INTT Physical Measurements

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Goal

- Obtain the parameters for the affine transform that will put each sensor in its final position
  - Account for deviations from nominal introduced by manufacturing and assembly processes

Procedure

The transform that puts the sensor to its final position is the same as the transformation matrix from the sensor’s local coordinate system to the sPHENIX global coordinate system.

Compute the final transform as a sequence of transforms

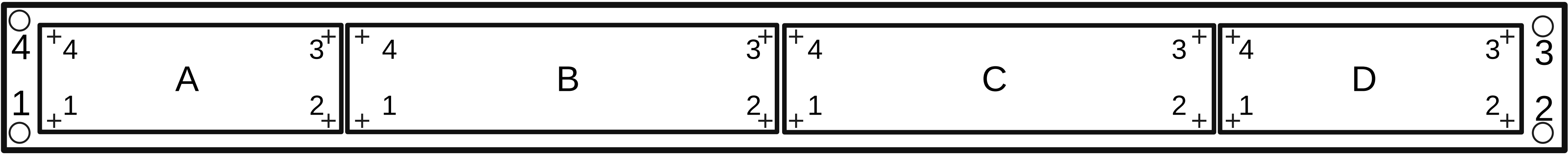
(sensor -> ladder) (ladder -> barrel) (barrel -> global)

- For each step, use survey data to find the actual values of these transforms
- Compare the actual transforms with nominal transforms for quality assurance

Timeline

Done	Next Week (Hopefully)	Final Assembly
(sensor -> ladder)	(ladder -> barrel)	(barrel -> global)

Sensor-Ladder Transform



- 4 Holes at each corner of the ladder (1 – 4 starting low-left and going CCW)

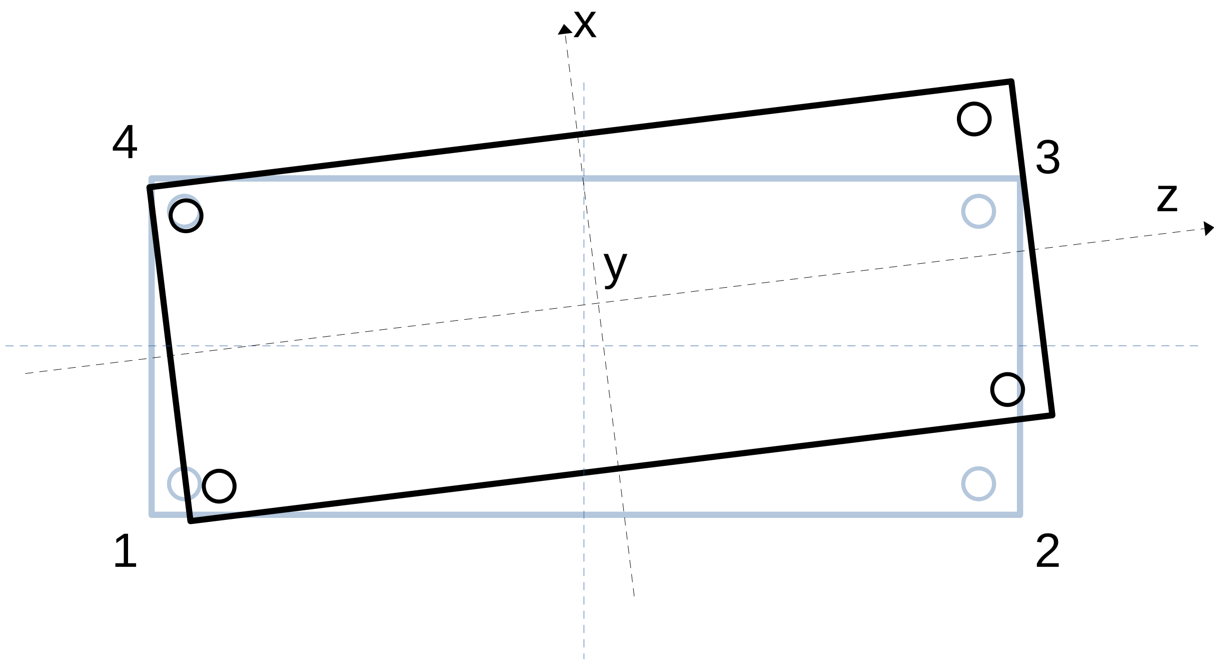
- 4 Sensors (A – D going from -z to +z)
  - Each sensor has 4 marks (crosses) (1 – 4 starting low-left and going CCW)

