



CONACYT

Consejo Nacional de Ciencia y Tecnología



NEUTRINO MASSES AND SELF-INTERACTING DARK MATTER IN A Z-Z' MIXING MODEL

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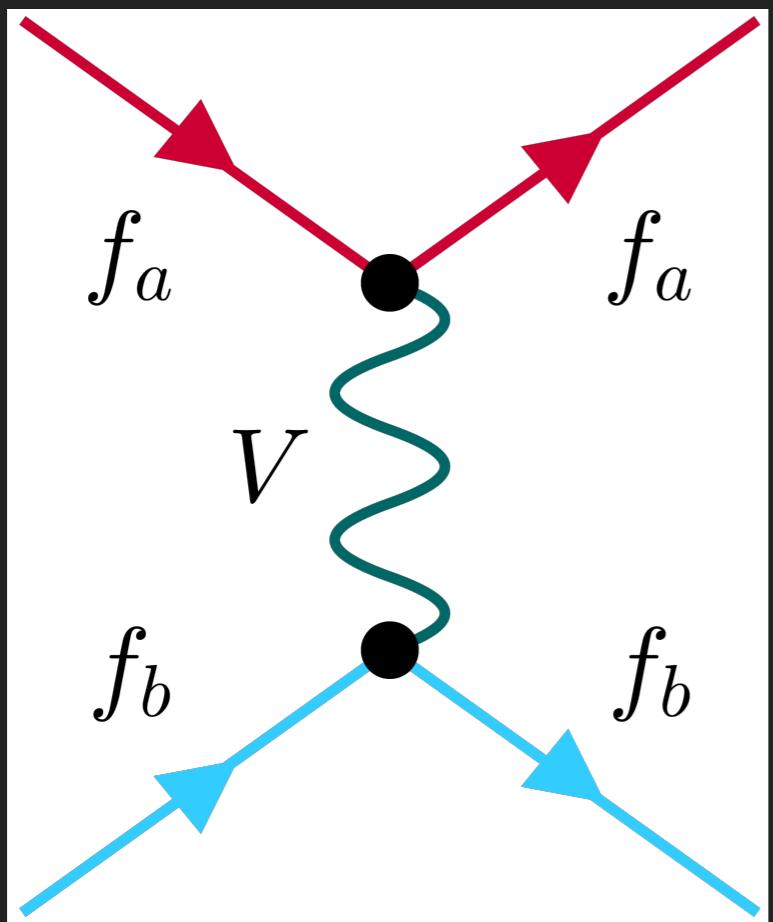
PHENO 2023

NEUTRINO MASSES AND SELF-INTERACTING DARK MATTER IN A Z-Z' MIXING MODEL

- ▶ Light new Physics
- ▶ Light Z' models
- ▶ Experimental probes of a light Z'
- ▶ Dark Matter
- ▶ Z' portal to dark matter
- ▶ Dark U(1) & SIDM

LIGHT NEW PHYSICS

- Consider $f_a f_b \rightarrow f_a f_b$ scattering process in the t-channel



$$\mathcal{M} \sim \frac{g_a g_b}{t - m_V^2}$$

$$t = (p_a^i - p_a^f)^2 = (p_b^i - p_b^f)^2$$

$$\mathcal{O}_{ab} \bar{f}_a f_a \bar{f}_b f_b$$

$$m_V^2 \gg t$$

$$\mathcal{O}_{ab} \sim \frac{g_a g_b}{m_V^2}$$



$$\mathcal{O}_{ab} \sim \frac{g_a g_b}{t - m_V^2}$$

LIGHT NEW PHYSICS

- ▶ CEvNS:
- ▶ Z boson exchange CS
- ▶ Background can be controlled reasonably well
- ▶ Parity Violating scatterings:
 - ▶ $A_{PV} \sim \frac{\sigma_L - \sigma_R}{\sigma_L + \sigma_R}$
 - ▶ Z + Photon exchange CS
 - ▶ Observable only sees Interference terms and Z couplings PV

Z' MODELS

- ▶ Massive neutral vector boson
- ▶ Inspired by
 - ▶ GUT (e.g. E6 (London,Rosner Phys. Rev. D **34**, 1530,...))
 - ▶ Extra dimensions (e.g. Masip, Pomarol, Phys. Rev. D **60**, 096005,...)
 - ▶ String theory (e.g. Cvetič, Langacker, Phys. Rev. D **54**, 3570,...)
 - ▶ ...

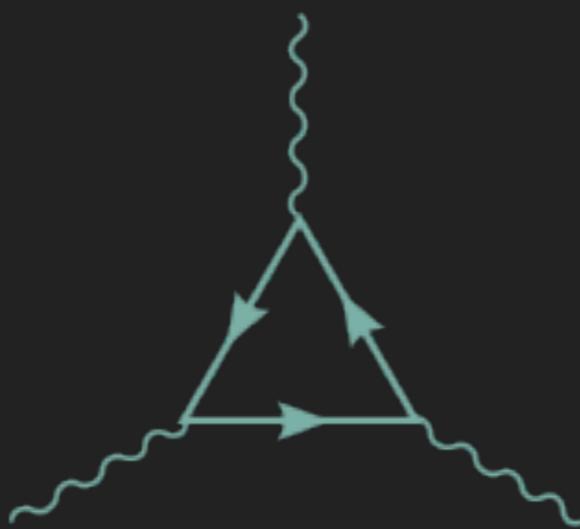
$$\mathcal{L}_{Z'}^{int} = Z'_\mu (g_{Z'}^{f_L} \bar{f}_L \gamma^\mu f_L + g_{Z'}^{f_R} \bar{f}_R \gamma^\mu f_R) = Z'_\mu \bar{f} \gamma^\mu (g_{Z'}^{f_V} - \gamma_5 g_{Z'}^{f_A}) f$$

Z' MODELS

- ▶ SM fermions may be charged under the new gauge symmetry, or acquire couplings through the kinetic/mass Z - Z' -photon mixing (Babu,Kolda,March-Russell, Phys. Rev. D **57**, 6788)
- ▶ Z' may acquire mass through spontaneous symmetry breaking or through the Stueckelberg mechanism (e.g. Feldman,Liu,Nath, Phys. Rev. D **75**, 115001)

U(1)' ANOMALIES

- ▶ Gauged U(1)' \rightarrow Anomaly cancellation
- ▶ Top-down approach : U(1)' from GUTs have no anomalies (e.g. SM obtained from SU(5), SO(10),...)
- ▶ Bottom-up : U(1)' anomaly cancellation conditions define possible models

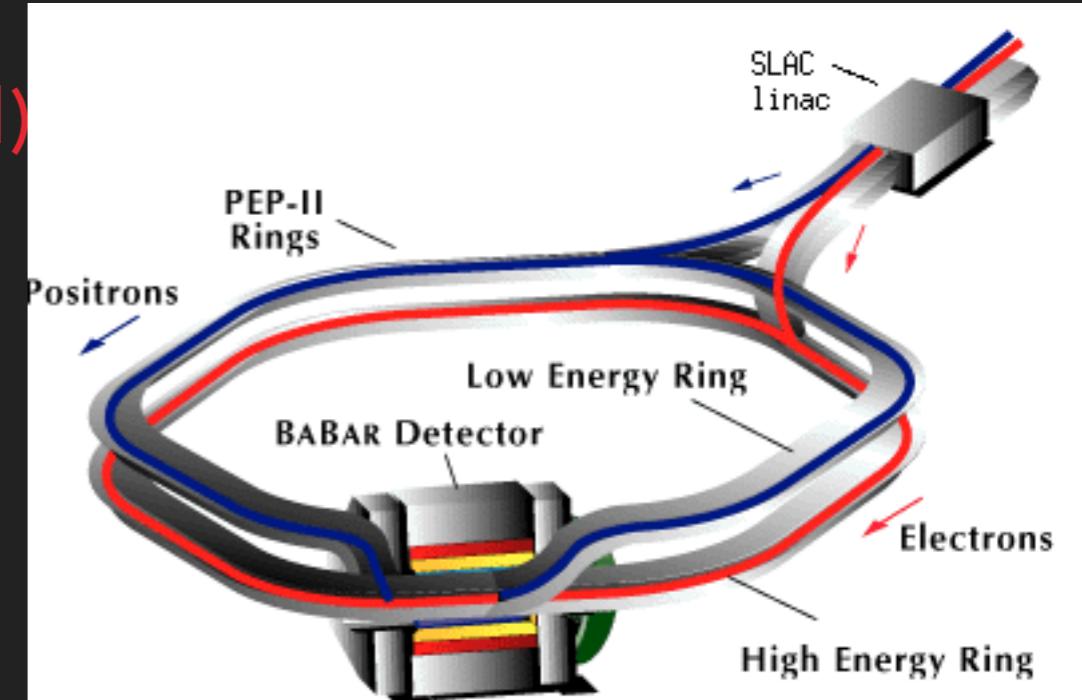


U(1)' ANOMALIES

- ▶ Some anomaly free (vector-like) U(1)' charge assignments:
 - $B - L$
 - $B - 2L_\alpha - L_\beta$
 - $B - 3L_\alpha$
 - $L_\alpha - L_\beta$
 - Dark charge

