A_1^n Experiment in Hall A

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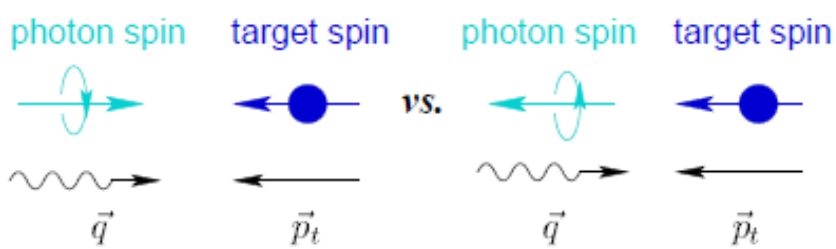
Outline:

- A_1^n physics motivation
- A_1^n experiment setup in Hall A
- A_1^n target system
- Extract A_1^n from $A_1^{^3He}$

▪ A_1^n physics:

Neutron spin structure at high x:

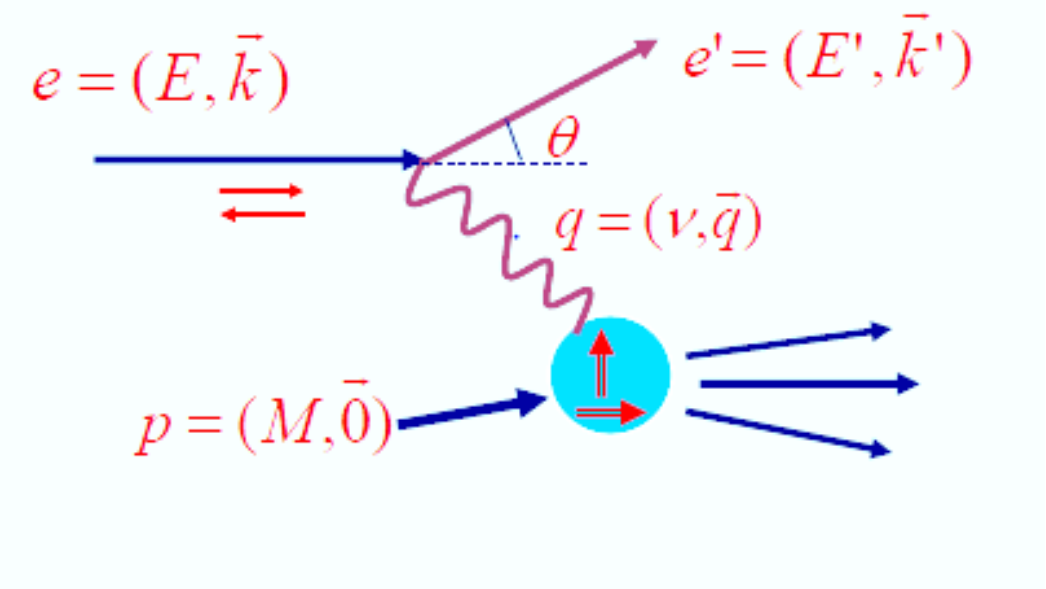
- Test fundamental predictions of nucleon structure (pQCD, RCQM, quark-hadron duality……)
- Flavor decomposition of polarized pdfs
- Virtual photon asymmetry: $A_1(x,Q^2) = \frac{\sigma_{1/2}-\sigma_{3/2}}{\sigma_{1/2}+\sigma_{3/2}}$



$$A_1(x,Q^2) = \frac{g_1(x,Q^2)-\gamma^2 g_2(x,Q^2)}{F_1(x,Q^2)} \approx \frac{g_1(x,Q^2)}{F_1(x,Q^2)} \text{ at large } Q^2 \quad \gamma^2=\frac{Q^2}{\nu^2}=\frac{4M^2x^2}{Q^2}$$

At large Q^2, A_1 has only weak-independence on Q^2

Polarized Inclusive Electron Scattering



- longitudinally polarized electrons scattering of polarized nuclei target.
- Virtual photon probe of quark structure
- Four momentum transfer $Q^2 = -q^2 = 4EE`sin^2\frac{\theta}{2}$
- Invariant Mass $W^2 = M^2 + 2M\upsilon - Q^2$

- **Electron Asymmetry**

$$A_{\parallel} = \frac{\sigma_{\downarrow\Uparrow} - \sigma_{\uparrow\Uparrow}}{\sigma_{\downarrow\Uparrow} + \sigma_{\uparrow\Uparrow}} = \frac{1-\varepsilon}{(1-\varepsilon R)w_1}\left[M\left(E + E^{`} cos\theta\right)G_1 - Q^2 G_2\right]$$

$$A_{\perp} = \frac{\sigma_{\downarrow\Rightarrow} - \sigma_{\uparrow\Rightarrow}}{\sigma_{\downarrow\Rightarrow} + \sigma_{\uparrow\Rightarrow}} = \frac{(1-\varepsilon)E^{`}}{(1-\varepsilon R)w_1}\left[MG_1 + 2EG_2\right] cos\theta$$

- **Virtual photon asymmetry**

$$A_1 = \frac{1}{D(1+\eta\xi)} A_{\parallel} - \frac{1}{d(1+\eta\xi)} A_{\perp}$$

Here:

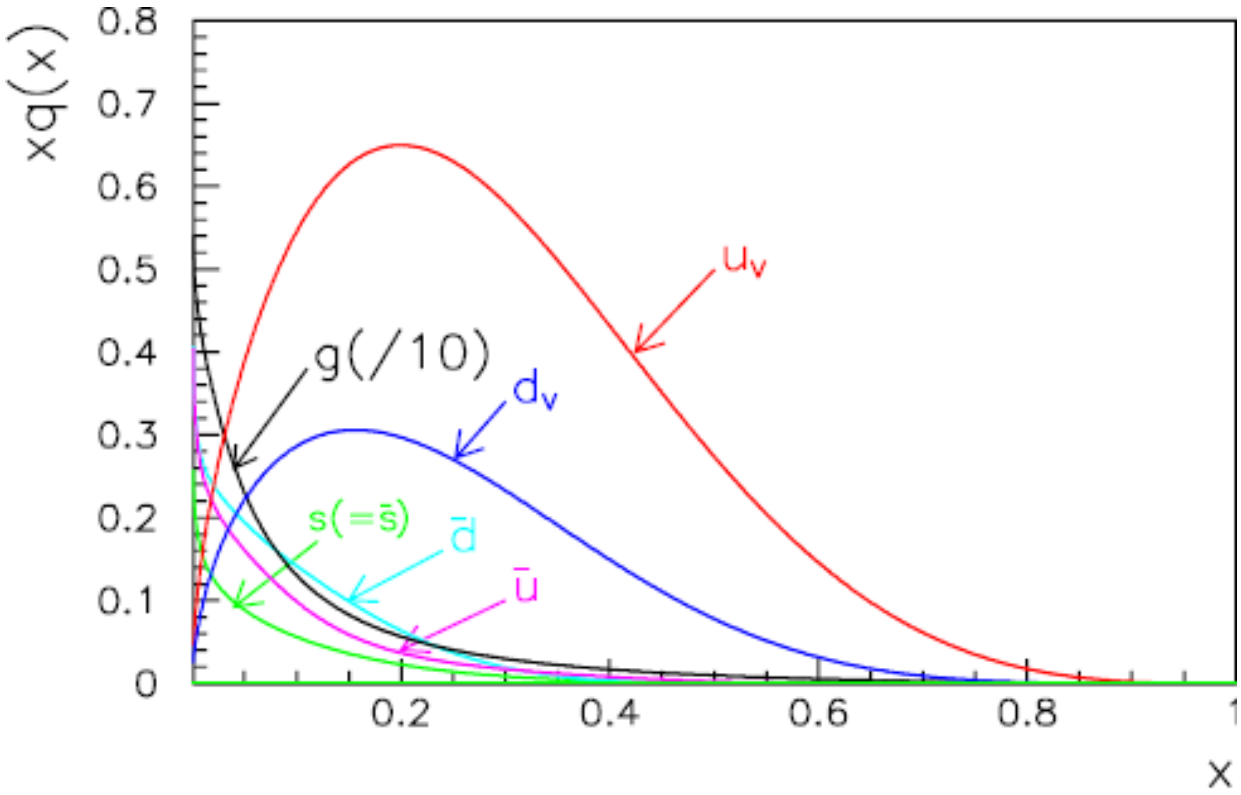
$$D = \frac{1-(1-y)\epsilon}{1+\epsilon R}$$

$$\epsilon = 1/\left[1 + 2(1 + 1/\gamma^2 tan^2 \frac{\theta}{2}\right]$$

$$\eta = \epsilon\sqrt{Q^2}/(E - E^{`}\varepsilon)$$

$$\xi = \eta\, 2\epsilon/(1+\epsilon)$$

$$d = D\sqrt{2\epsilon/(1+\epsilon)}$$



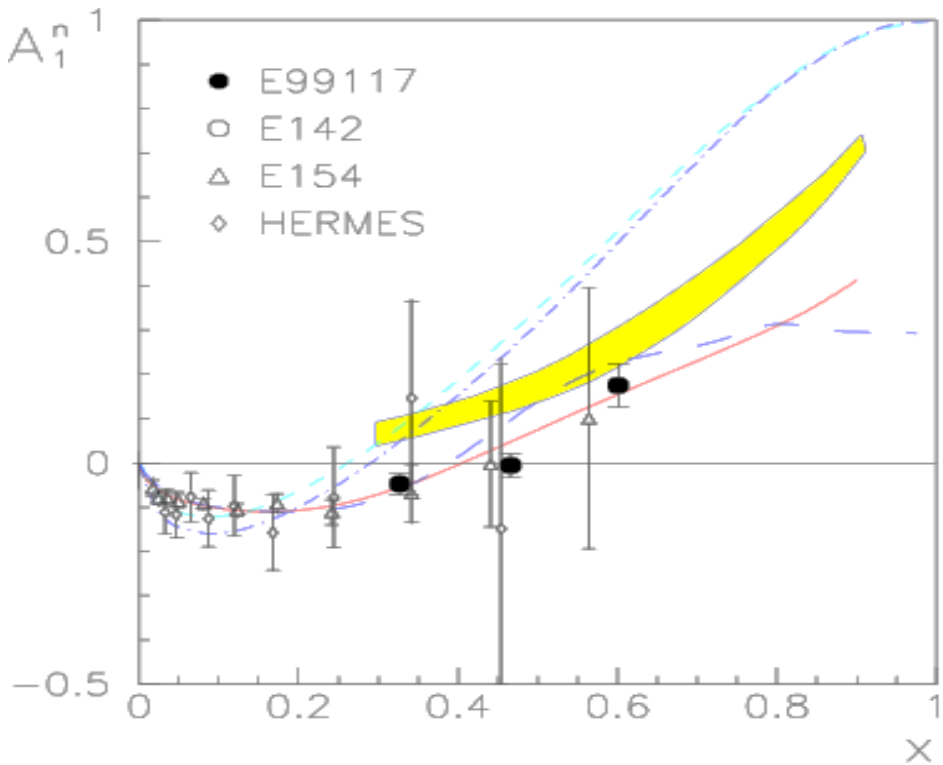
- Low x: sea region, large contribution from quark-antiquark pairs and gluons
- High x: valence region, valence quarks dominate, a relative clean region to study the nucleon structure

