Astrophysical signatures of Axino dark matter

Seng Pei Liew (U. of Tokyo)

(based on...)

Phys. Lett. B 721 (2013) , pp. 111;
arXiv: 1301.7536
JCAP 1405 (2014) 044;
arXiv: 1403.6621

SUSY 2014, Manchester

Axion as a solution of the Strong CP problem

$$L = \theta \frac{1}{16\pi^2} F^a_{\mu\nu} \tilde{F}^{a\mu\nu}$$ from non-perturbative effects

but $\theta \ll 10^{-9}$ from experiments (fine-tuning problem)

Introduce a new field a such that $$L = \frac{a}{16\pi^2 f_a} F^a_{\mu\nu} \tilde{F}^{a\mu\nu}$$

at the minimum of the potential, $\langle a \rangle = -f_a \theta$

$$L = \frac{a}{16\pi^2 f_a} F^a_{\mu\nu} \tilde{F}^{a\mu\nu}$$

for U(1) and SU(2) gauge couplings

supersymmetrize

$$\mathcal{L}_{\tilde{a}\lambda A} = i\frac{\alpha_Y C_Y}{16\pi f_a}\bar{\tilde{a}}\gamma_5[\gamma^\mu,\gamma^\nu]\tilde{B}B_{\mu\nu} + i\frac{\alpha_W C_W}{16\pi f_a}\bar{\tilde{a}}\gamma_5[\gamma^\mu,\gamma^\nu]\tilde{W}^a W^a_{\mu\nu}$$

axino

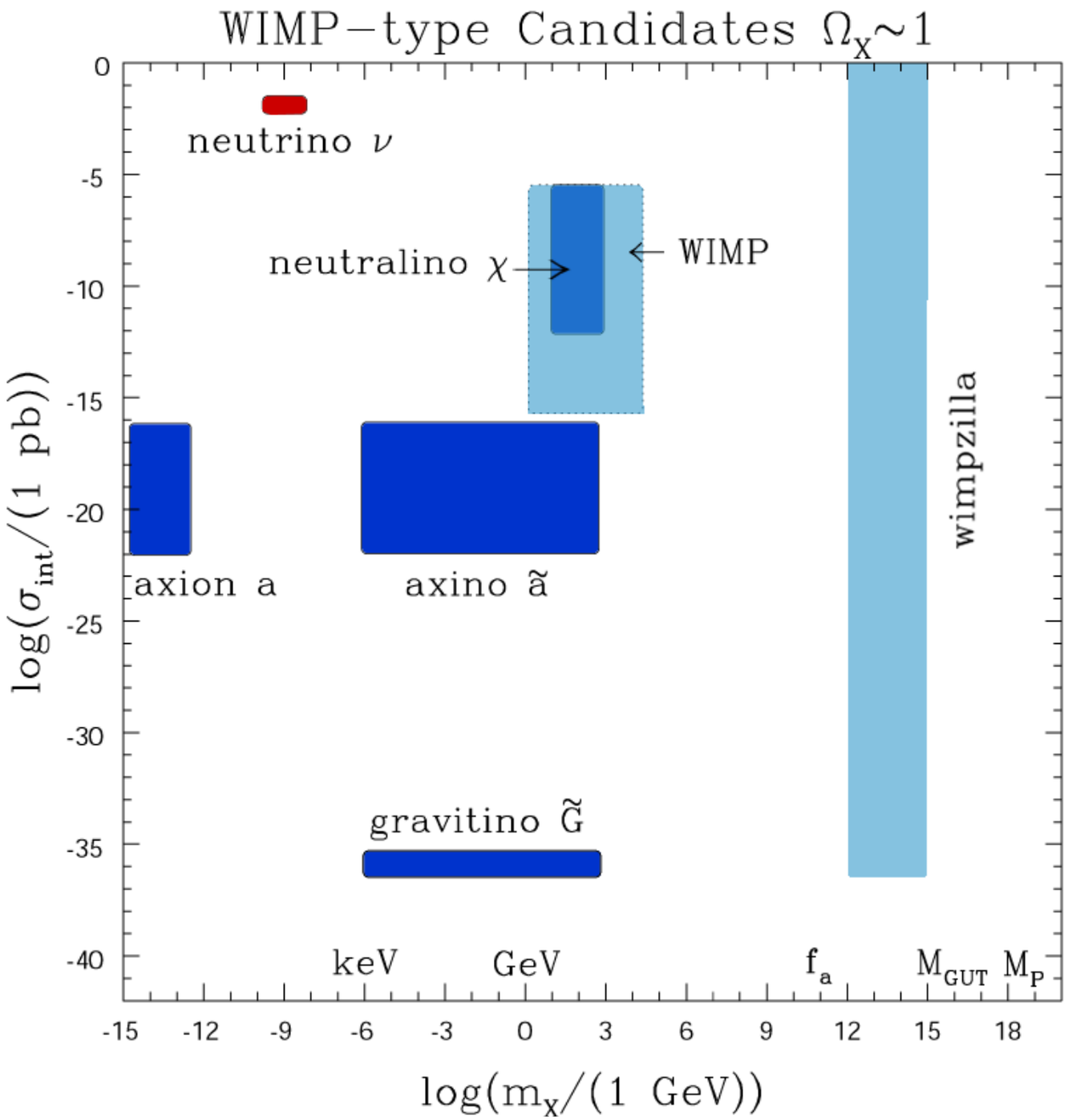
bino

wino

appears in both KSVZ and DFSZ models

Axino can be a DM candidate (mass: keV~TeV)

[hep-ph/0404052]



130 GeV γ-line

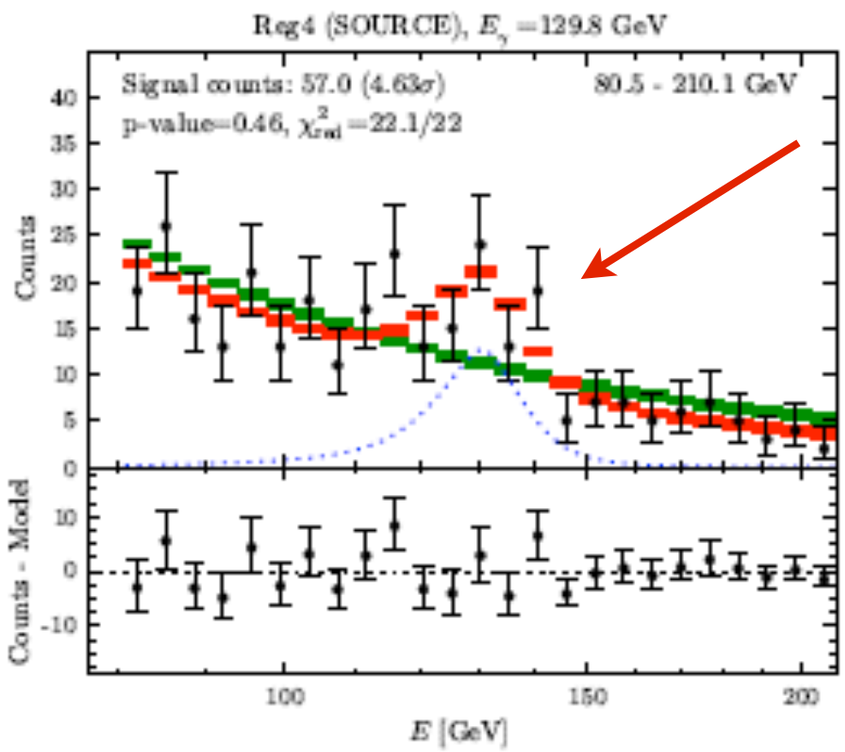
Studies on γ-rays from the Fermi data

T. Bringmann, X. Huang, A. Ibarra, S. Vogl, C. Weniger [arXiv:1203.1312]
C. Weniger [arXiv:1204.2797]
E. Tempel, A. Hektor and M. Raidal [arXiv:1205.1045]

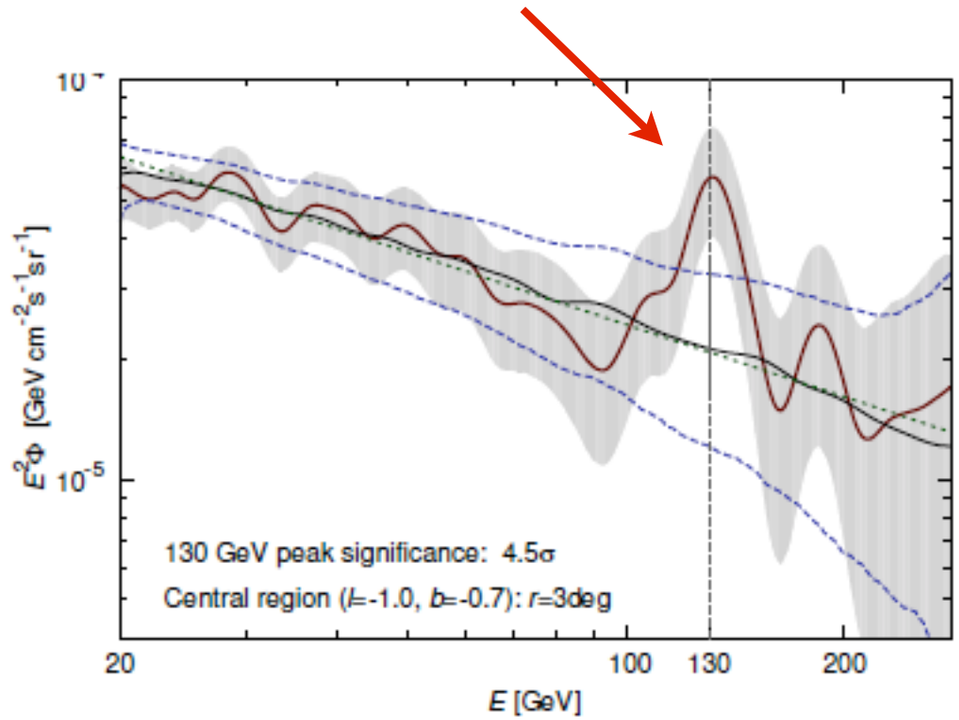
and many more...

