Dark Matter candidates in left-right symmetric models with CP symmetry

Yu-Feng Zhou

collaborators:

L.M.Wang, W.L.Guo， Y.L.Wu， Ci Zhuang

Kavli Institute for Theoretical Physics (KITPC), Institute of theoretical physics (ITP), Chinese Academy of Sciences (CAS).

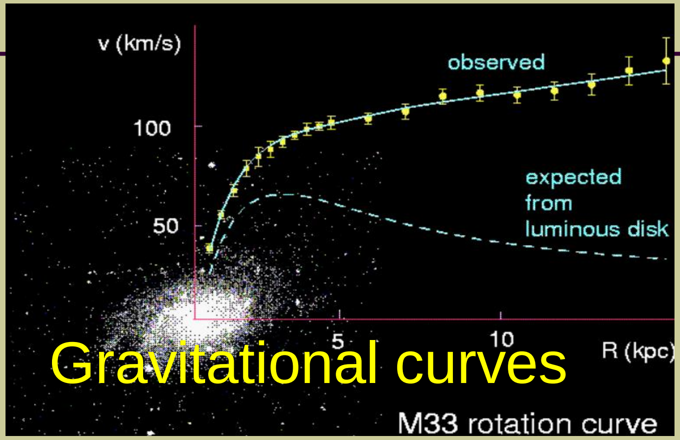
PRD79,055015(2009);PRD81,075014(2010),

ArXiv:1008.4479(PRD)

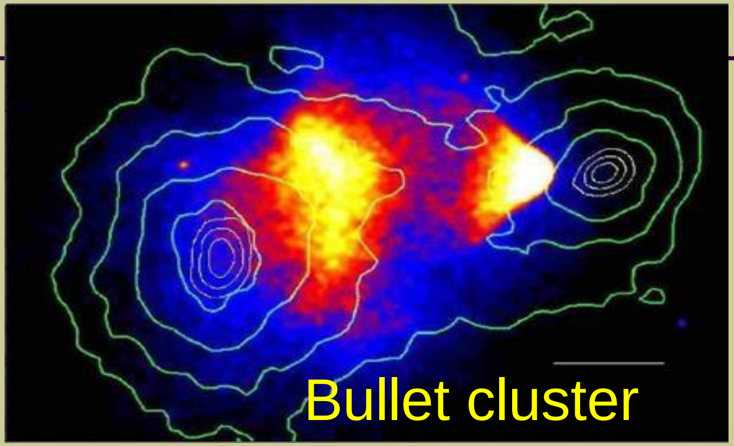
Outline

- **Introduction**
  - Evidences of DM, current status of DM exp. searches
- **Dark matter stabilized by P and CP symmetries**
  - Symmetries used for the stability of DM
  - Auto stable DM in left-right symmetric models with CP symmetry
  - Relic abundance constraints & predictions for direct detections
- **Tiny DM decay induced by soft C- breaking terms**
  - Soft C-breaking term and the role of triplets
  - A natural explanation to PAMELA and Fermi LAT data
  - Predictions for cosmic-ray neutrinos and diffuse gamma rays

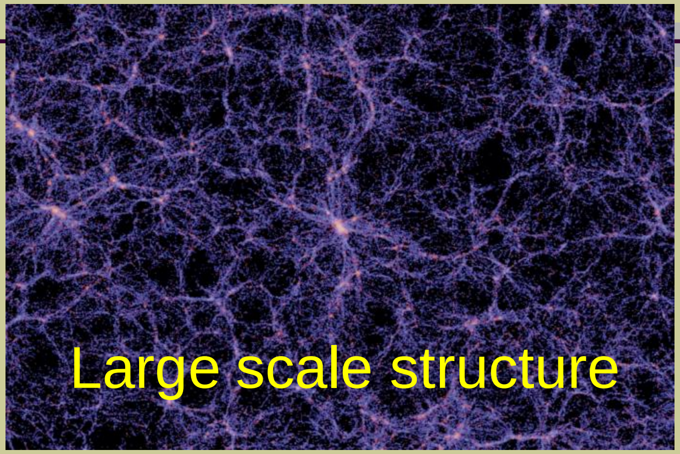
Evidences of DM from gravitational effects



