Thermal Freeze Out & the Neutrino Portal

David McKeen TRIUMF

Snowmass RF6 "Dark Sectors"

Dec. 4, 2020

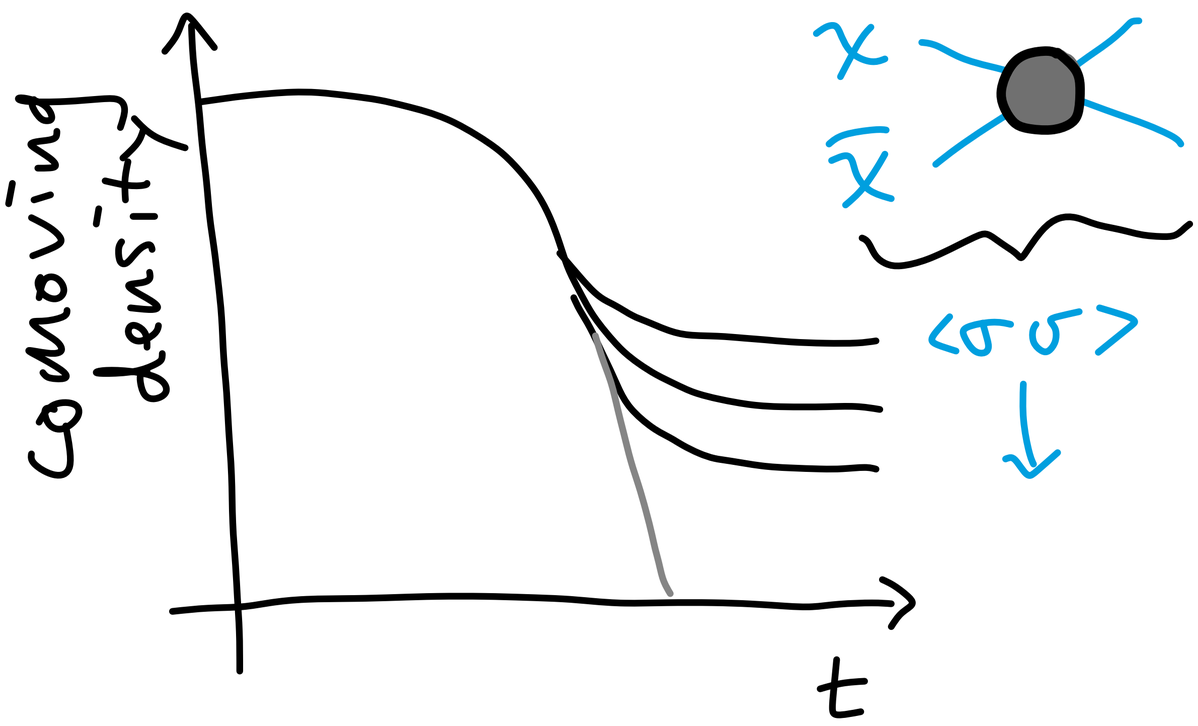
Plan

Thermal Relics (see also talk by Shelton)

Neutrino Portal

Two scenarios

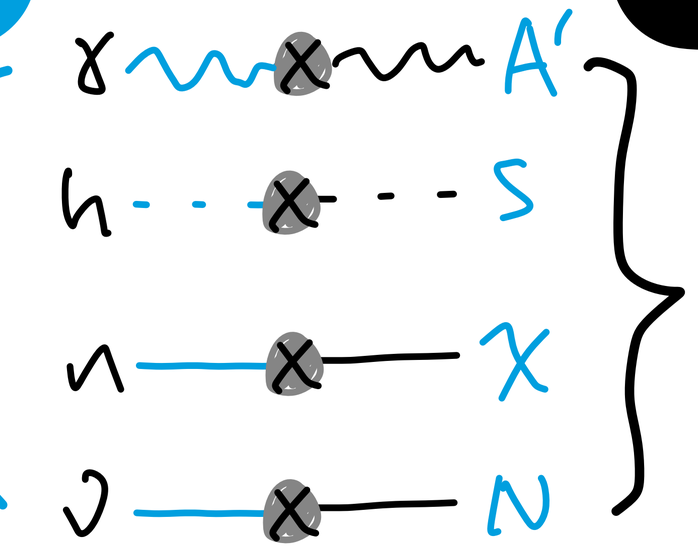
Thermal Relics



- Generic possibility to produce DM
- Relative insensitivity to initial conditions
- Everything we "know" is...

Portals: Coupling to a Dark Sector

SM neutral particles



Dark Sector neutral particles

A Simple Setup

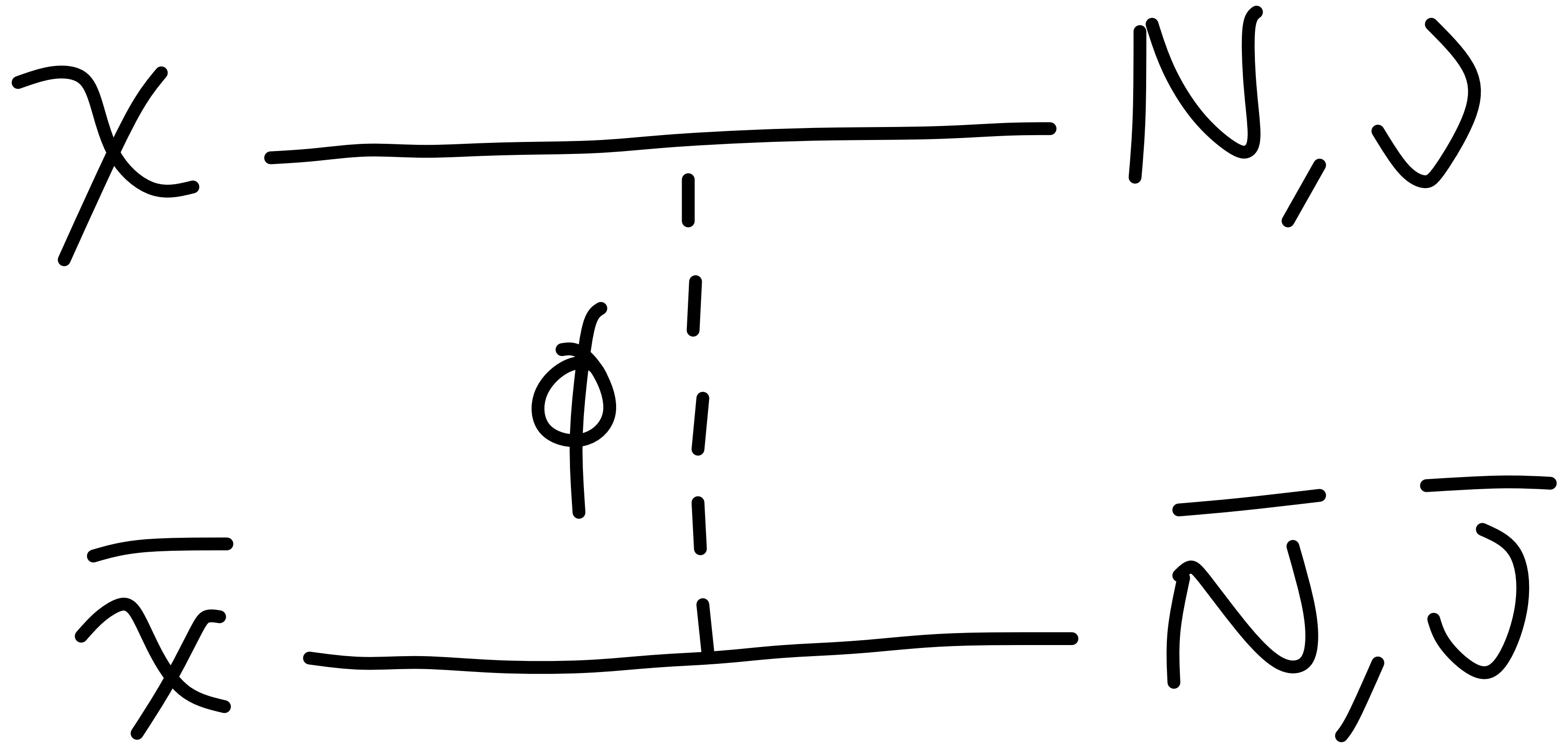
$$\mathcal{L} \supset -\lambda_i \bar{N} H L_i - y\, \bar{\chi} \phi N + M N N + h.c.$$

