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Semi-Inclusive Deep-Inelastic Scattering and Kaons from CLAS6

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Workshop on
Probing Strangeness in Hard Processes
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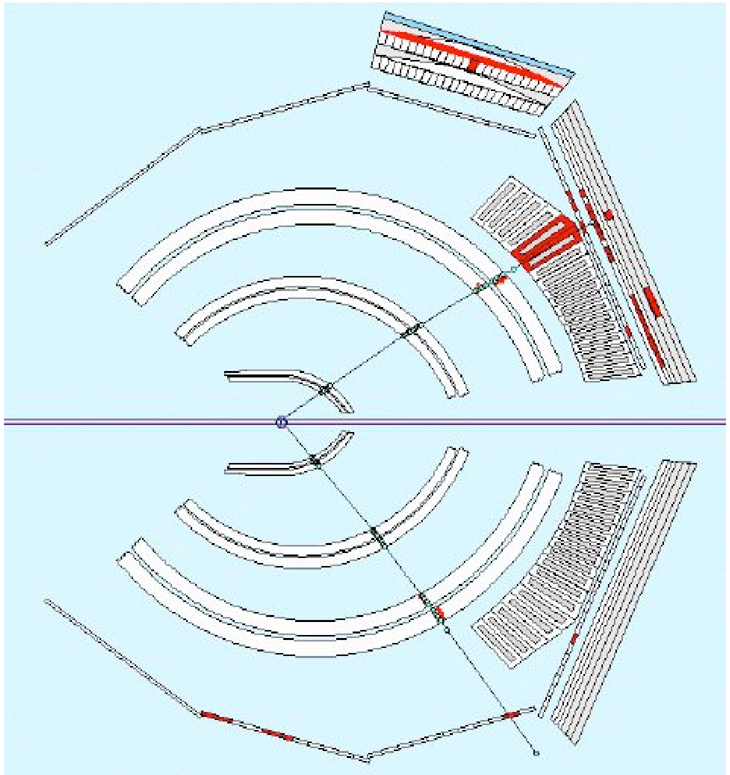
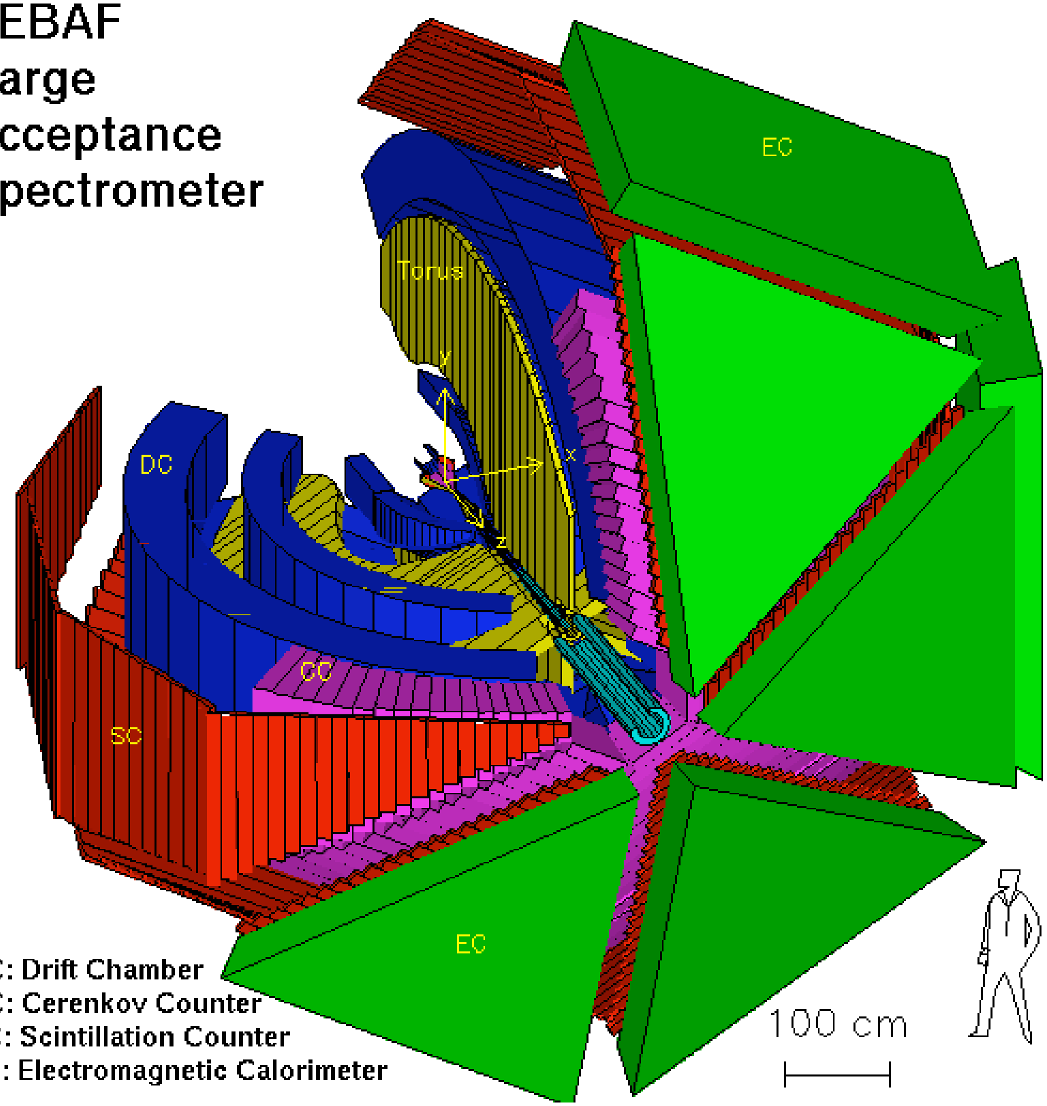
eg1-dvcs with CLAS



