Charged & Neutral Pion Polarizability Experiments
Run Report
September 21, 2022
GlueX Collaboration Meeting

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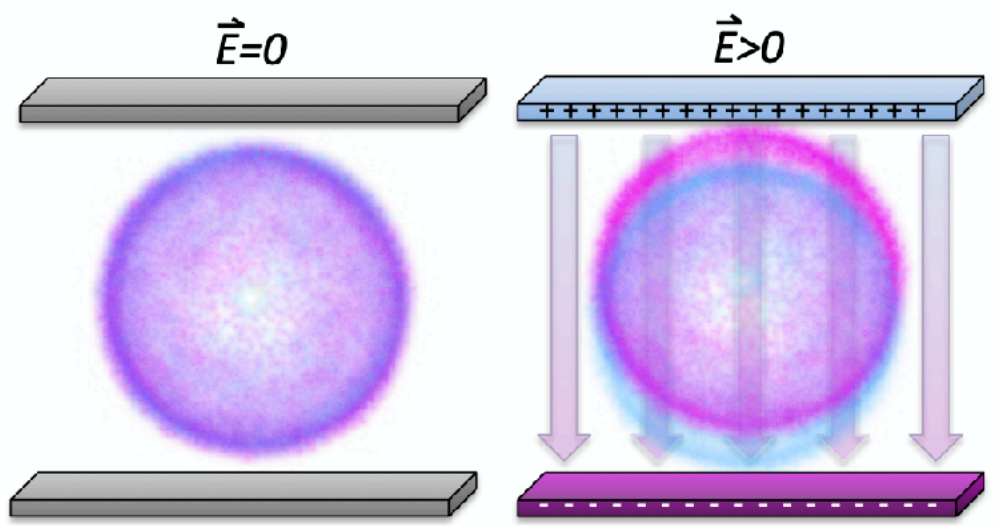
“Thought experiment”: measure pion electromagnetic polarizability by placing pion in a capacitor at very high electric field



$$E \approx \frac{0.1 GeV}{1\ fm} = 10^{23} \frac{volts}{m}$$

Pion surrounded by pion cloud

Pion core surrounded by displaced pion cloud: displacement gives E.M. polarizability

Small numbers because hadrons are “stiff”!

Electric polarizability $= \alpha \approx 10^{-4} \times Volume$

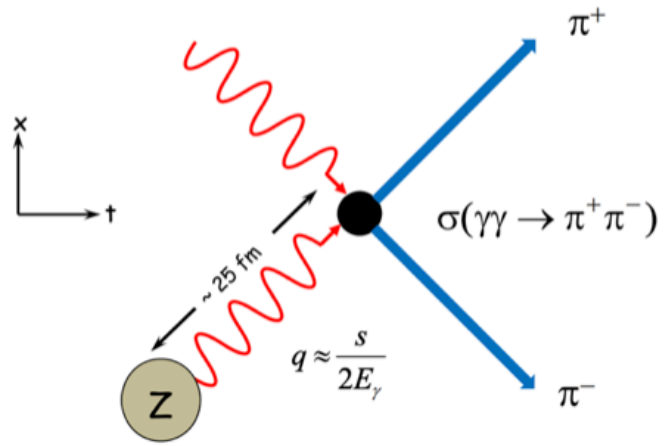
Magnetic polarizability $= \beta \approx 10^{-4} \times Volume$

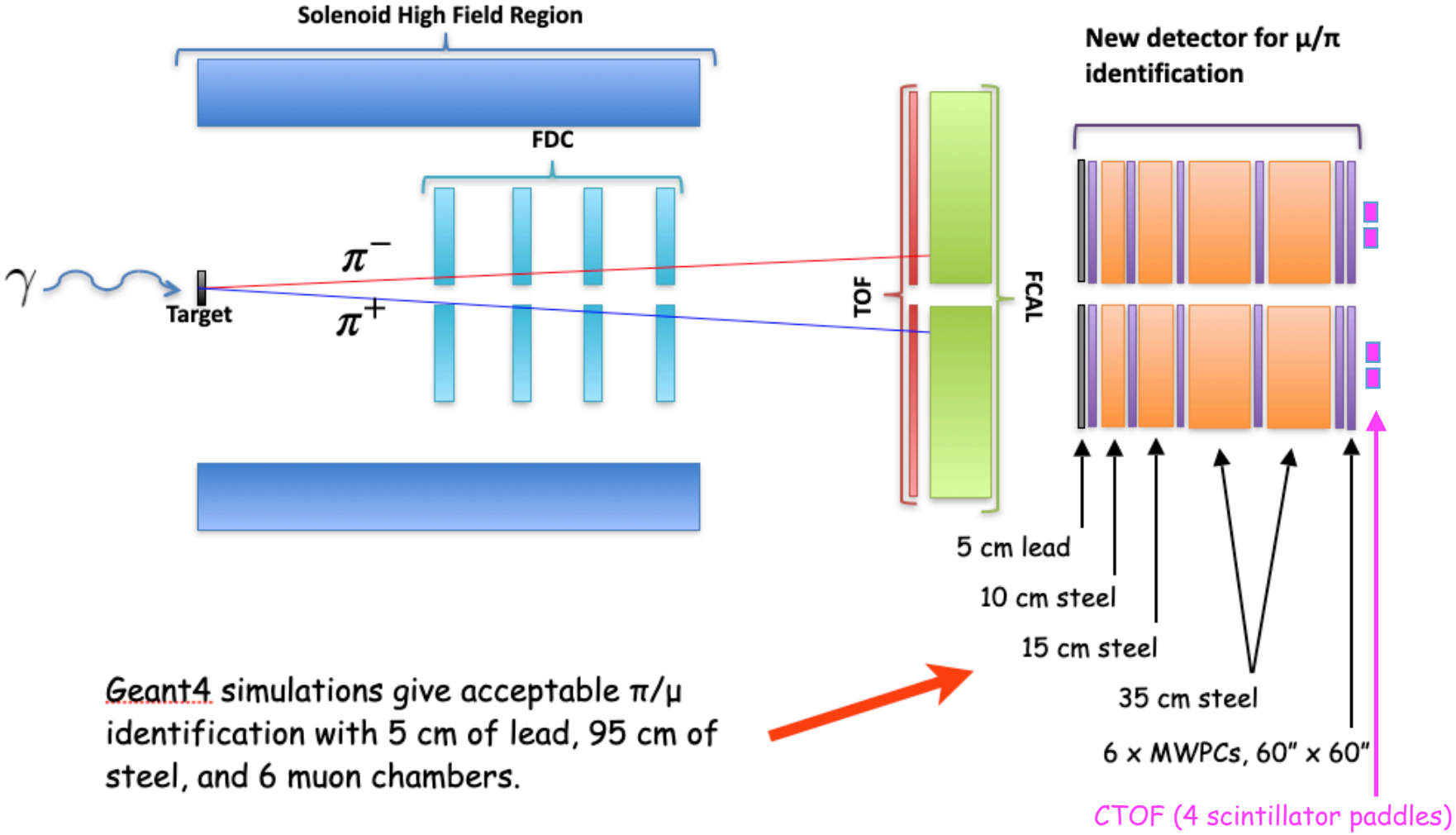
Polarizabilities encode information about the excited states of hadrons: test effective field theories for QCD

CPP and NPP experiment at Jlab GlueX

Primakoff process:

very low-t photoproduction $\gamma A \rightarrow \pi^+\pi$





Geant4 simulations give acceptable π/μ identification with 5 cm of lead, 95 cm of steel, and 6 muon chambers.

CPP and NPP Running Conditions

Configuration	Nominal GlueX I	Charged Pion Polarizability	Neutral Pion Polarizability
Electron Beam Energy	11.6 GeV	11.6 GeV	11.6 GeV
Coherent Peak Energy	8.4-9.0 GeV	4.5-6 GeV	4.5-6 GeV
Current	150 nA	30 nA	30 nA
Radiator thickness	50 μm diamond	50 μm diamond	50 μm diamond
Collimator aperture	5 mm	3.4 mm	3.4 mm
Peak polarization	35%	73%	73%
Tagging ratio	0.6	0.56	0.56
Flux 5.5-6.0 GeV	-	11 MHz	11 MHz
Flux 8.4-9.0 GeV	20 MHz	-	-
Flux 0.3-11.3 GeV	367 MHz	56 MHz	56 MHz
Target Position	65 cm	1 cm	1 cm
Target, length	LH2, 30 cm	^{208}Pb, 0.03 cm	^{208}Pb, 0.03 cm
Start Counter and DIRC	Nominal	Removed	Removed
Tagger microscope	Nominal for Peak at 9 GeV	Moved for Peak at 6 GeV	Moved for Peak at 6 GeV
Muon Detector	None	Installed behind FCAL	Not needed
Trigger	FCAL/BCAL (40 kHz)	TOF (30 kHz)	FCAL/BCAL (10 kHz)

Early run activities/commissioning

In order to perform the CPP and NPP experiments, the GlueX detector was modified in many ways and complemented with a new muon detector system. Early in the run we completed the following activities:

1. Installed and commissioned ten new detectors downstream of GlueX (6 MWPCs and 4 TOF scintillators) including massive iron absorbers between MWPC planes in a new muon detector system.

2. Moved the tagger microscope from its 9 GeV location for GlueX down to 6 GeV and verified operation.

3. Aligned a new diamond (JD70-103) and verified 70% polarization in the coherent peak.

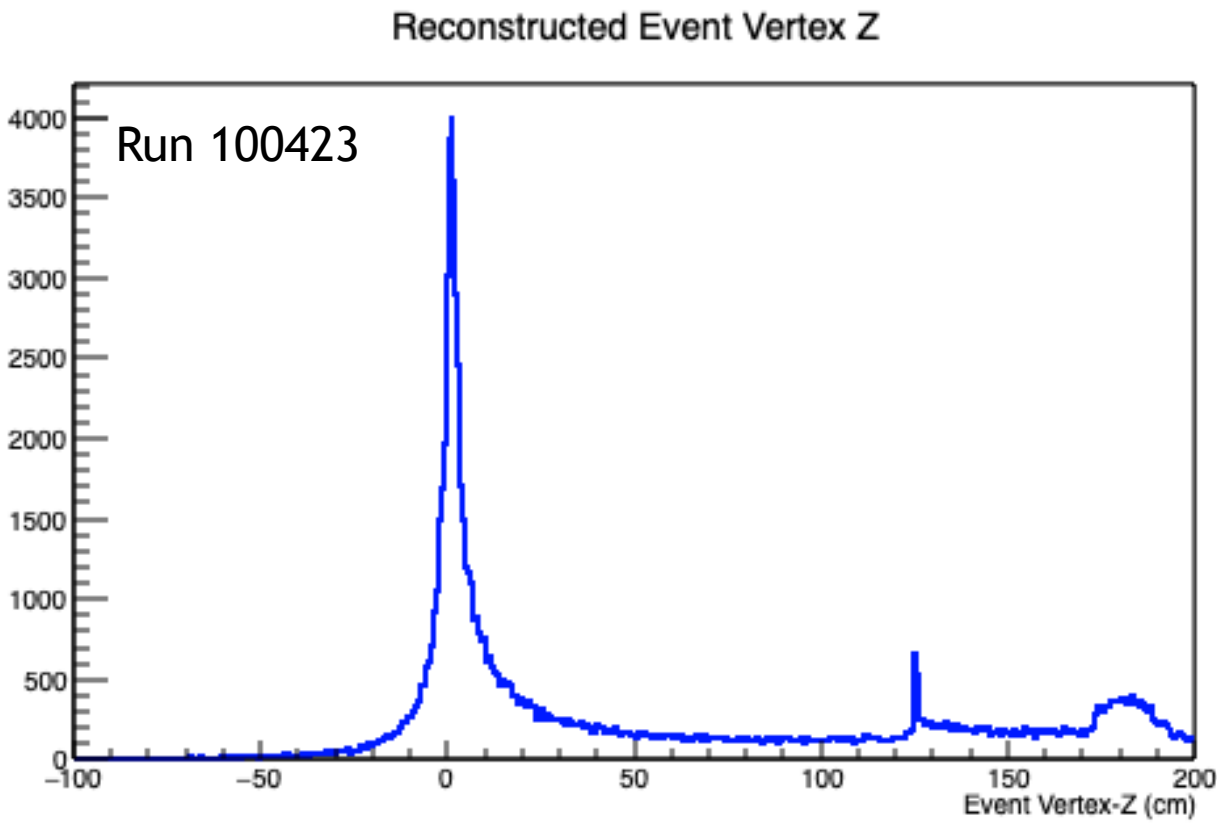
4. Developed and commissioned a new trigger based on the TOF system to trigger on two charged particles.

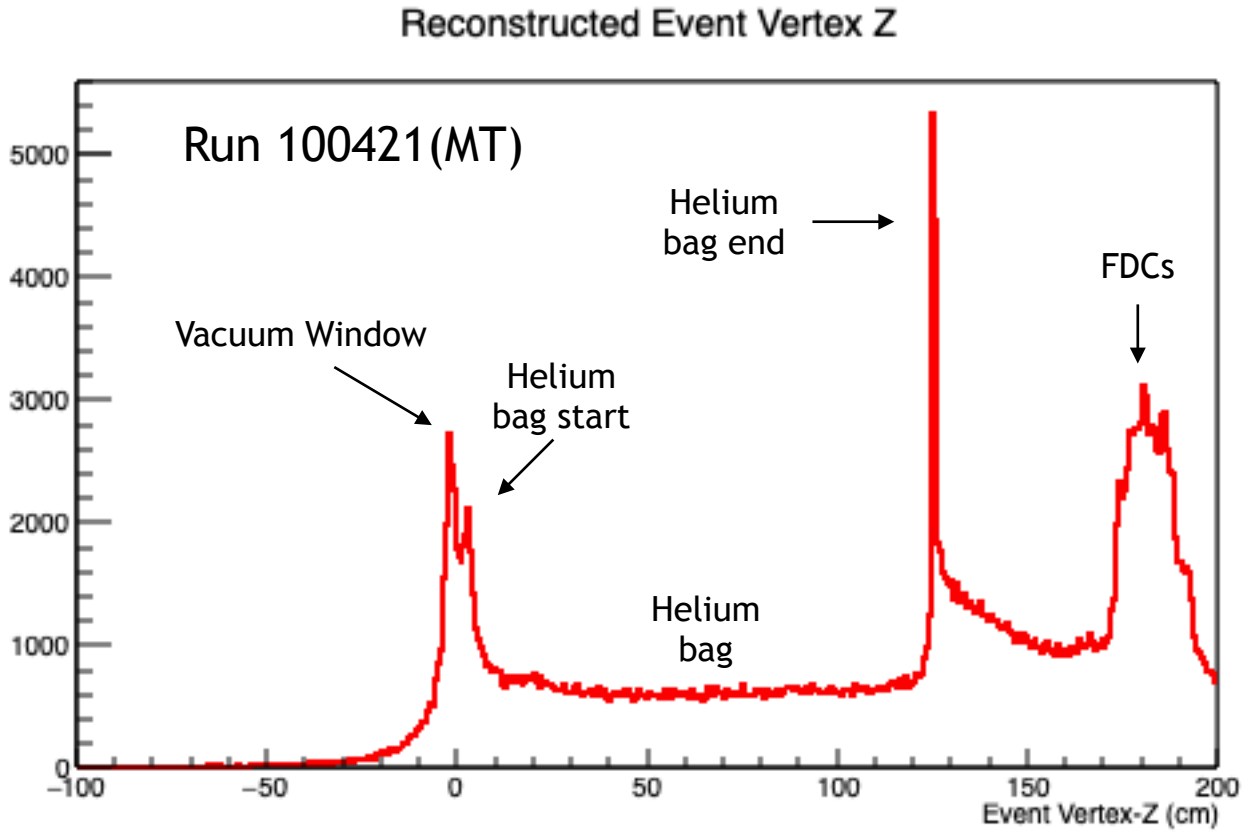
5. Installed and aligned a lead shield frame near the beamline.

