A general framework for direct detection of Dark Matter

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Boston U./Stanford U./SLAC

w/ L. Fitzpatrick, W. Haxton, N. Lubbers, Y. Xu
(hep-ph/1203.3542 + to appear)

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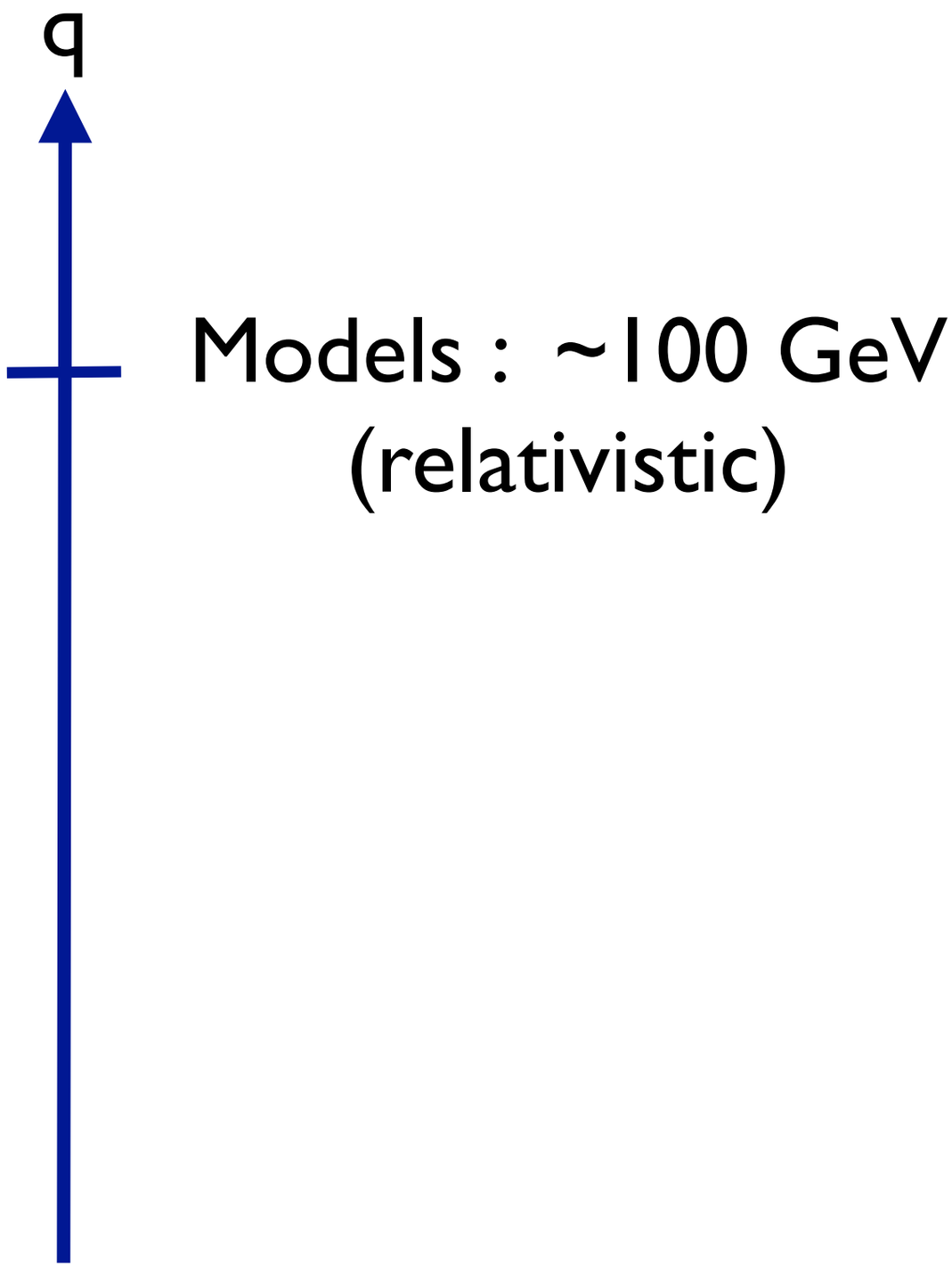

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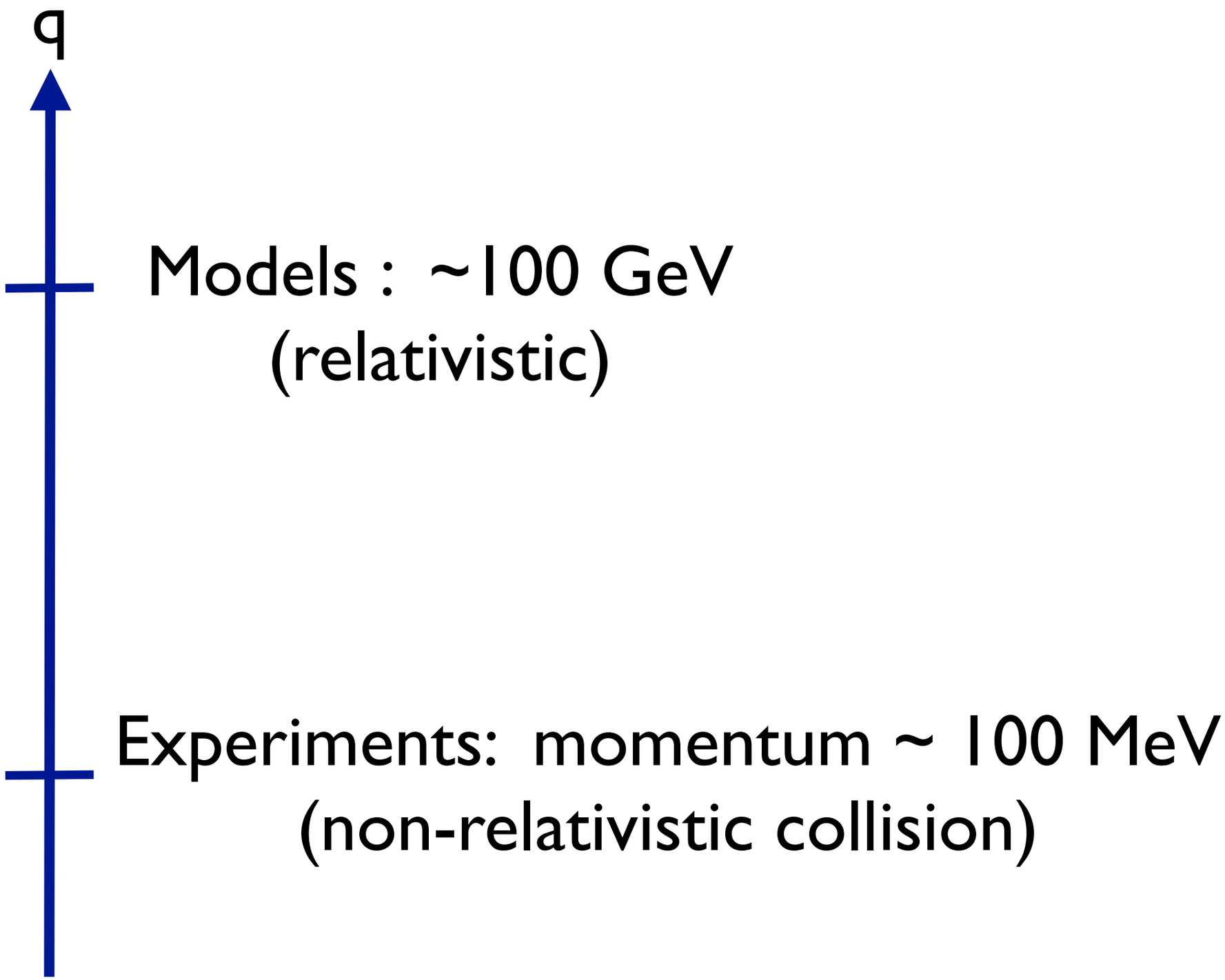

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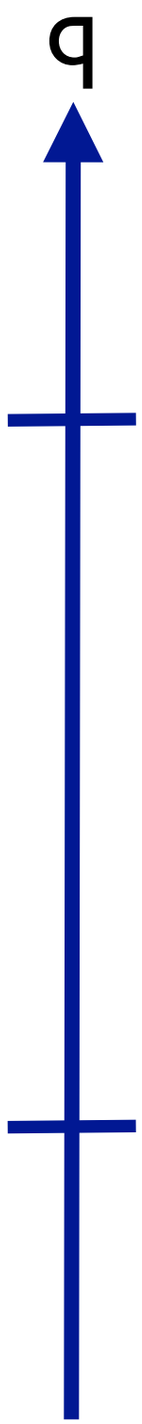

Models : ~100 GeV
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Why use these?
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JCAP 1011 (2010) 042

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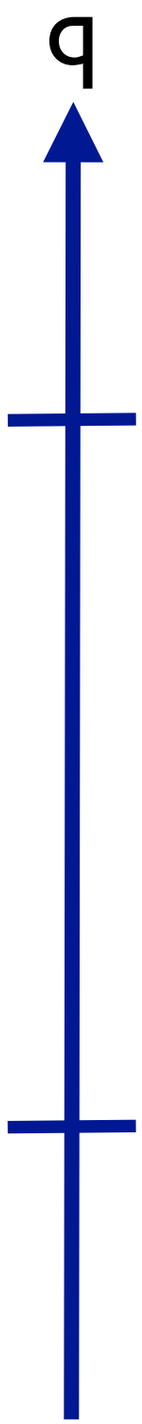

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NR Effective Theory

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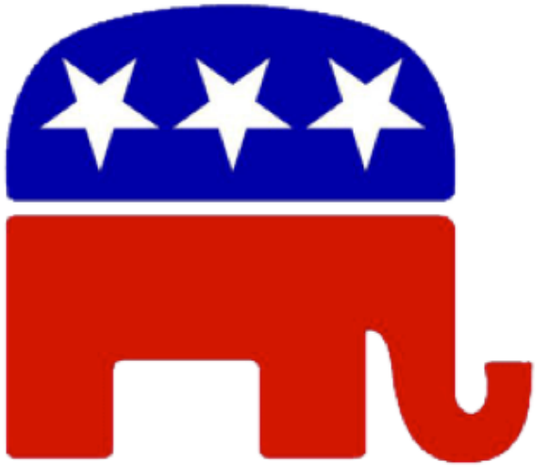

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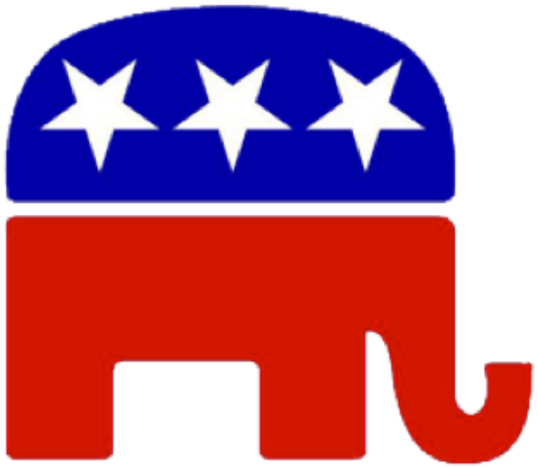

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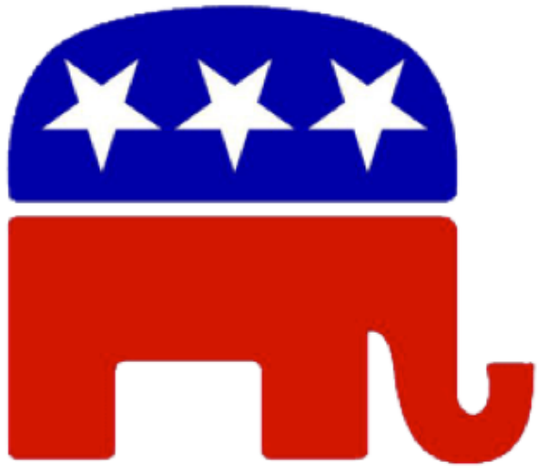

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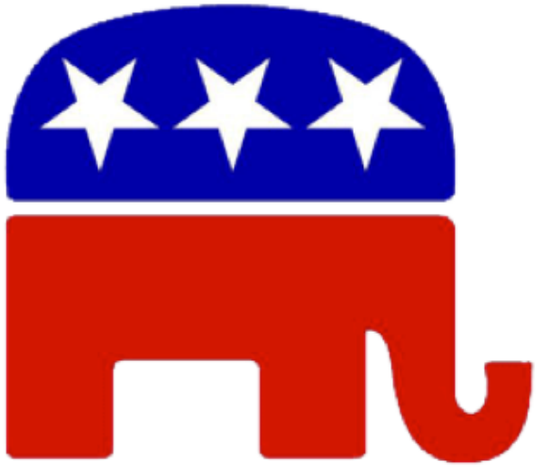

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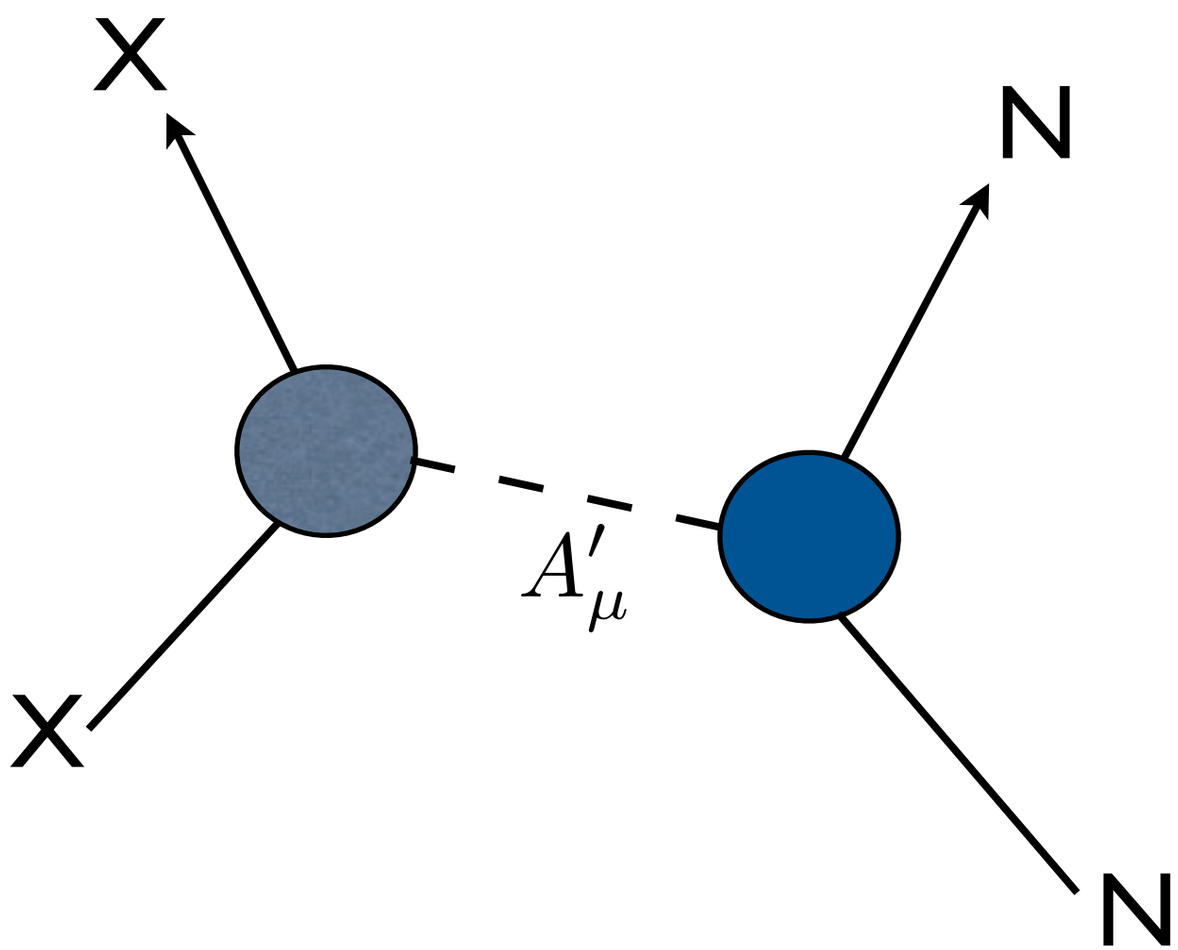
Non trivial momentum dependence can dominate!



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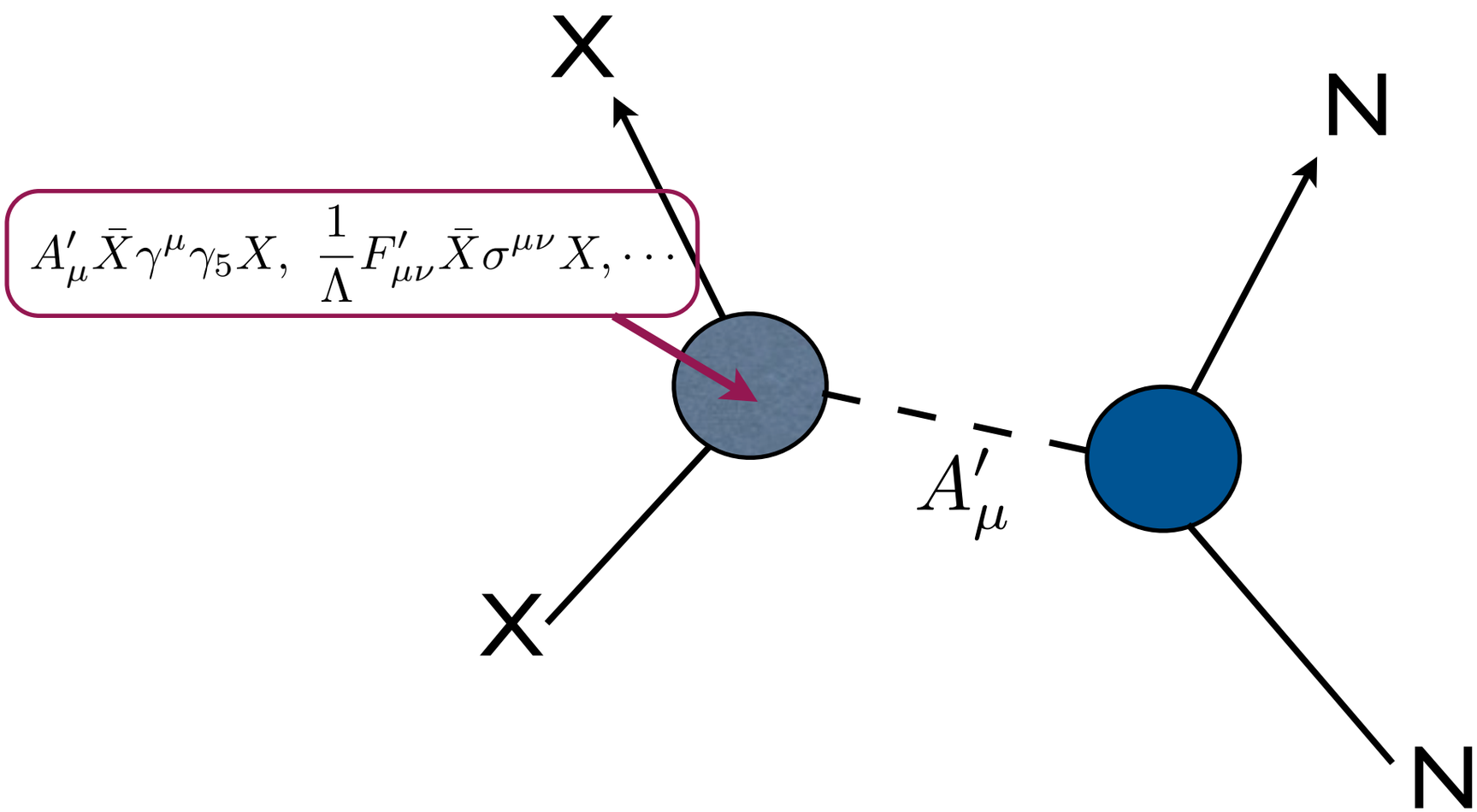

