Joint neutron polarizability extraction and dark sector search using deuteron photodisintegration

Cornelis J.G. Mommers, 2025-09-25

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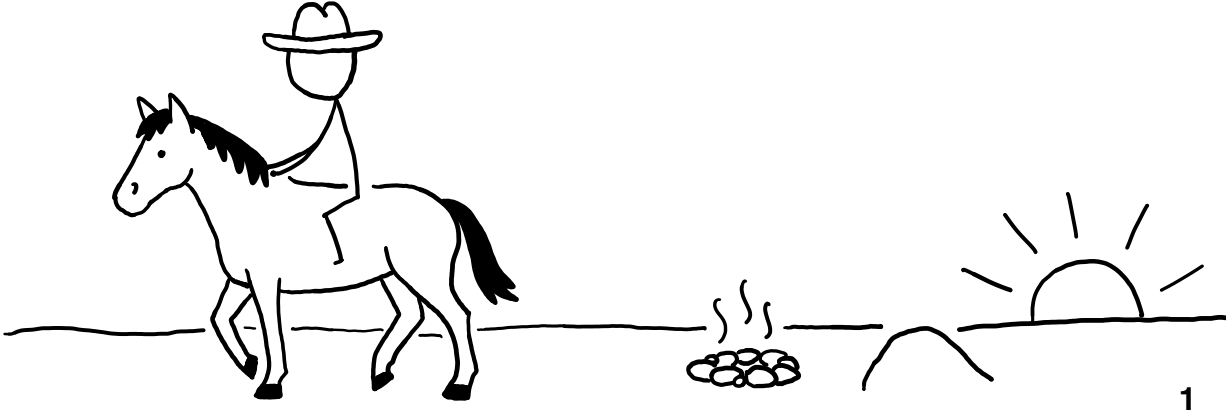
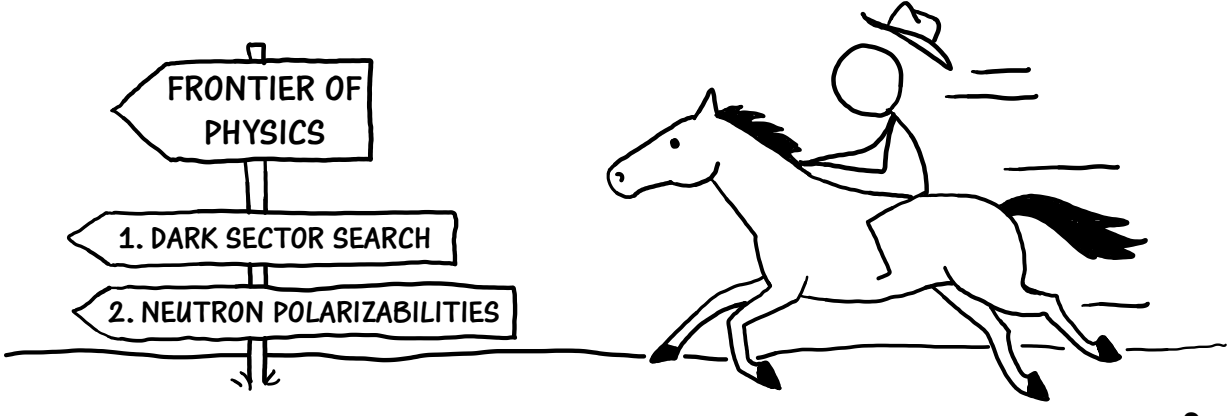
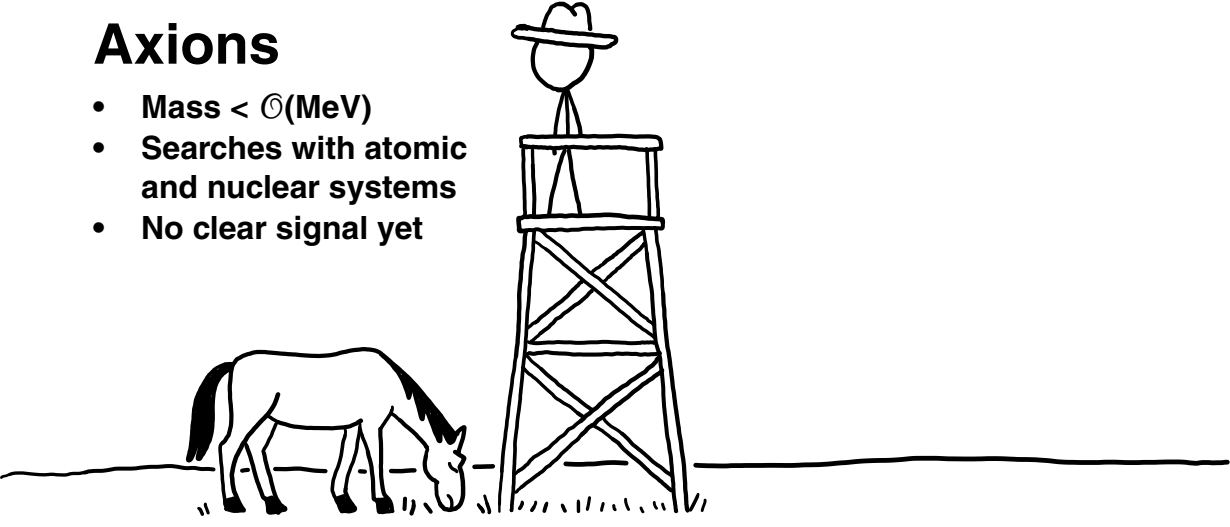
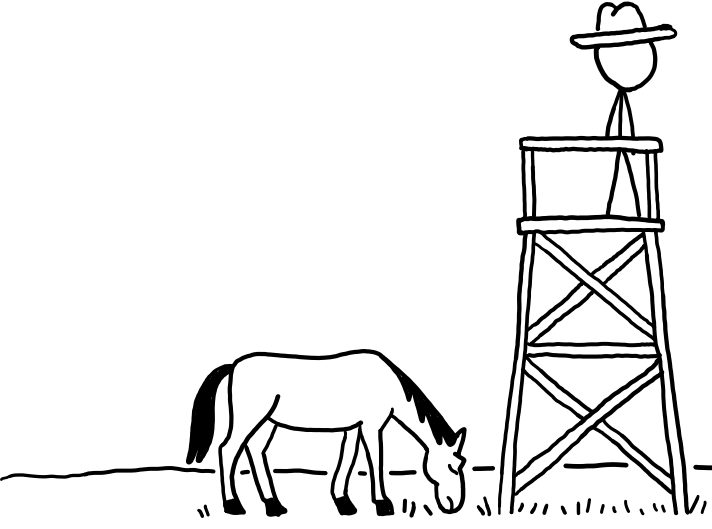



FRONTIER OF PHYSICS
1. DARK SECTOR SEARCH
2. NEUTRON POLARIZABILITIES

Axions

- Mass < $\mathcal{O}$(MeV)
- Searches with atomic and nuclear systems
- No clear signal yet

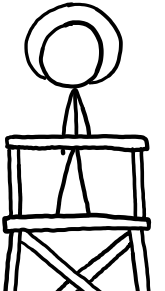




WIMPS

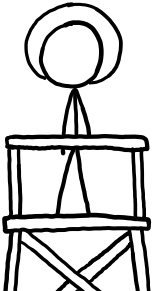
- Mass > $\mathcal{O}$(GeV)
- Searches with high-energy colliders
- No clear signal yet

