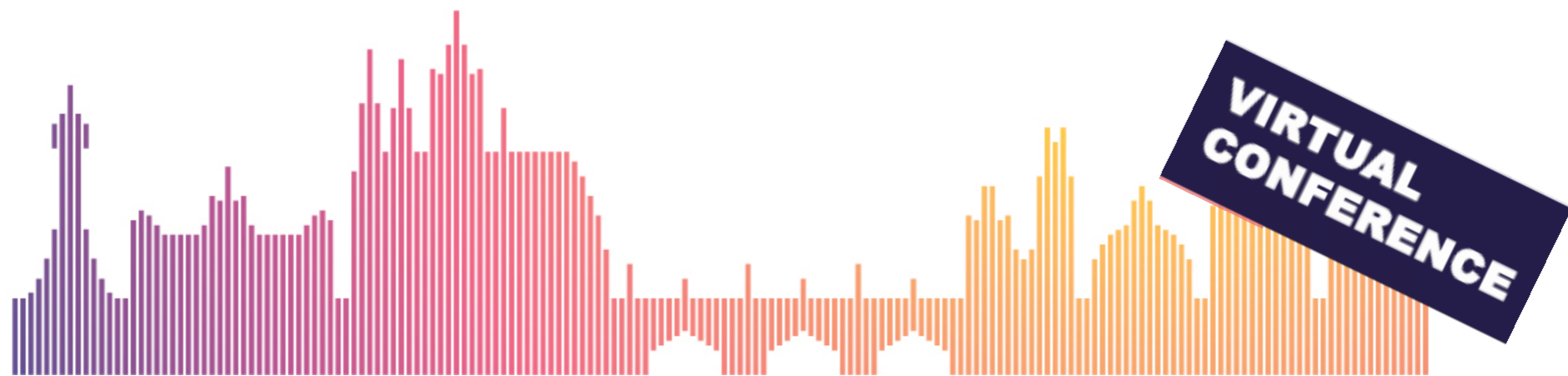


# Neutrino Portals to Dark Matter



**Salvador Rosauro-Alcaraz**

In collaboration with M. Blennow, E. Fernández-Martínez, A. Olivares-Del Campo, S. Pascoli and A. Titov  
Based on [Eur.Phys.J. C79 \(2019\) 55](#)



Instituto de  
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UAM-CSIC

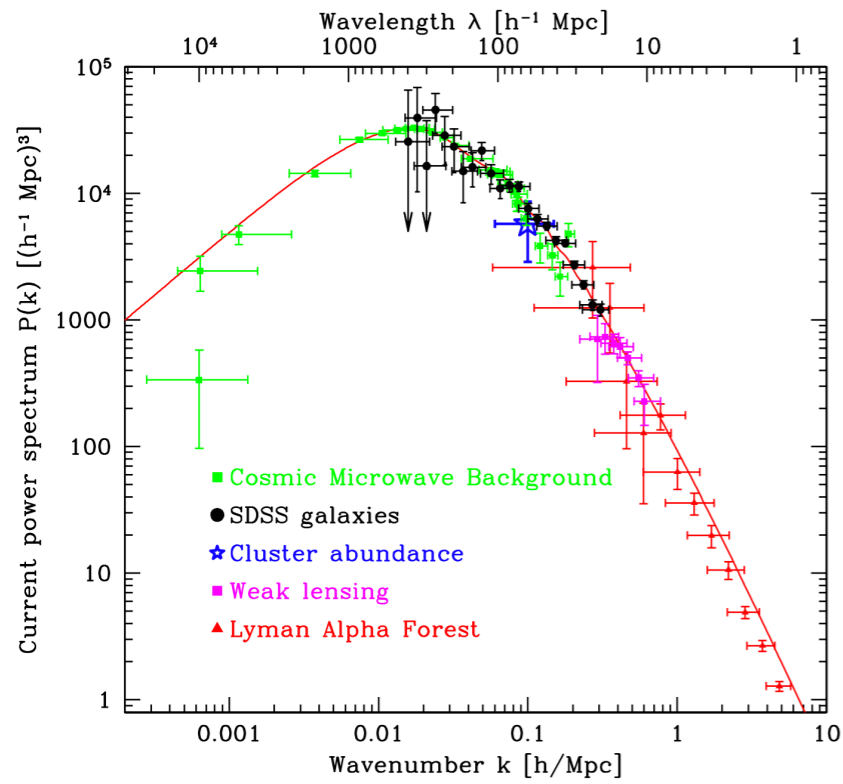
**ICHEP 2020**

40<sup>th</sup> International Conference on High Energy Physics

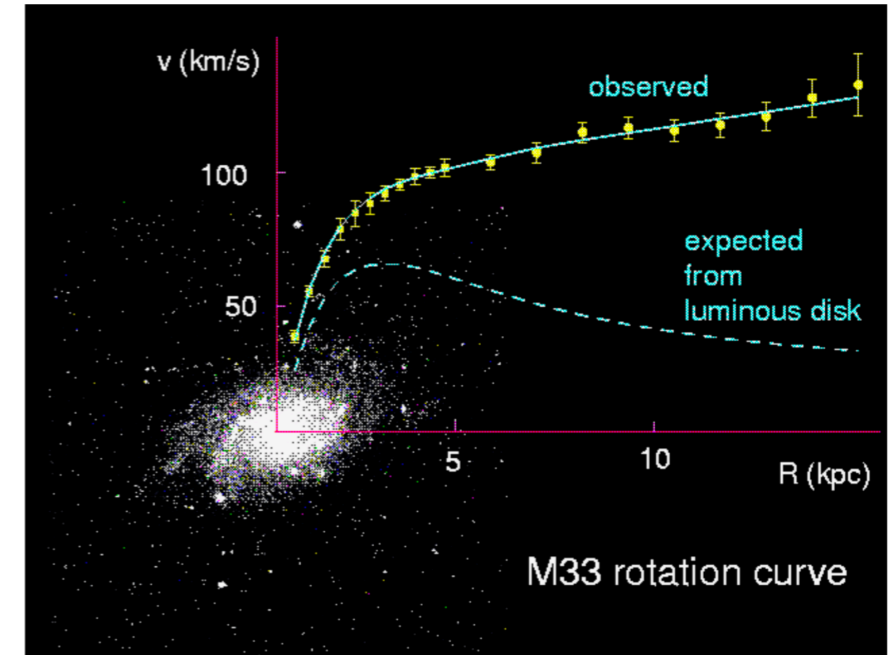


Universidad Autónoma  
de Madrid

# Dark Matter

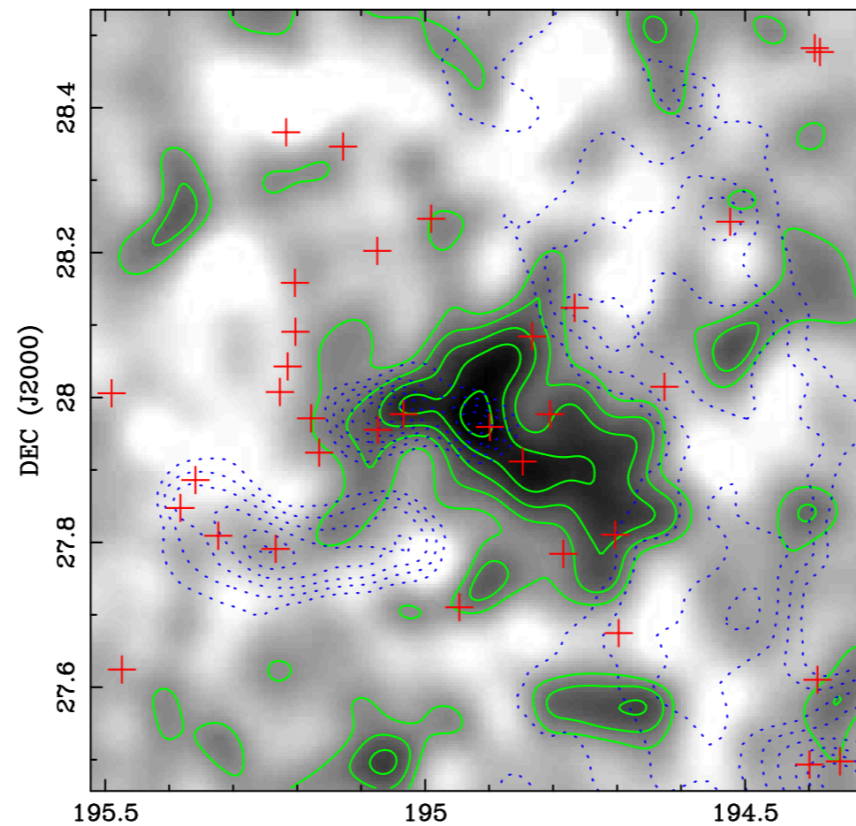


M. Tegmark *et al.*  
arXiv:0310725



D. P. Roy, arXiv:physics/0007025

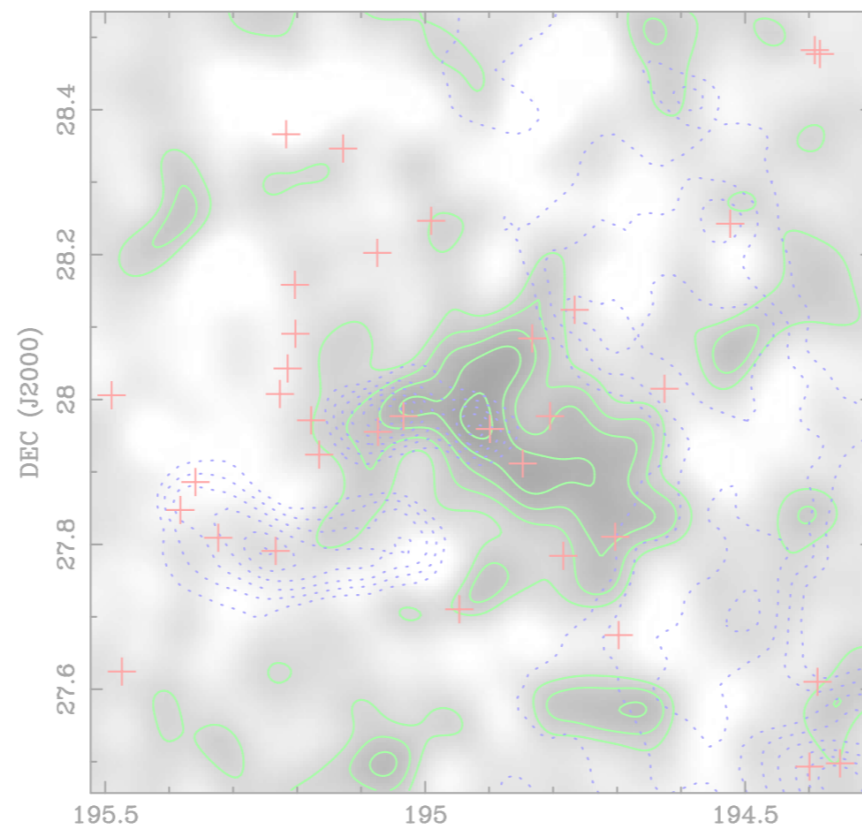
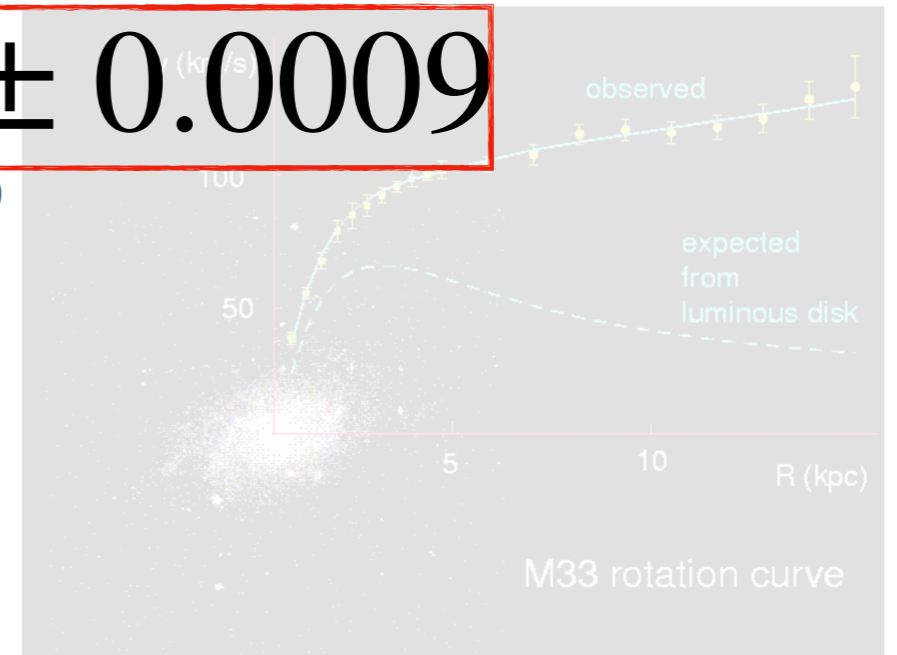
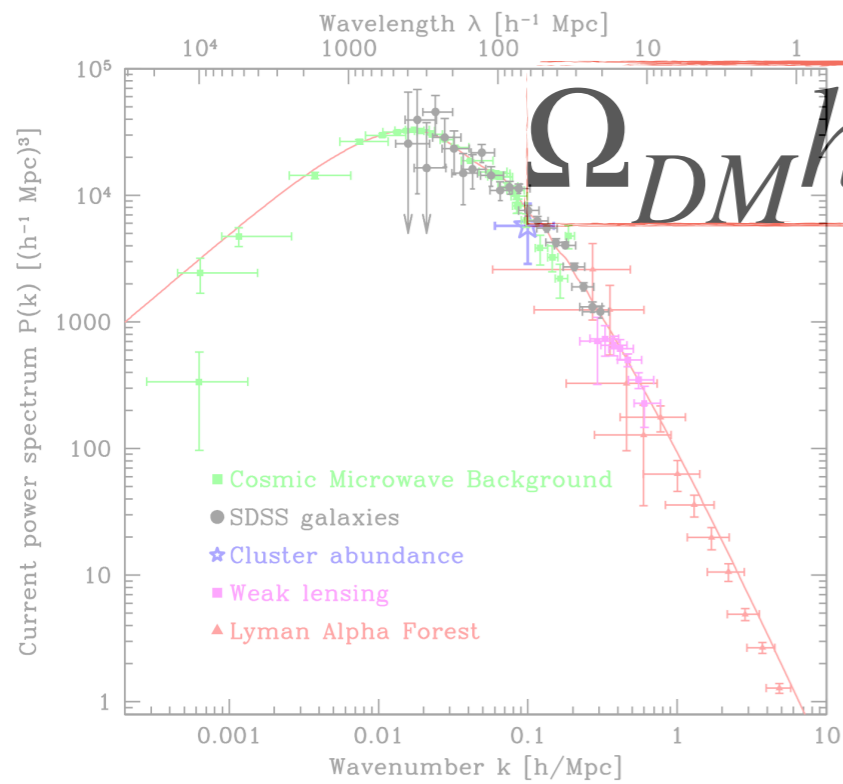
R. Gavazzi *et al.*  
arXiv:astro-ph/0904.0220