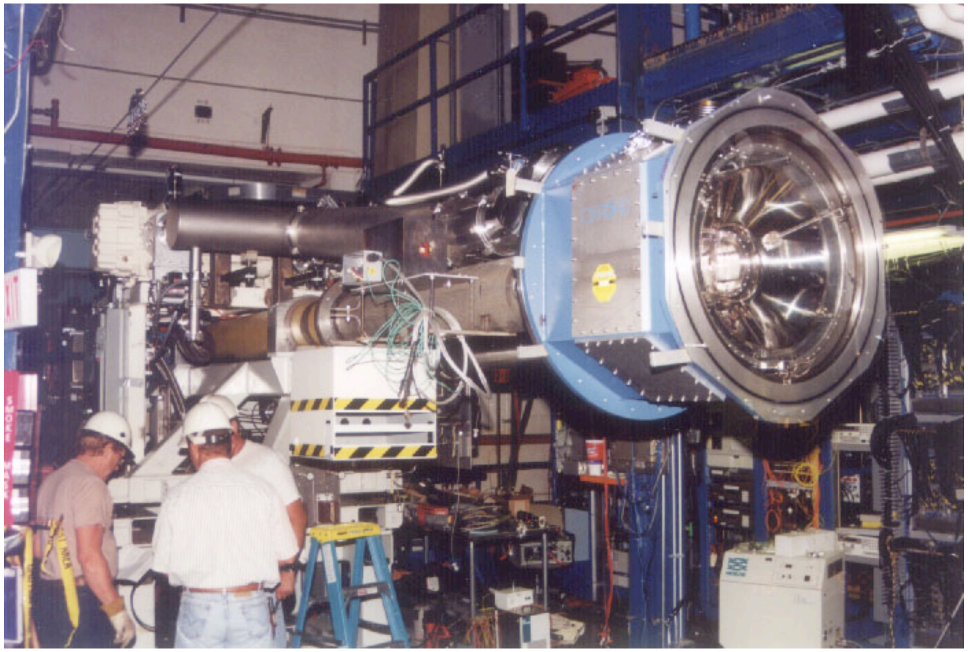


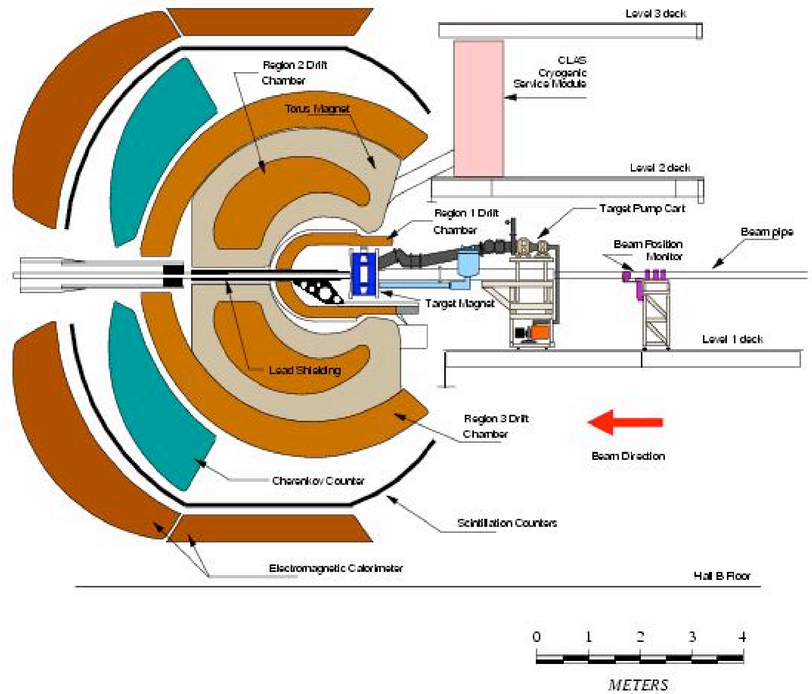
eg1-dvcs ran for 120 days in 2009 on NH_3, ND_3 and C targets

We have an order of magnitude more DIS data than in eg1

The Inner Calorimeter greatly increased π^0 detection

Longitudinally Polarized Target





- Dynamic nuclear polarization of NH_3 and ND_3
- Polarizations of 70-80% for p and 25-40% for d
- Luminosity 10^{35} $cm^{-2}s^{-1}$

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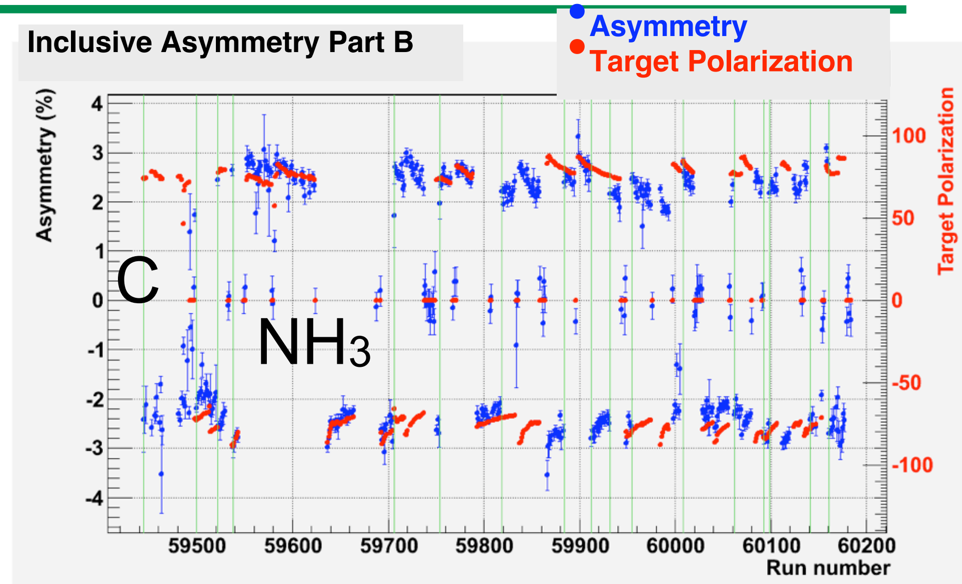
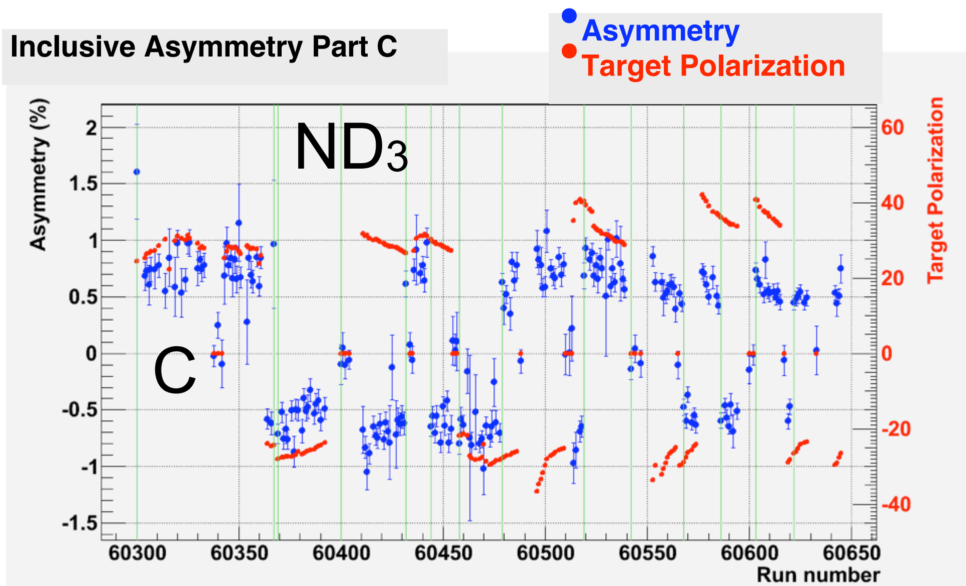
Double Spin Asymmetries

Proton polarization (red) between 70 and 90%

Inclusive asymmetries, integrated over all kinematic variables (blue), are proportional to $P_b P_t$

