# Heavy Gas Cherenkov Update

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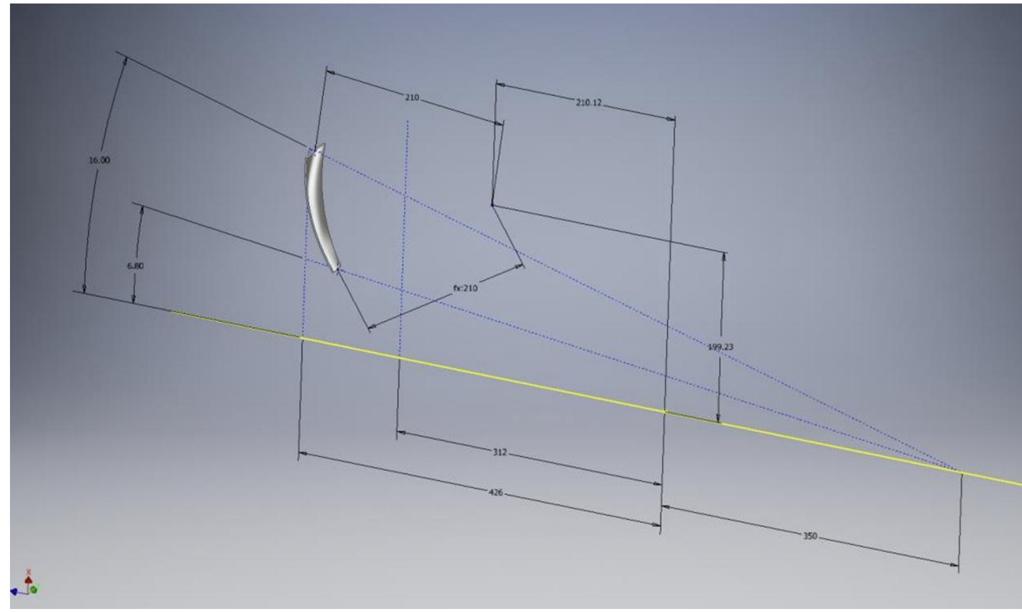
SoLID Collaboration Meeting
Feb 19-20, 2026

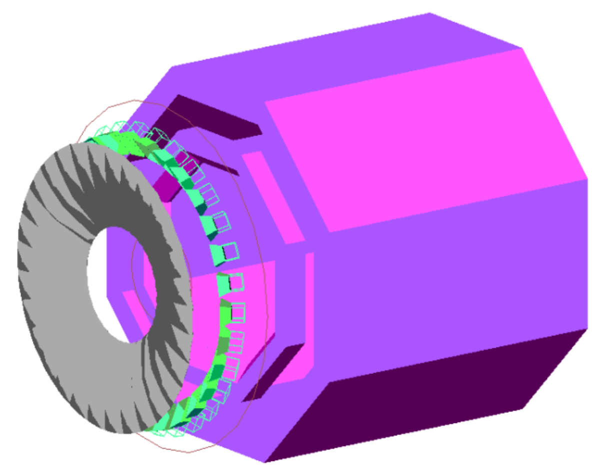
# Outline

- Engineering design and study
  - Mirror tolerance and mounting
  - hermetic electrical connector
  - Mirror reflectivity test
- HGC PID with AIML

# HGC mirror configuration

- Spherical r=210cm
- 12 deg wide
- Inner and outer radial edges defined by theta angle 6.8-16deg line relative to SIDIS target center z=-350cm
- Main mounting at the outer radial edge, assisting mounting at inner radial edge

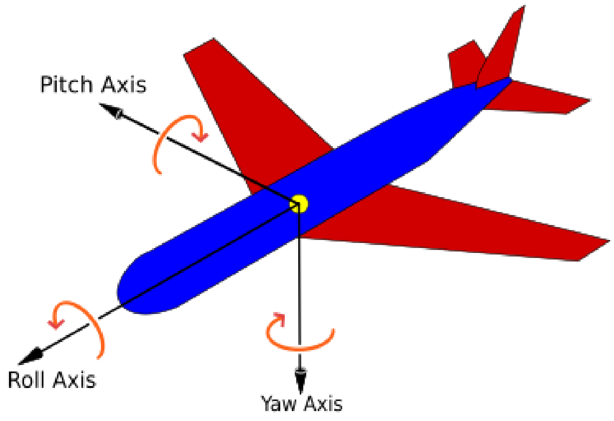


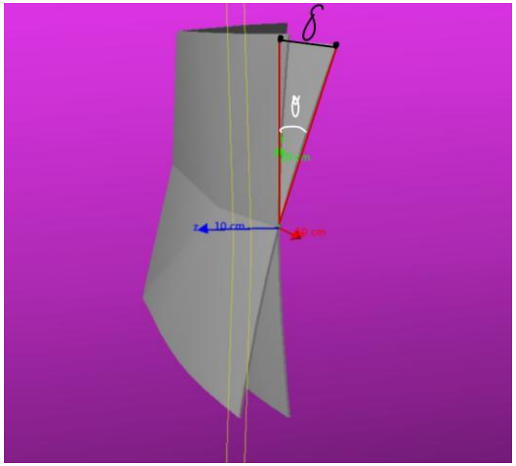
Duke student Diego Ayala

# HGC mirror movement

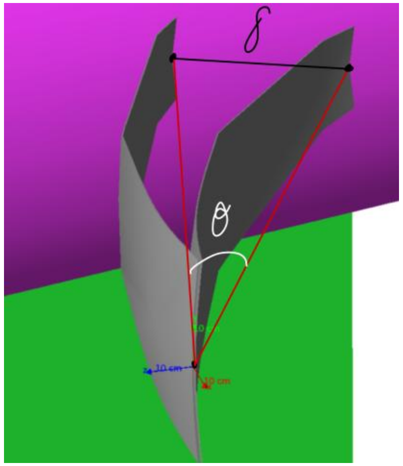
- 3 simple movements along the main mounting point at outer edge
- More combined movement study in the future



