DIRECT DETECTION IN GAUGE PORTAL

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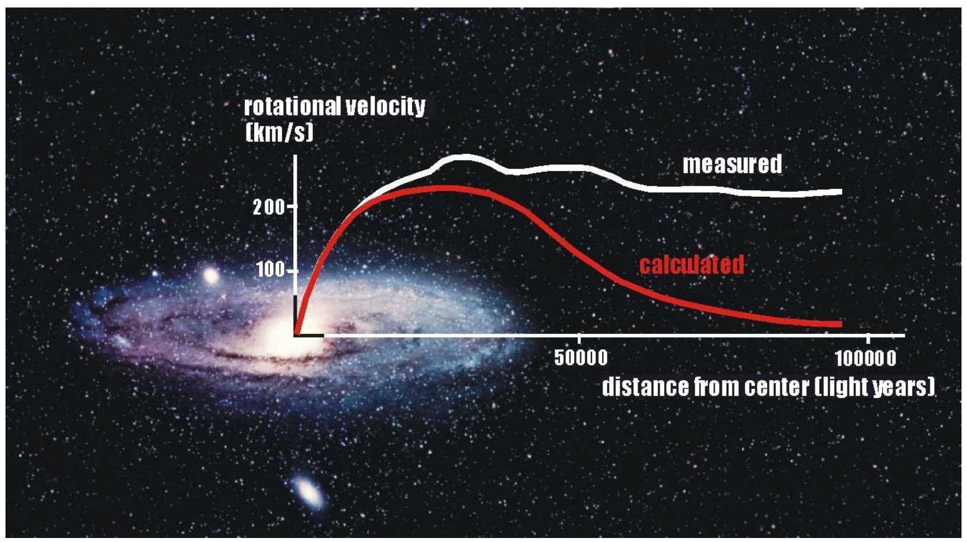
2019.05.18@重庆大学_23rd LHC mini workshop

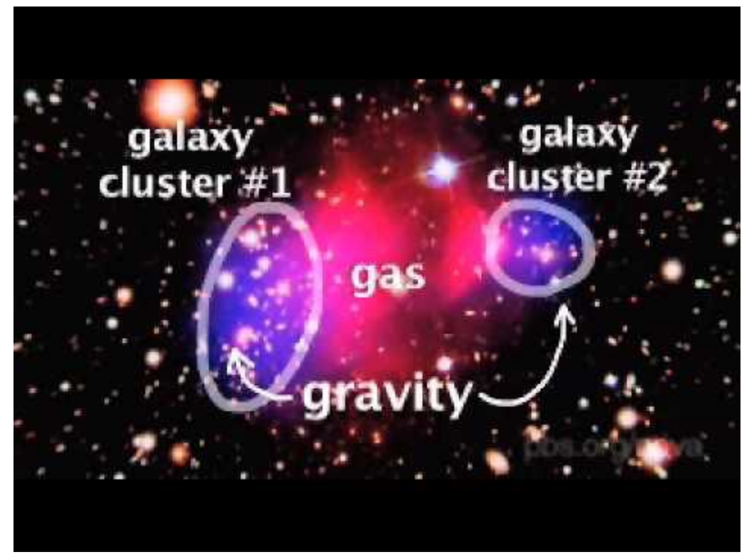
要点预览

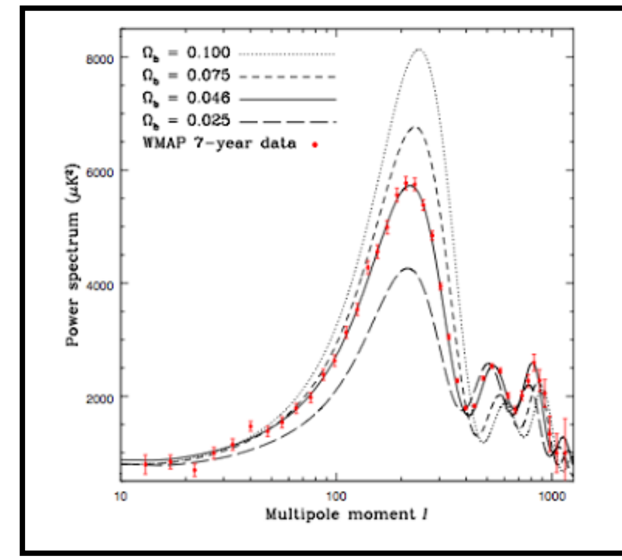
	Main points of DDs in gauge portal
1	Velocity suppressed cross section is reachable by the current DD technique!
2	Effects of twist-2 operators are crucial for direct detections in some parameter space.
3	Spin-dependent cross section may play important role in rolling out WIMPs
4	DD cross section of scalar-type electroweak multiplet DM are first analytically calculated by us!

W. Chao, G.J. Ding, X.G. He and M.J. Ramsey-Musolf, 1812.07829
W. Chao, 1904.09785

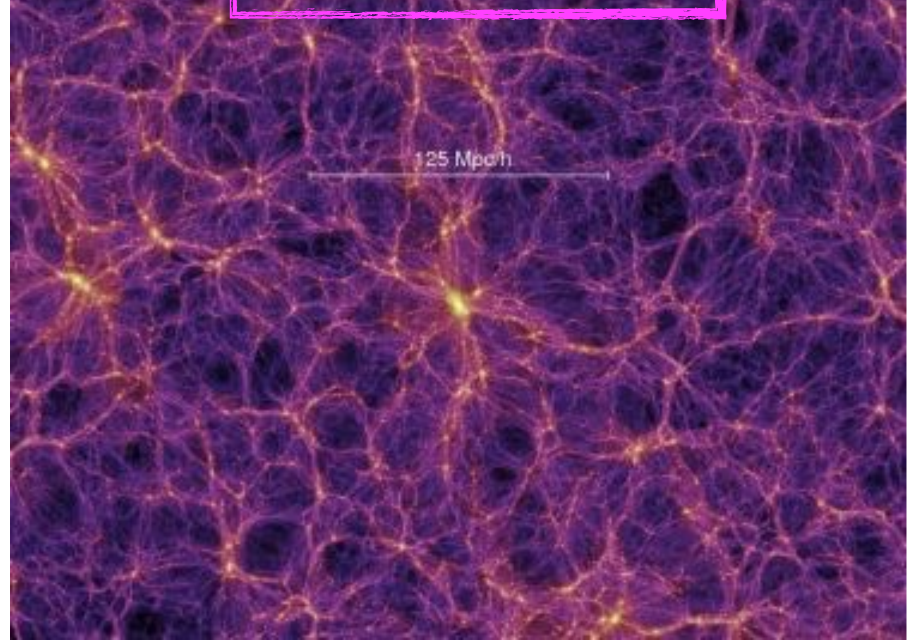
Evidence of DM







大尺度结构



暗物质雨

What is dark matter

We do not exactly know!

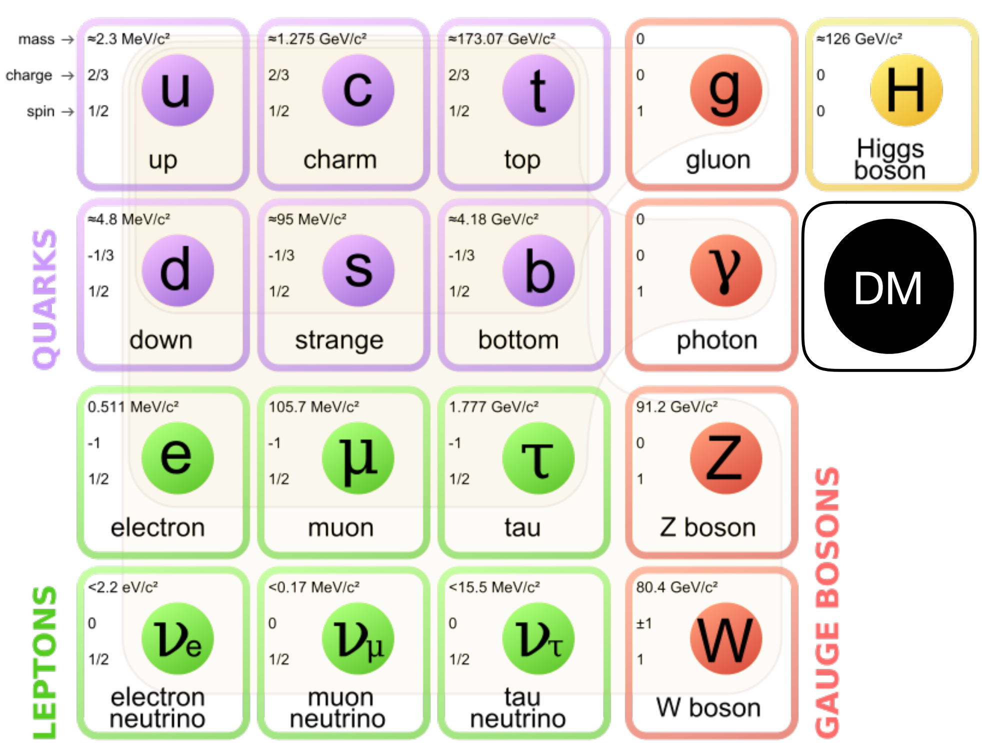
Mass

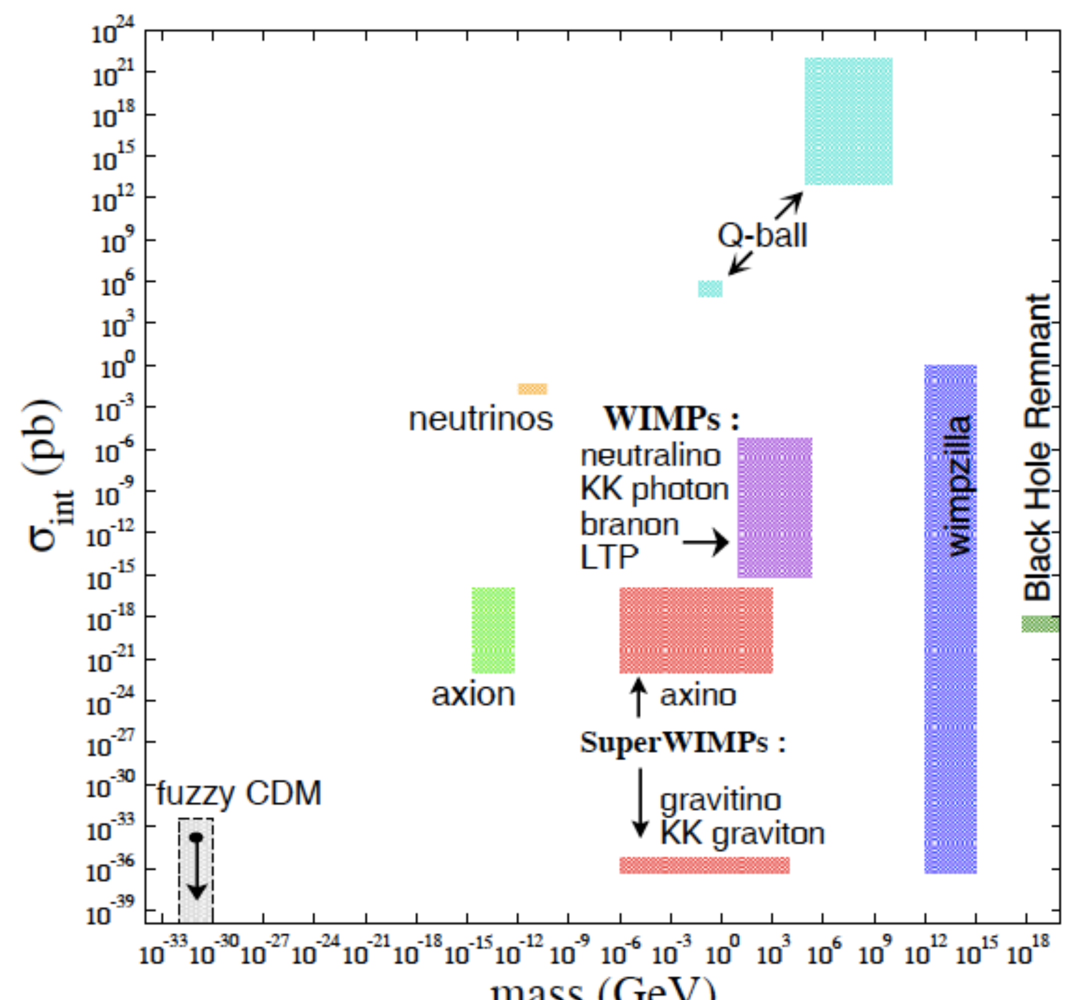
Spin

Interactions

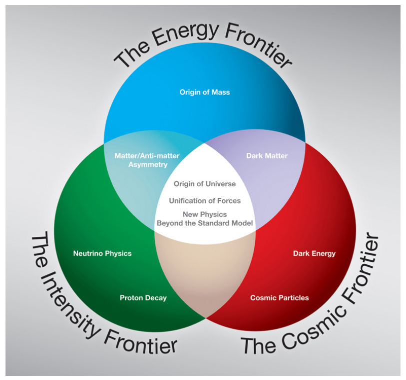
Neutral, non-baryonic, weakly interacting particle!