Nucleon Structure at large x

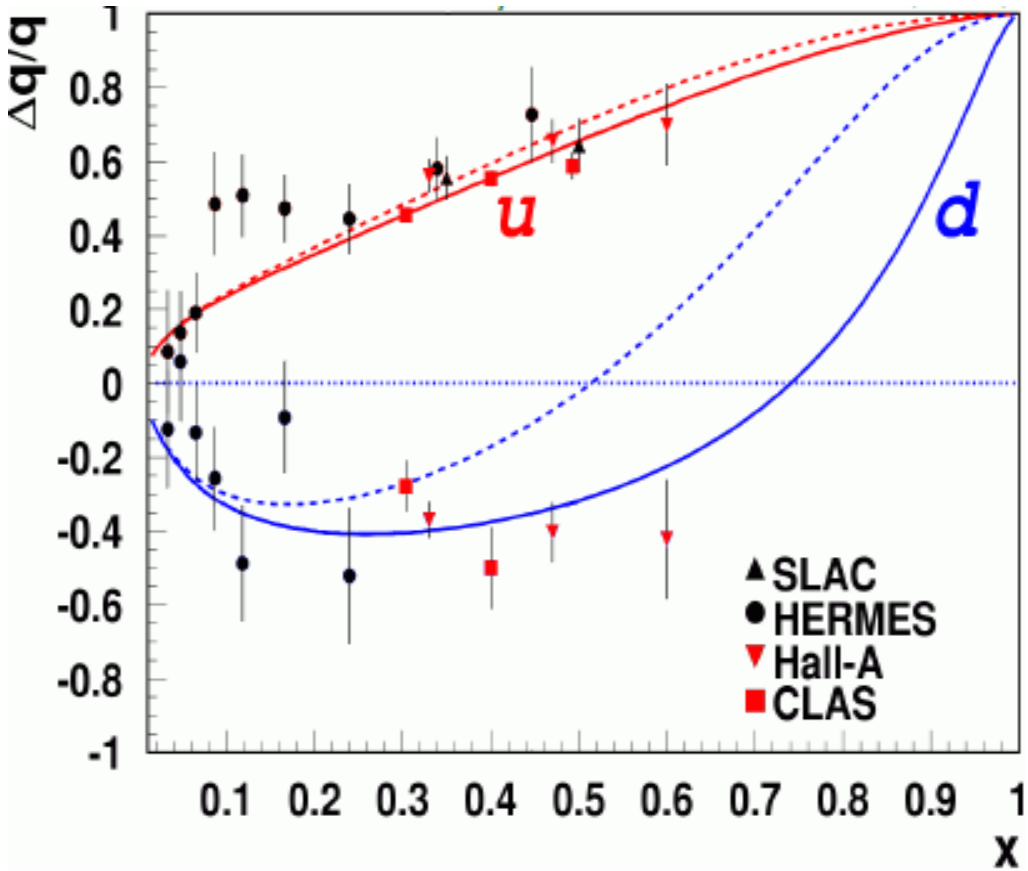
Neutron Wavefunction (Spin and Flavor Symmetric)

$$|n\uparrow\rangle = \frac{1}{\sqrt{2}}|d\uparrow(ud)_{S=0}\rangle + \frac{1}{\sqrt{18}}|d\uparrow(ud)_{S=1}\rangle - \frac{1}{3}|d\downarrow(ud)_{S=1}\rangle$$
$$-\frac{1}{3}|u\uparrow(dd)_{S=1}\rangle - \frac{\sqrt{2}}{3}|u\downarrow(dd)_{S=1}\rangle$$

Nucleon Model	**d/u**	$\Delta d/d$	$\Delta u/u$	A_1^n	A_1^p
SU(6)	1/2	-1/3	2/3	0	5/9
Valence Quark + hyperfine	0	-1/3	1	1	1
pQCD + HHC	1/5	1	1	1	1

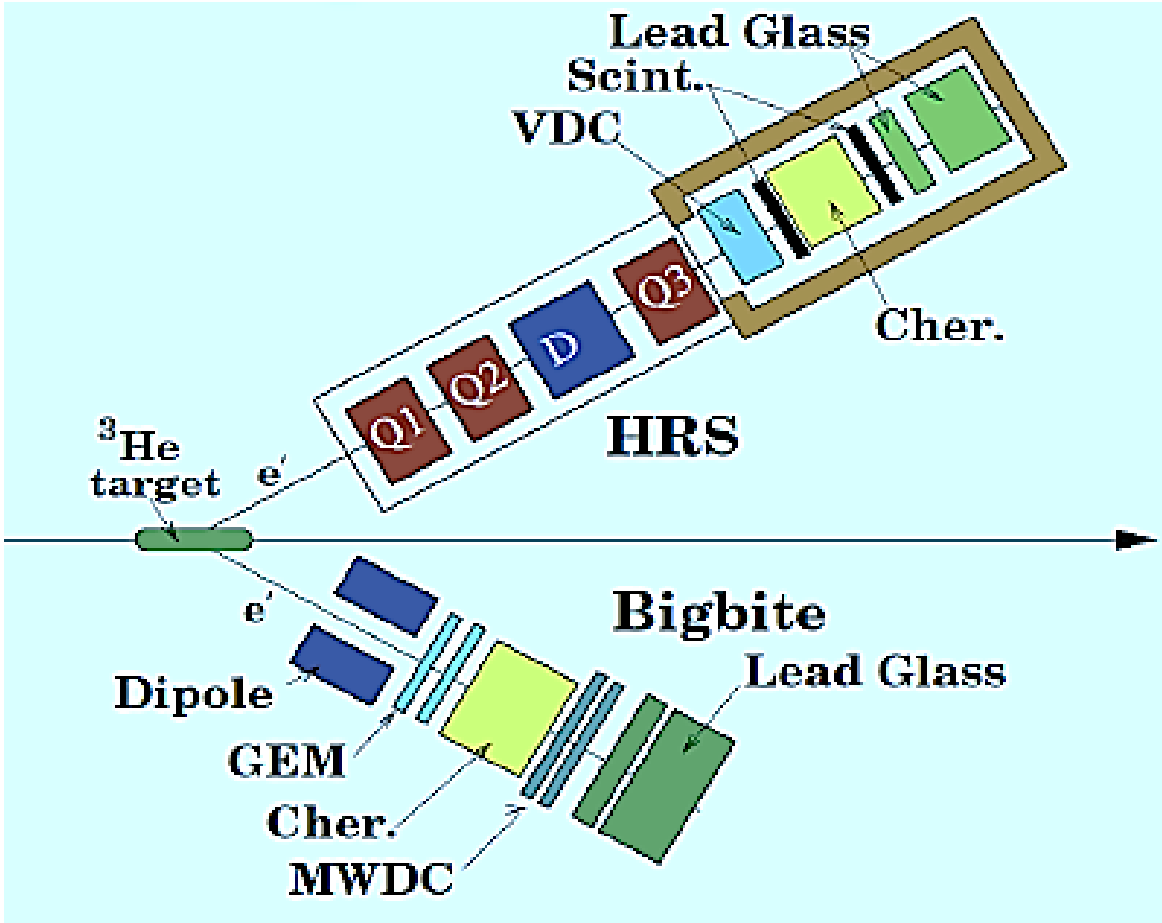


- Data better agree with models: RCQM (yellow band)
- Also agree with statistical model (lower dashed curve), NLO QCD fit constraint (red line)
- Data not agree with pQCD assume HHC (zero quark OAM, two upper curves) → non-zero quark orbital angular momentum?
- See X. Zheng et al., PRL **92**, 012004 (2004); PRC **70**, 065207 (2004)



