Resistive DLC foils for Micromegas

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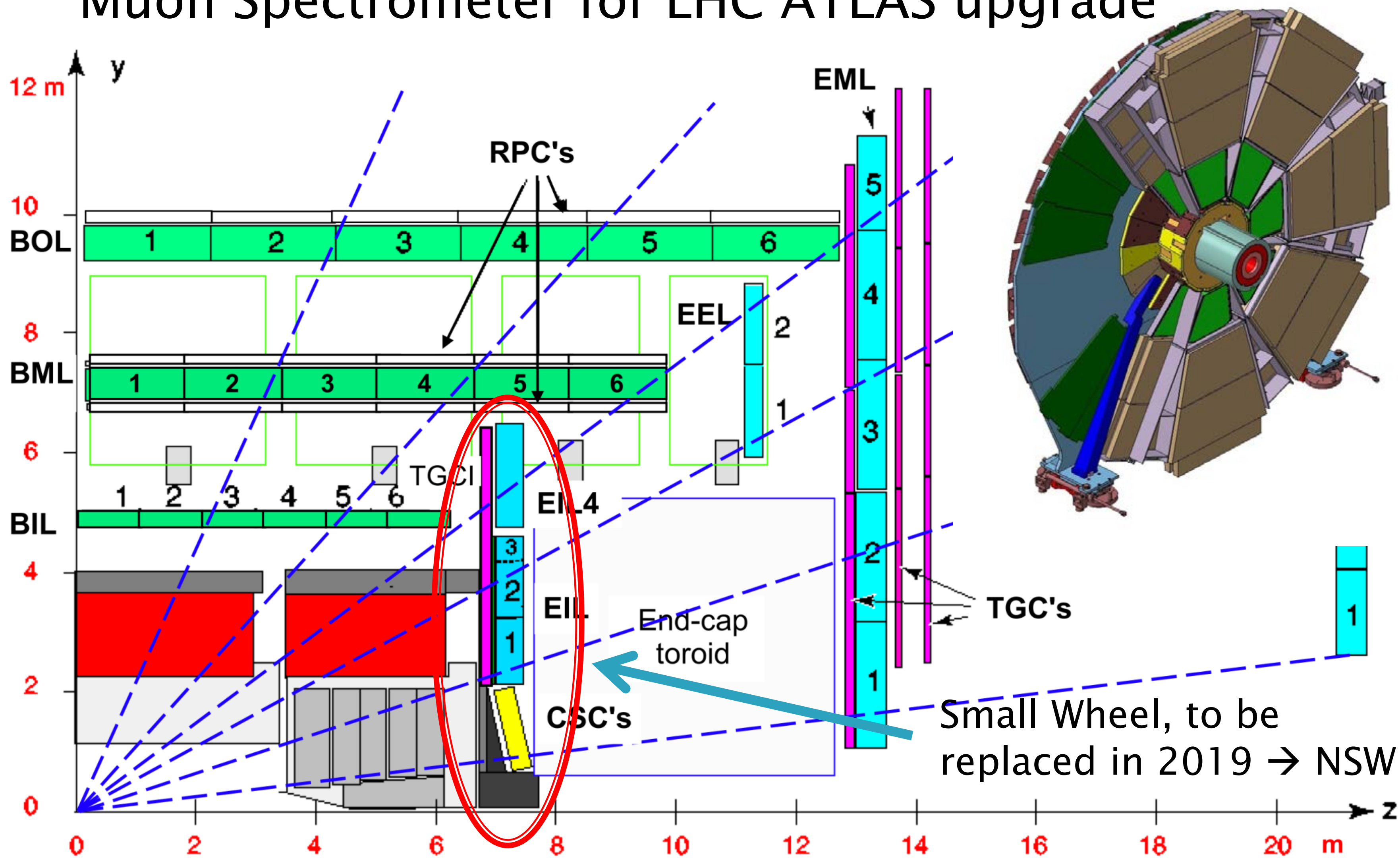
2017/5/20 ND280 upgrade workshop @ Tokai

