Dark Matter Searches using Cosmic-ray Antiprotons

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Outline

- Introduction
- Possible DM annihilation component
- Direct detection constraint
- Discussion

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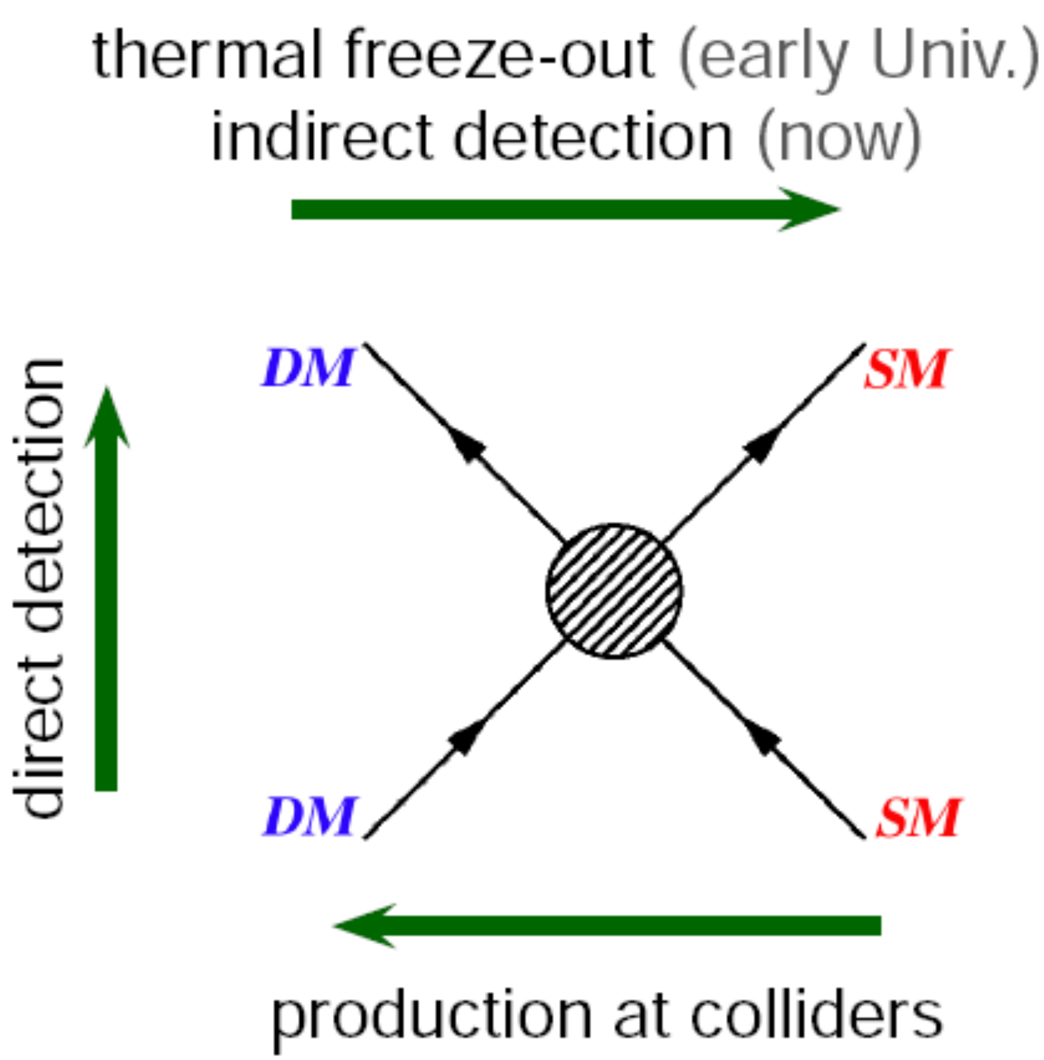
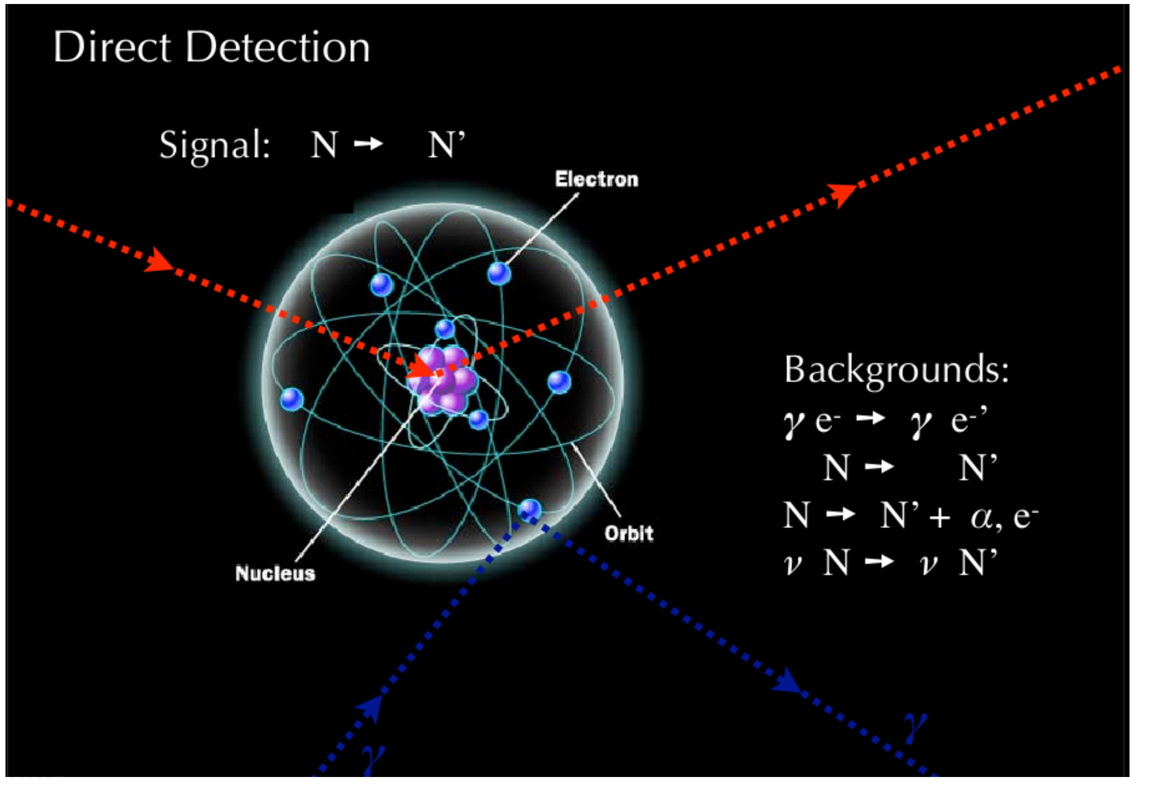
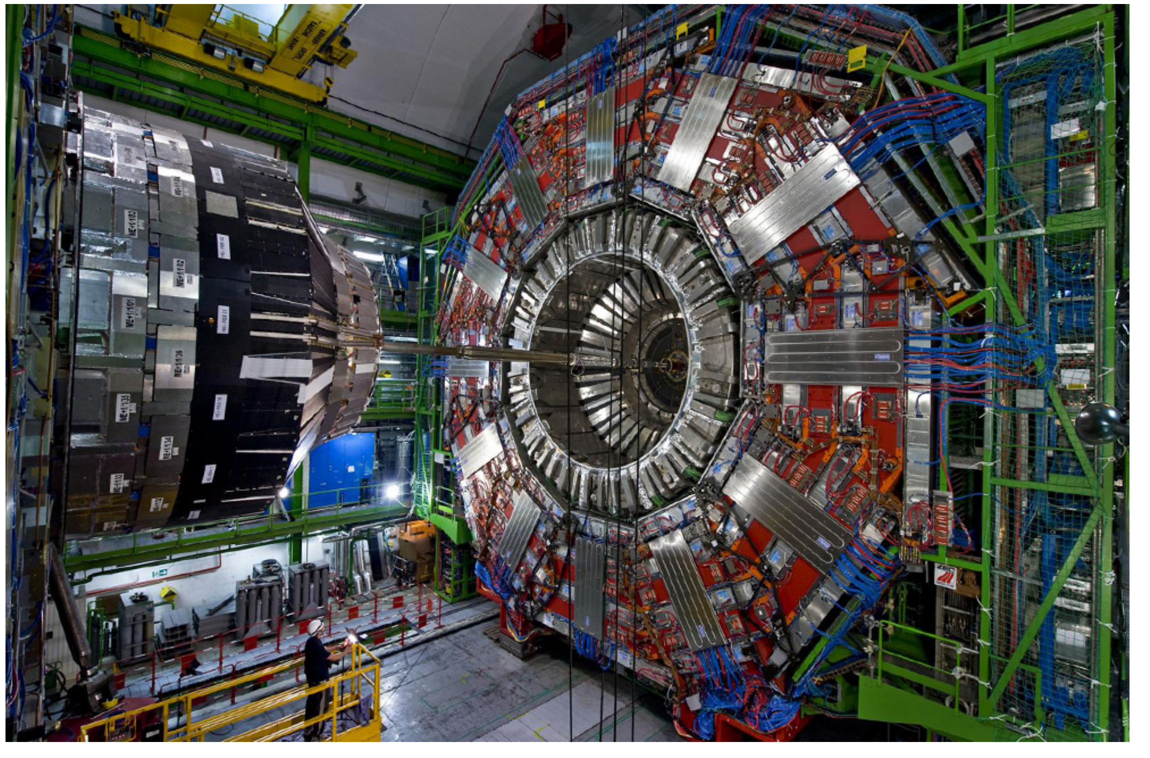
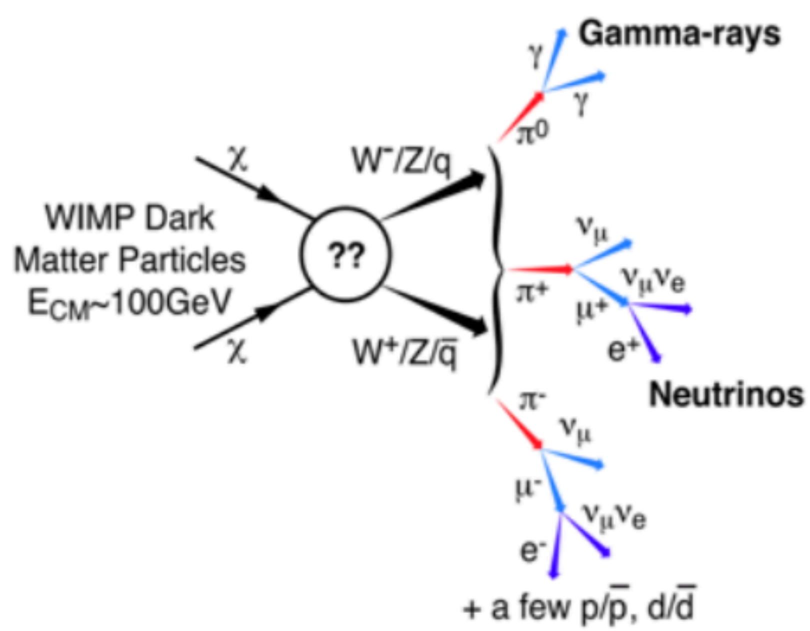
Detection of Dark Matter



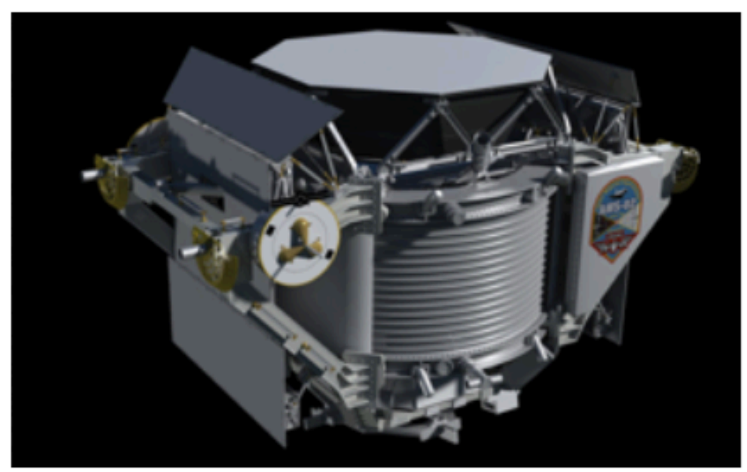




Indirect detection



$DAMPE(e^- + e^+, \gamma)$



$AMS02(e^-, e^+, \bar{p})$

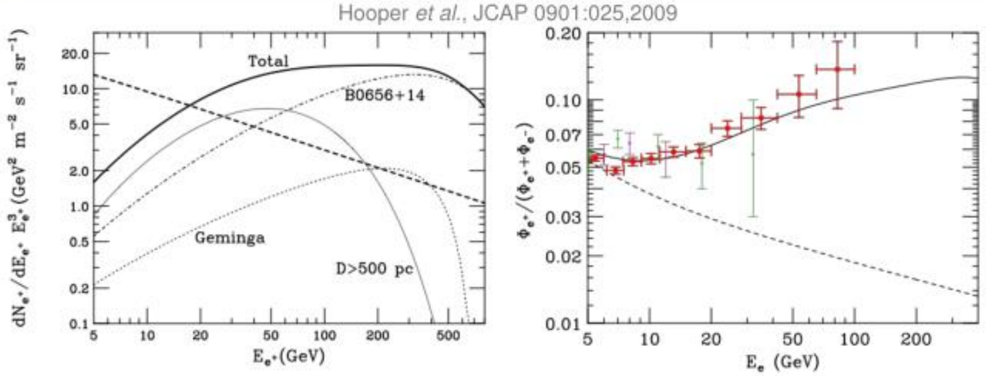
$Fermi(\gamma, e^- + e^+)$

Why antiprotons?

