Recent Aspects of Dark Matter phenomenology

Yann Mambrini, LPT Orsay, University Paris XI

http://www.ymambrini.com/My_World/Physics.html

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Outline

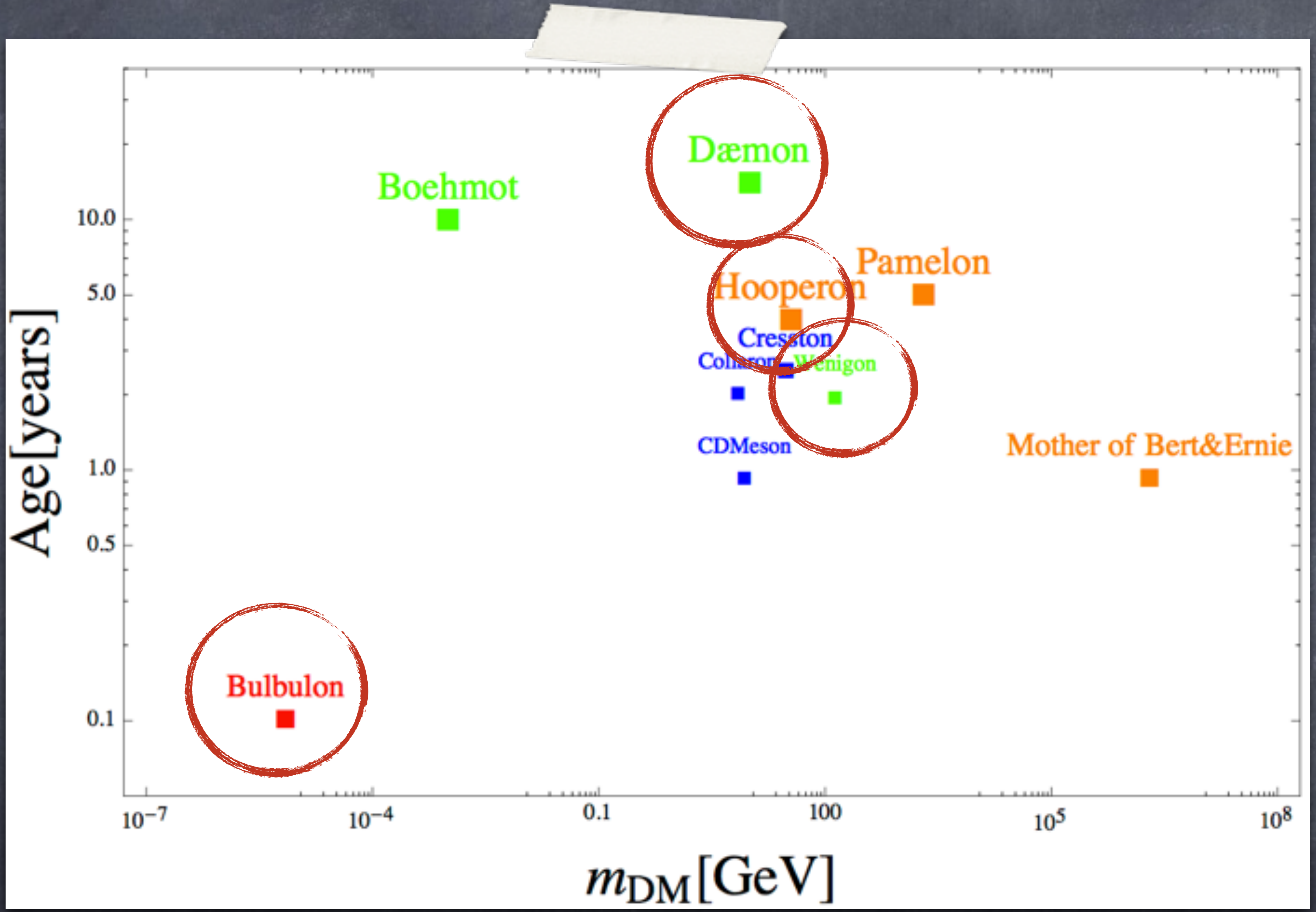
- Introduction
- Experimental status
- Theoretical status
- Conclusion

Toolbox to build a model of dark matter

One should first ask :

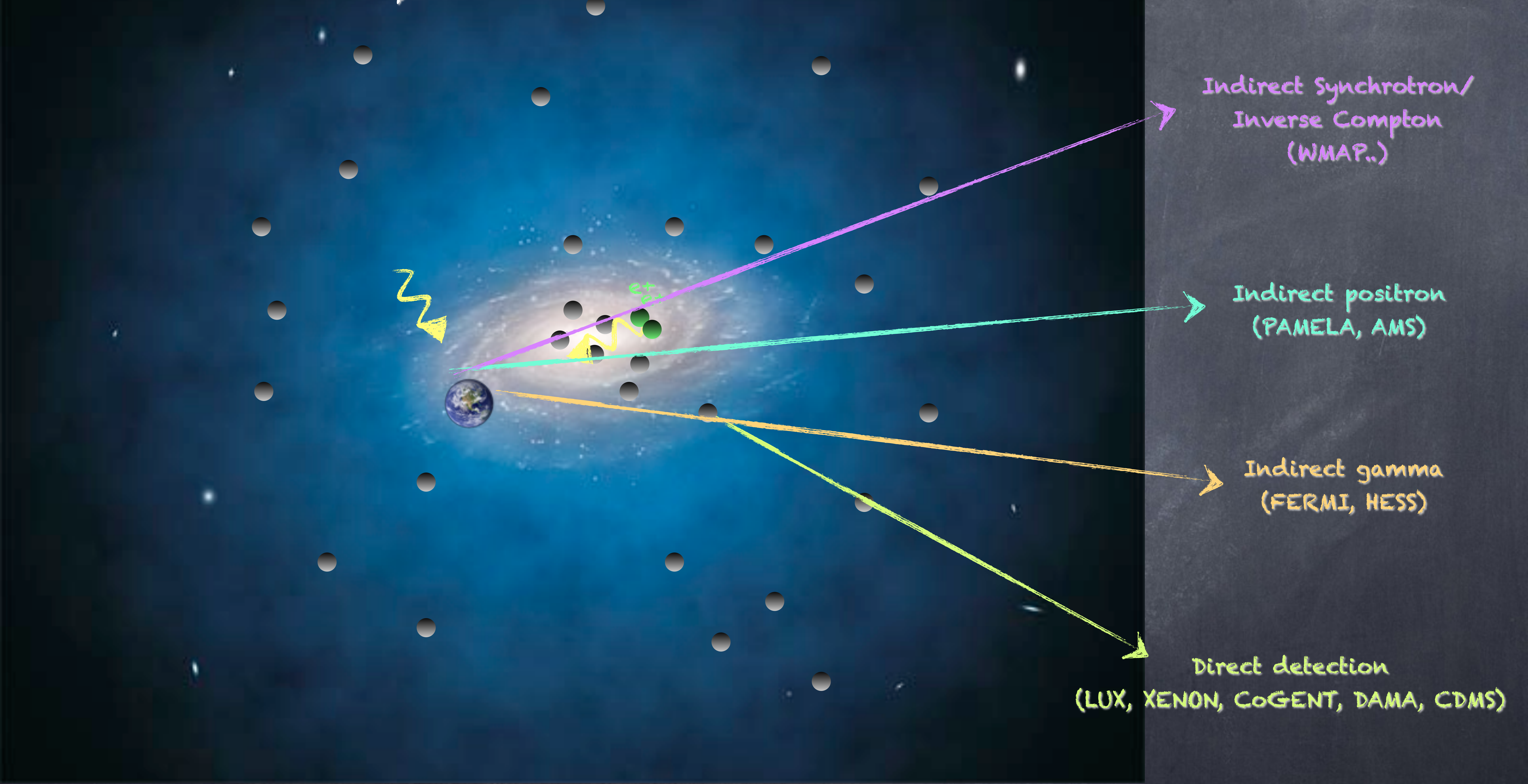
« which constraints / theoretical issue(s) / [signal(s)] I really want to solve? »

Signals/constraints: A map of the problematic*

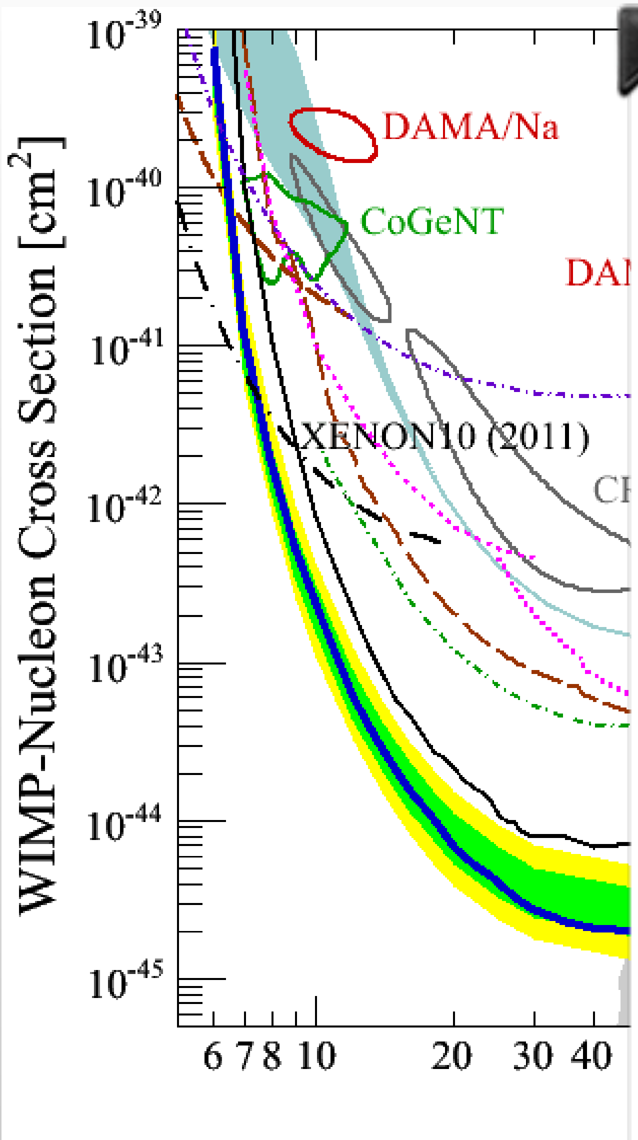


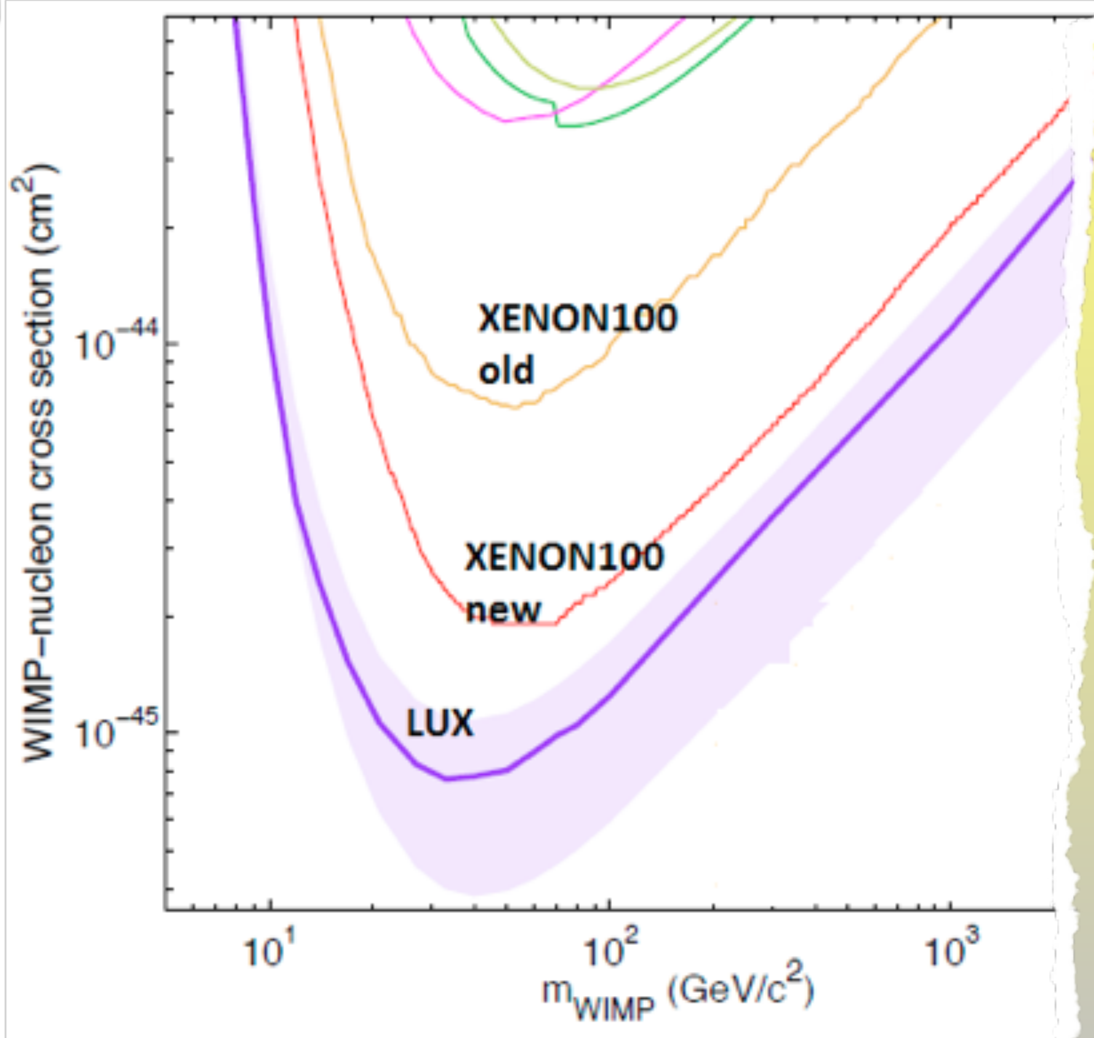
Plot extract from http://resonaances.blogspot.com/

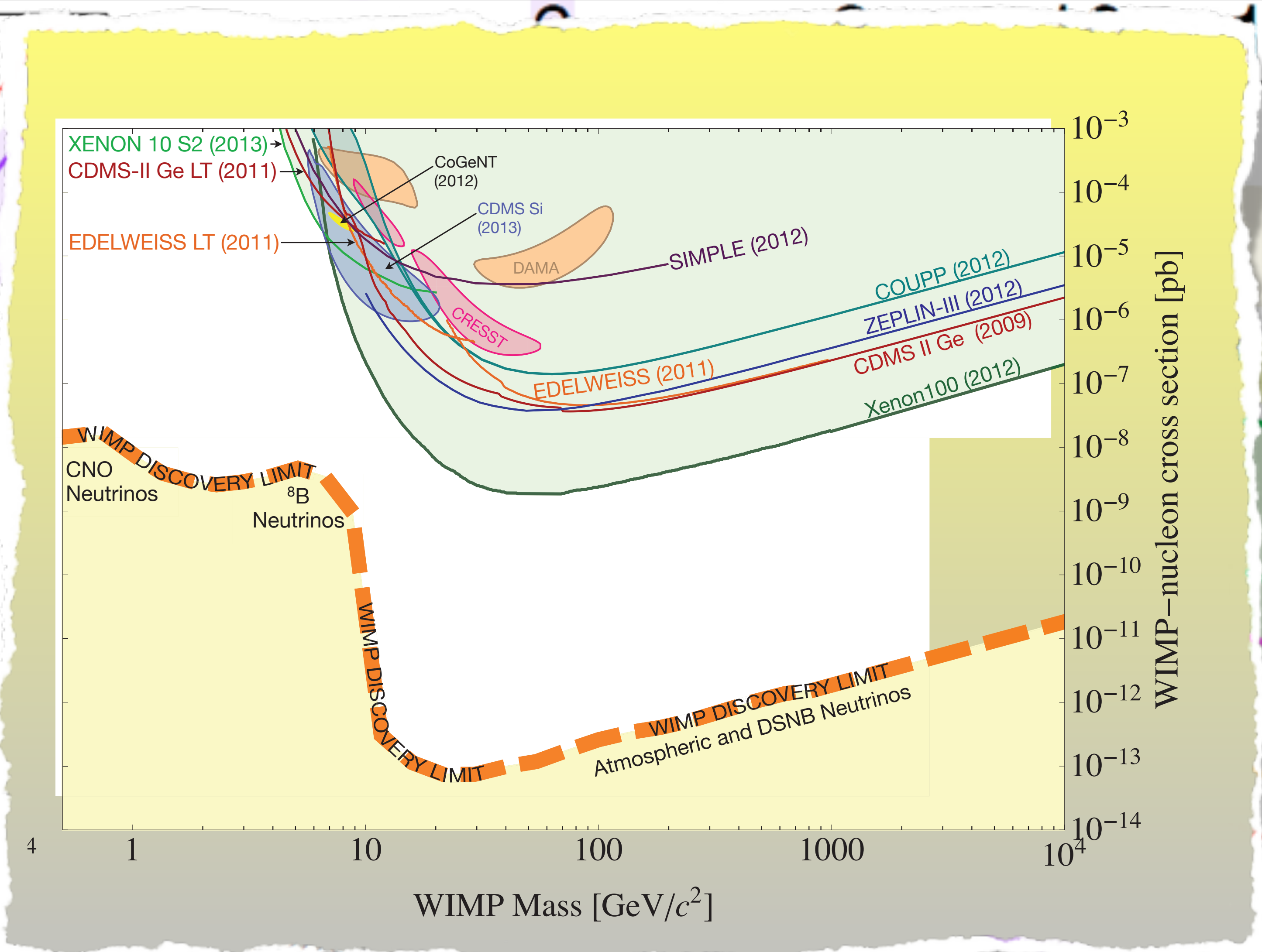
Detection of Dark Matter



Direct detection of Dark Matter : LUX (10/13)

