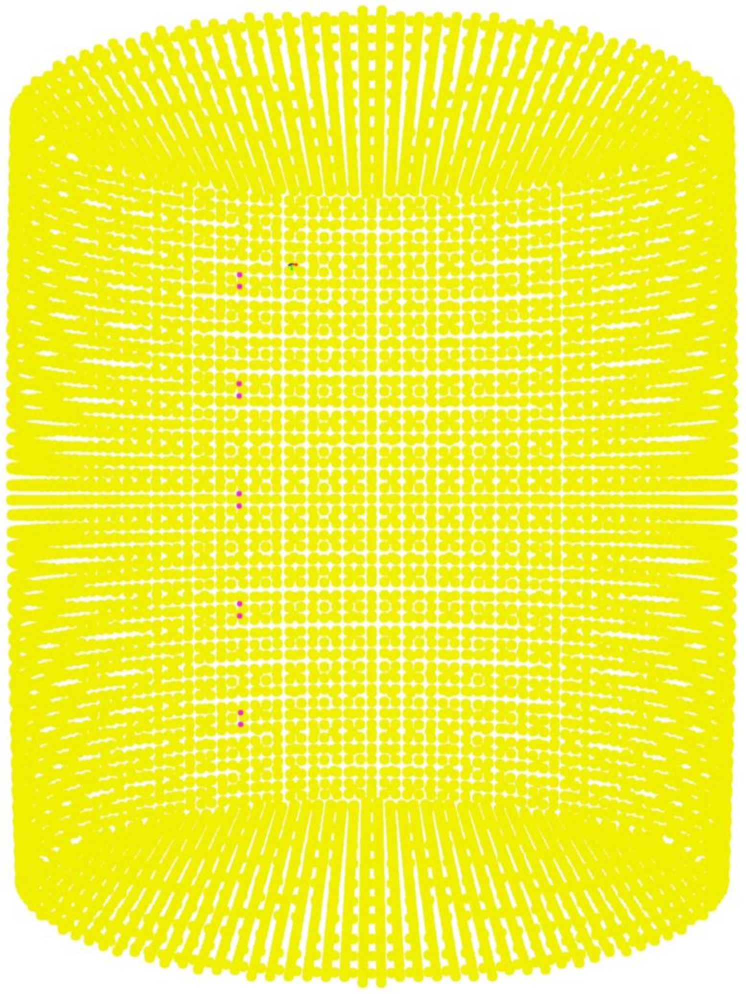
Aug 23, 2021

Feature Recognition and labelling for Photogrammetry Calibration of the Super-Kamiokande Detector



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Acknowdgements:
Supervisor: Blair Jamieson
Ali Ajmi

Github

Introduction

Neutrino

- Subatomic particle, similar to an electron (but no electrical charge).
- One of the most abundant particles in the universe.
- Incredibly difficult to detect.

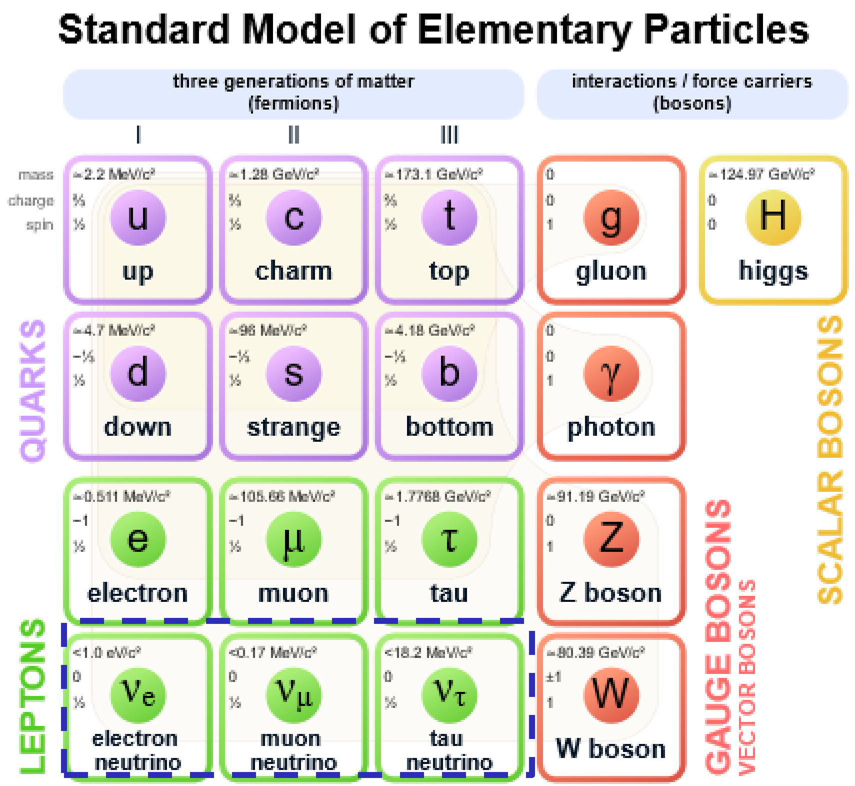


Fig: standard model[1]

How is neutrino detected?

Super Kamiokande (Super-K)

1

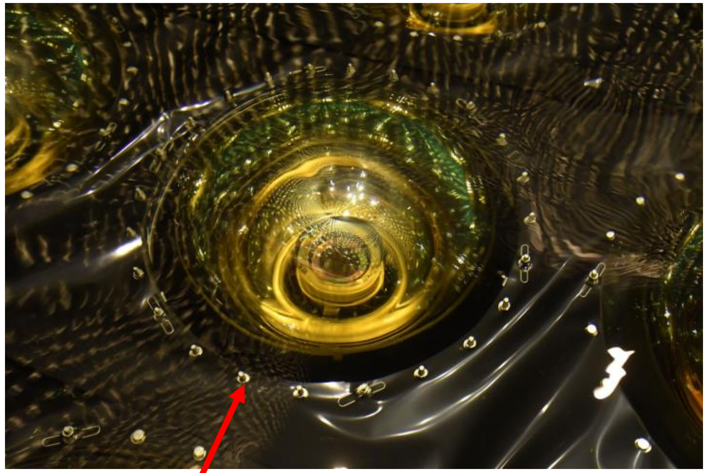
Fig: Model of Super-Kamiokande detector[2]

~11,000 PMTS

2

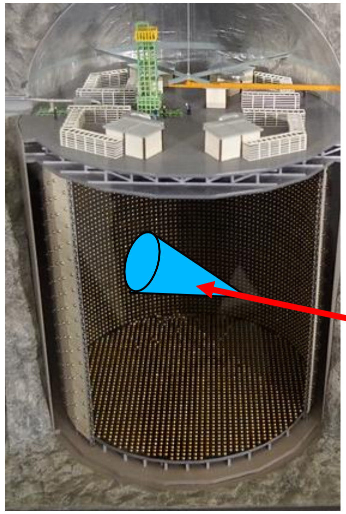
PMT[3]

3



Bolts for mounting PMT to wall.

4



Cherenkov radiation

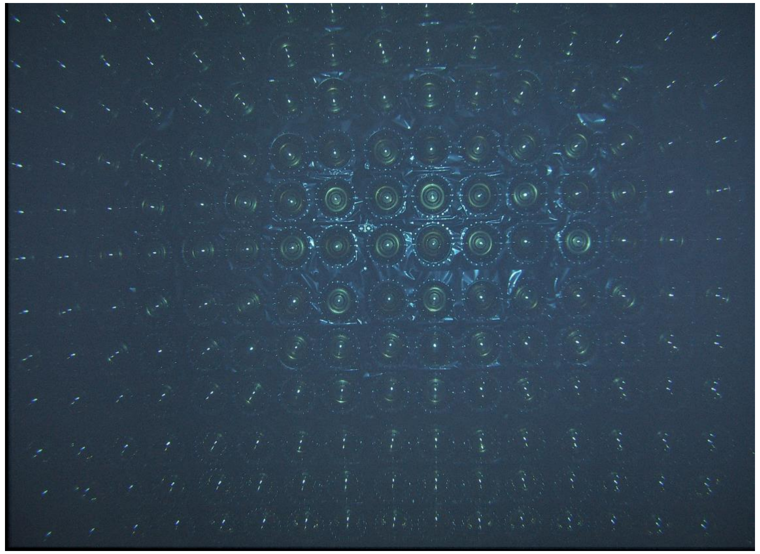
- Produced when charged particles move faster than speed of light in a medium(water).[2]

