APS-DNP 2004 Session DA:

Probing the Gluonic and Quark Structure of Matter

projector test

DA1. First Experiments with a Polarized Hydrogen Jet Target in RHIC

Willy Haeberli

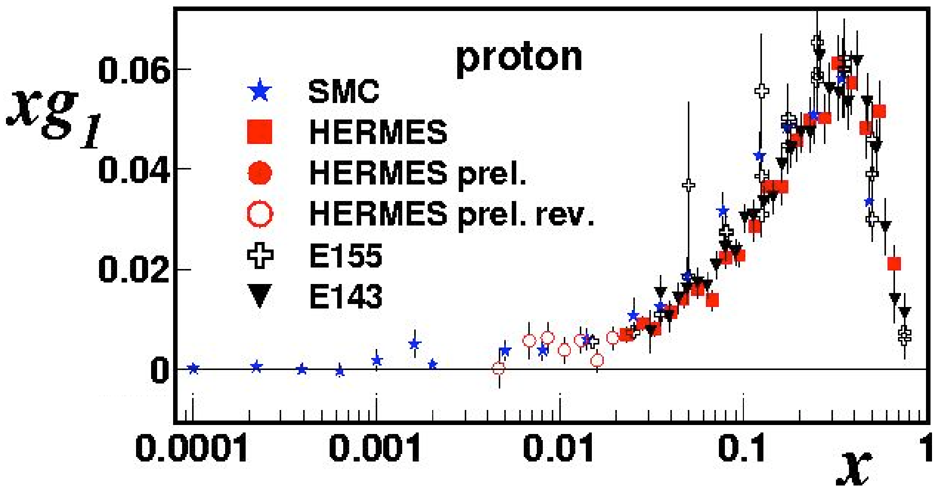
Department of Physics, University of Wisconsin-Madison

Measuring the Polarization of High-Energy Protons

WHY?
HOW?

What accounts for the spin of the nucleon?

K. Rith DIS 2004

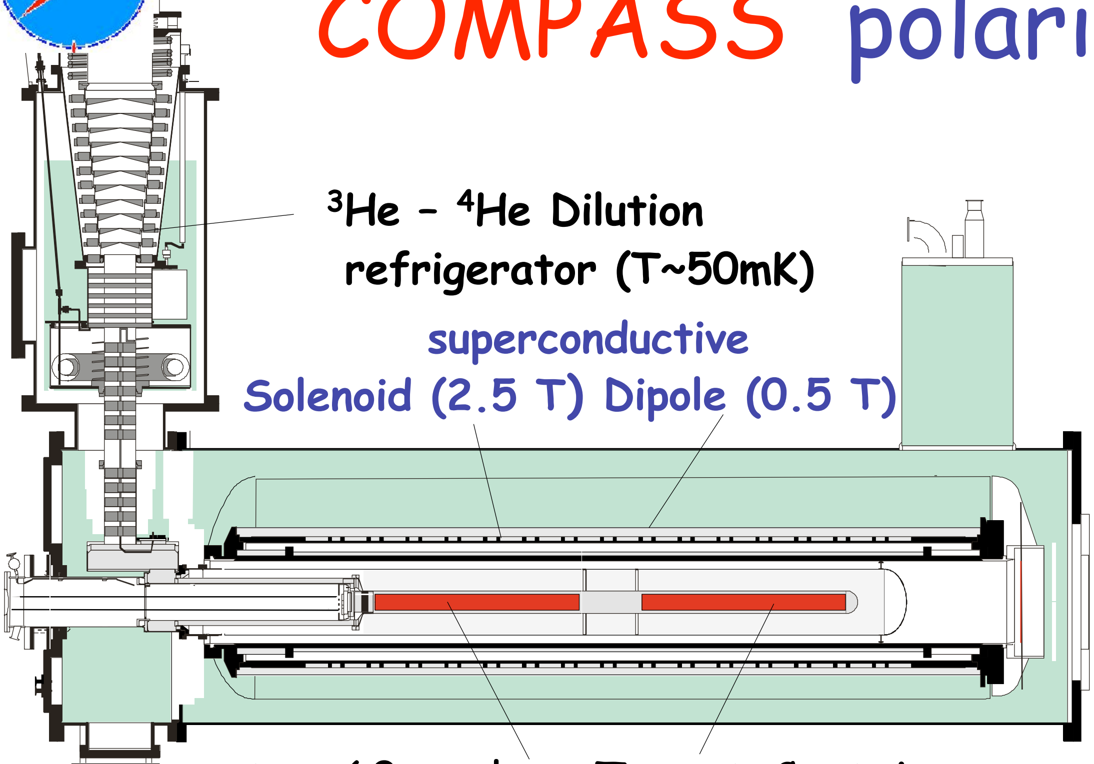


The (old) proton spin puzzle:
Only ~(20±4)% of proton spin isaccounted for by spins of quarks and antiquarks

DIS of **polarized** HE leptons (e,μ) from **polarized** nucleons at SLAC, CERN, HERA:

Good agreement with two very different experimental methods………

COMPASS polarized LiD target



spin combinations:

1	→	←
2	←	→

reversed every 8 hours

Target pol reversed every 8 hours

E_μ = 160 GeV, $p_B \sim -76\%$

1.8*10^7 μ^+/sec (time ave)

polarized LiD-target , $p_T \sim$ 50%

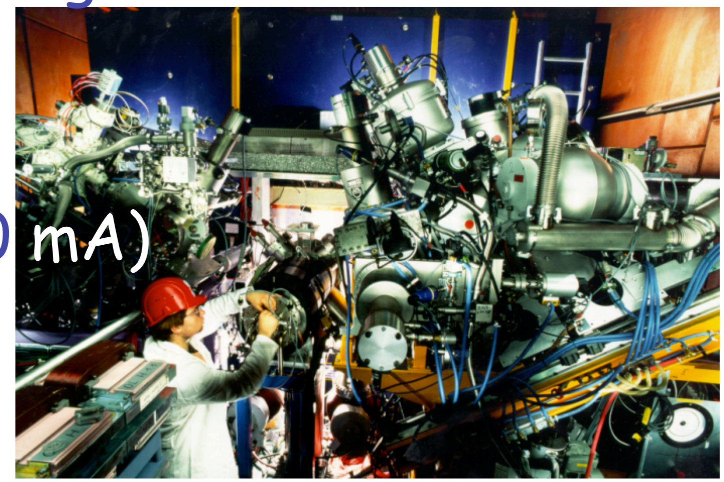
Luminosity: ~ 5*10^{32} $cm^{-2}\ s^{-1}$

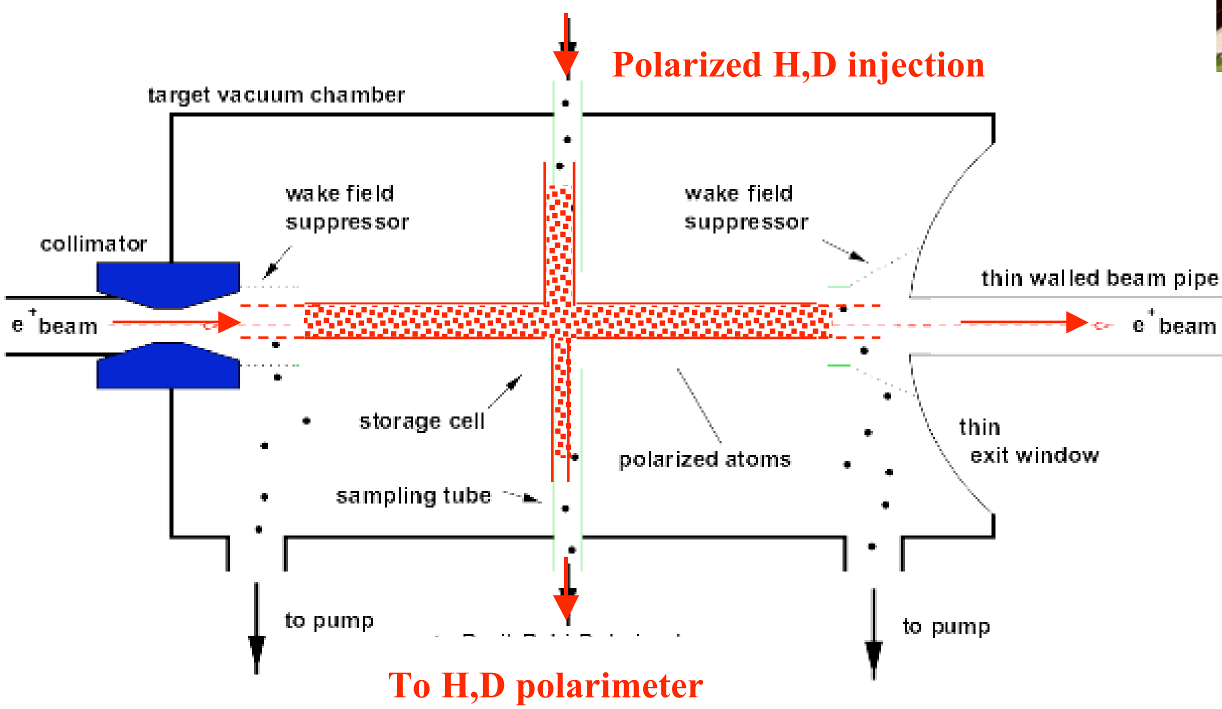
Polarization: ~50%

Dilution 40%

HERMES internal target

- Pure polarised gas targets: $\vec{H}$, $\vec{D}$, target
- polarisation: $p_T \sim 85\%$
- target thickness 10^{14} $\vec{H}/cm^2$
- Luminosity: $6*10^{33}$ cm^{-2} s^{-1}($\vec{D}$ @ 50 mA)
- → spin reversal every **120 sec**



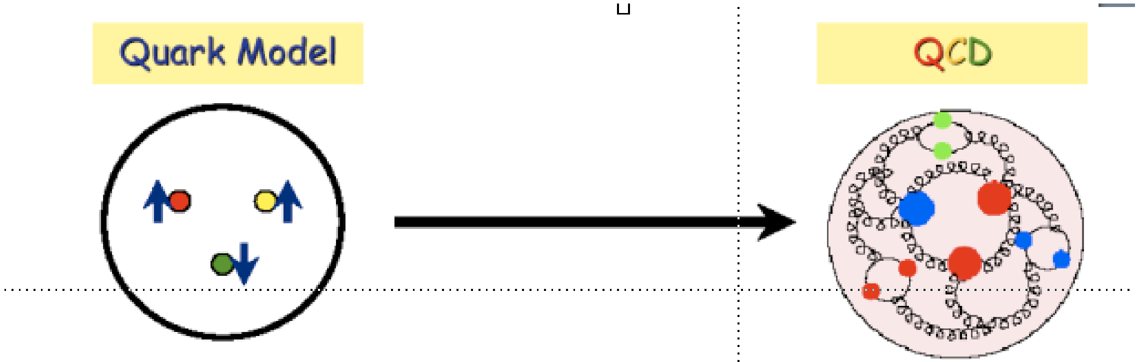


Factor 100 gain from use of “storage cell”
(S. Price)

. . .

Gluons: key contributor to the proton spin?

slide adapted from W. Vogelsang (BNL)



$$\frac{1}{2} = +\langle S_q \rangle + \langle S_g \rangle + \langle L_{q,g} \rangle$$

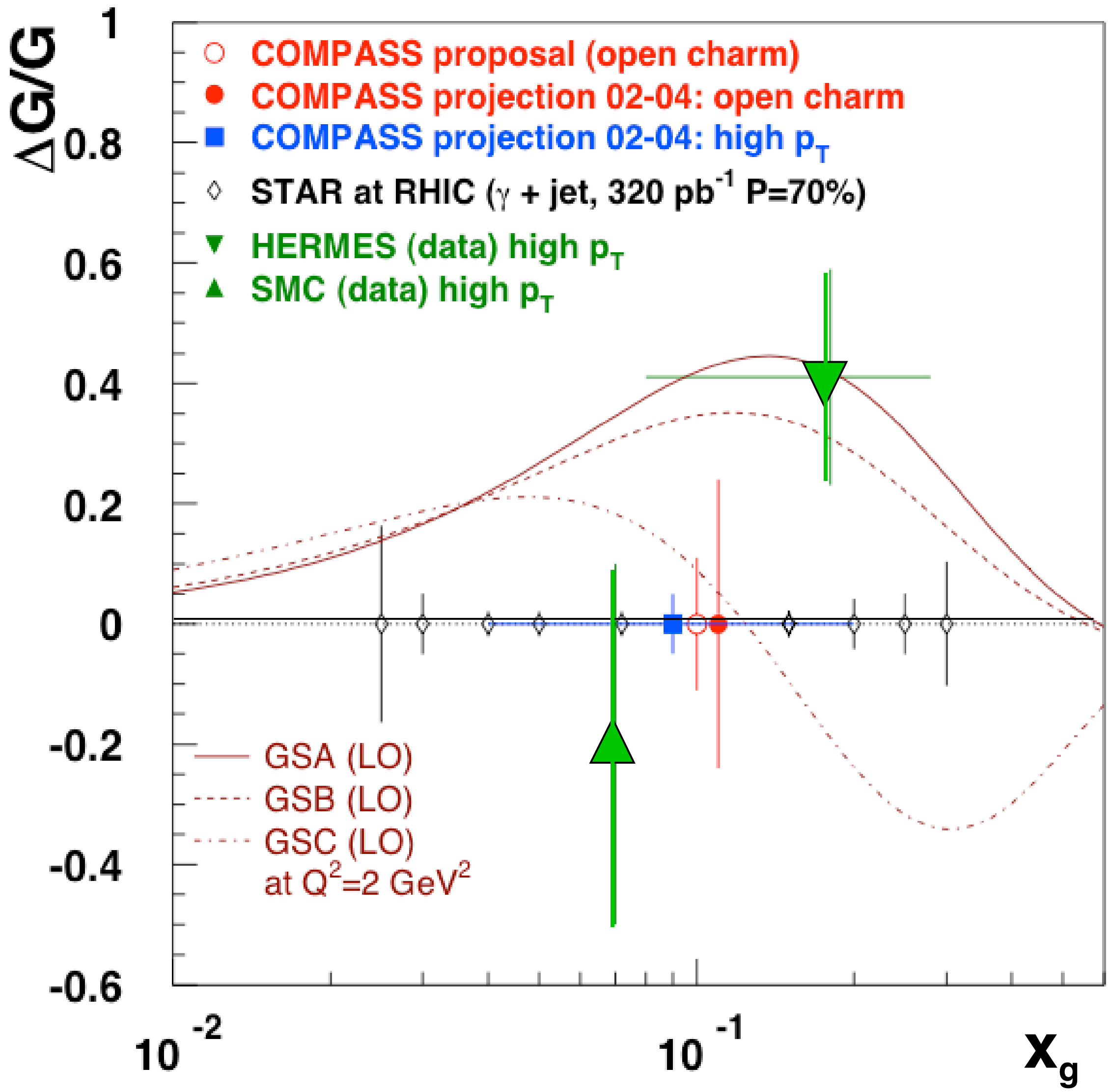
0.1 **Gluon?** **Orbital?**

- $\langle \mathbf{S_g} \rangle = \int_0^1 \mathbf{dx\, \Delta g(x, Q^2)} \propto \frac{1}{\alpha_s(\mathbf{Q^2})}$ **in QCD**

$$\langle S_g \rangle = +0.3 \quad (\text{Rho et al., chiral bag})$$

Gluons: Measurements of ΔG/G

from F. H. Heinsius, COMPASS Collab - DIS April 2004

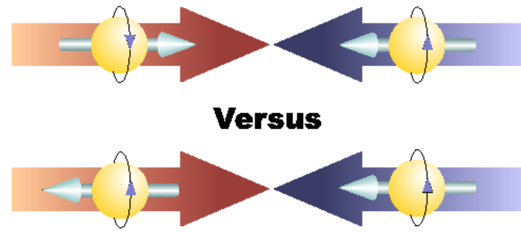


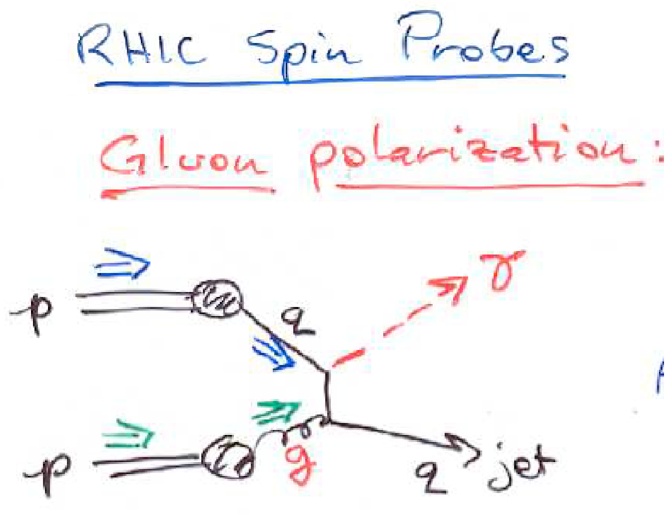
PHENIX and STAR at RHIC will measure ΔG by collisions of longitudinally polarized HE protons - A_{LL}

