Semi-Inclusive DIS Using BB+SBS: Two New Physics Ideas

Andrew Puckett
Los Alamos National Laboratory
SBS Collaboration Meeting
3/20/2010

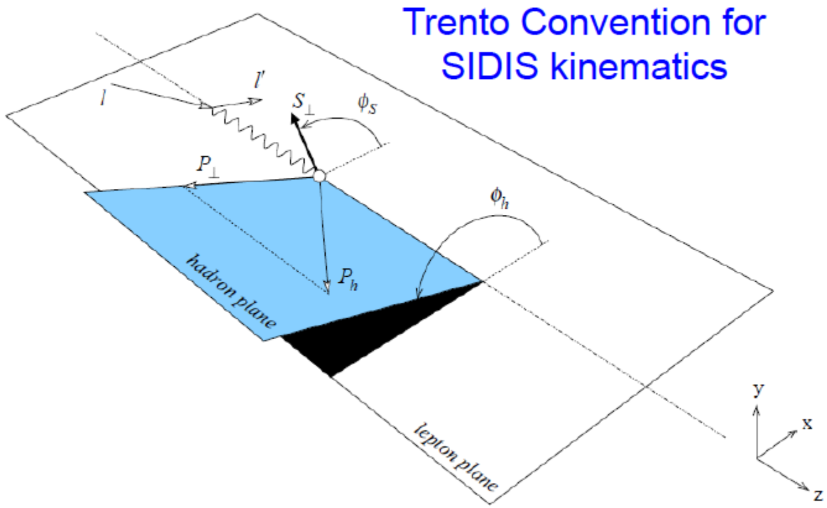
Outline

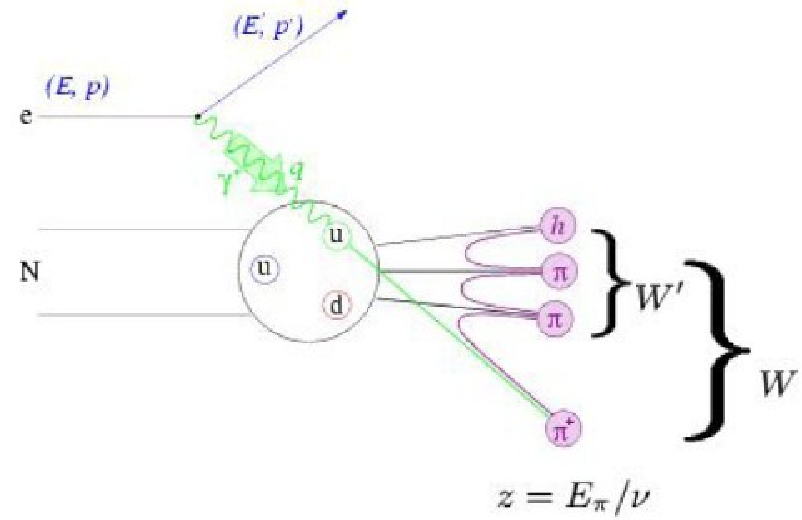
- **LANL (A. Puckett + X. Jiang) interest in SBS development**
- **Introduction: Semi-Inclusive DIS**
- **BigBite+Super BigBite in Hall A**
- **Two New Physics Ideas:**
  - **Spin-flavor decomposition using double-spin asymmetries with longitudinally polarized p, d, ^{3}He targets**
  - **Constraining Charge Symmetry Violating PDFs through SIDIS measurements on unpolarized ^{3}H, ^{3}He, and ^{1}H targets**
- **SIMC + BB + SBS = *fast* Monte Carlo simulation to develop the physics program/analysis tools for BB + SBS coincidence experiments**

LANL interest in SBS development

- Physics interests: mainly SIDIS
  - Pol. targets, nucleon spin-flavor decomposition
  - Transverse SSA, TMD PDFs
  - Study Charge Symmetry Violation through SIDIS
- General technical interests and possible contributions (within our DOE+LANL funding profile FY 2010-2011):
  - BigBite performance from existing data (E06-010/011: Transversity)
    - Optics, background rates, Monte Carlo simulation, acceptance studies
  - SBS development:
    - Optics, acceptance MC, design layout, study impacts to SIDIS physics case
    - SBS detector tests; Addition of MRPC-based TOF detectors in SBS?
  - Trigger:
    - Availability of single-arm *hadron* trigger in BB and SBS?

Introduction—Semi-Inclusive DIS





$$N(e, e'h)X$$

- "Flavor-tagging" the struck quark
- Assumptions:
  - Hard scattering
  - Independent fragmentation
- SIDIS holds enormous promise to enhance understanding of nucleon structure:
  - Flavor decomposition of polarized and unpolarized PDFs
  - Transverse spin and momentum structure

SIDIS Kinematics

$$Q^2 = -q^2 = -(k-k')^2$$

$$x = \frac{Q^2}{2\,q\cdot p} = \frac{Q^2}{2\mathrm{M}\,\nu}$$

$$W^2 = (p+q)^2 = M^2 + 2\mathrm{M}\,\nu - Q^2 = M^2 + Q^2\left(\frac{1-x}{x}\right)$$

$$z = \frac{E_h}{\nu}$$

$$\vec{p}_T = \vec{p}_h - \frac{\vec{p}_h\cdot\vec{q}}{\vec{q}^{\,2}}\vec{q}$$

$$\tan(\phi_h) = \frac{(\vec{p}_h)_y}{(\vec{p}_h)_x}$$

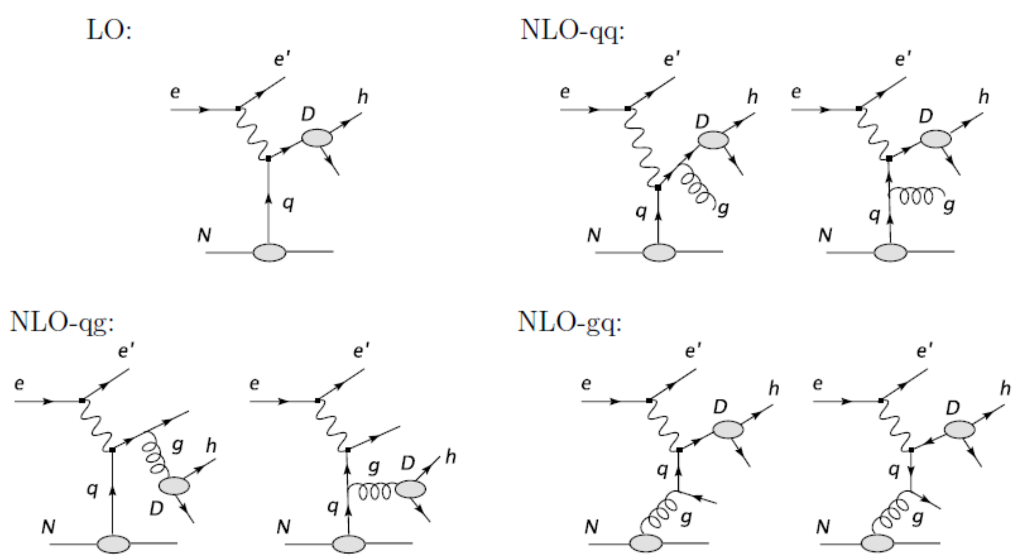
$$W'^2 = M_X^2 = (p+q-p_h)^2$$

- **Four-momentum transfer squared**
- **Fractional momentum of struck quark**
- **Invariant mass of hadronic final state**
- **Fraction of virtual photon energy carried by hadron**
- **Hadron transverse momentum w.r.t. q**
- **Hadron azimuthal angle w.r.t. scattering plane**
- **Invariant mass of final state excluding detected hadron; i.e., missing mass**

SIDIS, quark-parton model and QCD

$$\frac{\left(\frac{d^3\sigma^{N(e,e'h)X}}{dx\,dQ^2\,dz}\right)}{\left(\frac{d^2\sigma^{N(e,e')X}}{dx\,dQ^2}\right)} = 1/N_{DIS}\frac{dN^h_{SIDIS}}{dz} \stackrel{QPM}{=} \frac{\sum_q e_q^2 q(x,Q^2) D_q^h(z,Q^2)}{\sum_q e_q^2 q(x,Q^2)}$$

Hadron multiplicity



- **SIDIS cross section factorizes into simple products (LO) or convolutions (NLO) of universal PDFs and fragmentation functions**

Fragmentation Functions

Under assumptions of isospin symmetry, charge conjugation invariance, and neglecting strange quarks, there are only two independent light-quark F.F.s to charged pions; "favored" and "unfavored"

$$u, \bar{u} \overset{isospin}{\Leftrightarrow} d, \bar{d}$$

$$u, d, s \overset{C}{\Leftrightarrow} \bar{u}, \bar{d}, \bar{s}$$

$$\pi^{\pm} \overset{isospin, C}{\Leftrightarrow} \pi^{\mp}$$

$$D_u^{\pi^+} = D_d^{\pi^-} = D_{\bar{d}}^{\pi^+} = D_{\bar{u}}^{\pi^-} \equiv D^+$$