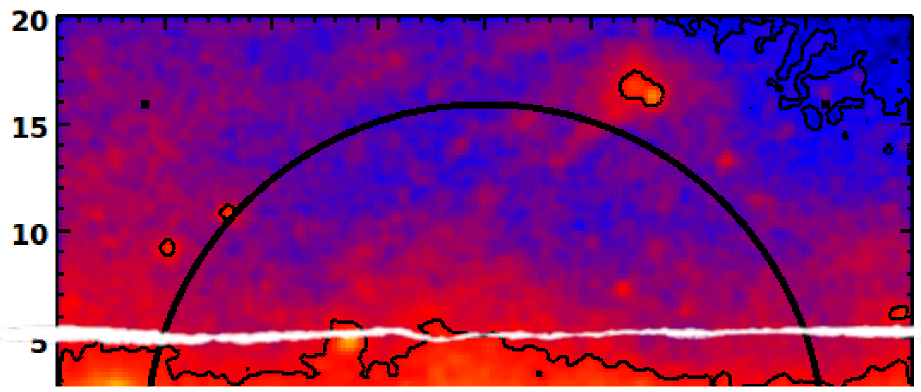


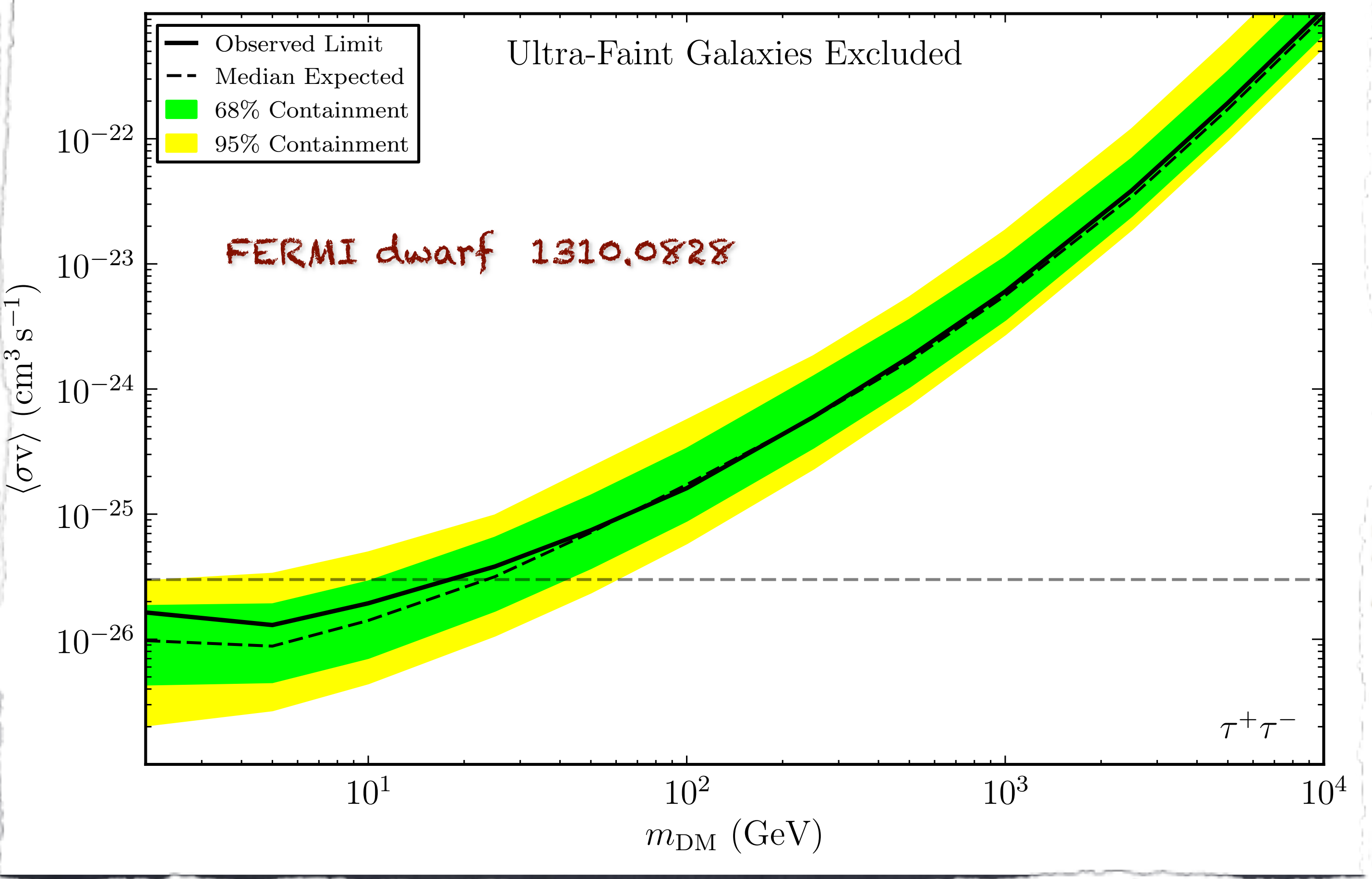


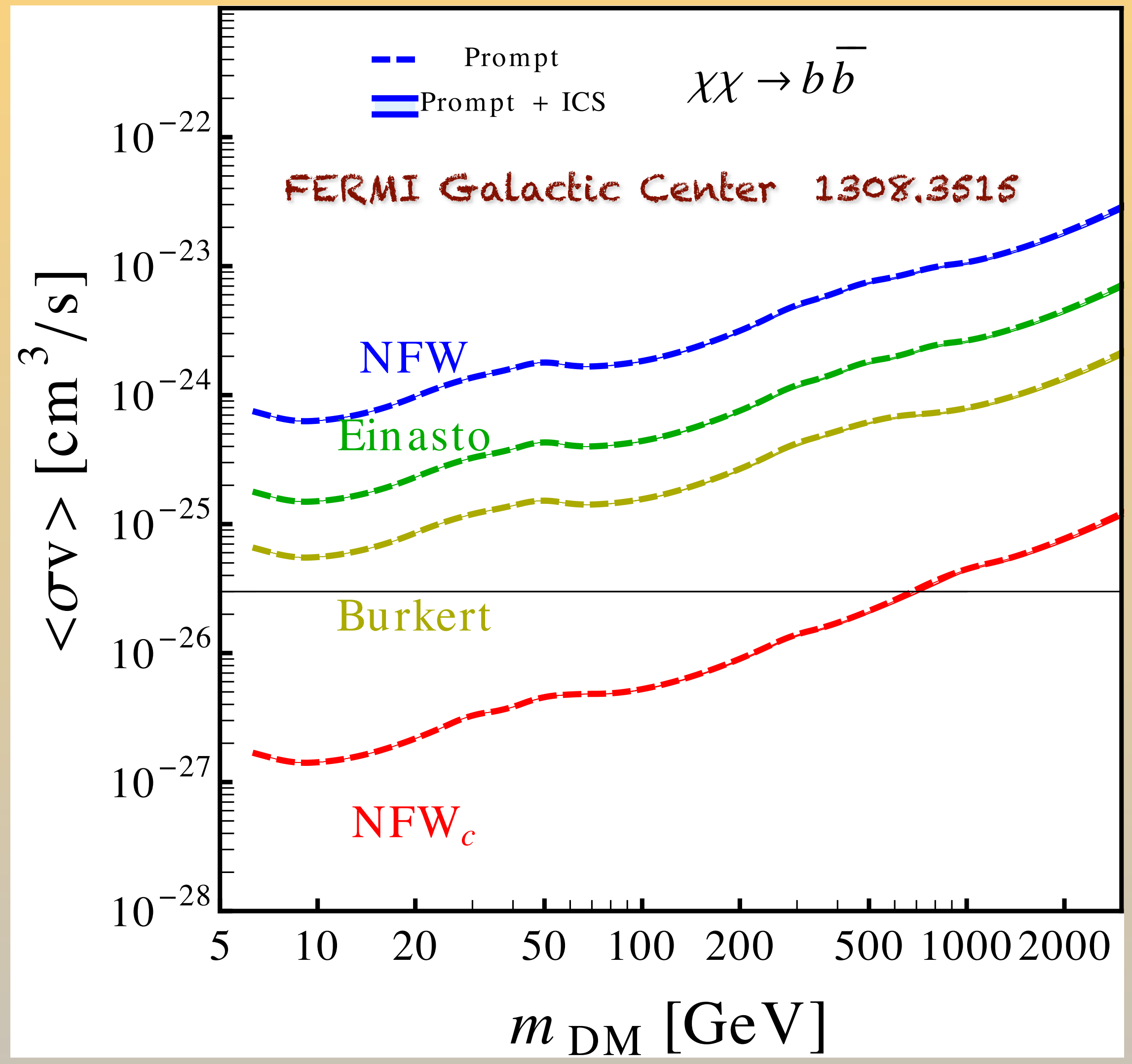


XENON100 (07/12)

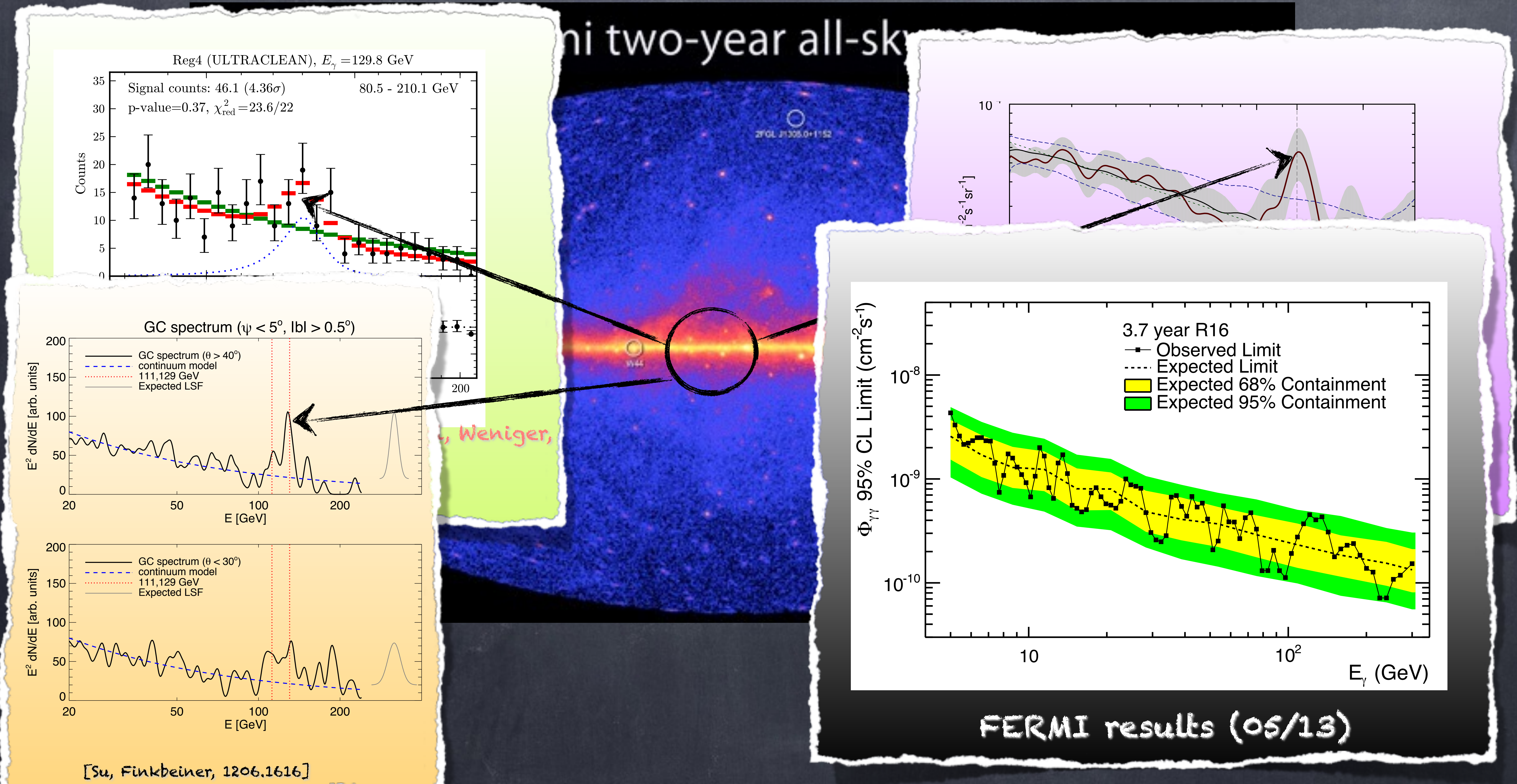
Indirect γ : FERMI (08/13)







Observation of a line : Galactic Center (05/12)



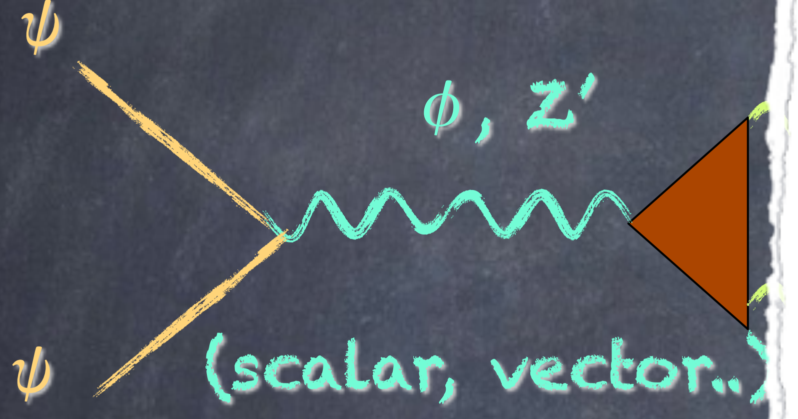
Several models appeared quickly in the market

Ibarra, Lopez Gehler, Pato : «Dark matter constraints from box-shaped gamma-ray features», 1205.0007; Dudas, Mambrini, Pokorski, Romagnoni: «Extra U(1) as a natural source of a monochromatic gamma ray line», 1205.1520; Cline : «130 GeV dark matter and the Fermi gamma-ray line», 1205.2688; Choi, Seto : «A Dirac right-handed sneutrino dark matter and its signature in the gamma-ray lines», 1205.3276; Kyae, Park, «130 GeV Gamma-Ray Line from Dark Matter decay», 1205.4151; Min Lee, Park, Park : «Fermi Gamma-Ray Line at 130 GeV from Axion-Mediated Dark Matter», 1205.4675; Ajaraman, Tait, Whiteson : «Two Lines or Not Two Lines? That is the Question of Gamma Ray Spectra, 1205.4723; Buckley, Hooper : «Implications of a 130 GeV Gamma-Ray Line for Dark Matter», 1205.6811; Chu, Hambye, Scarna, Tytgat: «What if Dark Matter Gamma-Ray Lines come with Gluon Lines», 1206.2279; Das, Ellwanger, Mitropoulos : «A 130 GeV photon line from dark matter annihilation in the NMSSM», 1206.2639; Kang, Li, Li, Liu : «Brightening the (130 GeV) Gamma-Ray Line», 1206.2863; Feng, Yuan, Fan : «Tentative wiggle in the cosmic ray electron/positron spectrum at 100 GeV : a dark matter annihilation signal in accordance with the 130 GeV gamma-ray line?», 1206.4758; Cohen, Lisanti, Slatyer, Wacker : «Illuminating the 130 GeV Gamma Line with Continuum Photons», 1207.0800; Cholis, Tavakoli, Ullio : «Searching for the continuum photons correlated to the 130 GeV gamma-ray line;, 1207.1468; Frandsen, Haish, Kahlhoefer, Mertsch, Schmidt-Hoberg : «Loop-induced dark matter direct detection signal from gamma-ray lines», 1207.3971; Park, Park : «Radiatively decaying scalar dark matter throigh U(1) mixings and the Fermi 130 GeV gamma-ray line», 1207.4981; Bergstrom, Bertone, Conrad, Farnier, Weniger : «Investigating Gamma-Ray Lines from Dark Matter with Future Observatories», 1207.6773; Tulin, Yu, Zurek : «Three Exceptions for Thermal Dark Matter with Enhanced Annihilation to Gamma-Gamma», 1208.0009; Hooper, Linden : «Are Lines From Unassociated Gamma-Ray Sources Evidence For Dark Matter Annihilation?», 1208.0828; Cline, Moore, Frey : «Composite magnetic dark matter and the 130 GeV line», 1208.2685; Bai, Shelton : «Gamma Lines without a Continuum : Thermal Models for the Fermi-LAT 130 GeV Gamma Line», 1208.4100; Laha, Ng, Dasgupta, Horiuchi : «Galactic Center Radio constraints on Gamma-Ray Lines from Dark Matter Annihilation», 1208.5488; Bergrstrom, «The 130 Fingerprint of Right-handed Neutrino dark matter», 1208.6082; Wang, Han : «130 GeV gamma-ray line and enhacement of h -> gamma gamma in the Higgs triplet model plus a scalar dark matter», 1209.0376; Weiner, Yavin : «UV Completion of Magnetic Inelastic Dark Matter and RayDM for the Fermi Line(s)», 1209.1093; Mambrini : «Don't tell me you are really reading all these references!!», 130218xx; Fan, Reece :»A Simple Recipe for the 111 and 128 GeV Lines», 1209.1097; Baek, Ko, Senaha : «Can Zee-Babu model implemented with scalar dark matter explain both Fermi/LAT 130 GeV gamma-ray excess and neutrino physics?», 1209.1685; Shakya : «A 130 GeV Gamma Ray Signal from Supersymmetry», 1209.2427; Rao, Whiteson : «Where are the Fermi Lines Coming From?», 1210.4934; Schmidt-Hoberg, Staub, Wolfgang Winkler, «Enhanced diphoton rates at FERMI and the LHC», 1211.2835; Fazran, Rezaei Akbarieh, «natural explanation for 130 GeV photon line in vector boson dark matter model», 1211.4685; Gorbukov, Tyniakov, «On the offset of the DM cusp and the interpretation of the 130 GeV line as a DM signal», 1212.0488; Kopp, Neil, Primulando, Zupan : «From gamma ray line signals of dark matter to the LHC», 1301.1683; Jackson, Servant, Shaughnessy, Tait, Taoso : «gamma--ray lines and One Loop Continuum from s-channel Dark Matter Annihilation, 1302.1802;

Models type 1 : resonance channel(s)

Dudas, Y. M., Romagnoni, Pokorski, 2009/2009/2012
Gustafsson, Lundstrom, Bergstrom, Edsjo, 2007
Jackson, Servant, Shaughnessz, Tait, Taoso , 2009
Das, Ellwanger, Mitropoulos, 2012

ψ = DM candidate

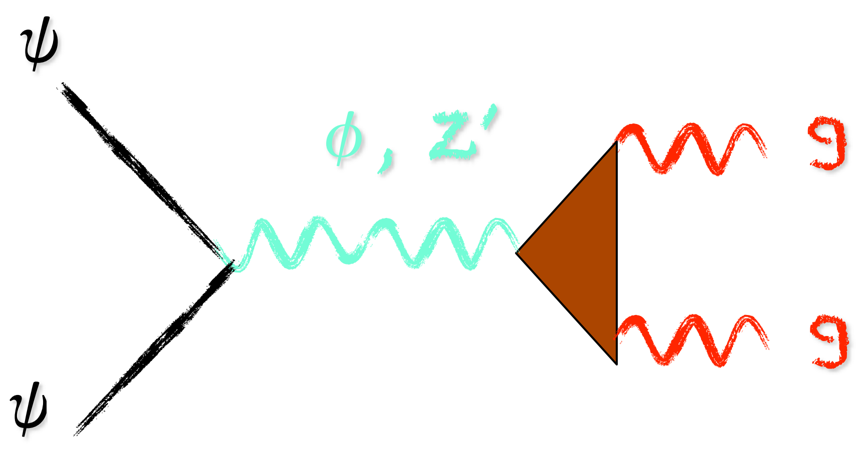


= Mψ

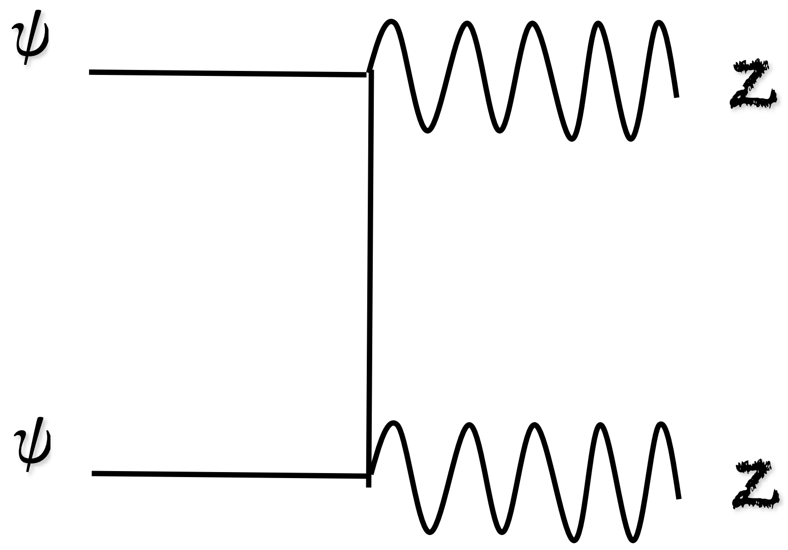
t rest)

(GeV)

WMAP



Chu, Hambye, Scarna, Tytgat
1206.2279



Dudas, Mambrini, Pokorski, Romagnoni
1205.1520

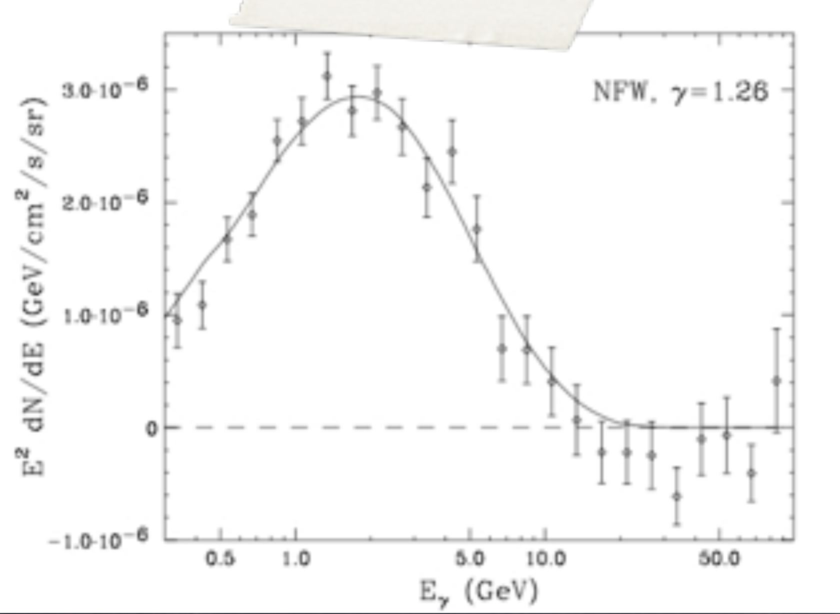
- Does not need to be ... the coup...

