Investigation of the Reaction Mechanism for D (e,e'p)n

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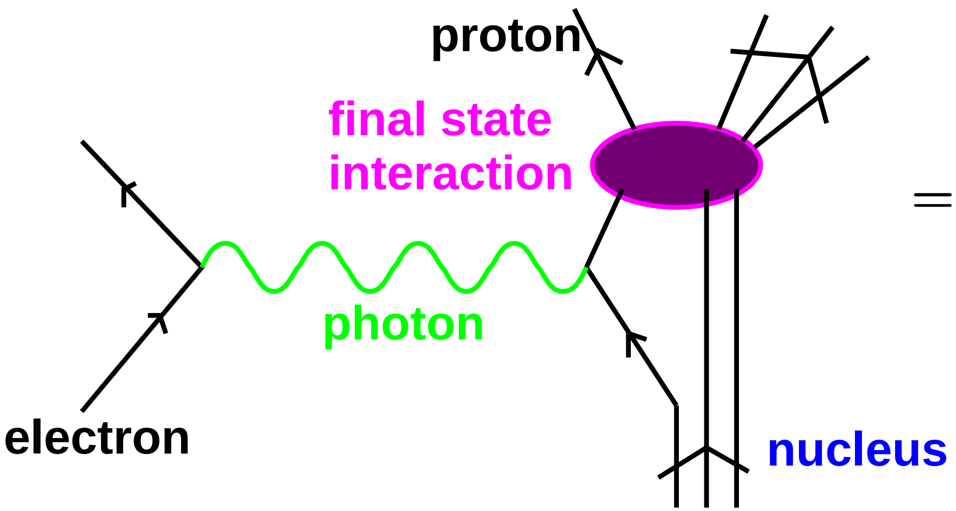
Kim Egiyan Memorial Workshop

What can we learn from the Deuteron?

- Reaction mechanism: FSI, MEC, ….
- Deuteron Structure: wave function, D-wave content, 6-quark admixture, …
- Deuteron as a lab: neutron form factor measurements, color transparency, …

The Reaction



$$\left(\frac{d\sigma^5}{d\epsilon' d\Omega_e d\Omega_N}\right)^h_{fi} = \frac{m_N\, m_f\, p_N}{8\pi^3\, m_i}\,\sigma_{Mott}\, f_{rec}^{-1}$$
$$[\left(v_L \mathcal{R}^L_{fi} + v_T \mathcal{R}^T_{fi} + v_{TT}\mathcal{R}^{TT}_{fi} + v_{TL}\mathcal{R}^{TL}_{fi}\right)$$
$$+h\left(v_{T'}\mathcal{R}^{T'}_{fi} + v_{TL'}\mathcal{R}^{TL'}_{fi}\right)]$$

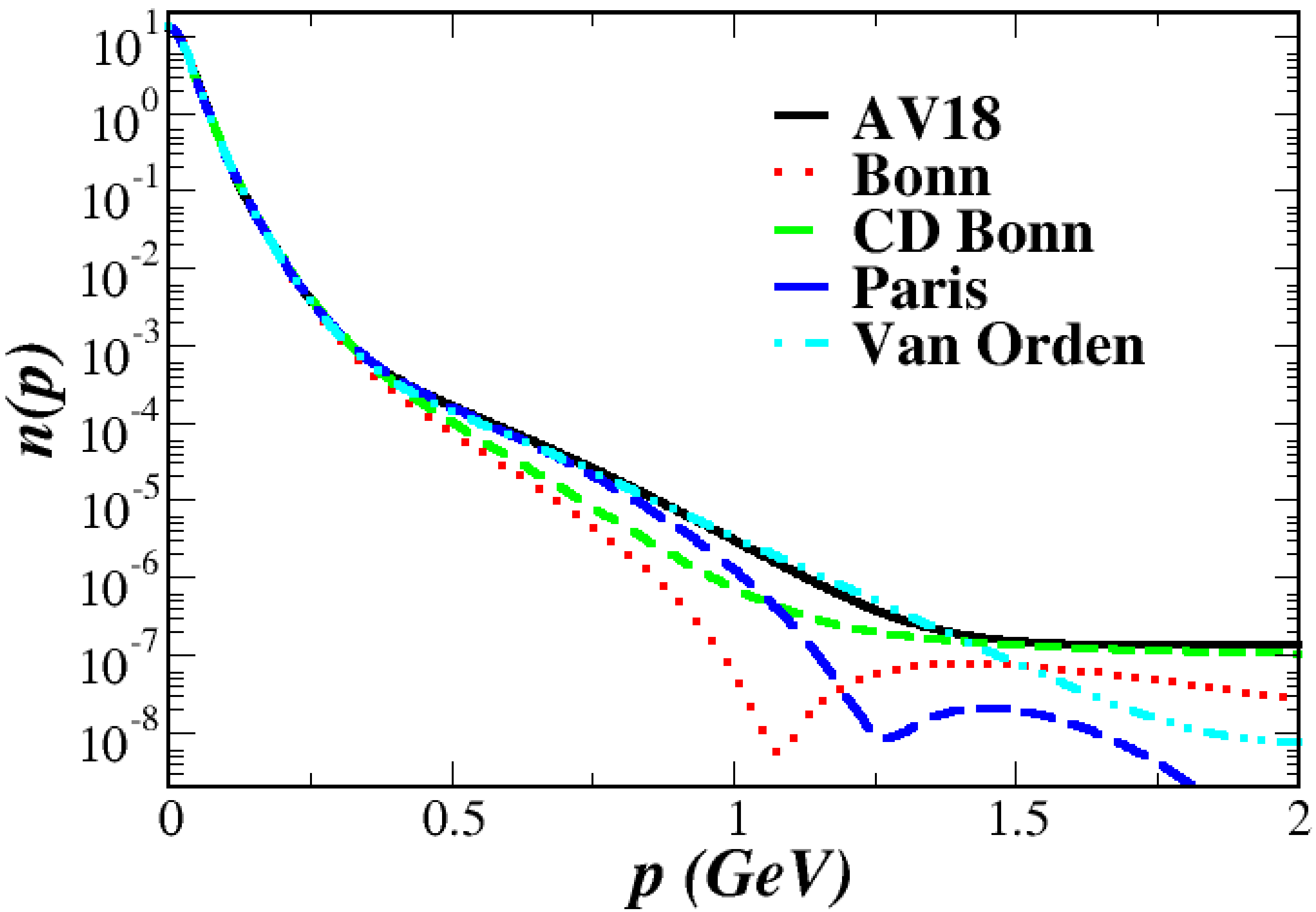
$$\begin{aligned}
\mathcal{R}^L_{fi} &\equiv |\rho(\vec{q})_{fi}|^2 \\
\mathcal{R}^T_{fi} &\equiv |J_+(\vec{q})_{fi}|^2 + |J_-(\vec{q})_{fi}|^2 \\
\mathcal{R}^{TT}_{fi} &\equiv 2\,\Re\,[J^*_+(\vec{q})_{fi}\, J_-(\vec{q})_{fi}] \\
\mathcal{R}^{TL}_{fi} &\equiv -2\,\Re\,[\rho^*(\vec{q})_{fi}\,(J_+(\vec{q})_{fi} - J_-(\vec{q})_{fi})] \\
\mathcal{R}^{T'}_{fi} &\equiv |J_+(\vec{q})_{fi}|^2 - |J_-(\vec{q})_{fi}|^2 \\
\mathcal{R}^{TL'}_{fi} &\equiv -2\,\Re\,[\rho^*(\vec{q})_{fi}\,(J_+(\vec{q})_{fi} + J_-(\vec{q})_{fi})]
\end{aligned}$$