EXPERIMENTAL EFFECTS OF A Z'

- ▶ BaBar (BaBar collaboration, J. P. Lees et al., Phys. Rev. Lett. 113 (2014) 201801)
- ▶ $e^-e^+ \rightarrow \gamma Z' (\rightarrow e^-e^+/\mu^-\mu^+)$
- ▶ $g_{Z'}^e \neq 0$, $g_{Z'}^\mu \neq 0$ (for muon final state channel)



EXPERIMENTAL EFFECTS OF A Z'

- ▶ LHCb (LHCb collaboration, R. Aaij et al., Phys. Rev. Lett. 120, 061801 (2018))
- ▶ $pp \rightarrow \dots (Z' \rightarrow \mu^-\mu^+)$
- ▶ ($g_{Z'}^u \neq 0$ and/or $g_{Z'}^d \neq 0$) and $g_{Z'}^\mu \neq 0$



EXPERIMENTAL EFFECTS OF A Z'

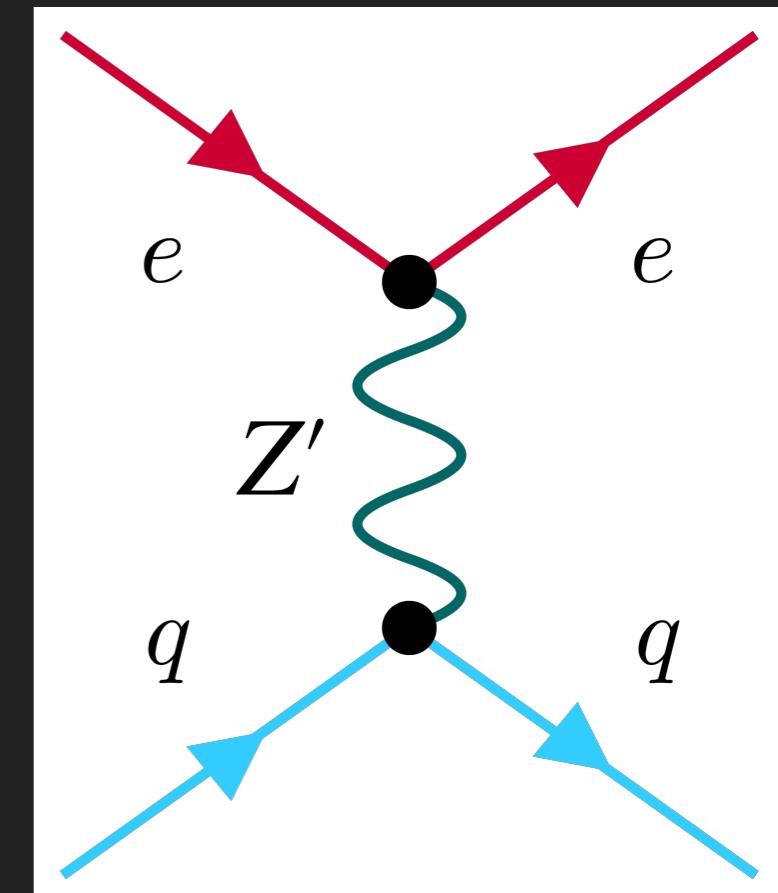
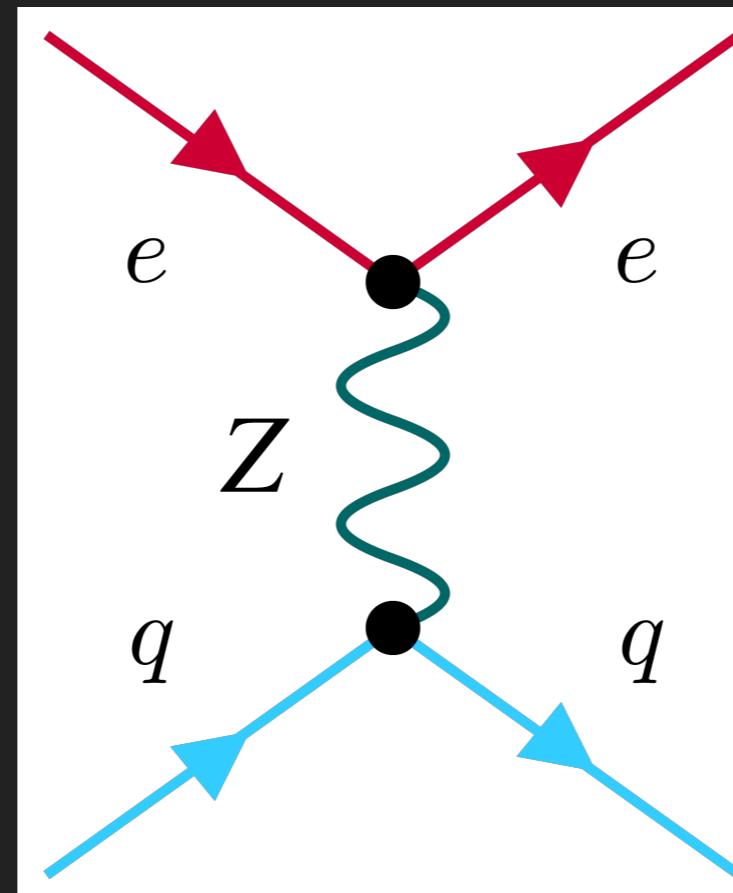
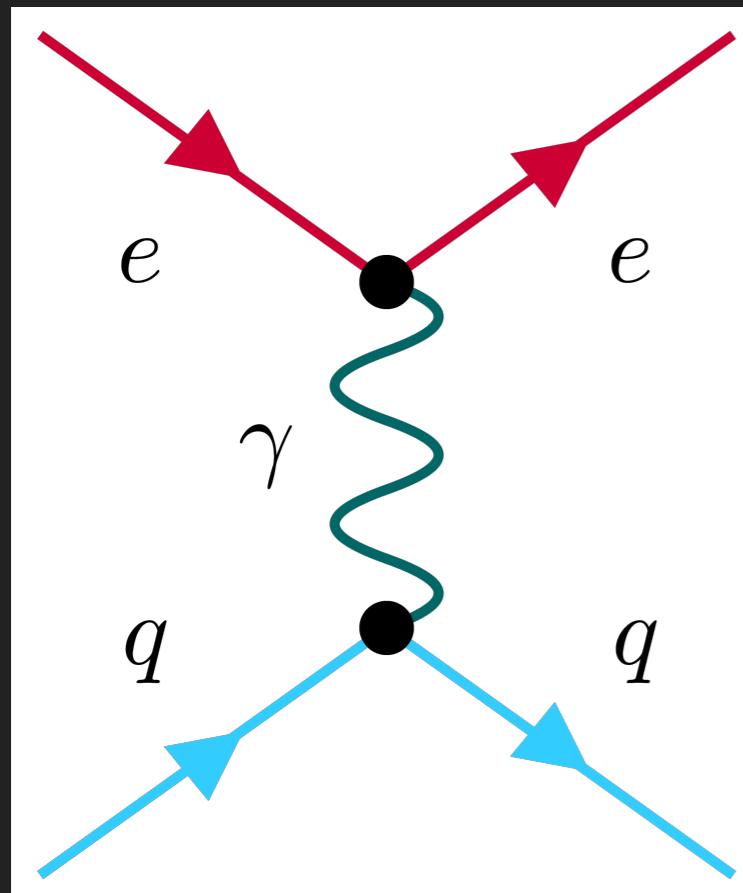
- ▶ Beam dumps
- ▶ Electrons: $e^- N_Z \rightarrow e^- N_Z Z' (\rightarrow e^- e^+)$
- ▶ ($g_{Z'}^u \neq 0$ and/or $g_{Z'}^d \neq 0$) and $g_{Z'}^e \neq 0$
- ▶ E141, E137, E774, NA64, KEK, ...
- ▶ Protons: $\pi^0 \rightarrow \gamma Z' (\rightarrow e^+ e^-)$
- ▶ ($g_{Z'}^u \neq 0$ and/or $g_{Z'}^d \neq 0$) and $g_{Z'}^e \neq 0$
- ▶ ν -CALT, NOMAD

