PANIC'11, July 24-28

Sticky Dark Matter in Effective Field Theory approach (arXiv:1108.xxxx)

Andriy Badin* (Duke University)
Alexey Petrov (Wayne State University)

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*presenting author

Outline

- Motivation
- Formalism
- Different scenarios
- Conclusions

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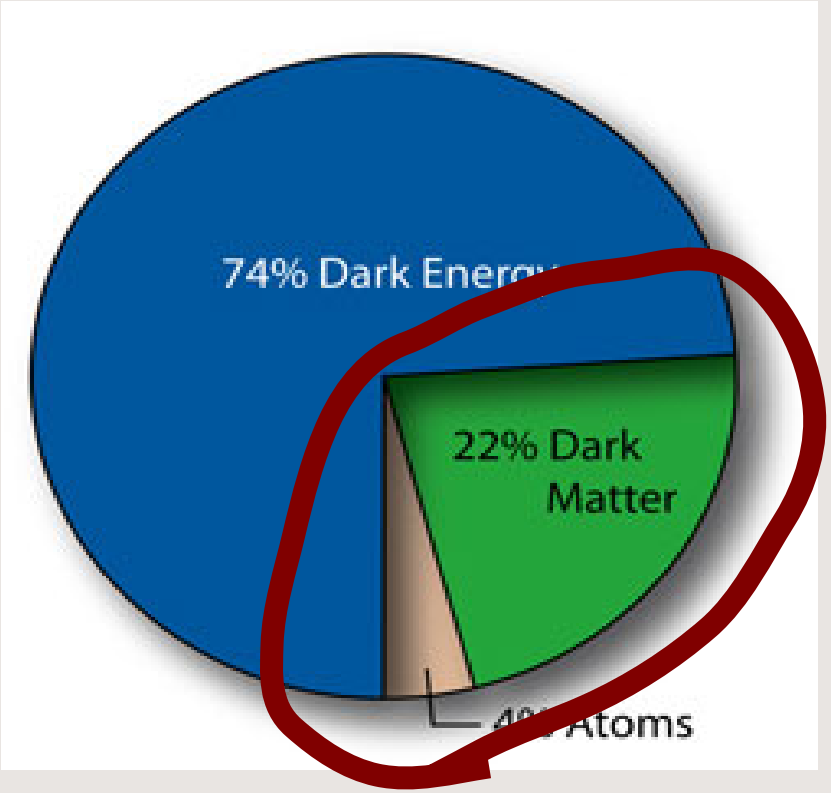
Motivation



- Hard to ignore something like this

- Somewhat controversial evidence from direct detection experiments*

*http://cdms.berkeley.edu/
http://people.roma2.infn.it/~dama/web/home.html
http://cogent.pnnl.gov/

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Possible solutions

- IDM [1]
- ResDM [2]
- Alternatives to DM [3]

Drawbacks

- Rather developed models
- Finely tuned

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[1] D.Tucker-Smith, N.Weiner, Phys. Rev.D64, 043502 (2001).
[2] Y.Bai and P.J.Fox,JHEP **0911**, 052 (2009)
[3] B.Feldstein, A.L.Fitzpatrick, E.Katz, B.Tweedie, JCAP 1003, 029 (2010)

Alternative!