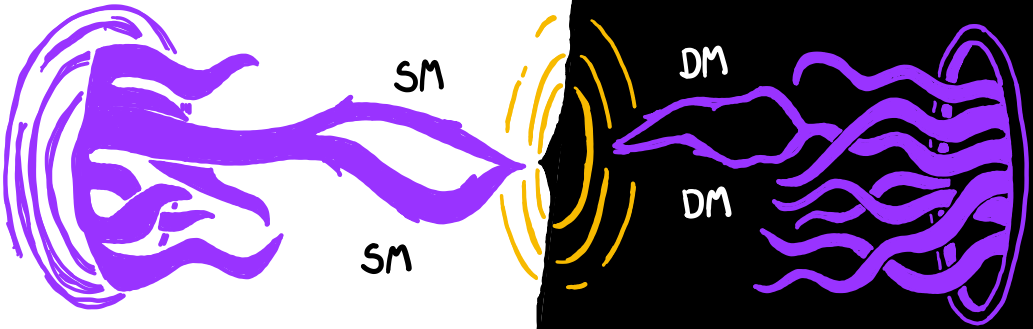
Light dark matter

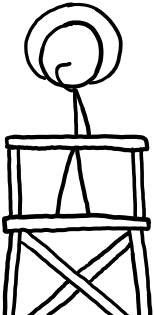


Light dark matter

- Increasing interest
- Exists dark sector (uncharged under SM gauge symmetries)
- ‘Portal’ to dark sector via mediator particle



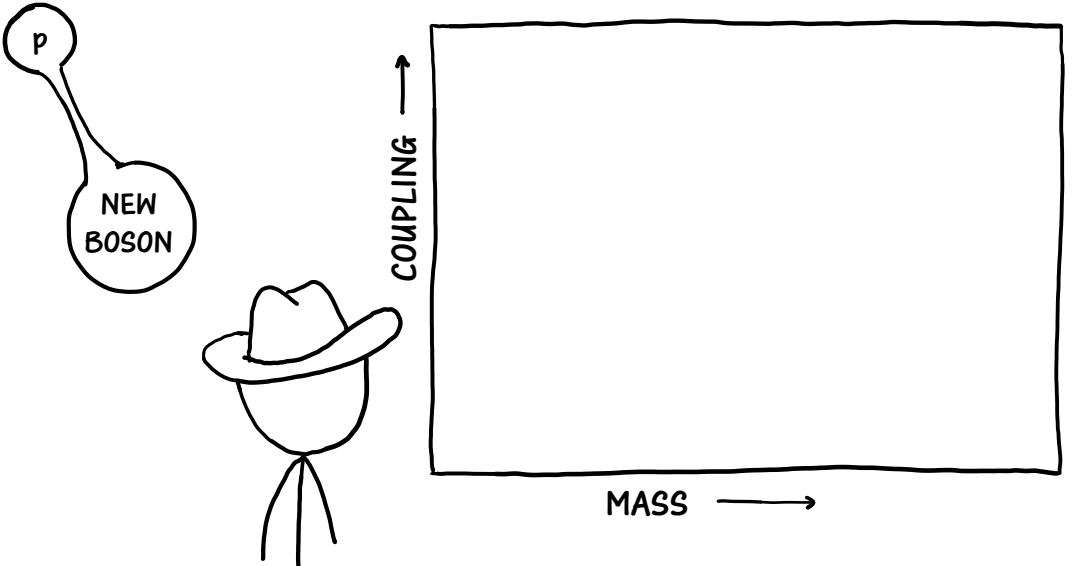




Light dark matter

- Mediator mass ~$\mathcal{O}$(MeV)
- Searches with low-energy, high-intensity experiments
- Dark photon, dark Higgs, etc.

Exclusion limits (proton)



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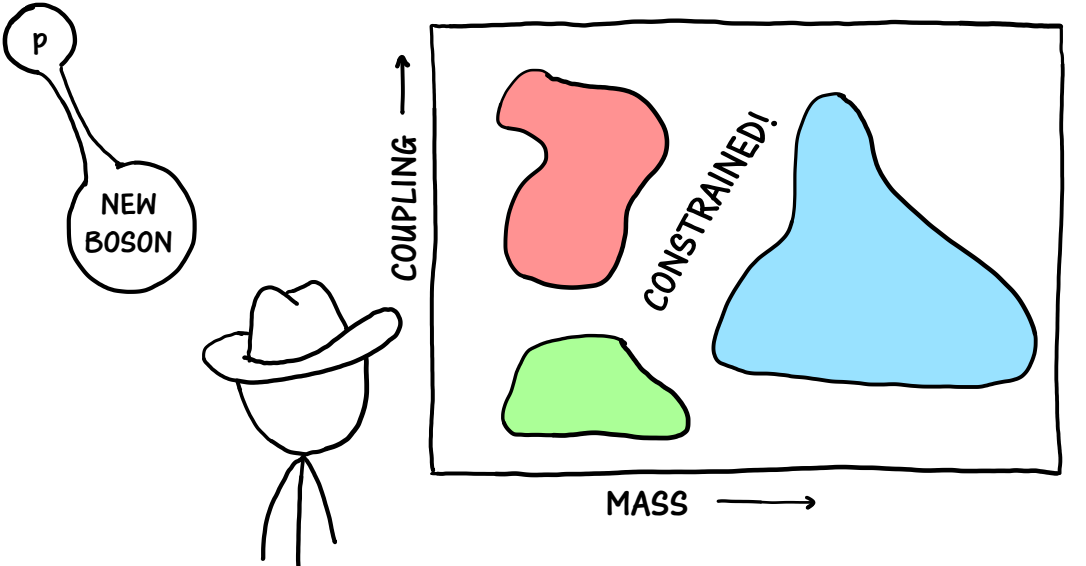
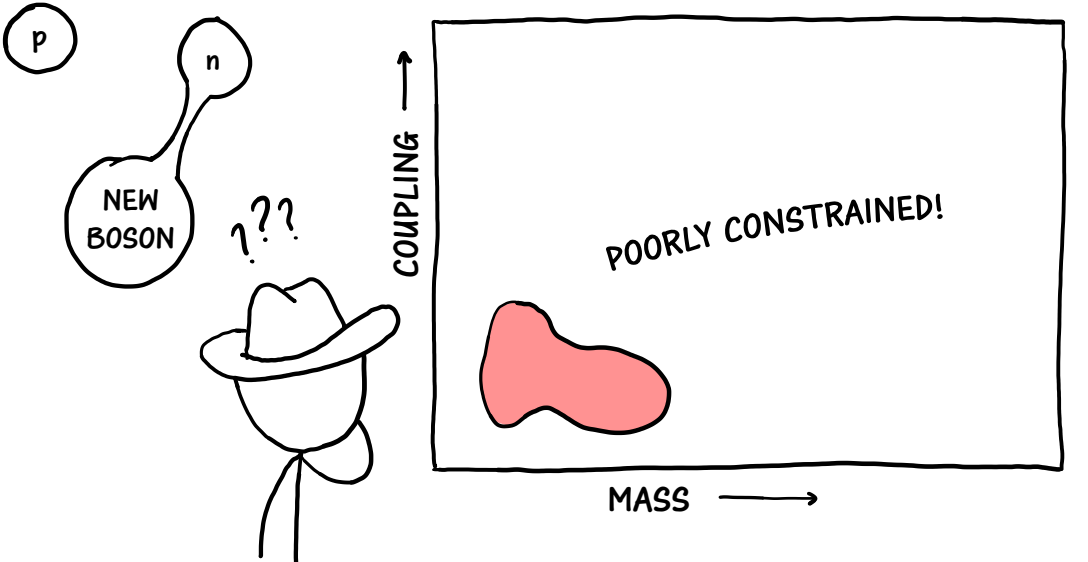
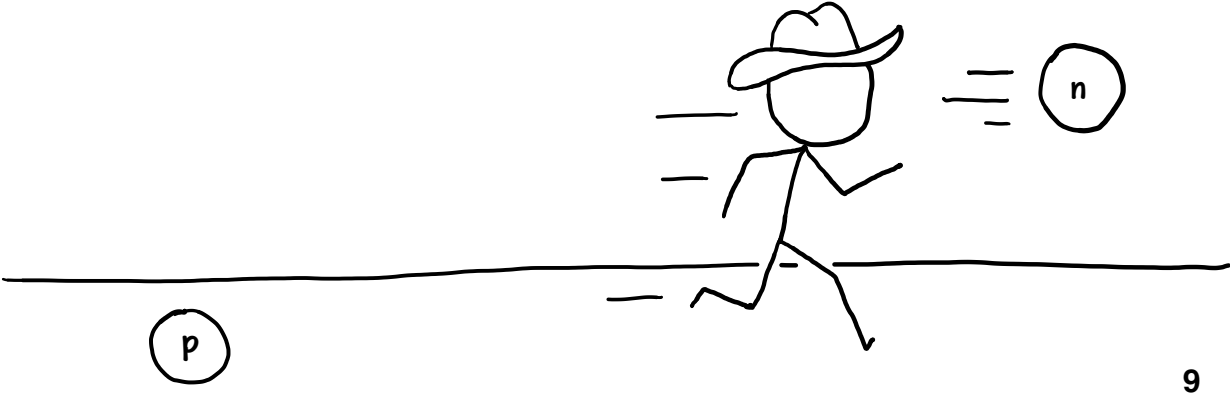


