KEK JPARC SOKENDAI SUMMER PROGRAM

IWCD - COSMIC RAY MUON CALIBRATION PIPE

Saurabh Patil(サウラブ パチル), Supervisors- Masaki ISHITSUKA (石塚 正基), Ryosuke AKUTSU (阿久津 良介),

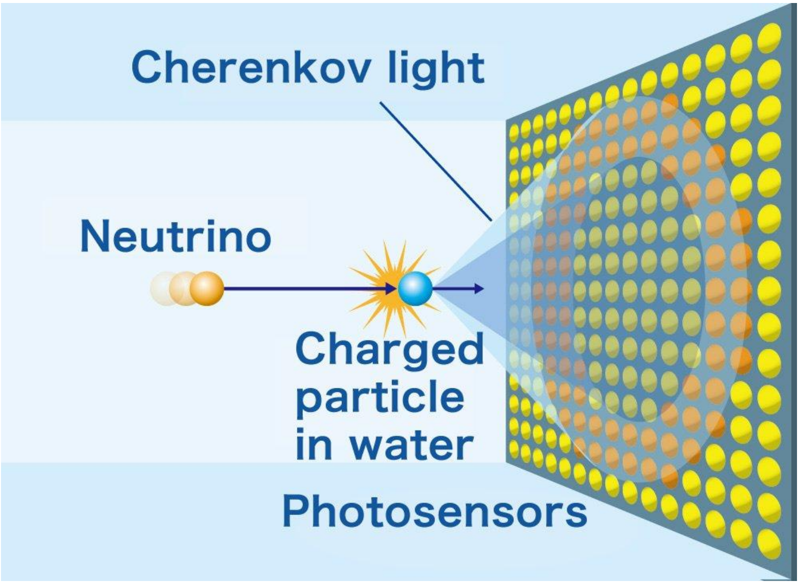
Tsunayuki MATSUBARA (松原 綱之) and KEK/J-PARC ニュートリノグループ

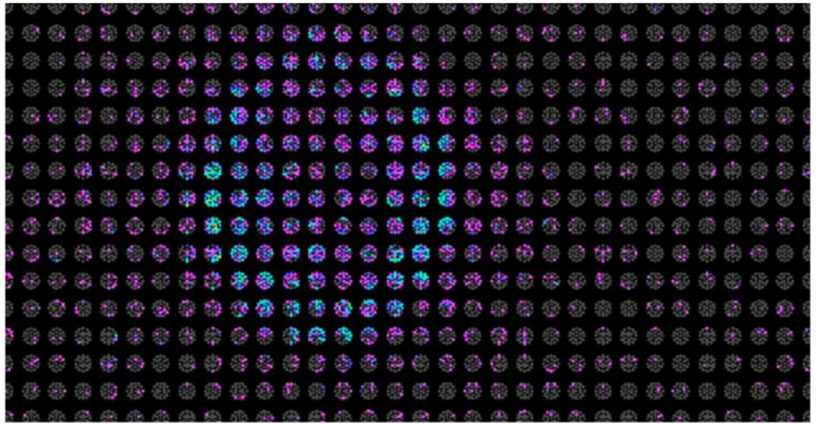
Introduction

- I am Saurabh Patil
- I am from India
- Currently Masters Student at TU Delft, Netherlands
- Studying –Mechanical (Precision Engineering)

Water Cherenkov Detector

- Cherenkov radiation observed when a charged particle travels through a transparent medium (like water) faster than the speed of light in that specific medium.
- As the high-speed particle travels, it emits a forward-pointing cone of blue light; a distinct circular pattern known as a Cherenkov ring.
- A Water Cherenkov detector is a large, light-tight tank filled with ultra-pure water and lined with highly sensitive light sensors (mPMTs) to capture these faint rings of light.
- The IWCD will observed Cherenkov light produced by neutrinos from JPARC accelerator.
- By analyzing the size, sharpness, and intensity of the recorded ring, physicists can reconstruct the particle's trajectory, measure its energy, and identify its type (such as distinguishing a muon from an electron).



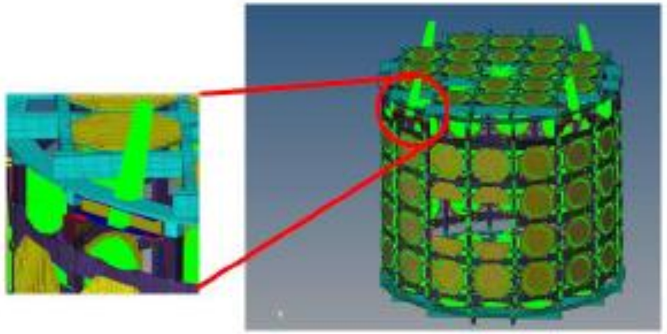


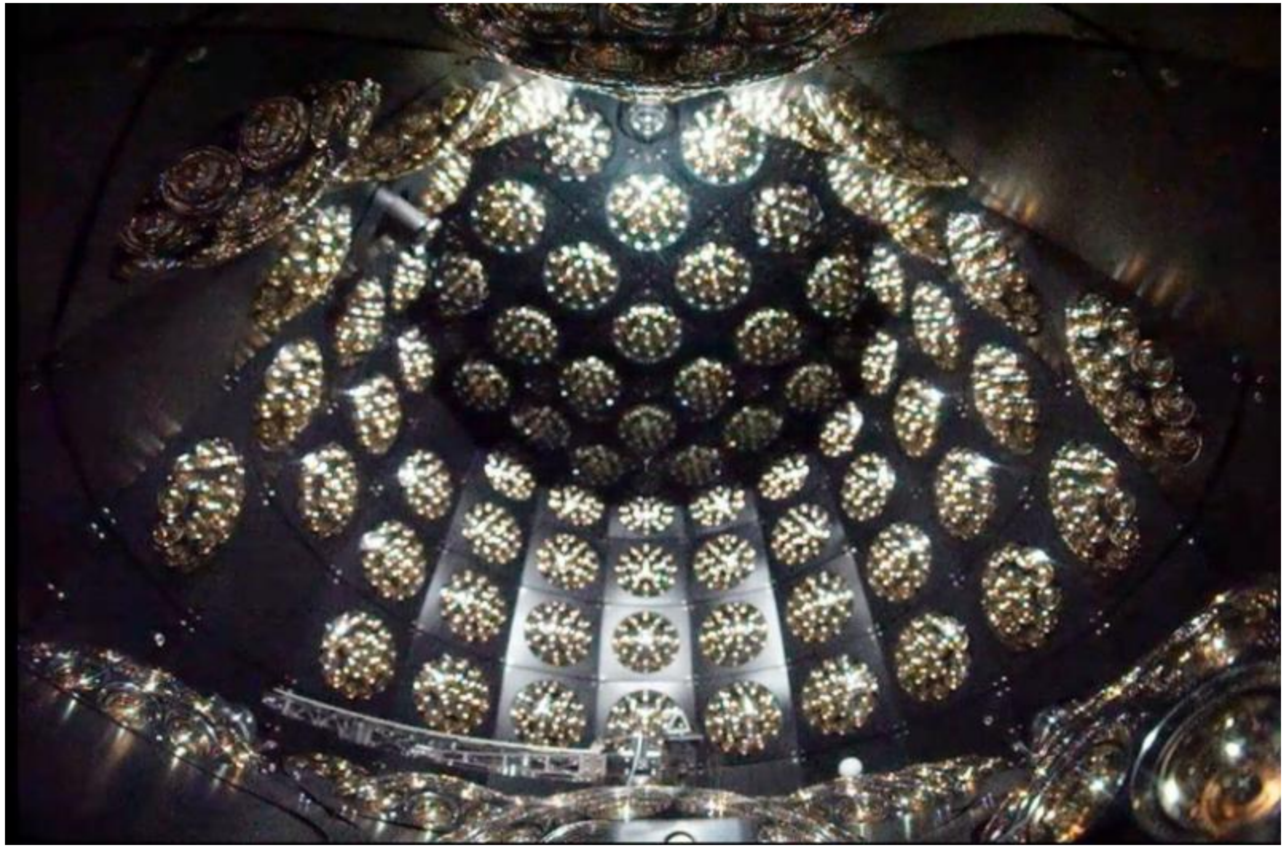
Cherenkov lights observed by the IWCD detector (simulation)

