Spin Physics and Applications with Polarized 3He Target

June 10, 2011

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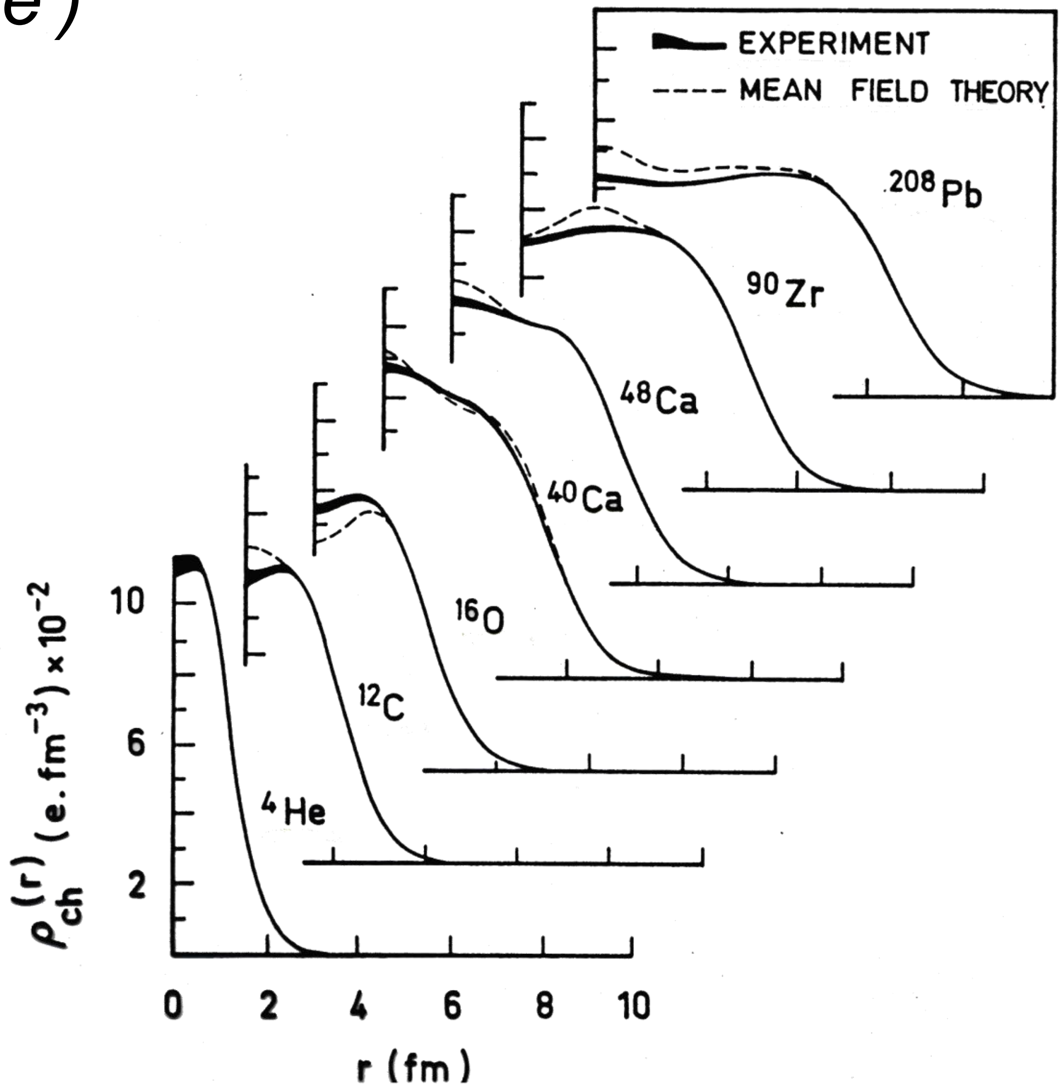
Overview

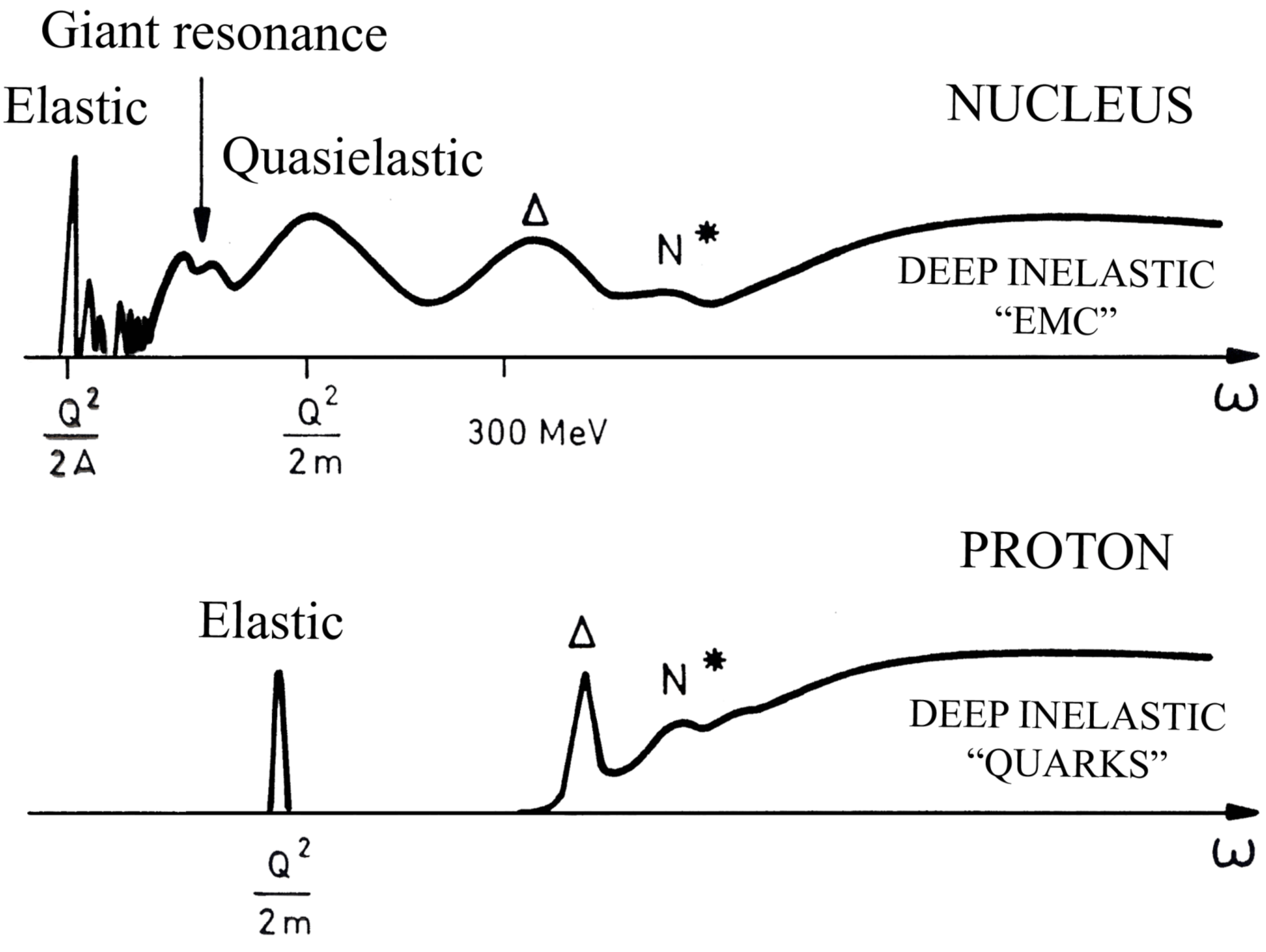
- **Electron Scattering-Kinematics, Spin Structure Function** $p(\vec{e}, e'\pi^+)n$
- **Single Spin Asymmetries Measurement with Transversely Polarized ^{3}He**
- **Production of Polarized ^{3}He Target at KNU**
- **MRI Applications of Polarized ^{3}He**

Ground State Charge Density; Saclay

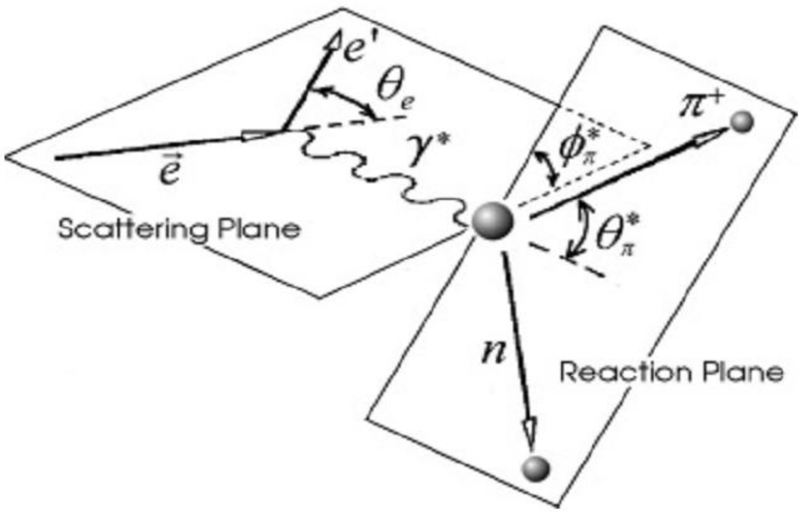
(e,e')



Energy Transfer Dependence of Cross-Section: *(e,e')*



Cross sections and Beam Asymmetries



$$p(\vec{e}, e\pi^+)n$$

Q^2 = 1.7 – 4.5 GeV^2
W = 1.15 – 1.7 GeV

PRC 77, 0152081 (2008)
K. Park, W. Kim et al.

