Extraction of neutron structure from tagged structure functions

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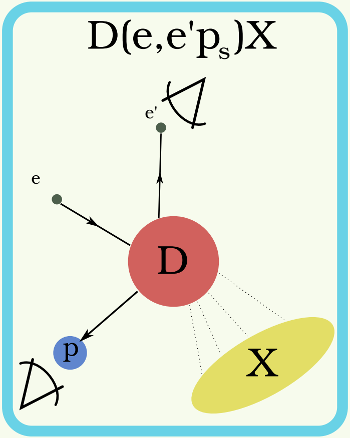
Outline

Semi-inclusive DIS of the Deuteron

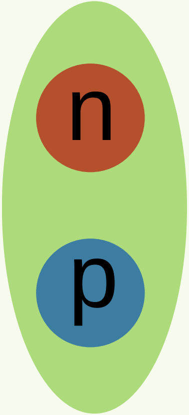


- Detection of a slow spectator proton
- Study the influence of partonic dof at nucleonic length scales
- At low proton momenta: extraction of neutron structure function
  - Helps constrain quark models of the nucleon
  - Gives us u/d pdf ratio at high x
- At higher proton momenta: probe high density configurations, nucleon modifications,6 quark configurations,...?
- For kinematics with high FSI: study space-time evolution of hadronization

Model Ingredients

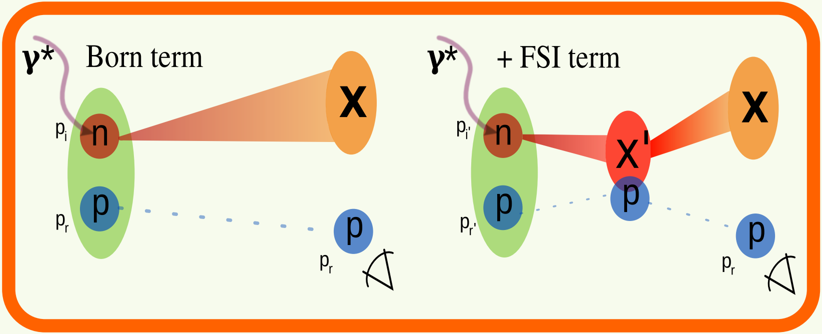
- Quantify effect of FSI
- X?: details about composition and space-time evolution (function of (x, Q^2)) of produced hadronic system after DIS unknown
- Use general properties of soft scattering theory, without specifying X
- Factorized approach: split photon interaction and rescattering part
  In $D(e, e'N)N$: works well up to $p_s \approx 400$ MeV

Virtual Nucleon Approximation



- Consider only *pn* component of Deuteron
- Spectator proton is on-shell
- Deuteron wf normalization obeys baryon number conservation $\int \alpha |\Phi_D(p)|^2 d^3p = 1$, but violates momentum sum rule $\int \alpha^2 |\Phi_D(p)|^2 d^3p < 1$
- Neglect negative energy contribution of virtual neutron propagator
  $\rightarrow p_s \leq 700$ MeV
- Photon interactions with exchanged mesons are neglected
  $\rightarrow Q^2 > 1\text{GeV}^2$

Reaction diagrams



$$\frac{d\sigma}{dxdQ^2 d\phi_{e'} \frac{d^3 p_s}{2E_s(2\pi)^3}} = \frac{2\alpha_{EM}^2}{xQ^4}\left(1-y-\frac{x^2y^2m_n^2}{Q^2}\right)\left(F_L^D(x,Q^2) + v_T F_T^D(x,Q^2) + v_{TL}\cos\phi F_{TL}^D(x,Q^2) + \cos 2\phi F_{TT}^D(x,Q^2)\right)$$

Factorization

- Relate Deuteron structure functions to the neutron ones for a moving nucleon at $\hat{x} \approx \frac{x}{2-\alpha_s}$...