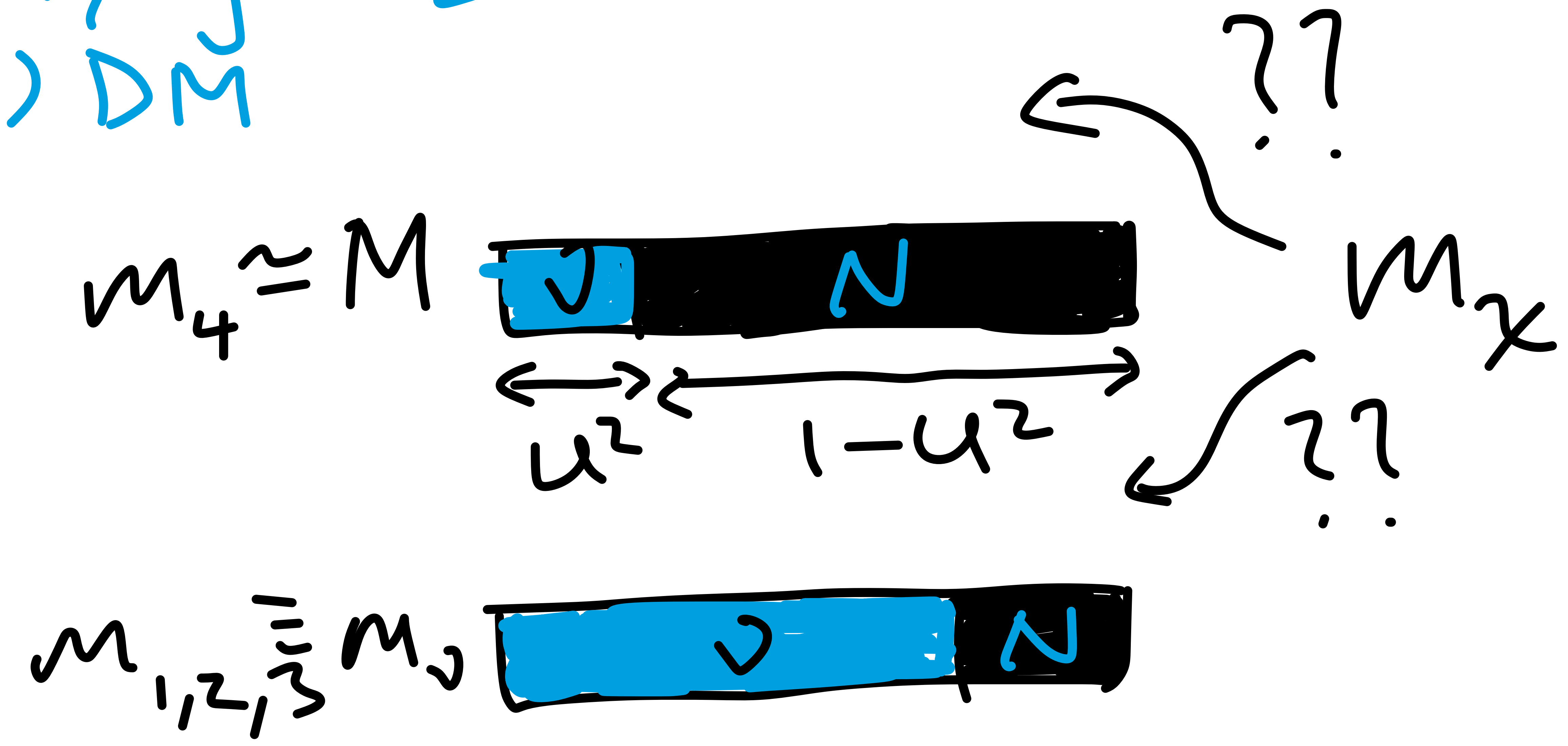
$\Downarrow$ $-\lambda_i v \bar{N} \nu$

$\uparrow\uparrow$ charged w/r/t, e.g. $\mathbb{Z}_2$ $\Rightarrow$ DM

(MNN:) more on this later...

Allows for

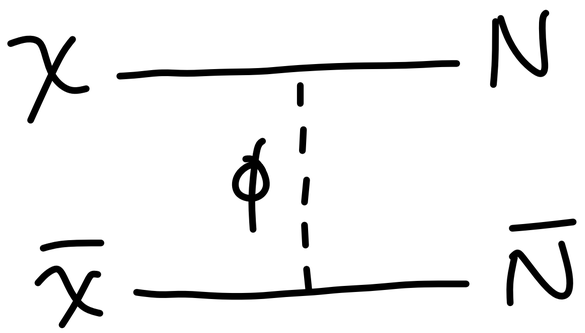




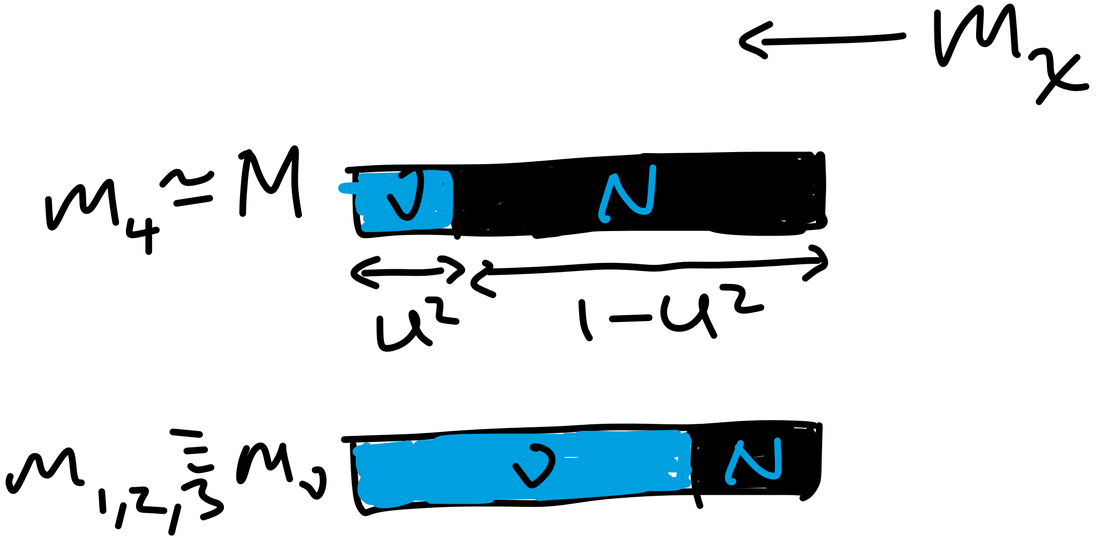
N.B. Minimal setup (Majorana N) $\Rightarrow$ $U = \sqrt{\dfrac{m_\nu}{M}}$

