Automated Assembly of CMS Phase 2 Stacked Tracker Modules

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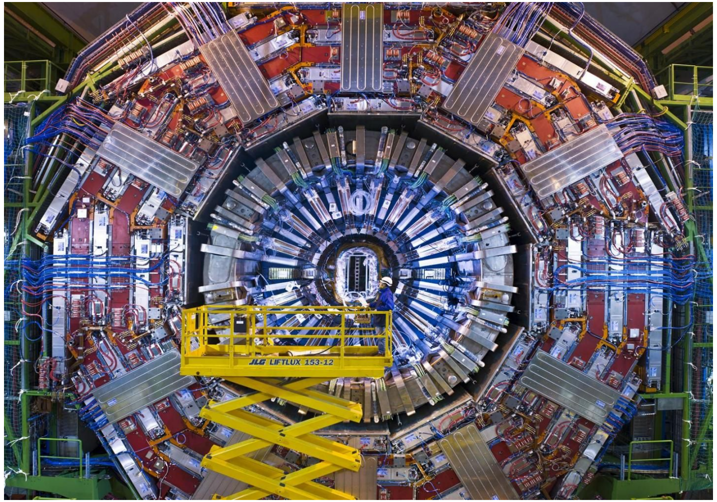
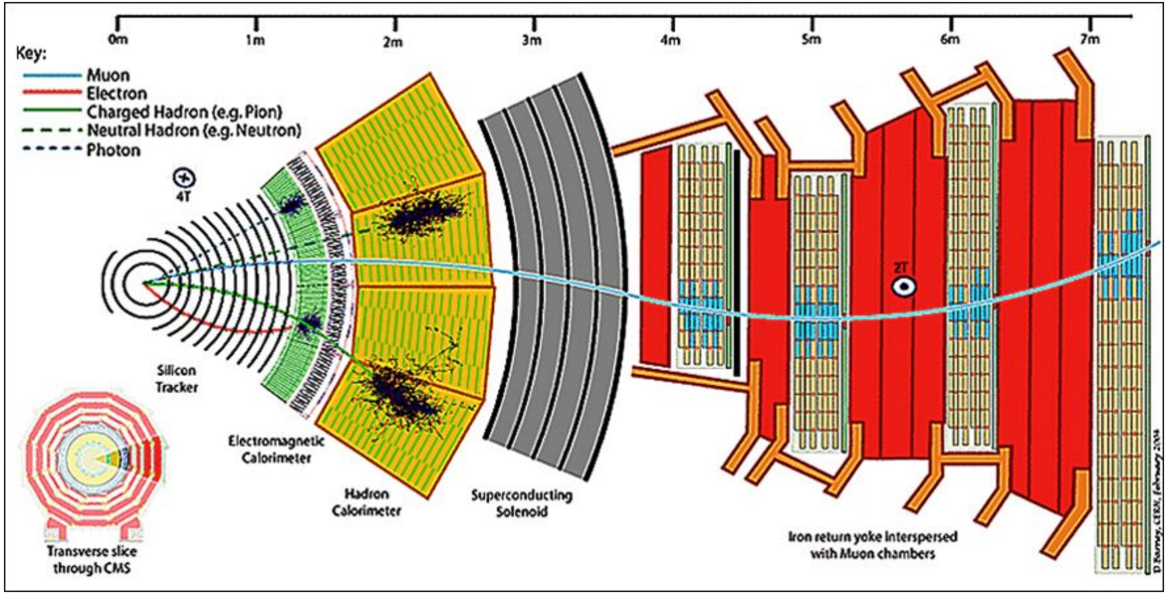
The CMS Detector

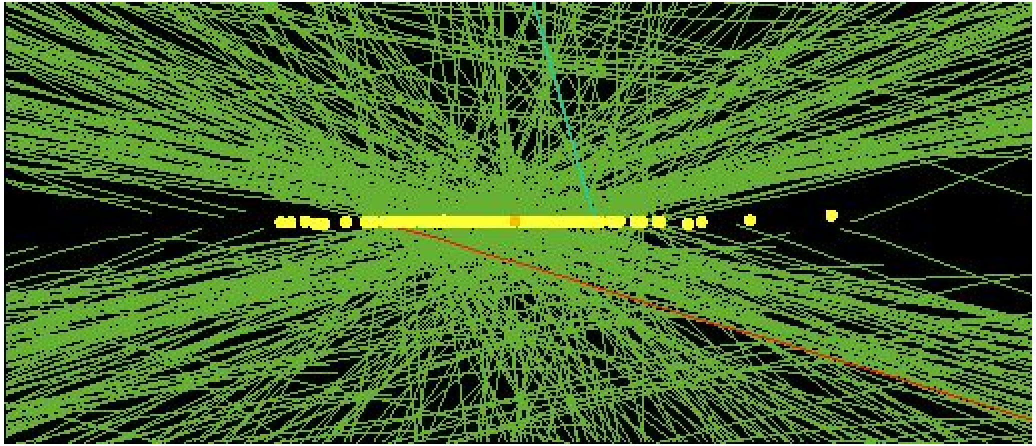




Weight ≈14000 tonnes
Diameter ≈ 15 m
Length ≈ 21.5m
Magnetic Field ≈4 T

High Luminosity LHC

- The LHC will be ungraded to the High Luminosity LHC over the coming years
- Instantaneous luminosity is expected to reach $5x10^{34}cm^{-2}s^{-1}$ in the 2020s
- Higher luminosity leads to an increase in number of interactions per bunch crossings (pile up)