Gravitational curves

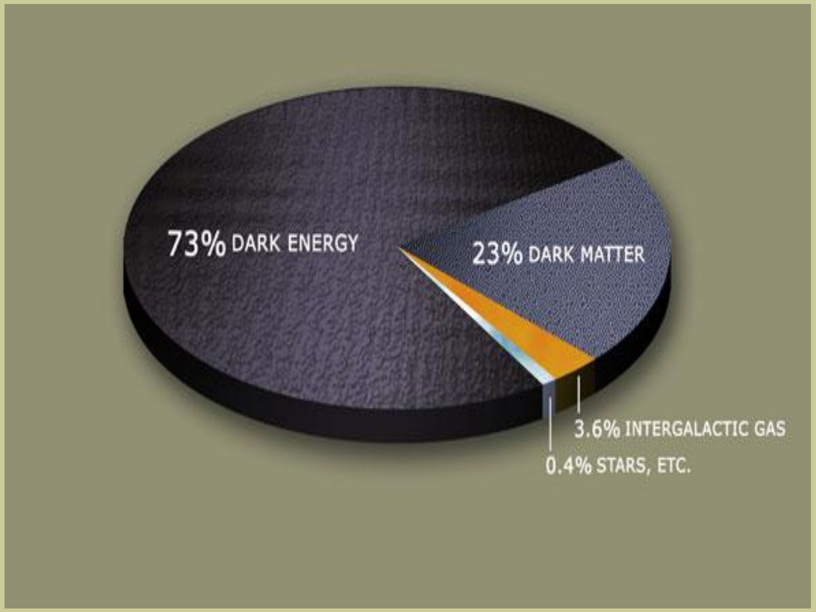


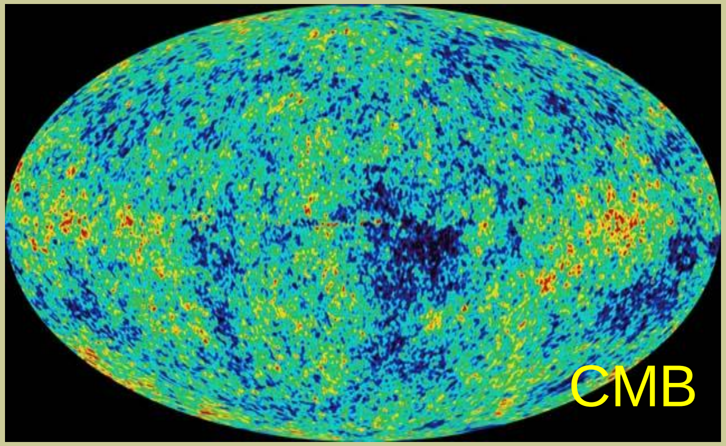
Bullet cluster



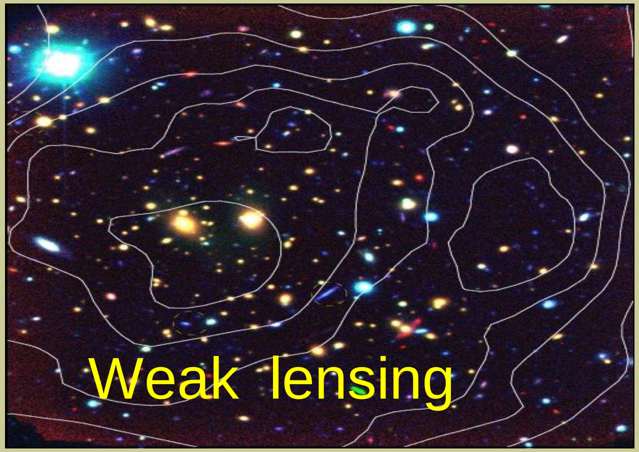
Large scale structure

Strong lensing



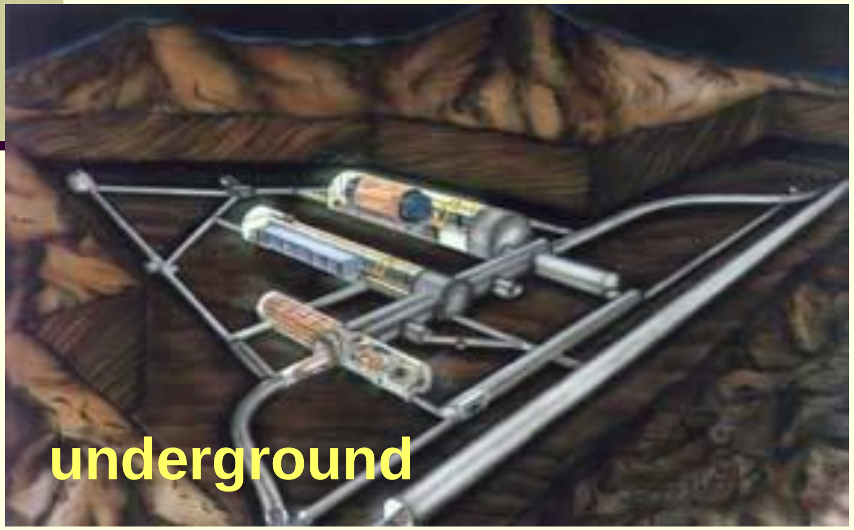


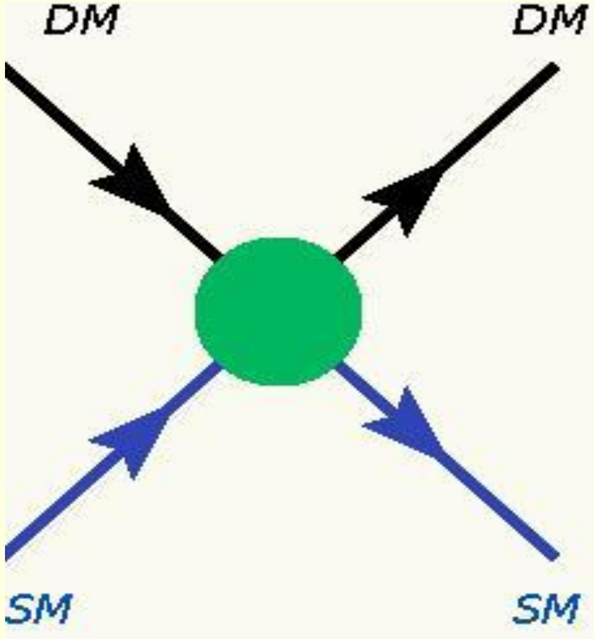
CMB

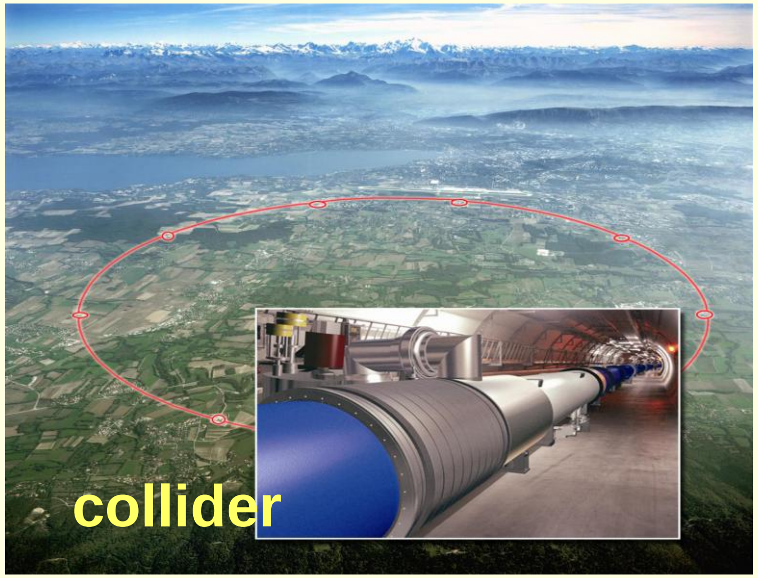


Weak lensing

Searching for non-gravitational effects

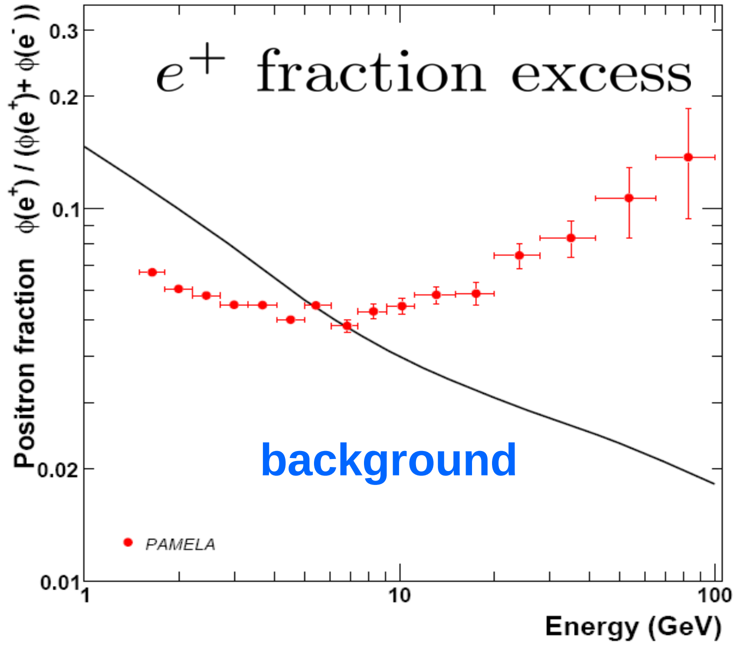


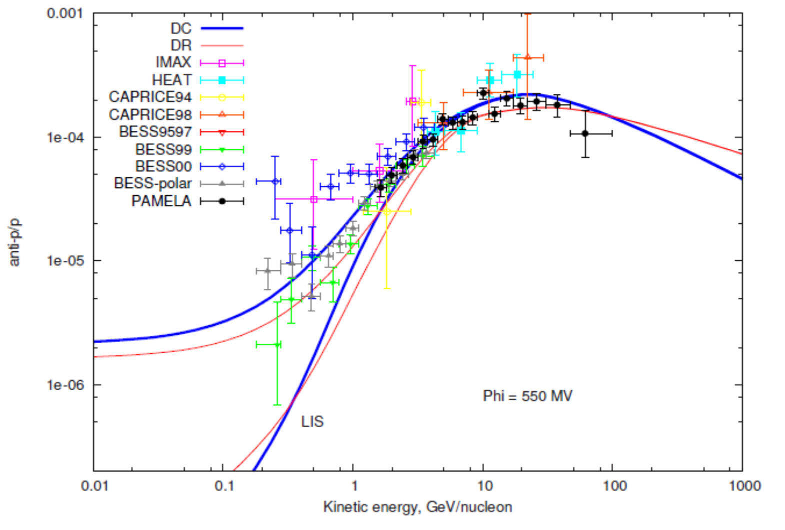




Hint of DM ? Positron fraction

Nature 458, 607 (2009)





PAMELA

if interpreted as DM signal

- Large annihilation cross section **now,** boost factor problem.
  - *Sommerfeld enhancement ?*
  - *Resonance enhancement ?*
  - *Non-thermal DM ?*
  - *DM may slightly decay ?*
- Mainly annihilation/decay into leptons, not quarks
  - *Light final states <1GeV ?*
  - *Leptophilic interaction ?*

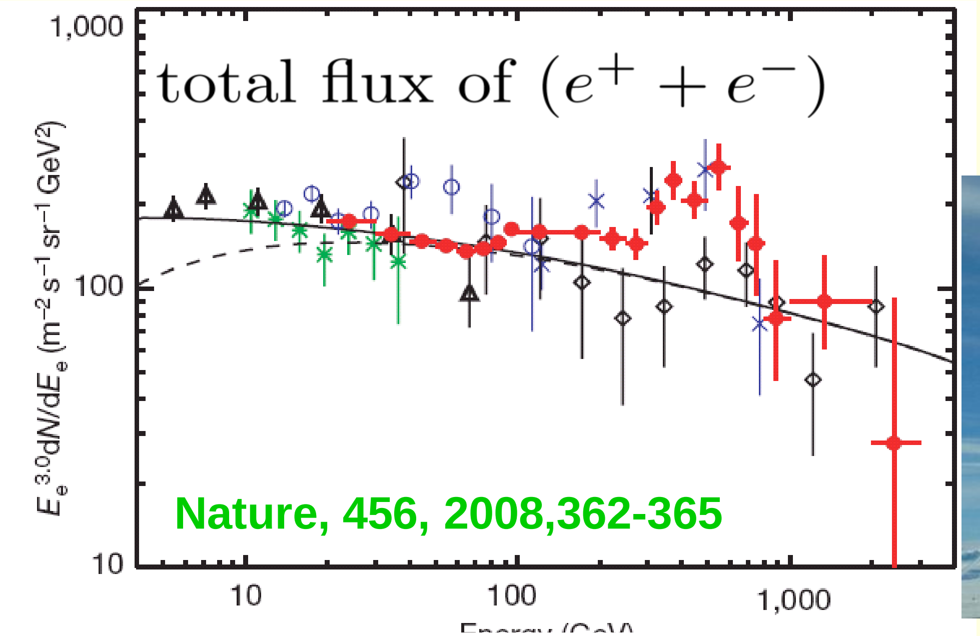
Hint of DM? electrons plus positrons

ATIC/PPB-BETS

Excess in the total flux

peak at ~600 GeV

rapid drop below 800GeV

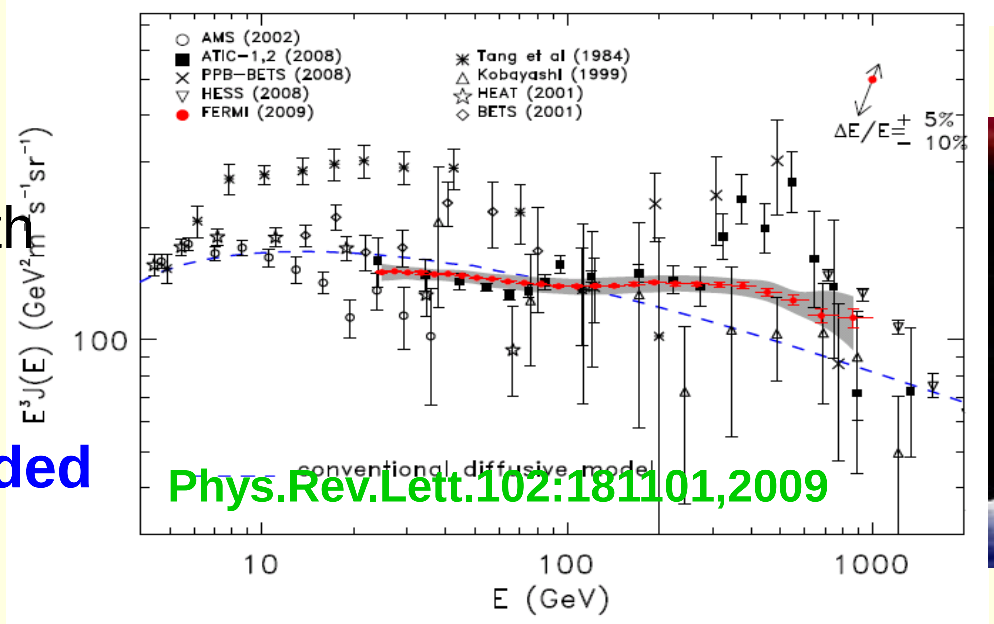


Nature, 456, 2008,362-365

Fermi LAT

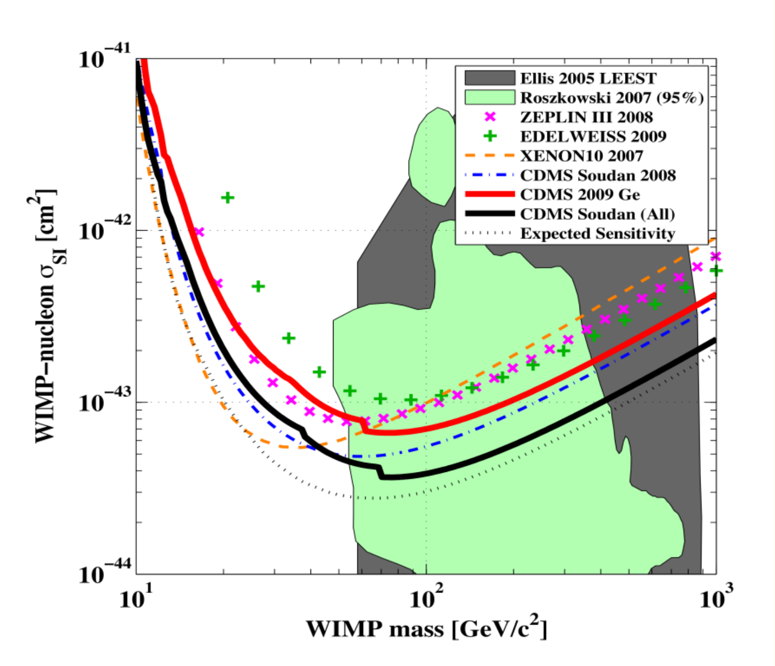
Spectrum harder than expected background with power index around ~3.

