DARK MATTER RELIC AND ITS IMPLICATIONS ON THE UNDERGROUND LABORATORY AND LHC SEARCH

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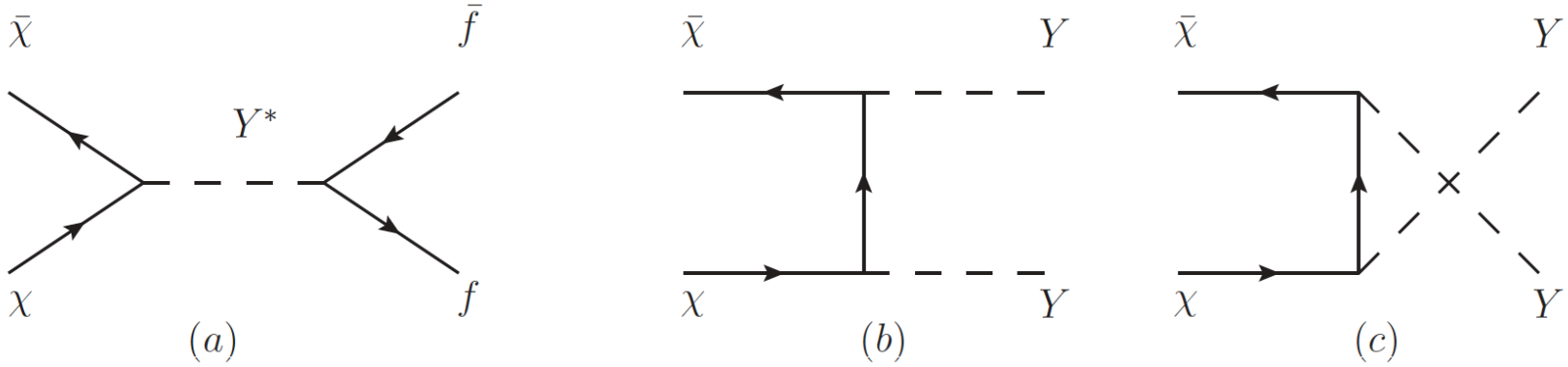
CONTENT

1. Dark Matter Relic
2. Dark Matter Direct Detection
3. Mono-jet Constraint
4. Compare to Effective Operator Approach
5. Conclusions

FERMIONIC DM & SCALAR MEDIATOR

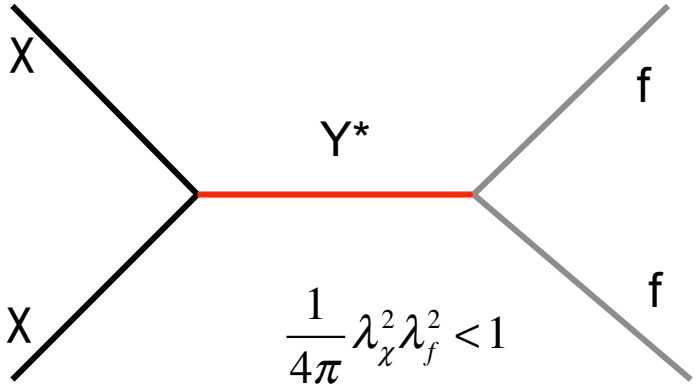
$$\Delta L = \bar{\chi}(\lambda_s^{\chi} + i\lambda_p^{\chi}\gamma^5)\chi Y + \bar{f}(\lambda_s^{f} + i\lambda_p^{f}\gamma^5) f Y$$



(a) $$\langle \sigma v \rangle = \frac{1}{4\pi}\lambda_\chi^2\lambda_f^2 \frac{4m_\chi^2}{(4m_\chi^2 - m_Y^2)^2 + m_Y^2\Gamma_Y^2}\sqrt{1-\frac{m_f^2}{m_\chi^2}} \cong 1pb\cdot c$$

(b) $$\langle \sigma(\bar{\chi}\chi \to YY)v \rangle = \frac{1}{16\pi}\lambda_\chi^4 \frac{\vec{p}_\chi^{\,2}}{(2m_\chi^2 - m_Y^2)^2}\sqrt{1-\frac{m_Y^2}{m_\chi^2}}$$ for $m_\chi > m_Y$

THE GOAL



1. Preserve the kinematics of mediator
2. Cross-sections are related
3. Translate into mass relation

$$\sigma v = \sum_{q=u,d,s,c,b,t} N_C \frac{\lambda^{\chi 2}\lambda^{f 2}}{4\pi} \frac{\vec{p}_\chi^{\,2}\vec{p}_q^{\,2}}{E^2((4m_\chi^2 - m_Y^2)^2 + m_Y^2\Gamma_Y^2)} \frac{|\vec{p}_q|}{|\vec{p}_\chi|} \frac{2|\vec{p}_\chi|}{E} \cong 1 pb.c$$

$$\sigma(\chi N \to \chi N) = \frac{\lambda_\chi^2\lambda_f^2}{4\pi} f_N^2 \frac{m_\chi^2 m_N^2}{(m_\chi^2 + m_N^2)^2 m_Y^4} < 10^{-8}\, pb$$

$$\sigma(\bar{f}f \to \bar{\chi}\chi) = \frac{\lambda_\chi^2\lambda_f^2}{4\pi} \frac{\vec{p}_\chi^{\,2}\vec{p}_f^{\,2}}{E^2((4E^2 - m_Y^2)^2 + m_Y^2\Gamma_Y^2)} \frac{|\vec{p}_\chi|}{|\vec{p}_f|} < 0.1 pb$$

Y WIDTH

$$\Omega_D h^2 \sim 0.1\left(\frac{3\times10^{-26} cm^3/\sec}{<\sigma_{ann} v_{rel}>}\right)$$

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

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

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

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

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

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

$$\langle \sigma v_{rel} \rangle^{ss} = \frac{\lambda_s^{\chi 2} \lambda_s^{f 2}}{2\pi} \frac{p_\chi^2 p_f^3}{E^3 (4E^2 - m_Y^2)^2} + \frac{\lambda_s^{\chi 4}}{2\pi} \frac{E m_\chi^2 p_\chi^2 p_Y}{[4(E^2 - m_Y^2) m_\chi^2 + m_Y^4]^2}$$

$$E \sim m_\chi + m_\chi/10$$

$$\langle \sigma v_{rel} \rangle^{pp} = \frac{\lambda_p^{\chi 2} \lambda_p^{f 2}}{2\pi} \frac{E p_f}{(4E^2 - m_Y^2)^2} + \frac{\lambda_p^{\chi 4}}{2\pi} \frac{m_\chi^2 p_\chi^4 p_Y (E^2 - m_Y^2)^2}{E^3 [4(E^2 - m_Y^2) m_\chi^2 + m_Y^4]^2}$$

$$0 < Max\{\lambda_\chi, \lambda_f\} < 0.3$$

$$0.3 < Max\{\lambda_\chi, \lambda_f\} < 1$$

$$1 < Max\{\lambda_\chi, \lambda_f\} < 3$$

$\lambda_\chi \sim \lambda_f$ $\qquad$ $\lambda_\chi \sim \lambda_f / 20$ $\qquad$ $\lambda_\chi \sim 100 \lambda_f$

RELIC WITH Y-WIDTH

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

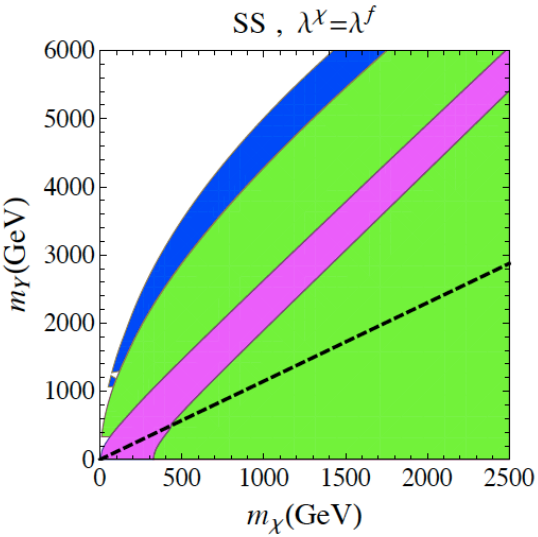
$$\langle \sigma v_{\rm rel} \rangle^{SP} = N_c \frac{\lambda_s^{\chi 2} \lambda_p^{f 2}}{2\pi} \frac{p_\chi^2 p_f}{E[(4E^2 - m_Y^2)^2 + m_Y^2 \Gamma_{SP,Y}^2]} + \frac{\lambda_s^{\chi 4}}{2\pi} \frac{E m_\chi^2 p_\chi^2 p_Y \, \theta(m_\chi - m_Y)}{[4(E^2 - m_Y^2)m_\chi^2 + m_Y^4]^2} ,$$