Response functions

What goes into the calculation?

- Deuteron wave function
- Current operators
- Final state interaction

Deuteron Wave Functions



very high missing momentum studied in Kim's experiment in Hall B (deuteron) and a Hall A experiment (He-3)

I use AV18 and Wally's w.f.

Comparing Theory and Experiment - a practical issue

Acceptance averaging

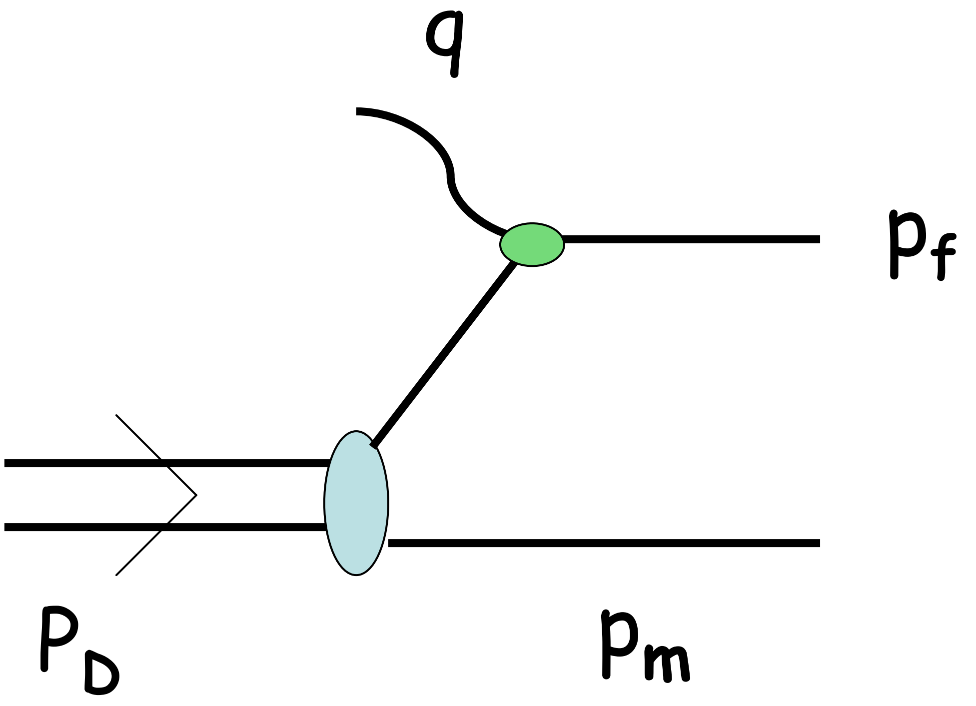
-bin size matters

-the deuteron wave function falls off rapidly with momentum, so do observables

worst case: pmiss = 50 MeV/c, x = 1 cross section changes by a factor of 2 every 10 MeV/c (Paul Ulmer, priv. com.)

Feed theory results into Monte Carlo codes - need fast codes or huge data grid files.

Plane Wave Impulse Approximation (PWIA)



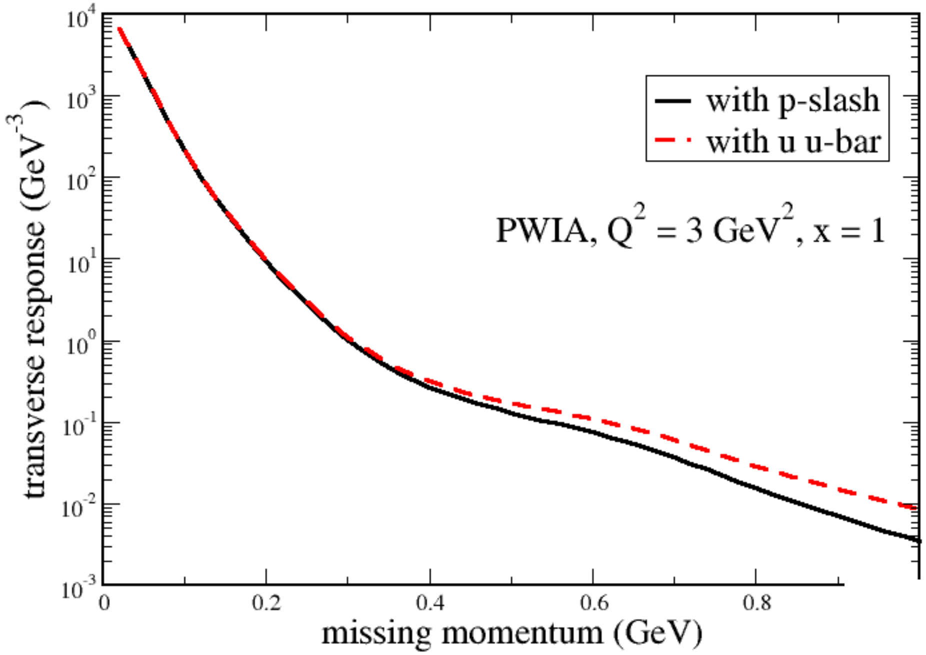
Higher Missing Momenta

$$J^{\mu}_{PWIA} = \bar{u}(p_m)\,\Gamma_{DNN}\,\frac{(\hat{P}_D - \hat{p_m} + m)^T}{(M_D - E_n)^2 - \vec{p}_m^{\,2} - m^2}\,\Gamma^{\mu,T}_{\gamma^* N}\,\bar{u}(p_f)^T$$