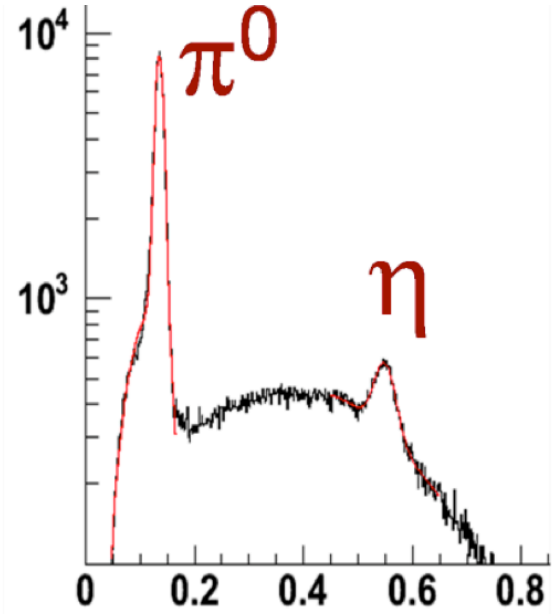




Deuteron polarization (red) between 25 and 40%

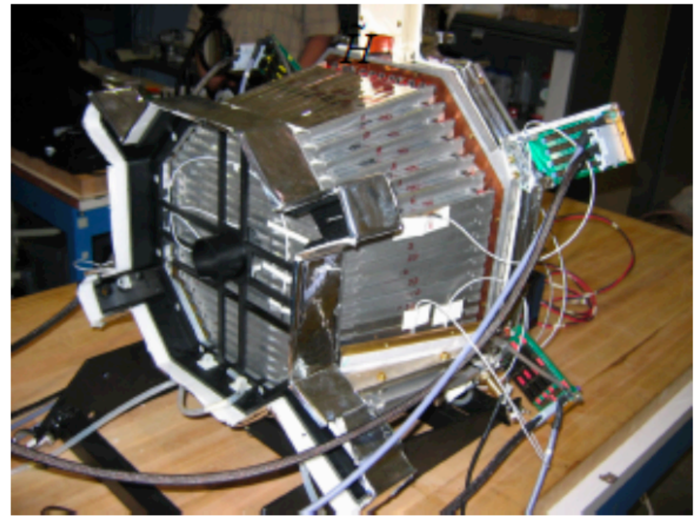
Inclusive asymmetries, integrated over all kinematic variables (blue), are proportional to $P_b P_t$

Inner Calorimeter



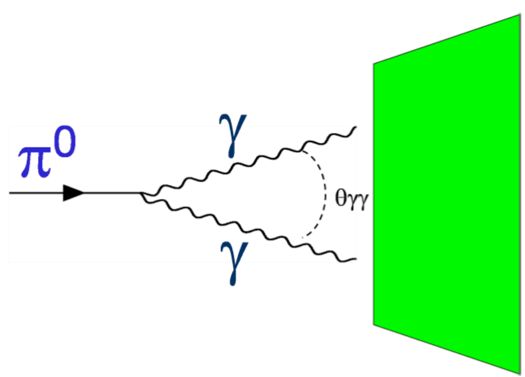
$$M_{\gamma\gamma} = \sqrt{2E_{\gamma_1}E_{\gamma_2}\left(1-\cos\theta_{\gamma\gamma}\right)}$$

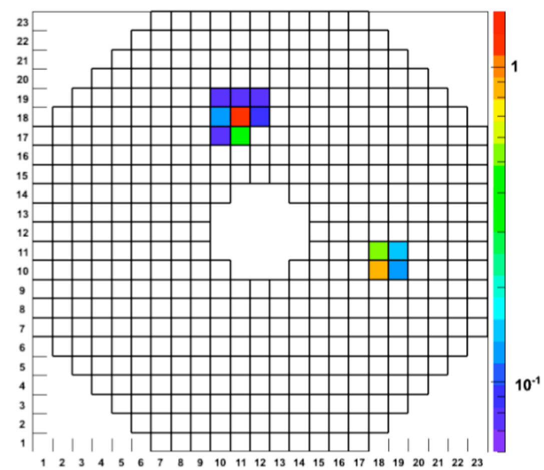
Inner Calorimeter (**IC**)



The IC measures angles below 18-22° depending on the distance from the target

Most of eg1-dvcs had IC coverage below 18°





Experimental Details

Run Period	Beam Energy	files (2min 0.4M trig.)	Nominal IC location
Part A NH_3/C	5.887 4.730	15490	-57.5 cm
Part B NH_3/C	5.954	33506	-67.5 cm
Part C ND_3/C	5.752	14659	-67.5 cm

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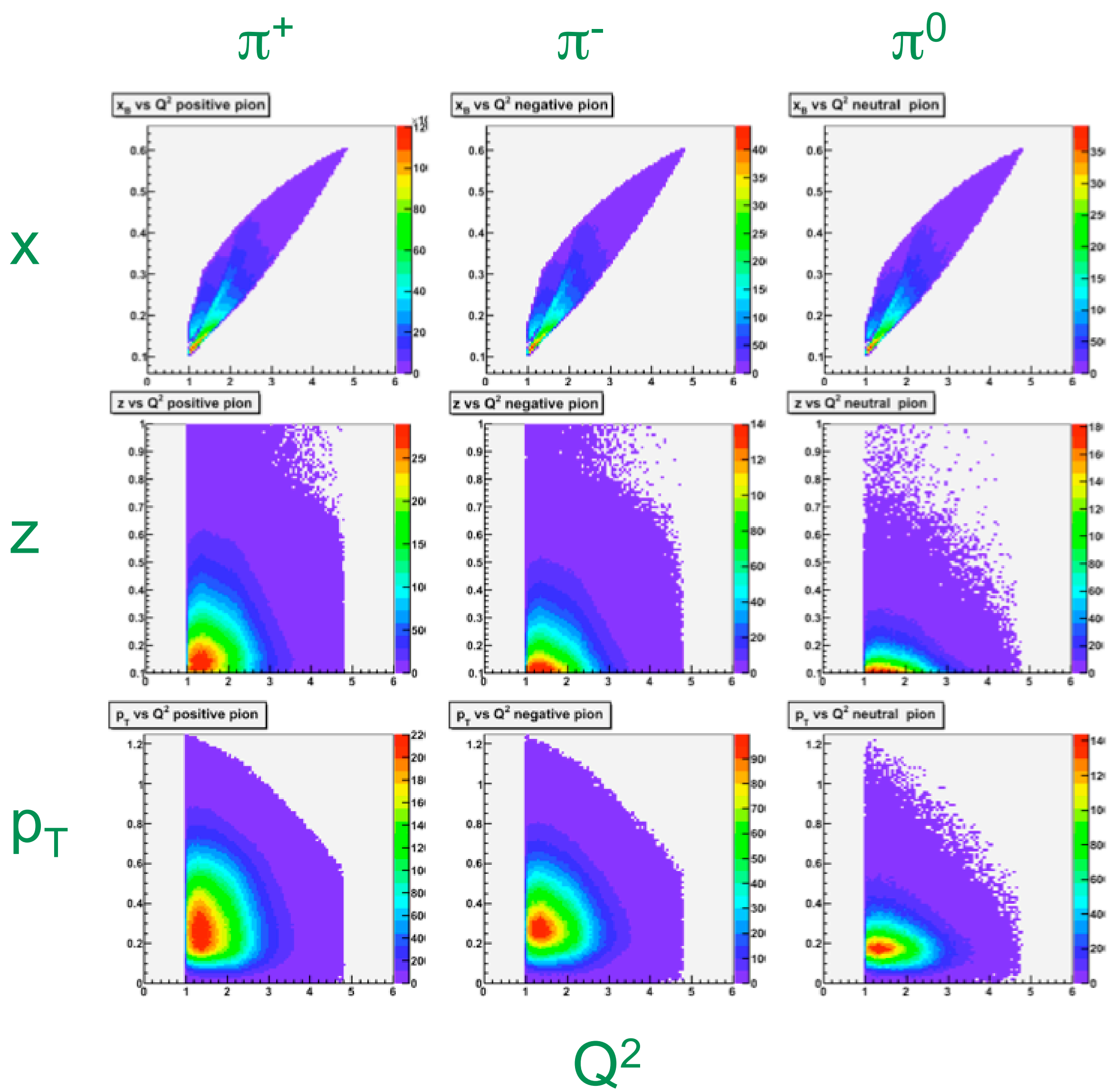
SIDIS Kinematic Coverage in eg1-dvcs