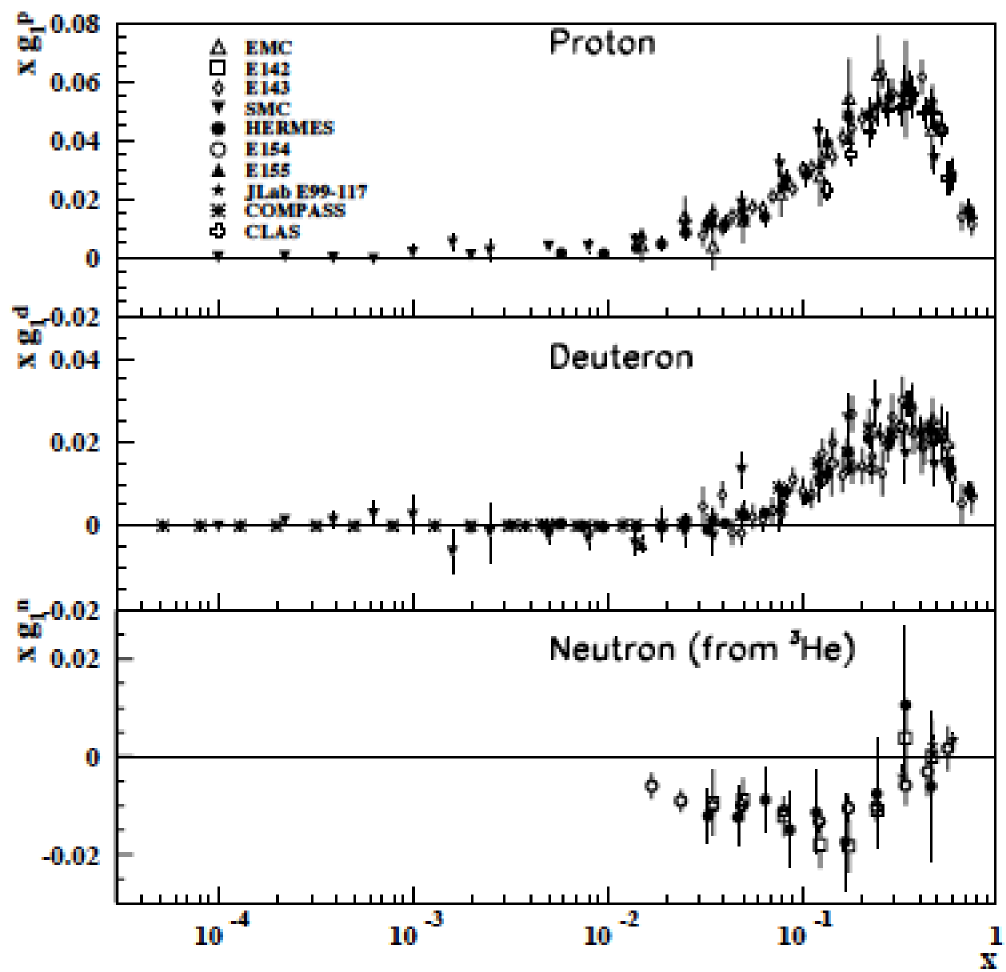
$$D_d^{\pi^+} = D_u^{\pi^-} = D_{\bar{u}}^{\pi^+} = D_{\bar{d}}^{\pi^-} \equiv D^-$$

$$D_s^{\pi^+} = D_s^{\pi^-} = D_{\bar{s}}^{\pi^+} = D_{\bar{s}}^{\pi^-} \equiv D^s$$

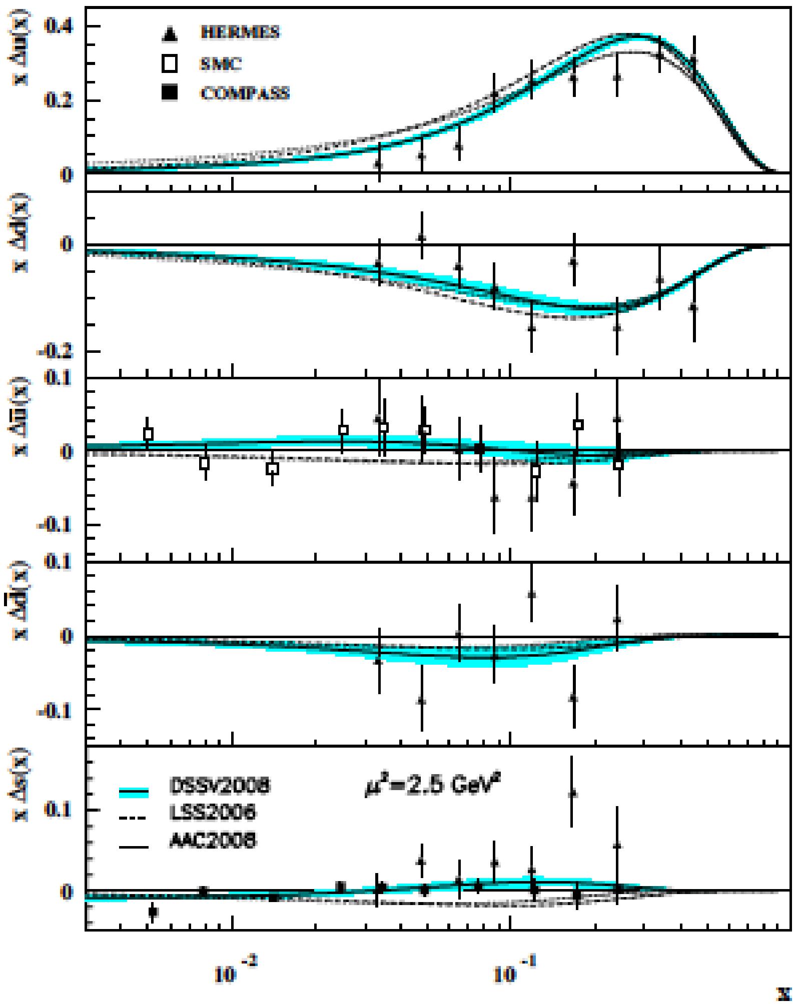
$$D_u^{\pi^0} = D_d^{\pi^0} = D_{\bar{u}}^{\pi^0} = D_{\bar{d}}^{\pi^0} \overset{?}{=} \frac{D^+ + D^-}{2}$$

Spin-flavor decomposition

- Spin structure functions $g_{1p,n}$ reasonably well determined after multi-decade effort
- Inclusive DIS experiments generally do not provide enough independent observables for flavor-separated quark/antiquark, valence/sea polarizations



HERMES+COMPASS+SMC spin-flavor

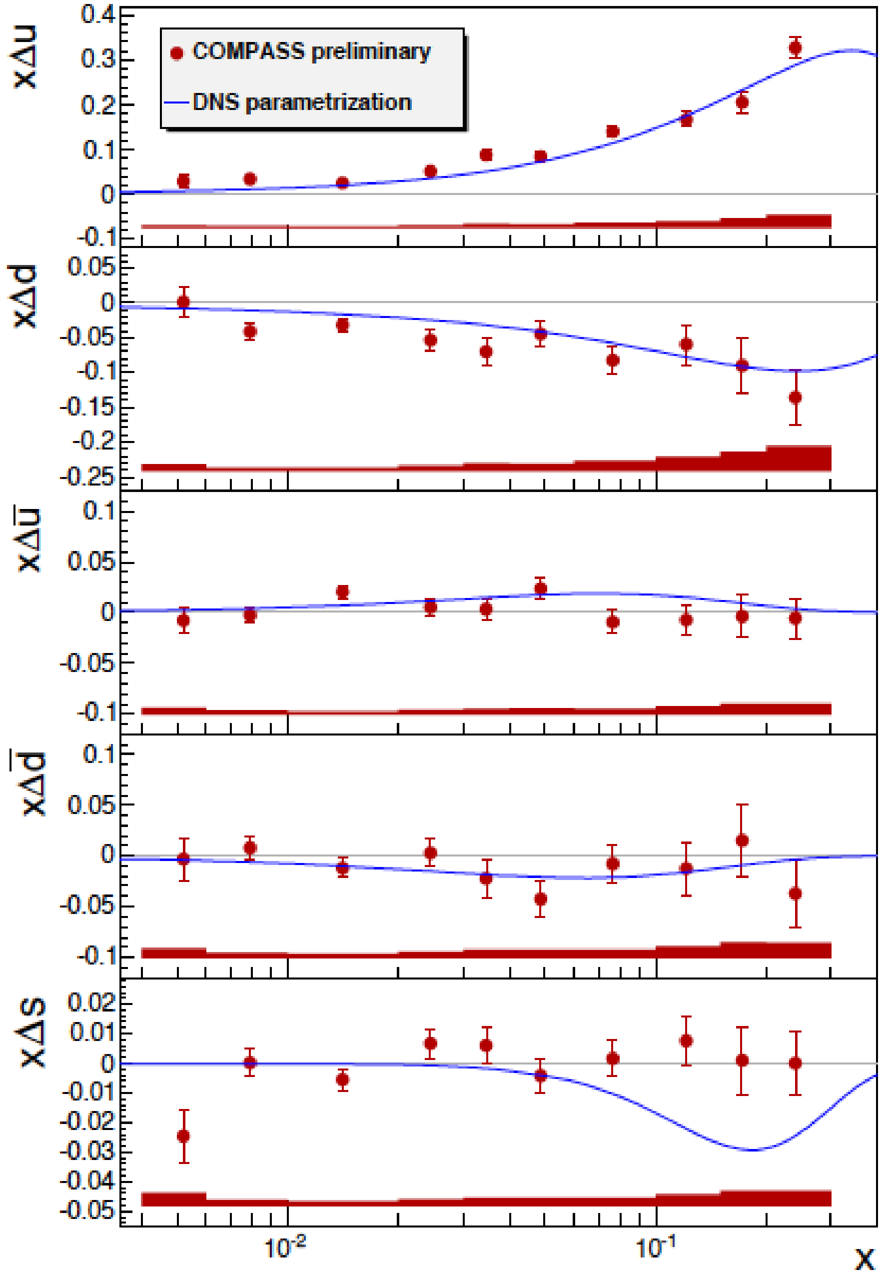


- Limited spin-flavor separated data available from SIDIS experiments at HERMES, COMPASS, and SMC
- LO extraction using "purity method":

