HEP 2013
Stockholm
18-24 July 2013
(info@eps-hep2013.eu)

Experimentally Viable Mass of the Fermionic Dark Matter

Based on Phys.Rev. D87 (2013) 115016
In coll. with Kwei-Chou Yang

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2013.07.18 (Thu) 18:15-18:30pm

Outline

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  - Relic Abundance
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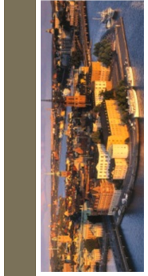
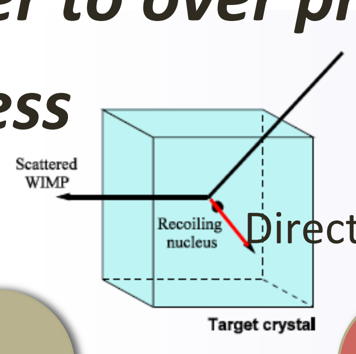
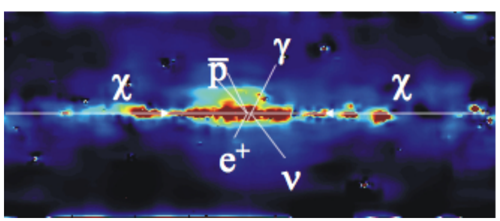


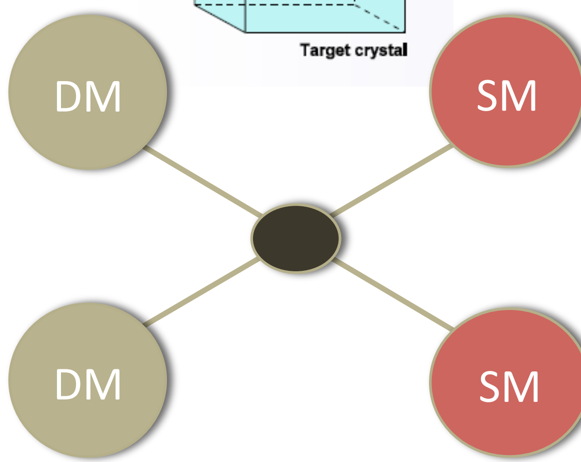
Dark Matter Introduction

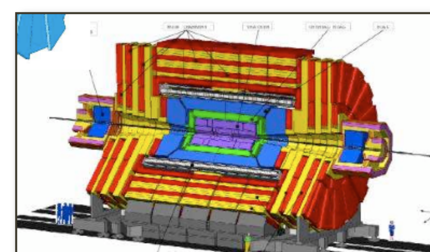
- ***CMB, Bullet Clusters, Galactic Rotational Curve,… evidence in various scales.***
- ***Interaction weak to escape experimental searches but not too weaker to over produce DM relic***
- ***Invisible, Chargeless***
- ***BSM fermion, scalar…***



Direct detection

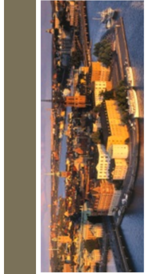


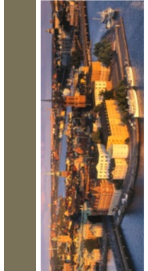




Indirect detection
Relic →

← Collider





Dark Matter Searches

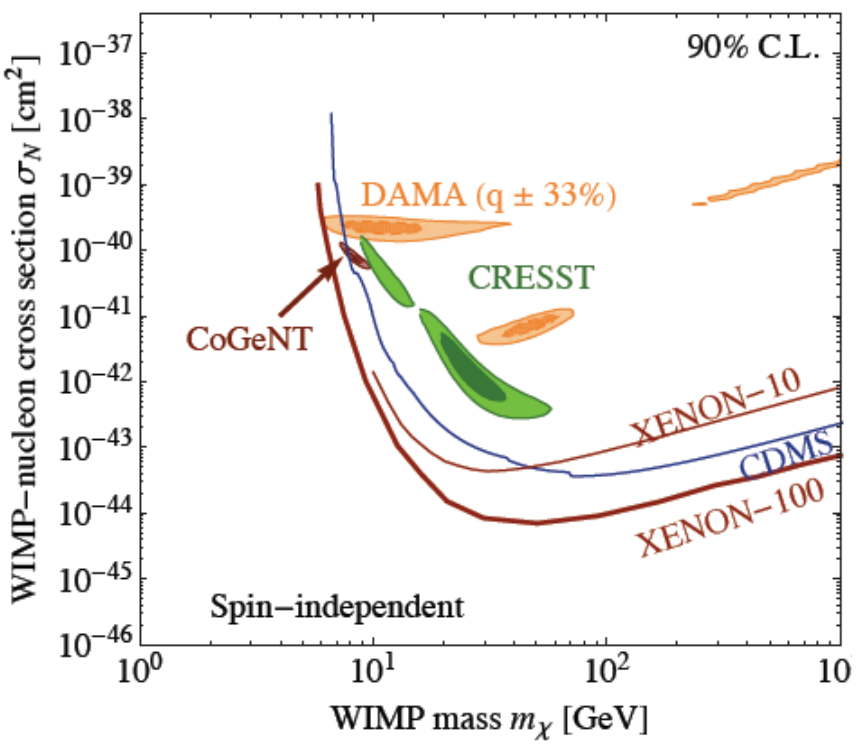
Relic $\Omega_\chi h^2 \simeq \frac{0.1\ \mathrm{pb}\cdot c}{\langle \sigma_{\mathrm{ann}} v_{\mathrm{rel}} \rangle}$ ~ 0.1

