Laser Based Alignment System (LBAS)

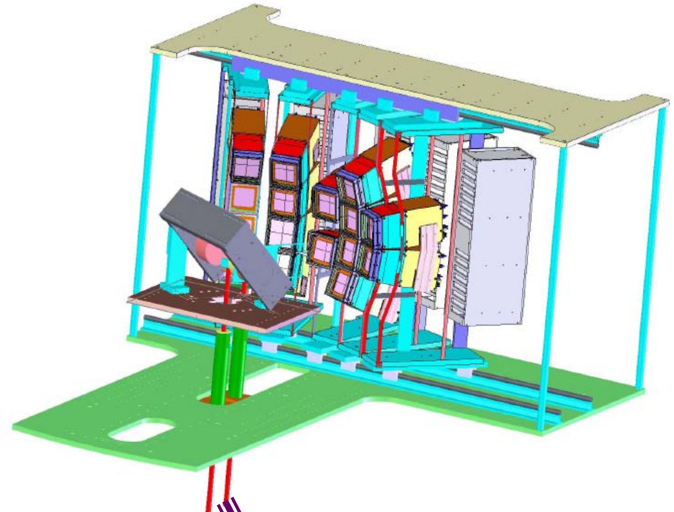
Position determination of fragile
objects in nuclear physics experiments

14 August, 2008

Outline

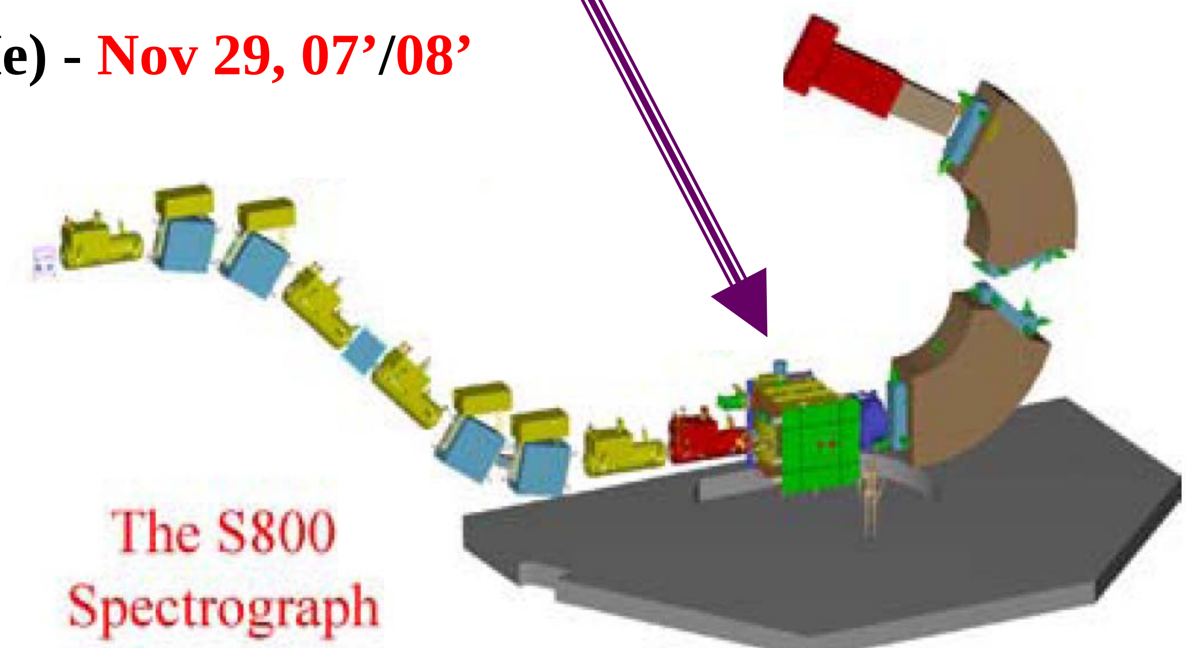
- NSCL transfer reaction experiments
  - Inverse kinematics
- Experimental setup – things to be measured
- Requirement for position measurements
- Laser Based Alignment System (LBAS)
- Using LBAS on an experiment
- Details of the measurements
  - HiRA
  - Micro-Channel Plate Detector
  - Target
  - S800 Spectrometer
- Conclusion

NSCL Experiments – Transfer reactions



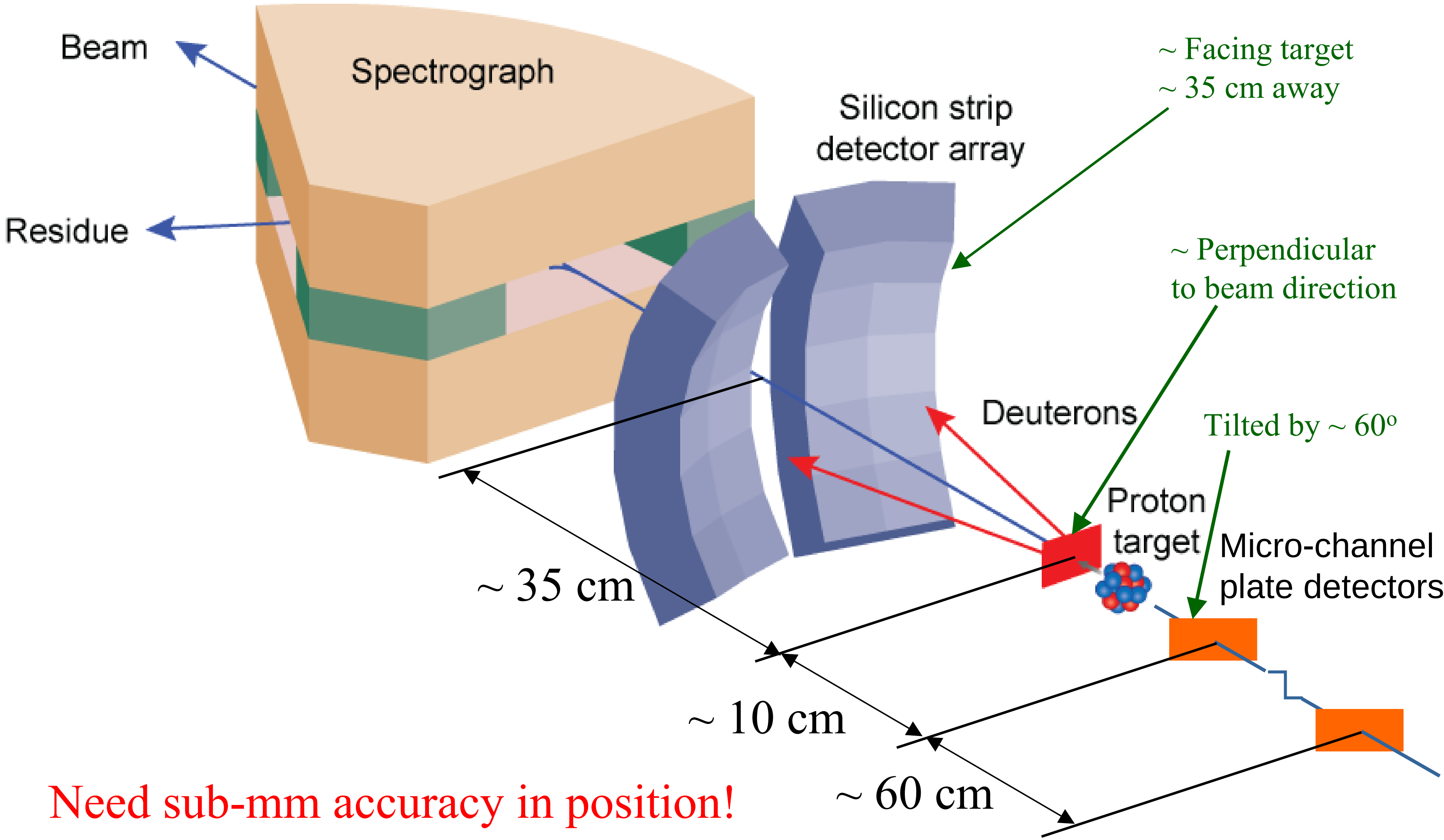
Inverse kinematics at 35 MeV/A

1. ^{46}Ar(p,d) & ^{34}Ar(p,d) - Oct 19, 07'
2. ^{56}Ni(p,d) & ^{56}Ni(d,^{3}He) - Nov 29, 07'/08'



