Probing ϕ Mesons in Deuteron Break-up Reactions

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Hadron-Nucleon Scattering

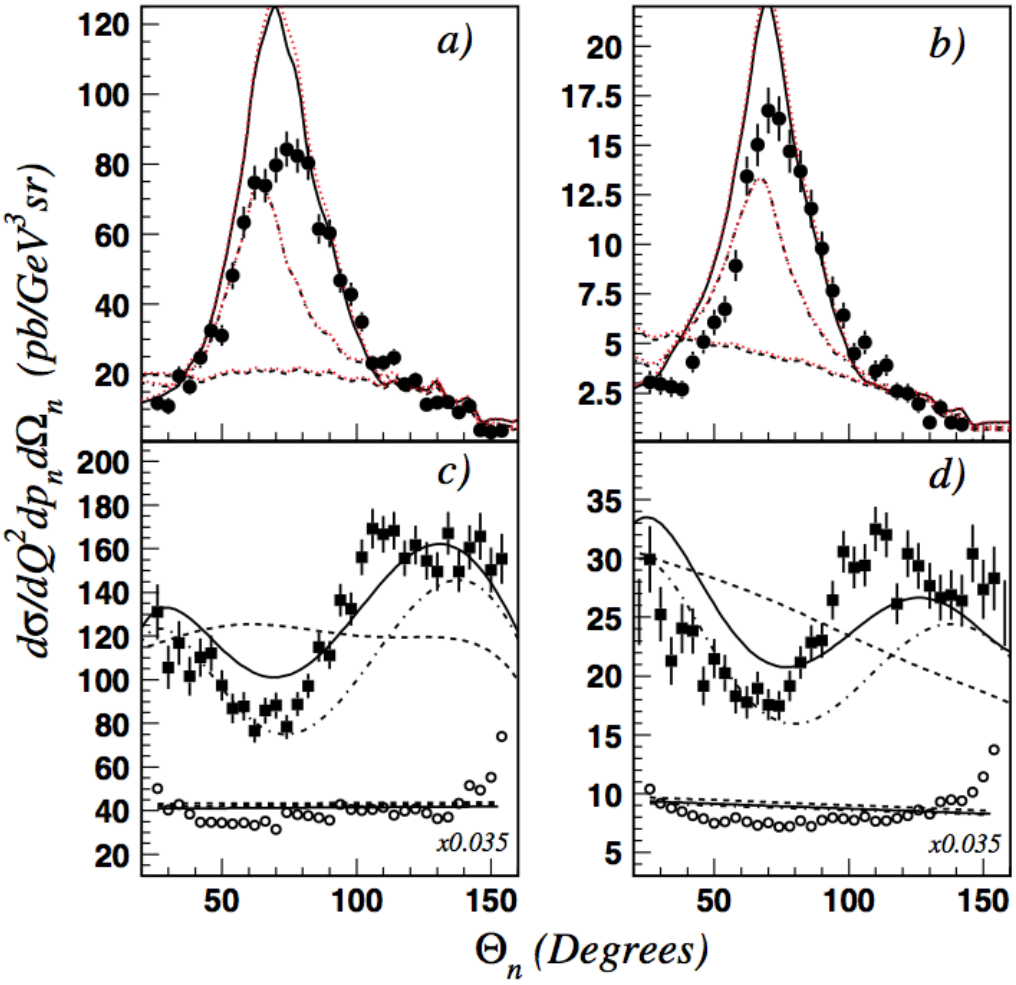
- Hadron-nucleon interactions, such as heavy quarkonium scattering, can be difficult to experimentally probe.
- The reaction $^2H(\gamma, hp)n$ may prove a fruitful means of probing these interactions.
- The trick lies in analyzing the effects of final state interactions—deuteron electrodisintegration serves as an example.

Deuteron Electrodisintegration

- Deuteron electrodisintegration, i.e. $^2H(e,e'p)n$ was experimentally studied by Egiyan *et al.* (PRL 98, 262502), and subsequently by Boeglin *et al.* (PRL 107, 262501).
- Observing a fast proton ($p_p > 1$ GeV) ensures that the proton was struck, and ensures the eikonal regime.
- For particular values of p_n, the differential cross-section is plotted against θ_{nq}.
- The results show valleys and peaks around $\theta_{nq} = 70^\circ$ depending on p_n.