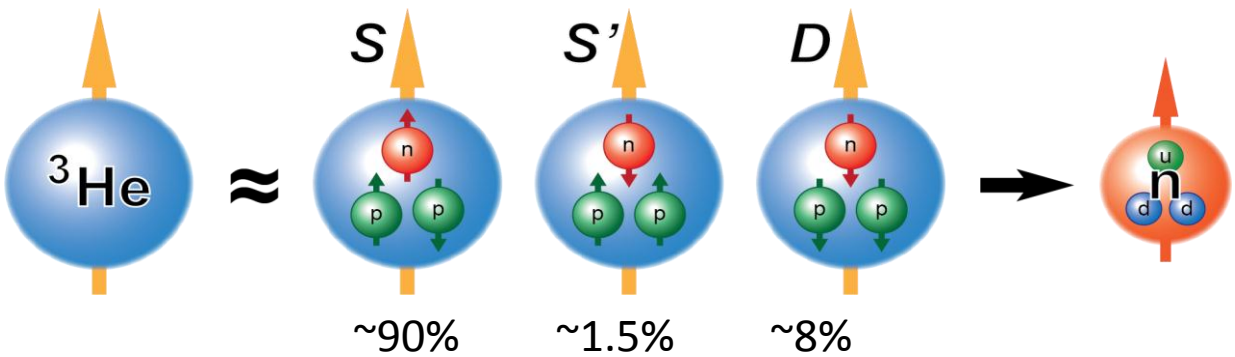
- Dashed curve predictions from pQCD with hadron helicity conservation
- Solid curve predictions from pQCD assume non-zero angular momentum
- See H. Avakian, S. Brodsky, A. Deur, F. Yuan, Phys. Rev. Lett.99:082001(2007)

A_1^n experiment setup in Hall A



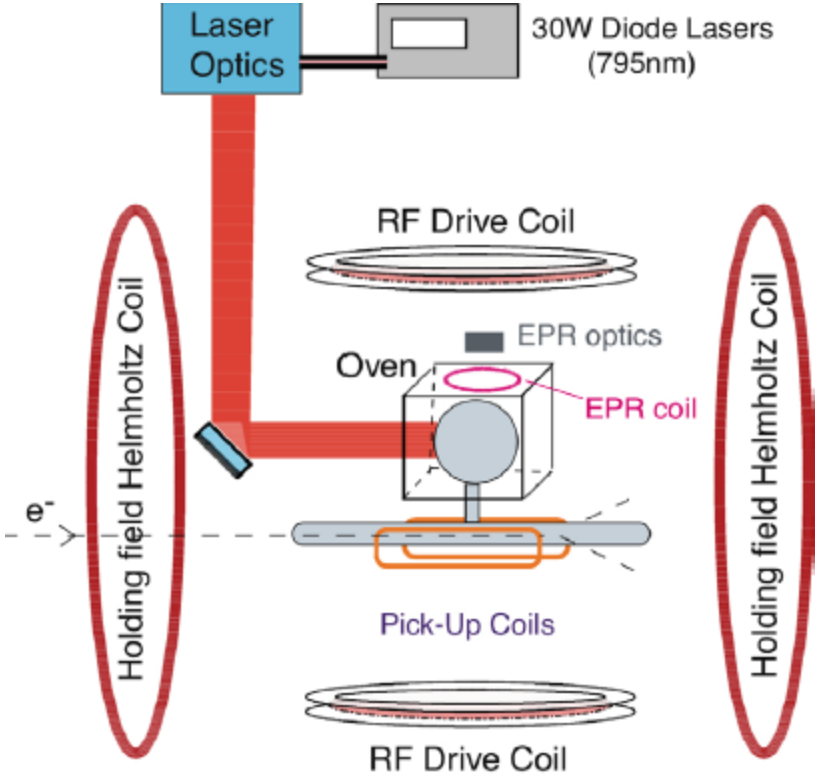
- **Bigbite**
- Large angular acceptance :50+ msr solid angle
- Large momentum acceptance

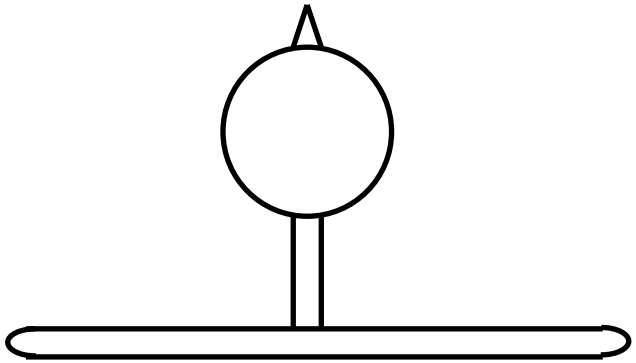
- **A_1^n target system**
- Free neutron lifetime is short ~886s
- ^{3}He ground state:



- Polarized ^{3}He --> polarized neutron target

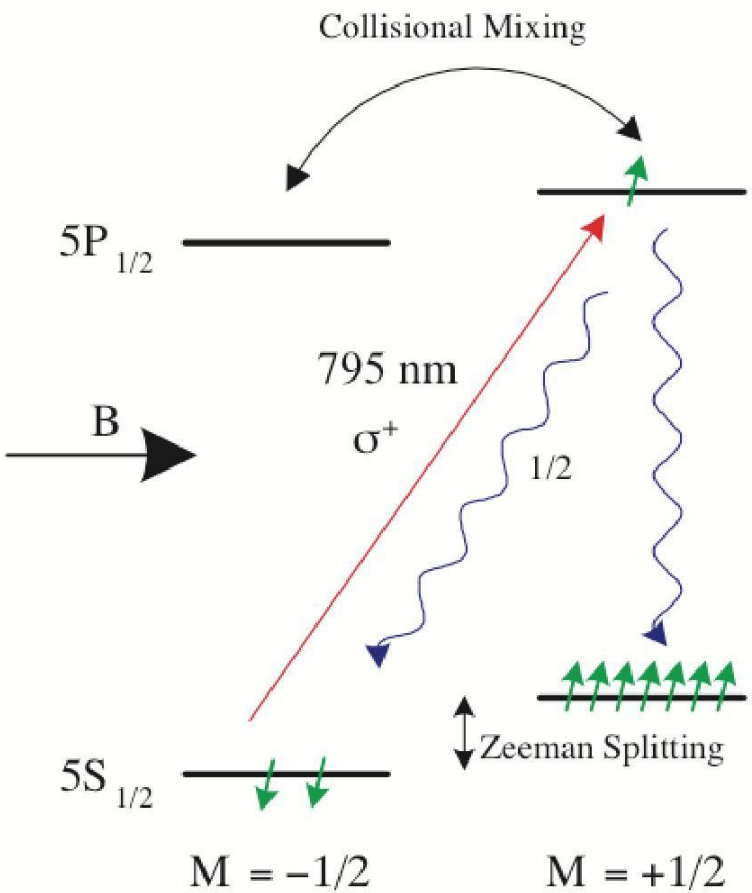
Target system

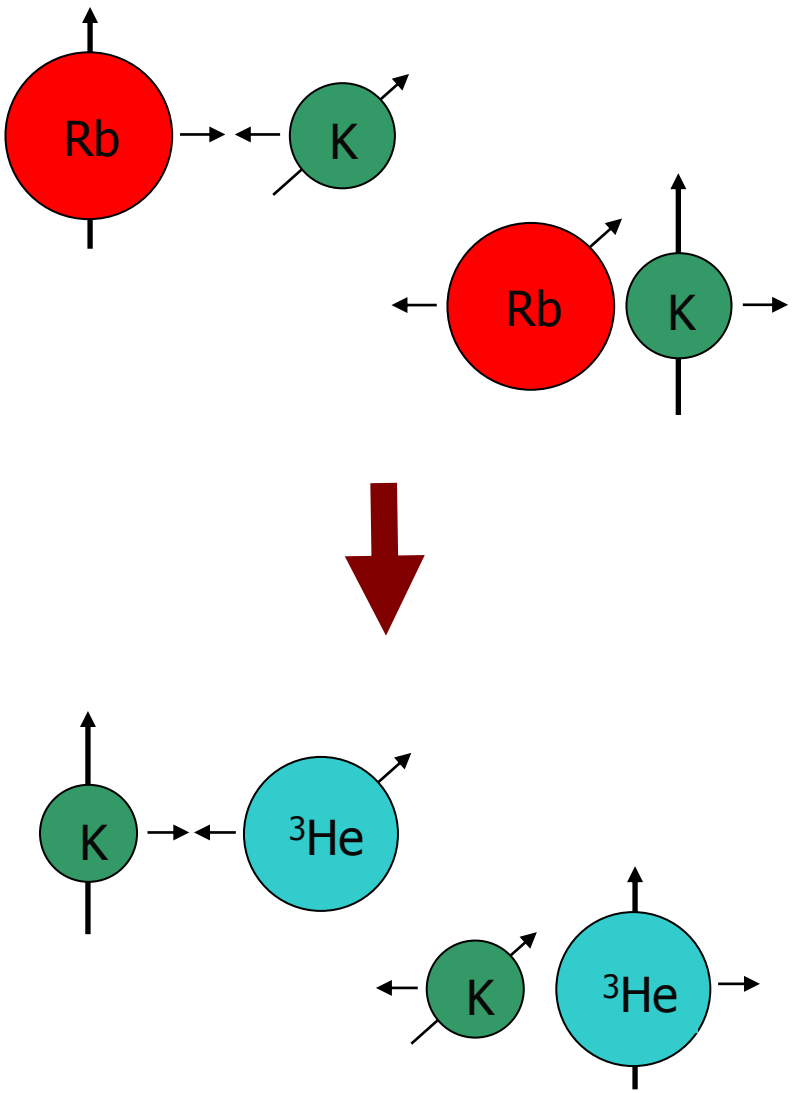




- Double-chamber (previous experiment)
  - Pumping chamber for optical pumping normally oven temperature 230$^{\circ}C$
  - Target chamber (40 cm) for electron scattering
  - Cell is in high pressure