collaboration

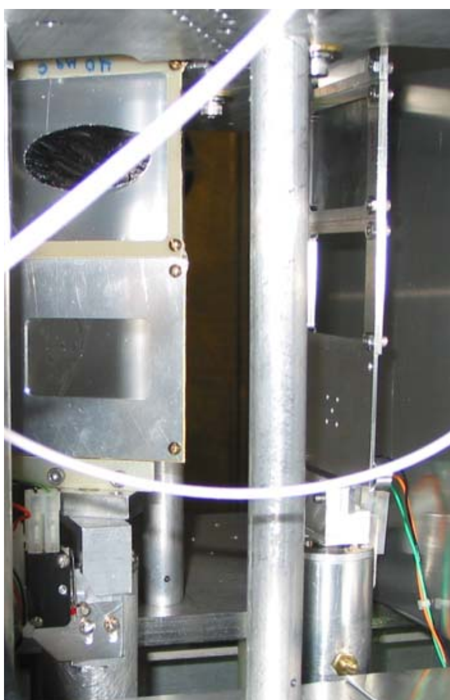
Experimental setup

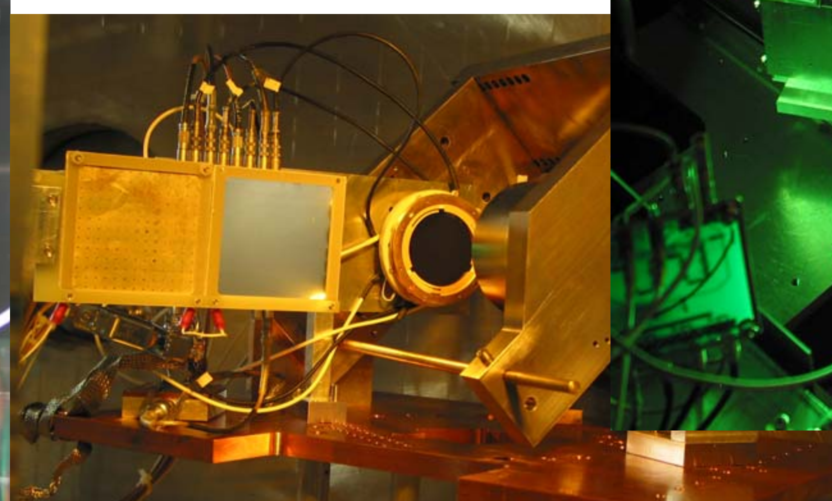


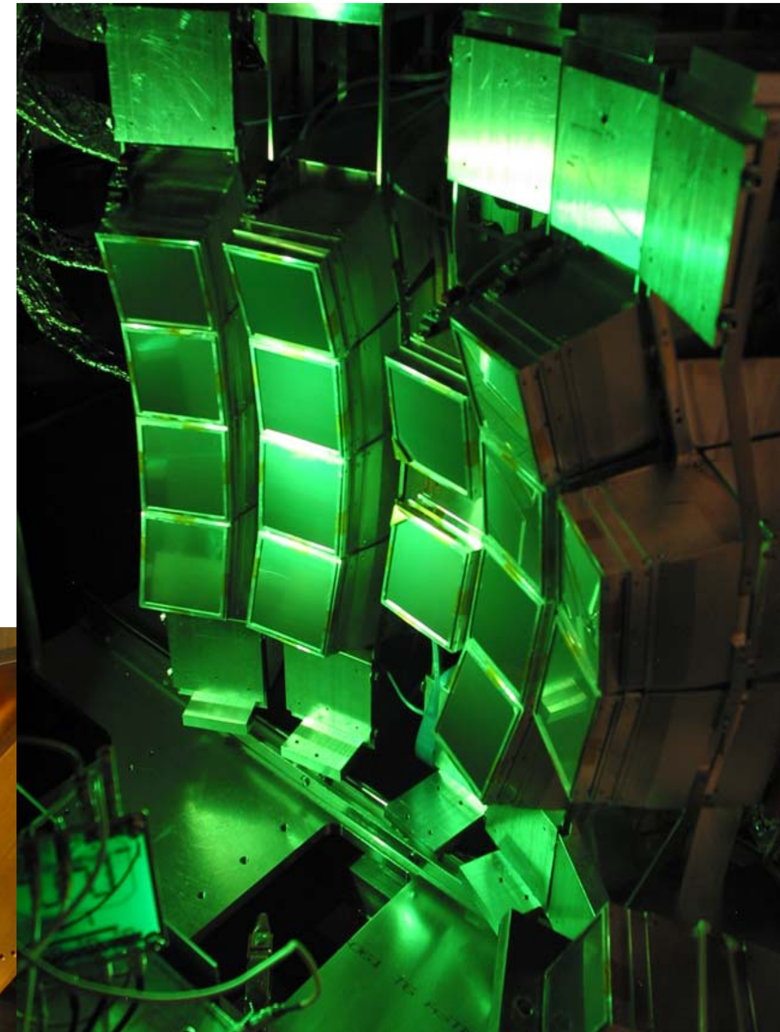
Need sub-mm accuracy in position!

Requirement for position measurements

- Must be non-contact
  - Mechanical measurements may alter the configuration of our setup (HiRA, target, MCP, etc) and damage our detectors and target foils

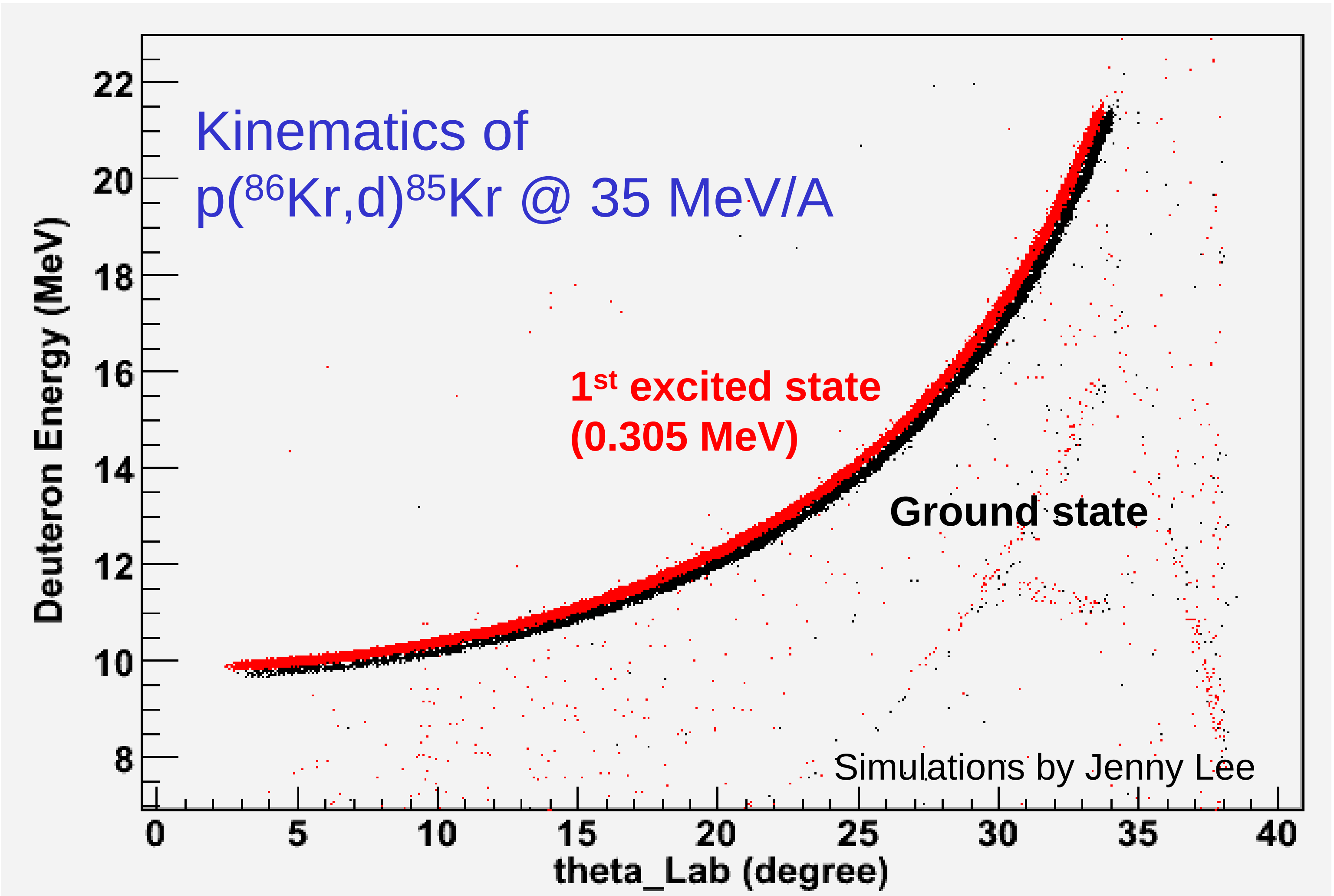






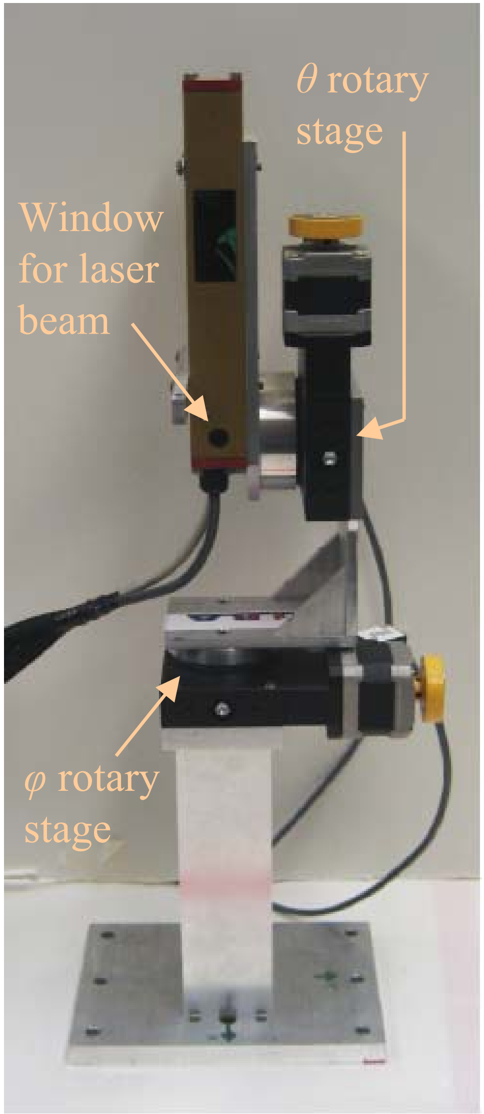
Requirement for position measurements

- Accurate (sub-millimeter) position measurements
  - e.g. to resolve nucleus of different excited states



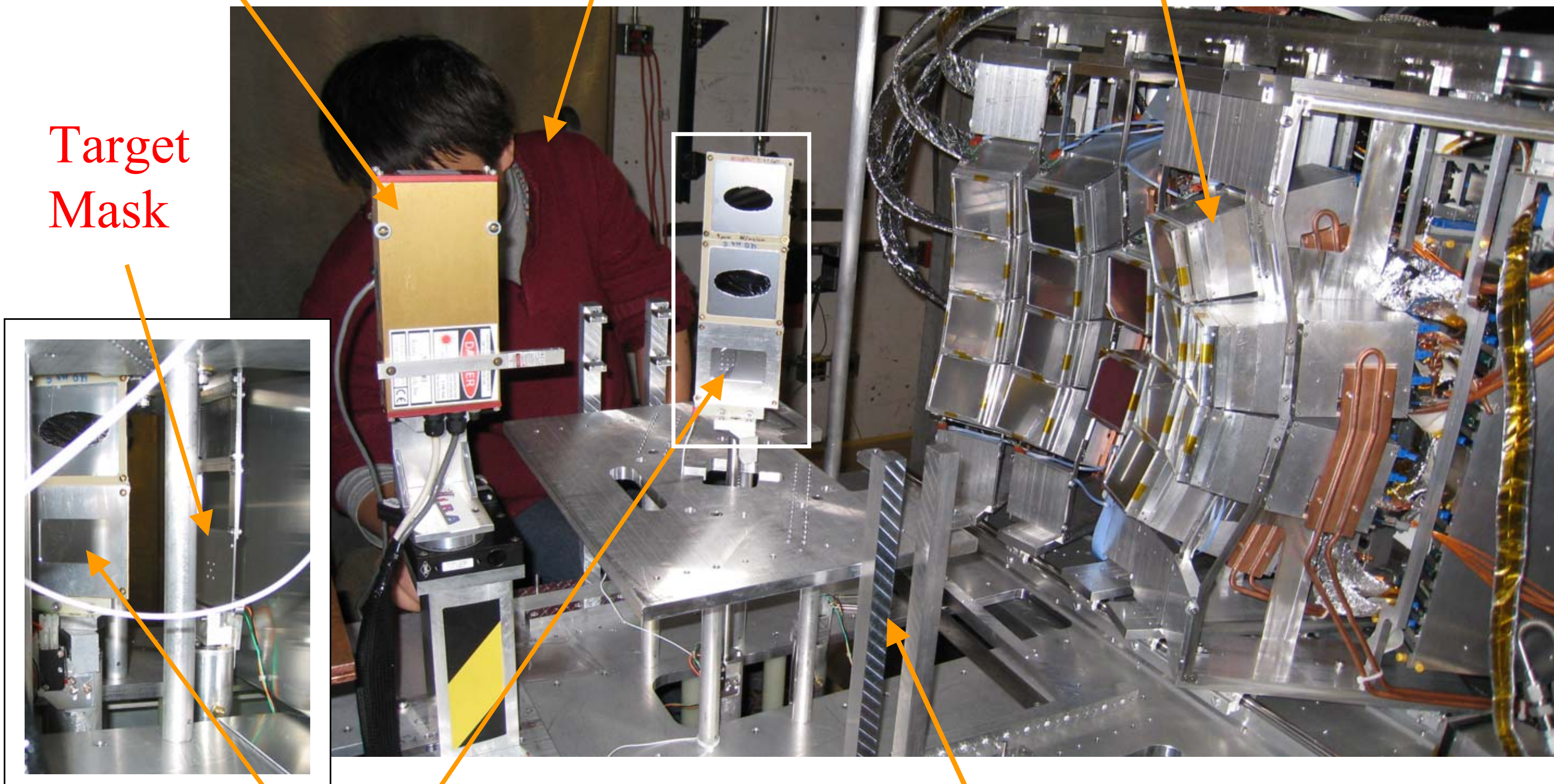
Laser Based Alignment System (LBAS)