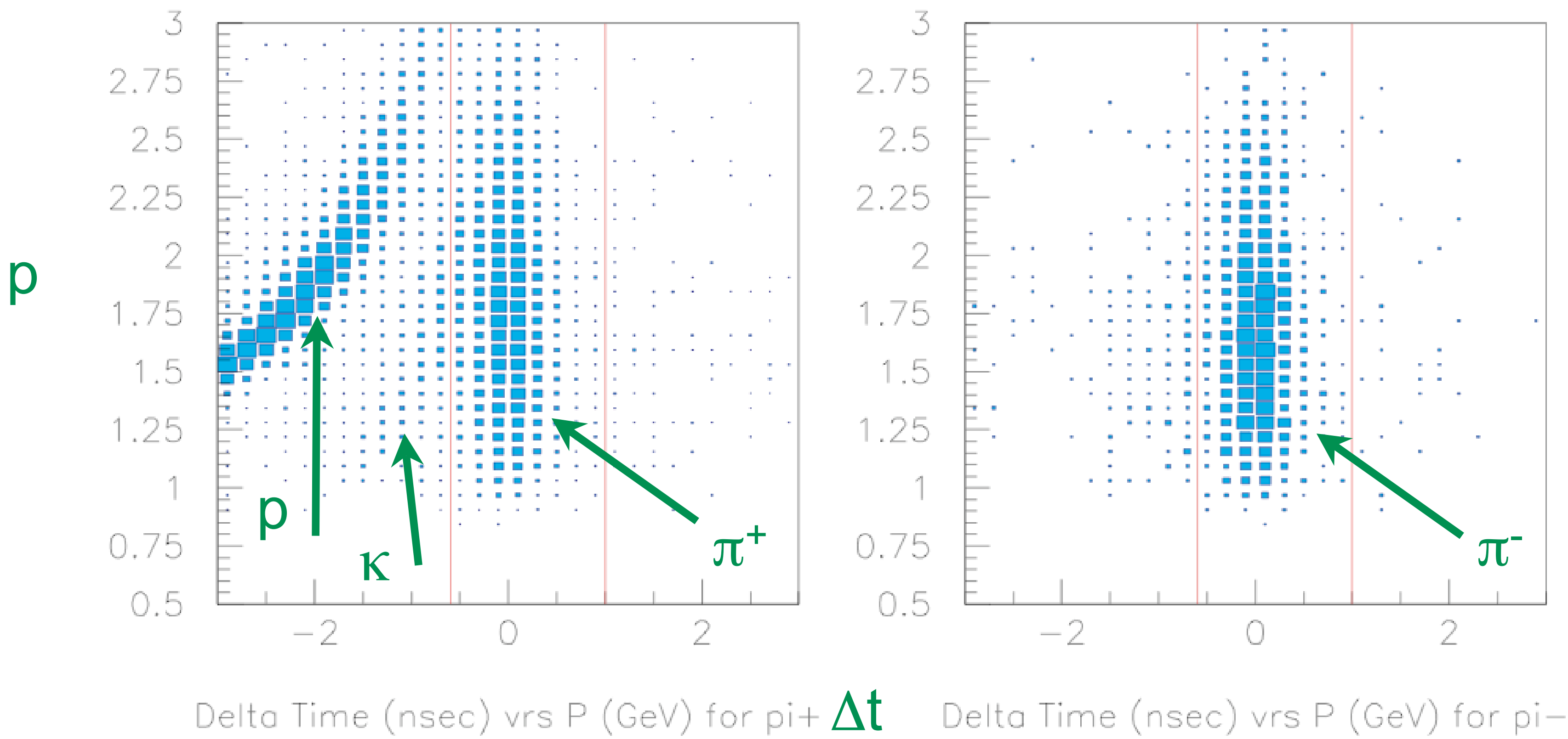
Because the IC cuts off electrons below 18^{O} and the target above 45^{O}, we measure DIS in a small stripe in the x-Q^2 plane

There is nearly full coverage in z and p_T

Kaon kinematics are similar

The p_T distributions for π^+ and π^- are different from π^0 because most π^0 s come from the IC (small angles) whereas the charged pions are obscured by the IC.