$$F_T^D(x,Q^2) = [2F_{1N}(\hat{x},Q^2) + \frac{p_T^2}{m_i\hat{\nu}} F_{2N}(\hat{x},Q^2)] \times S^D(p_r)(2\pi)^3 2E_r$$

- ...times a distorted spectral function that contains a plane-wave and FSI part

$$S^D(p_r) = \frac{2}{3}\sum_{M,s_r}\left| \overbrace{\Phi_D^M(p_i s_i, p_r s_r)}^{PW} - \overbrace{\int \frac{d^3 p_{r'}}{(2\pi)^3} \chi(p_{r'}, m_{x'}) \langle p_r X|\mathcal{F}|p_{r'} X'\rangle \frac{\Phi_D^M(p_{i'} s_i, p_{r'} s_r)}{(p_{r'}^z - p_r^z + \Delta')}}^{FSI} \right|^2$$

FSI: Generalized eikonal approximation

- Scattering amplitude is parametrized with the standard diffractive form

$$\langle p_r, X|\mathcal{F}|p_{r'} X'\rangle = \sigma_{\text{tot}}(W, Q^2)(i + \epsilon(W, Q^2))e^{\frac{\beta(W,Q^2)}{2}t}\delta_{s_r,s_{r'}}\delta_{s_X s_{X'}}$$

- Eikonal regime gives approximate conservation law $p_s^- = p_{s'}^-$ in the high q limit. This leads to $m_X^2 > m_{X'}^2$, and yields pole values in the FSI integral of

$$\Delta' = \frac{\nu + M_D}{|\vec{q}|}(E_s - m_p) + \frac{m_X^2 - m_{X'}^2(p_{i'} = 0)}{2|\vec{q}|} \quad \text{for } m_{X'}^2(p_{i'} = 0) \leq m_X^2\,,$$

$$\Delta' = \frac{\nu + M_D}{|\vec{q}|}(E_s - m_p) \quad \text{for } m_{X'}^2(p_{i'} = 0) > m_X^2\,.$$

Comparison with Deeps: some formulas

- Use $R = \frac{d\sigma_L}{d\sigma_T} \approx 0.18$ to relate F_{1N} and F_{2N} for a moving nucleon:

$$F_{1N}(\alpha_i, \hat{x}, Q^2) = \frac{2\hat{x}}{1+R}\left[\left(\frac{\alpha_i}{\alpha_q} + \frac{1}{2\hat{x}}\right)^2 - \frac{p_T^2}{2Q^2}R\right] F_{2N}(\alpha_i, \hat{x}, Q^2)$$

- Model cross section gives us

$$\frac{d\sigma}{d\hat{x}dQ^2d^3p_s} = \frac{4\pi\alpha}{Q^2\hat{x}}\frac{|q|}{m_i}\left(1 - y - \frac{x^2y^2m^2}{Q^2}\right)\left(\frac{Q^2}{|\,q\,|^2} + \frac{2\tan^2\frac{\theta_e}{2}}{1+R}\right) \times \left|\frac{\alpha_i}{\alpha_q} + \frac{1}{2\hat{x}}\right|^{-1}\left[\left(\frac{\alpha_i}{\alpha_q} + \frac{1}{2\hat{x}}\right)^2 + \frac{p_T^2}{2Q^2}\right] F_{2N}(\alpha_i, \hat{x}, Q^2) S^D(p_s)$$

- Extract $F_{2N}P(\vec{p}_s)$ like Deeps [`Klimenko et al., PRC73, 035212`]