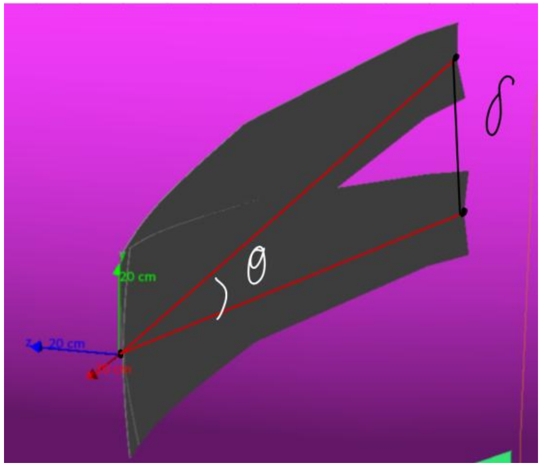

roll



pitch



yaw



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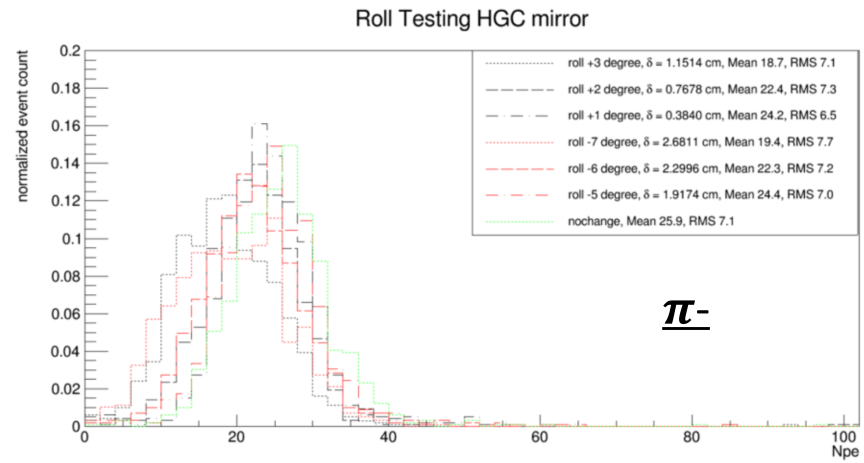
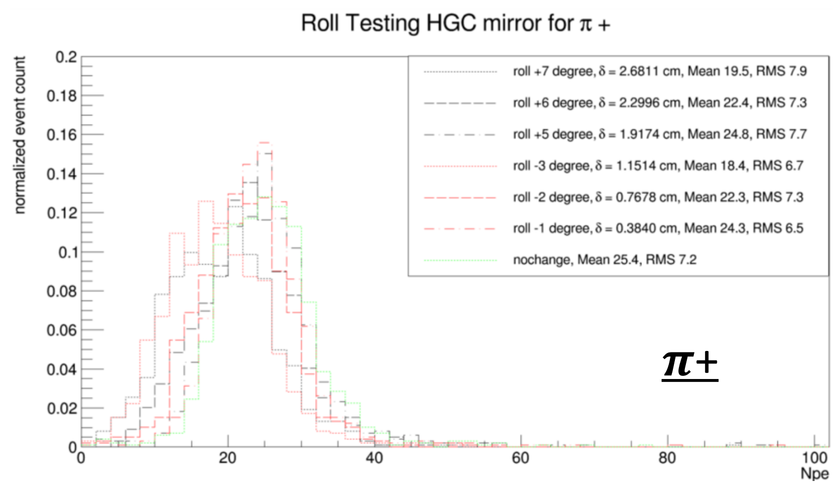
# HGC mirror movement study (roll of 30 mirrors as example)

- simulation at 2.5GeV and 8 deg where there are least photons
- Roll has different result for + and – charged particles due to solenoid field
- Move mirrors and compare Npe at different location relative to the original location
- At least 80% of original Npe for new location to define the allowed tolerance

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# HGC mirror movement study

- move 30 mirrors all together with roll,pitch,yaw to check tolerance
- Tolerance defined at 80% Npe change
  - Angle is simply the rotation angle
  - shift for a point position change with the corresponding angle
    - For pitch and yaw, at inner radial edge mid point
    - For roll, at outer radial edge corner point
- Less tolerance in roll and pitch and more tolerance in yaw (less likely because mirrors are next one another)

**$\pi$-**

| Rotation | Tolerance Angle | Tolerance Shift (cm) |
|---|---|---|
| Roll | ± 2° | 0.7678 |
| Pitch | ± 2° | 4.7463 |
| Yaw | ± 7° | 16.5742 |