Particle Zoo

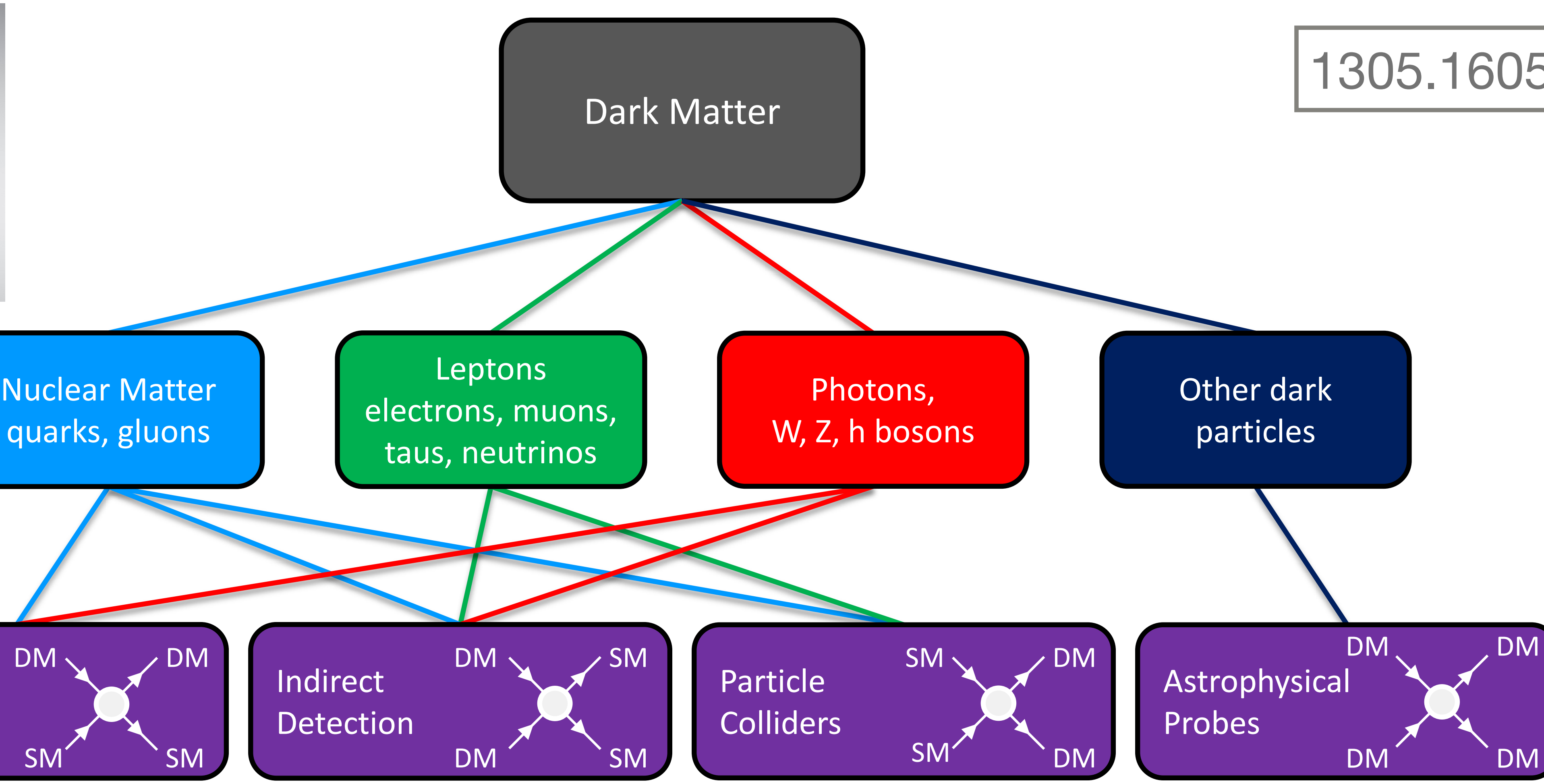


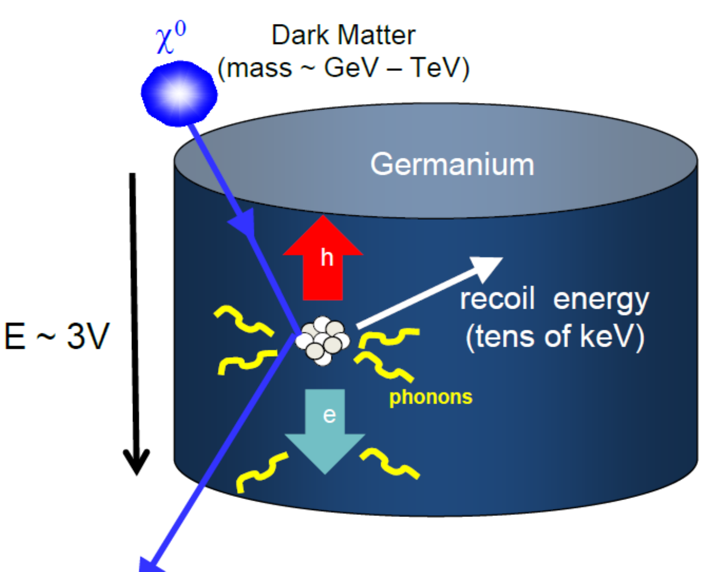


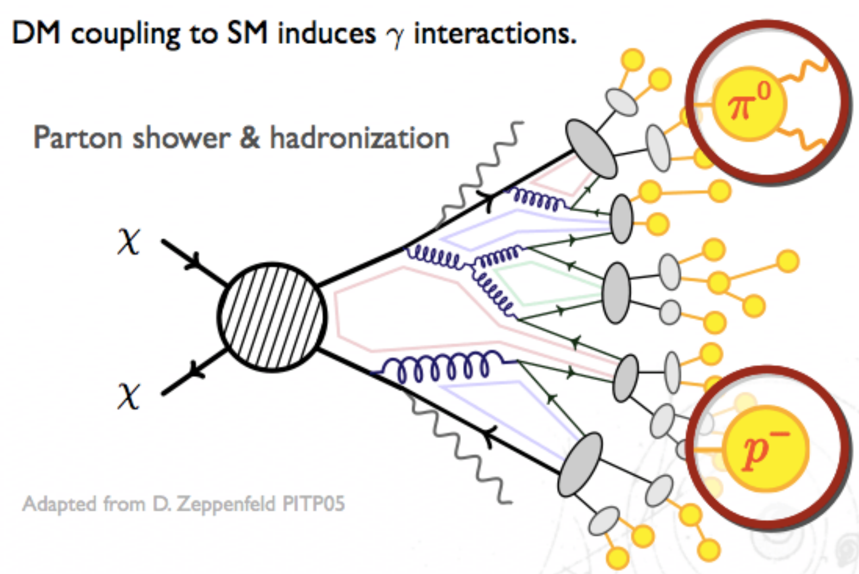
Ways of probing DM

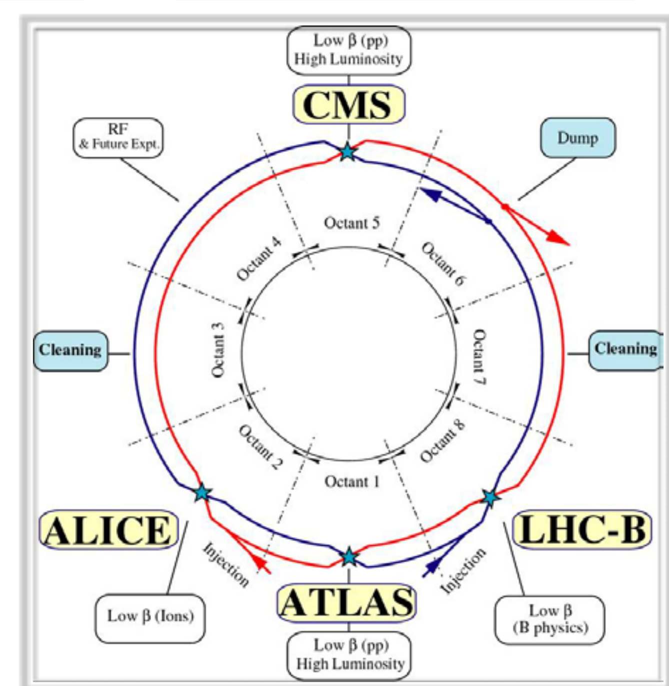


1305.1605

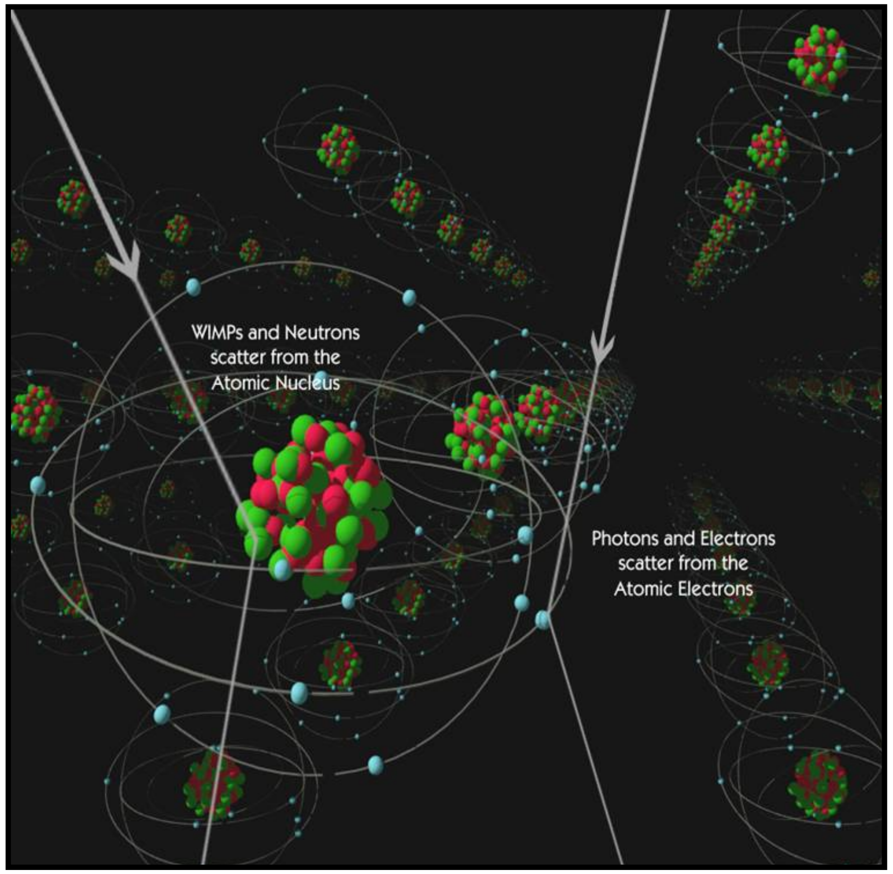


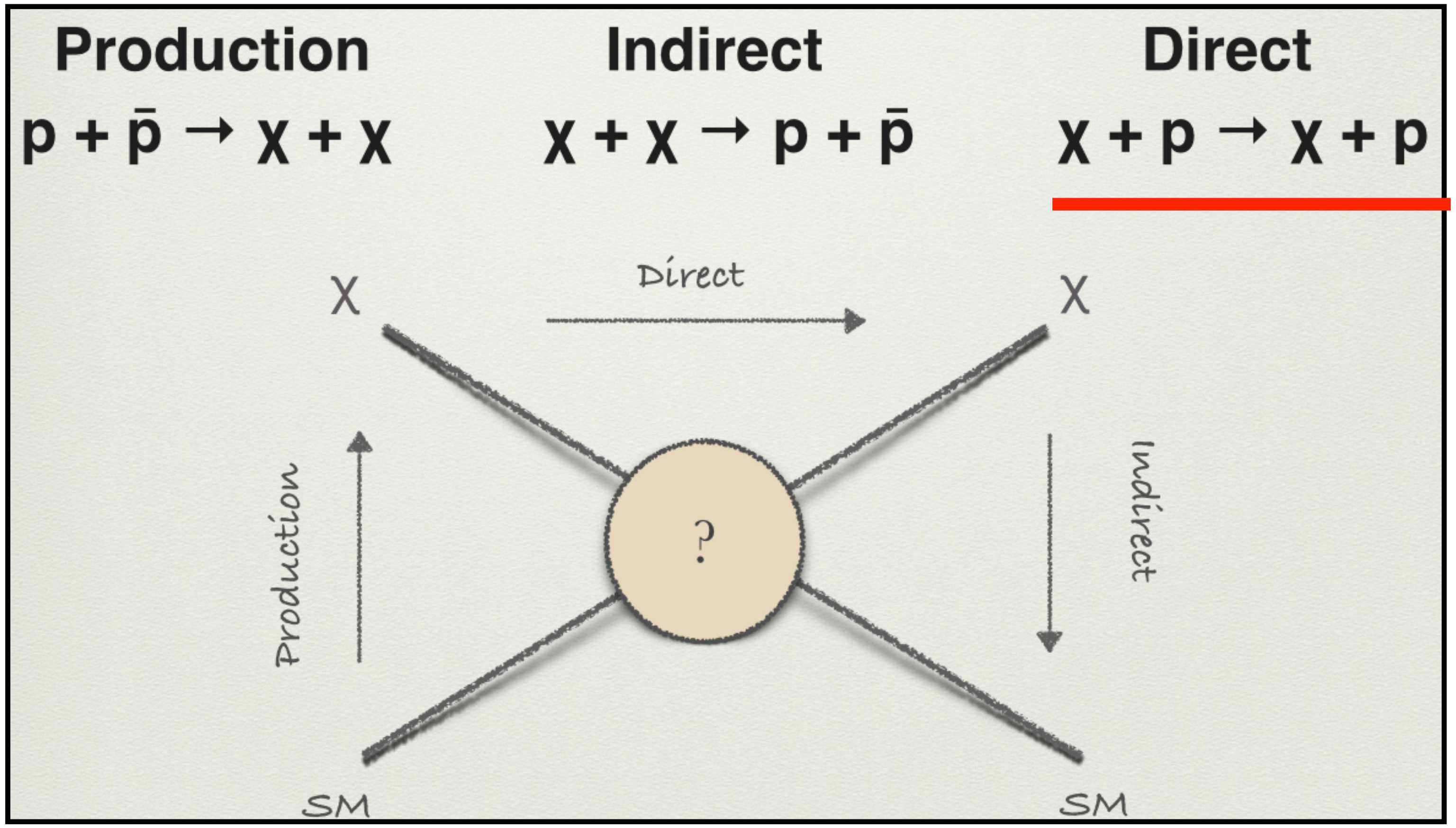






DM Direct detections





Event rate per unit time

$$R \equiv N_A \frac{\rho_0}{m_\chi} \frac{m_A \sigma_0}{2\mu_A^2} \int F^2(E_R) dE_R \int_{v_{\min}}^{v_{\max}} d^3v \frac{f(v)}{v}$$

