Results/Programs from IMP and THU
—— Some GEM R&D works and the CEE spectrometer

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Collaborators:

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CCNU: Nu Xu

SINAP: Yugang Ma, Fei Lu

DUKE/THU: Haiyan Gao…
1 GEM activities at THU and IMP
   Introduction and Experimental Setup
   Non-uniformity effects of the inter-foil distance of GEM detector
   Assembly of Large area GEM detector
2 The CEE experiment
   Introduction
   Conceptual design
   Progress of the R&D studies
3 Summary
GEM detector demands from SOLID

- JLAB 12 GeV upgrade
- Nearly whole space coverage in C.M.
- Multi-subsystems including GEM, Cerenkov, MRPC
- About 1.5T central field by solenoid
- Measuring high energy electron and hadrons

Physical goal of SOLID:
Semi-inclusive eN process to detect the TMDs of nucleons.

- Large GEM detector is demanded in SOLID
- Possible demand in CEE for its TPC read out.

About 200 scientist from about 50 institutes from 8 countries.
From China: USTC, CIAE, PKU, THU, LZU, IMP, HSU, SDU etc.
Small GEM detector test

**Detector**
- 2D GEM
- 1D GEM detector

**Electronics**
- CASA-GEM board

**Specifications**
- Gain: $2 \sim 40 \text{mV/fC}$
- Dynm. Rng.: $0 \sim 1000 \text{fC}$
- Shap. time: $20 \sim 80 \text{ns}$
- INL: $< 1 \%$
- Power: $10 \ (11) \ \text{mW/ch for Anode (Cath.)}$
- ENC: $< 2000 \text{e (Anode, Input Cap: 50pF),}$
  $< 3000 \text{e (Cathode, Input Cap: 100pF)}$

Developed by Z. Deng, THU
Readout Board Dimension

• 2-D read out

Extracted from the lowest foil

Design of Readout

• 1-D readout

Strip: W=100+100 μm

5×16 strips in 5cm
W = 625 μm

7×16 strips in 5cm
W = 446 μm
Experimental Setup

- **Trigger**
  - Extracted from the lowest foil
  - [Image of a waveform with labels](image)
  - [Image of the trigger setup](image)

- **ADC+ DAQ**
  - VME based DAQ
  - [Graphs showing calibration](image)
  - [Diagram of the ADC modules calibrated with pulser](image)

**X: 500 800 1100 1400 1700 2000 2300 (mv)**
The latest setup

Adjustable thick Slit

Precise movable platform

detector

CASAGEM box

VME DAQ

Acknowledgement: 96 channels peak sensitive ADC from Prof. Boqiang Ma’s group (PKU)
Cluster size analysis

- Using larger strip distance/width to save cost, however, strip width cannot go beyond a certain value.

W = 446 μm

W = 625 μm
Cluster size (2nd moment analysis)

\[
E[x^2] = \frac{\sum_{i=1}^{16} (x_i - \bar{x})^2 a_i}{\sum_{i=1}^{16} a_i}
\]

\(x_i\) is the position of fired strip  
\(a_i\) is the amplitude of signal  
\(\bar{x}\) is the mean position
Energy Resolution with Fe-55

FWHM:  X: 22%      Y: 25%      total: 22%
Spatial Resolution with Fe-55

\[ n = \rho w \phi \Omega \eta / 4\pi \]

\[ n = c_2 w^2 \]

\[ \sigma^2_{tot} = \sigma^2_{GEM} + c_0 n \]

\[ \sigma_{Geometry} = c_2 w \]

\[ \sigma^2_{tot} = \sigma^2_{GEM} + c_0 w^2 \]
Spatial Resolution with Fe-55

$\sigma_{\text{tot}} = 432 \ \mu\text{m}$
Spatial resolution

\[ \delta_{\text{theo}} = \frac{w}{\sqrt{12}} \]

- \( \sigma_{\text{GEM}} = 204 \pm 13(\mu m) \)

<table>
<thead>
<tr>
<th>strip width((\mu m))</th>
<th>(\delta_{\text{exp}}(\mu m))</th>
<th>(\delta_{\text{theo}}(\mu m))</th>
</tr>
</thead>
<tbody>
<tr>
<td>200</td>
<td>56 (\pm) 15</td>
<td>58</td>
</tr>
<tr>
<td>X:446 Y:625</td>
<td>204 (\pm) 13</td>
<td>221</td>
</tr>
<tr>
<td>446</td>
<td>159 (\pm) 22</td>
<td>129</td>
</tr>
</tbody>
</table>

\( \chi^2 / \text{ndf} \) = 5.084 / 2

\( p0 \) = 4.161e+04 \(\pm\) 5307

\( p1 \) = 3488 \(\pm\) 236.1
Non-uniformity effects of the inter-foil distance

- Why this study?