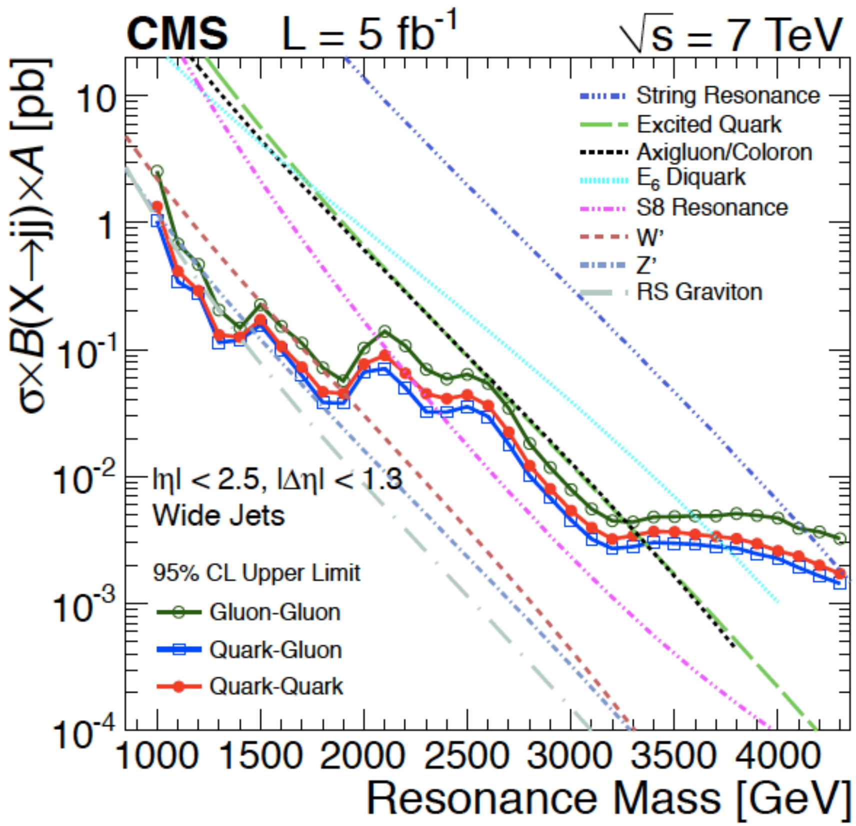
DM Direct Detection: 10^{-9} ~10^{-10} pb

DM Indirect Detection

Monojet + missing transverse energy

Di-Jet Resonance Search

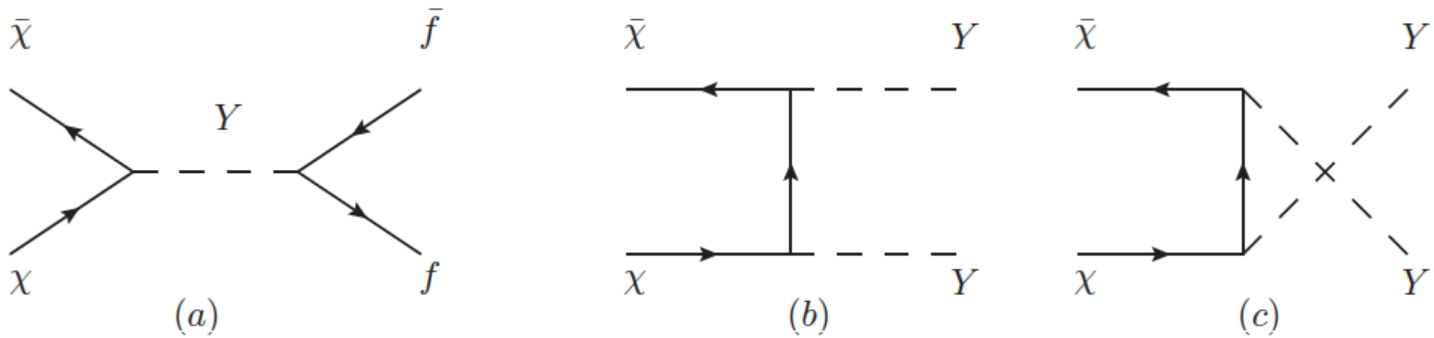




SM + Fermionic DM + Scalar Y

- Effective $Y\overline{\chi}(\lambda_s^\chi + i\lambda_p^\chi\gamma^5)\chi + Y\bar{f}(\lambda_s^f + i\lambda_p^f\gamma^5)f$