Exclusion limits (neutron)

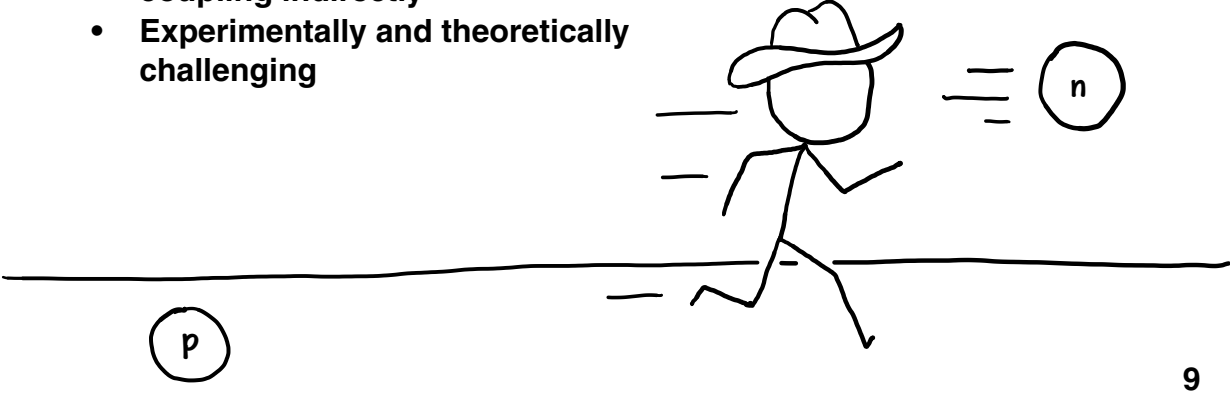


Why neutron coupling ill constrained?

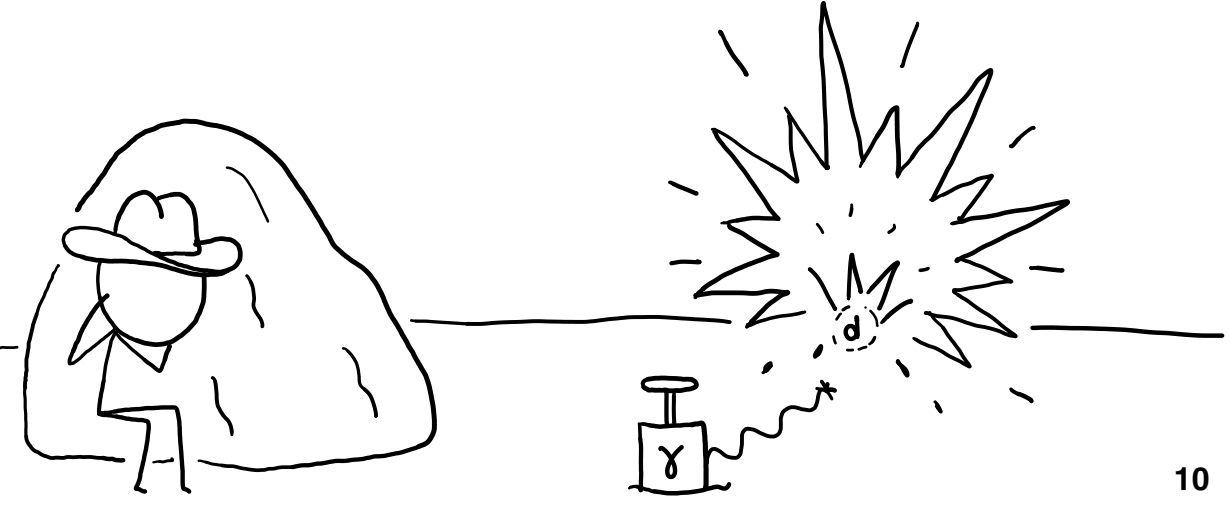


Why neutron coupling ill constrained?

- In lab no free neutron target
- Unlike proton coupling, must infer neutron coupling indirectly
- Experimentally and theoretically challenging