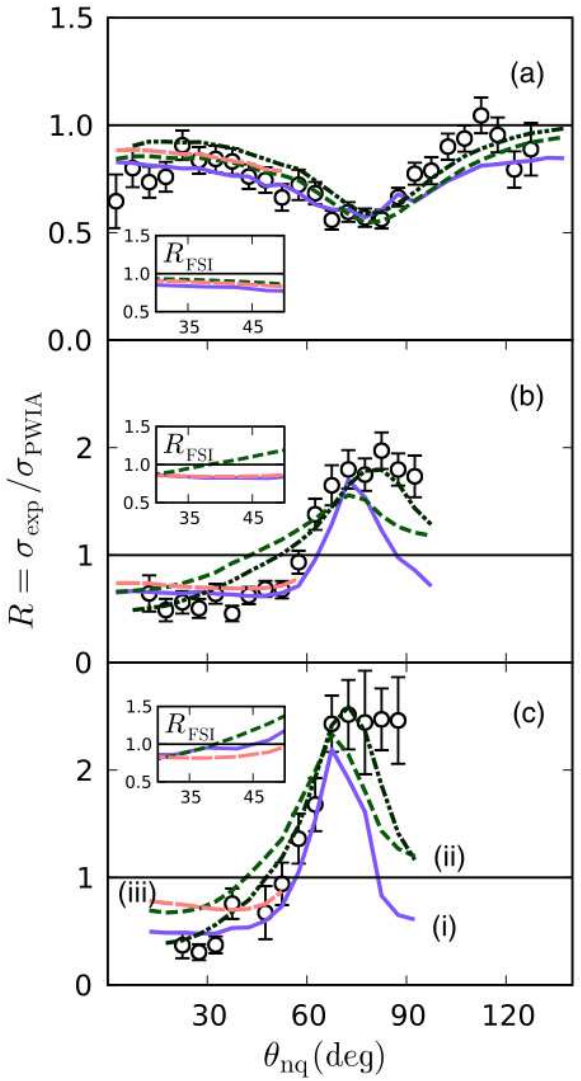
Egiyan *et al.* (PRL 98, 262502)

- Peak at $\theta_{nq} \approx 70°$ for $p_n \in (400, 600)$ MeV.
- Valley at $\theta_{nq} \approx 70°$ for $p_n \in (200, 300)$ MeV.
- Dashed, dash-dotted, and solid are respectively PWIA, PWIA+FSI, and PWIA+FSI+MEC+$N\Delta$.
- Left and right columns are respectively $Q^2 \approx 2$ GeV^2 and $Q^2 \approx 3$ GeV^2.



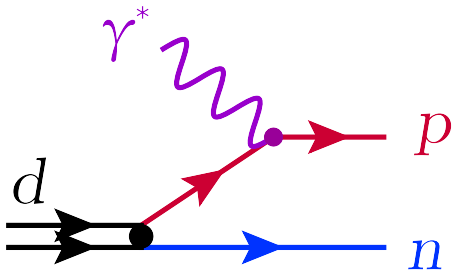
Boeglin *et al.* (PRL 107, 262501)

- Peak at $\theta_{nq} \approx 75^\circ$ for $p_n = 400, 500$ MeV.
- Valley for $p_n = 200, 300$ MeV.
- Purple line is theoretical prediction by Sargsian (PRC 82, 014612), black (dash-dotted) and green by Laget (PLB 609, 49) with and without MEC and $N\Delta$, respectively.
- $Q^2 = 3.5$ GeV^2.

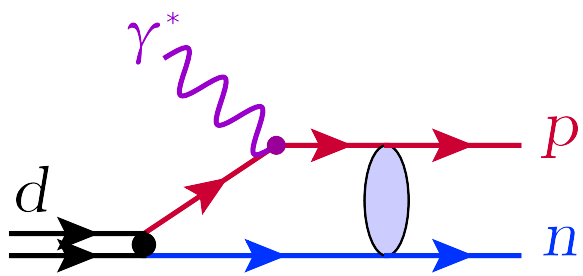


Final State Interactions

- These results are due to final state interactions (FSI's).
- In Feynman diagram language, the most relevant reactions are



(a) PWIA

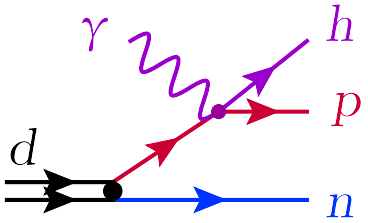


(b) pn rescattering

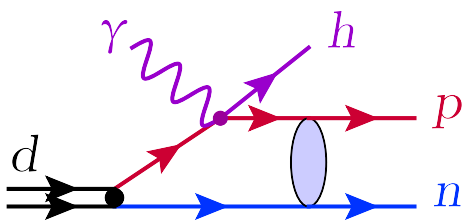
- The plane wave impulse approximation (PWIA) is just the product of the electron-proton scattering amplitude and the deuteron wave-function.
- PWIA is corrected by a scattering of the proton off the spectator neutron.
- I'll neglect further corrections (MEC, $N\Delta$, *etc.*).

Hadron Production

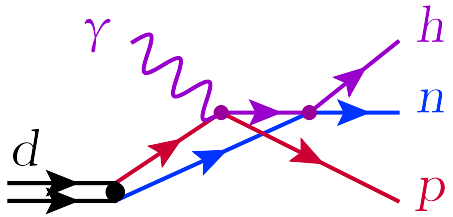
- What if a hadron is produced in photodisintegration? (Real photons.)
- There would be three particles in the final state—another FSI.



