The Coannihilation Codex

Michael J. Baker

with

Joachim Brod, Sonia El Hedri, Anna Kaminska, Joachim Kopp, Jia Liu, Andrea Thamm, Maikel de Vries, Xiao-Ping Wang, Felix Yu, José Zurita

arXiv:1510.03434

JGU Mainz

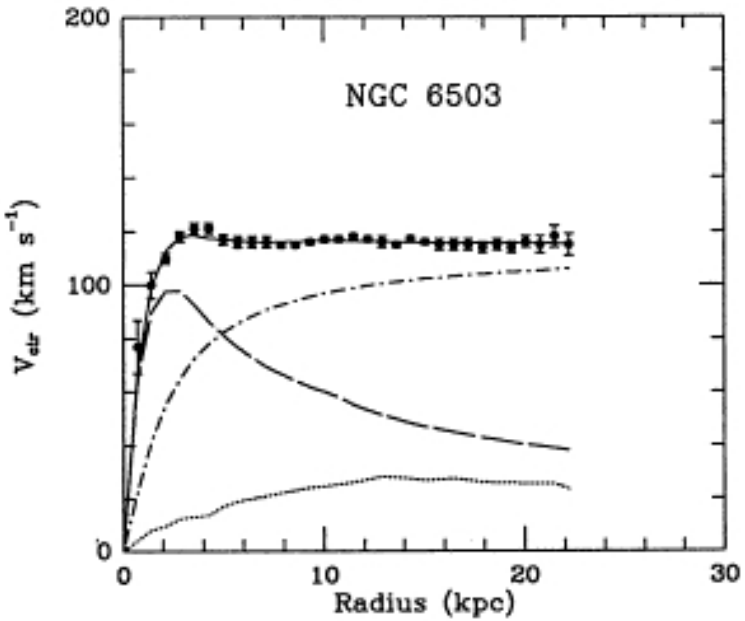
UC Davis - 29 February 2016

JOHANNES GUTENBERG UNIVERSITÄT MAINZ

Outline

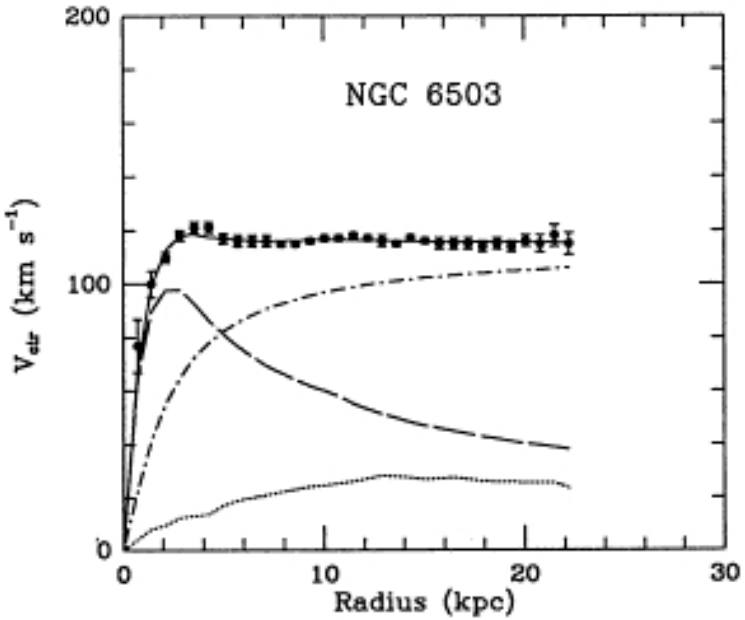
Outline

Dark Matter

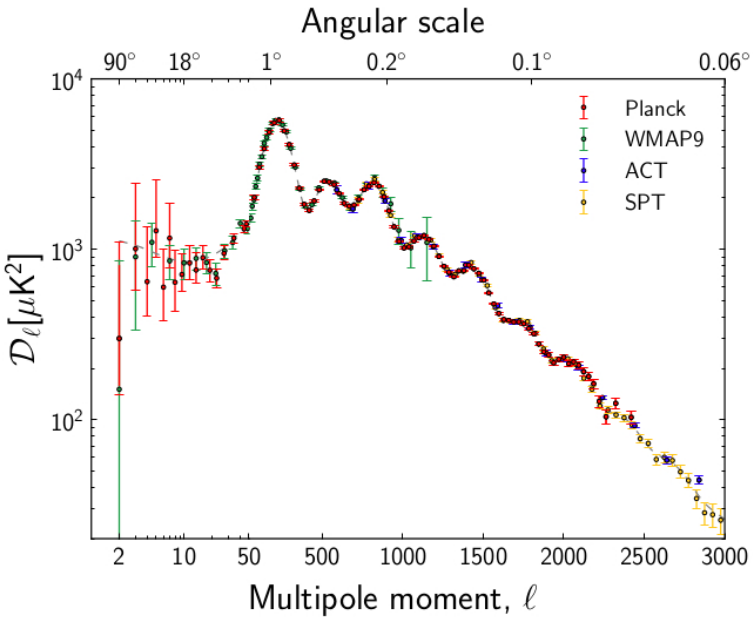


Begeman, Broeils & Sanders, 1991

Dark Matter

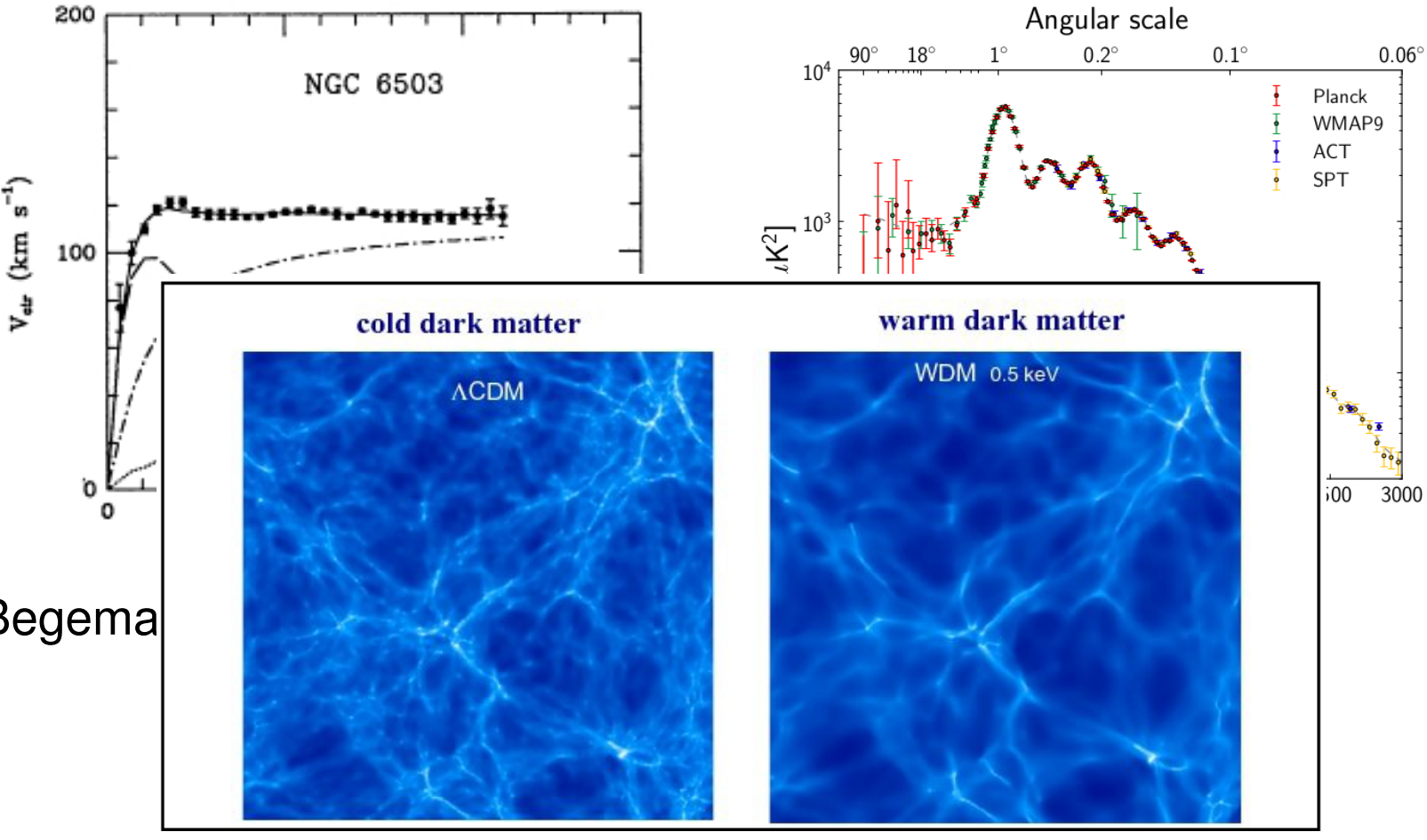


Begeman, Broeils & Sanders, 1991



Planck, 2013

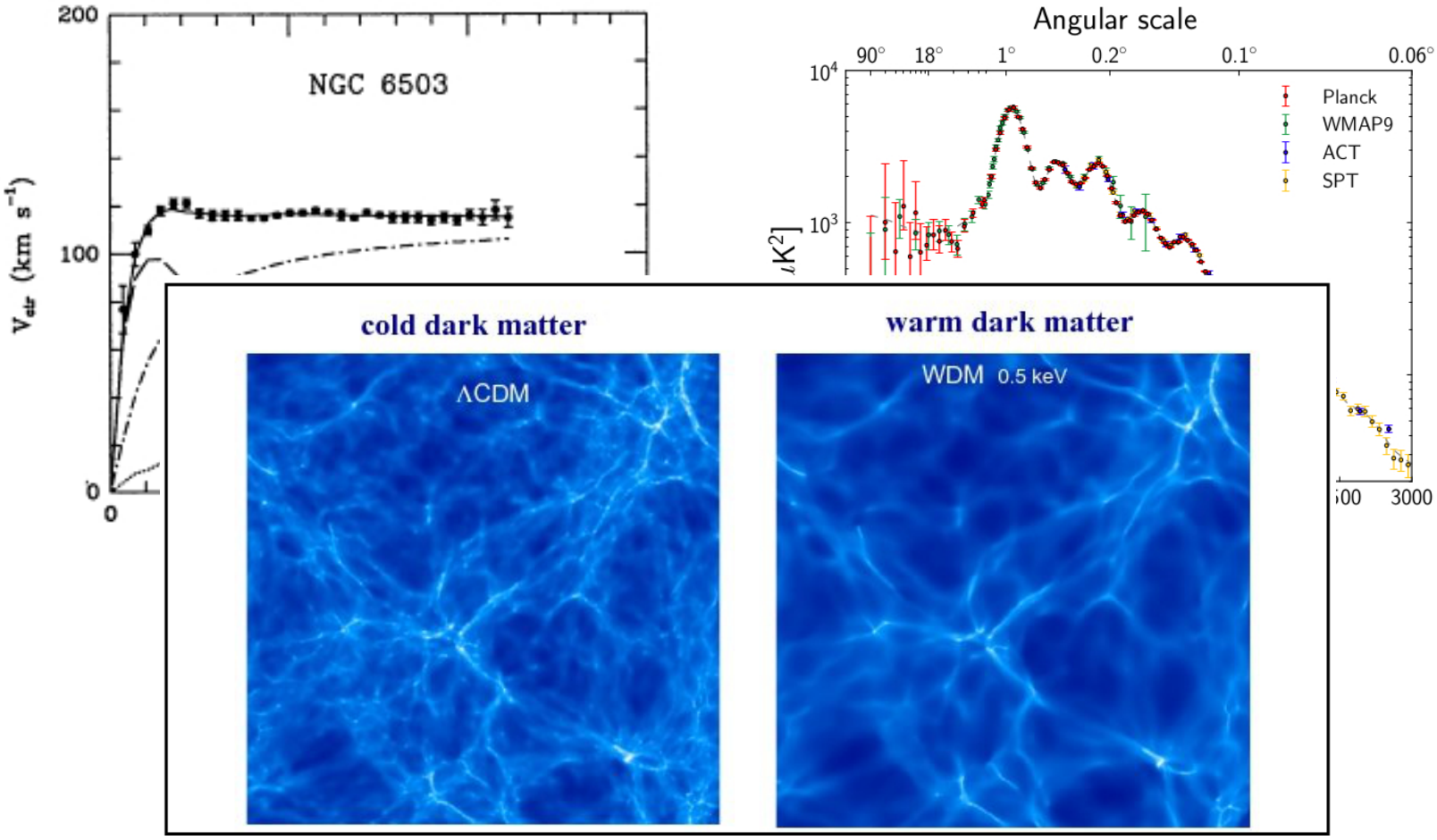
Dark Matter



Begema

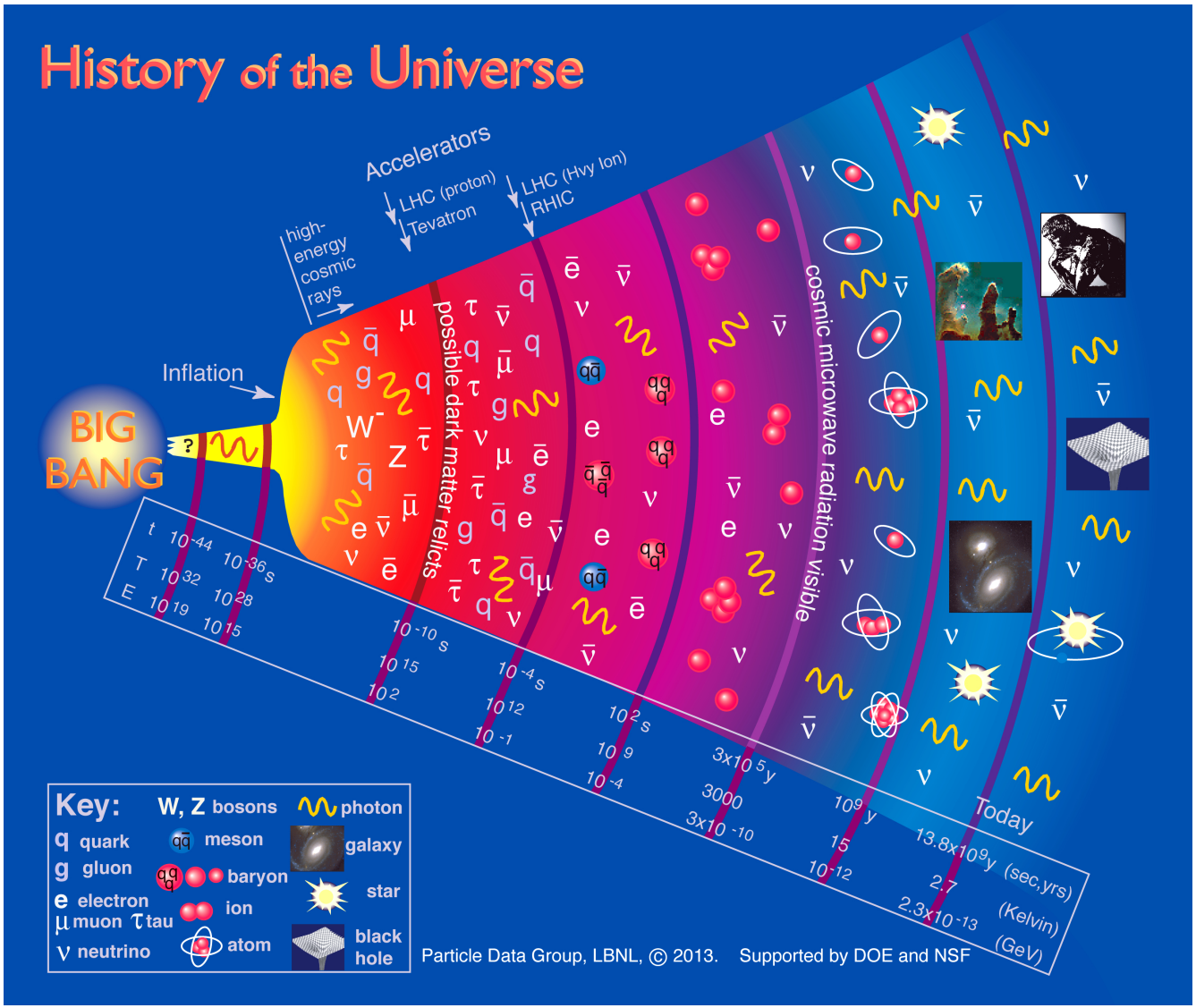
Viel, Becker, Bolton & Haehnelt, 2013

Dark Matter



$$\Omega_{\text{nbm}} h^2 = 0.1198 \pm 0.0026$$

Relic Density from Thermal Freeze-out

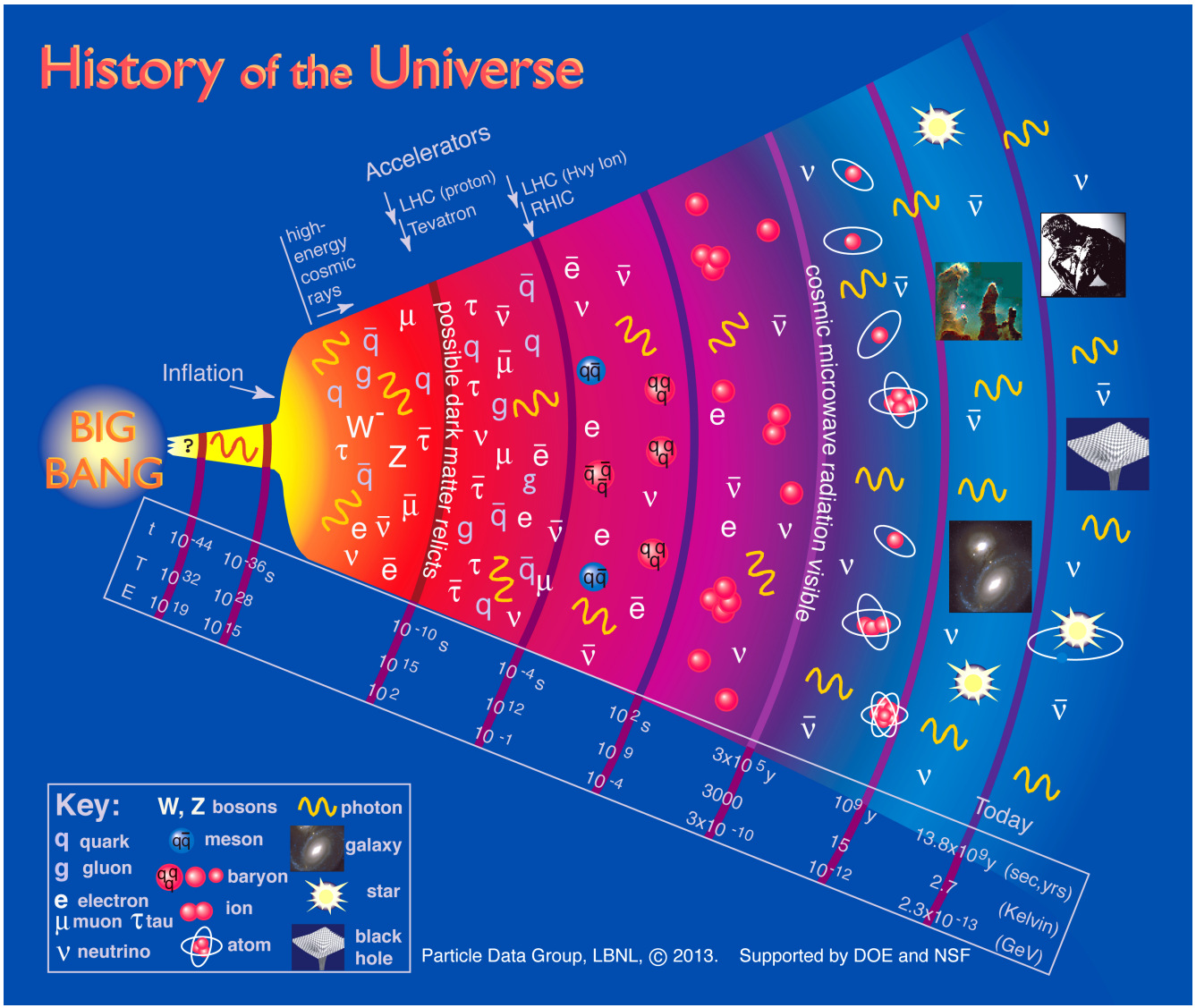


$$\mathrm{DM\ DM} \leftrightarrow \mathrm{SM\ SM}$$

$$H(T) \text{ vs. } \Gamma(T)$$

$$\Gamma(T) = n(T)\sigma(T)v(T)$$

Relic Density from Thermal Freeze-out

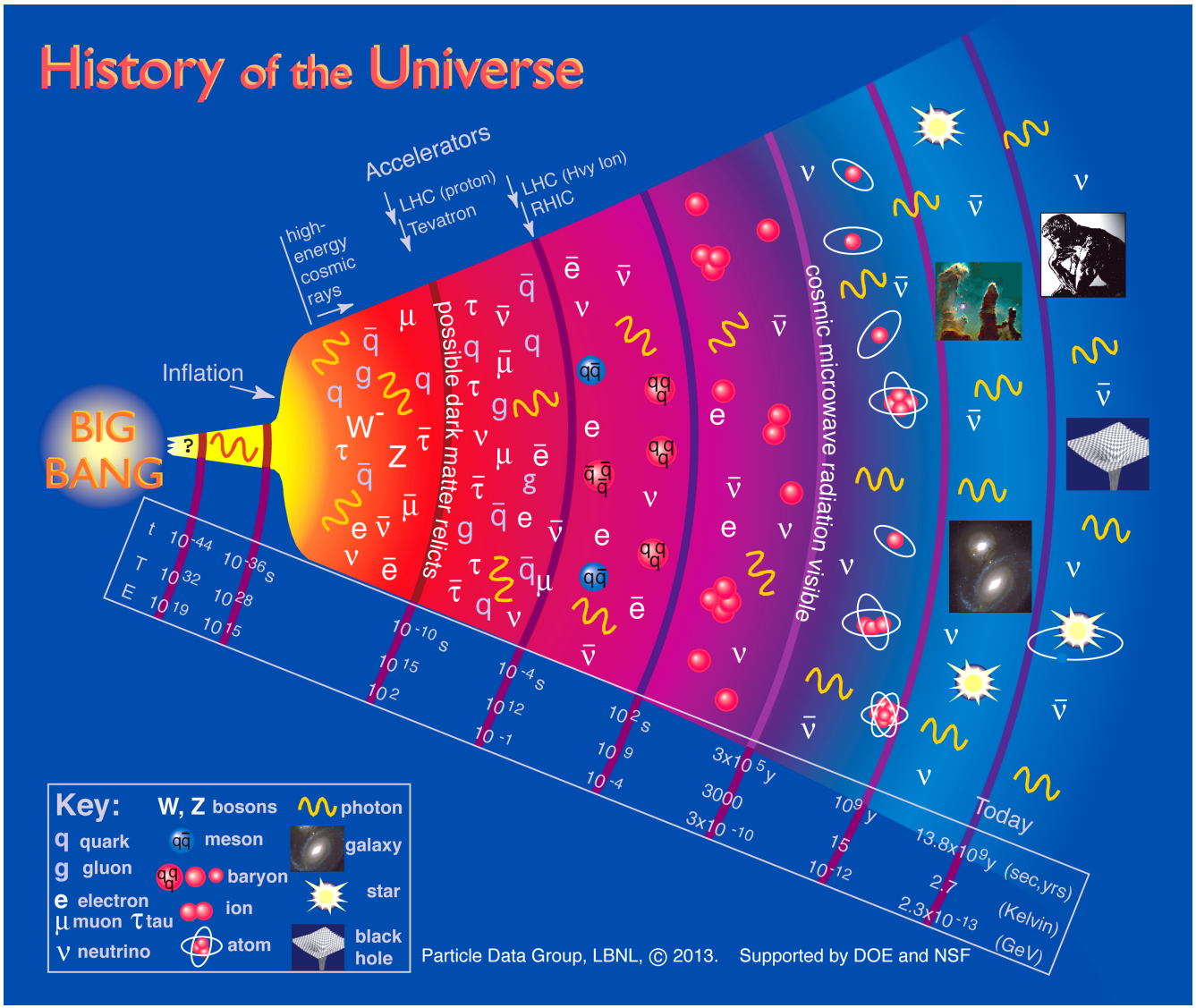


$$\mathrm{DM\ DM} \leftrightarrow \mathrm{SM\ SM}$$

$$H(T) \text{ vs. } \Gamma(T)$$

$$\Gamma(T) = n(T)\sigma(T)v(T)$$

Relic Density from Thermal Freeze-out

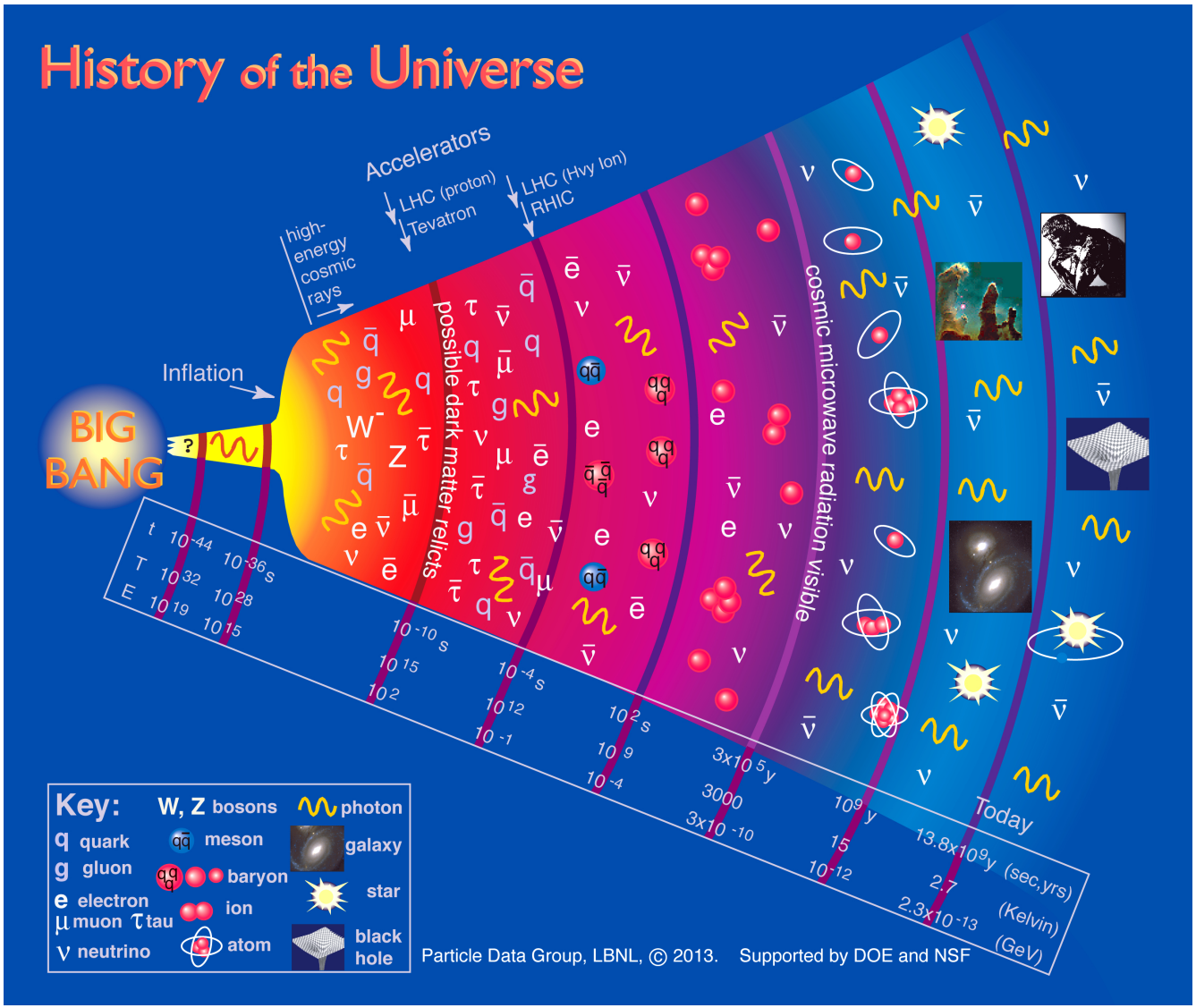


$$\mathrm{DM\ DM} \leftrightarrow \mathrm{SM\ SM}$$

$$H(T) \text{ vs. } \Gamma(T)$$

$$\Gamma(T) = n(T)\sigma(T)v(T)$$

Relic Density from Thermal Freeze-out

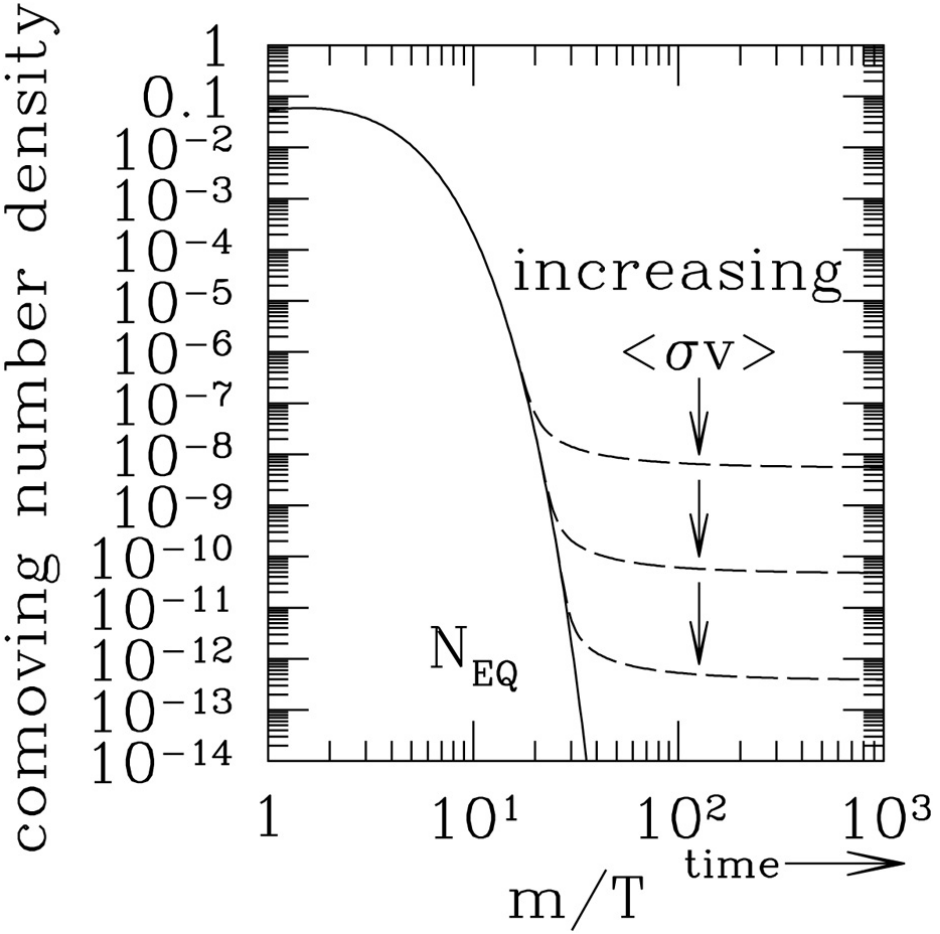


$$\mathrm{DM\ DM} \leftrightarrow \mathrm{SM\ SM}$$

$$H(T) \text{ vs. } \Gamma(T)$$

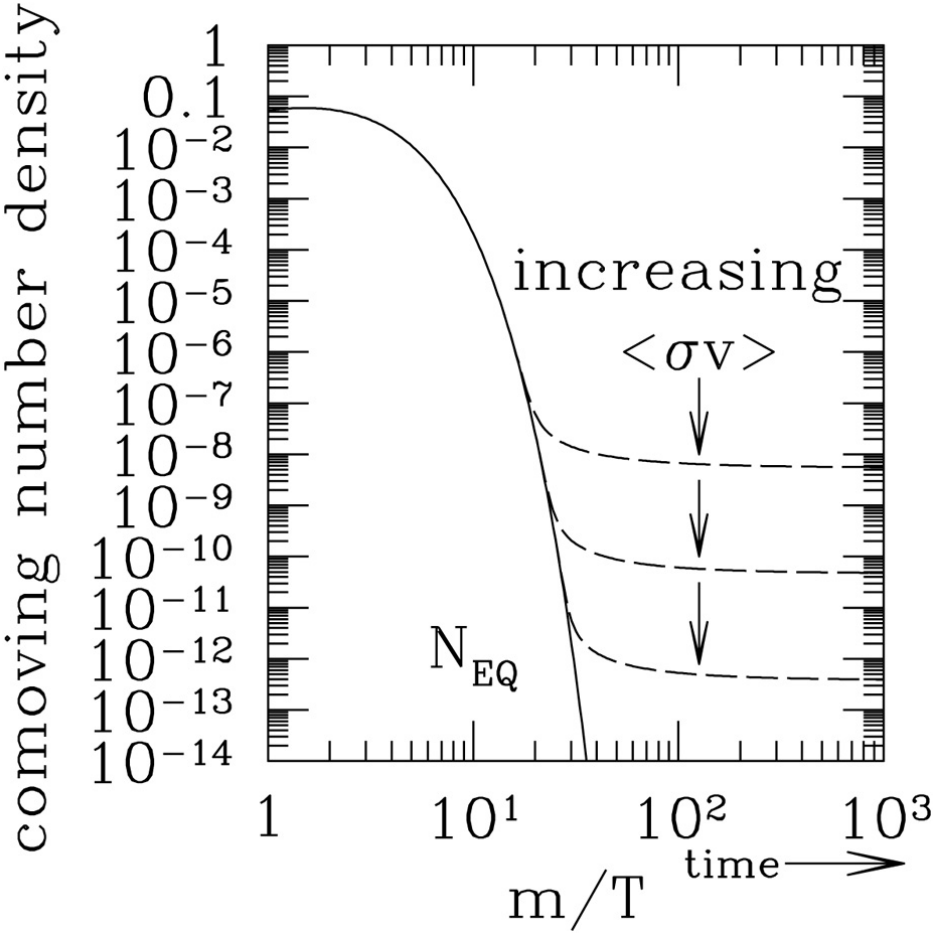
$$\Gamma(T) = n(T)\sigma(T)v(T)$$

Relic Density from Thermal Freeze-out



$$\frac{dn}{dt} = -\langle \sigma v \rangle (n(t)^2 - n_{\mathrm{eq}}(t)^2) - 3H(t)n(t)$$

Relic Density from Thermal Freeze-out



$$\frac{dn}{dt} = -\langle\sigma v\rangle(n(t)^2 - n_{\mathrm{eq}}(t)^2) - 3H(t)n(t)$$

The WIMP Miracle

$$\frac{\Omega_{\rm DM} h^2}{0.12} \sim \mathcal{O}(1) \frac{T_0^3}{M_{\rm Pl}^3 H_0^2 \langle \sigma_{\rm ann} v \rangle} \sim \frac{1}{\langle \frac{\sigma_{\rm ann}}{1\rm pb} \frac{v/c}{0.1} \rangle}$$

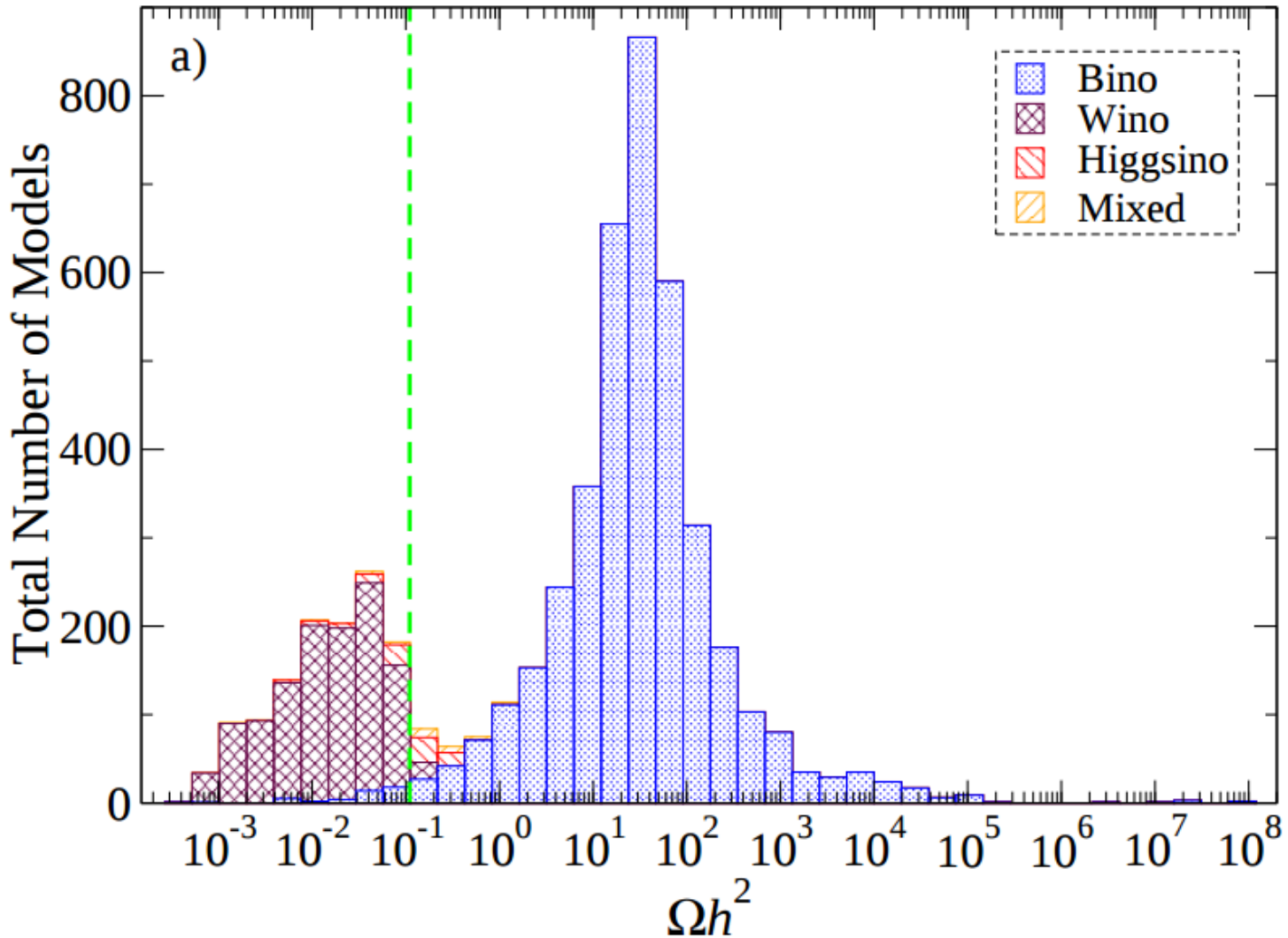
$$\sigma_{\rm ann} \propto \frac{g^4}{m_{\rm DM}^2}$$

The WIMP Miracle

$$\frac{\Omega_{\rm DM} h^2}{0.12} \sim \mathcal{O}(1) \frac{T_0^3}{M_{\rm Pl}^3 H_0^2 \langle \sigma_{\rm ann} v \rangle} \sim \frac{1}{\langle \frac{\sigma_{\rm ann}}{1{\rm pb}} \frac{v/c}{0.1} \rangle}$$

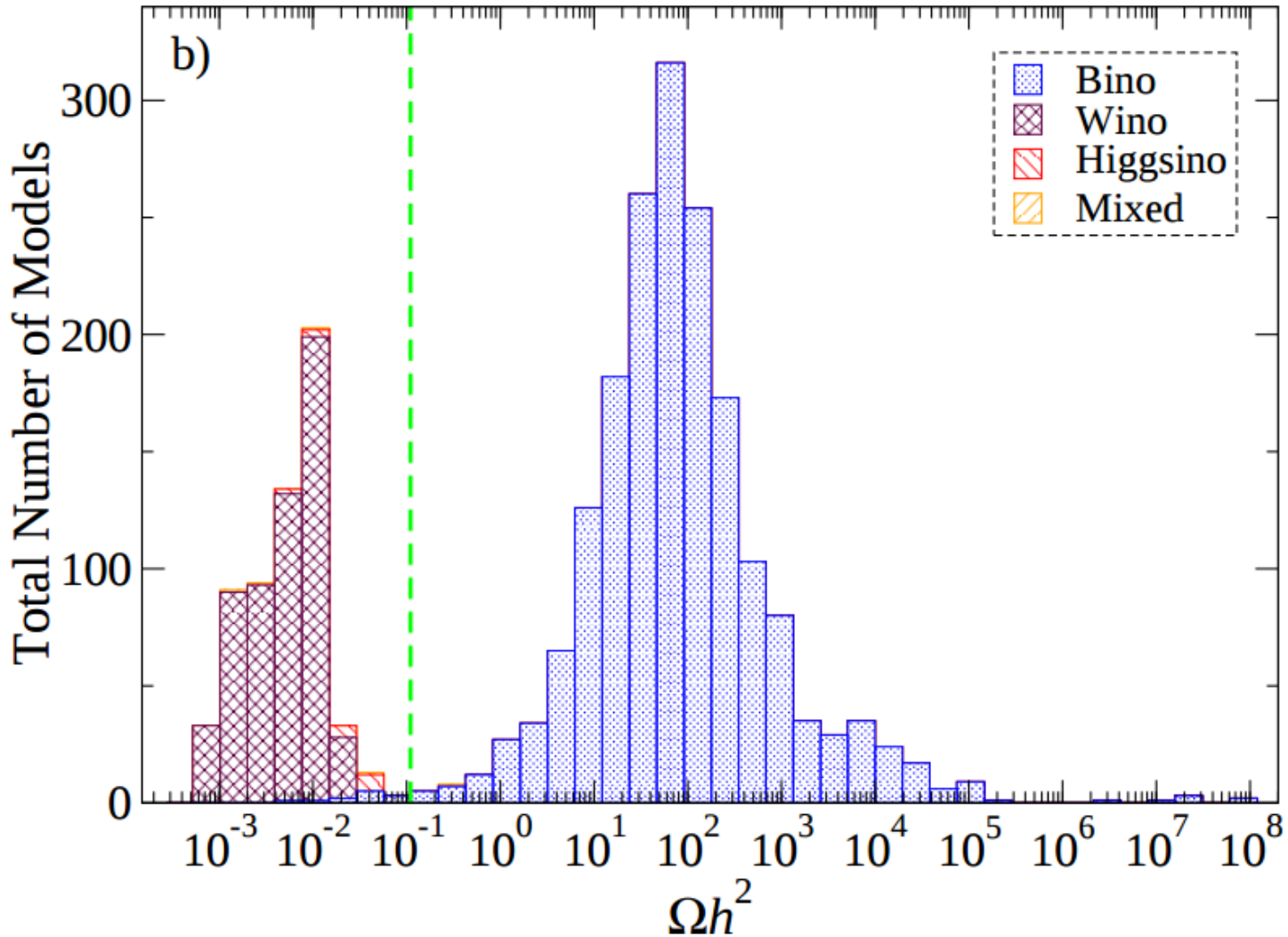
$$\sigma_{\rm ann} \propto \frac{g^4}{m_{\rm DM}^2}$$

The WIMP Miracle in SUGRA



Baer, Box and Summy: 1005.2215

The WIMP Miracle in SUGRA



Baer, Box and Summy: 1005.2215

Three Exceptions

PHYSICAL REVIEW D VOLUME 43, NUMBER 10 15 MAY 1991

Three exceptions in the calculation of relic abundances

Kim Griest
Center for Particle Astrophysics and Astronomy Department, University of California, Berkeley, California 94720

David Seckel
Bartol Research Institute, University of Delaware, Newark, Delaware 19716
(Received 15 November 1990)

Forbidden annihilation
Resonant annihilation
Coannihilation

Three Exceptions

PHYSICAL REVIEW D VOLUME 43, NUMBER 10 15 MAY 1991

Three exceptions in the calculation of relic abundances

Kim Griest
Center for Particle Astrophysics and Astronomy Department, University of California, Berkeley, California 94720

David Seckel
Bartol Research Institute, University of Delaware, Newark, Delaware 19716
(Received 15 November 1990)

