
感謝(감사) 합니다

Cheon, Hwa Sung (천화성, 千和聖)

Yonsei University, Seoul, Korea

Collaborate with C.S.Kim and Sin Kyu Kang

The Eighth Particle Physics Phenomenology Workshop (PPP8), May 20 - 23, 2009, NCKU, Tainan

Concluding Remarks
- Summary of workshop -

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PAMELA/ATIC and DAMA anomalies in an Extended Seesaw Model

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Why is an Extended Seesaw Model?

(S.K.Kang, C.S.Kim, Phys. Lett. , (2007) 248 [arXiv:hep-ph/0607072])

Why is an Extended Seesaw Model?

(S.K.Kang, C.S.Kim, Phys. Lett. , (2007) 248 [arXiv:hep-ph/0607072])

We have an another problem
in our Universe.

Why there is more matter than antimatter in the present Universe?

JCAP 0805:004,2008 (hep-ph/0710.2416)
(C.S.Kim, Sin Kyu Kang, HSCheon)

$$\mathcal{L} = \mathcal{L}_{SM} + Y_D \nu_D H N + M_N N N + Y N \phi S + m_S S S + \frac{1}{2}(\partial_\mu \phi)^2 - \frac{1}{2} m_\phi^2 \phi^2 - \frac{\lambda_s}{4}\phi^4 - \lambda H^\dagger H \phi^2 + h.c.$$

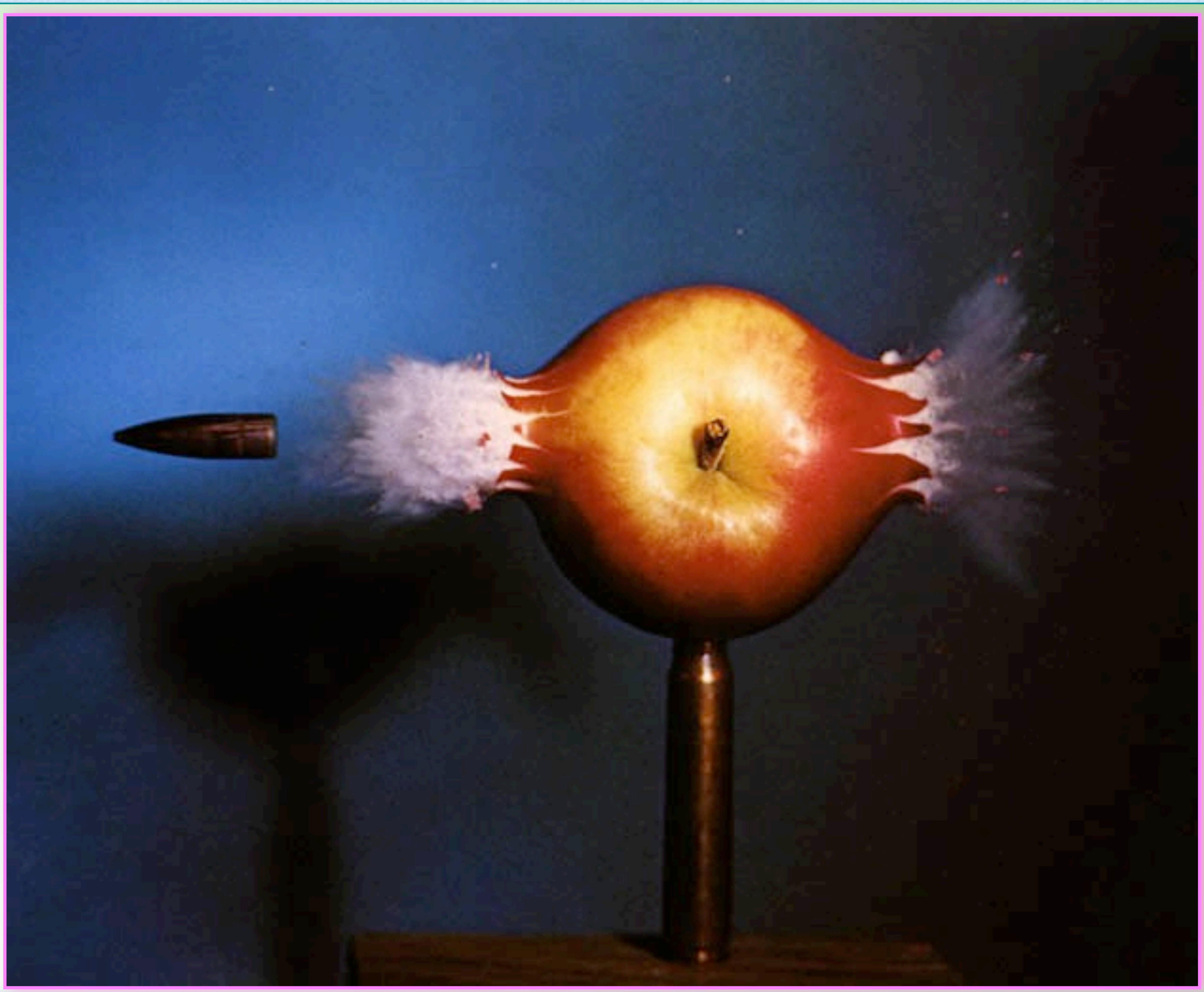
L_{SM} : the Standard model Lagrangian, H : Higgs doublet
N : Heavy Majorana neutrino field, φ: Singlet Higgs field (SH)
S : Singlet intermediate Majorana neutrino field (SMN)

Our model is described by **seven** parameters : 1. dimensionless self coupling, λ_s 2.the mass of ϕ, M_ϕ, 3. dimensionless coupling of φ to the Higgs field, λ, 4, the mass of Heavy Majorana neutrino, $M_{N,}$ 5 the mass of S, $M_{S,}$ 6. Dirac Yukawa coupling, $Y_{D,}$ 7. Singlet Yukawa coupling, Y.