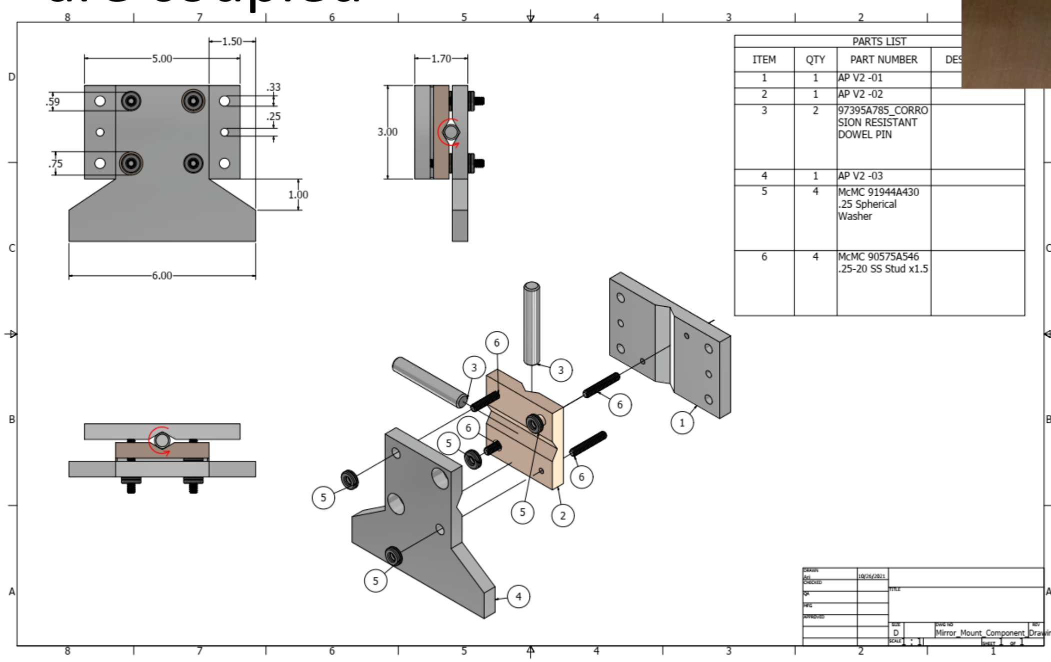
**$\pi$+**

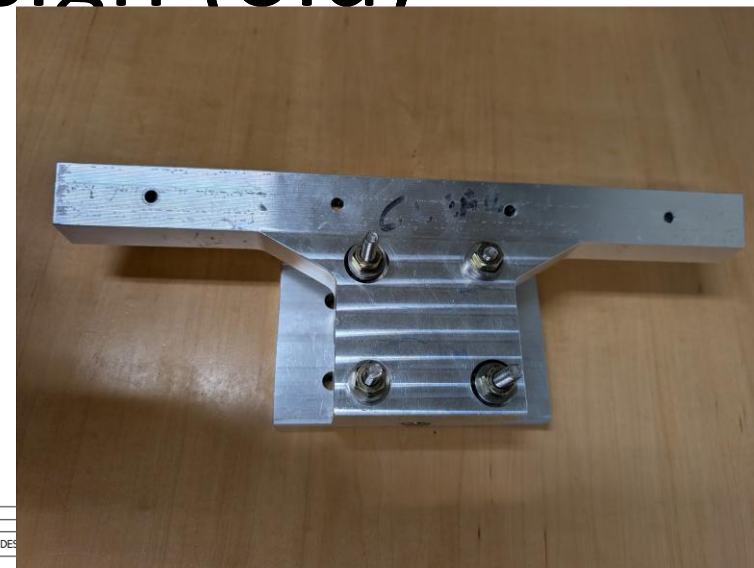
| Rotation | Tolerance Angle | Tolerance Shift (cm) |
|---|---|---|
| Roll | ± 2° | 0.7678 |
| Pitch | ± 2° | 4.7463 |
| Yaw | ± 6° | 14.2159 |

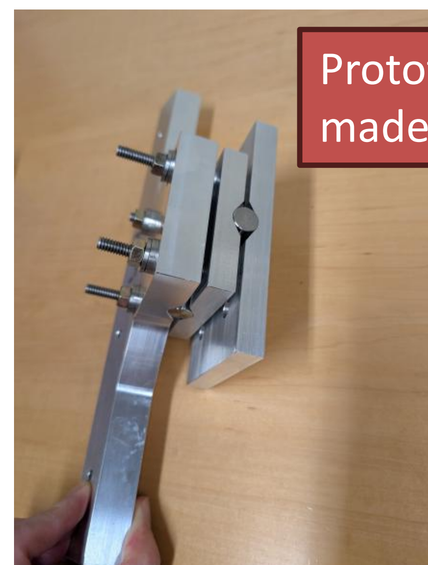
Duke student Diego Ayala

# Mirror Mounting design (old)

- At outer edge
- Mainly for roll and pitch
- Each use two screws and a pin
- But roll and pitch adjustments are coupled



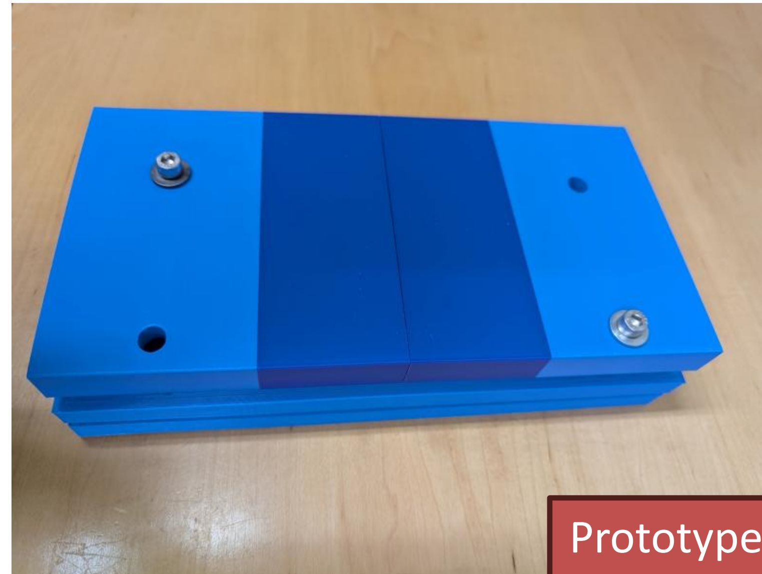


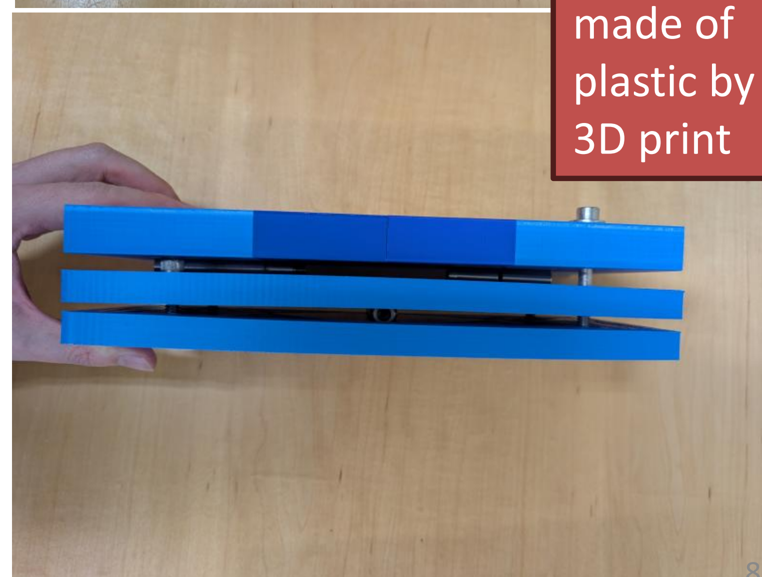
Prototype made of Al

Duke engineer Gary Swift and student Simon Gorbaty

# Mirror Mounting design (new)

- Similar design to the old one
- Longer length to allow for more adjustment
- roll and pitch adjustments are decoupled by allowing screws in holes
- Not finalized yet