Forbidden annihilation
Resonant annihilation
Coannihilation

Three Exceptions

PHYSICAL REVIEW D VOLUME 43, NUMBER 10 15 MAY 1991

Three exceptions in the calculation of relic abundances

Kim Griest
Center for Particle Astrophysics and Astronomy Department, University of California, Berkeley, California 94720

David Seckel
Bartol Research Institute, University of Delaware, Newark, Delaware 19716
(Received 15 November 1990)

Forbidden annihilation
Resonant annihilation
Coannihilation

Three Exceptions

PHYSICAL REVIEW D VOLUME 43, NUMBER 10 15 MAY 1991

Three exceptions in the calculation of relic abundances

Kim Griest
Center for Particle Astrophysics and Astronomy Department, University of California, Berkeley, California 94720

David Seckel
Bartol Research Institute, University of Delaware, Newark, Delaware 19716
(Received 15 November 1990)

Forbidden annihilation
Resonant annihilation
Coannihilation

Coannihilation

$$\mathrm{DM} \quad \mathrm{DM} \quad \leftrightarrow \quad \mathrm{SM}_1 \quad \mathrm{SM}_2$$

$$\mathrm{DM} \quad X \quad \leftrightarrow \quad \mathrm{SM}_1 \quad \mathrm{SM}_2$$

$$X \quad X \quad \leftrightarrow \quad \mathrm{SM}_1 \quad \mathrm{SM}_2$$

$$\mathrm{DM} \quad \mathrm{SM}_1 \quad \leftrightarrow \quad X \quad \mathrm{SM}_2$$

$$\frac{dn}{dt} = -\langle \sigma_{\mathrm{eff}} v \rangle (n(t)^2 - n_{\mathrm{eq}}(t)^2) - 3Hn$$

$$\sigma_{\mathrm{eff}} \sim \sigma_{\mathrm{DMDM}} + 2\sigma_{\mathrm{DM}X}(1+\Delta)^{3/2} e^{-x_f \Delta} + \sigma_{XX}(1+\Delta) e^{-2x_f \Delta}$$

$$\Delta = \frac{m_{\mathrm{DM}} - m_X}{m_{\mathrm{DM}}}, \qquad x_f = \frac{m_{\mathrm{DM}}}{T_f}$$

Coannihilation

$$\begin{array}{cccc} \mathrm{DM} & \mathrm{DM} & \leftrightarrow & \mathrm{SM}_1 \quad \mathrm{SM}_2 \\ \mathrm{DM} & X & \leftrightarrow & \mathrm{SM}_1 \quad \mathrm{SM}_2 \\ X & X & \leftrightarrow & \mathrm{SM}_1 \quad \mathrm{SM}_2 \\ \mathrm{DM} & \mathrm{SM}_1 & \leftrightarrow & X \quad \mathrm{SM}_2 \end{array}$$

$$\frac{dn}{dt} = -\langle \sigma_{\mathrm{eff}} v \rangle (n(t)^2 - n_{\mathrm{eq}}(t)^2) - 3Hn$$

$$\sigma_{\mathrm{eff}} \sim \sigma_{\mathrm{DMDM}} + 2\sigma_{\mathrm{DM}X}(1+\Delta)^{3/2} e^{-x_f \Delta} + \sigma_{XX}(1+\Delta) e^{-2x_f \Delta}$$

$$\Delta = \frac{m_{\mathrm{DM}} - m_X}{m_{\mathrm{DM}}}, \qquad x_f = \frac{m_{\mathrm{DM}}}{T_f}$$

Coannihilation

$$\begin{array}{cccc} \mathrm{DM} & \mathrm{DM} & \leftrightarrow & \mathrm{SM}_1 \quad \mathrm{SM}_2 \\ \mathrm{DM} & X & \leftrightarrow & \mathrm{SM}_1 \quad \mathrm{SM}_2 \\ X & X & \leftrightarrow & \mathrm{SM}_1 \quad \mathrm{SM}_2 \\ \mathrm{DM} & \mathrm{SM}_1 & \leftrightarrow & X \quad \mathrm{SM}_2 \end{array}$$

$$\frac{dn}{dt} = -\langle \sigma_{\mathrm{eff}} v \rangle (n(t)^2 - n_{\mathrm{eq}}(t)^2) - 3Hn$$

$$\sigma_{\mathrm{eff}} \sim \sigma_{\mathrm{DMDM}} + 2\sigma_{\mathrm{DM}X}(1+\Delta)^{3/2} e^{-x_f \Delta} + \sigma_{XX}(1+\Delta) e^{-2x_f \Delta}$$

$$\Delta = \frac{m_{\mathrm{DM}} - m_X}{m_{\mathrm{DM}}}, \qquad x_f = \frac{m_{\mathrm{DM}}}{T_f}$$

Coannihilation

$$\begin{array}{cccc} \mathrm{DM} & \mathrm{DM} & \leftrightarrow & \mathrm{SM}_1 \quad \mathrm{SM}_2 \\ \mathrm{DM} & X & \leftrightarrow & \mathrm{SM}_1 \quad \mathrm{SM}_2 \\ X & X & \leftrightarrow & \mathrm{SM}_1 \quad \mathrm{SM}_2 \\ \mathrm{DM} & \mathrm{SM}_1 & \leftrightarrow & X \quad \mathrm{SM}_2 \end{array}$$

$$\frac{dn}{dt} = -\langle \sigma_{\mathrm{eff}} v \rangle (n(t)^2 - n_{\mathrm{eq}}(t)^2) - 3Hn$$