- The measured positions of these points will provide the transforms of the ladder and sensors to a common, measurement frame
  - Then we know the sensor to ladder transform by knowing each one's transform to a common frame

Computing Measured Transforms

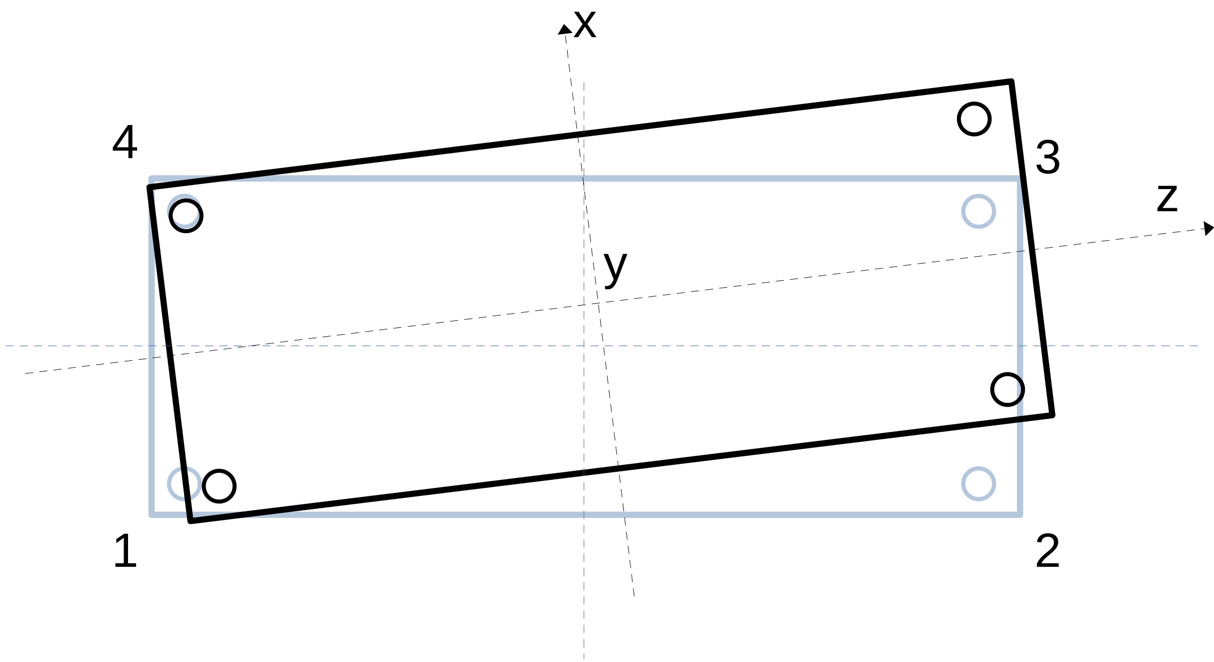
- Used diagonals to find measured coordinate system
  - +z || (u 1->3) - (u 2->4)
  - +x || (u 1->3) + (u 2->4)
  - +y = (+z) cross (+x)
    - (u i->j) is a unit vector pointing from corner i to corner j

- Therefore:
  - Measured coordinate axes are the columns of the 3D rotation matrix that rotates from local frame to measurement frame