Photographing detector wall with Underwater drone

1

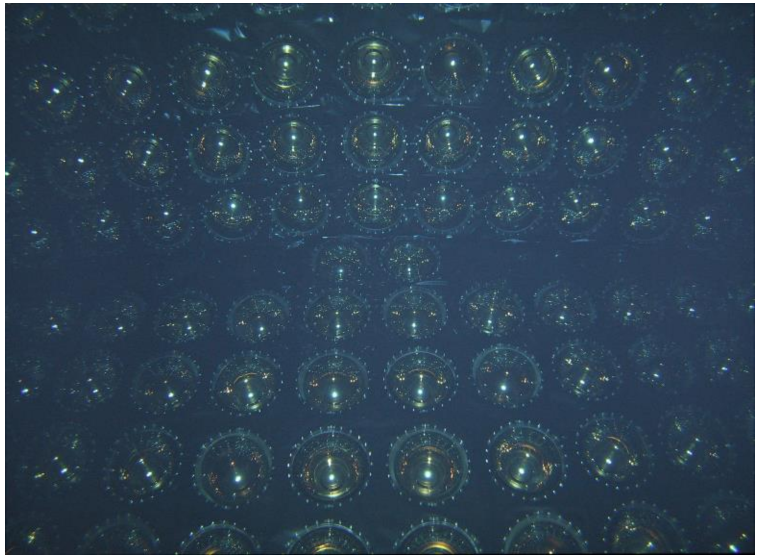
>15000 img

2



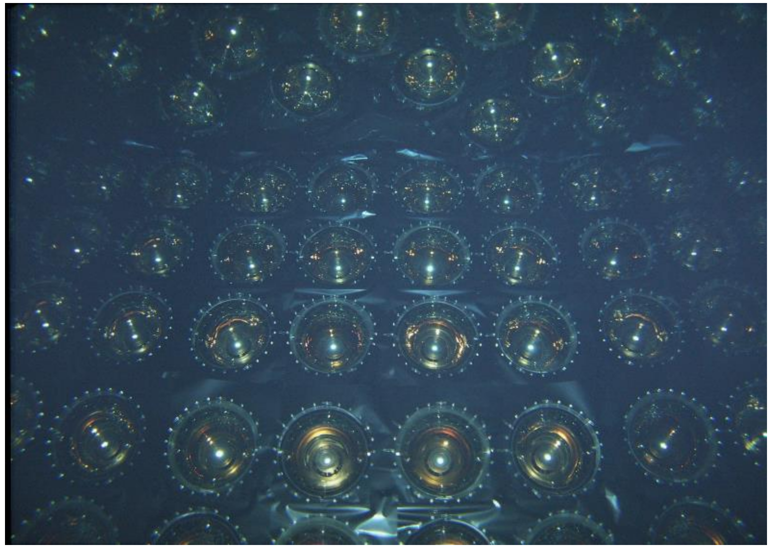
239.jpg

3



379.jpg

4



Need for automation?

- Over 15000 images.

Problem statement:

Feature detection:
- Want to identify pixel locations of bolts in an image.

Feature labelling:
- Identify each PMT in all images and assign a unique ID(identity/label) to each PMT.

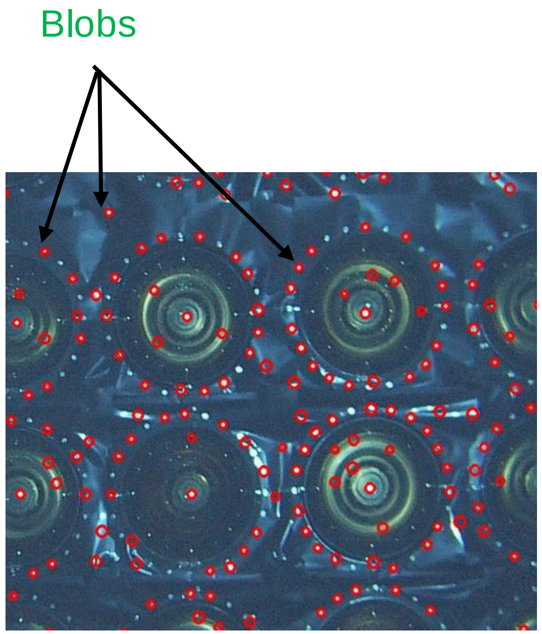
Ultimately: Find the geometry of entire detector / location of PMTs in the detector wall.

Method

1. Blob detection:

- To find bolts.

Blob: *In computer vision, blob detection methods are aimed at detecting regions in a digital image that differ in properties, such as brightness or color, compared to surrounding regions.*



2. Hough-Ellipse detection:

- Find ellipses in some range of size(minor axis) in the image.
- (Manually set First, but were able to automate.)

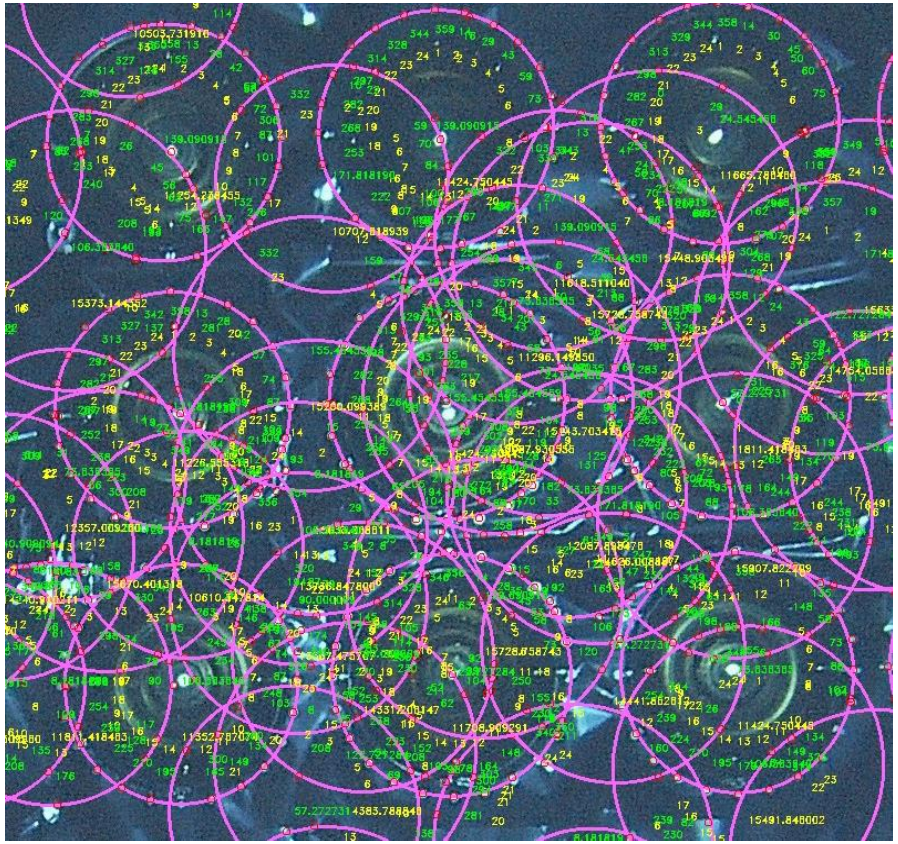
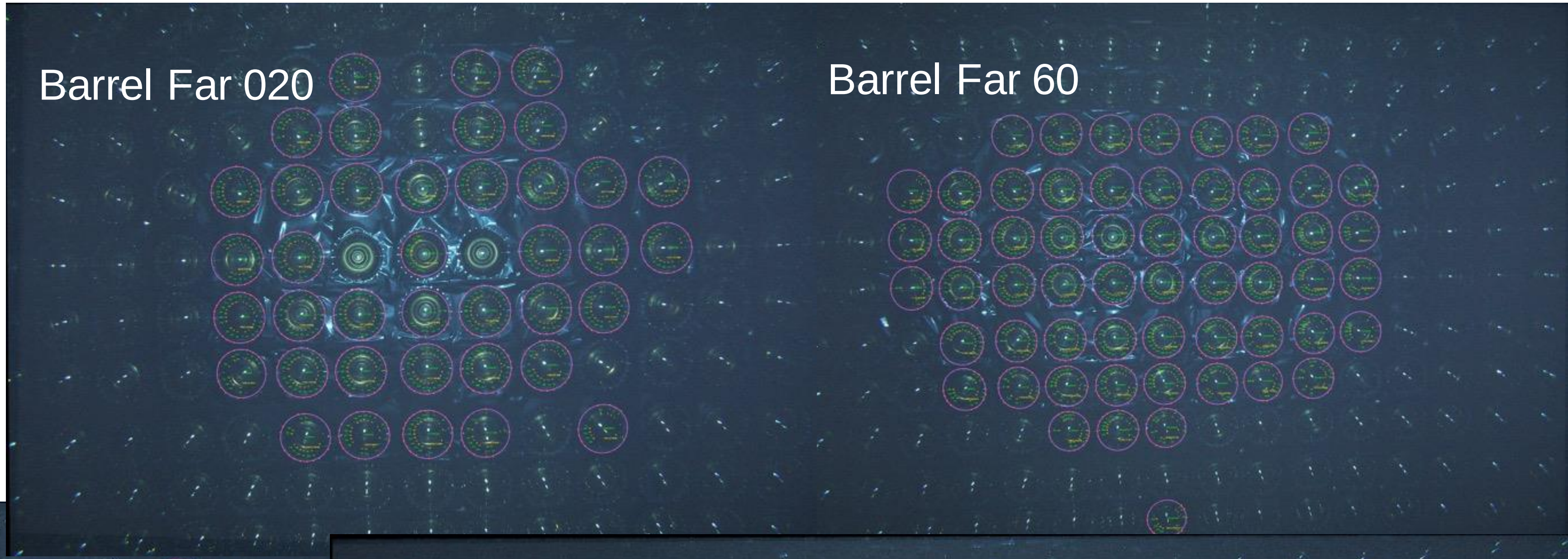


