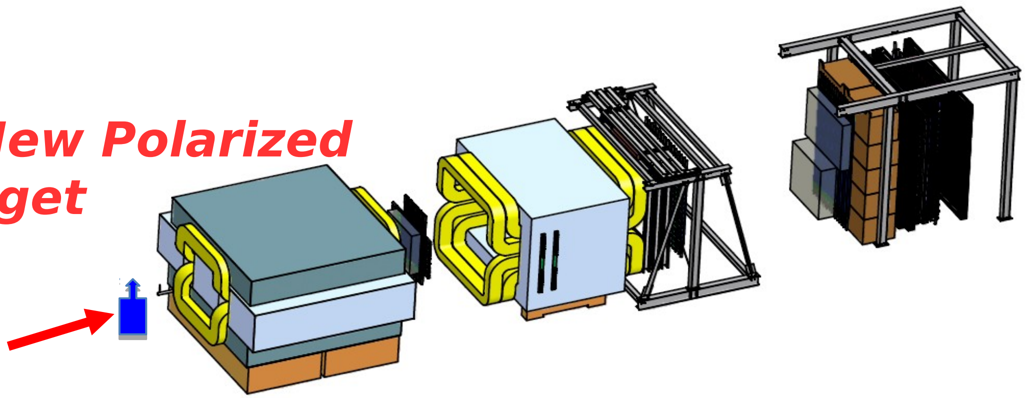
Polarized Fixed Target Dimuon Drell-Yan Experiment at Fermilab

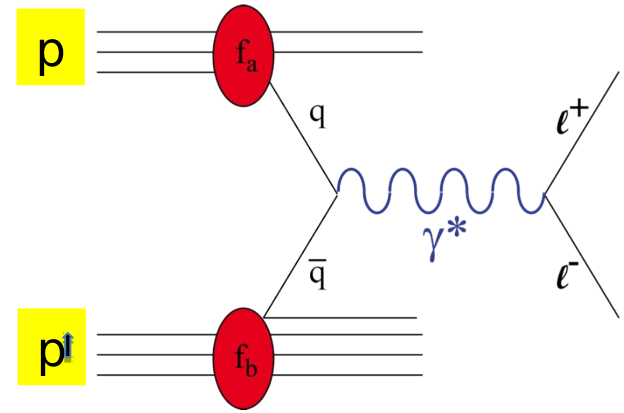
Ming Liu
Los Alamos National Laboratory
(E1039 Collaboration)

E1039 Experiment @Fermilab

Take advantage of the current E906 Drell-Yan Exp. @Fermilab, develop a new polarized hadron physics program

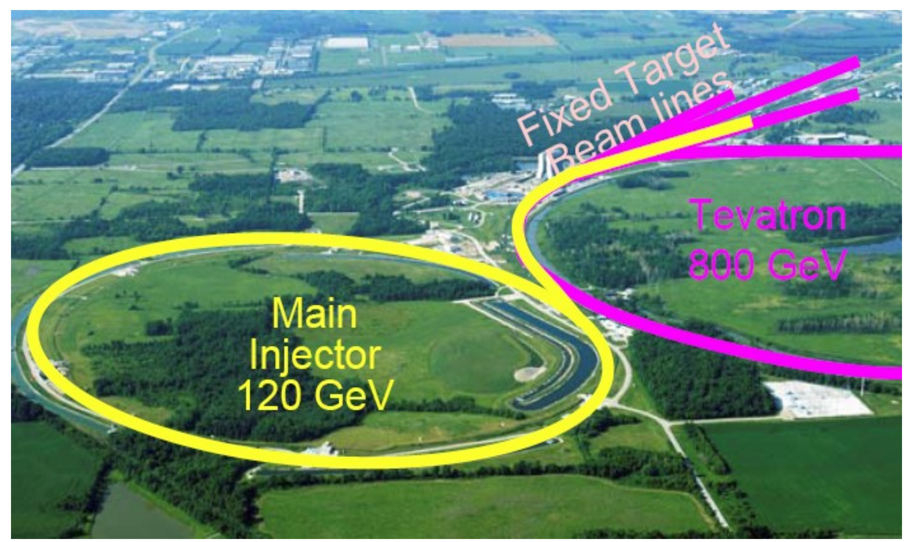
A New Polarized Target





Drell-Yan Transverse Single Spin Asymmetry Study at Fermilab:

- Polarized Target Drell-Yan, E1039 (LOI submitted 2013)
  - Polarized proton (NH_3) target, design & construction at LANL
- Polarized 120 GeV proton beam from the Fermilab's Main Injector, E-1027

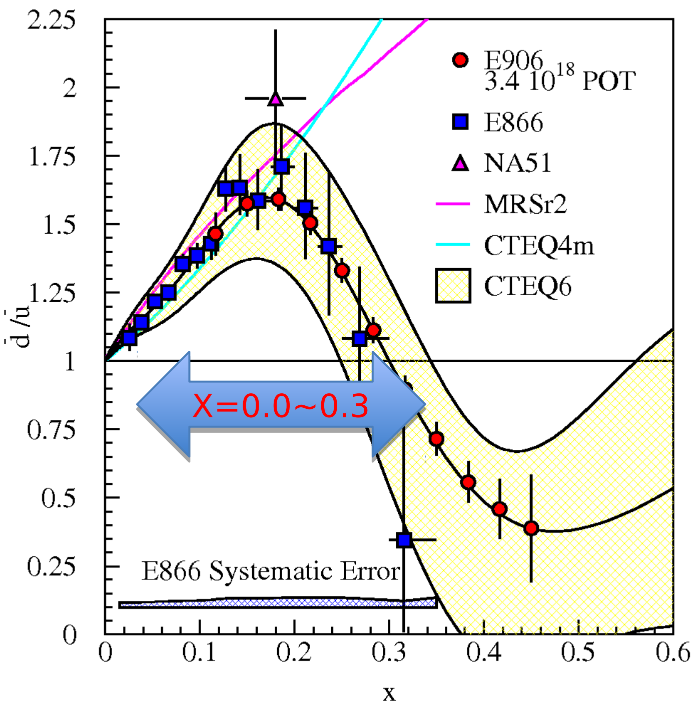


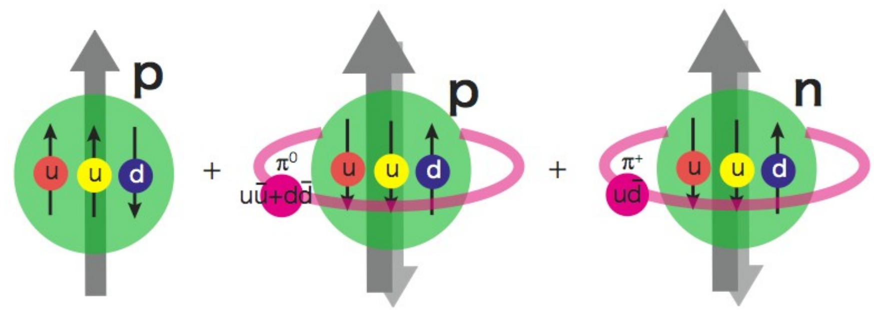
The Physics: all about sea quarks

- ***Sea-quark*** flavor asymmetry
- ***Sea-quark*** orbital angular motion and Sivers functions at x = 0.0 ~ 0.4
- Proton spin puzzle

$$|P\rangle = c_1|p\rangle + c_2|p,\pi^0\rangle + c_3|n,\pi^+\rangle + \ldots$$

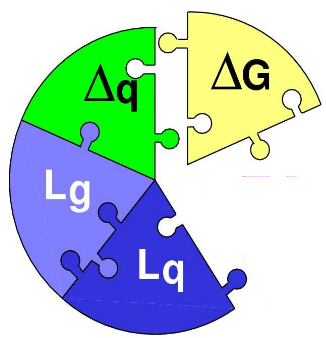
dbar/ubar asymmetry





L = 0

L = 1



Spin Crisis?

$$\frac{1}{2} = \frac{1}{2}\Delta q + L_q^z + \Delta G + L_g^z$$

$\Delta q \sim 30\%$ $(pol.\ SIDIS)$

$\Delta G \sim \frac{1}{2} \times 30\%$ $(RHIC-spin)$

$L \sim 30\%?$ $(FNAL?)$

Single-spin asymmetry in $p\,p^{\uparrow} \rightarrow \pi X$

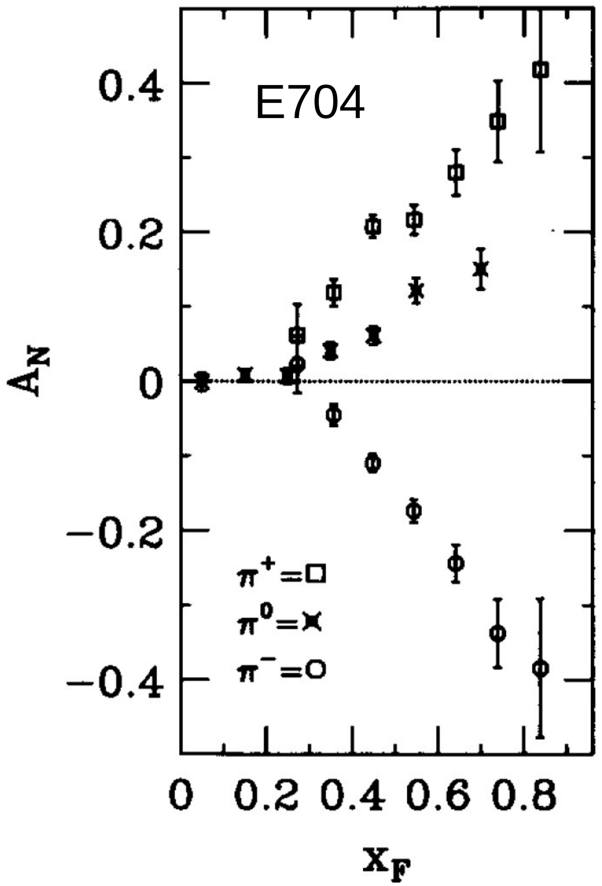
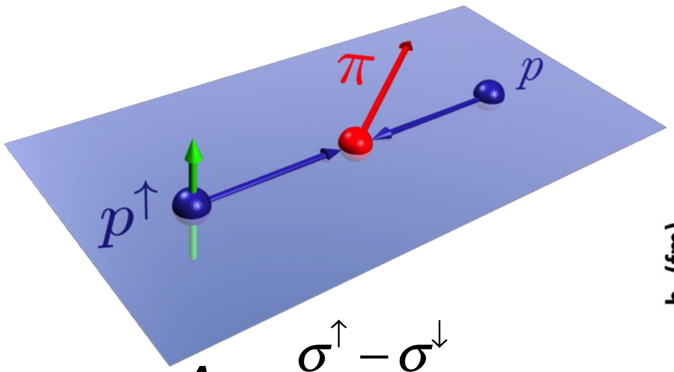


Fig. 4. A_N versus x_F for π^+, π^- and π^0 data.