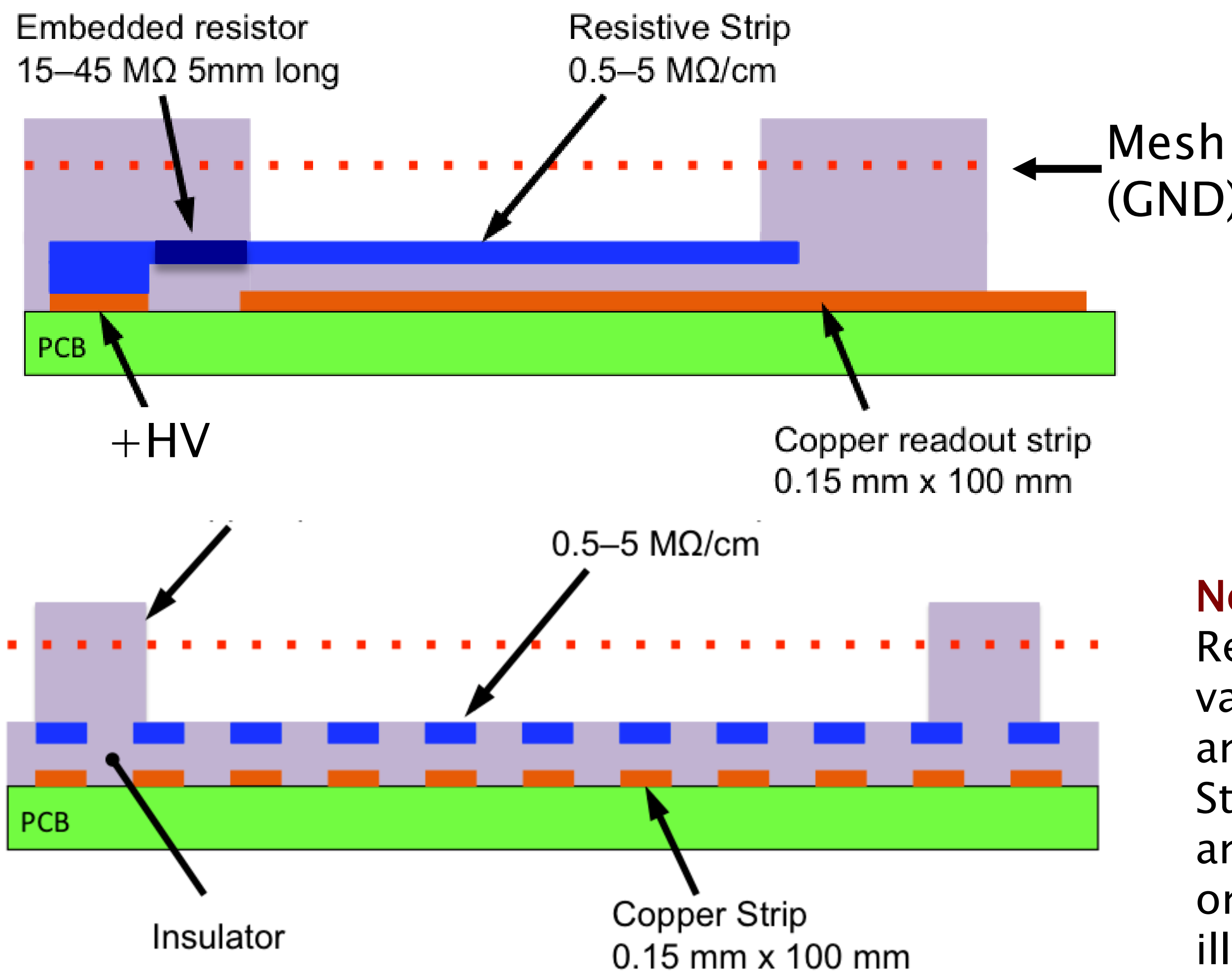
Our original physics motivation…

Muon Spectrometer for LHC ATLAS upgrade



Small Wheel, to be replaced in 2019 → NSW

Resistive-strip protection concept for ATLAS Micromegas

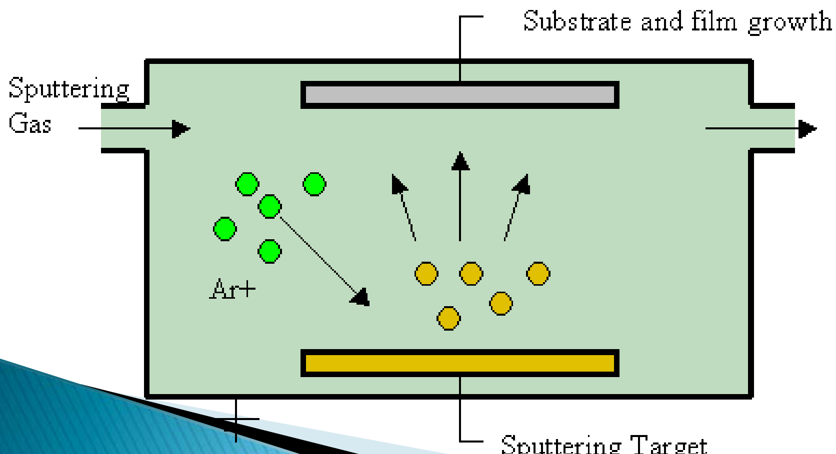


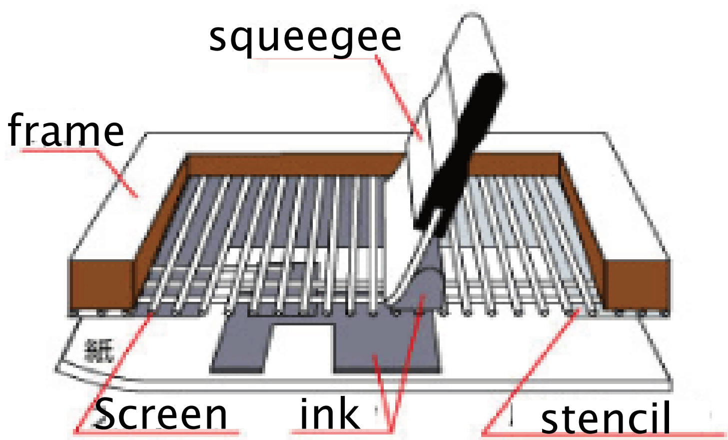
Note:
Resistance values and Strip pitches and sizes are only for illustration

Two options for resistive electrodes of ATLAS MM

- Sputtering+liftoff
  - Pros.
    - Large area (>2m)
    - Fine pattern (<100μm)
    - Uniform resistivity
    - Strong attachment on substrate
  - Cons.
    - Production speed
      (Now, it will be OK, next slide)
    - High cost

- Screen printing
  - Pros.
    - Large area (>2m)
    - Fast production speed
    - Low cost for mass production
  - Cons.
    - Stability of resistivity
    - Thick pattern (~20 μm)
    - Lower tolerance for breakdown for high voltage

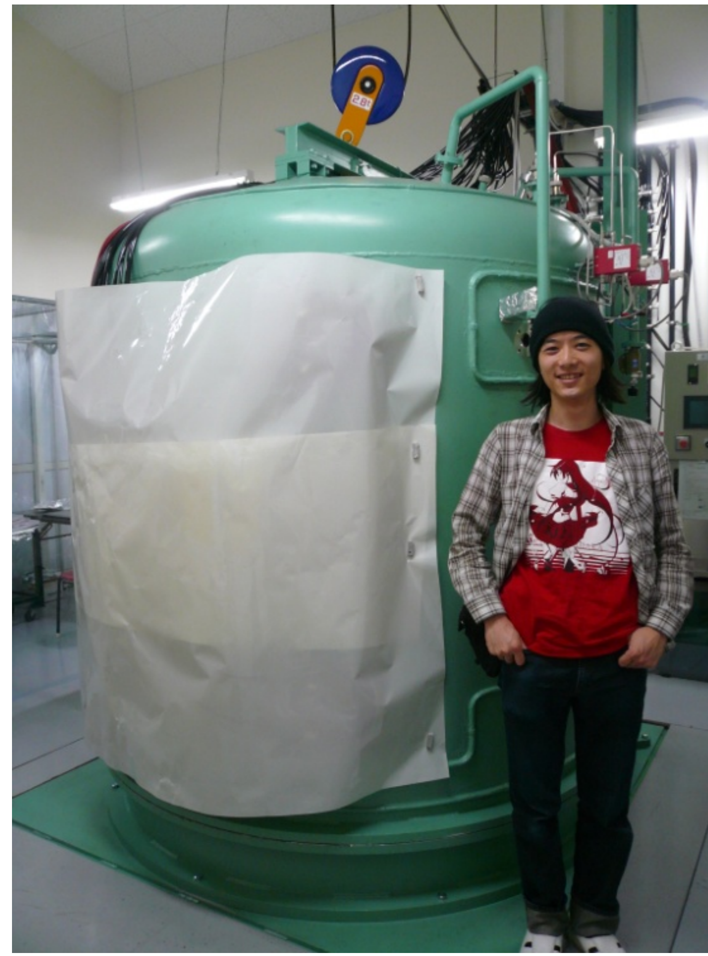




Sputtering process

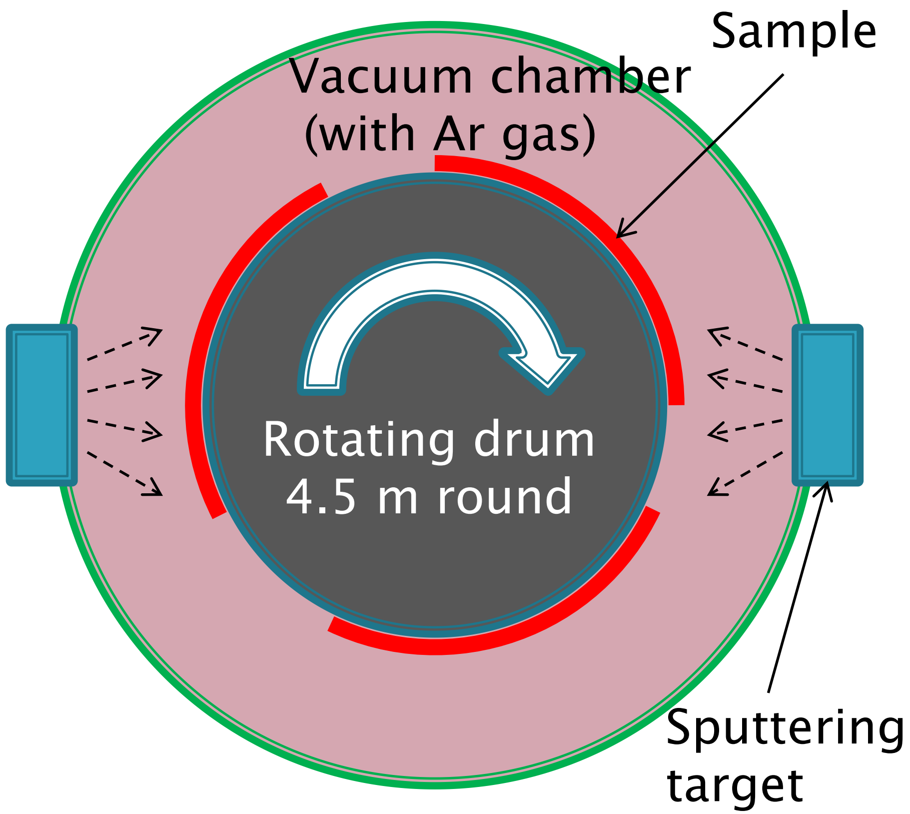
Be-Sputter
The door to the next generation is nanotechnology.
株式会社 ビースパッタ

- Sputtering company
- They have large sputtering chamber
  - Φ1800 X H2000
  - 1m X 4.5m (flexible board) can be sputtered
- They have special technology for uniform sputtering for large area



