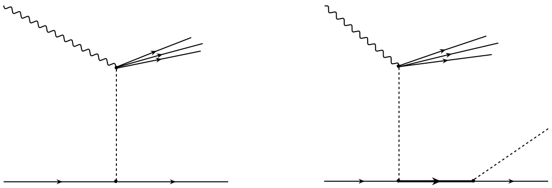


Numerical estimates of chiral cloud contributions to tagged proton electroproduction

T. Hobbs, Indiana Univ.

January 17, 2014

The TOPT Sullivan process (*see Tim Londergan's talk!*)

- $|N\rangle \;=\; \sqrt{Z_2}\,|N\rangle_0 \;+\; \sum_{M,B}\int dy\, f_{MB}(y)\,|M(y); B(1-y)\rangle$
  $y = k^+/P^+$: k meson, P nucleon

- time-ordered PT in the **inf. momentum frame (IMF)**

$$f_{\pi^- N}(y) = \frac{2g^2_{\pi NN}}{16\pi^2}\int_0^\infty \frac{dk^2_\perp}{(1-y)}\frac{F^2_{\pi N}(s_{\pi N})}{y\,(m_N^2 - s_{\pi N})^2}\left(\frac{k^2_\perp + y^2 m_N^2}{1-y}\right)$$

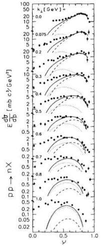
$$F_{\pi N}(s_{\pi N}) = \exp[\,-(s_{\pi N} - m_N^2)\,/\,\Lambda^2]\;\;(\textit{for example!})$$

$$s_{\pi N} = \frac{m_\pi^2 + k^2_\perp}{y} + \frac{m_N + k^2_\perp}{1-y}$$

- a similar procedure gives $f_{\rho N}(y)$

- $$F_{\pi N}(s_{\pi N}) = \exp[-(m_N^2 - s)/\mathbf{\Lambda}^2]$$

  Λ controls model output; must be **constrained**



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Flavour and spin of the proton and the meson cloud

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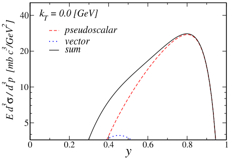
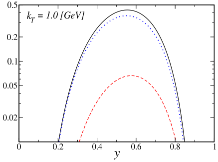
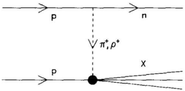
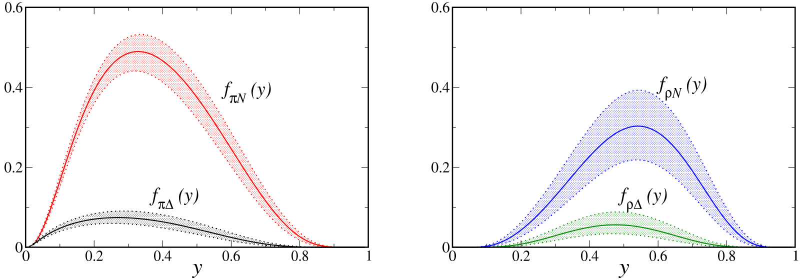
- **hadroproduction** fits: e.g., $pp \to nX$, $pp \to \Delta^{++}X$







hadronic splitting functions



- $\Lambda_N = (1.56 \pm 0.07)$ GeV $\quad\quad \Lambda_\Delta = (1.39 \pm 0.07)$ GeV

for $y \in [0.05, 0.20]$, $\pi - \Delta$ modes are $\sim$ **30% of $\pi - N$;
ρ-exchange minimal

form factors and model dependence

UV regularization may be achieved in various ways

- **s-dependent** form factor, e.g.:

$$F_{\pi N}(s_{\pi N}) = \exp[\,-(s_{\pi N} - m_N^2)\;/\;\boldsymbol{\Lambda}^2]$$

$$F_{\pi N}(s_{\pi N}) = \left(\frac{m_N^2 + \Lambda^2}{m_N^2 + s_{\pi N}}\right)^n, \quad n \in 1, 2$$

