A WIMP Dark Matter particle around the corner?

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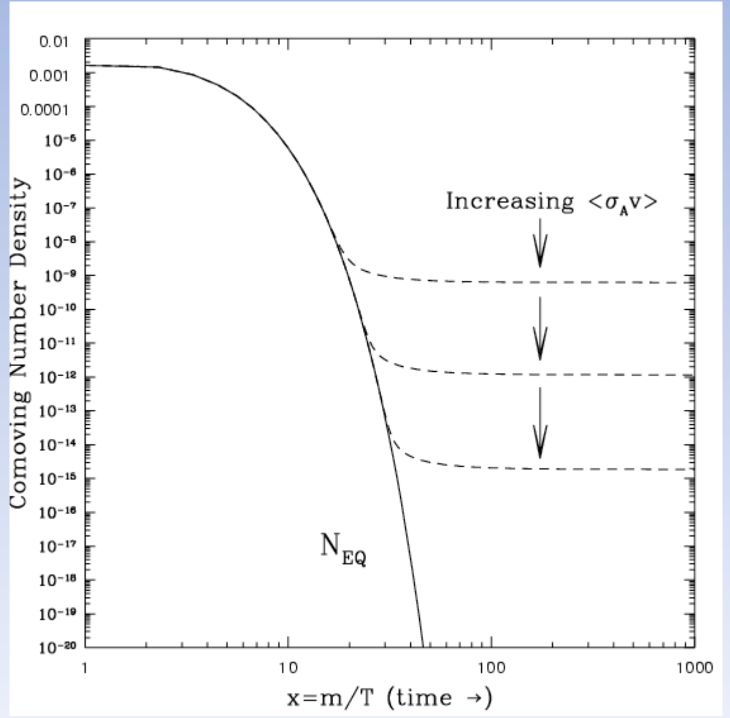
DM thermal relic density scenario (WIMP)

- most straightforward way to explain $\Omega_{DM} \simeq 26\%$ ← $\Omega_{DM} h^2 \simeq 0.12$
  - DM particle thermalizes with the SM thermal bath
    - cannot stay for long in thermal equilibr. once $T < m_{DM}$ ← $n_{DM}^{Eq.} \propto e^{-m_{DM}/T}$
      - once $\Gamma_{annih.} < H$: freeze out of DM particle number

$\frac{n_{DM}^{Eq}}{s}$



m_{DM}/T

⇒ $\Omega_{DM} \propto 1/\langle \sigma_{annih.} v \rangle$

- for electroweak couplings or couplings of order unity: $\Omega_{DM} \simeq 26\%$ requires $m_{DM} \sim \mathrm{EW\ scale}$

↑ $\langle \sigma_{annih.} v \rangle \simeq 10^{-26}\ \mathrm{cm}^3/\mathrm{sec}$

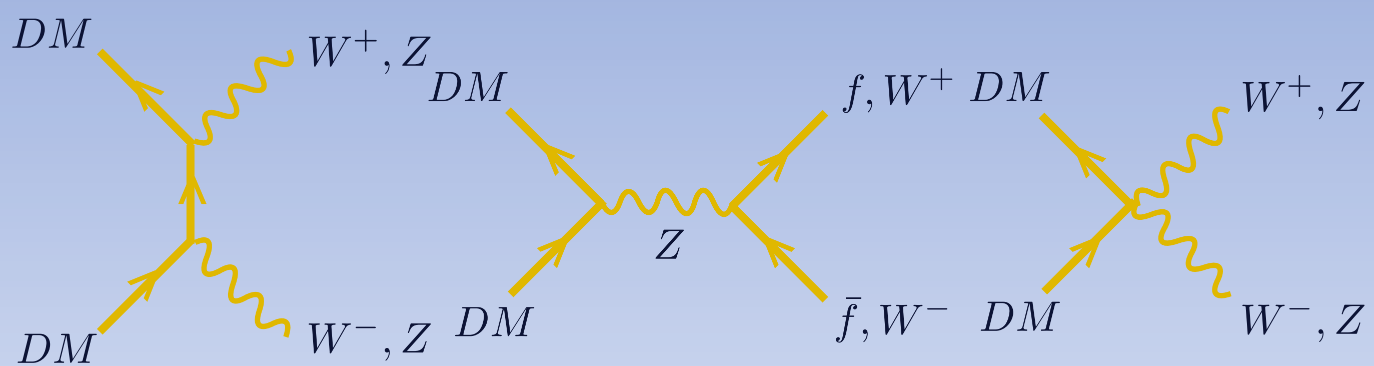
Most straightforward WIMP scale ~ TeV

examples: a fermion $SU(2)_L$ DM doublet ($Y_{DM} = 1/2$): $m_{DM} = 1.1\,\mathrm{TeV}$

a fermion $SU(2)_L$ DM triplet ($Y_{DM} = 0$): $m_{DM} = 3.1\,\mathrm{TeV}$

a scalar $SU(2)_L$ DM doublet ($Y_{DM} = 1/2$): $m_{DM} \geq 540\,\mathrm{GeV}$

a scalar $SU(2)_L$ DM triplet ($Y_{DM} = 0$): $m_{DM} \geq 2.5\,\mathrm{TeV}$



see e.g. Cirelli, Strumia et al. '07

⇒ around the corner! ← (but not necessarily at LHC!)

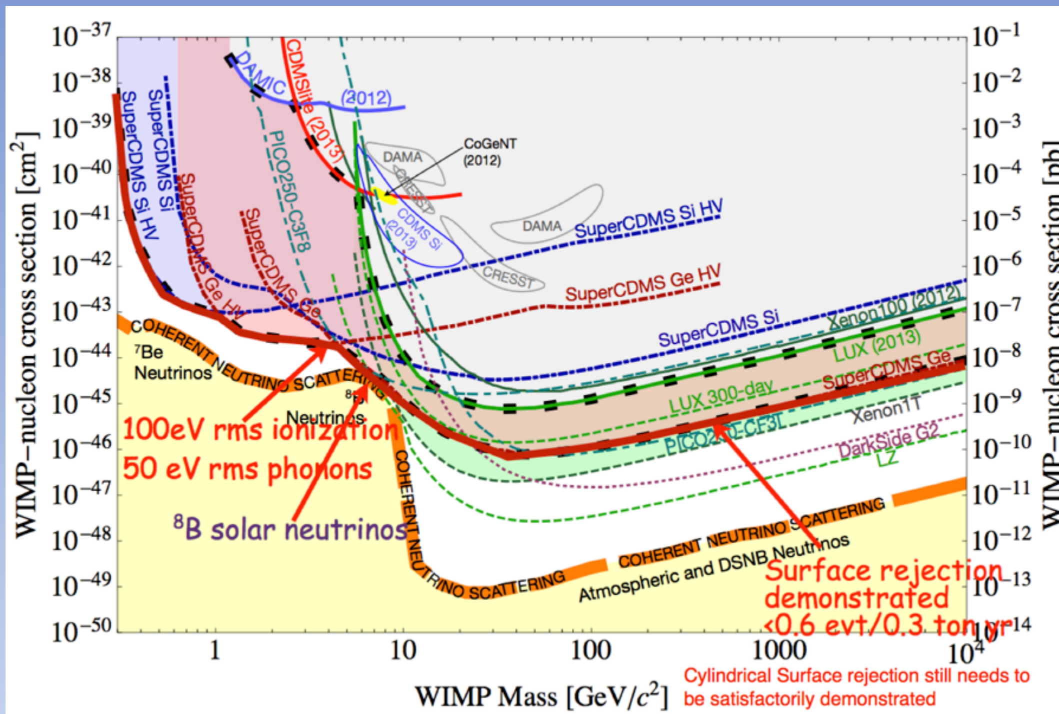
WIMP scale could also be lower or higher

if driven by larger couplings up to ~100 TeV: unitarity bound

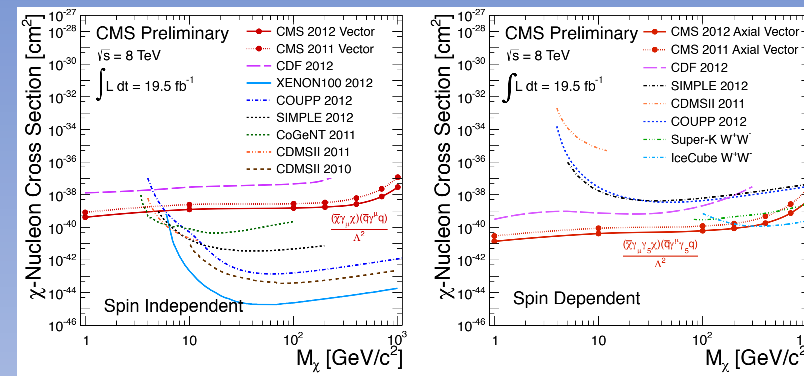
if Fermi suppression, or driven by smaller couplings, or interplay of channels, or small mass splittings, ...