$$A^h(x, Q^2) = \frac{\sum_q e_q^2 \Delta q(x, Q^2) \int D_q^h(z, Q^2) dz}{\sum_q e_q^2 q(x, Q^2) \int D_q^h(z, Q^2) dz}$$

• **Recent preliminary COMPASS proton+deuteron data; x<.3**

• **Antiquark/strange quark; i.e., sea polarization compatible with zero over the full measured range**



Spin-flavor using BB+SBS

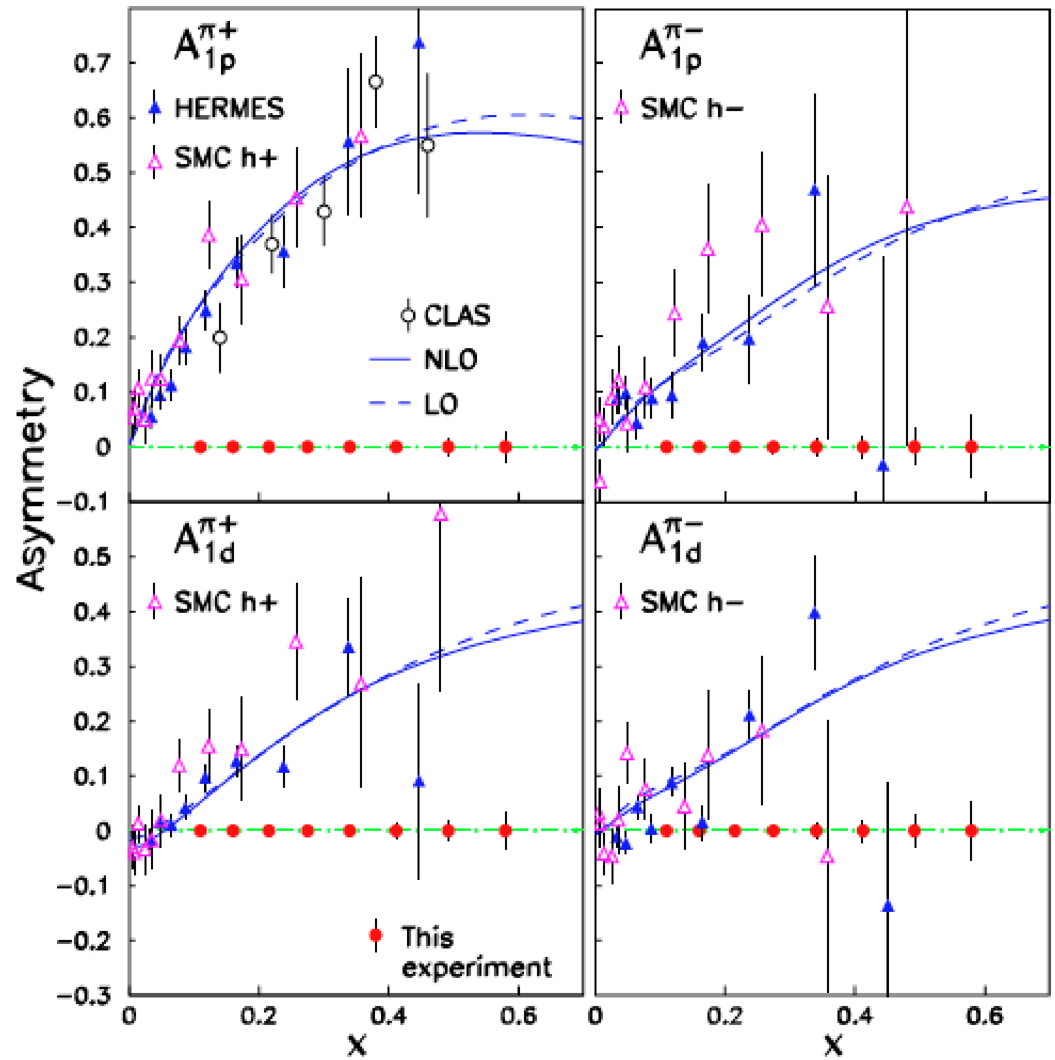
E′ GeV	θ_e deg.	x	W GeV	Q^2 GeV^2	θ_q deg.	z_π	p_h GeV/c	W'_π GeV	η^π_{cm}	x^π_F
							$\theta_h = 7.5°$			
1.000	25.000	0.110	4.193	2.061	2.40	0.40	4.00	3.25	1.48	0.38
1.200	25.000	0.135	4.098	2.473	2.93	0.41	4.00	3.16	1.57	0.39
1.400	25.000	0.160	4.001	2.886	3.48	0.42	4.00	3.08	1.67	0.40
1.600	25.000	0.187	3.902	3.298	4.05	0.43	4.00	2.99	1.79	0.41
1.800	25.000	0.215	3.799	3.710	4.64	0.44	4.00	2.90	1.92	0.43
2.000	25.000	0.244	3.694	4.122	5.26	0.44	4.00	2.80	2.06	0.44
2.200	25.000	0.275	3.586	4.535	5.89	0.45	4.00	2.71	2.21	0.45
2.400	25.000	0.307	3.474	4.947	6.56	0.47	4.00	2.61	2.35	0.46
2.600	25.000	0.340	3.359	5.359	7.25	0.48	4.00	2.50	2.43	0.48
2.800	25.000	0.375	3.240	5.771	7.96	0.49	4.00	2.39	2.40	0.49
3.000	25.000	0.412	3.116	6.184	8.70	0.50	4.00	2.28	2.26	0.50
3.200	25.000	0.451	2.987	6.596	9.48	0.51	4.00	2.16	2.05	0.52
3.400	25.000	0.491	2.852	7.008	10.29	0.53	4.00	2.03	1.84	0.53
3.600	25.000	0.534	2.710	7.420	11.12	0.54	4.00	1.89	1.62	0.54
3.800	25.000	0.580	2.561	7.833	12.00	0.56	4.00	1.74	1.42	0.54
4.000	25.000	0.628	2.402	8.245	12.91	0.57	4.00	1.58	1.23	0.55

Table 1: The nominal kinematics for the central BigBite angle of 25° and SBS angle of 7.5°. The SBS momentum acceptance is assumed to be 3.0 GeV/c to 5.0 GeV/c, with the nominal centrual value ($p_{SBS} = 4.00$ GeV/c). The central z and W' values are also listed. Data of all x-bins will be collected simultaneously.