# Dark Matter

$$\Omega_{DM} h^2 = 0.1193 \pm 0.0009$$

Planck Collaboration, arXiv:1807.06209

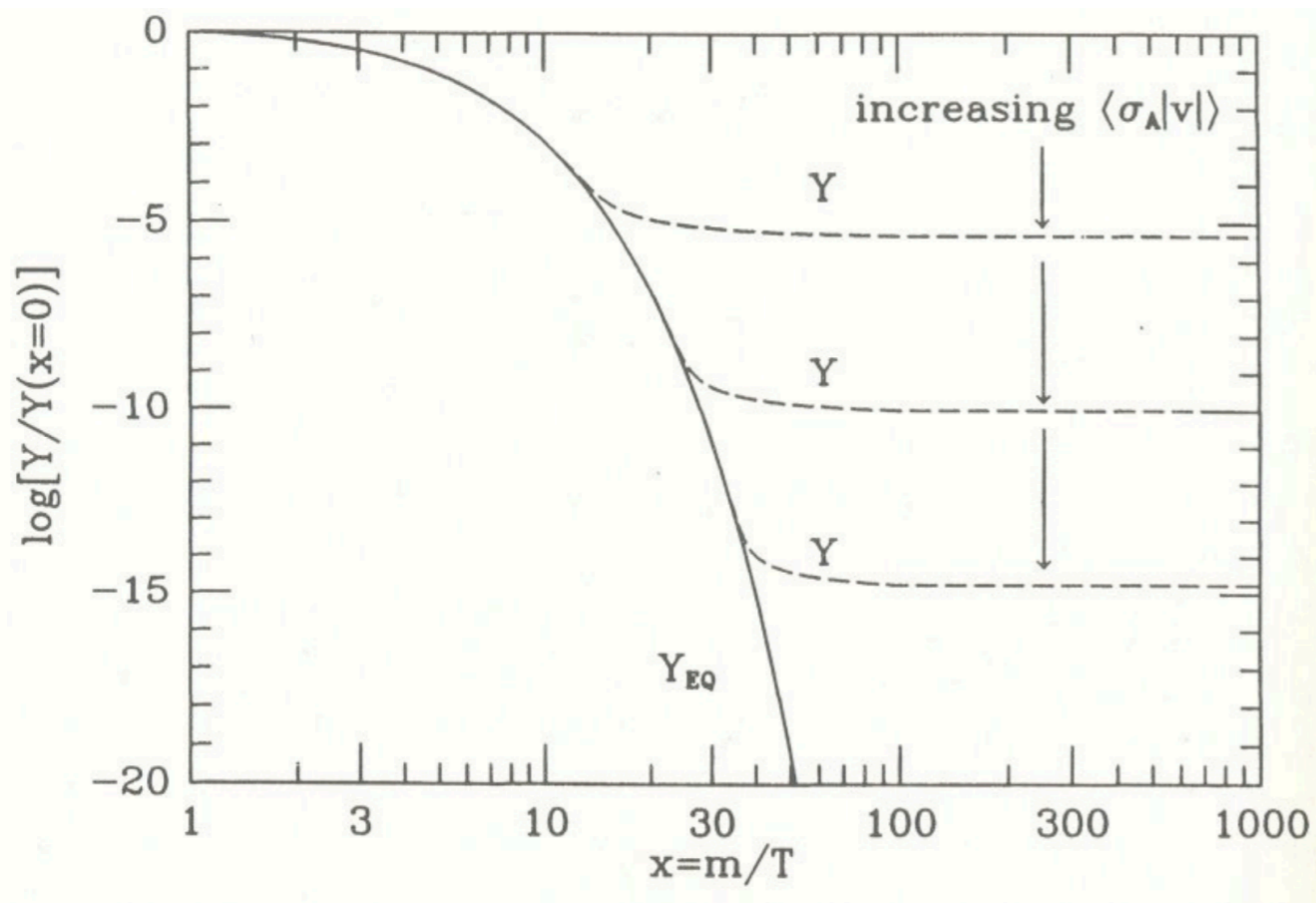


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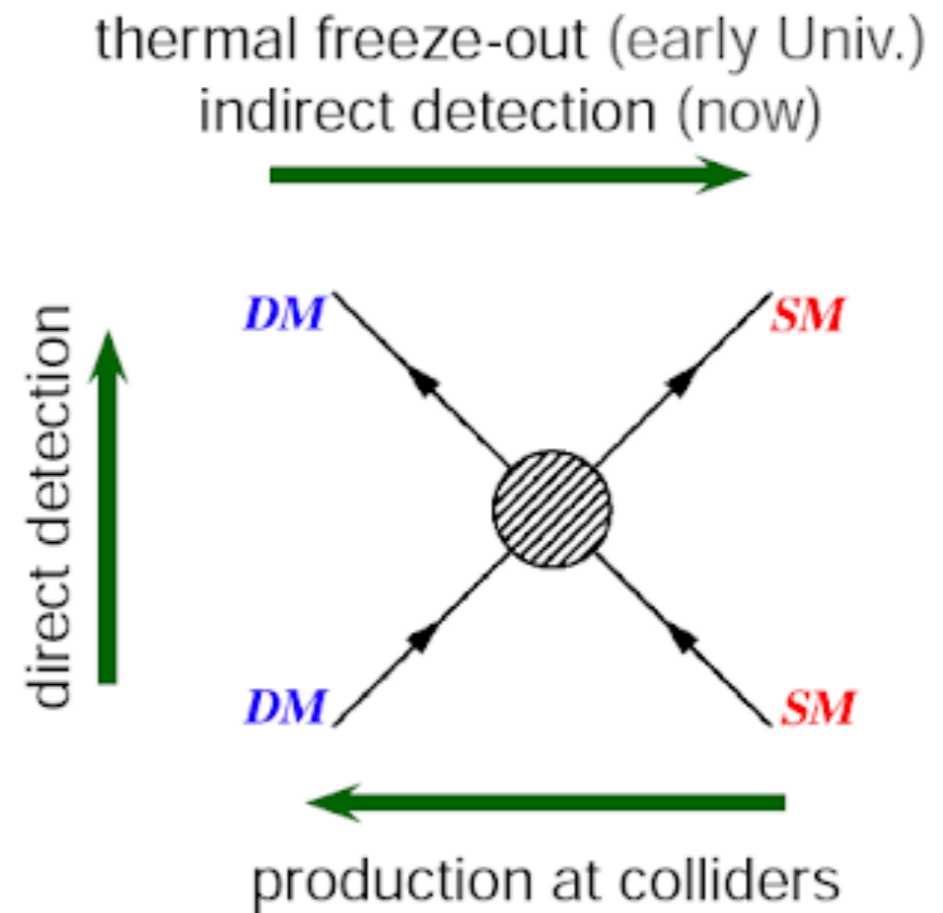
$$\Omega_{DM}h^2 = 0.1193 \pm 0.0009$$

Planck Collaboration, arXiv:1807.06209

## Thermal freeze-out



The Early Universe, E. Kolb & M. Turner



J. Feng, MPIK webpage

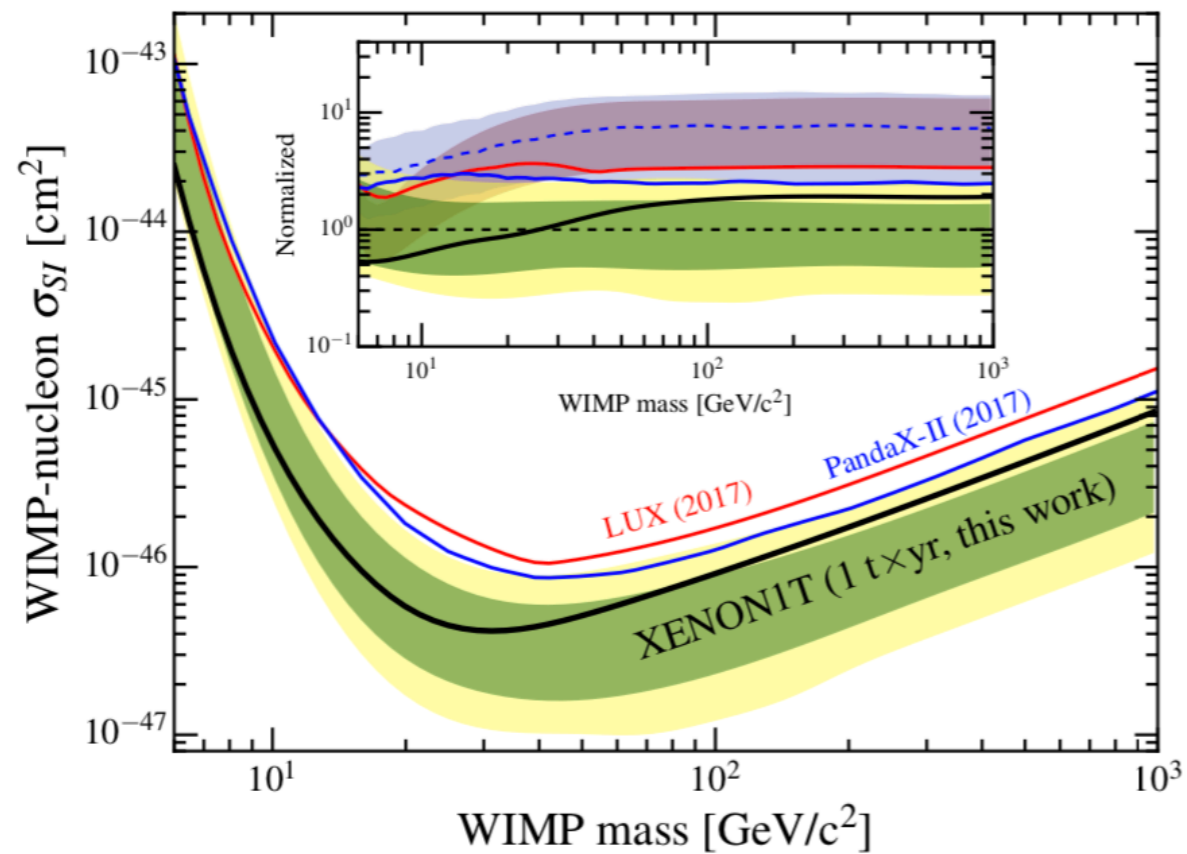
[https://www.mpi-hd.mpg.de/lin/research\\_DM.en.html](https://www.mpi-hd.mpg.de/lin/research_DM.en.html)