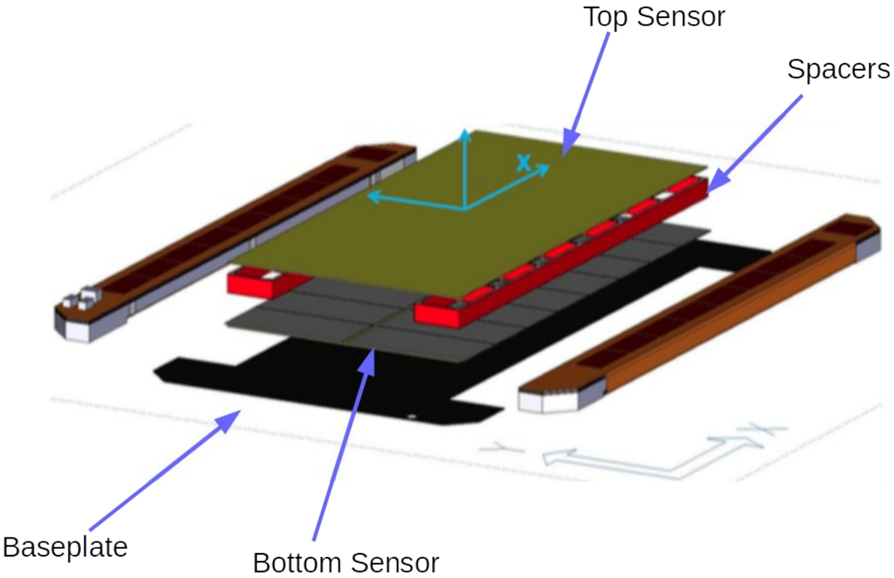


Simulation of high pile up event

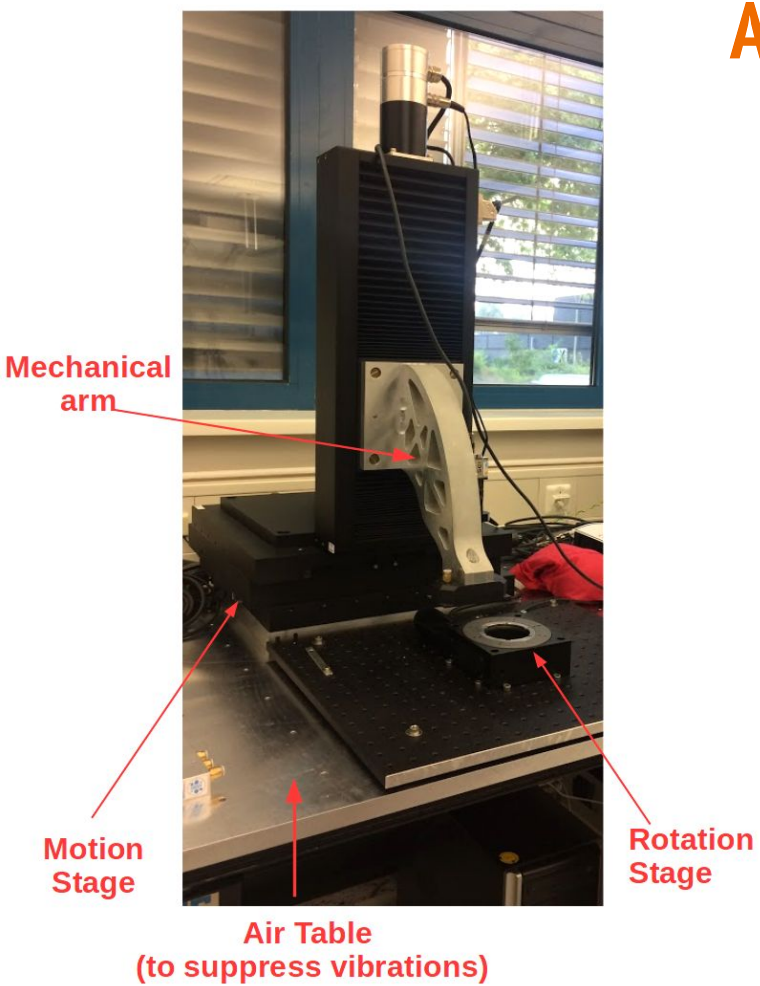
- Huge increase in data volumes
- Many interactions are lower energy collisions which will not be relevant in the search for new physics

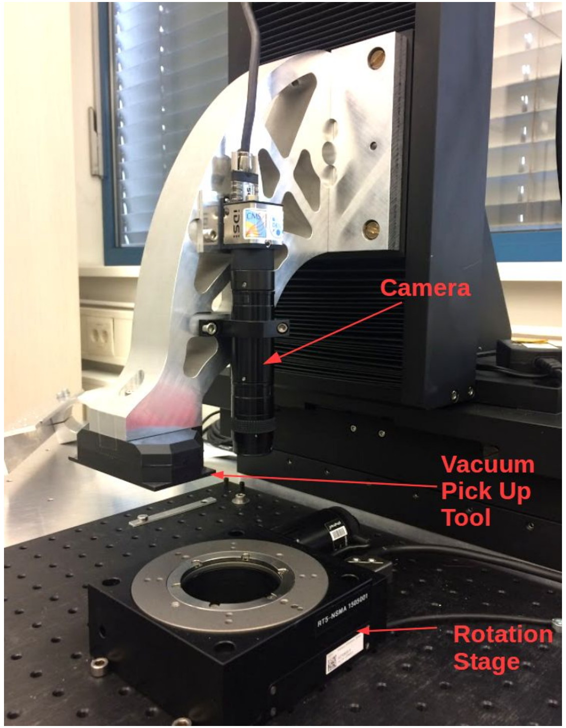
Stacked Sensor Module for HL LHC

- Rejection of low p_T particles based on the curvature of their trajectories in a magnetic field reduces data volumes
- Module consists of two closely spaced silicon sensors
- Relative alignment of sensors is crucial to p_T discrimination
- Relative rotational alignment < 0.8 mrad ≈ 0.04°

