LEON MANUEL GARCIA DE LA VEGA

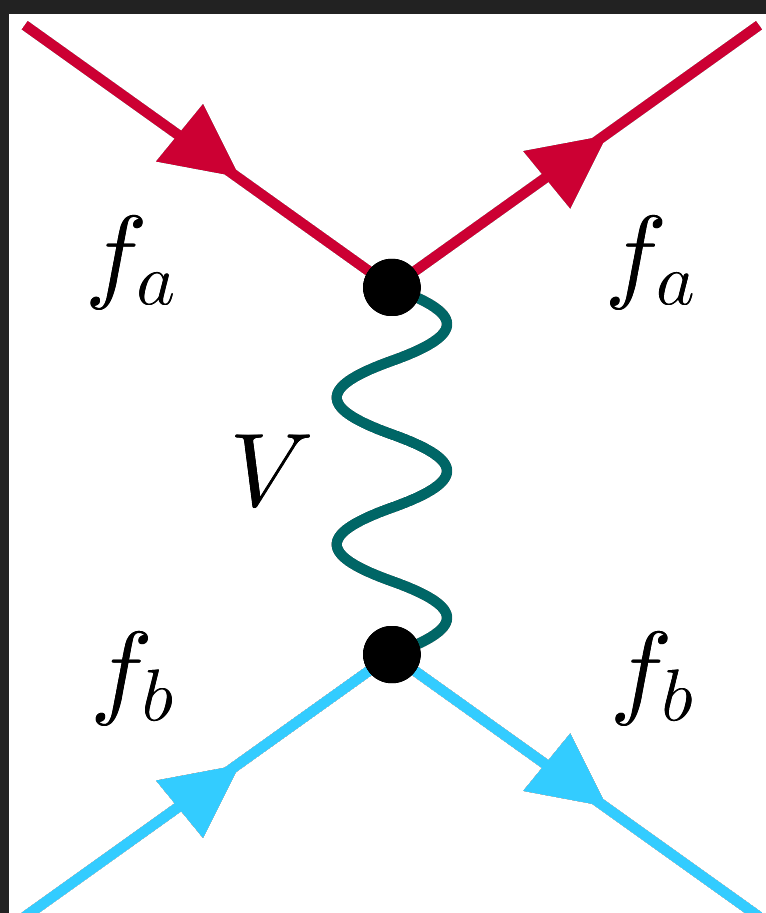
FISICA NUEVA EN EXPERIMENTOS DE BAJAS ENERGIAS EN MODELOS DE MATERIA OSCURA Y NEUTRINOS MASIVOS

LIGHT (VERY)-WEAKLY COUPLED NEW PHYSICS IN "LOW ENERGY" EXPERIMENTS

- 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 $f_a f_b \to f_a f_b$ scattering process in the t-channel



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

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

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

$m_V^2 >> t$

$m_V^2 \sim t\ ,\ g << 1$

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

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

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,…)
  - …

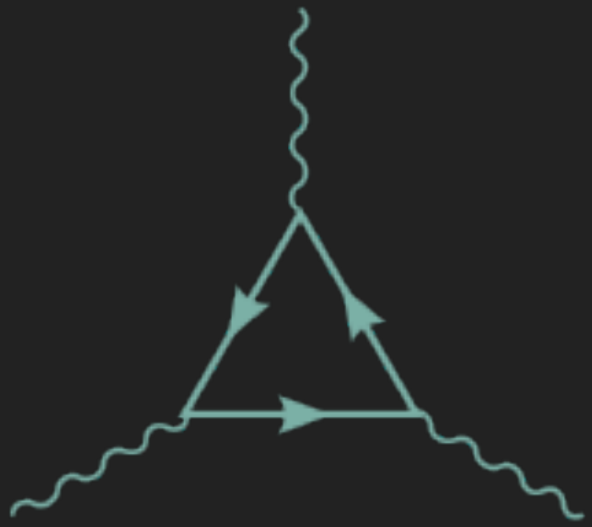
$$\mathscr{L}^{int}_{Z'} = Z'_\mu (g^{f_L}_{Z'} \bar{f}_L \gamma^\mu f_L + g^{f_R}_{Z'} \bar{f}_R \gamma^\mu f_R) = Z'_\mu \bar{f} \gamma^\mu (g^{f_V}_{Z'} - \gamma_5 g^{f_A}_{Z'}) f$$

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)′ -> 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

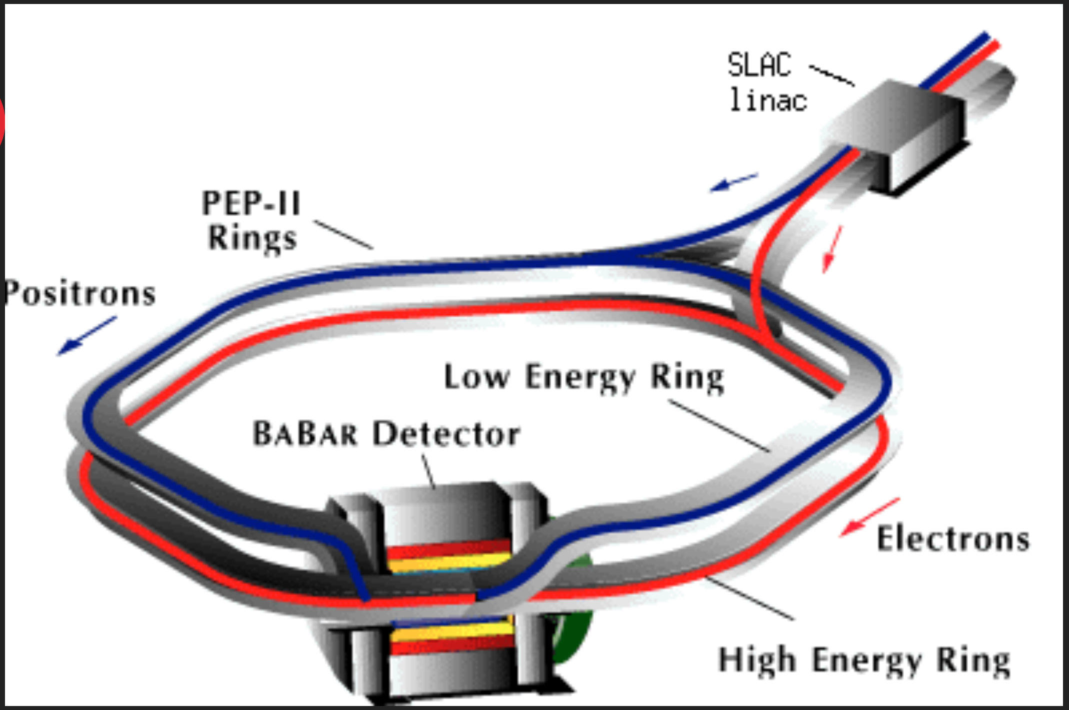


U(1)' ANOMALIES

- 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)
- $e^-e^+ \to \gamma Z'(\to e^-e^+/\mu^-\mu^+)$
- $g^e_{Z'} \neq 0\,,\, g^\mu_{Z'} \neq 0$ (for muon final state channel)