# What about direct detection?

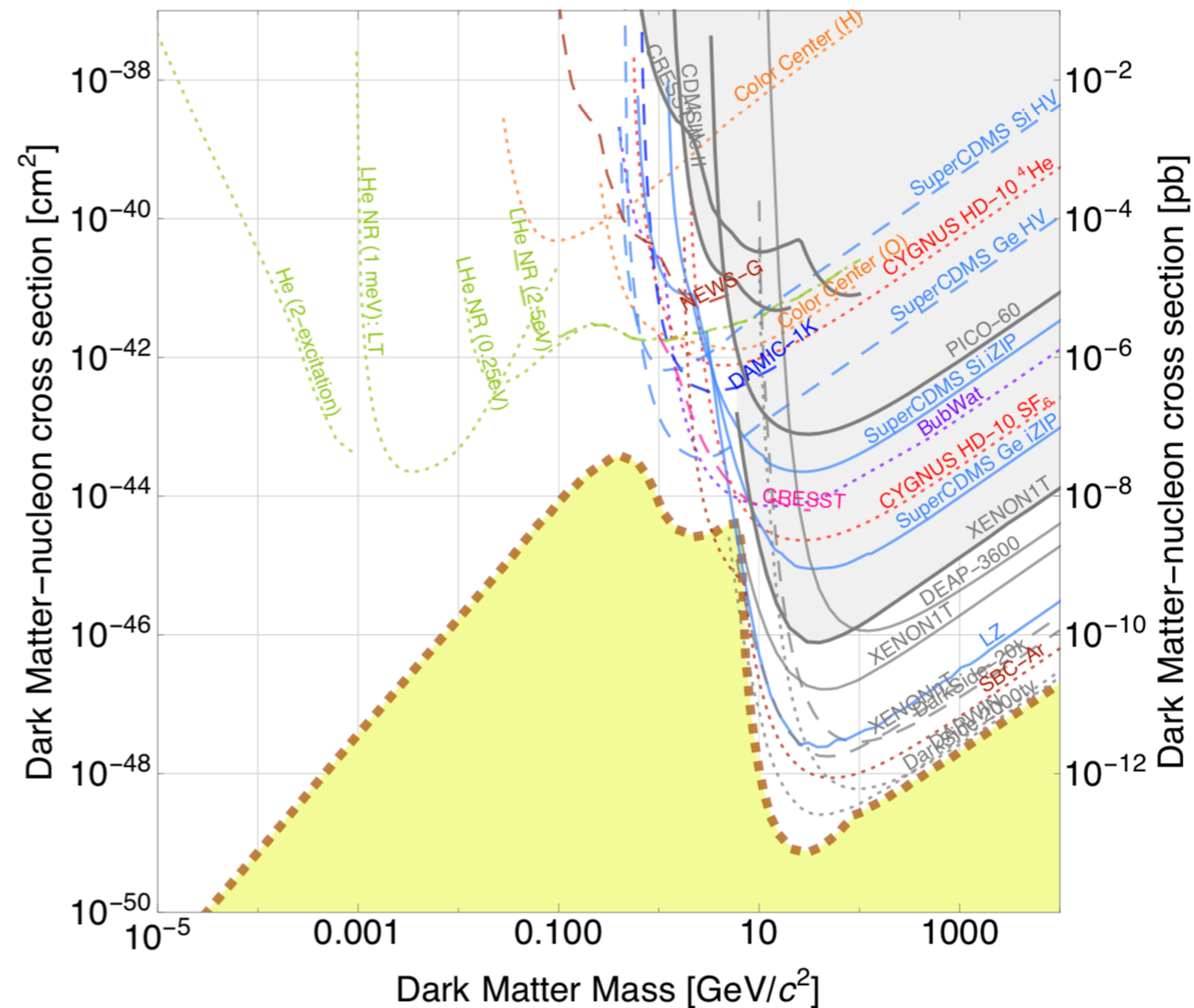
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Planck Collaboration, arXiv:1807.06209

XENON Collaboration, arXiv:1805.12562



E. Adelberger et al., arXiv:1701.04591



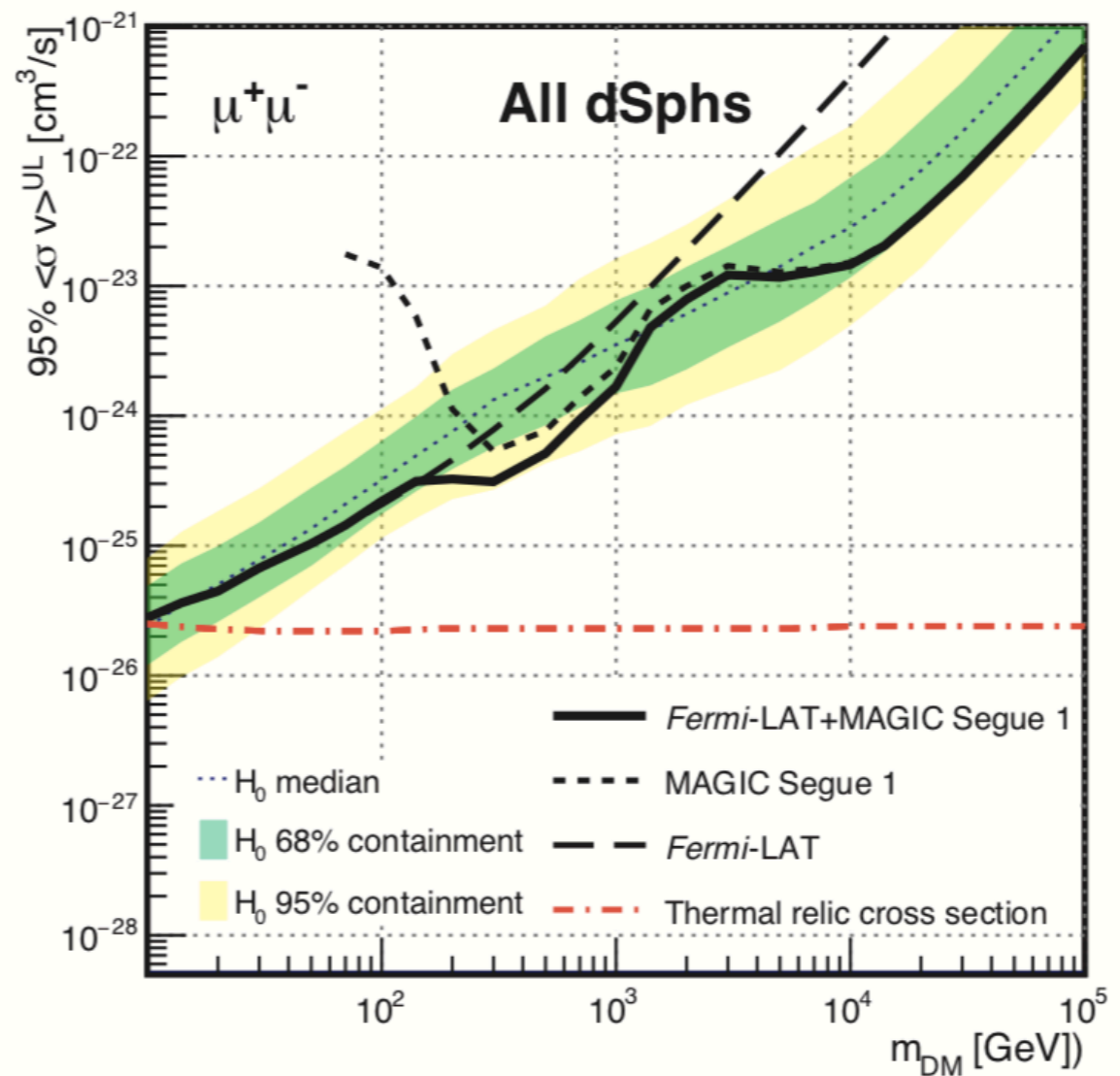
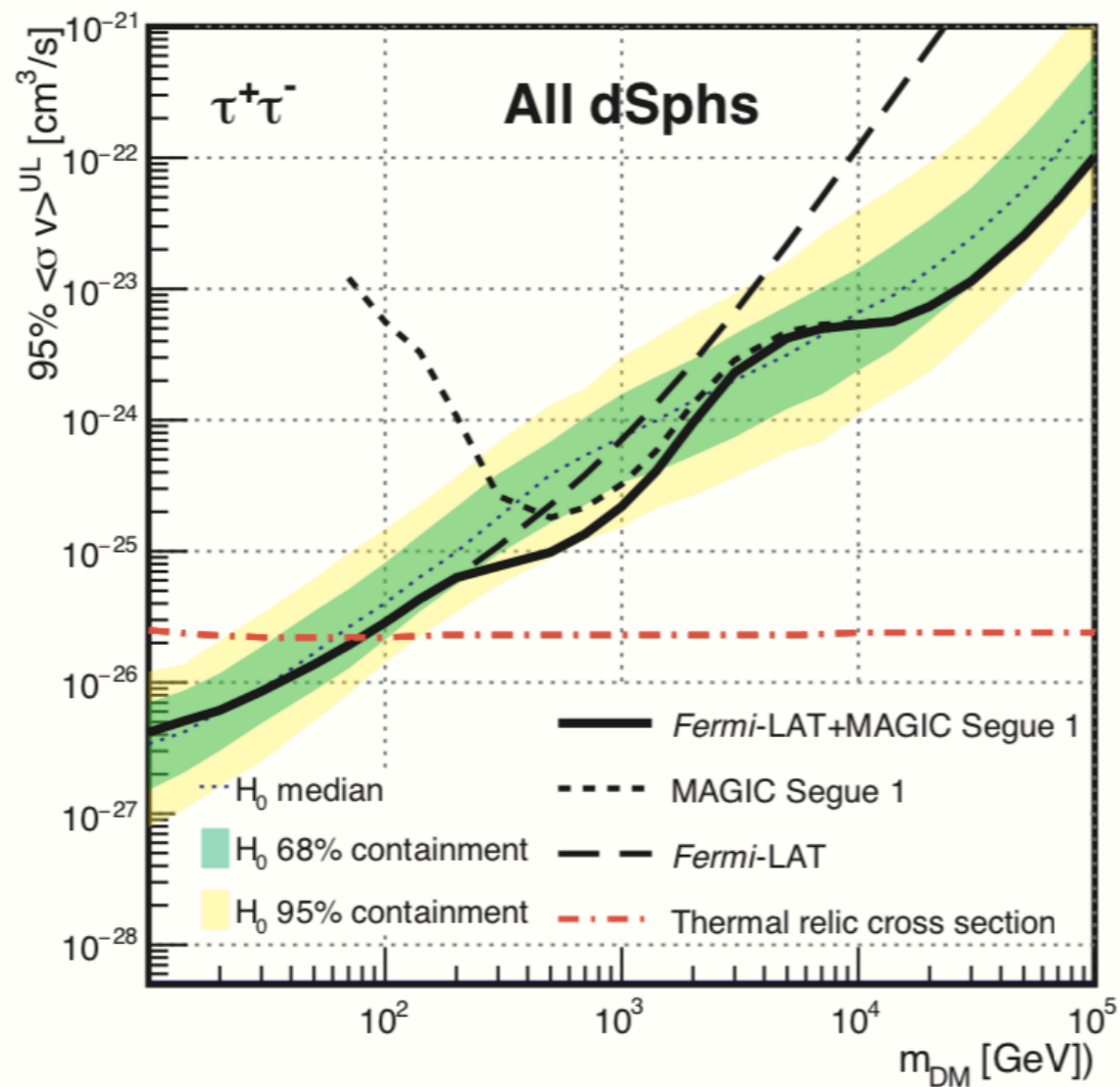


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Planck Collaboration, arXiv:1807.06209

Fermi-LAT Collaboration, arXiv:1601.06590

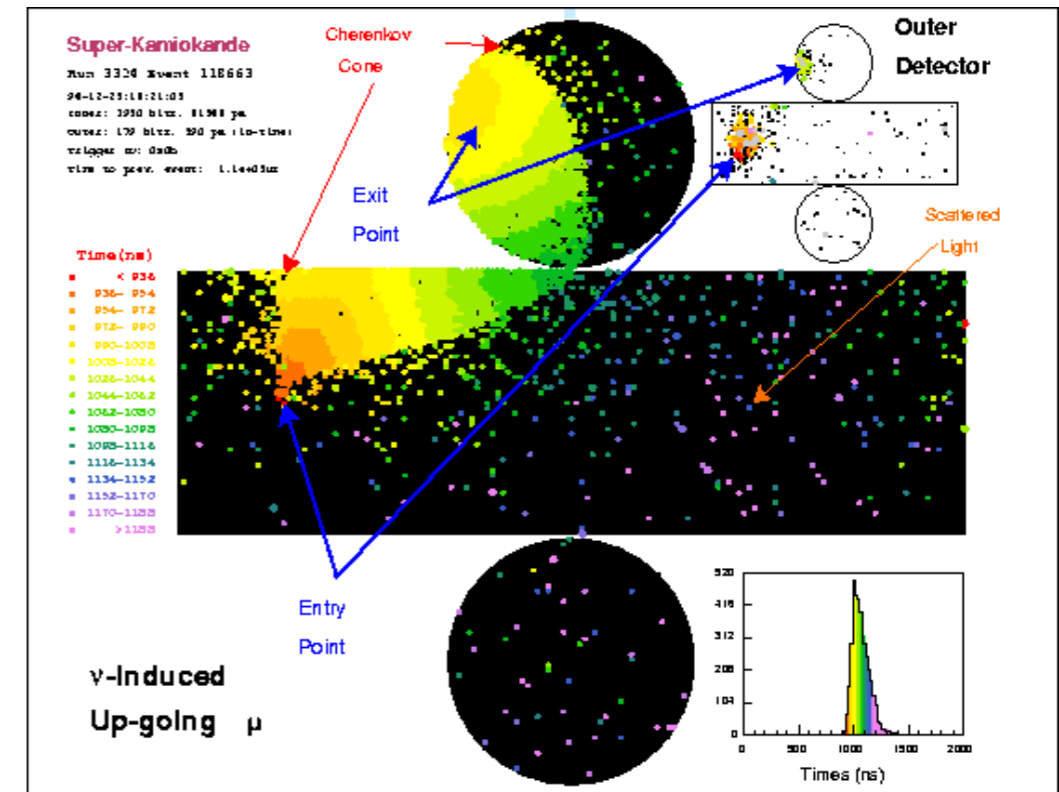


# Neutrino-dark matter interactions

In the Standard Model

$$\mathcal{L}_{\nu int} \supset \frac{g}{\sqrt{2}} \bar{\nu}_{\alpha} \gamma^{\mu} P_L l_{\alpha} W_{\mu}^{+} + \frac{g}{2 \cos \theta_W} \bar{\nu}_{\alpha} \gamma^{\mu} P_L \nu_{\alpha} Z_{\mu}$$