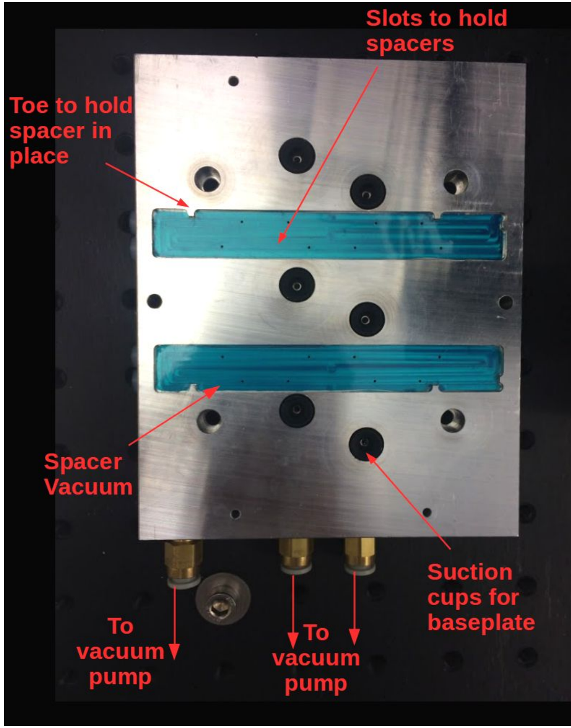


Assembly Equipment



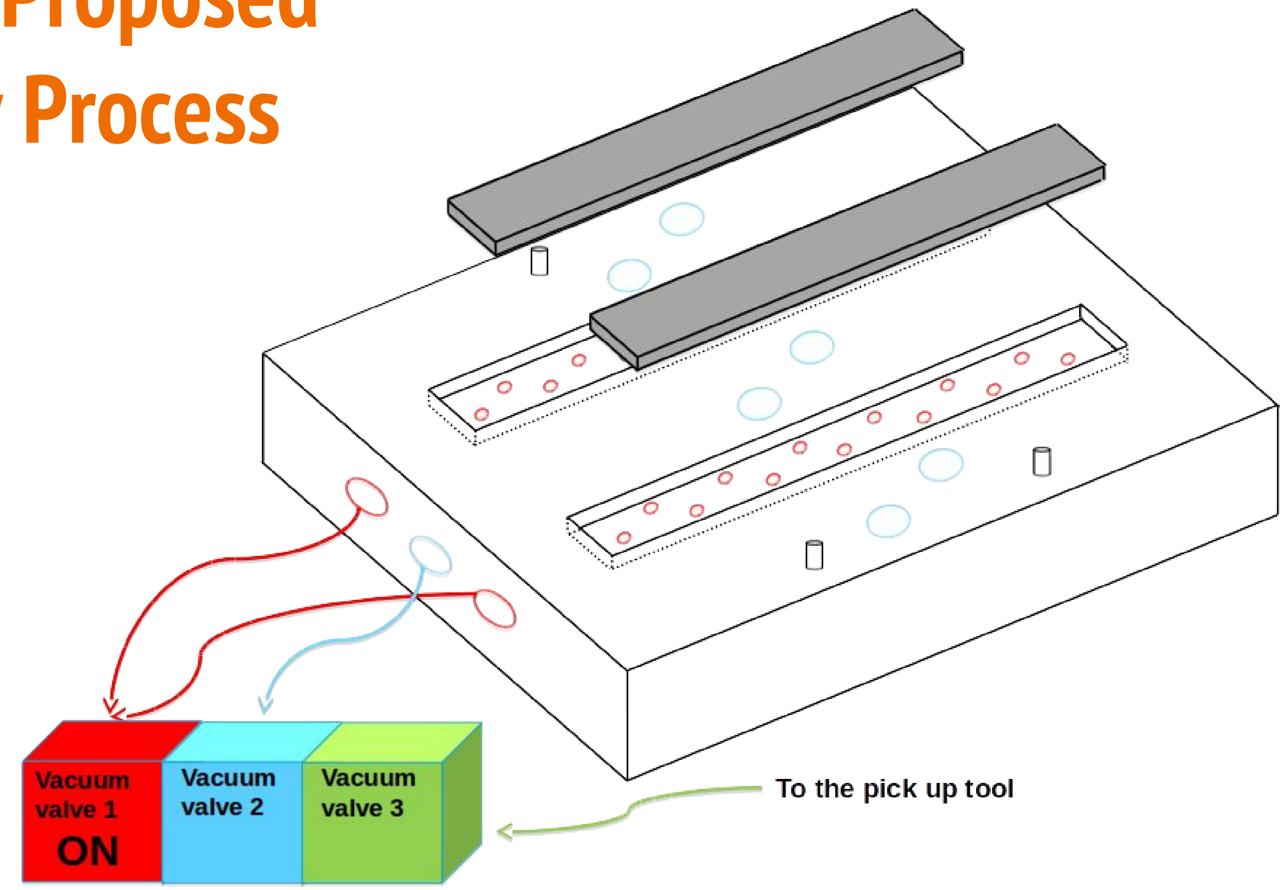


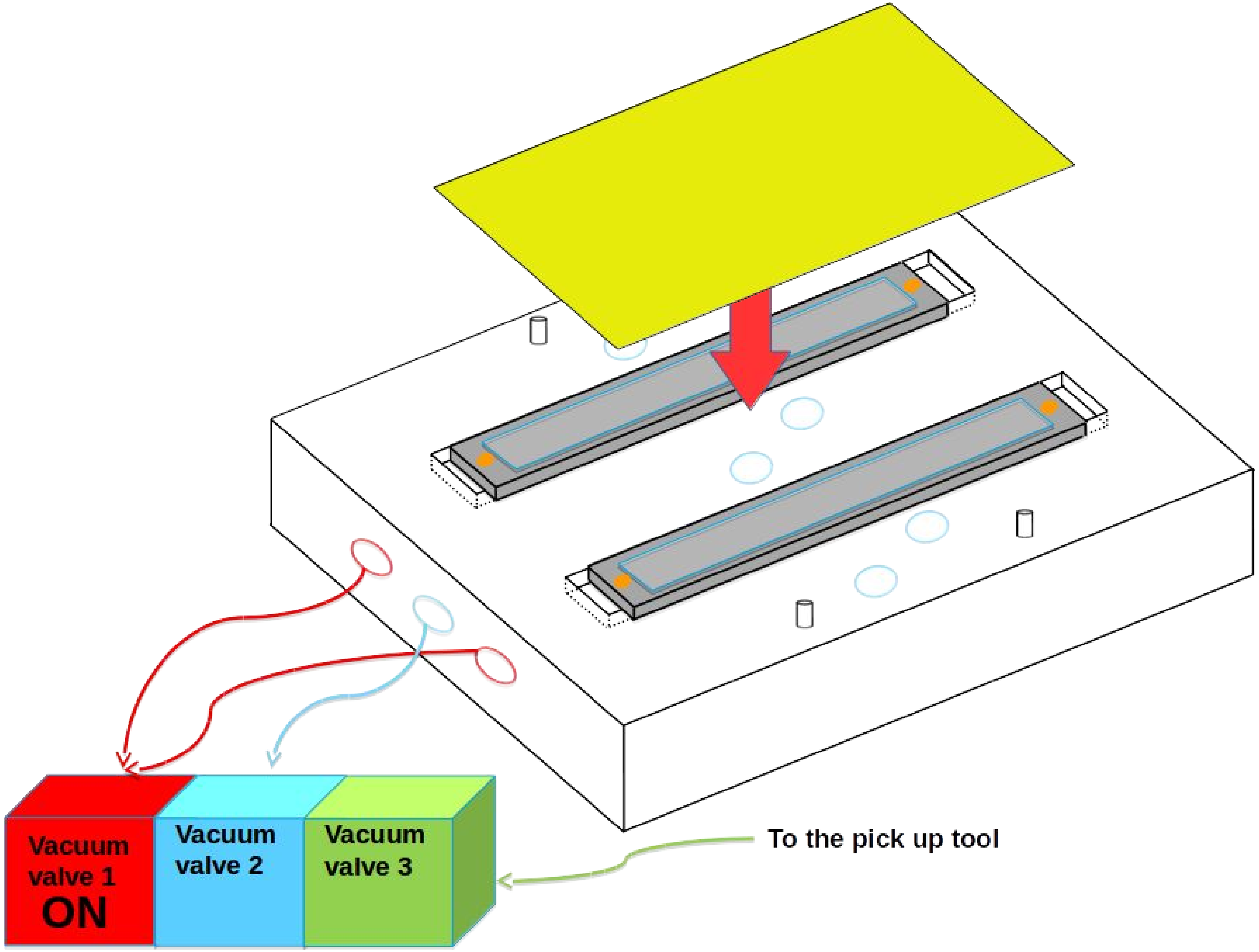
Mechanical Arm

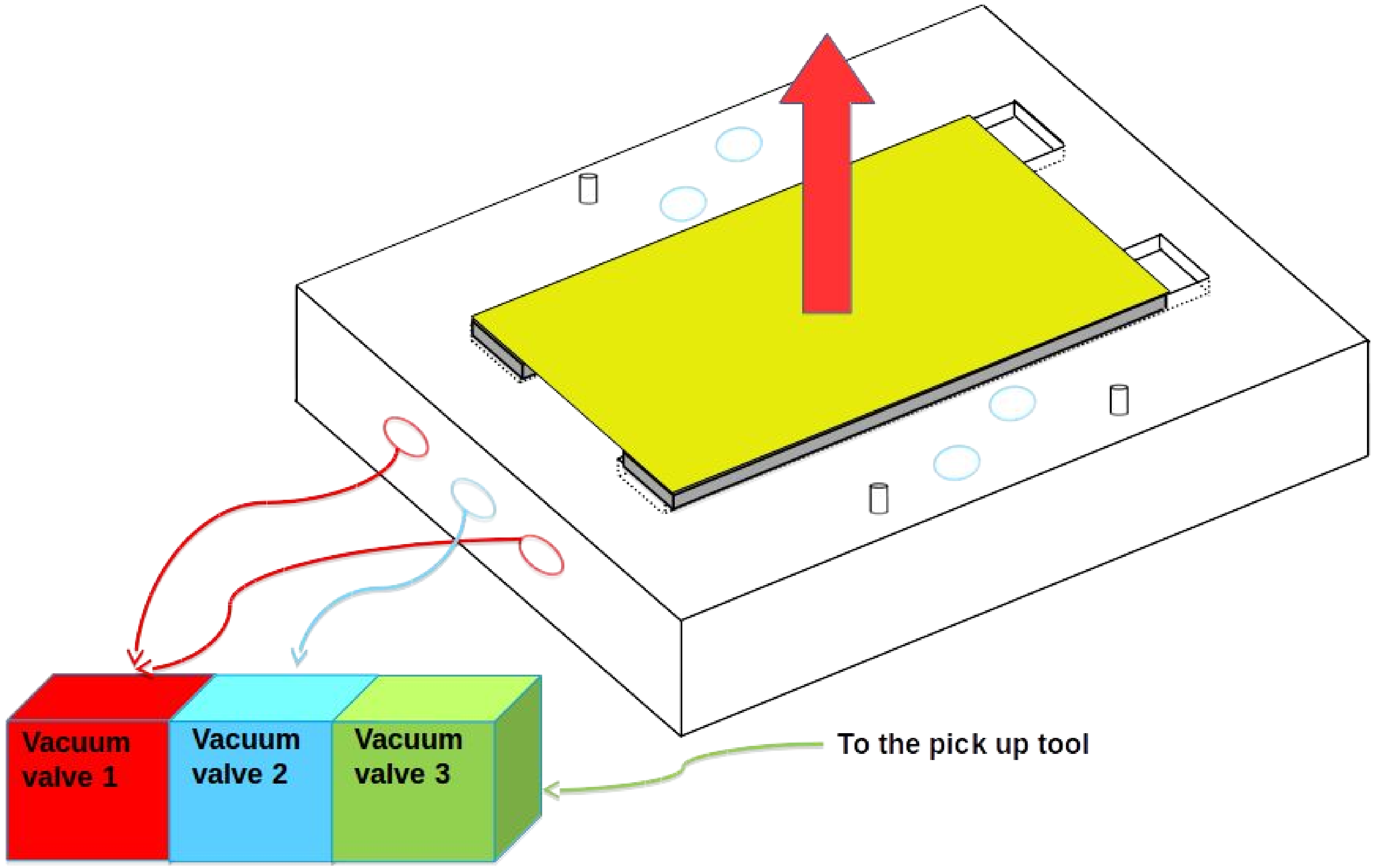


Assembly Platform

Outline of Proposed Assembly Process




Vacuum
valve 1
ON
Vacuum
valve 2
Vacuum
valve 3
To the pick up tool