- DM annihilation



- Similar formula for SS, SP, PS, PP

$$\langle\sigma v_{\rm rel}\rangle^{SS} = N_c\frac{\lambda_s^{\chi 2}\lambda_s^{f2}}{2\pi}\frac{p_\chi^2 p_f^3}{E^3[(4E^2-m_Y^2)^2+m_Y^2\Gamma_{SS,Y}^2]} + \frac{\lambda_s^{\chi 4}}{2\pi}\frac{E m_\chi^2 p_\chi^2 p_Y\,\theta(E-m_Y)}{[4(E^2-m_Y^2)m_\chi^2+m_Y^4]^2}$$

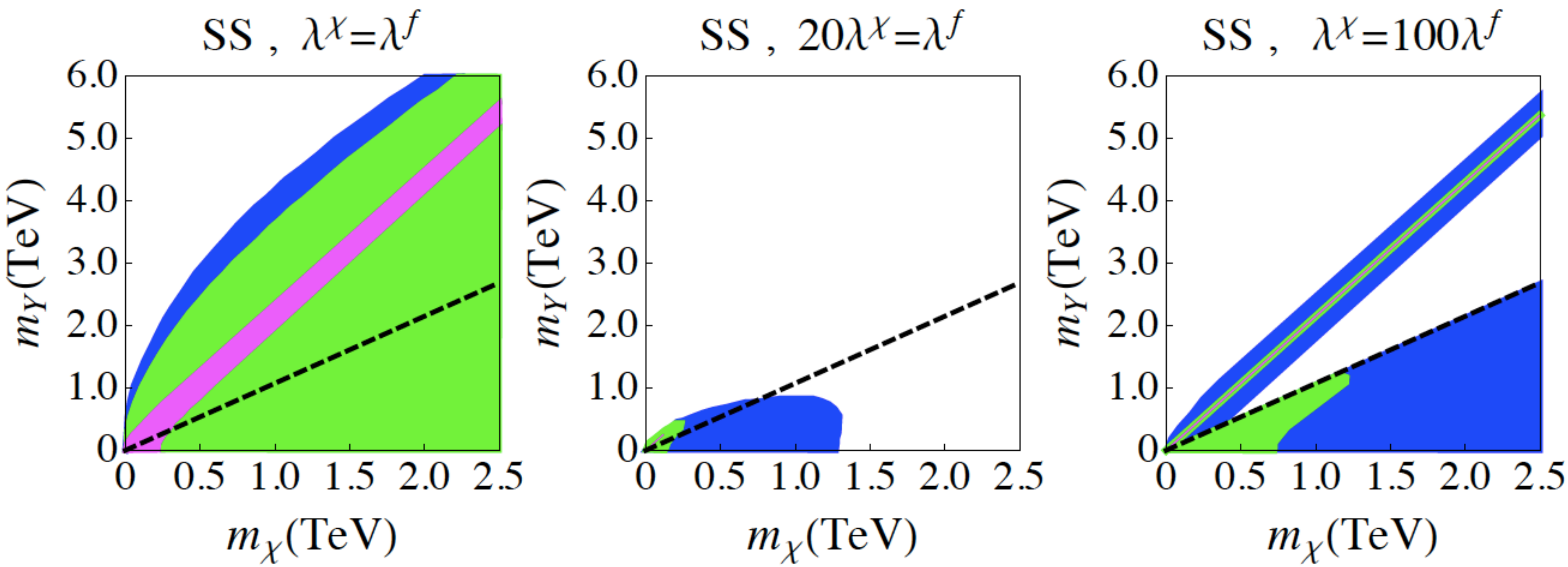
- DM relic $\Omega_\chi h^2 \simeq \frac{0.1\ {\rm pb}\cdot c}{\langle\sigma_{\rm ann}v_{\rm rel}\rangle}$ ~ 0.1 fix coupling to $\lambda_\chi^4, \lambda_f^4(m_\chi, m_Y)$

Plot m_χ v.s. m_Y with Right Relic

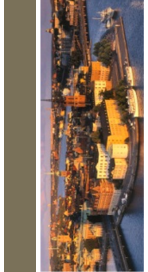
$Max\{\lambda_\chi, \lambda_f\}$

$$m_Y \sim E \sim m_\chi + \tfrac{3}{40} m_\chi$$

Color code: 0 < Magenta < 0.3 < Green < 1 < Blue < 3 ~ Perturbativity < $\sqrt{4\pi}$



Similar plots for SP, PS and PP cases



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χ-N Scattering Direct Detection