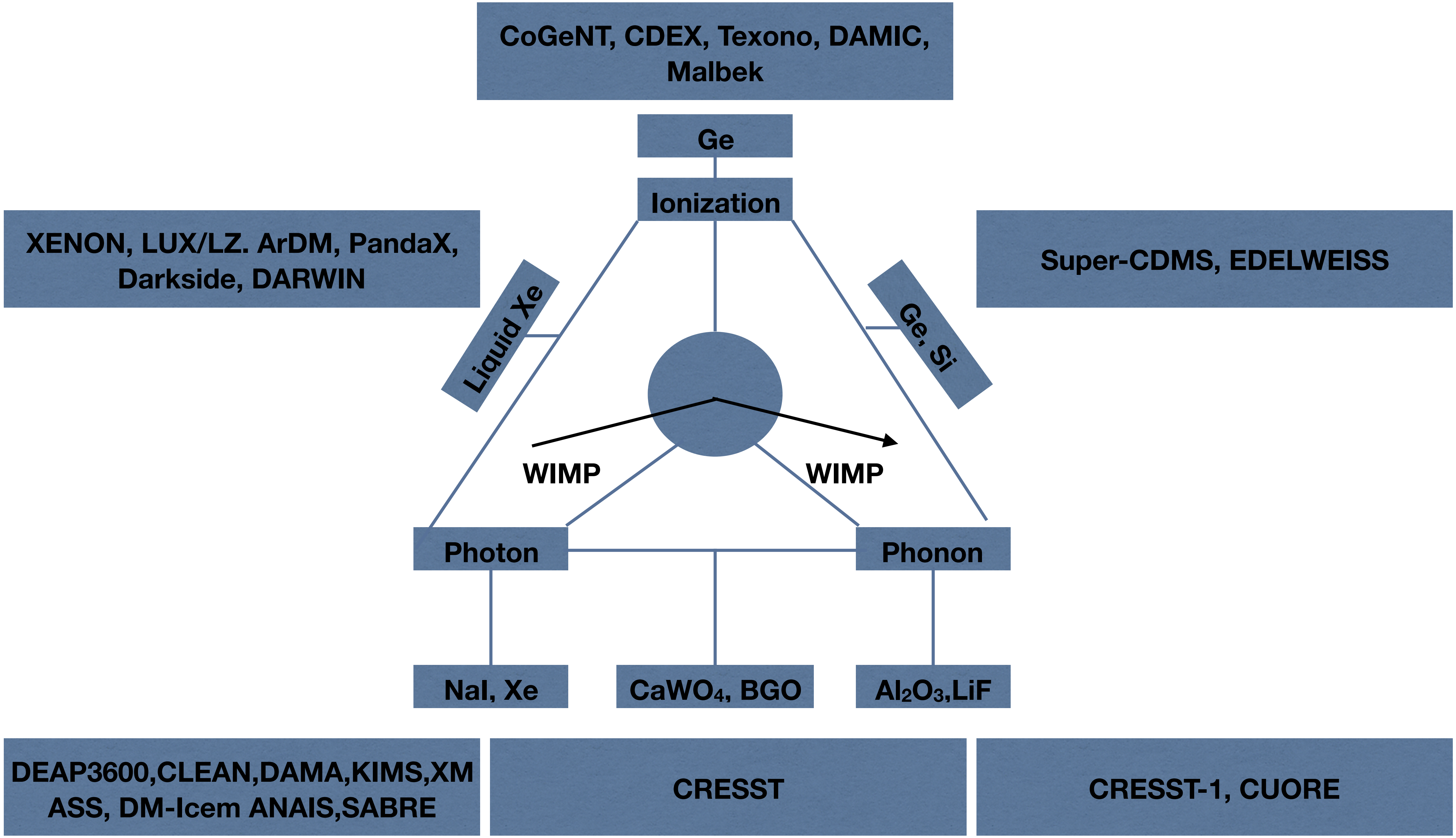
DM number density around the earth

Nuclear physics

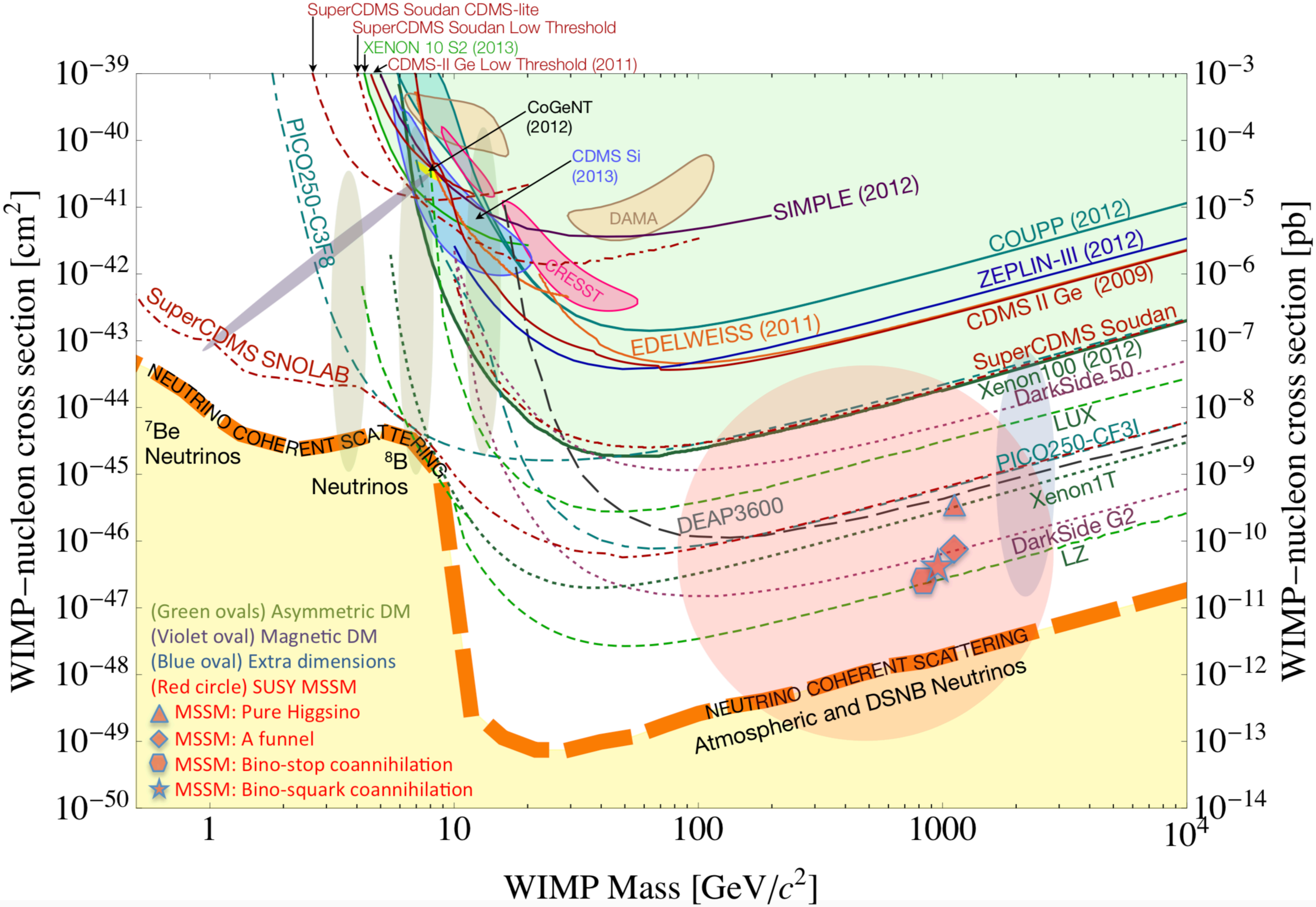
Particle physics

Maxwell-Botzmann velocity distribution

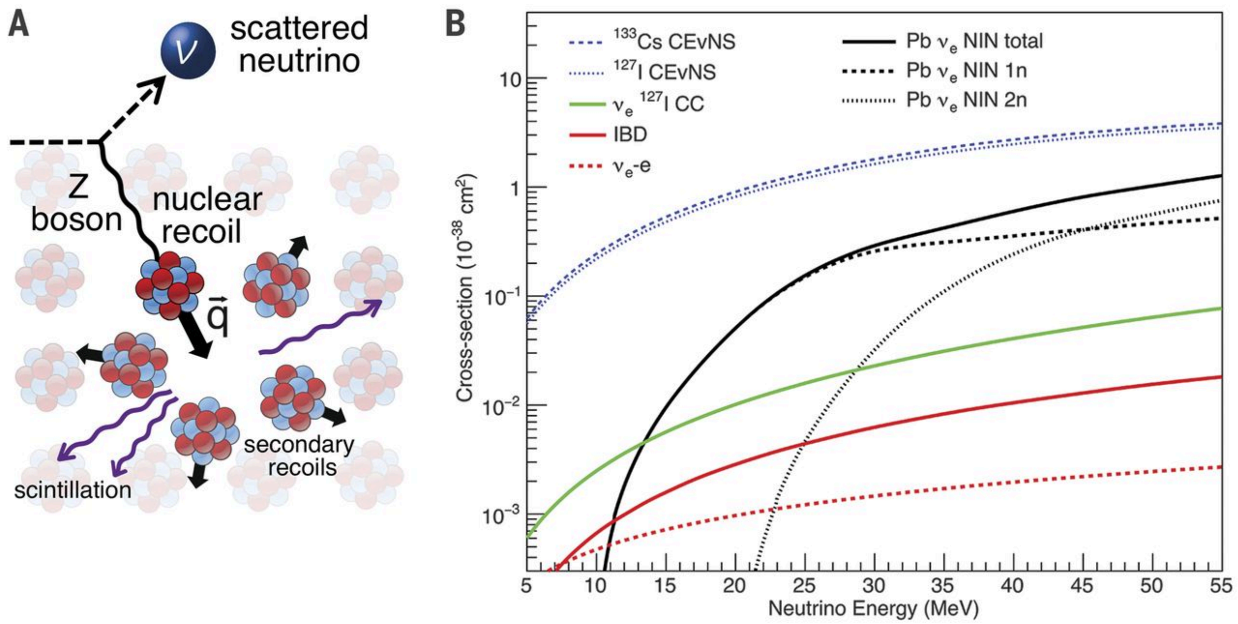
Detecting technologies



Where to go for Direct detections

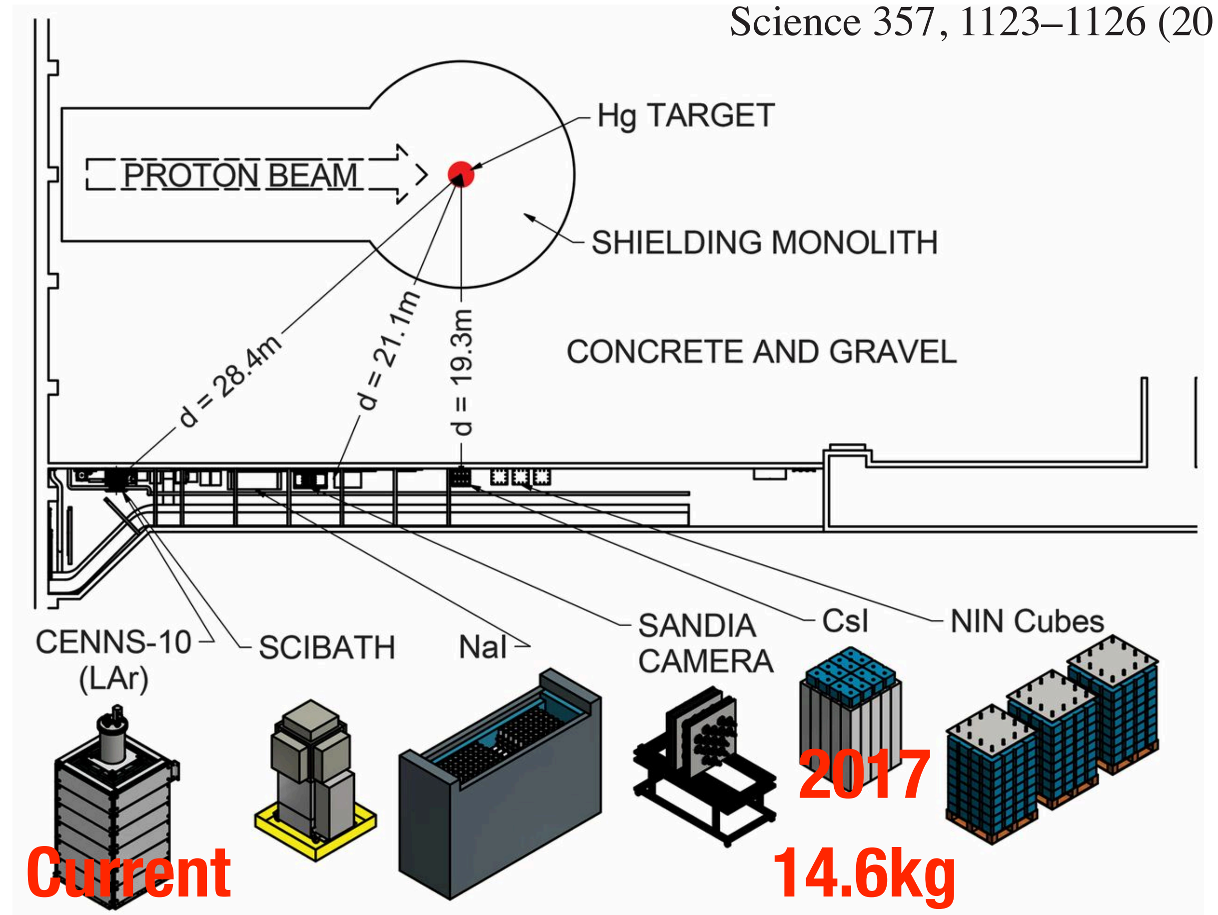


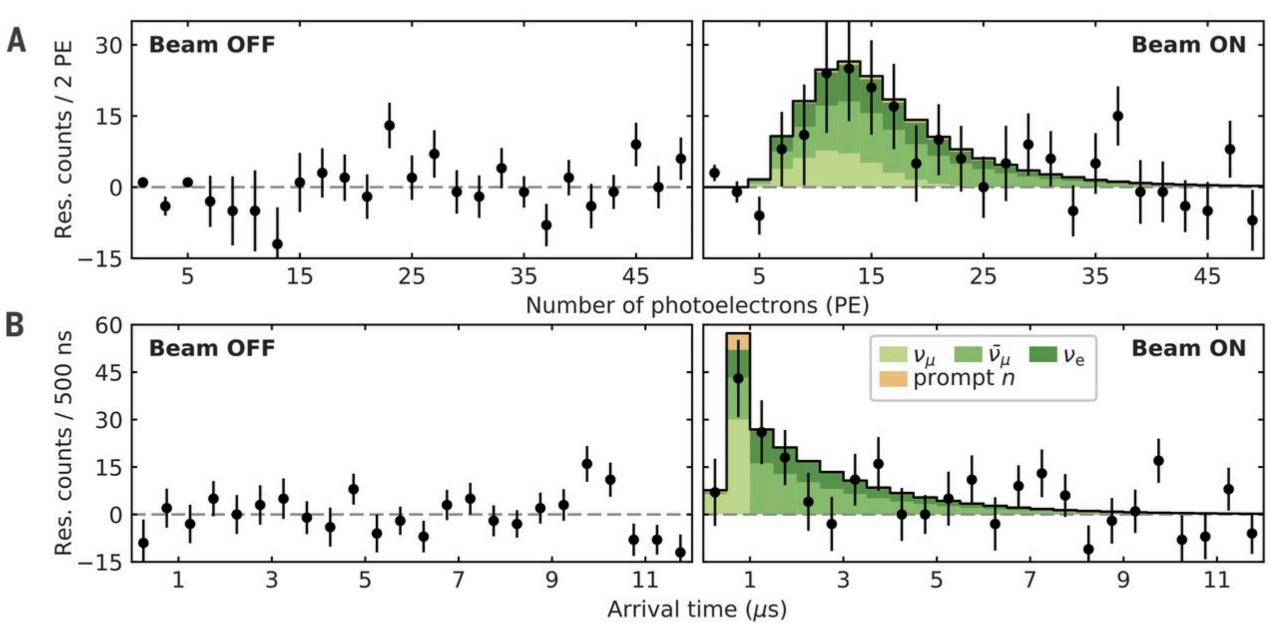
CONHERENT



GOAL: Measure N² dependence of CEvNS process

Science 357, 1123–1126 (2017)

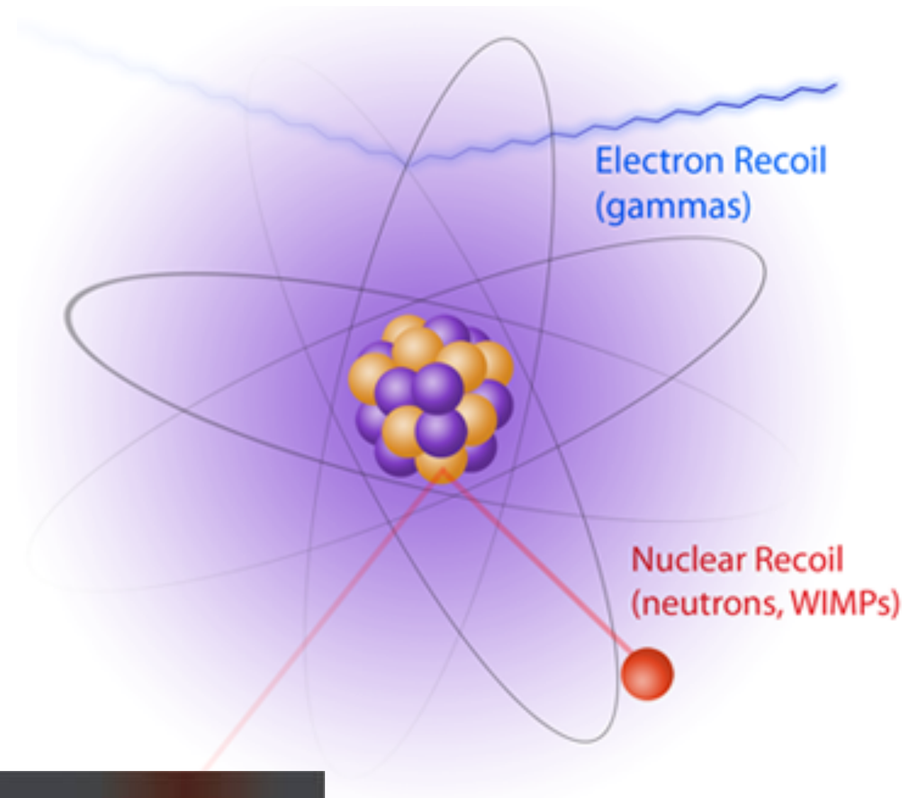




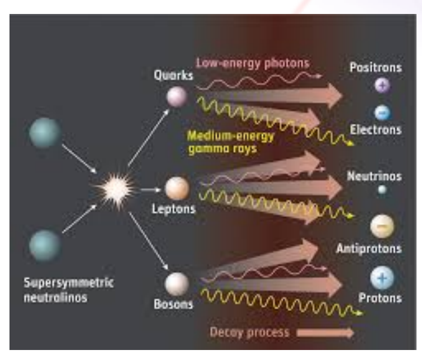
Confirm CEvNS at 6.7 sigma

Beam ON coincidence window	547 counts
Anticoincidence window	405 counts
Beam-on bg: prompt beam neutrons	7.0 ± 1.7
Beam-on bg: NINs (neglected)	4.0 ± 1.3
Signal counts, single-bin counting	136 ± 31
Signal counts, 2D likelihood fit	**134 ± 22**
Predicted SM signal counts	**173 ± 48**