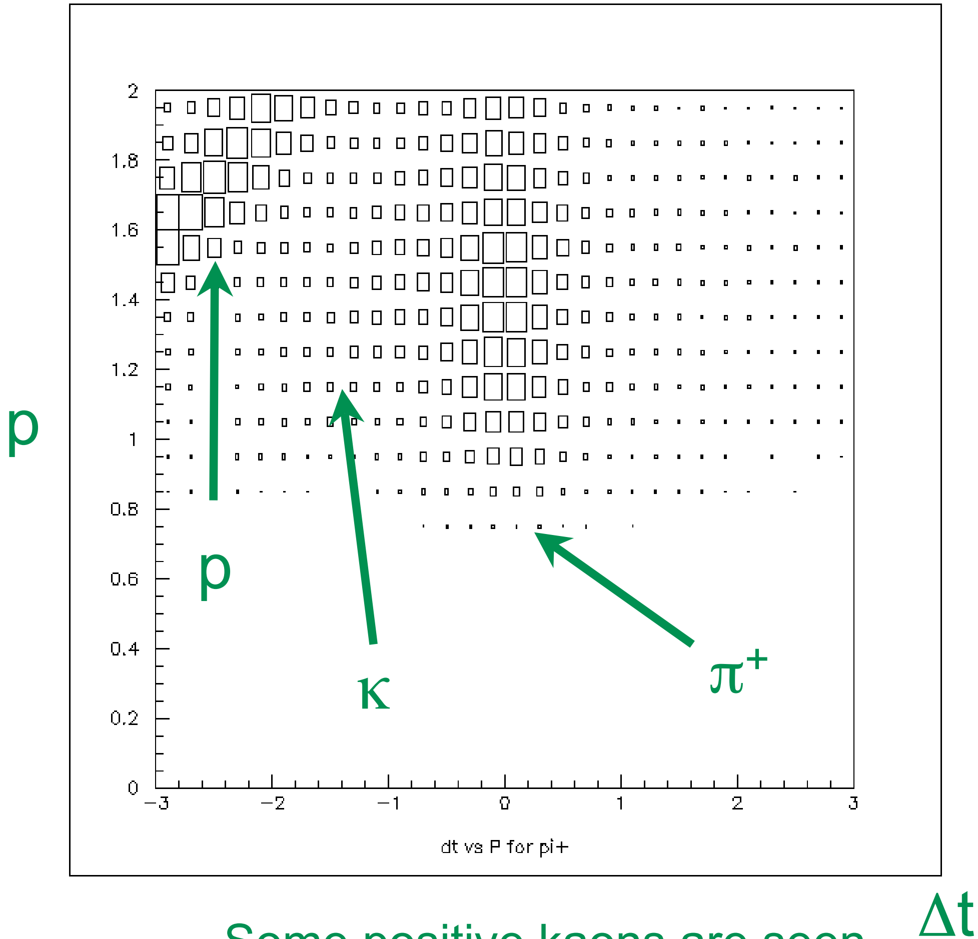
Kaon Identification in eg1b

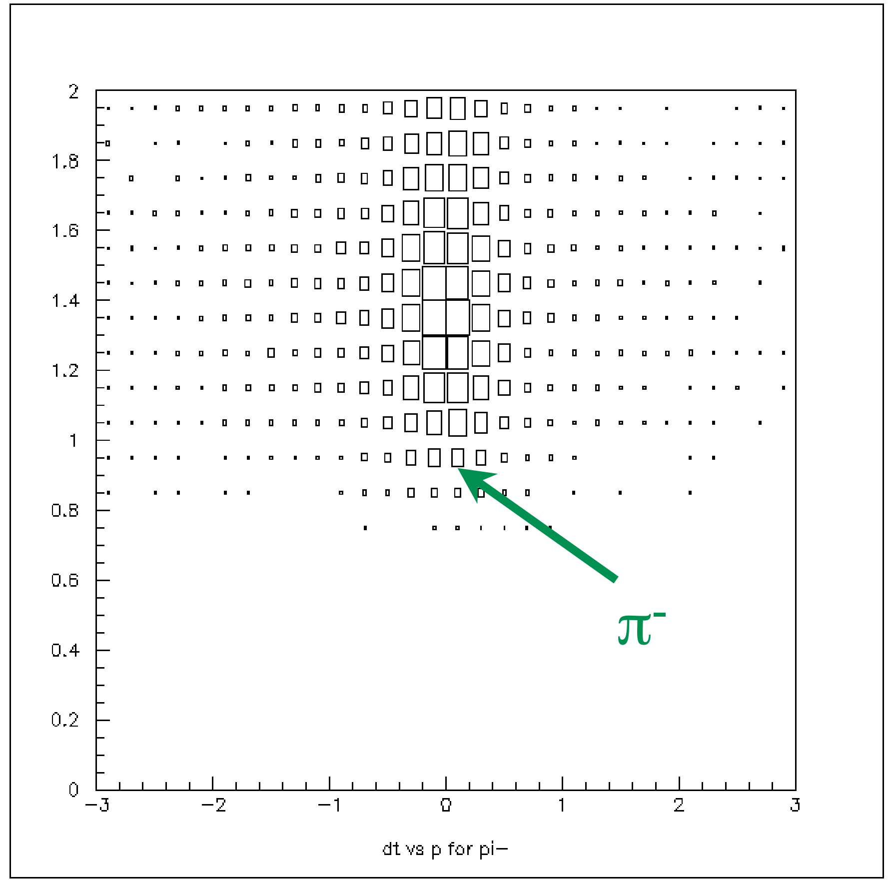


Positive kaons are clearly seen between the straight pion band and the curved proton band

Negative kaons populate the region to the left of the straight negative pion band

Kaon Identification in eg1-dvcs



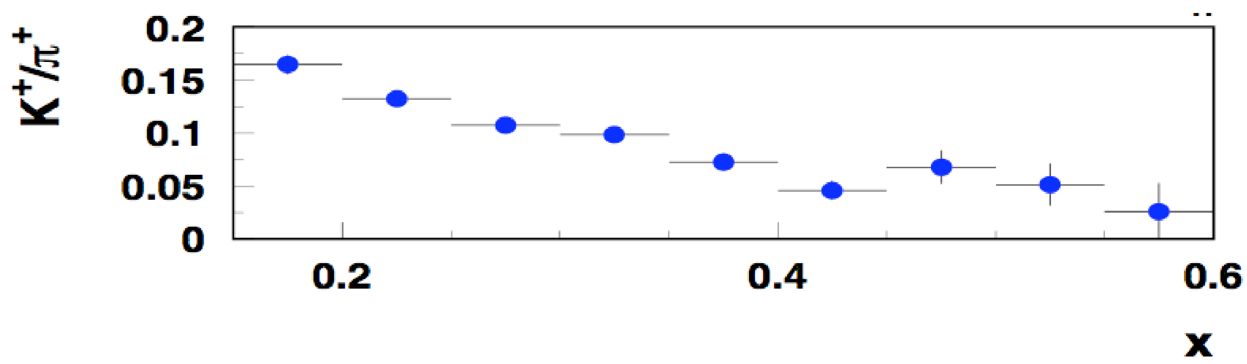


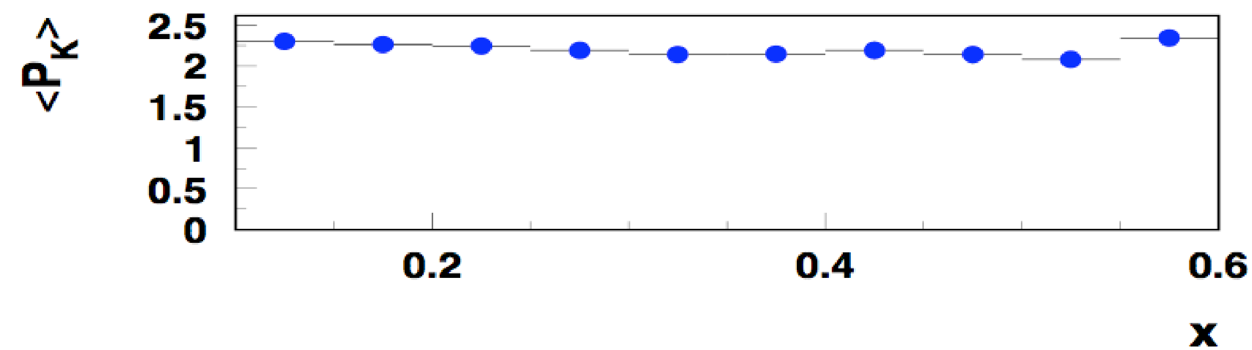
Some positive kaons are seen between the vertical band of pions and the corner band for protons. However, TOF does not provide a clean kaon sample

There may be some negative kaons present to the left of the vertical band of pions, but the background is very high

Lund MC Predictions for κ^+

- Lund Monte Carlo for eg1b which is at a similar beam energy
- Negative kaons are at least a factor of three worse compared to negative pions
- Since the IC obscures small angles in eg1-dvcs, one can expect this ratio to be worse at low x in eg1-dvcs





A reasonable ratio estimate of 5% means, all apart from systematics, that the statistical error bars will be 4-5 times bigger for positive kaons than for positive pions. If systematics are under control, this could still produce a significant result.