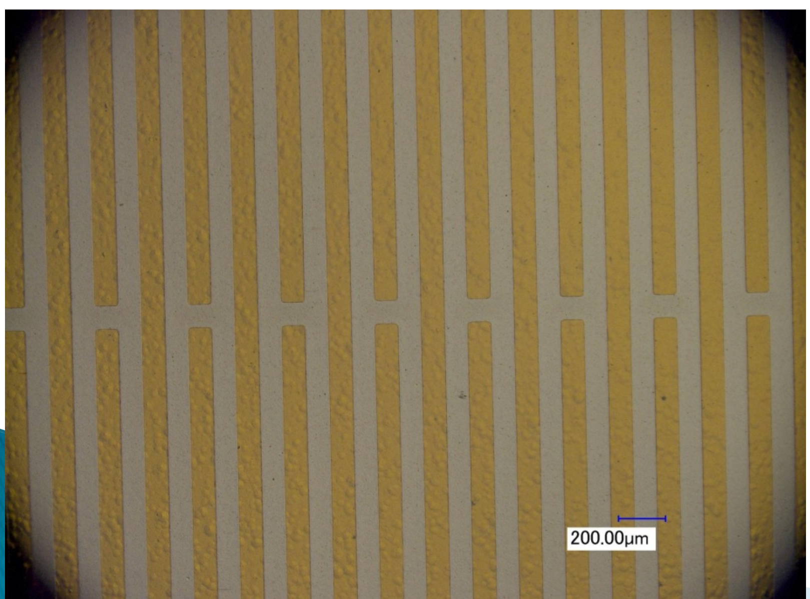
Sputtering facility in Be-Sputter

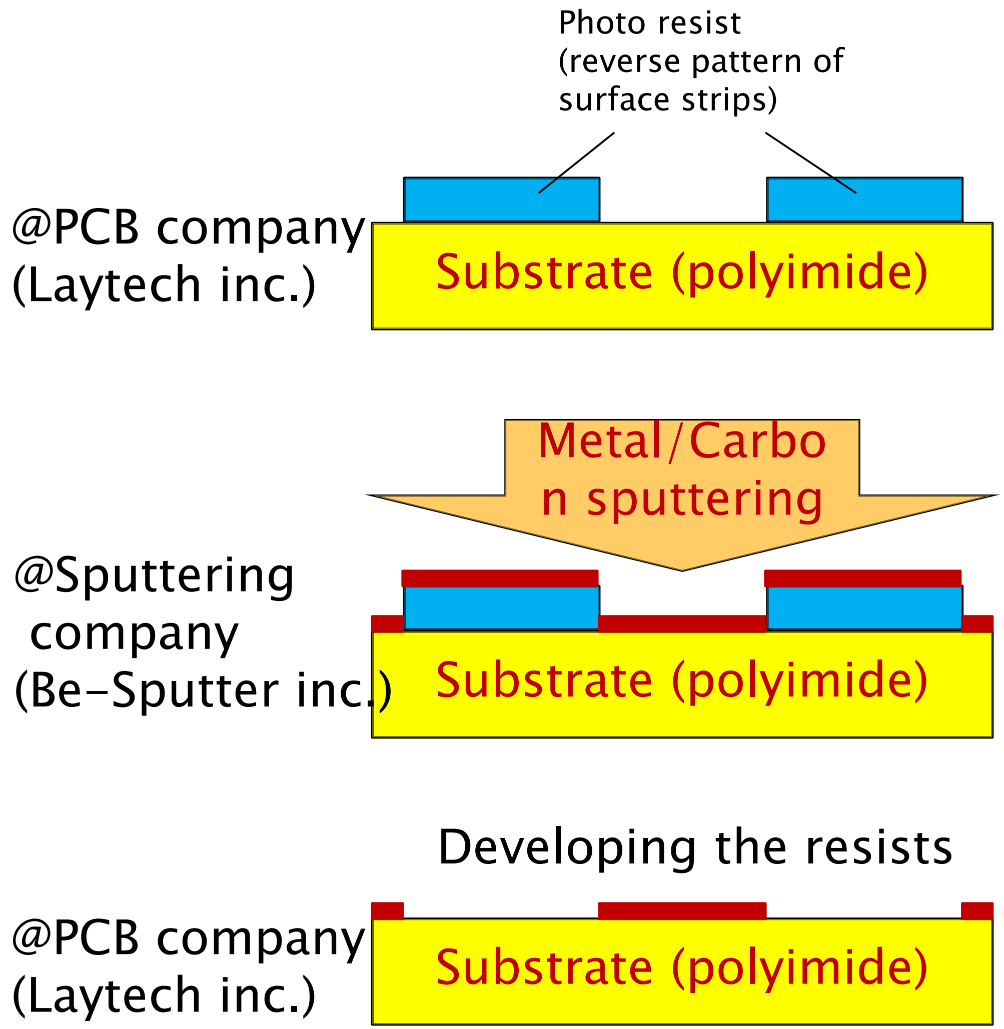
- Large size sputtering is available.
  - 4.5m X 1m
- Two layer stack sputtering is available
  - Using two separated target
- Very good uniformity
  - Less than nm size difference, using their special technology



Liftoff process using sputtering

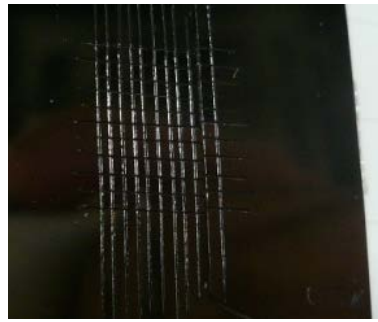
- Very fine structure (a few tens micro meter) can be formed using photo resist. (same as PCB)
- Surface resistivity can be controlled by sputtering material and their thickness



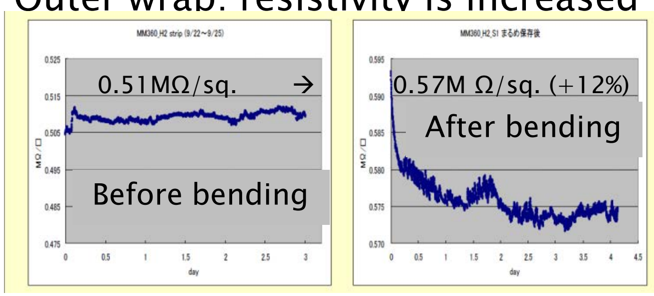


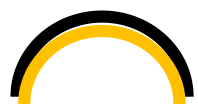
Mechanical robustness for thick sputtering carbon

- Adhesion test
  - Cross-cut test
    (JIS k5400-8.5 standard,
    similar to the ISO 2409)
  - No peeled carbon founded

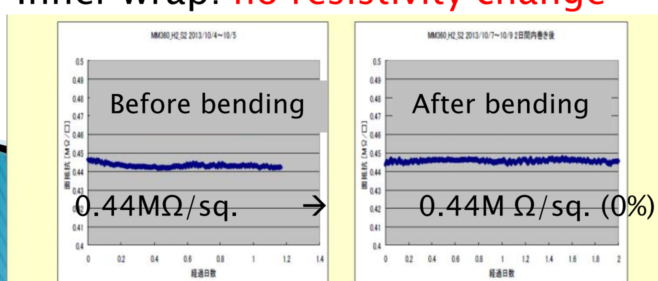


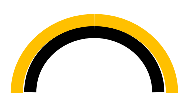
- Bending test
  - Bending diameter > 4cm
    → No resistivity change found
  - Jackknife bending
    → Conductivity is lost
  - Bending diameter = 1.2cm
    → Outer wrap: resistivity is increased 10-20%





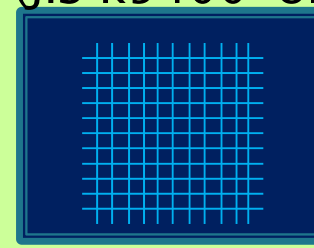
→ Inner wrap: no resistivity change



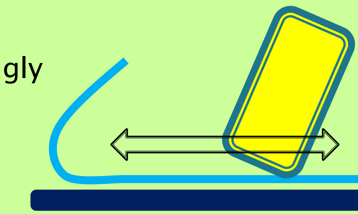


Cross-cut test (JIS k5400-8.5)

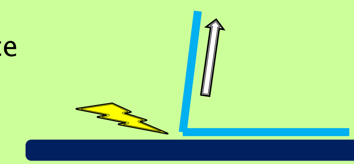
Making cut lines as grid
(11 x 11, 1mm pitch)



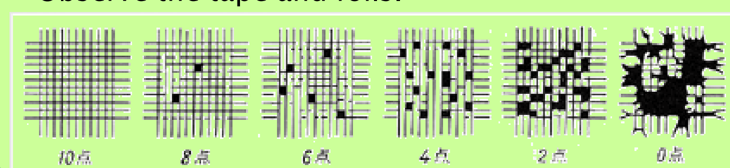
Tape up the foils strongly



Peel off the tape at once



Observe the tape and foils.