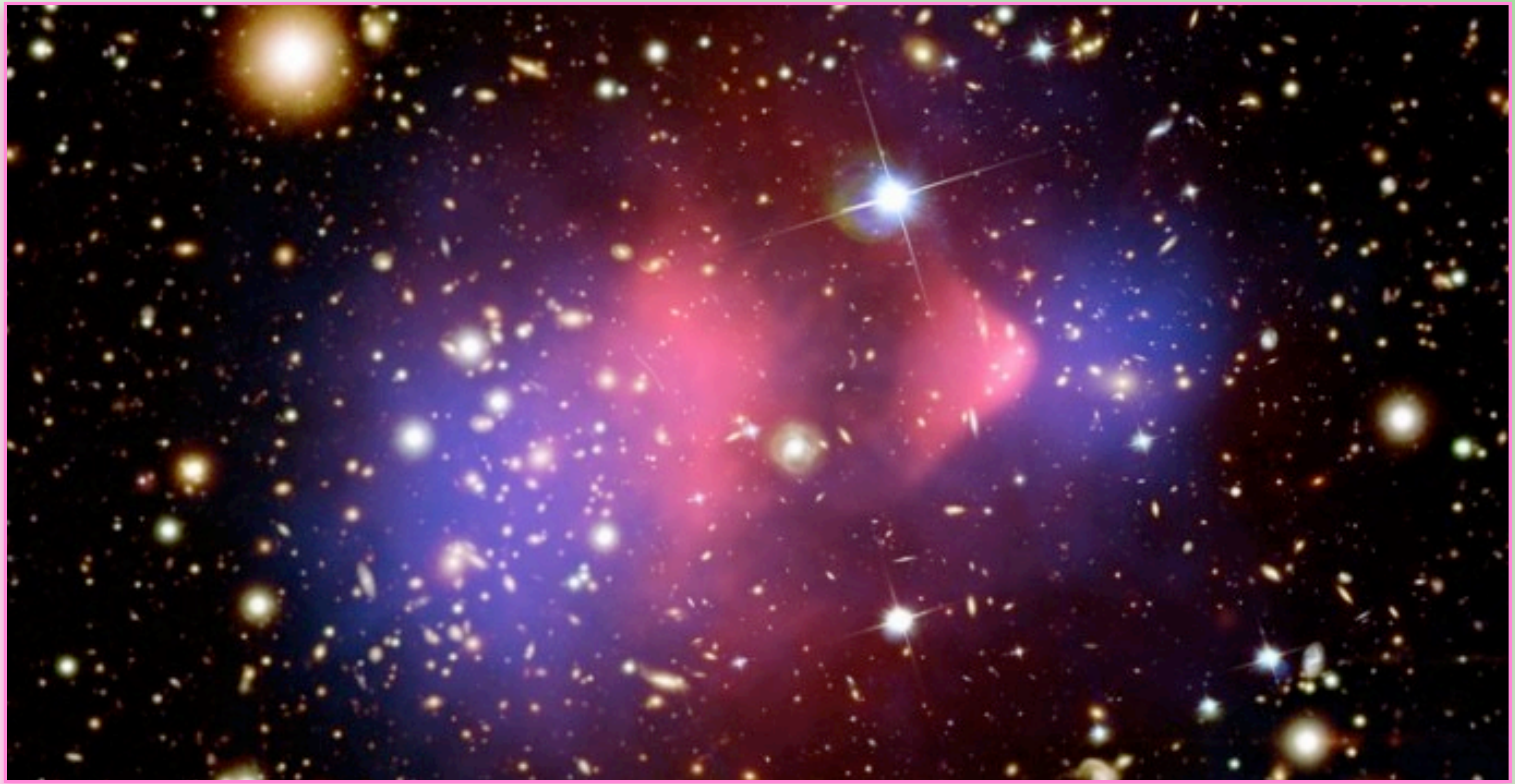
(Leptogenesis : Yesterday from Prof. Mu-Chun Chen's Lecture, Prof. C.S.Chen's talk,
Prof. T.Asaka's talk, S.Kanemura's talk, Prof. D.Zhuridov's talk
Neutrino have mass : Neutrino oscillation : Prof. Hung-Lian's lecture, Prof. T.Kikuchi's talk)

But, here we consider an extended seesaw model which introduce doubly coexisting DM model

Problems



the Bullet apple



http://antwrp.gsfc.nasa.gov/apod/ap060824.html

The Matter of the Bullet Cluster : Collisionless DM

http://antwrp.gsfc.nasa.gov/apod/ap070820.html

Dark Matter Core in the Abell 520 cluster :
Unknown interaction between DM particles

Credit: X-ray: NASA/CXC/UVic./A. Mahdavi et al. optical/lensing: CFHT/UVic./H. Hoekstra et al.

DAMA experiment

(R. Bernabei et al. [DAMA Collaboration], arXiv:0804.2741 [astro-ph], Prof. H. Wong talk, Prof. S.T.Lin's talk)

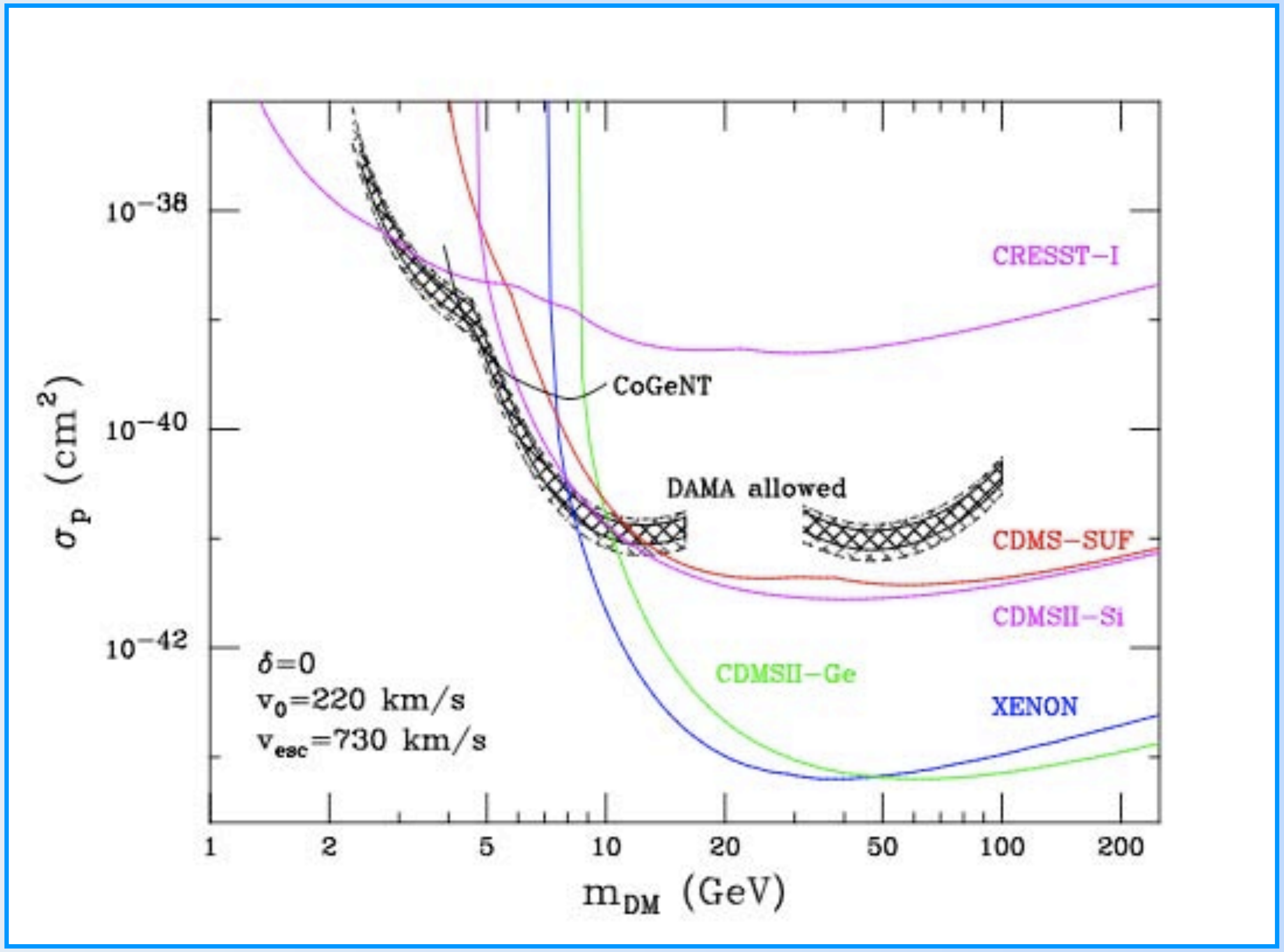
Last year, the DAMA collaboration announced the model independent annual modulation signature for dark matter particles in recoil scattering off NaI(Tl) detectors at the Gran Sasso Najtional Laboratory.

