Hall C - 12 GeV pCDR

Max. Central Momentum: 11 GeV/c, 9 GeV/c
Min. Scattering Angle: 5.5 deg, 10 deg
Momentum Resolution: 0.15% - 0.2%
Solid Angle: 2.1 msr, 4.4 msr
Momentum Acceptance: 40%
Target Length Acceptance: 50 cm
Opening Angle with HMS: 16 deg, 25 deg
Configuration: QQ(DQ)
Bend Angle: 18.4 deg
Hall C at 12 GeV:
HMS + SHMS

- Charged particle detection with momentum up to beam energy  \( z = E_h/\nu = 1 \)
- Small angle capability essential to measure charged particle along momentum transfer  \( \theta_h \parallel q \pm \text{few } ^\circ \)
- Precision L/T separations
  \[
  \sigma = \Gamma(\sigma_T + \varepsilon \sigma_L + \varepsilon \cos(2\phi)\sigma_{TT} + [\varepsilon(\varepsilon+1)/2]^{1/2}\cos(\phi)\sigma_{LT})
  \]
- General Infrastructure for Dedicated Experiments

- Exclusive and Semi-Exclusive Reactions (\( z > 0.3 \)) at high \( Q^2 \)
- Separation of Polarized and Unpolarized Structure Functions over large range of \( x \) and \( Q^2 \)
Hall C at 12 GeV:
SHMS Carriage and Shield House

16° SHMS-HMS angle.

Hard connections to pivot yield 0.01° scattering angle, 0.5mm pointing reproducibility.

1m shielding typ.
Hall C at 12 GeV:
Co-Existence of SHMS with HMS

HMS: QQQD

SHMS: QQ(QD)
Hall C at 12 GeV: HMS

Option: replace Cherenkov with FPP
Hall C at 12 GeV:
HMS Performance
### Hall C at 12 GeV: HMS Performance

<table>
<thead>
<tr>
<th>Parameter</th>
<th>HMS Performance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Range of Central Momentum</td>
<td>0.4 to 7.3 GeV/c</td>
</tr>
<tr>
<td>Momentum Acceptance</td>
<td>±10%</td>
</tr>
<tr>
<td>Momentum Resolution</td>
<td>0.1% - 0.15%</td>
</tr>
<tr>
<td>Scattering Angle Range</td>
<td>10.5 to 90 degrees</td>
</tr>
<tr>
<td>Maximum Target Length at 90 degrees</td>
<td>10 cm</td>
</tr>
<tr>
<td>Horizontal Angle Acceptance</td>
<td>±32 mrad</td>
</tr>
<tr>
<td>Vertical Angle Acceptance</td>
<td>±85 mrad</td>
</tr>
<tr>
<td>Solid Angle Acceptance</td>
<td>8.1 msr</td>
</tr>
<tr>
<td>Horizontal Angle Resolution</td>
<td>0.8 mrad</td>
</tr>
<tr>
<td>Vertical Angle Resolution</td>
<td>1.0 mrad</td>
</tr>
<tr>
<td>Vertex Reconstruction Resolution</td>
<td>0.3 cm</td>
</tr>
<tr>
<td>Maximum Flux within Acceptance</td>
<td>~5 MHz</td>
</tr>
<tr>
<td>Electron-hadron discrimination</td>
<td>1000:1 at 98% efficiency</td>
</tr>
<tr>
<td>Pion-kaon discrimination</td>
<td>100:1 at 95% efficiency</td>
</tr>
</tbody>
</table>
Hall C at 12 GeV:
SHMS Quads - Based on Existing HMS-Q1

- Slightly increased gradient (8.6 T/m) compared to HMS-Q1
- TOSCA (JLab) and external feasibility study show there are no issues
- Design and Tooling still available at company ➔ affordable
Hall C at 12 GeV:
SHMS Combined Function Magnet

