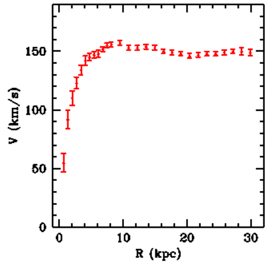
Leptonic Higgs

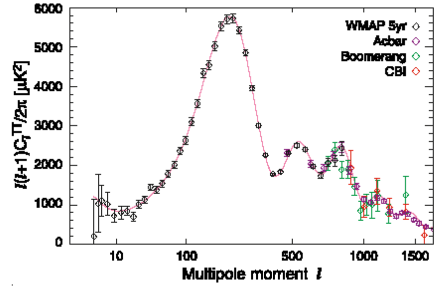
- Portal to the Dark Side

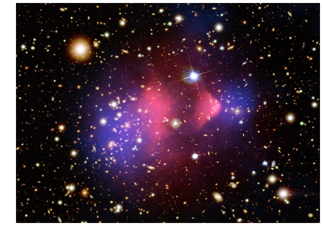
Hock Seng Goh
(UC Berkeley)

Joint Argonne & IIT workshop 2009

arXiv:0902.0814
with L. Hall and P. Kumar

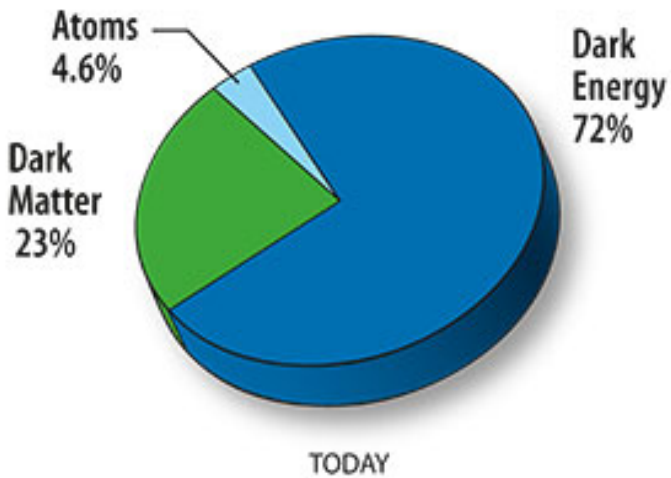






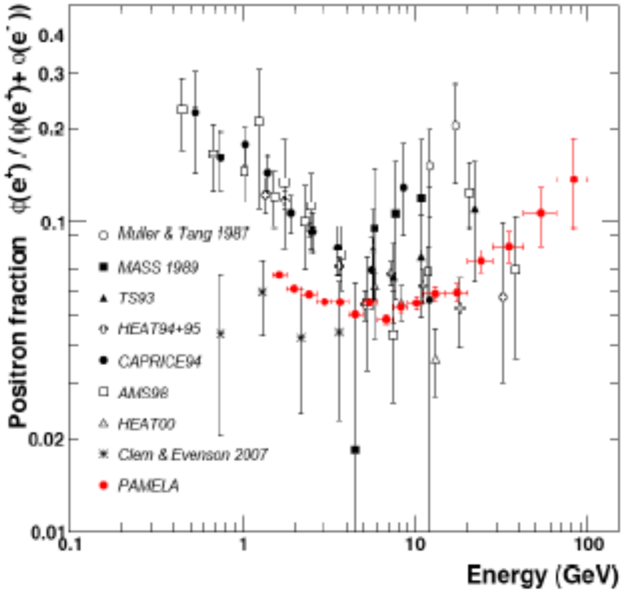
Dark matter exist !

(Modified Gravity is always a possibility although it has become harder)

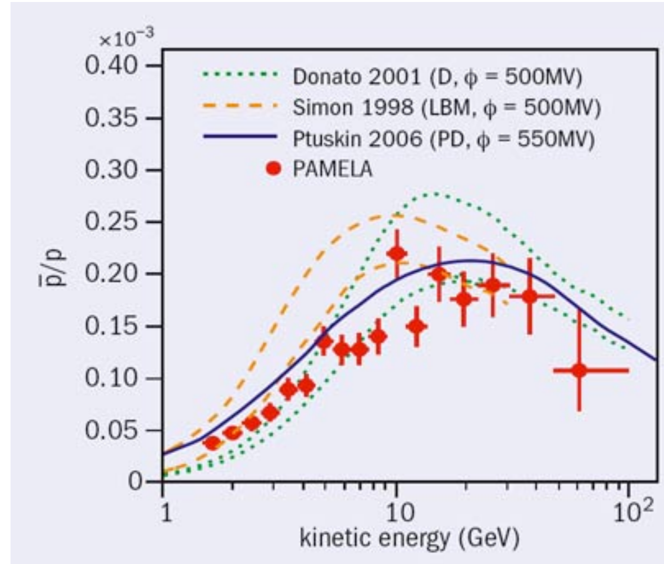


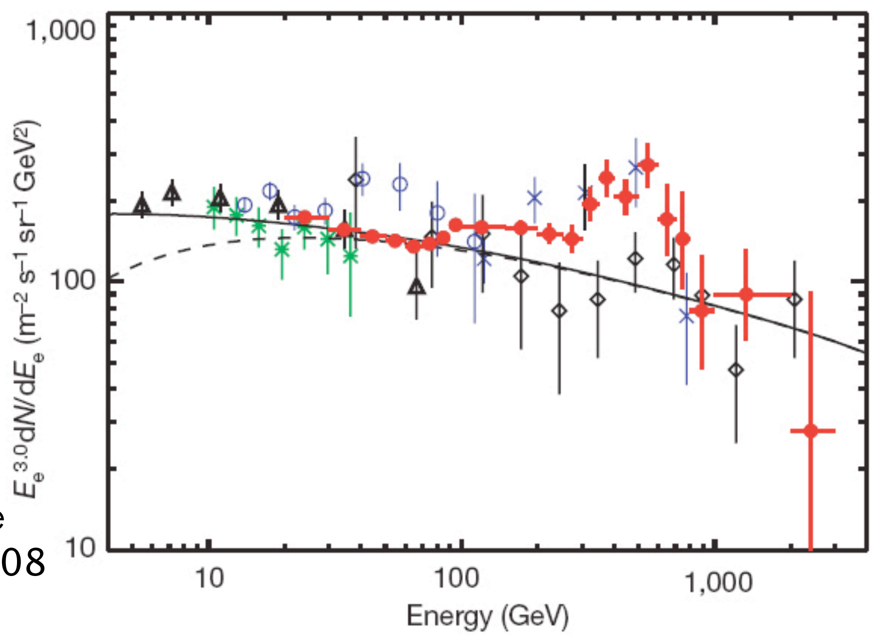
The question is :

What are they ??

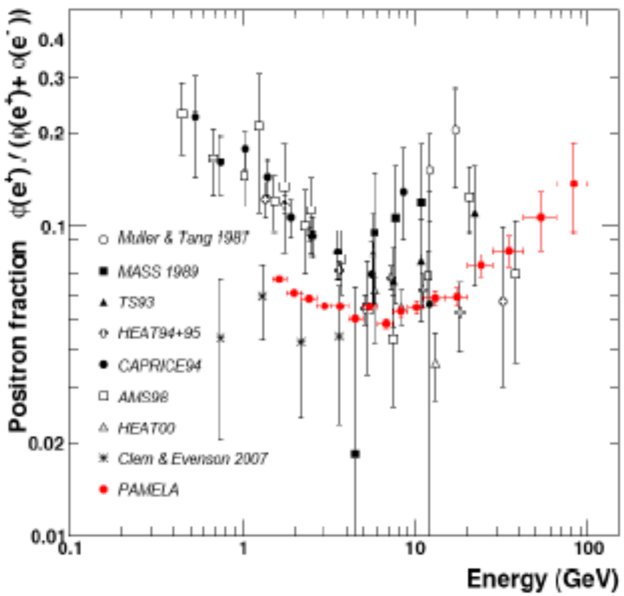


PAMELA
arXiv:0810.4995
Adriani et al., 2008





ATIC -- Nature
Wefel et al., 2008



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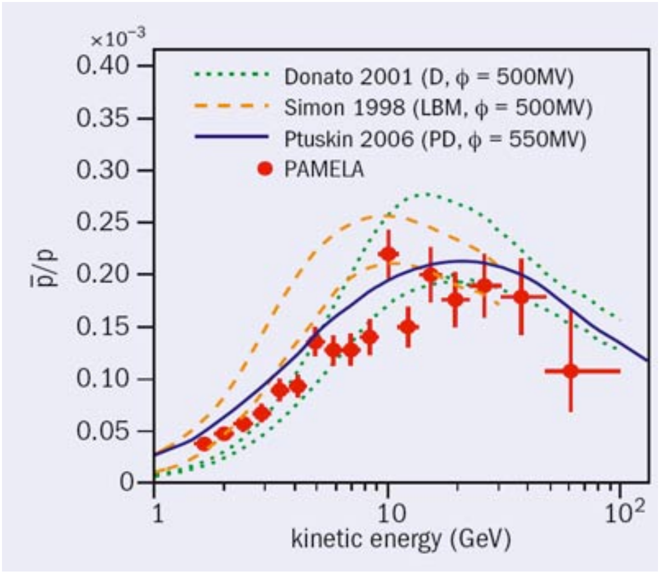