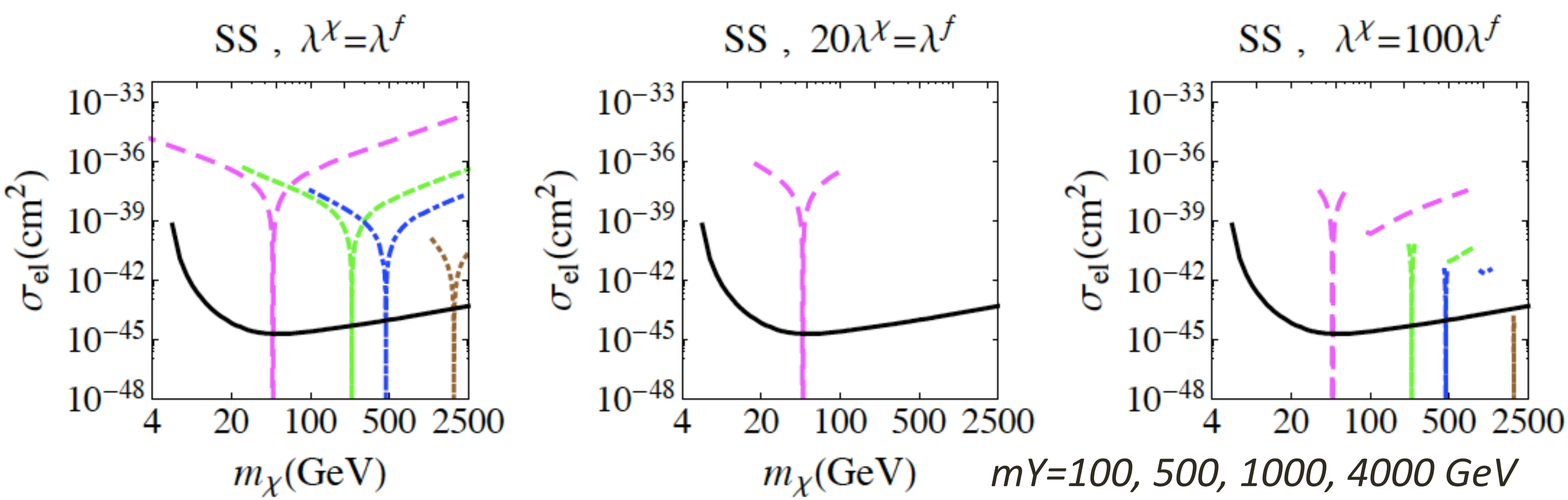
$$\sigma_{el}^{SS}(\chi N \to \chi N) = \frac{\lambda_s^{\chi 2}\lambda_s^{f 2}}{\pi}\frac{m_\chi^2 m_N^2}{(m_\chi + m_N)^2 m_Y^4} f_N^2$$

$$p = \mu v \qquad v \sim 10^{-3} c$$

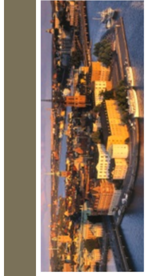
		Pseudo-scalar velocity Suppression
		1
SP	$p^2 / 2m_N^2$	***10^{-6}***
PS	$p^2 / 2m_\chi^2$	***10^{-10}***
PP	$p^4 / 3m_N^2 m_\chi^2$	***10^{-12}***

PS, PP are very rarely constrained by ***Xenon100***

$P=10^{-3}$ for $m_\chi = 100\ m_N$



mY=100, 500, 1000, 4000 GeV



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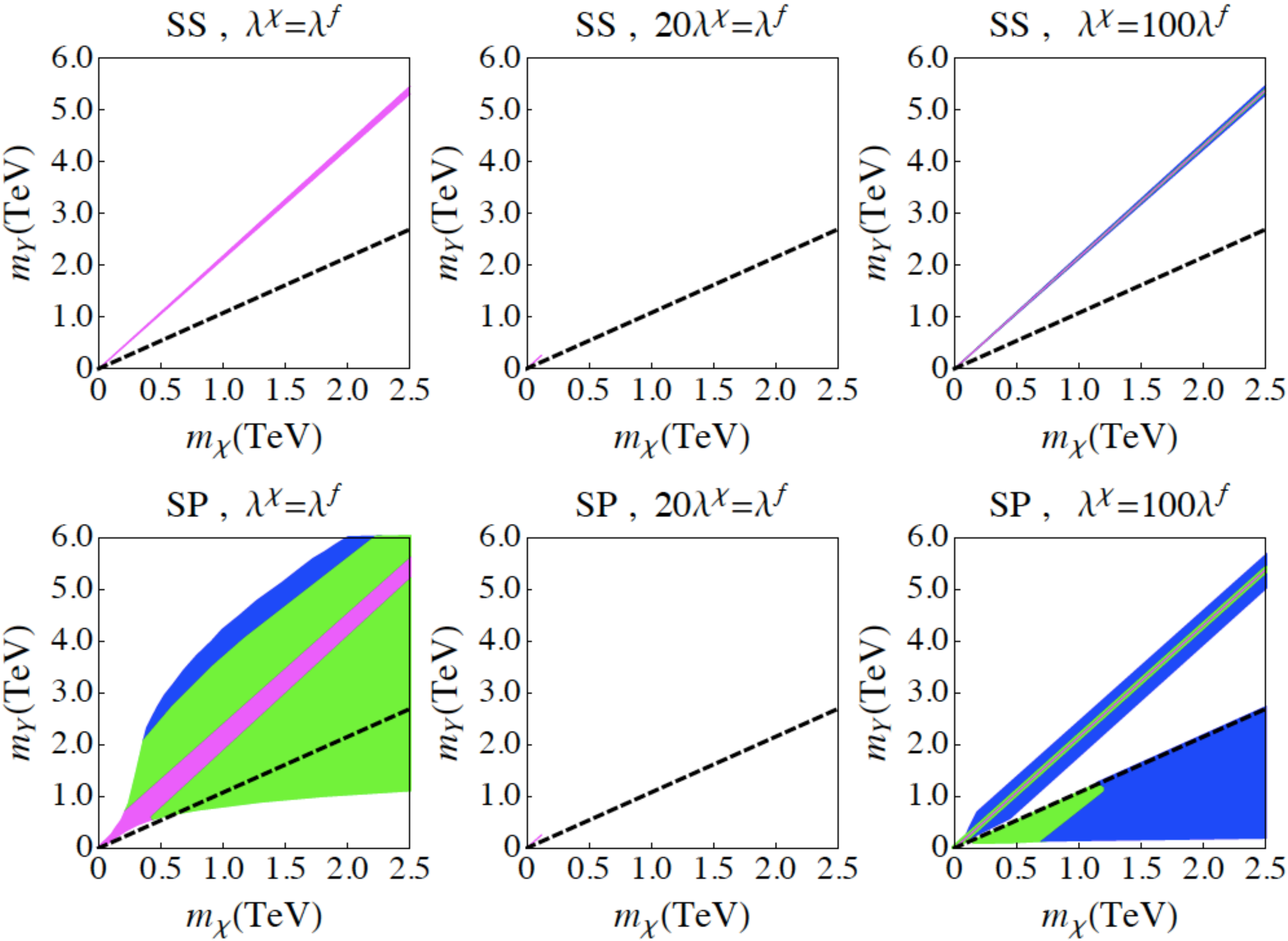
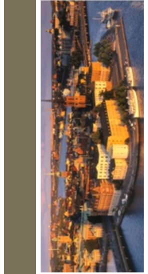
Relic+Direct Detections Results





