# Parity-violating asymmetry in $\vec{\gamma} d \to np$: Theory

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# Observable

- Asymmetry in $\vec{\gamma}d \to np$:

$$A_L^\gamma = \frac{\sigma_+ - \sigma_-}{\sigma_+ + \sigma_-}$$

  $\sigma_\pm$: total break-up cross section with $\pm$ photon helicity

- Related to photon circular polarization in $np \to d\vec{\gamma}$:

$$P_\gamma = \frac{\tilde{\sigma}_+ - \tilde{\sigma}_-}{\tilde{\sigma}_+ + \tilde{\sigma}_-}$$

  $\tilde{\sigma}_\pm$: total capture cross section with $\pm$ photon helicity

- Different from asymmetry in $\vec{n}p \to d\gamma$

# $np \to d\vec{\gamma}$ at threshold

- LO EFT($\not\pi$) result:

$$P_\gamma = -16\frac{M}{\kappa_1\left(1-\gamma a^{^1S_0}\right)}\left[\left(1-\frac{2}{3}\gamma a^{^1S_0}\right)\frac{\mathcal{C}^{(^3S_1-^1P_1)}}{\mathcal{C}_0^{(^3S_1)}} + \frac{\gamma a^{^1S_0}}{3}\frac{\mathcal{C}^{(^1S_0-^3P_0)}_{(\Delta I=0)} - 2\mathcal{C}^{(^1S_0-^3P_0)}_{(\Delta I=2)}}{\mathcal{C}_0^{(^1S_0)}}\right]$$

$\to$ Sensitive to isoscalar and isotensor

- Compare to $\vec{n}p \to d\gamma$:

$$A_\gamma = \frac{32}{3}\frac{M}{\kappa_1\left(1-\gamma a^{^1S_0}\right)}\frac{\mathcal{C}^{(^3S_1-^3P_1)}}{\mathcal{C}_0^{(^3S_1)}}$$

$\to$ Sensitive to isovector

Savage (2001); MRS, R.P. Springer (2010)

# Detailed model calculations

Liu, Hyun, Desplanques [Phys. Rev. C **69**, 065502 (2004)]

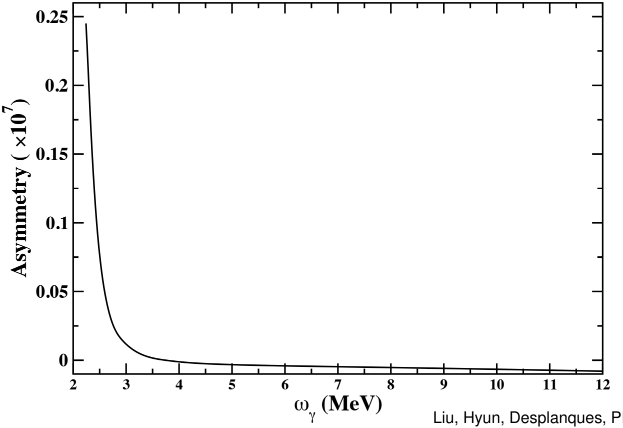
- Ingredients:
  - $\omega_\gamma \leq 12\,\text{MeV}$
  - Argonne $v_{18}$ + DDH
  - Two-body currents for $M1$ transition
- Results:
  - $A_L^\gamma = c_1 h_\pi^1 + c_2 h_\rho^0 + c_3 h_\rho^1 + c_4 h_\rho^2 + c_5 h_\omega^0 + c_6 h_\omega^1$
  - $c_2, c_4, c_5 \gg c_1 \gg c_3, c_6$
  - Confirmed suppression of isovector contribution $\propto h_\pi^1$

Results (cont.):

- At $\omega_\gamma = 2.235\,\text{MeV}$ with DDH best values:

$$A_L^\gamma \approx [-8.44 h_\rho^0 - 17.65 h_\rho^2 + 3.63 h_\omega^0 + O(c_1, c_3, c_6)] \times 10^{-3}$$
$$\approx 2.53 \times 10^{-8} \quad \text{for DDH best values}$$