Hybrid (Rb/K Mixing) Optical Pumping





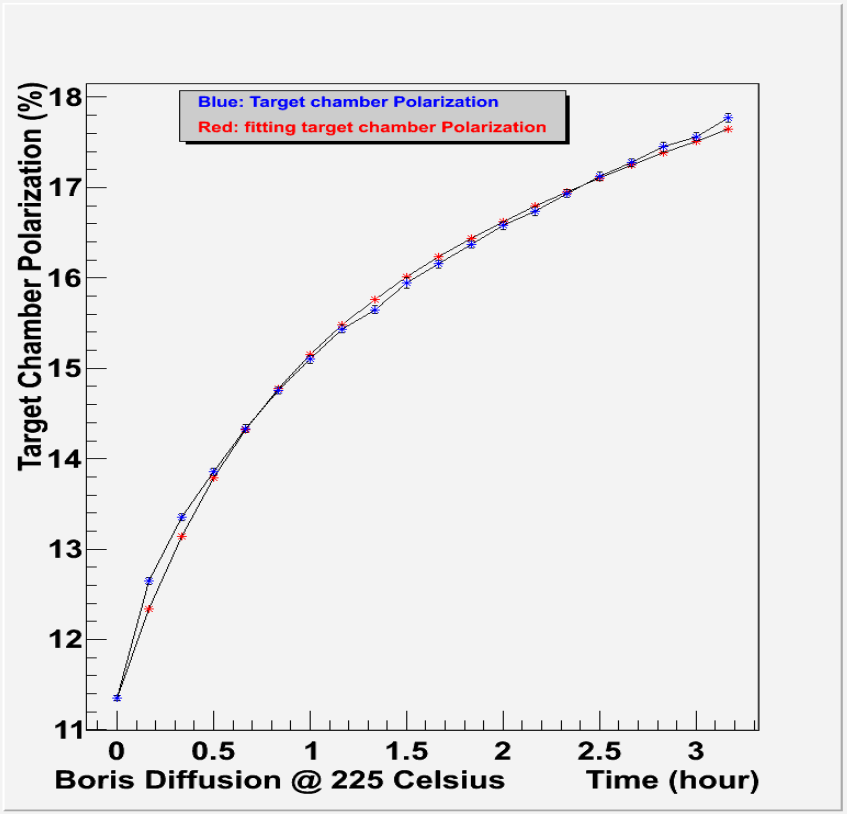
Diffusion model

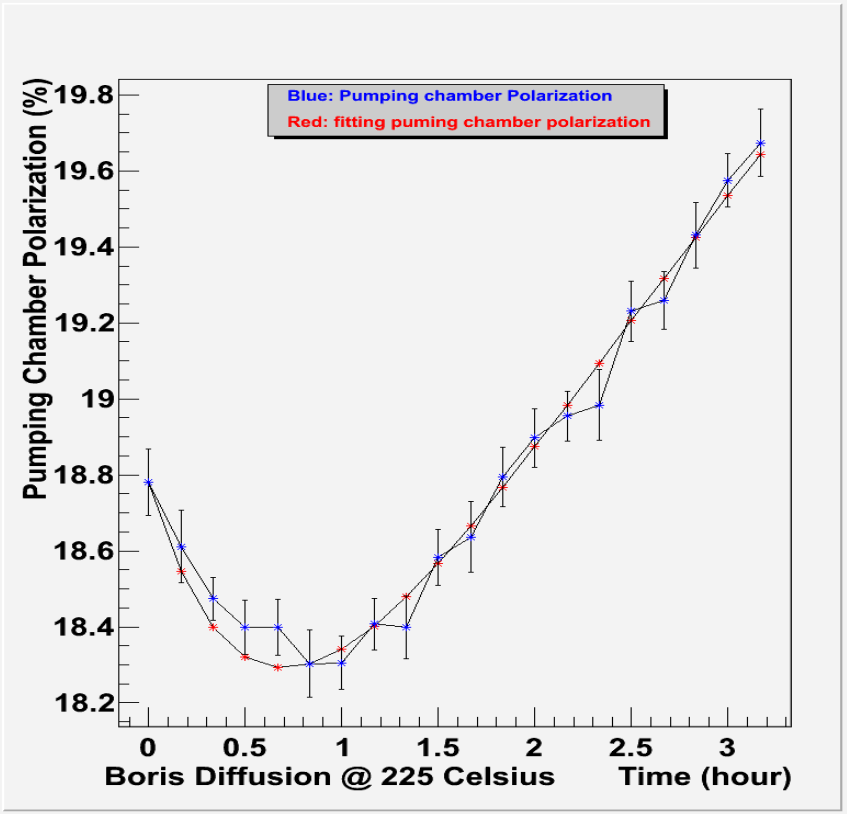
$$\frac{dP_p}{dt} = -G_p(P_p - P_t) - \left((1+x)f_{opc}r_{SE} + \Gamma_p\right)P_p + \langle P_{Rb}\rangle f_{opc}r_{SE} \ ,$$

