Dark Matter Multiplicity

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Martin Schmaltz

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arXiv: 1505.03542
follow up arXiv: 1507.04351

DARK MATTER

1) Gravitational Interactions.

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2) Other interactions with SM (no EM!)

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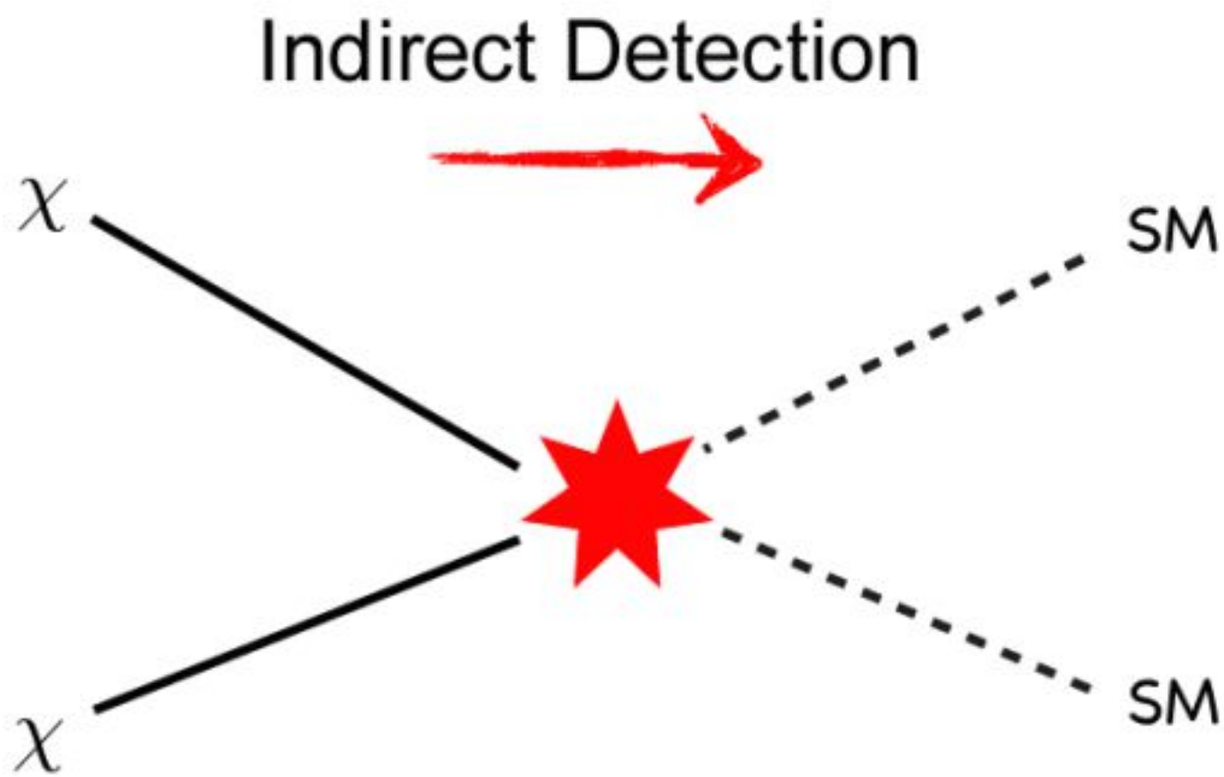
1) Gravitational Interactions.

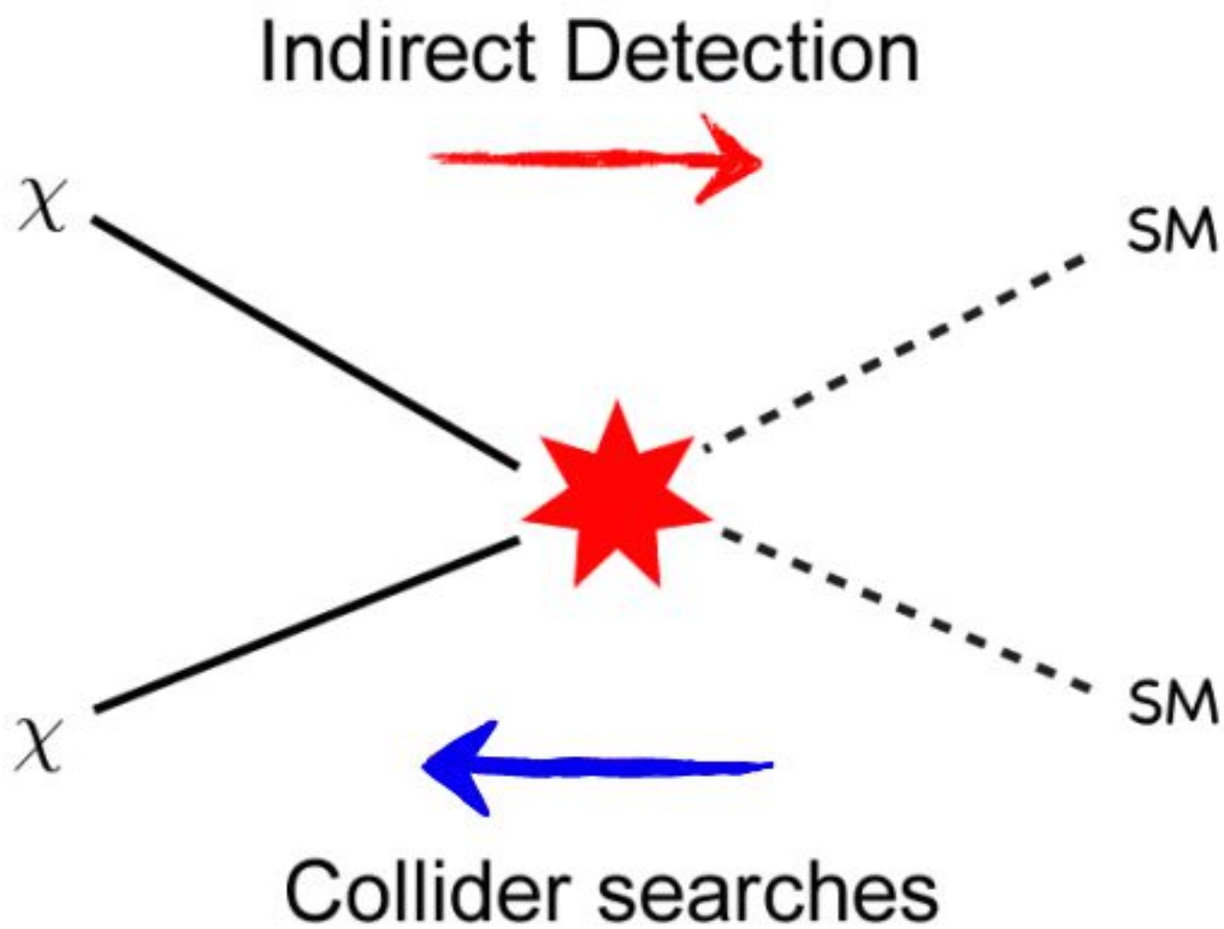
2) Other interactions with SM (no EM!)

- ·) Indirect Detection
- ·) Direct Detection
- ·) Collider Searches

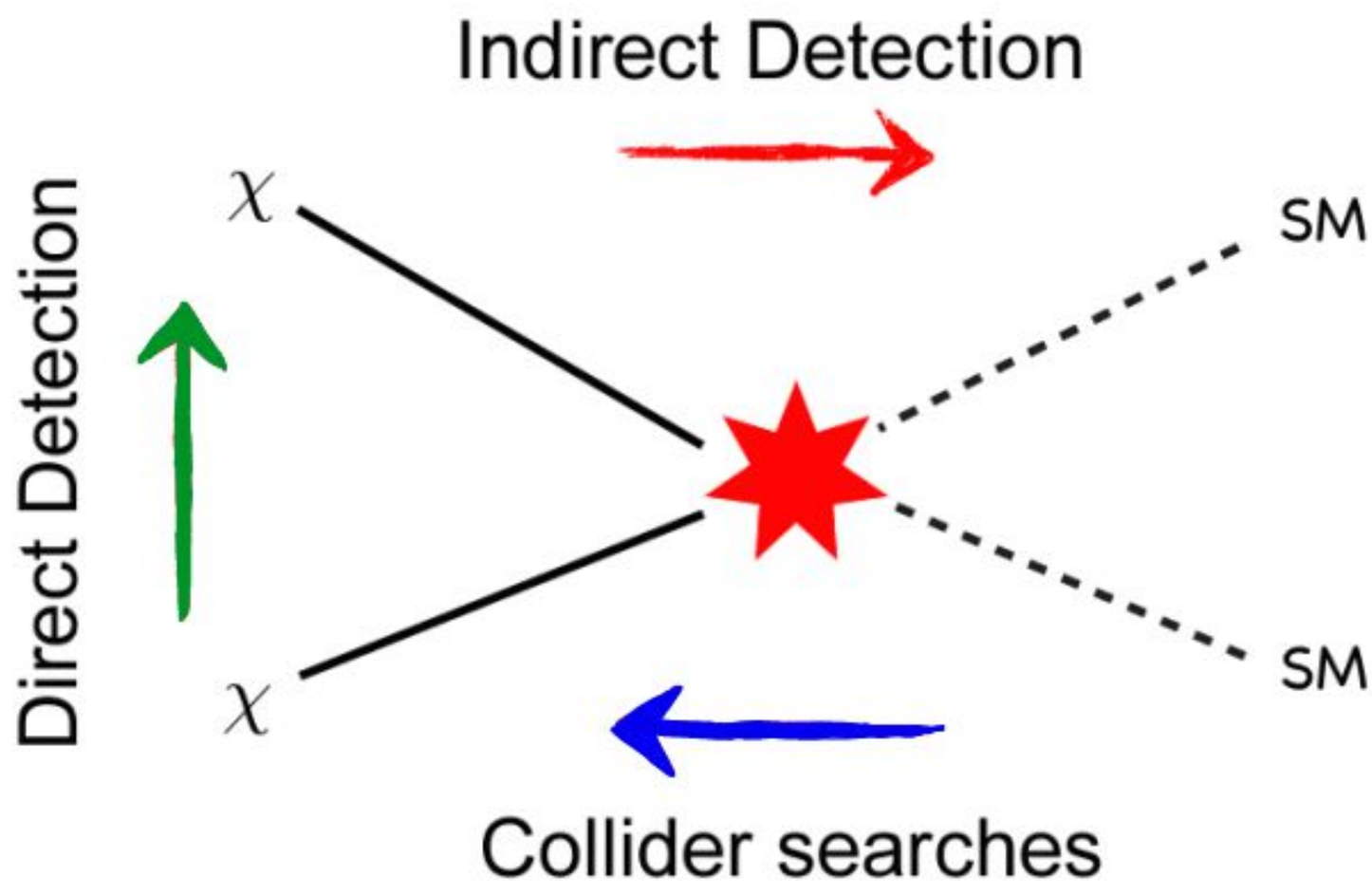
BREAK IT



BREAK IT, MAKE IT



BREAK IT, MAKE IT, SHAKE IT



MULTIPLICITY?