Dark matter shares its elusive nature with neutrinos

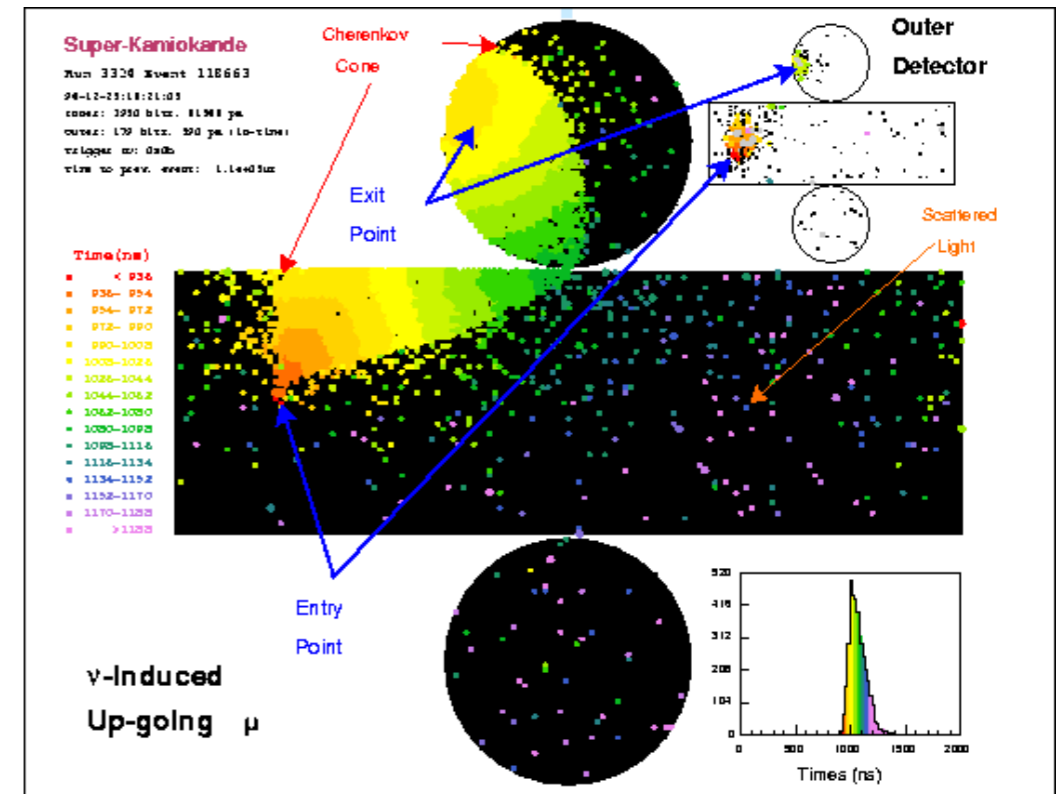


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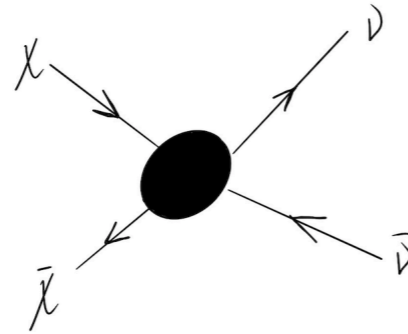
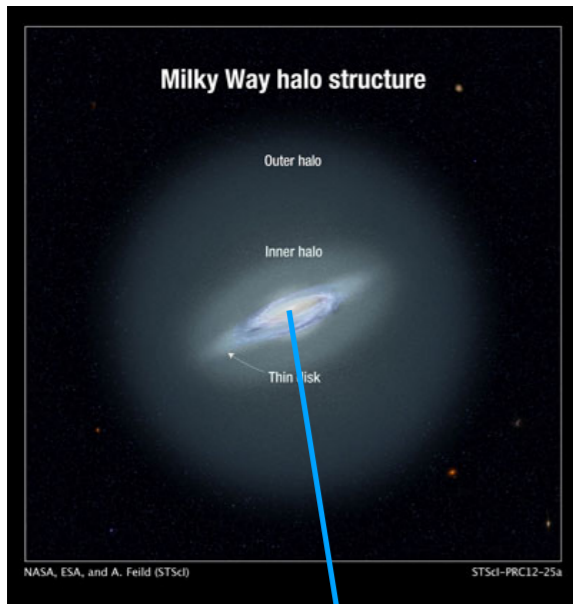
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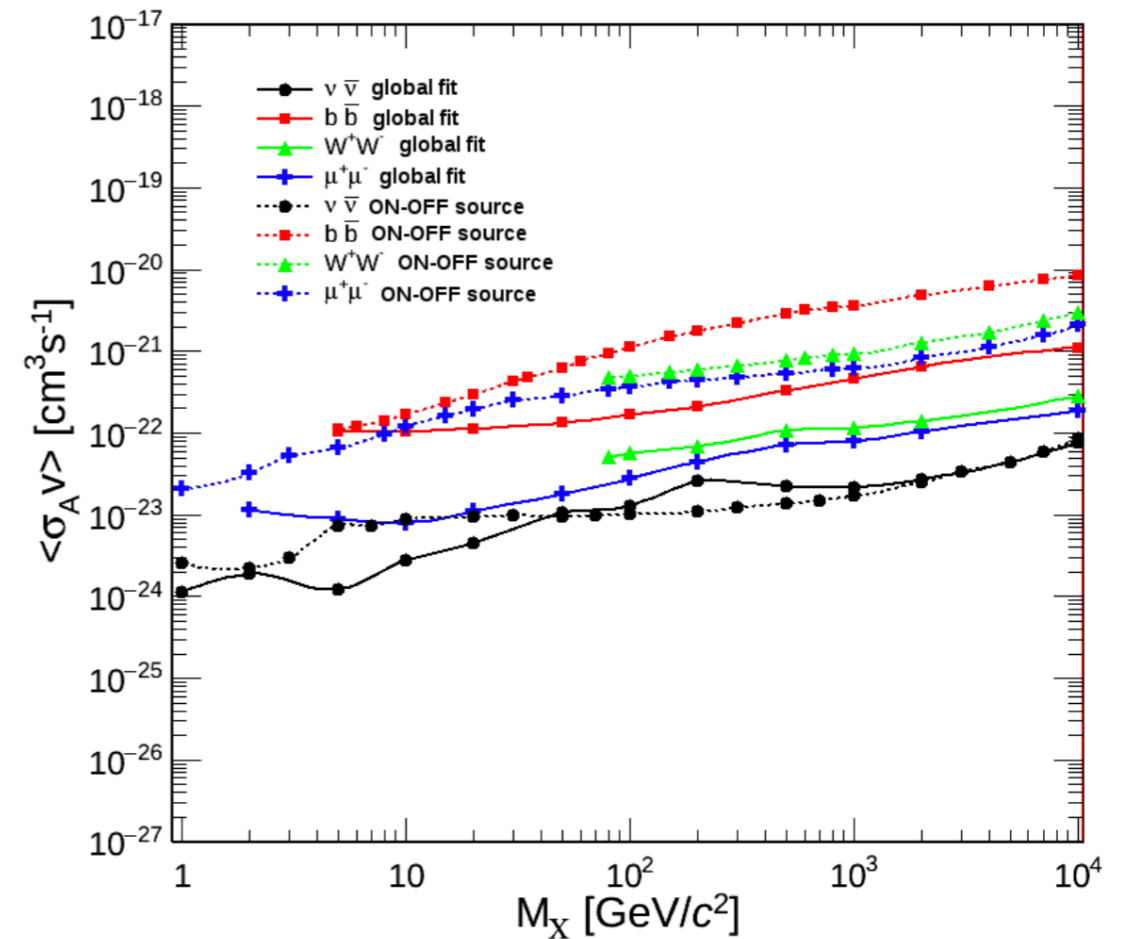
Could dark matter be primarily interacting with neutrinos?



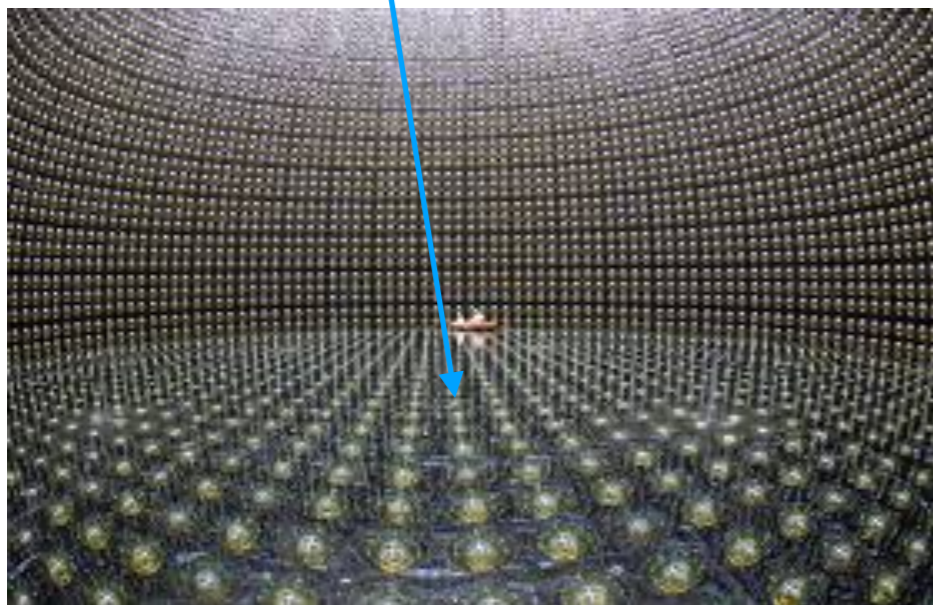
# Constraints on DM-SM interactions



Indirect detection with neutrinos

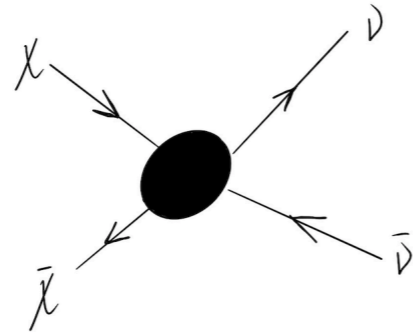
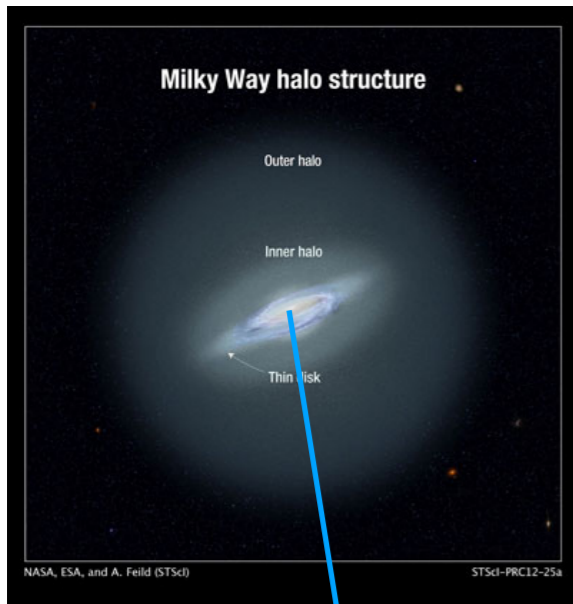


$$E_\nu = m_\chi$$



Super-Kamiokande Collaboration, arXiv:1510.07999  
 H. Yüksel *et al.*, arXiv:0707.0196  
 A. Olivares-Del Campo *et al.*, arXiv:1711.05283