Actually the DAMA have already found DM signal

R. Bernabei et al., Phys. Lett. B 389 (1996) 757; R. Bernabei et al.,Phys. Lett. B 424 (1998) 195; R. Bernabei et al., Phys. Lett. B 450 (1999) 448; P. Belli et al.Phys. Rev. D 61 (2000) 023512; R. Bernabei et al., Phys. Lett. B 480 (2000) 23;
R. Bernabei et al., Phys. Lett. B 509 (2001) 197; R. Bernabei et al., Eur. Phys.
J. C 23 (2002) 61; P. Belli et al., Phys. Rev. D 66 (2002) 043503; R. Bernabei et al., Il Nuovo Cim. A 112 (1999) 545; R. Bernabei et al., Eur. Phys. J. C 18 (2000) 283; R. Bernabei el al., La Rivista del Nuovo Cimento 26 n.1 (2003) 1-73; R. Bernabei et al., Int. J. Mod. Phys. D 13 (2004) 2127; R. Bernabei et al., Int. J. Mod. Phys. A 21 (2006) 1445; R. Bernabei et al., Eur. Phys. J. C 47 (2006) 263; R. Bernabei et al., Int. J. Mod. Phys. A 22 (2007) 3155; R. Bernabei et al., Eur. Phys. J. C 53 (2008) 205; R. Bernabei et al., Phys. Rev. D 77 (2008) 023506; R. Bernabei et al., preprint ROM2F/2008/02, arXiv:0802.4336 [astro-ph].37;R. Bernabei et al., Phys. Lett. B408 (1997) 439; P. Belli et al., Phys. Lett. B460 (1999) 236; R. Bernabei et al., Phys. Rev. Lett. 83 (1999) 4918; P. Belli et al.,Phys. Rev. C60 (1999) 065501; R. Bernabei et al., Il Nuovo Cimento A112 (1999) 1541; R. Bernabei et al., Phys. Lett. B 515 (2001) 6; F. Cappella et al., Eur. Phys. J.-direct C14 (2002) 1; R. Bernabei et al., Eur. Phys. J. A 23 (2005) 7; R. Bernabei et al., Eur. Phys. J. A 24 (2005) 51;R. Bernabei et al., Astrop. Phys. 4 (1995) 45; R. Bernabe

(P. Gondolo & G. Gelmini) and (F.J.Petriello & K.M. Zurek) found that
there is a region of WIMP parameter space
which can simultaneously accommodate DAMA experiment
and the null results of the other direct dark matter detection experiments

F.J.Petriello & K.M. Zurek arXiv:0806.3989 [hep-ph],
Christopher Savage, Graciela Gelmini, Paolo Gondolo, Katherine Freese,
arXiv:0808.3607 [astro-ph]



$$3\text{GeV} \lesssim \quad m_{DM} \quad \lesssim 8\text{GeV}$$

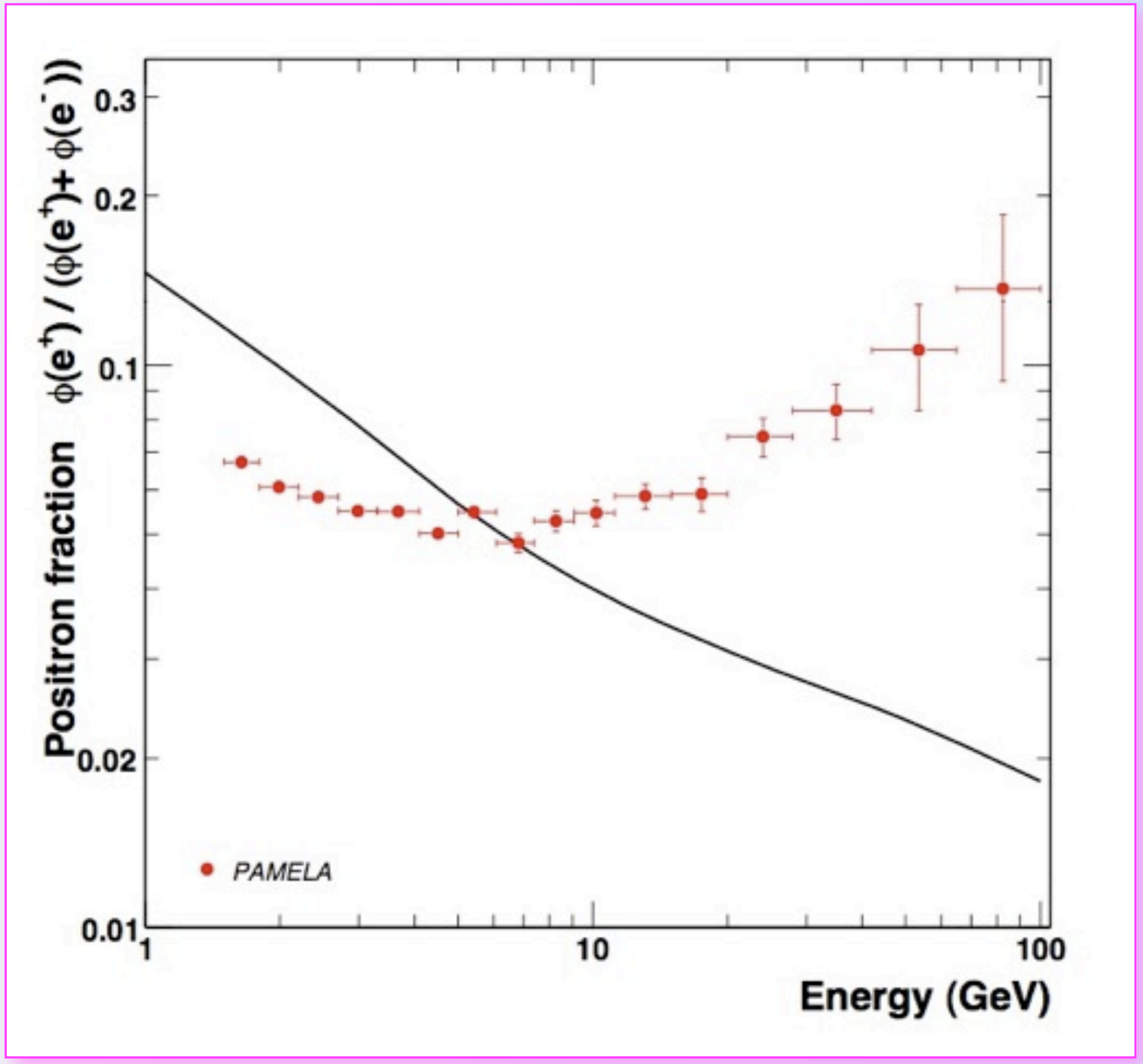
$$3 \times 10^{-41}\, cm^2 \lesssim \quad \sigma_p^{SI} \quad \lesssim 5 \times 10^{-39}\, cm^2$$