- Small and portable
- Measure (r, θ, φ) of a point in space
  - Converted to (x, y, z) afterwards
- Use triangulation to measure distance
  - Range: 25.4 cm – 40.6 cm
  - Resolution: 45.6 µm
- 2 rotary stages provides angles θ and φ
  - Capable of measuring 360°
  - Resolution: less than 0.006°



The LBAS laser

Using LBAS on an experiment



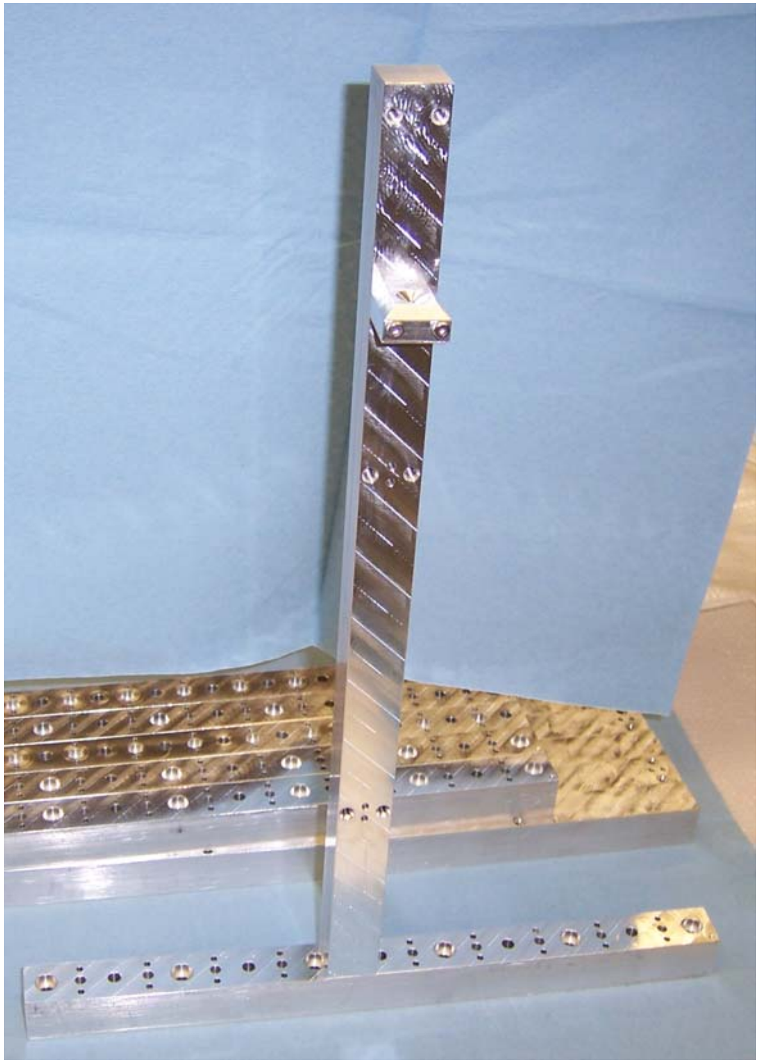
Using LBAS on an experiment

- Measure edges of the apparatus relative to the laser
- Determine the position of the apparatus relative to the laser

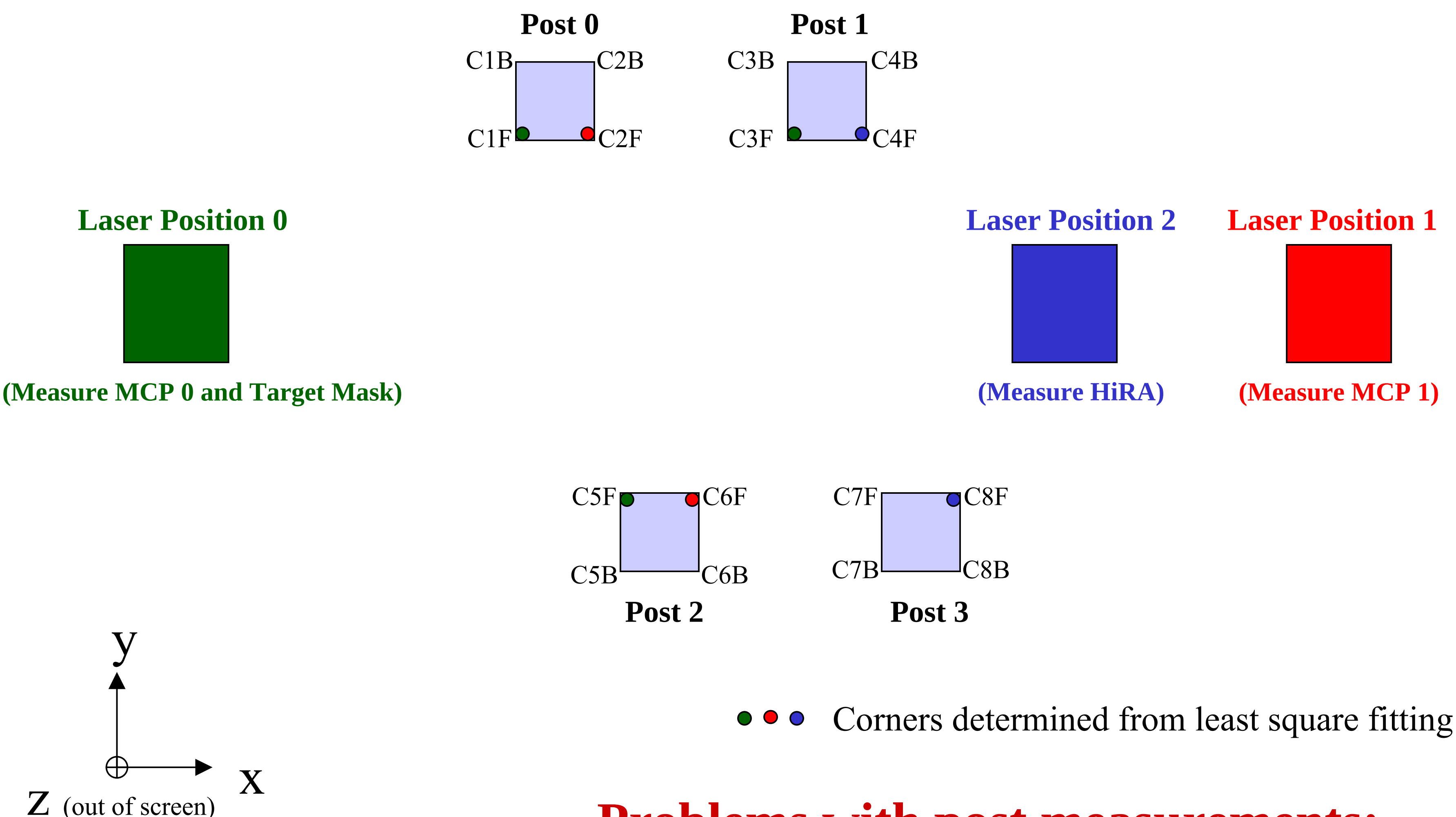
- Make measurements at different laser positions
  - due to limitation in its range
  - need to know the laser positions relative to each other
- Measure reference objects with different positions of lasers
- Match all the positions into a global laboratory coordinate system

Limitations of LBAS

- Laser measurement
  - LBAS works best on determination of sharp edges
  - Objects with simple shapes are preferred
  - The size of the object should be large enough
- Data analysis
  - More accurate to analyze measurements on a plane (for plane fitting)
  - Should incorporate as much information as possible in analysis (e.g. dimensions of the object from mechanical drawings)
- These considerations should be taken into account in the design of reference posts



