{\pm} h_1, W^{\pm} h_2$

4. Constraints on the IDM with U(1)

1. **EWPD oblique parameters:** S, T
2. **Theoretical constraints including vacuum stability**
3. **LEP data**
4. **LHC Higgs data**
5. **Relic density & Direct dark matter detection**

EWPD constraints



$$\Pi_{WW}(p^2) = \Pi_{WW}(0) + p^2\Pi'_{WW}(0) + \cdots$$

$$\Pi_{ZZ}(p^2) = \Pi_{ZZ}(0) + p^2\Pi'_{ZZ}(0) + \cdots$$

$$\alpha S = 4s^2c^2\left[\Pi'_{ZZ}(0) - \frac{c^2 - s^2}{sc}\Pi'_{Z\gamma}(0) - \Pi'_{\gamma\gamma}(0)\right]$$

$$\alpha T = \frac{\Pi_{WW}(0)}{M_W^2} - \frac{\Pi_{ZZ}(0)}{M_Z^2}$$

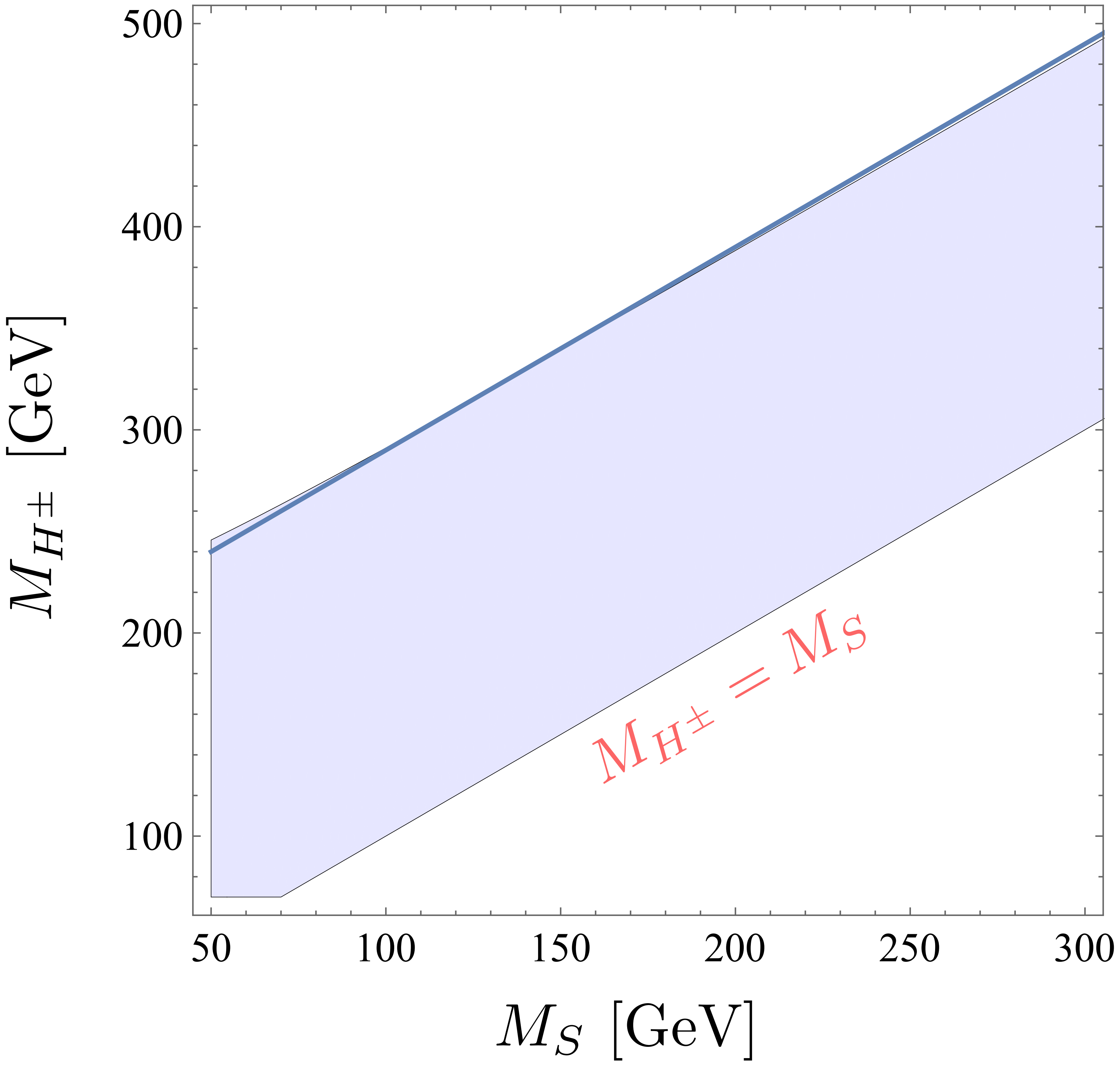
T: decisive constraint

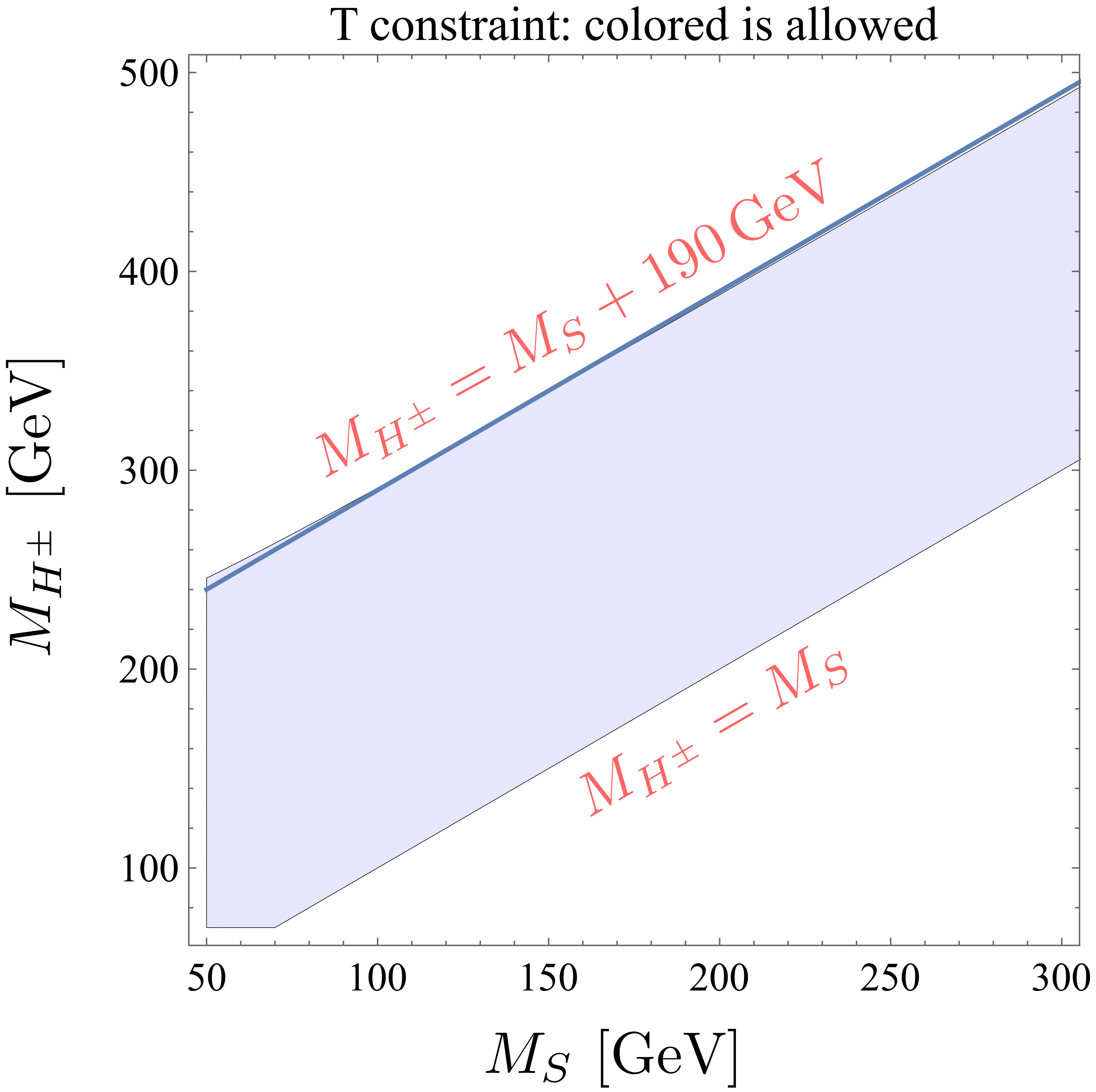
$$\boxed{\begin{aligned} T = \frac{1}{32\pi^2\alpha v^2}\big[&f_c(M^2_{h^+}, M^2_{h_2}) + f_c(M^2_{h^+}, M^2_{h_1}) \\ &- f_c(M^2_{h_2}, M^2_{h_1})\big], \end{aligned}}$$

$$f_c(x,y) = \begin{cases} \frac{x+y}{2} - \frac{xy}{x-y}\log\left(\frac{x}{y}\right), & x \neq y \\ 0, & x = y \end{cases}.$$

$$\boxed{S = 0.06 \pm 0.09, \qquad T = 0.1 \pm 0.07}$$

T constraint: colored is allowed




T constraint: colored is allowed
$M_{H^\pm} = M_S + 190\,\mathrm{GeV}$
$M_{H^\pm} = M_S$
$M_{H^\pm}$ [GeV]
500
400
300
200
100
50
100
150
200
250
300
M_S [GeV]

Two benchmark points

1. $M_{H^\pm} = M_S + 190\,\mathrm{GeV}$

2. $M_{H^\pm} = M_S + 10\,\mathrm{GeV}$

3 missing scalars at the LHC: h1, h2, H+

$$\boxed{2.\ \ M_{H^\pm} = M_S + 10\,\mathrm{GeV}}$$

$$H^\pm \to W^{\pm *} h_{1,2} \to \boxed{f\bar{f}'} h_{1,2}$$

Very soft
w/ pT<5 GeV

→

NOT probed
at the LHC

The object selection

Leptons
$p_\mathrm{T} > 7$ GeV
$\lvert\eta\rvert < 2.47(2.7)$ for $e(\mu)$,
excluding $1.37 < \lvert\eta^e\rvert < 1.52$

ATLAS, mono-V, 1810.04995

Charged Higgs:
missing signal

Theoretical constraints

1. **Perturbativity:**

$$|\lambda_i| \leq 8\pi.$$

2. **Vaccum stability:**

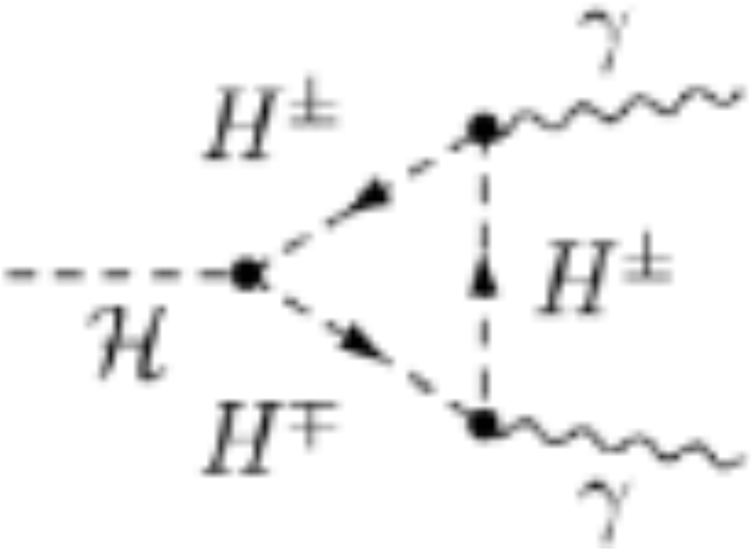
$$\lambda_{34} > 0.$$

3. **Tree level unitarity:**

$$|a_i| \leq 8\pi$$

$$\begin{aligned} a_{1,2} &= \lambda_3 \pm \lambda_4, \quad a_3 = \lambda_3, \quad a_4 = \lambda_3 + 2\lambda_4, \\ a_{5,6} &= -\lambda_1 - \lambda_2 \pm \sqrt{(\lambda_1 - \lambda_2)^2 + \lambda_4^2}, \\ a_{7,8} &= -3\lambda_1 - 3\lambda_2 \pm \sqrt{9(\lambda_1 - \lambda_2)^2 + (2\lambda_3 + \lambda_4)^2}, \\ a_9 &= -2\lambda_1, \quad a_{10} = -2\lambda_2. \end{aligned}$$