Positron excess

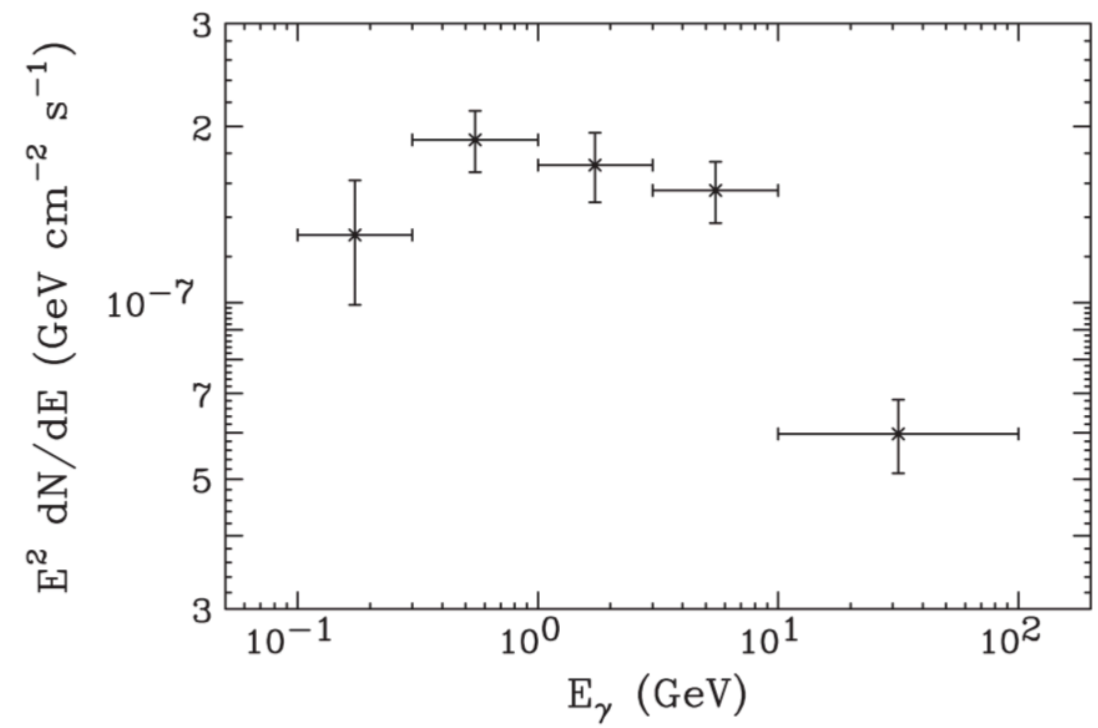
Pulsars as Source of $e^{\pm}$

Hooper *et al.*, JCAP 0901:025,2009



- Combination of global, galactic contribution and two nearby mature pulsars, Geminga (157 pc) and B0656+14 (290 pc), could fit PAMELA excess
- Parameters of pulsars, however, poorly known

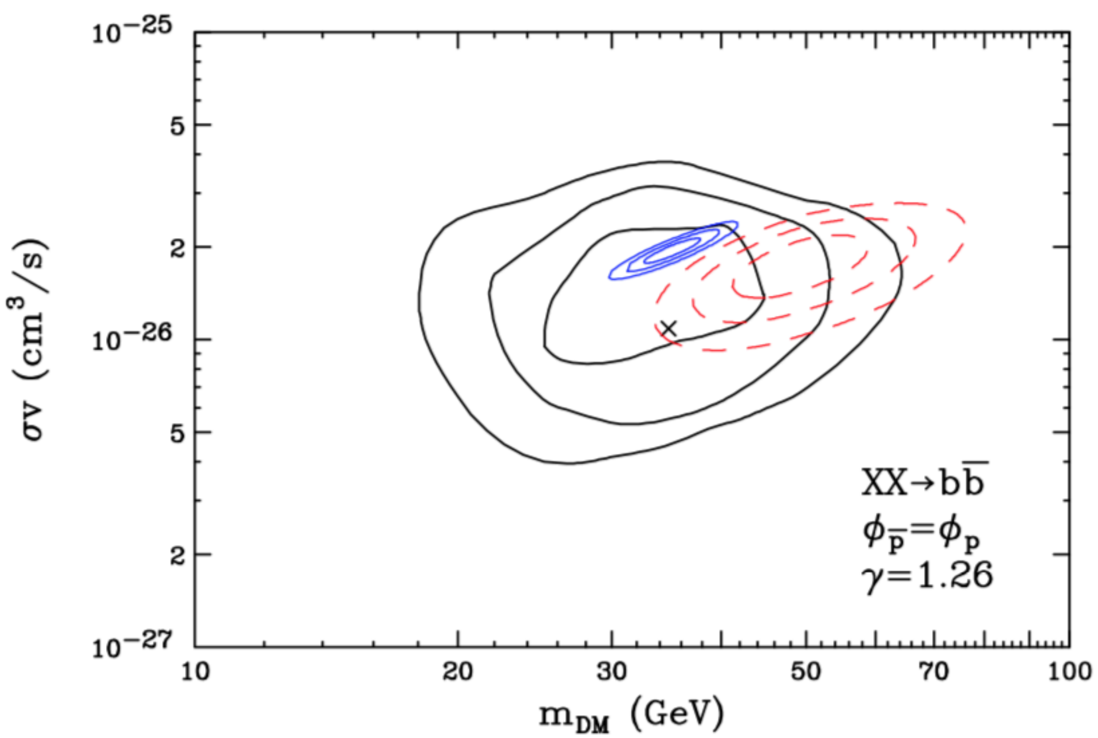
GeV excess



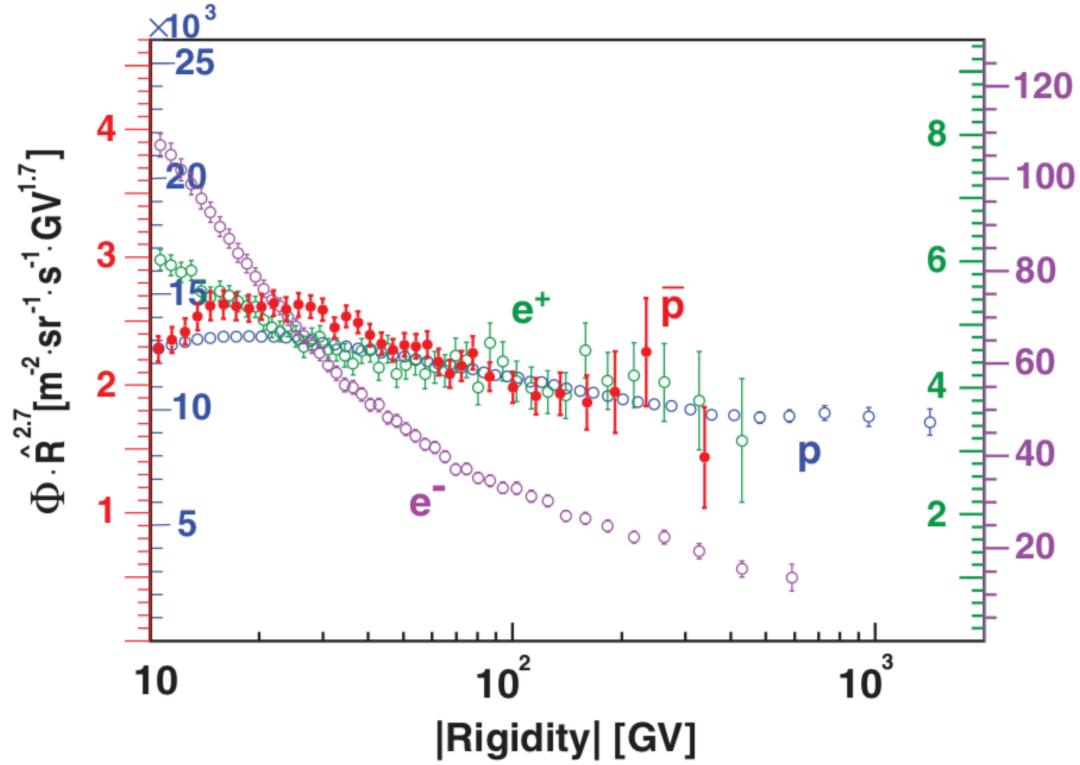
Dan Hooper et al. (2011)

Why antiprotons?

Antiproton "excess" (PAMELA)



Dan Hooper et al. (2015)



AMS Collaboration (2016)

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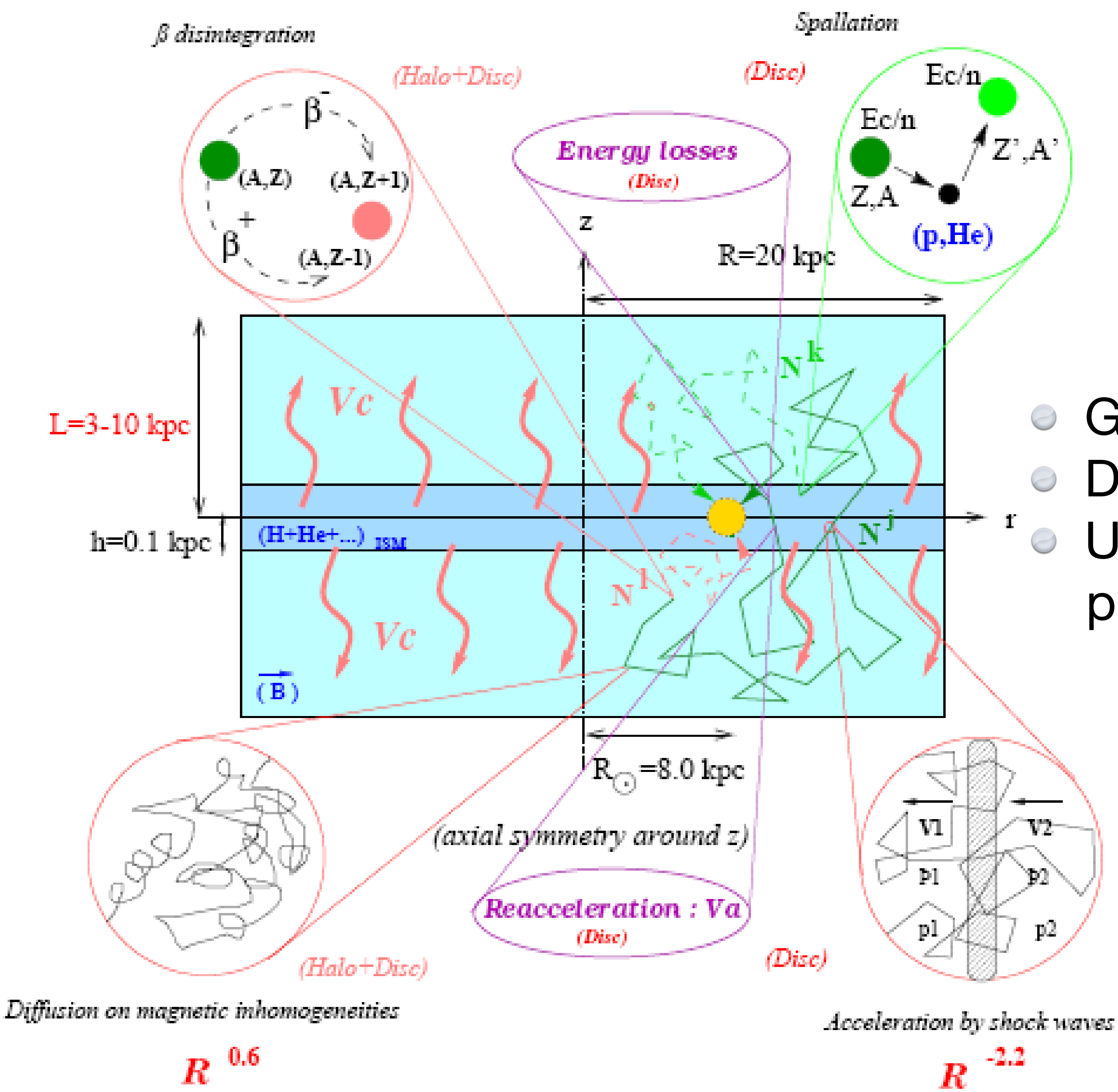
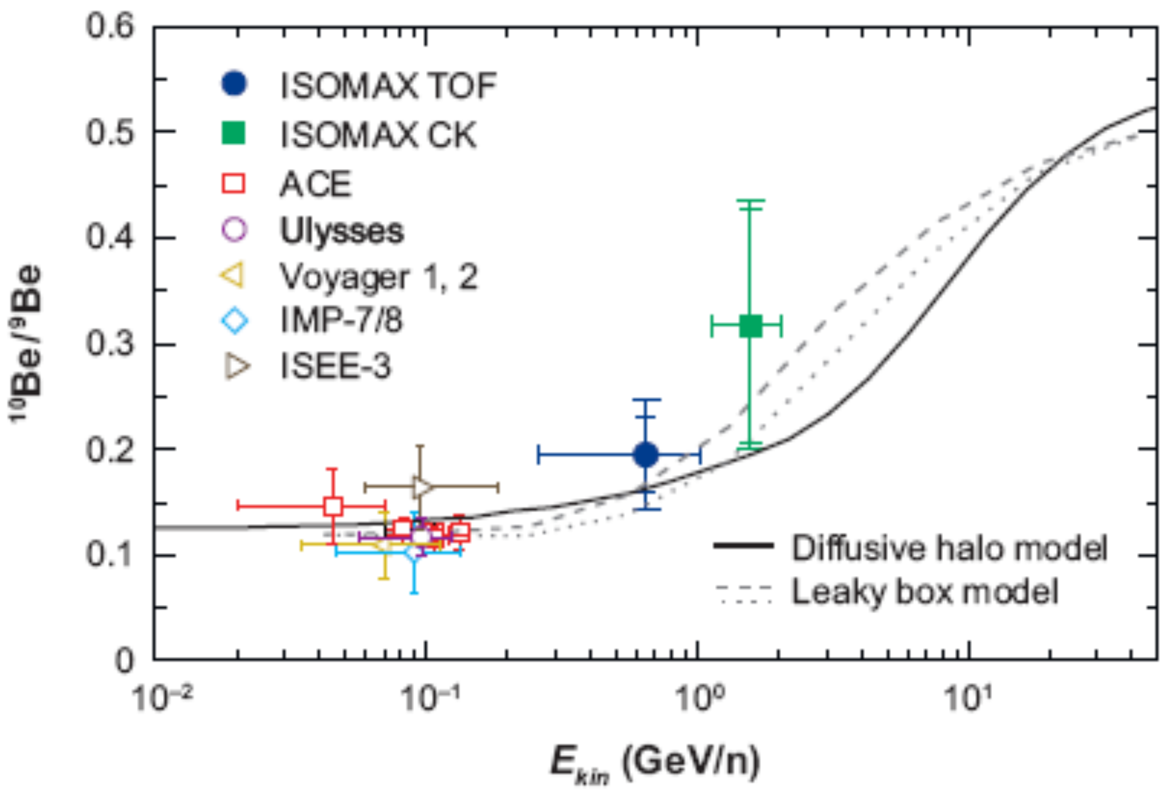
Cosmic-ray Propagation