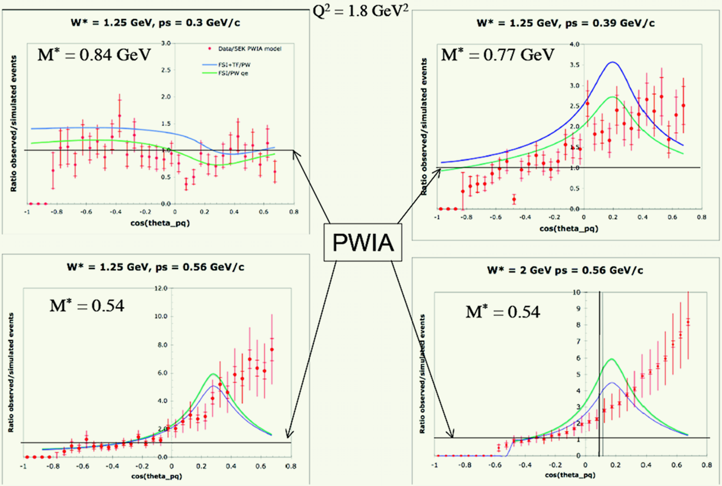
$$(F_{2N}P)_{\text{model}} = \frac{\left(\frac{d\sigma}{d\hat{x}dQ^2d^3p_s}\right)_{\text{model}}}{\frac{4\pi\alpha}{Q^2\hat{x}}\left[\frac{y^*}{2(1+R)} + (1-y^*) + \frac{p_i^2\hat{x}^2y^{*2}}{Q^2}\frac{1-R}{1+R}\right]}$$

Comparison with Deeps: approach

- Use SLAC parametrization for neutron structure functions (as in Deeps data analysis)
- Take $\sigma_{\text{tot}}(W, Q^2)$ (and $\beta(W, Q^2)$) as free parameter in the distorted spectral function. Fits are done for each W, Q^2 over the 5 measured spectator momenta (300-560 MeV).
- Deuteron wave function: $\Phi_D(p) = \Phi_D^{\text{NR}}(p)\sqrt{\frac{M_D}{2(M_D - E_s)}}$
- Off-shell scattering amplitude in FSI taken equal to on-shell one

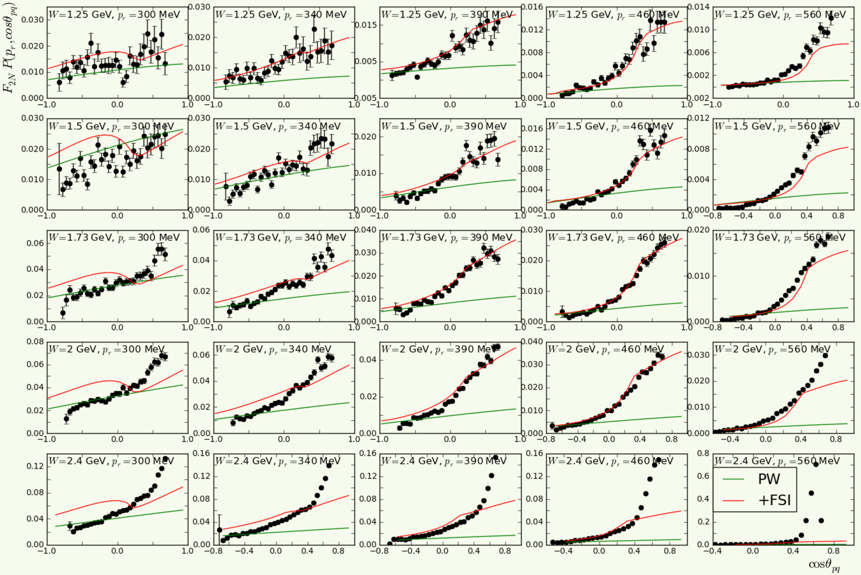
Situation before

Results from "Deeps": Comparison w/ FSI model (CdA et al.)