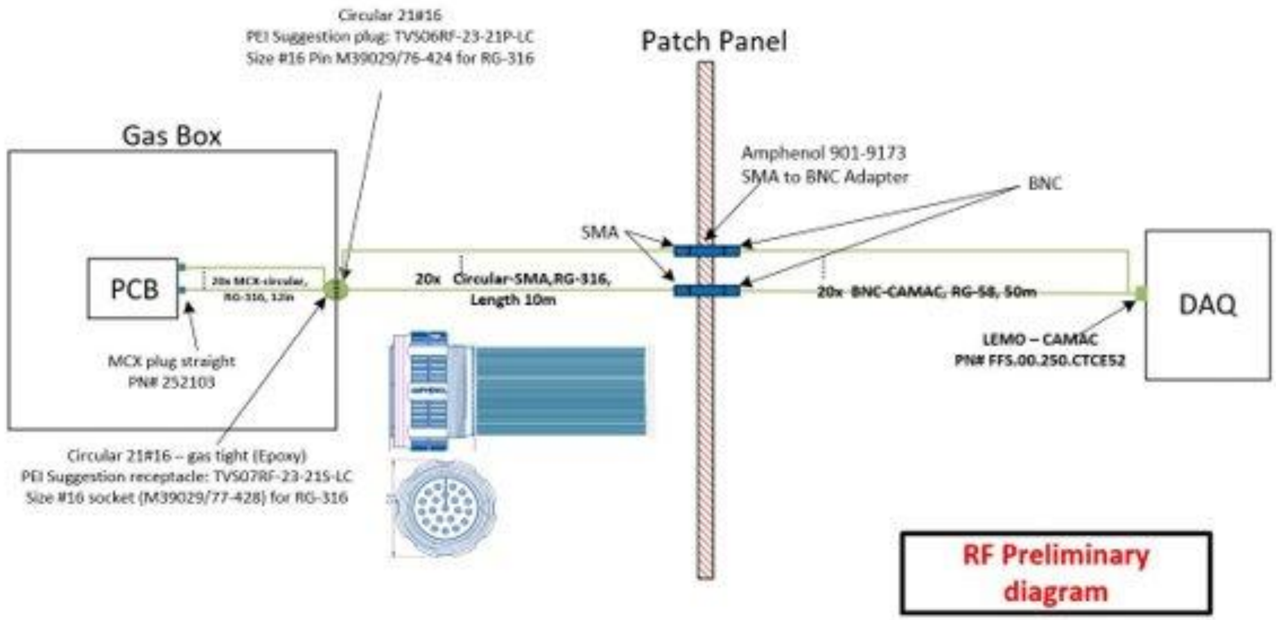


Prototype made of plastic by 3D print

Duke engineer Mark Emamian

# hermetic electrical connector

straight MCX plugs -> ~20cm RG316 cable -> gas tight connector -> ~10m RG316 cable -> patch panel (SMA-BNC) -> 30-50m RG58 cable -> DAQ crate (LEMO-CAMAC)

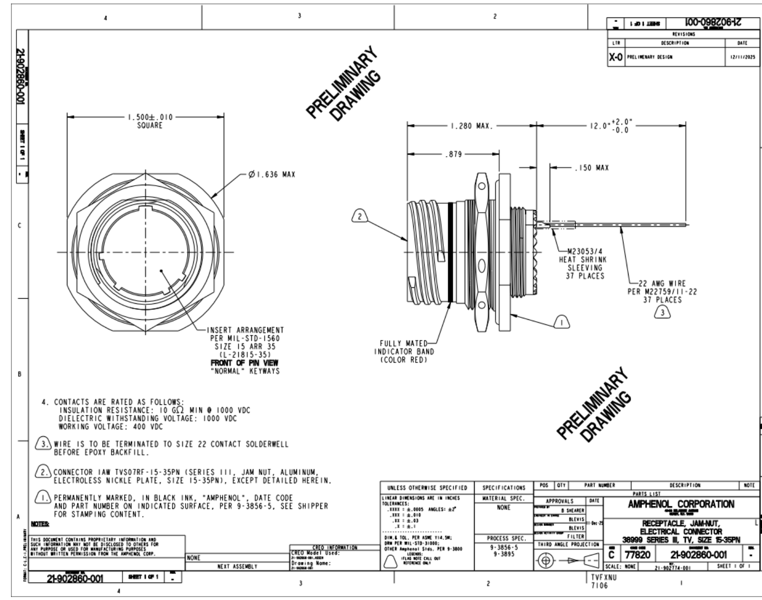




- With help from Jack McKisson from JLab
- Talking to company PEI-Genesis who works with Amphenol

# hermetic electrical connector PEI-Genesis (Amphenol) solution

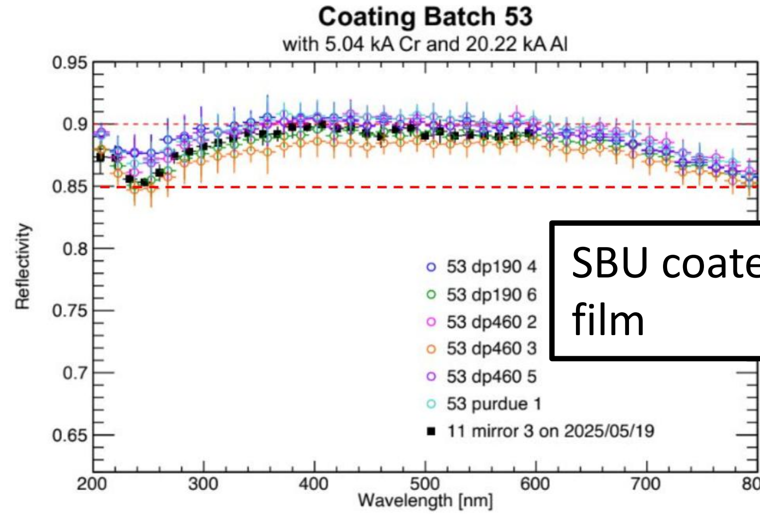
- For HGC, per sector
  - 4 RF connectors with 21 signal coaxial (giving us 4 spares total)
  - 1 power connector with 16 HV pair and 1 LV triple
- for LGC, per sector
  - 3 RF connectors with 21 signal coaxial (giving us 18 spares total)
  - 1 power connector with 9 HV pair and 1 LV triple
- Quantity and cost
  - HGC 4*30=120 RF connectors, 30 power connectors
  - LGC 3*30=90 RF connectors, 30 power connectors
  - Total $1000*210+$1000*60=$270k (guesstimation)




- Good solution exists, though not cheap
- Need customized design and prototype ~$20k for a few of them (where to have funding?)

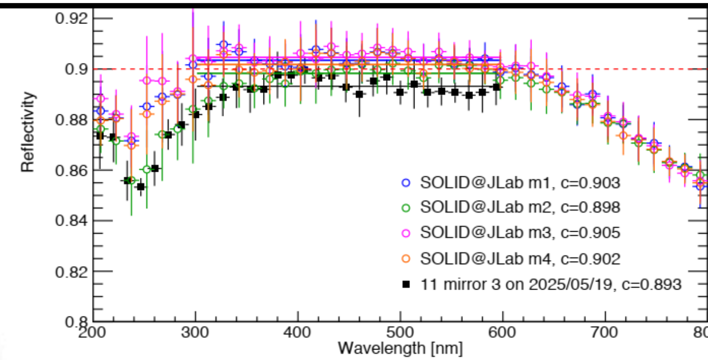
# Mirror reflection test at SBU/BNL

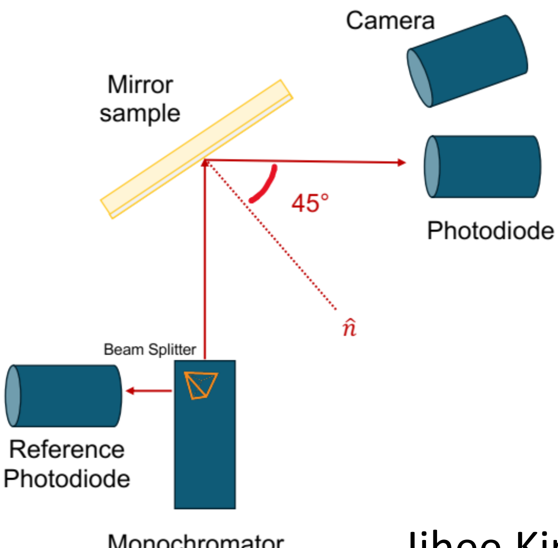
- small mirror test setup can test samples with size limit 7x7cm
- Another setup with large mirror exist but need more setup effort
- Setup currently optimized for 300nm, needs further optimization for 200nm for better accuracy