See T. Bringmann, C. Weniger [arXiv:1208.5481] **for a review**

From the Galactic Center, they found

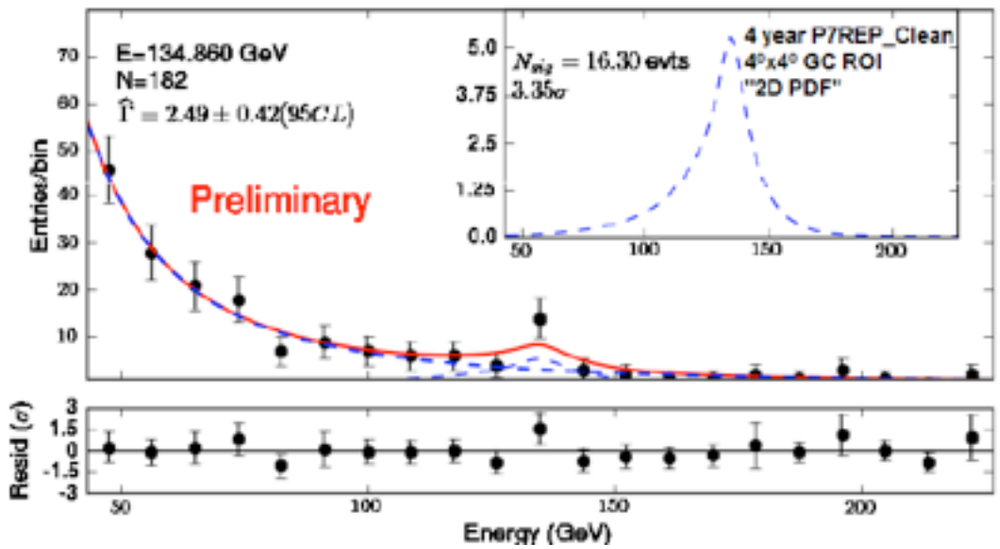


C. Weniger [arXiv:1204.2797]



E. Tempel, A. Hektor and M. Raidal [arXiv:1205.1045]

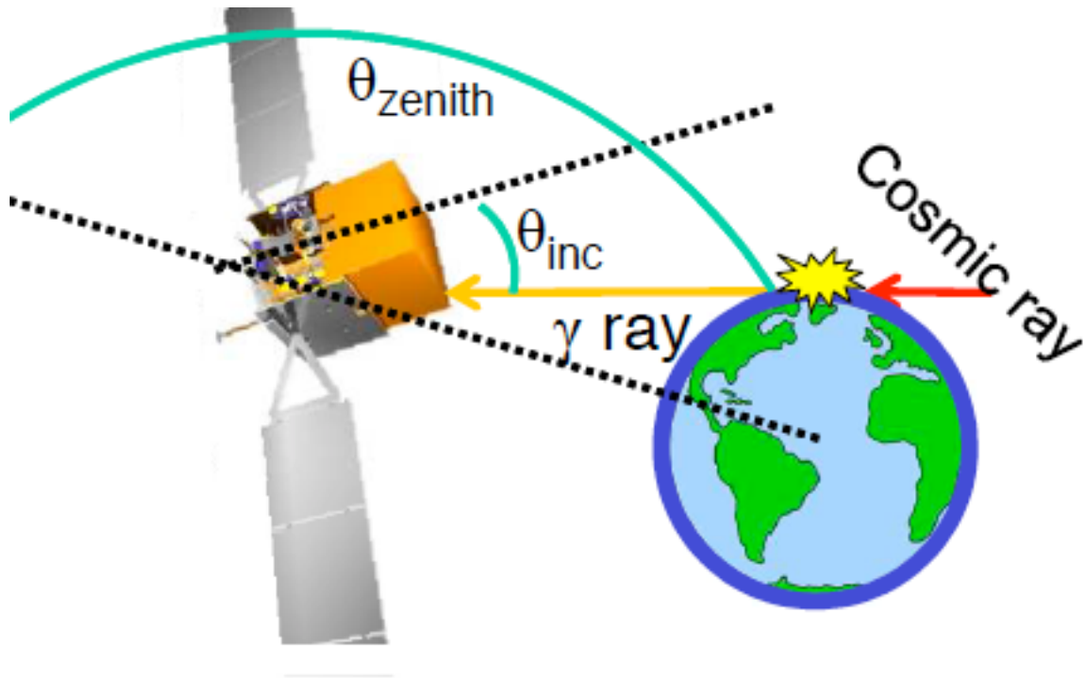
A DM signal?



- Less significant feature from the Fermi Collaboration
- γ-lines from the Earth limb?
- Instrumental?

Still inclonclusive...

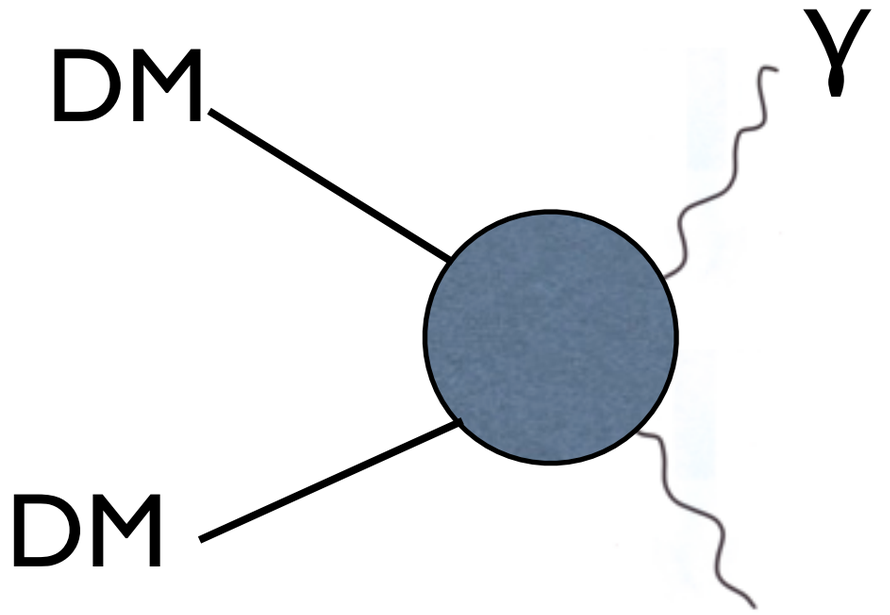
Summary & Updates:
C. Weniger [arXiv:1303.1798]



From A. Albert's talk, the Fermi Symposium Nov. 2012

Neutralino

- Annihilating DM

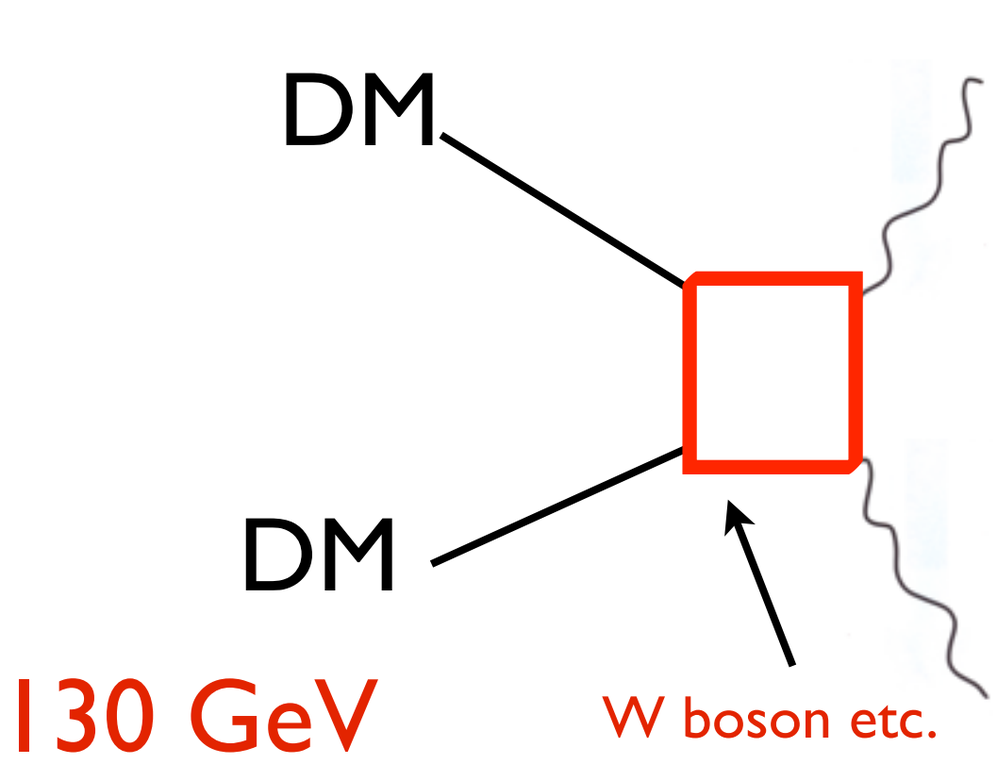


130 GeV

$$\langle \sigma v \rangle_{\chi\chi \to \gamma\gamma} \simeq 10^{-27} \mathrm{cm}^3 \mathrm{s}^{-1}$$