- Over 31,000 Cross-Sections Measured
- Over 4,000 Asymmetries Measured

$$\frac{\partial^5 \sigma}{\partial E_f \partial \Omega_e \partial \Omega_\pi^*} = \Gamma_v \times \frac{d^2\sigma}{d\Omega_\pi^*},$$

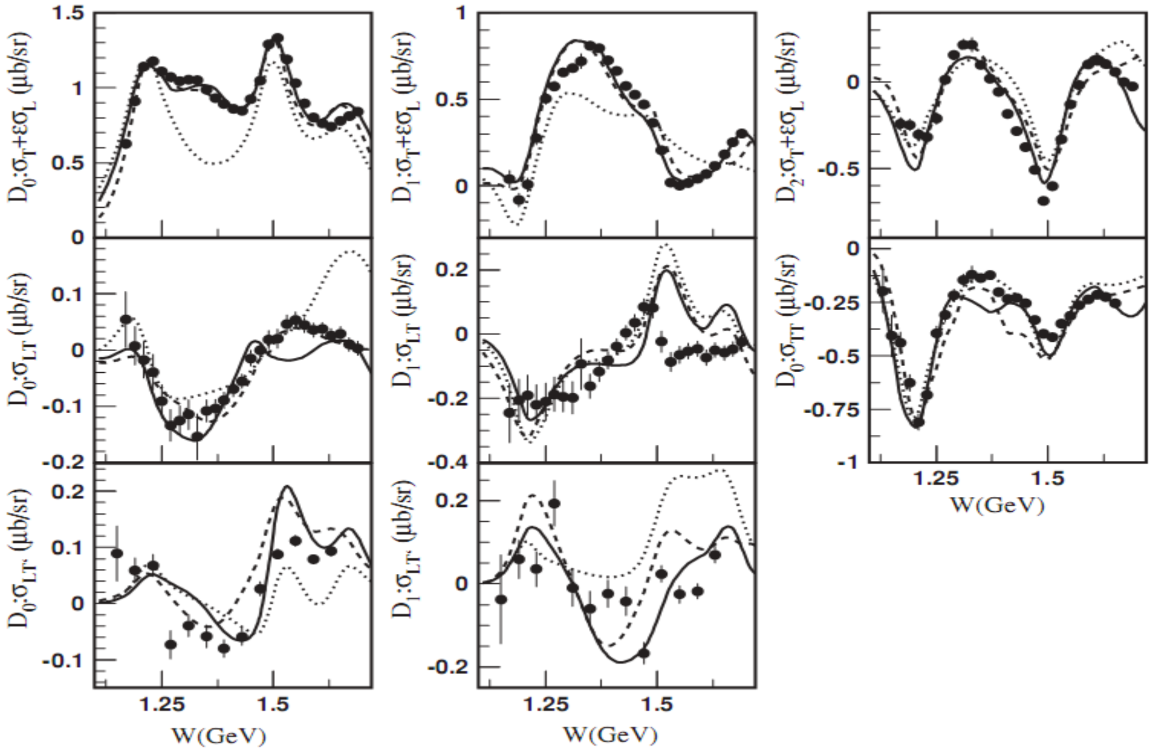
where

$$\Gamma_v = \frac{\alpha}{2\pi^2 Q^2} \frac{(W^2 - M_p^2) E_f}{2 M_p E_e} \frac{1}{1-\epsilon}$$

$$\epsilon = \left[1 + 2\left(1 + \frac{\nu^2}{Q^2}\right)\tan^2\frac{\theta_e}{2}\right]^{-1}$$

$$\frac{d^2\sigma}{d\Omega_\pi^*} = \sigma_T + \epsilon\sigma_L + \epsilon\sigma_{TT}\cos 2\phi_\pi^* + \sqrt{2\epsilon(1+\epsilon)}\sigma_{LT}\cos\phi_\pi^* + h\sqrt{2\epsilon(1-\epsilon)}\sigma_{LT'}\sin\phi_\pi^*.$$

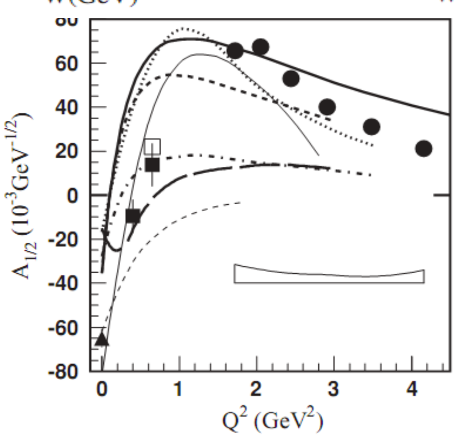
Electroexcitation of the Roper resonance for $1.7<Q^2<4.5$ GeV^2



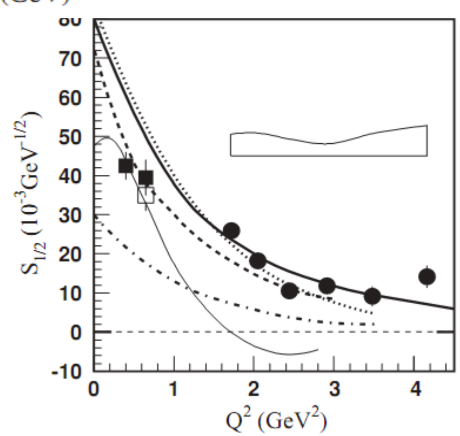
G. Aznauiy, K. Park, W.Kim P RC 78 (2008),
PRC 80 (2009).

Dispersion Relation

Unitary Isobar Model.



Transverse



Longitudinal

Helicity Amplitude for:

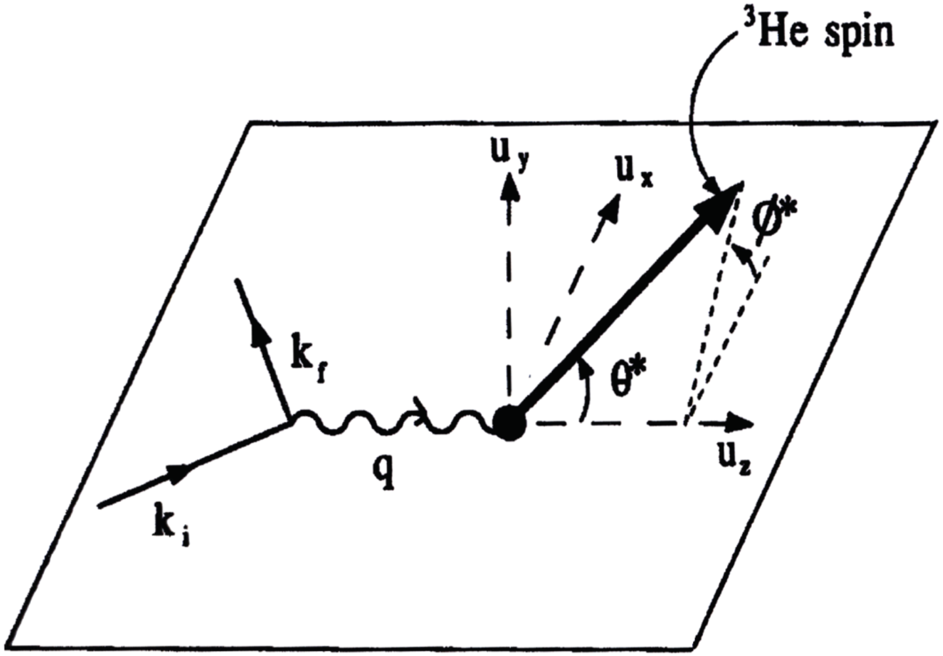
$$\gamma^* p \rightarrow N(1440)P_{11}$$

Transition:

A first Radial Excitation of the 3q Ground State

Additional Nuclear Structure Information

$$\vec{p}(\vec{e}, e' p)\pi^0$$

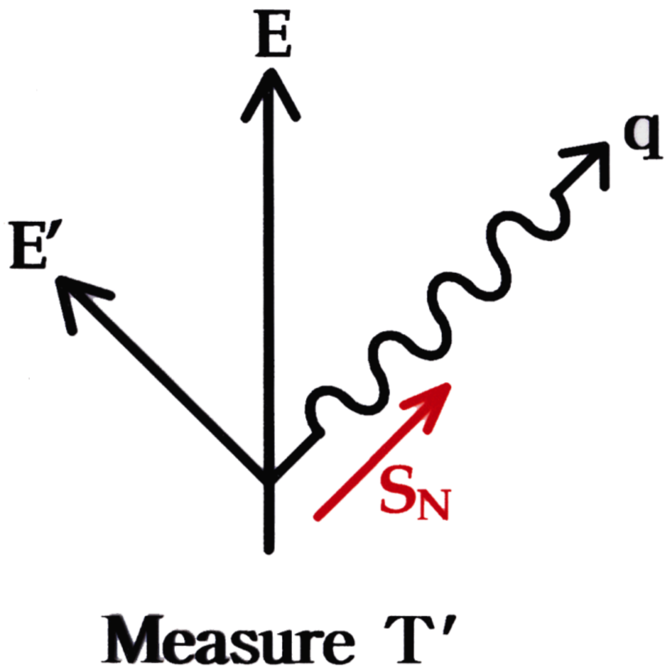


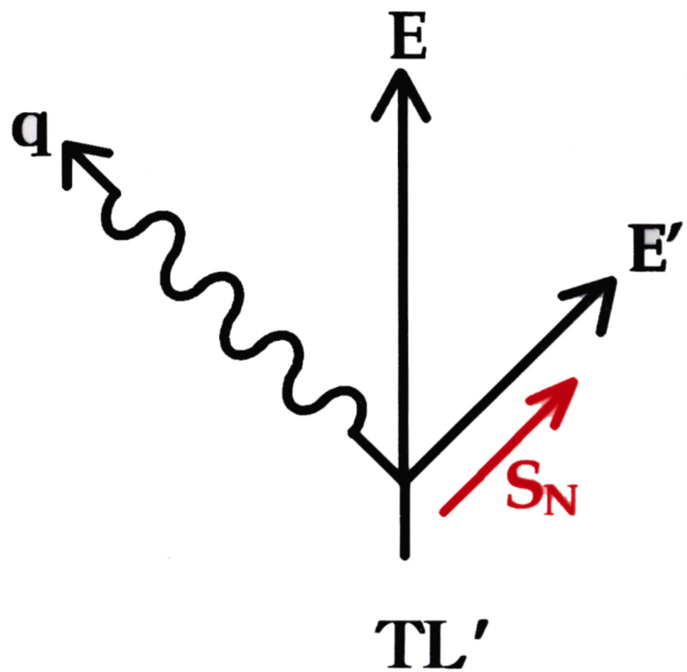
$$\frac{d^2\sigma}{d\Omega d\omega} = \sum \pm \Delta h(\theta^*, \phi^*)$$

$$A = \frac{\cos\theta^* v_{T'} R_{T'} + 2\sin\theta^* \cos\phi^* v_{TL'} R_{TL'}}{v_L R_L + v_T R_T}$$