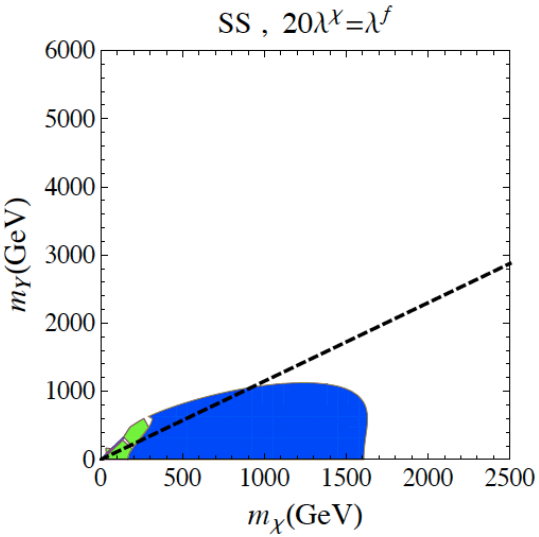
$$\langle \sigma v_{\rm rel} \rangle^{PS} = N_c \frac{\lambda_p^{\chi 2} \lambda_s^{f 2}}{2\pi} \frac{p_f^3}{E[(4E^2 - m_Y^2)^2 + m_Y^2 \Gamma_{PS,Y}^2]} + \frac{\lambda_p^{\chi 4}}{2\pi} \frac{m_\chi^2 p_\chi^2 p_Y^5 \, \theta(m_\chi - m_Y)}{E^3[4(E^2 - m_Y^2)m_\chi^2 + m_Y^4]^2} ,$$

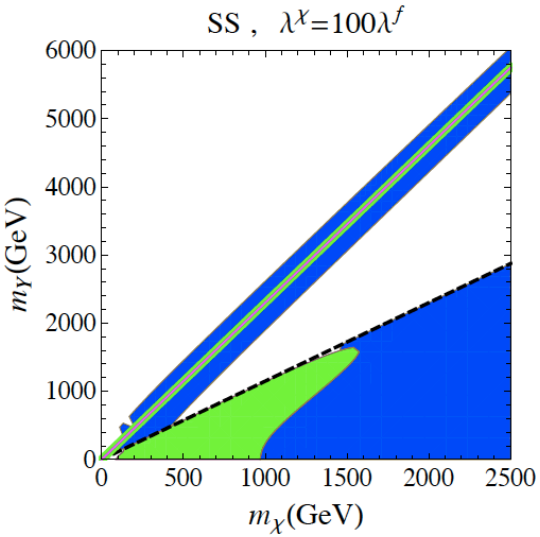
$$\langle \sigma v_{\rm rel} \rangle^{PP} = N_c \frac{\lambda_p^{\chi 2} \lambda_p^{f 2}}{2\pi} \frac{E p_f}{[(4E^2 - m_Y^2)^2 + m_Y^2 \Gamma_{PP,Y}^2]} + \frac{\lambda_p^{\chi 4}}{2\pi} \frac{m_\chi^2 p_\chi^2 p_Y^5 \, \theta(m_\chi - m_Y)}{E^3[4(E^2 - m_Y^2)m_\chi^2 + m_Y^4]^2} ,$$

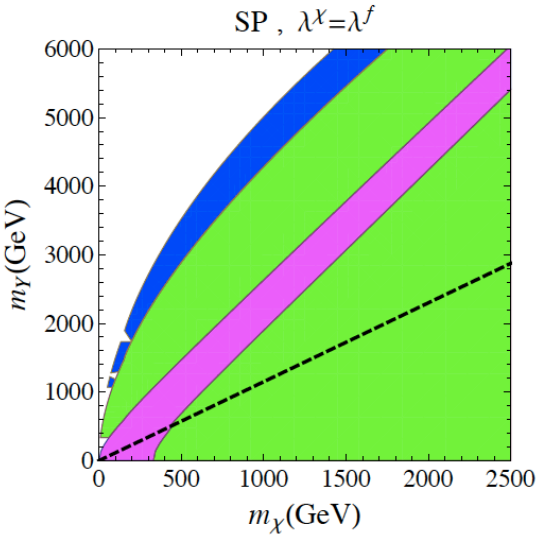
DARK MATTER RELIC CONSTRAINT PART I

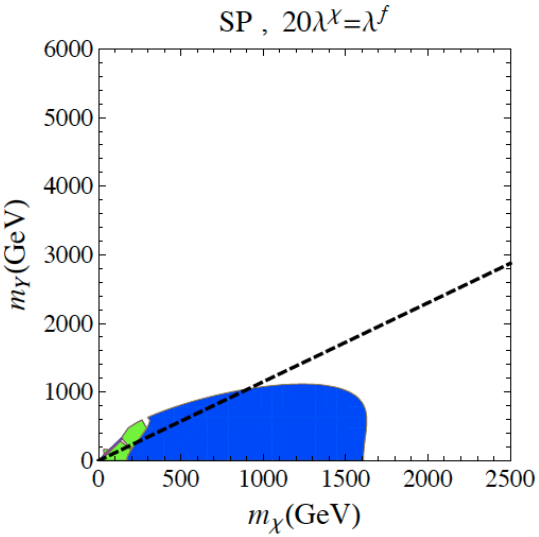
$$\Omega_\chi h^2 \simeq \frac{0.1\ \mathrm{pb}\cdot c}{\langle \sigma_{\mathrm{ann}} v_{\mathrm{rel}} \rangle}$$

