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# JLAB'S HALL A AFTER THE 12 GEV UPGRADE

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An overview is presented of the planned physics program for JLab's Hall A following the 12 GeV upgrade with emphasis on the equipment needed to achieve the desired experimental goals. Results of simulations of sample experiments with anticipated uncertainties are presented.

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## 1. *Introduction*

The 12 GeV upgrade planned for Jefferson Lab will make possible a very broad physics research program. In Hall A, a versatile collection of instruments is planned addressing a wide variety of experiments. Reactions in the program include:

- inclusive electron scattering,
- semi-inclusive measurements,
- exclusive process measurements,
- near threshold charm production.

JLab's Hall A is already equipped with a wide array of proven precision instruments [1]. In addition, new instruments are planned in order to address the experimental possibilities presented by the upgraded beam. Planned new equipment includes:

- The MAD (medium acceptance device): an 8 GeV/c magnetic spectrometer built from two large combined-function superconducting magnets. The MAD would provide moderate momentum resolution ($\sigma p/p \approx 1 \times 10^{-3}$), large solid angle acceptance ($\Delta\Omega \approx 30$ msr), and large momentum acceptance ($\Delta P/P \approx \pm 15\%$). The MAD will be equipped with a detector package commensurate with the particle ID requirements of the experimental program and the performance parameters of the MAD itself. The choice of design parameters for the MAD is driven by the array of experiments shown in Table 1.

- A large acceptance ($\Delta\Omega \approx 0.1$ sr) high resolution photon calorimeter made up of 676 PbF2 crystals ($26 \times 26 \times 200$ mm$^3$). The layout of a real compton scattering (RCS) experiment using the photon calorimeter at 12 GeV is shown in Fig. 1.

*TABLE 1. Array of envisioned experiments in Hall A at 12* GeV *with experimental requirements.*

| Experiments | $P_{\rm max}$ $(\frac{\rm GeV}{c})$ | Angle | $\Delta\Omega$ (msr) | $\frac{\Delta P}{P}$ (%) | $P_{\rm res}$ (%) | Ang. res. | Luminosity ($\times 10^{37}$) | e or h |
|---|---|---|---|---|---|---|---|---|
| d/u ($^3$H/$^3$He) | 6 | 15–30° | 15–30 | 30 | 0.3 | 1–3 | 10 | e |
| $A_1^{\rm n}$, $g_{\rm 1n}$ | 6–7 | 15–30° | 15–30 | 30 | 0.3 | 2–3 | 0.1 | e |
| $g_{\rm 2n}$ | 6 | 15–30° | 15–30 | 30 | 0.3 | 2–3 | 0.1 | e |
| $A_1^{\rm p}$, $g_{\rm 1p}$ | 6–7 | 15–30° | 15–30 | 30 | 0.3 | 2–3 | 0.01 | e |
| Spin Duality | 6–7 | 12–25° | 12–25 | 30 | 0.3 | 2–3 | 0.1 | e |
| $g_1$ at high E | 6–7 | 12° | 12 | 30 | 0.3 | 1–3 | 0.1 | e |
| DIS-Parity | 6–7 | 12–15° | 12–15 | 30 | 0.3 | 1–3 | 100 | e |
| Semi-$\pi^+/\pi^-$ | 6 | 15–25° | 15–25 | 30 | 0.3 | 2–3 | 5 | e |
| $\rm d_{bar}/u_{bar}$ | 6 | 15–25° | 15–25 | 30 | 0.3 | 2–3 | 40 | e |
| $\Delta$u, d, s | 6 | 15–25° | 15–25 | 30 | 0.3 | 2–3 | 0.1 | e |
| Transversity | 6 | 15–38° | 15–30 | 30 | 0.3 | 2–3 | 0.1 | e |
| $\pi$ struc. Fun. | 3 | 15–22° | 15–25 | 30 | 0.3 | 2–3 | 0.1 | e |
| Charm | 6–7 | 12–15° | 12–15 | 30 | 0.3 | 1–3 | 40 | e |
| Hadronization | 6 | 12–30° | 12–30 | 30 | 0.3 | 2–3 | 40 | e |
| $x > 1$ | 7 | 12–60° | 12–30 | 30 | 0.3 | 1–3 | 40 | e |
| $G_{\rm en}$ | 6 | 15–20° | 15–20 | 30 | 0.3 | 2–3 | 0.1 | e |
| $G_{\rm ep}/G_{\rm mp}$ | 7-8 | 15–35° | 15–30 | 30 | 0.3 | 2–3 | 40 | p, FPP |
| CT (e,e′p) | 7-8 | 15–35° | 15–30 | 30 | 0.3 | 2–3 | 40 | p |
| CT with FPP | 7 | 15–40° | 15–30 | 30 | 0.3 | 2–3 | 10 | p, FPP |
| CT in $\pi$ prod. | 6 | 12–30° | 12–30 | 30 | 0.3 | 2–3 | 20 | p |
| $\pi^\pm$ photoprod. | 6 | 12–30° | 12–30 | 30 | 0.3 | 2–3 | 20 | p |
| $\pi^0$ photoprod. | 7 | 12–90° | 12–30 | 30 | 0.3 | 2–3 | 20 | p, FPP |
| K$\lambda$ | 6 | 12–90° | 12–30 | 30 | 0.3 | 2–3 | 20 | p |
| y-d | 4 | 20–40° | 20–40 | 30 | 0.3 | 2–3 | 20 | p, FPP |