RHIC: c.m.energies up to 500 GeV

RHIC experiments will measure ΔG

$$A_{LL} = \frac{1}{P_{beam}^2} \frac{N^{\downarrow\uparrow} - N^{\uparrow\uparrow}}{N^{\downarrow\uparrow} + N^{\uparrow\uparrow}}$$





G. Bunce DUBNA-SPIN-03

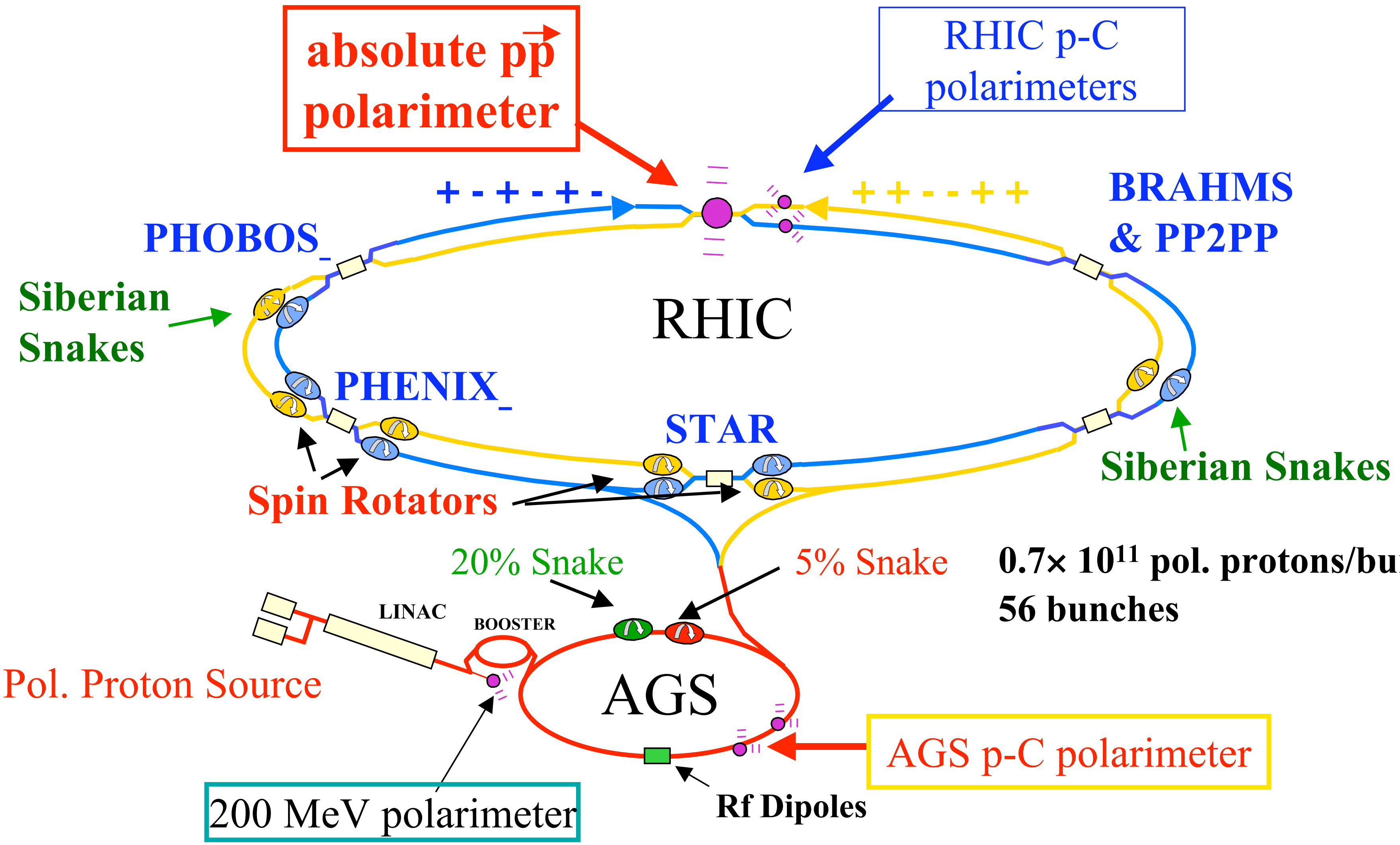
Colliding polarized protons couple directly to gluons (rather than via charge) - measure parton asymmetries.

Measure polarization of gluons through γ, jets, π pi's, heavy quarks.

BUT HOW DOES ONE KNOW P_{beam}?

The RHIC Complex 50 < $\sqrt{s}$ < 500 GeV

present performance: L=4x10^{30}s^{-1}cm^{-2}, P_{beam} ~ 40%



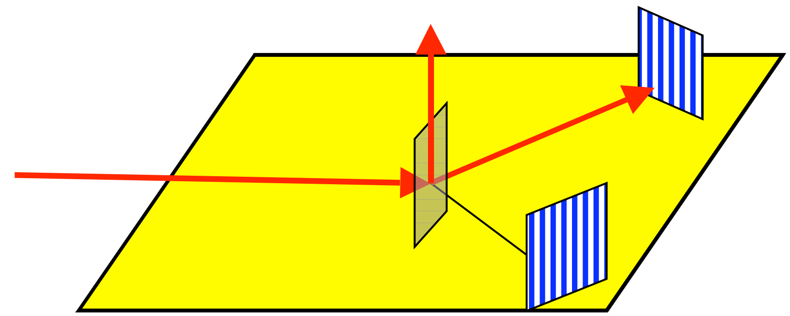
0.7× 10^{11} pol. protons/bunch
56 bunches

Measuring polarization of proton beam

$$\sigma_{L,R} = \sigma_0 (1 \pm A(\theta) P)$$

$$\hat{n} = \hat{k}_{in} \times \hat{k}_{out}$$

$$\text{"}asymmetry\text{"} \quad \varepsilon = PA = \frac{N_L - N_R}{N_L + N_R}$$



Reverse P to eliminate instrumental asymmetry

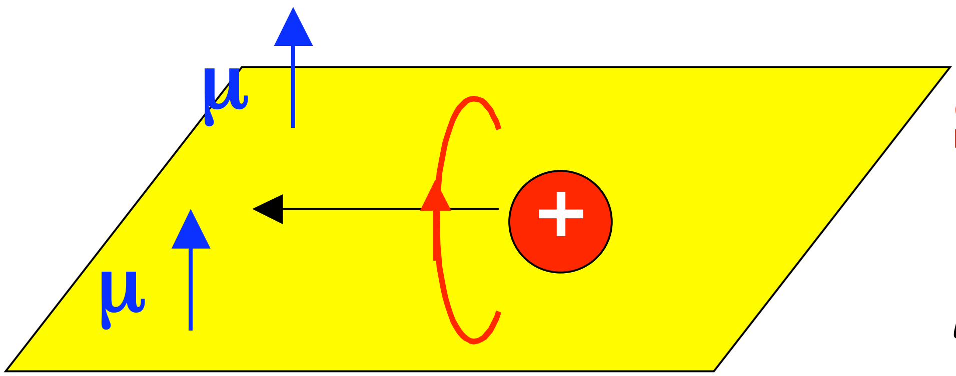
$$\varepsilon = PA = \frac{R-1}{R+1} \quad \text{with } R = \sqrt{\frac{(N_L / N_R)^{\uparrow}}{(N_L / N_R)^{\downarrow}}}$$

- **What mechanism is sensitive to P at high energy?**
- **Need to know analyzing power A.**

Magnetic Moment Scattering

Mott (1929), J. Schwinger (Phys. Rev. 73, 1948)

"It is the purpose of this note to suggest a second mechanism for polarizing fast neutrons - the spin-orbit interaction arising form the motion of the neutron magnetic moment in the in the nuclear Coulomb field."



Spin-orbit coupling:

$$\vec{\mu} \cdot \vec{B} \rightarrow \vec{\ell} \cdot \vec{s}$$

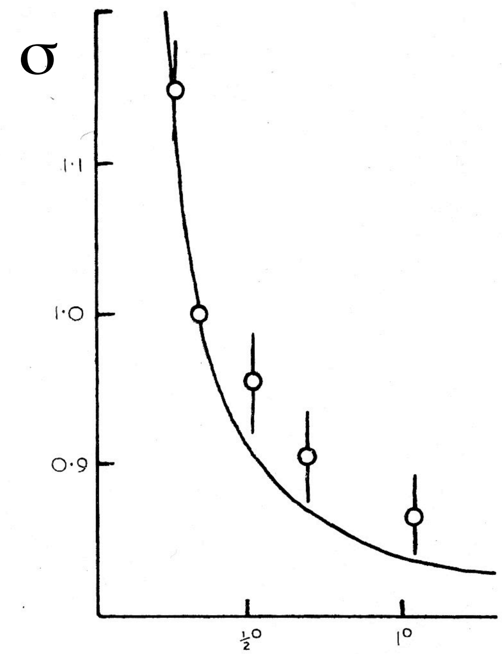
Analyzing power in small-angle neutron scattering…..

Phil. Mag. 1, 175 (1956)

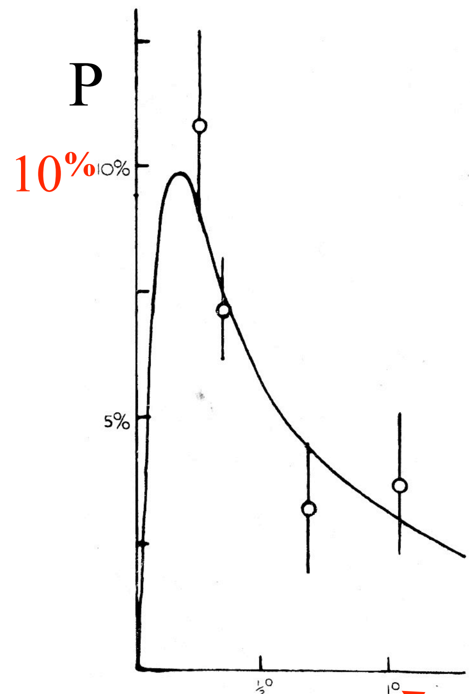
XV. *The Scattering of High Energy Neutrons by a Coulomb Field*

By R. G. P. Voss* and R. Wilson†
The Clarendon Laboratory, Oxford‡

[Received October 28, 1955]



differential cross sections averaged over polarization. Thes
pared with the theoretical curve normalized to unity at 1/3°.



g a beryllium target at 26°, plotted ve
1 the theoretical curve, normalized to

U(n,n)U
100 MeV

1^0

Coulomb-nuclear interference ("CNI")

CNI Analyzing Power in High-Energy pp Scattering

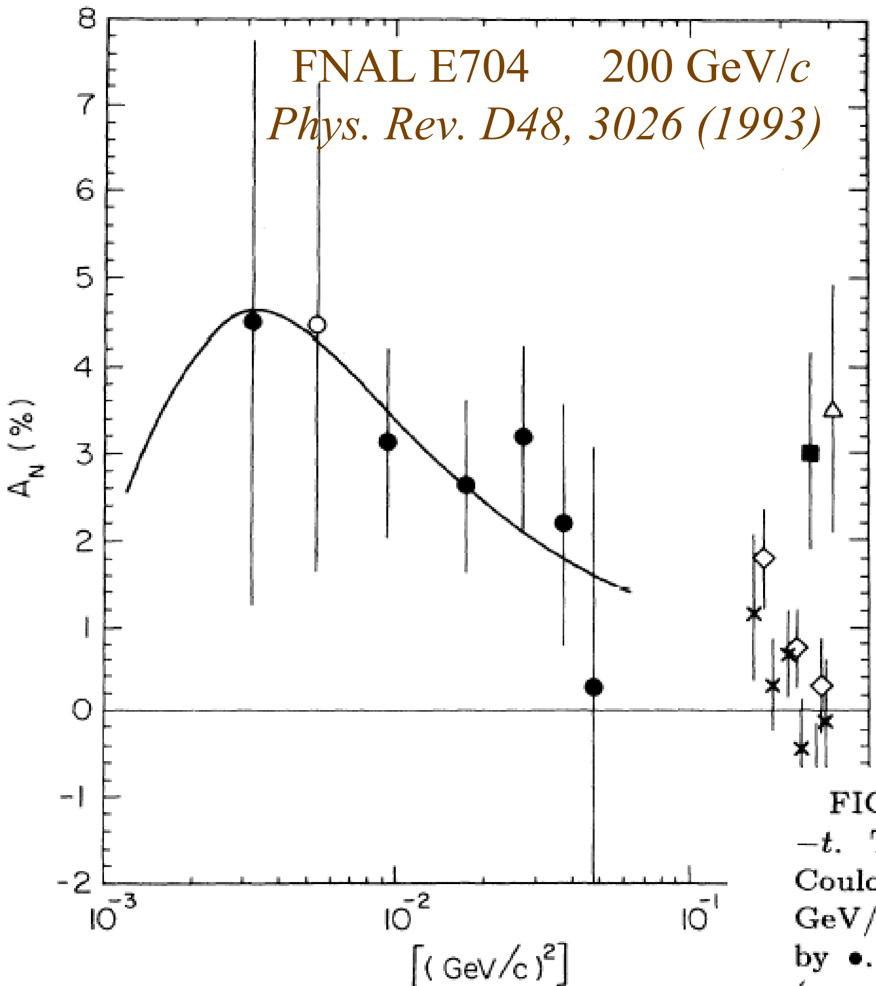
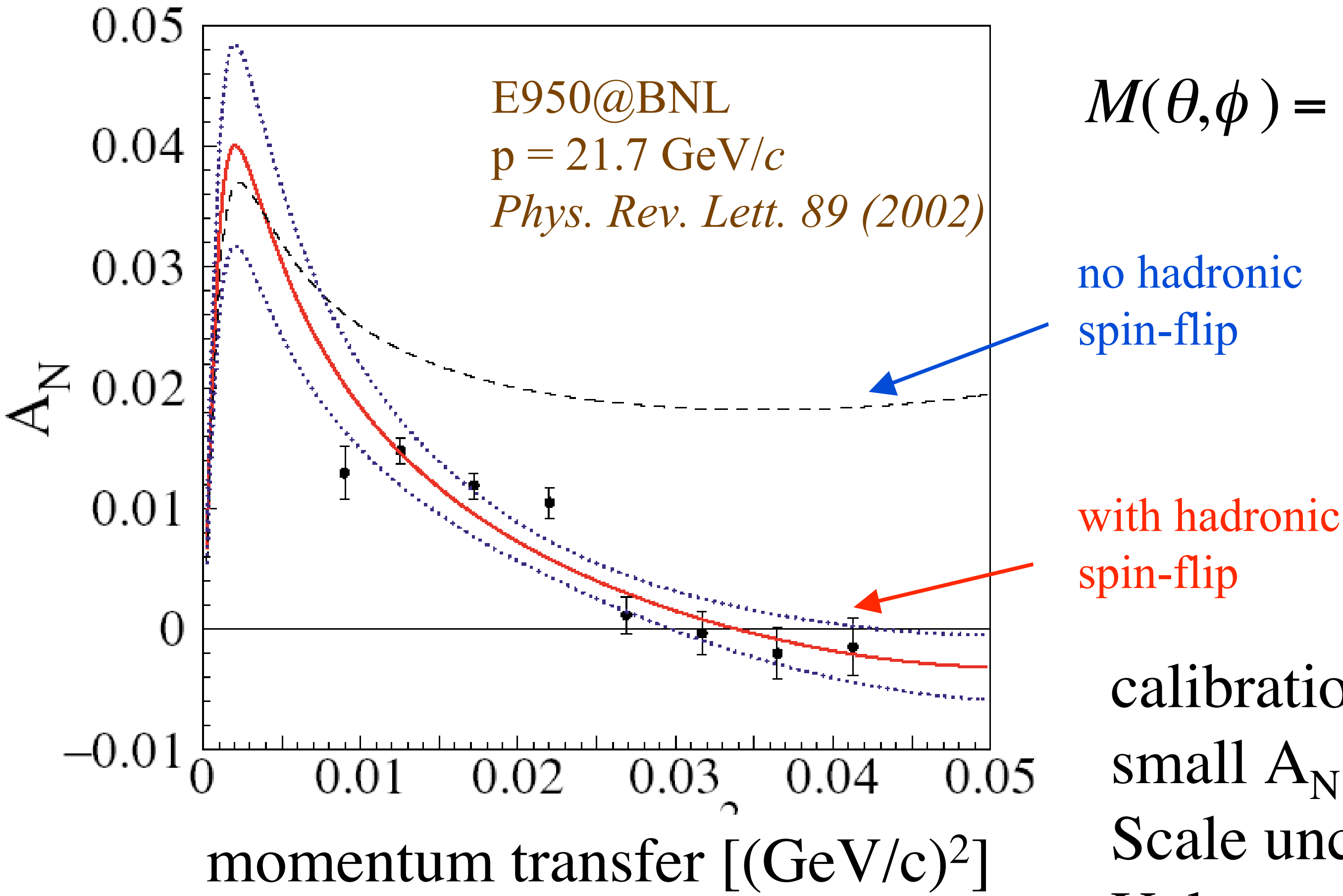


FIG. 8. A_N data for pp elastic scattering as a function of $-t$. The solid curve is the theoretical prediction [2] in the Coulomb-nuclear interference region. ○ is measured at 185 GeV/c [24] and the results of this measurement are indicated by ●. The other data points are measured at 300 GeV/c (cross) and 100 GeV/c (diamond) [16], 176 ± 12 GeV/c (triangle) [17], and at 150 GeV/c (black square) [15], using a polarized target.