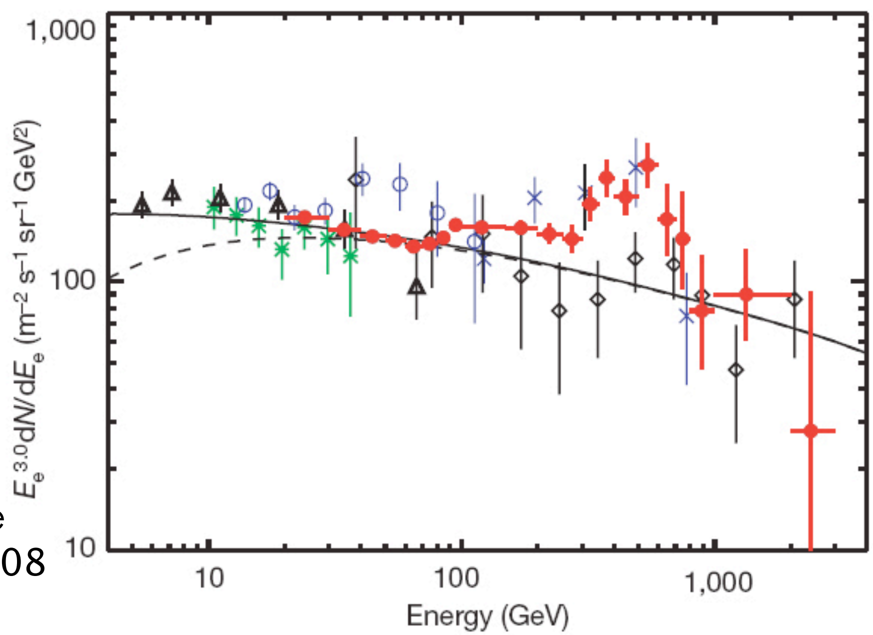

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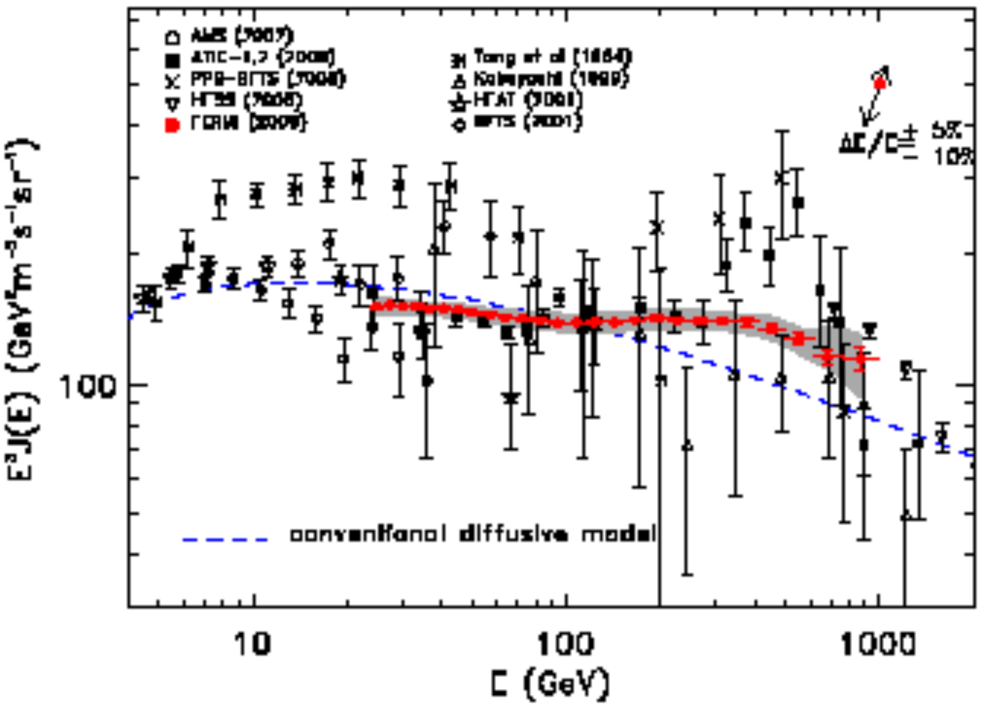
Note :

Lot of e+,e-

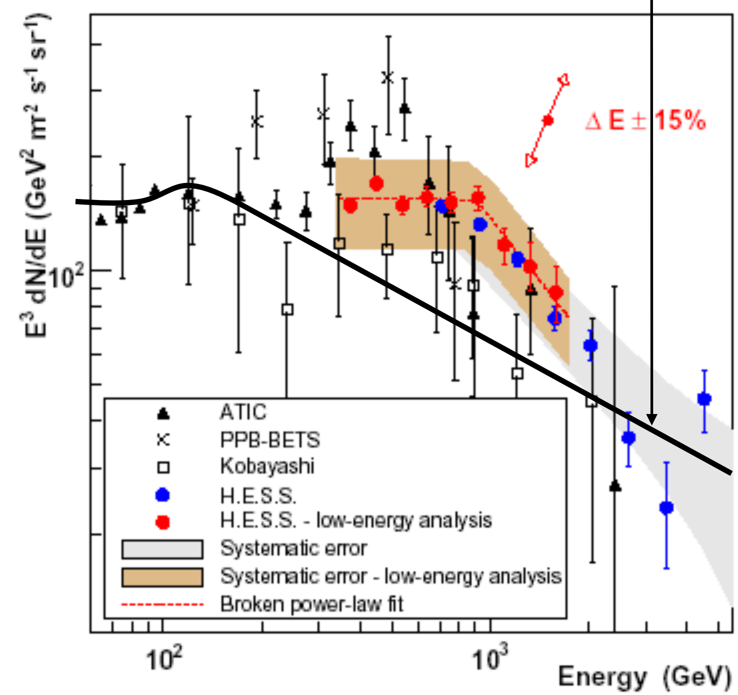
very little p-

Fermi - 0905.0025



Possible estimated BG

HESS – 0905.0105



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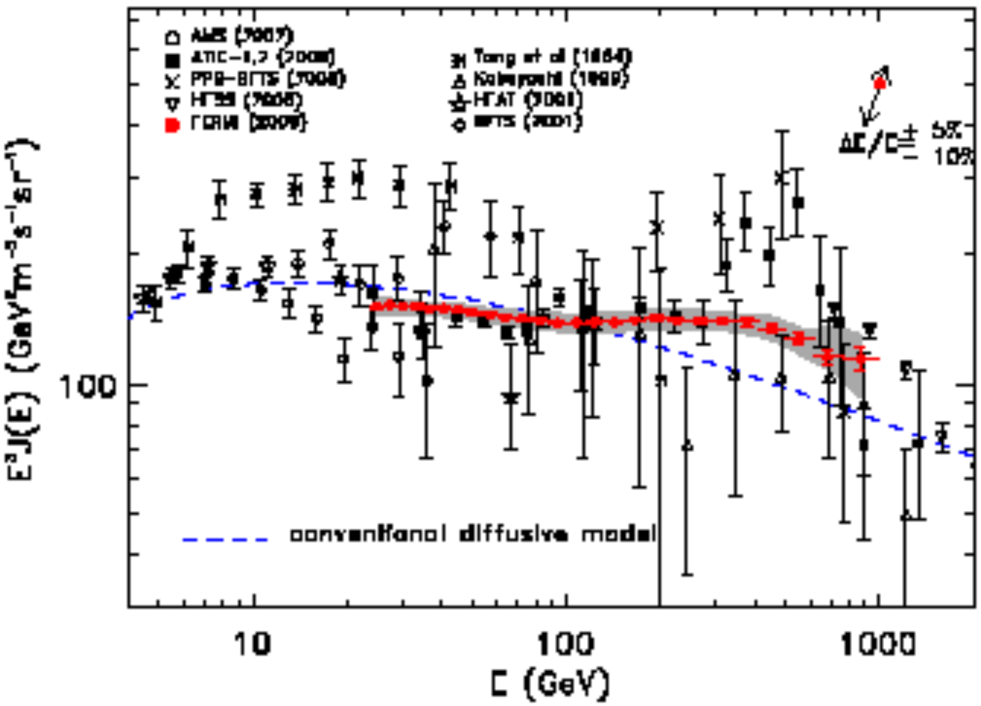

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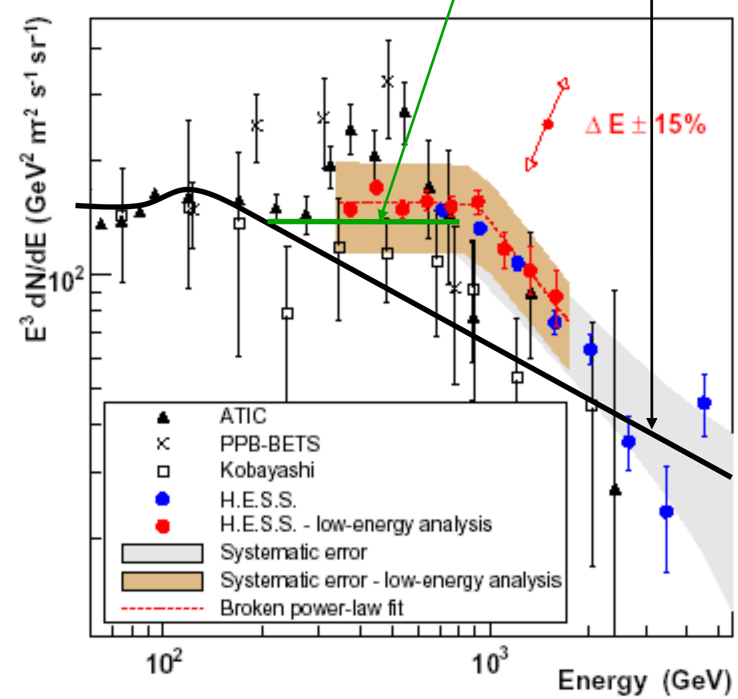

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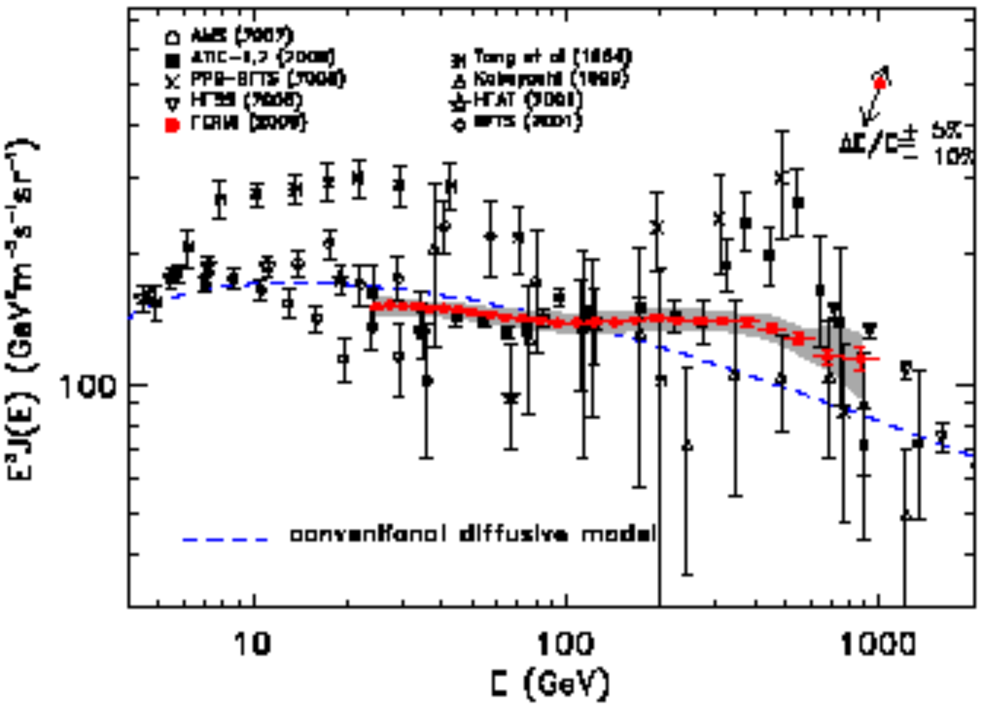