For free nucleons: $$\sum_s u(p,s)\bar{u}(p,s) = \frac{\hat{p}+m}{2m}$$

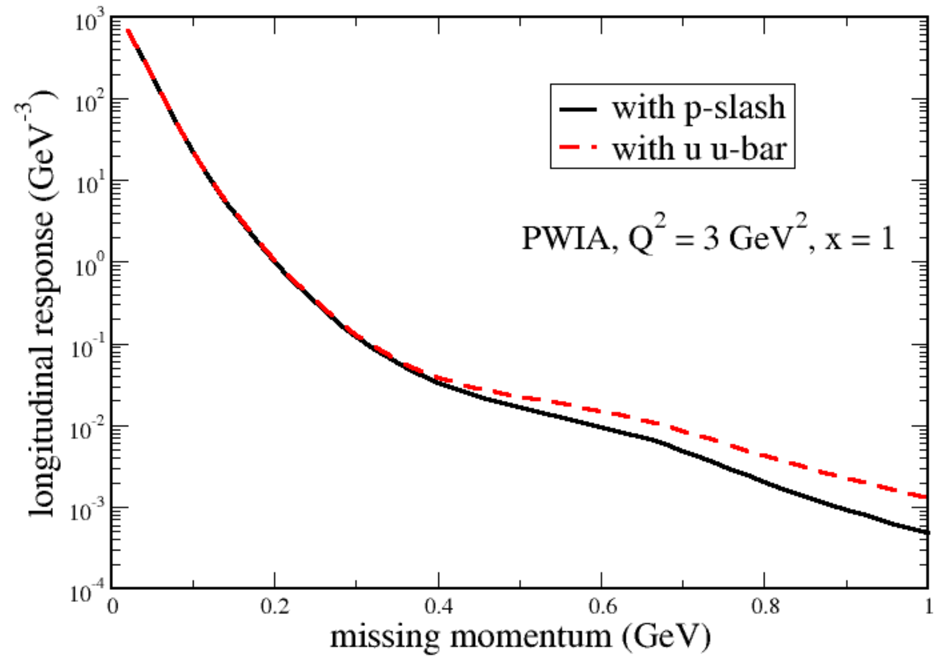
This approximation leads to $$j^{\mu} = \bar{u}(p_f)\,\Gamma^{\mu}_{\gamma^* N}\,u(P_D - p_m)$$

and the non-relativistic wave function

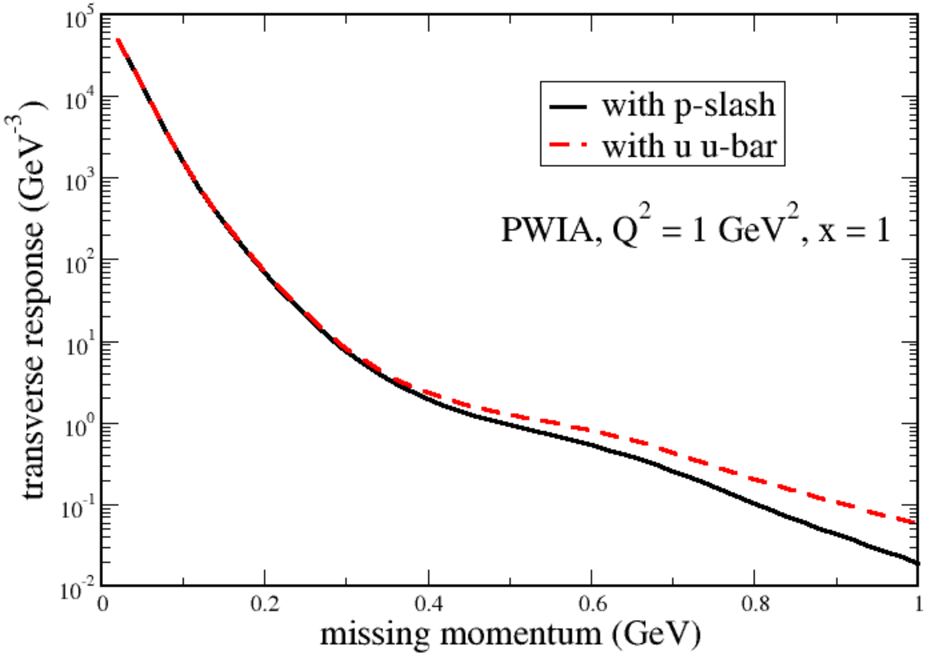


PWIA -
quality of on-shell approximation
for p-slash

Note: this does not include any off-shell effects in the current operator itself!