6. Developed and deployed software to readout, monitor and analyze the new detectors.

7. Determined the optimized fraction of MT target running to full target running

Optimizing fraction of MT target running





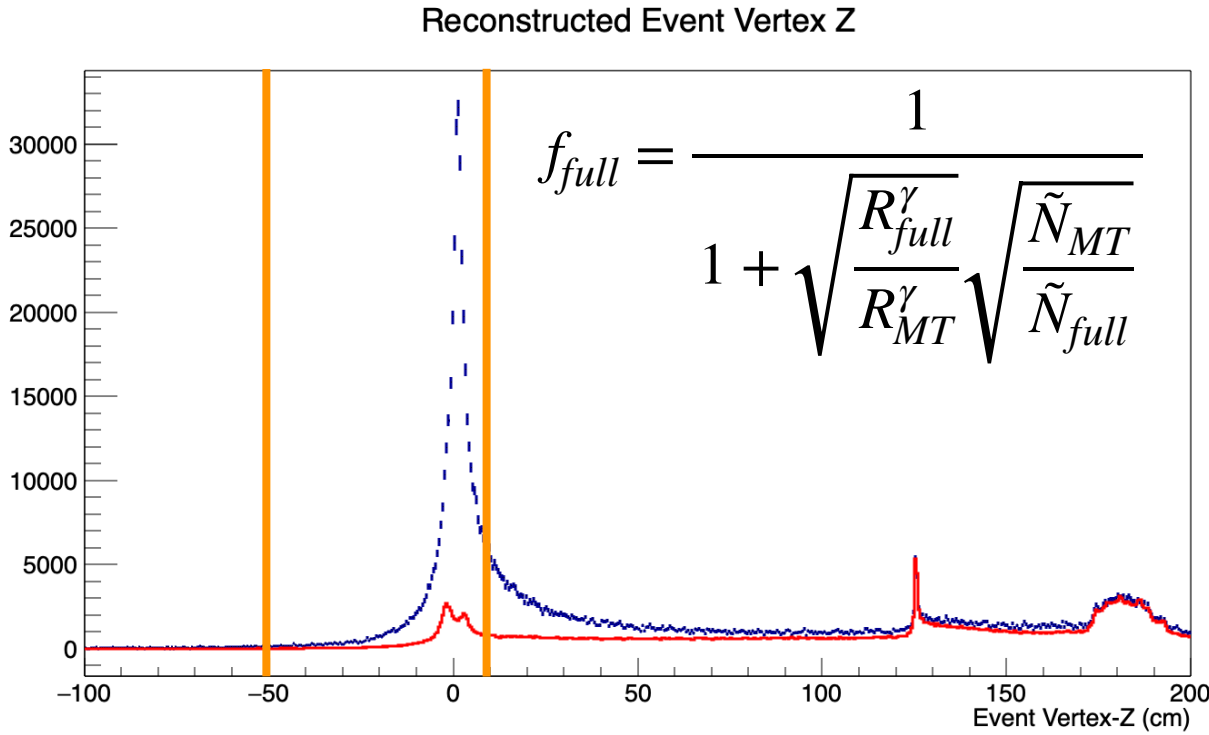
Normalize yields to number of PS triggers, and correct for live time

$$\tilde{N}_{full} = \frac{N_{full}}{LT_{full} N^{PS}_{full}}, \qquad \tilde{N}_{MT} = \frac{N_{MT}}{LT_{MT} N^{PS}_{MT}}.$$

Could also normalize by matching helium bag end window

Optimizing fraction of MT target running

Integration Interval	$\tilde{N}_{MT}/\tilde{N}_{full}$ PS norm	$\tilde{N}_{MT}/\tilde{N}_{full}$ He norm
-50cm to 50cm	0.17	0.15
-10cm to 10cm	0.12	0.11
-20cm to 10cm	0.12	0.11
-50cm to 10cm	0.12	0.11



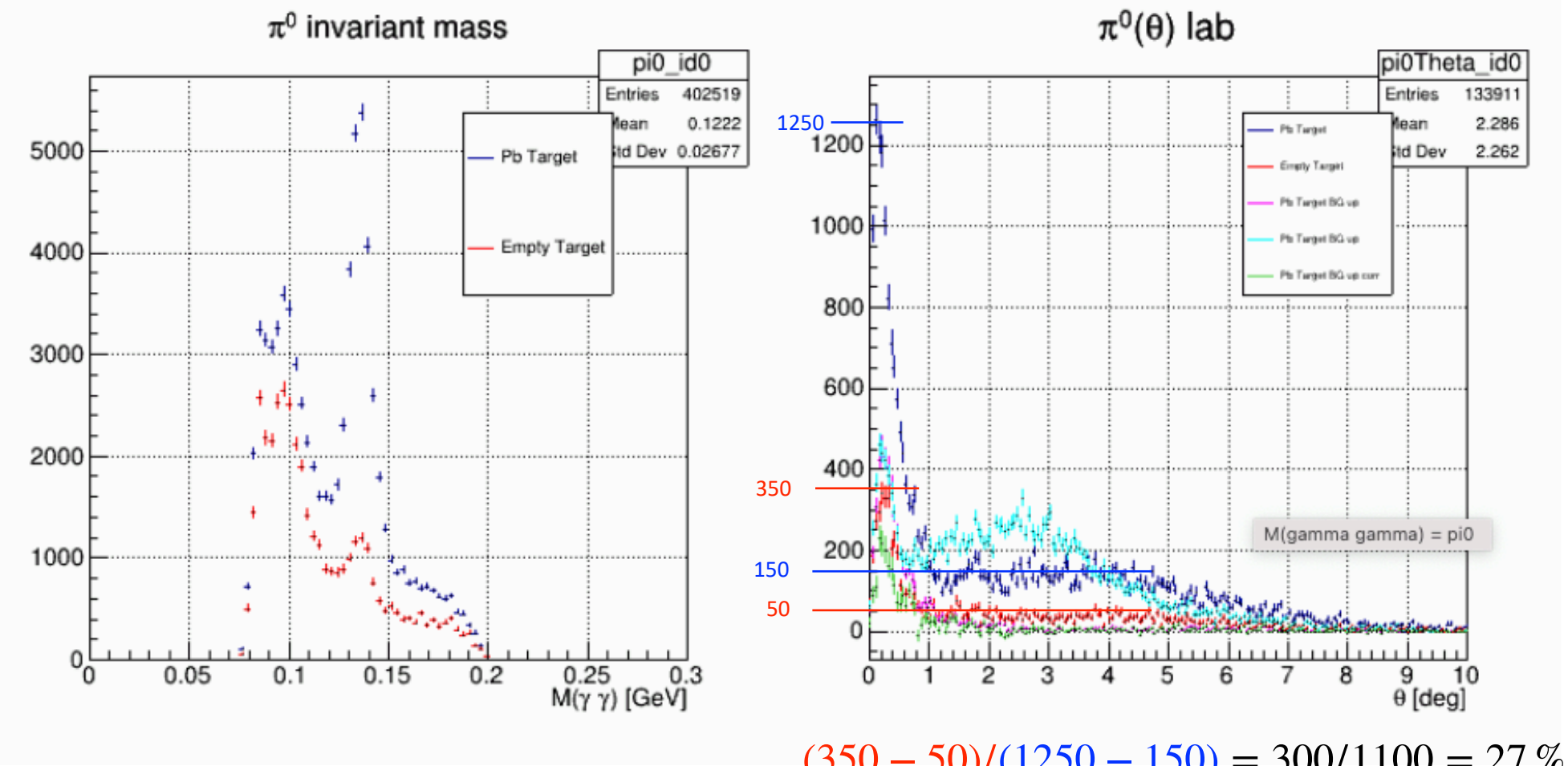
$$f_{full} = \frac{1}{1 + \sqrt{\frac{R^{\gamma}_{full}}{R^{\gamma}_{MT}}}\sqrt{\frac{\tilde{N}_{MT}}{\tilde{N}_{full}}}}$$

Assumption about photon rate

Full Target @ 30 nA
Empty Target @ 60 nA

$$\frac{R^{\gamma}_{full}}{R^{\gamma}_{MT}} = \frac{1}{2}, \qquad f_{full} \sim 80\,\%\,.$$

MT to Full running fraction comparable in neutral channel



$$(350 - 50)/(1250 - 150) = 300/1100 = 27\ \%$$

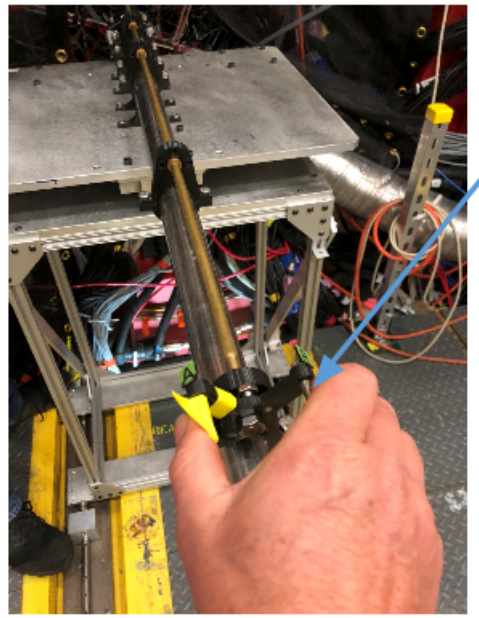
Not 5%, and not 50%. Good qualitative argument

Production Sequence:

Full Target: 30 nA	45	45	→	135	135	→	amorphous	~ x8
MT Target: 60 nA	45	45	→	135	135	→	amorphous	~ x2

+2 TAC runs and straight track running

Switching between full and empty target



Grab threaded studs to rotate clockwise 90° to put lead in beam, rotate ccw 90° to put blank frame in beam

Production Sequence:

Full Target: 30 nA	45	45	→	135	135	→	amorphous	~ x8
MT Target: 60 nA	45	45	→	135	135	→	amorphous	~ x2

+2 TAC runs and straight track running

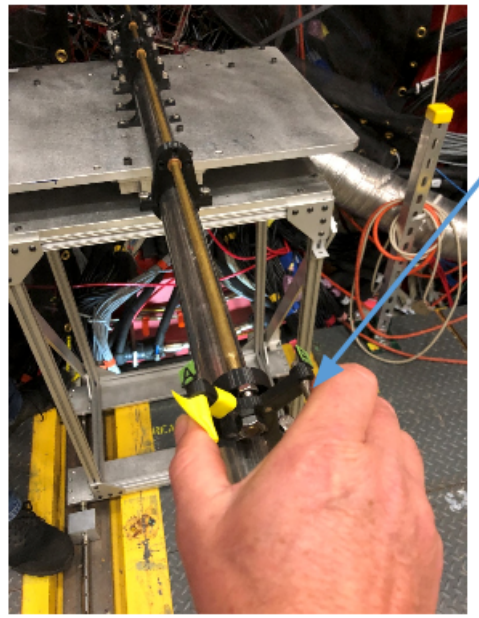
Run Range: 100385 - 101622

- 25 PAC days
- ~130 billion triggers
- 589 total "good" production runs

589	Total Full Runs
152	Total MT runs
246	PARA FULL
256	PERP FULL
87	AMO FULL
29	AMO MT

RCDB Query
event_count > 1000000
daq_run == 'PHYSICS_CPP'
beam_on_current > 10
solenoid_current > 100
collimator_diameter != 'Blocking'

Switching between full and empty target



Grab threaded studs to rotate clockwise 90° to put lead in beam, rotate ccw 90° to put blank frame in beam

Run Extension—Beam stability plot?

Basically, we were approved for 25 days of running.
Of those….