- Quadrupole “inside” Dipole to reduce current density
- TOSCA (JLab) and external feasibility study
  - cryostability
  - coil, conductor conservative
  - force containment will require careful engineering, but no excessive forces
  - energy quench within allowable margins
- “Can be built without prototyping or R&D”
### Hall C at 12 GeV:
#### SHMS Specifications

<table>
<thead>
<tr>
<th>Parameter</th>
<th>SHMS Specifications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Range of Central Momentum</td>
<td>2 to 11 GeV/c</td>
</tr>
<tr>
<td>Momentum Acceptance</td>
<td>-15% to +25%</td>
</tr>
<tr>
<td>Momentum Resolution</td>
<td>&lt; 0.2%</td>
</tr>
<tr>
<td>Scattering Angle Range</td>
<td>5.5 to 25 degrees</td>
</tr>
<tr>
<td>Maximum Target Length at 90 degrees</td>
<td>50 cm</td>
</tr>
<tr>
<td>Horizontal Angle Acceptance</td>
<td>±18 mrad</td>
</tr>
<tr>
<td>Vertical Angle Acceptance</td>
<td>±50 mrad</td>
</tr>
<tr>
<td>Solid Angle Acceptance</td>
<td>4 msr (LSA tune)</td>
</tr>
<tr>
<td></td>
<td>2 msr (SSA tune)</td>
</tr>
<tr>
<td>Horizontal Angle Resolution (yptar)</td>
<td>2-4 mrad</td>
</tr>
<tr>
<td>Vertical Angle Resolution (xptar)</td>
<td>1-2 mrad</td>
</tr>
<tr>
<td>Target Resolution (ytar)</td>
<td>0.2 - 0.6 cm</td>
</tr>
<tr>
<td>Maximum Flux within Acceptance</td>
<td>~5 MHz</td>
</tr>
<tr>
<td>Minimum Acceptable e/h discrimination</td>
<td>1000:1 at 98% efficiency</td>
</tr>
<tr>
<td>Minimum Acceptable π/K discrimination</td>
<td>100:1 at 95% efficiency</td>
</tr>
</tbody>
</table>
Hall C at 12 GeV: SHMS Small-Solid-Angle Tune Model

\[ \geq 5.5^\circ \leq 11 \text{ GeV/c} \]

Eff. Sol. Angle \( \sim 2 \text{ msr} \)
Hall C at 12 GeV:
SHMS Large-Solid-Angle Tune Model

\[ \geq 10^\circ \ \leq 8.8 \text{ GeV/c} \]

Eff. Sol. Angle \(~ 4 \text{ msr}\)
Hall C at 12 GeV:
SHMS Acceptance

Point Target

LSA Tune
SSA Tune
Hall C at 12 GeV:
SHMS Acceptance

50cm Target (viewed at 90°)

LSA Tune
SSA Tune
Hall C at 12 GeV: Detectors
Small Solid Angle Tune Resolutions

![Graphs showing tune resolutions at different angles](image-url)
Hall C at 12 GeV: Detectors: Detector Package in the Shield House
## Hall C at 12 GeV: Detectors

### SHMS Detector Requirements

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tracking Resolution (each of two points)</td>
<td>$\leq 100 , \mu\text{m}$</td>
</tr>
<tr>
<td>Multiple Scattering</td>
<td>$\text{DC} &lt; \sim 1% , X_0$</td>
</tr>
<tr>
<td></td>
<td>Nothing upstream of DC at low momentum.</td>
</tr>
<tr>
<td></td>
<td>Minimum material upstream of Cerenkovs</td>
</tr>
<tr>
<td>Size</td>
<td>From $85 \times 110 , \text{cm}^2$ at DC</td>
</tr>
<tr>
<td></td>
<td>To $115 \times 150 , \text{cm}^2$ at LGC</td>
</tr>
<tr>
<td>Particle Identification</td>
<td>Combination of Techniques to cover this wide momentum range.</td>
</tr>
</tbody>
</table>
## Hall C at 12 GeV: Detectors: Size Summary