Be serious about the DD



SD cross section

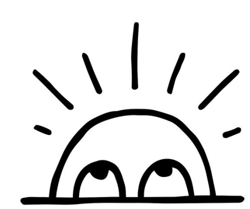


SERIOUS

SI cross section

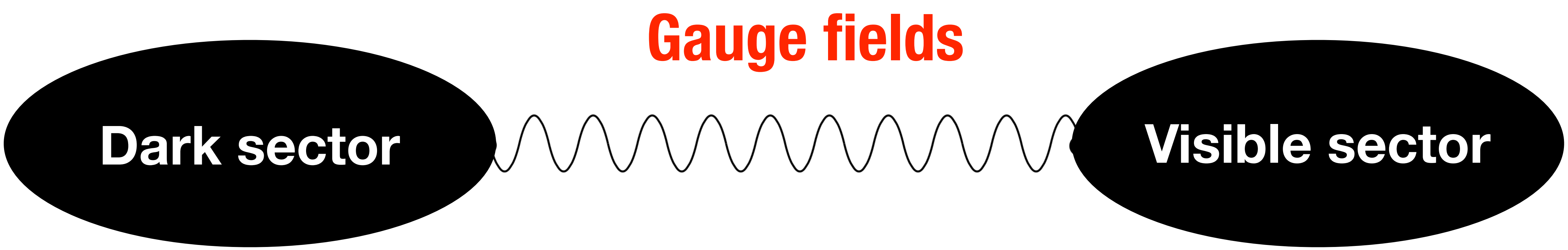
LO effects ✓ ✗

v-suppressed ✗ ✓



NLO effects ✗ ✓

DDs in gauge portal



Type of the gauge field:

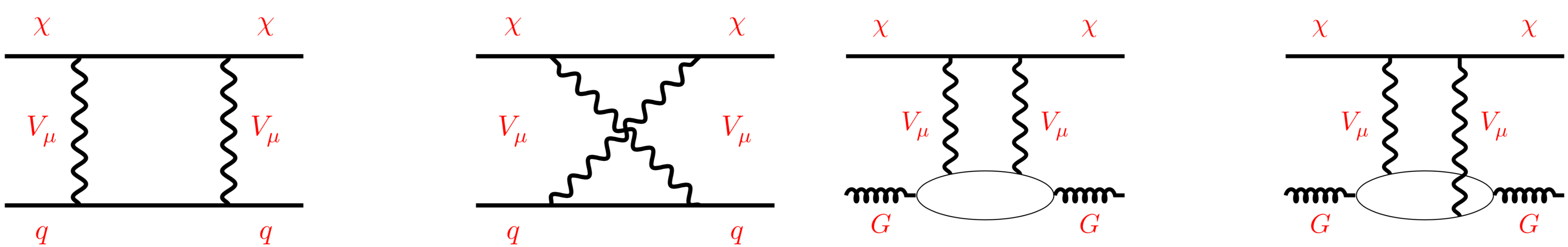
- **Z'** — **U(1) extension of SM**
- **W/Z** — **Minimal dark matter**

Lagrangian	Scenario	DD cross section
$\mathscr{L} \sim \frac{1}{2} g_V \bar{\chi} \gamma^\mu \gamma^5 V_\mu \chi - \frac{1}{2} m_\chi \bar{\chi} \chi + \zeta g_V \bar{q} \gamma^\mu q V_\mu$	A	SI but v suppressed
$\mathscr{L} \sim \frac{1}{2} g_V \bar{\chi} \gamma^\mu \gamma^5 V_\mu \chi - \frac{1}{2} m_\chi \bar{\chi} \chi + \zeta g_V \bar{q} \gamma^\mu \gamma^5 q V_\mu$	B	SD

DD cross sections

Scenario	DD cross section at leading order
A	$\sigma_{\rm SI}^{\rm LO} \approx \dfrac{36\pi\zeta^2\alpha_V^2\mu^2 v^2}{m_V^4}$
B	$\sigma_{\rm SD}^{\rm LO} = 64\pi\zeta^2\alpha_V^2\dfrac{\mu^2}{m_V^4}(\sum_q \Delta_q^N)^2 J_N(J_N+1)$

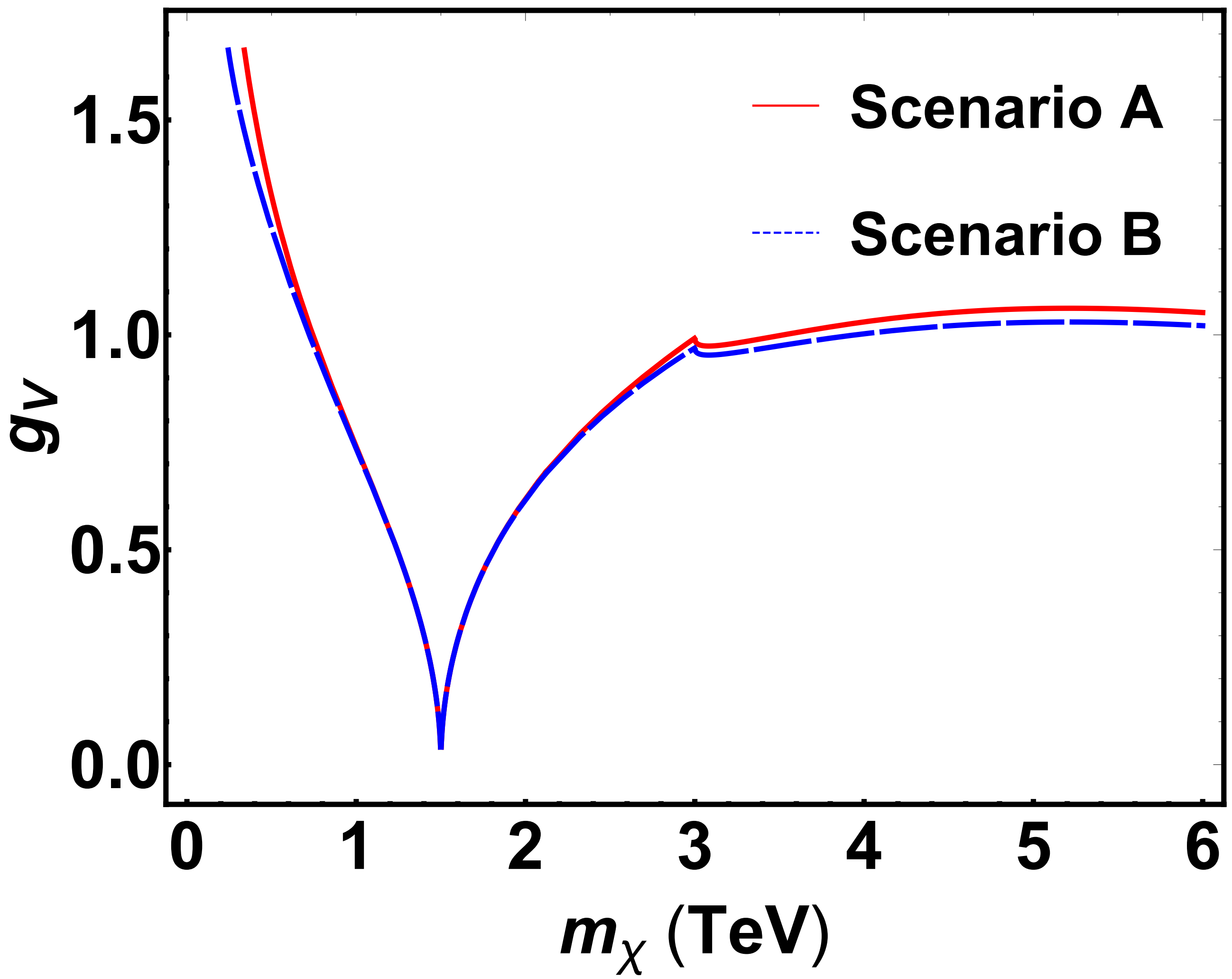
At the next-to-leading order:

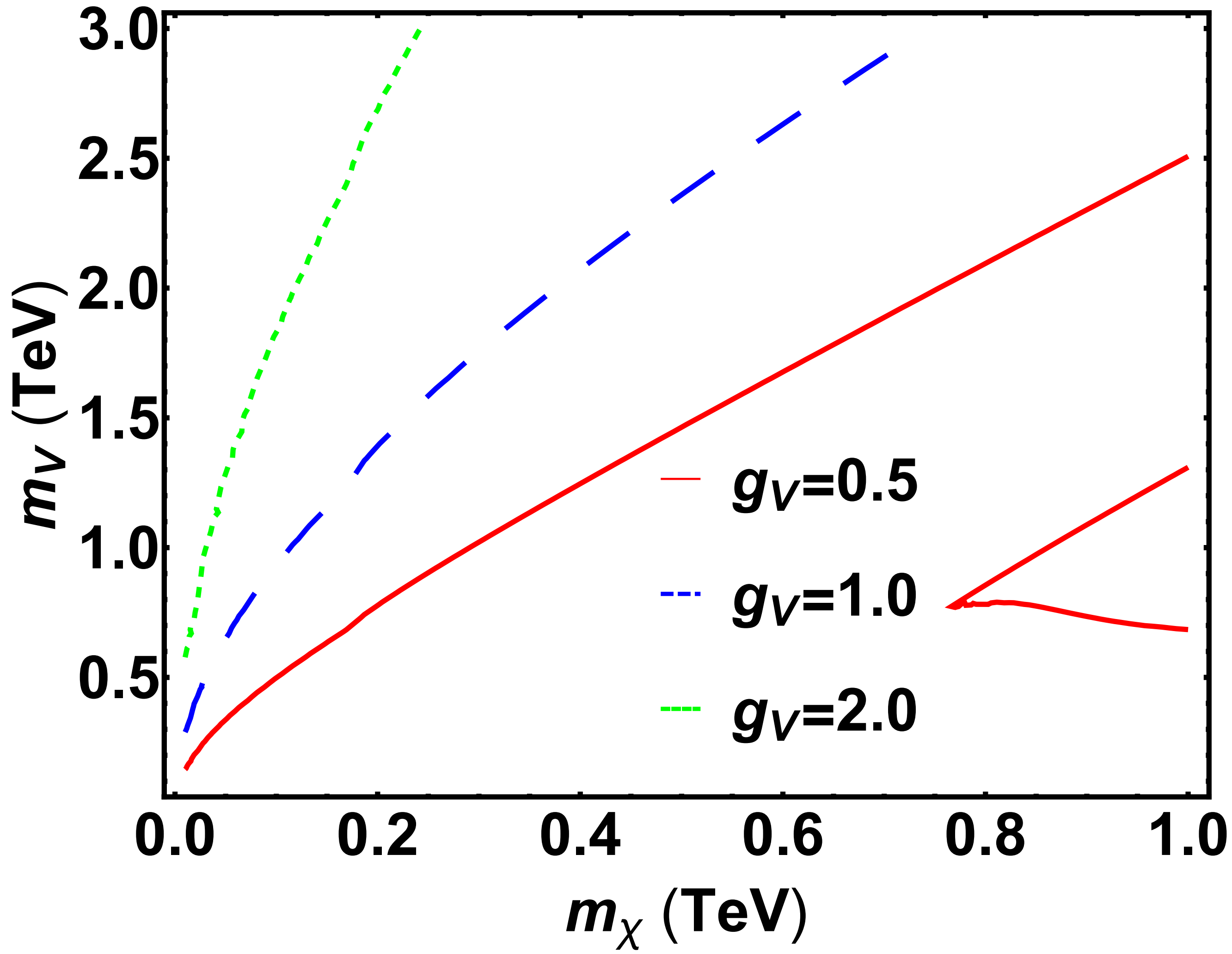


$$\mathscr{L}_{\rm eff} = \sum_{p=q,g} \frac{1}{2}\kappa_{1p}\bar{\chi}\chi\mathcal{O}_s^p + \frac{1}{2}\kappa_{2q}\bar{\chi}i\partial^\mu\gamma^\nu\chi\mathcal{O}_{\mu\nu}^q + \frac{1}{2}\kappa_{3q}\bar{\chi}i\partial^\mu i\partial^\nu\chi\mathcal{O}_{\mu\nu}^q ,$$

$$\mathcal{O}_{\mu\nu}^q = \frac{1}{2}\bar{q}\left(\partial_\mu\gamma_\nu + \partial_\nu\gamma_\mu - \frac{1}{2}g_{\mu\nu}\gamma\cdot\partial\right)q$$

