Neutrino Portal Dark Matter

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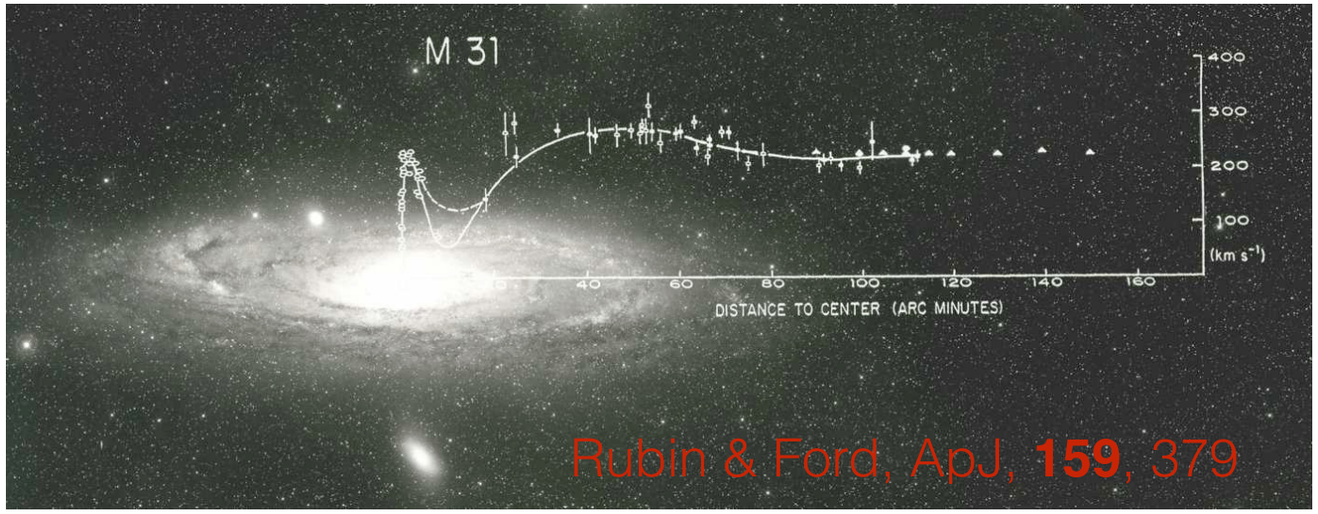
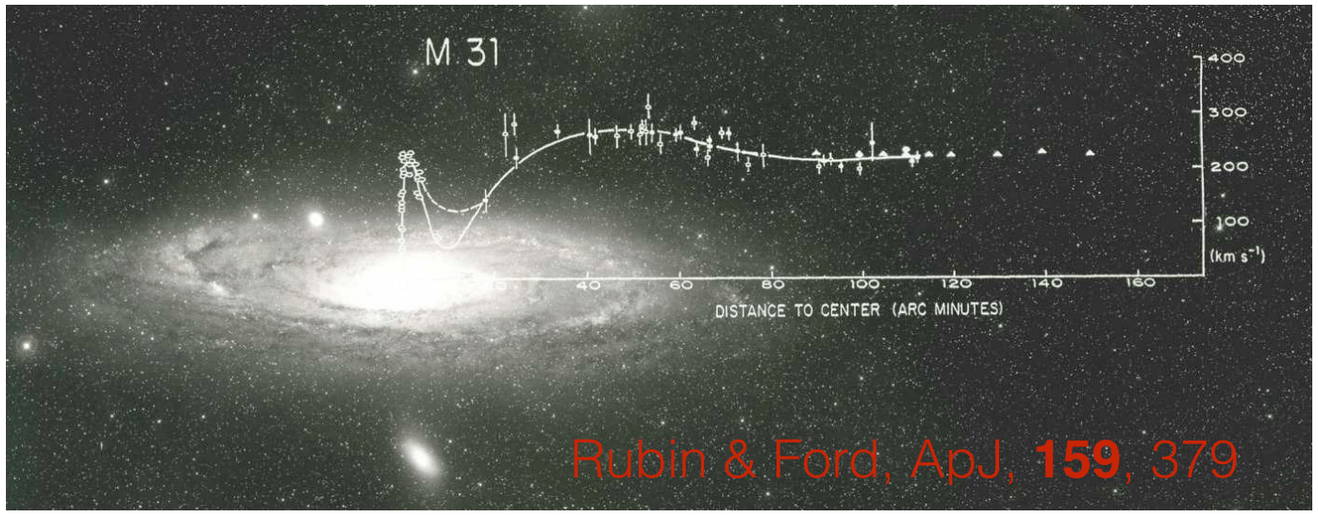
University of Pittsburgh
WIN2017

Bridget Bertoni, Seyda Ipek, DM and Ann Nelson
Batell, Han, DM, and Shams Es Haghi

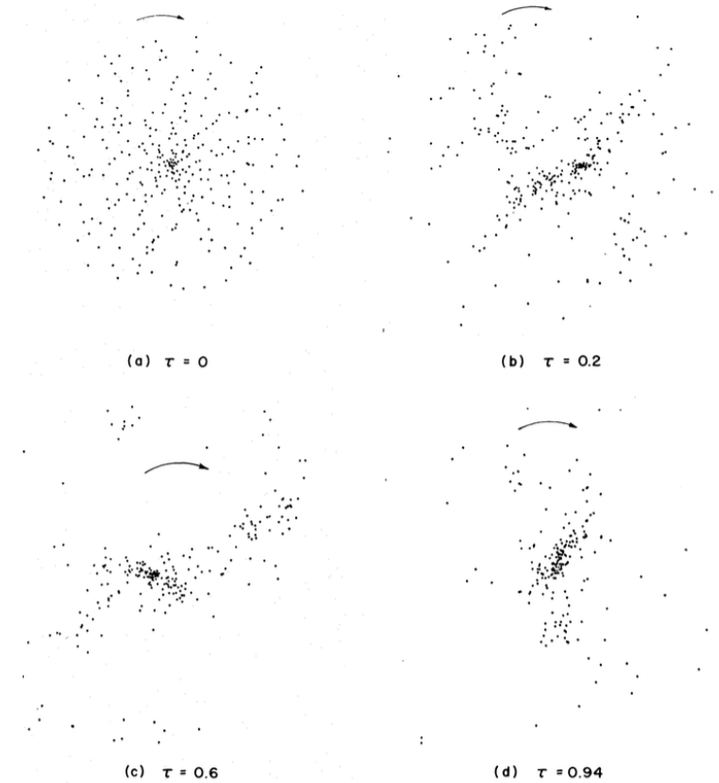
Why Dark Matter?



Rubin & Ford, ApJ, **159**, 379



Ostriker & Peebles, ApJ, **186**, 467 ('73)



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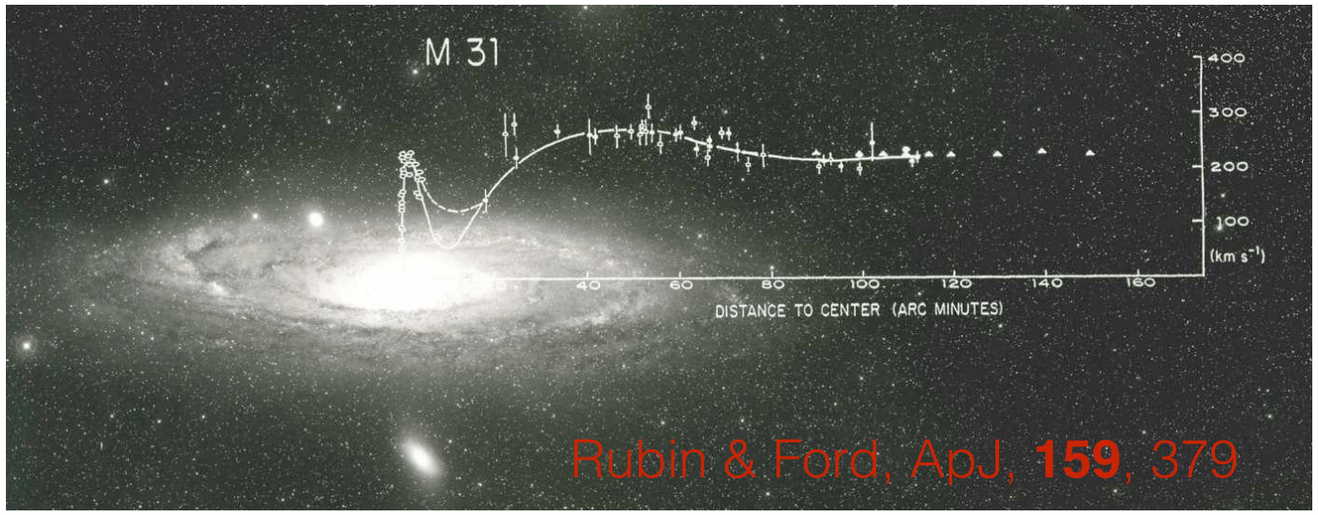

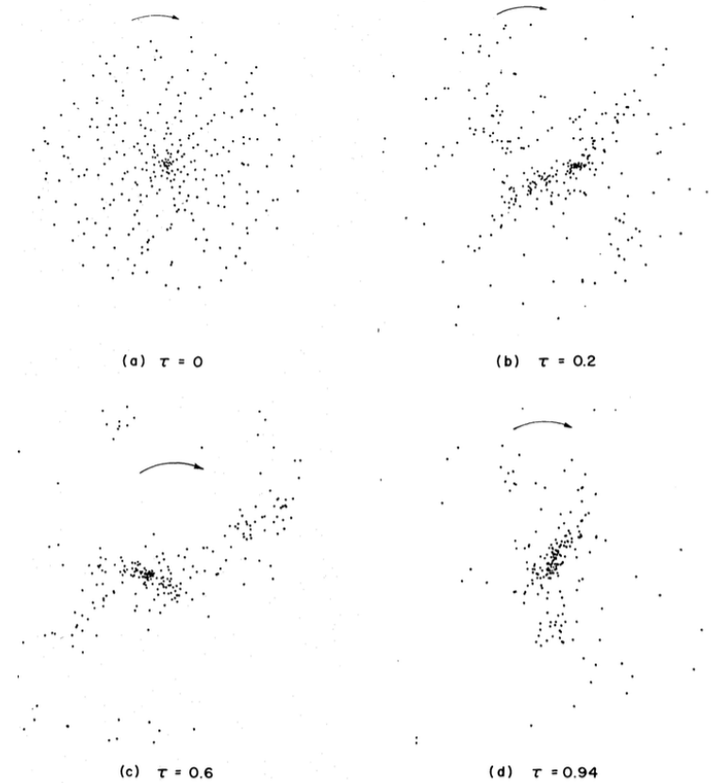

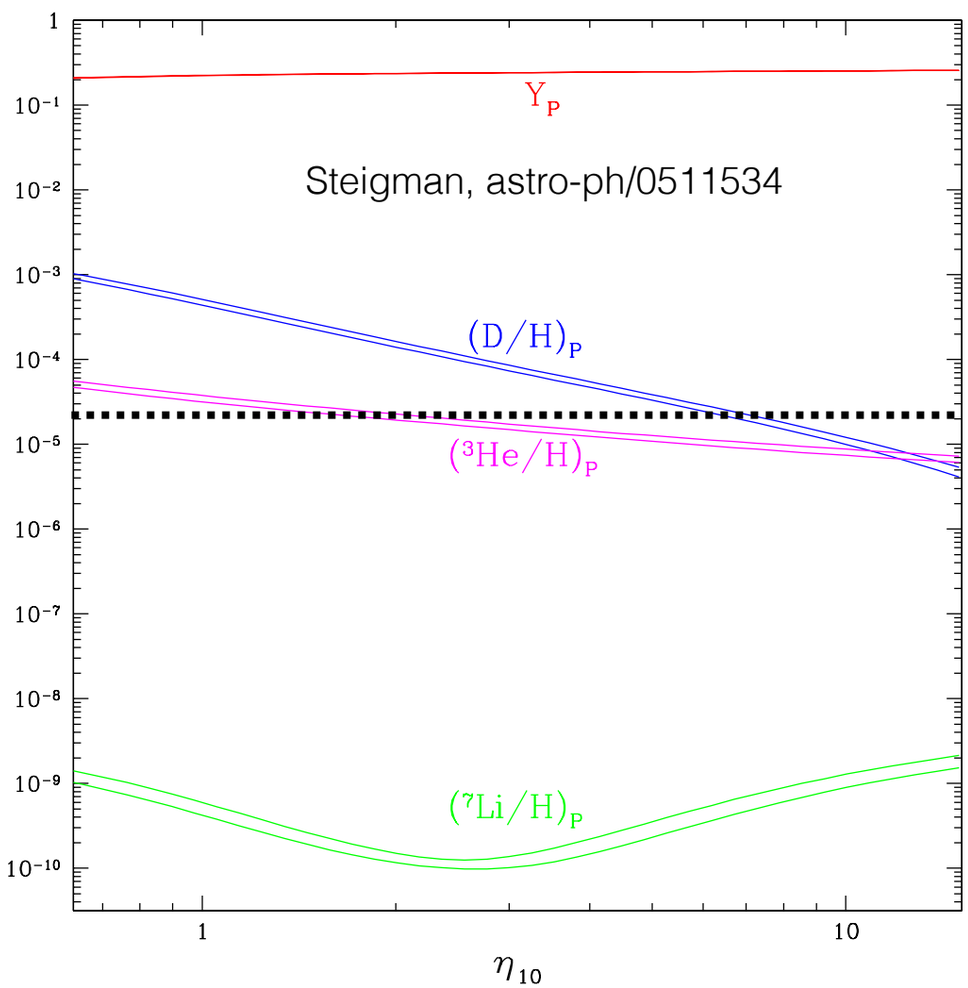

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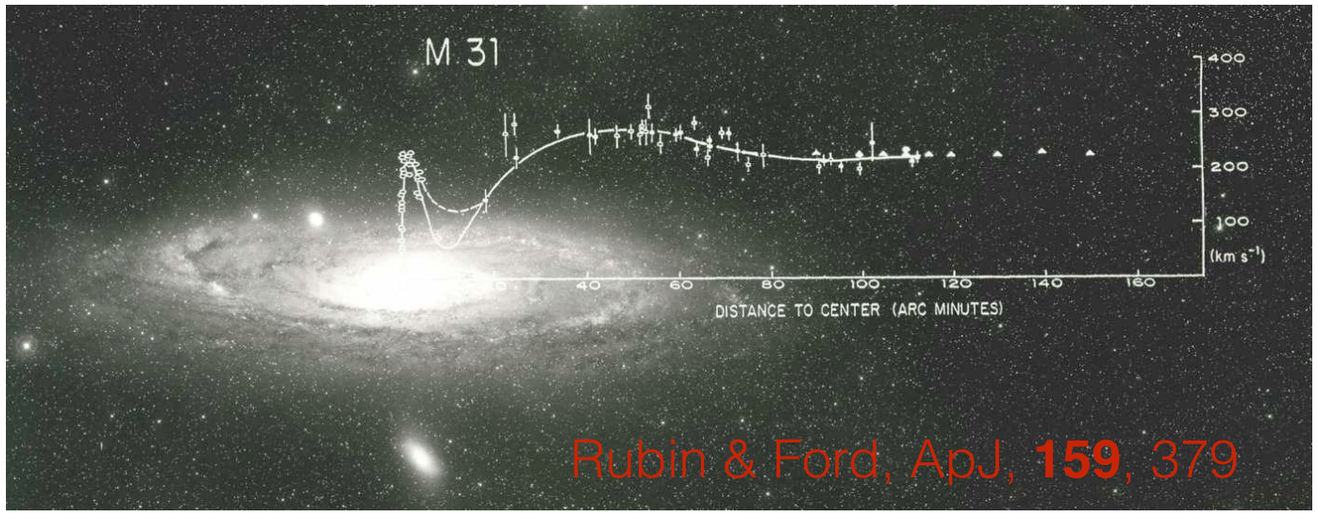