~Two Possibilities

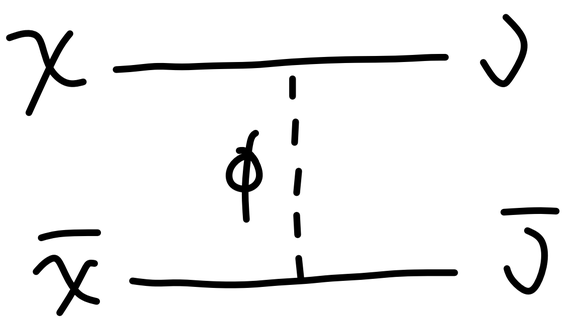
Case 1:



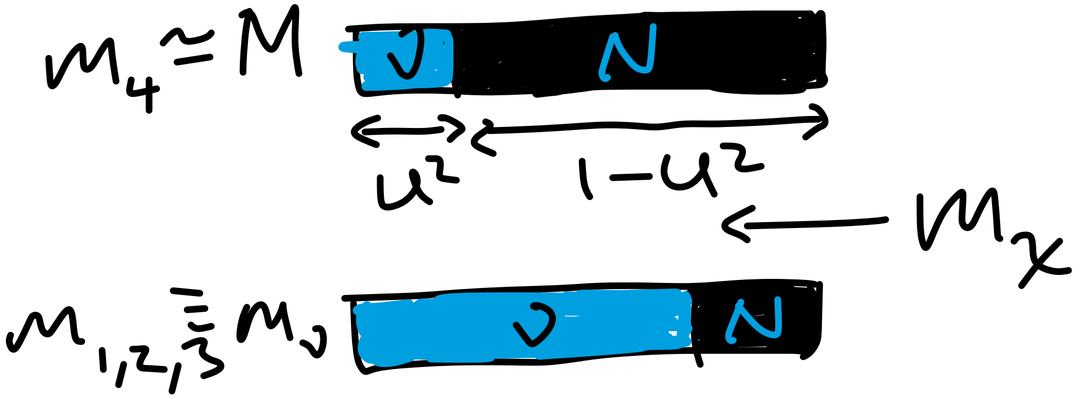
$\sigma v \propto (1-u^2)^4$



Case 2:



$\sigma v \propto u^4$

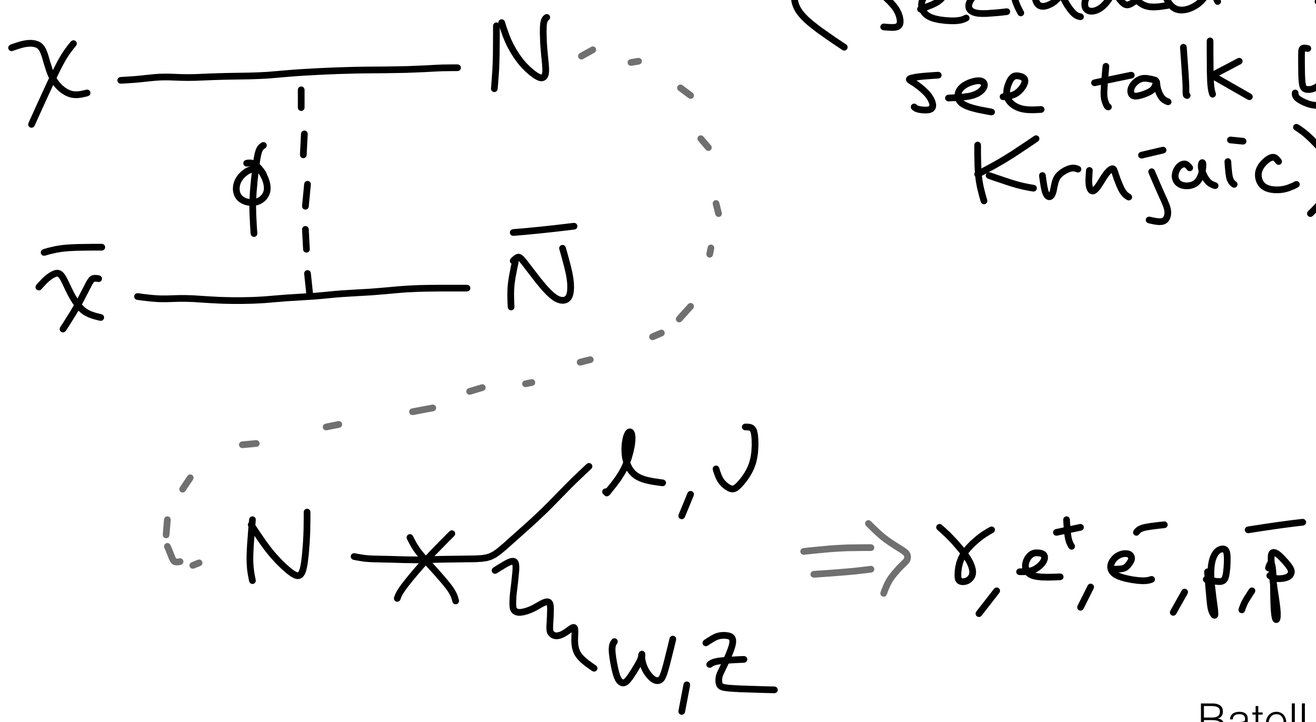


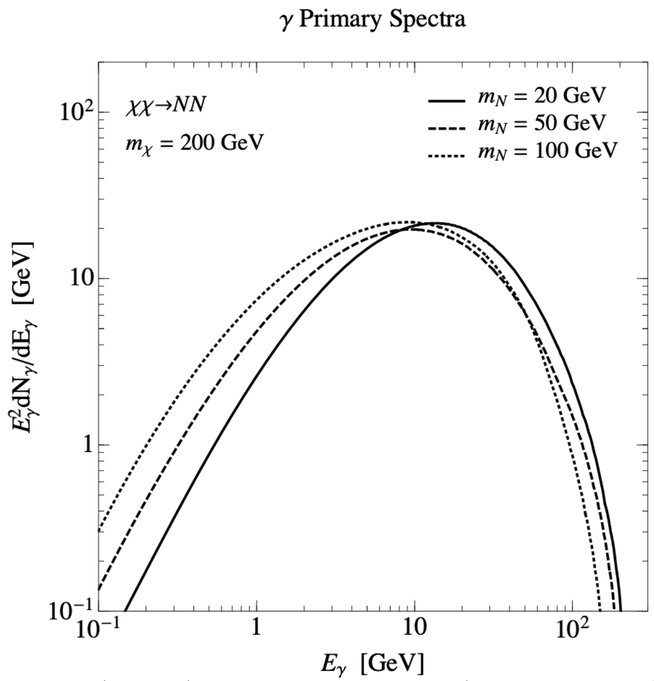
Case 1: Annihilation to heavy neutrinos

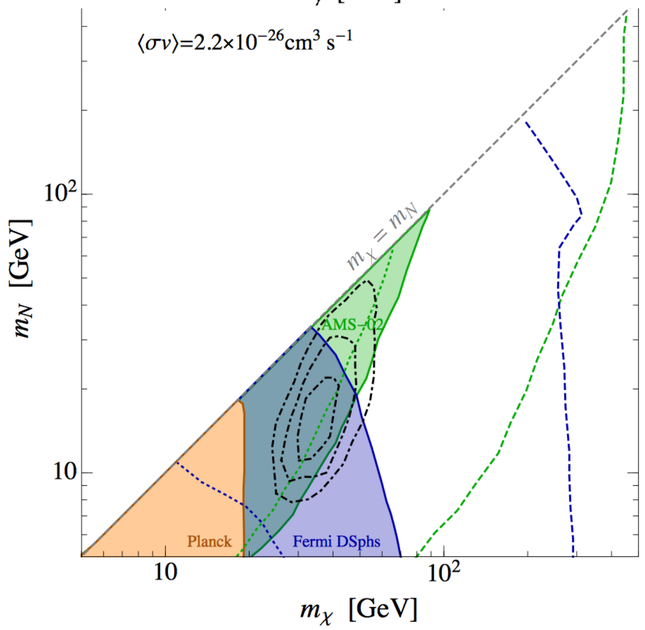
⇒ Indirect Detection

$\sigma v \propto (1-U^2)^4$, U can be tiny

("secluded" DM see talk by Krnjaic)

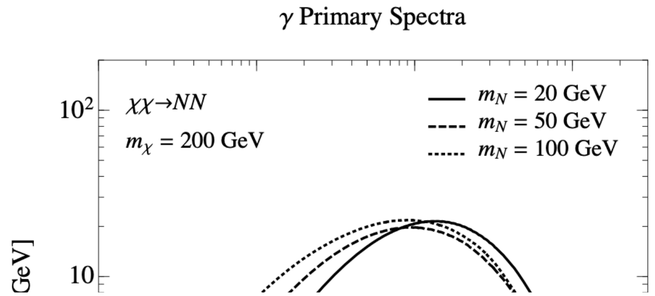






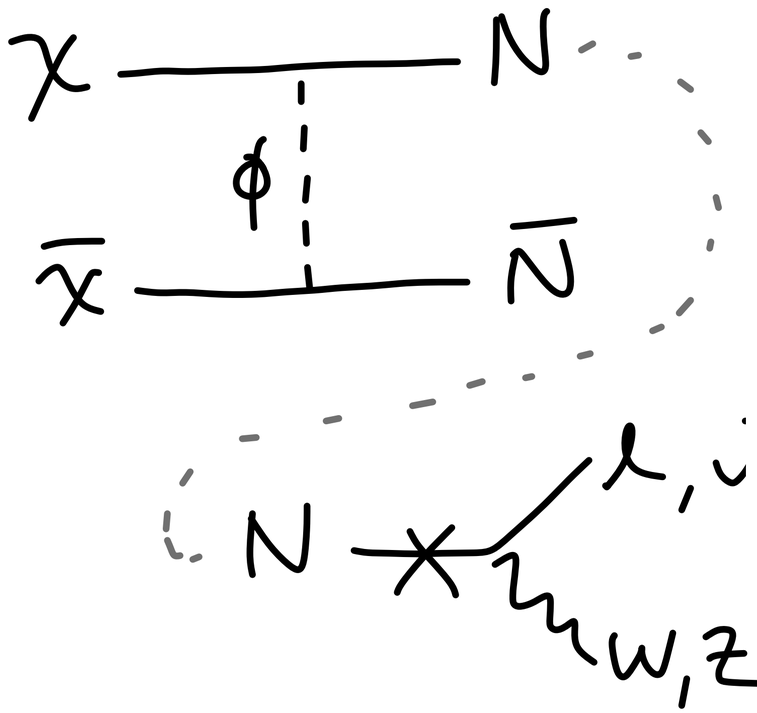
Batell, Han, & Shams Es Haghi 1704.08708 other work by Krnjaic et al., Escudero et al., Blennow et al.