A_N vs momentum transfer

Polarized protons from Hyperon decay (low rate)

CNI Analyzing Power p-Carbon Scattering



$$M(\theta,\phi) = g(\theta) + h(\theta)(\hat{n}\cdot\vec{\sigma})$$

$$A = \frac{2(\mathrm{Re}(g^* h)}{|g|^2 + |h|^2}$$

calibration only at 22 GeV/c

small A_N

Scale uncertainty ~30%

Unknown energy dependence

But large count rates

need for accurate absolute A_N measurement

Beam Polarization Calibration

Elastic scattering of IDENTICAL particles (pp):
beam analyzing power = target analyzing power
(Change in reference frame)

- Measure asymmetry $\boldsymbol{\varepsilon_{tgt}}$ when unpolarized beam is scattered from **polarized target** of KNOWN polarization P_t - *measures A*

$$\varepsilon_{tgt} = P_t A$$

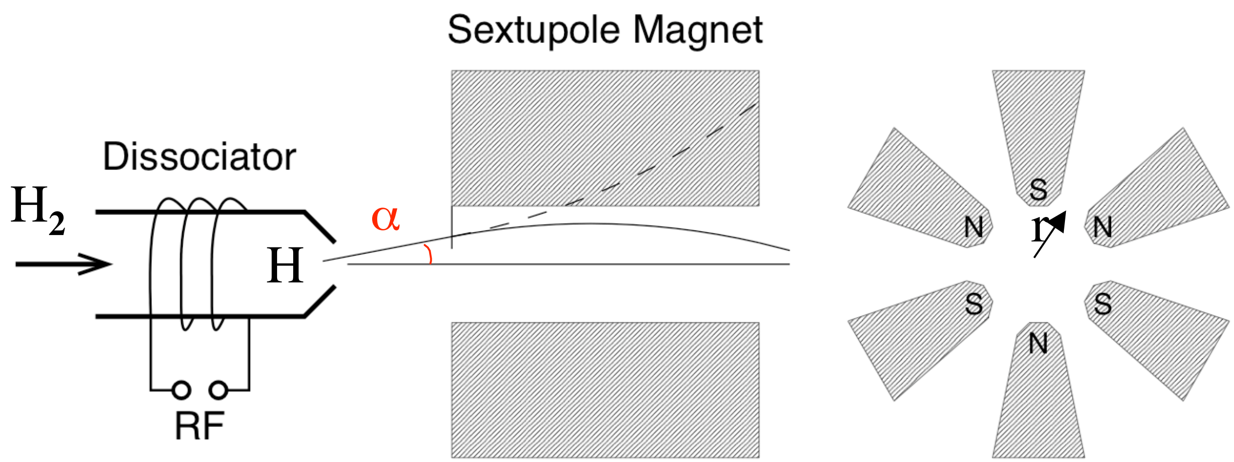
- Measure asymmetry $\boldsymbol{\varepsilon_{beam}}$ when **polarized beam** is scattered from unpolarized target

$$\varepsilon_{beam} = (-) P_b A$$

Both experiments done simultaneously

$$P_b = P_t \left(\varepsilon_{beam} / \varepsilon_{tgt} \right)$$

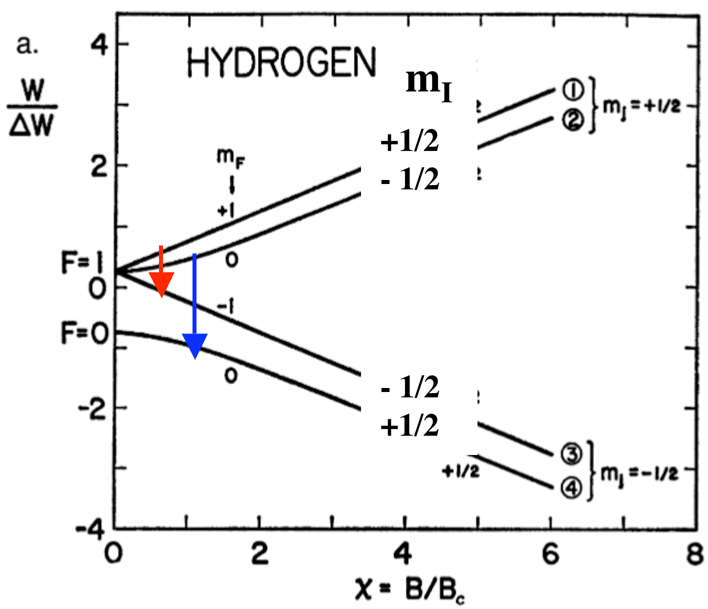
The Polarized Target - Principle

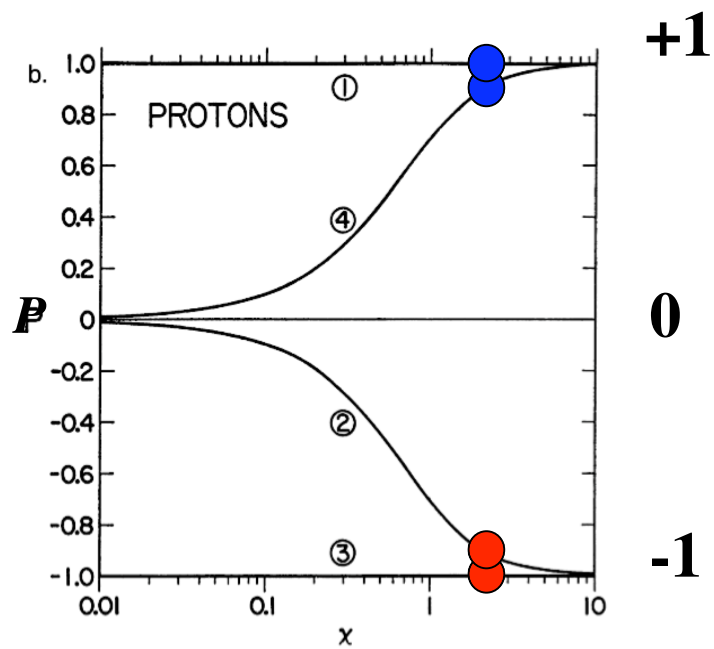


$$|B| \propto r^2$$

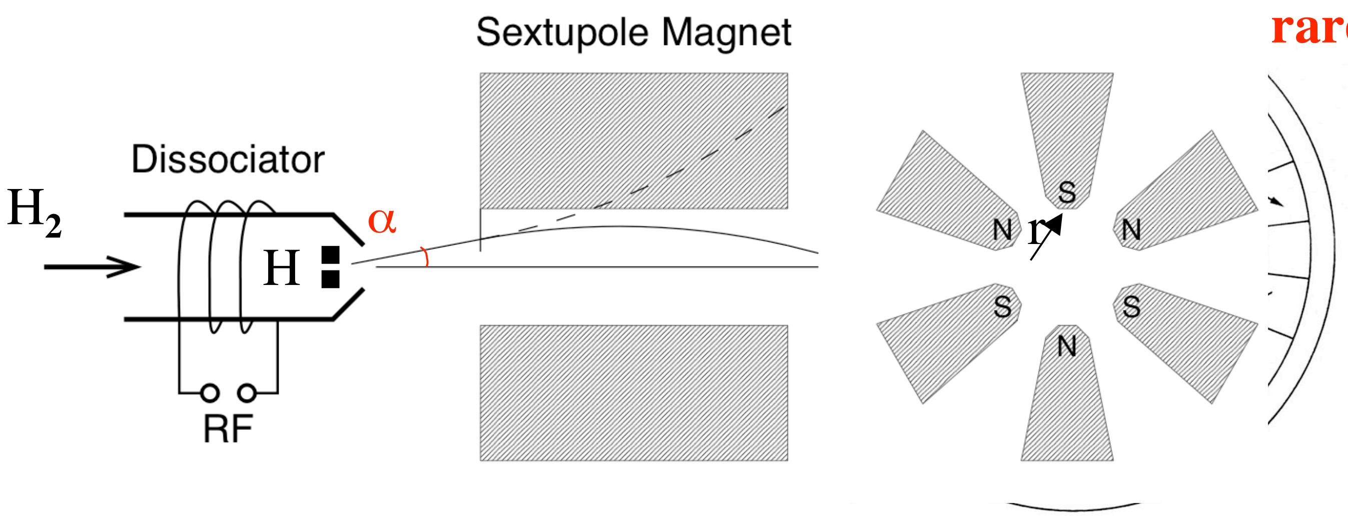
$$\vec{F}_r = \pm k\vec{r}$$

acceptance angle α





. . . . . . .and Practice



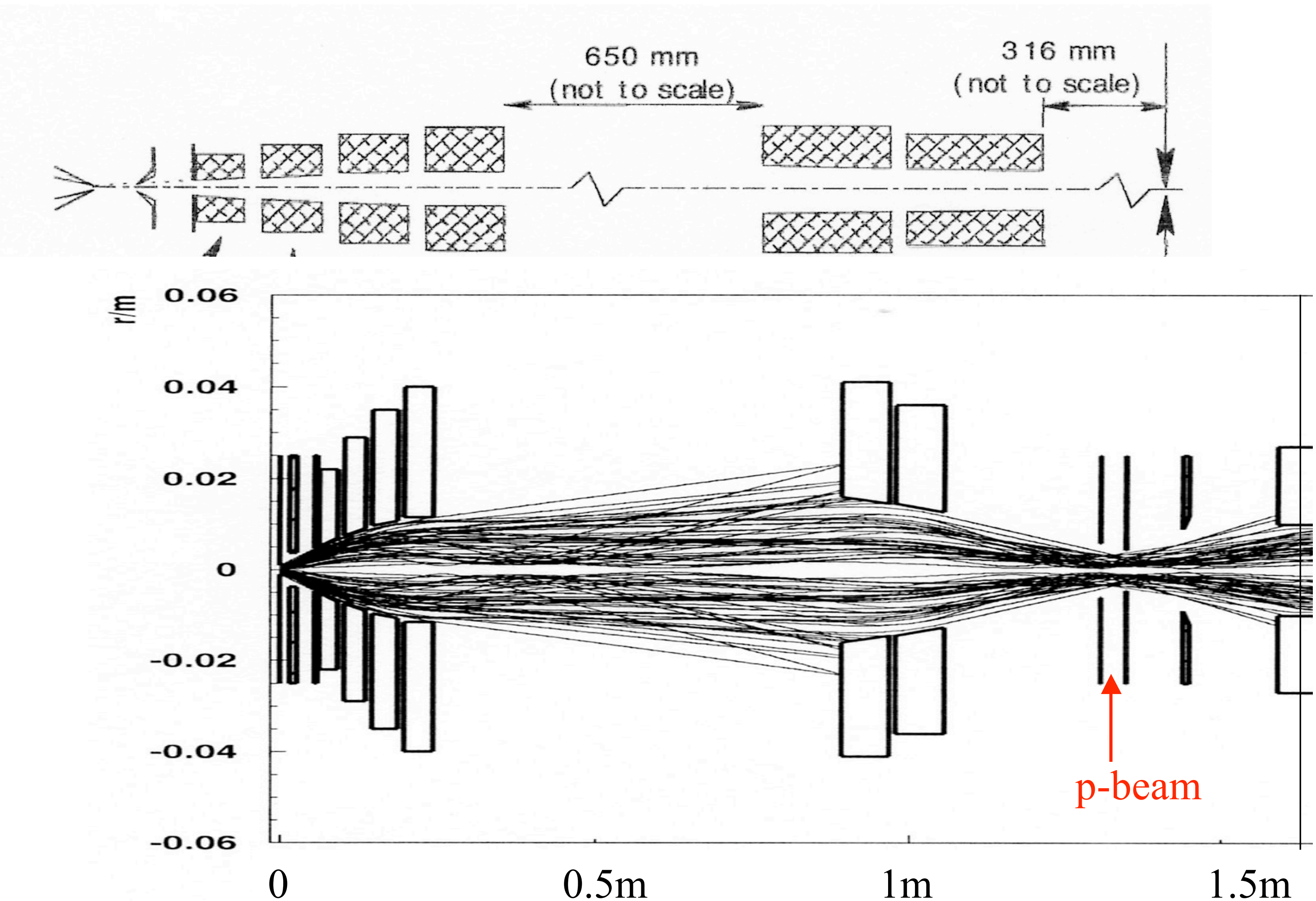
rare-earth perm. magnets,
pole tip 1.5T,
max δ|B|/ δr =6T/cm)

overall design:
Tom Wise, UW

- Cooled dissociator nozzle to reduce v and v-spread.
- recombination: dissociation depends on gas flow and nozzle temp
- Beam attenuation: rest gas and intrabeam scattering
- Magnet design (taper, lengths, z-position) needs:
  velocity distribution, dissociator H output vs gas flow, nozzle T
  beam forming geometry
- differential pumping

OPTIMIZATION: COMPUTER MODELLING

H-jet sextupole separation magnet system.



The Polarized H-jet at RHIC

Hyperfine state
(1),(2),(3),(4)

↓

(1),(2)

↓

Pz+ : (1),(4) (transition (2)→(4))

Pz- : (2),(3) (tranistion (1)→(3))

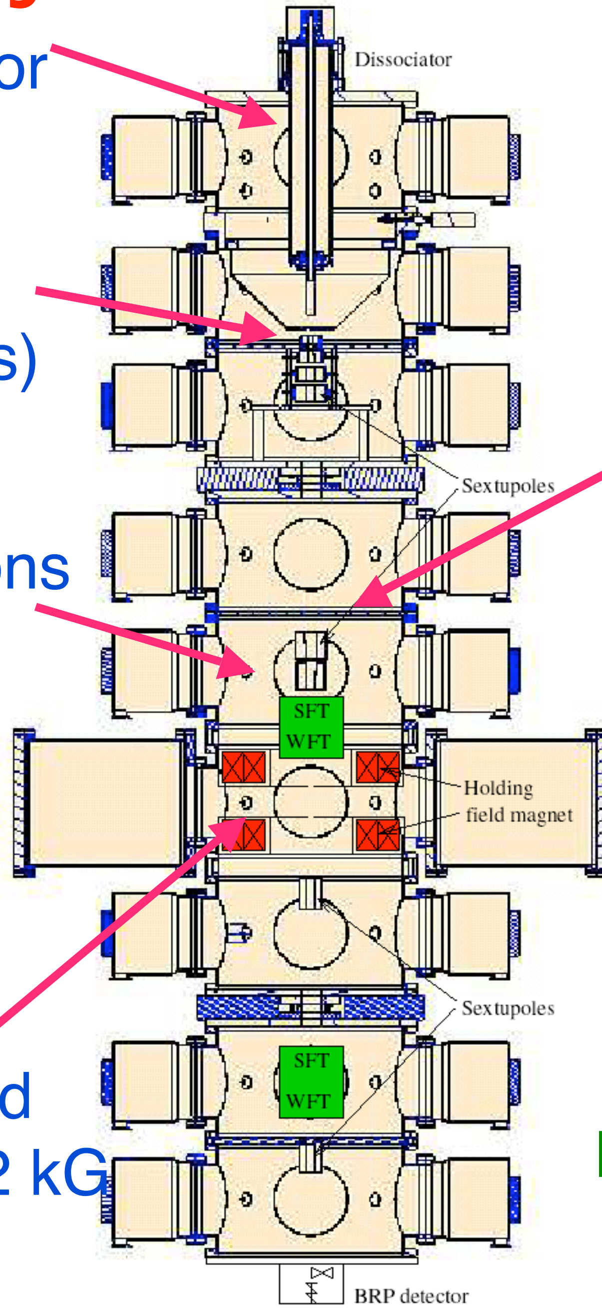
Beam intensity:
$(1.2\pm0.2)10^{17}$H/s

H_2 dissociator

separation magnets (sextupoles)

RF transitions

holding field magnet 1.2 kG

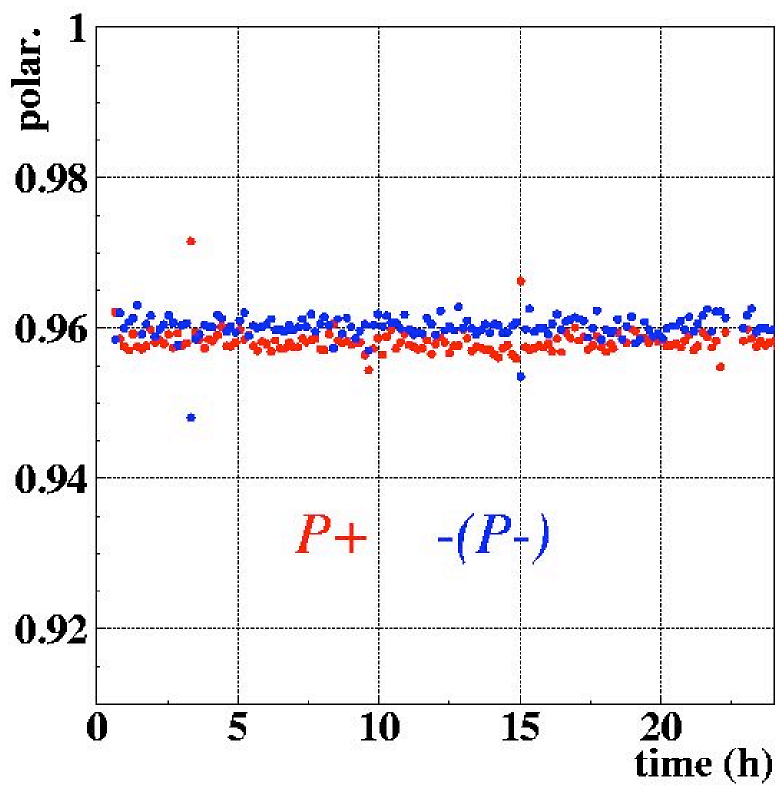


focusing magnets (sextupoles)

recoil Chamber Silicon Det.

