**R&D of Commercially Manufactured Large GEM Foils**

**Motivation**
- Currently CERN is the only main distributor of GEM foils.
- Many physics experiments are either already using or are developing detectors that incorporate GEM technology. This has created a large demand in the particle and nuclear physics communities for GEM foils.
- To help alleviate this demand, Tech-Etch has succeeded in the commercialization of GEM foils via the single-mask and double-mask processes.
- The single-mask process is critical for the production of large area (~<1 m long) GEM foils.

**Single-Mask Process**
- (a): Coating of bare foil (~5 μm copper and ~50 μm polyimide layers) with photore sist and use of laser direct imaging to apply single-mask micro pattern.
- (b): The removal of unexposed photore sist, etching of front side copper layer, and removal of the chrome adhesive.
- (c): EDA chemistry is used to etch the front side of the polyimide layer.
- (d): The back side copper layer is etched via electrolytic etching.
- (e): The etching of the back side polyimide is done using EDA chemistry.

**Tech-Etch GEM Production**
- Three foil sizes have been produced by Tech-Etch: 10x10, 40x40 and just recently 50x50 cm².
- There were three 10x10 cm² manufacturing lots produced for Temple University consisting of 6/12/6 foils respectively.
- There is one 40x40 cm² manufacturing lot produced for Temple University consisting of 3 foils.
- The electrical and geometrical properties of all 10x10 and 40x40 cm² single-mask GEM foils have been analyzed.
- The geometrical properties of all 10x10 and 40x40 cm² single-mask GEM foils were taken after about an hour of nitrogen flushing time.

**Electrical Analysis**
- The electrical quality of a GEM foil is determined by its leakage current.
- Leakage current measurements are performed in a class 1,000 clean room.
- The foil is placed in an air tight enclosure which is flushed with nitrogen.
- Leakage current results measured at Temple University were taken after about an hour of nitrogen flushing time.

**Optical Analysis**
- Geometrical properties such as pitch, inner (polyimide layer) and outer (copper layer) hole diameters are determined using an automated 2D CCD scanner.
- This CCD scanner is unique in the micro-pattern community as it allows the scanning of the entire active area of the GEM foil.
- By changing the lighting options of the CCD scanner, one is sensitive to either the inner (back lighting) or outer (front lighting) hole diameters.

**Geometrical Properties**
- **10x10 cm² Single-Mask GEM Foils**
  - The mean pitch = 139 μm and inner (outer) hole diameters = 58.5 (71.5) μm across all foils are consistent with previous GEM foils produced via the double-mask process: pitch = 139 μm, inner (outer) diameters = 56.7 (78.4) μm.
  - These foils have excellent hole uniformity. The inner and outer hole deviations from the mean were found to be about +/- 6 μm, with the inner hole diameters having the largest deviation.
  - Simple calculations were done which show such a deviation in hole uniformity would not have a significant affect on the restructured hit resolution or resolution of a potential tracking detector.
  - Tech-Etch inner and outer hole diameter measurements (includes only 9 holes) agree with those measured at Temple University (includes all holes).
- **40x40 cm² Single-Mask GEM Foils**
  - Due to travel limitations of the CCD scanner, larger foils needed to be divided into 6 scan regions.
  - The mean geometrical properties across all foils were found to be similar to those of the 10x10 cm² foils: pitch = 139 μm, inner (outer) hole diameters = 53.1 (78.5) μm.
  - The mean inner and outer hole deviations were all found to be below +/- 10 μm, with the inner (outer) hole deviations widths ranging from 9 to 1.1 to 1.8 μm.

**EIC Foil Design**
- A common EIC GEM foil design has been established between Florida Tech, Temple University, and Uva.
- Common foil design to be manufactured at Tech-Etch and used in three different prototype EIC tracking detectors.
- Each foil segment has an opening angle of 30.1 degrees, and has a maximum height and width of 974.51 and 610 mm.
- The foil has a total of 24 HV segments, each with an area of about 107 cm².
- There are 8 azimuthal and 16 radial HV segments.
- The unique design simultaneously satisfies all three institutions GEM stretching and assembling techniques, including building chambers via screws or glue.

**Summary**
- Commercialization of single-mask and double-mask GEM foils has been established at Tech-Etch.
- With the switch from Kapton to Apical material, all foils were found to have exceptional electrical properties, with the leakage current being reduced by about an order of magnitude (typically below 1 nA).
- The geometrical properties of the Tech-Etch single-mask 10x10 and 40x40 cm² GEM foils were found to be consistent with each other and previously produced double-mask and single-mask CERN foils.
- The single-mask foils also showed very good inner and outer hole diameter uniformity across the entire active area.
- Production of 50x50 cm² single-mask foils is well underway at Tech-Etch, and they are now fine tuning their manufacturing parameters for commercial foils.
- Tech-Etch is actively into upgrading their manufacturing facilities to accommodate foils on the order of 1 m long.