Super-Rosenbluth Separation

Simultaneous Measurements of T' and TL' asymmetries

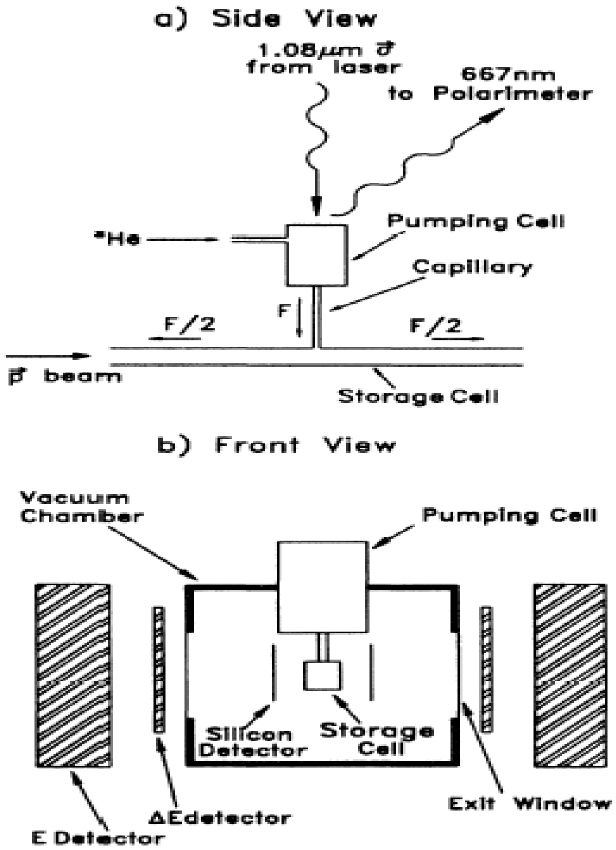


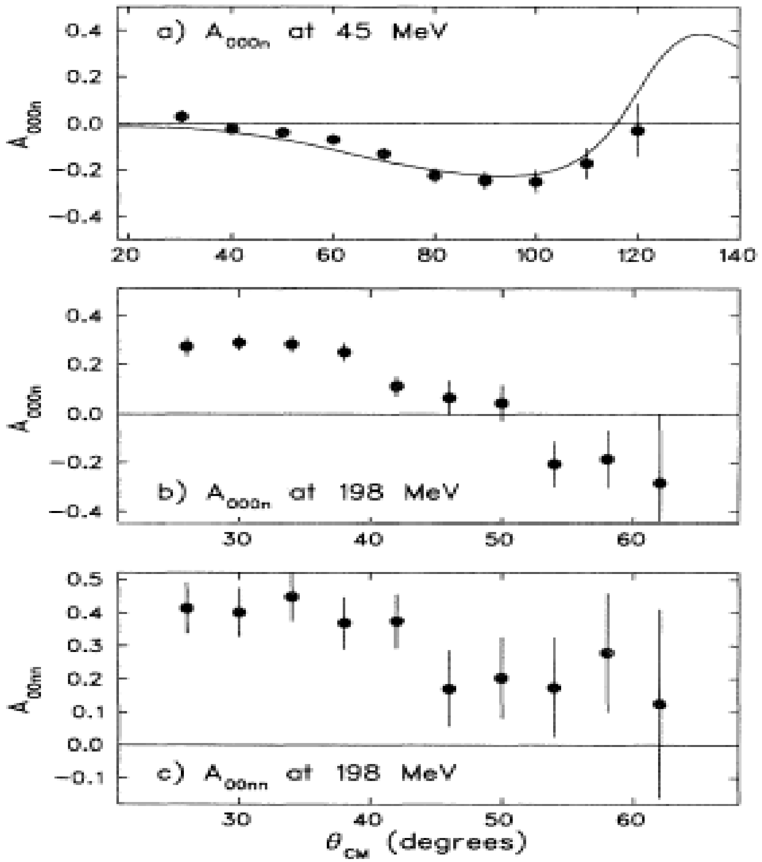


Symmetric Detector

Measurement of Spin Observables Using a Storage Ring with Polarized Beam and Polarized Internal Gas Target

$\overrightarrow{{}^3He}\,(\vec{p},p')$ **IUCF K. Lee et al., PRL 70, 738 (1993)**

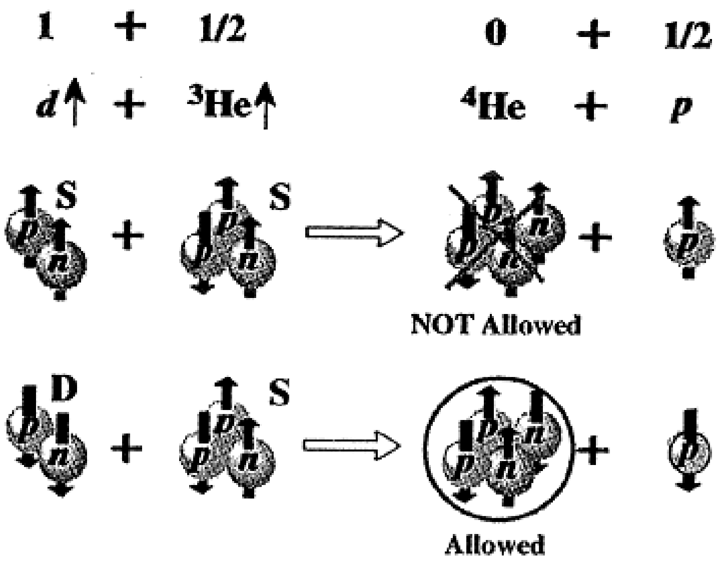


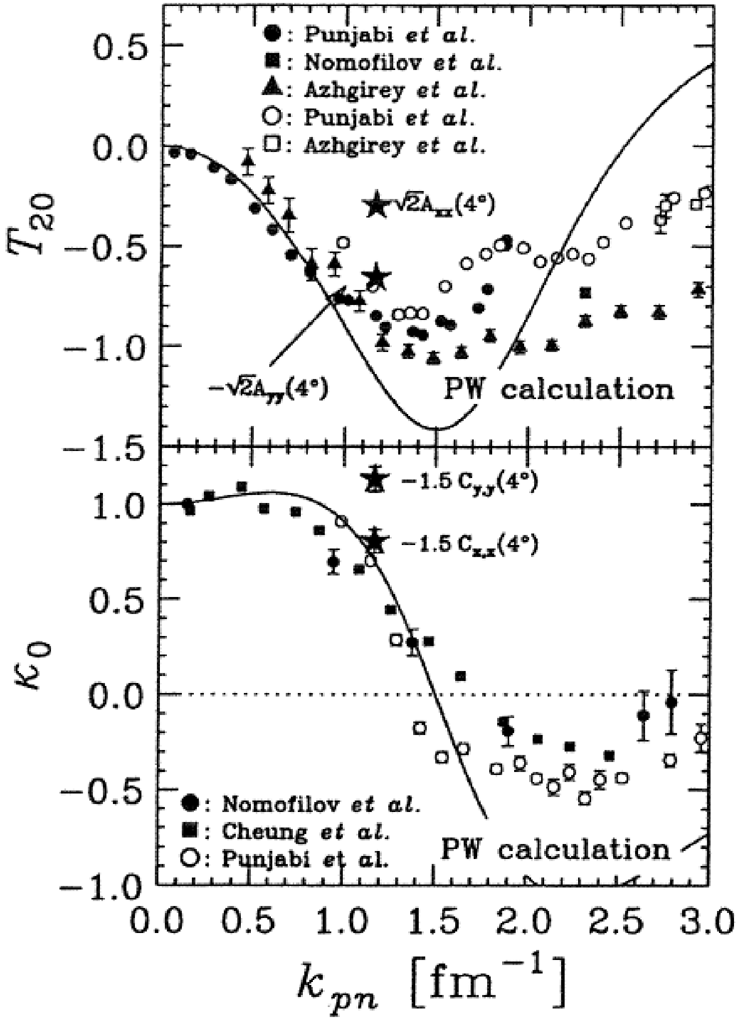


Polarization Correlation Coefficient

T. Uesaka et al.,
PL B 467 (1999),
RIKEN

$$^{3}\vec{He}\left(\overrightarrow{d},p\right)\ ^{4}He$$





“Neutron Transversity” Experiment at JLab

Xiaodong Jiang, W. Kim et. al.

- Introduction

  Collins effect: transversely polarized quarks generate left-right bias in fragmentation.

  Sivers effect: quarks’ transverse motion generate left-right bias in “effective” density.

- HERMES and COMAPSS results of SIDIS target single-spin asymmetry.
  - HERMES proton published results.
  - COMPASS deuteron published results.

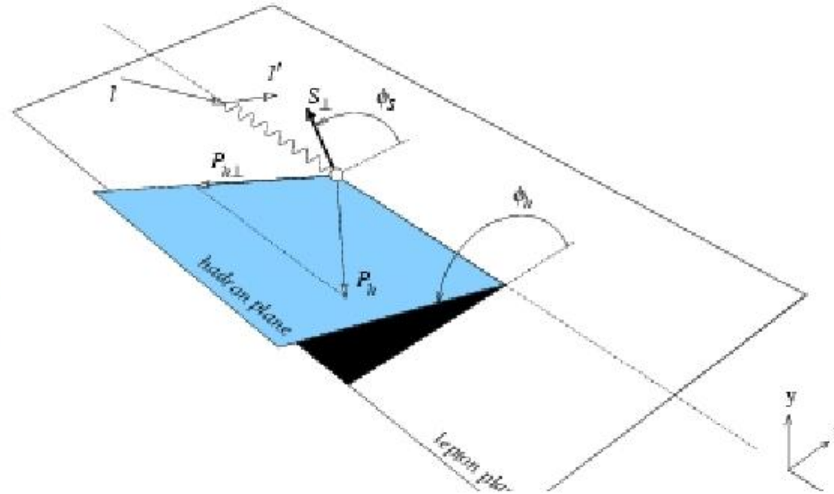
- **JLab Hall A “Neutron Transversity” Experiment (E06-010 SIDIS).**
  - **Preliminary results of ^{3}He single-spin asymmetries A_{UT}.**

Left-Right Asymmetries

Left-Right Asymmetries

Collins and Sivers Effects can be Separated in Semi-Inclusive Deep-Inelastic Scattering Experiments

$$A_{UT}(\phi_h^l, \phi_S^l) = \frac{N^\uparrow - N^\downarrow}{N^\uparrow + N^\downarrow}$$



$$\sigma_{UT} \propto S_T(1-y)\frac{P_{h\perp}}{zM_h}\sin(\phi_h^\ell + \phi_S^\ell)\cdot\sum e_q^2\, h_1^q(x)\otimes H_{1q}^{\perp h}(z, P_{h\perp}^2)$$
$$+ \; S_T(1-y+\frac{y^2}{2})\frac{P_{h\perp}}{zM_N}\sin(\phi_h^\ell - \phi_S^\ell)\cdot\sum e_q^2\, f_{1T}^{\perp q}(x)\otimes D_{1q}^h(z_h, P_{h\perp}^2)$$

Collins effect (linked with transversity h_1) and Sivers effect (linked with T-Odd distribution f_{1T}) can be separate through the angular dependence of the asymmetries.