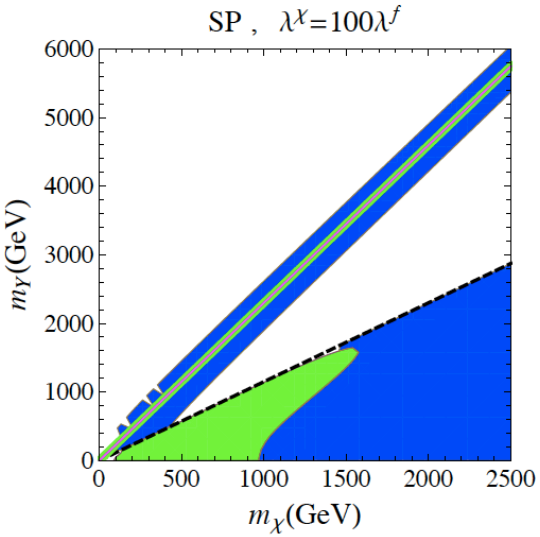




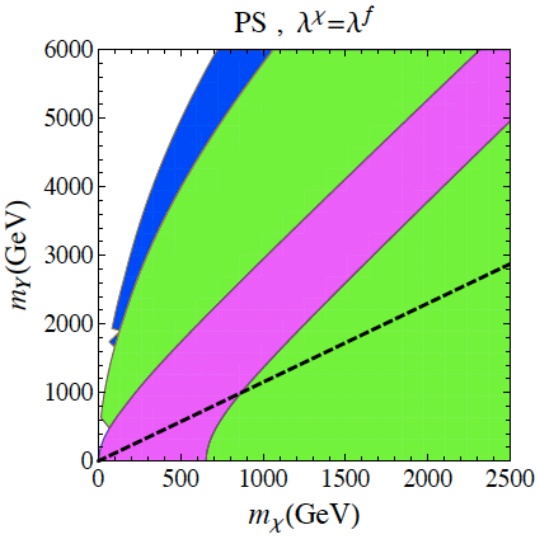


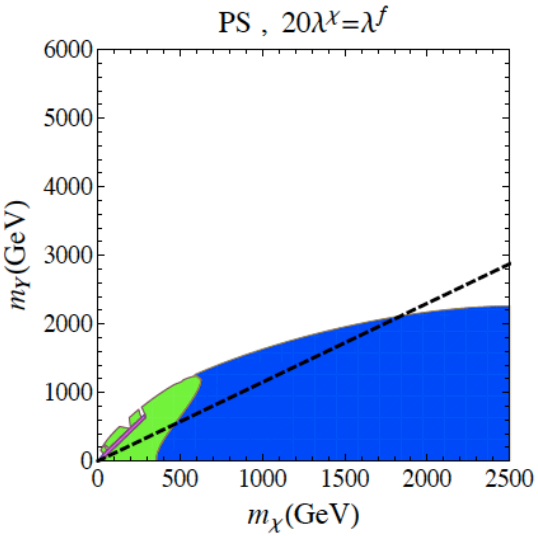


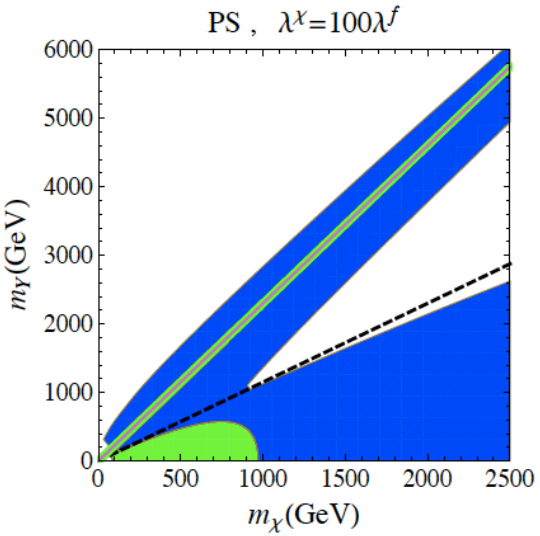


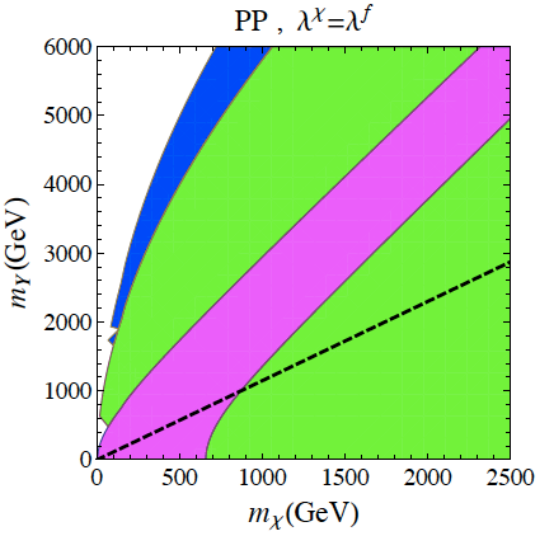


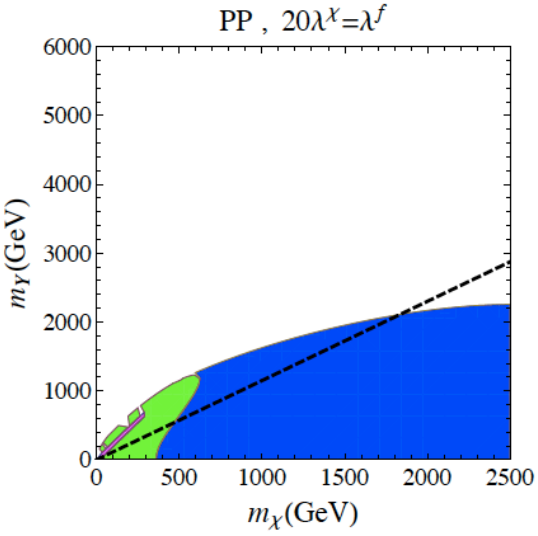
DARK MATTER RELIC CONSTRAINT PART II

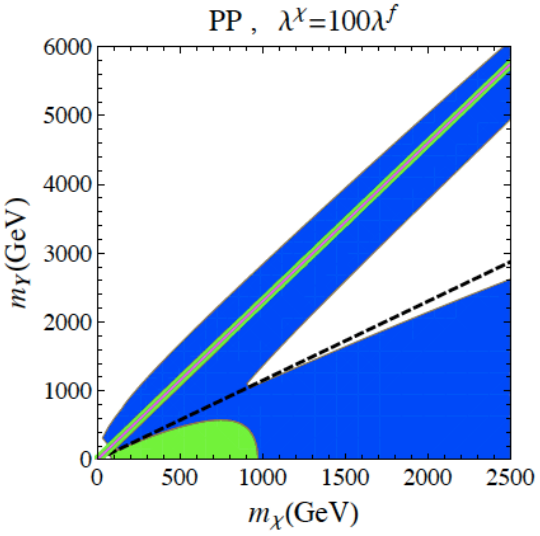




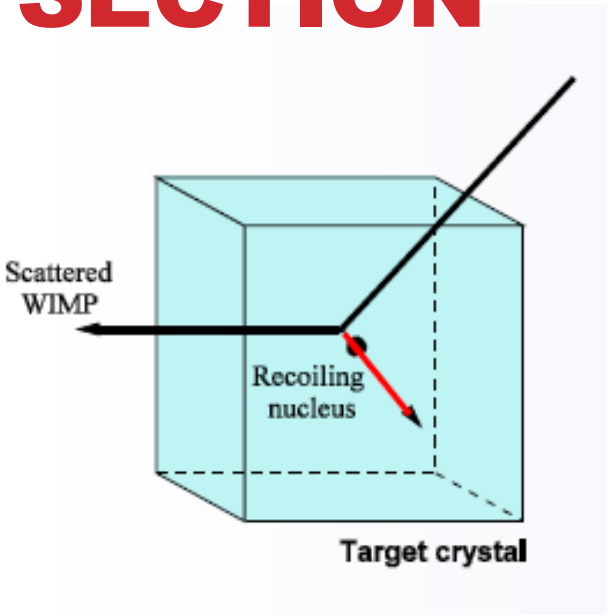








ELASTIC D-N CROSS SECTION



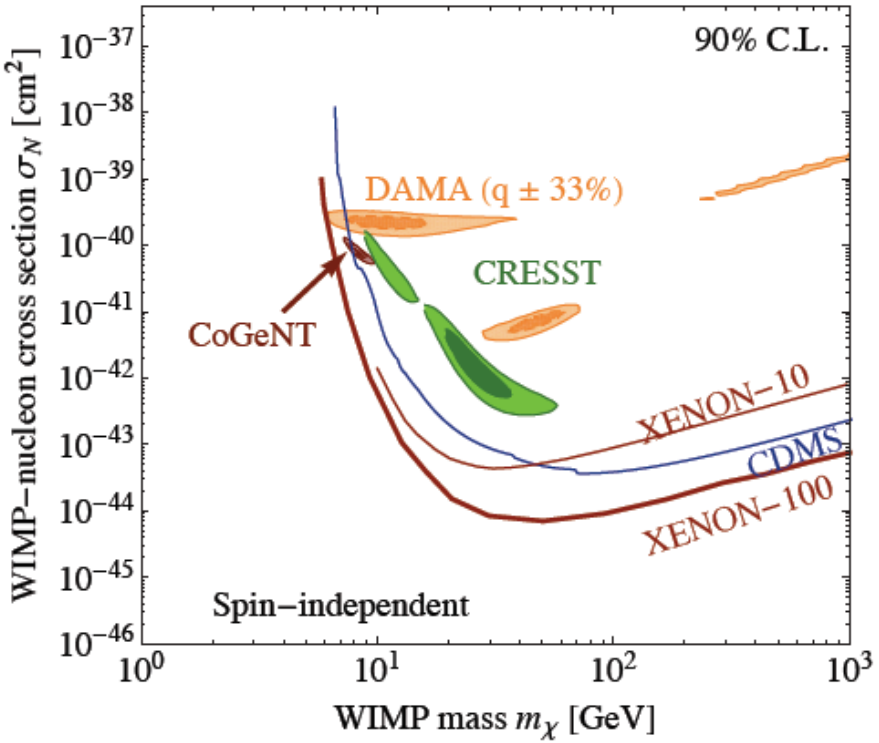
1. Loss sensitivity due to low kinetic energy for light dark matter.

2. Collider is better to probe light dark matter.

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

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

$$p \sim m_\chi 10^{-3} c$$



DM COUPLE TO QUARK & NUCLEON

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

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

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

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

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

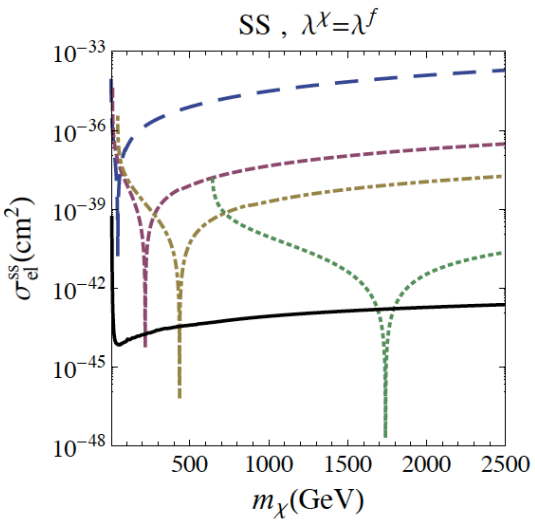
$$f_{T_G}^{(N)} = 1 - \sum_{q=u,d,s} m_N f_{T_q}^{(N)}$$

