Progresses on Minimal Dark Matter

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mainly based on Cirelli, S, Taoso work in progress

Astroparticle Physics 2014, Amsterdam, 23 June 2014

Where is New Physics?

$\boxed{\text{Data: no answer so far, everything agrees with Standard Model}}$

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1 The Fermi scale is "natural" [$\Rightarrow \Lambda_{\rm NP} \lesssim$ TeV]

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Examples: Supersymmetry composite Higgs models

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"Standard" approach on Dark Matter:

it is a byproduct of theories that solve the HP, e.g. Neutralino in supersymmetry

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2 Short distance assumptions [$\Lambda_{\rm NP} \gg$ TeV is possible]

3 Multiverse: Fermi scale anthropic, near-critical, .. [$\Lambda_{\rm NP} \gg$ TeV is possible]

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2 and 3 open **new avenues for Dark Matter model building**

Philosophy: Focus on DM, and try to preserve SM successes (B, L, flavour and CP violation, ...) + DM stability, just by gauge invariance

Approach: add to the SM extra particle χ
and determine its "good" quantum numbers

"good" = i) stable ii) lightest component neutral iii) allowed

$\boxed{\mathcal{L} = \mathcal{L}_{\rm SM} + c\,\bar{\chi}(i\hat{D} - M_\chi)\chi}$ $\left[+c\left(|D_\mu\chi|^2 - M_\chi^2|\chi|^2\right) \text{ if scalar, c} = 1 \text{ or } 1/2\right]$

other terms forbidden by Lorentz + gauge invariance (fermions)/by hand (scalars)

$\boxed{M_\chi \text{ is the only one free parameter, fixed if we impose thermal relic abundance!}}$

[In "standard" SUSY many parameters obscure phenomenology]

Minimal Dark Matter: candidates

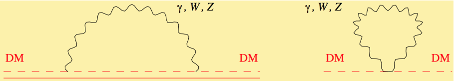
Allowed: χ neutral under g, γ, and almost under Z (direct detection)

$$\Rightarrow \boxed{\chi = n\text{-tuplet of } SU(2)_L \qquad Y = 0}$$

Stable: No renormalizable nor dim-5 operators that lead to decay

$\Rightarrow$ first candidates are $n = 5$ fermion and $n = 7$ scalar

Lightest component neutral: $M_Q - M_{Q=0} \simeq Q(Q + \frac{2Y}{c_{\theta_w}})\Delta M$



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Ibe Matsumoto Sato 1212.5989

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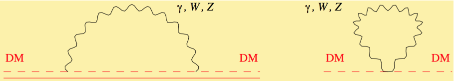

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Avoid g_2 Landau pole before M_{Pl} $\Rightarrow$ n not too large

In practice: $n \leq 8$ for scalars, $n \leq 5$ for fermions

[issue from 2-loop? Nardecchia et al, work in progress]

Summary of candidates

Table from Cirelli Strumia 0903.3381

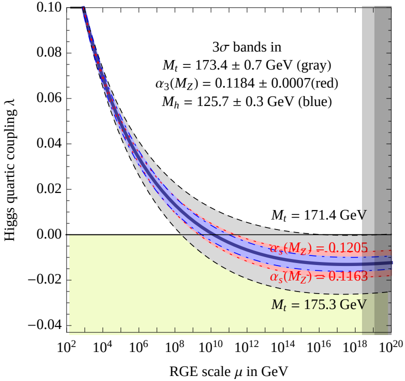
Quantum numbers			DM can	DD	Stable?
$SU(2)_L$	$U(1)_Y$	Spin	decay into	bound?	
2	1/2	S	EL	×	×
2	1/2	F	EH	×	×
3	0	S	HH^*	√	×
3	0	F	LH	√	×
3	1	S	HH, LL	×	×
3	1	F	LH	×	×
4	1/2	S	HHH^*	×	×
4	1/2	F	(LHH^*)	×	×
4	3/2	S	HHH	×	×
4	3/2	F	(LHH)	×	×
5	0	S	(HHH^*H^*)	√	×
5	0	F	–	√	√
5	1	S	$(HH^*H^*H^*)$	×	×
5	1	F	–	×	√
5	2	S	$(H^*H^*H^*H^*)$	×	×
5	2	F	–	×	√
6	1/2, 3/2, 5/2	S	–	×	√
7	0	S	–	√	√
8	1/2, 3/2 ...	S	–	×	√

Masses if χ thermal relic: $M_3 \simeq 3$ TeV $M_5 \simeq 10$ TeV $M_7 \sim 25$ TeV

Standard Model vacuum is metastable

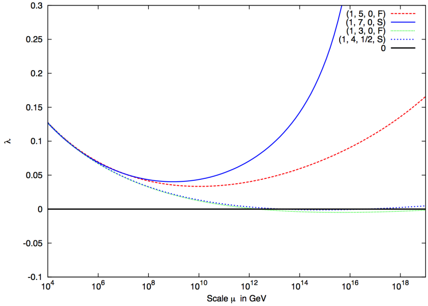
but $\boxed{\textit{if} \text{ BICEP confirmed NP } \textit{could} \text{ be necessary to correct } \lambda \text{ running}}$