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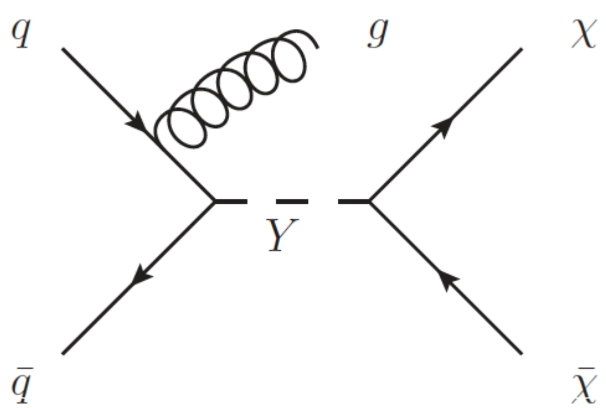
DM in Mono-jet + Missing E_T

Invisible Y



For light DMs

SM BG p p → j Z→ j ν ν

ALTAS 1202.0158 MadGraph5

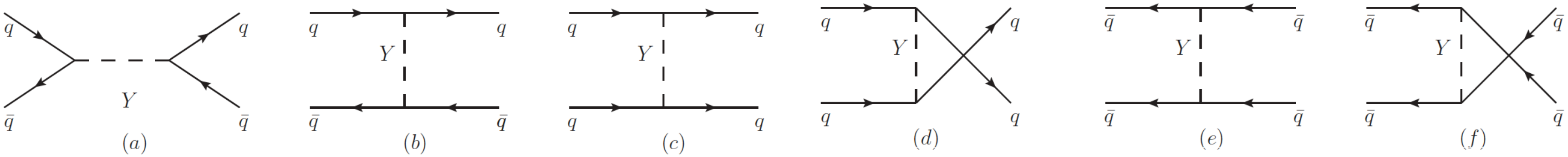
VeryHighPT: 7 TeV, 1fb-1 missing $E_T > 300$GeV