Large boost factor still needed



Phys.Rev.Lett.102:181101,2009

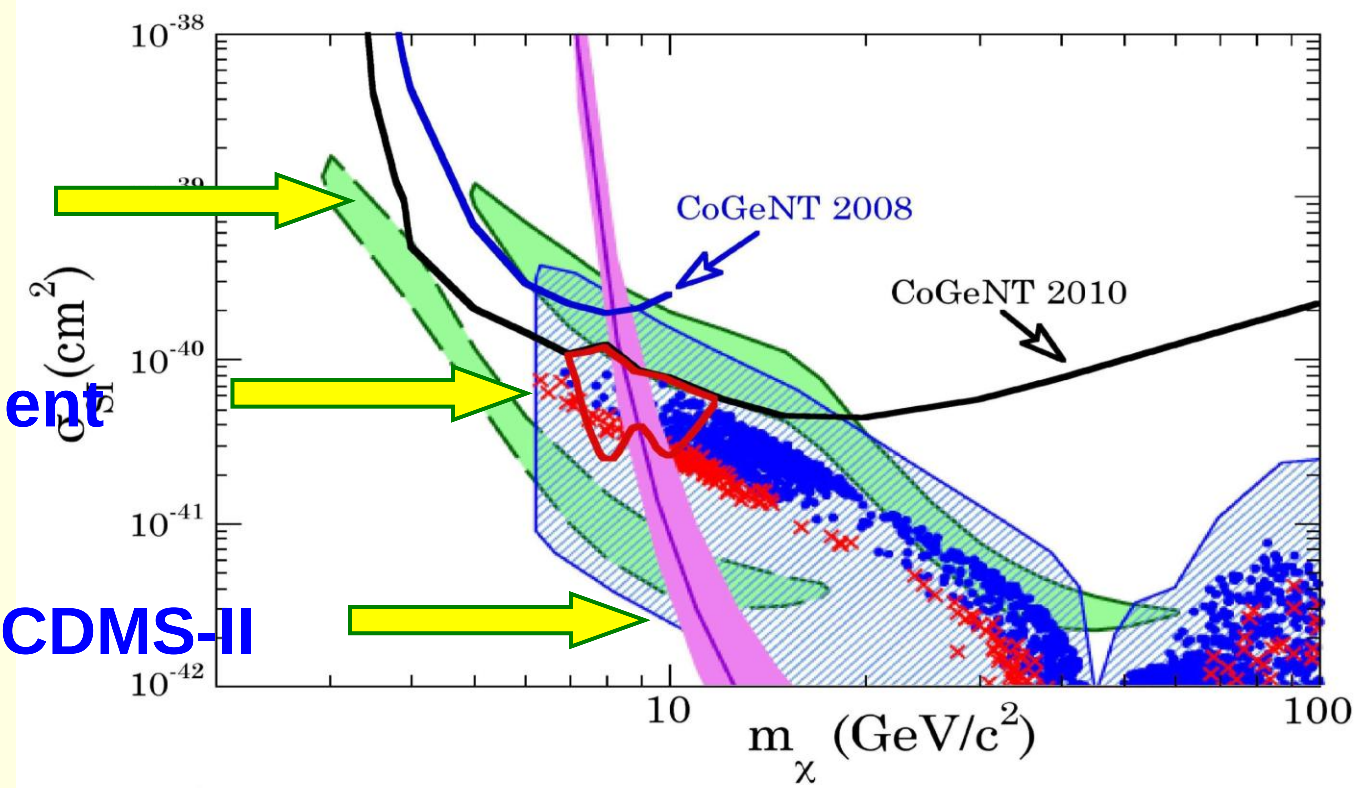
Under ground experiments



DAMA

CoGent

CDMS-II



J. Li’s Talk

CDMS-II, arXiv:0912.3592

CoGeNT, arXiv:1002.4703,

Xenon100, arXiv:1005.0380

Hint on light DM ?

Symmetries for DM stability

- **Symmetries important for keeping particle stable**

  electron:U(1) em. symmetry, lightest charged particle

  proton: U(1) B-L symmetry, lightest baryon

- **DM are often protected by symmetries**

Well known examples

SUSY: R-parity,

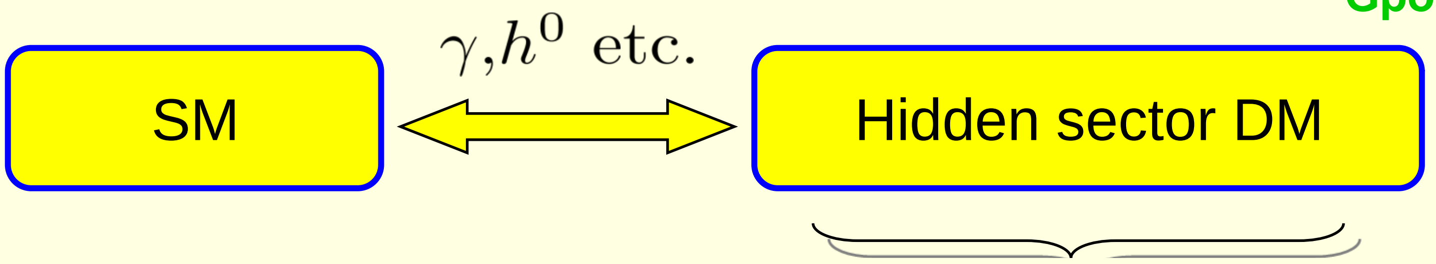
UED: KK-parity,

Little Higgs: T-parity

Ackerman,buckley,Carroll, Kamonkowski 08'
Feng, Tu, Yu 08', Feng, Kaplinghat, Tu, Yu 09'
Foot etal. 10'

Symmetries for hidden sector DM

Pospelov, Ritz, voloshin 07'
Gpoalakrishnal,Jung,Wells 08'
Gpoalakrishnal,Lee,Wells 08'
Mambrini 10'



Symmetry not shared wiht SM sector

- **Hidden sector U(1) symmetry**

exact U(1)

Broken U(1): a massive Z', a scalar ϕ

$$\mathcal{L} = \mathcal{L}_{SM} + \overline{\psi'} i\gamma^\mu(\partial_\mu + ieA'_\mu)\psi'$$

kinetic mixing

$$-\frac{1}{4}\kappa F_{\mu\nu}F'^{\mu\nu}$$

Higgs portal

$$-\lambda\phi^\dagger\phi H^\dagger H$$

- **Hidden custodial symmetry vector DM**

$$\mathcal{L} = -\frac{1}{4}F_{\mu\nu a}F^{\mu\nu a} + (D^\mu\phi)^\dagger(D_\mu\phi) - \mu^2\phi^\dagger\phi - \lambda(\phi^\dagger\phi)^2$$

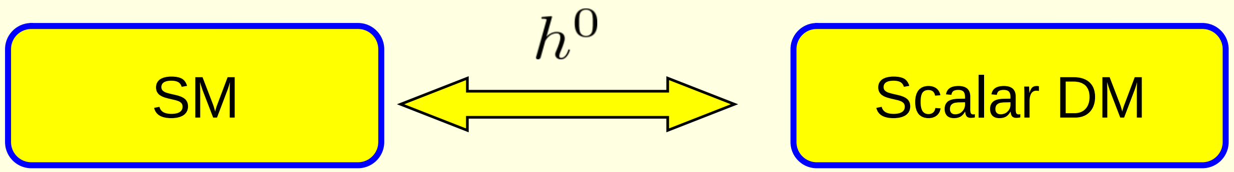
Hambye 08'

DM in minimal extensions of the SM

Simplest extension to SM: scalar DM

P and CP broken

$Z_2 : D \to -D$



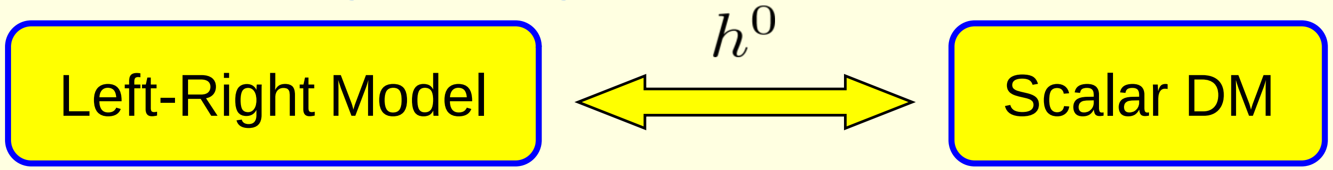
$$\mathcal{L} = \mathcal{L}_{SM} - \frac{m_0^2}{2} D^2 - \frac{\lambda_D}{4} D^4 - \lambda D^2 H^\dagger H$$

Silveira, Zee, 1985
McDondald, 1994,
Burgess, Pospelov & Veldhuis, 2001
Barger,Langacker, KcCaskey, 2007
Shafi, Okada, 2009
He,Li, Tsai, 2007,2009

Extension to LRM with scalar DM

P and CP symmetry

auto stable !