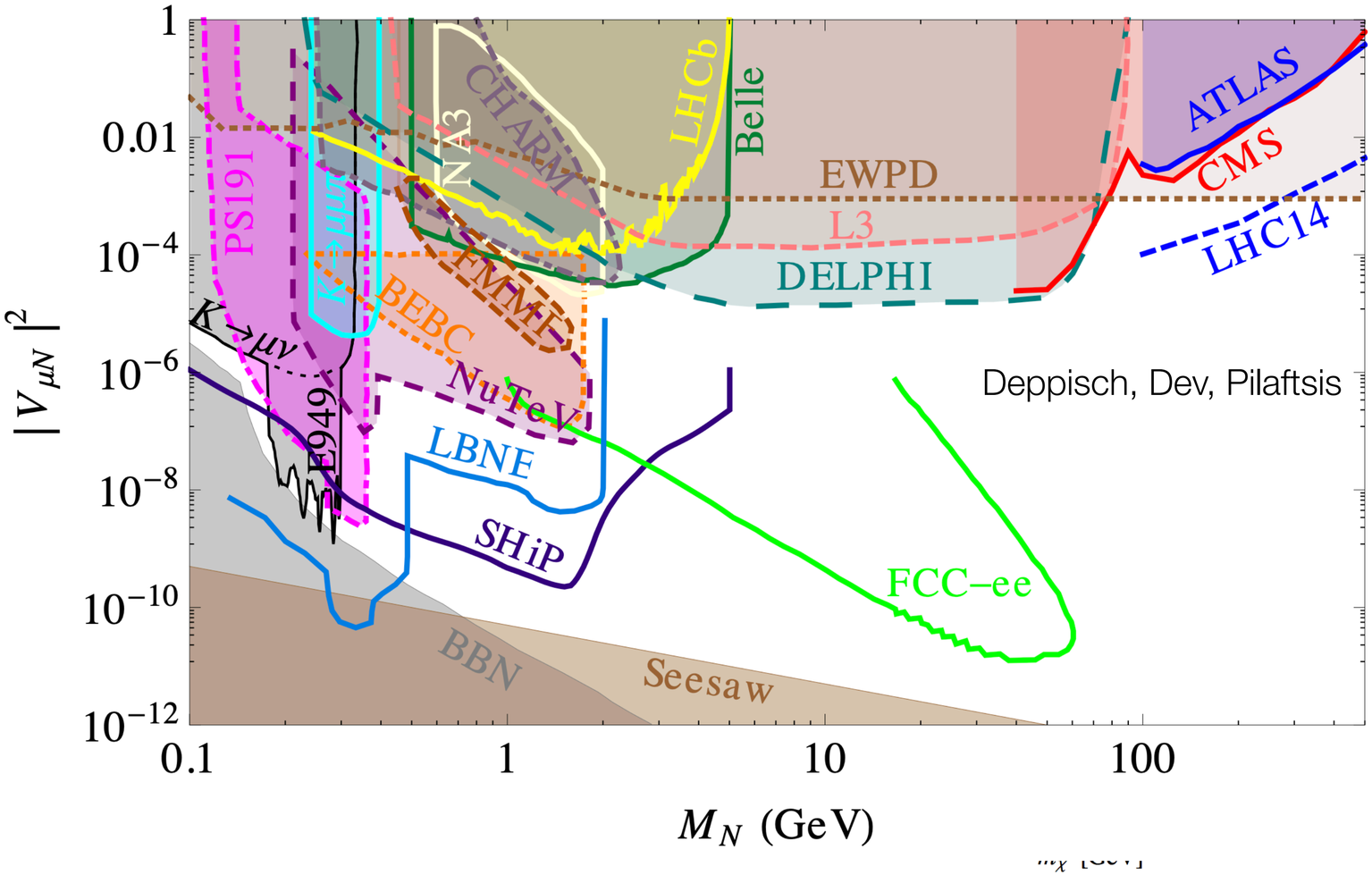
Case 1: Annihilation to heavy neutrinos



⇒ Indirect De-

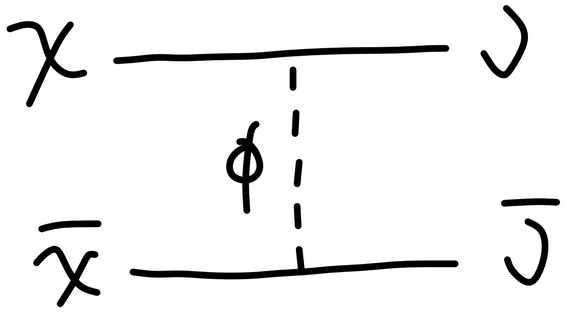
$\sigma v \propto (1-v^2)^4, 1$





Batell, Han, & Shams Es Haghi 1704.08708 other work by Krnjaic et al., Escudero et al., Blennow et al.

Case 2: Annihilation to light neutrinos



$\sigma v \propto U^4$

To avoid overclosing universe, need U to be not tiny & also do not want to pull up m_ν — not possible in minimal seesaw $U = \sqrt{m_\nu / M}$.

Can this be realized?

A Simple* Setup

Bertoni, Ipek, DM, & Nelson
Batell, Han, DM & Shams Es Haghi

$$\mathcal{L} \supset -\lambda_i \bar{N}_R H L_i - y\, \bar{X} \phi N + M \bar{N}_R N_L + \text{h.c.}$$

$$-\bar{N}_R (\lambda_i v \nu_i + M N_L), \qquad (M \nu_i - \lambda_i v N_L)$$

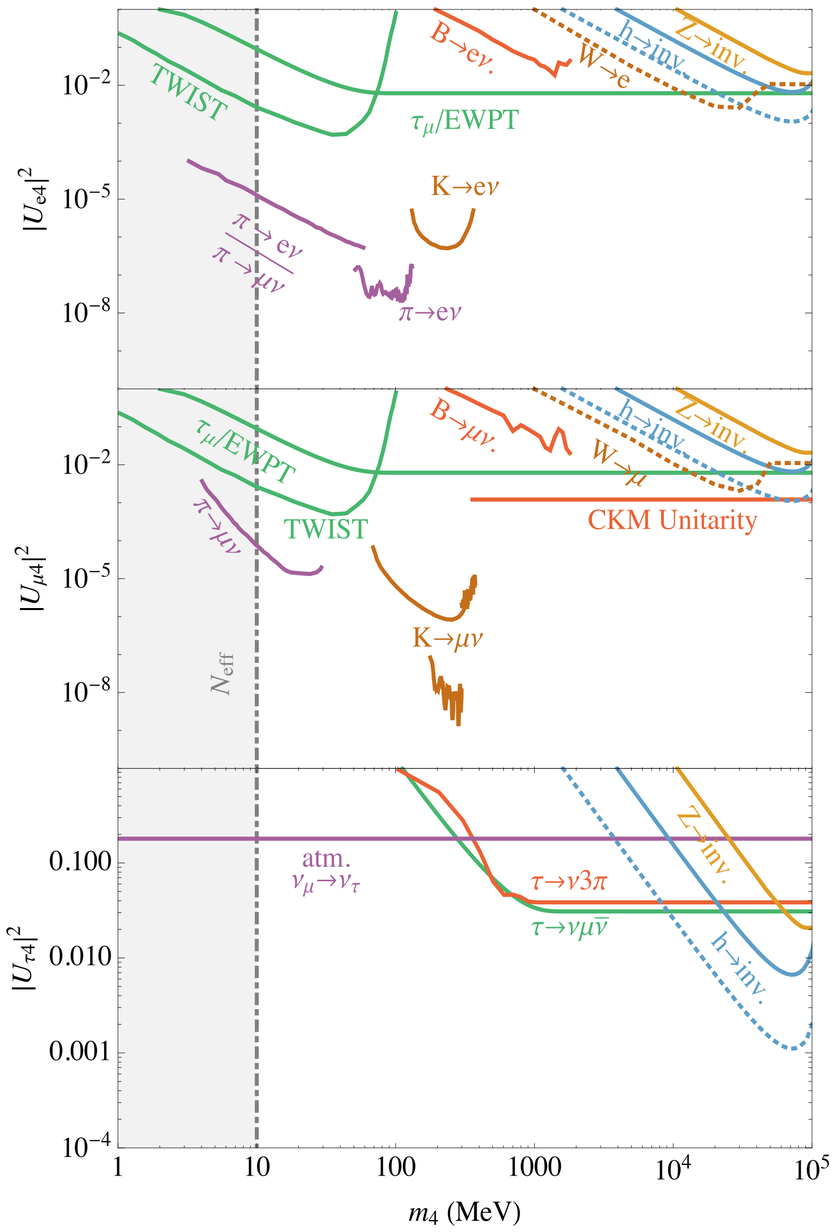
massless

Dirac Pair

$$\Rightarrow U \simeq \frac{\lambda v}{M} \neq \sqrt{\frac{m_\nu}{M}}$$

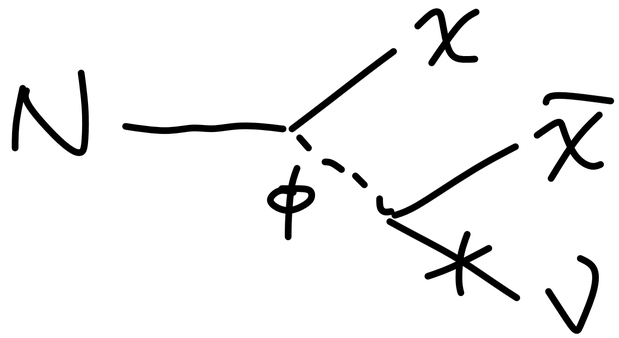
Mixing angle and m_ν decoupled. (Other physics generates m_ν)

What are the consequences?