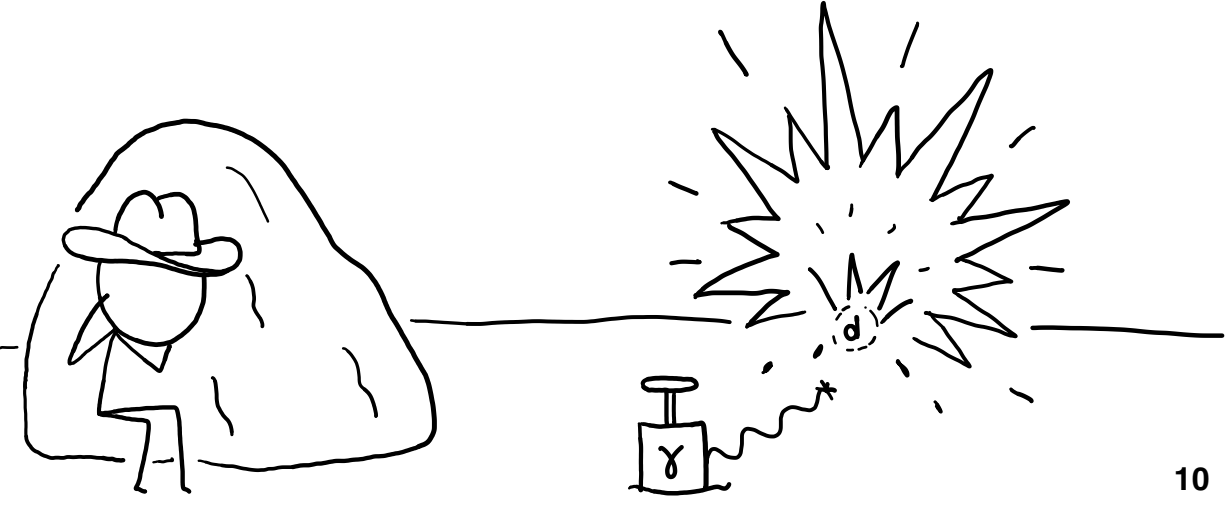


Solution: quasi-free neutrons



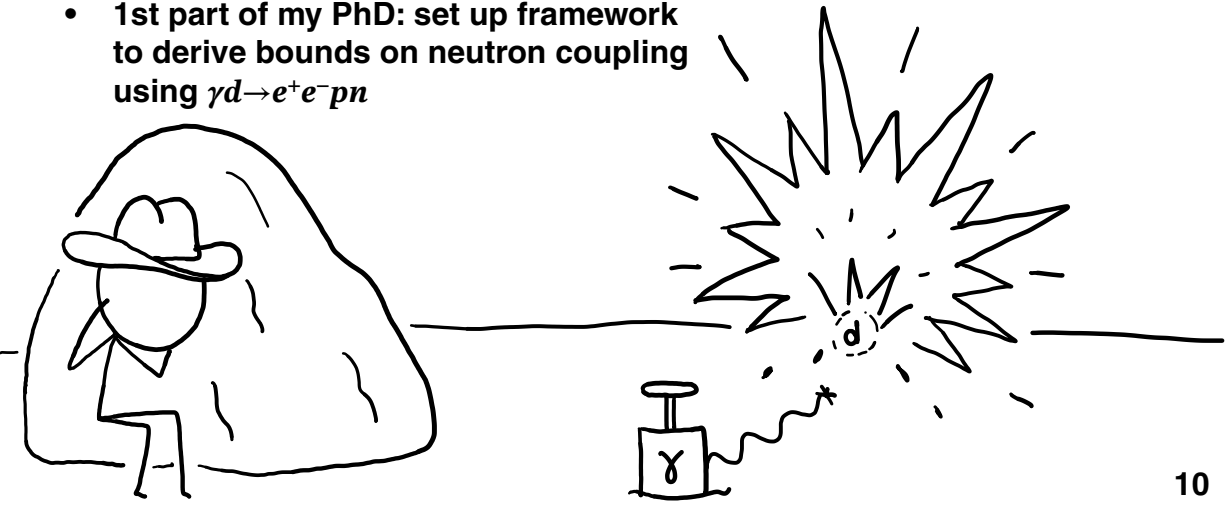
Solution: quasi-free neutrons

- **Quasi-free = in bound system, but behave as if free**

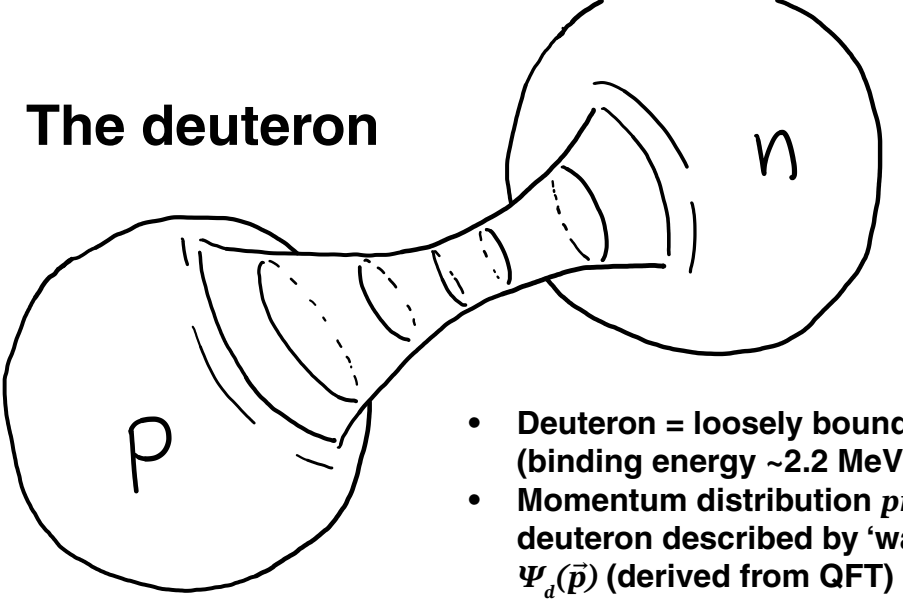


Solution: quasi-free neutrons

- Quasi-free = in bound system, but behave as if free
- 1st part of my PhD: set up framework to derive bounds on neutron coupling using $\gamma d \rightarrow e^+ e^- p n$

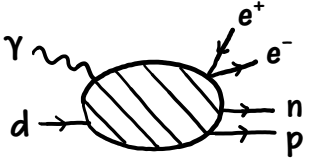


The deuteron



- Deuteron = loosely bound pn pair (binding energy ~2.2 MeV)
- Momentum distribution pn inside deuteron described by 'wave function' $\Psi_d(\vec{p})$ (derived from QFT)

Amplitudes to lowest order



$\hookrightarrow M(d\gamma \to e^+e^-pn)$

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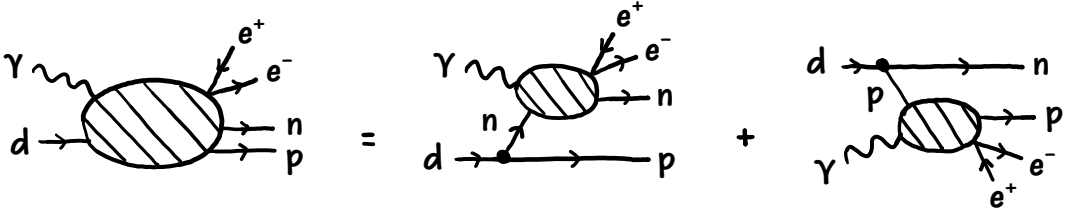

$$\hookrightarrow M(d\gamma \to e^+e^-pn) = M_0^{(n)}(d\gamma \to e^+e^-pn) + M_0^{(p)}(d\gamma \to e^+e^-pn)$$

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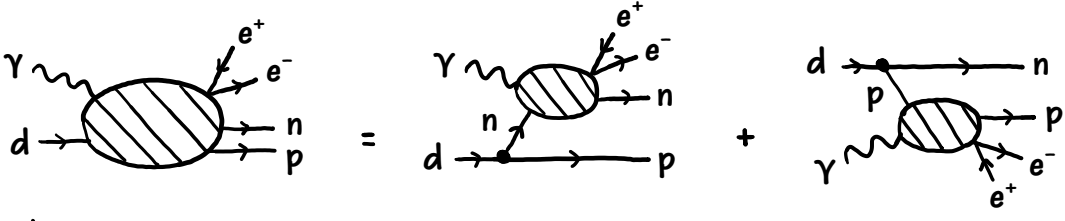

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In d rest frame, $M_0^{(n)}(d\gamma \to e^+e^-pn) \sim \Psi_d(|p_p|)$

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Neutron quasi-free peak

In d rest frame,

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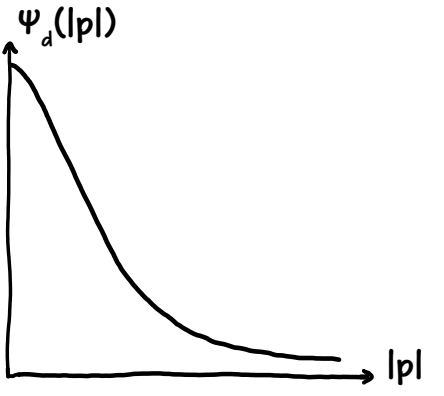

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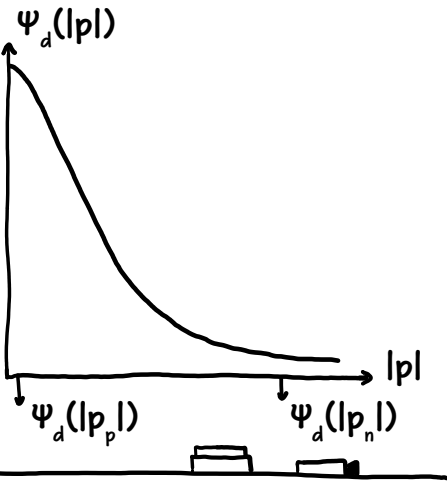
$|p_p| \to 0$

processes on neutron enhanced!