(c) PWIA



(d) pn rescattering



(e) hn rescattering

- We will find a second rescattering peak.

ϕ Photoproduction

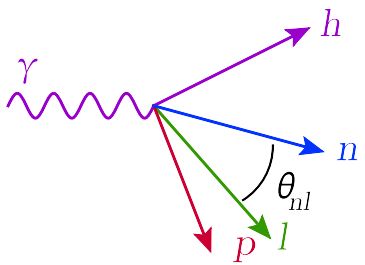
- As a particular example, look at $\phi(1020)$ as the hadron.
- ϕ photoproduction from the proton has been studied extensively, such as by Mibe *et al.* (PRL 95, 182001).
- The exact form of the ϕN scattering amplitude is unknown, but vector meson dominance (VMD) seems to reproduce coherent ϕ production from the deuteron—*cf.* Mibe *et al.* (PRC 76, 052202)—and will serve as a proof of principle.

Kinematics and Definitions

- Momentum transfer for photoproduction is defined thus:

$$l = p_\gamma - p_\phi$$
$$t = l^2$$

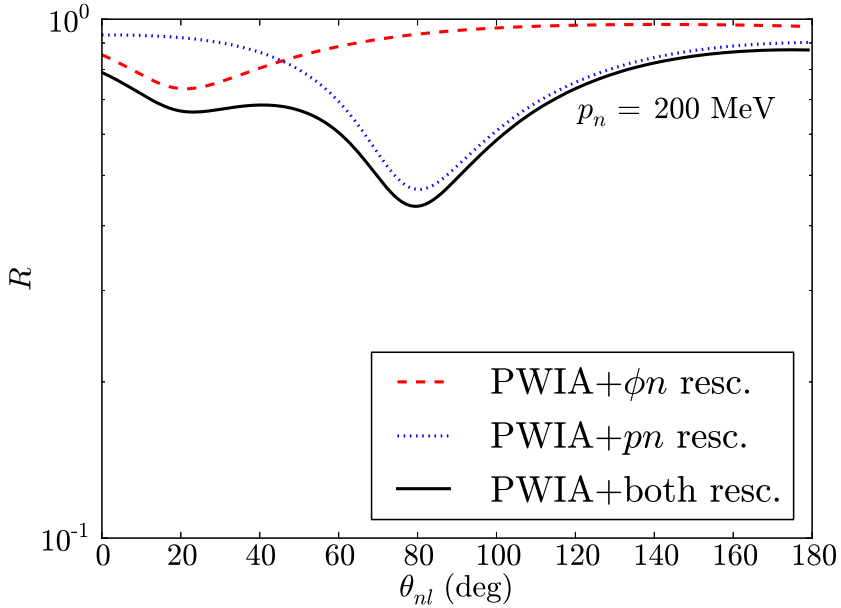
- Differential cross-section is plotted against θ_{nl}, illustrated by this graphic:

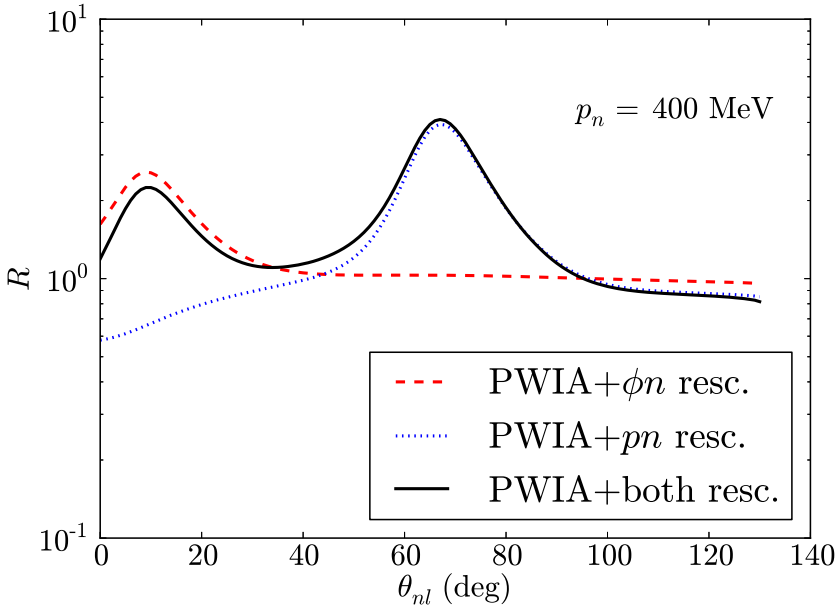


- The cross-section ratio is plotted instead of absolute cross-section.

$$R = \frac{\left(\frac{d^5\sigma}{dp_\phi d\Omega_\phi d\Omega_p}\right)}{\left(\frac{d^5\sigma_{\mathrm{PWIA}}}{dp_\phi d\Omega_\phi d\Omega_p}\right)}$$