- EFT approach
- No up-front assumptions about underlying physics
- Explore classes of models rather than models themselves
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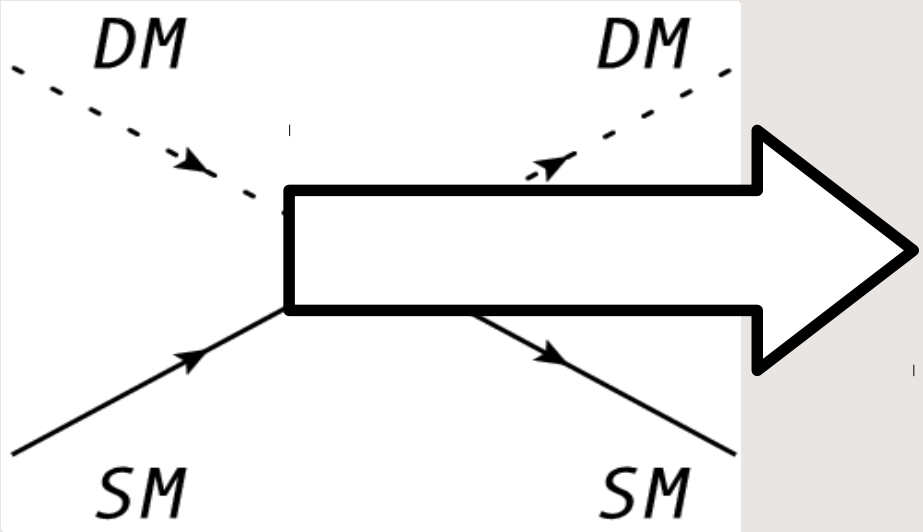
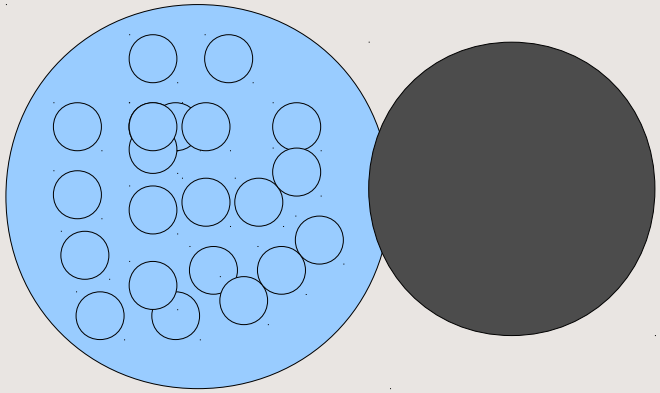
Direct detection

- DM – non-relativistic with mass few GeV – 10's GeV
- SM – mass 10's GeV





DM can not see internal structure of target nuclei!

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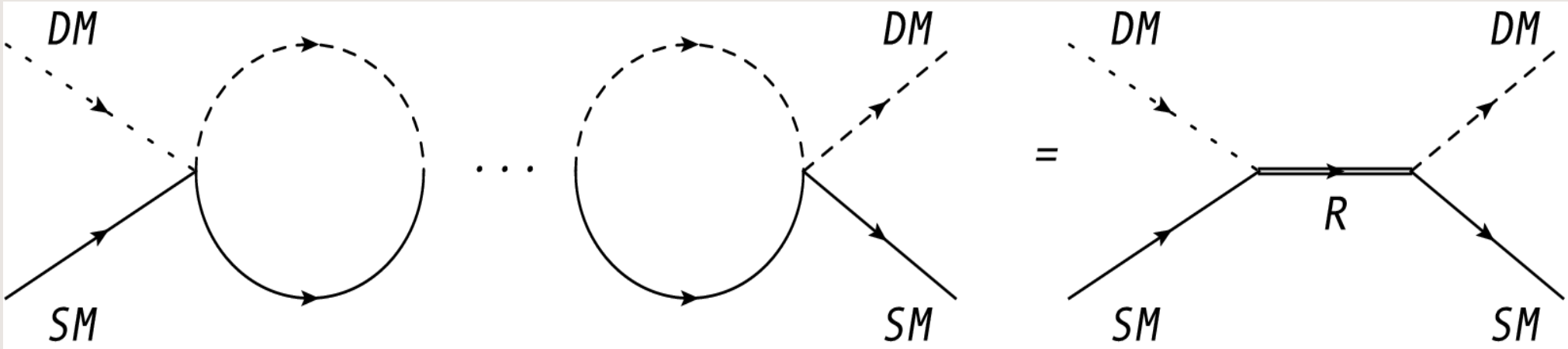
Concept of Sticky DM



