Research and Development of Commercially Manufactured Large GEM Foils

Bernd Surrow
EIC (Electron-Ion Collider) Overview

Micro-pattern R&D program

EIC large area GEM detector R&D program

Summary
Long-range plan 2015: US Nuclear Science Advisory Committee

“We recommend a high-energy high-luminosity polarized EIC (Electron-Ion Collider) as the highest priority for new facility construction following the completion of FRIB (Facility for Rare Isotope Beams)”
Electron-Ion Collider: New ep/eA collider facility

Energy range / Beam species:
- 5-21 GeV polarized electrons
- 50-250 GeV polarized protons or up to 100 GeV/n up to U ions

Luminosity: \( \sim 10^{34} \) \( \sim 10^{32} \) \( \text{cm}^{-2} \text{s}^{-1} \) for ep (eA) collisions

Polarization: Electrons, protons, \(^3\)He

Energy range / Beam species:
- 3-10 GeV polarized electrons
- 20-100 GeV polarized protons up to Pb ions

Luminosity: \( \sim 10^{34} \) e-nucleons \( \text{cm}^{-2} \text{s}^{-1} \)

Polarization: Electrons, protons, d, \(^3\)He
EIC Overview

Overview: Study wide range of processes at EIC

- **Inclusive Measurements:**
  - Nucleon spin structure
  - Nuclear structure
  - Gluon spin contribution
  - Elastic form factors

- **Semi-Inclusive Measurements:**
  - TMD's
  - Spin structure functions
  - PDF's / Forms factors (flavor-tagged)

- **Exclusive Measurements:**
  - DVCS
  - GPD's
  - Tomographic imaging of proton
EIC Overview

ep/eA kinematics

EIC event topology (E_e = 5 GeV, E_p = 50 GeV)

EIC event topology (E_e = 10 GeV, E_p = 250 GeV)

$E_e / E_p = 0.1$

$E_e / E_p = 0.04$
**EIC Overview**

- **Electron-Ion Collider: Detector concepts**

  - **Main detector concepts:**
    - Hermetic detector, **low mass inner tracking system**, good PID
    - **Forward / Rear tracking:** GEM
    - Forward hadronic calorimetry
    - **Moderate radiation hardness requirements**, low pile-up, low multiplicity

  - Detector concept: Brookhaven National Laboratory
  - Detector concept: Jefferson Laboratory
Detector R&D program

- January 2011: BNL in association with JLab and DOE Office of NP, announced a generic detector R&D program to address the scientific requirements for measurements at a future EIC facility.

Goals:

- Enable successful design and timely implementation of an EIC experimental program
- Develop instrumentation solutions that meet realistic cost expectations
- Stimulate the formation of user collaboration to design and build experiments

- Funded by DOE, Office of NP, managed by BNL with ~$1M-$1.5M / year

- Program explicitly open to international participation

- Key to success: Standing EIC Detector Advisory Committee
Overview

- **R&D effort** focuses on intermediate tracking system:
  - **Barrel tracking system** based on MicroMegas detectors (Dedicated barrel / curved MM EIC R&D program) manufactured as cylindrical shell elements and
  - **Rear / Forward tracking system** based on triple-GEM detectors manufactured as planar segments (Collaboration of FIT/ TU / UVA)

- **R&D effort - Main strategy:**
  - Design and assembly of large cylindrical MicroMegas detector elements and large planar triple-GEM detectors
  - Test and characterization of MicroMegas and triple-GEM prototype detectors
  - Design and test of new, common chip readout system employing CLAS12 'DREAM' chip development, ideally suited for micro-pattern detectors
  - Utilization of light-weight materials
  - Development and commercial fabrication of various critical detector elements
  - European/US collaborative effort on EIC detector development (*CEA Saclay, and Temple University*)
Micro-pattern detector R&D program

- **MicroMegas detector program**
  - Curved MicroMegas for barrel based on carbon structure glued on thin PCB
  - Idea validated for CLAS12 tracker
  - Need to increase size: PCB size, mesh tension, capacitance and gain homogeneity
  - Transition to resistive technology for MicroMegas detectors / No measurable sparking