- covariant, **t-dependent** expressions –

$$F_{\pi N}(t) = \left(\frac{m_N^2 + \Lambda^2}{m_N^2 + t}\right)^n, \quad n \in 1, 2$$

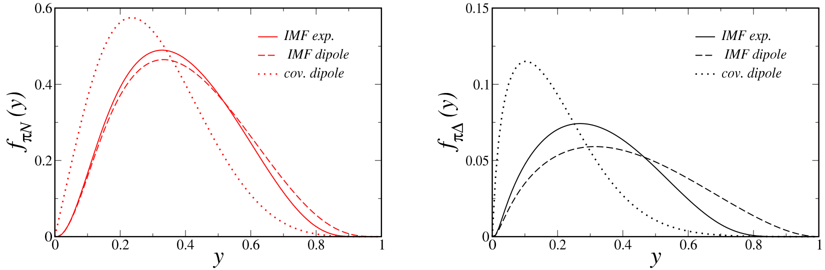
$$t = k^2 = (P - p)^2$$

(though there are issues related to *reciprocity* and mom. conservation)

- **dimensional regularization**

$\rightarrow$ a **systematic**, well-defined scheme (e.g., $\overline{MS}$)

e.g., qualitative behaviors for $f_{\pi N}(y)$, $f_{\pi\Delta}(y)$ differ significally according to the functional form of $F(s_{\pi B})$:

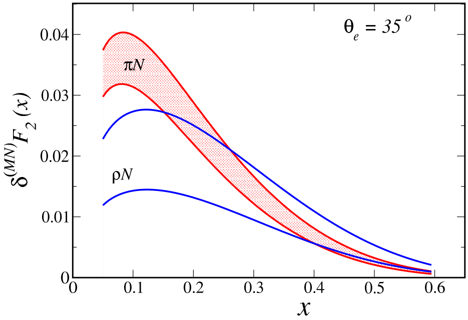


- N. B. *formal* limitations to **covariant** approach:

$$\rightarrow f_{\pi N}(y) \neq f_{N\pi}(1-y)$$

inclusive: $\delta^{(\pi N)} F_2(x, Q^2) = \int_x^1 dy \; f_{\pi N}(y) \; F_2^{\pi}(\frac{x}{y}, Q^2)$

- $E = 11$ GeV scattering from π^-, ρ^-; $0.05 \leq x \leq 0.6$ $25^\circ \leq \theta_e \leq 45^\circ$, though Q^2 dependence in $F_2^{\pi}(x, Q^2) \sim \log(\log(Q^2/\Lambda^2_{QCD}))$ is weak



**$F_2^{\pi}(x, Q^2) \approx F_2^{\rho}(x, Q^2)$

tagging in $k_\perp$

$$e + n \to e' + p + X$$

- **spectator tagging** in the target fragmentation region (TFR) $\to$ finite $k_\perp$ intervals

$$\begin{aligned}
\delta^{(\pi N)} F_2(x, k_\perp^2, Q^2) &= \int_x^1 dy f_{\pi N}(y, k_\perp^2)\ F_2^\pi(\frac{x}{y}, Q^2) \\
f_{\pi N}(y, k_\perp^2) &= 2\int_{k_\perp}^{k_\perp+\epsilon} dk'_\perp k'_\perp \cdot f_{\pi N}(y, k'^2_\perp) \\
f_{\pi N}(y) &= \int_0^\infty dk_\perp^2\ f_{\pi N}(y, k_\perp^2)
\end{aligned}$$

$$R(x, k_\perp^2, Q^2) = \delta^{(\pi N)} F_2(x, k_\perp^2, Q^2) \Big/ \delta^{(\pi N)} F_2(x, Q^2),$$

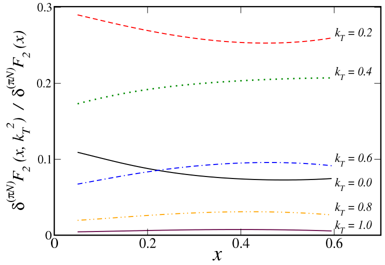
The parameter $\epsilon = \mathbf{0.1}$ GeV is a $k_\perp$ bin size