EXPERIMENTAL EFFECTS OF A Z'

- LHCb (LHCb collaboration, R. Aaij et al., Phys. Rev. Lett. 120, 061801 (2018))
- $pp \to \ldots (Z' \to \mu^- \mu^+)$
- ($g^u_{Z'} \neq 0$ and/or $g^d_{Z'} \neq 0$) and $g^\mu_{Z'} \neq 0$

EXPERIMENTAL EFFECTS OF A Z'

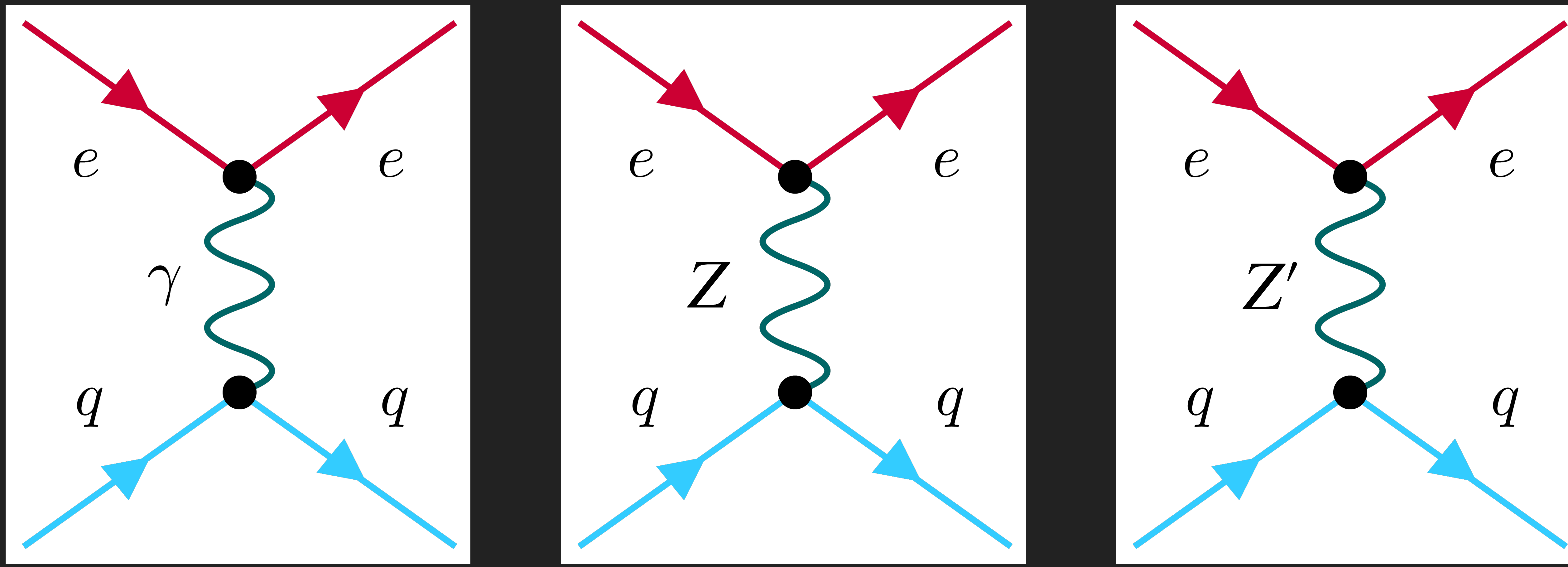
- Beam dumps
  - Electrons: $e^- N_Z \to e^- N_Z Z'(\to e^- e^+)$
  - ($g_{Z'}^u \neq 0$ and/or $g_{Z'}^d \neq 0$) and $g_{Z'}^e \neq 0$
  - E141,E137,E774,NA64, KEK,…
  - Protons: $\pi^0 \to \gamma Z'(\to e^+ e^-)$
  - ($g_{Z'}^u \neq 0$ and/or $g_{Z'}^d \neq 0$) and $g_{Z'}^e \neq 0$
  - ν-CAL I ,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

