Rachel Montgomery, on behalf of the CLAS12 RICH Group:

A Ring Imaging Cherenkov (RICH) Detector for CLAS12
CEBAF Upgrade at Jefferson Lab

**JLab 12GeV Upgrade:**
- Shutdown 2012
- Electron beam 6GeV to 12GeV
- Upgrade existing, install new detectors; new hall
- First beam delivery **Feb 2014**

Max E = 10.9GeV,
Max I = 90μA
Luminosity $10^{35}$cm$^{-2}$s$^{-1}$
Longitudinal polarization = 75-85%

Continuous Electron Beam Accelerator Facility

https://www.jlab.org/12-gev-upgrade
CLAS12 Physics Program:
- Internal nucleon dynamics, 3-D imaging of the nucleon; mapping of TMDs and GPDs
- Good separation of π, K, p over the full kinematics $3 \text{–} 8 \text{ GeV}/c$ necessary!
  - π/K separation of $\sim 4\sigma$ up to $8 \text{ GeV}/c$
  - RICH

<table>
<thead>
<tr>
<th>Physics Program</th>
<th>Particle Identification Requirement</th>
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<td>Internal nucleon dynamics</td>
<td>Flavour tagging</td>
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<td>Quark hadronisation in nuclear medium</td>
<td>Constraining models</td>
</tr>
<tr>
<td>Spectroscopy</td>
<td>Rare processes</td>
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Hall B, CLAS $\rightarrow$ CLAS12: Polarised/unpolarised lepton scattering experiments with close to full angular coverage

CLAS12 Physics Program:
- **Internal nucleon dynamics**, 3-D imaging of the nucleon; mapping of TMDs and GPDs
- **Good separation of** $\pi$, $K$, $p$ over the full kinematics $3 \rightarrow 8$ GeV/c necessary!
  - $\pi/K$ separation of ~4σ up to 8 GeV/c
- **RICH**
• **6 Radial Sectors:** 1.2m gap; ~6m² window  
• **Hybrid Imaging RICH:**  
  • Aerogel radiator (SiO₂ + Air, n=1.01 - 1.13, δ = 0.05 – 0.6 g/cm³)  
  • Visible light photon detectors  
  • Focussing mirror system → minimise area
Direct Case (proximity):
- $\theta < 12^\circ$, $p = 3 - 8\text{GeV}/c$

Reflected Case:
- $\theta > 12^\circ$, $p = 3 - 6\text{GeV}/c$

\[
\cos \theta_c = \frac{1}{n\beta}
\]
Radiator Material: Aerogel (n=1.04 to 1.06)

- Momentum range (3 – 8 GeV/c)
- Constrained depth, low-material budget (3.2% $X_0$)
- **Characterise optical properties**: reflected case and simulation input
  - **Refractive index** (prism method), transmittance (spectrophotometer), **thickness profile** (coordinate machine)
  - Different manufacturers: Novosibirsk, Matsushita, Aspen
Photon Detectors – Requirements, Hamamatsu H8500

**Requirements:**
- Position sensitive
- Pixel sizes $< 1\text{ cm} \times 1\text{ cm}$
- Efficient single photon detection crucial
- High packing fraction
- Sensitivity to visible light

✓ Hamamatsu H8500 MAPMT

### MAPMT Parameter | H8500
---|---
Active Area (mm x mm) | 49 x 49
Number of Pixels | 64 (8 x 8)
Pixel Size (mm x mm) | 5.8 x 5.8
Packing Fraction (%) | 89
Range (nm) | 260 - 650

![Hamamatsu H8500 MAPMT](image)

1-10 GeV/c, mixed hadrons

10 GeV/c, $n=1.05$, Novosibirsk, $t=3\text{ cm}$

$<\text{Hits}> = 10.87$

(need least 7 for $\pi/K$ goal in direct light case)

No. Hits
Photon Detectors – Single Photoelectron Scans

0° 10° 20° 30°

0.04mm steps

0.05mm steps

0.5mm steps

Relative Efficiency
Background Corrected Yields:

<table>
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<tr>
<th>Data Set</th>
<th>Algorithm</th>
<th>Aerogel Yield (NPE)</th>
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<td>1cm</td>
<td>Cluster</td>
<td>9.22 ± 0.29</td>
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<td>1cm</td>
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<td>2cm</td>
<td>Cluster</td>
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n.b. 10% uncertainty from gain calibration

Data Vs Simulation:

Muon Signal Charge (1cm) $<\text{NPE}> = 30$

Aerogel Yield (1cm)
Testbeam Prototype Setup
– Direct Light Configuration

Side View:

Aerogel

Cherenkov Light

Ring of MAPMTs

Beam

Mixed hadrons (0-15GeV/c)

MAPMTs:
- 28 H8500 MAPMTs (14 normal, 14 UV-extended windows)
- Readout MAROC3 electronics (ADC)

Aerogel (Novosibirsk):
- Varying n, thickness, transparencies
- Transparency monitored – laser and photodiode
Testbeam Prototype Images – Direct Light Configuration

Freq.