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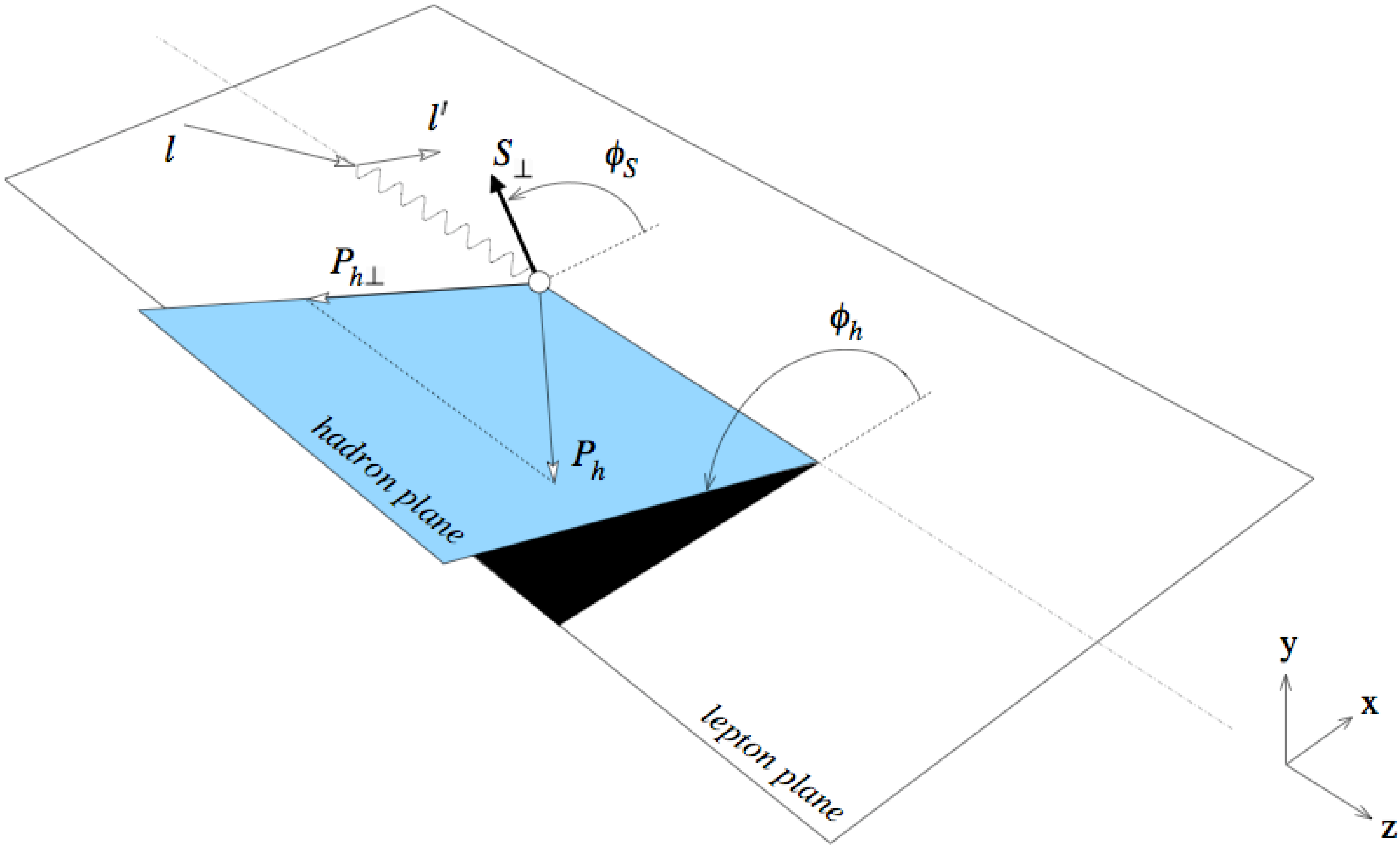
Polarized SIDIS Kinematics



Differential Cross Section

Bacchetta, et al., JHEP 2(2007)093

$$\frac{d\sigma}{dx\,dy\,d\psi\,dz\,d\phi_h\,dP_{h\perp}^2} =$$

$$\frac{\alpha^2}{xyQ^2}\frac{y^2}{2(1-\varepsilon)}\left(1+\frac{\gamma^2}{2x}\right)\Bigg\{F_{UU,T}+\varepsilon F_{UU,L}+\sqrt{2\varepsilon(1+\varepsilon)}\cos\phi_h\,F_{UU}^{\cos\phi_h}$$

$$+\varepsilon\cos(2\phi_h)\,F_{UU}^{\cos 2\phi_h}+\lambda_e\sqrt{2\varepsilon(1-\varepsilon)}\sin\phi_h\,F_{LU}^{\sin\phi_h}$$

$$+S_{\|}\left[\sqrt{2\varepsilon(1+\varepsilon)}\sin\phi_h\,\boxed{F_{UL}^{\sin\phi_h}}+\varepsilon\sin(2\phi_h)\,\boxed{F_{UL}^{\sin 2\phi_h}}\right]$$

$$+S_{\|}\lambda_e\left[\sqrt{1-\varepsilon^2}\,\boxed{F_{LL}}+\sqrt{2\varepsilon(1-\varepsilon)}\cos\phi_h\,F_{LL}^{\cos\phi_h}\right]\Bigg\}$$

Only includes terms important for longitudinal asymmetries A_{UL}, A_{LU} and A_{LL} since A is a polarized difference over an unpolarized sum

TMDs and Fragmentation

The observables are the structure functions such as $F^{\sin\phi}_{UL}$, not the TMD distribution or fragmentation functions. Therefore p_T and k_T are only indirectly determined through the following convolutions. Four-fold differential data in x, z, Q^2 and P_T are essential to test the factorization built in below. eg1-dvcs can do this.

$$\mathcal{C}\big[w\,f\,D\big] = x \sum_a e_a^2 \int d^2\boldsymbol{p}_T\, d^2\boldsymbol{k}_T\, \delta^{(2)}\big(\boldsymbol{p}_T - \boldsymbol{k}_T - \boldsymbol{P}_{h\perp}/z\big)\, w(\boldsymbol{p}_T, \boldsymbol{k}_T)\, f^a(x, p_T^2)\, D^a(z, k_T^2),$$

$$F_{UL}^{\sin\phi_h} = \frac{2M}{Q}\,\mathcal{C}\left[-\frac{\hat{\boldsymbol{h}}\cdot\boldsymbol{k}_T}{M_h}\left(x h_L H_1^{\perp} + \frac{M_h}{M}\, g_{1L}\frac{\tilde{G}^{\perp}}{z}\right) + \frac{\hat{\boldsymbol{h}}\cdot\boldsymbol{p}_T}{M}\left(x f_L^{\perp} D_1 - \frac{M_h}{M}\, h_{1L}^{\perp}\frac{\tilde{H}}{z}\right)\right]$$

$$F_{UL}^{\sin 2\phi_h} = \mathcal{C}\left[-\frac{2\,(\hat{\boldsymbol{h}}\cdot\boldsymbol{k}_T)\,(\hat{\boldsymbol{h}}\cdot\boldsymbol{p}_T) - \boldsymbol{k}_T\cdot\boldsymbol{p}_T}{M M_h}\, h_{1L}^{\perp} H_1^{\perp}\right],$$

$$F_{LL} = \mathcal{C}\big[g_{1L} D_1\big]$$

$$F_{LL}^{\cos\phi_h} = \frac{2M}{Q}\,\mathcal{C}\left[\frac{\hat{\boldsymbol{h}}\cdot\boldsymbol{k}_T}{M_h}\left(x e_L H_1^{\perp} - \frac{M_h}{M}\, g_{1L}\frac{\tilde{D}^{\perp}}{z}\right) - \frac{\hat{\boldsymbol{h}}\cdot\boldsymbol{p}_T}{M}\left(x g_L^{\perp} D_1 + \frac{M_h}{M}\, h_{1L}^{\perp}\frac{\tilde{E}}{z}\right)\right]$$