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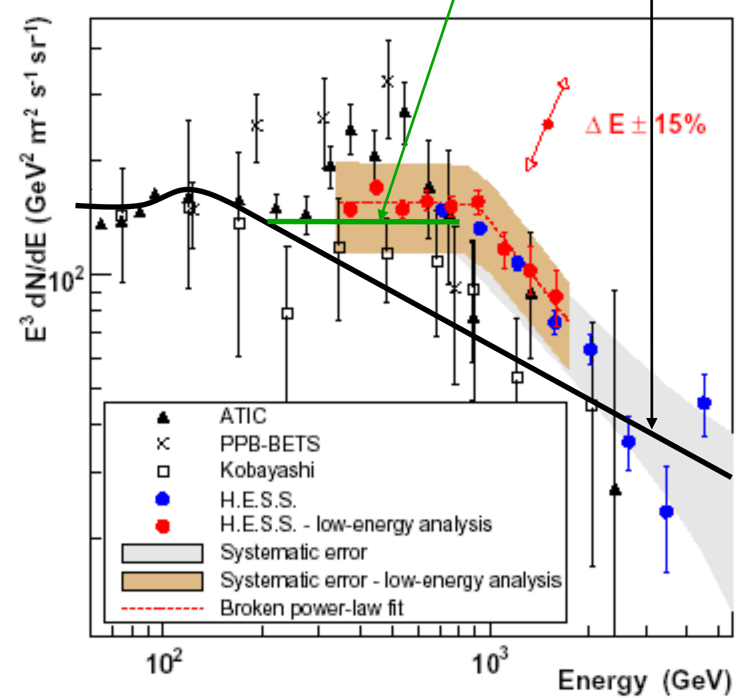
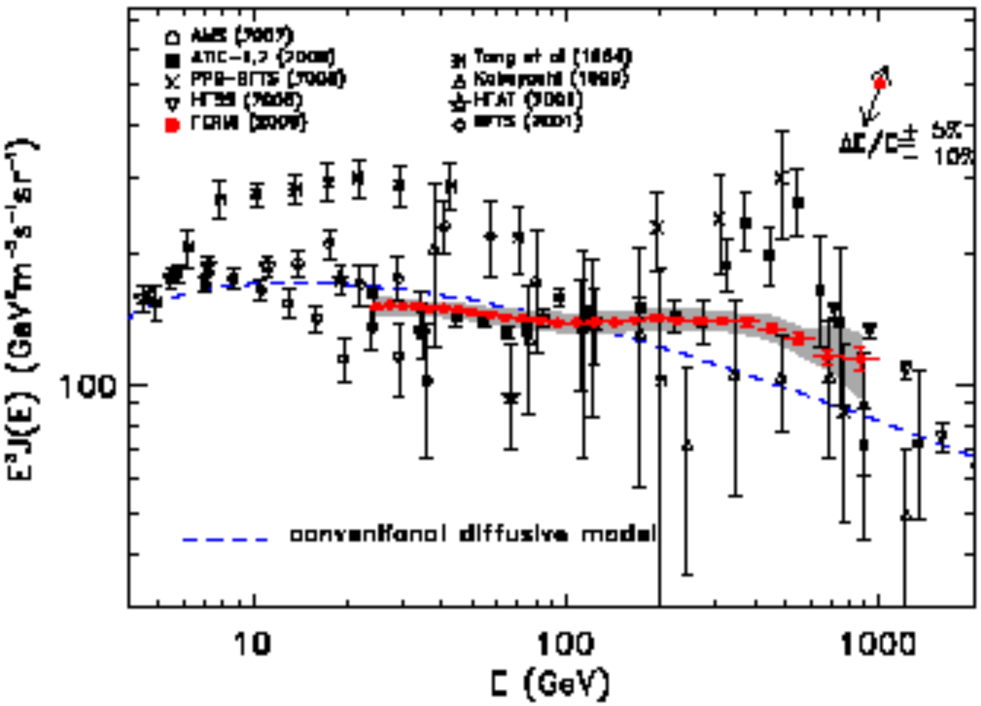


The observation could mean

- We need a new understanding of the background
- We have observed close by pulsars
- We have observed dark matter

Fermi - 0905.0025



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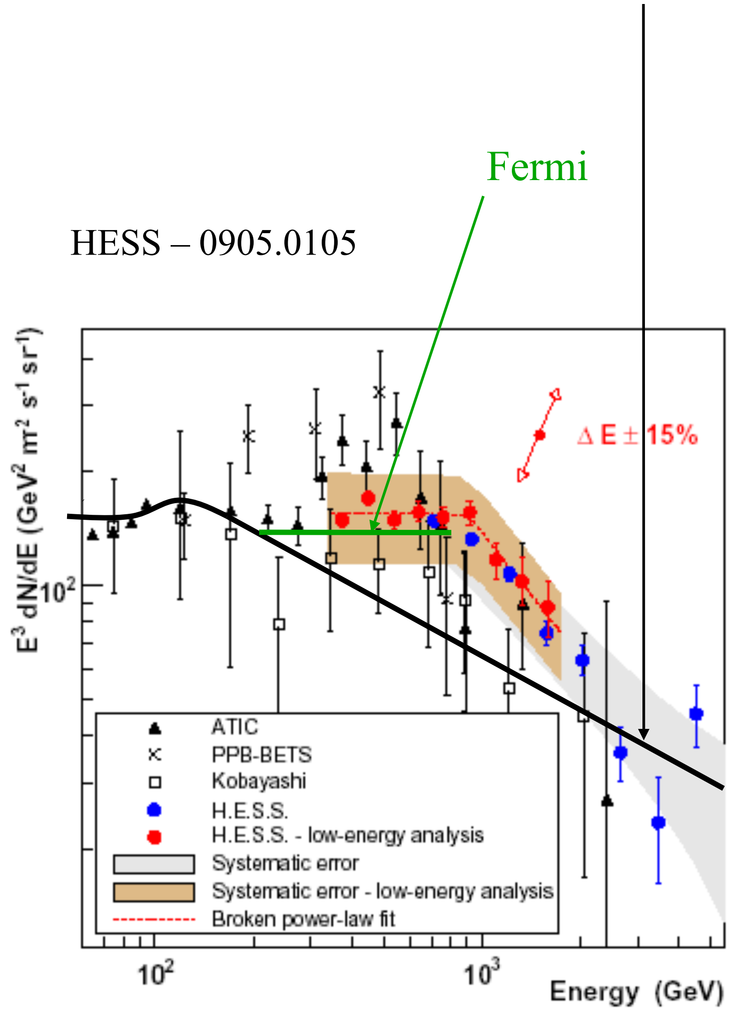

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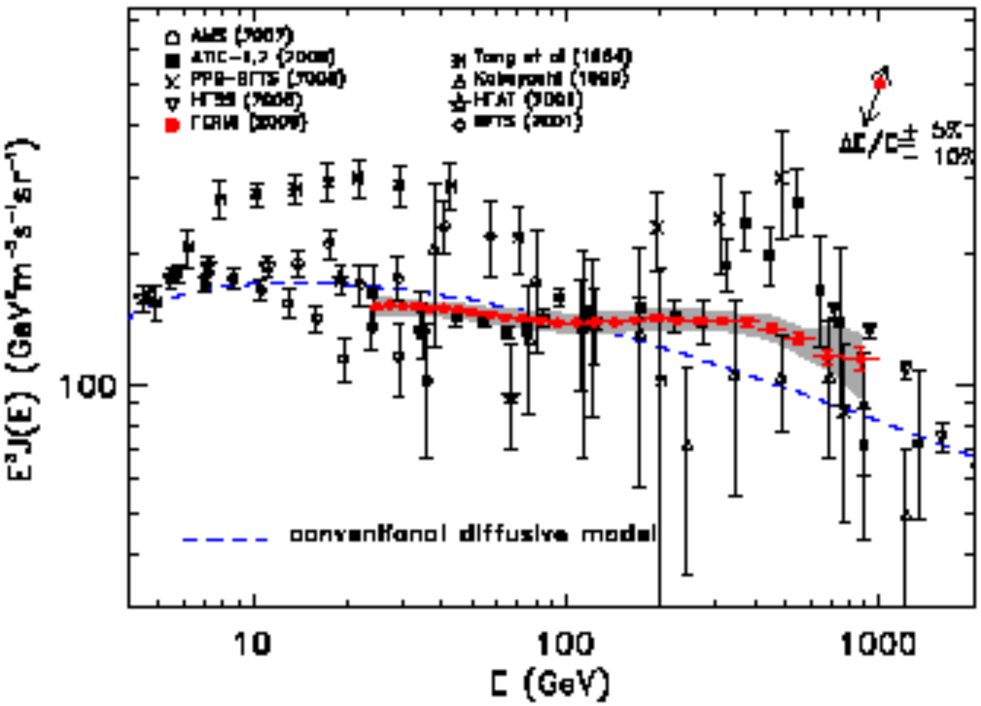

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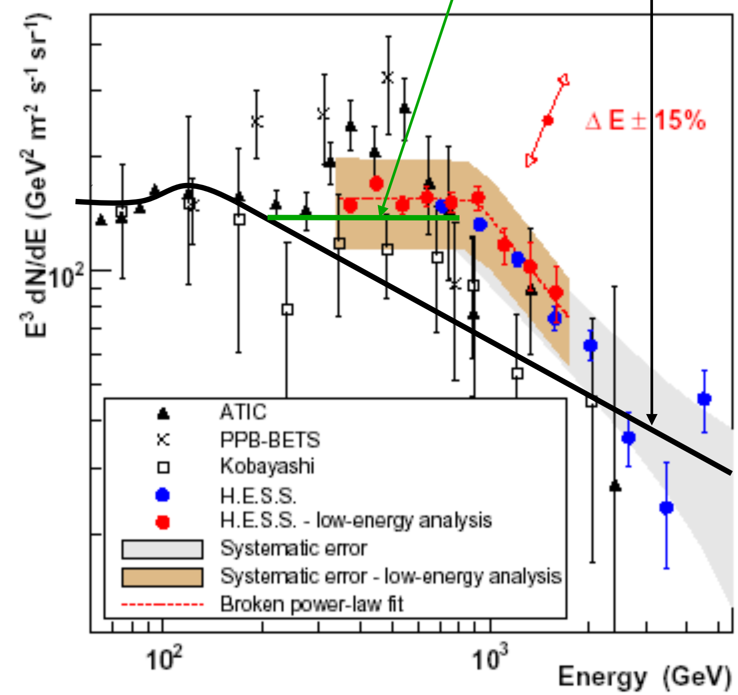

Background

Pulsars

Dark matter

IF it is Dark matter, things become more interesting. (At least for us)

What do we learn from the data?