Introduction

- Worked on Mechanical Design of WCTE before..
- Loved working on it

Happy this worked

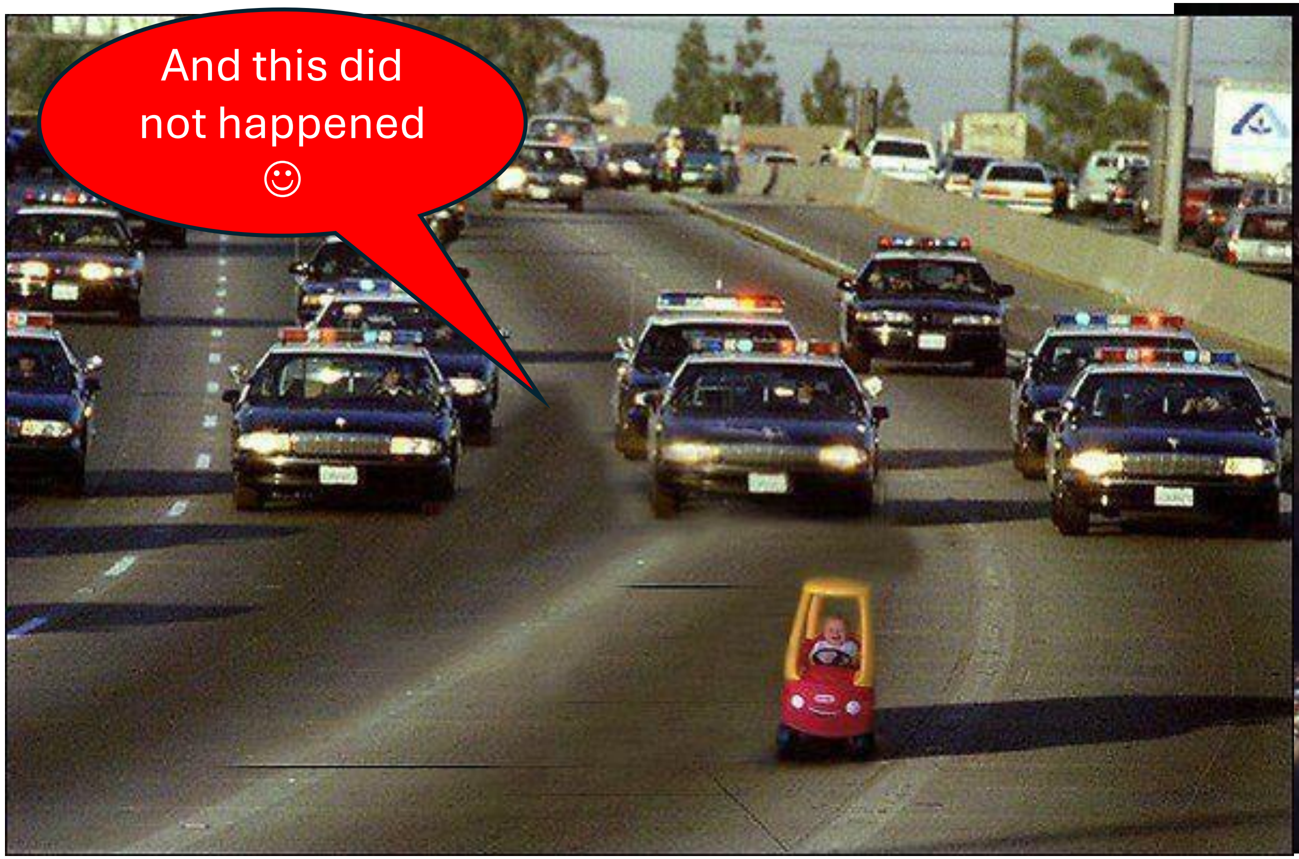


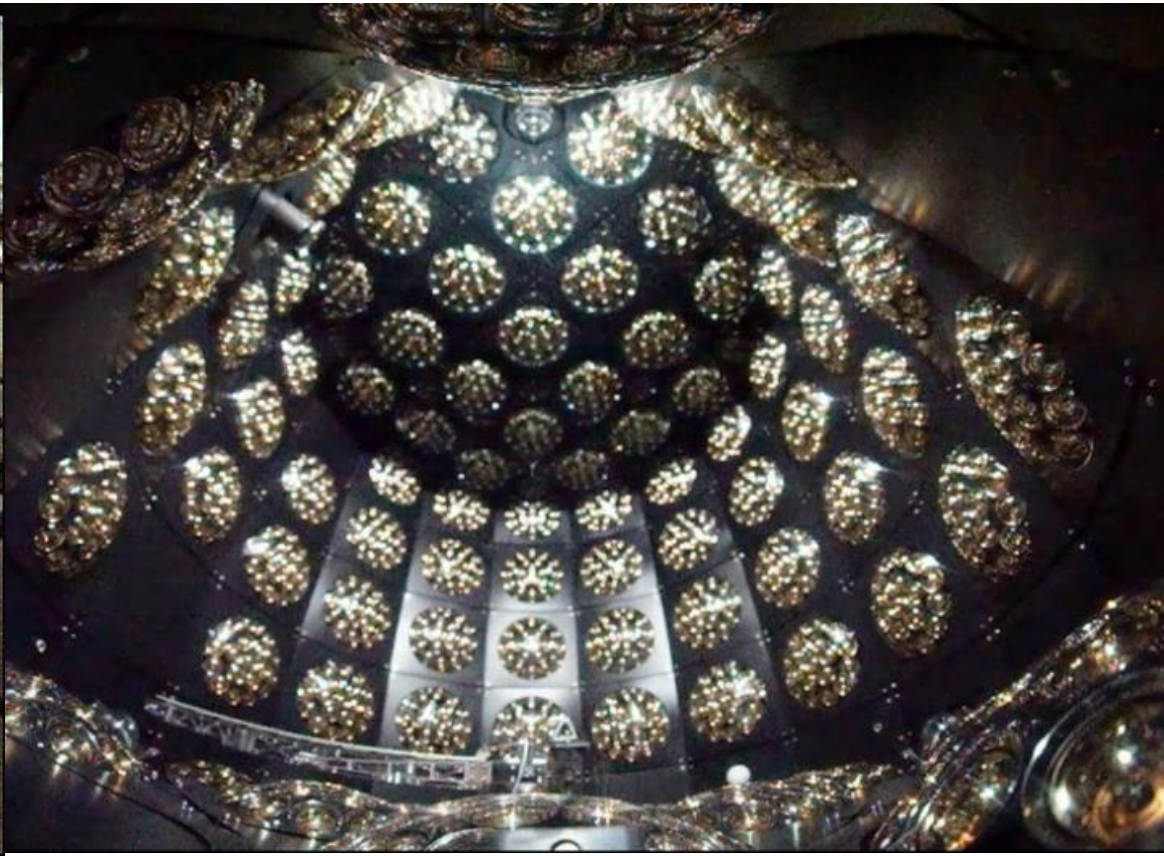


Water Cherenkov Test Experiment Cern-T9

Introduction

- Worked on Mechanical Desing of WCTE before





About IWCD

- IWCD is a movable water Cherenkov near detector to observe J-PARC bean neutrinos flying towards Hyper-Kamiokande,
- The tank has an
  - Inner Detector (radius 3.5 m, height 8 m)
  - Outer Detector (radius 4.4 m, height 10 m),
- Photodetection by about **400 multi-PMT modules** (50 cm diameter module with 19 PMTs -8 cm aperture).
- Observe JPARC accelerator neutrinos before neutrino oscillations

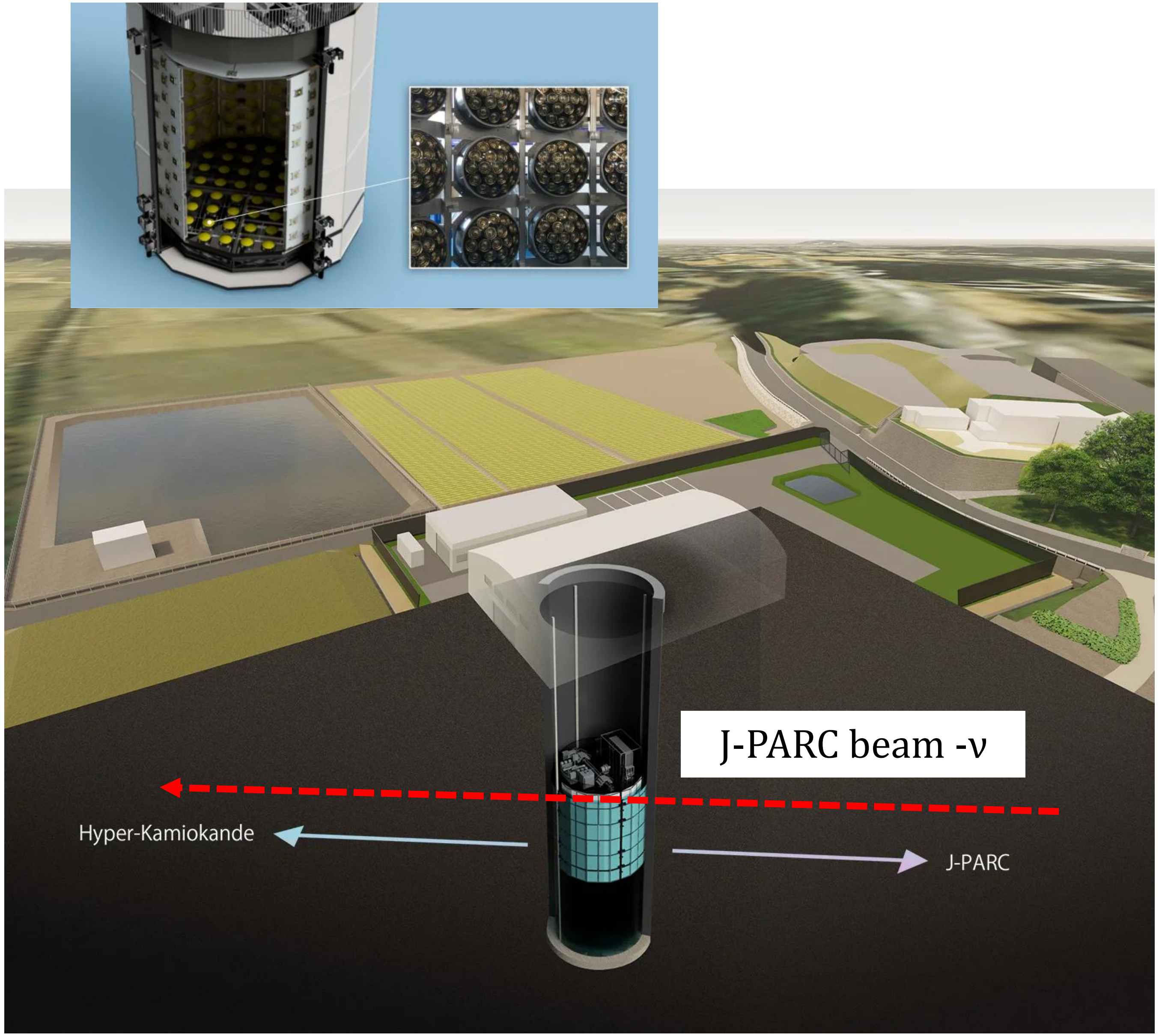
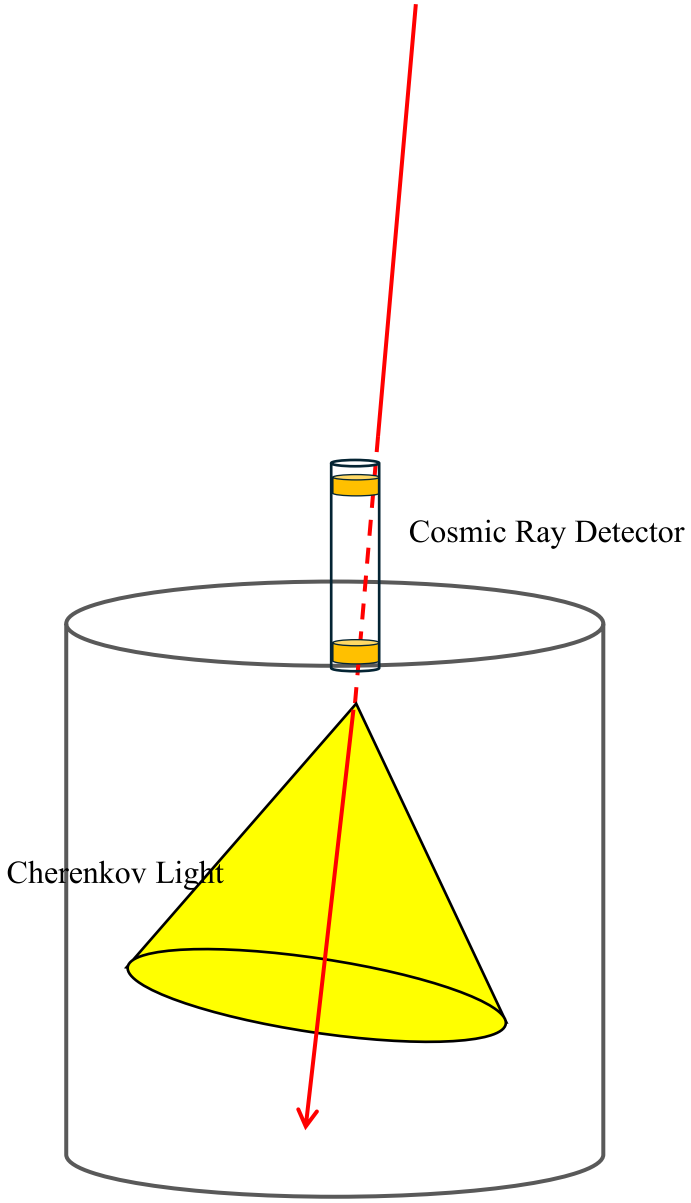


Fig 1: IWCD

Motivation of the Project

- The IWCD will consider events at a 1 m distance from the Inner Detector wall surface.
- To calibrate the Fluidical volume event consideration the idea is to use a know source of muons to calibrate.
- The cosmic ray muon pipe serves this purpose.
- High-energy muons, generated by primary cosmic rays interacting in the atmosphere, produce Cherenkov light upon traversing the water volume.
- The pipe extends in to the fluidical volume and the position of the event is at the end of the pipe. This information can be used to check the biases in the event re construction algorithm,



Cosmic Ray Muon Pipe in IWCD

- The cosmic ray pipe will be installed on the lid top and is expected to be used at variable calibration ports on the lid.
- The device will be lower from the calibration port shaft.
- When one of such muon travel in a way that it is detected by the two scintillator we now know the exact position of the vertex of the Cherenkov light.
- This information is then used to check the biases in the event reconstruction algorithm

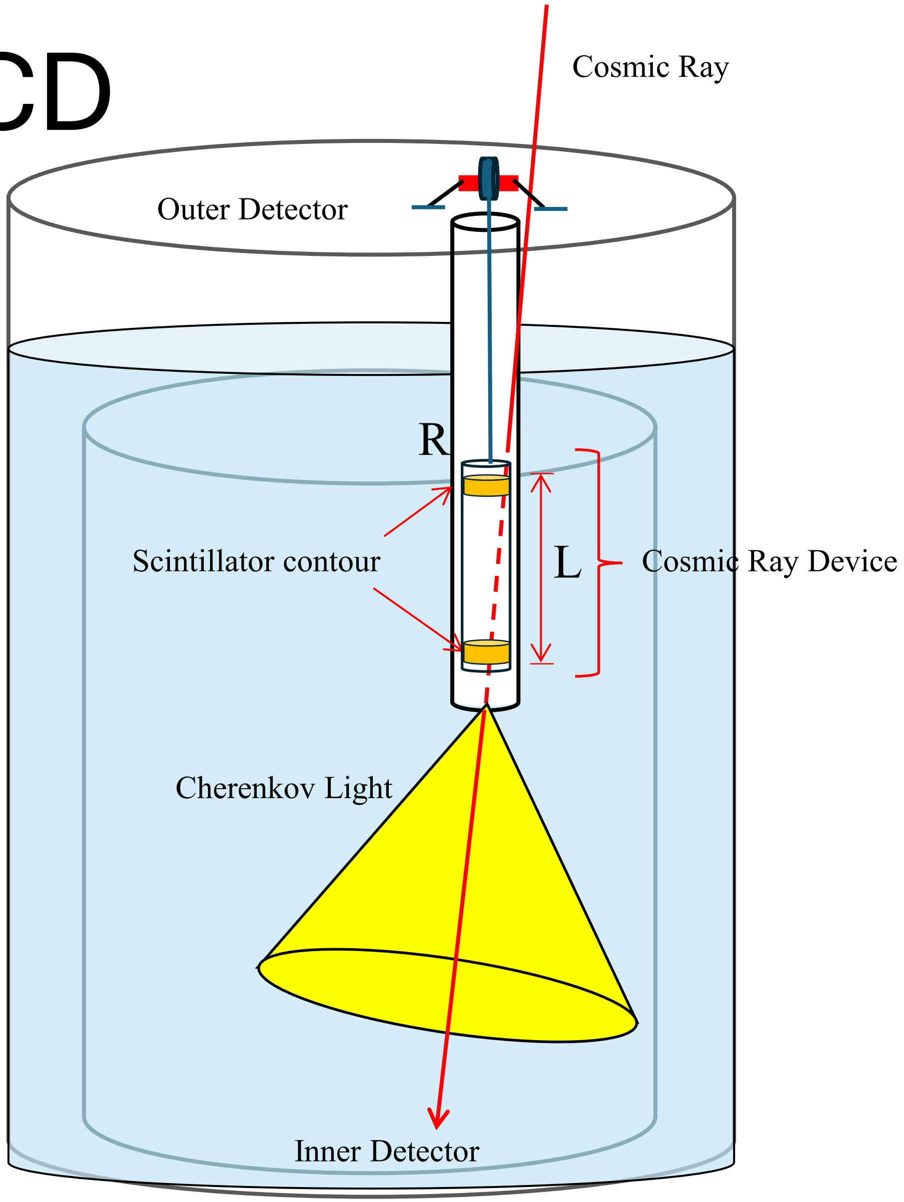


Fig 2: IWCD Detector with Cosmic Ray Pipe

Goal 1: Estimation of cosmic muon rate through the device

- Calculating the Geometrical Acceptance and Effective Area

Analytical derivation of the geometric factor of a particle detector having circular or rectangular geometry