Computing Measured Transforms

- Used the average of measured corners as the measured center
- This is the translation (in the measurement frame) that should be applied after applying the rotation from previous slide
- The 4D affine transformation matrix is the rotation matrix augmented with this translation



Transform Parameters

- The 4D affine transformation matrix has the following form:

$$\begin{bmatrix} & [R] & & dx \\ & & & dy \\ & & & dz \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

- dx, dy, dz are the Cartesian translation between coordinate system origins

- [R] is the rotation matrix that transforms a vector in the child system to the parent system

- Equivalently, [R] is the rotation applied to the child system, if it started as aligned with the parent system, to achieve its final orientation

Transform Parameters

- The 4D affine transformation matrix has the following form:

$$\begin{matrix} & & & dx \\ & [R] & & dy \\ & & & dz \\ 0 & 0 & 0 & 1 \end{matrix}$$

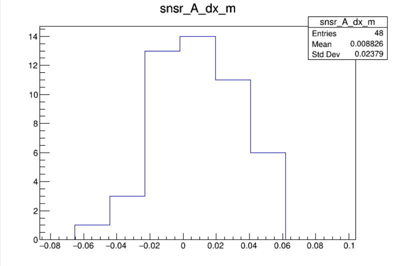
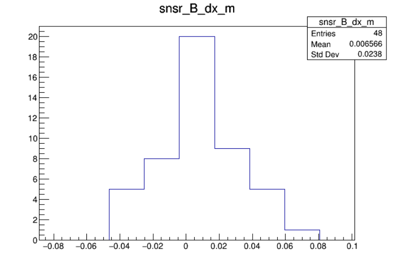
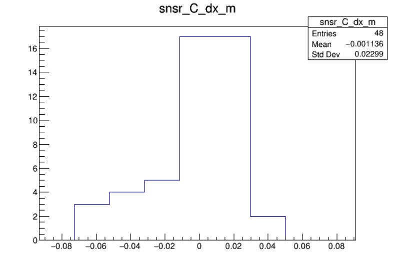
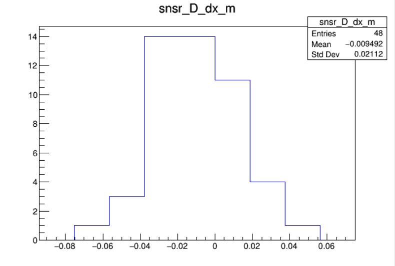
- [R] is parameterized by Tait-Bryan angles alpha, beta, gamma

- Rotate gamma about z axis
- Rotate beta about new y axis
- Rotate alpha about new x axis

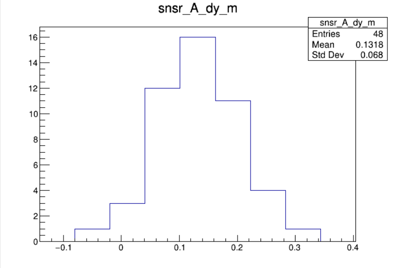
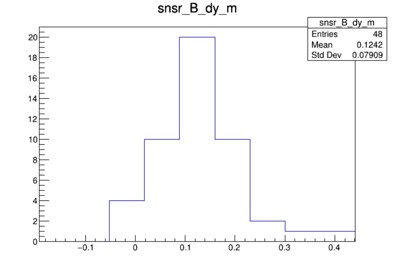
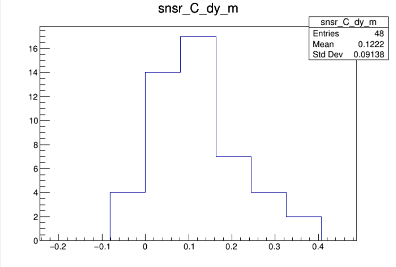
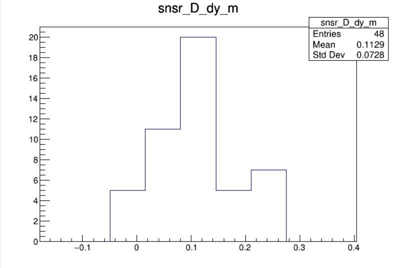
$X_1 Y_2 Z_3$	$\alpha = \arctan\left(\frac{-R_{23}}{R_{33}}\right)$ $\beta = \arctan\left(\frac{R_{13}}{\sqrt{1 - R_{13}^2}}\right)$ $\gamma = \arctan\left(\frac{-R_{12}}{R_{11}}\right)$