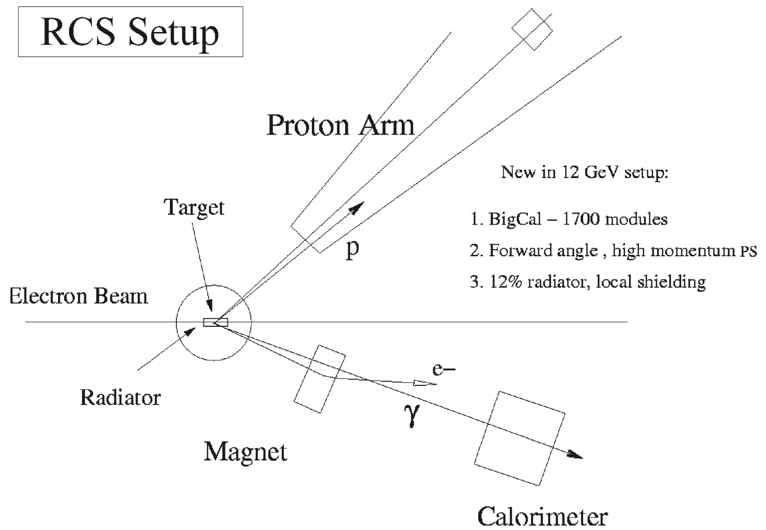


*Fig. 1. Layout of a real Compton scattering (RCS) experiment in Hall A at 12* GeV. *Photons are detected in the calorimeter while coincident protons are detected in the MAD.*

## 2. *The MAD*

The MAD is actually a relatively simple device consisting of two combined-function superconducting magnets. Each magnet contains dipole and quadrupole magnetic field components superimposed on each other. The superposition of quadrupole and dipole are required to achieve the strong focussing needed to get reasonable solid angle (requires a quadrupole doublet with minimum space between the magnets) and moderate momentum resolution with large momentum acceptance. Separating the quadrupole and dipole functions would result in either a much larger spectrometer and detector array or greatly reduced acceptance. The total vertical bend of 30° (10°+20°) is sufficient to eliminate any direct line of sight from the detectors to the target and delivers the desired momentum resolution. Preliminary studies (see Fig. 2) indicate that building the magnets is feasible, there being no overly large fields or forces on the conductors with currents less than the "critical currents" for existing superconducting wire. In the event that a particular experiment has needs not met by the "standard" tune of the MAD, the quadrupole and dipole field strengths in the magnets can be independently set allowing some latitude in the optical properties. Further versatility is achieved by changing the initial distance between the target and the first magnet. Lengthening that initial drift makes it possible to get to smaller scattering angles with an associ-

