Simulation and Heavy Gas Cherenkov Update

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SoLID Collaboration Meeting
June 21-22, 2024

Duke University
University of Regina
Stony Brook University

Outline

- Study e/pi PID using LGC+EC with traditional method and AI/ML
- HGC tank funding application at Regina

Study e/pi PID using LGC+EC

- Goal is to have high electron efficiency > 95% and pion rejection as follows
  - EC only, 10-100
  - LGC only, ~1000
  - LGC+EC, 1e4-1e5

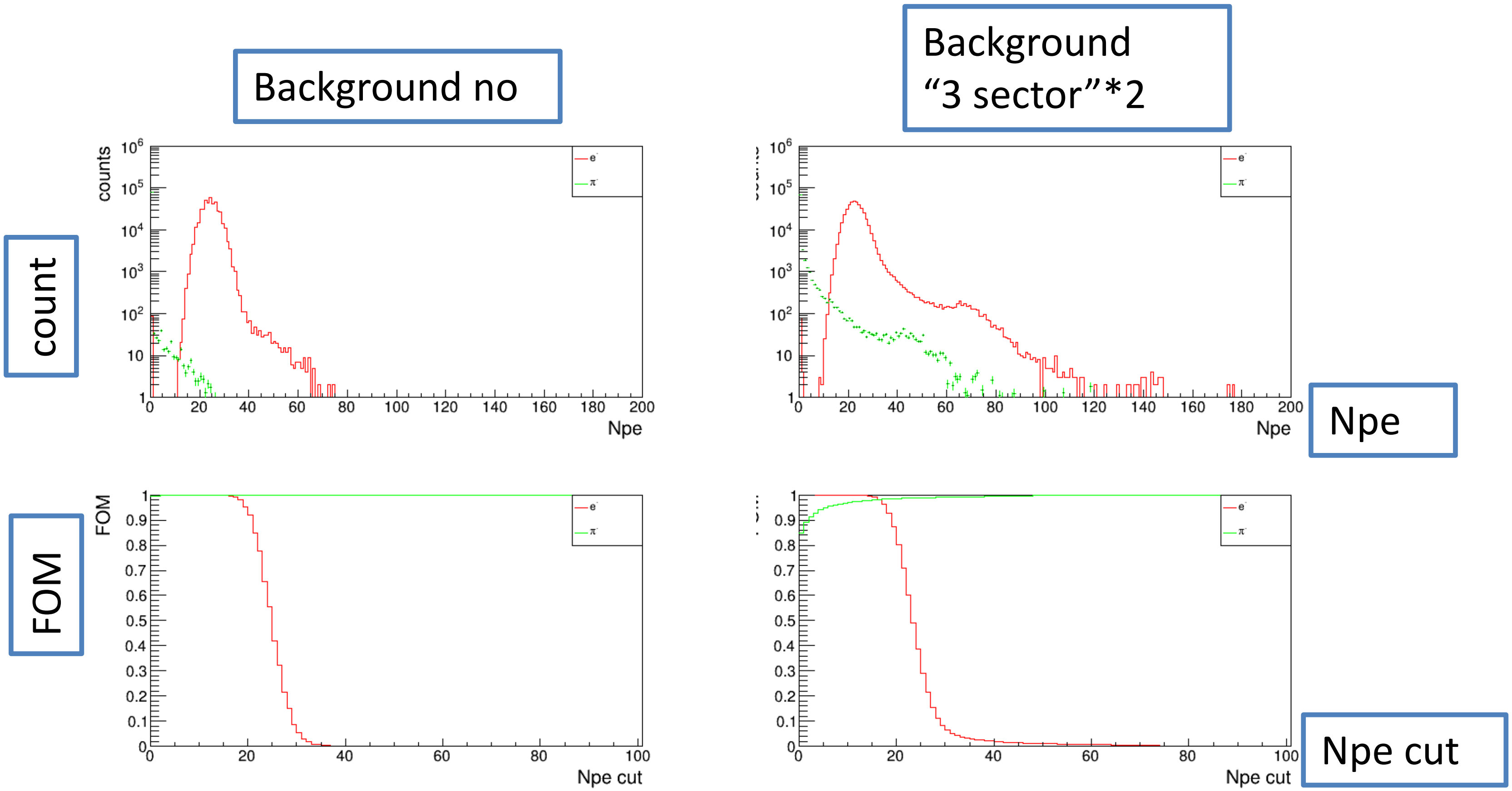
- Using full SoLID setup in simulation, then
  - Simulate e and pi with 1e6 events each (more needed)
  - Simulate "beamOnTarget" as background
  - Mix background with each single particle event according to luminosity
  - Output LGC,EC,track info into text file one event per row

Similar to HGC pi/k study
https://solid.jlab.org/DocDB/0004/000451/001/solid_hgc_zwzhao_202205.pdf

LGC only

Traditional Method

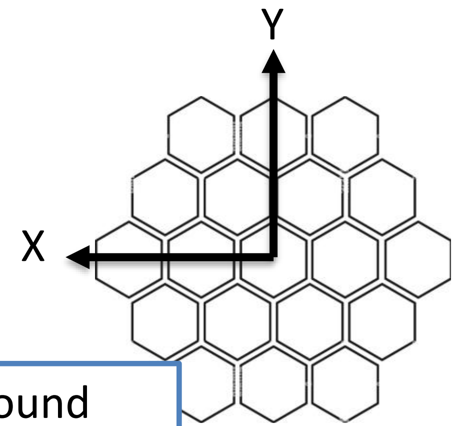
- LGC performance by Npe cut
- Figure of Merit cut:
  - electron: efficiency =(Nevent of >Npe)/Ntotal (1 of 2 blocks)
  - pion: 1-1/rejection = (Nevent of <Npe)/Ntotal ((1 of 2 blocks)