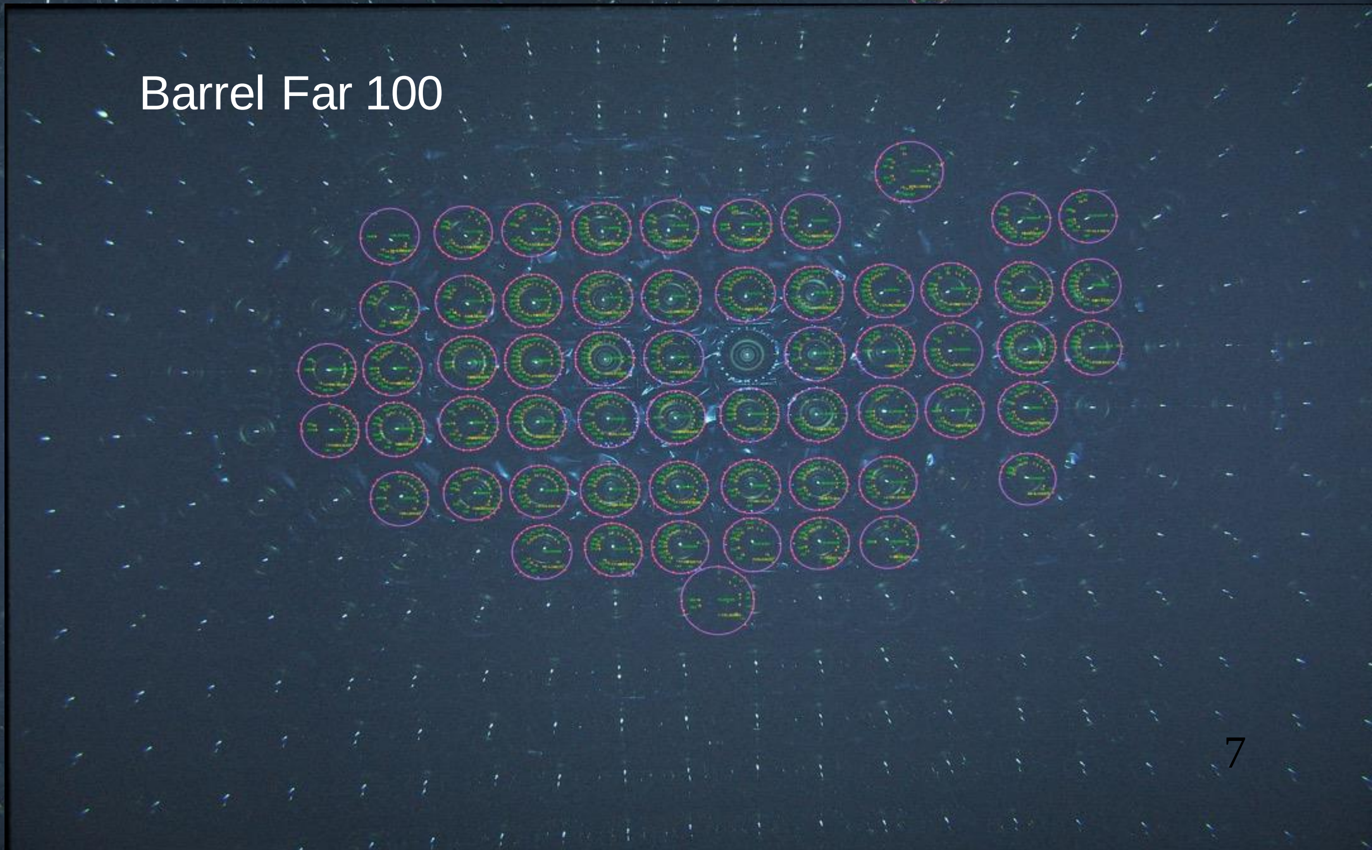
Fig: cropped image after ellipse detection

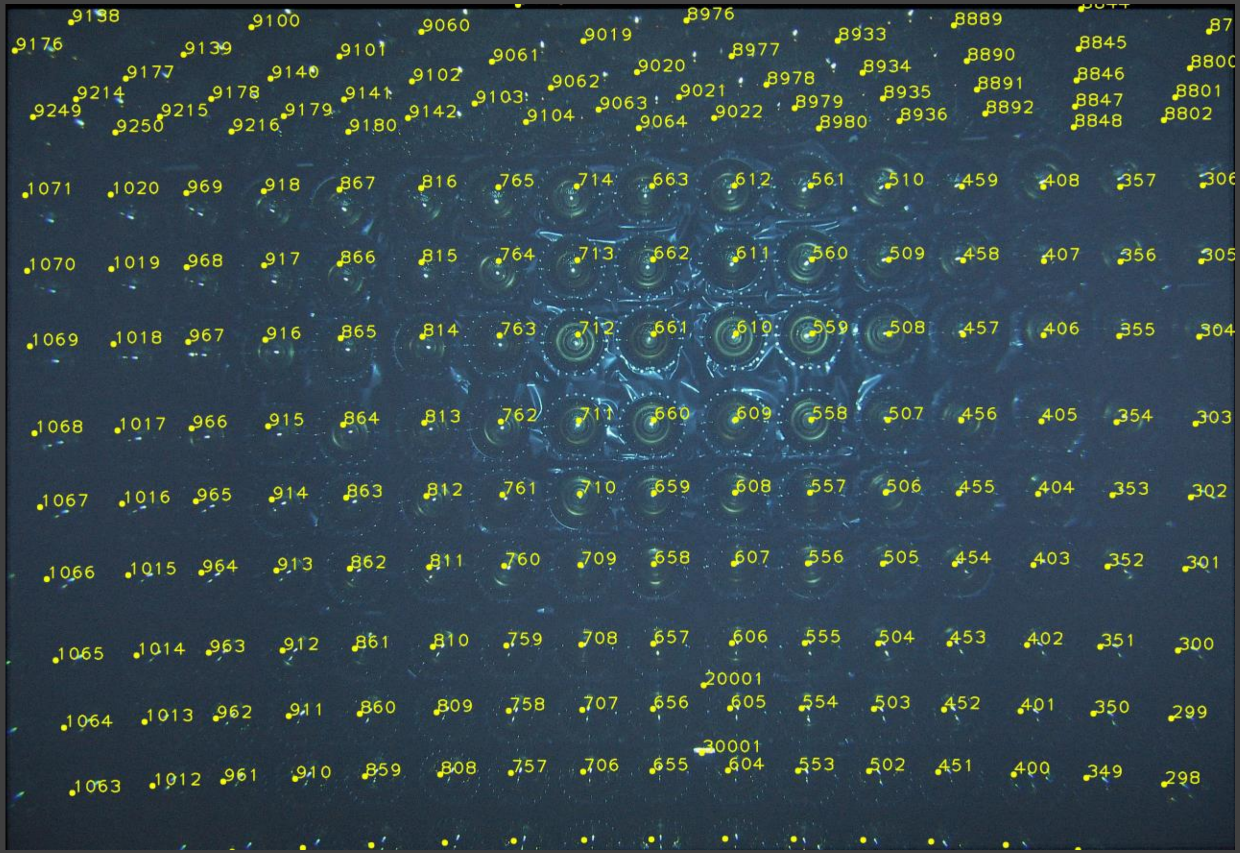
3. Remove false PMTs:

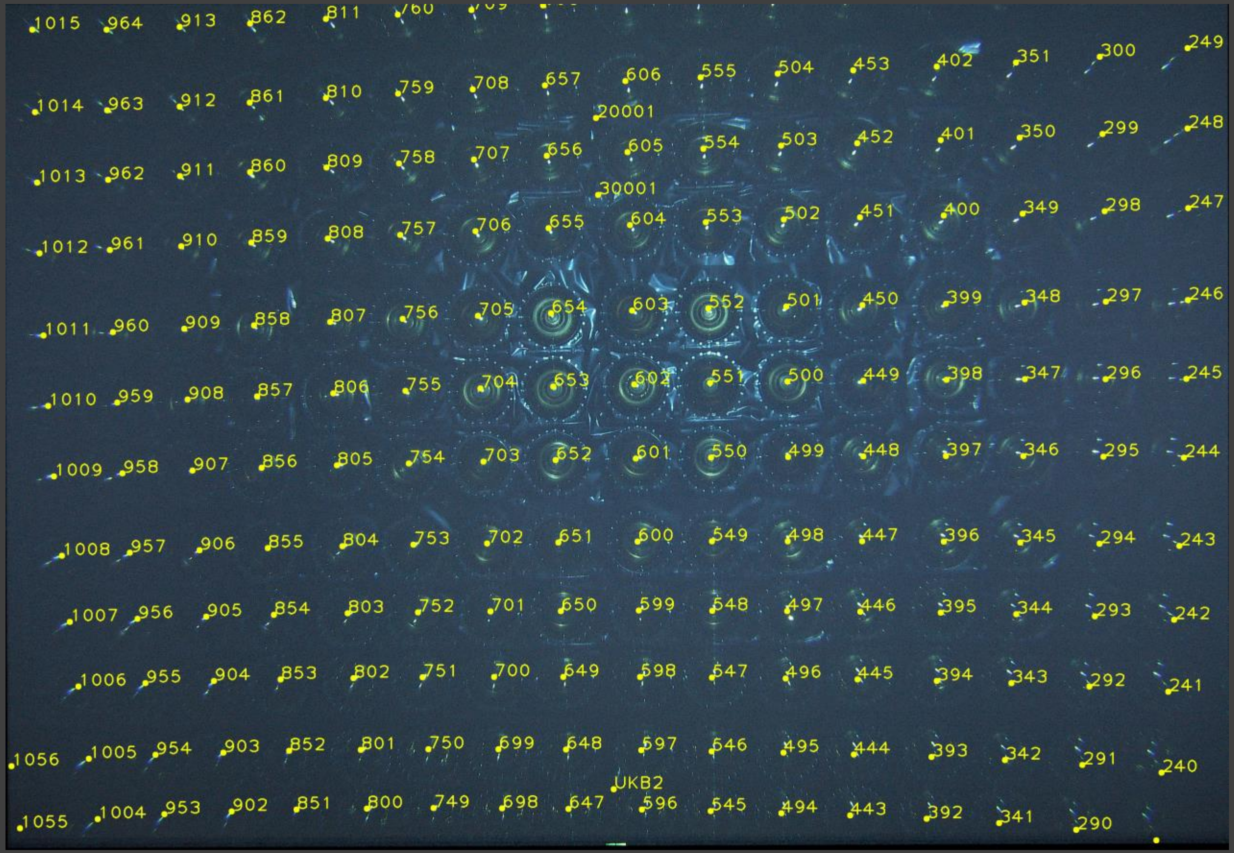
- Remove bolts that are not in 15-degree angle pattern from PMT center.
- Remove intersecting ellipse that has fewer number of bolts.