Vacuum
valve 1
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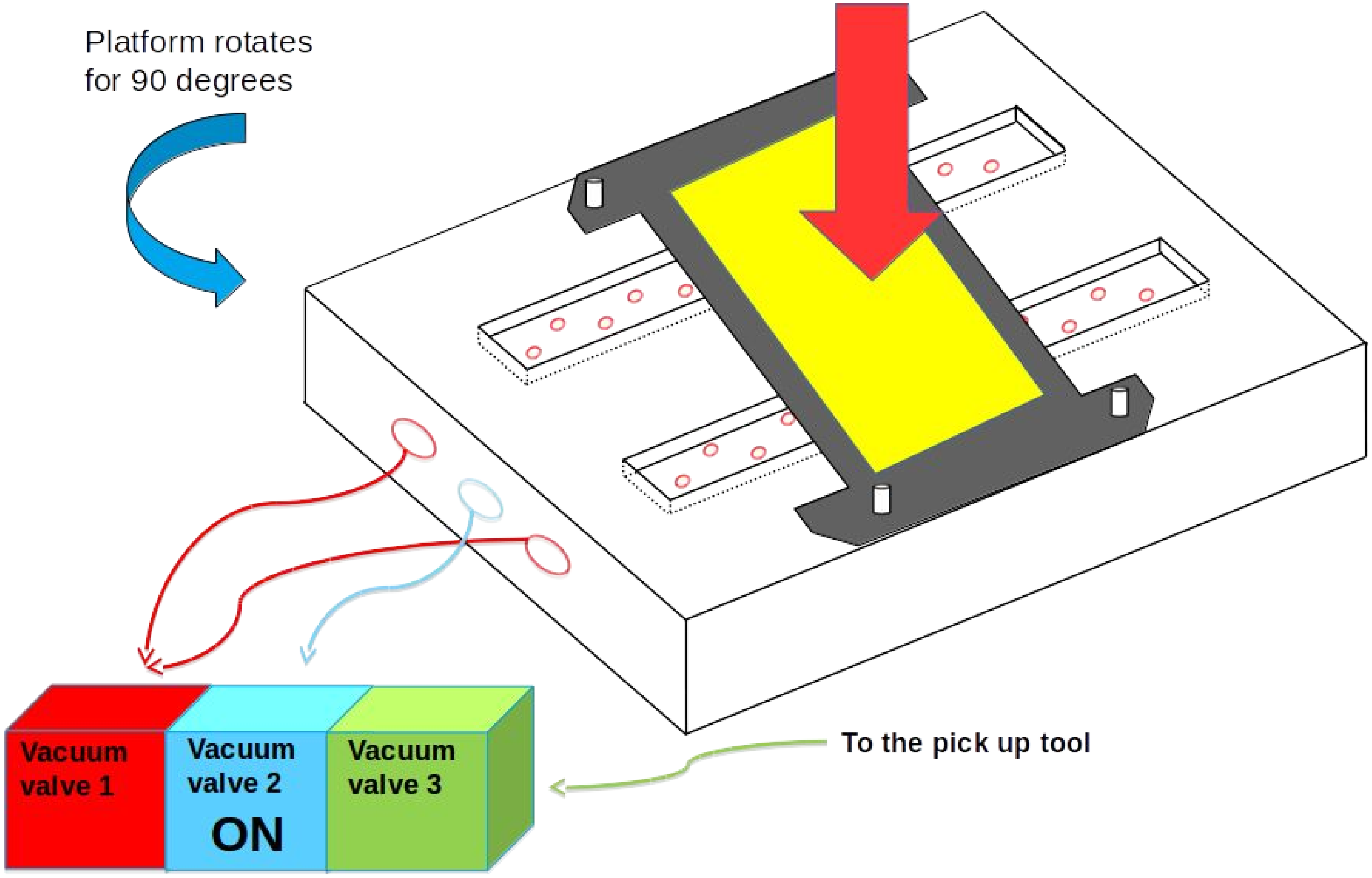
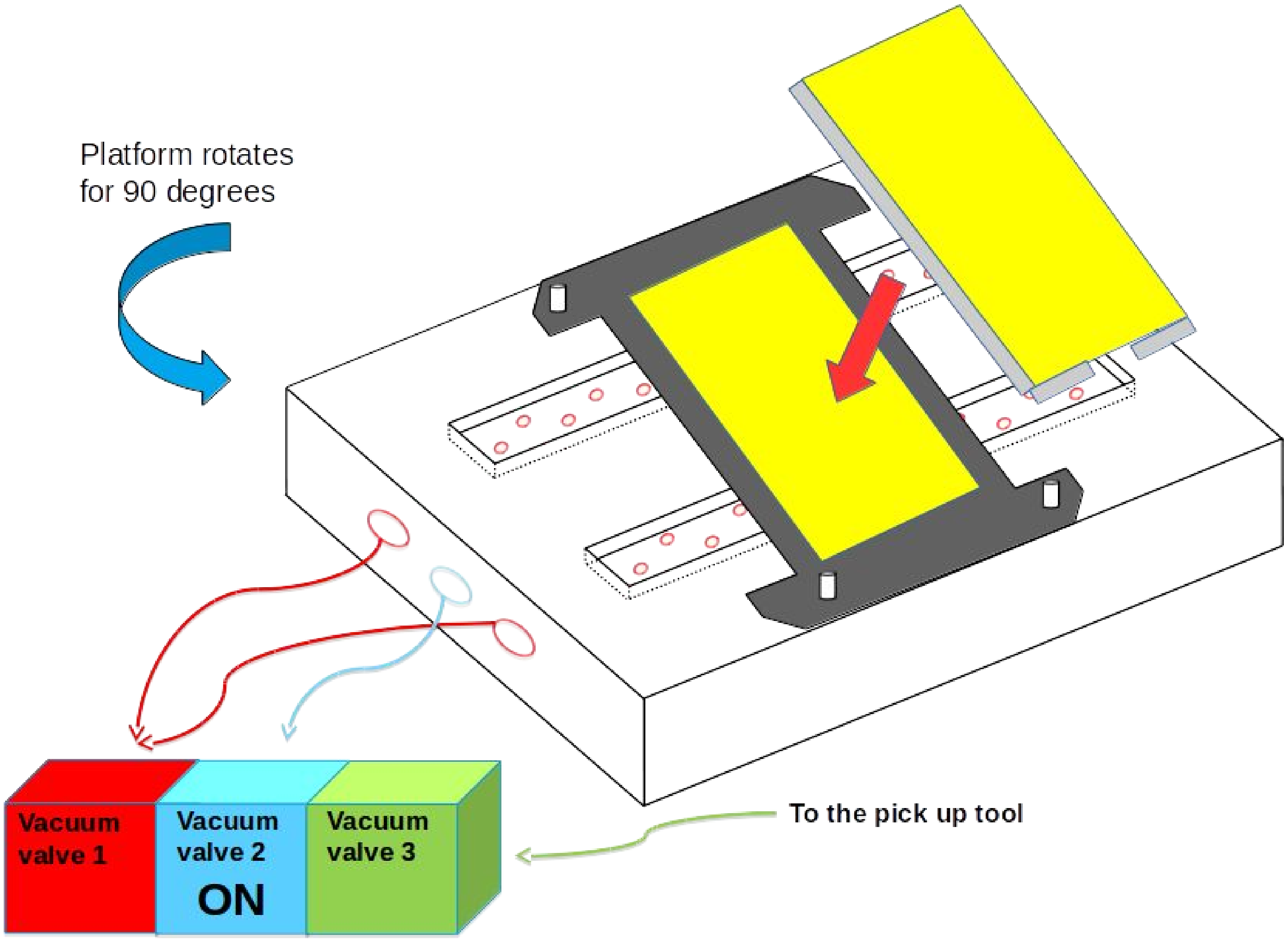
To the pick up tool


Platform rotates
for 90 degrees
Vacuum
valve 1
Vacuum
valve 2
ON
Vacuum
valve 3
To the pick up tool

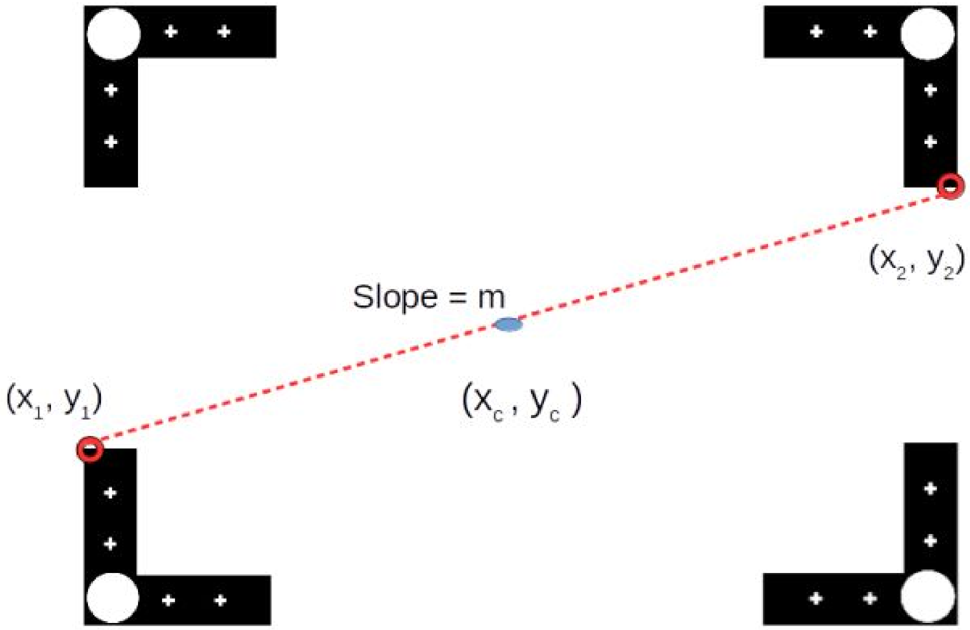

Platform rotates
for 90 degrees
To the pick up tool
Vacuum
valve 1
Vacuum
valve 2
ON
Vacuum
valve 3

Defining Orientation of the Sensor

(x,y) coordinates of opposite corners are used to define the orientation of the sensor

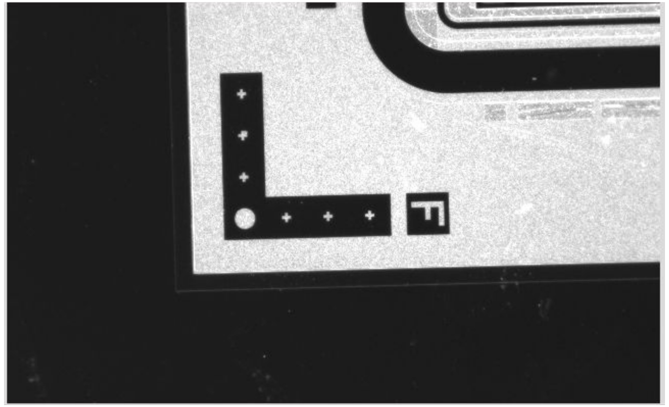
Slope of the line joining these points defines angular orientation