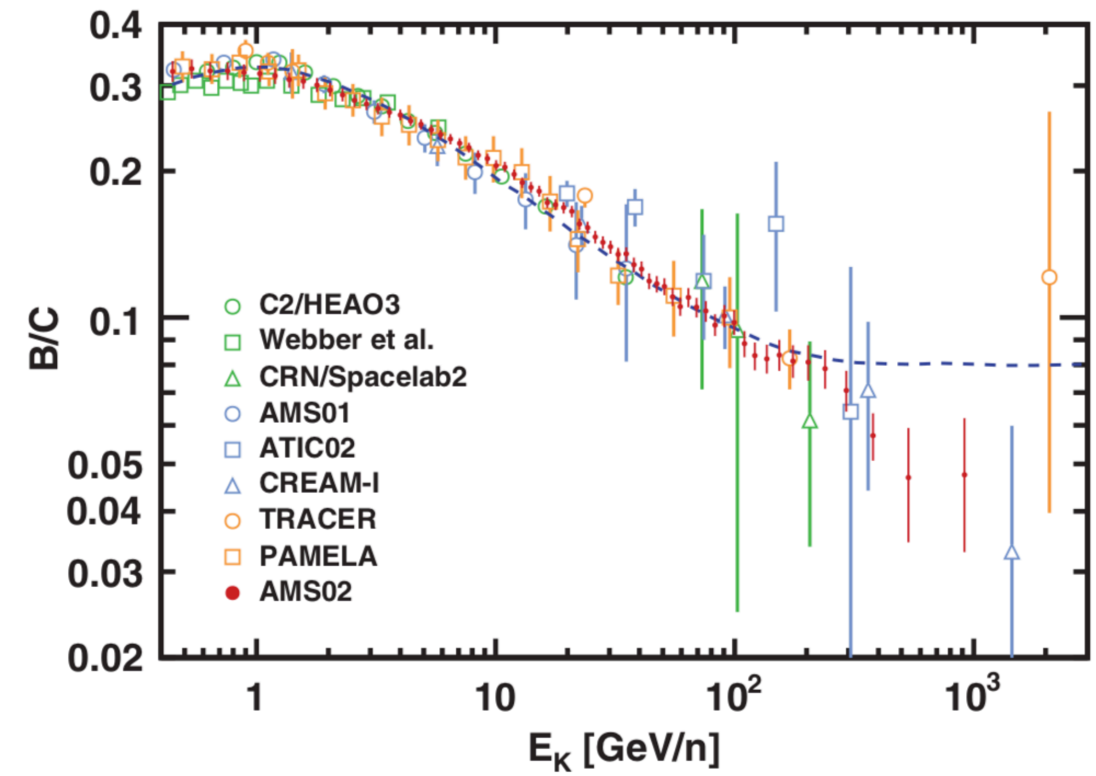
Maurin et al. (2002)

- Galprop code
- DR model
- Use MCMC to take a full scan of the parameter space

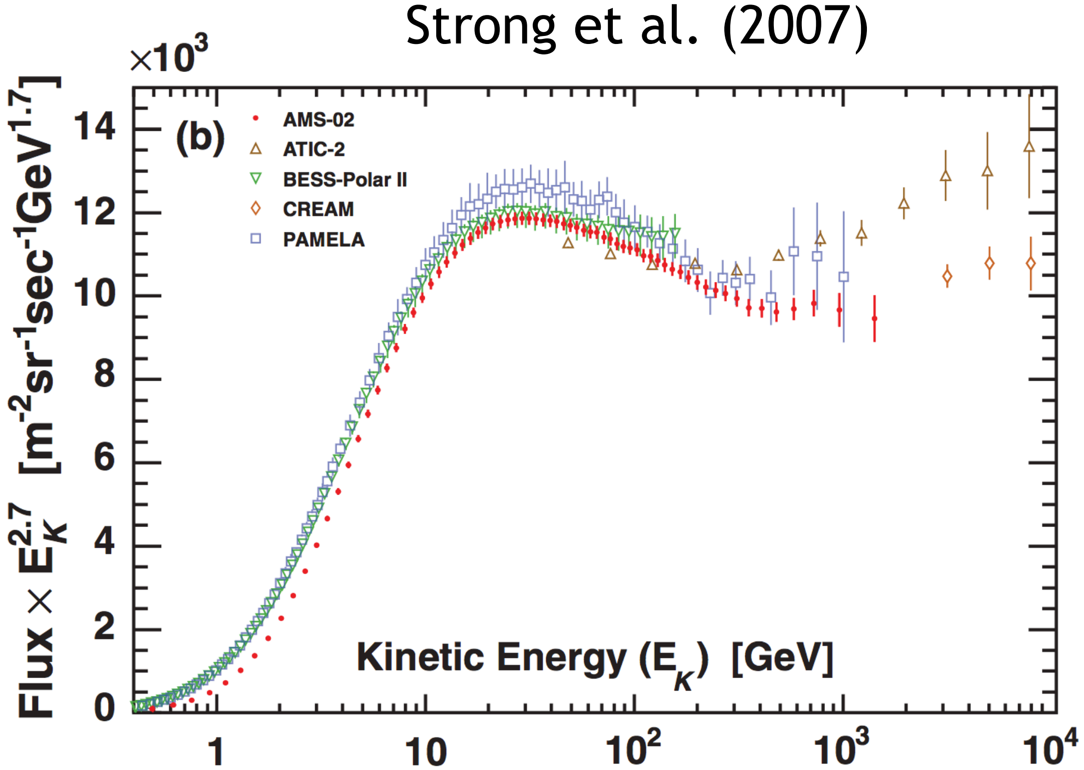
Source injection and propagation parameters



Strong et al. (2007)

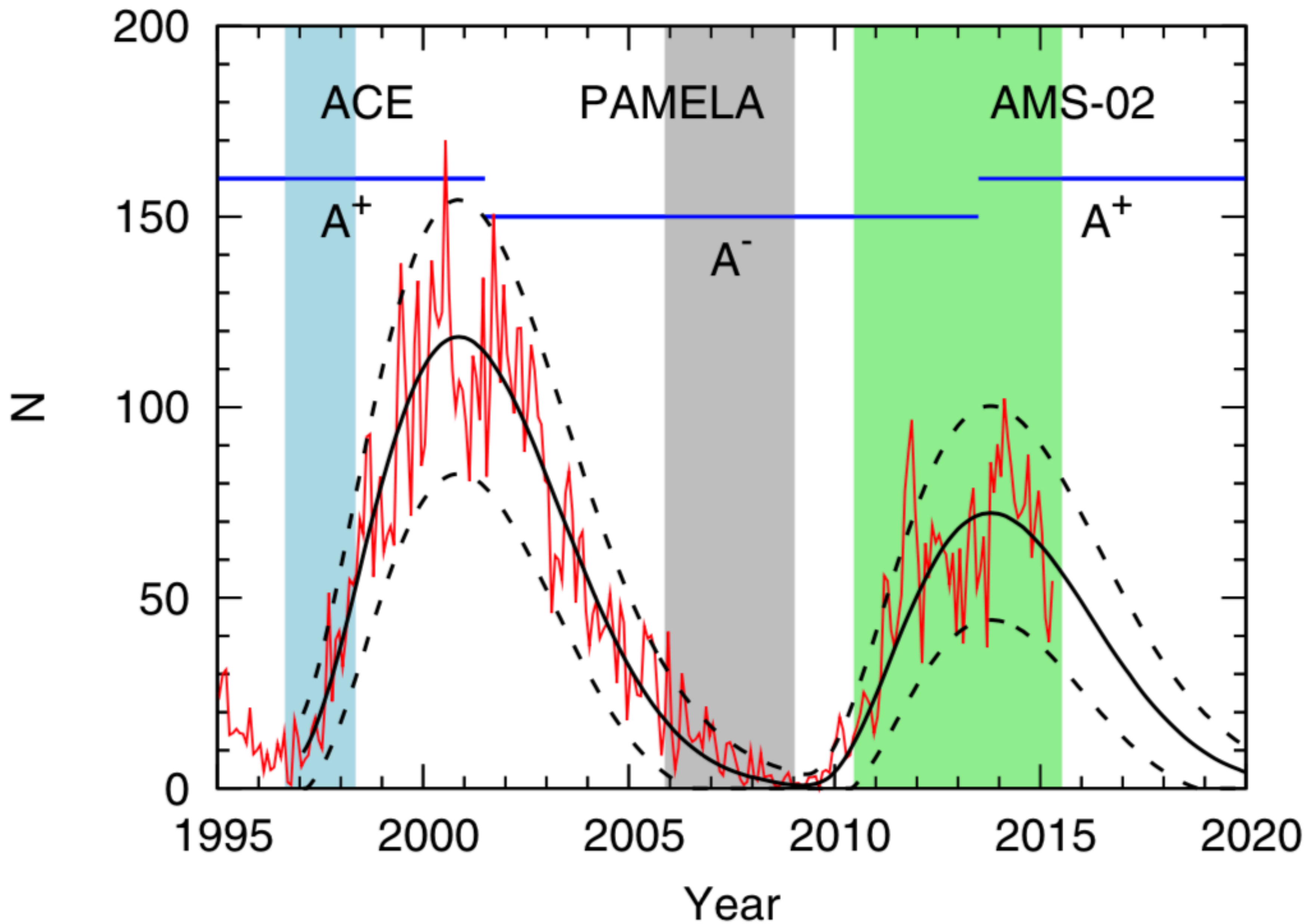


AMS Collaboration (2016)



AMS Collaboration (2016)

Solar Modulation



$$\Phi = \Phi_0 + \Phi_1 \times \frac{N(t)}{N_{\max}}$$

Q. Yuan et al. 2017

Bayesian framework

$$\mathcal{P}(\langle\sigma v\rangle)|_{m_\chi} \propto \int \mathcal{L}(m_\chi, \langle\sigma v\rangle, \boldsymbol{\theta}_{\rm bkg}, \kappa) p(\boldsymbol{\theta}_{\rm bkg}) p(\kappa) d\boldsymbol{\theta}_{\rm bkg} d\kappa$$