LHC Higgs precision data (1) diphoton rate



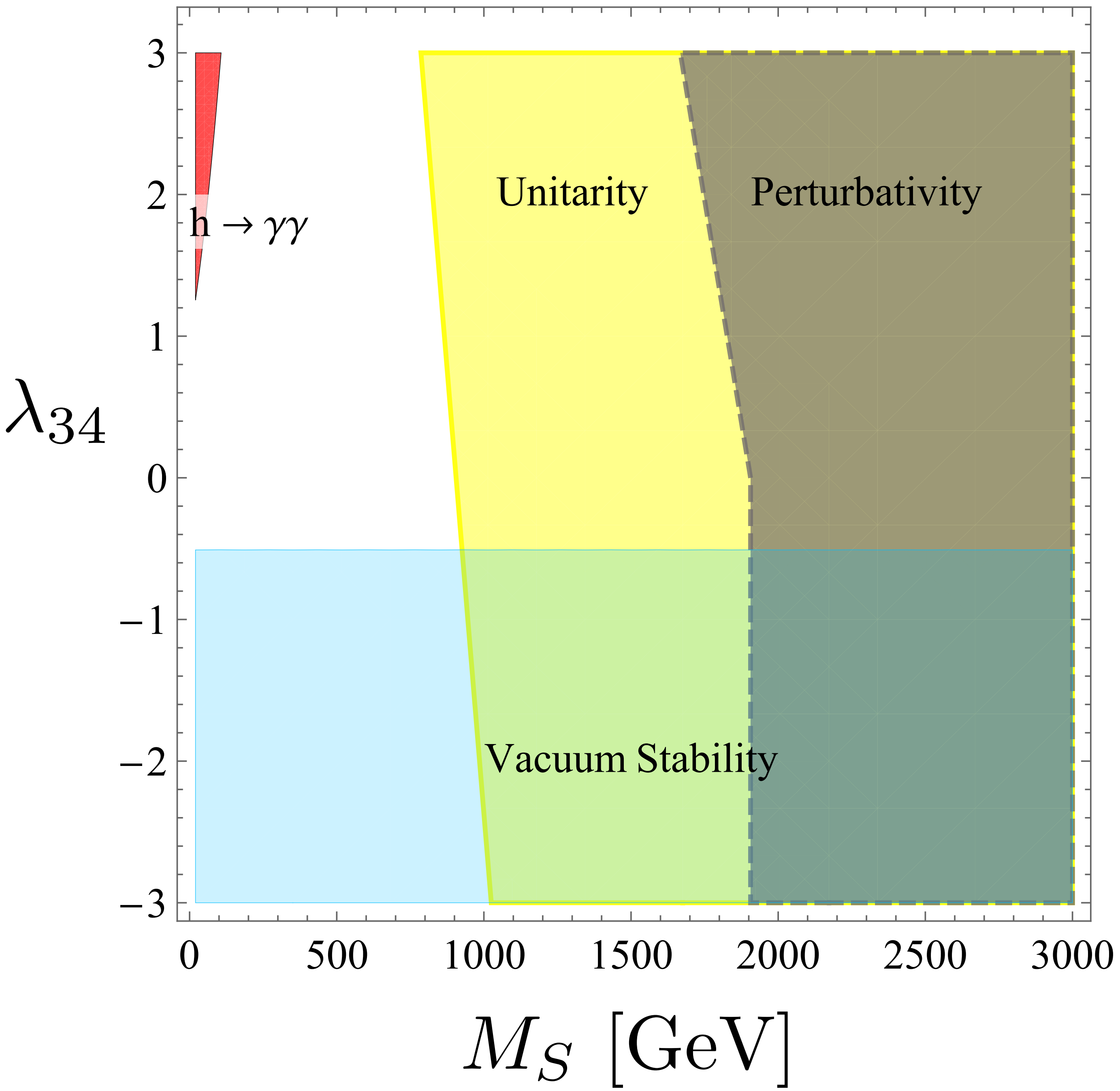
$$\Gamma(h \to \gamma\gamma)$$
$$= \frac{\alpha^2 G_F m_h^2}{128\sqrt{2}\pi^3} \left| \sum_i N_{ci} Q_i^2 F_i + g_{hH^\pm H^\mp} \frac{m_W^2}{m_{H^\pm}^2} F_0(\tau_{H^\pm}) \right|^2,$$

$$\Delta M \equiv M_{H^\pm} - M_S$$

$$|\kappa_\gamma - 1| < 0.1$$

Colored regions: excluded

$$\Delta M = 190\,\mathrm{GeV}$$

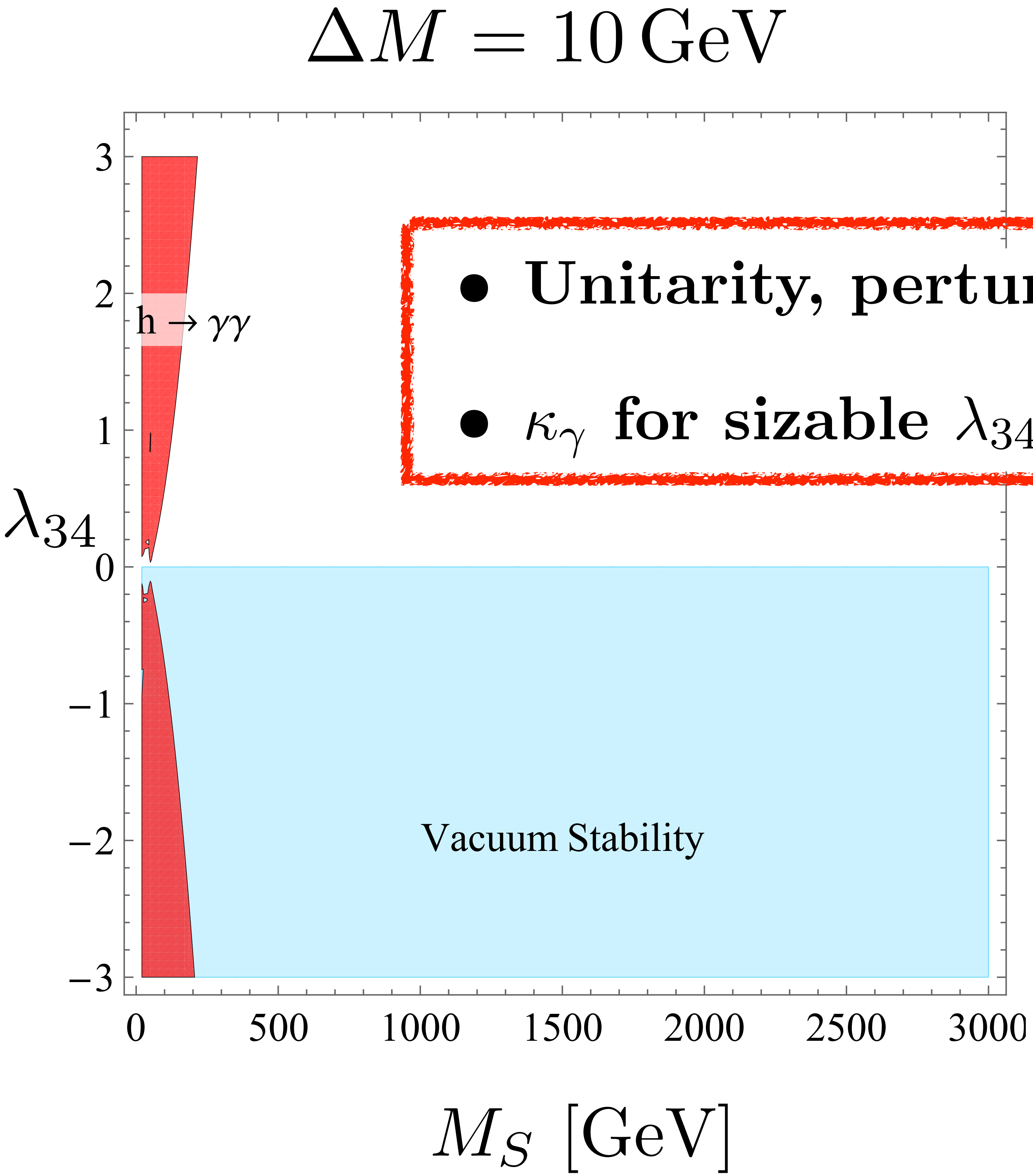


- **κ_γ: weakly constraining to light M_S**
- **Upper bounds on M_S**

$\Delta M \equiv M_{H^\pm} - M_S$

$|\kappa_\gamma - 1| < 0.1$

Colored regions: excluded



- **Unitarity, perturbativity: no constraint.**
- κ_γ **for sizable** λ_{34} **excludes light** M_S**.**

LHC Higgs precision data
(2) Higgs invisible decay

When $M_S < m_h/2$,

$\mathcal{B}_{\rm inv} < 0.28$ [**ATLAS JHEP 08 (2016) 045**]

- **For** $M_S \ll m_H$, $|\lambda_{34}| < 0.019$.
- **For** $M_S \simeq 60$ GeV, $|\lambda_{34}| < 0.036$.

Relic density

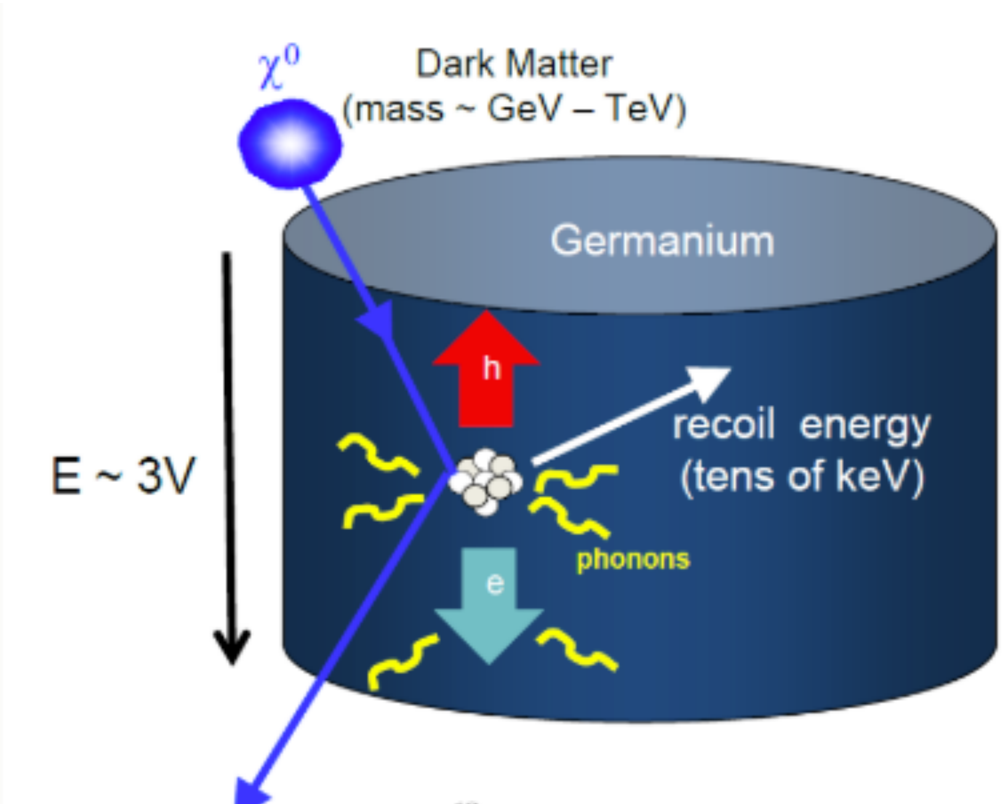
Planck, Astron. Astrophys. 594 (2016) A13,

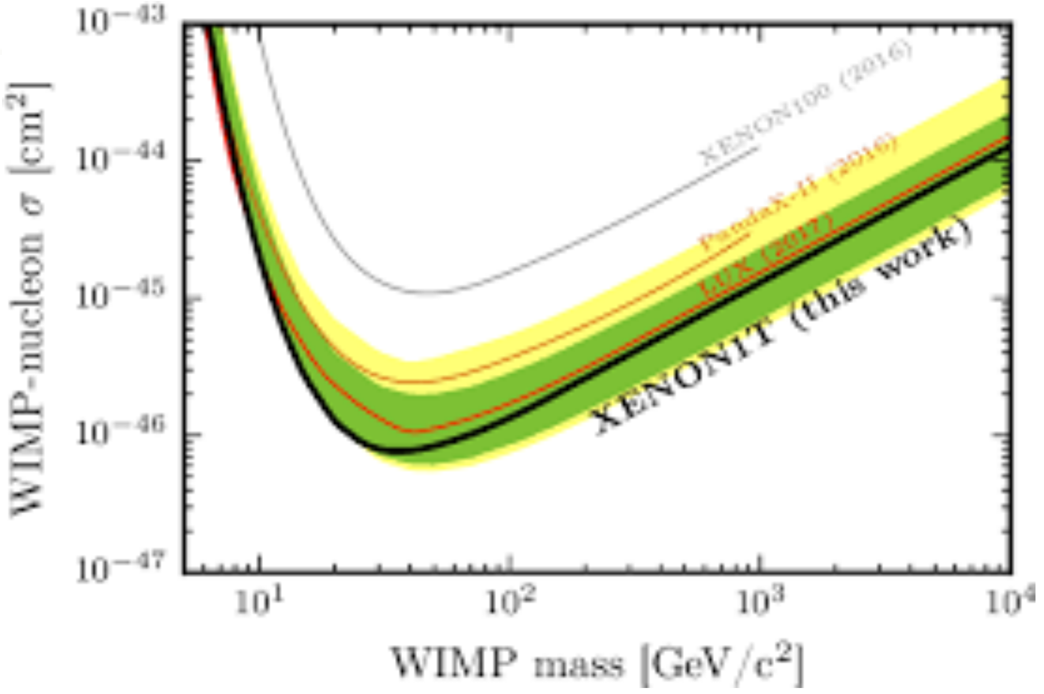
$$\Omega_{\mathrm{DM}}^{\mathrm{Planck}} h^2 = 0.1184 \pm 0.0012$$