- Dark matter mass ~ multi TeV
- Large annihilation cross section

- Like lepton better than quark

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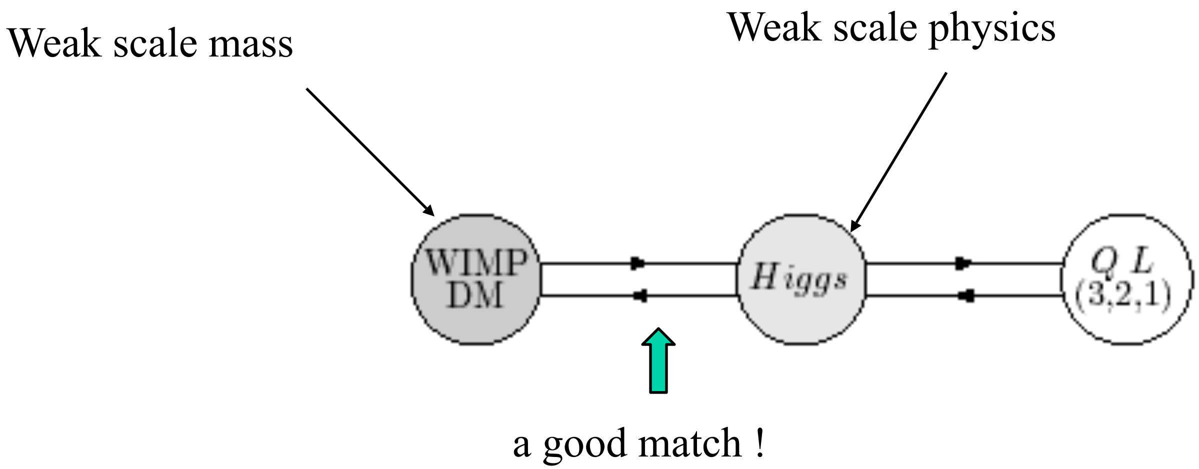
One problem at a time

Outline

- Basic idea of Leptonic Higgs messenger
- Fitting to observation - e, γ, ν
- LHC signals ?? Higgs searches + τ Physics
- Some explicit models
- Conclusion

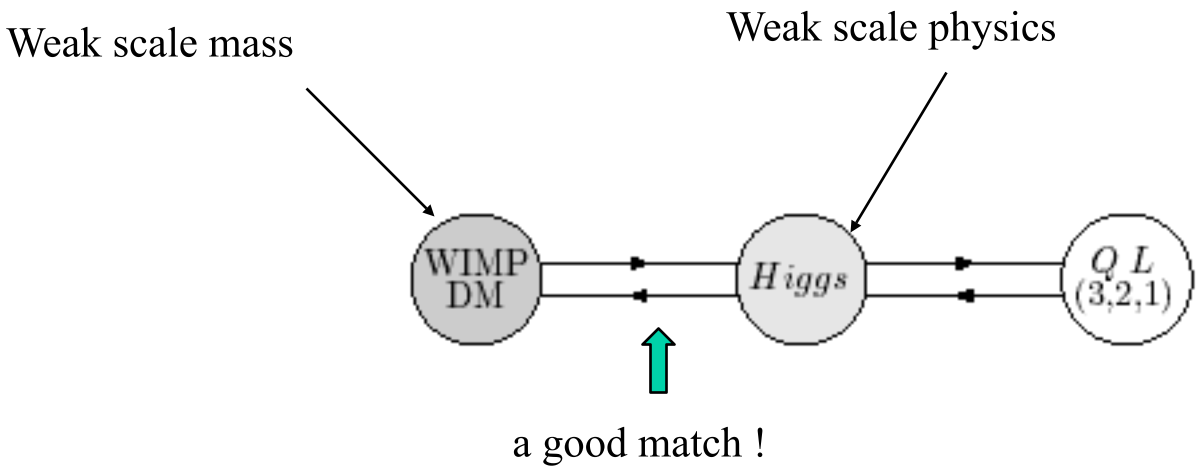


General picture if DM is SM singlet

- Silveira & Zee

Higgs portal

- March-Russell etc.



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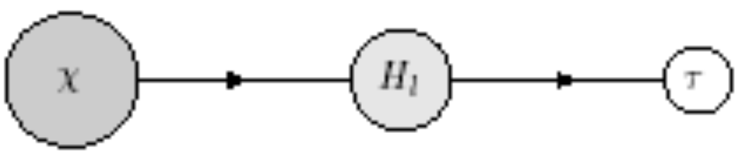
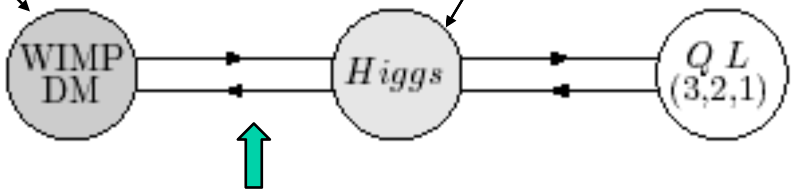


Weak scale mass

Weak scale physics



a good match !

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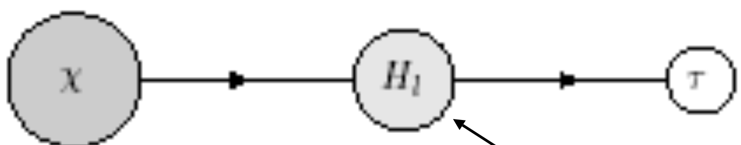
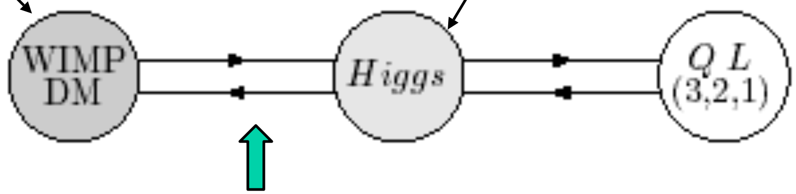


Leptonic Higgs

Weak scale mass

Weak scale physics



a good match !

General picture if DM is SM singlet

- Silveira & Zee

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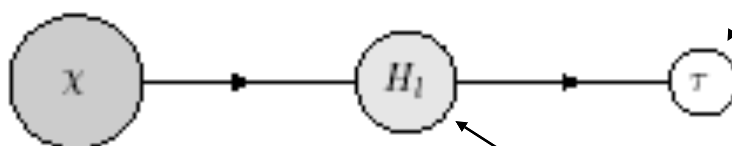
Then, this is the result



Leptonic Higgs

Many other ideas on leptonic symmetry

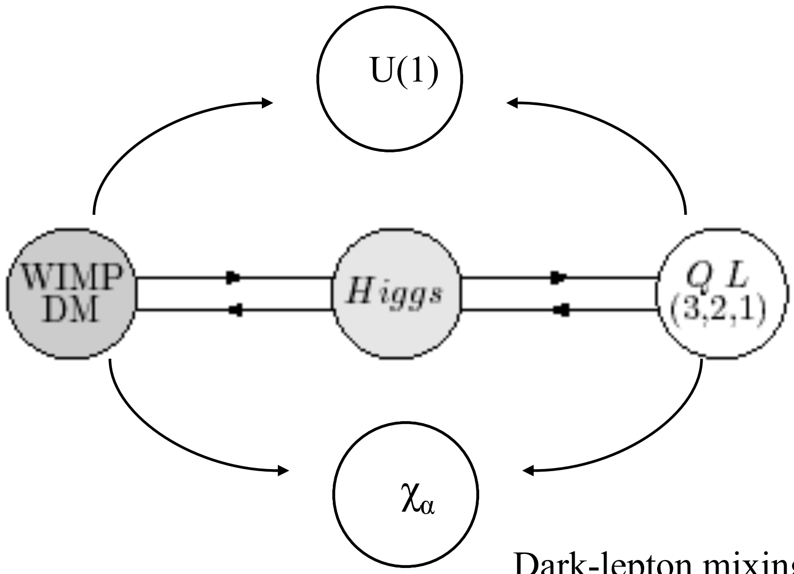
Spin :

Where lepton have larger charge. Ex : hyper charge, B-L, l , μ-τ, ….

1

0

1/2



Dark-lepton mixing.

(Complete list !)

2-Higgs-doublet model

	Inert Higgs		SUSY		???		Leptonic Higgs	
Models	I		II		III		IV	
	VEV	A_f	VEV	A_f	VEV	A_f	VEV	A_f
u	2	$\cot\beta$	2	$\cot\beta$	2	$\cot\beta$	2	$\cot\beta$
d	2	$-\cot\beta$	1	$\tan\beta$	1	$\tan\beta$	2	$-\cot\beta$
ν								
l	2	$-\cot\beta$	1	$\tan\beta$	2	$-\cot\beta$	1	$\tan\beta$

Barger, Hewett, Phillips **Phys.Rev.D41:3421,1990**.

Leptonic Higgs : Type IV 2HDM

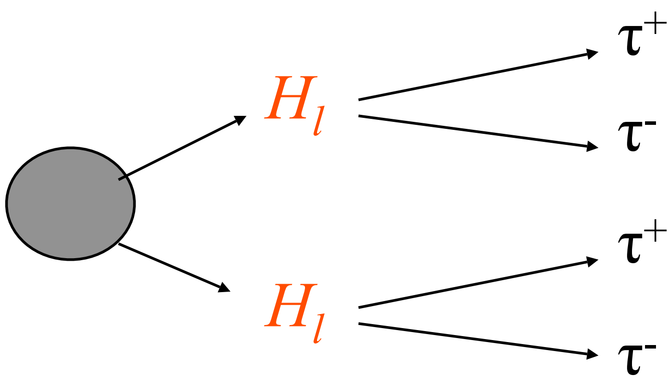
$$Q_i H_q u_j + Q_i H_q d_j + L_i H_l e_j + f(H_l)\, \mathrm{O}_{dark}$$

Has a Chiral Leptonic symmetry (parity) where

$$L = (-,+) \qquad e = (+,-) \qquad H_l = (-,-)$$

Basic picture :

Annihilation or decay



Or other topology and different leptonic final state depending on dark matter model

H_q and H_l unavoidable mix.

$$H_q^0 = v_q + h_q + ia_q \qquad H_l^0 = v_l + h_l + ia_l$$

$$A = a_l \cos\beta - a_q \sin\beta \qquad Z_P = a_l \sin\beta + a_q \cos\beta$$

$$H = h_l \cos\alpha - h_q \sin\alpha \qquad h = h_l \sin\alpha + h_q \cos\alpha$$

$$\tan\beta = \frac{v_l}{v_q} \neq 0$$

Leptonic Higgs $\equiv$ $\tan\beta \ll 1$

(leptonic parity)

$$\Rightarrow \quad \tan\alpha \propto v_l = 1$$

Leptonic Higgs

- 2HDM with chiral leptonic symmetry

- $v_l = v_q$

(Technically natural as it can be induced by $\mu^2 H_q^\dagger H_l$)

- leptonic Higgs mass is constrained

Constraint on the parameters

$$m_H + m_A > 185 \text{ GeV}$$ ← From LEP

$$|m_H - m_A| < m_Z$$ ← Prevent H from decaying to Z

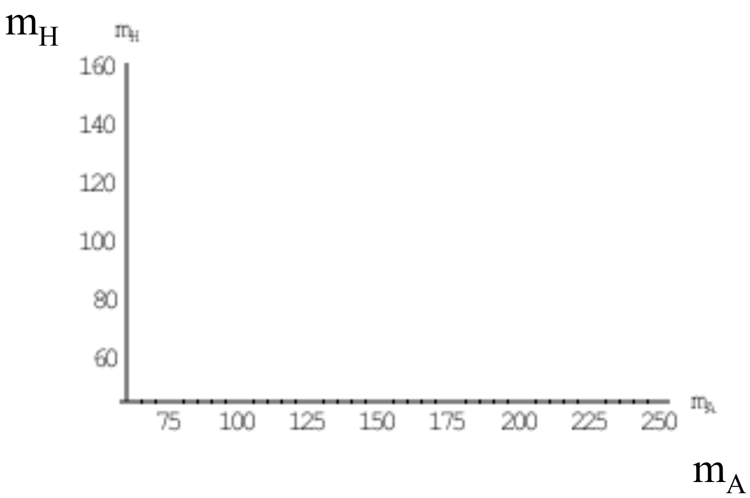
$$m_H < 2m_W$$ ← Prevent H from decaying to W

$$m_H < 2m_A$$ ← Prevent H from decaying to AA (spectrum is too soft)