SIDIS_He3, z=-350cm, P=3GeV, theta=12deg, phi=0-360deg

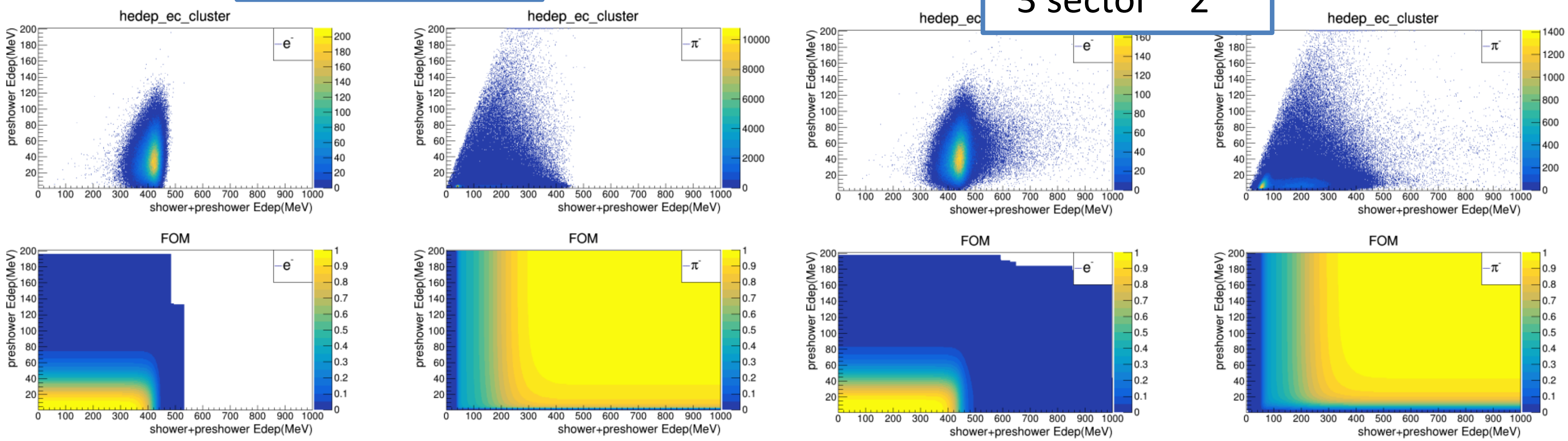
EC only

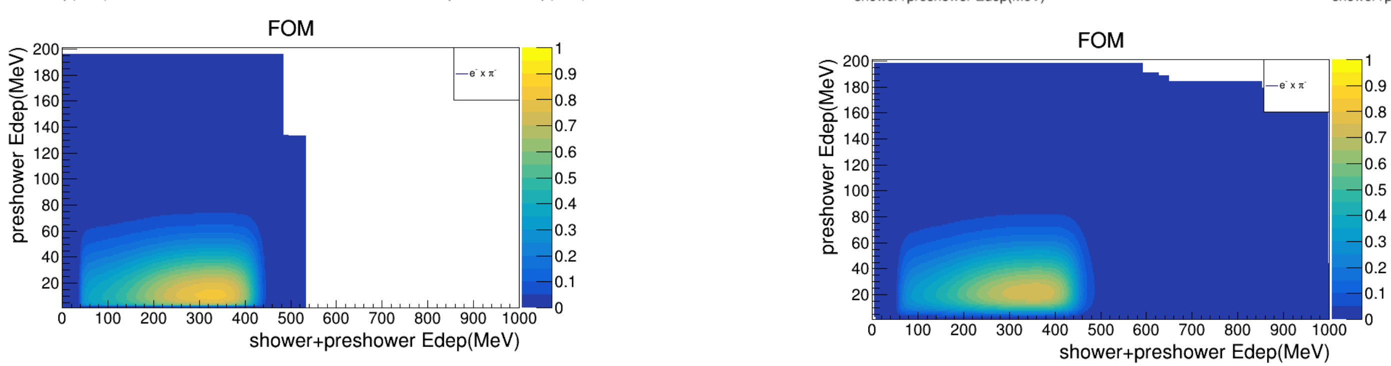
- EC using 18+1 module cluster for offline PID
- Cut on Edep of preshower+shower (total) and preshower (ps)
- Figure of Merit cut
  - electron: total>v1 and ps>v2 (1 of 4 blocks)
  - pion: total<v1 and ps<v2 (1 of 4 blocks)