- Energy dependence:




Liu, Hyun, Desplanques, PRC69 (2004)

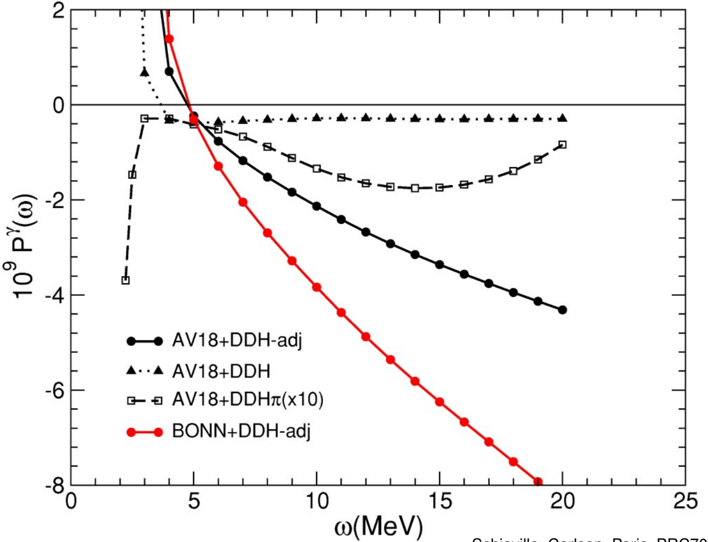
# Model dependence

Schiavilla, Carlson, Paris [Phys. Rev. C **70**, 044007 (2004)]

- Ingredients:
  - Argonne $v_{18}$ or Bonn + DDH
  - Two different PV parameter sets:
    - DDH best values
    - DDH-adj: fix $\rho, \omega$ couplings from $\vec{p}p$ scattering
- Results:
  - PV pion-exchange suppressed
  - Highly sensitive to short-distance details of PC potentials
  - At $\omega_\gamma = 2.2259\,\text{MeV}$:

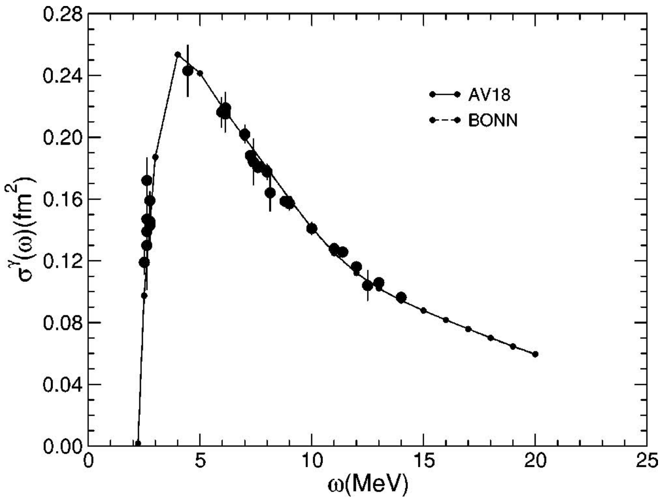
| Bonn+DDH-adj | AV18+DDH-adj | AV18+DDH |
|---|---|---|
| $9.05 \times 10^{-8}$ | $5.19 \times 10^{-8}$ | $2.38 \times 10^{-8}$ |

# Model dependence




Schiavilla, Carlson, Paris, PRC70 (2004)

# Parity-conserving cross section



# $A_L^\gamma$ in EFT($\not\pi$) beyond threshold

$$
\begin{aligned}
A_L^\gamma &= \frac{\sigma_+ - \sigma_-}{\sigma_+ + \sigma_-} \\
&= 2\frac{M_N}{(\vec{p}^{\,2} + \gamma_t^2)} \frac{1}{|Y|^2 + |E1_v|^2 \frac{M_N^2 \vec{p}^{\,2}}{(\vec{p}^{\,2}+\gamma_t^2)^2}} \Bigg[ \mathrm{Re}[Y^* V] + 2\mathrm{Re}[X^* W] \\
&\quad + \frac{1}{3}\vec{p}^{\,2}\mathrm{Re}[E1_v^*(U_1 + 2U_2)] + \ldots \Bigg]
\end{aligned}
$$