LIGHT NEW PHYSICS

PV SCATTERING

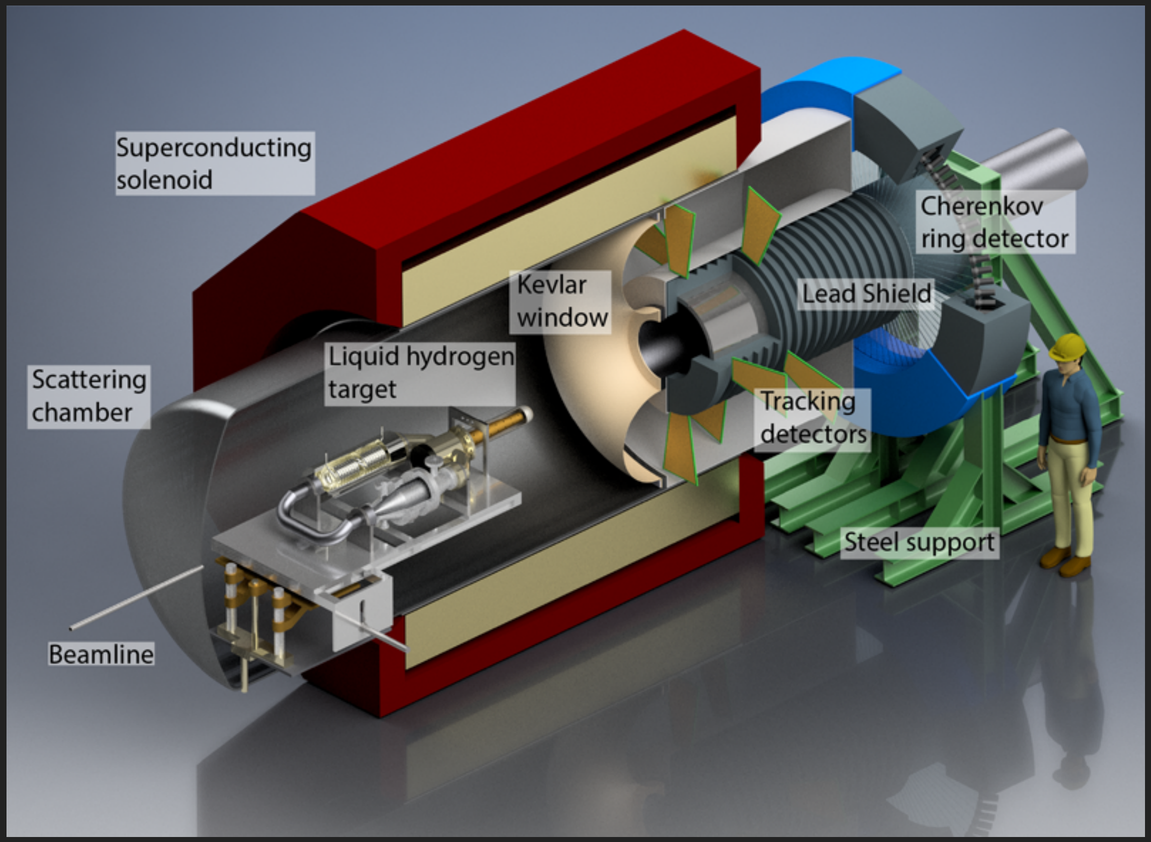
- Polarized electron-Nucleus scattering

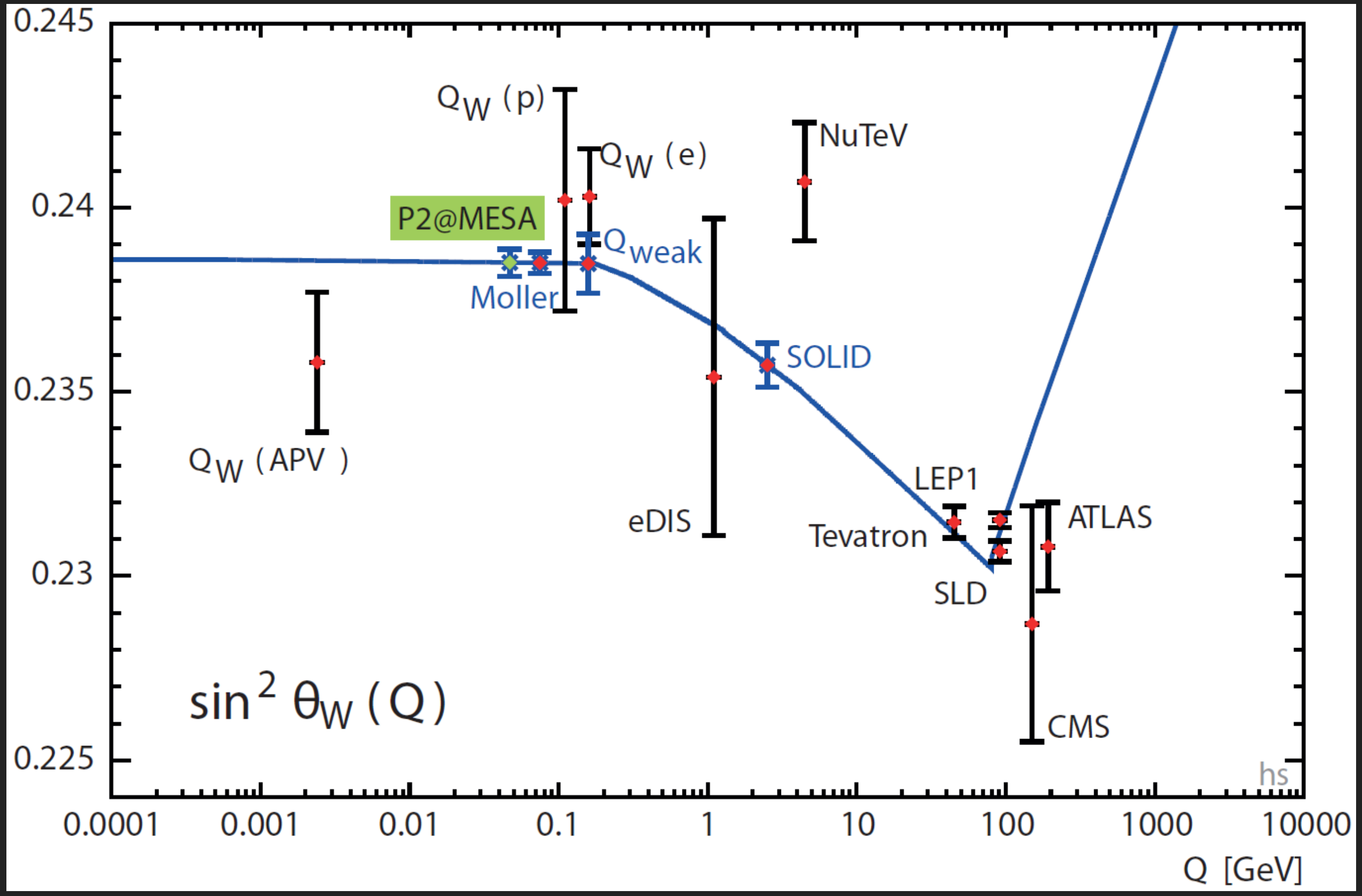
$$A_{PV} \sim \frac{\sigma_L - \sigma_R}{\sigma_L + \sigma_R}$$



