

# *Spin Structure in the Resonance Region*

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The RSS collaboration has measured the spin structure functions of the proton and the deuteron at Jefferson Lab using the lab's polarized electron beam, the Hall C HMS spectrometer and the UVA polarized solid target. The asymmetries  $A_{\parallel}$  and  $A_{\perp}$  were measured at the elastic peak and in the region of the nucleon resonances ( $0.70 \text{ GeV} < W < 1.98 \text{ GeV}$ ) at an average four momentum transfer of  $Q^2 = 1.3 \text{ GeV}^2$ . The extracted spin structure functions and their kinematic dependence make a significant contribution in the study of higher-twist effects and polarized duality tests.



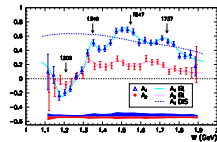
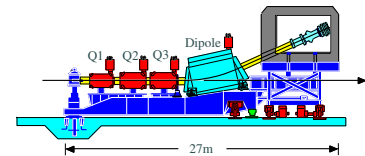
# Outline

## Overview & Introduction

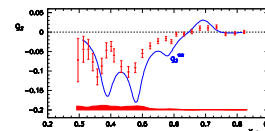
## Extracting Physics from Data

$$A_{Born} = \frac{1}{C_N f_{RC}} \times \left( \frac{A_{raw}}{f P_{beam} P_{target}} - C_D \right) + A_{RC}$$

## Experimental Setup



## Results



## Summary

# *E-01-006: Resonance Spin Structure*

Jefferson Lab experiment E-01-006 measured the Nucleon Spin Structure in the Resonance Region via inclusive scattering of polarized  $e^-$  off polarized proton and deuteron targets, for parallel and perpendicular alignments.

also measured at (quasi-) elastic kinematics

*consistent setup*  
*minimal model input*

$A_{\parallel}$  &  $A_{\perp}$

$A_1$  &  $A_2$

$g_1$  &  $g_2$

⇒  $W$  Dependence

⇒ Polarized Local Duality

⇒ Higher Twist Effects

# *World Data Context*

## Proton, Deuteron

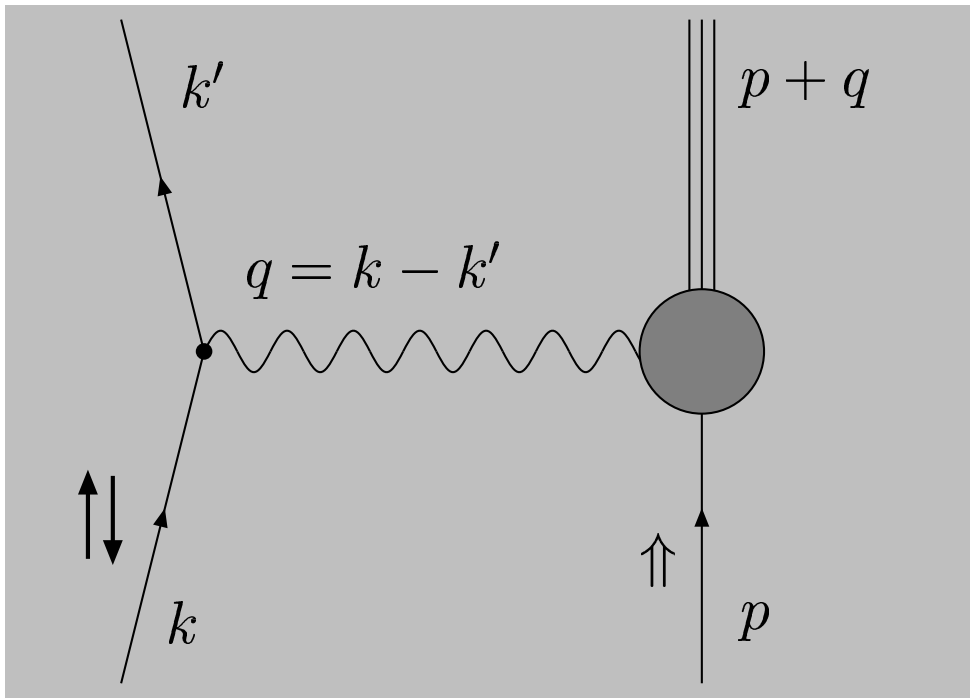
*parallel* data taken in Hall B (just prior and subsequently), at SLAC (previously), and DESY (previously and since)