G R Thomas and D M Willis
SRC, Radio and Space Research Station, Ditton Park, Slough, SL3 9JX

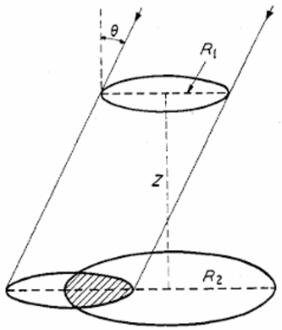


Figure 1 Relevant geometry for the application of the 'shadow area' approach to unequal circular areas

$$\boxed{S(\theta) = 2R^2\left(\arccos(k) - k\sqrt{1-k^2}\right)}$$

- where, $d = L\tan\theta$ $\quad k = \dfrac{d}{2R} = \dfrac{L\tan\theta}{2R}$

Ref: *Analytical derivation of the geometric factor of a particle detector having circular or rectangular geometry,"* J. Phys. E: Sci. Instrum. 5(3), 260. https://doi.org/10.1088/0022-3735/5/3/024

Goal 1: muon flux study through variable aperture

- The flux data is of the form: $\boxed{[\Phi] = \text{particles} \cdot \text{cm}^{-2} \cdot \text{s}^{-1} \cdot \text{sr}^{-1} \cdot \text{GeV}^{-1}}$

  Note the azimuthal flux is assumed constant

- For the rate per second Γ: $$\Gamma = \int\int \Phi(E,\theta) \cdot A_{\text{eff}}(\theta,\phi)\, d\Omega\, dE$$

- $$\boxed{\Gamma \approx \sum_i [\Phi_{\text{total}}(u_i)] \cdot S(u_i) \cdot u_i \cdot (2\pi \cdot \Delta u)}$$

```
contribution = fine_flux[i] * S_overlap * u * (2 * np.pi * d_cos_fine)
total_rate += contribution
```

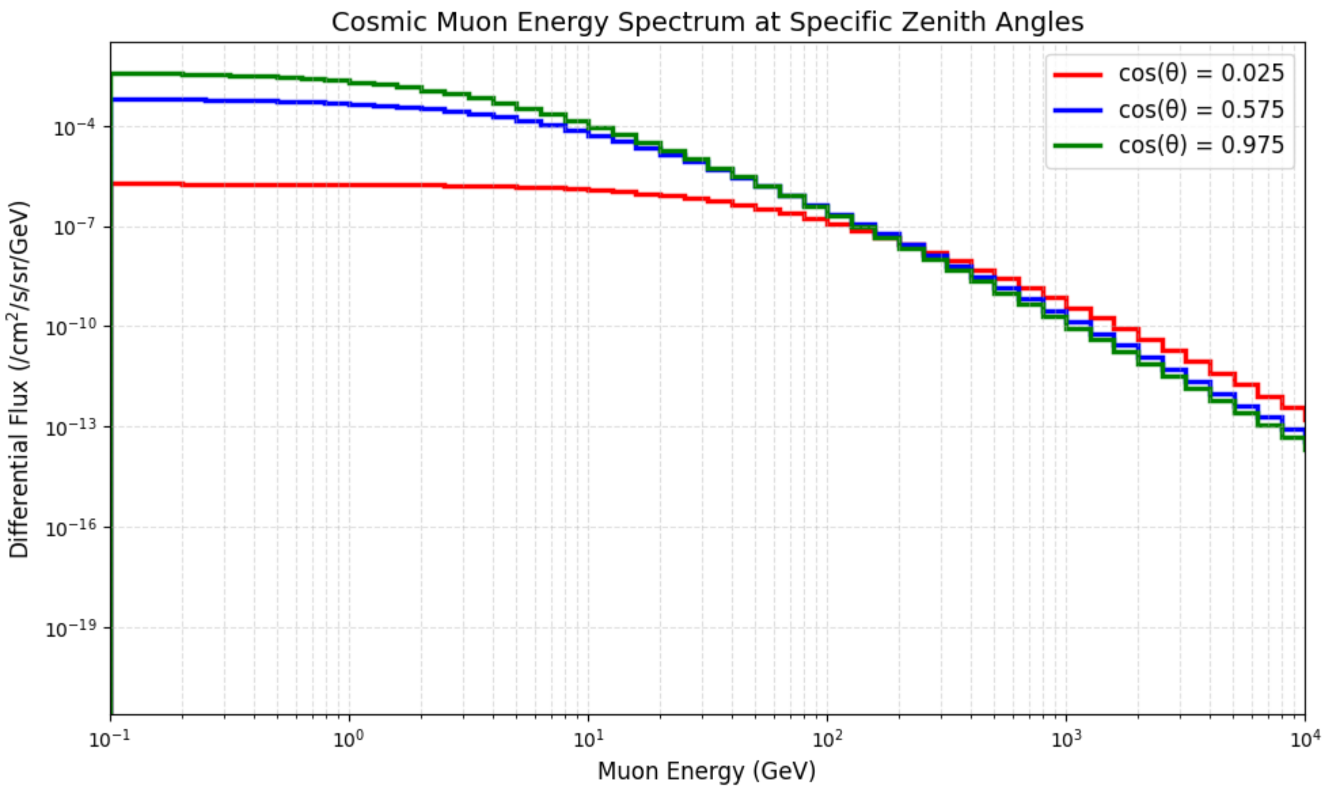
- `fine_flux[i]`: $\Phi_{\text{total}}(u_i)$ (The pre-integrated particle density).
- `S_overlap`: $S(u_i)$ (The overlapping geometric shadow).
- `u`: $\cos\theta$ (The projection factor for effective area).
- `2 * np.pi * d_cos_fine`: $2\pi\,\Delta u$ (The solid angle element of the sky ring).

Multiplying this final sum by 86,400 seconds/day yields the final design metric: Total Muons per Day.

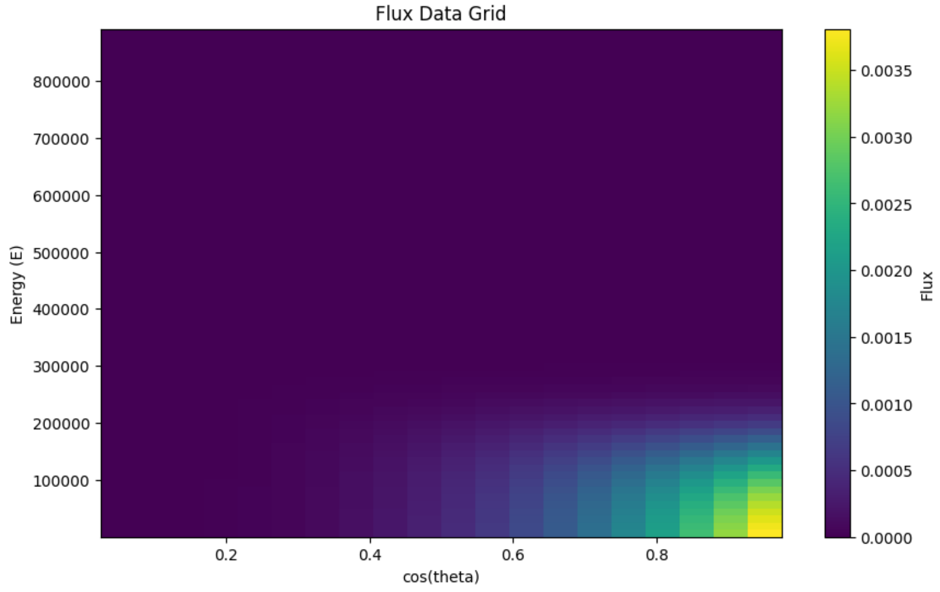
```
# Cosmic muon surface flux (Gaisser + low-energy correction)
# cosTheta_mean  E_mean[GeV]  E_lower[GeV]  E_upper[GeV]  flux[/cm2/s/sr/GeV]
0.0250 1.122018e-01 1.000000e-01 1.258925e-01 1.839180e-06
0.0250 1.412538e-01 1.258925e-01 1.584893e-01 1.836929e-06
0.0250 1.778279e-01 1.584893e-01 1.995262e-01 1.834099e-06
0.0250 2.238721e-01 1.995262e-01 2.511886e-01 1.830545e-06
0.0250 2.818383e-01 2.511886e-01 3.162278e-01 1.826084e-06
0.0250 3.548134e-01 3.162278e-01 3.981072e-01 1.820489e-06
0.0250 4.466836e-01 3.981072e-01 5.011872e-01 1.813479e-06
0.0250 5.623413e-01 5.011872e-01 6.309573e-01 1.804705e-06
0.0250 7.079458e-01 6.309573e-01 7.943282e-01 1.793740e-06
0.0250 8.912509e-01 7.943282e-01 1.000000e+00 1.780065e-06
0.0250 1.122018e+00 1.000000e+00 1.258925e+00 1.763049e-06
0.0250 1.412538e+00 1.258925e+00 1.584893e+00 1.741938e-06
0.0250 1.778279e+00 1.584893e+00 1.995262e+00 1.715845e-06
0.0250 2.238721e+00 1.995262e+00 2.511886e+00 1.683742e-06
0.0250 2.818383e+00 2.511886e+00 3.162278e+00 1.644473e-06
0.0250 3.548134e+00 3.162278e+00 3.981072e+00 1.596777e-06
0.0250 4.466836e+00 3.981072e+00 5.011872e+00 1.539356e-06
0.0250 5.623413e+00 5.011872e+00 6.309573e+00 1.470970e-06
0.0250 7.079458e+00 6.309573e+00 7.943282e+00 1.390593e-06
```

Fig 5: Input Data Snap *add citqatio the paper

Input Flux Plot



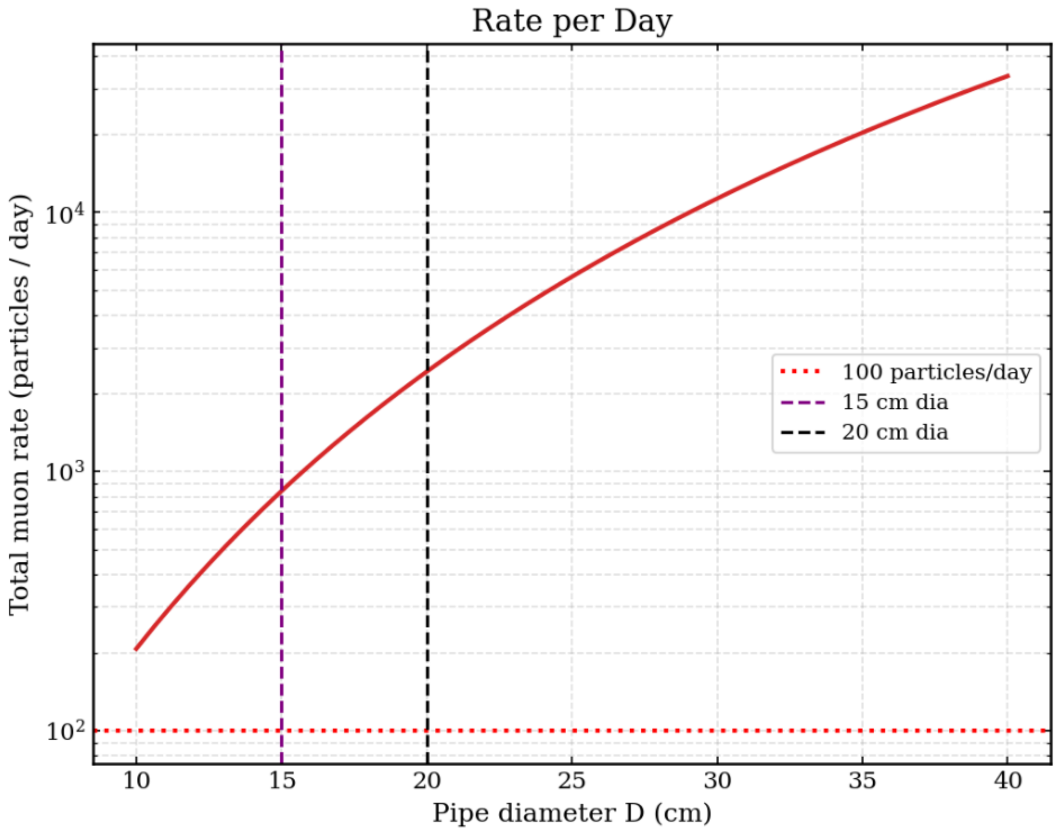
Cosmic muon flux vs energy distribution for different azimuthal angles



same input plot with heat map * make the labels bi

the muon flux data used was created by Ozaki San at TUS, for noise study created by high energy atmospheric muon creating short lived isotopes

Results



Calculating rates...