Different laser positions - Top view

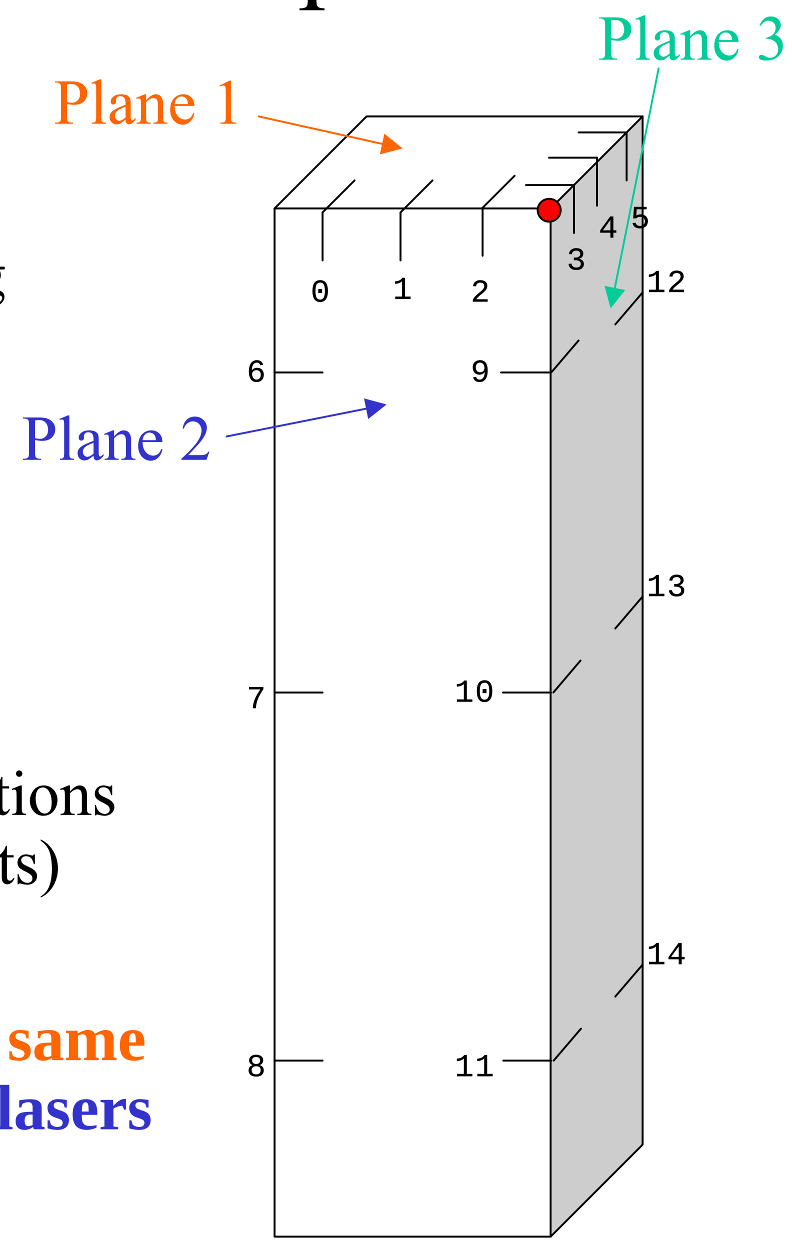


Schematic drawing –
Diagram not drawn to scale

Problems with post measurements: to be discussed later

Transforming different laser positions

- Measure 5 edges of each post
(3 scans are made on each edge)
- Determine 3 planes by plane fitting
  - Fit the planes individually, or
  - Require that the planes are mutually perpendicular
- Determine the corner from the intersection of the 3 planes
- Deduce other corners and ball positions (to match global laser measurements) using the planes determined
- **Now we have the positions of the same corners with respect to different lasers (or laser positions)**



Transforming different laser positions

- Transformation between different laser positions:

$$\mathbf{x}_a = \mathbf{R}\mathbf{x}_b + \mathbf{d}$$

where $\mathbf{x}_a$ and $\mathbf{x}_b$ are the same point in space relative to different laser positions

- Rotation Matrix (**R**)
  - Characterized by 3 Euler angles: θ_x, θ_y and θ_z

$$\mathbf{R} = \mathbf{R}(\theta_x)\mathbf{R}(\theta_y)\mathbf{R}(\theta_z)$$

- Translation vector (**d**)
  - Characterized by 3 vector components d_x, d_y, and d_z

$$\mathbf{d} = (d_x, d_y, d_z)$$

- Altogether **6** parameters to be determined

Transforming different laser positions

- Results: Laser 0 → Laser 2
  - Rotation: $(\theta_x, \theta_y, \theta_z) = (-0.16^o, -0.30^o, -0.00^o)$
  - Translation: $(d_x, d_y, d_z) = ($-401.59 mm, 0.58 mm, -1.17 mm)

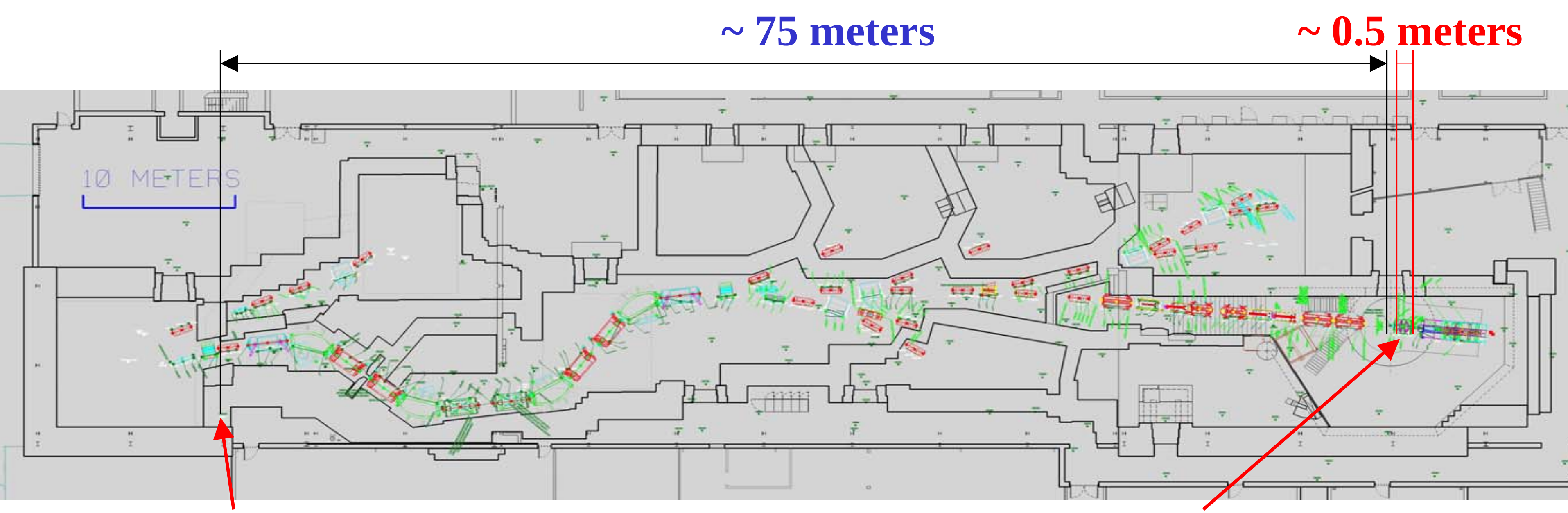
We moved the laser ~ 40 cm along beam direction from laser 0 to laser 2

The aluminum plate is not flat!

- Laser 1 → Laser 2 cannot be determined from fitting as the data is insufficient
  - Only the translation vector is calculated (by subtracting the two laser measurements on the same point)
  - Translation: $(d_x, d_y, d_z) = (123.15 \text{ mm}, -0.84 \text{ mm}, 0.15 \text{ mm})$

Transforming into global coordinates

- Matching LBAS measurements with global measurements (by Dave Sanderson's laser), using its ball measurements
- We can then know the position of our apparatus relative to the entire laboratory – important to relate our apparatus to the magnetic elements of the S800 spectrometer for beam tracking.



Origin of the global laser

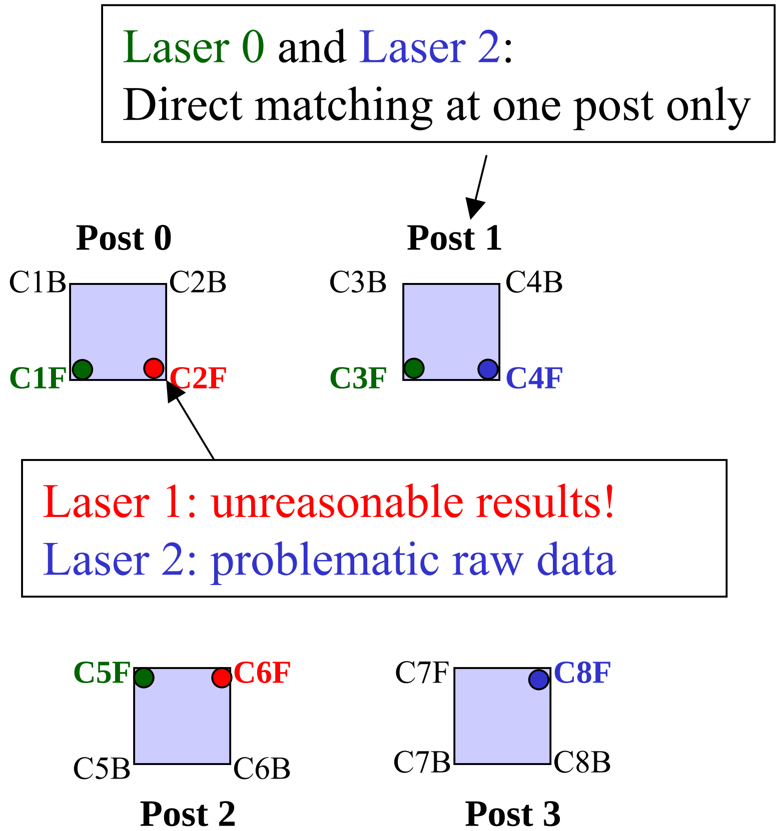
We are here! Distance scale ~ 0.5 m

Transforming into global coordinates

- Same procedure as transforming different laser positions
- Results: Dave → Laser 0
  - Rotation: $(\theta_x, \theta_y, \theta_z) = (0.21^o, 0.01^o,$ **5.68^o**$)$
  - Translation: (d_x, d_y, d_z) = (-74728.3 mm, -14487.8 mm, 5585.4 mm)
- Results: Dave → Laser 2
  - Rotation: $(\theta_x, \theta_y, \theta_z) = (0.01^o, -0.06^o,$ **5.47^o**$)$
  - Translation: (d_x, d_y, d_z) = (-75191.7 mm, -14193.2 mm, 5512.7 mm)
- S800 beam line angle (Dave) : **5.46^o**
  - Laser 2 measurements show a better agreement with Dave's results

Problems with reference measurements

- Post measurements: **not enough or too many errors**!
  - 1 (out of 2) corner determination of laser 1 has to be discarded
  - 1 (out of 3) corner determination of laser 2 has problems in raw data
  - Global laser measurements on post 2 (both post and ball) are problematic
- The balls and corners are **too far apart**
  - Larger error introduced when deducing ball positions from corner positions
- All posts at the **same height**
  - The fitting would be too sensitive to errors in vertical direction