DM – SM interactions:

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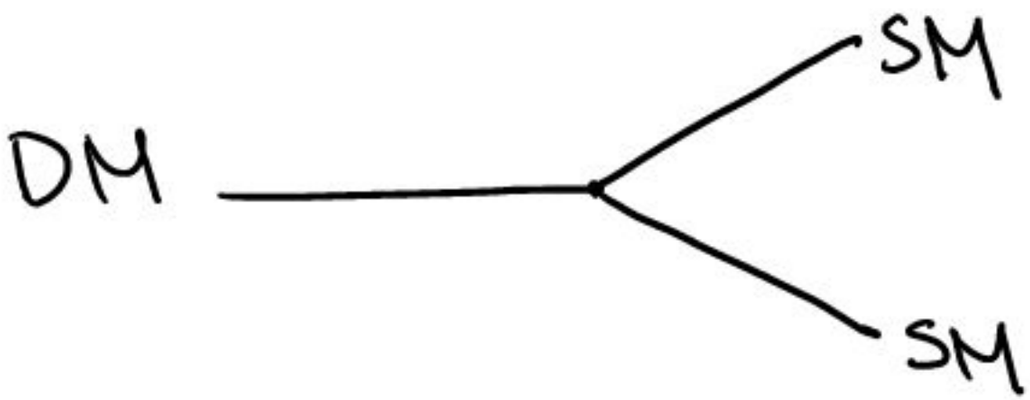
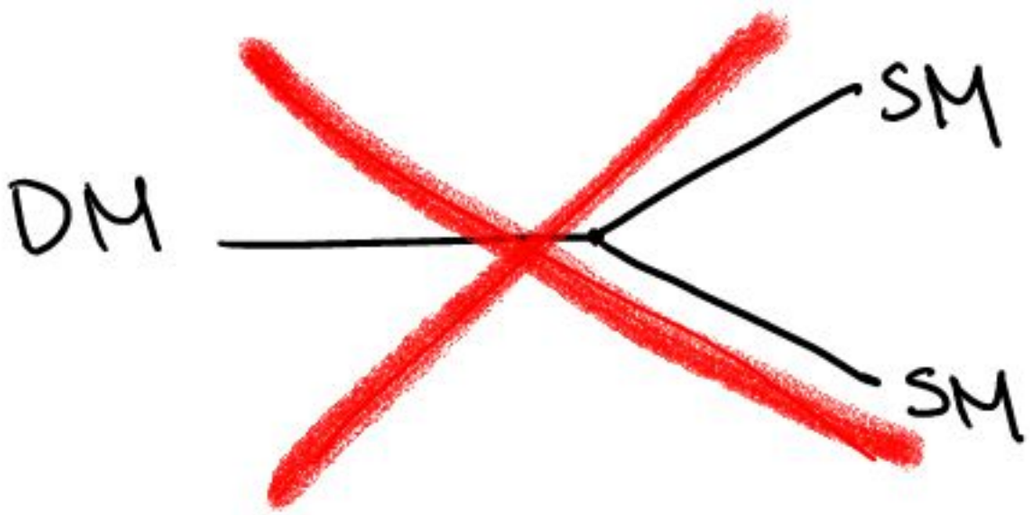
- 

MULTIPLICITY?

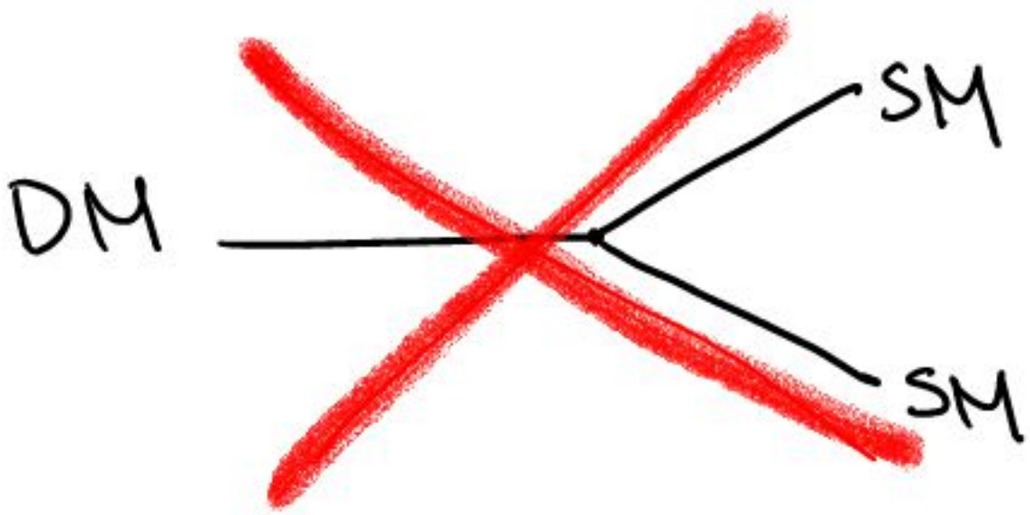
DM – SM interactions:

- 

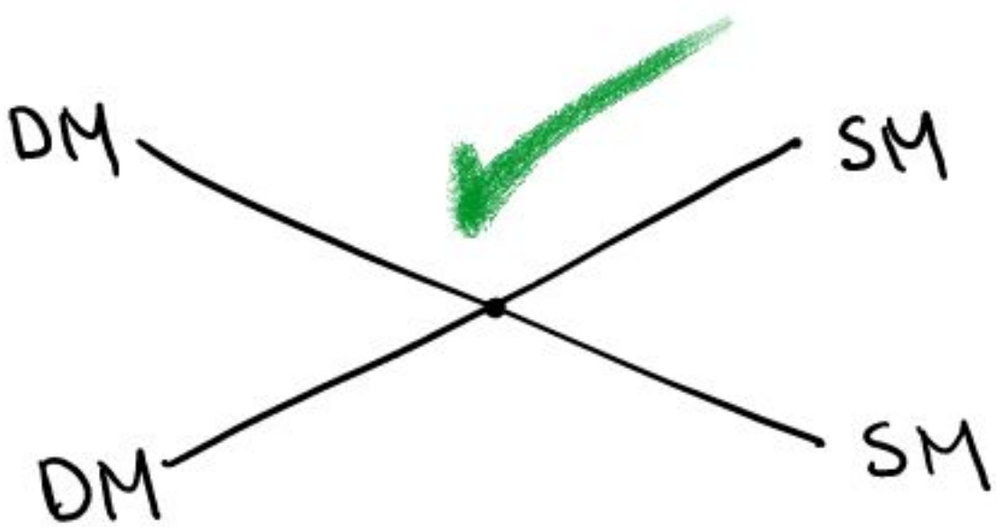
DM decay!

MULTIPLICITY?

DM – SM interactions:

- 

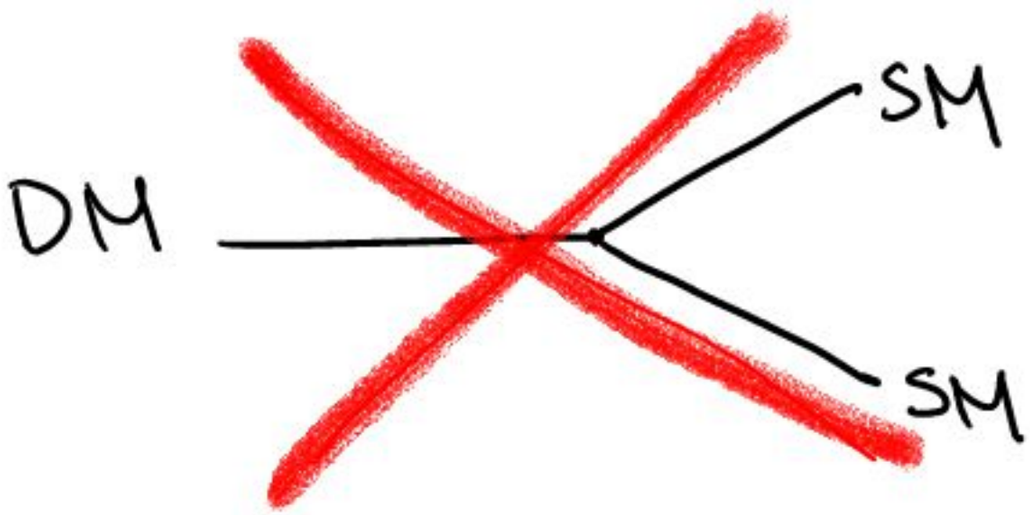
DM decay!

- 

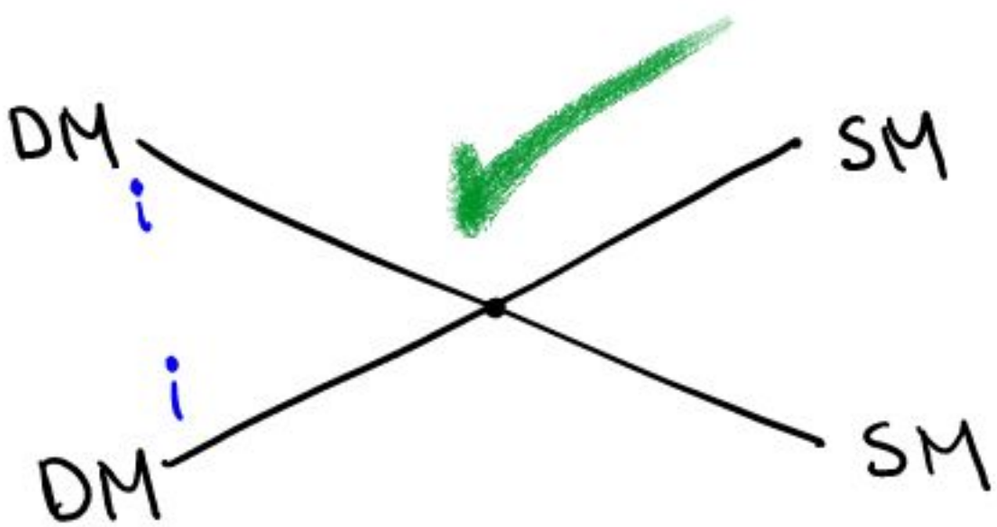
OK!

MULTIPLICITY?

DM – SM interactions:

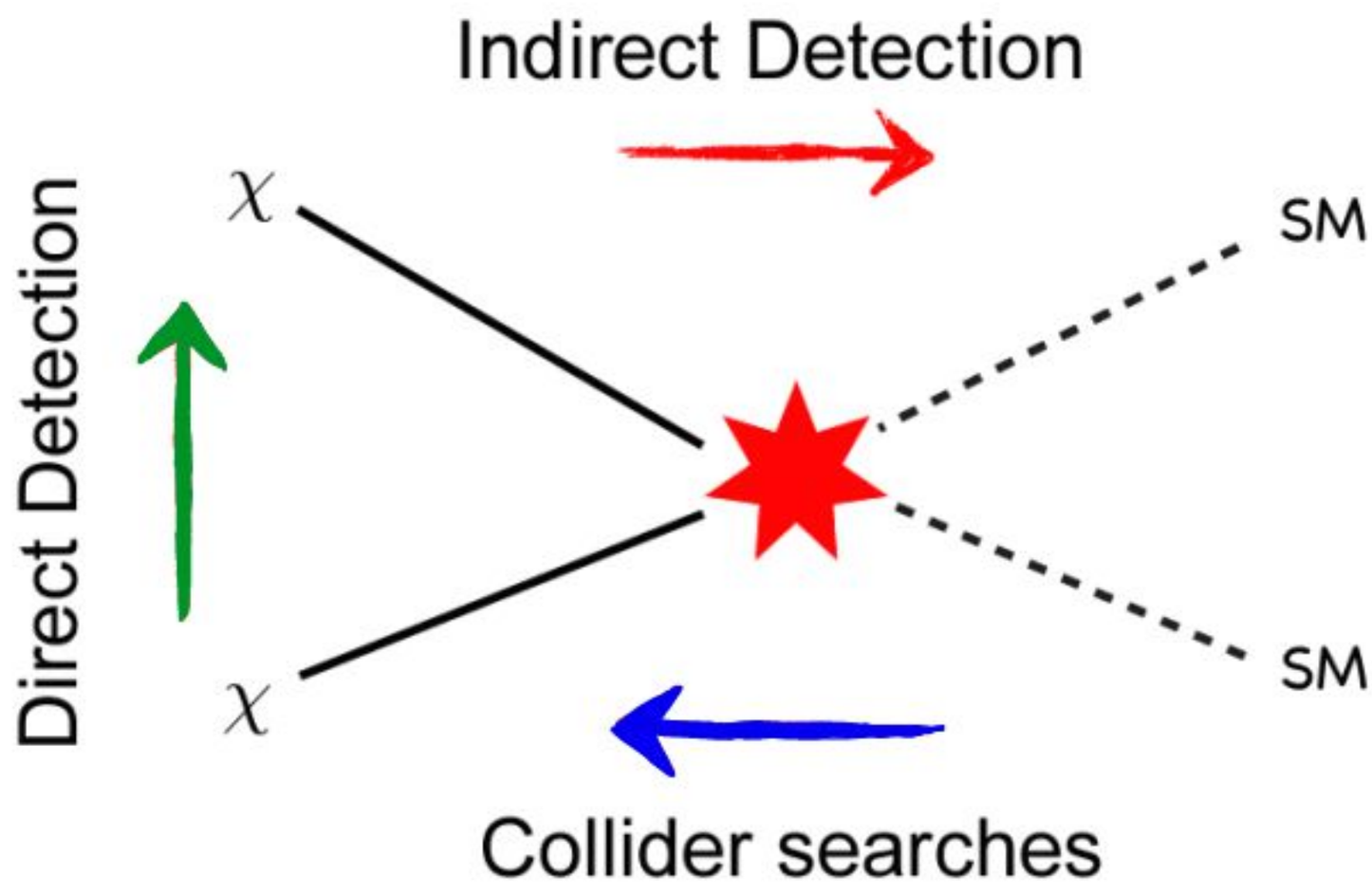
- 

DM decay!