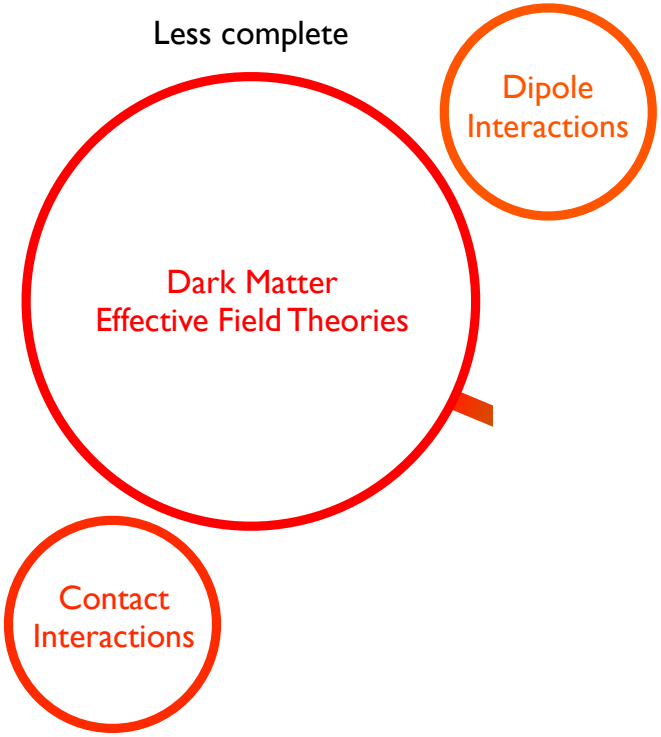
$$\sigma_{\mathrm{eff}} \sim \sigma_{\mathrm{DMDM}} + 2\sigma_{\mathrm{DM}X}(1+\Delta)^{3/2} e^{-x_f \Delta} + \sigma_{XX}(1+\Delta) e^{-2x_f \Delta}$$

$$\Delta = \frac{m_{\mathrm{DM}} - m_X}{m_{\mathrm{DM}}}, \qquad x_f = \frac{m_{\mathrm{DM}}}{T_f}$$

Coannihilation in the literature

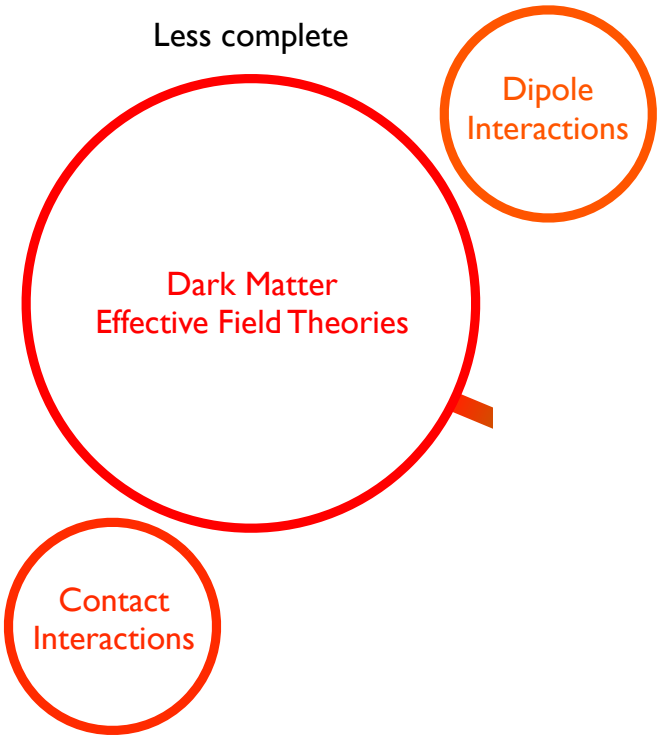
Bino-Higgsino: 1601.01569, 1510.06151, 1510.02760, 1509.08838
Bino-gluino: 1509.03613, 1508.04811
Bino-wino: 1509.03613, 1506.08206
Bino-stau: 1509.08838, 1509.07152
Bino-sleptons: 1506.08202
Bino-stop: 1509.08838
Neutralino-chargino: 1509.08485, 1507.02288, 1506.08202
Neutralino-sbottom: 1507.01001
Neutralino-gluino: 1510.03498
Radiative Neutrino Mass Models: 1512.07961, 1509.04068, 1507.067
Scalar DM & vector-like quark mediator: 1511.04452
Triplet-Quadruplet DM: 1601.01354
Lepton-flavored DM: 1510.00100
Kaluza-Klein DM: 1601.00081
Inert Zee model: 1511.01873
Flavoured DM: 1510.04694

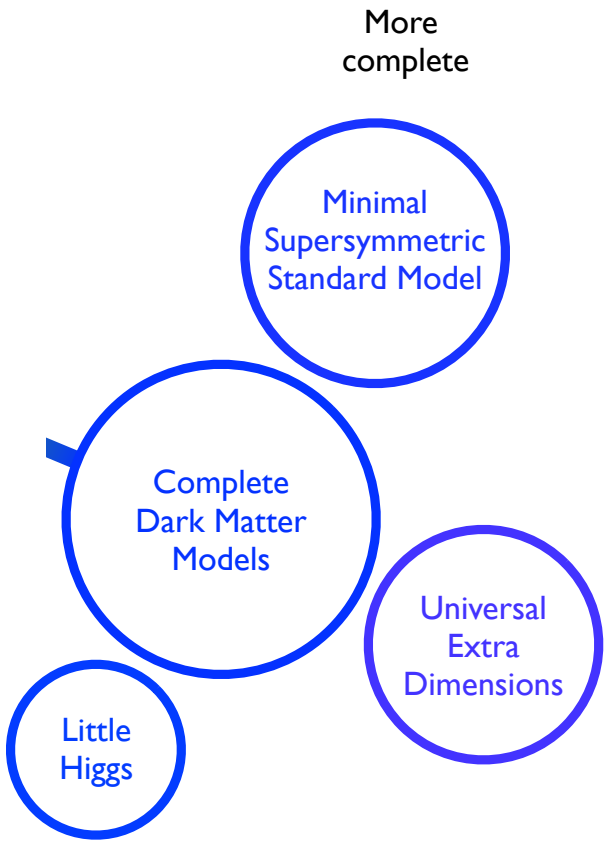
Theoretical Framework



Abdallah *et al.*, 1506.03116

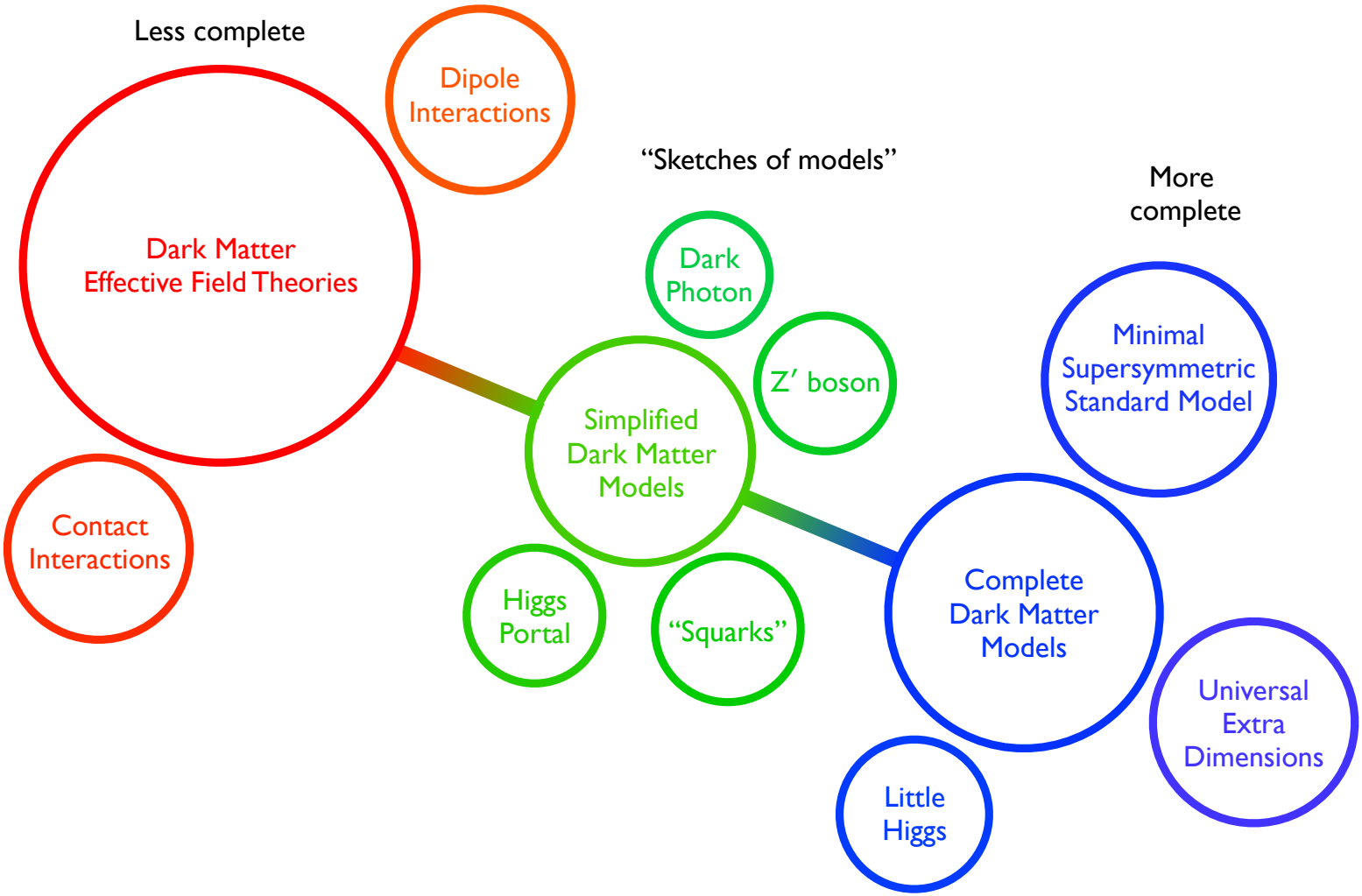
Theoretical Framework





Abdallah *et al.*, 1506.03116

Theoretical Framework



Abdallah *et al.*, 1506.03116

Simplified Models of DM at the LHC

Simplified Models for Dark Matter Searches at the LHC
Abdallah *et al.* 1506.03116

. . . outlines a set of simplified models of DM for searches at the LHC

Dark Matter Benchmark Models for Early LHC Run-2 Searches: Report of the ATLAS/CMS Dark Matter Forum
Abercrombie *et al.* 1507.00966

. . . a minimal basis of dark matter models that should influence the design of the early Run-2 searches. At the same time, a thorough survey of realistic collider signals of Dark Matter

Our Goal

A complete classification of simplified coannihilation models

Our Goal

A complete classification of simplified coannihilation models

The Coannihilation Codex

Our Goal

A complete classification of simplified coannihilation models

The Coannihilation Codex

- A bottom-up framework for discovering dark matter at the LHC
- LHC phenomenology testing DM freeze-out
- Identify lesser studied models & searches
- In the event of a signal, gives a framework for the inverse problem

Outline

Assumptions

To complete a classification we need to make some assumptions

- DM is a thermal relic
- DM is a colourless, electrically neutral particle in $(1, N, \beta)$
- Coannihilation diagram is 2-to-2 via dimension four, tree-level couplings
- New particles have spin 0, 1/2 or 1

Assumptions

To complete a classification we need to make some assumptions

- DM is a thermal relic
- DM is a colourless, electrically neutral particle in $(1, N, \beta)$
- Coannihilation diagram is 2-to-2 via dimension four, tree-level couplings
- New particles have spin 0, 1/2 or 1

Assumptions

To complete a classification we need to make some assumptions

- DM is a thermal relic
- DM is a colourless, electrically neutral particle in $(1, N, \beta)$
- Coannihilation diagram is 2-to-2 via dimension four, tree-level couplings
- New particles have spin 0, 1/2 or 1

Assumptions

To complete a classification we need to make some assumptions

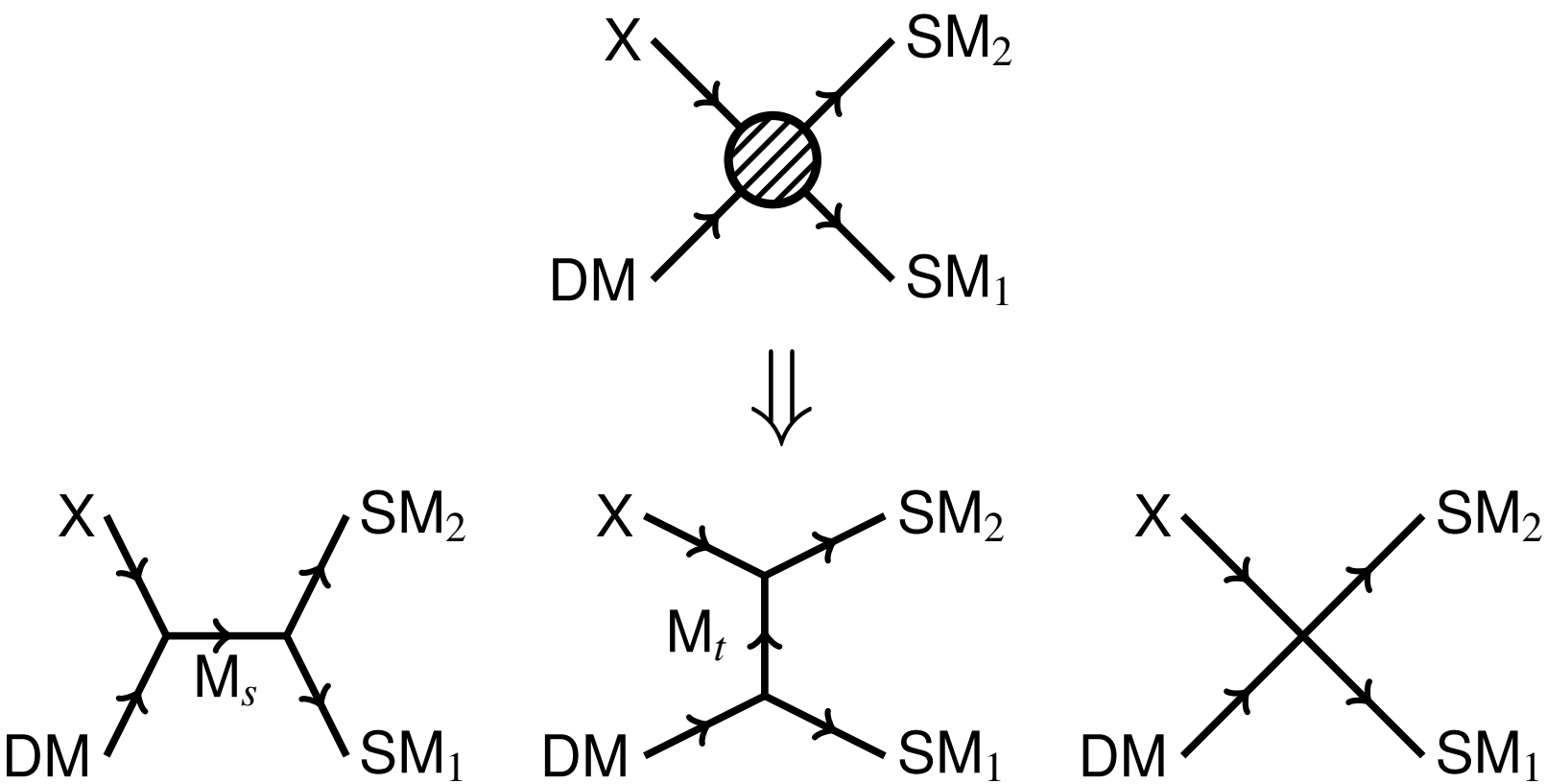
- DM is a thermal relic
- DM is a colourless, electrically neutral particle in $(1, N, \beta)$
- Coannihilation diagram is 2-to-2 via dimension four, tree-level couplings
- New particles have spin 0, 1/2 or 1

Assumptions

To complete a classification we need to make some assumptions

- DM is a thermal relic
- DM is a colourless, electrically neutral particle in $(1, N, \beta)$
- Coannihilation diagram is 2-to-2 via dimension four, tree-level couplings
- New particles have spin 0, 1/2 or 1

Coannihilation Diagrams



Classification Procedure

- Work in unbroken $SU(2)_L \times U(1)_Y$
- Given SM field content, iterate over SM_1 and SM_2 to find all possible X using
  - Gauge invariance
  - Lorentz invariance
  - $\mathbb{Z}_2$ parity (to prevent DM decay)
- Then find all s-channel and t-channel mediators, using same restrictions and
  - Dimension four, tree-level couplings
  - Gauge bosons only couple through kinetic terms

Classification Procedure

- Work in unbroken $SU(2)_L \times U(1)_Y$
- Given SM field content, iterate over SM_1 and SM_2 to find all possible X using
  - Gauge invariance
  - Lorentz invariance
  - $\mathbb{Z}_2$ parity (to prevent DM decay)
- Then find all s-channel and t-channel mediators, using same restrictions and
  - Dimension four, tree-level couplings
  - Gauge bosons only couple through kinetic terms

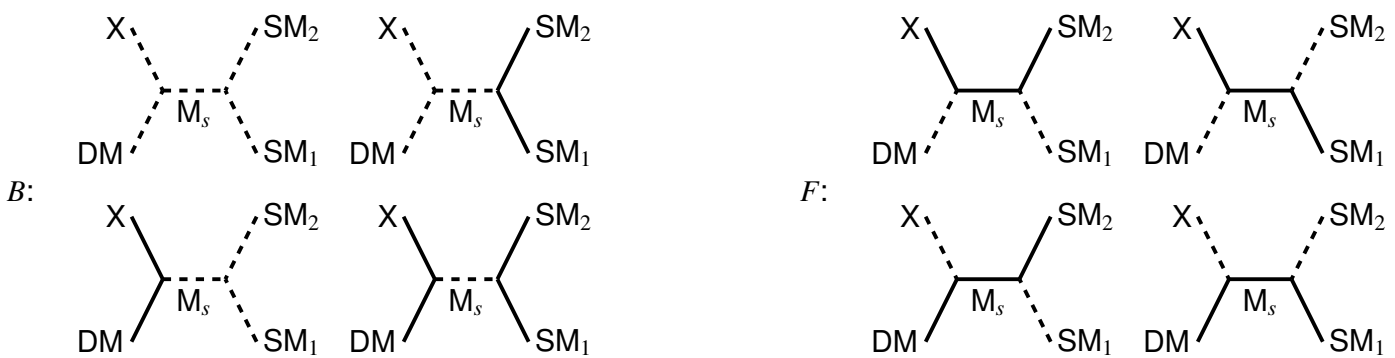
Classification Procedure

- Work in unbroken $SU(2)_L \times U(1)_Y$
- Given SM field content, iterate over SM_1 and SM_2 to find all possible X using
  - Gauge invariance
  - Lorentz invariance
  - $\mathbb{Z}_2$ parity (to prevent DM decay)
- Then find all s-channel and t-channel mediators, using same restrictions and
  - Dimension four, tree-level couplings
  - Gauge bosons only couple through kinetic terms

s-channel classification - sample

DM in $(1, N, \beta)$

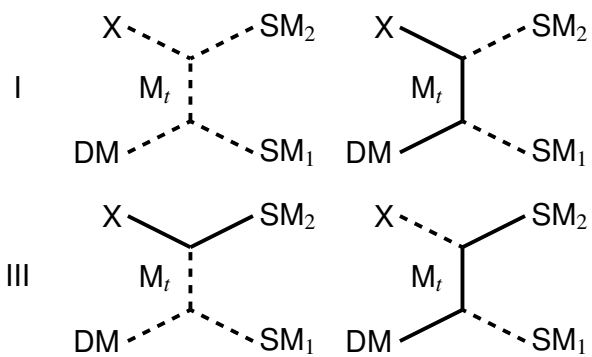
ID	X	$\alpha+\beta$	M_s	Spin	$(SM_1\ SM_2)$	SM_3	M-X-X
ST11	$(3, N\pm1, \alpha)$	$\frac{7}{3}$	$(3,2,\frac{7}{3})$	B	$(Q_L\overline{\ell_R}), (u_R\overline{L_L})$		
ST12				F	$(u_R H)$		
ST13		$\frac{1}{3}$	$(3,2,\frac{1}{3})$	B	$(d_R\overline{L_L}), (\overline{Q_L d_R}), (u_R L_L)$		
ST14				F	$(u_R H^\dagger), (d_R H)$	Q_L	
ST15		$-\frac{5}{3}$	$(3,2,-\frac{5}{3})$	B	$(\overline{Q_L}\,\overline{u_R}), (Q_L\ell_R), (d_R L_L)$		
ST16				F	$(d_R H^\dagger)$		
ST17	$(3, N\pm2, \alpha)$	$\frac{4}{3}$	$(3,3,\frac{4}{3})$	B	$(Q_L\overline{L_R})$		✓ $\alpha=-\frac{2}{3}$
ST18				F	$(Q_L H)$		
ST19		$-\frac{2}{3}$	$(3,3,-\frac{2}{3})$	B	$(\overline{Q_L Q_L}), (Q_L L_L)$		✓ $\alpha=\frac{1}{3}$
ST20				F	$(Q_L H^\dagger)$		

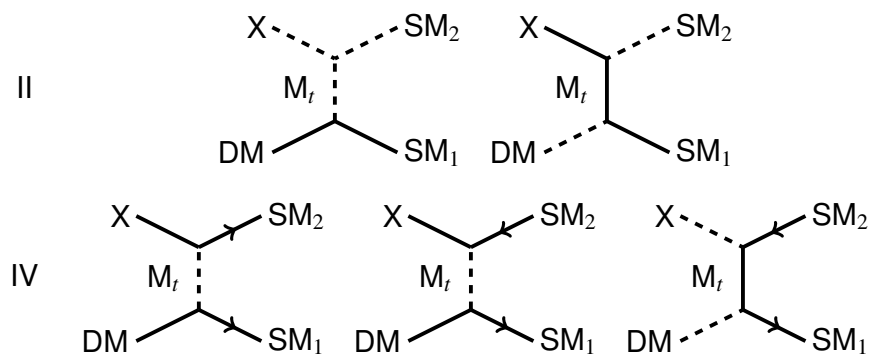


t-channel classification - sample

DM in $(1, N, \beta)$

ID	X	$\alpha+\beta$	M_t	Spin	$(SM_1\ SM_2)$	SM_3
TU26	$(1, N\pm2, \alpha)$	0	$(1, N\pm1, \beta-1)$	I	$(HH^\dagger)$	
TU27			$(1, N\pm1, \beta+1)$	II	$(L_L H)$	
TU28			$(1, N\pm1, \beta-1)$	III	(HL_L)	
TU29			$(\bar{3}, N\pm1, \beta-\frac{1}{3})$	IV	$(Q_L\overline{Q_L})$	
TU30			$(1, N\pm1, \beta+1)$	IV	$(L_L\overline{L_L})$	
TU31		-2	$(1, N\pm1, \beta+1)$	I	$(H^\dagger H^\dagger)$	
TU32			$(1, N\pm1, \beta+1)$	II	$(L_L H^\dagger)$	
TU33			$(1, N\pm1, \beta+1)$	III	$(H^\dagger L_L)$	





Classification: hybrid models

ID	X	$\alpha+\beta$	SM partner	Extensions
H1	$(1, N, \alpha)$	0	B,$W_i^{N\geq 2}$	SU1, SU3, TU1, TU4–TU8
H2		-2	ℓ_R	SU6, SU8, TU10, TU11
H3	$(1, N\pm 1, \alpha)$	-1	$H^\dagger$	SU10, TU18–TU23
H4			L_L	SU11, TU16, TU17
H5	$(3, N, \alpha)$	$\frac{4}{3}$	u_R	ST3, ST5, TT3, TT4
H6		$-\frac{2}{3}$	d_R	ST7, ST9, TT10, TT11
H7	$(3, N\pm 1, \alpha)$	$\frac{1}{3}$	Q_L	ST14, TT28–TT31

7 models

Classification: s-channel

ID	X	$\alpha+\beta$	M_s	Spin	$(SM_1\ SM_2)$	SM_3	M-X-X
SU1	$(1,N,\alpha)$	0	$(1,1,0)$	B	$(u_R\overline{u_R}),(d_R\overline{d_R}),(Q_L\overline{Q_L})$ $(\ell_R\overline{\ell_R}),(L_L\overline{L_L}),(HH^\dagger)$	$B,W_i^{N\geq 2}$	✓
SU2				F	(L_LH)		
SU3			$(1,3,0)^{N\geq 2}$	B	$(Q_L\overline{Q_L}),(L_L\overline{L_L}),(HH^\dagger)$	$B,\ W_i$	✓
SU4				F	(L_LH)		
SU5		-2	$(1,1,-2)$	B	$(d_R\overline{u_R}),(H^\dagger H^\dagger)$		✓
SU6				F	$(L_LH^\dagger)$	ℓ_R	
SU7			$(1,3,-2)^{N\geq 2}$	B	$(H^\dagger H^\dagger),(L_LL_L)$		$\checkmark(\alpha=\pm1)$
SU8				F	$(L_LH^\dagger)$	ℓ_R	
SU9		-4	$(1,1,-4)$	B	$(\ell_R\ell_R)$		$\checkmark(\alpha=\pm2)$
SU10	$(1,N\pm1,\alpha)$	-1	$(1,2,-1)$	B	$(d_R\overline{Q_L}),(\overline{u_R}Q_L),(\overline{L_L}\ell_R)$	$H^\dagger$	
SU11				F	(ℓ_RH)	L_L	
SU12		-3	$(1,2,-3)$	B	$(L_L\ell_R)$		
SU13				F	$(\ell_RH^\dagger)$		
SU14	$(1,N\pm2,\alpha)$	0	$(1,3,0)$	B	$(L_L\overline{L_L}),(Q_L\overline{Q_L}),(HH^\dagger)$		$\checkmark(\alpha=0)$
SU15				F	(L_LH)		
SU16		-2	$(1,3,-2)$	B	$(H^\dagger H^\dagger),(L_LL_L)$		$\checkmark(\alpha=\pm1)$
SU17				F	$(L_LH^\dagger)$		