Background no

Background "3 sector"*2

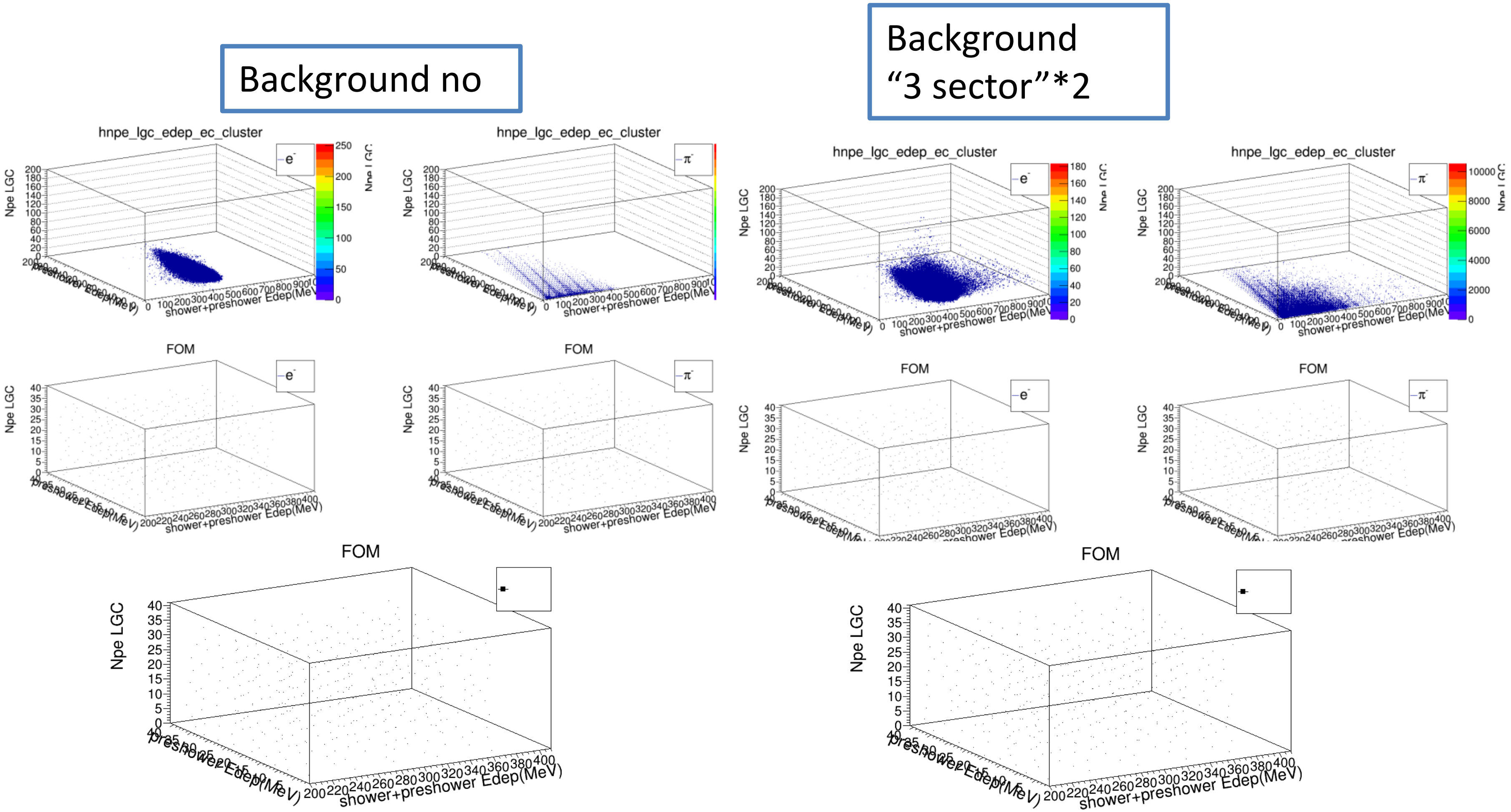




SIDIS_He3, z=-350cm, P=3GeV, theta=12deg, phi=0-360deg

LGC+EC

- Figure of Merit cut
  - electron: 4 of 8 blocks in 3D space
  - Pion: other 4 blocks



SIDIS_He3, z=-350cm, P=3GeV, theta=12deg, phi=0-360deg

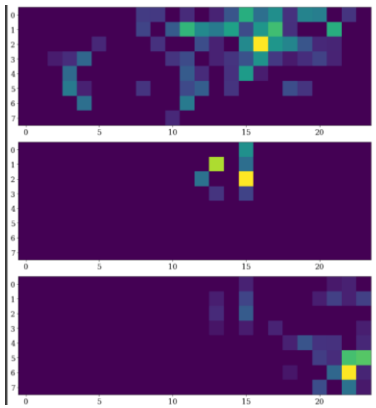
ML data format

Just examples

/group/solid/www/solid/html/files/AIML/
https://solid.jlab.org/files/AIML/

solid_hgc_sim/background3sector/solid_SIDIS_He3_hgc_moved_pim_1e5_row_pixel.csv.zip

	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



solid_hgc_sim/background3sector/solid_SIDIS_He3_hgc_moved_km_1e5_row_pixel.csv.zip

	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]

- One event per row
- detector info in each column
- last column as label

ML model

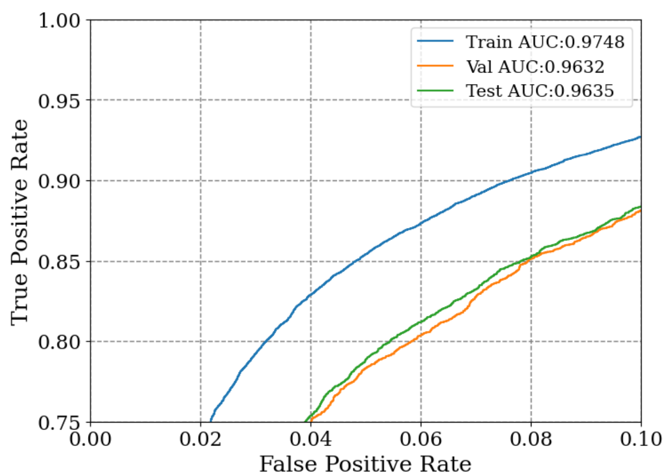
Just examples

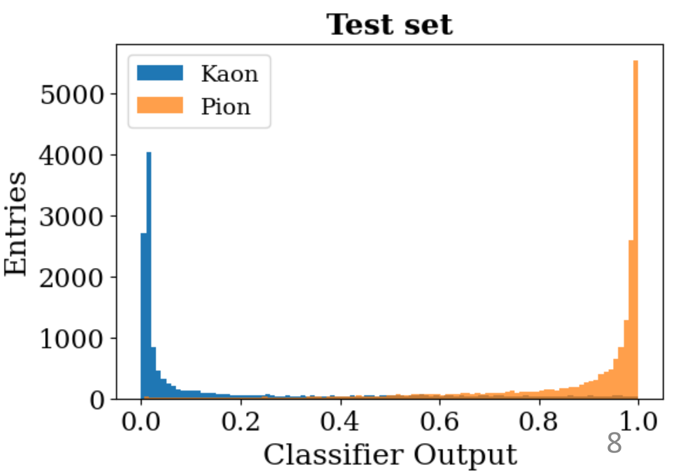
```
def get_custom_model_v0(inp_shape=54):
    # Kishan's model
    inp = Input(shape=inp_shape)
    hidden = Dense(256, activation="relu")(inp)
    hidden = BatchNormalization()(hidden)
    hidden = Dropout(0.15)(hidden)
    hidden = Dense(128, activation="relu")(hidden)
    hidden = BatchNormalization()(hidden)
    hidden = Dropout(0.15)(hidden)
    hidden = Dense(128, activation="relu")(hidden)
    hidden = BatchNormalization()(hidden)
    hidden = Dropout(0.15)(hidden)
    hidden = Dense(64, activation="relu")(hidden)
    hidden = BatchNormalization()(hidden)
    hidden = Dropout(0.15)(hidden)
    hidden = Dense(32, activation="relu")(hidden)
    hidden = BatchNormalization()(hidden)
    hidden = Dropout(0.15)(hidden)
    hidden = Dense(16, activation="relu")(hidden)
    hidden = BatchNormalization()(hidden)
    hidden = Dropout(0.15)(hidden)
    out = Dense(1, activation="sigmoid")(hidden)

    model = tf.keras.models.Model(inputs=inp,
outputs=out)

    return model
```