--- Final Rate Table (L = 100.0 cm) ---

Dia (cm)	Rad (cm)	Rate/sec	Rate/day
10.00	5.00	2.3978e-03	207.17
11.00	5.50	3.2891e-03	284.18
12.00	6.00	4.4239e-03	382.23
13.00	6.50	5.8465e-03	505.14
14.00	7.00	7.6019e-03	656.80
15.00	7.50	9.7370e-03	841.28
16.00	8.00	1.2312e-02	1063.73
17.00	8.50	1.5375e-02	1328.44
18.00	9.00	1.8994e-02	1641.07
19.00	9.50	2.3226e-02	2006.71
20.00	10.00	2.8137e-02	2431.07

Muon Flux rate for 1m pipe

The required statistics of muon rate is 100 particles /day, the

Goal 3: Mechanical Design Requirements

- Pipe Length ≤1m for boundary fucidial cvol

- Pipe Diameter ≤ 200mm
- Pipe Material SS304 or SS316
- Water tightness– up to 3m in water operational depth

- PMT – 2 inch or 3 inch PMT
- Cable bend radius(assuming RJ174 – 10 X D) > 40 mm (max radius it bend out)
- Water tightness around the cable as well
- The device needs to be lowered into the tank

Pipe Selection SS304/316 (JIS G 3459)

<u>If 200 OD port</u>

- NPS -6
- OD 165.20 mm
- SCHEDULE 5
- ID = 165.2 -2*(2.8) =159.6 mm

<u>If 240 mm port</u>

- NPS-8
- OD- 216.3mm
- SCHEDULE 5
- ID = 216.3-2*(2.8)= **210.7 mm**

配管用ステンレス鋼鋼管 SUS-TP SUS304TP, SUS304HTP, SUS304LTP, SUS321TP, SUS321HTP JIS G 3459

Stainless steel pipes

呼び方		外径	呼び厚さ														
			Sch 5S		Sch 10S		Sch 20S		Sch 40		Sch 80		Sch 120		Sch 160		
A	B	D (mm)	厚さ t (mm)	単位質量 W (kg/m)	厚さ t (mm)	単位質量 W (kg/m)	厚さ t (mm)	単位質量 W (kg/m)	厚さ t (mm)	単位質量 W (kg/m)	厚さ t (mm)	単位質量 W (kg/m)	厚さ t (mm)	単位質量 W (kg/m)	厚さ t (mm)	単位質量 W (kg/m)	
6	1/8	10.5	1.0	0.237	1.2	0.278	1.5	0.336	1.7	0.373	2.4	0.484					1
8	1/4	13.8	1.2	0.377	1.65	0.499	2.0	0.588	2.2	0.636	3.0	0.807					2
10	3/8	17.3	1.2	0.481	1.65	0.643	2.0	0.762	2.3	0.859	3.2	1.12					3
15	1/2	21.7	1.65	0.824	2.1	1.03	2.5	1.20	2.8	1.32	3.7	1.66			4.7	1.99	4
20	3/4	27.2	1.65	1.05	2.1	1.31	2.5	1.54	2.9	1.76	3.9	2.26			5.5	2.97	5
25	1	34.0	1.65	1.33	2.8	2.18	3.0	2.32	3.4	2.59	4.5	3.31			6.4	4.40	6
32	1 1/4	42.7	1.65	1.69	2.8	2.78	3.0	2.97	3.6	3.51	4.9	4.61			6.4	5.79	7
40	1 1/2	48.6	1.65	1.93	2.8	3.19	3.0	3.41	3.7	4.14	5.1	5.53			7.1	7.34	8
50	2	60.5	1.65	2.42	2.8	4.02	3.5	4.97	3.9	5.50	5.5	7.54			8.7	11.2	9
65	2 1/2	76.3	2.1	3.88	3.0	5.48	3.5	6.35	5.2	9.21	7.0	12.1			9.5	15.9	10
80	3	89.1	2.1	4.55	3.0	6.43	4.0	8.48	5.5	11.5	7.6	15.4			11.1	21.6	11
90	3 1/2	101.6	2.1	5.20	3.0	7.37	4.0	9.72	5.7	13.6	8.1	18.9			12.7	28.1	12
100	4	114.3	2.1	5.87	3.0	8.32	4.0	11.0	6.0	16.2	8.6	22.6	11.1	28.5	13.5	33.9	13
125	5	139.8	2.8	9.56	3.4	11.6	5.0	16.8	6.6	21.9	9.5	30.8	12.7	40.2	15.9	49.1	14
150	6	165.2	2.8	11.3	3.4	13.7	5.0	20.0	7.1	28.0	11.0	42.3	14.3	53.8	18.2	66.6	15
200	8	216.3	2.8	14.9	4.0	21.2	6.5	34.0	8.2	42.5	12.7	64.4	18.2	89.8	23.0	111	16
250	10	267.4	3.4	22.4	4.0	26.2	6.5	42.2	9.3	59.8	15.1	94.9	21.4	131	28.6	170	17
300	12	318.5	4.0	31.3	4.5	35.2	6.5	50.5	10.3	79.1	17.4	131	25.4	185	33.3	237	18
350	14	355.6							11.1	95.3	19.0	159	27.8	227	35.7	284	19
400	16	406.4							12.7	125	21.4	205	30.9	289	40.5	369	20
450	18	457.2							14.3	158	23.8	257	34.9	367	45.2	464	21
500	20	508.0							15.1	185	26.2	314	38.1	446	50.0	570	22
550	22	558.8							15.9	215	28.6	378	41.3	532	54.0	679	23
600	24	609.6							17.5	258	31.0	447	46.0	646	59.5	815	24
650	26	660.4							18.9	302	34.0	531	49.1	748	64.2	953	25

W＝0.02491 t (D－t)

呼び方：100A×Sch40　または　4B×Sch40

jis.jts-tokyo.com

Ref: https://jis.jts-tokyo.com/stainless-pipes-standards/

PMT selection & guide

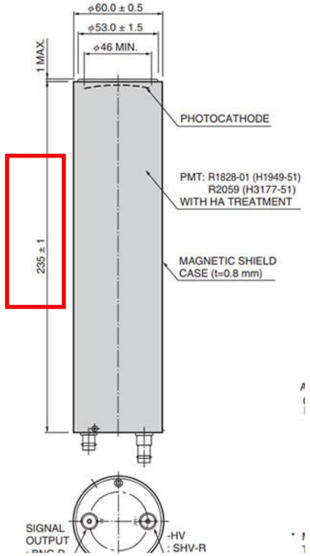
PMT:

- Standard 2 Inch PMT
- 60 mm Diameter
- PMT Length = **236 mm**

Photomultiplier tube assembly

H1949-51

Contact us >



60.0 mm diameter PMT assembly, Built-in PMT:R1828-01, For high energy physics

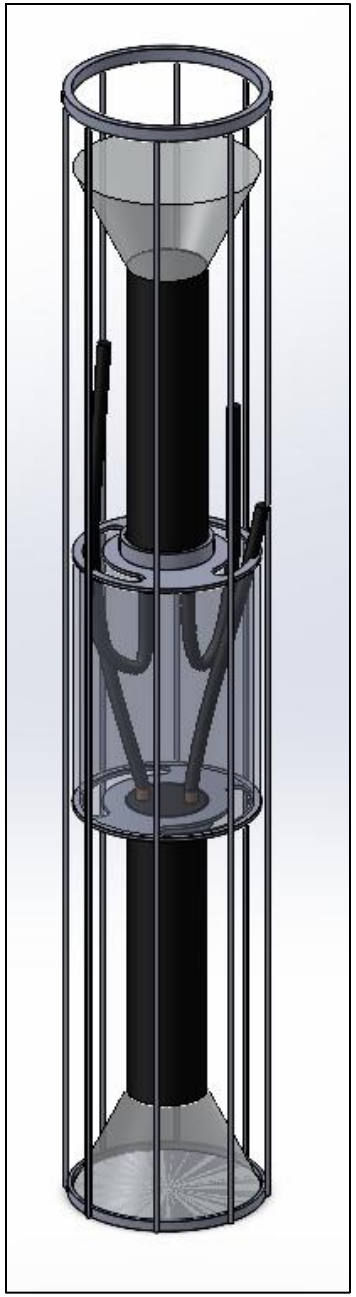
Ref: https://www.hamamatsu.com/jp/en/product/optical-sensors/pmt/pmt-assembly/head-on-type/H1949-51.html

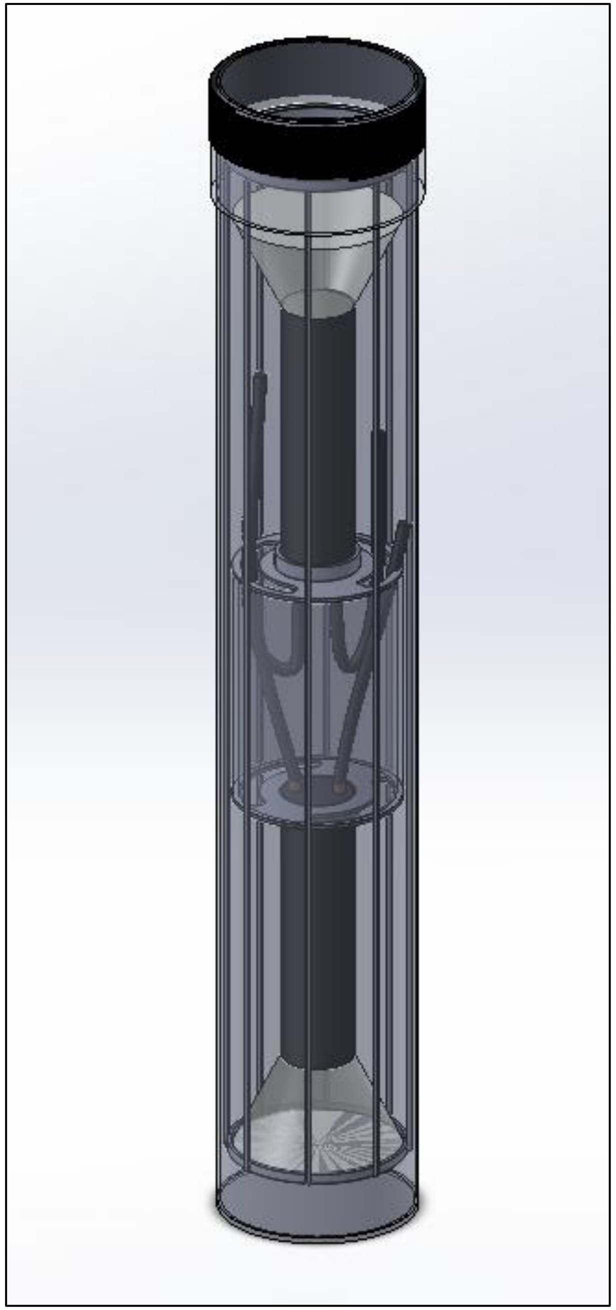
Guide:

- Desired in a PMMA conical guide with shortest length
- Current assumptions 80 mm length
- Wrote to a supplier for quote, waiting for response