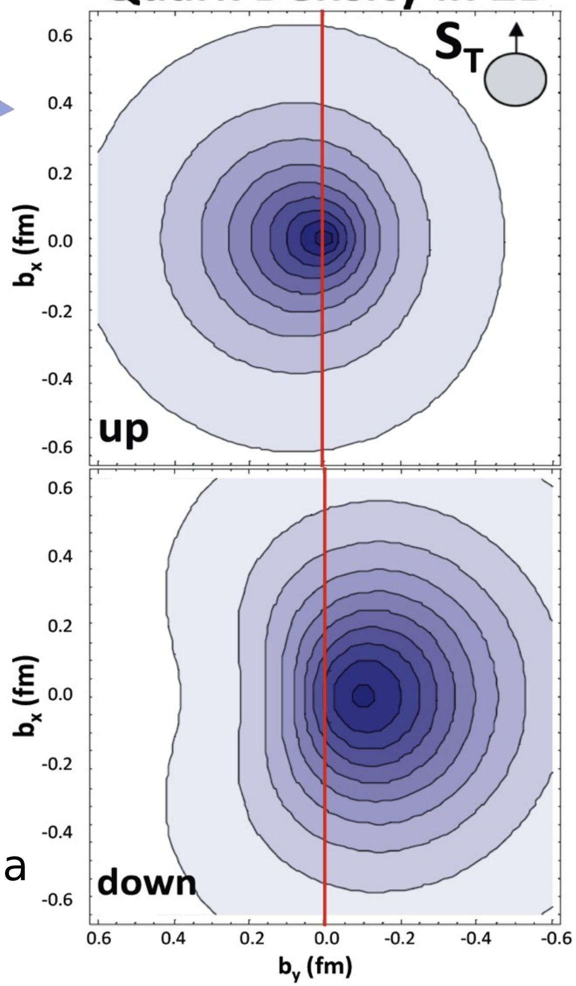
$$A_N = \frac{\sigma^{\uparrow} - \sigma^{\downarrow}}{\sigma^{\uparrow} + \sigma^{\downarrow}}$$

π^+ ($u\bar{d}$) favors left

π^- ($d\bar{u}$) favors right

One possible explanation (Sivers effect): quark transvers motion generates a left-right asymmetry

Quark Density in 2D



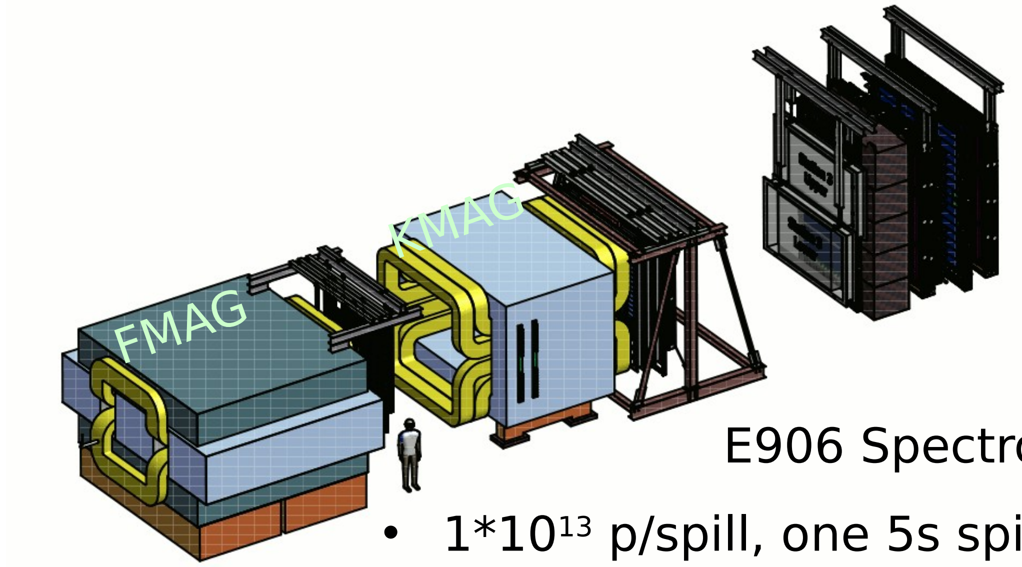
Lattice QCD PRL98:222001,2007.

