Transverse Pion Asymmetries

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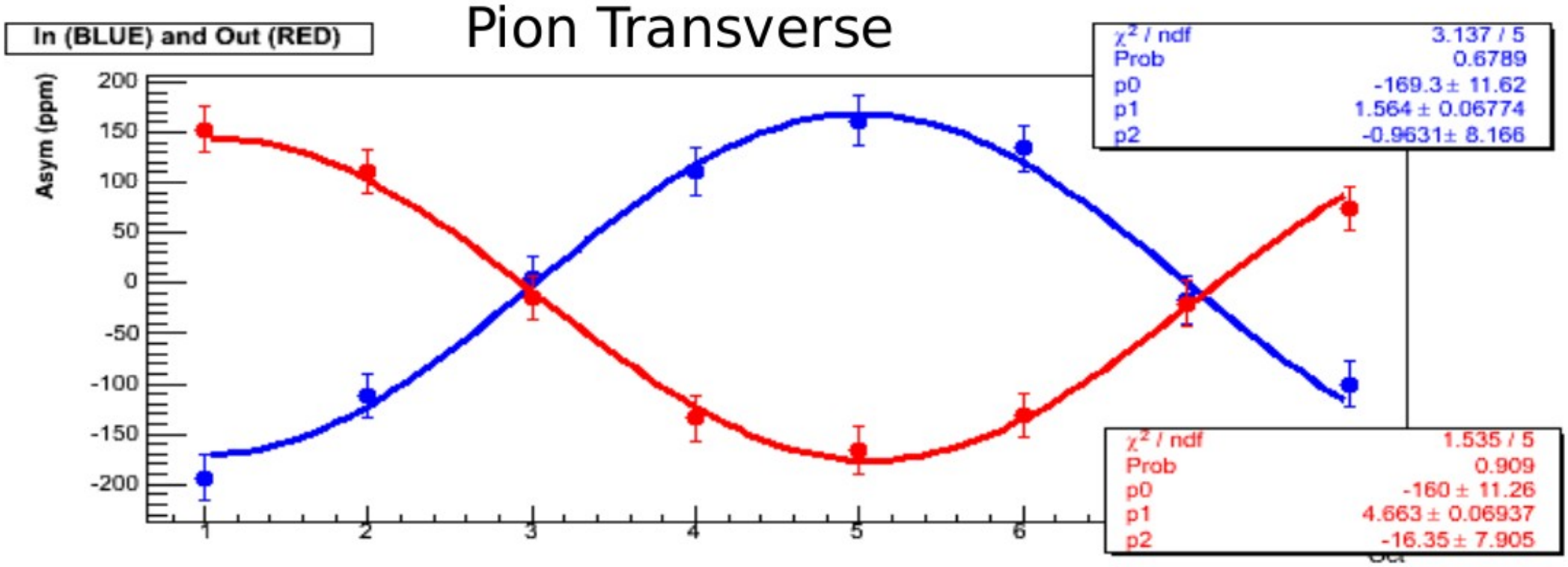
Outline:

- Data
- Transverse elastic review
- Transverse pion
- OOP Longitudinal pion
- Theory Support

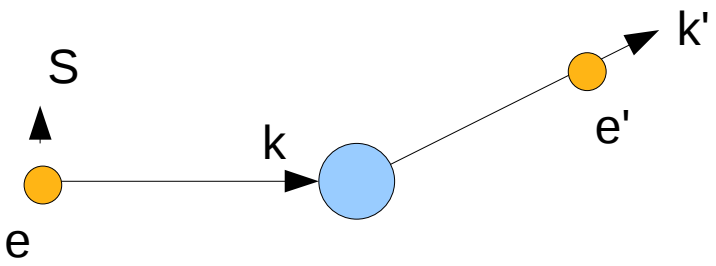
Data: The Transverse Spin Azimuthal Asymmetry in Inclusive Pion Production



- See e.g. A. Coppens, Jan. 2008 collaboration meeting
- Can we understand this?
- A. Afanasev: "Yes, LT' spin- and phi-dependent terms in pion electroproduction" (in his recent conversations with E. Beise, C. Ellis, D. Beck) A_n ~ 100 ppm.