Gallery of Success









Feature labelling

Image Labelling approach.

- Use PMT coordinate from design.
- Perform R^3 ->R^2 transformation.

(Using camera's transformation matrix.)

ID	x	y	z
00018-00	1690	2	-569
00019-00	1690	2	-491
00020-00	1690	2	-424
00021-00	1690	2	-357
00022-00	1690	2	-279
00023-00	1690	2	-212
00024-00	1690	2	-145
00025-00	1690	2	-67

Fig: *location of all PMTs in detector wall (from design)*

Rotation matrix

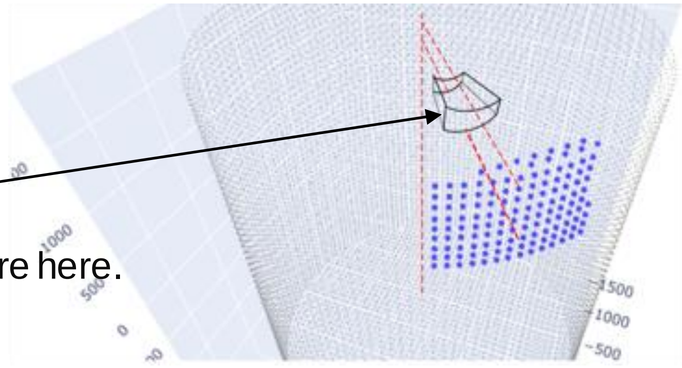
Translation matrix

$$\begin{bmatrix} u \\ v \\ 1 \end{bmatrix} = \begin{bmatrix} f_x & 0 & c_x \\ 0 & f_y & c_y \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix} \begin{bmatrix} r_{11} & r_{12} & r_{13} & t_x \\ r_{21} & r_{22} & r_{23} & t_y \\ r_{31} & r_{32} & r_{33} & t_z \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} X_w \\ Y_w \\ Z_w \\ 1 \end{bmatrix}$$

Knowns and unknowns

- Orientation is can be calculated from drone data(using yaw, pitch, roll).
- Drone position is unknown. Only Z coordinate known.

- **t**=-R***p** (**t**= translation vector, **p**=drone position)



Bounding solid.
Camera somewhere here.

Pattern matching

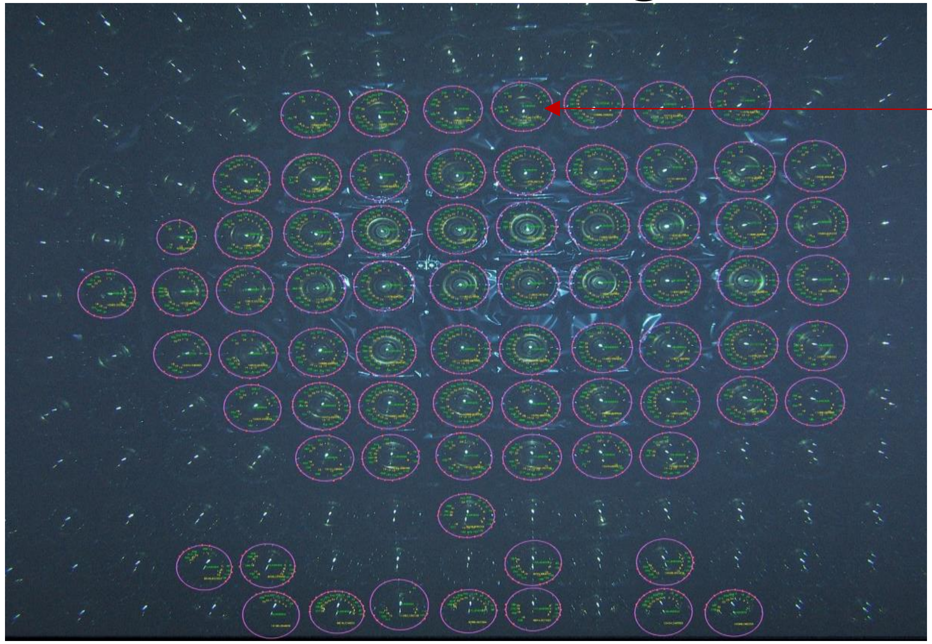


Fig. Hough-ellipses

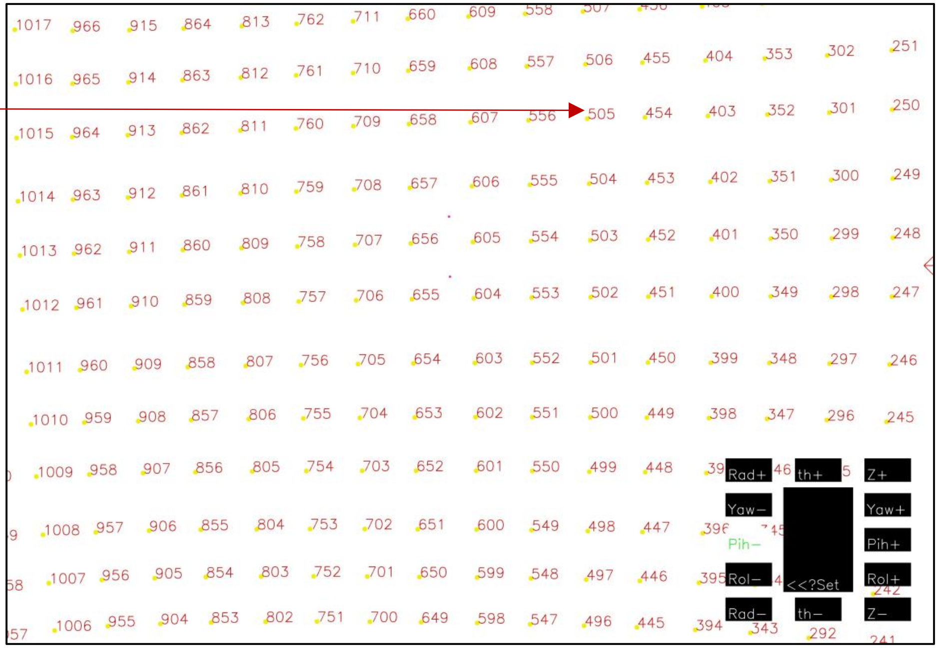


Fig. Perspective projected points

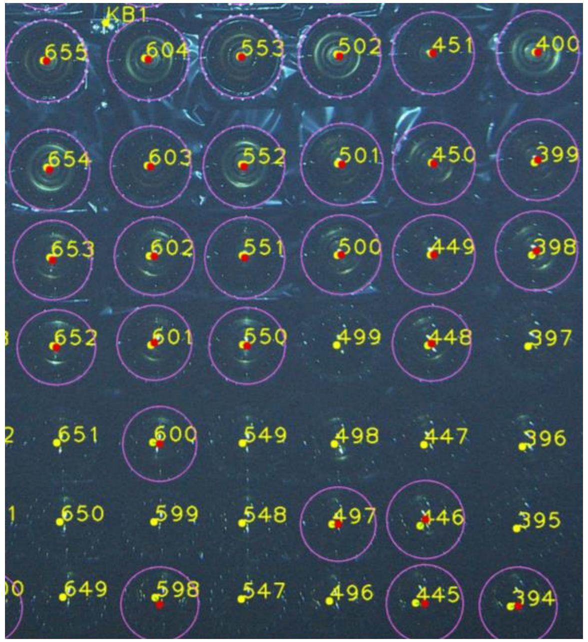
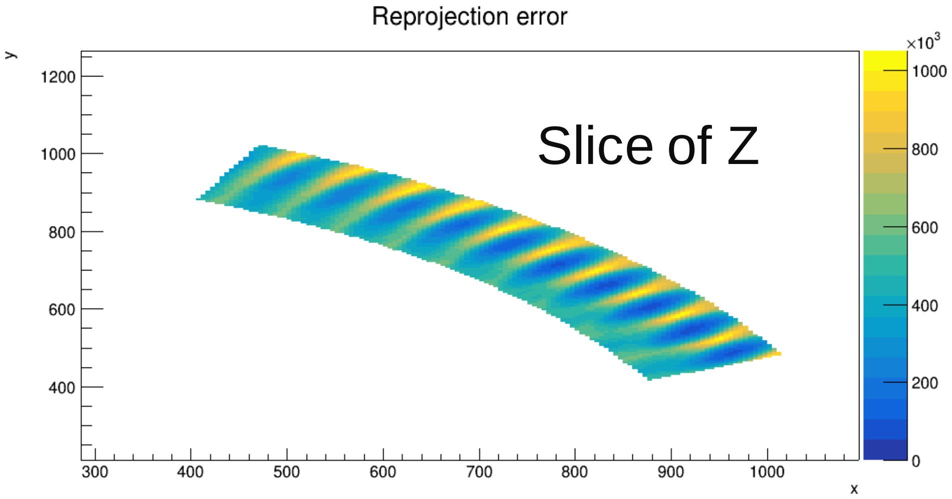


Fig. Cropped img



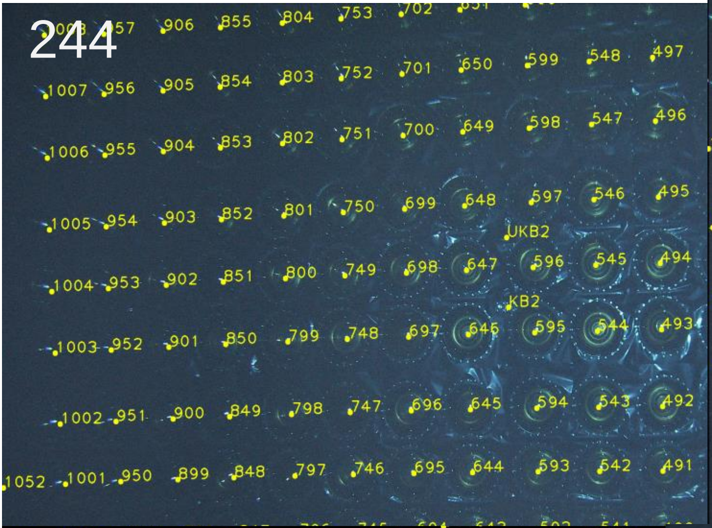
{ A } = set of coordinates of all hough-ellipses.