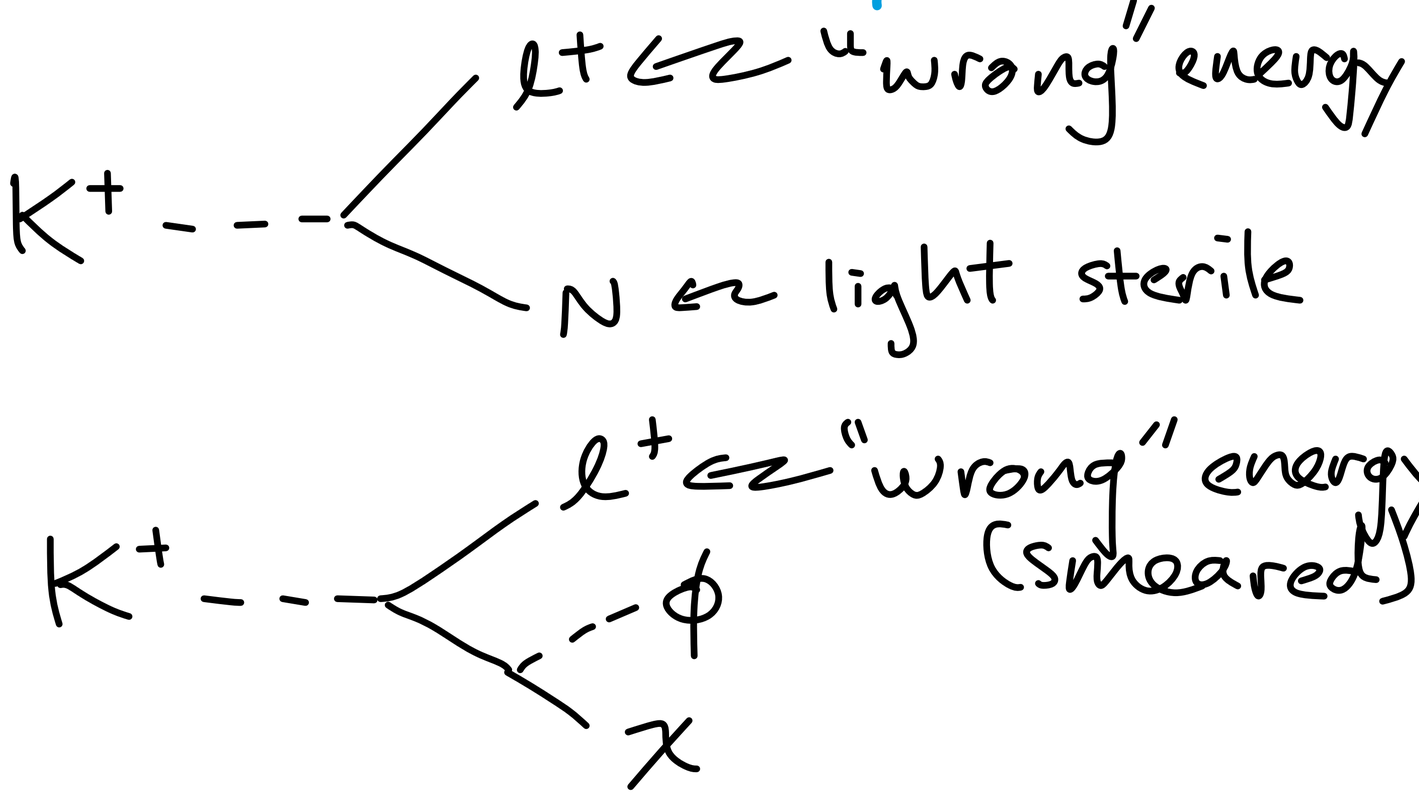
How large can mixing angle be?

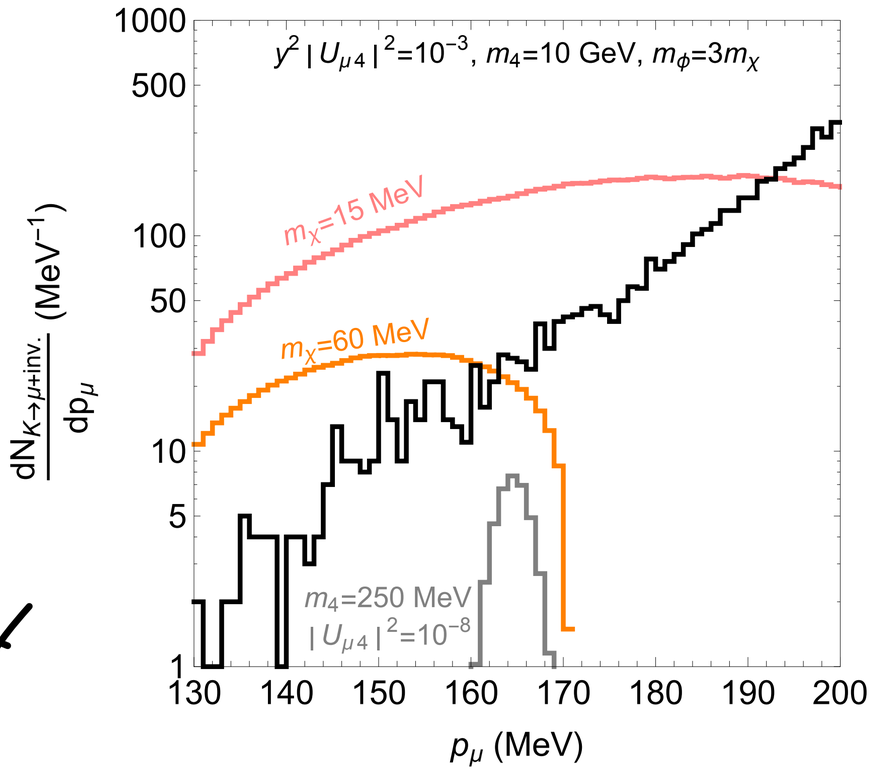
Note: N decays invisibly



Missing energy, funny kinematics

Meson Decays





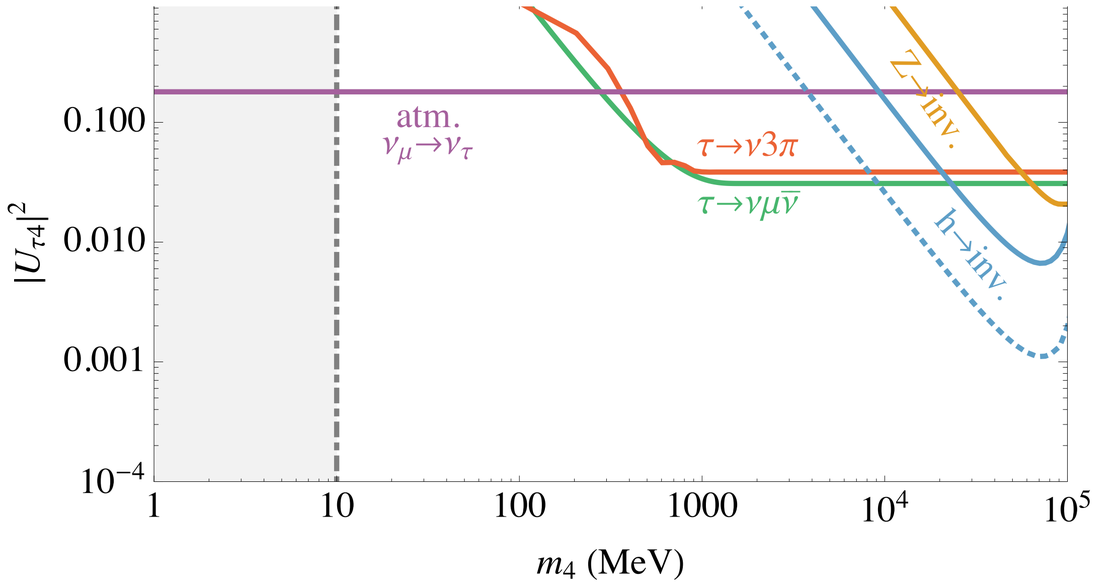
E949 : 10^{12} K

NA62 : 10^{13} K

(PIENU, ...)