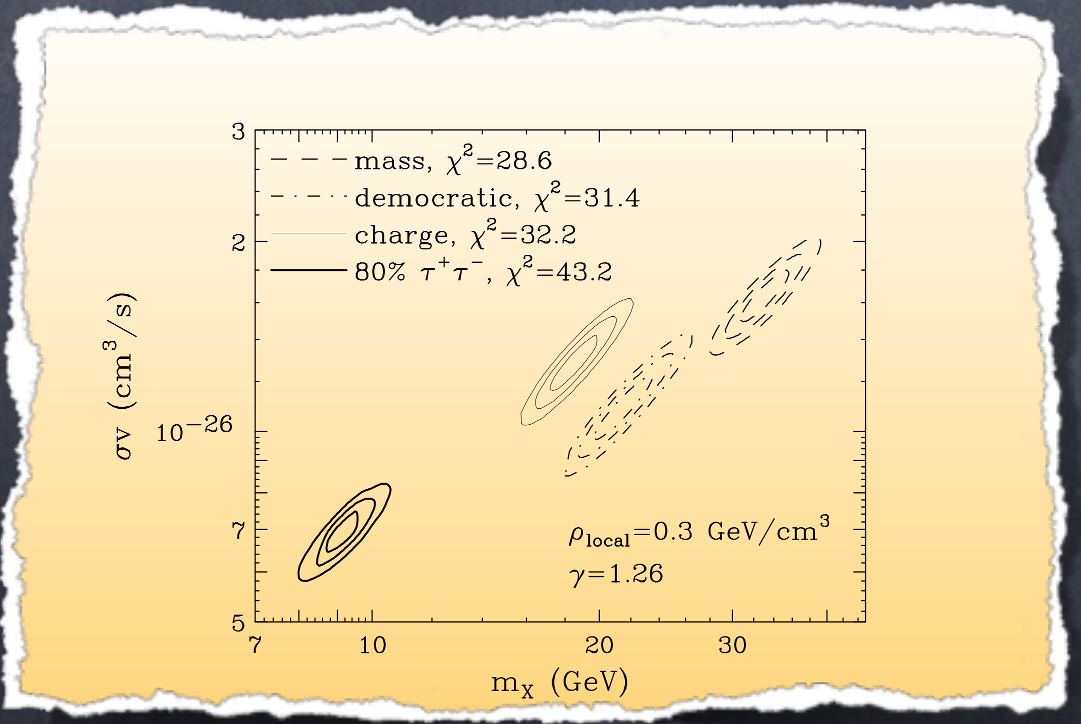
- Usually, $\gamma\,\gamma$ and γ ... 49.5 GeV. It happens if ϕ ... line.

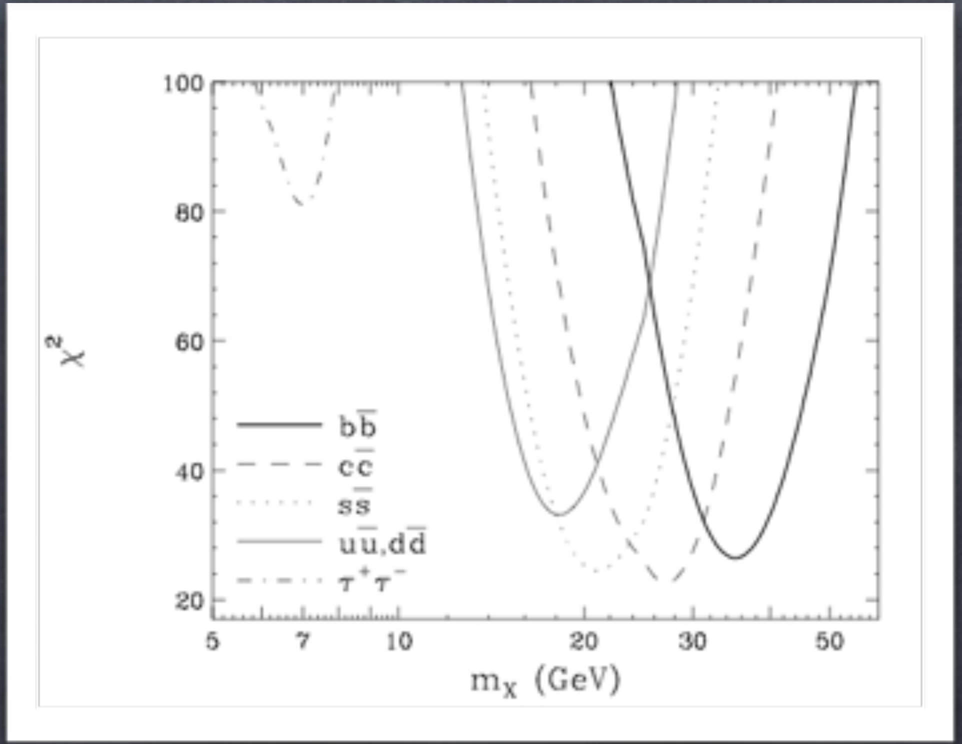
Galactic center signal? « Hooperon »

T. Daylan, D. P. Finkbeiner, D. Hooper, T. Linden, S. K. N. Portillo, N. L. Rodd, and T. R. Slatyer, [1403.6503]

30 GeV dark matter mass from GC bbar final state, NFW-like profile





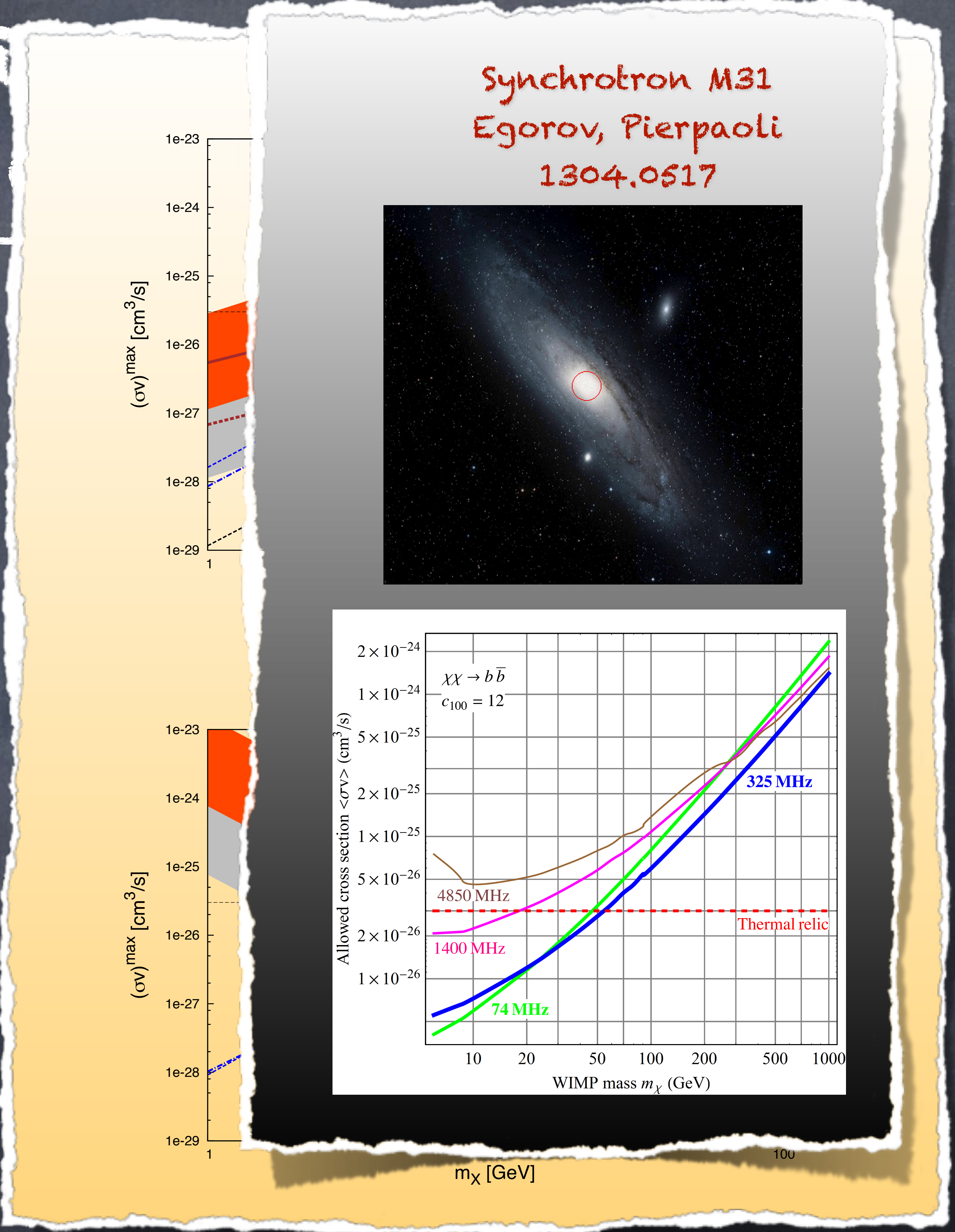


Synchrotron emi
effective

To restrict the annihilation cross section for a given DM mass and final state

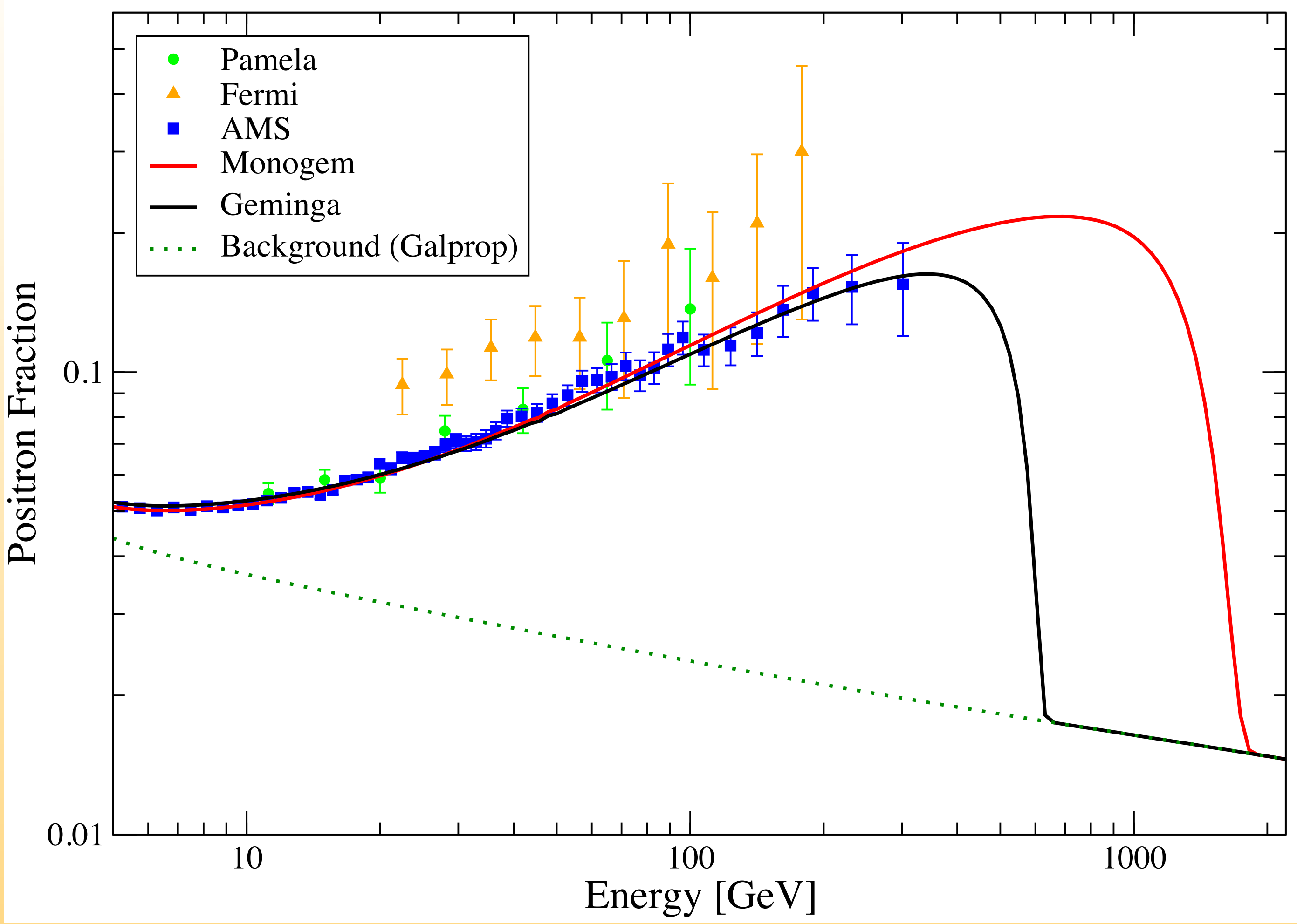
It seems that nearby galaxies are even more restrictive

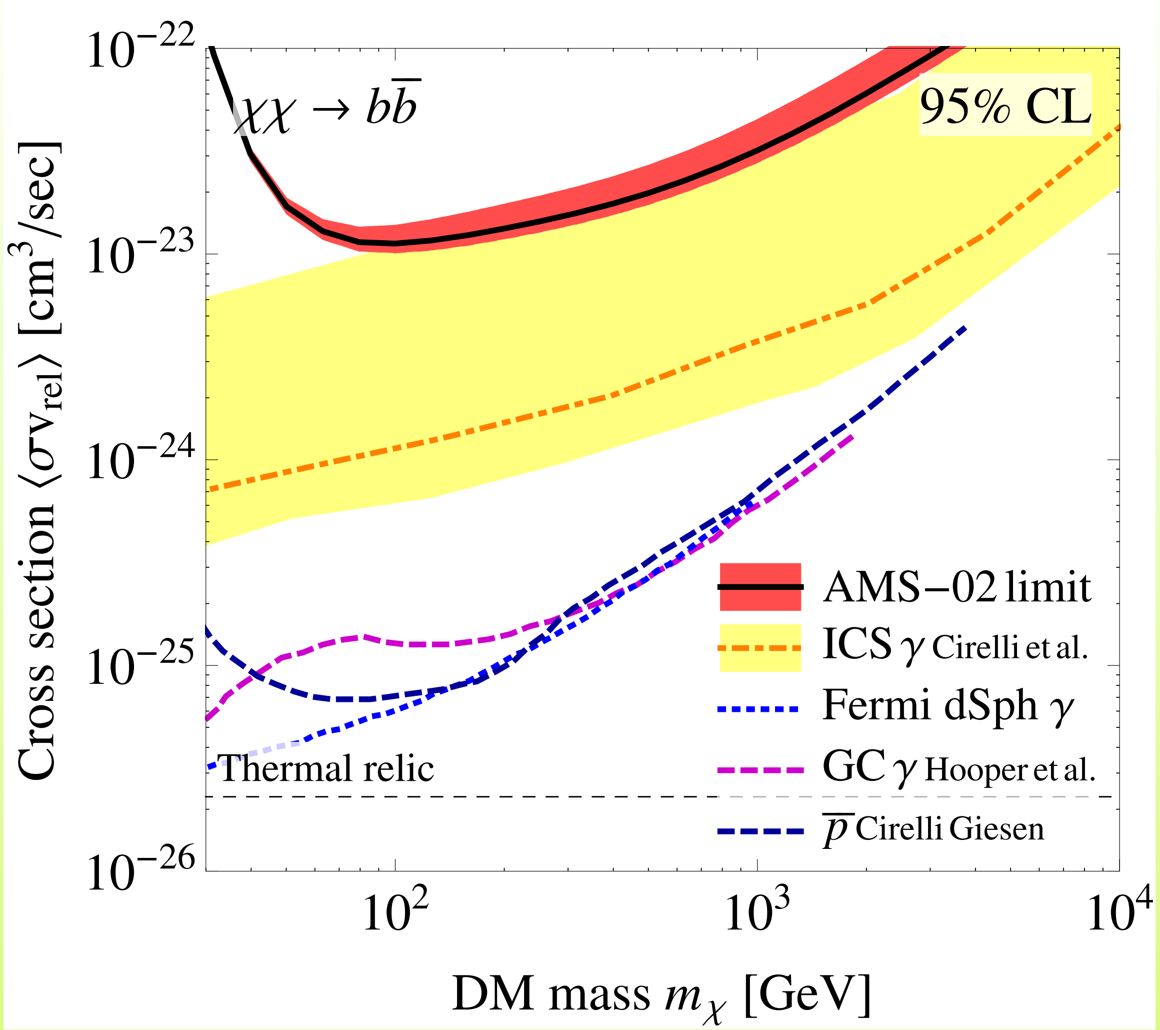
We can in the first step look at effective couplings



Indirect positron : AMS-02 (04/13)

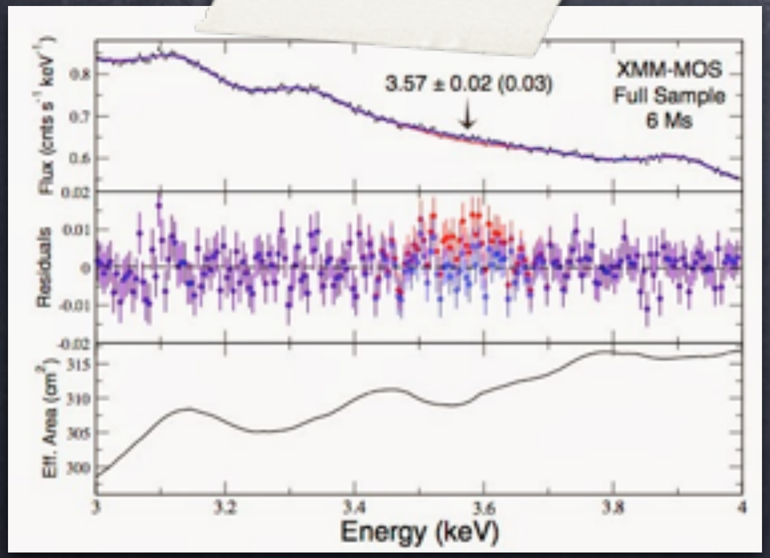
+ SNR's explanation [Mertsch, Sarkar: 1402.0855]