Polarimeter

Nuclear polarization of H-atoms



Efficiency of RF transitions: *(99.7±0.2)%*

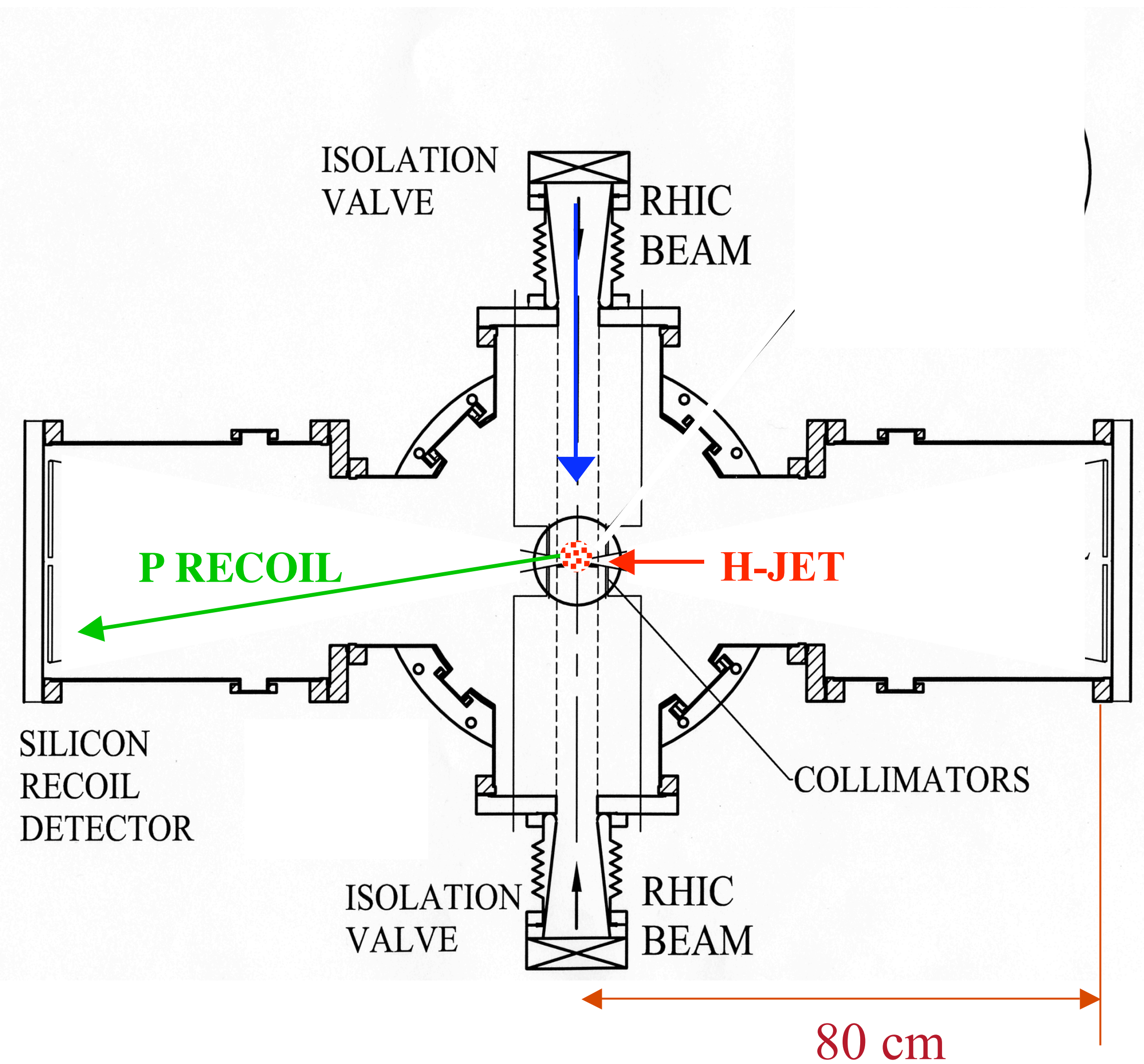
ideal proton polarization for B=1.2kG: *P = 0.960*

plus ~3% dilution from H_2

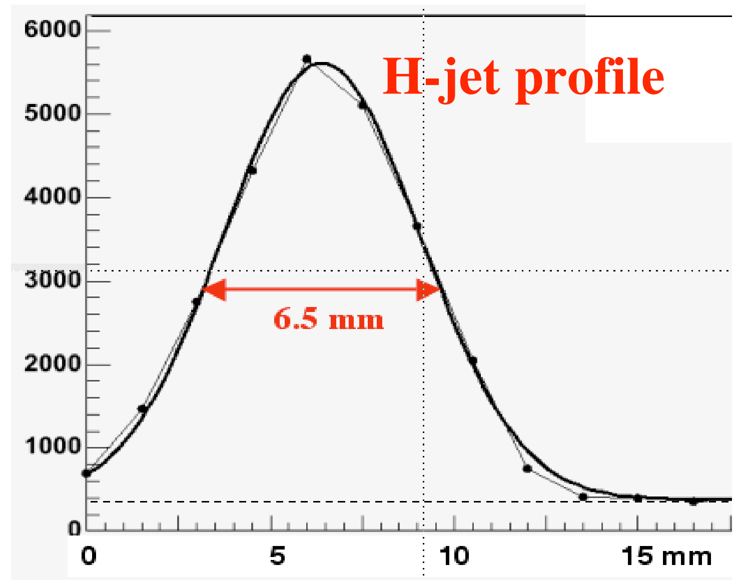
P = 0.924 ±2%

bunch-field depolarization <0.1%

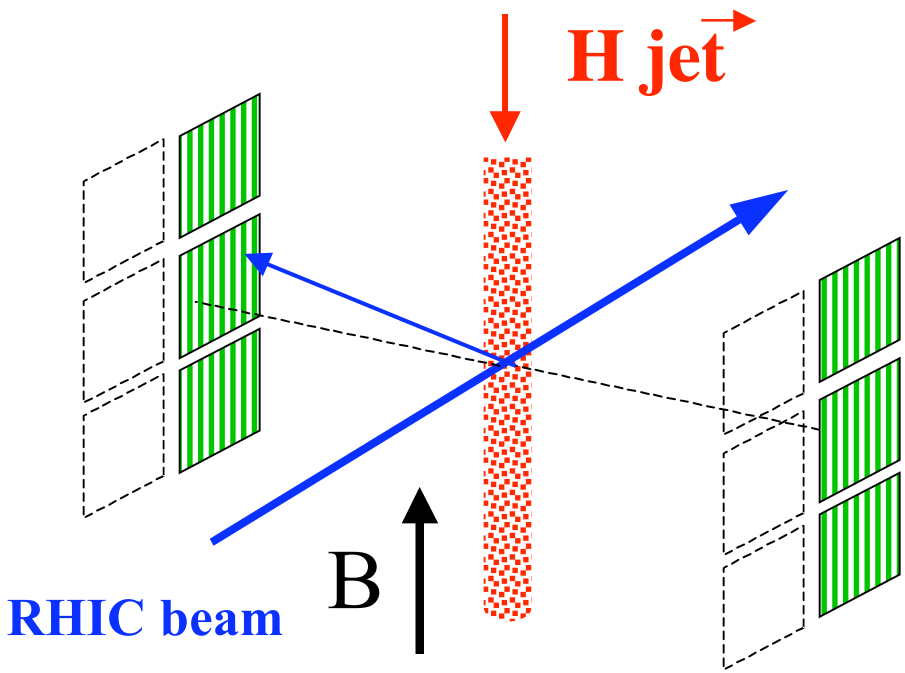
Scattering Chamber (top view)



Target thickness:
$(1.3 \pm 0.2) \times 10^{12}$ H/cm^2



Recoil Detectors



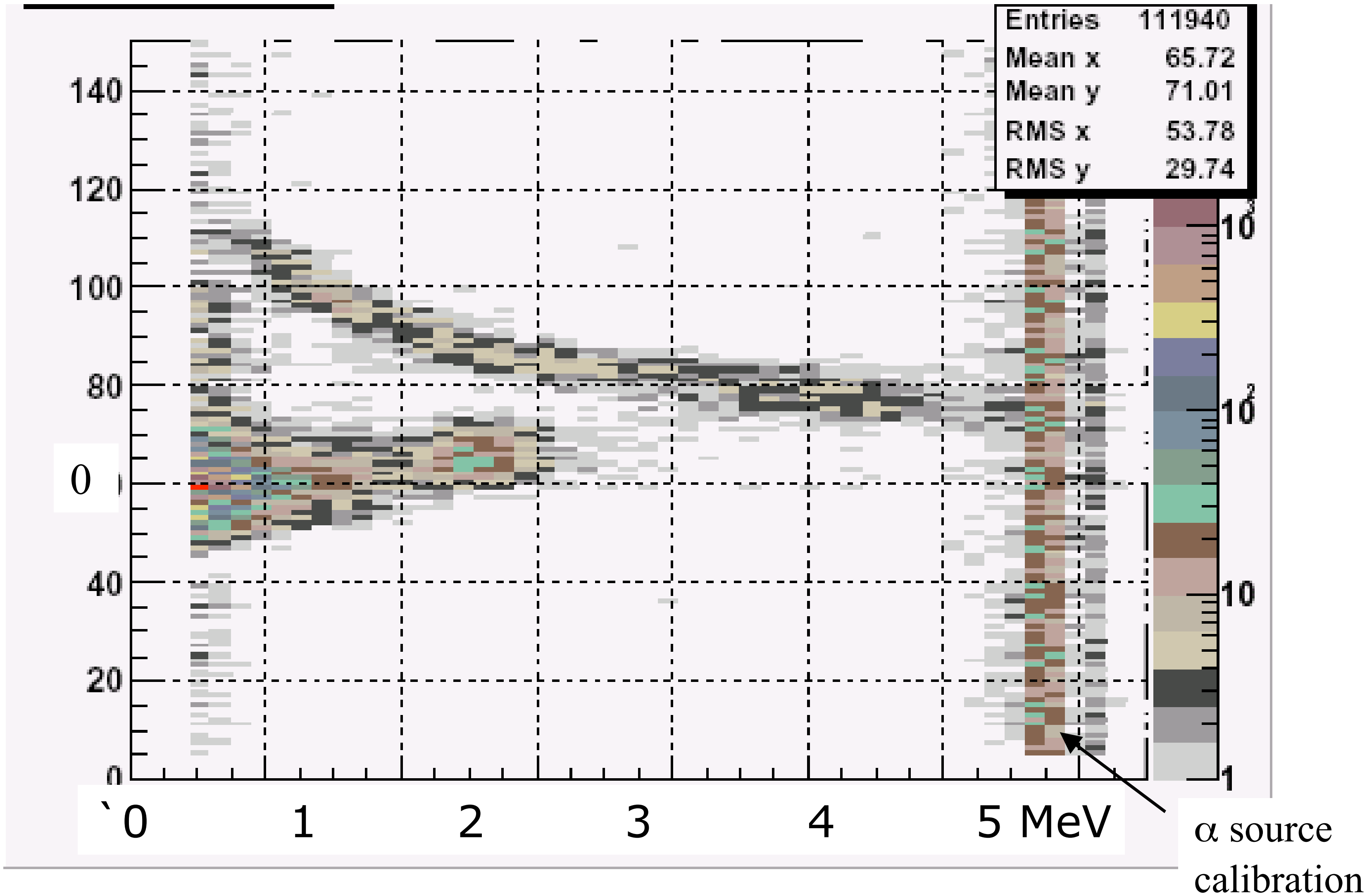
Recoil detectors (blue beam):

6 detectors 70x64 mm
16 strips (5 mrad each)

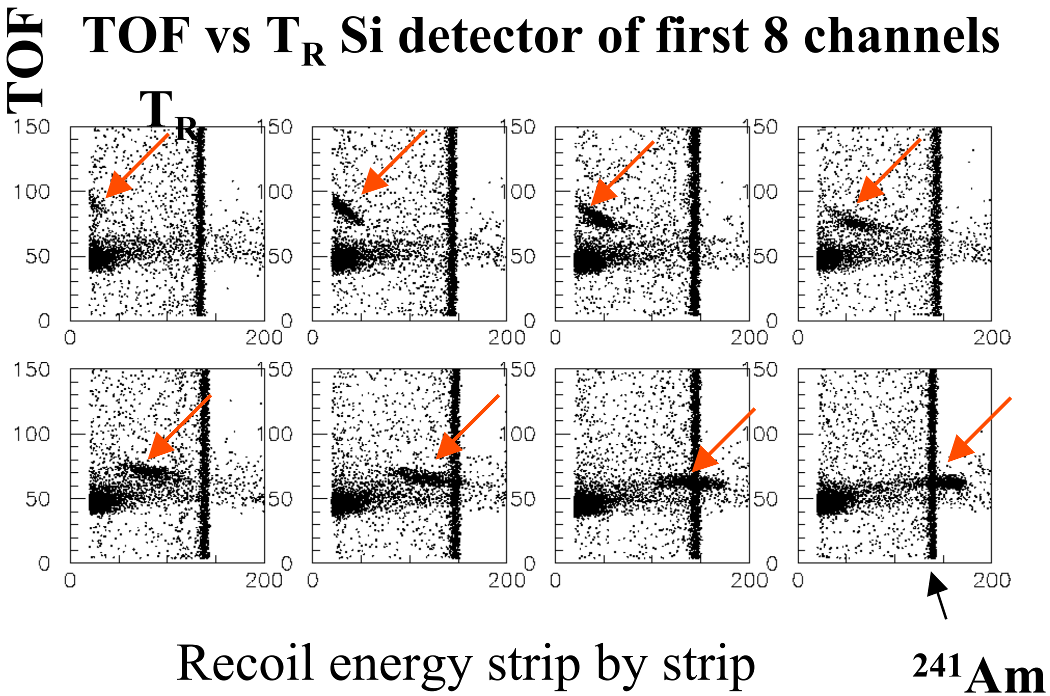
Measure

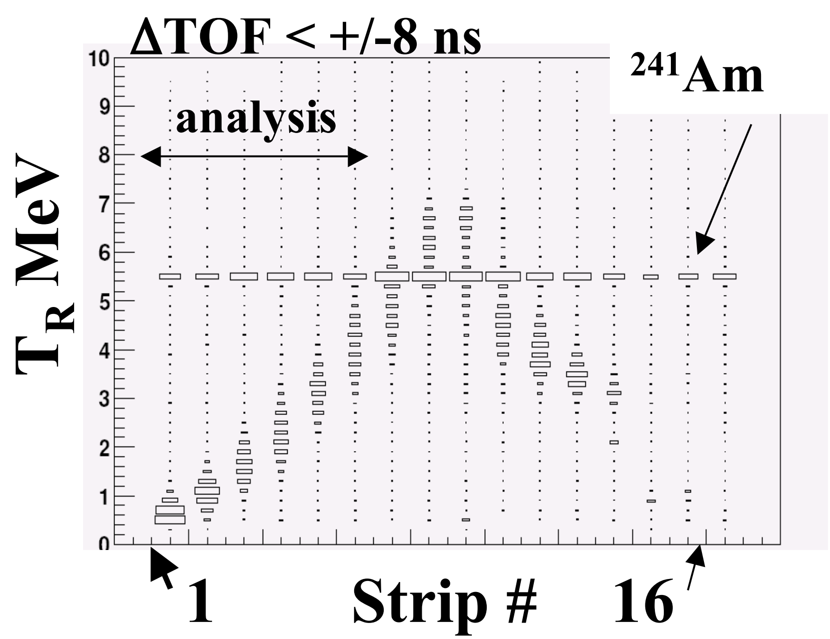
- **Energy:** **1~7MeV**
  resolution < 50 keV
- **TOF:** **16~80 ns**
  resolution < 2 ns
- **Angle:** **10~100 mrad (89.5 - 84$^{O)}$**
  resolution 5 mrad