Guo, Wang, Wu, YFZ, Zhuang,PRD79,055015(2009);

A LR model with spontaneous P and CP violation

- Gauge interaction: $SU(2)_L \otimes SU(2)_R \otimes U(1)_{B-L}$

Flavor contents

$$\begin{aligned}
\phi &= \begin{pmatrix} \phi_1^0 & \phi_1^+ \\ \phi_2^- & \phi_2^0 \end{pmatrix}, \chi = \begin{pmatrix} \chi_1^0 & \chi_1^+ \\ \chi_2^- & \chi_2^0 \end{pmatrix}, \\
\Delta_{L,R} &= \begin{pmatrix} \delta_{L,R}^+/\sqrt{2} & \delta_{L,R}^{++} \\ \delta_{L,R}^0 & -\delta_{L,R}^+/\sqrt{2} \end{pmatrix}, \\
S &= \frac{1}{\sqrt{2}}(S_\sigma + iS_D)
\end{aligned}$$

- **Two bi-doublet required for spontaneous CP violation.**
- **Only one bi-doublet cannot give the correct CP phase**

P- and CP-transformations

	P	CP
$\phi \to$	$\phi^\dagger \to$	ϕ^*
$\chi \to$	$\chi^\dagger \to$	χ^*
$\Delta_{L(R)} \to$	$\Delta_{R(L)} \to$	$\Delta_{L(R)}^*$
$S \to$	$S \to$	S^*

If P and CP are only broken spontaneously

Terms forbidden

$$(S - S^*)^{1,3}$$

$$(S - S^*)\mathrm{Tr}(\phi^\dagger \phi)$$

$$(S - S^*)\mathrm{Tr}(\Delta_L^\dagger \Delta_L + \Delta_R^\dagger \Delta_R)$$

⇓

S_D is stable → DM candidate

After EWSB

- S_D does not participate gauge Interactions, as it is gauge singlet
- Require that S_D does not develop a nonzero VEV → S_D a DM particle

- Relevant scalar interactions

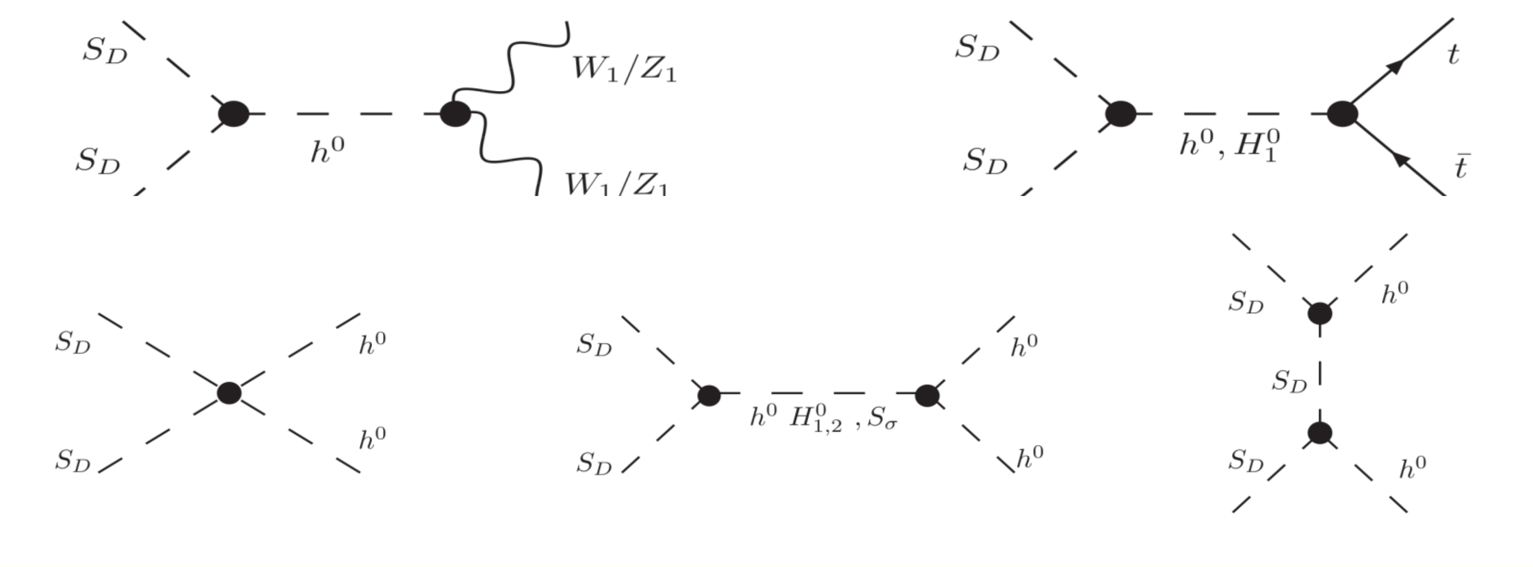
$$
\begin{aligned}
-\mathcal{V}_0 \quad = \quad & \frac{1}{\sqrt{2}}\tilde{\mu}_0^3(S+S^*) - \tilde{\mu}_S^2 SS^* - \frac{1}{4}\tilde{\mu}_\sigma^2(S+S^*)^2 + \sqrt{2}\tilde{\mu}_{\sigma S}(S+S^*)SS^* \\
& + \frac{1}{6\sqrt{2}}\tilde{\mu}_{3\sigma}(S+S^*)^3 + \tilde{\lambda}_S(SS^*)^2 - \frac{1}{4}\tilde{\lambda}_{\sigma S}(S+S^*)^2 SS^* - \frac{1}{16}\tilde{\lambda}_\sigma(S+S^*)^4 \\
& + \sum_{i=1}^{5}\left[-\frac{1}{\sqrt{2}}\tilde{\mu}_{i,\sigma}(S+S^*) + \tilde{\lambda}_{i,S}SS^* - \frac{1}{4}\tilde{\lambda}_{i,\sigma}(S+S^*)^2\right]O_i \,,
\end{aligned}
$$

Guo, Wu, YFZ, PRD81,075014 (2010)

$$
\begin{aligned}
O_1 &= \mathrm{Tr}(\Delta_L^\dagger\Delta_L + \Delta_R^\dagger\Delta_R), \\
O_2 &= \mathrm{Tr}(\phi^\dagger\phi), O_3 = \mathrm{Tr}(\phi^\dagger\tilde{\phi} + \tilde{\phi}^\dagger\phi) \\
O_4 &= \mathrm{Tr}(\chi^\dagger\chi), O_5 = \mathrm{Tr}(\chi^\dagger\tilde{\chi} + \tilde{\chi}^\dagger\chi) \;.
\end{aligned}
$$

DM annihilation

Main annihilation channels



Thermally averaged cross section & relic density

$$\langle\sigma v\rangle = \sigma_0 x^{-n} = \frac{1}{m_D^2}\left[\omega - \frac{3}{2}(2\omega - \omega')x^{-1} + \ldots\right]_{s/4m_D^2=1} ,$$

$$\Omega_{DM}h^2 = 1.07\times 10^9\,\frac{(n+1)x_f^{n+1}}{g_*^{1/2}M_{Pl}\,\sigma_0}\,\mathrm{GeV}^{-1}$$

Relic density and direct detection

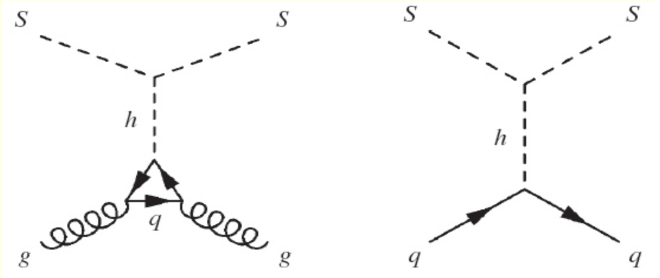
$$0.105 \le \Omega_{DM} h^2 \le 0.117$$

- Parameter space from relic density

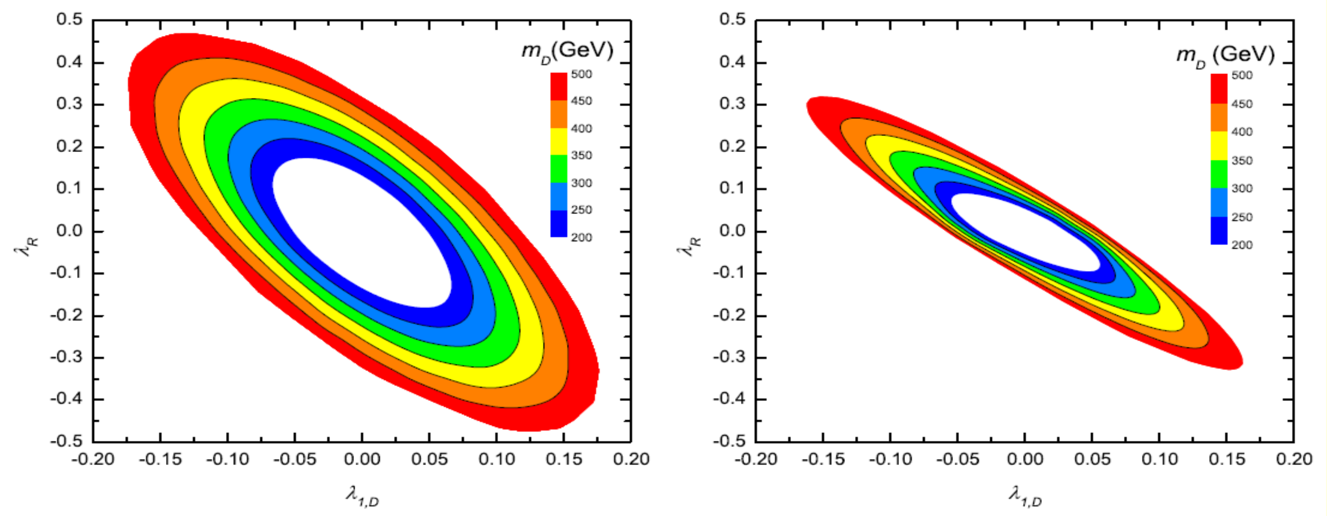
$$\begin{aligned} -1 \le &\ \lambda_R &\le 1, \\ -1 \le &\ \lambda_{1,D} &\le 1, \\ 200\,\mathrm{GeV} \le &\ m_D &\le 500\,\mathrm{GeV}. \end{aligned}$$