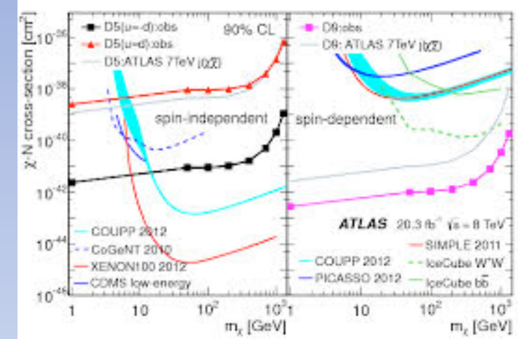
DM search: 3 main types of experiments

Direct detection: DM-N collision:



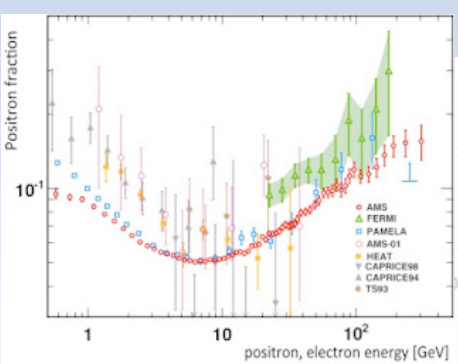
Colliders: DM pair production:

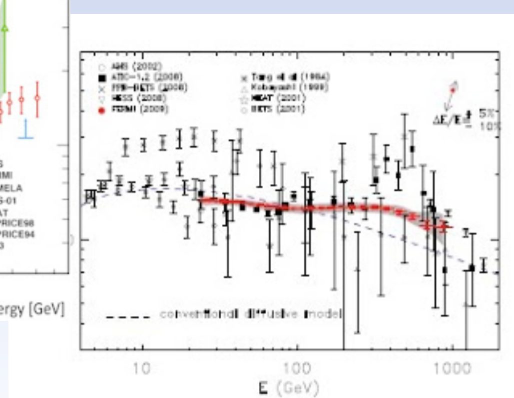


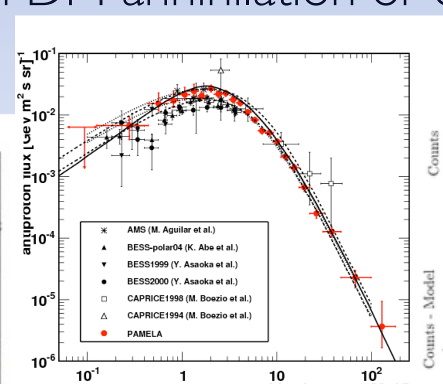


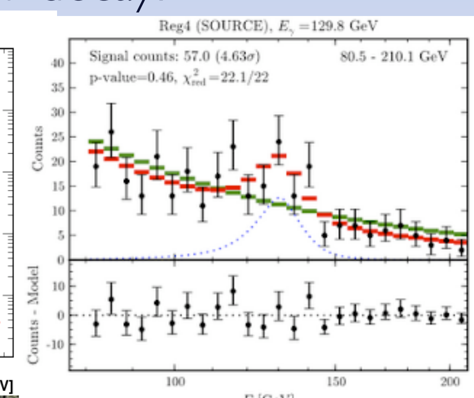
Monojets,
monophoton,
monoW/Z,
cascade decays,
....

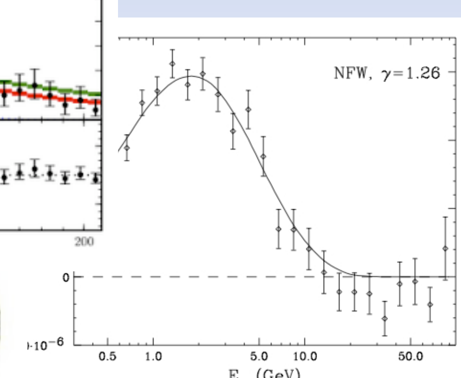
Indirect detection: cosmic rays from DM annihilation or decay:











3 main types of phenomenological approaches

Effective operators: most model independent approach

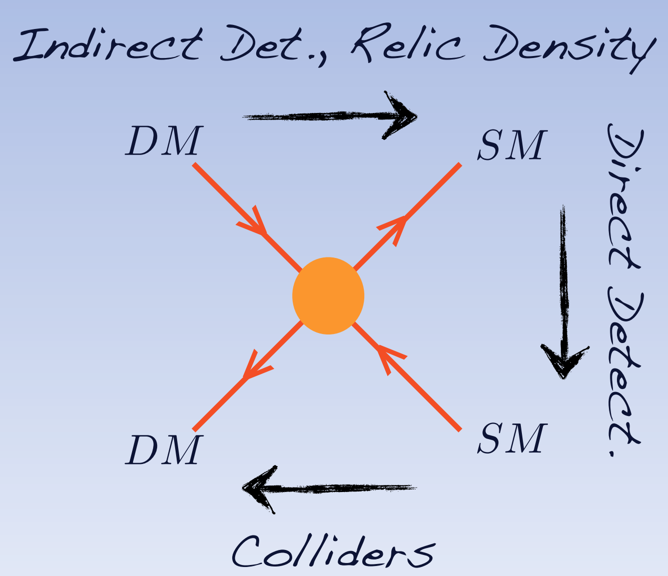
Explicit DM-SM mediator setups

Explicit DM models

Effective operator approach

from determining and analysing the full series of effective operators quadratic in the DM field (or linear for a DM decay)

is well justified for DM direct and indirect detection, not necessarily for collider studies



Effective oper. approach: fermion dark matter coupled to quarks

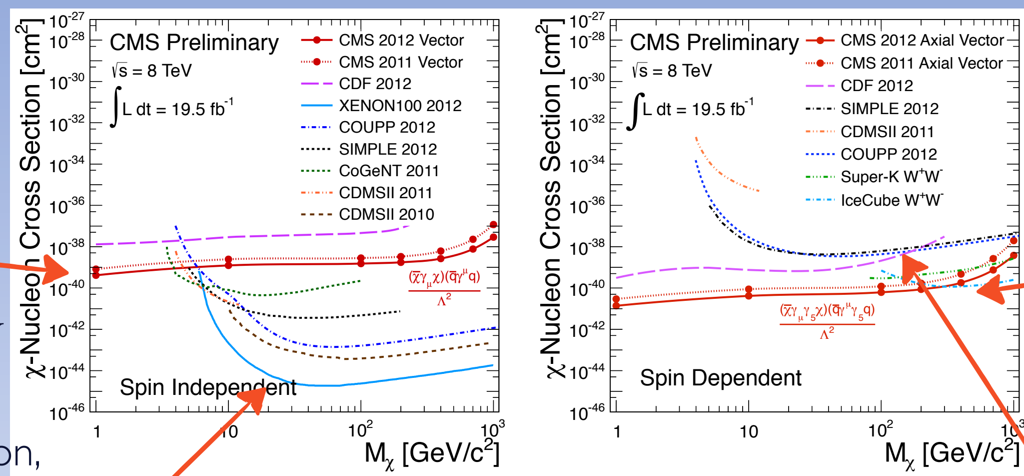
examples: vector and axial operators

$$\mathcal{O} = \frac{1}{\Lambda^2}\bar{\psi}_{DM}\gamma_\mu\psi_{DM}\,\bar{q}\,\gamma^\mu q$$

spin-independent direct detect.

$$\mathcal{O} = \frac{1}{\Lambda^2}\bar{\psi}_{DM}\gamma_\mu\gamma_5\psi_{DM}\,\bar{q}\,\gamma^\mu\gamma_5 q$$

spin-dependent direct detect.



Colliders:

$\Lambda \gtrsim 1\,\mathrm{TeV}$

for m_{DM} up to $\sim 1\,\mathrm{TeV}$

from monojets, mono-photon, mono-W, ...

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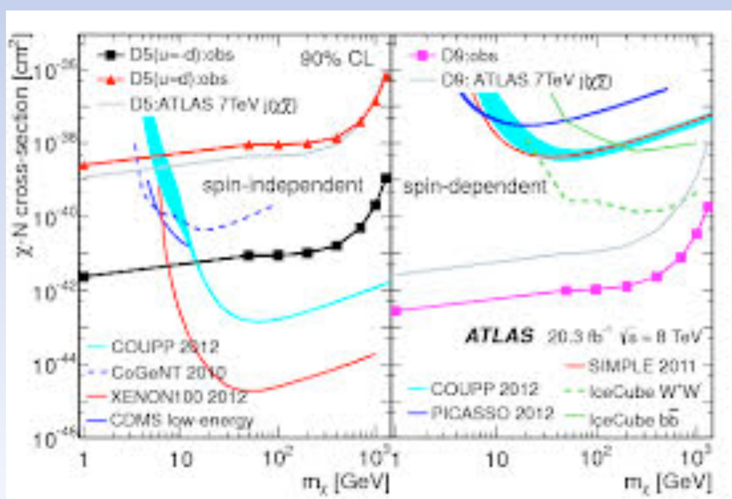


Direct Detect.:

$\Lambda \gtrsim 10\,\mathrm{TeV}$

for $10\,\mathrm{GeV} \gtrsim m_{DM} \gtrsim 1\,\mathrm{TeV}$

Direct Detect.:

$\Lambda \gtrsim 600\,\mathrm{GeV}$

for $10\,\mathrm{GeV} \gtrsim m_{DM} \gtrsim 1\,\mathrm{TeV}$

N.B.: Xenon1T will probe Λ effective scale values up to 3-4 times higher!

Effective oper. approach: fermion dark matter coupled to Higgs

examples: parity even and odd operators

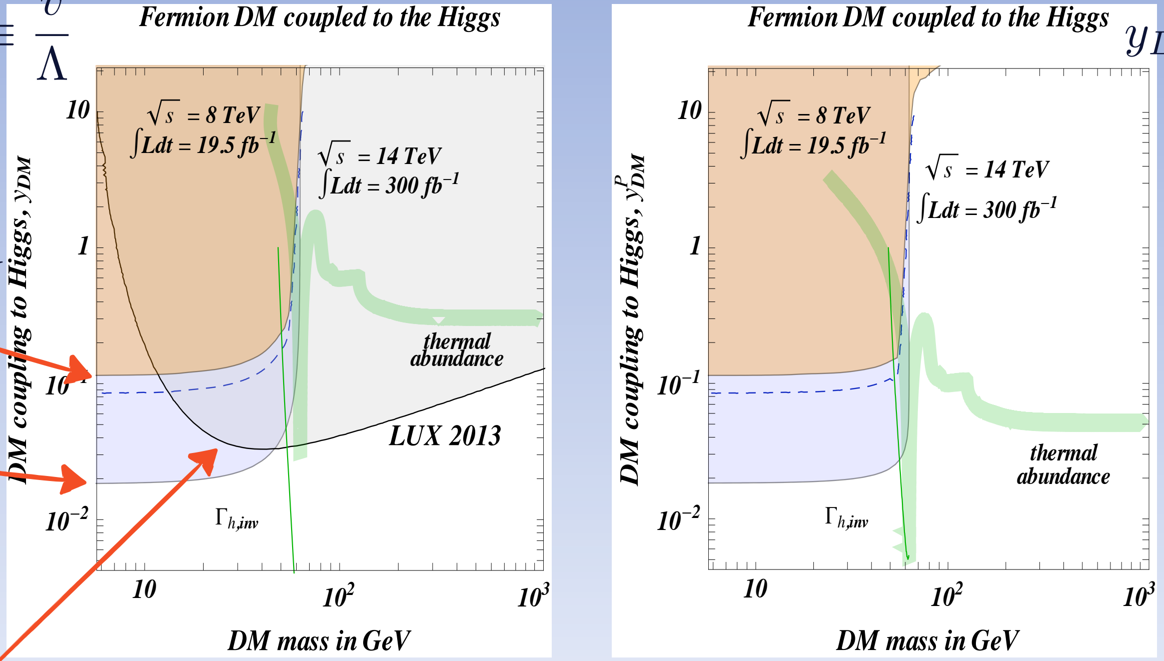
$$\mathcal{O} = \frac{1}{\Lambda} H^\dagger H \, \bar{\psi}_{DM} \psi_{DM}$$

spin-independent direct detect.

$$\mathcal{O} = \frac{1}{\Lambda} H^\dagger H \, \bar{\psi}_{DM} i\gamma_5 \psi_{DM}$$

spin-dependent direct detect.

$$y_{DM} \equiv \frac{v}{\Lambda}$$



$$y_{DM} \equiv \frac{v}{\Lambda}$$

LHC monojets

for m_{DM} up to $\sim 60\,\mathrm{GeV}$

LHC: Higgs boson invisible decay width

Direct Detect.:

$\Lambda \gtrsim 10\,\mathrm{TeV}$

for $10\,\mathrm{GeV} \gtrsim m_{DM} \gtrsim 1\,\mathrm{TeV}$

....