Work in progress,
with Wally Van Orden

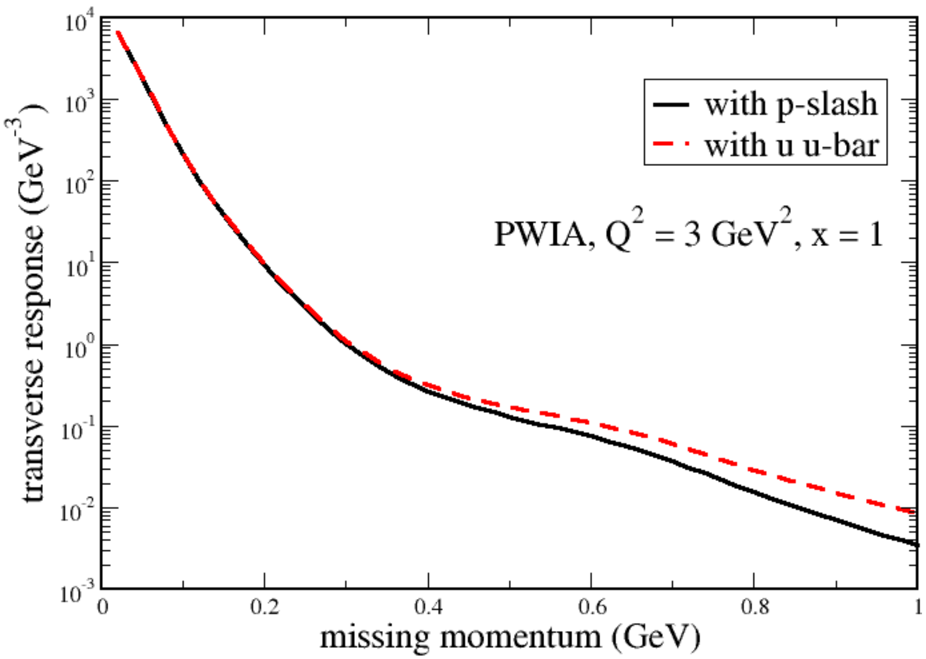


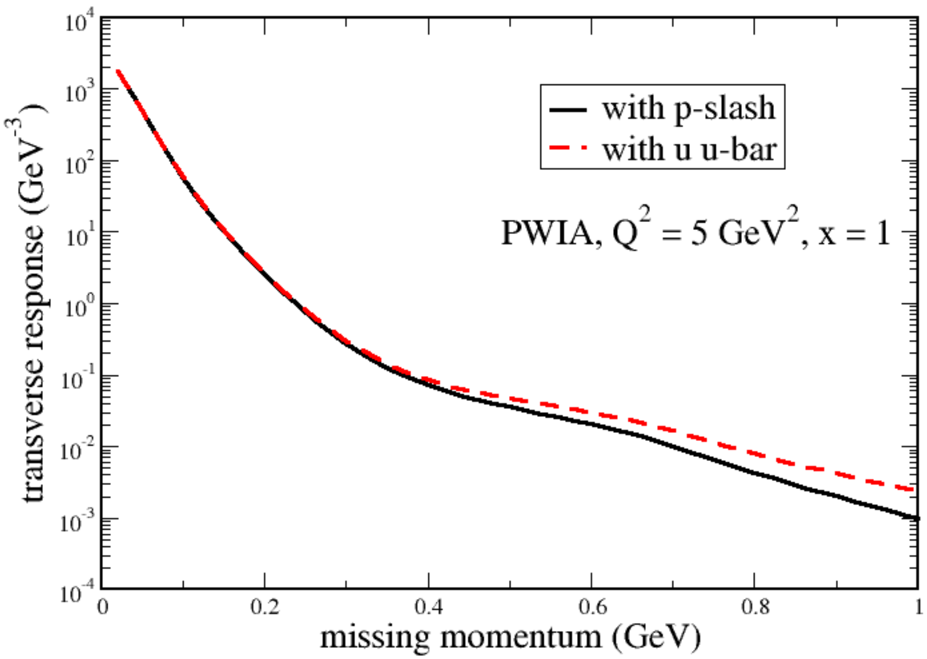
PWIA -

quality of on-shell approximation

for p-slash

Dependence on Q^2





Some Numerical Values – ratio of exact/approximated transverse response

missing momentum 0.2 GeV: 0.96 at Q^2 = 1 GeV^2

0.96 at Q^2 = 3 GeV^2

0.96 at Q^2 = 5 GeV^2

missing momentum 0.4 GeV: 0.84 at Q^2 = 1 GeV^2

0.84 at Q^2 = 3 GeV^2

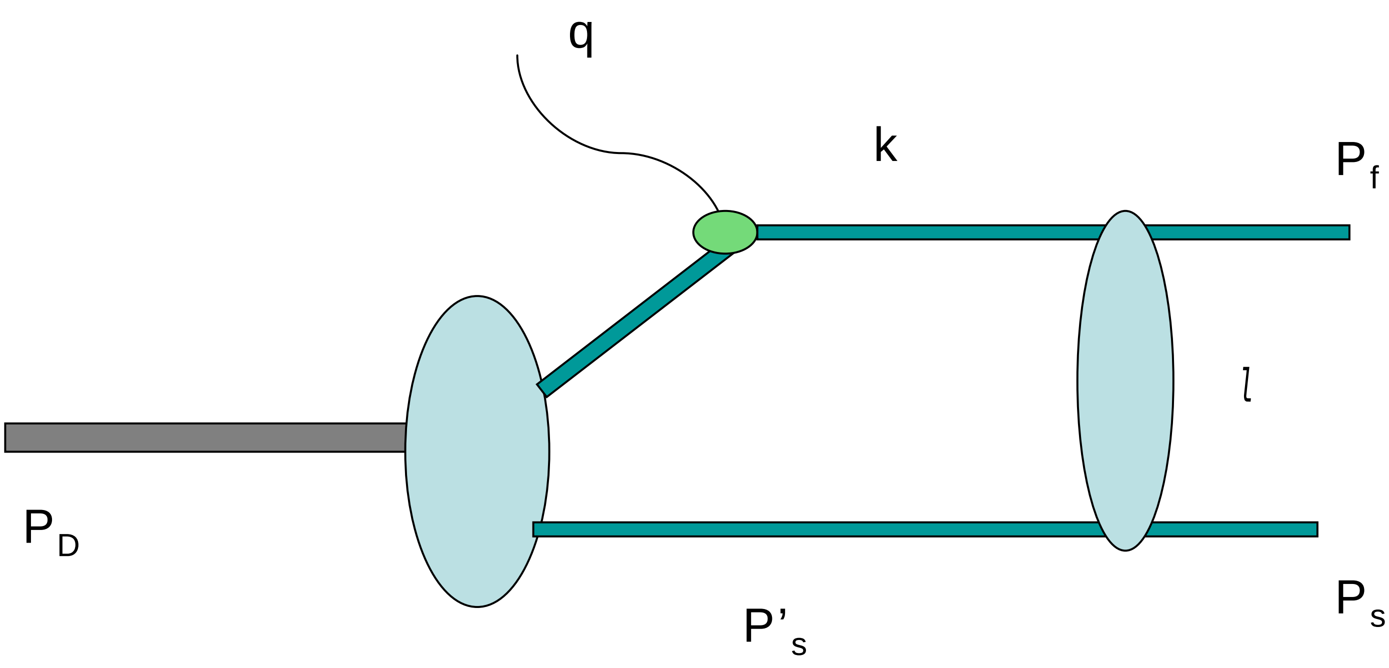
0.84 at Q^2 = 5 GeV^2

missing momentum 0.6 GeV: 0.66 at Q^2 = 1 GeV^2

0.68 at Q^2 = 3 GeV^2

0.69 at Q^2 = 5 GeV^2

Final State Interaction (FSI)