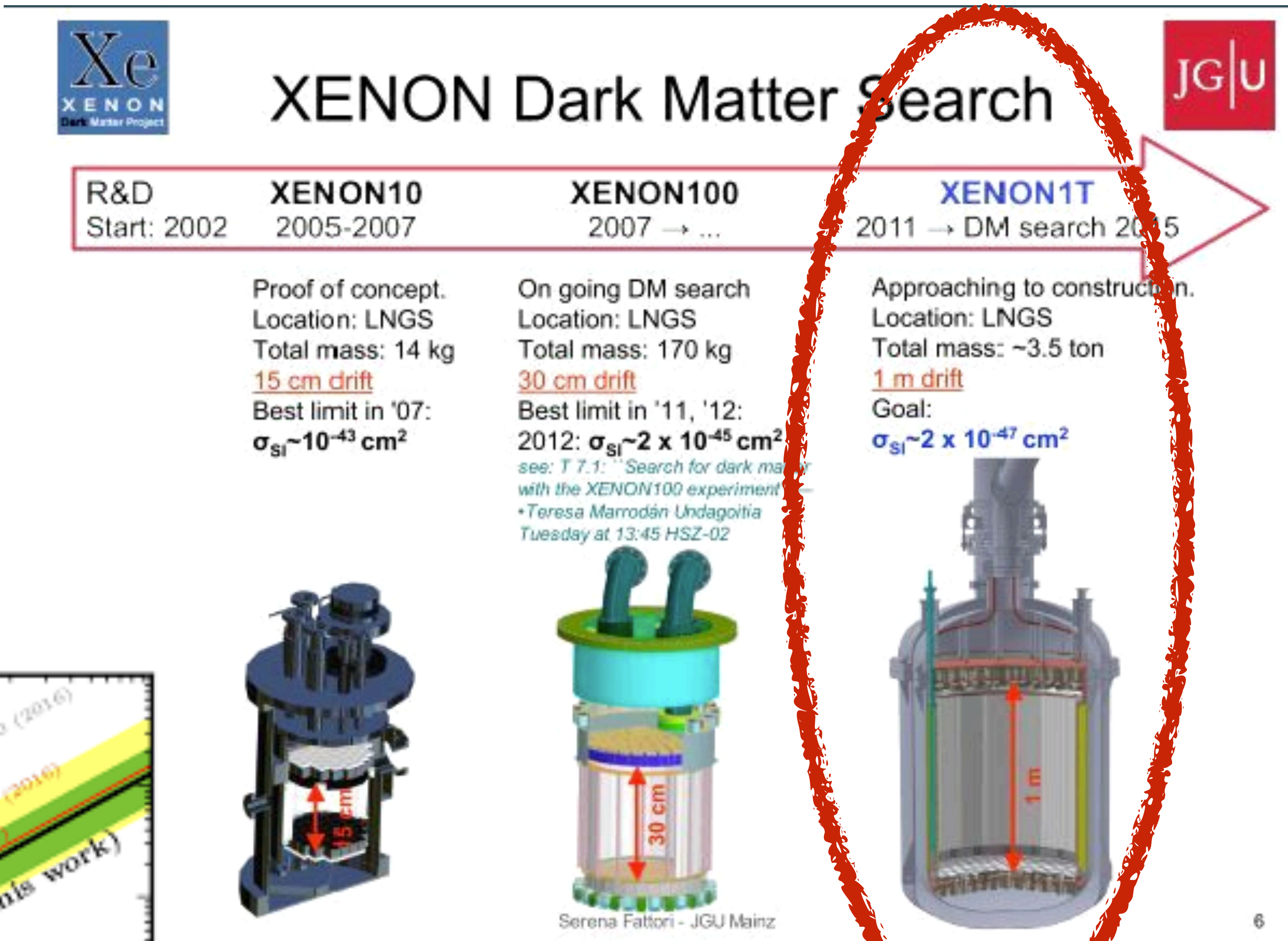
Avoid the over-closure of the Universe,

$$\boxed{\Omega_{H,A} h^2 < \Omega_{\mathrm{DM}}^{\mathrm{Planck}} h^2}$$

Direct detection of DM







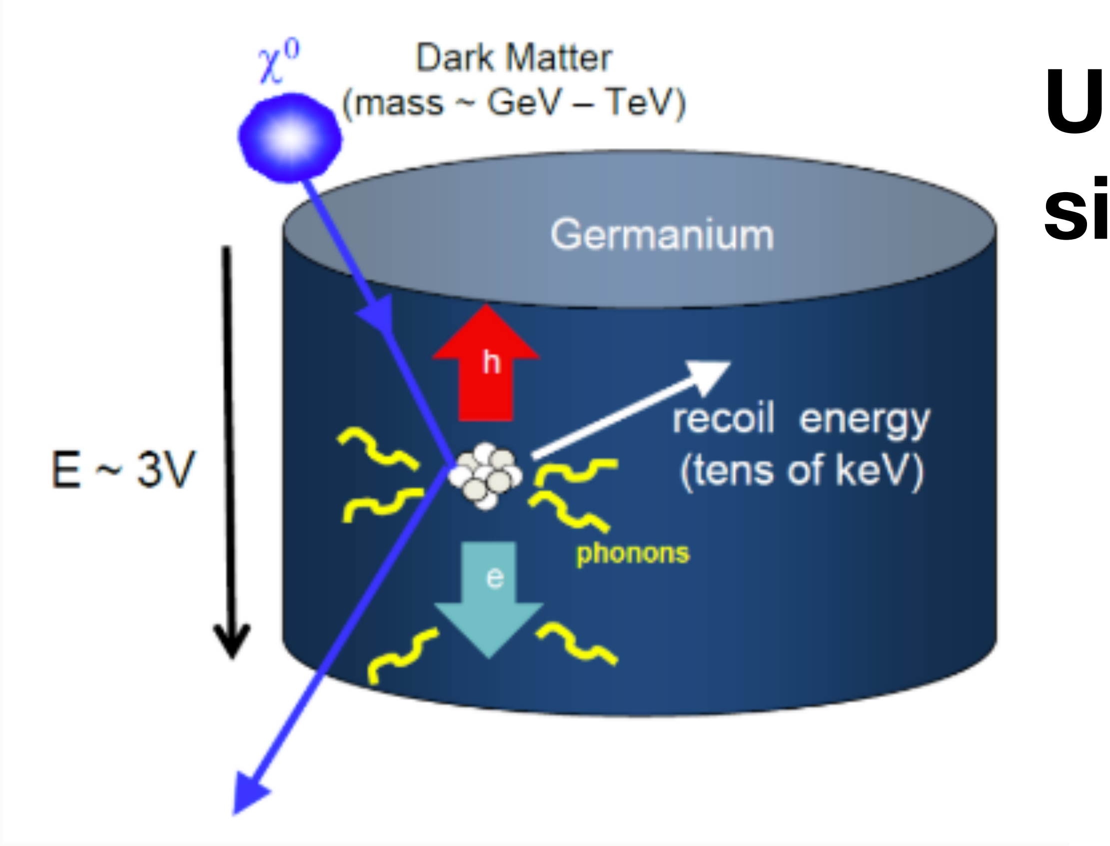
XENON Dark Matter Search

R&D	XENON10	XENON100	XENON1T
Start: 2002	2005-2007	2007 → ...	2011 → DM search 2015
	Proof of concept. Location: LNGS Total mass: 14 kg 15 cm drift Best limit in '07: σ_{SI}~10^{-43} cm^2	On going DM search Location: LNGS Total mass: 170 kg 30 cm drift Best limit in '11, '12: 2012: σ_{SI}~2 x 10^{-45} cm^2 *see: T 7.1: ``Search for dark matter with the XENON100 experiment'' – •Teresa Marrodán Undagoitia Tuesday at 13:45 HSZ-02*	Approaching to construction. Location: LNGS Total mass: ~3.5 ton 1 m drift Goal: σ_{SI}~2 x 10^{-47} cm^2

Serena Fattori - JGU Mainz

6

Direct detection of DM

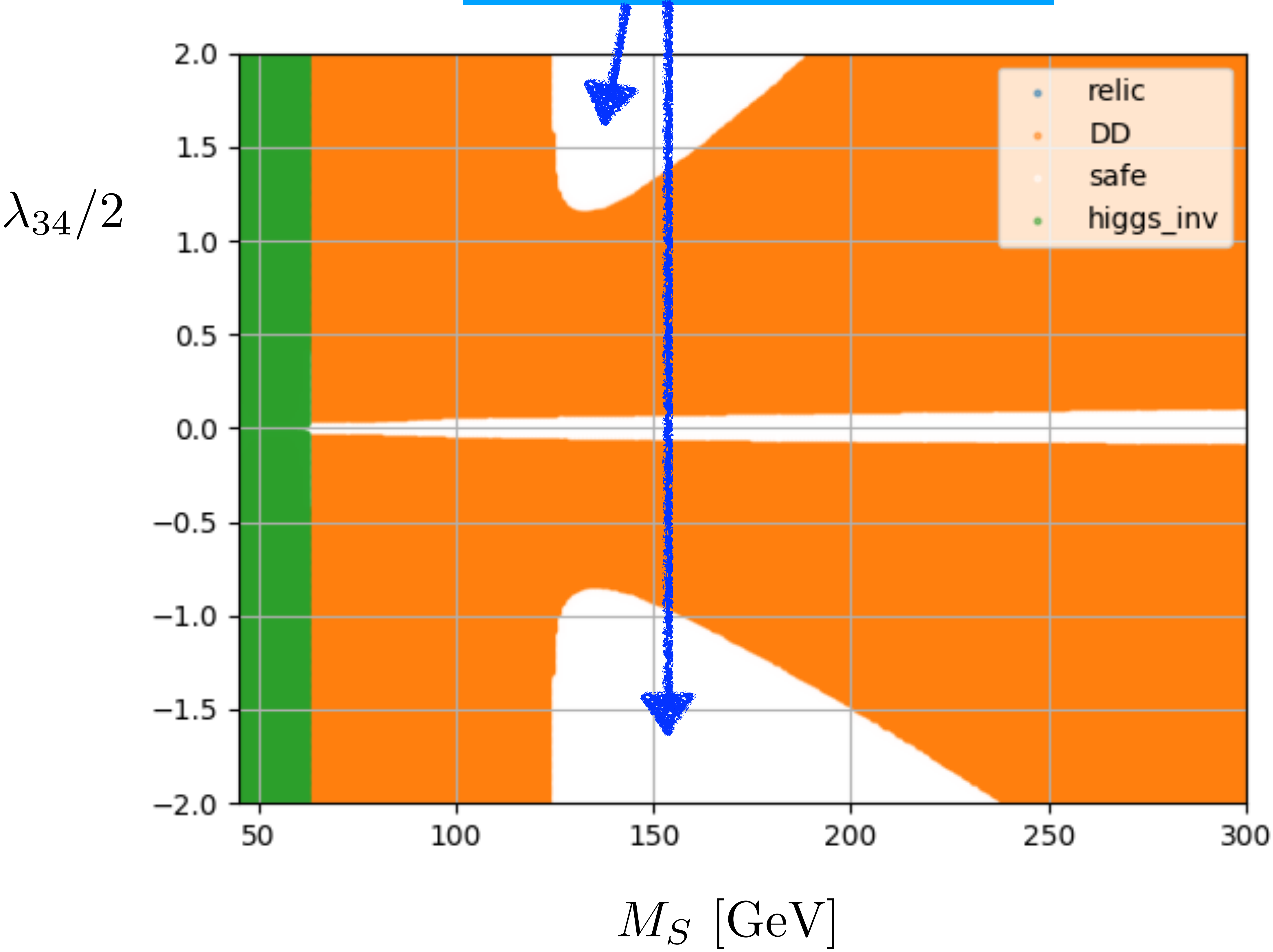


Use the rescaled DM cross section since the inert DM is only a part of DM.