Neutralino

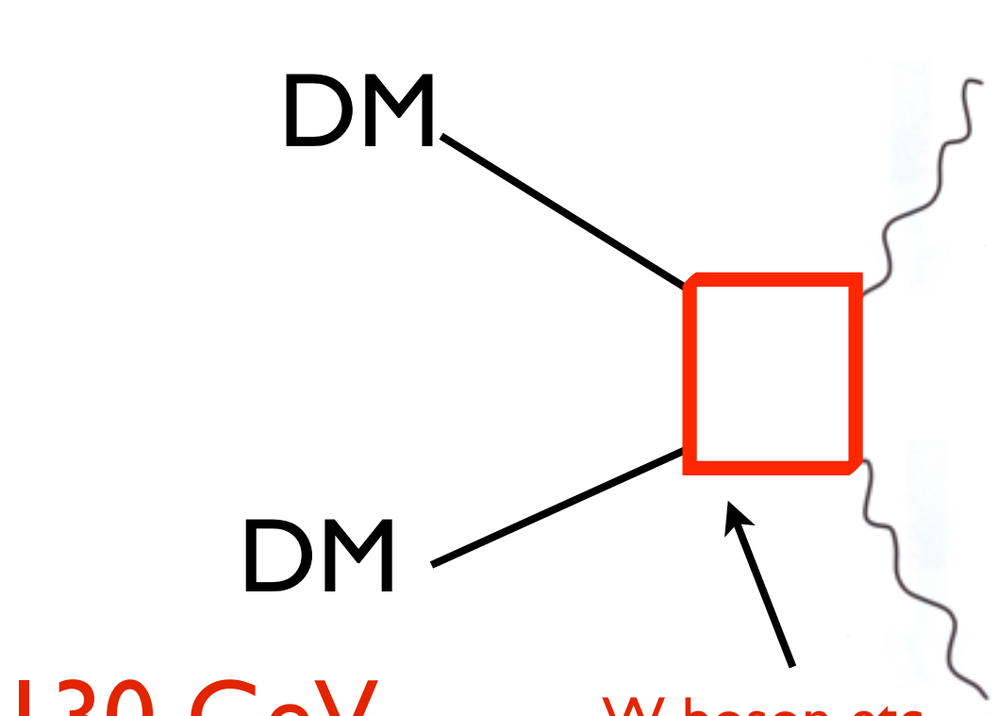
- γ from loop effects



Neutralino

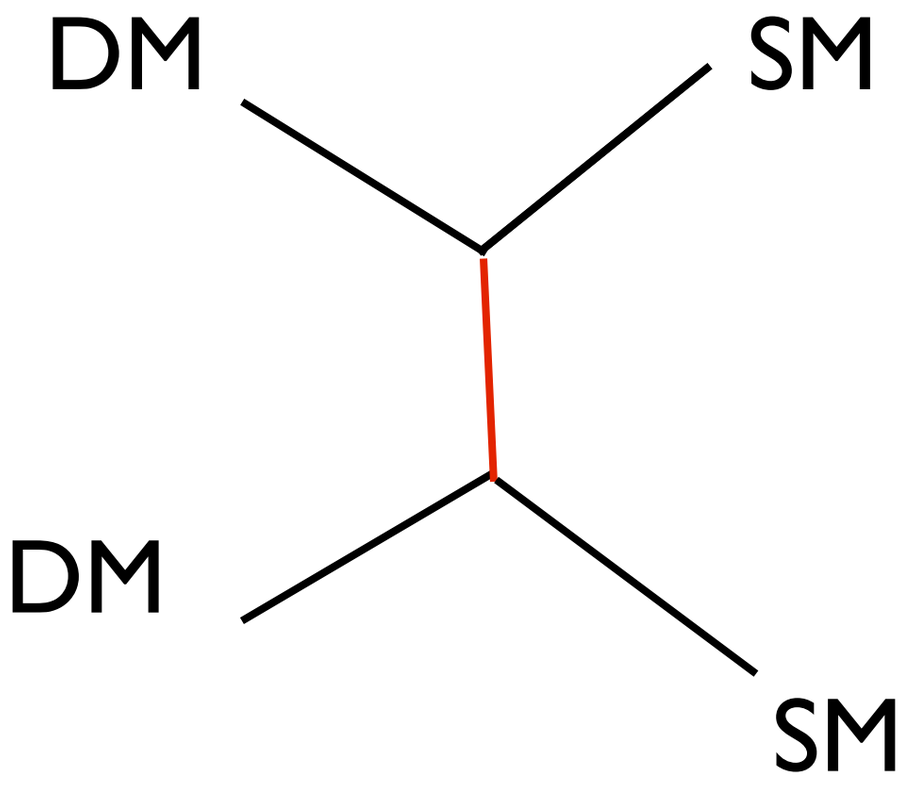
- γ from loop effects

Typically...



130 GeV

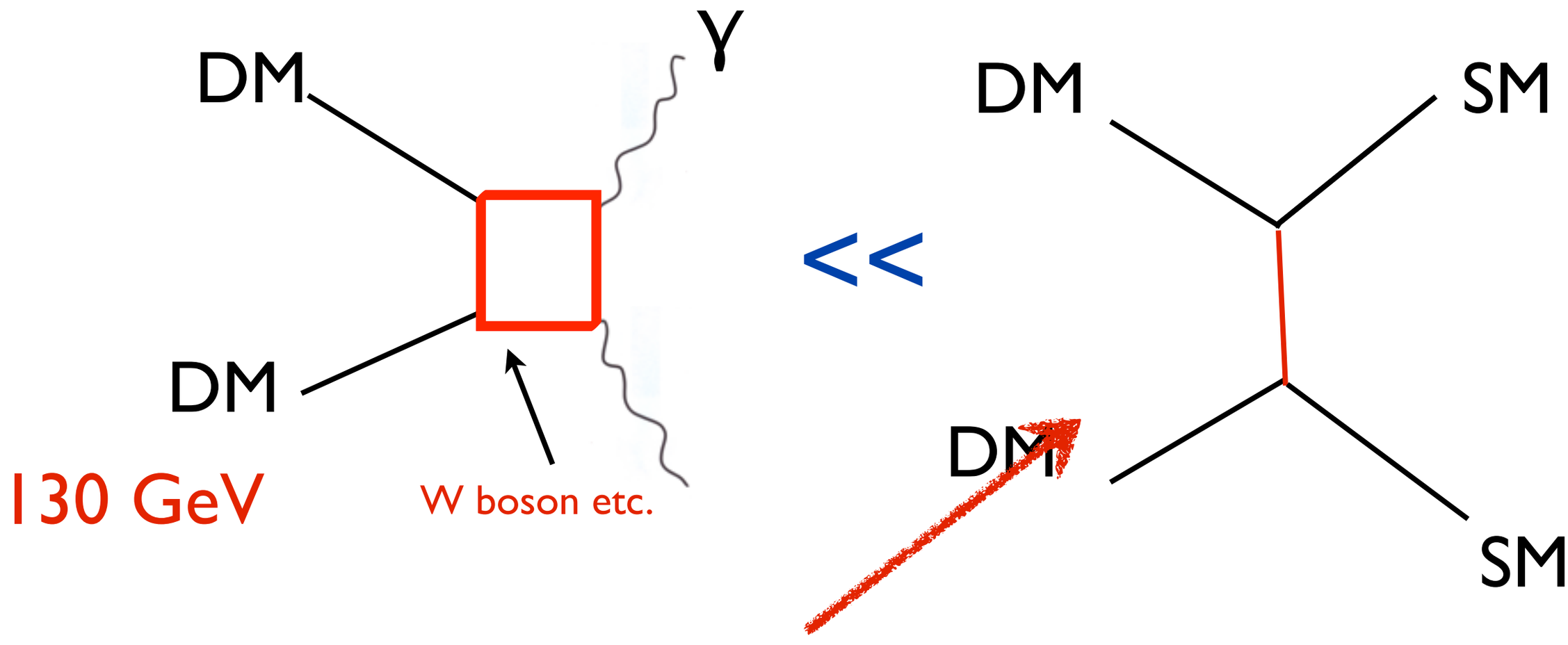
<<



Neutralino

- γ from loop effects

Typically...



Too much continuum γ & antiprotons!