THERE WILL BE TEXT OR A PLOT ON THIS SLIDE BY TOMORROW

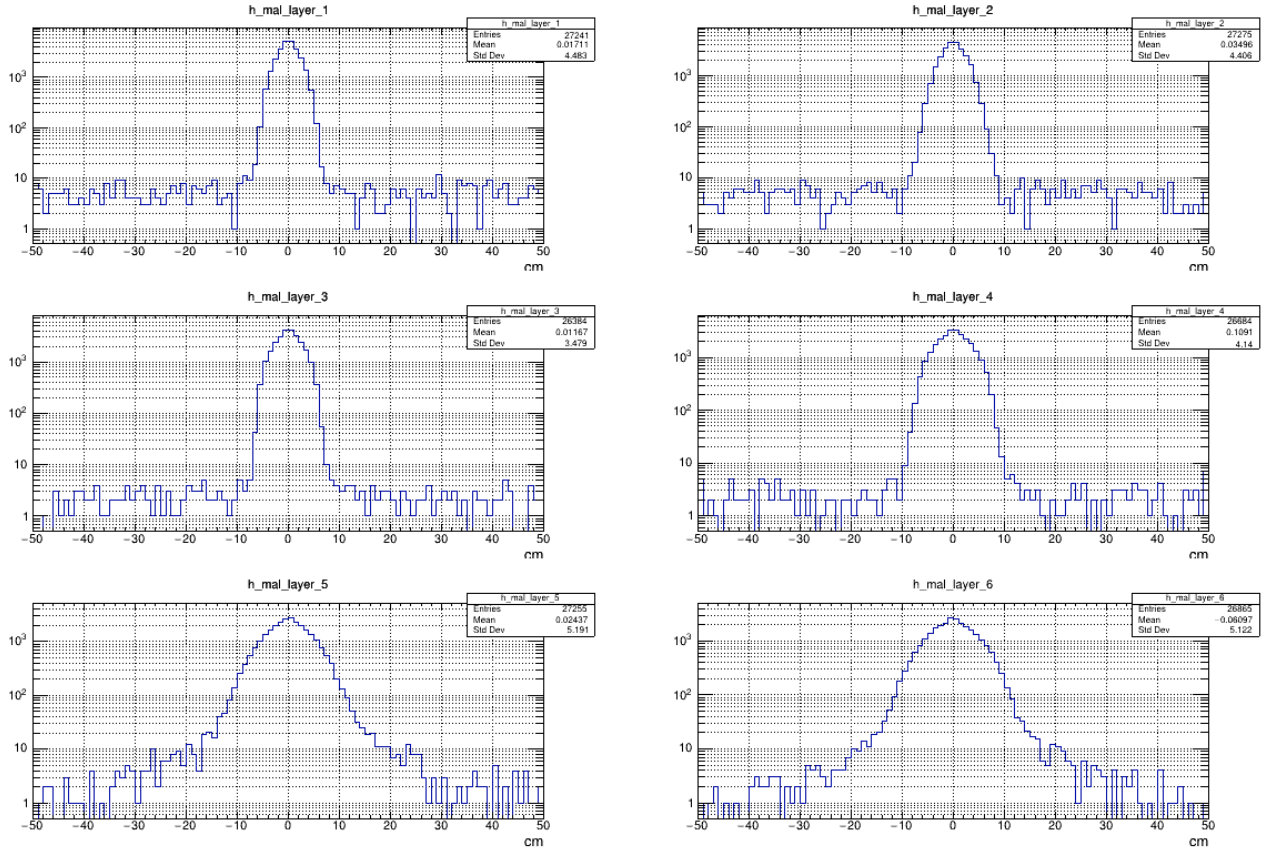
Preliminary MWPC inefficiency study by Ilia

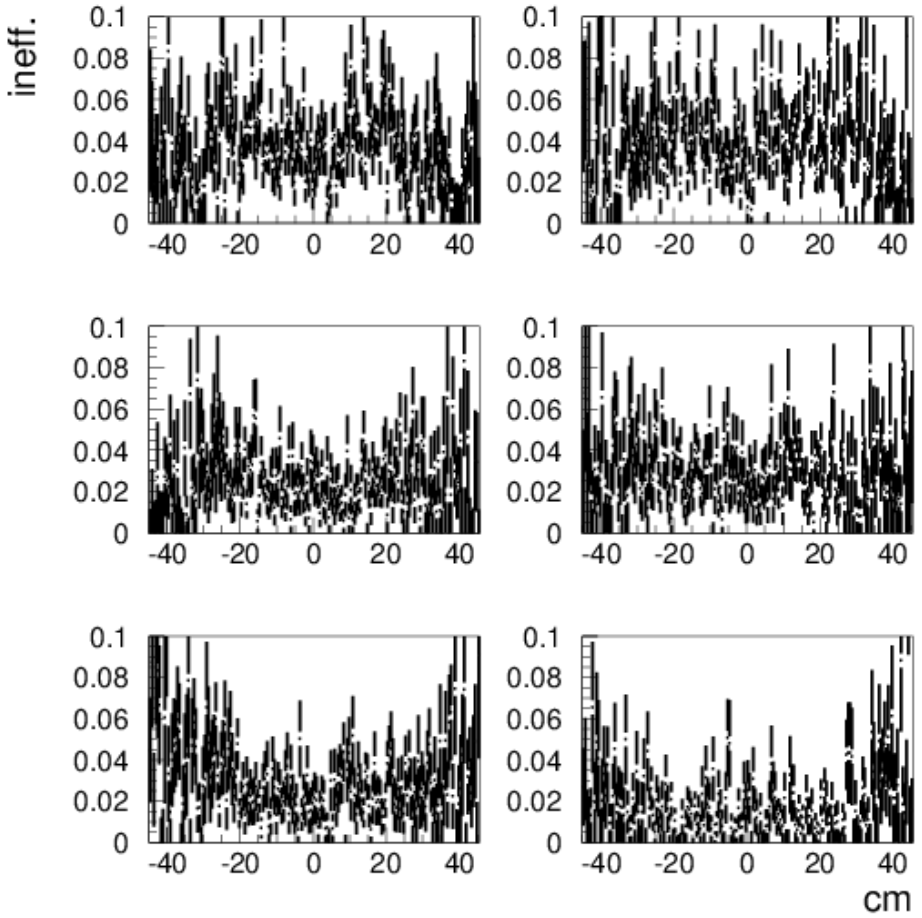
~ 12 runs. Selects tracks using all MWPC planes, matching tracks and FCAL hits.

Ilia's MWPC Inefficiency Study

The plane being checked is marked as "ineffficient" if there are no hits 5 sigma from the position extrapolated from other planes.

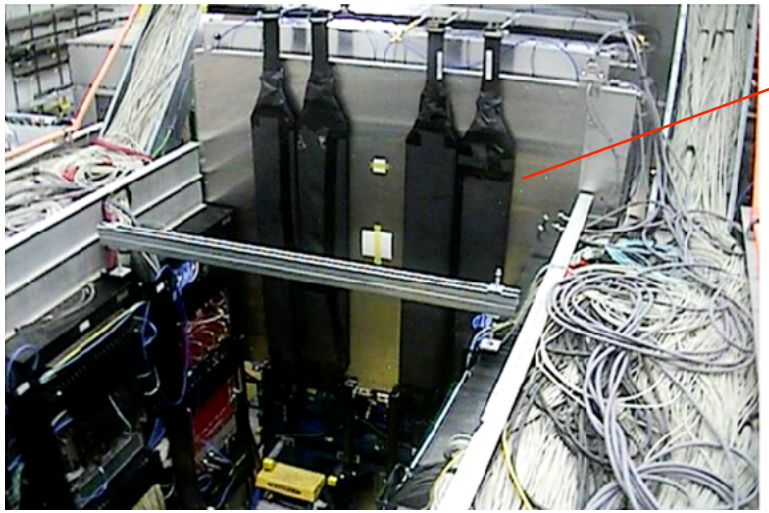
The estimated sigma is about 2 cm in plane 1, increasing to about 5 cm in planes 5 and 6 due to multiple scattering

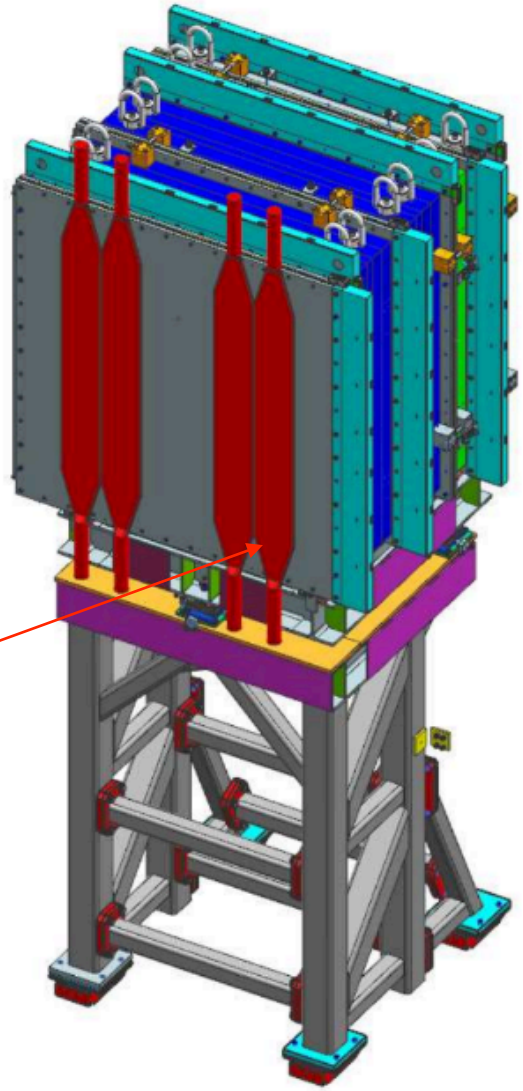




CTOF Trigger

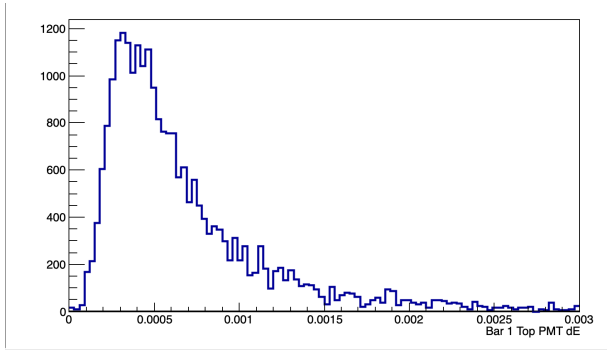
CTOF = Scintillators at back of wire chambers—read out at both ends. Test MWPC efficiency, and also to create a muon trigger that will be added to the front panel trigger supervisor

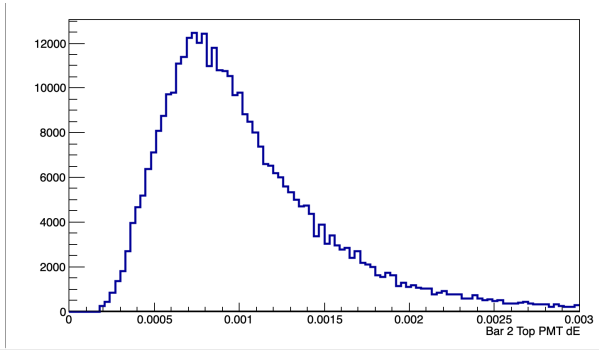


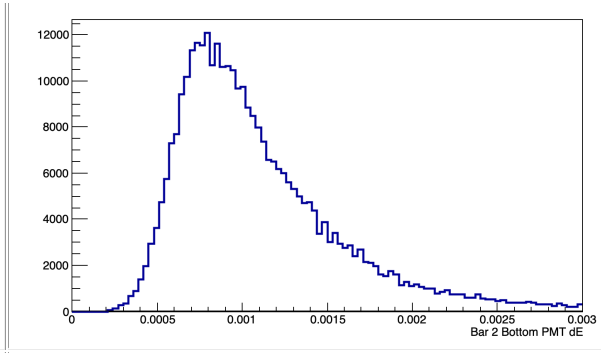


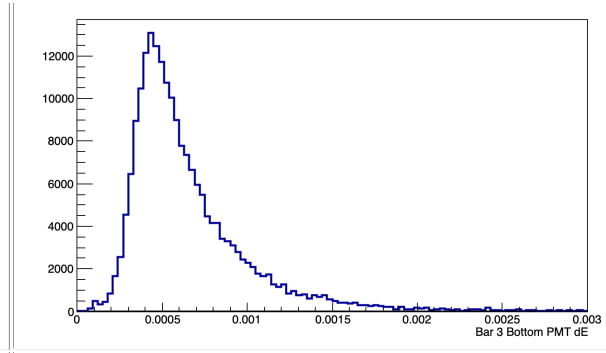
4 scintillators, 8 PMTs

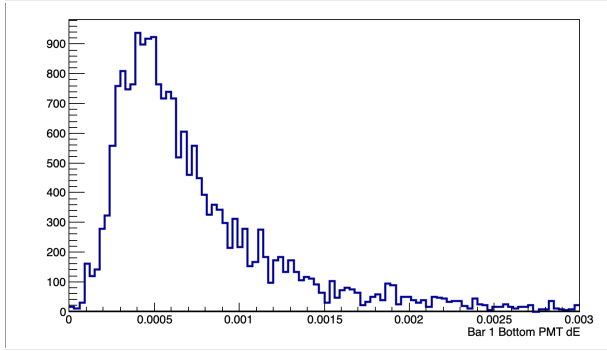
Pulse Integrals with Threshold Cuts ADC and TDC