- 

i index: multiplicity

BREAK IT, MAKE IT, SHAKE IT



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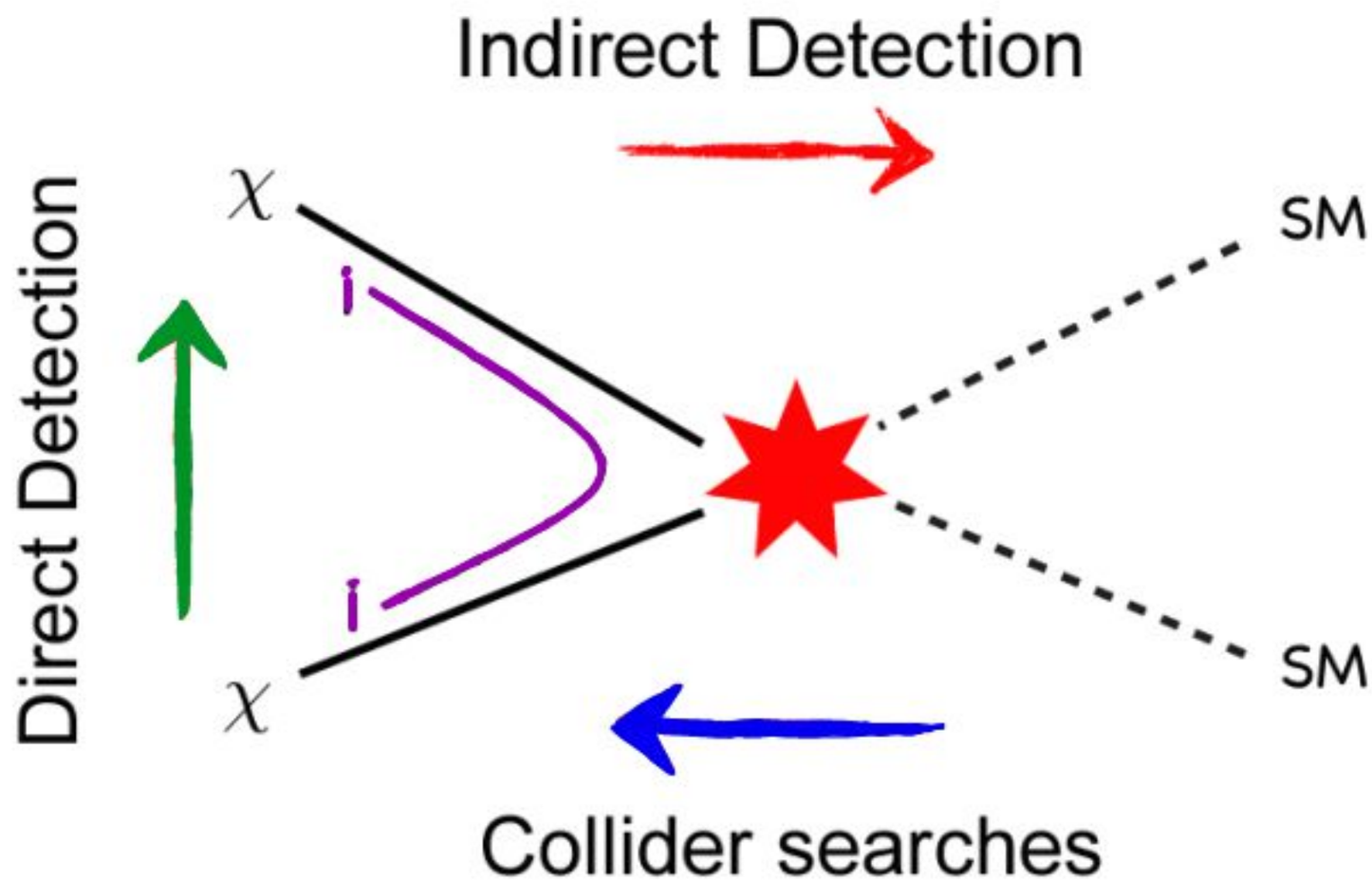

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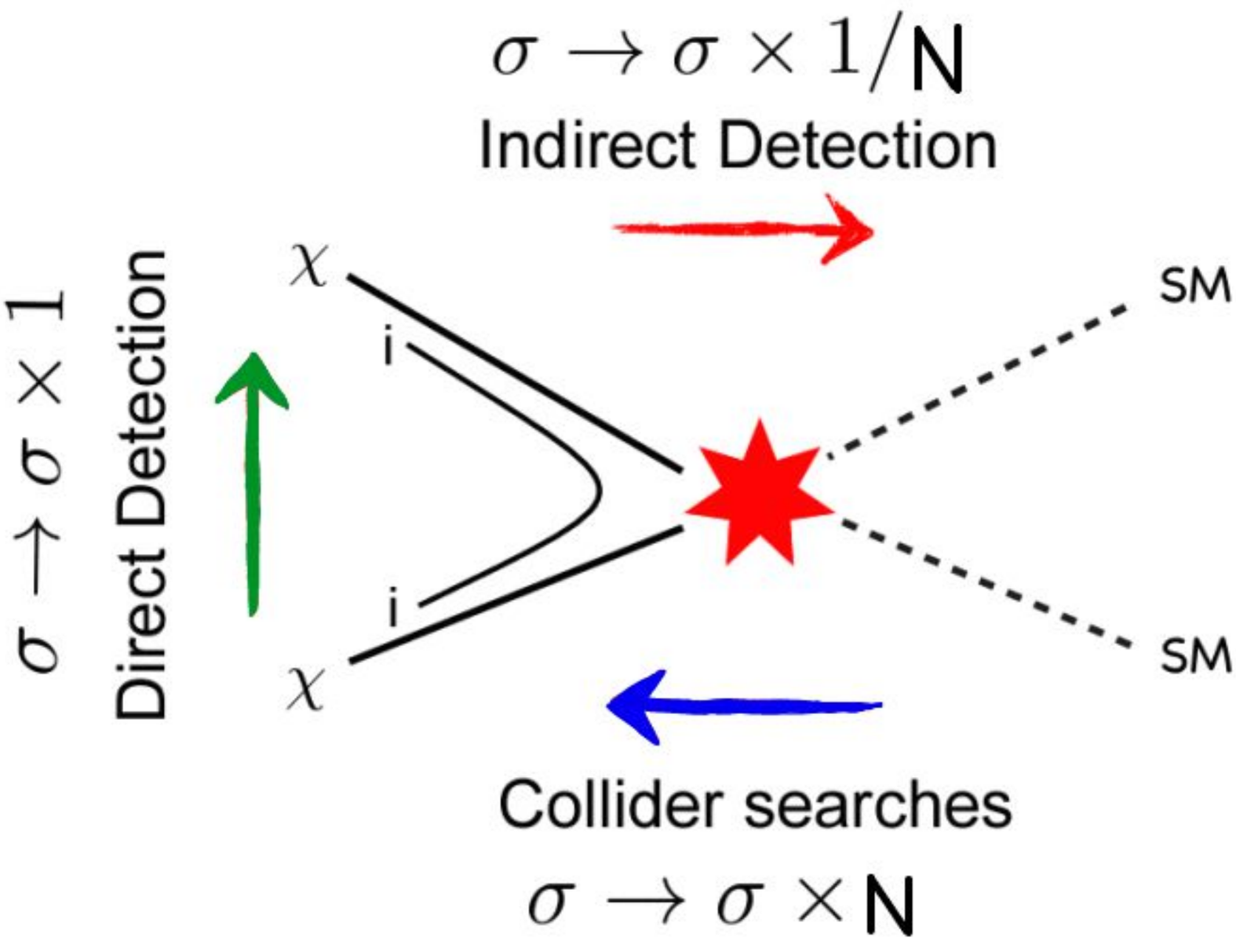
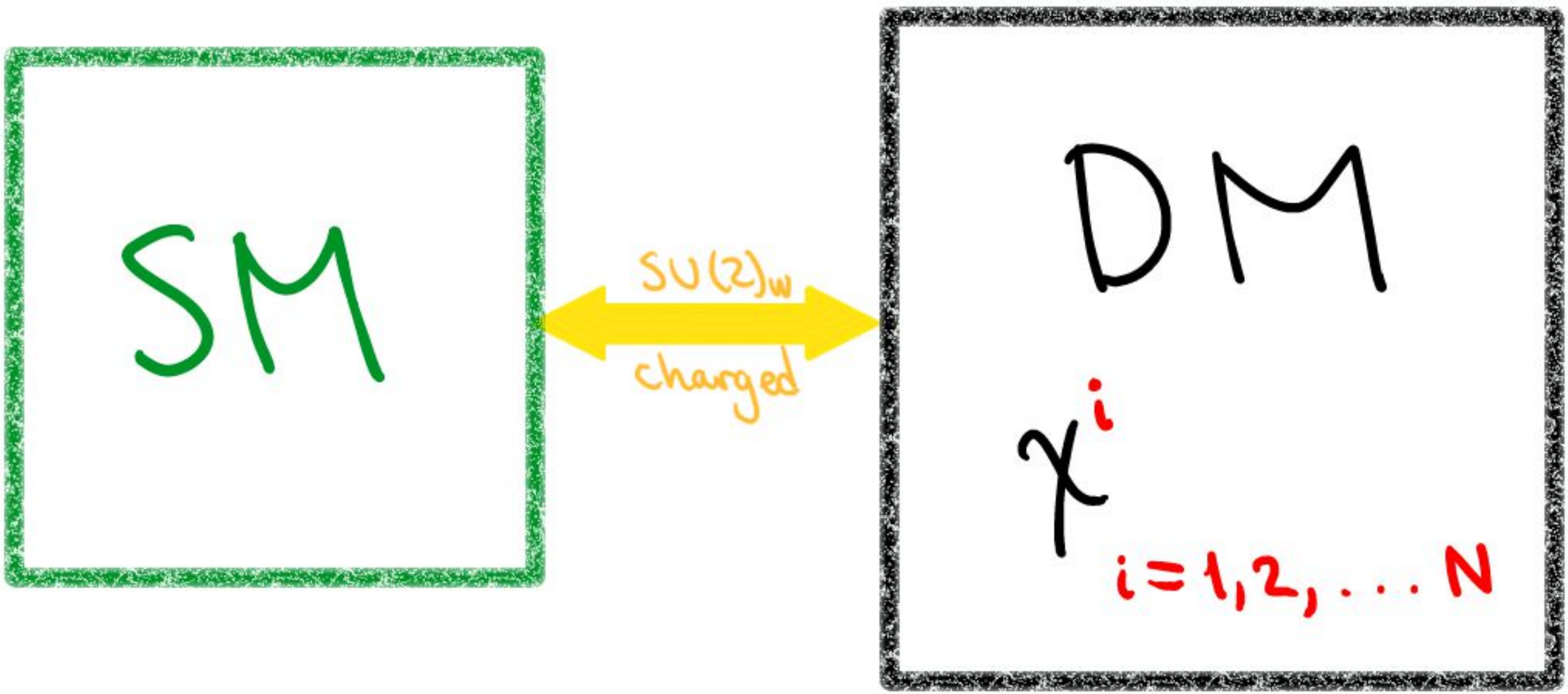


Concrete

Realization...