$$\frac{dP_t}{dt} = G_t(P_p - P_t) - \Gamma_t P_t \ ,$$

$$P_p(0) = A, \quad P_t(0) = B,$$

$$\frac{dP_p(\infty)}{dt} = \frac{dP_t(\infty)}{dt} = 0.$$

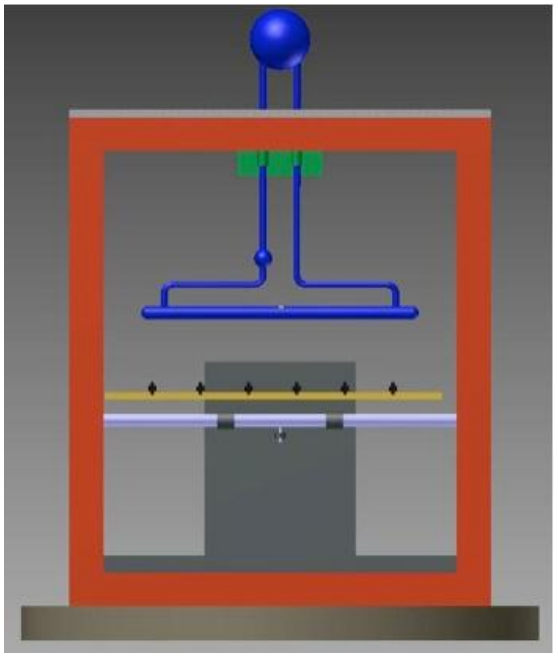


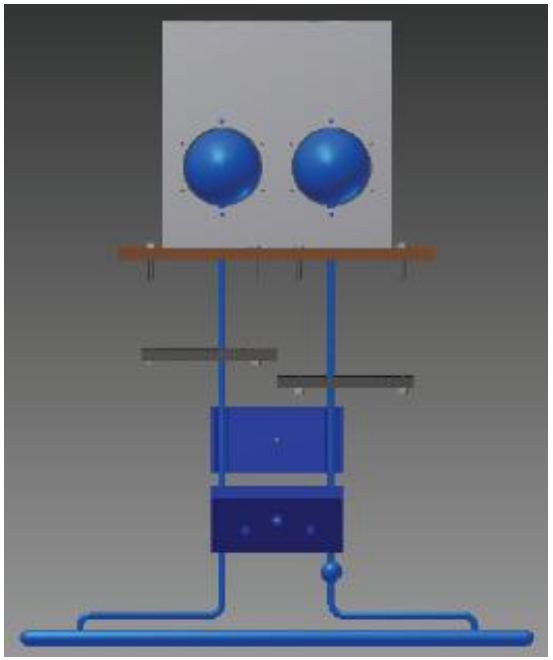


Upgraded target system for A_1^n

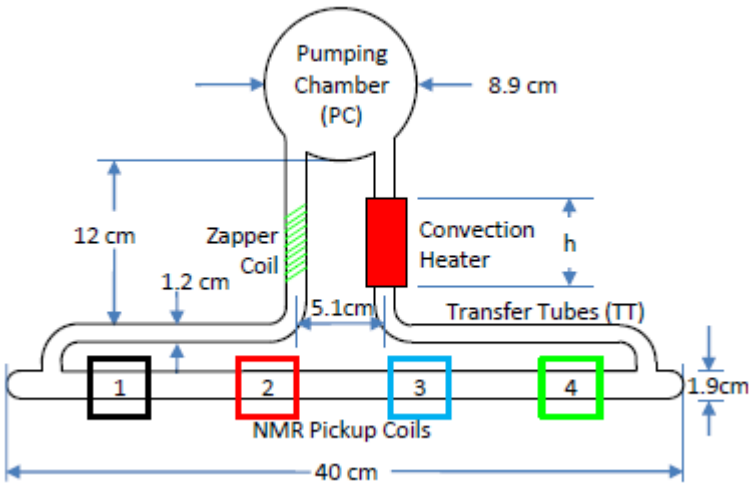
- **Increase luminosity for A_1^n:**
- Gas must be polarized quick enough
- ^{3}He must mix quickly between two chambers
- The portion of target exposed to high radiation should be made of metal.

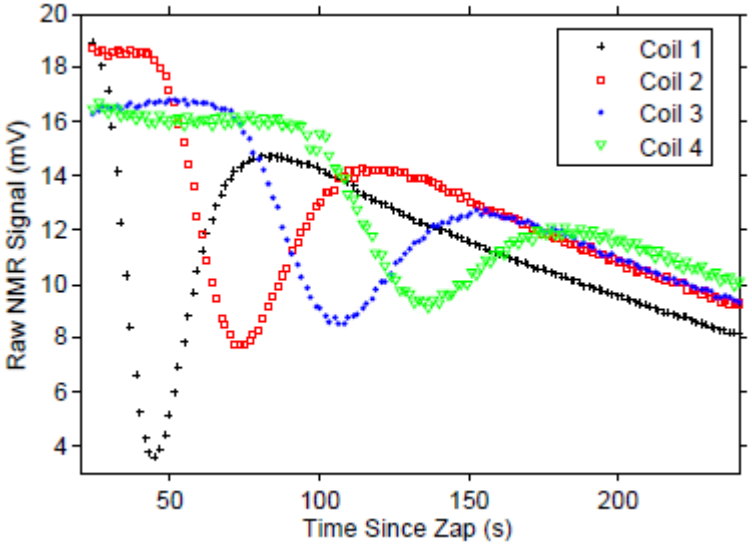
Convection cell, hybrid alkali, narrowed lasers, metal end windows?



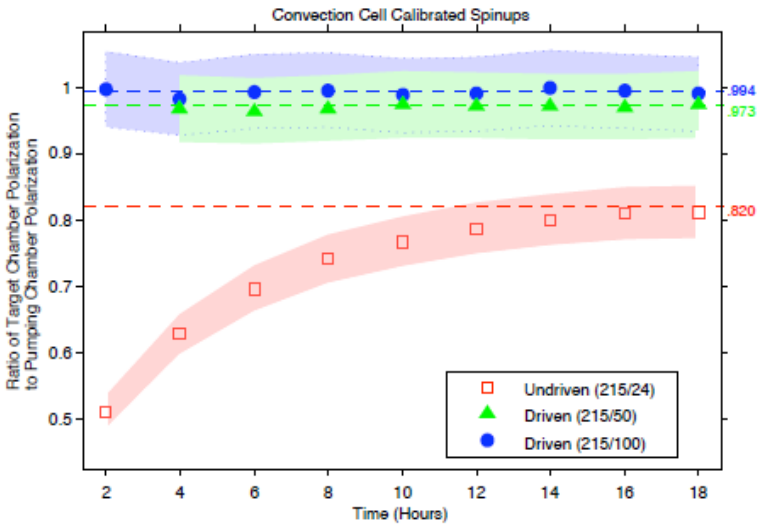


Convection-driven gas-flow test





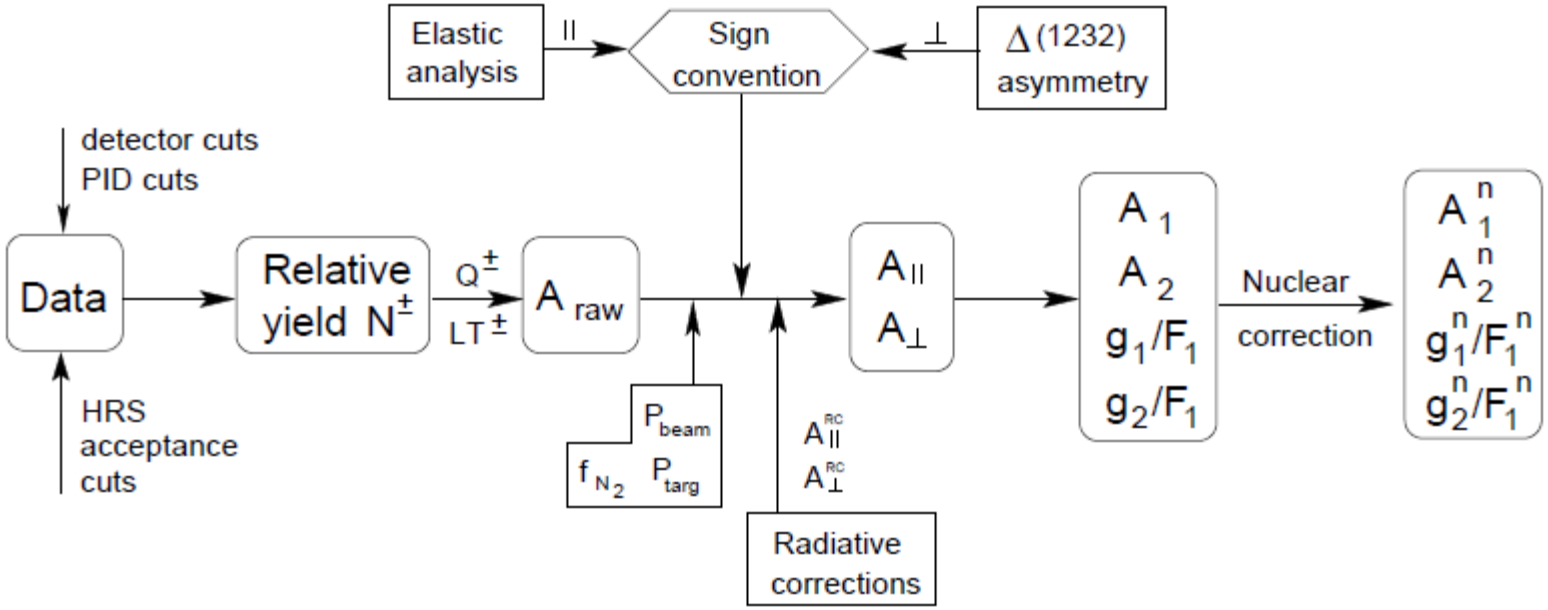
- Heater drives convection
- Zapper coil depolarizes slug of gas
- Coils #1 - #4 monitor passage of depolarized slug.
- Heater temperature can be changed to adjust speed of gas.
- See Dolph, Singh, et al., PRC v84, pg 065201 (2011)