Single Spin Asymmetries in Charged Pion Production from Semi-Inclusive Deep Inelastic Scattering on a Transversely Polarized ^{3}He Target

- The first measurement of target single spin asymmetries in the semi-inclusive 3He(e, $e'\pi^{\pm}$)X reaction on a transversely polarized target.
- Conducted at Jefferson Lab using a 5.9 GeV electron beam, covers a range of $0.14 < x < 0.34$ with $1.3 < Q^2 < 2.7\ GeV^2$
- Collins and Sivers moments were extracted from the angular dependence of the measured SSAs.

Angular Dependence of the Spin-Dependent Asymmetry

In the scattering of an unpolarized lepton beam by a transversely polarized target is described at leading twist in terms of the moments equations:

- Collins: $A_C \equiv 2\langle \sin(\phi_h + \phi_S) \rangle$
- Sivers: $A_S \equiv 2\langle \sin(\phi_h - \phi_S) \rangle$

$$
\begin{aligned}
A(\phi_h, \phi_S) &= \frac{1}{P} \frac{Y_{\phi_h,\phi_S} - Y_{\phi_h,\phi_S+\pi}}{Y_{\phi_h,\phi_S} + Y_{\phi_h,\phi_S+\pi}} \\
&\approx A_C \sin(\phi_h + \phi_S) + A_S \sin(\phi_h - \phi_S) \\
&+ A_{pretz} \sin(3\phi_h - \phi_S),
\end{aligned}
$$

P : target polarization

ϕ_h and ϕ_S : azimuthal angles of the hadron and the target spin relative to the lepton scattering plane

Approach of Nucleon Effective Polarization

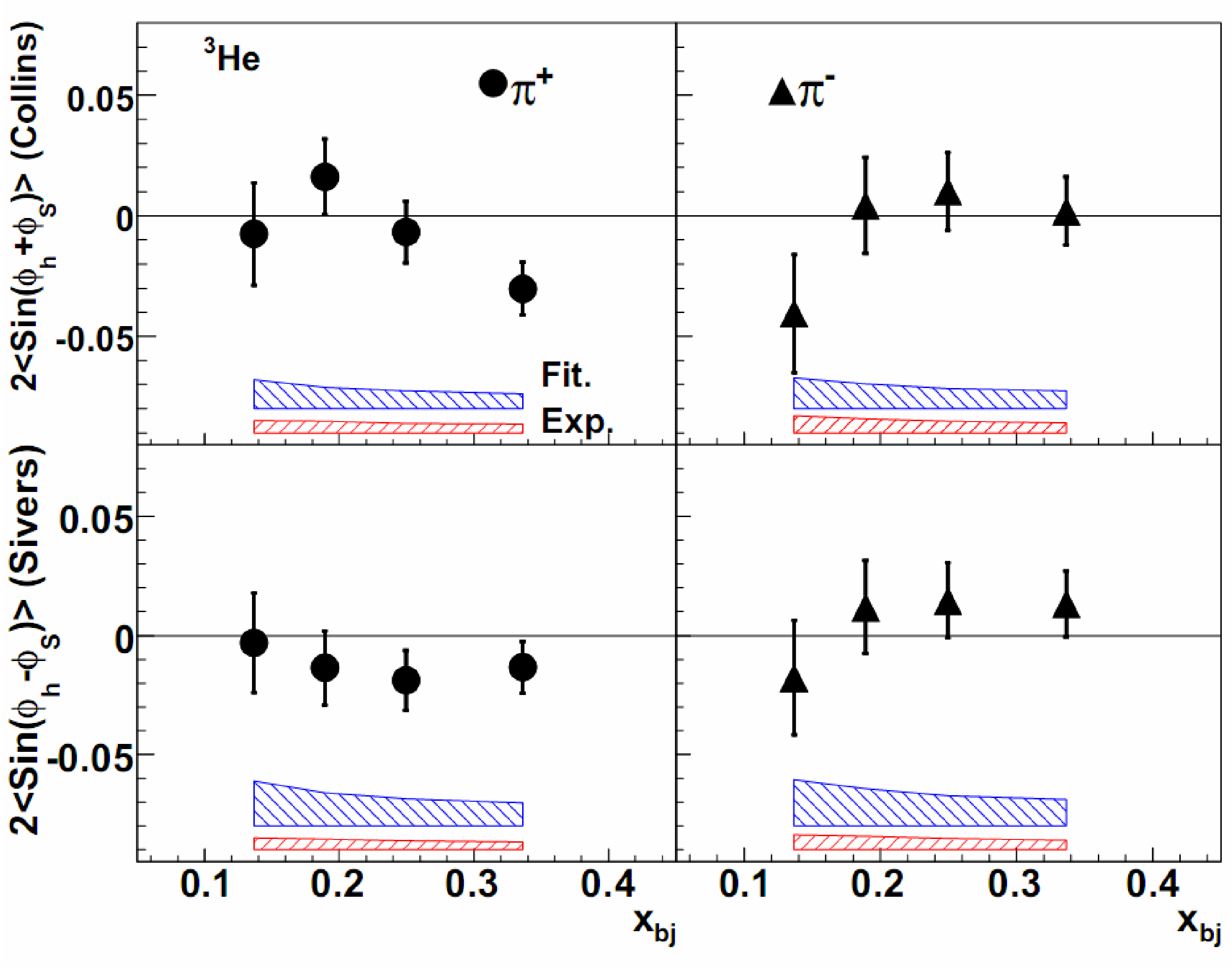
- 3He is uniquely advantageous in the extraction of neutron information because:
  - In 3He nucleus, the nuclear spin resides predominantly on the neutron
  - While in deuteron, combined effects of proton and neutron are probed
- Recent calculations by Scopetta of the 3He Collins/Sivers SSAs have shown the approach of Nucleon Effective Polarization:

$$A_{^3\mathrm{He}}^{C/S} = P_n \cdot (1 - f_p) \cdot A_n^{C/S} + P_p f_p \cdot A_p^{C/S}$$

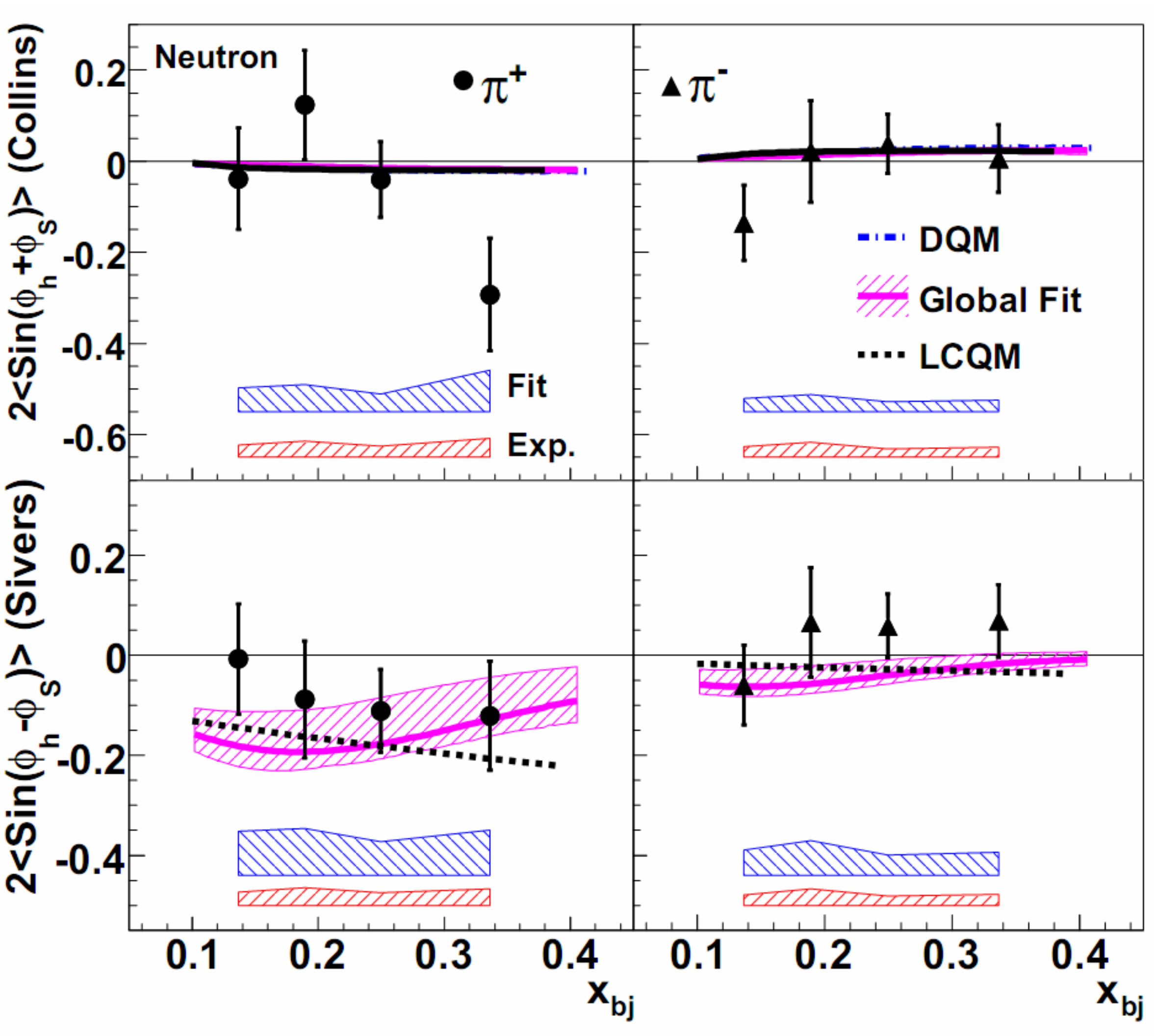
where $P_n = 0.86^{+0.036}_{-0.02}$ $(P_p = -0.028^{+0.009}_{-0.004})$

is the neutron (proton) effective polarization

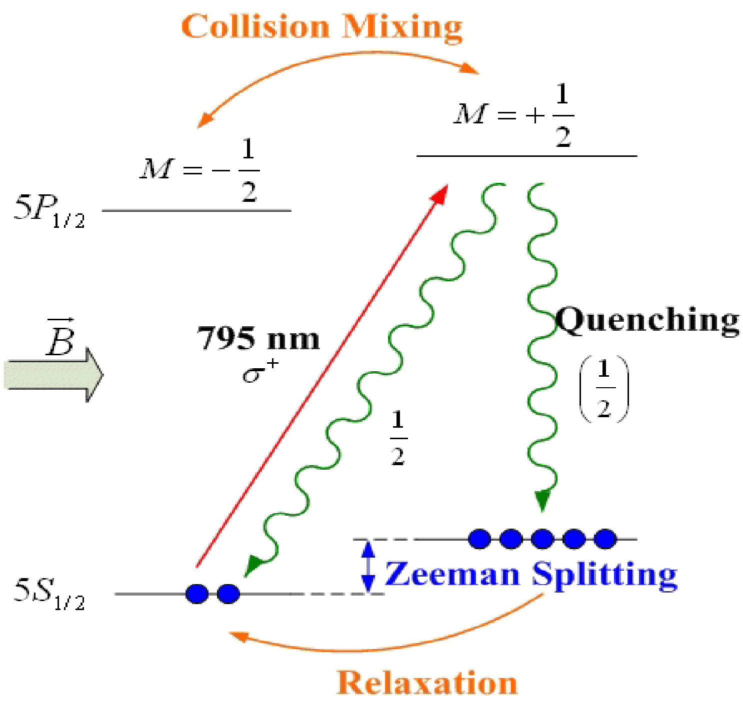
Collins and Sivers Moments on 3He for both π+ and π− Electro-Production