VMD Model





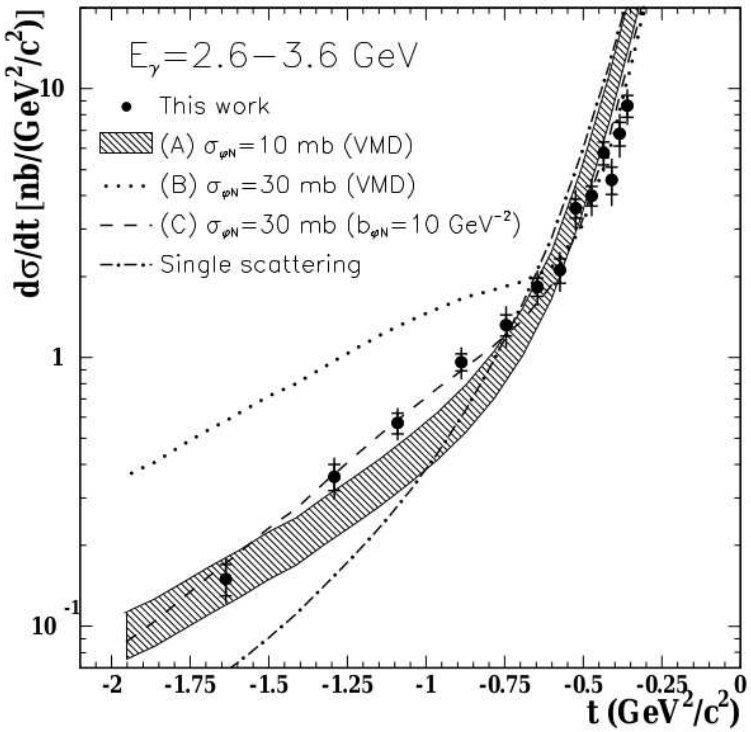
There is a distinct peak for each FSI!

Other models

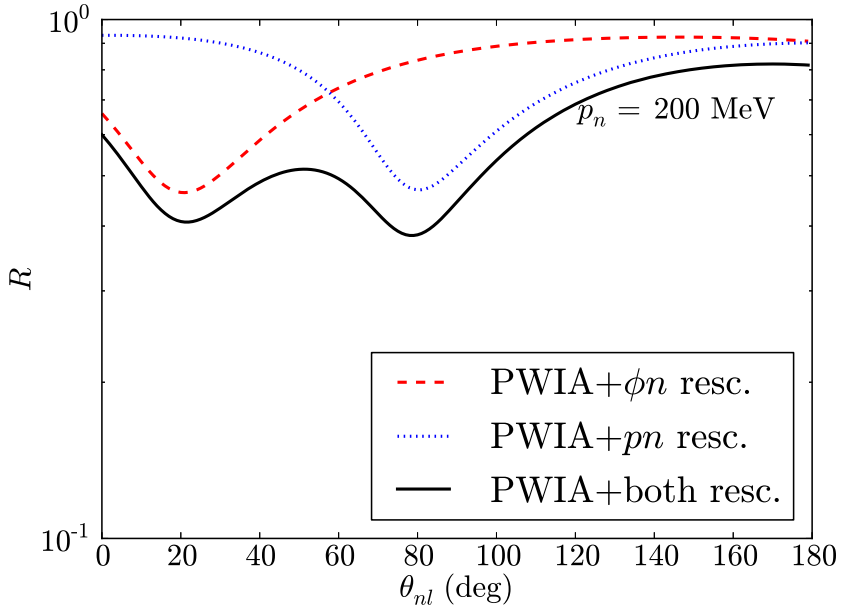
Mibe *et al.* (PRC 76, 052202) point out—two models fit the data:

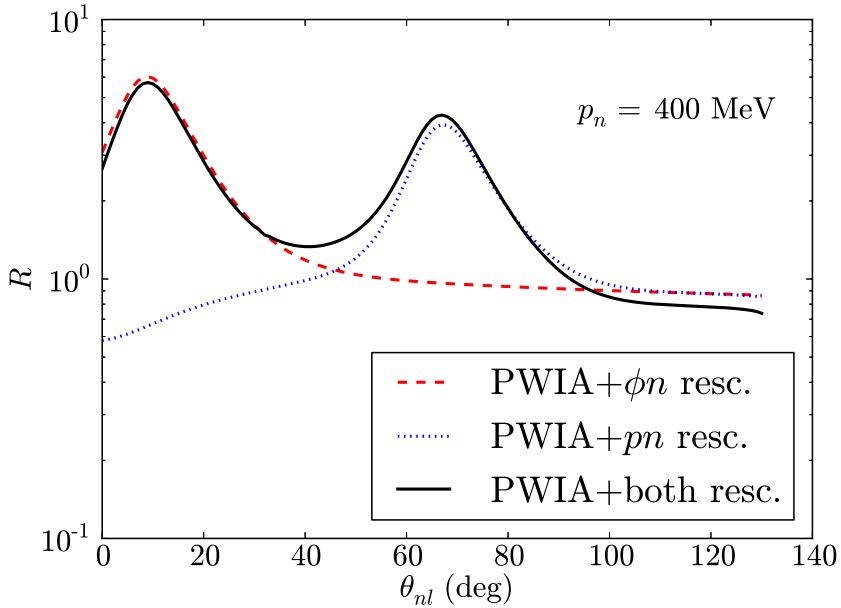
1. VMD with $\sigma_{\phi N} = 10$ mb
2. $\sigma_{\phi N} = 30$ mb, and $B = 10$ GeV^{-2}