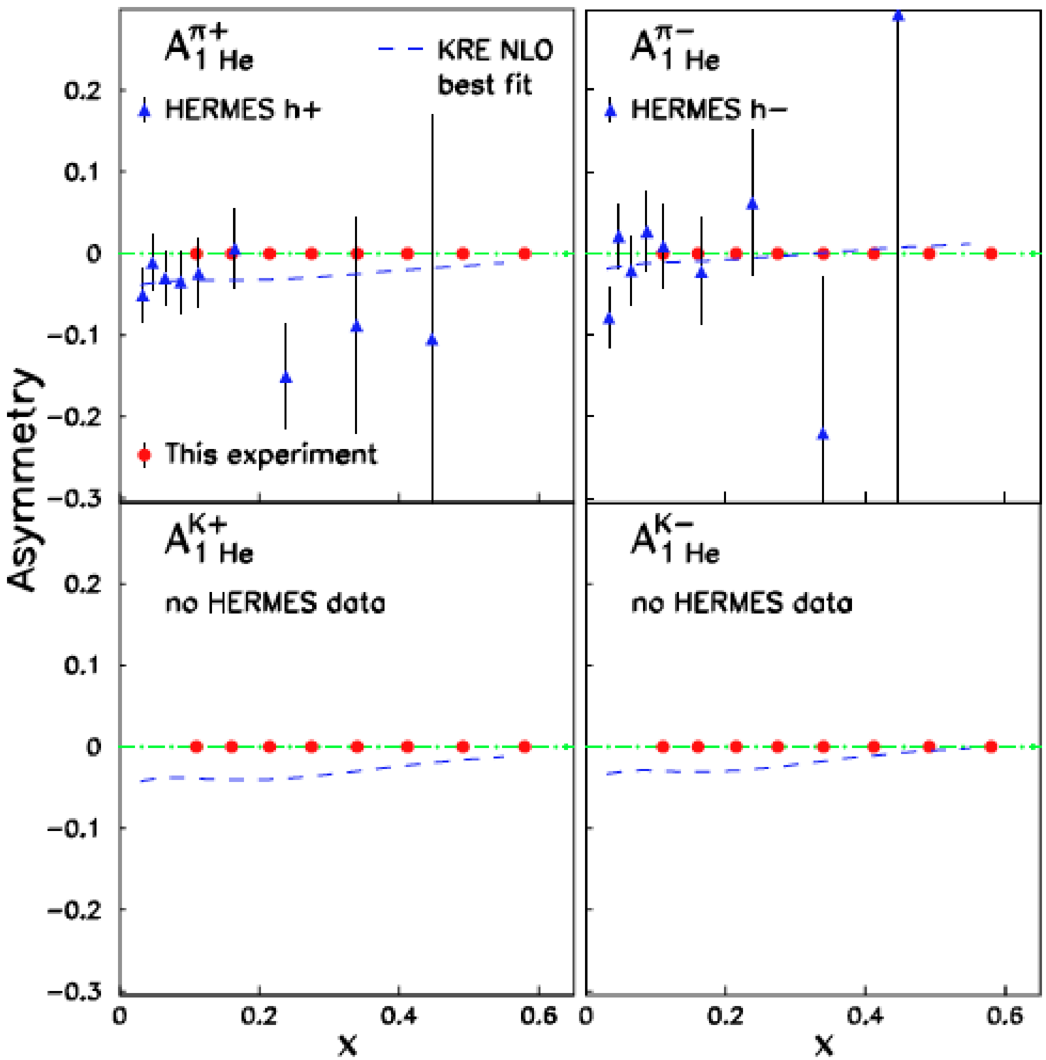
- **Use three targets in same detector configuration:**
- **Polarized p (NH_3), d (LiD), and n (^3He) targets with comparable statistics for each target**
- **11 GeV beam, BigBite at 25°, SBS at 7°:**
  - **0.1<x<.65**
  - **2<Q^2<8 GeV^2**
  - **0.4<z<0.6**
  - **W' > 1.6 GeV**

p, d, $\pi^{\pm}$ projected uncertainties

- 30 days NH_3
- 40 days LiD
- Assumptions (as in semi-SANE proposal):
  - P_{beam} = 85%
  - 3 cm tgt. thick.
  - 80 nA beam
  - $P_{tgt.}$ =
    - 80% (NH3)
    - 22% (LiD)