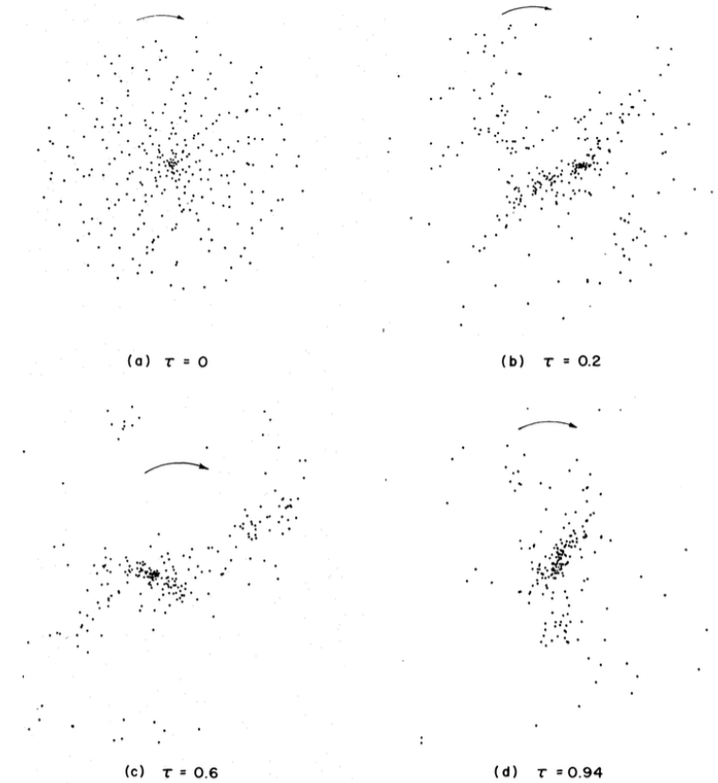

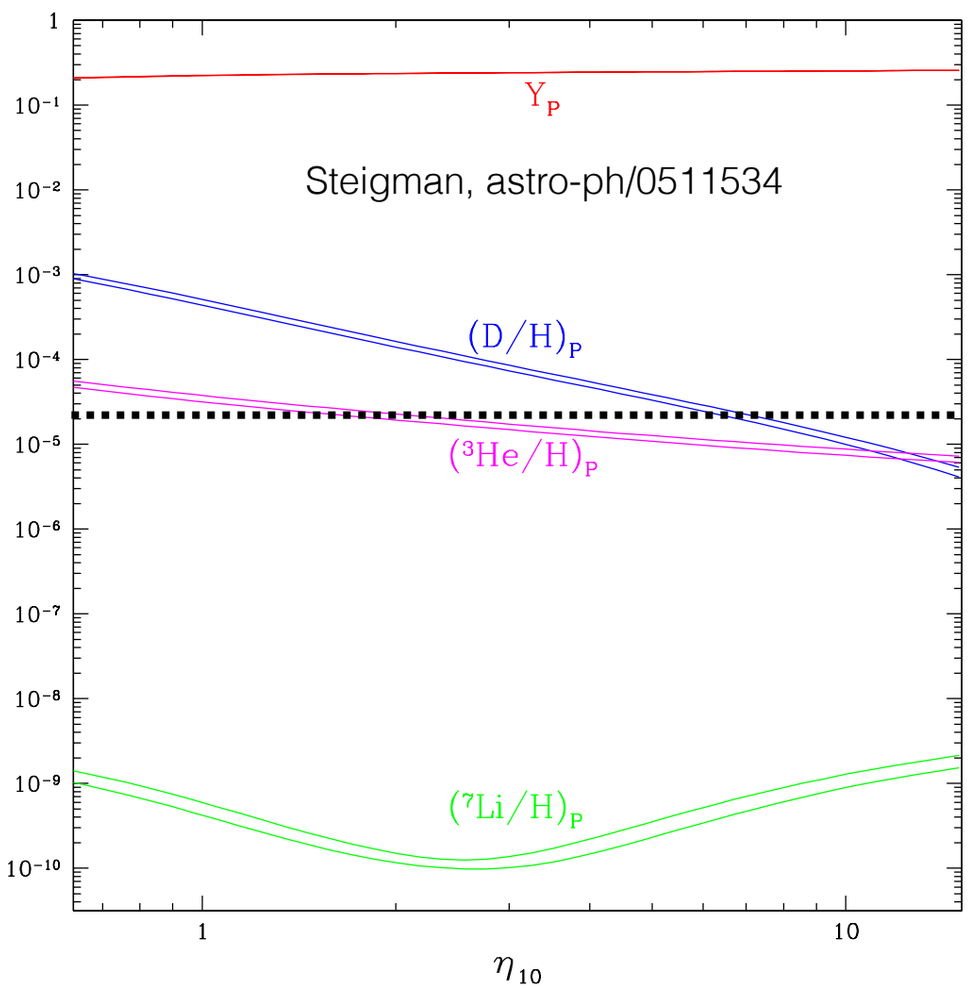

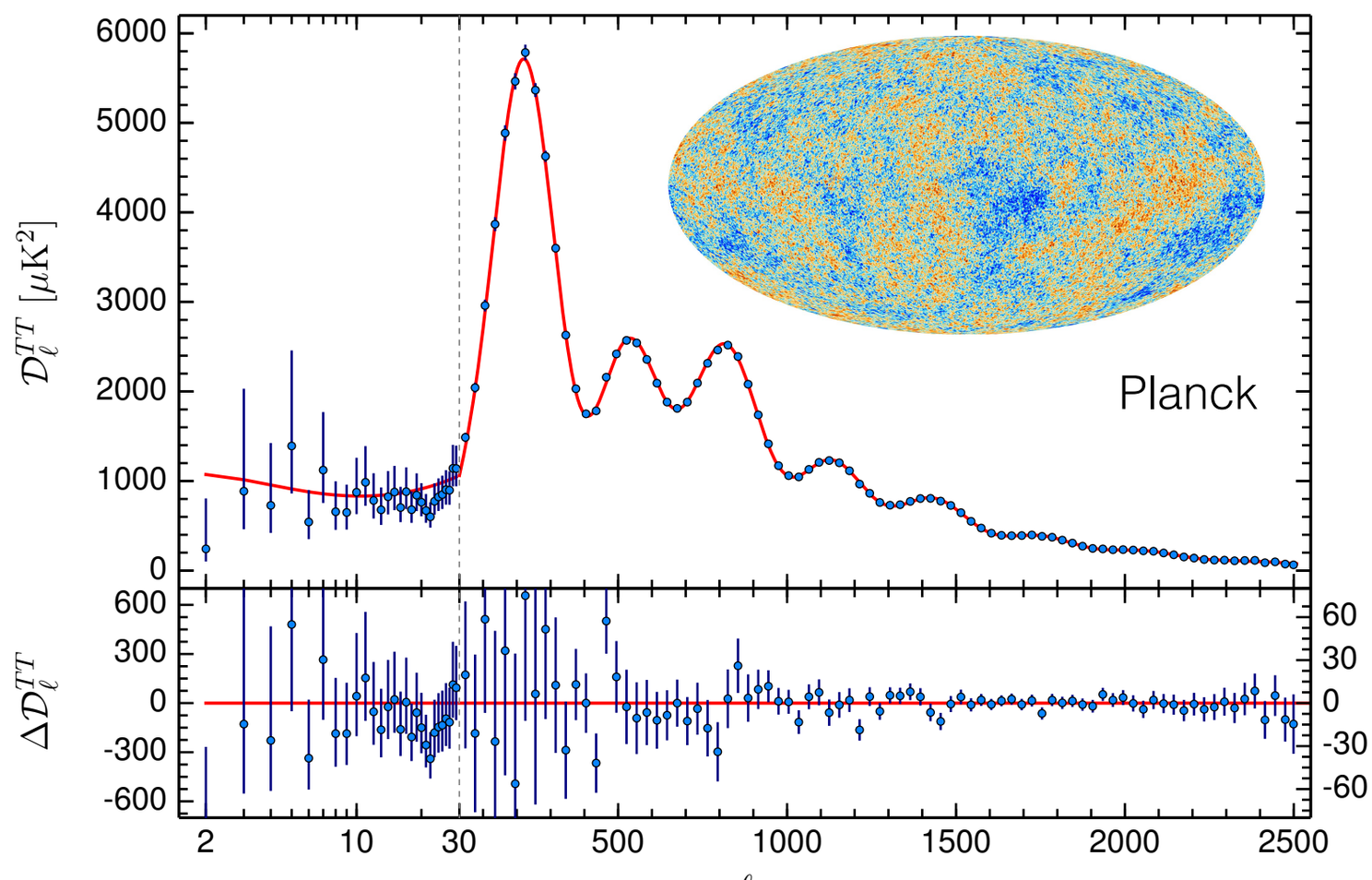

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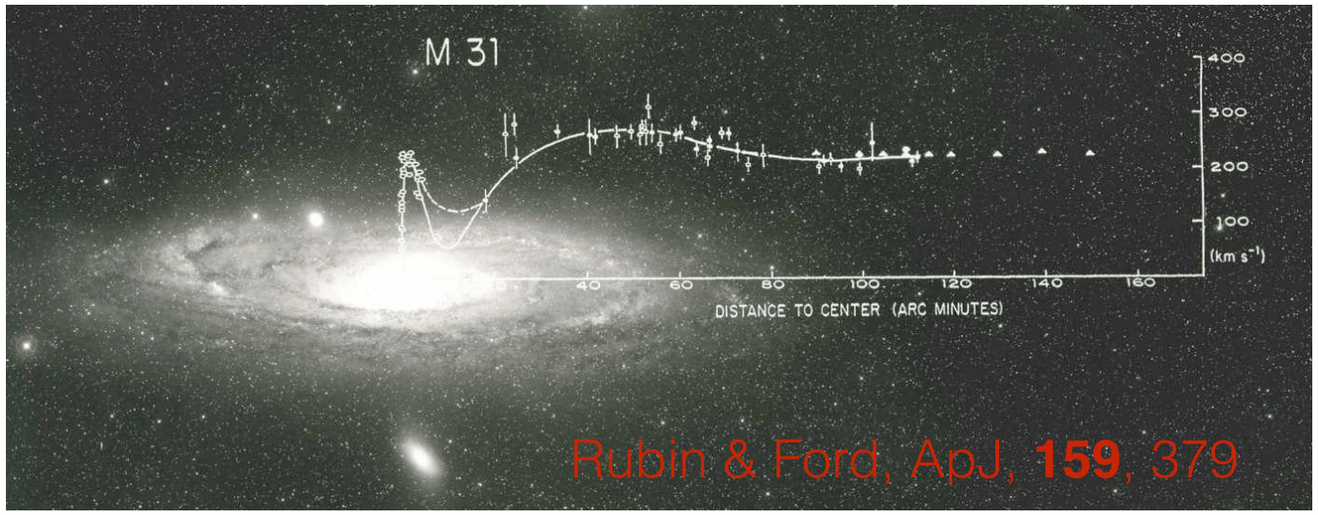
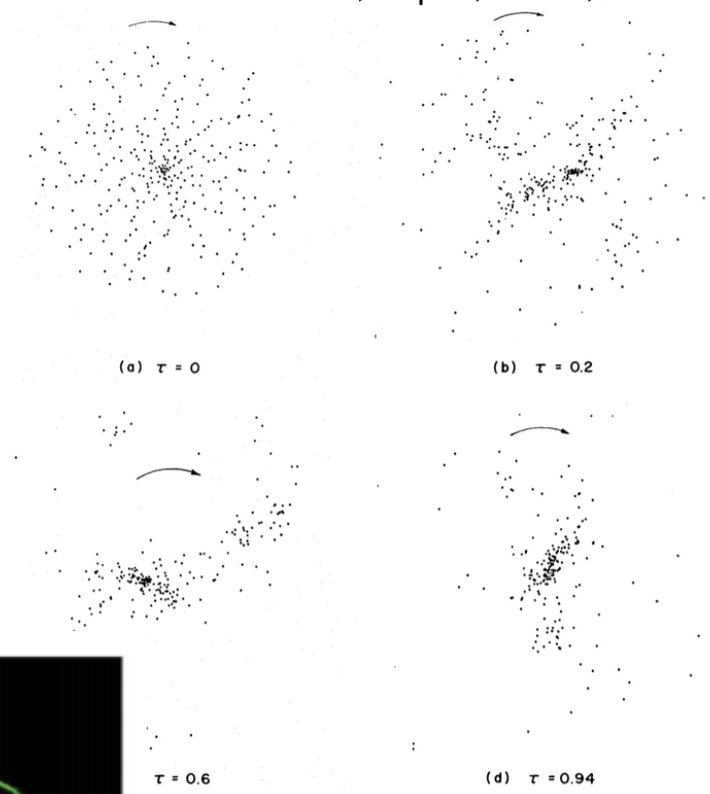
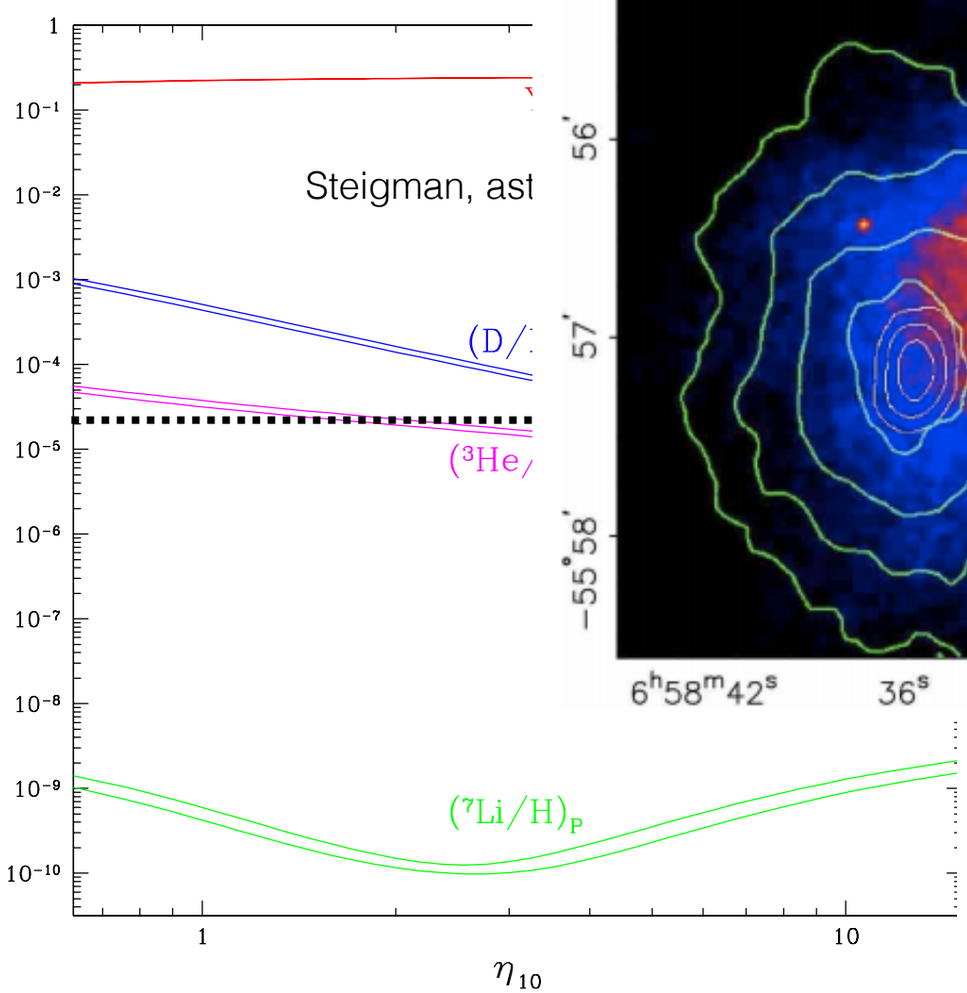
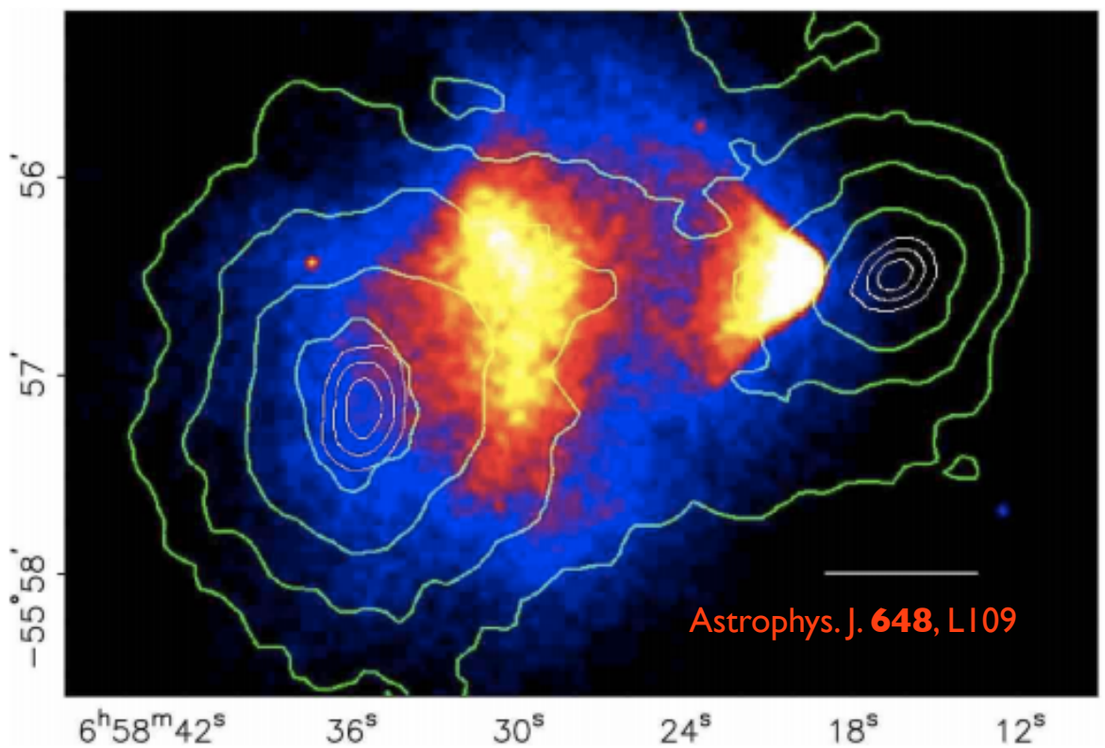
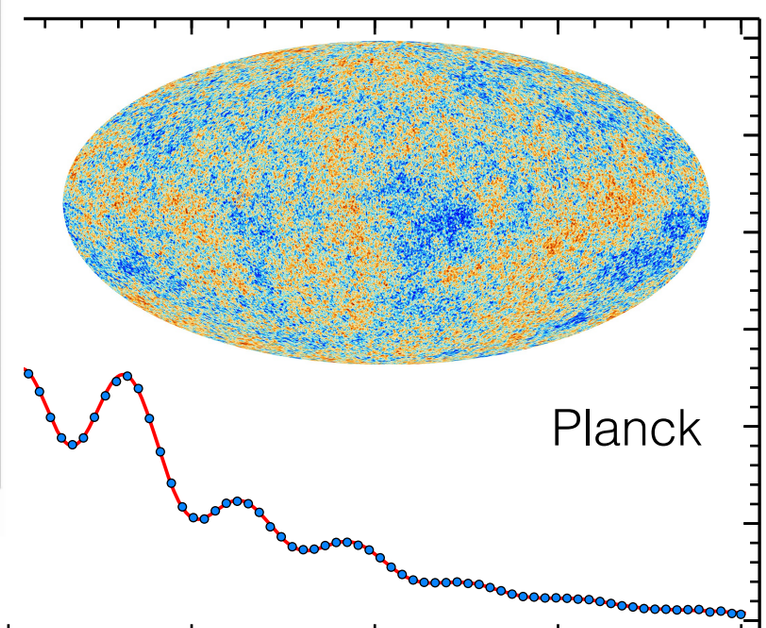
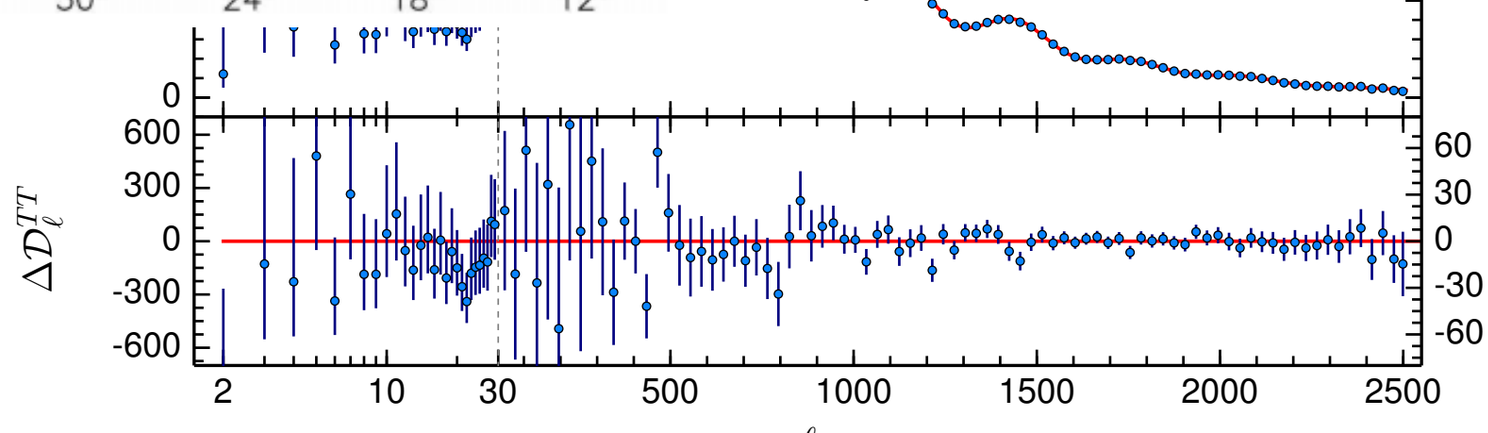