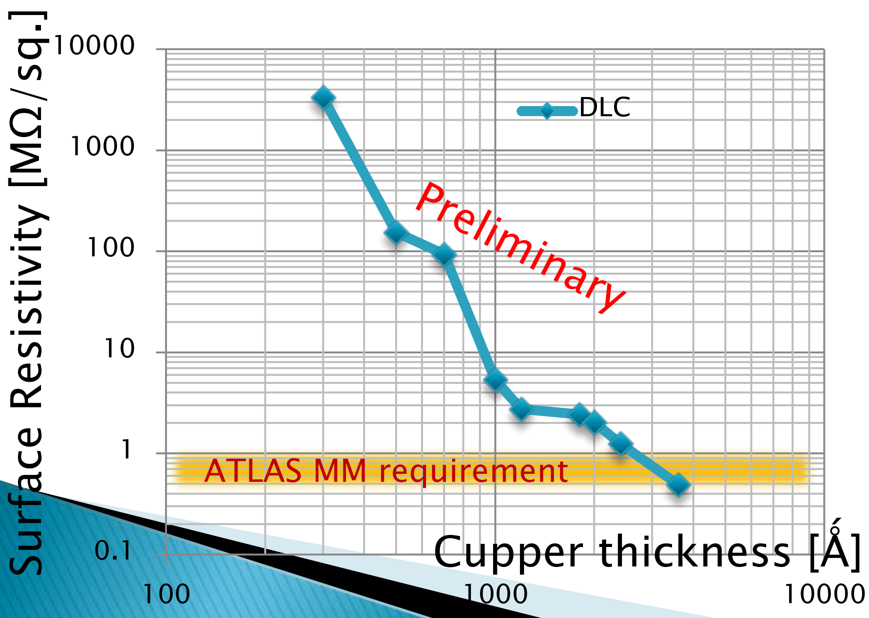
Chemical robustness for new sputtering carbon

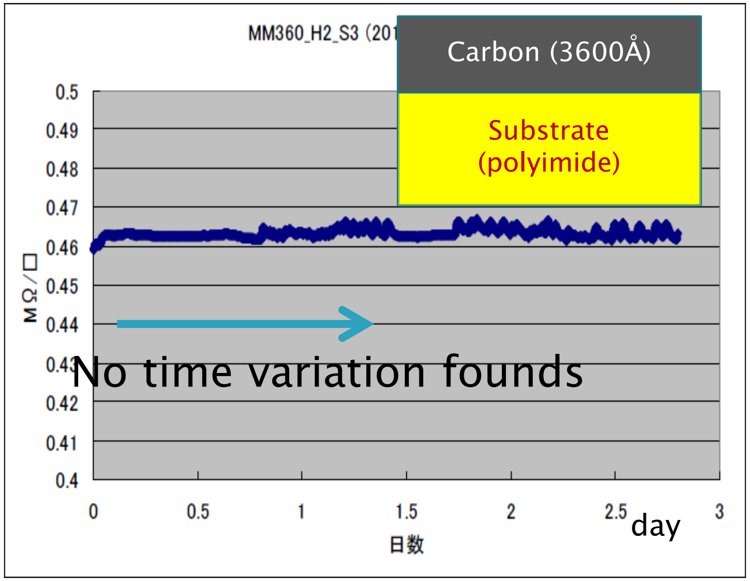
- Acid and alkali for PCB processing
  - Hydrochloric acid
  - Nitric acid
  - Sulfuric acid
  - Sodium carbonate
    → No damage on sputtered carbon
  - Sodium hydroxide
    → No damage for short dip
    → Peeling is found after 90 minutes dipping
- **Almost all process of PCB production will not affect to the sputtering carbon**

Resistivity and it's stability

- Resistivity dependence on carbon thickness
  - 300Å → 2GΩ/sq.
  - 3600Å → 500kΩ/sq.
  - Conductivity is not proportional to the thickness (t < 1000Å)
  - At t > 1000Å, good reproducibility found
- No time variation founds after several days from sputtering

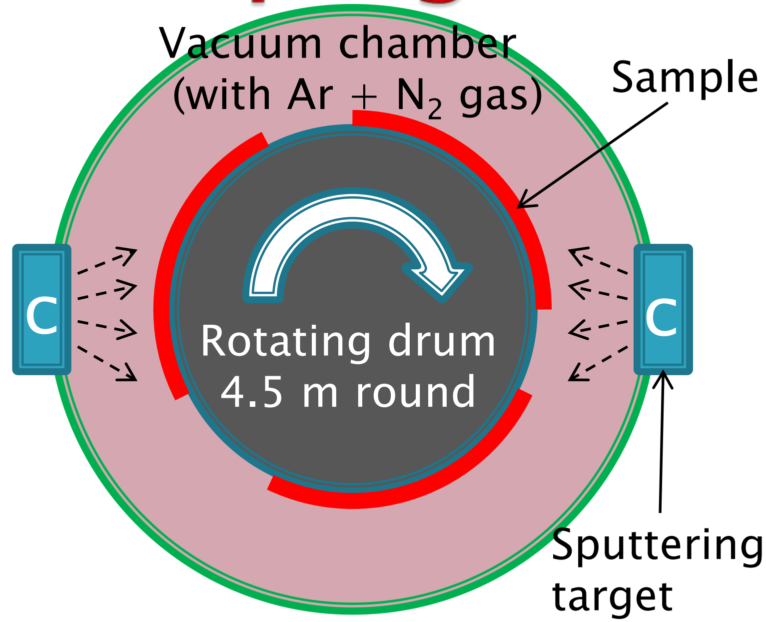
- However, deposition rate is very slow.
  - 500-600Å / hours are maximum rate in industrial chamber.
  - For ATLAS MM, 3600Å = 6hours are needed!!
  - The MSW foils were made by this longtime sputtering.
  - But **we need faster way for mass production.**

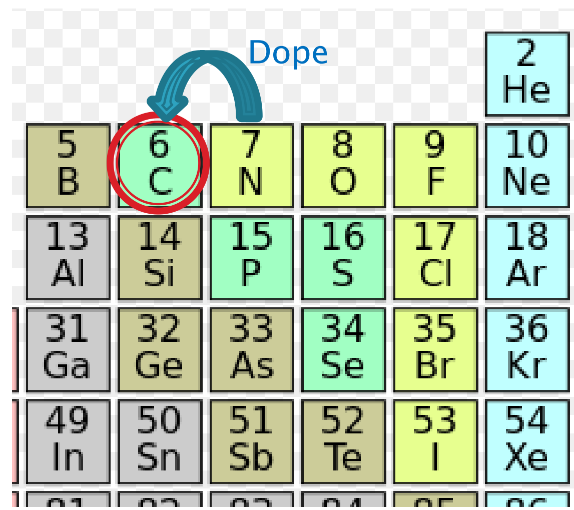




New idea: Nitrogen doping

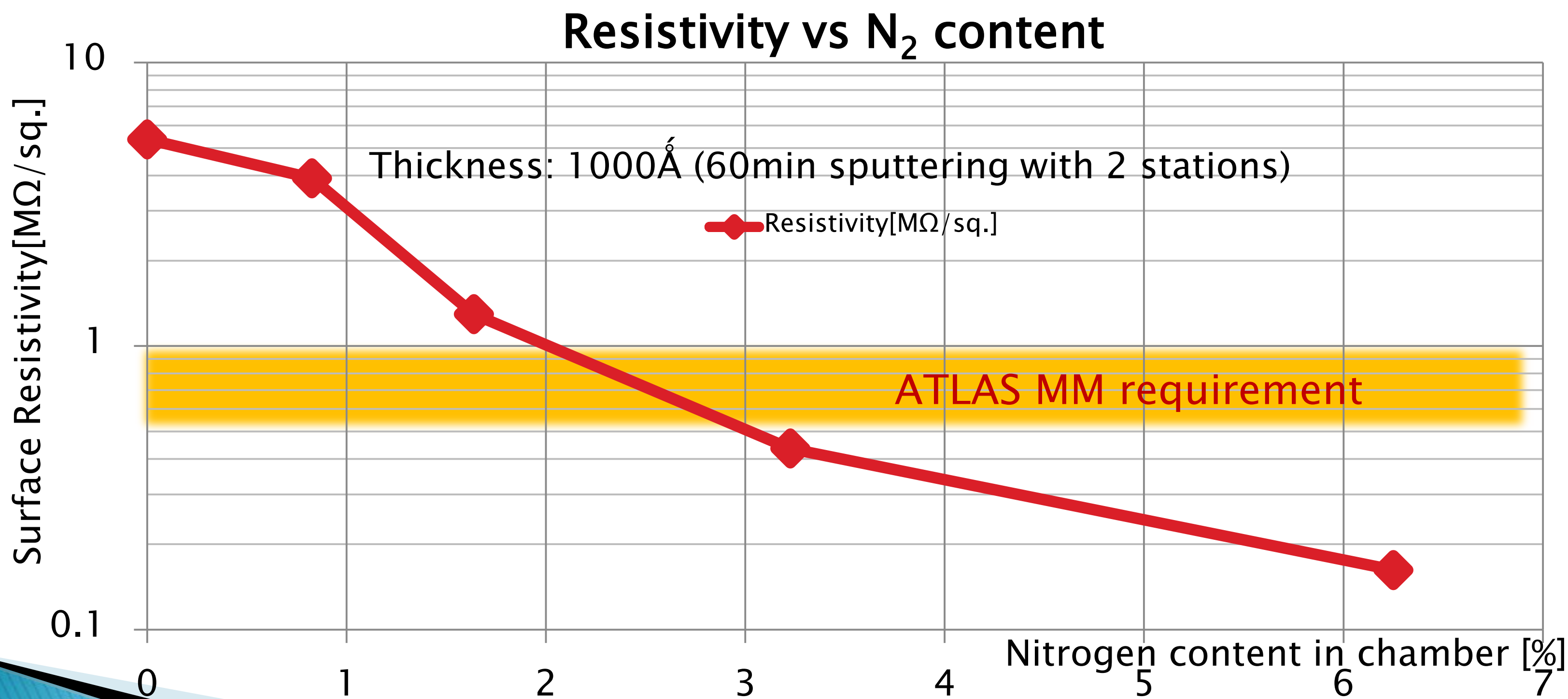
- The structure of the sputtered carbon is amorphous diamond like carbon (a-DLC).
- It is thought that the charge carrier is very few in the DLC
- So, I got an idea of nitrogen doping as a supplier of carrier electrons.
    - This is same story as the n-type semiconductor production.
- The nitrogen is easy to introduce into the sputtering chamber with Argon gas.