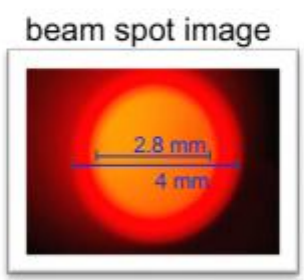


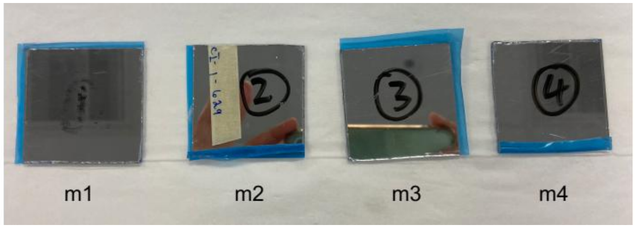

SBU coated lexan film

ECI coated CLAS12 LTCC lexan mirror samples tested with reflectivity 80% above 200nm and reaching 90% > 300nm, to be used for beamtest



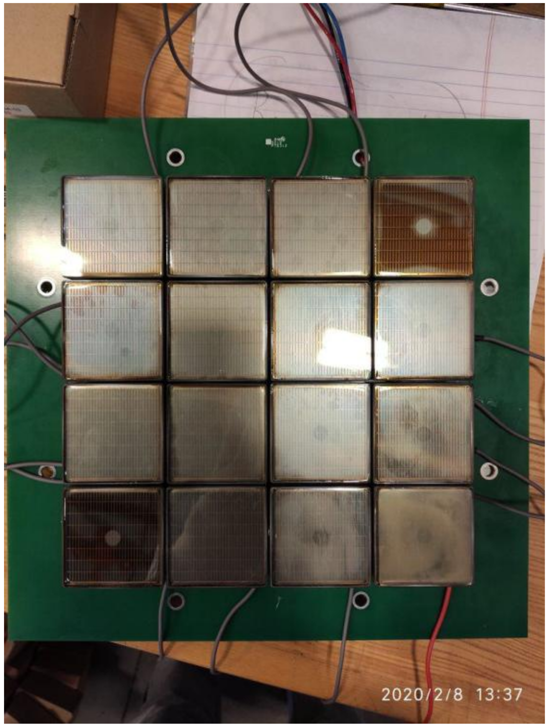




Jihee Kim, Kong Tu, Mahmodol Mojumder, Jaydeep Datta

# Cherenkov Readout

## HGC 4x4 MAPMT array



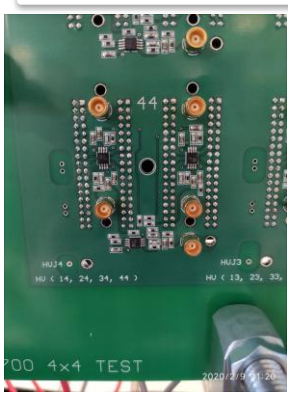

Light Gas Cherenkov (LGC)

Heavy Gas Cherenkov (HGC)

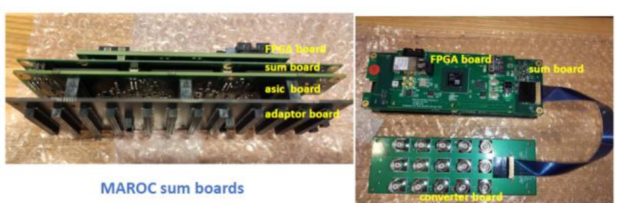
- Threshold detector : identify electron and reject pion for LGC and identify pion and reject kaon for HGC
- 30 sectors of 3x3 or 4x4 MAPMT array

64-pixel MAPMT H12700-03 WLS coated readout by pmt and quad and pixel

Simple sum readout (pmt+quad)




MAROC sum readout (pmt+quad+pixel)

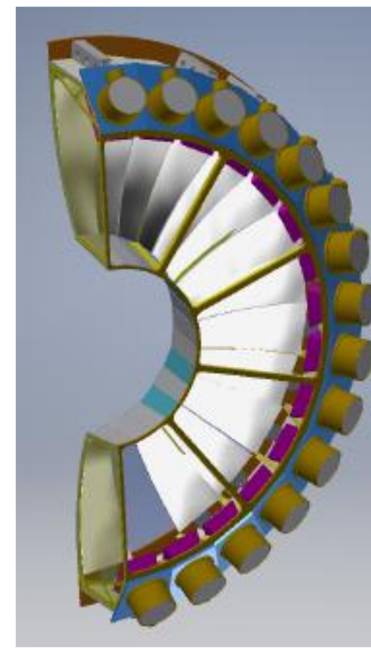



MAROC sum boards

pixel / maroc

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 1 / 32 | 2 / 30 | 3 / 31 | 4 / 29 | 5 / 33 | 6 / 35 | 7 / 34 | 8 / 36 |
| 9 / 28 | 10 / 26 | 11 / 27 | 12 / 25 | 13 / 37 | 14 / 39 | 15 / 38 | 16 / 40 |
| 17 / 24 | 18 / 22 | 19 / 23 | 20 / 21 | 21 / 41 | 22 / 43 | 23 / 42 | 24 / 44 |
| 25 / 20 | 26 / 18 | 27 / 19 | 28 / 17 | 29 / 45 | 30 / 47 | 31 / 46 | 32 / 48 |
| 33 / 16 | 34 / 14 | 35 / 15 | 36 / 13 | 37 / 49 | 38 / 51 | 39 / 50 | 40 / 52 |
| 41 / 12 | 42 / 10 | 43 / 11 | 44 / 9 | 45 / 53 | 46 / 55 | 47 / 54 | 48 / 56 |
| 49 / 8 | 50 / 6 | 51 / 7 | 52 / 5 | 53 / 57 | 54 / 59 | 55 / 58 | 56 / 60 |
| 57 / 4 | 58 / 2 | 59 / 3 | 60 / 1 | 61 / 61 | 62 / 63 | 63 / 62 | 64 / 64 |