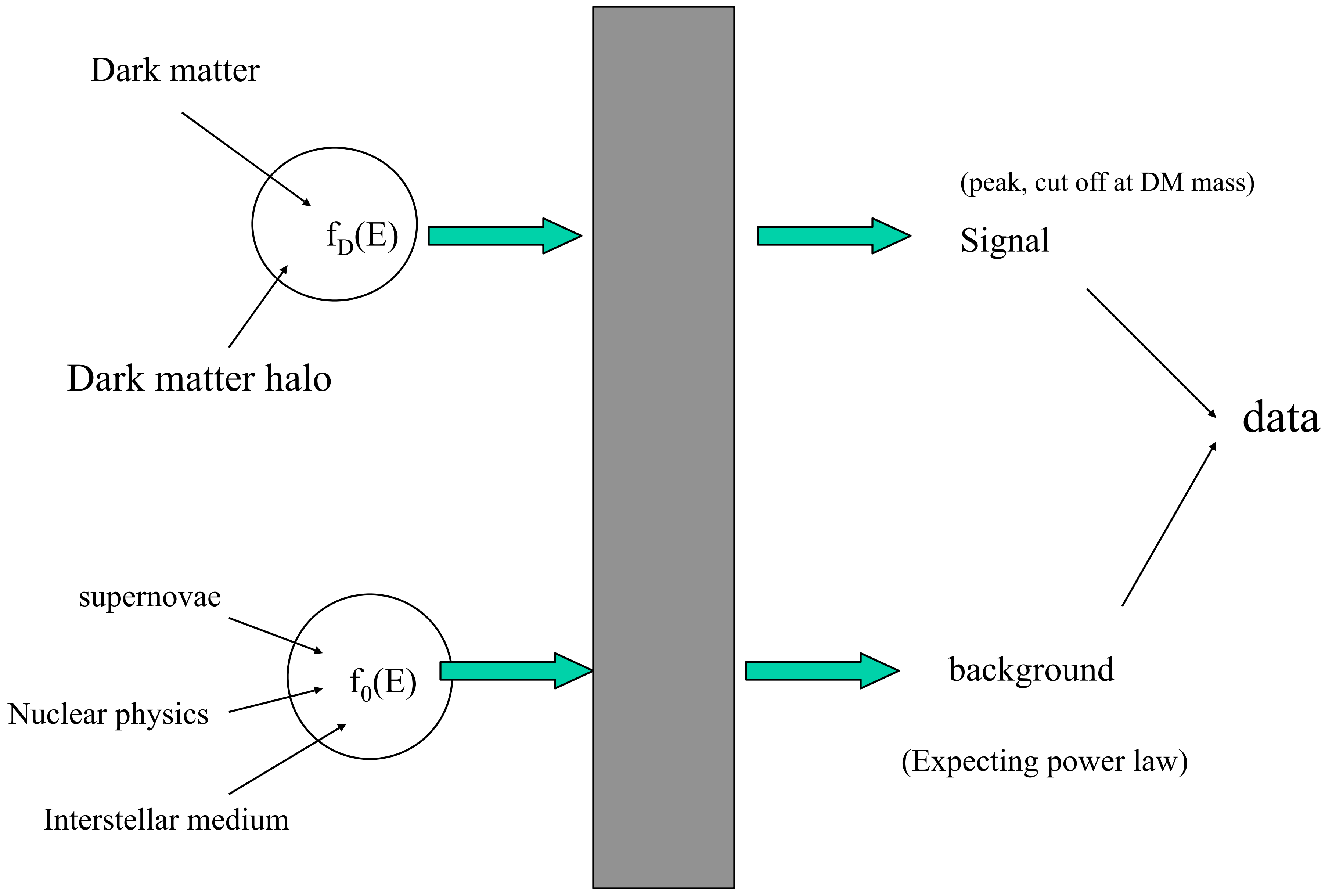
⇓

$$60 \sim \frac{2m_Z}{3} < m_A < 2m_W + m_Z \sim 250$$

$$45 \sim \frac{m_Z}{2} < m_H < 2m_W \sim 160$$



Fitting Observations


Dark matter
$f_D(E)$
Dark matter halo
(peak, cut off at DM mass)
Signal
data
supernovae
$f_0(E)$
Nuclear physics
Interstellar medium
background
(Expecting power law)

Injection spectrum :

$$Q^{e^+}_{annih}(E', \vec{r'}) = \frac{\rho^2_\chi(\vec{r'})}{2m^2_\chi} \langle \sigma\, v \rangle \frac{dN_{e+}}{dE'}(E')$$

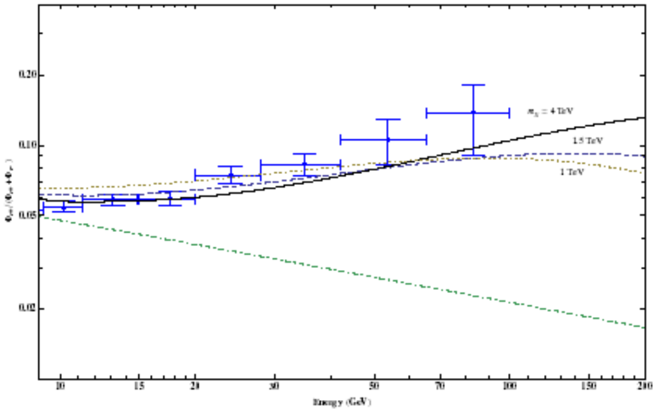
$$Q^{e^+}_{decay}(E', \vec{r'}) = \frac{\rho_\chi(\vec{r'})}{m_\chi} \Gamma_\chi \frac{dN_{e+}}{dE'}(E')$$

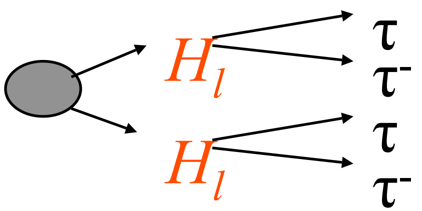
Roughly fix by leptonic Higgs scenario

Depend on DM model.
one number parameterized by Boost factor B :

$$< \sigma v > = B < \sigma v >_{thermal}$$

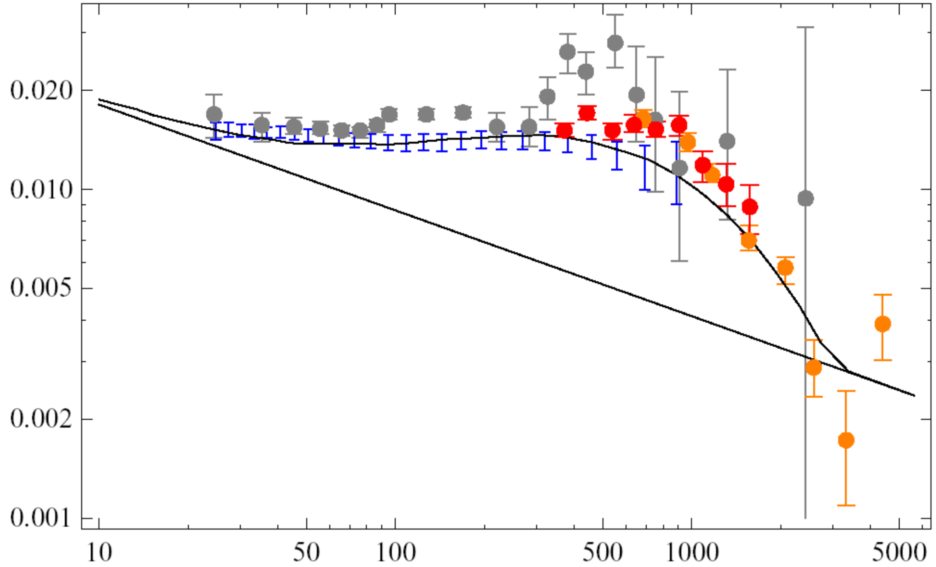
We can fit the data with 2 parameter : mχ and B (not sensitive on leptonic Higgs mass)