- Established formalism
- Element dependent and model independent results

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S-wave scattering[1]

$$\mathcal{L} = \psi^\dagger[i\partial_0 + \frac{\vec{\nabla}^2}{2m}]\psi + \phi^\dagger[i\partial_0 + \frac{\vec{\nabla}^2}{2M}]\phi + C_2^s(\psi\phi)^\dagger(\psi\phi)$$

- Very similar to deuteron creation in NN EFT
- Pole in scattering amplitude tells us location of bound state. In effective range expansion in reads as:

$$\mathcal{A} = \frac{4\pi}{\mu}\frac{1}{-1/a_0 - ik + \frac{1}{2}r_0k^2}$$

$$\sigma = \frac{4\pi}{k^2}\sin^2\delta_0$$

$$k\cot\delta_0 = -\frac{1}{a_0} + \frac{1}{2}r_0k^2$$

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S-wave scattering – not so optimistic

- Bound state is formed in limit of large scattering length $a_0 \gg 1/\Lambda$
- No current scattering data can be used. Order of magnitude estimates lead to $\Lambda \sim 10^3\, TeV$
- Cosmological consequences are unknown

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P-wave [1]

$$\begin{aligned}\mathcal{L} &= \psi^\dagger[i\partial_0 + \frac{\vec{\nabla}^2}{2m}]\psi + \phi^\dagger[i\partial_0 + \frac{\vec{\nabla}^2}{2M}]\phi + C_2^p(\psi \overleftrightarrow{\nabla} \psi)^\dagger(\phi \overleftrightarrow{\nabla} \phi) \\ &+ (\text{ higher derivatives terms})\end{aligned}$$

- ✔ P-wave scattering amplitude has two poles in two lower quadrants
- ✔ Naturally produces narrow resonance behavior used in resonant Dark Matter model[2] to explain difference in signals between DAMA and CDMS.

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P-wave, ER expansion

$$T_l = \frac{4\pi}{m}\frac{2l+1}{k\cot\delta_l - ik}P_l(\cos\theta)$$

$$k^{2l+1}\cot\delta_l = -\frac{1}{a_l} + \frac{r_l}{2}k^2$$

$$S_1 = -\frac{k+i\gamma_1}{k-i\gamma_1}\frac{E-E_0-i\Gamma(E)/2}{E-E_0+i\Gamma(E)/2}, \quad \text{where}$$

$$E = \frac{k^2}{2\mu}, \quad E_0 = \frac{\gamma^2+\tilde{\gamma}^2}{2\mu}, \quad \Gamma(E) = -4\gamma\sqrt{\frac{E}{2\mu}}$$

Narrow resonance there!

$$C_2^p = \frac{3\pi a_1(m_\chi + m_N)}{16 m_\chi m_N} = \frac{3\pi}{16}\left(\frac{m_\chi + m_N}{m_\chi m_N}\right)^{5/2}\frac{\Gamma}{(2E_0)^{5/2}}$$

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Matching

- Take heavy particle limit since interacting fields are non-relativistic.

$$\phi(x) = \frac{e^{-imv\cdot x}}{\sqrt{2m}}(\phi_m + \chi_m).$$

$$\psi = \begin{pmatrix} \psi_L \\ \psi_R \end{pmatrix} = \sqrt{\frac{m+E}{4E}} \begin{pmatrix} (1 + i\frac{\vec{\sigma}\cdot\vec{\nabla}}{m+E})\chi \\ (1 - i\frac{\vec{\sigma}\cdot\vec{\nabla}}{m+E})\chi \end{pmatrix}$$

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- p-wave-only scattering is possible for scalar-fermion and scalar-scalar pairs of DM-SM particles. Fermion-fermion pair has admixture of s-wave