20k events

8GeV/c, n=1.04, t=2cm

8GeV/c, n=1.06, t=2cm

20k events
Testbeam Prototype Setup – Reflected Light Configuration

- **Absorbers**: Novosibirsk, CERN AMS samples
- \( n = 1.05, \ t = 2\text{cm}, \text{ varying transparency} \)

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**Planar Mirrors**

- 2cm

**Aerogel**

- 450mm

**Cherenkov Light**

**Beam**

**MAPMTs**

- Not full ring

**Mirror**

- Spherical and Elliptical
- Focal length \(~1\text{m}\)
Radiator $n=1.05, \ t=6\text{cm}$; Beam $p = 6\text{GeV/c}$: Comparison with and without absorbers:

- Without Absorbers
- With Absorbers
**Summary and Outlook**

**CLAS12:**

**Components Testing:**

**Cosmic Stand:**

**Testbeams:**

**Outlook:**

- Technical design report currently underway
- Completion and installation of one complete RICH sector planned for beginning of CLAS12 data taking
Thanks for your Attention

...Any Questions?
Radiator Selection

- Liquid (n=1.28)
  - Cherenkov angle vs Momentum (GeV/c)
  - π
  - K
  - p
- Aerogel (n=1.03)
  - Cherenkov angle vs Momentum (GeV/c)
- Gas (n=1.0014)
  - 2 mrad
  - 8 mrad

R. A. Montgomery, Baryons 2013, 27/06/13
Simulation Studies:
- **Geant4** framework
- **Pattern reconstruction**: Maximum Likelihood, ray tracing ansatz

**Requirements:**
- **Direct** case, aim: 8GeV/c π/K separation 5.5mrad
  - require 7 detected photoelectrons
- **Reflected** case, at least 3 detected pe’s for algorithm
Photon Detectors – Requirements, Hamamatsu H8500

**Requirements:**
- Position sensitive
- Pixel sizes $< 1\text{cm x 1cm}$
- Efficient *single photon* detection crucial
- High packing fraction
- Sensitivity to *visible light*

**Hamamatsu H8500 MAPMT**

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<td>89</td>
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<td>Range (nm)</td>
<td>260 - 650</td>
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Detector Characterisations:
- Uniformity studies
- Single photon signal losses
- Crosstalk studies
- H9500, H7546 amongst tested

15% loss of SPE signal
Cosmic Prototype for MAPMT Simulation Model Validations

Scintillator Bars

Matsushita Aerogel n=1.05

H8500

Muon Cosm Prototype for MAPMT Simulation Model Validations

Aerogel

Cherenkov Light

H8500 MAPMT

Geant4 Simulation

Signal Charge (QDC Bins)

Y-ID

X-ID

Data

R. A. Montgomery, Baryons 2013, 27/06/13
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Data Vs Sim:

- Muon hit in MAPMT window well-modelled
- Aerogel yield requires pixel single photon resolution variations

Muon Signal Charge (1cm) $<\text{NPE}> = 30$
Cosmic Prototype: Trigger Rate, Data Sets and Event Topology

Data Sets:
- **1cm** aerogel
- **2cm** aerogel (2 x 1cm tiles)
- **Masked** data – MAPMT window covered

<table>
<thead>
<tr>
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<th>No. Events</th>
<th>No. Central Hits</th>
<th>Eff. (%)</th>
</tr>
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<tr>
<td>1cm</td>
<td>135 832</td>
<td>1 205</td>
<td>0.89</td>
</tr>
<tr>
<td>2cm</td>
<td>198 000</td>
<td>1 797</td>
<td>0.91</td>
</tr>
<tr>
<td>Masked</td>
<td>189 000</td>
<td>1 749</td>
<td>0.93</td>
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**Typical Event:**

- **Muon**
- **Aerogel**

Only central muon hits are used, to maximise ring coverage:

$<\text{Eff}> = 0.91 \pm 0.01$
Prototype Studies at Testbeams

- **CERN PS East Area, T9 beam test area** (Jul-Aug 2012 and Nov-Dec 2012):

  - Primary beam: $p^+ + \text{Beam Target (Al)}$

  - Secondary Beam:
    - $p^+/+, \pi^+/+, K^+/-, e^+/-$
    - Momentum: $0 - 15\text{GeV/c}$

  - Testbeams:
    - Negative polarity; momenta 6, 7, 8 GeV/c
    - At 8 GeV/c, $\pi:K \sim 60:1$
Prototype Detector Setup: FE Electronics

Prototype: 1952 Channels; 33 FE Cards; 3 Backplanes; 3 Control Boards

Readout – MAROC3:
- 64 channel charge ADC readout
- x4 Pre-amp – equalise gains
- digital outputs available