Lopez-Honorez, Schwetz, Zupan 12

De Simone, Giudice, Strumia 14

....

Direct Detect.: no relevant bound

Systematic study of effective theory for γ-line production from DM decay

- γ-line: no astrophysics background → DM "smoking gun"
  ↪ promising experiments: Fermi, HESS-2, CTA, ...

- one perfectly possible scenario: γ-lines from radiative 2-body DM decay
  ↪ e.g. if DM is stable due to accidental sym. as for the proton
  ↓
  very slow decay can be expected as for the proton from UV physics inducing low energy effect. operators

a GUT induced dim-6 operator gives cosmic ray fluxes of order experimental sensitivity!

Gustafsson, T.H., Scarna 13

for a scalar DM candidate:

$$\begin{aligned}
O^{(5)YY}_{\phi_{DM}} &\equiv \phi_{DM} F_{Y\mu\nu} F^{\mu\nu}_{Y} & \phi_{DM} &= (1,0)\\
O^{(5)YL}_{\phi_{DM}} &\equiv \phi_{DM} F_{L\mu\nu} F^{\mu\nu}_{Y} & \phi_{DM} &= (3,0)\\
O^{(5)LL}_{\phi_{DM}} &\equiv \phi_{DM} F_{L\mu\nu} F^{\mu\nu}_{L} & \phi_{DM} &= (1/3/5,0)\\
O^{(5)YY'}_{\phi_{DM}} &\equiv \phi_{DM} F_{Y\mu\nu} F^{\mu\nu}_{Y'} & \phi_{DM} &= (1,0)\\
O^{(5)LY'}_{\phi_{DM}} &\equiv \phi_{DM} F_{L\mu\nu} F^{\mu\nu}_{Y'} & \phi_{DM} &= (3,0)
\end{aligned}$$

$$\begin{aligned}
O^{1YY}_{\phi_{DM}} &\equiv \phi_{DM} F_{Y\mu\nu} F^{\mu\nu}_{Y} \phi & \phi_{DM}\cdot\phi &= (1,0)\\
O^{1YL}_{\phi_{DM}} &\equiv \phi_{DM} F_{L\mu\nu} F^{\mu\nu}_{Y} \phi & \phi_{DM}\cdot\phi &= (3,0)\\
O^{1LL}_{\phi_{DM}} &\equiv \phi_{DM} F_{L\mu\nu} F^{\mu\nu}_{L} \phi & \phi_{DM}\cdot\phi &= (1/3/5,0)\\
O^{1YY'}_{\phi_{DM}} &\equiv \phi_{DM} F_{Y\mu\nu} F^{\mu\nu}_{Y'} \phi & \phi_{DM}\cdot\phi &= (1,0)\\
O^{1LY'}_{\phi_{DM}} &\equiv \phi_{DM} F_{L\mu\nu} F^{\mu\nu}_{Y'} \phi & \phi_{DM}\cdot\phi &= (3,0)\\
O^{2Y}_{\phi_{DM}} &\equiv D_\mu \phi_{DM} D_\nu \phi F^{\mu\nu}_{Y} & \phi_{DM}\cdot\phi &= (1,0)\\
O^{2L}_{\phi_{DM}} &\equiv D_\mu \phi_{DM} D_\nu \phi F^{\mu\nu}_{L} & \phi_{DM}\cdot\phi &= (3,0)
\end{aligned}$$

for a fermion DM candidate:

$$\begin{aligned}
O^{(5)Y}_{\psi_{DM}} &\equiv \bar\psi \sigma_{\mu\nu} \psi_{DM} F^{\mu\nu}_{Y} & \psi_{DM}\cdot\psi &= (1,0)\\
O^{(5)L}_{\psi_{DM}} &\equiv \bar\psi \sigma_{\mu\nu} \psi_{DM} F^{\mu\nu}_{L} & \psi_{DM}\cdot\psi &= (3,0)
\end{aligned}$$

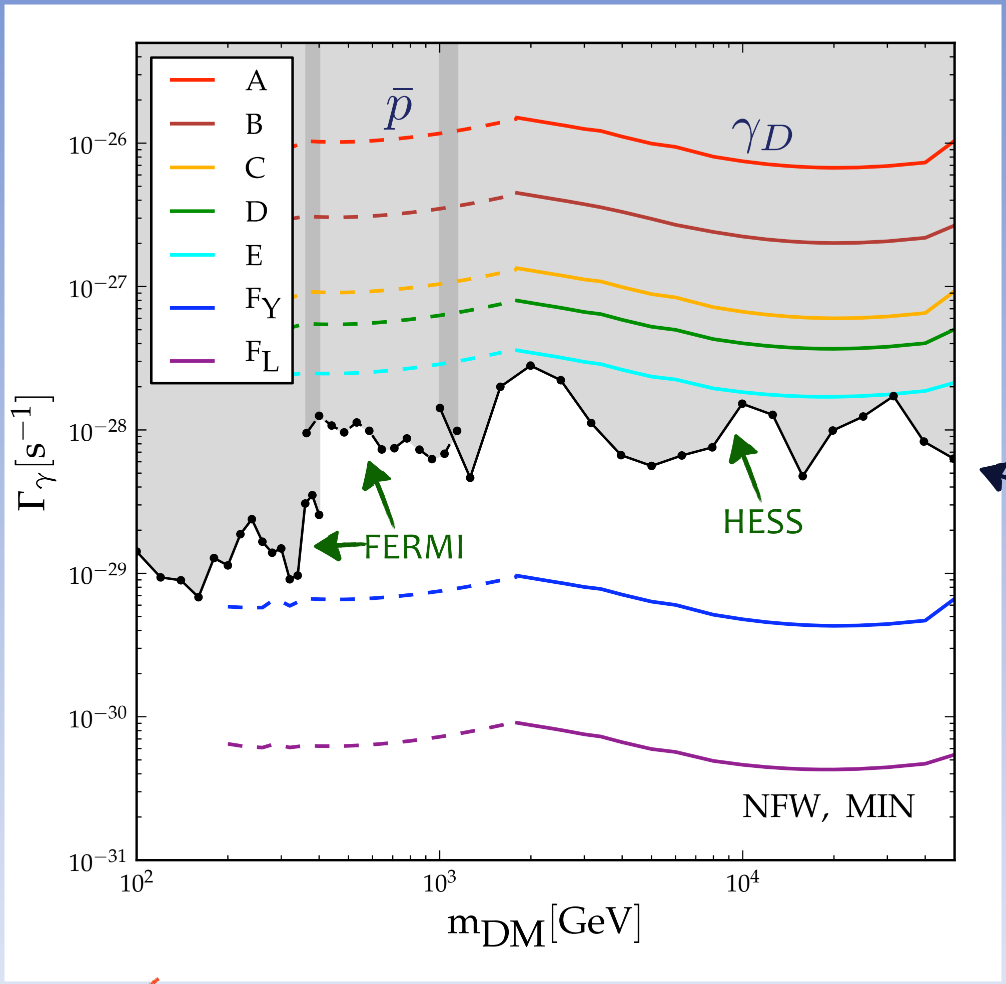
$$\begin{aligned}
O^{1Y}_{\psi_{DM}} &\equiv \bar\psi \sigma_{\mu\nu} \psi_{DM} F^{\mu\nu}_{Y} \phi & \bar\psi\cdot\psi_{DM}\cdot\phi &= (1,0)\\
O^{1L}_{\psi_{DM}} &\equiv \bar\psi \sigma_{\mu\nu} \psi_{DM} F^{\mu\nu}_{L} \phi & \bar\psi\cdot\psi_{DM}\cdot\phi &= (3,0)\\
O^{2Y}_{\psi_{DM}} &\equiv D_\mu \bar\psi \gamma_\nu \psi_{DM} F^{\mu\nu}_{Y} & \bar\psi\cdot\psi_{DM} &= (1,0)\\
O^{2L}_{\psi_{DM}} &\equiv D_\mu \bar\psi \gamma_\nu \psi_{DM} F^{\mu\nu}_{L} & \bar\psi\cdot\psi_{DM} &= (3,0)\\
O^{3Y}_{\psi_{DM}} &\equiv \bar\psi \gamma_\mu D_\nu \psi_{DM} F^{\mu\nu}_{Y} & \bar\psi\cdot\psi_{DM} &= (1,0)\\
O^{3L}_{\psi_{DM}} &\equiv \bar\psi \gamma_\mu D_\nu \psi_{DM} F^{\mu\nu}_{L} & \bar\psi\cdot\psi_{DM} &= (3,0)
\end{aligned}$$

for a spin-1 DM candidate:

$$\begin{aligned}
O^{(5)Y}_{V_{DM}} &\equiv F^{DM}_{\mu\nu} F^{\mu\nu}_{Y} \phi & \phi &= (1,0)\\
O^{(5)L}_{V_{DM}} &\equiv F^{DM}_{\mu\nu} F^{\mu\nu}_{L} \phi & \phi &= (3,0)
\end{aligned}$$

$$\begin{aligned}
O^{1}_{V_{DM}} &\equiv F^{DM}_{\mu\nu} F^{\mu\rho}_{Y} F^{\nu}_{Y'\rho} & &\\
O^{2Y}_{V_{DM}} &\equiv F^{DM}_{\mu\nu} F^{\mu\nu}_{Y} \phi\phi' & \phi\cdot\phi' &= (1,0)\\
O^{2L}_{V_{DM}} &\equiv F^{DM}_{\mu\nu} F^{\mu\nu}_{L} \phi\phi' & \phi\cdot\phi' &= (3,0)\\
O^{3YY'}_{V_{DM}} &\equiv D^{DM}_{\mu} \phi D^{DM}_{\nu} \phi' F^{\mu\nu}_{Y} & \phi\cdot\phi' &= (1,0)\\
O^{3LY'}_{V_{DM}} &\equiv D^{DM}_{\mu} \phi D^{DM}_{\nu} \phi' F^{\mu\nu}_{L} & \phi\cdot\phi' &= (3,0)
\end{aligned}$$