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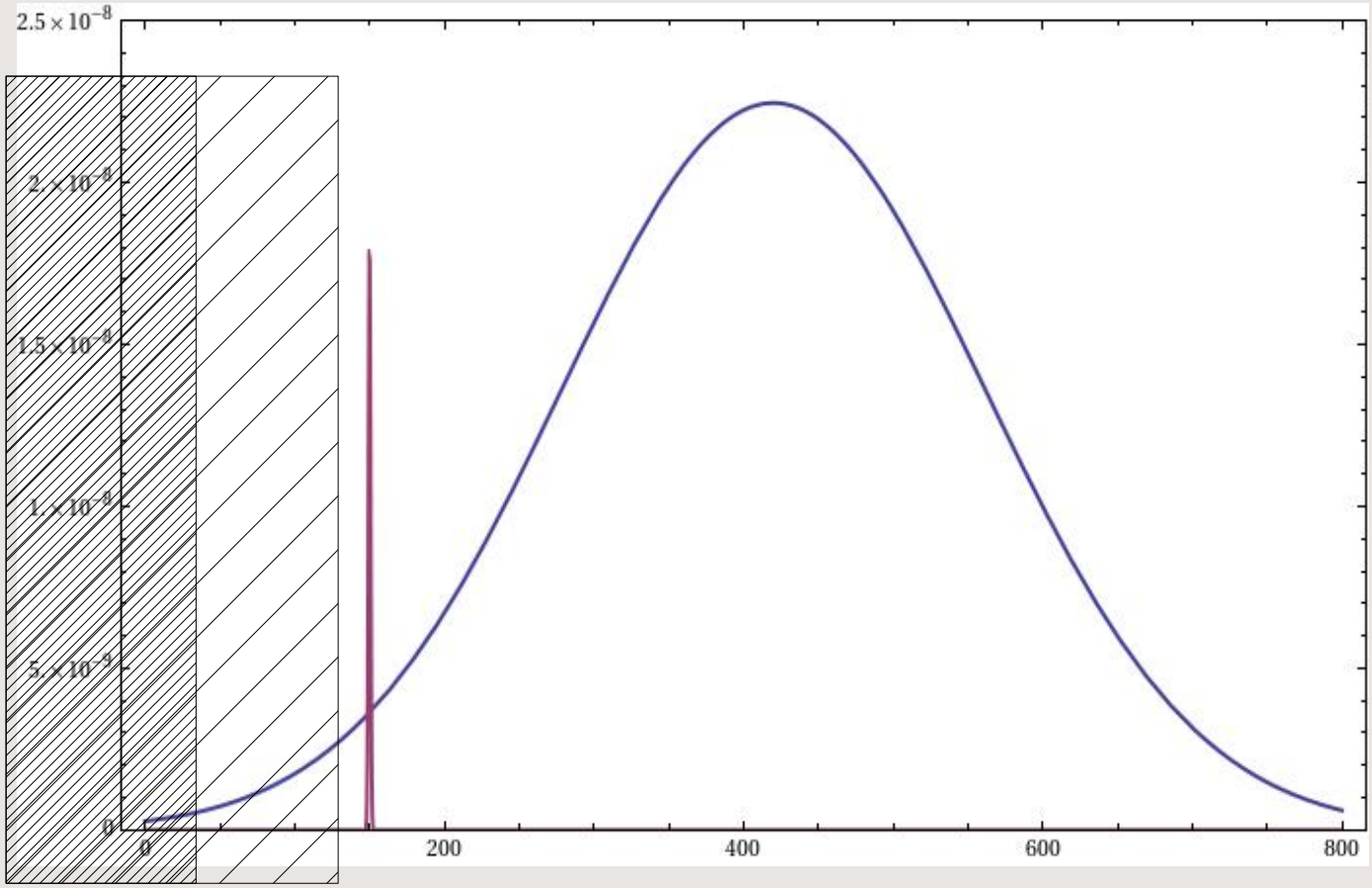
Results and outlook



Sensitivity of two different direct detection experiments

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Results and outlook

- Extensive analysis of ALL direct detection experiments is needed
- Potentially can explain all direct detection experiment
- Link between direct detection experiments and interaction of DM with SM fields (quarks, leptons and gauge bosons) at the level of EFT needs to be established. Hints from nuclear physics?
- Other types of interaction?