LIGHT NEW PHYSICS

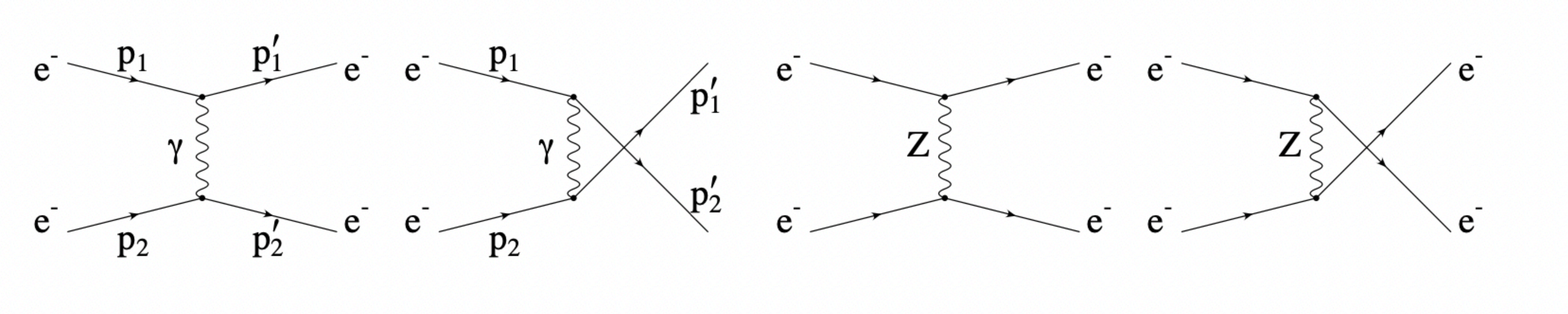
PARITY VIOLATION AT LOW ENERGIES



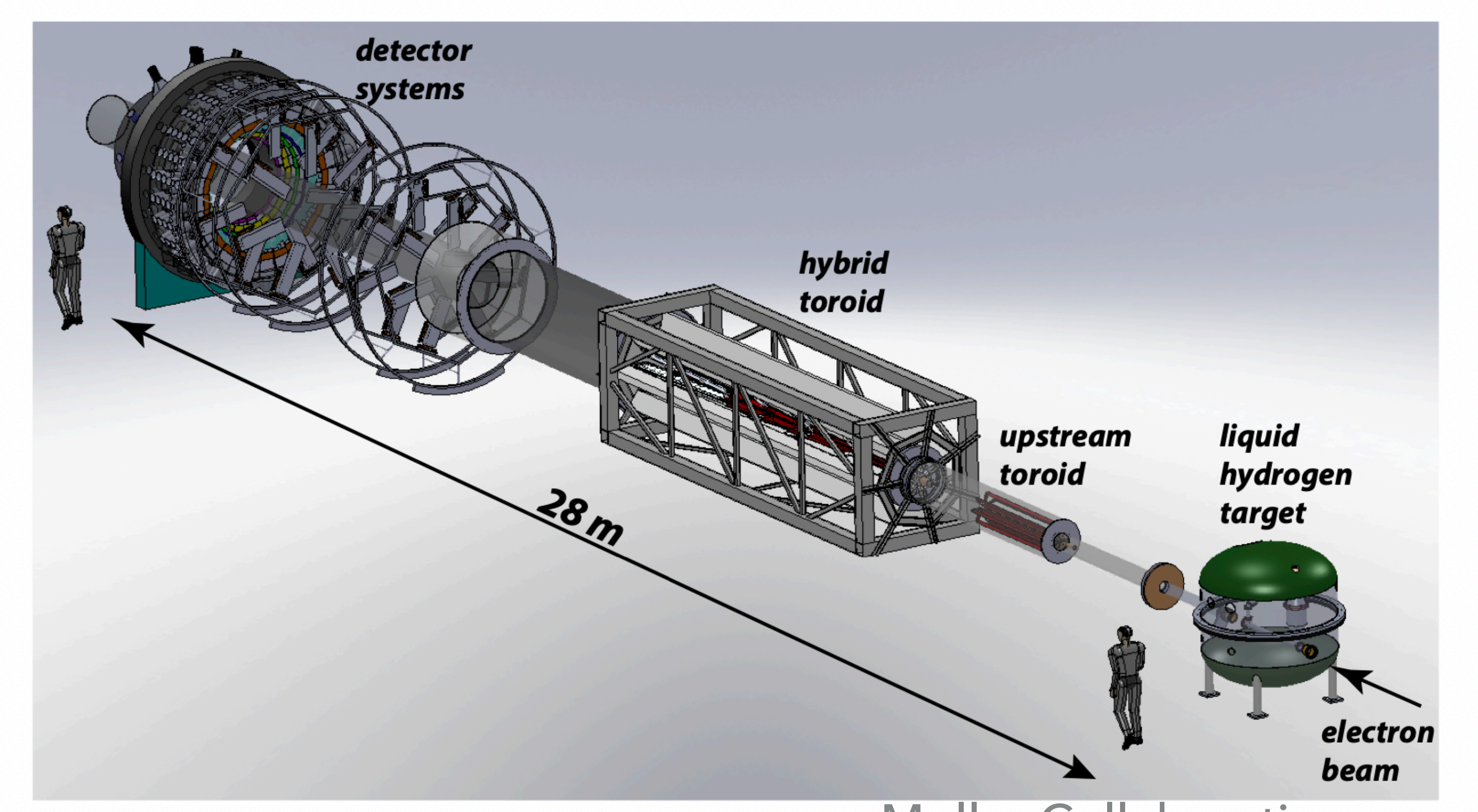


- P2 experiment @ MESA
- 155 MeV Polarized electron - Nucleus scattering

LIGHT NEW PHYSICS



- Moller @ JLab
- Polarized electron scattering on unpolarized electrons