https://en.wikipedia.org/wiki/Euler_angles#Tait%E2%80%93Bryan_angles

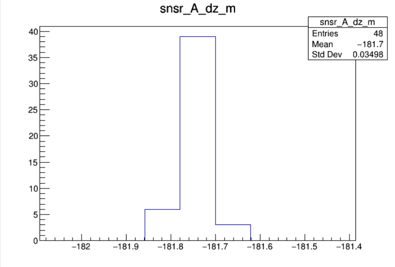
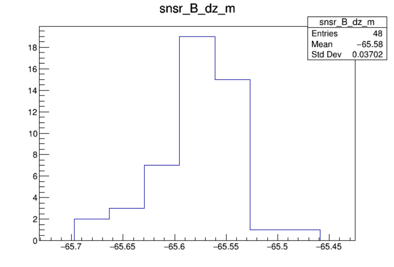
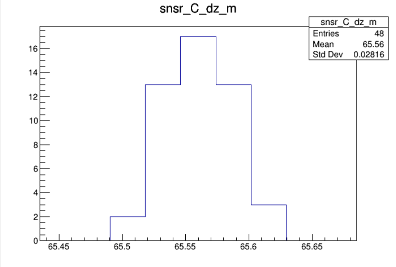
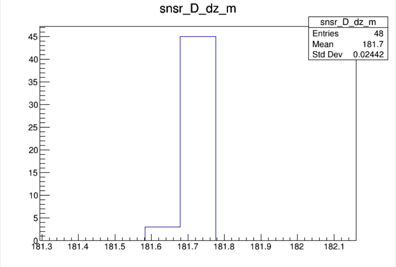
dx Distribution

	Sensor A	Sensor B	Sensor C	Sensor D
mean (um)	8.8	6.6	-1.1	-9.5
std. dev. (um)	23.8	23.8	23.0	21.1
plot (mm)				

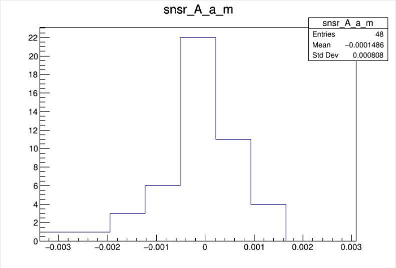
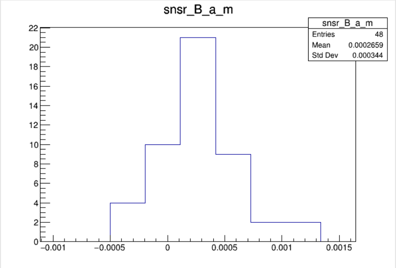
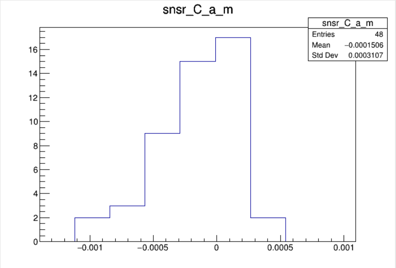
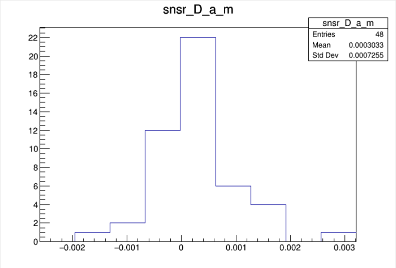
dy Distribution

