How dark matter cares about topological superstrings

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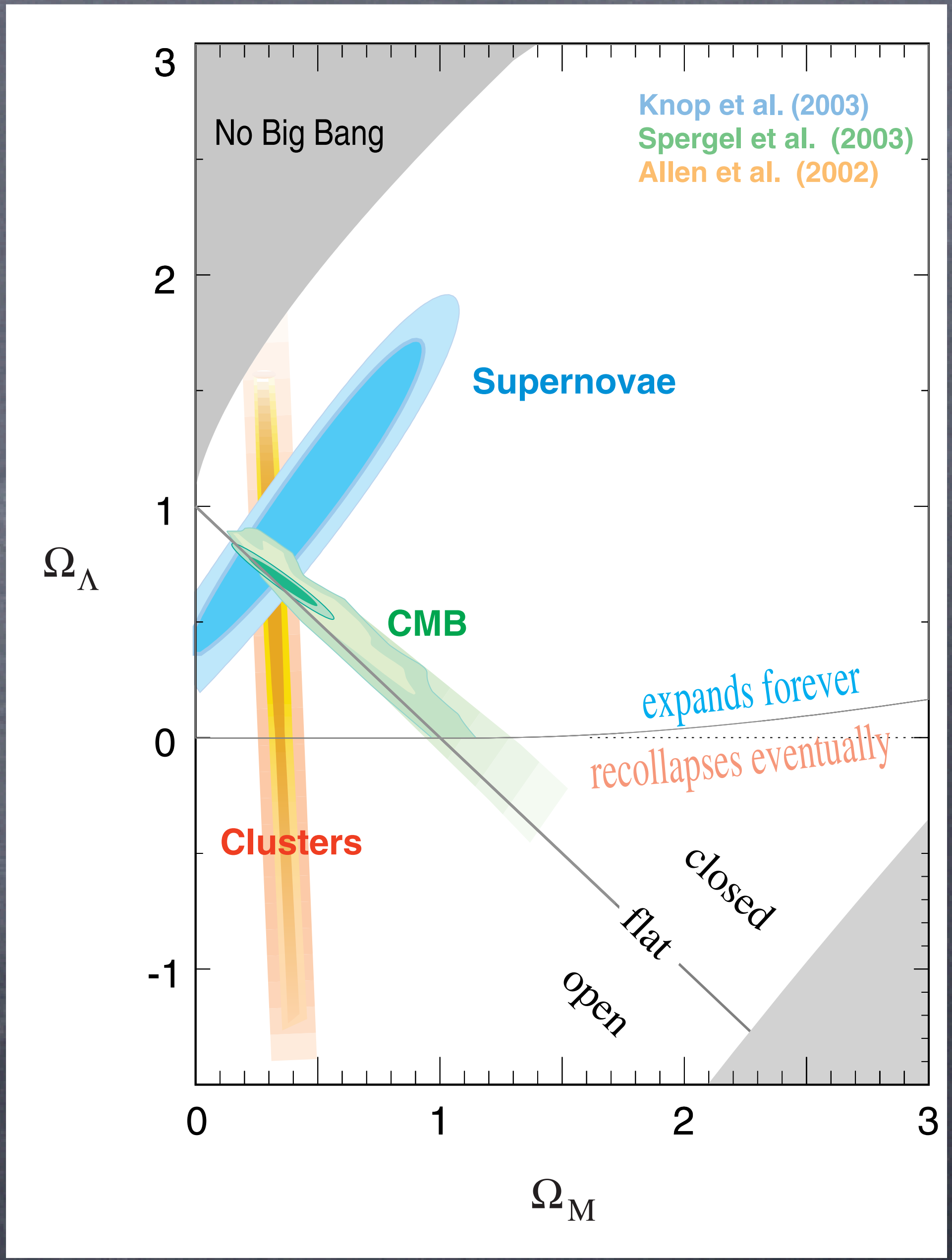
Dark Matter

- Observations of SN CMB and galaxy clusters have provided three stringent constraints on $\Omega_{\rm M}$ and Ω_Λ



- Results favor $(\Omega_{\rm M}, \Omega_\Lambda) \approx (0.3, 0.7)$

- Baryonic matter constrained by CMB and BBN

$$\Omega_{\rm B} = 4\% \pm 0.4\% \Rightarrow \Omega_{\rm DM} = 23\% \pm 4\% \quad \Omega_{\rm DM} h^2 = 0.113 \pm 0.003$$

WIMP

- Thermal freeze-out abundance of DM can be related to thermally averaged WIMP annihilation cross section

$$\Omega_{\rm DM} h \sim \frac{10^{-10}\ {\rm GeV}^{-2}}{\langle \sigma v \rangle}$$

- Typical weak cross section is

$$\langle \sigma v \rangle \sim \frac{\alpha^2}{M_{\rm weak}^2} \sim 10^{-9}\ {\rm GeV}^{-2} = 3 \times 10^{-26}\ {\rm cm}^3{\rm s}^{-1}$$