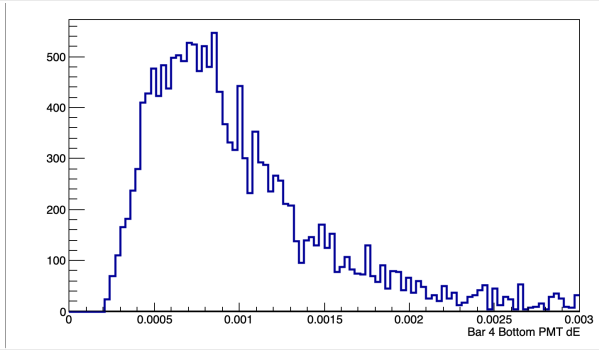


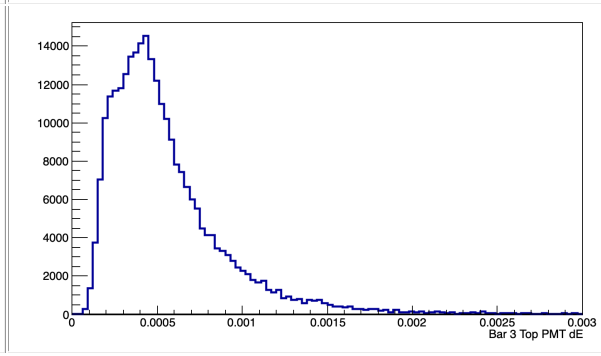


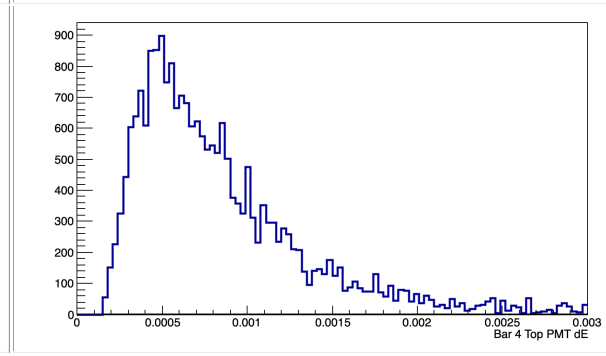




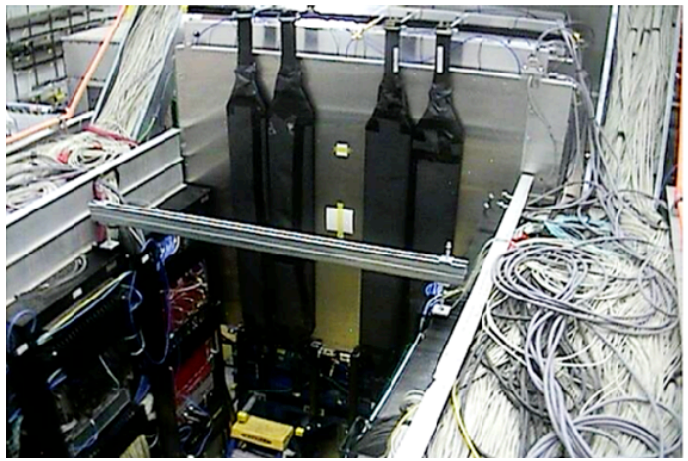


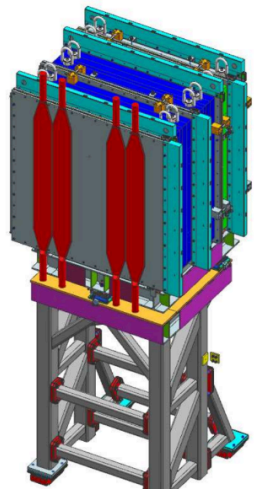




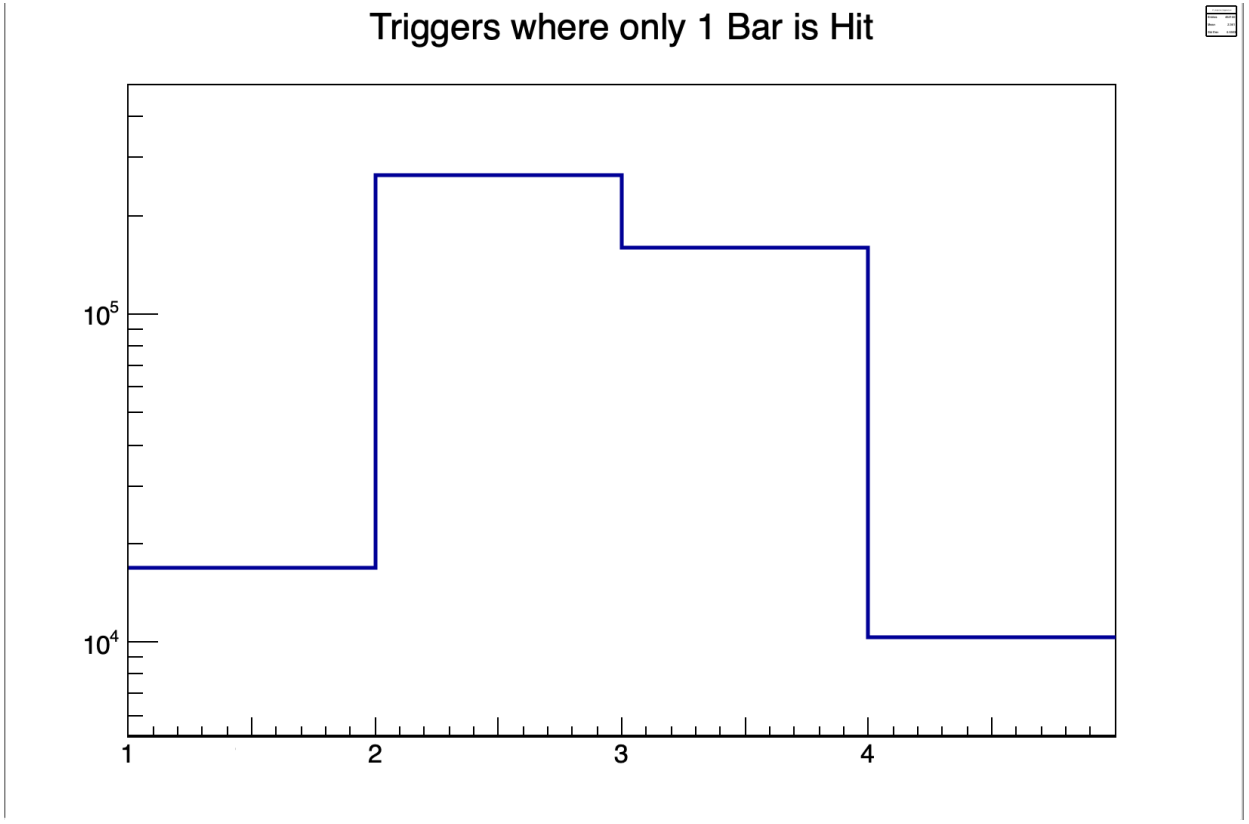


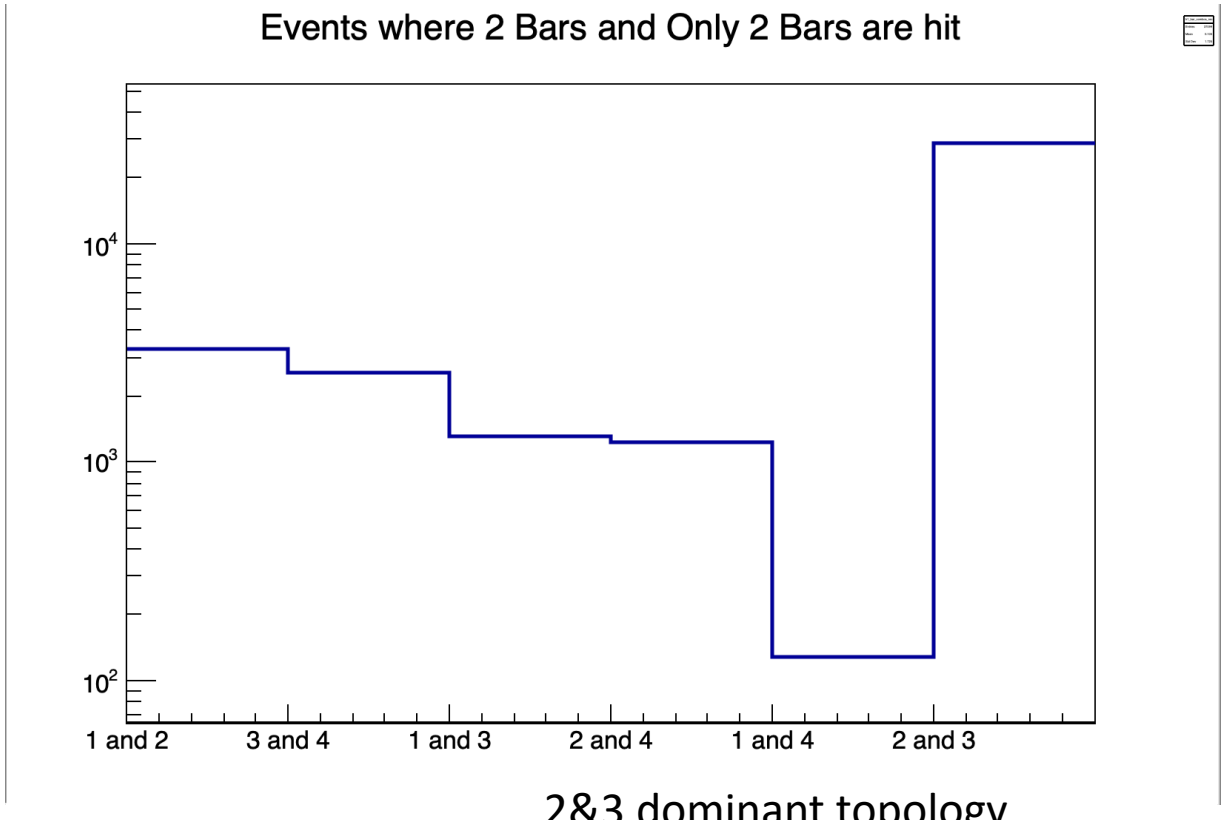
Nice minimum ionizing peaks





Counting Plots log(y) ADC and TDC





2&3 dominant topology

conjecture: good dimuon events

Continue to develop study

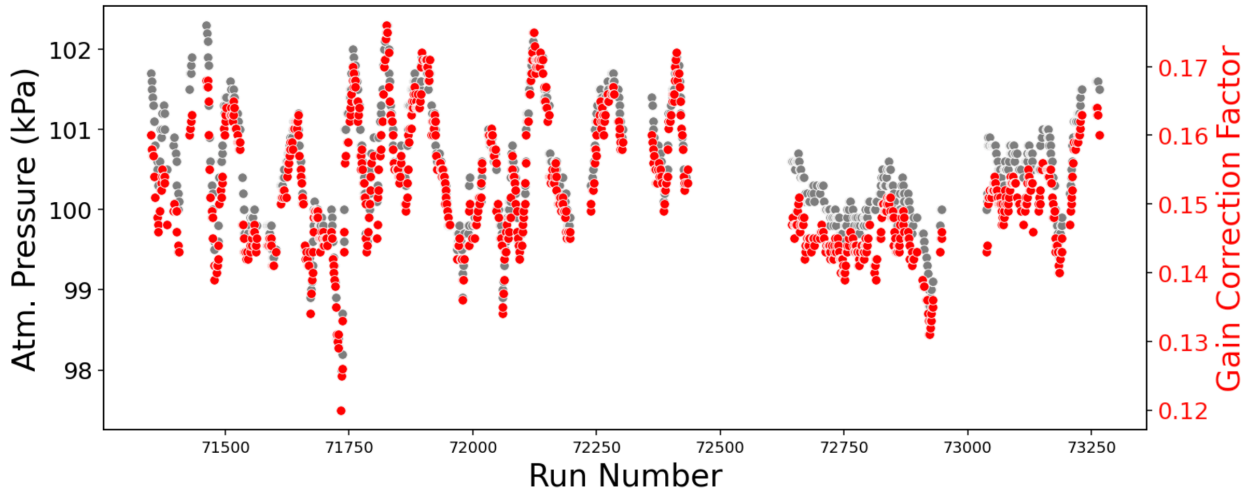
Use as pure muon sample for training/testing neural net!

Preliminary AIEC CPP results

- Goal: Implement ML system to calibrate and control the GlueX Central Drift Chamber
- How: Recommends anode voltages and calibration values in response to changing environmental and experimental conditions.

Traditional CDC Operation

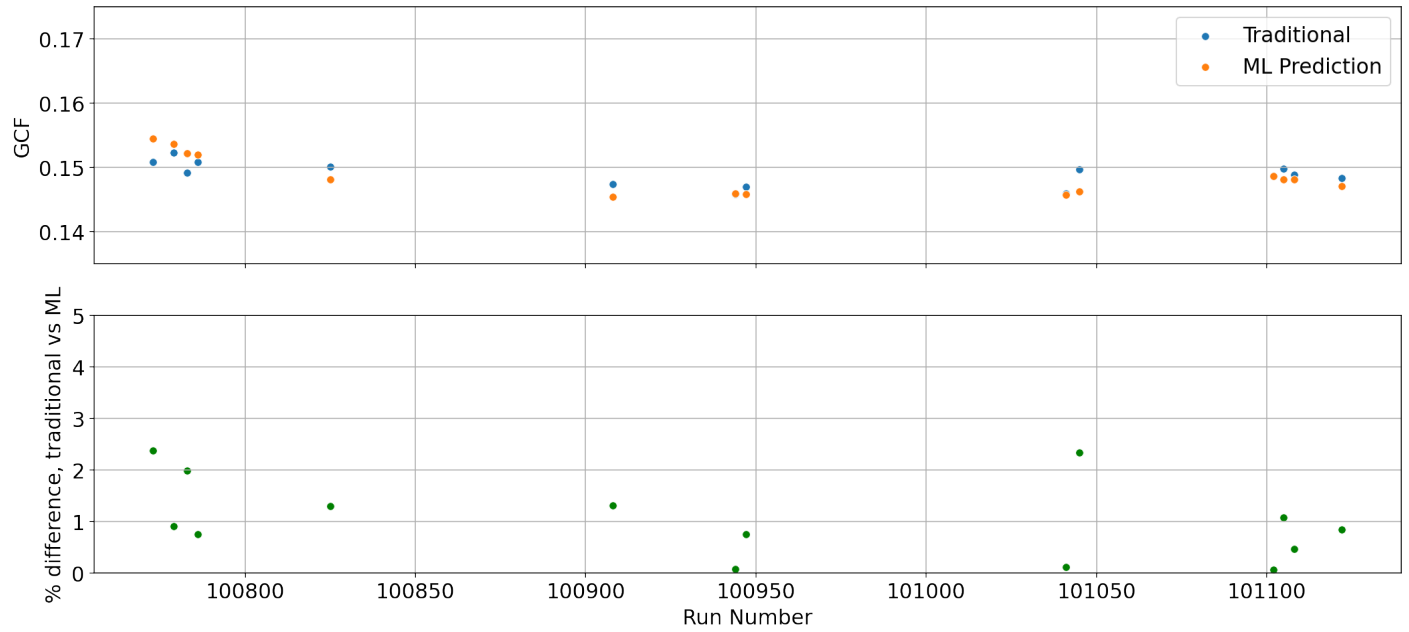
- HV maintained at constant 2125 V
- Gain Correction Factor fluctuates with atmospheric pressure, beam currents, etc
- Gain Correction Factor obtained from fit to dE/dx at p=1.5 GeV/c