Scheme of setup 1

- Extra spacer to extend the gap at one side

Scheme of setup 2
The gain exhibits a linear dependence on the relative change of the distance.

1% distance variation causes approximately 1.2% variation in gain.
• Cluster size shows insignificant effect.
Neither does the spatial resolution show neither dependence on the distance changing.

- Spatial resolution shows neither dependence on the distance changing.
Larger area GEM detector assembling

Scheme of the triple GEM 45cm*45cm

- Mylar foil
- Drift cathode
- GEM 1
  - 2mm
- GEM 2
  - 2mm
- GEM 3
  - 2mm
- Readout board

Pad:
- 2mm*7mm
- 7mm*7mm
- 7.5mm*12.5mm

- Larger area GEM detector being assembled and debugged.
Larger area GEM detector assembling

- Clean room of Prof. Limin Duan’s group in IMP.
- Debug going on.
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3 Summary
To understand the nuclear equation of state

1. \( T_{\text{ini}} \), \( T_{\text{C}} \): LHC, RHIC
2. \( T_{E} \): RHIC, SPS
3. Large \( \mu_{B} \): FAIR, CSR

CEE:
A spectrometer for cool dense nuclear matter studies
1) Low temperature, high baryon density
2) Quarkyonic matter?
3) Particularly, symmetry energy \( E_{\text{sym}}(\rho) \)

Diagram:
- Temperature \( T/T_{\text{C}} \)
- Baryon Chemical Potential \( \mu_{B}/T_{\text{C}} \)
- Quark-gluon plasma
- Partonic Matter
- Hadronic Matter
- Chemical freeze-out
Symmetry energy at supra-saturation density

• In the hadron phase, the iso-vector part of the nuclear potential, namely the symmetry energy, is a key point.

⇒ Nuclear and astrophysics input  ⇒ Density dependence not fixed  ⇒ HIRFL-CSR energy is preferential $E_{\text{sym}}(\rho)$ studies
  • Because $\rho \sim 2\rho_0$ density achievable

Neutron Star—a remote cool dense nuclear object

Proton fraction in neutron star
M-R relation
D-Urca process
Core-crust transition density etc…
Esym(\(\rho\)) at supra-saturation studies at HIRFL-CSR

\[
E \frac{d^3\sigma}{dp^3} = 1 \frac{d^3\sigma}{p_t dy dp_t d\phi}
\]
Pre-CEE collaboration
Design of the Dipole

Prototype of a superconductive magnet (Made in IMP, for FAIR)
TPC: Conceptual Design

Read out area
~1.1 m × 0.9 m

Pad. number
~10000

Pad size
~9 mm × 1.1 mm

Max. drift leng.
~ 50 cm

Working gas
90% Ar + 10% CH₄

E Field
150V/cm

dE/dx range
Z<=6, π, p, d, t, He-C

Double track res.
2.5 cm

Max. Multi.
200

B, E
Particle bending due to B
Ionized electrons drift due to E
Collect signal when e arrive
TOF (time of flight): Conceptual Design

MRPC:
- Very high V over gaps between glasses in stack;
- Ionization and avalanche occurs
- Collect the induced signal from pad

<table>
<thead>
<tr>
<th>T0+TOF</th>
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</thead>
<tbody>
<tr>
<td>Time resolution</td>
</tr>
<tr>
<td>Occupancy</td>
</tr>
<tr>
<td>Total Area</td>
</tr>
<tr>
<td># channels</td>
</tr>
</tbody>
</table>
PID for TPC+iTOF

$\delta p = 10\%$  $\delta p = 5\%$  $\delta p = 2\%$

$\delta t = 50\text{ps}$  $\delta t = 100\text{ps}$  $\delta t = 200\text{ps}$
Forward MWDC conceptual design

- High track density at small angle
  - Many heavy fragments
  - High rate at small angle

→ Forward tracking needed

MWDC:
- E field is formed in cell
- Track leaves ionizations
- Deduce drift length from $t_d$
- Construct track from multi cells

<table>
<thead>
<tr>
<th>MWDC</th>
<th></th>
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</thead>
<tbody>
<tr>
<td>Transv. Hit resolution</td>
<td>0.3 mm</td>
</tr>
<tr>
<td># of layers</td>
<td>3*3</td>
</tr>
<tr>
<td># of channels</td>
<td>3000</td>
</tr>
<tr>
<td>Total area</td>
<td>8 m²</td>
</tr>
<tr>
<td>Momentum</td>
<td></td>
</tr>
<tr>
<td>Resolution</td>
<td>5%</td>
</tr>
</tbody>
</table>
Coverage and PID with MWDC+eTOF