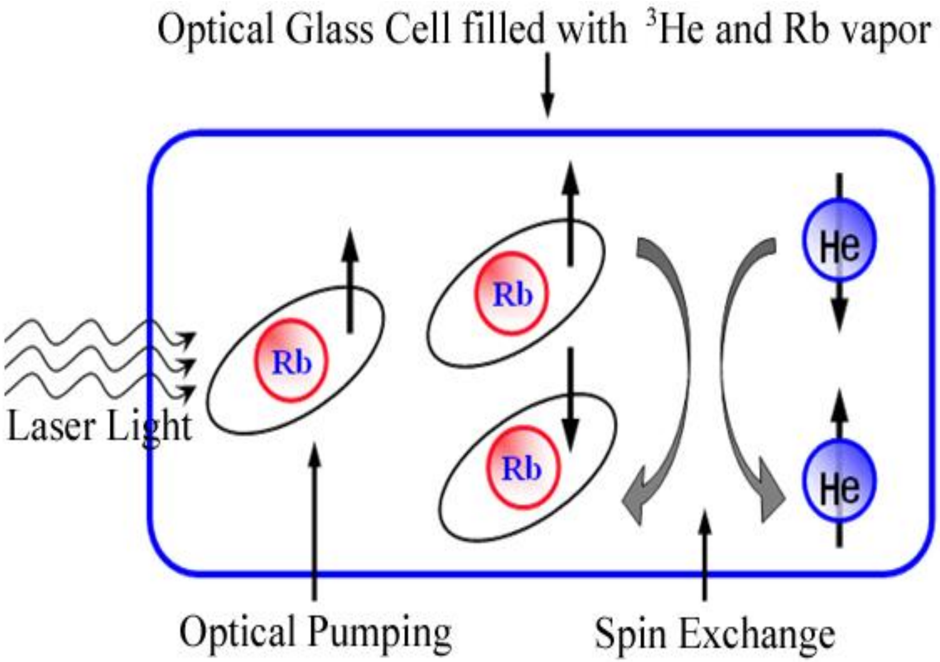


Collins and Sivers Moments on Neutron for both π+ and π− Electro-Production

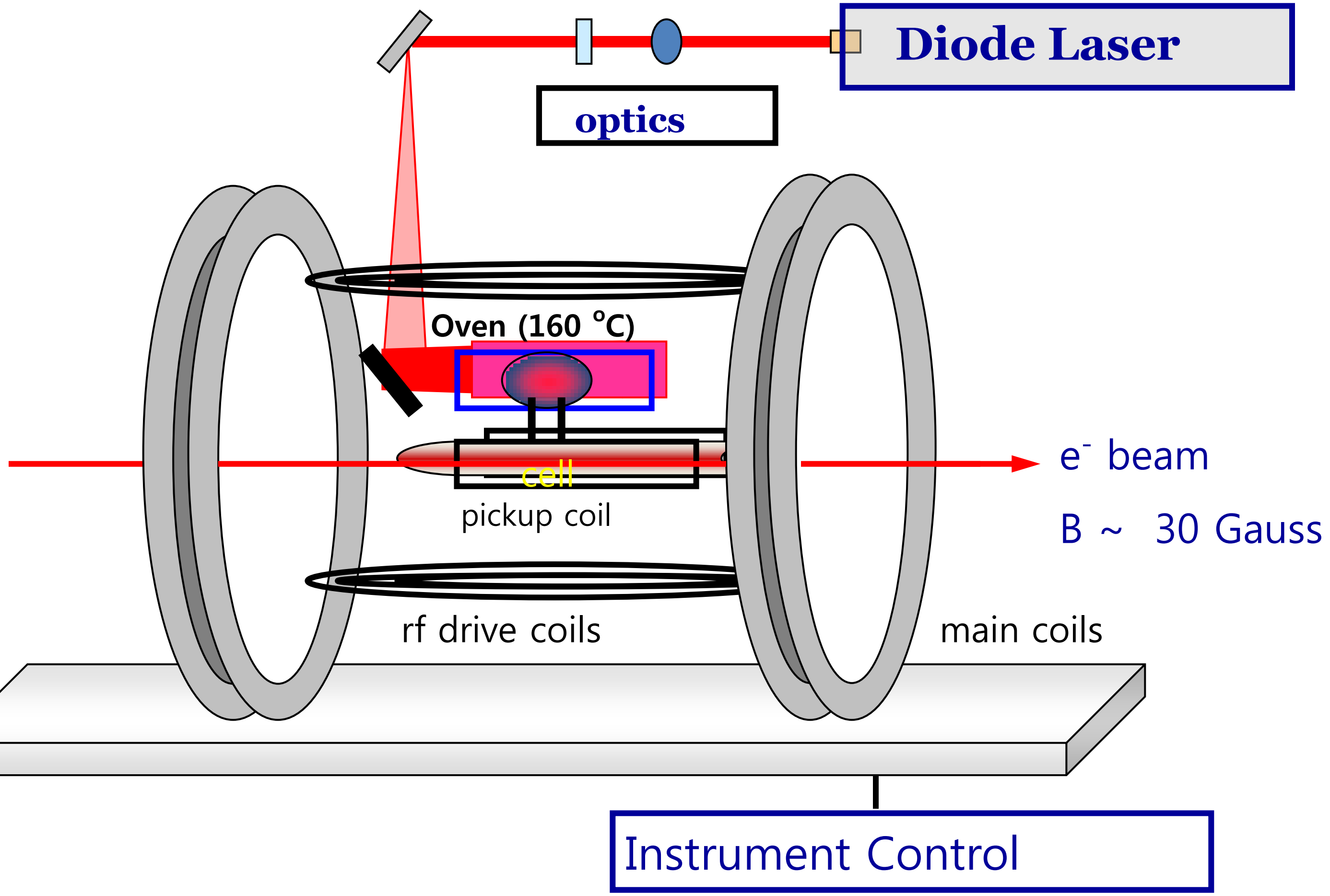


Optical Pumping and Spin Exchange



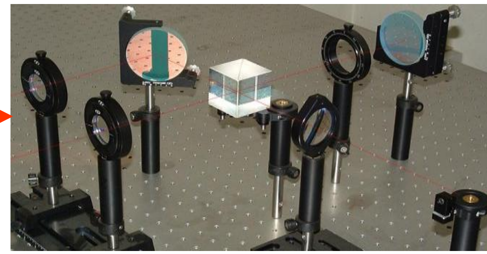


Polarized ^{3}He Setup with Electron Beams



Experimental Setup

Laser



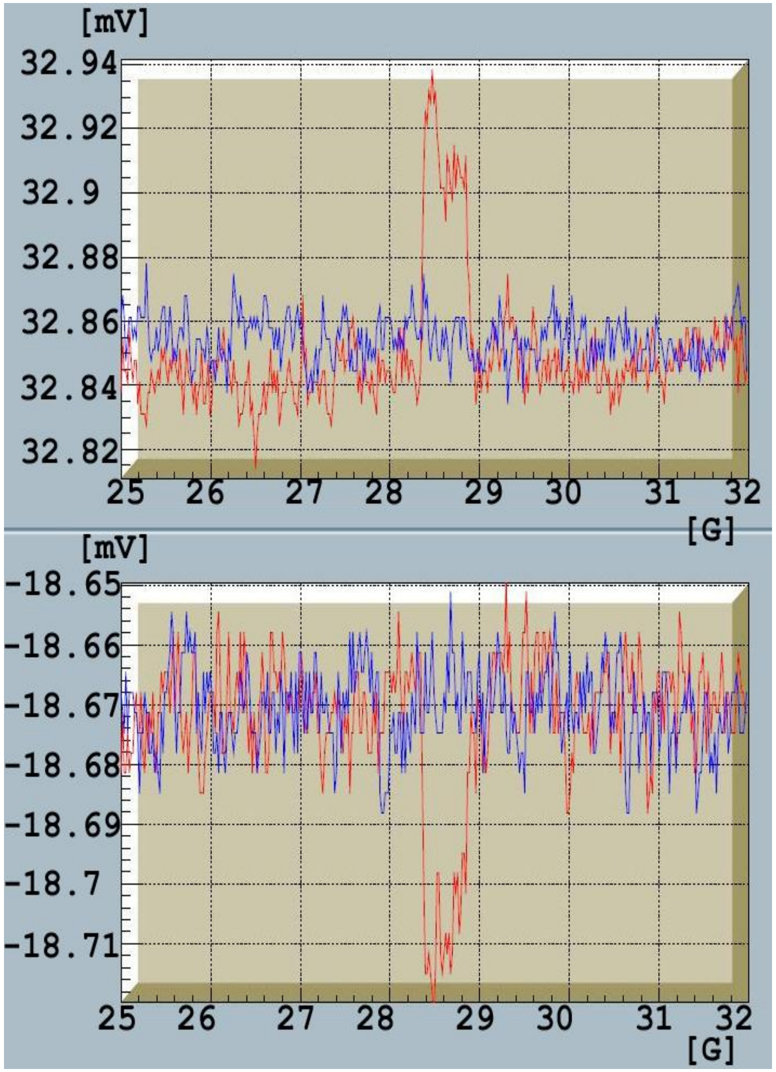
Optics system

Oven, coils and heaters

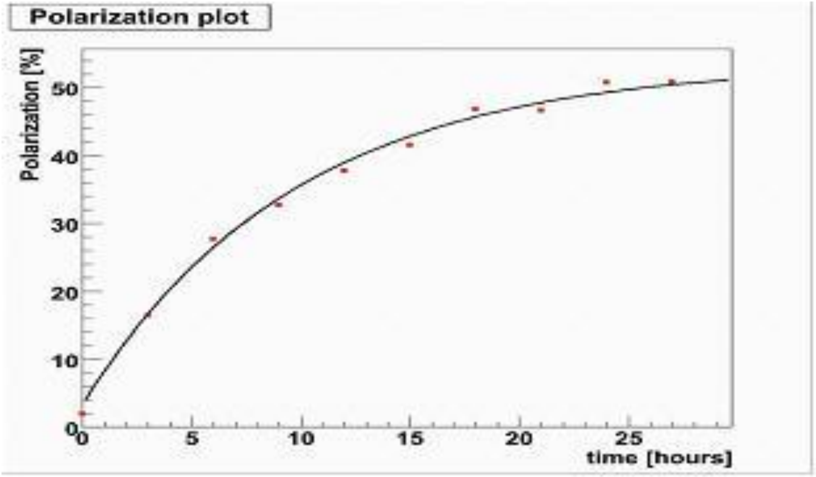
Ion pump and gas panel

500^0C Oven to bake cell assembly

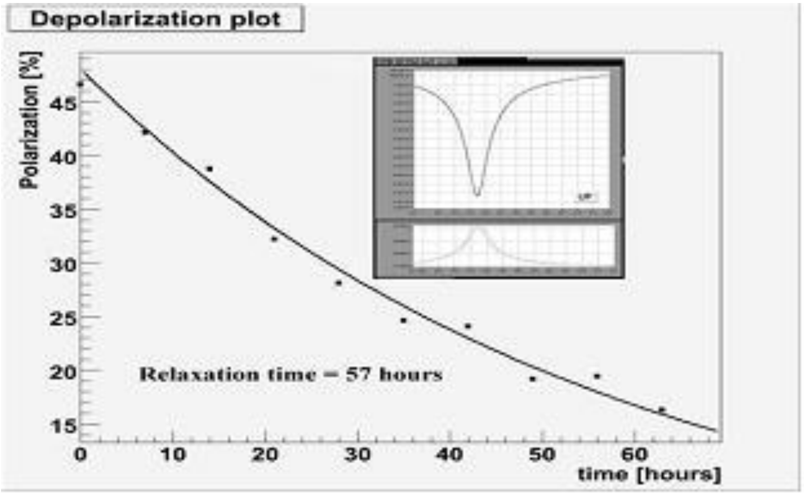