{ B_j } = set of all reprojected points for specific camera position(j).

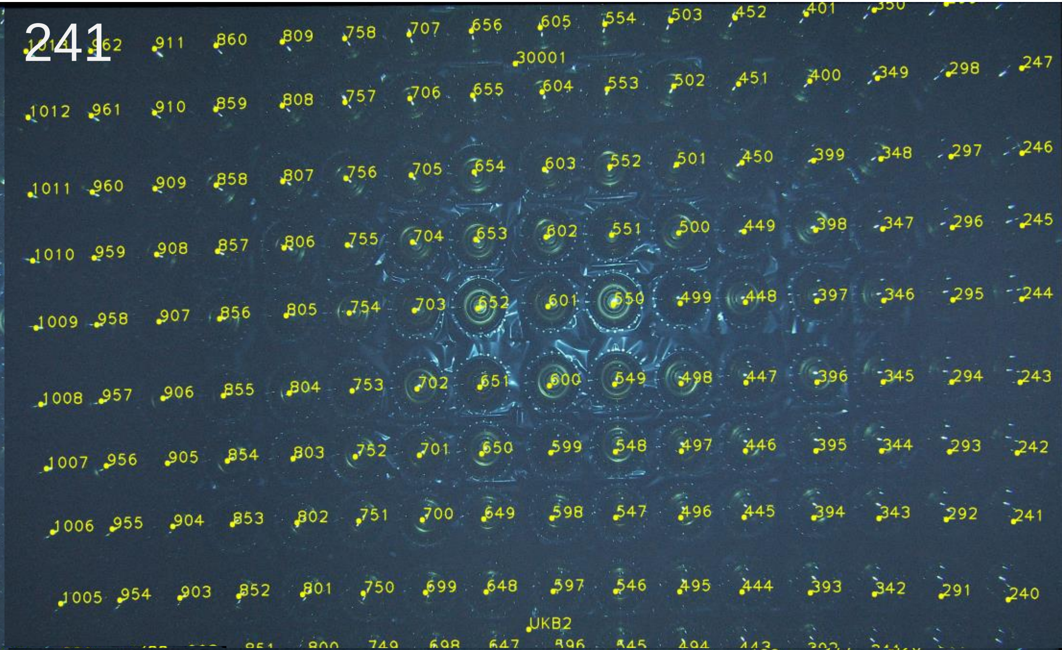
d_{ij} = min distance between i^{th} element of A and members of set B_j.

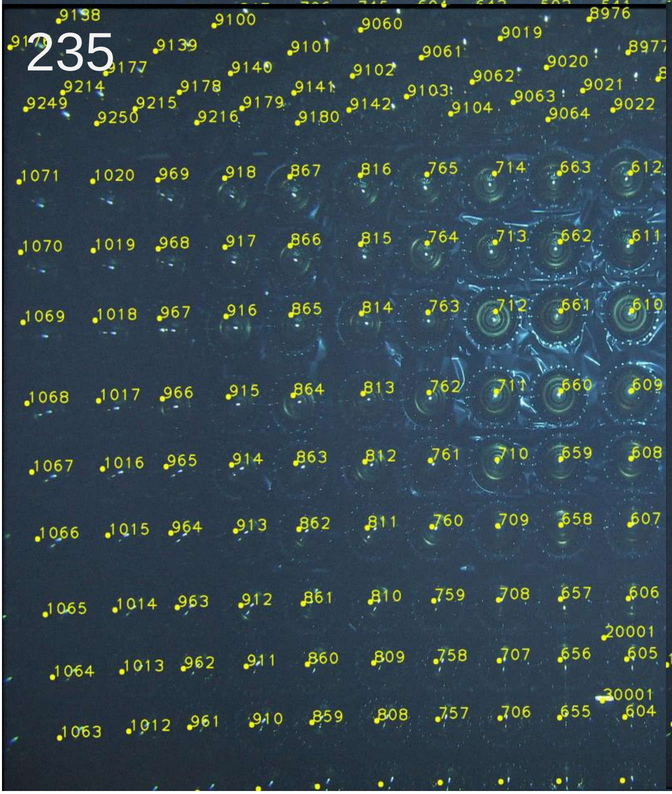
$d_j = \Sigma d_{ij}$ (Find min d among all j)

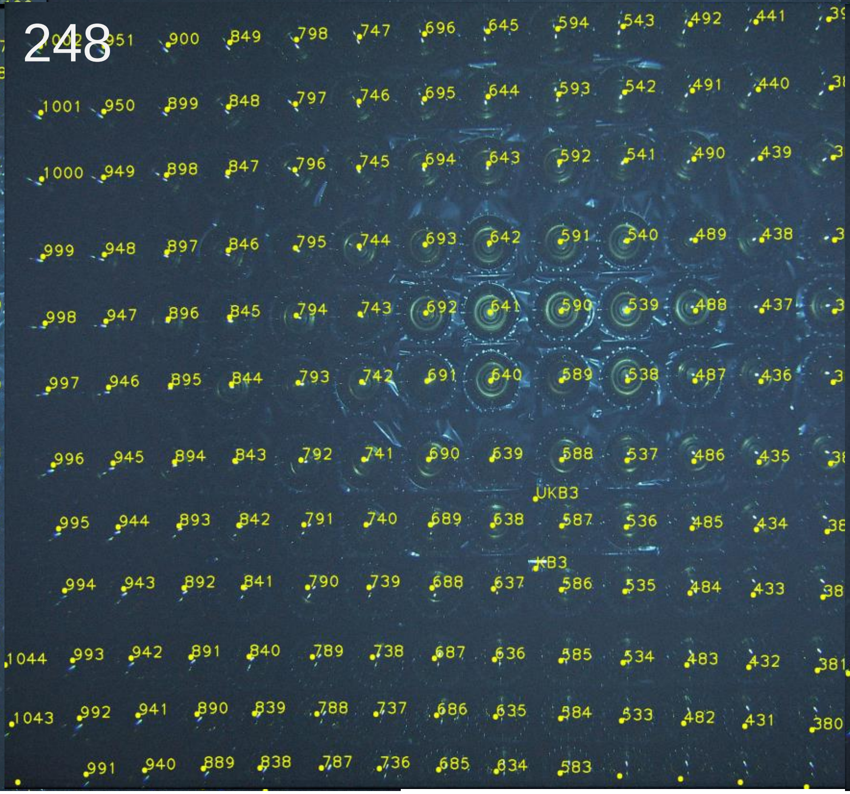
Results:

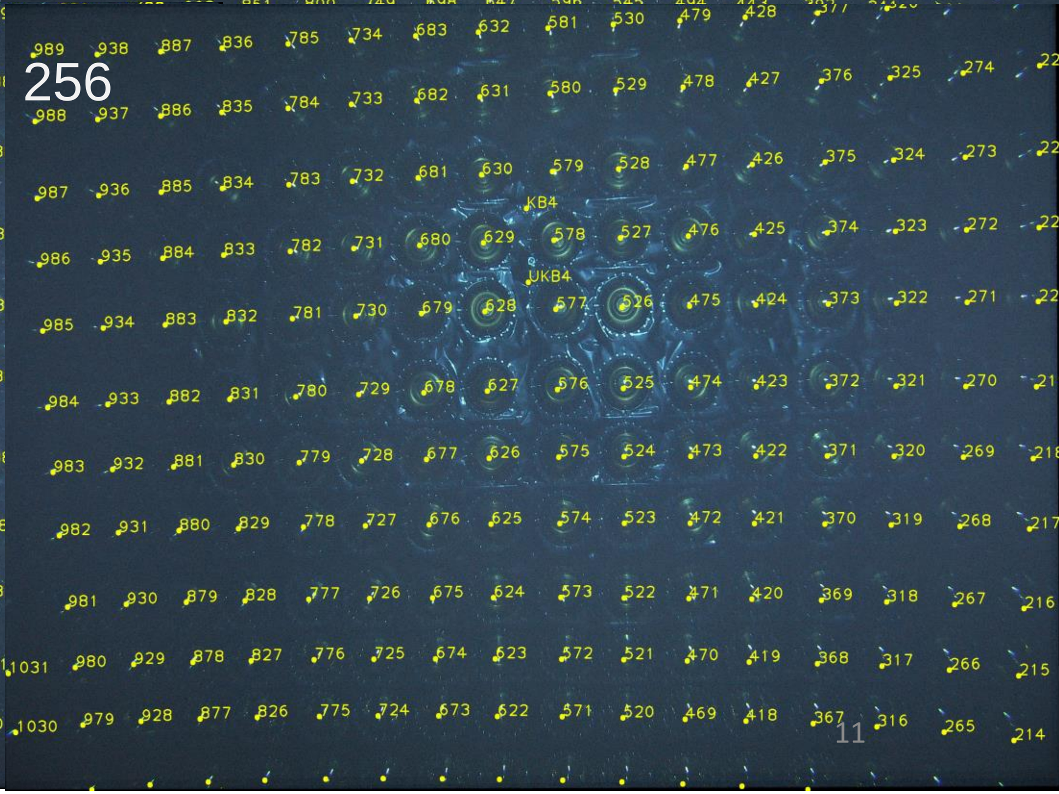

244
UKB2
KB2


238
20001
30001


241
30001
UKB2


235
20001
30001


248
UKB3
KB3


256
KB4
UKB4

Future work:

- Investigate the failure cases.
- Try to further constrain the camera location.
- Label the ring of the detector to reconstruct part of the detector.
- Label the whole detector.
- Perform pattern matching by scanning not only the camera position but also the camera orientation.