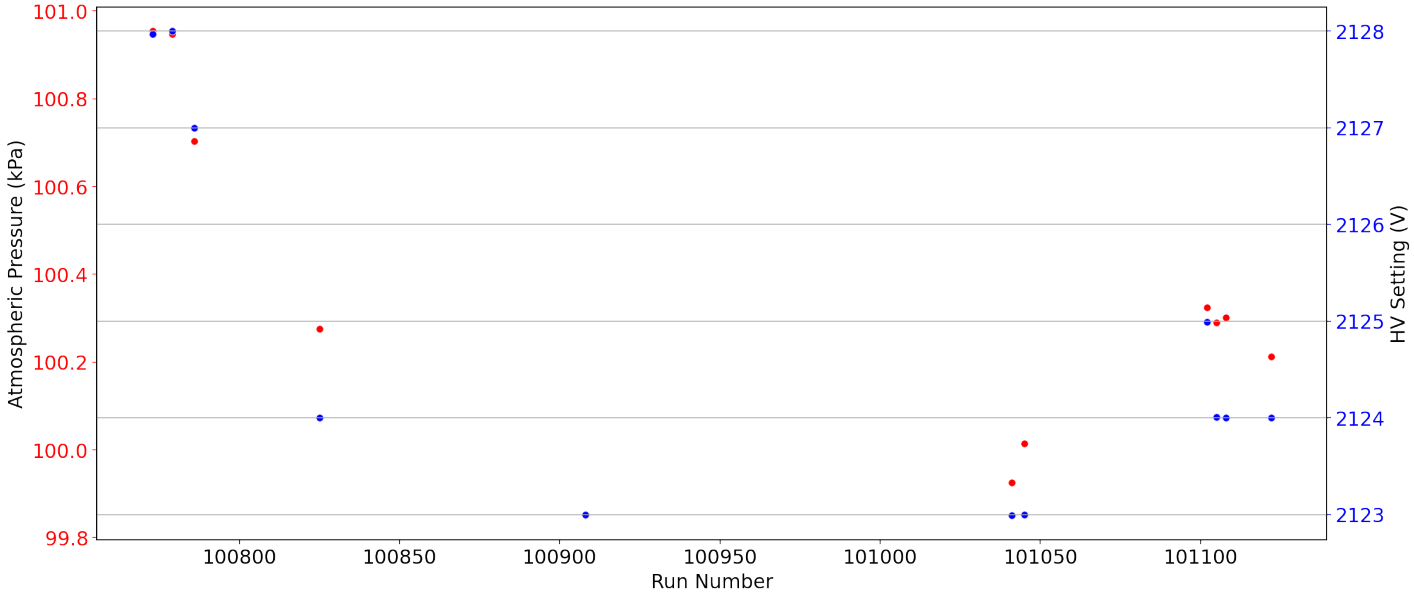


Preliminary AIEC CPP results

Current Implementation

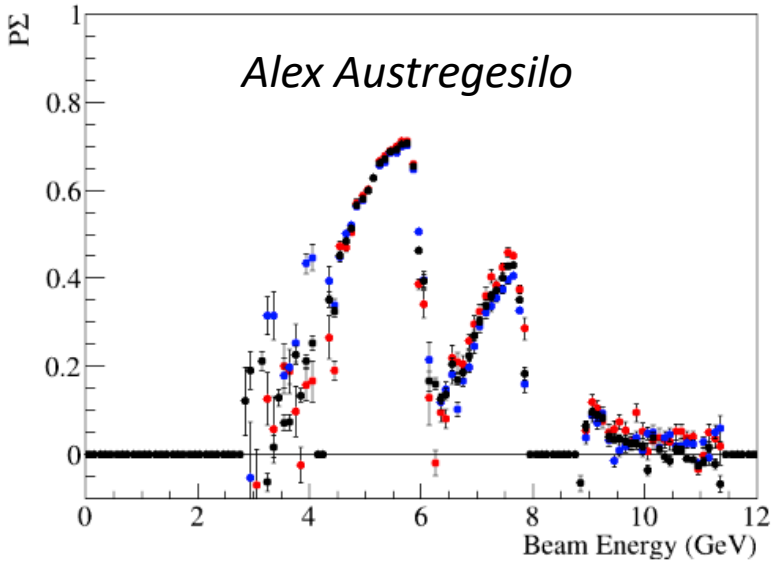
- HV determined from GCF predicted from a Gaussian Process
- Input features include gas temperature, atmospheric pressure, high voltage board current
- Model inference performed just before each run
- Preliminary analysis shows < 3% difference compared to traditionally obtained Gain Correction Factor

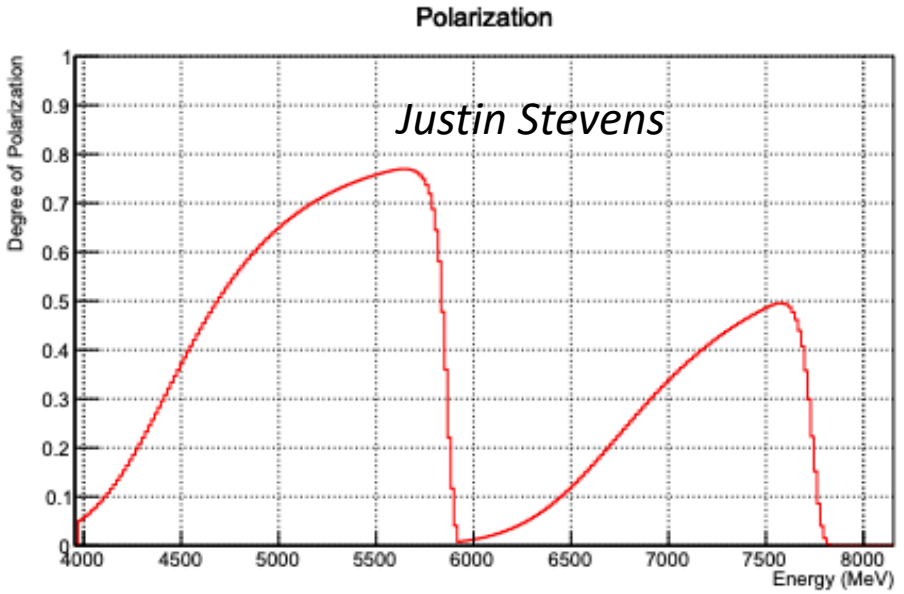


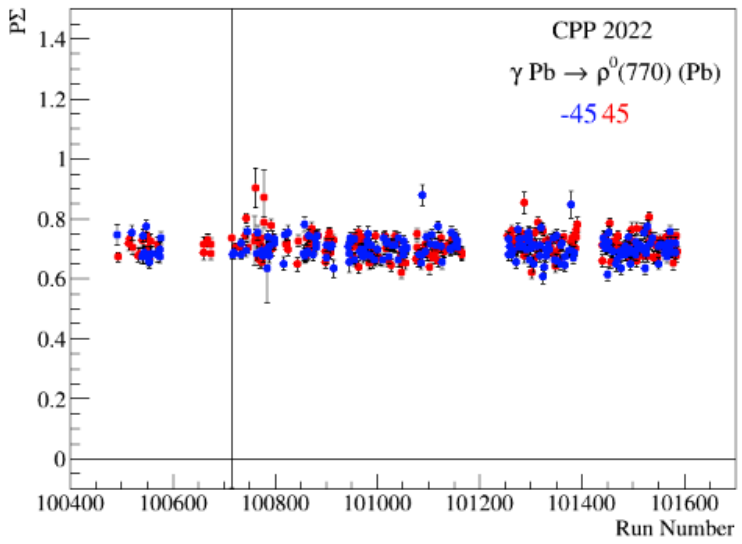


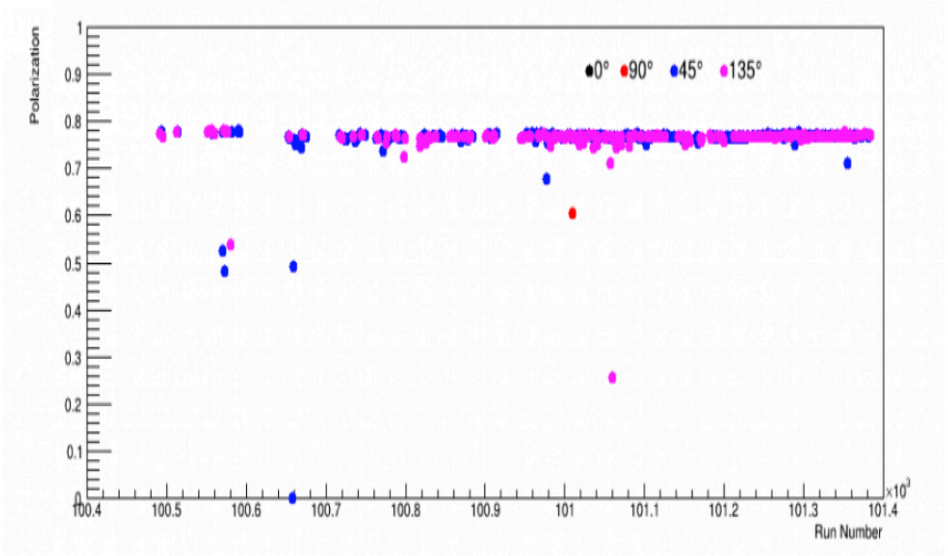
Polarization

Peak Polarization $\sim 80\,\%$

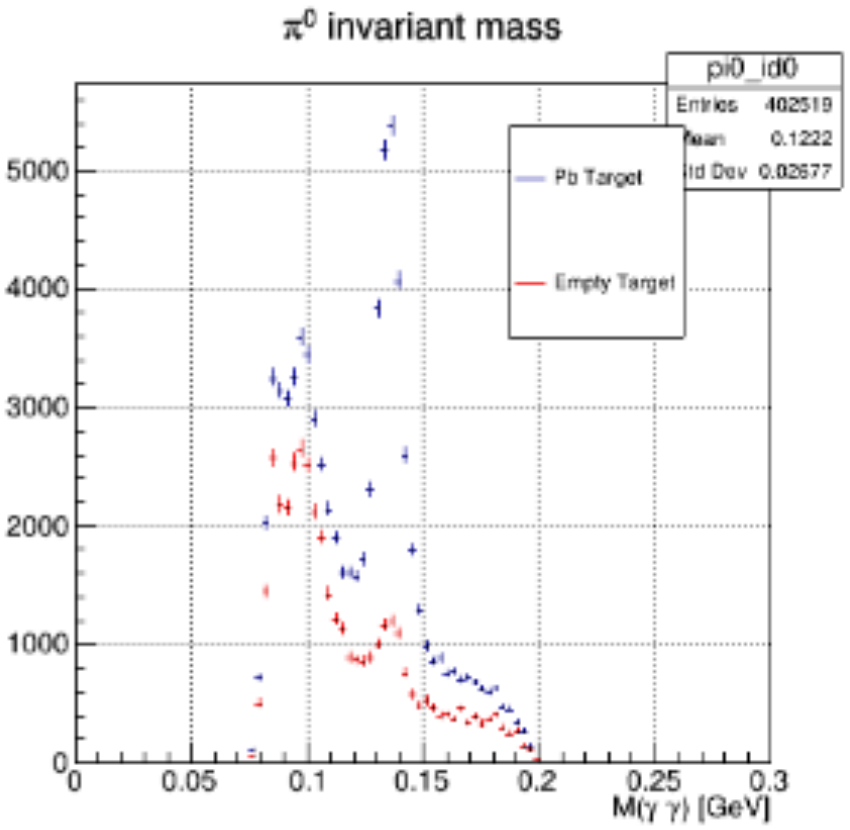


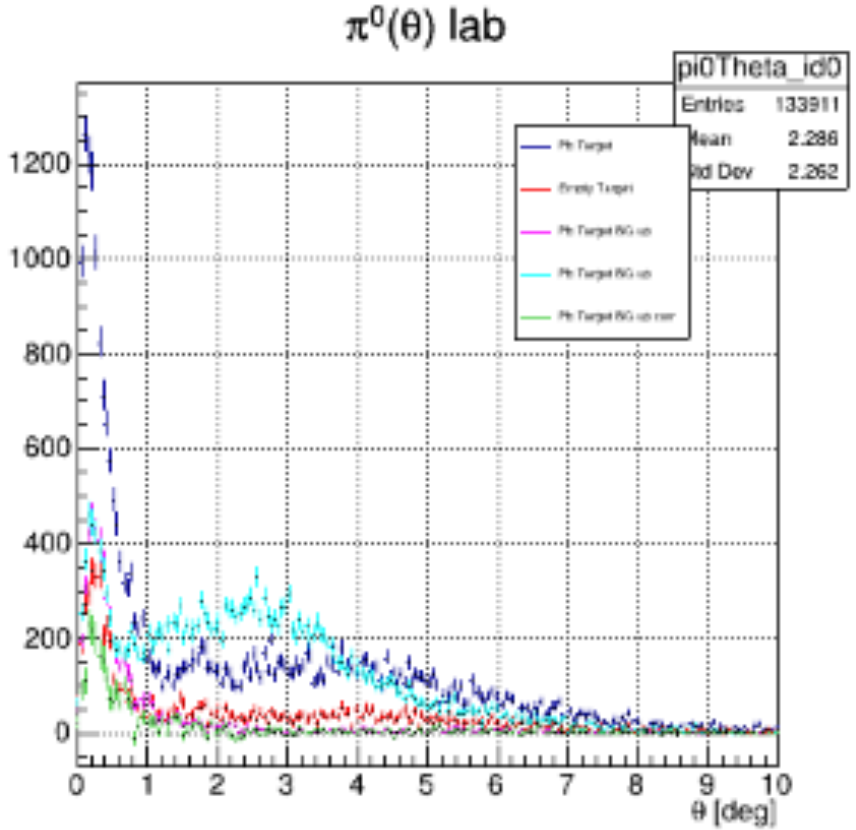


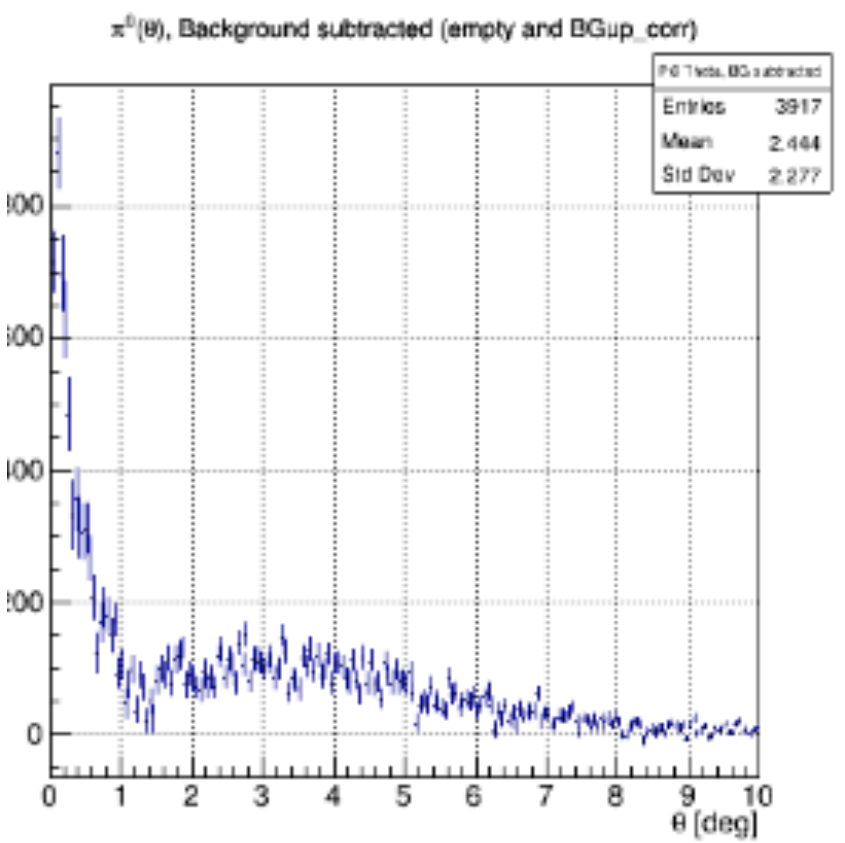




Very Preliminary Look at Neutral Channel (Beni)