- yielding thermal relic density

$$\Omega_{\rm DM} h \sim 0.1$$

SUSY Essentials

Rotations ☛ angular momentum operators L_i

Spacetime symmetries → **Boosts ☛ boosts operators** K_i

Translations ☛ momentum operators P_μ

SUSY is the symmetry that results when these 10 generators are further supplemented by fermionic operators Q_α

R parity is defined by $R_p = (-1)^{3(B-L)+2S}$

All SM particles have $R_p = 1$ and all superpartners have $R_p = -1$

Conservation of R-parity implies $\Pi \, R_p = 1$ at each vertex
☛ yielding an elegant way to forbid proton decay in SUSY models

Dark Matter Detection

- Neutralino LSP (χ^0) are prime candidates for dark matter

Goldberg, PRL 50, 1419 (1983)

- Annihilation hindered because of p-wave barrier
- Direct Detection in CDMS, XENON, COUPP, KIMS, etc.
- Indirect Detection:
  excess of $\gamma, e^{\pm}, \nu$ from dense astrophysical environments
- ID via monoenergetic gamma-rays from $\chi^0\chi^0 \to \gamma\gamma, \gamma Z$ are loop induced in the MSSM and for the bino are small

$(\mathrm{BR} \sim 0.1\%)$

Bergstrom, Ullio, NPB 504, 27 (1997); PRD 57, 1962 (1998)

Bern, Gondolo, Perelstein, PLB 411 86, (1997)

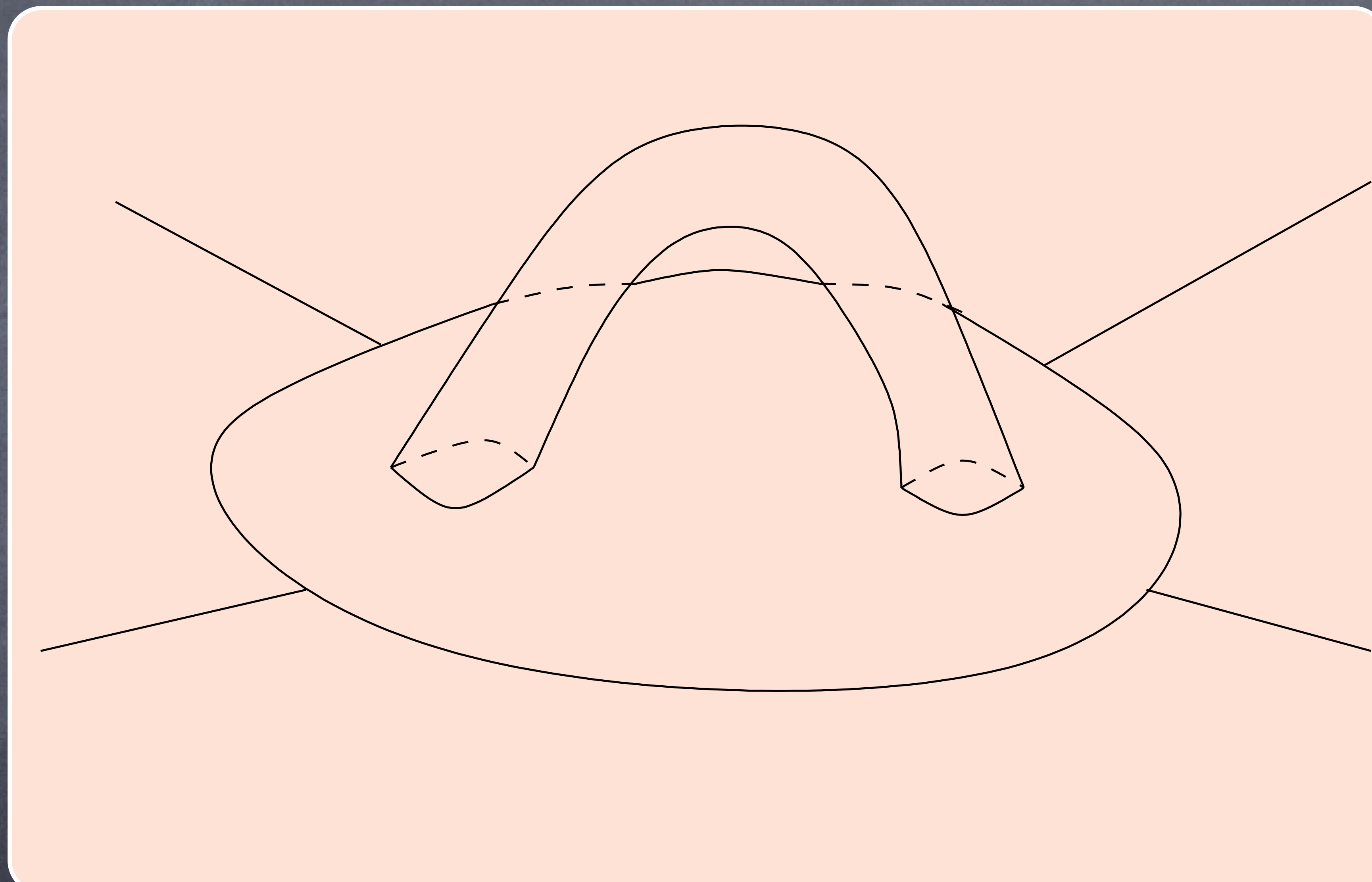
$\chi^0\chi^0$ s-wave annihilation into gauge bosons