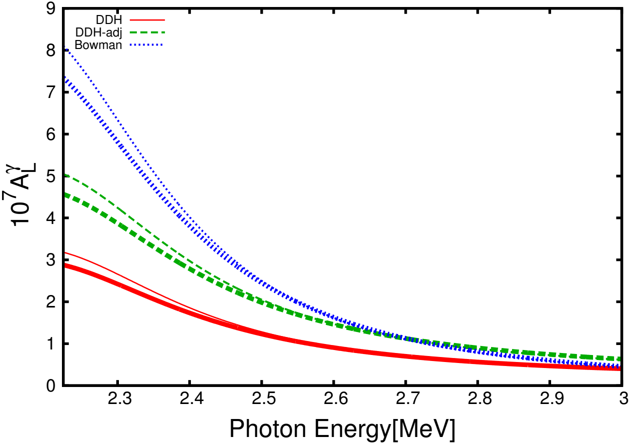
where

- $Y, E1_v, X$: parity-conserving amplitudes
- $V, W, U_i$: parity-violating amplitudes
- Expansion of each amplitude: $Y = Y_{LO} + Y_{NLO} + \cdots$, etc

Vanasse, MRS (2014)

# $A_L^\gamma$ in EFT($\not\pi$): NLO results

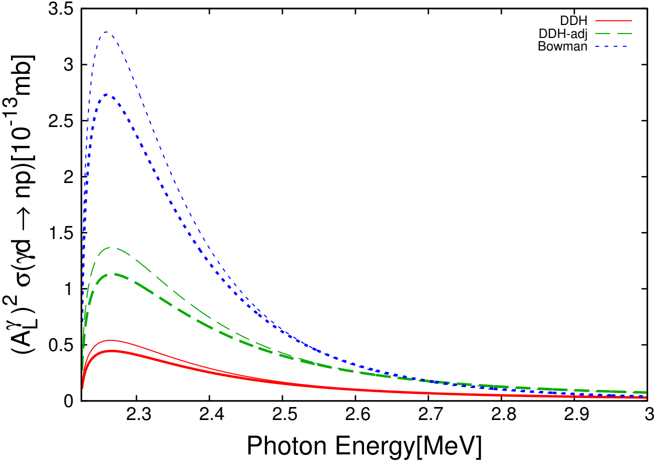
- Fix PV couplings to model estimates
- "Reasonable ranges:" $A_L^\gamma$ varies over orders of magnitude and sign




Vanasse, MRS (2014)

# Where to measure?

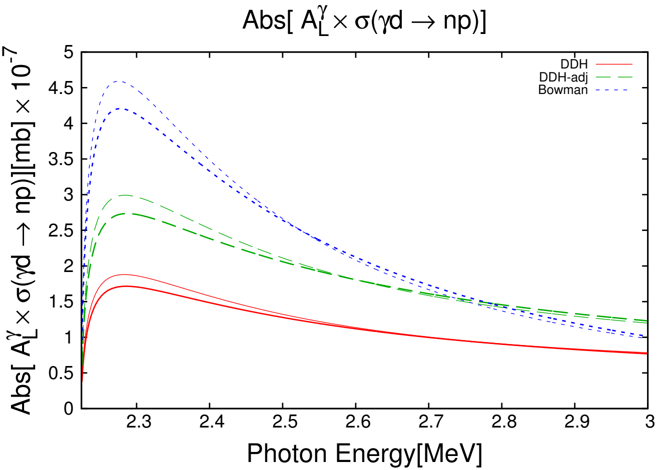
- $A_L^\gamma$ max at threshold $\Rightarrow$ low count rate
- Simplified figure of merit $(A_L^\gamma)^2 \times \sigma(\gamma d \rightarrow np)$