pixel map

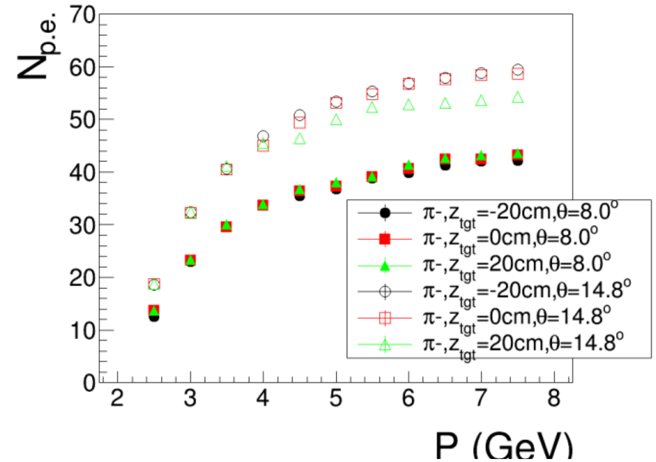


HGC half

# HGC simulation and Npe

- HGC PID using Npe cut
  - pion efficiency = (Nevent of Npe>cut)/Ntotal
  - kaon efficiency = (Nevent of cut<Npe)/Ntotal
    = 1-1/rejection
    - For both eff and rejection, the higher the better
- Assuming pion/kaon rate 10:1, with pion eff 95%, kaon eff 90% (rejection 10), kaon contamination in pion is at 1%

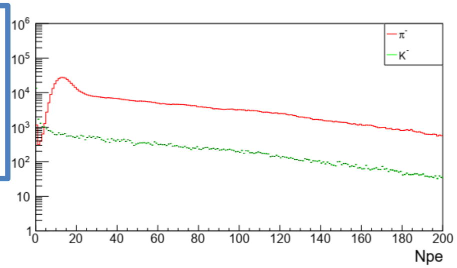
Geant4 simulation

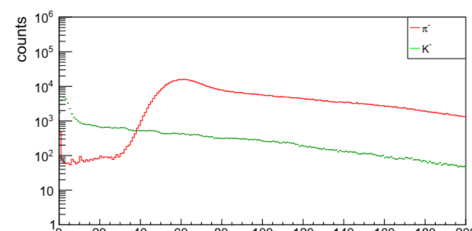



P=2.5GeV, Theta=8deg

P=7.5GeV, Theta=14.5deg

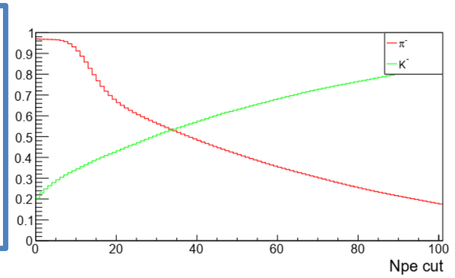
count

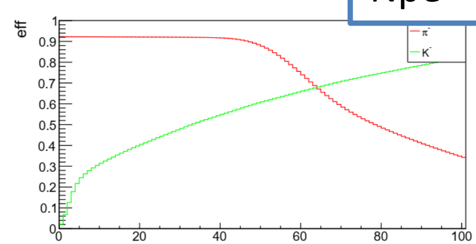



Npe

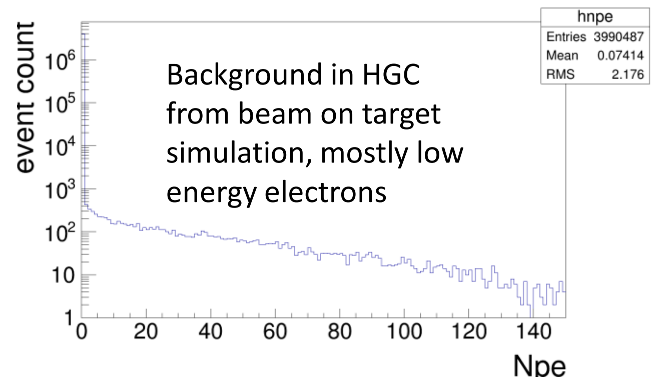
efficiency




Npe cut

To get both eff high, Npe cut can only give 50% – 60%, which is too low to be useful




Simulation signal and background merging

- Use 3 neighboring sectors for background
- Only use pion and kaon not decayed
- A safety factor 2 to reduce pion Npe
- Another safety factor 2 to increase background Npe

Spatial information can be used, but not easy for rule based traditional algorithm

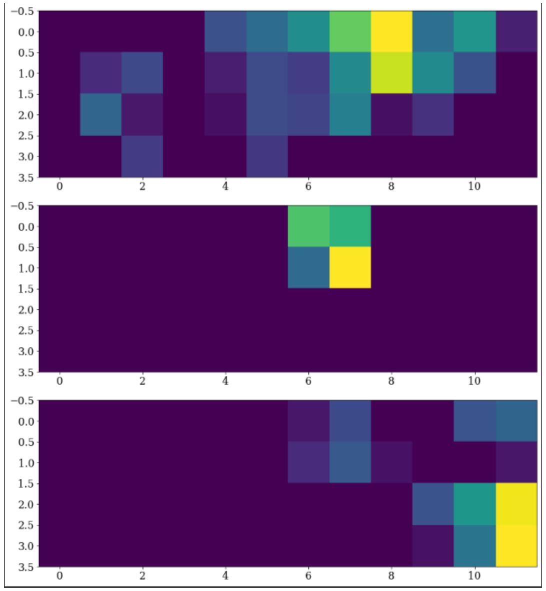
# HGC (3-sector event view)