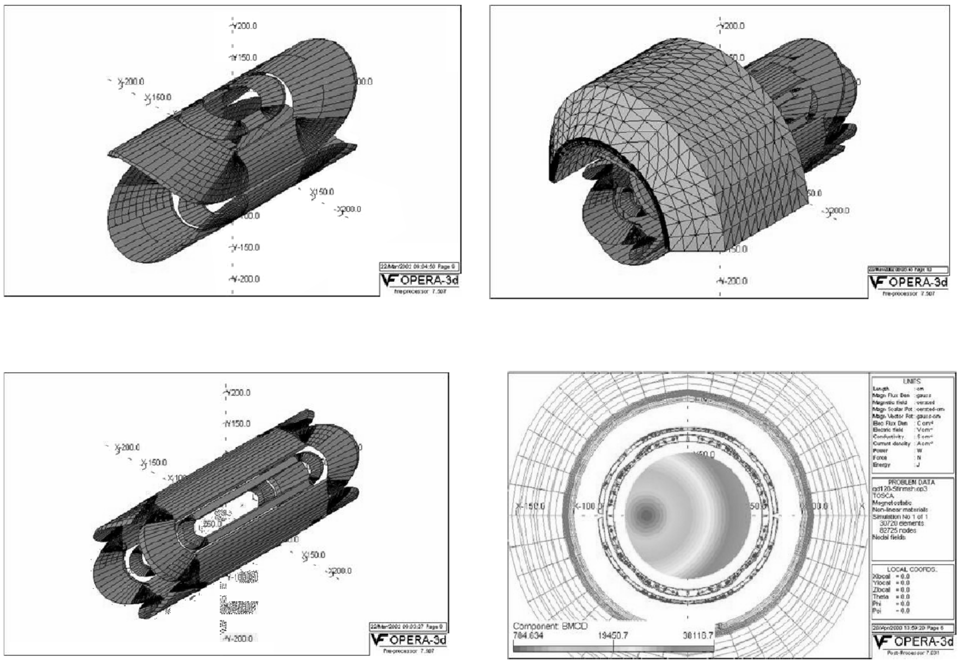


*Fig. 2. Results of magnetostatic studies of MAD magnets. Upper left shows the coil configuration for the dipole component. Lower left shows the coil configuration for the quadrupole component. Upper right shows the dipole and quadrupole coils together with yoke iron surrounding them. Lower right shows the resulting modulus of the magnetic field in the bore of the magnet (note the bull's-eye pattern indicative a dipole superimposed on a quadrupole).*

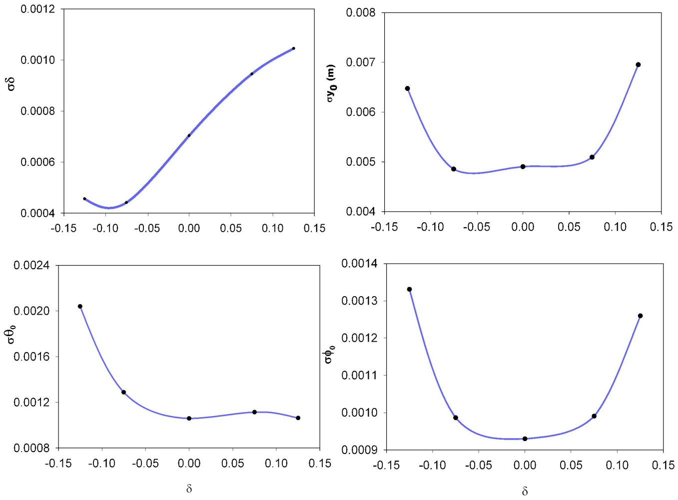


*Fig. 3. Simulated momentum (upper left), vertical angle (lower left), transverse target location (upper right), and transverse (horizontal) angle resolutions for the MAD at 6* GeV/c *central momentum using the Hall A polarized* $^3$He *target and detector performance based on the proposed detector package.*

ated loss of solid angle, 30 msr at 35° goes to 15 msr at 15°. Using magnetic field maps generated while studying the feasibility of building the magnets, raytracing studies have been performed to evaluate the resolution and acceptance capabilities of the MAD as well as providing a means of evaluating the potential background problems associated with doing experiments with the MAD. Figure 3 shows the anticipated resolution properties of the MAD taking into account multiple scattering in the standard Hall A polarized $^3$He target, He atmosphere in the MAD itself, and the detector system. The detector system planned for the MAD includes scintillators, drift chambers, gas and aerogel Čerenkovs, an electromagnetic calorimeter, and a focal plane polarimeter. Fig. 4 shows the anticipated layout and some of the parameters for the detectors.