*no perpendicular* measurements

## Neutron

concurrent effort in Jefferson Lab's Hall A

# Asymmetries and Spin Structure



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

$$A_{\perp} = \frac{\sigma^{\uparrow\leftarrow} - \sigma^{\downarrow\leftarrow}}{\sigma^{\uparrow\leftarrow} + \sigma^{\downarrow\leftarrow}}$$

$$A_1 = \frac{\sigma_{1/2}^T - \sigma_{3/2}^T}{\sigma_{1/2}^T + \sigma_{3/2}^T}$$

$$A_2 = \frac{\sigma_{1/2}^{TL}}{\sigma_{1/2}^T + \sigma_{3/2}^T}$$

$$A_{\parallel} = D (A_1 + \eta A_2)$$

$$A_{\perp} = d (A_2 - \zeta A_1)$$

$$g_1 = \frac{F_1}{1+\gamma^2} (A_1 + \gamma A_2) \quad g_2 = \frac{F_1}{1+\gamma^2} (A_2/\gamma - A_1)$$

$$D = \frac{1-E'\epsilon/E}{1+\epsilon R}$$

$$d = D \sqrt{\frac{2\epsilon}{1+\epsilon}}$$

$$\eta = \frac{\epsilon \sqrt{Q^2}}{E-E'\epsilon}$$

$$\zeta = \frac{\eta(1+\epsilon)}{2\epsilon}$$

$$Q^2 = -q^2$$

$$\gamma^2 = \frac{Q^2}{\nu^2}$$

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

# Physics from Data

$$A_{raw} = \frac{N^{\downarrow\uparrow} - N^{\uparrow\uparrow}}{N^{\downarrow\uparrow} + N^{\uparrow\uparrow}} \quad \text{or} \quad \frac{N^{\downarrow\Rightarrow} - N^{\uparrow\Rightarrow}}{N^{\downarrow\Rightarrow} + N^{\uparrow\Rightarrow}}$$

**charge, deadtime normalized:**  $N^i \rightarrow N^i/Q_i$

$$A_{Born} = \frac{1}{C_N f_{RC}} \times \left( \frac{A_{raw}}{f \mathcal{P}_{beam} \mathcal{P}_{target}} - C_D \right) + A_{RC}$$

$\mathcal{P}_{beam}$  Beam Polarization

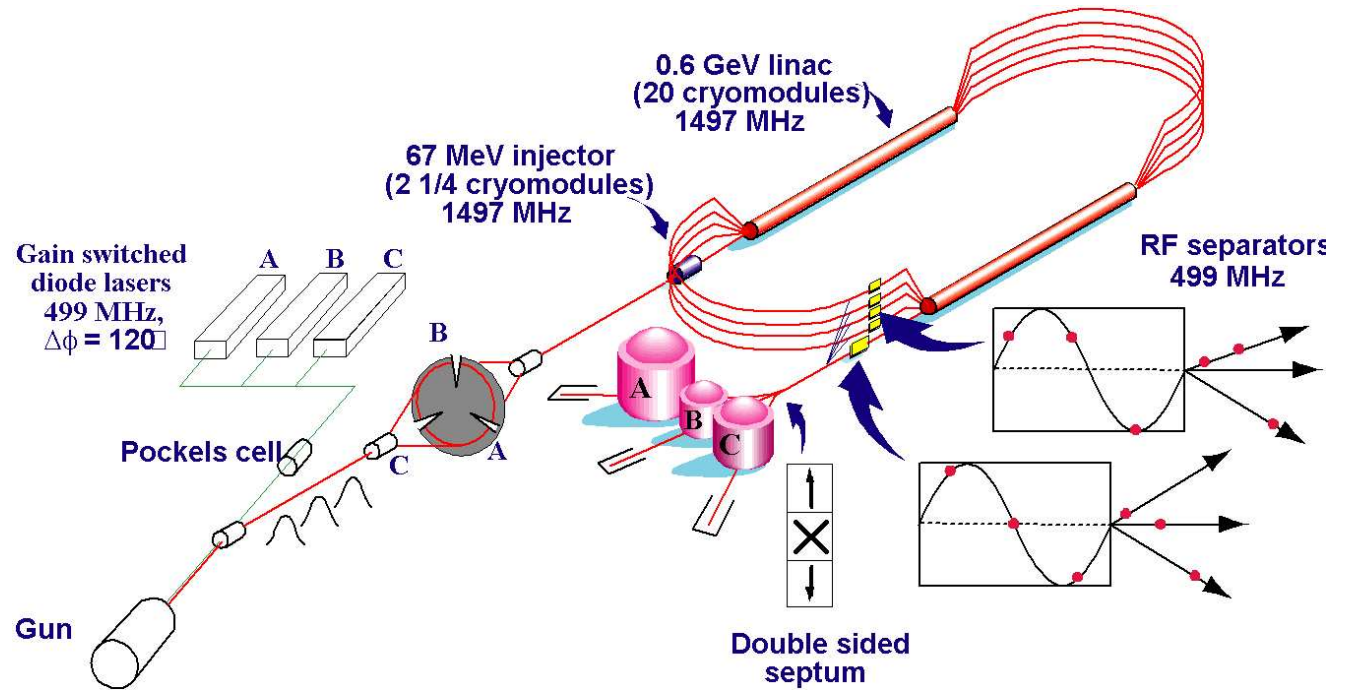
$\mathcal{P}_{target}$  Target Polarization