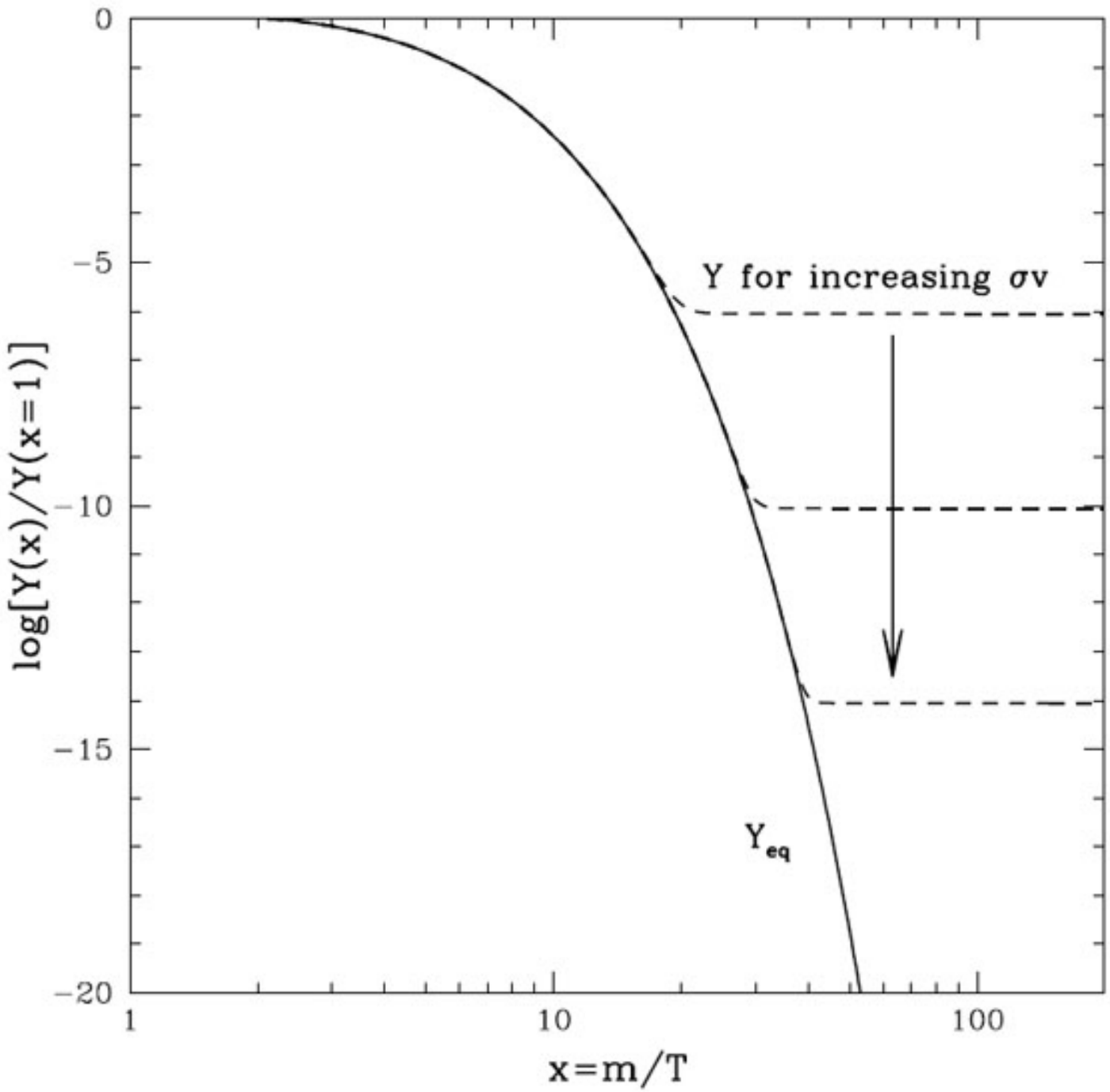




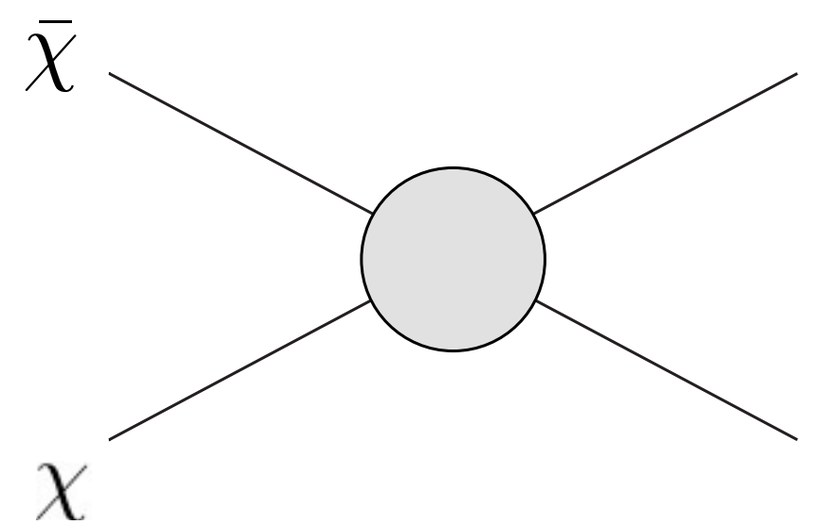


General consensus on energy budget of Universe

Consider thermal relic DM



Needs a coupling to light stuff



How do you generate that coupling

Model Building a Dark Sector
or: what is a "portal"?

Standard Model symmetries

$$SU(3)_c \times SU(2)_L \times U(1)_Y \to SU(3)_c \times U(1)_{\rm em}$$

Standard Model particle content

$$\left.\begin{array}{l} \ell = \begin{pmatrix} \nu_L \\ e_L \end{pmatrix} \quad e_R \\ \\ q = \begin{pmatrix} u_L \\ d_L \end{pmatrix} \quad u_R \;\; d_R \end{array}\right\} \times 3$$

$$H = \begin{pmatrix} \rho^+ \\ v + h + \rho^0 \end{pmatrix} \qquad G^a_\mu,\; W^b_\mu,\; B_\mu \to G^a_\mu,\; A_\mu$$

Renormalization: lower dim. operators (fewer fields/particles) more important

Model Building a Dark Sector
or: what is a “portal”?

Standard Model symmetries $SU(3)_c \times SU(2)_L \times U(1)_Y \to SU(3)_c \times U(1)_{\rm em}$

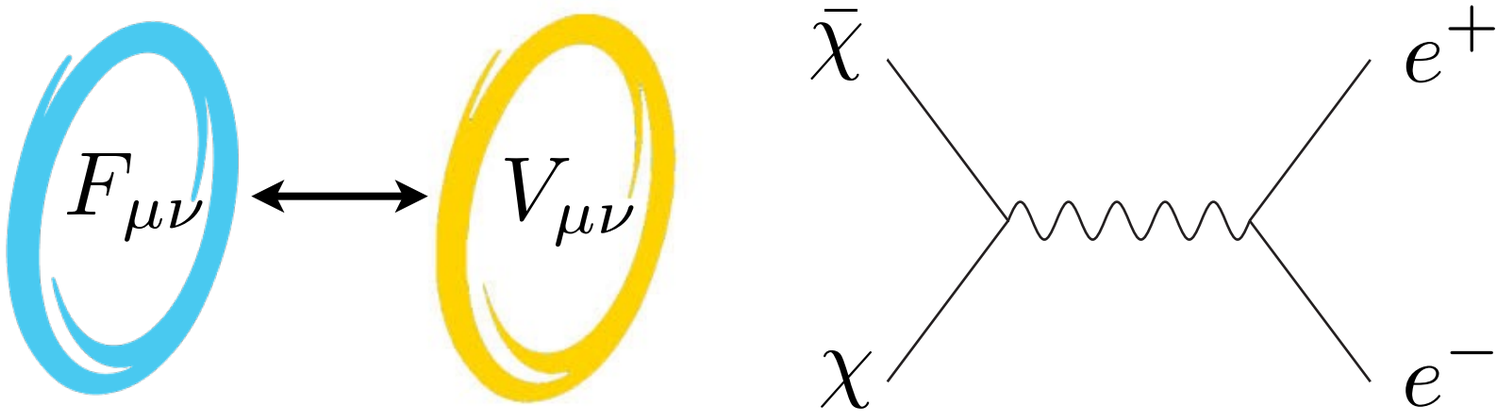
Portals: coupling via stuff uncharged w.r.t. SM

Lead to minimal difficulties incorporating hidden sectors

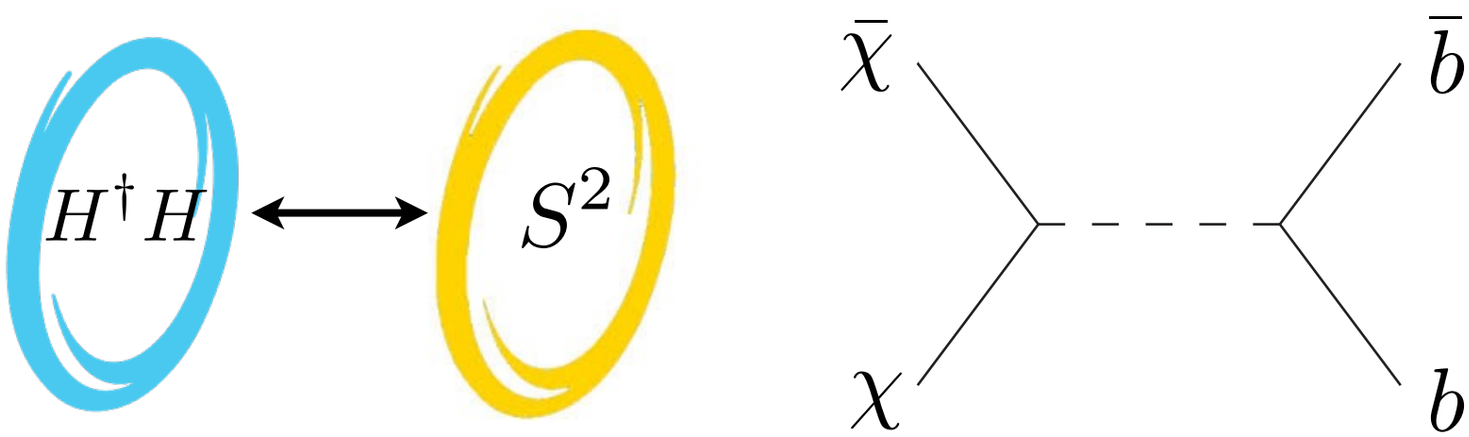
neutrino: $\ell H \longleftrightarrow N$

kinetic mixing: $F_{\mu\nu} \longleftrightarrow V_{\mu\nu}$

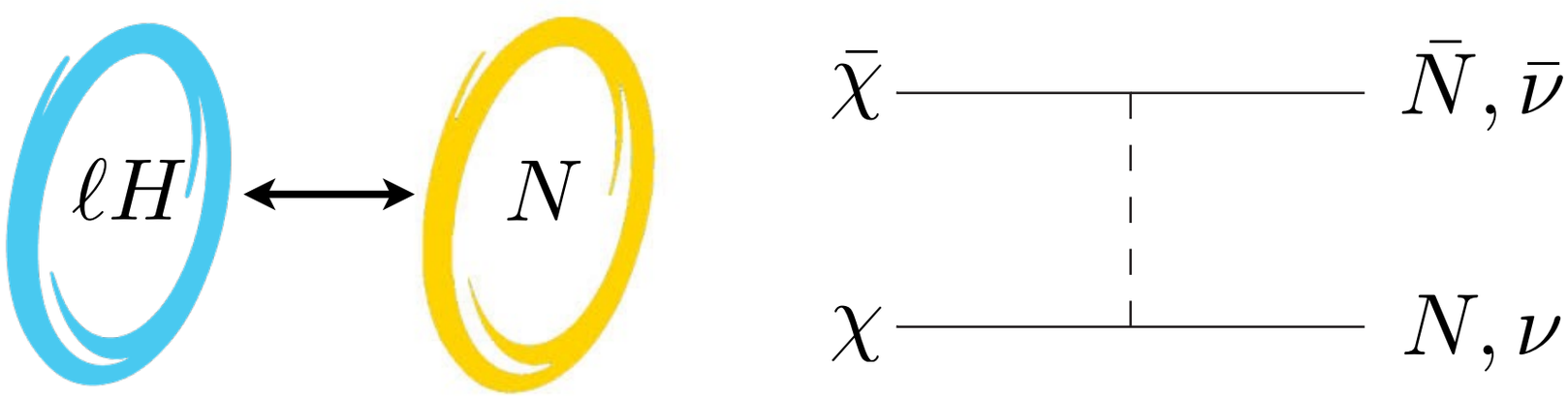
Higgs: $H^\dagger H \longleftrightarrow S^2$