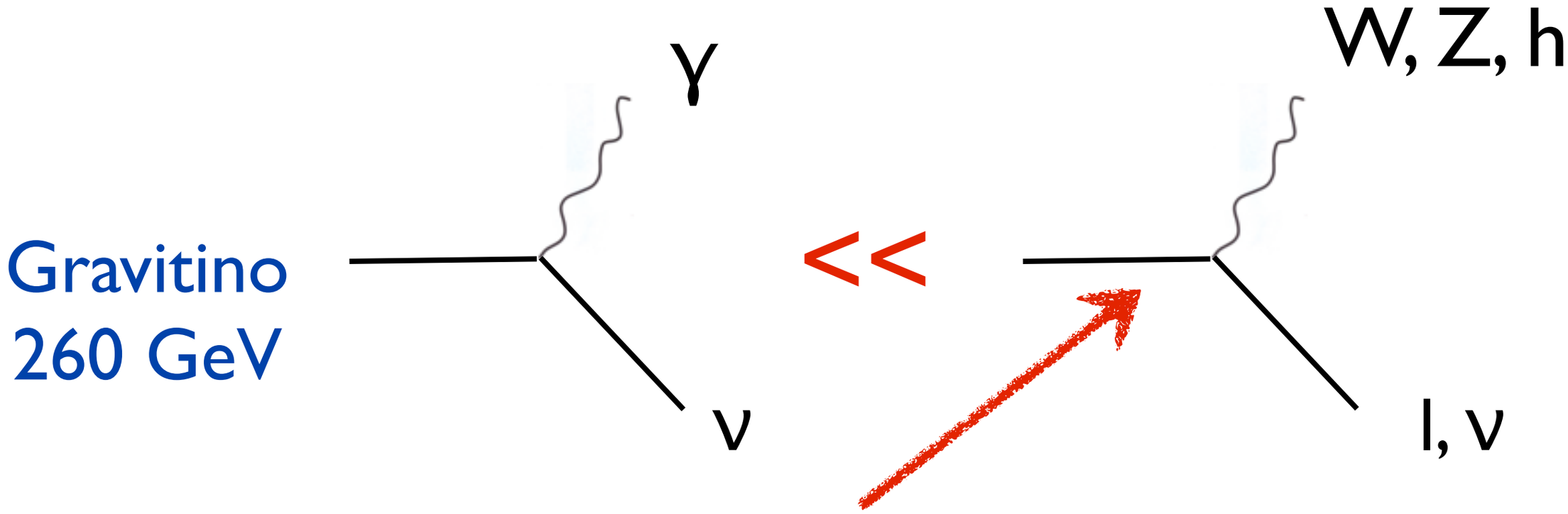
Gravitino

F. Takayama, M. Yamaguchi [hep-ph/0005214]

Decaying DM

- Small bilinear R-parity violation
- Long lifetime Lifetime ~ 10^{28} sec

W. Buchmuller, M. Garny [arXiv:1206.7056]



Too much continuum γ & antiprotons!

Axino

- Small bilinear R-parity violation
- Long lifetime

→ Decaying DM

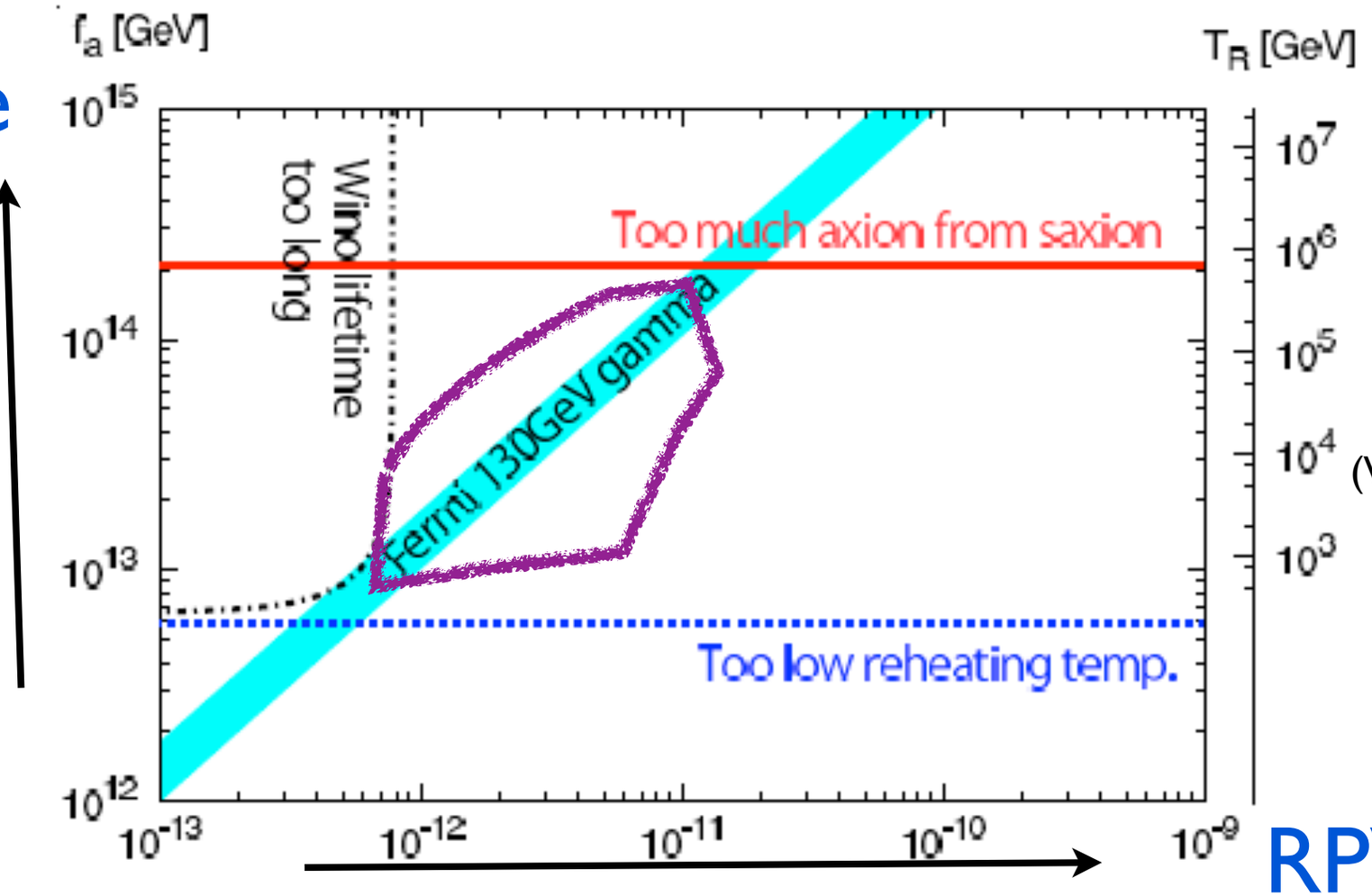
$$\mathcal{L} = i\frac{\alpha_Y C_Y}{16\pi f_a}\bar{\tilde{a}}\gamma_5[\gamma^\mu,\gamma^\nu]\tilde{B}B_{\mu\nu} + i\frac{\alpha_W C_W}{16\pi f_a}\bar{\tilde{a}}\gamma_5[\gamma^\mu,\gamma^\nu]\tilde{W}^a W^a_{\mu\nu}$$

Branching ratio large enough to explain the 130-GeV γ-line!

Results

M. Endo, K. Hamaguchi, SPL, K. Mukaida, K. Nakayama [arXiv:1301.7536]

PQ Scale



(Wino NLSP, similar for Bino NLSP)

RPV parameter

From Ruchayskiy's talk

Unidentified spectral line at $E \sim 3.5$ keV

Boyarsky et al. 2014 [1402.4119]	
M31 galaxy	XMM-Newton, center & outskirts
Perseus cluster	XMM-Newton, outskirts only
Blank sky	XMM-Newton

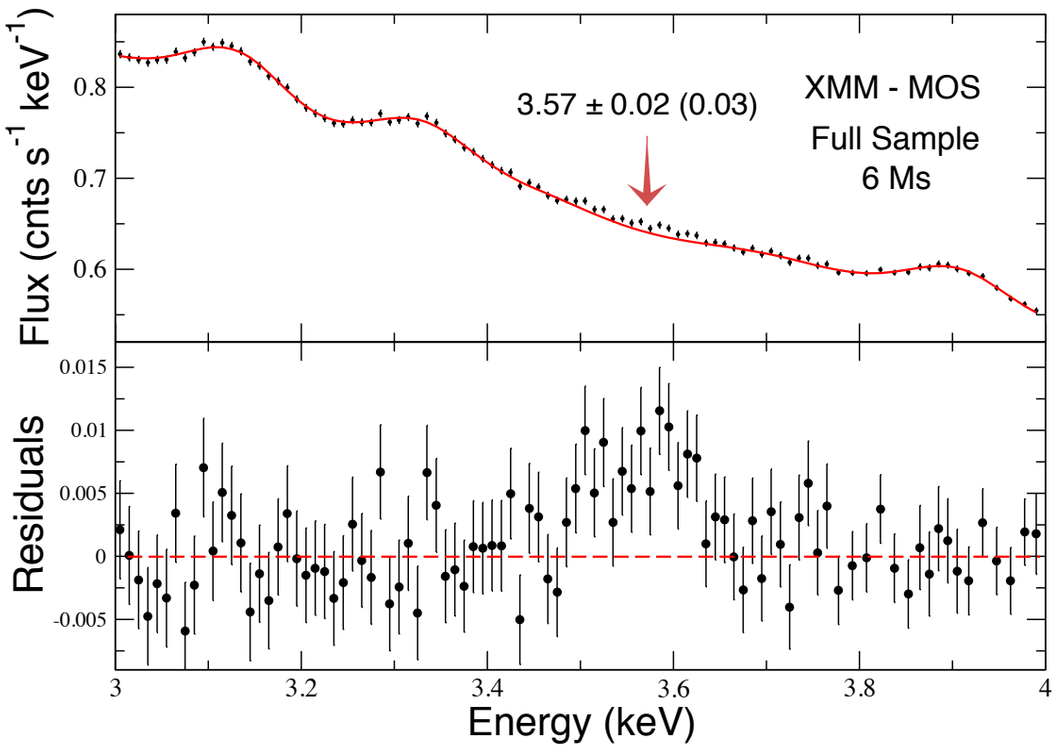
Bulbul et al. 2014 [1402.2301]	
73 clusters	XMM-Newton, central regions of clusters only. Up to $z = 0.35$, including Coma, Perseus
Perseus cluster	Chandra, center only
Virgo cluster	Chandra, center only