<table>
<thead>
<tr>
<th>Detector</th>
<th>30-cm Target</th>
<th>50-cm Target</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>X size</td>
<td>Y size</td>
</tr>
<tr>
<td>Atm. Gas Č</td>
<td>75</td>
<td>80</td>
</tr>
<tr>
<td>Drift Chambers</td>
<td>85</td>
<td>80</td>
</tr>
<tr>
<td>Scint. Hodo 1</td>
<td>90</td>
<td>90</td>
</tr>
<tr>
<td>Heavy Gas Č</td>
<td>100</td>
<td>95</td>
</tr>
<tr>
<td>Aerogel Č</td>
<td>110</td>
<td>100</td>
</tr>
<tr>
<td>TRD</td>
<td>110</td>
<td>100</td>
</tr>
<tr>
<td>Scint. Hodo 2</td>
<td>110</td>
<td>100</td>
</tr>
<tr>
<td>Shower Counter</td>
<td>115</td>
<td>120</td>
</tr>
</tbody>
</table>

**SHMS Detector Active Areas (cm)**

- Will design detectors assuming 50-cm target
- Will instrument assuming 30-cm target (both as viewed at 90°)
Hall C at 12 GeV: Detectors

Wire Chambers - Stack-up Design
Hall C at 12 GeV: Detectors

Wire Chambers - SOS Resolution

- ssres sdc1u1 t=sdcres(1)
- ssres sdc1u2 t=sdcres(2)
- ssres sdc1x1 t=sdcres(3)
- ssres sdc1x2 t=sdcres(4)
- ssres sdc1v1 t=sdcres(5)
- ssres sdc1v2 t=sdcres(6)
SHMS will use a COMBINATION of PID techniques to cover the entire momentum range of interest.

Electron/Hadron Separation:

- Time-of-Flight at low momentum.
- Shower counter over full range.
- $e^-$ always trigger Cerenkov counters.
- Additional upstream Cerenkov at high energy
<table>
<thead>
<tr>
<th>Energy Range (GeV/c)</th>
<th>Particle Type</th>
<th>Detector Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 to 3</td>
<td>Pion/Kaon</td>
<td>Aerogel Cerenkov</td>
</tr>
<tr>
<td></td>
<td>Kaon/Proton</td>
<td>TOF &amp; Aerogel</td>
</tr>
<tr>
<td>3 to 5.5</td>
<td>Pion/Kaon</td>
<td>$C_{4}F_{10}$ Cerenkov</td>
</tr>
<tr>
<td></td>
<td>Kaon/Proton</td>
<td>Aerogel</td>
</tr>
<tr>
<td>5.5 to 11</td>
<td>Pion/Kaon</td>
<td>Atm. Press. Cerenkov, $C_{4}F_{10}$ Cerenkov and $dE/dx$</td>
</tr>
<tr>
<td></td>
<td>Kaon/Proton</td>
<td>$C_{4}F_{10}$ at &gt; 1 atm.</td>
</tr>
</tbody>
</table>
Hall C at 12 GeV: Detectors:

Atmospheric Pressure Cerenkov

2.5 m long
Ne (n-1 = 67 x 10^{-6})
and/or
Ar (n-1 = 283 x 10^{-6})

- Atmospheric pressure - thin windows.
- Use only above 6 GeV (e.g., e/π separation for x > 1 experiment)
- Improves e/π (argon) or π/K (neon).
- Expect ~10 p.e.
Hall C at 12 GeV: Detectors: Particle Identification Summary

- **e/π Separation**
- **π/K Separation**
- **K/P Separation**

**Graphs**

- **#Sigma** vs. **Momentum (GeV/c)**

**Legend**

- Aerogel Cerenkov n=1.02
- Aerogel Cerenkov n=1.015
- Atmospheric Gas Cerenkov (Argon)
- Atmospheric Gas Cerenkov (Neon)
- C4P10 Variable Pressure Cerenkov
- TOP over 2m Baseline
- TMD
- dE/dx in Drift Chambers
The FPP being built for the HMS can also fit in the SHMS.
Pion Form Factor