LIGHT NEW PHYSICS

PV SCATTERING

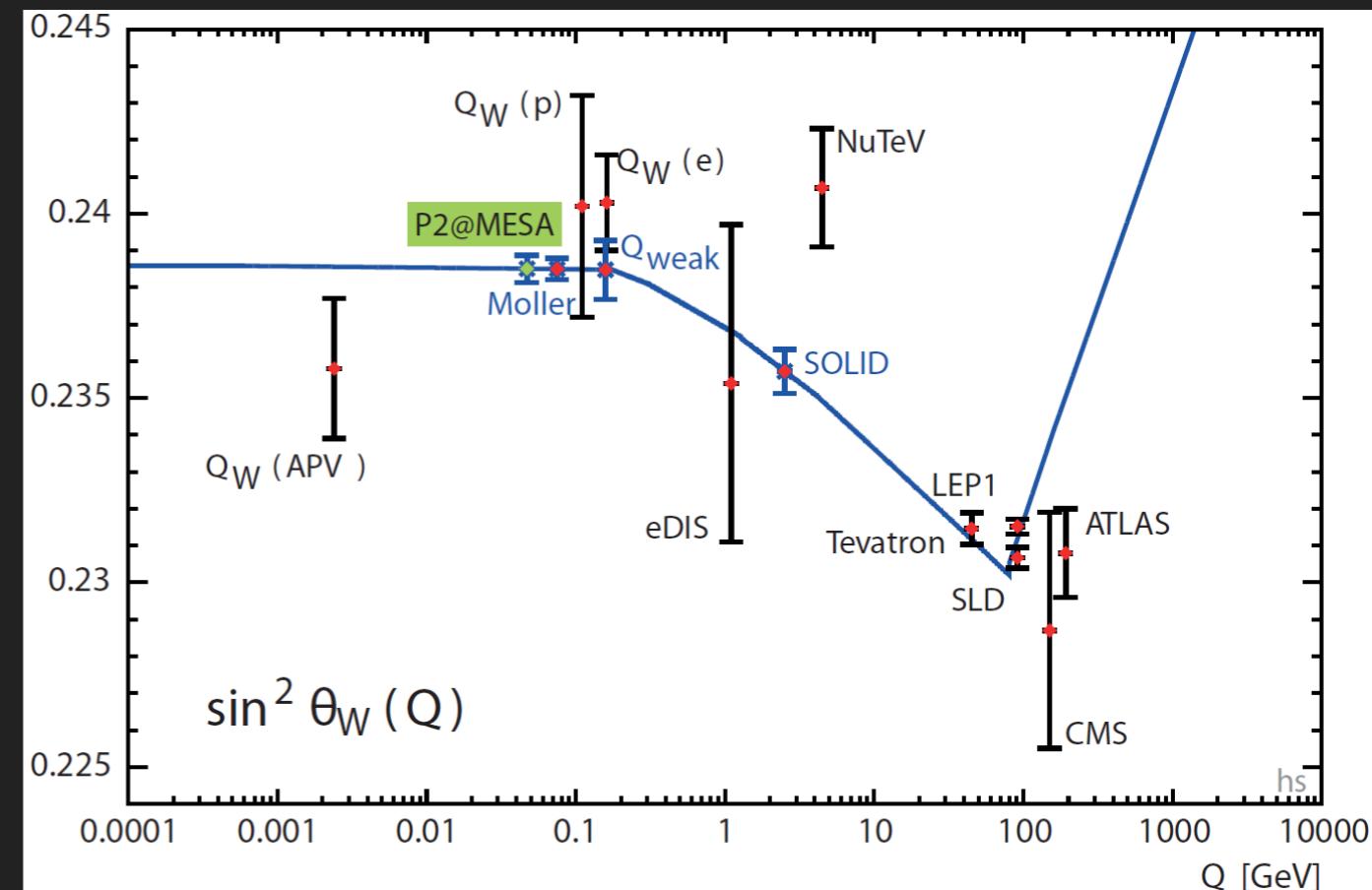
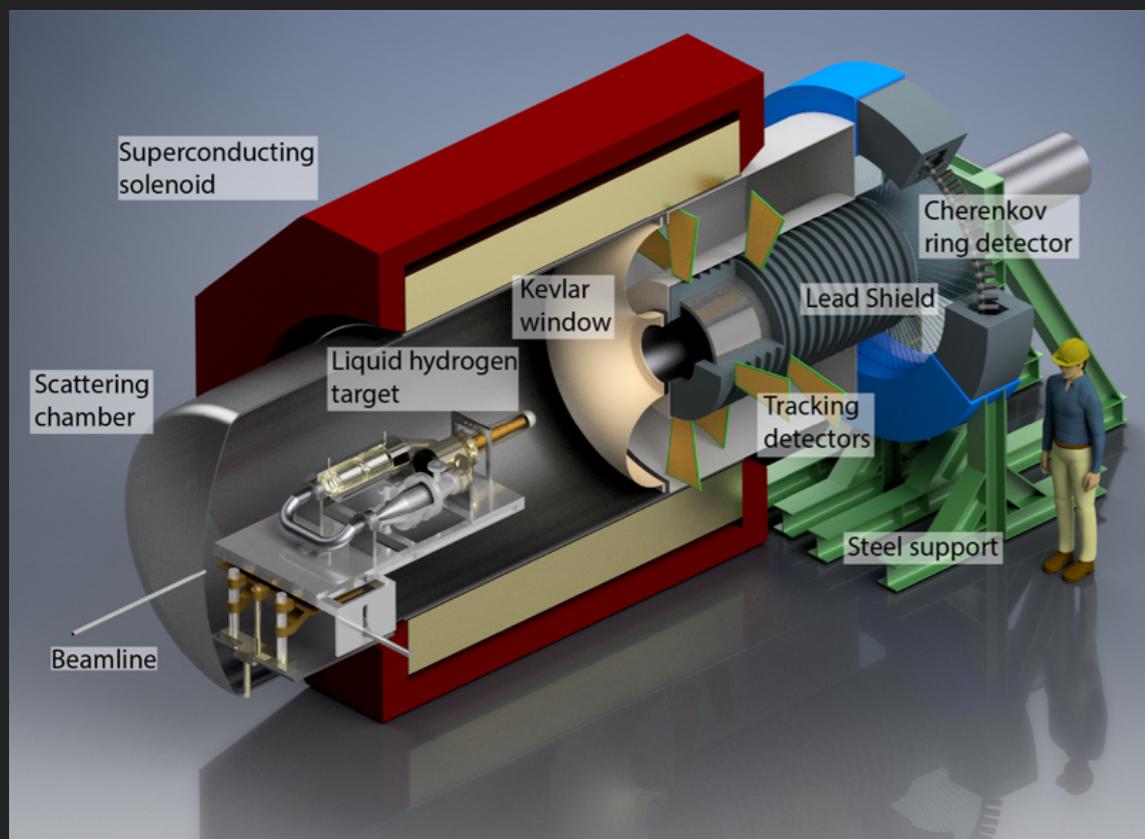
- ▶ Polarized electron-Nucleus scattering