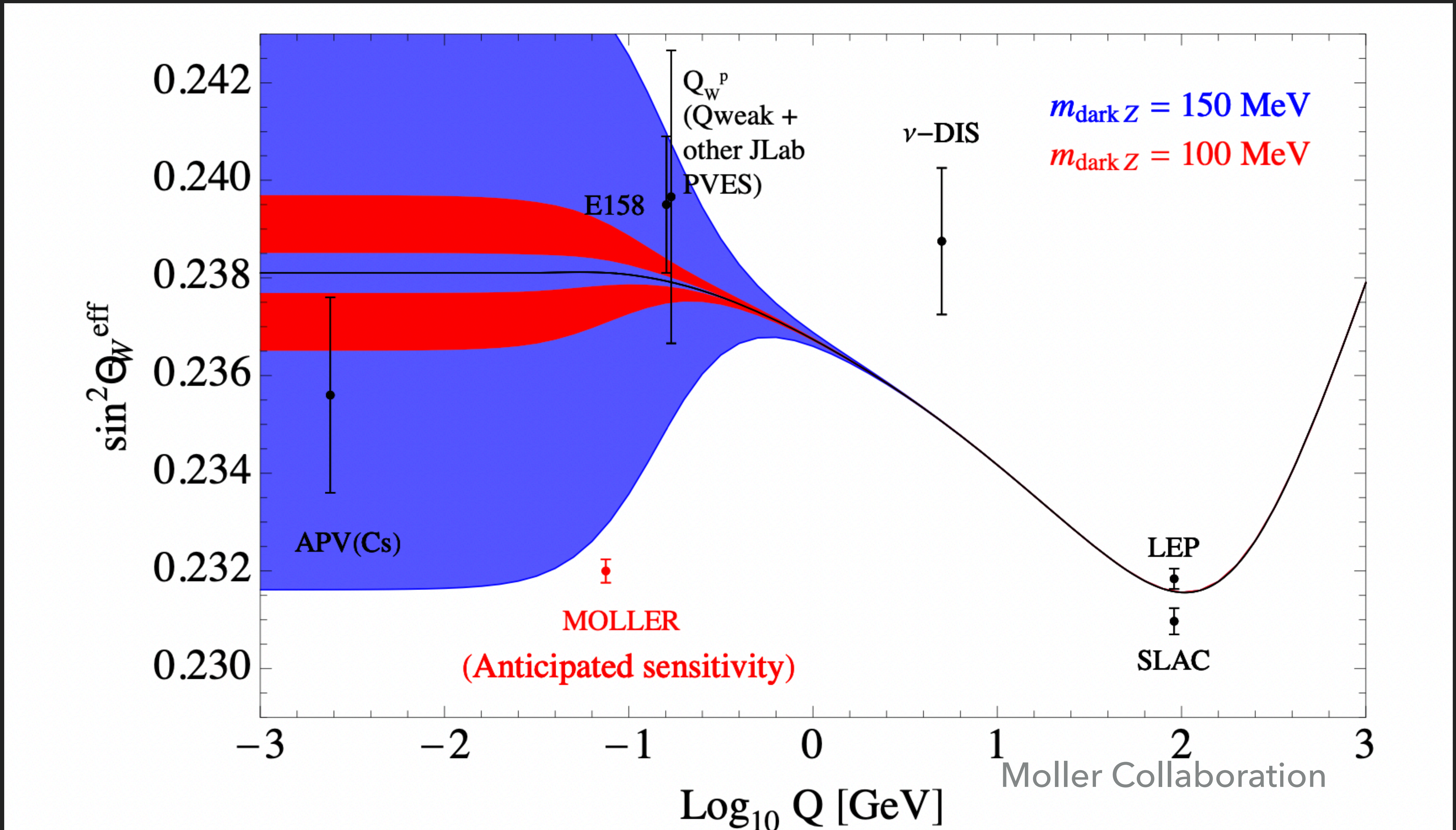


Moller Collaboration

https://arxiv.org/pdf/1411.4088.pdf

LIGHT NEW PHYSICS

PARITY VIOLATION AT LOW ENERGIES



Moller Collaboration

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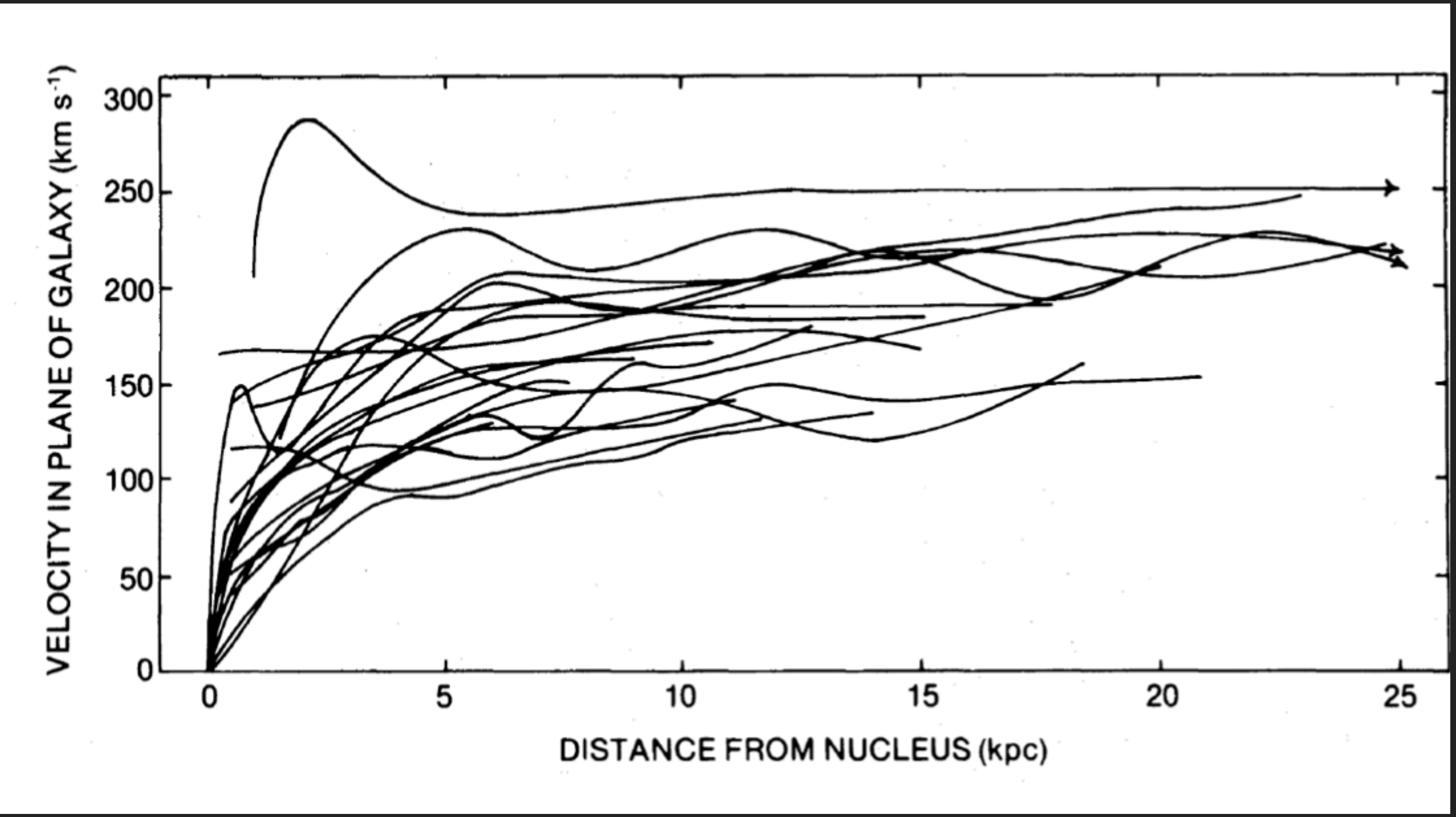
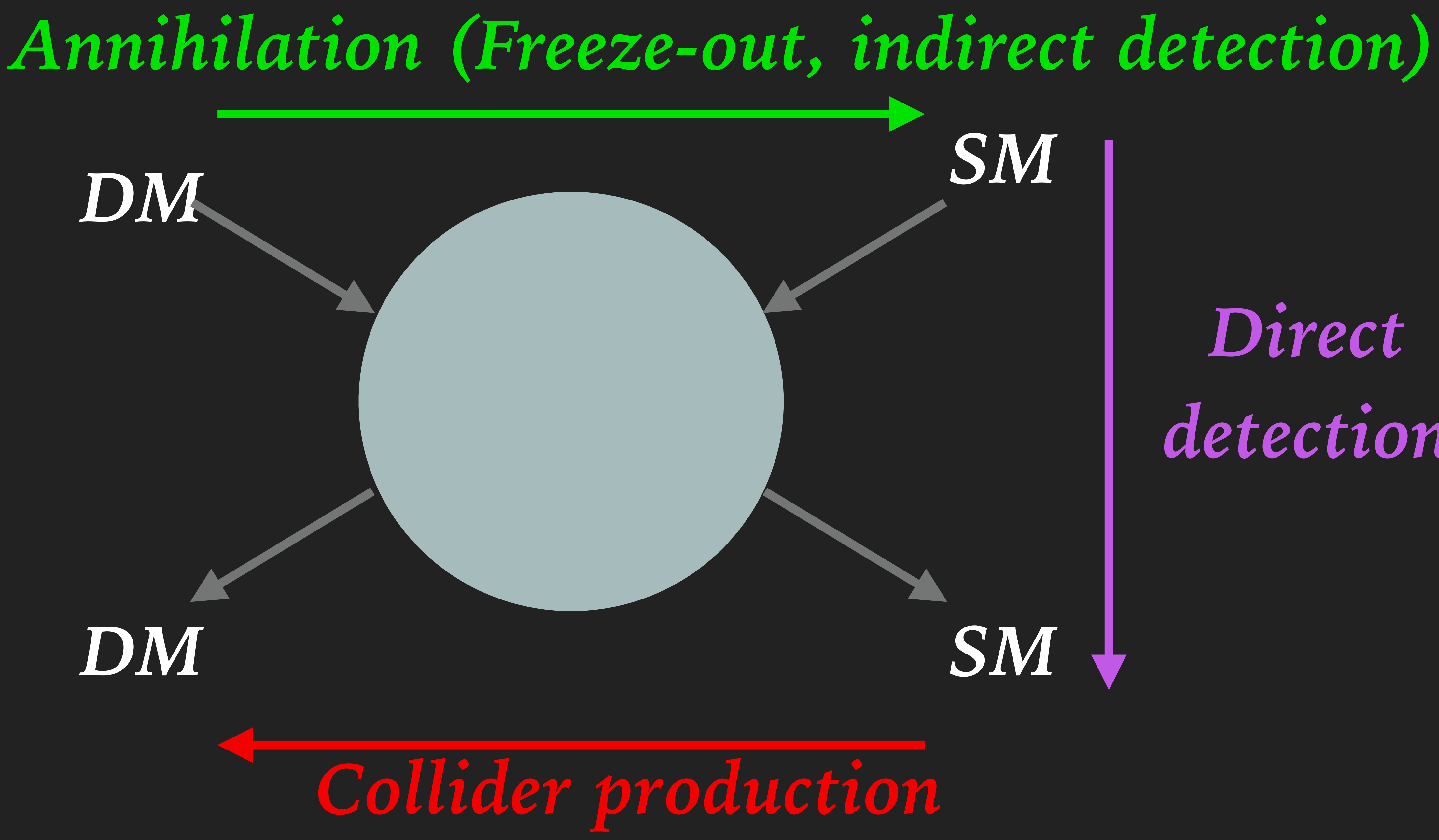
DARK MATTER

