HALL-A Upgrade

- Introduction
- MAD spectrometer
- Background simulation
- Detector system
- Infrastructure
- Physics examples
- Summary

PAC on 12 GeV
January 17-22, 2003

Kees de Jager
JEFFERSON LABORATORY
Introduction

- Initial design of Hall A upgrade focused on
  - Nucleon structure functions in valence region \((x \geq 0.5)\)
    \[ A_1, g_2, F_2^n/F_2^p, \ldots \]
  - Leading to general requirements
    - High luminosity \((\geq 10^{38} \text{ cm}^{-2} \text{ s}^{-1})\)
    - Large acceptance in momentum and angle
    - Medium resolution \((\delta p/p \approx 10^{-3})\)
    - Intermediate excitation \((p_{\text{max}} \approx 6-7 \text{ GeV/c})\)
- Suitable candidate combined-function warm-bore SC magnets
Design of MAD

- Configuration to be optimized
  - nested (cosθ, cos2θ) coils
  - warm bore and yoke with 120 cm ID
- Resulted in 3 T dipole with 4.5 T quadrupole gradient
- Elliptical shape of yoke for closer approach to beam line
Mechanical Elements
MAD Infrastructure

- Background simulation (see later) require no target-detector line-of-sight
  ✓ Increase deflection in second magnet from 10° to 22°
- Peak field in bore -1 to 4 T in coils -2 to 5 T, acceptable forces
- Very stable cryogenics with
  ✓ a critical temperature ≥ 7 K
  ✓ $\alpha$ between 0.15 and 0.72, implying quench delayed until LHe evaporated
- Stored energy 15 and 25 MJ
- Four independent power supplies
- Total weight 2 * 250 (magnet) + 500 (shield house) ton $\approx$ 1000 ton
- Support requires angular and radial motion
  ✓ no pivot mount (autocollimated laser for alignment)
  ✓ 90° steerable wheels
- Three vacuum systems
  ✓ cryosystem
  ✓ spectrometer helium bag
  ✓ gas Cerenkov
Optics Simulation

Ingredients:
- TOSCA produced field maps
- SNAKE for particle transport
- Fit transfer functions

Results shown for three cases
- No measurement error: understanding of optics with 200 µm beam spot
- Standard errors: $\sigma_x = \sigma_y = 100$ µm and $\sigma_\theta = \sigma_\phi = 0.5$ mrad
- 0.5 * standard errors

MCEEP and SIMC available for experiment simulation
Predicted Optical Performance

Momentum Resolution

θ Resolution

y Resolution

φ Resolution
## MAD Performance Summary

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Spectrometer angle</th>
<th>Acceptance</th>
<th>Resolution ($\sigma$)</th>
<th>Acceptance</th>
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</thead>
<tbody>
<tr>
<td>Spectrometer angle</td>
<td>35° &lt;-&gt; (linear interpolation) &lt;-&gt; 12°</td>
<td>acceptance</td>
<td>resolution ($\sigma$)</td>
<td>acceptance</td>
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<td>Momentum</td>
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<tr>
<td>Target coordinate</td>
<td>± 6 cm @ 90°</td>
<td>0.26 cm</td>
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</table>
GEANT Simulation

**Ingredients**

- EM interactions + Mott
- SNAKE field maps
- MAD configuration with
  - Target 15 cm LH2 with 180 µm thick Al window
  - Scattering chamber with 0.5 mm thick Al window
  - 2 m air
  - 100 µm plastic window
  - 5 m He

**Conclusions**

- Increase deflection by second magnet to 22° to avoid line-of-sight
- Place collimators at target chamber, entrance of MAD1 and centre of MAD2
- At 25° with 50 µA on 15 cm LH2 100 MHz photons with 0.7 MeV average energy
Basic Detector Package

- Drift Chamber
- S1
- Cherenkov
- S2
- Calo
- MAD magnet
- He
- N₂ / He
- MWPC
- ep 11
- ep 12
- ep 13
- n - 1 = 0.000166
# Detector introduction

## MAD Single Rates (KHz)

\[ E = 11 \text{ GeV} \]

70 uA, 15 cm L\( ^2 \) target, \( L=3 \times 10^{38} \text{ s}^{-1} \text{ cm}^{-2} \)

<table>
<thead>
<tr>
<th>( P ) (GeV/c)</th>
<th>( \theta=15 \text{ degree} )</th>
<th>( \theta=25 \text{ degree} )</th>
<th>( \theta=35 \text{ degree} )</th>
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<td>( e ) ( \pi^- ) ( \pi^+ )</td>
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<td>4.5</td>
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<td>0.1 0.03 30 280</td>
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</table>

## Main concerns

- High rate of low-energy photons
- Pion suppression
Trigger Scintillators

- Three trigger planes S0, S1 and S2(V+H)
  - S0/S1 before/after drift chamber package
    - 0.5 m * 2 m * 0.5 cm with 1 cm overlap
  - S2 two orthogonal planes just before calorimeter
    - 0.6 m * 2.5 m * 5 cm
  - Each plane segmented in 16 paddles, read out at both ends
- Main trigger formed by S1+S2
  - Timing determined by S2 (s < 150 ps)
  - S0 to determine trigger efficiency
- Discriminator set to reduce soft photon background
  - 50 kHz/paddle in S0 and S1, 100 Hz in S2
Wire Chambers