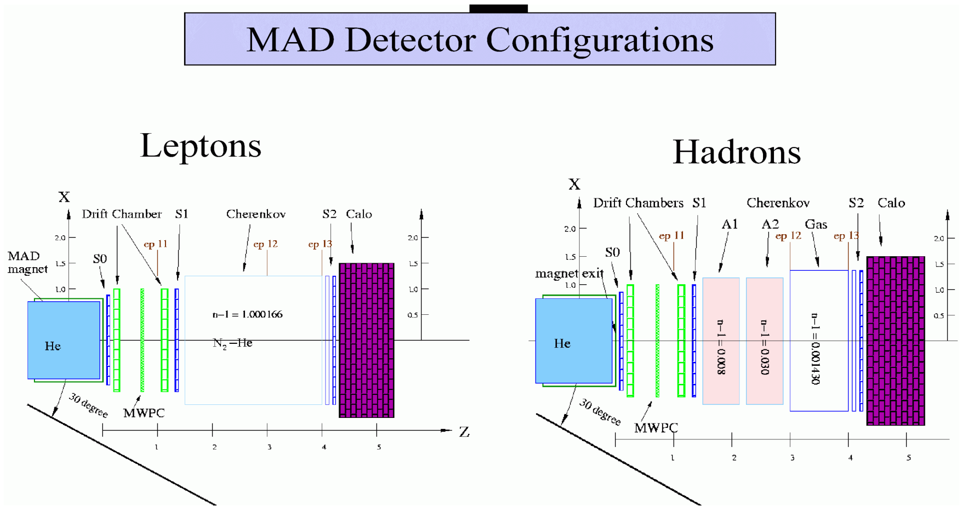


*Fig. 4. MAD detector configuration for lepton detection on the left and hadron detection on the right.*

## 3. Experimental program

Many experiments have been studied in great detail and as mentioned above can be found in the Hall A PCDR [2]. Space limitations here prevent doing any kind of justice to that enormous body of work. Studies of the quark flavor and spin decomposition in the nucleon are presented here as an example of the kind of research that will be possible in Hall A after the 12 GeV upgrade. In the 80's, technical advances for producing polarized beams and polarized targets triggered a new experimental effort which focused on the spin structure of the nucleon. This effort culminated with the test of the Bjorken sum rule, a fundamental sum rule of

QCD, and the determination of the quark contribution to the spin of the nucleon. Although a large experimental effort has gone into measuring the full kinematic regime, there has never been a facility where the valence quark region could be measured with precision. The statistical precision of the world data is quite poor, for $x_{\rm Bj} > 0.4$. While the valence quark momentum distribution is peaked around 0.3, the sea quarks and the gluons tarnish the experimental picture in this regime. A clean and unambiguous contribution from the "valence quarks" can only be expected when $x$ is larger than 0.5. Unfortunately, in this kinematic region the probability of finding any of the valence quarks becomes rather small leading to a poor statistical determination of the key observables. Taking advantage of the energy upgrade and the unprecedented polarized luminosity in Hall A, this situation will be improved dramatically. A detailed mapping of the spin structure function of the proton and neutron as a function of the scale probed is expected to have a profound impact on our understanding of the structure of the nucleon.

For example, in most dynamical models of the nucleon, its polarization asymmetry $A_1^{\rm n,p}$, which reflects the quark spin wave-function, is expected to be large and positive in the valence quark region. At large momentum transfers, the asymmetry, $A_1^{\rm n,p}$, is expected to approach 1 when $x_{\rm Bj} \to 1$. This reflects the fact that in the valence region the struck quark, which carries most of the nucleon momentum, also carries all of its spin. A detailed examination of the present neutron data shows no sign of the expected behavior (see Fig. 5). However, a dramatic improvement can be achieved in the measurement of the neutron asymmetry using the 11 GeV polarized beam and a polarized $^3$He target combined with the proposed MAD spectrometer in Hall A, as shown in Fig. 5.

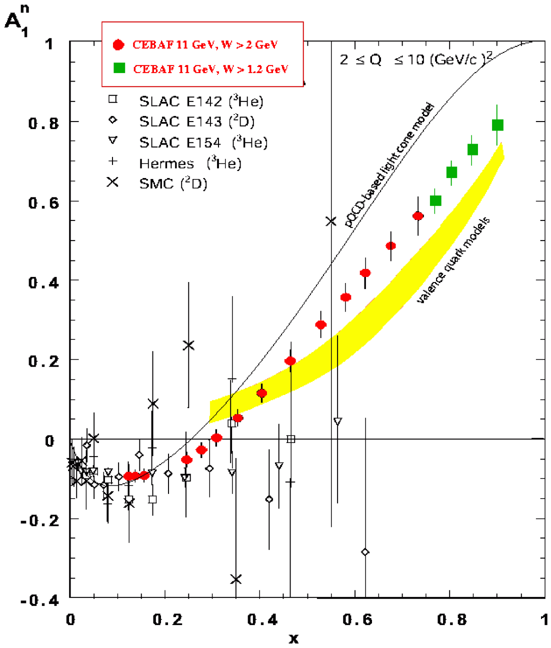


*Fig. 5. A measurement of the neutron polarization asymmetry $A_1^{\rm n}$, determined by the spin structure of the valence quarks made possible by the combination of an 11 GeV beam and the MAD spectrometer in Hall A. The shaded area represents a range of valence quark models; the solid line is a prediction of a pQCD light-cone quark model.*