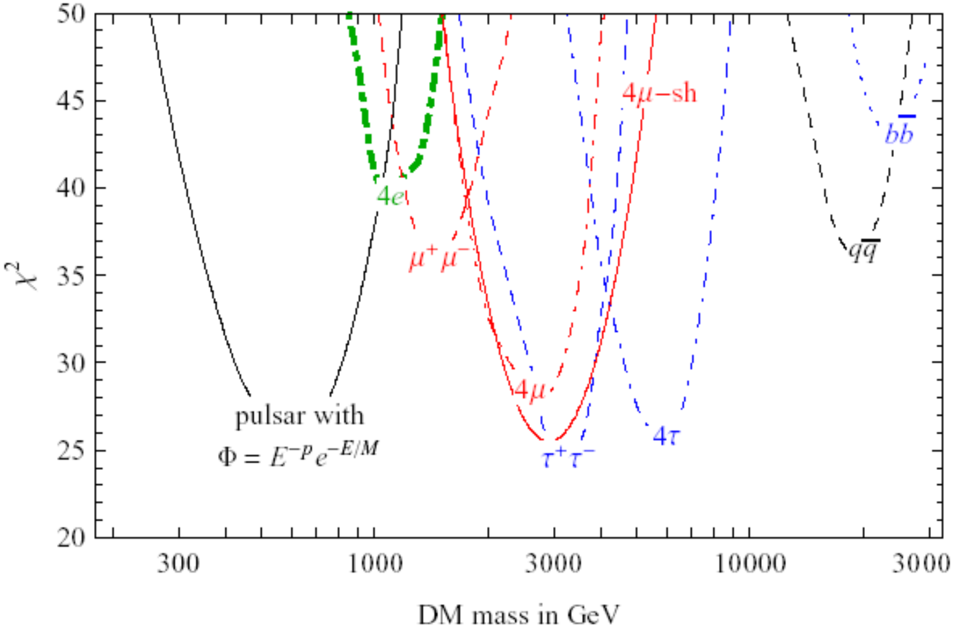


B = 10,000

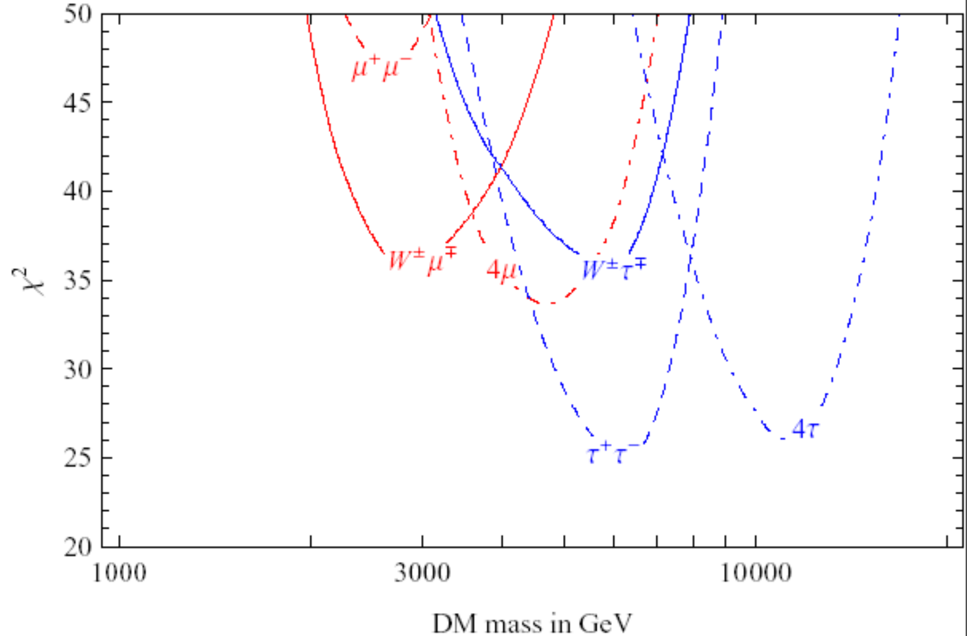
DM mass = 4 TeV



DM annihilation



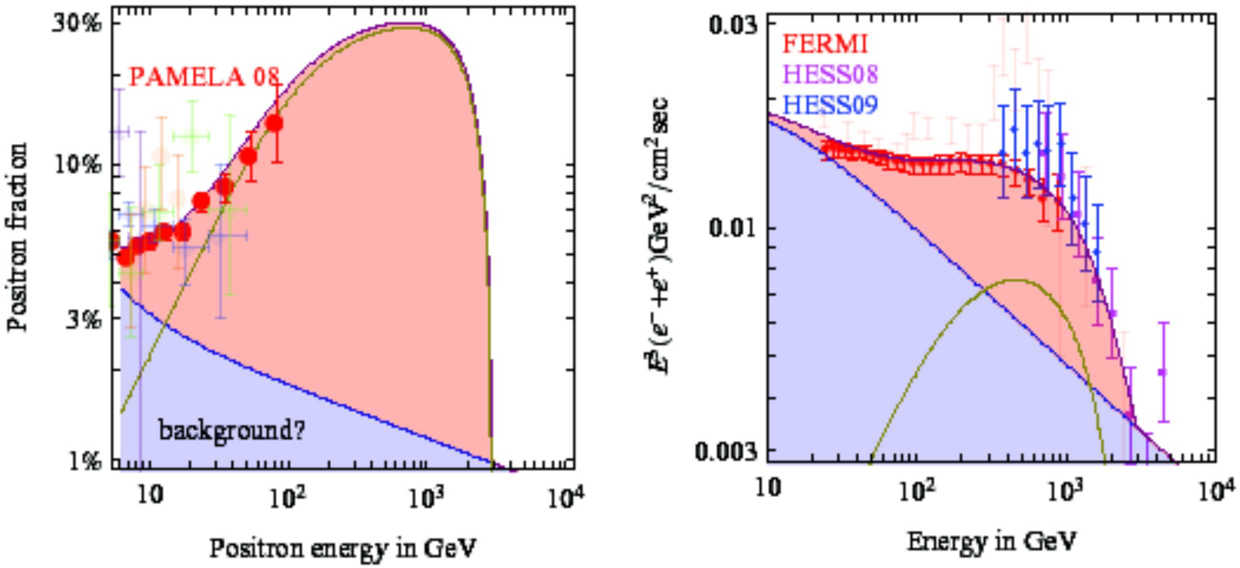
DM decay



Best DM fit : 2 τ , 4 μ and 4 τ.

arXiv:0905.0480

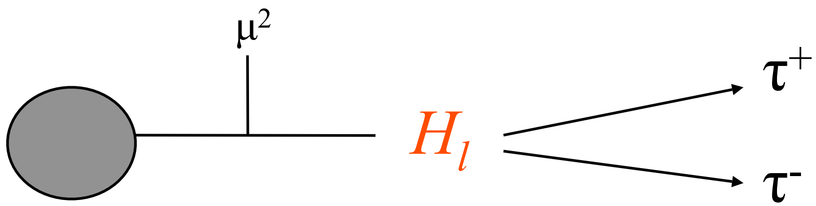
P. Meade, M. Papucci, A Strumia, T. Volansky



DM with $M = 3$. TeV that annihilates into $\tau^+\tau^-$ with $\sigma v = 2.0 \times 10^{-22}$ cm^3/s

P. Meade, M. Papucci, A Strumia, T. Volansky

arXiv:0905.0480

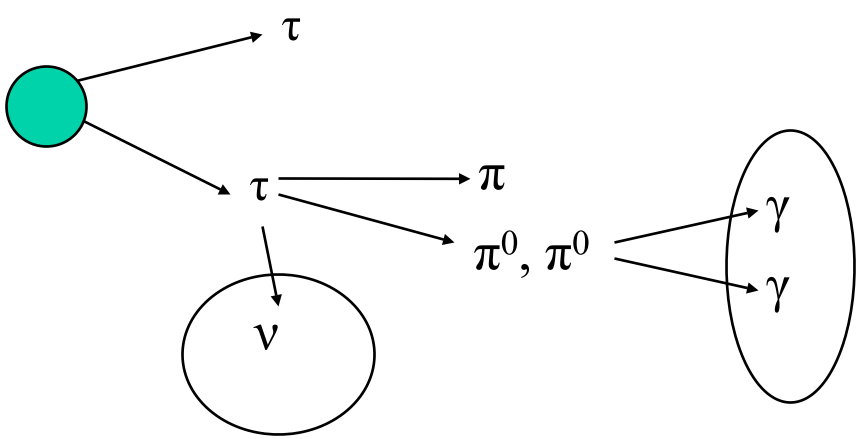


(Best fit decay channel)

$$\mu^2 H_D^\dagger H_l$$

(with $\mu^2 \sim \frac{v^4}{M_{GUT}^2}$)

Photon and neutrino



Lot of neutrino

Dominated by π^0 decay.

other from

- final state radiation
- inverse compton scattering
- synchrotron radiation

Resolve the tension by requiring $B^{e}_{total} = \# B^{\nu}_{total}$

and/or Isothemal DM profile

Decaying dark matter is safe from these constraints

(quite strong from neutrino but still safe)

Summary from observation

Annihilating DM

- We need a total boost factor ~ 10,000
  (Sommerfceld :10 ; local clump :10 ; B=100)

- DM mass is ~ 4 TeV
- Tension from gamma ray and neutrino
- Need Non-thermal production, or something else

Decaying DM

- Life-time ~ 10^{26} s (understood by spontaneously broken parity)
- DM mass is ~ 4 – 8 TeV (depends on model)
- Safe from gamma ray and neutrino constraints but that from neutrino remain strong.
- Thermal production ??

Leptonic Higgs phenomenology

At

LHC

(Brooks talk tomorrow)

SM like

(in the sense of production at hadron collider)

Leading approximation :

H_q ® h

H_l ® H, A

New scalars

There are also charged Higgs that we will not discuss here

Constraint on the parameters

$$m_H + m_A > 185 \text{ GeV}$$ ← From LEP

$$|m_H - m_A| < m_Z$$ ← Prevent H from decaying to Z

$$m_H < 2m_W$$ ← Prevent H from decaying to W

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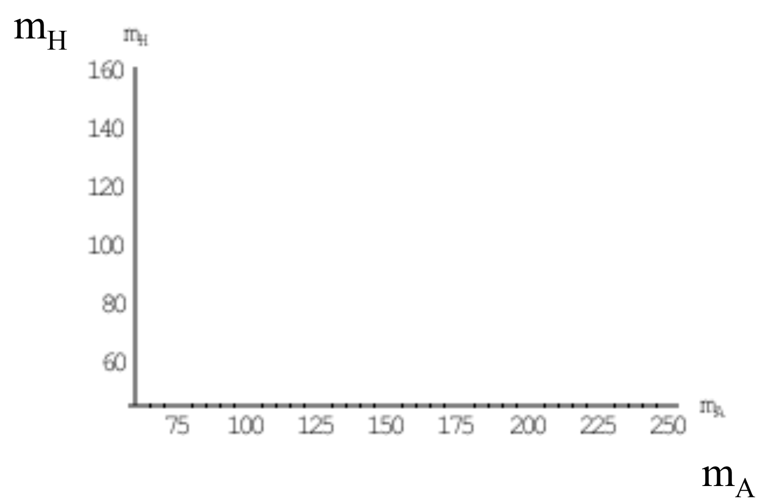

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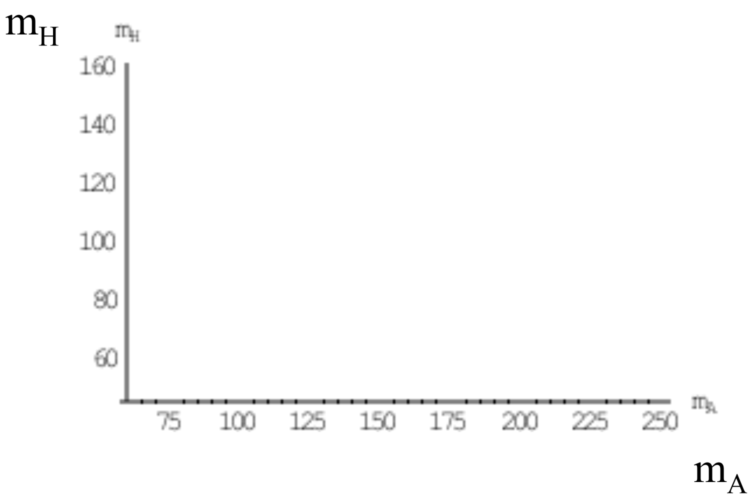
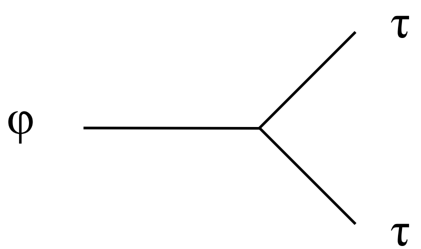
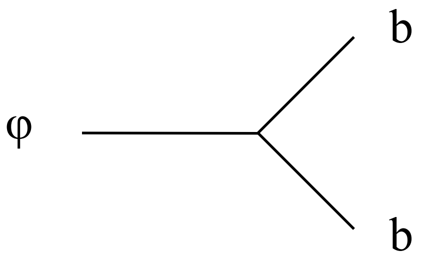
Imply non-decoupling at the LHC