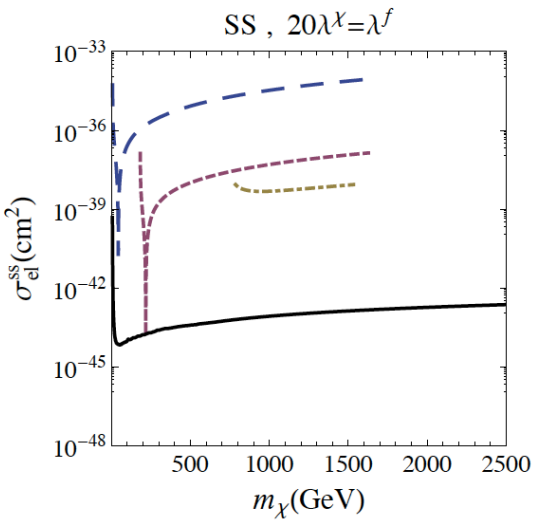
$$f_N = \sum_{q=u,d,s} f_{T_q}^{(N)} \frac{m_N}{m_q} + \frac{2}{27} f_{T_G}^{(N)} \sum_{Q=c,b,t} \frac{m_N}{m_Q}$$ ~18

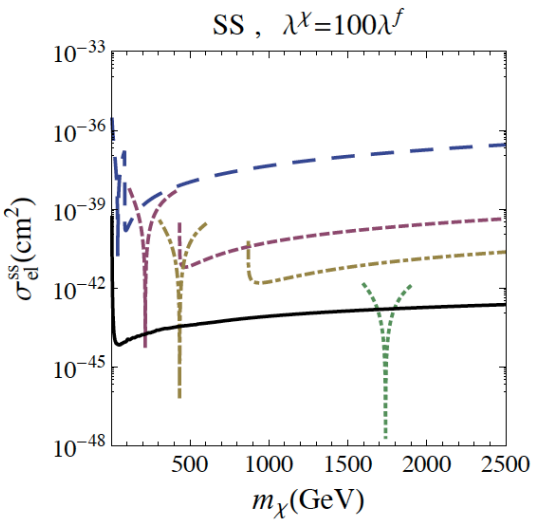
$$f_{T_u}^{(p)} = 0.023, \quad f_{T_d}^{(p)} = 0.034, \quad f_{T_s}^{(p)} = 0.14, \quad f_{T_G}^{(p)} = 0.803,$$
$$f_{T_u}^{(n)} = 0.019, \quad f_{T_d}^{(n)} = 0.041, \quad f_{T_s}^{(n)} = 0.14, \quad f_{T_G}^{(n)} = 0.8.$$