Results : Polarized ^{3}He



^{3}He NMR Signal

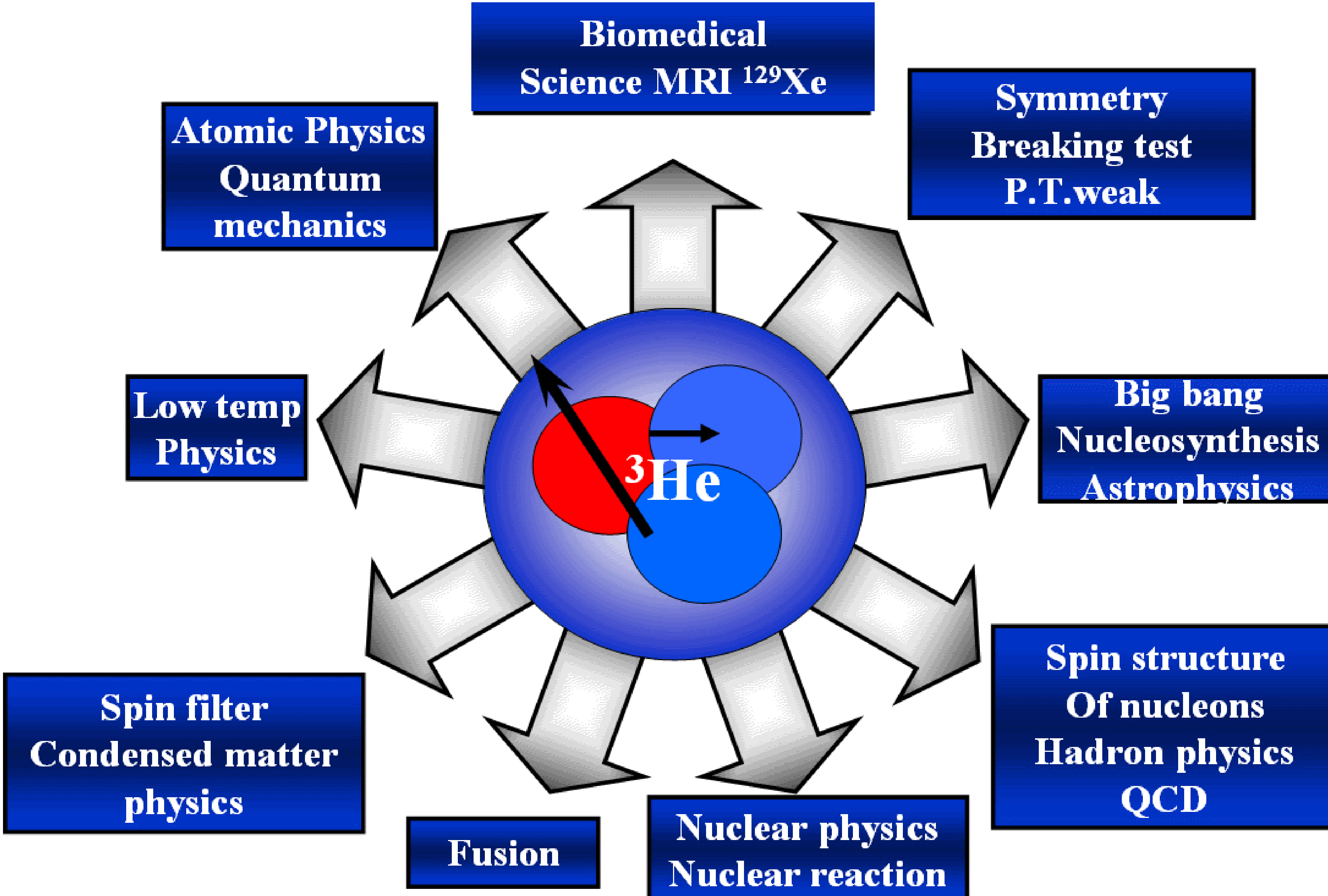


Polarization Dependence on time



Exponential Decay of polarization

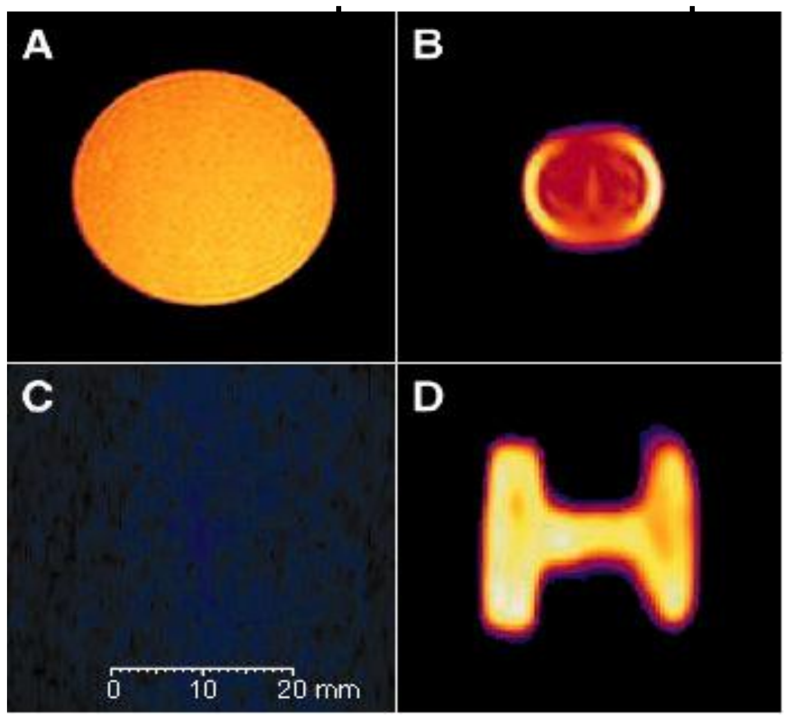
2007.9.5 Polarized ^{3}He achieved in Korea for the first time


Biomedical
Science MRI ^{129}Xe
Atomic Physics
Quantum
mechanics
Symmetry
Breaking test
P.T.weak
Low temp
Physics
Big bang
Nucleosynthesis
Astrophysics
^{3}He
Spin filter
Condensed matter
physics
Spin structure
Of nucleons
Hadron physics
QCD
Fusion
Nuclear physics
Nuclear reaction