Better tracking spatial resolution (1.5mm, 0.75mm, 0.3mm)
Silicon Pixel conceptual design

Cathode

Gas

e- e-

Topmetal Chip

Silicon wafer

Pixel Size: 80 µm x 80 µm

Topmetal chip
R&D the Si pixel detector

1) Online test done at Berkeley, May, 2014
2) Spatial Resolution < 0.5mm!
3) Further test at IMP planned in Sept. 2014
R&D of MWDC array

Conventional electronics

FLADC for timing measurement
1 Using R-T relation, one can reconstruct the track and deduce the residue.

2 Correct the STR till the residue distribution is optimized.
MWDC array performance

$\sigma = 220 \, \mu m$

Yi Han, XZG et al, Chin. Phys. C, to be published.

100cm*100cm MWDC array constructed.

40cm *40cm MWDC array in construction.

Day one beam test, ~May 2015.
To fit the drift length measured by X, U and V wires by minimizing the $\chi^2$

$$\chi^2 = \sum_i \frac{[x_i - (a'\cos\alpha_i + c'\sin\alpha_i)z_i - (b'\cos\alpha_i + d'\sin\alpha_i)]^2}{[1 + (a'\cos\alpha_i + c'\sin\alpha_i)^2](\delta d_i)^2}$$

Analytically a set of equations can be derived and solved:

\[
\begin{align*}
\sum_i (z_i^2(\cos\alpha_i)^2a' + z_i(\cos\alpha_i)^2b' + z_i^2\sin\alpha_i\cos\alpha_ic' + z_i\sin\alpha_i\cos\alpha_id' - x_iz_i\cos\alpha_i) &= 0 \\
\sum_i (z_i(\cos\alpha_i)^2a' + (\cos\alpha_i)^2b' + z_i\sin\alpha_i\cos\alpha_ic' + \sin\alpha_i\cos\alpha_id' - x_i\cos\alpha_i) &= 0 \\
\sum_i (z_i^2\sin\alpha_i\cos\alpha_i a' + z_i\sin\alpha_i\cos\alpha_i b' + z_i^2(\sin\alpha_i)^2c' + z_i(\sin\alpha_i)^2d' - x_iz_i\sin\alpha_i) &= 0 \\
\sum_i (z_i\sin\alpha_i\cos\alpha_i a' + \sin\alpha_i\cos\alpha_i b' + z_i(\sin\alpha_i)^2c' + (\sin\alpha_i)^2d' - x_i\sin\alpha_i) &= 0
\end{align*}
\]

Then the parameters of the straight track can be derived.

3D residue distribution from Geant 4 simulation. (include track finding)
Wire Frame/Tension Preset

Soldering Wire and Frame

Leak rate Test

Wiring:
Frame=1.6m × 1.6m.

A Large MWDC to be completed

Installed for Beam Test
**R&D-MRPC**

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**Nature**

April, 2011

“Observation of the Antimatter Helium-4 Nucleus”

by STAR Collaboration


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**Table:**

<table>
<thead>
<tr>
<th>Momentum</th>
<th>500MeV</th>
<th>600MeV</th>
<th>800MeV</th>
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<tbody>
<tr>
<td>Pion sample</td>
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<tr>
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<td>56</td>
<td>47</td>
<td>45</td>
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<tr>
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</tr>
<tr>
<td>#3</td>
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<tr>
<td>Proton sample</td>
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</tr>
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<td>32</td>
<td>36</td>
</tr>
<tr>
<td>#2</td>
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</tr>
<tr>
<td>#3</td>
<td>31</td>
<td>31</td>
<td>35</td>
</tr>
</tbody>
</table>
Production and QC of large MRPC by THU
**Summary and acknowledgement**

→ **GEM R&D for SOLID:**

1. GEM R&D has been started in THU in collaboration with Prof. Duan from IMP. The performance of the small GEM prototype is demonstrated good. Using a novel method, the non-uniformity effects of the inter-foil distance is studied. Large area GEM detector assembly is ongoing.

→ **CEE at HIRFL-CSR:**

2. The conceptual design of the CEE is presented. R&D work for most of the sub-systems have been well started. Performance of MWDC and MRPC have been tested and meet the requirement of CEE.

**Acknowledgement:**

**Funding:** 1. NSFC, 2. Tsinghua University Initiative Scientific Research Program.

Thank You for your attention!