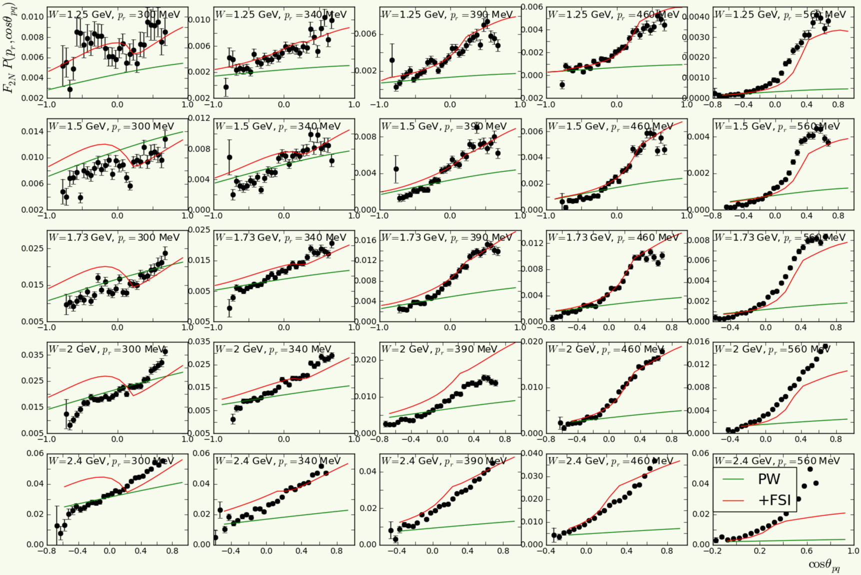


Calculation by `C. degli Atti et al.` [Slide from S. Kuhn]

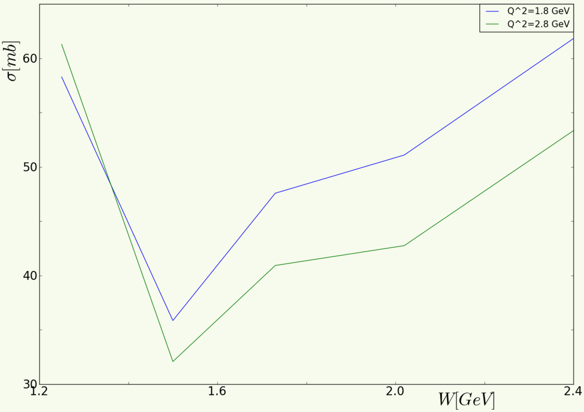
$Q^2 = 1.8\text{GeV}^2$: σ free, $\beta = 8\text{GeV}^{-2}$, $\epsilon = -0.5$



$Q^2 = 2.8\mathrm{GeV}^2$: σ free, $\beta = 8\mathrm{GeV}^{-2}$, $\epsilon = -0.5$