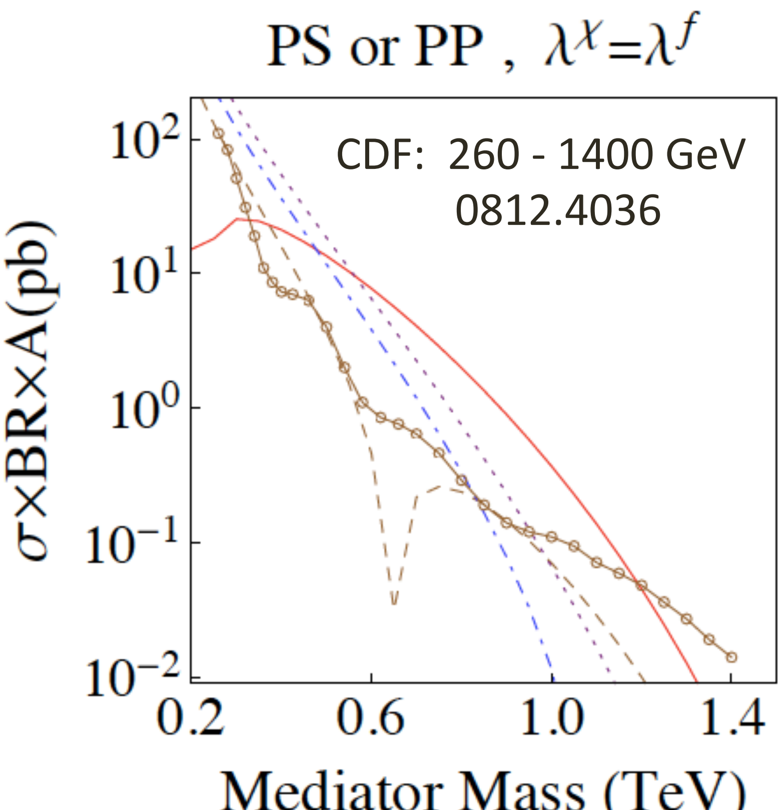
$\sigma_{1j} < 0.045$pb

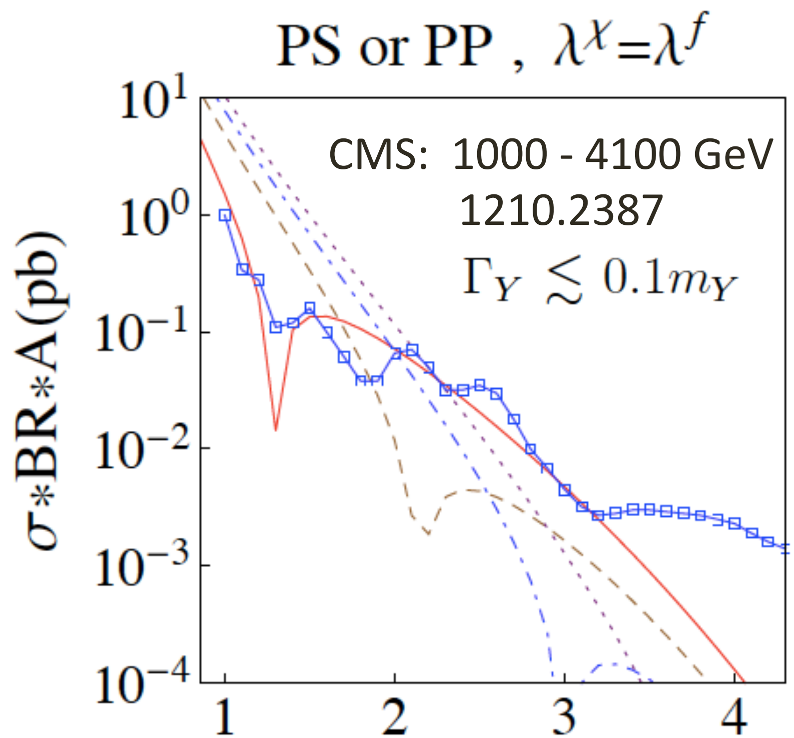
Dijet Resonances Search for Y

visible Y

Review 1110.5302 by R.M. Harris & K. Kousouris

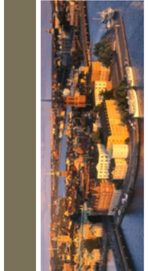






m_χ = 500, 1000, 1500, 2000 GeV

m_χ = 100, 300, 500, 700 GeV



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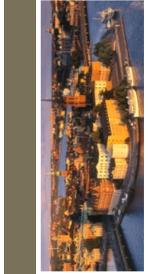
Other Constraints

- Indirect detection: No constraint on SS and SP cases due to v^2 suppression, but mx < 30 GeV of PS and PP cases is disfavored by Fermi-LAT.

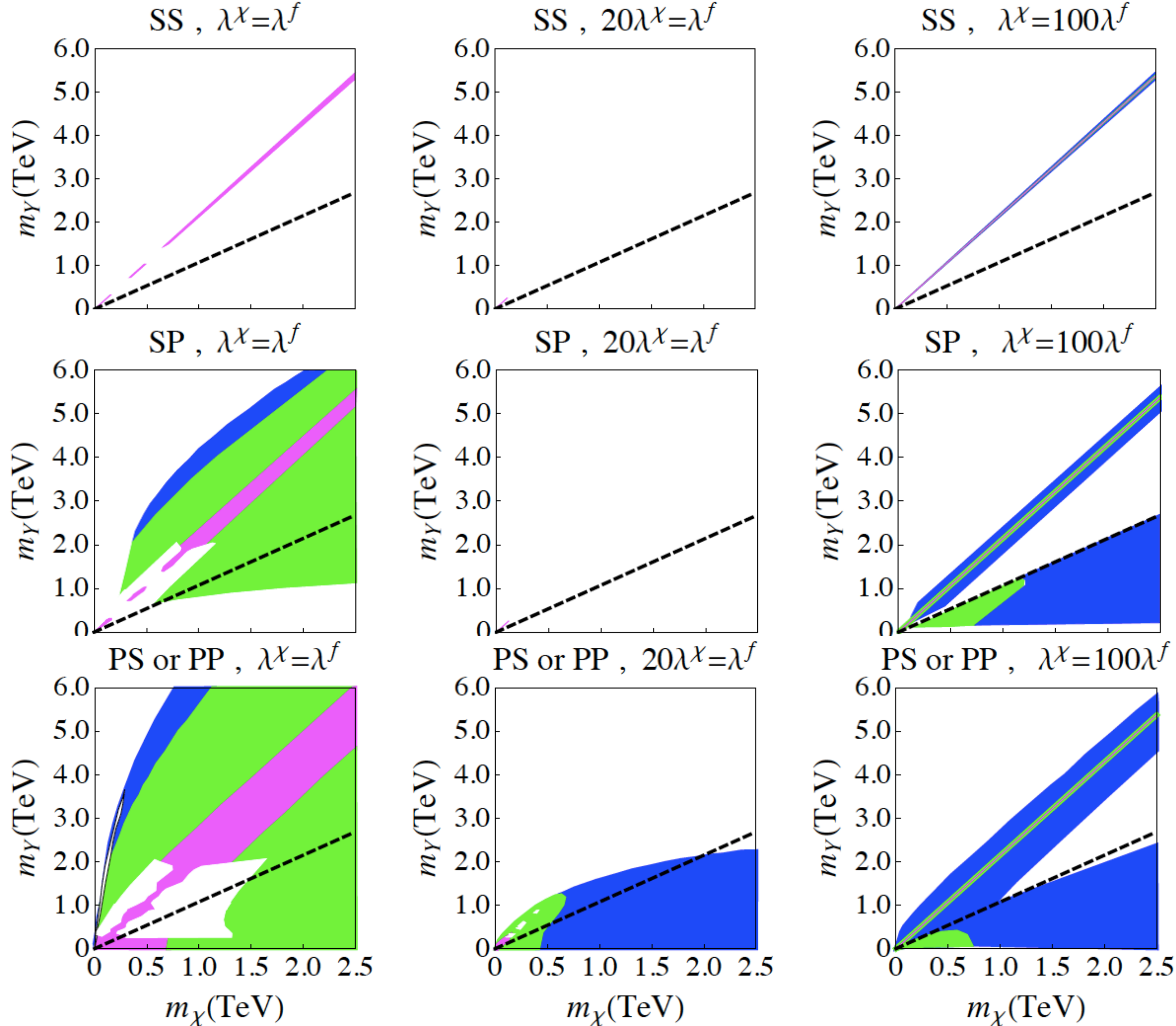
- Di-photon search: This loop effect is too small in our uniform coupling case.