Access Sea Quarks Sivers Distributions

B-Field

z

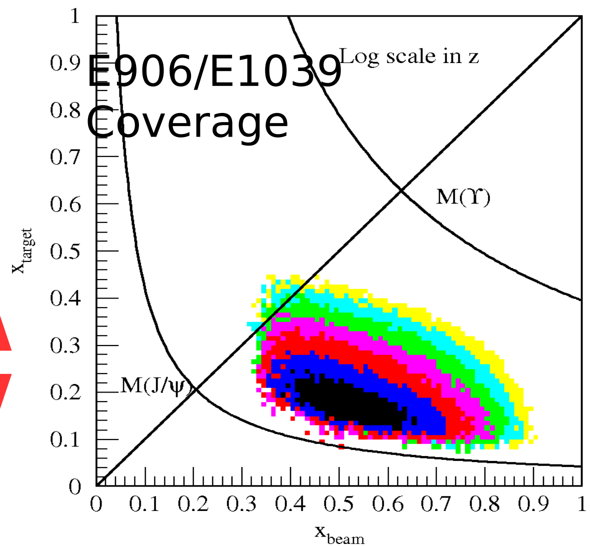
p beam 120 GeV

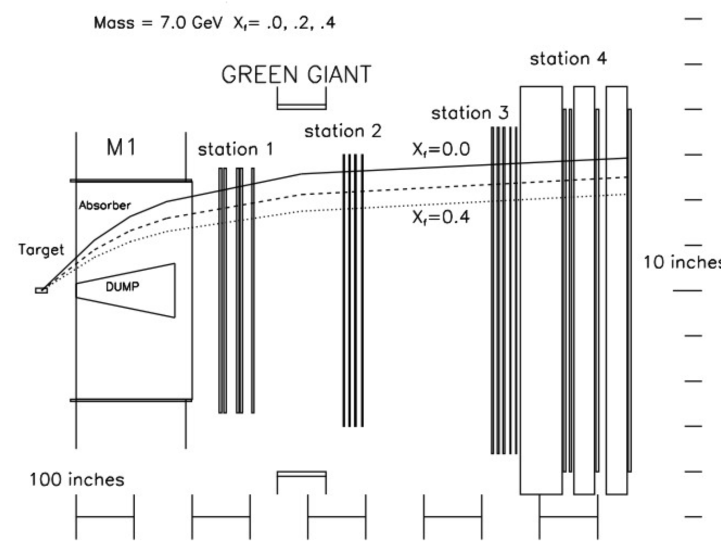


E906 Spectrometer

- $1*10^{13}$ p/spill, one 5s spill/minute
- Kinematic range 4 < M <8 GeV

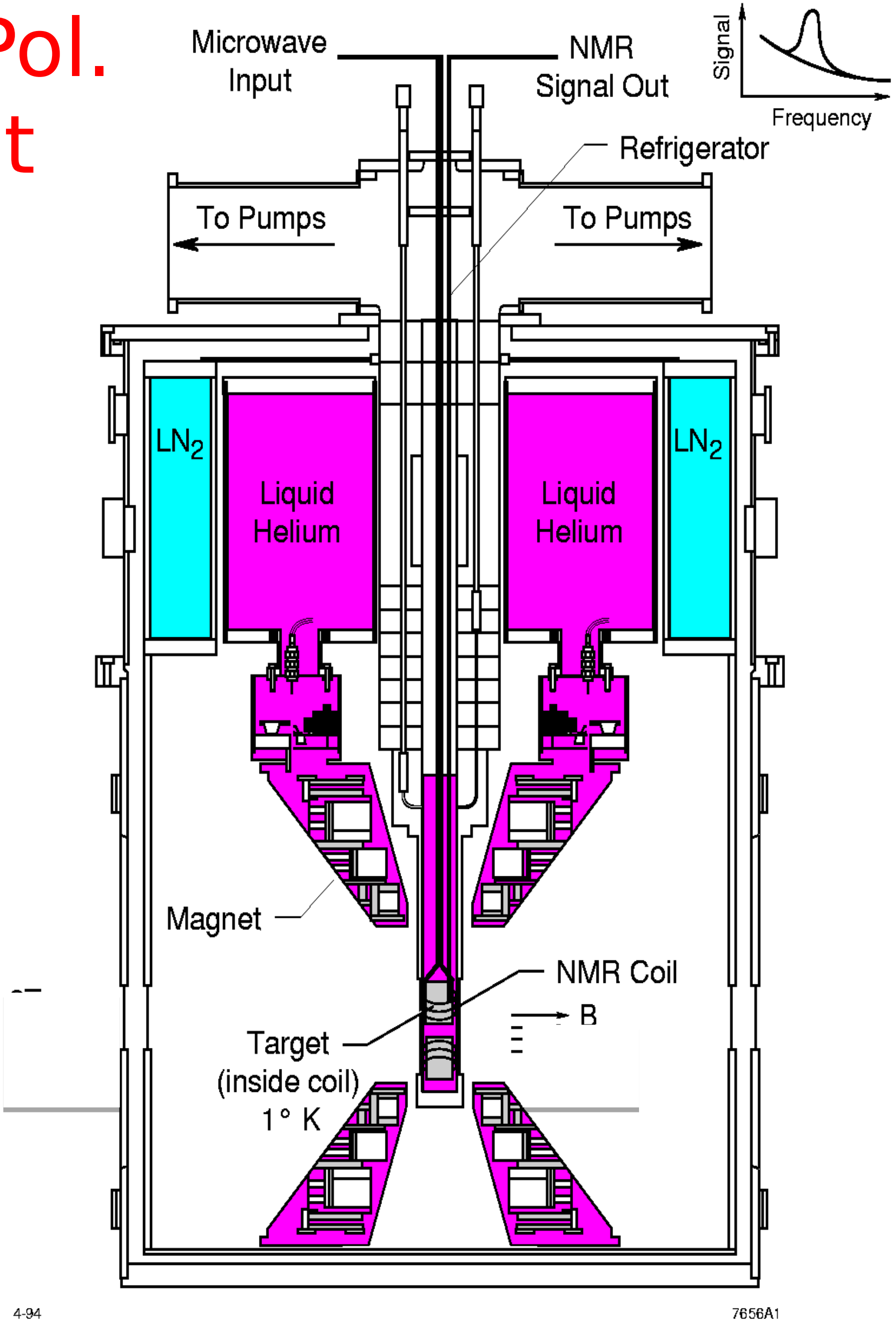
Target sea-quark





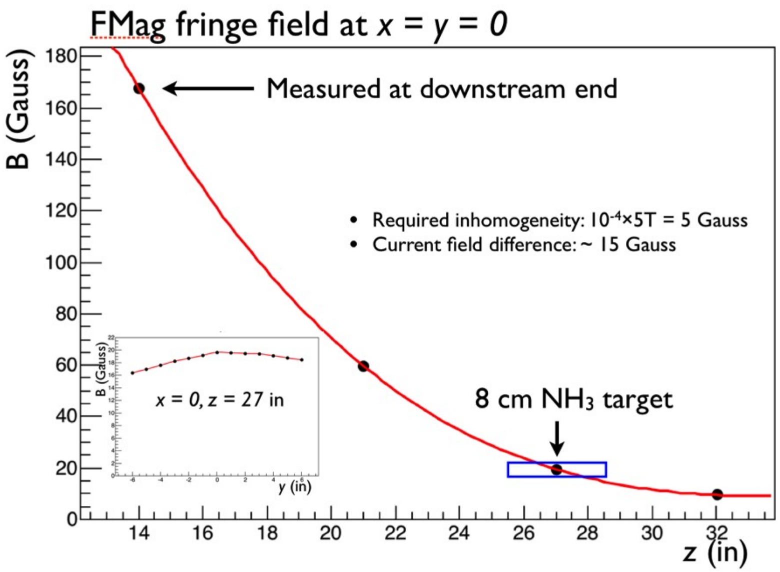
LANL/UVa High Density Pol. Proton (Neutron) Target

- Superconducting dipole magnet
  - Temperature ~ 1 K
  - Magnetic Field: 5 Tesla
  - 8cm long NH_3 target
- Proved capable of handling high luminosity
  - Same technology used at Jlab
- Magnet tested good at UVa in early 2014
- At Oxford now to rotate the field orientation

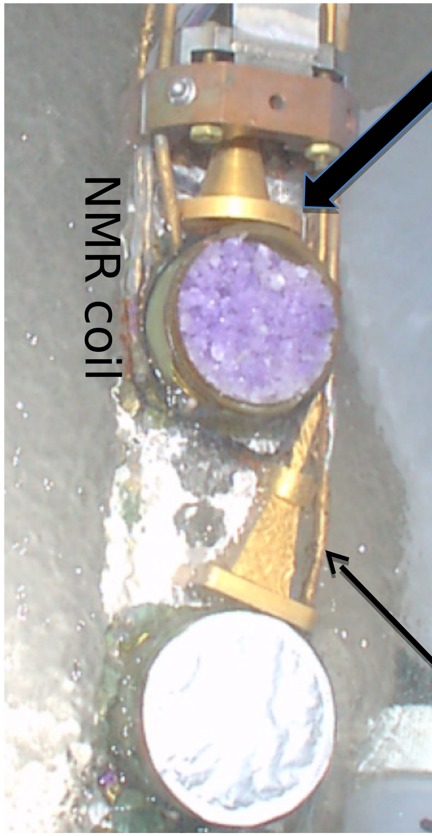


Magnet Tested at UVa

$$\frac{d\vec{B}}{\vec{B}} < 10^{-4}$$



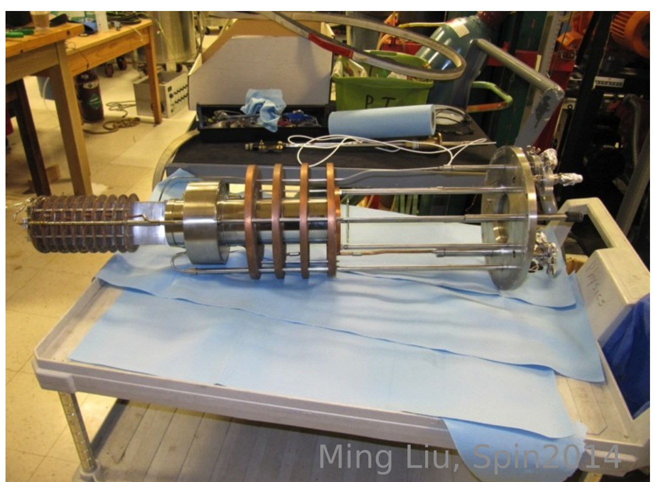
LANL/UVa NH_3 Target Parameters:

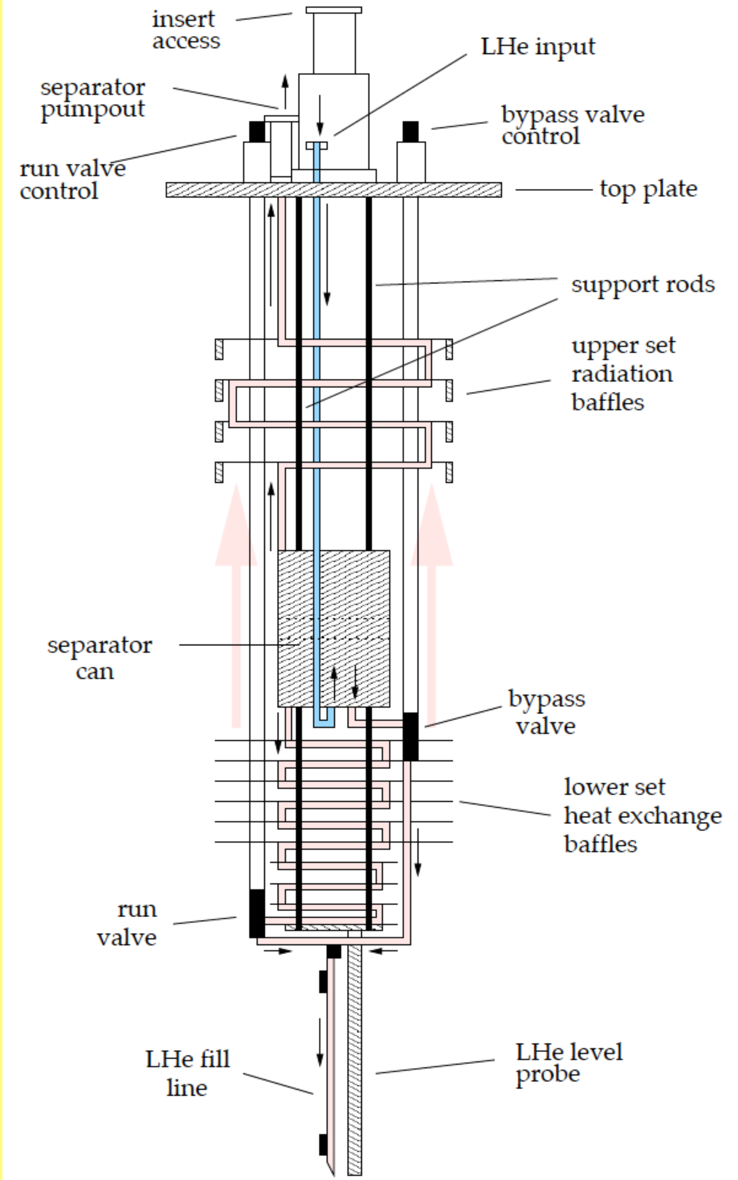


- Cylinder Φ : 2cm (x,y), length 8cm (z)
- ρ= .82 g/cm³ frozen NH_3
- Packing Fraction = .6
- Dilution Factor = 3/17 NH_3
- 5.1 g/cm² (NH_3) + .44 g/cm² He
- 4.2 * 10^{23} H/cm²

µ-wave horn

JLAB target





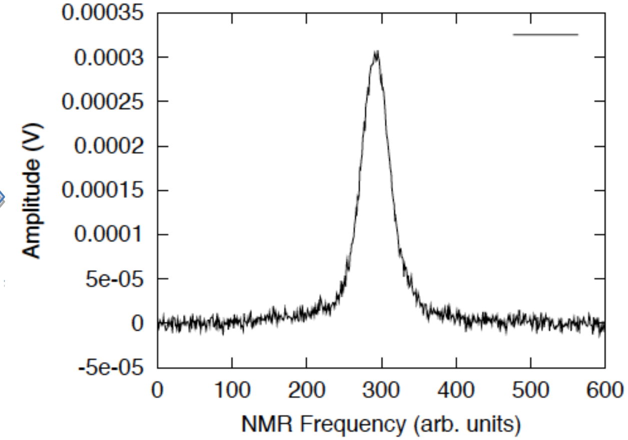
Refrigerator from UVa

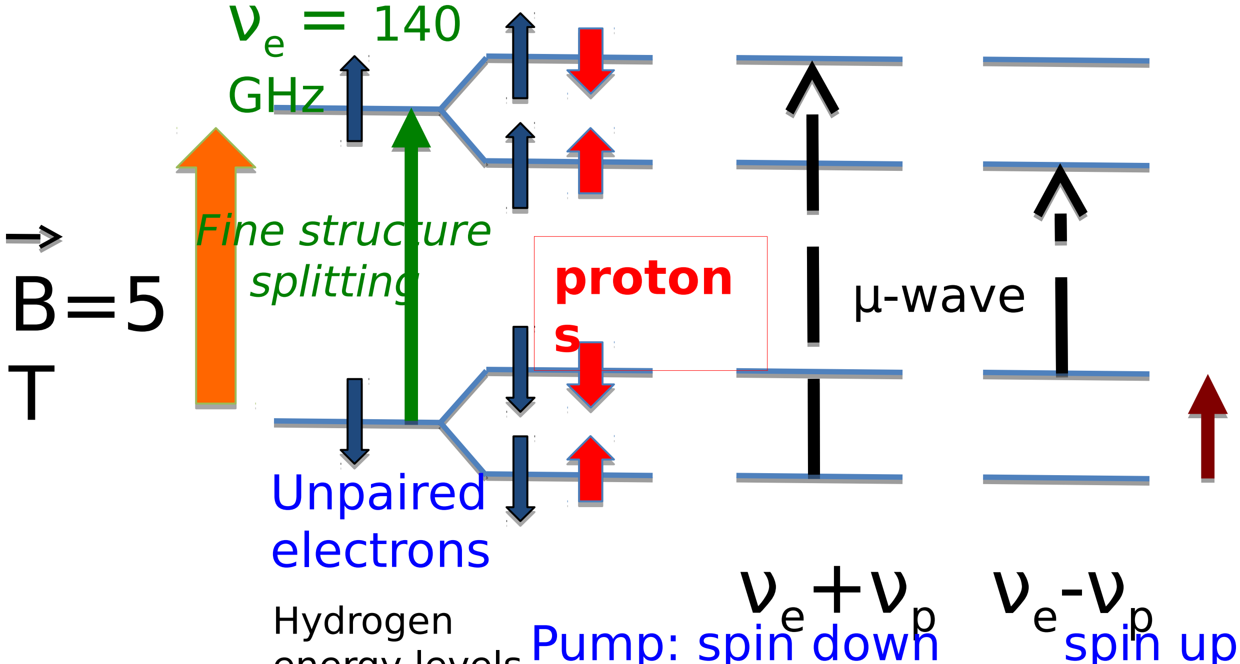
Target Polarization and NMR System

- Measure proton polarization with NMR at 214 MHz, Q-meter system for signals, large dynamic range with high sensitivity.
- Absorption of RF indicates spin up, stimulated emission for spin down

$$P_i = \tanh\left[\frac{\mu_i g_i H}{2k_B T}\right]$$

Thermal Equilibrium TE:
T=1K, H=5T
$P_e = .998$
$P_p = .005$ since $\mu_N / \mu_B \sim 10^{-3}$