Our Proposal



DM Story

·) Our paper:

$$\left.\begin{array}{ll} \chi \sim (1,3)_0 & \text{in SM} \\ \sim N & \text{in } SU(N)_d \end{array}\right\} \begin{array}{l}\text{"wino-like"} \\ \text{Dirac DM}\end{array}$$

·) $\left\{\begin{array}{l} \chi^{\pm i} \\ \chi^{0 i} \end{array}\right.$ $\quad \delta M_\chi \equiv M_{\chi^\pm} - M_{\chi^0} \sim 160$ MeV

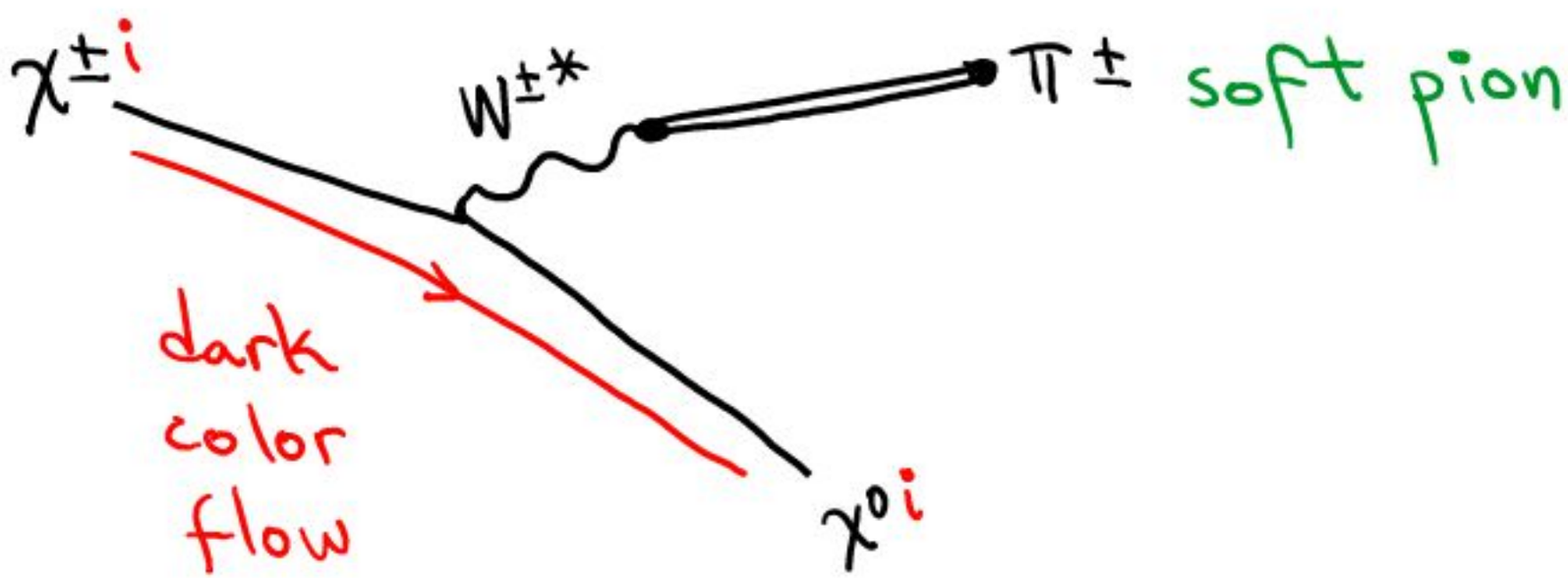
after EWSB

•) $SU(N)_d$: dark color (conserved quantum number)

$\Rightarrow$ χ^{0i} stabilized

$\therefore$ χ^{0i}: (degenerate) DM

•)

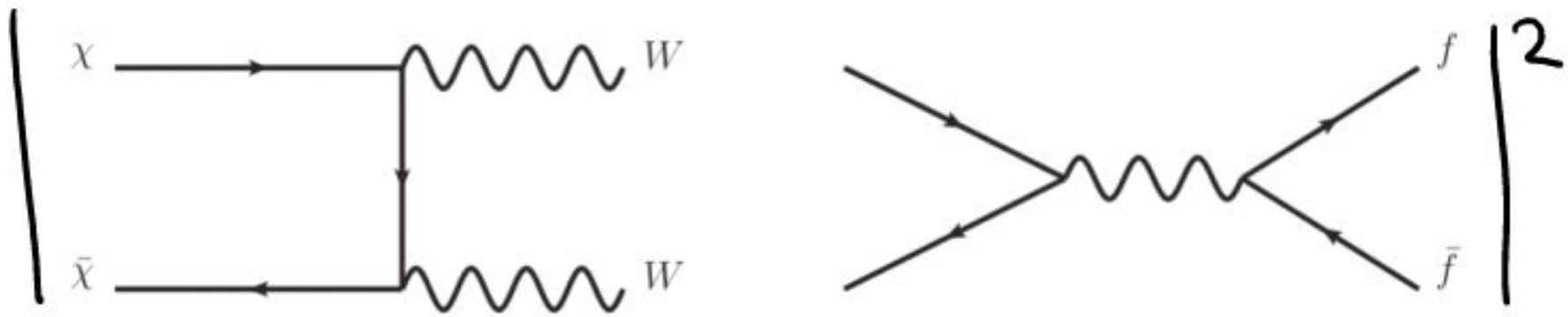


BREAK IT!

break it!

DS THERMAL HISTORY

$\langle \sigma v \rangle_{ann} \sim$

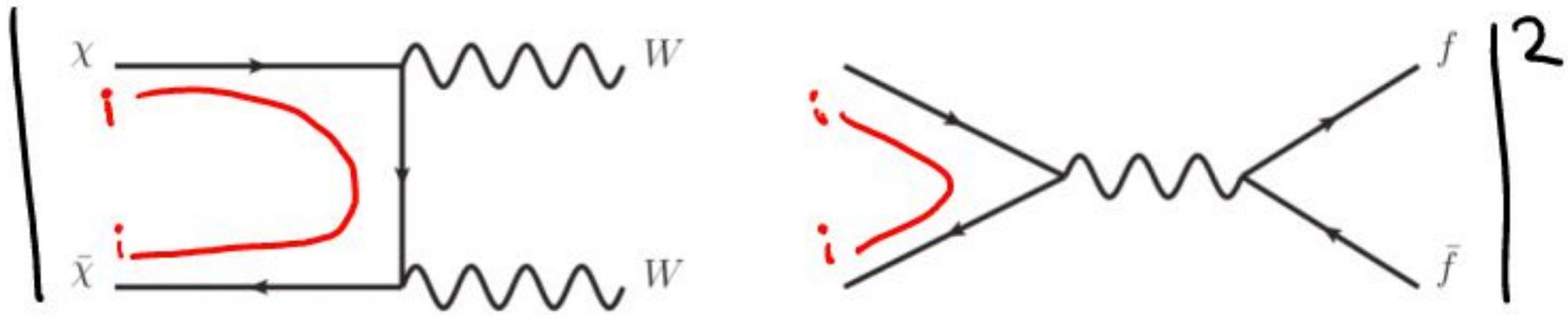


$$\Omega_{dm} = 0.26 \sim \frac{1}{\langle \sigma v \rangle_{ann}^{wino}} \sim \frac{1}{\alpha_W^2 / M_{wino}^2} = \frac{M_{wino}^2}{\alpha_W^2}$$

break it!

DS THERMAL HISTORY

$\langle \sigma v \rangle_{ann} \sim$

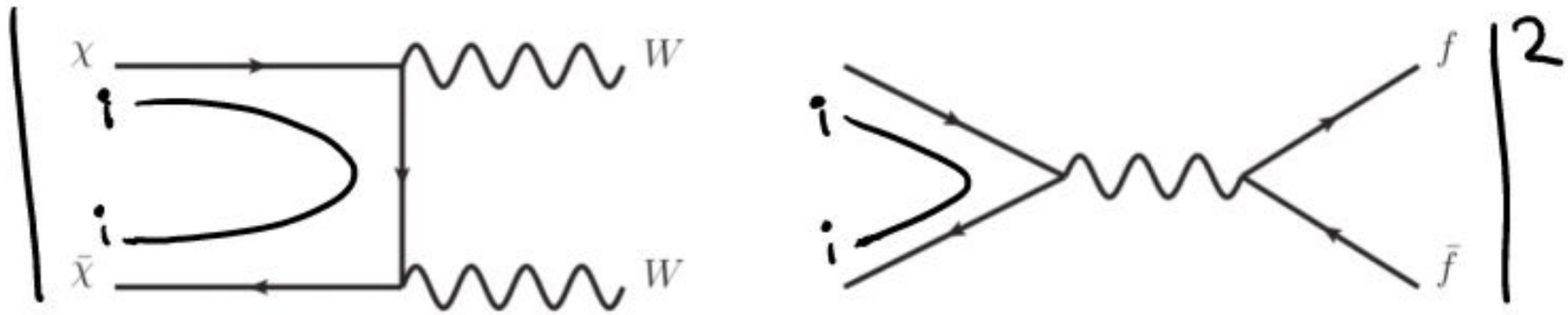


$$\Omega_{dm} = 0.26 \sim \frac{1}{\langle \sigma v \rangle^{us}_{ann}} \sim \frac{1}{\alpha_w^2 / M_\chi^2 \, 2N} = \frac{2N M_\chi^2}{\alpha_w^2}$$

break it!