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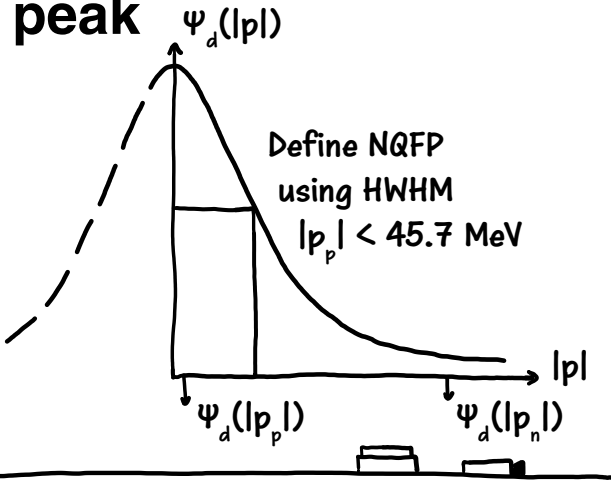
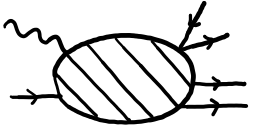


The main idea

At NQFP $d\gamma \rightarrow e^+e^-pn$ 'proportional to' $n\gamma \rightarrow e^+e^-n$



Infer neutron observables using the deuteron!

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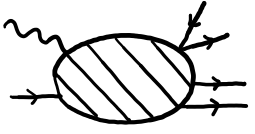

= BSM CONTRIBUTION + QED BACKGROUND

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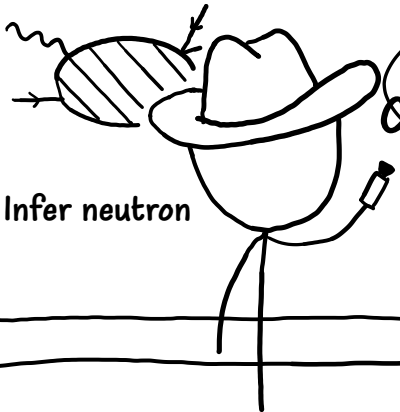
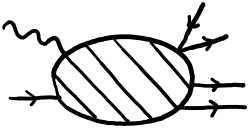


BSM CONTRIBUTION + QED BACKGROUND

Infer neutron ing the deuteron!

BSM



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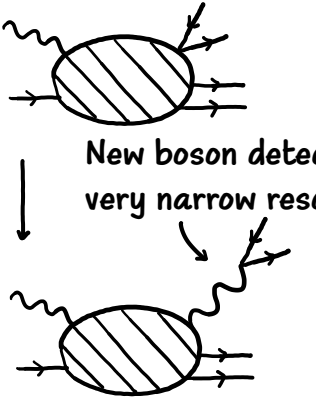
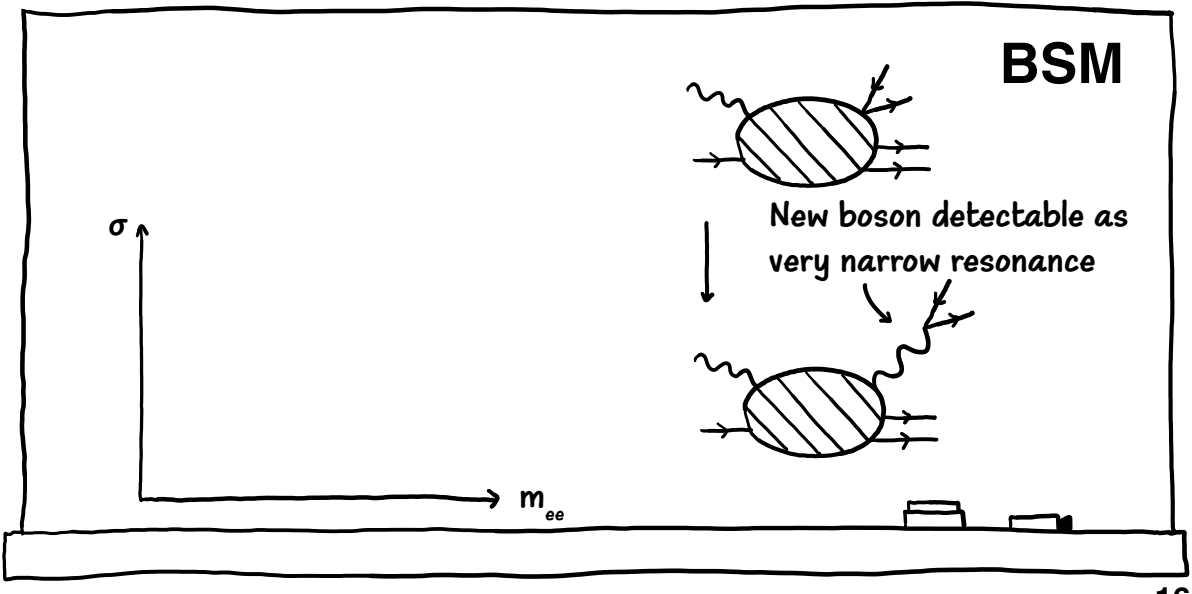
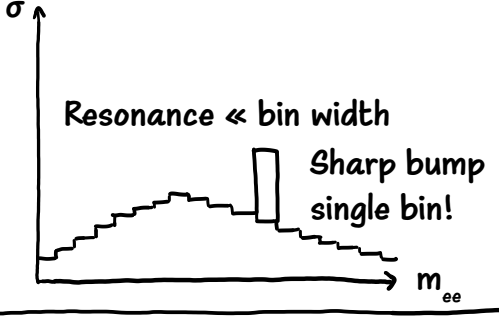
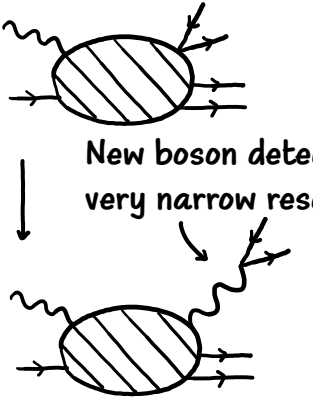