References

[1] "Standard model of elementary particles" by chriswalf, is licenced under CC-BY-SA-3.0

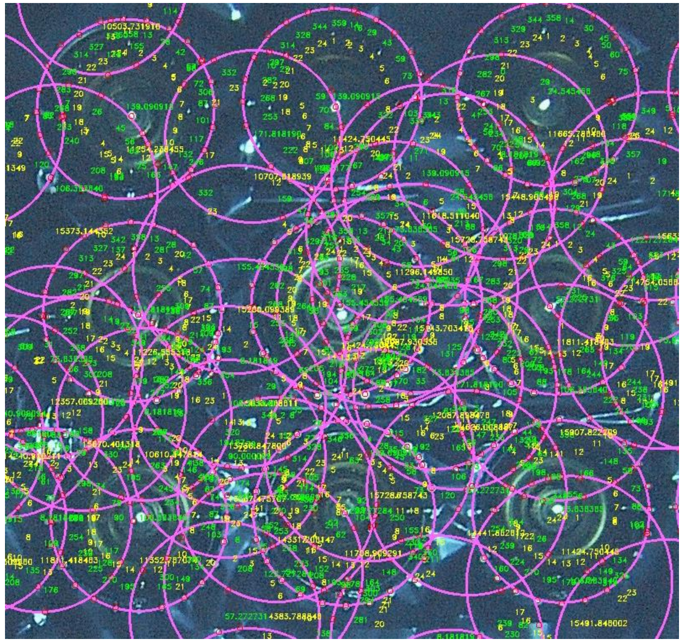
[2] "スーパーカミオカンデタンク内公開 Super-Kamiokande_insidetank" by nvslive is licensed under CC BY-NC 2.0

[3] "Photomultiplier Tube (PMT) at Kamioka SkyDome" by kawanet is licensed under CC BY 2.0

Backup slides

3. Hough-Ellipse detection:

- Find ellipses in some range of size(minor axis) in the image.
- (Manually set First, but were able to automate.)

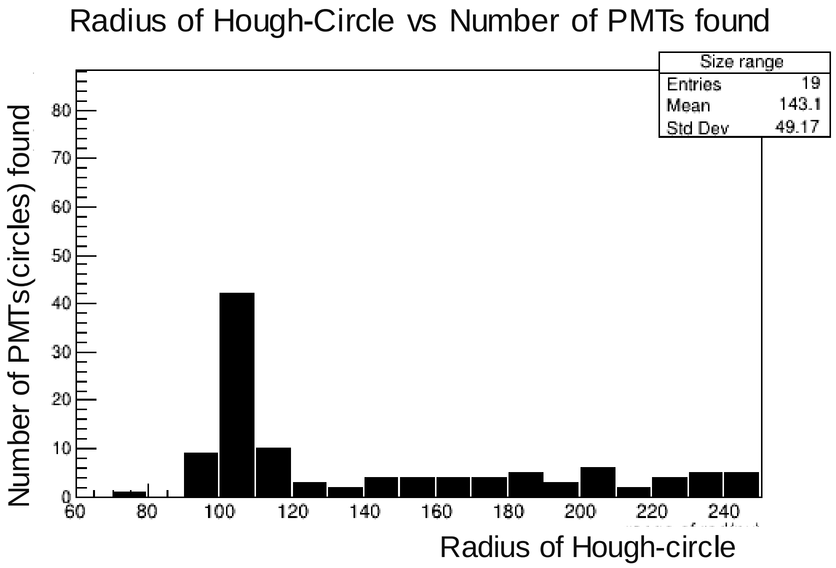


4. Remove false PMTs:

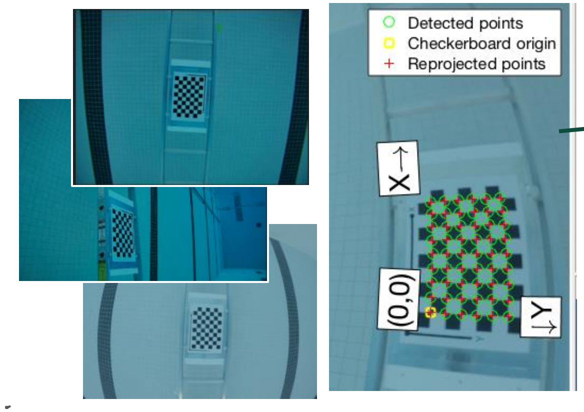
- Remove bolts that are not in 15-degree angle pattern from PMT center.
- Remove intersecting ellipse that has fewer number of bolts.

2. Automating size of ellipse estimation (Hough-Circle detection):

- To get the estimate of min and max radius of PMTs in the image.



Overview of photogrammetry analysis



Calibration photos → Optics calibration

Photos of detector → Undistorted images

Feature detection

Feature labeling

3D stereoscopic reconstruction

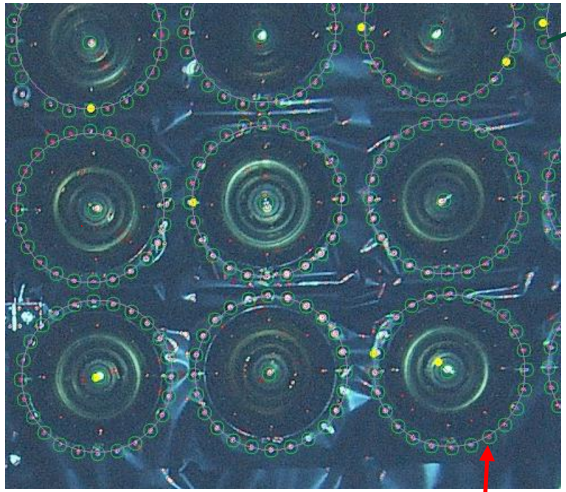
Rotation matrix

Translation matrix

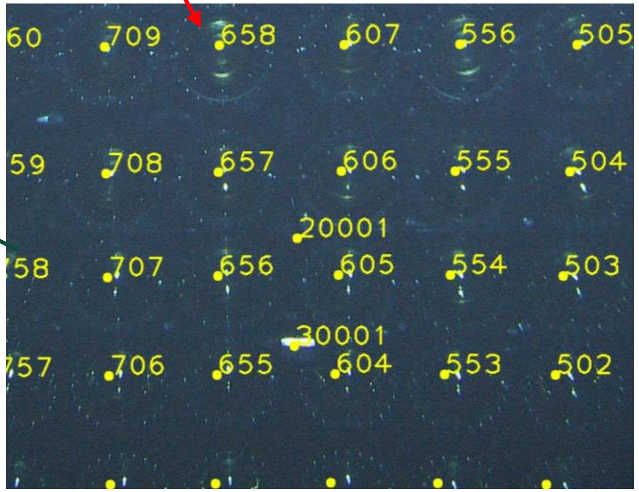
$$\begin{bmatrix} u \\ v \\ 1 \end{bmatrix} = \begin{bmatrix} f_x & 0 & c_x \\ 0 & f_y & c_y \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix} \begin{bmatrix} r_{11} & r_{12} & r_{13} & t_x \\ r_{21} & r_{22} & r_{23} & t_y \\ r_{31} & r_{32} & r_{33} & t_z \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} X_w \\ Y_w \\ Z_w \\ 1 \end{bmatrix}$$

Camera constants

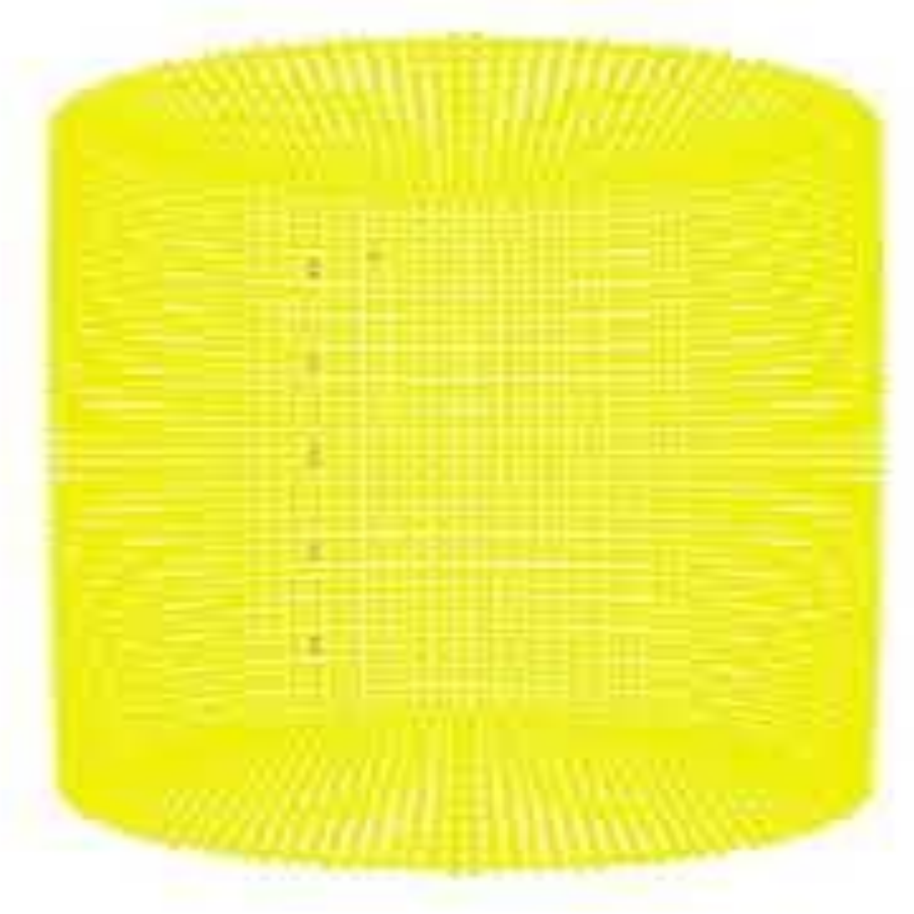
label

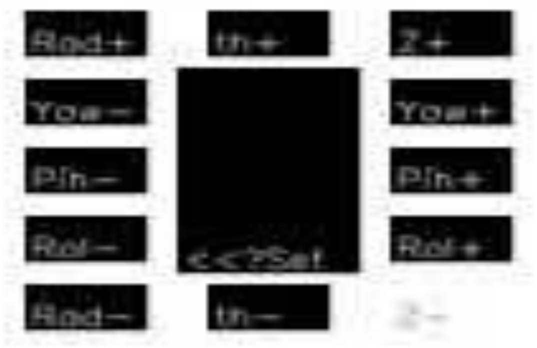


Feature(bolt)