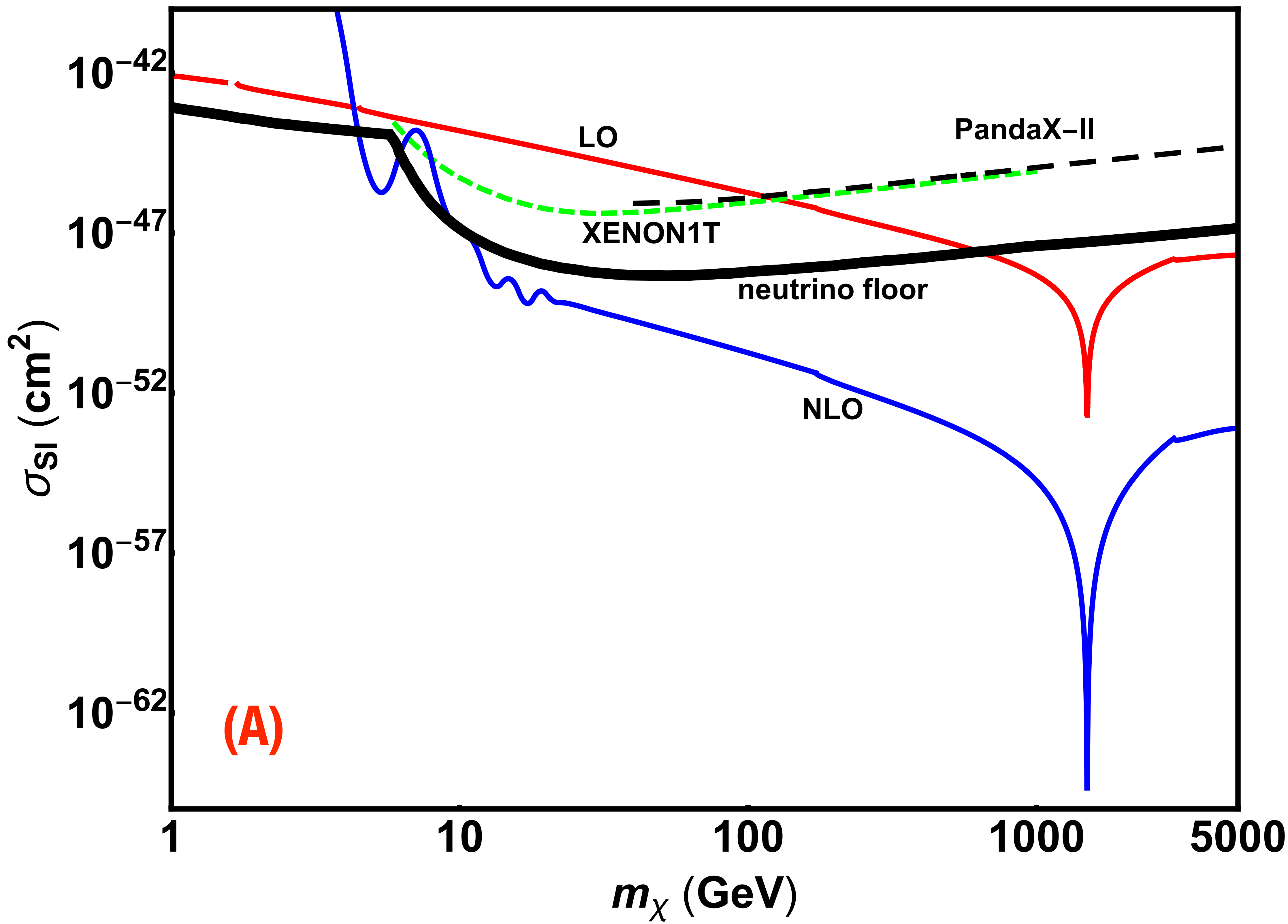
Numerical results in Z' portal



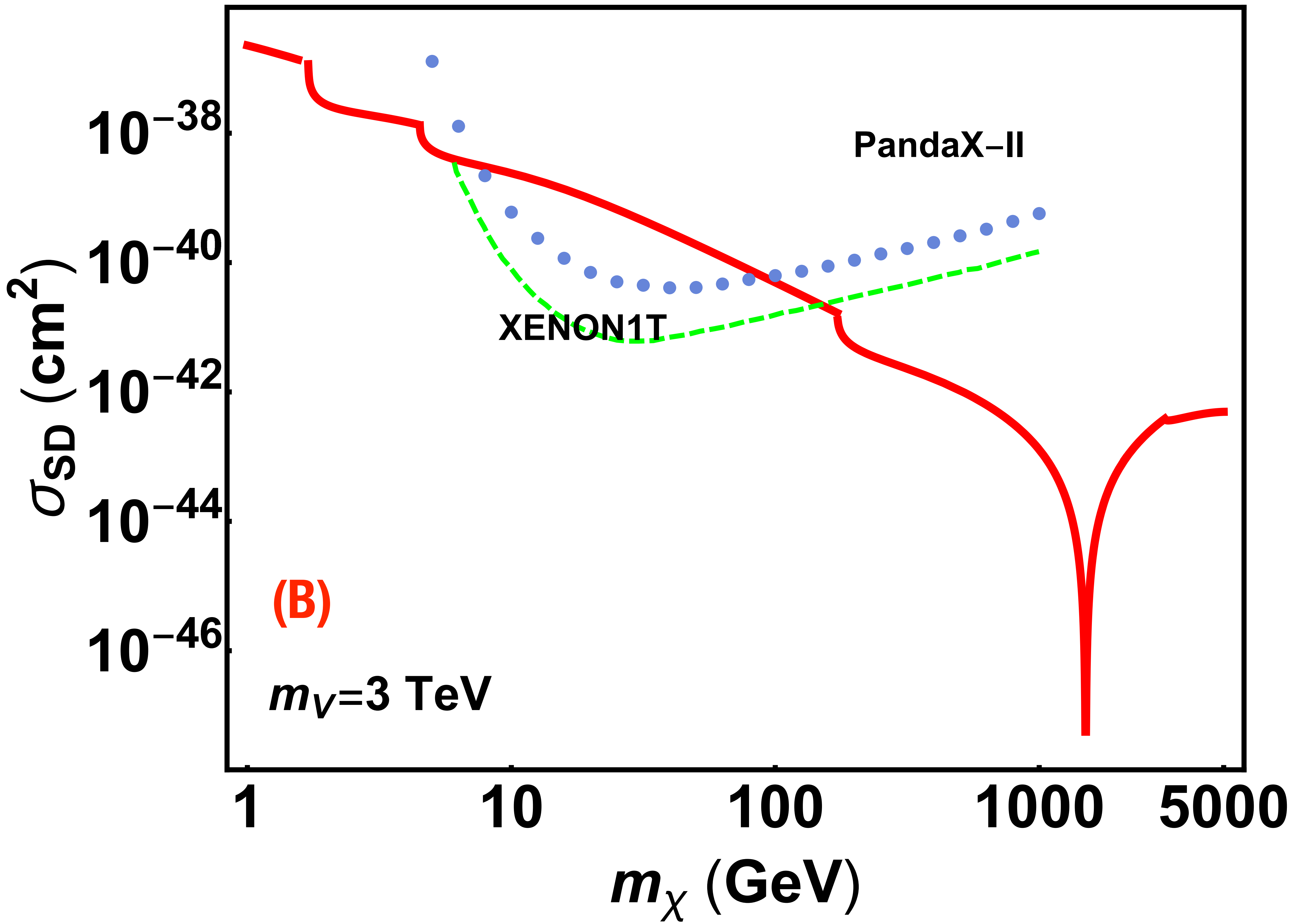


Constraints of the relic abudance

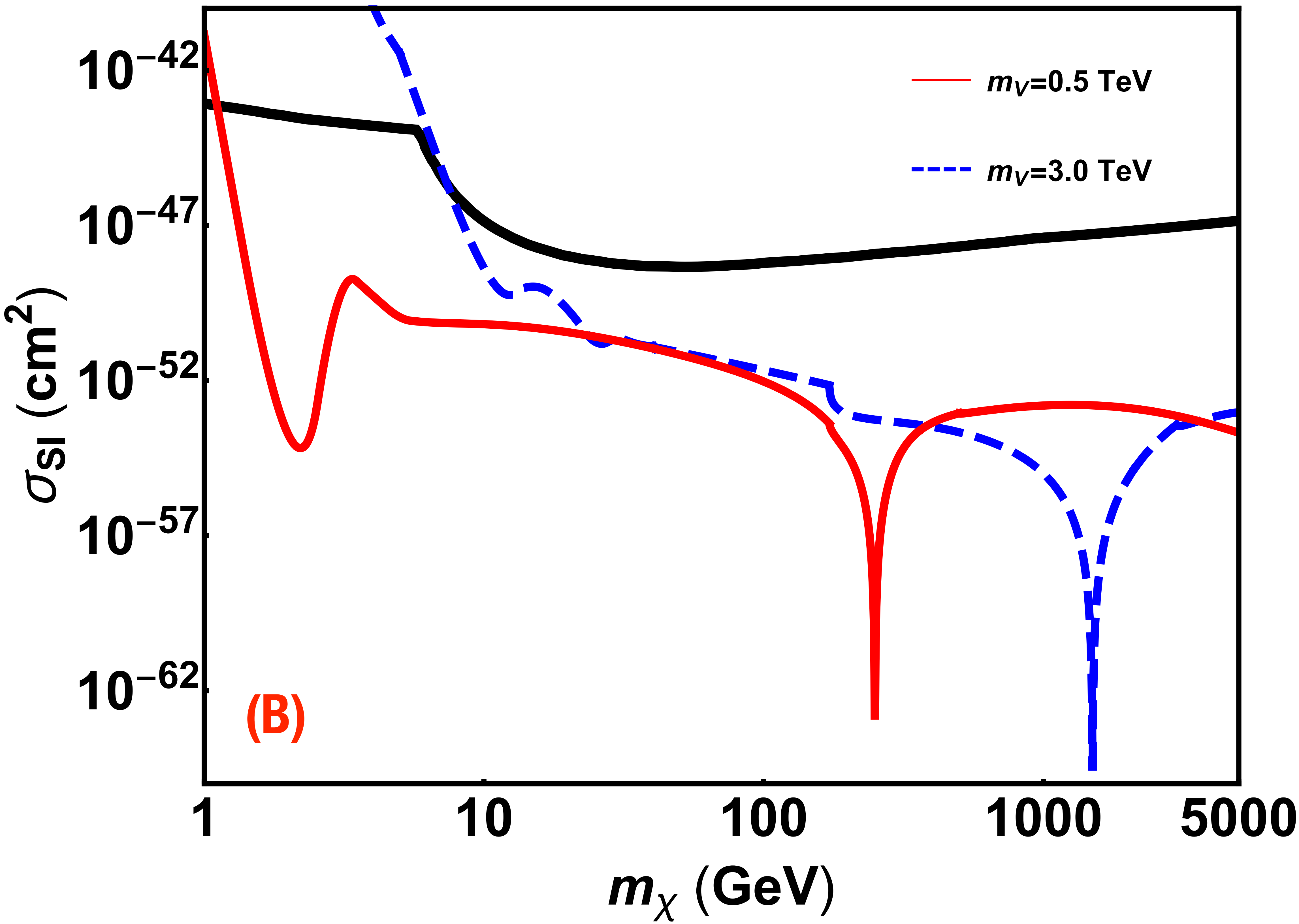
Numerical results in Z' portal



Numerical results in Z’ portal



Numerical results in Z’ portal



Scalar-type EW multiplet DM in W-portal

Why interesting?

Strumia, et al., NPB 2006

Quantum numbers $SU(2)_L$	$U(1)_Y$	Spin	DM can decay into	DM mass in TeV	$m_{DM^\pm} - m_{DM}$ in MeV	Events at LHC $\int \mathcal{L}\, dt = 100/\text{fb}$	σ_{SI} in $10^{-45}\,\text{cm}^2$
2	1/2	0	EL	0.54 ± 0.01	350	$320 \div 510$	0.2
2	1/2	1/2	EH	1.1 ± 0.03	341	$160 \div 330$	0.2
3	0	0	HH^*	2.0 ± 0.05	166	$0.2 \div 1.0$	1.3
3	0	1/2	LH	2.4 ± 0.06	166	$0.8 \div 4.0$	1.3
3	1	0	HH, LL	1.6 ± 0.04	540	$3.0 \div 10$	1.7
3	1	1/2	LH	1.8 ± 0.05	525	$27 \div 90$	1.7
4	1/2	0	HHH^*	2.4 ± 0.06	353	$0.10 \div 0.6$	1.6
4	1/2	1/2	(LHH^*)	2.4 ± 0.06	347	$5.3 \div 25$	1.6
4	3/2	0	HHH	2.9 ± 0.07	729	$0.01 \div 0.10$	7.5
4	3/2	1/2	(LHH)	2.6 ± 0.07	712	$1.7 \div 9.5$	7.5
5	0	0	(HHH^*H^*)	5.0 ± 0.1	166	$\ll 1$	12
5	0	1/2	–	4.4 ± 0.1	166	$\ll 1$	12
7	0	0	–	8.5 ± 0.2	166	$\ll 1$	46

- Natural DM candidate without requiring any other symmetry
- Higgs vacuum stability
- Avoiding constraints of DD as they are superheavy

Scalar-type EW multiplet DM in W-portal

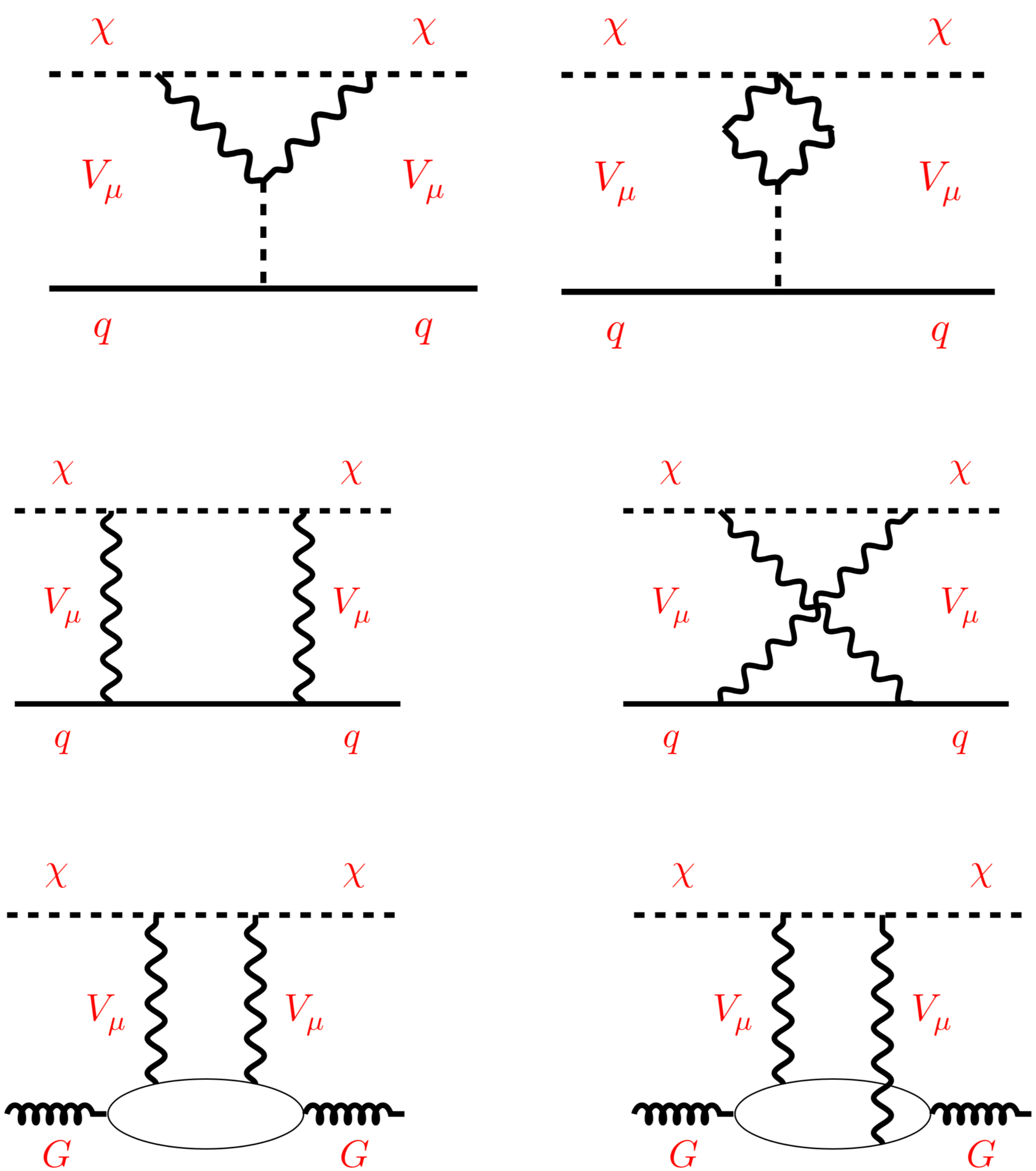
How about the direct detection cross section

Fermion	$\mathscr{L}^W_{\rm eff} = (n^2-(1\pm 2Y)^2)\frac{\pi\alpha_2^2}{16M_W}\sum_q\left[(\frac{1}{M_W^2}+\frac{1}{m_h^2})[\bar{\mathcal{X}}\mathcal{X}]m_q[\bar q q] - \frac{2}{3M}[\bar{\mathcal{X}}\gamma_\mu\gamma_5\mathcal{X}][\bar q\gamma_\mu\gamma_5 q]\right]$
Scalar	**No effective lagrangian！ only some arguments.**

Questions：

- No twist-2 effective operators in the Lagrangian?
- No effective gluon-DM operators in the Lagrangian?
- What is the situation when Higgs-portal interactions are included in SDM?