- First dedicated EIC large radius resistive 1D (Z) MM prototype 120 degree section, R=22.5cm, L=45cm

- Further extensive cosmic-ray testing / Analysis in progress

- Next: 2D design (C / Z)

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Triple-GEM detector program

- $r_{\text{in}} \sim 10\text{cm}$ and $r_{\text{outer}} \sim 100\text{cm}$
- Different assembly techniques (Stretching / Frame support / Spacer) by FIT, TU and UVA
- Light-weight design: $< 1\% X_0$
- All services (HV, gas and FEE connections) at outer radius

Mylar foils plus spacer

Cathode (HV)

3 mm spacer (Drift volume)

3 x GEM foils + 2mm spacer grid / spacer rings

2mm spacer (Induction gap)

Readout electrode

spacer + Mylar foil

Exploded view of a triple-GEM segment
EIC large area GEM detector R&D program

- EIC forward / rear GEM planer detectors
  - Concept of GEM rear and forward tracking disks supporting 12 30degree sectors
  - Overlapping edges to reduce dead areas
  - Material based on carbon fiber
EIC large area GEM detector R&D program

- EIC triple-GEM detector GEM foil layout

  - Common GEM foil design by FIT, TU, UVA
  - All HV connections at outer radius
  - 8 radial and 16 azimuthal HV segments with about 100cm² each

Courtesy: FIT, UVA

38th International Conference on High Energy Physics (ICHEP 2016)
Chicago, IL, August 3-10, 2016
EIC large area GEM detector R&D program

- **EIC triple-GEM detector 2D readout foil layout**
  - r-\(\phi\) symmetry for 2D readout layer
  - Lines at constant \(\phi\) angle read out separately
  - Pads at constant \(r\) (BLUE) connected and readout separately
  - Routing lines in orange
  - Connection to SAMTEC multi-pin connector connected to APV / DREAM readout module

2D readout foils produced by Tech-Etch, independent of GEM production facility
EIC large area GEM detector R&D program

- **EIC triple-GEM detector Front-End Electronics**
  - FEE development by Saclay
    - profiting from DREAM chip design
    - first used for MicroMegas detector
  - Adapted for triple-GEM detector prototype besides APV based readout

### Dream Chip vs. APV25-S1 Chip

<table>
<thead>
<tr>
<th></th>
<th>Dream Chip</th>
<th>APV25-S1 Chip</th>
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<tbody>
<tr>
<td>Number of channels</td>
<td>64</td>
<td>128</td>
</tr>
<tr>
<td>Memory size</td>
<td>512</td>
<td>160</td>
</tr>
<tr>
<td>Latency</td>
<td>16µs</td>
<td>8µs</td>
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<tr>
<td>Noise (e-RMS)</td>
<td>2100 (On 180pF)</td>
<td>1200 (On 20pF)</td>
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<tr>
<td>Sampling frequency</td>
<td>1-40MHz</td>
<td>10-50MHz</td>
</tr>
<tr>
<td>Dynamic range</td>
<td>50-600fC</td>
<td>150fC</td>
</tr>
<tr>
<td>Input capacitance</td>
<td>150pF</td>
<td>18pF</td>
</tr>
<tr>
<td>Shaping time</td>
<td>70ns</td>
<td>50ns</td>
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MM / Triple-GEM prototypes in Saclay cosmic-ray teststand

FEE development by Saclay profiting from DREAM chip design first used for MicroMegas detector. Adapted for triple-GEM detector prototype besides APV based readout.

### FET Gain

<table>
<thead>
<tr>
<th>HV (V)</th>
<th>FET Gain</th>
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<tr>
<td>2460</td>
<td>×3</td>
</tr>
<tr>
<td>2480</td>
<td>×10×5</td>
</tr>
<tr>
<td>2500</td>
<td>×10×6</td>
</tr>
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<td>2520</td>
<td>×10×7</td>
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<tr>
<td>2540</td>
<td>×10×8</td>
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<td>2560</td>
<td>×10×9</td>
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<td>2580</td>
<td>×4×10</td>
</tr>
<tr>
<td>2600</td>
<td></td>
</tr>
<tr>
<td>2620</td>
<td></td>
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<td>2640</td>
<td></td>
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Commercial GEM foil production: Overview

- Commercial production of GEM foils by Tech-Etch Inc. starting first with 10X10cm$^2$ and 40X40cm$^2$ double-mask technique using Kapton base material.