Upper bounds on γ-line intensity from DM decay



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upper bounds depending on operator

direct γ-line search

possibilities of operator discrimination

combined with the fact that op. can give more than one line

N.B.: an observable γ-line could also be due to the possible fact that the DM particle is not absolutely neutral

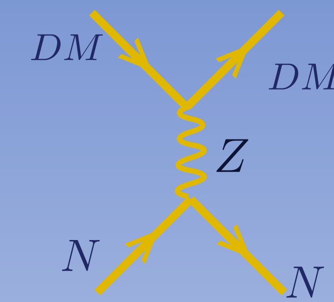
El Asaiti, T.H., Scarna 14

DM millicharge

Explicit mediator approach: Z mediator for fermion DM

e.g. assuming DM/SM specific mediator:

- Z mediator: fermion DM: vector and axial DM coupling to the Z



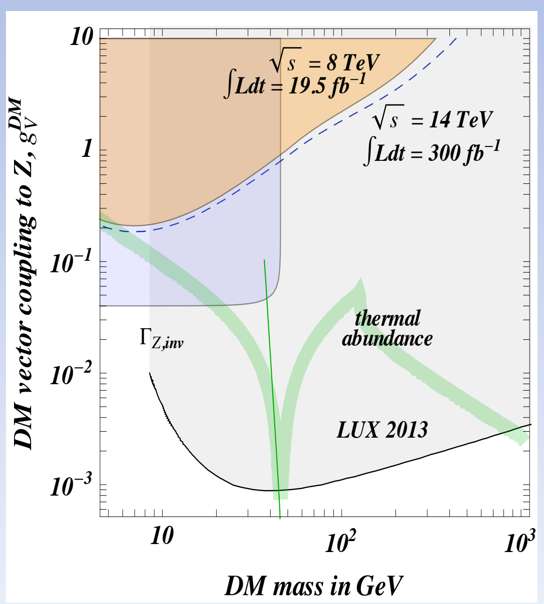
$$\mathcal{L} \ni -Z_\mu \frac{g}{\cos\theta_W} \bar{\psi}_{DM} (g_V^{DM} + g_A^{DM} \gamma_5) \gamma^\mu \psi_{DM}$$

For direct detection: the Z can be integrated out → same discussion than with effective operators

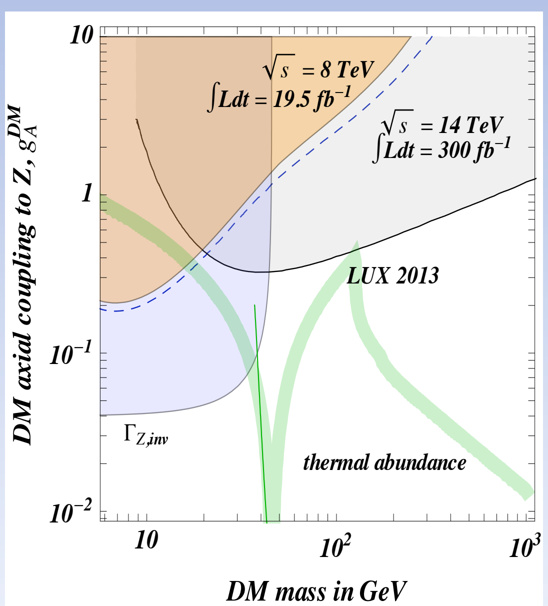
$$\frac{1}{\Lambda} \sim \frac{g_{V,A}^{DM}}{m_Z} \frac{g}{\cos\theta_W}$$

For colliders: the Z must be kept explicit

g_V^{DM}



g_A^{DM}



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....

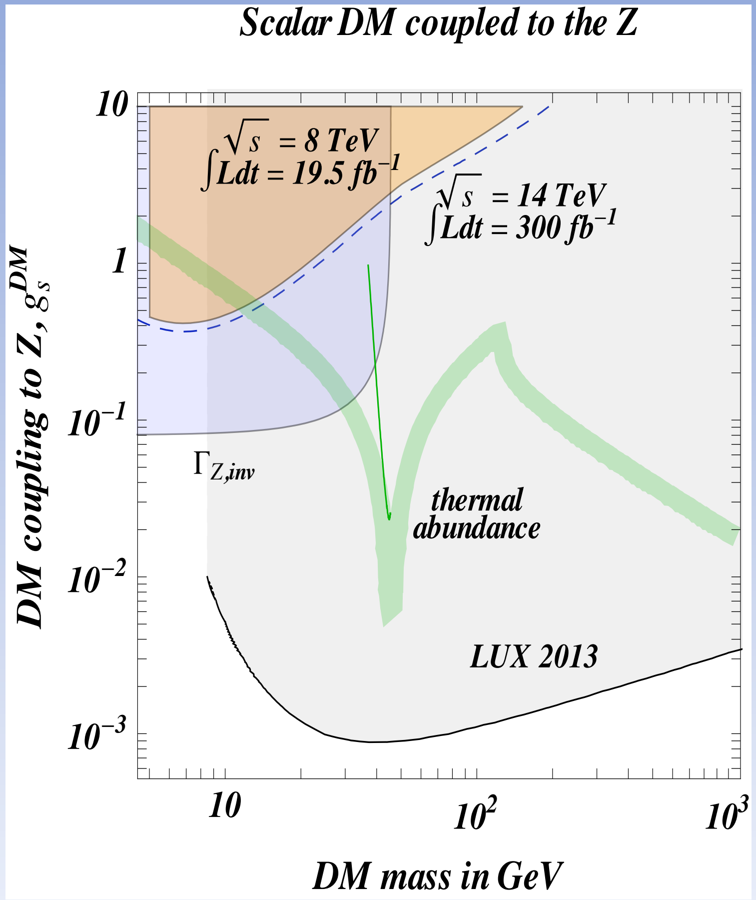
totally excluded for "standard" Z couplings

still largely open for $m_{DM} > 60\,\mathrm{GeV}$

Explicit mediator approach: Z mediator for scalar DM

$$L \ni -Z_\mu \frac{g}{\cos\theta_W} g_\phi \left[\phi^*_{DM}\partial^\mu\phi_{DM} - \partial^\mu\phi^*_{DM}\phi_{DM}\right]$$

similar to fermion DM vector case



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totally excluded for "standard" Z couplings

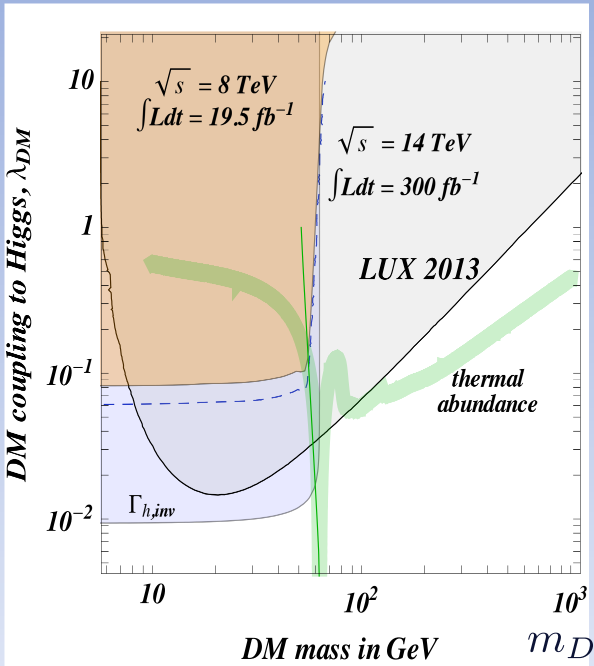
Explicit mediator approach: Higgs mediator

- Fermion DM: lowest gauge invariant interaction: dim-5 ⇒ back to effective oper. discussion

$$\mathcal{O} = \frac{1}{\Lambda} H^\dagger H \; \bar{\psi}_{DM} \psi_{DM}$$

- Scalar DM: Higgs portal interaction: $\mathcal{L} \ni \lambda_{DM} H^\dagger H \; \phi^*_{DM} \phi_{DM}$

λ_{DM}



m_{DM} (GeV)

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⇓

begin to be pretty much constrained below $100\,\mathrm{GeV}$

N.B.: Xenon1T will probe it up to $\sim 10\,\mathrm{TeV}$ for $\lambda_{DM} \sim 1$

up to $\sim 1\,\mathrm{TeV}$ for $\lambda_{DM} \sim 10^{-1}$

Z' mediator

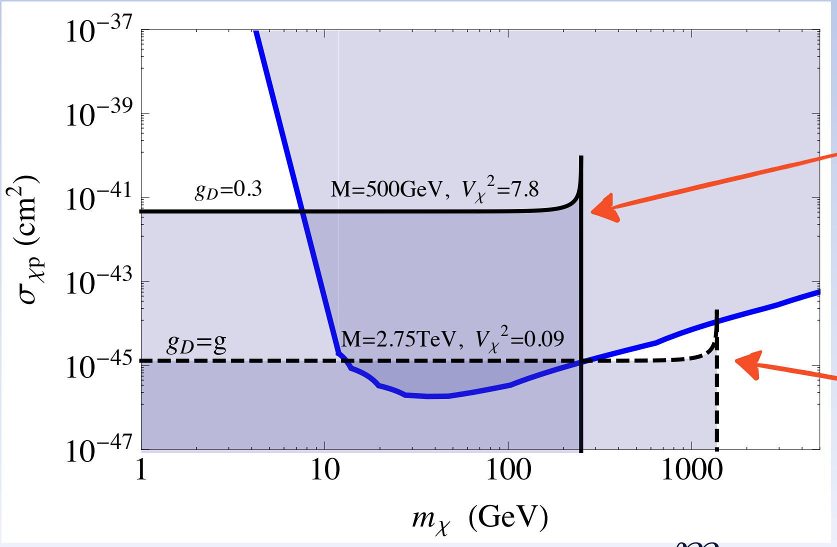
Similar phenomenology than for the Z exchange except that:

- bounds relax if Z' couplings to SM fields are smaller than for Z
- bounds relax for increasing values of $m_{Z'}$ and fixed m_{DM}

Direct detection: put an upper bound on Z'-DM couplings → ← LHC Z' direct search: put a lower bound on Z'-DM couplings

→ to escape Z' detection via large invisible Z decay width

σ_{DM-N}



m_{DM}

LHC direct search $m_{Z'} = 500\,\mathrm{GeV}$

LUX

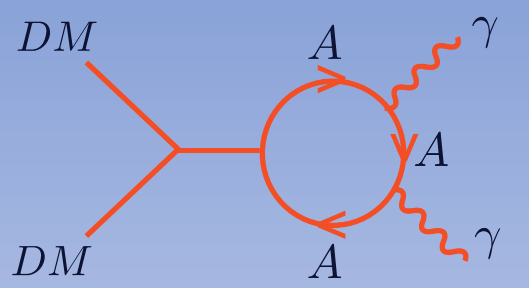
LHC direct search $m_{Z'} = 2.75\,\mathrm{TeV}$

Arcadi, Mambrini, Tytgat, Zaldivar 14

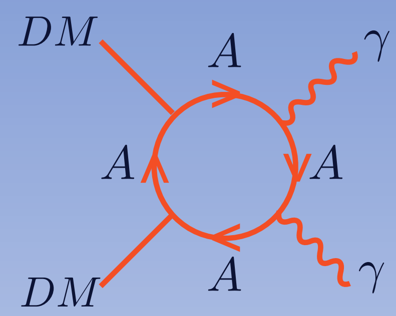
Mediator for γ-lines and "gluon-lines"

- γ-line emission production proceeds through photon emission from a charged particle in a loop

as for well known examples: $h \to \gamma\gamma,\ \pi^0 \to \gamma\gamma, \ldots$

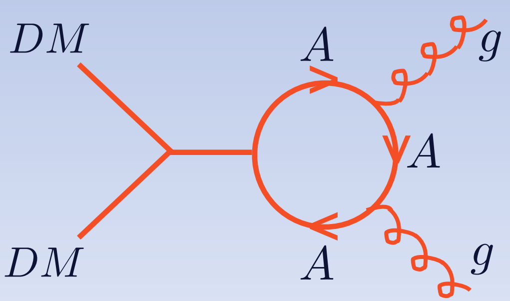


$\Longleftrightarrow$

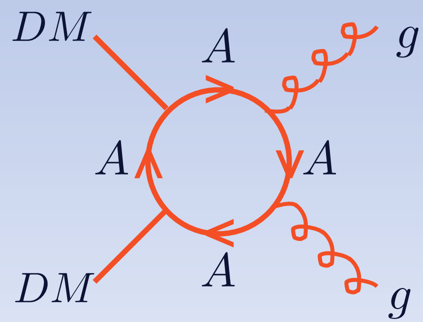


if the charged particle emitting the γ-line is also colored: "gluon lines":

as for well known examples: $h \to \gamma\gamma,\ \pi^0 \to \gamma\gamma, \ldots$



$\Longleftrightarrow$



Chu, T.H., Scarna, Tytgat 12

$$R = \frac{n_g}{n_\gamma}$$

depends on $SU(3)_c$ representation for A

is basically known: $R \propto \frac{\alpha_s^2}{\alpha^2} \cdot \frac{c}{Q_A^4} \sim 50 - 100$

$\Rightarrow$ many experimental consequences!

“Gluon lines” associated to γ-lines

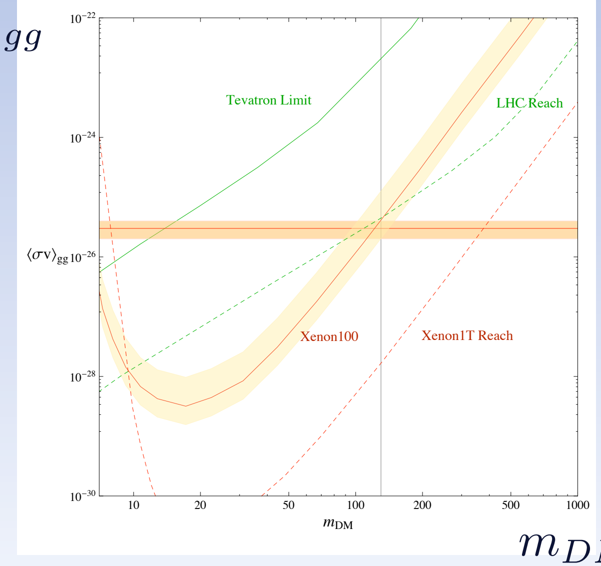
Many experimental consequences!

- gluon “lines” may lead to observable $\bar{p}$ flux for $m_{DM} \sim$ few hundreds GeV
- gluon “lines” may lead to observable γ continuum flux
- gluon exchange leads to DM-$Nucleon$ cross section: observable for $m_{DM} \lesssim 500\,\mathrm{GeV}$
- possibility of gluon fusion DM pair production at LHC
- gluon “lines” production gives a DM annihilation cross section of the right order of magnitude for fitting observed relic density

for a γ-line observed around current experimental sensitivity

direct detection and collider upper bounds on $DM DM \to gg$ cross section

$\langle\sigma v\rangle_{gg}$



m_{DM}

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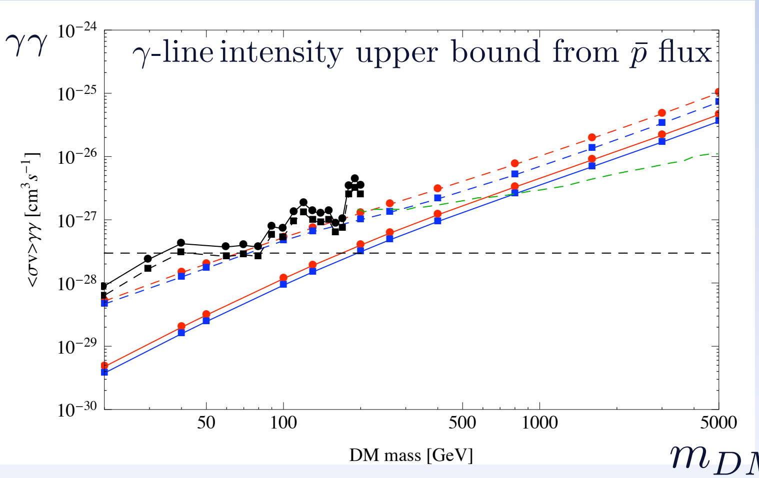
$\langle\sigma v\rangle_{\gamma\gamma}$



m_{DM}

Whenever DM couples to gluon: many experimental possibilities

Explicit models

DM models can be classified according to various criteria:

Minimal models	→ ←	More theoretically motivated global models
Visible sector DM models	→ ←	Hidden sector DM models
ad hoc DM stability	→ ←	justified DM stability

$$\tau_{DM} > \tau_{Universe}$$

$$\tau_{DM} > 10^{26-29}\ \mathrm{sec}$$

The stabilization mechanism determines many structural features of the all DM scenario

DM/EW scale similarity just so	→ ←	DM/EW scale similarity explained

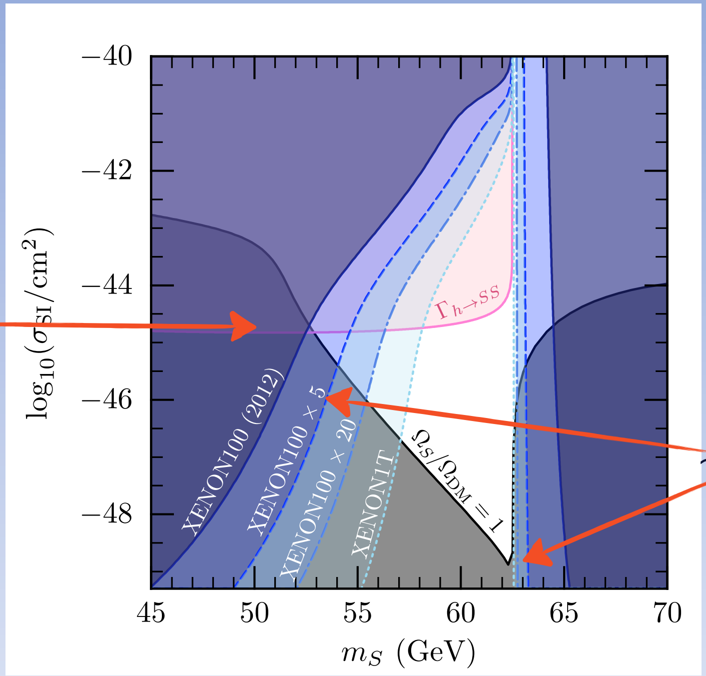
Explicit models: the simplest example: a real scalar singlet

a real singlet S odd under Z_2 parity: $S \to -S$

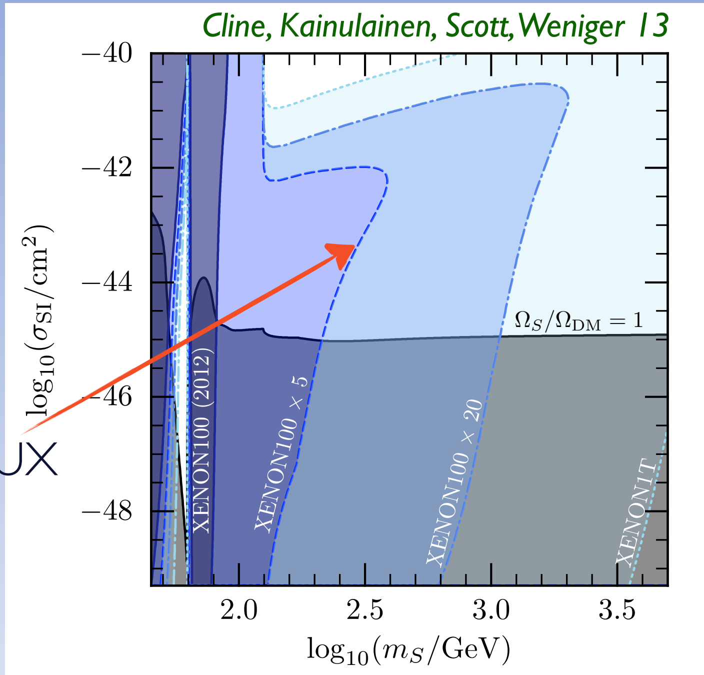
$$\mathcal{L} \ni -\frac{1}{2}\mu_S^2 S^2 - \frac{1}{24}\lambda_S S^4 - \frac{1}{2}\lambda_{hs} H^\dagger H S^2 \qquad m_S^2 = \mu_S^2 + \frac{1}{2}\lambda_{hs} v^2$$

For m_S fixed, λ_{hs} can be fixed by $\Omega_{DM} \simeq 26\%$ constraint: everything is fixed!