$f$  Dilution Factor

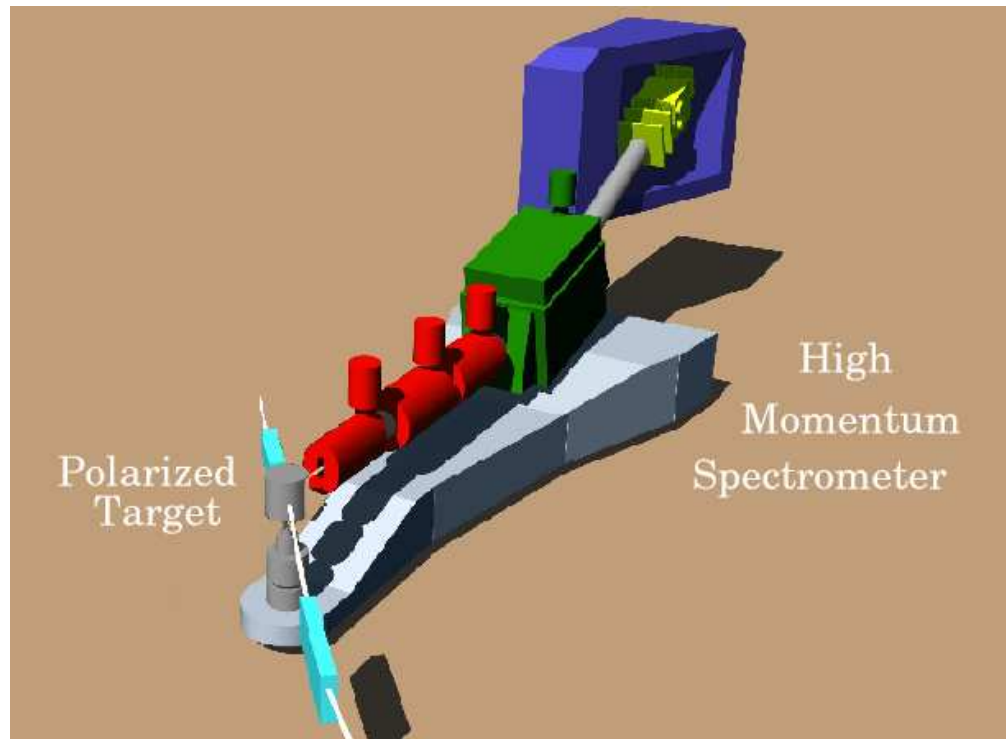
$A_{RC}, f_{RC}$  Radiative Corrections

$C_N, C_D$  Nitrogen Corrections

# Continuous Electron Beam Accelerator Facility



Hall C



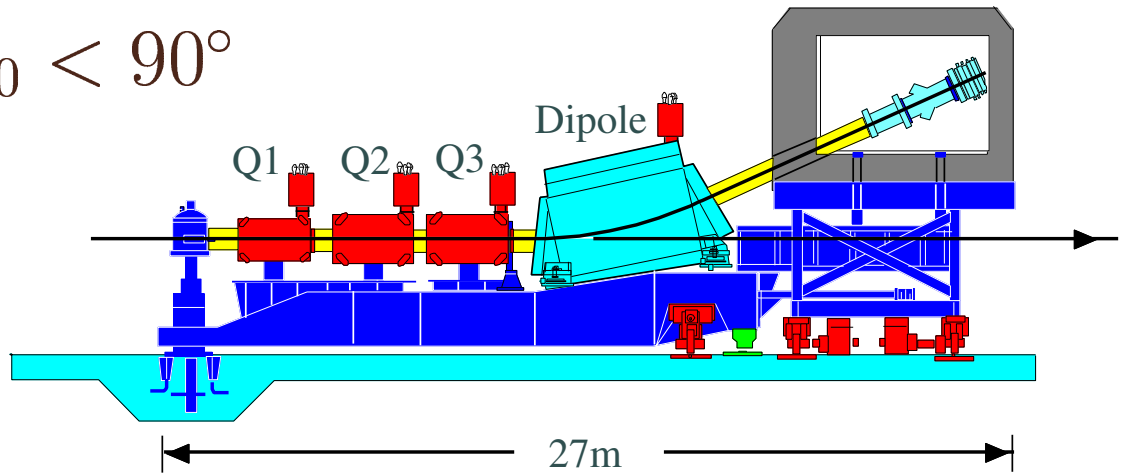
## Thomas Jefferson National Accelerator Facility