- Switch to single-mask technique using Apical base material up to 50X50cm$^2$

- Continuous feedback between Tech-Etch Inc. and TU resulted in excellent GEM foils in terms of electrical and optical uniformity.

- Critical: “There should be enhanced efforts on industrialization. CERN management will talk to large LHC collaborators to consider placing orders outside CERN” (Silvia Dalla Torre, RD51 mini week, June 6-9, 2016) - Essential for further development towards larger foils at Tech-Etch Inc.
Commercial GEM foil production: Electrical tests

- Setup of leakage current measurement at Temple University
- All Tech-Etch GEM foil leakage currents have been measured consisting of:
  - 3 manufacturing lots of 10 x 10 cm² consisting of 6/12/6 foils
  - 3 40 x 40 cm² foils
- All foils were found to display consistent leakage currents with typical values < 1 nA
- Tech-Etch found same results when measuring the leakage current prior to shipping
  - Critical step for achieving low leakage current was changing polyamide material from Kapton to Apical
  - Leakage currents from 3 10 x 10 cm² single mask GEM foils produced by CERN have also been measured
  - CERN foils use same polyamide material (Apical) as Tech-Etch
  - CERN foils were also found to have typical leakage current < 1 nA
Commercial GEM foil production: CCD scanning

- Optical properties of foils measured using GEM scanner based on 2D CCD scanner
- Initial setup: X/Y stage 30cm / 15cm
- High resolution CCD camera with 12 X microscope zoom lens
- Light scheme on top and bottom allows to measure outer and inner hole diameter besides pitch
- Image analysis and control based on MathLab
EIC large area GEM detector R&D program

Commercial GEM foil production: Optical uniformity (1)

- Inner hole diameter distributions comparison for CERN and Tech-Etch foils
- All foils have been optically scanned to measure pitch, inner/outer hole diameters, and their uniformity
- In general: CERN foils show similar geometrical properties as Tech-Etch foils

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Commercial GEM foil production: Optical uniformity (2)

- Split 40cmX40cm² GEM foil into 6 areas
- Average deviation from inner (outer) hole mean is found to be small, 1-2µm and comparable to CERN foils
- Inner hole diameter deviation from mean
- Red arrows mark +/- 10µm position
Commercial GEM foil production: CCD scanner upgrade

- Upgrade CCD camera to accommodate larger sizes using long Newport linear stages.
- Machining of all parts (~90) underway / Projected completion by end of August 2016.
- Assembly and setup in September 2016.
- Test scan expected in late fall 2016.

Starting in late fall 2016:
- Samples: 40cm X 40cm foils (EIC) / 50cm X 50cm (ALICE) and larger EIC prototype (CERN) in collaboration with FIT and UVA.
- Other samples: CMS large foils - Independent optical probe of gain uniformity in collaboration with CMS / CERN.
Prototyping phase

Prototype based on STAR FGT design using commercially produced components: GEM foils, 2D readout foil, frames and spacer rings / Test using X-ray scanner and cosmic-rays
Summary / Outlook

- **EIC detector designs** feature micro-pattern detectors in Barrel (**MicroMegas**) and Forward/Rear direction (**GEM**) using common chip readout system.

- Planar rear and forward triple-GEM detectors with $r_{in} \sim 10\text{cm}$ and $r_{outer} \sim 100\text{cm}$ / Light-weight material - Common prototype GEM foil design by FIT, TU and UVA.

- **Commercial fabrication of various components** including HV foils, 2D readout foils, and GEM foils by Tech-Etch Inc.
  - RD 51 stressed the need for industrialization.
  - Tech-Etch Inc. has successfully produced single-mask GEM foils up to $50 \times 50\text{cm}^2$.
  - Excellent electrical and optical performance comparable to CERN using Apical base material.
  - Further development relies critically on large-scale orders.

- Build and test (X-ray scan and Cosmic-ray testing) larger prototypes.

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