$$A_{PV} \sim \frac{\sigma_L - \sigma_R}{\sigma_L + \sigma_R}$$



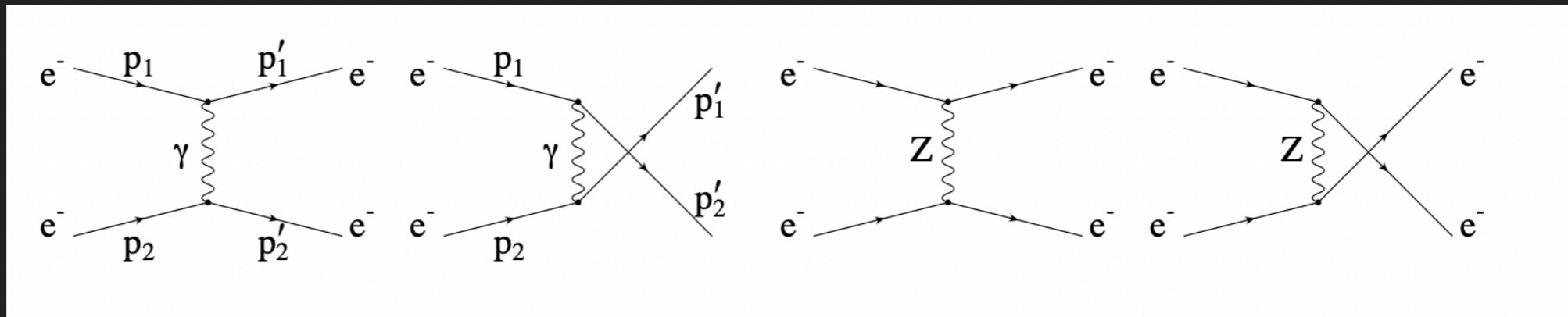
LIGHT NEW PHYSICS

PARITY VIOLATION AT LOW ENERGIES

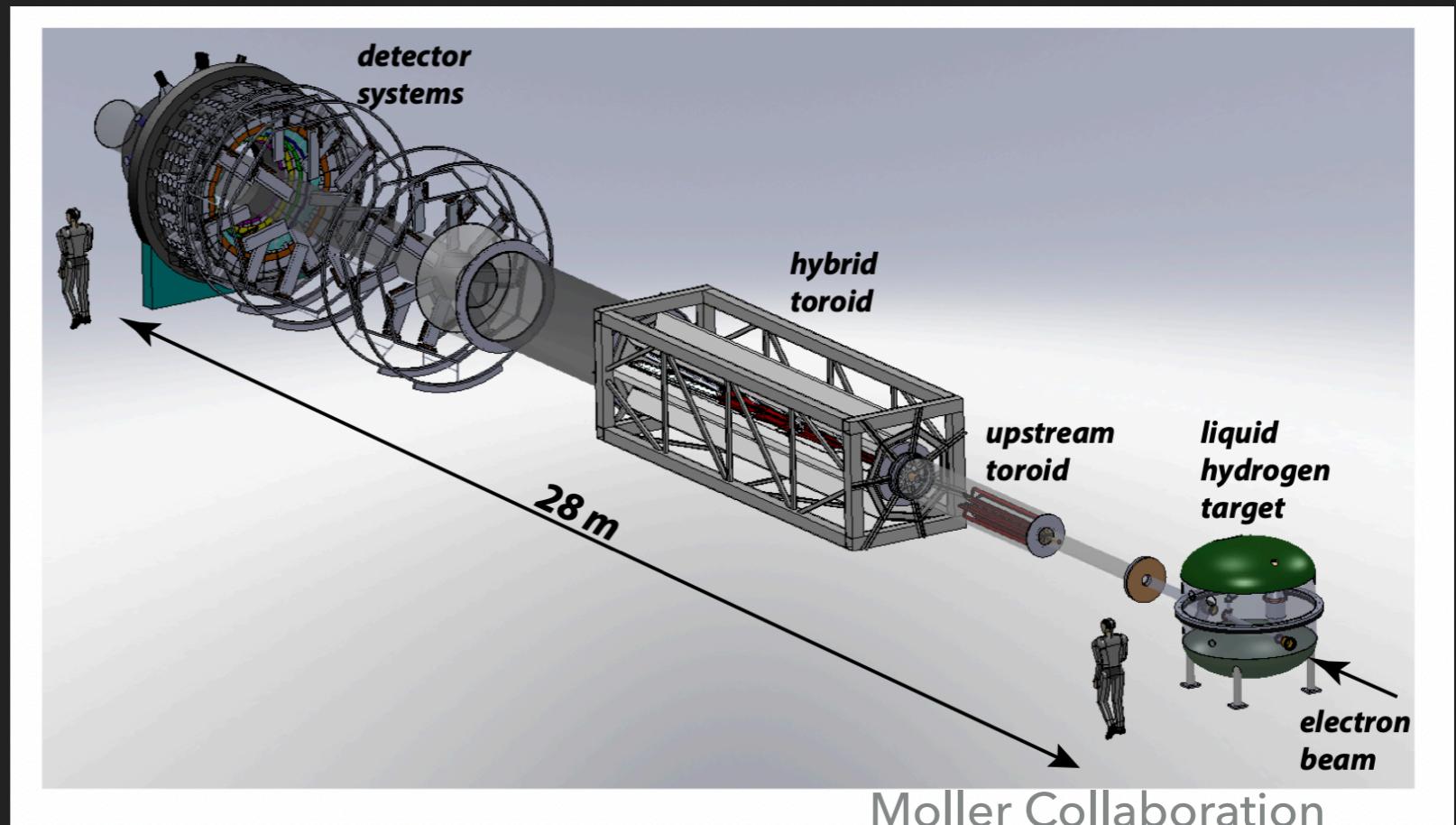


- ▶ P2 experiment @ MESA
- ▶ 155 MeV Polarized electron - Nucleus scattering

LIGHT NEW PHYSICS

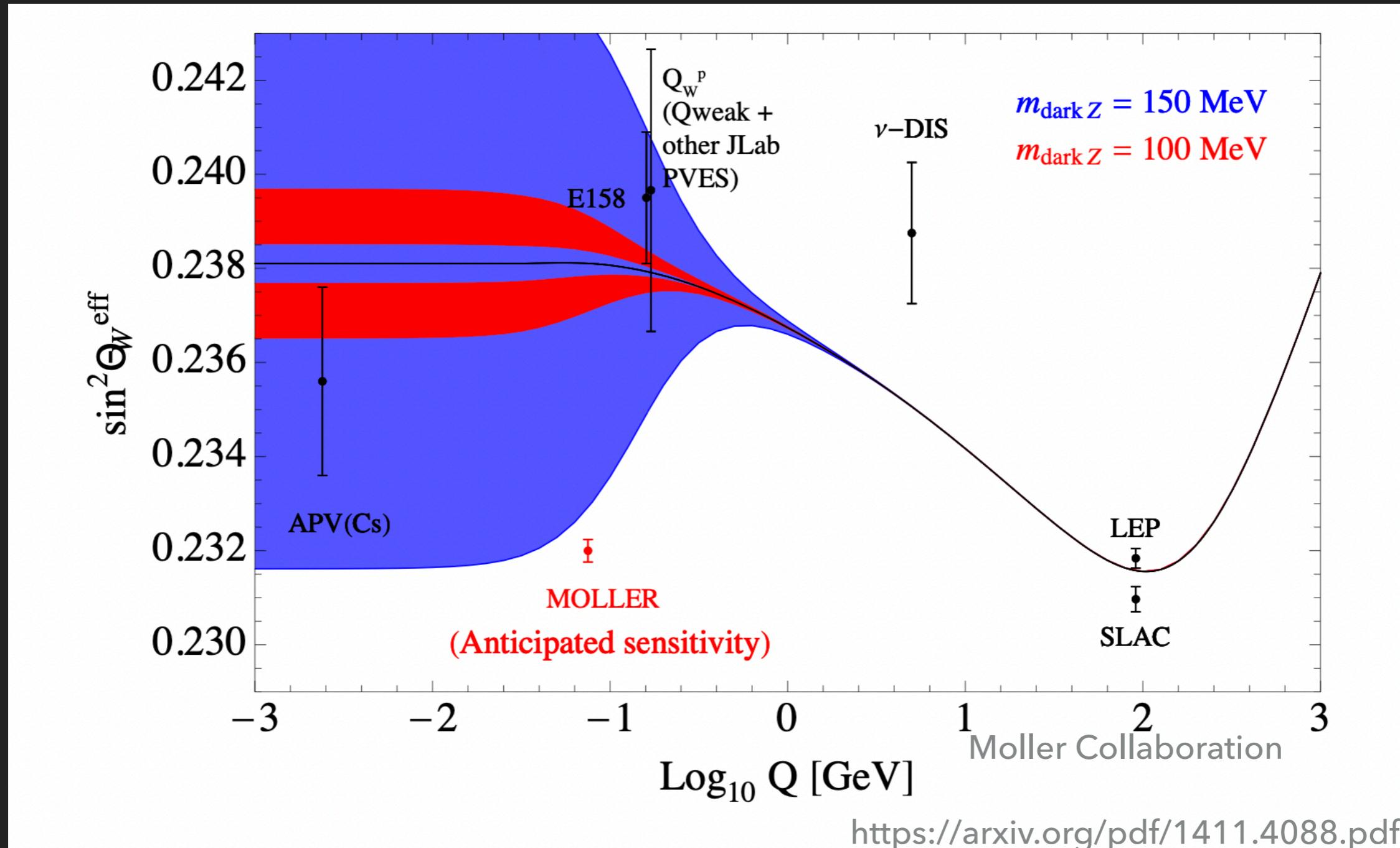


- ▶ Moller @ JLab
- ▶ Polarized electron scattering on unpolarized electrons