F.J.Petriello & K.M. Zurek, 2008

PAMELA experiment

(O. Ariani et al. arXiv:0810.4995 [astro-ph], Nature 458, 607, 2009)

Prof. C.R.Chen, Prof. H.Wong, Prof. X.J.Bi, Prof. D.Zhuridov's talks



PAMELA positron fraction with theoretical models;

annihilation of DM in the galactic halo ?

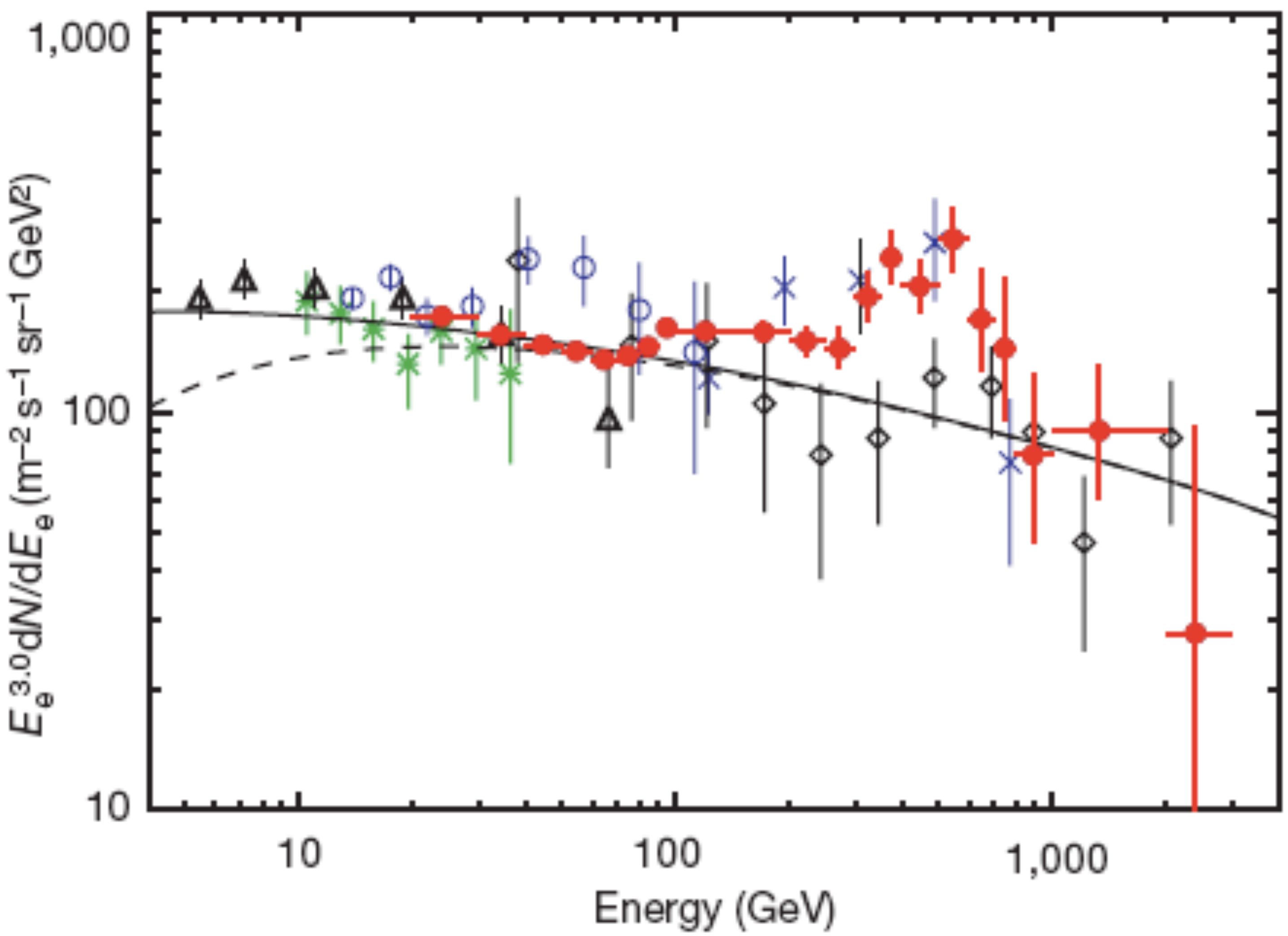
pair production near pulsars ?

$M_X > 100$ GeV

ATIC (e-e+) experiment

(J. Chang et al., Nature 456, 362, 2008)

Prof. C.R.Chen, Prof. H.Wong, Prof. X.J.Bi, Prof. D.Zhuridov's talks



An excess of galactic cosmic ray electrons at energies of ~300 - 800 GeV

1. an unseen astrophysical object (such as pulsar or micro-quasar) that accelerates electrons to those energies

2. the electrons could arise from the annihilation of DM particles

$M_\chi > 600$ GeV

The only one kind of DM (ex : WIMP) may NOT be enough to explain these all observations.

We consider two kinds of DM candidates which can be coexisted from an Extended Seesaw Model

Our doubly coexisting DM

(C.S.Kim, Sin Kyu Kang, HSCheon arXiv:0807.0981 [hep-ph], PLB675, 203, 2009)

$$\mathcal{L} = \mathcal{L}_{JCAP} + Y_\Phi \bar{S}\Phi S + \frac{1}{2} m^2_{H^0} H^\dagger H - \frac{\lambda_1}{4} H^\dagger H H^\dagger H + \frac{1}{2} m^2_{\Phi^0}\Phi^2 - \frac{\lambda_2}{4}\Phi^4 - \lambda_3 \phi^2 \Phi^2 - \lambda_4 H^\dagger H \Phi^2$$

L_{JCAP} : the Lagrangian of JCAP 0805:004,2008
We newly introduced a heavy Singlet Scalar field Φ.