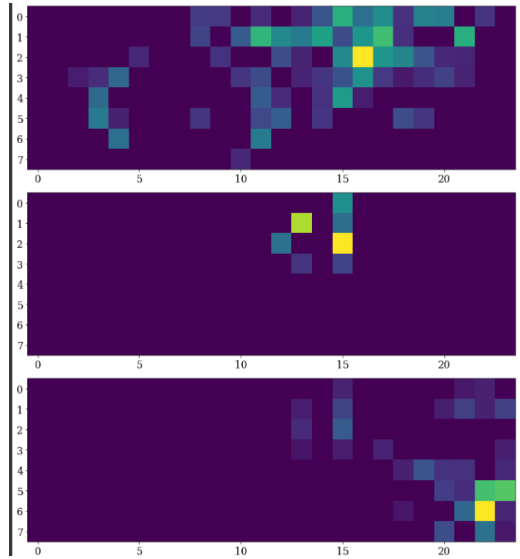
pmt

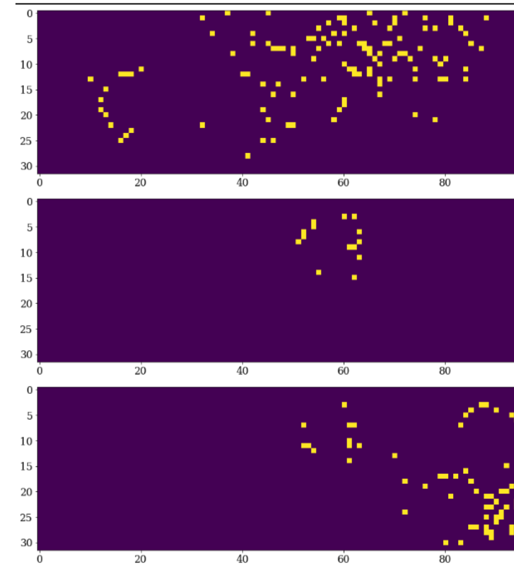
quad

pixel

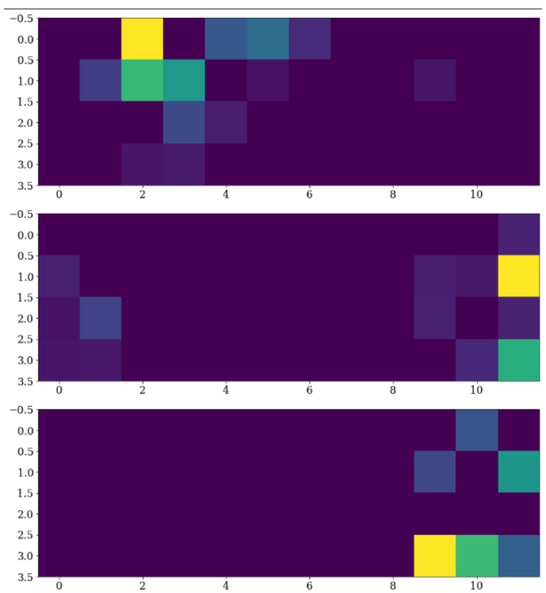
3 events of Pion +bg

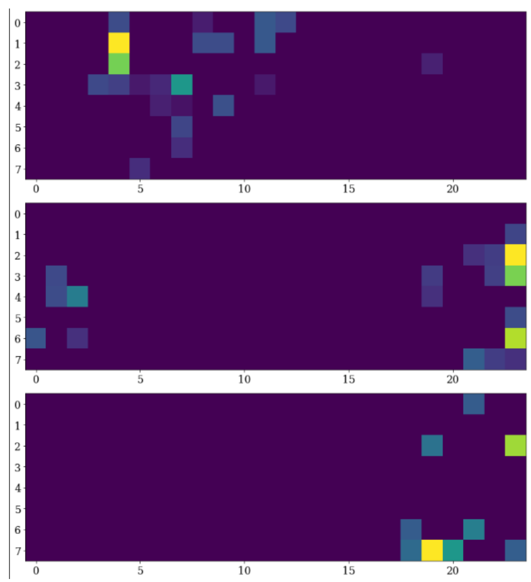


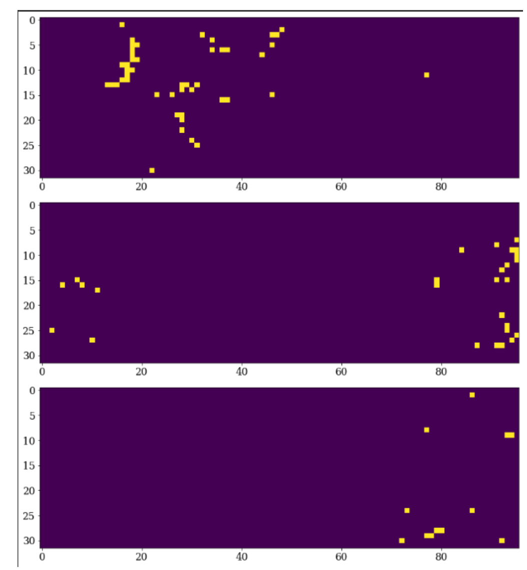




3 events of kaon +bg







```
       0    1    2    3    4    ...     3074      3075      3076     3077  3078
0          0    0    0    0    0  ...  4934.06  -957.444   773.560  3130.01     1
1          0    0    0    0    0  ...  6330.81   858.745  1258.640  3130.01     1
2          0    0    0    0    0  ...  5621.80 -1550.810   110.266  3130.01     1
3          0    0    0    0    0  ...  5706.73 -1519.000   345.001  3130.01     1
4          0    0    0    0    0  ...  4574.93  1088.980 -1216.480  3130.01     1
...      ...  ...  ...  ...  ...  ...      ...       ...       ...      ...   ...
99995      0    0    0    0    0  ...  7399.62  -909.056   532.744  3130.01     1
99996      0    0    0    0    0  ...  5497.90  1309.600  -455.812  3130.01     1
99997      0    0    0    0    0  ...  6662.41   351.042  -814.176  3130.01     1
99998      0    0    0    0    0  ...  5970.38  -725.987   724.503  3130.01     1
99999      0    0    0    0    0  ...  5189.04  -350.627 -1545.720  3130.01     1

[100000 rows x 3079 columns]
       0    1    2    3    4    ...     3074      3075      3076     3077  3078
0          0    0    0    0    0  ...  4106.00   277.924  -846.833  3130.01     0
1          0    0    0    0    0  ...     0.00     0.000     0.000     0.00     0
2          0    0    0    0    0  ...  3281.10 -1390.420   794.323  3130.01     0
3          0    0    0    0    0  ...  4942.21  1325.020  -283.395  3130.01     0
4          0    0    0    0    0  ...  5308.49  1451.740  -904.008  3130.01     0
...      ...  ...  ...  ...  ...  ...      ...       ...       ...      ...   ...
99995      0    0    0    0    0  ...  4665.86  -559.912 -1062.220  3130.01     0
99996      0    0    0    0    0  ...     0.00     0.000     0.000     0.00     0
99997      0    0    0    0    0  ...  4329.50  -805.390  -996.263  3130.01     0
99998      0    0    0    0    0  ...  5739.35  -673.397   751.146  3130.01     0
99999      0    0    0    0    0  ...  3088.49  1377.370  -653.491  3130.01     0

[100000 rows x 3079 columns]
```