The 30 mb model was inspired by a result of $\sigma_{\phi N} = 35^{+17}_{-11}$ mb in nuclear media, found at SPring-8 by Ishikawa *et al.* (PLB 608, 215)



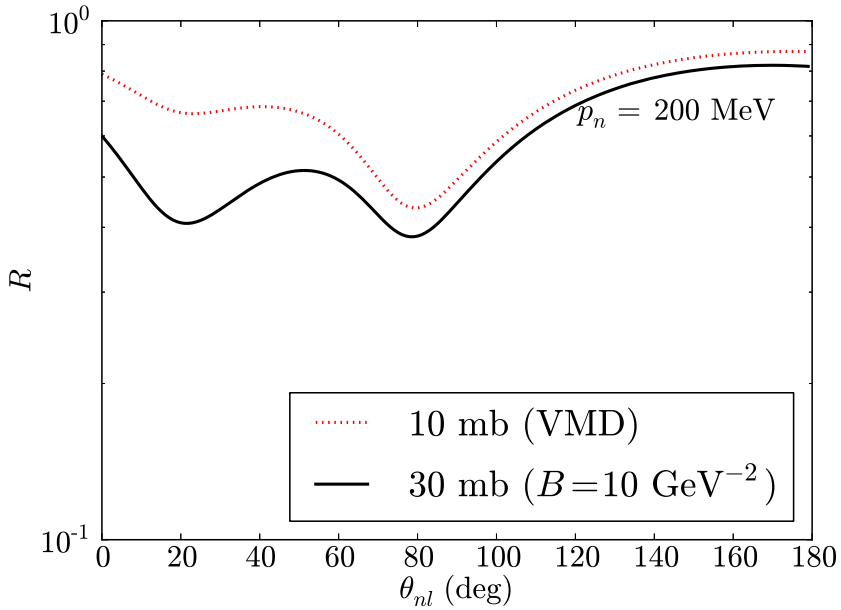
Alternative Model

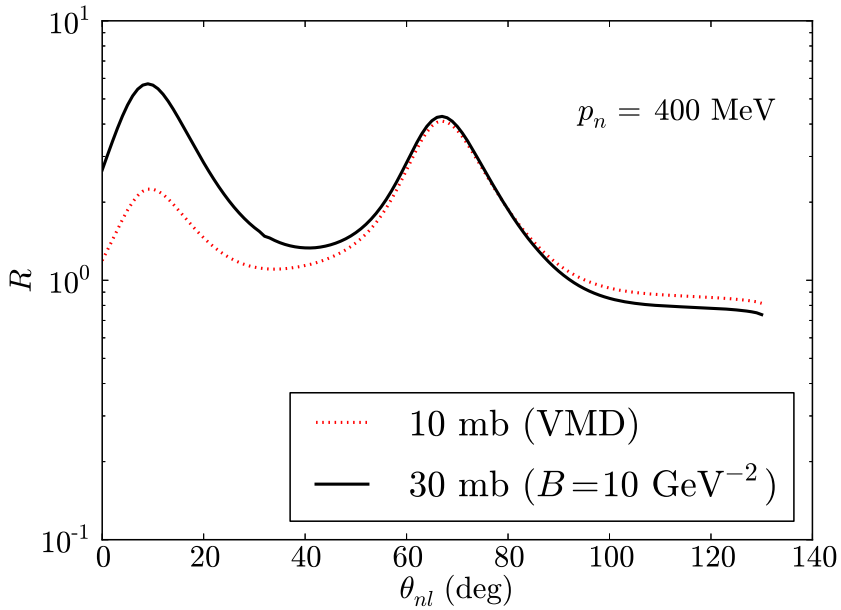




$\sigma_{\phi N} = 30$ mb and $B = 10$ GeV^{-2}

Alternative Model

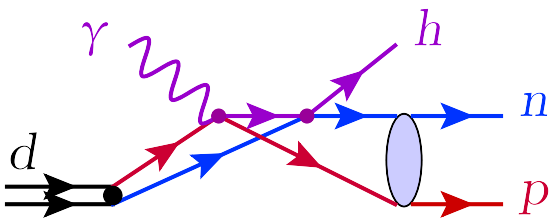


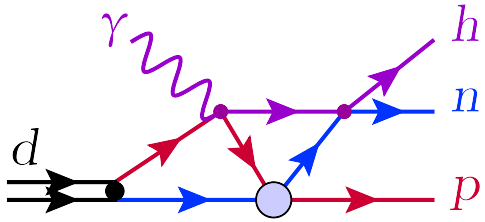


There's a clear difference between the models.