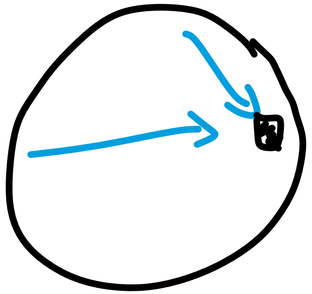
=> Can probe unexplored parameter space

Large ν_τ Mixing

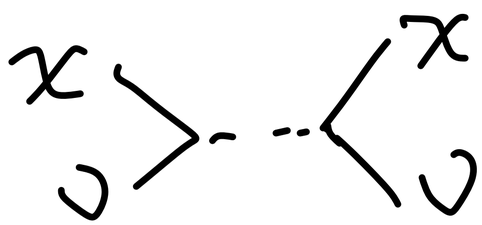


$\sqrt{1-U^2}\,\nu_\tau + U N$

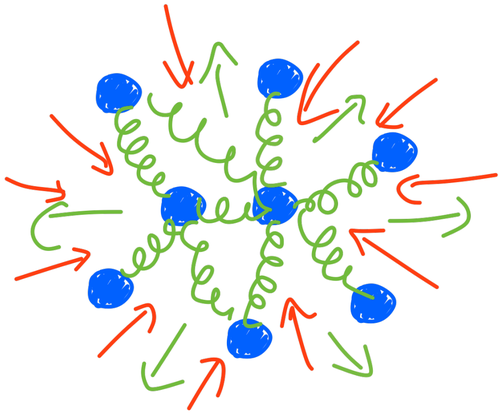
sees diff. matter potential than ν_μ



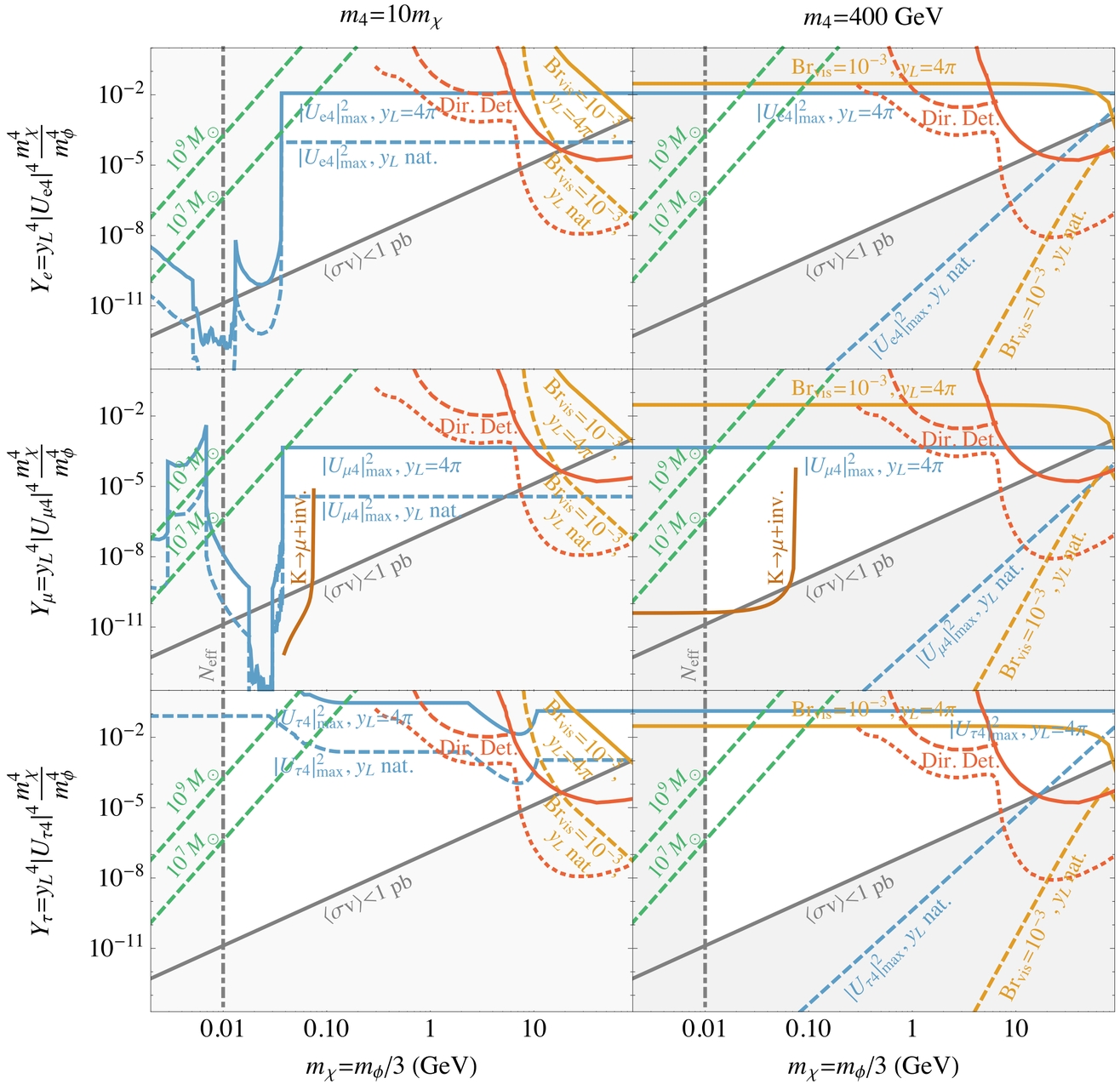
Can affect structure formation



=> Suppress small scales if $m_{x,\phi}$ $\mathcal{O}$(10-100 MeV)