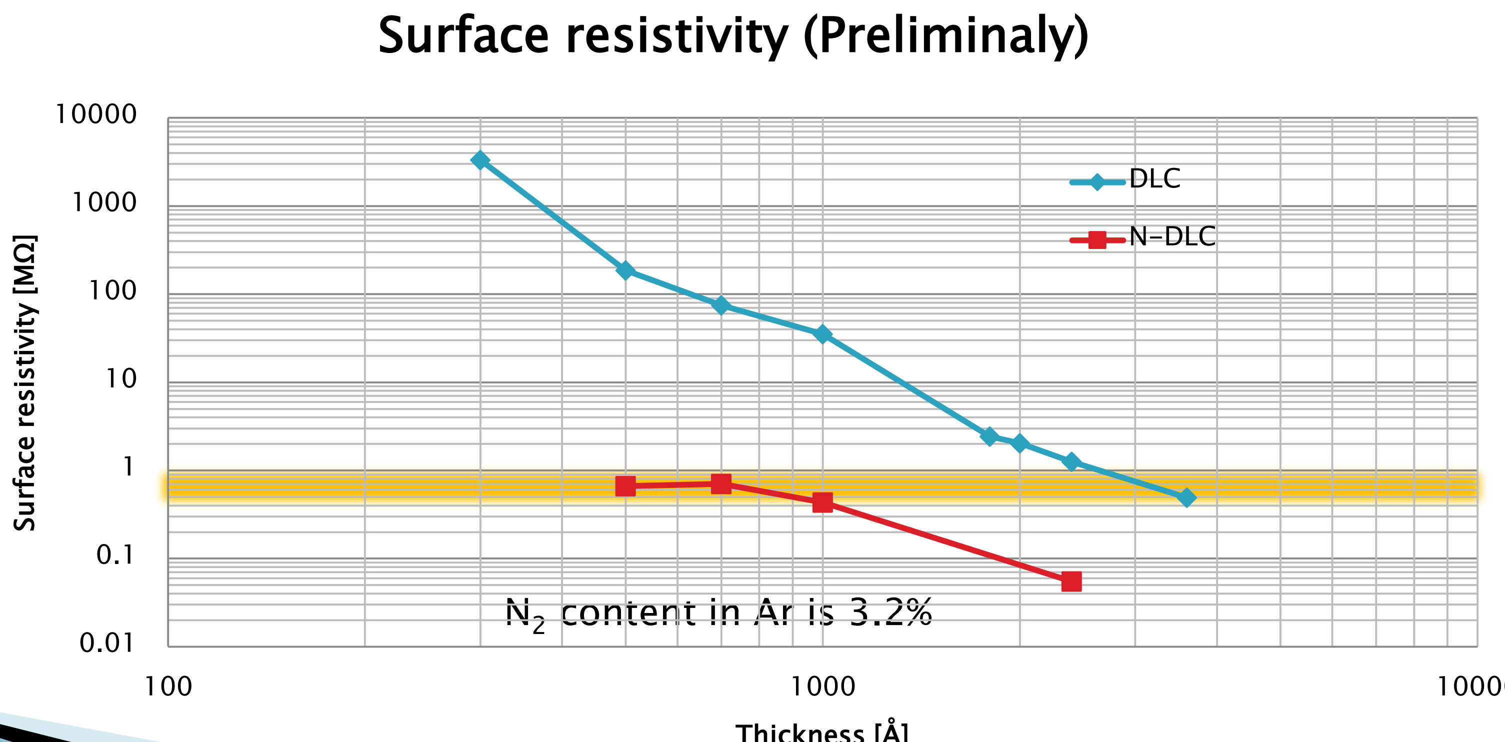
Resistivity vs N_2 content (June, 2014)

- The resistivity is strongly reduced by nitrogen doping.
- Surface resistivity of 1000Å foils:
  - Pure carbon → 5MΩ/sq.
  - 3.2% N_2 in Ar → 400kΩ/sq.