Recoil energy vs. time-of-flight

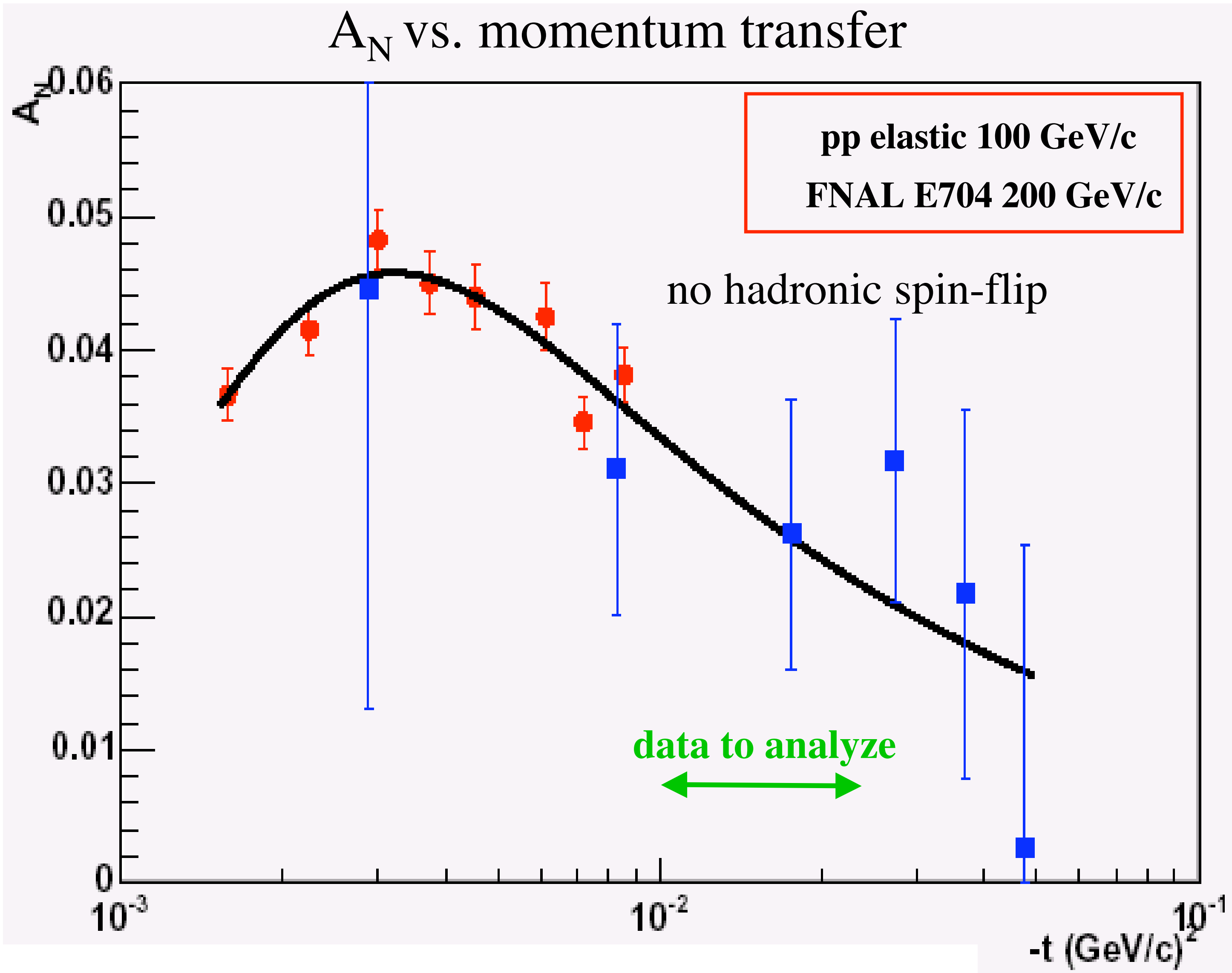


Identifying recoil protons vs recoil angle (=strip #)





pp Analyzing Power 100GeV/c



Polarization of 100 GeV Beam

$$P_{beam} = P_{target} \left\langle \frac{\varepsilon_{beam}}{\varepsilon_{target}} \right\rangle = 0.39 \pm 0.03 \text{ (stat)}$$

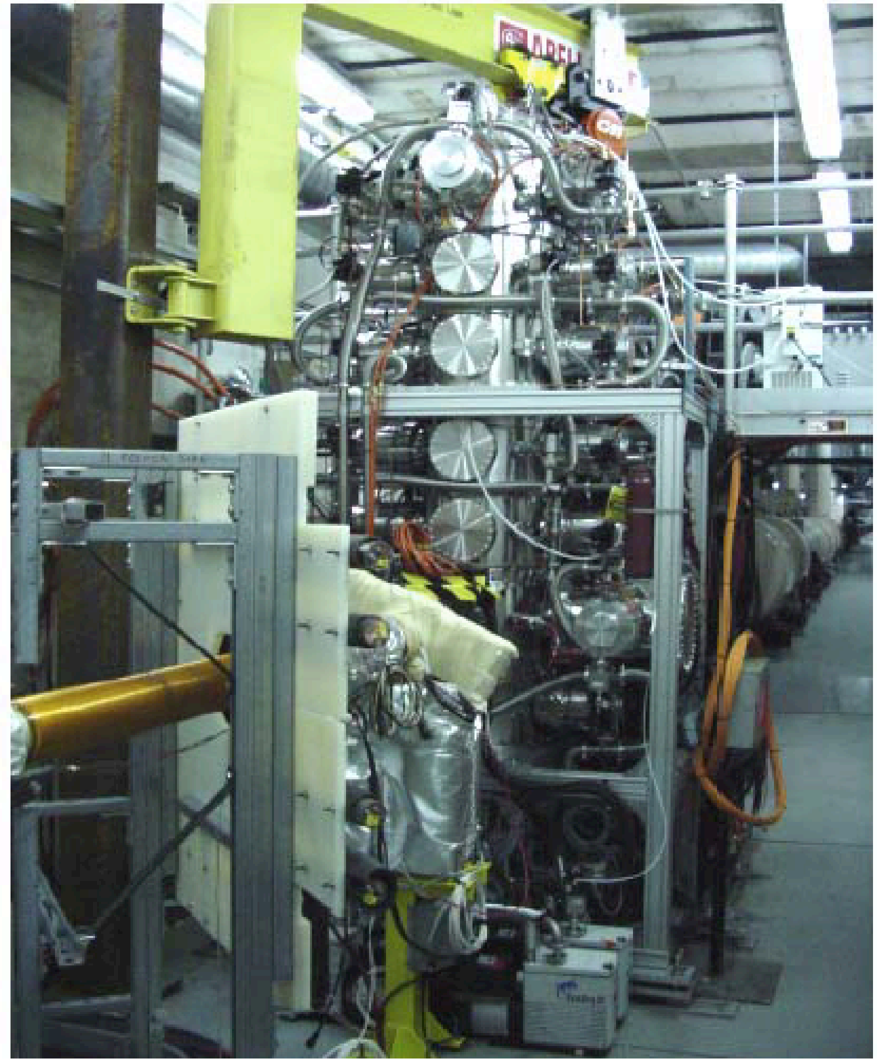
$\sim 10^6$ pp events

Plans:

- study systematic errors and improve statistics for absolute calibration accuracy ±5%
- analyze wider t-range to study pp interaction
- bunch field depolarization with 110 bunches
- improved measurement of H_2 contamination of H-beam
- measure beam polarization at injection
- measure blue and yellow beam polarization

H-Jet collaborators:

Wisconsin:, T. Wise, M. Chapman, W.H.
BNL: A. Bravar, G. Bunce, R. Gill, Z. Li,
A. Khodinov, A. Kponou, Y. Makdisi,
W. Meng, A. Nass, S. Rescia, A. Zeler
Kyoto: H. Okada, N. Saito
ITEP-Moscow: I. Alekseev, D. Svirida
IUCF: E. Stephenson
RIKEN-BNL: O. Jinnouchi,
Rikkyo U: K. Kurita
ANL: H. Spinka

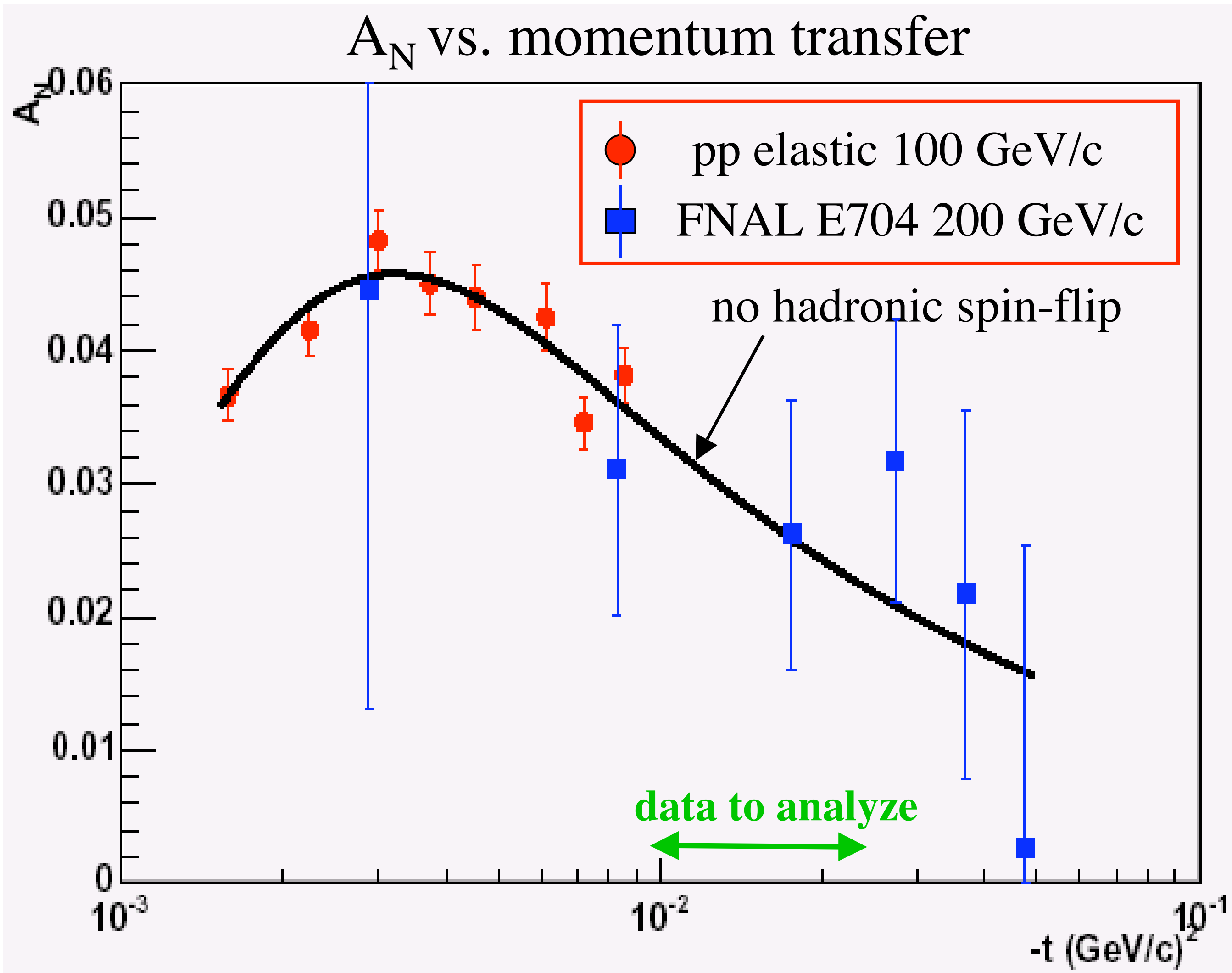


THE UNIVERSITY of WISCONSIN MADISON

BROOKHAVEN NATIONAL LABORATORY


1.26 km
RHIC
G-2
BOOSTER
LINAC
AGS

pp Analyzing Power 100GeV/c



Recoil angle	89.5°	
Recoil energy	0.53 MeV	5.3MeV

Plans

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  for absolute calibration accuracy ±5%
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  H_2 contamination of H-beam
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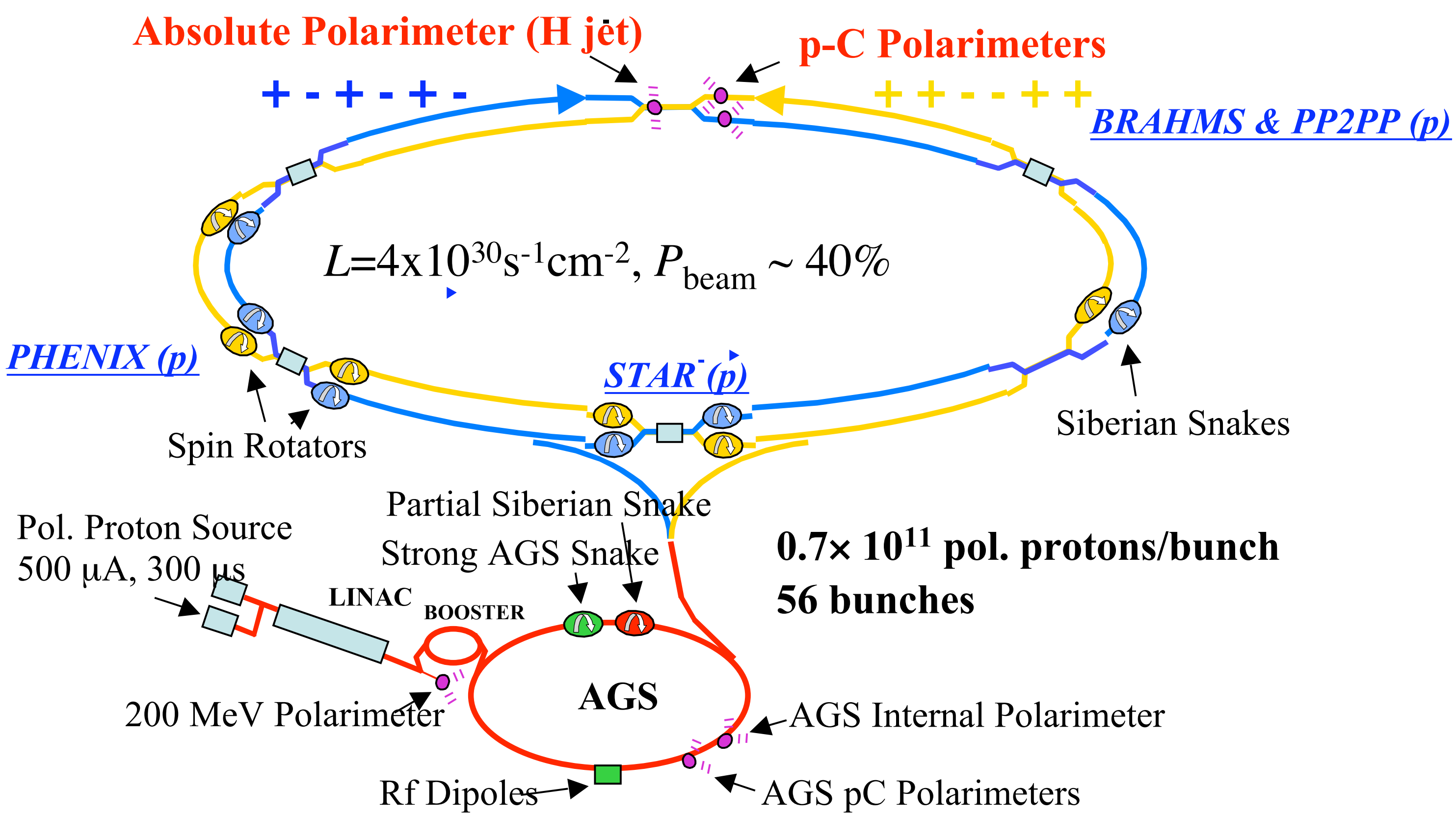
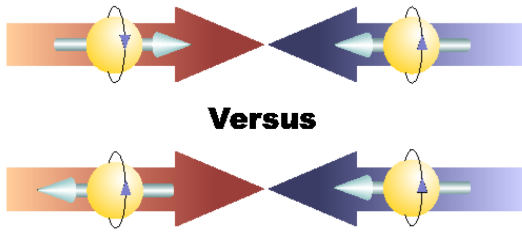
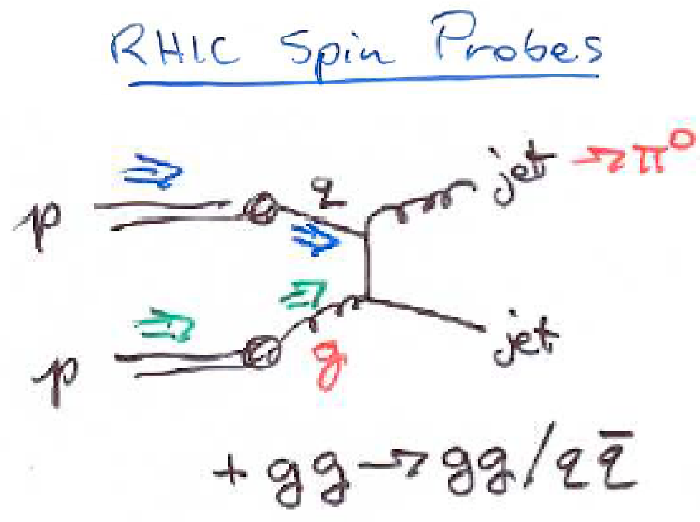
RHIC pp accelerator complex



RHIC experiments will measure ΔG

$$A_{LL} = \frac{1}{P_{beam}^2} \frac{N^{\downarrow\uparrow} - N^{\uparrow\uparrow}}{N^{\downarrow\uparrow} + N^{\uparrow\uparrow}}$$





G. Bunce DUBNA-SPIN-03

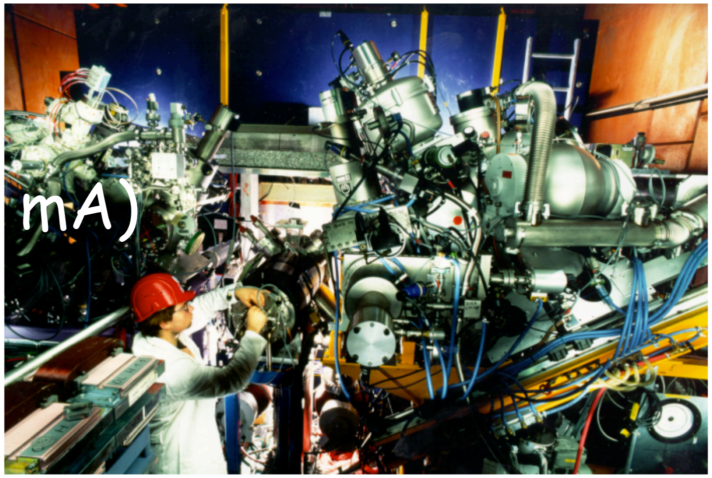
Colliding polarized protons couple directly to gluons (rather than via charge) - measure parton asymmetries.