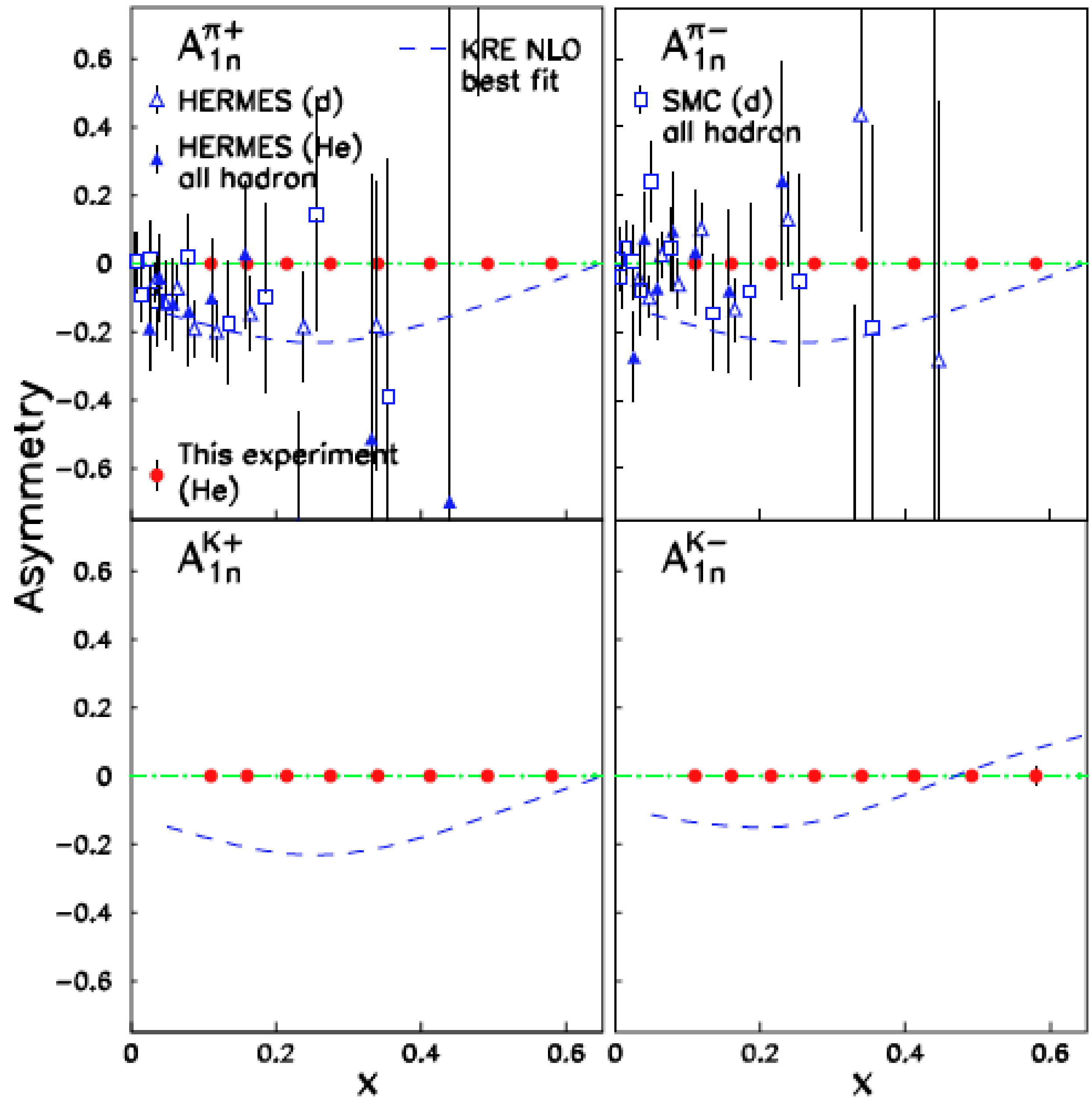


^{3}He $\pi^{\pm}$, $K^{\pm}$ projected uncertainties

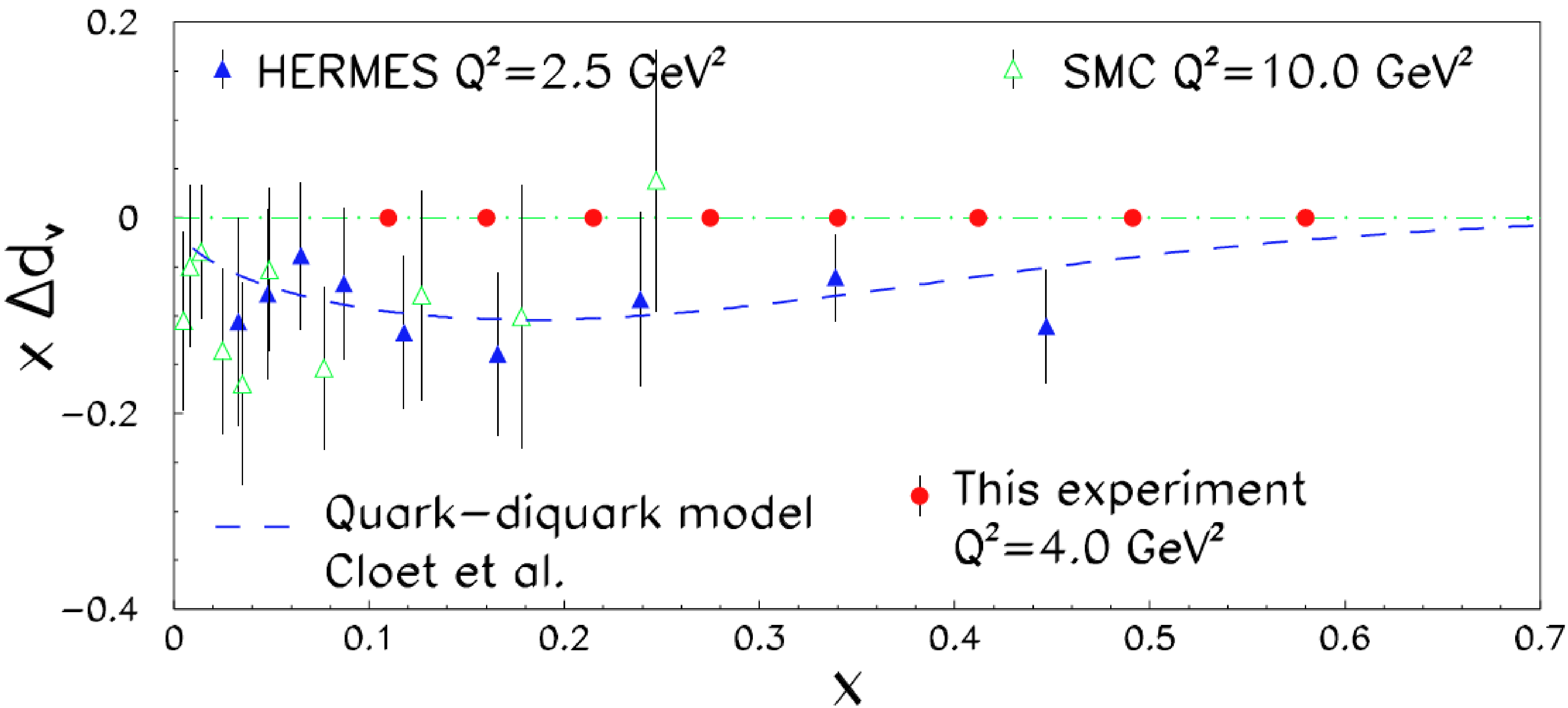


- 20 days ^{3}He
  - Assumptions:
    - 85% P_{beam}, I_{beam}=40 uA
    - 60 cm, 10 atm room temp. ^{3}He gas, P_{tgt} = 65%
- We can also extend the measurements to K sector for ^{3}He

Neutron $\pi^{\pm}$, $K^{\pm}$ projected uncertainties



Projected uncertainties, $x\Delta d_v$



Biggest improvement compared to existing data is in valence d quark polarization

Charge Symmetry Violating PDFs

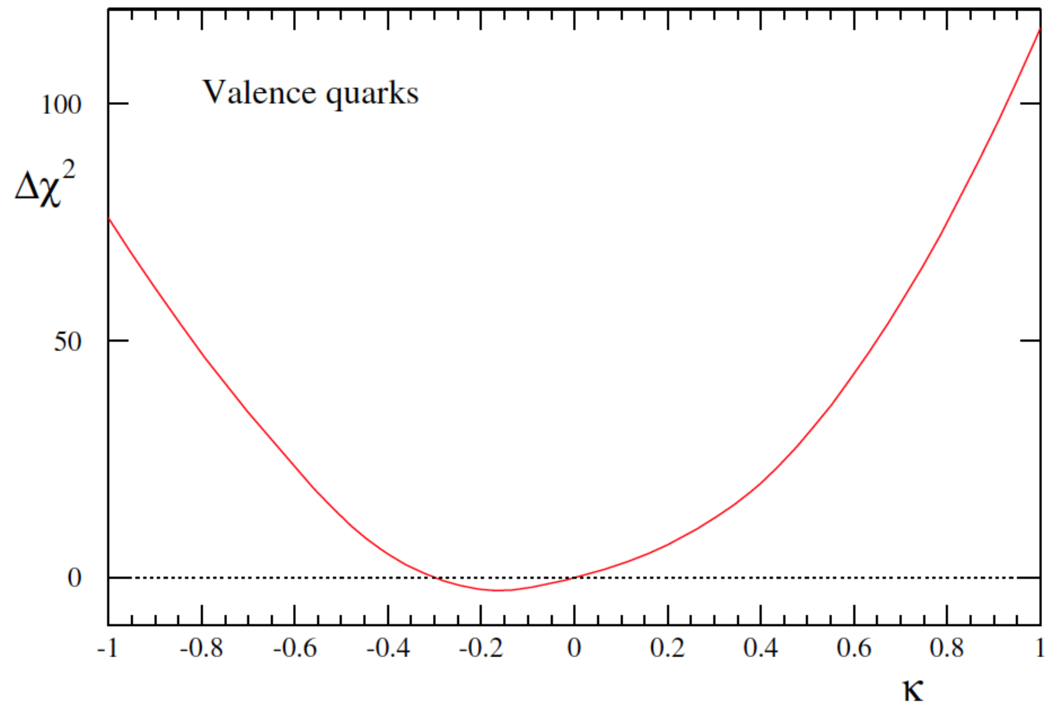
- Charge symmetry implies invariance under 180-degree rotations about the "2" axis in isospin space
- Well-respected experimentally in *nuclei* (fractional % level)
- Generally *assumed* to hold at the partonic level in *nucleons*
- Current experimental limits roughly at the 5-10% level
  - Londergan, Murdock, Thomas, Phys. Rev. D 72, 036010 (2005)
- First attempt to include CSV contribution in global analysis by MRST:
  - EPJ C 35, 325 (2004)
  - Parametrization of CSV PDFs satisfying:

$$\delta u = u_p - d_n$$
$$\delta d = d_p - u_n$$

$$\int_0^1 dx\, \delta d_V = \int_0^1 dx\, \delta u_V = 0$$
$$\delta u_v = -\delta d_v = \kappa f(x)$$
$$f(x) = (1-x)^4 x^{-0.5} (x - .0909)$$

• **Best fit value of CSV parameter in MRST global fit:**

$$\kappa = -0.2$$
$$-0.8 \leq \kappa \leq +0.65 \, (90\% \, C.L.)$$

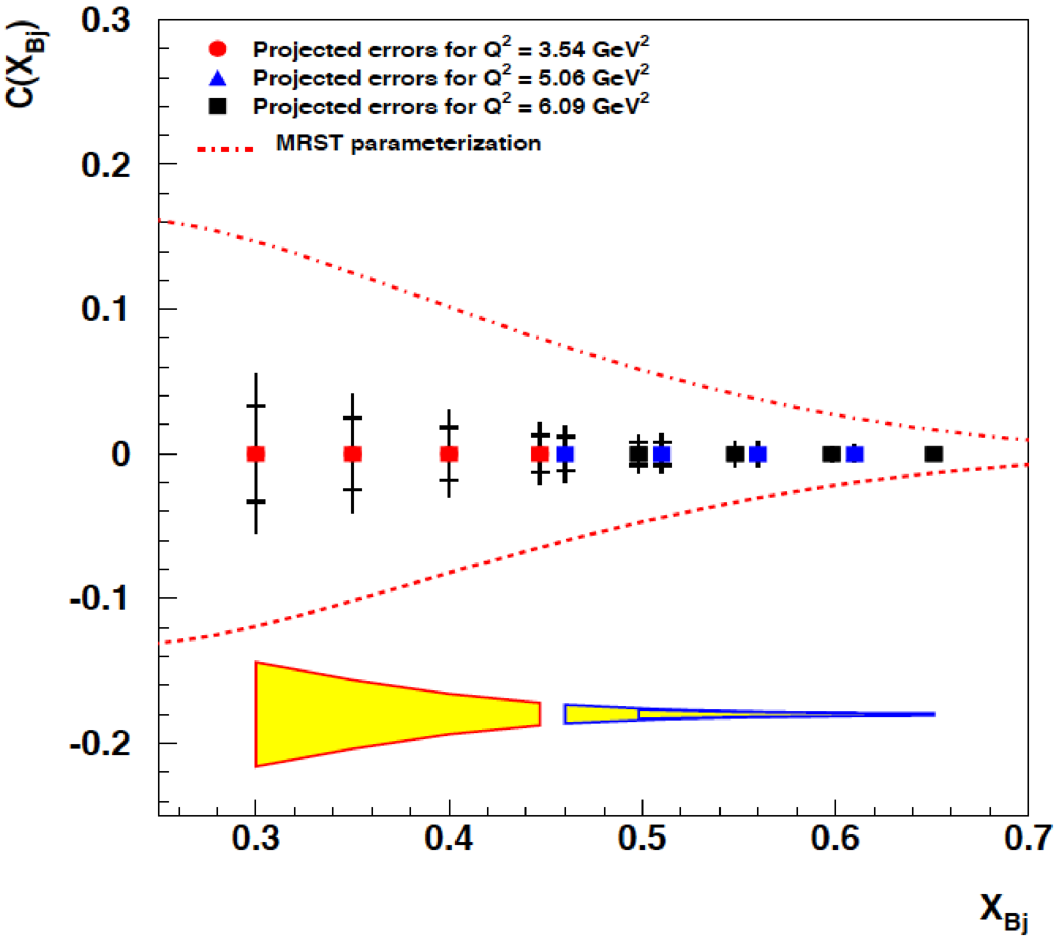


EPJ C 35, 325 (2004)

Phys. Rev. D 72, 036010 (2005)

- **Possible dedicated experiments:**
  - **pion-induced Drell-Yan**
  - **SIDIS on deuterium**
  - ***SIDIS on ^3He, ^3H?***

SIDIS on Deuterium: PR09-002



- Conditionally approved proposal to measure precise charged pion yield ratios Y^+/Y^-
- Using HMS+SHMS in Hall C
- *Potential for $^3H+^3He$ targets in Hall A with large-acceptance spectrometers begs the question:*
  - Can we do even better than PR09-002?