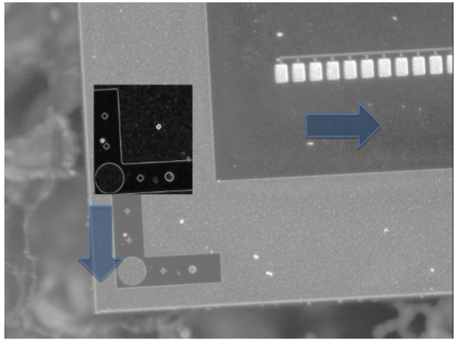
Midpoint (x_c, y_c) of this line defines the position of the sensor

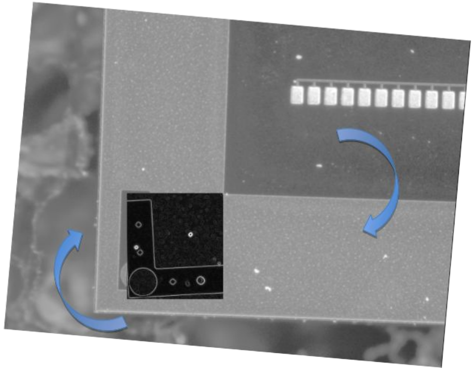


Locating Corner Markers

- Camera is manually brought to the sensors corner
- An image is taken and passed to pattern recognition software
- A template matching algorithm identifies the position and angular orientation of the marker

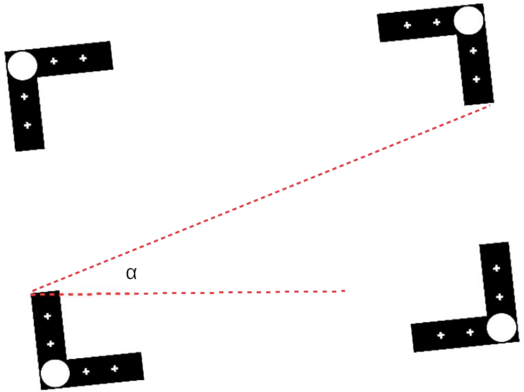


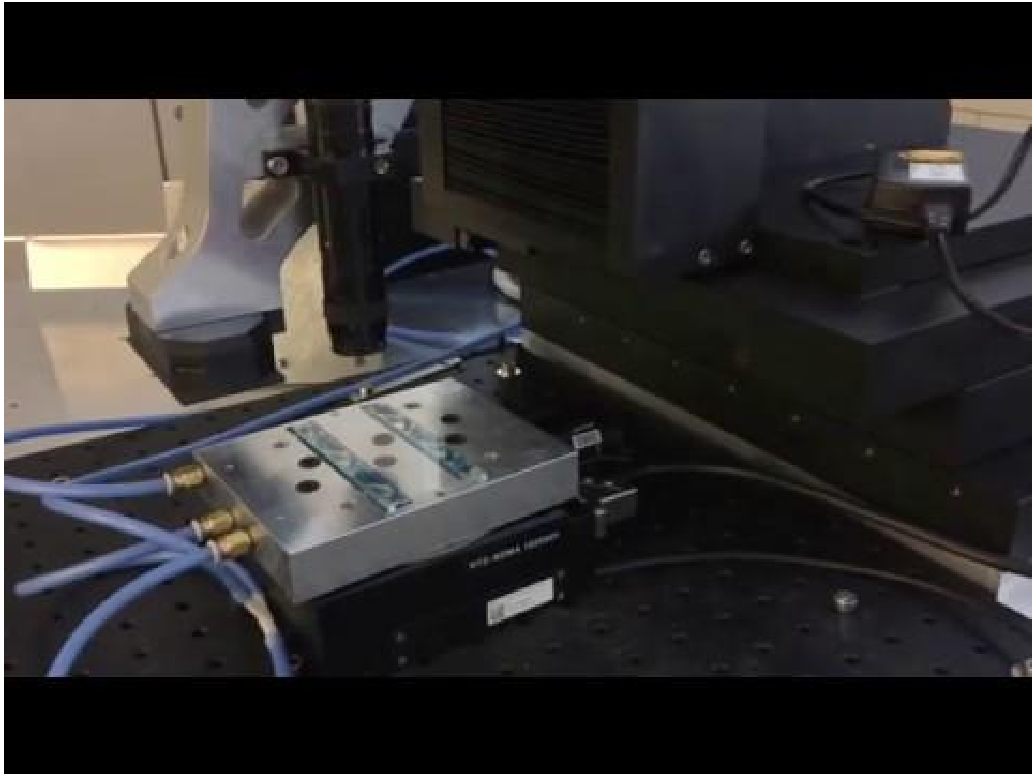




Finding the Opposite Corner

The length, width and angular orientation of detected marker are used calculate the position of the oppositely diagonal marker using trigonometry