Essential:
- 9 GeV/c
  (at $Q^2 = 6 \text{ GeV}^2$)
- 5.5 degrees
  (with HMS at 10.5 degrees!)
- precise L/T
  (smooth acceptances)
(Semi-)Exclusive Meson Production

- Can access deep exclusive charged $\pi/K$ electroproduction to $Q^2 \sim 10$
- Large range in $z$ (0.3-0.8), $x$ (0.2-0.7), $Q^2$ (3-10 GeV$^2$), and $p_T$ in semi-exclusive meson electroproduction for duality and factorization studies and, if applicable, spin/flavor parton distributions
Proton-Delta Transition

Can access magnetic transition form factor up to $Q^2 = 18$ GeV$^2$ (typ. $Q^2 \sim 15$ GeV$^2$)

Assumption: $E_2/M_1$ remains small. If not $\rightarrow$ higher $Q^2$ may be possible
Crossing Charm Threshold

\[ \gamma p \rightarrow \pi^+ n \text{ with } \Theta_{cm} \text{ at } 90^\circ \]

Requires detection of two charged particles with \( \sim 6.5 \text{ GeV/c} \) momentum

Small Cross Sections require high luminosity hall

\[ \gamma p \rightarrow \pi^0 p \] also possible using BigCal (under construction)

\[ \gamma n \rightarrow \pi^- p \text{ with } \Theta_{cm} \text{ at } 90^\circ \]
Separated Structure Functions

\[ \Delta \varepsilon > 0.3 \quad H, D(e,e') \quad x = 0.8 \]

\[ \sigma + R \rightarrow F_1 \text{ and } F_2 \text{ (} F_1 \text{ and } F_L \text{)} \]
\[ + A_{\parallel} + A_{\perp} \rightarrow g_1 \text{ and } g_2 \]
\[ + x > 1 \text{ in Nucleus} \]
Structure Function Moments

\[ M_n(Q^2) = \int_0^1 dx \, x^{n-2} F_2(x,Q^2) \]

Lattice QCD
- \( F_2 \)
- \( p - n \)
- \( Q^2 = 4 \text{ GeV}^2 \)
  \( (x_{@W^2=4} = 0.56) \)
- \( n = 2, 4 \)

Experiment
- "\( F_2 \)"
- \( 2p - d \)
  (or CTEQ/MRST/GRVS)
- Lack of large \( x \)
  (resonances and elastic!)

+ Structure Functions + Duality Studies + \( Q^2 \) Evolution Studies
**Requirements:**

- spectrometers at 12.5 degrees (HMS + SHMS = 12 msr)
- ~2 kW cryogenic cooling (QWeak wants 2.2 kW, ~ 90 µA and 60 cm LD2)
- 1% Polarimetry (Qweak wants 1.4%)

Utilizes Hall C infrastructure
Color Transparency

A(e,e'p) requires $Q^2 > 12$ GeV$^2$

A(e,e'π) can reach $Q^2 = 14$ GeV$^2$ at larger $t$
Hall C at 12 GeV:
HMS + SHMS

- Charged particle detection with momentum up to beam energy $z = E_h/\nu = 1$
- Small angle capability essential to measure charged particle along momentum transfer $\theta_h // q \pm \text{few } ^{\circ}$
- Precision L/T separations
  $$\sigma = \Gamma(\sigma_T + \varepsilon \sigma_L + \varepsilon \cos(2\phi)\sigma_{TT} + [\varepsilon(\varepsilon+1)/2]^{1/2}\cos(\phi)\sigma_{LT})$$
- General Infrastructure for Dedicated Experiments

- Exclusive and Semi-Exclusive Reactions ($z > 0.3$) at high $Q^2$
- Separation of Polarized and Unpolarized Structure Functions over large range of $x$ and $Q^2$