- Maximized for $\omega \approx [2.259, 2.264]$ MeV

# Alternative figure of merit

- Alternative figure of merit $(A_L^\gamma) \times \sigma(\gamma d \to np)$




- Maximized for slightly higher $\omega$

# Large $N_c$: Application to measurements

Longitudinal asymmetry in $\vec{p}p$ scattering

- Experimental result

$$A_L^{\vec{p}p}(E = 13.6\ \text{MeV}) = (-0.93 \pm 0.21) \times 10^{-7}$$

- Constraint on LECs in large-$N_c$ limit

$$(-1.5 \pm 0.3) \times 10^{-10}\ \text{MeV}^{-1} = \frac{4\left[\mathcal{C}^{(^1S_0-^3P_0)}_{(\Delta I=0)} + \mathcal{C}^{(^1S_0-^3P_0)}_{(\Delta I=1)} + \mathcal{C}^{(^1S_0-^3P_0)}_{(\Delta I=2)}\right]}{\mathcal{C}_0^{(^1S_0)}}$$

$$\to \frac{4\left[\mathcal{C}^{(^3S_1-^1P_1)}/3 + \mathcal{C}^{(^1S_0-^3P_0)}_{(\Delta I=2)}\right]}{\mathcal{C}}$$

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Eversheim et al (1991); Phillips, MRS, Springer (2009)

- Induced circular polarization in $np \to d\vec{\gamma}$

$$
\begin{aligned}
P_\gamma &= (1.8 \pm 1.8) \times 10^{-7} \\
&\to -\frac{16 M_N}{\mathcal{C}} \frac{1}{\kappa_1 (1 - \gamma a^{^1S_0})} \left( \mathcal{C}^{(^3S_1 - ^1P_1)} (1 - \frac{5}{9} \gamma a^{^1S_0}) \right. \\
&\qquad \left. - \frac{2}{3} \gamma a^{^1S_0} \mathcal{C}^{(^1S_0 - ^3P_0)}_{(\Delta I = 2)} \right)
\end{aligned}
$$

- In large-$N_c$ limit $\mathcal{C}^{(^1S_0 - ^3P_0)}_{(\Delta I=2)} \sim \mathcal{C}^{(^3S_1 - ^1P_1)}$
- If $\mathcal{C}^{(^1S_0 - ^3P_0)}_{(\Delta I=2)} \ll \mathcal{C}^{(^3S_1 - ^1P_1)}$ predict $P_\gamma$ outside of current bound

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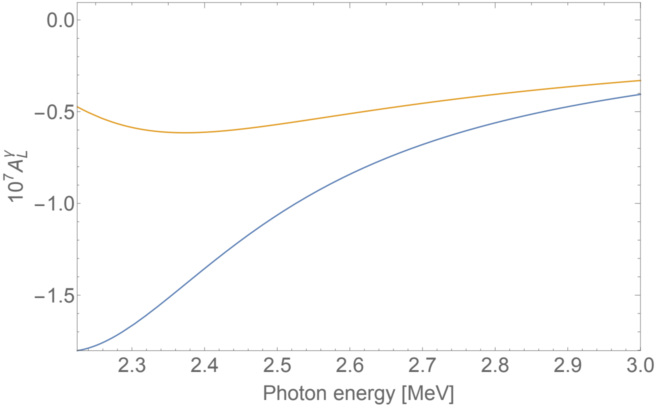
Knyaz'kov et al (1983/84); Vanasse, MRS, Springer (2016)

# Preliminary: $A_L^\gamma$ at LO in large-$N_c$ limit

- Sensitive to isoscalar and isotensor couplings
  $\rightarrow$ LO in large $N_c$
- Extract two independent couplings from $\vec{p}p$ and $P_\gamma$




Knyaz'kov et al (1983/84); Eversheim et al. (1991)

# Conclusion

- $\vec{\gamma}d \to np$ complementary to $\vec{n}p \to d\gamma$
- Sensitive to isoscalar and isotensor PV couplings
  $\to$ LO in large $N_c$
- Measure close to threshold $\to$ simplified figures of merit
- Expected size: few$\times 10^{-8}$ to few $\times 10^{-7}$(?)