- Prediction for direct detection

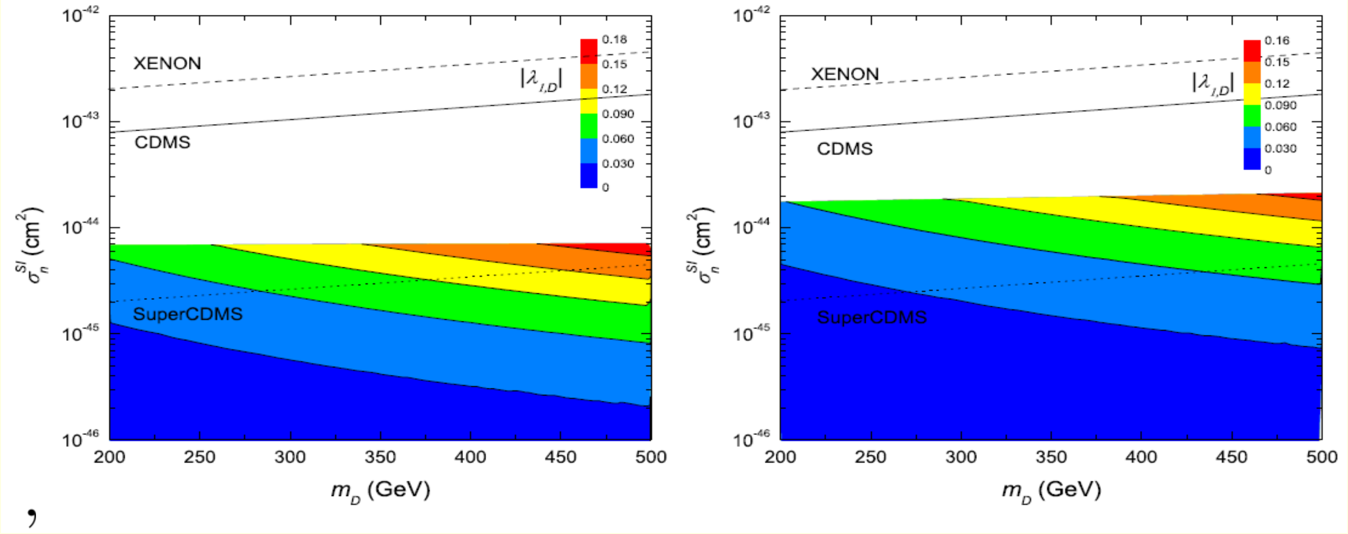
  rate



$$\sigma_{\mathcal{N}} = \frac{4M^2(\mathcal{N})}{\pi}(Zf_p + (A-Z)f_n)^2 ,$$

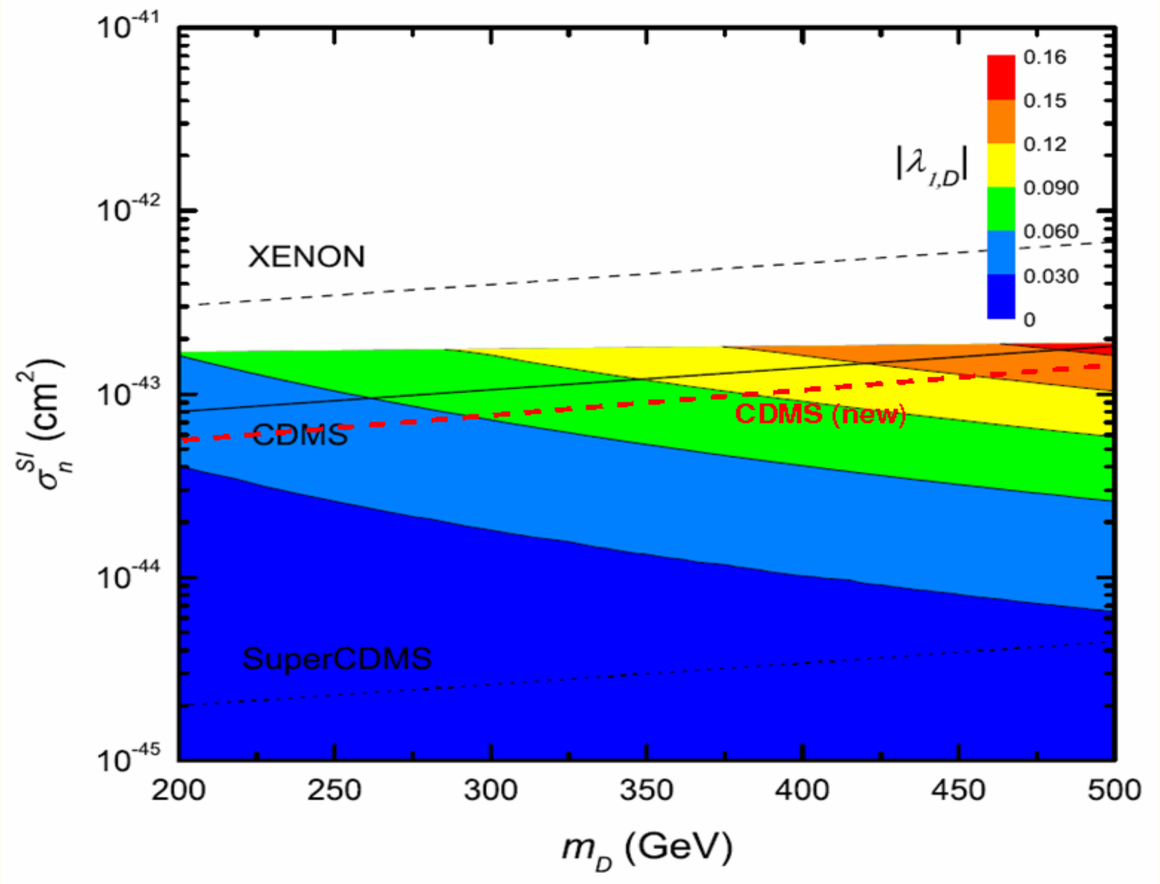


one bi-doublet case **two bi-doublet case**



Guo, Wang, Wu, YFZ, Zhuang,PRD79,055015(2009);

A special case: large Yukawa couplings to light quarks



- Relic density is dominated by heavy quarks, not light ones
- DM-nucleus scattering is sensitive to light quark Yukawa couplings

DM decay through soft C-breaking terms

Guo, Wu, YFZ, PRD81,075014 (2010)

DM decay may avoid the boost factor problem

- Including soft C-breaking term

dominant part: C- and P-even

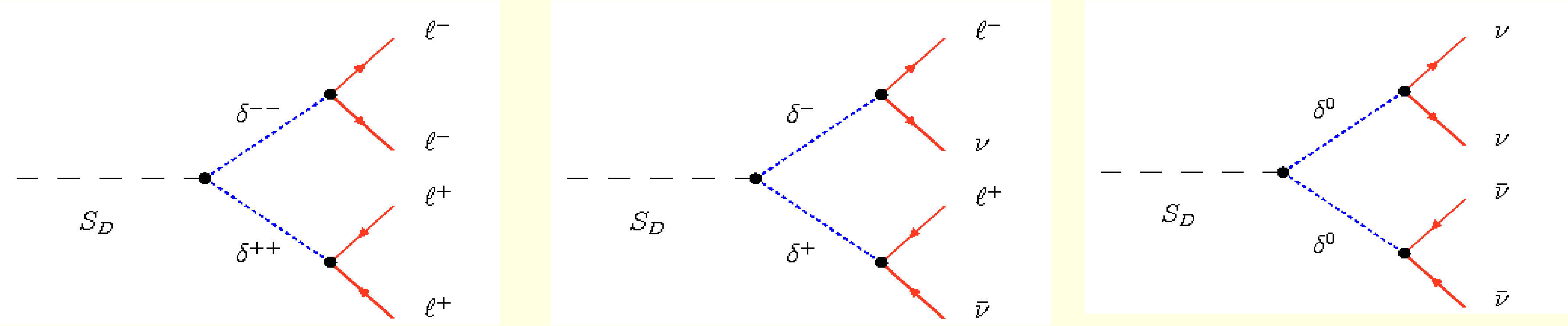
$$\boxed{\mathcal{V} = \mathcal{V}_0 + \mathcal{V}_1 .}$$

tiny part: C-odd

$$-\mathcal{V}_1 = \mu_\epsilon (S - S^*) \left[\sum_{i=1}^{5} \zeta_i O_i + \zeta_6 (S + S^*)^2 + \zeta_7 (S - S^*)^2 \right] .$$

$$\begin{aligned} O_1 &= \mathrm{Tr}(\Delta_L^\dagger \Delta_L + \Delta_R^\dagger \Delta_R), O_2 = \mathrm{Tr}(\phi^\dagger \phi), O_3 = \mathrm{Tr}(\phi^\dagger \tilde{\phi} + \tilde{\phi}^\dagger \phi) \\ O_4 &= \mathrm{Tr}(\chi^\dagger \chi), O_5 = \mathrm{Tr}(\chi^\dagger \tilde{\chi} + \tilde{\chi}^\dagger \chi) \ . \end{aligned}$$

DM decay through triplets



- Decay through left-handed triplet can naturally explain the PAMELA/Fermi data
  - Triplets with nonzero B-L number do not couple to quarks through Yukawa interactions

  - Indirect channels WW, WZ, and ZZ suppressed by tiny triplet VEV required by neutrino masses.

$$\frac{\Gamma(\delta_L^{++} \to W^+W^+)}{\Gamma(\delta_L^{++} \to \ell^+\ell^+)} \approx \frac{g^4}{16}\left(\frac{v_L m_{\delta_L}}{Y_{\ell\ell} m_W^2}\right)^2 ,$$

Positron signals

- Diffusion eq.

Sources from DM decay

$$-K(E)\cdot\nabla^2 f_e - \frac{\partial}{\partial E}(b(E)f_e) = Q \qquad Q(r,E) = \frac{\rho(r)}{m_D}\sum_k \Gamma_k \frac{dn_E^k}{dE}$$

$$f(E,r,z) = \frac{1}{m_D}\int_E^{m_D} dE' G_e(E,E',r,z)\sum_k \Gamma_k \frac{dn_E^k}{dE}$$

Background

$$\begin{aligned}
\Phi_{e^-}^{prim}(E) &= \frac{0.16E^{-1.1}}{1+11E^{0.9}+3.2E^{2.15}}\ , \\
\Phi_{e^-}^{sec}(E) &= \frac{0.7E^{0.7}}{1+110E^{1.5}+600E^{2.9}+580E^{4.2}}\ , \\
\Phi_{e^+}^{sec}(E) &= \frac{4.5E^{0.7}}{1+650E^{2.3}+1500E^{4.2}}\ ,
\end{aligned}$$

e^+ fraction and total $(e^+ + e^-)$ flux

mass parameters

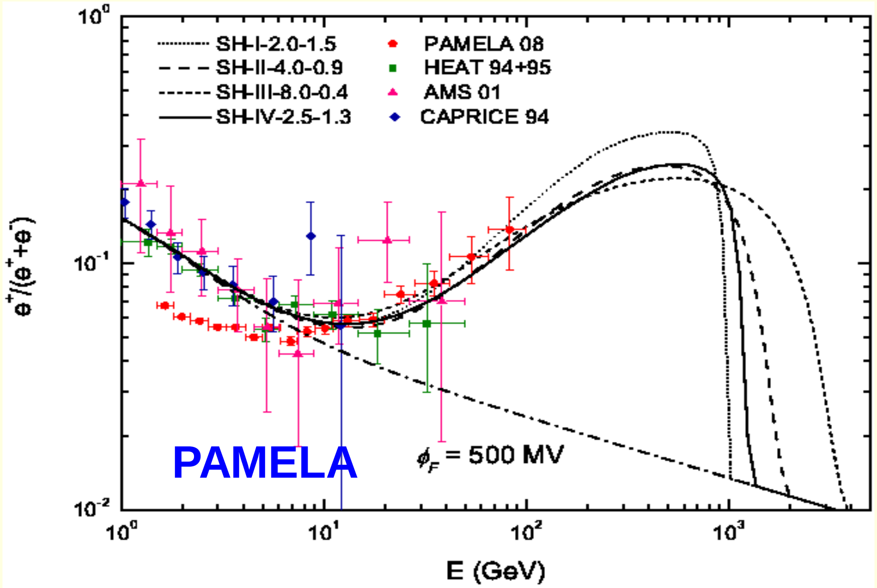
case	m_D (TeV)	τ_D (10^{26} s)	$2m_{\delta_L}/m_D$
SH(LH)-I	2.0	1.5	0.8 (0.1)
SH(LH)-II	4.0	0.9	0.8 (0.1)
SH(LH)-III	8.0	0.4	0.8 (0.1)
SH(LH)-IV	2.5	1.3	0.8 (0.1)