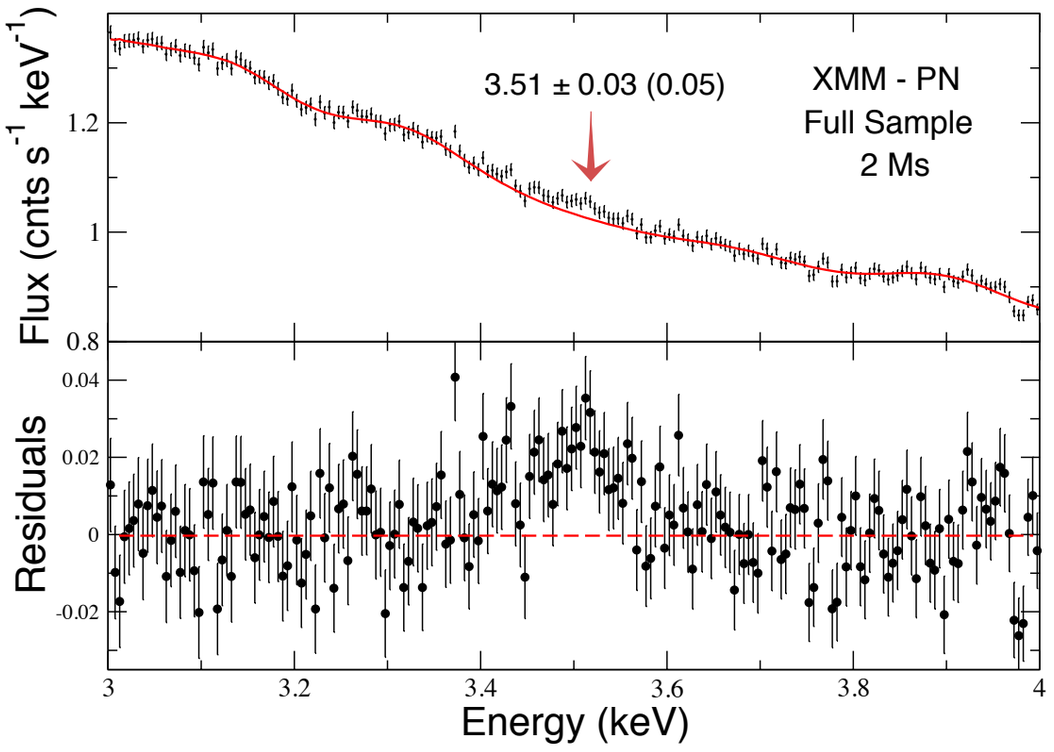
Position: 3.5 keV. Statistical error for line position $\sim$ 30 eV. Systematics (~ 50 eV – between cameras, determination of known instrumental lines)

Lifetime: $\sim 10^{28}$ sec (uncertainty $\mathcal{O}(10)$)

Stacked X-ray spectrum

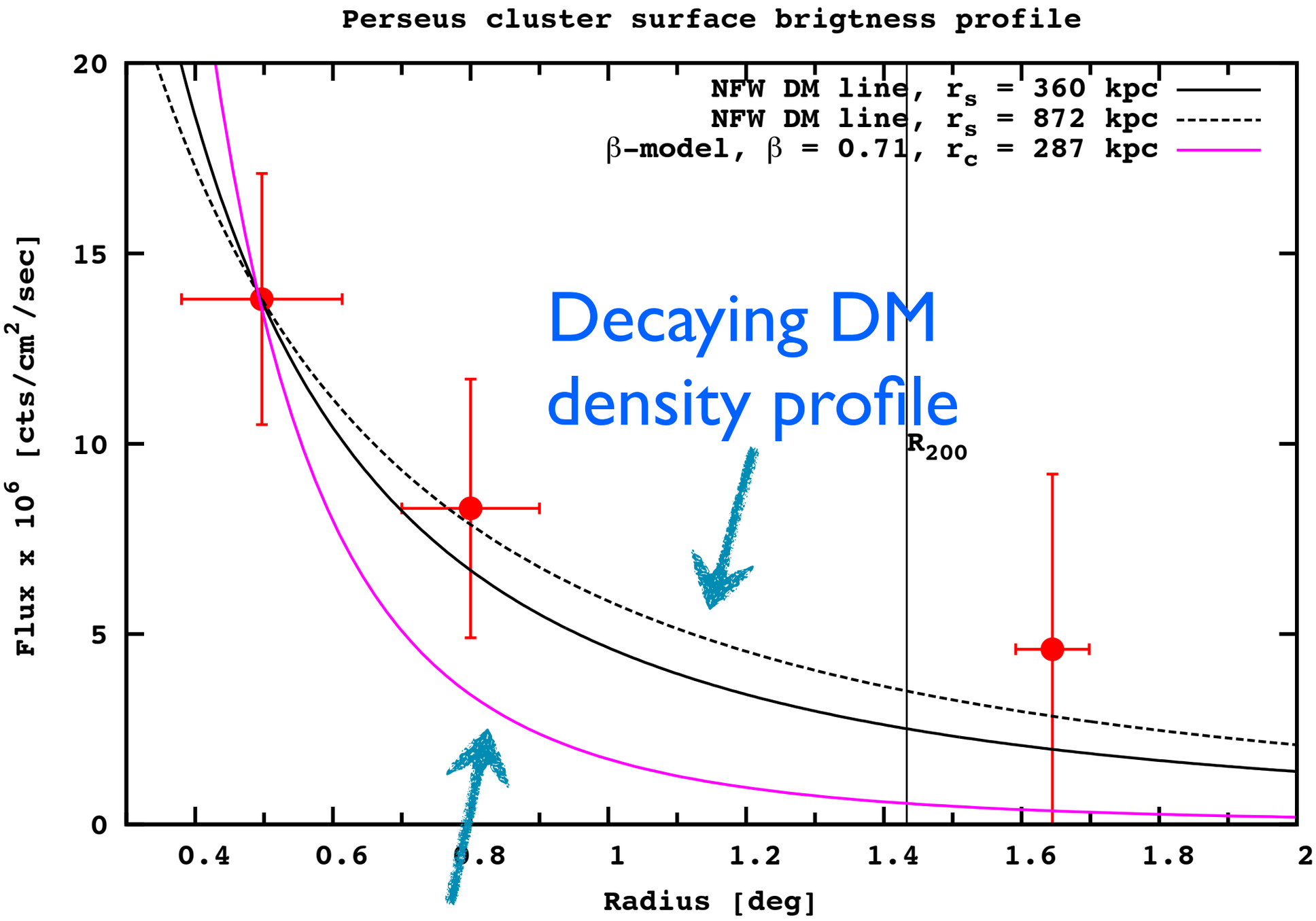
[1402.2301]





All spectra are blue-shifted to the same frame of reference and backgrounds are similarly subtracted