# HGC PID with AIML

- Simple google colab code

"train_pid_solid.ipynb"

https://colab.research.google.com/drive/13Y18LYnazxFZfu_nABrsn3gDZS6mF8Ga?usp=sharing

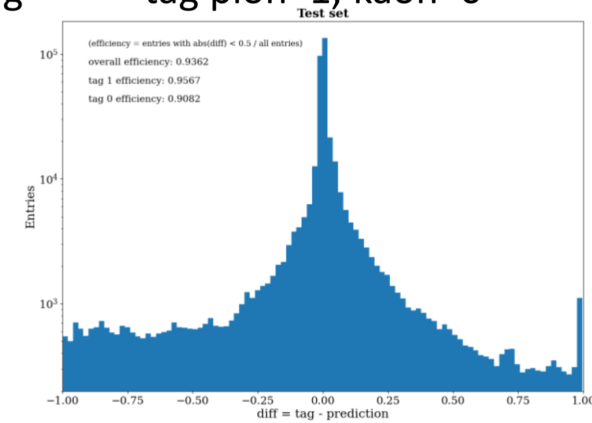
- Simple csv file with each row to include Npe in each readout unit
- Just a few layers of neural network

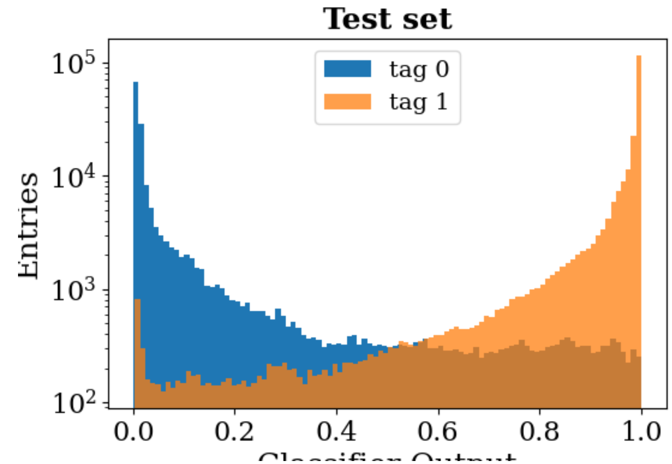
P=2.5GeV, Theta=8deg

tag pion=1, kaon=0

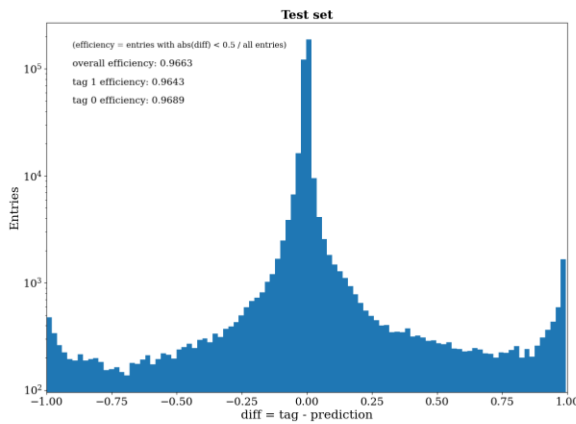
eff(pi/k)

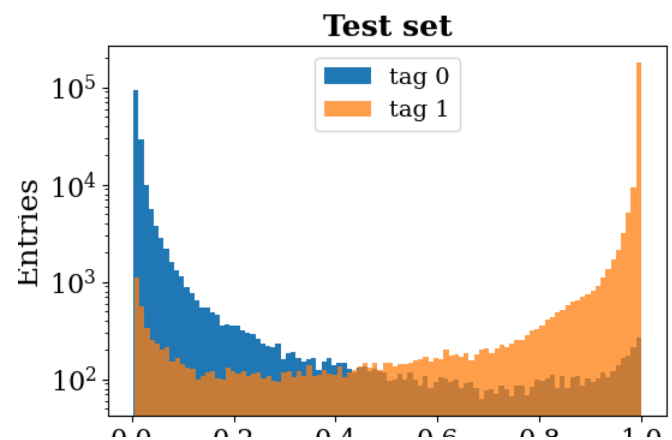
Pmt
0.9567/0.9082



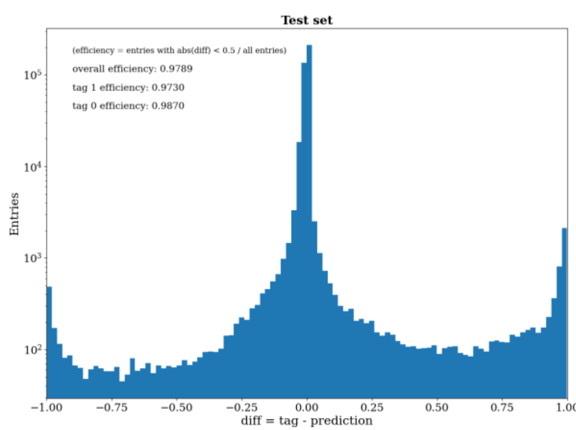



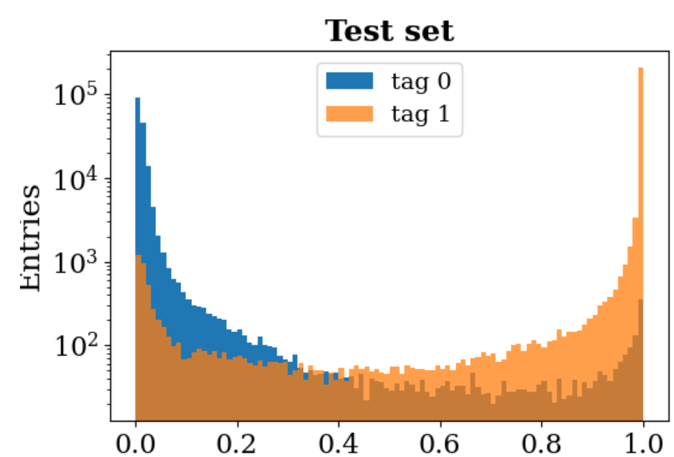

Quad,
0.9643/0.9689




pixel
0.9730/0.9870



# HGC AIML result

| eff(pi/k) | Pmt | Quad | pixel |
|---|---|---|---|
| 8deg 2.5GeV | 0.9567/0.9082 | 0.9643/0.9689 | 0.9730/0.9870 |
| 14.5deg 7.5GeV | 0.9866/0.9871 | 0.9885/0.9950 | 0.9885/0.9943 |
| 8-14.5deg 2.5-7.5GeV | 0.9673/0.9500 | 0.9722/0.9716 | 0.9755/0.9762 |

- Quad and pixel are similar
- Pmt seems not enough
- Error at 1% level