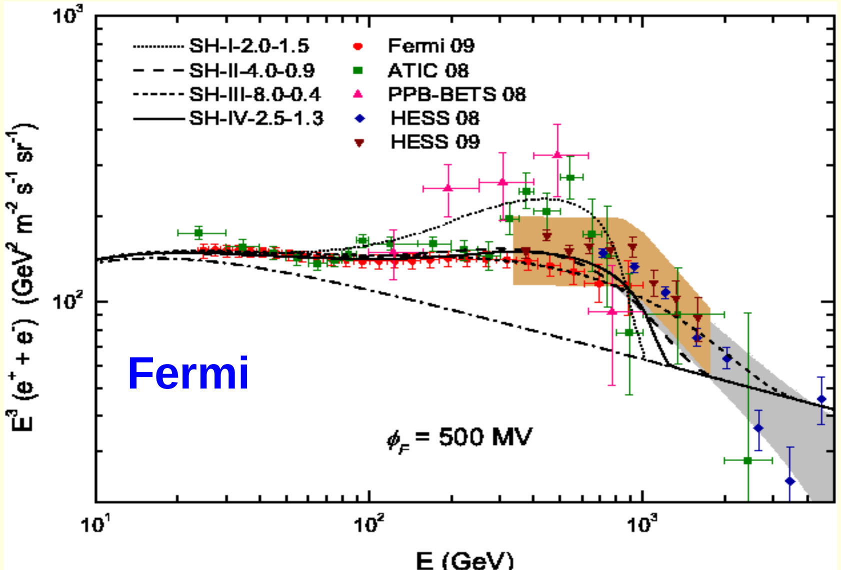
Consider 3 cases with final states dominated by different lepton flavor

I: $4e,\ 2e2\nu_e,\ 4\nu_e$
II: $4\mu,\ 2\mu2\nu_\mu,\ 4\nu_\mu$
III: $4\tau,\ 2\tau2\nu_\tau,\ 4\nu_\tau$

- **Explain PAMELA data well. for all type of lepton final states.**
- **mu/tau final states favored by Fermi**
- **tau-lepton final states predict High neutrino-induced muon flux.**

Guo, Wu, YFZ, PRD81,075014 (2010)





Predictions for up-going muon flux

Neutrino flux from DM decay

$$\frac{d\Phi_{\nu_\mu}}{dE_{\nu_\mu}} = \rho_\odot r_\odot \frac{1}{4\pi m_D} \left(\sum_{\alpha=e,\mu,\tau} P_{\nu_\alpha \to \nu_\mu} \sum_k \Gamma_k \frac{dn^k_{\nu_\alpha}}{dE_{\nu_\alpha}} \right) J_{\Delta\Omega} \Delta\Omega \ ,$$

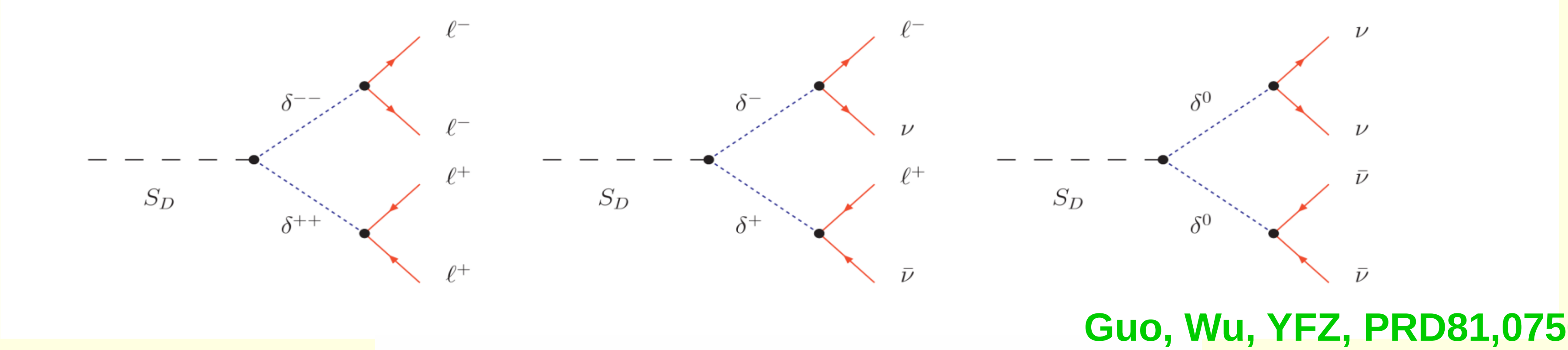
Muon flux from neutrinos

$$\Phi_\mu = \int_{E_{thr}}^{m_D/2} dE_{\nu_\mu} \frac{d\Phi_{\nu_\mu}}{dE_{\nu_\mu}} \int_{E_{thr}}^{E_{\nu_\mu}} dE_\mu \, L(E_\mu) \sum_{a=p,n} n_a \sum_{x=\nu_\mu,\bar{\nu}_\mu} \frac{d\sigma^a_x(E_{\nu_\mu})}{dE_\mu} \ .$$

$$L(E_\mu) = \frac{1}{\rho\beta_\mu} \ln \frac{\alpha_\mu + \beta_\mu E_\mu}{\alpha_\mu + \beta_\mu E_{thr}} \ ,$$

Predictions for up-going muon flux

Triplets couple to neutrinos and charged-leptons with the same strength



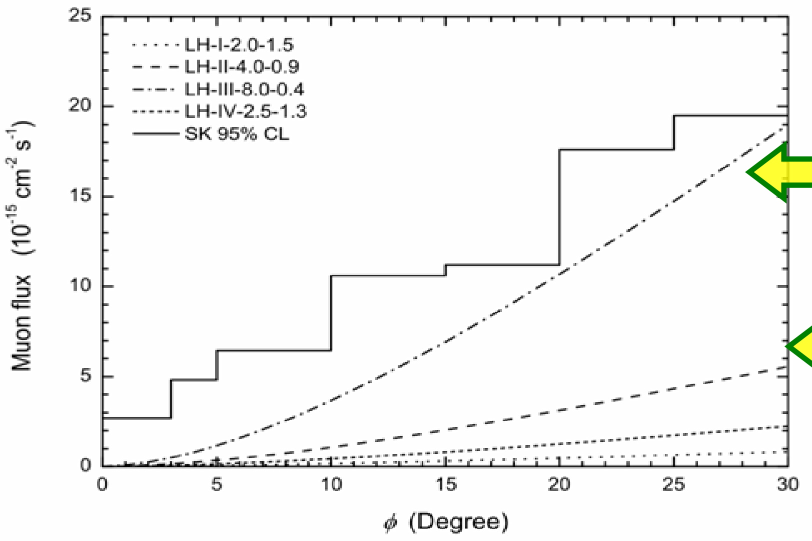
Guo, Wu, YFZ, PRD81,075014 (2010)

Final states

I: $4e$, $2e2\nu_e$, $4\nu_e$

II: 4μ, $2\mu2\nu_\mu$, $4\nu_\mu$

III: 4τ, $2\tau2\nu_\tau$, $4\nu_\tau$



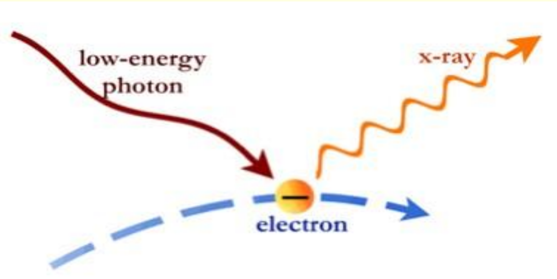
$\tau-$ type final states

$\mu-$ type final states

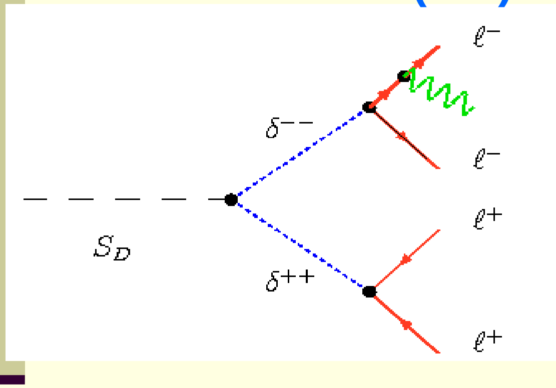
up-going muon flux can reach the current SK bound

Diffuse gamma-rays

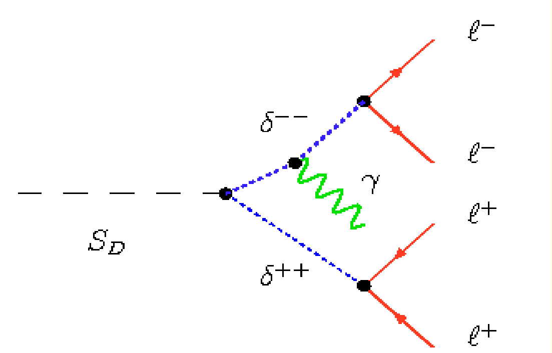
Inverse Compton scattering (ICS)



Final state radiation (FSI)