Newport News, Virginia

# High Momentum Spectrometer

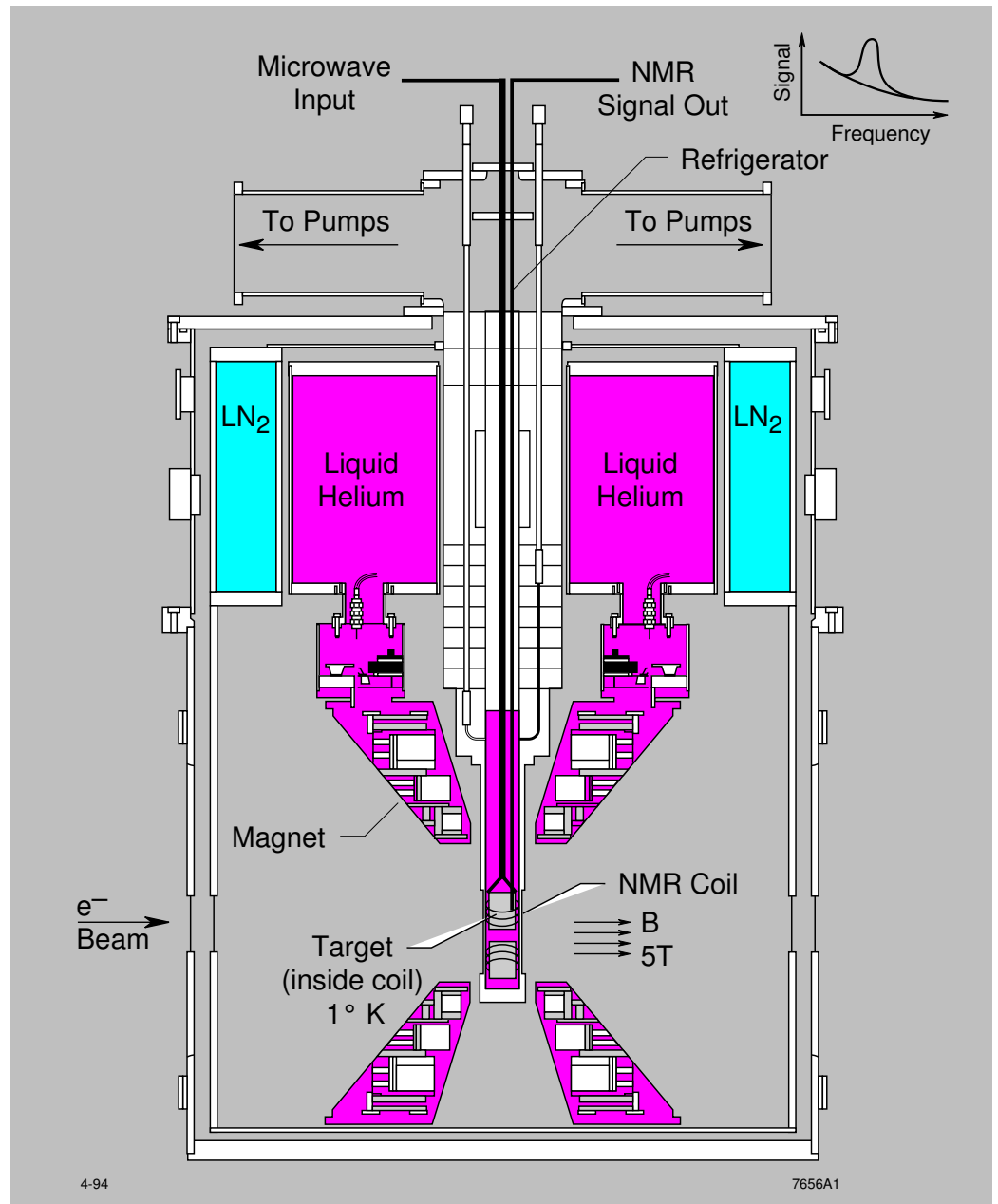
- movable:  $12.5^\circ < \theta_0 < 90^\circ$
- 1 dipole magnet, 3 quadrupoles
  - $\pm 9\%$  acceptance
  - $0.5 < p_0 < 7.5 \text{ GeV}/c$
- for RSS:  $\theta_0 = 13.12^\circ$ ,  $p_0 = 4.095, 4.723 \text{ GeV}/c$
- shielded detector package
  - scintillator hodoscopes, wire drift chambers
  - gas Cerenkov, segmented Pb glass calorimeter
- well-studied tracking, reconstruction
  - provides electron ID, event time, momentum & energy
  - determines track position & direction at target