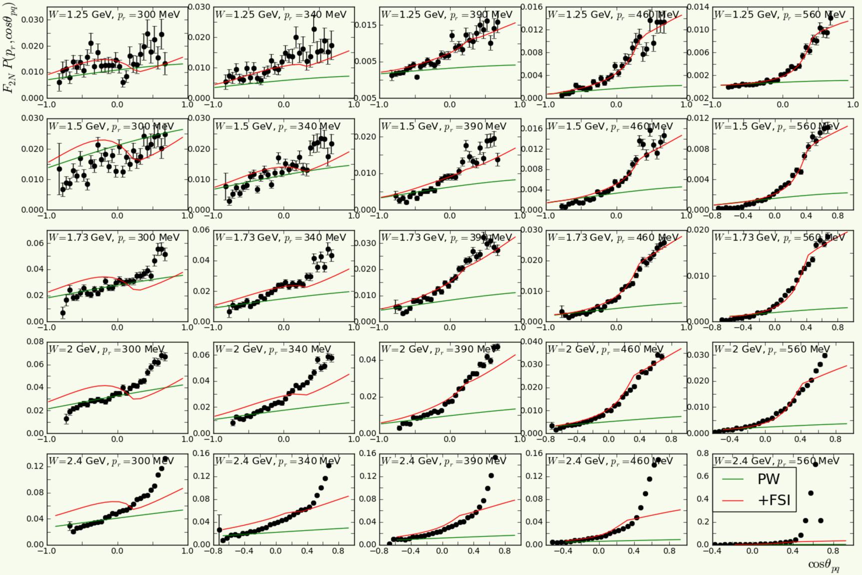


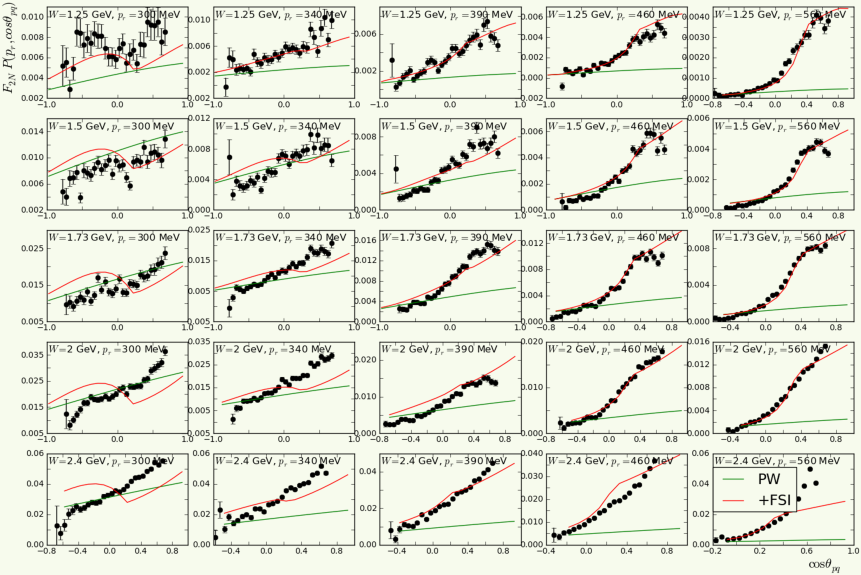
σ parameter, $\beta = 8\text{GeV}^{-2}, \epsilon = -0.5$



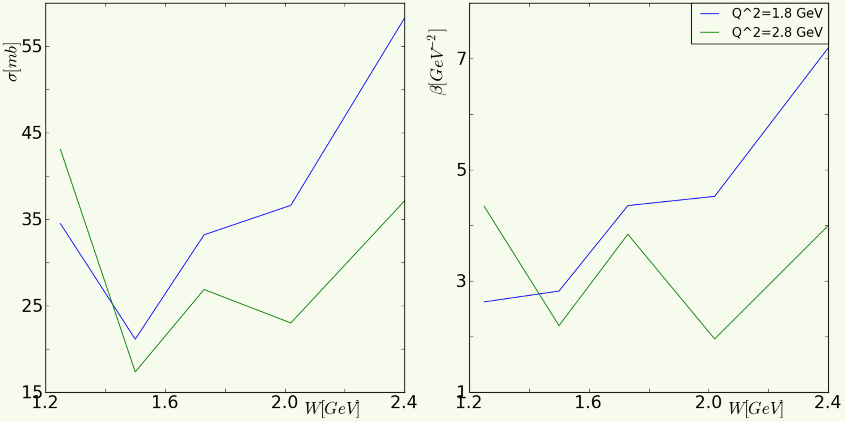
- σ rises with W, no sign of plateau yet
- σ drops with Q^2, CT effect?