Transverse Elastic Scattering (Vector Analyzing Power, “VAP”)

- E.g. Diaconescu + Ramsey-Musolf:



(imagine that k' is not in plane)

$$\sigma_{VAP} \sim \vec{S} \cdot (\vec{k} \times \vec{k}\,')$$

$$\sigma_{VAP} \xrightarrow{P} \sigma_{VAP}$$

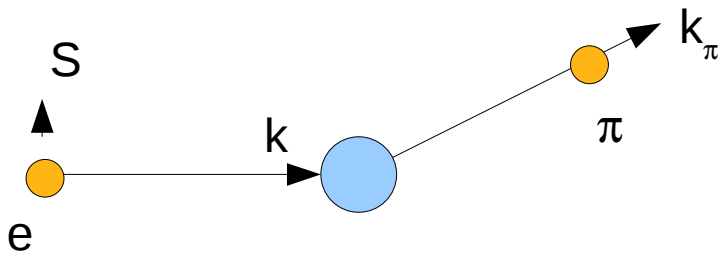
$$\sigma_{VAP} \xrightarrow{T} -\sigma_{VAP}$$

- In Born Approx (1 photon exch), <u>for elastic scattering</u>, T-invariance must be obeyed
- Therefore, 2 photon exch must be included to generate a non-zero VAP.

Transverse Elastic Scattering Continued

- Generally, transverse asymmetries are suppressed by $1/\gamma$ (e.g. Wells et al, SAMPLE)
- Based on this, $A_n^{elastic} \sim \alpha/\gamma$ (Phillips, King, et al, G0) ~ ppm at 3 GeV, ~ 10 ppm at 362 MeV.

Transverse Inclusive Pion Production: General Considerations



(imagine that k' is not in plane)

$$\sigma_{\pi,VAP} \sim \vec{S} \cdot (\vec{k} \times \vec{k}_\pi)$$

$$\sigma_{\pi,VAP} \xrightarrow{P} \sigma_{\pi,VAP}$$

$$\sigma_{\pi,VAP} \xrightarrow{T} -\sigma_{\pi,VAP}$$

- For inelastic scattering, you don't have to obey time-reversal.
- Donnelly + Raskin electron kinematic and polarization factors:

$$V_T = \frac{1}{v_0}\left\{2\left(\frac{kk' \sin\theta_e}{q}\right)^2 - Q^2\right\}, \qquad (2.19c)$$

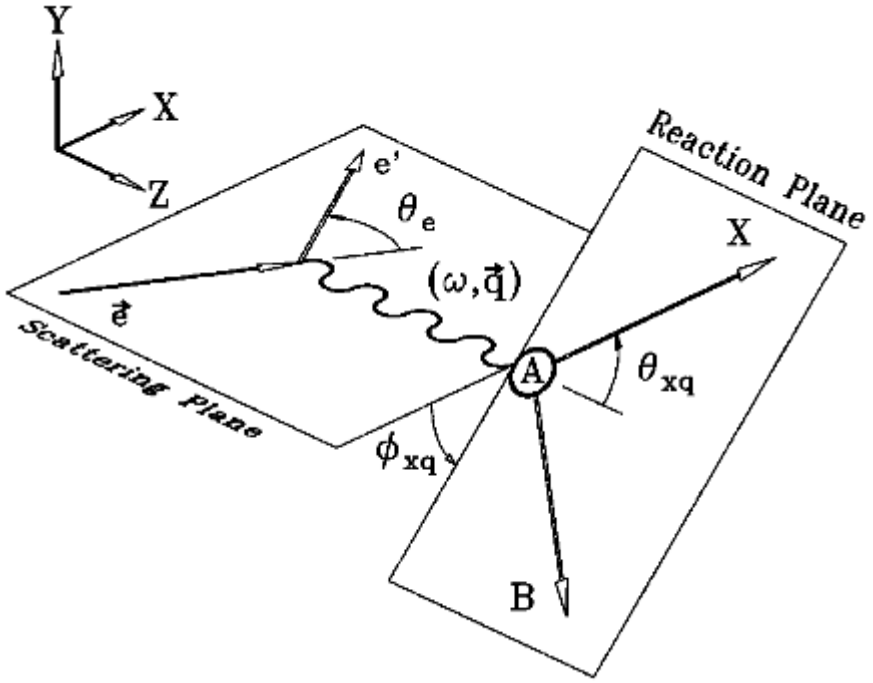
$$V_{TL'} = \frac{\sqrt{2}hm_e s}{v_0}\left(\frac{Q^2}{q^2}\right)[k' \sin\theta_e \cos\zeta + (k - k'\cos\theta_e)\sin\zeta\cos\eta], \qquad (2.19g)$$

$$longitudinal \rightarrow \zeta = 0 \rightarrow s = \gamma$$
$$transverse \rightarrow \zeta = \pi/2 \rightarrow s = 1$$

Transverse Inclusive Pions

- These kinematical factors are multiplied by nuclear response functions, dependent on the process.
- Assuming the response functions are of same order, indeed in the limit $Q^2 \to m_e^2$ and $momenta \to E_e$ (photoproduction limit) gives $V_{TL'}/V_T \to m_e/E_e = 1/\gamma$
- So, naively, $A_n^{\pi} \sim 1/\gamma$ = 1400 ppm, or 700 ppm treating Brems photons as a dilution.
- Afanasev: 100 ppm. Wrong beam energy?
- What about the response functions?