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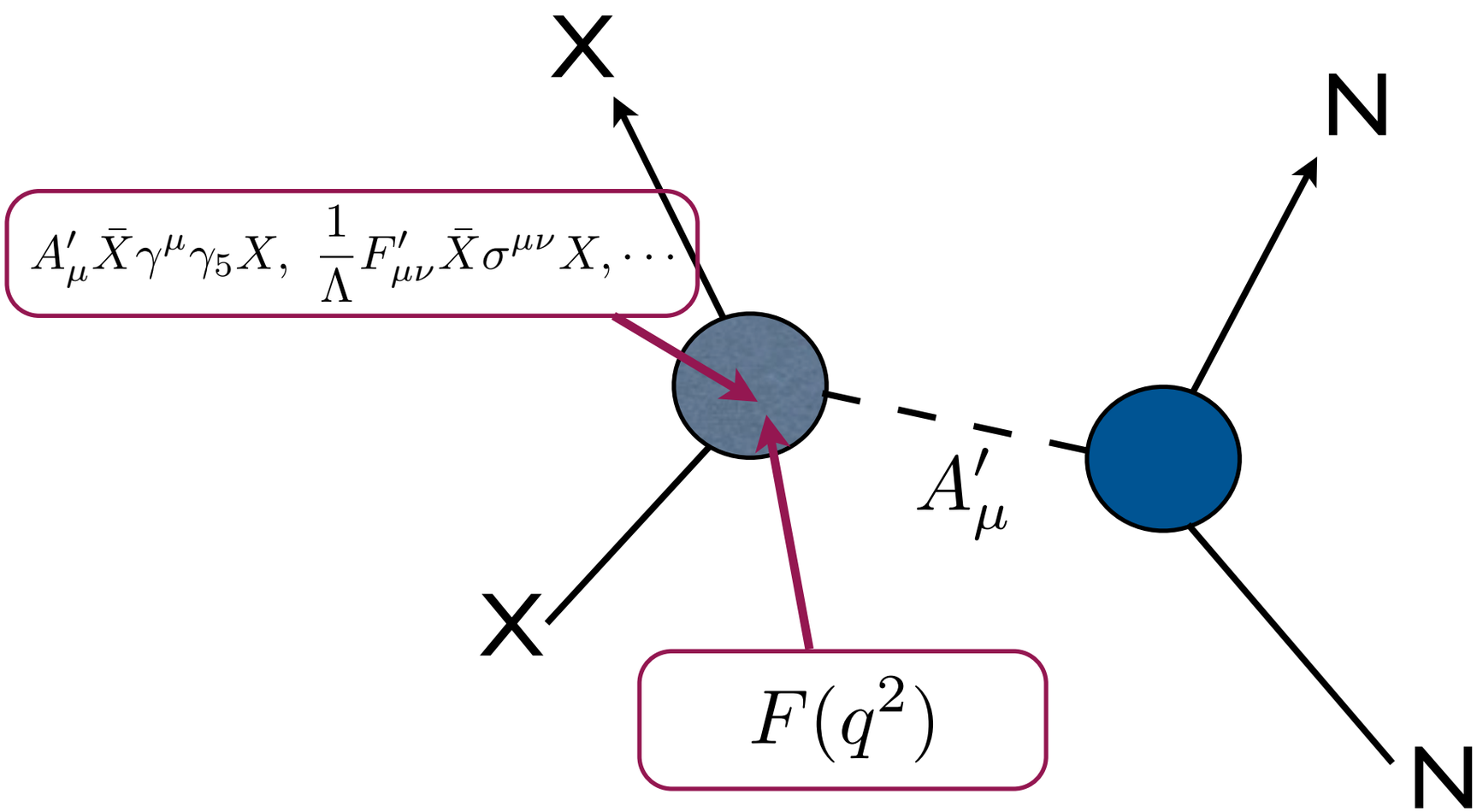

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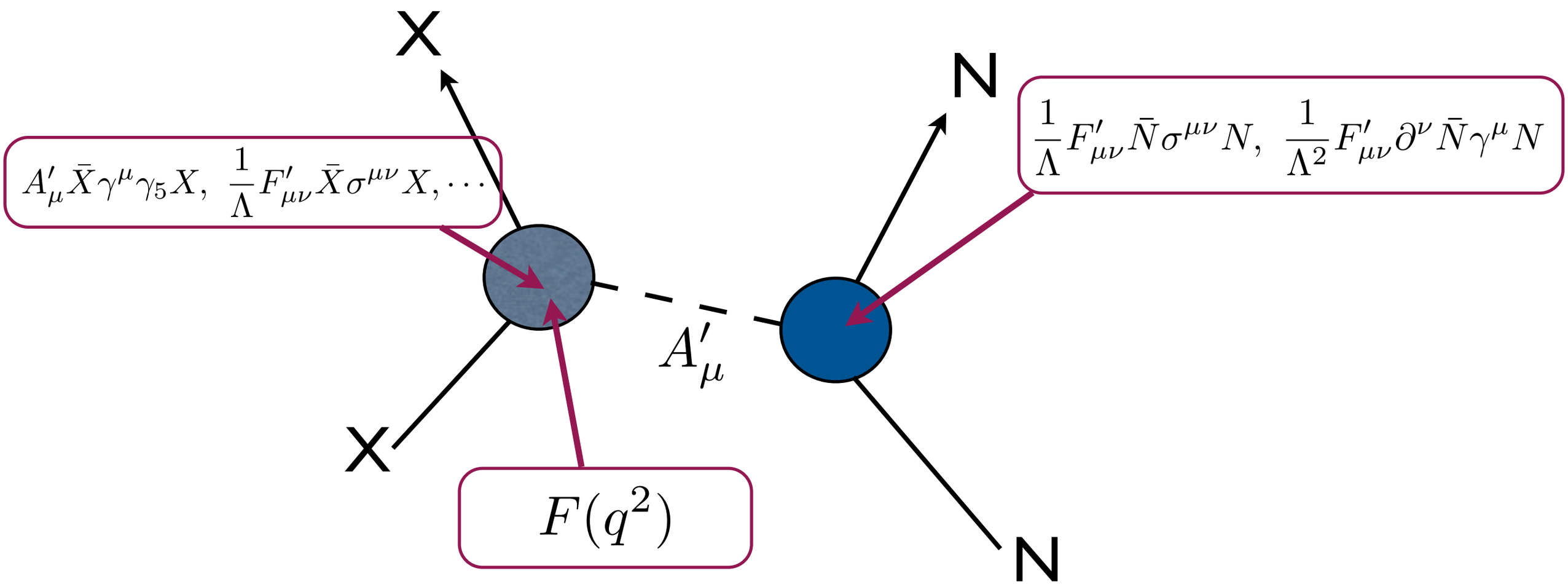

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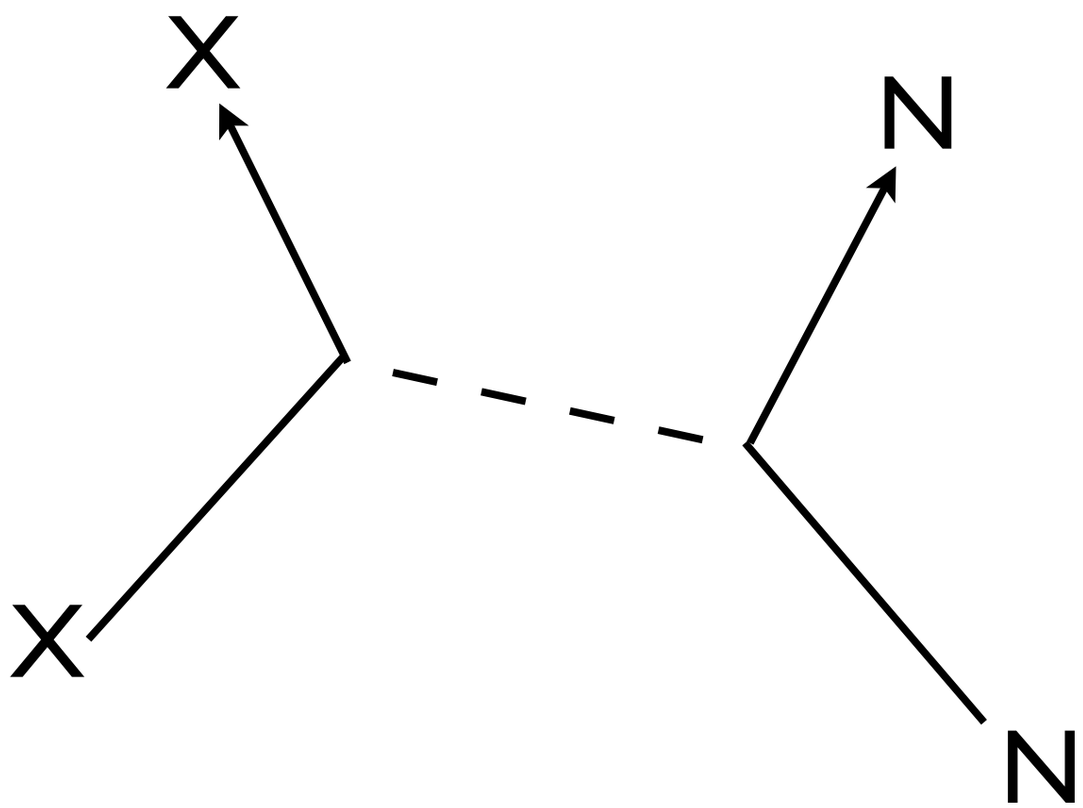

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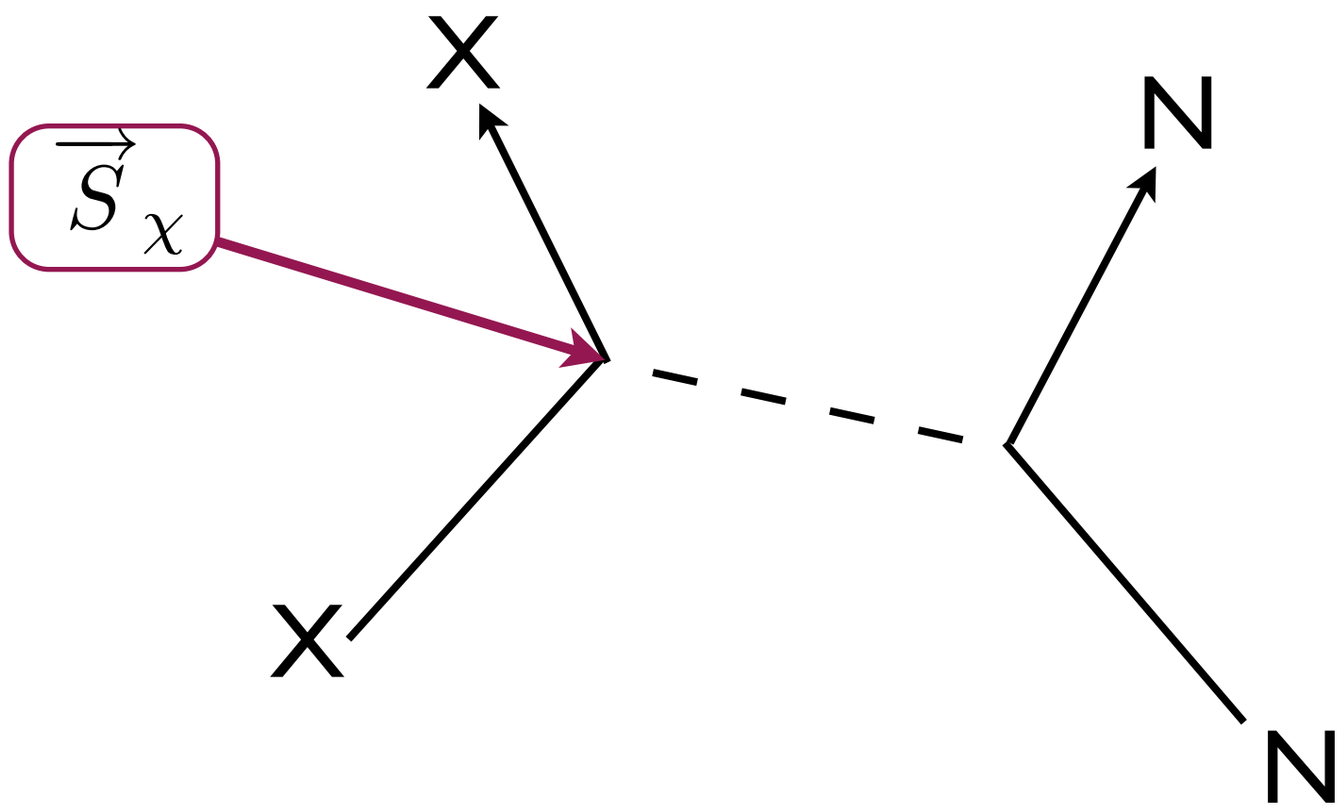

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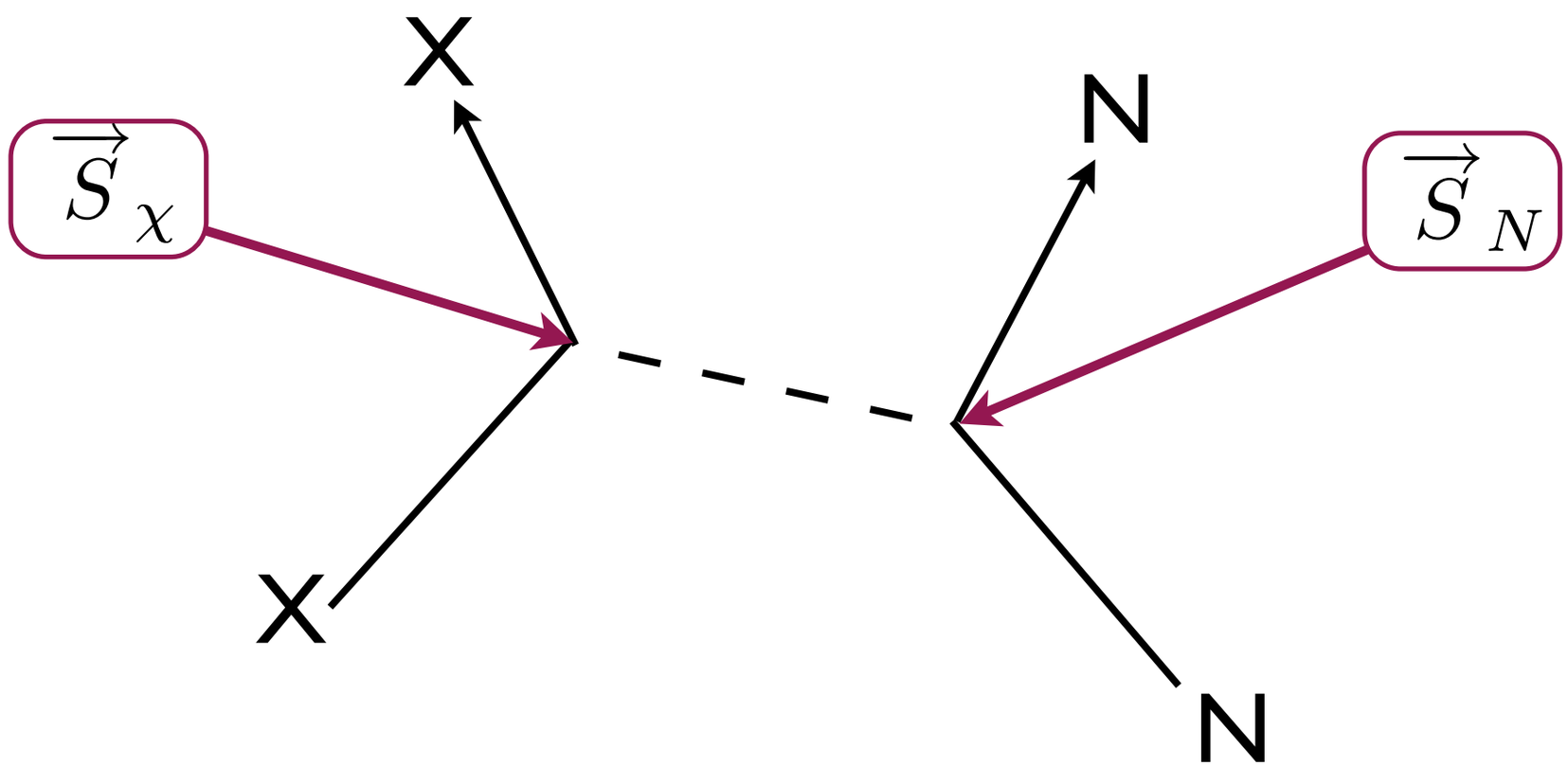

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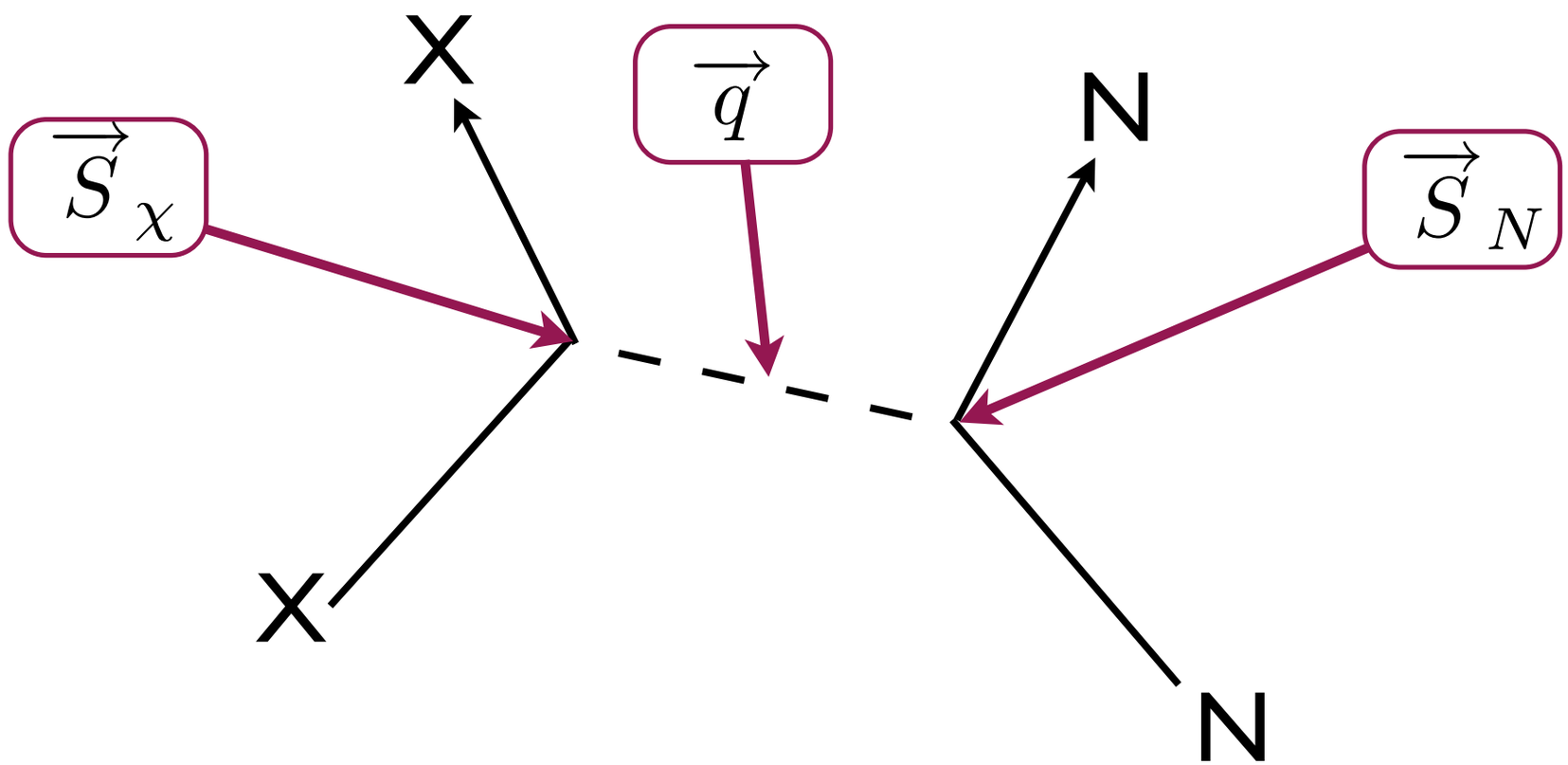