$Q^2 = 1.8\text{GeV}^2$: σ and β free, $\epsilon = -0.5$

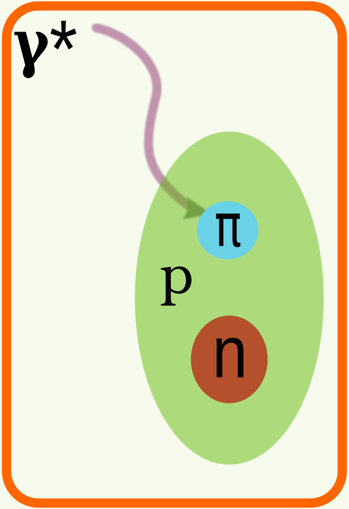



$F_{2N}\, P(p_r, cos\theta_{pq})$
W=1.25 GeV, p_r =300 MeV
W=1.25 GeV, p_r =340 MeV
W=1.25 GeV, p_r =390 MeV
W=1.25 GeV, p_r =460 MeV
W=1.25 GeV, p_r =560 MeV
W=1.5 GeV, p_r =300 MeV
W=1.5 GeV, p_r =340 MeV
W=1.5 GeV, p_r =390 MeV
W=1.5 GeV, p_r =460 MeV
W=1.5 GeV, p_r =560 MeV
W=1.73 GeV, p_r =300 MeV
W=1.73 GeV, p_r =340 MeV
W=1.73 GeV, p_r =390 MeV
W=1.73 GeV, p_r =460 MeV
W=1.73 GeV, p_r =560 MeV
W=2 GeV, p_r =300 MeV
W=2 GeV, p_r =340 MeV
W=2 GeV, p_r =390 MeV
W=2 GeV, p_r =460 MeV
W=2 GeV, p_r =560 MeV
W=2.4 GeV, p_r =300 MeV
W=2.4 GeV, p_r =340 MeV
W=2.4 GeV, p_r =390 MeV
W=2.4 GeV, p_r =460 MeV
W=2.4 GeV, p_r =560 MeV
PW
+FSI
$\cos\theta_{pq}$

σ and β parameters, $\epsilon = -0.5$



History: Chew-Low technique



- Used for extraction of the π^+ formfactor: consider proton as $n - \pi^+$ system
- Extrapolate the longitudinal cross section to the unphysical $t = m_\pi^2$ pole

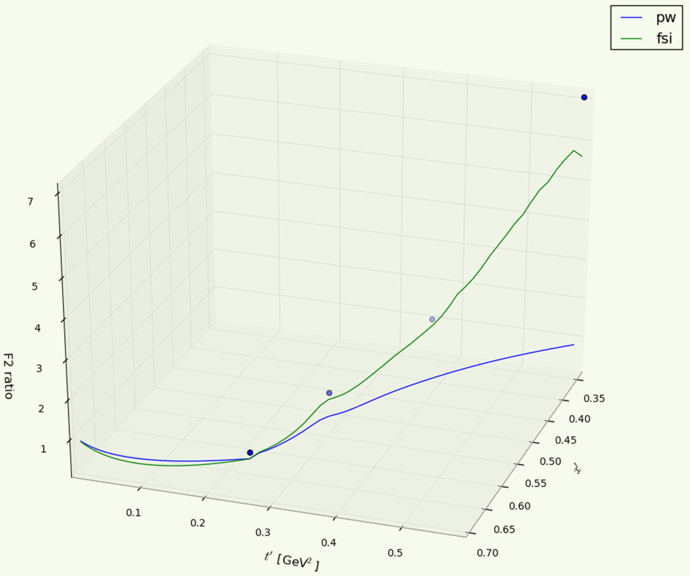
Applied to deuteron (*work in progress*)

- Take limit $t' = p_i^2 - m_n^2 = (M_D - p_s)^2 - m_n^2 \to 0$: plane-wave part of the spectral function has a quadratic pole while the FSI part hasn't.
- Extract the free neutron structure function through

$$\lim_{t' \to 0} F_{2N}^{\text{extr}}(Q^2, \hat{x}, t') = \frac{t'^2}{[\text{Res}(\Phi_D(t'=0))]^2} \frac{F_L^{D,\exp}(x, Q^2) + v_T F_T^{D,\exp}(x, Q^2)}{\frac{2\hat{x}\nu}{m_n}\left[\left(\frac{\alpha_i}{\alpha_q} + \frac{1}{2\hat{x}}\right)^2 + \frac{p_T^2}{2Q^2}\left(\frac{Q^2}{|q|^2} + \frac{2\tan^2\frac{\theta_e}{2}}{1+R}\right)\right]}$$