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Technical back-up

P-wave

$$
\begin{aligned}
k_\pm &= i(\gamma + i\tilde{\gamma}) = \sqrt{\frac{2}{a_1 r_1}}\left[\pm 1 + \frac{i}{r_1}\sqrt{\frac{2}{a_1 r_1}}\right], \\
k_1 &= \frac{i}{6}\left(|r_1| + \frac{|a_1|^{1/3}|r_1|^2}{v} + \frac{v}{|a_1|^{1/3}}\right), \\
v &= \left(108 + |a_1||r_1|^3 + 108\sqrt{1 + |a_1||r_1|^3/54}\right)^{1/3} \\
r_1 &= \sqrt{\frac{m_\chi m_N}{8E_0(m_\chi + m_N)}}\,\frac{16E_0^2 - \Gamma^2}{\Gamma} \\
a_1 &= \left(\frac{8E_0(m_\chi + m_N)}{m_\chi m_N}\right)^{3/2}\frac{2\Gamma}{(16E_0^2 - \Gamma^2)^2}
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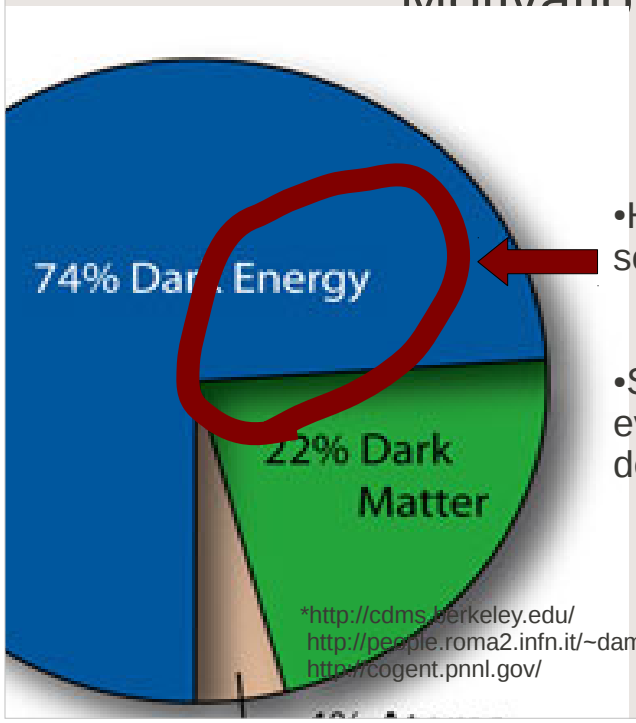

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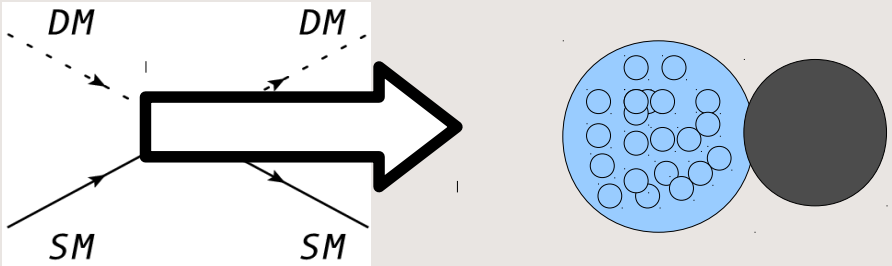

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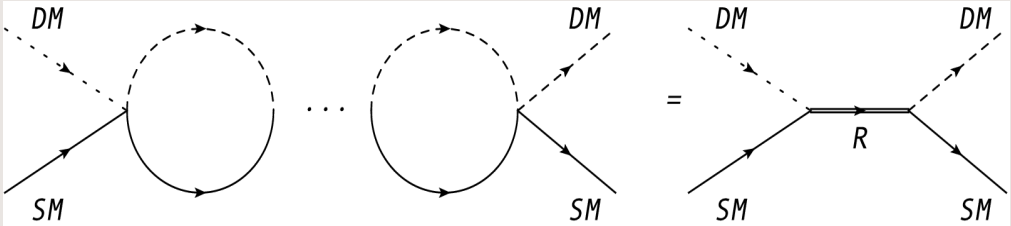