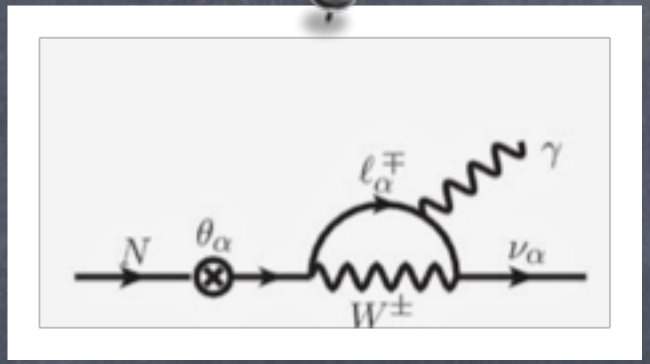




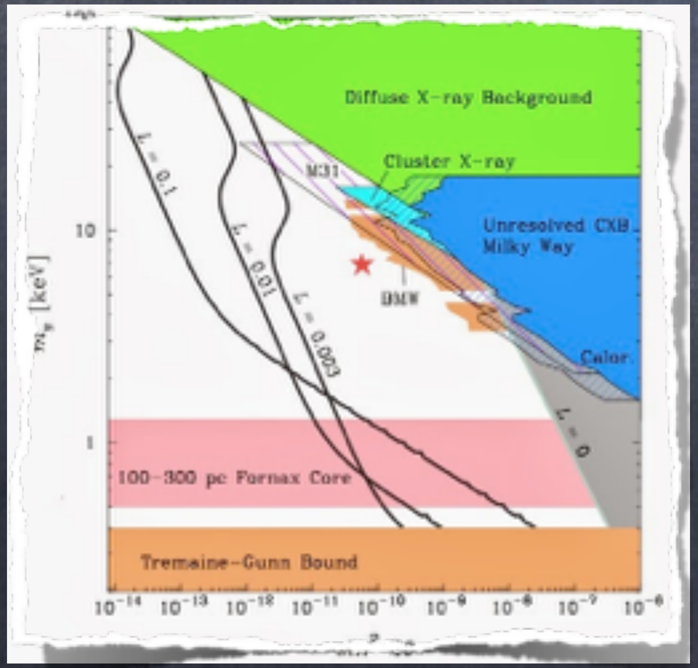
X-ray (3.56 keV) Line by XMM Newton

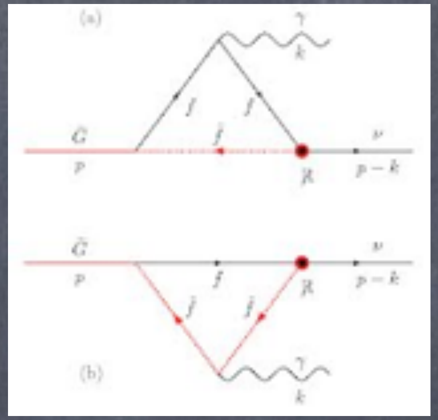
3.5 keV
Bulbul et al. [1402.2301]
Lifetime ~10^28 seconds
$<\sigma v>$ ~ 10^-16 GeV^-2



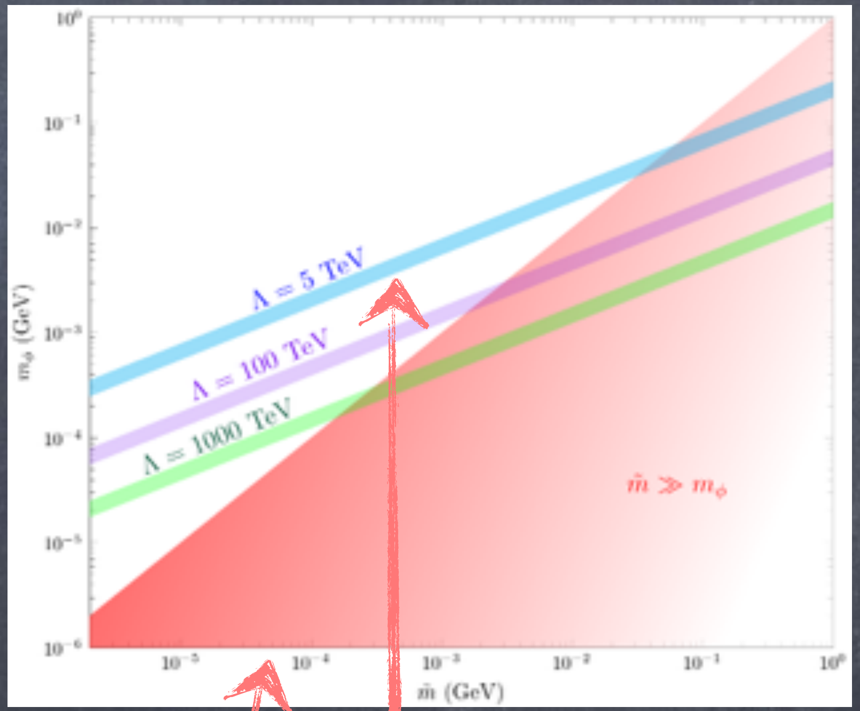


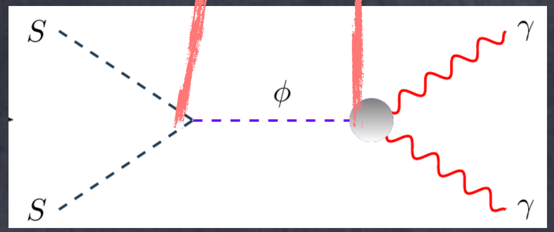
Lifetime ~10^28 seconds
Sterile neutrino Boyarski et al. [1402.4119]





Gravitino: problem,
Lifetime ~10^30 seconds
or Trh~ 170 GeV
Roszkowski et al.
[1403.6530]





Annihilating DM
[Dudas Heurtier
Mambrini]

Toward an effective approach

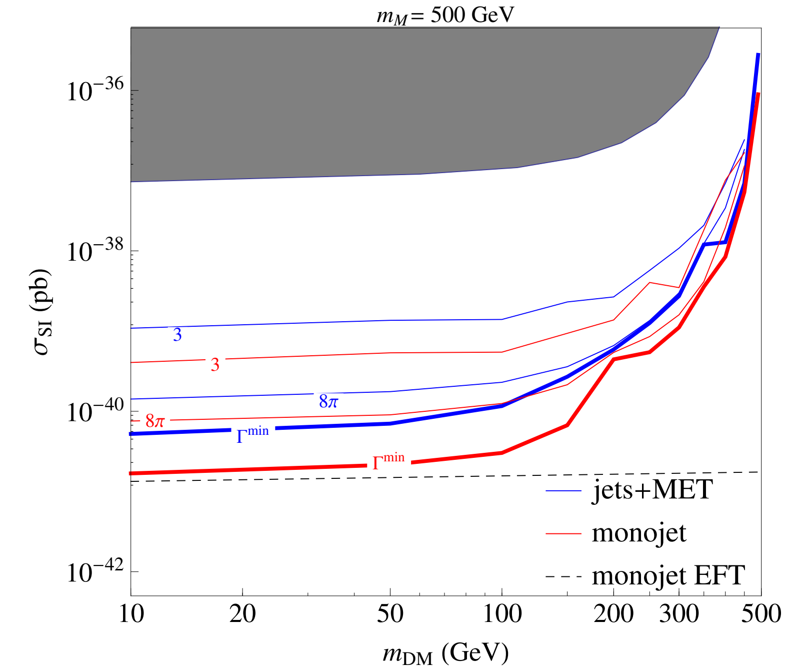
There is a time for concept and a time for pragmatism. Can we cook model buildings the same way with or without data?

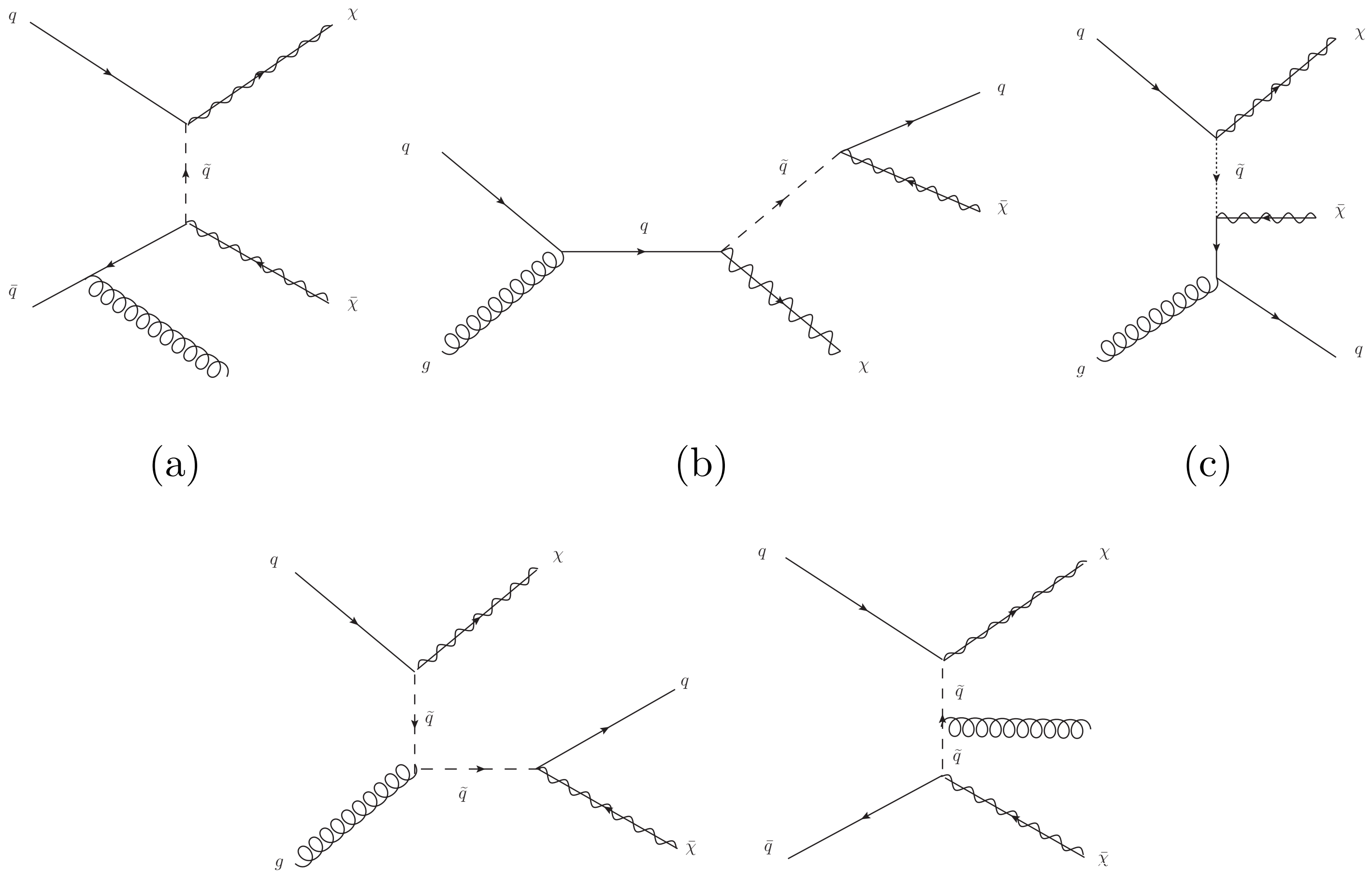
Personally speaking, I would have a tendency to say no.

However, as a theorist, I should ask myself the question:

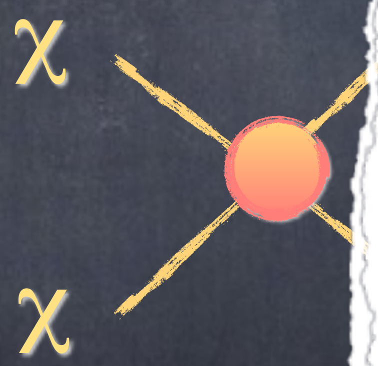
at what price can I forget about formal concepts and microscopic approach in fitting data

Limit of the approach
Papucci, Zurek [1402.2285]

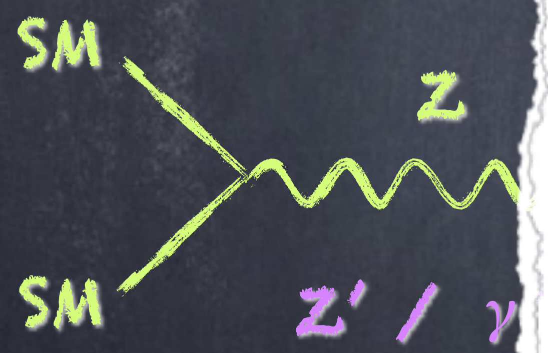


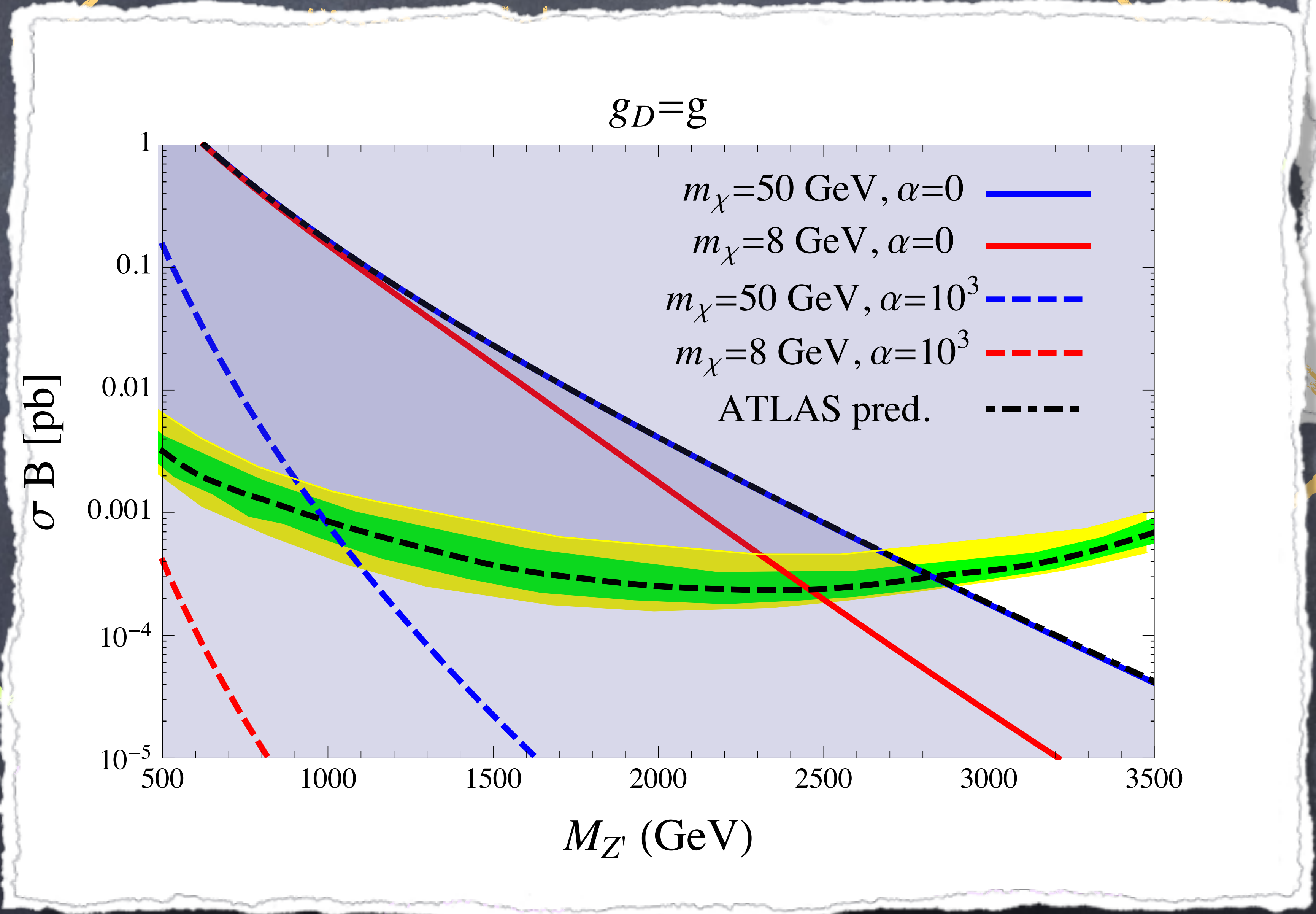


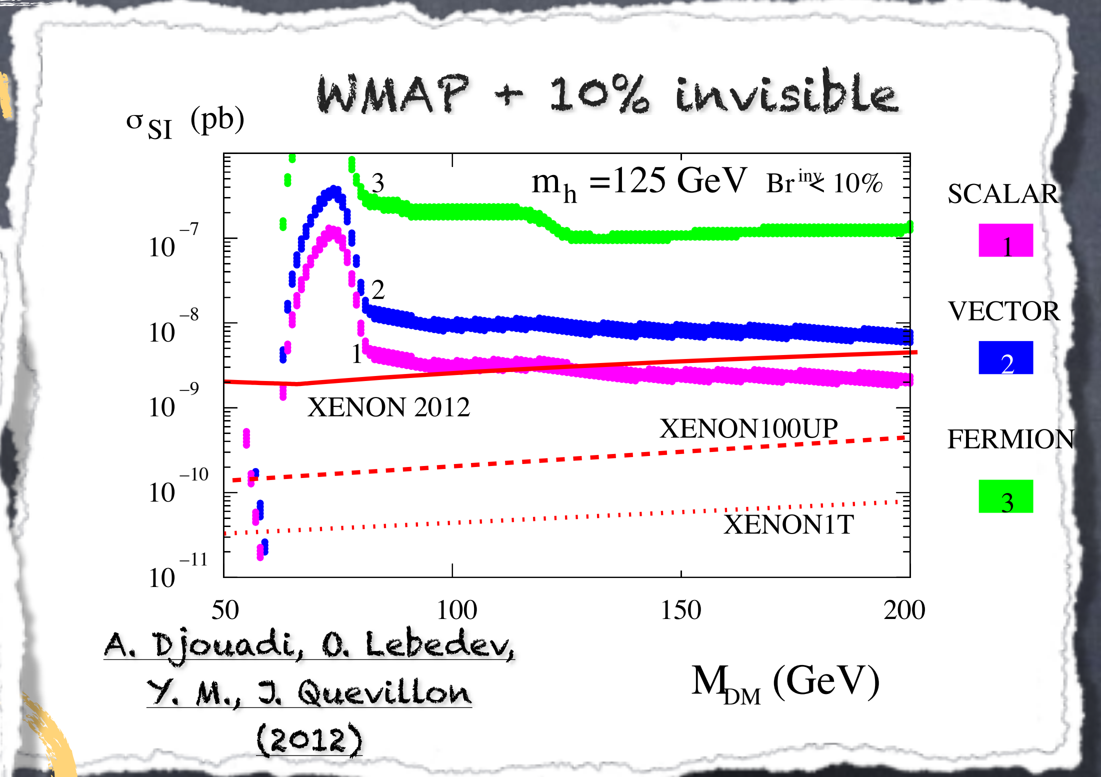
(a) (b) (c)

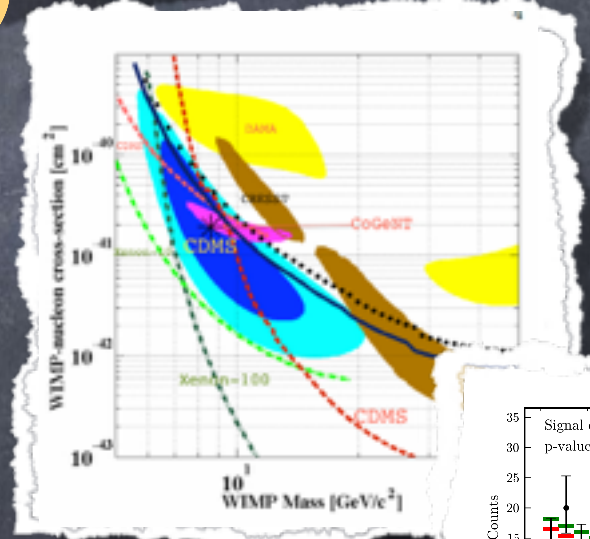


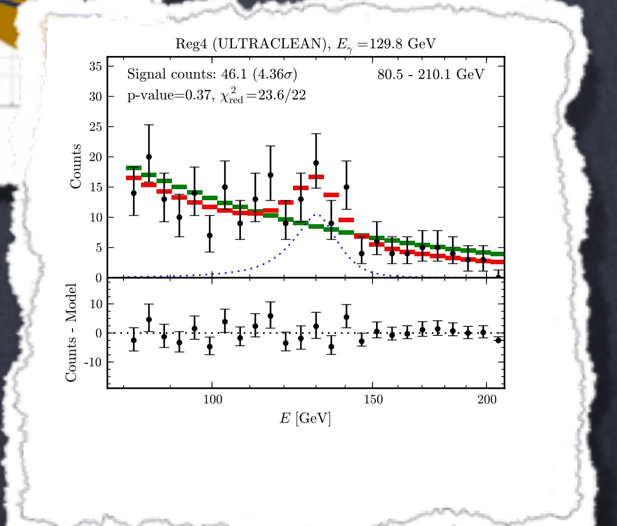
What is the mediator(s)?