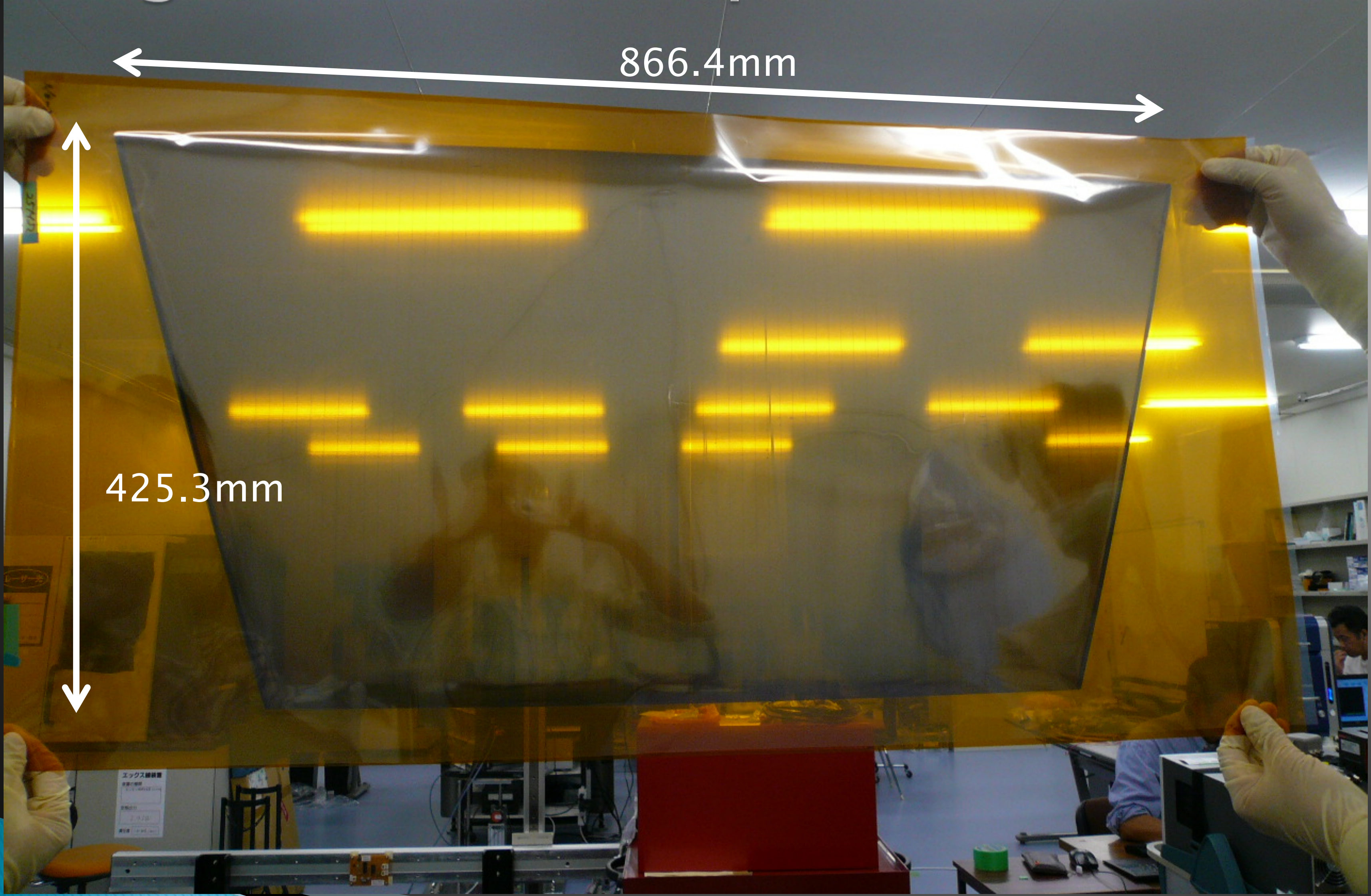


Resistivity vs thickness

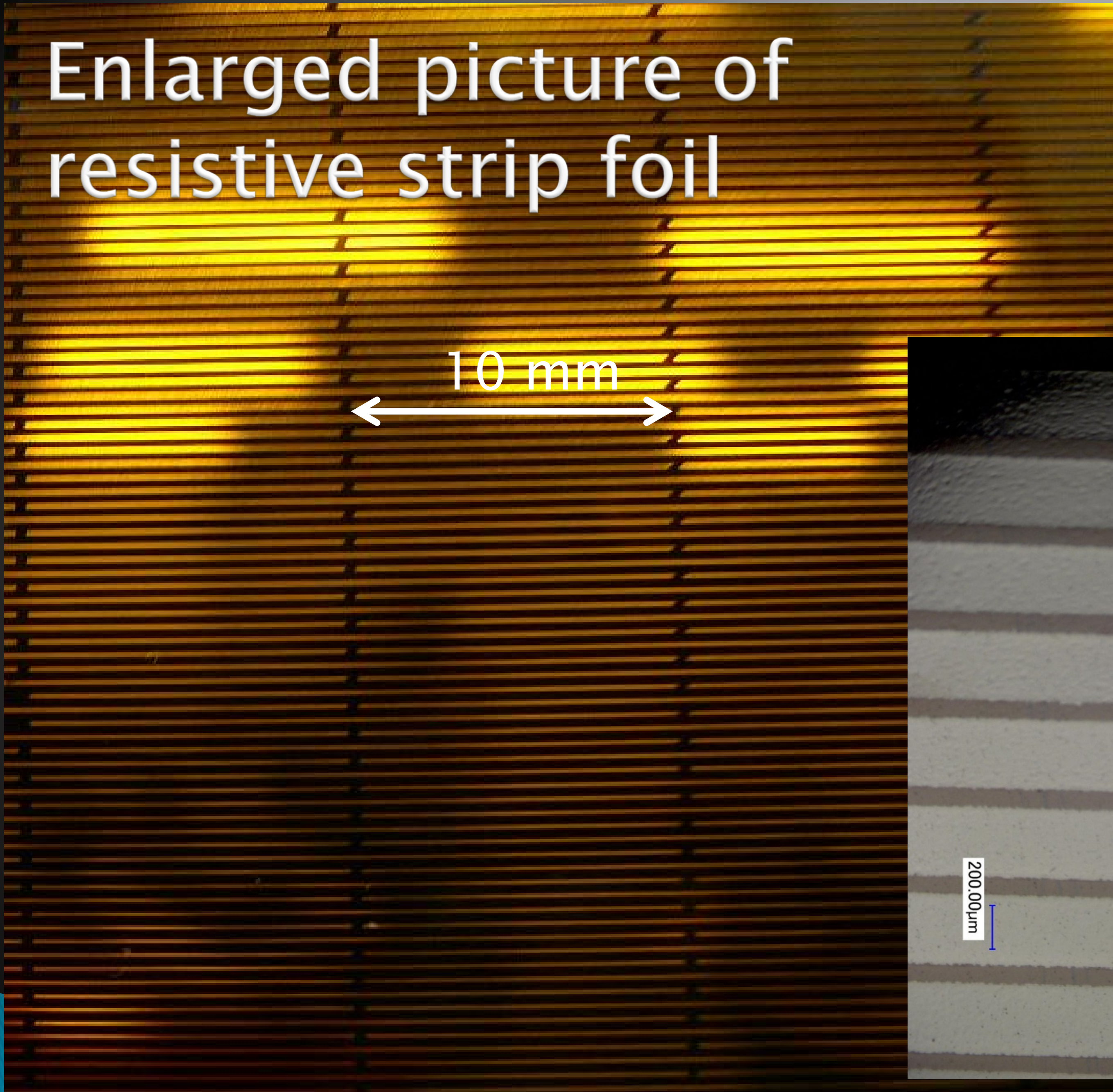
- For 3.2% N_2 content foils
  - 2400Å → 55kΩ/sq.
  - 700Å → 700kΩ/sq. (42min. sputter)

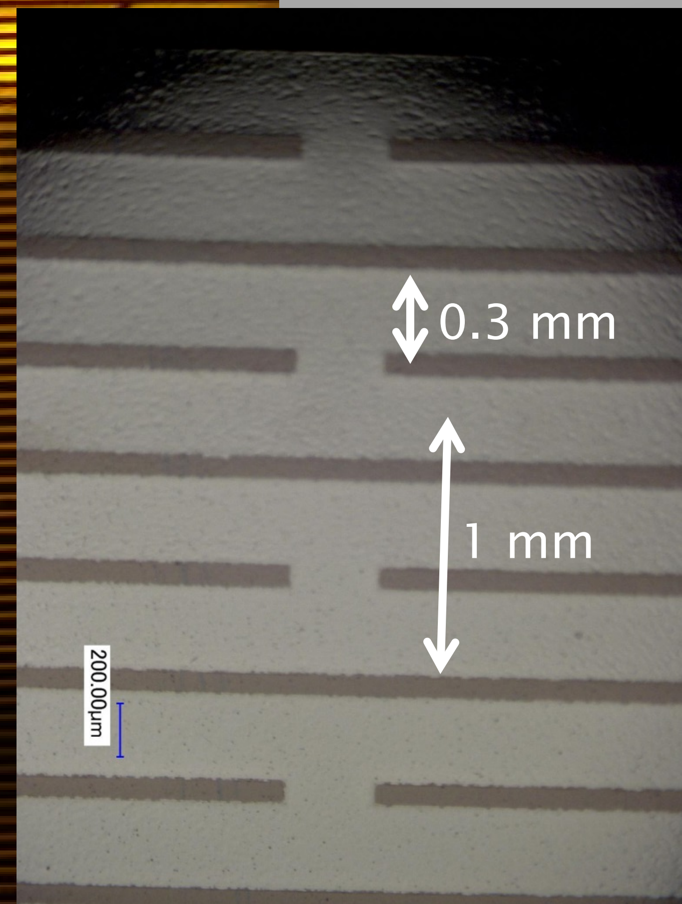


Large resistive strip foil for MSW



Enlarged picture of resistive strip foil

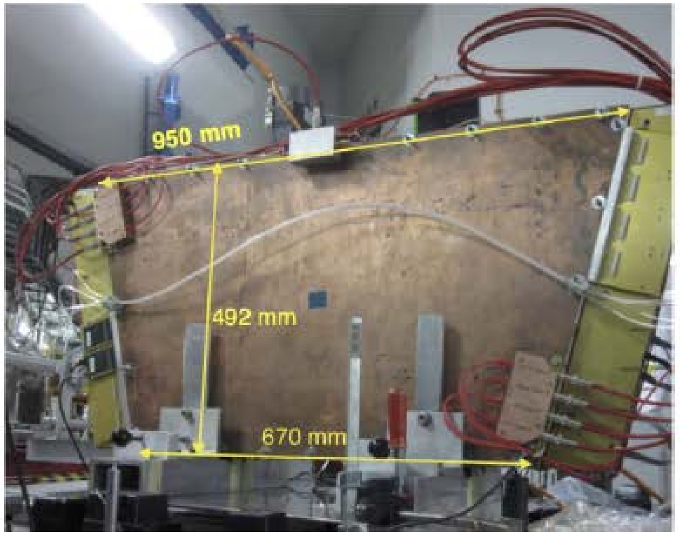




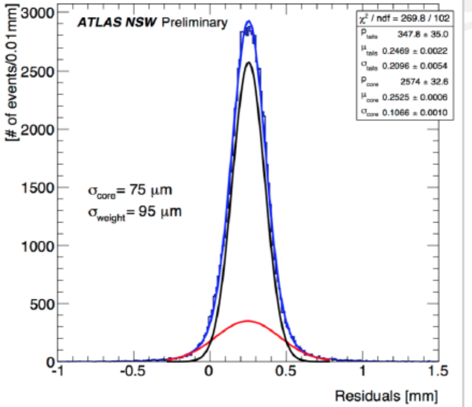
Medium size multi-layer chambers (MMSW – NSW-like MM Quadruplet)