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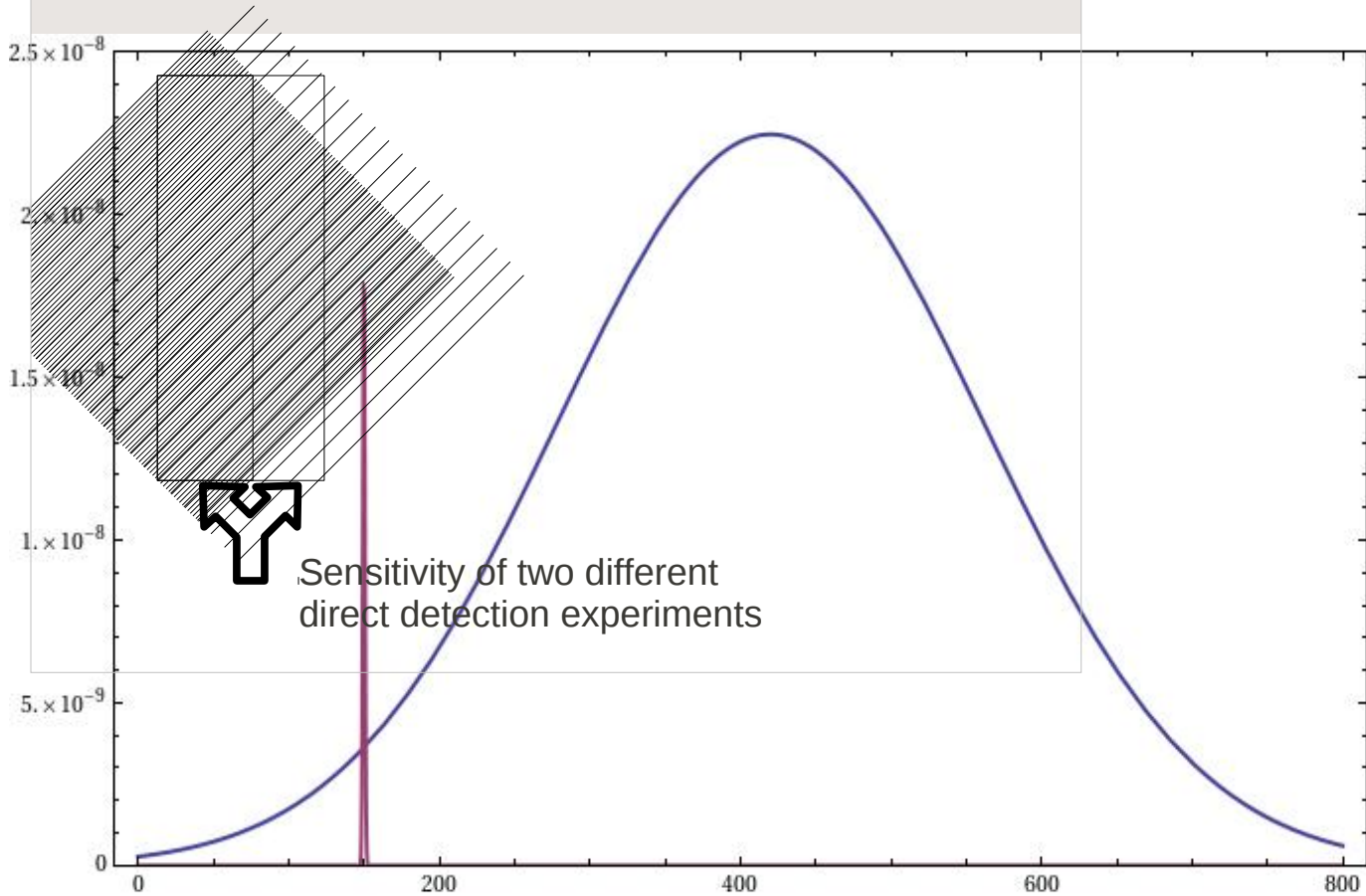

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