LIGHT NEW PHYSICS

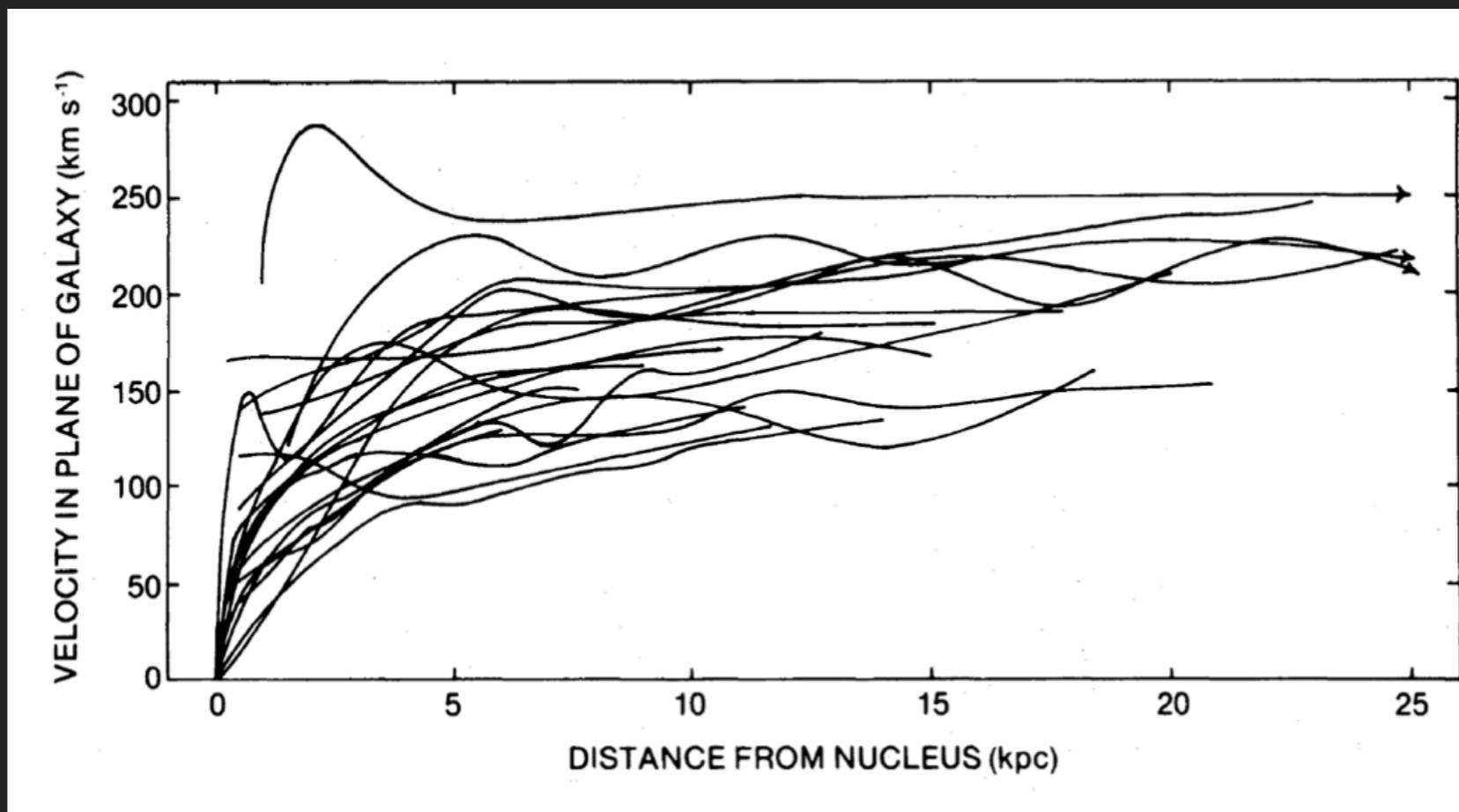
PARITY VIOLATION AT LOW ENERGIES



LIGHT DARK MATTER AND LOW ENERGY PHYSICS WITH A Z'

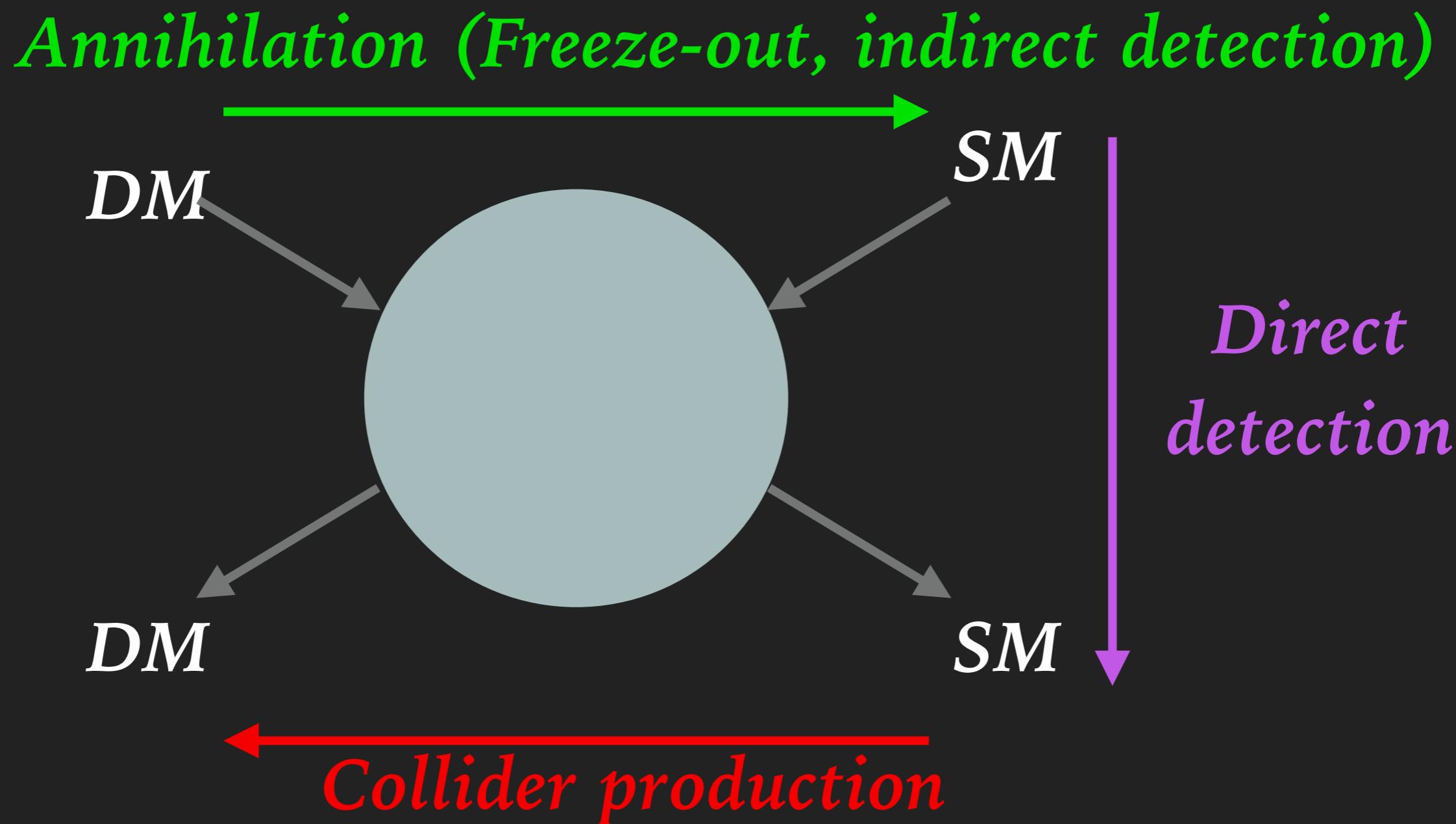
DARK MATTER

- ▶ ~ 27 % of Universe content is nonbaryonic matter
- ▶ We have only observed DM gravitationally
- ▶ Early Universe production mechanism?
- ▶ Short-range interaction with Baryonic Matter?