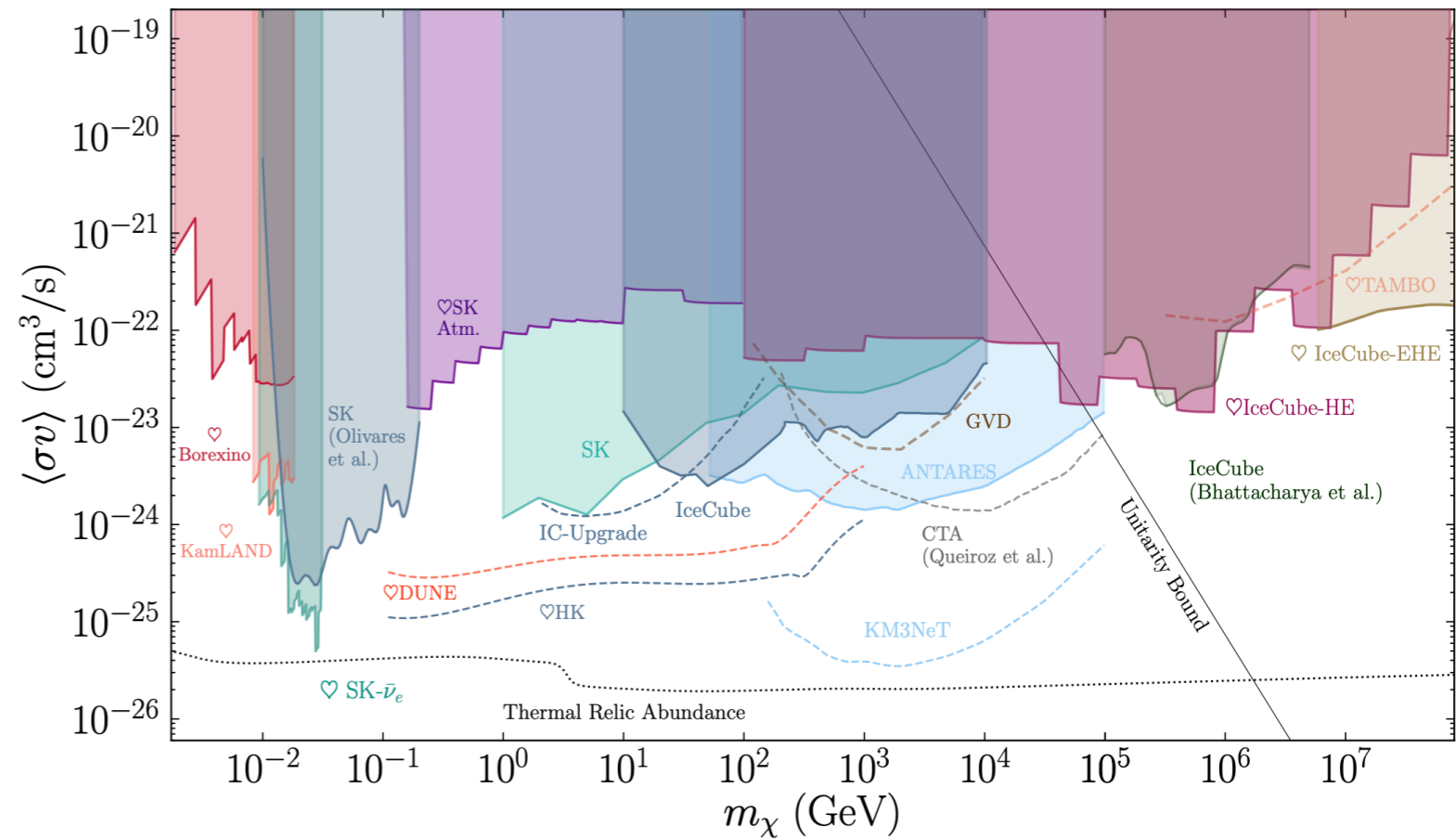
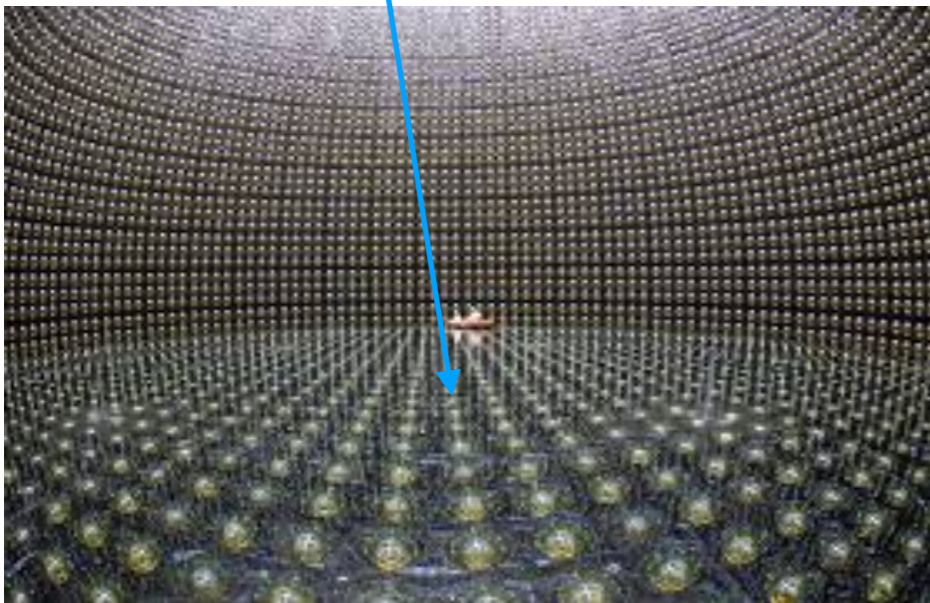
# Constraints on DM-SM interactions



Indirect detection with neutrinos



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# Can we couple DM to SM neutrinos?

Gauge invariance

$$L_{L\alpha} = \begin{pmatrix} \nu_{L\alpha} \\ l_{L\alpha} \end{pmatrix}$$

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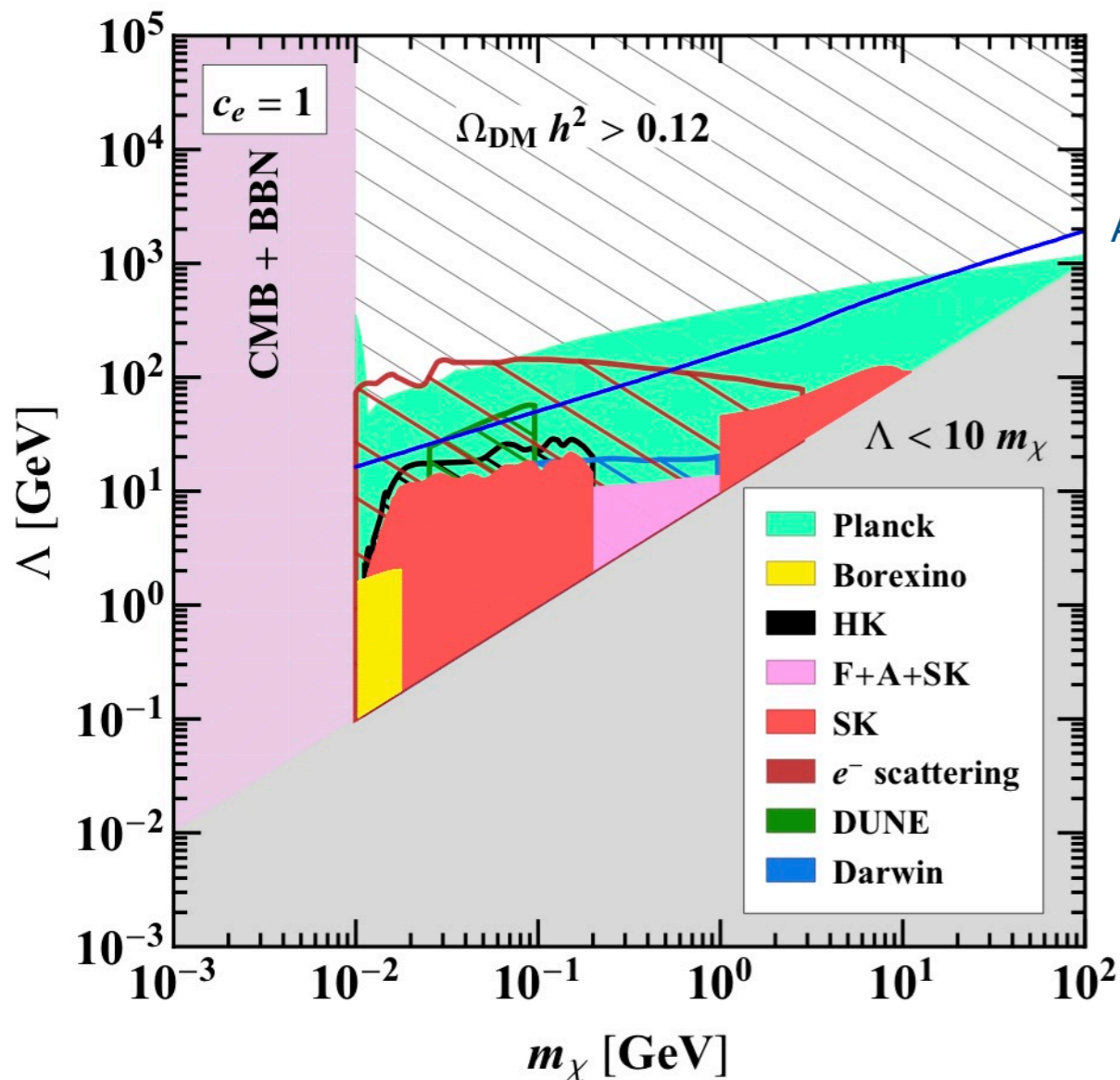


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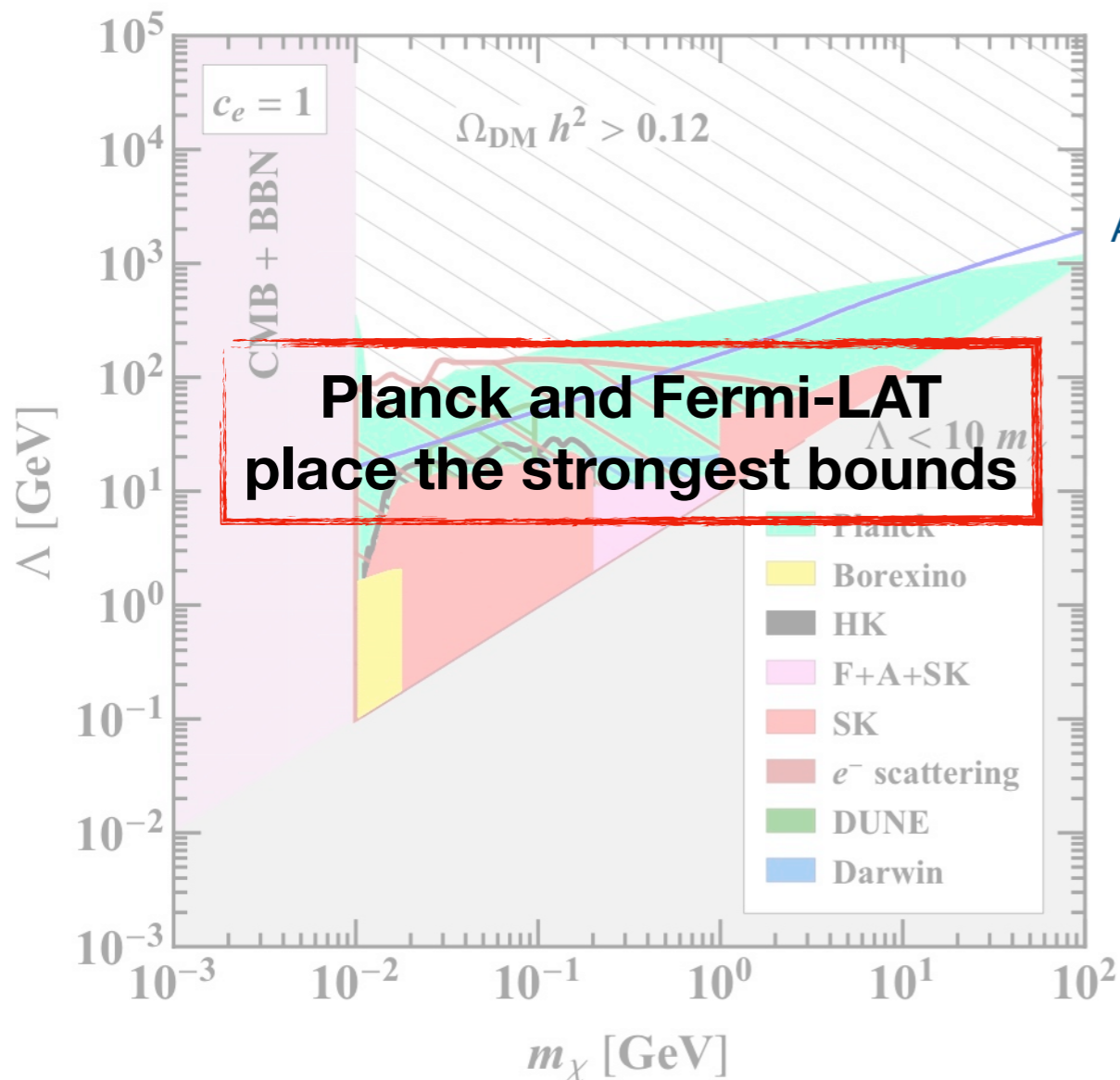
D. McKeen & N. Raj, arXiv:1812.0512  
 N. Klop & S. Ando, arXiv:1809.00671  
 R. Essig et al., arXiv:1801.10159  
 A. Olivares-Del Campo et al., arXiv:1805.09830