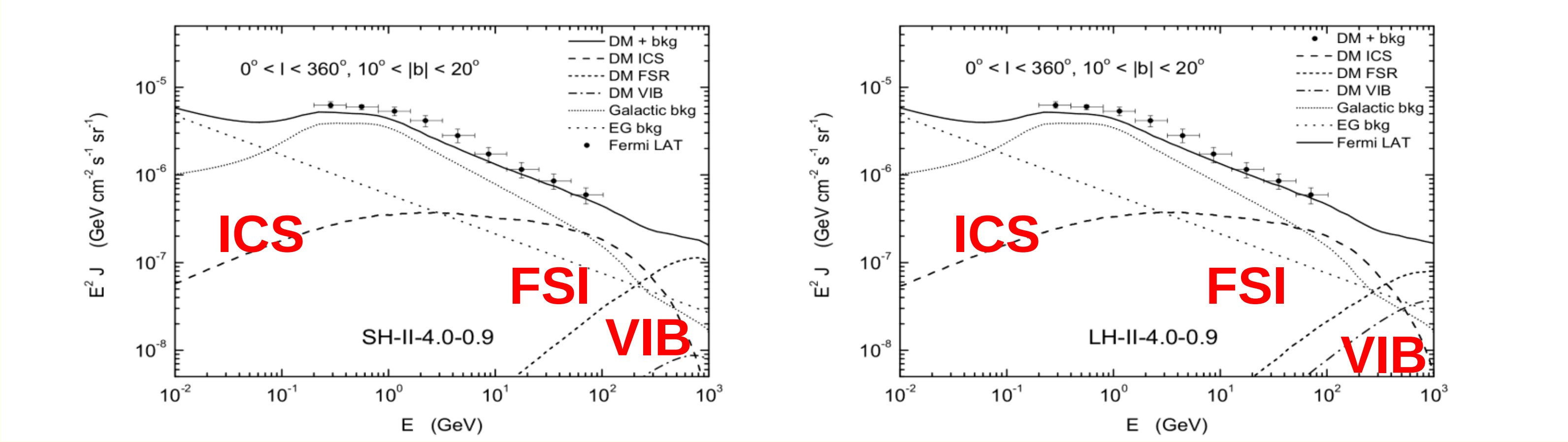


Virtual internal bremsstrahlung (VIB)

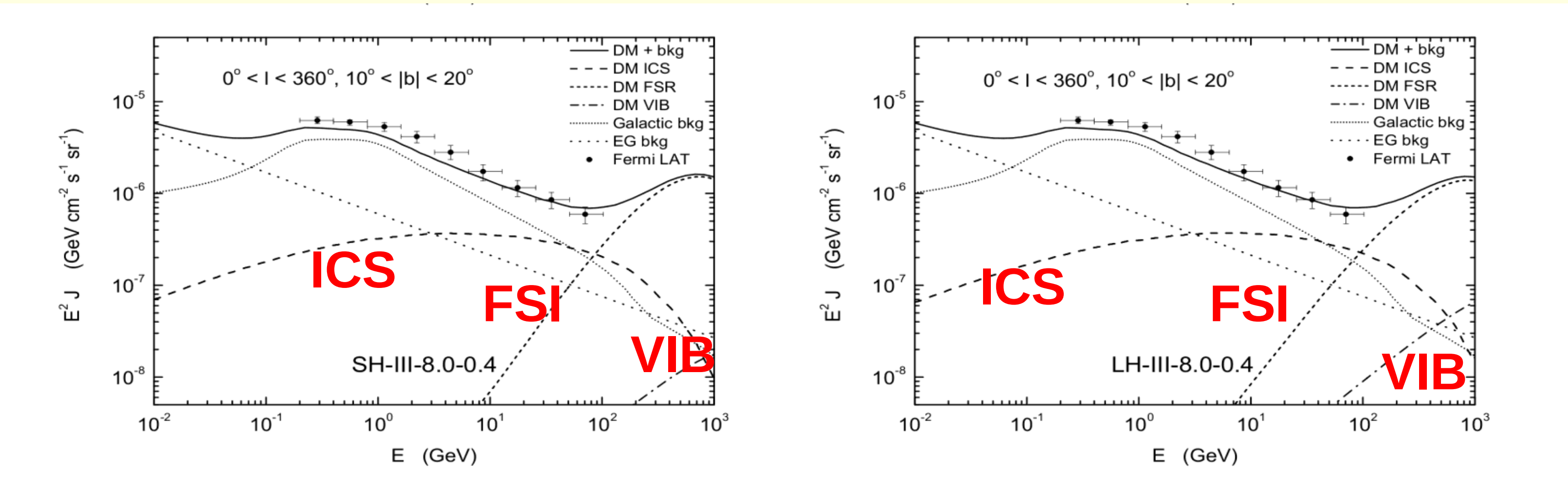


SH-III case

LH-III case



$\mu-$ type final states



$\tau-$ type final states

Guo, Wu, YFZ, PRD81,075014 (2010)

Summary

- We proposed a LR model with auto-stable scalar DM candidate which is stabilized by the C and CP-symmetries.
- The predictions for DM direct detection cross section can be close to the current exp. sensitivity.
- Tiny DM particle decay can be induced by adding tiny soft C-violation interactions. The decay trough triplet scalars provides a natural explanation to the current PAMELA, Fermi-LAT data.
- The model has testable predictions for neutrino-induced muon flux and has new sources of very high energy gamma-rays, which can be tested by future experiments.

Thank You!

Workshop coming soon

ITP annual topical workshop

Dark matter and Baryogenesis

Dec. 13-15. ITP, Beijing

Activities in the next year

“Dark Matter and New Physics”

KITPC-Program (Sept.21-Nov.6)

International coordinator

E. Aprile
K.Freese
C.Q.Geng
S.Matsumoto
Q.Shafi
S.F.Su
H.T.Wang
J.Wefel

Local coordinator

X.J.Bi
J.Chang
K.X.Ni
Q.Yue
C.G.Yang
Y.F.Zhou

“Dark Side of the Universe (DSU11)”

Workshop (Sept.26-30)

International committee

C.Balazs
D.Delepine
S.Khalil
A.Klypin
P. Ko
C.Munoz
J. Silk
Q.Shafi
K.Olive
Y.L.Wu

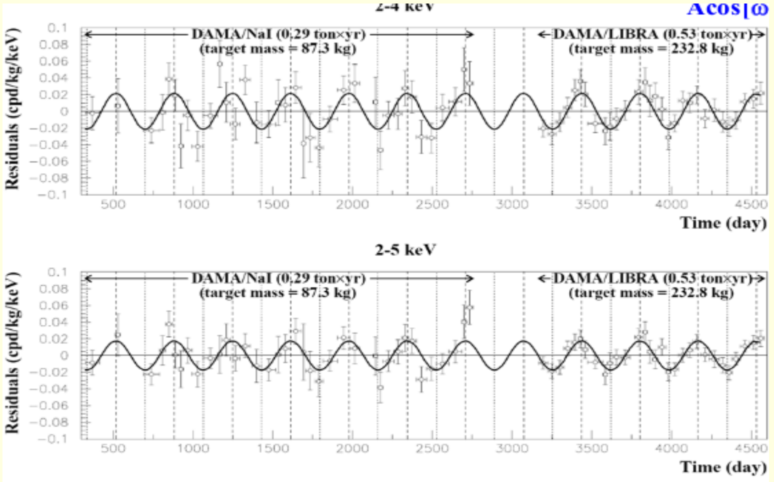
Local committee

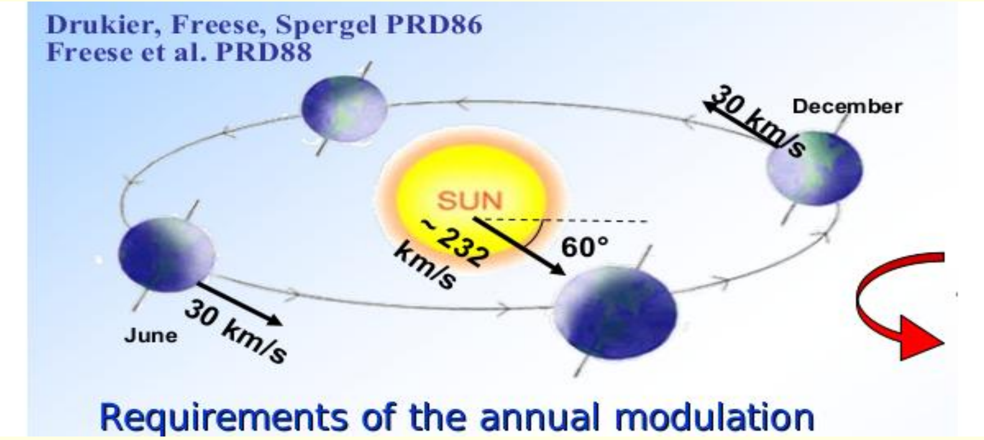
X.J.Bi, R.G.Cai,
X.L.Cheng, Q.G.Huang
C.F.Qiao, M. Li,
B.Qin, H.J.He,
Y.F.Zhou, S.H.Zhu