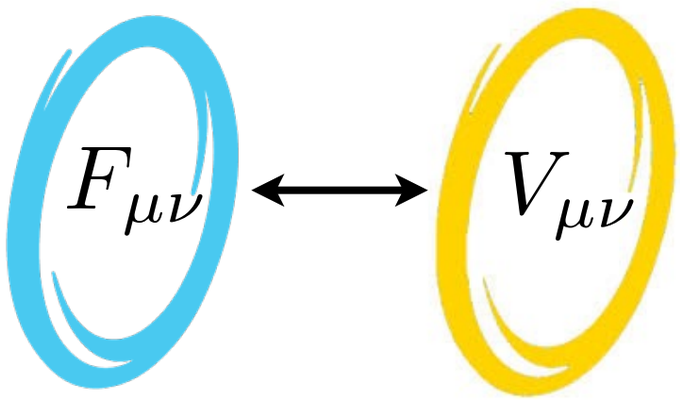
Vector Portal

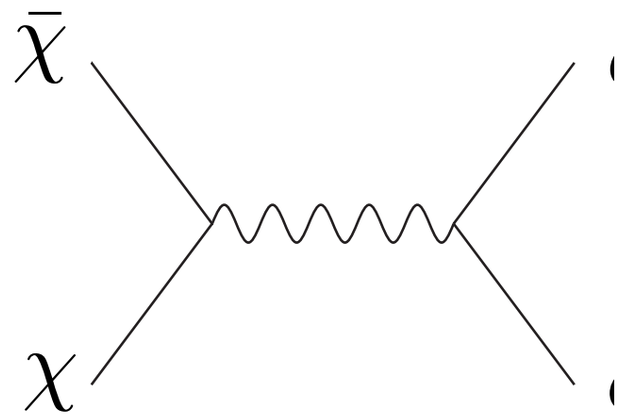


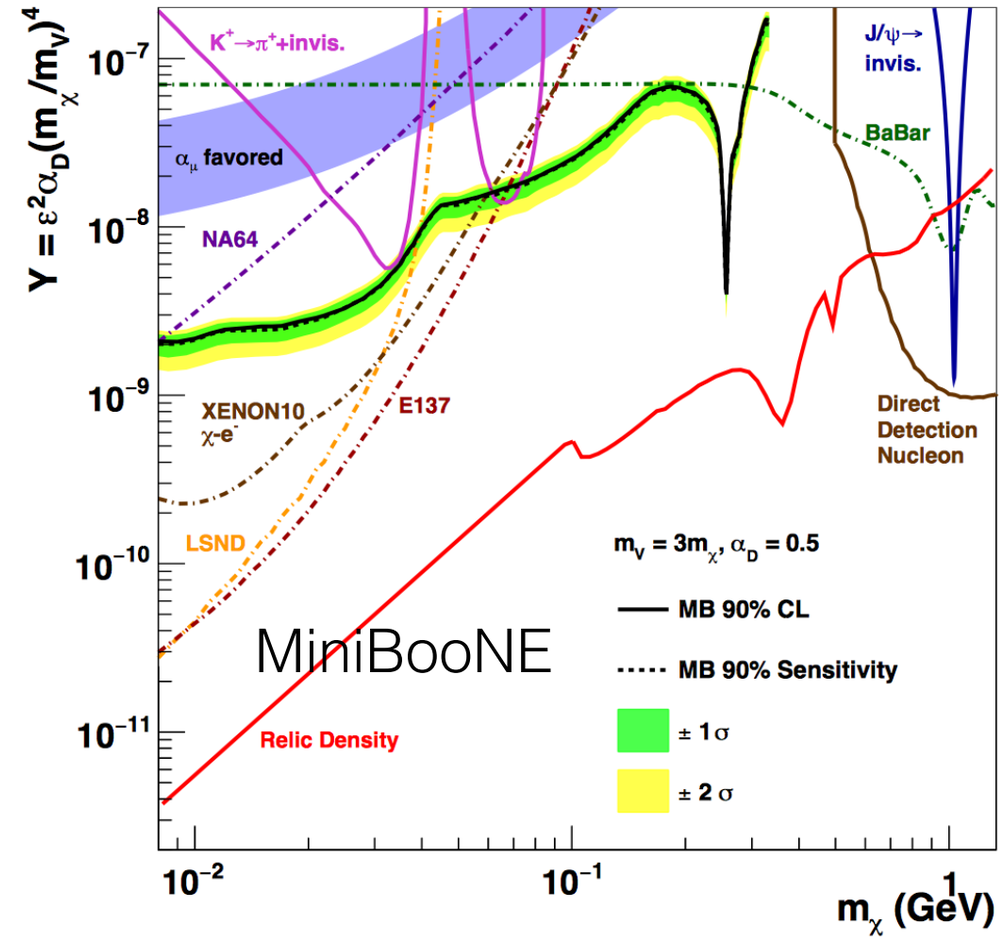
Higgs Portal

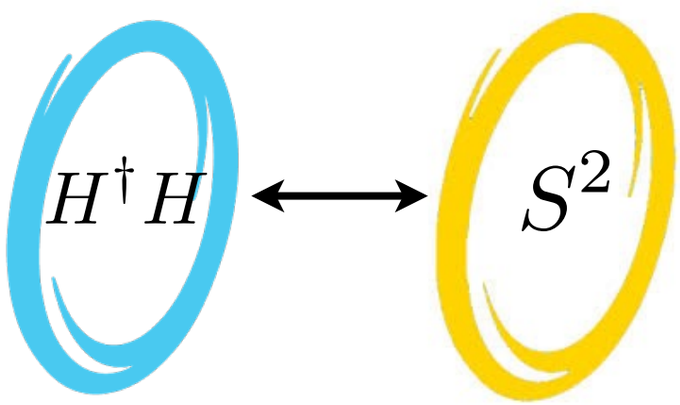


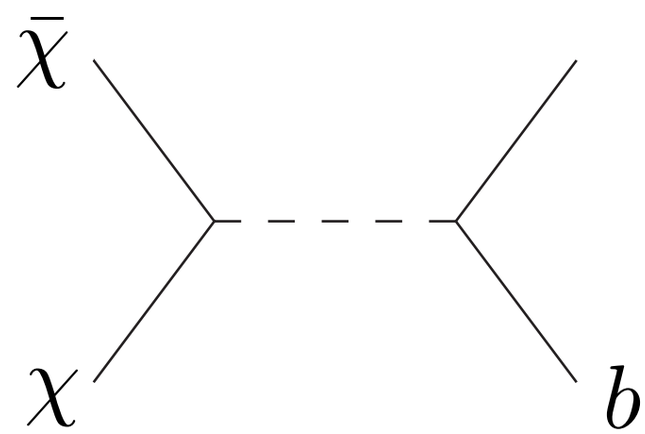
Neutrino Portal

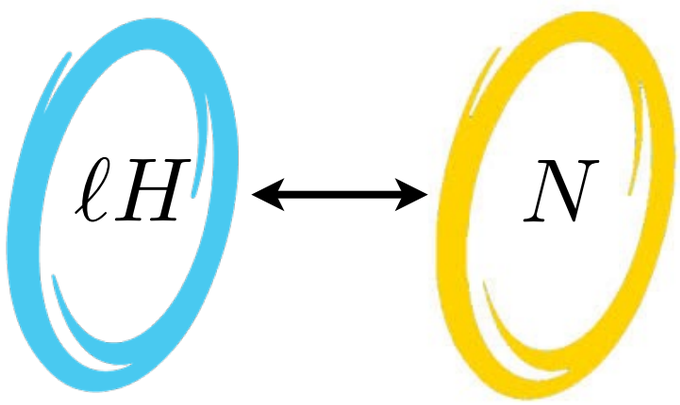


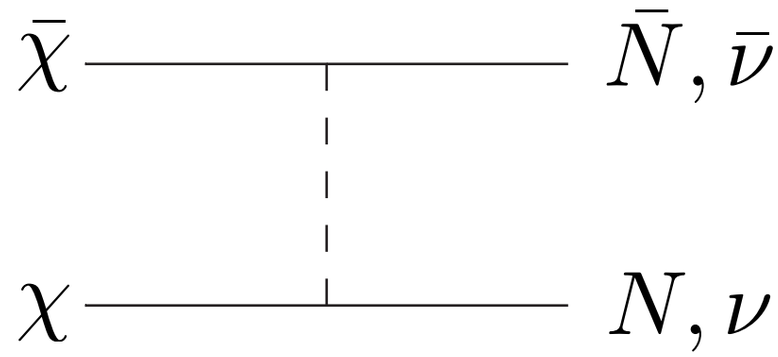




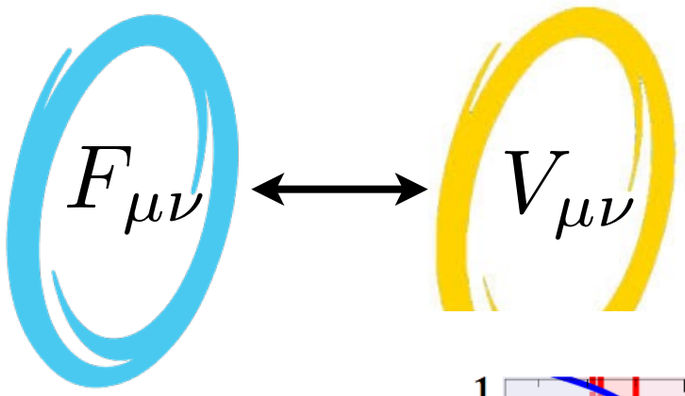


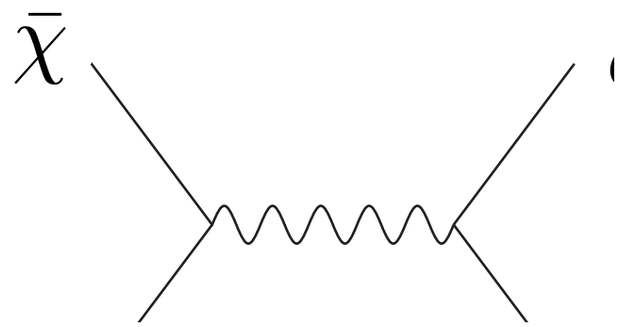


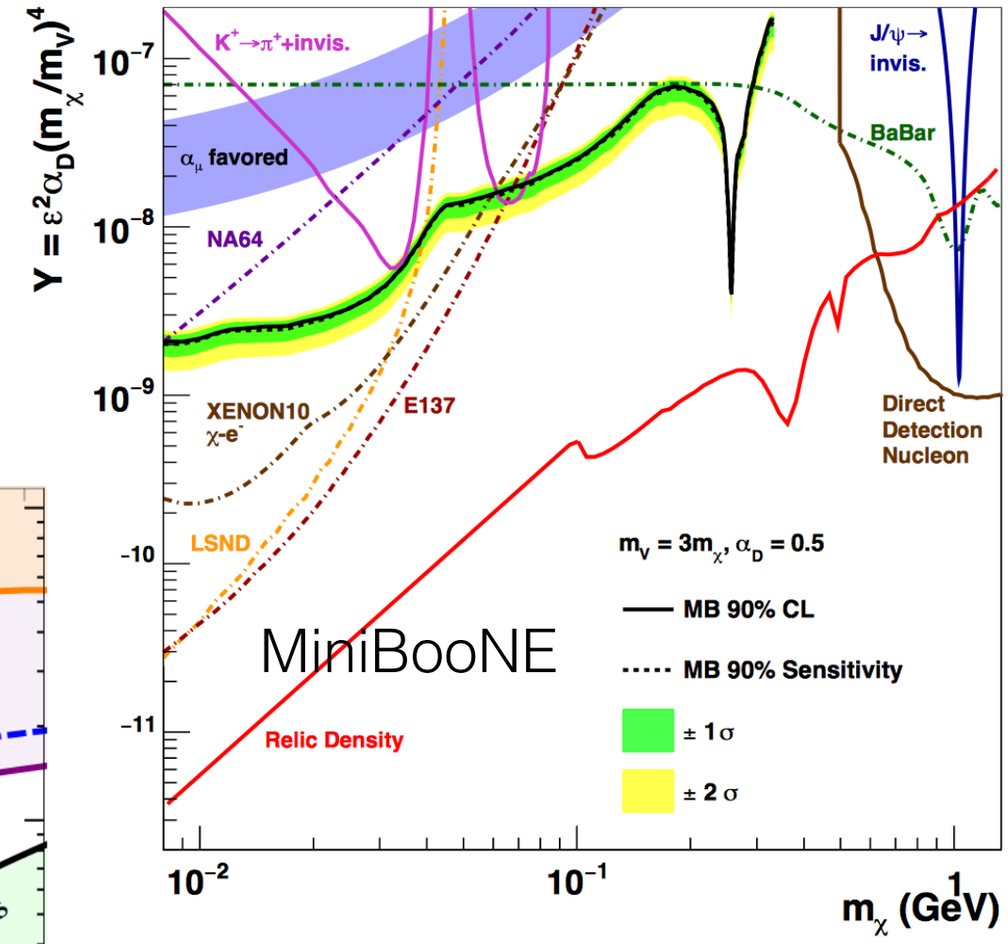


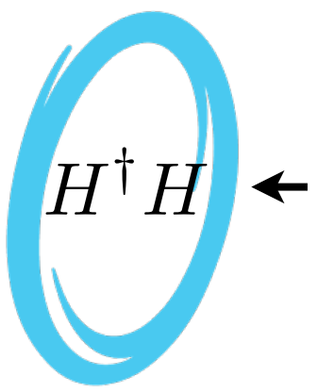


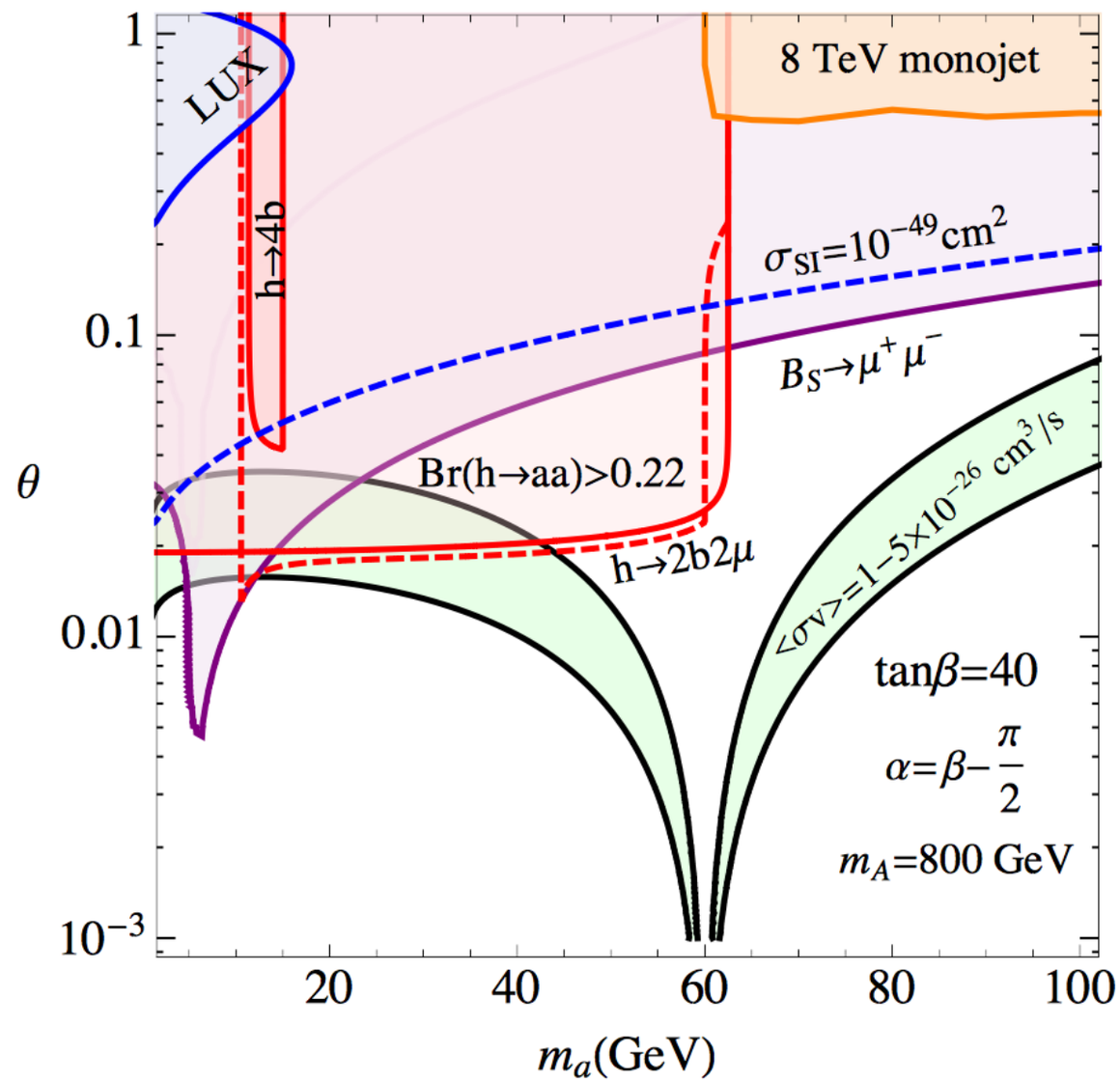
Neutrino Portal

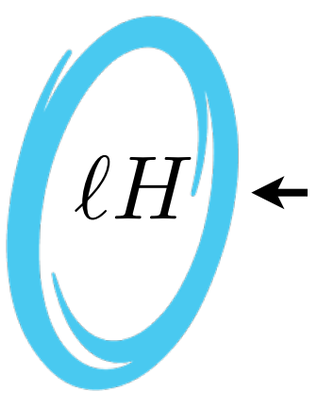




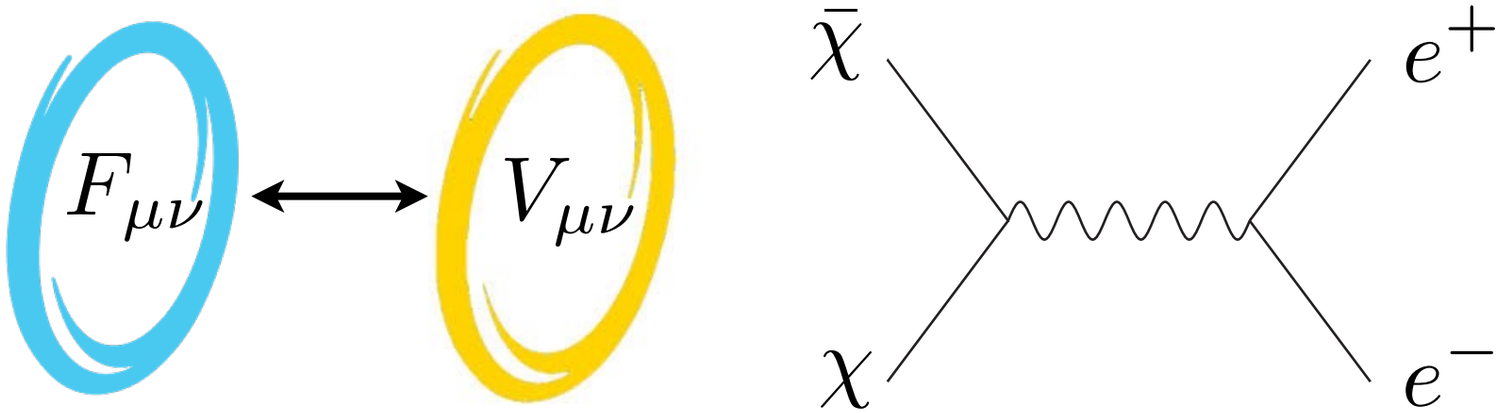




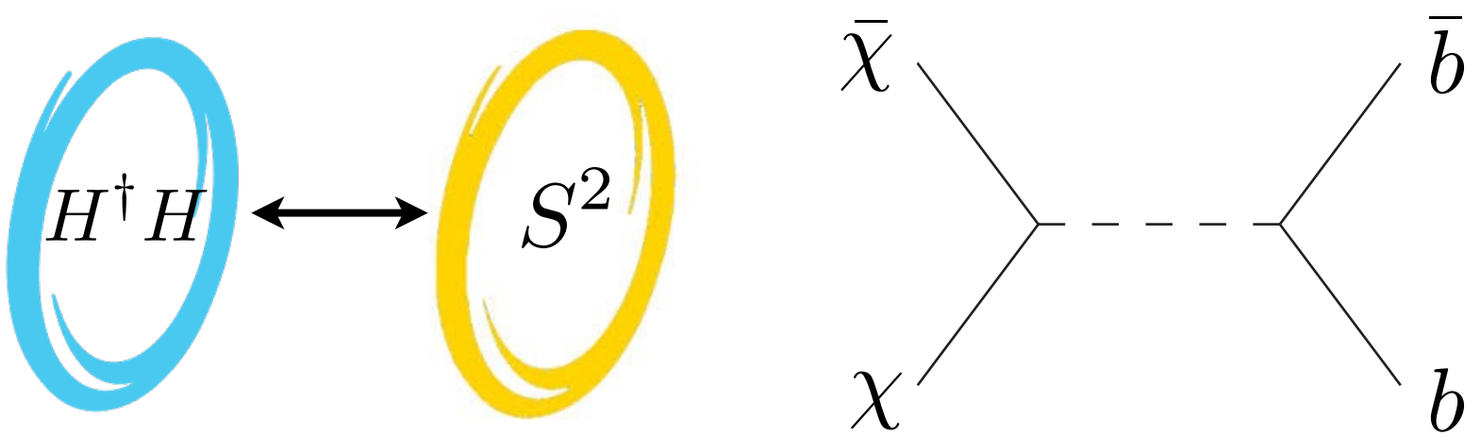




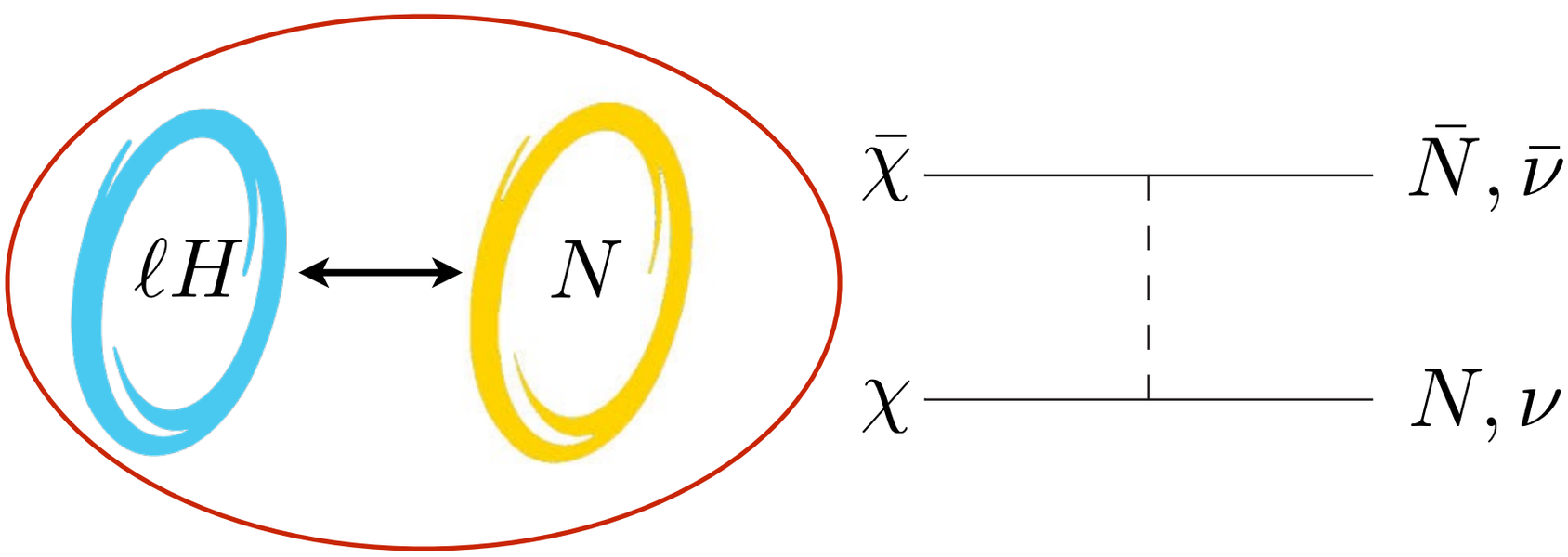
Neutrino Portal



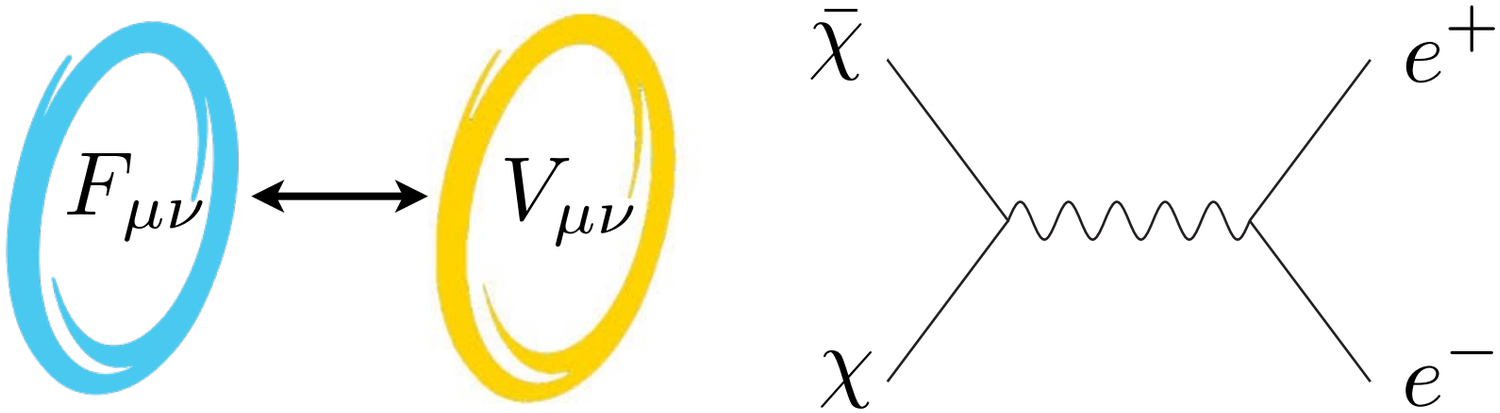
Vector Portal



Higgs Portal



Neutrino Portal



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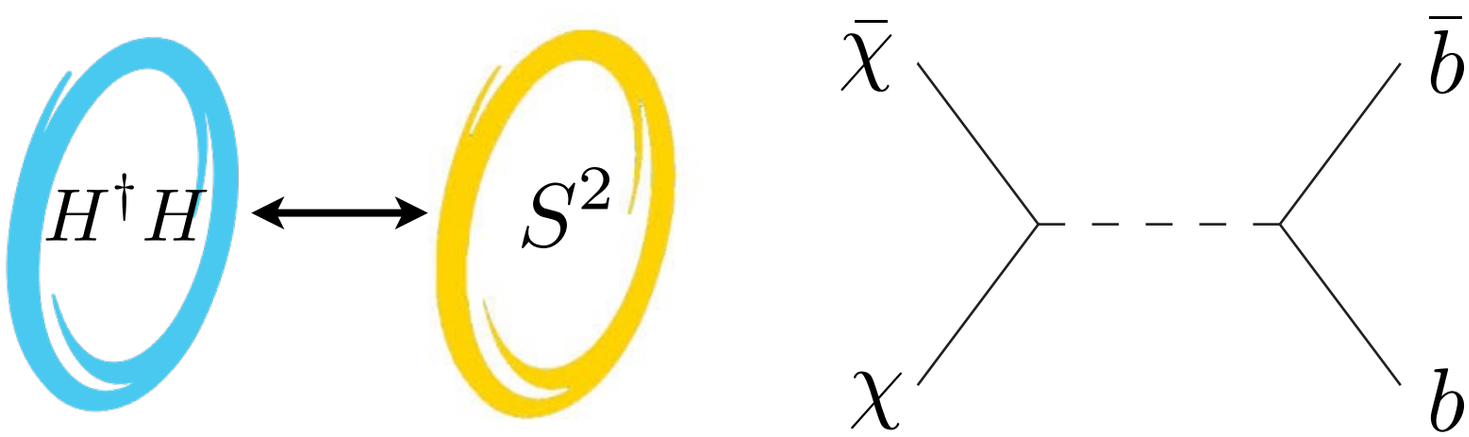