“The Fifth Response Function”: Longitudinal Spin Out-of-Plane Asymmetry in Exclusive Pion Production



$$\frac{d^5\sigma}{d\omega\, d\Omega_e\, d\Omega_x} = K\sigma_{\text{Mott}}\{v_L f_L + v_T f_T + v_{TT} f_{TT}\cos 2\phi_{xq} + v_{LT} f_{LT}\cos\phi_{xq} + hP_B v'_{LT} f'_{LT}\sin\phi_{xq}\},$$

See e.g.
* Dolfini et al (OOPS), 1999.
* Donnelly + Raskin
* Raskin + Donnelly
* Drechsel + Tiator
* ...

- Indeed, for longitudinally polarized beam and unpolarized target, there is a helicity-dependent, phi-dependent term.
- Phi is the OOP angle.
- It is in the LT' term, as suggested by Afanasev.

G0 Transverse Pion and the Fifth Response Function

- Donnelly + Raskin:

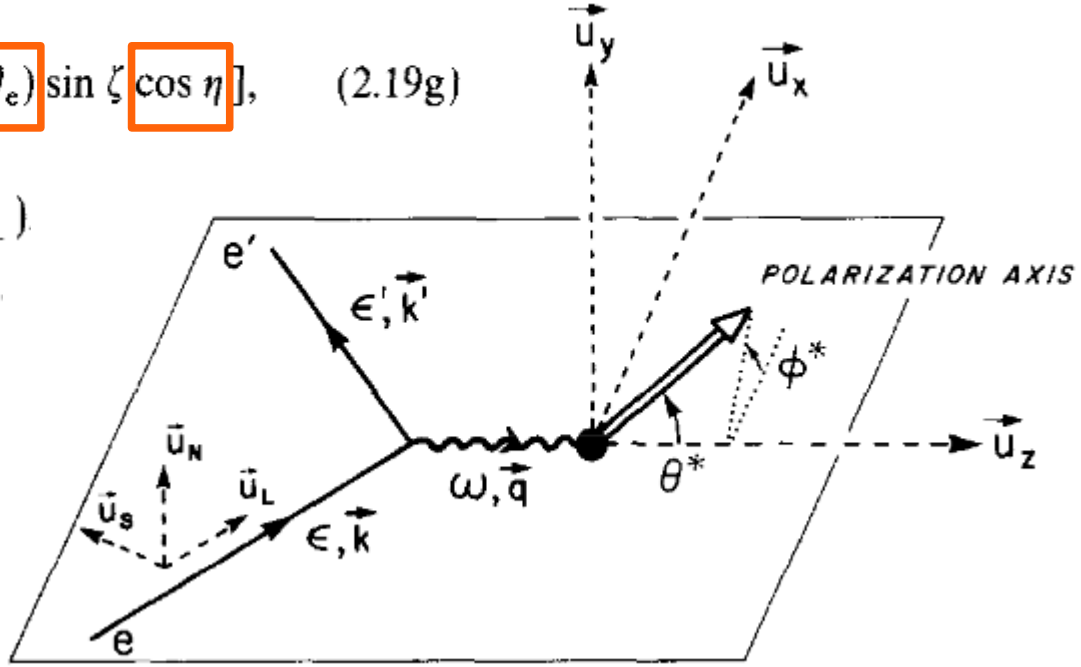
$$V_{TL'} = \frac{\sqrt{2}hm_e s}{v_0}\left(\frac{Q^2}{q^2}\right)[k' \sin\theta_e \cos\zeta + (k - k'\cos\theta_e)\sin\zeta \cos\eta], \qquad (2.19g)$$

where $\mathbf{s} = hs(\cos\zeta \mathbf{u}_{\parallel} + \sin\zeta \mathbf{u}_{\perp})$