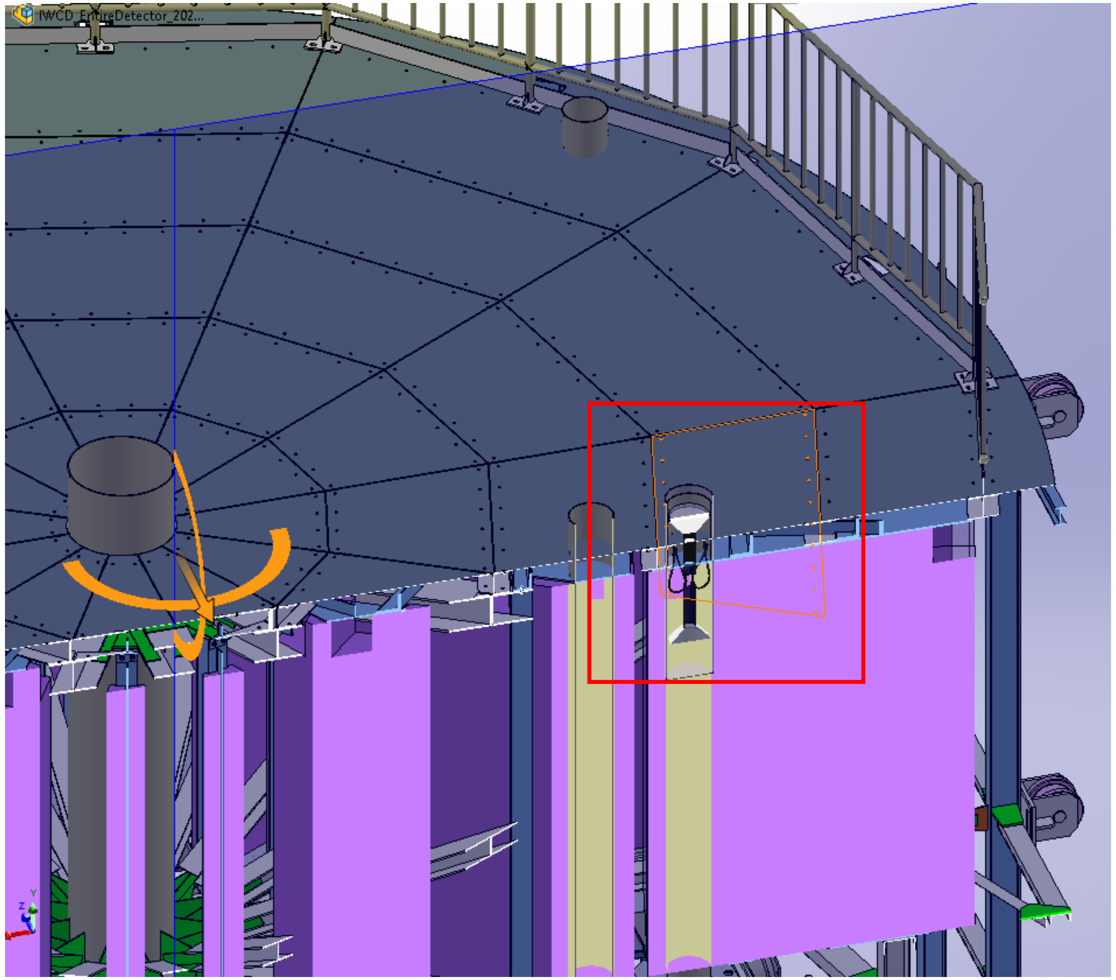
Frame Design

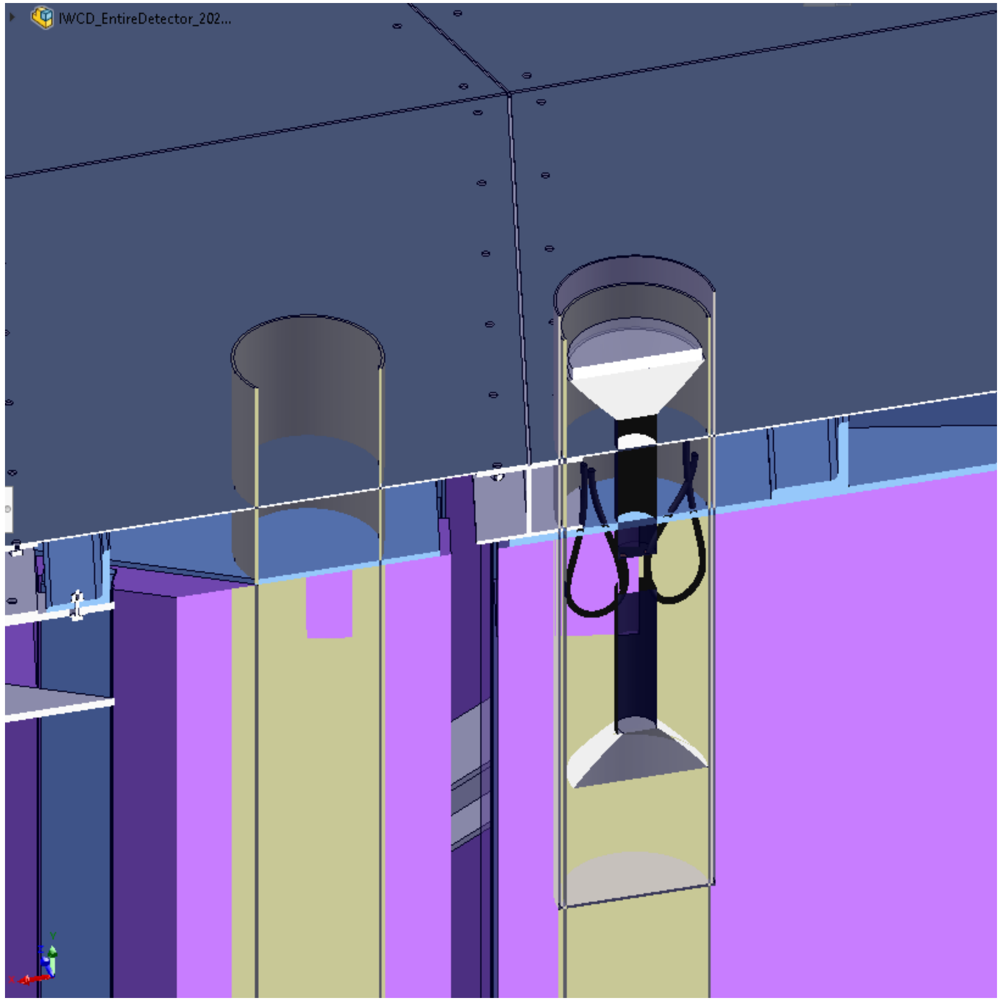
- SS304 off the shelf or cut weld components
- One single frame to slide into the Pipe
- Yet to define manufacturing process
- Space for cable pull out
- Water tight





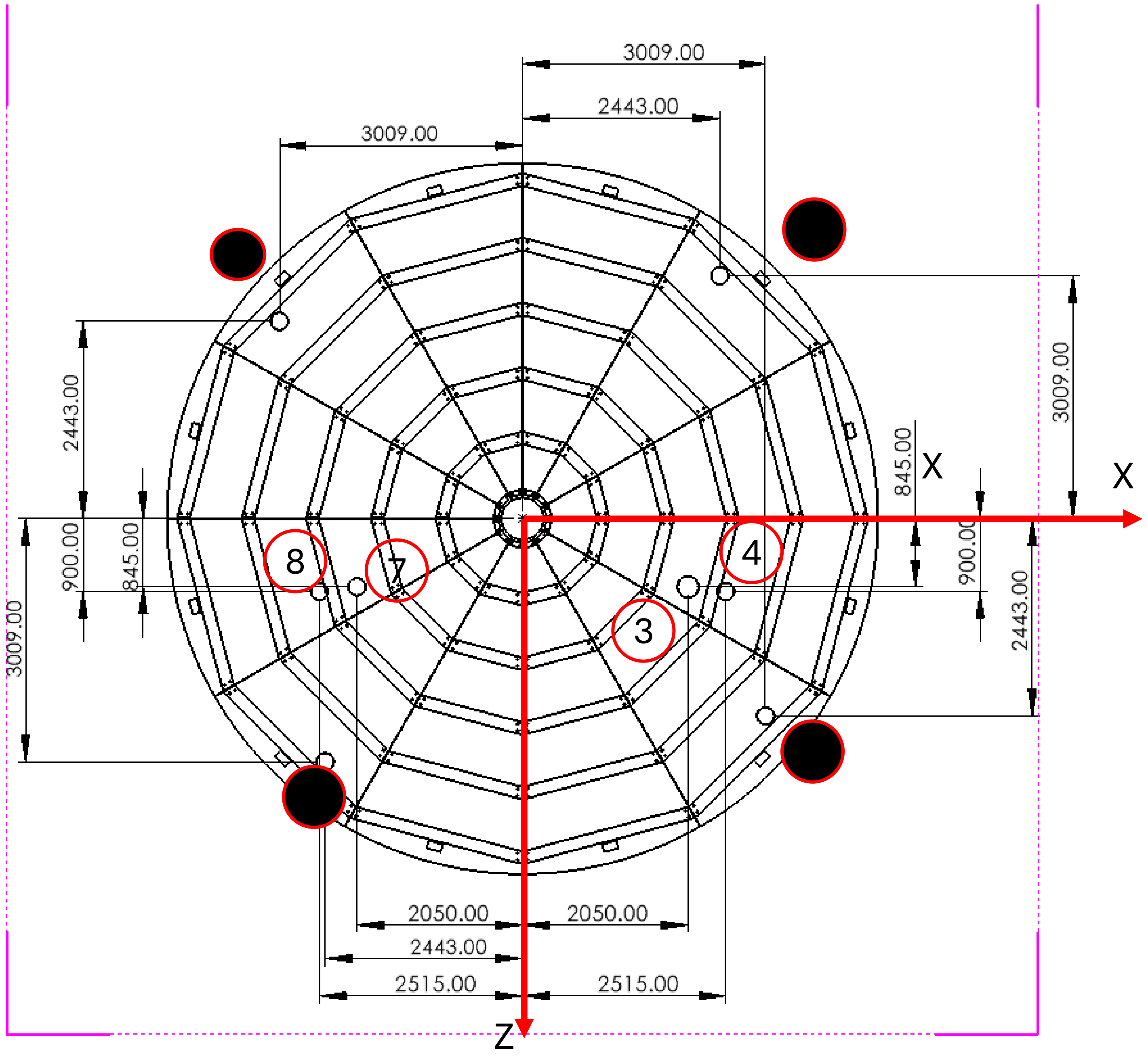
With the whole assembly





WC Sim Simulation

3	(205, 400, 84.5)
8	(-251.5, 400, 90.0)

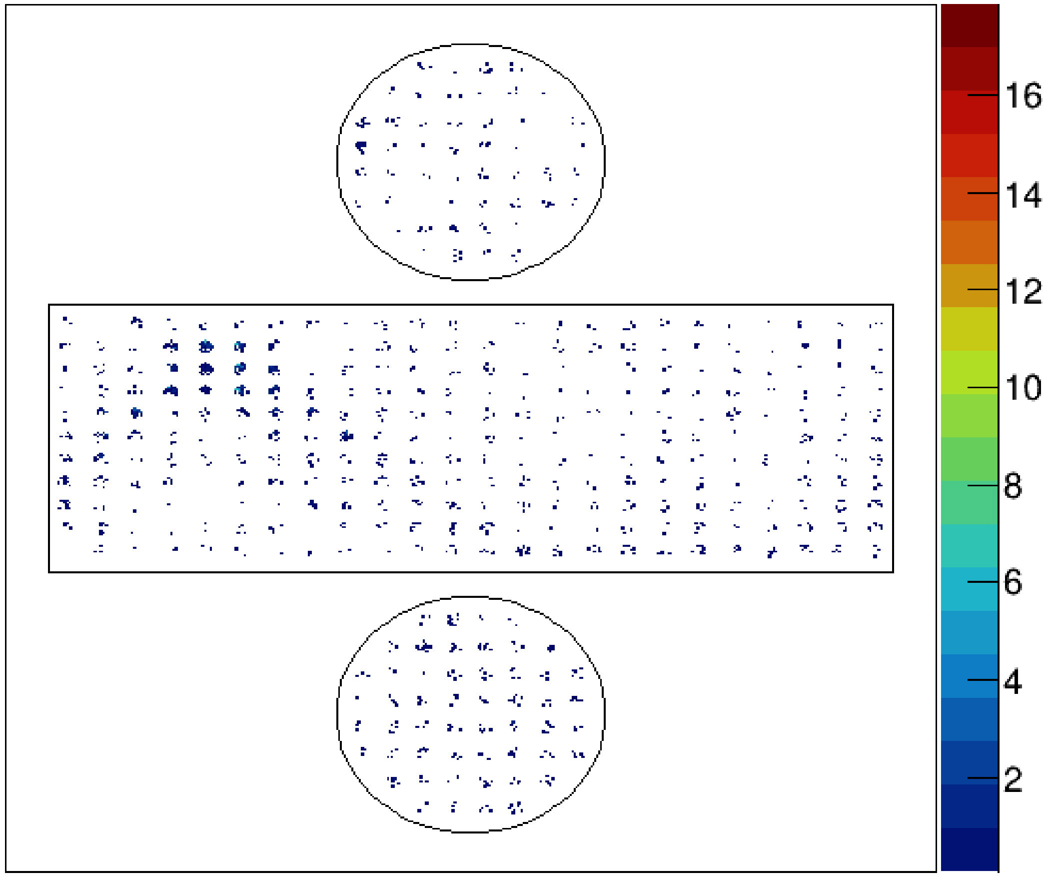


Event Display – Point 1 – (400 MeV , 1000 MeV)