ν_p = 214 MHz, Larmor freq, measure Q factor
Hyperfine splitting

Polarization Measurement: NMR Basics

The polarised nucleons give the target material a complex susceptibility $x(\omega)$ where

$$x(\omega) = x'(\omega) - i x''(\omega) \quad (1)$$

← RF absorption

and is a function of the applied angular frequency ω. The polarisation P is related to $x(\omega)$ by the relation

$$P = K \int_0^\infty x''(\omega)\, d\omega. \quad (2)$$

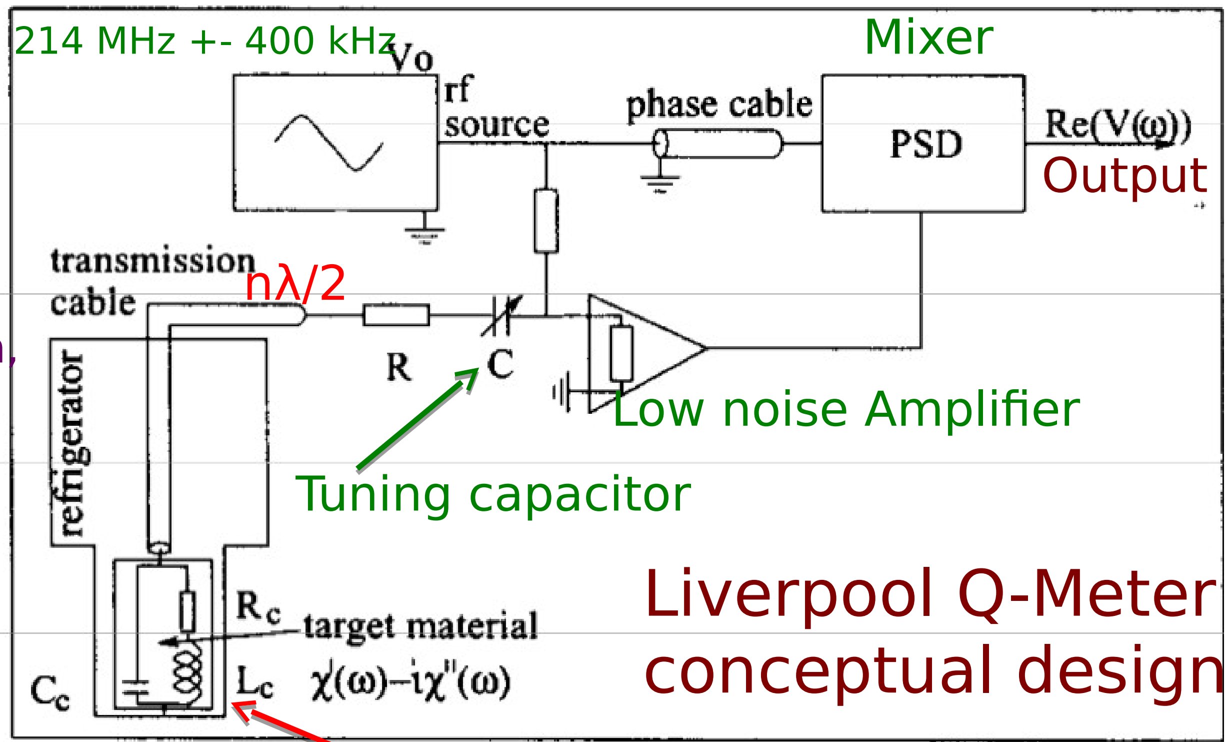
The method used for observing the resonance signal in most polarised targets is the Q-meter technique. The whole or a sample of the polarised target material is contained within a coil of inductance L_0. The material modifies the inductance of this coil by the relation

$$L(\omega) = L_0(1 + 4\pi\eta x(\omega)), \quad (3)$$

Applies a constant RF current to a series LC tank circuit

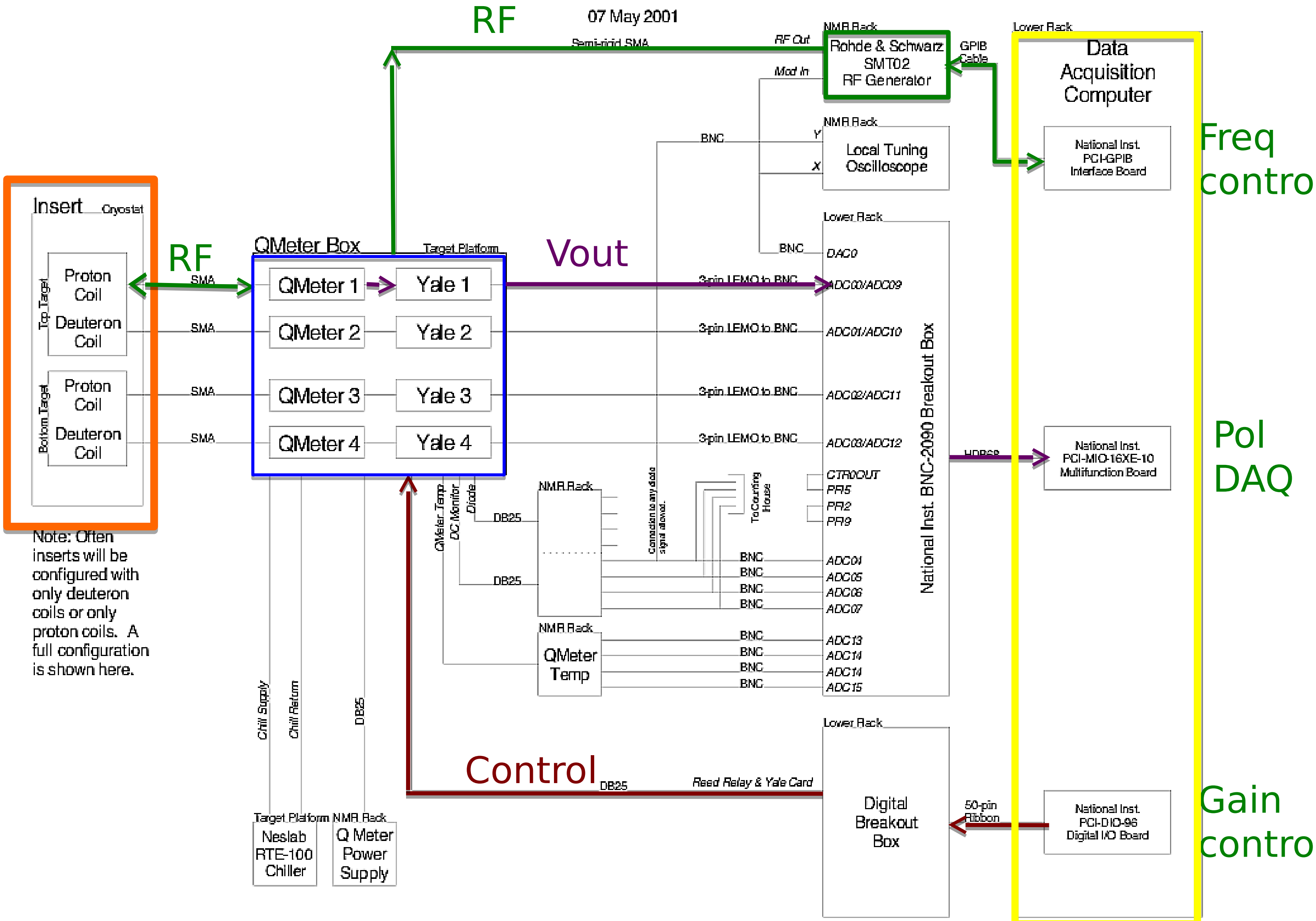
Measures voltage across tank
Voltage increases for absorption, decreases for emission:

$Q \approx (\omega_0 L) / R_0$
$V \propto 1/Q$



Inductor surrounding NH_3

Actual NMR System from JLab (E93-026)