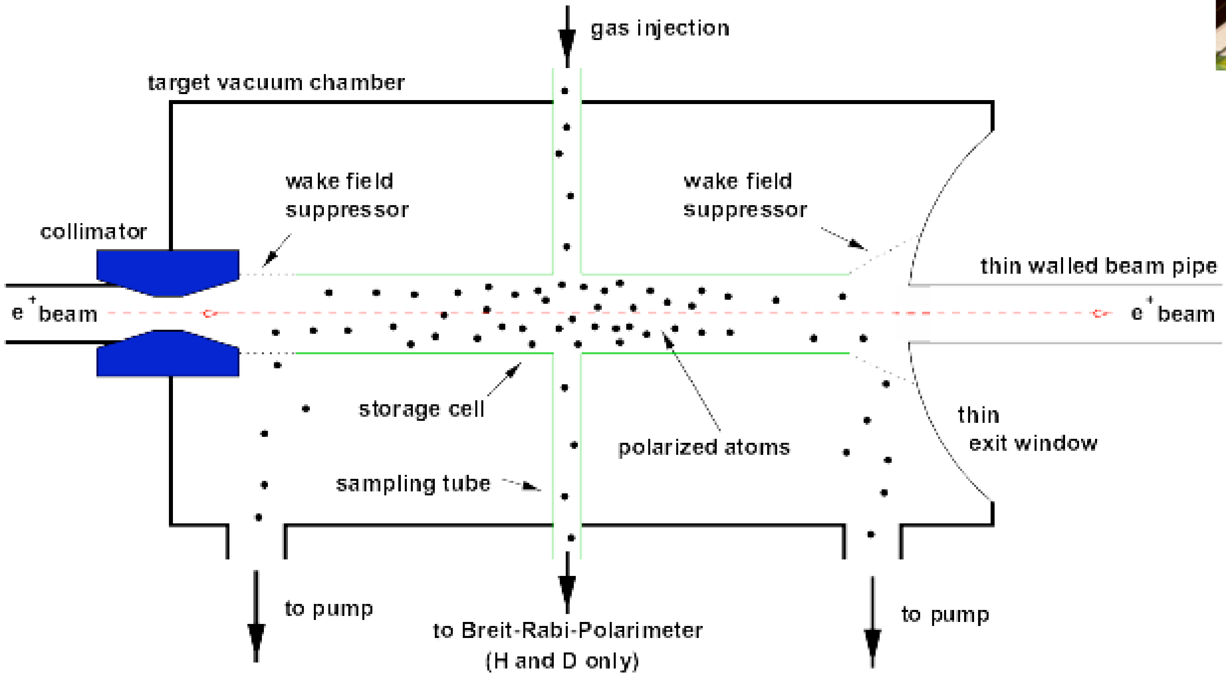
Measure polarization of gluons through γ, jets, π pi's, heavy quarks.

→ **BUT HOW DOES ONE KNOW P_{beam}?** ←

HERMES internal target

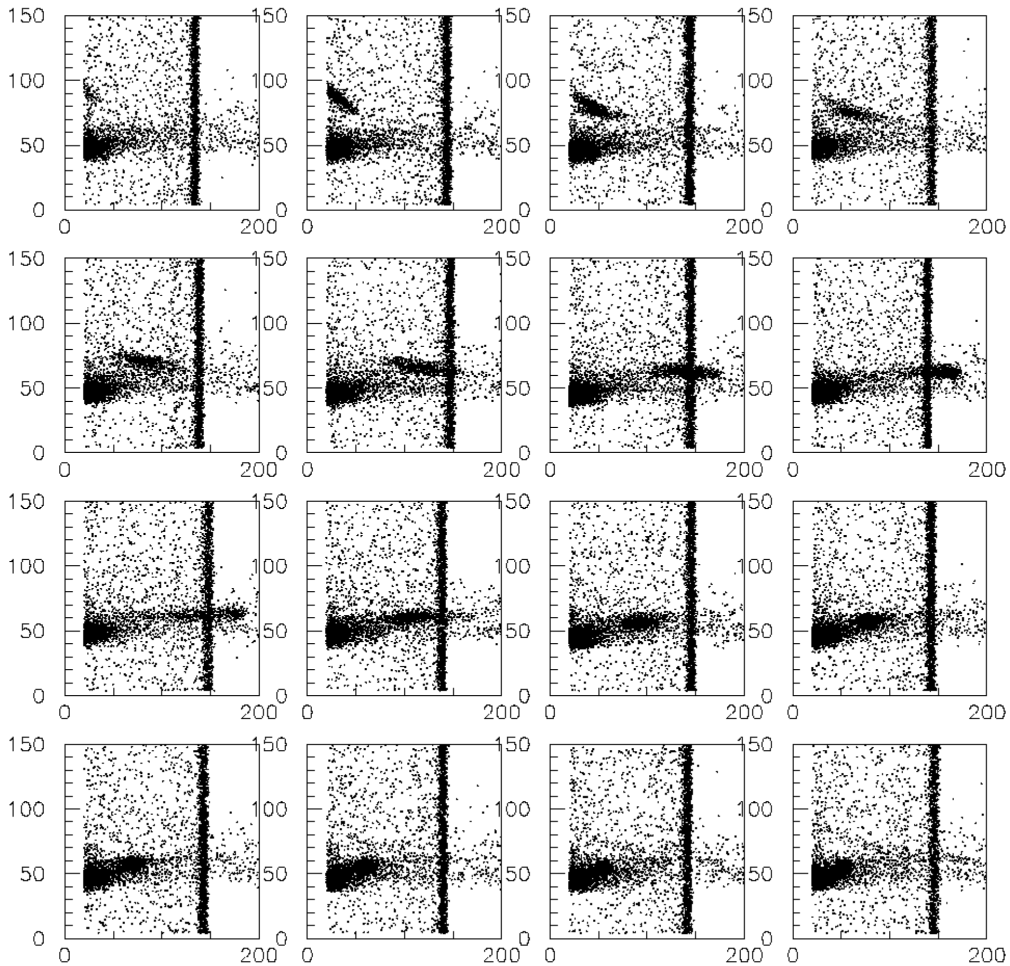
- Pure polarised gas targets: $\vec{H}$, $\vec{D}$,
- target polarisation: $p_T \sim 85\%$
- Luminosity: $6*10^{33}$ cm^{-2} s^{-1}($\vec{D}$ @ 50 mA)
- → spin reversal every 120 sec

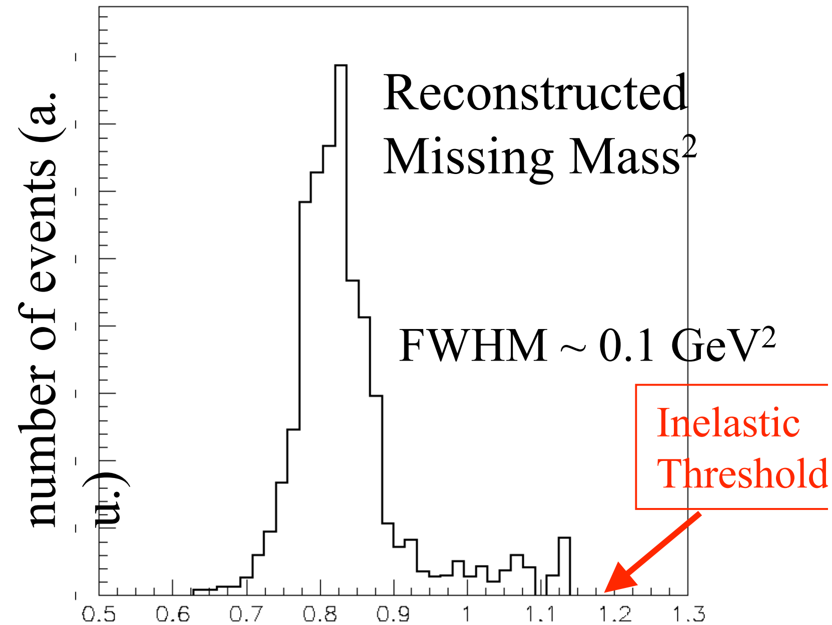


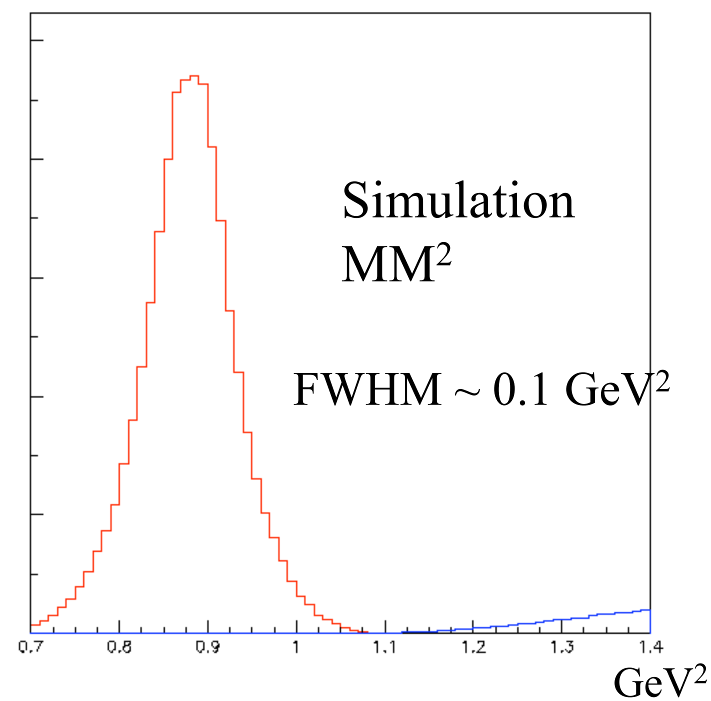


Factor 100 gain from use of storage cell

The Data (a sample)

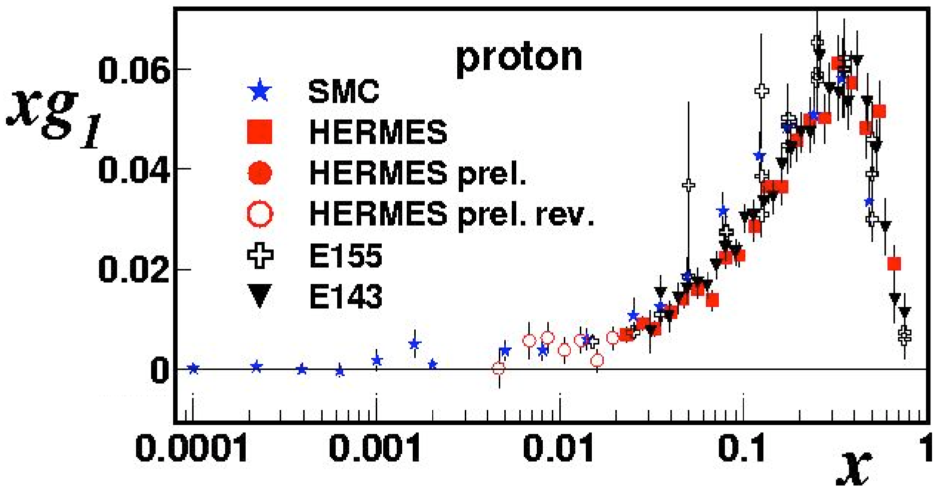






What accounts for the spin of the nucleon?

K. Rith DIS 2004



DIS of **polarized** HE leptons from **polarized** nucleons at SLAC, CERN, HERA:
The (old) proton spin puzzle:
Only ~20% of proton spin is accounted for by spins of quarks and antiquarks

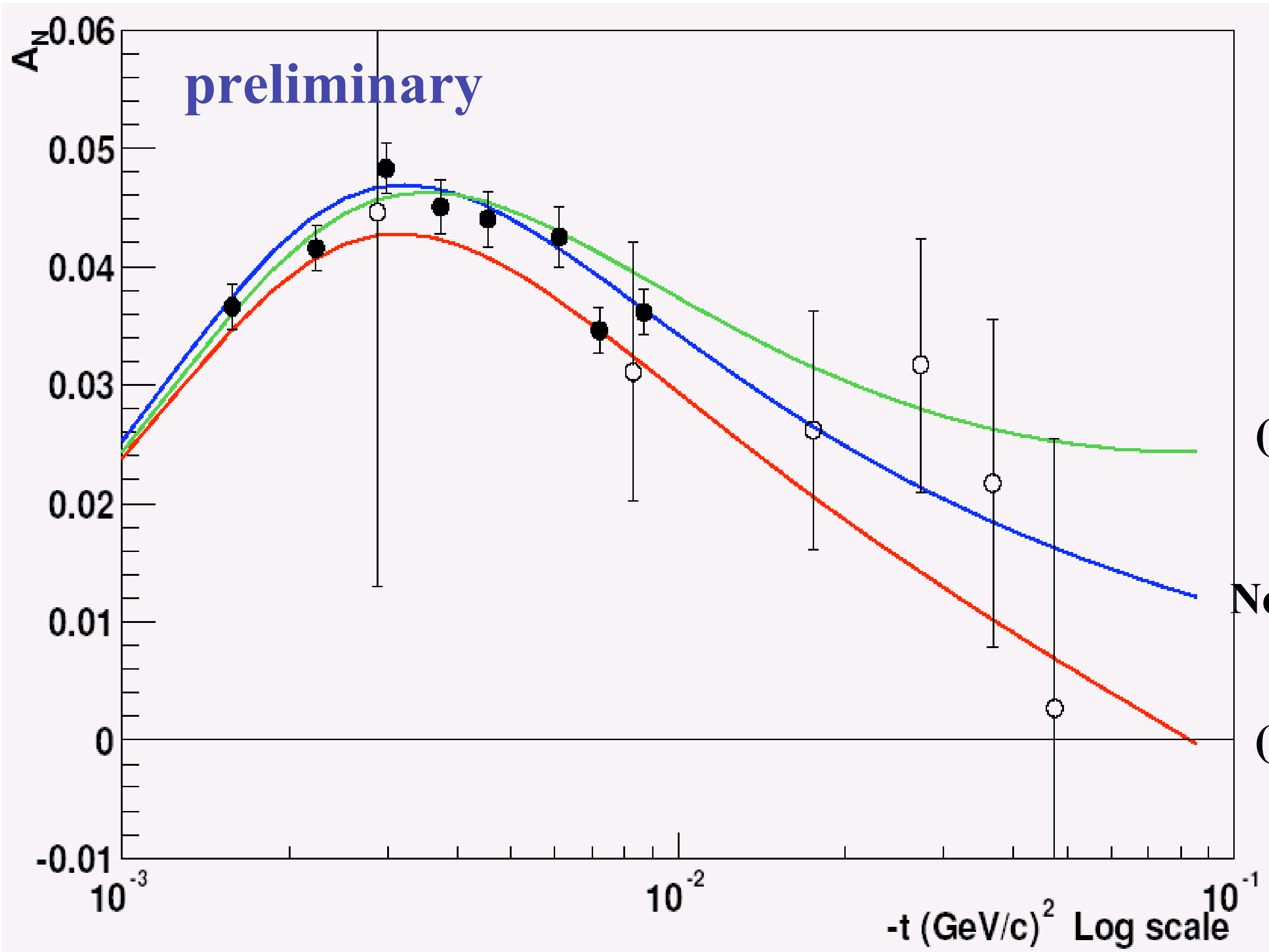
QCD analysis of Q^2 dependence:

$\Delta u + \Delta d + \Delta s \cong 0{,}20 \pm 0{,}04 \pm ..$

Two experimental methods:

- thick solid polarized target + low intensity e or μ beam
- Thin polarized gas target + high intensity beam

Comparison with some models (Not Fitting)



(Re r5= -0.02)

Non-hadron spin flip

(Re r5= +0.02)

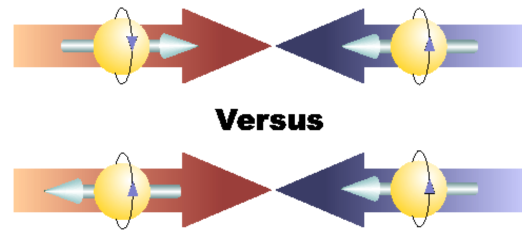
CONCLUSIONS:

- Demonstrated feasibility of accurate beam polarization calibration at high energy
- calibration of p-C polarimeter
- measurement of pp A_N (8 angles, ±~10%)
- H-jet does not interfere with p-beam life time
- 3% measurement requires <200 hrs with improved beam intensity
- method covers entire energy range of RHIC

one important step towards a precise determination of ΔG……

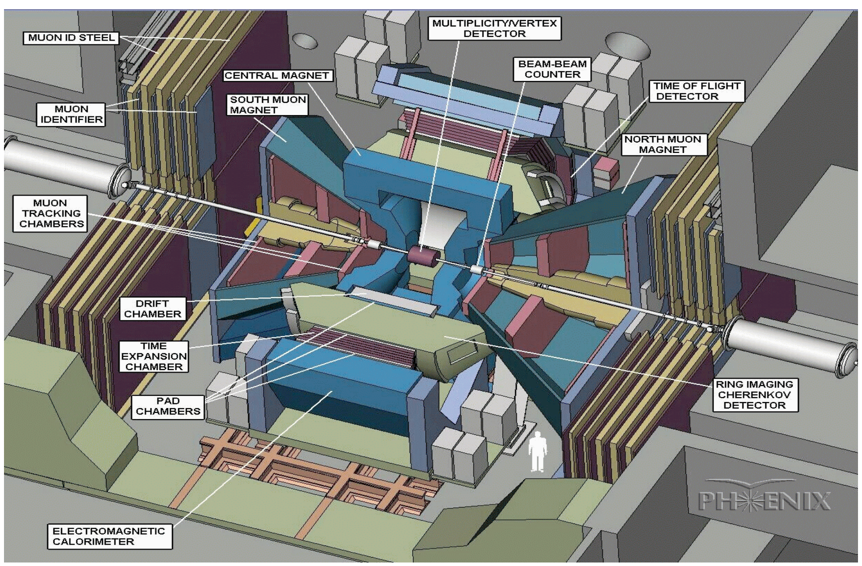
RHIC experiments will measure ΔG

$$A_{LL} = \frac{1}{P_{beam}^2} \frac{N^{\downarrow\uparrow} - N^{\uparrow\uparrow}}{N^{\downarrow\uparrow} + N^{\uparrow\uparrow}}$$



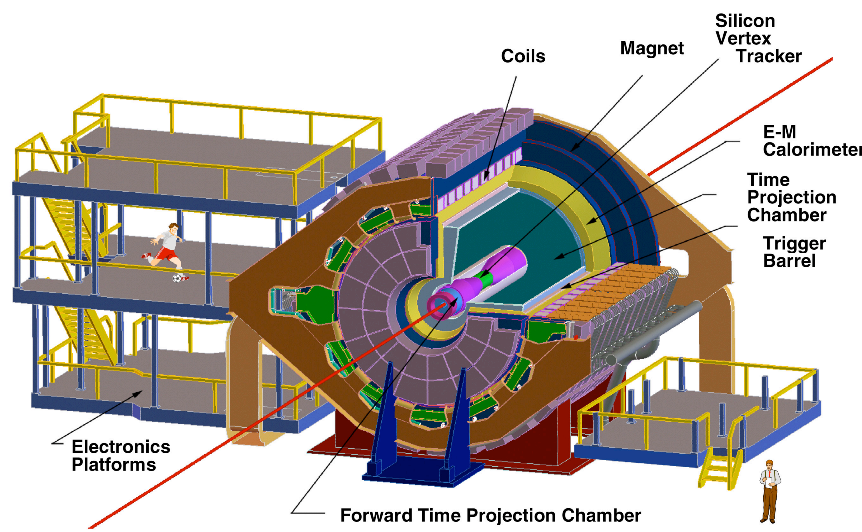
BUT HOW DOES ONE KNOW P_{beam}?

- PHENIX

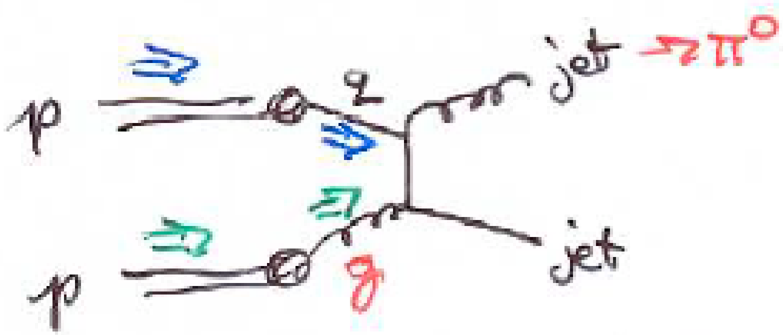


- Axial Field

- STAR



- Solenoidal field



$$+\, gg \to gg / q\bar{q}$$

Polarization of 100 GeV Beam

$$P_{beam} = P_{t\arg et}\left\langle \frac{\varepsilon_{beam}}{\varepsilon_{t\arg et}} \right\rangle = 0.40 \pm 0.03$$

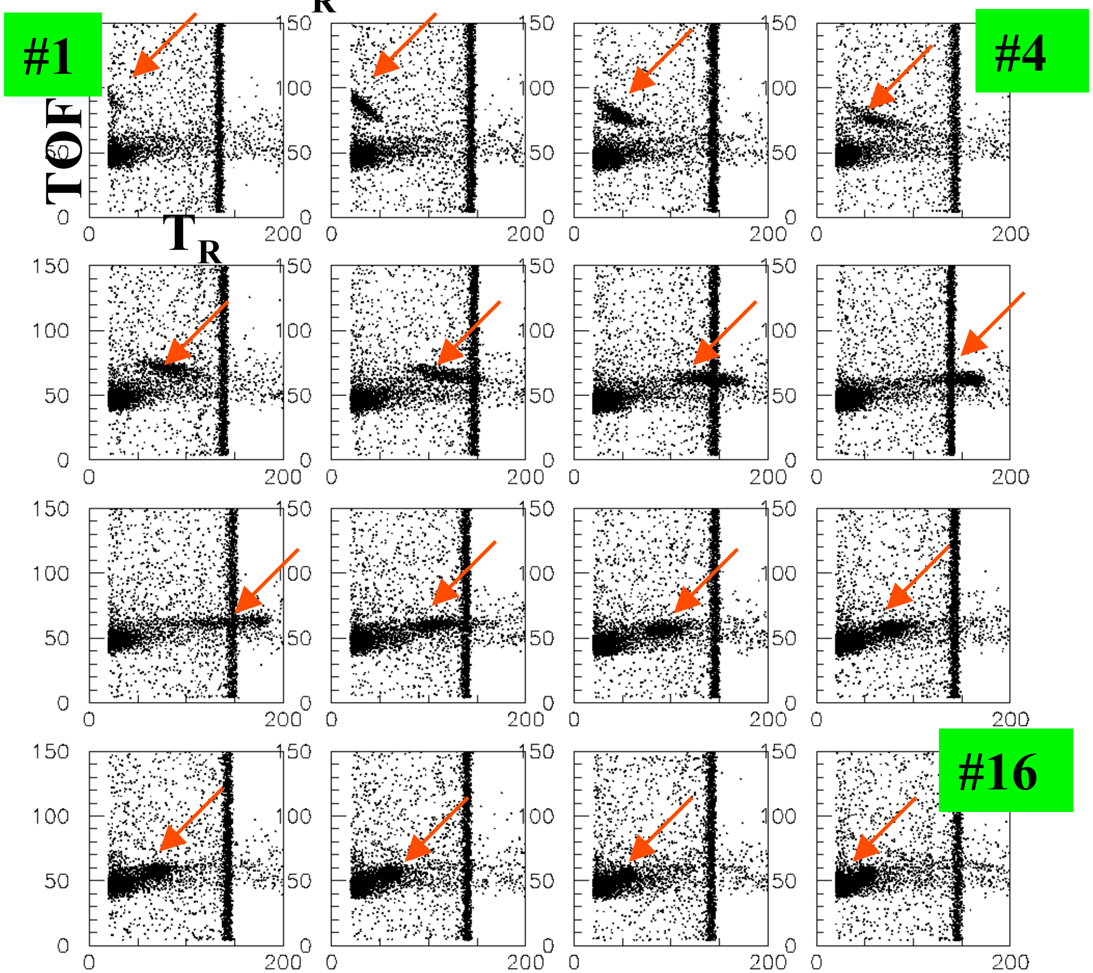
Eventual goal of calibration: ±3%

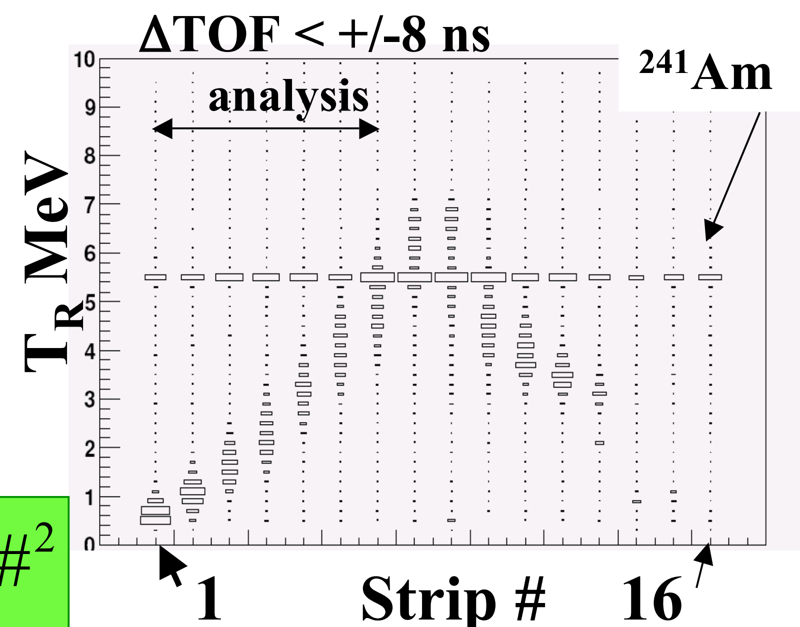
Plans:

- analyze wider t-range to study pp intercaction
- improve statistics
- bunch field depolarization with 110 bunches
- improved measurement of H_2 contamination of H-beam
- measure beam polarization at injection
- measure blue and yellow beam polarization

Forward scattering particle ID ;
Correlation of Energy and position

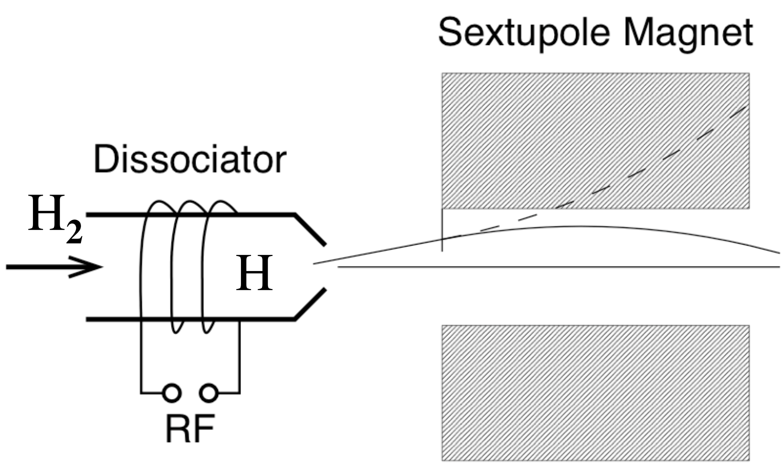
TOF vs T_R Si detector of 16channels

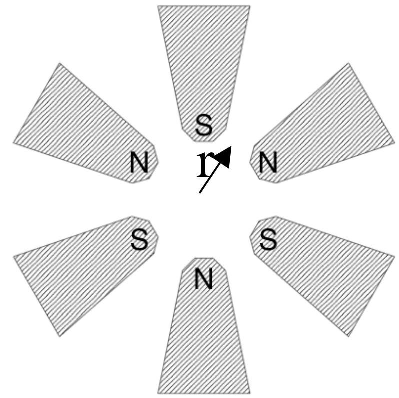




$$T_R \approx 2m_p \sin\vartheta_R{}^2 \Rightarrow 2m_p ch\#^2$$

The Polarized Target - Principle

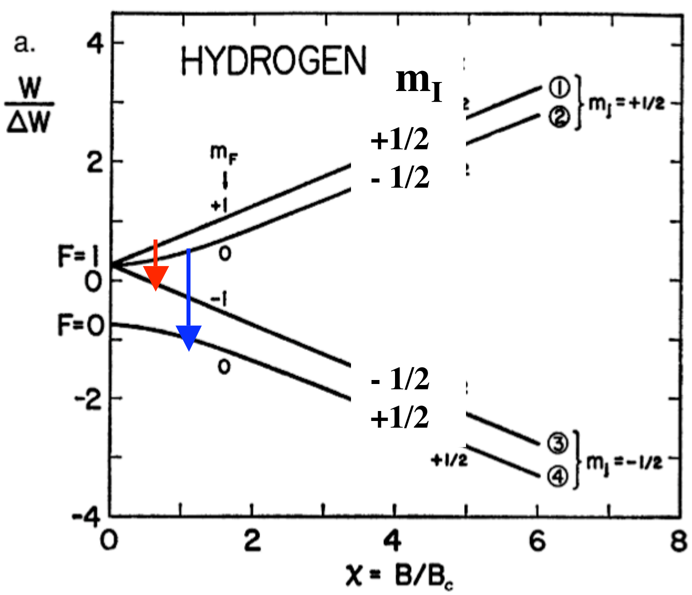


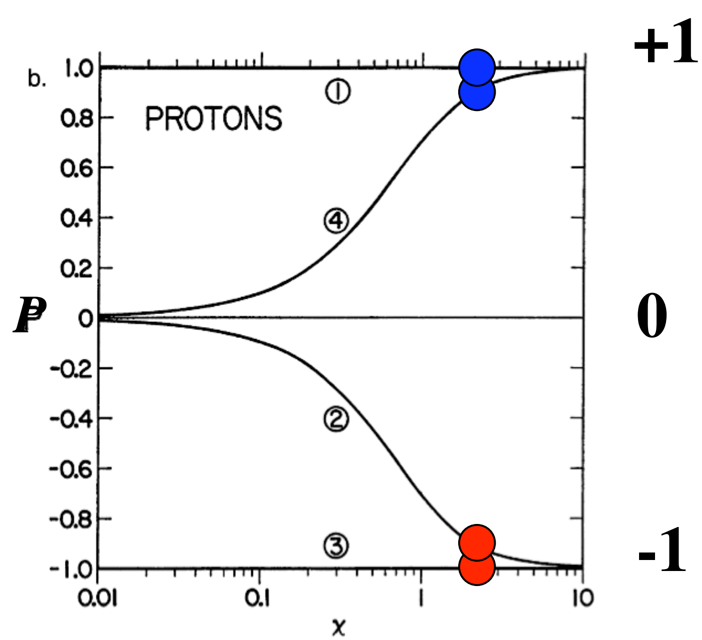


$$|B| \propto r^2$$

$$\vec{F}_r = \pm k\vec{r}$$

acceptance angle α





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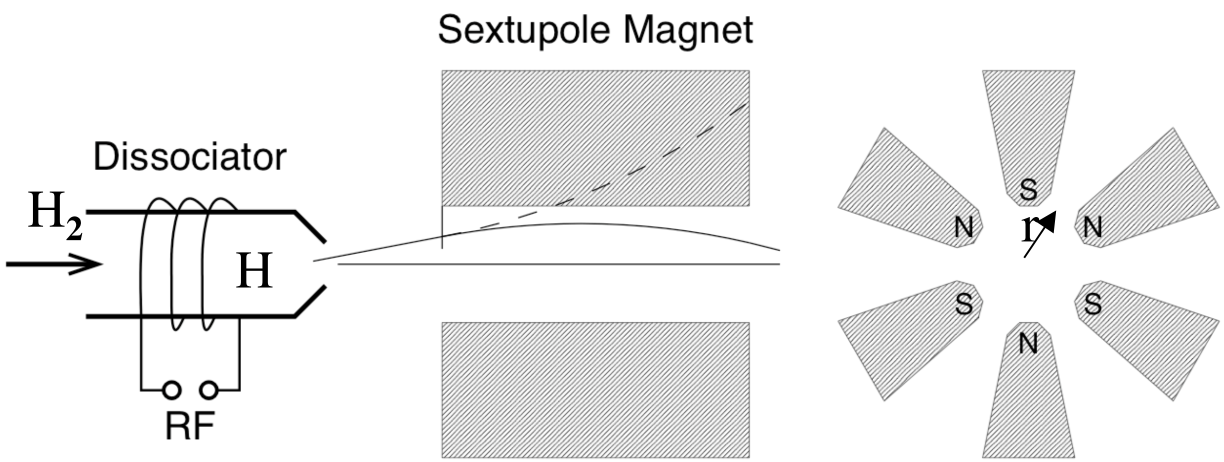
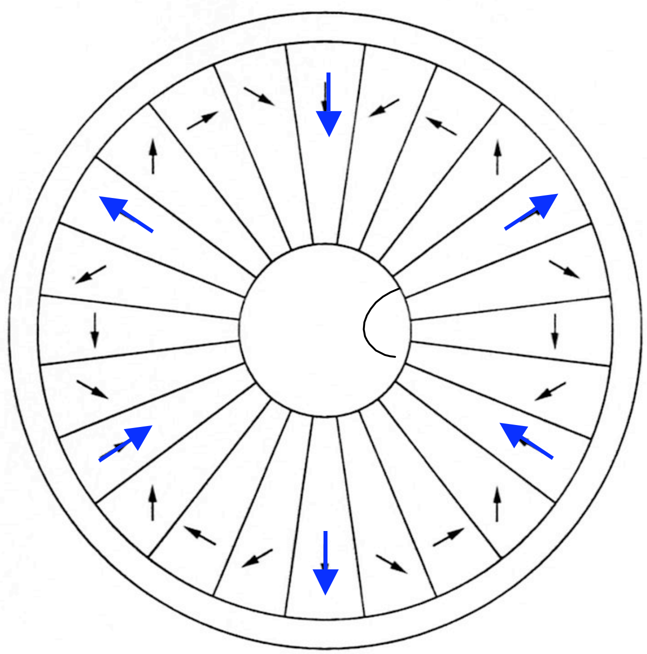