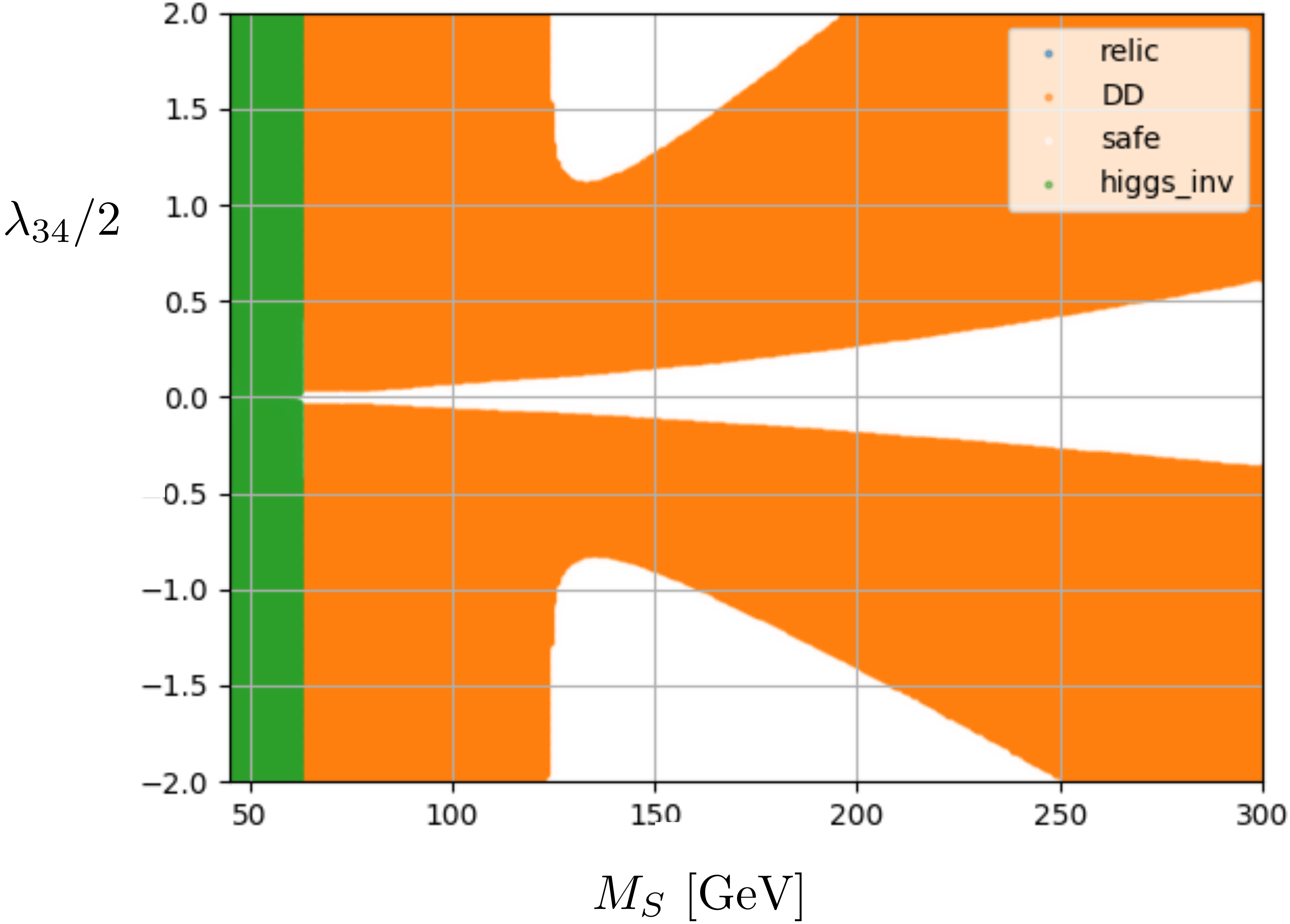
$$\boxed{\hat{\sigma}_{\rm SI} = \frac{\Omega_{\rm DM}}{\Omega_{\rm DM}^{\rm Planck}} \sigma_{\rm SI}}$$

Using MICROMEGA
Colored regions: excluded

$\Delta M = 10\,\mathrm{GeV}$



$\Delta M = 190\,\mathrm{GeV}$

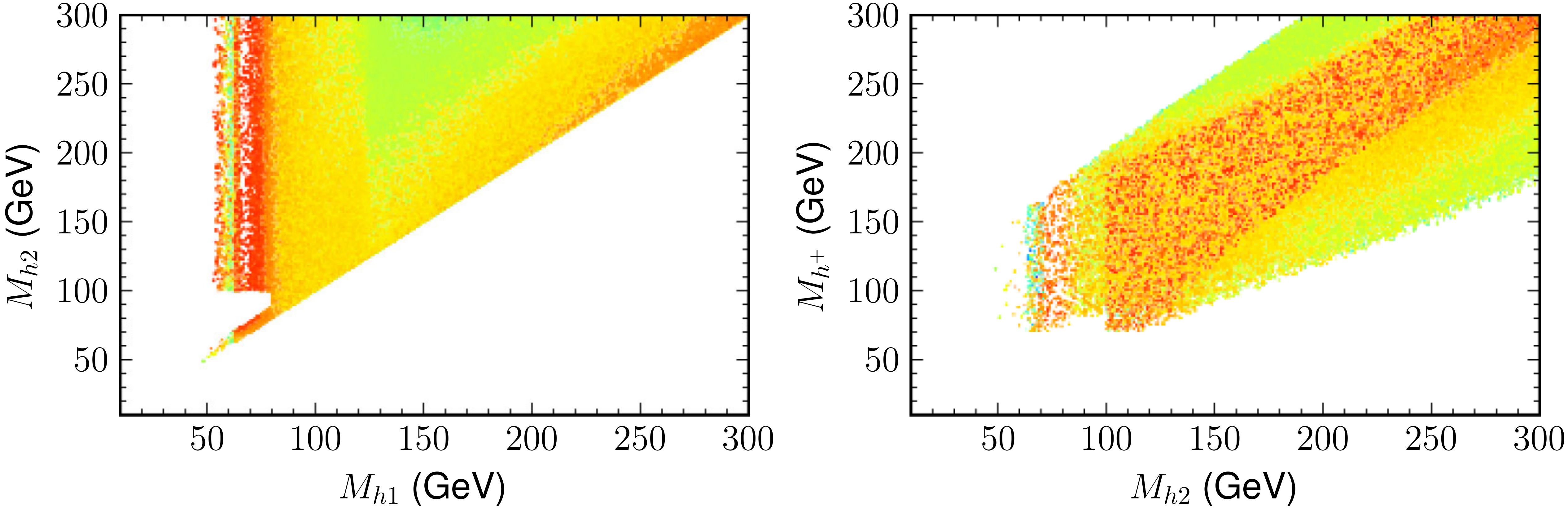


5. LHC phenomenology of the IDM with U(1)

Q. Characteristic LHC signals of $\mathrm{IDM}_{U(1)}$, distinct from IDM_{Z2}

IDM$_{Z2}$

- **One DM particle, h_1.**
- $M_{h_1} = M_{h_2}$**: broken at loop level.**
- $M_{H^\pm}$**: much heavier than the DM mass.**



PHYS. REV. D **97,** 035011 (2018)

IDM$_{Z2}$

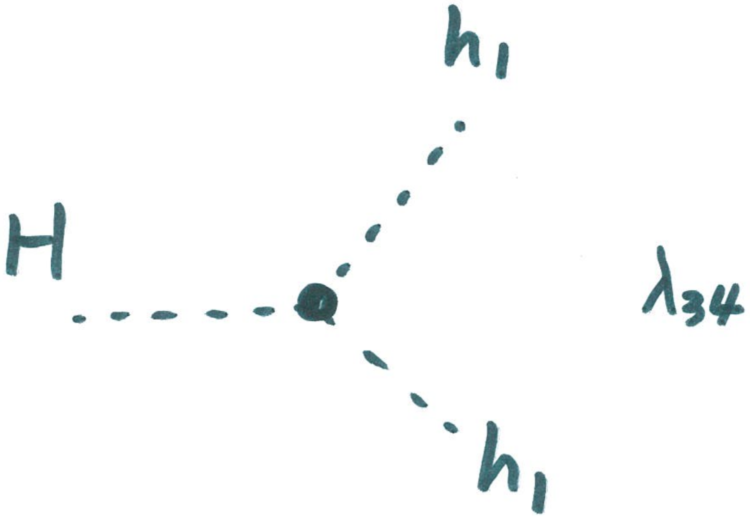
- **One DM particle,** h_1**.**
- $M_{h_1} = M_{h_2}$**: broken at loop level.**
- $M_{H^\pm}$**: much heavier than the DM mass.**

IDM$_{U(1)}$

- **Two DM particles,** h_1 **or** h_2**.**
- $M_{h_1} = M_{h_2}$**: protected by** $U(1)$ **symmetry**
- $M_{H^\pm}$**: within 190 GeV from the DM mass.**