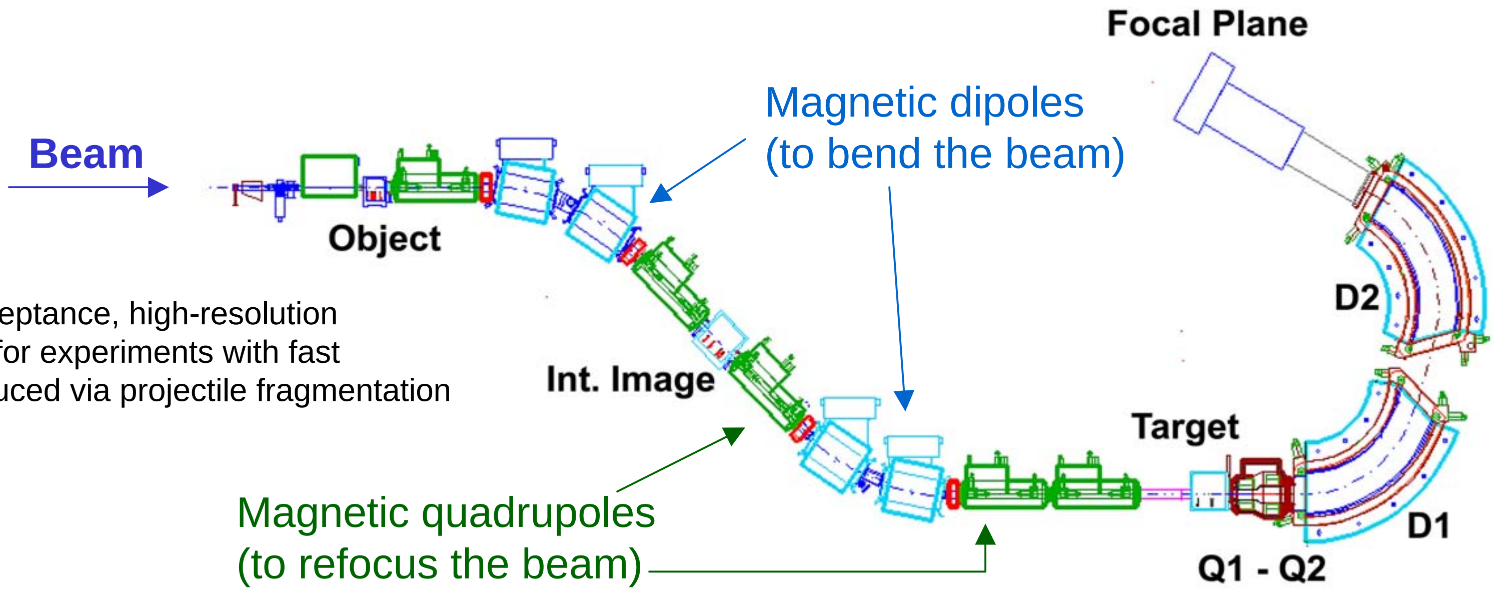


Corners determined from least square fitting:

- **Laser Position 0 (Measure MCP 0 and Target Mask)**
- **Laser Position 1 (Measure MCP 1)**
- **Laser Position 2 (Measure HiRA)**

S800 Spectrograph

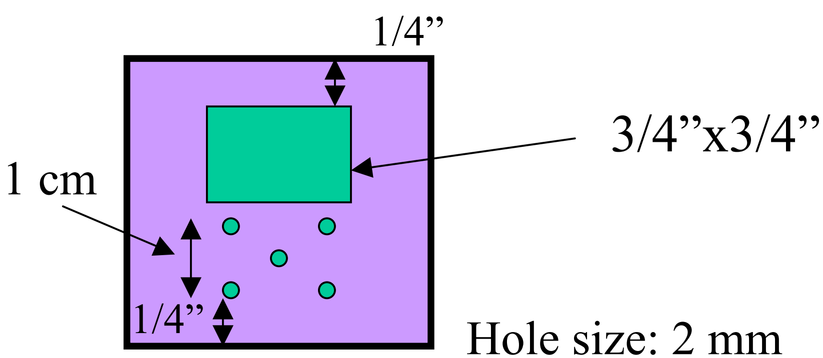
- Separate the residue from beam
- Measure residue properties (e.g. momentum)
- Beam tracking (to determine beam angle and position at the time of collision) requires the knowledge of the S800 magnetic elements including their position relative to the target.



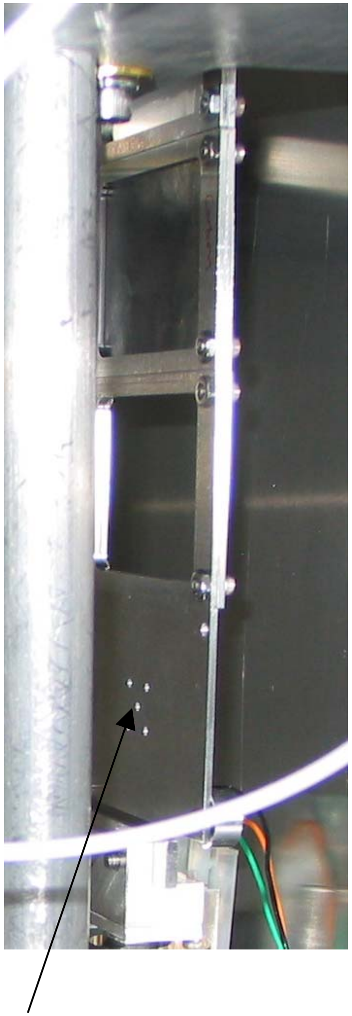
The S800 is a large-acceptance, high-resolution spectrograph designed for experiments with fast radioactive beams produced via projectile fragmentation

Target

- $(CH_2)_n$ target of different thickness
- Large target to accommodate large beam spot
- During experiment, the target can be changed using a target ladder
- Center of the target is found using a target mask, which has 5 holes on it
- Need to determine the center of each hole
- Center of the target = position of center hole



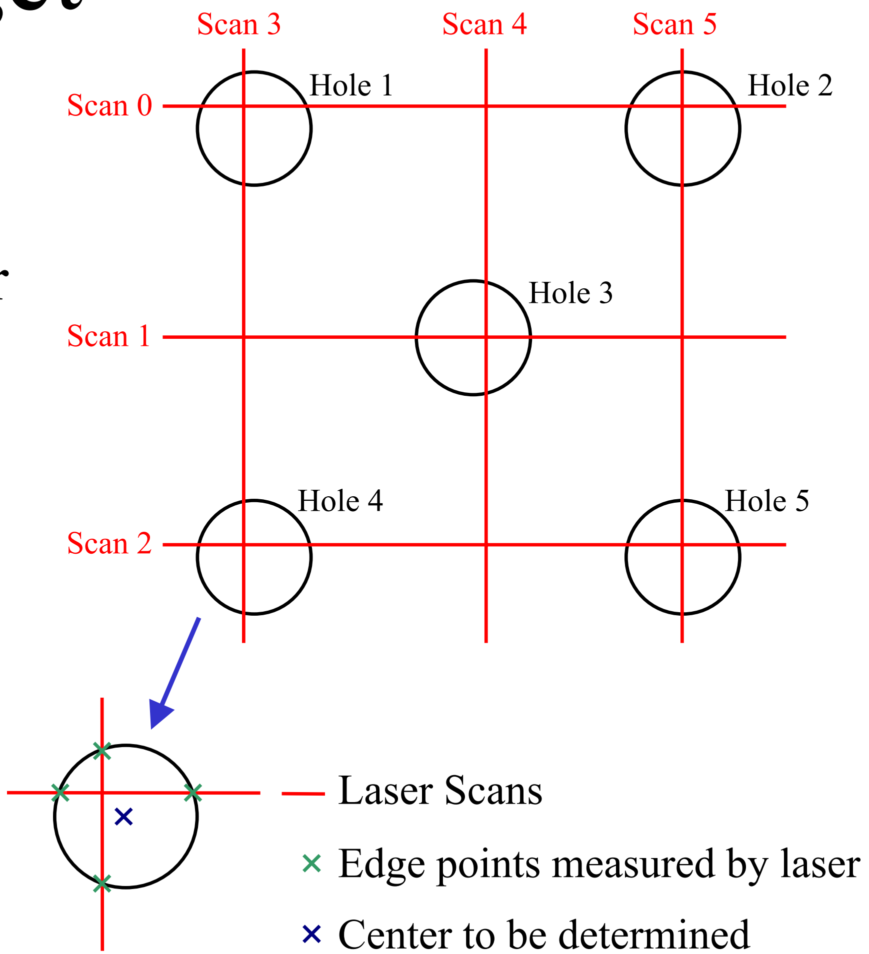
Hole size: 2 mm



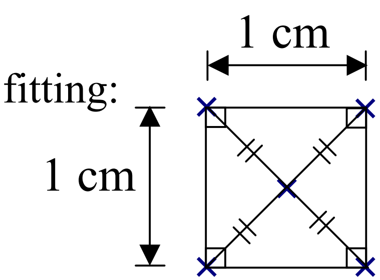
A hole on the target mask

Target

- 2 scans on each hole, giving 4 edges points each
- Plane fitting to find the plane for all edge points
- Obtain a first-order estimate of the centers by averaging the scanned edge points
- Use fitting to find a better estimate, requiring
  - All centers lie on the plane determined
  - Distance between centers fixed
  - Right angle at 4 corners



Constrains imposed in fitting:

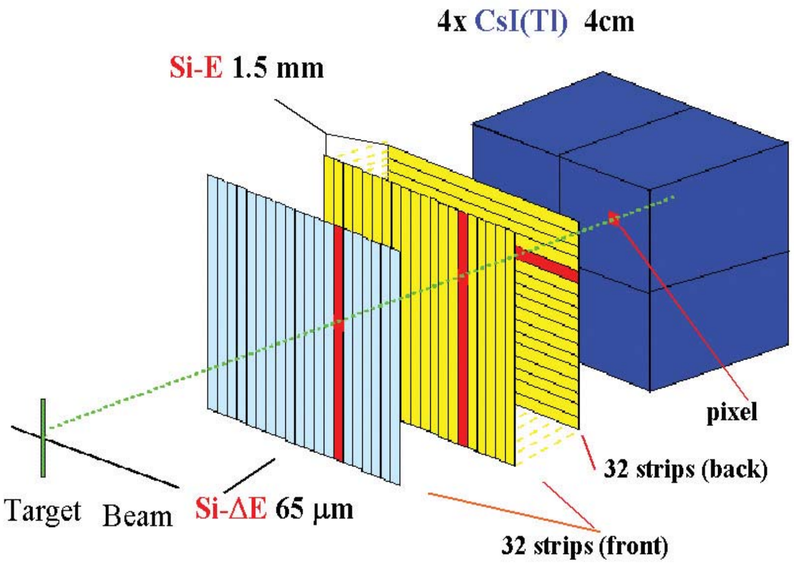


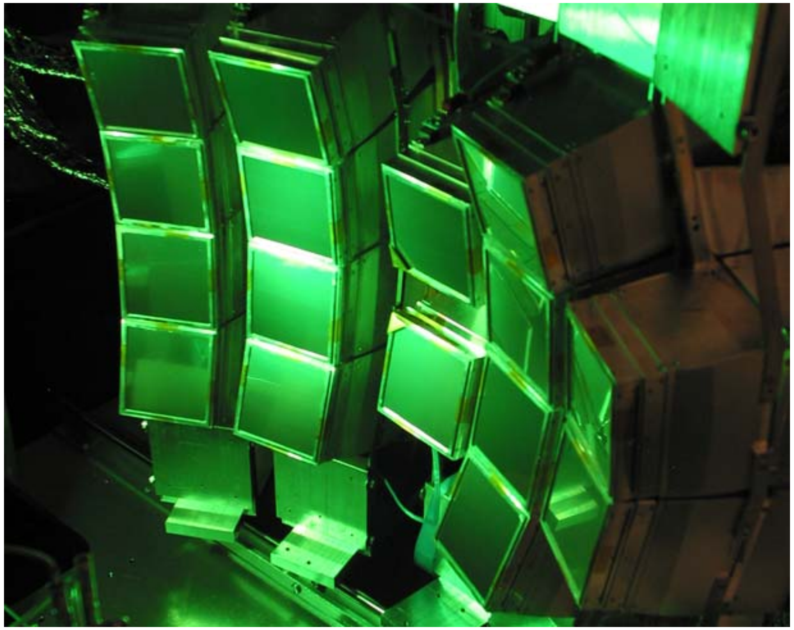
Target

- Results
  - 1~2 data points (among 20) found to be problematic from plane fitting
  - Target mask tilted by 0.7^{o} with respect to the beam
  - Small discrepancy (< 0.2 mm) between first-order estimate and refined estimate
- Problems in determining the radius of the hole
  - The holes appeared to be elliptic instead of circular
  - May due to the distance from laser to target mask (~ 36 cm apart)
  - Asymmetric shape of the finite-size laser beam spot?

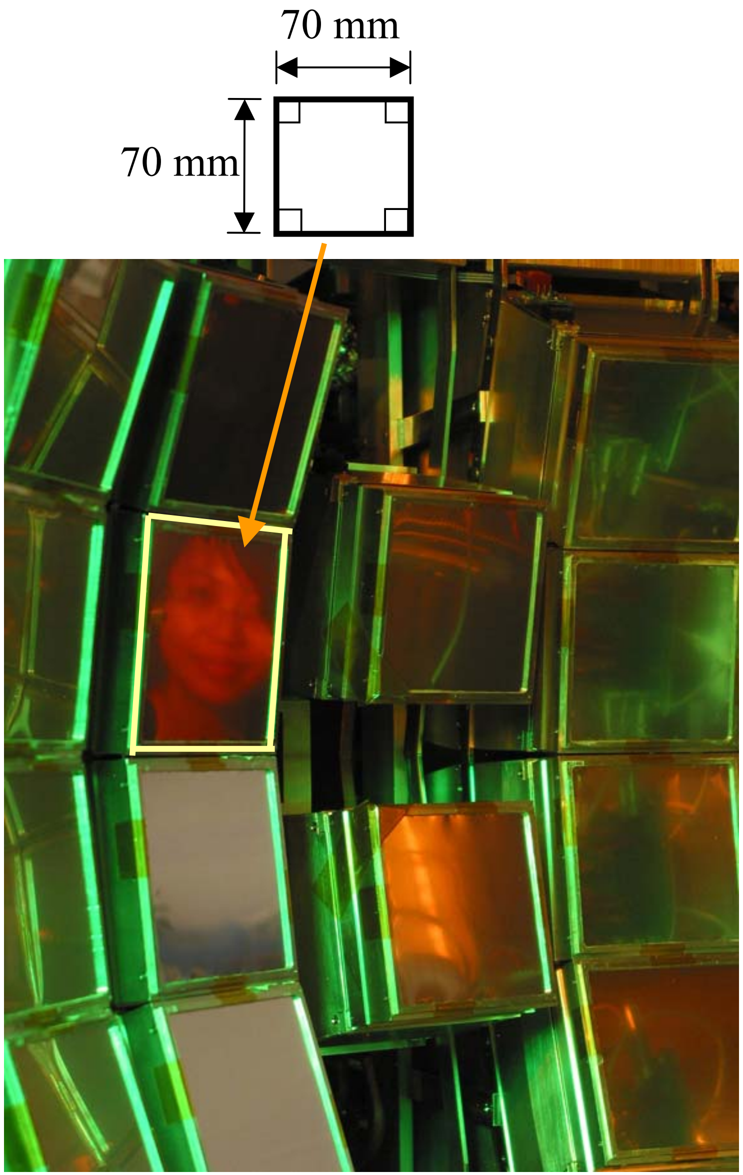
HiRA Detectors

- The **Hi**gh **R**esolution **A**rray
- Detect the light particles (deuteron, proton, ^{3}He etc.) produced in the reaction.
- 16 telescopes, all ~35 cm away from the target and facing target
  - Each telescope contains 2 Silicon detectors plus 4 CsI.
  - E (middle) detector has 32 strips arranged vertically and horizontally, forming 32×32 = 1024 pixels, each with size ~2 mm × 2 mm
- Need to know the position of every pixel relative to the target, in order to determine the scattering angle





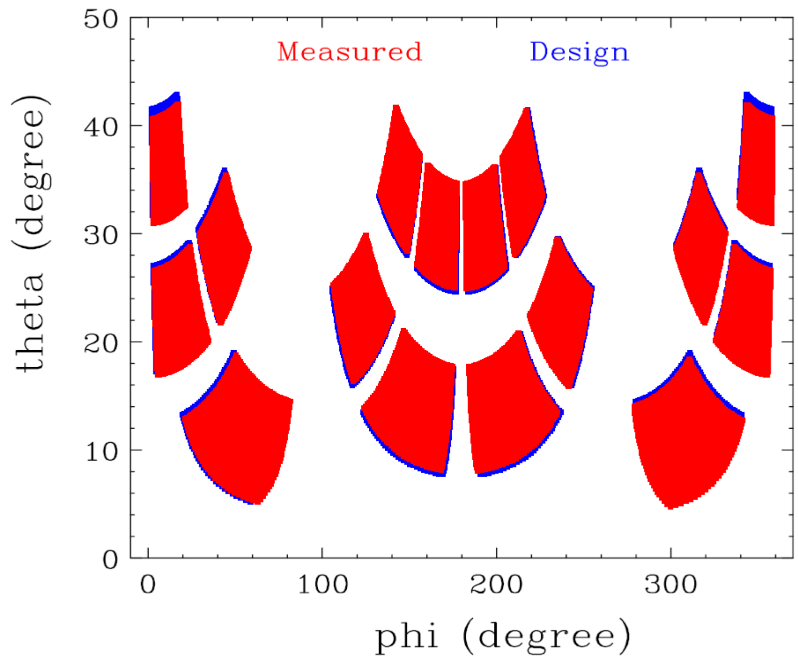
LBAS measurements of HiRA Detectors

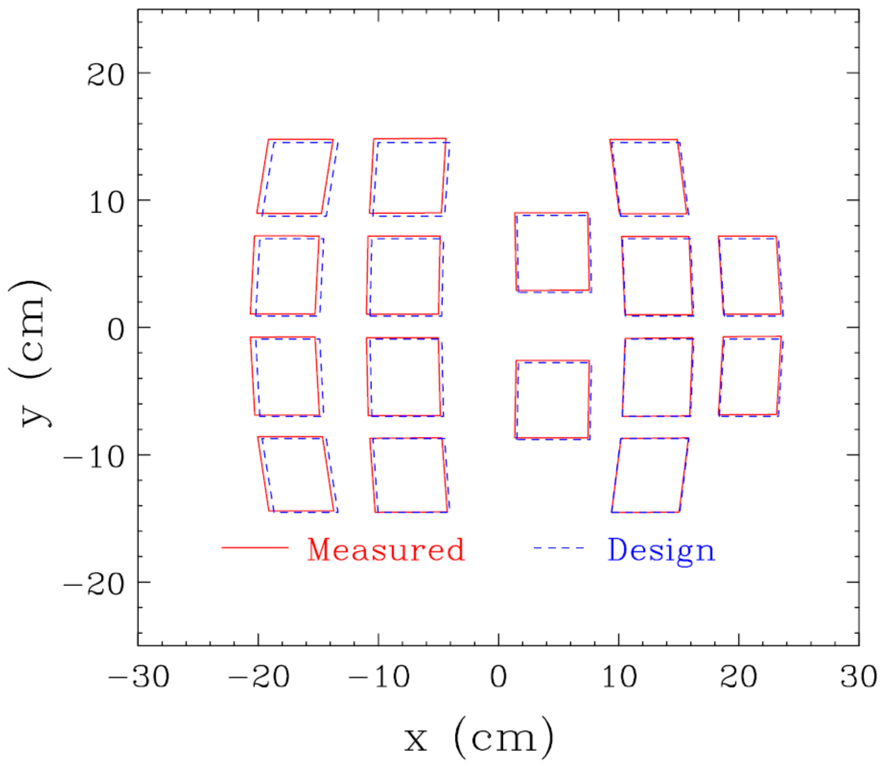


- Measure the frame of each telescope (3 scans on each side of the frame)
- Determine the 4 corners by fitting
- Require the 4 corners to form a square
  - Lying on the same plane
  - Equal side length
  - Right angles at each corner
- Deduce the pixel positions using mechanical drawings
- Transform the pixels into the target frame
- Compare with design

HiRA Detectors

- Results: comparison with design
  - Most of them in good agreement
  - Some of the telescopes are off by 1 to 2 strips