Double rescattering

- The treatment would not be complete without double rescattering:





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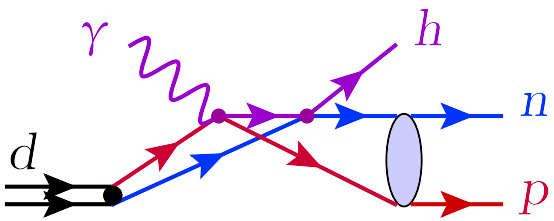
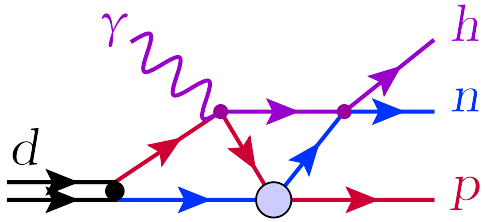
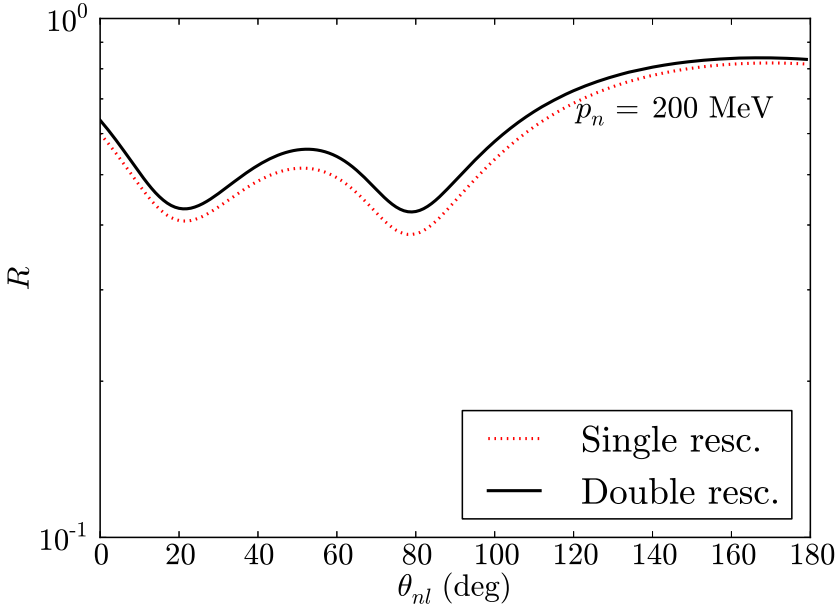
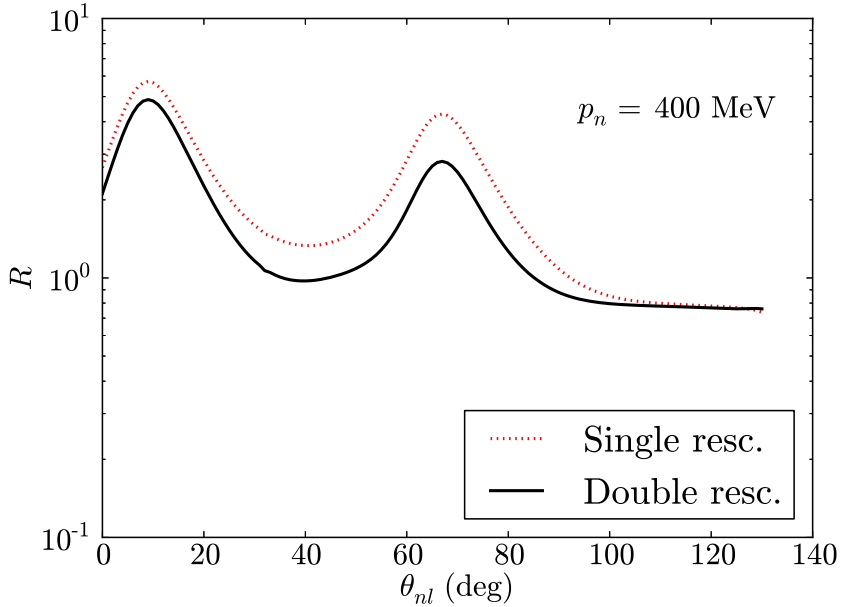