But, here we assume that the mass of Φ is light, 1 GeV. (Prof. X.J.Bi's talk)

(~GeV scale force mediator :
N. Arkani-Hamed, D. P. Finkbeiner, T.R. Slatyer, N. Weiner, PRD79, 015014, 2009,
I. Cholis, L. Goodenough, N. Weiner, arXiv:0802.2922,
I. Chollis, D. P. Finkbeiner, L. Goodenough, N. Weiner, arXiv:0810.5344
D. P. Finkbeiner, T. R. Slatyer, N. Weiner, I. Yavin, arXiv:0903.1037)

After spontaneous symmetry breaking, (Prof. Ling-Fong Li's lecture)

$$
\begin{aligned}
V = \quad & \frac{1}{2}m_\phi^2\phi^2 - \frac{1}{2}m_h^2h^2 - \frac{1}{2}m_\Phi^2\Phi^2 + 2\lambda_4 v_h v_\Phi h\Phi + \frac{\lambda_s}{4}\phi^4 + \frac{\lambda_1}{4}v_h h^3 + \frac{\lambda_1}{16}h^4 \\
+ \quad & \frac{\lambda_2}{4}\Phi^4 + \lambda_2 v_\Phi \Phi^3 + \frac{\lambda}{2}\phi^2 h^2 + \lambda v_h \phi^2 + \lambda_3\phi^2\Phi^2 + 2\lambda_3 v_\Phi \Phi\phi^2 \\
+ \quad & \frac{\lambda_4}{2}h^2\Phi^2 + \lambda_4 v_\Phi h^2\Phi + \lambda_4 v_h h\Phi^2 + h.c.,
\end{aligned}
$$

where

$$
\begin{aligned}
m_\phi^2 &= m_{\phi^0}^2 + \lambda v_h^2 + 2\lambda_3 v_\Phi^2 \\
m_h^2 &= \frac{1}{2}m_{H^0}^2 - \frac{3}{4}\lambda_1 v_h^2 - \lambda_4 v_\Phi^2 \\
m_\Phi^2 &= m_{\Phi^0}^2 - 3\lambda_2 v_\Phi^2 - \lambda_4 v_h^2
\end{aligned}
$$

$$h \to h + v_h \qquad \Phi \to \Phi + v_\Phi$$

Since there exists a mixing mass term between h and Φ, we rotate them with Φ = sh′ + cΦ′ and h = ch′ – sΦ′, where s : sinθ and c : cosθ

$$
\begin{aligned}
V_{eff} = \quad & \frac{m'^2_\phi}{2}\phi^2 + \frac{m'^2_h}{2}h'^2 + \frac{m'^2_\Phi}{2}\Phi'^2 + \frac{\lambda_4}{2}h'^2\Phi'^2 \\
+ \quad & \frac{1}{2}(\lambda c^2 + 2\lambda_3 s^2)\phi^2 h'^2 + (\frac{\lambda}{2}s^2 + \lambda_3 c^2)\phi^2\Phi'^2 \\
+ \quad & \kappa_1 h'^3 + \kappa_2 \Phi'^3 + \alpha\Phi'\phi^2 + \beta h'^2\Phi' + \gamma h'\phi^2 + \delta h'\Phi^2 \\
+ \quad & \left(\frac{\lambda_1}{16}c^4 + \frac{\lambda_4}{2}c^2s^2 + \frac{\lambda_2}{4}s^4\right)h'^4 + \left(\frac{\lambda_2}{4}c^4 + \frac{\lambda_4}{2}c^2s^2 + \frac{\lambda_1}{16}s^4\right)\Phi'^4
\end{aligned}
$$

where

$$
\begin{aligned}
\kappa_1 &= \lambda_4 cs(cv_\Phi + sv_h) + \frac{\lambda_1}{4}c^3 v_h + \lambda_2 v_\Phi s^3 \\
\kappa_2 &= \lambda_2 c^3 v_\Phi - \lambda_4 cs(cv_h - sv_\Phi) - \frac{\lambda_1}{4}s^3 v_h \\
\alpha &= -\lambda v_h s + 2\lambda_3 v_\Phi c \\
\beta &= \lambda_4[v_\Phi c^3 - v_h s^3 + 2sc(cv_h - sv_\Phi)] + cs[-\frac{3}{4}\lambda_1 v_h c + 3\lambda_2 v_\Phi s] \\
\gamma &= 2\lambda_3 s v_\Phi + \lambda v_h c. \\
\delta &= (\lambda_4 v_h c^3 - 2\lambda_4 cs(sv_h + cv_\Phi) + \frac{3}{4}\lambda_1 v_h cs^2 + 3\lambda_2 v_\Phi c^2 s + \lambda_4 v_\Phi s^3
\end{aligned}
$$

The Lagrangian containing the field S becomes,

$$\mathcal{L}_S = -m_S S^T S + (sY_\Phi) h' S^T S + (cY_\Phi)\Phi' S^T S$$

where

$$m_S = (m_{S^0} - Y_\Phi v_\Phi)$$

We demand that

In order to guarantee the stability of two dark matter candidates,

* $Z_2 \times Z'_2$ Symmetry should be conserved

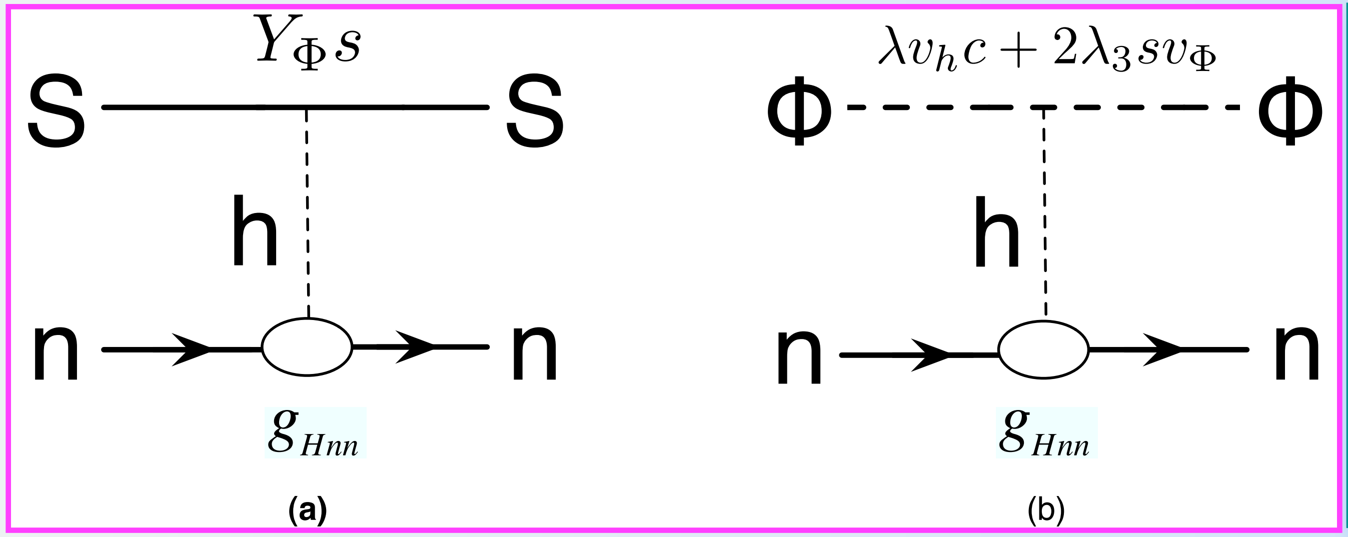
so that by the $Z_2 \times Z'_2$ Symmetry

Singlet Majorana neutrino particle, S	: (−, +)
Singlet Scalar particle, ϕ	: (+, −)

The Next Odd particle can **Not** decay into the lightest odd particle if $Z_2 \times Z'_2$ Symmetry is conserved.