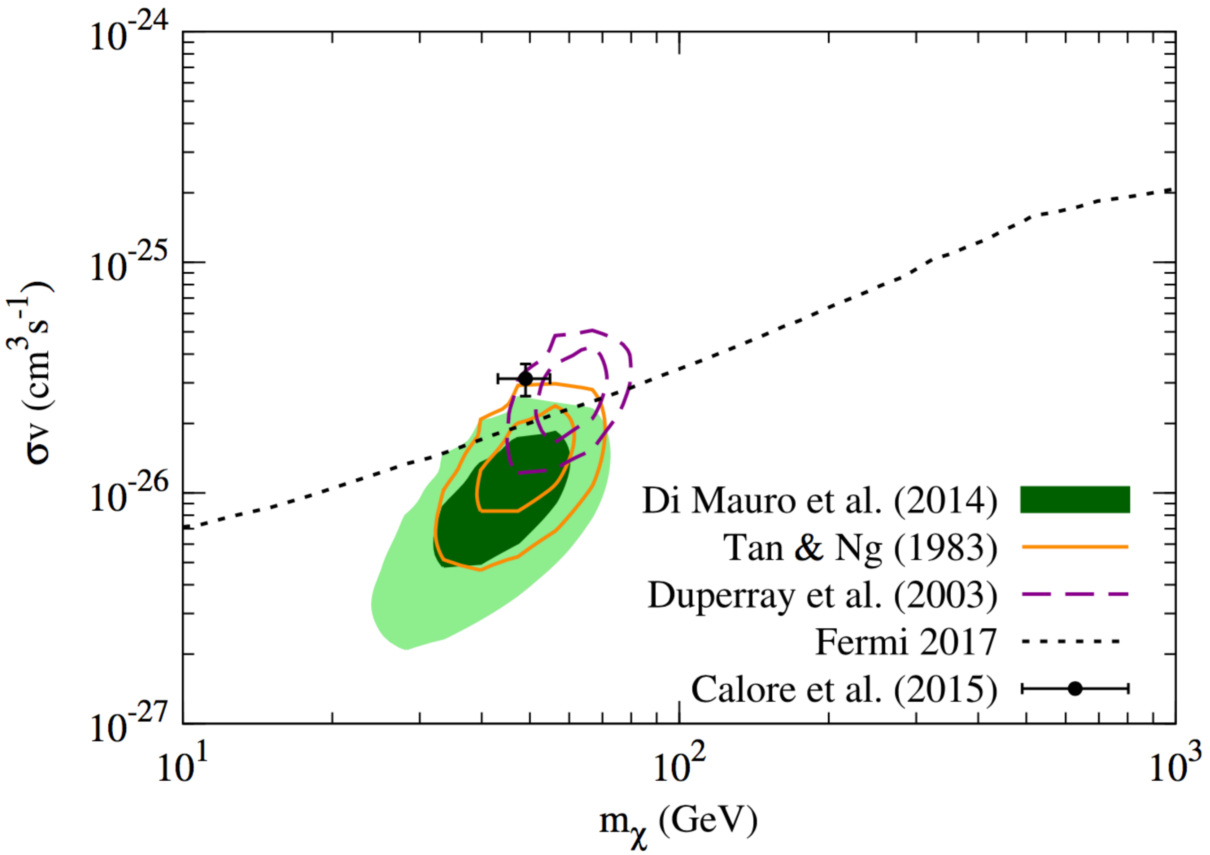
κ : antineutron/antiproton ratio

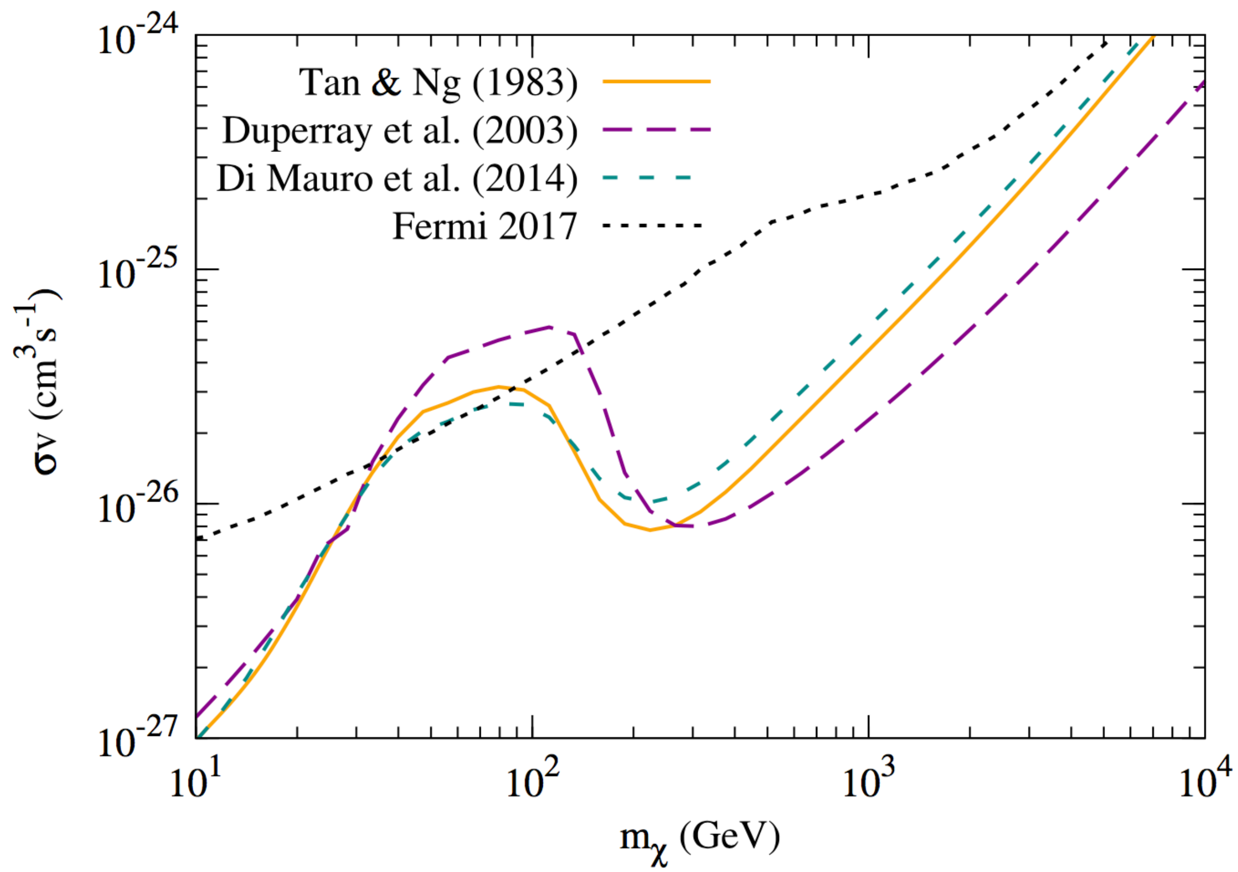
p : prior of k

θ : a set of background parameters

- Not assume background parameters in advance
- Give each set of parameters a “probability”
- Incorporate all uncertainties in an unified way

Credible region & Upper limit

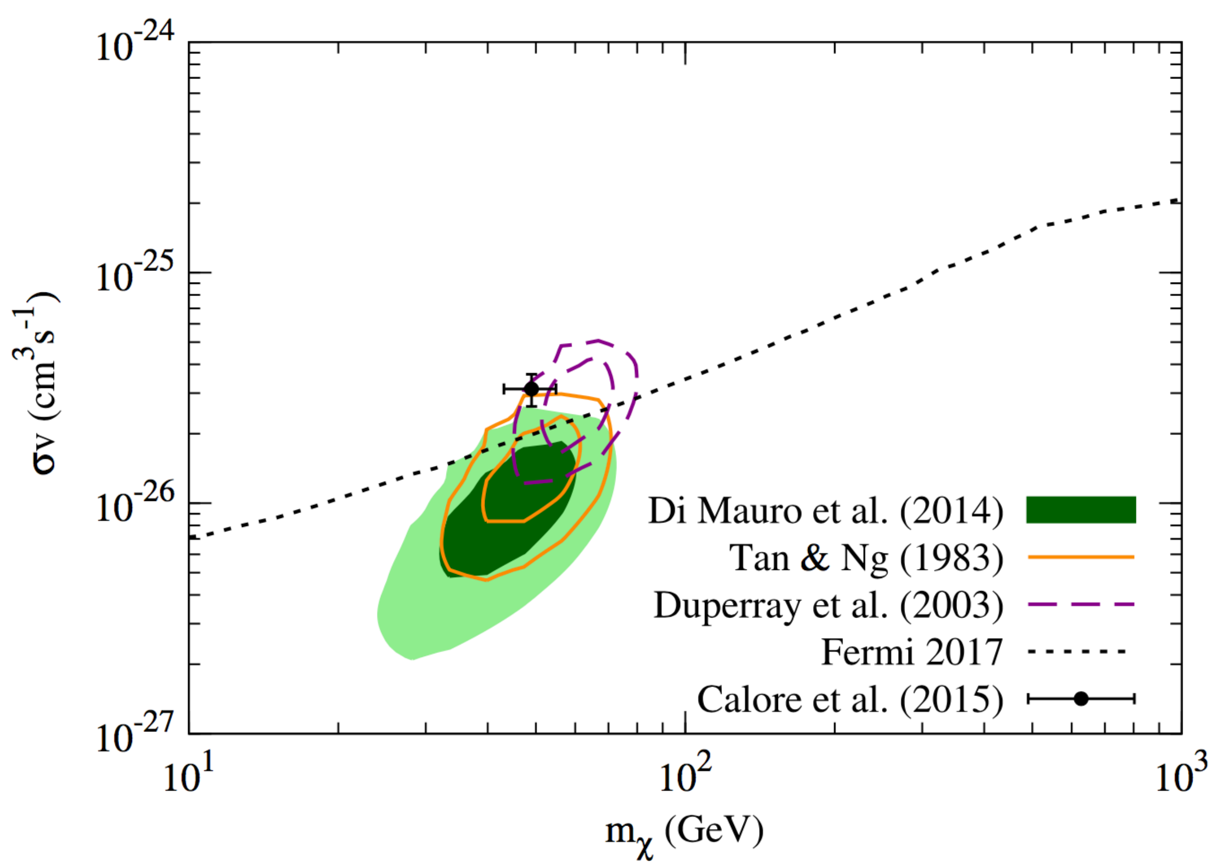




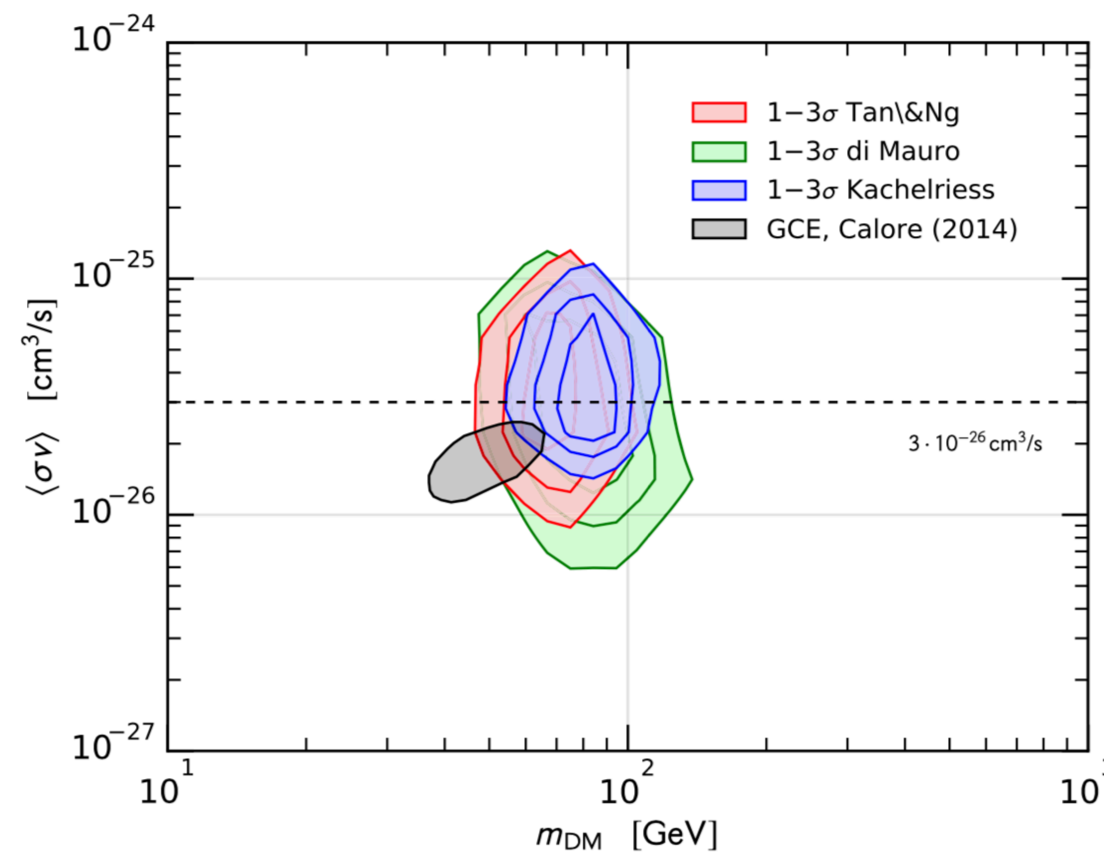
- Favored mass of DM particles ~10 GeV
- DM parameters are consistent with that of in the GeV excess
- Upper limits on the DM annihilation cross section is stronger than that set by the Fermi-LAT observation

M.Y. Cui et al. (2017)

Credible region & Upper limit

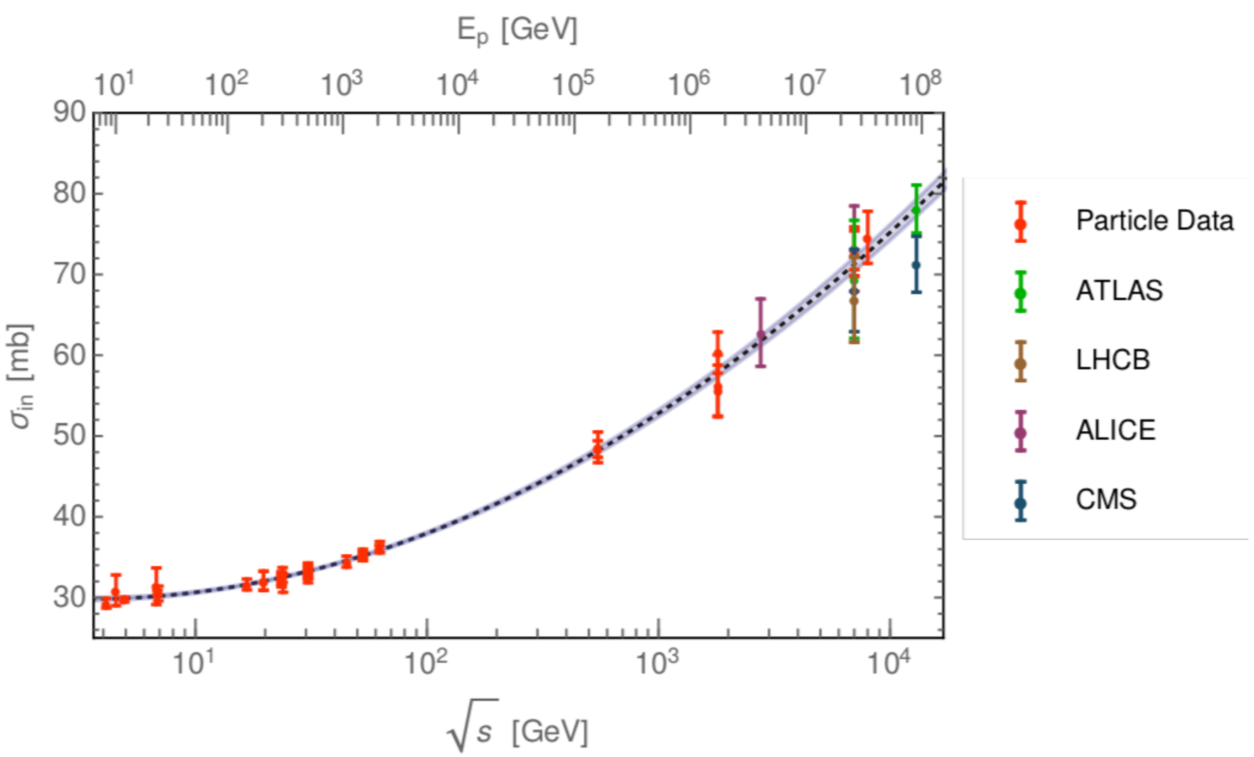


M.Y. Cui et al. (2017)