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D. McKeen & N. Raj, arXiv:1812.0512  
 N. Klop & S. Ando, arXiv:1809.00671  
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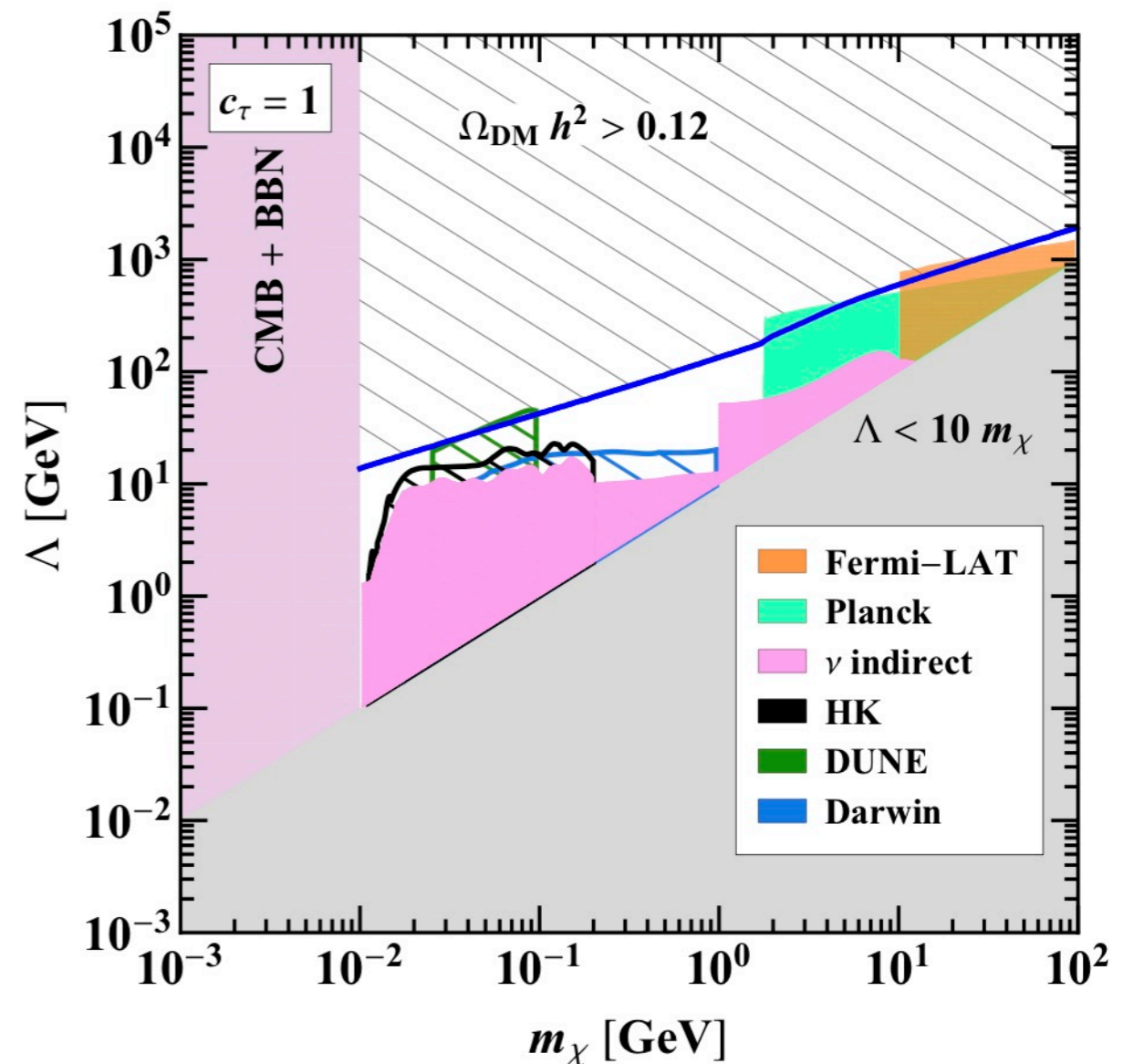
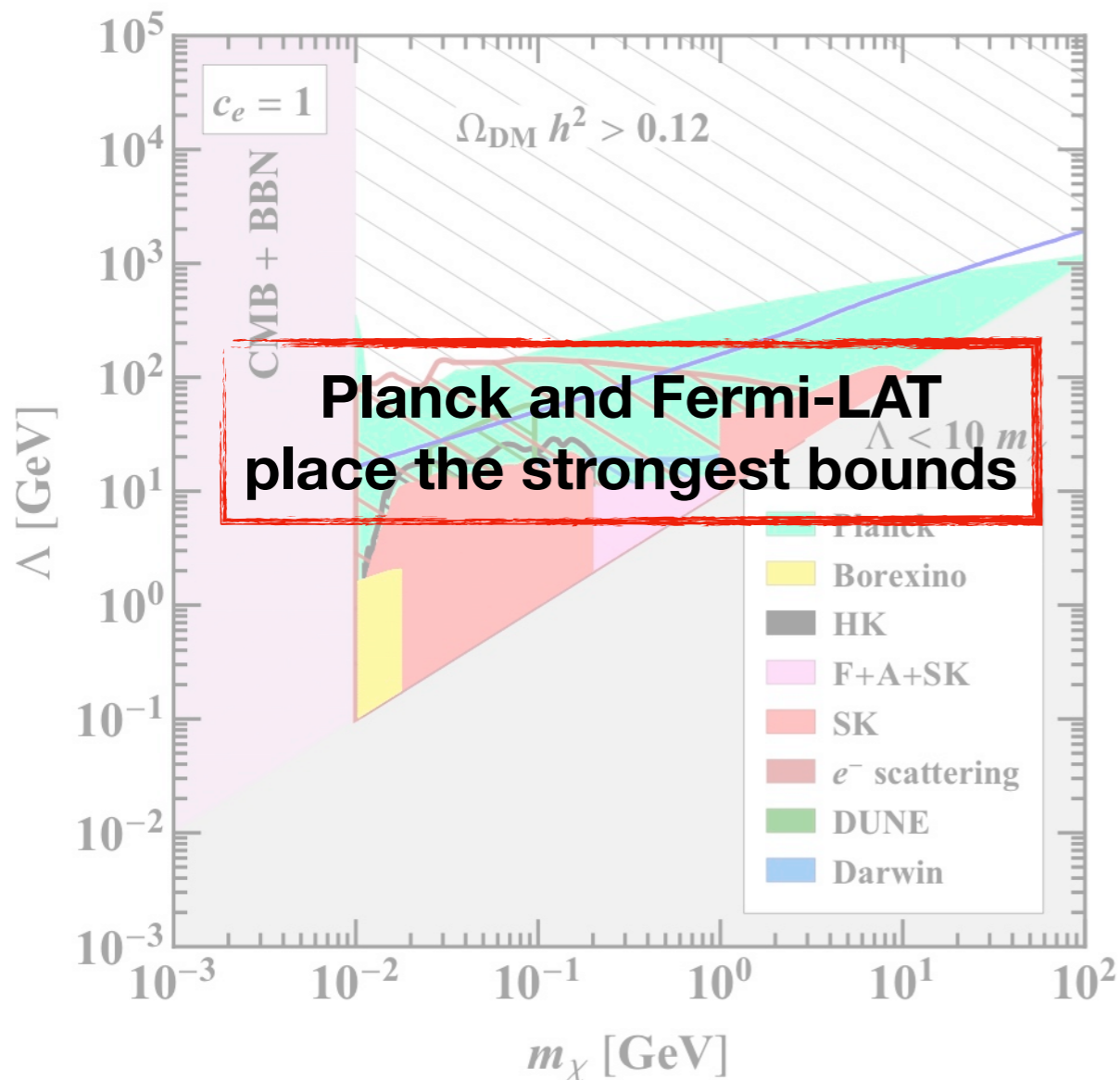


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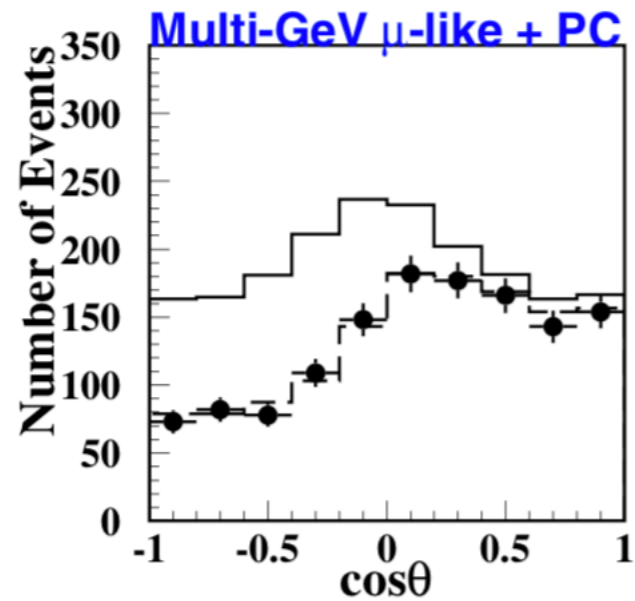
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# Neutrino masses

Super-Kamiokande collaboration,  
arXiv:0105023



Neutrino oscillations

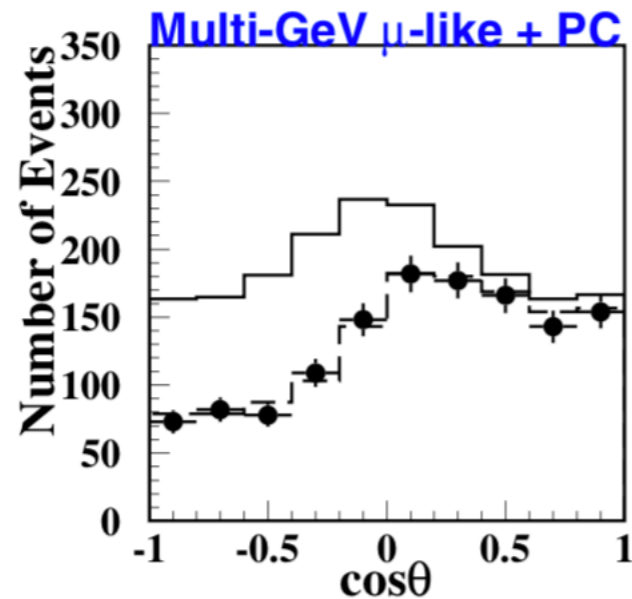


Massive neutrinos



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Massive neutrinos



## Type-I Seesaw mechanism

P. Minkowsky, Phys.Lett. **B67** (1977) 421

T. Yanagida, 1979

M. Gell-Mann, P. Ramon and R. Slansky,

arXiv:1306.4669

S. L. Glashow, NATO Sci.Ser. B **61** (1980) 687

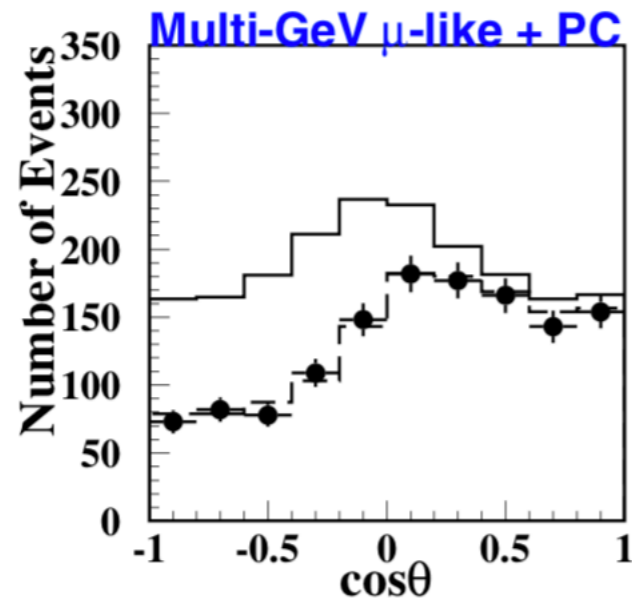
R. N. Mohapatra and G. Senjanovic,

Phys. Rev. Lett. **44** (1980) 912

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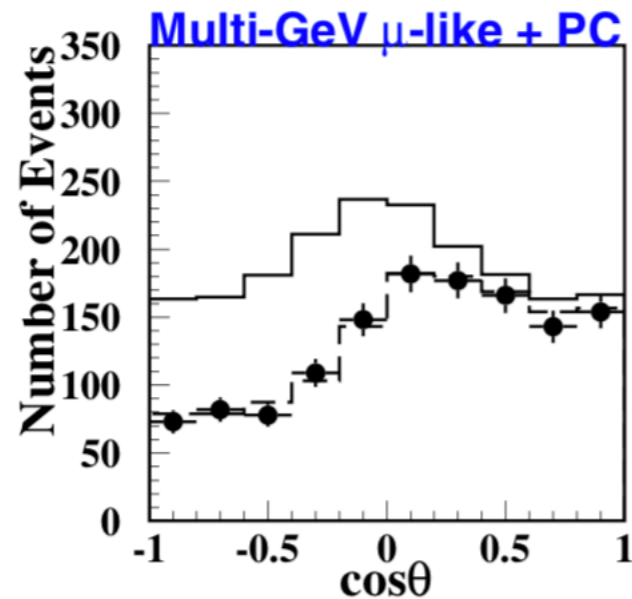
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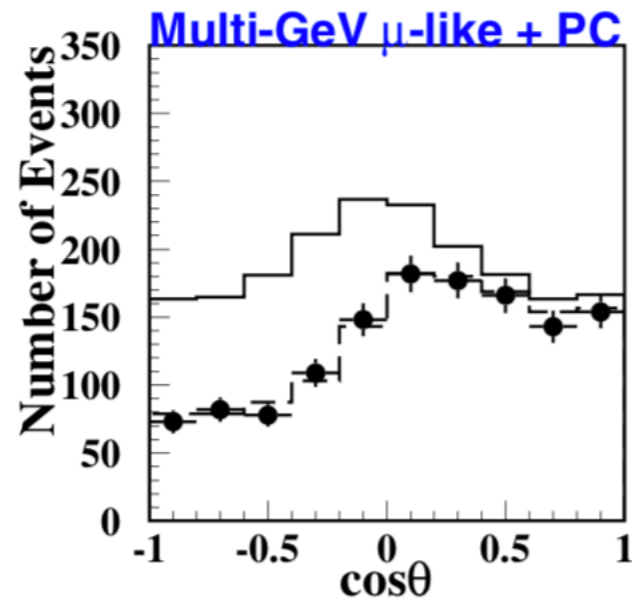
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$$Y_\nu \sim 1, m_\nu \sim 0.01 eV \rightarrow M_M \sim 10^{15} GeV, \theta \sim 10^{-13}$$

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arXiv:0105023



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Little hope to have  
experimental signatures



# Low-scale Seesaw

## Approximate L conservation

R. N. Mohapatra, Phys. Rev. Lett. 56 (1986)

R. N. Mohapatra and J. W. F. Valle,  
Phys. Rev. D34 (1986)

J. Bernabeu *et al.*, Phys. Lett. B187 (1987)

M. Malinsky *et al.*, arXiv:0506296

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$$\mu_L \rightarrow 0, m_\nu = 0 \quad \theta \sim \mathcal{O}(1)$$