Gravity vs. Pressure



Summary Plot

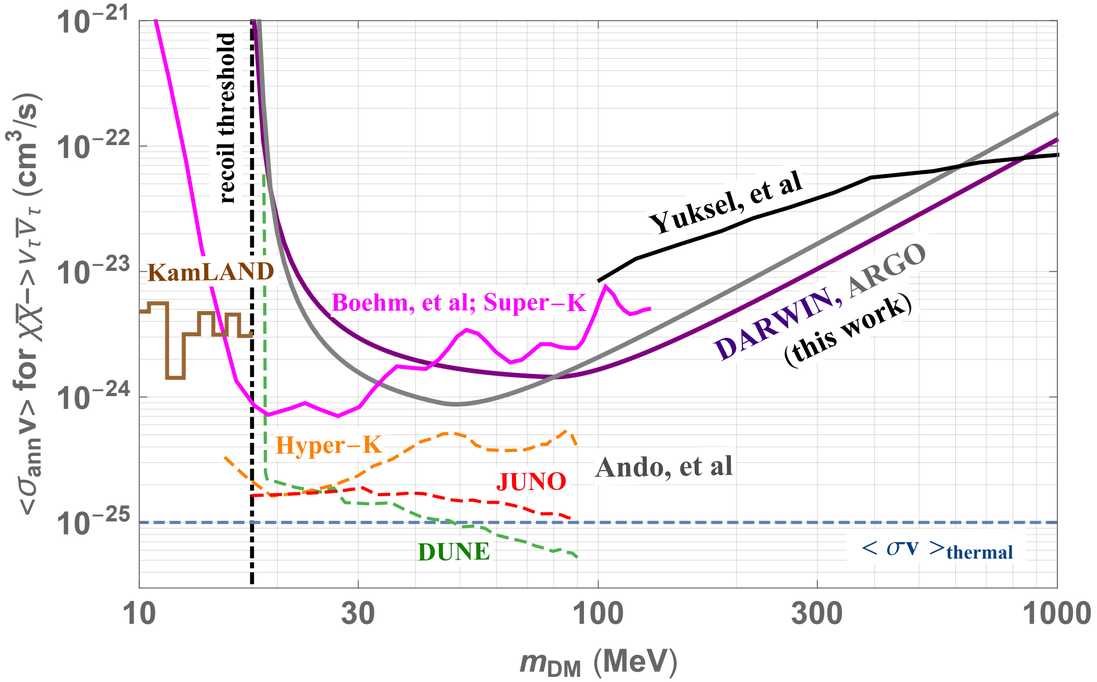
cf. Berlin's talk

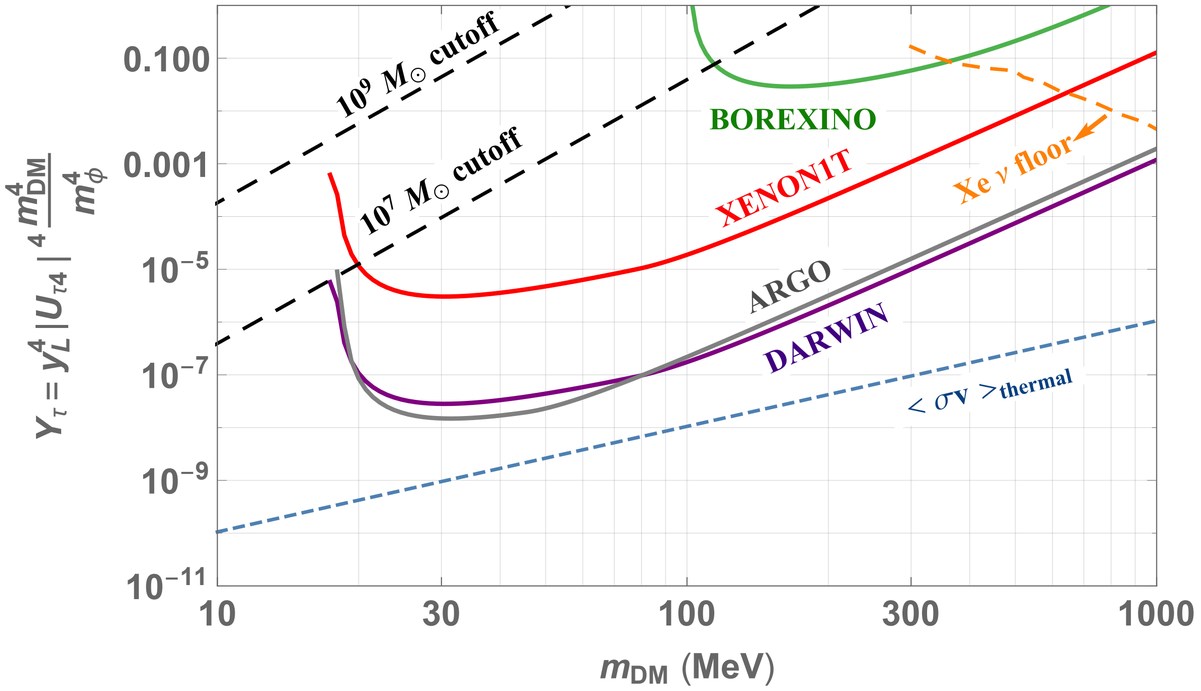
↑

$\langle\sigma v\rangle$ ← constrain annihilation

With some assumptions about dark sector params, sterile mass

Indirect Detection in Case 2





See also Cherry & Shoemaker, Boehm et al., Beacom et al.

Work w/ N. Raj

Wrap Up

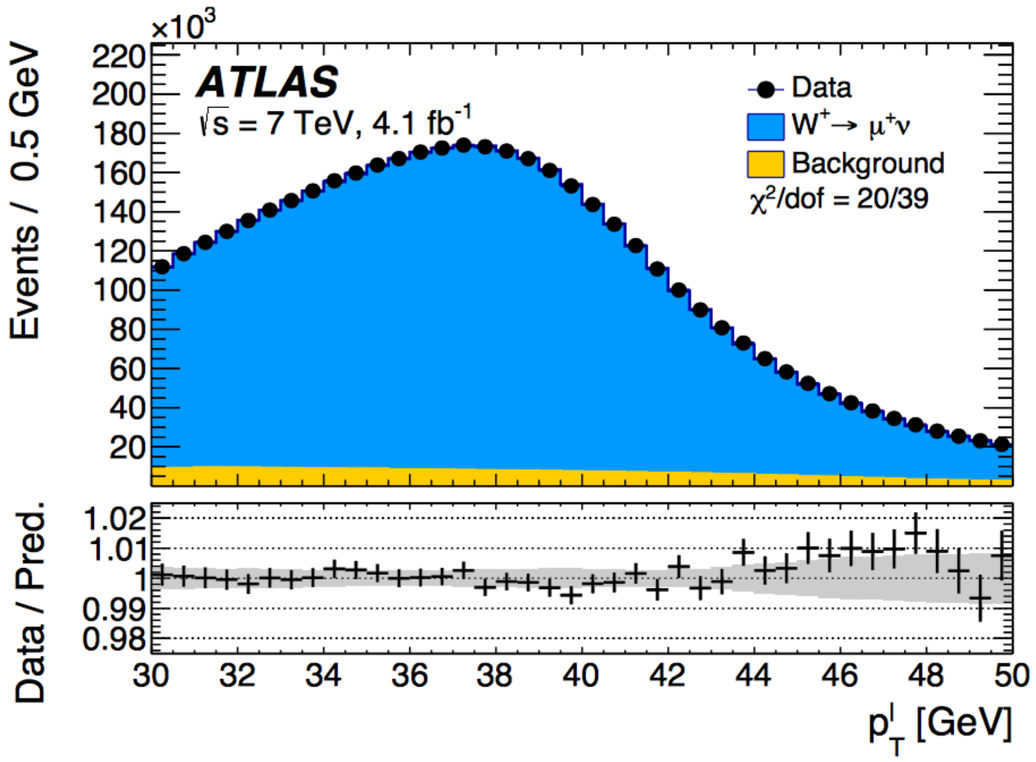
Neutrino portal well motivated

Can serve as a way for DM to interact with SM

"Secluded" scenario very easy to implement — annihilation to light ν's requires more work

Lots of implications, more study needed!

Backup



Can look at Funny kinematics in W± decays

Challenging...

↕ ~ μ^2

Supernova neutrinos
Interesting if $m_{\chi,\phi} \sim$ 10s MeV