Characteristic of leptonic Higgs :



y_τ is enhanced by $1/\tan\beta$

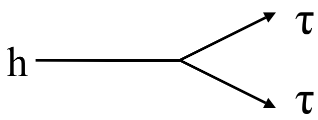


y_b is not enhanced
(only a tiny bit)

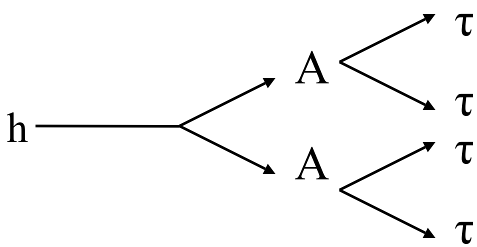
Unlike SUSY

Potential LHC signals

• "SM" Higgs searches can change

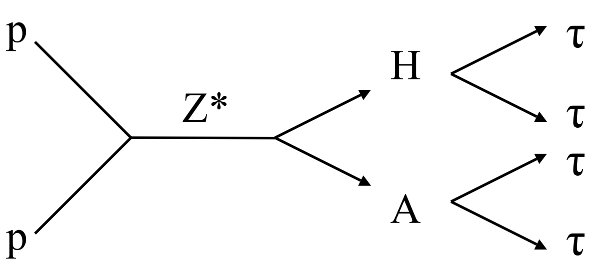


(enhanced by larger tau yukawa, suppressed by small L-Q mixing)



(If the quartic coupling is large)

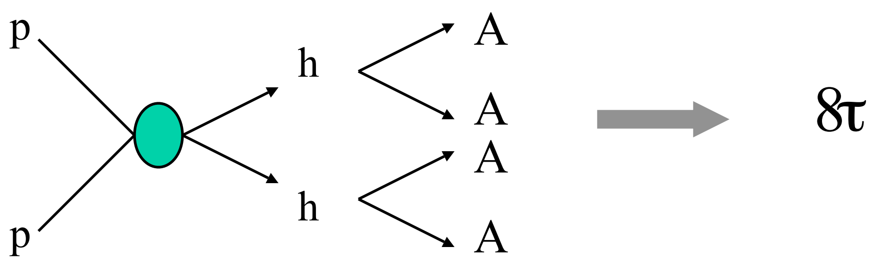
• New states A, H



(dependent only on mass of A, H)

350 fb for 100 GeV H, A

Can also have



~ 35 fb for 120 GeV h

It could happen that τ physics determine the fate of the Higgs searches !

We will need : efficient τ-tagging

reconstruction τ momentum

Note : from other talks at Pheno, trading a τ-pair with a μ-pair helps due to much smaller BG.

Higgs $\longrightarrow$ 2 τ

h→2τ and H →2τ (mass ~ 115 – 145 GeV)

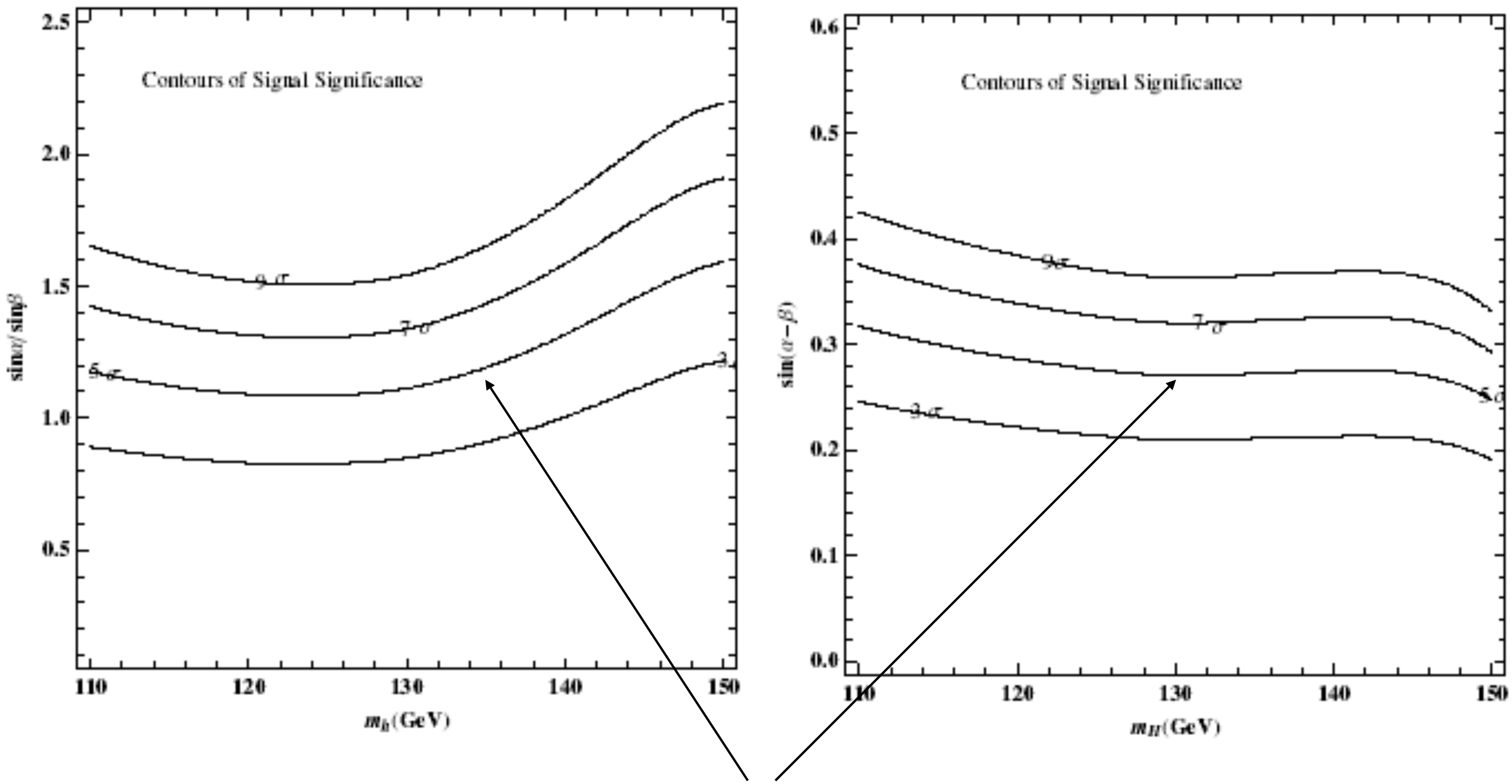
$$\sigma_{VBF}(h) \times BR(h \to \bar{\tau}\tau) \approx [\sigma_{VBF}^{SM} \times BR(h_{SM} \to \bar{\tau}\tau)] \frac{\left(\frac{\sin^2\alpha}{\sin^2\beta}\right)}{[1 + \left(\frac{\sin^2\alpha}{\sin^2\beta} - 1\right) BR(h_{SM} \to \bar{\tau}\tau)]}$$

$$\sigma_{VBF}(H) \times BR(H \to \bar{\tau}\tau) \approx [\sigma_{VBF}^{SM} \times BR(h_{SM} \to \bar{\tau}\tau)] \frac{\sin^2(\alpha - \beta)}{BR(h_{SM} \to \bar{\tau}\tau)}.$$

3 – 4 σ discovery at LHC with

30 fb^{-1} and 14 TeV

Enhancement factor

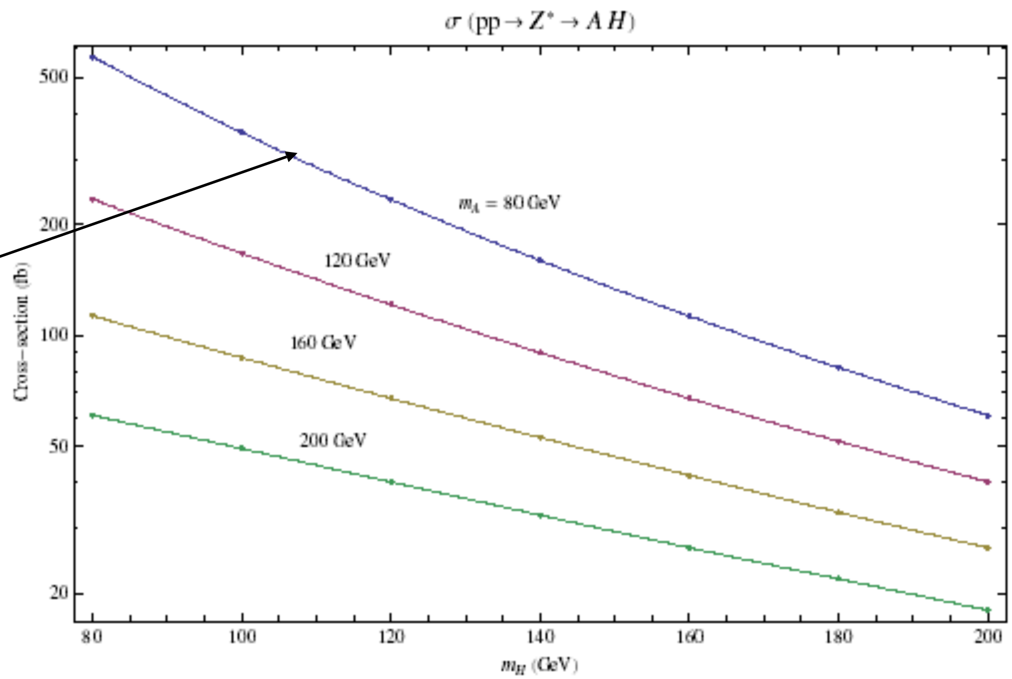


Contours of Signal Significance
9 σ
7 σ
5 σ
3 σ
sinα/sinβ
m_h(GeV)
Contours of Signal Significance
9σ
7 σ
5 σ
3 σ
sin(α−β)
m_H(GeV)

5 σ curve

Higgses $\longrightarrow$ 4 τ

H, A production → 4 τ event



mA=80 GeV

mH=100 GeV

σ(Z*)=350 fb

Similar to large tanβ MSSM but $Br_{\tau\tau} = 1 >> 0.08$

Further study needed !

$H \rightarrow AA \rightarrow 4\tau$ event

CMS, ATLAS are studying the reach of this signal (Higgs working group)

No existing study available except a similar one for the NMSSM with m_A = 7 GeV, m_h=120

The claim is

- 20 σ discovery with 300 fb^{-1} ~ > 5 σ with 30 fb^{-1}
- h heavier than 130 GeV become hard as tt background rise
- we expect heavier A will not reduce the efficiency, but Br suppressed by the small phase space if h is light.

Need further study with heavy Higgs

Conclusion

- Astrophysical observation provided interesting information about DM.
- Leptonic Higgs can serve as a messenger of DM to explain the observed PAMELA/Fermi/HESS data.
- No DM at the LHC
- Higgs physics at the LHC could be very different and τ may be the key to find the Higgs
- For possible models ? Please see our paper.