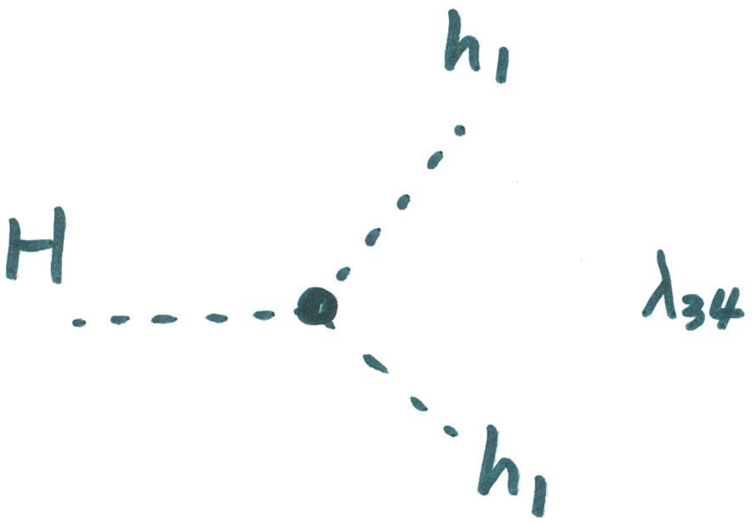
IDM$_{Z2}$

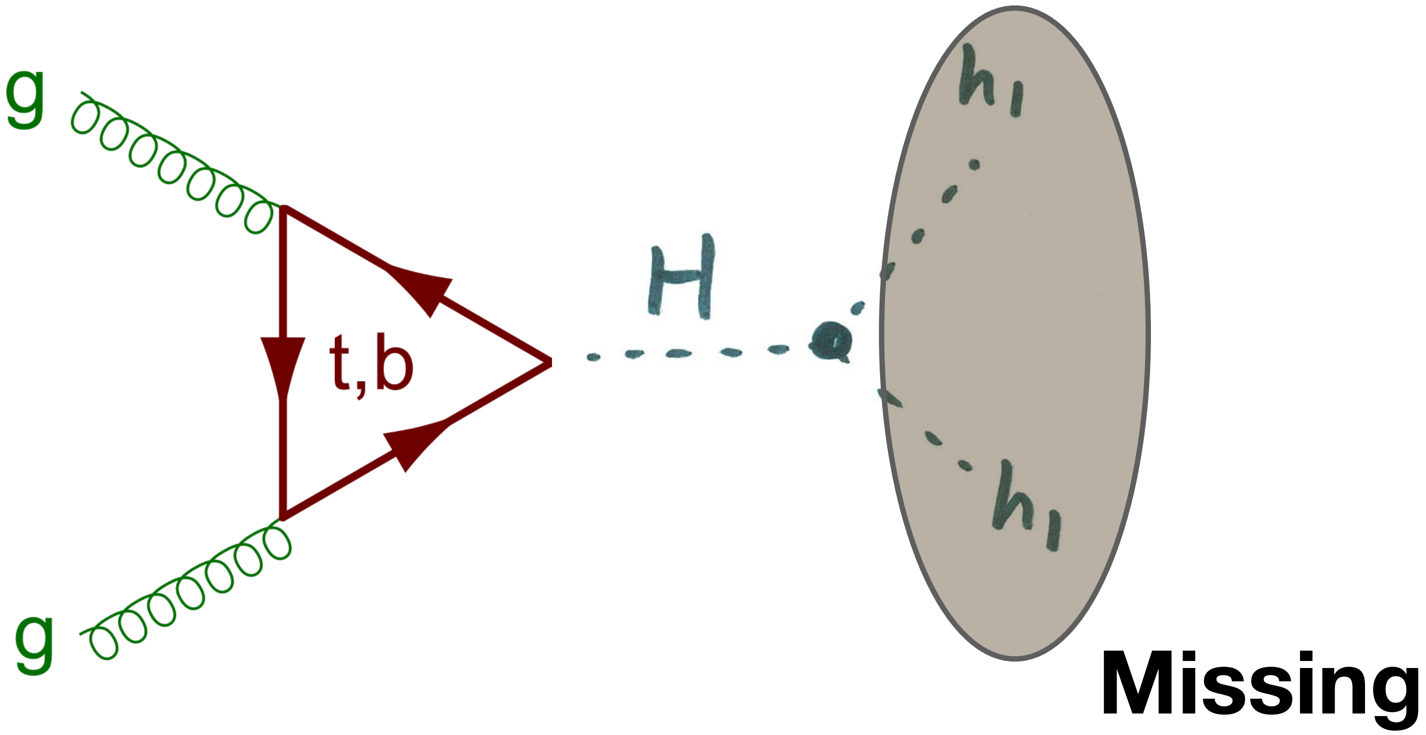
- **One DM particle,** h_1**.**



IDM$_{Z2}$

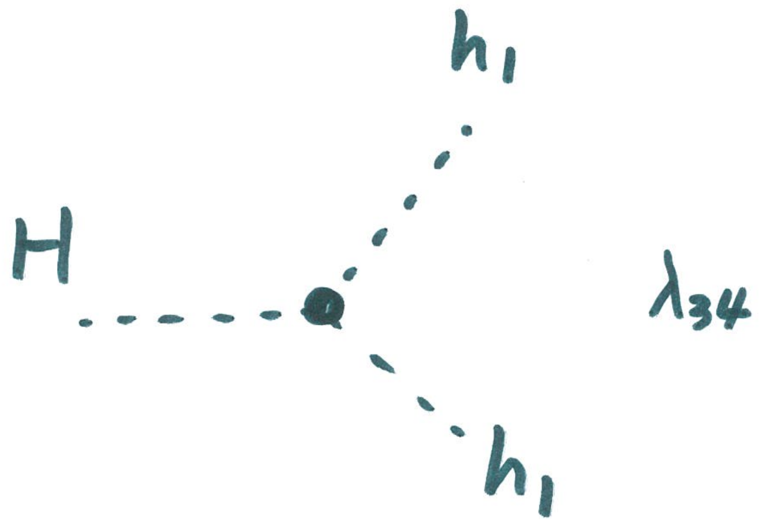
- **One DM particle, h_1.**

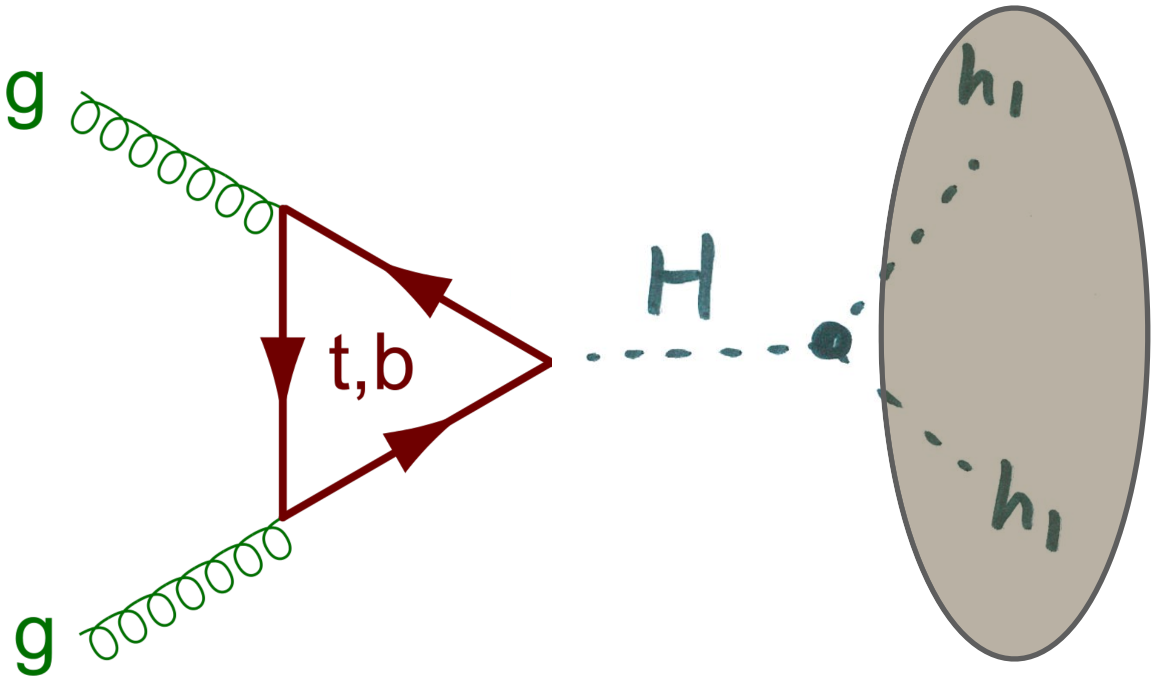




IDM$_{Z2}$

- **One DM particle, h_1.**

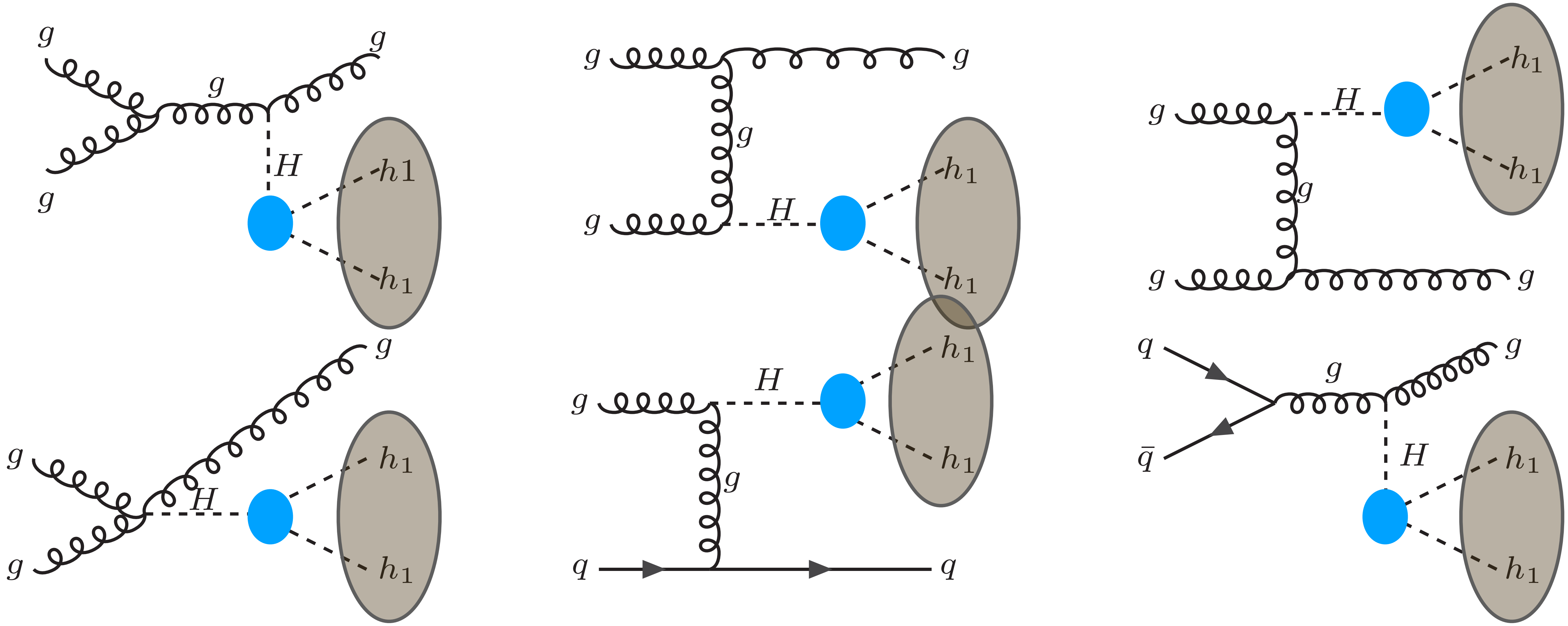




Main tagging particle

IDM$_{Z2}$

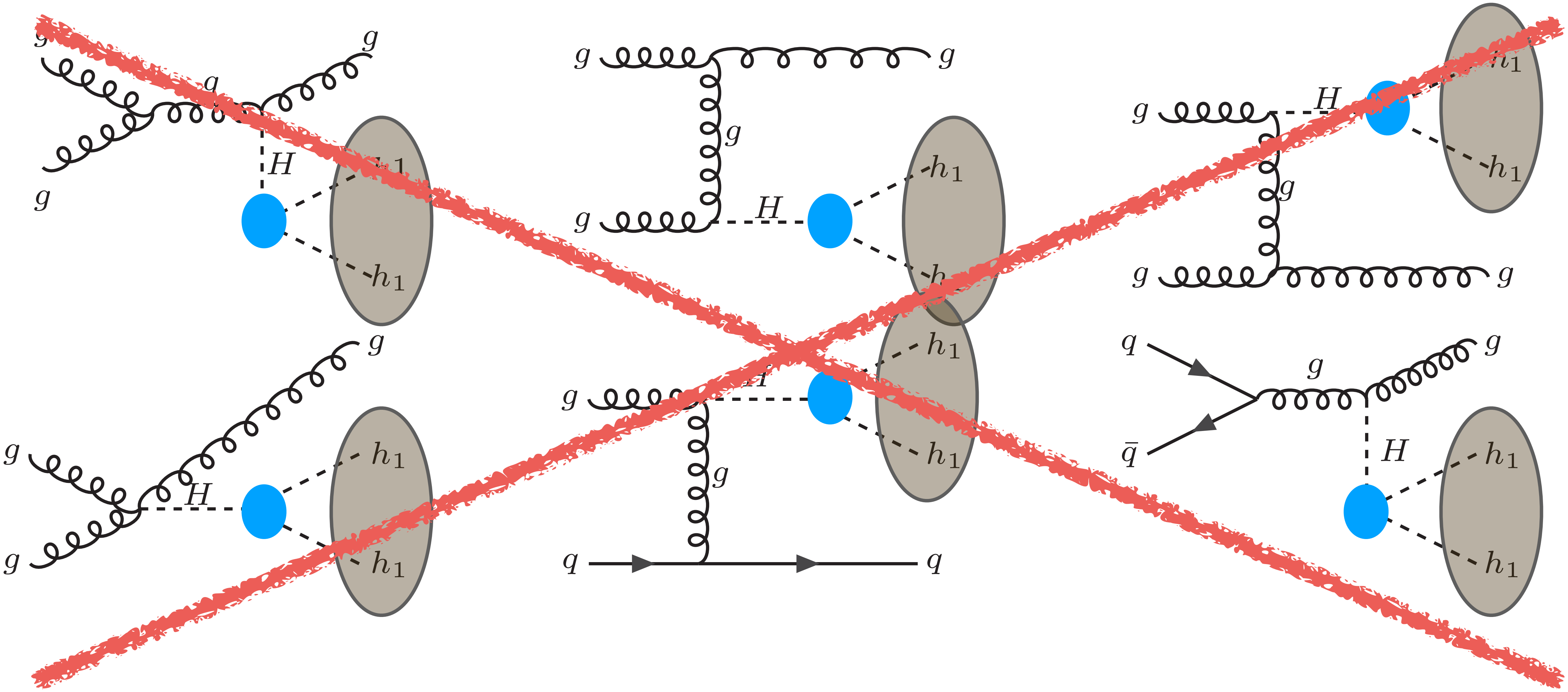
Mono-jet signal at the LHC



λ_{34}-dependent

IDM$_{Z2}$

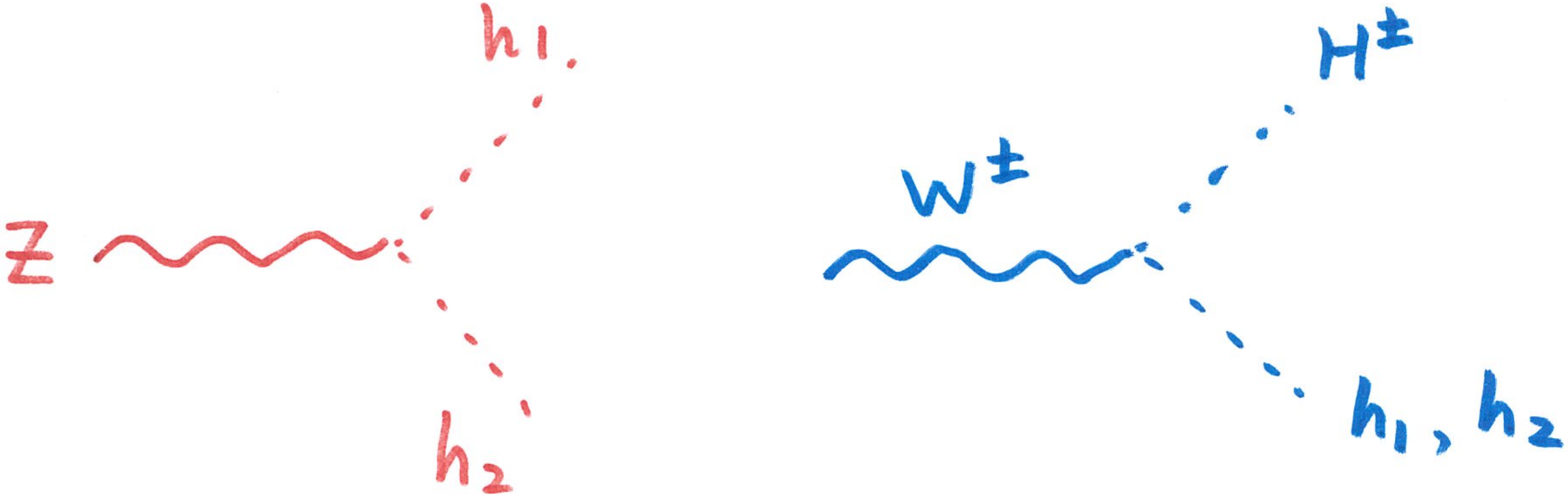
Mono-jet signal at the LHC



If $\lambda_{34} = 0$

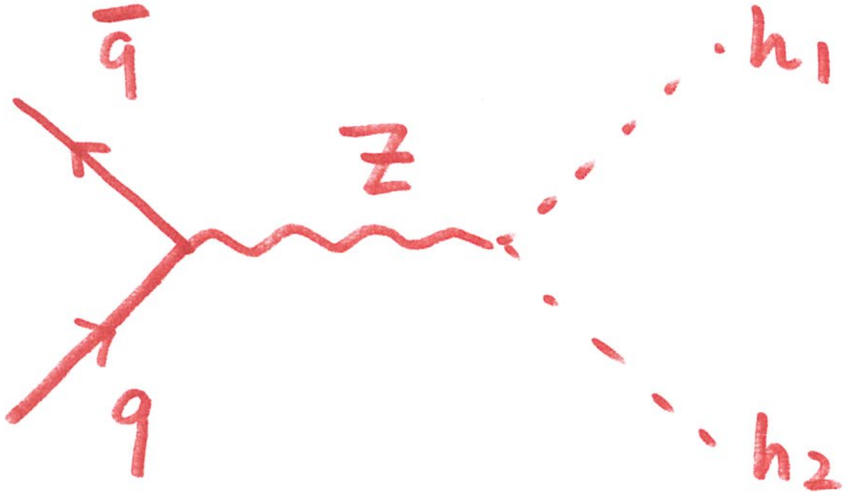
IDM$_{U(1)}$

- **Two DM particles, h_1 or h_2.**
- $M_{h_1} = M_{h_2}$**: protected by $U(1)$ symmetry**
- $M_{H^\pm}$**: within 190 GeV from the DM mass.**