DS THERMAL HISTORY

$\langle \sigma v \rangle_{ann} \sim$



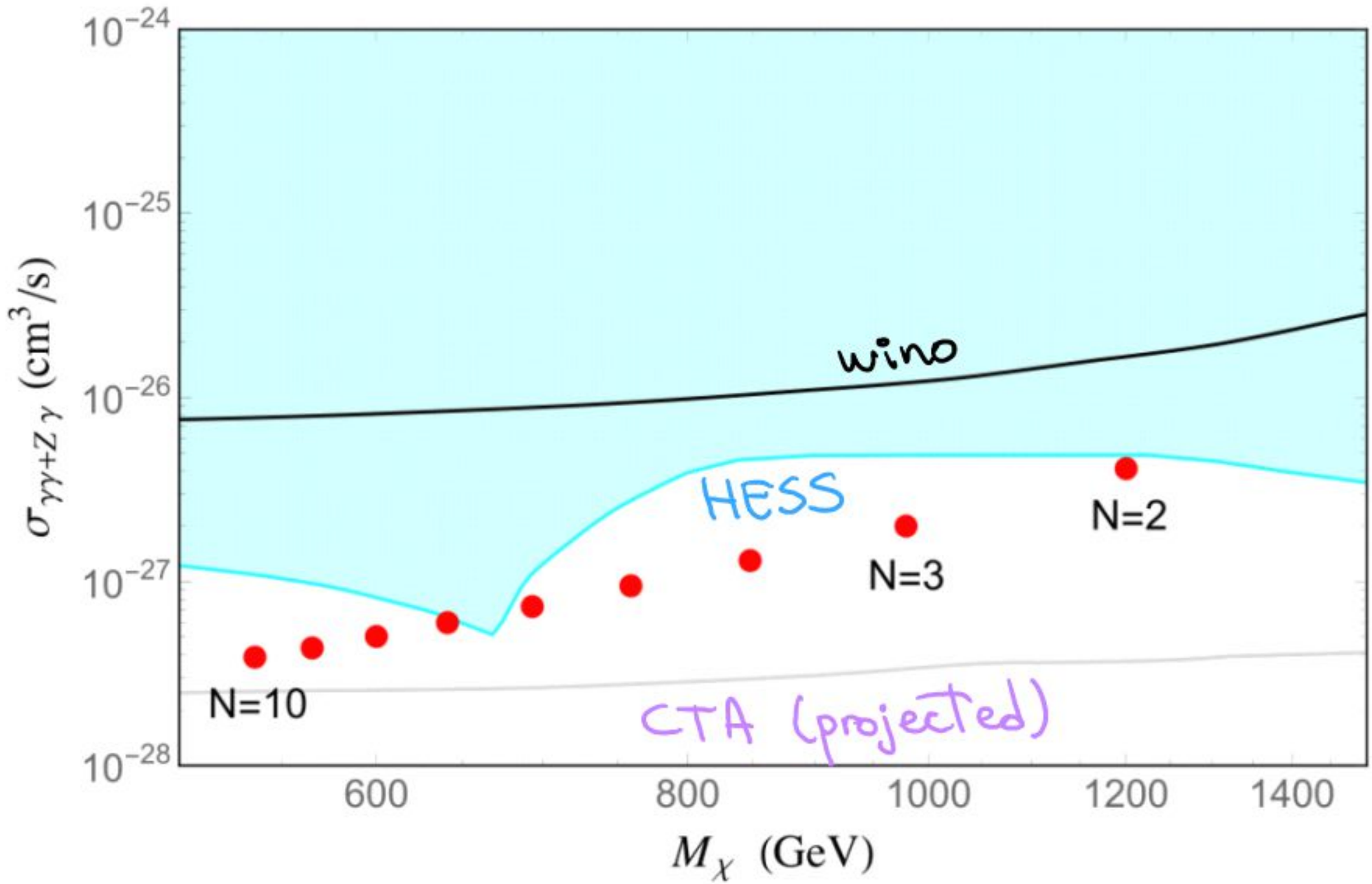
$$\Omega_{dm} = 0.26 \sim \frac{1}{\langle \sigma v \rangle^{us}_{ann}} \sim \frac{1}{\alpha_w^2 / M_\chi^2 \, 2N} = \frac{2N M_\chi^2}{\alpha_w^2}$$

$$\Rightarrow M^2_{wino} = 2N \, M_\chi^2 \quad \therefore \quad M_\chi = M_{wino} / \sqrt{2N}$$

$N = 2$	$N = 3$	$N = 4$	$N = 5$	Generic N
1.2 TeV	1.0 TeV	0.9 TeV	0.8 TeV	$\sim 2.4/\sqrt{2N}$ TeV

break it!

INDIRECT DETECTION



MAKE IT!

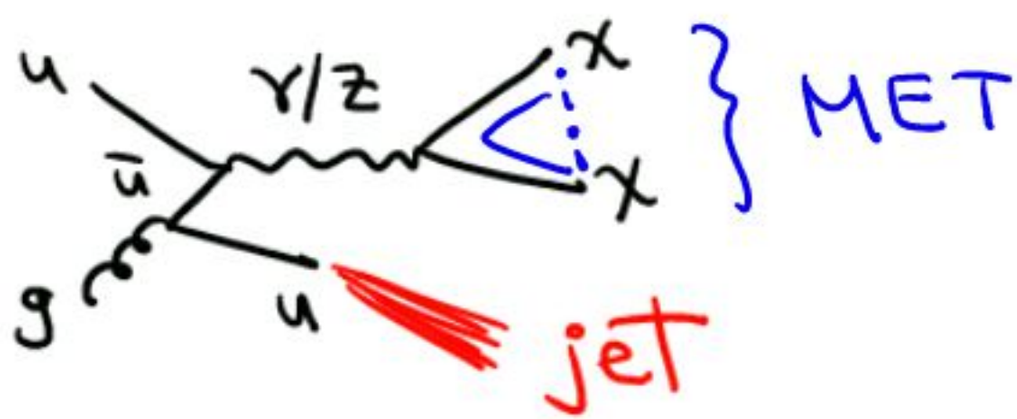
make it

COLLIDER SEARCHES

- $\sigma^{ours}_{pair\,prod} = \sigma^{wino}_{pair\,prod} \times 2N$
- $N\uparrow \Rightarrow M_\chi \downarrow$

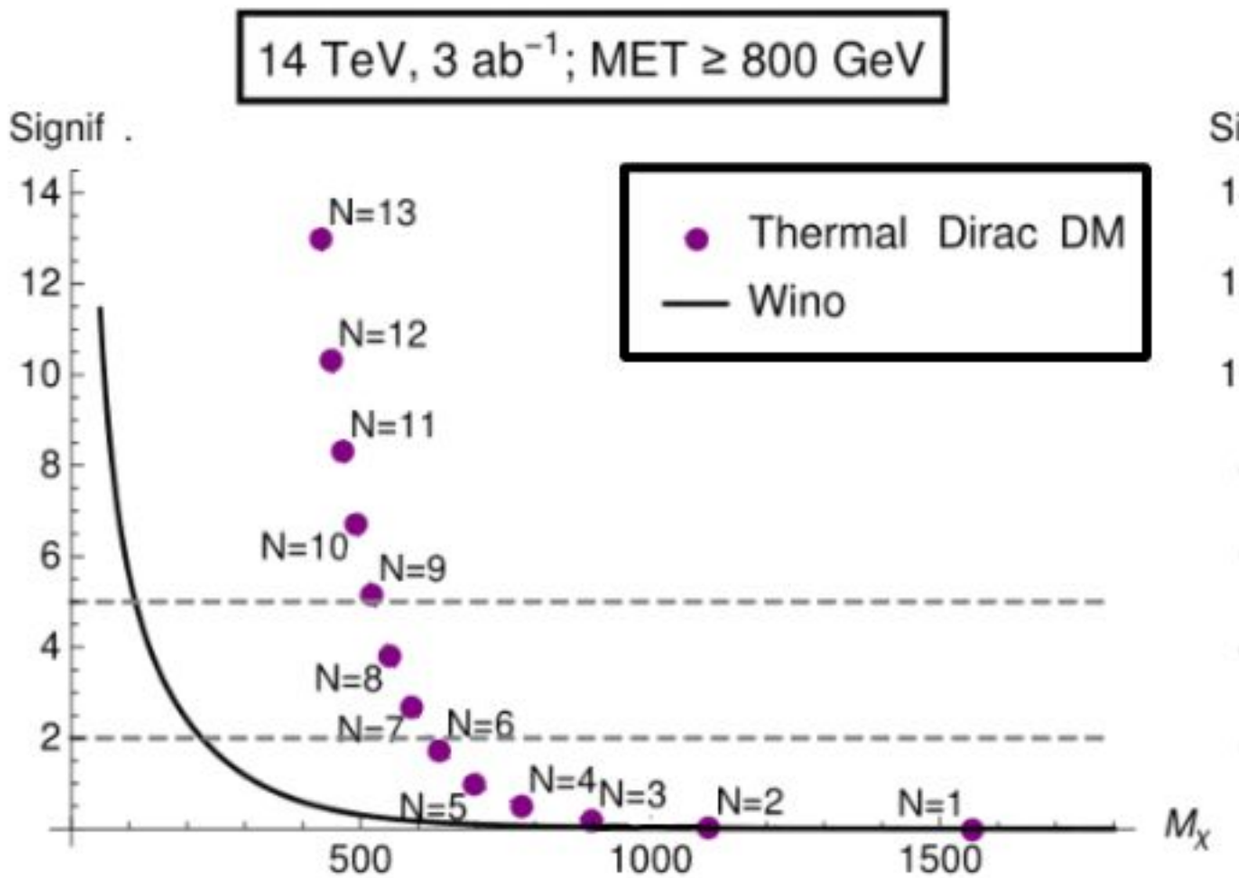
} improvements

- Monojet searches (MET + j):

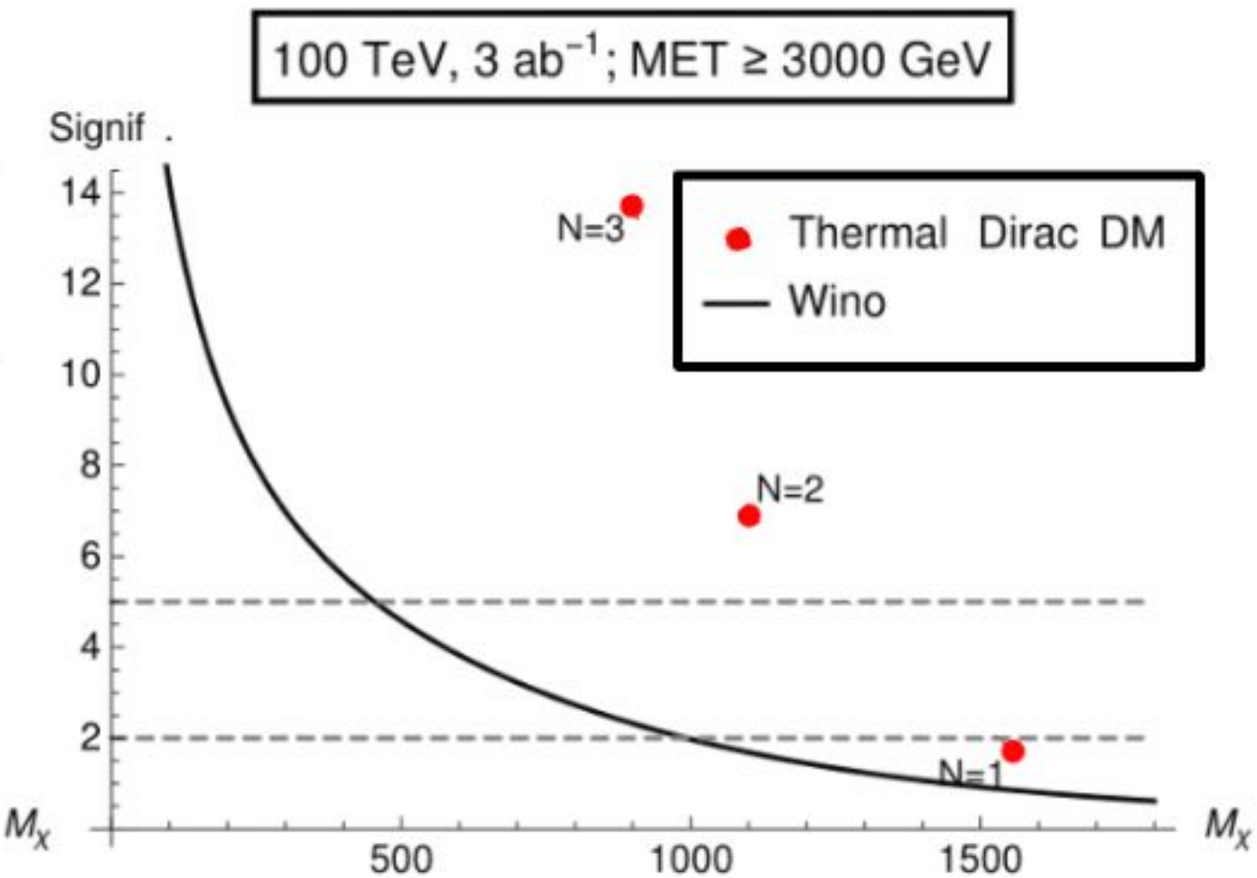


- Disappearing tracks: $\chi^\pm$ detected, no SM-bckg!

HL-LHC



FHC



- Run 1 (8 TeV) @ ATLAS + CMS recasted data rules out $N \geq 20$.

1 min. of

The Gauge

Story

GLOBAL...