Scalar-type EW multiplet DM in W-portal



Results：

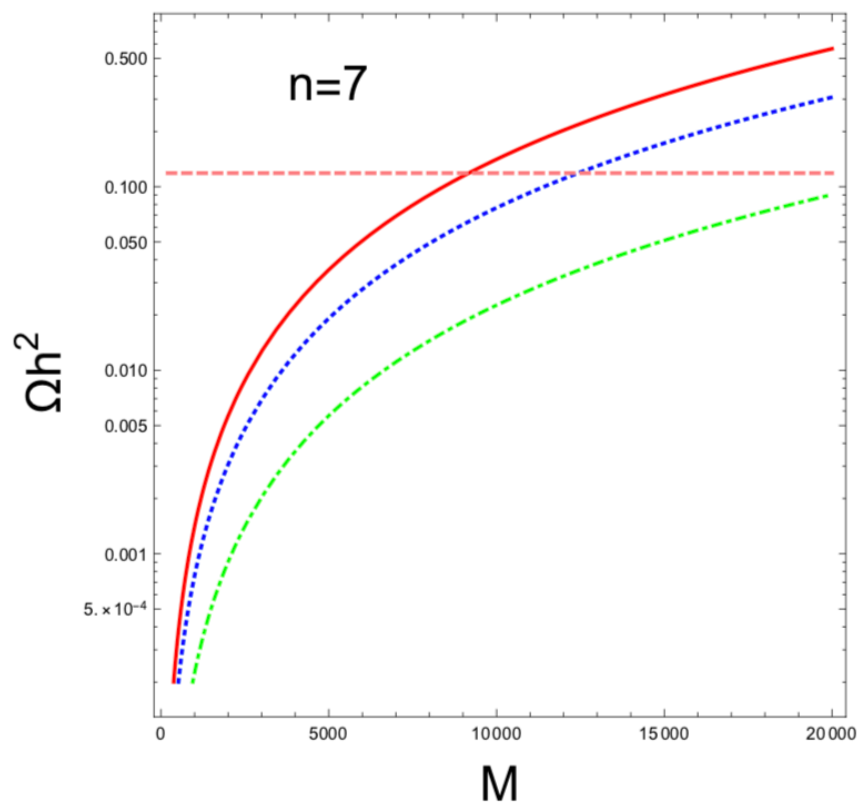
$$\mathscr{L} = \frac{(n^2-1)\alpha^2}{4}\left[\zeta_1 \phi^2 \bar{q} m_q q + \zeta_2 \phi i\partial^\mu i\partial^\nu \phi O^q_{\mu\nu}\right]$$

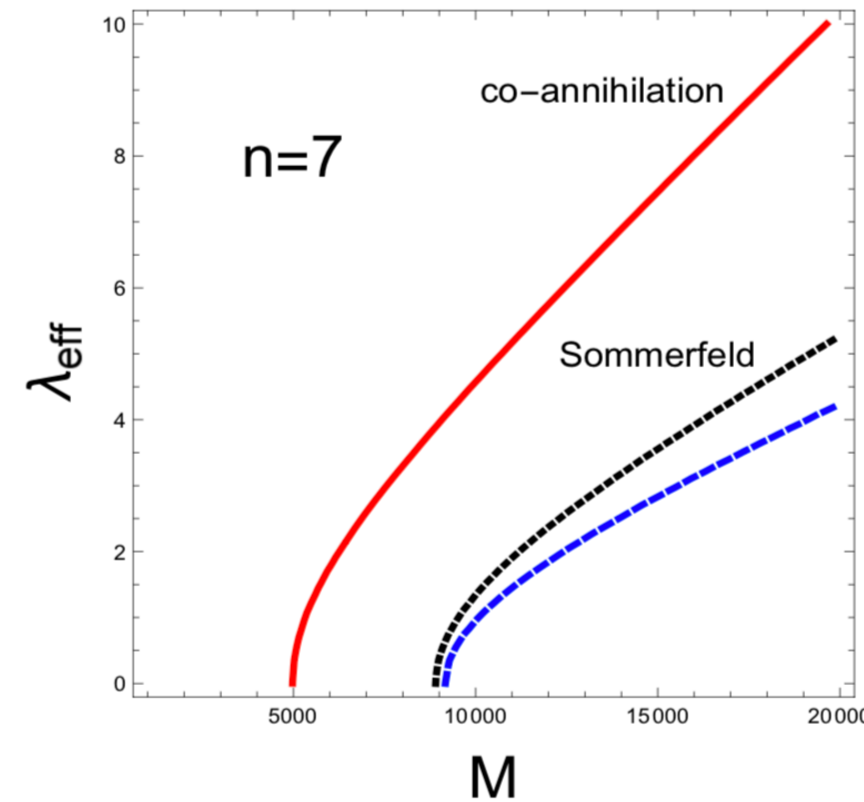
$$\zeta_1 = m^2(2C_0 + C_1 - 2Z_{11}) + 8Z_{00} - Y_2 - 4Z_{00}$$

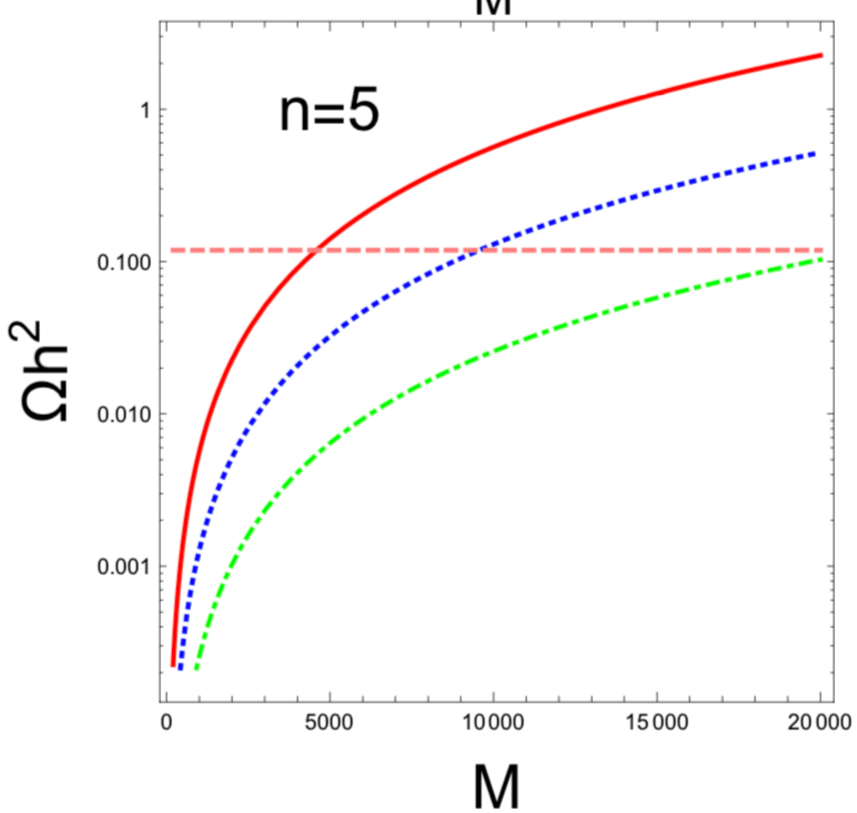
$$\zeta_2 = -8m^2 Z_{11} - 32Z_{00} - 8Y_2$$

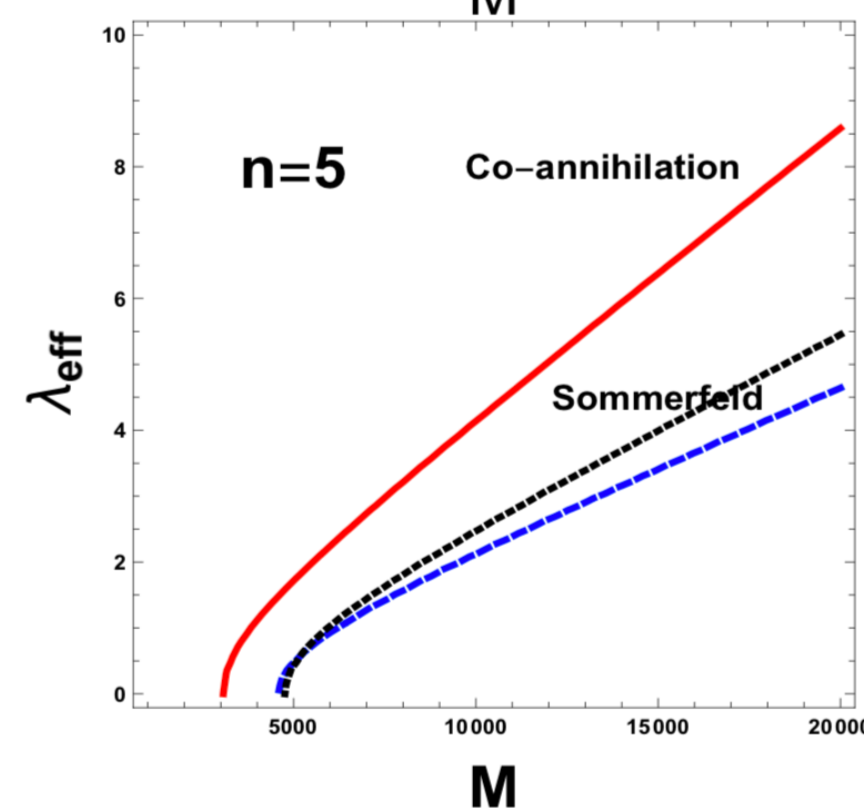
- C,Z,Y, are integration functions
- Gluon results are on the way
- RGE running should be included in DD
- When Higgs portal interactions are included, only twist-2 contribution is unique.

Numerical results

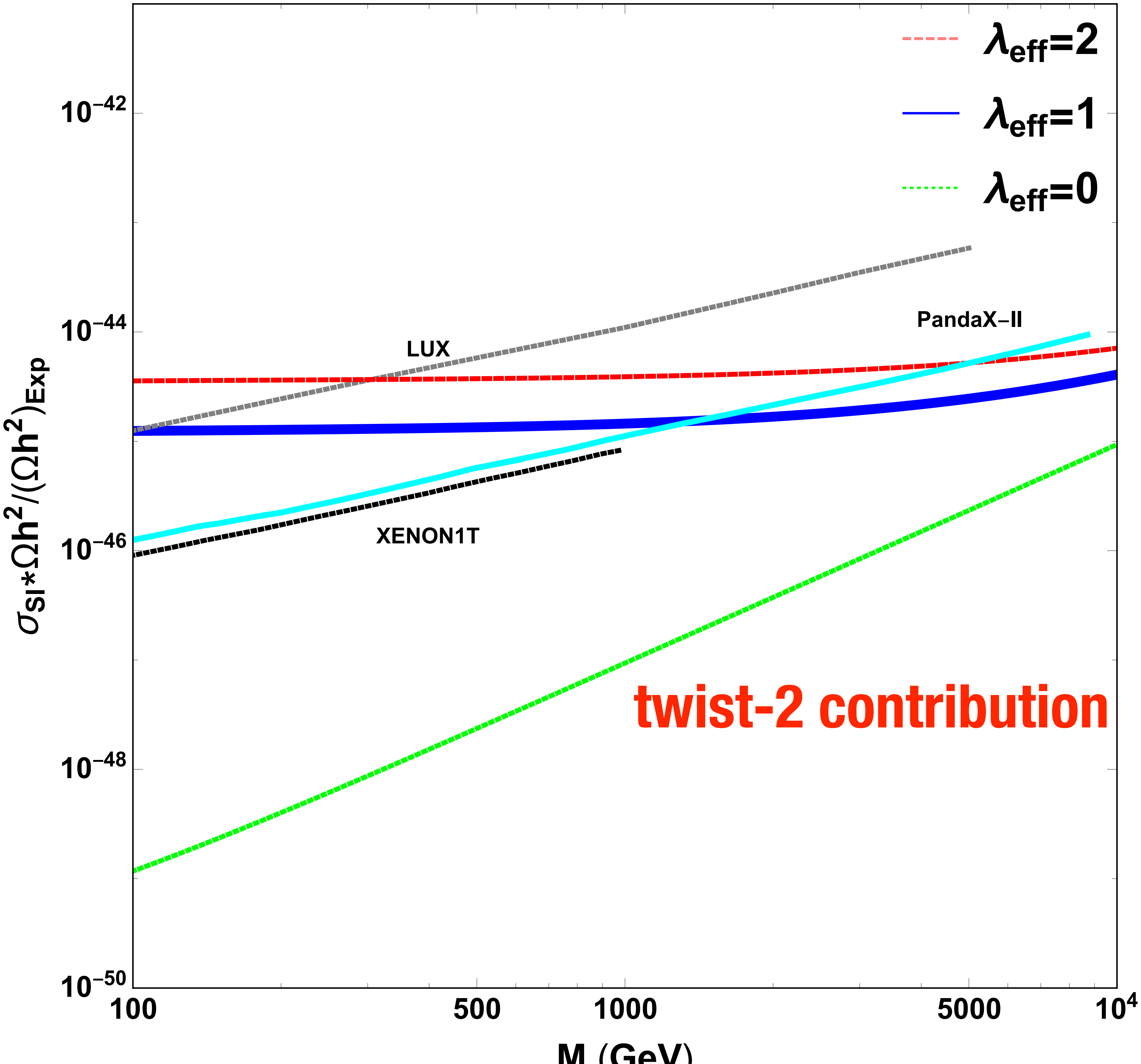








Numerical results



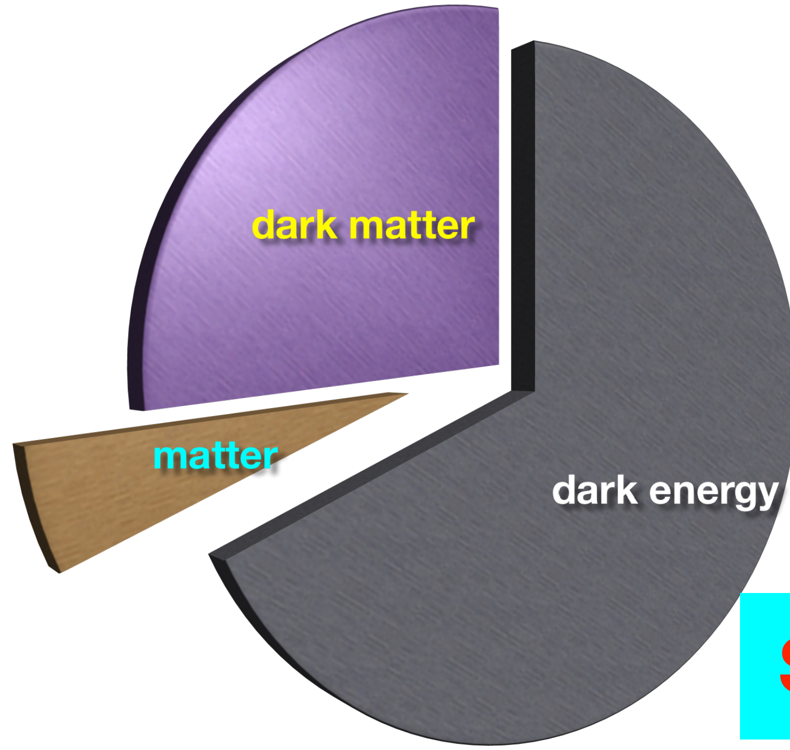
Conclusions

	Main points of DDs in gauge portal
1	Velocity suppressed cross section is reachable by the current DD technique!
2	Effects of twist-two operators are crucial for light DM.
3	Spin-dependent cross section may play important role in rolling out WIMPs
4	DD cross section of scalar-type electroweak multiplet DM are first analytically calculated by us!

Outlooking

What is this? @ 26.8%

Well-studied @ 4.9%



Still no signal!!!

1933 | 1959 | 1975 | *t* | 2006 | 2012 | 2019

Astrophysical observations

Confirm the particle DM

Sensitivity greatly improved

Precision calculations!