- Simple model with some layers of neural network works well so far
- AUC (area under an ROC (receiver operating characteristic) curve) is a graph showing the performance of a classification model at all classification thresholds
- Choose any threshold to get how good the classification is for all types as figure of merit





ML code on google colab

1. “train_pid_solid.ipynb” row (latest)

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

2. “TrainSoLID_PID.ipynb” image for Cherenkov

https://colab.research.google.com/drive/1AIBIrOgJloSpwV2v3qcGtbKvnC5z2ZlM?usp=sharing

Help from data science group:
Kishansingh Rajput
Malachi Schram

FOM of e/pi separation

Very preliminary

To reach 1e4-1e5 pion rejection, FOM needs to be 0.99990-0.99999

Traditional PID (Bg_no/Bg_3d)	LGC	EC	LGC+EC
PVDIS_LD2	0.999/0.930	0.908/0.845	0.998/0.985
SIDIS_He3	0.999/0.982	0.904/0.866	0.997/0.994

AIML PID (Bg_no/Bg_3d)	LGC	EC	LGC+EC
PVDIS_LD2	0.99979/0.99175	0.99701/0.99492	
SIDIS_He3	0.99992/0.99962	0.99729/0.99535	

Next: more events and more memory efficient training

PVDIS_LD2, z=10cm, P=2.5GeV, theta=22deg, phi=0-360deg

ML use FOM at 0.5 threshold, use row as data format and LGC use PMT sensor size with track info

More AI/ML study

- Hadron PID?
- Reduce GEM background,missing layer and track finding?
- Combine PID and tracking?
- Detector optimization?

Simulation tasks
a short list

- Besides individual detector optimization
- EC data and sim comparison using hallc beam test 2022
- GEM response data and sim comparison using hallc beam test 2022
- GEM layout and dead area (maybe not final design, but go beyond current simple ideal donut shape)
- Combined PID

Canadian Funds for SoLID HGC Vessel

- **Our grant application through CFI Innovation Fund (IF) 2023 competition was successful**
  - Canada Foundation for Innovation (CFI) is a Federal Agency that funds research infrastructure. There is a ~C$400 million IF competition every two years, covering all disciplines
  - CFI funds must be matched by other agencies to qualify for award, typically provincial or institutional funds
  - This can reduce pressure on funds provided by US–DOE

Funds Awarded (Canadian Dollars)	
INNOVATION.CA Canada Foundation for Innovation / Fondation canadienne pour l'innovation	$509.5k
innovation Saskatchewan	$300k
University of Regina	$209.5k
TOTAL	**$1019k**

Canadian Funds for SoLID HGC Vessel

- **Context: CFI–IF also provided funds for MOLLER electronics in 2021 competition** (Manitoba led)

- **Thanks to our co-applicants, for their support of this CFI–IF application:**
  - Klaus Dehmelt (Stony Brook)
  - Abhay Deshpande (Stony Brook)
  - Haiyan Gao (Duke)
  - Michael Paolone (NMSU)
  - Nikos Sparveris (Temple)
  - Aram Teymurazyan (Regina)
  - Zhiwen Zhao (Duke)

- **An important part of the CFI-IF application is the EDI plan.** Once the SoLID Collaboration is fully constituted, it will be essential that we have a DEI policy (as GlueX does)

Next Steps

1. **Before the funds can be released, UofR must sign written agreement with JLab acceptable to CFI**

- Can either be modification of existing NPUA or new ICRADA

THE AGREEMENT MUST COVER:

a) Ownership and de facto control of infrastructure
   – UofR already has NPUA with JLab, which states (Article V) that the detector will become property of JLab when it arrives at the lab

b) Long–term maintenance and operating plans for useful life of infrastructure
   – We assume this will be part of SoLID operations covered by JLab

c) Reporting and audit requirements
   – Expect these to only involve accounts at UofR

d) Documentation to support the fair market value of in–kind contribution (other parts of HGC) from US–DOE
   – Assume we will use most recent SoLID budget estimate

Next Steps

2. There is a deadline by which CFI funds must be spent

- This is years away, but I will have to show continuous project activity, as otherwise CFI will close project and take back unspent funds