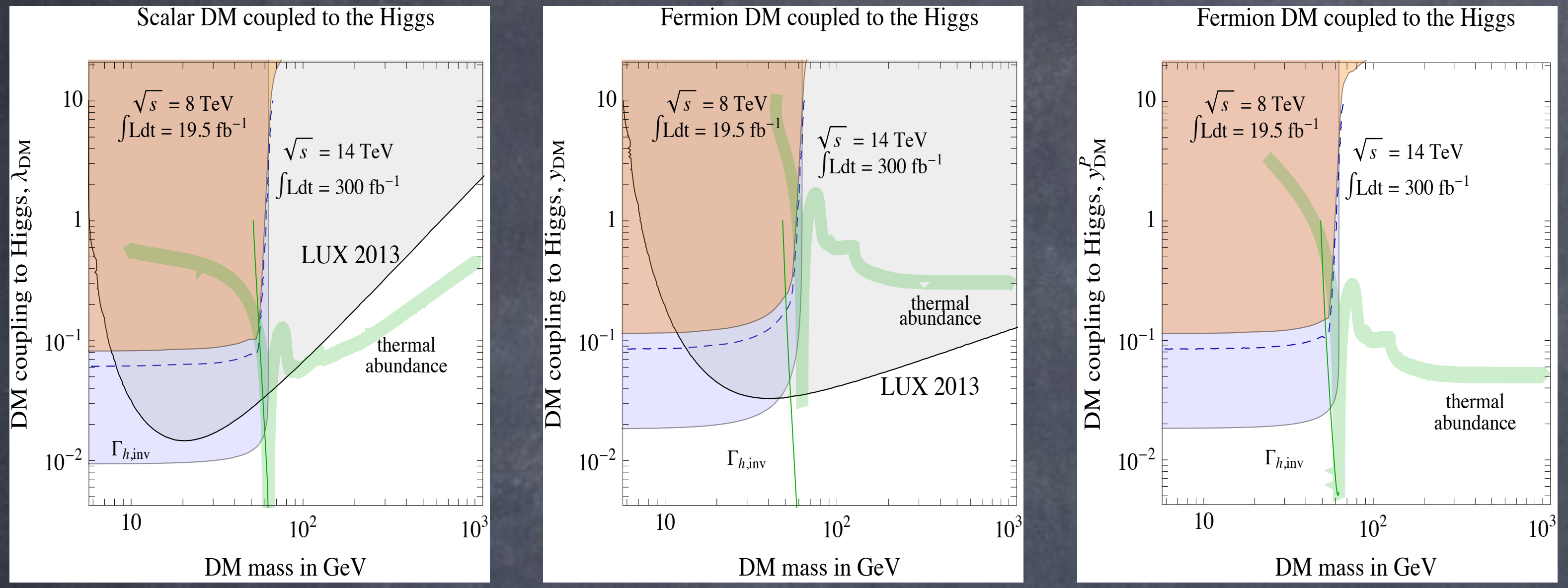




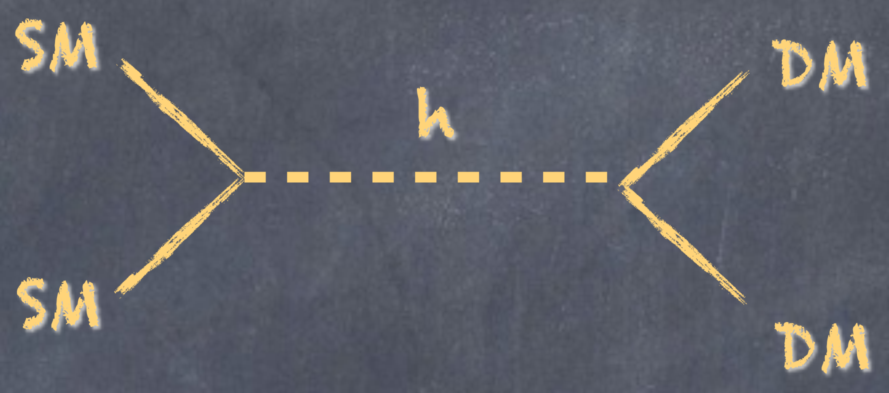
Hidden photon (mirror dark matter)

Can explain excess observed by CRESST/CoGENT/DAMA or FERMI monochromatic line

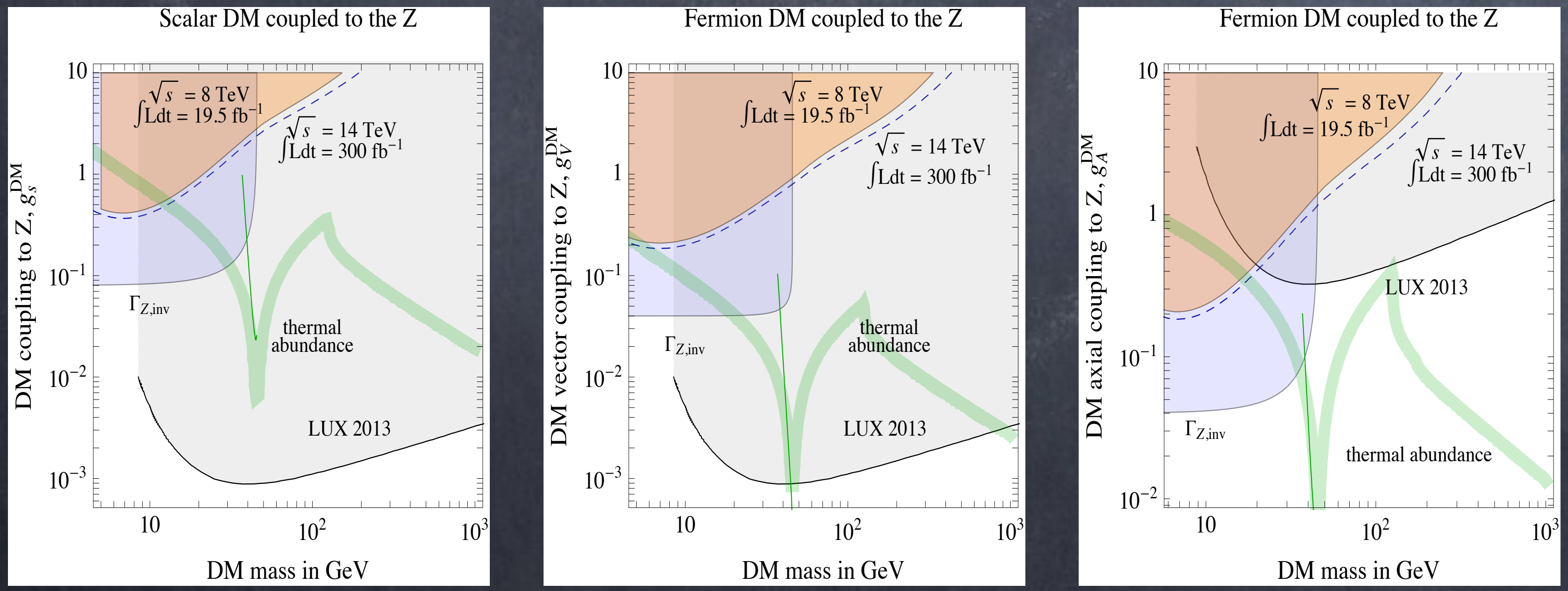
Beyond the simple couplings

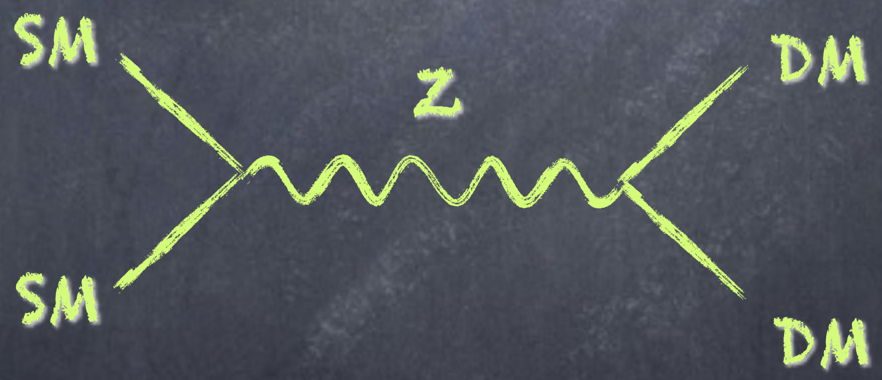


A. De Simonea, G. F. Giudice, A. Strumia, 1402.628



$$\mathcal{L} = -H^\dagger H\left[\bar{\psi}_{\rm DM}\frac{(y_{\rm DM}+iy^P_{\rm DM}\gamma_5)}{2v}\psi_{\rm DM}+\frac{\lambda_{\rm DM}}{4}s^2_{\rm DM}\right].$$

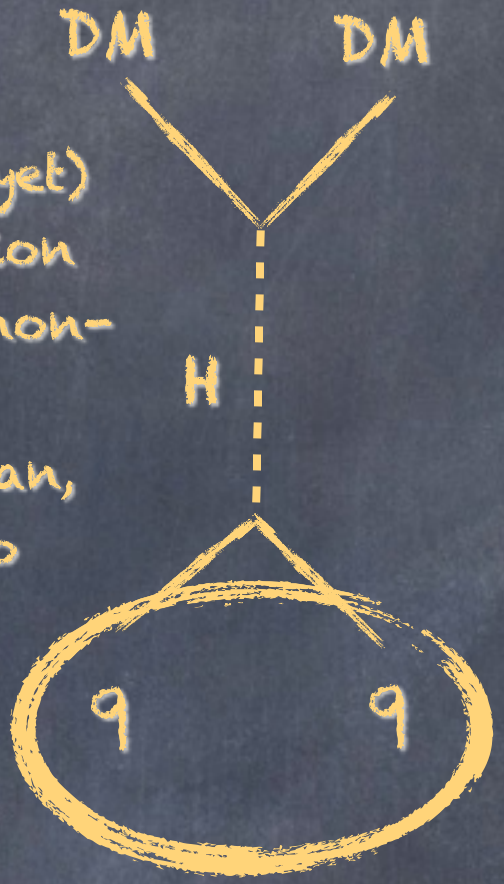




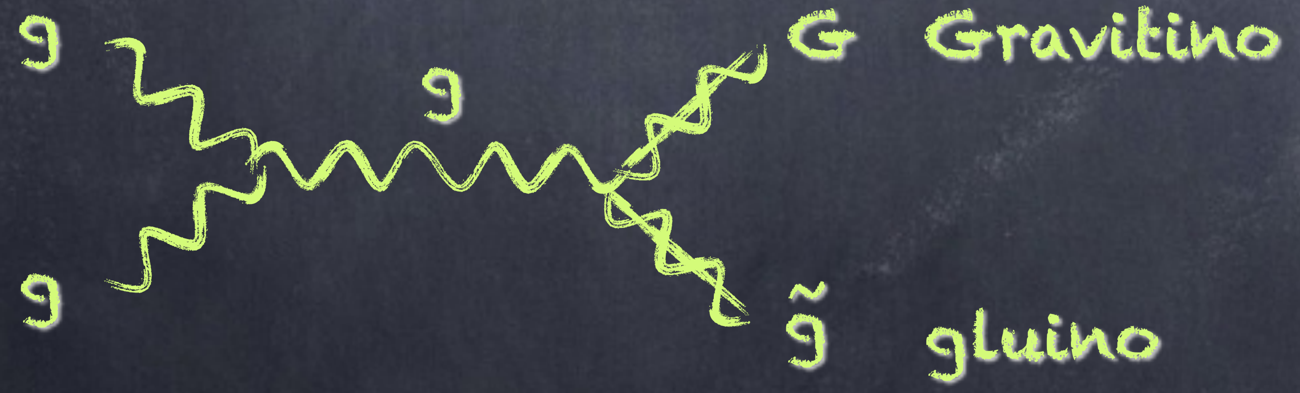
$$\mathcal{L} = \frac{4i}{v^2}(H^\dagger D^\mu H)\Big[\bar{\psi}_{\rm DM}\gamma_\mu(g_V^{\rm DM}+\gamma_5 g_A^{\rm DM})\psi_{\rm DM}+g_s^{\rm DM}(s^*_{\rm DM}(i\partial_\mu s_{\rm DM}$$

What is the (s)mediator ?

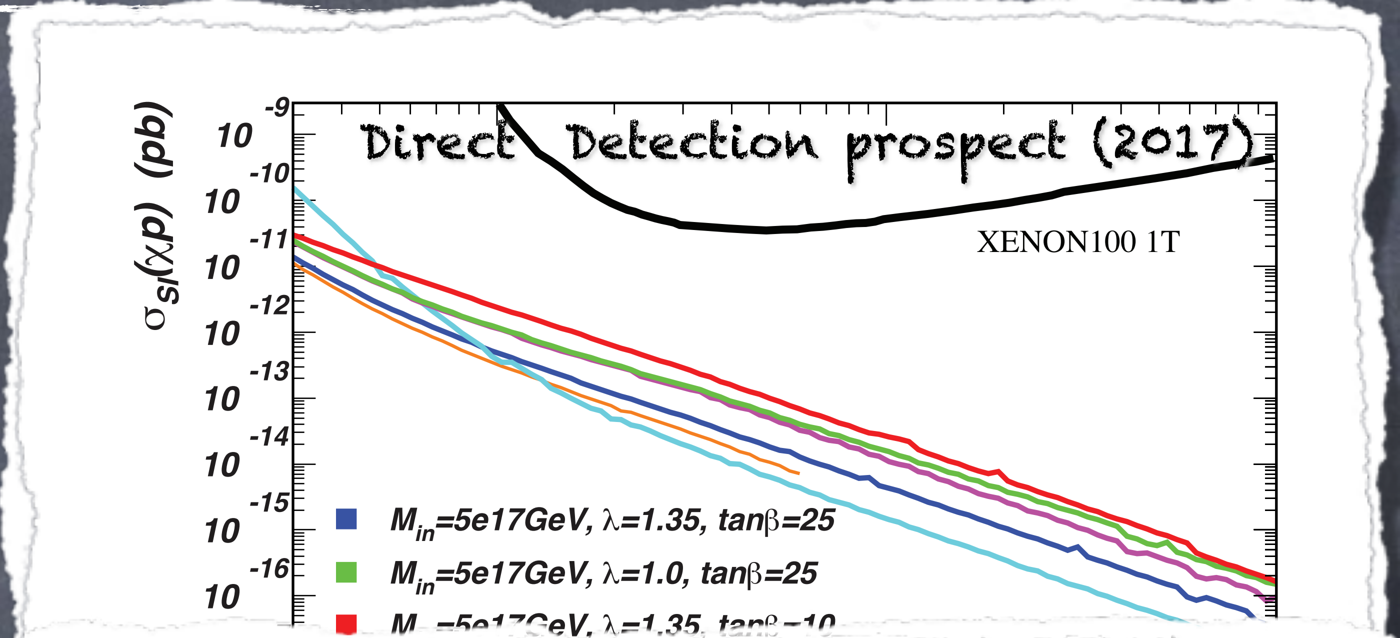
Neutralino
in (N)MSSM
No exclusions (yet)
Possible detection
+ possibility of non-
SUSY scalar
Cotta, Rajaraman,
Tait, Wijangco
1305.6609



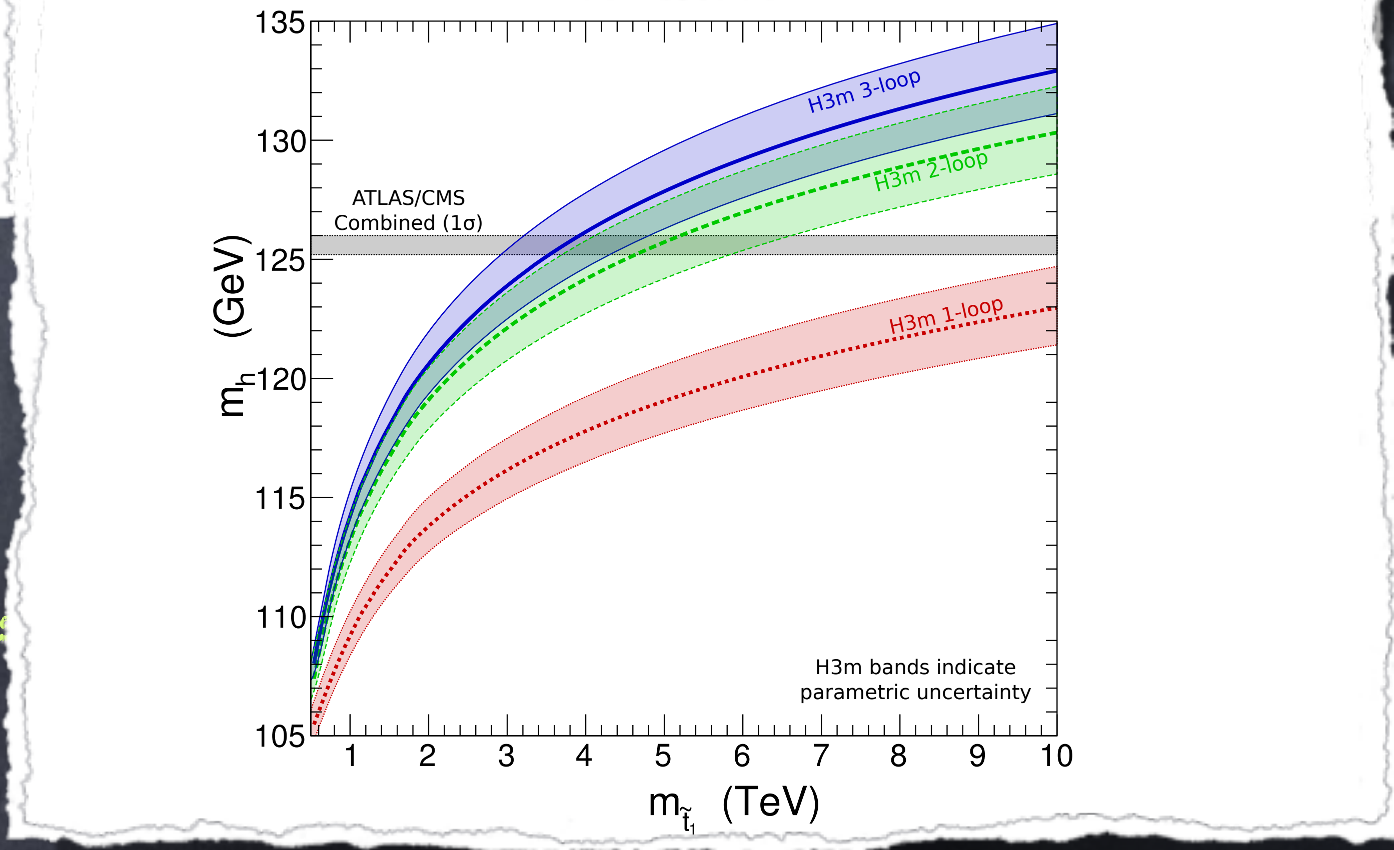
BUT in coherent Supergravity
scenario, difficult to observe
due to Higgs mass :
mh = Mz + Log(Mst/Mt) => heavy
scalar sector => Heavy Higgses