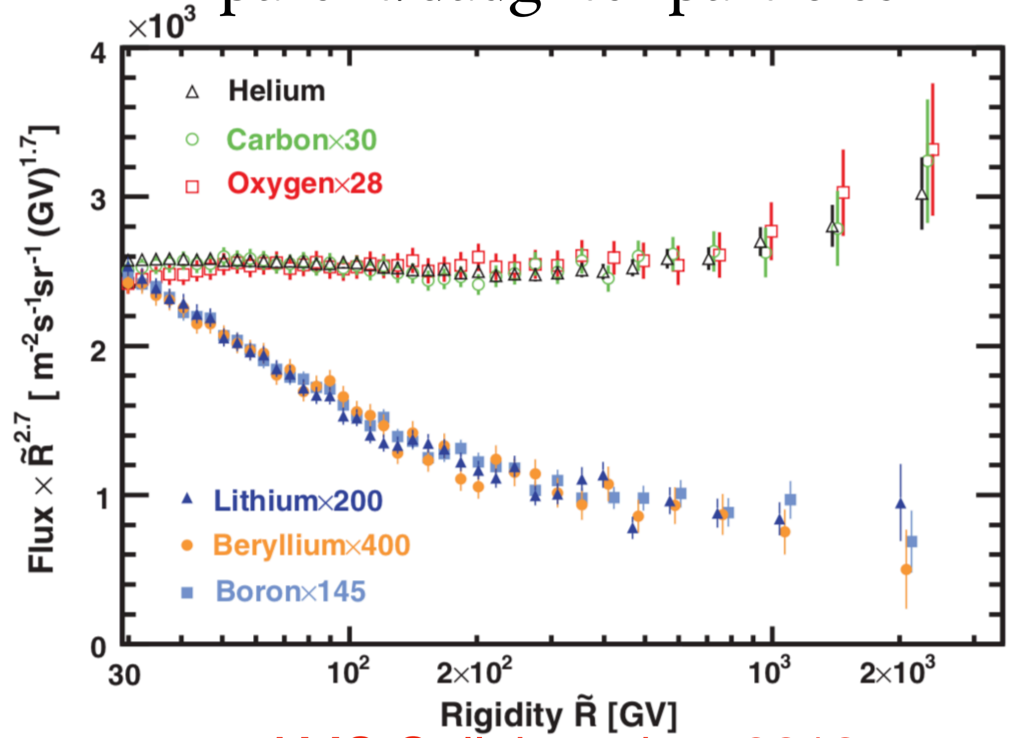
Cuoco et al. (2017)

Improvement

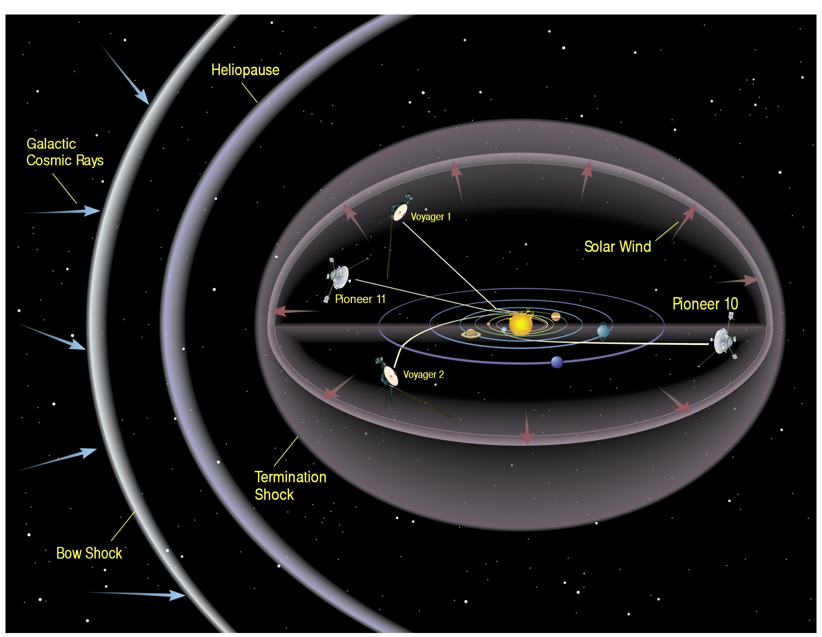


M.W. Winkler, JCAP, 2018

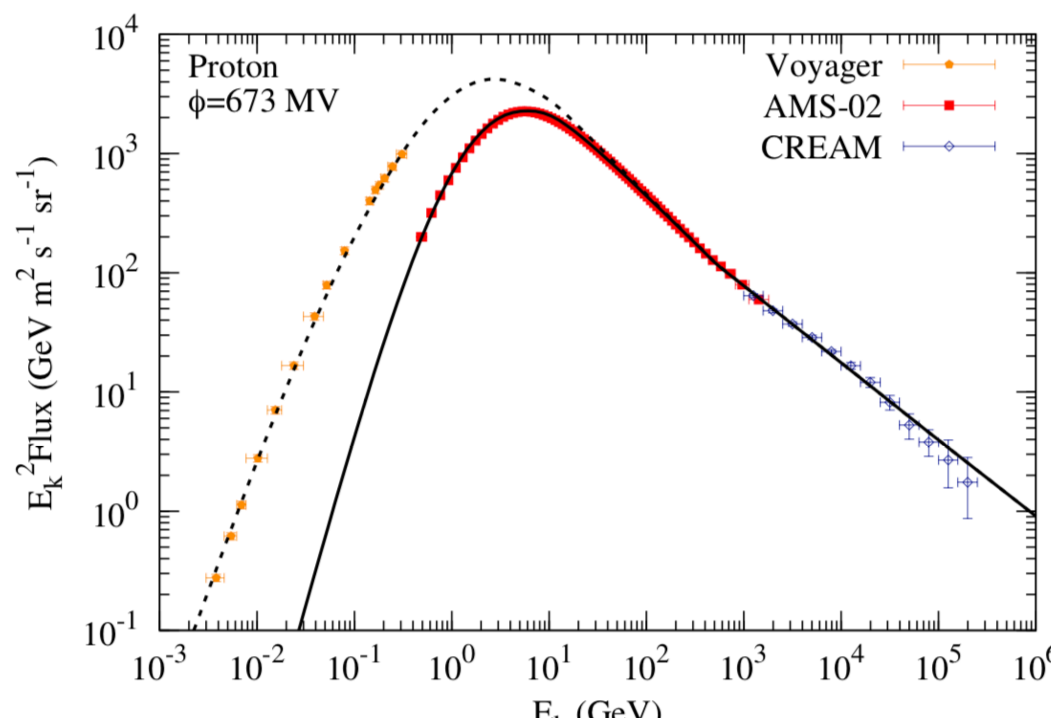
parent/daughter particles



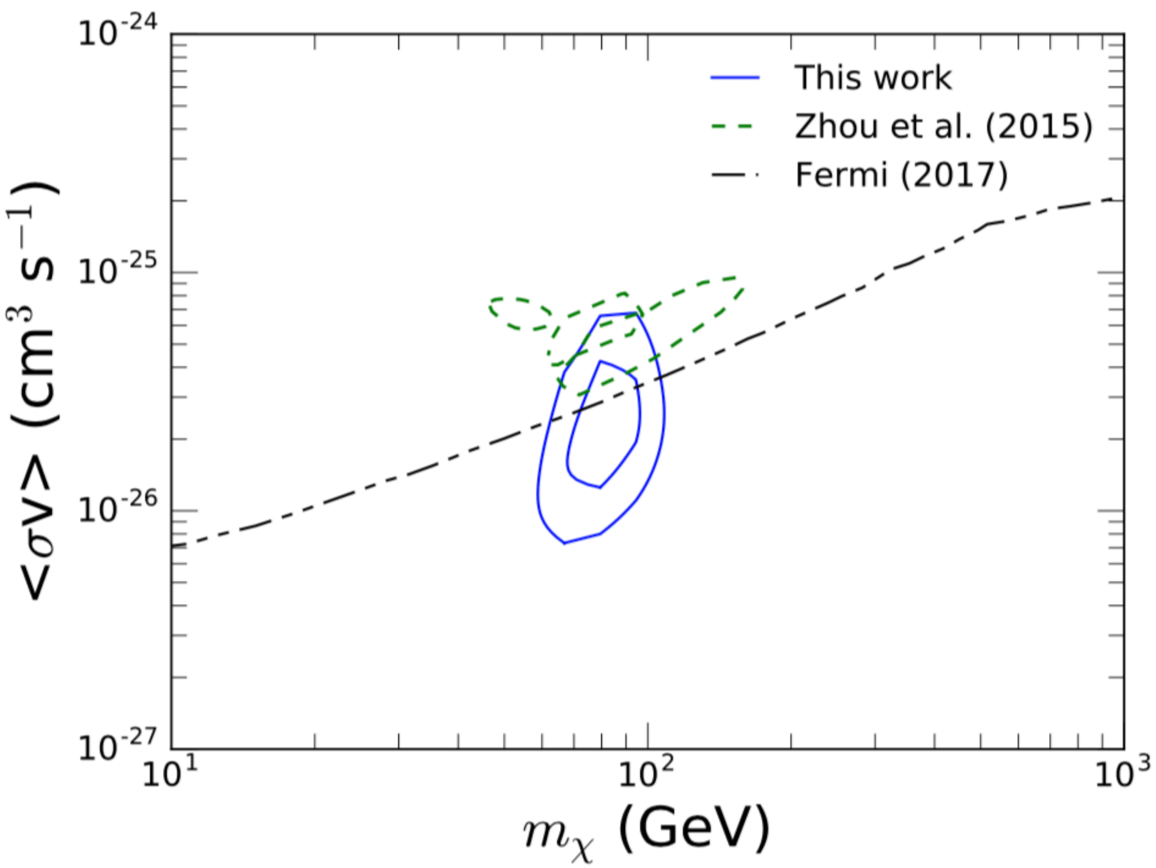
AMS Collaboration, 2018

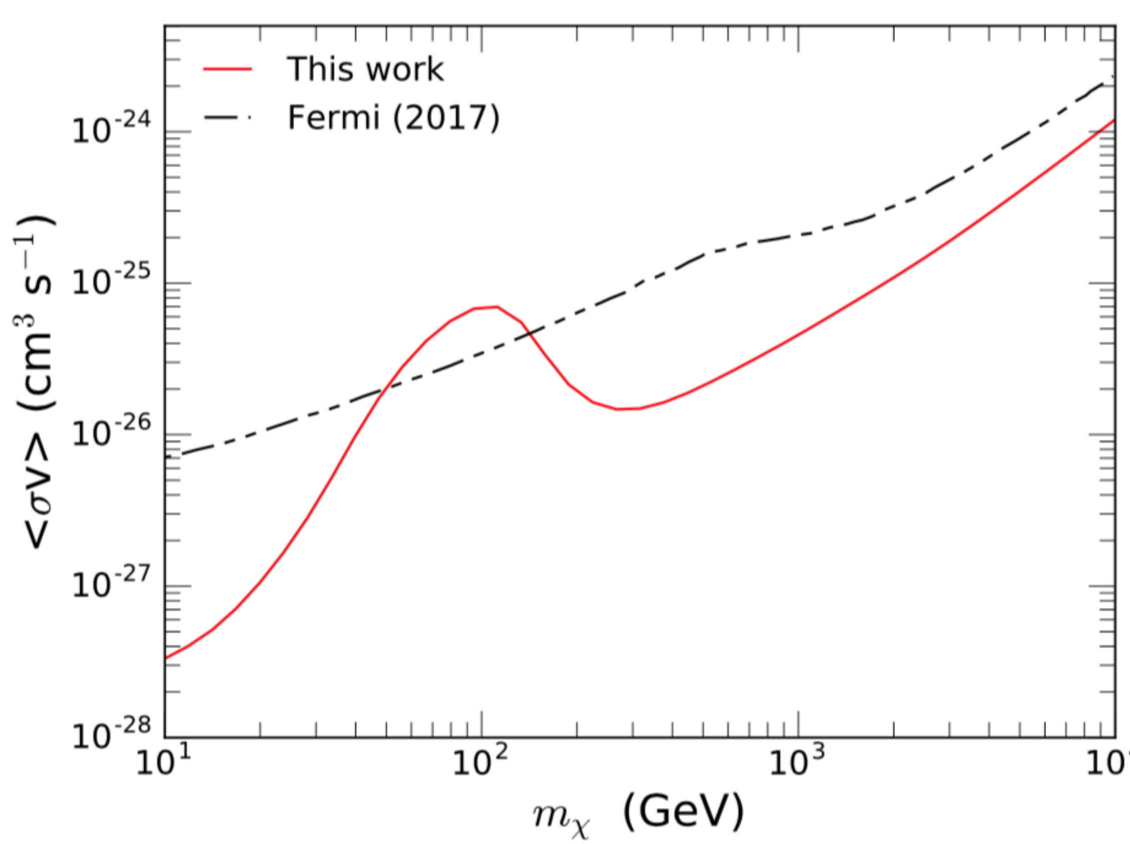


Voyager 1



Credible region & Upper limit





M.Y. Cui et al. (2018)