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One Dirac  
singlet neutrino

$$m_{1,2,3} = 0, m_4 = \sqrt{M_N^2 + \frac{1}{2} \sum_{\alpha=e,\mu,\tau} |Y_{\nu\alpha}|^2 v^2}, \quad \theta_\alpha = \frac{v}{\sqrt{2}} \frac{Y_{\nu\alpha}}{M_N}$$



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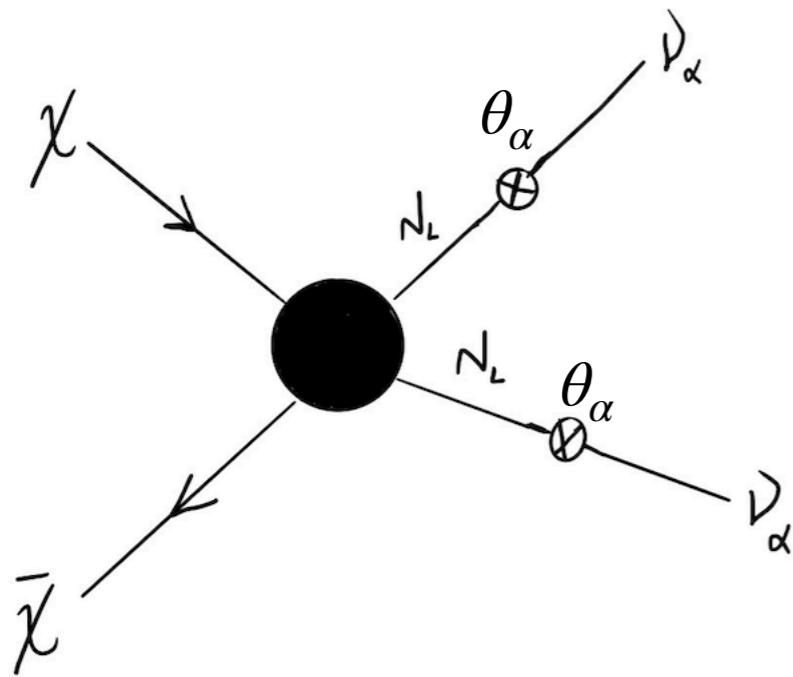
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# Neutrino Portal to Dark Matter



Couple dark matter to singlet neutrinos



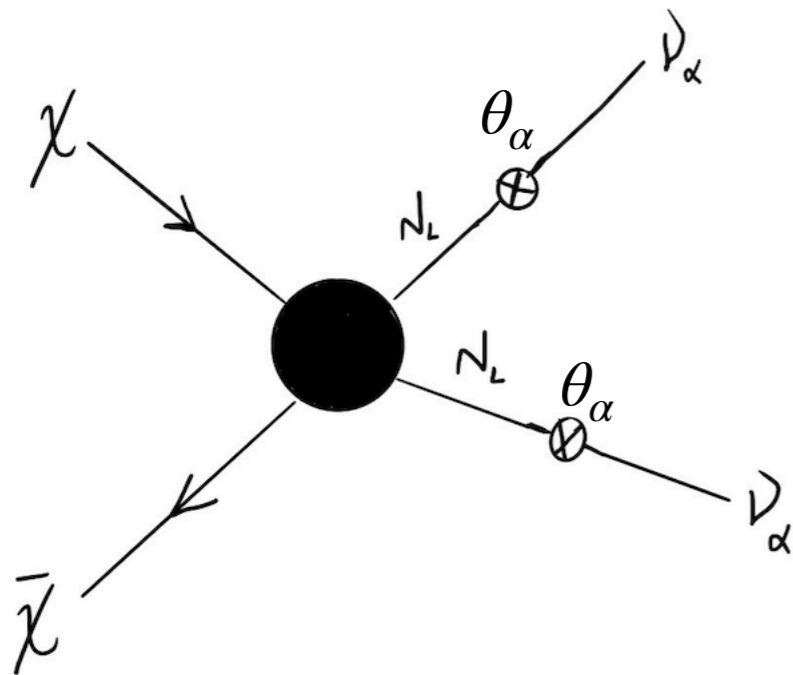
Coupling to active neutrinos  
through large mixing

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Couple dark matter to singlet neutrinos



Coupling to active neutrinos through large mixing

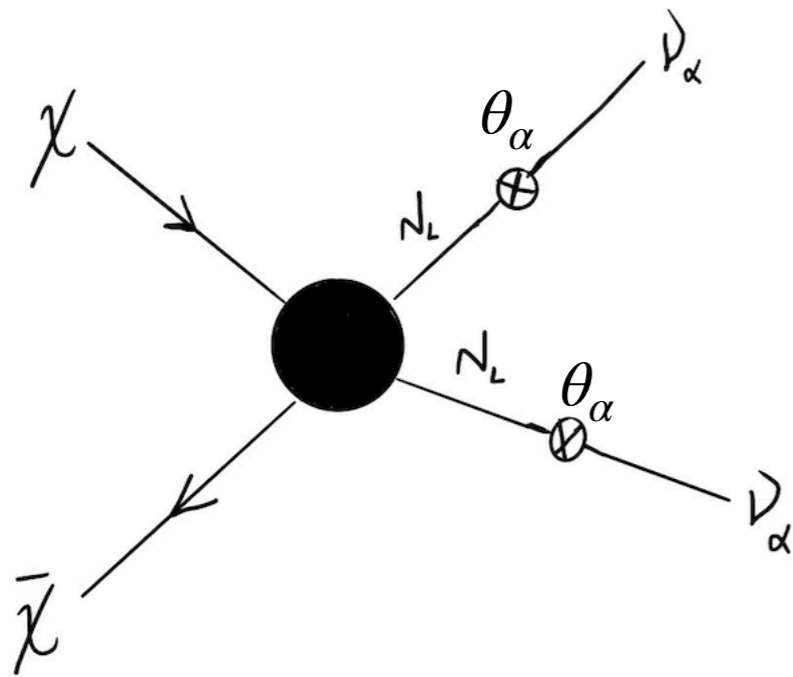


Two possible mediators

Scalar mediator

$$\mathcal{L}_{int} \supset -y_L \bar{\chi} S N_L + h.c.$$

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Couple dark matter to singlet neutrinos



Coupling to active neutrinos through large mixing

Two possible mediators

Scalar mediator

Vector mediator

$$\mathcal{L}_{int} \supset -y_L \bar{\chi} S N_L + h.c.$$

$$\mathcal{L}_{int} \supset g' \bar{\chi}_R \gamma^\mu \chi_R Z'_\mu + g' \bar{N}_L \gamma^\mu N_L Z'_\mu$$

# Scalar mediator

$$\mathcal{L}_{DM} = \mathcal{L}_\nu + \bar{\chi} \left( i\partial_\mu \gamma^\mu - m_\chi \right) \chi - y_L \bar{\chi} S N_L + h.c.$$

B. Bertoni *et al.*, arXiv:1412.3113  
B. Batell *et al.*, arXiv:1709.07001

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**Coupling between DM  
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**Coupling between DM  
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**Annihilation to  
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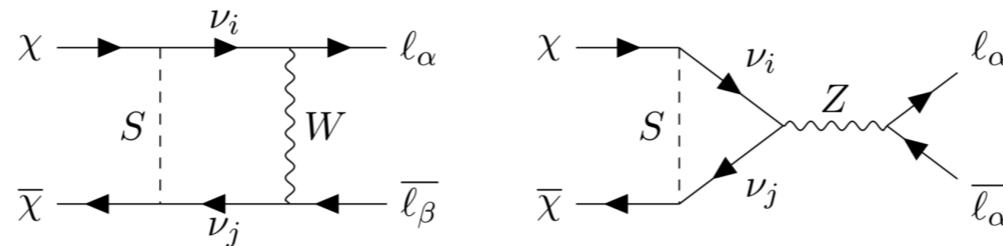
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**At one loop**



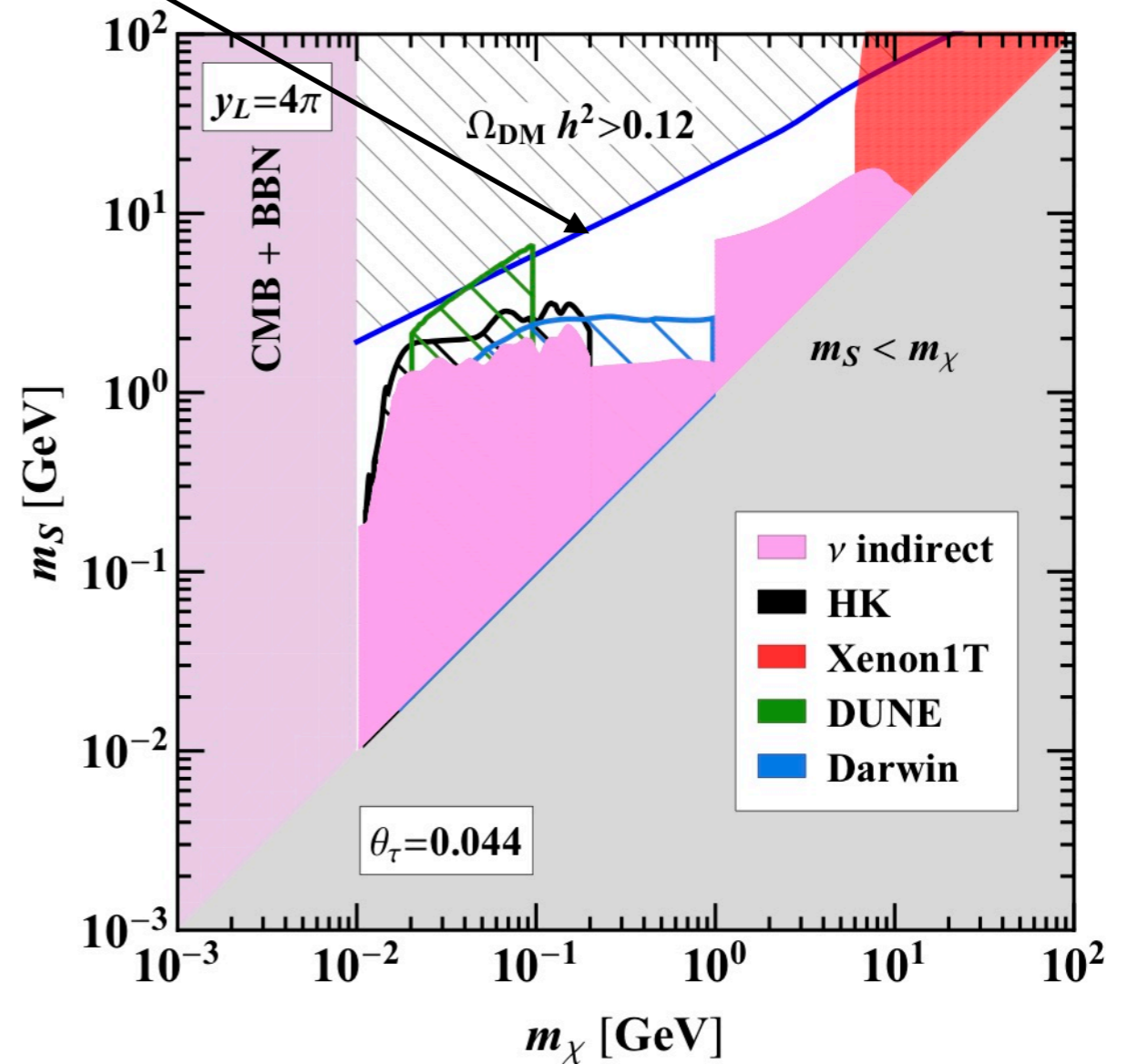
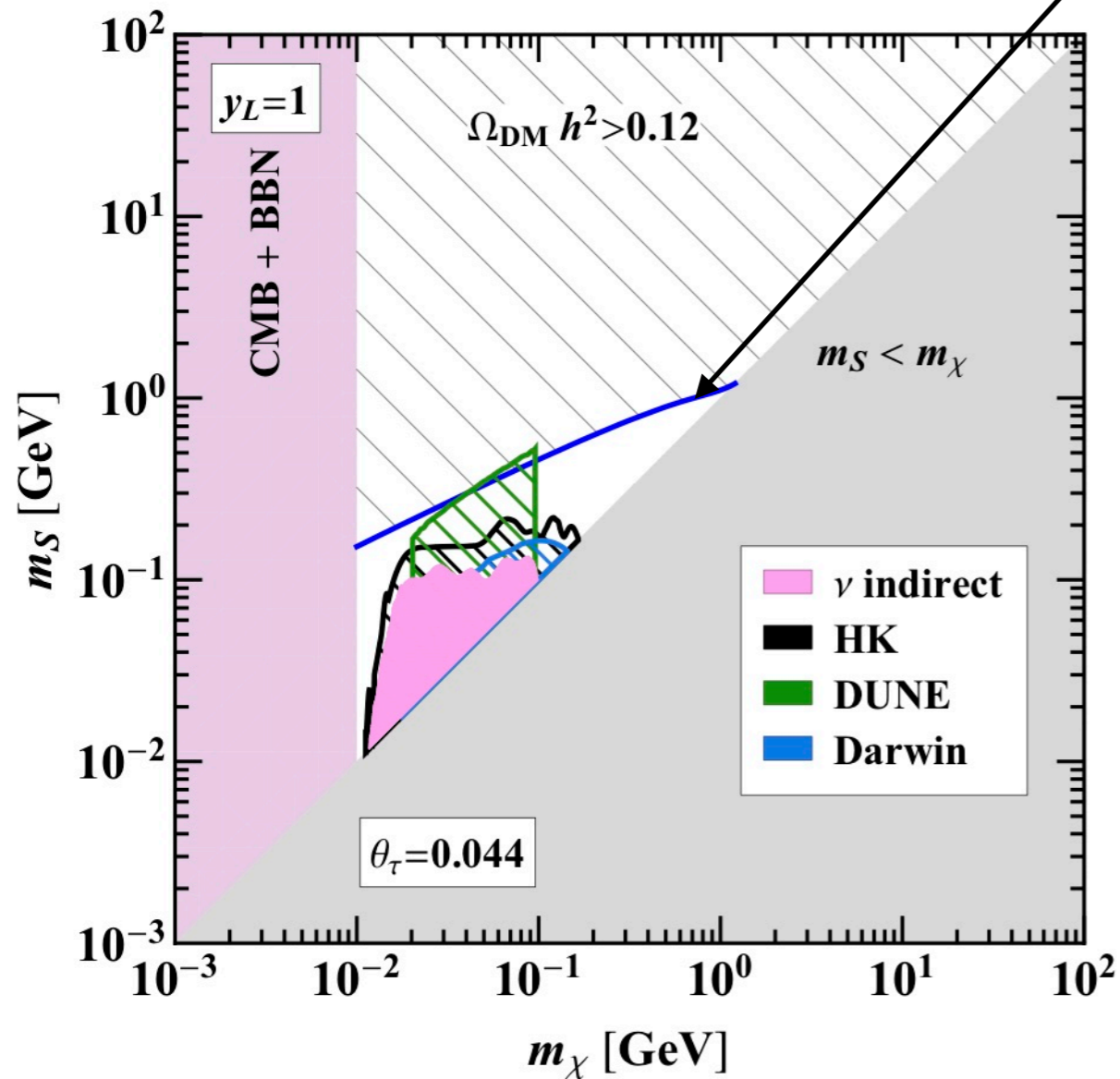
$$\mathcal{L} \supset -a_{SW} \frac{g^2}{m_W^2} \bar{\chi} \gamma^\mu P_R \chi \bar{l}_\alpha \gamma_\mu P_L l_\beta - a_Z \frac{g}{\cos \theta_W} \bar{\chi} \gamma^\mu P_R \chi Z_\mu + h.c.$$