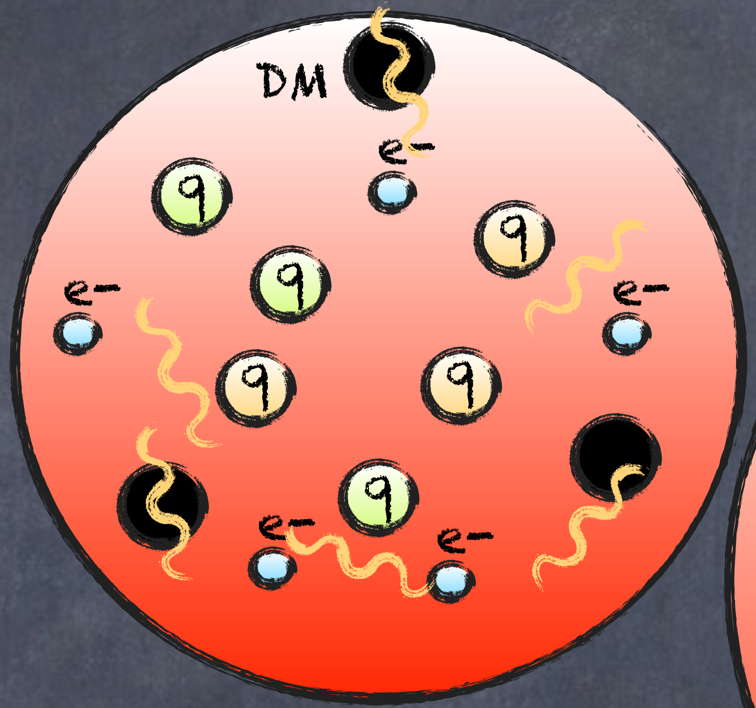
Gravitino dark
matter
No detection hopes

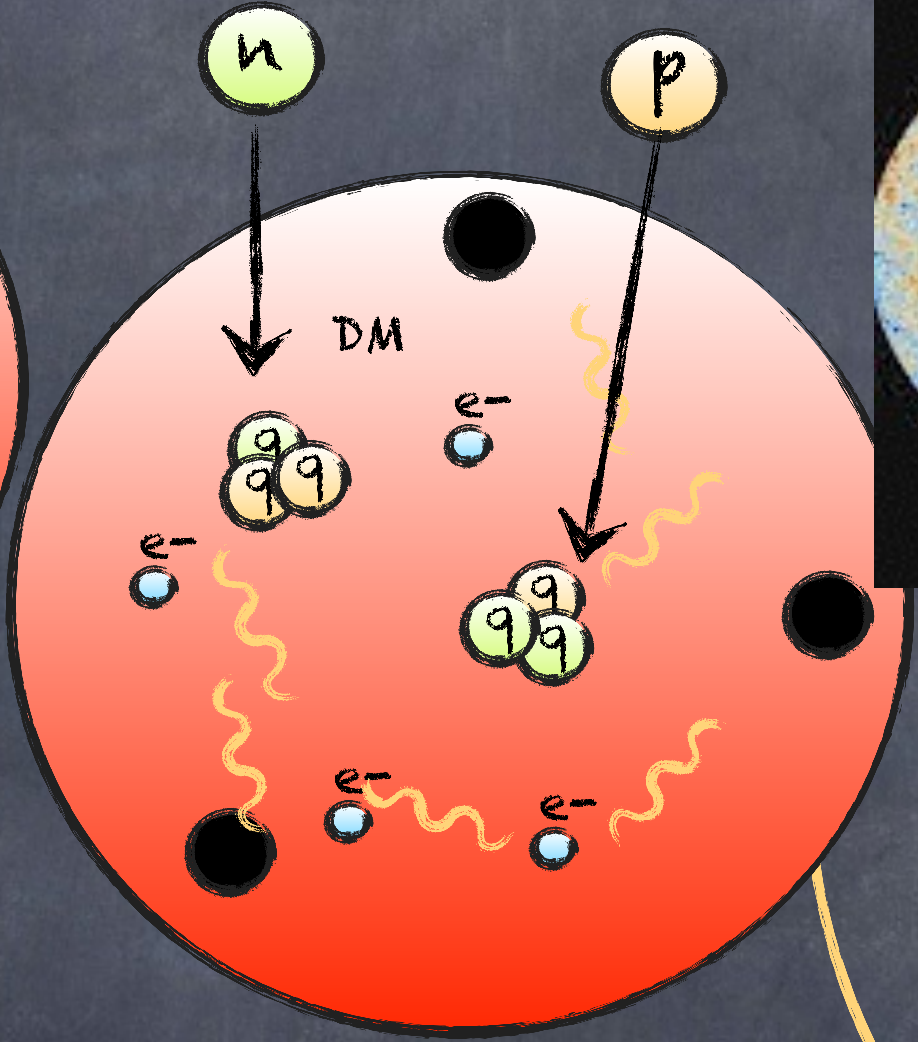


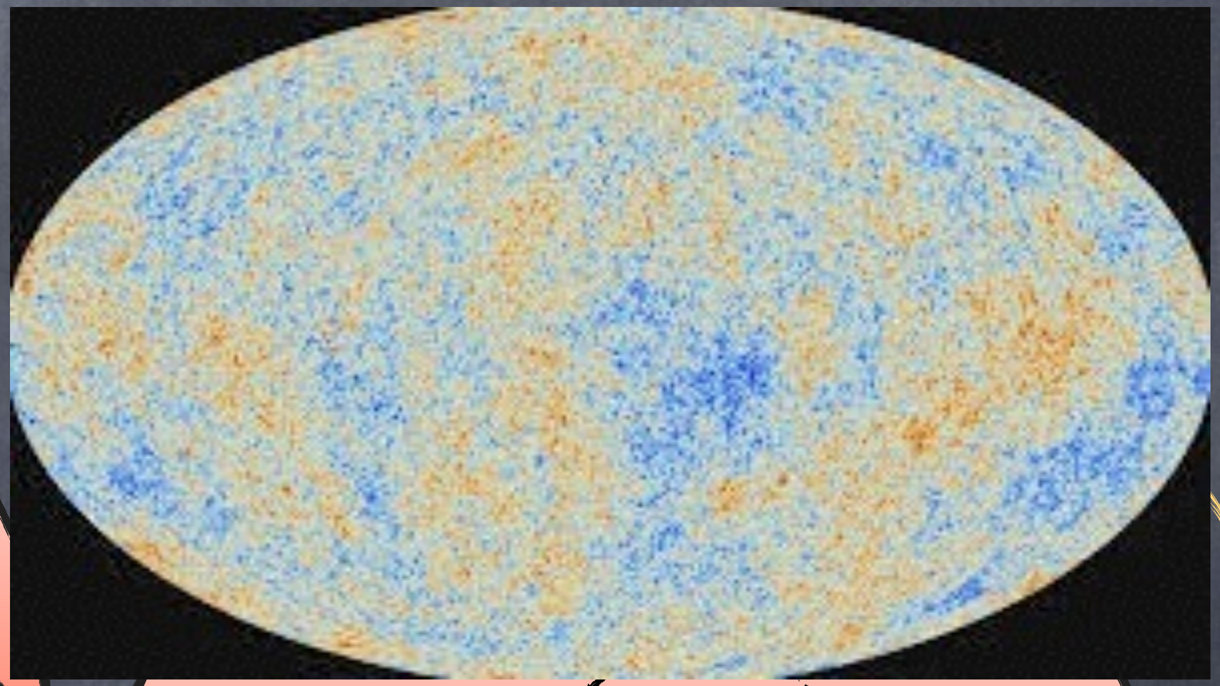
Feng, Kant, Profumo, Sanford
3 loops Higgs
1306.2318

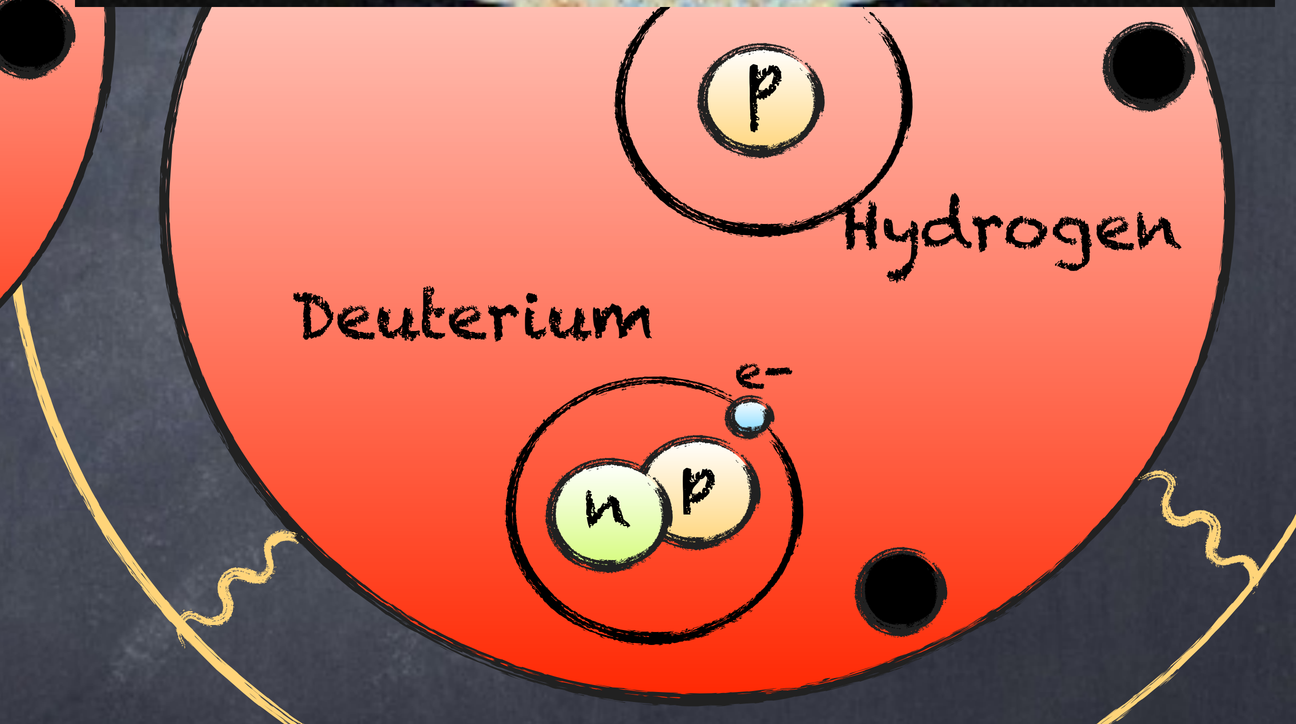


A little thermal history of the Universe









$$f \sim \frac{e^{-\frac{E}{T}}}{1 \pm e^{-\frac{E}{T}}}$$

$$\rho_{DM} \sim e^{-\frac{m}{T}}$$

Equilibrium:
Thermal bath

Dark Matter
decoupling

Nucleosynthesis

T_{RH}
time

10 GeV
10-5 sec

300 keV
1 min

1 eV
300000 years

Chu, Mambrini, Quevillon, Zaldivar, 1306.4677

Insi...

$$\frac{dn}{dT} = 3\frac{n}{T} - \ldots$$

Two p...

Dark matte...

- Mм ...

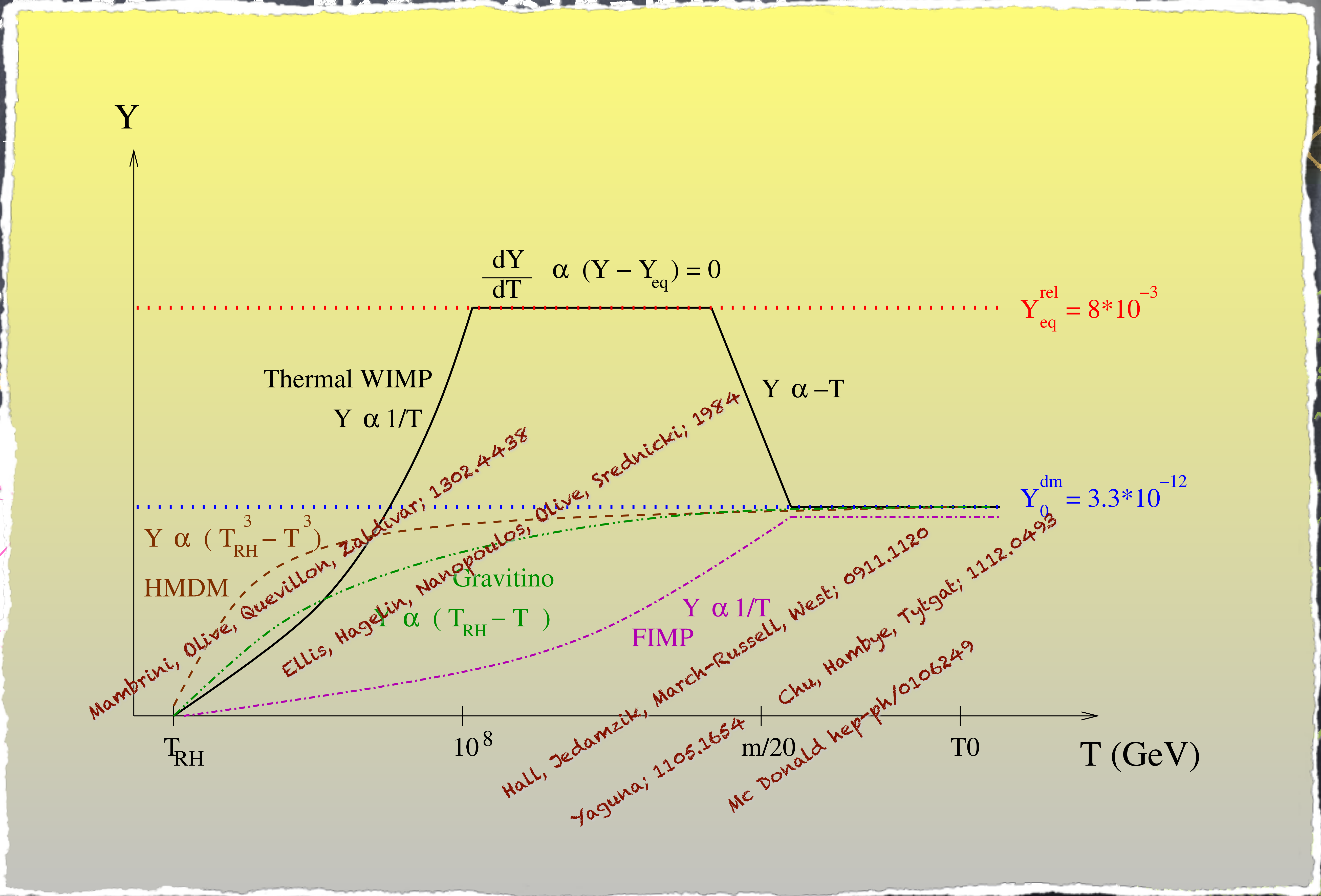
$|\mathcal{M}$ ...

$$\Rightarrow \frac{dY}{dT} \propto \ldots$$

$$\Rightarrow Y(T) \propto \ldots$$

$g_D \simeq g_{EW}$

$g_D \simeq 10^{-10}$ ...



Chu, Hambye
Tytgat
1112.0493

... is produced
...m with the SM
...s at TRH
~ gEW
...eze out (FO)
...> ~ 10^-9 The
...r decouples
Boltzman
...> << H(T)
...MP
...iggs portal..)

Prospective - Conclusion

- No real DM signals (yet) or.. too many!!
- WIMP paradigm tested
- Thermal history?
- Fundmental LHC searches
- Promising next years...