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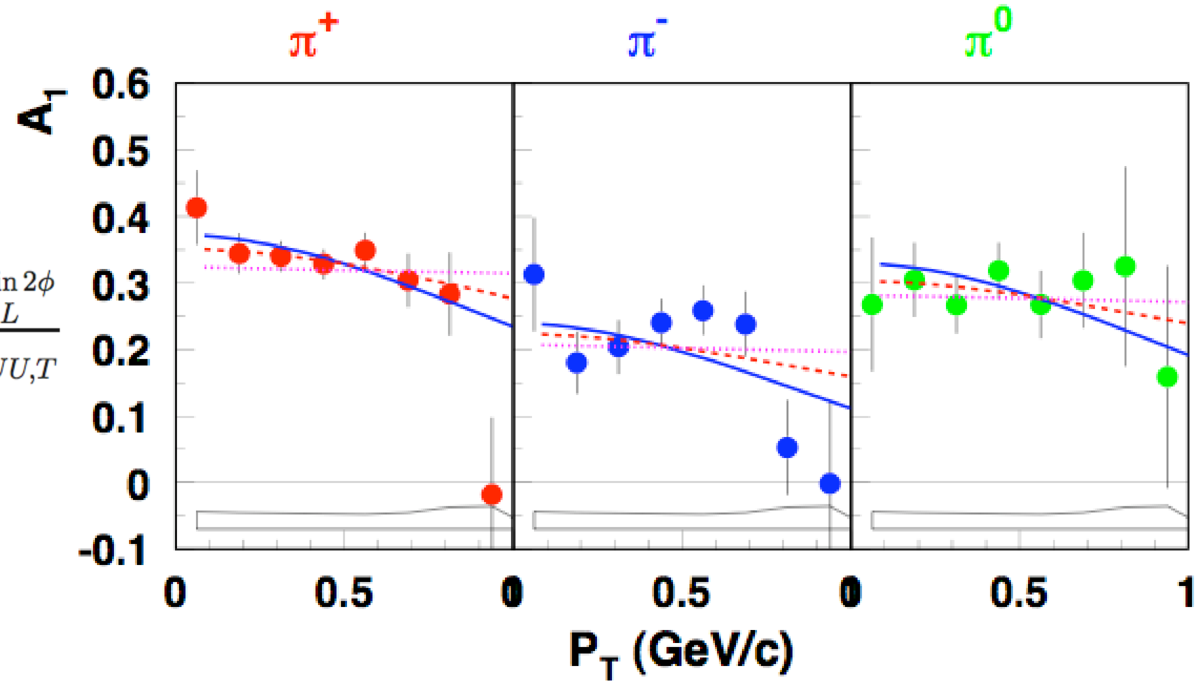
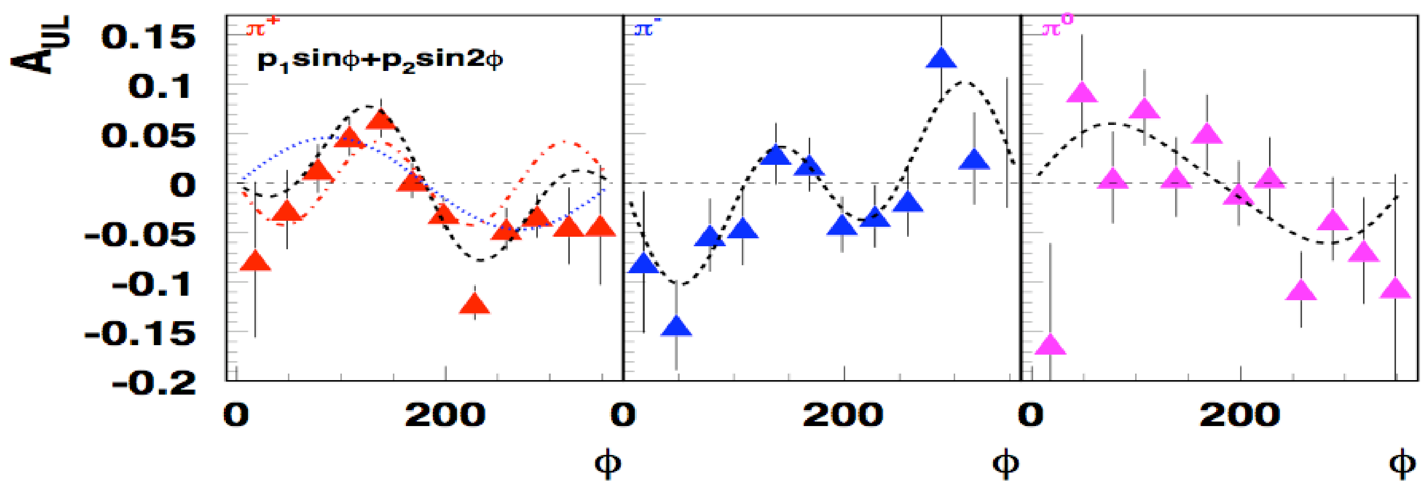
Asymmetries from eg1b

$$A_1 \equiv \frac{F_{LL}}{F_{UU,T}}$$

$$A_{UL}^{\sin 2\phi}(x) = \frac{\int dy\, [\cos\theta_\gamma (1-y)/Q^4] F_{UL}^{\sin 2\phi}}{\int dy\, [(1-y+\frac{1}{2}y^2)/Q^4] F_{UU,T}}$$



Existing data from the eg1b experiment which ran in the year 2000. Here the kaon sample was too small to effectively analyze. eg1-dvcs has an order of magnitude more data



$A_1 \approx g_1/F_1$ for eg1-dvcs

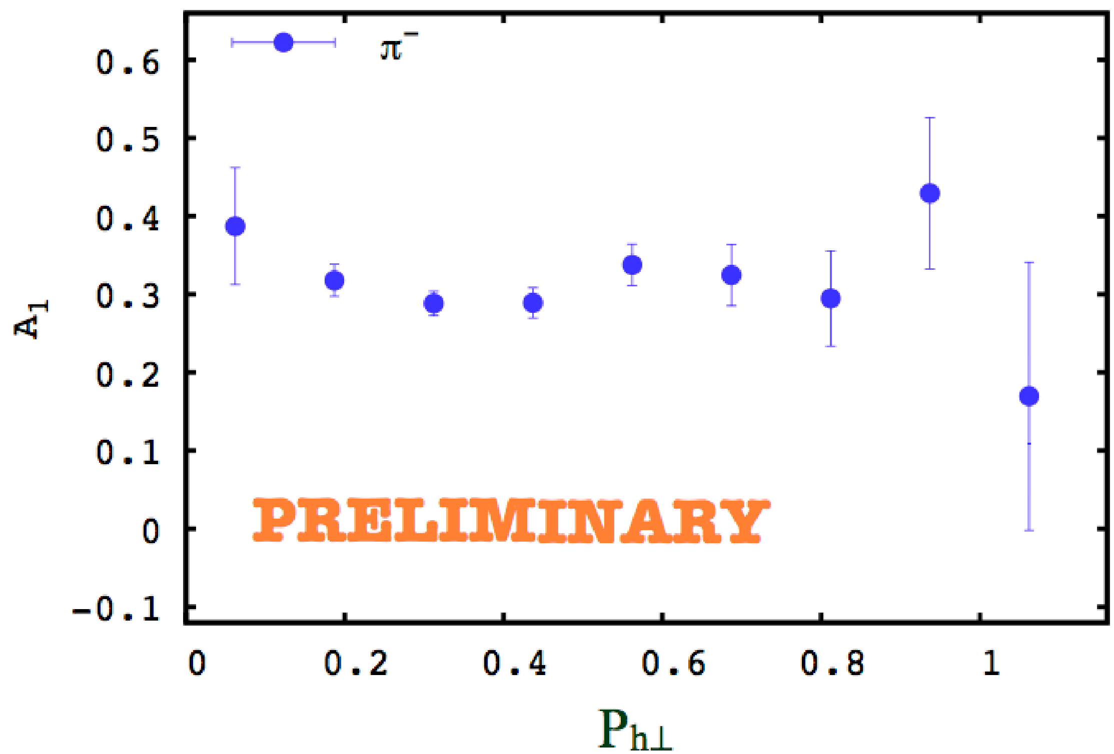
$$f_1^q(x,k_T) = f_1(x)\frac{1}{\pi\mu_0^2}\exp\left(-\frac{k_T^2}{\mu_0^2}\right)$$

$$g_1^q(x,k_T) = g_1(x)\frac{1}{\pi\mu_2^2}\exp\left(-\frac{k_T^2}{\mu_2^2}\right)$$

$$D_1^q(z,p_T) = D_1(z)\frac{1}{\pi\mu_D^2}\exp\left(-\frac{p_T^2}{\mu_D^2}\right),$$

$$\frac{g_1}{F_1} \propto \frac{\sum_q e_q^2 g_1^q(x) D_1^{q\to\pi}(z)}{\sum_q e_q^2 f_1^q(x) D_1^{q\to\pi}(z)} e^{-z^2 P_T^2 \frac{(\mu_0^2-\mu_2^2)}{(\mu_D^2+z^2\mu_0^2)(\mu_D^2+z^2\mu_2^2)}}$$