Tool to visualize camera position and image of detector





Bounding the Unknowns

- Intended to point camera radially outwards. (Not true. So far noticed offset of up to 17^0).
- Can estimate bound for radial position(cylindrical coordinate) using size of PMTs in image.
- Can estimate the angle made by r as Camera dir+-range(20 for now).
- Can estimate Z as z from drone data+-offset.

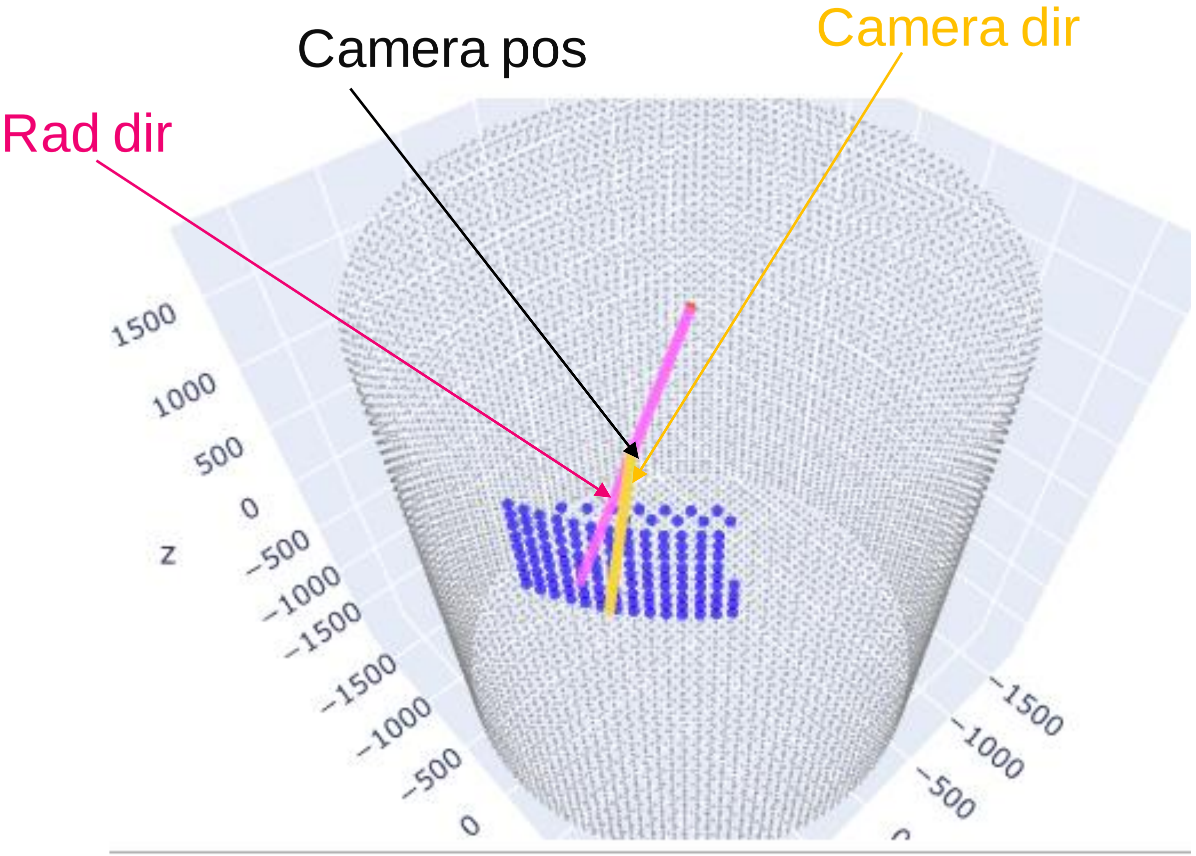
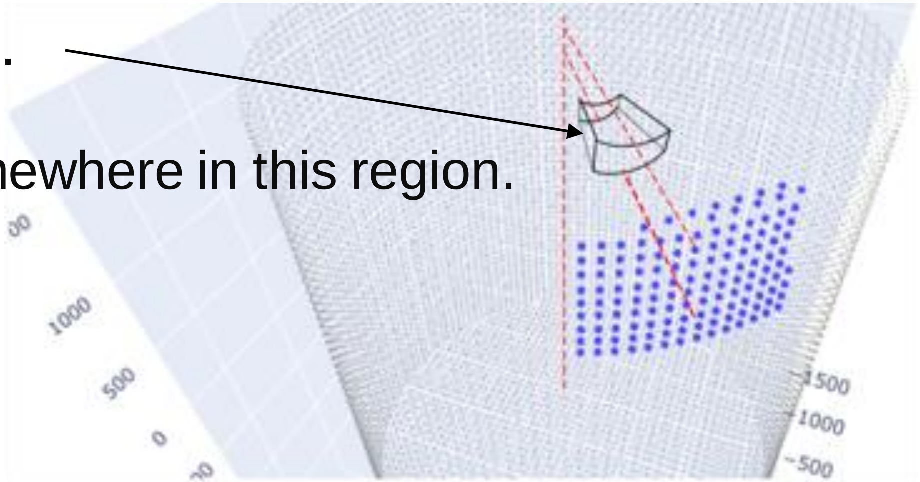


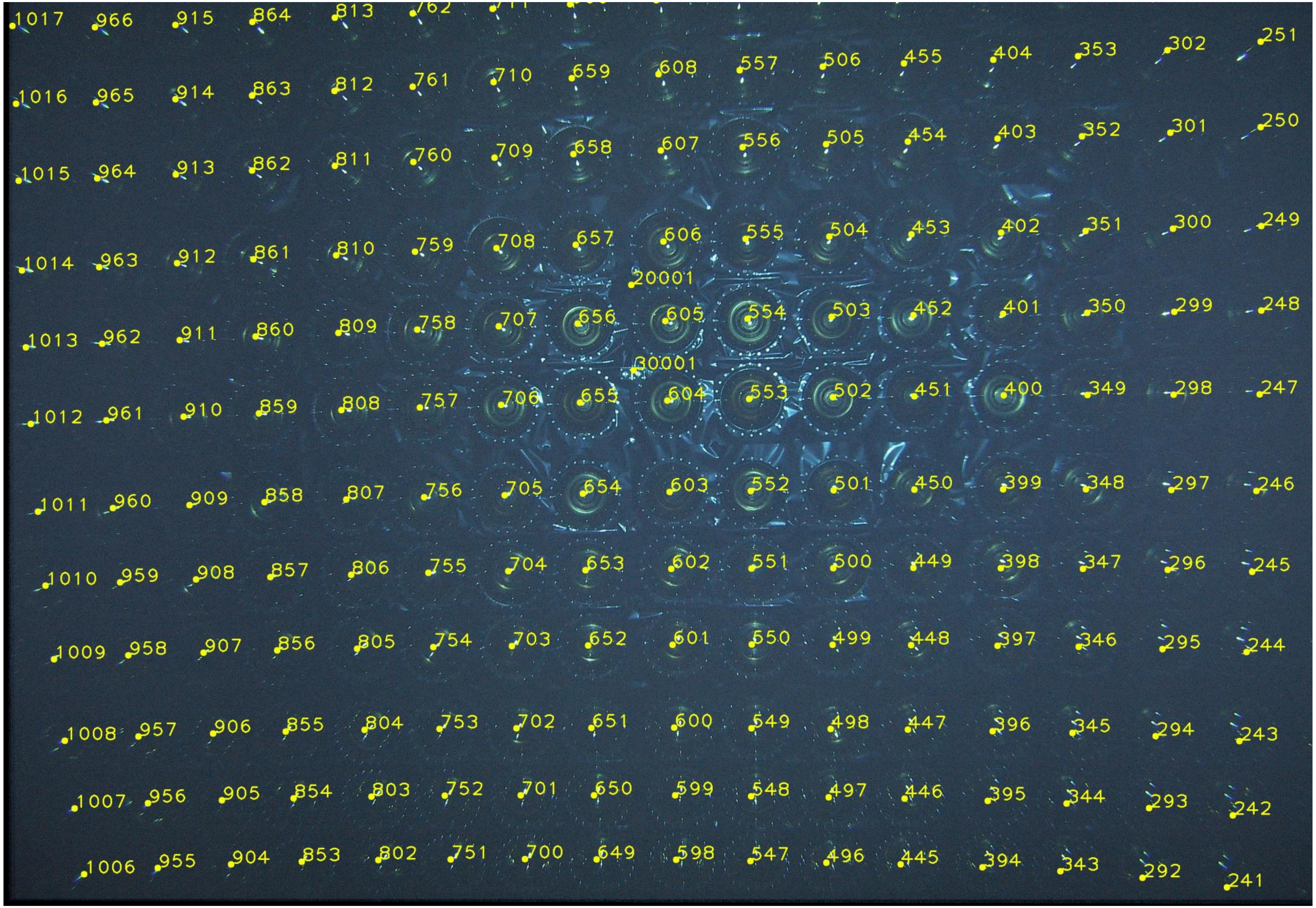
Fig: *Detector. Showing radial direction, camera position, and direction camera is pointing.*

Bounding solid.