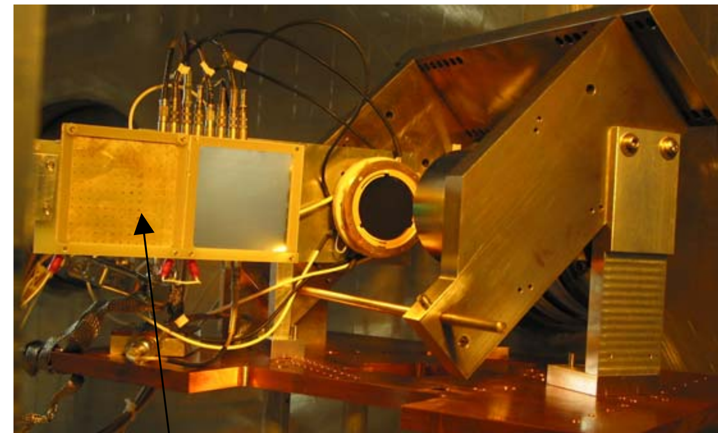




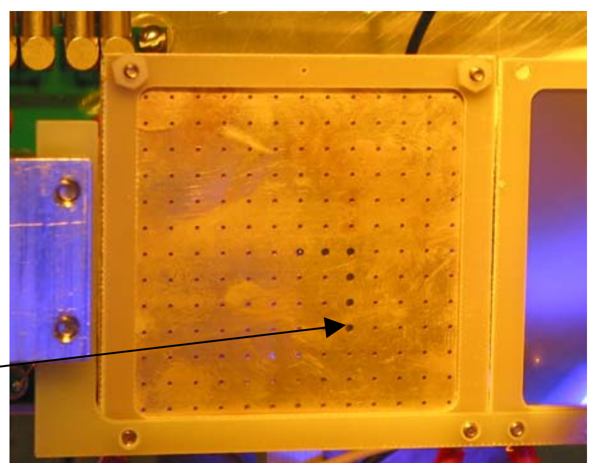
- Distance from center of telescope (Si face) to target: 35.97 cm (discrepancy less than 0.12 cm; 35.5 cm by design)
- Telescopes do not face the target exactly; tilt < 2.6^{o}
- Systematic discrepancies – distortion in mounting structure

Micro-Channel Plate (MCP) Detector

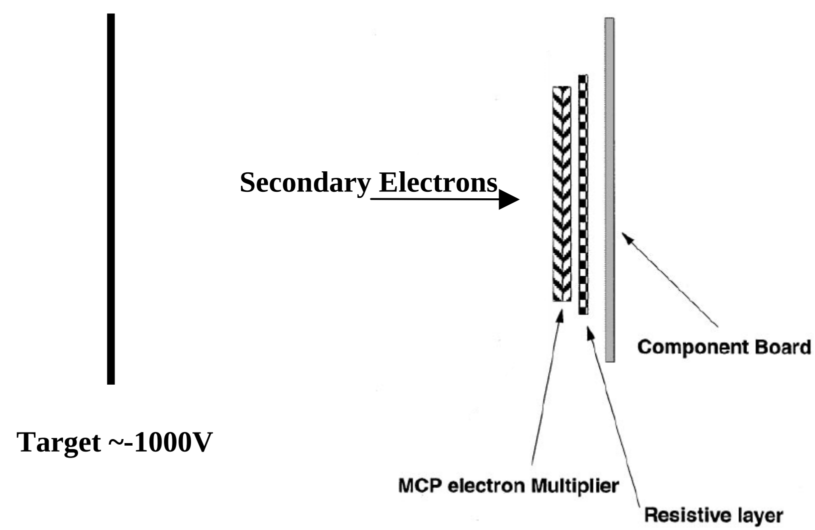
- Provide position and timing information of an ion traversing the target
- The beam position can be calibrated using a MCP mask
- The 6 larger holes of the MCP mask are measured with laser



MCP mask



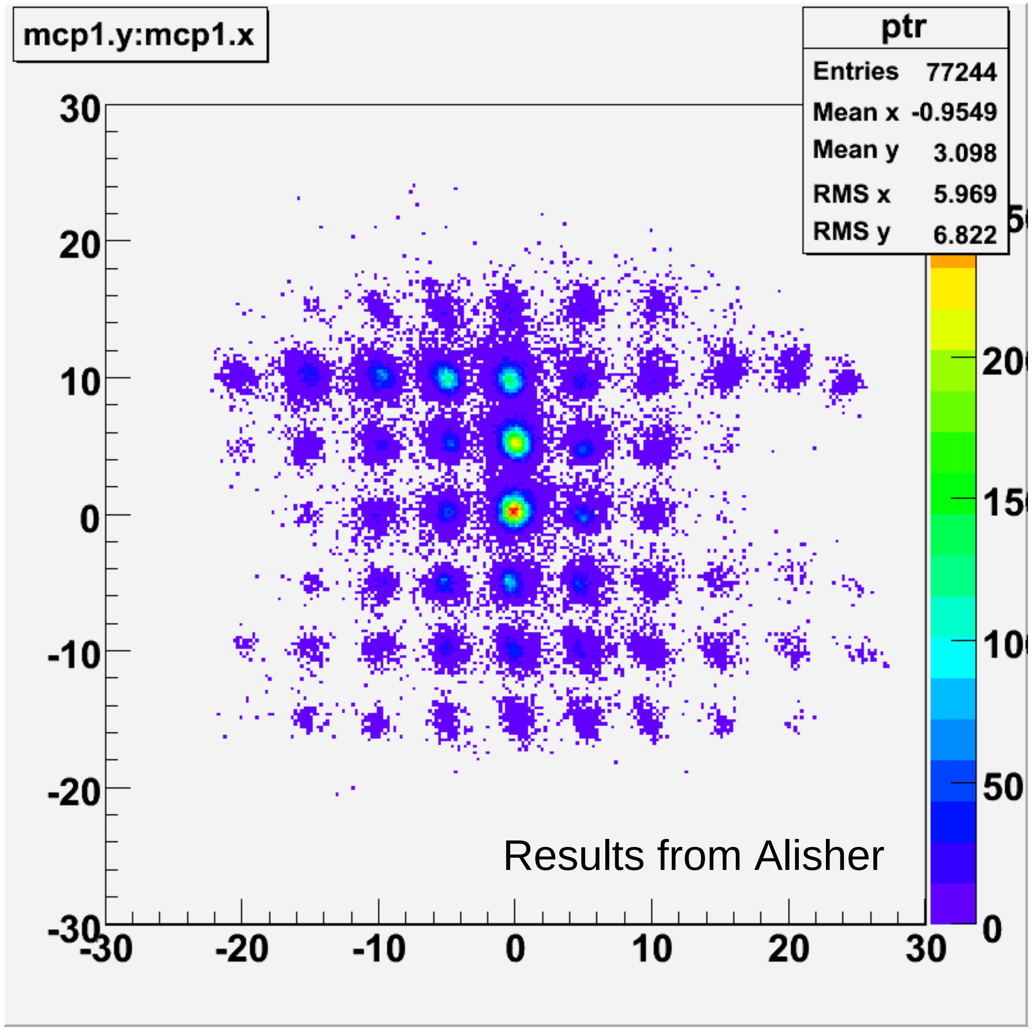
Larger holes (5 mm spacing between holes)



Micro-Channel Plate (MCP) Detector

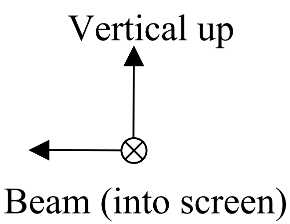
Calibration of MCP

- Need to convert the coordinates (used in analysis) here into global coordinates for beam tracking
  - To determine the exact position, angle where the beam hits the target
  - Especially important when the beam size is large (~ 2-3 cm in diameter for radioactive beam such as ^{56}Ni)

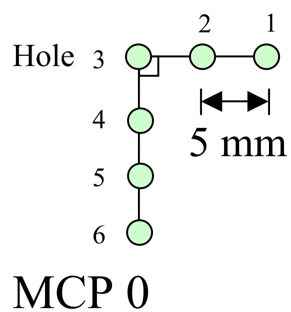


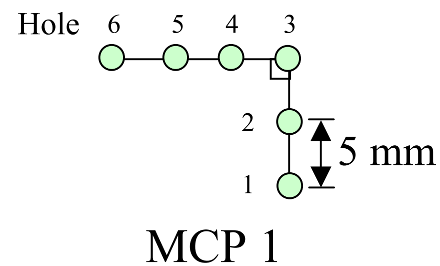
Micro-Channel Plate (MCP) Detector

- Same method as the target
  - Data: 4 edges points on each hole
  - Analysis: Plane fitting → estimate center → refine estimate by fitting with constrain



Configuration of the larger holes:



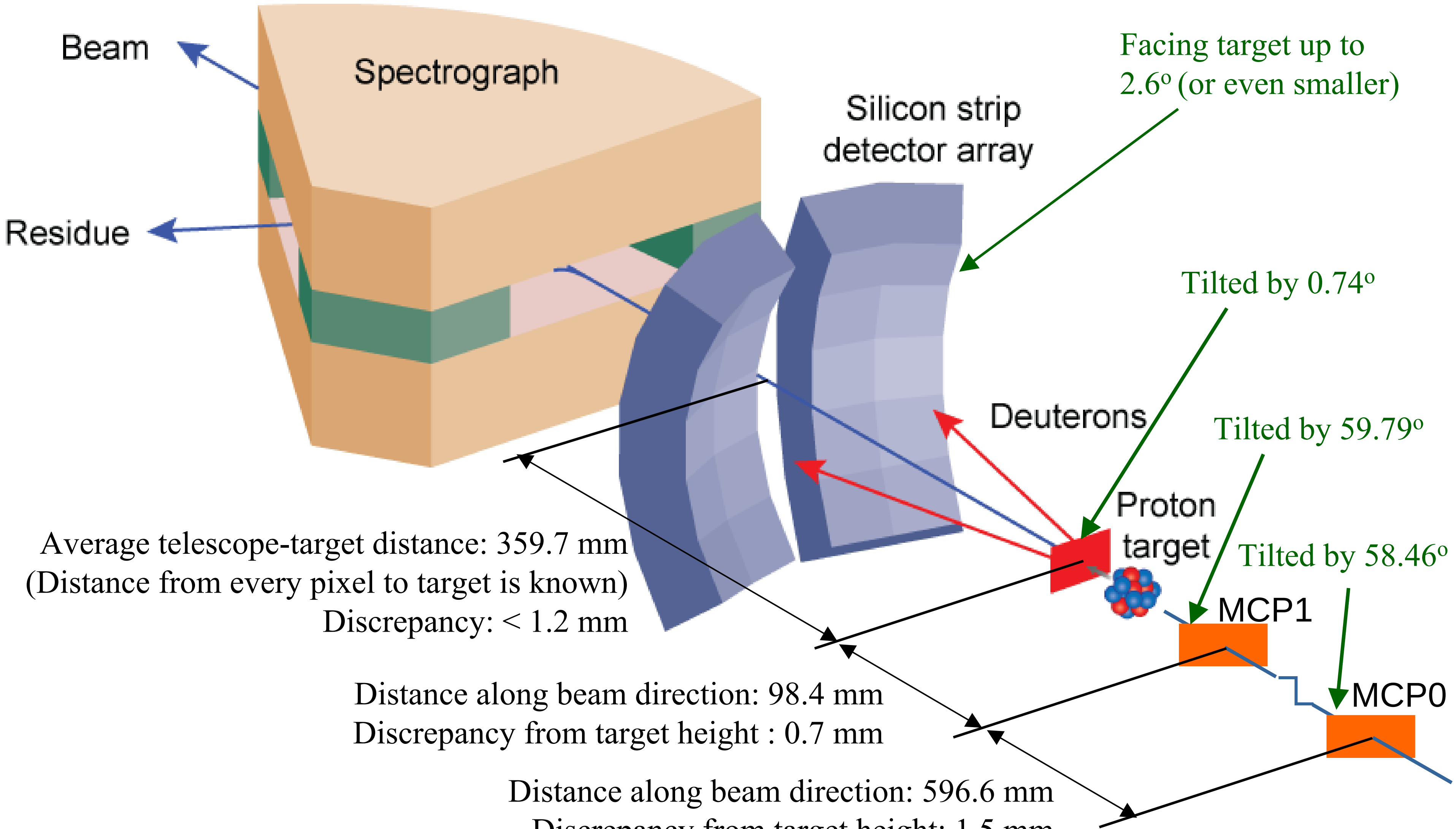


- Results
  - Angle between MCP and beam: 58.46^{o} for MCP 0, 59.79^{o} for MCP 1
  - ~ 1.5 mm off in height between target and MCP 0
  - ~ 0.7 mm off in height between target and MCP 1
  - The radius of the holes are better determined compared with target mask