- eg1-dvcs data (25%) of total
- P_T dependence $\rightarrow \mu_0 \neq \mu_2$
- Also for π^+ and π^0
- Would like this for kaons, but these are hard to find in eg1-dvcs



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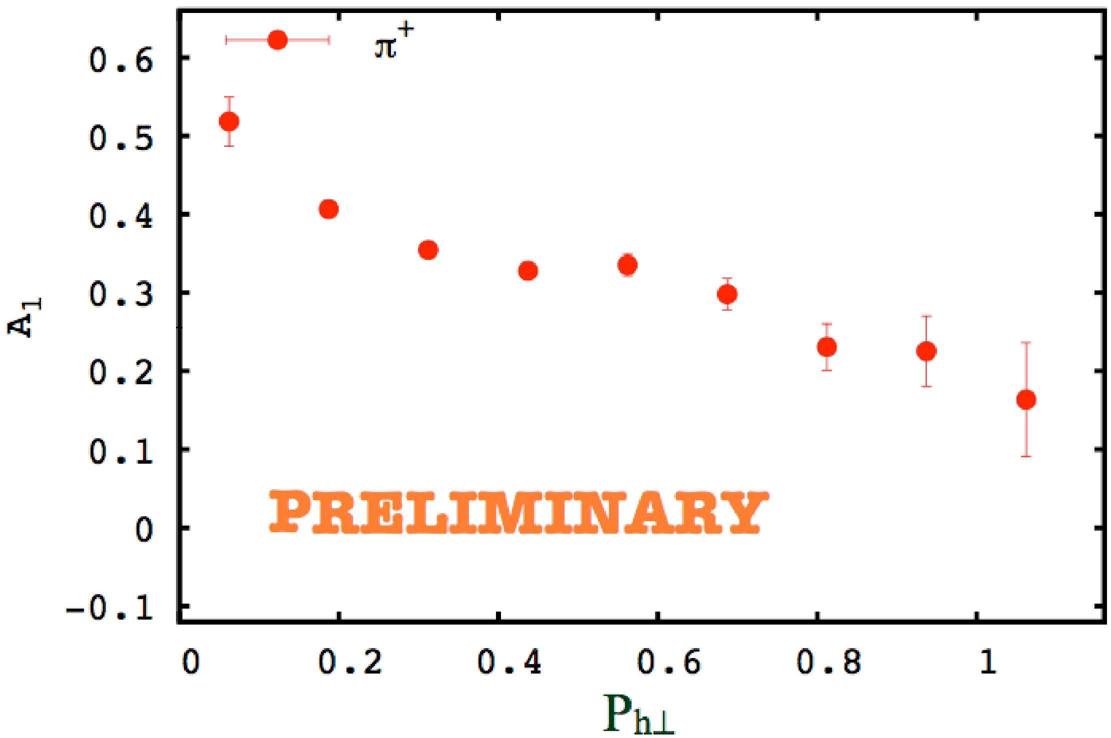


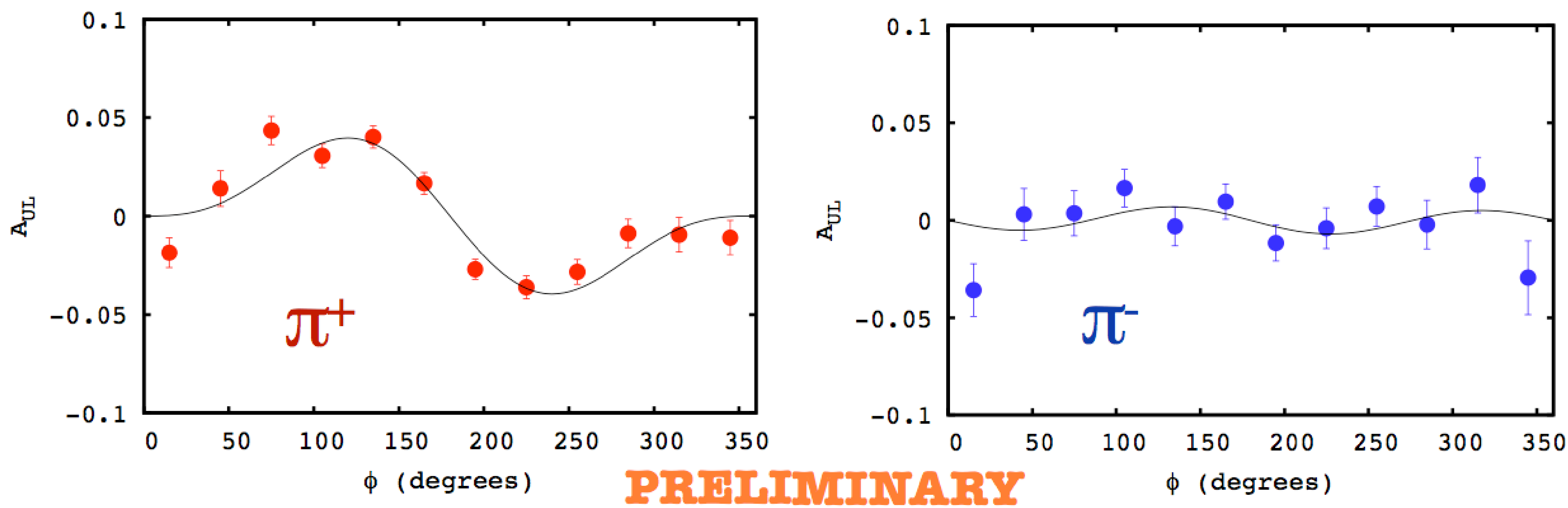
A_{UL} for eg1-dvcs

The target spin asymmetries as a function of ϕ have both $\sin\phi$ and $\sin 2\phi$ components.

$A^{\sin\phi}_{UL}$ (higher twist) is significant for π^+

$A^{\sin 2\phi}_{UL}$ (leading twist) is small suggesting, like eg1b and HERMES, that the Collins favored and unfavored fragmentation functions are nearly equal and opposite.

The analysis is currently being refined



Conclusions

- A_{LL}:
  - Eg1-dvcs measures $A_{LL} \rightarrow g_1/F_1$ better than ever before, allowing us to look for differences in the transverse momentum distributions for polarized vs. unpolarized quarks.
  - We can measure for π^+, π^-, π^0, and possibly κ^+ to explore the flavor-dependence of these quantities.
  - Kaon data will be hard to come by using only CLAS6 (without a RICH detector). Careful background checks on what we call π or κ will need to be done in our analysis.
- A_{UL}:
  - $A^{\sin\phi}_{UL}$ is non-zero, indicating that higher-twist is important
  - $A^{\sin2\phi}_{UL}$ is small suggesting that the Collins favored and unfavored fragmentation functions are nearly equal and opposite.
- Outlook:
  - EG1-dvcs analysis will improve over the next year
  - This greatly inreases the eg1b statistics. CLAS12 will do much better.