- s-wave annihilation demands that χ^0 have same helicity
- Since $\chi^0\chi^0$ is the A term of a chiral superpotential WW and the two gauge bosons $(\sim F^2)$ are in the F term of the same or different WW there is a violation of R-symmetry by two units ➪ $\Delta r = 2$
- R-charge deficit related to Euler characteristic of the string worldsheet $\chi = 2 - 2g - h$ via $|\Delta r| \leq -2\chi$ ➪ $\chi < 0$
- Therefore require

$$\chi = -1$$

$$g = 1,\ h = 1$$

Topology



Antoniadis, Narain, Taylor, NPB 7729, 235 (2005)

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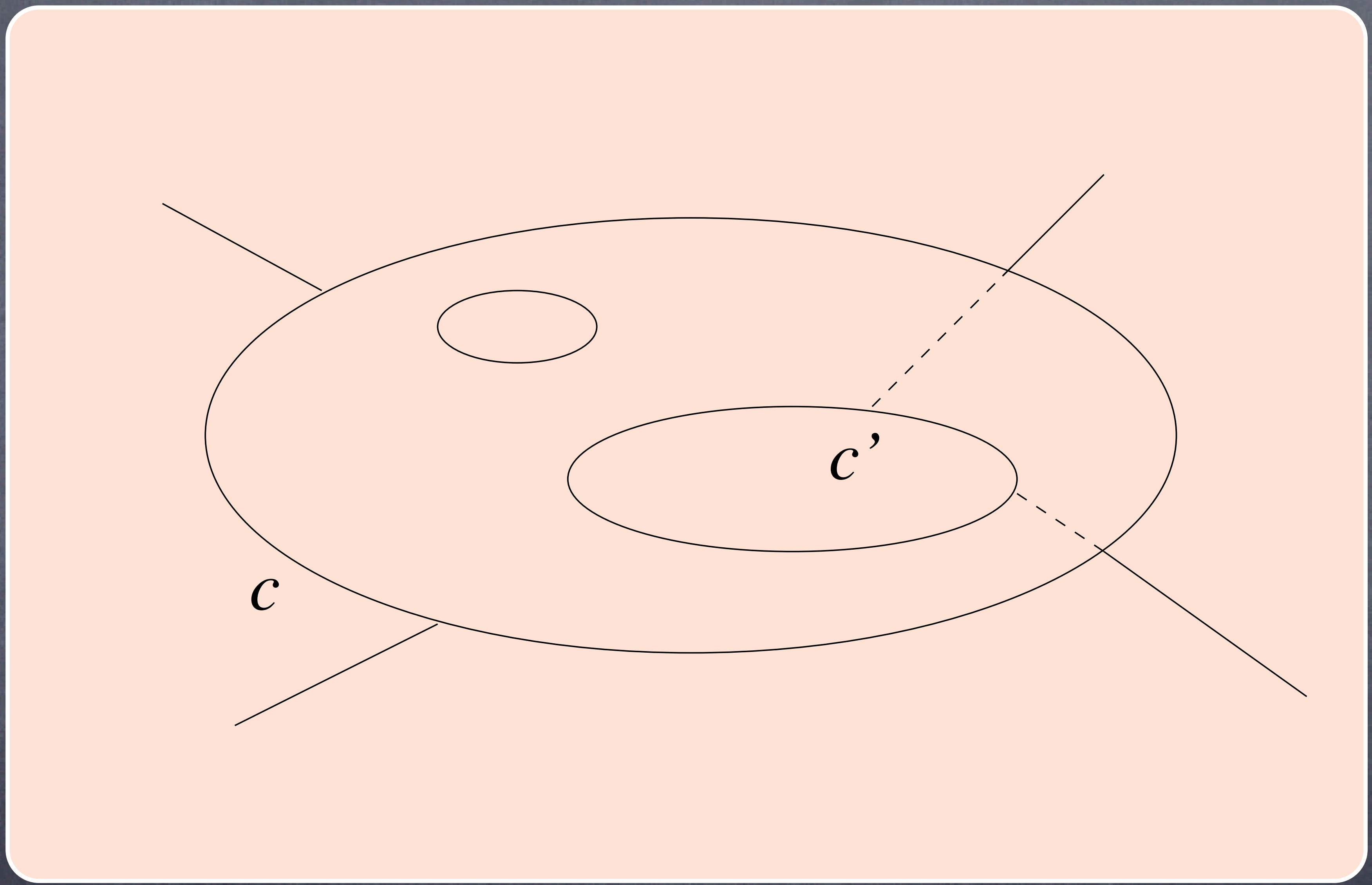
- Therefore require