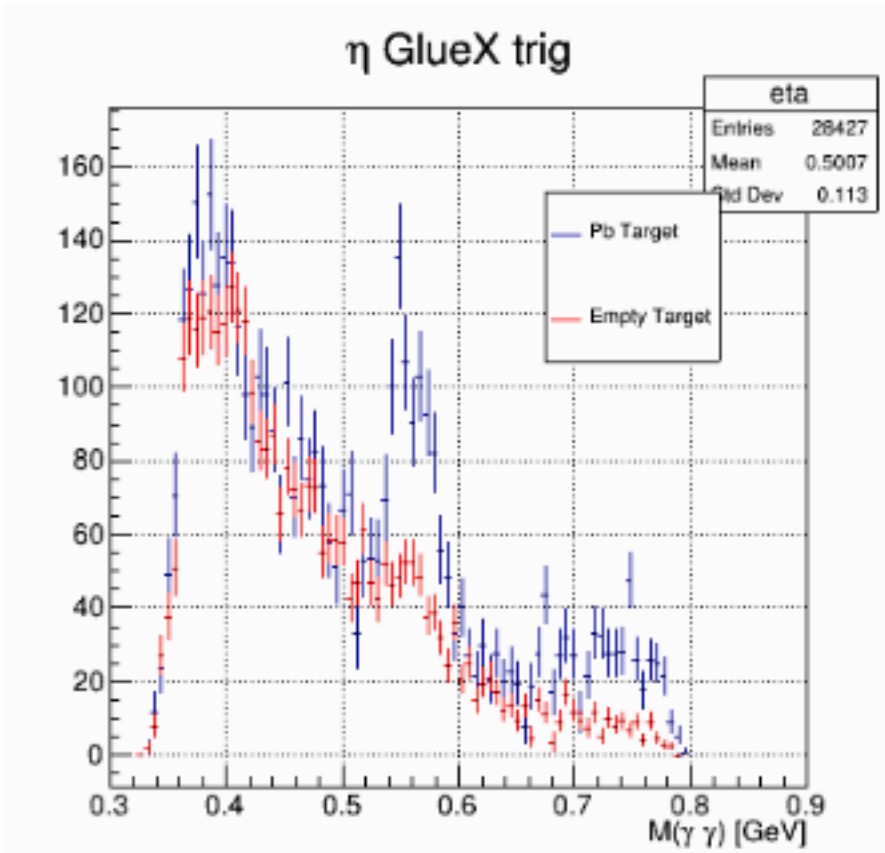


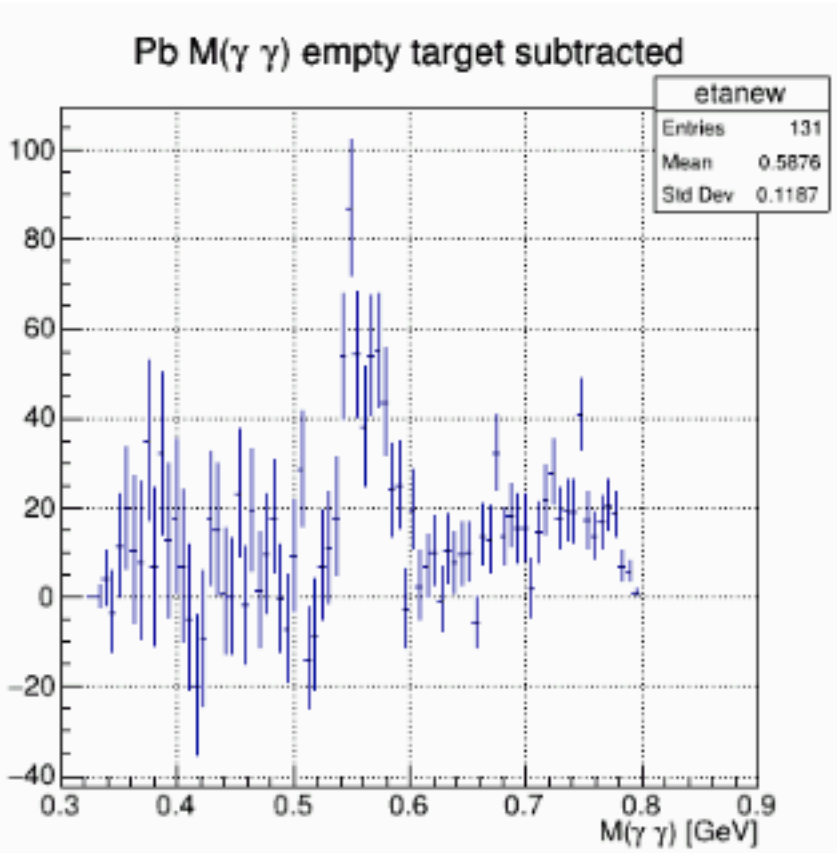




Very Preliminary Look at Neutral Channel (Beni)

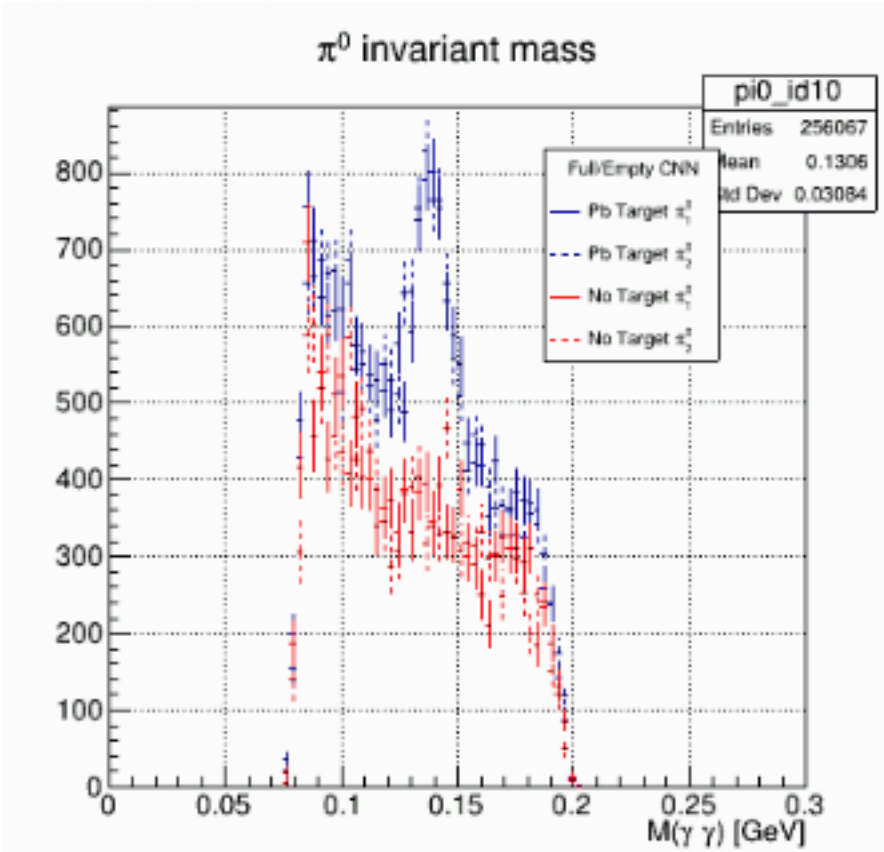
M(gamma gamma) = eta

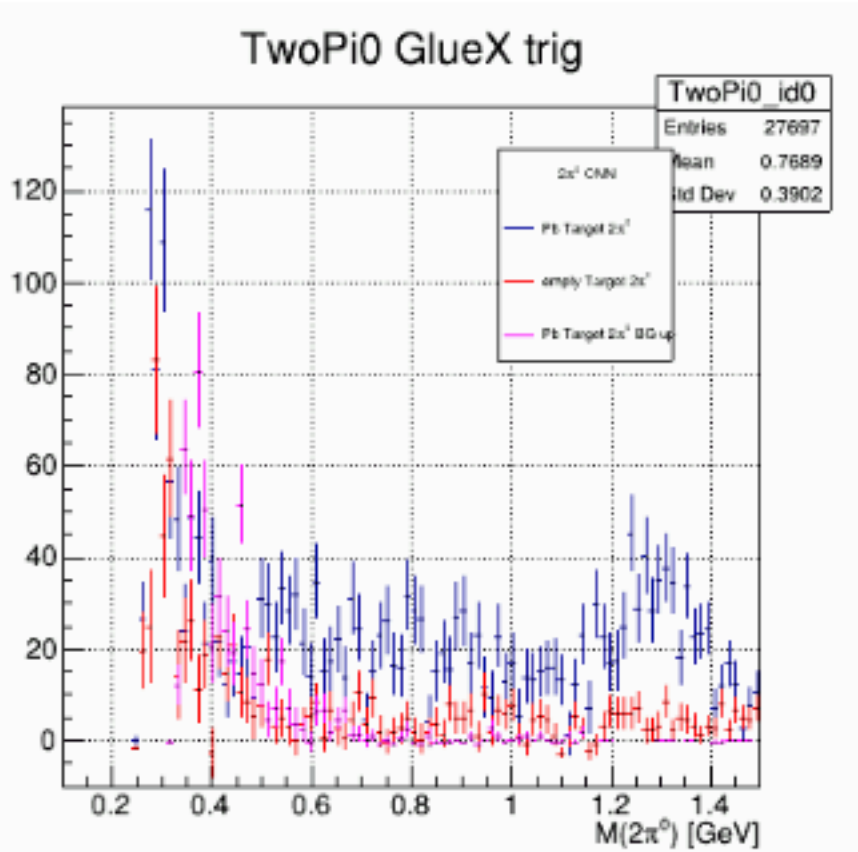




Very Preliminary Look at Neutral Channel (Beni)