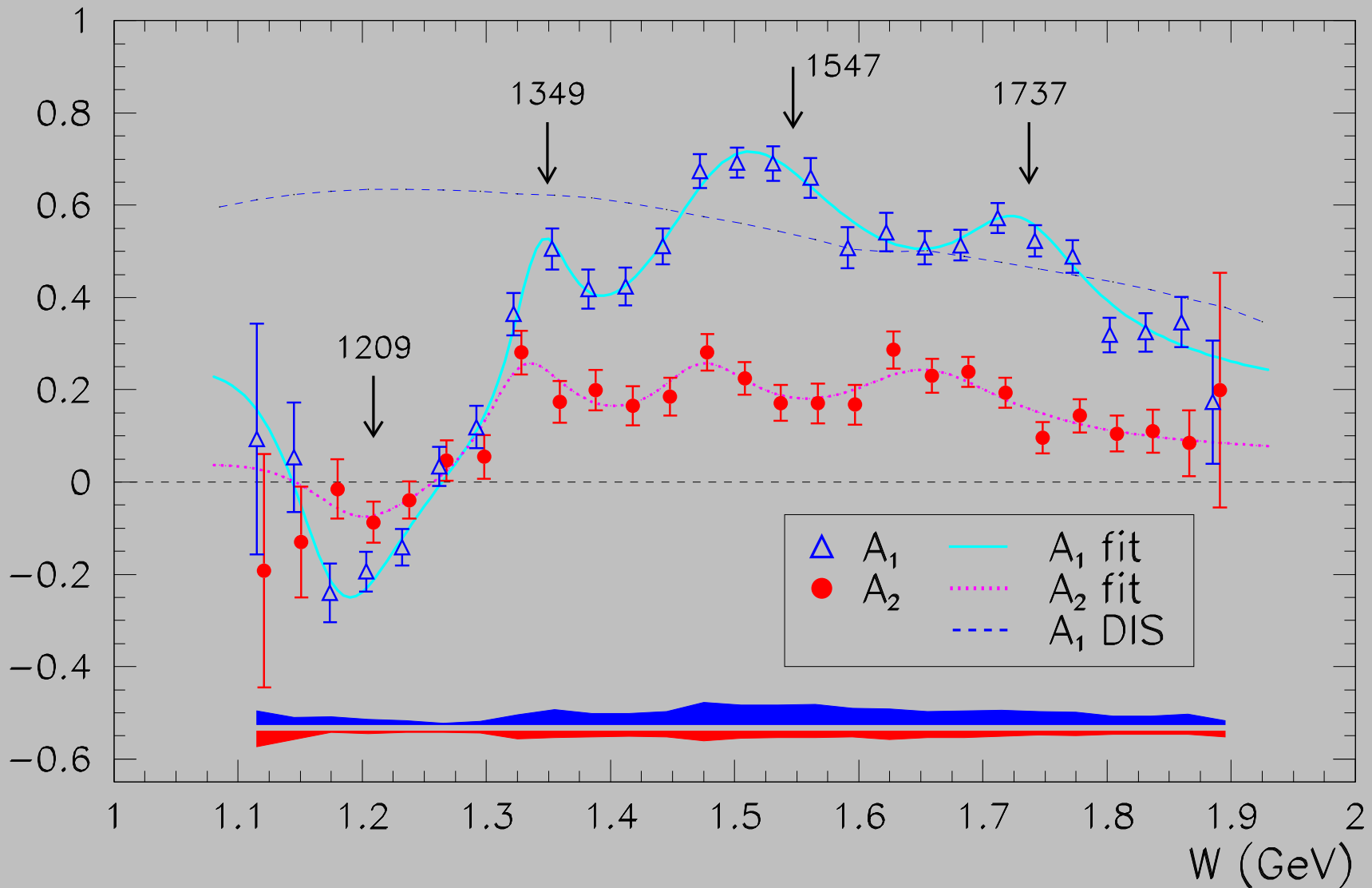


# UVa Polarized Target

- frozen  $\text{NH}_3$ ,  $\text{ND}_3$ , LiD
- $^4\text{He}$  evaporation refrigerator
- 5T polarizing field
- remotely movable insert
- dynamic nuclear polarization driven by microwaves
- NMR system for polarization measurement