- $\sim 27\,\%$ 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


Annihilation (Freeze-out, indirect detection)
DM
SM
DM
SM
Direct detection
Collider production

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)'
  - LMGDLV, E. Peinado, J. Wudka , arXiv:2210.14863

DARK U(1)'

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$U(1)_D$	0	1	-1	0	0	1	-1	$Q_{\rm D}$	$-Q_{\rm D}$

$$m^2_{\tilde{Z}\,X} = \frac{1}{4}\begin{pmatrix} g_{\rm z}^2 v_{\rm SM}^2 & -2v_2^2\, g_{\rm D} g_{\rm z} \\ -2v_2^2\, g_{\rm D} g_{\rm z} & 4g_{\rm D}^2(v_2^2 + v_\phi^2)) \end{pmatrix}$$

- 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

DARK U(1)'

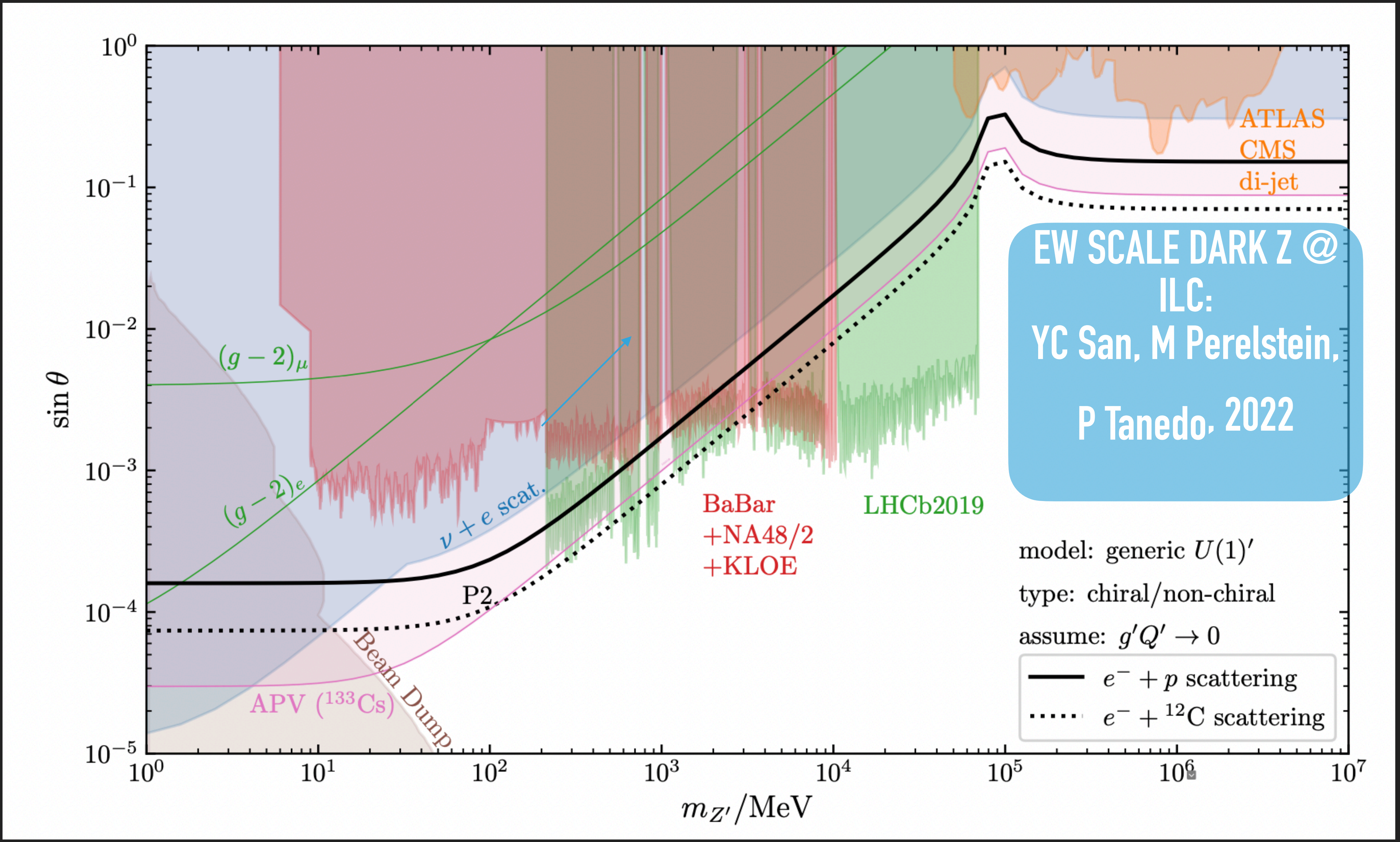
- Physical gauge bosons couple to both SM and dark currents

$$\mathcal{L}_{\mathrm{NC}} = -eJ^{\mu}_{\mathrm{EM}}A^{\mu} - Z_{\mu}(\cos\theta_{\mathrm{X}}\frac{g_{\mathrm{Z}}}{2}J^{\mu}_{\mathrm{NC}} + \sin\theta_{\mathrm{X}}g_{\mathrm{D}}J^{\mu}_{\mathrm{DC}}) - Z'_{\mu}(-\sin\theta_{\mathrm{X}}\frac{g_{\mathrm{Z}}}{2}J^{\mu}_{\mathrm{NC}} + \cos\theta_{\mathrm{X}}g_{\mathrm{D}}J^{\mu}_{\mathrm{DC}})$$

$$J^{\mu}_{\mathrm{NC}} = \sum t^3_L(r)\overline{f}_r\gamma^{\mu}(1-\gamma^5)f_r - 2s^2_W J^{\mu}_{\mathrm{EM}} \quad , \quad J^{\mu}_{\mathrm{DC}} = \frac{g_{\mathrm{D}}}{3}\overline{\chi}\gamma^{\mu}\chi + g_{\mathrm{D}}(\overline{N}\gamma^{\mu}N - \overline{N'}\gamma^{\mu}N')$$

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

DARK U(1)'