Comparison of water and 3He MRI

2 Tesla

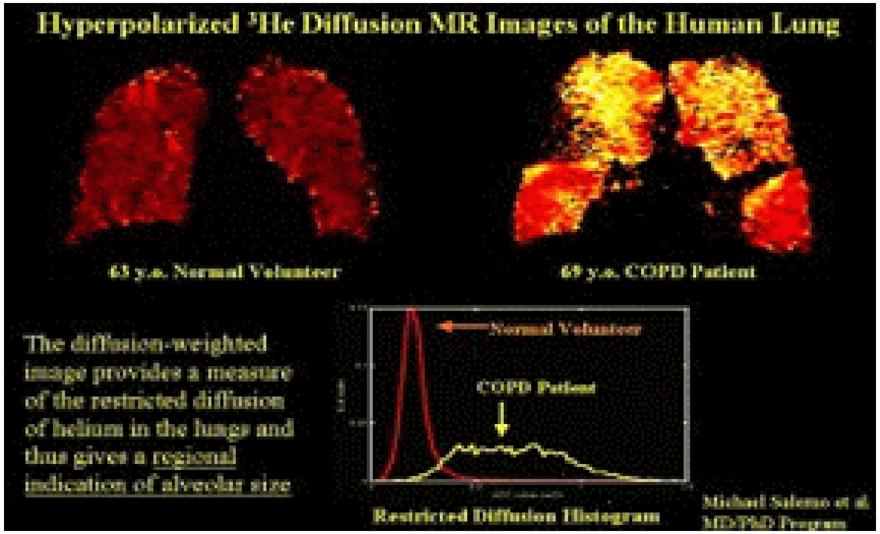
21 Gauss



Water

He 3

Image of low-field MRI



Healthy and unhealthy lungs

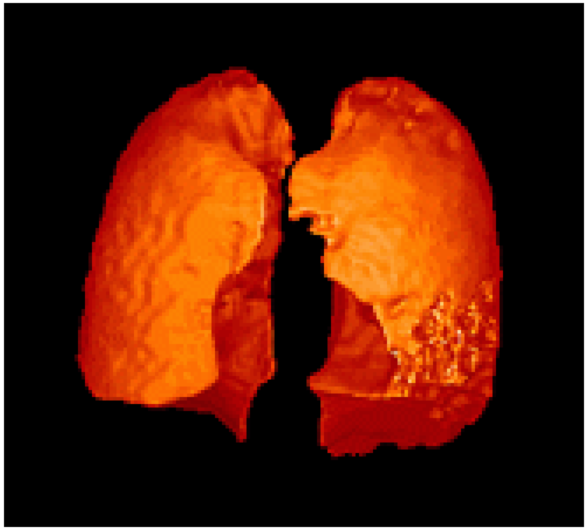


Image of human lung

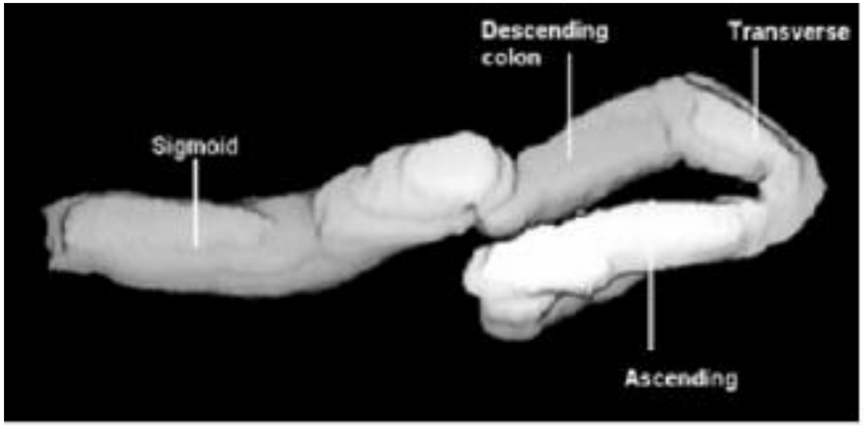
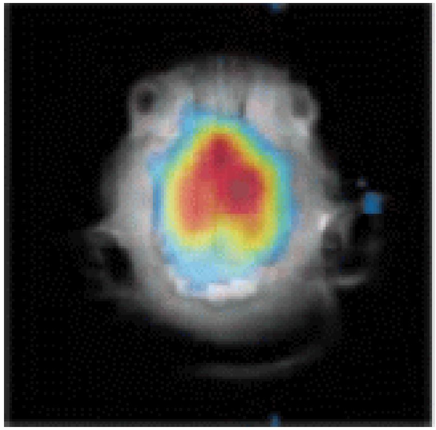
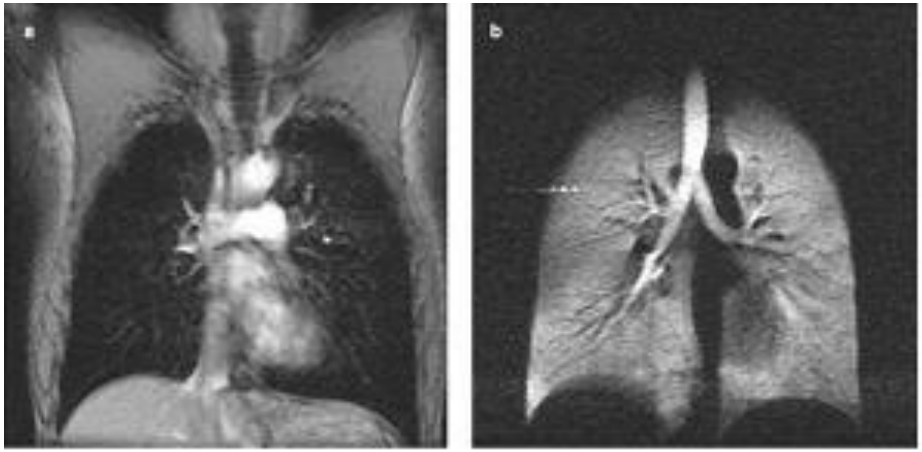


Image of polarized 3He injecting into dog's intestine

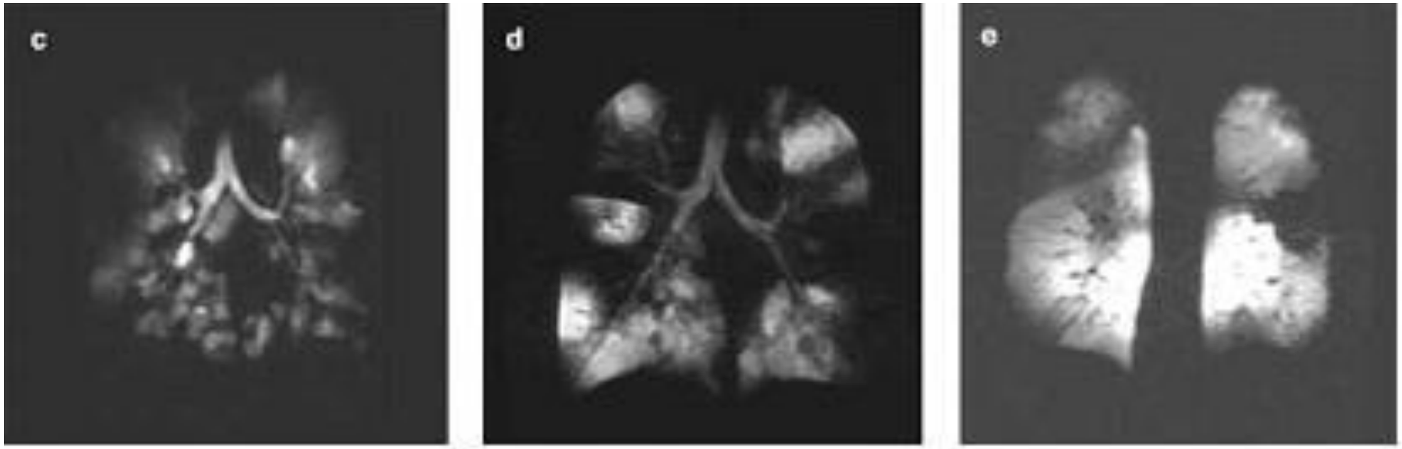


MRI of mouse brain using ^{129}Xe

Low-field MRI Image for medical diagnosis

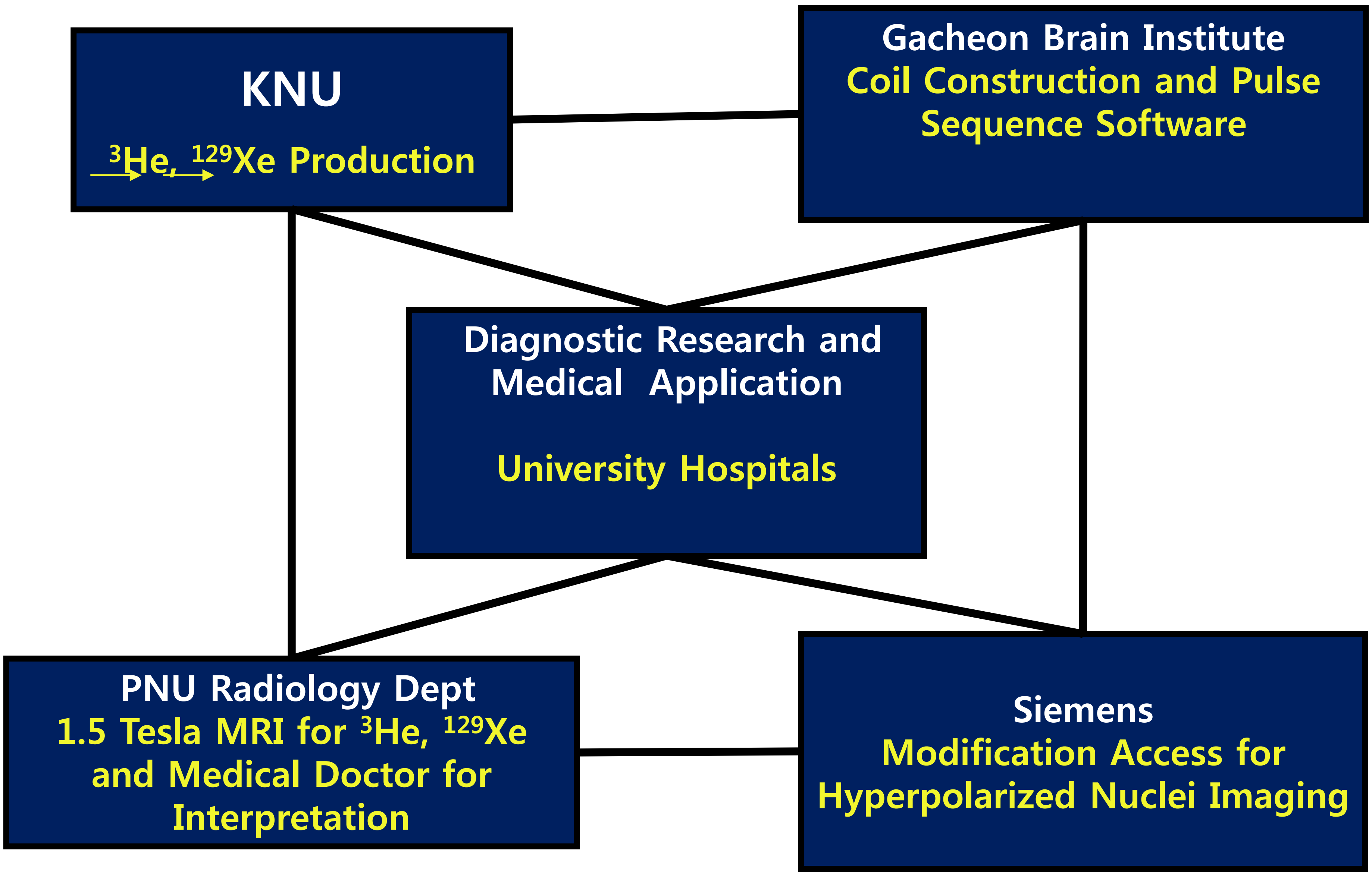


Comparison MRI Image of human body
(a) 20,000 Gauss ^{1}H MRI (b) 20 Gauss polarized ^{3}He MRI