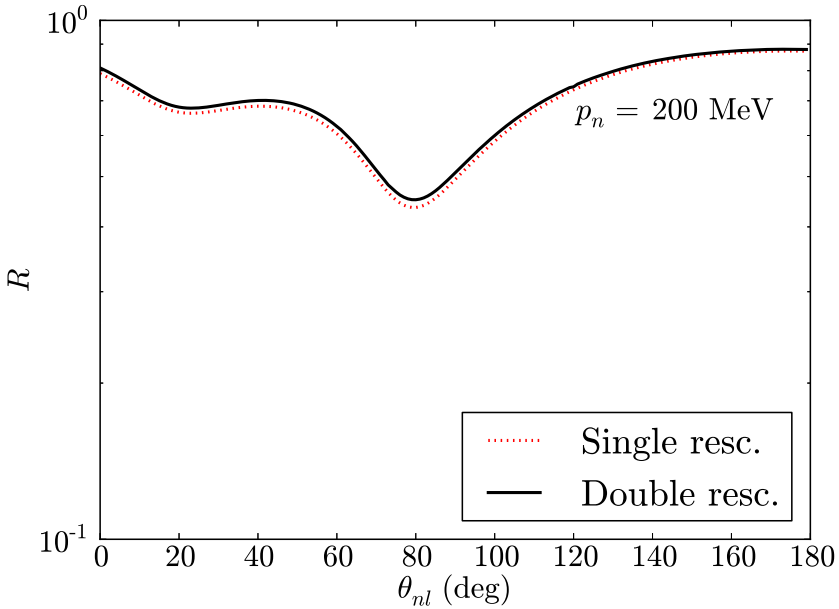
- This suppresses the rescattering peaks and valleys in the 30 mb model.

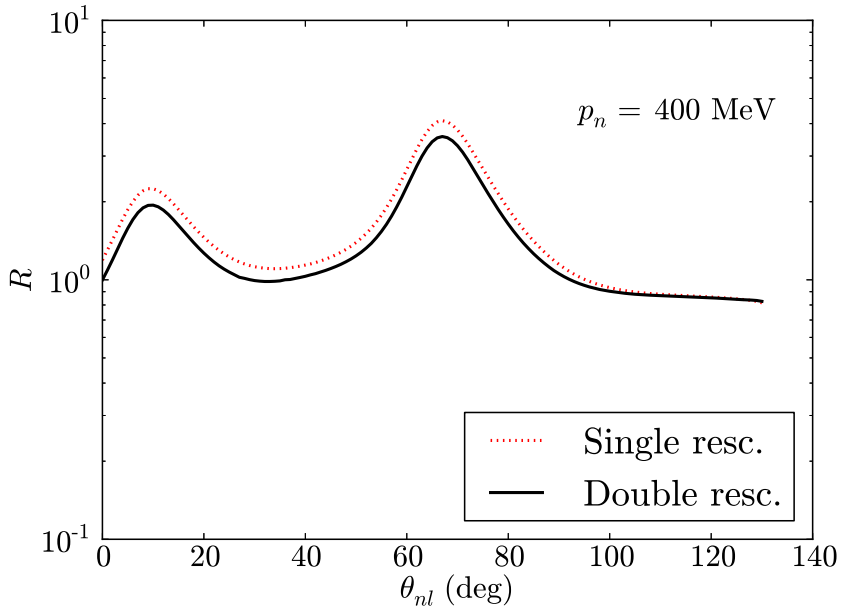




Double rescattering

- For VMD, the suppression is negligible.