CSV PDFs using SBS+BB

- Key idea: Exploit mirror symmetry of A=3 nuclei to measure SIDIS π^+/π^- ratios between 3He and 3H to extract the p/n π^+/π^- ratios virtually free of nuclear corrections
- We are starting to investigate sensitivity to CSV terms, work with theorists to develop the physics case/feasibility studies

- Similar (though not identical) to E12-06-118, F2n/F2p, d/u
- Large-acceptance key to keep 3H density low, mitigate safety concerns
- Phys. Rev. C 68, 035201 (2003):
  - Nuclear effects cancel in the $^3H/^3He$ F_2 structure function ratio to within 1-2%
  - Clean extraction F_2n/F_2p

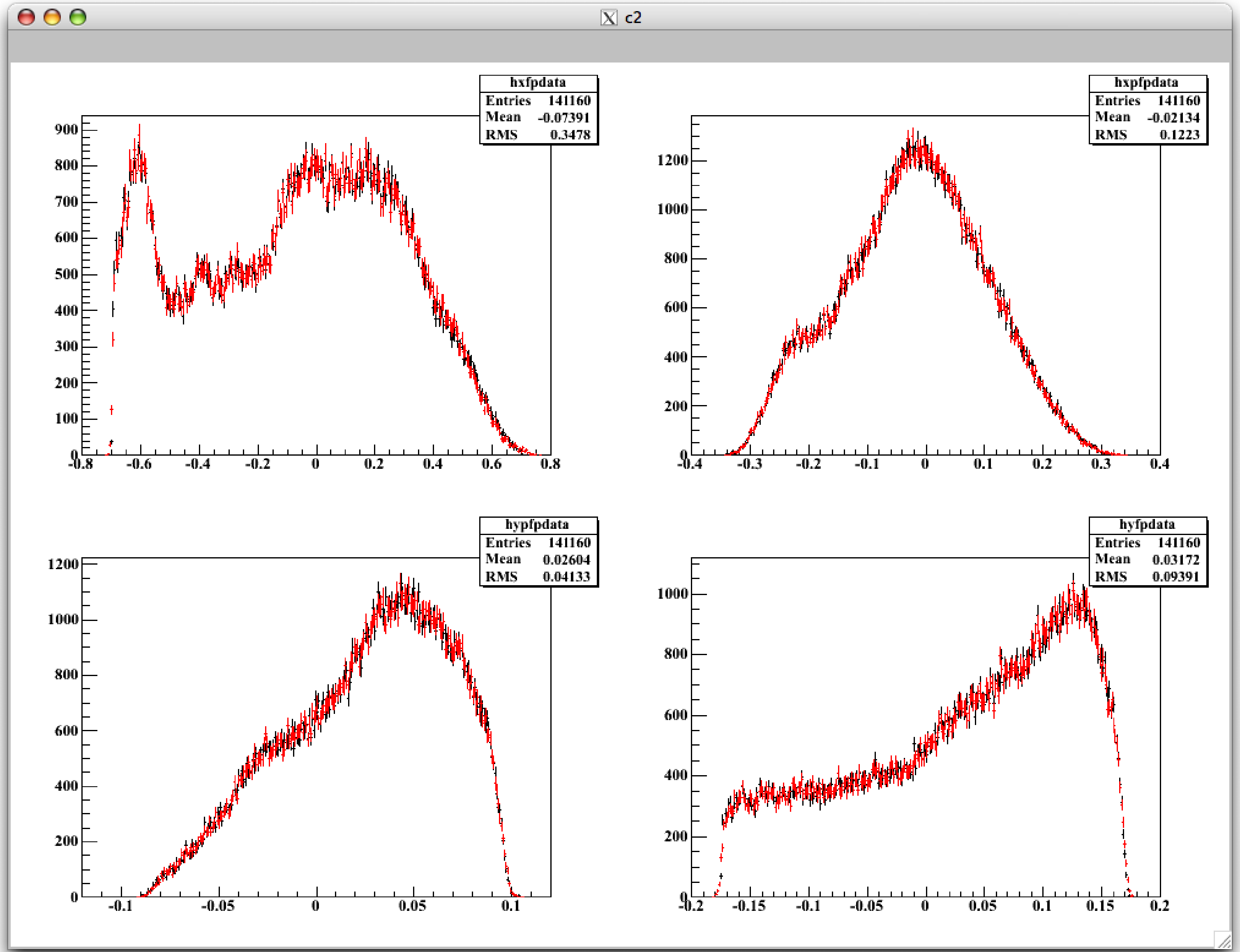
$$\frac{\sigma^{\pi^{\pm}}_{{}^{3}H}}{\sigma^{\pi^{\pm}}_{{}^{3}He}} \overset{?}{=} \frac{\sigma^{\pi^{\pm}}_{n}}{\sigma^{\pi^{\pm}}_{p}}$$

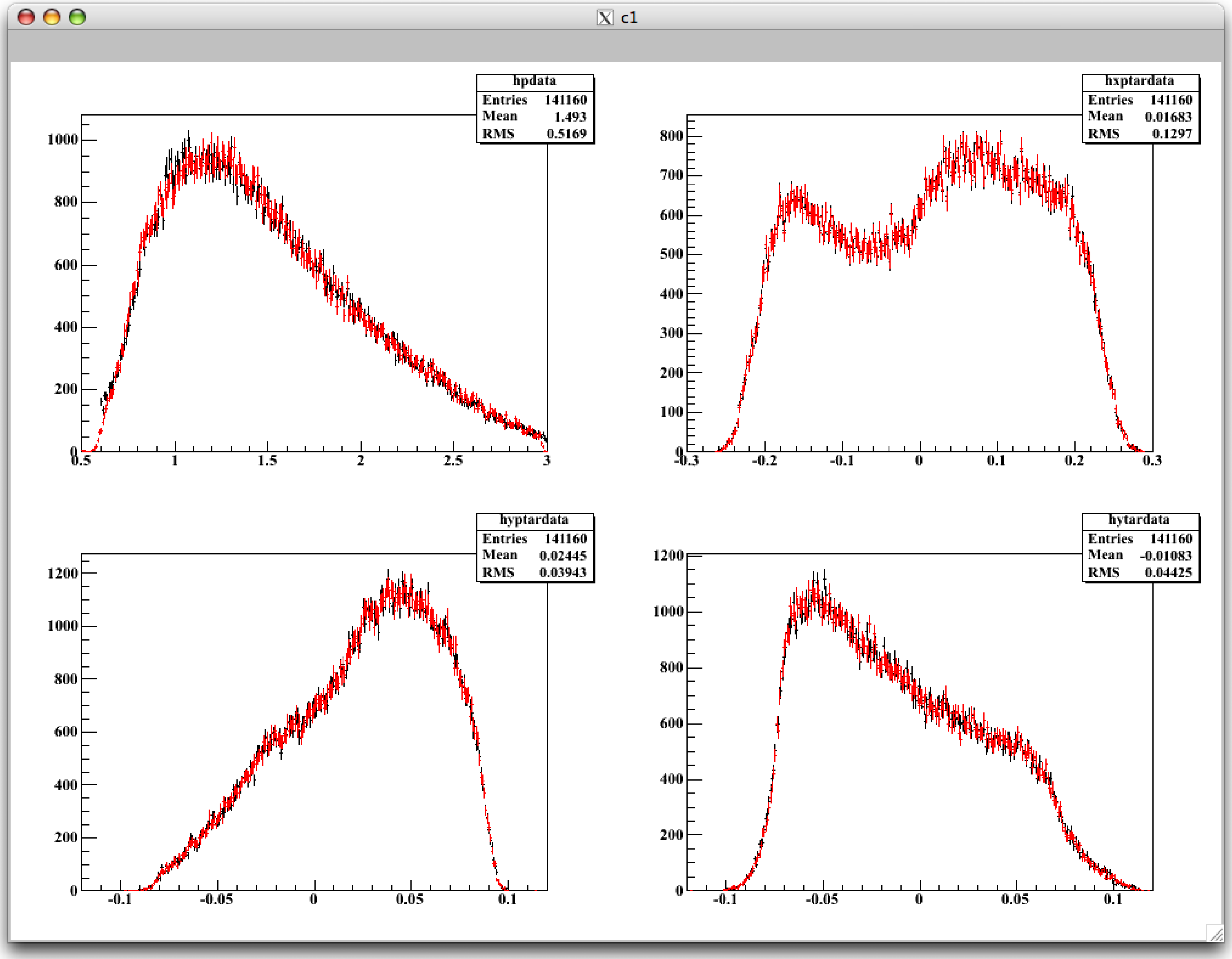
- **Key question: Does the near-cancellation of nuclear effects for inclusive structure functions carry over to semi-inclusive pion yields?**
- **Main advantage for this experiment over SIDIS measurements on deuterium is likely to be smaller theoretical uncertainties**
- **Last piece of the puzzle = SIDIS measurements on an unpolarized proton target in the same configuration**
- **n/p ratio + free proton data with same systematics allows extraction of free neutron with small theory uncertainties**
- **Regardless of this specific physics motivation; the opportunity for SIDIS measurements on both A=3 nuclei likely too good to pass up**