BSM
New boson detectable as very narrow resonance
σ
m_{ee}

BSM


σ
Resonance « bin width
Sharp bump
single bin!
m_{ee}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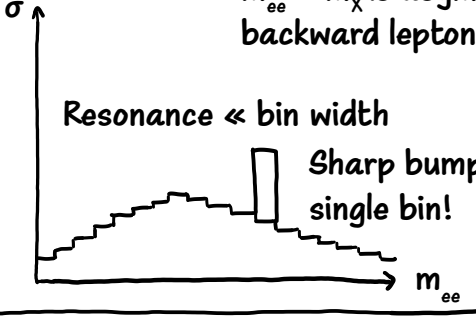
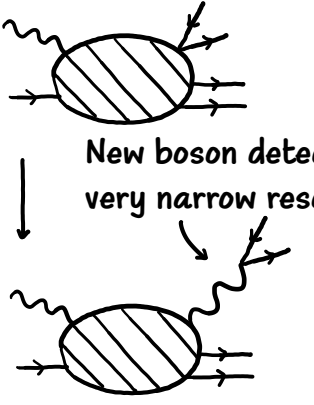
BSM

Kinematics s.t.
$m_{ee} \approx m_X$ is asymetric
backward leptons





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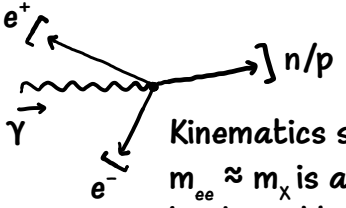

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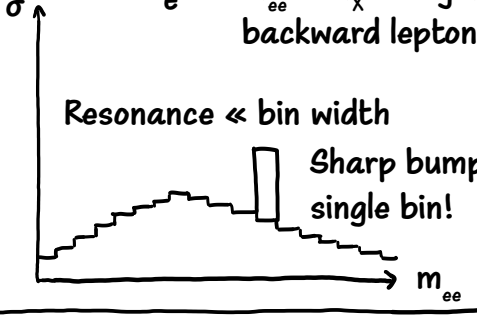

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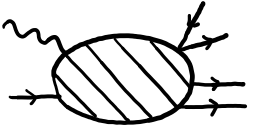

New boson detectable as
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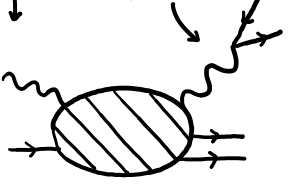

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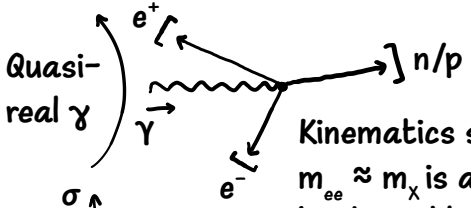

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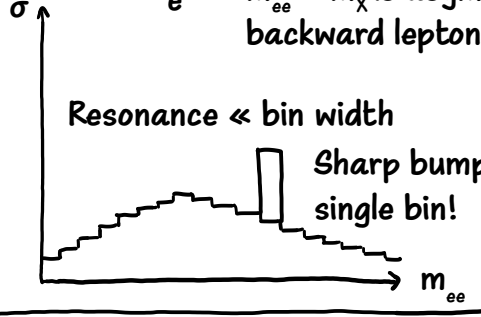

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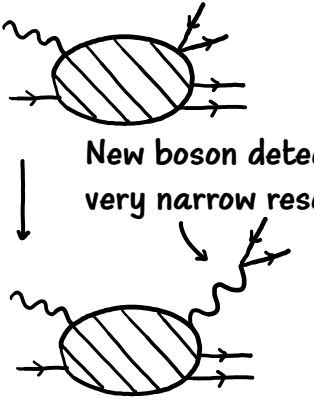

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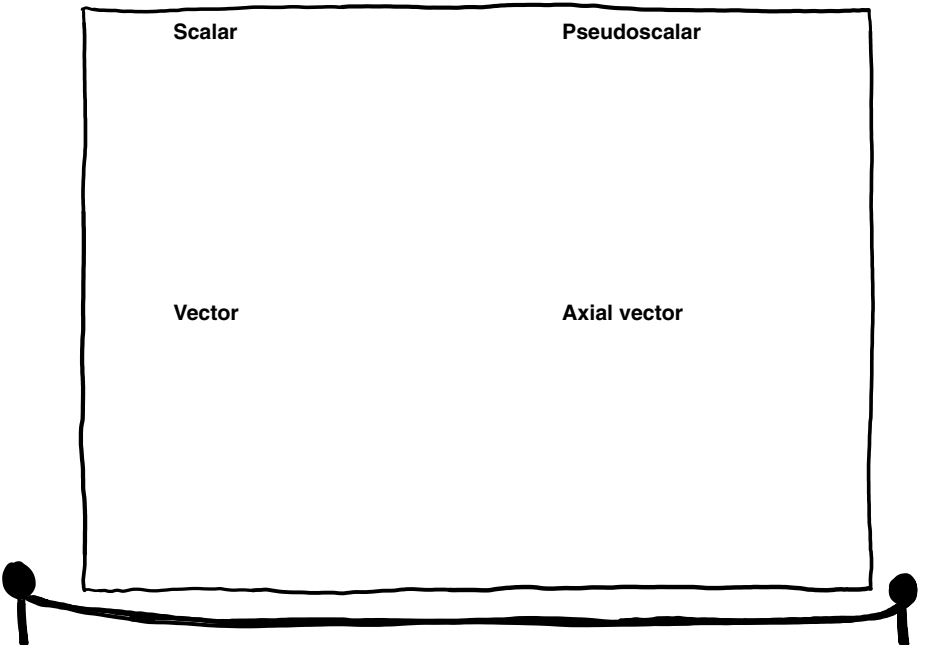
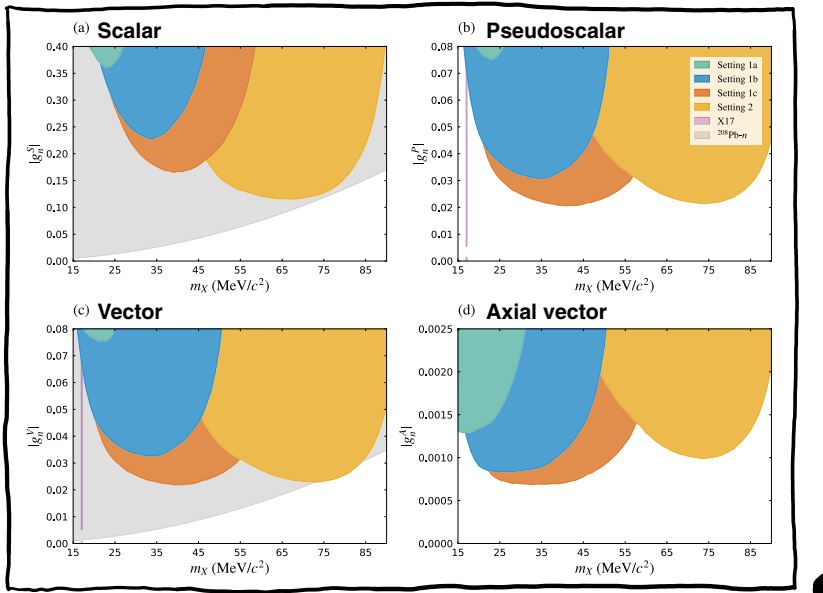
Results



Results

- Projected exclusion limits MAGIX@MESA
- $L = 7.2 \times 10^8$ nb^{-1}
- $\delta m_{ee} = 0.1$ MeV
- Competitive results pseudoscalar and axial vector