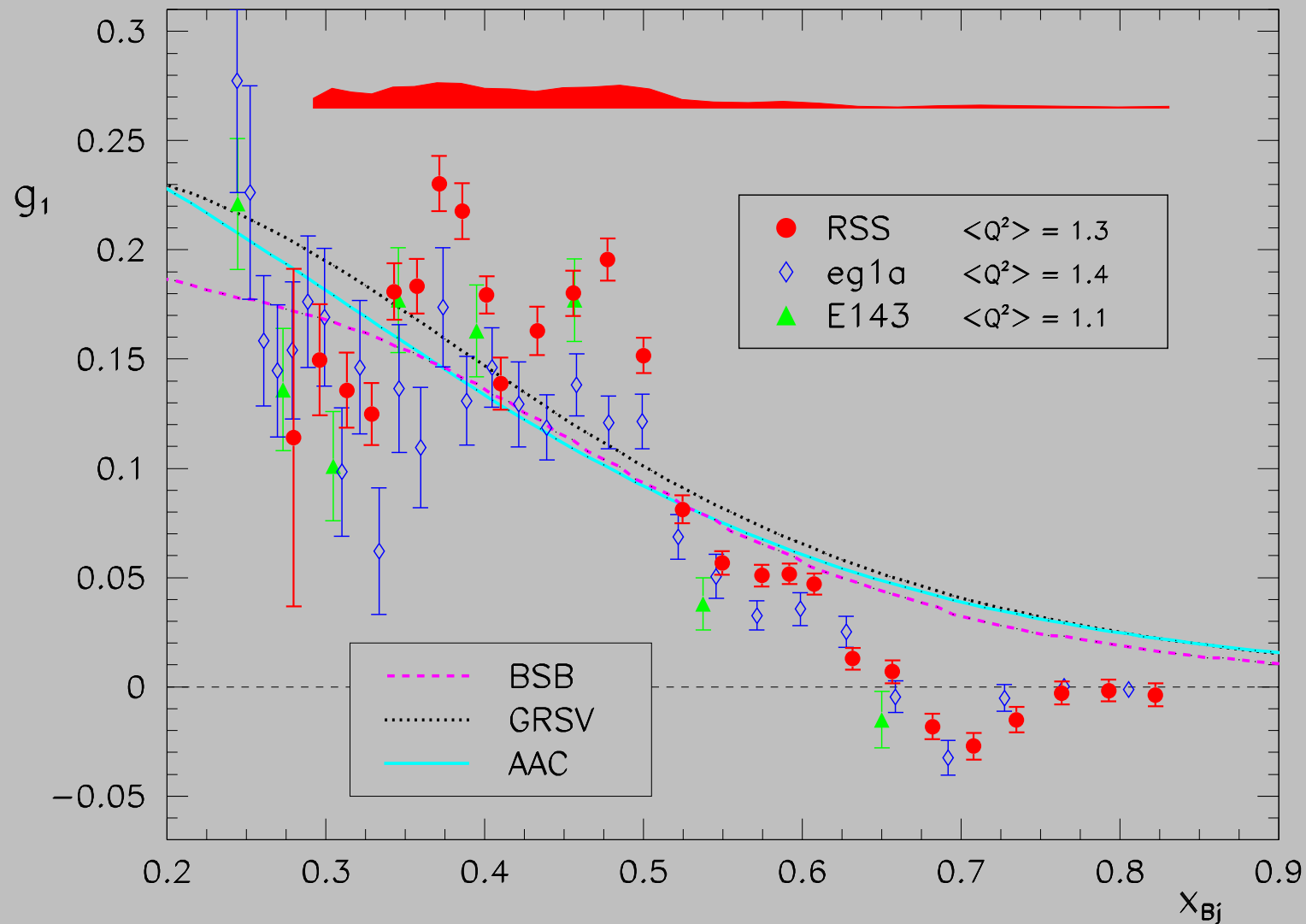


# Results: Proton $A_1, A_2$



fits inspired by Stein et al., Phys. Rev. **D12**, 1884 (1975)

# Results: Proton $g_1$



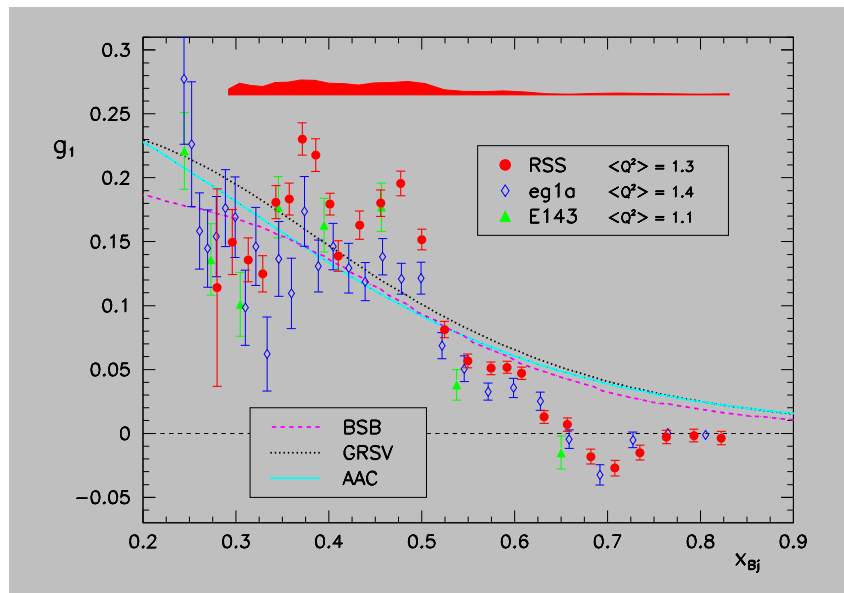
BSB: Bourrely, Soffer, and Buccella, Eur. Phys. J. **C41**, 327 (2005)

GRSV: Gluck, Reya, Stratmann, and Vogelsang, Phys. Rev. **D53**, 4775 (1996)

AAC: Hirai, Kumano, and Saito (*Asymmetry Analysis Coll.*), Phys. Rev. **D69**, 054021 (2004)