$$\chi = -1$$

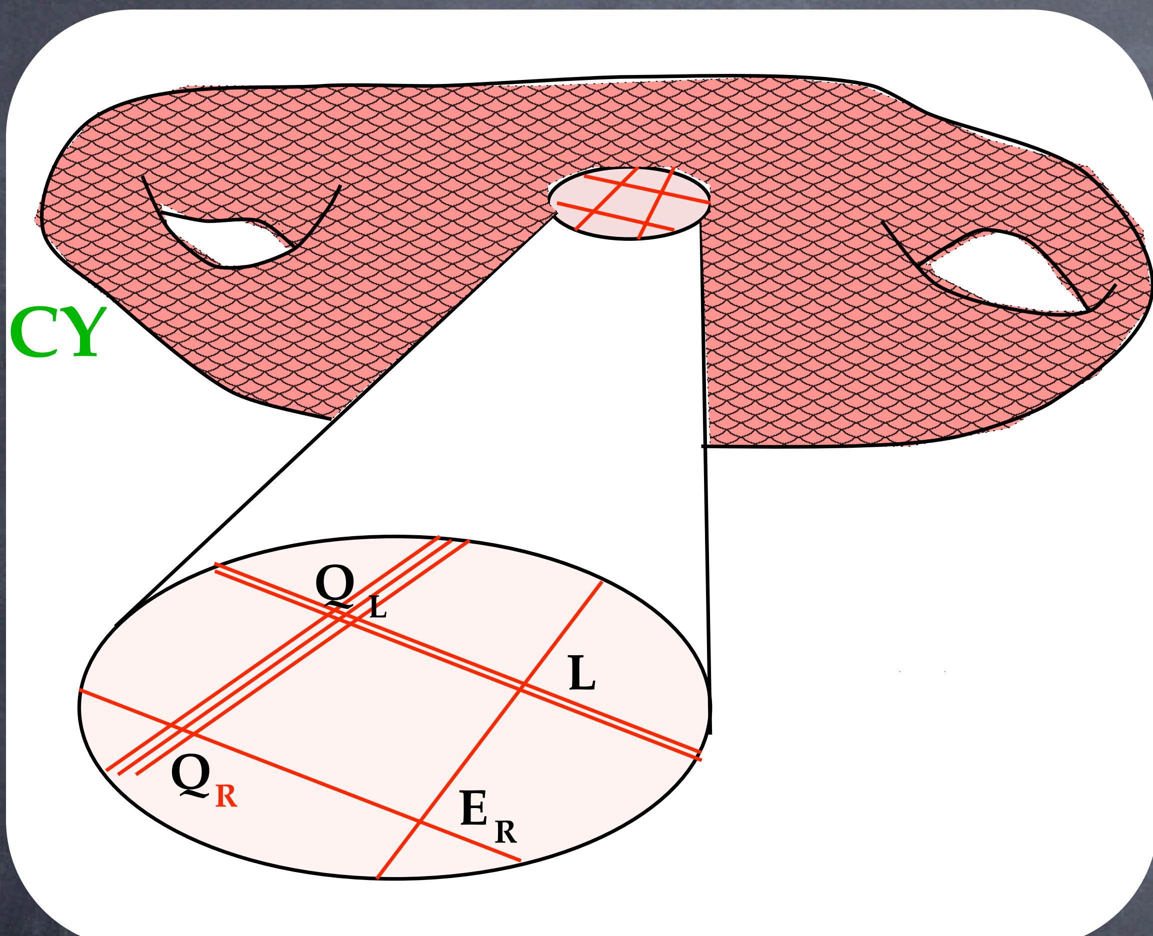
$$g = 0,\ h = 3$$

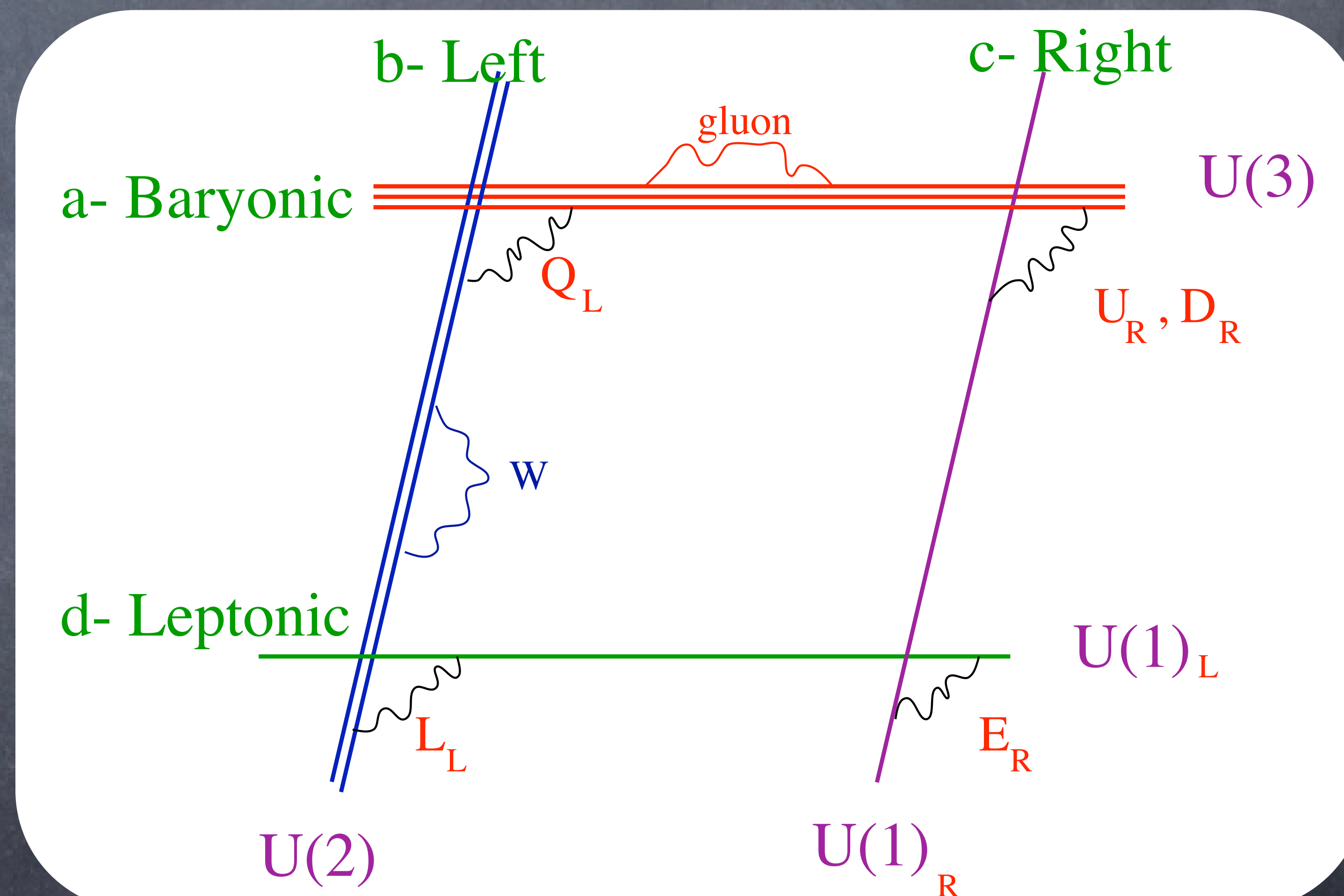
Topology



Antoniadis, Narain, Taylor, NPB 7729, 235 (2005)

SM from intersecting D-branes





Stacks, boundaries, and effective interactions

- Effective Lagrangian calculable from topology of compactified dimensions if gaugino and gauge boson vertices are attached to two different boundaries

- Additional non-topological contributions if emitted gauge bosons are in same stack as gauginos and vertices are attached to same boundary

$$\begin{aligned}\mathcal{L}_{\rm eff} &= 3g_s^3 N M_s^{-3}\tilde{F}^{(0,3)}\left(\mathrm{Tr}WW\right)\left(\mathrm{Tr}WW\right)|_{\theta\theta} + \mathrm{h.c} \\ &= \frac{3}{8}g_s^3 N M_s^{-3}\tilde{F}^{(0,3)}\left(\mathrm{Tr}\lambda\lambda\right)\left(\mathrm{Tr}FF\right) + \mathrm{h.c}\end{aligned}$$

- $N = 6 =$ number of stacks traced out in empty boundary

- $F^{(0,3)} = 3N\tilde{F}^{(0,3)} \equiv$ genus zero topological partition function on a worldsheet with $h = 3$ boundaries

Constraint from relic abundance