Conclusion

- LBAS measurements can achieve ~ 0.3 mm accuracy, using the analysis method mentioned here
- The approach used here is systematic and general, and can be applied to other experiments
- Problematic measurements:
  - Global laser measurements: 1 post (out of 4)
  - Post measurements (LBAS):
    - Position 1: 1 post (out of 2)
    - Position 2: 1 post (out of 3)
  - Target measurements: ~ 10%
  - HiRA measurements: ~ 5%
  - MCP measurements: ~ 0% (!)

Experimental setup



Suggestions

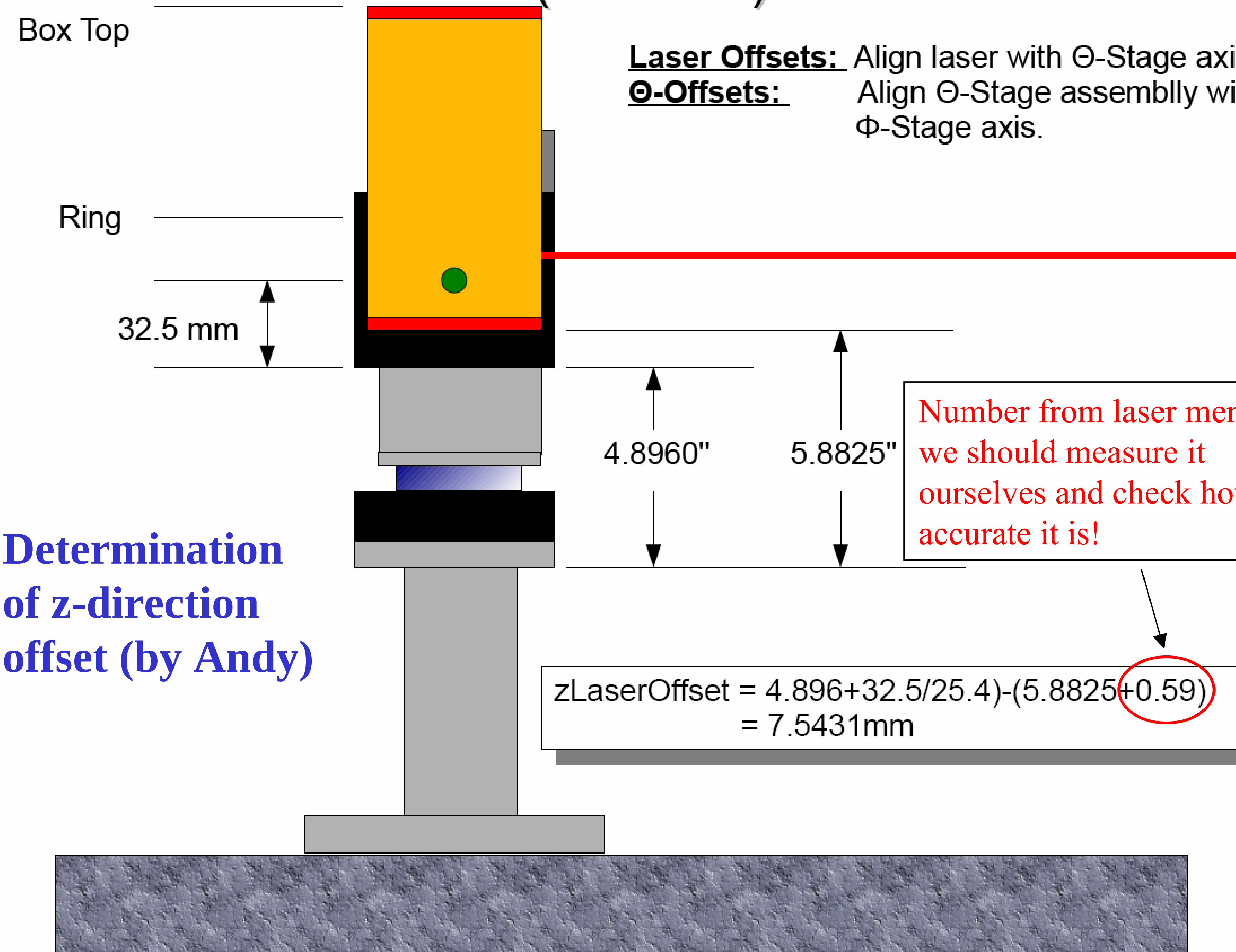
- Study the performance of LBAS laser in more detail
  - Off points are frequently encountered on scans across smooth surfaces
  - The accuracy of the laser varies with range
- Data analysis of LBAS should be done promptly after measurements
- The reference objects should be redesigned
  - Should accommodate corner measurement (for LBAS) and ball measurement (for global laser)
  - Design posts with different heights
- Cross-checking for the laser offset correction
- New Excel fitting package available!

Measurement Method (Z-Offset)

**Not to scale*

Laser Offsets: Align laser with Θ-Stage axis.

Θ-Offsets: Align Θ-Stage assemblly with Φ-Stage axis.



Number from laser menu; we should measure it ourselves and check how accurate it is!

zLaserOffset = 4.896+32.5/25.4)-(5.8825+0.59)
= 7.5431mm

Determination of z-direction offset (by Andy)

~ The End ~

Transforming different laser positions

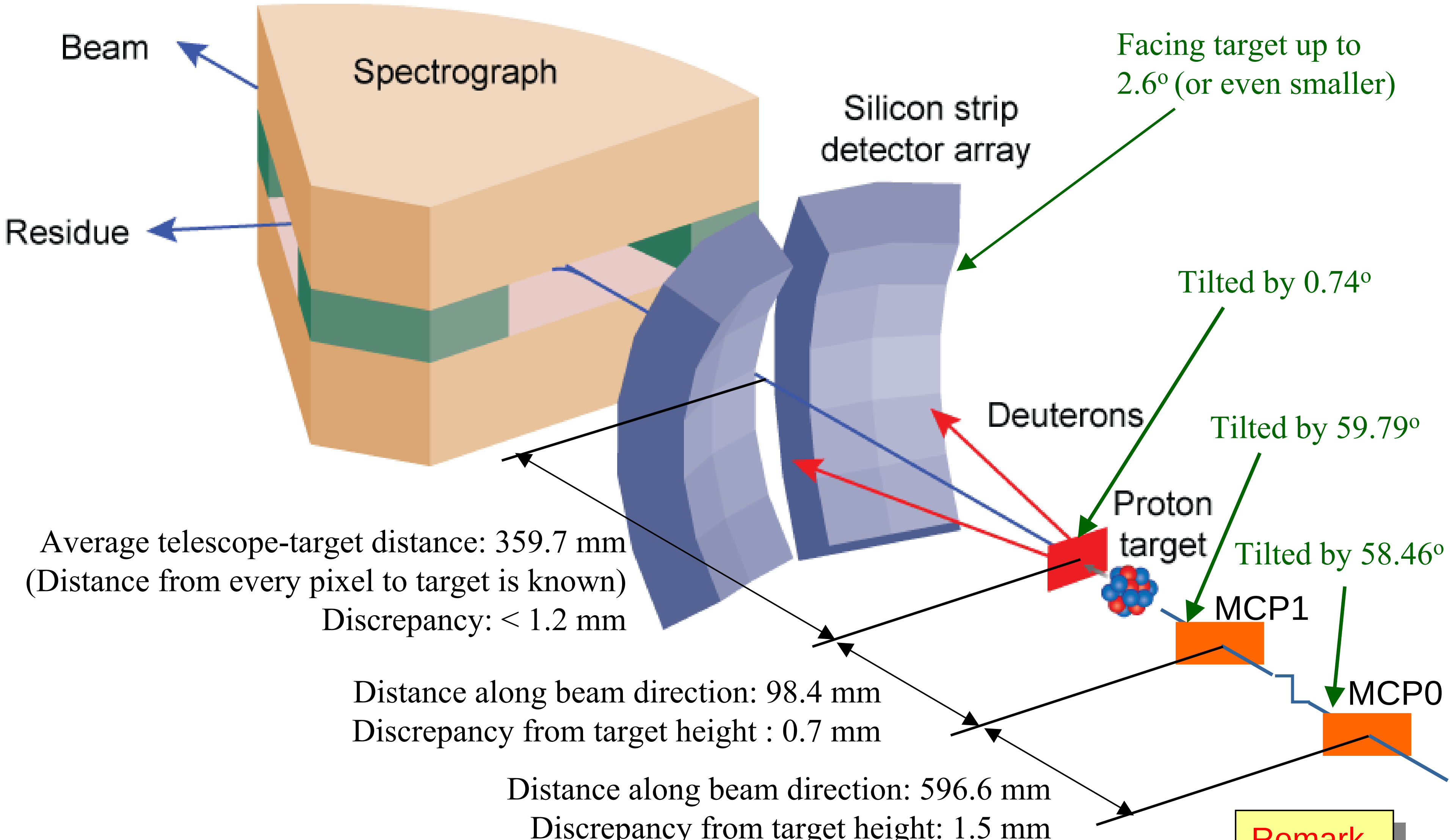
- The parameters of transformation are determined from least square fitting
  - Minimizing the discrepancy

$$\chi^2 = \sum_i \left\| \mathbf{x}_{ai} - \mathbf{R}\mathbf{x}_{bi} - \mathbf{d} \right\|^2$$

where $\mathbf{x}_{ai}$ and $\mathbf{x}_{bi}$ are measurements of a point i relative to different laser positions

Backup slide

Actually…the MCPs are tilted the other way!
(but I found it hard to draw that way…)



Remark