Surface brightness profile



Decaying DM density profile

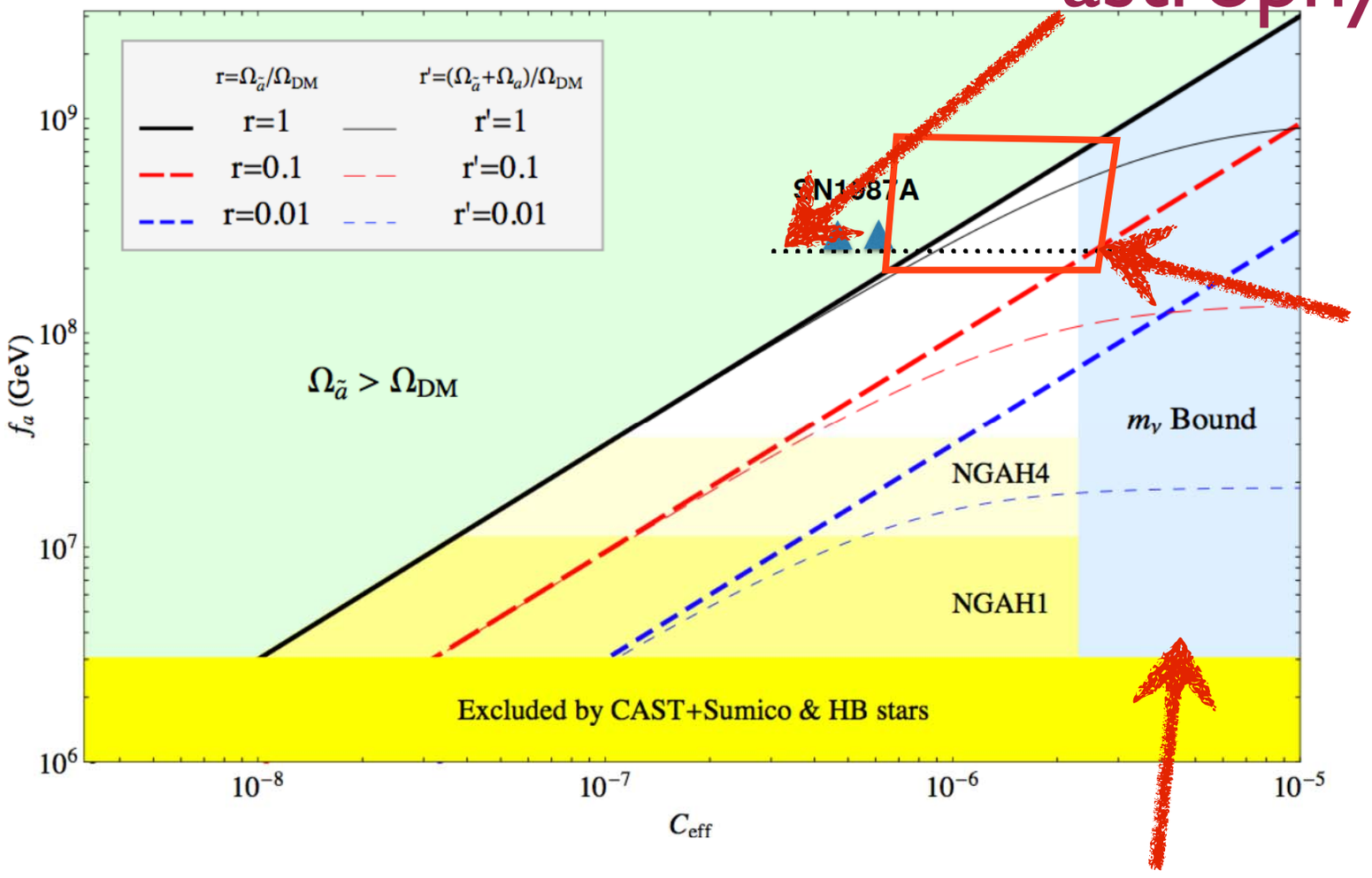
isothermal beta profile (gas distribution)

Axino (~ 7 keV)

- bilinear R-parity violation

[1403.1536]

astrophysical bound

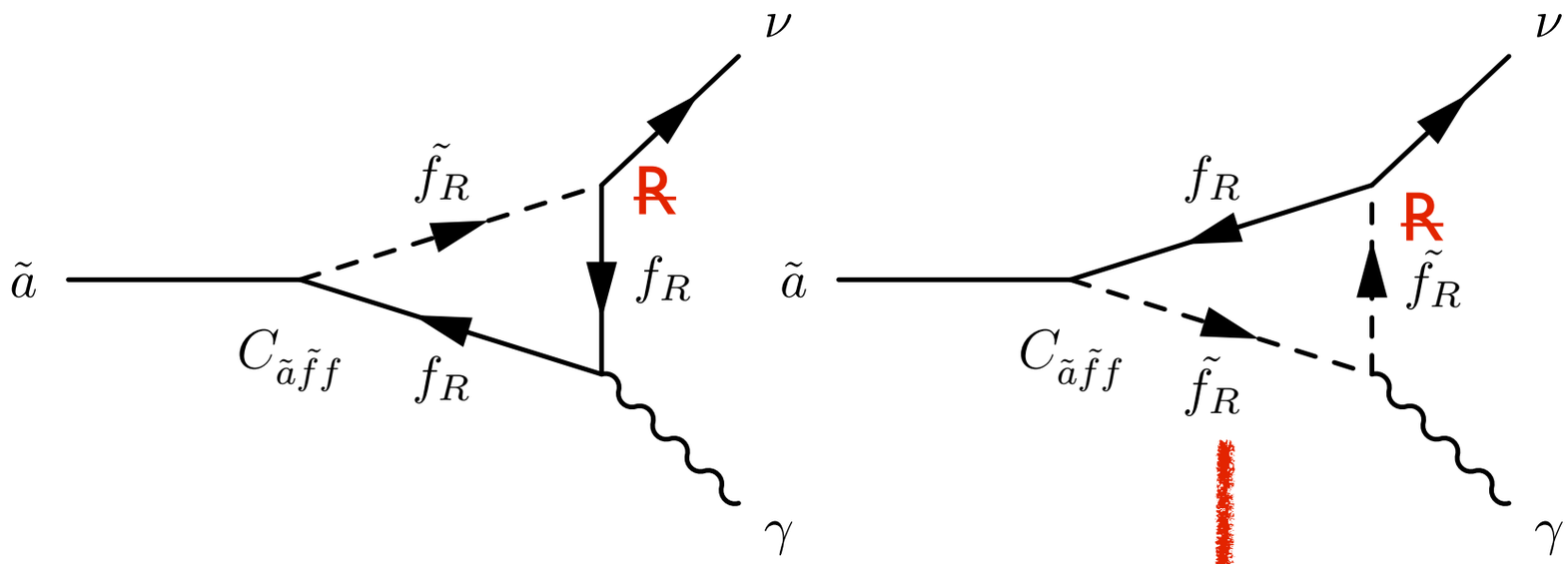


parameter space

constraint due to tree-level contribution to neutrino mass

Axino (~ 7 keV)

- trilinear R-parity violation [1403.6621]



$$\tau_{\tilde{a}} \simeq 8.7 \times 10^{27}\ \mathrm{sec} \left(\frac{\lambda_{i33}\hat{g}}{10^{-4}}\right)^{-2} \left(\frac{m_{\tilde{a}}}{7\ \mathrm{keV}}\right)^{-3} \left(\frac{f_a/v}{10^8}\right)^{2} \left(\frac{m_{\tilde{\tau}_R}}{100\ \mathrm{GeV}}\right)^{4} \left(\frac{m_\tau}{1.77\ \mathrm{GeV}}\right)^{-2}$$

can avoid astrophysical bound

where does $C_{\tilde{a}\tilde{f}f}$ come from and what is $\hat{g}$?

For DFSZ models,
Higgs fields carry non-zero Peccei-Quinn charges

[hep-ph/0607076]

axion superfield — Higgs superfield

$$K_{eff} = \frac{A}{f_a}[x_{H_i} H_i^\dagger H_i]$$

$$\mathcal{L}_{\rm mixing} = x_{H_1}\frac{\mu v_2}{f_a}\,\tilde{a}\tilde{H}_1 + x_{H_2}\frac{\mu v_1}{f_a}\,\tilde{a}\tilde{H}_2 \qquad \left(W_{eff} = \mu H_1 H_2 \right)$$

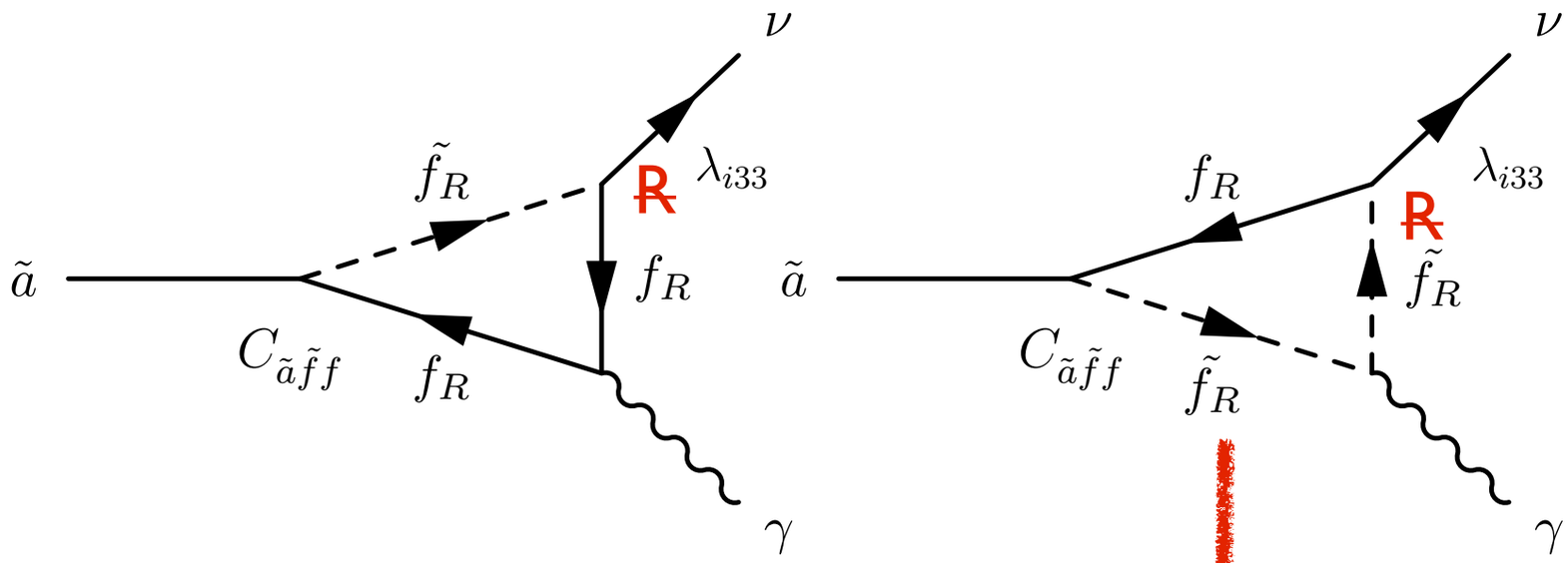
axino-higgsino mixing + higgsino-gaugino mixing

$$\mathcal{L}_{\tilde{a}\tilde{f}f} = C_{\tilde{a}\tilde{f}_L f_L}\tilde{f}_L^*\bar{\tilde{a}}P_L f + C_{\tilde{a}\tilde{f}_R f_R}\tilde{f}_R^*\bar{\tilde{a}}P_R f^c + \text{h.c.}$$