To generate measured relic density $\Omega_{\rm DM}h^2 = 0.113 \pm 0.003$

requires annihilation rate

$$\begin{aligned} \langle \sigma v \rangle|_{\rm eff} &= \sigma v|_{WW} + \sigma v|_{gg} + \sigma v|_{BB} \\ &\simeq 3 \times 10^{-26}\ {\rm cm}^3/{\rm s} \end{aligned}$$

for each gluon or W pair

$$\begin{aligned} \sigma v|_{W^i W^i} &= \sigma v|_{g^i g^i} \\ &= \frac{c}{4\pi}\left(3 g_s^3 N \tilde{F}^{(0,3)}\right)^2 \frac{1}{M_s^2}\left(\frac{m_{\chi^0}}{M_s}\right)^4 \end{aligned}$$

To account non-topological contributions to $\chi^0\chi^0 \to BB$ define

$$\zeta = \frac{\mathcal{M}(BB)}{\mathcal{M}(W^3 W^3)}$$

Relic constraint is

$$[1 + 0.083(\zeta^2 - 1)]\left(\frac{\tilde{F}^{(0,3)}}{2.8}\right)^2 \left(\frac{g_s}{0.2}\right)^6 \left(\frac{m_{\chi^0}/M_s}{0.5}\right)^4 \left(\frac{2\ {\rm TeV}}{M_s}\right)^2 \approx 1$$

Smoking Gun

- Rewrite cross sections in terms of γ, Z, $W^{\pm}$, g

$$\sigma v|_{\gamma\gamma} = \sigma v|_{W^3W^3}\,(\sin^2\theta_{\rm W} + \zeta\cos^2\theta_{\rm W})^2$$

$$\sigma v|_{ZZ} = \sigma v|_{W^3W^3}\,(\cos^2\theta_{\rm W} + \zeta\sin^2\theta_{\rm W})^2$$