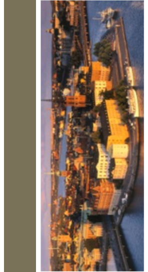
- Y is fat when $\lambda_\chi, \lambda_f > 1 \Rightarrow \Gamma_Y > m_Y$

- Narrow width $\lambda_\chi, \lambda_f < 0.3 \Rightarrow \Gamma_Y < 0.1 m_Y$



總結果





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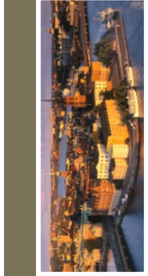
Conclusions

- Fermionic DM couple universally to the SM quarks through scalar particle Y with scalar or pseudo-scalar coupling.
- Viable mass domain (m_χ, m_Y) is small for SS, SP cases but is large for PS, and PP cases.
- Direct detection favors DM pseudo-scalar coupling case due to velocity suppression.
- Mono-jet further constrain PS and PP further. Di-jet further constrain all cases.
- DM may be near if Y found.



Thank you very much.

Di-Jet Visible Y Search

SEARCHES FOR DIJET RESONANCES AT HADRON COLLIDERS arXiv: 1110.5302

ROBERT M. HARRIS (Fermilab) and KONSTANTINOS KOUSOURIS(CERN)

$$\sigma = \sum_{ij} \int dx_1 dx_2 f_i(x_1, \mu_F^2) f_j(x_2, \mu_F^2) \hat{\sigma}_{ij} \left(\alpha_s(\mu_R^2), \frac{Q^2}{\mu_F^2}, \frac{Q^2}{\mu_R^2} \right)$$

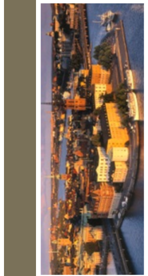
$$\frac{dL_{ij}}{d\tau} = \int_0^1 \int_0^1 dx_1 dx_2 f_i(x_1) f_j(x_2) \delta(x_1 x_2 - \tau)$$

$$\tau = x_1 x_2 = \frac{\hat{s}}{s}$$

$$\hat{\sigma}(m) = \frac{16\pi \times \mathcal{N} \times \mathcal{A}_{\cos\theta^*} \times BR \times \Gamma_R^2}{\left(m^2 - m_R^2\right)^2 + m_R^2 \Gamma_R^2}$$

$$\frac{1}{\left(m^2 - m_R^2\right)^2 + m_R^2 \Gamma_R^2} \approx \frac{\pi}{m_R \Gamma_R} \delta(m^2 - m_R^2)$$

$$\sigma_{had}(m_R) = 16\pi^2 \times \mathcal{N} \times \mathcal{A}_{\cos\theta^*} \times BR \times \left[\frac{1}{s} \frac{dL(\bar{y}_{min}, \bar{y}_{max})}{d\tau} \right]_{\tau = m_R^2/s} \times \frac{\Gamma_R}{m_R}$$