Final State Interaction (FSI)

Use Generalized Eikonal Approximation, following Sargsian, Strikman, Frankfurt

$$S(\vec{r}) = 1 - \theta(z)\,\exp(i\Delta z)\Gamma(\vec{b})$$

Current matrix elements: $\mathcal{M}_{fi} =< f|S\,J_{em}|i >$

Profile function and N N scattering amplitude:

$$\Gamma(\vec{b}) = \frac{1}{2\pi i k}\int d^2\,\vec{l}\;\exp(-i\vec{l}\cdot\vec{b})\;\;f(\vec{l})$$

NN scattering amplitude in the c.m. frame:

$$\begin{aligned} f(\vec{l}) = \quad & A(\vec{l}) + B(\vec{l})\,(\vec{\sigma}_1 + \vec{\sigma}_2)\cdot\hat{n} + C(\vec{l})\,(\vec{\sigma}_1\cdot\hat{n})\,(\vec{\sigma}_2\cdot\hat{n}) + \\ & D(\vec{l})\,(\vec{\sigma}_1\cdot\hat{m})\,(\vec{\sigma}_2\cdot\hat{m}) + E(\vec{l})\,(\vec{\sigma}_1\cdot\hat{h})\,(\vec{\sigma}_2\cdot\hat{h}) \end{aligned}$$

Central FSI

$$A(l) = \frac{k\ \sigma_{tot}^{NN}}{4\pi}(\rho + i)\ \exp(-0.5\, l^2\, b_o^2)$$ or $$A = A_o \cdot \exp(-\beta_A l^2)$$

NN scattering parameters from:

- Phase-shift analysis
- Proton – nucleus Glauber analysis

$$\Gamma(\vec{b}) = \frac{\sigma_{tot}^{NN}(1 - i\,\rho)}{4\pi b_o^2}\ \exp\left(-\frac{\vec{b}^2}{2\, b_o^2}\right)$$

typical value: $b_0 = 0.5$ fm

Issues:

New Hall A, Hall B data have very high energy transfers, no pn phase shift analysis/data available above 1.7 GeV

values from pA not necessarily appropriate for deuteron, also limited to energies of 1GeV or less

Spin-Orbit FSI

$$B(l) = \gamma \, \frac{k \; \sigma_{tot}^{NN}}{4\pi} (\rho_s + i) \, l \; \exp(-0.5 \, l^2 \, b_s^2)$$

spin-orbit profile function:

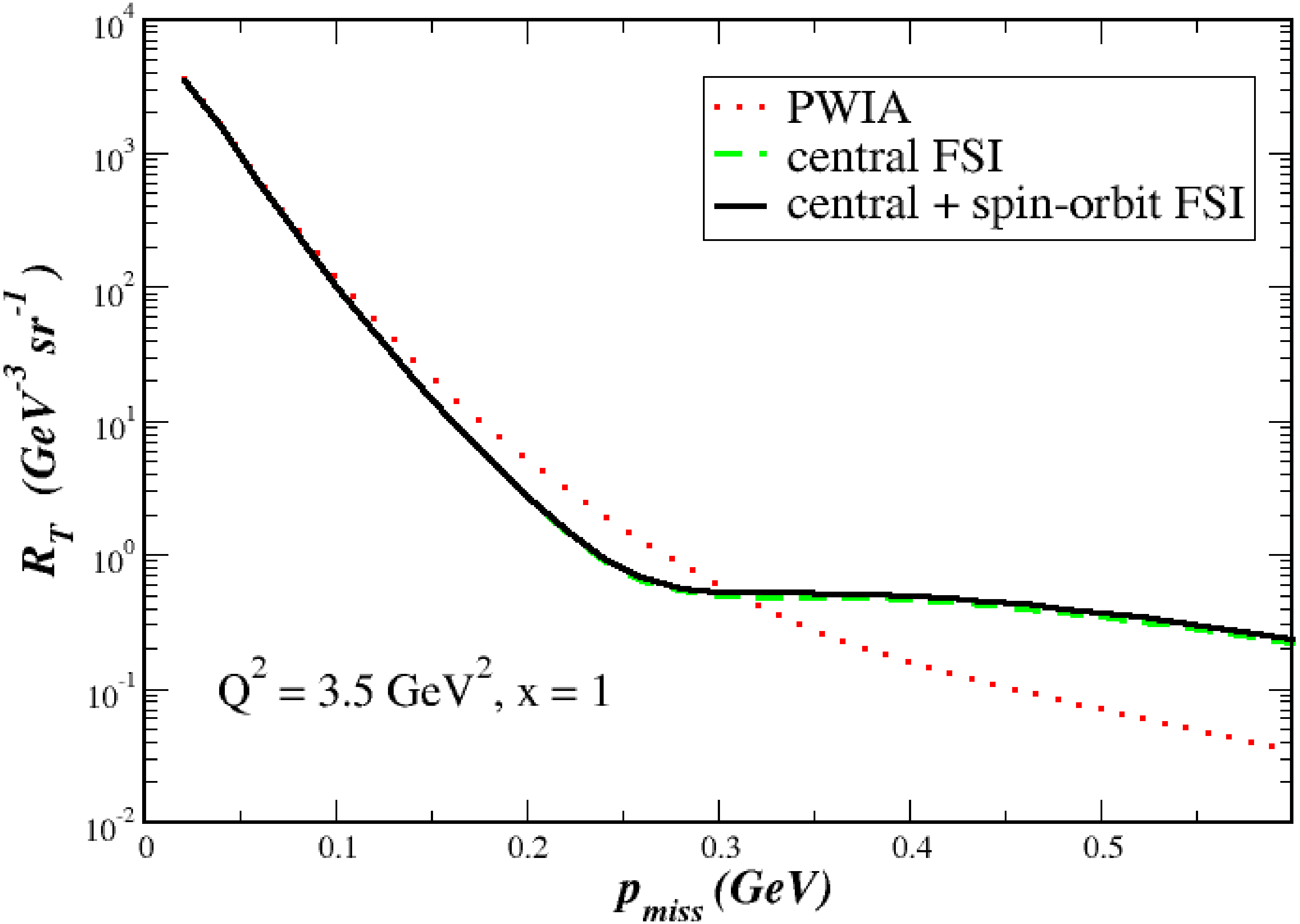
$$\Gamma_s(\vec{b}) = -i \, \gamma \, \frac{\sigma_{tot}^{NN}}{4\pi \, b_s^4} (1 - i\rho_s) \, b \; \exp(-\frac{b^2}{2 \, b_s^2})$$