SM

$SU(2)_W$

charged

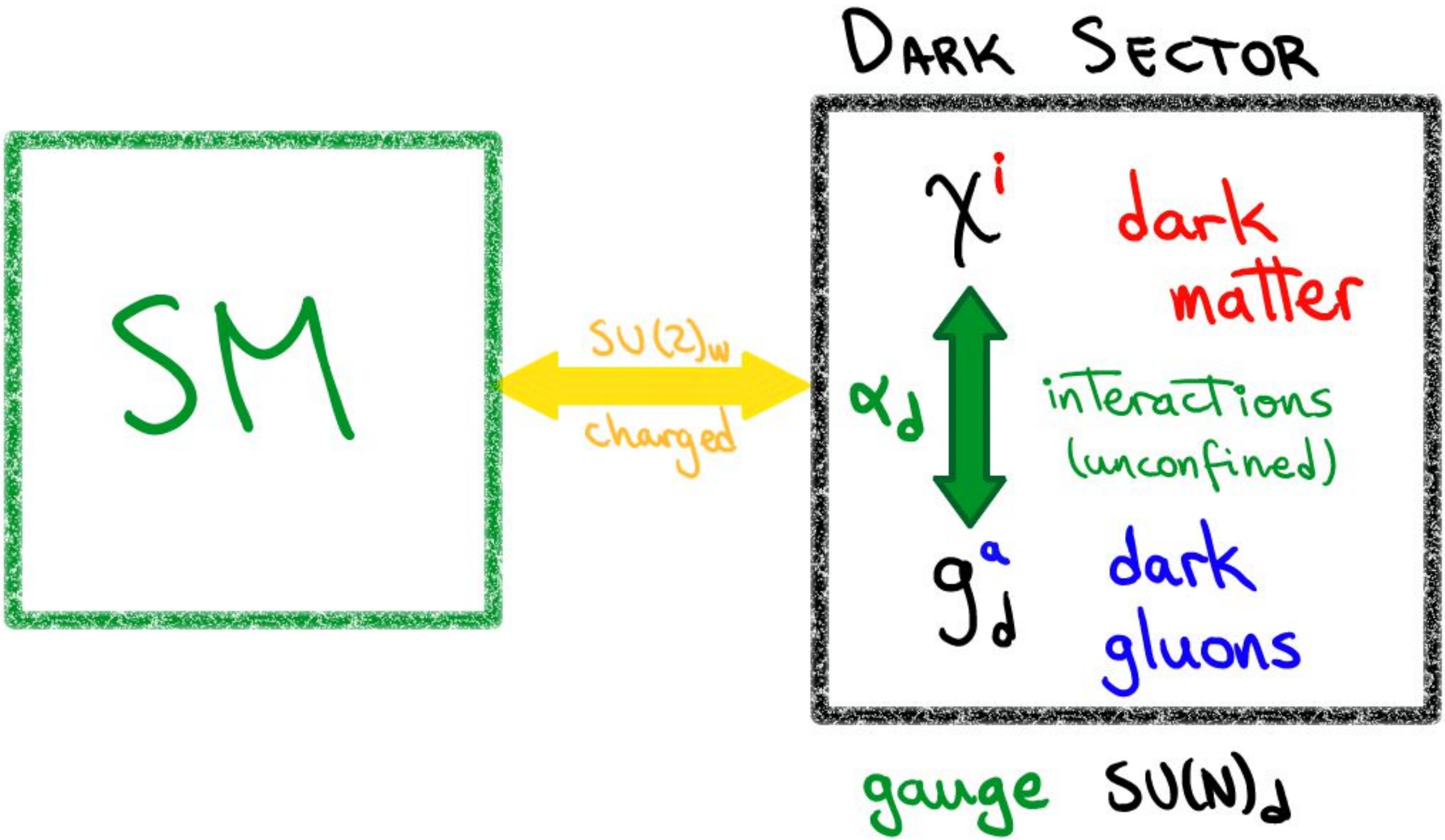
DM

global $SU(N)_d$

χ^i

$i = 1, 2, \ldots N$

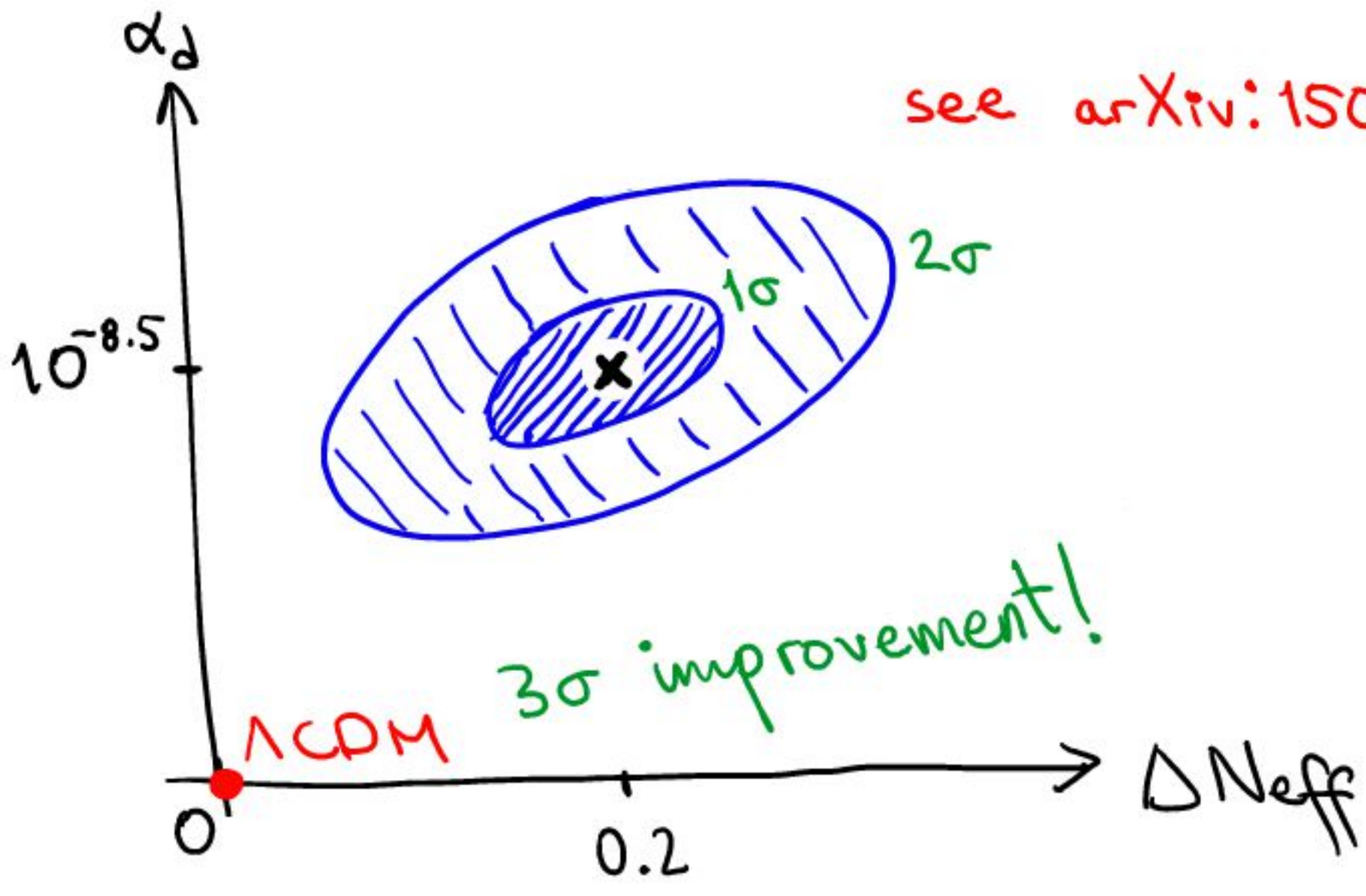
GAUGE IT!


DARK SECTOR
SM
$SU(2)_W$
charged
χ^i
dark matter
α_d
interactions (unconfined)
g_d^a
dark gluons
gauge $SU(N)_d$

THE RESULTS

- g_d: dark radiation
- $\chi^i - g_d$: interactions

see arXiv: 1507.04351



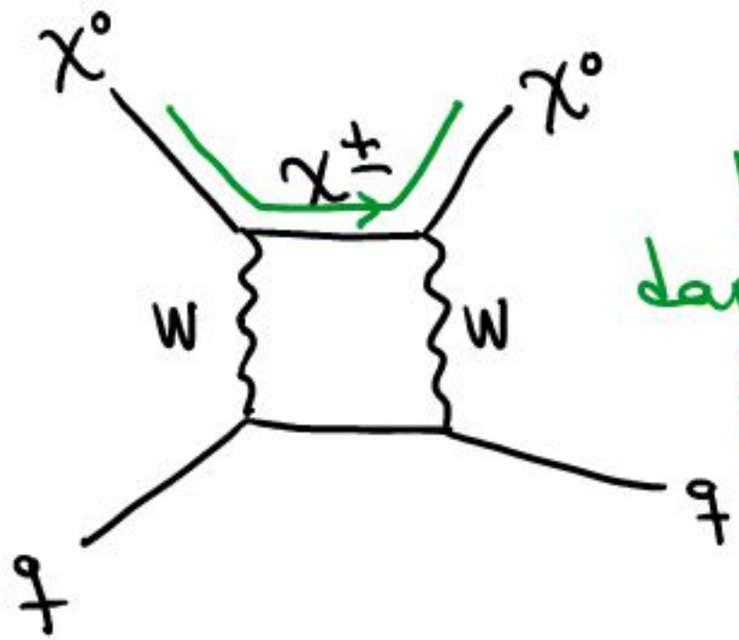
Thanks!

BACK-UP

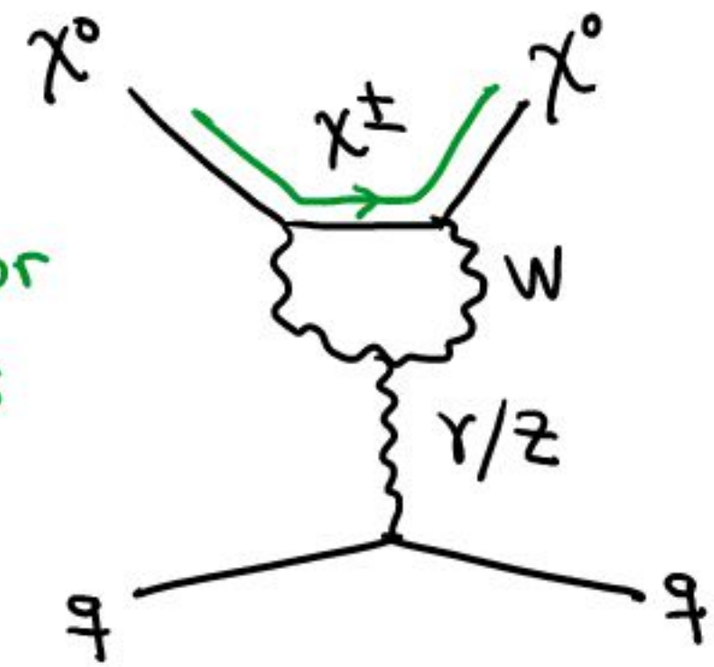
SLIDES

shake it!