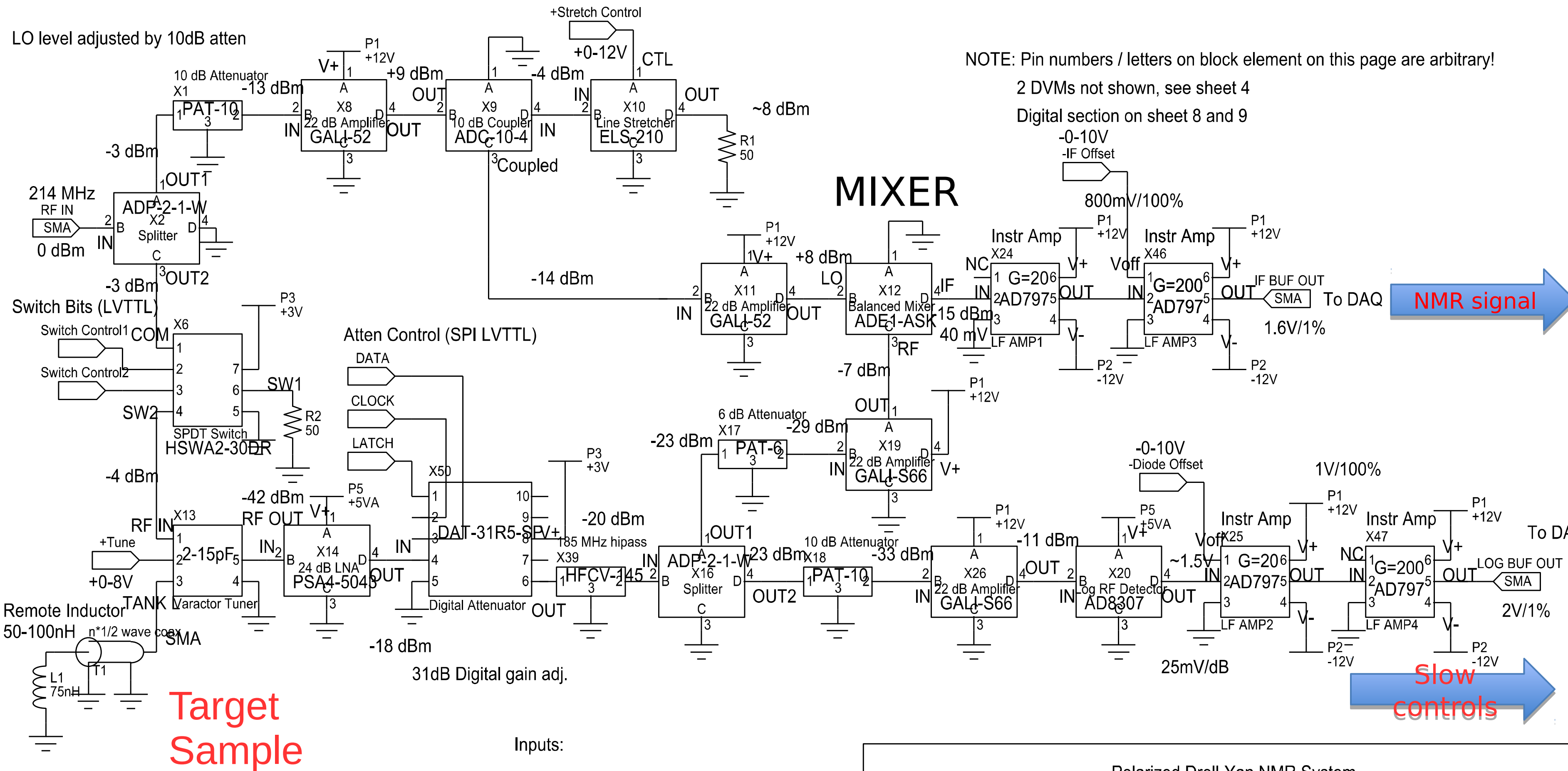
LANL Q-meter Design

- Follow general Liverpool design, but:
  - Use modern RF microwave electronics from Mini-Circuits, etc.
  - Use 16 bit ADCs and DACs from Analog Devices, etc.
  - Replace mechanical controls/adjustments with electronic ones (DACs or digital)
  - On board temperature and voltage monitors

- House in double wide VME modules and VME crate
  - VME module has 1 analog and 1 digital circuit board
  - Includes RF and analog processing, ADCs + DACs
  - USB interface on each module for standalone testing

- Ethernet <-> VME interface module for readout and controls using LabVIEW
- Power and forced air cooling from crate, <7 W per VME module

RF/IF detailed Diagram



Controls:

5 RF atten bits, TTL, octal rotary switch

2 RF switch bits, TTL, DPDT switch

Vstretch, 0 to +10V, 10 turn 1K pot

2 Voffsets, 0 to -1V,-10V, 10 turn 1K, 500 ohm pots

Vtune, 0 to +8V, 10 turn 1K pot

Inputs:

RF In, 0dBm 214MHz

Outputs:

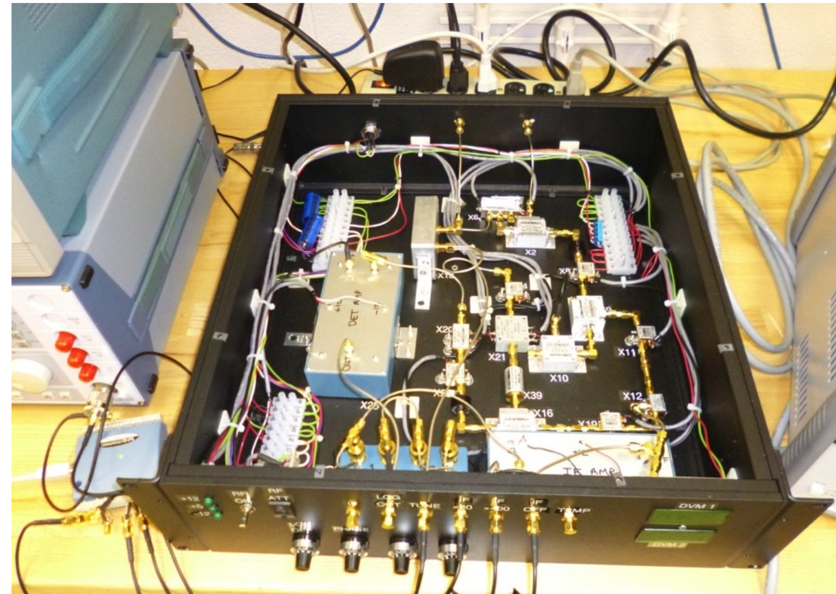
IF Buf Out, 50 ohm, +-2.5V

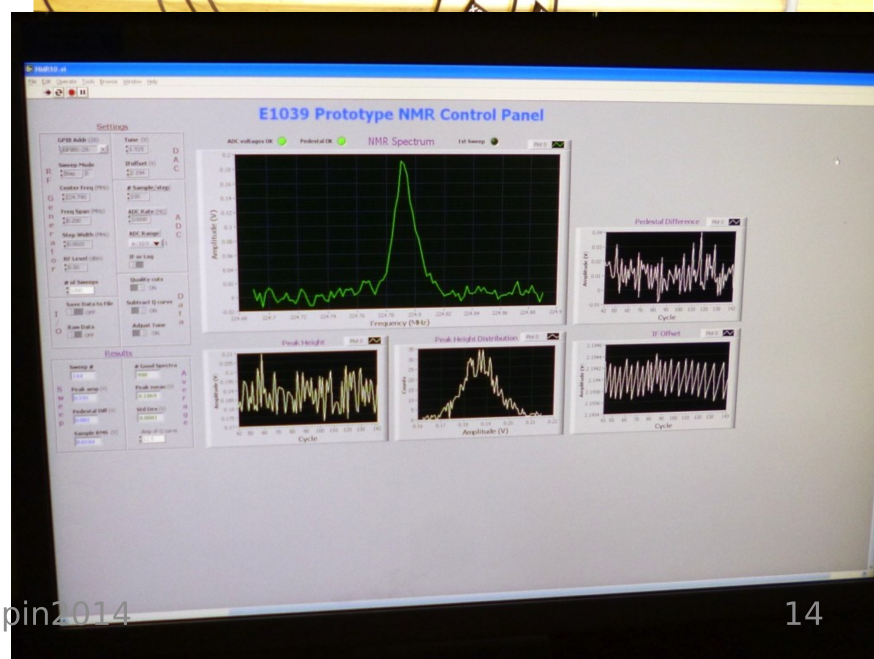
Log Amp Buf Out, 50 ohm,+-2.5V

Remote Inductor, ~75nH

Polarized Drell-Yan NMR System			
Size: A	No: 1	Analog Block Diagram	Rev: 140
Sheet: 1 of 9			Revised: 05-Mar-2014
Drawn by: PLM			Created: 29-Oct-2013
File: z:\users\patrickmcgaughey\desktop\nmr_schematic\prodnmr8.sch			

Prototype RF/IF Deck Using Commercial Parts



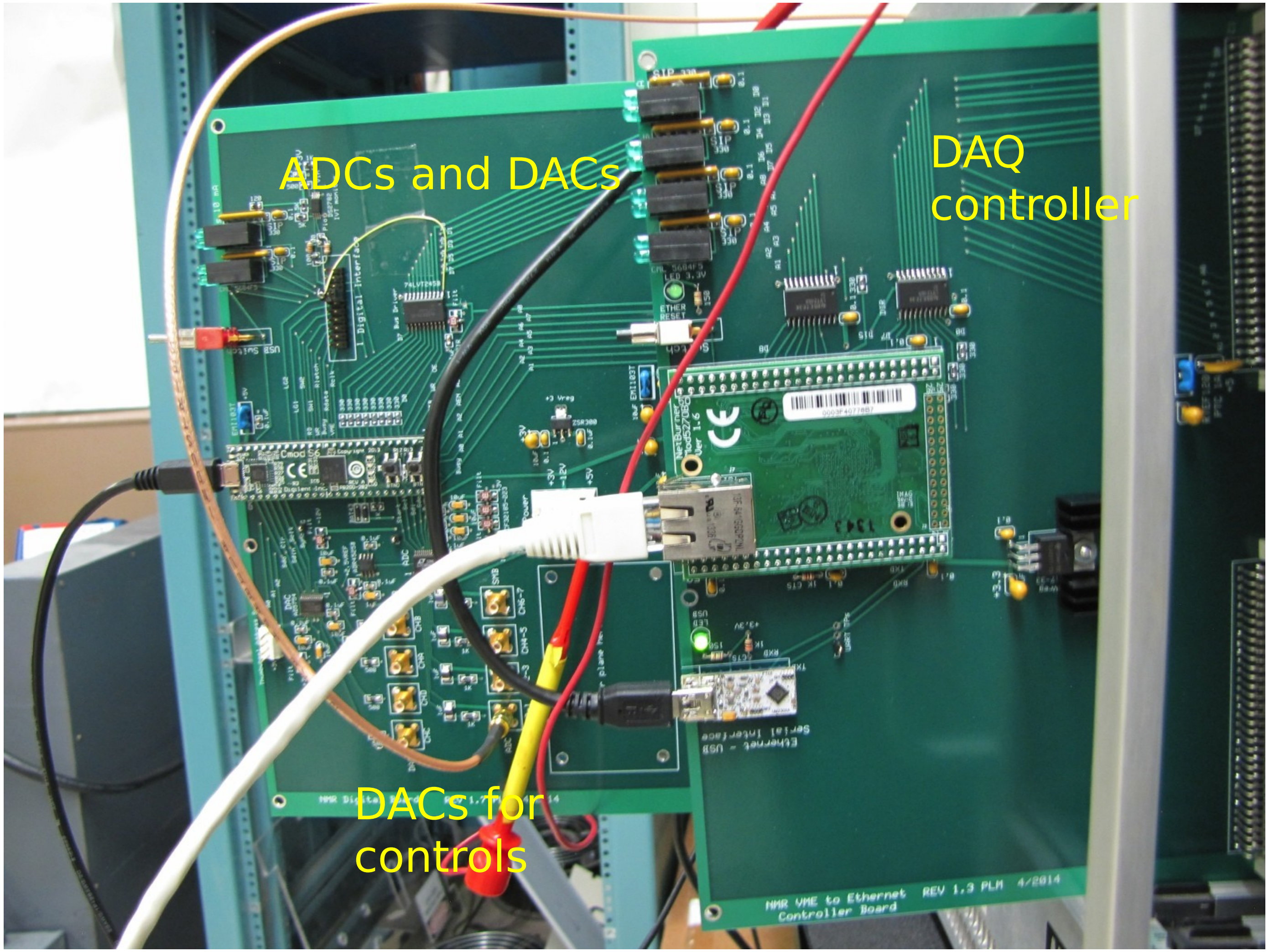


- Successfully tested at Uva with NH_3 target in 2014
- Extremely low noise
- Excellent thermal stability, no need for additional cooling fan
- Currently working on VME system design, whole-chain tested working last week