Typical values: γ = 0.16, b_s = 0.65 fm > b_0

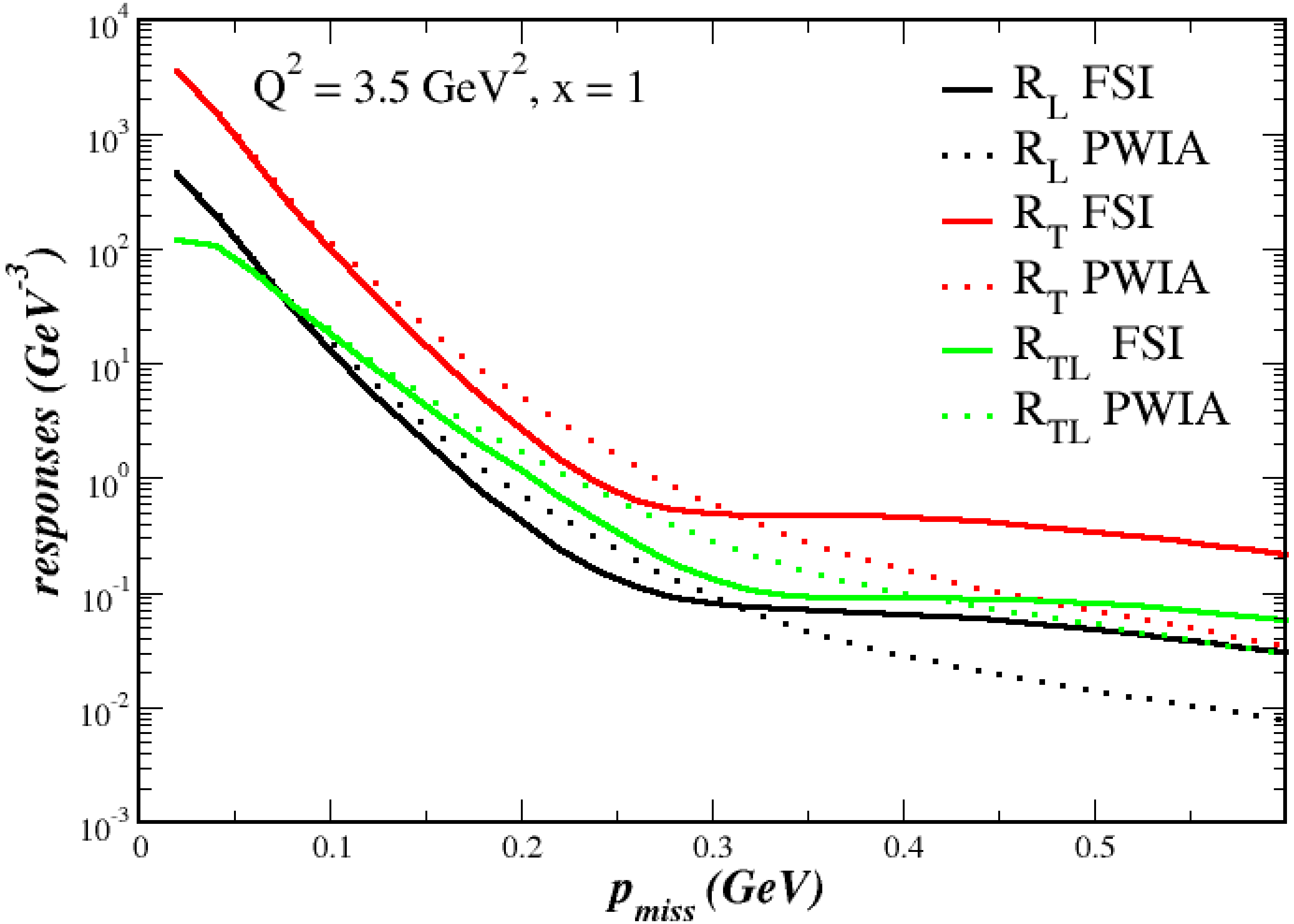
smaller than the central part

less well known

Central and Spin-Orbit FSI

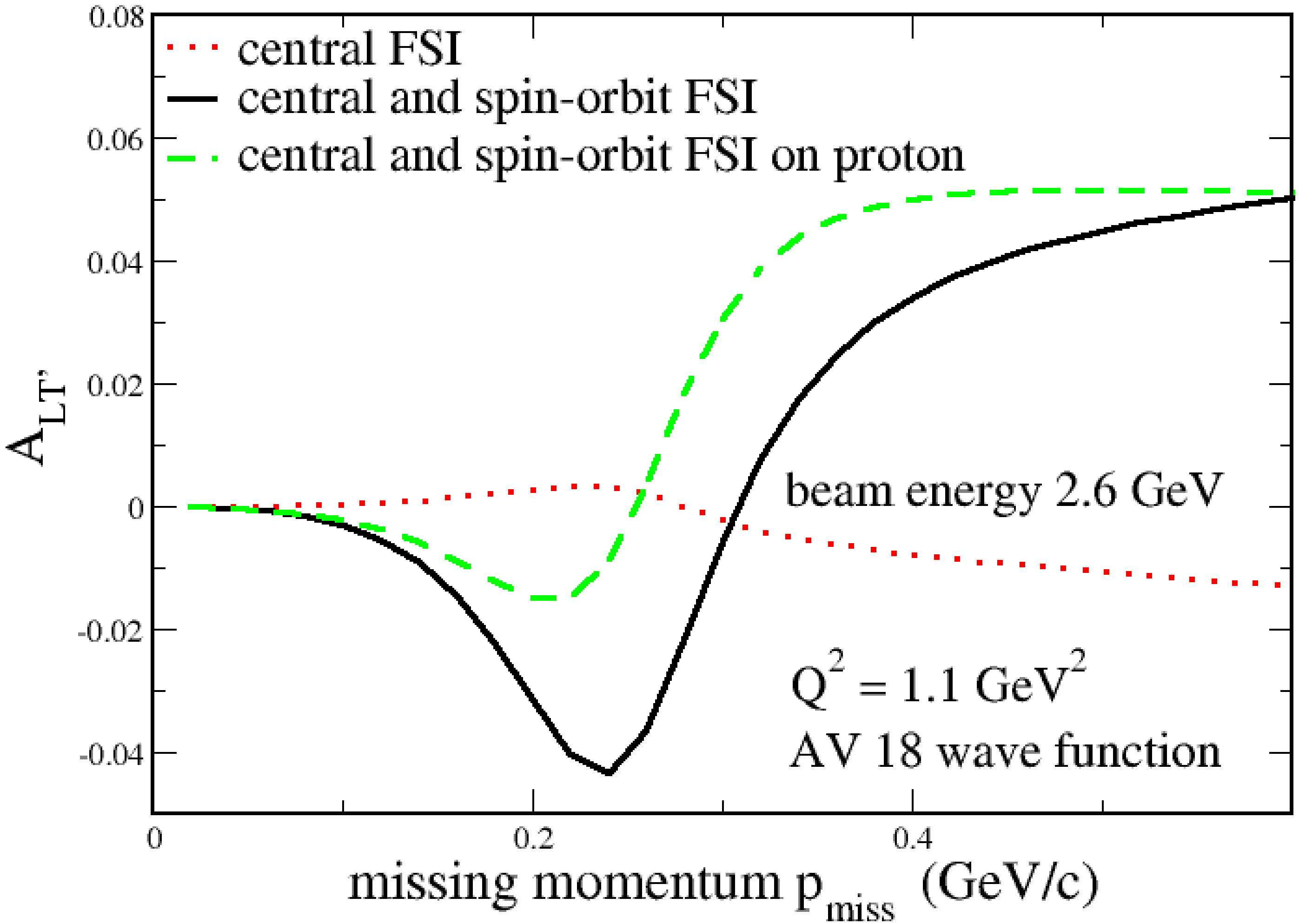


Different Response Functions

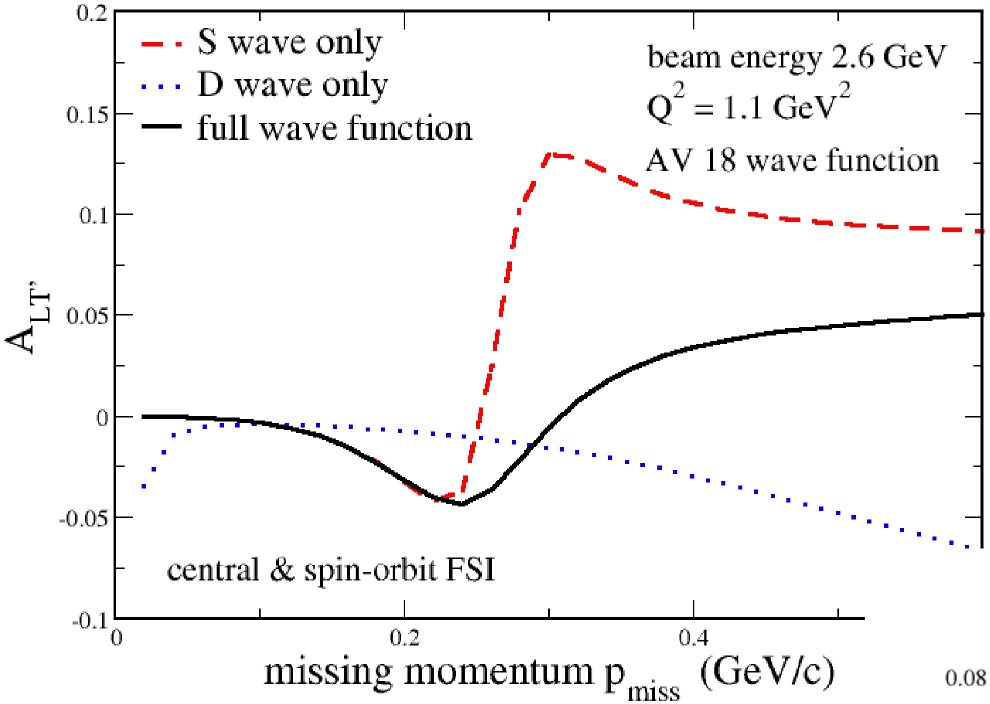


The LT' Asymmetry

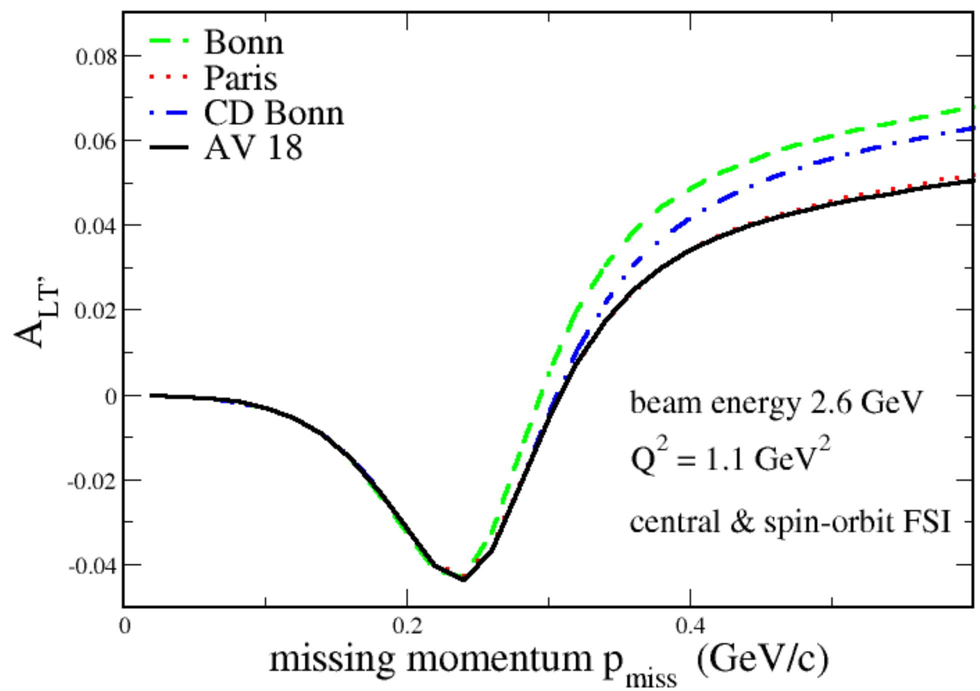
$$A_{LT'} = \frac{v_{LT'} R_{LT'}}{v_L R_L + v_T R_T + v_{TT} R_{TT}}$$



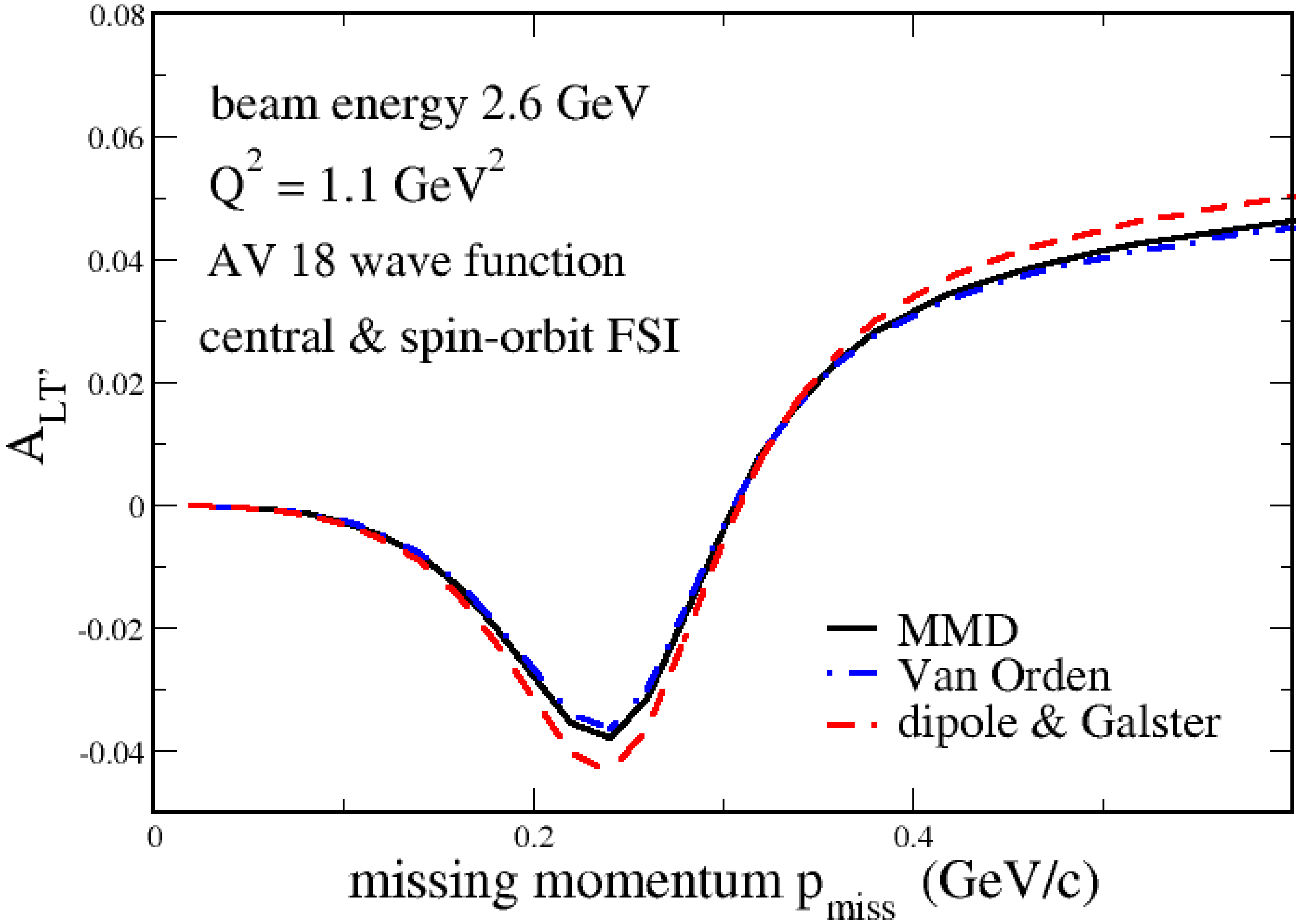
LT' Asymmetry is zero in PWIA!



Sensitivity to the wave function



Sensitivity to form factor parametrizations



Summary & Outlook

-great work done on the experimental side by Kim & colleagues – experiment is exploring new regions

-some of these regions (high missing momentum) pose a real challenge to theory

-very interesting observables are out there, waiting to be explored

Deuteron Benchmarking Project

Let's compare our theoretical calculations, assumptions, and parametrizations step-by-step – everyone is invited to participate!

First iteration - please send in your results by January 31, 2007:
Plane Wave Impulse Approximation calculation, with a non-relativistic reduction of the D -> NN vertex function

Please use the following with your calculation, if possible:
wave function - AV18 parametrization subroutine will be provided shortly
nucleon form factors: dipole parametrization with neutron electric form factor = 0

Results will be posted on this website:
http://hule.fiu.edu/highnp.html

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