The first medium size MM Quadruplets (MMSW) were build at CERN and studied to

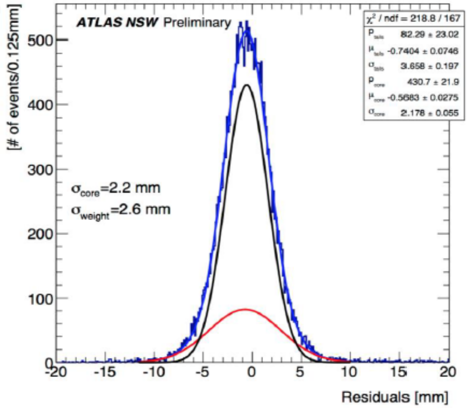
- re-validate the single layer detector performance
- test performance of a quadruplet and functionality of the stereo doublet (second coordinate)
- validate construction methods with respect to the mechanical requirements



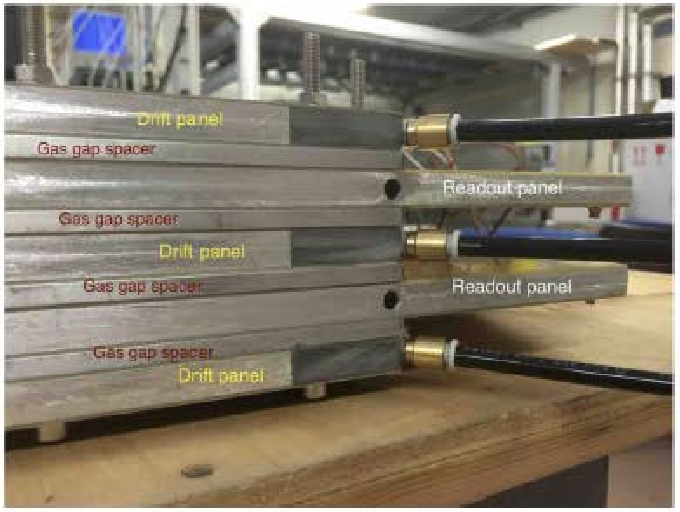
Spatial resolution in precision coordinate obtained by a single layer (left) and the second coordinate measured with a stereo doublet of the MMSW



Spatial resolution of precision coordinate of the MMSW
Residuals between the first and the second layer of the MMSW, both with strips measuring the precision coordinate, divided by √2 (assuming similar resolution for both layers).



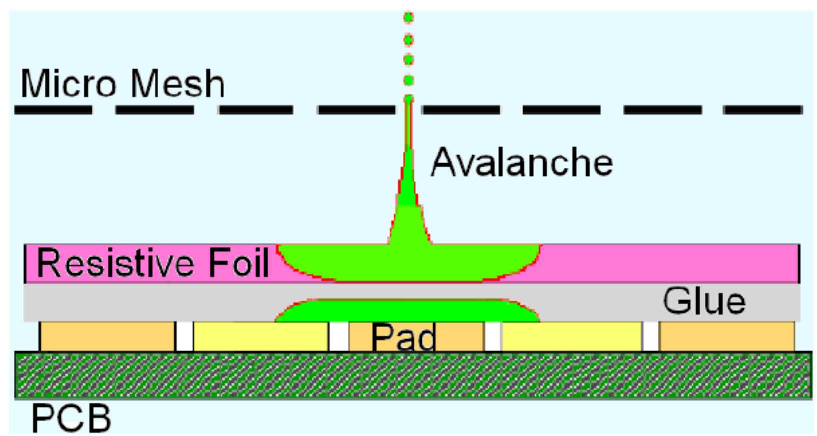
Spatial resolution of second coordinate of the MMSW
Residual distributions from the hit position difference between the 2nd coordinate hit, reconstructed using the centroid method in the stereo readout 3 and 4 layers of MMSW, with a 2nd coordinate hit reconstructed in one reference chamber at a distance 20 cm from the MMSW.



The measurements were performed with the MMSW quadruplet operated with an amplification voltage $HVamp = 580 V. The data were acquired during PS/T9 with a 6 GeV/c π+/p$ beam.

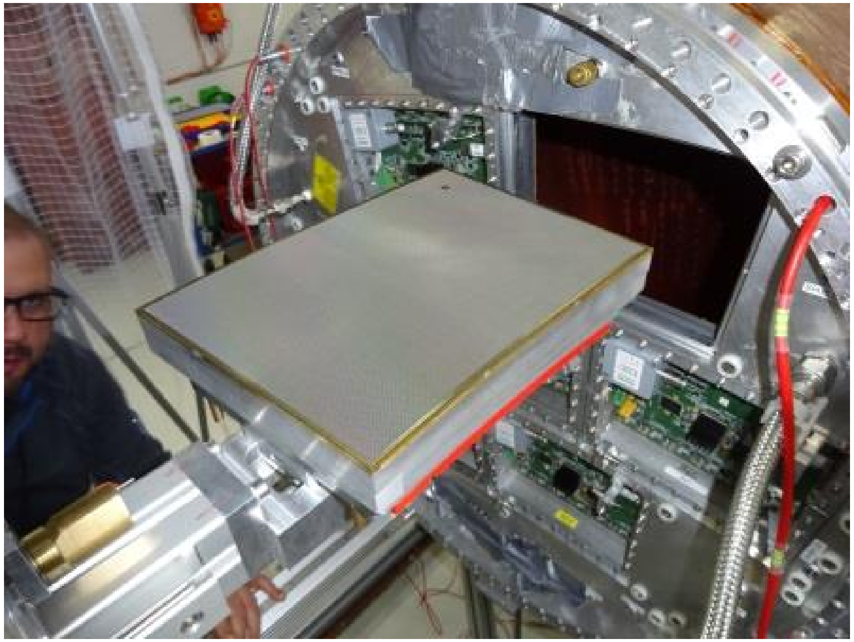
Resistive MM for TPC readout

- In ATLAS endcap/forward detector
  - Very high rate (~100kHz/cm^2) of incident particle
  - → Resistive strip is needed for both high rate and lower charge distribution
- For TPC readout (ILC / T2K ND)
  - Resistive layer with no pattern is enough