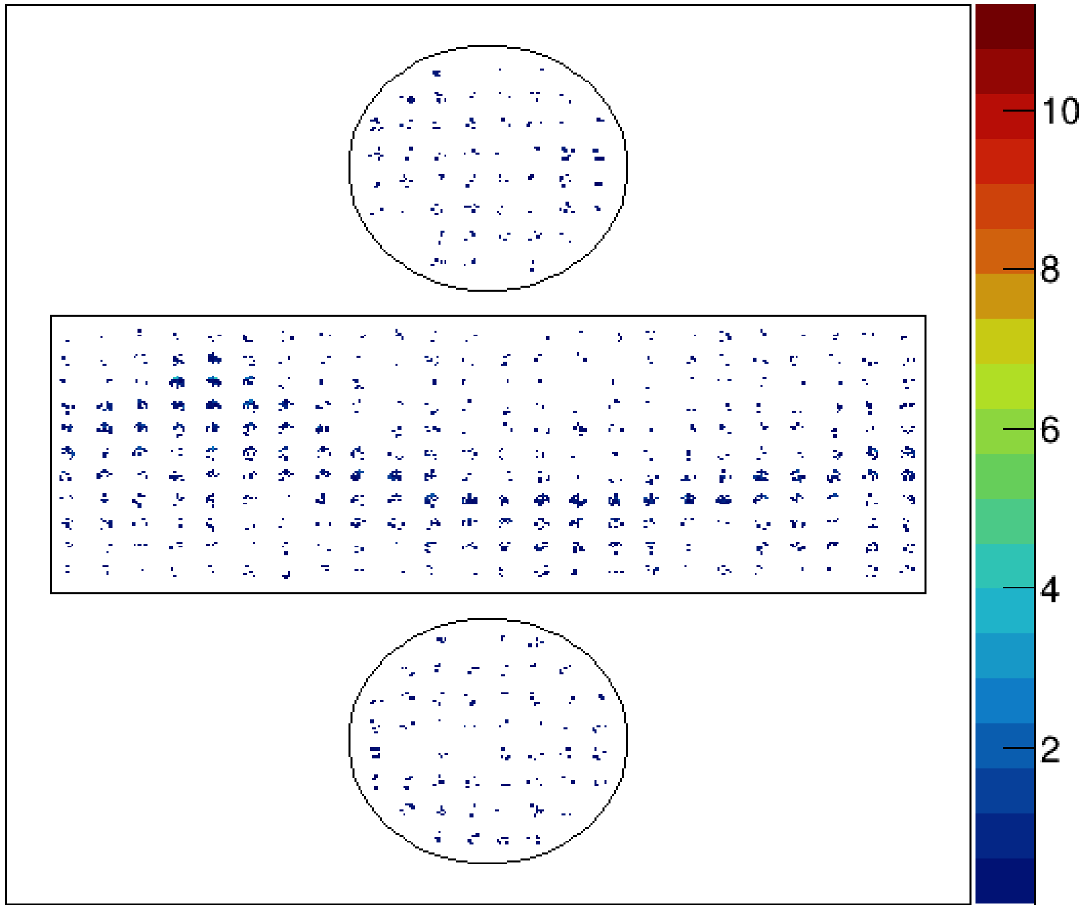
3	(205, 300, 84.5)

Radius [cm]	Coordinate [cm]	Vector ($\hat{x}$, $\hat{y}$, $\hat{z}$)	Zenith angle[deg], z=0
For ALL	205, 300, 84.5	0 -1 0	0
1	205, 300, 84.5	0.019996 -0.999800 0.000000	1.145
2	205, 300, 84.5	0.039968 -0.999201 0.000000	2.29
3	205, 300, 84.5	0.059892 -0.998205 0.000000	3.43
4	205, 300, 84.5	0.079745 -0.996815 0.000000	4.57
5	205, 300, 84.5	0.099504 -0.995037 0.000000	5.71
6	205, 300, 84.5	0.119145 -0.992877 0.000000	6.84
7	205, 300, 84.5	0.138648 -0.990342 0.000000	7.96
8	205, 300, 84.5	0.157991 -0.987441 0.000000	9.09
9	205, 300, 84.5	0.177153 -0.984183 0.000000	10.20
10	205, 300, 84.5	0.196116 -0.980581 0.000000	11.3

Goal 2: Event Displays– 400 MeV



R =10 cm – 0 deg

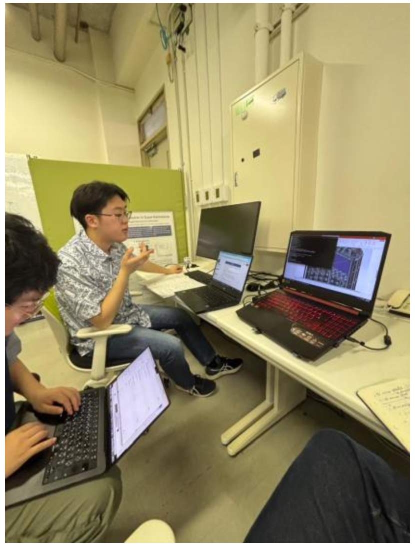


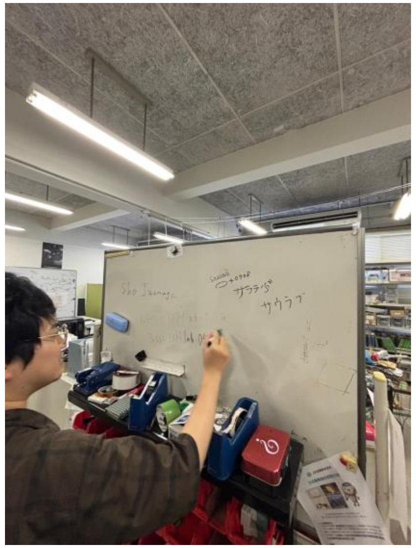
R =10 cm – 11 deg

So Far .....

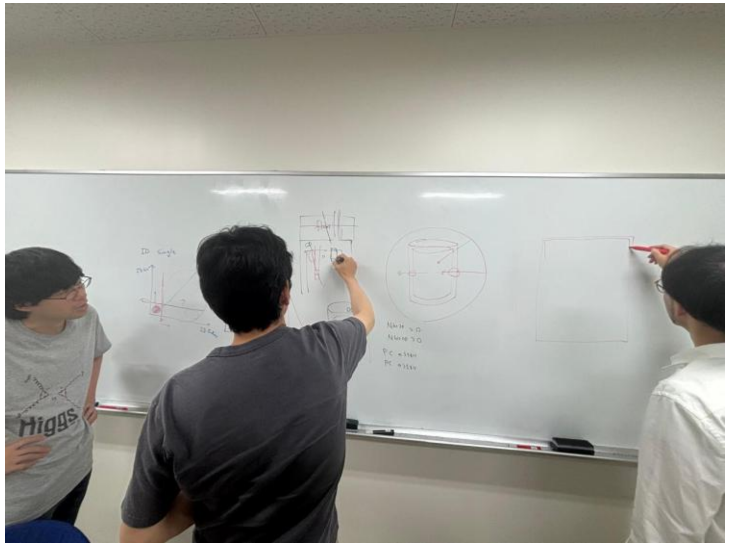
1. Flux through the aperture calculations
2. Event Display
3. Defining design requirements for the Final Design
4. Iterations and Ideas on Mechanical Design
5. Flux Calculations recheck

JPARC-Tour by Matsubara
(grateful to him for this)





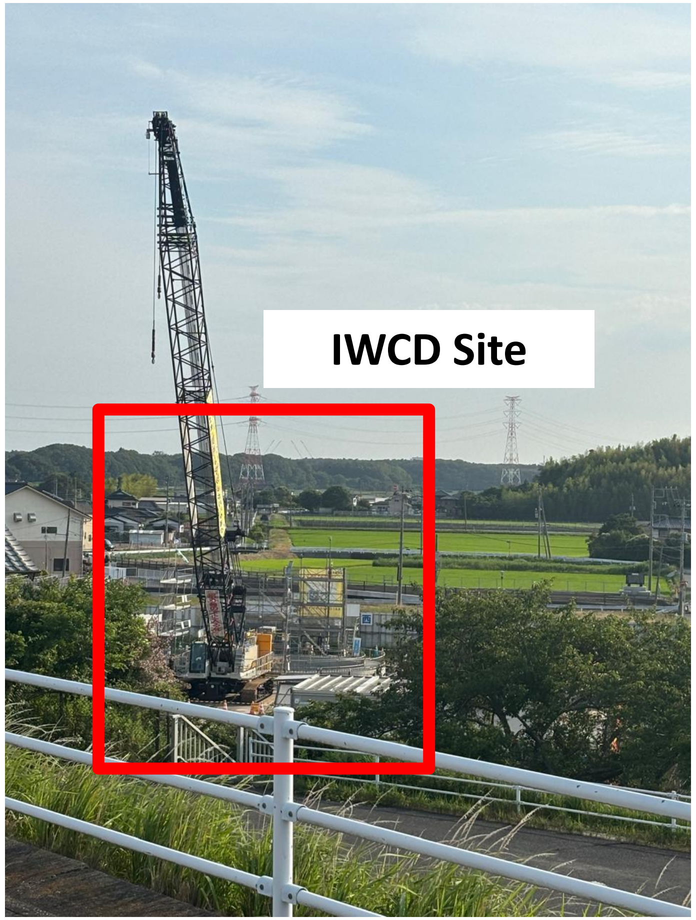
3 days Work at Tokyo Univ. of Science –event displays
Prof. Ozaki (right) and Prof. Ishitsukas students (left)

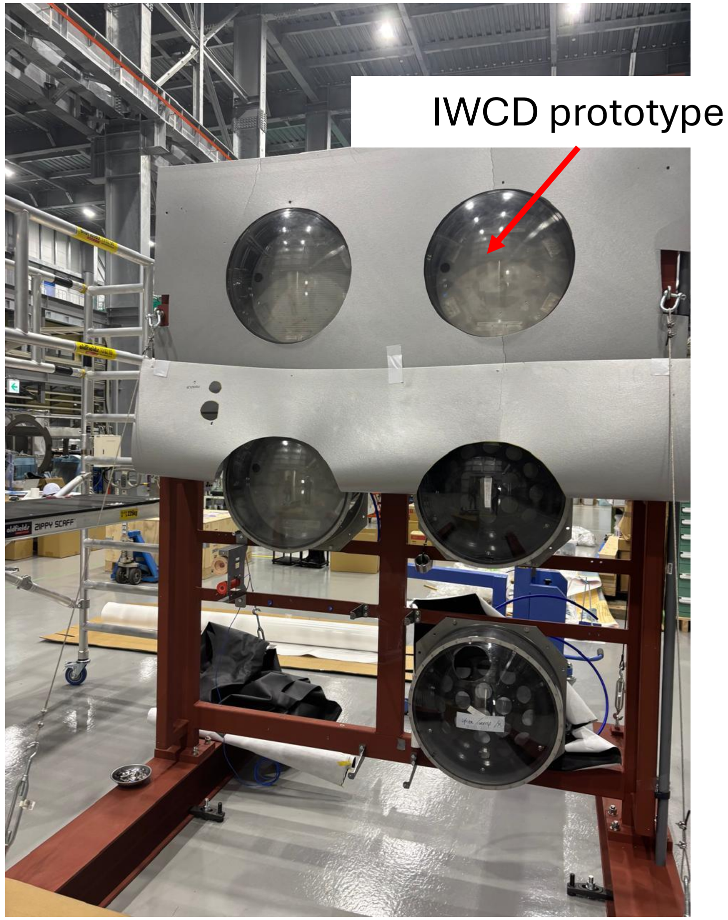


Meeting at Science Tokyo (Tokodai) – meeting on work discussion
Ishitsuka-san, Akutsu-san and Mastumoto-san

Izakaya Dinner at
Sakashita-sans farewell

More Photos





Moving Forward Plan of Next 15 days

Next

1. Discussion and Conclusions from Event Display
2. Design the **installation rack**
3. Design of Lifting Lug
4. Structural Simulation Check
5. Cable water tight design
6. Overall Assembly Procedure