**Coupling between DM and charged leptons/quarks**



# Scalar mediator

$$\Omega_{DM} h^2 = \Omega_{DM} h^2 |_{Planck}$$



Only neutrino detectors can probe the parameter space

# Vector mediator

$$\mathcal{L}_{DM} = \mathcal{L}_\nu + g' \bar{\chi}_R \gamma^\mu \chi_R Z'_\mu + g' \bar{N}_L \gamma^\mu N_L Z'_\mu - \frac{1}{4} Z'_{\mu\nu} Z'^{\mu\nu} + \frac{1}{2} m_{Z'}^2 Z'_\mu Z'^\mu$$

**Coupling between DM  
and light neutrinos**

$$\mathcal{L}_{int} \supset g' \sum_{i,j} U_{si} U_{sj}^* \bar{\nu}_i \gamma^\mu P_L \nu_j Z'_\mu$$

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**Annihilation to  
light neutrinos**

$$\langle \sigma v_r \rangle \approx \frac{g'^4}{8\pi} \left( \sum_{\alpha=e,\mu,\tau} |U_{\alpha 4}|^2 \right)^2 \frac{m_\chi^2}{(4m_\chi^2 - m_{Z'}^2)^2}$$

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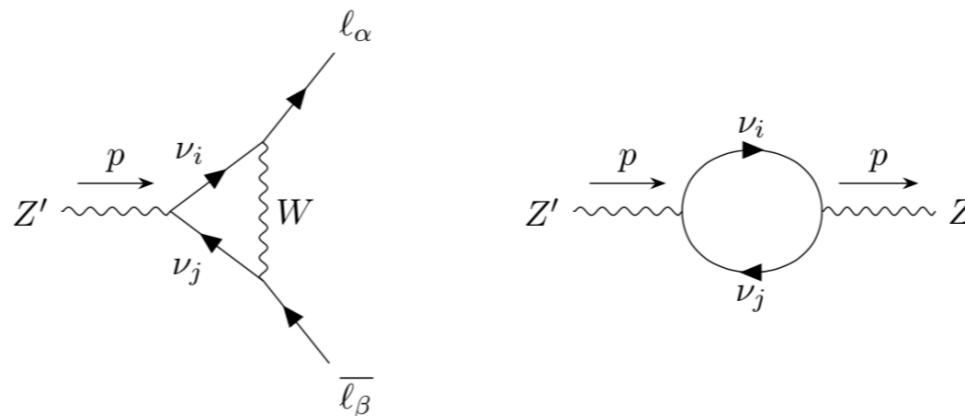
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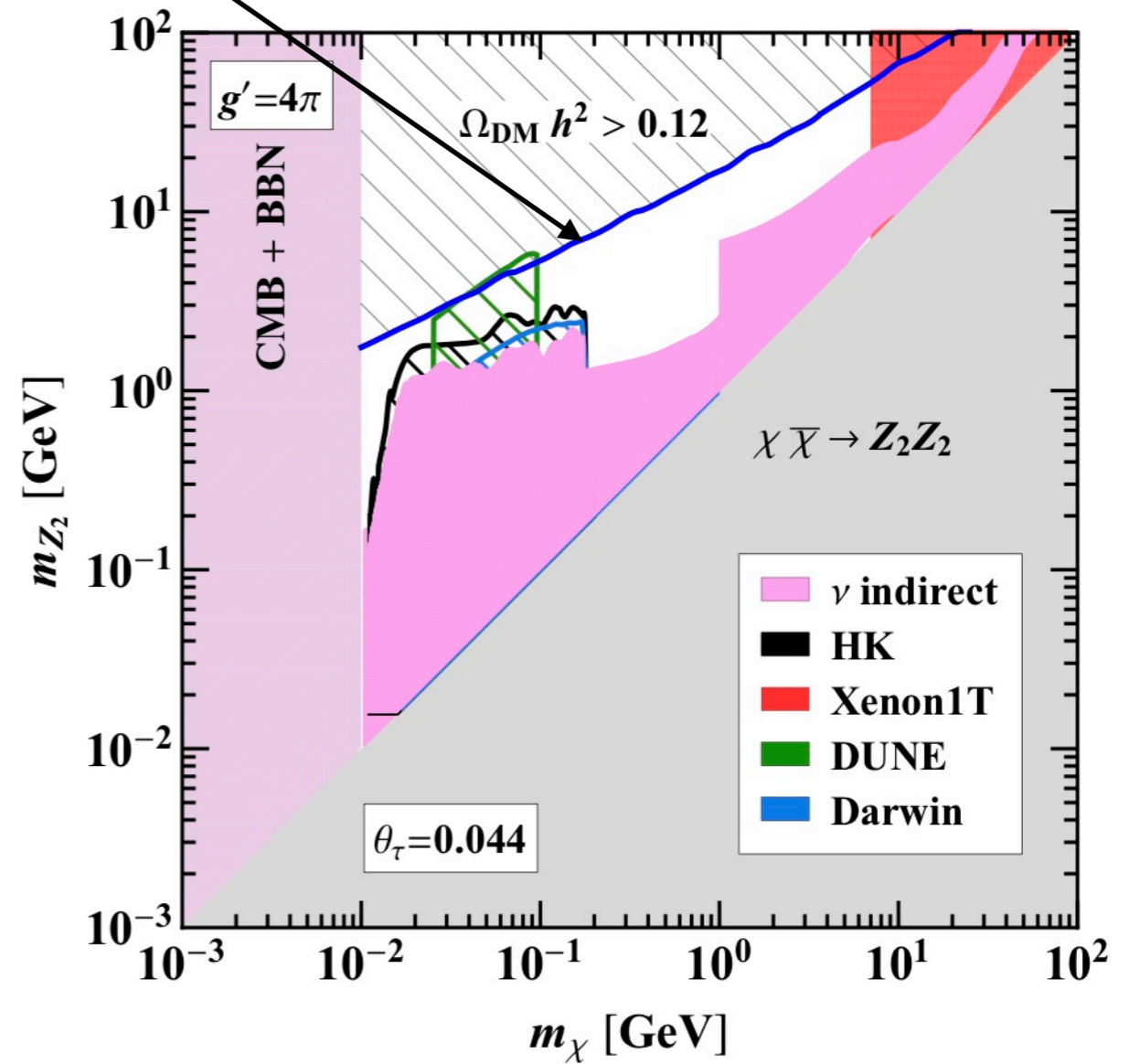
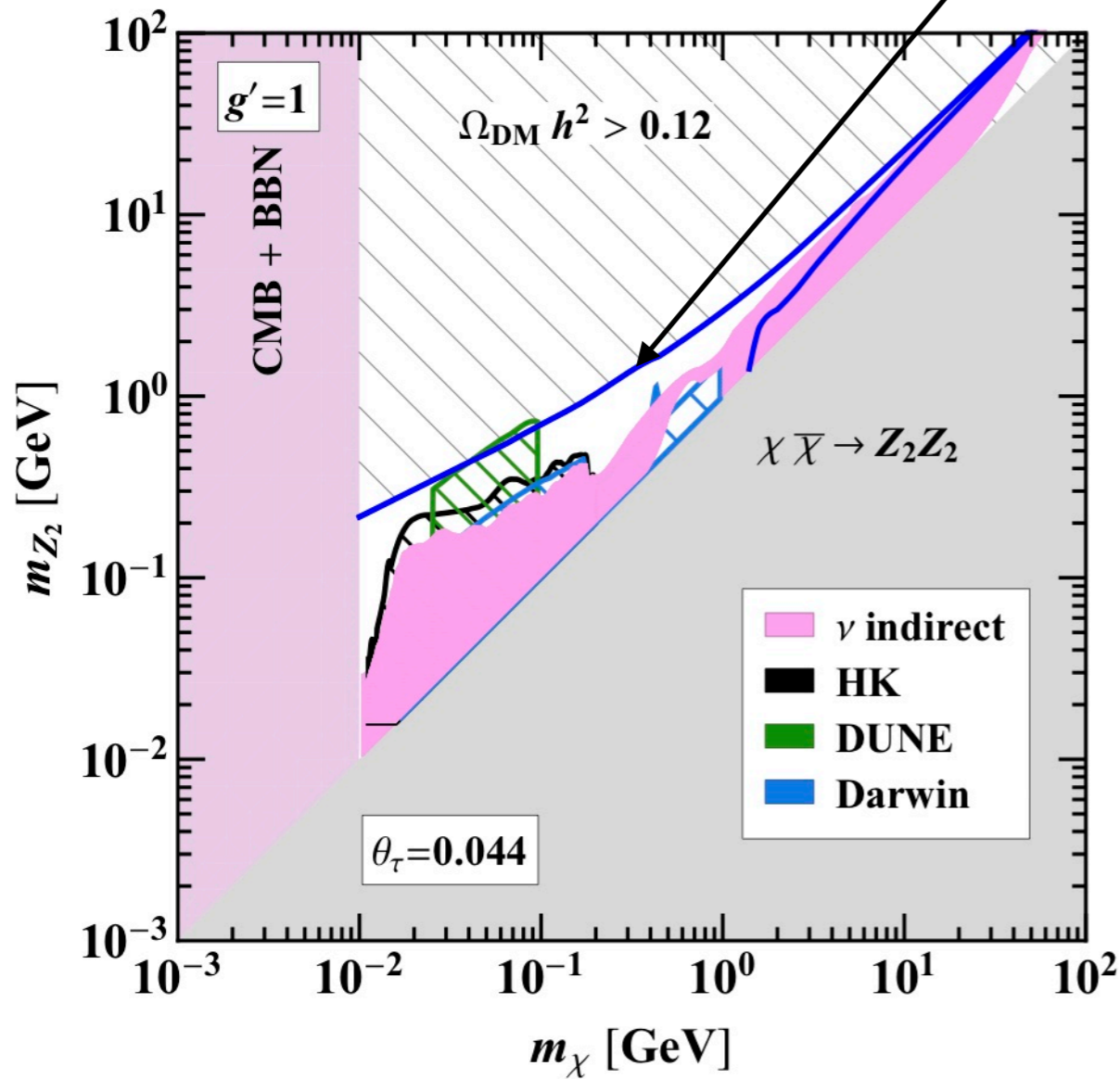
Coupling to charged leptons and quarks



$$\mathcal{L} \supset -a_W g' \bar{l}_\alpha \gamma^\mu P_L l_\beta Z'_\mu - \frac{\sin \epsilon}{2} Z'_{\mu\nu} Z'^{\mu\nu} + \delta m^2 Z'_\mu Z'^\mu + h.c.$$

# Vector mediator

$$\Omega_{DM} h^2 = \Omega_{DM} h^2 |_{Planck}$$



Most parameter space already probed by neutrino experiments



# Conclusions

Still no definite signal for DM-SM interactions other than gravitationally



DM-neutrino interactions

**Avoid all direct  
and indirect searches?**

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DM-neutrino interactions

Avoid all direct  
and indirect searches?

Coupling to  
lepton doublet

Gauge invariance



Planck and  
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$$m_\chi < m_{\tau(\mu)}, c_e \sim 0$$

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Couple DM to **singlet neutrinos** and explain relic abundance

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**Thank you!**