Higgs invisible width



~ LUX



LUX direct detection requires: $53\,\mathrm{GeV} \lesssim m_{DM} \lesssim 63\,\mathrm{GeV}$
or $m_{DM} \gtrsim 160\,\mathrm{GeV}$

Dwarf galaxies γ-ray flux requires: $m_{DM} \gtrsim 50\,\mathrm{GeV}$

Future: Xenon1T will probe m_{DM} up to $7\,\mathrm{TeV}$
except for: $55\,\mathrm{GeV} \lesssim m_{DM} \lesssim 62.5\,\mathrm{GeV}$

Fermi+CTA will probe m_{DM} up to $5\,\mathrm{TeV}$

$\Rightarrow$ shows how a model is getting very squeezed when it depends on only very few parameters

Explicit models: the illustrative Wino example

e.g. a fermion $SU(2)_L$ triplet DM

have only gauge interactions with SM fields:
relic density totally fixed by value of m_{DM}

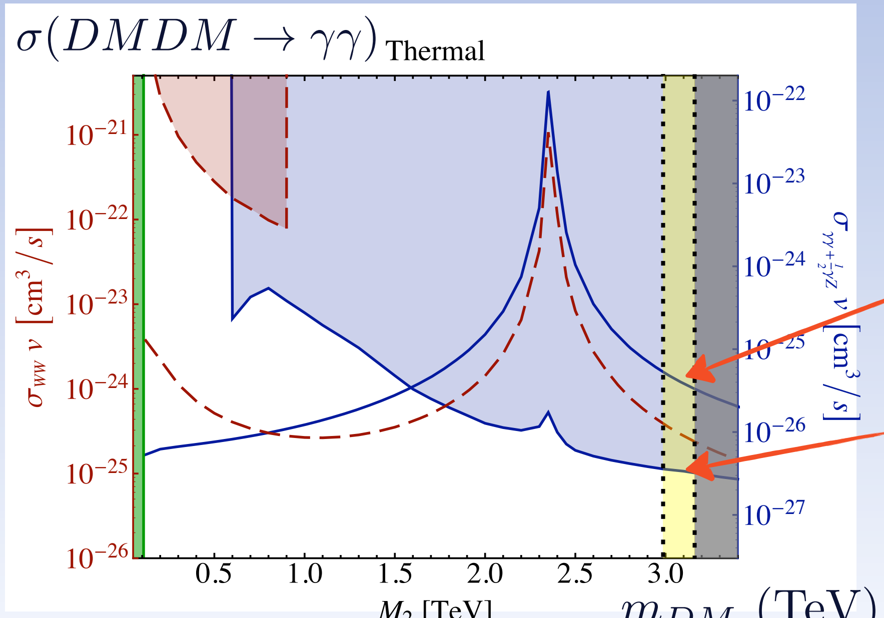
$\Omega_{DM} \simeq 26\%$ requires $m_{DM} \simeq 3.1\,\mathrm{TeV}$

too high for LHC
direct detection: $\sigma_{DM-N} \simeq 10^{-47}\,\mathrm{cm}^2$
far future: Darwin?

But Indirect detection remains!! → production of γ-line is Sommerfeld enhanced

Hisano et al. 03-09

Cohen, Lisanti, Pierce, Slatyer 13



⇒ we should soon see a signal or exclude this model!

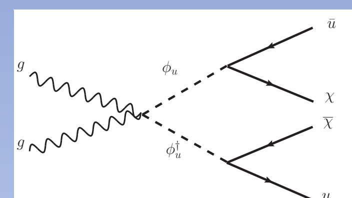
Explicit models: DM coupled to a colored partner

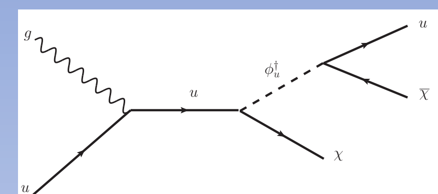
many proposals to couple DM directly to a colored partner

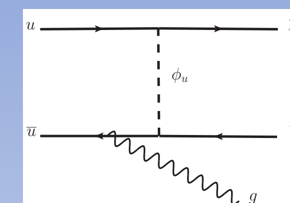
- Example: $\mathcal{L} \ni \lambda_u \, \bar{\chi}_{DM} \, u_R \, \phi_c$ *Bai, Berger 13*

  scalar colored triplet

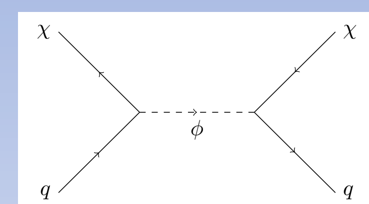
  many ways to produce DM at colliders in unsuppressed way

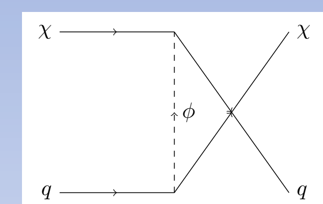






  unsuppressed direct detection in s channel

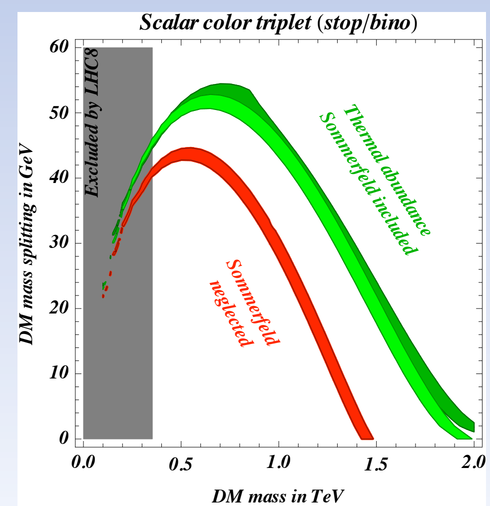




- DM coannihilation with a color partner

  example: bino in thermal equilibrium with a stop or a gluino

  De Simone, Giudice, Strumia 14



- ...

"Hand-made" to be testable at LHC rather than for any other reason

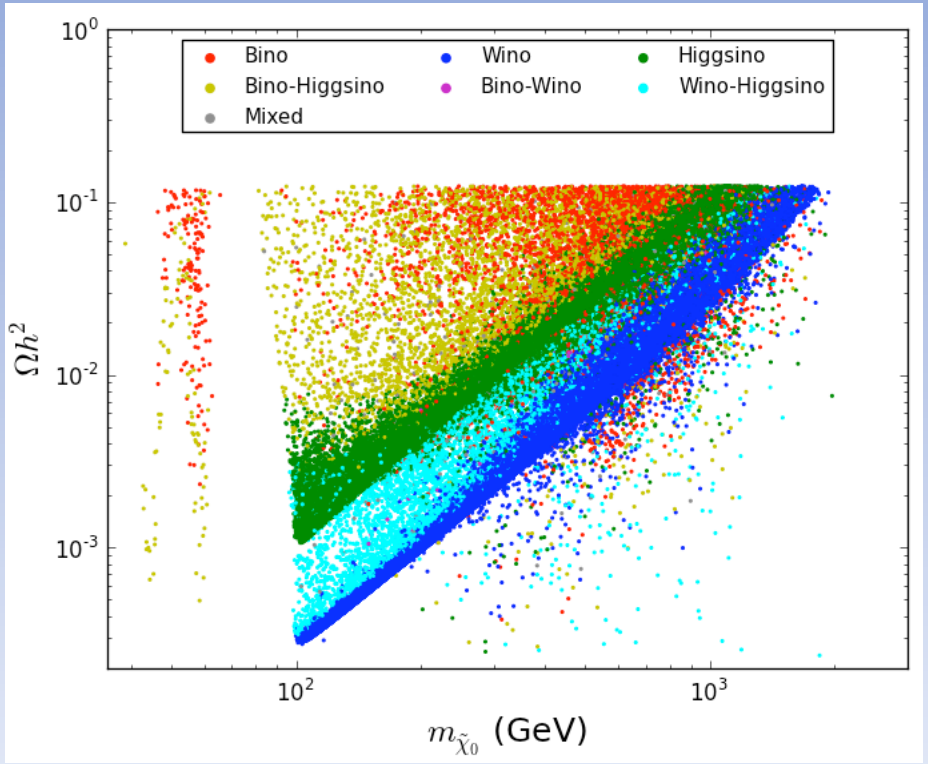
Explicit models: MSSM neutralino

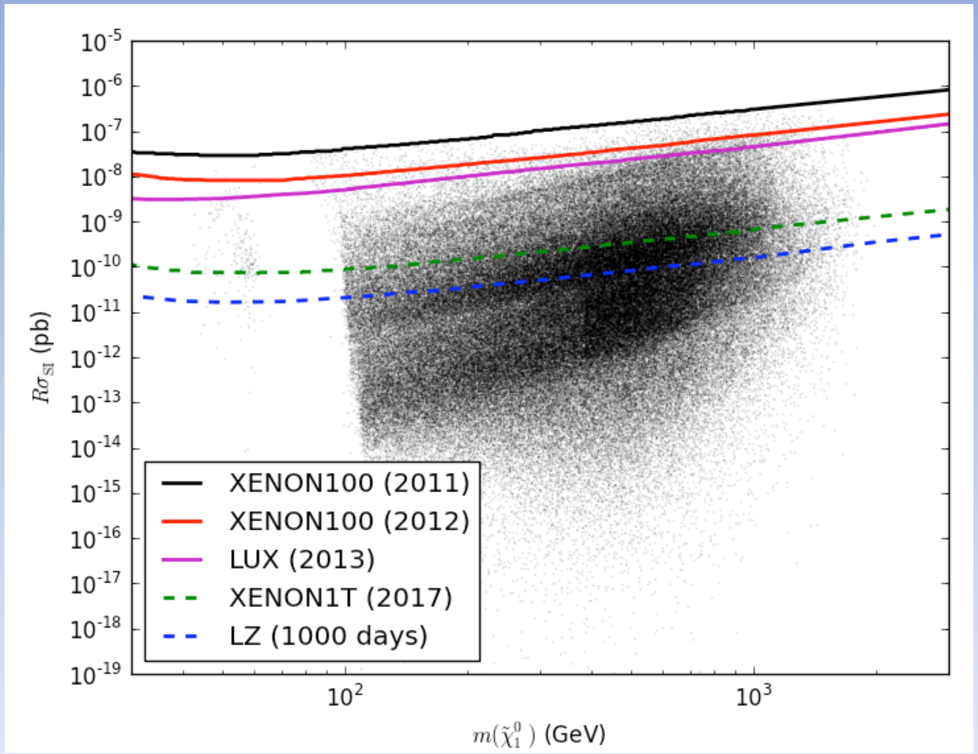
well motivated theoretically (less than before)