$C_{\tilde{a}\tilde{f}f} \simeq \hat{g}\frac{v}{f_a}$ = gauge coupling x axino-higgsino-gaugino mixing

Axino (~ 7 keV)

- trilinear R-parity violation [1403.6621]



stau

$$\tau_{\tilde{a}} \simeq 8.7 \times 10^{27}\ \text{sec} \left(\frac{\lambda_{i33}\hat{g}}{10^{-4}}\right)^{-2} \left(\frac{m_{\tilde{a}}}{7\ \text{keV}}\right)^{-3} \left(\frac{f_a/v}{10^8}\right)^{2} \left(\frac{m_{\tilde{\tau}_R}}{100\ \text{GeV}}\right)^{4} \left(\frac{m_\tau}{1.77\ \text{GeV}}\right)^{-2}$$

can avoid astrophysical bound

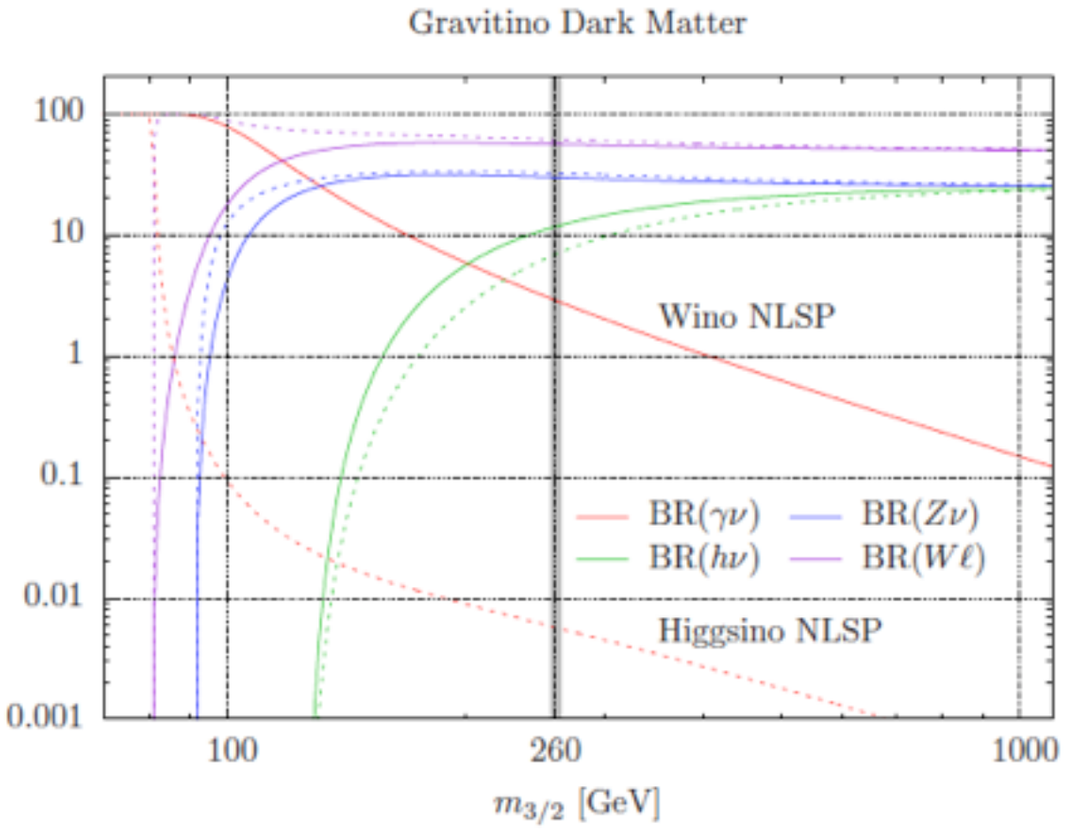
light stau!

Conclusion

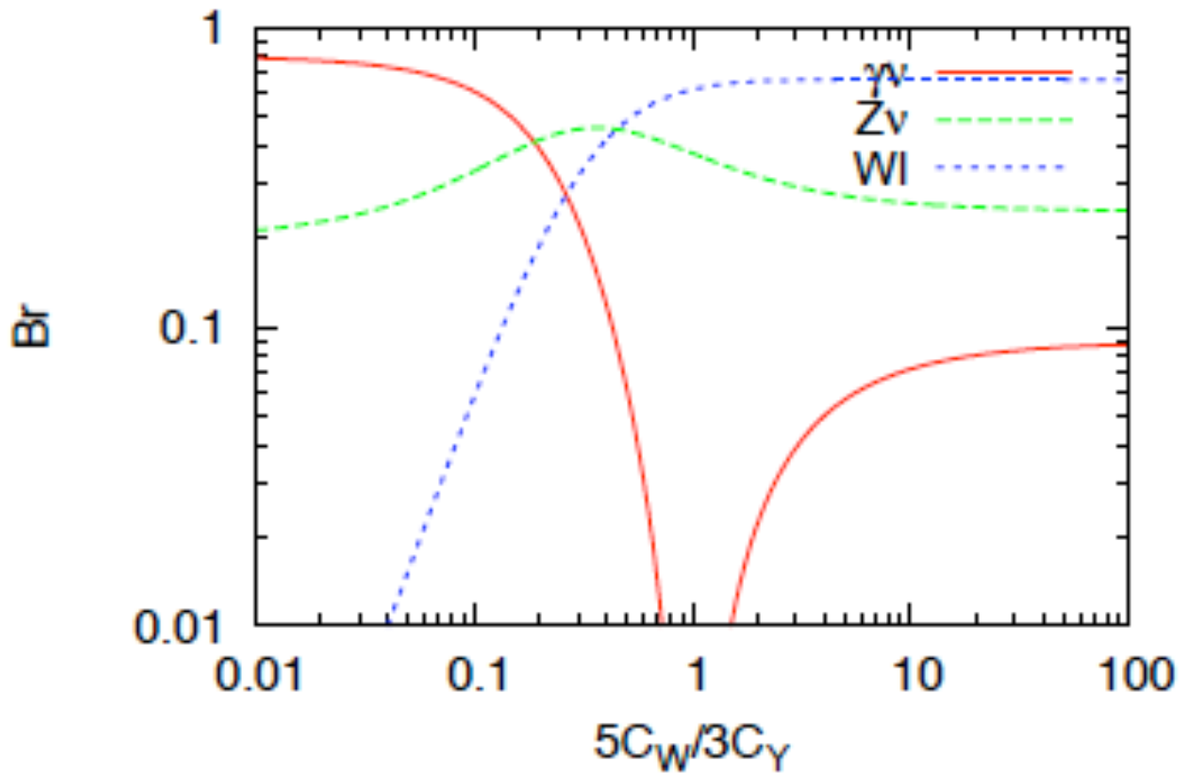
- Axino Dark Matter is interesting!
- With R-parity violation, we could “see” axino DM from via indirect detection.
- Axino DM can explain several recently observed astrophysical anomalies.