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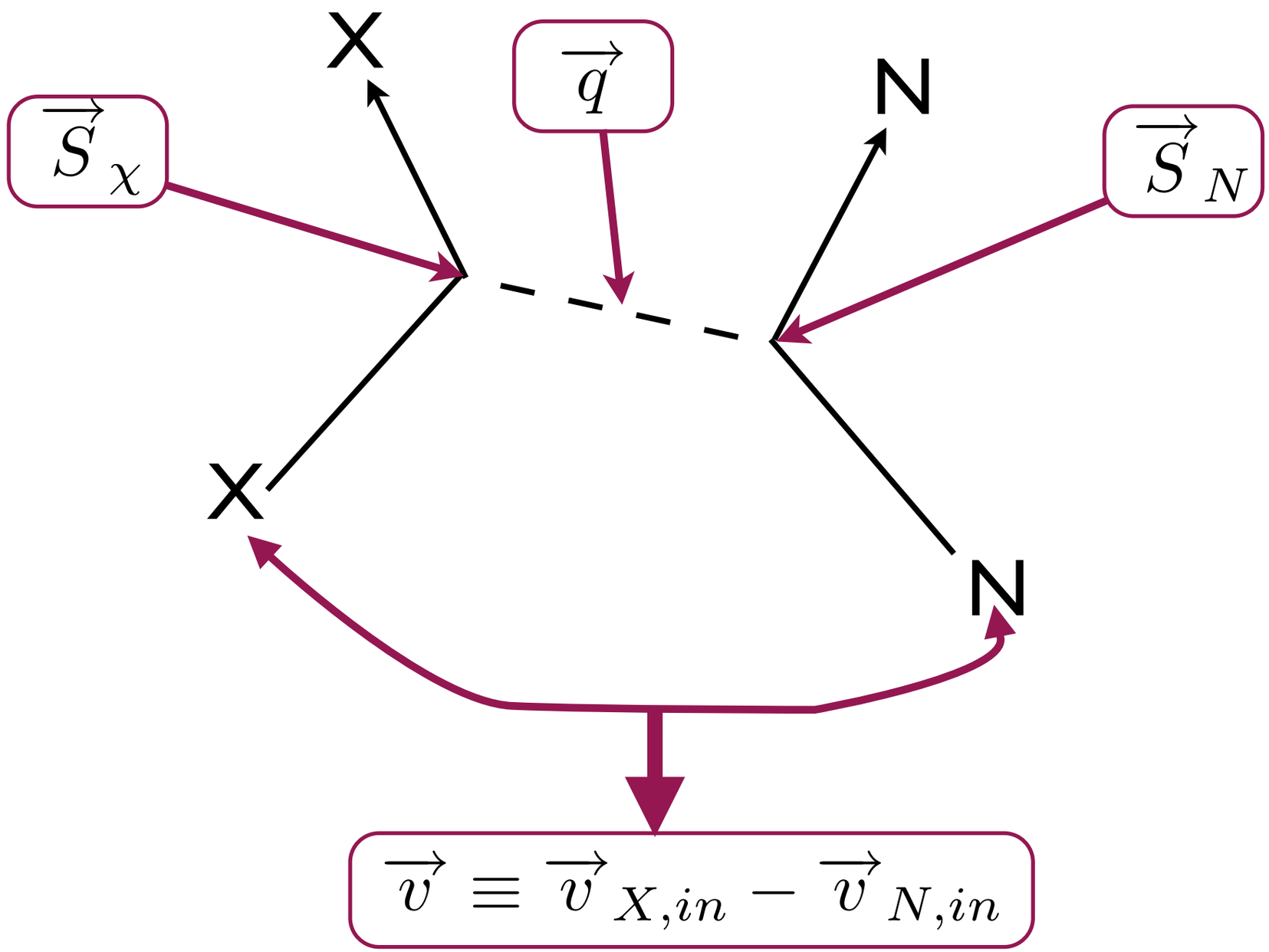

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Assumptions for NR effective theory:

1. Elastic collision.
2. Operators which do not violate CP.
3. We will consider operators which arise from an exchange of spin one or less.

Parity EVEN, spin-independent:

$$\mathbf{1},\ v^2 \qquad\qquad i\,\overrightarrow{S}_\chi \cdot (\overrightarrow{q} \times \overrightarrow{v})$$

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Any DM model can be described in terms of these ops!

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DM-nucleon
NR Eff. Thy

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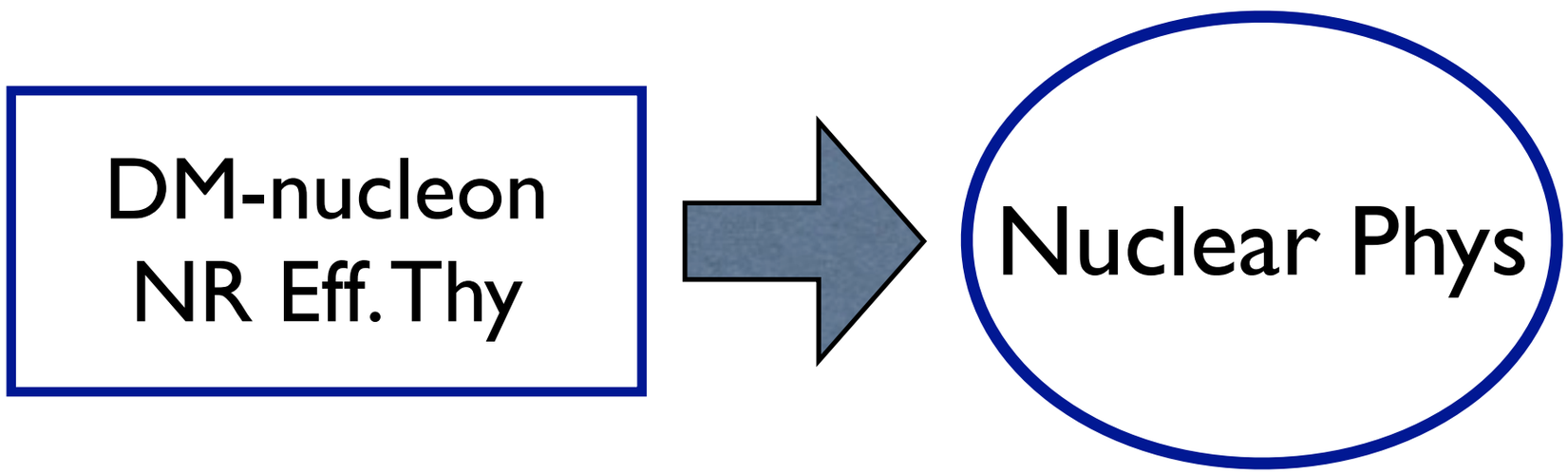

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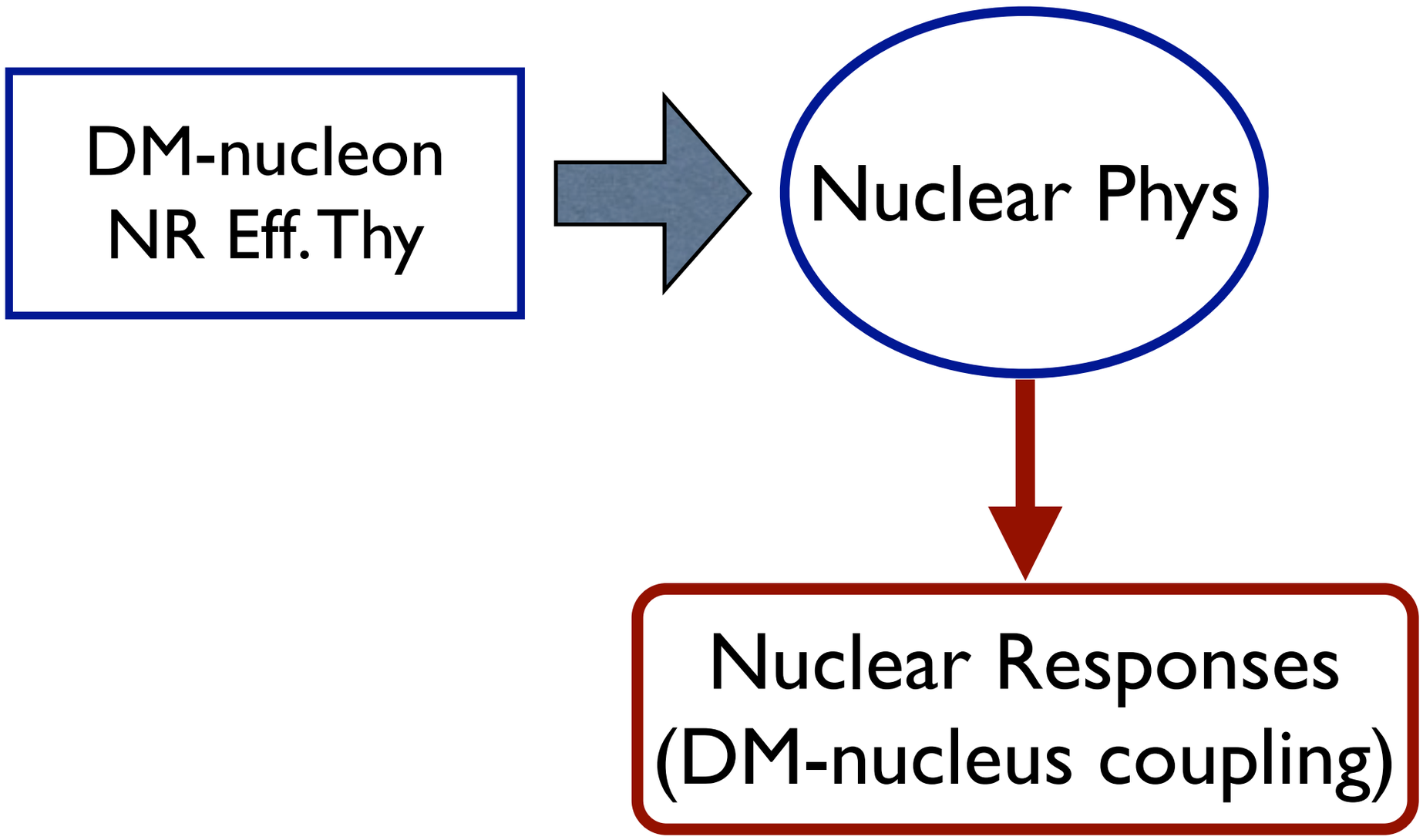

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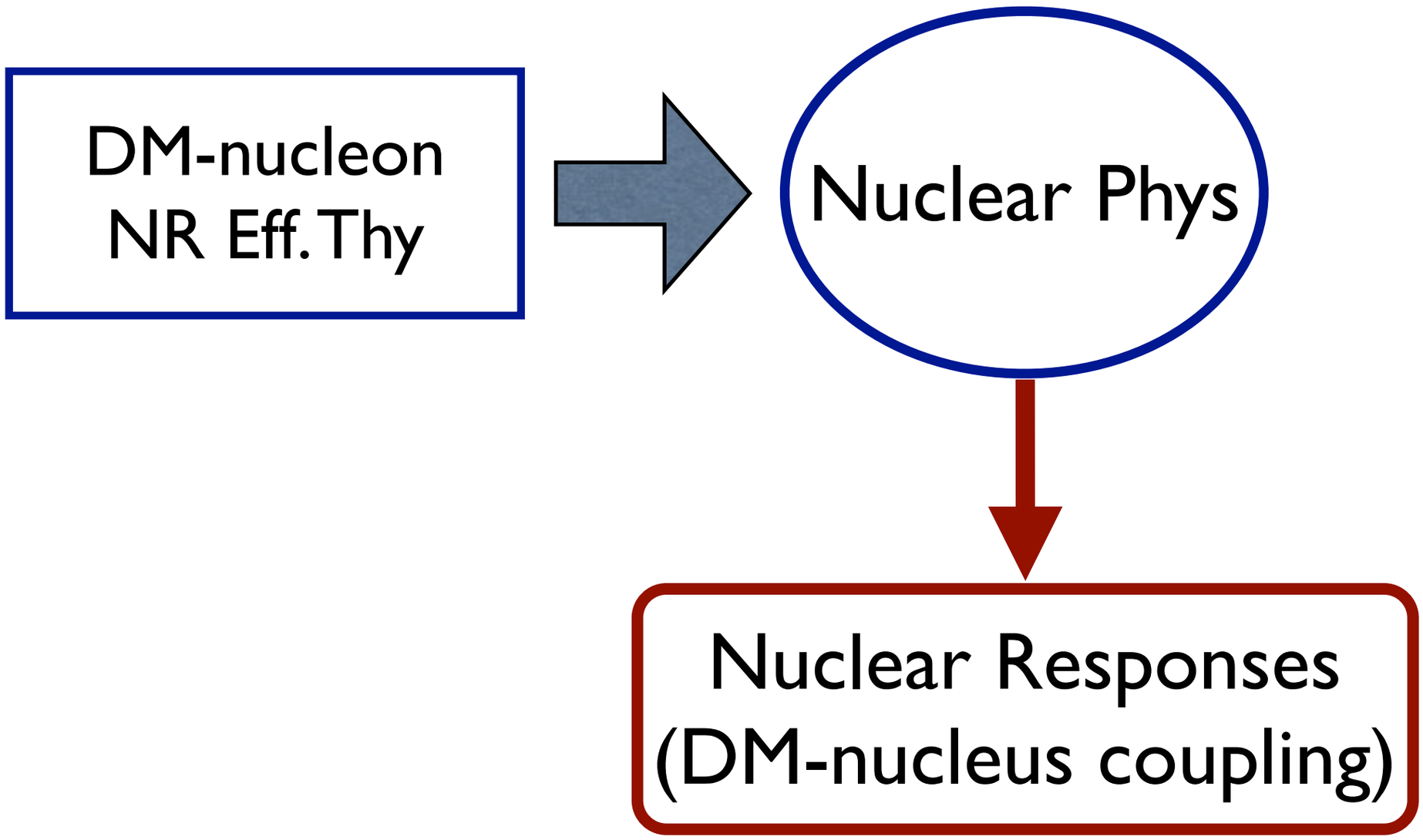

Experiment: Are there new ways to see nuclei?