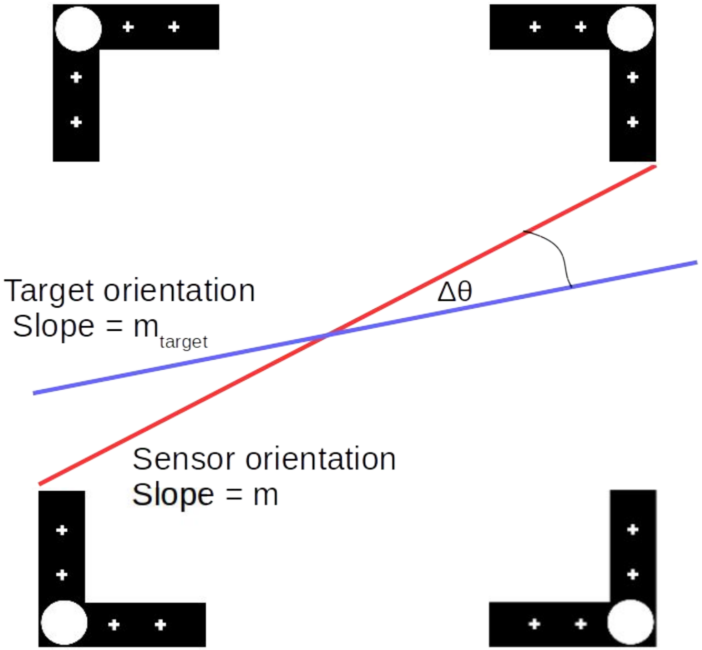




Aligning the Sensor

The target slope is defined by the orientation of the top sensor

Angular correction $\Delta\theta$ needed is easily calculated



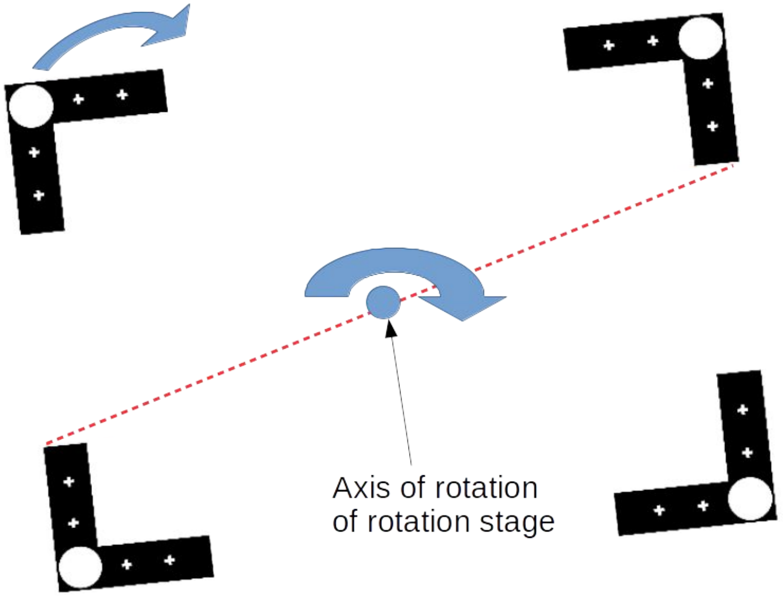
Rotating the Sensor

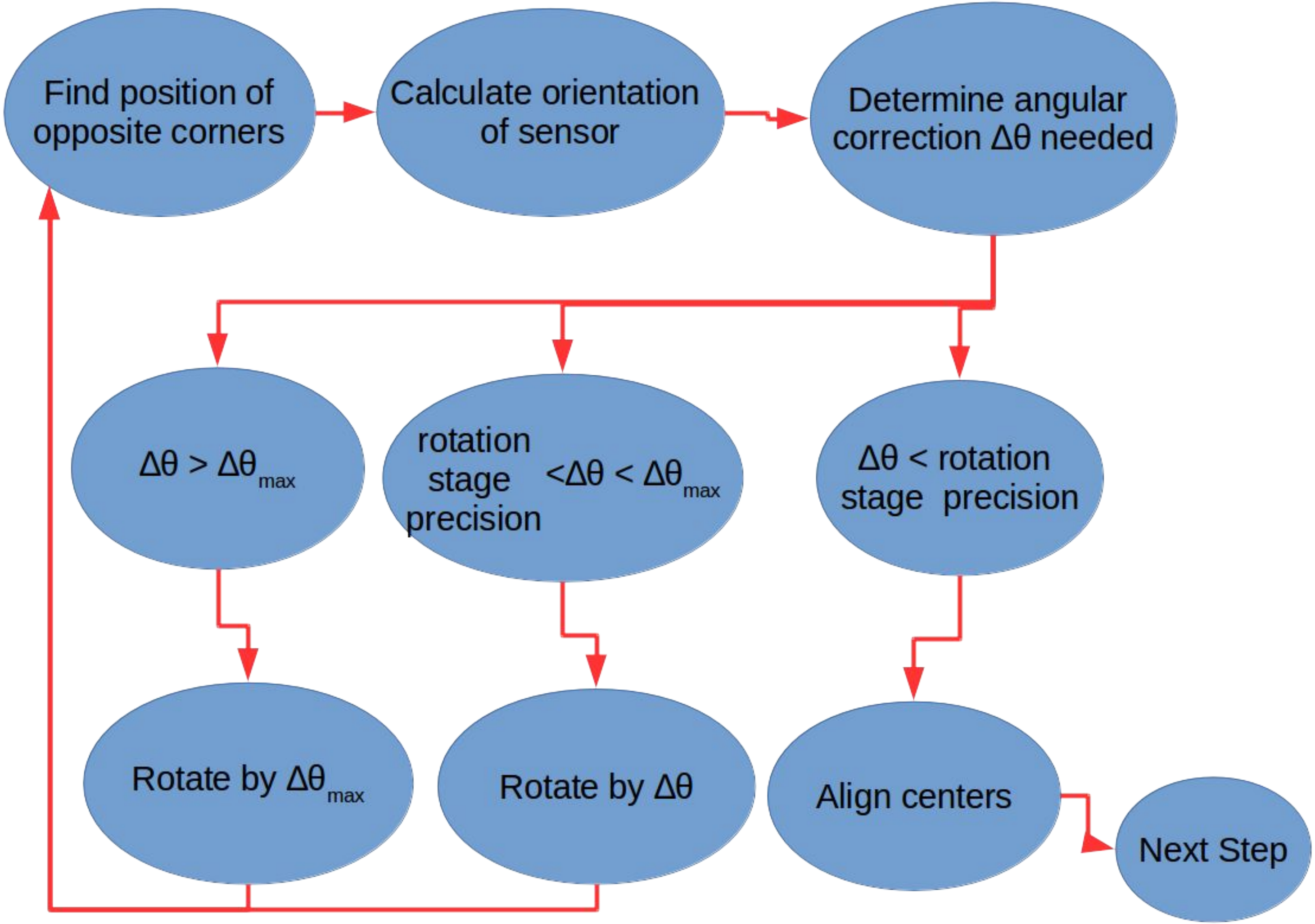
Axis of rotation stage is in the centre of the sensor

Rotating the sensor moves the corners in both x and y

Camera has a small frame of view (only a few mm^2)

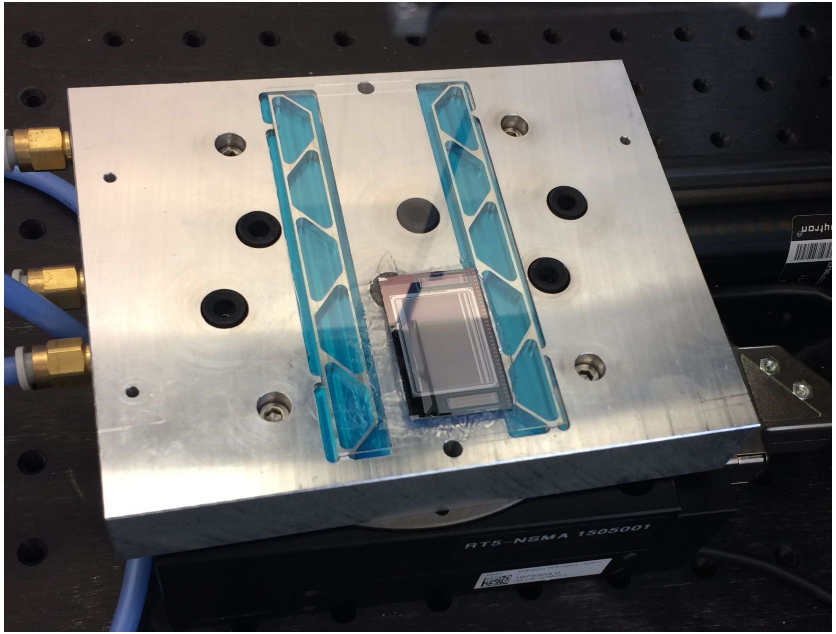
If the marker moves out of the camera's frame of view it can no longer be detected by pattern recognition