SU type - 17 models

ID	X	$\alpha+\beta$	M_s	Spin	$(SM_1\ SM_2)$	SM_3	M-X-X
ST1	$(3,N,\alpha)$	$\frac{10}{3}$	$(3,1,\frac{10}{3})$	B	$(u_R\overline{\ell_R})$		$\checkmark\alpha=-\frac{5}{3}$
ST2		$\frac{4}{3}$	$(3,1,\frac{4}{3})$	B	$(d_R\overline{\ell_R}),(Q_L\overline{L_L}),(\overline{d_R}d_R)$		$\checkmark\alpha=-\frac{2}{3}$
ST3				F	(Q_LH)	u_R	
ST4			$(3,3,\frac{4}{3})^{N\geq 2}$	B	$(Q_L\overline{L_L})$		$\checkmark\alpha=-\frac{2}{3}$
ST5				F	(Q_LH)	u_R	
ST6		$-\frac{2}{3}$	$(3,1,-\frac{2}{3})$	B	$(\overline{Q_LQ_L}),(\overline{u_R}\overline{d_R}),(u_R,\ell_R),(Q_LL_L)$		$\checkmark\alpha=\frac{1}{3}$
ST7				F	$(Q_LH^\dagger)$	d_R	
ST8			$(3,3,-\frac{2}{3})^{N\geq 2}$	B	$(\overline{Q_LQ_L}),(Q_LL_L)$		$\checkmark\alpha=\frac{1}{3}$
ST9				F	$(Q_LH^\dagger)$	d_R	
ST10		$-\frac{8}{3}$	$(3,1,-\frac{8}{3})$	B	$(\overline{u_R}\overline{u_R}),(d_R\ell_R)$		$\checkmark\alpha=\frac{4}{3}$
ST11	$(3,N\pm1,\alpha)$	$\frac{7}{3}$	$(3,2,\frac{7}{3})$	B	$(Q_L\overline{\ell_R}),(u_R\overline{L_L})$		
ST12				F	(u_RH)		
ST13		$\frac{1}{3}$	$(3,2,\frac{1}{3})$	B	$(d_R\overline{L_L}),(\overline{Q_L}\overline{d_R}),(u_RL_L)$		
ST14				F	$(u_RH^\dagger),(d_RH)$	Q_L	
ST15		$-\frac{5}{3}$	$(3,2,-\frac{5}{3})$	B	$(\overline{Q_L}\overline{u_R}),(Q_L\ell_R),(d_RL_L)$		
ST16				F	$(d_RH^\dagger)$		
ST17	$(3,N\pm2,\alpha)$	$\frac{4}{3}$	$(3,3,\frac{4}{3})$	B	$(Q_L\overline{L_R})$		$\checkmark\alpha=-\frac{2}{3}$
ST18				F	(Q_LH)		
ST19		$-\frac{2}{3}$	$(3,3,-\frac{2}{3})$	B	$(\overline{Q_LQ_L}),(Q_LL_L)$		$\checkmark\alpha=\frac{1}{3}$
ST20				F	$(Q_LH^\dagger)$		

ST type - 20 models

U: X uncoloured

T: X $SU(3)$ triplet

O: X $SU(3)$ octet

E: X $SU(3)$ exotic

ID	X	$\alpha+\beta$	M_s	Spin	$(SM_1\ SM_2)$	SM_3	M-X-X
SO1	$(8,N,\alpha)$	0	$(8,1,0)^{\neq g[s2]}$	B	$(d_R\overline{d_R}),(u_R\overline{u_R}),(Q_L\overline{Q_L})$		$\checkmark\alpha=0$
SO2			$(8,3,0)^{N\geq 2}$	B	$(Q_L\overline{Q_L})$		$\checkmark\alpha=0$
SO3		-2	$(8,1,-2)$	B	$(d_R\overline{u_R})$		$\checkmark\alpha=\pm1$
SO4	$(8,N\pm1,\alpha)$	-1	$(8,2,-1)$	B	$(d_R\overline{Q_L}),(Q_L\overline{u_R})$		
SO5	$(8,N\pm2,\alpha)$	0	$(8,3,0)$	B	$(Q_L\overline{Q_L})$		$\checkmark\alpha=0$
SE1	$(6,N,\alpha)$	$\frac{8}{3}$	$(6,1,\frac{8}{3})$	B	(u_Ru_R)		$\checkmark\alpha=-\frac{4}{3}$
SE2		$\frac{2}{3}$	$(6,1,\frac{2}{3})$	B	$(Q_LQ_L),(u_Rd_R)$		$\checkmark(\alpha=-\frac{1}{3})$
SE3			$(6,3,\frac{2}{3})^{N\geq 2}$	B	(Q_LQ_L)		$\checkmark\alpha=-\frac{1}{3}$
SE4		$-\frac{4}{3}$	$(6,1,-\frac{4}{3})$	B	(d_Rd_R)		$\checkmark\alpha=\frac{2}{3}$
SE5	$(6,N\pm1,\alpha)$	$\frac{5}{3}$	$(6,2,\frac{5}{3})$	B	(Q_Lu_R)		
SE6		$-\frac{1}{3}$	$(6,2,-\frac{1}{3})$	B	(Q_Ld_R)		
SE7	$(6,N\pm2,\alpha)$	$\frac{2}{3}$	$(6,3,\frac{2}{3})$	B	(Q_LQ_L)		$\checkmark\alpha=-\frac{1}{3}$

SO and SE type - 5 and 7 models

Classification: t-channel

ID	X	$\alpha+\beta$	M_t	Spin	$(SM_1\ SM_2)$	SM_3
TU1	$(1,N,\alpha)$	0	$(1,N\pm1,\beta-1)$	I	$(HH^\dagger)$	$B,\ W_i^{N\geq 2}$
TU2			$(1,N\pm1,\beta+1)$	II	(L_LH)	
TU3			$(1,N\pm1,\beta-1)$	III	(HL_L)	
TU4			$(\bar{3},N\pm1,\beta-\frac{1}{3})$	IV	$(Q_L\overline{Q_L})$	$B,\ W_i^{N\geq 2}$
TU5			$(\bar{3},N,\beta-\frac{4}{3})$	IV	$(u_R\overline{u_R})$	$B,\ W_i^{N\geq 2}$
TU6			$(\bar{3},N,\beta+\frac{2}{3})$	IV	$(d_R\overline{d_R})$	$B,\ W_i^{N\geq 2}$
TU7			$(1,N\pm1,\beta+1)$	IV	$(L_L\overline{L_L})$	$B,\ W_i^{N\geq 2}$
TU8			$(1,N,\beta+2)$	IV	$(\ell_R\overline{\ell_R})$	$B,\ W_i^{N\geq 2}$
TU9		-2	$(1,N\pm1,\beta+1)$	I	$(H^\dagger H^\dagger)$	
TU10			$(1,N\pm1,\beta+1)$	II	$(L_LH^\dagger)$	ℓ_R
TU11			$(1,N\pm1,\beta+1)$	III	$(H^\dagger L_L)$	ℓ_R
TU12			$(1,N\pm1,\beta+1)$	IV	(L_LL_L)	
TU13			$(3,N,\beta+\frac{4}{3})$	IV	$(\overline{u_R}d_R)$	
TU14			$(\bar{3},N,\beta+\frac{2}{3})$	IV	$(d_R\overline{u_R})$	
TU15		-4	$(1,N,\beta+2)$	IV	$(\ell_R\ell_R)$	
TU16	$(1,N\pm1,\alpha)$	-1	$(1,N,\beta+2)$	II	(ℓ_RH)	L_L
TU17			$(1,N\pm1,\beta-1)$	III	$(H\ell_R)$	L_L
TU18			$(1,N,\beta+2)$	IV	$(\ell_R\overline{L_L})$	$H^\dagger$
TU19			$(1,N\pm1,\beta-1)$	IV	$(\overline{L_L}\ell_R)$	$H^\dagger$
TU20			$(\bar{3},N,\beta+\frac{2}{3})$	IV	$(d_R\overline{Q_L})$	$H^\dagger$
TU21			$(3,N\pm1,\beta+\frac{1}{3})$	IV	$(\overline{Q_L}d_R)$	$H^\dagger$
TU22			$(\bar{3},N\pm1,\beta-\frac{1}{3})$	IV	$(Q_L\overline{u_R})$	$H^\dagger$
TU23			$(3,N,\beta+\frac{4}{3})$	IV	$(\overline{u_R}Q_L)$	$H^\dagger$
TU24		-3	$(1,N\pm1,\beta+1)$	IV	$(L_L\ell_R)$	
TU25			$(1,N,\beta+2)$	IV	(ℓ_RL_L)	
TU26	$(1,N\pm2,\alpha)$	0	$(1,N\pm1,\beta-1)$	I	$(HH^\dagger)$	
TU27			$(1,N\pm1,\beta+1)$	II	(L_LH)	
TU28			$(1,N\pm1,\beta-1)$	III	(HL_L)	
TU29			$(\bar{3},N\pm1,\beta-\frac{1}{3})$	IV	$(Q_L\overline{Q_L})$	
TU30			$(1,N\pm1,\beta+1)$	IV	$(L_L\overline{L_L})$	
TU31		-2	$(1,N\pm1,\beta+1)$	I	$(H^\dagger H^\dagger)$	
TU32			$(1,N\pm1,\beta+1)$	II	$(L_LH^\dagger)$	
TU33			$(1,N\pm1,\beta+1)$	III	$(H^\dagger L_L)$	

TU type - 33 models

ID	X	$\alpha+\beta$	M_t	Spin	$(SM_1\ SM_2)$	SM_3
TO1	$(8,N,\alpha)$	0	$(\bar{3},N\pm1,\beta-\frac{1}{3})$	IV	$(Q_L\overline{Q_L})$	
TO2			$(\bar{3},N,\beta-\frac{4}{3})$	IV	$(u_R\overline{u_R})$	
TO3			$(\bar{3},N,\beta+\frac{2}{3})$	IV	$(d_R\overline{d_R})$	
TO4		-2	$(\bar{3},N,\beta+\frac{2}{3})$	IV	$(d_R\overline{u_R})$	
TO5			$(3,N,\beta+\frac{4}{3})$	IV	$(\overline{u_R}d_R)$	
TO6	$(8,N\pm1,\alpha)$	-1	$(\bar{3},N,\beta+\frac{2}{3})$	IV	$(d_R\overline{Q_L})$	
TO7			$(3,N\pm1,\beta+\frac{1}{3})$	IV	$(\overline{Q_L}d_R)$	
TO8			$(\bar{3},N\pm1,\beta-\frac{1}{3})$	IV	$(Q_L\overline{u_R})$	
TO9			$(3,N,\beta+\frac{4}{3})$	IV	$(\overline{u_R}Q_L)$	
TO10	$(8,N\pm2,\alpha)$	0	$(\bar{3},N\pm1,\beta-\frac{1}{3})$	IV	$(Q_L\overline{Q_L})$	
TE1	$(6,N,\alpha)$	$\frac{8}{3}$	$(\bar{3},N,\beta-\frac{4}{3})$	IV	(u_Ru_R)	
TE2		$\frac{2}{3}$	$(\bar{3},N\pm1,\beta-\frac{1}{3})$	IV	(Q_LQ_L)	
TE3			$(\bar{3},N,\beta-\frac{4}{3})$	IV	(u_Rd_R)	
TE4			$(\bar{3},N,\beta+\frac{2}{3})$	IV	(d_Ru_R)	
TE5		$-\frac{4}{3}$	$(\bar{3},N,\beta+\frac{2}{3})$	IV	(d_Rd_R)	
TE6	$(6,N\pm1,\alpha)$	$\frac{5}{3}$	$(\bar{3},N,\beta-\frac{4}{3})$	IV	(u_RQ_L)	
TE7			$(\bar{3},N\pm1,\beta-\frac{1}{3})$	IV	(Q_Lu_R)	
TE8		$-\frac{1}{3}$	$(\bar{3},N,\beta+\frac{2}{3})$	IV	(d_RQ_L)	
TE9			$(\bar{3},N\pm1,\beta-\frac{1}{3})$	IV	(Q_Ld_R)	
TE10	$(6,N\pm2,\alpha)$	$\frac{2}{3}$	$(\bar{3},N\pm1,\beta-\frac{1}{3})$	IV	(Q_LQ_L)	

TO and TE type - 10 and 10 models

ID	X	$\alpha+\beta$	M_t	Spin	$(SM_1\ SM_2)$	SM_3
TT1	$(3,N,\alpha)$	$\frac{10}{3}$	$(3,N,\beta-\frac{4}{3})$	IV	$(u_R\ell_R)$	
TT2			$(1,N,\beta-2)$	IV	$(\overline{\ell_R}u_R)$	u_R
TT3		$\frac{4}{3}$	$(3,N\pm1,\beta-\frac{4}{3})$	II	(Q_LH)	u_R
TT4			$(1,N\pm1,\beta-1)$	III	(HQ_L)	u_R
TT5			$(1,N,\beta-2)$	IV	(ℓ_Rd_R)	
TT6			$(3,N\pm1,\beta-\frac{1}{3})$	IV	$(Q_L\overline{L_L})$	
TT7			$(1,N\pm1,\beta-1)$	IV	(L_LQ_L)	
TT8			$(3,N,\beta+\frac{2}{3})$	IV	$(d_R\overline{\ell_R})$	
TT9			$(3,N,\beta-\frac{2}{3})$	IV	$(\overline{d_R}\ell_R)$	
TT10		$-\frac{2}{3}$	$(3,N\pm1,\beta-\frac{1}{3})$	II	$(Q_LH^\dagger)$	d_R
TT11			$(1,N\pm1,\beta+1)$	III	$(H^\dagger Q_L)$	d_R
TT12			$(3,N,\beta+\frac{4}{3})$	IV	$(\overline{u_R}d_R)$	
TT13			$(3,N\pm1,\beta+\frac{4}{3})$	IV	$(\overline{Q_L}Q_L)$	
TT14			$(3,N,\beta-\frac{4}{3})$	IV	$(u_R\ell_R)$	
TT15			$(1,N,\beta+2)$	IV	(ℓ_Ru_R)	
TT16			$(3,N\pm1,\beta-\frac{1}{3})$	IV	$(Q_L\overline{L_L})$	
TT17			$(1,N\pm1,\beta+1)$	IV	(L_LQ_L)	
TT18			$(3,N,\beta-\frac{2}{3})$	IV	$(\overline{d_R}\overline{u_R})$	
TT19			$(3,N,\beta+\frac{4}{3})$	IV	$(\overline{u_R}\ell_R)$	
TT20			$(3,N,\beta+\frac{2}{3})$	IV	$(d_R\ell_R)$	
TT21		$-\frac{8}{3}$	$(1,N,\beta+2)$	IV	(ℓ_Rd_R)	
TT22	$(3,N\pm1,\alpha)$	$\frac{7}{3}$	$(3,N,\beta-\frac{4}{3})$	II	(u_RH)	
TT23			$(1,N\pm1,\beta-1)$	III	(Hu_R)	
TT24			$(3,N,\beta-\frac{4}{3})$	IV	$(u_R\overline{L_L})$	
TT25			$(1,N\pm1,\beta-1)$	IV	$(\overline{L_L}u_R)$	
TT26			$(3,N\pm1,\beta-\frac{1}{3})$	IV	$(Q_L\overline{\ell_R})$	
TT27			$(1,N,\beta-2)$	IV	$(\overline{\ell_R}Q_L)$	
TT28		$\frac{1}{3}$	$(3,N,\beta-\frac{4}{3})$	II	$(u_RH^\dagger)$	Q_L
TT29			$(3,N,\beta+\frac{2}{3})$	II	(d_RH)	Q_L
TT30			$(1,N\pm1,\beta+1)$	III	$(H^\dagger u_R)$	Q_L
TT31			$(1,N\pm1,\beta-1)$	III	(Hd_R)	Q_L
TT32			$(3,N,\beta-\frac{4}{3})$	IV	(u_RL_L)	
TT33			$(1,N\pm1,\beta+1)$	IV	(L_Lu_R)	
TT34			$3,N,\beta-\frac{2}{3})$	IV	$(\overline{d_R}Q_L)$	
TT35			$(3,N\pm1,\beta+\frac{4}{3})$	IV	$(\overline{Q_L}d_R)$	
TT36			$(3,N,\beta+\frac{2}{3})$	II	$(d_RH^\dagger)$	
TT37			$(1,N\pm1,\beta+1)$	III	$(H^\dagger d_R)$	
TT38			$(3,N,\beta+\frac{2}{3})$	IV	(d_RL_L)	
TT39			$(1,N\pm1,\beta+1)$	IV	(L_Ld_R)	
TT40			$(3,N\pm1,\beta-\frac{1}{3})$	IV	$(Q_L\ell_R)$	
TT41			$(1,N,\beta+2)$	IV	(ℓ_RQ_L)	
TT42			$(3,N,\beta+\frac{4}{3})$	IV	$(\overline{u_R}\overline{Q_L})$	
TT43			$(3,N\pm1,\beta+\frac{4}{3})$	IV	$(\overline{Q_L}\overline{u_R})$	
TT44	$(3,N\pm2,\alpha)$	$\frac{4}{3}$	$(3,N\pm1,\beta-\frac{4}{3})$	II	(Q_LH)	
TT45			$(1,N\pm1,\beta-1)$	III	(HQ_L)	
TT46			$(3,N\pm1,\beta-\frac{4}{3})$	IV	$(Q_L\overline{L_L})$	
TT47			$(1,N\pm1,\beta-1)$	IV	$(\overline{L_L}Q_L)$	
TT48		$-\frac{2}{3}$	$(3,N\pm1,\beta-\frac{4}{3})$	II	$(Q_LH^\dagger)$	
TT49			$(1,N\pm1,\beta+1)$	III	$(H^\dagger Q_L)$	
TT50			$(3,N\pm1,\beta-\frac{4}{3})$	IV	(Q_LL_L)	
TT51			$(1,N\pm1,\beta+1)$	IV	(L_LQ_L)	
TT52			$(3,N\pm1,\beta+\frac{4}{3})$	IV	$(\overline{Q_L}Q_L)$	

TT type - 52 models

Complete Classification

We have written down all possible simplified models of 2-to-2 coannihilating dark matter!

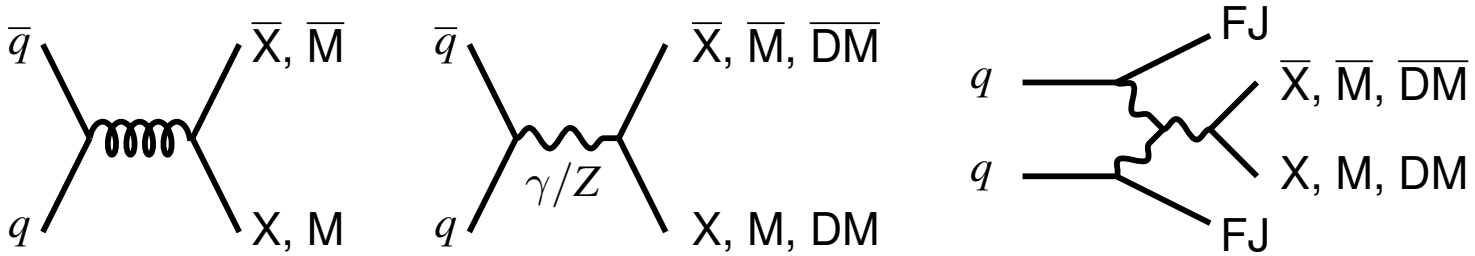
LHC Phenomenology

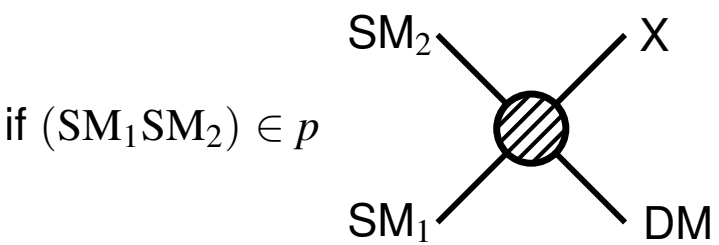
Complete Classification

We have written down all possible simplified models of 2-to-2 coannihilating dark matter!

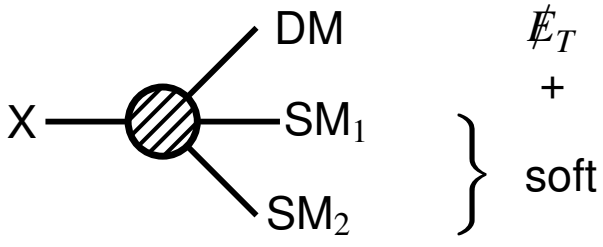
LHC Phenomenology

LHC Production: Common





Decays: Common

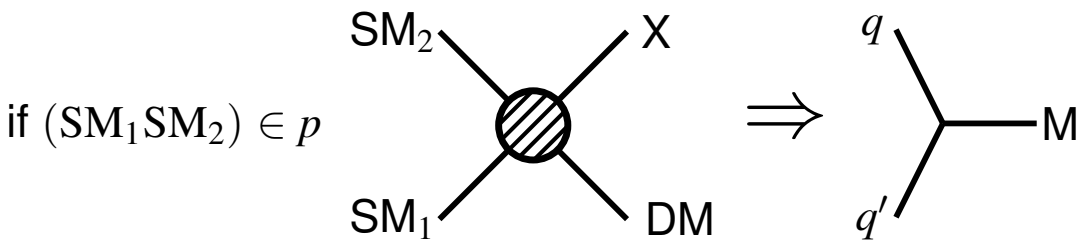


Signature Table: Common

	$pp \to \ldots$	Prod. via	Signatures	Search
common	DM + DM + ISR	gauge int. or $SM_1 \in p$ for t-channel	mono-Y + $\not{E}_T$	[55,56,62,63,104]
	$\begin{cases} X\ (\to SM_1^{soft}\ SM_2^{soft}\ DM) \\ X\ (\to SM_1^{soft}\ SM_2^{soft}\ DM) \\ ISR \end{cases}$	gauge int. or $SM_2 \in p$ for t-channel	mono-Y + $\not{E}_T$ mono-Y + $\not{E}_T$ + $\leq$ 4 SM	[55,56,62,63,104] Partial coverage [105]
	DM + X ($\to SM_1^{soft}\ SM_2^{soft}$ DM) + ISR	$(SM_1\ SM_2) \in p$	mono-Y + $\not{E}_T$ mono-Y + $\not{E}_T$ + $\leq$ 2 SM	[55,56,62,63,104] Partial coverage [105]