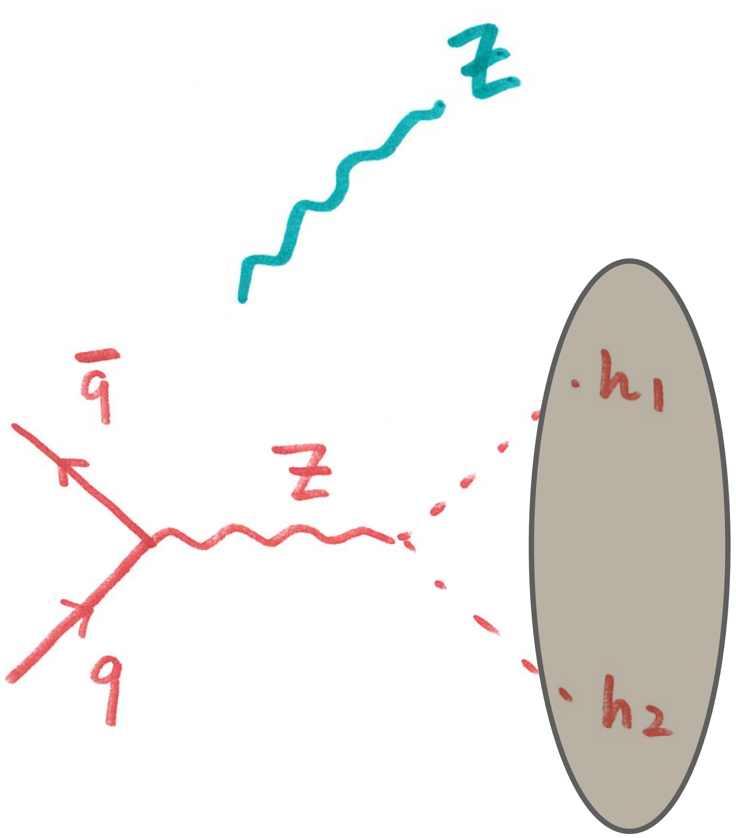


origin: gauge couplings

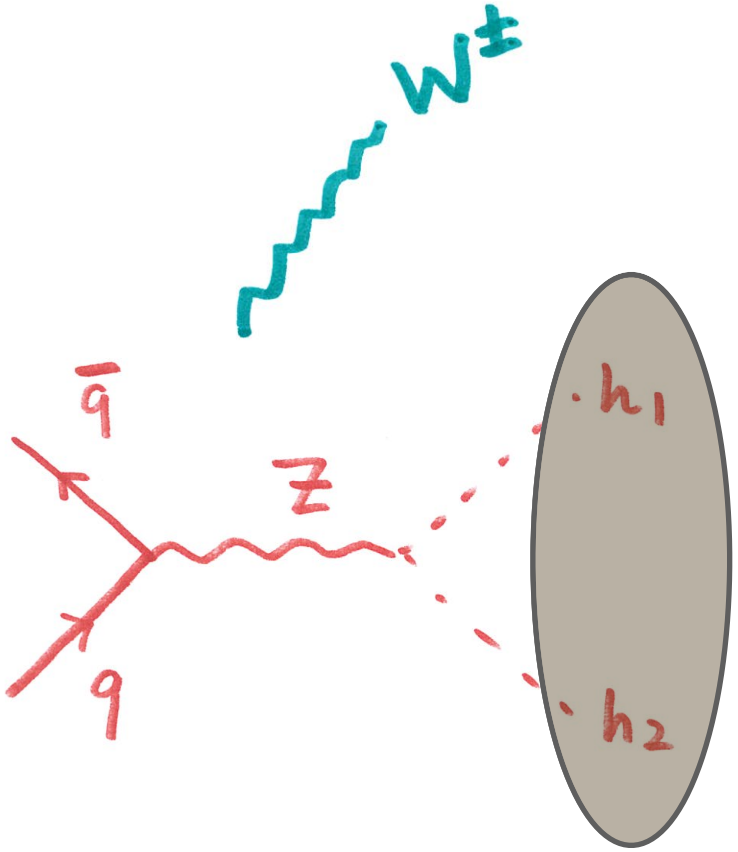
IDM$_{U(1)}$



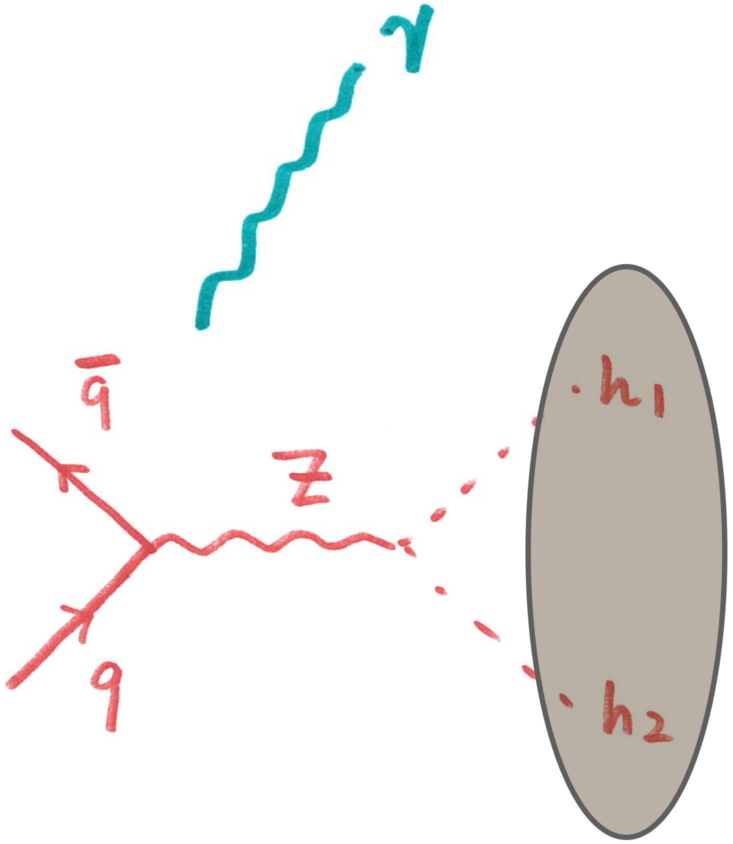
IDM$_{U(1)}$



mono-Z

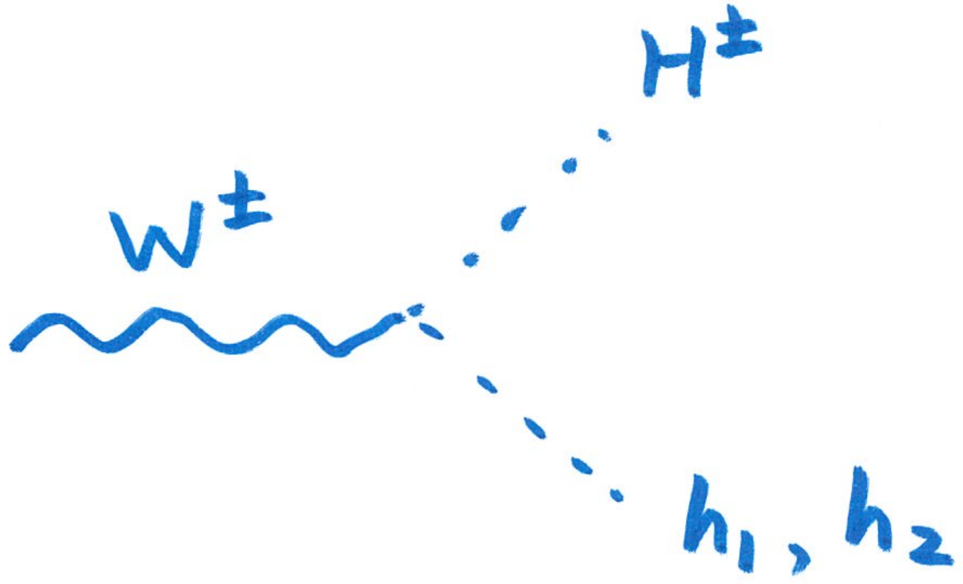


mono-W



mono-γ

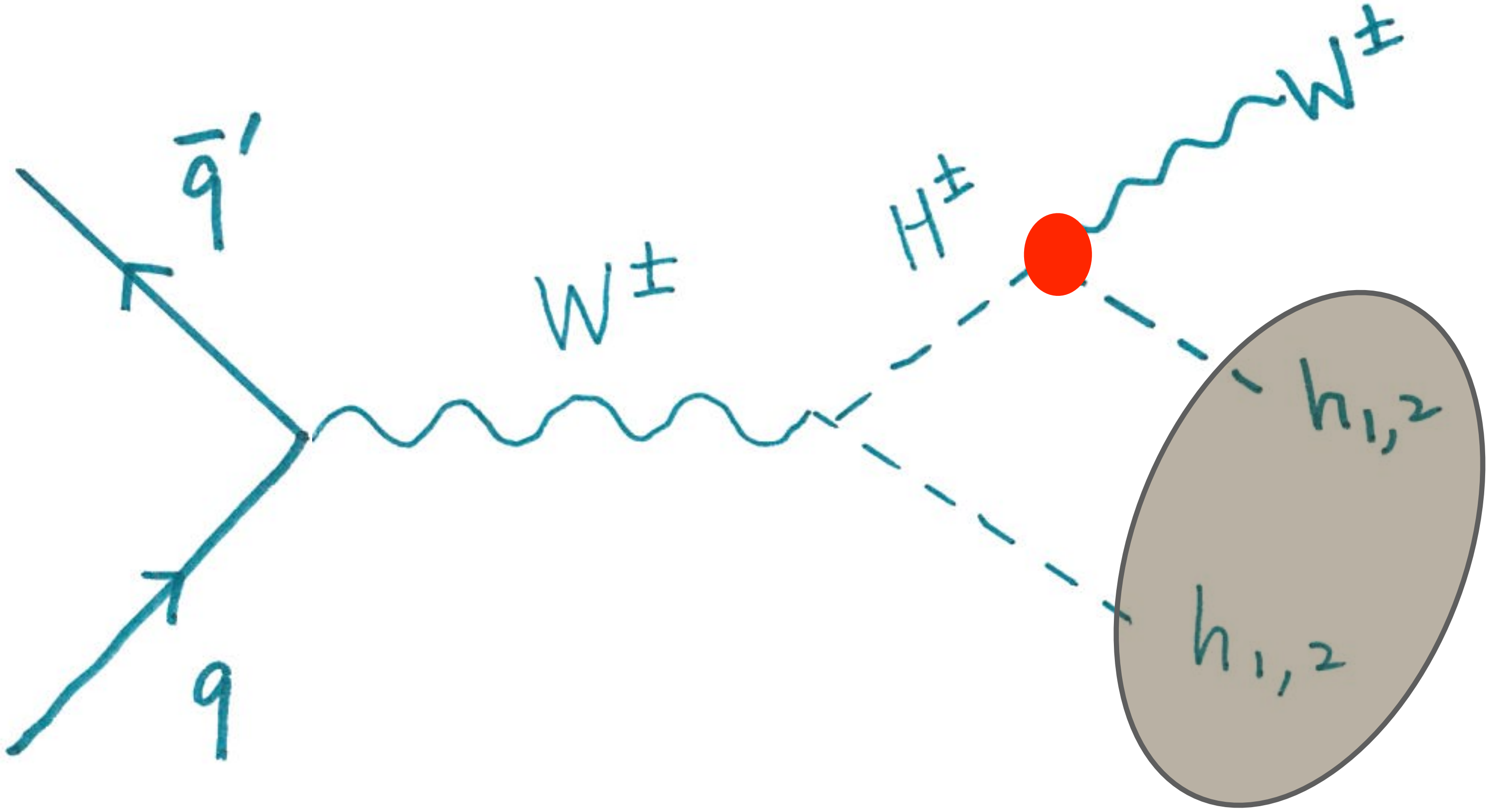
IDM$_{U(1)}$



Two different signals, according to ΔM.