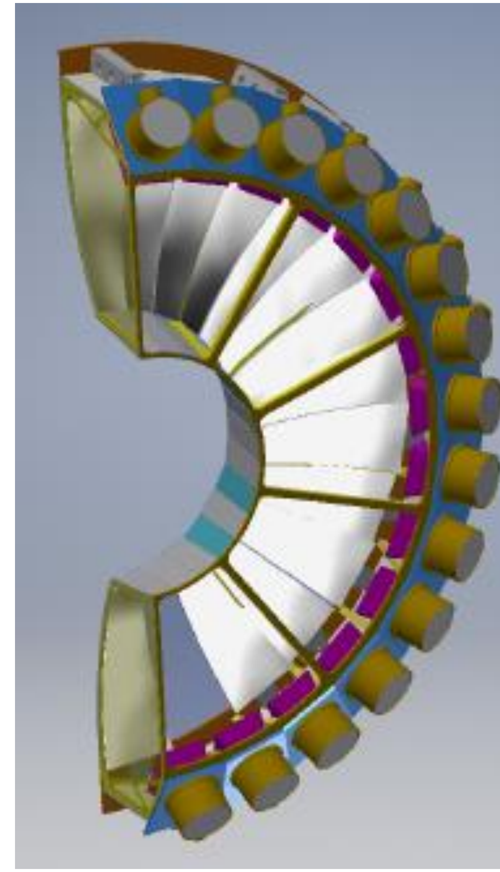
- **UofR has issued a Request for Tender (RFT) for SoLID HGC Vessel, to determine cost increases since 2022 application**
  - Canadian Government does not recognize inflation, these are expected to be absorbed by de–scoping items, if required
  - Some assumed inflation was in application. Was it enough?
  - A preliminary RFT provided cost estimates in IF application
  - RFT bids are due August 20. Vendors expected to be notified in early September
- **RFT assumes we purchase bulk items (aluminum, nuts & bolts, etc) in 2025, with machining and pressure testing to occur 2026–27, delivery to JLab in 2027–28**
- **Really need HGC design to be finalized by 2026. Concerned that delays will cause problems with CFI reporting requirements**

backup

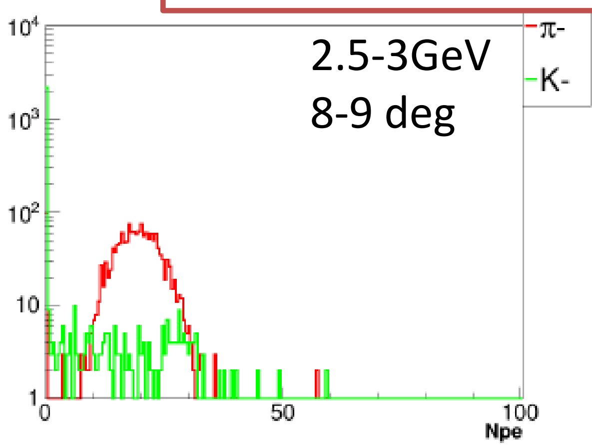
Cherenkov

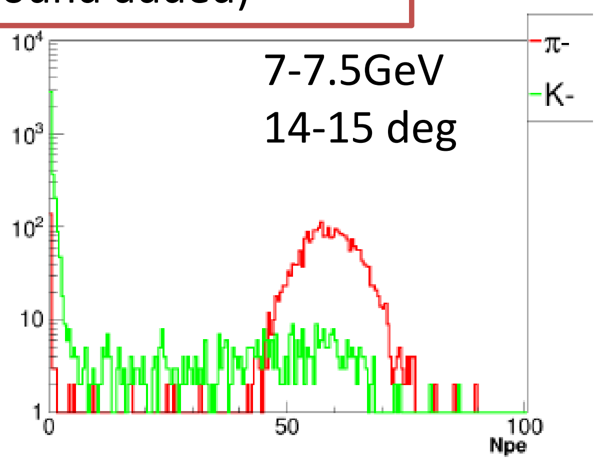
HGC:

- Threshold detector: identify pi and reject kaon
- 30 sectors of 4x4 MAPMT array
- Background rate 4MHz/MAPMT
- Not in trigger
- More difficult than LGC in offline analysis
  - Npe and ring size have strong angle and momentum dependance (combine with tracking info)
  - Kaon decay 10-30% into pi and muon which will have Cherenkov light like pion
  - Higher background (within 50ns, each sector has 3Npe from background and minimum 10Npe from signal)



Sim of pi and K (no background added)





For offline analysis, can AI/ML help with better signal particle identification while suppress more background by using spatial information?

HGC Npe (Number of photoelectron)

- N of pe determined by z,p,theta at vertex
- distribution of pe determined by z,p,theta and phi at vertex