P. S. Bhupal Dev,
W.Rodejohann,
XJ Xu,
Y Zhang,2021

DARK U(1)'

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

NEUTRINO SECTOR

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

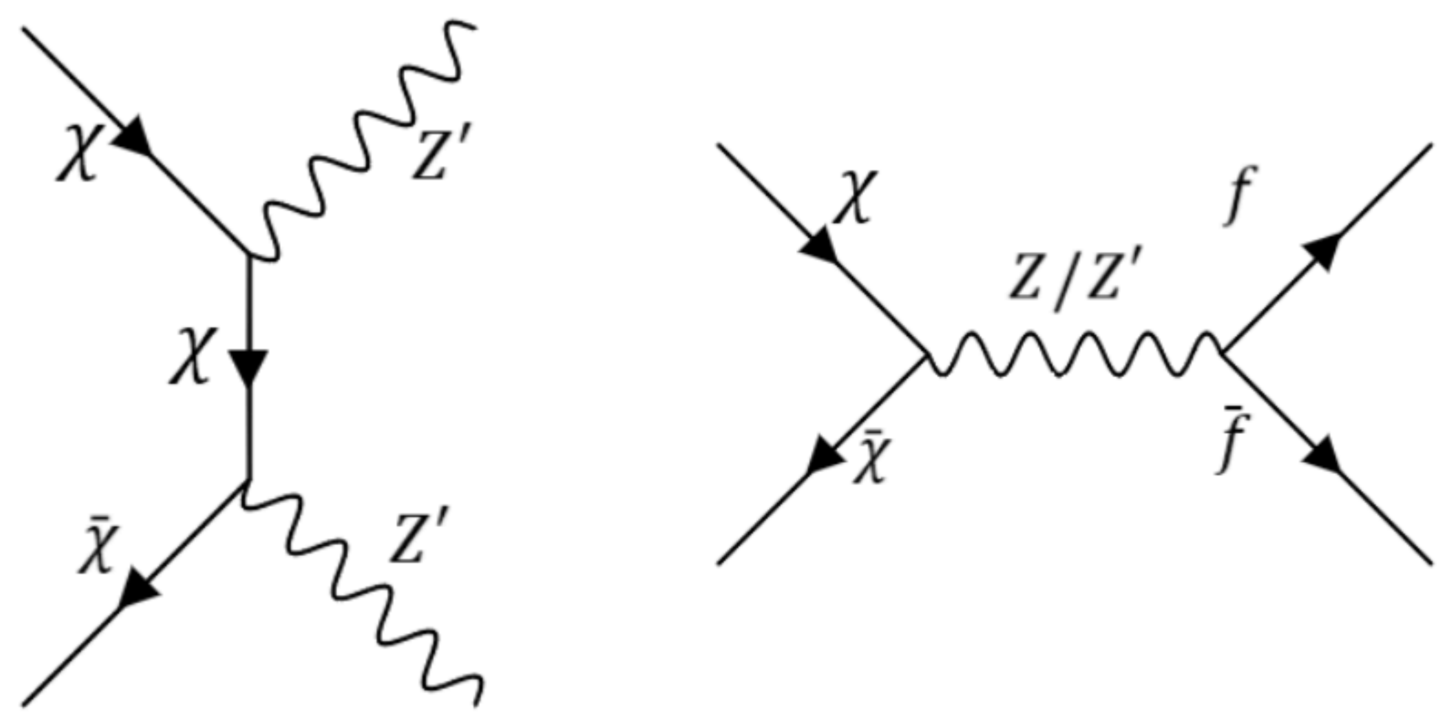
- In the (ν_L, N, N', F) basis:

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

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

DARK MATTER PHENO

- Relic density through annihilation to Z' and SM fermions



(a) t-channel annihilation into $Z'Z'$

(b) Z/Z' mediated resonant annihilation into $\bar{f}f$

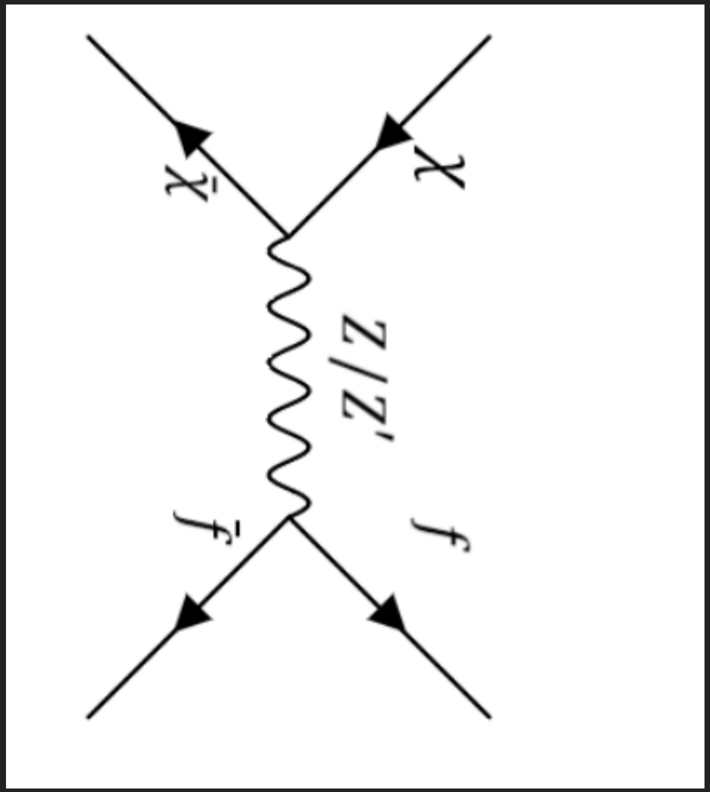
- LMGDLV, E. Peinado, J. Wudka , arXiv:2210.14863