example of multiparameter situation ⇒ many channels

$pMSSM$ (19 parameters)

Rizzo 14, ...





relic density point out a neutralino below ~3 TeV (i.e. gauge driven, or loop driven, ...) but could be higher

a neutralino as light as ~20-30 GeV is still possible (in fully general MSSM) *Calibbi et al 12*

still not much probed by direct detection but Xenon1T, LZ, ..., will probe it substantially

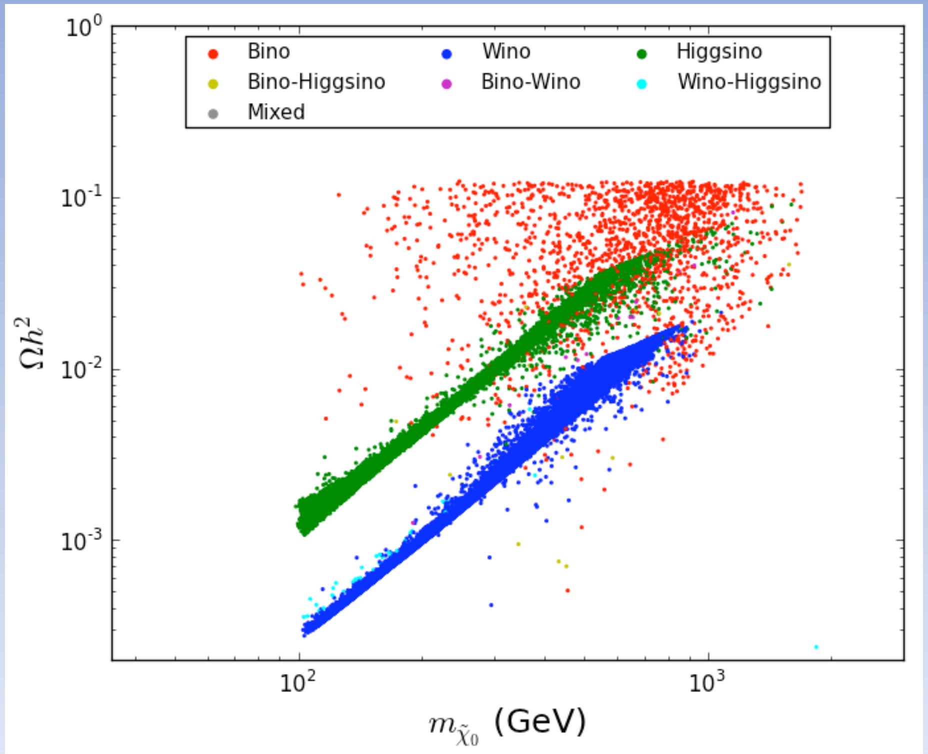
Explicit models: MSSM neutralino

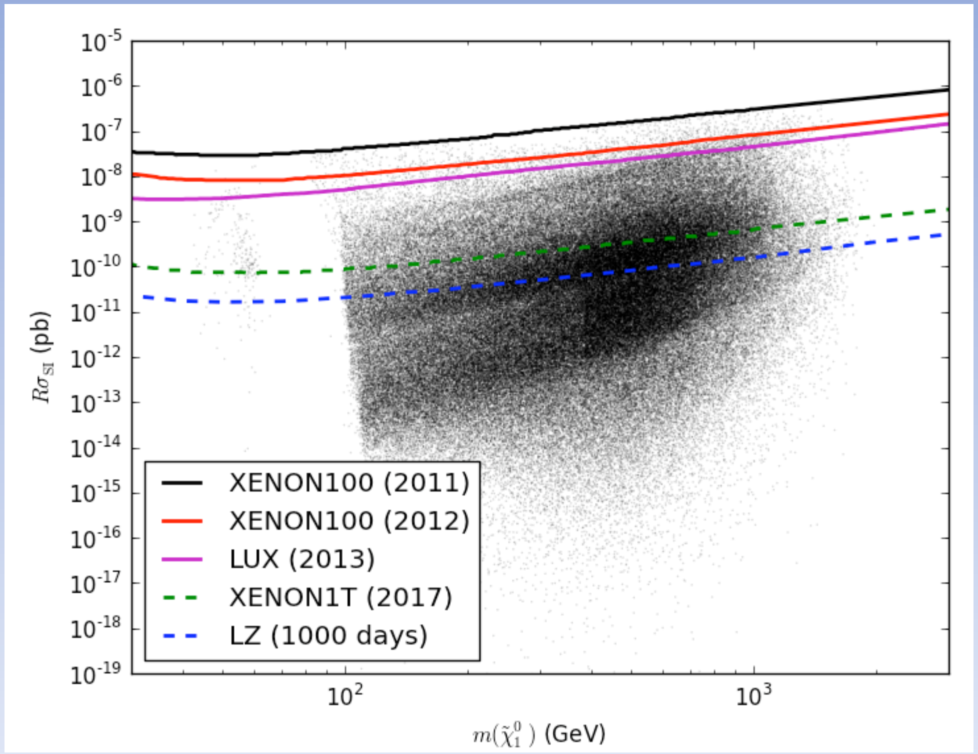
well motivated theoretically (less than before)

example of multiparameter situation ⇒ many channels

$pMSSM$ (19 parameters)

Rizzo 14, ...





e.g. bino with coannihilation or resonance can still saturate the observed Ω_{DM}

still not much probed by direct detection but Xenon1T, LZ, ..., will probe it substantially

example of multichannel model with good experimental perspective (but no guarantee)

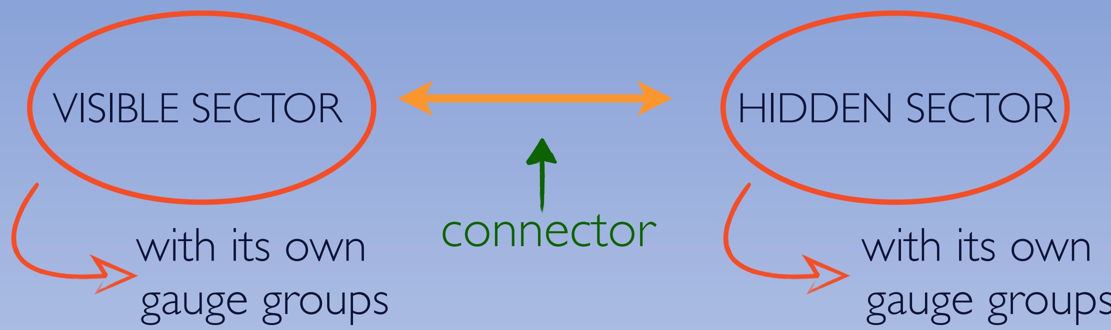
Explicit models: Hidden sector models

DM could be part of an all hidden sector

....

"Secluded DM" *Pospelov, Ritz, Voloshin 07*

....



including DM stabilization mechanism and DM annihilation

Testability depends on connector size: no more LHC, Direct/Indirect Detect., as soon as the connector coupling is sizably below unity

↓

only gravitational probes remain:
- extra radiation constraint
- DM self-interaction constraints (halo formation, bullet cluster,...)
- BBN, ...

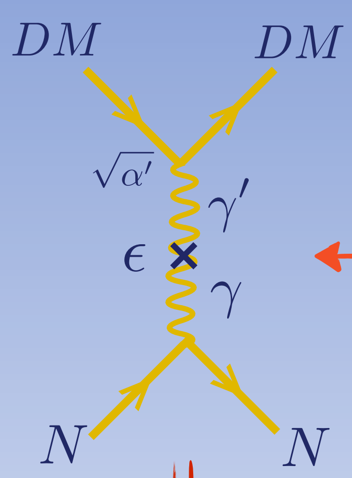
Berezhiani, Comelli, Villante 01
Feng, Tu, Yu 08
Ackerman, Buckley, Carroll, Kamionkowski, 09
Feng, Kaplinghat, Tu, Yu 09
Berezhiani, Lepidi 09
Mc Dermott, Yu, Zurek 10 , ...