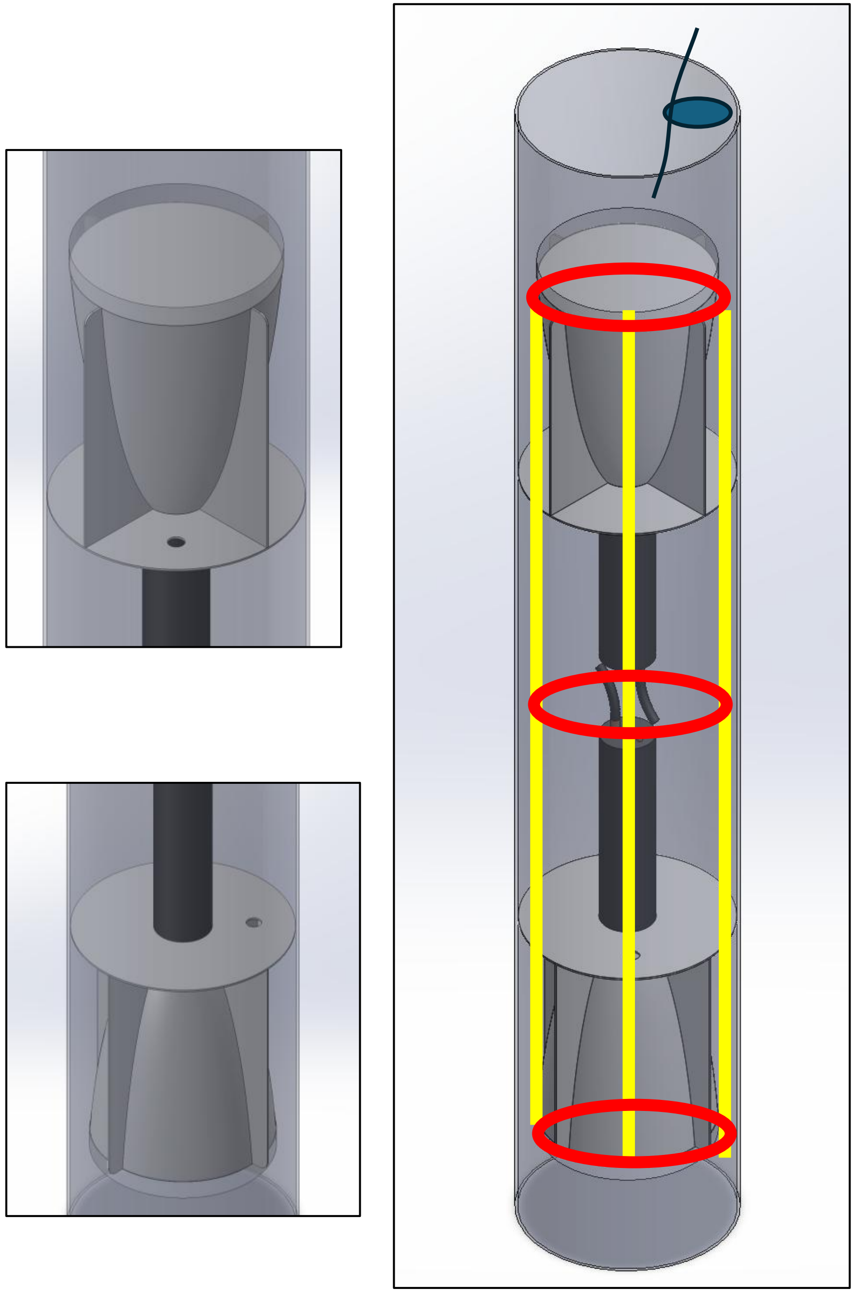
Thanks

Acknowledgement to

Akutsu-san, Mastubara-san, Ishitsuka-san, Ozaki-san, Piotr-san, Meghan-san, Matsumoto-san , Tanamura-san and Neutrino Group for all the learnings and support

Sakshita-san and KEK Admin team for the opportunity.

With Added Frame



Code Verification

- Check against the approximation of 1 particle/s through a palm (D= 8 cm).

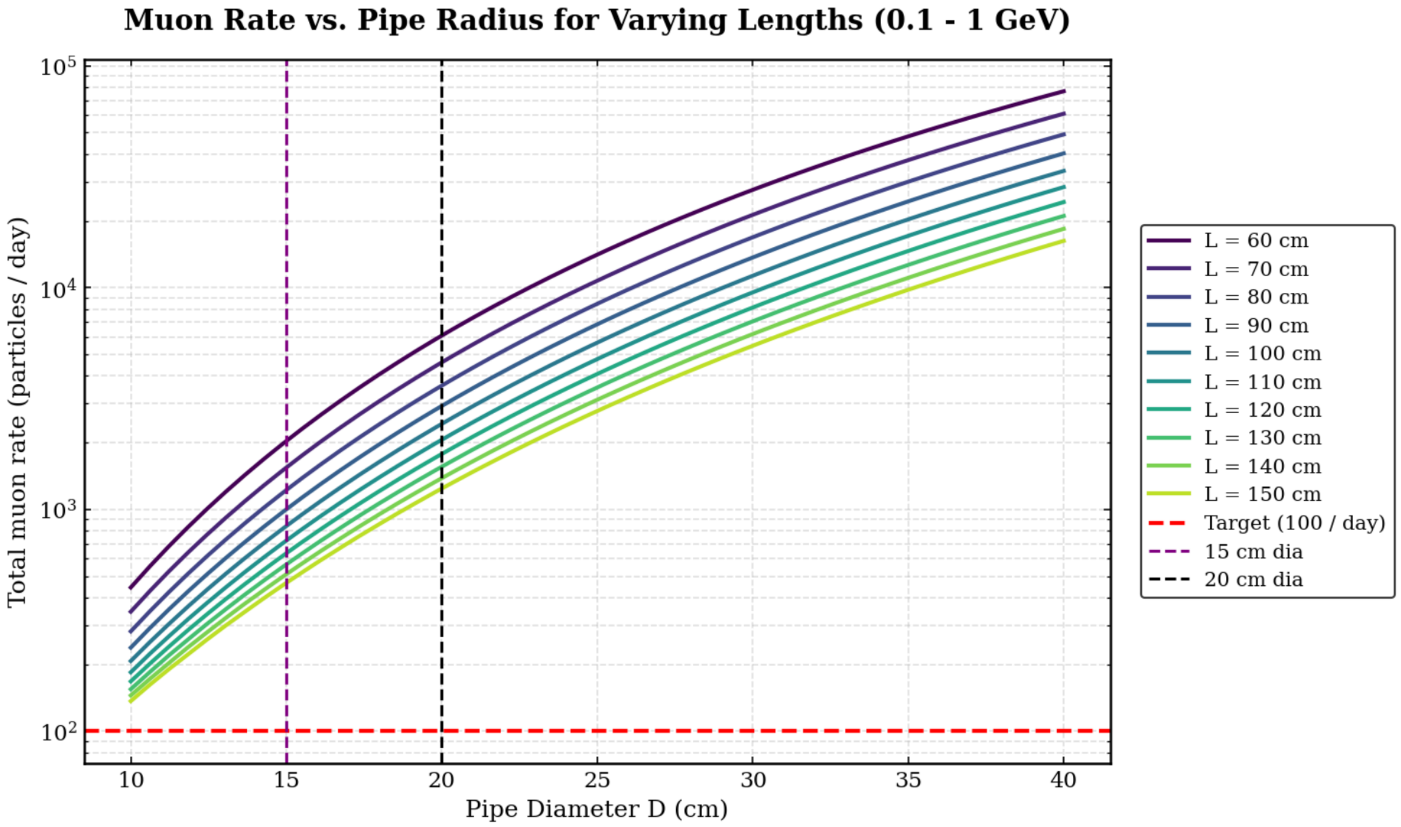
```
Calculating rates...

--- Final Rate Table (L = 1.0 cm) ---
Dia (cm)     | Rad (cm)     | Rate/sec          | Rate/day
---------------------------------------------------------
10.00        | 5.00         | 9.5555e-01        | 82559.24
10.61        | 5.31         | 1.0828e+00        | 93551.89
11.22        | 5.61         | 1.2179e+00        | 105230.60
11.84        | 5.92         | 1.3611e+00        | 117595.35
12.45        | 6.22         | 1.5121e+00        | 130646.10
13.06        | 6.53         | 1.6711e+00        | 144382.83
13.67        | 6.84         | 1.8380e+00        | 158805.53
14.29        | 7.14         | 2.0129e+00        | 173914.18
14.90        | 7.45         | 2.1957e+00        | 189708.75
15.51        | 7.76         | 2.3864e+00        | 206189.26
```

Flux rate is around 0.95 ≈ 1

What I discussed with Akutsu San

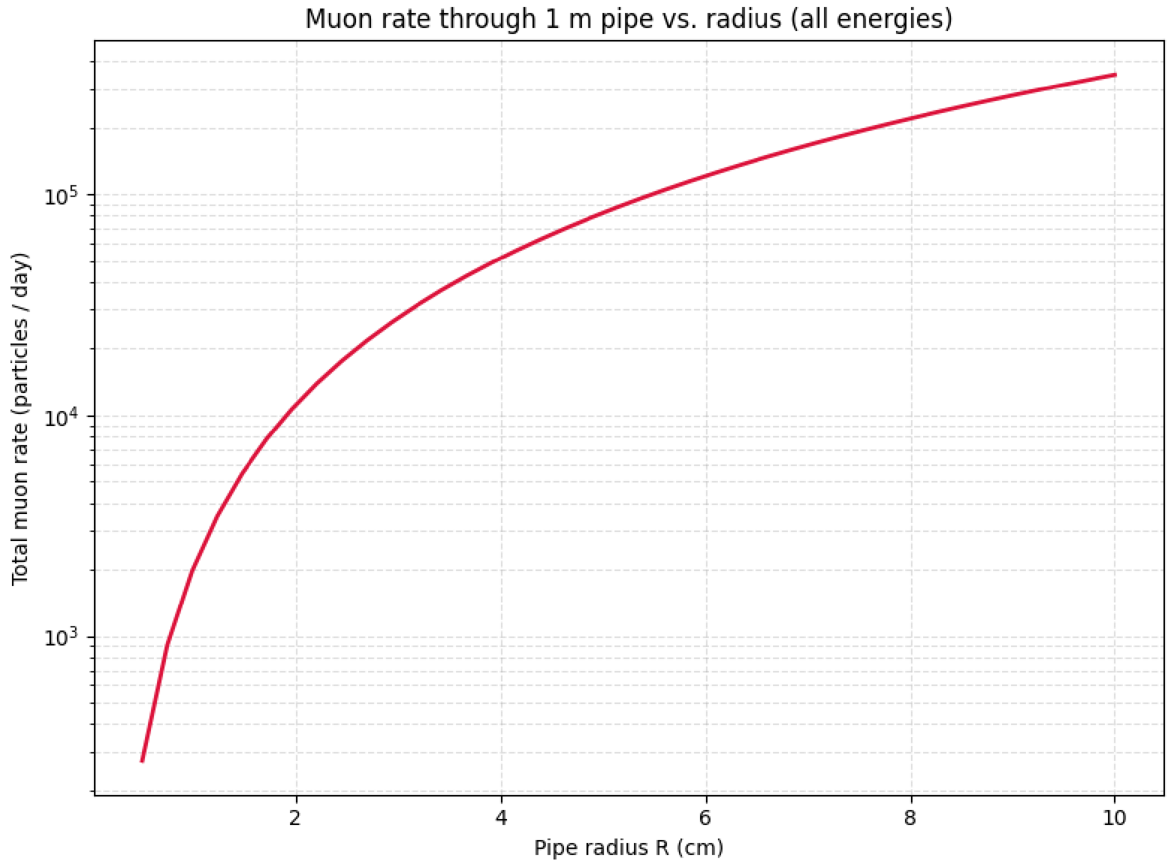
- Design the rack for the detector assembly
- Check the wire bend clearance
- Try to check the flux for lower radius
- It would be better if the calibration port can be moved around
- Reach out the company for custom light guide

Results

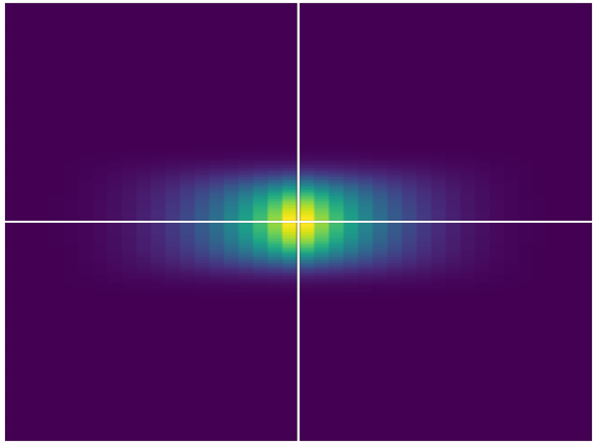


flux variations for different lenghts

Goal 1: muon flux study through variable aperture



Differential number of events observed perday vs radius (L=100cm)