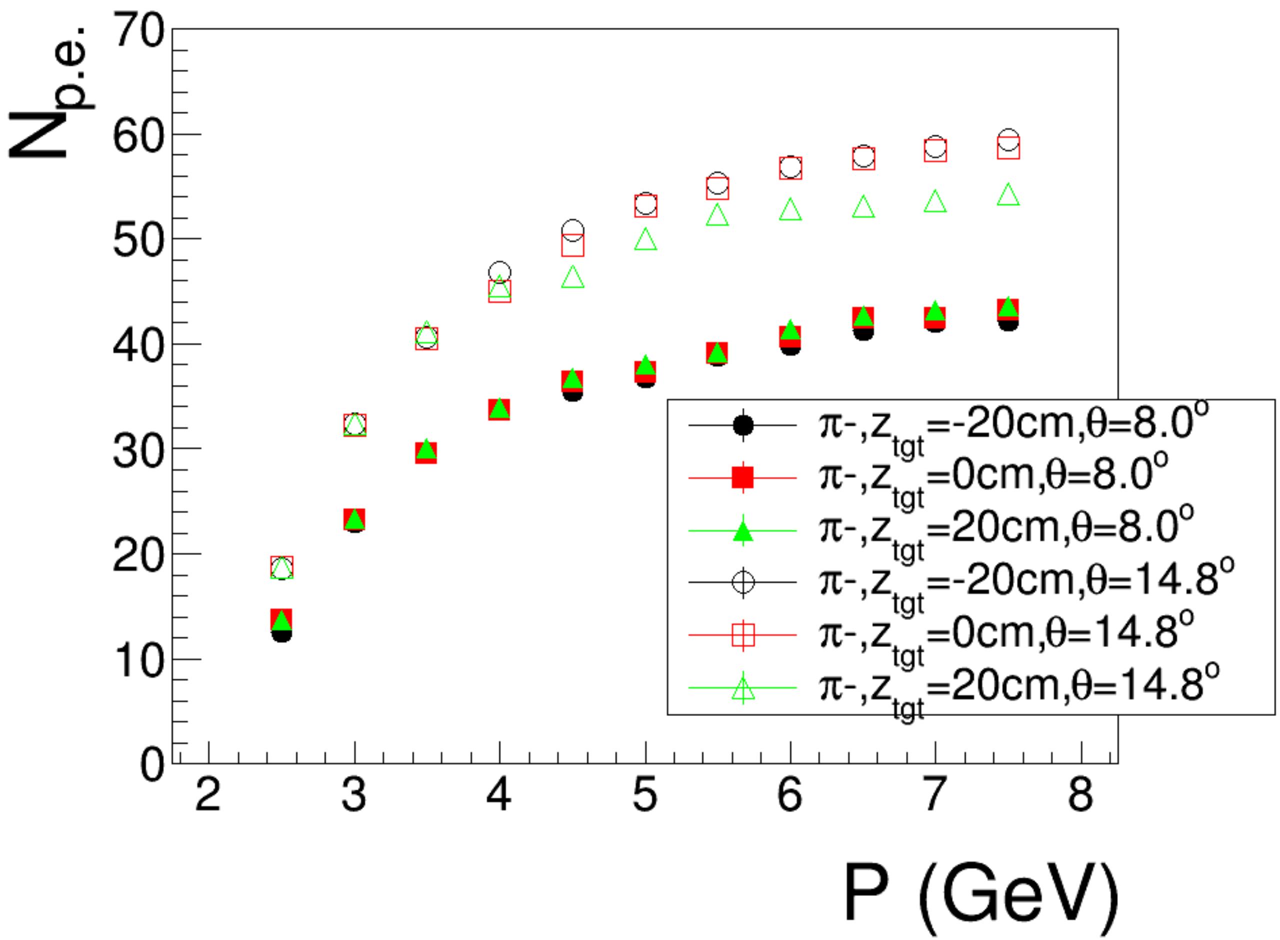
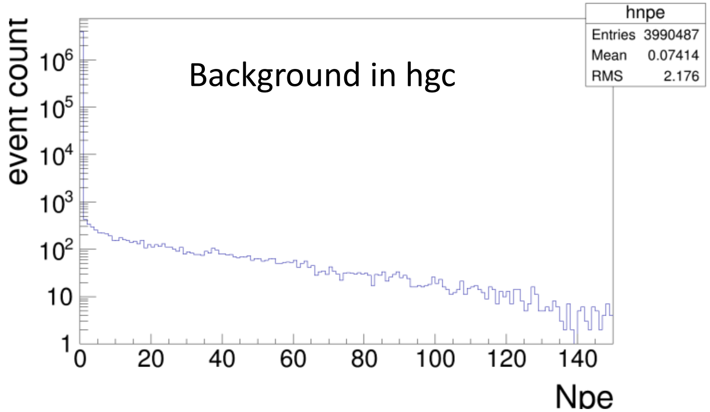


Figure 83: Simulated number of photoelectrons of negative pions as a function of momentum at various polar angles and target vertex positions. A very similar output is obtained for positive pions.

HGC background mixing

- Pion from target center z=-350cm
  at fixed angle and mom with 0.5 sim safety factor
- kaon from target center z=-350cm
  at fixed angle and mom without sim safety factor



- Background from "beamontarget" (without sim safety factor)
  - File "/cache/halla/solid/sim/solid_gemc/SIDIS_He3_JLAB_VERSION_1.3/pass8/farm_solid_SIDIS_He3_moved_BeamOnTarget_0.561e10_skim_HGCwinCF1.root"
  - SoLID SIDIS He3 run use 15uA beam, so there 15e-6/1.6e-19*50e-9=4.7e6 e- within 50ns time window
  - this skim file has 0.561e10 beam e-. It is 0.561e10/4.7e6=1194 of 50ns time window
  - This file has 3990487 not-empty-anydetector events and ~9000 not-empty-hgc event. So each 50ns time window, there are 9000/1194=7.5 events in hgc
  - If only mixing Npe and considering background is symmetric for 30 sectors
    - In each sector, 50ns time window has 7.5/30=0.25 events in hgc
    - 1 HGC signal events should be in 1 or 2 sectors, but to know which 2 sector, we need to tracking info. So we can simply consider 3 neighboring sectors around the sector with highest Npe
    - In 1/2/3 sectors, 50ns time window has 0.25/0.5/0.75 events in hgc

HGC only

HGC FOM

- HGC performance can be judged by the following figure of merit:
  1. FOM pion:
     efficiency =(Nevent of >Npe)/Ntotal
  2. FOM kaon:
     1-1/rejection = (Nevent of <Npe)/Ntotal

Decay from target to HGC
- 2.5GeV pion 4.6% kaon 30%
- 7.5GeV pion 1.6% kaon 11.5%
- Evenly kinematics pion 2.7% kaon 18%
- at most 1% decay within target and hope tracking can exclude those

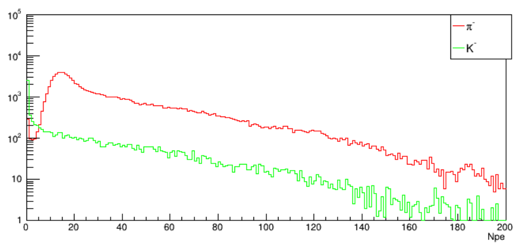
FOM	P=2.5GeV, Theta=8deg alltrack	P=2.5GeV, Theta=8deg Nodecaytrack	P=7.5GeV, Theta=14.5deg alltrack	P=7.5GeV, Theta=14.5deg nodecaytrack
No background	0.93	0.99	0.92	0.98
"3 sector" background	0.57	0.60	0.78	0.80
"3 sector double" background	0.52	0.53	0.64	0.66