DIRECT DETECTION



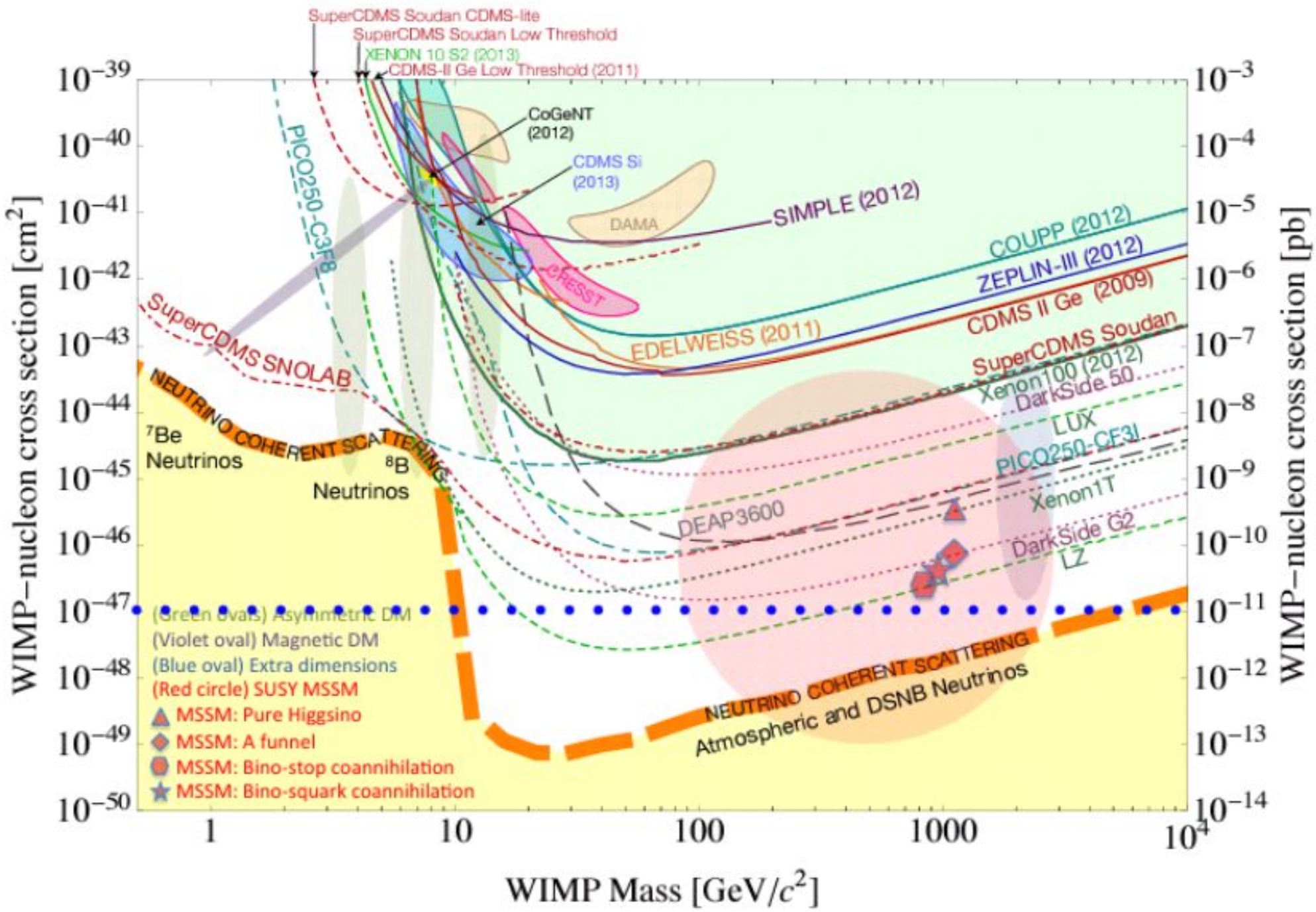
NO dark color factors



- $\sigma_{DD}^{SI} \sim 10^{-47}\,\mathrm{cm}^2 \quad (M_\chi \gg M_W^2)$.

- No improvement.

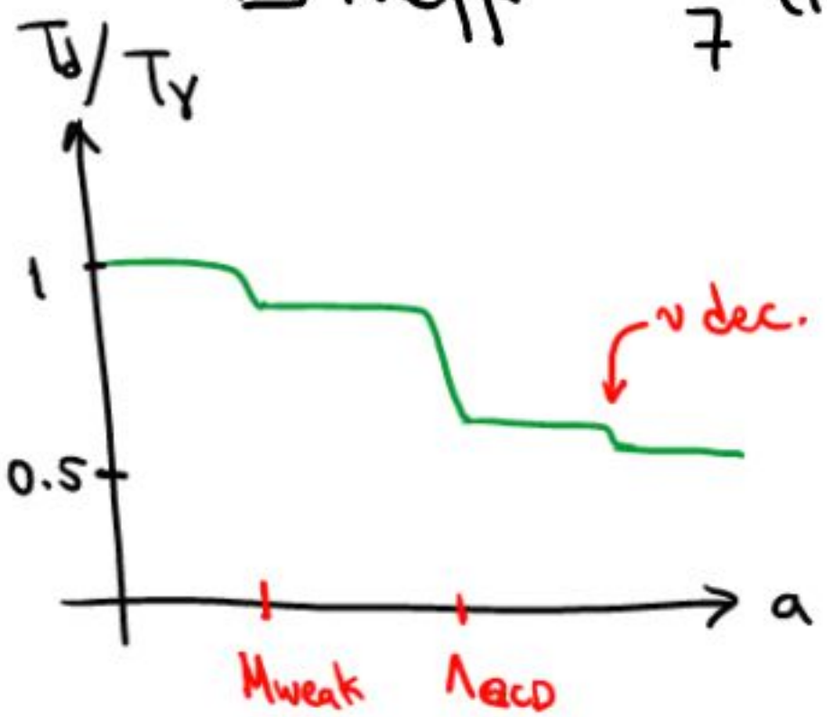
$$\sigma_{SI} = 1.3 \times 10^{-47}\ \mathrm{cm}^2$$



Snowmass CF1 Summary: WIMP Dark Matter Direct Detection arxiv:1310.8327

DARK RADIATION

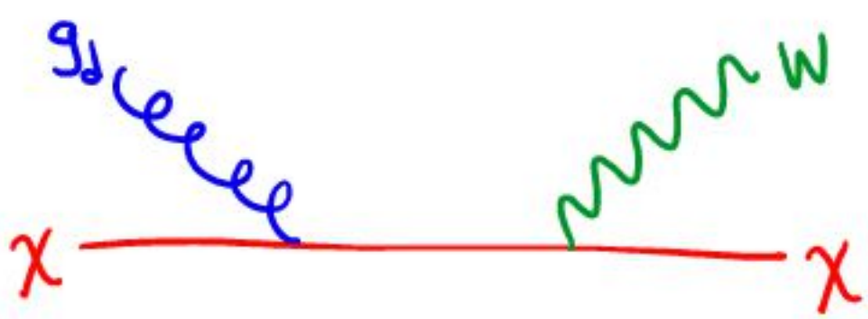
$$\Delta N_{eff} = \frac{8}{7}(N^2-1)\left(\frac{T_d}{T_\gamma}\right)^4 \qquad \left(g(T) \equiv \sum_i g_i \left(\frac{T_i}{T_\gamma}\right)^4\right)$$



$T_d/T_\gamma \sim 1/2$ @ rec.

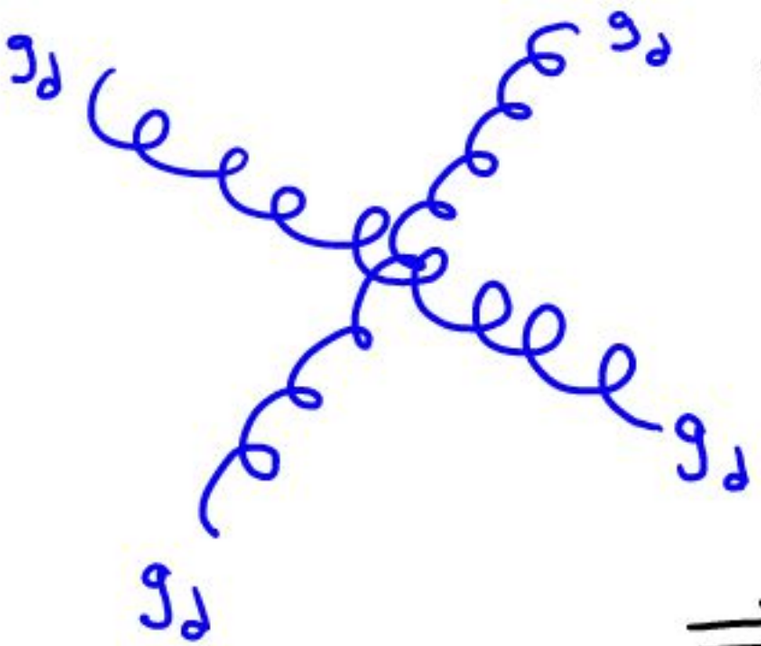
$$\Rightarrow \Delta N_{eff} \approx \frac{N^2-1}{16}$$

α_d s.t. eq. @ $T_d = M_\chi$?



$$\Gamma \sim \alpha_d \alpha_w M_\chi, \quad H \sim \frac{M_\chi^2}{M_{pl}}$$

$$\therefore \Gamma \gtrsim H \Rightarrow \alpha_d \gtrsim 10^{-13}$$



$$\Gamma \sim \alpha_d^2 T \quad ; \quad H \sim \frac{T^2}{M_{pl}}$$

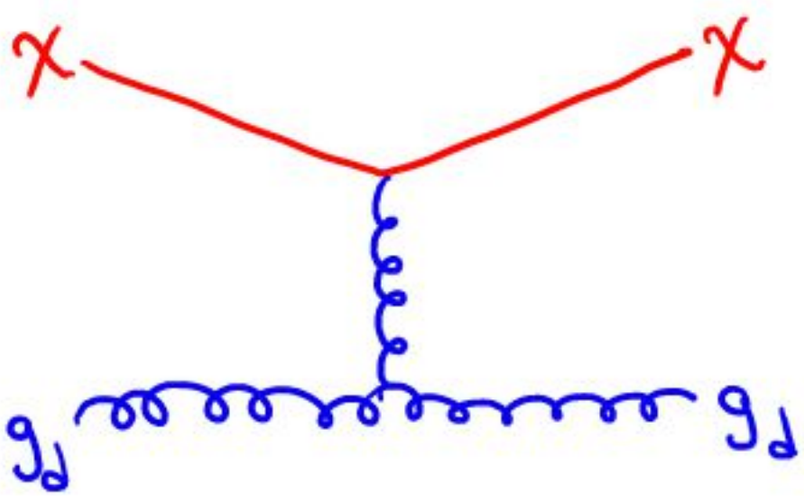
$$\Gamma \gtrsim H \text{ @ rec} \Rightarrow \alpha_d \gtrsim 10^{-13}$$

$\Rightarrow$ dark gluons are perfect fluid.

$c^2_{visc} = 0$ for perfect fluid (1/3 for ν)

$c^2_{eff} = 1/3$ for both.