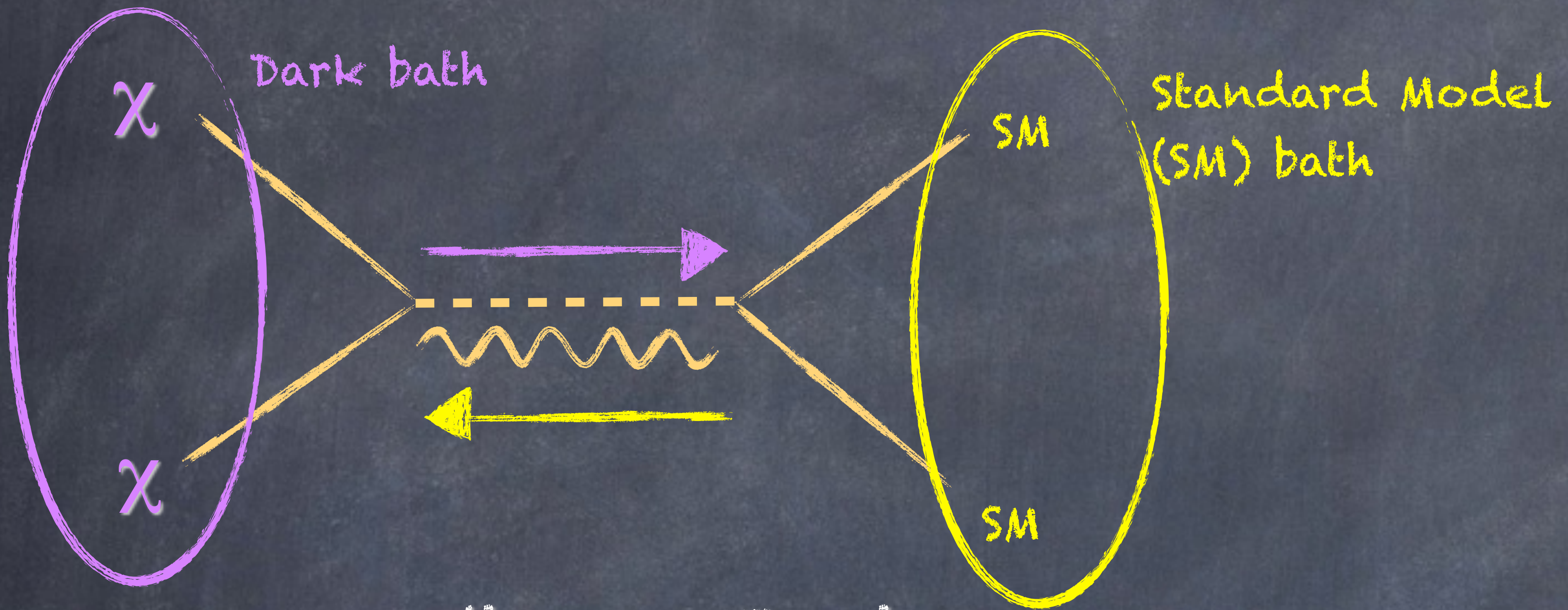
Dark Matter candidates

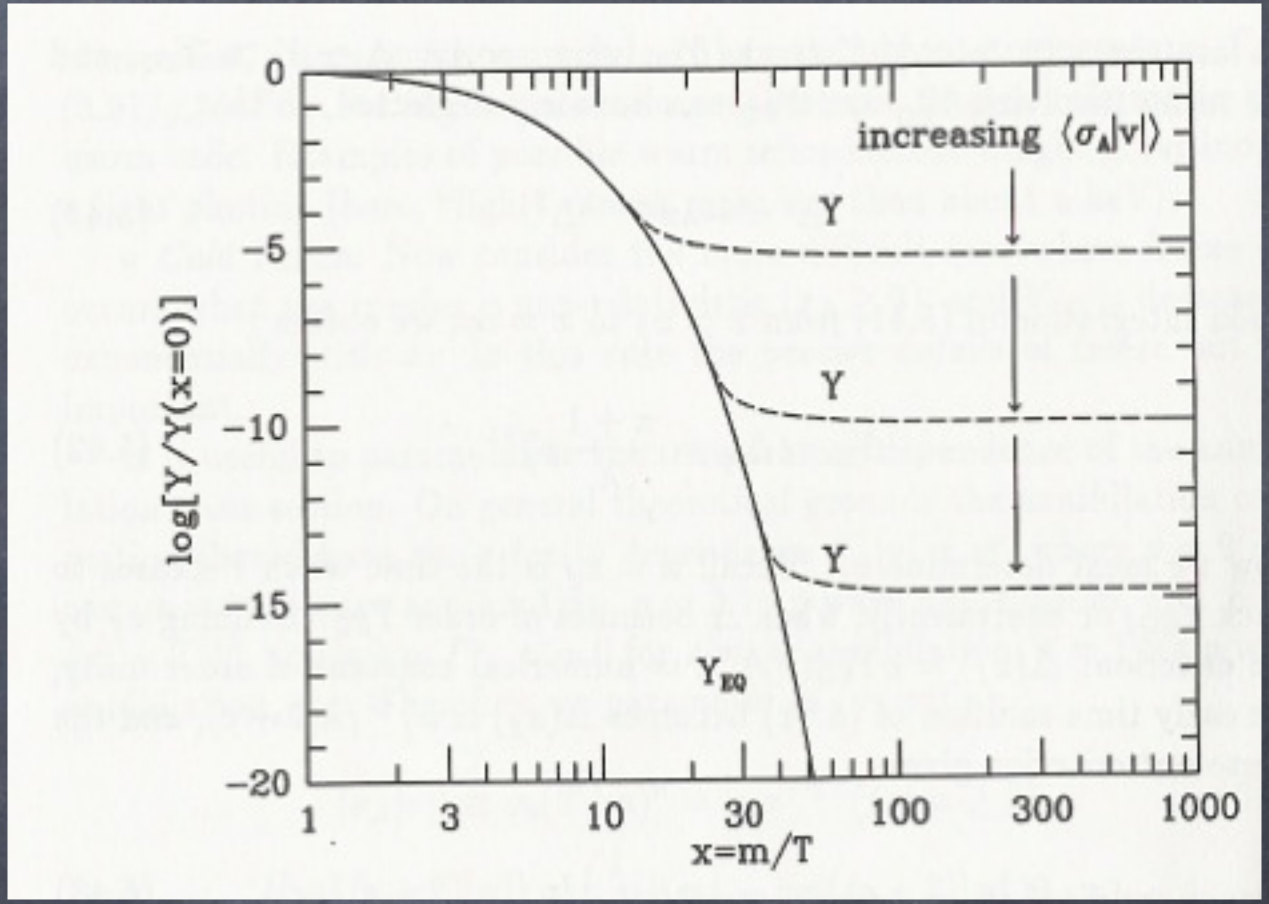
Neutralino
Gravitino
KK modes
ν_R
Hidden fermonic sector
Dark U(1)
Sterile neutrino
Phantom dark matter
Higgs doublet
Mirror dark matter
Stable extra gauge boson..

Mass/coupling classification

- Weakly coupling (neutralino, sterile neutrino..)
- Planck induced coupling (gravitino)
- Intermediate («feeble») coupling (FIMP, SO(10) theories)
- Dark coupling (Extra U(1), dark photons)

A little thermal history of the Universe (III)





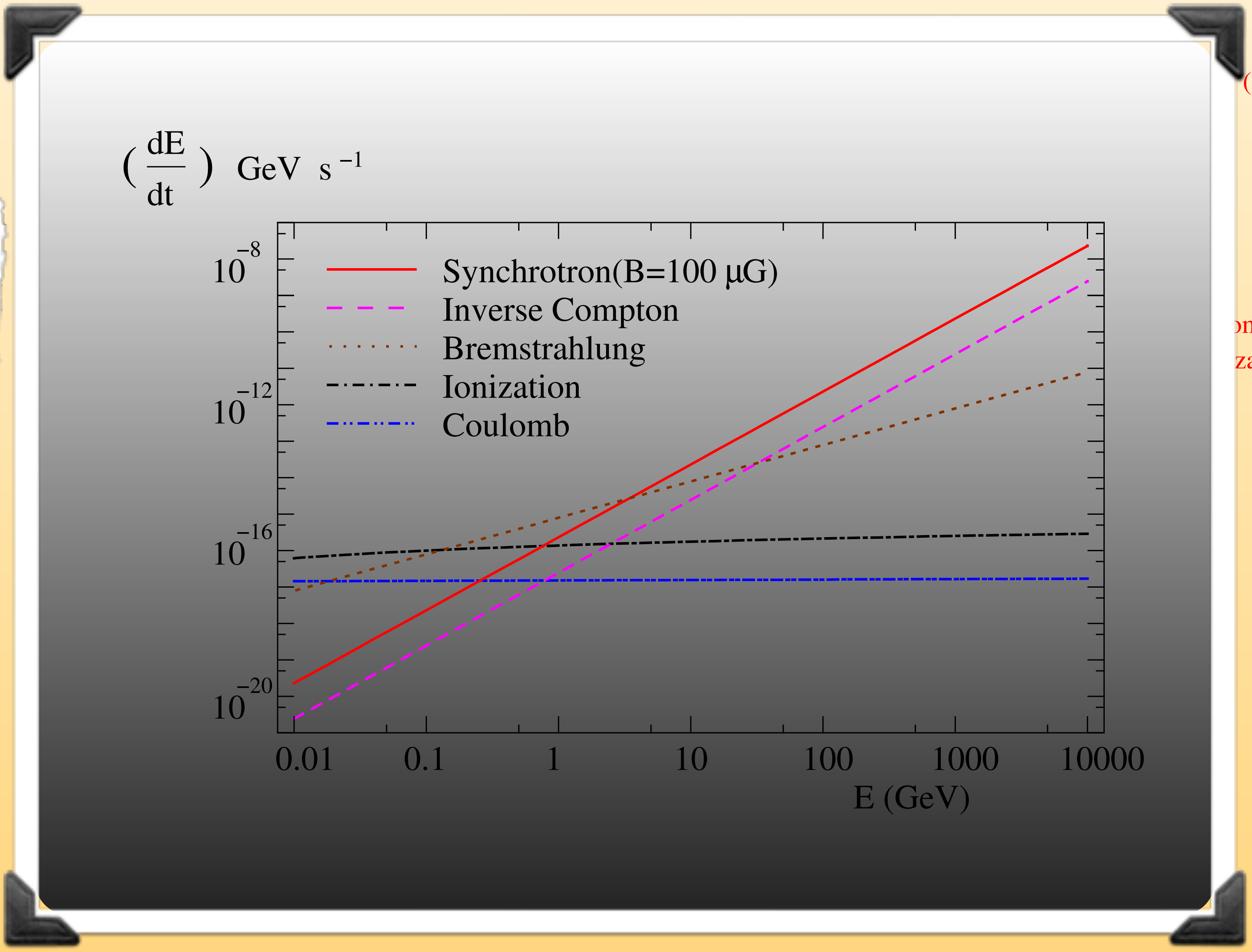
Boltzmann Equation
for a density of dark particle n :

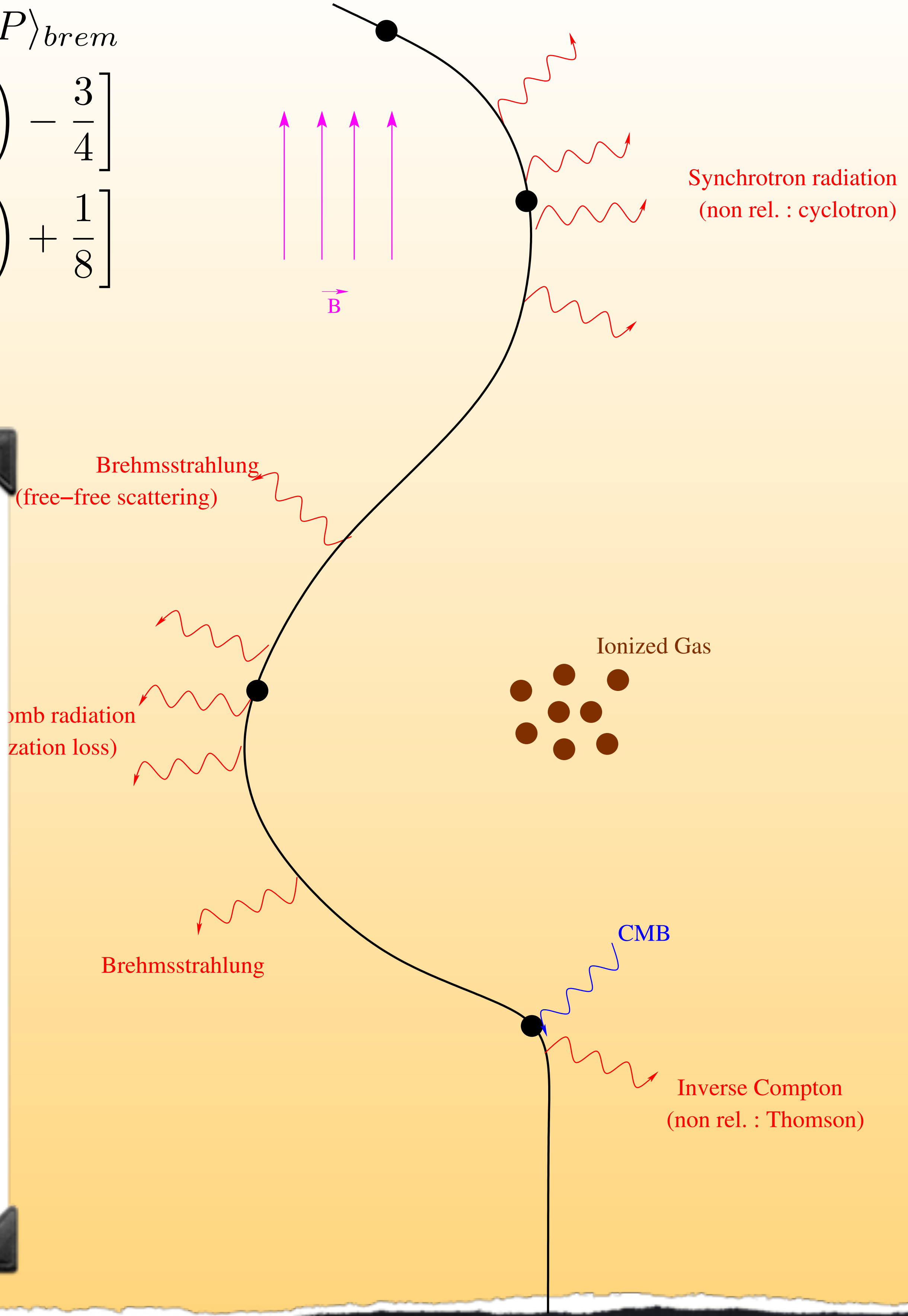
$$\frac{dn}{dt} = -3\,H\,n - \langle \sigma v \rangle [\, n^2 - n_{eq}^2 \,] \qquad (H = \dot{R} / R)$$

$$\Omega h^2 \sim \frac{3.10^{-27}\,cm^3\,s^{-1}}{\langle \sigma v \rangle} \sim 0.1 \;\Rightarrow\; \langle \sigma v \rangle \sim 3.10^{-26}\,cm^3\,s^{-1}$$

Important assumption: the dark matter was in thermal equilibrium in the Standard Model bath (plasma) since the early history of the Universe.

$$
\begin{aligned}
\langle P \rangle &= \langle P \rangle_{synch} + \langle P \rangle_{IC} + \langle P \rangle_{Coul} + \langle P \rangle_{I} + \langle P \rangle_{brem} \\
&= \frac{4}{3}\sigma_T c U_B + \frac{4}{3}\sigma_T c U_{rad} - 2\pi r_0^2 m_e c^3 Z n \frac{1}{\beta}\left[\ln\left(\frac{E m_e c^2}{4\pi r_0 \hbar^2 c^2 n Z}\right) - \frac{3}{4}\right] \\
&\quad - 2\pi r_0^2 m_e c^3 \frac{1}{\beta} \sum_{s=H,He} Z_s n_s \left[\ln\left(\frac{(\gamma-1)\beta^2 E^2}{2 I_s^2}\right) + \frac{1}{8}\right]
\end{aligned}
$$