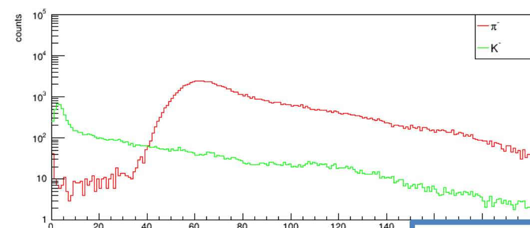
P=2.5GeV, Theta=8deg alltrack

P=7.5GeV, Theta=14.5deg alltrack

"3 sector" background

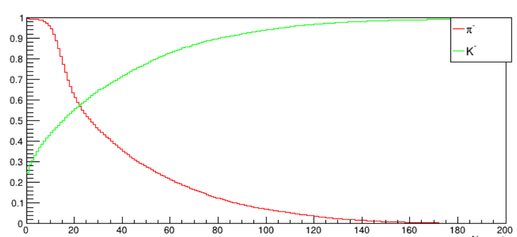
count

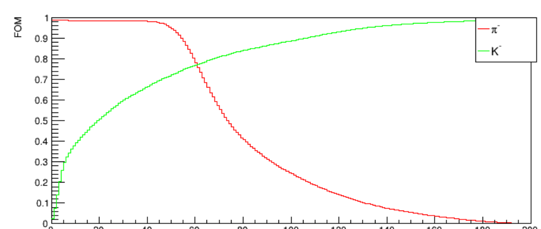




Npe

FOM





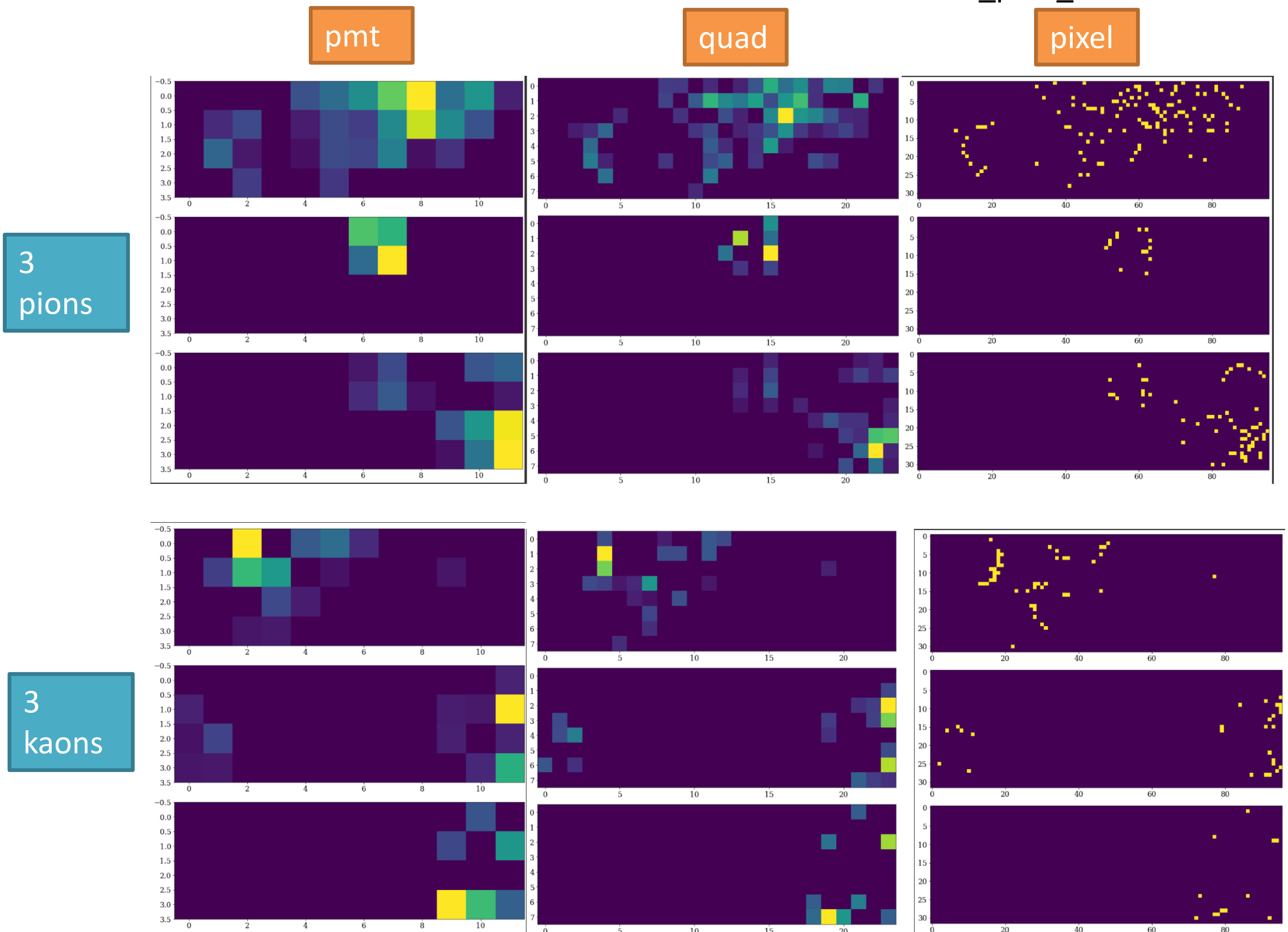
Npe cut

alltrack and nodecaytrack seem having similar FOM for Npe cut with background

Go beyond Npe cut to use sensor location info with traditional ray tracing or AI/ML