LHC Production: s-channel

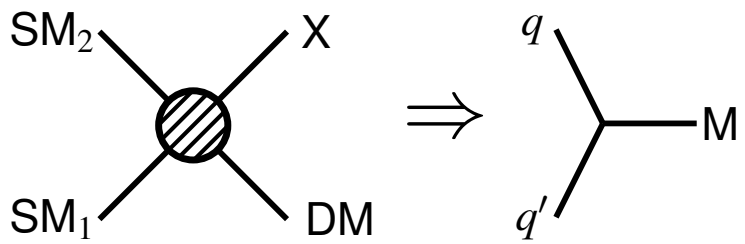
Gauge boson production +



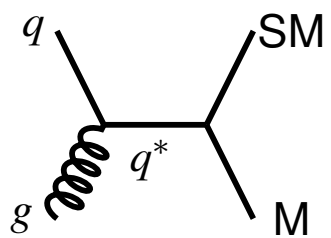
LHC Production: s-channel

Gauge boson production +

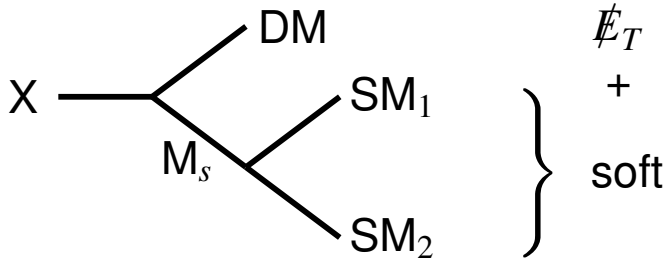
if $(\mathrm{SM}_1\mathrm{SM}_2) \in p$



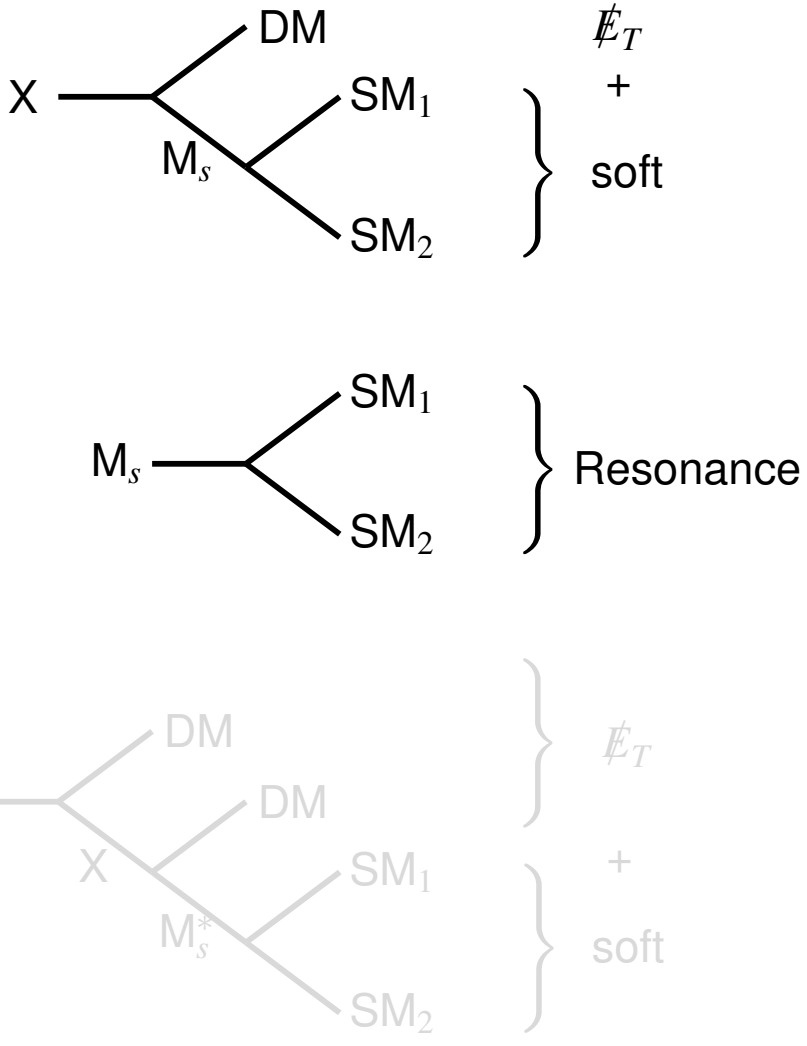
if $\mathrm{SM}_1/\mathrm{SM}_2 \in p$



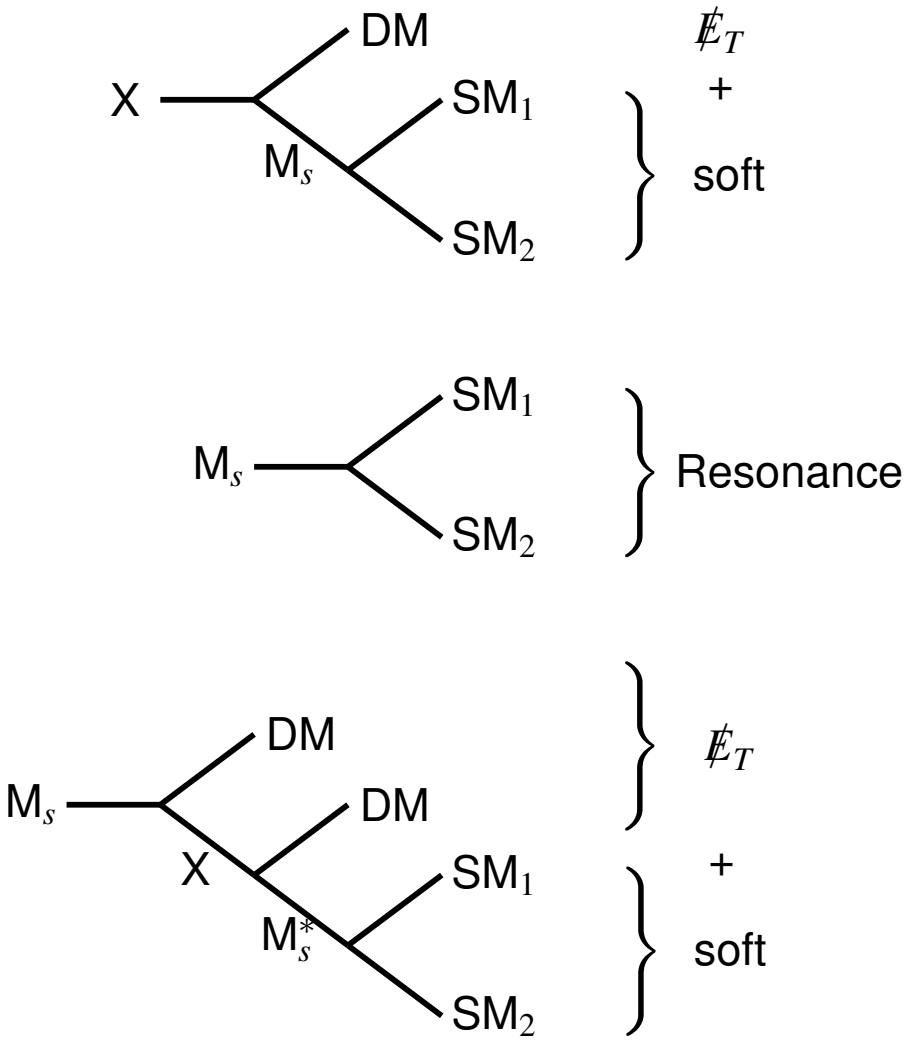
Decays: s-channel



Decays: s-channel



Decays: s-channel



Signature Table: s-channel

	$pp \to \ldots$	Prod. via	Signatures	Search
s-channel	$\begin{cases} M_s\ (\to [SM_1\ SM_2]^{res}) \\ M_s\ (\to [SM_1\ SM_2]^{res}) \end{cases}$	gauge int.	2 resonances	[106-112]
	$\begin{cases} M_s\ (\to [SM_1\ SM_2]^{res}) \\ M_s\ (\to DM + X\ (\to SM_1^{soft}\ SM_2^{soft}\ DM)) \end{cases}$		resonance + $\not{E}_T$ resonance + $\not{E}_T$+ $\leq$ 2 SM	No search No search
	$\begin{cases} M_s\ (\to DM + X\ (\to SM_1^{soft}\ SM_2^{soft}\ DM)) \\ M_s\ (\to DM + X\ (\to SM_1^{soft}\ SM_2^{soft}\ DM)) \end{cases}$		$\not{E}_T$+ $\leq$ 4 SM	[113-124]
	$M_s\ (\to [SM_1\ SM_2]^{res})$	$(SM_1\ SM_2) \in p$	1 resonance	[125-146]
	$M_s\ (\to DM + X\ (\to SM_1^{soft}\ SM_2^{soft}\ DM))$		$\not{E}_T$+ $\leq$ 2 SM	[120-122,124] [104,147-153]
	$SM_{1,2} + M_s\ (\to [SM_1\ SM_2]^{res})$	$SM_{2,1} \in p$	1 resonance + 1 SM	Partial coverage [154,155]
	$\begin{cases} SM_{1,2} \\ M_s\ (\to DM + X\ (\to SM_1^{soft}\ SM_2^{soft}\ DM)) \end{cases}$		$\not{E}_T$ + 1 $\leq$ 3 SM	[114,120-124] [147-153,156-158]

LHC Production: t-channel

Gauge boson production +
Coannihilation diagram +

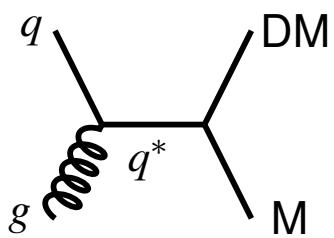
if $\mathrm{SM}_1 \in p$

if $\mathrm{SM}_2 \in p$

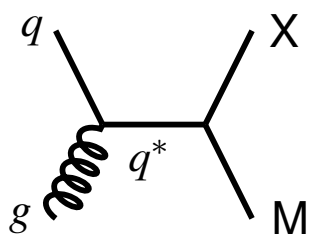
LHC Production: t-channel

Gauge boson production +
Coannihilation diagram +

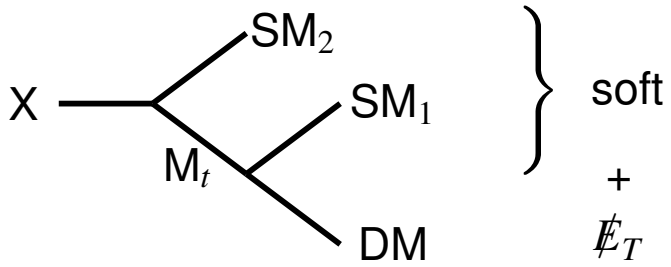
if $\mathrm{SM}_1 \in p$



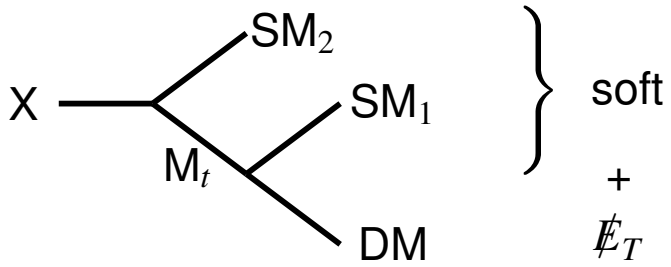
if $\mathrm{SM}_2 \in p$



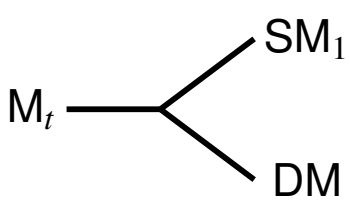
Decays: t-channel



Decays: t-channel



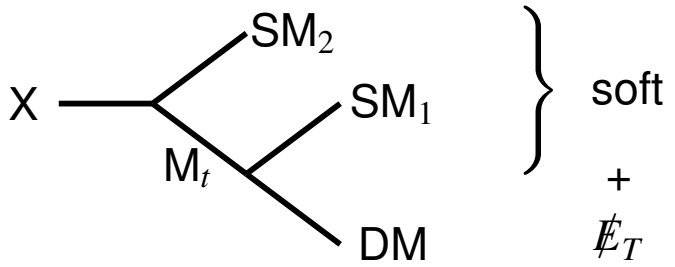
soft + $\not{E}_T$

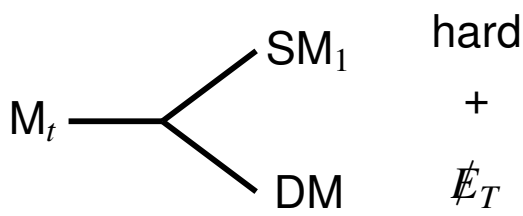


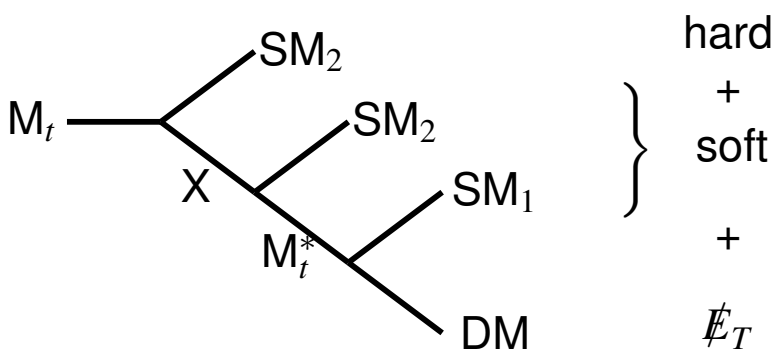
hard + $\not{E}_T$

hard + soft + $\not{E}_T$

Decays: t-channel







Signature Table: t-channel

	$pp \to \ldots$	Prod. via	Signatures	Search
t-channel	$\begin{cases} \mathrm{M}_t\ (\to \mathrm{SM}_1\ \mathrm{DM}) \\ \mathrm{M}_t\ (\to \mathrm{SM}_1\ \mathrm{DM}) \end{cases}$	gauge int.	$\not{E}_T + \leq 2$ SM	[120-122,124] [104,147-153]
	$\begin{cases} \mathrm{M}_t\ (\to \mathrm{SM}_1\ \mathrm{DM}) \\ \mathrm{M}_t\ (\to \mathrm{SM}_2 + \mathrm{X}\ (\to \mathrm{SM}_1^{\mathrm{soft}}\ \mathrm{SM}_2^{\mathrm{soft}}\ \mathrm{DM})) \end{cases}$		$\not{E}_T + \leq 4$ SM	[106-112] [114,119-124]
	$\begin{cases} \mathrm{M}_t\ (\to \mathrm{SM}_2 + \mathrm{X}\ (\to \mathrm{SM}_1^{\mathrm{soft}}\ \mathrm{SM}_2^{\mathrm{soft}}\ \mathrm{DM})) \\ \mathrm{M}_t\ (\to \mathrm{SM}_2 + \mathrm{X}\ (\to \mathrm{SM}_1^{\mathrm{soft}}\ \mathrm{SM}_2^{\mathrm{soft}}\ \mathrm{DM})) \end{cases}$		$\not{E}_T + \leq 6$ SM	[113,114,120-124] [116-118,159-163]
	$\mathrm{DM} + \mathrm{M}_t\ (\to \mathrm{SM}_1\ \mathrm{DM})$	$\mathrm{SM}_1 \in p$	$\not{E}_T + \leq 1$ SM	[55,56,62,63] [104,149]
	$\begin{cases} \mathrm{DM} \\ \mathrm{M}_t\ (\to \mathrm{SM}_2 + \mathrm{X}\ (\to \mathrm{SM}_1^{\mathrm{soft}}\ \mathrm{SM}_2^{\mathrm{soft}}\ \mathrm{DM})) \end{cases}$		$\not{E}_T + \leq 3$ SM	[114,120-124] [152,153,156-158]
	$\begin{cases} \mathrm{M}_t\ (\to \mathrm{SM}_1\ \mathrm{DM}) \\ \mathrm{X}\ (\to \mathrm{SM}_1^{\mathrm{soft}}\ \mathrm{SM}_2^{\mathrm{soft}}\ \mathrm{DM}) \end{cases}$	$\mathrm{SM}_2 \in p$	$\not{E}_T + \leq 3$ SM	[114,120-124] [152,153,156-158]
	$\begin{cases} \mathrm{M}_t\ (\to \mathrm{SM}_2 + \mathrm{X}\ (\to \mathrm{SM}_1^{\mathrm{soft}}\ \mathrm{SM}_2^{\mathrm{soft}}\ \mathrm{DM})) \\ \mathrm{X}\ (\to \mathrm{SM}_1^{\mathrm{soft}}\ \mathrm{SM}_2^{\mathrm{soft}}\ \mathrm{DM}) \end{cases}$		$\not{E}_T + \leq 5$ SM	[113,114,116-124] [159-161,164]

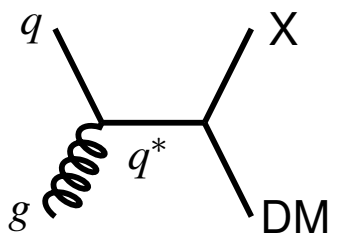
LHC Production: hybrid models

Gauge boson production +

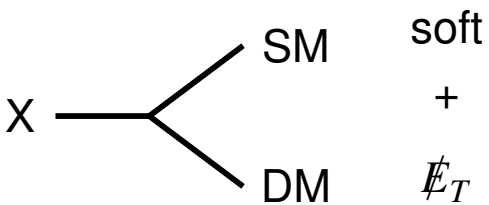
LHC Production: hybrid models

Gauge boson production +

if SM $\in p$



Decays: hybrid models



Signature Table: hybrid models

	$pp \to \ldots$	Prod. via	Signatures	Search
hybrid	$\begin{cases} \text{X} (\to \text{DM} + \text{SM}_3^{\text{soft}}) \\ \text{X} (\to \text{DM} + \text{SM}_3^{\text{soft}}) \end{cases}$	gauge int. or $\text{SM}_3 \in p$	$\not{E}_T + \leq 2$ SM	[120-122,124] [104,147-153]
	DM + X ($\to$ DM + $\text{SM}_3^{\text{soft}}$)	$\text{SM}_3 \in p$	$\not{E}_T + \leq 1$ SM	[128,129,149] [55,56,62,63,104]

Signature Table

	$pp \to \ldots$	Prod. via	Signatures	Search
common	DM + DM + ISR	gauge int. or $SM_1 \in p$ for t-channel	mono-Y + $\not{E}_T$	[55,56,62,63,104]
	$\begin{cases} X\ (\to SM_1^{soft}\ SM_2^{soft}\ DM) \\ X\ (\to SM_1^{soft}\ SM_2^{soft}\ DM) \\ ISR \end{cases}$	gauge int. or $SM_2 \in p$ for t-channel	mono-Y + $\not{E}_T$ mono-Y + $\not{E}_T$ + $\leq$ 4 SM	[55,56,62,63,104] Partial coverage [105]
	DM + X ($\to SM_1^{soft}\ SM_2^{soft}$ DM) + ISR	$(SM_1\ SM_2) \in p$	mono-Y + $\not{E}_T$ mono-Y + $\not{E}_T$ + $\leq$ 2 SM	[55,56,62,63,104] Partial coverage [105]
s-channel	$\begin{cases} M_s\ (\to [SM_1\ SM_2]^{res}) \\ M_s\ (\to [SM_1\ SM_2]^{res}) \end{cases}$	gauge int.	2 resonances	[106-112]
	$\begin{cases} M_s\ (\to [SM_1\ SM_2]^{res}) \\ M_s\ (\to DM + X\ (\to SM_1^{soft}\ SM_2^{soft}\ DM)) \end{cases}$		resonance + $\not{E}_T$ resonance + $\not{E}_T$ + $\leq$ 2 SM	No search No search
	$\begin{cases} M_s\ (\to DM + X\ (\to SM_1^{soft}\ SM_2^{soft}\ DM)) \\ M_s\ (\to DM + X\ (\to SM_1^{soft}\ SM_2^{soft}\ DM)) \end{cases}$		$\not{E}_T$ + $\leq$ 4 SM	[113-124]
	$M_s\ (\to [SM_1\ SM_2]^{res})$	$(SM_1\ SM_2) \in p$	1 resonance	[125-146]
	$M_s\ (\to DM + X\ (\to SM_1^{soft}\ SM_2^{soft}\ DM))$		$\not{E}_T$ + $\leq$ 2 SM	[120-122,124] [104,147-153]
	$SM_{1,2} + M_s\ (\to [SM_1\ SM_2]^{res})$	$SM_{2,1} \in p$	1 resonance + 1 SM	Partial coverage [154,155]
	$\begin{cases} SM_{1,2} \\ M_s\ (\to DM + X\ (\to SM_1^{soft}\ SM_2^{soft}\ DM)) \end{cases}$		$\not{E}_T$ + 1 $\leq$ 3 SM	[114,120-124] [147-153,156-158]
t-channel	$\begin{cases} M_t\ (\to SM_1\ DM) \\ M_t\ (\to SM_1\ DM) \end{cases}$	gauge int.	$\not{E}_T$ + $\leq$ 2 SM	[120-122,124] [104,147-153]
	$\begin{cases} M_t\ (\to SM_1\ DM) \\ M_t\ (\to SM_2 + X\ (\to SM_1^{soft}\ SM_2^{soft}\ DM)) \end{cases}$		$\not{E}_T$ + $\leq$ 4 SM	[106-112] [114,119-124]
	$\begin{cases} M_t\ (\to SM_2 + X\ (\to SM_1^{soft}\ SM_2^{soft}\ DM)) \\ M_t\ (\to SM_2 + X\ (\to SM_1^{soft}\ SM_2^{soft}\ DM)) \end{cases}$		$\not{E}_T$ + $\leq$ 6 SM	[113,114,120-124] [116-118,159-163]
	DM + $M_t\ (\to SM_1\ DM)$	$SM_1 \in p$	$\not{E}_T$ + $\leq$ 1 SM	[55,56,62,63] [104,149]
	$\begin{cases} DM \\ M_t\ (\to SM_2 + X\ (\to SM_1^{soft}\ SM_2^{soft}\ DM)) \end{cases}$		$\not{E}_T$ + $\leq$ 3 SM	114,120-124] [152,153,156-158]
	$\begin{cases} M_t\ (\to SM_1\ DM) \\ X\ (\to SM_1^{soft}\ SM_2^{soft}\ DM) \end{cases}$	$SM_2 \in p$	$\not{E}_T$ + $\leq$ 3 SM	[114,120-124] [152,153,156-158]
	$\begin{cases} M_t\ (\to SM_2 + X\ (\to SM_1^{soft}\ SM_2^{soft}\ DM)) \\ X\ (\to SM_1^{soft}\ SM_2^{soft}\ DM) \end{cases}$		$\not{E}_T$ + $\leq$ 5 SM	[113,114,116-124] [159-161,164]
hybrid	$\begin{cases} X\ (\to DM + SM_3^{soft}) \\ X\ (\to DM + SM_3^{soft}) \end{cases}$	gauge int. or $SM_3 \in p$	$\not{E}_T$ + $\leq$ 2 SM	[120-122,124] [104,147-153]
	DM + X ($\to$ DM + SM_3^{soft})	$SM_3 \in p$	$\not{E}_T$ + $\leq$ 1 SM	[128,129,149] [55,56,62,63,104]

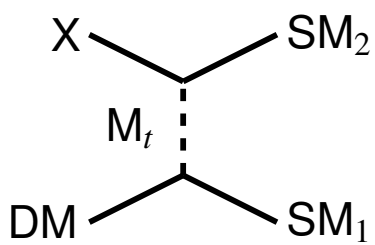
Outline

Bino-gluino Coannihilation

Label	Field	Rep.	Spin assignment
DM	Bino	(1,1,0)	Fermion
X	Gluino	(8,1,0)	Fermion
M	Squark	(3,1,4/3)	Scalar

$$\mathrm{DM} \sim (1, N, \beta)$$
$$X \sim (8, N, \alpha)$$
$$\alpha + \beta = 0$$
$$\mathrm{M} \sim (3, N, \beta + 4/3)$$

t-channel: IV



Bino-gluino Coannihilation

$$X \sim (8, N, \alpha) \qquad \alpha + \beta = 0$$

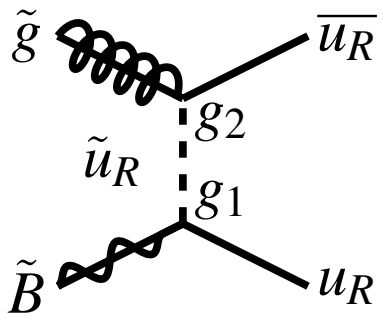
$$\mathrm{M} \sim (3, N, \beta + 4/3) \qquad \text{Spin: IV}$$

ID	X	$\alpha+\beta$	M_t	Spin	$(\mathrm{SM}_1\ \mathrm{SM}_2)$	SM_3
TO1	$(8, N, \alpha)$	0	$(\bar{3}, N \pm 1, \beta - \frac{1}{3})$	IV	$(Q_L \overline{Q_L})$	
TO2			$(\bar{3}, N, \beta - \frac{4}{3})$	IV	$(u_R \overline{u_R})$	
TO3			$(\bar{3}, N, \beta + \frac{2}{3})$	IV	$(d_R \overline{d_R})$	
TO4		-2	$(\bar{3}, N, \beta + \frac{2}{3})$	IV	$(d_R \overline{u_R})$	
TO5			$(3, N, \beta + \frac{4}{3})$	IV	$(\overline{u_R} d_R)$	
TO6	$(8, N \pm 1, \alpha)$	-1	$(\bar{3}, N, \beta + \frac{2}{3})$	IV	$(d_R \overline{Q_L})$	
TO7			$(3, N \pm 1, \beta + \frac{1}{3})$	IV	$(\overline{Q_L} d_R)$	
TO8			$(\bar{3}, N \pm 1, \beta - \frac{1}{3})$	IV	$(Q_L \overline{u_R})$	
TO9			$(3, N, \beta + \frac{4}{3})$	IV	$(\overline{u_R} Q_L)$	
TO10	$(8, N \pm 2, \alpha)$	0	$(\bar{3}, N \pm 1, \beta - \frac{1}{3})$	IV	$(Q_L \overline{Q_L})$	

Bino-gluino Coannihilation

$$\text{DM} \sim (1,1,0)_F \qquad X \sim (8,1,0)_F$$

$$\text{M} \sim (3,1,4/3)_B \quad (\text{SM}_1\text{SM}_2) = (u_R\overline{u_R})$$



Bino-gluino Coannihilation

$$\text{DM} \sim (1,1,0)_F \qquad X \sim (8,1,0)_F$$

$$\text{M} \sim (3,1,4/3)_B \quad (\text{SM}_1\text{SM}_2) = (u_R\overline{u_R})$$

	$pp \to \ldots$	Prod. via	Signatures	Search	Strength
common	DM + DM + ISR	gauge int. or $\text{SM}_1 \in p$ for t-channel	mono-Y + $\not{E}_T$	[55,56,62,63,104]	$g_1^4\alpha_i$
	X ($\to \text{SM}_1^{\text{soft}}\ \text{SM}_2^{\text{soft}}$ DM) X ($\to \text{SM}_1^{\text{soft}}\ \text{SM}_2^{\text{soft}}$ DM) ISR	gauge int. or $\text{SM}_2 \in p$ for t-channel	mono-Y + $\not{E}_T$ mono-Y + $\not{E}_T$ + $\leq$ 4 SM	[55,56,62,63,104] Partial coverage [105]	$\alpha_s^2\alpha_i$, $g_2^4\alpha_i$
	DM + X ($\to \text{SM}_1^{\text{soft}}\ \text{SM}_2^{\text{soft}}$ DM) + ISR	$(\text{SM}_1\ \text{SM}_2) \in p$	mono-Y + $\not{E}_T$ mono-Y + $\not{E}_T$ + $\leq$ 2 SM	[55,56,62,63,104] Partial coverage [105]	$g_1^2 g_2^2\alpha_i$