NMR Control VME System: Work in Progress

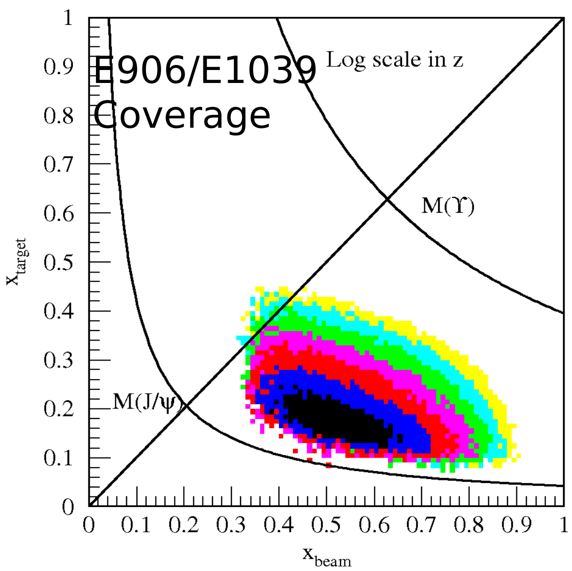
ADC input: 4 channels/16-bit
DACs output: 4 channels/16-bit

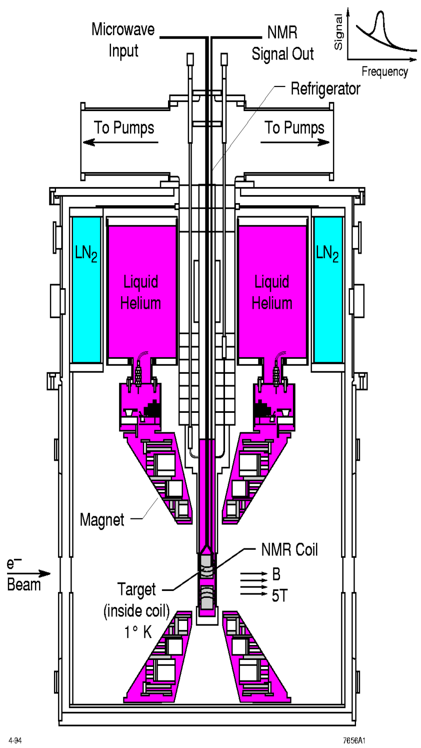
<u>Tested fully functional last week!</u>

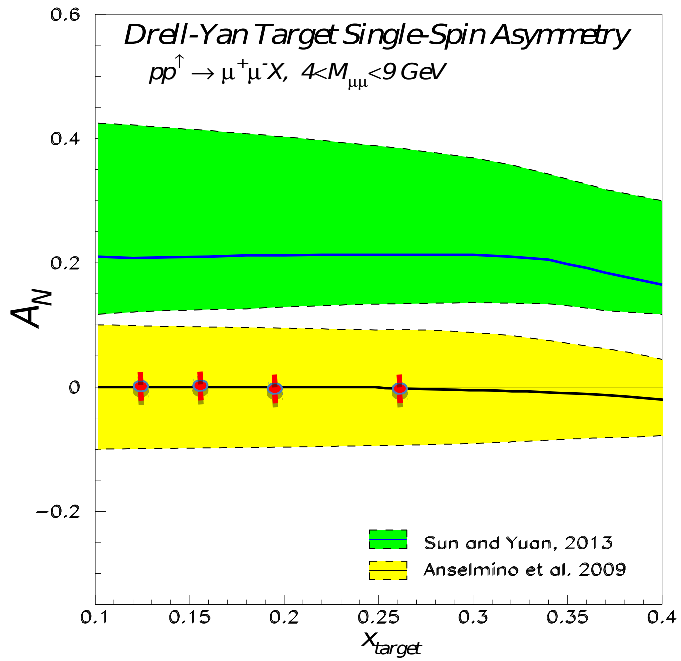


Summary and Outlook

- A new high density polarized proton (deuteron) targets being developed at LANL/Uva
- A new Drell-Yan experiment approved with polarized target at Fermilab, E1039
- Expect the first precise measurements of the poorly known sea-quark Sivers distributions, and explore sea quark orbital motion effects, help to solve the "Nucleon Spin Crisis"
- First run: ~ 2016







backup

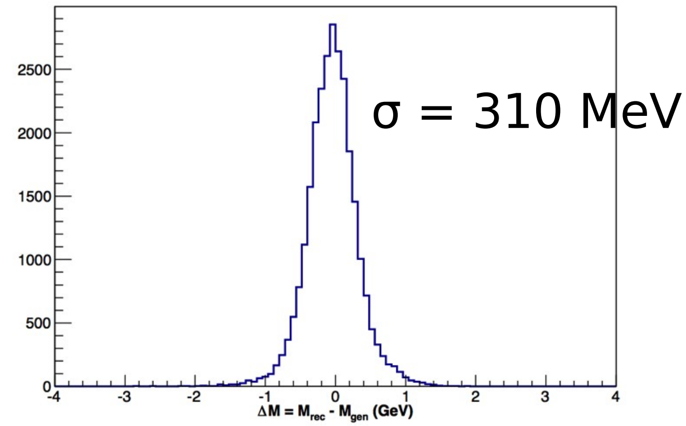
Expected Signal: Target and Beam Performance

Target

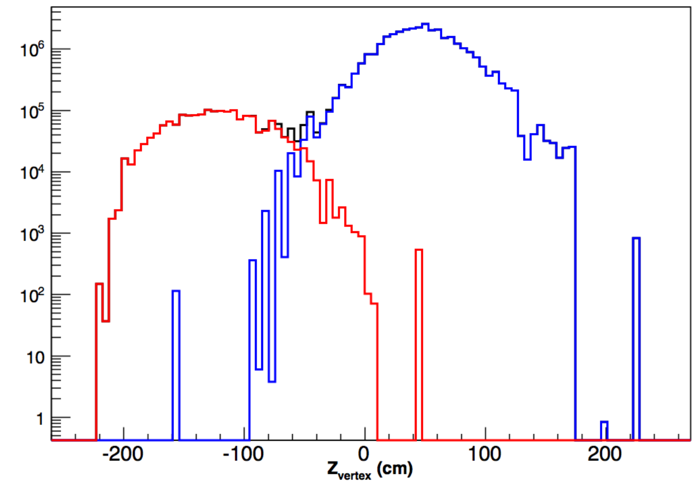
- Polarization: 85%
- Packing fraction 0.6
- Dilution factor: 0.176
- Density: 0.89 g/cm^3

Beam

- Beam: $1*10^{13}$ p/spill; spill is 5 s
- Luminosity: $4.4*10^{35}$ /cm^2/sec
- 120 GeV protons
- KTev beam line
- $\sqrt{s}$ = 15 GeV
- One year L = 7.2 $*10^{42}$/cm^2
- POT = $2.7*10^{18}$ (187 days)