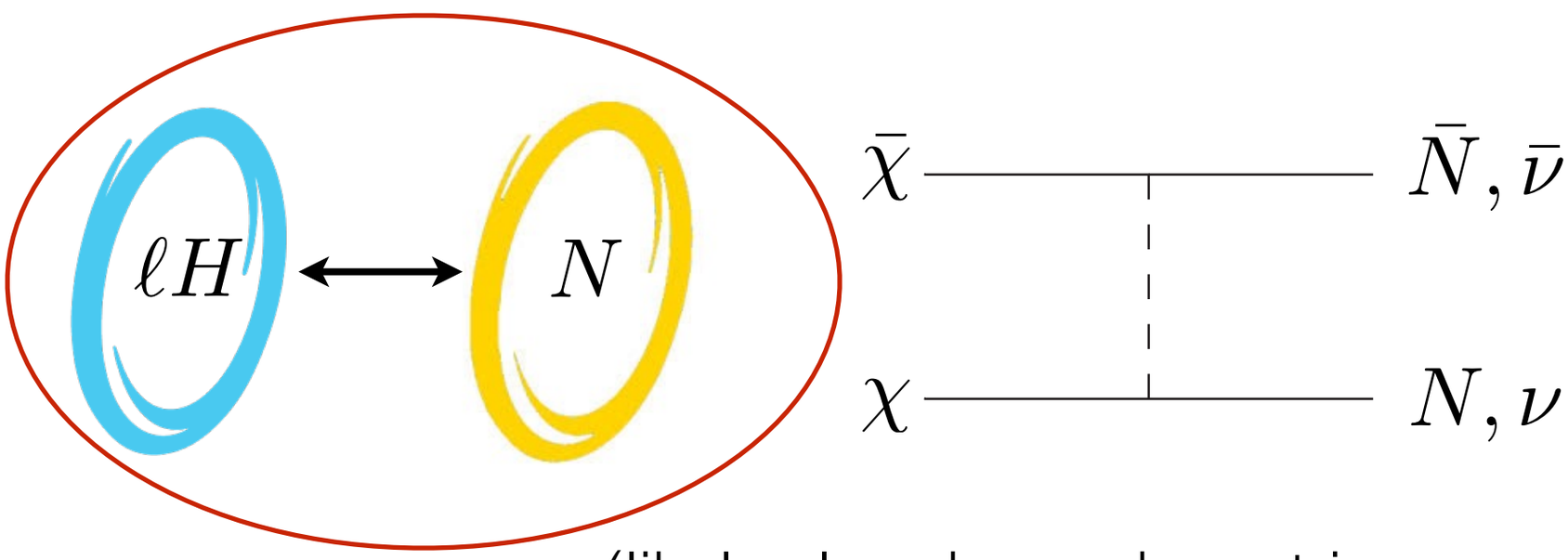


Higgs Portal



Neutrino Portal

(likely already used: neutrino masses)

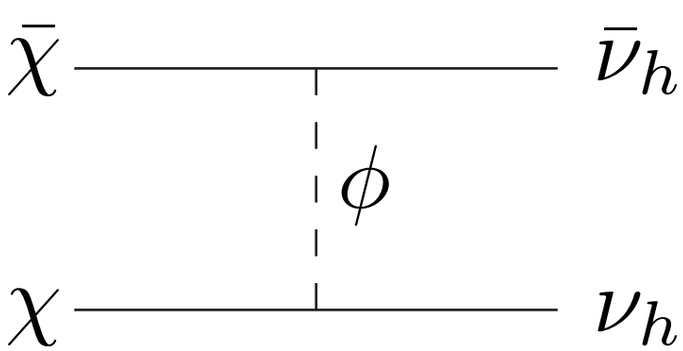
Basic Idea

$$\mathcal{L} \supset -\lambda \bar{L} H N - y \bar{N} \chi \phi + \text{h.c.} \to -\lambda v \bar{\nu} N - y \bar{N} \chi \phi + \text{h.c.}$$

$$\nu_l = \sqrt{1 - U^2}\nu + UN$$

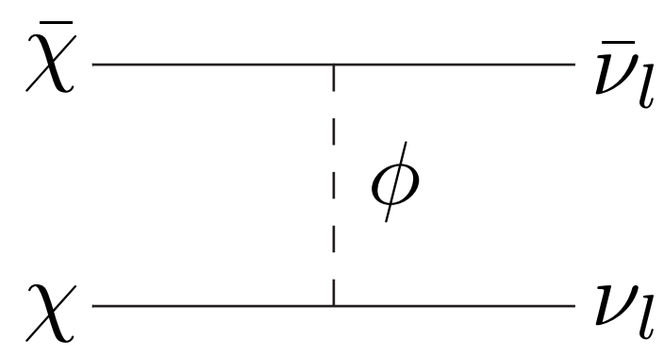
$$\nu_h = -U\nu + \sqrt{1 - U^2}N$$

Case I: $m_\chi > M$



$$\propto 1 - U^2$$

Case II: $m_\chi < M$



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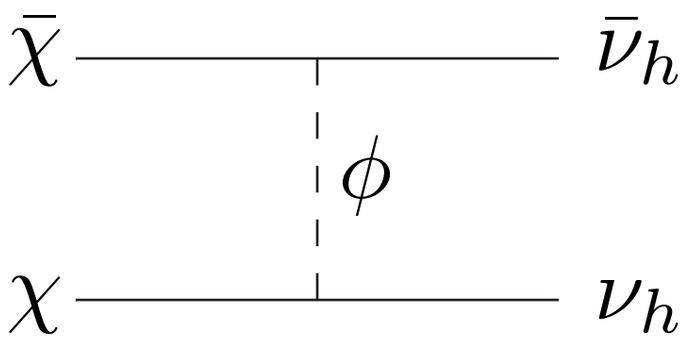

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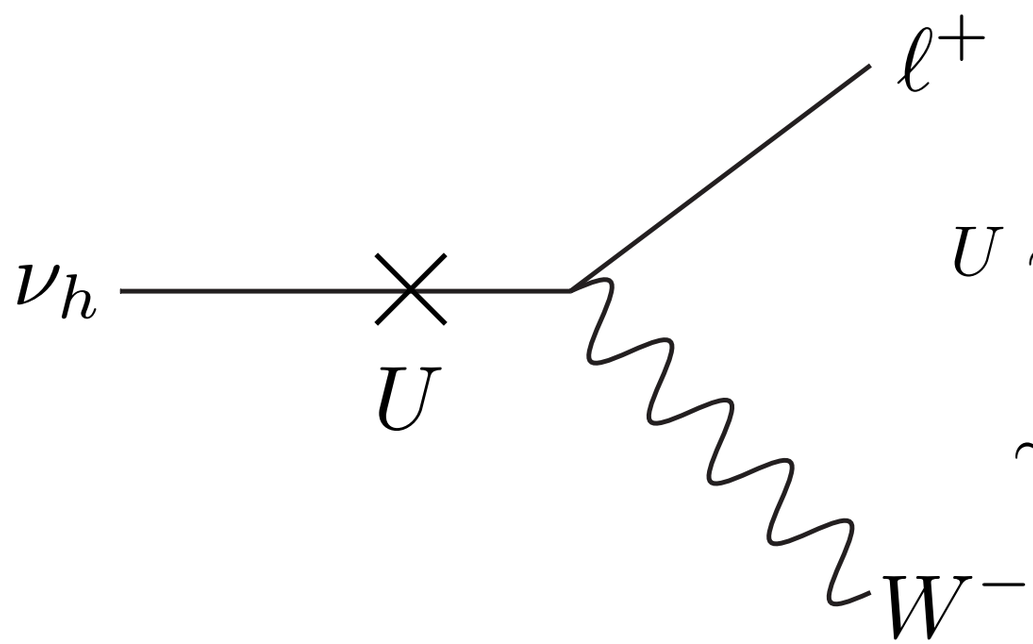
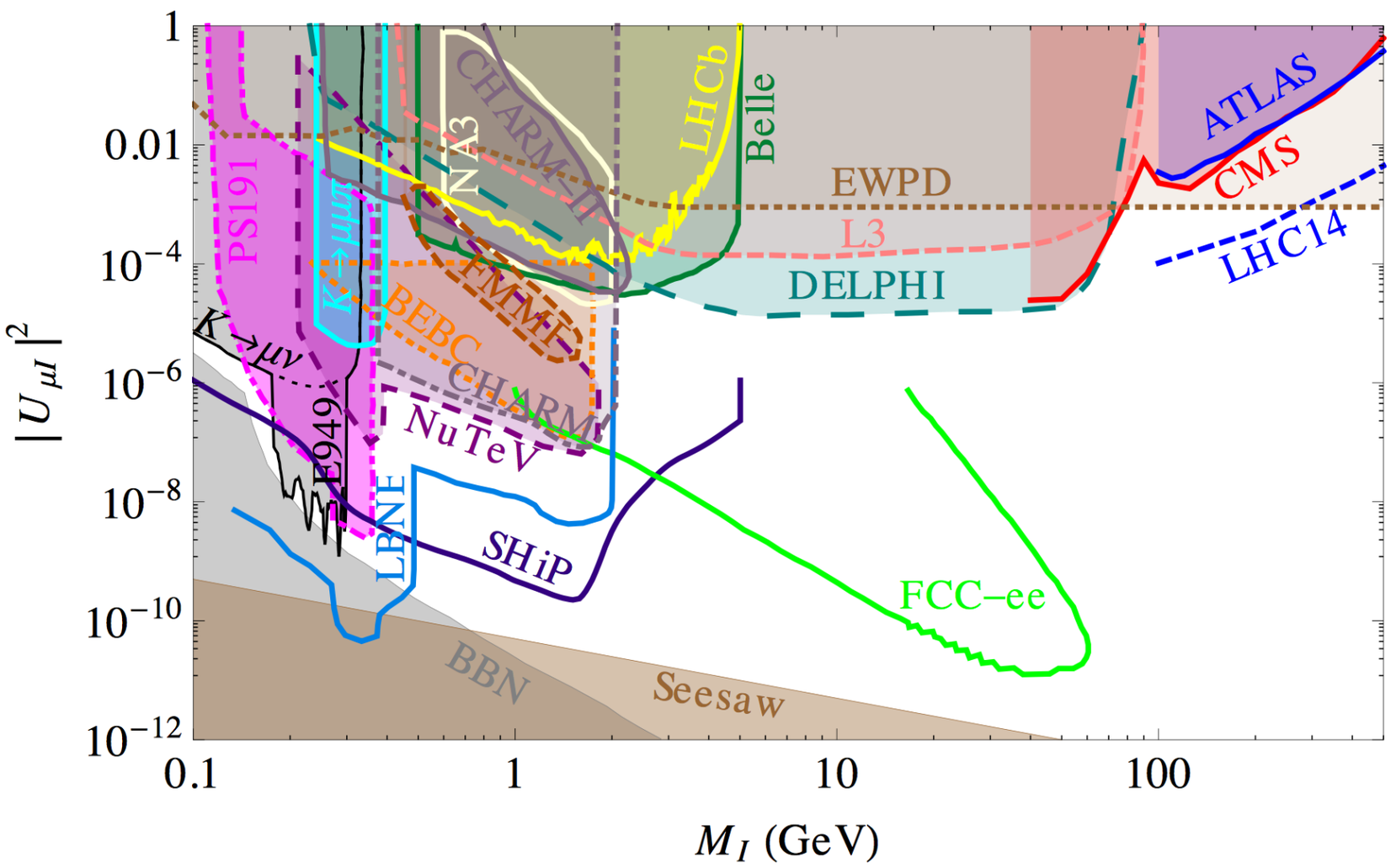


U can be small

$$U \sim \sqrt{\frac{m_l}{m_h}}$$

$$\sim 10^{-6}\sqrt{\frac{100\ \text{GeV}}{m_h}}$$



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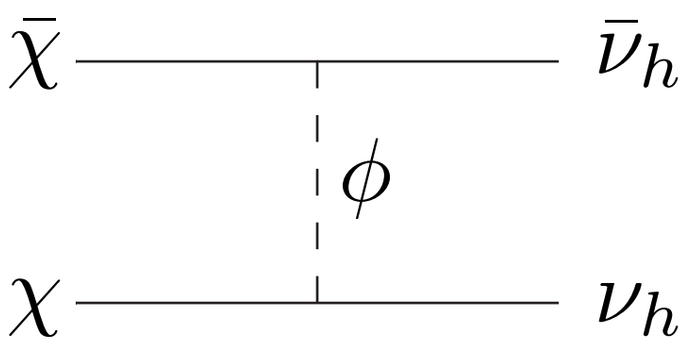