Power Spectrum



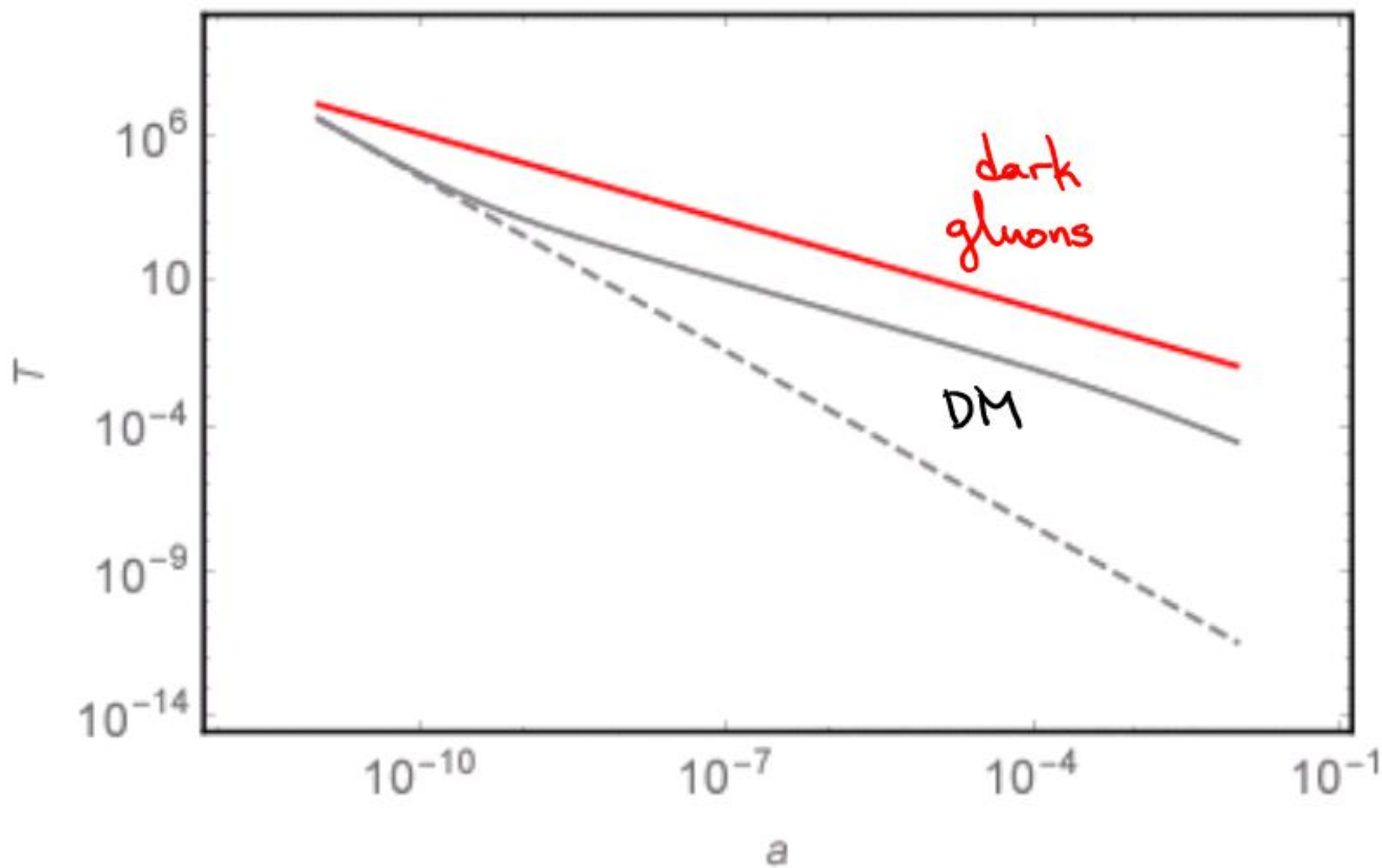
$$|\mathcal{M}|^2 \sim \frac{\alpha_d^2 M_\chi^2 \omega^2}{t^2}$$

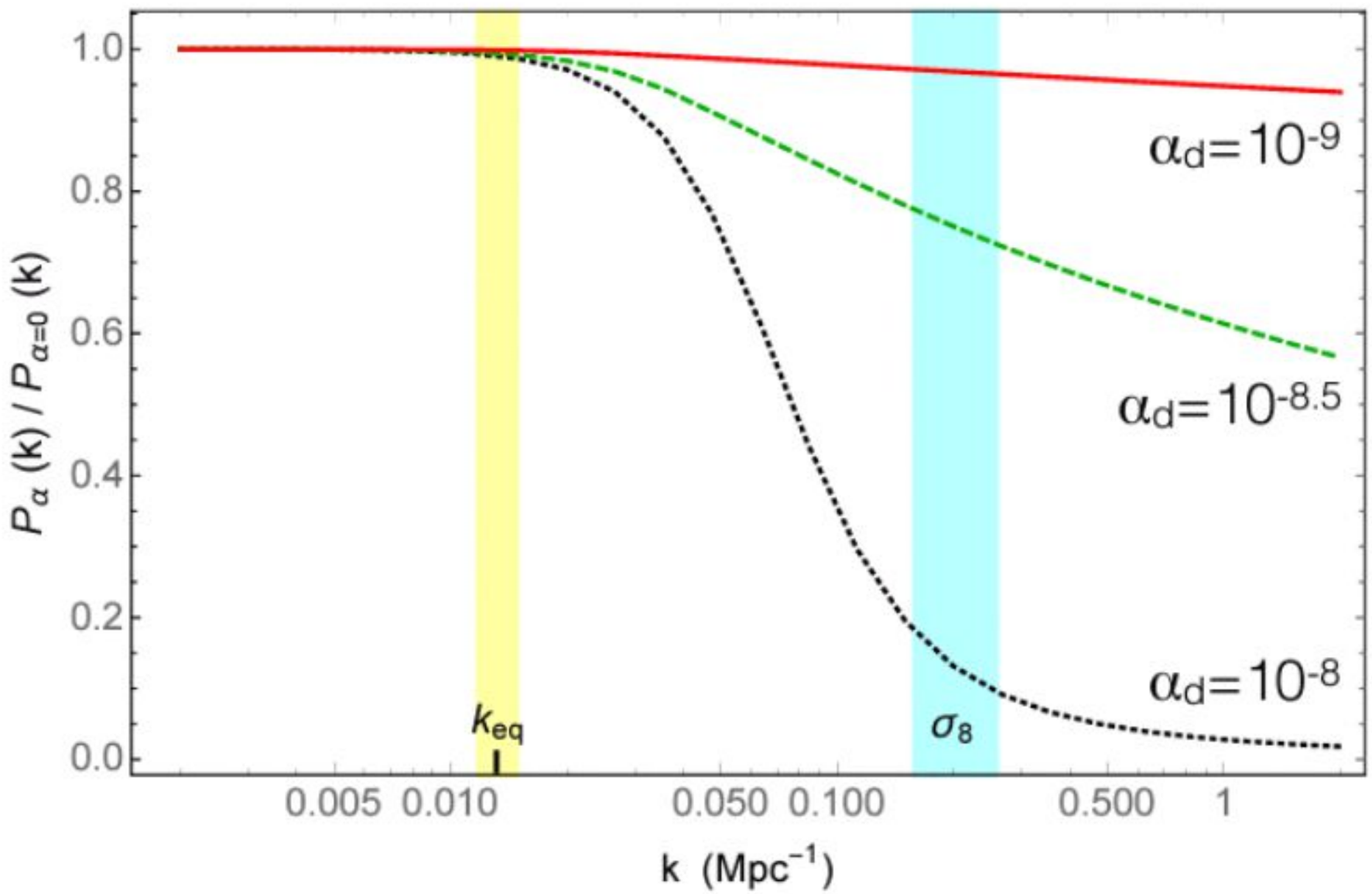
$$\Gamma \sim \frac{\alpha_d^2 T_d^3}{M_\chi T_\chi} \log(T_d / \underbrace{m_{Debye}}_{g_d T_d})$$

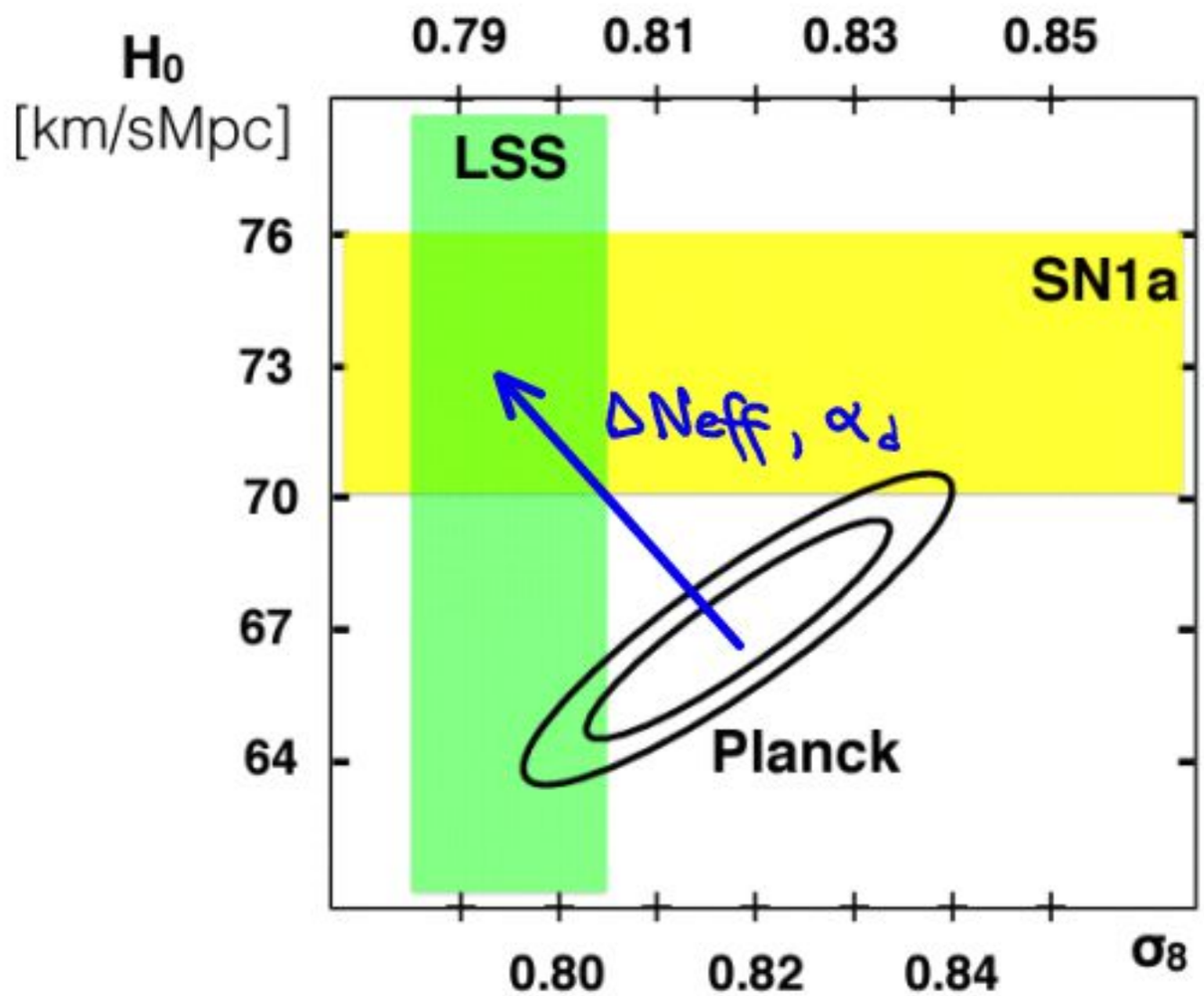
For non-rel χ $T_\chi \sim a^{-2}$; $T_d \sim a^{-1}$ $\Rightarrow \Gamma \sim a^{-1}$; $H \sim \frac{T^2}{M_{pl}} \sim a^{-2}$

$\Rightarrow$ Later on Γ becomes important $\Rightarrow$ χ recouples to g_d.

$\therefore$ Now: $\Gamma \sim \frac{\alpha_d^2}{M_\chi} T_d^2 \log(1/g_d) \times \left(\frac{T_d}{T_\chi}\right) \sim H \Rightarrow T_\chi \propto T_d$!


dark
gluons
DM
10^{6}
10
10^{-4}
10^{-9}
10^{-14}
T
10^{-10}
10^{-7}
10^{-4}
10^{-1}
a


1.0
0.8
0.6
0.4
0.2
0.0
P_α (k) / $P_{\alpha=0}$ (k)
$\alpha_d=10^{-9}$
$\alpha_d=10^{-8.5}$
$\alpha_d=10^{-8}$
k_{eq}
σ_8
0.005 0.010
0.050 0.100
0.500 1
k (Mpc^{-1})

DR ($N_{eff}\uparrow$) $\Rightarrow z_{eq}\downarrow \Rightarrow \rho_{dm}\uparrow \Rightarrow H_0\uparrow$

$\alpha_d \Rightarrow$ Power Spectrum Suppression $\Rightarrow \sigma_8\downarrow$