Backup

Gravitino vs Axino

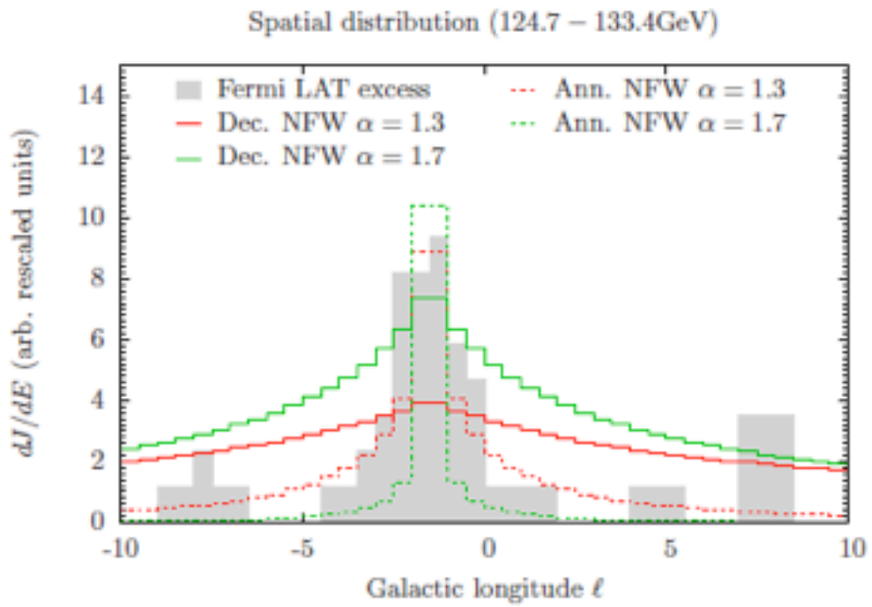


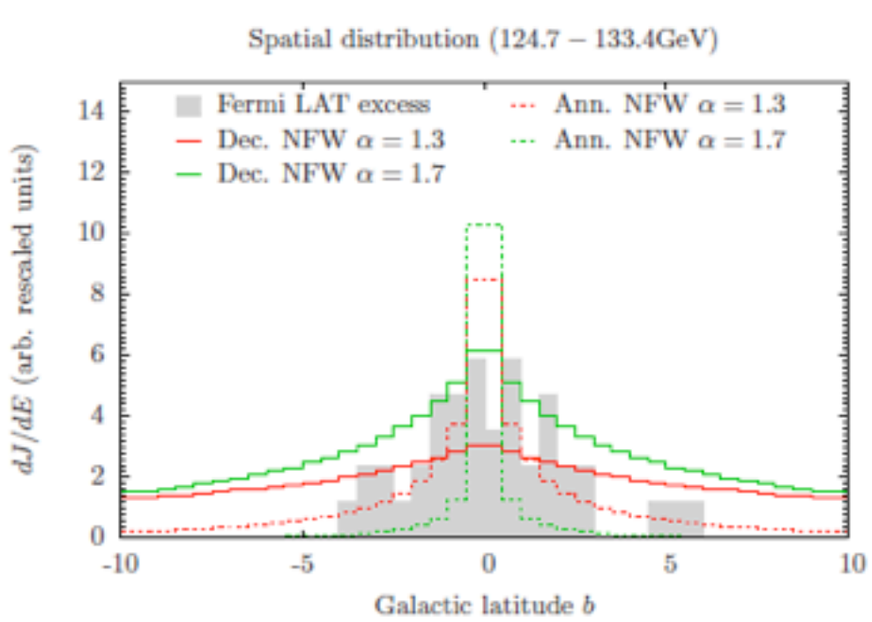
W. Buchmuller, M. Garny [arXiv:1206.7056]



M. Endo, K. Hamaguchi, SPL, K. Mukaida, K. Nakayama [arXiv:1301.7536]

Annihilating DM vs. Decaying DM





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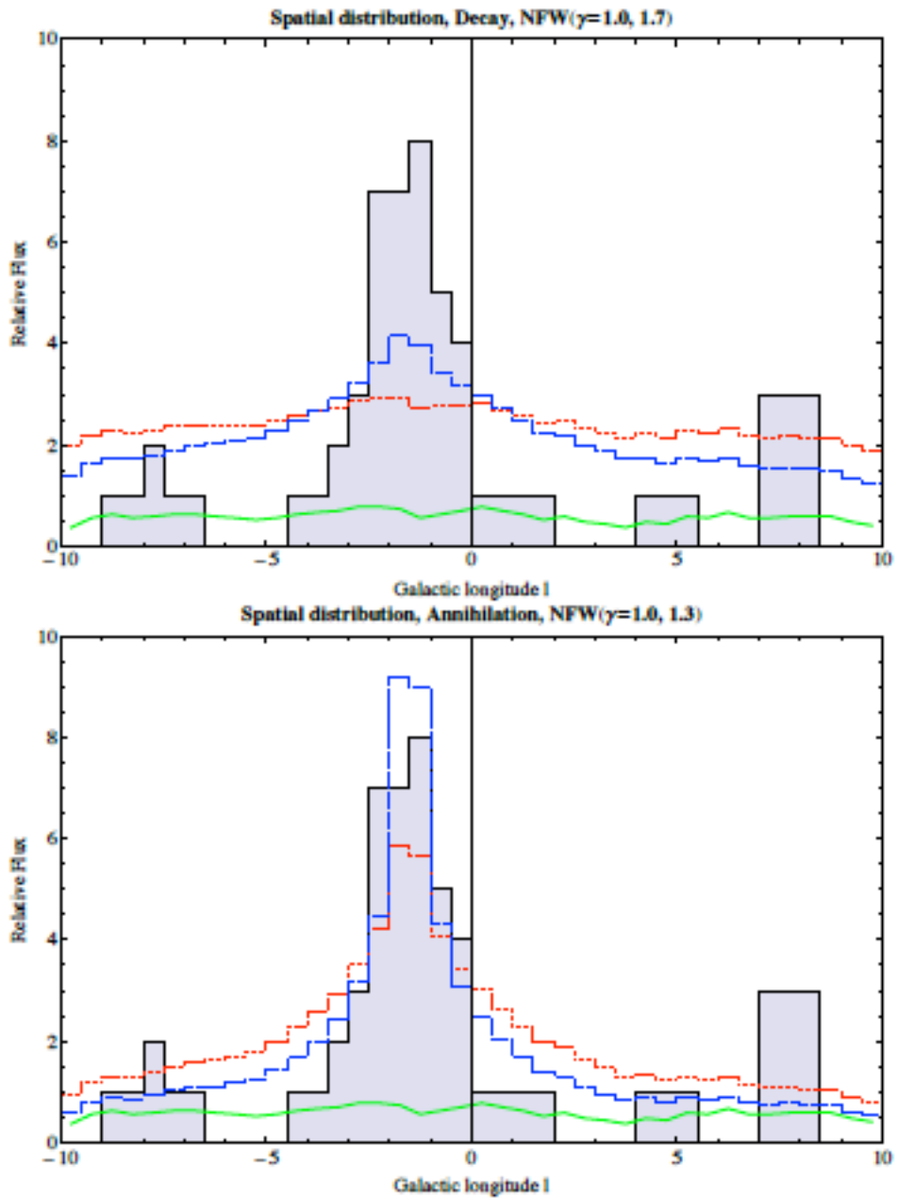


J.C. Park, S.C. Park [arXiv:1207.4981]

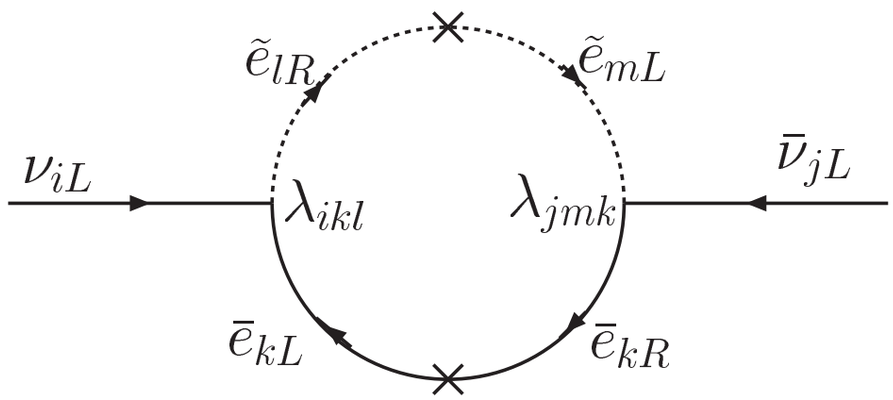
Neutrino masses from bilinear RPV

$$M_N|_{tree} = \begin{pmatrix} M_\chi & m^T \\ m & 0_{3\times 3} \end{pmatrix}$$

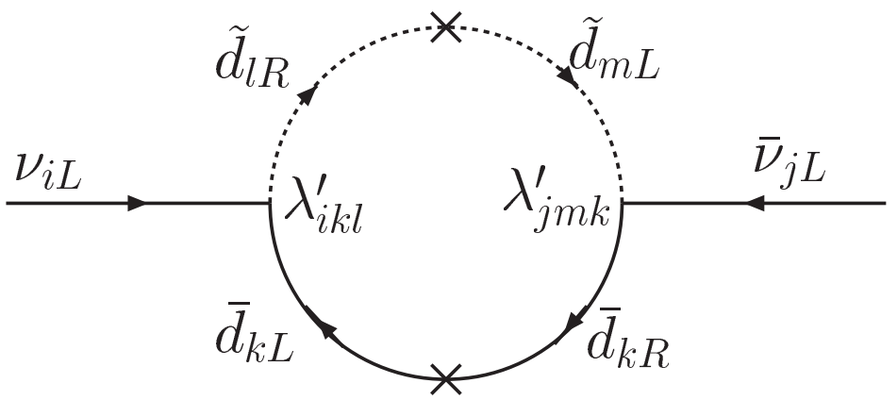
$$m_\nu \sim g^2 \langle \tilde{\nu} \rangle^2 / m_{\tilde{B}(\tilde{W})}$$

For gaugino masses of $O(100)\,\mathrm{GeV}$, $\grave{\kappa_i}' \equiv \langle \tilde{\nu}_i \rangle / v \lesssim \grave{1}0^{-7}$

Neutrino masses from trilinear RPV



(a)



(b)

$$M^{\nu}_{ij} = \frac{1}{16\pi^2}\sum_{k,l,m}\lambda_{ikl}\lambda_{jmk}m_{e_k}\frac{(\tilde{m}^{e2}_{LR})_{ml}}{m^2_{\tilde{e}_{Rl}} - m^2_{\tilde{e}_{Lm}}}\log\left(\frac{m^2_{\tilde{e}_{Rl}}}{m^2_{\tilde{e}_{Lm}}}\right) + (i \leftrightarrow j)$$

$$\lambda_{i33} \lesssim 0.02 \quad \text{when } m_{\tilde{\tau}_L} = 5m_{\tilde{\tau}_R} = 500 \text{ GeV}$$