acceptance angle α

H-Jet Design Features

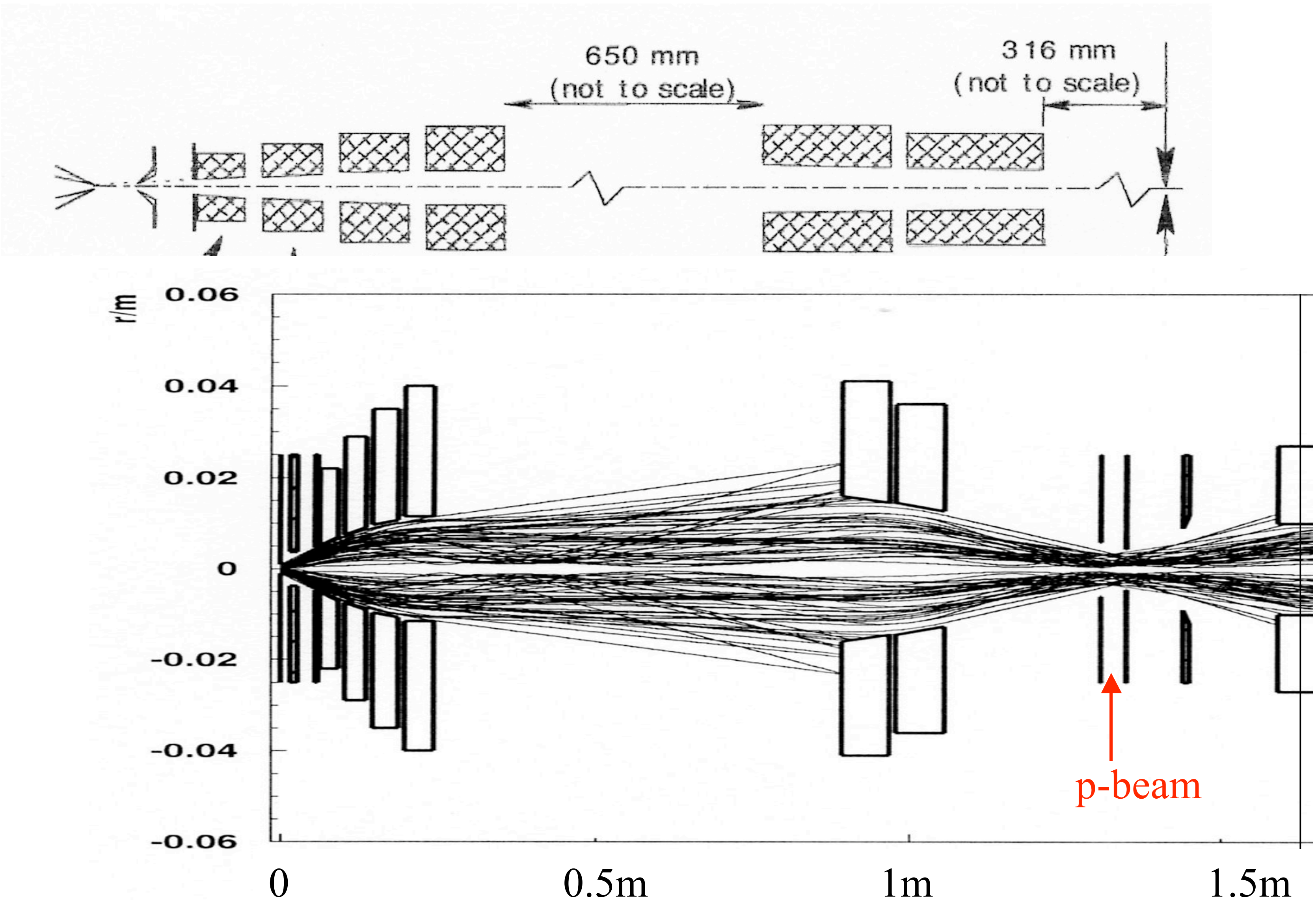


permanent magnet sextupole
pole tip field 1.5T

- Sextupoles: rare-earth permanent magnets (gradient up to 6 T/cm)
- Magnet geometry:
  2 magnet groups reduce chromatic aberrations
- magnet gaps reduce gas attenuation
- taper increases acceptance
- RF transitions of high efficiency
- very uniform guide field to avoid bunch field depolarization
- Field shaping for adiabatic transport

responsible for design: T. Wise UW

H-jet sextupole separation magnet system.



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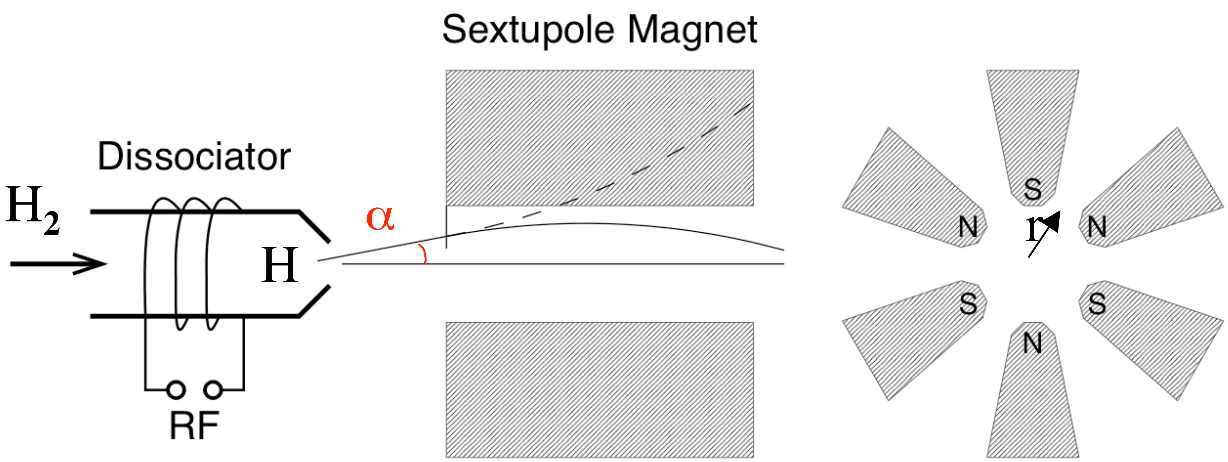

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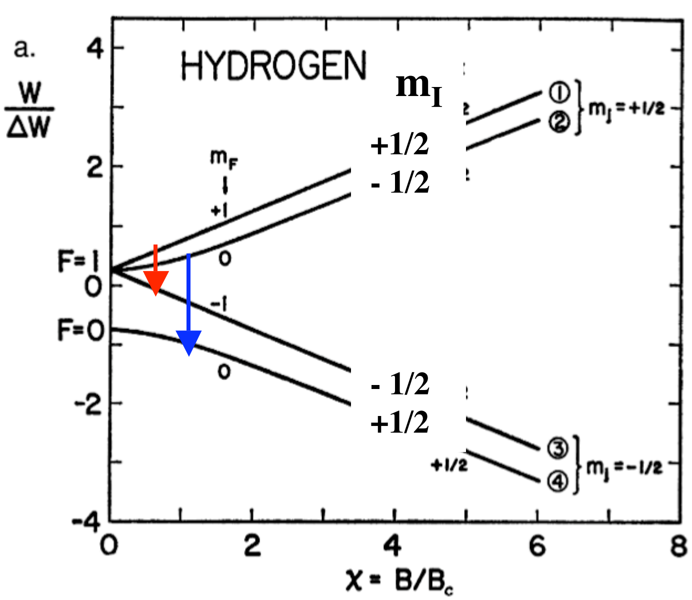

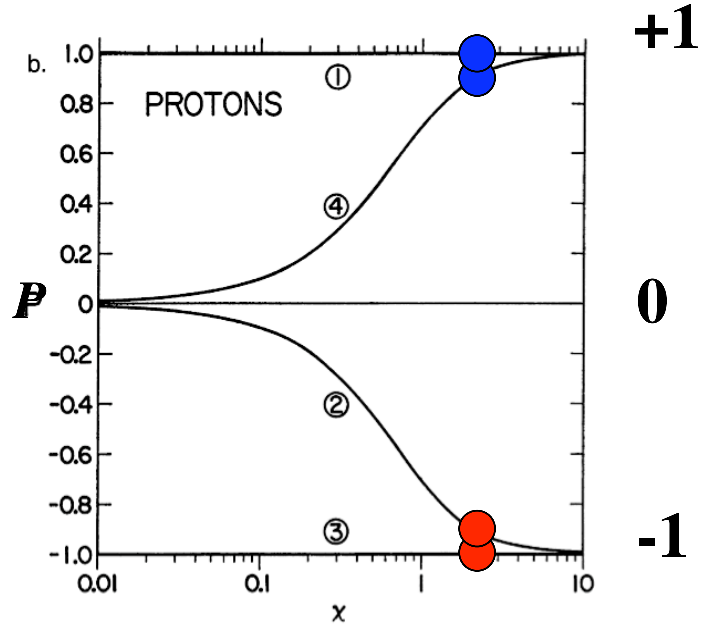

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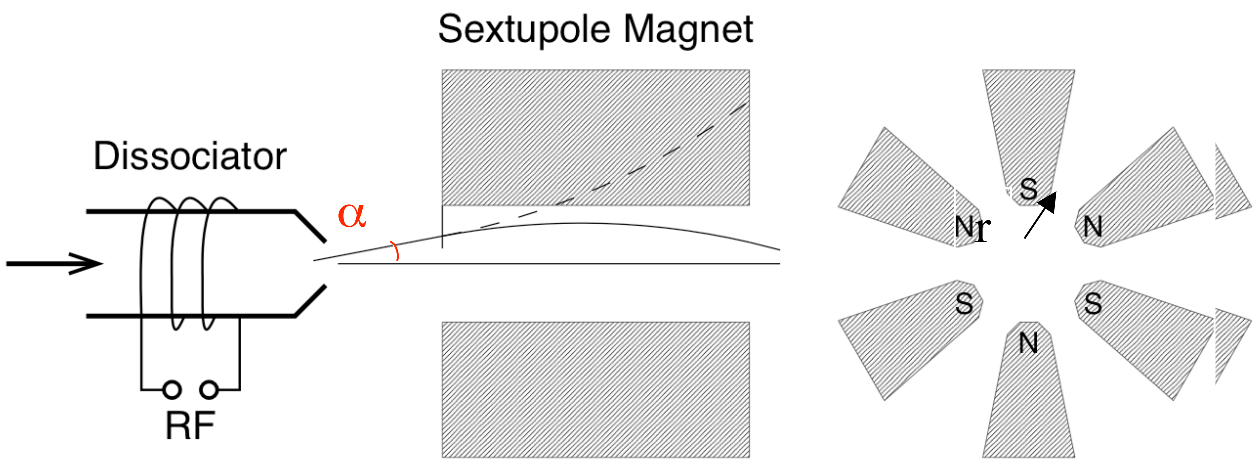

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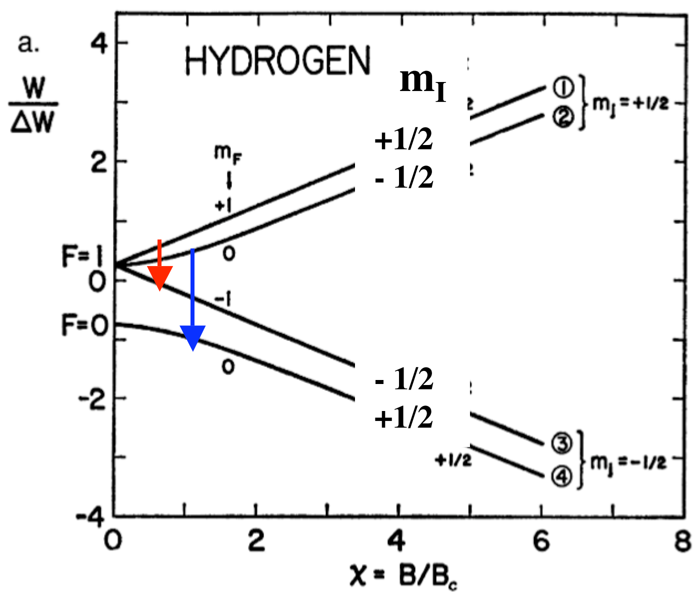
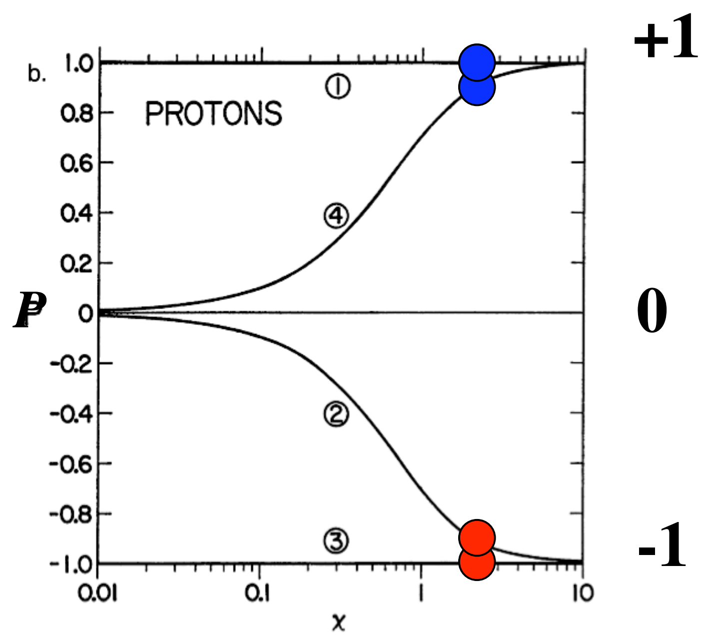
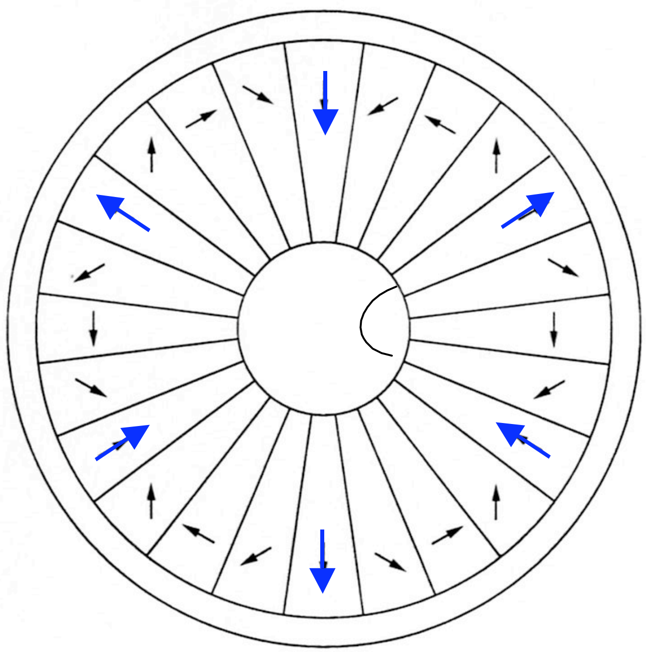




H-Jet Design Features



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