IDM$_{U(1)}$

$$\Delta M = 190\,\mathrm{GeV}$$

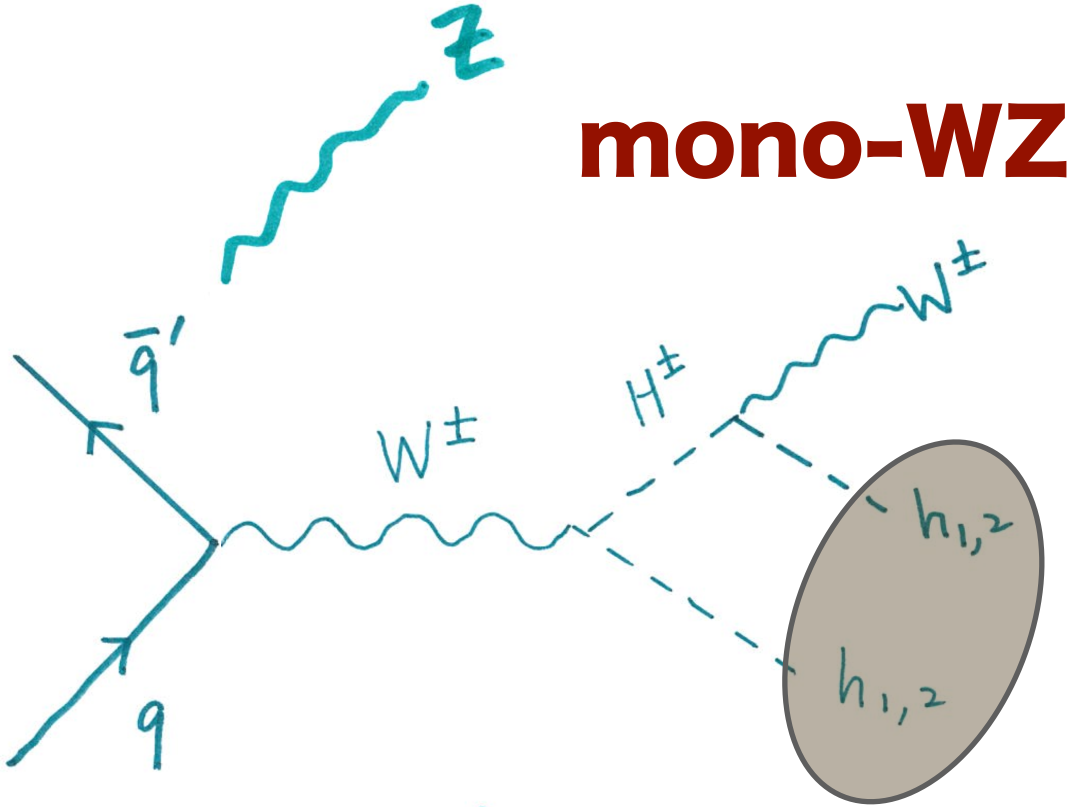


Br=1

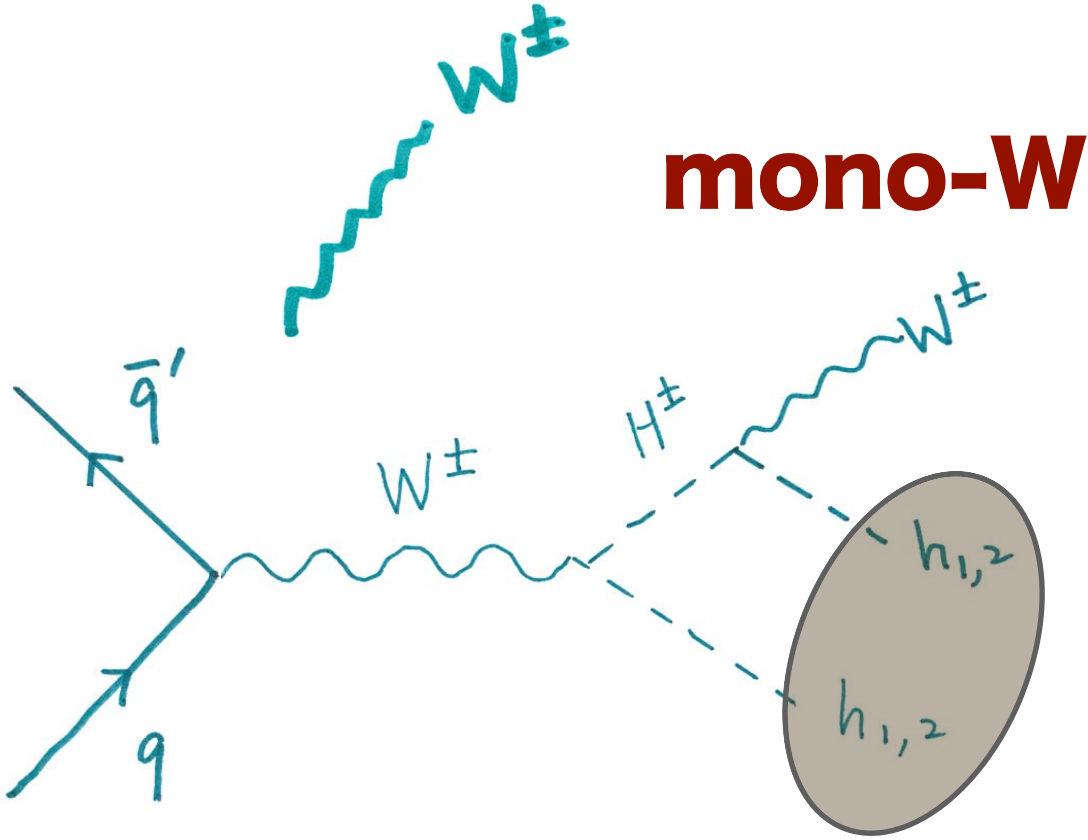
mono-W: 2→2 process

IDM$_{U(1)}$

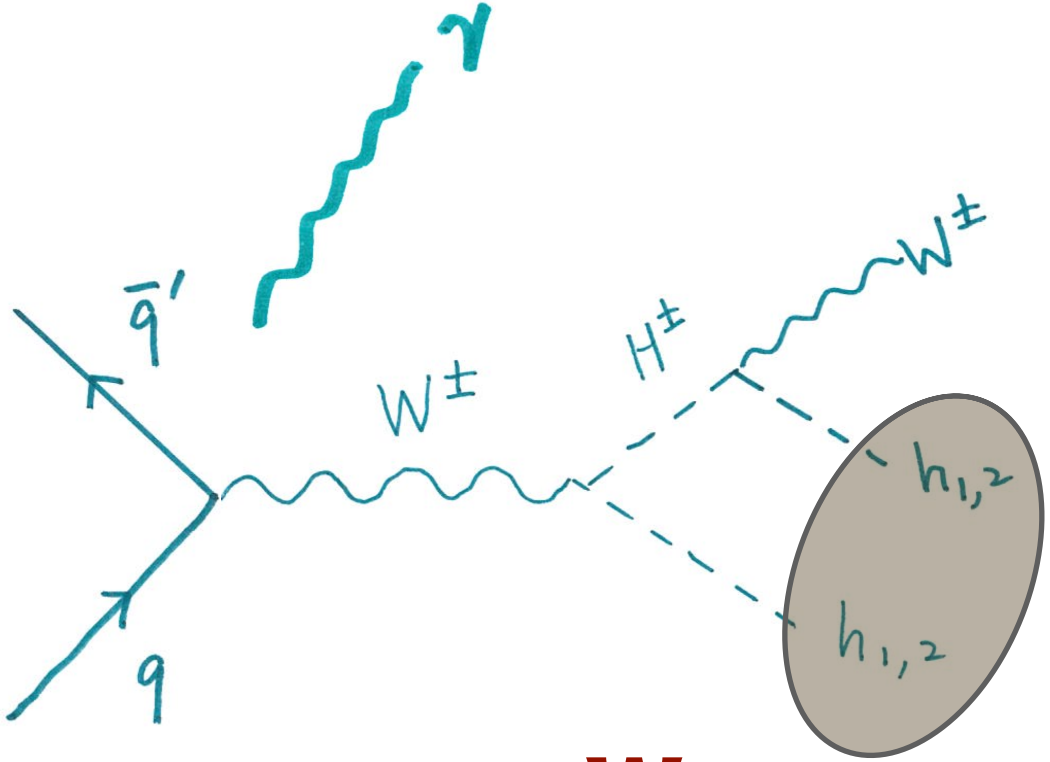
$$\Delta M = 190\,\mathrm{GeV}$$



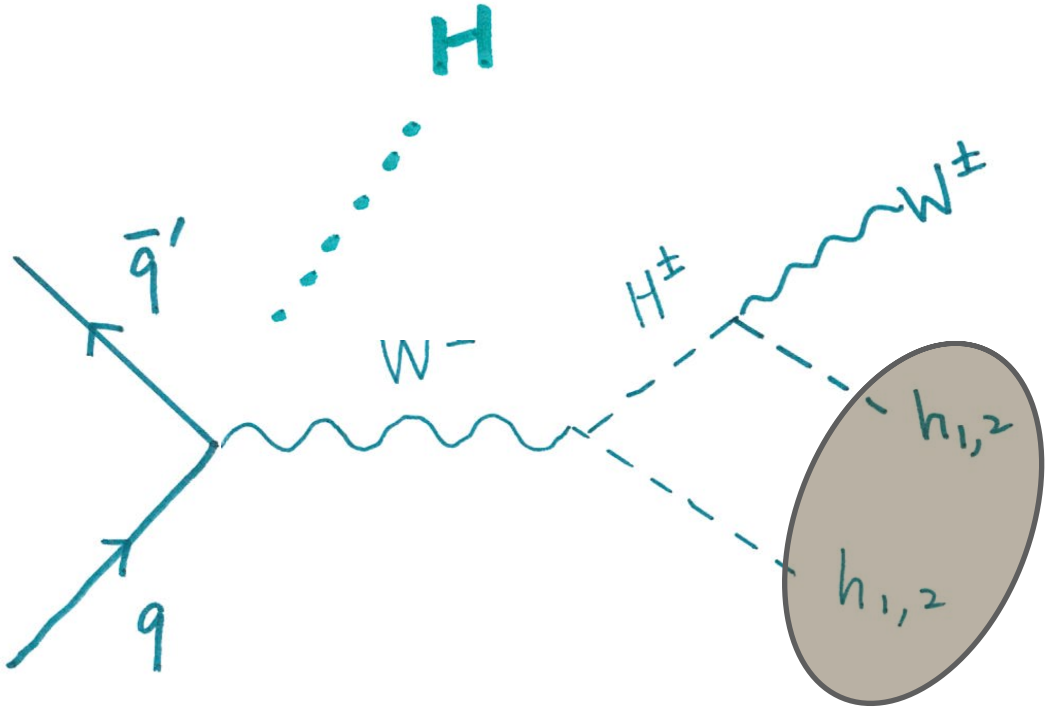
mono-WZ



mono-WW



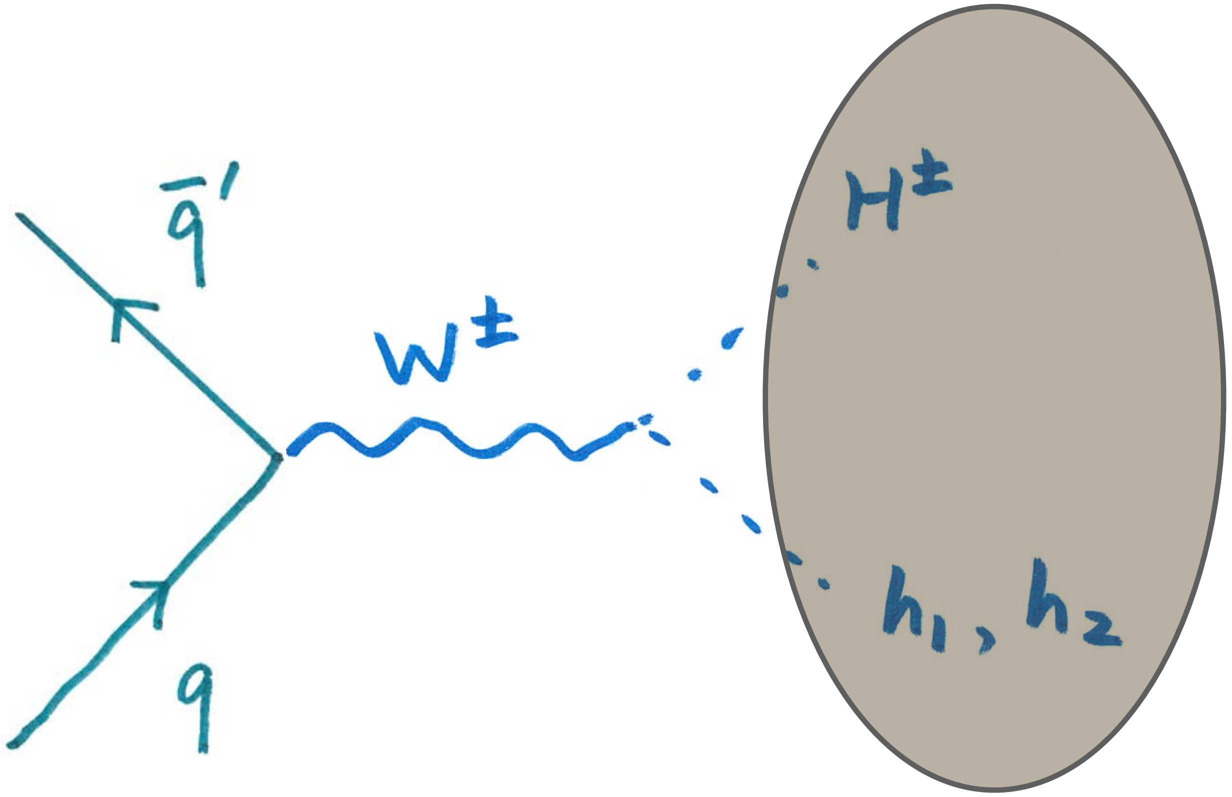
mono-Wγ



mono-WH

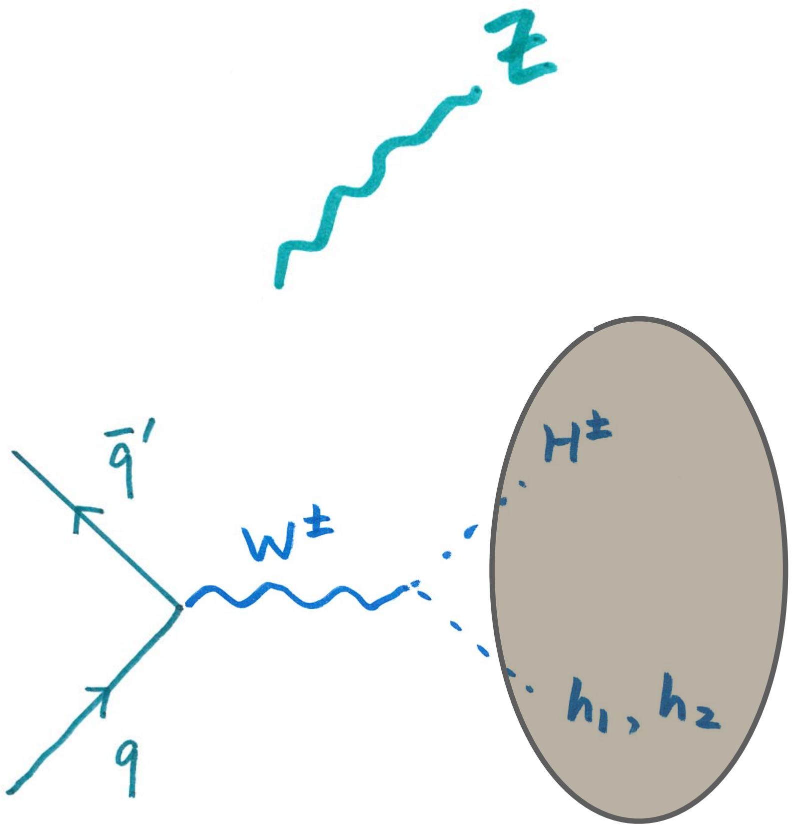
IDM$_{\mathrm{U(1)}}$

$$\Delta M = 10\,\mathrm{GeV}$$

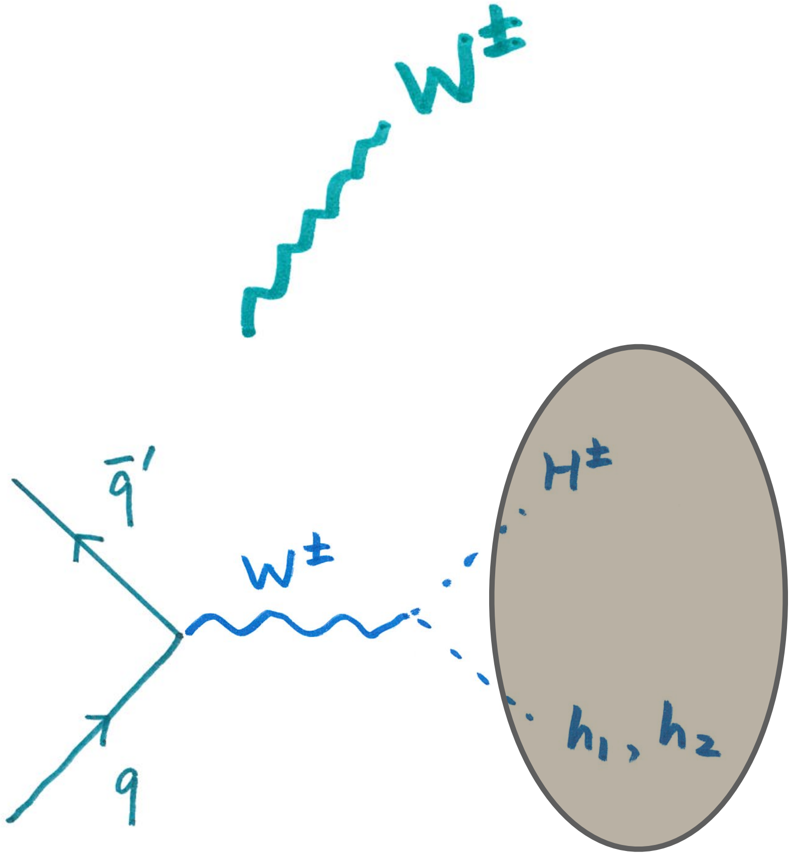


$\mathrm{IDM}_{U(1)}$

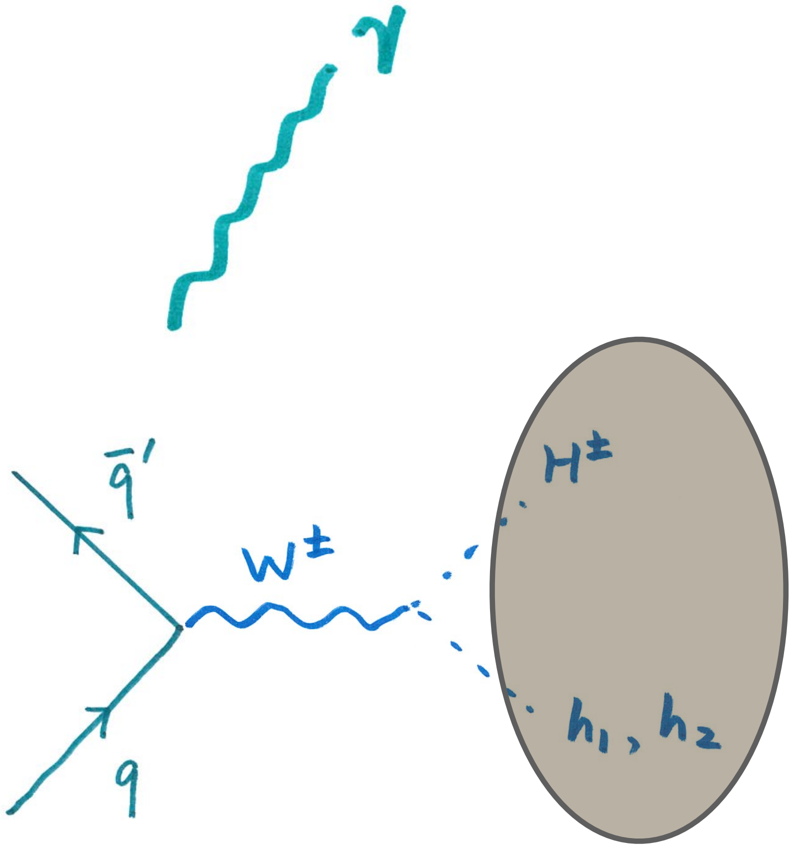
$$\Delta M = 10\,\mathrm{GeV}$$



mono-Z



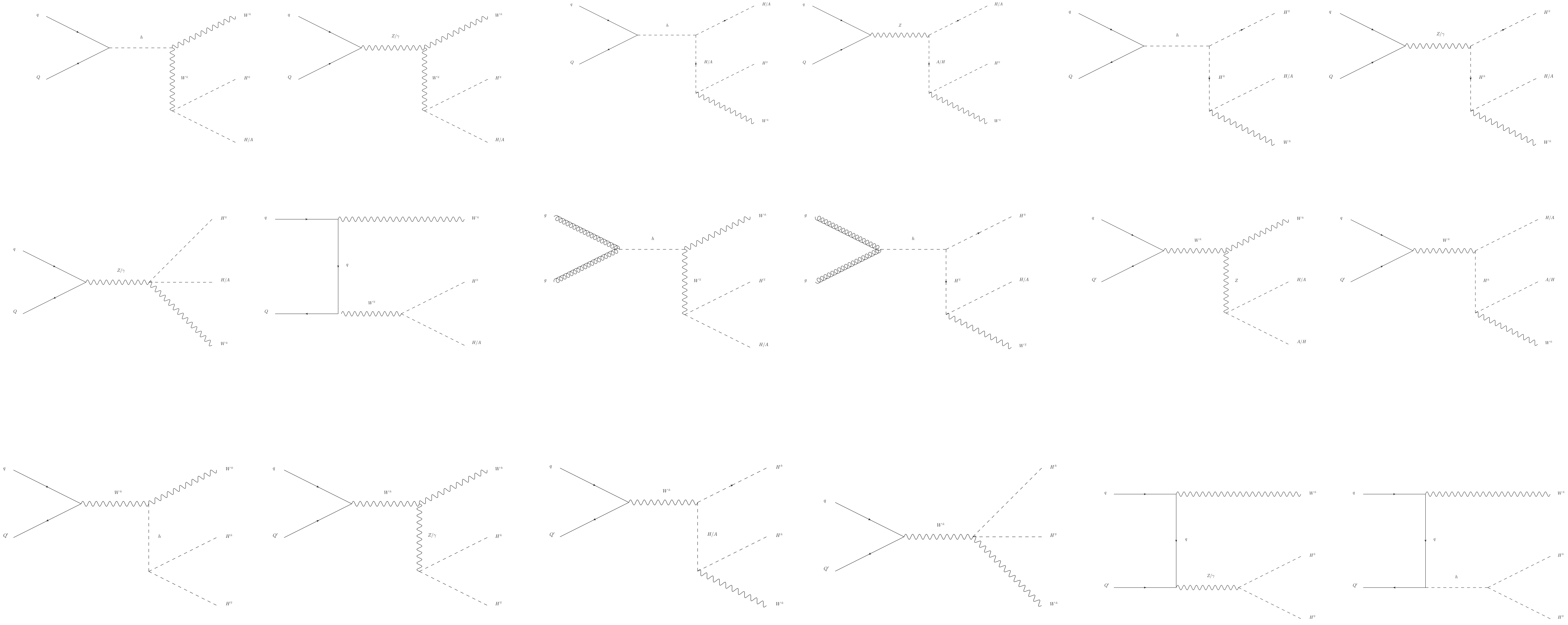
mono-W



mono-γ

Full processes are much more involved.

eg. mono-W



mono-V

$$\Delta M = 10\,\mathrm{GeV}$$

for $\lambda_{34} = 0$

Missing: $h_1 h_1, h_1 h_2, h_2 h_2, H^+ H^-, H^\pm h_1, H^\pm h_2$

significance $\mathcal{Z}$

M_S	**mono-Z** **(no-cut)**	**mono-γ** $(E_T^\gamma > 10\ \mathrm{GeV}, \lvert\eta\rvert < 2.5)$	**mono-W** **(no-cut)**
60	**8.13**	😄 **13.91**	**17.88**
70	**5.60**	**9.09**	**12.35**
200	**0.40**	**0.43**	**0.86**

- **High pT cut reduces the significance**
- **Even intermediate inert DM is difficult to probe.**

mono-V, mono-VV

$$\Delta M = 190\,\mathrm{GeV}$$

for $\lambda_{34} = 0$

Missing: $h_1 h_1, h_1 h_2, h_2 h_2$

significance $\mathcal{Z}$

M_S	**mono-Z** **(no-cut)**	**mono-γ** ($E_T^\gamma > 10$ GeV, $\lvert\eta\rvert < 2.5$)	**mono-W** **(no-cut)**	**mono-WW** **(no-cut)**
50	**4.34**	**6.92**	**120.47**	**90.66**
70	**1.56**	**1.87**	**77.85** 😁	**68.23**
200	**0.10**	**0.07**	**9.35**	**14.81**

7. Conclusions

- IDM with U(1) is well-motivated simple model for DM.
- There are two DM particles, neutral scalar and pseudo-scalar bosons, because the mass degeneracy between them is protected by U(1).
- The distinctive features are from Z-h1-h2 and W-H^+-h1.
- mono-W and mono-WW shall lead to smoking-gun signatures.