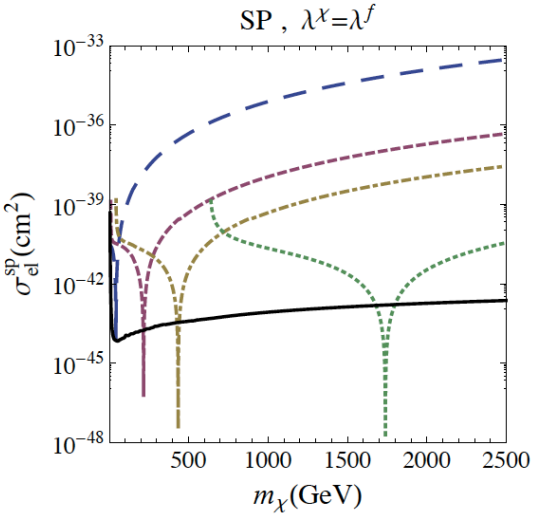
DarkSUSY

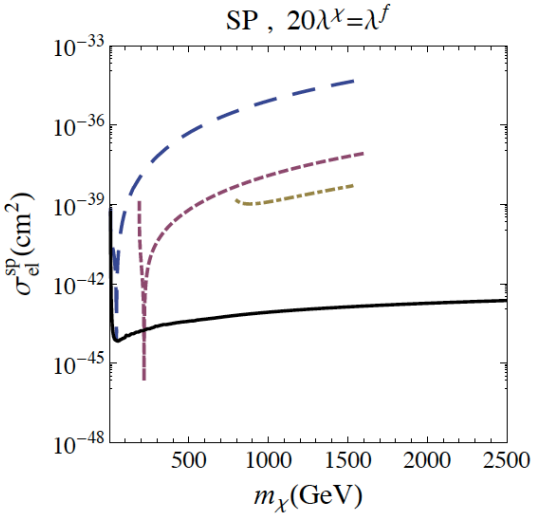
D-N X-SECTION IMPLIED BY RELIC I

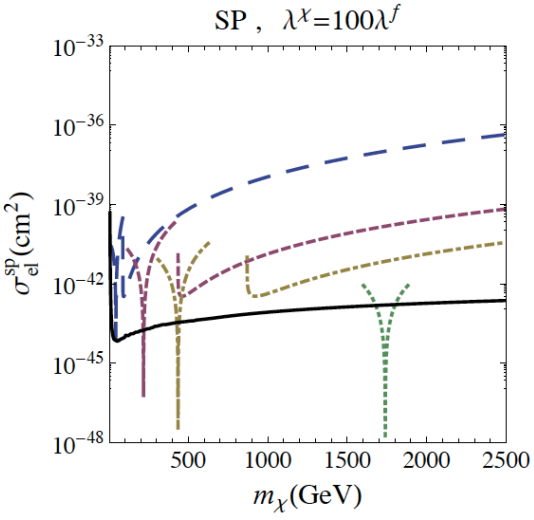




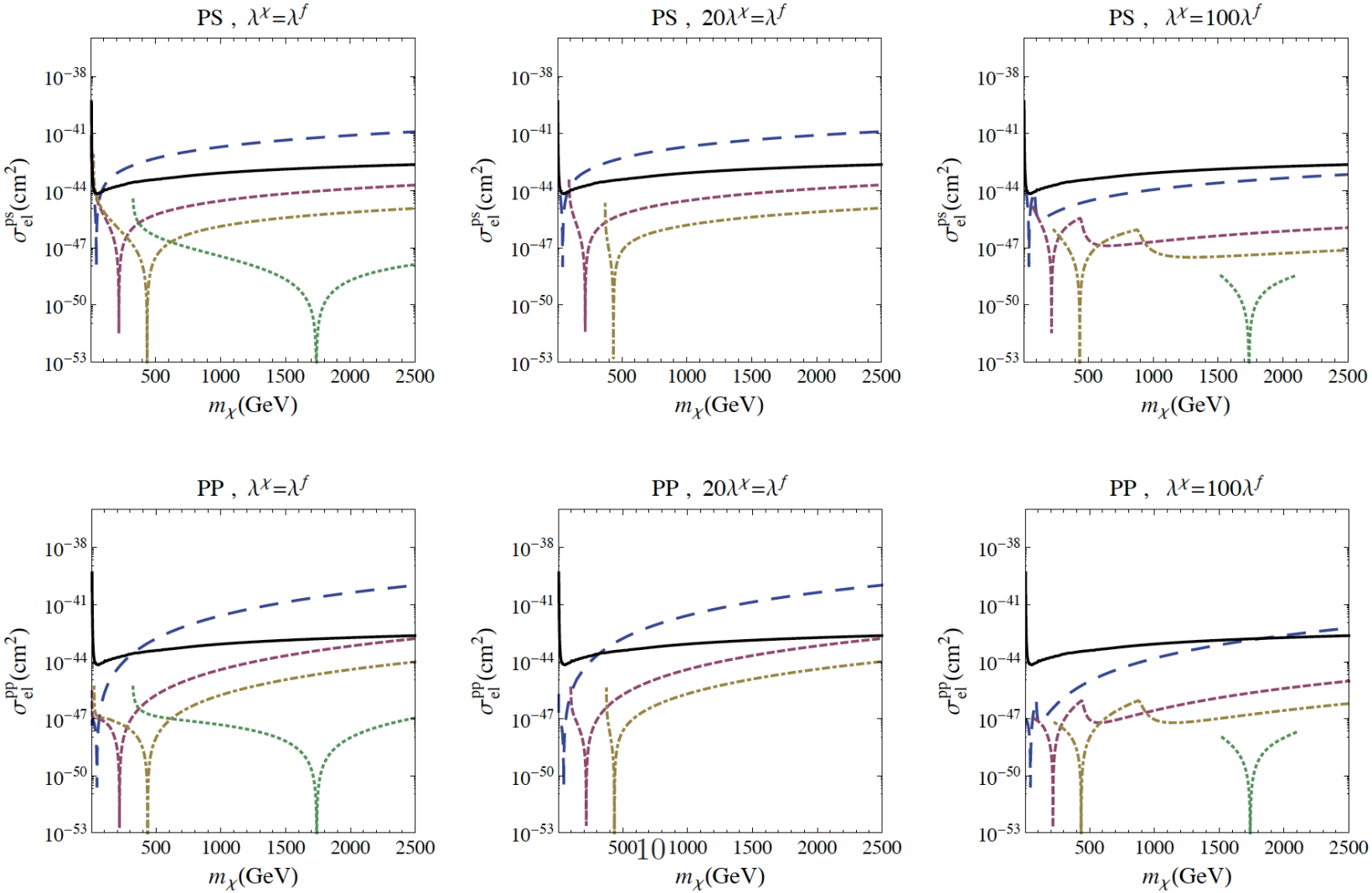




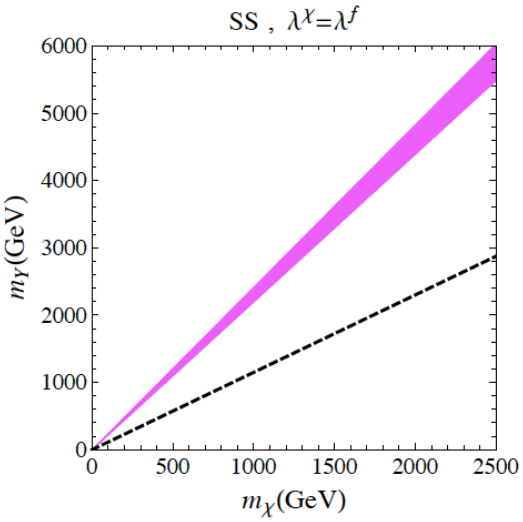


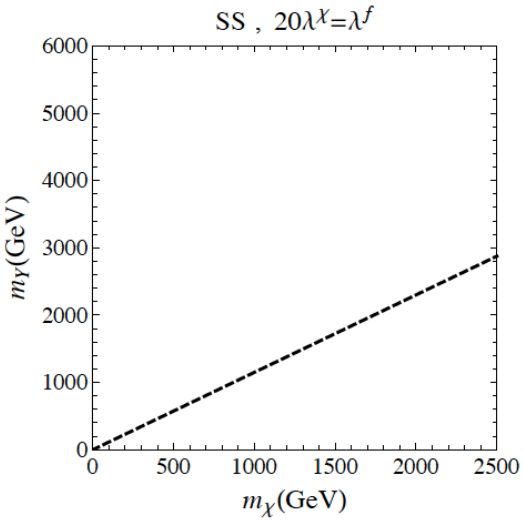


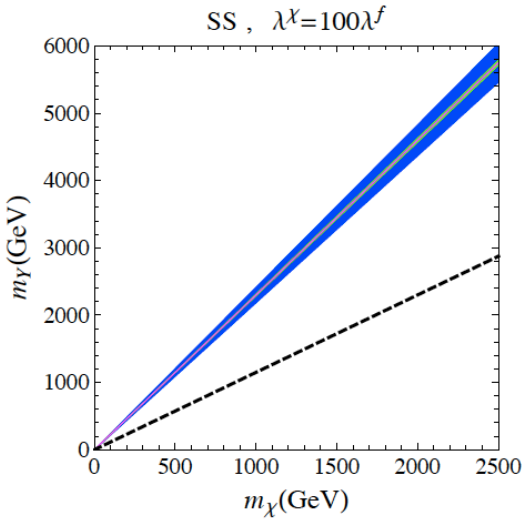
D-N X-SECTION IMPLIED BY RELIC II

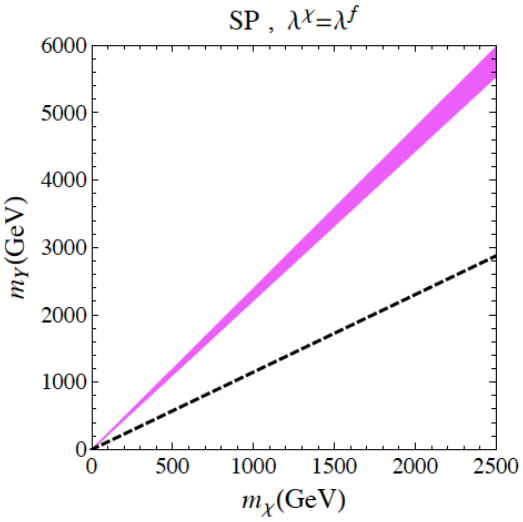


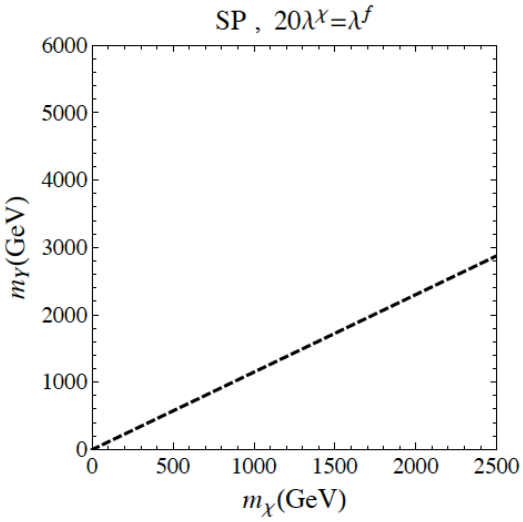
DM DIRECT DETECTION CONSTRAINT I

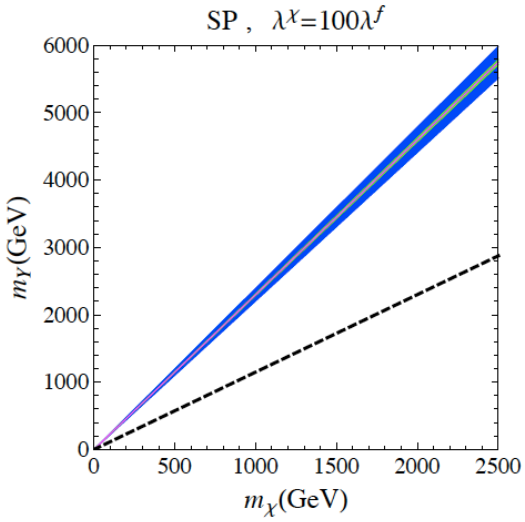




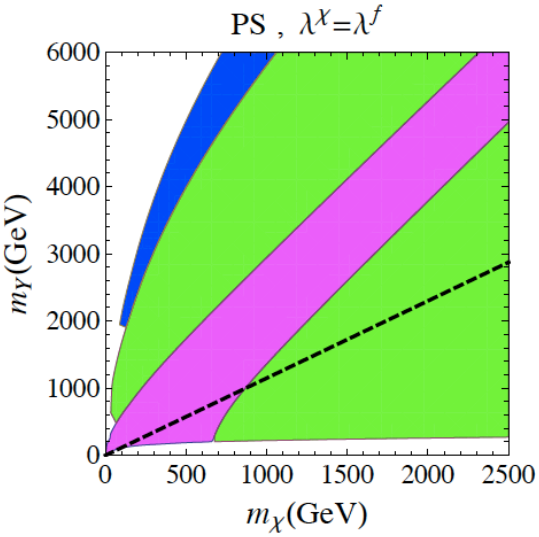


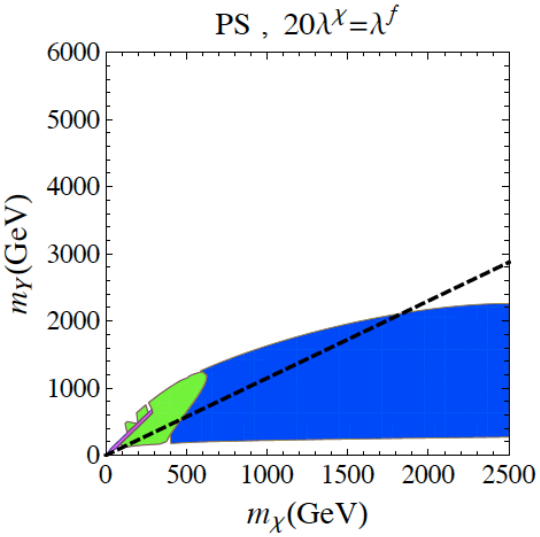


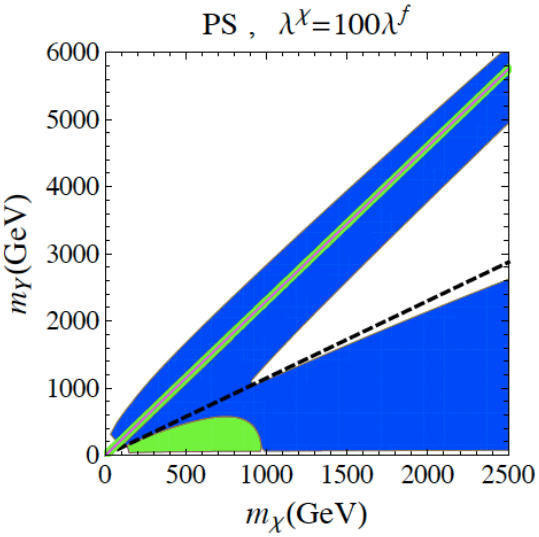


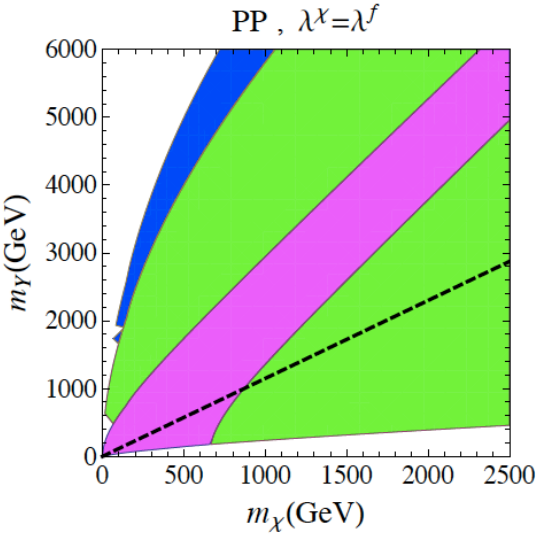


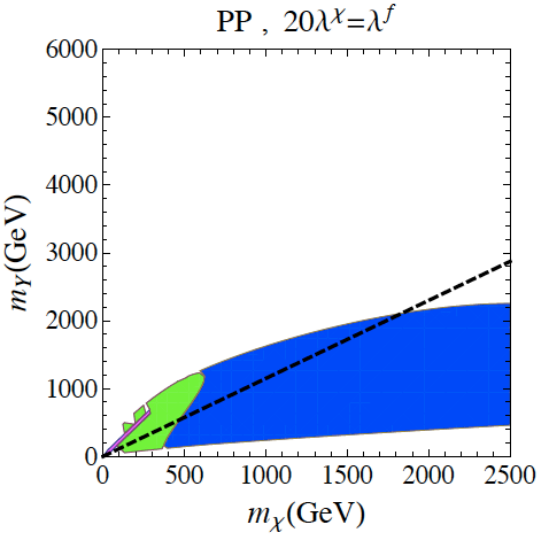
DM DIRECT DETECTION CONSTRAINT II

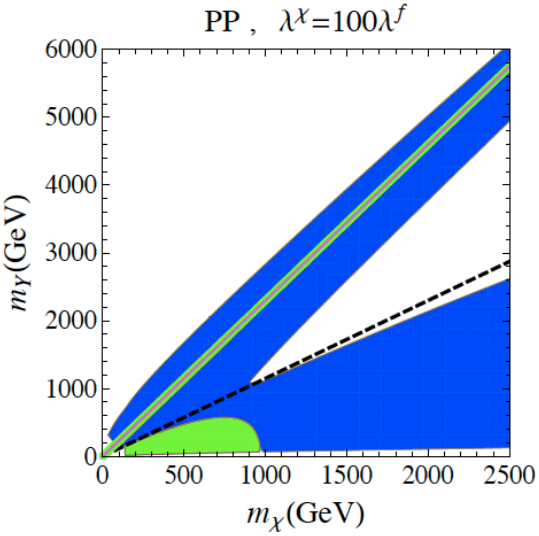




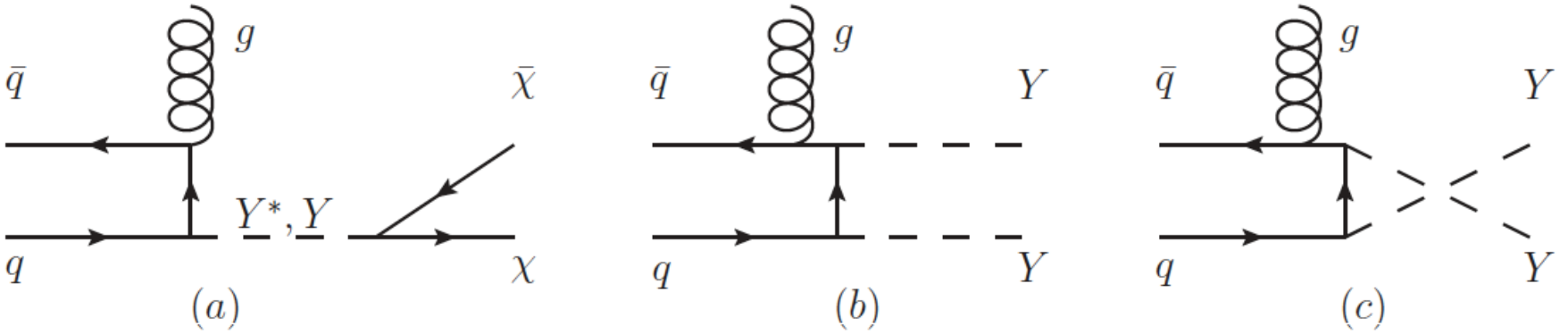