Values of $x_{\rm Bj}$ greater than 0.8 cannot be reached at 11 GeV due to kinematics limitations, nor can they be reached at high-energy facilities due to luminosity limitations. However, if the validity of duality between the spin distribution measured in DIS and that measured in the resonance region has been verified, values of $A_1^{\rm n,p}$ for $x_{\rm Bj}$ up to 0.9 can be achieved. These measurements are important to understand how to reconcile a constituent quark picture of the nucleon with one involving current quarks and gluons. The knowledge of the polarization asymmetries $A_1^{\rm n,p}$ makes possible a flavor decomposition of the valence quark spin distributions assuming a value for the ratio $d/u$. In the constituent quark model, it is expected that $\Delta u/u \to 1$ while $\Delta d/d \to 1/4$ when $x_{\rm Bj} \to 1$. A different result is obtained in the quark-parton model when pQCD quark helicity conservation is used, namely $\Delta u/u \to 1$ and $\Delta d/d \to 1$. These predictions can be tested and spin distributions extracted in a comprehensive analysis if one complements the inclusive data with semi-inclusive asymmetry measurements of charged pions on the proton, deuterium and $^3$He. Fig. 6 shows the level of precision achievable in determining the valence quark distributions using the 11 GeV beam and the MAD spectrometer in Hall A. Factorization of the quark distributions and the fragmentation functions has been assumed. The validity of this assumption will be tested in a separate series of studies.

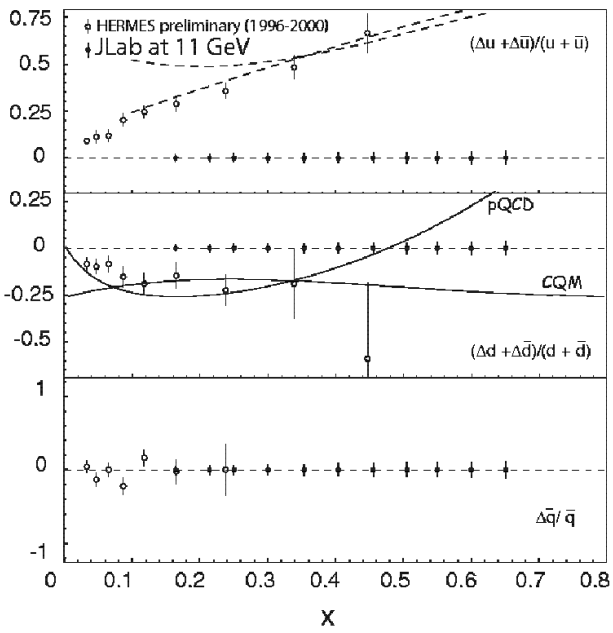


*Fig. 6. A semi-inclusive measurement of $\pi^+$ and $\pi^-$ production on the proton and $^3$He makes possible a spin and flavor decomposition of the nucleon spin quark distributions. Factorization is assumed but will be tested and quantified by several additional measurements.*

## 4. Summary

Hall A at 12 GeV (the nominal 12 GeV in Hall D will actually give 11 GeV in Hall A) will have a versatile complement of experimental equipment capable of addressing a broad spectrum of interesting physics.

*Acknowledgements*

The development of the plans for Hall A after the 12 GeV Upgrade involved a lot of work by many dedicated people. The entire Hall A staff and many members of the Hall A Collaboration contributed to the work presented here. The Southeastern Universities research Association (SURA) operates the Thomas Jefferson National Accelerator facility under DOE Contract No. DE-AC05-84-ER4015.

References

[1] J. Alcorn et al., Nucl. Instrum. Meth. A **522** (2003) 171.

[2] Hall A 12 GeV Upgrade PCDR, http://hallaweb.jlab.org/12GeV/.

HALLA A JLABA NAKON POSTIZANJA 12 GeV

Predstavlja se plan fizičkih istraživanja u Halli A JLaba nakon podizanja energije na 12 GeV, s naglaskom na potrebnu opremu za postizanje željenih eksperimentalnih ciljeva. Izlažu se ishodi simulacija nekih mjerenja s očekivanim pogreškama.