- Two drift chambers 1 m apart with standard MWPC in between
- Drift chambers
  - 0.6 m * 2.5 m
  - 3 groups (u,v,x) each of four planes
  - Requiring 2 out of 4 planes yields very high efficiency
  - 75 µm resolution, 3 mm between sense wires
  - Dead time ~ 300 ns/cm/wire, negligible effect of 100 MHz soft photons
- MWPC for track selection
  - 3 mm wire distance
• Mixture of He/N₂ adjusted to optimize $N_{pe}$
• 12 mirrors pairwise with 1 m radius
• Winston cones for bottom 2 pairs
• Average efficiency ~98%
## EM Calorimeter

- **Main purpose**: pion rejection
- **Construction**: 3.2 m * 1 m lead (2.2 mm)-plastic (10 mm) sandwich
- **Arrangement**: 10 cm * 100 cm strips, 22 X0 deep
- **Readout**: Every 5 even/odd plastic strips read out on alternate sides
- **Energy resolution**: \( \sim 0.1 / \sqrt{E} \)
- **Pion suppression**: \( e/\pi \sim 100 \)

### Data Acquisition

- **Combination**: VME/NIM/CAMAC
- **Components**: Flash ADC’s and pipeline TDC’s
- **Upgrade**: HRS from Fastbus to VME
Hadron Extension

- Drift Chambers
- S1
- Cherenkov
- S2
- Calo

- MWPC
- He
- 30 degree
- ep 11
- ep 12
- ep 13

- X
- Z

- n = 0.008
- n = 0.030
- n = 0.001430

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Particle Identification

- **Shorten Gas Cerenkov to 1 m**
- **Install two aerogel Cerenkovs with**
  - $\text{n} = 1.008$ and $1.030$
- **0.6 m * 2.5 m * 15 cm**
- **Magnetic shield either complete box or individual PMT’s**
- **Good identification over full momentum range**

### Index

<table>
<thead>
<tr>
<th>Index</th>
<th>$p_\pi$ (GeV/c)</th>
<th>$p_K$ (GeV/c)</th>
<th>$p_p$ (GeV/c)</th>
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</table>
Particle Identification (cont.)

Index = 1.008 Thickness = 15 cm

- π⁺
- K⁺
- N.P.E. = 1.5

Index = 1.03 Thickness = 10 cm

- π⁺
- K⁺
- ρ
- N.P.E. = 1.5
Focal Plane Polarimeter

- Double CH2 analyzer
  - Each 2 m * 3.5 m * 0.5 m (~% ton!)
- Tracking 2.5 m * 4 m
  - 4 multilayer straw chambers
  - 2 cm drift cell
- Use aerogel for $\pi^+$ rejection
Overview of MAD and HRS
Calorimeter

- Calorimeter on floor successful for photon/electron detection in coincidence experiments (e,e'p\gamma or e,e'X)
- Existing A/C calorimeter
  1700 lead-glass blocks 4 * 4 * 40 cm³
- Improved version
  ✓ Use PbF₂
  ✗ Higher density -> better energy resolution
  ✗ Higher refractive index -> lower e⁻ threshold
  ✗ Enhanced UV transmission
  ✗ Lower critical energy -> less e⁺e⁻ pairs
  ✓ 1296 elements 26 * 26 * 200 mm³
Beam Line

- Beam emittance deteriorates factor 2 (longitudinal) to 10 (transverse)
- Little effect on quality of data, no need for significant modifications
- Arc dipoles modified from C- to H-yoke

- Energy measurement
  - ARC measurement requires remapping of all dipoles
  - EP instrument only useable up to 6 GeV

- Beam polarimeters
  - Møller reduce dipole bend angle from 11° to 7°
    - add quadrupole
  - Compton lift beam line by 8 cm
# Research Program

## Experimental Requirements for MAD

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<th>No.</th>
<th>Exp's</th>
<th>Pmax (GeV/c)</th>
<th>Angle (degrees)</th>
<th>Acc(angle) (msr)</th>
<th>Acc(mom) (%)</th>
<th>Res(mom) (%)</th>
<th>Res(ang) H, V (mr)</th>
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</table>
Neutron (Proton) Spin Structure A1

![Graph showing neutron spin structure A1 vs. Bjorken x for different experiments and models.]

VALENCE SPIN STRUCTURE USING SEMI-INCLUSIVE DEEP INELASTIC SCATTERING

HERMES preliminary (1996-2000)
JLab at 11 GeV

\[ \frac{\Delta q}{q} \]
Neutron (Proton) Spin Structure $g_2$

Graphs showing data for neutron spin structure $g_2$ at different energies. The graphs compare data from various models and experiments, including SLAC data and projected errors at 12 GeV.

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Few-Body Systems

Induced Polarization (90°_{\text{cm}}) vs. Photon Energy (GeV)

- Stanford
- Tokyo
- JLab
- MAD 4 GeV 30 days
- MAD 2.8 GeV 7 days
- Sargsian

Deuteron Form Factor
\[ F_{g}(Q^{2}) = |\Lambda(Q^{2})|^{1/2} \]

He Form Factor
\[ F_{g}(Q^{2}) = |\Lambda(Q^{2})|^{1/2} \]

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PAC for 12 GeV, January 17 - 22, 2003, 27
Summary

• MAD design has met all specifications
  Large acceptance
    ✓ angle 30 msr
    ✓ momentum 30 %
  Medium resolution
    ✓ angle few mrad
    ✓ momentum $10^{-3}$

• MAD with HRS and ECAL provides versatile and powerful instrumentation for large variety of experiments