M(4gamma) = pi0 + pi0

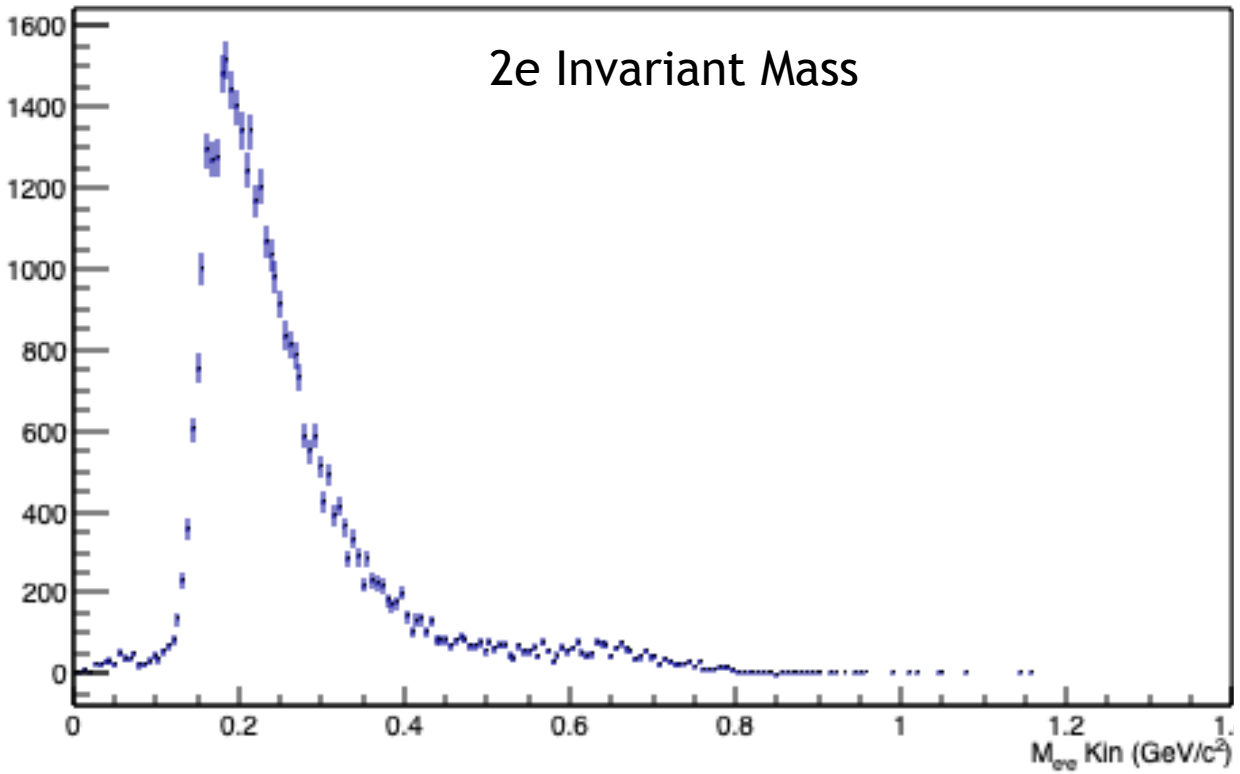




Very Preliminary Look at Charged Channel

$\gamma Pb^{208} \rightarrow e^+e^-(Pb^{208})$

FCAL Triggers only

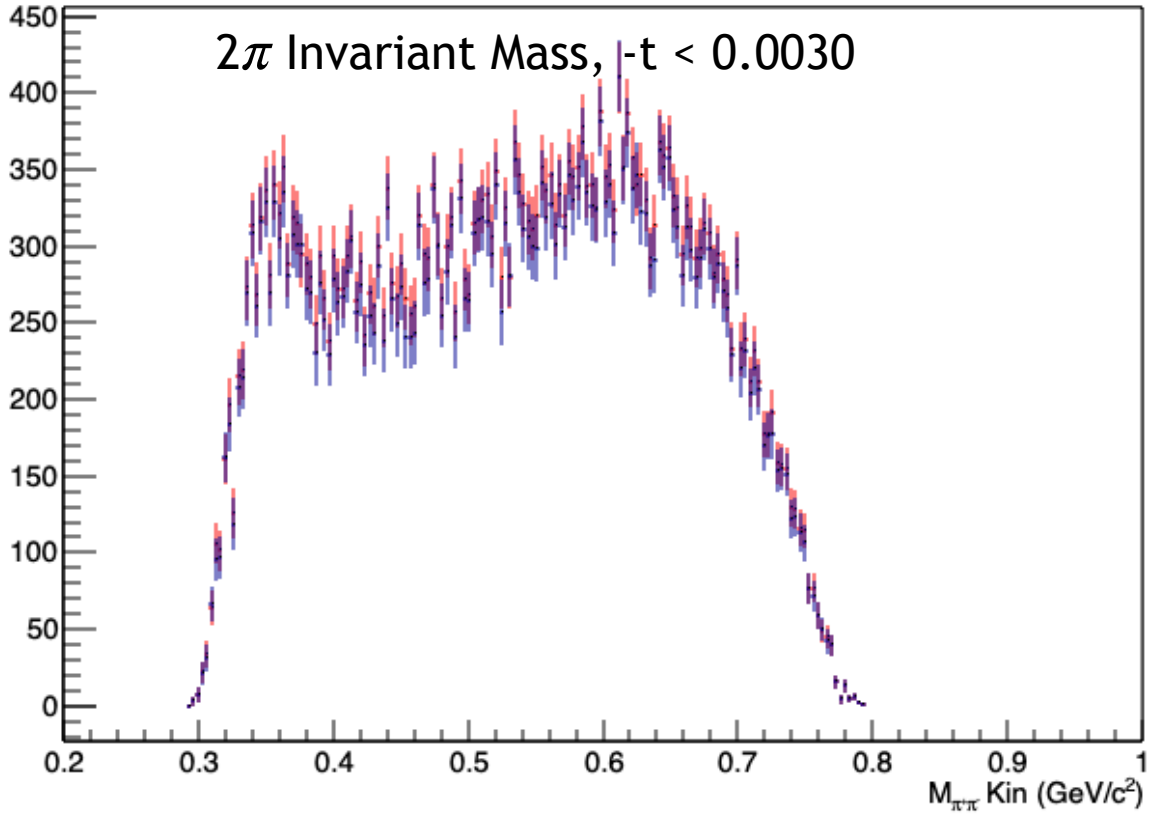


$\gamma Pb^{208} \rightarrow \pi^+\pi^-(Pb^{208})$

FCAL Triggers only

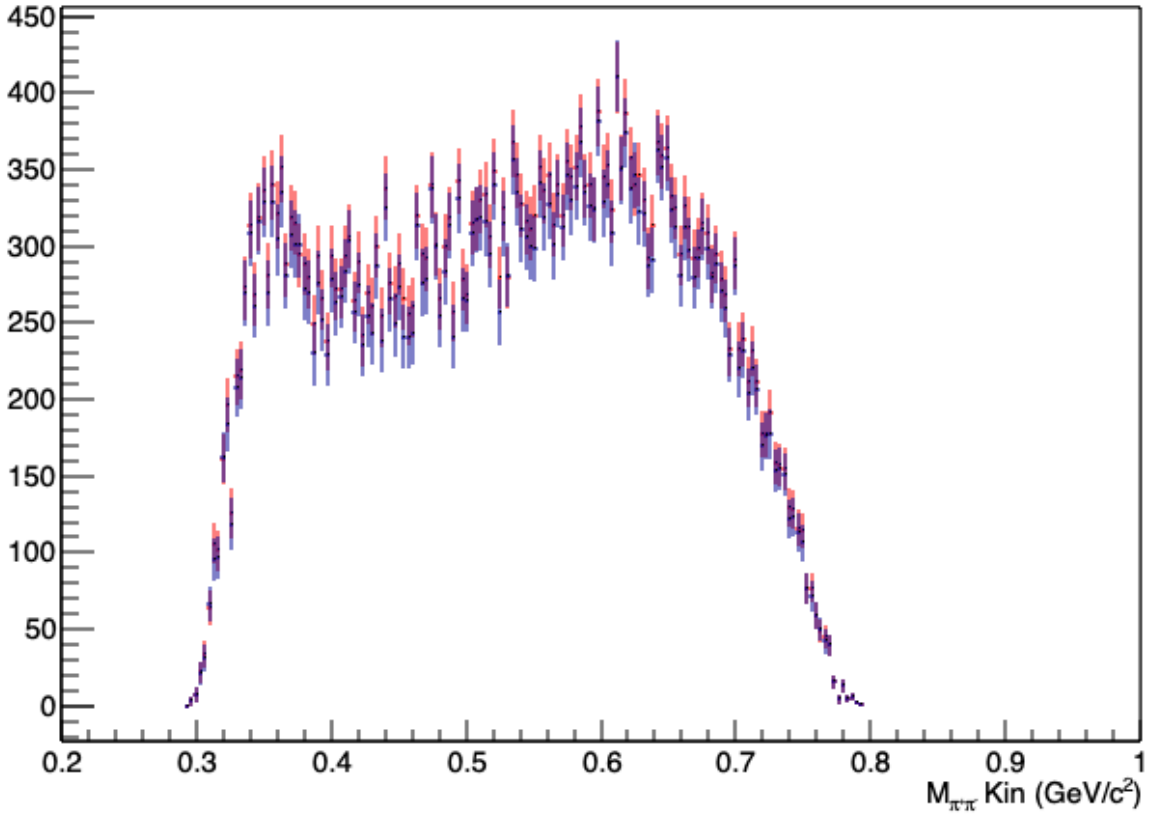
No MT subtraction

Post MT subtraction



Very Preliminary Look at Charged Channel

2π Invariant Mass, -t < 0.0030



$\gamma Pb^{208} \rightarrow \pi^+\pi^-(Pb^{208})$

FCAL Triggers only

No MT subtraction

Post MT subtraction

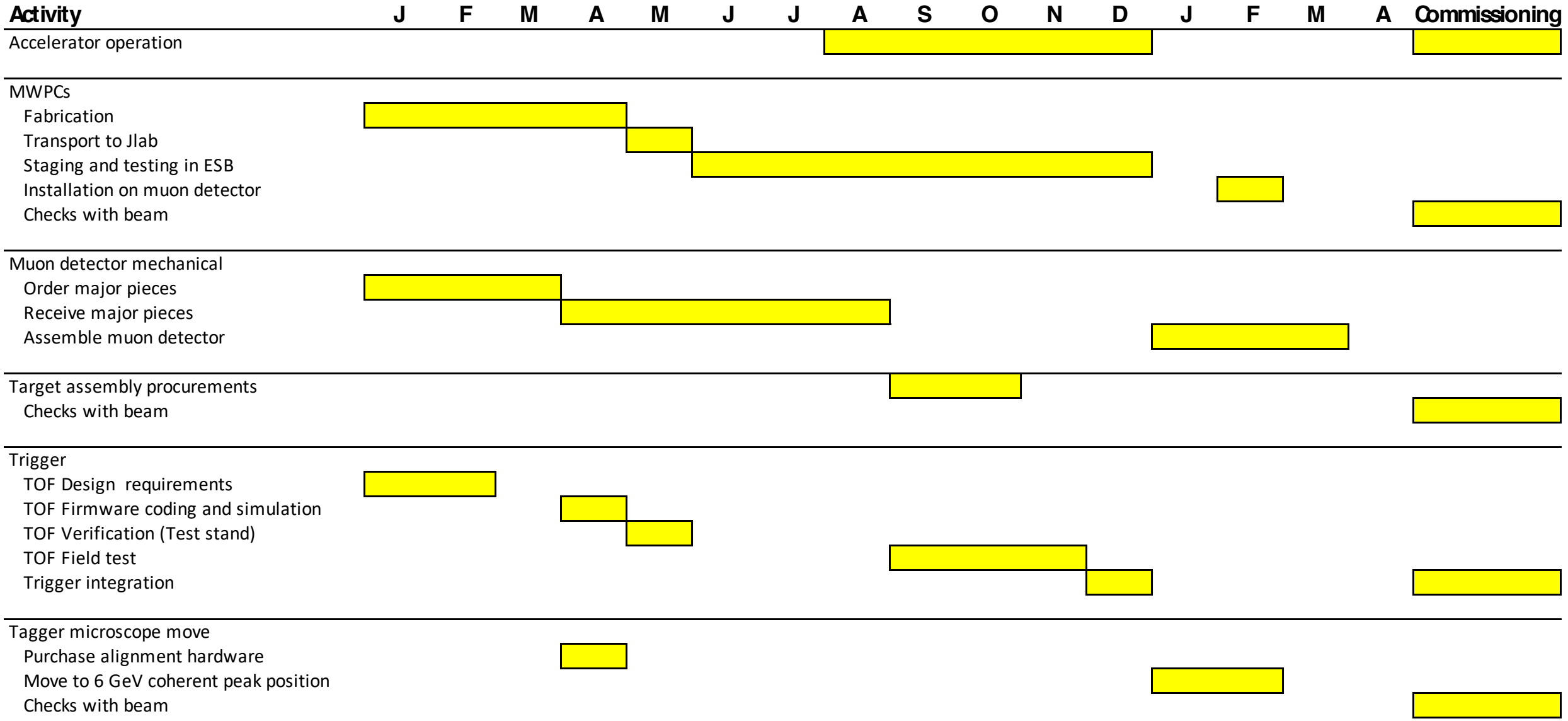
Full Percentage	82.0		80.0
Empty Percentage	18.0		20.0
Configuration	Triggers	Percentage of Total	Goal
Total	129,152,986,149	100.0	100.0
PARA 135 MT	11,029,617,055	8.5	9.4
PERP 45 MT	10,750,416,953	8.3	9.4
AMORPH MT	1,449,786,920	1.1	1.2
PARA 135 FULL	50,014,247,612	38.7	37.6
PERP 45 FULL	49,739,935,530	38.5	37.6
AMORPH FULL	6,168,982,079	4.8	4.8
Events/PAC day (est)	5,184,000,000	Assumed run efficiency	0.4
Empty Target	Triggers	Percentage of Empty	Goal
Total	23,229,820,928	100.0	
Para 45/135	11,029,617,055	47.5	47.0
Perp 45/135	10,750,416,953	46.3	47.0
Amorph	1,449,786,920	6.2	6.0
Empty (PAC Days)	4.48	203.7	2.2
Full Target	Triggers	Percentage of Full	Goal
Total	105,923,165,221	100.0	
Para 45/135	50,014,247,612	47.2	47.0
Perp 45/135	49,739,935,530	47.0	47.0
Amorph	6,168,982,079	5.8	6.0
Full (PAC Days)	20.43	102.2	20.0
Full+Empty (PAC Days)	24.91	112.2	22.2

Special thanks to Albert Fabrizi and Elton for maintaining the run spreadsheet!

[Link to Albert's spreadsheet]

7/14/2022	101061		Amorph			30457848				Empty	30 nA Production
7/14/2022	101062	45 PERP	JD70-103 50um 45/135 deg		240,722,239					Empty	60 nA Production
7/15/2022	101063	45 PERP	JD70-103 50um 45/135 deg		243,283,439					Empty	60 nA Production
7/15/2022	101064	135 PARA	JD70-103 50um 45/135 deg	240,821,917						Empty	60 nA Production
7/15/2022	101065	135 PARA	JD70-103 50um 45/135 deg	241,493,378						Empty	60 nA Production
7/15/2022	101066		Amorph			60753445				Empty	60 nA Production
7/15/2022	101067	135 PARA	JD70-103 50um 45/135 deg							Empty	wrong setting junk
7/15/2022	101068	45 PERP	JD70-103 50um 45/135 deg		240,190,327					Empty	60 nA Production
7/15/2022	101069	45 PERP	JD70-103 50um 45/135 deg		240,171,084					Empty	60 nA Production
7/15/2022	101070	135 PARA	JD70-103 50um 45/135 deg	240,509,952						Empty	60 nA Production
7/15/2022	101071	135 PARA	JD70-103 50um 45/135 deg	234,657,372						Empty	60 nA Production
7/15/2022	101072		Amorph			8835233				Empty	60 nA Production
7/15/2022	101073		Amorph			39033204				Empty	60 nA Production
7/15/2022	101074		Amorph							Empty	
7/15/2022	101075		Amorph							Pb	DAQ Test
7/15/2022	101076	45 PERP	JD70-103 50um 45/135 deg					18,485,504		Pb	30 nA Production
7/15/2022	101077	45 PERP	JD70-103 50um 45/135 deg					240,984,459		Pb	30 nA Production
7/15/2022	101078	45 PERP	JD70-103 50um 45/135 deg					21,854,394		Pb	30 nA Production
7/15/2022	101079	45 PERP	JD70-103 50um 45/135 deg					241,138,678		Pb	30 nA Production
7/15/2022	101080	135 PARA	JD70-103 50um 45/135 deg				240,689,937			Pb	30 nA Production
7/15/2022	101081	135 PARA	JD70-103 50um 45/135 deg				241,025,752			Pb	30 nA Production

Back up


Activity
J
F
M
A
M
J
J
A
S
O
N
D
J
F
M
A
Commissioning
Accelerator operation
MWPCs
Fabrication
Transport to Jlab
Staging and testing in ESB
Installation on muon detector
Checks with beam
Muon detector mechanical
Order major pieces
Receive major pieces
Assemble muon detector
Target assembly procurements
Checks with beam
Trigger
TOF Design requirements
TOF Firmware coding and simulation
TOF Verification (Test stand)
TOF Field test
Trigger integration
Tagger microscope move
Purchase alignment hardware
Move to 6 GeV coherent peak position
Checks with beam