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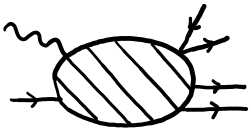
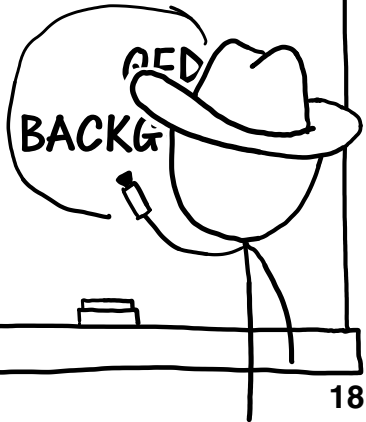


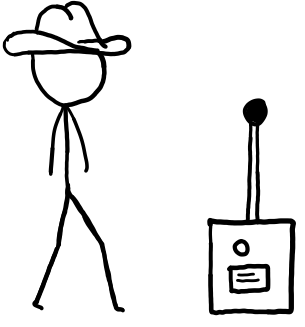
= BSM CONTRIBUTION +

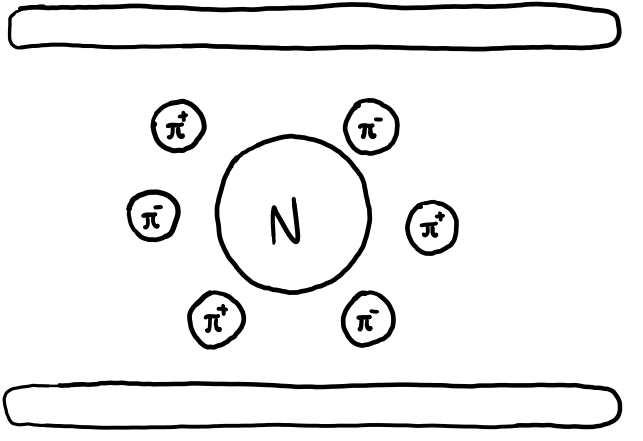


Infer neutron observables using the deuteron!

QED BG sensitive to polarizabilities

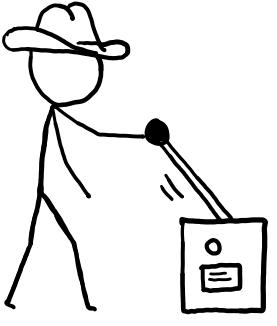
- QED background ~ Compton scattering ~ neutron polarizabilities
- Electric/magnetic polarizabilities quantify E/M moments induced in response to external E/M field

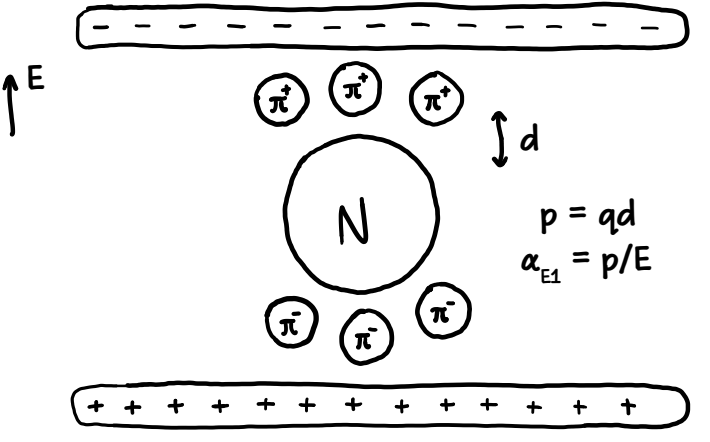




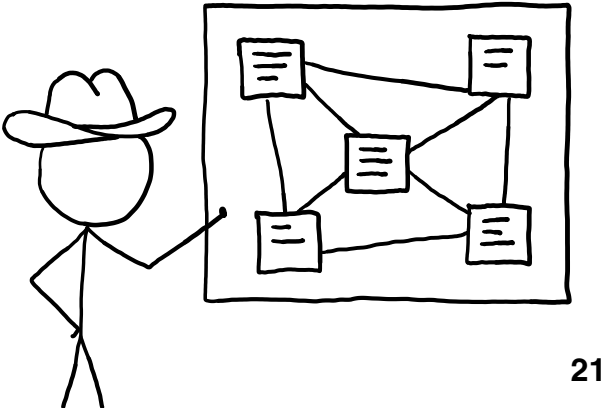
What are polarizabilities?

- Nucleon deforms along direction electric field
- Similar for magnetic polarizabilities





- **Like couplings, proton polarizabilities ‘directly’ accessible, but neutron polarizabilities must be inferred**



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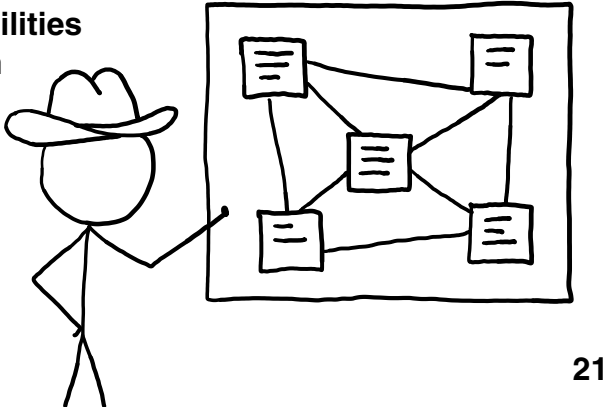

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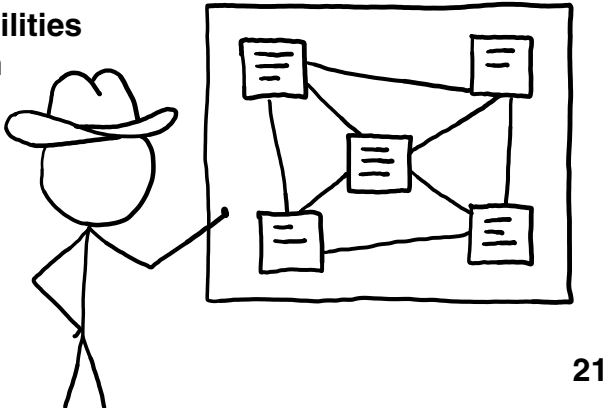
- Turns out: (1st order) kinematic regions sensitive to BSM and neutron polarizabilities similar!



Joint neutron polarizability extraction and new physics search feasible?

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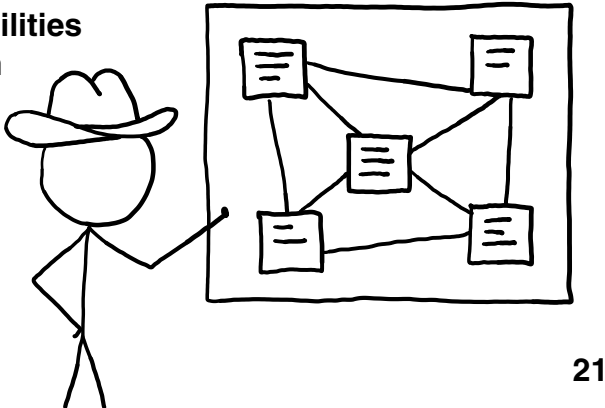
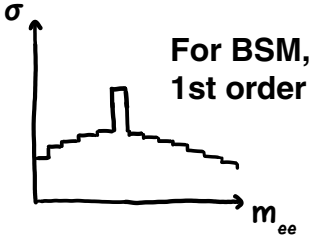