SIMC + BB + SBS

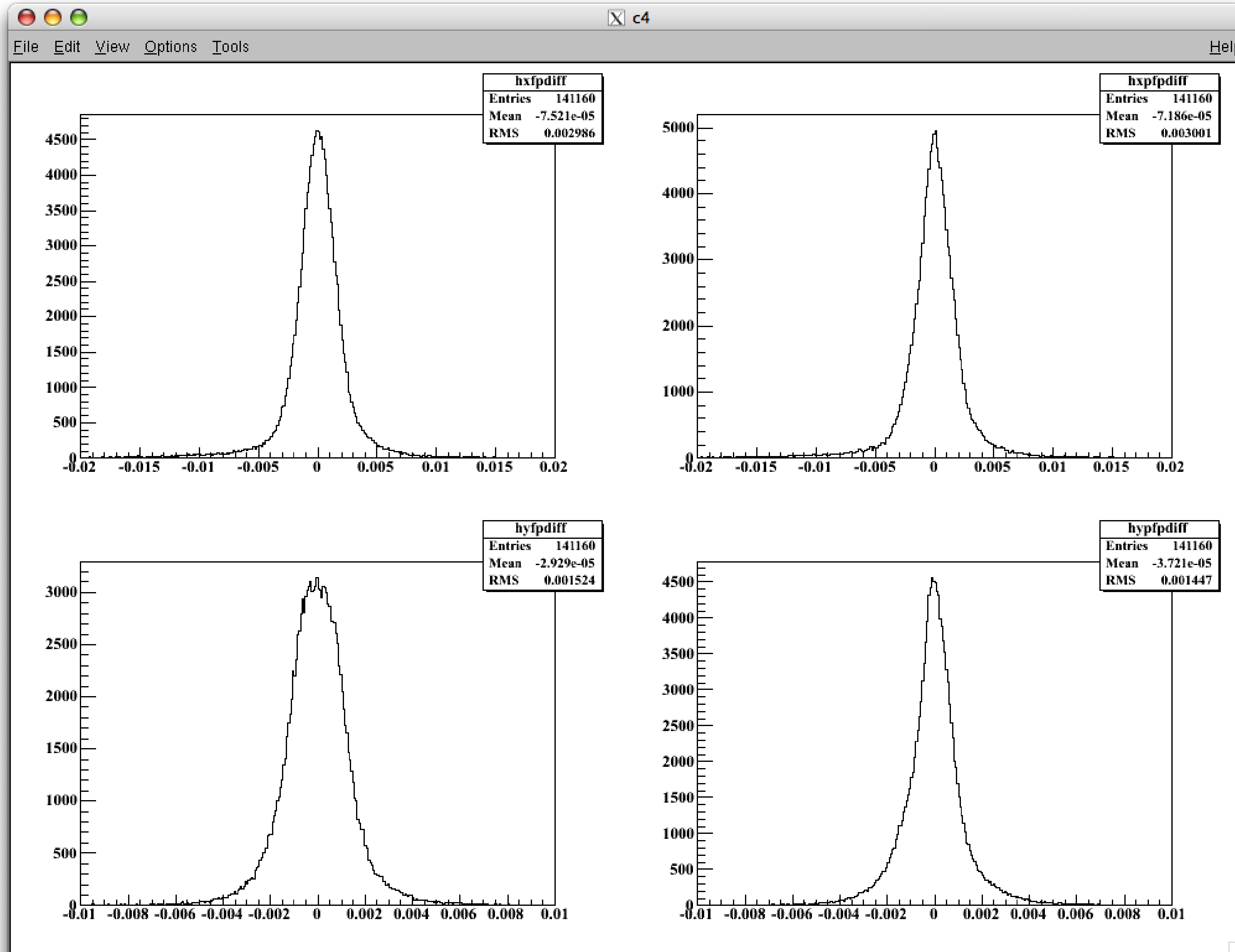
- SIMC provides a powerful framework for the simulation and analysis of coincidence experiments using magnetic spectrometers
- I am currently developing a model of BigBite using realistic optics from the sieve-slit/H(e,e'p) calibrations from transversity
- Developed a multi-purpose optics fitting code (polynomial expansions, SVD least-squares fitting a la Hall C)
- Works very well for BigBite
- I can easily extend the same techniques to add an SBS model to SIMC—fast Monte Carlo to study acceptance, develop physics program and analysis tools for BB+SBS coincidence experiments

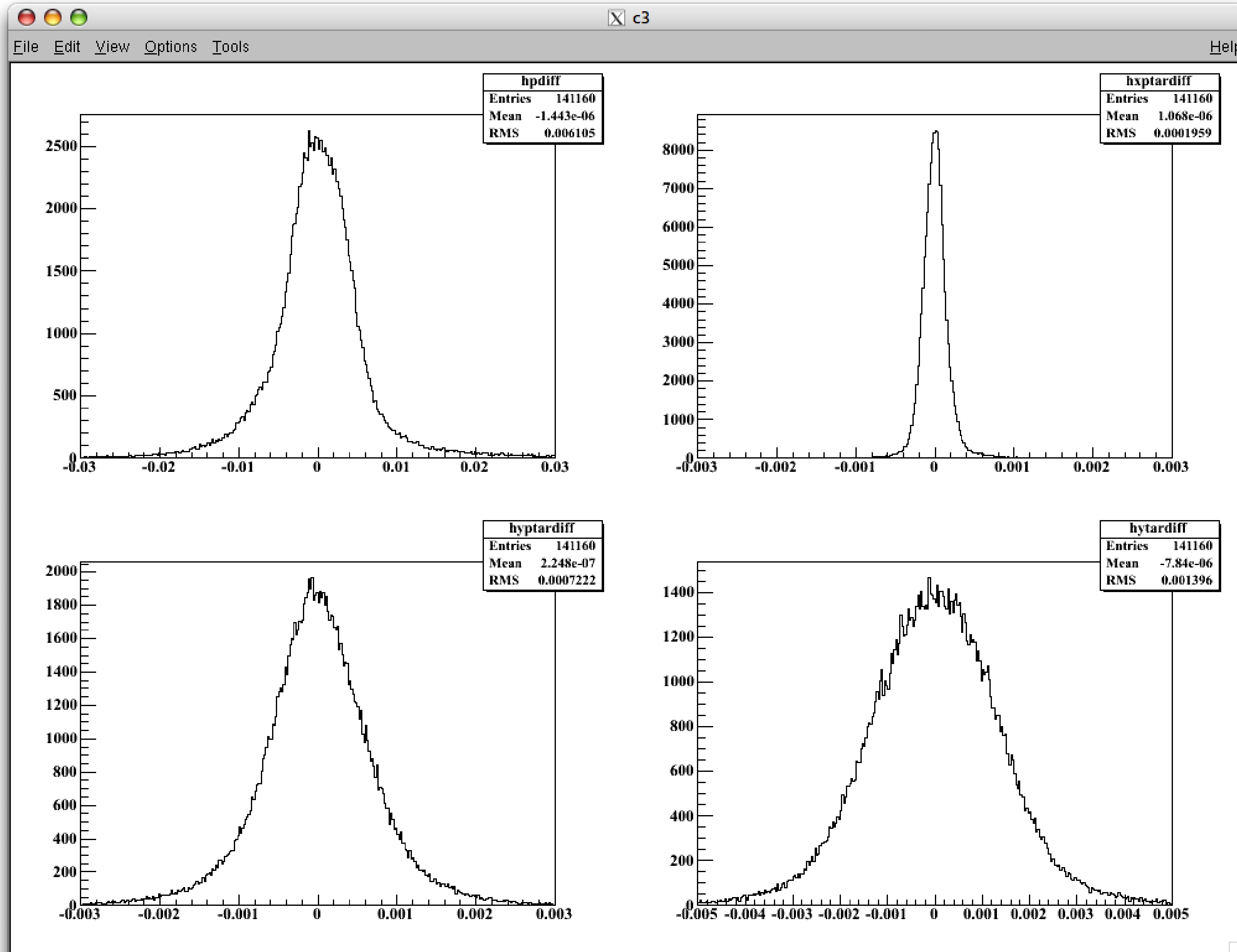
Pretty Pictures: BigBite Optics Fitting for SIMC Model