Bino-gluino Coannihilation

$$\mathrm{DM} \sim (1,1,0)_F \qquad X \sim (8,1,0)_F$$

$$\mathrm{M} \sim (3,1,4/3)_B \qquad (\mathrm{SM}_1\mathrm{SM}_2) = (u_R\overline{u_R})$$

	$pp \to \ldots$	Prod. via	Signatures	Search	Strength
t-channel	$\begin{cases}\mathrm{M}_t\ (\to \mathrm{SM}_1\ \mathrm{DM}) \\ \mathrm{M}_t\ (\to \mathrm{SM}_1\ \mathrm{DM})\end{cases}$	gauge int.	$\not{E}_T + \leq 2$ SM	[120-122,124] [104,147-153]	α_s^2
	$\begin{cases}\mathrm{M}_t\ (\to \mathrm{SM}_1\ \mathrm{DM}) \\ \mathrm{M}_t\ (\to \mathrm{SM}_2 + \mathrm{X}\ (\to \mathrm{SM}_1^{\mathrm{soft}}\ \mathrm{SM}_2^{\mathrm{soft}}\ \mathrm{DM}))\end{cases}$		$\not{E}_T + \leq 4$ SM	[106-112] [114,119-124]	α_s^2
	$\begin{cases}\mathrm{M}_t\ (\to \mathrm{SM}_2 + \mathrm{X}\ (\to \mathrm{SM}_1^{\mathrm{soft}}\ \mathrm{SM}_2^{\mathrm{soft}}\ \mathrm{DM})) \\ \mathrm{M}_t\ (\to \mathrm{SM}_2 + \mathrm{X}\ (\to \mathrm{SM}_1^{\mathrm{soft}}\ \mathrm{SM}_2^{\mathrm{soft}}\ \mathrm{DM}))\end{cases}$		$\not{E}_T + \leq 6$ SM	[113,114,120-124] [116-118,159-163]	α_s^2
	$\mathrm{DM} + \mathrm{M}_t\ (\to \mathrm{SM}_1\ \mathrm{DM})$	$\mathrm{SM}_1 \in p$	$\not{E}_T + \leq 1$ SM	[55,56,62,63] [104,149]	$\alpha_s g_1^2$
	$\begin{cases}\mathrm{DM} \\ \mathrm{M}_t\ (\to \mathrm{SM}_2 + \mathrm{X}\ (\to \mathrm{SM}_1^{\mathrm{soft}}\ \mathrm{SM}_2^{\mathrm{soft}}\ \mathrm{DM}))\end{cases}$		$\not{E}_T + \leq 3$ SM	[114,120-124] [152,153,156-158]	$\alpha_s g_1^2$
	$\begin{cases}\mathrm{M}_t\ (\to \mathrm{SM}_1\ \mathrm{DM}) \\ \mathrm{X}\ (\to \mathrm{SM}_1^{\mathrm{soft}}\ \mathrm{SM}_2^{\mathrm{soft}}\ \mathrm{DM})\end{cases}$	$\mathrm{SM}_2 \in p$	$\not{E}_T + \leq 3$ SM	[114,120-124] [152,153,156-158]	$\alpha_s g_2^2$
	$\begin{cases}\mathrm{M}_t\ (\to \mathrm{SM}_2 + \mathrm{X}\ (\to \mathrm{SM}_1^{\mathrm{soft}}\ \mathrm{SM}_2^{\mathrm{soft}}\ \mathrm{DM})) \\ \mathrm{X}\ (\to \mathrm{SM}_1^{\mathrm{soft}}\ \mathrm{SM}_2^{\mathrm{soft}}\ \mathrm{DM})\end{cases}$		$\not{E}_T + \leq 5$ SM	[113,114,116-124] [159-161,164]	$\alpha_s g_2^2$

Using the Codex II

Underexplored DM Models

Leptoquark Mediated DM - ST11

ID	X	$\alpha+\beta$	M_s	Spin	$(SM_1\ SM_2)$	SM_3	M-X-X
ST11	$(3, N\pm1, \alpha)$	$\frac{7}{3}$	$(3, 2, \frac{7}{3})$	B	$(Q_L\overline{\ell_R}), (u_R\overline{L_L})$		

DM in $(1, N, \beta)$

Field	Rep.	Spin and mass assignment
DM	(1,1,0)	Majorana fermion
X	(3,2,7/3)	Dirac fermion
M	(3,2,7/3)	Scalar

Leptoquark Mediated DM - ST11

ID	X	$\alpha+\beta$	M_s	Spin	$(SM_1\ SM_2)$	SM_3	M-X-X
ST11	$(3, N\pm1, \alpha)$	$\frac{7}{3}$	$(3, 2, \frac{7}{3})$	B	$(Q_L\overline{\ell_R}), (u_R\overline{L_L})$		

DM in $(1, N, \beta)$

Field	Rep.	Spin and mass assignment
DM	(1,1,0)	Majorana fermion
X	(3,2,7/3)	Dirac fermion
M	(3,2,7/3)	Scalar

Leptoquark Mediated DM - ST11

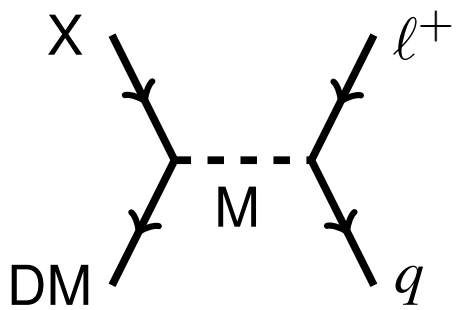
Field	Rep.	Spin and mass assignment
DM	(1,1,0)	Majorana fermion
X	(3,2,7/3)	Dirac fermion
M	(3,2,7/3)	Scalar

$$\mathcal{L} \supset \mathcal{L}_{\text{kin}} + y_D \overline{\text{X}}\, \text{M}\, \text{DM} + y_{Q\ell} \overline{Q_L} \text{M} \ell_R + y_{Lu} \overline{L_L} \text{M}^c u_R + h.c.$$

$$\Delta = \frac{m_{\text{X}} - m_{\text{DM}}}{m_{\text{DM}}} \qquad y^{ij}_{Q\ell} = y_{Lu} = 0 \qquad y_D = y^{11}_{Q\ell}$$

Leptoquark Mediated DM - ST11

Field	Rep.	Spin and mass assignment
DM	(1,1,0)	Majorana fermion
X	(3,2,7/3)	Dirac fermion
M	(3,2,7/3)	Scalar

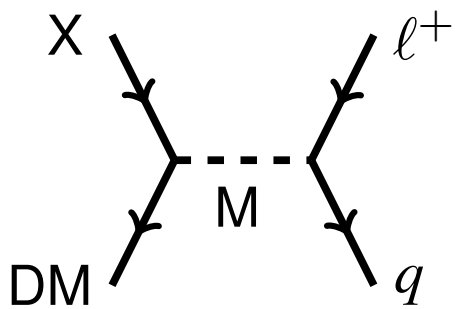


$$\mathcal{L} \supset \mathcal{L}_{\text{kin}} + y_D \overline{\text{X}}\, \text{M}\, \text{DM} + y_{Q\ell} \overline{Q_L} \text{M} \ell_R + y_{Lu} \overline{L_L} \text{M}^c u_R + h.c.$$

$$\Delta = \frac{m_{\text{X}} - m_{\text{DM}}}{m_{\text{DM}}} \qquad y^{ij}_{Q\ell} = y_{Lu} = 0 \qquad y_D = y^{11}_{Q\ell}$$

Leptoquark Mediated DM - ST11

Field	Rep.	Spin and mass assignment
DM	(1,1,0)	Majorana fermion
X	(3,2,7/3)	Dirac fermion
M	(3,2,7/3)	Scalar

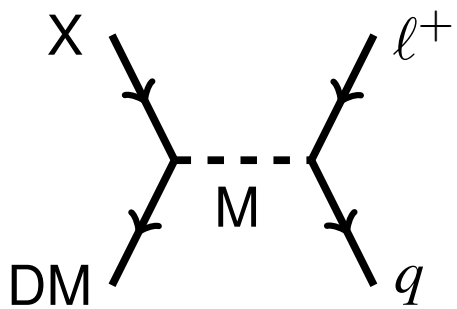


$$\mathcal{L} \supset \mathcal{L}_{\text{kin}} + y_D \overline{\text{X}}\, \text{M}\, \text{DM} + y_{Q\ell} \overline{Q_L} \text{M} \ell_R + y_{Lu} \overline{L_L} \text{M}^c u_R + h.c.$$

$$\Delta = \frac{m_{\text{X}} - m_{\text{DM}}}{m_{\text{DM}}} \qquad y^{ij}_{Q\ell} = y_{Lu} = 0 \qquad y_D = y^{11}_{Q\ell}$$

Leptoquark Mediated DM - ST11

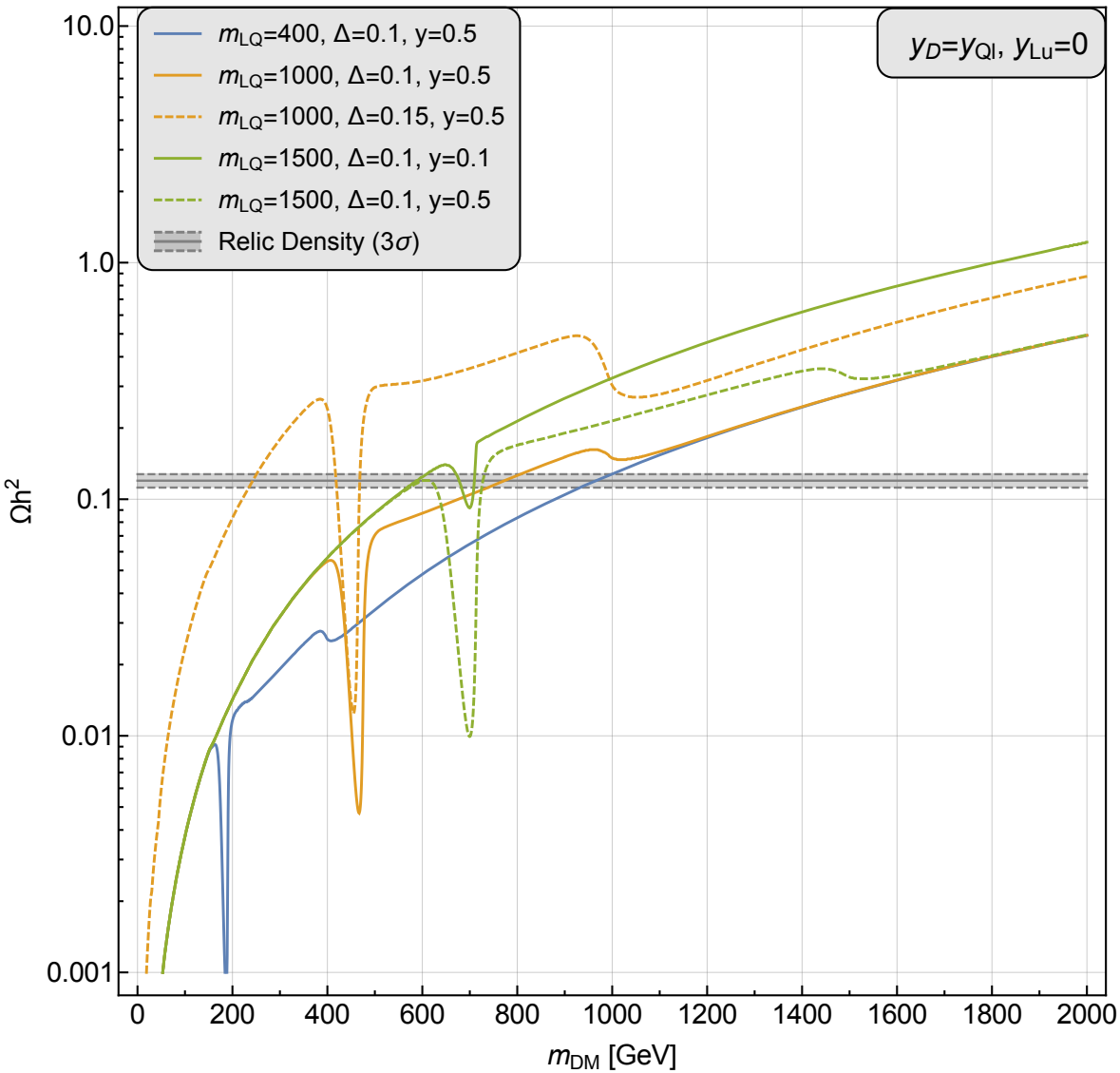
Field	Rep.	Spin and mass assignment
DM	(1,1,0)	Majorana fermion
X	(3,2,7/3)	Dirac fermion
M	(3,2,7/3)	Scalar



$$\mathcal{L} \supset \mathcal{L}_{\text{kin}} + y_D \overline{\text{X}}\, \text{M}\, \text{DM} + y_{Q\ell} \overline{Q_L} \text{M} \ell_R + y_{Lu} \overline{L_L} \text{M}^c u_R + h.c.$$

$$\Delta = \frac{m_{\text{X}} - m_{\text{DM}}}{m_{\text{DM}}} \qquad y^{ij}_{Q\ell} = y_{Lu} = 0 \qquad y_D = y^{11}_{Q\ell}$$

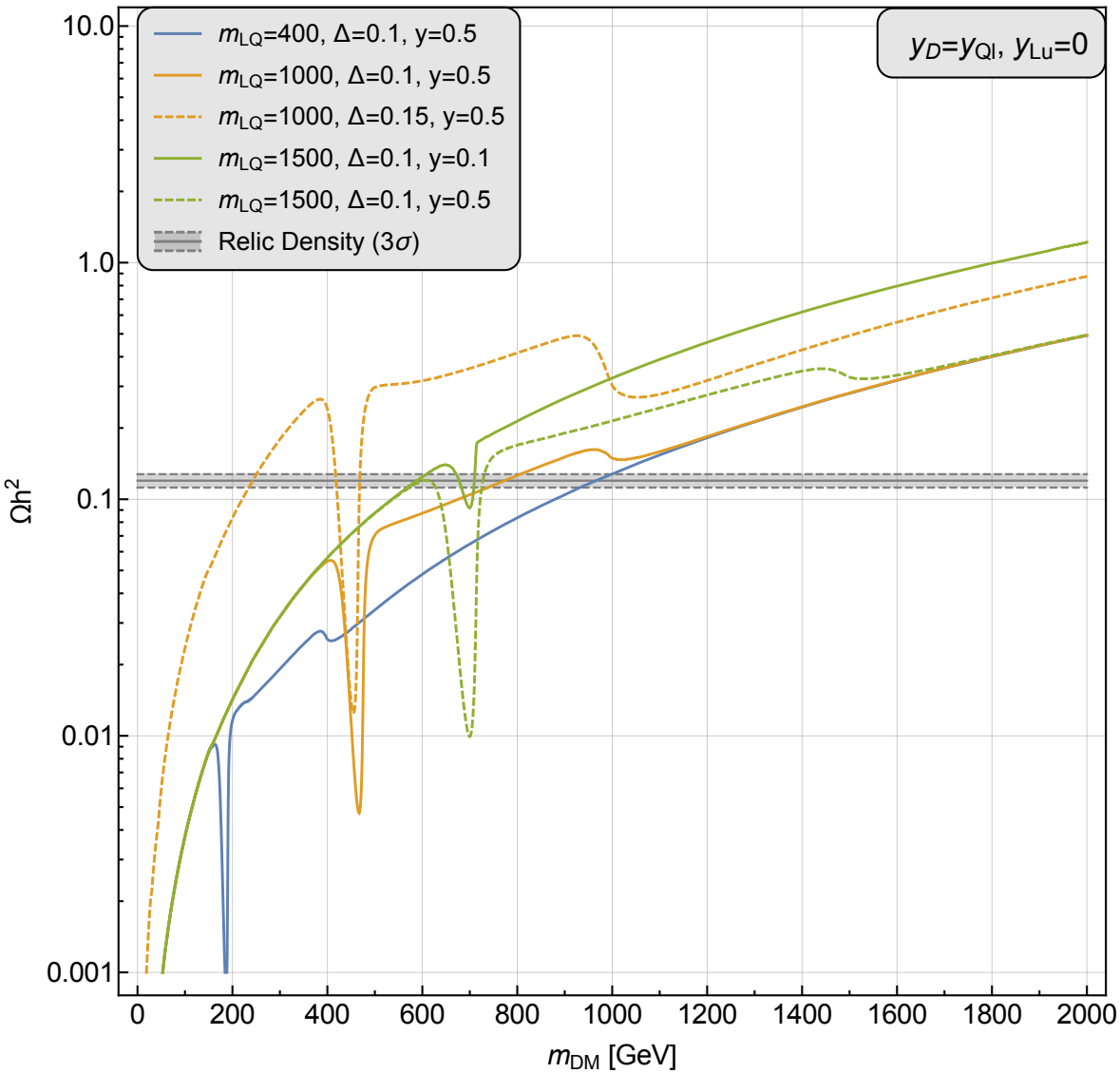
Leptoquark Mediated DM - ST11 - Relic Density



$$\sigma_{\text{ann}} \propto \frac{1}{m^2}$$

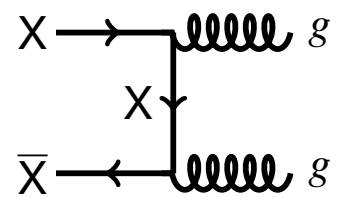
e.g.,

Leptoquark Mediated DM - ST11 - Relic Density

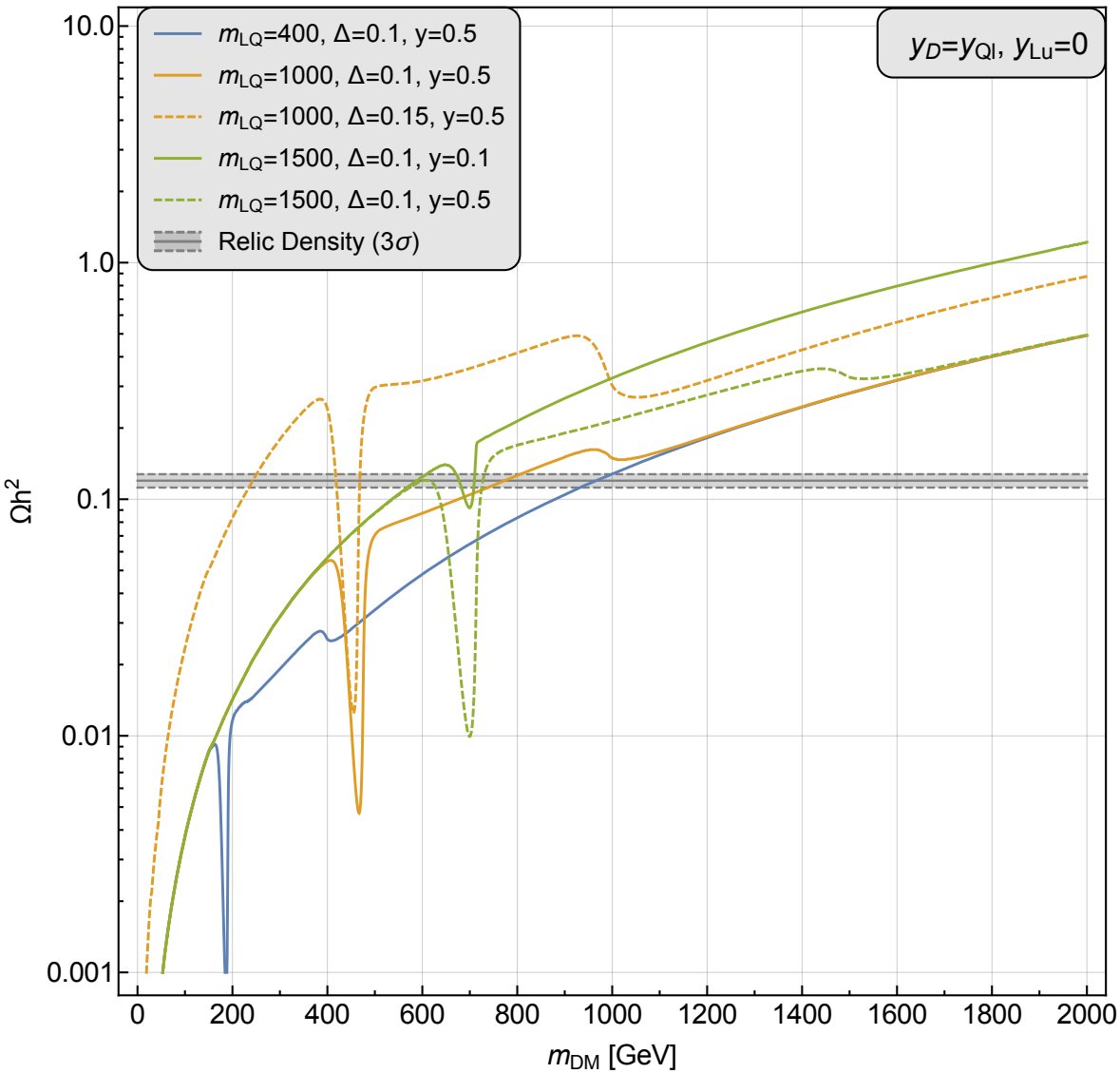


$$\sigma_{\text{ann}} \propto \frac{1}{m^2}$$

e.g.,

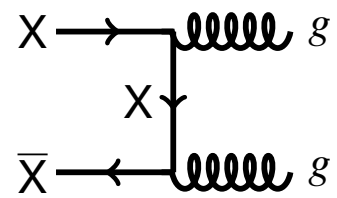


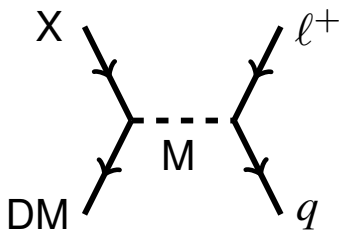
Leptoquark Mediated DM - ST11 - Relic Density



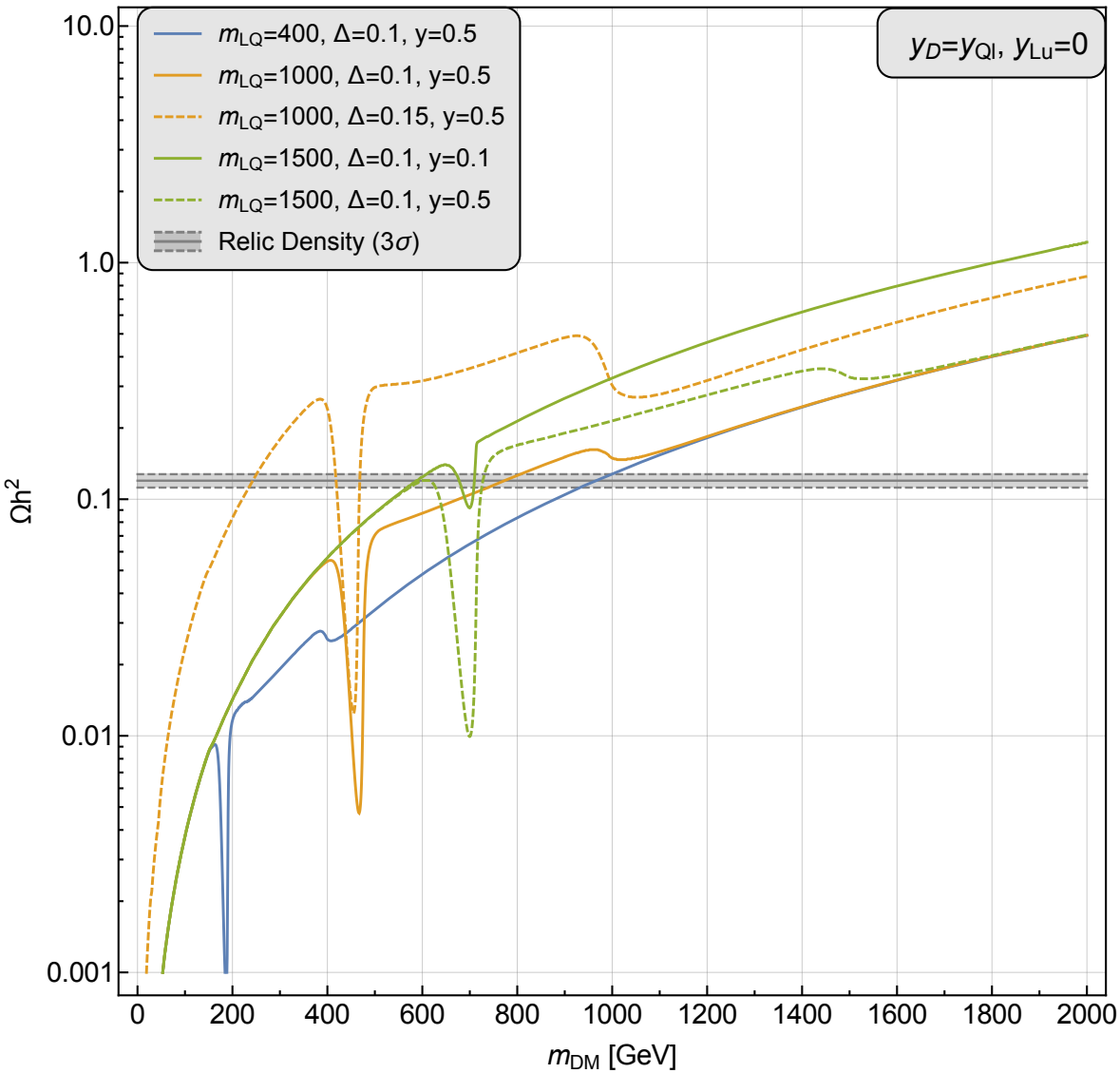
$$\sigma_{\text{ann}} \propto \frac{1}{m^2}$$

e.g.,



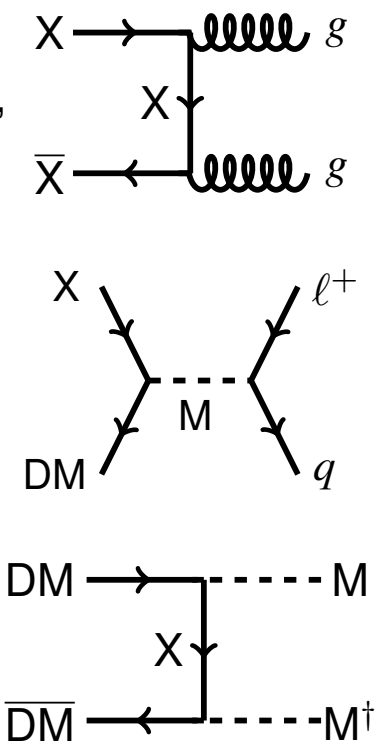


Leptoquark Mediated DM - ST11 - Relic Density



$$\sigma_{\text{ann}} \propto \frac{1}{m^2}$$

e.g.,



Leptoquark Mediated DM - ST11 - Signatures

$$\mathrm{DM} \sim (1,1,0)_F \qquad X \sim (3,2,7/3)_F \qquad \mathrm{M} \sim (3,2,7/3)_B \qquad (\mathrm{SM}_1\mathrm{SM}_2) = (Q_L\overline{e_R})$$