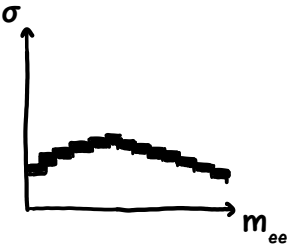
Complications



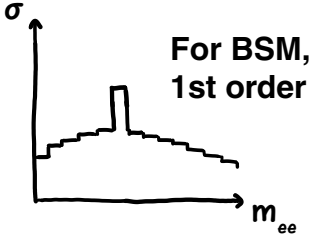
For BSM, QED BG
1st order okay

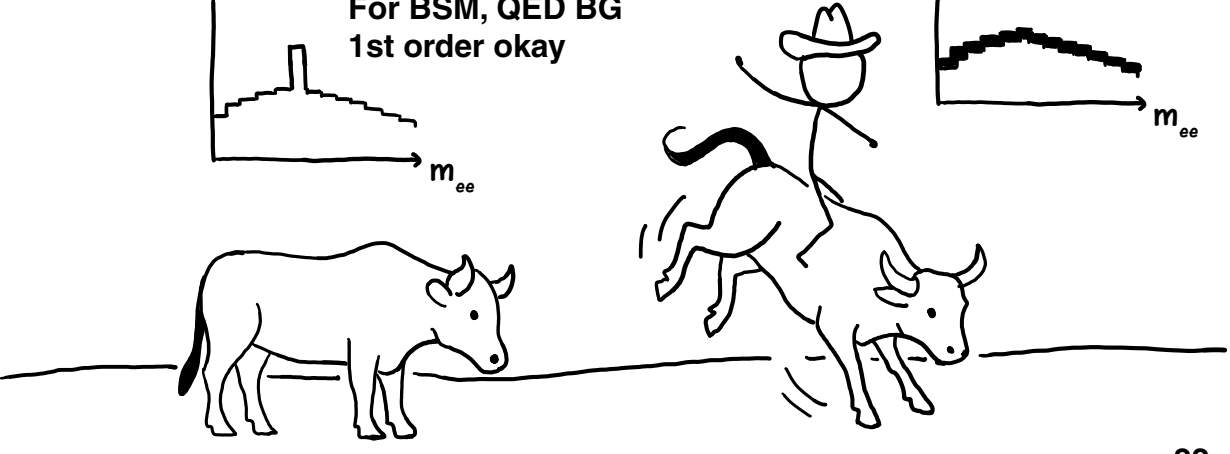
Complications

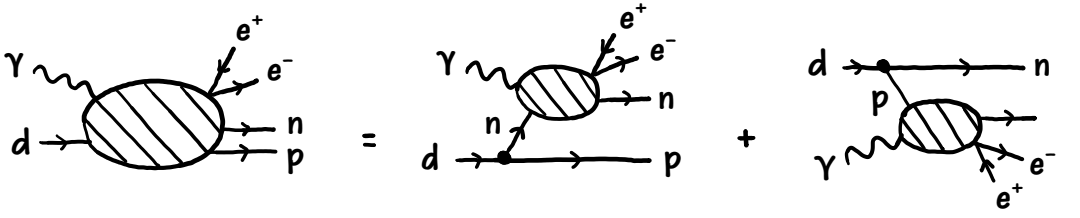
For polarizabilities,
need BG higher orders



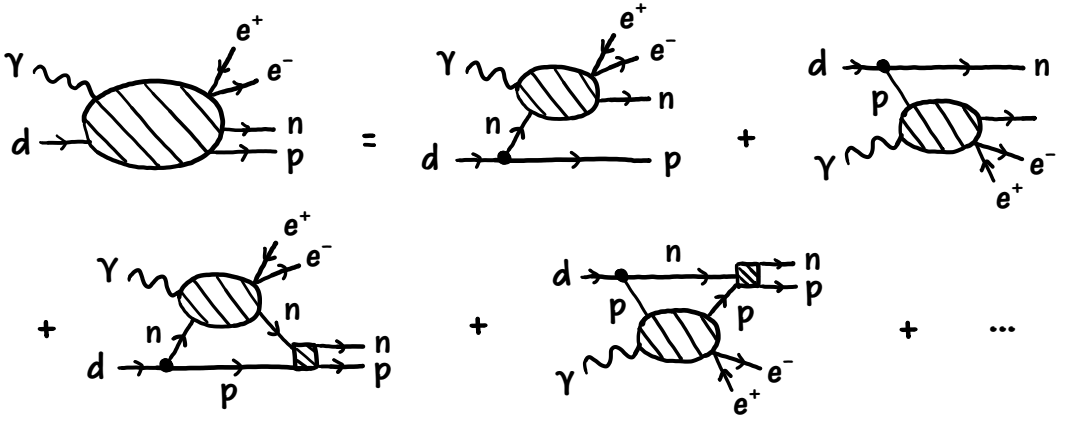
For BSM, QED BG
1st order okay





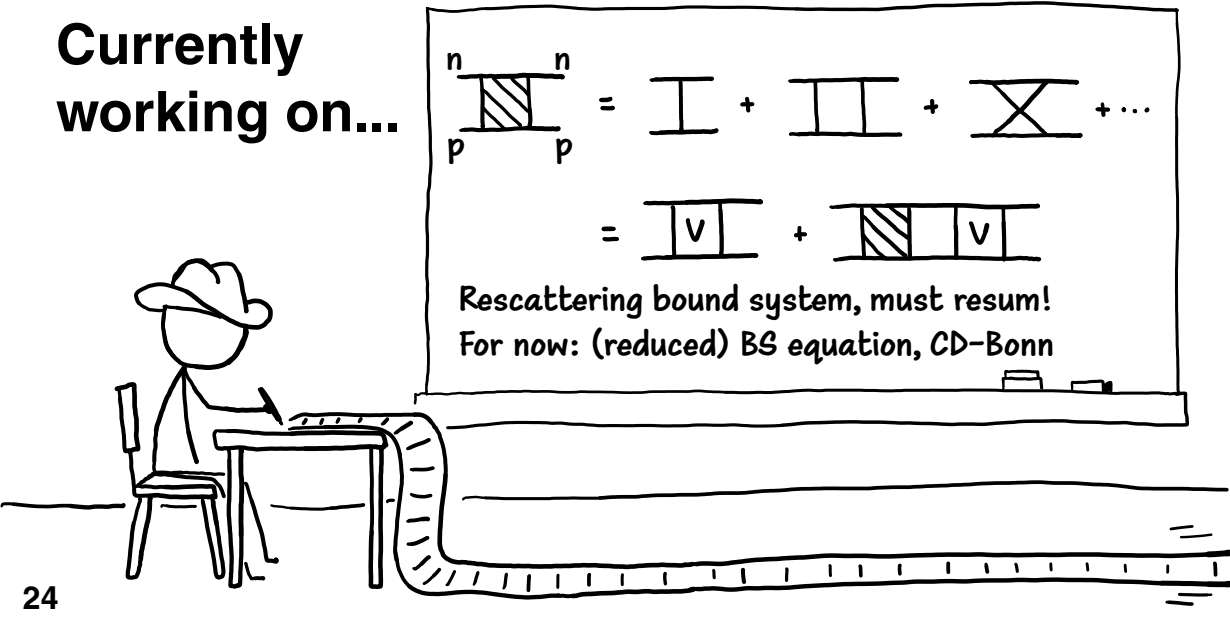


Higher-order terms



Higher-order terms

Currently working on...



Conclusion

- Increasing interest in new $\mathcal{O}$(MeV) boson
- At same time, need for better extraction neutron polarizabilities
- *Both* can be accessed using $\gamma d \to e^+ e^- pn$
- But, can both be extracted simultaneously?
- Keep your eyes peeled for an answer!

Thank you for your attention!

Questions?