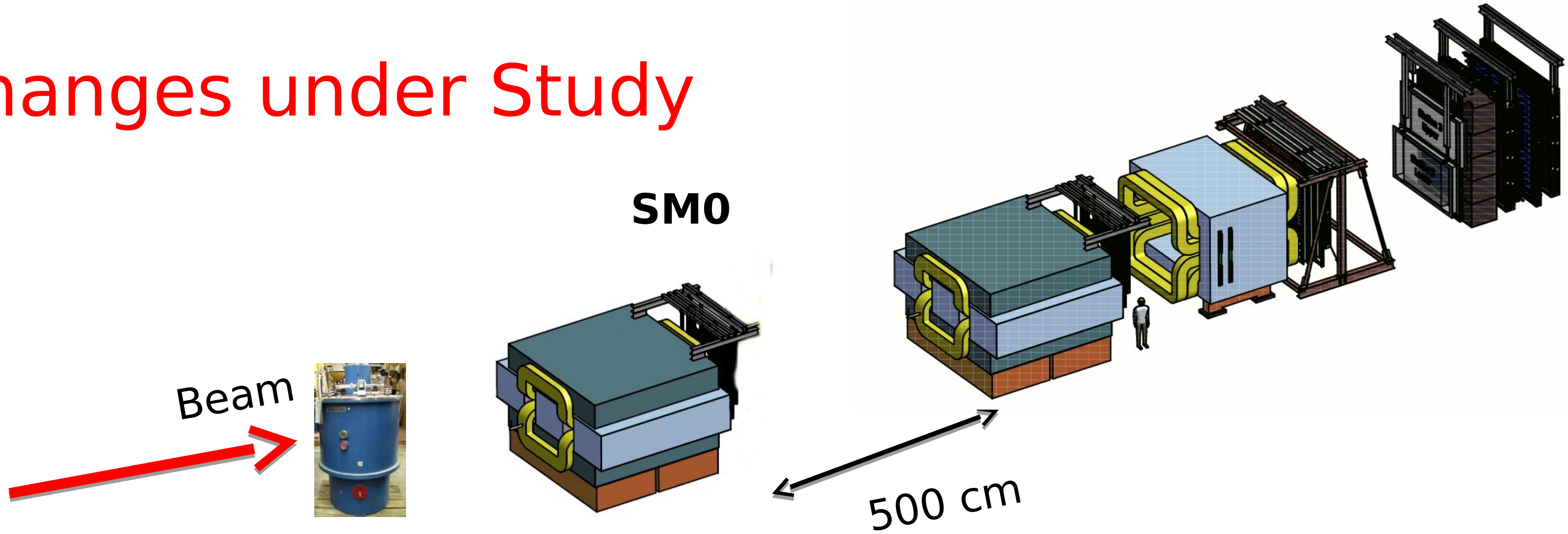


Dimuon Mass Resolution



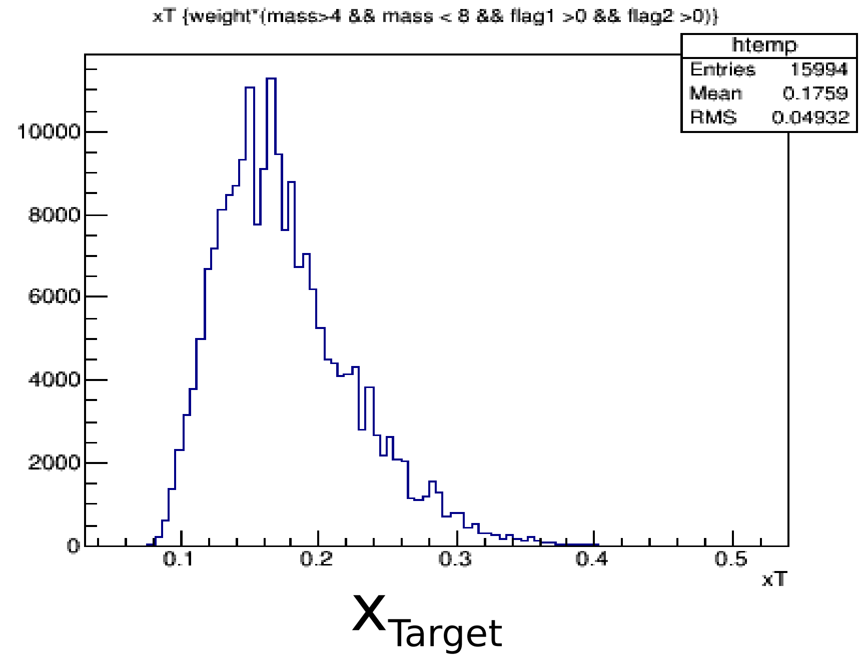
Reconstructed Vertex

Changes under Study



Add third magnet SM0 ~500cm upstream

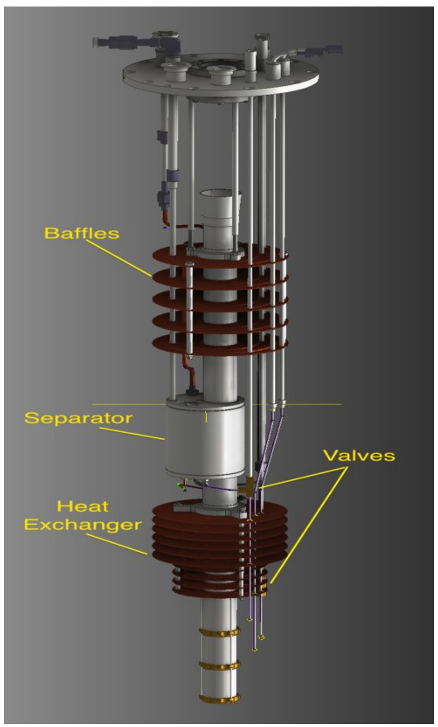
- **Improves Dump-Target separation**
- **Moves $\langle x_2 \rangle$ from .21 to .176**
- **Reduces overall acceptance**
- **Adds shielding problems**
- **Tracking near target to improve vtx**

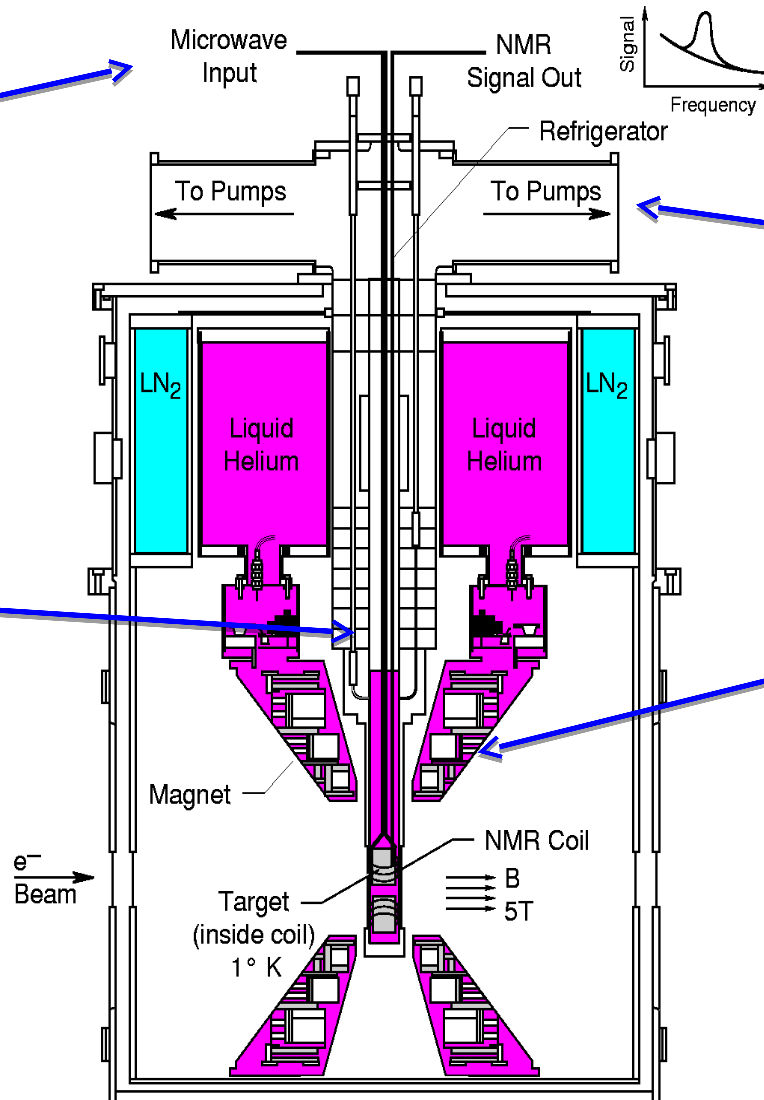


LANL Polarized Target System

Microwave: Induces electron spin flips
- Tube + Power equip:

Cryostat: UVa





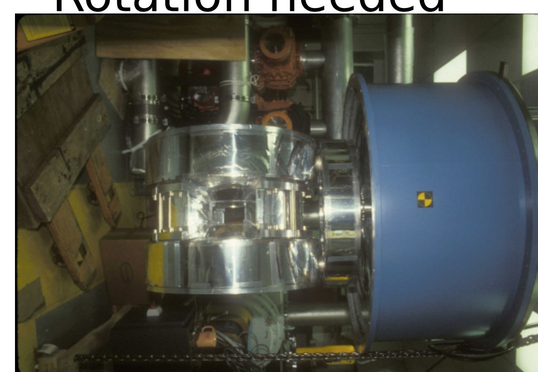
NMR: Polarization measurement

Roots pump system used to pump on ^{4}He vapor to reach 1K

10,000 m³/hr

Superconducting Coils for Magnet: 5T

Rotation needed

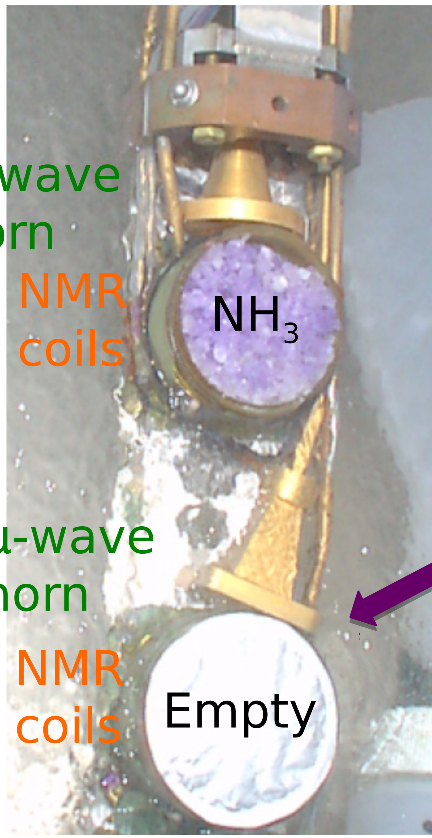


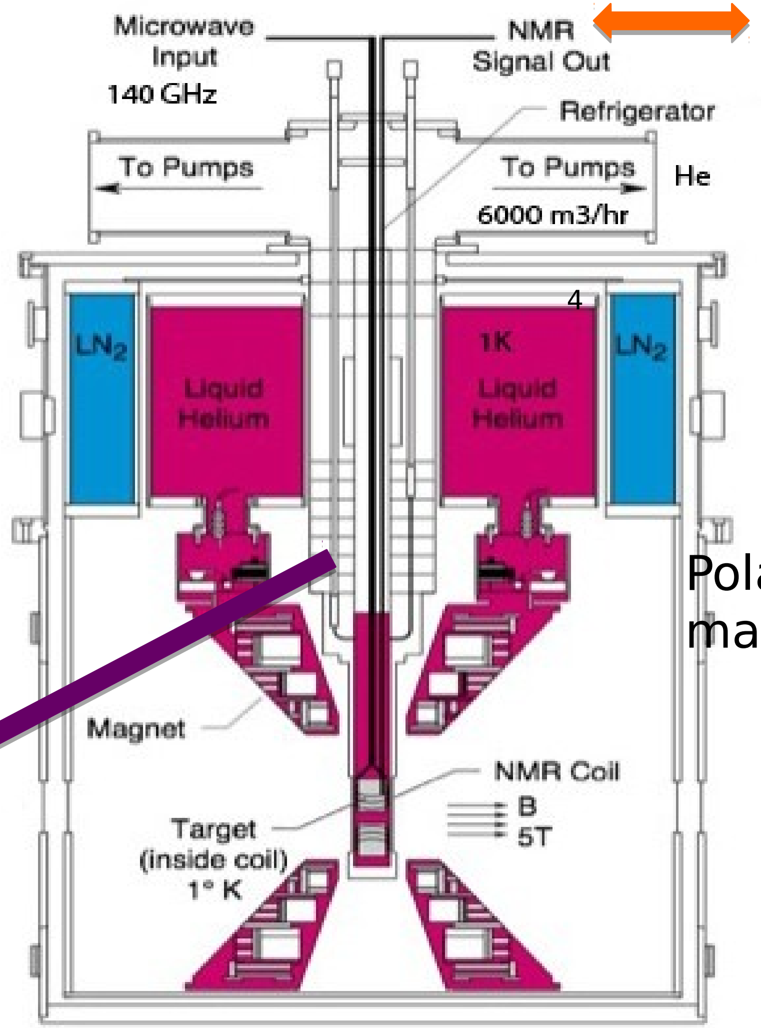
Target material: frozen NH_3 (ND_3)