DAMA experiment

(direct search exp : Prof. H.wong's talk
Prof. C.L.Shan's talk, Prof. S.T.Lin's talk)



Feynman diagrams relevant to
(a) S-nucleon elastic scattering
(b) Φ-nucleon elastic scattering

$$\sigma_S \approx \frac{(Y_\Phi s)^2 |\mathcal{A}_n|^2}{\pi} \left(\frac{m_*^2}{m_h^4}\right),$$

$$\sigma_\phi = \frac{(\lambda v_h c + 2\lambda_3 s v_\Phi)^2 |\mathcal{A}_n|^2}{4\pi} \left(\frac{m_*^2}{m_\phi^2 m_h^4}\right)$$

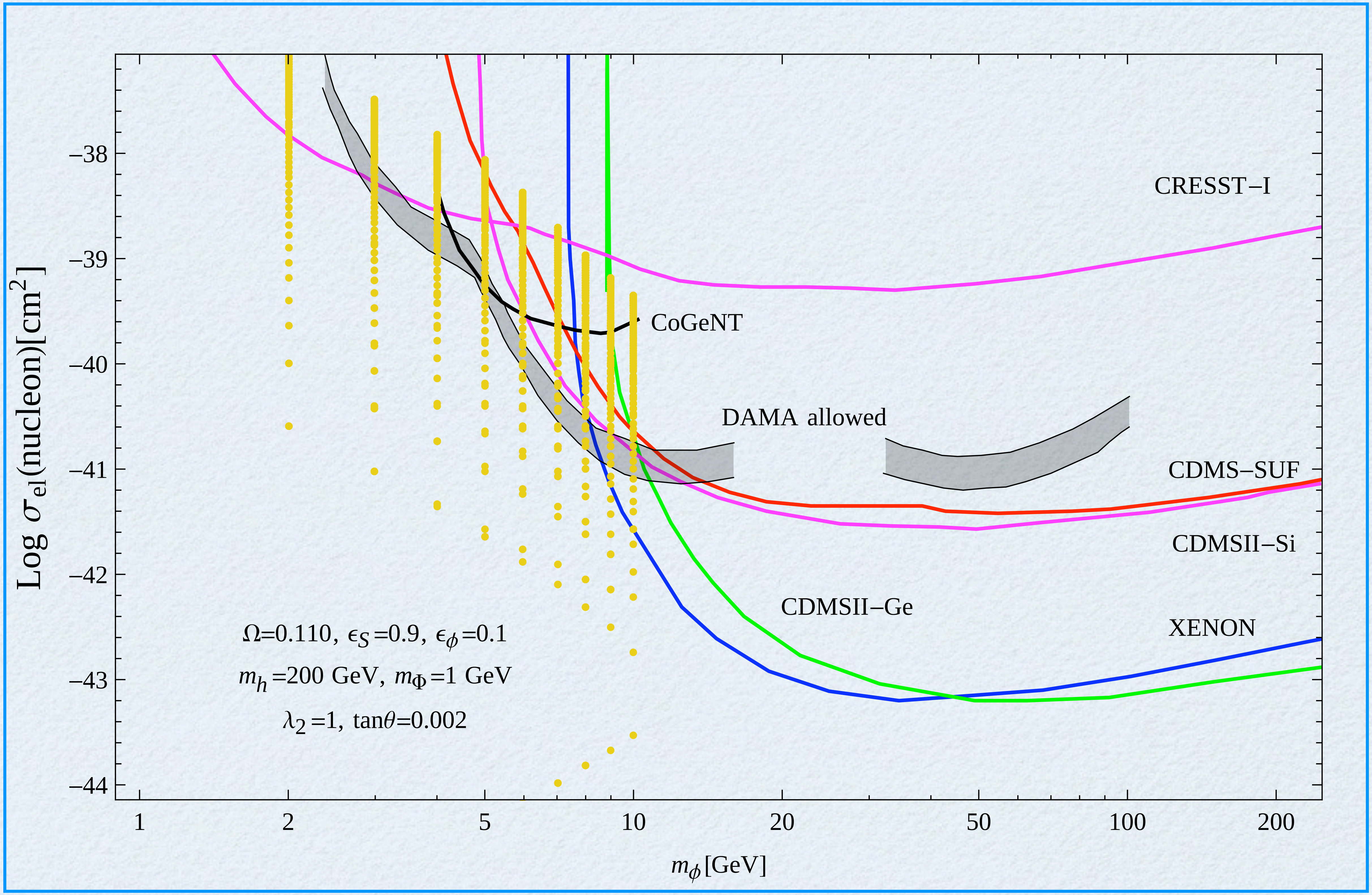
where $m_* = m_S m_n/(m_S + m_n)$. So far most experiments of direct detection assume that there exist the only one kind of dark matter, whereas we assume that two kinds of dark matter can be coexisted. So in order to compare our results with experimental data we use a following relation,

$$\frac{\sigma_{el}}{m_0} = \frac{\epsilon_S}{m_S}\sigma_S + \frac{\epsilon_\phi}{m_\phi}\sigma_\phi$$

(Cao, Ma, Wudka, Yuan)

where is the σ_{el} is the cross section of DM-nucleon elastic scattering and m_0 is the mass of WIMP.

$$\Omega_S h^2 + \Omega_\Phi h^2 = \Omega_{\rm CDM} h^2 = 0.110 \pm 0.006 \qquad \epsilon_i = \frac{\Omega_i h^2}{\Omega_{CDM} h^2}$$



Orange colored region : the possible parameter region of our model.
So our model can explain the region accommodated the DAMA with other null experiments.