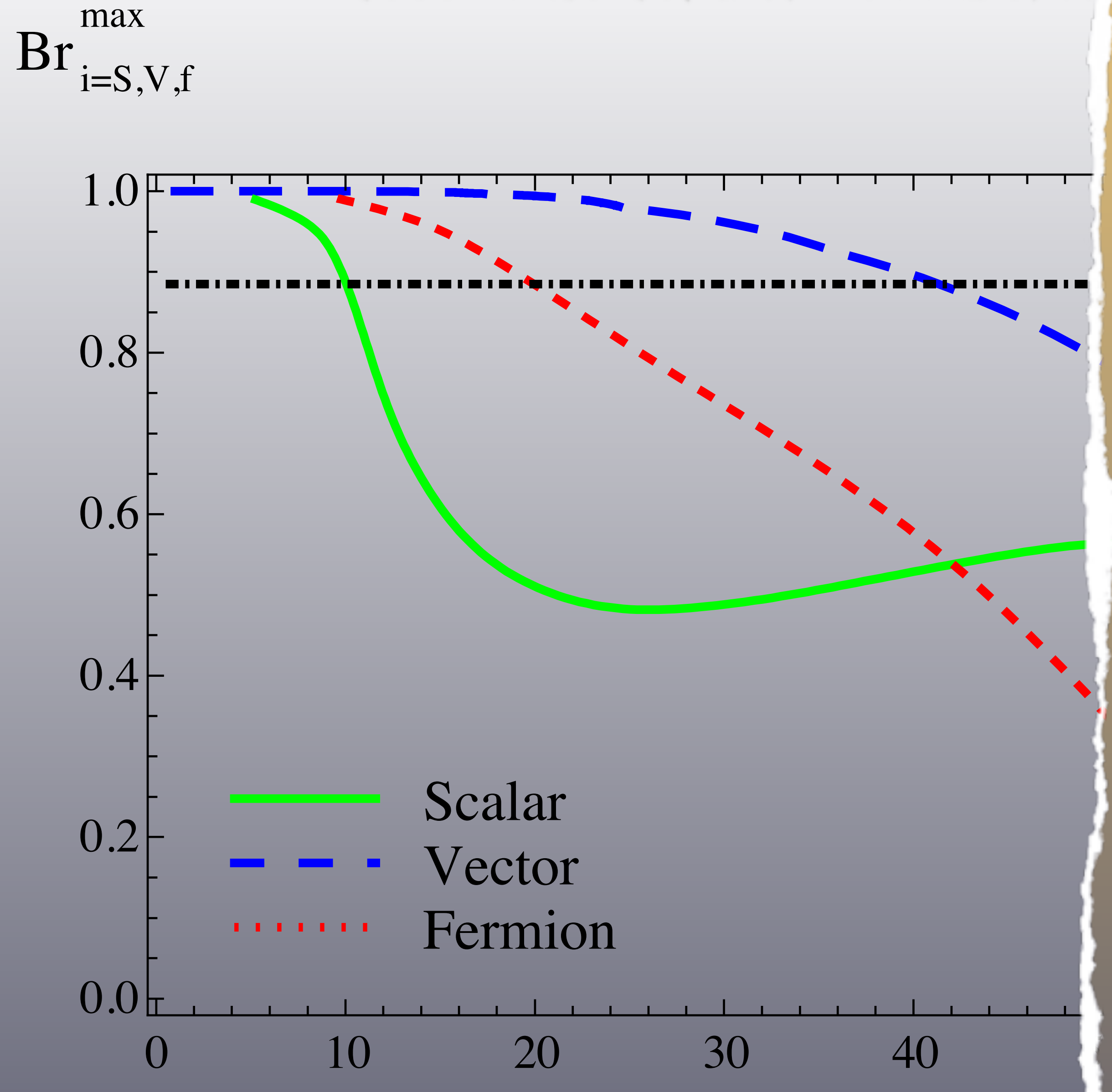


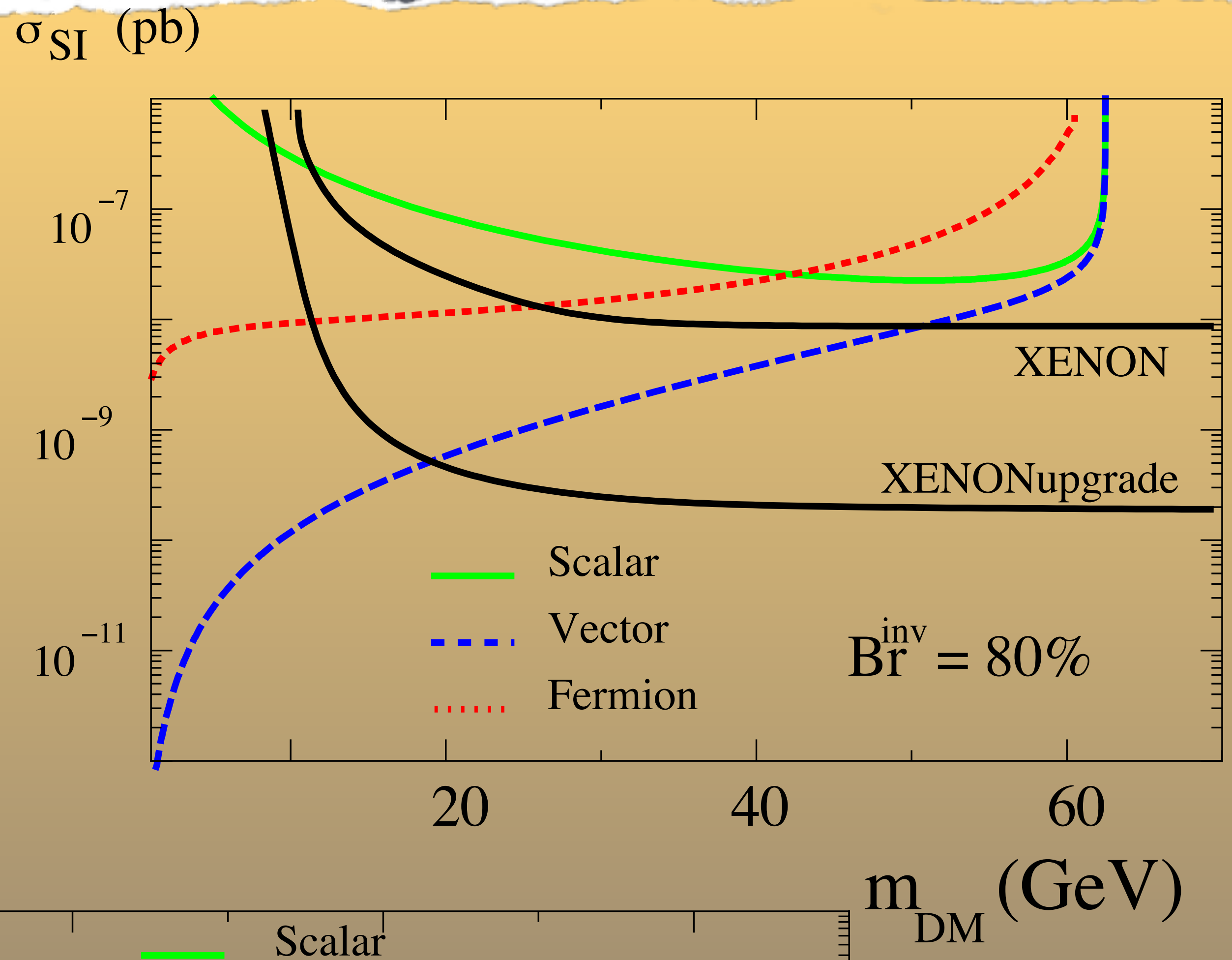


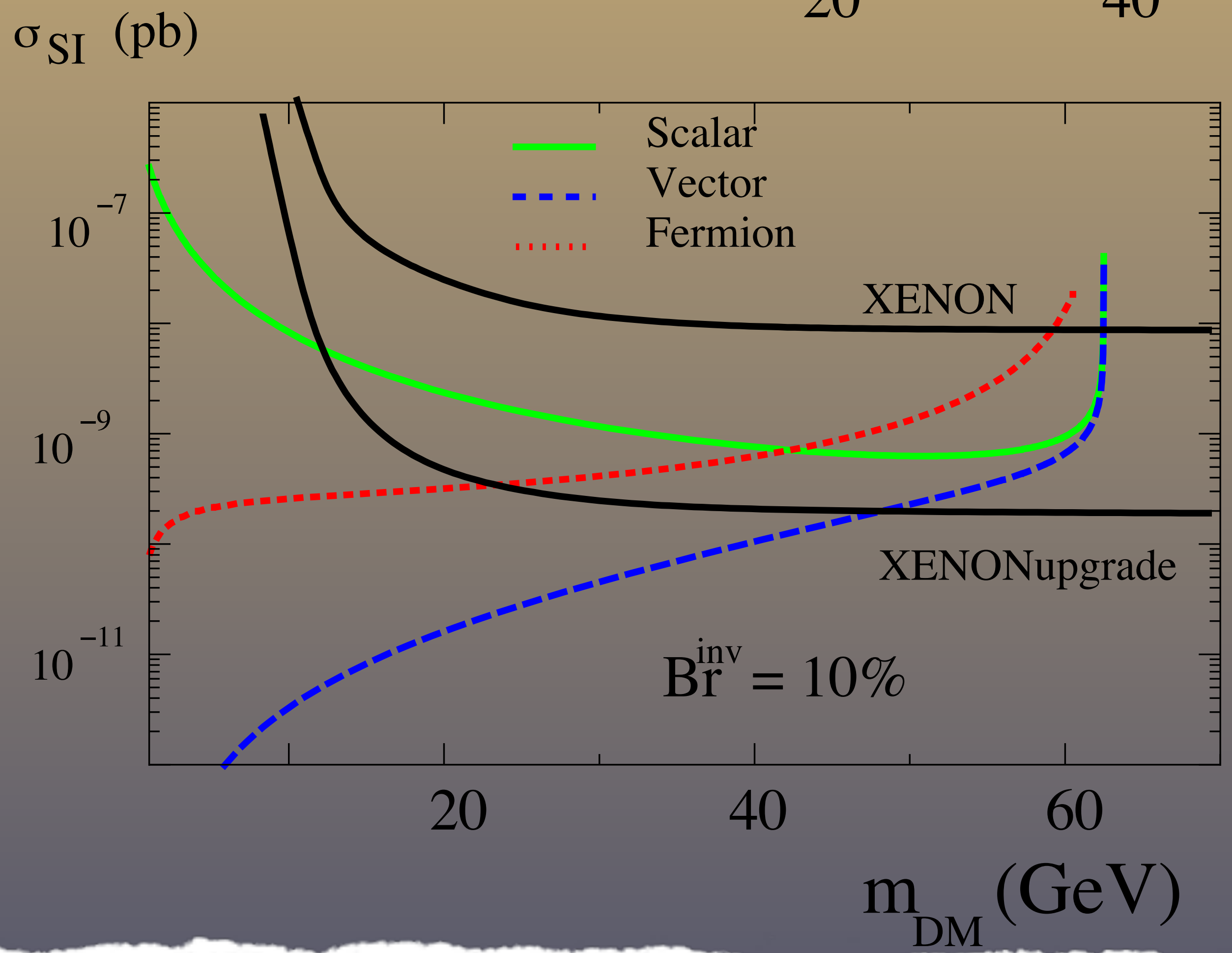
Sea

A. Djouadi, A. Falkowski, Y. M.,
J. Quevillon 2012

Without WMAP constra



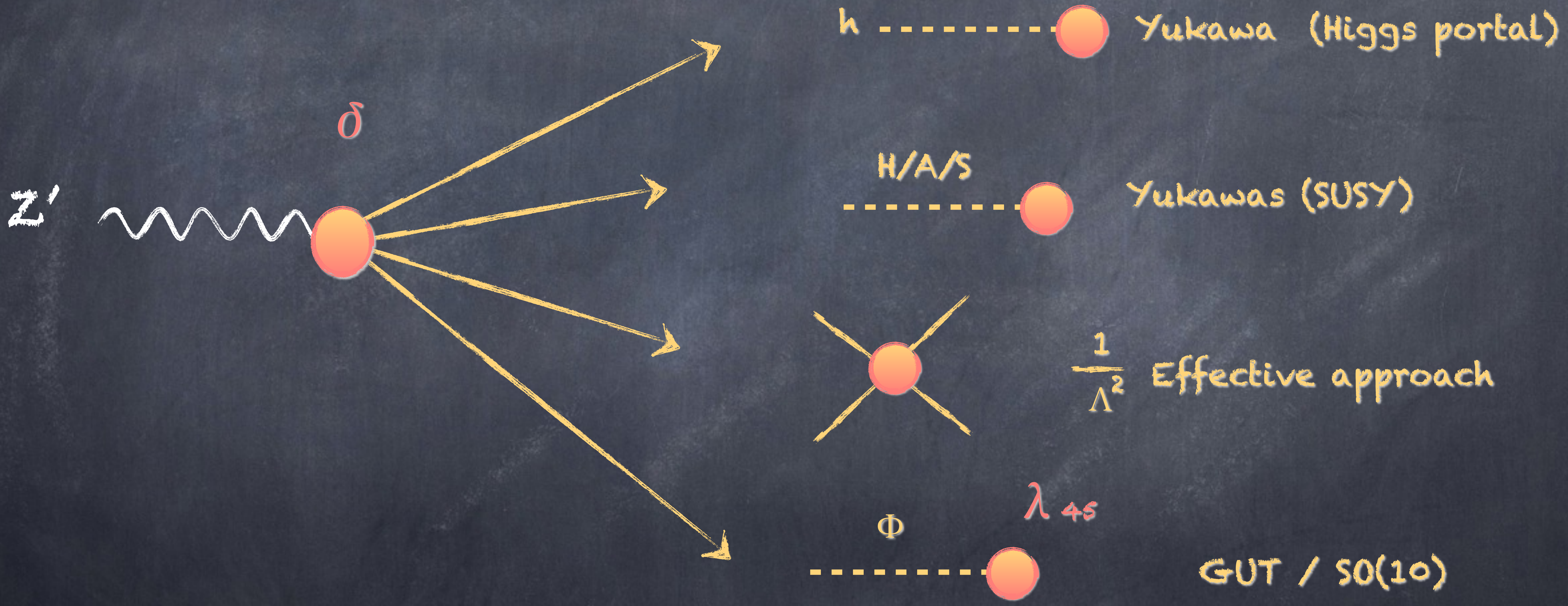




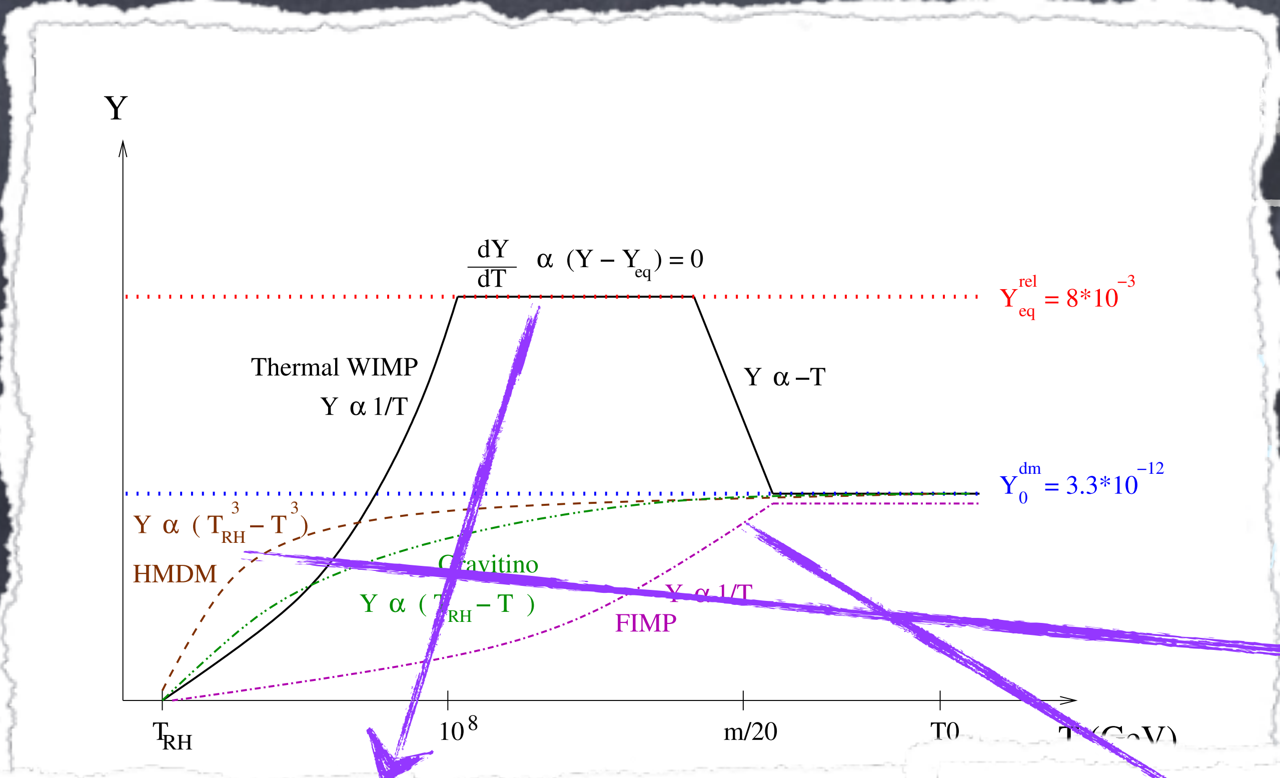
Conclusion: LHC can easily compete with direct detection experiments

A concrete example

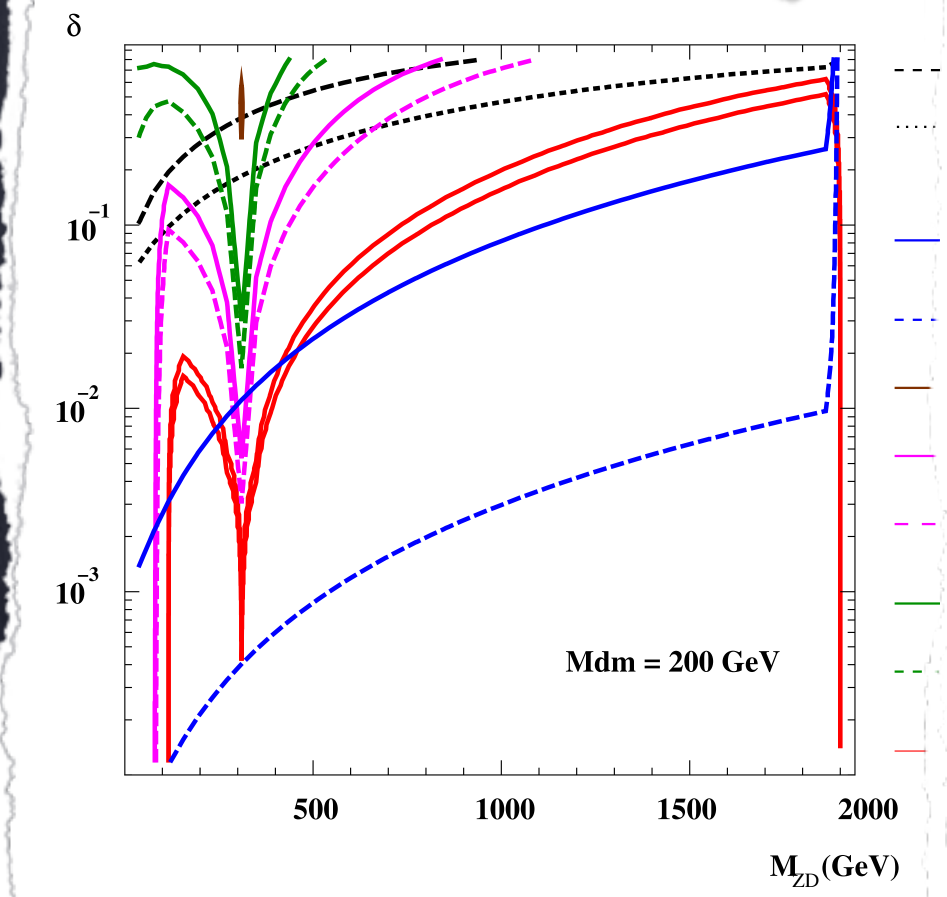
In all what follows I will take Z′ as a mediator for illustration but..



exemple : Extra U(1)

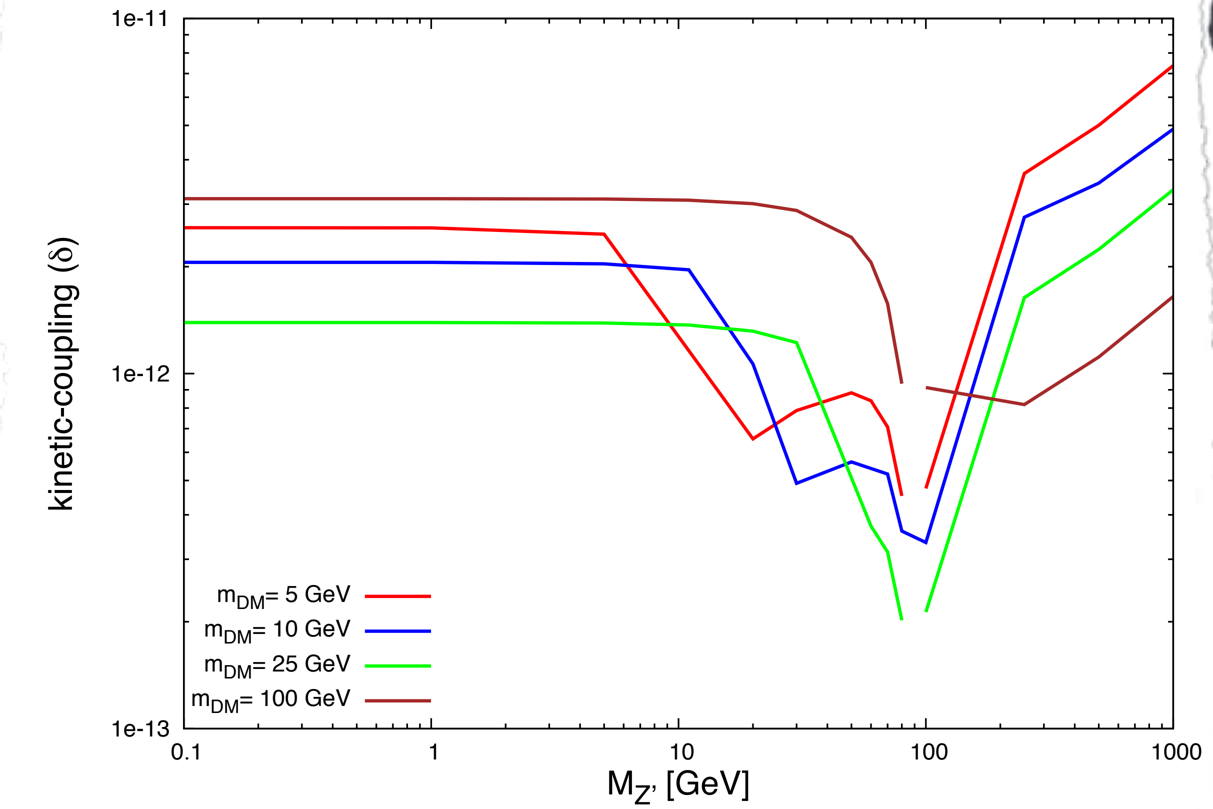


$M_{Z'} < T_{RH}$, $\delta \sim g_{EW}$



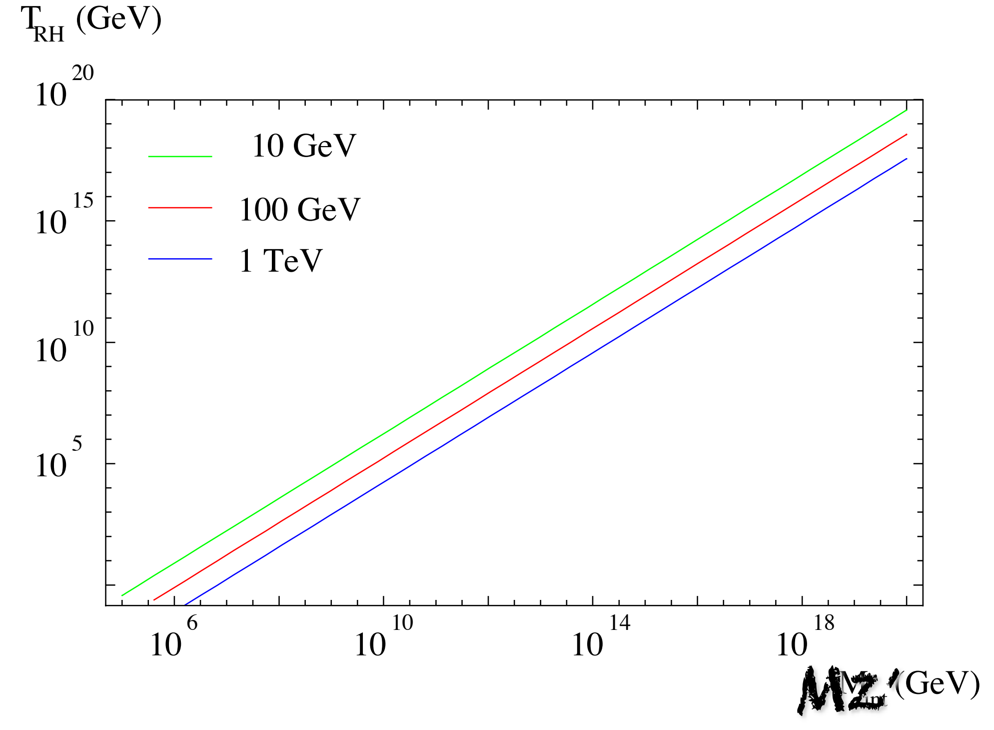
Y. M. (2011)

$M_{Z'} < T_{RH}$, $\delta \sim 10^{-11}$



X. Chu, Y. M., J. Quevillon, B. Zaldivar (2013)

$M_{Z'} > T_{RH}$, $\delta \sim g_{EW}$



Y. M., K. Olive., J. Quevillon, B. Zaldivar (2013)