Y width

$$\Gamma(Y \to \bar{\chi}\chi)_S = \frac{1}{8\pi} m_Y \lambda_s^{\chi 2} \beta_\chi^3 \, \theta(m_Y - 2m_\chi) \,,$$

$$\Gamma(Y \to \bar{\chi}\chi)_P = \frac{1}{8\pi} m_Y \lambda_p^{\chi 2} \beta_\chi \, \theta(m_Y - 2m_\chi) \,,$$

$$\Gamma(Y \to \bar{f}f)_S = \frac{N_c}{8\pi} m_Y \lambda_s^{f 2} \beta_f^3 \,,$$

$$\Gamma(Y \to \bar{f}f)_P = \frac{N_c}{8\pi} m_Y \lambda_p^{f 2} \beta_f \,,$$

$$\beta_\chi = \sqrt{1 - 4m_\chi^2/m_Y^2}$$

$$\beta_f = \sqrt{1 - 4m_f^2/m_Y^2}$$

$$E \sim m_\chi + \tfrac{3}{40} m_\chi$$

$$\Omega_D h^2 \sim 0.1 \left(\frac{3\times 10^{-26}\, cm^3/\sec}{<\sigma_{ann} v_{rel}>} \right)$$

$$\Gamma_{SS,Y} = \Gamma(Y \to \bar{\chi}\chi)_S + \Gamma(Y \to \bar{f}f)_S \,,$$

$$\Gamma_{SP,Y} = \Gamma(Y \to \bar{\chi}\chi)_S + \Gamma(Y \to \bar{f}f)_P \,,$$

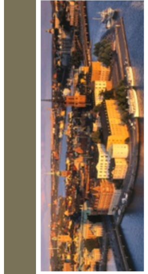
$$\Gamma_{PS,Y} = \Gamma(Y \to \bar{\chi}\chi)_P + \Gamma(Y \to \bar{f}f)_S \,,$$

$$\Gamma_{PP,Y} = \Gamma(Y \to \bar{\chi}\chi)_P + \Gamma(Y \to \bar{f}f)_P \,,$$

$$\lambda_\chi, \lambda_f > 1 \Rightarrow \Gamma_Y > m_Y$$

$$\lambda_\chi, \lambda_f < 0.3 \Rightarrow \Gamma_Y < 0.1 m_Y$$

Narrow width



χ-N Elastic Cross-section

$$\sigma_{el}^{SS}(\chi N \to \chi N) = \frac{\lambda_s^{\chi 2}\lambda_s^{f 2}}{\pi}\frac{m_\chi^2 m_N^2}{(m_\chi + m_N)^2 m_Y^4} f_N^2 ,$$

$$\sigma_{el}^{SP}(\chi N \to \chi N) = \frac{\lambda_s^{\chi 2}\lambda_p^{f 2}}{\pi}\frac{m_\chi^2 p^2}{2(m_\chi + m_N)^2 m_Y^4} g_N^2 ,$$

$$\sigma_{el}^{PS}(\chi N \to \chi N) = \frac{\lambda_p^{\chi 2}\lambda_s^{f 2}}{\pi}\frac{p^2 m_N^2}{2(m_\chi + m_N)^2 m_Y^4} f_N^2 ,$$

$$\sigma_{el}^{PP}(\chi N \to \chi N) = \frac{\lambda_p^{\chi 2}\lambda_p^{f 2}}{\pi}\frac{p^4}{3(m_\chi + m_N)^2 m_Y^4} g_N^2 ,$$

$$\mu \equiv m_\chi m_N/(m_\chi + m_N)$$

$$p = \mu v$$

$$v \sim 10^{-3} c$$

with mD = 100 mN

$$\langle N | m_q \bar{q} q | N \rangle = m_N f_{T_q}^{(N)} \bar{u}_N u_N$$

$$f_N = \sum_{q=u,d,s} f_{T_q}^{(N)} \frac{m_N}{m_q} + \frac{2}{27} f_{TG}^{(N)} \sum_{Q=c,b,t} \frac{m_N}{m_Q}$$

Dark SUSY

$$f_{T_u}^{(p)} = 0.023, \quad f_{T_d}^{(p)} = 0.034, \quad f_{T_s}^{(p)} = 0.14, \quad f_{TG}^{(p)} = 0.803,$$
$$f_{T_u}^{(n)} = 0.019, \quad f_{T_d}^{(n)} = 0.041, \quad f_{T_s}^{(n)} = 0.14, \quad f_{TG}^{(n)} = 0.8.$$

$$g_N = (1-\eta)\Delta u^{(N)} \frac{m_N}{m_u} + (1-\eta z)\Delta d^{(N)} \frac{m_N}{m_d} + (1-\eta w)\Delta s^{(N)} \frac{m_N}{m_s}$$

$$\Delta u^{(p)} = \Delta d^{(n)} = 0.77 ,$$
$$\Delta d^{(p)} = \Delta u^{(n)} = -0.40 ,$$
$$\Delta s^{(p)} = \Delta s^{(n)} = -0.12 .$$

$$\langle N' | \bar{q} i \gamma_5 q | N \rangle \simeq (1 - \eta \delta_q) \Delta q^{(N)} \frac{m_N}{m_q} \bar{u}'_N i \gamma_5 u_N$$

where $\delta_u = 1, \delta_d = z$, and $\delta_s = w$ with $\eta = (1 + z + w)^{-1}, z = m_u/m_d$, and $w = m_u/m_s$.