Camera is somewhere in this region.



Example of a Correctly labelled image



Narrowing search volume

- b=p1=density of calibrated water(salt)/density of hk-water.

Can be easily derived assuming that the pressure sensor Is reading the pressure correctly.

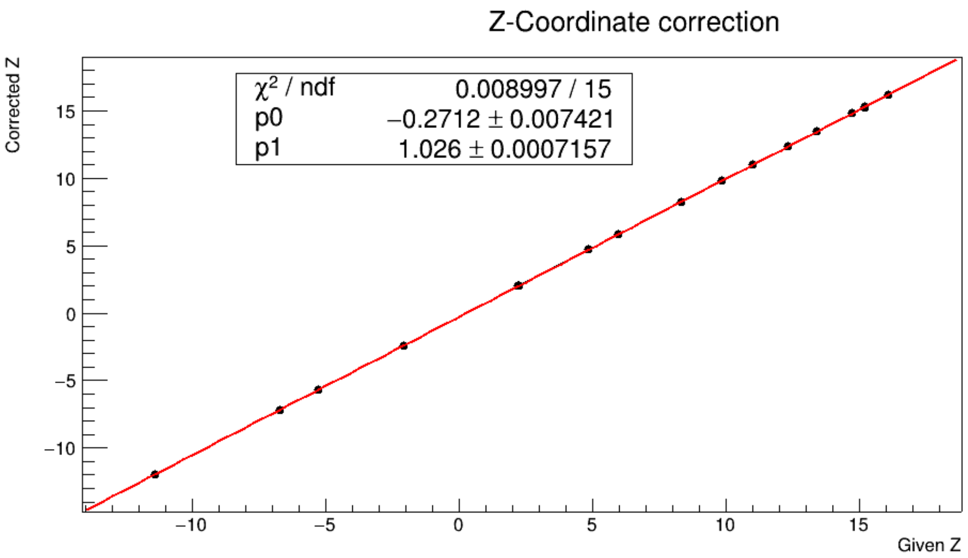


***Fig**: depth correction.* $Z_{hk\text{-}water} = c + b^{*} Z_{calibrated\text{-}water}$

Try to relate offset of brightest point from the center to predict if the camera was pointing at angle less than or more than radially outward direction.

The brightest spot should have been in the center if the camera was pointing radially outward.

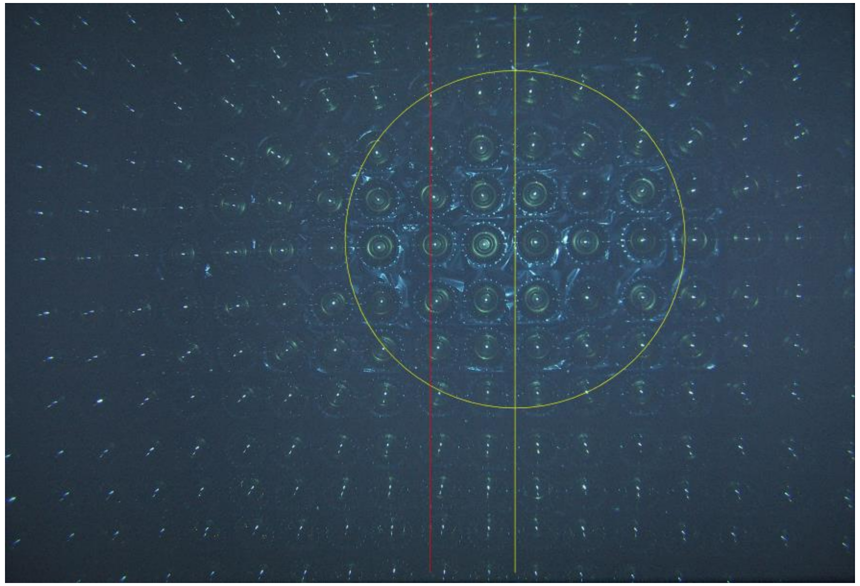
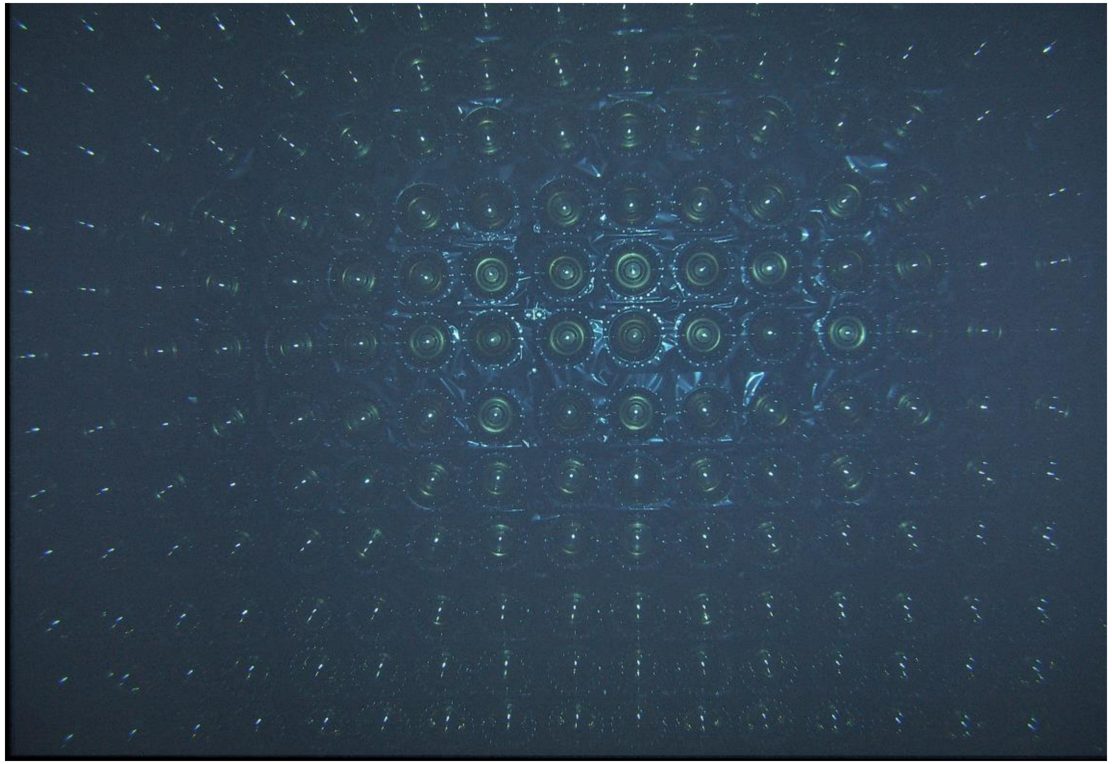


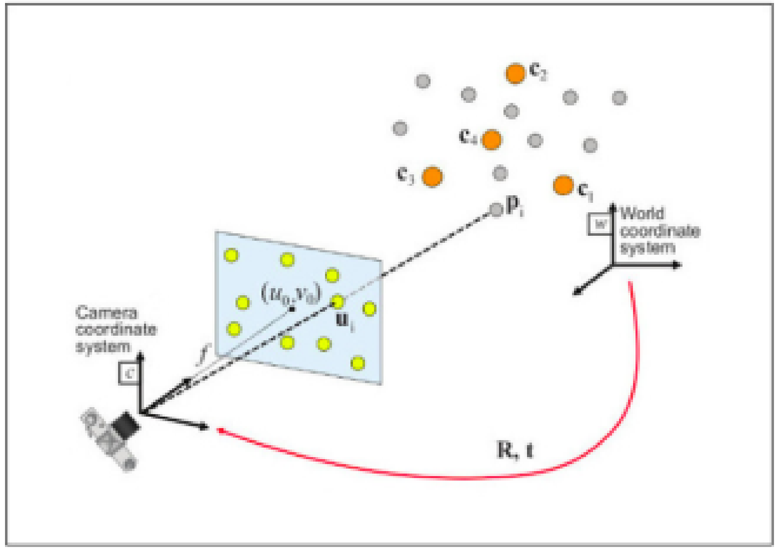
***Fig**: Finding brightest spot in the image.*

See the pattern?

- Now match the pattern.
- Best match pattern is correct label(actual camera position).



Introduction to camera (simply $R^3 \rightarrow R^2$ transformation)



Since camera intrinsic matrix doesn't change, if we know rotation and translation vector for certain orientation and position of the camera, we know everything.

Points expressed in the world frame $\mathbf{X}_w$ are projected into the image plane $[u, v]$ using the perspective projection model Π and the camera intrinsic parameters matrix $\mathbf{A}$:

Rotation matrix.

Translation matrix.

$$\begin{bmatrix} u \\ v \\ 1 \end{bmatrix} = \begin{bmatrix} f_x & 0 & c_x \\ 0 & f_y & c_y \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix} \begin{bmatrix} r_{11} & r_{12} & r_{13} & t_x \\ r_{21} & r_{22} & r_{23} & t_y \\ r_{31} & r_{32} & r_{33} & t_z \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} X_w \\ Y_w \\ Z_w \\ 1 \end{bmatrix}$$

Since world frame is rotation and translation of camera frame.

Camera intrinsic parameters.
Is a property of camera(doesn't change)

This term changes the coordinate from World frame to Camera frame.