DARK MATTER PHENO

- Direct detection through Z-Z' mixing

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

-



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

DARK MATTER PHENO

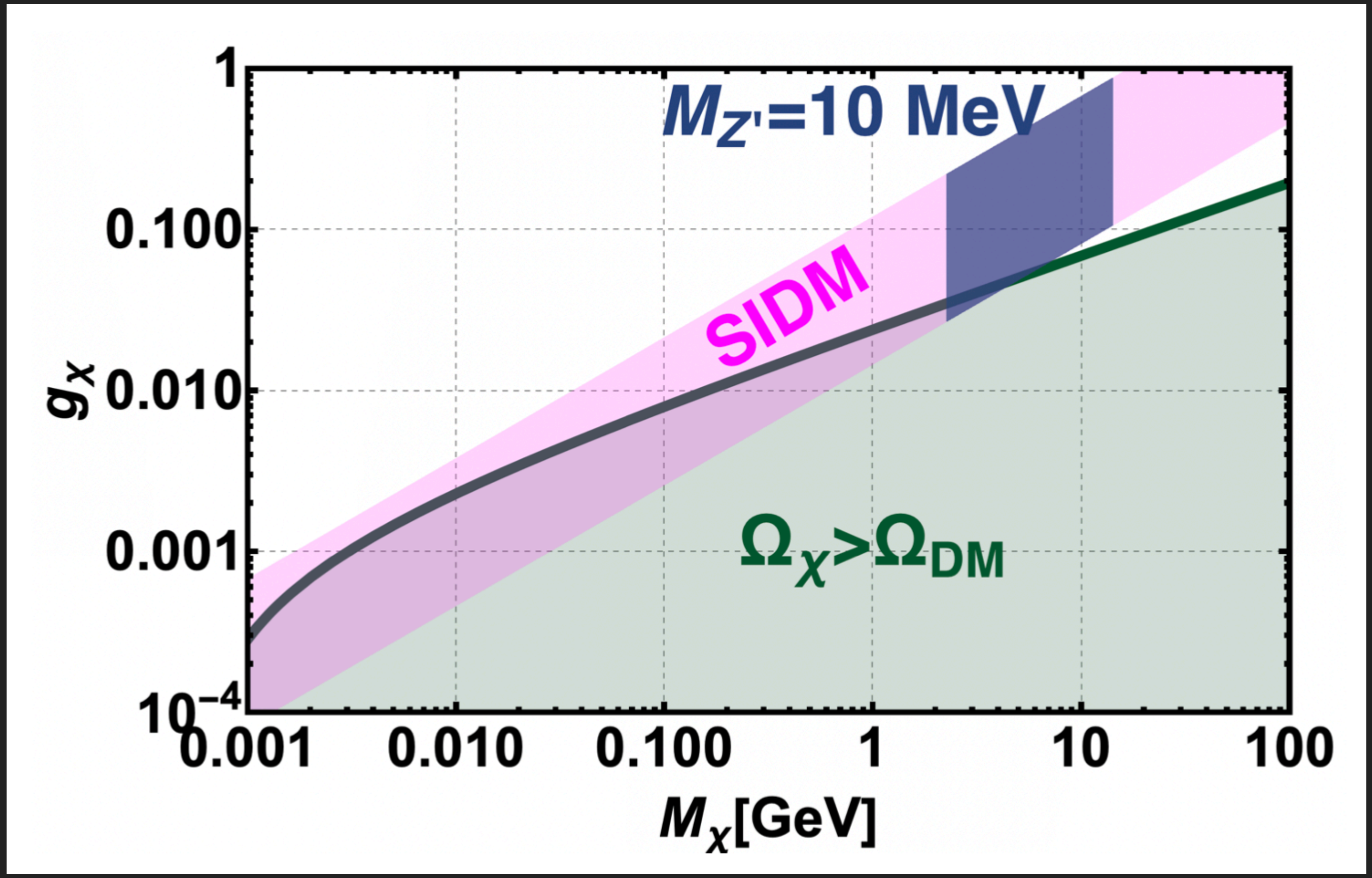
- Self Interacting Dark Matter
- Missing satellites problem
  - Numerical simulations of galaxy dynamics predict a larger number of subhalos (small satellite galaxies) than observed in the MW
- Cusp vs. Core
  - Numerical simulations of galaxy dynamics predict galaxy centers to be cuspier than observed

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

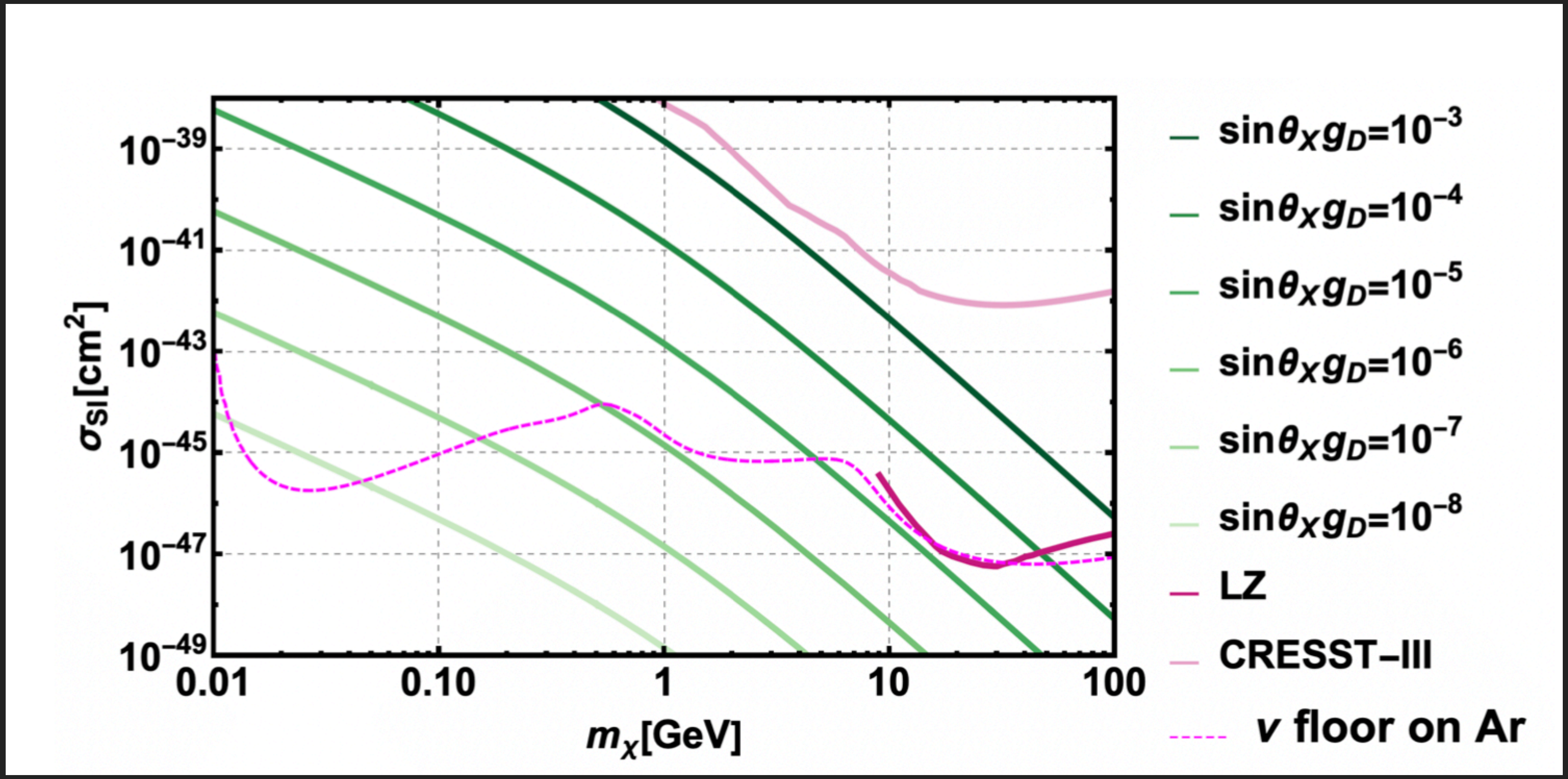
- t-channel annihilation relic density:
- SIDM with $M_{Z'} \sim 10 MeV$ but no prediction for Direct Detection



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

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

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