Pulse NMR

- Another polarimetry to measure polarization
- If we use metal, RF is heavily attenuated, the NMR technique of adiabatic fast passage (AFP) is not suitable for hybrid glass/metal cells
- We are working on it now.

From ^{3}He to neutron

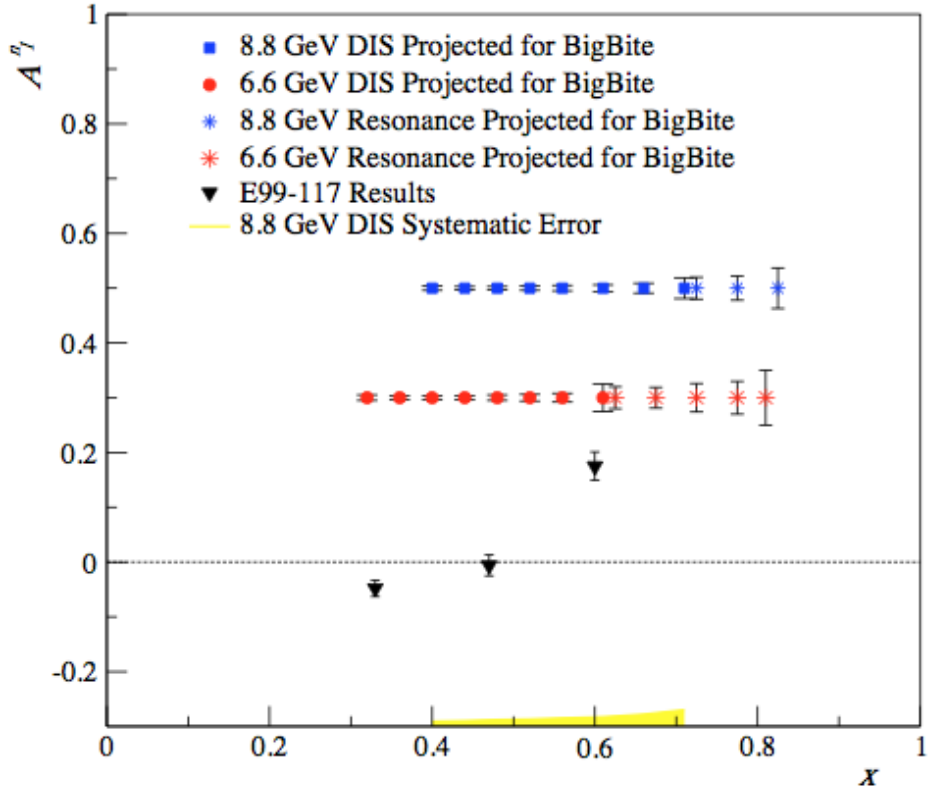


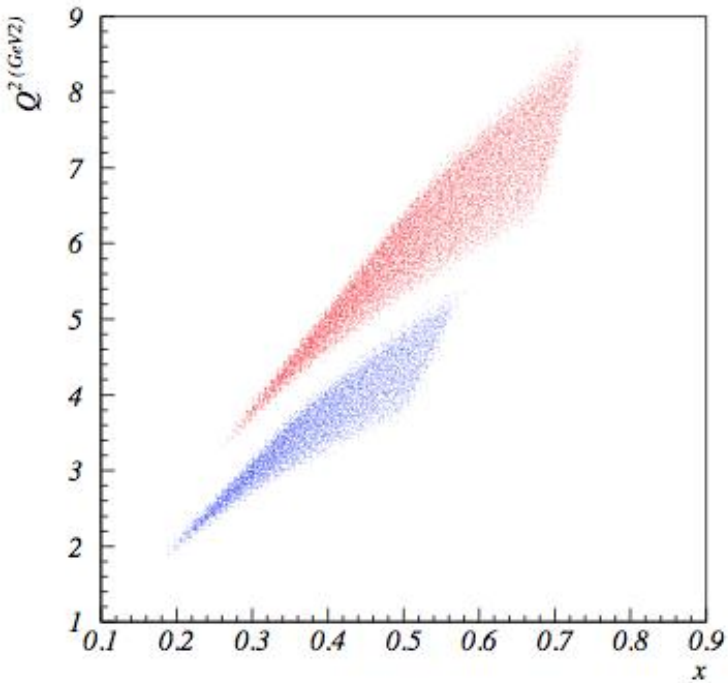
- S, S', D, Δ isobar in 3He wavefunction:

$$A_1^n = \frac{F_2^{3He}}{P_n F_2^n (1+\frac{0.056}{P_n})}\left[A_1^{3He} - 2\frac{F_2^p}{F_2^{3He}} P_p A_1^p \left(1-\frac{0.014}{2P_p}\right)\right]$$

- See Phys. Rev. C65, 064317 (2002)

Expected Results from A_1^n





Note: resonance region data included within BB acceptance

Summary

- Will measure A_1^n up to x = 0.71 in DIS over a wide Q^2 range , test of CQM, pQCD and the role of quark OAM…..;
- allows the study of Q^2 dependence;
- Combined with precision proton data, extract polarized parton distributions