	Sensor A	Sensor B	Sensor C	Sensor D
mean (um)	131.8	124.2	122.2	112.9
std. dev. (um)	68.0	79.1	91.4	72.8
plot (mm)				

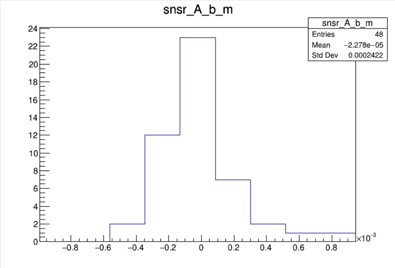
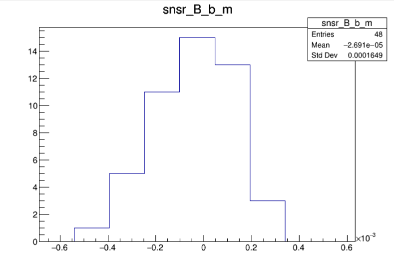
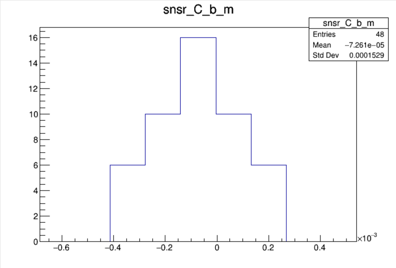
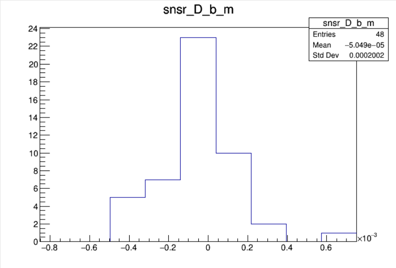
dz Distribution

	Sensor A	Sensor B	Sensor C	Sensor D
mean (mm)	-181.7	-65.58	65.56	181.70
std. dev. (um)	35.0	37.0	28.2	24.4
plot (mm)				

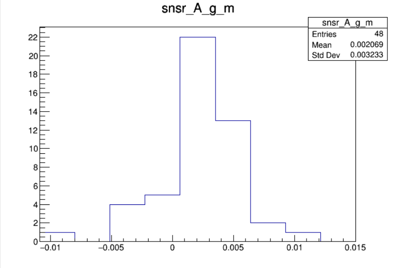
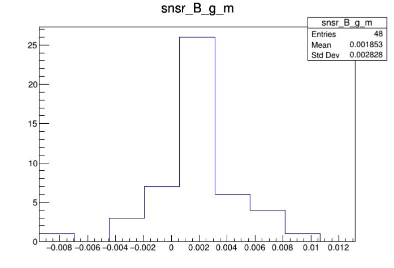
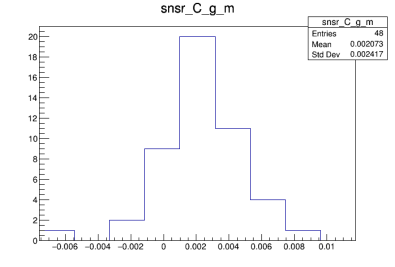
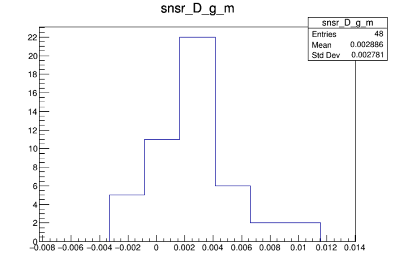
alpha Distribution