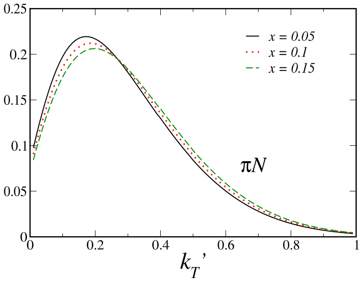
$k_\perp$ dependence

- tagged to inclusive structure functions:

$$\rightarrow \delta^{(\pi N)} F_2(x, k_\perp^2) \Big/ \delta^{(\pi N)} F_2(x)$$

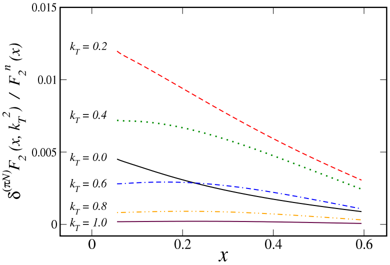
... at fixed $k_\perp$ ... ... and fixed x.

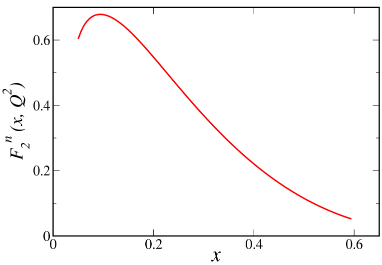




$\rightarrow$ $k_\perp$ spectrum dominated by lower momenta, $k_\perp \lesssim$ 400 MeV;
** weak x **dependence** – cancellations in the F_2^π ratio

$F_2^n(x) = 2x \sum_q [q + \bar{q}](x)$, $q \in \{u, d\}$ from LO CTEQ6.5, assuming *charge symmetry*





- N.B.: x distributions are for fixed θ_e, **not** fixed Q^2

  ** $Q^2 \to Q_0^2$ for $x \to 0$; $F_2^n(x, Q^2)$ non-monotonic!

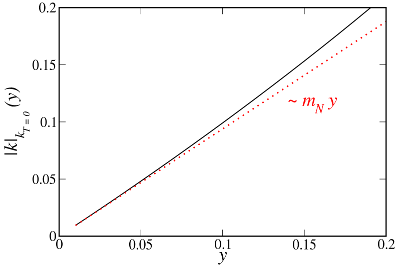
kinematical limits from $|\vec{k}|$ tagging

- $|\vec{k}| \in [60, 170]$ MeV

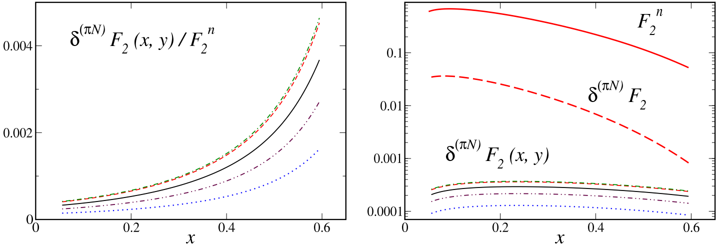
$$|\vec{k}| = \sqrt{k_\perp^2 + \frac{1}{4m_N^2(1-y)^2}\left(k_\perp^2 + (1-[1-y]^2)m_N^2\right)^2}$$

- in the limit $k_\perp^2 = 0$,

$$|\vec{k}|_{k_\perp^2=0} = \frac{y m_N}{2}\left(\frac{2-y}{1-y}\right) \;\rightarrow\; y \lesssim |\vec{k}|/m_N$$