• V. C. Rubin, et. al., *Astrophys. J.*, 238:471, 1980.

DARK MATTER



LIGHT DARK MATTER AND LOW ENERGY PHYSICS WITH A Z'

DARK U(1)'

- ▶ To evade experimental limits if SM is charged: $\sim g' < 10^{-4}$
- ▶ A natural explanation for small SM couplings can be that they arise from Z-Z' mass mixing

	L	N	N'	F	H_1	H_2	ϕ	χ_L	χ_R^c
$SU(2)_L$	2	1	1	1	2	2	1	1	1
$U(1)_Y$	$-1/2$	0	0	0	$1/2$	$1/2$	0	0	0
$U(1)_D$	0	1	-1	0	0	1	-1	Q_D	$-Q_D$

- ▶ RHN, DM charged under U(1)'
- ▶ SM not charged under U(1)', no anomalies
 - ▶ LMGDLV, E. Peinado, J. Wudka , arXiv:2210.14863

LIGHT DARK MATTER AND LOW ENERGY PHYSICS WITH A Z'

DARK U(1)'

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$$m_{\tilde{Z} X}^2 = \frac{1}{4} \begin{pmatrix} g_z^2 v_{\text{SM}}^2 & -2v_2^2 g_D g_z \\ -2v_2^2 g_D g_z & 4g_D^2(v_2^2 + v_\phi^2) \end{pmatrix}$$

- ▶ RHN and scalar charges result in seesaw neutrino masses
- ▶ H_2 charged under $U(1)_D$ induces Z-Z' mixing -> small SM couplings to Z'
- ▶ LMGDLV, E. Peinado, J. Wudka , arXiv:2210.14863

LIGHT DARK MATTER AND LOW ENERGY PHYSICS WITH A Z'

DARK U(1)'

- ▶ Physical gauge bosons couple to both SM and dark currents

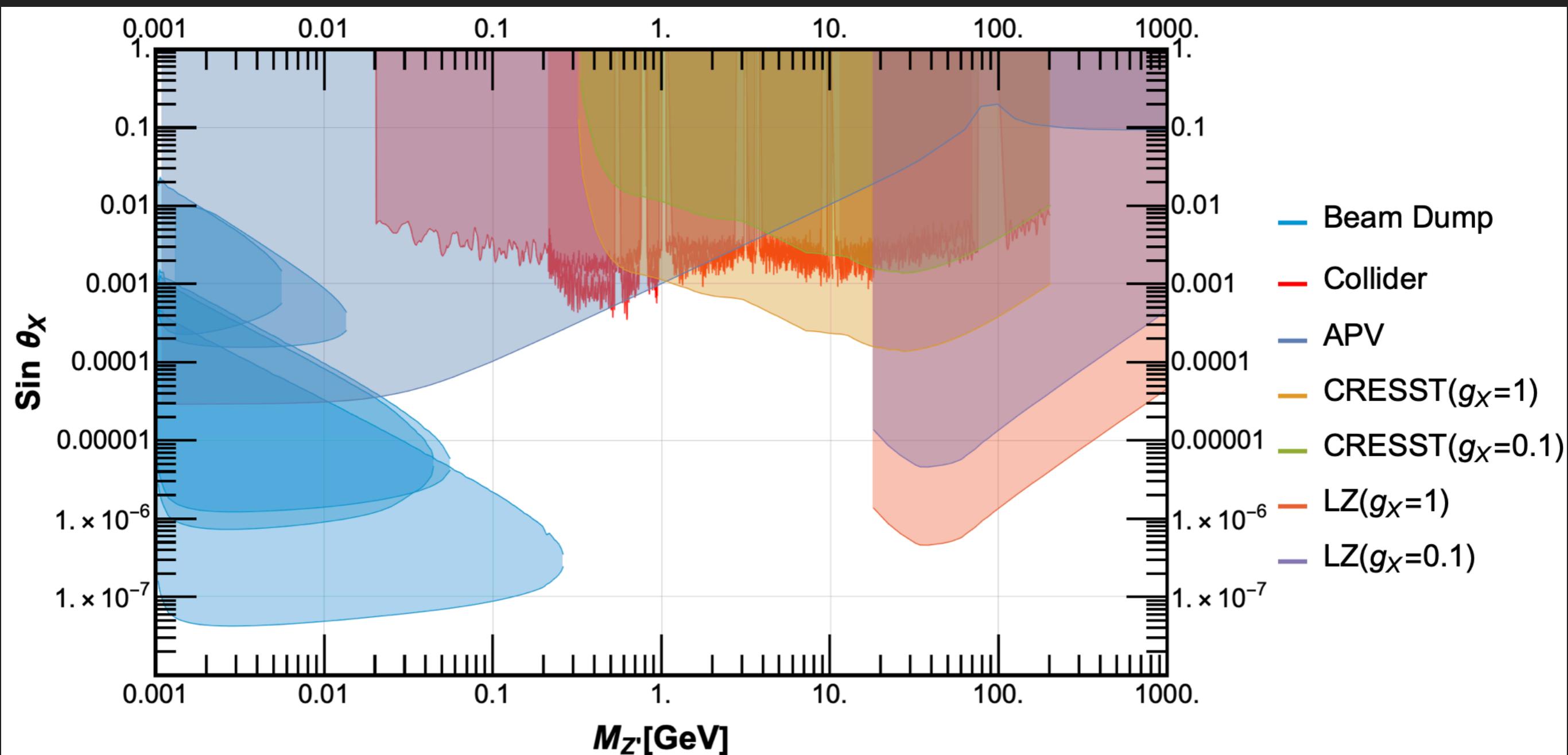
$$\mathcal{L}_{\text{NC}} = -e J_{\text{EM}}^\mu A^\mu - Z_\mu (\cos \theta_X \frac{g_z}{2} J_{\text{NC}}^\mu + \sin \theta_X g_D J_{\text{DC}}^\mu) - Z'_\mu (-\sin \theta_X \frac{g_z}{2} J_{\text{NC}}^\mu + \cos \theta_X g_D J_{\text{DC}}^\mu)$$

$$J_{\text{NC}}^\mu = \sum t_L^3(r) \bar{f}_r \gamma^\mu (1 - \gamma^5) f_r - 2 s_W^2 J_{\text{EM}}^\mu \quad , \quad J_{\text{DC}}^\mu = \frac{g_D}{3} \bar{\chi} \gamma^\mu \chi + g_D (\bar{N} \gamma^\mu N - \bar{N'} \gamma^\mu N')$$

- ▶ Z' inherits parity violating nature of Z couplings
- ▶ Sensitivity for light Z' in PV searches
- ▶ LMGDLV, E. Peinado, J. Wudka , arXiv:2210.14863

LIGHT DARK MATTER AND LOW ENERGY PHYSICS WITH A Z'

DARK $U(1)'$



LIGHT DARK MATTER AND LOW ENERGY PHYSICS WITH A Z'

DARK U(1)'

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- ▶ A natural explanation for small SM couplings can be that they arise from Z-Z' mass mixing

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- ▶ RHN, DM charged under U(1)'
- ▶ LMGDLV, E. Peinado, J. Wudka , arXiv:2210.14863

LIGHT DARK MATTER AND LOW ENERGY PHYSICS WITH A Z'