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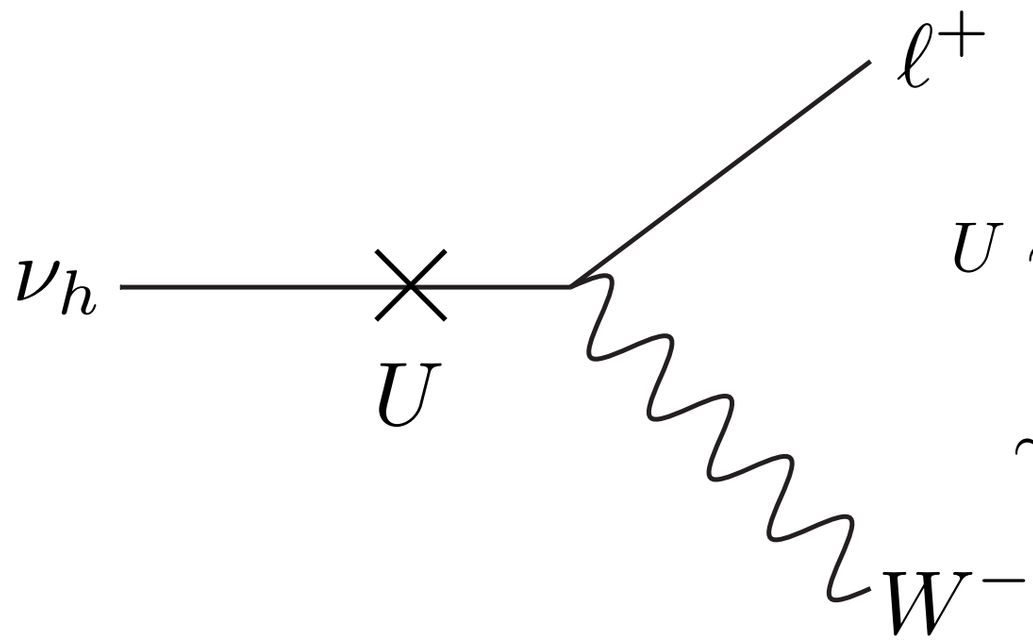

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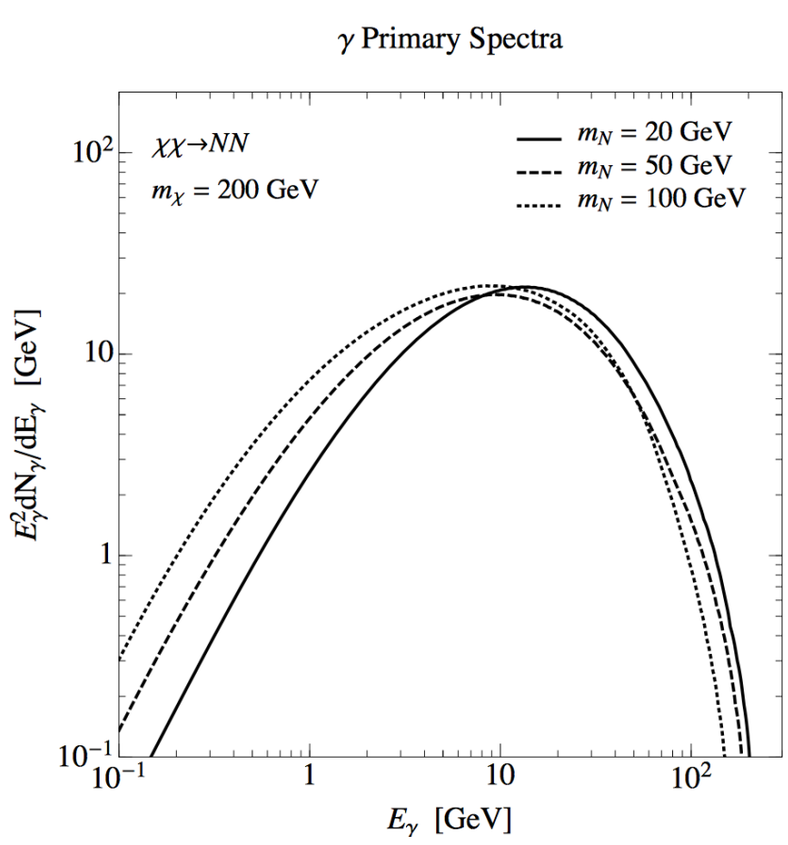

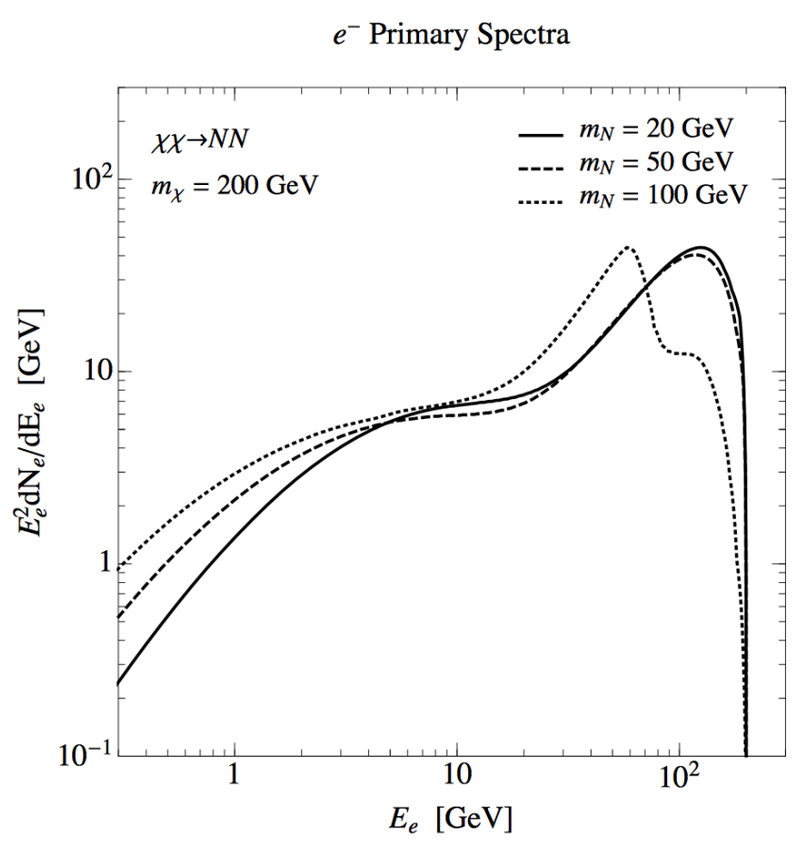

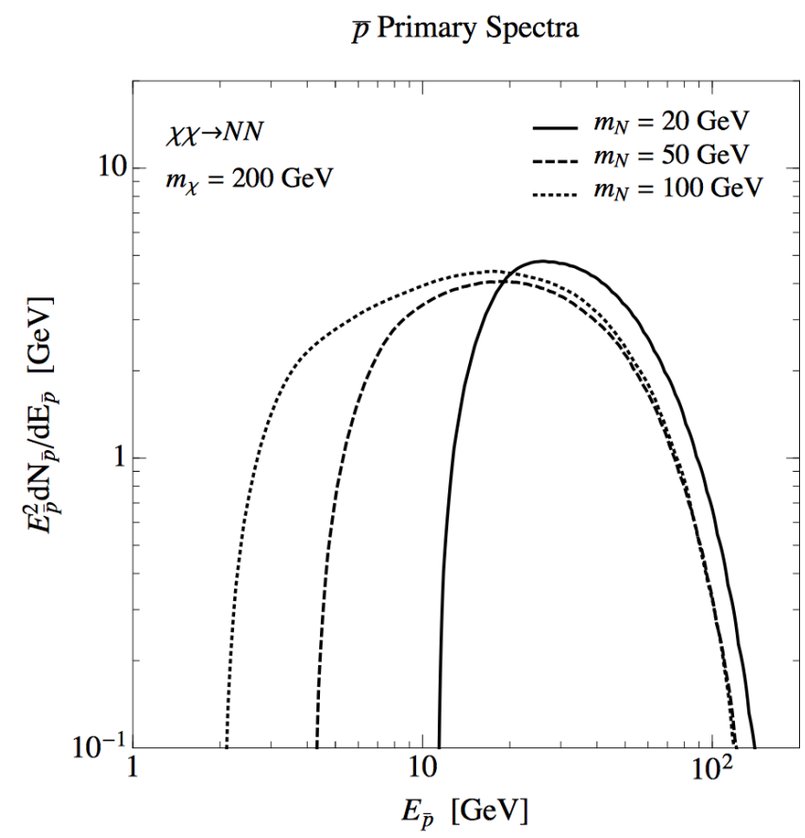

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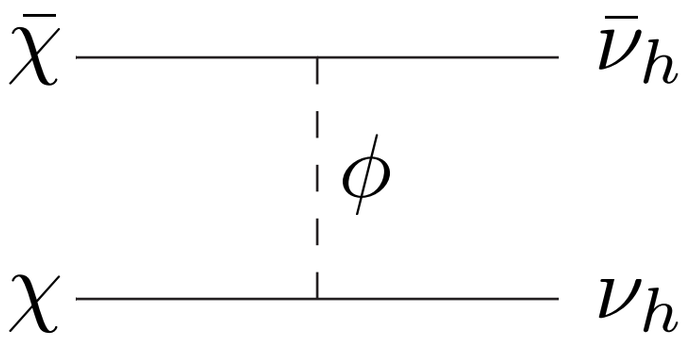
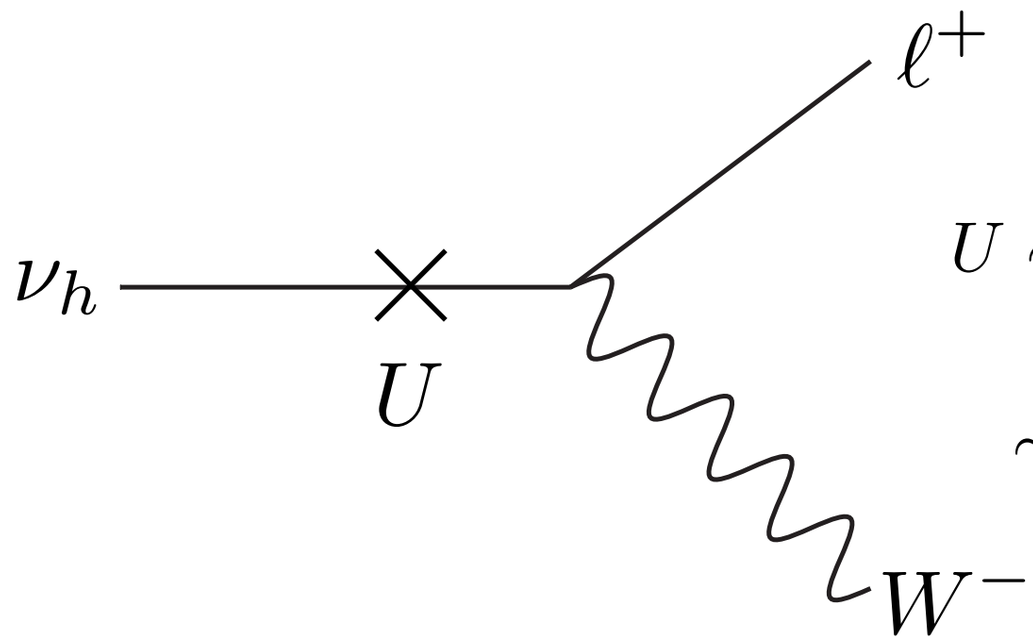


$$\propto 1 - U^2$$



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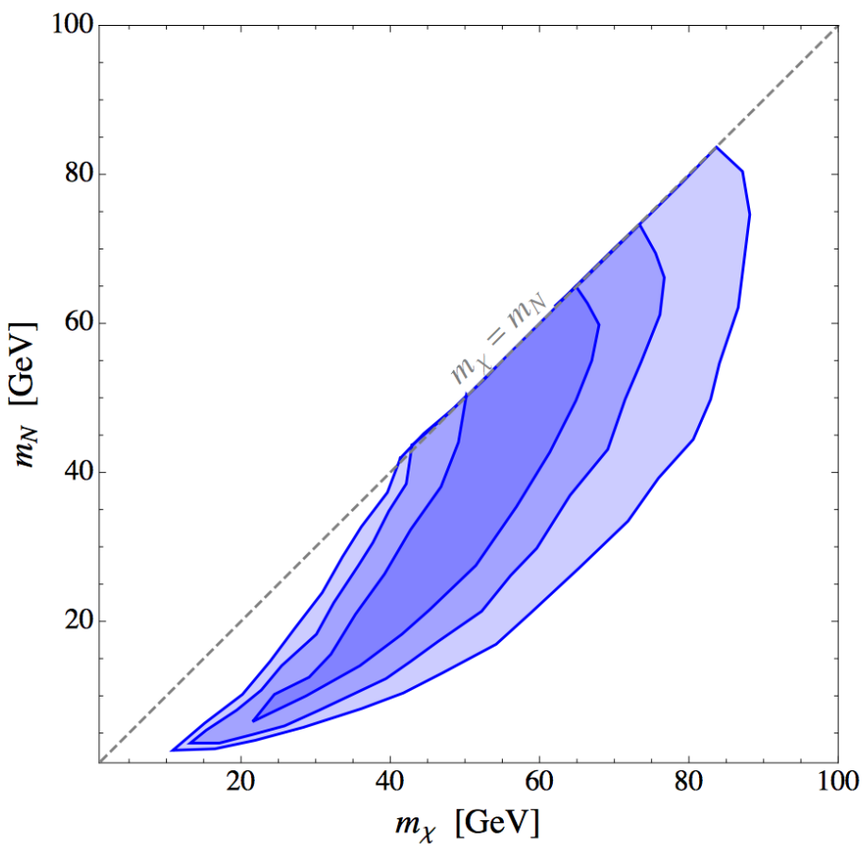

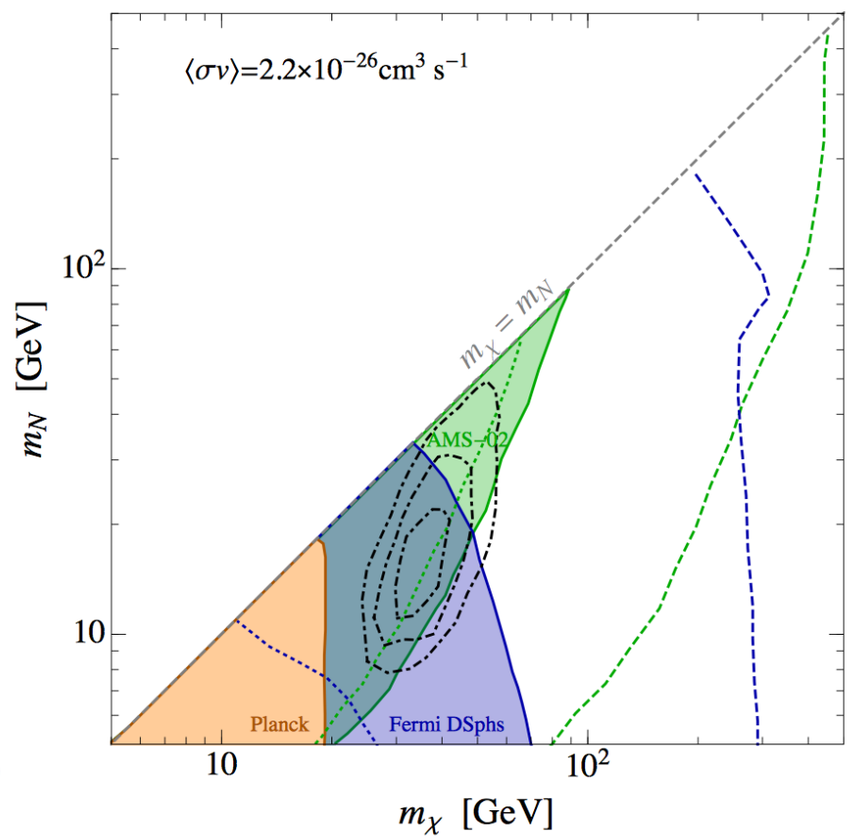

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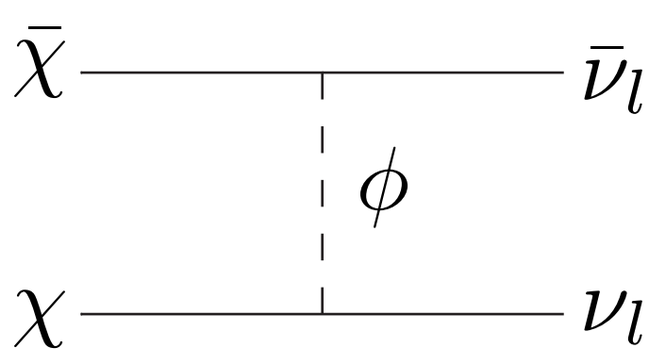


$\propto U^2$

$$\langle \sigma v \rangle = \frac{y^4 U^4}{32\pi} \frac{m_\chi^2}{m_\phi^4} \left(1 + \frac{m_\chi^2}{m_\phi^2}\right)^{-2}$$

$$\simeq 3 \times 10^{-26} \frac{\mathrm{cm}^3}{\mathrm{s}} \left(\frac{yU}{0.2}\right)^4 \left(\frac{m_\chi}{10\ \mathrm{GeV}}\right)^{-2} \left(\frac{m_\phi/m_\chi}{3}\right)^{-4}$$

Requires large mixing angle!