	Sensor A	Sensor B	Sensor C	Sensor D
mean (mrad)	-0.15	-0.27	-0.15	0.30
std. dev. (mrad)	0.81	0.34	0.31	0.73
plot (rad)				

beta Distribution

	Sensor A	Sensor B	Sensor C	Sensor D
mean (mrad)	-0.02	-0.03	-0.07	-0.05
std. dev. (mrad)	0.24	0.16	0.15	0.20
plot (rad)				

gamma Distribution

	Sensor A	Sensor B	Sensor C	Sensor D
mean (mrad)	2.07	1.85	2.07	2.89
std. dev. (mrad)	3.23	2.82	2.42	2.78
plot (rad)				

Notes on Results

- These are the parameters for the full transform from the sensor's frame to the ladder's frame
  - Therefore, each parameter should not necessarily have a mean of 0
  - However, all standard deviations should be small and indicate precision of assembly

- dz is the actual translation of each sensor along the ladder; ideally
  - dz = -181.75mm for sensor A
  - dz = -65.55mm for sensor B
  - dz = 65.55mm for sensor C
  - dz = 181.75mm for sensor D

- Other parameters should have mean 0

Conclusions

- Distributions of transform parameters are roughly bell-shaped
    - Nothing multi-modal or anomalous to suggest a systematic defect

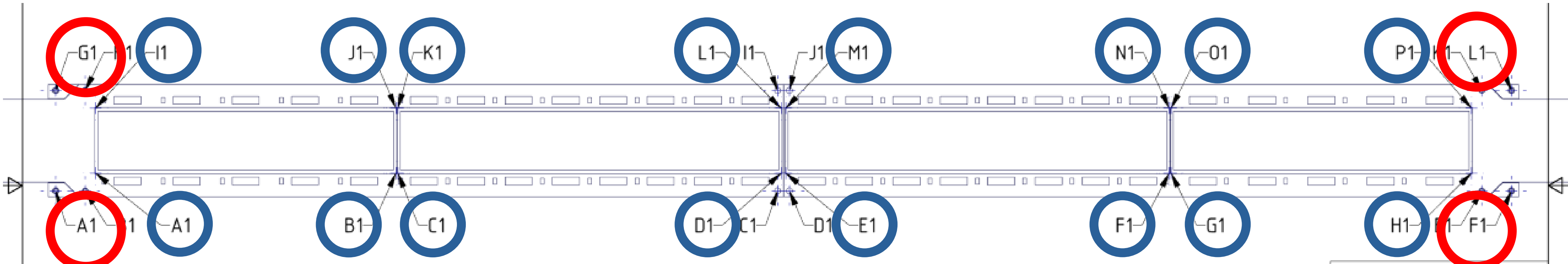
- Standard deviations of the spatial translations were on the order of ~30um
    - dy is slightly larger (expected)
- Indicate very precise placement of sensors on the ladder

- Standard deviations of the angular rotations were at worst on the order of ~2mrad

- Overall precision of spatial parameters is very good

Backup Slides

Nominal Ladder Marks



Hole Table

HOLE	XDIM	YDIM
A1	0.0000	0.0000
B1	10.0000	0.0000
C1	244.0000	0.0000
D1	248.0000	0.0000
E1	482.0000	0.0000
F1	492.0000	0.0000
G1	0.0000	34.0000
H1	10.0000	34.0000
I1	244.0000	34.0000
J1	248.0000	34.0000
K1	482.0000	34.0000
L1	492.0000	34.0000

Mark Table

Mark	XDIM	YDIM
A1	13.5000	6.0000
B1	115.0000	6.0000
C1	115.7000	6.0000
D1	245.2000	6.0000
E1	246.8000	6.0000
F1	376.3000	6.0000
G1	377.0000	6.0000
H1	478.5000	6.0000
I1	13.5000	28.0000
J1	115.0000	28.0000
K1	115.7000	28.0000
L1	245.2000	28.0000
M1	246.8000	28.0000
N1	376.3000	28.0000
O1	377.0000	28.0000
P1	478.5000	28.0000

A

A

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Image credit:
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