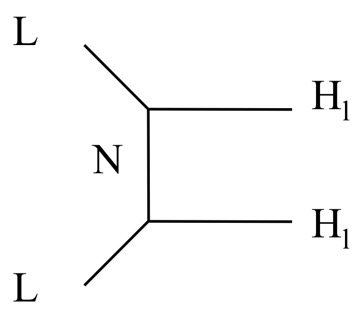
Backup 1 : Models

Models of dark matter

LLN model

$$L_{dark} = \lambda L H_l N + m_L L L^c + m_N N N$$

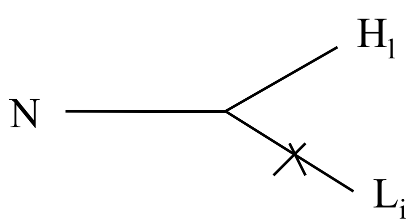
annihilation



Need $\lambda \sim 3\text{-}4$

$$\delta L_{dark} = \delta m^i L_i L^c + ...$$

decay



$$\chi \rightarrow (A, H) + \nu_l \rightarrow \tau^+ \tau^- \nu_l$$

or

$$\chi \rightarrow H^{\pm} + l^{\mp} \rightarrow \tau^{\pm} l^{\mp} \nu_\tau$$

Innert doublet model

$$L_{dark} = \lambda \,|\, H_l \,|^2 |\, H_D \,|^2 + \ldots.$$

$$\delta L_{dark} = \delta m H_I^{\dagger} H_l + \ldots\ldots.$$

Singlet scalar model

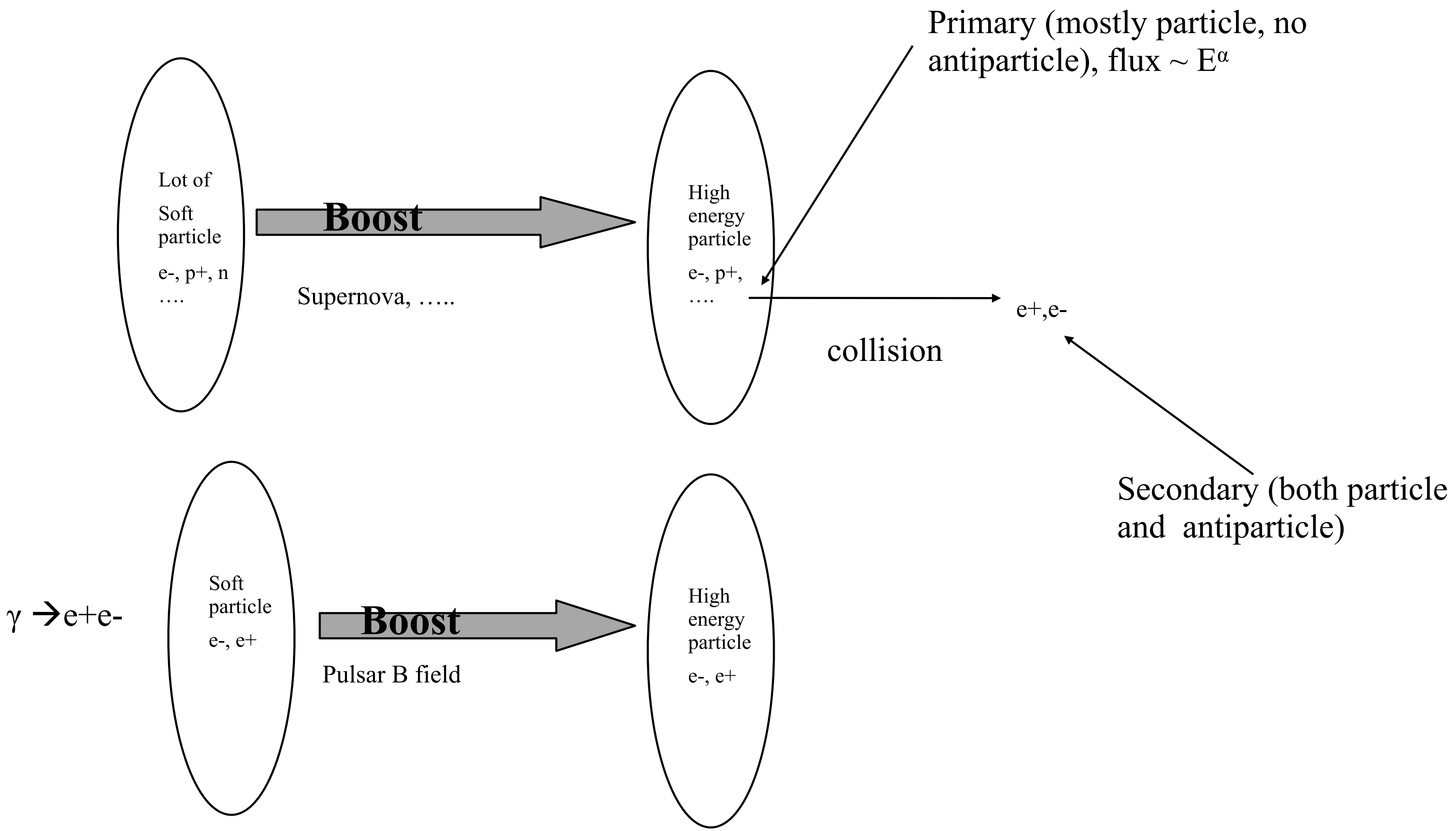
$$L_{dark} = \lambda \,|\, H_l \,|^2 \, (\Phi)^2 + \ldots.$$

$$\delta L_{dark} = \delta m \,|\, H_l \,|^2 \, \Phi + \ldots.$$

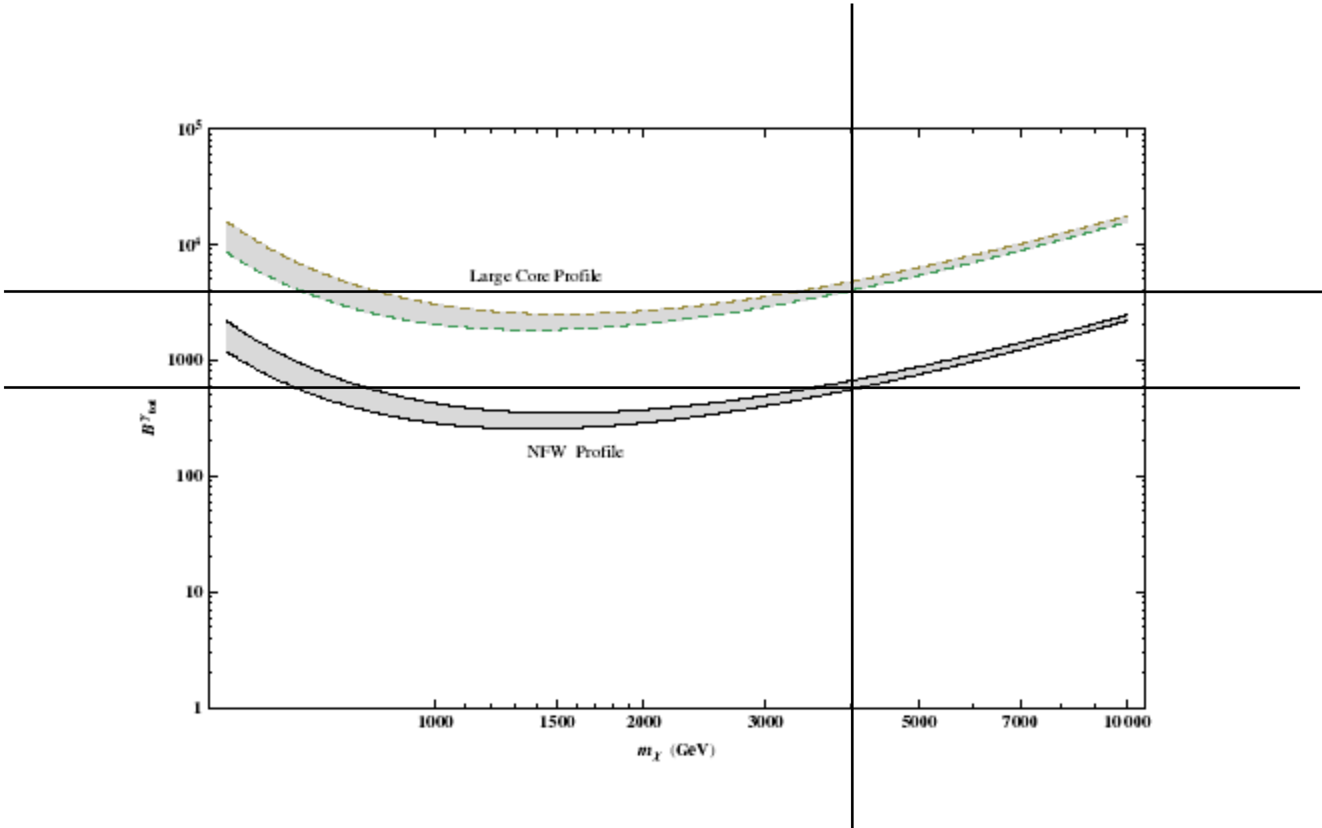
Summary of models

	annihilation	decay	symmetry
LLN	L, large coupling Little hierarchy	N, have both direct lepton and cascade τ, less Boost factor, DM mass	Chiral parity for both lepton and quark
singlet	No suppression on Hq mode	8 TeV DM No suppression on Hq mode	Z_6
Inert D	No suppression on Hq mode	Hq mode suppressed, decay to ZZ open but suppressed	Chiral parity for both lepton and quark, Z_4 Dark parity

Backup 2 : Astro source for high energy cosmic ray



Photon



$B^{\gamma}_{total} \leq 4000$

$B^{\gamma}_{total} \leq 600$

$B^{e}_{total} = 10000$ need $B^{e}_{total} = \# B^{\gamma}_{total}$

$\# = 1 - 10$ from astrophysics is reasonable

Neutrino

Constraints from Super-K is very stringent

Study by Jia Liu, Peng-fei Yin, Shou-hua Zhu shows

- 2 TeV dark matter annihilate to 2 τ that fit the Pamela/Atic will have the muon flux (induced by neutrino) 3 time bigger than the bound

- We have 4 TeV dark matter annihilate to 2 H to 4 τ

e are softer → boost factor larger

ν are softer too

} Expecting these effect compensate and give same muon flux

$B^{e}_{total} = 10000$ need $B^{e}_{total} = \# B^{\nu}_{total}$

= a few is reasonable

- Charged Higgs

    Barger, Hewett, Phillips Phys.Rev.D41:3421,1990.

    Yuval Grossman Nucl.Phys.B426:355-384,1994.

- Lightest CP even scalar (h SM like)

    Akeroyd . Phys.Lett.B377:95-101,1996. (LEP2)

    Akeroyd. J.Phys.G24:1983-1994,1998. (LHC)

    Shufang Su and Brooks. (decoupling limit)

- We should study the non-decoupling limit