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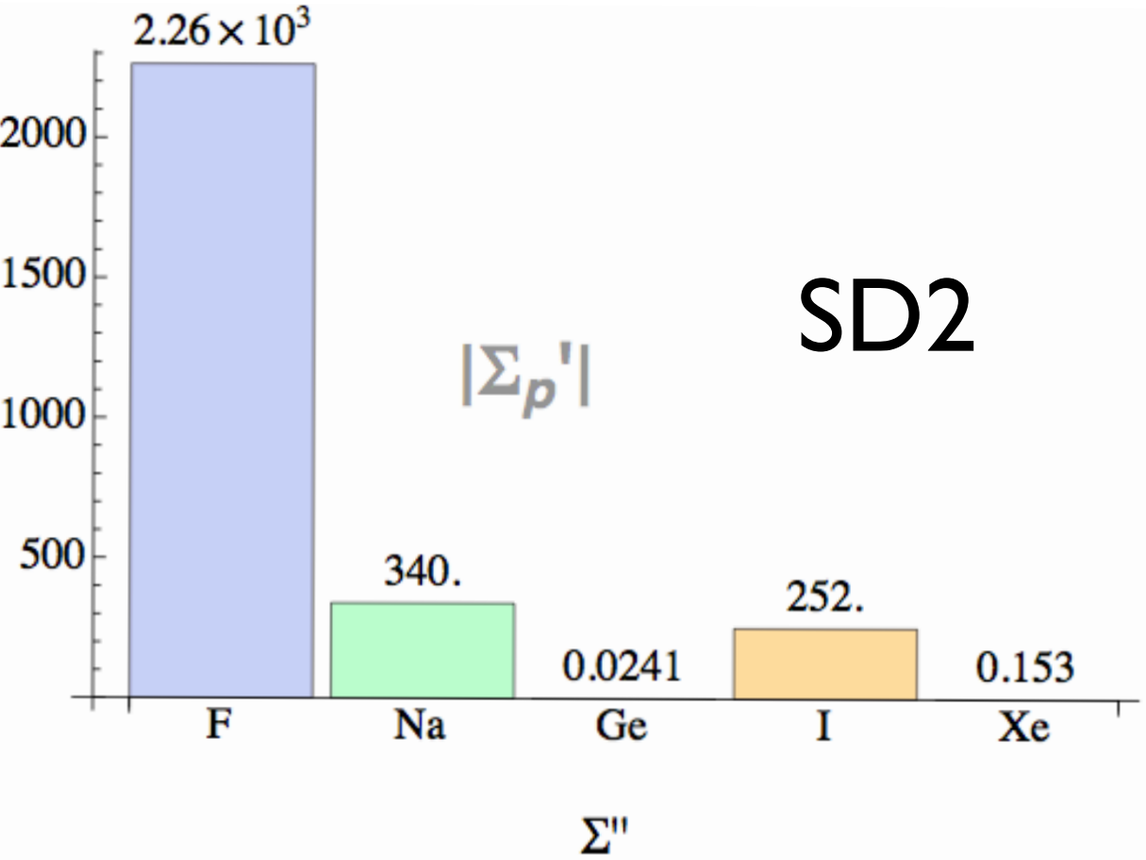
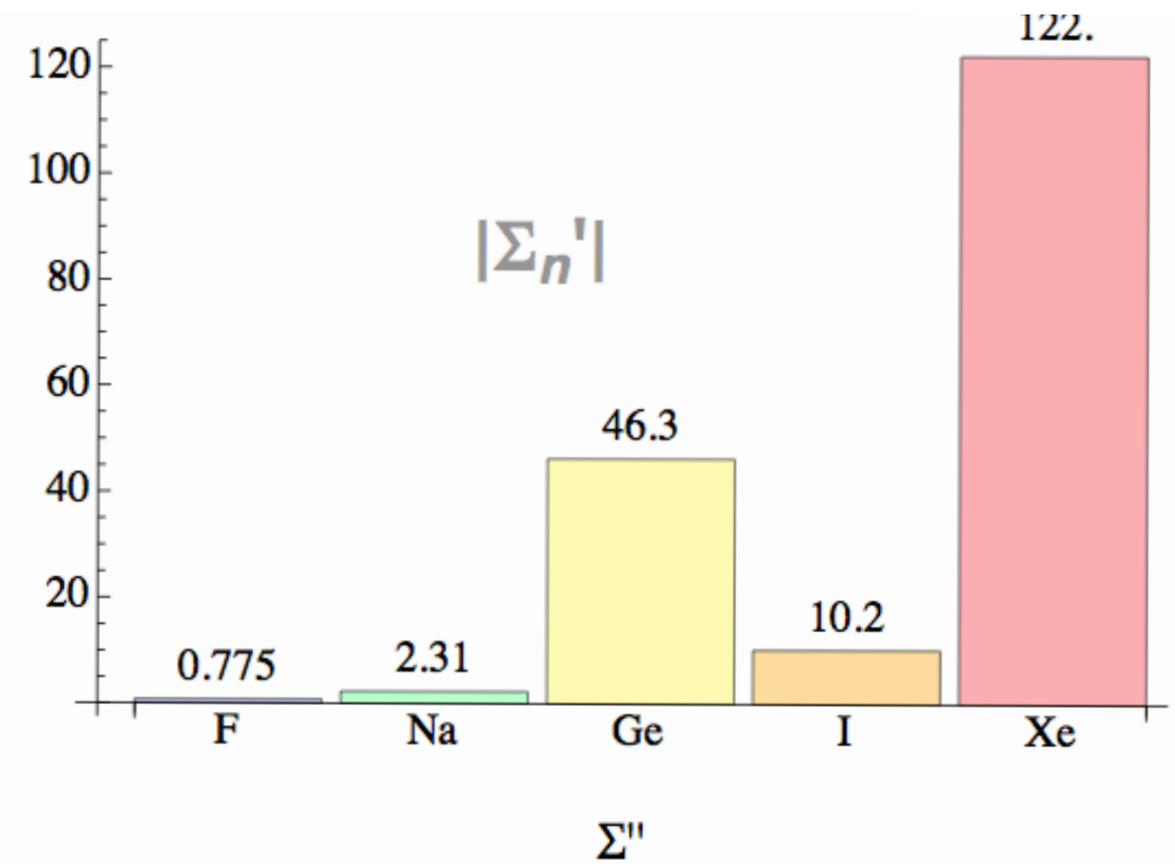
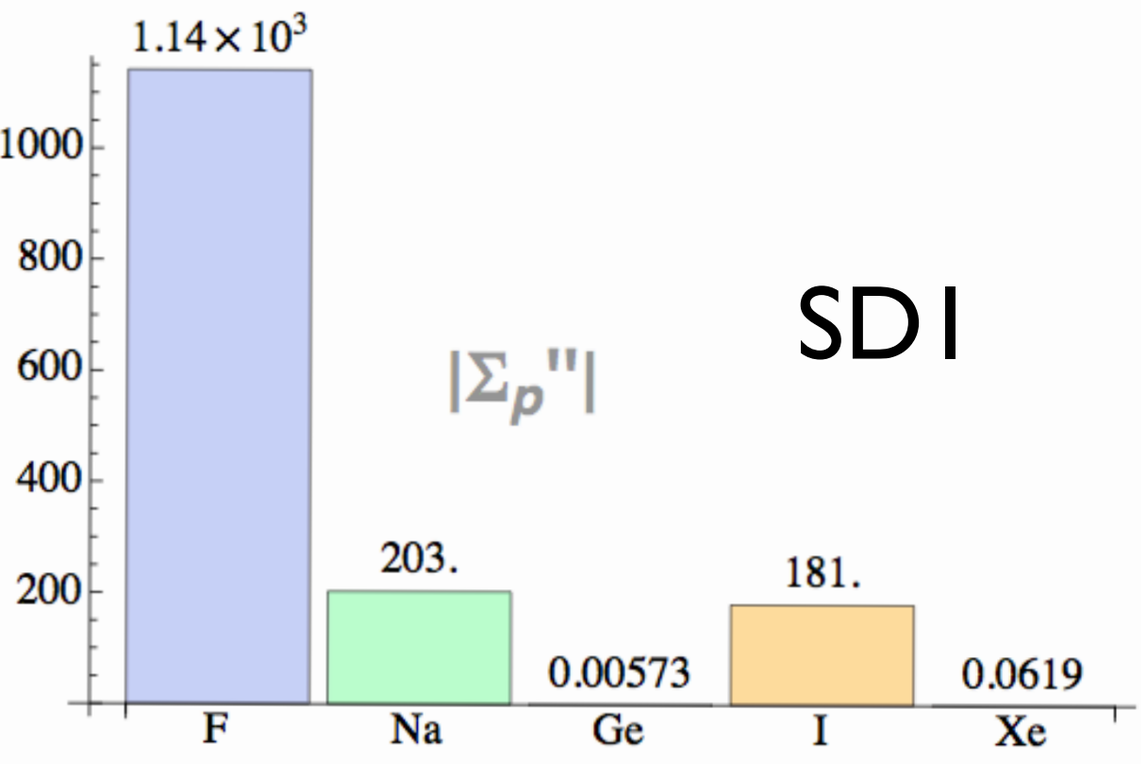
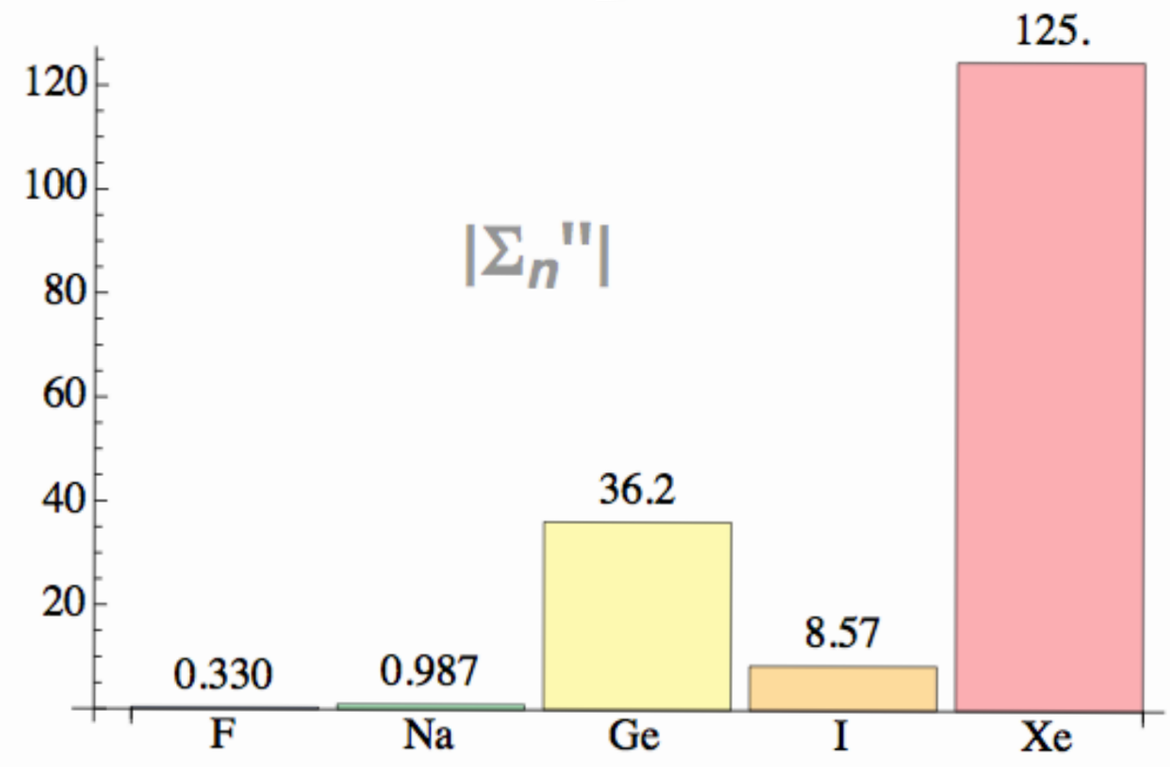
^{19}F:

$$
\begin{aligned}
F_{\Sigma'}{}^{(p,p)} &= e^{-2y}\left(1.81 - 4.85y + 4.88y^2 - 2.18y^3 + 0.364y^4\right) \\
F_{\Sigma'}{}^{(p,n)} &= e^{-2y}\left(-0.0331 + 0.0815y - 0.0511y^2 - 0.00142y^3 + 0.00602y^4\right) \\
F_{\Sigma'}{}^{(n,n)} &= e^{-2y}\left(0.000607 - 0.00136y + 0.000266y^2 + 0.000550y^3 + 0.0000997y^4\right) \\
F_{\Sigma''}{}^{(p,p)} &= e^{-2y}\left(0.903 - 2.37y + 2.35y^2 - 1.05y^3 + 0.175y^4\right) \\
F_{\Sigma''}{}^{(p,n)} &= e^{-2y}\left(-0.0166 + 0.0509y - 0.0510y^2 + 0.0199y^3 - 0.00237y^4\right) \\
F_{\Sigma''}{}^{(n,n)} &= e^{-2y}\left(0.000303 - 0.00107y + 0.00114y^2 - 0.000348y^3 + 0.0000320y^4\right) \\
F_{\tilde{\Delta}}{}^{(p,p)} &= e^{-2y}\left(0.0251 - 0.0201y + 0.00401y^2\right) \\
F_{\tilde{\Delta}}{}^{(p,n)} &= e^{-2y}\left(-0.0213 + 0.0170y - 0.00341y^2\right) \\
F_{\tilde{\Delta}}{}^{(n,n)} &= e^{-2y}\left(0.0181 - 0.0145y + 0.00290y^2\right) \\
F_{\tilde{\Phi}''}{}^{(p,p)} &= e^{-2y}\left(0.0392 - 0.0314y + 0.00627y^2\right) \\
F_{\tilde{\Phi}''}{}^{(p,n)} &= e^{-2y}\left(0.100 - 0.0800y + 0.0160y^2\right) \\
F_{\tilde{\Phi}''}{}^{(n,n)} &= e^{-2y}\left(0.255 - 0.204y + 0.0408y^2\right) \\
F_{M,\tilde{\Phi}''}{}^{(p,p)} &= e^{-2y}\left(-1.78 + 1.77y - 0.509y^2 + 0.0347y^3\right) \\
F_{M,\tilde{\Phi}''}{}^{(p,n)} &= e^{-2y}\left(-3.26 + 3.31y - 0.998y^2 + 0.0780y^3\right) \\
F_{M,\tilde{\Phi}''}{}^{(n,n)} &= e^{-2y}\left(-5.05 + 5.39y - 1.78y^2 + 0.172y^3\right) \\
F_{\Sigma',\Delta}{}^{(p,p)} &= e^{-2y}\left(-0.213 + 0.371y - 0.210y^2 + 0.0382y^3\right) \\
F_{\Sigma',\Delta}{}^{(p,n)} &= e^{-2y}\left(0.0923 - 0.161y + 0.0892y^2 - 0.0159y^3\right) \\
F_{\Sigma',\Delta}{}^{(n,n)} &= e^{-2y}\left(-0.00331 + 0.00503y - 0.000138y^2 - 0.000537y^3\right)
\end{aligned}
$$


SD2
$|\Sigma_p'|$
2.26×10^3
340.
0.0241
252.
0.153
F
Na
Ge
I
Xe
Σ''

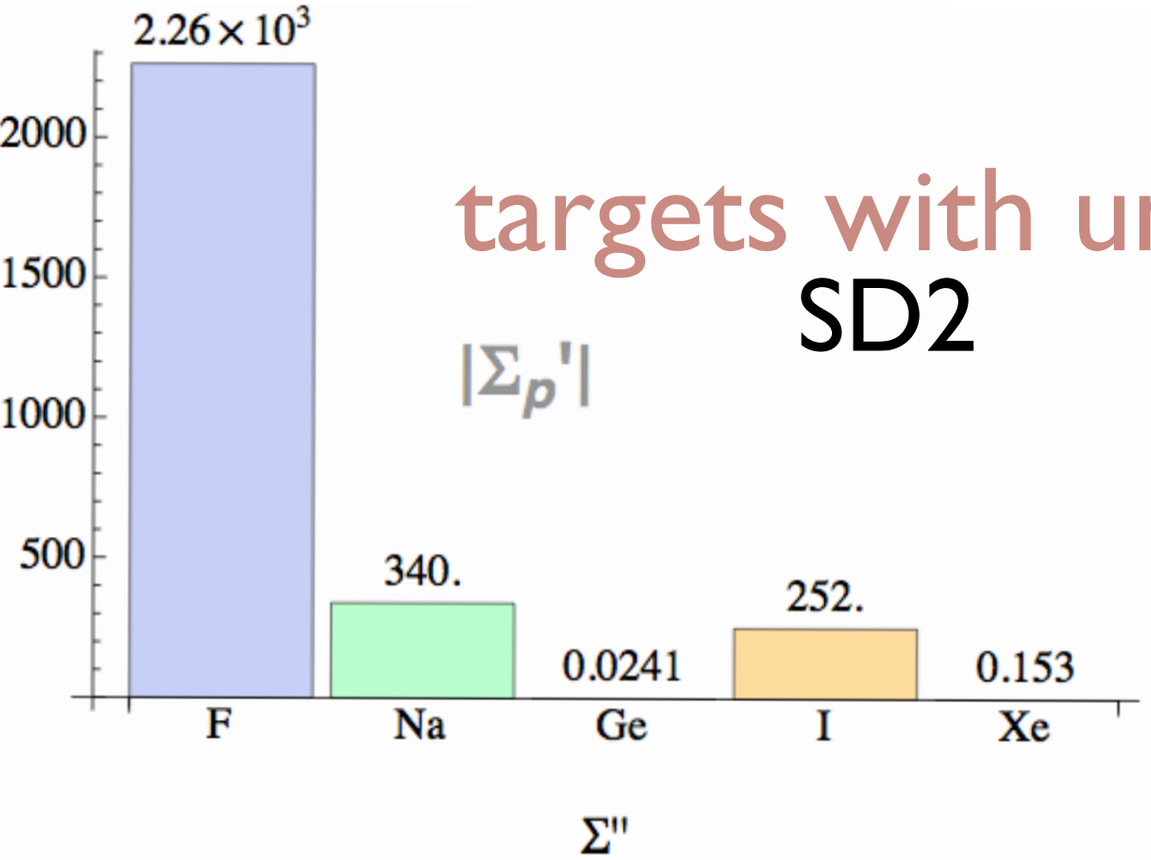

$|\Sigma_n'|$
0.775
2.31
46.3
10.2
122.
F
Na
Ge
I
Xe
Σ''

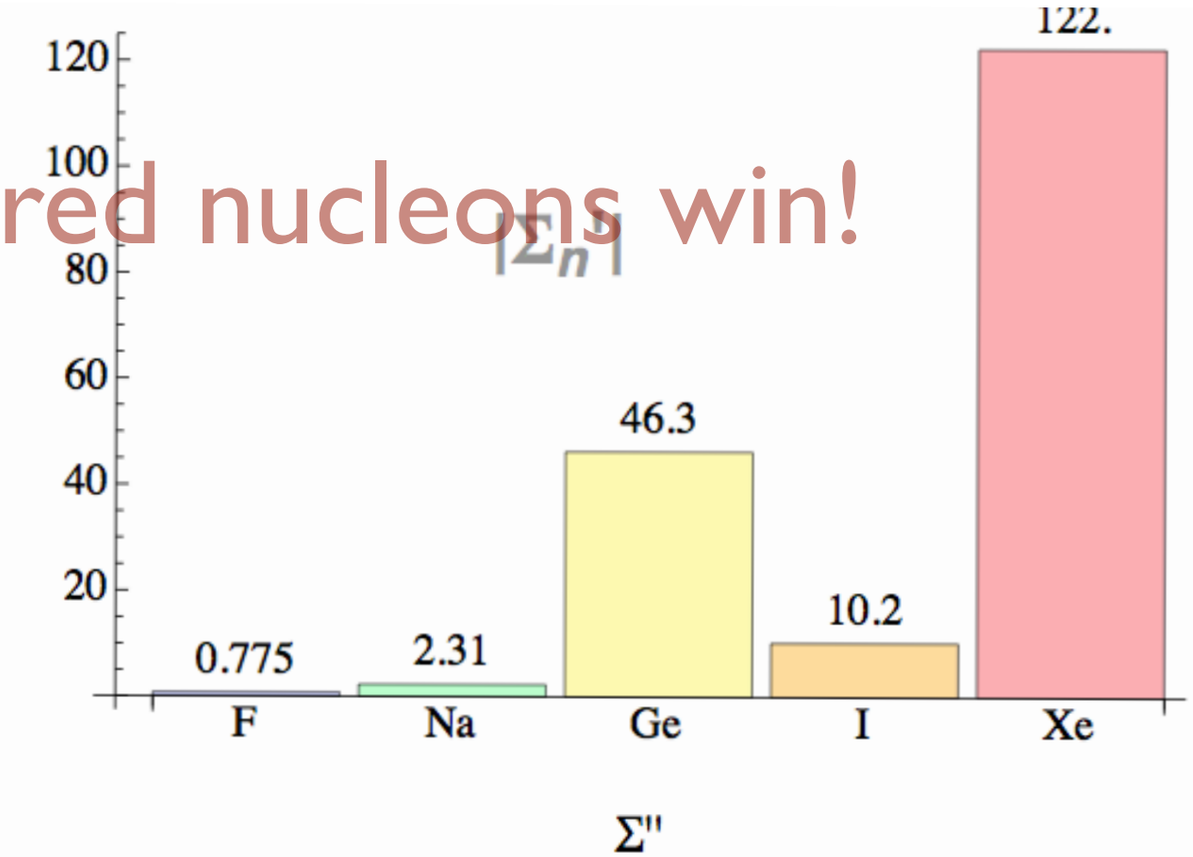

SD1
$|\Sigma_p''|$
1.14×10^3
203.
0.00573
181.
0.0619
F
Na
Ge
I
Xe


$|\Sigma_n''|$
0.330
0.987
36.2
8.57
125.
F
Na
Ge
I
Xe

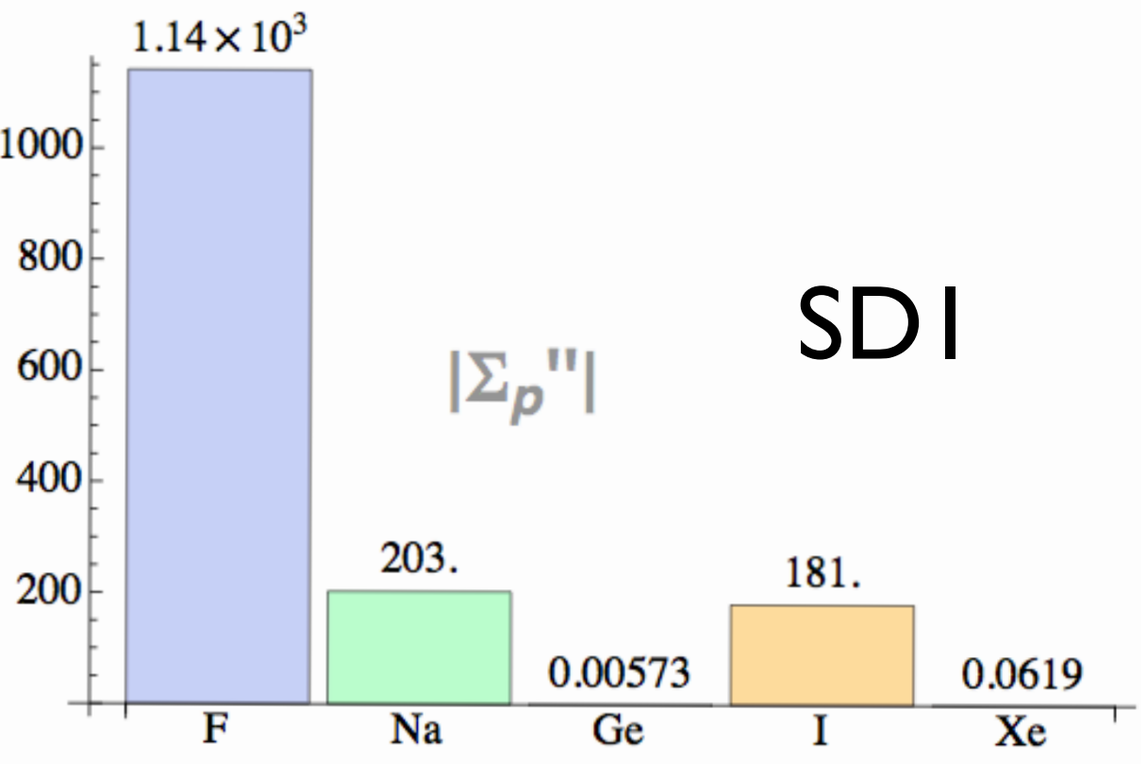
targets with unpaired nucleons win!