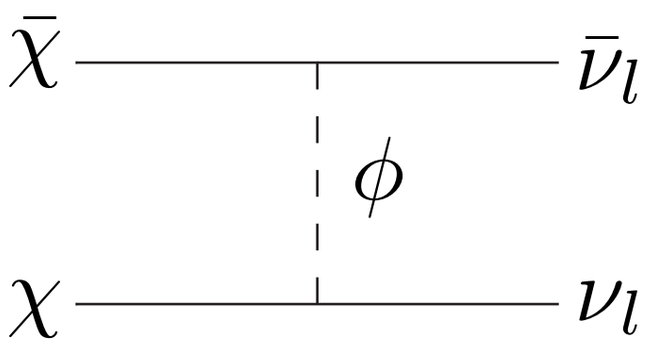
Minimal Model

$$\mathcal{L} \supset -\lambda_i \bar{L}_i H N_R - M_N \bar{N}_L N_R - \phi\bar{\chi}\left(y_L N_L + y_R N_R\right) + \mathrm{h.c.}$$
$$\rightarrow -\lambda_i v \bar{\nu}_{i\,L} N_R - M_N \bar{N}_L N_R - \phi\bar{\chi}\left(y_L N_L + y_R N_R\right) + \mathrm{h.c.}$$

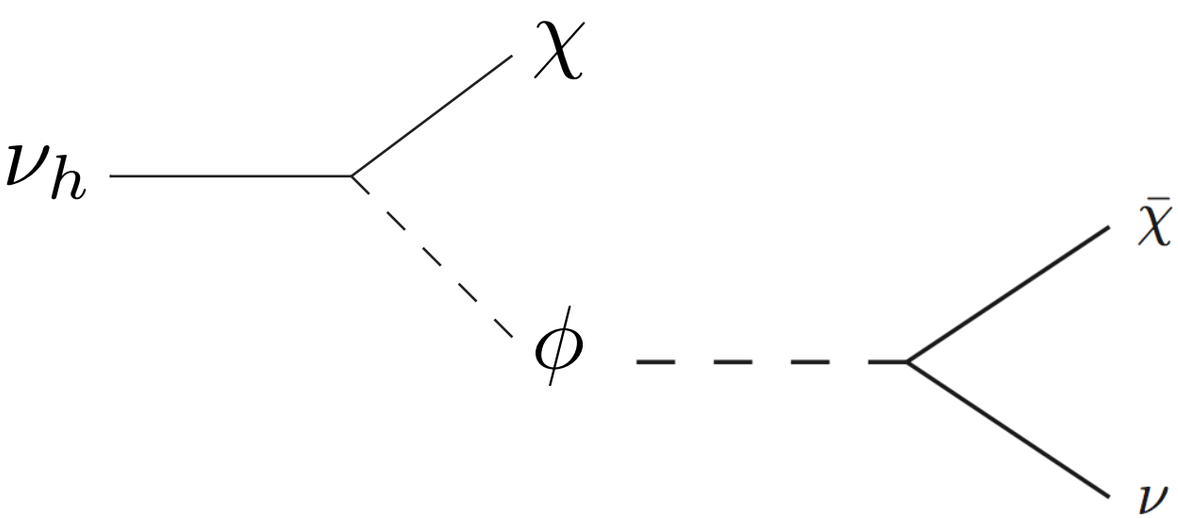
lepton number conserved (for small ν masses & large mixing)

Bertoni, Ipek, DM, & Nelson 1412.3113
Batell, Han, DM, & Shams Es Haghi *in prep.*

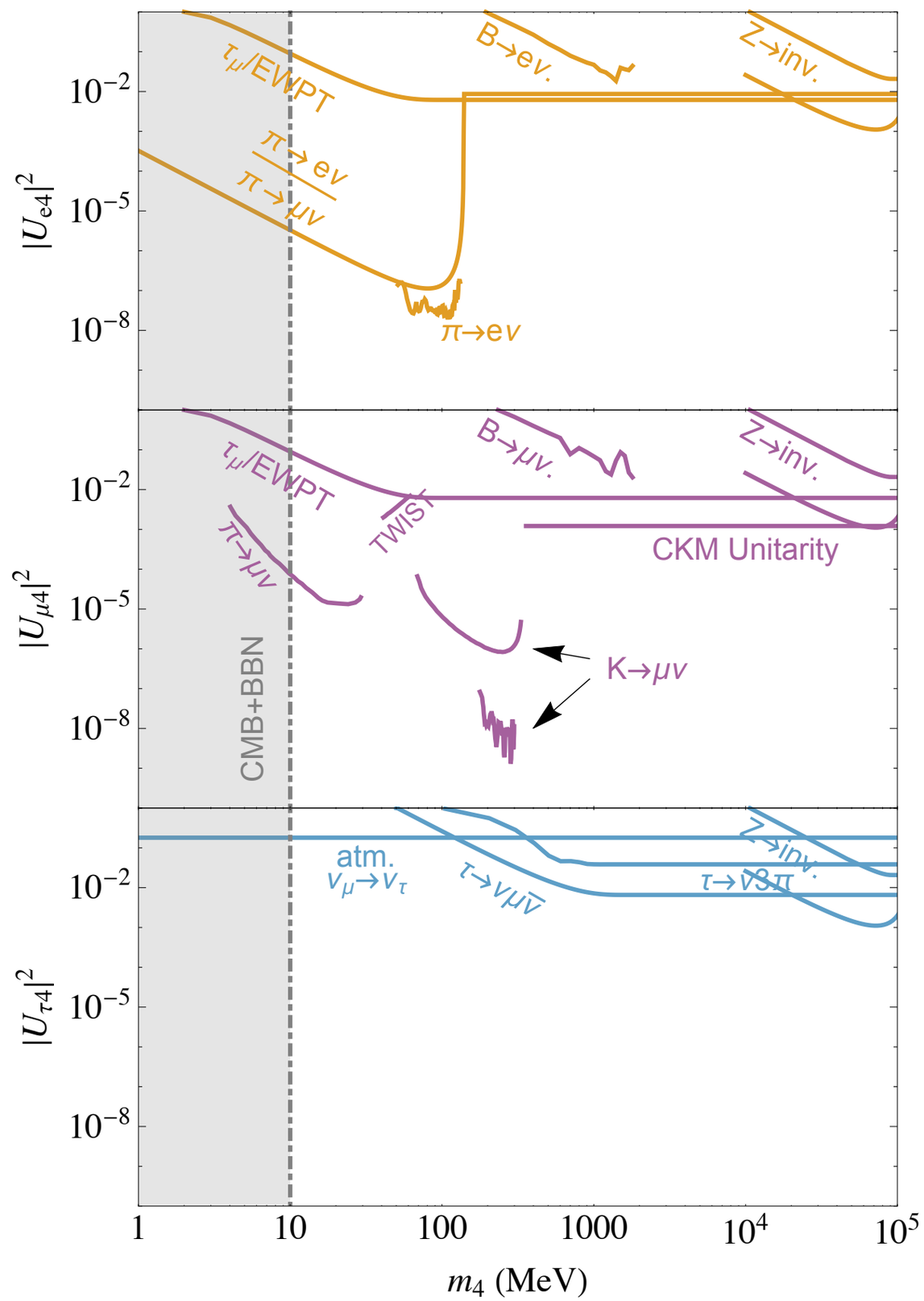
Case II: $m_\chi < M$



$$\propto U^2$$

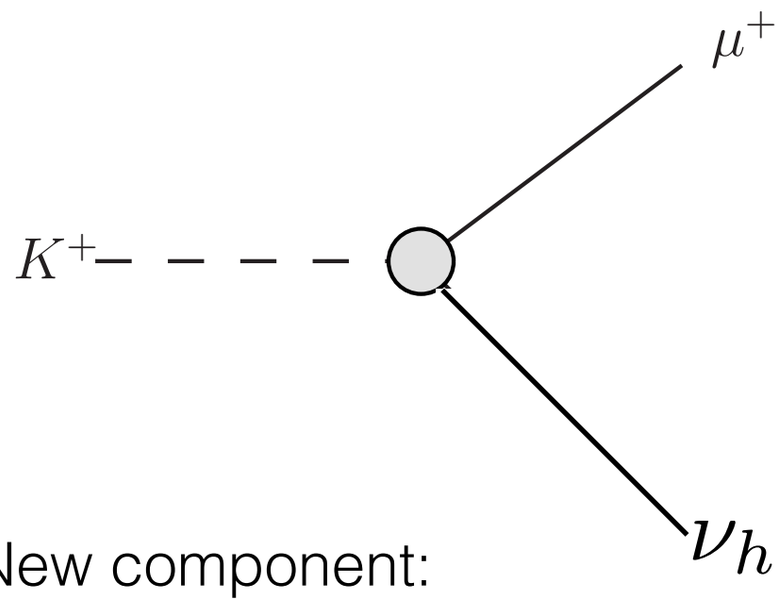


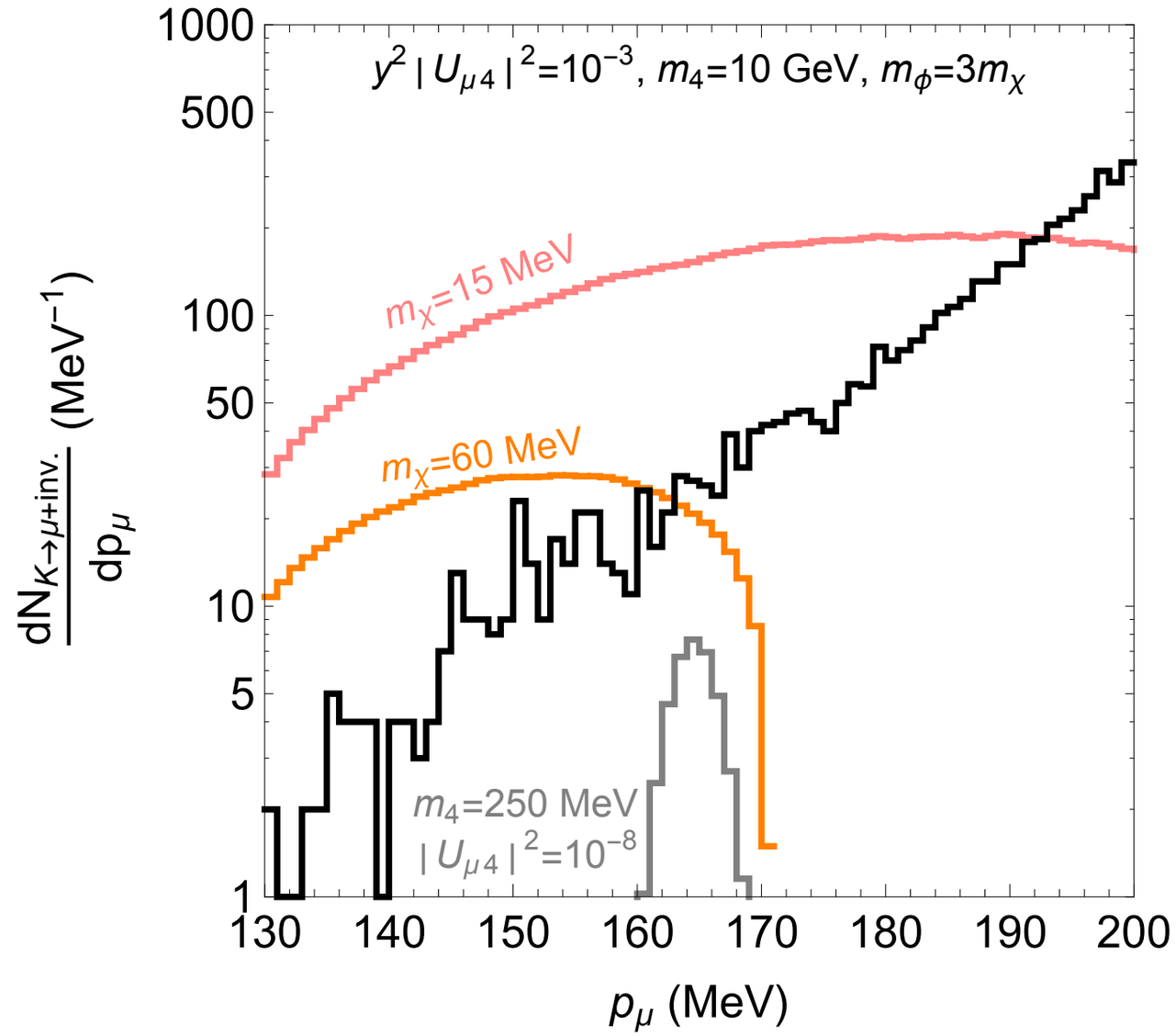
heavy neutrino decays invisibly!



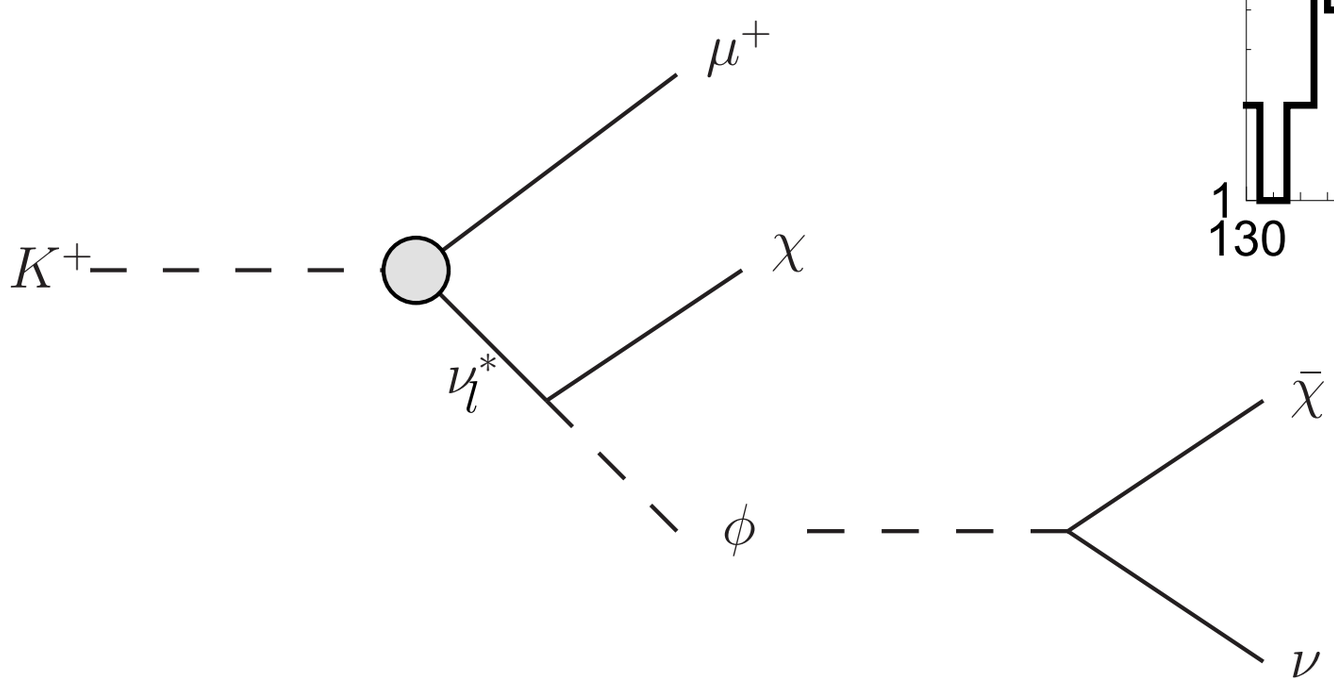
Bertoni, Ipek, DM, & Nelson 1412.3113
Batell, Han, DM, & Shams Es Haghi *in prep.*

Meson decays





New component:



E949: 10^{12} kaons

NA62 increase by ~order of mag.

Atmospheric Neutrino Oscillations

$\nu_\mu,\ \nu_{\tau N}$ Hamiltonian:

$$H = \left(\frac{\Delta m^2}{4E}\right)\begin{pmatrix} -\cos 2\theta & \sin 2\theta \\ \sin 2\theta & \cos 2\theta \end{pmatrix} + \begin{pmatrix} V_\mu & 0 \\ 0 & V_{\tau N} \end{pmatrix}$$

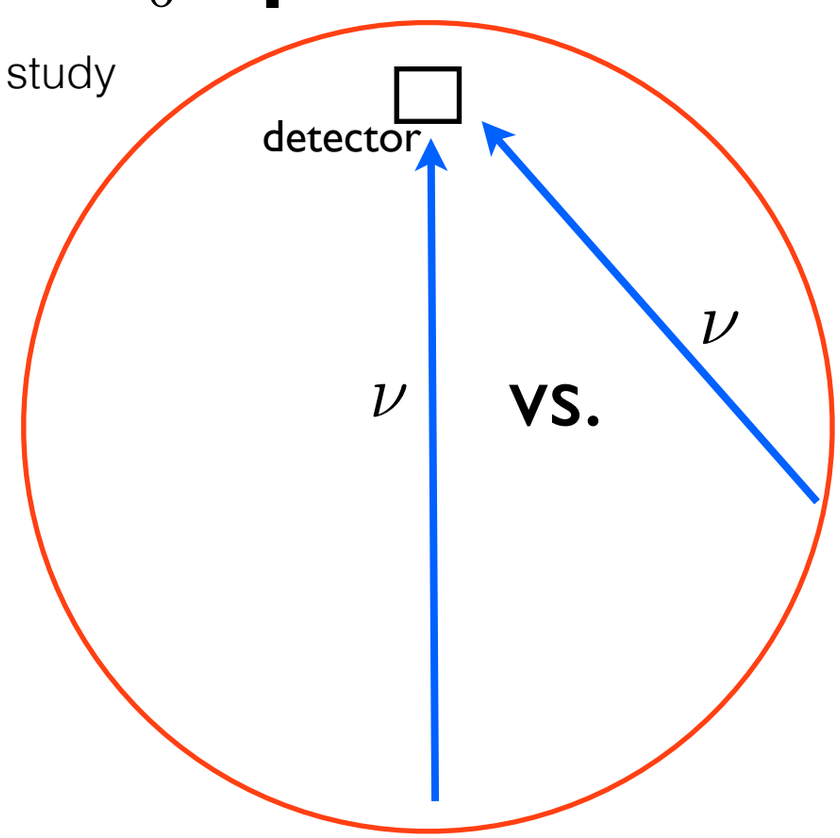
$$V_\mu = -\frac{G_F}{\sqrt{2}} n_n \sim \frac{1}{4000\ \mathrm{km}}$$

$$V_{\tau N} = -\frac{G_F}{\sqrt{2}} n_n \cos\theta_\tau$$

Non-standard int.