and $\mathbf{u}_{\perp} = \cos\eta \mathbf{u}_S + \sin\eta \mathbf{u}_N$

$longitudinal - spin \rightarrow \zeta = 0$

$transverse - spin \rightarrow \zeta = \pi/2$



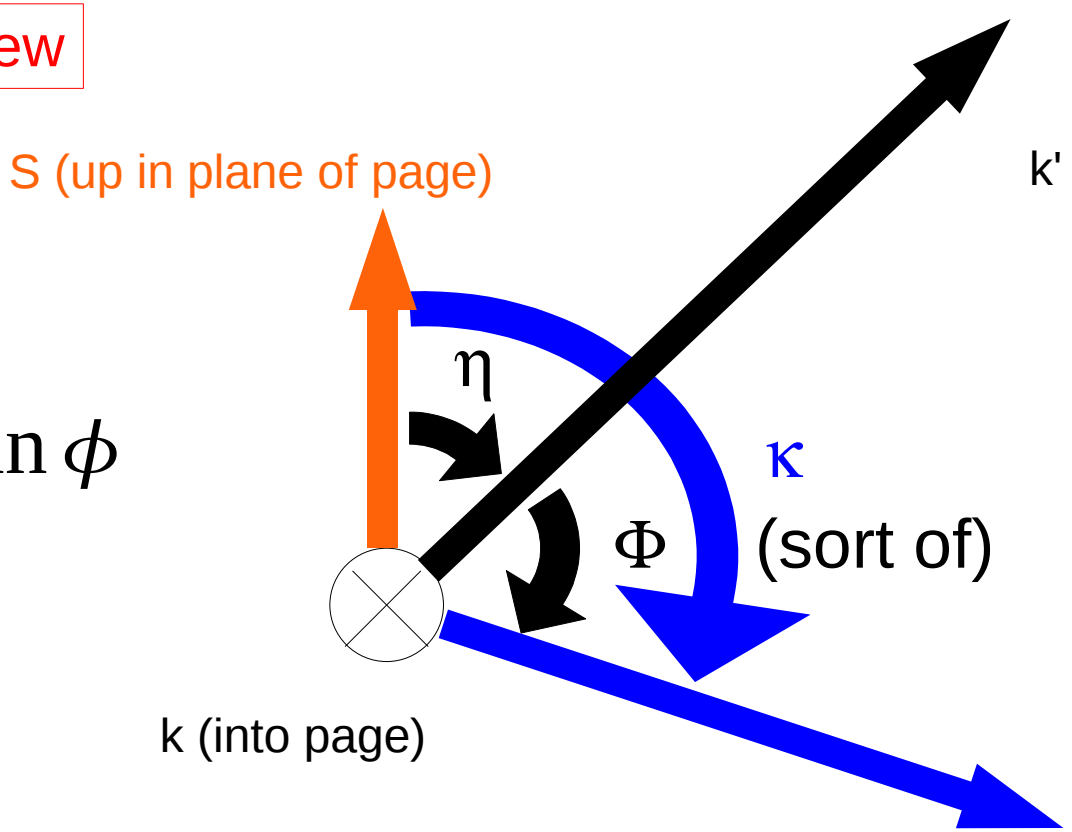
- Dolfini et al (based on Donnelly + Raskin):

$$\frac{d^5\sigma}{d\omega\, d\Omega_e\, d\Omega_x} = K\sigma_{\text{Mott}}\{v_L f_L + v_T f_T + v_{TT} f_{TT}\cos 2\phi_{xq} + v_{LT} f_{LT}\cos\phi_{xq} + hP_B v'_{LT} f'_{LT}\sin\phi_{xq}\},$$

Doug and I think this is basically the same $v_{LT'}$

Can this give what we call a "transverse asymmetry", that wouldn't violate something?

Beam's-Eye View



$$\sigma \sim h \cos\eta \sin\phi$$

Suppose $\eta + \phi = \kappa = constant$ and we integrate over η.

$$\sigma \sim \int h \cos\eta \sin\phi \, d\eta = h \int \cos\eta \sin(\eta + \kappa) \, d\eta \sim h \sin\kappa$$

which kind of makes sense

Conclusions

- We see a large azimuthal asymmetry in inclusive pion production for transverse polarization.
- It seems that Afanasev is correct in that this can be generated by the LT' term in exclusive pion production.
- Need a more detailed check with some theorists. Afanasev? Blunden?
- If the correct theoretical expression can be derived, then we can do the integral over the electron kinematics relevant to G0 (or communicate this to the theorists).