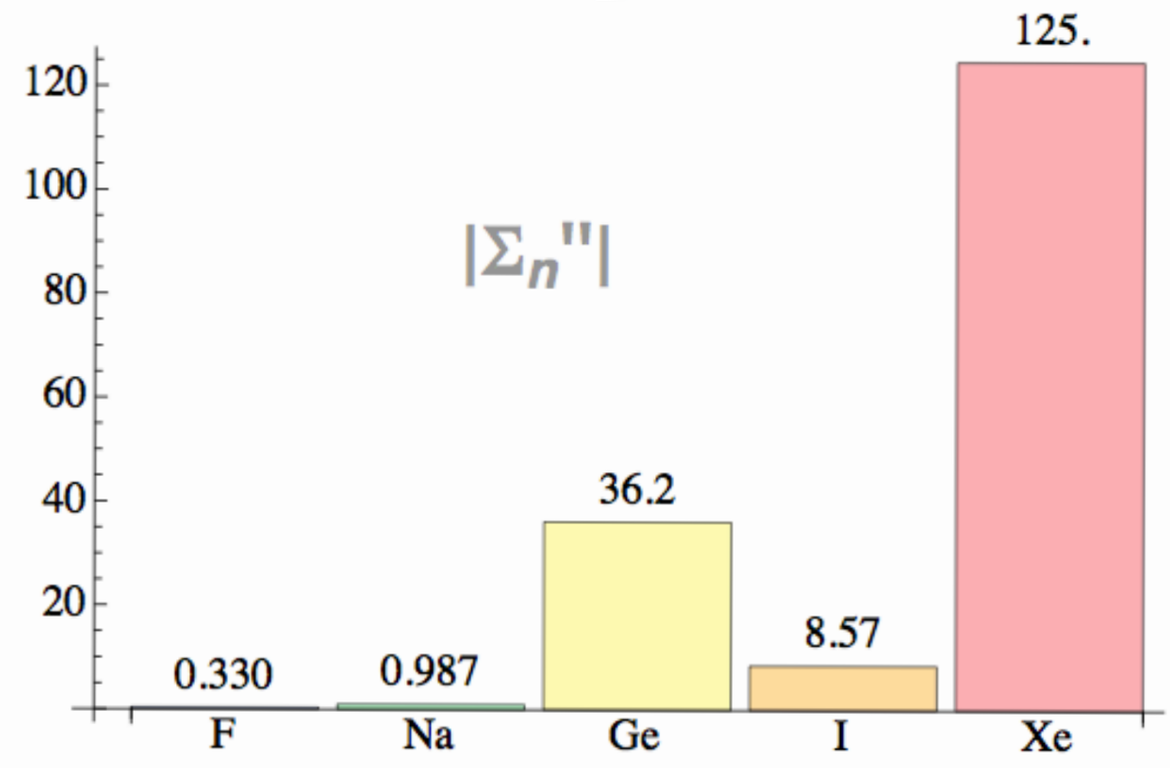
SD2



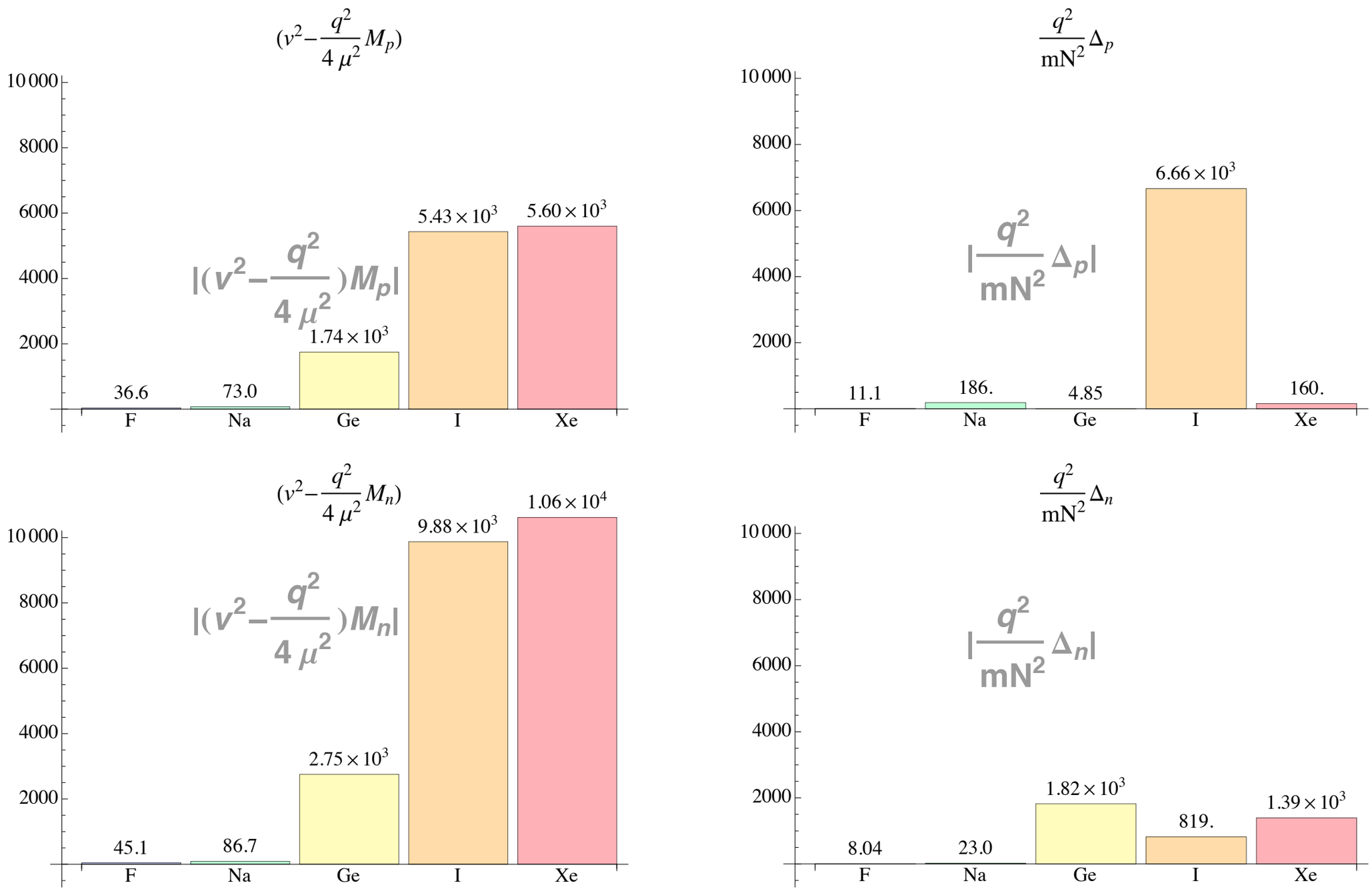


SD1





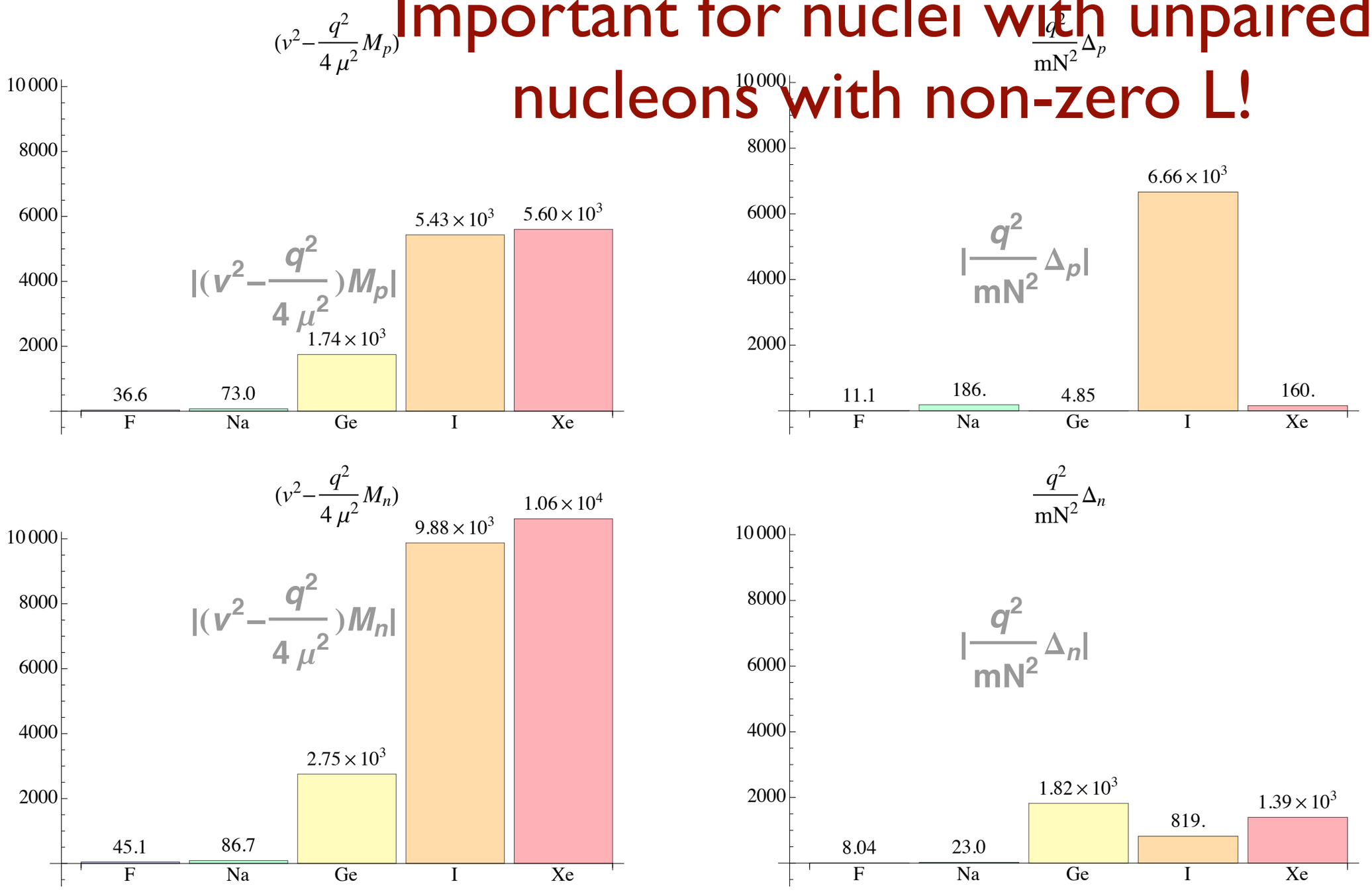
$$\vec{v}^{\perp} \cdot \vec{S}_{\chi}: \quad \left(v^2 - \frac{q^2}{4\mu_T^2}\right) M_N(q^2) + \frac{q^2}{m_N^2} \tilde{\Delta}_N(q^2)$$



$$m_{\chi} = 100 GeV$$

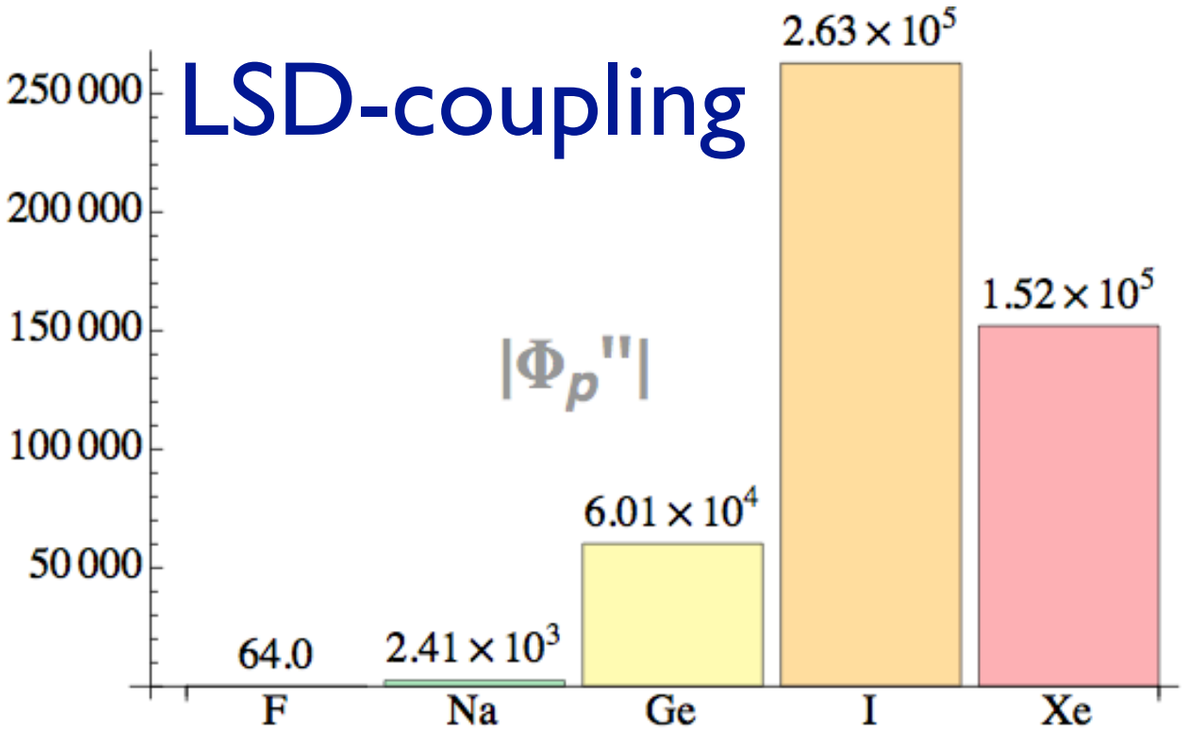
$$\vec{v}^{\perp} \cdot \vec{S}_{\chi}: \quad \left(v^2 - \frac{q^2}{4\mu_T^2}\right) M_N(q^2) + \frac{q^2}{m_N^2} \tilde{\Delta}_N(q^2)$$

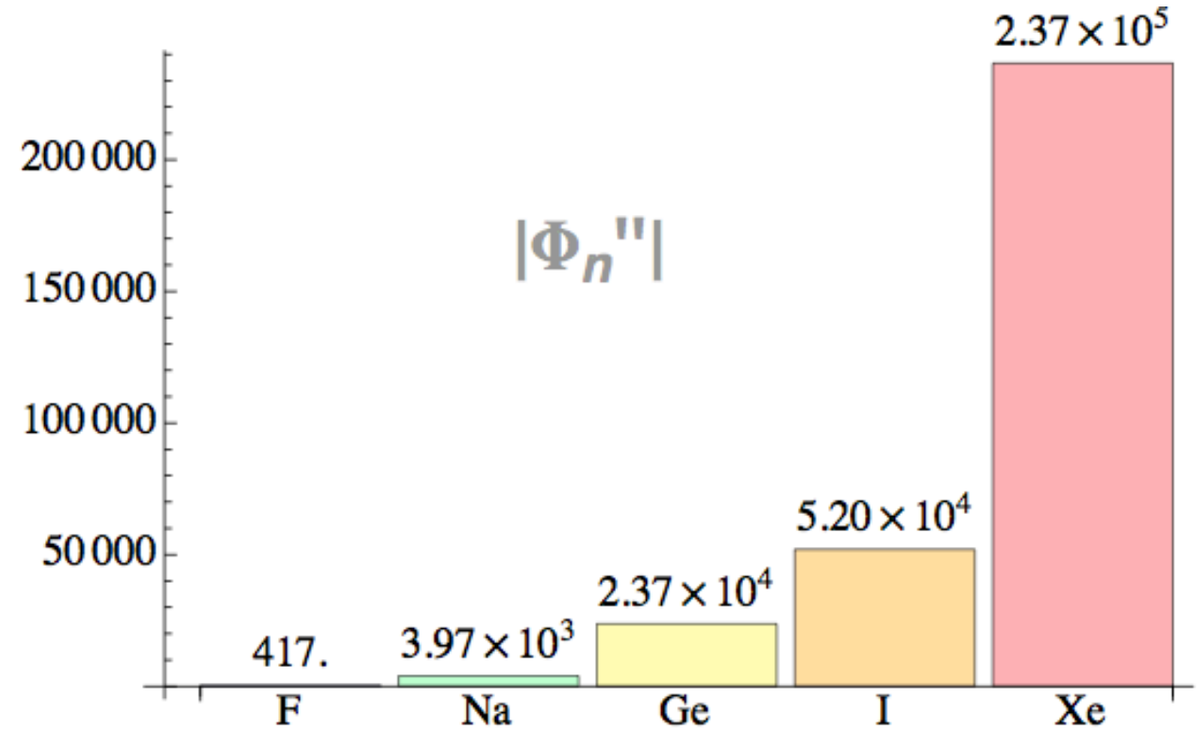
Important for nuclei with unpaired nucleons with non-zero L!