Implication for Higgs searches in LHC

(Prof. S.M.Wang's talk)

The invisible real Higgs decay width is given at three level by

$$\Gamma_{h\to\phi\phi} = \frac{(\lambda v_h c + 2\lambda_3 s v_\Phi)^2}{32\pi m_h}\left(1-\frac{4m_\phi^2}{m_h^2}\right)^{1/2} \qquad (\text{for} \quad 2m_\phi < m_h),$$

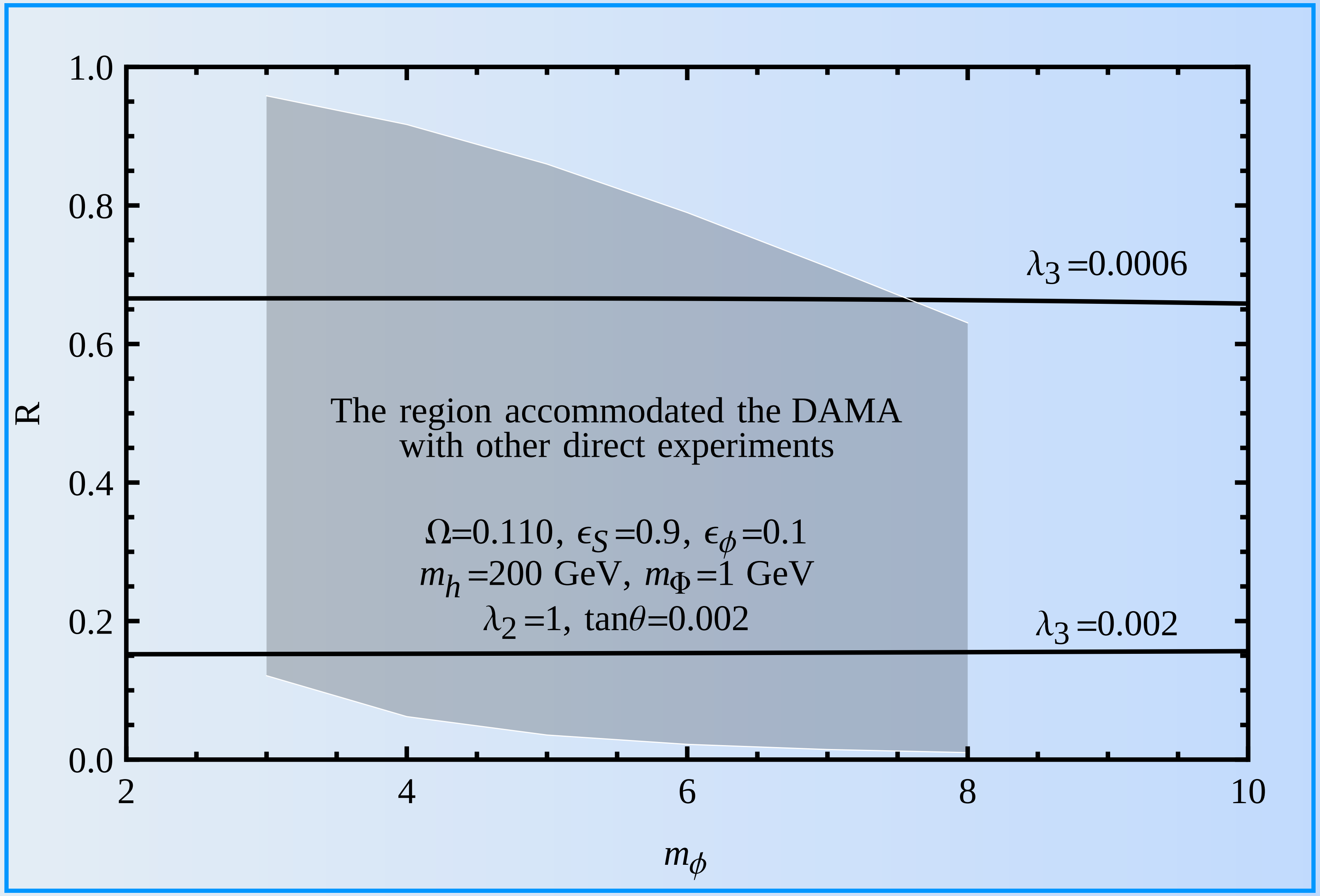
$$\Gamma_{h\to SS} = \frac{(Y_\Phi s)^2 m_h}{8\pi}\left(1-\frac{4m_S^2}{m_h^2}\right)^{3/2} \qquad (\text{for} \quad 2m_S < m_h)$$

Usually, in Singlet Scalar DM models,

If they satisfy the accommodation region of DAMA and other null experiments (around 10 GeV mass scale and 10^{-40} cm^2 nucleon cross section), they also can satisfy the WMAP relic density parameter.

As well as this kind of models show that the Higgs boson has a large branching ratio to pairs of DM particles. (Ex: m_S = 7 GeV, Higgs mass : 120 GeV, BR(h->φ,φ)=99.5%, m_h = 200 GeV, BR(h->φ,φ)~ 70%)
(S. Andreas, T. Hambye, and M. H.G. Tytgat, **JCAP 0810:034,2008**)

But if we assume that there exist another SM like light scalar boson, we can have the parameter region in which the invisible higgs decay is NOT strong



Plots of the ratio R as a function of m_ϕ.

As the case of λ_3 = 0.0006, we can get the parameter regions in which the invisible Higgs decay is NOT strong

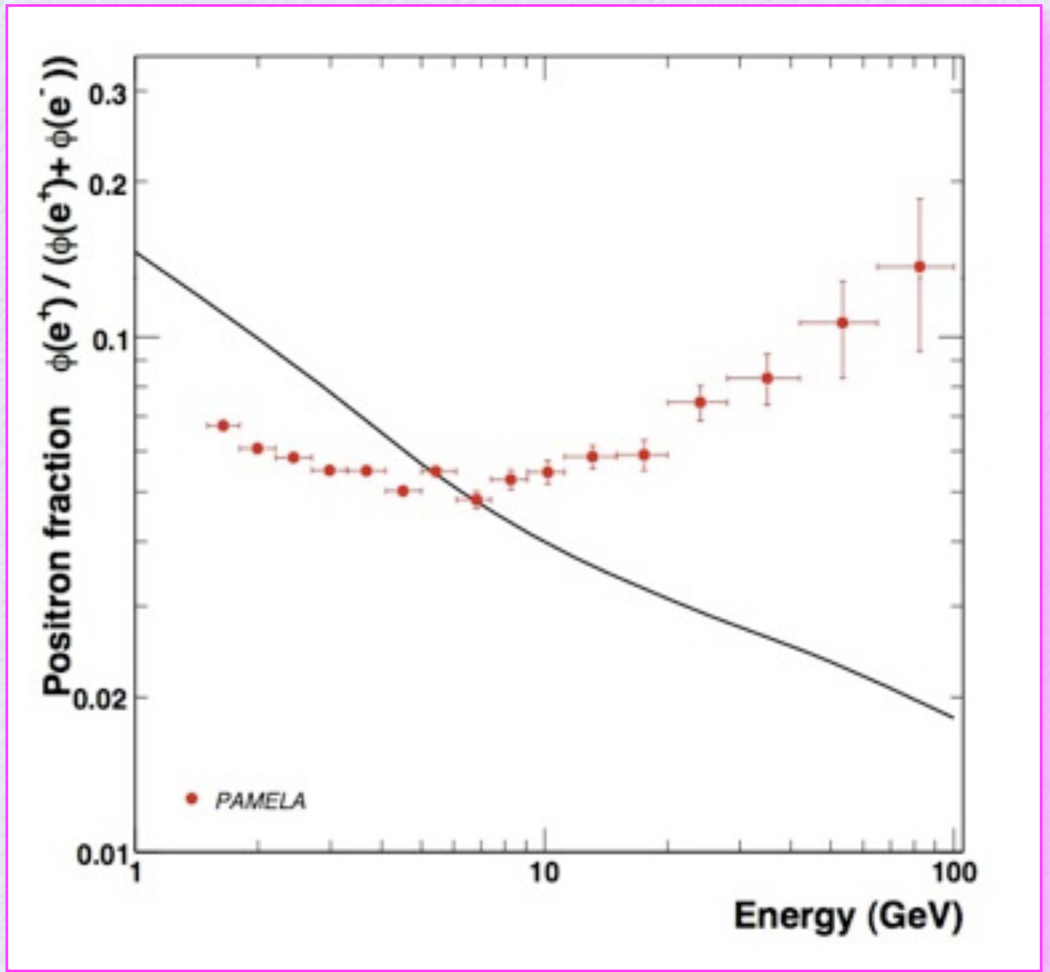
Ex : λ_3 = 0.0006, Br(h->φ,φ) = 40.2 %, λ_3 = 0.002, Br(h->φ,φ) = 87.9 %