NEUTRINO SECTOR

► $\mathcal{L}_\nu = Y_1^\nu \overline{L} \tilde{H}_1 F + Y_2^\nu \overline{L} \tilde{H}_2 N + M_1 \overline{N^c} N' + Y^N \overline{N^c} F \phi + Y^{N'} \overline{N'^c} F \phi^* + M_F \overline{F^c} F + h.c.$

► In the (ν_L, N, N', F) basis:

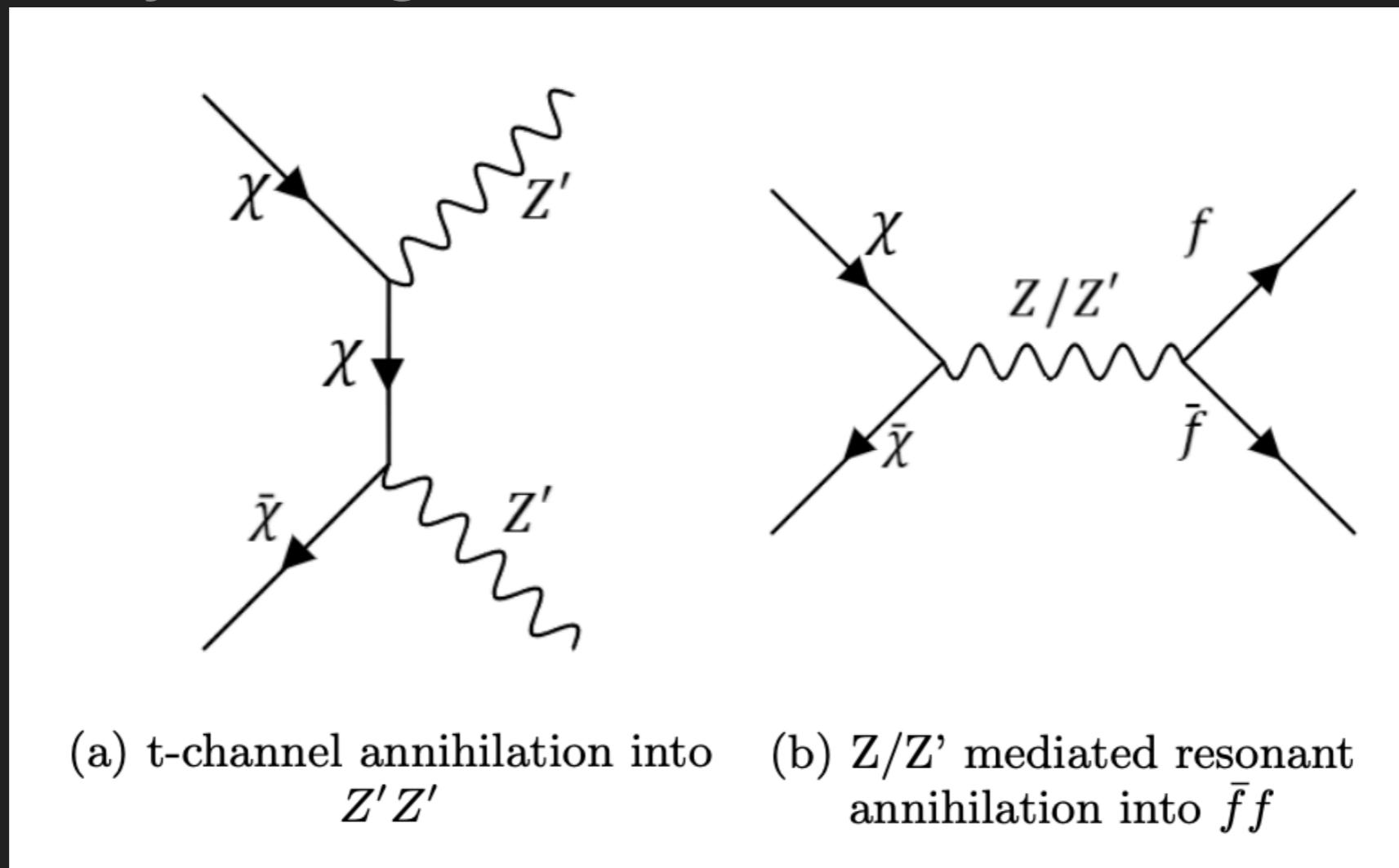
$$M = \begin{pmatrix} 0 & m_2^D & 0 & m_1^D \\ (m_2^D)^T & 0 & M_1 & Y^N v_\phi \\ 0 & (M_1)^T & 0 & Y^{N'} v_\phi \\ (m_1^D)^T & (Y^N)^T v_\phi & (Y^{N'})^T v_\phi & M_F \end{pmatrix}$$

► LMGDLV, E. Peinado, J. Wudka , arXiv:2210.14863

LIGHT DARK MATTER AND LOW ENERGY PHYSICS WITH A Z'

DARK MATTER PHENO

- ▶ Relic density through annihilation to Z' and SM fermions



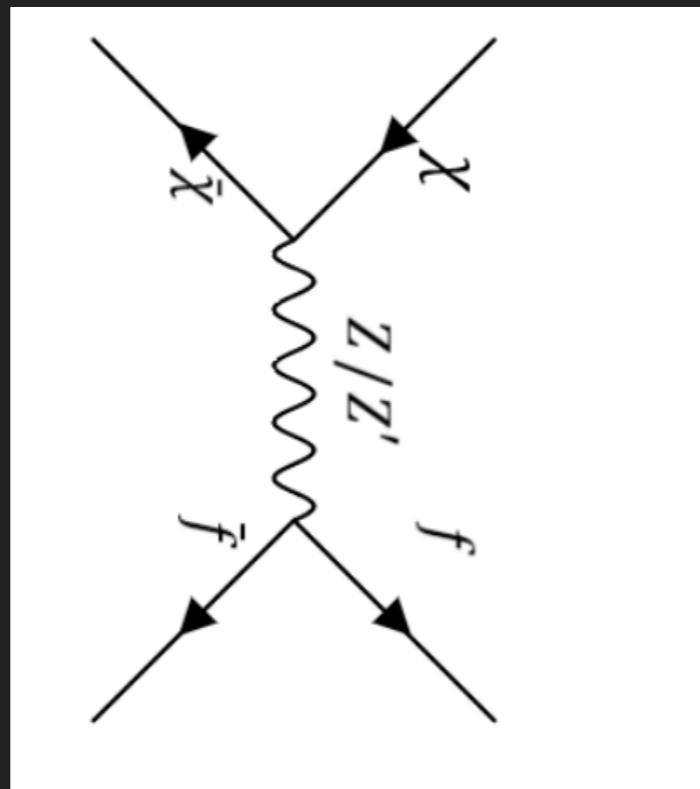
- ▶ LMGDLV, E. Peinado, J. Wudka , arXiv:2210.14863

LIGHT DARK MATTER AND LOW ENERGY PHYSICS WITH A Z'

DARK MATTER PHENO

- ▶ Direct detection through Z-Z' mixing

$$\sigma_{SI}^{Z,A} = \frac{\mu_{\chi N}^2 \sin^2 2\theta_X g_X^2 Q_\chi^2}{4\pi M_{Z'}^4} [Z(2g_{SM}^{Zu} + g_{SM}^{Zd}) + (A - Z)(g_{SM}^{Zu} + 2g_{SM}^{Zd})]$$