[see e.g. Espinosa Giudice Riotto 0710.2484, Hook et al 1404.5953]



Buttazzo et al 1307.3536

Correction from MDM:



Chao Gonderinger Ramsey-Musolf 1210.0491

(right-handed neutrinos not relevant if $\boxed{M_{\nu_R} \lesssim 10^{13}\ \text{GeV}}$ $\quad \beta_\lambda \supset -y_\nu^4 \frac{\#}{16\pi^2} \quad m_\nu \sim \frac{y_\nu^2 v^2}{M_{\nu_R}}$)

Why an EW fermion triplet?

Quantum numbers			DM can	DD	Stable?
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3	0	F	LH	$\surd$	$\times$

$\rightarrow$ Stable if one imposes L or $B-L$ (already in the SM!)

[also kills all higher-dimensional operators that could make it decay]

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→ Stable if one imposes L or $B-L$ (already in the SM!)

[also kills all higher-dimensional operators that could make it decay]

→ Not a big issue for m_h $\Rightarrow$ does not worsen fine-tuning

$$\delta m^2 = \frac{M^2}{(4\pi)^4}\frac{n(n^2-1)}{4} g_2^2 \left(6\ln\frac{M^2}{\bar{\mu}^2}-1\right)$$

$M_\chi \lesssim 1.0\sqrt{\Delta}$ TeV to have less than $(100/\Delta)$ % fine-tuning

[5-plet $M_\chi \lesssim 0.4\sqrt{\Delta}$ TeV, 7-plet $M_\chi \lesssim 0.06\sqrt{\Delta}$ TeV]

Farina Pappadopulo Strumia 1303.7244

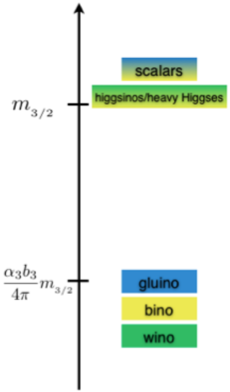
→ Helps with unification of gauge couplings

see e.g. "Split SUSY without SUSY" Frigerio Hambye 0912.1545

[Same running could put 5-plet in trouble, stay tuned with Nardecchia et al]

Why an EW fermion triplet?

→ Connection with SUSY with heavy scalars James Wells hep-ph/0306127



Keep all good features of Supersymmetry
DM, unification of gauge couplings,...

And accept a tuned m_h (e.g. anthropic)

→ All other scalars are heavier

→ Higgsinos also heavier if $\mu \sim m_{3/2}$

→ Wino LSP candidate for Dark Matter!

See also:
Arkani-Hamed Dimopoulos hep-th/0405159
Giudice Romanino hep-ph/0406088
...
Arvanitaki Craig Dimopoulos Villadoro 1210.0555
...
Hall Nomura Shirai 1403.8138

Progresses on

Minimal Dark Matter

$\rightarrow$ Modelling

$\rightarrow$ Phenomenology

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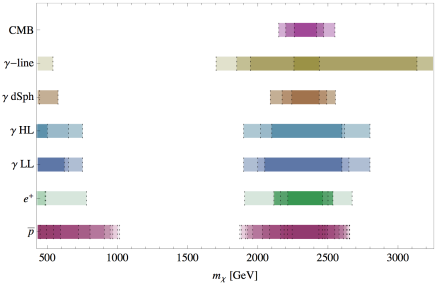
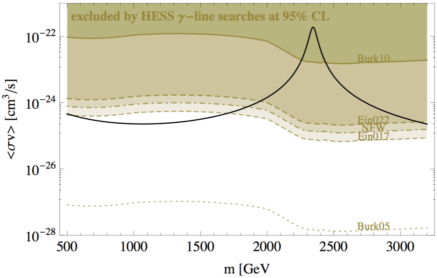
Indirect detection



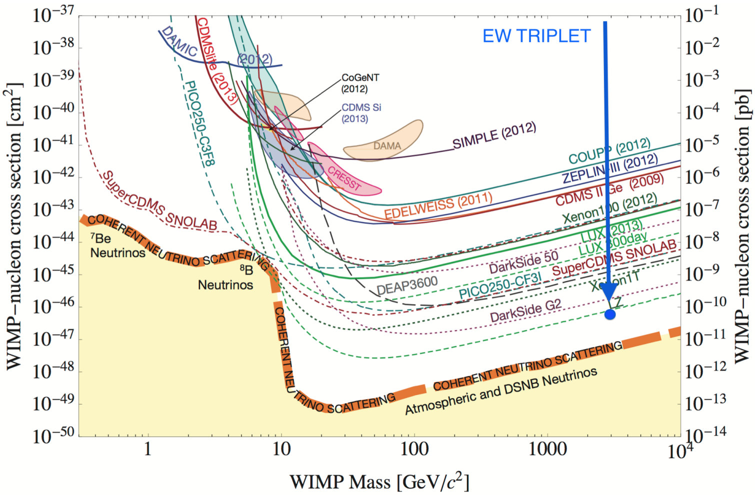
Large astrophysical uncertainties

Based on assumption that all DM is made of EW triplet

CTA expected to improve by a factor ~ 10



Hryczuk Cholis IengoTavakoli Ullio 1401.6212



2011: DM-gluon 2-loop 2013: new matrix elements $\Rightarrow$ $\sigma_{\rm SI} = 0.6 \times 10^{-46}\mathrm{cm}^2$