	$pp \to \ldots$	Prod. via	Signatures	Search	Strength
common	DM + DM + ISR	gauge int. or $\mathrm{SM}_1 \in p$ for t-channel	mono-Y + $\not{E}_T$	[55,56,62,63,104]	–
	X ($\to \mathrm{SM}_1^{\mathrm{soft}}\ \mathrm{SM}_2^{\mathrm{soft}}$ DM) X ($\to \mathrm{SM}_1^{\mathrm{soft}}\ \mathrm{SM}_2^{\mathrm{soft}}$ DM) ISR	gauge int. or $\mathrm{SM}_2 \in p$ for t-channel	mono-Y + $\not{E}_T$ mono-Y + $\not{E}_T$+ $\leq$ 4 SM	[55,56,62,63,104] Partial coverage [105]	$\alpha_s^2\alpha_i$
	DM + X ($\to \mathrm{SM}_1^{\mathrm{soft}}\ \mathrm{SM}_2^{\mathrm{soft}}$ DM) + ISR	$(\mathrm{SM}_1\ \mathrm{SM}_2) \in p$	mono-Y + $\not{E}_T$ mono-Y + $\not{E}_T$+ $\leq$ 2 SM	[55,56,62,63,104] Partial coverage [105]	–

Leptoquark Mediated DM - ST11 - Signatures

$$\mathrm{DM} \sim (1,1,0)_F \qquad X \sim (3,2,7/3)_F \qquad \mathrm{M} \sim (3,2,7/3)_B \qquad (\mathrm{SM}_1\mathrm{SM}_2) = (Q_L \overline{e_R})$$

	$pp \to \ldots$	Prod. via	Signatures	Search	Strength
s-channel	$\begin{cases} \mathrm{M}_s\ (\to [\mathrm{SM}_1\ \mathrm{SM}_2]^{\mathrm{res}}) \\ \mathrm{M}_s\ (\to [\mathrm{SM}_1\ \mathrm{SM}_2]^{\mathrm{res}}) \end{cases}$	gauge int.	2 resonances	[106-112]	α_s^2
	$\begin{cases} \mathrm{M}_s\ (\to [\mathrm{SM}_1\ \mathrm{SM}_2]^{\mathrm{res}}) \\ \mathrm{M}_s\ (\to \mathrm{DM} + \mathrm{X}\ (\to \mathrm{SM}_1^{\mathrm{soft}}\ \mathrm{SM}_2^{\mathrm{soft}}\ \mathrm{DM})) \end{cases}$		resonance + $\not{E}_T$ resonance + $\not{E}_T +\leq 2$ SM	No search No search	α_s^2
	$\begin{cases} \mathrm{M}_s\ (\to \mathrm{DM} + \mathrm{X}\ (\to \mathrm{SM}_1^{\mathrm{soft}}\ \mathrm{SM}_2^{\mathrm{soft}}\ \mathrm{DM})) \\ \mathrm{M}_s\ (\to \mathrm{DM} + \mathrm{X}\ (\to \mathrm{SM}_1^{\mathrm{soft}}\ \mathrm{SM}_2^{\mathrm{soft}}\ \mathrm{DM})) \end{cases}$		$\not{E}_T +\leq 4$ SM	[113-124]	α_s^2
	$\mathrm{M}_s\ (\to [\mathrm{SM}_1\ \mathrm{SM}_2]^{\mathrm{res}})$	$(\mathrm{SM}_1\ \mathrm{SM}_2) \in p$	1 resonance	[125-146]	–
	$\mathrm{M}_s\ (\to \mathrm{DM} + \mathrm{X}\ (\to \mathrm{SM}_1^{\mathrm{soft}}\ \mathrm{SM}_2^{\mathrm{soft}}\ \mathrm{DM}))$		$\not{E}_T +\leq 2$ SM	[120-122,124] [104,147-153]	–
	$\mathrm{SM}_{1,2} + \mathrm{M}_s\ (\to [\mathrm{SM}_1\ \mathrm{SM}_2]^{\mathrm{res}})$	$\mathrm{SM}_{2,1} \in p$	1 resonance + 1 SM	Partial coverage [154,155]	$\alpha_s (y_{Q\ell}^{11})^2$
	$\begin{cases} \mathrm{SM}_{1,2} \\ \mathrm{M}_s\ (\to \mathrm{DM} + \mathrm{X}\ (\to \mathrm{SM}_1^{\mathrm{soft}}\ \mathrm{SM}_2^{\mathrm{soft}}\ \mathrm{DM})) \end{cases}$		$\not{E}_T$ + 1 $\leq$ 3 SM	[114,120-124] [147-153,156-158]	$\alpha_s (y_{Q\ell}^{11})^2$

Leptoquark Mediated DM - ST11 - Signatures

$$\mathrm{DM} \sim (1,1,0)_F \qquad X \sim (3,2,7/3)_F \qquad \mathrm{M} \sim (3,2,7/3)_B \qquad (\mathrm{SM}_1\mathrm{SM}_2) = (Q_L\overline{e_R})$$

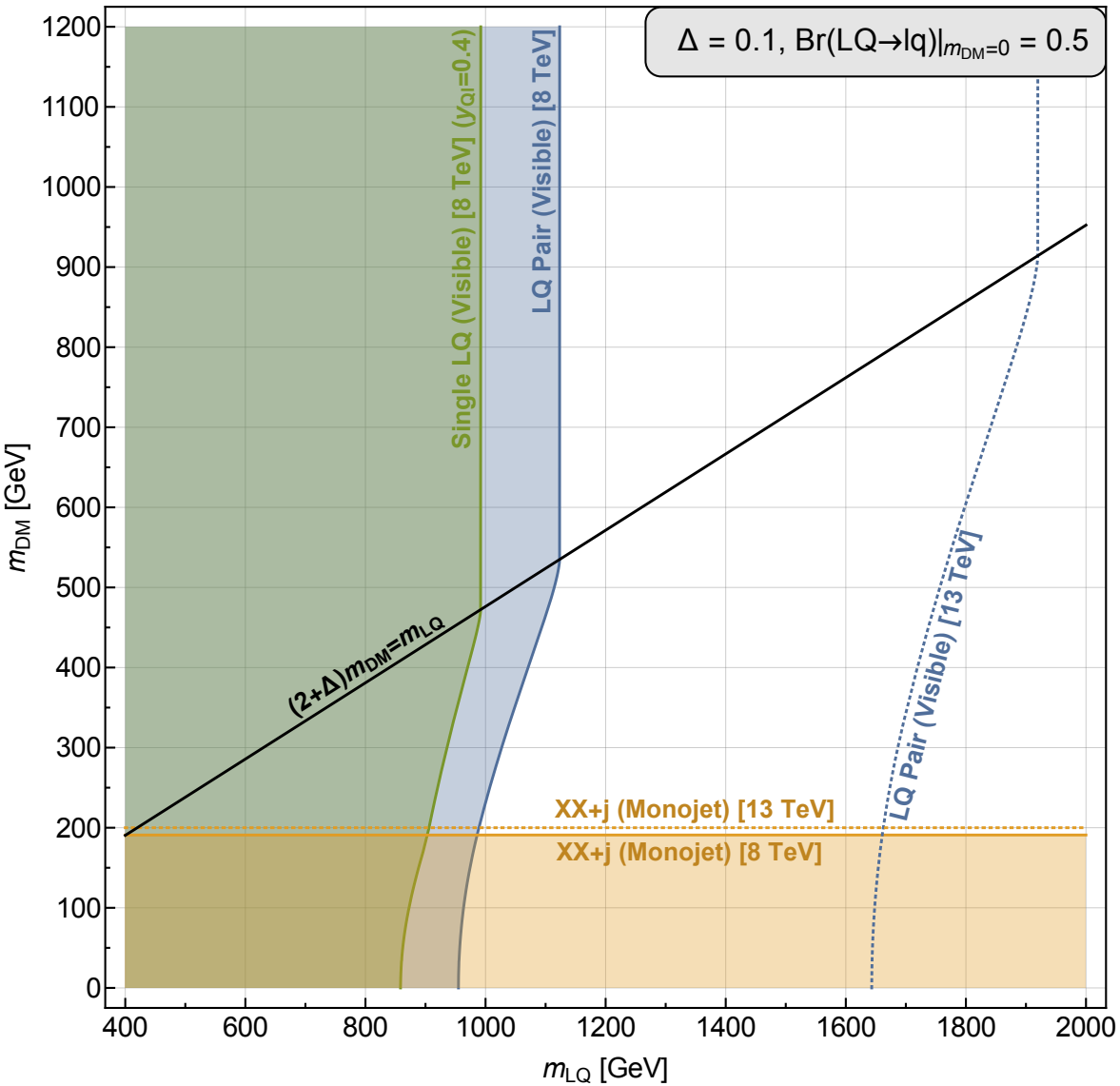
	$pp \to \ldots$	Signatures	Existing Searches	Strength	Search
common	DM + DM + ISR	mono-Y + $\not{E}_T$	[55,56,62,63,104]	–	–
	X ($\to$ $\mathrm{SM}_1^{\mathrm{soft}}$ $\mathrm{SM}_2^{\mathrm{soft}}$ DM) X ($\to$ $\mathrm{SM}_1^{\mathrm{soft}}$ $\mathrm{SM}_2^{\mathrm{soft}}$ DM) ISR	mono-Y + $\not{E}_T$ mono-Y + $\not{E}_T$ + $\leq$ 4 SM	[55,56,62,63,104] Partial coverage [105]	$\alpha_s^2\alpha_i$	(I) monojet + $\not{E}_T$ (II) monojet + $\not{E}_T$ + soft e
	DM + X ($\to$ $\mathrm{SM}_1^{\mathrm{soft}}$ $\mathrm{SM}_2^{\mathrm{soft}}$ DM) + ISR	mono-Y + $\not{E}_T$ mono-Y + $\not{E}_T$ + $\leq$ 2 SM	[55,56,62,63,104] Partial coverage [105]	–	–
s-channel	M_s ($\to$ [SM_1 SM_2]$^{\mathrm{res}}$) M_s ($\to$ [SM_1 SM_2]$^{\mathrm{res}}$)	2 resonances	[106-111,112]	α_s^2	(III) Leptoquark pair
	M_s ($\to$ [SM_1 SM_2]$^{\mathrm{res}}$) M_s ($\to$ DM + X ($\to$ $\mathrm{SM}_1^{\mathrm{soft}}$ $\mathrm{SM}_2^{\mathrm{soft}}$ DM))	resonance + $\not{E}_T$ resonance + $\not{E}_T$ + $\leq$ 2 SM	No search No search	α_s^2	(IV) Leptoquark + $\not{E}_T$ (V) Leptoquark + $\not{E}_T$ + j + e
	M_s ($\to$ DM + X ($\to$ $\mathrm{SM}_1^{\mathrm{soft}}$ $\mathrm{SM}_2^{\mathrm{soft}}$ DM)) M_s ($\to$ DM + X ($\to$ $\mathrm{SM}_1^{\mathrm{soft}}$ $\mathrm{SM}_2^{\mathrm{soft}}$ DM))	$\not{E}_T$ + $\leq$ 4 SM	[113,114-124]	α_s^2	(VI) 2e+2j + $\not{E}_T$ (I) monojet + $\not{E}_T$
	M_s ($\to$ [SM_1 SM_2]$^{\mathrm{res}}$)	1 resonance	[125-146]	–	–
	M_s ($\to$ DM + X ($\to$ $\mathrm{SM}_1^{\mathrm{soft}}$ $\mathrm{SM}_2^{\mathrm{soft}}$ DM))	$\not{E}_T$ + $\leq$ 2 SM	[120-122,124] [104,147-153]	–	–
	$\mathrm{SM}_{1,2}$ + M_s ($\to$ [SM_1 SM_2]$^{\mathrm{res}}$)	1 resonance + 1 SM	Partial coverage [154,155]	$\alpha_s(y_{Q\ell}^{11})^2$	(VII) Leptoquark + e
	$\mathrm{SM}_{1,2}$ M_s ($\to$ DM + X ($\to$ $\mathrm{SM}_1^{\mathrm{soft}}$ $\mathrm{SM}_2^{\mathrm{soft}}$ DM))	$\not{E}_T$ + 1 $\leq$ 3 SM	[114,120-124] [128,129,147-153,156-158]	$\alpha_s(y_{Q\ell}^{11})^2$	(VI) 2e + j + $\not{E}_T$ (VIII) e + $\not{E}_T$

Leptoquark Mediated DM - ST11 - Signatures

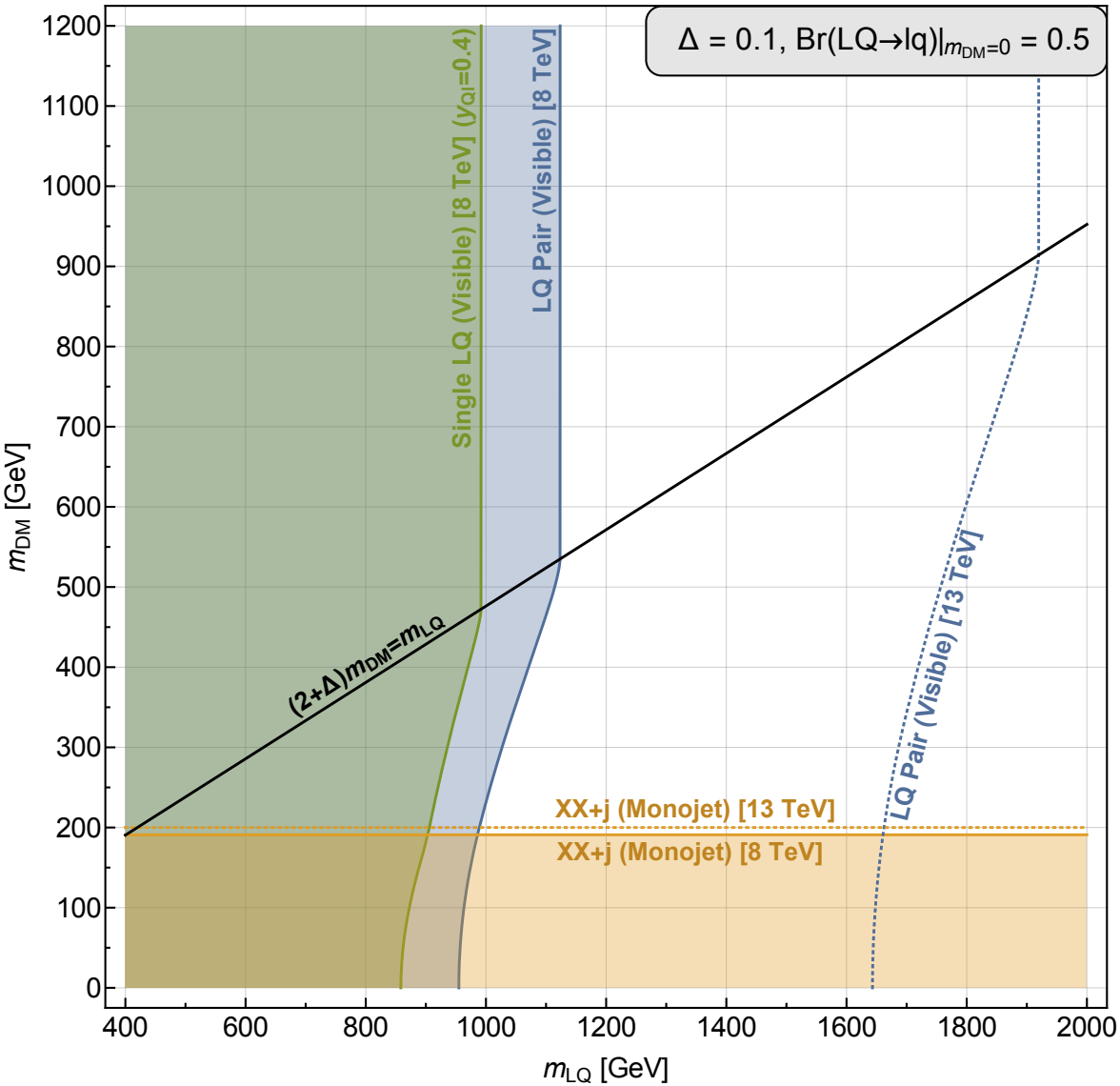
$$\mathrm{DM} \sim (1,1,0)_F \qquad X \sim (3,2,7/3)_F \qquad \mathrm{M} \sim (3,2,7/3)_B \qquad (\mathrm{SM}_1\mathrm{SM}_2) = (Q_L\overline{e_R})$$

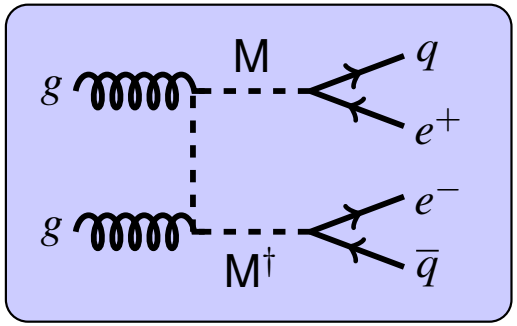
	$pp \to \ldots$	Signatures	Existing Searches	Strength	Search	
common	DM + DM + ISR	mono-Y + $\not{E}_T$	[55,56,62,63,104]	–	–	
	X ($\to$ $\mathrm{SM}_1^{\mathrm{soft}}$ $\mathrm{SM}_2^{\mathrm{soft}}$ DM) X ($\to$ $\mathrm{SM}_1^{\mathrm{soft}}$ $\mathrm{SM}_2^{\mathrm{soft}}$ DM) ISR	mono-Y + $\not{E}_T$ mono-Y + $\not{E}_T$ + $\leq$ 4 SM	[55,56,62,63,104] Partial coverage [105]	$\alpha_s^2\alpha_i$	(I) monojet + $\not{E}_T$ (II) monojet + $\not{E}_T$ + soft e	← ←
	DM + X ($\to$ $\mathrm{SM}_1^{\mathrm{soft}}$ $\mathrm{SM}_2^{\mathrm{soft}}$ DM) + ISR	mono-Y + $\not{E}_T$ mono-Y + $\not{E}_T$ + $\leq$ 2 SM	[55,56,62,63,104] Partial coverage [105]	–	–	
s-channel	M_s ($\to$ [SM_1 SM_2]$^{\mathrm{res}}$) M_s ($\to$ [SM_1 SM_2]$^{\mathrm{res}}$)	2 resonances	[106-111,112]	α_s^2	(III) Leptoquark pair	←
	M_s ($\to$ [SM_1 SM_2]$^{\mathrm{res}}$) M_s ($\to$ DM + X ($\to$ $\mathrm{SM}_1^{\mathrm{soft}}$ $\mathrm{SM}_2^{\mathrm{soft}}$ DM))	resonance + $\not{E}_T$ resonance + $\not{E}_T$ + $\leq$ 2 SM	No search No search	α_s^2	(IV) Leptoquark + $\not{E}_T$ (V) Leptoquark + $\not{E}_T$ + j + e	←
	M_s ($\to$ DM + X ($\to$ $\mathrm{SM}_1^{\mathrm{soft}}$ $\mathrm{SM}_2^{\mathrm{soft}}$ DM)) M_s ($\to$ DM + X ($\to$ $\mathrm{SM}_1^{\mathrm{soft}}$ $\mathrm{SM}_2^{\mathrm{soft}}$ DM))	$\not{E}_T$ + $\leq$ 4 SM	[113,114-124]	α_s^2	(VI) 2e+2j + $\not{E}_T$ (I) monojet + $\not{E}_T$	
	M_s ($\to$ [SM_1 SM_2]$^{\mathrm{res}}$)	1 resonance	[125-146]	–	–	
	M_s ($\to$ DM + X ($\to$ $\mathrm{SM}_1^{\mathrm{soft}}$ $\mathrm{SM}_2^{\mathrm{soft}}$ DM))	$\not{E}_T$ + $\leq$ 2 SM	[120-122,124] [104,147-153]	–	–	
	$\mathrm{SM}_{1,2}$ + M_s ($\to$ [SM_1 SM_2]$^{\mathrm{res}}$)	1 resonance + 1 SM	Partial coverage [154,155]	$\alpha_s(y_{Q\ell}^{11})^2$	(VII) Leptoquark + e	←
	$\mathrm{SM}_{1,2}$ M_s ($\to$ DM + X ($\to$ $\mathrm{SM}_1^{\mathrm{soft}}$ $\mathrm{SM}_2^{\mathrm{soft}}$ DM))	$\not{E}_T$ + 1 $\leq$ 3 SM	[114,120-124] [128,129,147-153,156-158]	$\alpha_s(y_{Q\ell}^{11})^2$	(VI) 2e + j + $\not{E}_T$ (VIII) e + $\not{E}_T$	