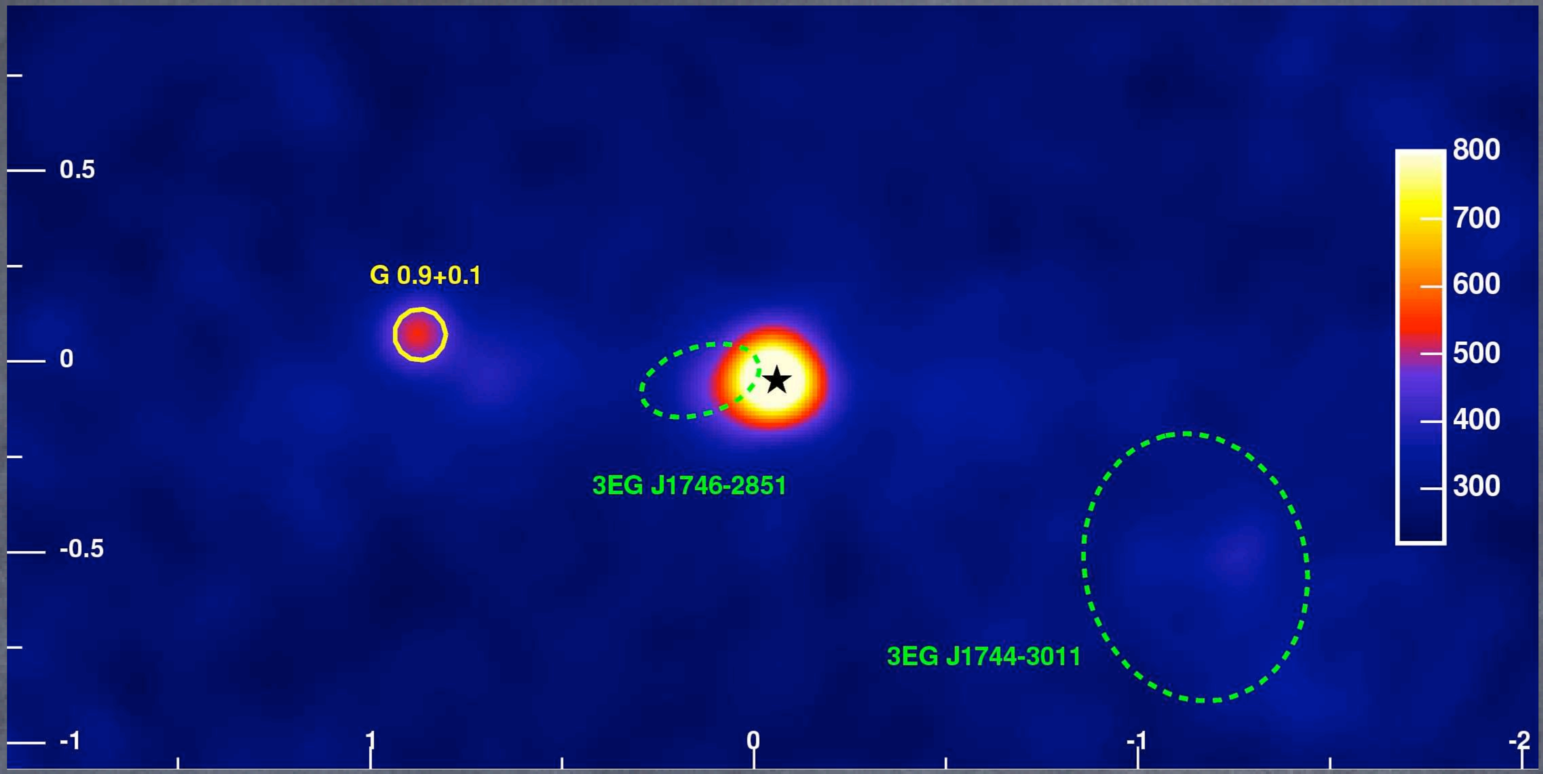
$$\sigma v|_{\gamma Z} = \sigma v|_{W^3W^3}\,2\;\cos^2\theta_{\rm W}\;\sin^2\theta_{\rm W}\;(1-\zeta)^2$$