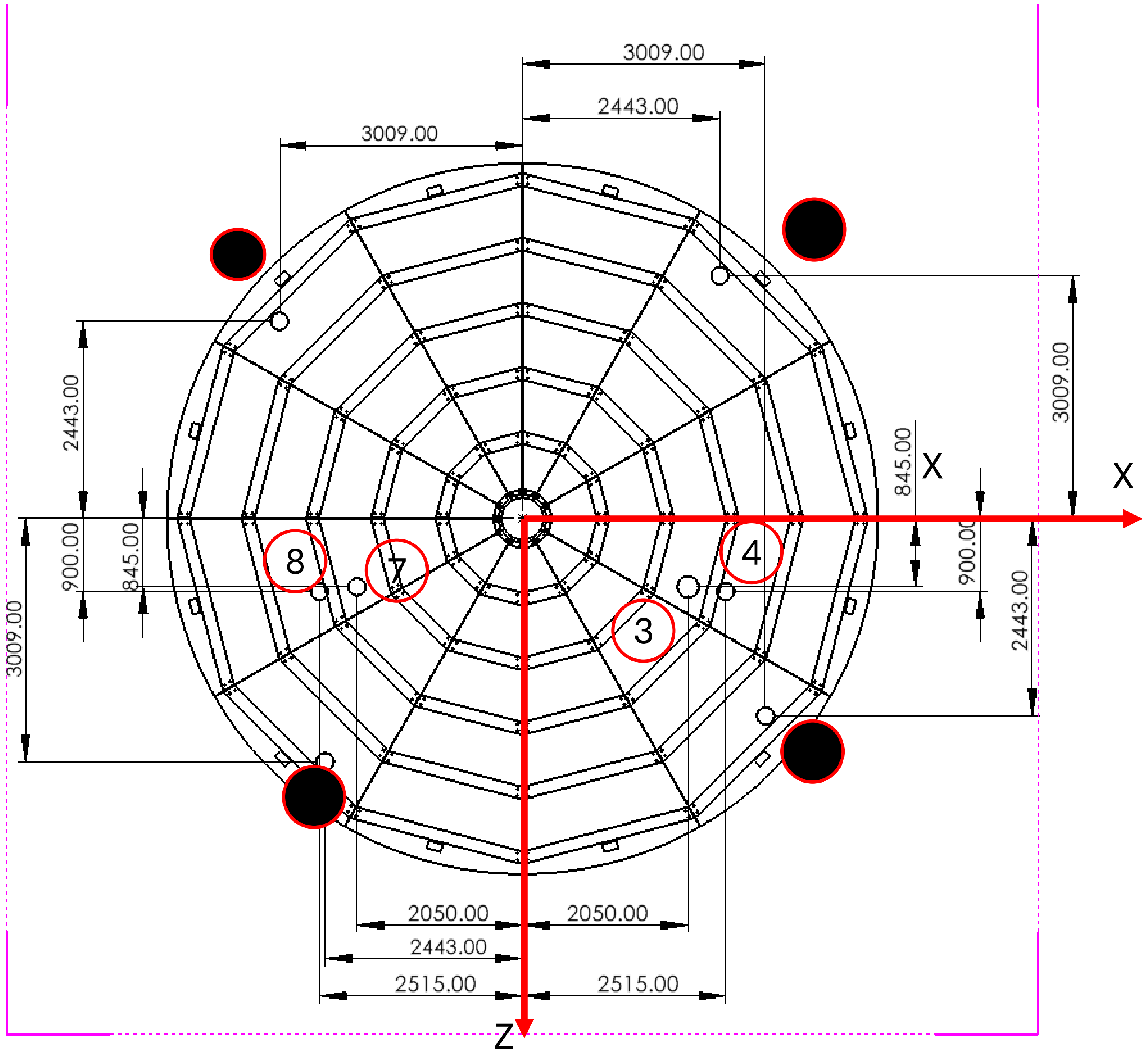


the heat map arranged in four quadrants for overall flux picture

WC Sim Simulation

3	(205, 400, 84.5)

8	(-251.5, 400, 90.0)

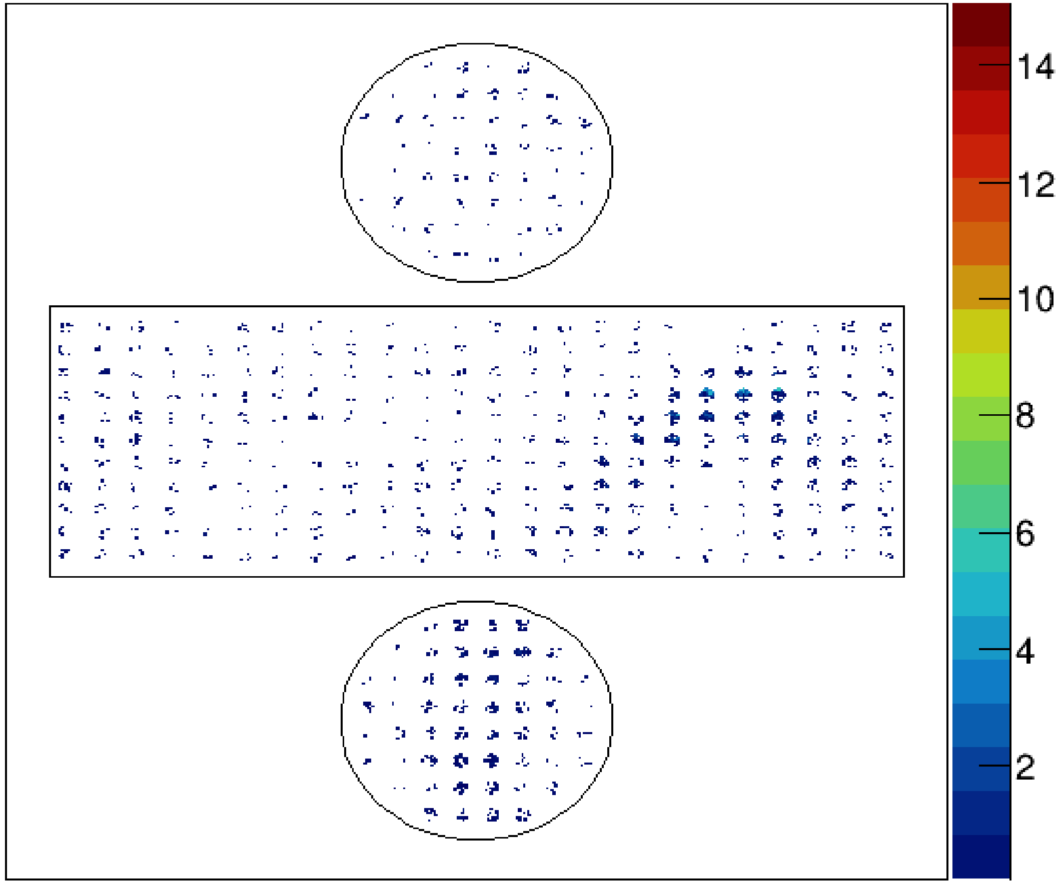


Event Display – Point 1 – (400 MeV , 1000 MeV)

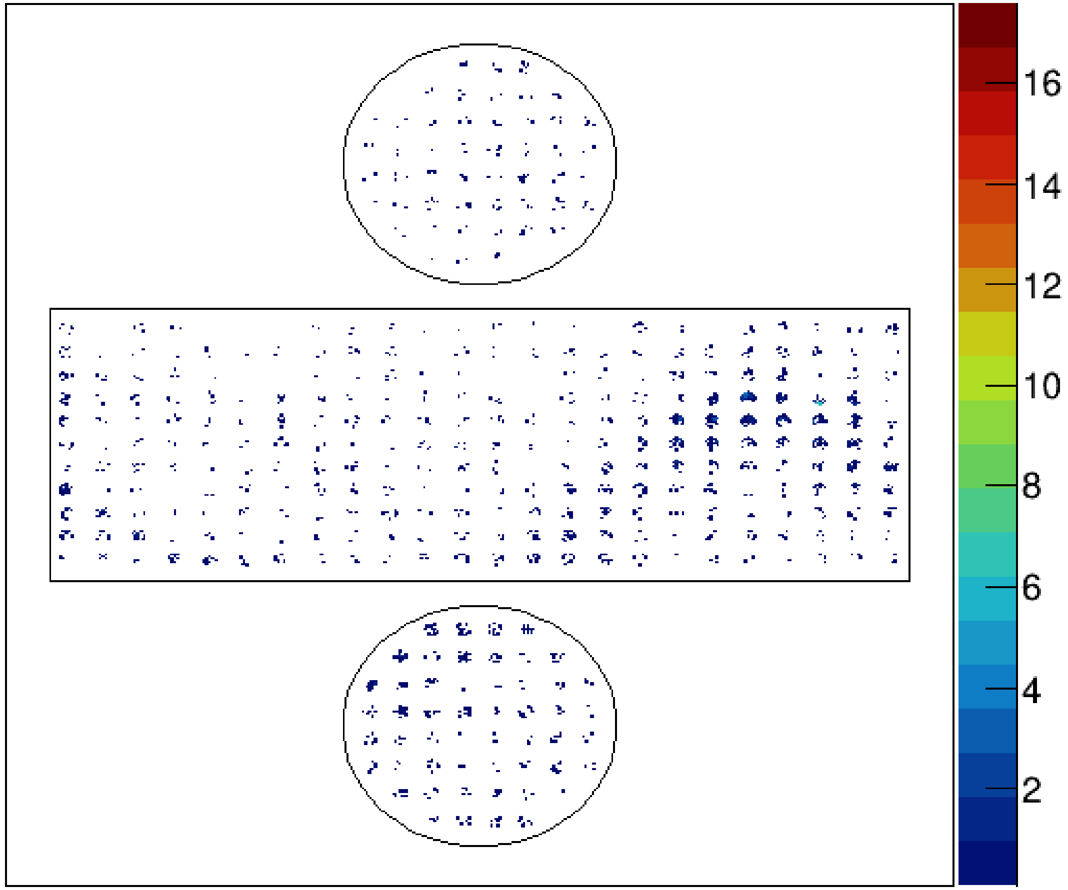
3	(205, 300, 84.5)

Radius [cm]	Coordinate [cm]	Vector $(\hat{x}, \hat{y}, \hat{z})$	Zenith angle[deg], z=0
For ALL	205, 300, 84.5	0 -1 0	0
1	205, 300, 84.5	0.019996 -0.999800 0.000000	1.145
2	205, 300, 84.5	0.039968 -0.999201 0.000000	2.29
3	205, 300, 84.5	0.059892 -0.998205 0.000000	3.43
4	205, 300, 84.5	0.079745 -0.996815 0.000000	4.57
5	205, 300, 84.5	0.099504 -0.995037 0.000000	5.71
6	205, 300, 84.5	0.119145 -0.992877 0.000000	6.84
7	205, 300, 84.5	0.138648 -0.990342 0.000000	7.96
8	205, 300, 84.5	0.157991 -0.987441 0.000000	9.09
9	205, 300, 84.5	0.177153 -0.984183 0.000000	10.20
10	205, 300, 84.5	0.196116 -0.980581 0.000000	11.3

Event Displays Pt 3- 400 MeV



R =10 cm – 0 deg



R =10 cm – 11deg

Event Display – Point 2 – (400 MeV , 1000 MeV)

8	(-251.5, 400, 90.0)

Radius [cm]	Coordinate [cm]	Vector ($\hat{x}$, $\hat{y}$, $\hat{z}$)	Zenith angle[deg], z=0	
For ALL	205, 300, 84.5	0 -1 0	0	
1	205, 300, 84.5	0.019996 -0.999800 0.000000	1.145	
2	205, 300, 84.5	0.039968 -0.999201 0.000000	2.29	
3	205, 300, 84.5	0.059892 -0.998205 0.000000	3.43	
4	205, 300, 84.5	0.079745 -0.996815 0.000000	4.57	
5	205, 300, 84.5	0.099504 -0.995037 0.000000	5.71	
6	205, 300, 84.5	0.119145 -0.992877 0.000000	6.84	
7	205, 300, 84.5	0.138648 -0.990342 0.000000	7.96	
8	205, 300, 84.5	0.157991 -0.987441 0.000000	9.09	
9	205, 300, 84.5	0.177153 -0.984183 0.000000	10.20	
10	205, 300, 84.5	0.196116 -0.980581 0.000000	11.3	

Code in Python