$\delta^{(\pi N)} F_2(x, y)$ at fixed $|\vec{k}|$

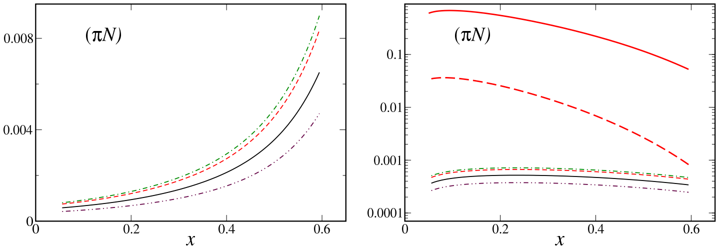


$$\delta^{(\pi N)} F_2(x, \mathbf{y} = \mathbf{0.05}) = f_{\pi N}(\mathbf{y} = \mathbf{0.05}) \cdot F_2^{\pi}(x)$$

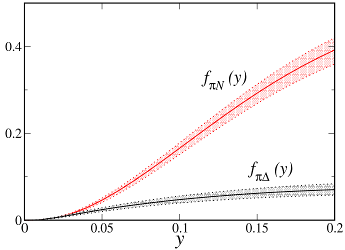
- $|\vec{k}| \in \{k_1, k_1 + 10\}$ MeV
  $k_1 = 60, 80, 100, 130, 160$ MeV

picture depends importantly on the $|\vec{k}|$ **binning scheme**
***(see talk by Thia)*

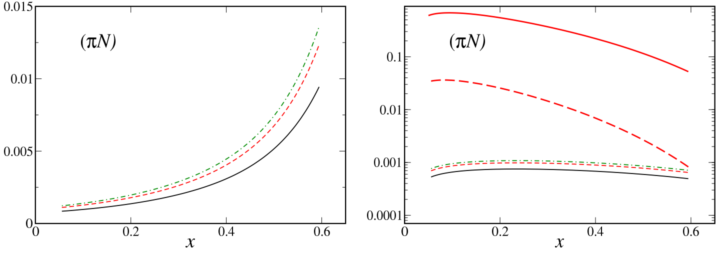
$\delta^{(\pi N)} F_2(x, y)$, $y = 0.075$



$\rightarrow$ again, dependence on y controlled by $\mathbf{f_{\pi N}(y)}$:



$\delta^{(\pi N)} F_2(x, y)$, $y = 0.1$

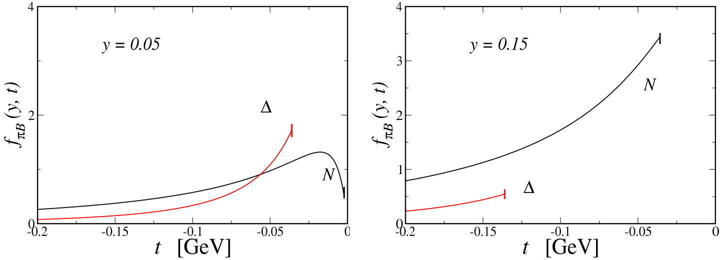


- at intermediate accessible y, measurements are sensitive only to $|\vec{K}| \gtrsim 100$ MeV

still, these are $\sim 1\%$ effects

preliminary t distributions

- covariant $f_{\pi N}(y,t)$ & $f_{\pi\Delta}(y,t)$ *before* t-integration



$$\pi N: \quad t_{max} = -m_N^2 y^2/(1-y)$$

$$\pi\Delta \quad t_{max} = -\left(m_\Delta^2 - (1-y)m_N^2\right) y \Big/ (1-y)$$

- form factor dependence and **extrapolation** to $t \sim m_\pi^2$ *in progress* (see talk by Christian Weiss!)

conclusions

- have a *preliminary* assessment of pion mode contributions to $F_2^n(x, Q^2)$

$\rightarrow$ at accessible y, $|\delta^{\pi N} F_2(x, y)| \Big/ F_2^n \sim 1\%$

** role of ρ **exchange** minimal at relevant kinematics $(0 \leq y \leq 0.2)$

- Δ decays enter at $\sim 30\%$ level and must be controlled systematically

- more thorough analysis of model dependence (**form factors,** Λ **determinations**) is required, and in progress

  $\rightarrow$ as is the $t \sim m_\pi^2$ **extrapolation**