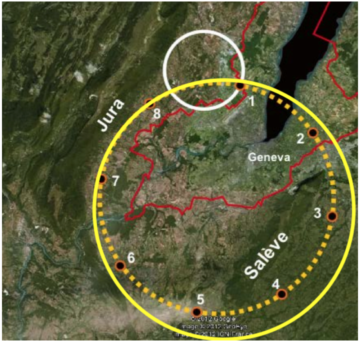
Farina Pappadopulo Strumia 1303.7244

Future colliders?

"The community needs studies of what could be probed at a 100 TeV machine and not elsewhere, and it needs them soon"

Michelangelo Mangano, 100 TeV kick-off meeting, Feb 2014, CERN

Currently unclear where particle physicists will put (EU? China? ???) money:



HL-LHC $\sqrt{s} = 14$ TeV, 3000 fb^{-1}, $\sim$ 2025-2035

HE-LHC $\sqrt{s} = 33$ TeV, needs new technology

VLHC $\sqrt{s} \sim 100$ TeV, start $\sim$ 2040(?), needs $\sim$ 100 km tunnel

ILC $\sqrt{s} = 0.5 - 1$ TeV, maybe Japan soon

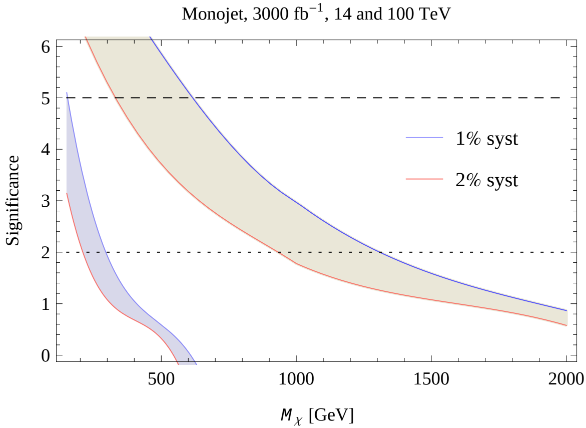
CLIC $\sqrt{s}$ up to 3 TeV, needs new technology

TLEP $\sqrt{s}$ up to 500 GeV, higher luminosity, needs $\sim$ 100 km tunnel

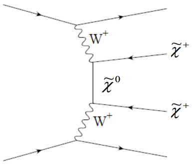
Hadron colliders: Monojets + missing energy

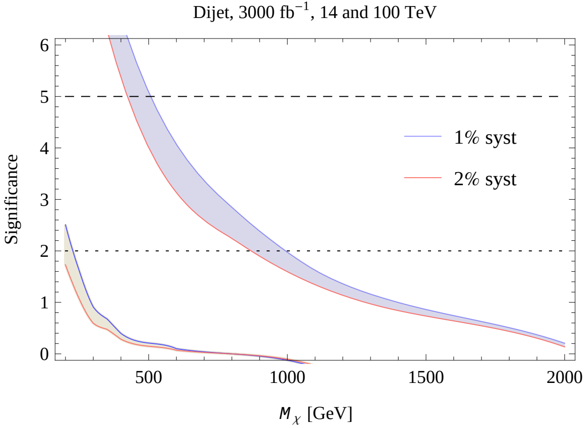
$$M_{\chi^\pm} - M_{\chi_0} = 165 \text{ MeV} > m_\pi \quad \Rightarrow \quad \text{lifetime } \tau = 44\text{cm}/(n^2 - 1)$$

Almost all $\chi^\pm$s decay to χ_0 + unseeable pions before reaching detectors



see also Low Wang 1404.0682





[Preliminary]

Conclusions

An EW fermion triplet to make Dark Matter

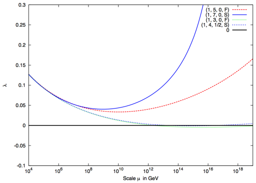
[needs non-standard attitude towards hierarchy problem]

→ Why interesting

✓stable by $B - L$ ✓not big contribution to m_h

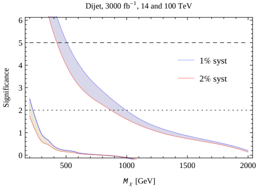
✓helps with unification of gauge couplings

✓stabilizes EW vacuum ✓mimics Wino LSP



→ Phenomenology

Hard to see, collider vs astro



<u>Outlook/in progress:</u> monophoton,...

ID prospects

EW quintuplet