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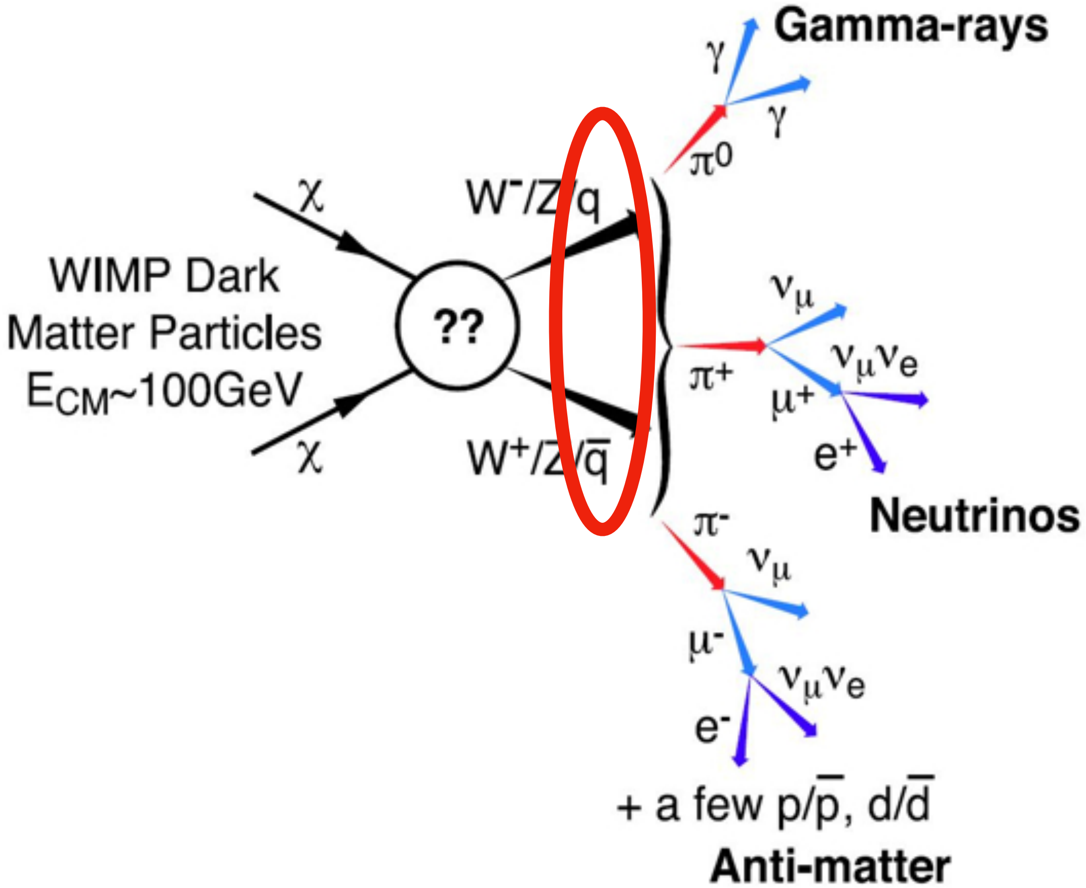
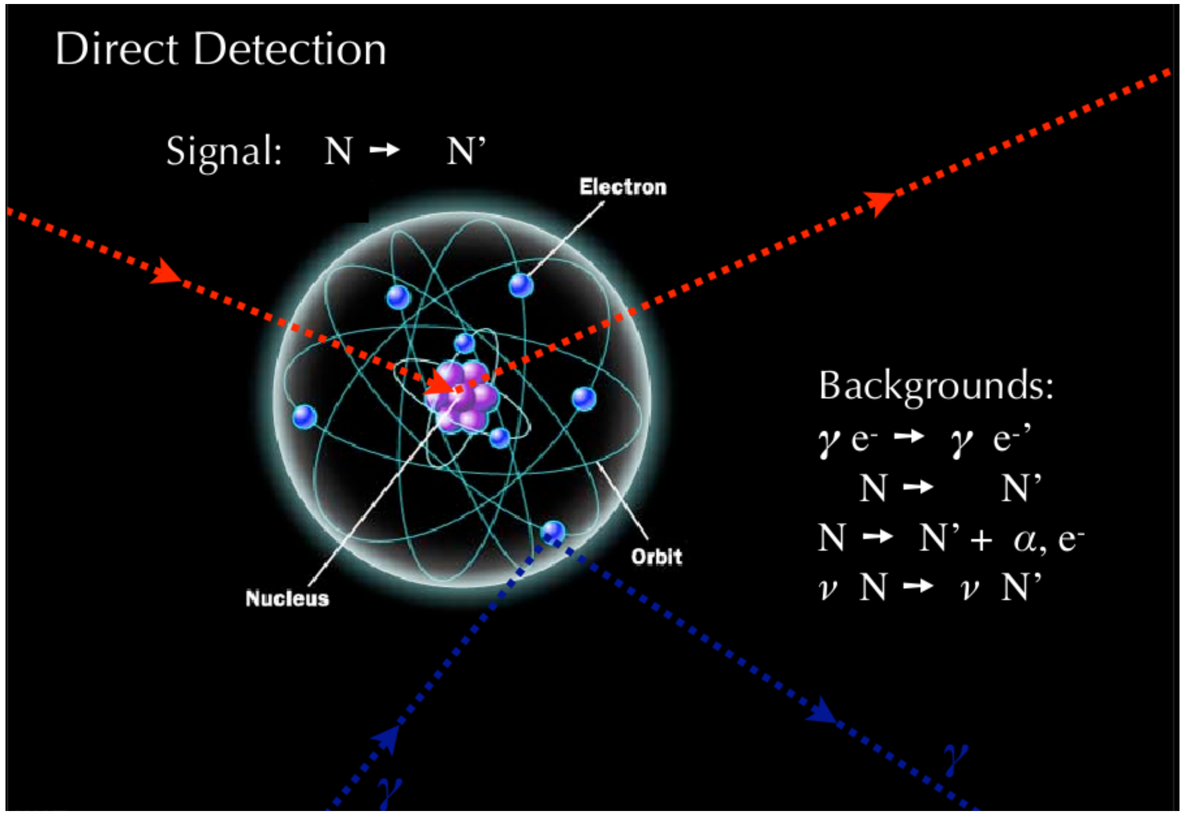
Indirect & Direct detection





- It indicates sizable couplings between DM and quarks

Direct detection constraint

$$\mathcal{L}_{\bar{p}}(\boldsymbol{\theta}_{\rm bkg}, \kappa, \phi_{\rm DM}) \propto \prod_i \exp\left[-\frac{(F_i - \kappa F_{{\rm bkg},i} - \phi_{{\rm DM},i})^2}{2\sigma_i^2}\right]$$

$$\mathcal{P}_{\rm DM} \propto \int \mathcal{L}_{\bar{p}}(\boldsymbol{\theta}_{\rm bkg}, \kappa, f\bar{\phi}_{\rm DM})\, p(\boldsymbol{\theta}_{\rm bkg})\, p(\kappa)\, p(f)\, d\boldsymbol{\theta}_{\rm bkg}\, d\kappa\, df$$

$$\ln \mathcal{L}_{\rm DD} = \sum_i \ln \mathcal{L}_i(m_\chi, \mathcal{R}) \qquad i = \texttt{PandaX-II},\ \texttt{LUX},\ \texttt{XENON1T}$$

- Propagation and proton spectral parameters are determined through a global fitting to the recent AMS-02 measurements on the B/C ratio and the Carbon and the proton flux
- Use the event rate R as the observable instead of the cross-section

Operators

$$\mathcal{O}_1^{(5)} = \frac{1}{\Lambda}(\bar{\chi}\chi)(H^\dagger H) \ , \ \ \mathcal{O}_2^{(5)} = \frac{1}{\Lambda}(\bar{\chi}i\gamma_5\chi)(H^\dagger H) \ ,$$

$$\mathcal{O}_3^{(5)} = \frac{e}{8\pi^2\Lambda}(\bar{\chi}\sigma^{\mu\nu}\chi)F_{\mu\nu} \ , \ \ \mathcal{O}_4^{(5)} = \frac{e}{8\pi^2\Lambda}(\bar{\chi}i\sigma^{\mu\nu}\gamma_5\chi)F_{\mu\nu}$$

$$\mathcal{O}_1^{(6)} = \frac{1}{\Lambda^2}(\bar{\chi}\gamma_\mu\chi)(H^\dagger iD^\mu H) \ , \qquad \mathcal{O}_2^{(6)} = \frac{1}{\Lambda^2}(\bar{\chi}\gamma_\mu\gamma_5\chi)(H^\dagger iD^\mu H)$$

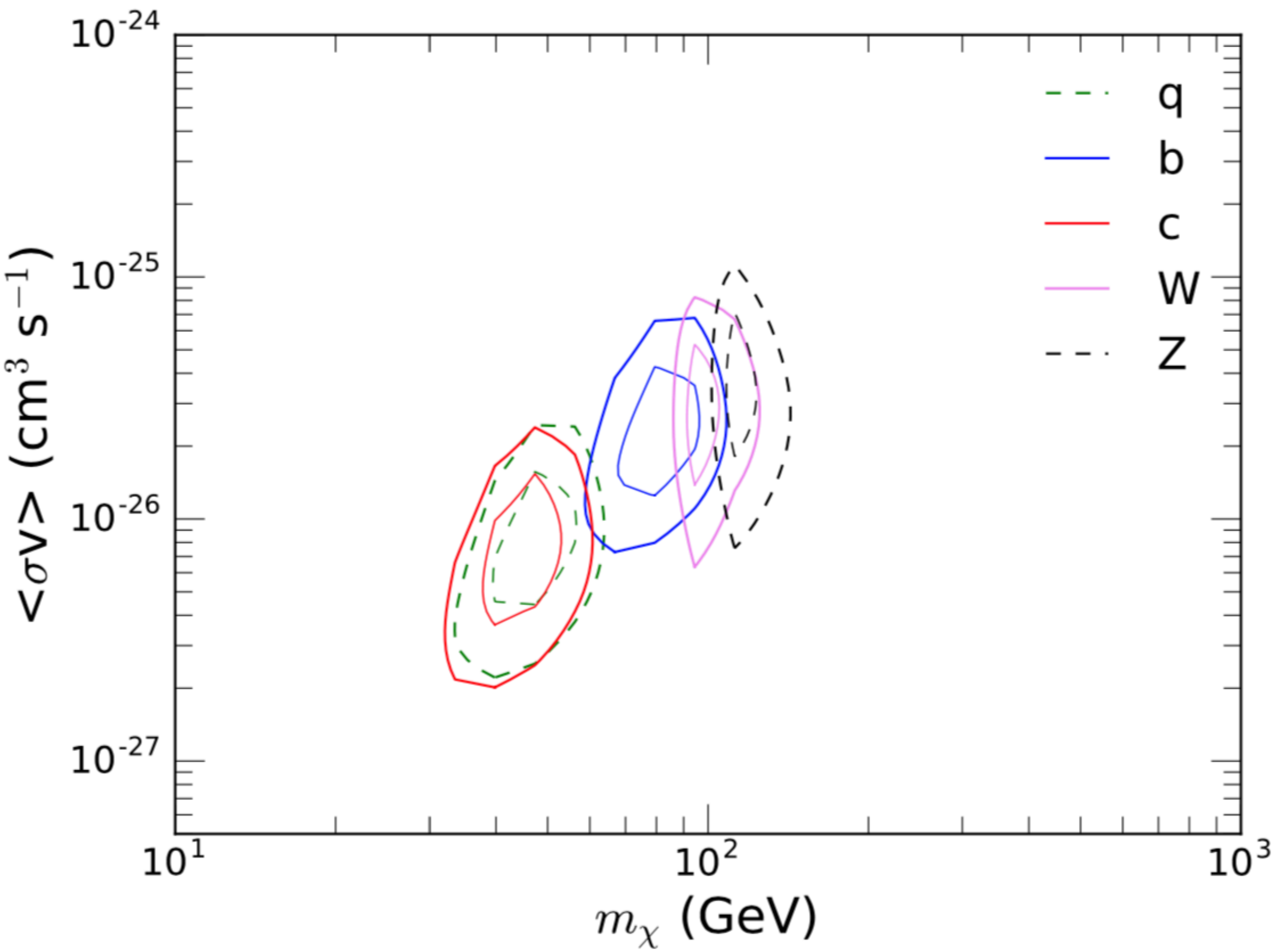
$$\mathcal{O}_3^{(6)} = \frac{1}{\Lambda^2}(\bar{\chi}\gamma_\mu\chi)(\bar{q}\gamma^\mu q) \ , \qquad \mathcal{O}_4^{(6)} = \frac{1}{\Lambda^2}(\bar{\chi}\gamma_\mu\gamma_5\chi)(\bar{q}\gamma^\mu q) \ ,$$

$$\mathcal{O}_5^{(6)} = \frac{1}{\Lambda^2}(\bar{\chi}\gamma_\mu\chi)(\bar{q}\gamma^\mu\gamma_5 q) \ , \qquad \mathcal{O}_6^{(6)} = \frac{1}{\Lambda^2}(\bar{\chi}\gamma_\mu\gamma_5\chi)(\bar{q}\gamma^\mu\gamma_5 q) \ ,$$

- Only fermion DM
- H is SM Higgs field
- F is EM field strength tensor
- q refers to the SM quarks