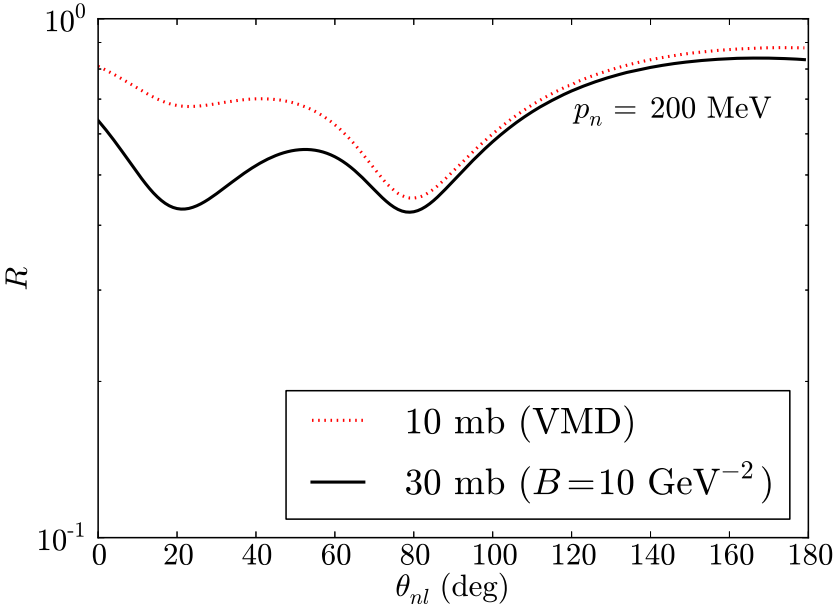


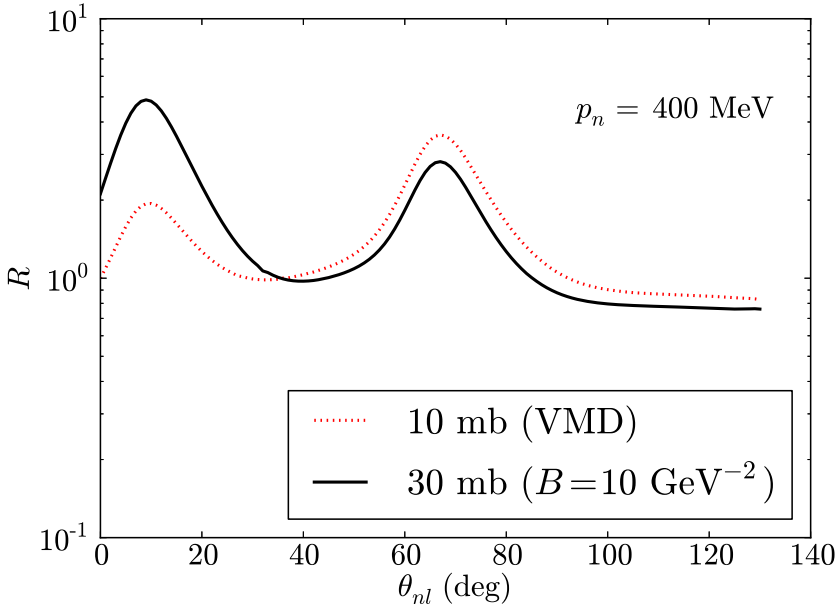


- This is because the double scattering amplitude is proportional to $\sigma_{\phi N}$.

Double rescattering

- There's still a clear difference between the models.





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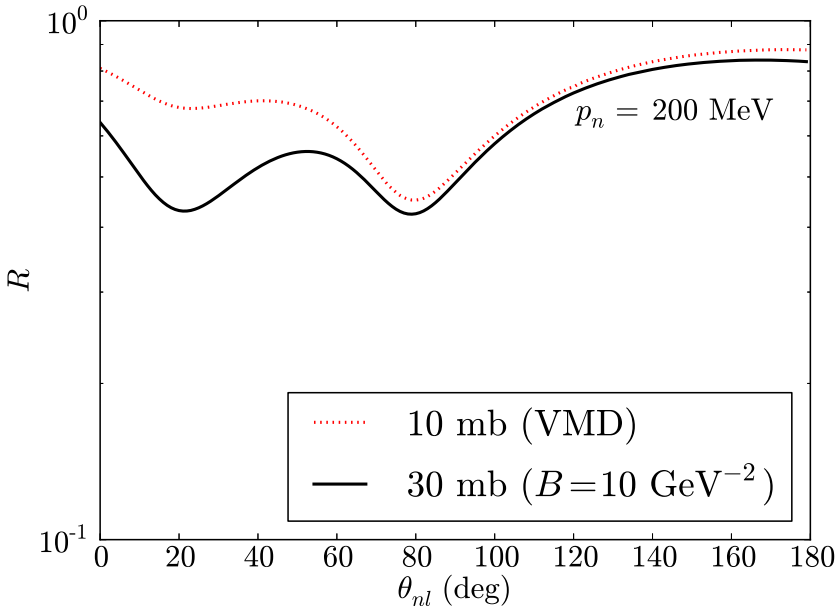

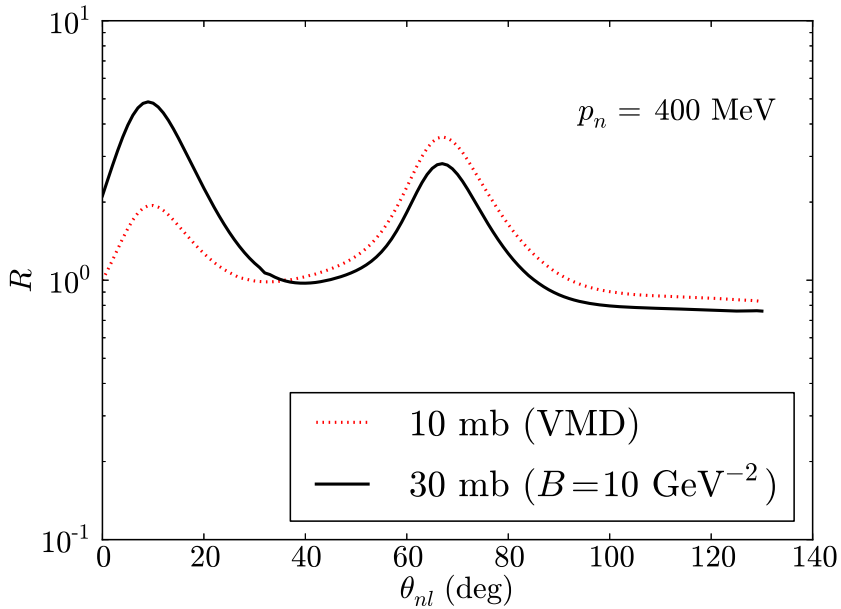

- Can the J-Lab data-mining group find evidence for this reaction and choose a preferred model?