BACKUP

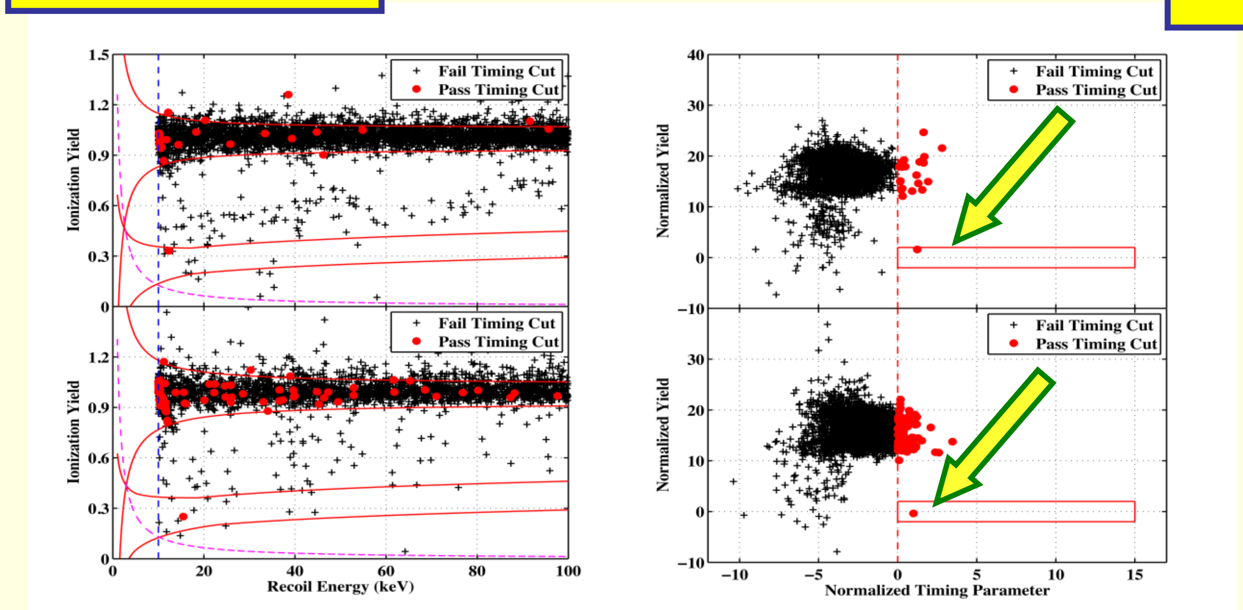
Underground DM searches

DAMA

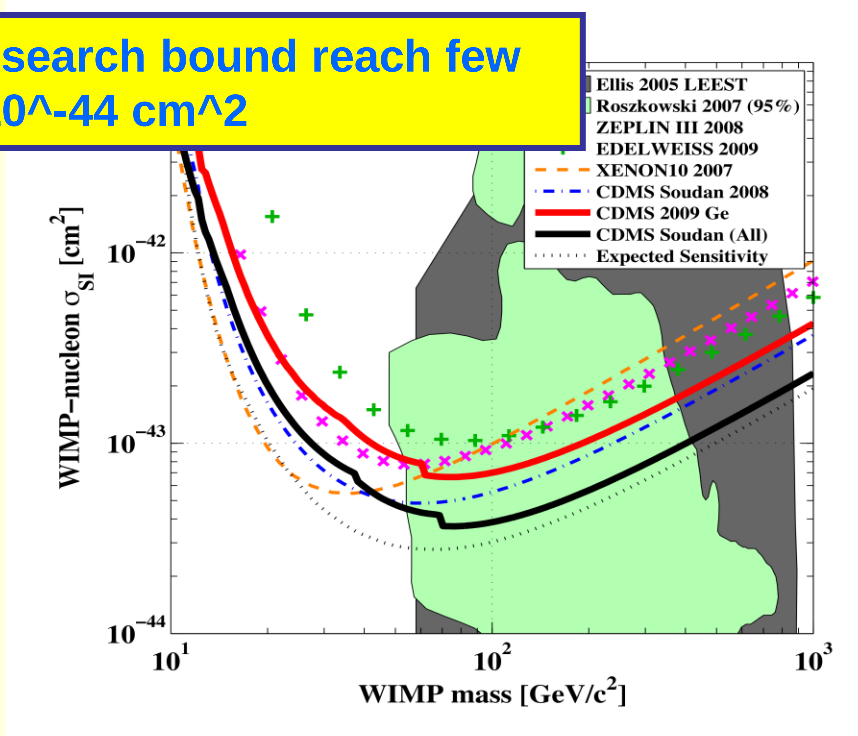




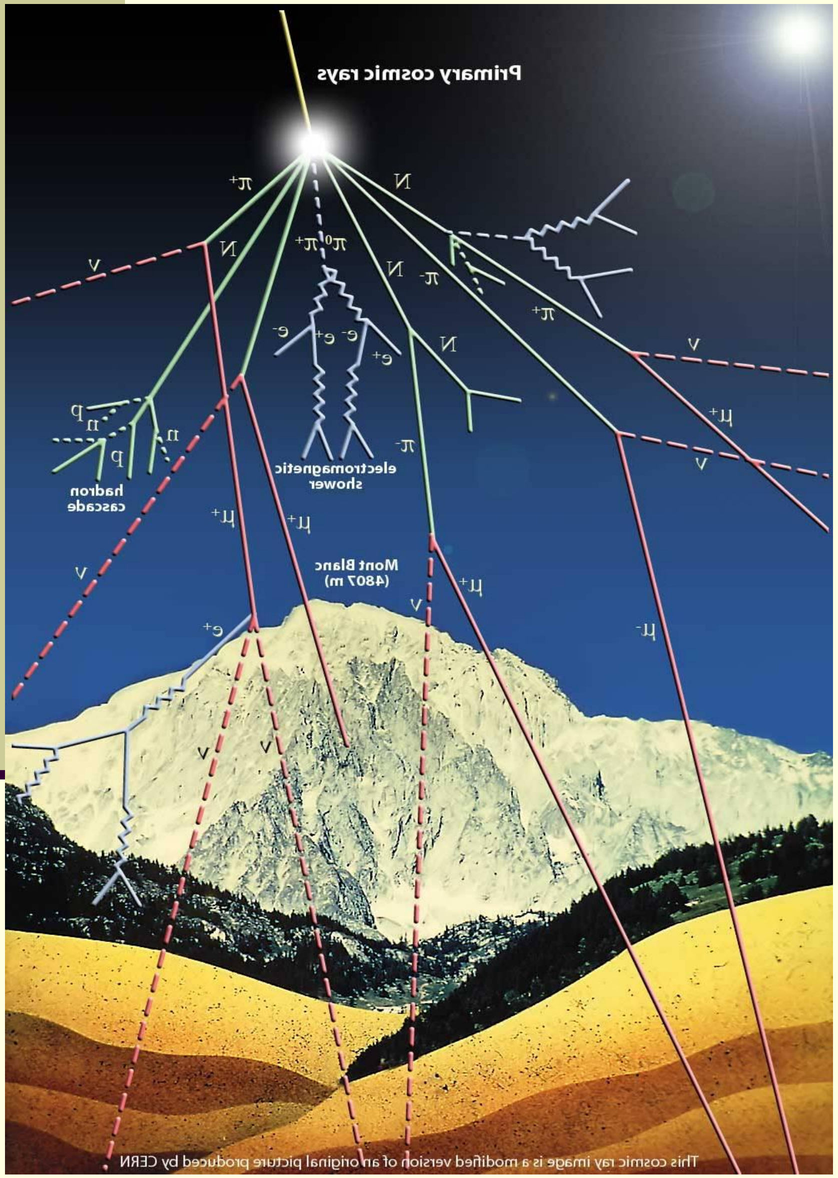
CDMS-II



Direct search bound reach few 10^-44 cm^2



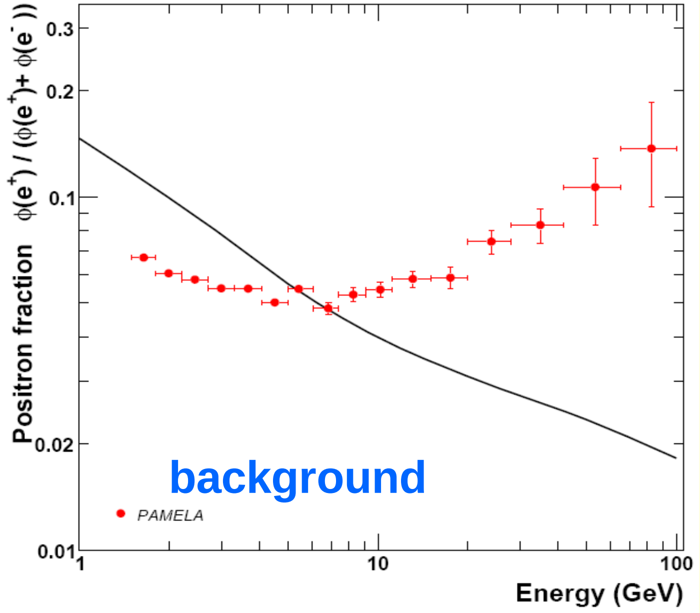
Hint of DM ? Positron fraction

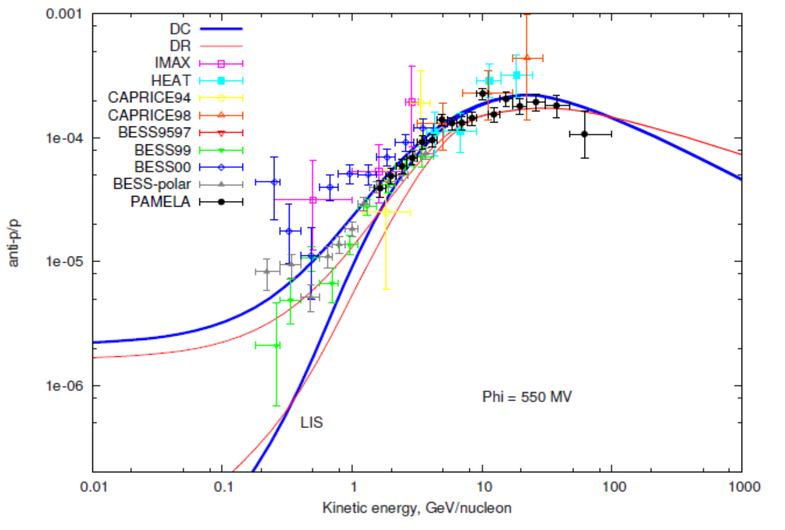


e^+ fraction excess

Nature 458, 607 (2009)

PAMELA





if interpreted as DM signal

- Large annihilation cross section **now**
- Mainly annihilation/decay into leptons, not quarks

KITPC 2011 program

- Topic: **dark matter and new physics**
- Time: Sept. 21-Nov. 06, 2011
- Coordinators:
  - International

Shafi, Qaisar (University of Delaware), Aprile, Elena (Columbia U.,USA) Wang, Tsz-king Henry(IOP,AS) Wefel, John (Louisiana State U., USA) Matsumoto, Shigeki (Toyama U., Japan), Su, Shu-Fang (Arizona U. USA) Geng, Chao-Qiang (NCTS),

  - Local

Bi, Xiao-Jun (IHEP) Ni, Kai-Xuan (SJTU) Yang, Chang-Geng (IHEP) Yue, Qian (Tsinghua U.) Zhou, Yu-Feng (ITP)

Welcome to Join the program !

- **Large SU(2)_L multiplets (minimal DM)**

Cirelli, Fornengol, Strumia 06'
Cirelli, Strumia, Tamburini 07'

$$\mathcal{L}_{SM} + \left\{ \begin{array}{c} \overline{\chi}(i\not{D} + M)\chi \\ |D_\mu \chi|^2 - M^2|\chi|^2 \end{array} \right.$$

χ:n-tuplet of $SU(2)_L$ group. $n \geq 5(7)$ for fermions (scalars)

Diffuse gamma-rays

- Gamma-rays from DM decay

$$\frac{d\Phi_\gamma}{dE_\gamma} = \frac{\rho_\odot r_\odot}{4\pi m_D} \, J_{\Delta\Omega} \left(\sum_k \Gamma_k \frac{dn_\gamma^k}{dE_\gamma} \right) \quad ,$$

  - Final state radiation
  - Virtual internal bremsstralung

- Inverse Compton scattering

$$\frac{d\Phi_{\gamma'}}{dE_{\gamma'}} = \frac{\alpha_{em}^2}{\Delta\Omega} \int_{\Delta\Omega} d\Omega \int_{LOS} ds \int \int f_{e^+}(E_e, r, z) \, u_\gamma(E_\gamma, r, z) \, f_{ICS} \frac{dE_e}{E_e^2} \frac{dE_\gamma}{E_\gamma^2} \quad . \quad (1$$