Explicit models: Hidden sector models with light connector

Simple example:

$$\mathcal{L} \ni -\frac{1}{4} F'_{\mu\nu} F_Y^{\mu\nu}$$

a DM fermion charged under an unbroken U(1) which kinetically mixes with the photon



$$\frac{1}{q^2} \to \frac{1}{E_r^2}$$

$E_r \sim$ few KeV

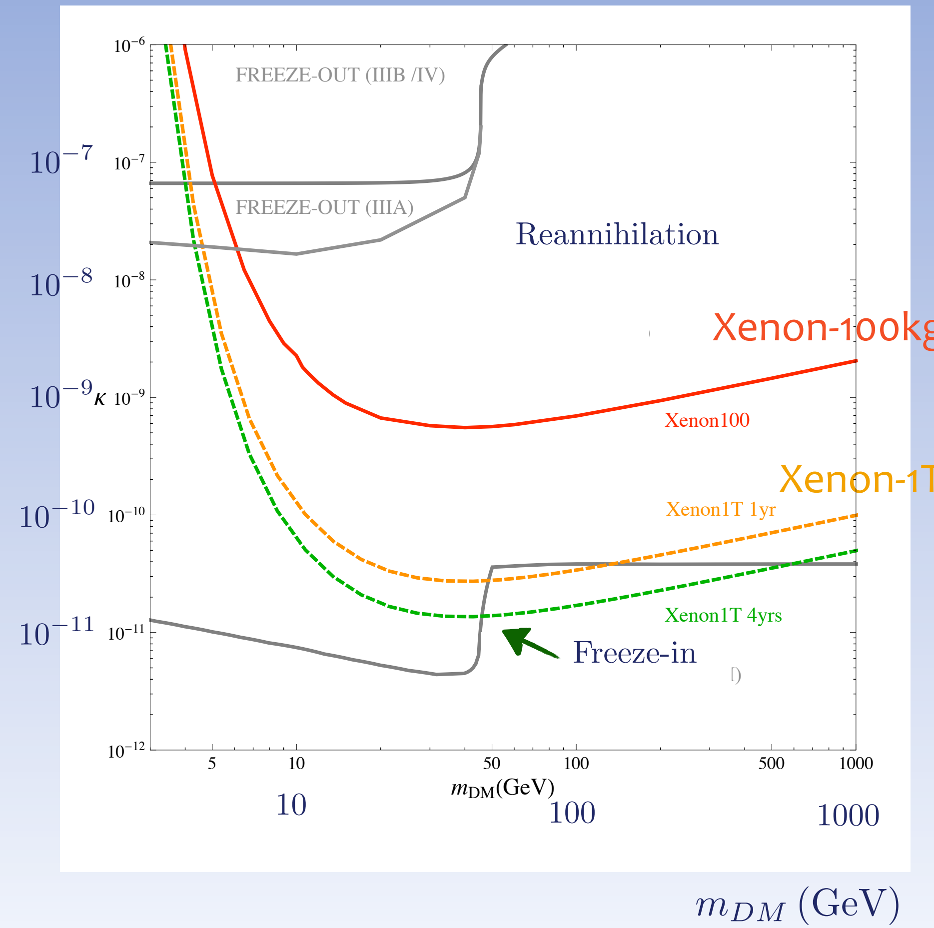
huge enhancement

direct detection sensitive to very small connector values

$$\frac{d\sigma}{dE_r} = \frac{1}{E_r^2}\frac{1}{v^2}\frac{2\pi\kappa^2 Z^2\alpha^2}{m_A} F_A^2(q r_A)$$

$$\kappa = \epsilon \cdot \sqrt{\frac{\alpha'}{\alpha}}$$

Chu, T.H., Tytgat 11



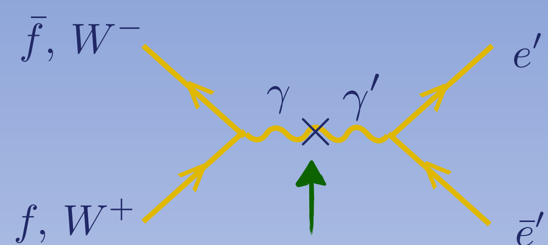
.....,
Scwhetz, Zupan 11
Fornengo, Panci, Regis 11
Chu, T.H., Tytgat 11

Visible sector/Hidden sector/Connector structure:
4 basic ways to get the observed relic density

here for scenario with only visible sector at end of inflation

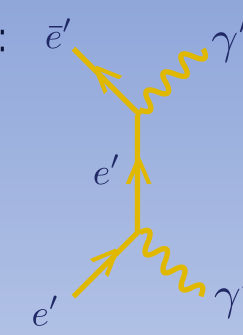
A DM fermion charged under a U(1) which kinetically mixes with the photon:

Connector processes:



$\mathcal{L} \ni -\frac{\varepsilon}{2} F_Y^{\mu\nu} F'_{\mu\nu}$

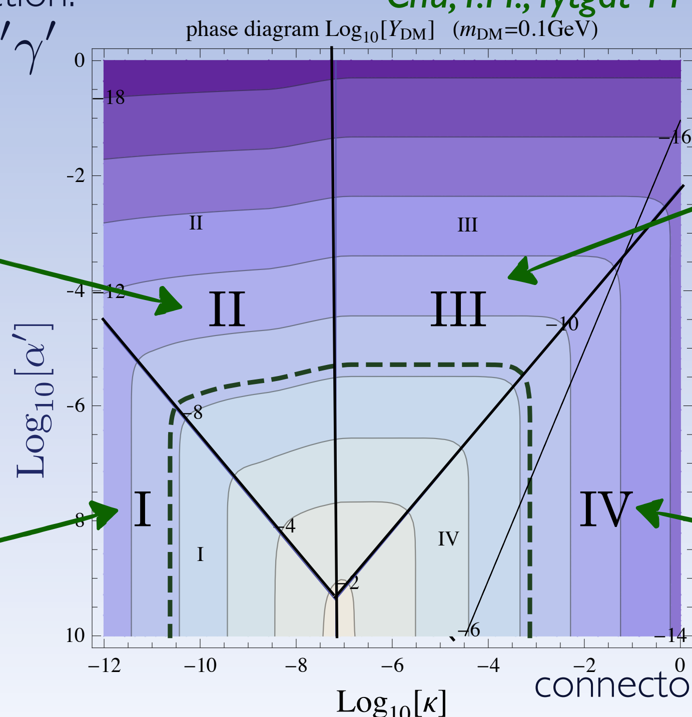
Hidden sector process:



hidden sector interaction:

$\bar{\psi}_{DM}\psi_{DM} \leftrightarrow \gamma'\gamma'$

Chu, T.H., Tytgat 11



Reannihilation regime

Hidden sector freeze-out regime

Freeze-in regime

Connector freeze-out regime

connector interaction:

$SM\, SM \leftrightarrow \bar{\psi}_{DM}\, \psi_{DM}$

See also Cheung, Ellor, Hall, Kumar 11 with slow decay

DM particle stability issue

A WIMP do decay unless a symmetry forbids it ← unlike various non WIMP models (e.g. at lower scale)

↓ many models: an ad-hoc Z_2 sym.

more attractive reason??

- based on having DM as a large electroweak multiplet: accidental symmetry *Cirelli, Fornengo, Strumia 06*
- based on a gauge symmetry: Z_2 remnant subgroup of broken GUT group
  - as R-parity in SUSY-GUT *Mohapatra 86, Martin 92, Aulakh, Melfo, Rasin, Senjanovic 98*
  - as Z_2^{B-L} in non-susy SO(10) *Kadastik, Kannike, Raidal 10, Frigerio, T.H. 10*
- based on a flavor symmetry *Hirsch, Morisi, Peinado, Valle 10. Kajiyama, Kannike, Raidal 11, Lavoura, Morisi, Valle 12, Lopez-Honorez, Merlo 13, Kile 13*
- hidden sector DM: various simple possibilities: -DM stable as electron
  -DM stable as lightest neutrino
  -DM stable as proton

  abelian or non-abelian accidental sym.

  T.H 07, T.H., Tytgat 09, Arina, T.H., Ibarra, Weniger 10

⇒ The stabilization mechanism determines many structural features of the all DM scenario

DM-EW scale coincidence

Main solutions remain:

- SUSY
- extra-dimensions: KK-DM, ...
- strongly coupled TeV scenarios: recent composite DM models, "baryonic" DM...

Given the LHC situation it's worth to be also open for alternatives even if more conjectural

→ recent revival of the old Coleman-Weinberg radiative sym. breaking mechanism:

DM being at TeV scale could drive EWSB: $v_{EW} \sim m_{DM} \sim TeV$

→ not a solution to hierarchy problem: assumes $\mu^2 \simeq 0$ at Planck scale

if this conjecture is done it gives $m_{DM} << m_{Planck}$

$v_{EW} \sim m_{DM} \sim TeV$

→ with inert doublet scalar DM *T.H., Tytgat 07*

→ with hidden vector DM *T.H., Strumia 13*

Carone, Ramos 13
Khoze 13
Lindner, Schmidt, Watanabe 13
Salvio, Strumia 14
Khoze, Mc Cabe, Ro 14,
....

Very short conclusion

Establishing DM as a particle:

- ↪ complementary phenomenological ways to test it from multichannel experiments
- ↪ very promising experimentally for the WIMP scenario for visible sector DM models
- ↪ clear possibilities for hidden sector DM models too
- ↪ potentially related to many other fundamental issues, at various possible levels

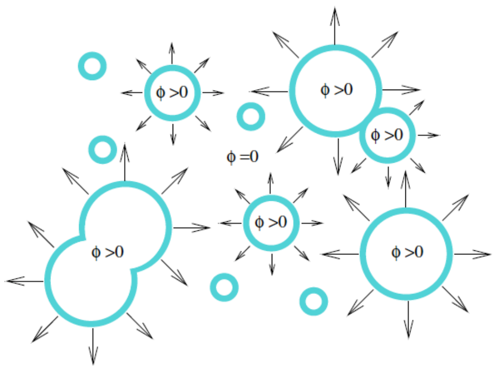
Is DM at TeV scale useful for anything else than DM??

relevant question even if: -one do not bring a solution for the hierarchy problem

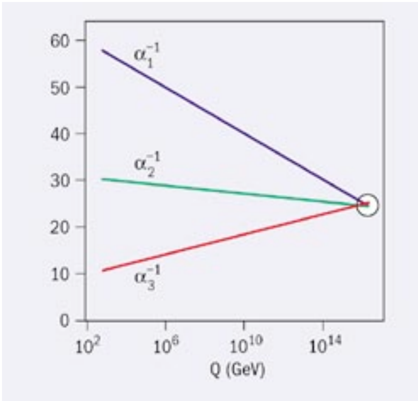
-one do not bring an explanation for $m_{DM} \sim \mathrm{TeV} \sim v_{EW}$

- DM at TeV scale could easily play a role for EW baryogenesis,

or even making it successful



- DM at TeV scale could constitute the unique ingredient missing for EW unification at GUT scale



$SO(10)$ setup with automatically stable fermion triplet DM

"split SUSY without SUSY"

- DM at TeV scale could easily play a role for EWSB dynamics