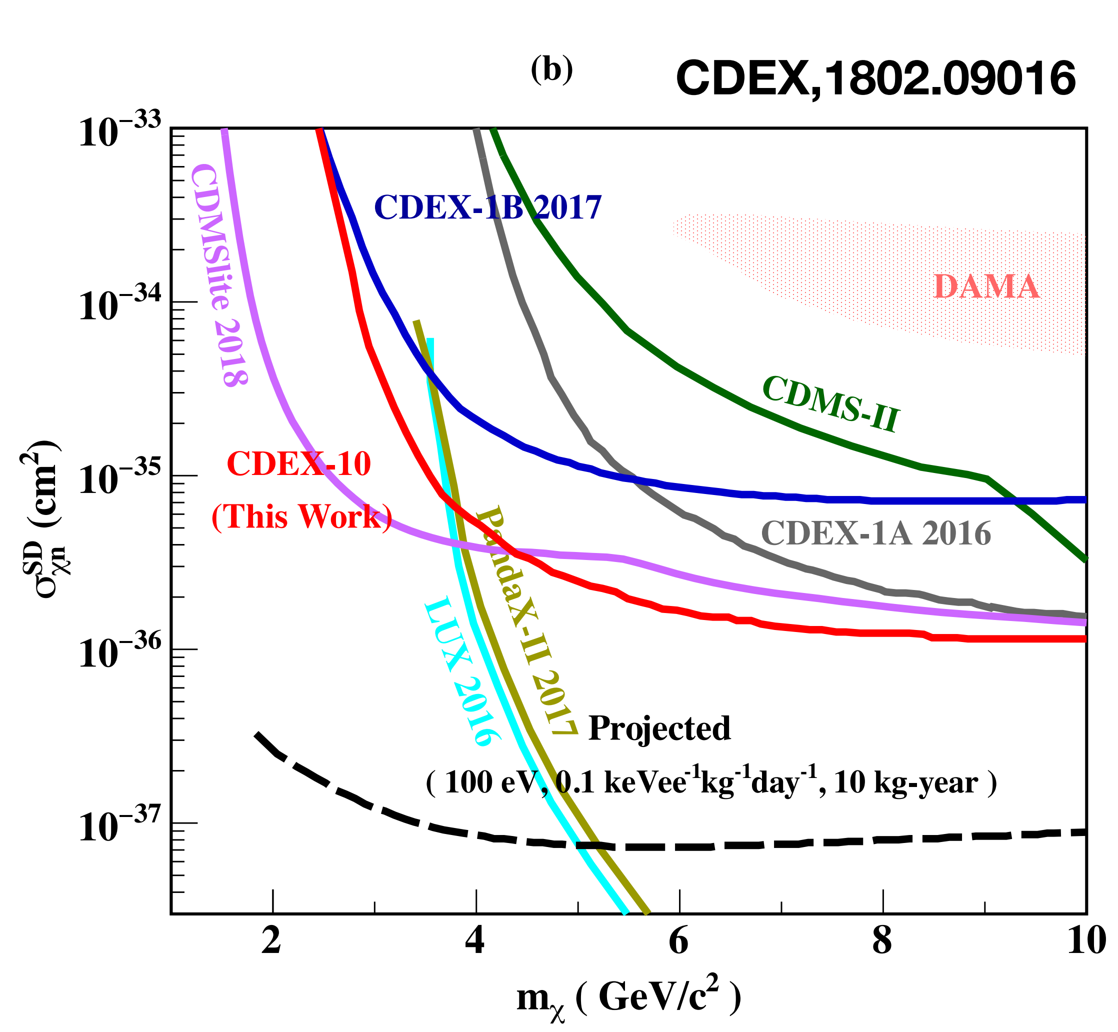
Thermal effects
DD cross section
…

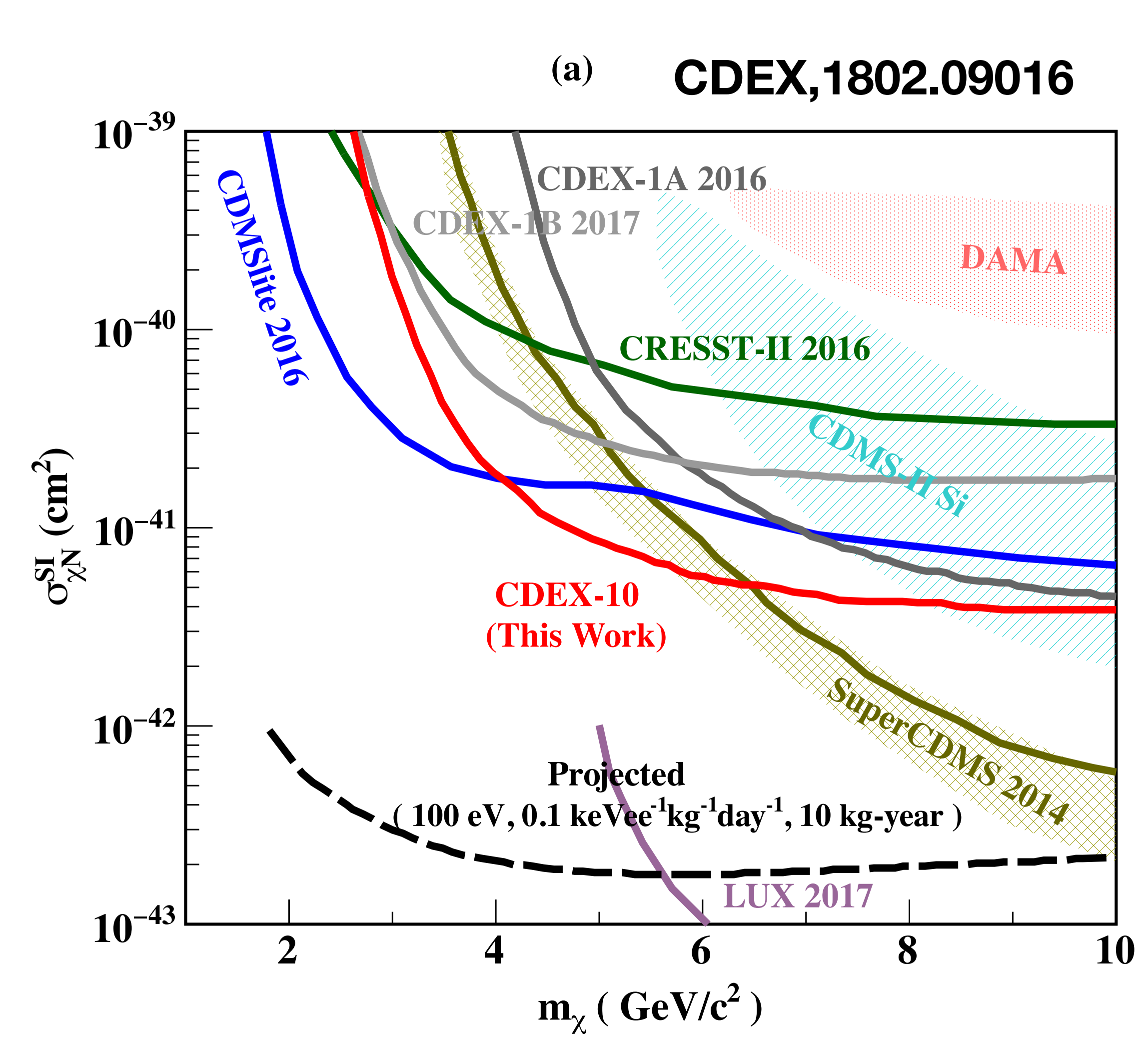
Give up WIMP?

Thanks

Back-up

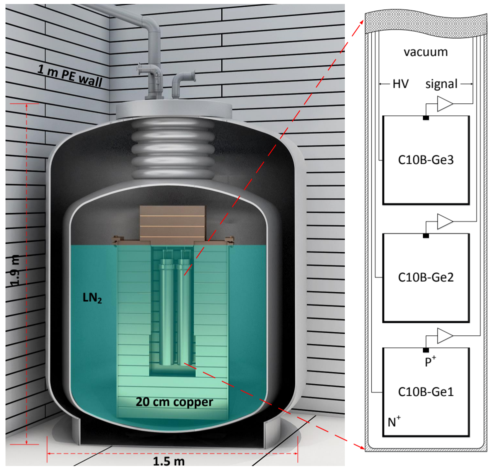
Recent Progress-CDEX



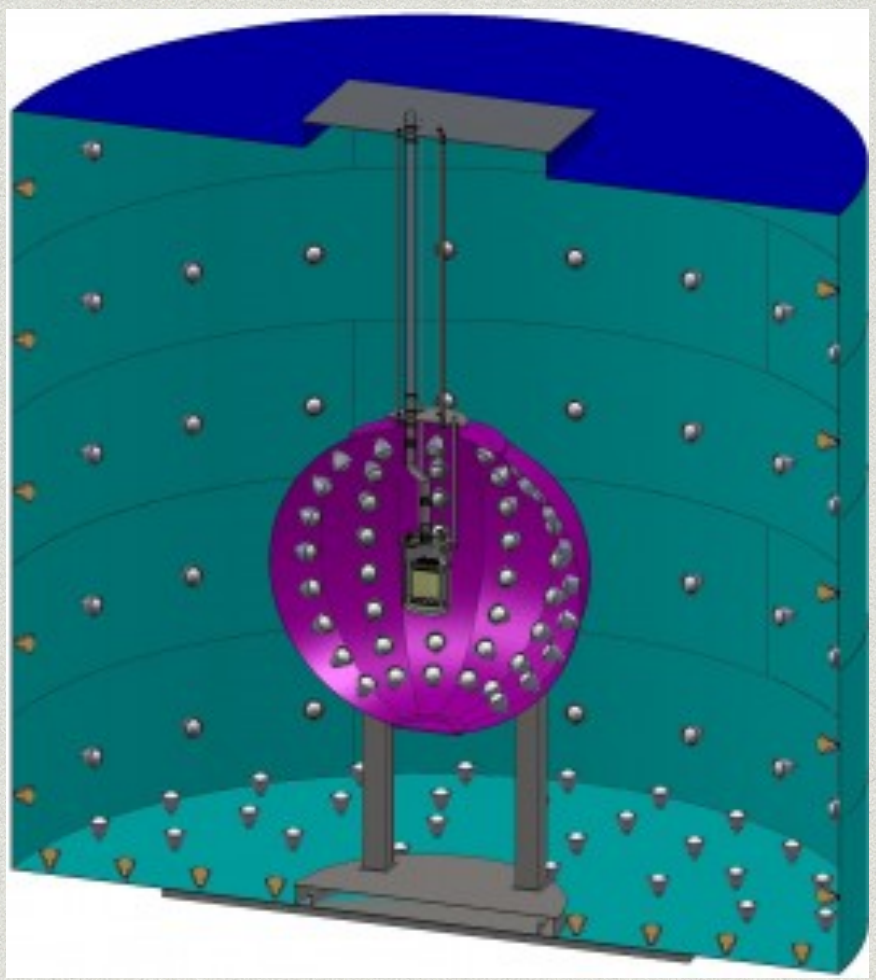


CDEX-10 ID:

- 10 Kg Ge
- Ionization
- 102.8 kg-days exposure
- Underground in CJPL



Recent Progress-DarkSide



ID of the DarkSide-50

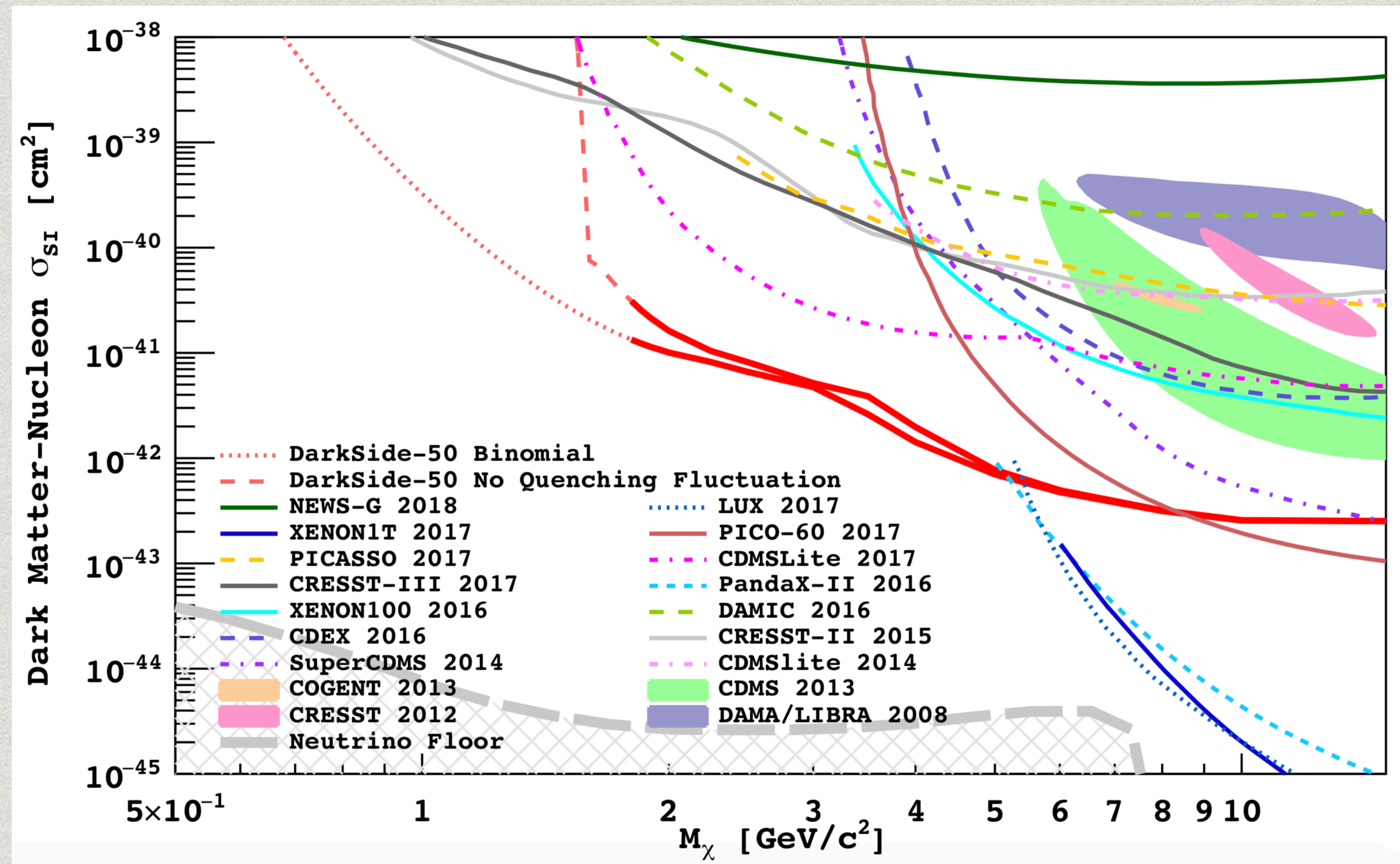
a **50 kg** dual-phase Liquid **Argon** TPC

Using Underground Argon: **depleted in ^{39}Ar**

In a **30 ton** borated liquid scintillator **neutron veto**

In a **1000 ton Water** Cherenkov Veto

Underground in Gran Sasso National Lab, Italy



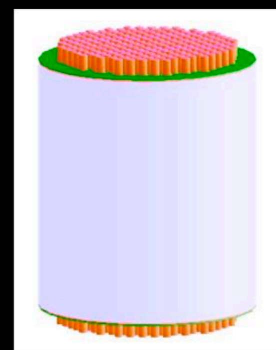
- **Dashed line: zero quench model, quenching a non-stochastic process**
- **Dotted line: binomial quench model, binomial quenching fluctuation s**