Irradiation @ NIST

NMR Connections to Target System

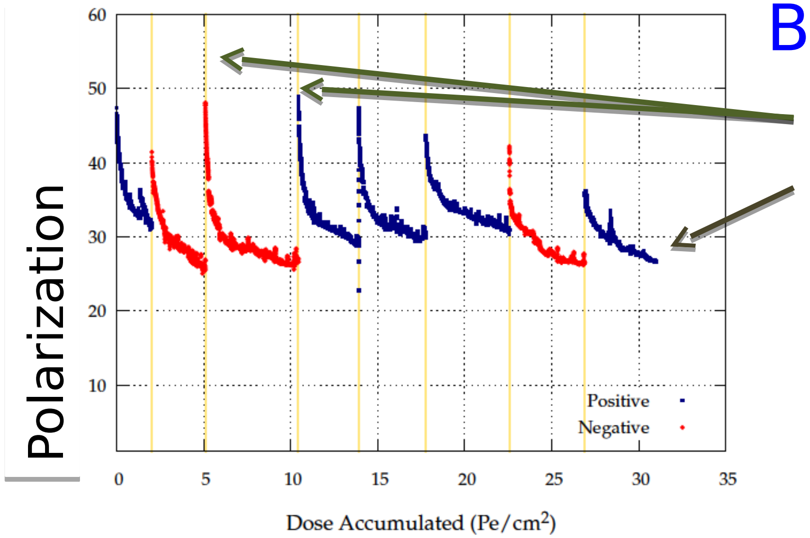
Target Ladder





NMR:
Constantly measures proton polarization

Polarized target, magnet + cryostat



Beam effects on polarized Target

- Anneal every 24 hours ~ 1hr at 80K (yellow line)
- Replace target material every 10 days (two active targets) , will take one shift
  - Replace target stick
  - Cool down
  - perform TE measurement
  - Turn on microwave, measure again

Polarization as a function of accumulated beam dose 2.5T target (D. Crab private communication)

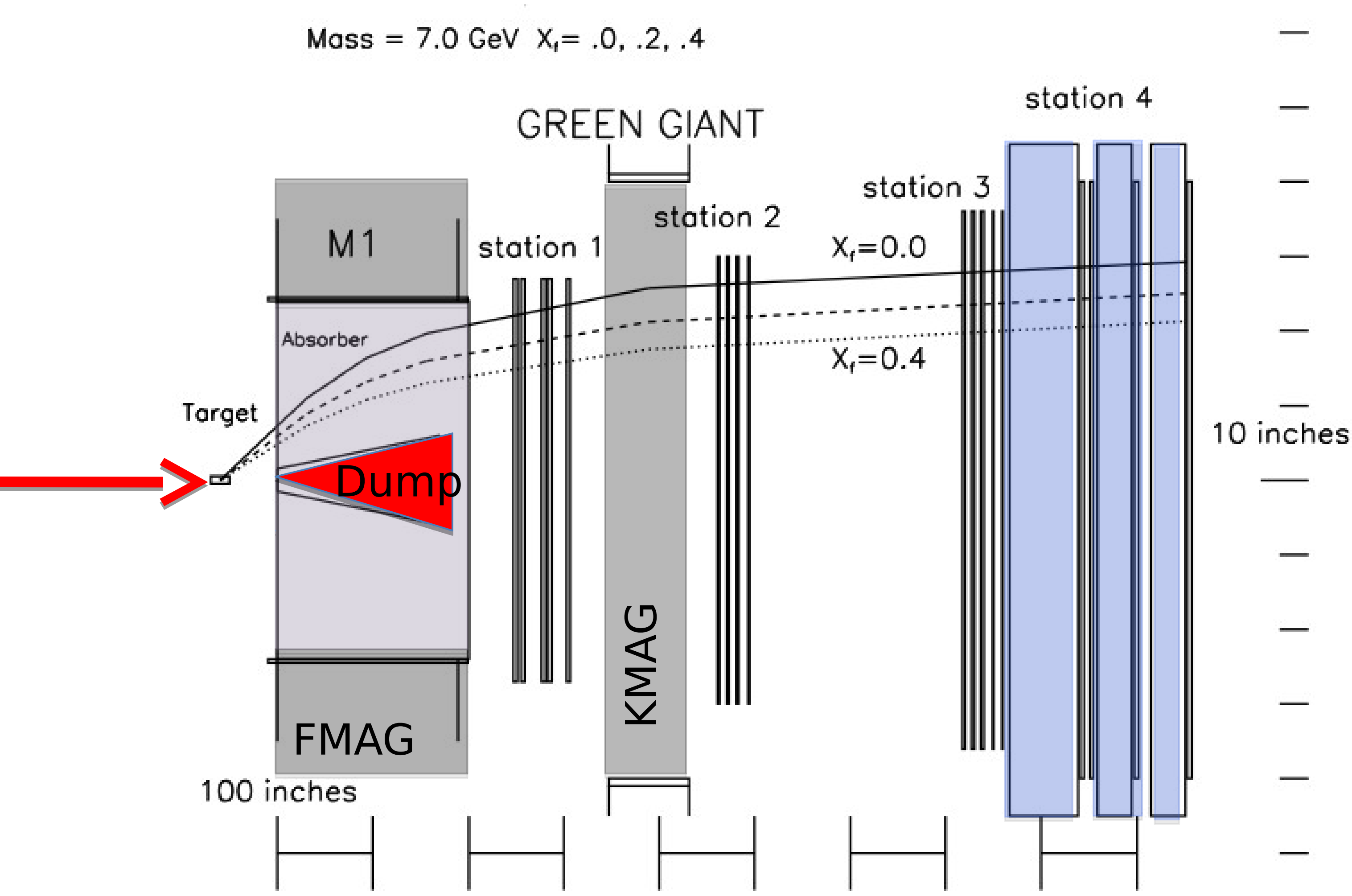
Systematics control:

- Reverse Polarization Direction once a day
- Reverse magnet field of Fmag and Kmag every two days
- Reverse magnetic field of target magnet every target replacement
- Background measurements every shift with target out

Systematic errors:

- Absolute: 1% (Luminosity precision on different pol directions)
- ΔA/A ~ 4% (Dominant effect polarization measurement)

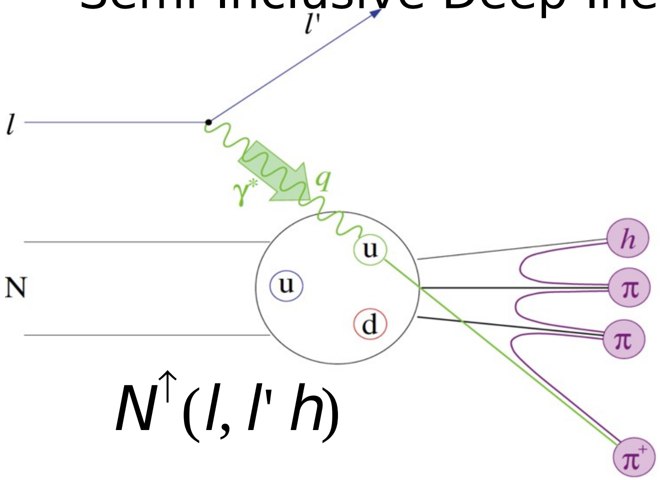
E906/E1039 Dimuon Spectrometer



- 4 scintillator hodoscope stations (x and y)
- 4 tracking stations (x and stereos) MWPC

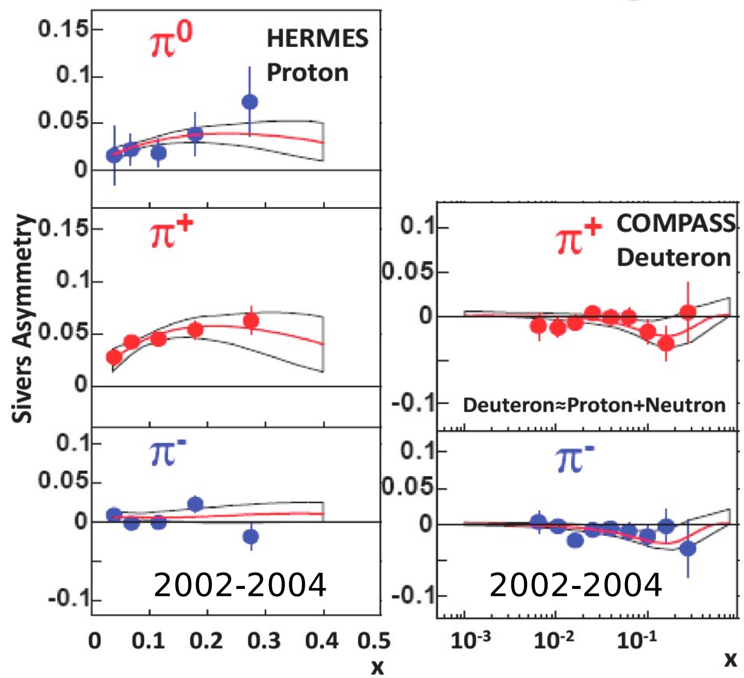
Quark Sivers Distributions: fit to HERMES and COMPASS data (2009)

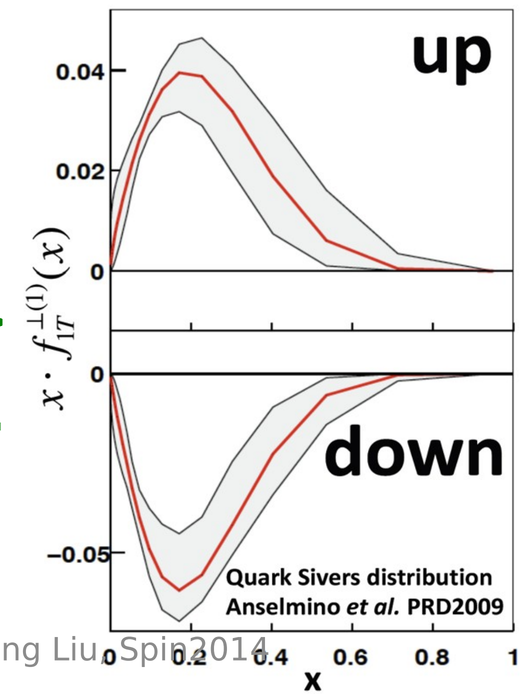
Semi-Inclusive Deep-Inelastic Scattering on transversely polarized targets



$$A_N = \frac{\sum_q e_q^2\, f_{1T}^{\perp,q}(x) \otimes D_1^q(z)}{\sum_q e_q^2\, f_1^q(x) \otimes D_1^q(z)}$$

1. **Involves quark fragmentation functions.**
2. **Valence quark overwhelmingly dominate.**
3. **Limited sensitivity to sea quark leads to zero sea quark Sivers distribution.**
4. **large uncertainties in Sivers distribution**





up-quark favors left (L_u>0),

down-quark favors right (L_d<0).

$L_u \approx - L_d$