# Results: Proton Duality

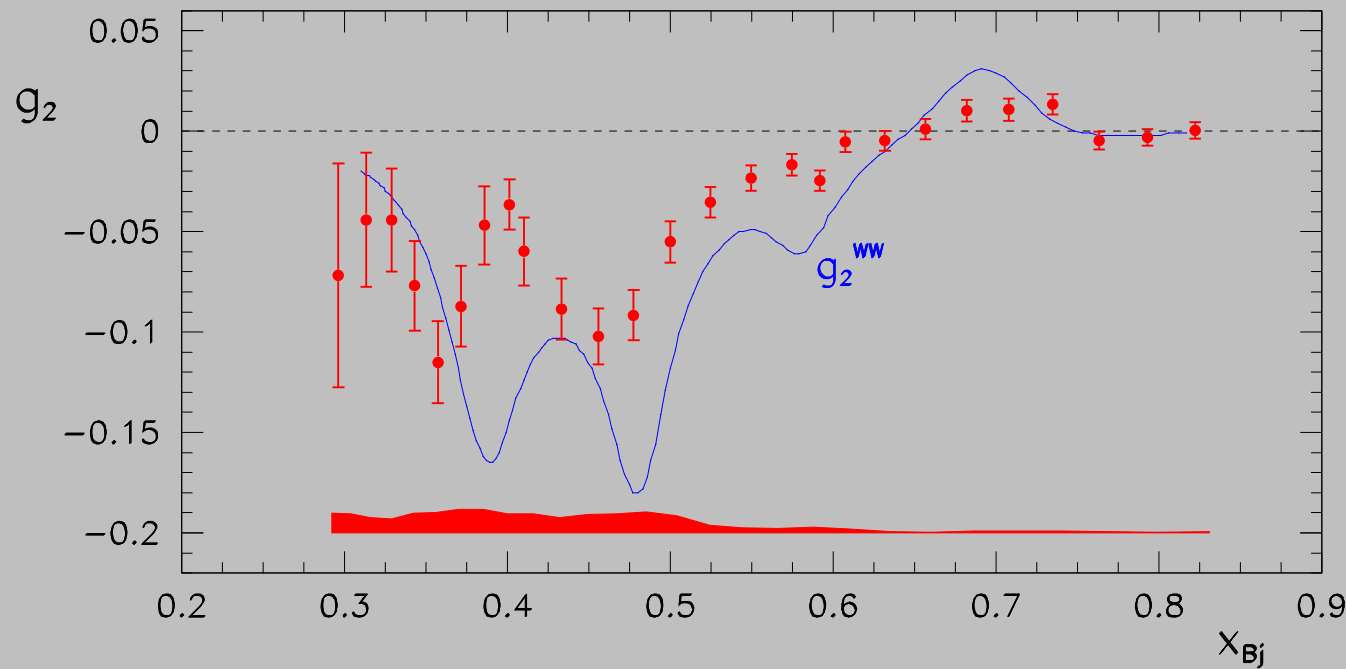
	$W$ Range	BSB	GRSV	AAC	Average
Delta	1.12 - 1.30	4.18	5.09	4.83	$4.80 \pm 0.68$
R1	1.30 - 1.40	1.26	1.40	1.31	$1.34 \pm 0.07$
R2	1.40 - 1.69	0.76	0.81	0.75	$0.78 \pm 0.04$
R3	1.69 - 1.81	0.81	0.88	0.81	$0.84 \pm 0.04$
global	1.08 - 1.91	1.10	1.23	1.14	$1.17 \pm 0.06$



Ratio of Integrals,  
PDF to Data

errors reflect *data* uncertainty only

# Results: Proton $g_2$



Other  $d_2$  Values:

**SLAC E155**

$\langle Q^2 \rangle = 5$

$0.0032 \pm 0.0017$

**Lattice QCD**

$\langle Q^2 \rangle = 5$

$0.002 \pm 0.003$

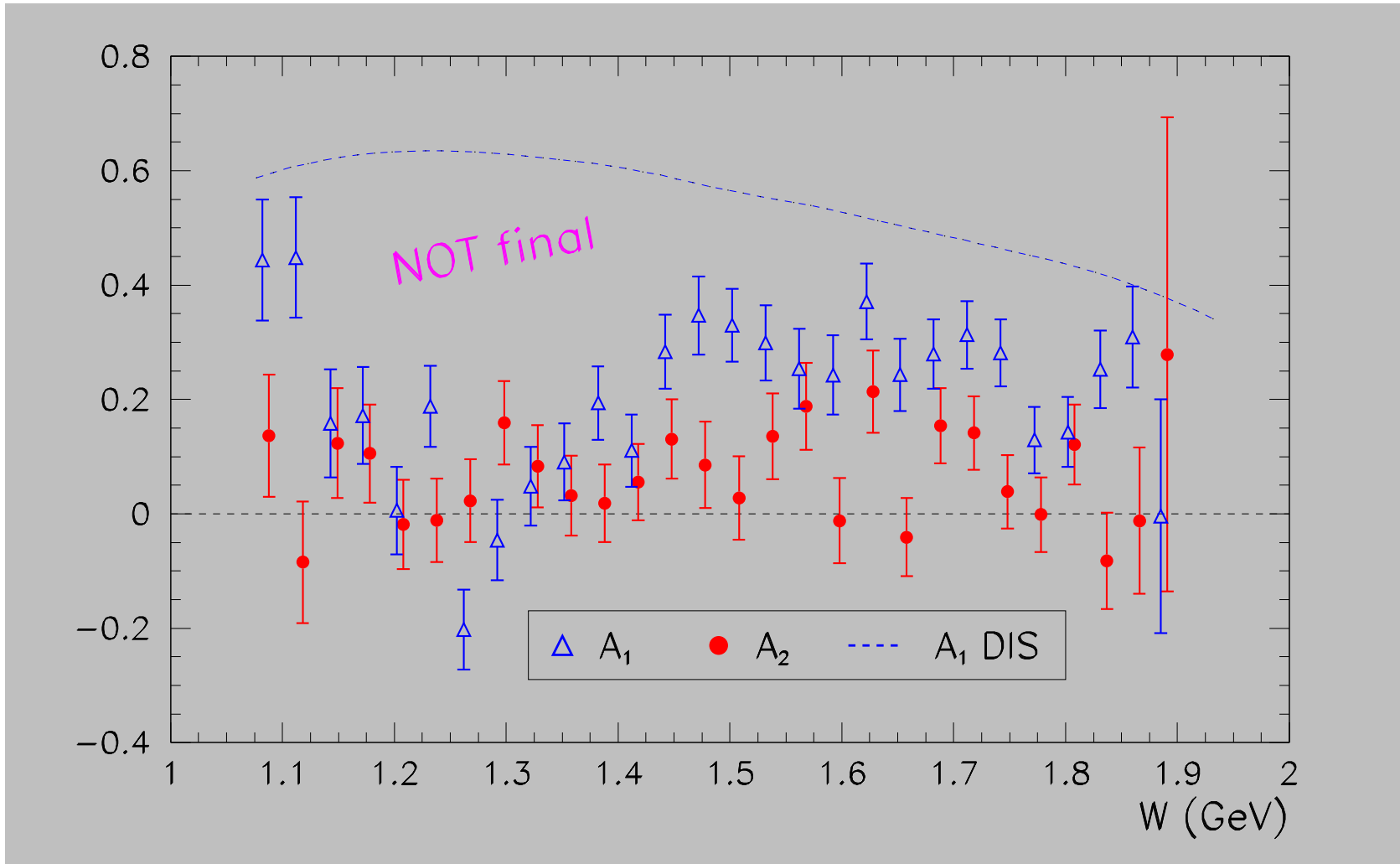
M. Gockeler *et al.*, Phys. Rev. D **72**, 054507 (2005)

$$d_2 = 3 \int_0^1 x^2 (g_2 - g_2^{\text{WW}}) dx = \int_0^1 x^2 (2g_1 + 3g_2) dx$$

$$\overline{d_2} = \int_{0.29}^{0.84} x^2 (2g_1 + 3g_2) dx = 0.0058 \pm 0.0009 \pm 0.0014$$

(stat)                      (syst)

# Results: Deuteron $A_1$ , $A_2$



**PRELIMINARY – no RCs applied!**

**Next: Extract Neutron  $A_1$  and  $A_2$**

# Summary

Jefferson Lab Experiment E-01-006...

represents the *first* measurement of perpendicular spin properties

provides the *only* consistent data set for spin structure extractions

allows the *first* evaluation of the higher twist components

enables a *minimally* model dependent investigation of local duality

...for Proton and Deuteron in the Resonance Region

PRL ready for submission

# *RSS Collaboration*

A. Aghalaryan, A. Ahmidouch, R. Asaturyan, F. Bloch, W. Boeglin, P. Bosted, C. Carasco, R. Carlini, J. Cha, J.P. Chen, M.E. Christy, L. Cole, L. Coman, D. Crabb, S. Danagoulian, D. Day, J. Dunne, M. Elaasar, R. Ent, H. Fenker, E. Frlez, L. Gan, D. Gaskell, J. Gomez, B. Hu, M. Jones, J. Jourdan, C. Keith, C.E. Keppel, M. Khandaker, A. Klein, L. Kramer, Y. Liang, J. Lichtenstadt, R. Lindgren, D. Mack, P. McKee, D. McNulty, D. Meekins, H. Mkrtchyan, R. Nasseripour, I. Niculescu, K. Normand, B. Norum, D. Pocanic, Y. Prok, B. Raue, J. Reinhold, J. Roche, D. Rohe, O.A. Rondón, N. Savvinov, B. Sawatzky, M. Seely, I. Sick, K. Slifer, C. Smith, G. Smith, S. Stepanyan, L. Tang, S. Tajima, G. Testa, W. Vulcan, K. Wang, G. Warren, F.R. Wesselmann, S. Wood, C. Yan, L. Yuan, J. Yun, M. Zeier, H. Zhu

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