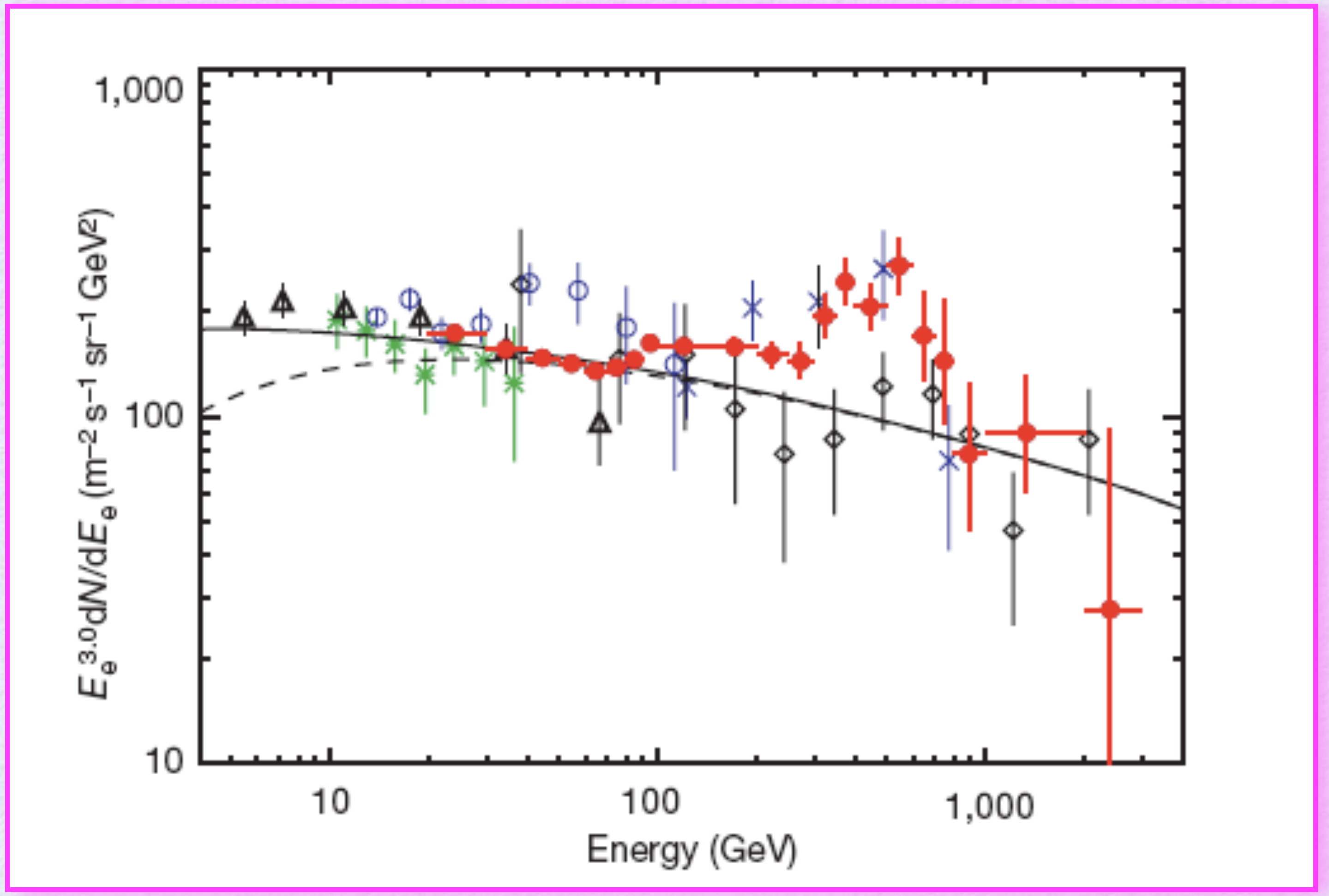
$$R = \frac{\Gamma_{h,total}(\mathrm{SM})}{\Gamma_{h\to\phi\phi} + \Gamma_{h\to\Phi\Phi} + \Gamma_{h,total}(\mathrm{SM})} \qquad (2m_S >> m_h)\ (2m_\phi < m_h)$$

PAMELA/ATIC experiments

(Indirect search : Prof. H.Wong's talk, Prof. X.J.Bi'talk, Prof. Prof. D.Zhuridov's talk)

PAMELA/ATIC experiments





We expect that our model can explain these experiments,

If m_s ~ 1 TeV, m_ϕ ~ 1 GeV (forbidden kinematically decay into hadronic),

by the Sommerfeld enhancement (prof. X.J.Bi talk) $S \sim \frac{\alpha m_S}{m_\phi} \sim 100$

But we are proceeding to calculate the our results about PAMELA/ATIC.

Conclusion

* We consider coexisting two kinds of DM, Singlet fermion and Singlet scalar, from an Extended Seesaw Model.

We expect to explain several problems of the observations into our model.

PAMELA/ATIC
-> Singlet Fermion (m_S ~ 1 TeV)

DAMA experiment & other null direct search experiments
-> Singlet Scalar (m_φ ~ 10 GeV)

So our model can explain the region accommodated the DAMA with other null experiments.

In the parameter region in which DAMA and other direct search experiments are satisfied by our model,
there exist the parameter region in which the invisible higgs decay is NOT strong

Thank you so much for listening my talk