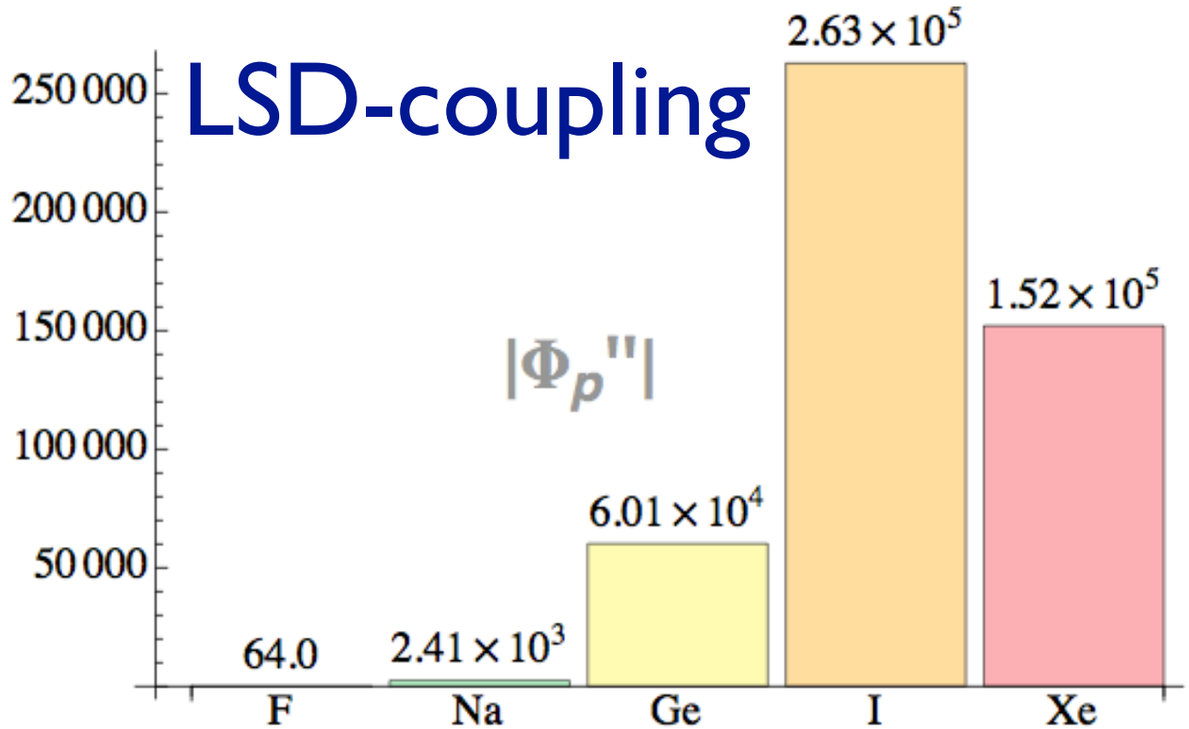


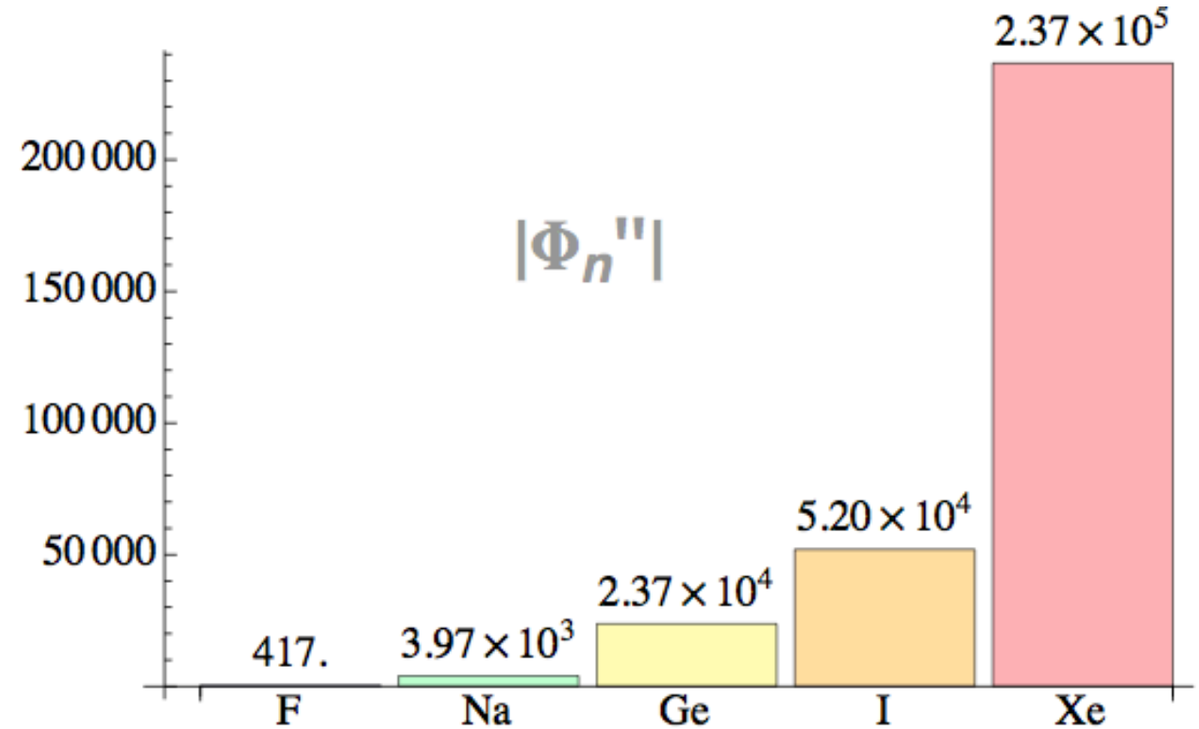
$$m_{\chi} = 100 GeV$$

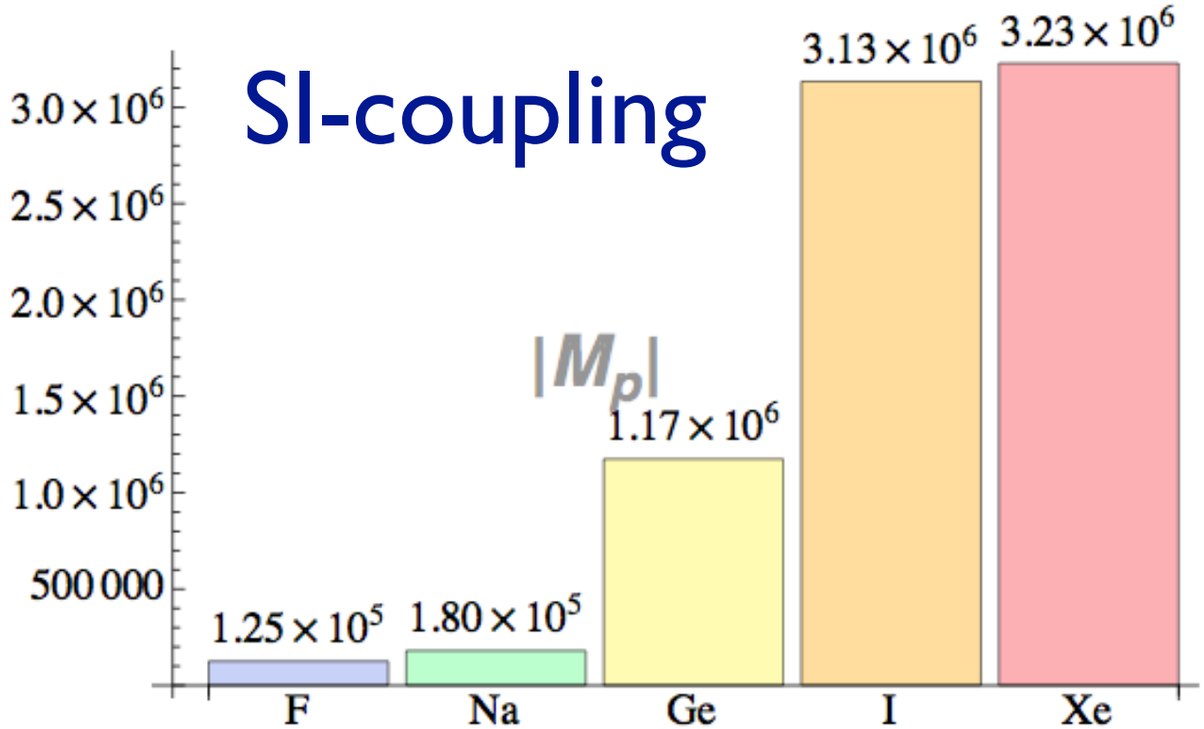
LSD-coupling

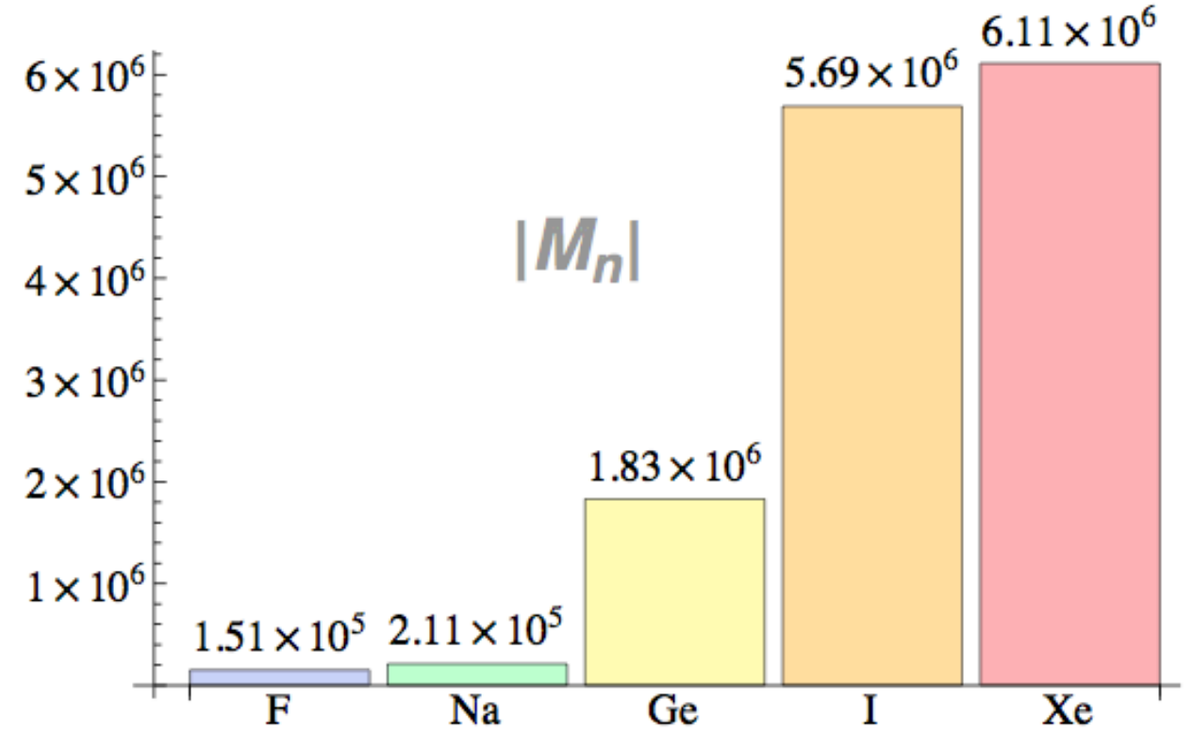


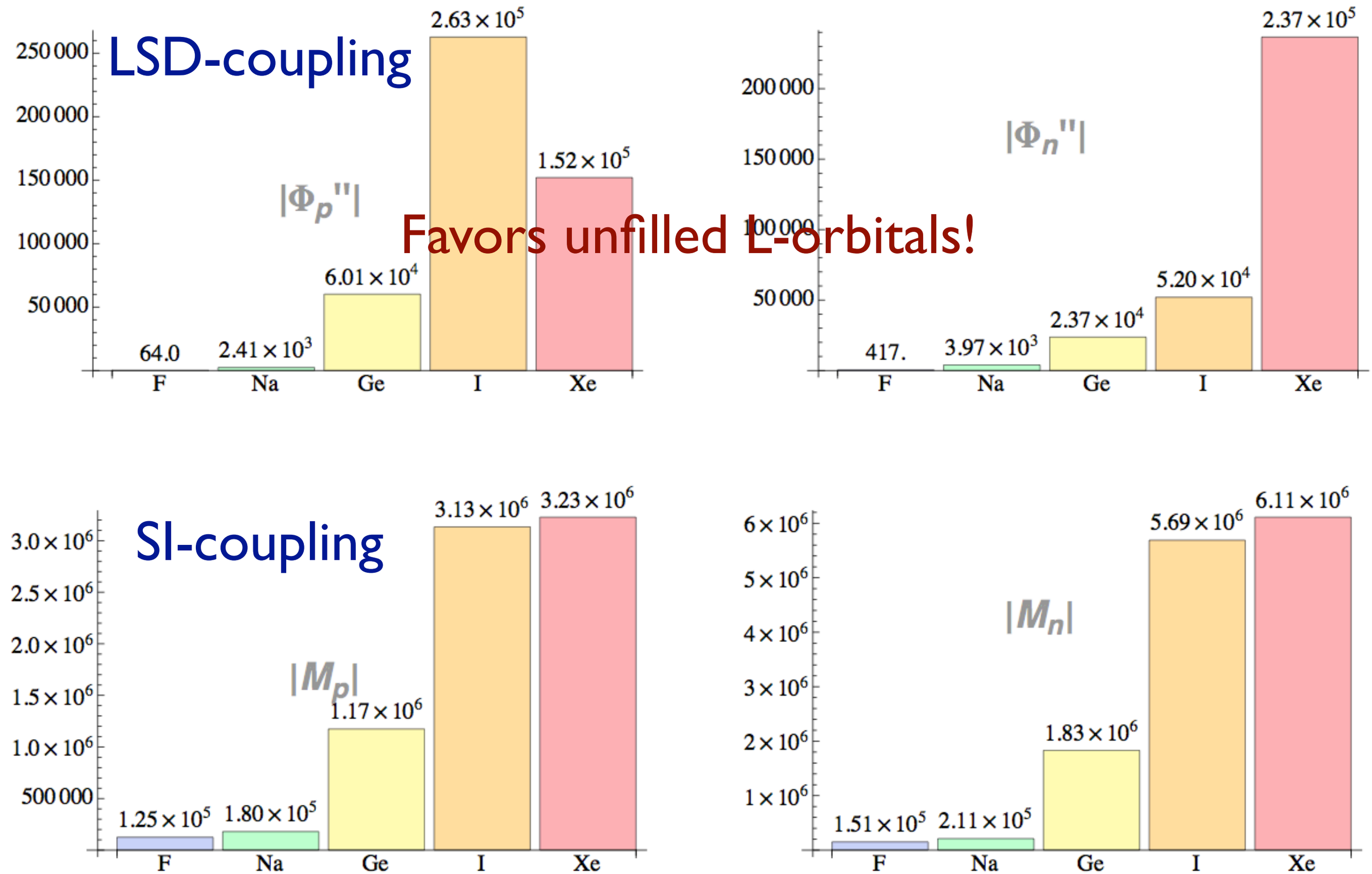



LSD-coupling
$|\Phi_p''|$
250 000
200 000
150 000
100 000
50 000
64.0
2.41×10^3
6.01×10^4
2.63×10^5
1.52×10^5
F
Na
Ge
I
Xe


$|\Phi_n''|$
200 000
150 000
100 000
50 000
417.
3.97×10^3
2.37×10^4
5.20×10^4
2.37×10^5
F
Na
Ge
I
Xe


SI-coupling
$|M_p|$
3.0×10^6
2.5×10^6
2.0×10^6
1.5×10^6
1.0×10^6
500 000
1.25×10^5
1.80×10^5
1.17×10^6
3.13×10^6
3.23×10^6
F
Na
Ge
I
Xe


$|M_n|$
6×10^6
5×10^6
4×10^6
3×10^6
2×10^6
1×10^6
1.51×10^5
2.11×10^5
1.83×10^6
5.69×10^6
6.11×10^6
F
Na
Ge
I
Xe


LSD-coupling
$|\Phi_p''|$
250 000
200 000
150 000
100 000
50 000
64.0
2.41×10^3
6.01×10^4
2.63×10^5
1.52×10^5
F
Na
Ge
I
Xe
$|\Phi_n''|$
200 000
150 000
100 000
50 000
417.
3.97×10^3
2.37×10^4
5.20×10^4
2.37×10^5
F
Na
Ge
I
Xe
Favors unfilled L-orbitals!
SI-coupling
$|M_p|$
3.0×10^6
2.5×10^6
2.0×10^6
1.5×10^6
1.0×10^6
500 000
1.25×10^5
1.80×10^5
1.17×10^6
3.13×10^6
3.23×10^6
F
Na
Ge
I
Xe
$|M_n|$
6×10^6
5×10^6
4×10^6
3×10^6
2×10^6
1×10^6
1.51×10^5
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1.83×10^6
5.69×10^6
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F
Na
Ge
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Xe

Light DM (3 GeV):