3 sector event view

Nodecaytrack, full, Bg_3s*2
z350_p2.5_theta8.0

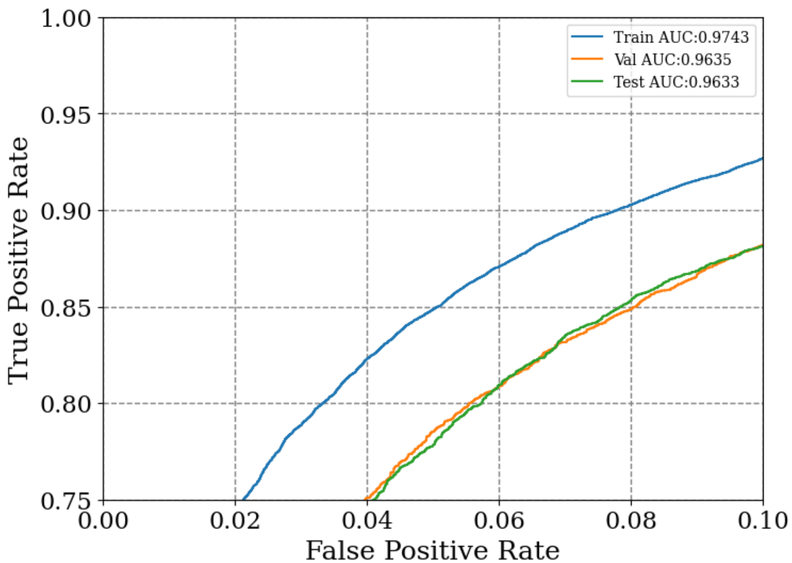


Nodecaytrack
image+track

ROC (pion)

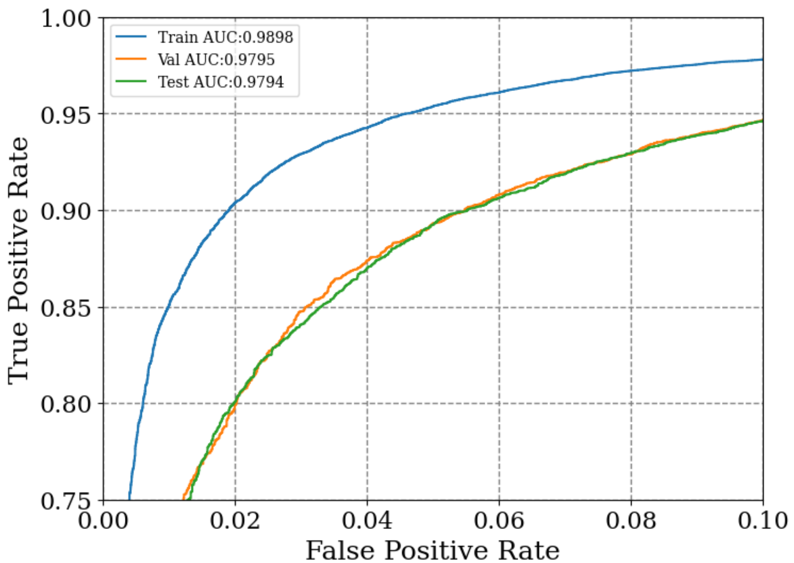
- An **ROC curve** (**receiver operating characteristic curve**) is a graph showing the performance of a classification model at all classification thresholds
- ROC error is at 0.01 level from data science group initial study

pmt



ROC_full_z350_p2.5_theta8.0_background3sectordouble_48_6_pion.png

quad



ROC_full_z350_p2.5_theta8.0_background3sectordouble_192_6_pion

FOM results

Nodecaytrack
image+track

		Bg_no		Bg_3s		Bg_3s*2	
z350_p2.5_theta8.0	pmt	0.996	0.996	0.965	0.920	0.900	0.770
	quad	0.996	0.996	0.975	0.960	0.950	0.880
z350_p7.5_theta14.5	pmt	0.999	0.998	0.996	0.995	0.994	0.991
	quad	0.999	0.998	0.998	0.996	0.996	0.994

- FOM is chosen as true pion eff at false kaon rate = 0.05
- Red is hgc only simulation, blue is full simulation
- Each model is individually trained and FOM obtained from test data
- More background can reduce FOM, smaller sensor size can increase FOM
- small angle low P is more difficult than large angle high P
- Pixel result is not shown as it require more data and cpu and mem to train, but the improvement is expected to be relatively small

Q&A with data science group

SoLID	Tracking	Cherenkov	EC
1. What are we trying to do? Articulate the objectives of the 3 efforts. * Including the figure of merit	improve the performance of GEM clustering improve the performance of tracking reconstruction	Improve Cherenkov PID beyond simple Npe cut. For HGC with background , efficiency (> 90%) and rejection (>10) Improve LGC with trigger design	Improve EC PID performance with background. We want to keep pion rejection > (50:1) with electron efficiency>90%.
2. Explain what is done today, and what are the limits of current practice? (baseline)	Not much	Not much, start to explore AI simple Npe cut performance degrade with high background	Not much. the traditional cuts couldn't keep the pion rejection as high due to energy leak at edge
3. If we are successful, what difference will it make?	a few times improvement on the speed and around 10% improvement on the tracking reconstruction efficiency and accuracy. GEM clustering will benefit SBS also	Improve Cherekov performance baseline at high background Help with readout choice to determine if pixel/quad/sum are needed	significantly improve the ECAL PID performance at the edges of EC
4. Data available (raw and simulated) * File format (root?) * Data format and variable summary (tabular?) * Data size (number of samples?) * Where is the data located? When can we have access?	Unlimited simulation data in root or text format available on ifarm as soon as we agree on a format	Unlimited simulation data in root or text format Both low rate and high rate data from HallC test (~10 thousands events) Cosmic with background data from bench (~thousands events) available on ifarm as soon as we agree on a format	Unlimited simulation data in root or text format Some low rate real data from Fermi lab test (~thousands events) available on ifarm as soon as we agree on a format
5. Timeline? * Publications/conferences?	Not sure	Working on note/short paper about readout aiming for next year. AI would be a nice part of it or a separated paper	Not sure
6. Who is available to work on this with the data science dept.?	Weizhi Xiong until Feb, someone else afterwards	Zhiwen Zhao, Bo Yu, Michael Paolone	Ye Tian, Zhenyu Ye