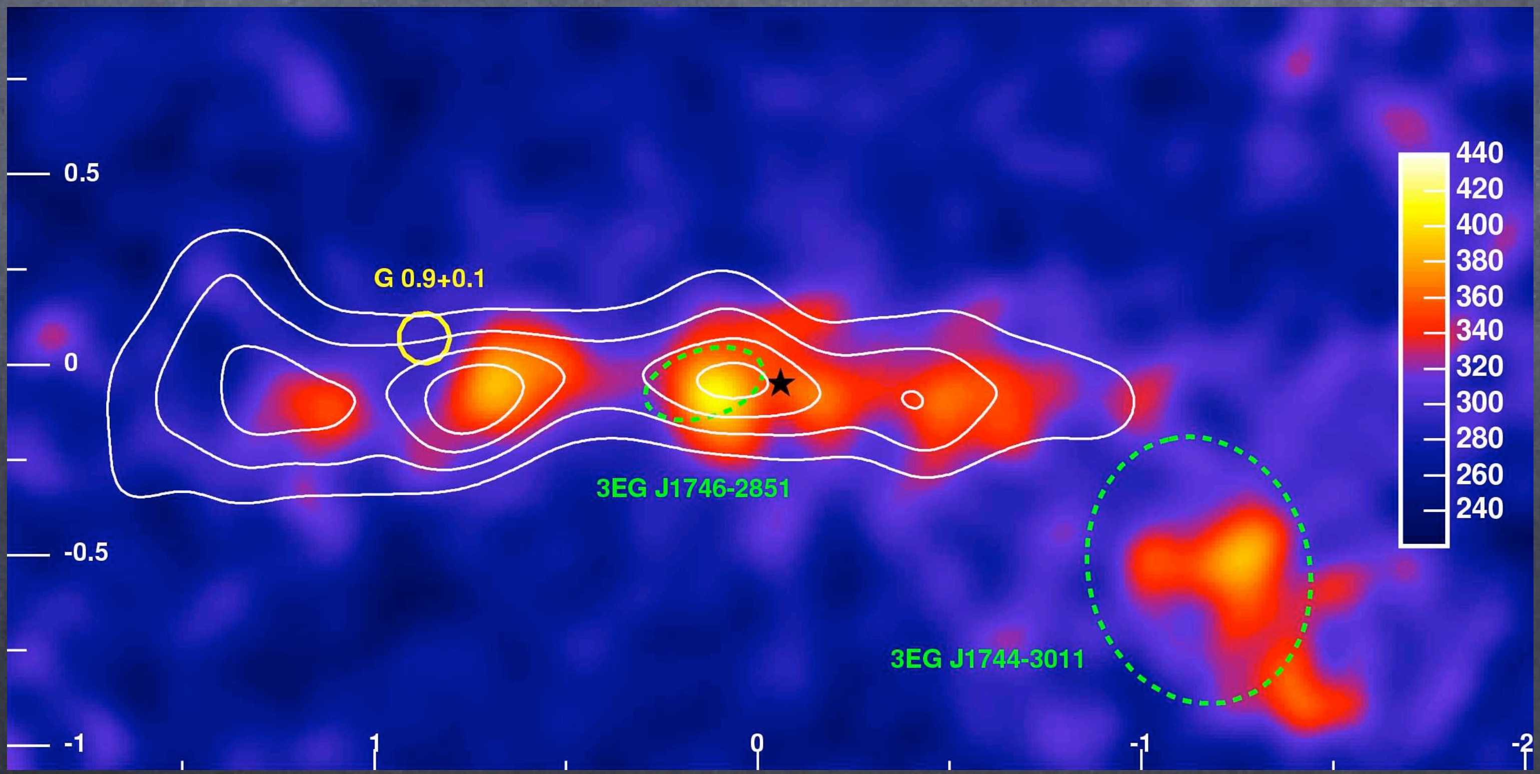
$$\sigma v|_{W^+W^-} = 2\,\sigma v|_{W^3W^3}$$

$$\sigma v|_{gg} = 8\,\sigma v|_{W^3W^3}$$

- For $\zeta \simeq 1$ obtain nearly 10% branching into $\gamma\gamma$ large number of gamma rays with energy $\sim m_{\chi^0}$

H.E.S.S and Galactic Center





H.E.S.S. Collaboration, Nature 439, 695 (2006)

Gamma-ray Flux from annihilation in GC

$$D_\odot \simeq 8.5 \text{ kpc}$$

$$\rho_\odot = 0.3 \text{ GeV/cm}^3$$

$$\phi^\gamma(\psi, E_\gamma) = \int \bar{J} \, \frac{1}{2} \, \frac{D_\odot}{4\pi} \, \frac{\rho_\odot^2}{m_\chi^2} \, \sum_f \langle \sigma v \rangle_f \, \frac{dN_f}{dE_\gamma} \, d\Omega$$