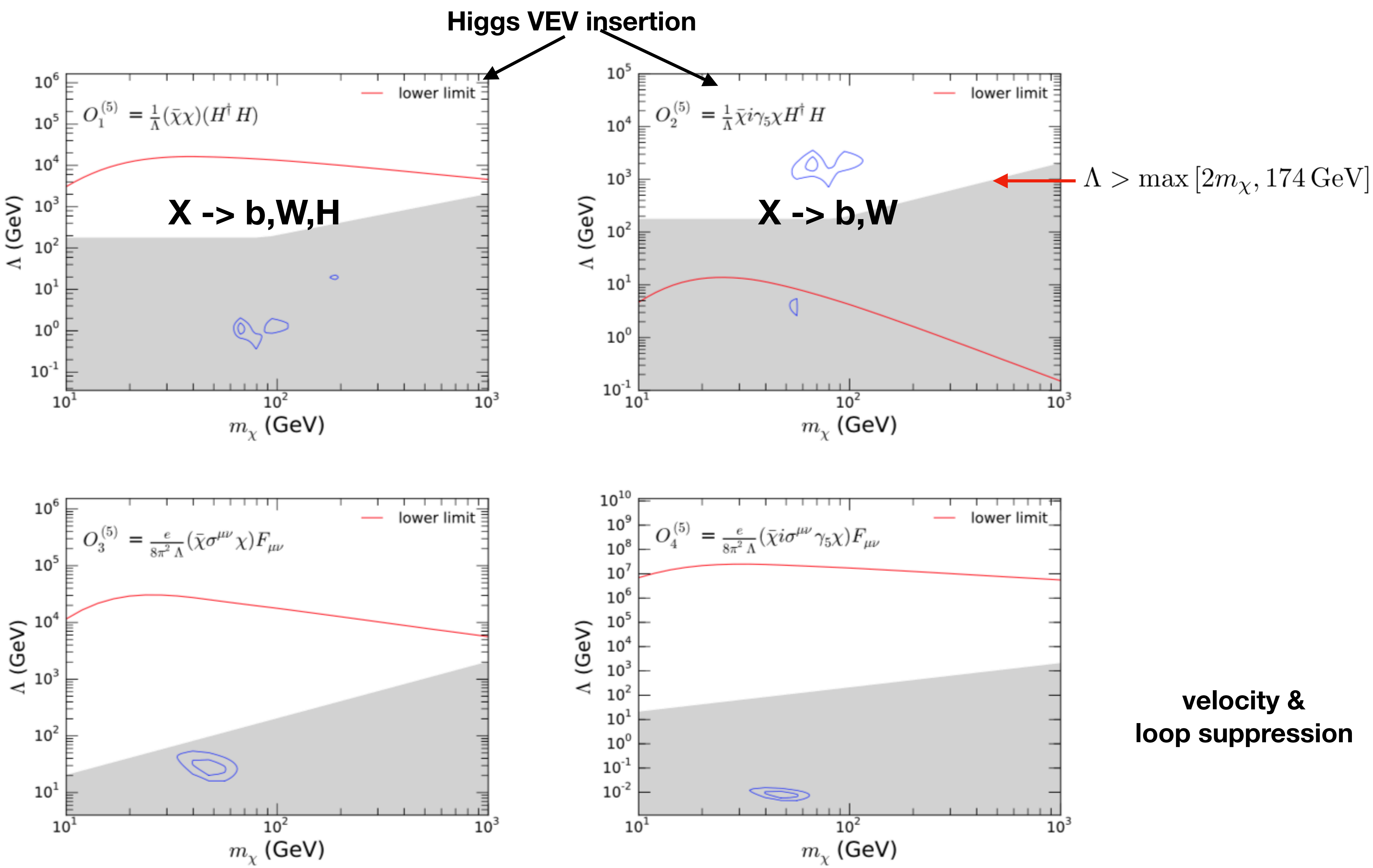
M.Y. Cui et al. (2018)

Credible regions for different DM annihilation channels



M.Y. Cui et al. (2018)

Dimension 5



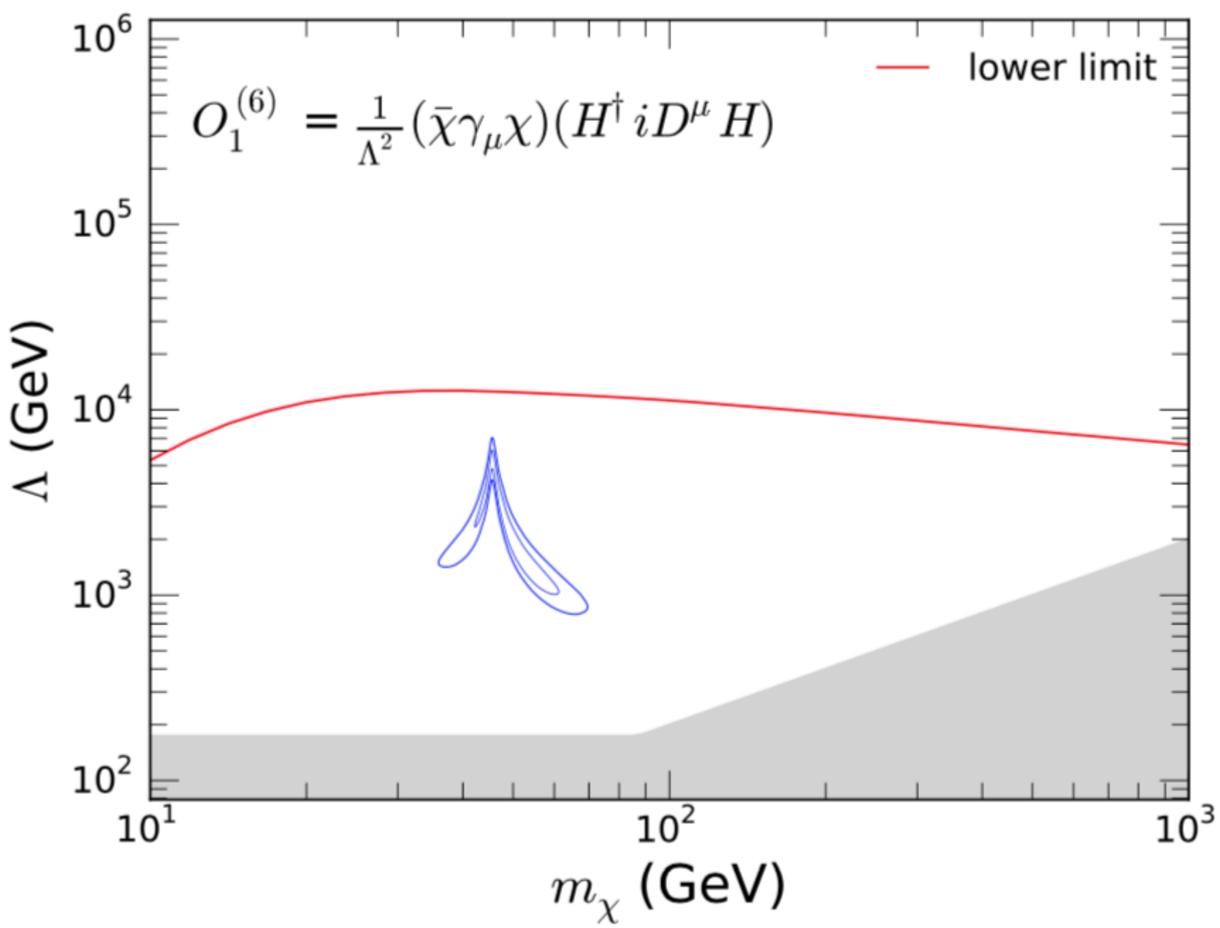
M.Y. Cui et al. (2018)

Dimension 6

resonance enhancement

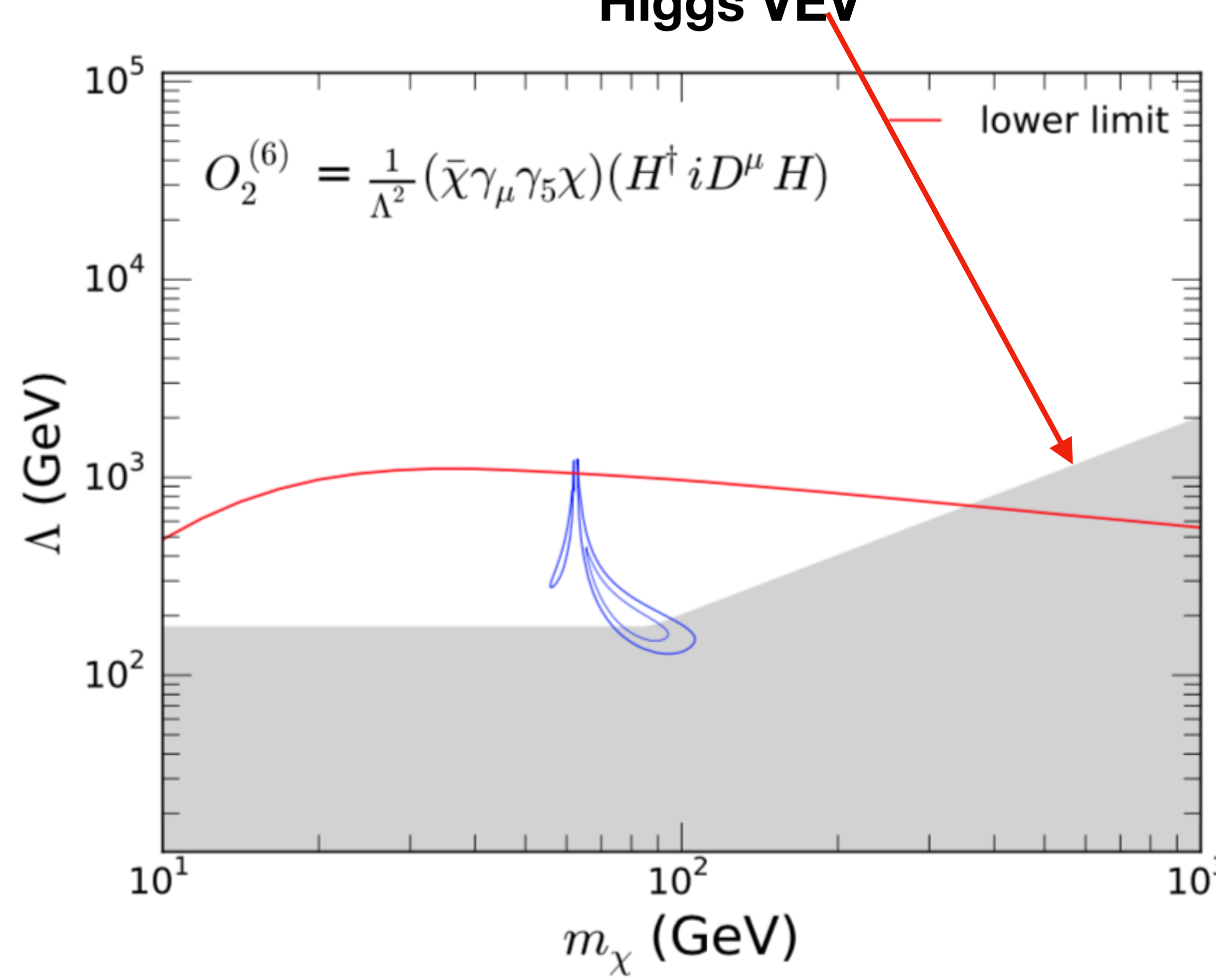
$$\Lambda > \max\left[2m_\chi, 174\,\mathrm{GeV}\right]$$