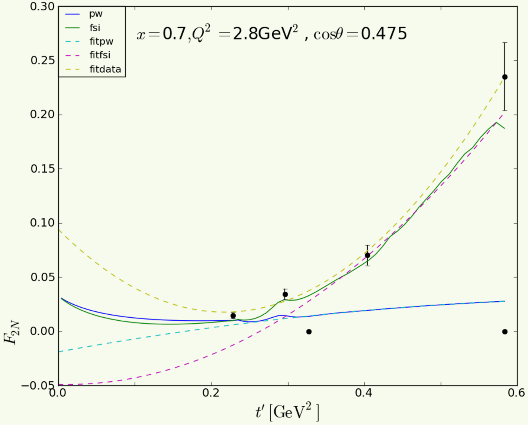
  This quantity has a quadratic dependence in t'.
- Do so for forward spectator proton: use the $\hat{x} < x$ region where F_{2N} is well known
- Take a descending trajectory through W and ps of the Deeps data for a fixed θ_s

Trajectory



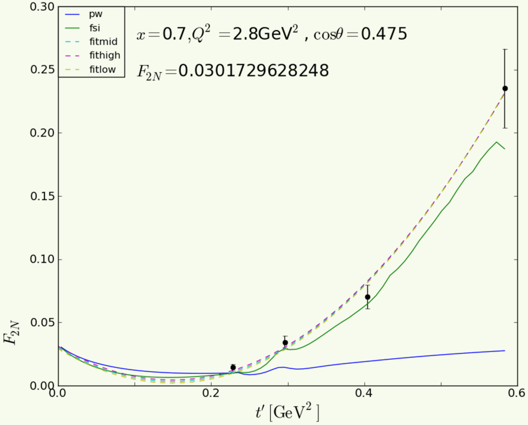
pw
fsi
F2 ratio
1
2
3
4
5
6
7
0.1
0.2
0.3
0.4
0.5
t' [GeV²]
0.35
0.40
0.45
0.50
0.55
0.60
0.65
0.70

Quadratic fit II



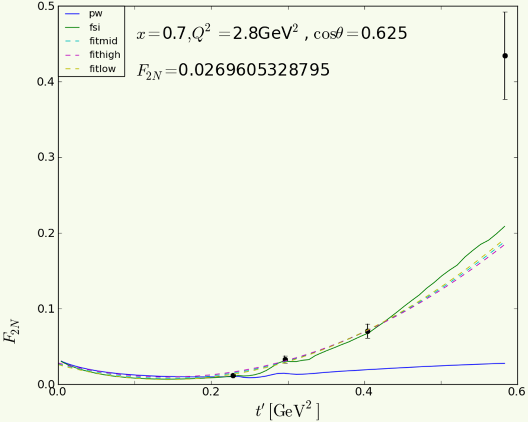
- Model curves end up in the right limit (F_{2N} is input)
- Quadratic fit in the $0.3 < \hat{x} < 0.5$ region doesn't really work. Need more data around the minimum (Bonus?).

Quadratic fit III



- Minimum depends on *FSI* term, use that
- Quadratic fit with data and extra constraints gives reasonable value
- Extrapolated value varies with θ_s

Quadratic fit III



- Minimum depends on *FSI* term, use that
- Quadratic fit with data and extra constraints gives reasonable value
- Extrapolated value varies with θ_s

Conclusions

- Model for semi-inclusive DIS on the deuteron based on general properties of soft rescattering.
- Fair description of the Deeps data
- Discrepancies at $p_s = 300$ MeV with high W. Possible breakdown of factorization at highest $p_s = 560$ MeV.
- Cross section rises with W and shows no signs of a plateau (hadronization) yet, drops with Q^2.
- Extraction of neutron form factor through extrapolation to the unphysical pole starting from the low x region shows promise, but we need more data!!