$$\bar{J} = (1/\Delta\Omega) \int_{\Delta\Omega} J(\psi) \, d\Omega$$

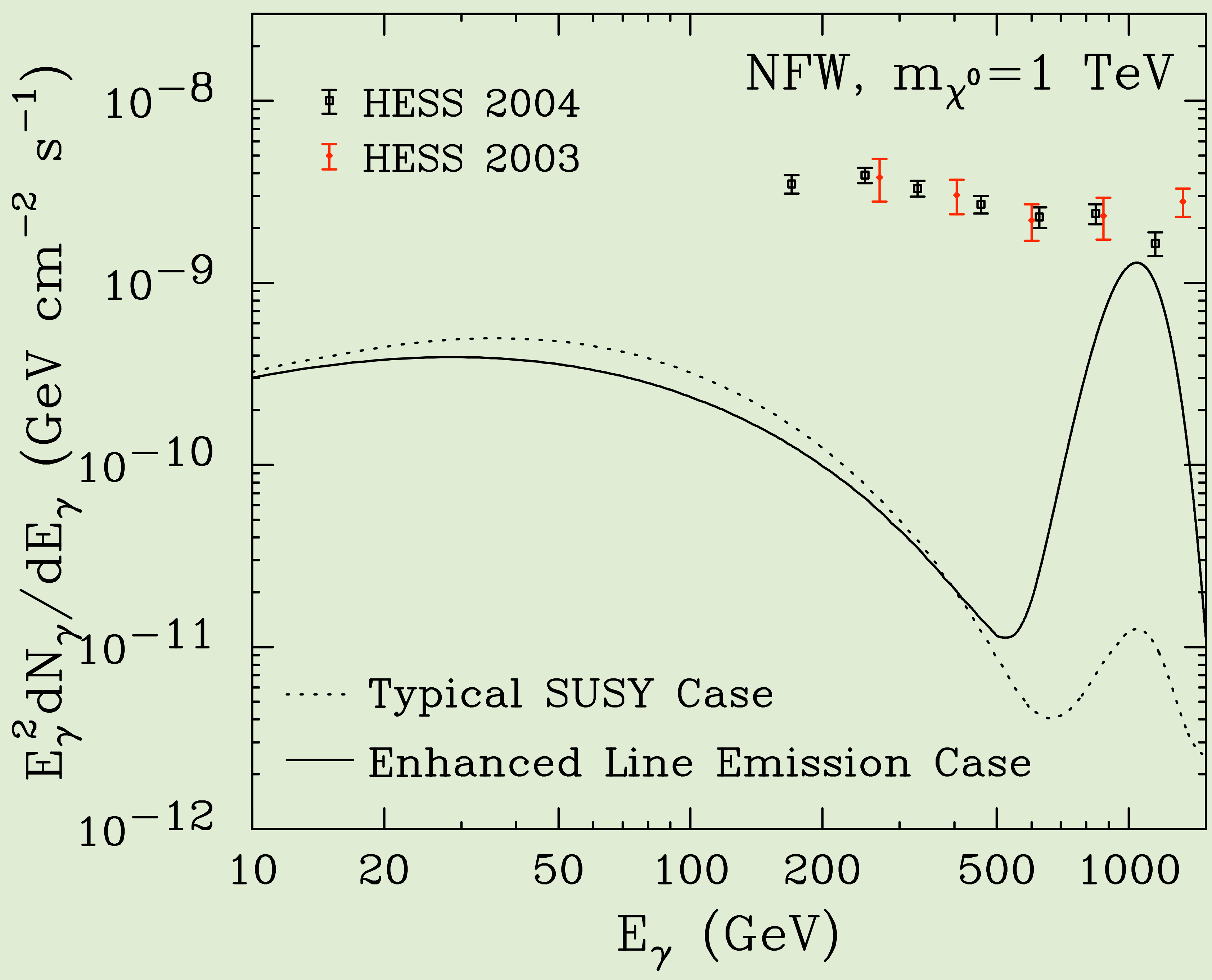
$$J(\psi) = (D_\odot \rho_\odot^2)^{-1} \int_{\ell=0}^{\infty} \rho^2[r(\ell,\psi)] d\ell$$

$$r^2 = \ell^2 + D_\odot^2 - 2\ell D_\odot \cos\psi$$

dN_f/dE_γ ☞ normalized photon spectrum per annihilation via channel f

$\rho(\vec{x})$ ☞ dark matter density at generic location $\vec{x}$ wrt to GC

Spectrum



L.A.A, H. Goldberg, D. Hooper, D. Marfatia and T. R. Taylor, PLB **683**, 321 (2010).

Direct Detection

- The (dimension 7) interaction operator relevant for DD is

QCD coupling strength

$$\mathcal{L}_{\rm eff} = \frac{\alpha_s}{\Lambda^3}\,\bar{\chi}\chi\;G^a_{\mu\nu}G^{\mu\nu a}$$

$$\Lambda = M_s(3Ng_s^2\tilde{F}^{(0,3)}/4)^{-1/3}$$

gluon field-strength tensor

- The spin independent elastic scattering cross section is

proton-WIMP coupling

$$\sigma = \frac{4}{\pi}m_p^2 f_p^2 = \frac{4}{\pi}m_p^2\left(\frac{8\pi}{9}\frac{m_p}{\Lambda^3}f_{\rm TG}\right)^2 = \frac{256}{81}\,\pi\,\frac{m_p^4}{\Lambda^6}\,f_{\rm TG}^2$$

reflects the gluon content of the nucleus and is measured to be ~ 0.83

Jungman, Kamionkowski, Griest, PR 267, 195 (1996)

- For $M_s = 2\ {\rm TeV} \Rightarrow \Lambda = 2.5\ {\rm TeV}$ ➡ $\sigma \approx 10^{-47}\ {\rm cm}^2$

well below current limits $\sigma < 2\times 10^{-43}\ {\rm cm}^2$ @90%CL

CDMS Collaboration arXiv:0912.3592

Remarks and Conclusions

- We constructed a model that generates a supersymmetric R-symmetry violating effective Lagrangian which allows for s-wave annihilation of neutralinos
(once gauginos acquire mass via an unspecified mechanism)
- The model allows for a neutralino relic abundance consistent with the measured dark matter density
- The branching fraction to monochromatic gamma rays is orders of magnitude larger than in the MSSM
- A very bright and distinctive gamma-ray line that may lie within the reach of current or next-generation gamma-ray telescopes is predicted