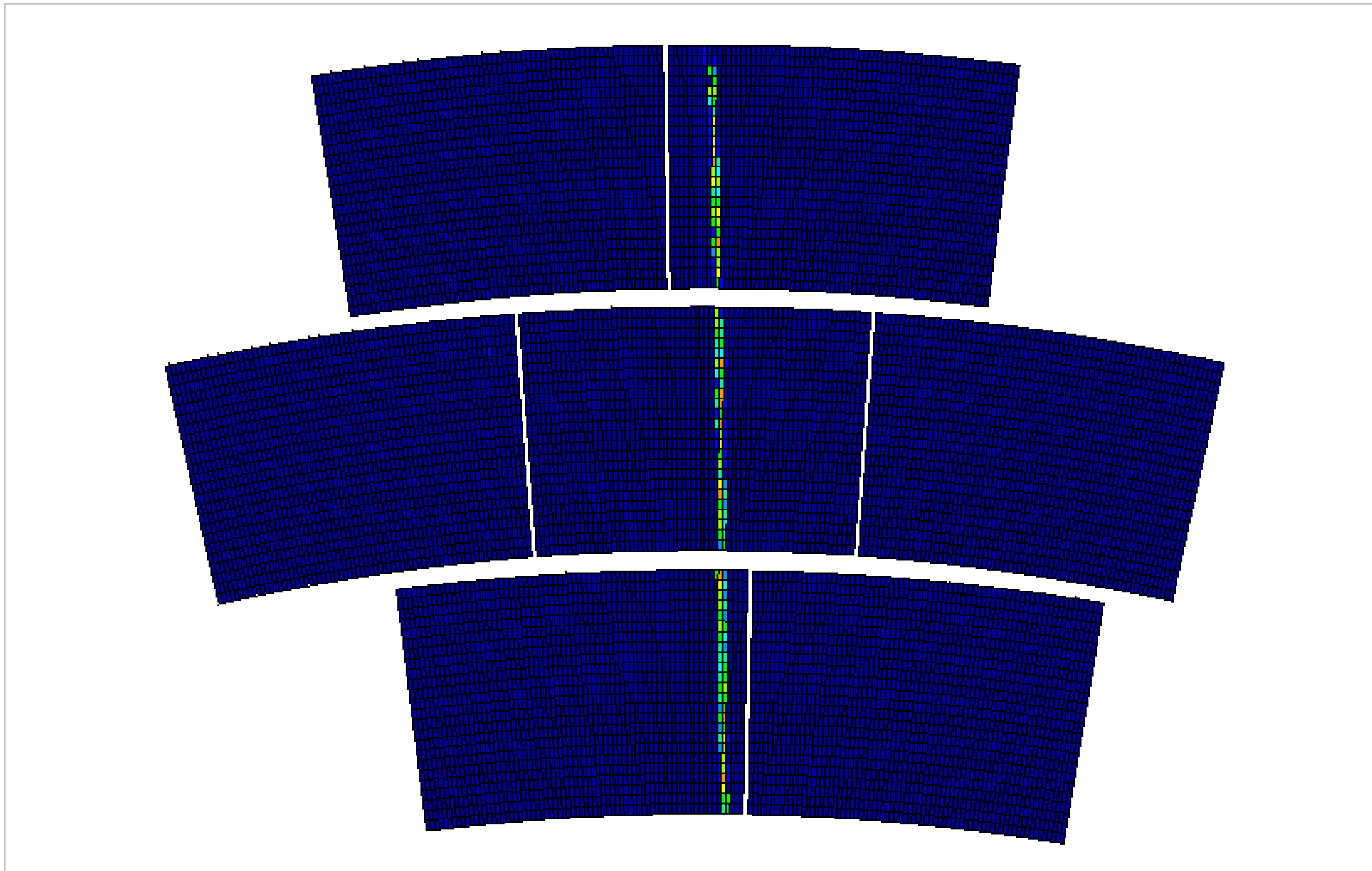


Collaboration with Saclay

- New Micromegas data taking in March 2015 at DESY
- 2 New modules with new (japanese) resistive anode: Diamond-like Carbon rather than Carbon-loaded kapton made at Rui's workshop

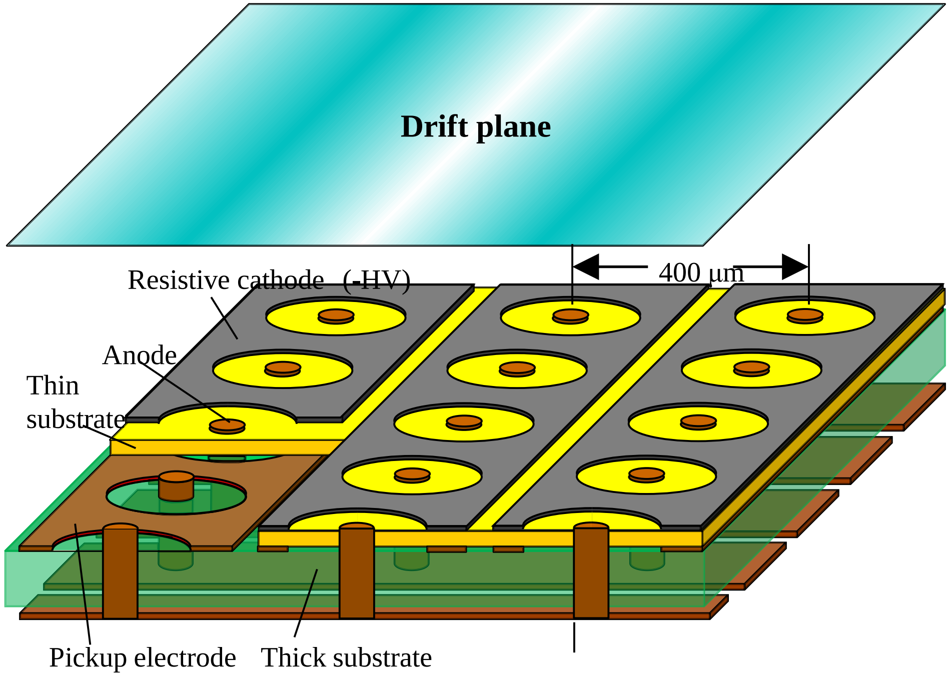


Events in the Large Prototype



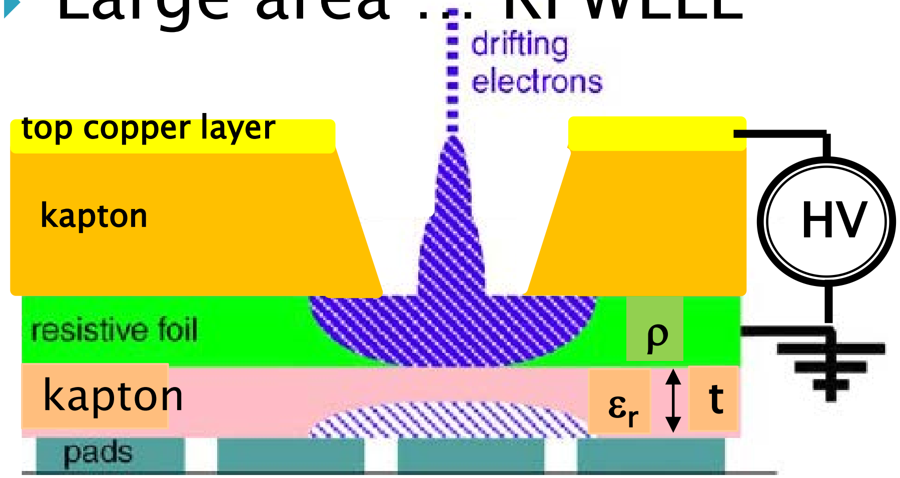
Recent DLC applications on MPGD

- Fine patterning … μ-PIC with resistive cathode

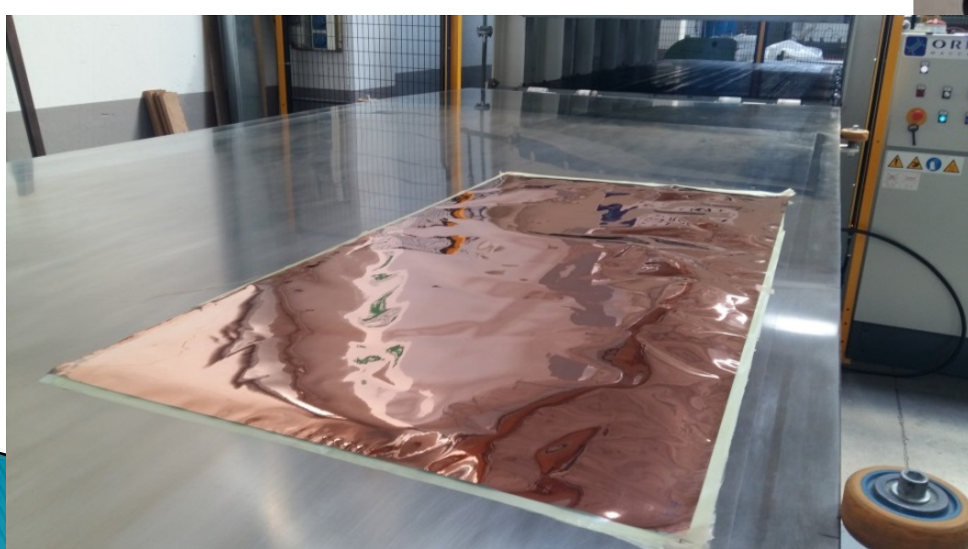


Recent DLC applications on MPGD

- Large area … RPWELL



✓ **gluing the DLCed foils on the readout -PCBs**



RD51 collaboration meeting
G. Bencivenni, Sep. 2016

Summary

- Resistive electrodes are important technology for MPGD readout to avoid spark
- DLC (carbon sputtering) is one of excellent solution to make fine pattern and various resistivity
- Large size (>1m^2) DLC foils can be provided using industrial company in Japan
- Small size and large size DLC-MM have been successfully tested in various MPGDs