The best exclusion limit in the range 1.8 GeV-6 GeV, 1802.06994

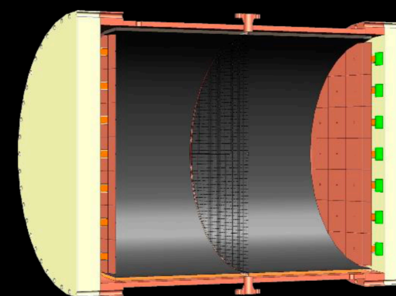
Recent Progress-PandaX

PandaX-I: 120 kg DM experiment 2009-2014

PandaX-II: 580 kg DM experiment 2014-2018



PandaX-xT: multi-ton DM experiment Future



PandaX-III: 200 kg to 1 ton HP gas ^{136}Xe 0vDBD experiment Future

Mar. 9 – June 30, low background with 10-fold reduction of Kr (Run9, 79.6 days)

Nov. 2016 – Mar. 2017, 2nd distillation campaign and recommissioning

2015

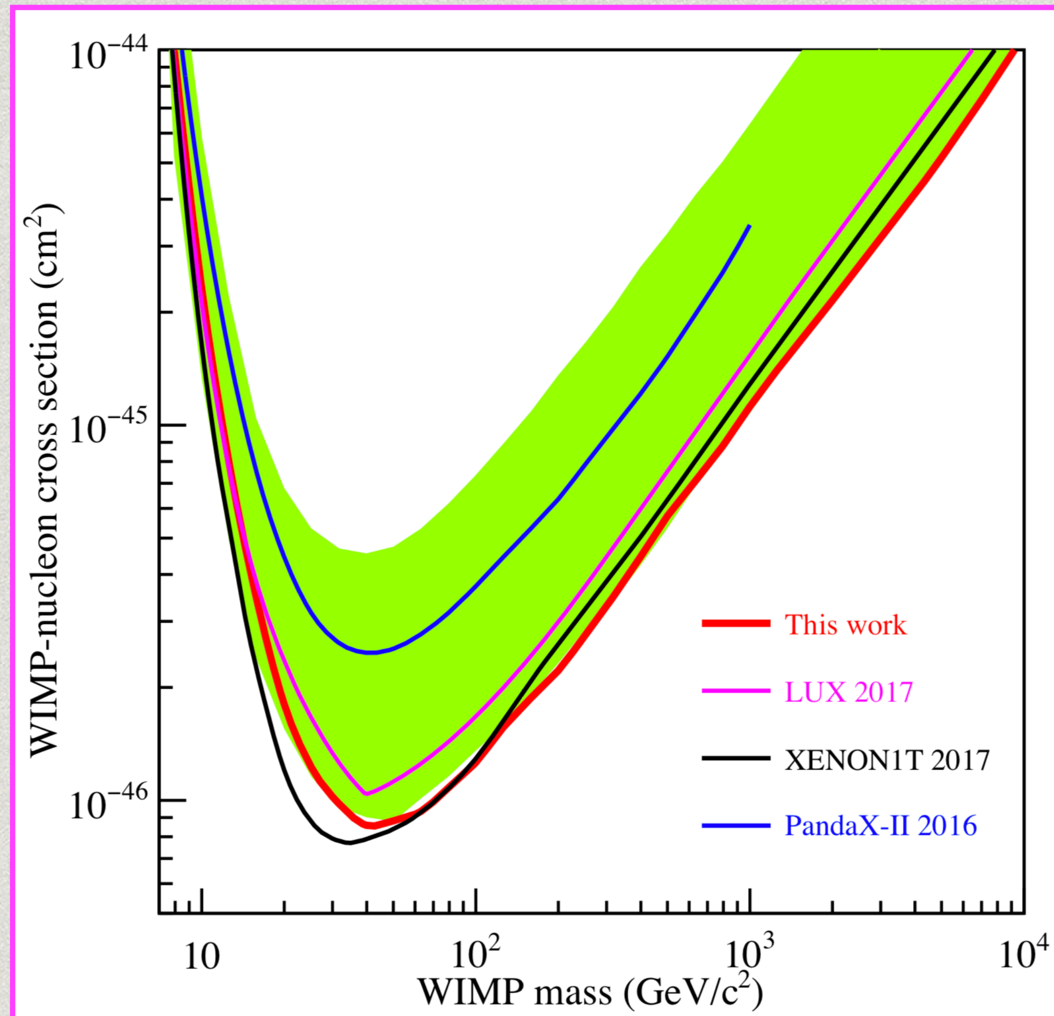
2016

2017

Nov. 22 – Dec. 14, Physics commission (Run8, 19.1 days, stopped due to high Krypton background)

Jul – Oct, ER calibration & tritium removal

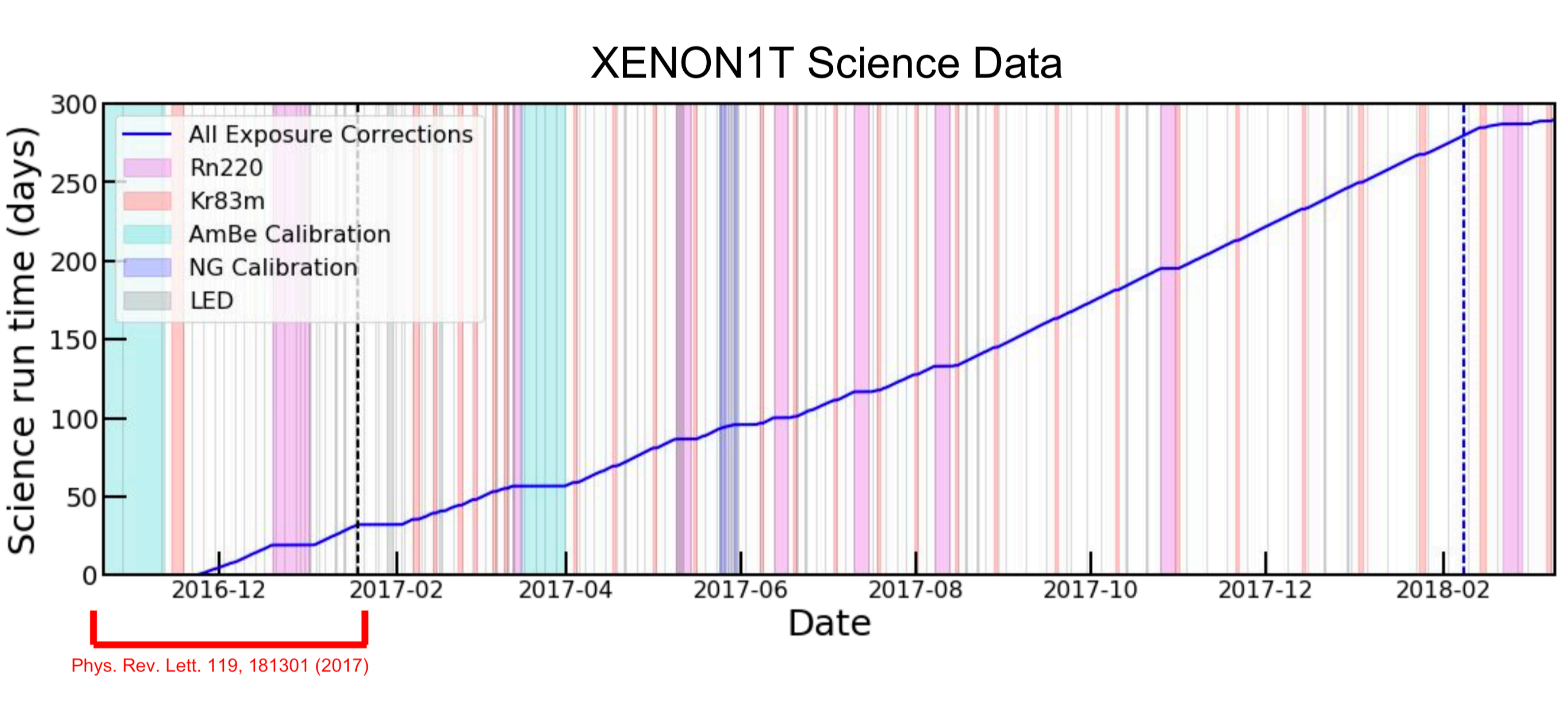
Apr.22 – July15, dark matter data taking (Run10, 77.1 days)

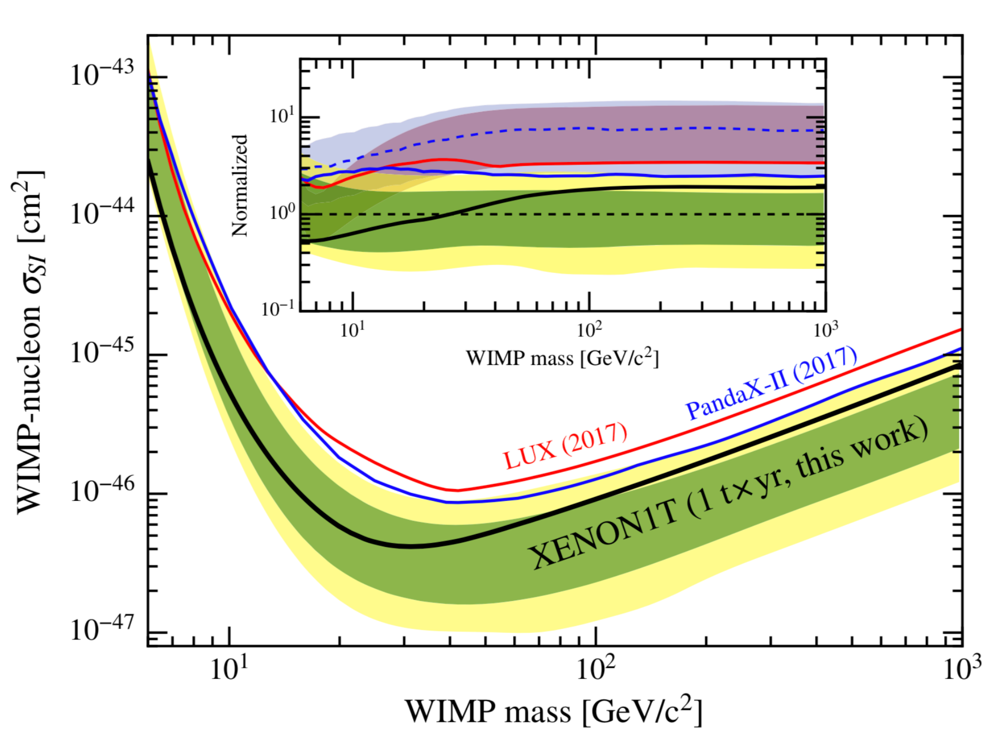


Exposure time: 54-Ton-Day

Recent Progress-XENON1T

XENON1T
Time: From 2016
Total: 3500 kg
Target: 2000 kg
Fiducial: >1000 kg
Sensitivity: ~10^{-47} cm^{-2}





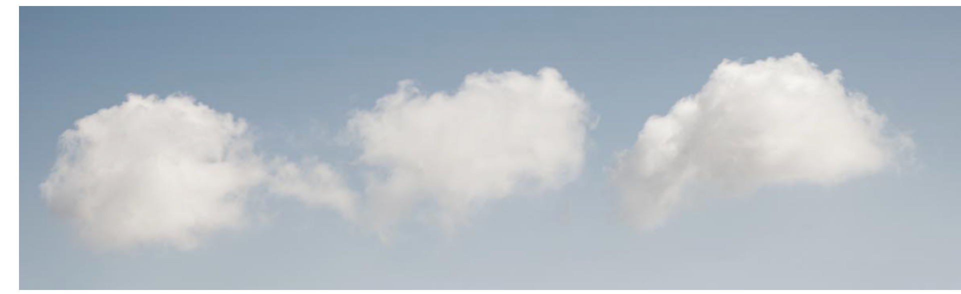
Exposure time

Updated exclusion limit

XENONnT
Time: From 2019
Total: 7500 kg
Target: 5900 kg
Fiducial: 4000 kg
Sensitivity: ~10^{-48} cm^{-2}

粒子物理天空中的乌云

二十世纪初物理学天空的乌云



历史总是有些相似!

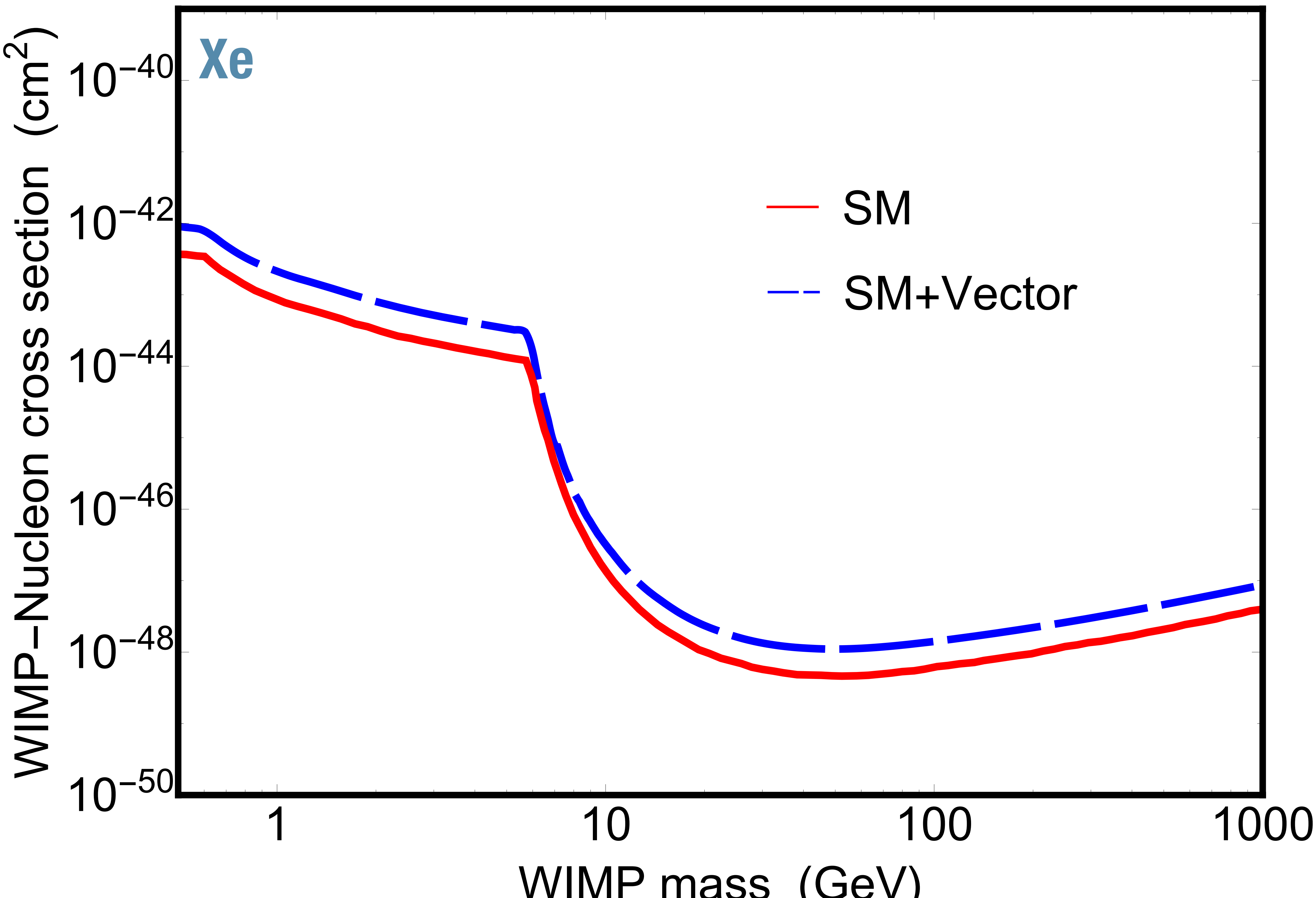
量子力学
广义相对论

- 黑体辐射
- 迈克逊-莫雷实验

具有确凿试验证据的超出标准模型的新物理

- 中微子物理;
- 暗物质;
- 重子数不对称;

Numerical results-1: vector interactions with X131



Numerical results-3: scalar interactions with X131