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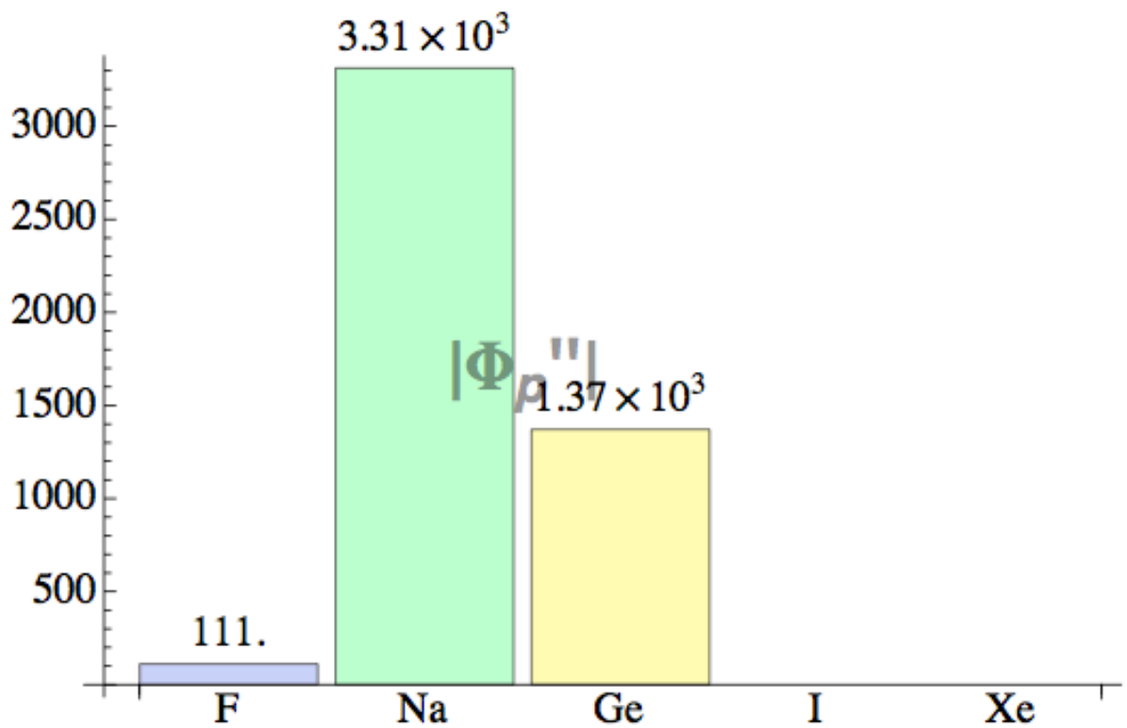
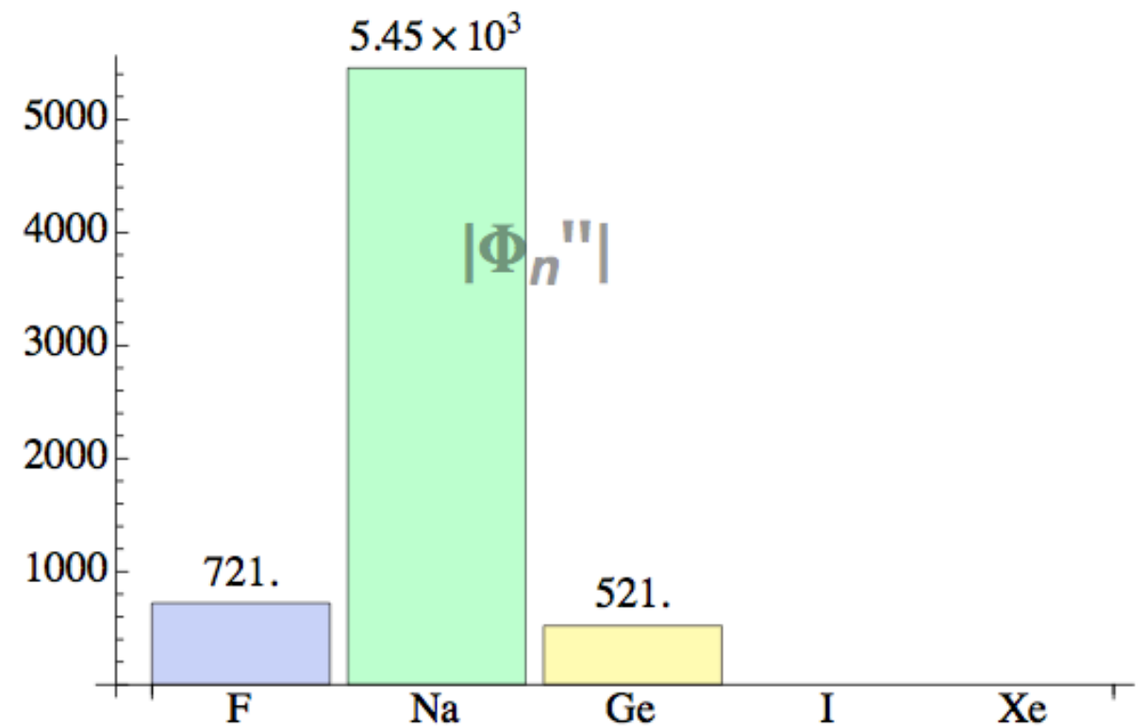
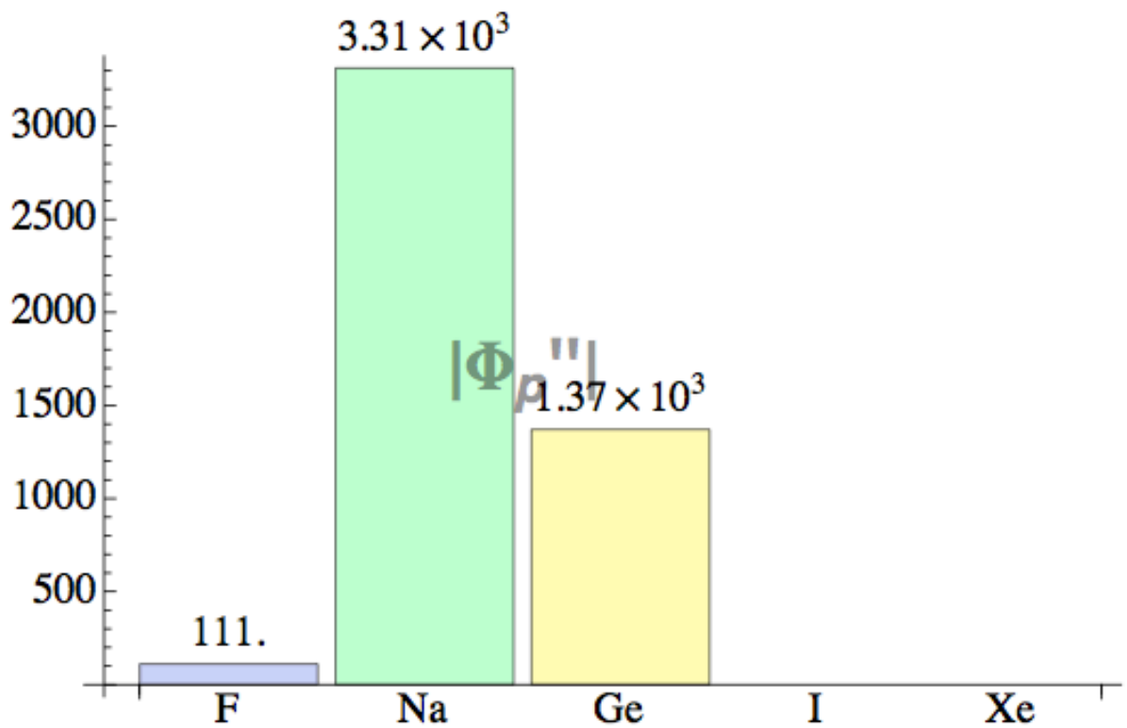
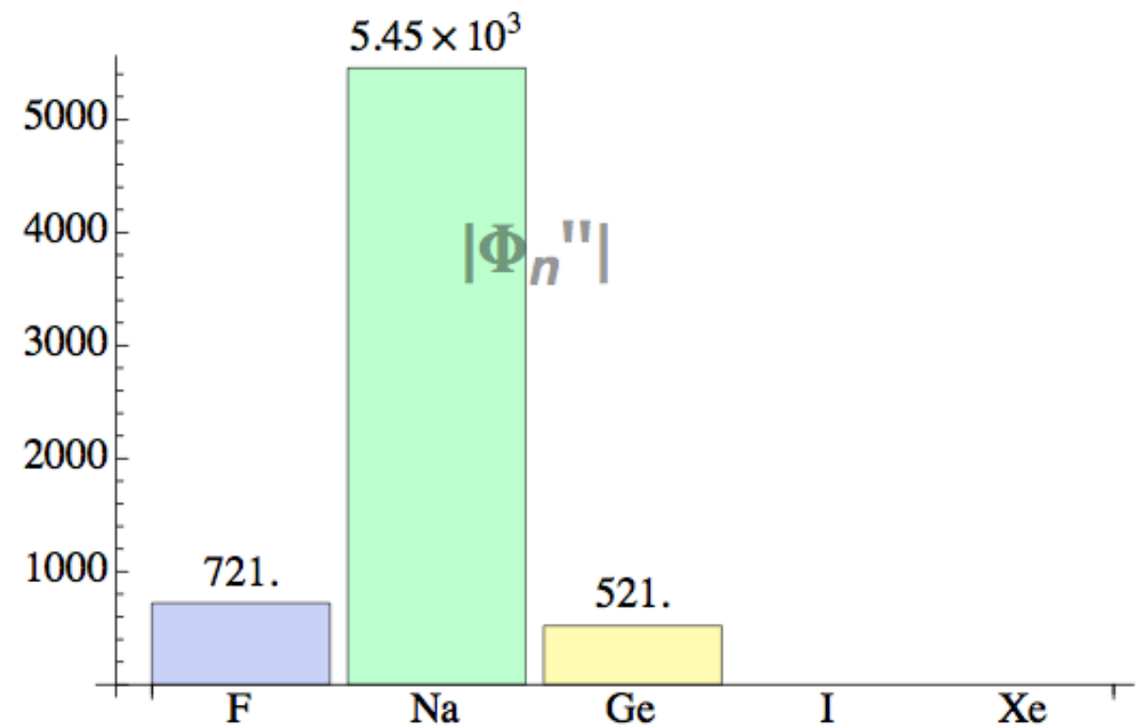




Light DM (3 GeV):





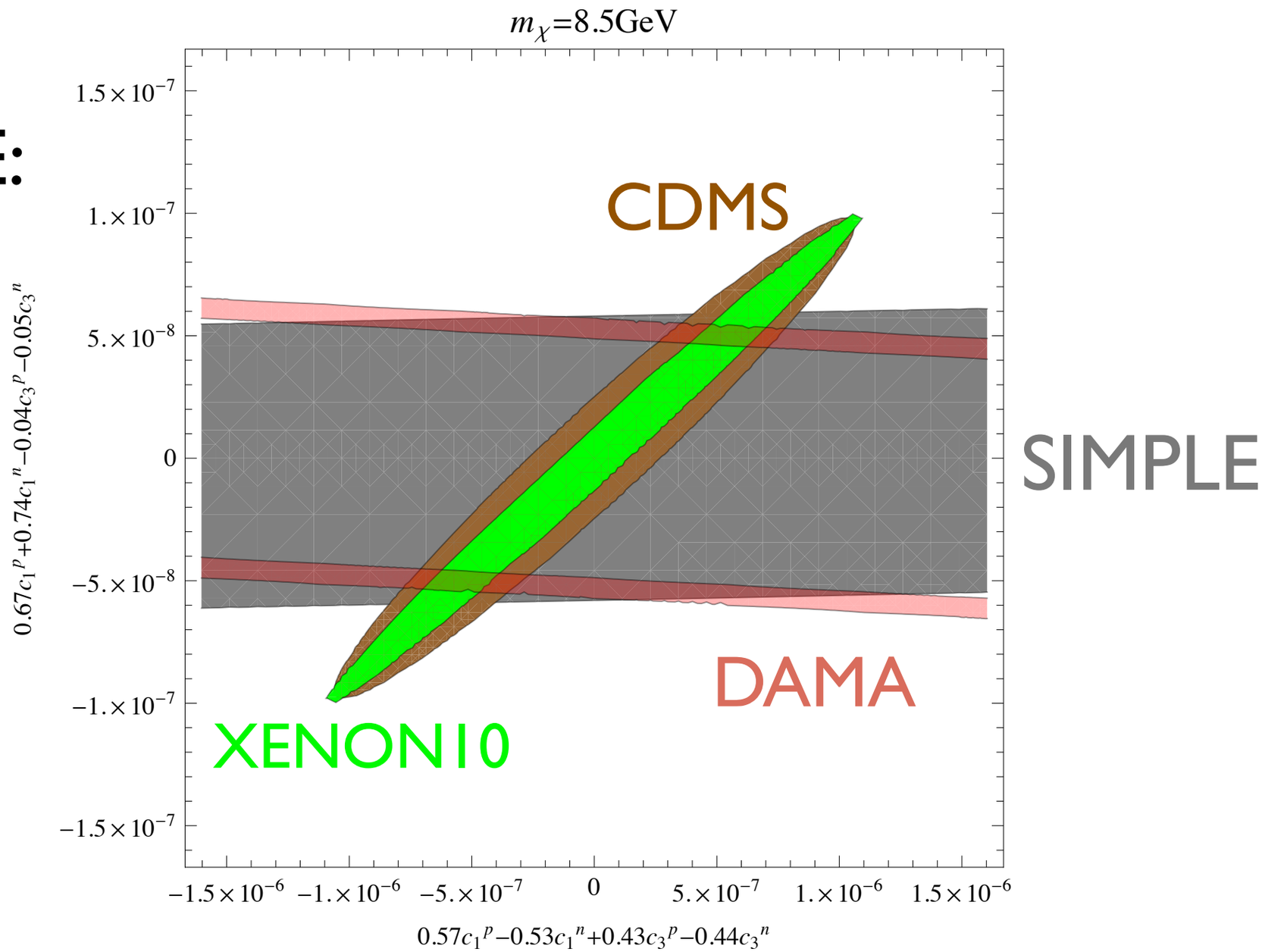
Sodium dominates!

Can this help DAMA?

Can this help DAMA? SI + LSD sector:

Can this help DAMA? SI + LSD sector:

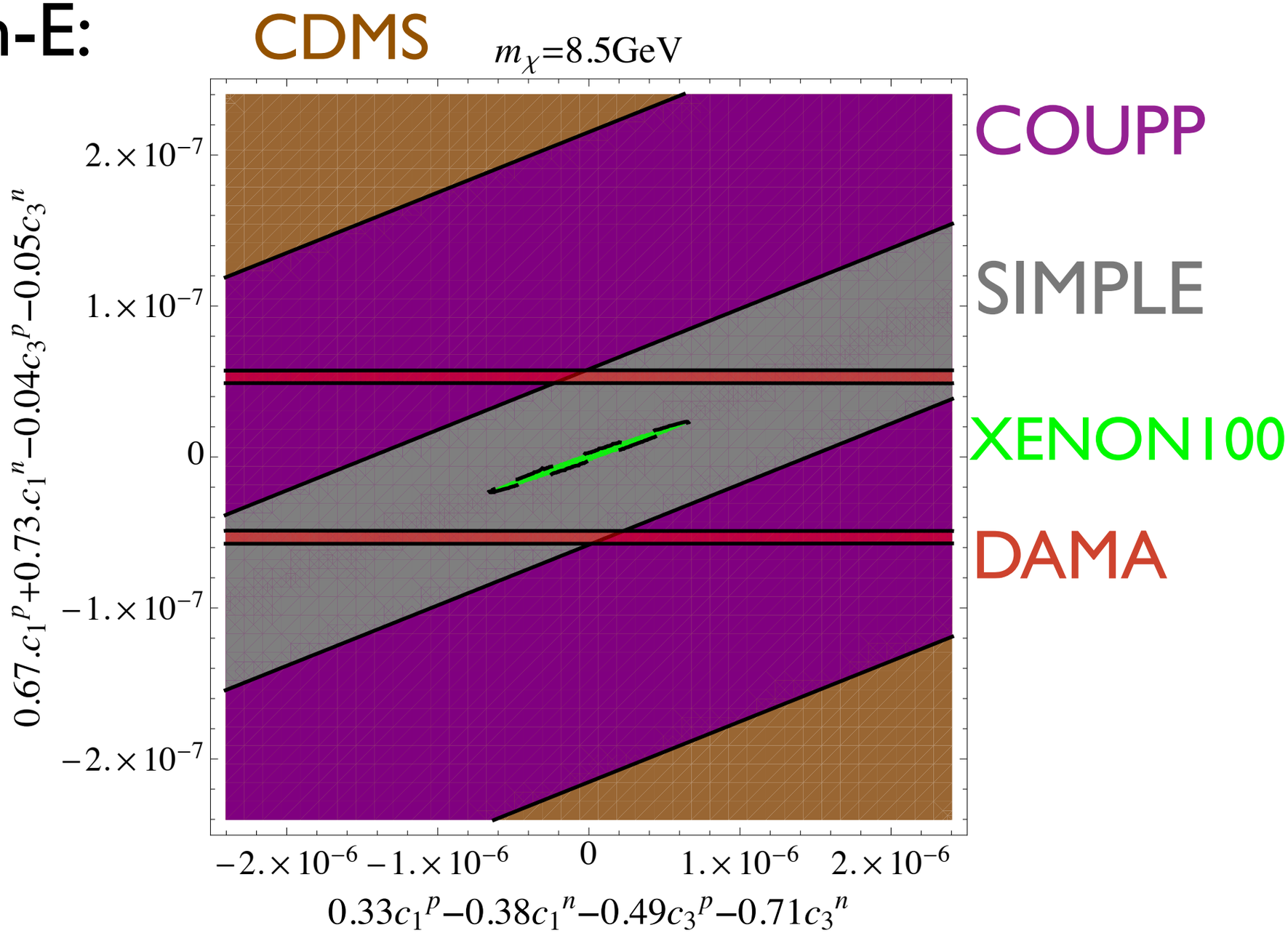
Low-E:



$$c_{1N}\ q^2 + c_{3N}\ m_N\ i\vec{v}\cdot(\vec{S}_N \times \vec{q})$$

High-E:

High-E:



$$c_{1N}\ q^2 + c_{3N}\ m_N\ i\vec{v}\cdot(\vec{S}_N \times \vec{q})$$

SI + LSD sector

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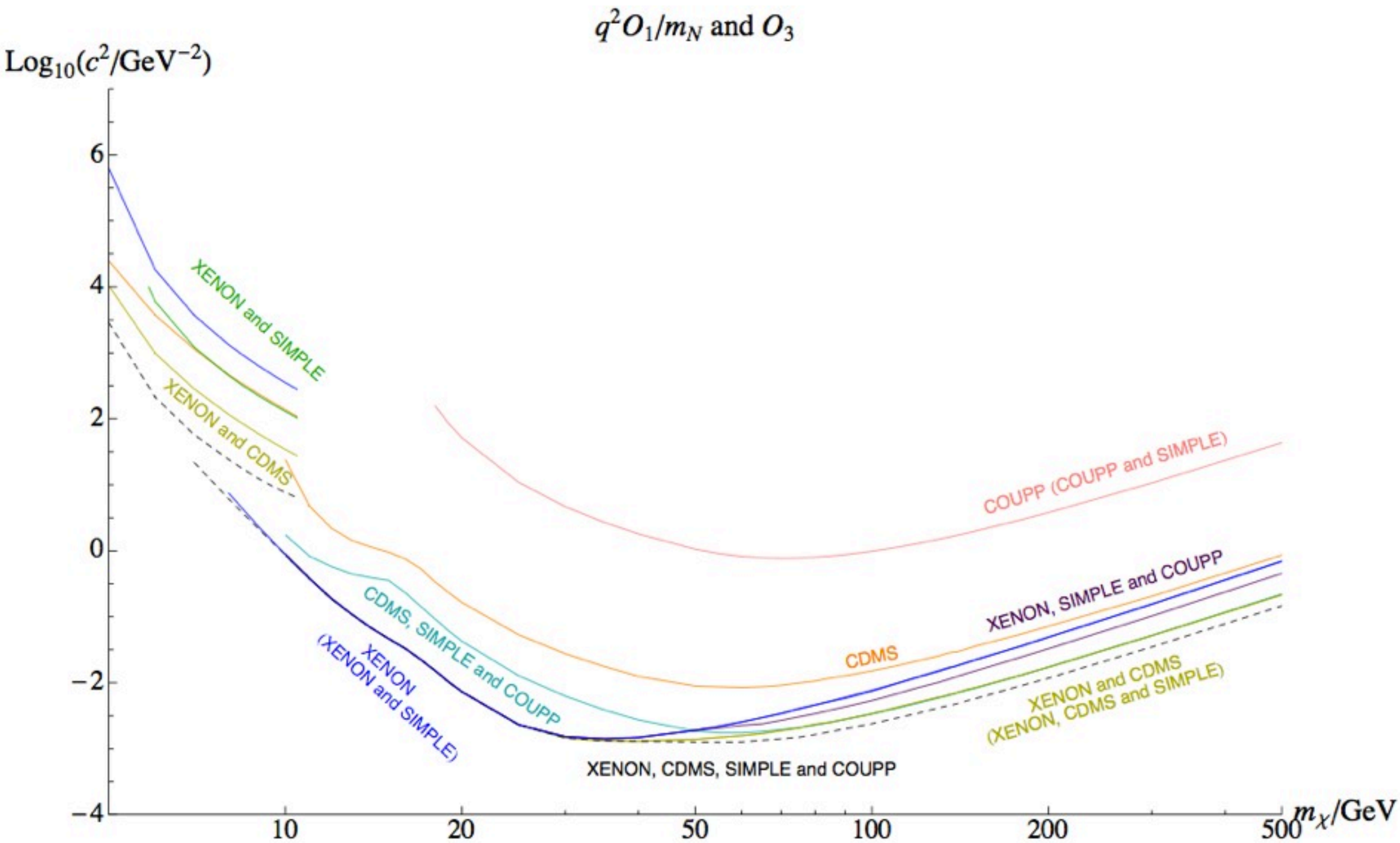
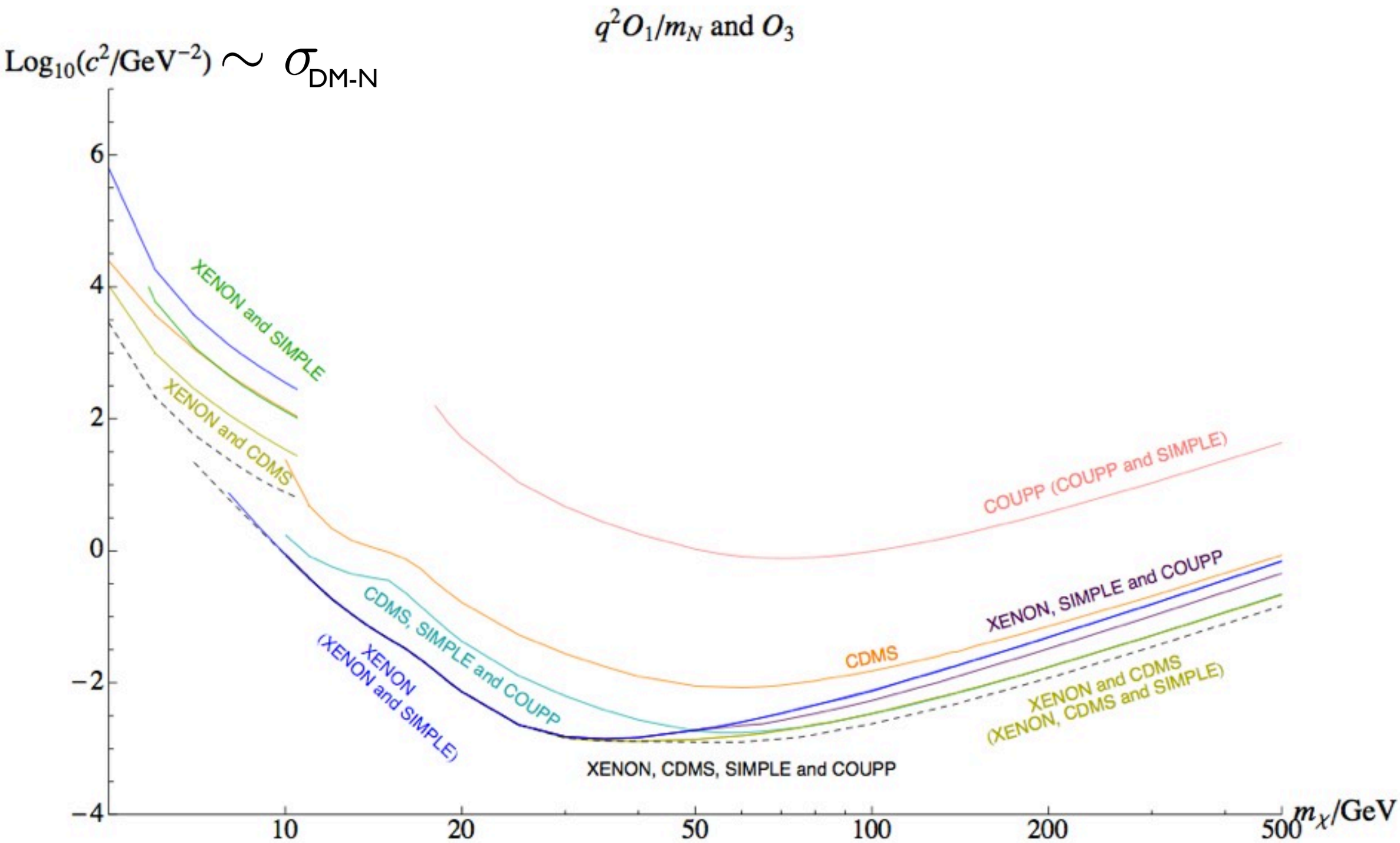
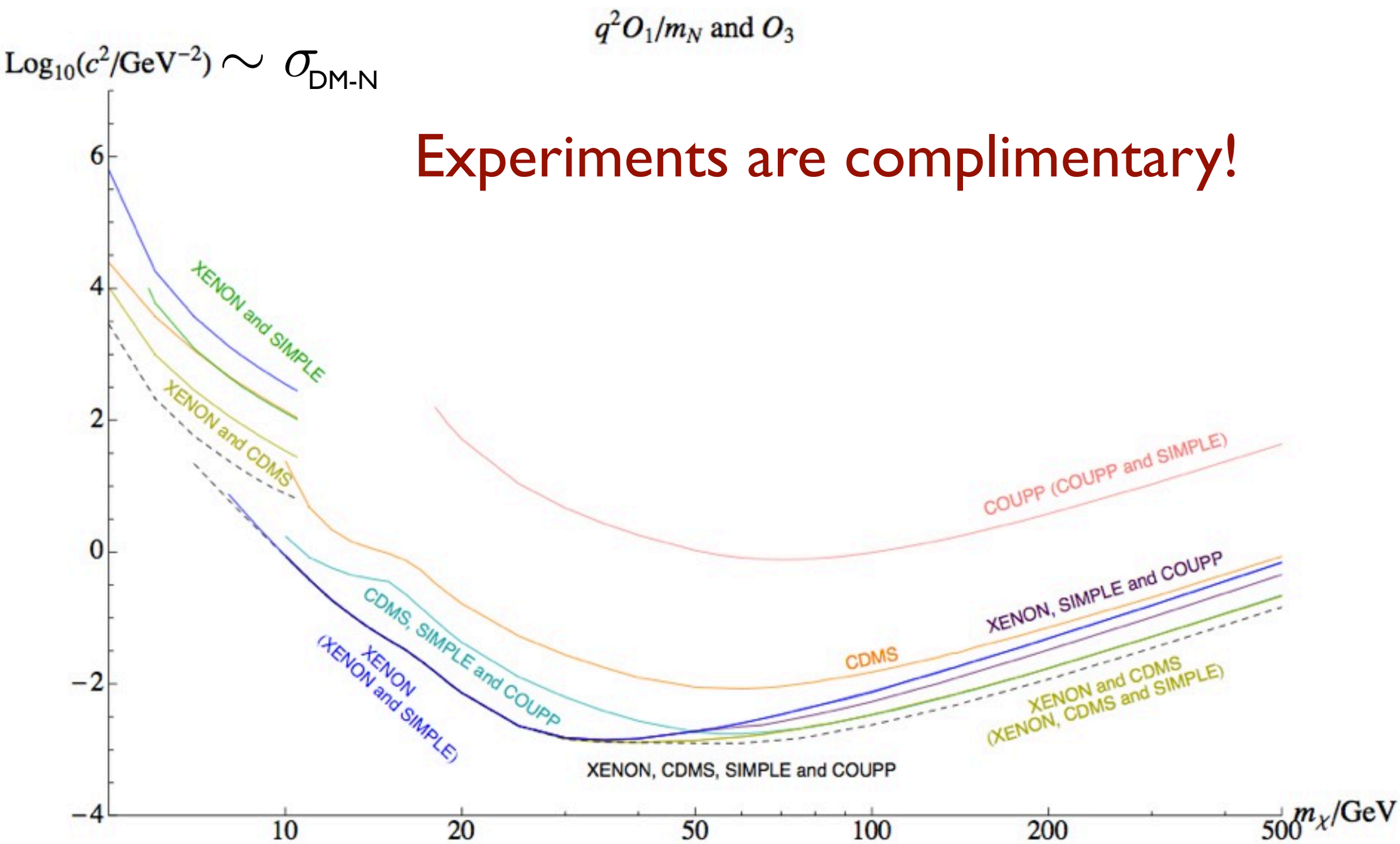


SI + LSD sector:



SI + LSD sector:



Experiments are complimentary!

LD(SI) + SD sector:

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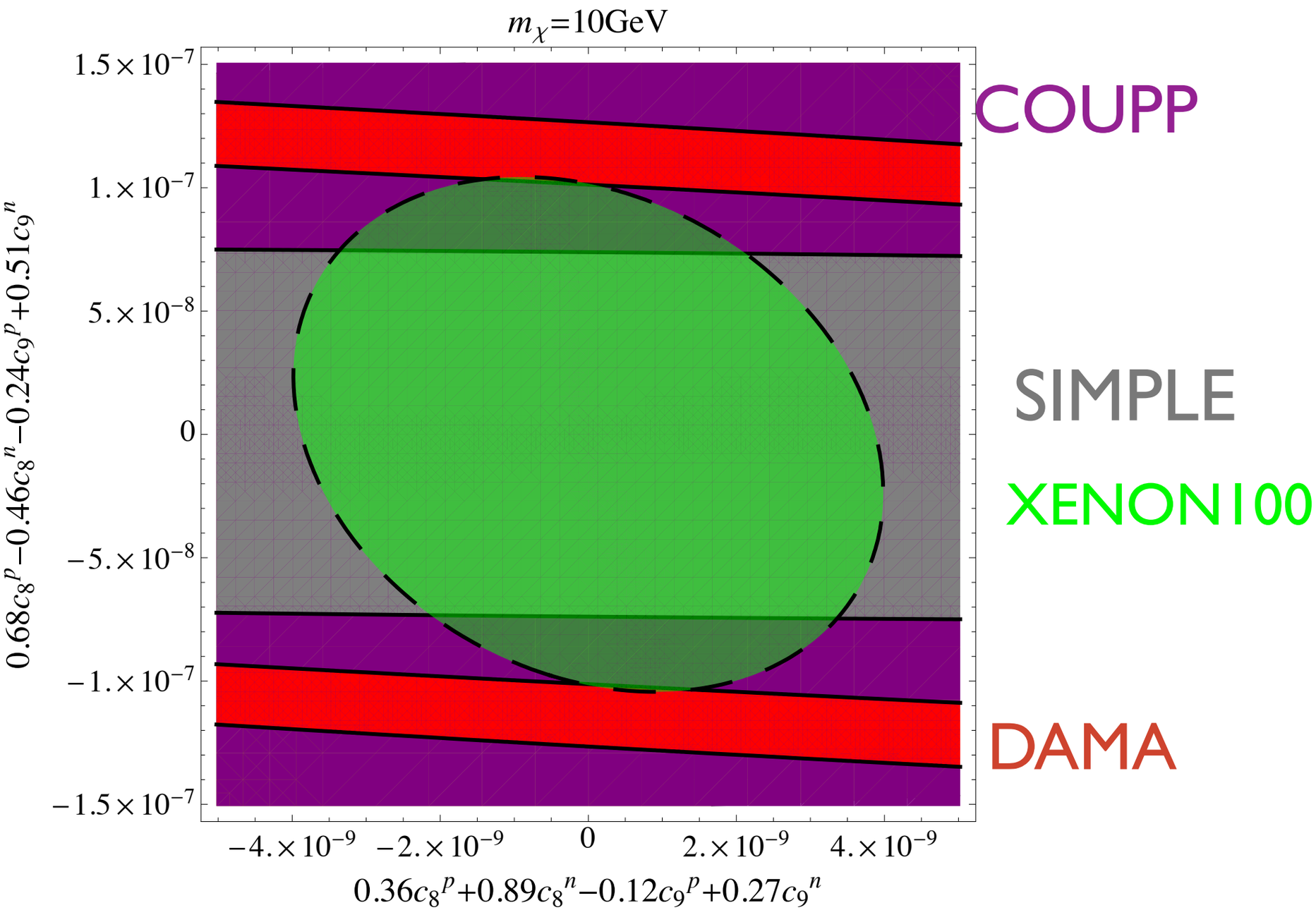
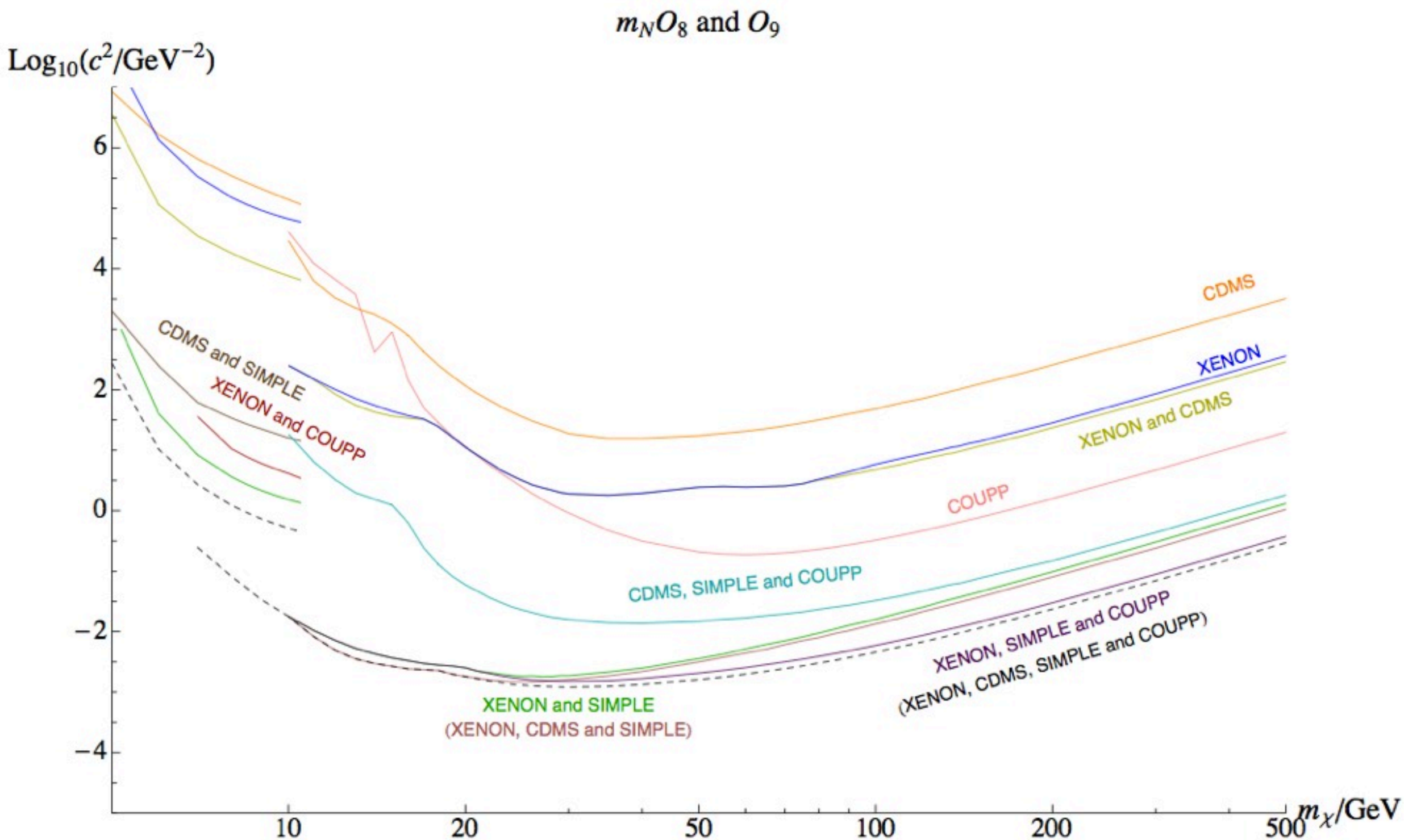
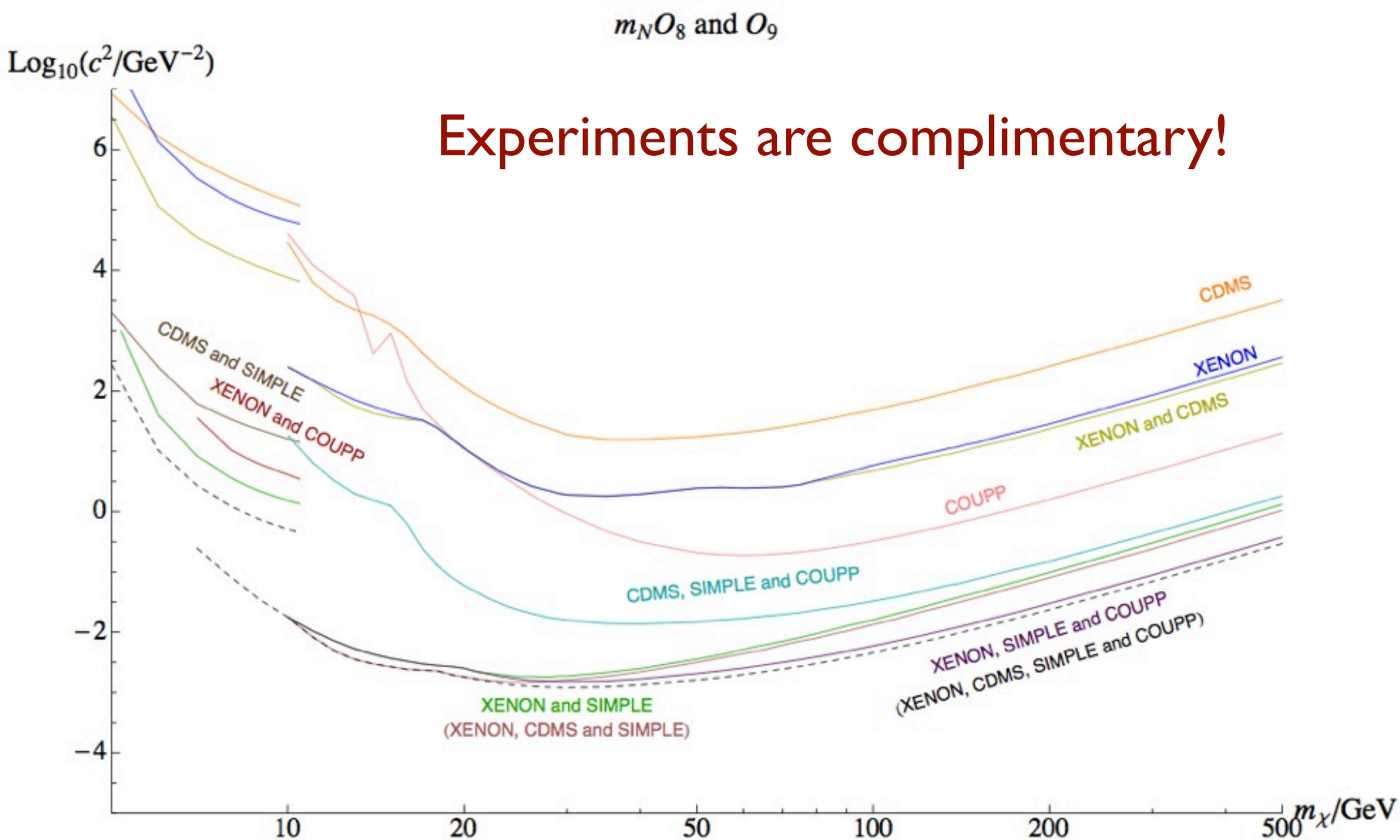


$$c_{8N}\ m_N \vec{S}_\chi \cdot \vec{v}^\perp + c_{9N}\ i\vec{S}_\chi \cdot (\vec{S}_N \times \vec{q})$$

LD(SI) + SD sector:



LD(SI) + SD sector:



Experiments are complimentary!

In Conclusion

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5. Having multiple targets is important!

Experiments are complimentary!