ST11 - Existing Collider Constraints

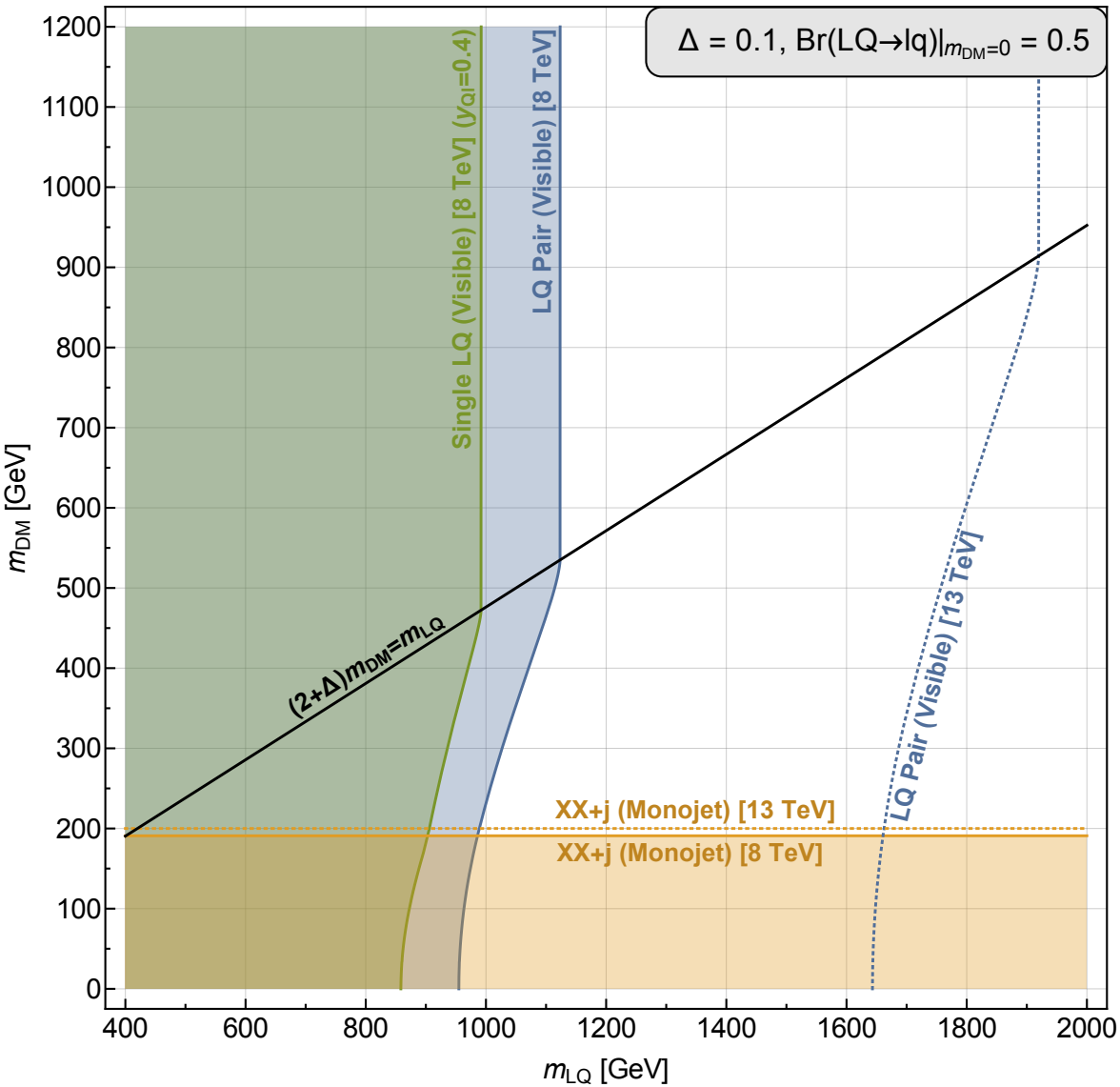


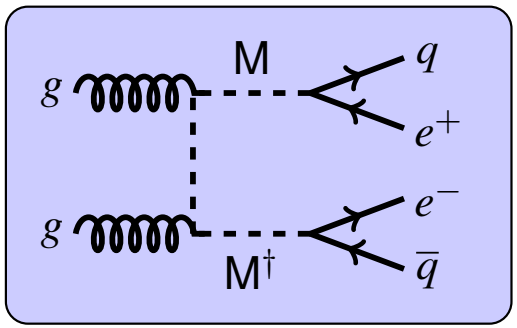
ST11 - Existing Collider Constraints

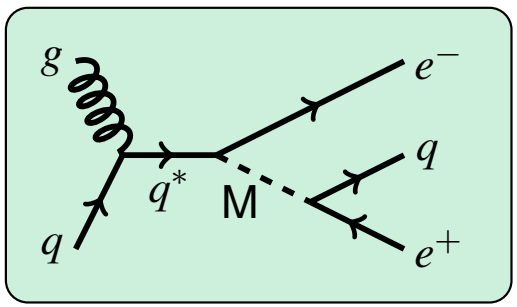




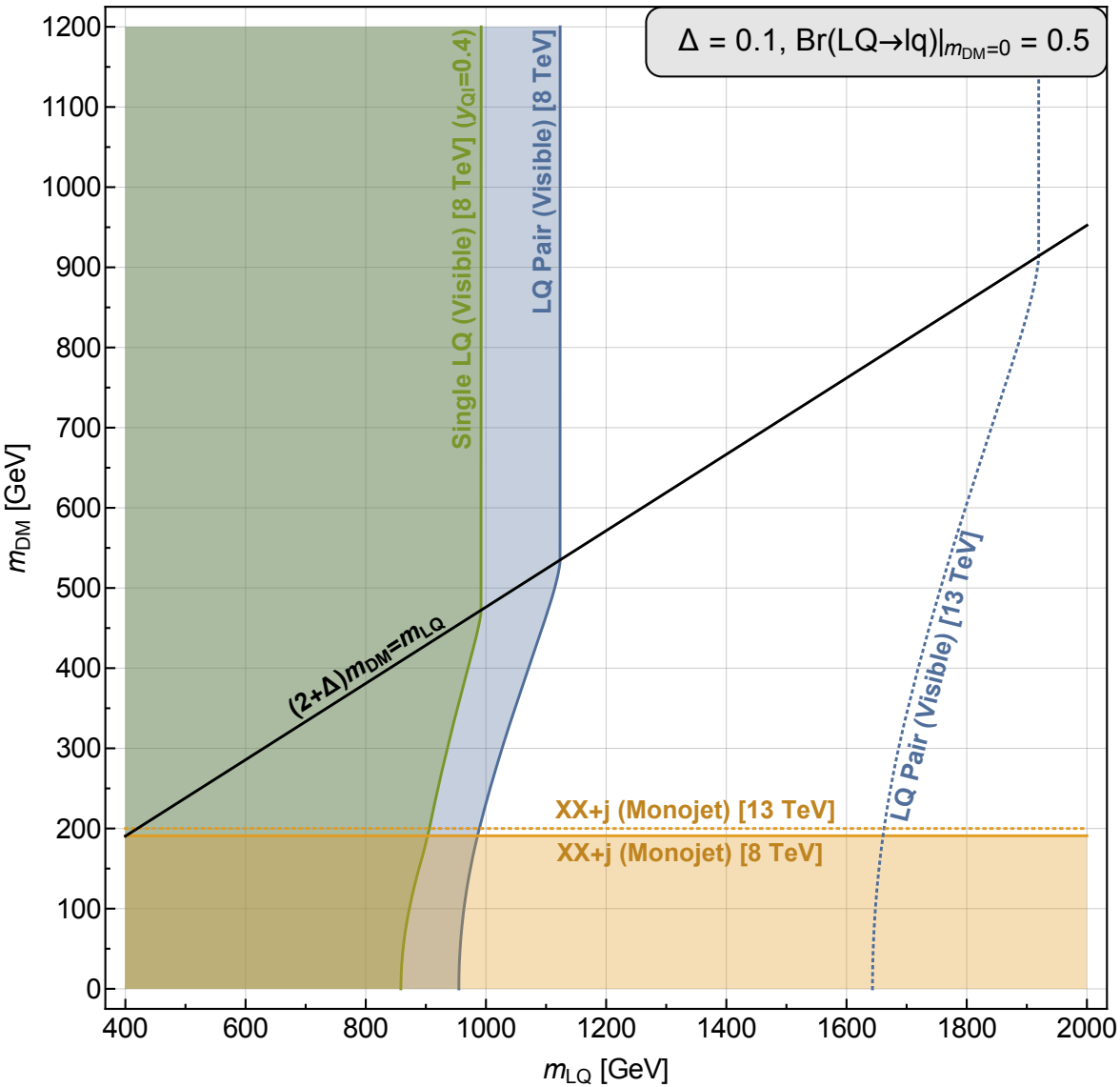
ST11 - Existing Collider Constraints

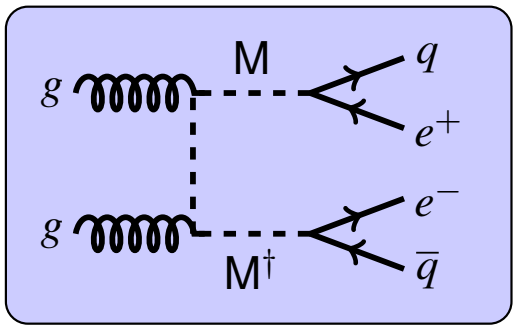


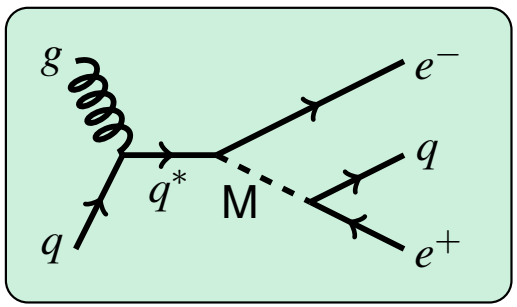


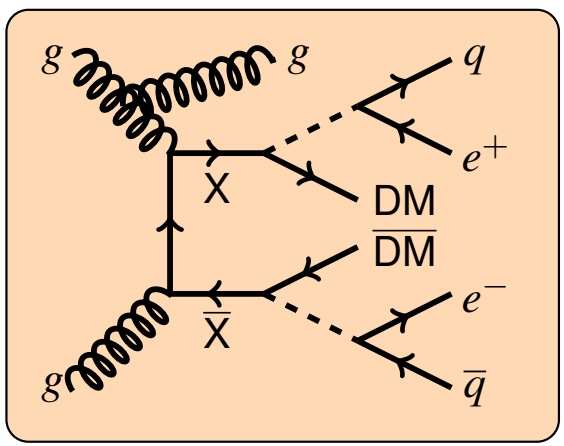


ST11 - Existing Collider Constraints

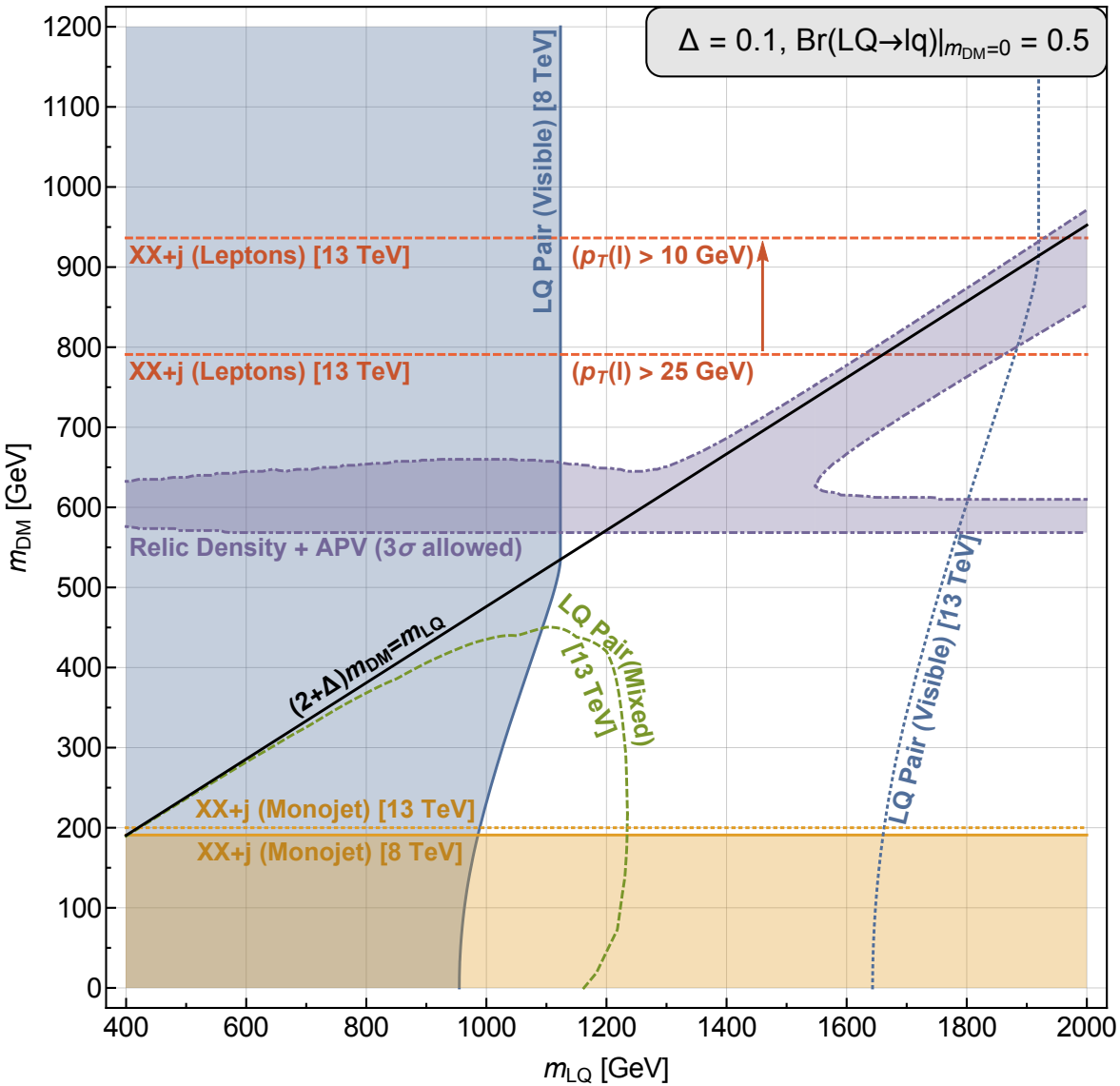


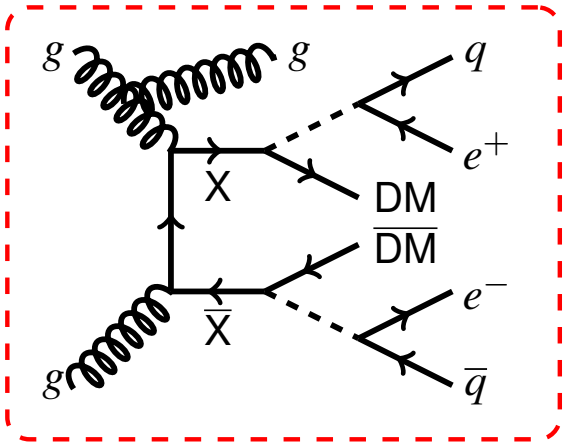




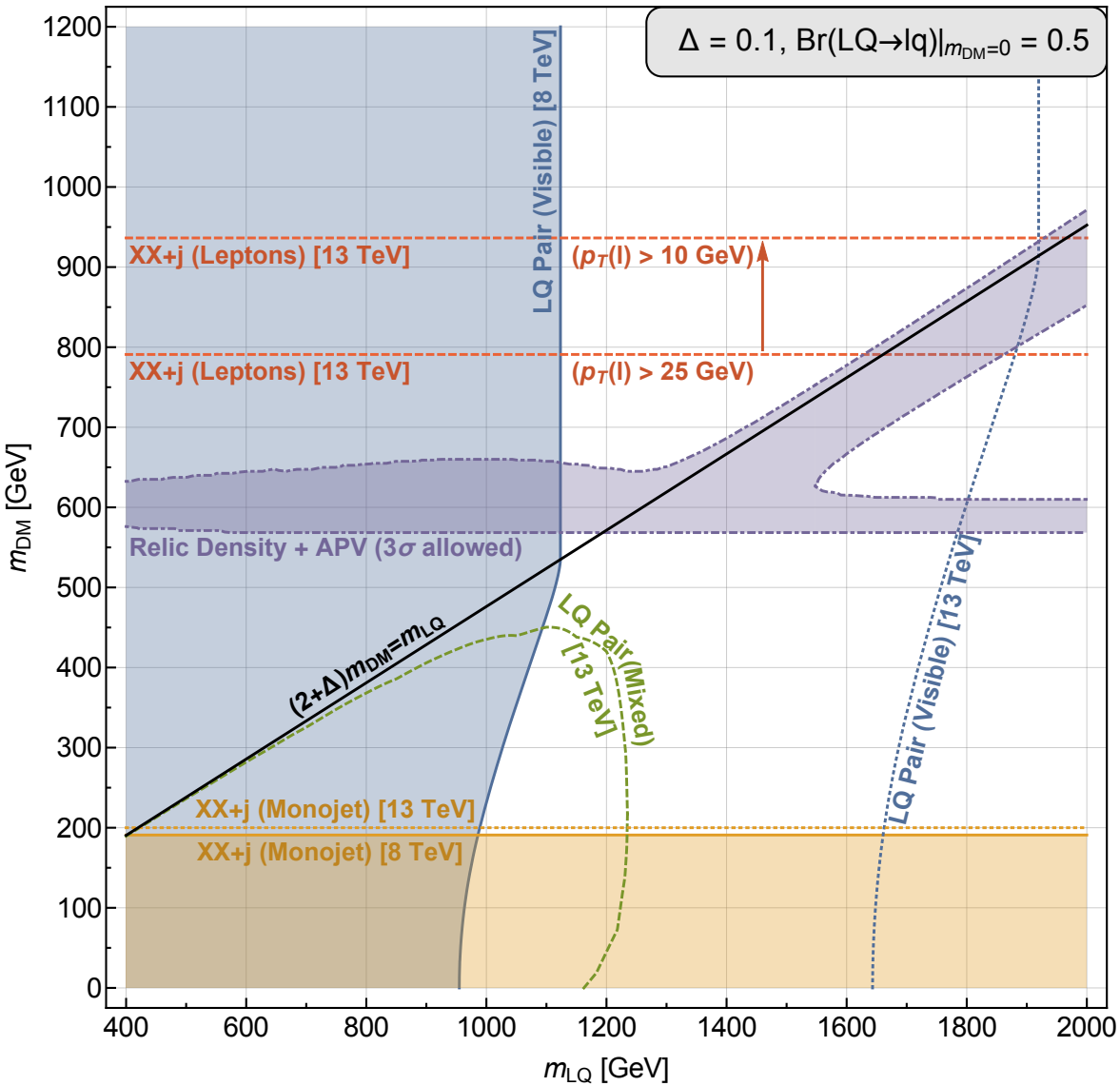


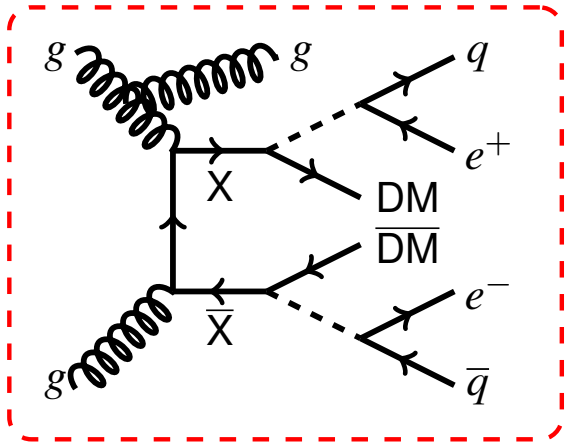
ST11 - Constraints from New Searches

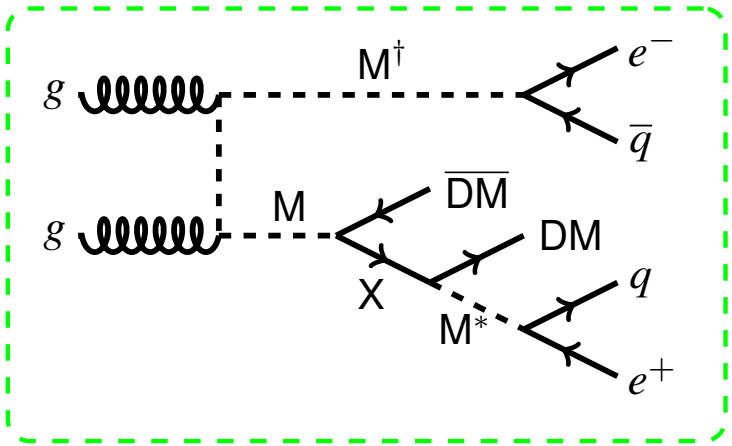




ST11 - Constraints from New Searches







Summary

- Coannihilation Codex gives a complete list of simplified models of coannihilation
- Guaranteed kinetic & coannihilation vertices $\rightarrow$ signatures
- Classify signatures of a wide range of models
  - Identify new signatures
  - Identify interesting models, e.g., leptoquarks and DM
- Huge number of coannihilating models of DM
  - with interesting collider signatures to study
  - at the LHC and future colliders

Summary

- Coannihilation Codex gives a complete list of simplified models of coannihilation
- Guaranteed kinetic & coannihilation vertices $\rightarrow$ signatures
- Classify signatures of a wide range of models
  - Identify new signatures
  - Identify interesting models, e.g., leptoquarks and DM
- Huge number of coannihilating models of DM
  - with interesting collider signatures to study
  - at the LHC and future colliders

Summary

- Coannihilation Codex gives a complete list of simplified models of coannihilation
- Guaranteed kinetic & coannihilation vertices $\rightarrow$ signatures
- Classify signatures of a wide range of models
  - Identify new signatures
  - Identify interesting models, e.g., leptoquarks and DM
- Huge number of coannihilating models of DM
  - with interesting collider signatures to study
  - at the LHC and future colliders

Summary

- Coannihilation Codex gives a complete list of simplified models of coannihilation
- Guaranteed kinetic & coannihilation vertices $\rightarrow$ signatures
- Classify signatures of a wide range of models
  - Identify new signatures
  - Identify interesting models, e.g., leptoquarks and DM
- Huge number of coannihilating models of DM
  - with interesting collider signatures to study
  - at the LHC and future colliders

Summary

- Coannihilation Codex gives a complete list of simplified models of coannihilation
- Guaranteed kinetic & coannihilation vertices $\rightarrow$ signatures
- Classify signatures of a wide range of models
  - Identify new signatures
  - Identify interesting models, e.g., leptoquarks and DM
- Huge number of coannihilating models of DM
  - with interesting collider signatures to study
  - at the LHC and future colliders

EWSB I

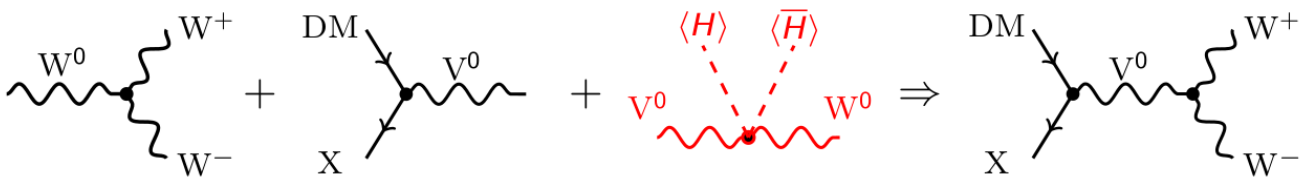
The main effect of EWSB on our models is from mixing:

- Due to $\mathbb{Z}_2$ symmetry, in t-channel models the effects of the mixing will be entirely in the dark sector
- Mediators in s-channel models may mix with SM particles, giving hybrid model like signatures

EWSB II

It is also possible to construct new 2-to-2 diagrams exist thanks to EWSB

E.g.: mixing between $W_i(1,3,0)$ and $V_i(1,5,0)$ in the 3–3–1 model



However, all diagrams are built from verticies present in our tables and LHC signatures (almost always) differ only by mixing angles and group theory factors

Cut-flow table - Mixed decay

	QCD	$W+1,2j$	$t\bar{t}$	$Z_{\nu\nu}+j$	$Z_{\tau\tau}+j$	W^+W^-	$WZ_{\nu\nu}+j$	WZ_{jj}	signal
$p_T(j_1) > 50$ GeV	2.1×10^{12}	4.4×10^{8}	1.3×10^{8}	7.0×10^{7}	1.3×10^{7}	1.2×10^{6}	1.3×10^{5}	3.1×10^{5}	600
$N_e^{\mathrm{h}} = 1, N_e \leq 2$	4.8×10^{9}	8.8×10^{7}	1.2×10^{7}	8.6×10^{4}	4.8×10^{5}	2.4×10^{5}	1.9×10^{4}	6.1×10^{4}	415
b-jet veto	4.0×10^{9}	8.2×10^{7}	5.0×10^{6}	8.2×10^{4}	4.6×10^{5}	2.2×10^{5}	1.9×10^{4}	5.4×10^{4}	395
$N_{\text{hard jets}} \leq 3$	3.9×10^{9}	8.2×10^{7}	4.3×10^{6}	8.2×10^{4}	4.6×10^{5}	2.2×10^{5}	1.9×10^{4}	5.4×10^{4}	335
Z veto	3.9×10^{9}	8.2×10^{7}	1.7×10^{6}	8.2×10^{4}	4.6×10^{5}	2.2×10^{5}	1.9×10^{4}	5.4×10^{4}	326
$\not{E}_T > 700$ GeV	133	1738	15	19	9	10	27	2	75
$m_T > 150$ GeV	132	16	10^{-3}	18	0.005	0.01	10	0.001	67
mass window	3	0.2	0	0.3	10^{-5}	10^{-5}	0.1	10^{-5}	24

Cut-flow table - XXj

	$t\bar{t}$	$Z_{\ell\ell}+j$	Diboson	$W_{\ell\nu}+j$	$t+j$	Signal
$\not{E}_T > 50$ GeV	1.9×10^7	7.9×10^6	1.1×10^6	1.9×10^8	5.6×10^5	8.5×10^4
$p_T^{\text{lead}} > 50$ GeV	1.8×10^7	6.1×10^6	5.9×10^5	1.5×10^8	4.6×10^5	7.1×10^4
$\Delta\phi_{j_1 j_2} < 2.5$	1.2×10^7	4.2×10^6	5.0×10^5	1.1×10^8	2.9×10^5	5.4×10^4
Z and μ veto	8.5×10^6	2.7×10^6	4.0×10^5	8.6×10^7	1.9×10^5	5.2×10^4
b veto	3.6×10^6	2.6×10^6	3.7×10^5	8.2×10^7	1.1×10^5	2.0×10^4
$N_l \geq 2$	2.5×10^4	4371	1076	9.8×10^4	382	1748
$\not{E}_T > 400$ GeV	12	11	0.07	780	2	118
$\left\lvert \frac{p_{T j_1}}{\not{E}_T} - 1 \right\rvert < 0.2$	1	11	0.07	148	0.2	85