Higgs VEV



Z exchange dominate

$m_\chi = m_Z/2$

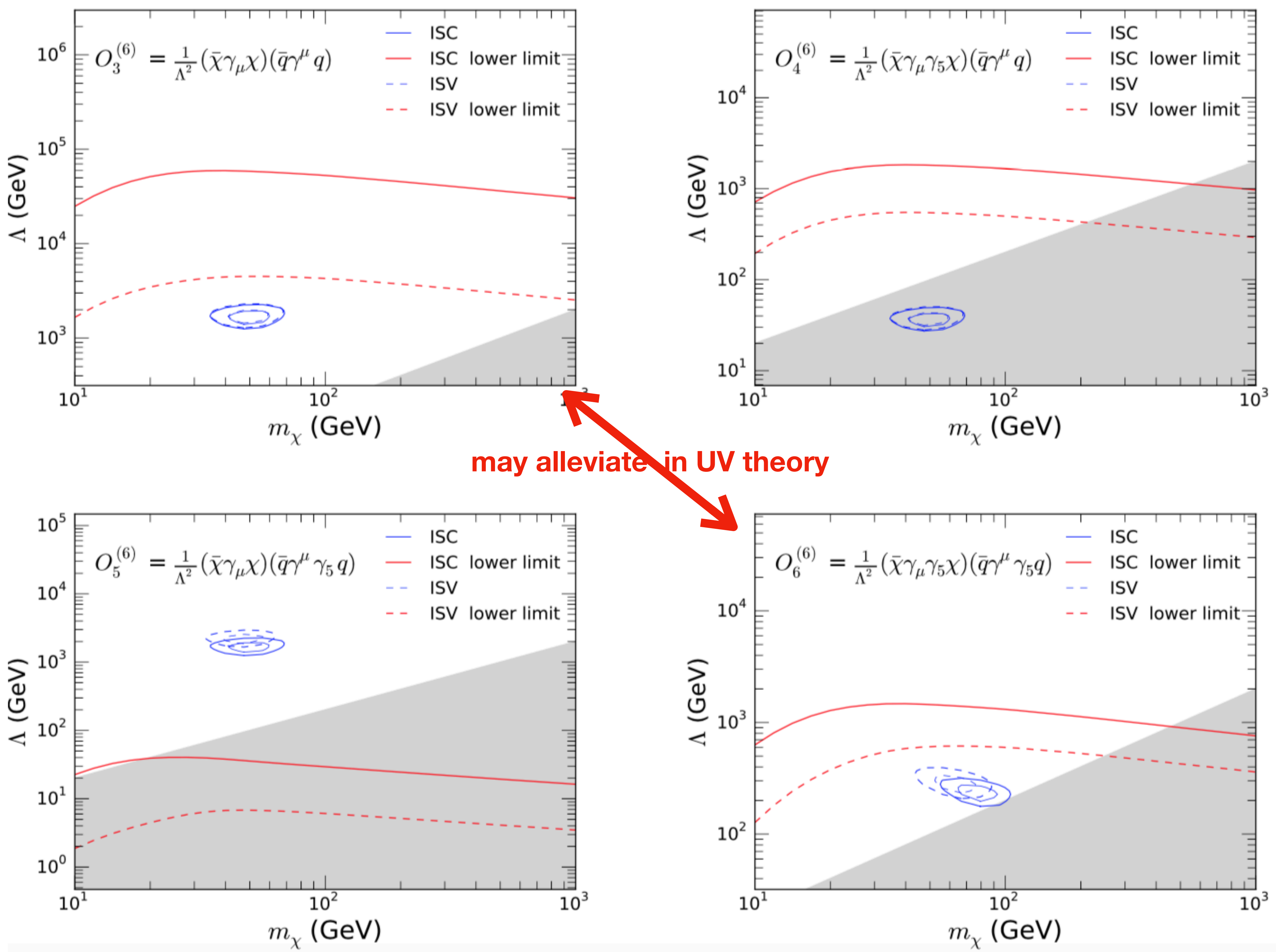


X -> H -> b,W,Z

$m_\chi \sim m_H/2$

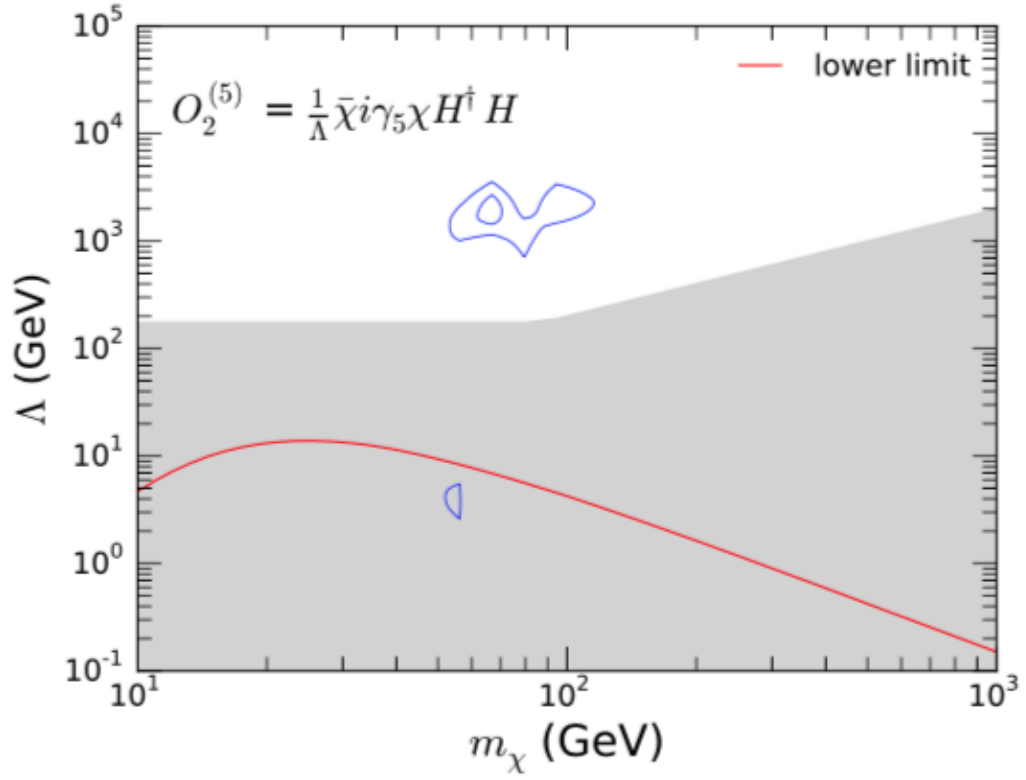
M.Y. Cui et al. (2018)

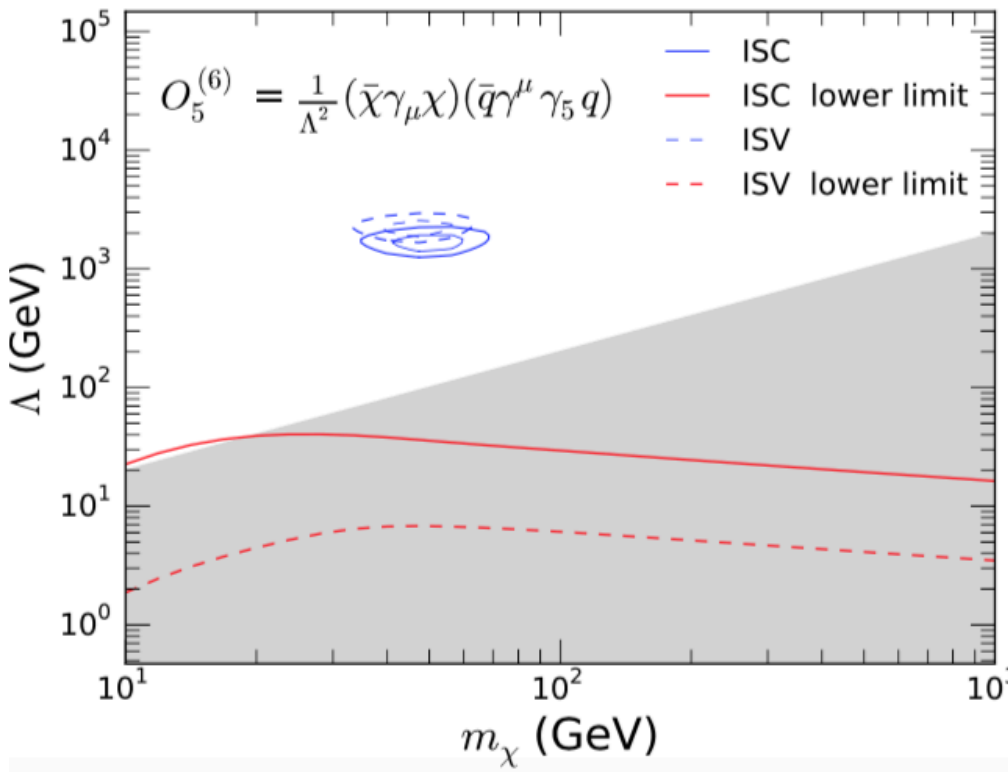
Dimension 6



M.Y. Cui et al. (2018)

Result





Can explain GCE as well !

M.Y. Cui et al. (2018)

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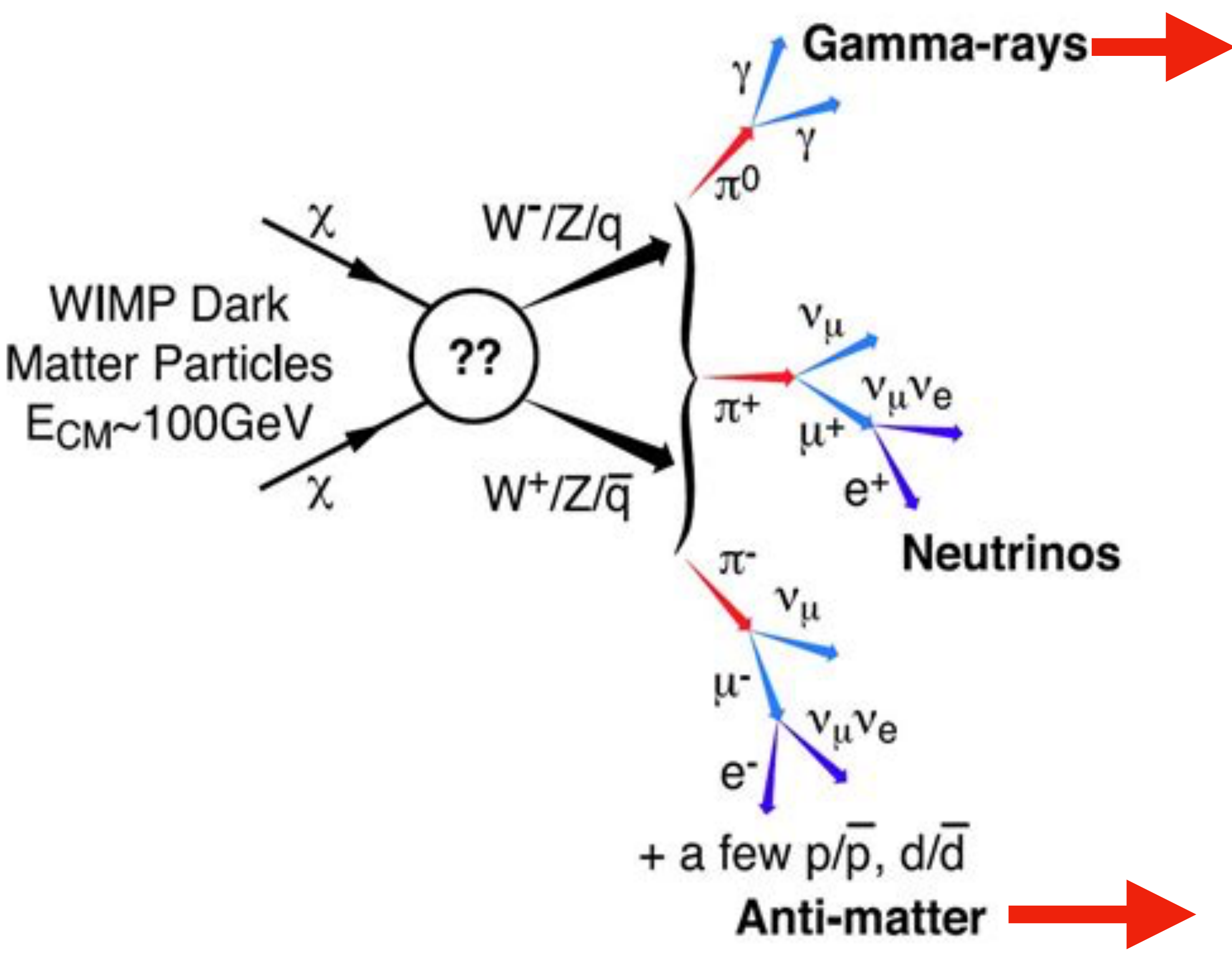
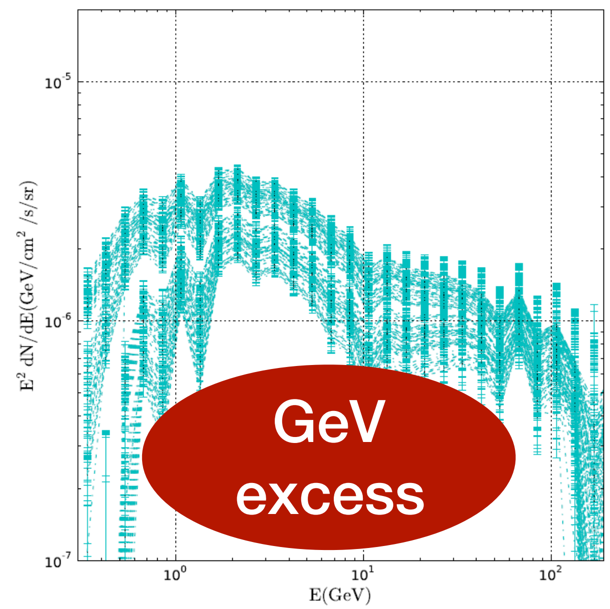
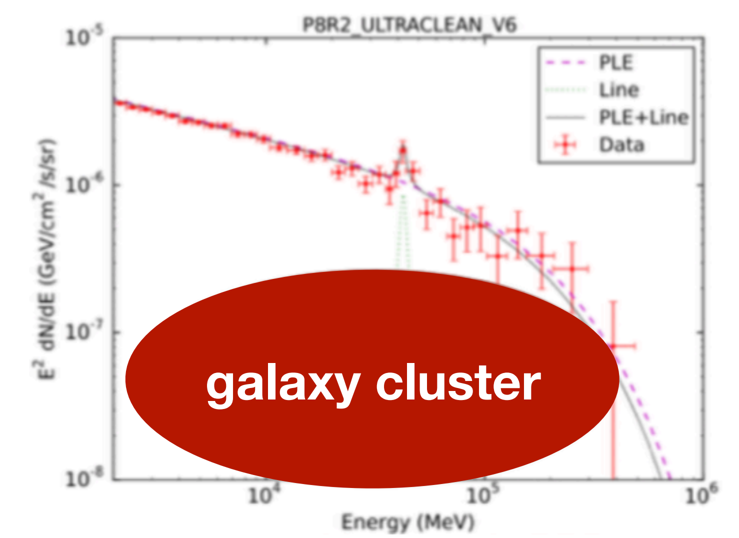
Unified Explanation

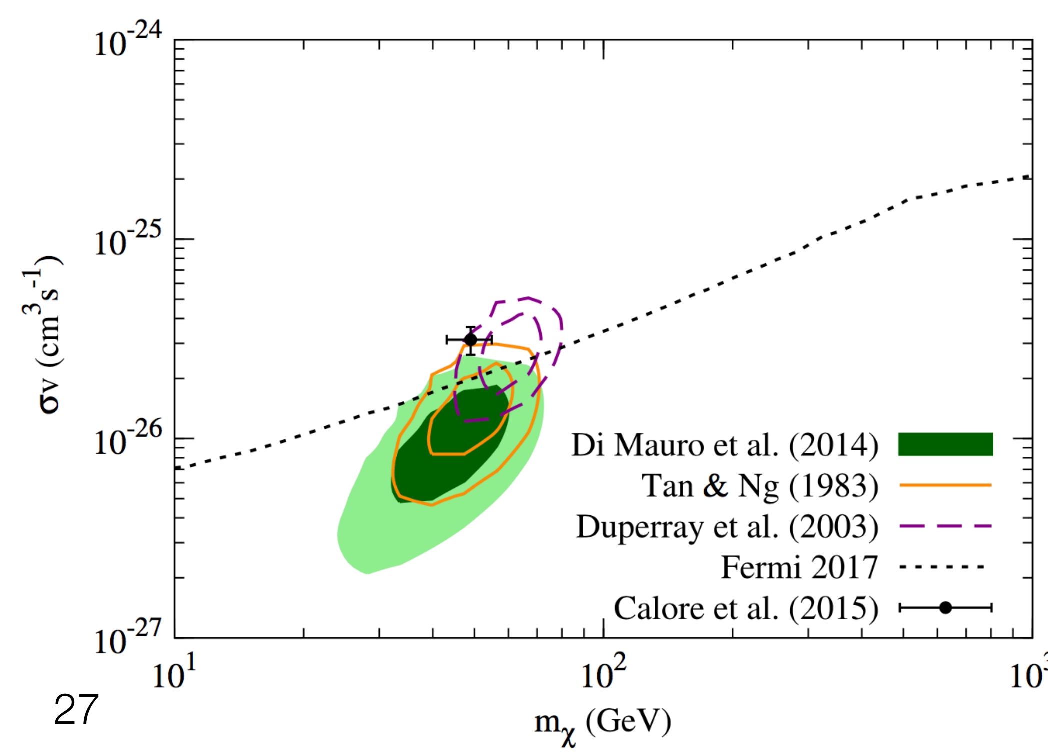




Zhou et al. 2015



Y. F. Liang et al. 2016



M.Y. Cui et al. 2017

Discussion

- Space-dependent propagation
- Large scale magnetic field
- Solar modulation

Thank you！

Backup

UV realization of O_1^5

$$\mathcal{L} \supset -\frac{m_S^2}{2} S^2 - y_\chi \,\bar{\chi}\chi S - \mu_p \, S H^\dagger H - \lambda_p \, S^2 H^\dagger H$$