$$\epsilon_{\tau\tau} = \frac{1}{6}\left(\frac{V_{\tau N}}{V_{\mathrm{nc}}} - 1\right) = \frac{\sin^2\theta_\tau}{6}$$

see de Gouvea for DUNE study



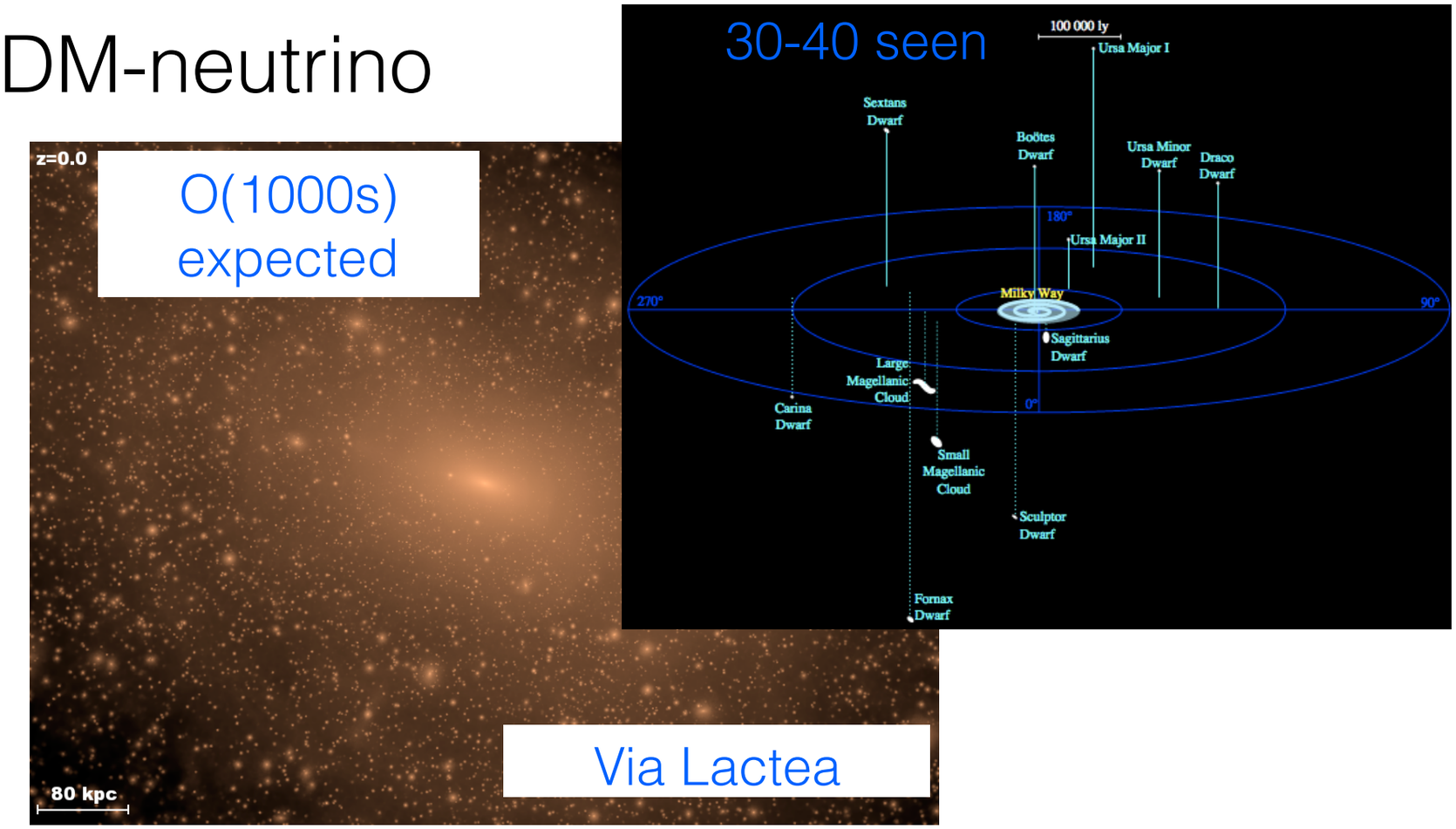
Oscillation pattern depends on amount of matter traversed

Super-K, arXiv:1410.2008

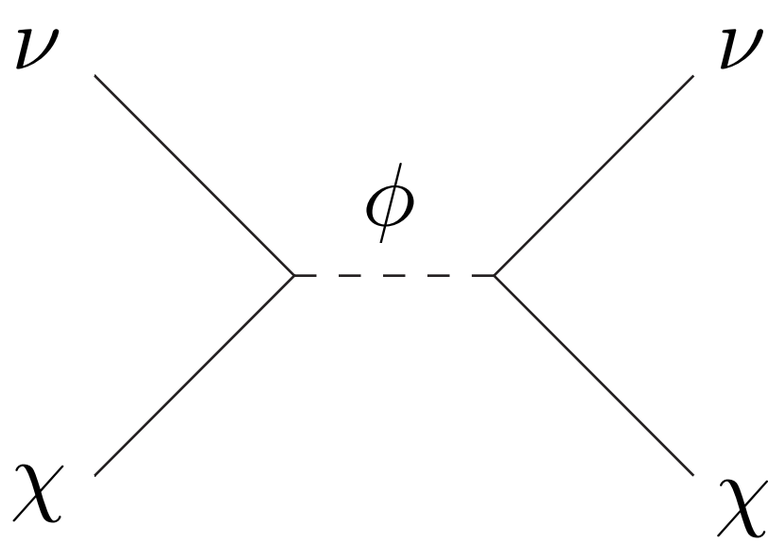
$\sin\theta_\tau < 0.42$ (stat. limited!)

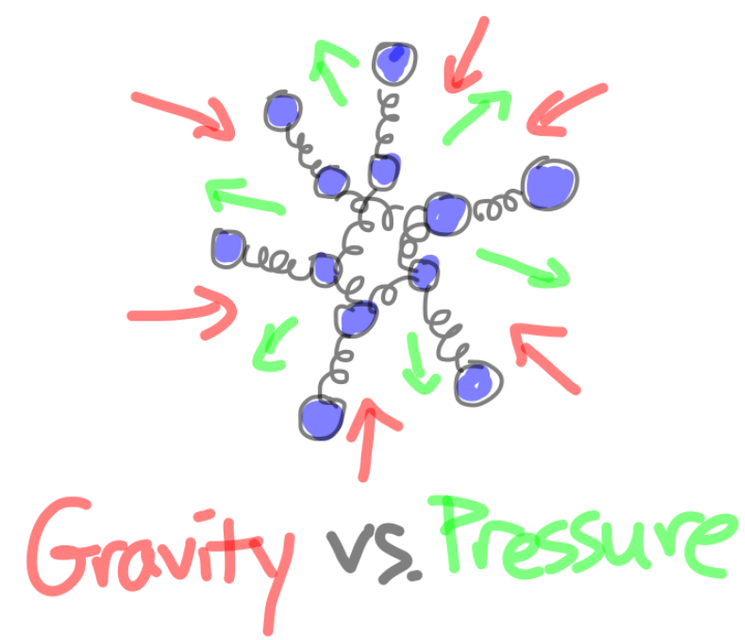
Are there hints for DM-neutrino interactions?

Count satellites of Milky Way galaxy:



DM-scattering on neutrinos

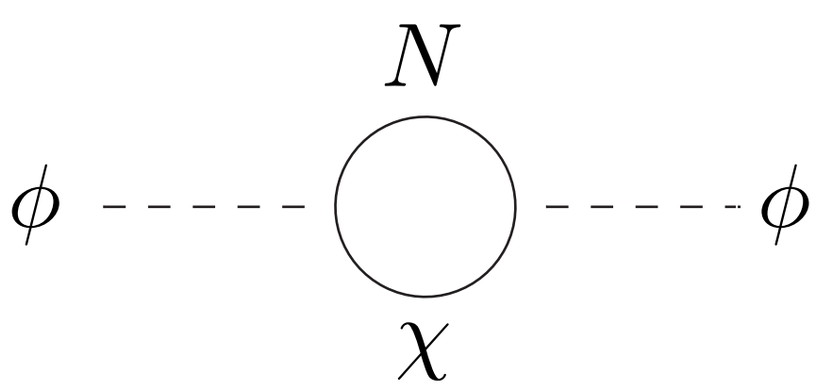




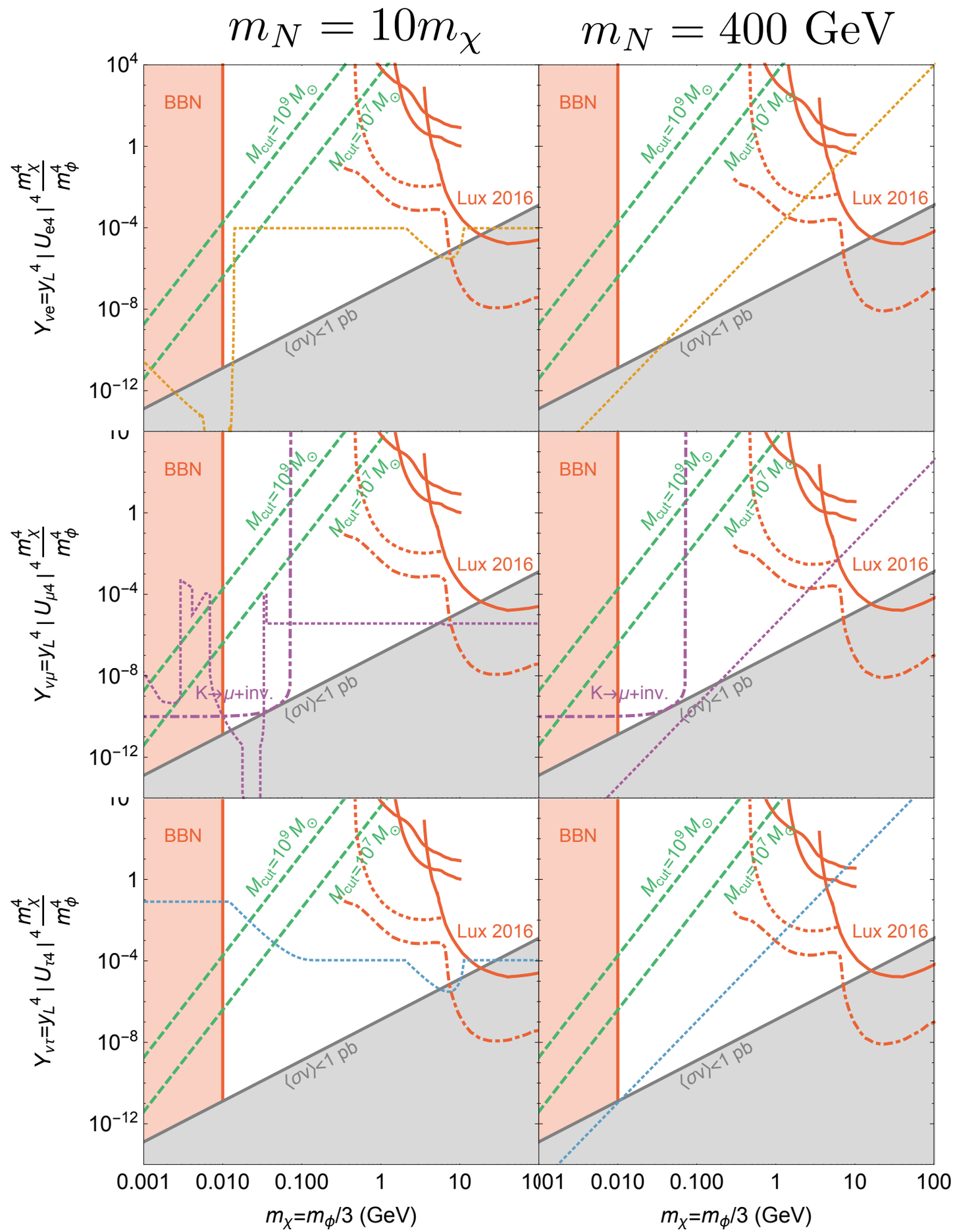
Boehm et al.
van den Aarssen et al.
Shoemaker et al.
Bertoni, Ipek, DM, & Nelson
Hooper, Kaplinghat, Strigari, & Zurek

Can summarize using particular combination of couplings:

$$Y \equiv y_L^4 \left(\sum_i |U_{i4}|^2 \right)^2 \frac{m_\chi^4}{m_\phi^4} = 32\pi m_\chi^2 \langle \sigma v \rangle$$

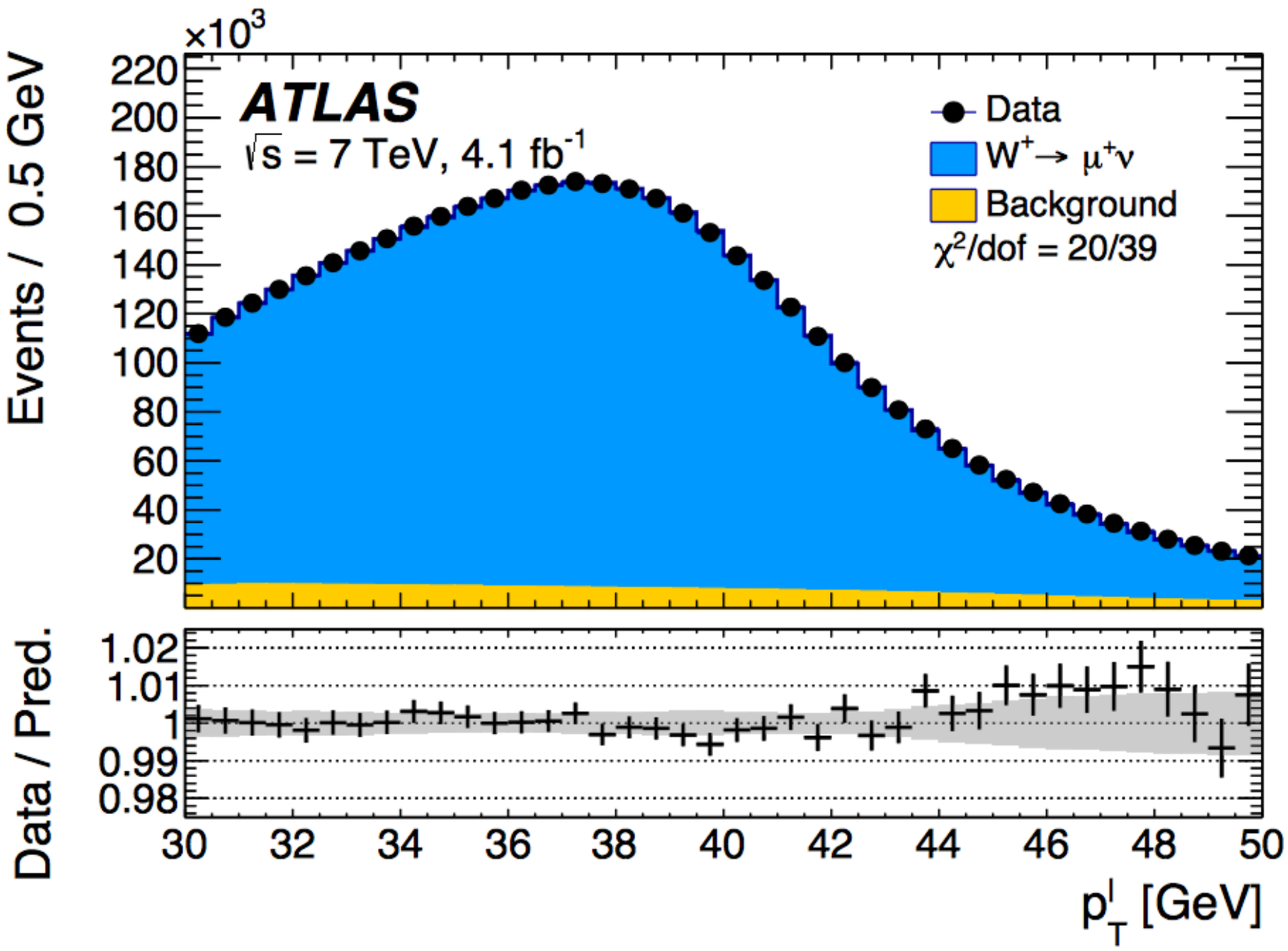


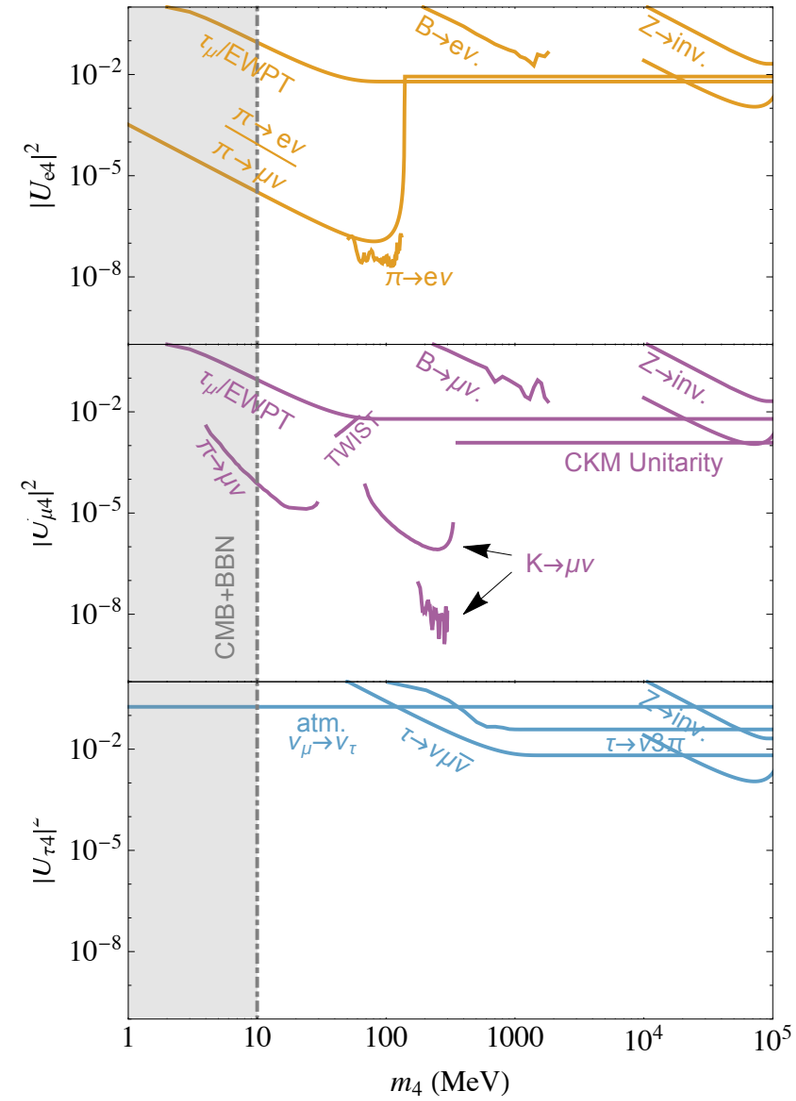
$$\delta m_\phi^2 \sim \frac{y^2}{16\pi^2} m_N^2$$



In progress…

ATLAS W mass measurement 1701.07240





$\sim 2U^2$

Wrap up

Lots of observations point to DM

We know some general characteristics of DM

Neutrino portal relatively less well studied

Interesting new probes—lots of connections across fields!