- ▶ LMGDLV, E. Peinado, J. Wudka , arXiv:2210.14863

DARK MATTER PHENO

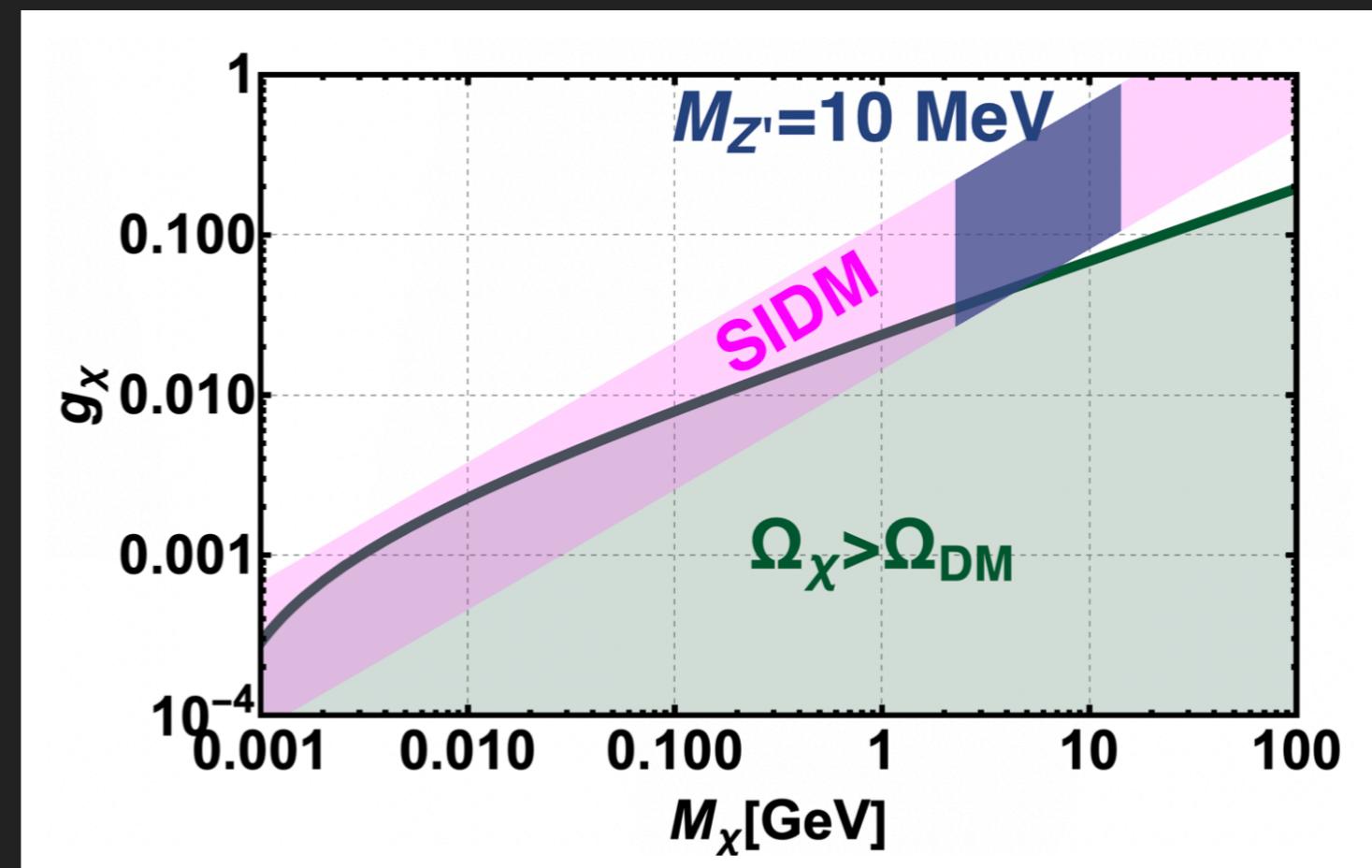
- ▶ Self Interacting Dark Matter
- ▶ Missing satellites problem
 - ▶ Numerical simulations of galaxy dynamics predict a larger number of subhalos (small satellite galaxies) than observed in the MW
- ▶ Cusp vs. Core
 - ▶ Numerical simulations of galaxy dynamics predict galaxy centers to be cuspier than observed

DARK MATTER PHENO

- ▶ Self Interacting Dark Matter
- ▶ Two possibilities:
 - ▶ Numerical simulations lack important details of baryonic matter dynamics
 - ▶ Numerical simulations lack important details of DM dynamics

DARK MATTER PHENO

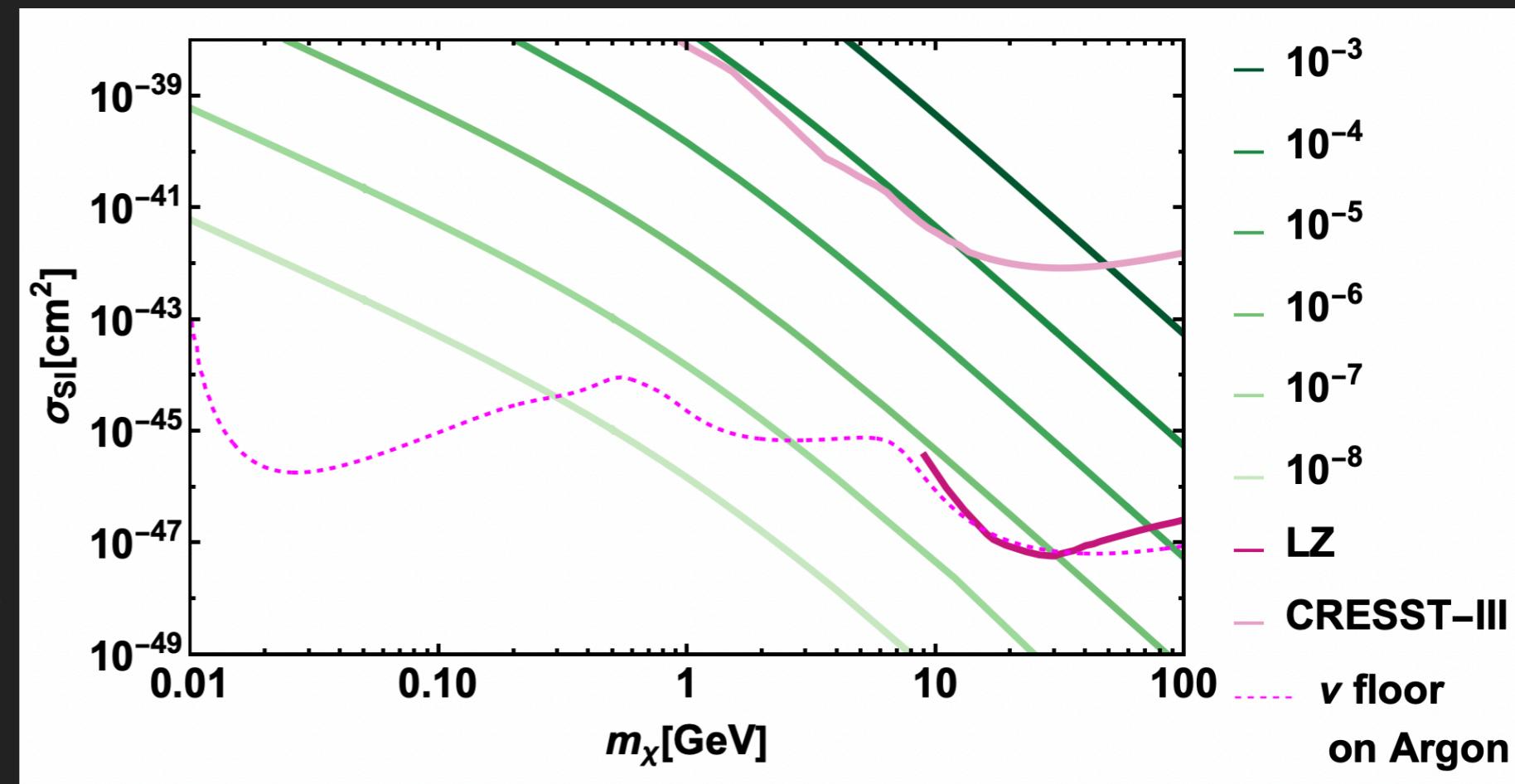
- ▶ t-channel annihilation relic density:
- ▶ SIDM with $M_{Z'} \sim 10 MeV$ but no prediction for Direct Detection
- ▶ LMGDLV, E. Peinado, J. Wudka , arXiv:2210.14863



LIGHT DARK MATTER AND LOW ENERGY PHYSICS WITH A Z'

DARK MATTER PHENO

- ▶ s-channel annihilation relic density:
- ▶ No SIDM scenario, but DD experiments can be sensitive to DM



- ▶ LMGDLV, E. Peinado, J. Wudka , arXiv:2210.14863

LIGHT DARK MATTER AND LOW ENERGY PHYSICS WITH A Z'

SUMMARY

- ▶ Parity Violation experiments & other low energy probes are powerful tools to explore light BSM constructions
- ▶ New Physics (and DM?) can live in MeV scale in simple but phenomenologically viable models