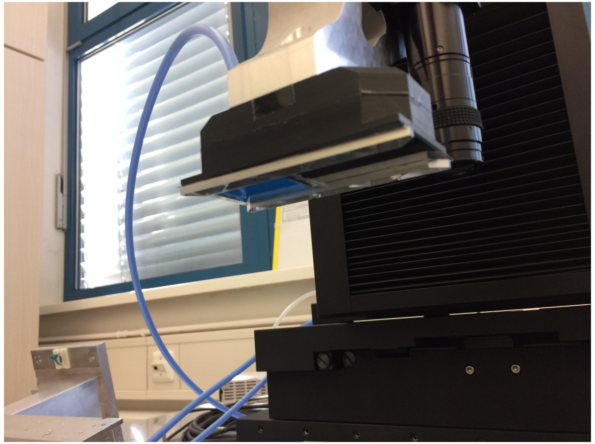

Find position of opposite corners
Calculate orientation of sensor
Determine angular correction Δθ needed
Δθ > Δθ max
rotation stage precision <Δθ < Δθ max
Δθ < rotation stage precision
Rotate by Δθ max
Rotate by Δθ
Align centers
Next Step

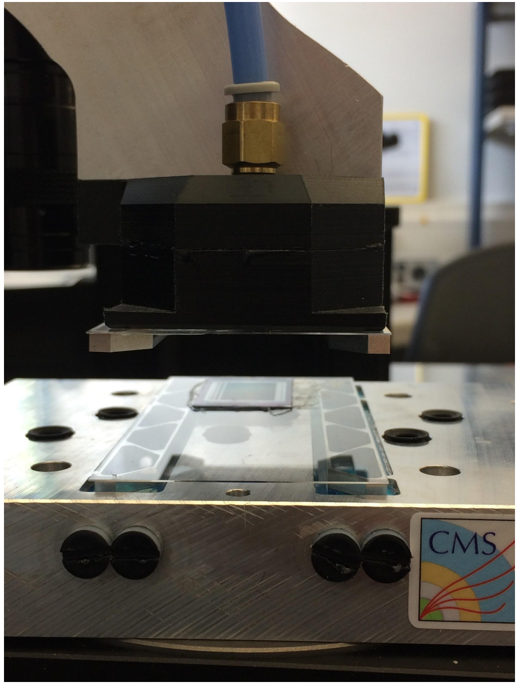
Making a Module: Silicon Pieces on Glass

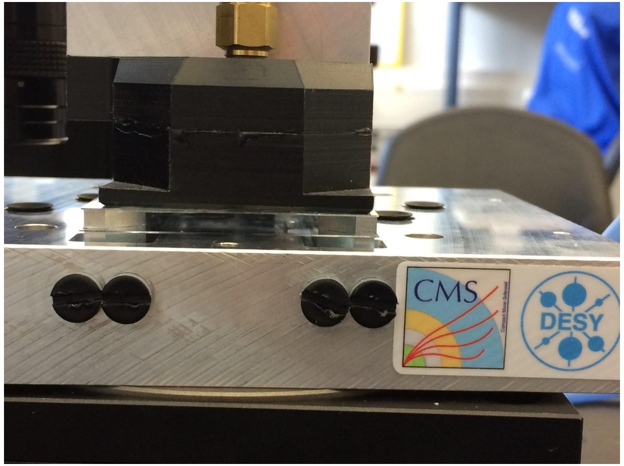
Pieces of silicon with corner markers were mounted on glass dummies



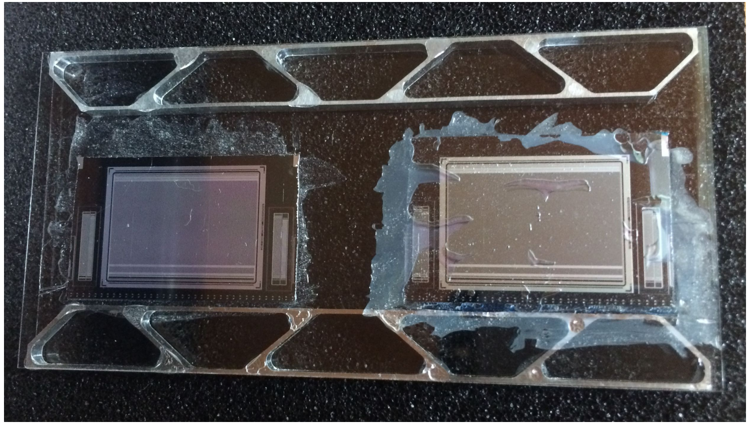
Automated Construction



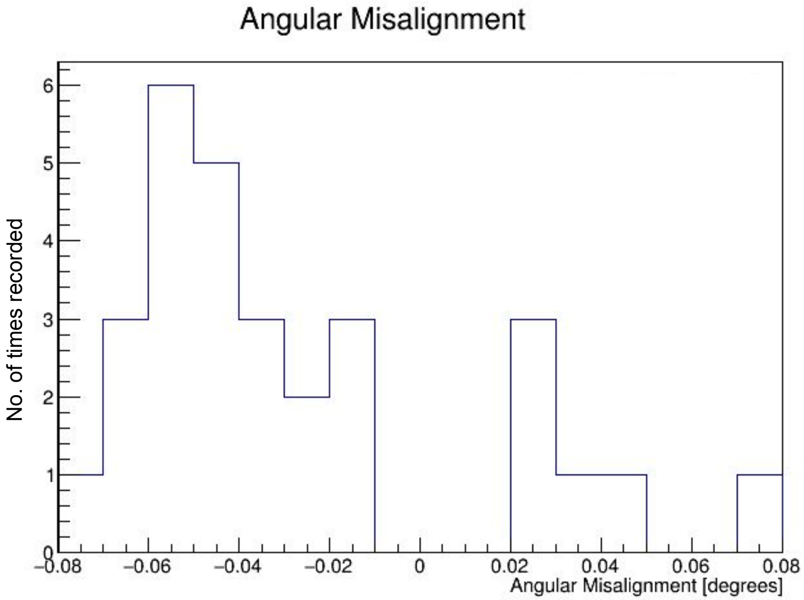




Checking Alignment



- Accuracy of orientation detection is limited by xy resolution of motion stage and size of the sensor to ±0.027°
- This would be significantly reduced with a larger sensor



- 30 measurements of the angular misalignment suggest the two sensors are misaligned by 0.05°
- This is approaching the precision required

Conclusion

- An automated procedure has been put in place to locate the corner markers of a silicon sensor and to extract its orientation
- An iterative process has been developed to bring a sensor to a predefined angular orientation
- A dummy module has been built with a relative alignment approaching the precision required
- Next steps for automated assembly:
  - Automation of xy alignment
  - Full sized dummy sensors
  - Investigation of systematic errors

Thank you for listening!