LHC MONOJET



$$\sigma^{ss}(\bar{f}f \to \bar{\chi}\chi) = \frac{\lambda_s^{\chi 2}\lambda_s^{f 2}}{4\pi}\frac{p_\chi^2 p_f^2}{E^2(4E^2 - m_Y^2)^2}\frac{p_\chi}{p_f}$$

$$\sigma^{sp}(\bar{f}f \to \bar{\chi}\chi) = \frac{\lambda_s^{\chi 2}\lambda_p^{f 2}}{4\pi}\frac{p_\chi^2 E^2}{E^2(4E^2 - m_Y^2)^2}\frac{p_\chi}{p_f}$$

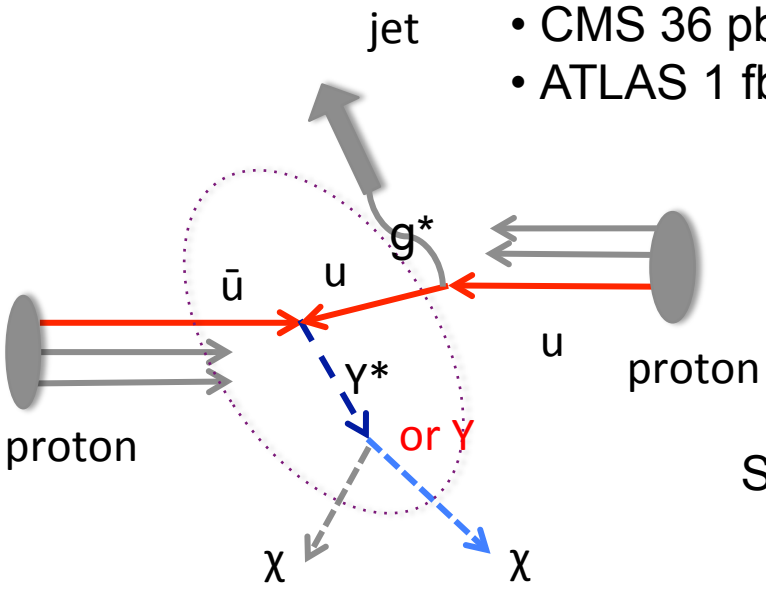
$$\sigma^{ps}(\bar{f}f \to \bar{\chi}\chi) = \frac{\lambda_p^{\chi 2}\lambda_s^{f 2}}{4\pi}\frac{p_f^2 E^2}{E^2(4E^2 - m_Y^2)^2}\frac{p_\chi}{p_f}$$

$$\sigma^{pp}(\bar{f}f \to \bar{\chi}\chi) = \frac{\lambda_p^{\chi 2}\lambda_p^{f 2}}{4\pi}\frac{E^2 E^2}{E^2(4E^2 - m_Y^2)^2}\frac{p_\chi}{p_f}$$

$$\sigma(\bar{f}f \to YY) = \frac{1}{16\pi}\lambda_f^4\frac{m_f^2}{(m_f^2 - m_Y^2)^2} \to 0$$

2-Y final state suppressed by light quark mass in the proton

MONOJET FROM LHC



Available Mono-Jet searches:

- CMS 36 pb−1
- ATLAS 1 fb−1: LowPt, HighPt and veryHighPt

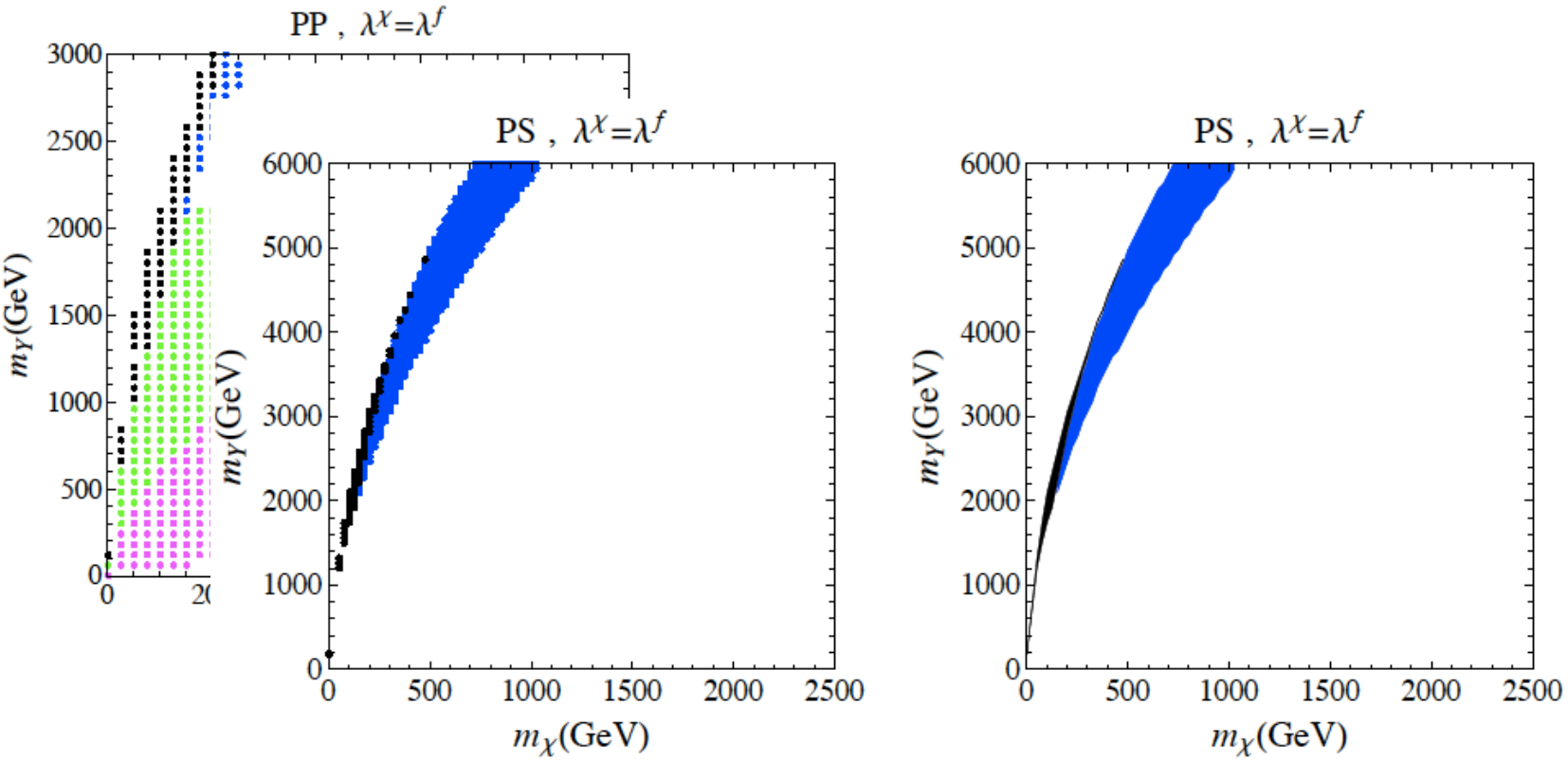
SM BG p p → j Z→ j ν ν , 2 to 2 process

VeryHighPT: 7 TeV, 1fb-1

missing E_T > 300GeV, missing $p_{T\,j1}$ > 350GeV

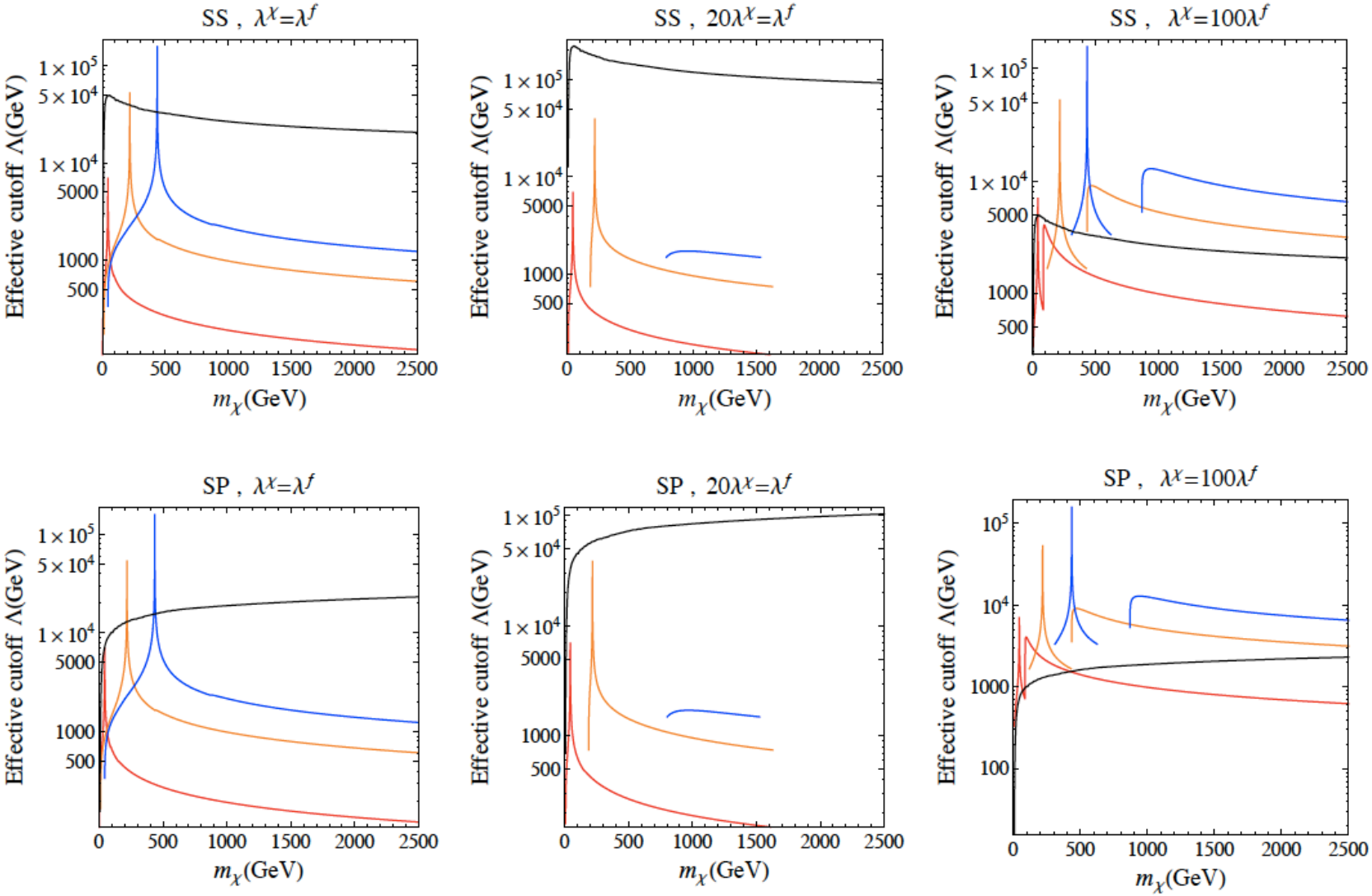
σ_{1j} < 0.045pb 1202.0158 ATLAS

P P → J CHI CHI~ INVISIBLE WIDTH

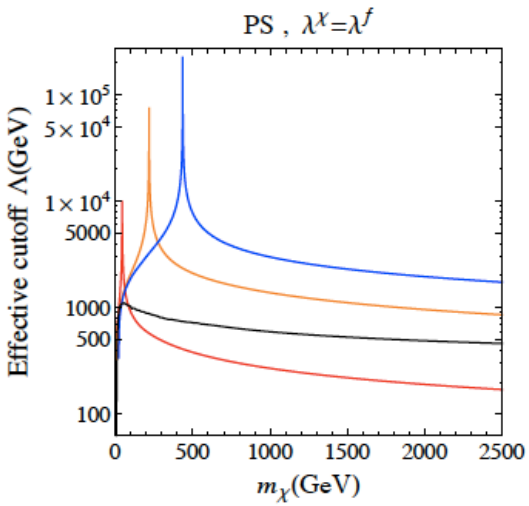


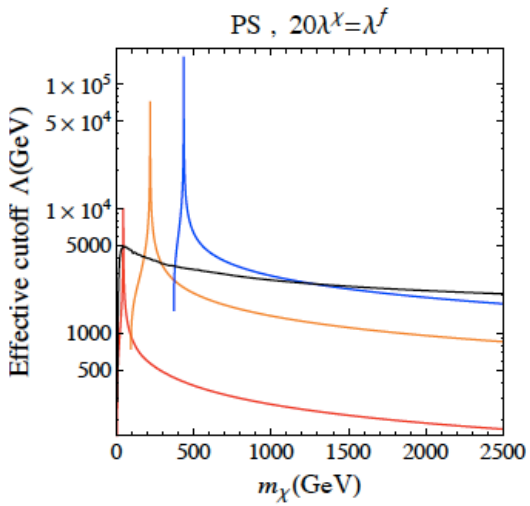
COME TO EFFECTIVE I

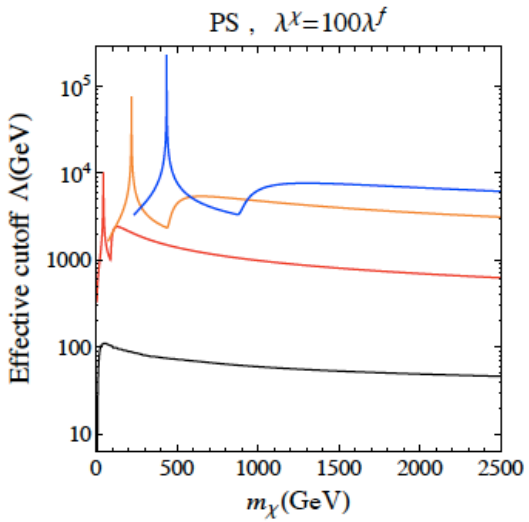
mY=100,500,1000

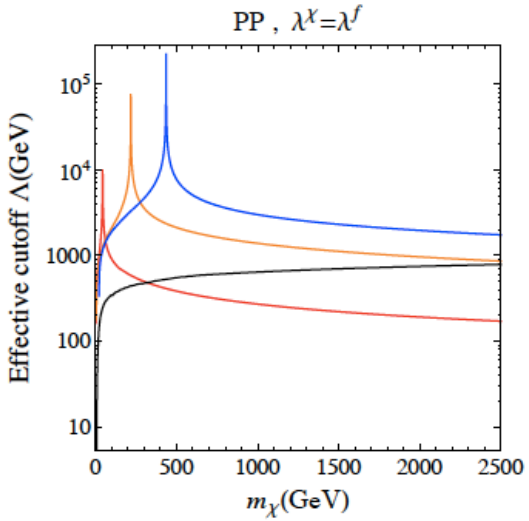


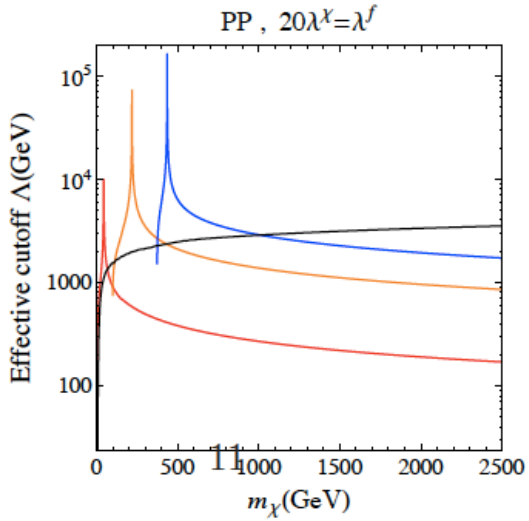
COME TO EFFECTIVE II

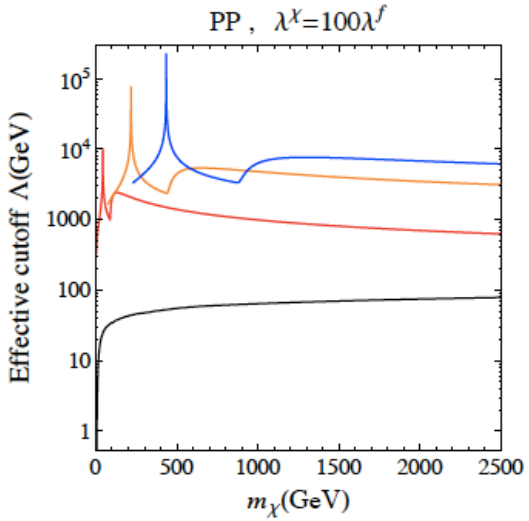


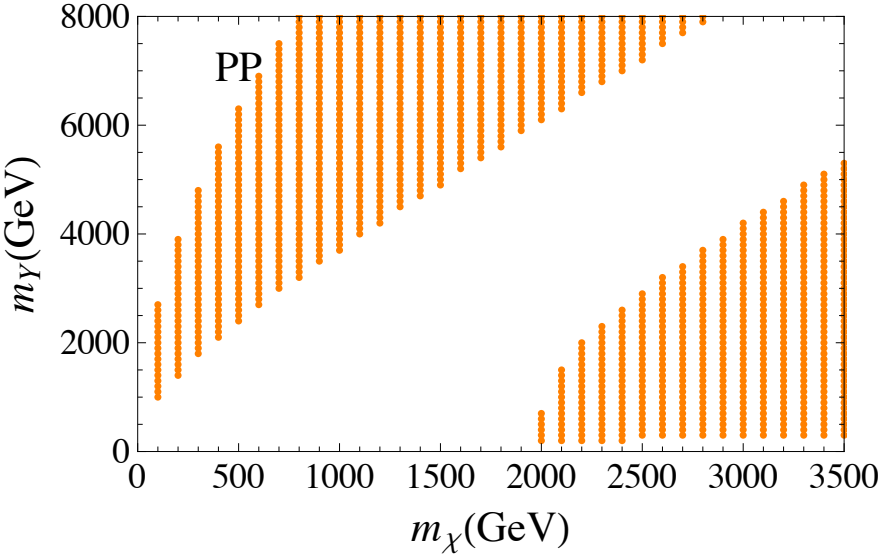


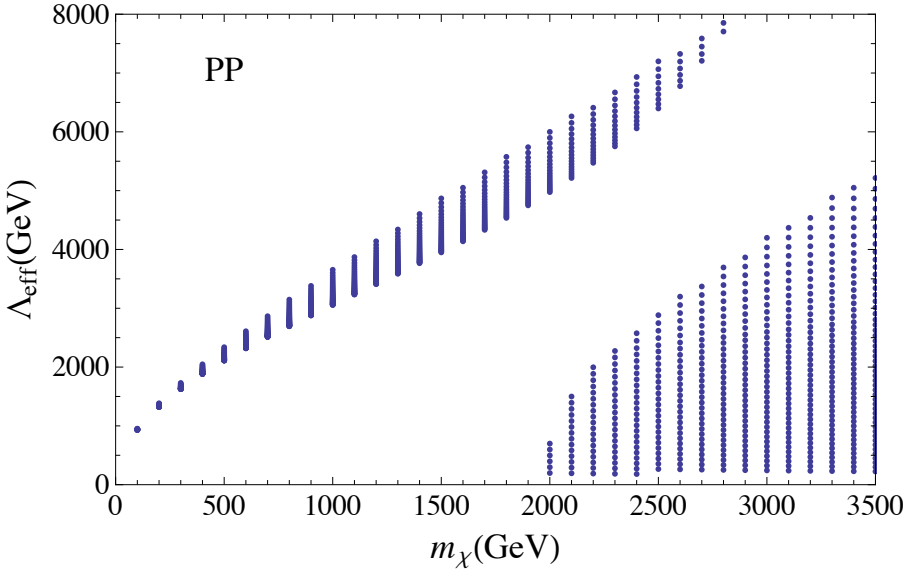









PP
8000
6000
4000
2000
0
0
500
1000
1500
2000
2500
3000
3500
m_Y(GeV)
m_χ(GeV)


PP
8000
6000
4000
2000
0
0
500
1000
1500
2000
2500
3000
3500
$\Lambda_{\rm eff}$(GeV)
m_χ(GeV)

CONCLUSIONS

We study a fermionic dark matter mediated by a new scalar particle Y to SM quarks.

Dark matter mass constrained by the relic abundance, direct detections, and LHC monojet bound

A pseudo-scalar mediator can satisfy DM relic and null result on DM direct detection due to momentum suppression between epoch of freeze-out and now.

Mono-jet constraints is not stronger than dark matter direct detection.

Thank you

GO TO HIGH PT

SM BG Mono-jet missing Et from p p → j z→ j v v , 2 to 2 process

Heavy mediator p p → j chi chi~ 2 to 3

Light mediator can be onshell prod p → j Y , 2 to 2, copiously