Unhealthy lung's MRI Image using polarized ^{3}He gas

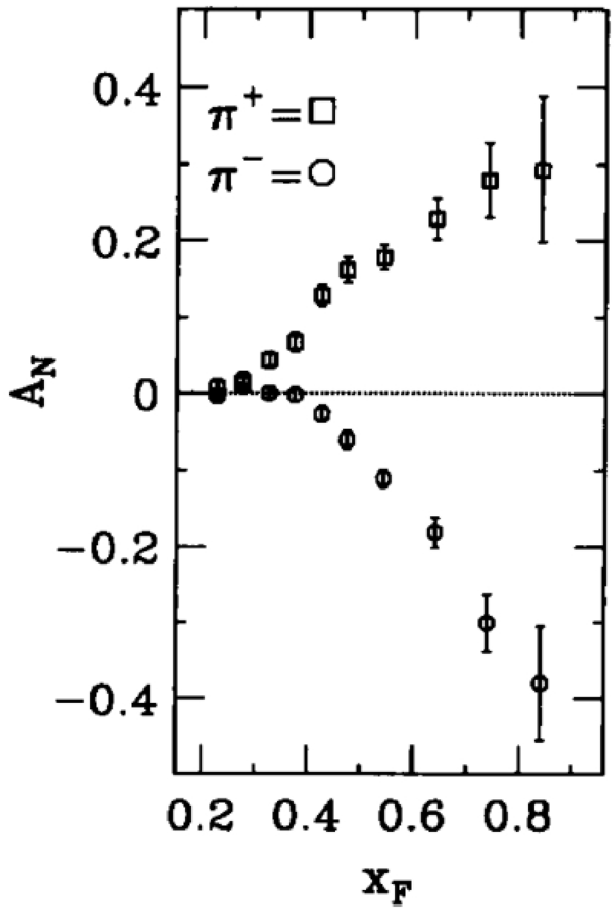
Plan for MRI Research



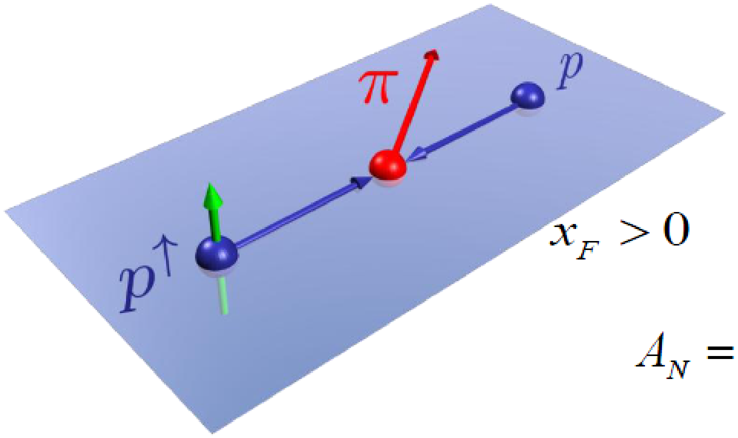
Summary

- The first measurement of the target single spin asymmetries in semi-inclusive charged pion electroproduction on a transversely polarized ^3He target.
- The extracted neutron results are consistent with the predictions of global phenomenolo gical fits and quark model calculations.
- Demonstrated the power of polarized ^3He as an effective polarized neutron target.
- 3He Applications for MRI

Quarks can tell left-right in $p\,p^{\uparrow} \rightarrow \pi X$



FNAL-E704: √s =20 GeV. PLB 264 (1991) 462.



$$A_N = \frac{\sigma^{\uparrow} - \sigma^{\downarrow}}{\sigma^{\uparrow} + \sigma^{\downarrow}}$$

$\pi^+ \ (u\bar{d})$ favors left

$\pi^- \ (d\bar{u})$ favors right

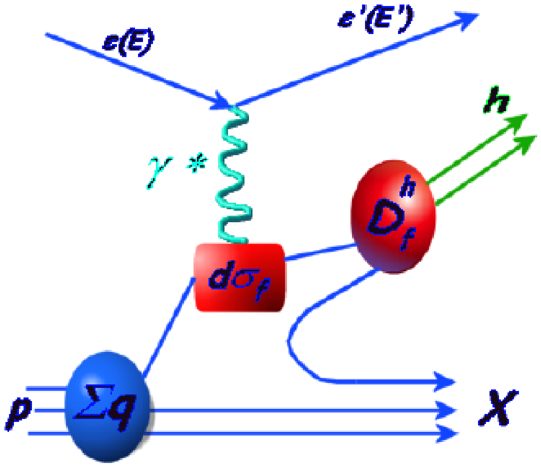
One explanation (Sivers effect):
quark's angular motion generates a left-right density difference.

up-quarks favor left (L_u>0), down-quarks favor right (L_d<0).

to access quark transversity distributions …

- Transversity distribution is chiral--odd, not accessible through inclusive deep-inelastic scattering. Need to be combined with another chiral-odd object, i.e. Collins fragmentation function.

Through target single spin asymmetry in semi-inclusive DIS.
J.C. Collins, NPB 396, 161(1993).

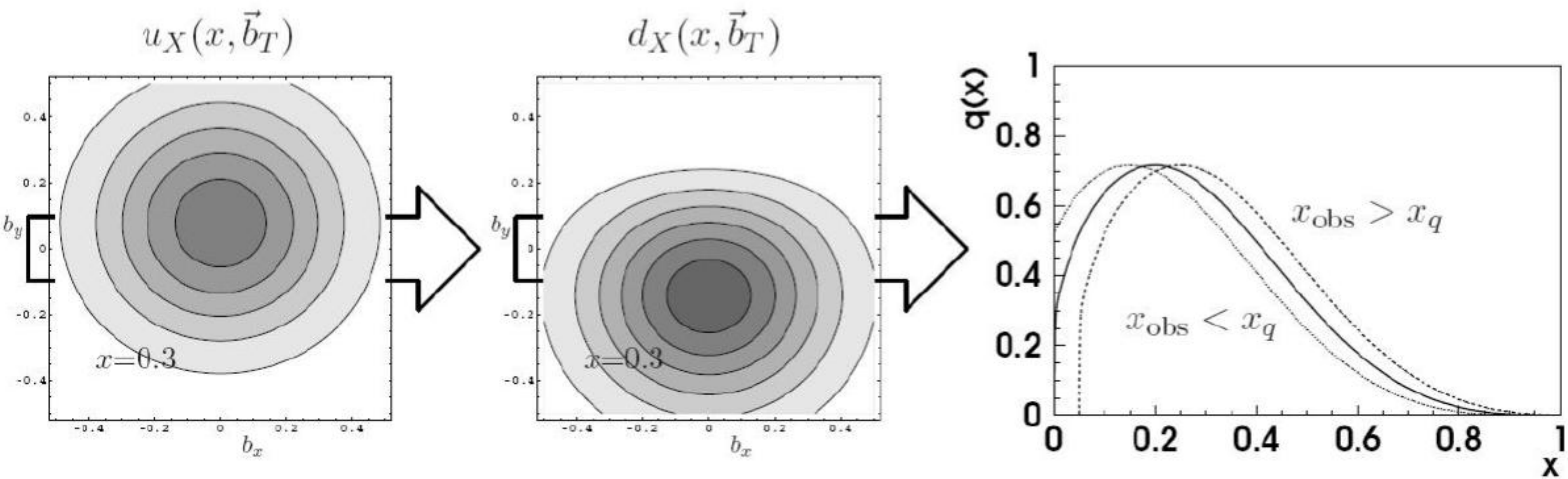


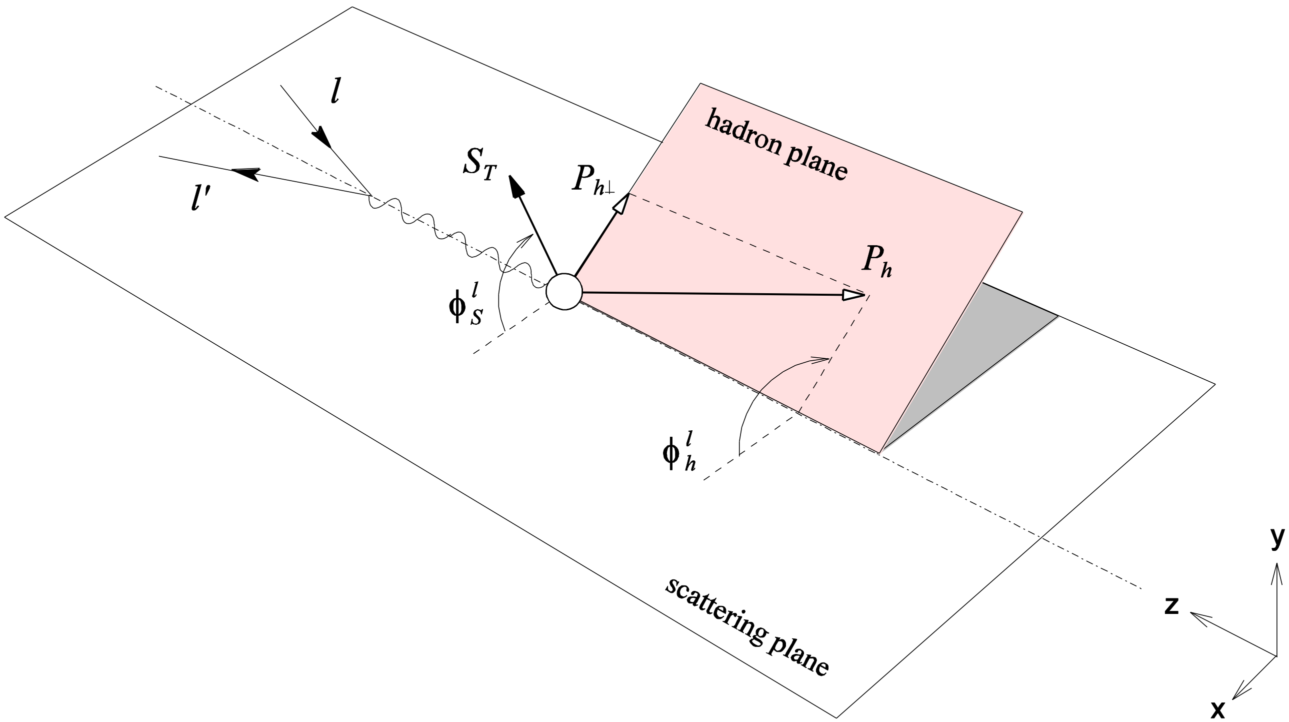
$$A_{UT}^{Collins}(x,z) \propto \frac{\sum_q e_q^2\, \delta q(x) \otimes H_{1q}^{\perp h}(z, P_{h\perp}^2)}{\sum_q e_q^2\, q(x) \otimes D_{1q}^{h}(z, P_{h\perp}^2)}$$

Collins frag. fun. can be accessed in e^+e^- collisions.

Sivers: with transverse motion, quarks on one side of the nucleon are moving towards the probe while on the other side are moving away from the probe.

Left and right are different.





l
l′
S_T
P_h⊥
hadron plane
P_h
ϕ_S^l
ϕ_h^l
scattering plane
y
z
x