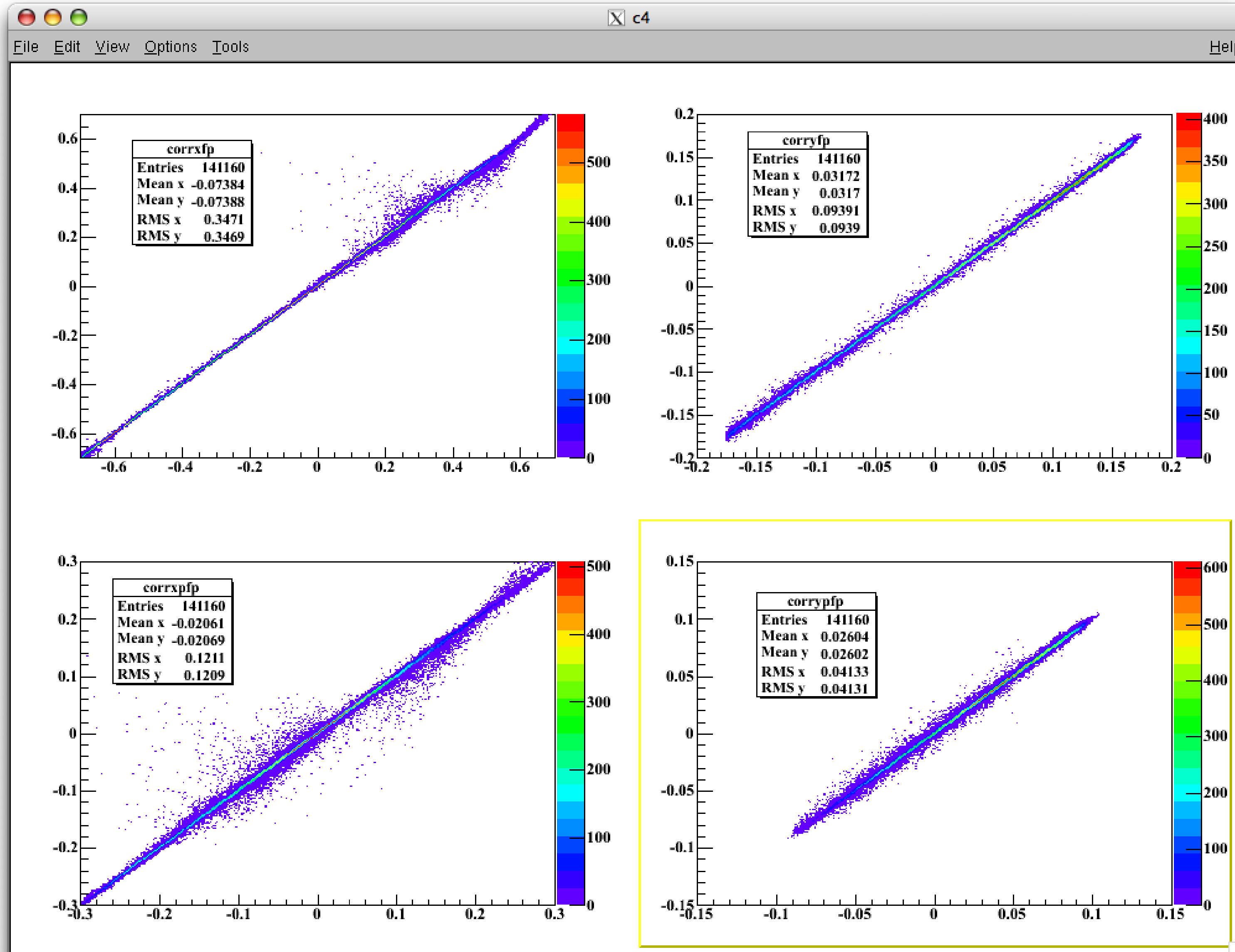


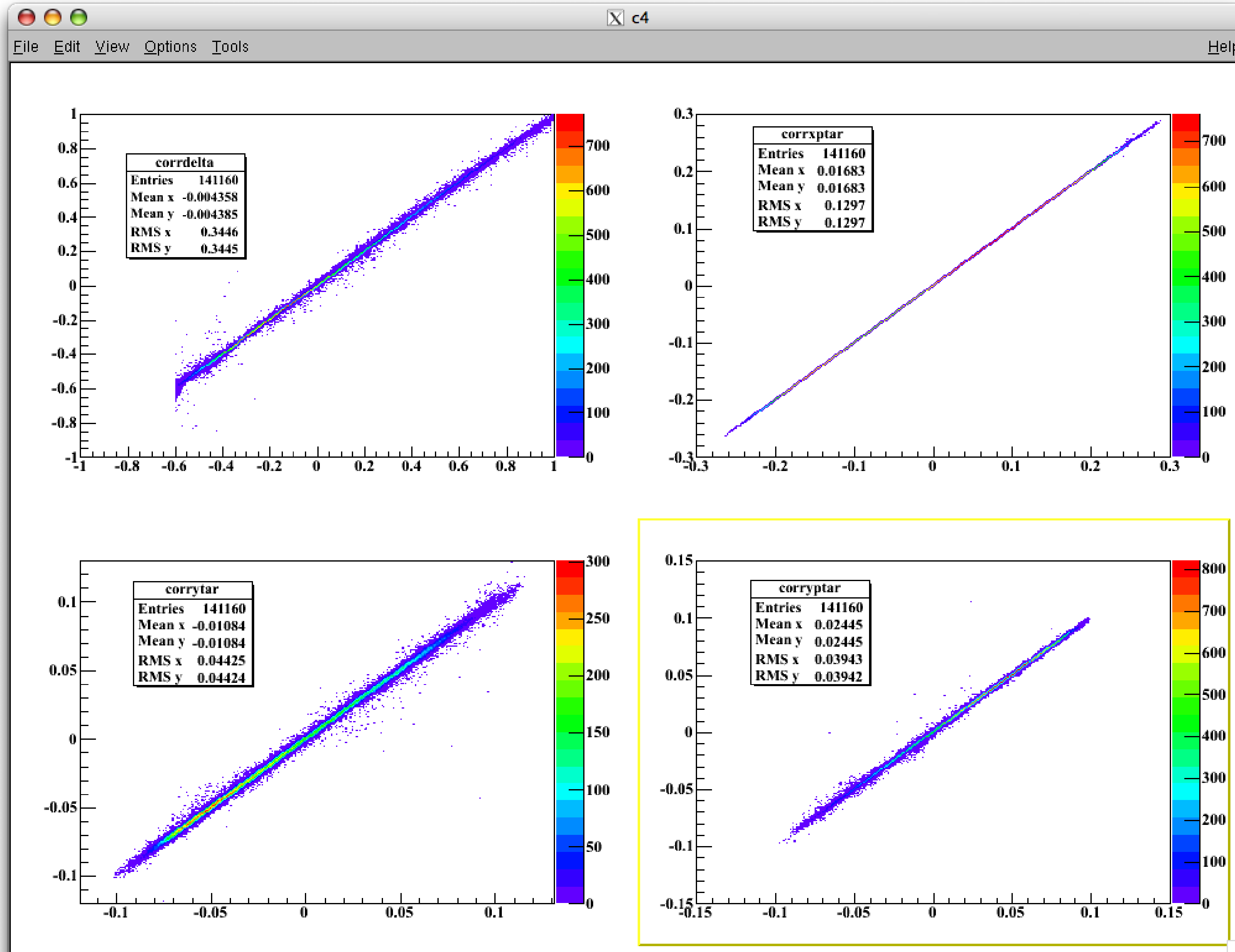


c1
hpdata
Entries 141160
Mean 1.493
RMS 0.5169
hxptardata
Entries 141160
Mean 0.01683
RMS 0.1297
hyptardata
Entries 141160
Mean 0.02445
RMS 0.03943
hytardata
Entries 141160
Mean -0.01083
RMS 0.04425


c4
File Edit View Options Tools Help
hxfpdiff
Entries 141160
Mean -7.521e-05
RMS 0.002986
hxpfpdiff
Entries 141160
Mean -7.186e-05
RMS 0.003001
hyfpdiff
Entries 141160
Mean -2.929e-05
RMS 0.001524
hypfpdiff
Entries 141160
Mean -3.721e-05
RMS 0.001447


c3
File Edit View Options Tools Help
hpdiff
Entries 141160
Mean -1.443e-06
RMS 0.006105
hxptardiff
Entries 141160
Mean 1.068e-06
RMS 0.0001959
hyptardiff
Entries 141160
Mean 2.248e-07
RMS 0.0007222
hytardiff
Entries 141160
Mean -7.84e-06
RMS 0.001396


c4
File Edit View Options Tools Help
corrxfp
Entries 141160
Mean x -0.07384
Mean y -0.07388
RMS x 0.3471
RMS y 0.3469
corryfp
Entries 141160
Mean x 0.03172
Mean y 0.0317
RMS x 0.09391
RMS y 0.0939
corrxpfp
Entries 141160
Mean x -0.02061
Mean y -0.02069
RMS x 0.1211
RMS y 0.1209
corrypfp
Entries 141160
Mean x 0.02604
Mean y 0.02602
RMS x 0.04133
RMS y 0.04131


c4
File Edit View Options Tools Help
corrdelta
Entries 141160
Mean x -0.004358
Mean y -0.004385
RMS x 0.3446
RMS y 0.3445
corrxptar
Entries 141160
Mean x 0.01683
Mean y 0.01683
RMS x 0.1297
RMS y 0.1297
corrytar
Entries 141160
Mean x -0.01084
Mean y -0.01084
RMS x 0.04425
RMS y 0.04424
corryptar
Entries 141160
Mean x 0.02445
Mean y 0.02445
RMS x 0.03943
RMS y 0.03942

Conclusion

- **LANL medium-energy spin-physics team (mainly A. Puckett and X. Jiang) strongly interested in SBS development for SIDIS experiments at 12 GeV**
- **We are presently working to develop two promising experiments for a BB+SBS SIDIS program—spin-flavor decomposition and CSV using 3H and 3He**
- **We are in a strong position to develop these ideas into full proposals**
- **We are also in a strong position to make a significant contribution to the SBS development effort, particularly in the area of simulations and development of analysis tools**