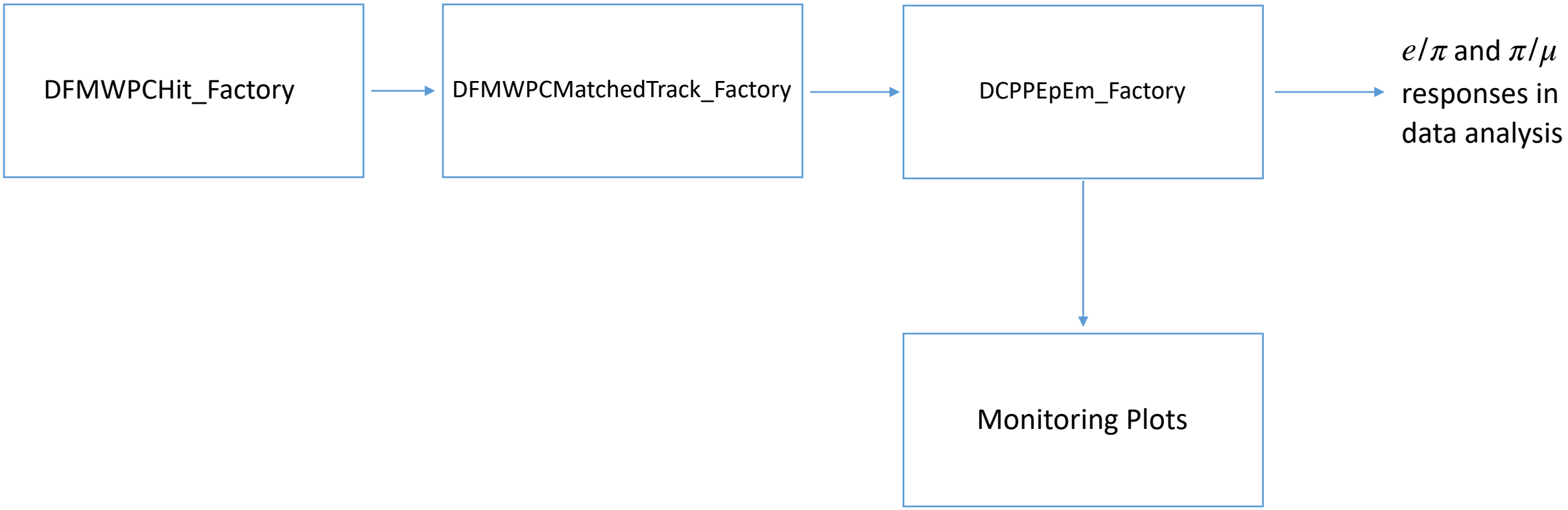
CPP software

Started holding weekly CPP software meetings to address needs prior to summer run

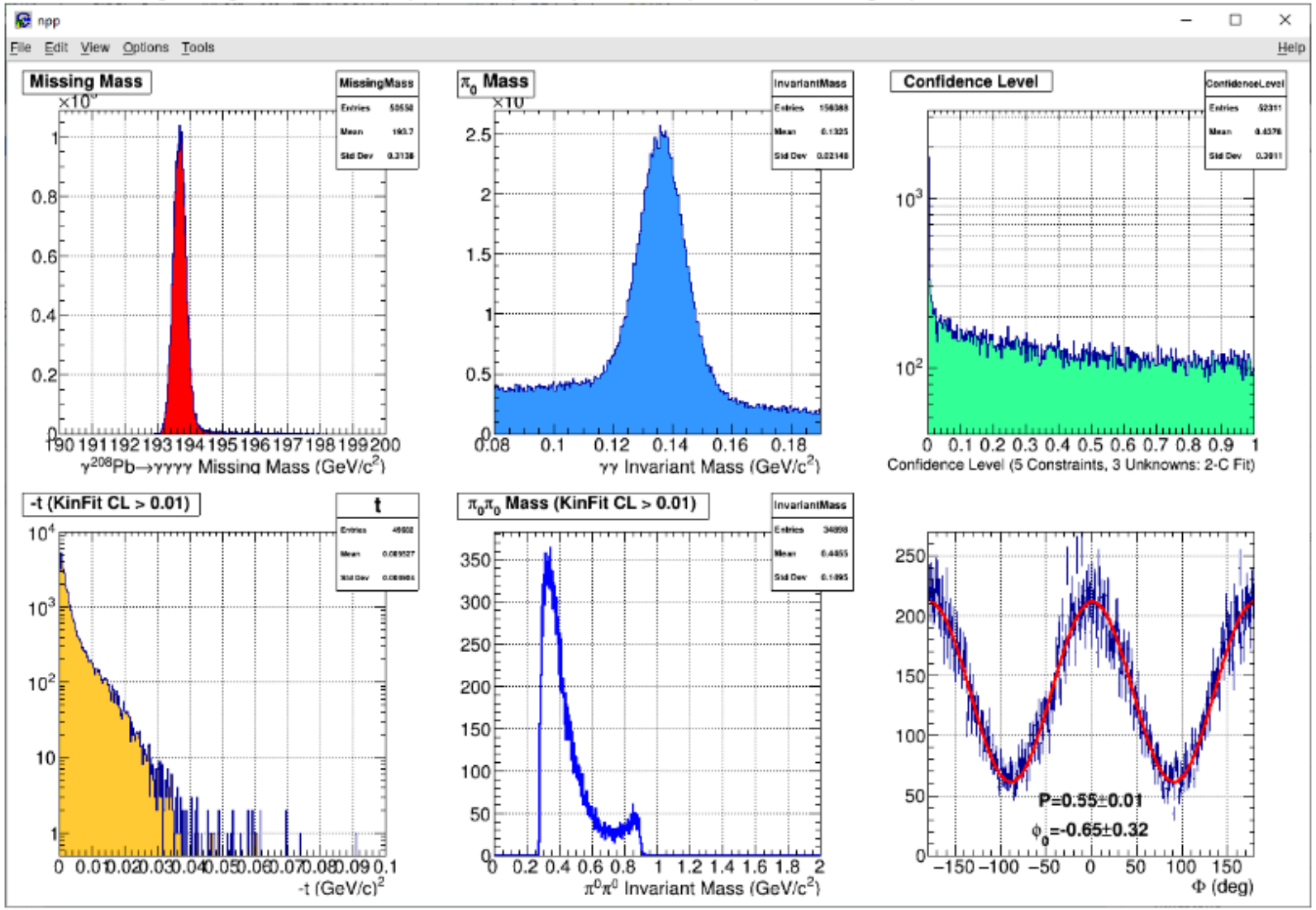
- Thursdays at 12:30 pm on zoom, listed on CPP meeting page

Achieved goals

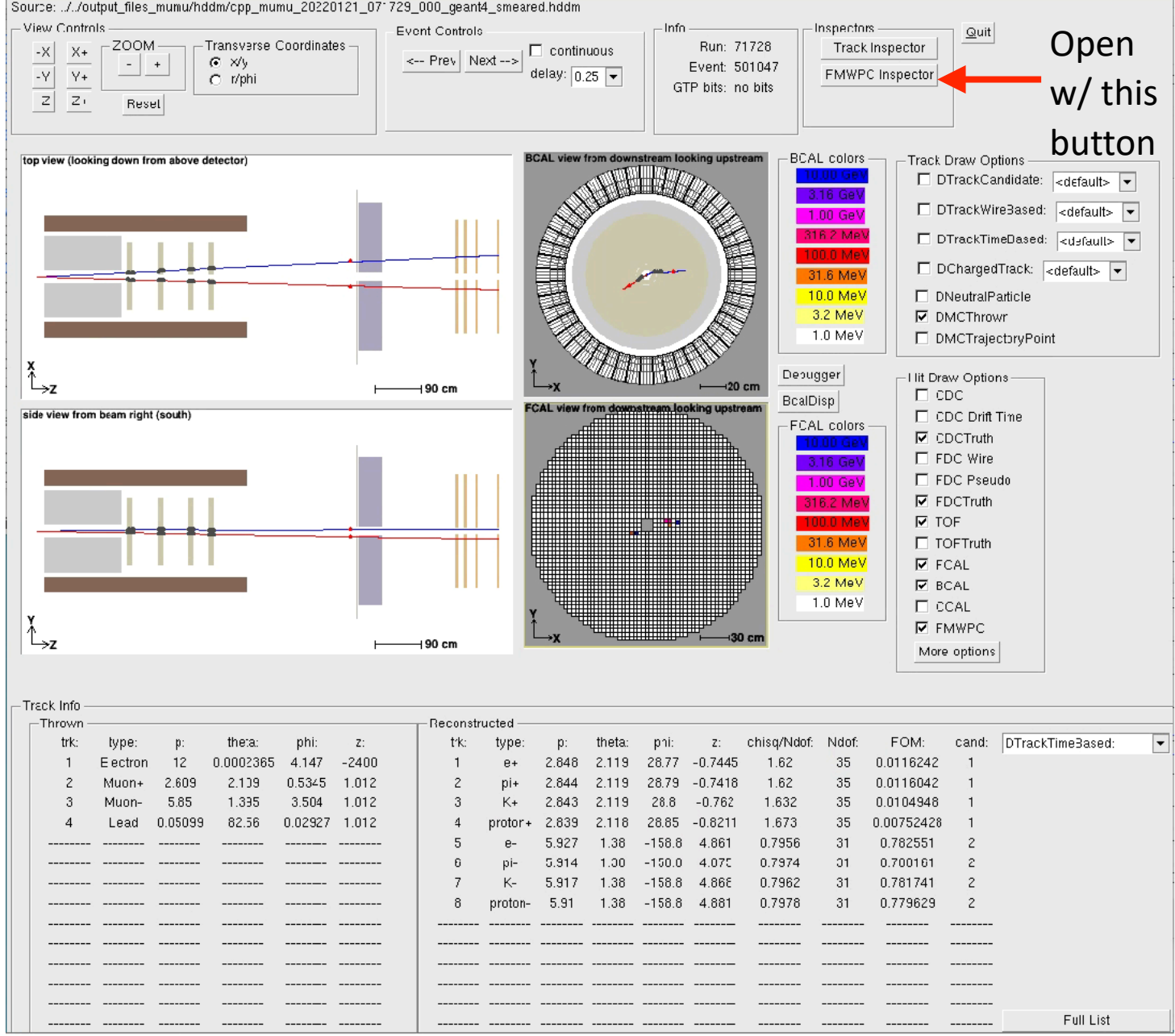
- AI/Machine Learning
  - MWPC Neural Net for μ/π separation, TMVA Neural Net for e/π separation
- DFMWPCHit_Factory: *for creating calibrated MWPC hits from non-calibrated MWPC hits*
- DFMWPCMatchedTrack_Factory: *for producing objects to be used with ML models*
  e.g. E_{fcal}/p, *# of MWPC wires hit, X,Y of projected track to face of MWPCs*
- DFMWPCEpEm_Factory: *for actually applying the μ/π, e/π inferences on their respective models*
- Monitoring plugins for producing kinematic plots in real time
- Updated HDView2 for CPP


DFMWPCHit_Factory
DFMWPCMatchedTrack_Factory
DCPPEpEm_Factory
e/π and π/μ responses in data analysis
Monitoring Plots

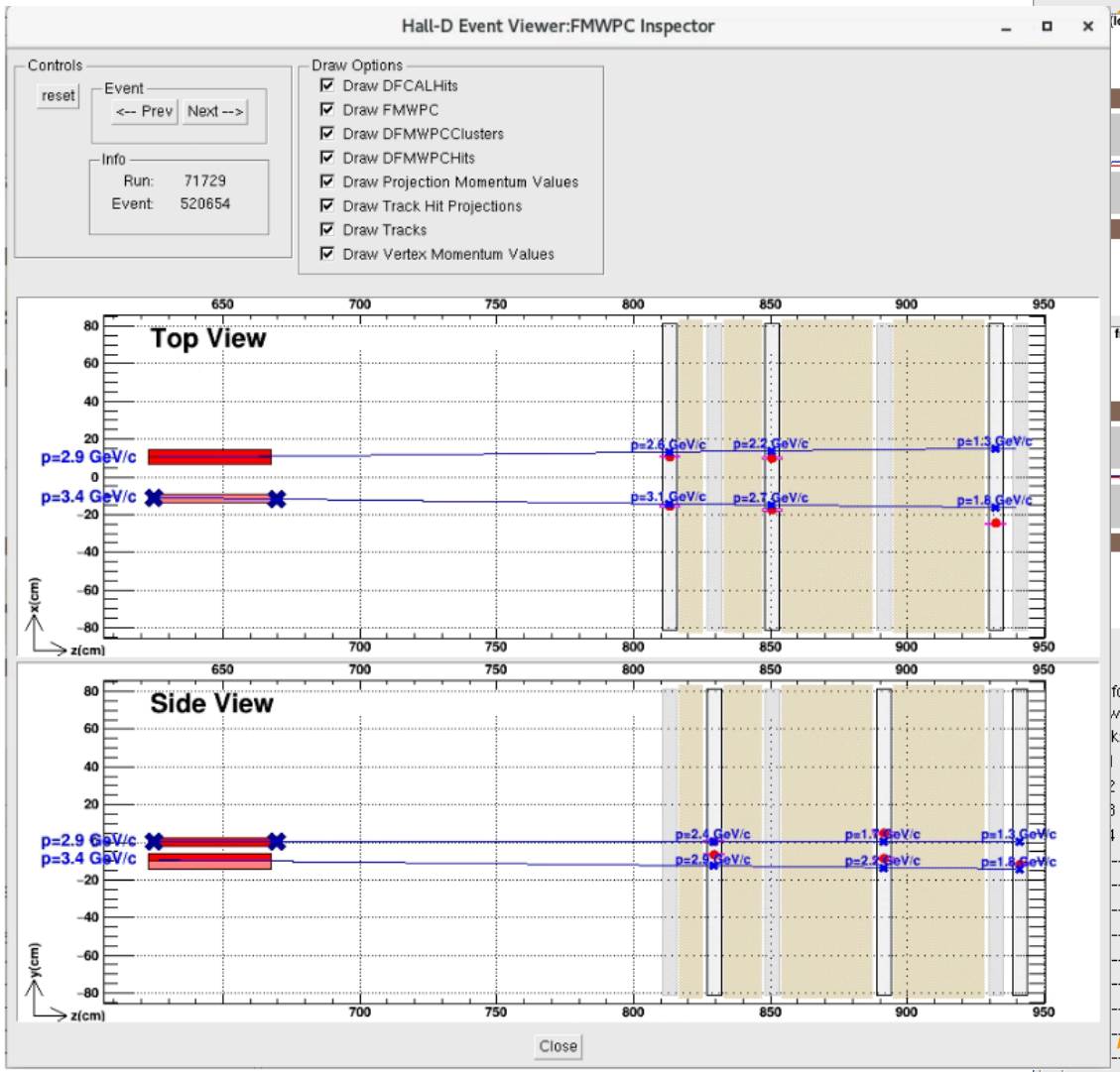
New monitoring histograms for NPP experiment (example for sample of pure MC signal):

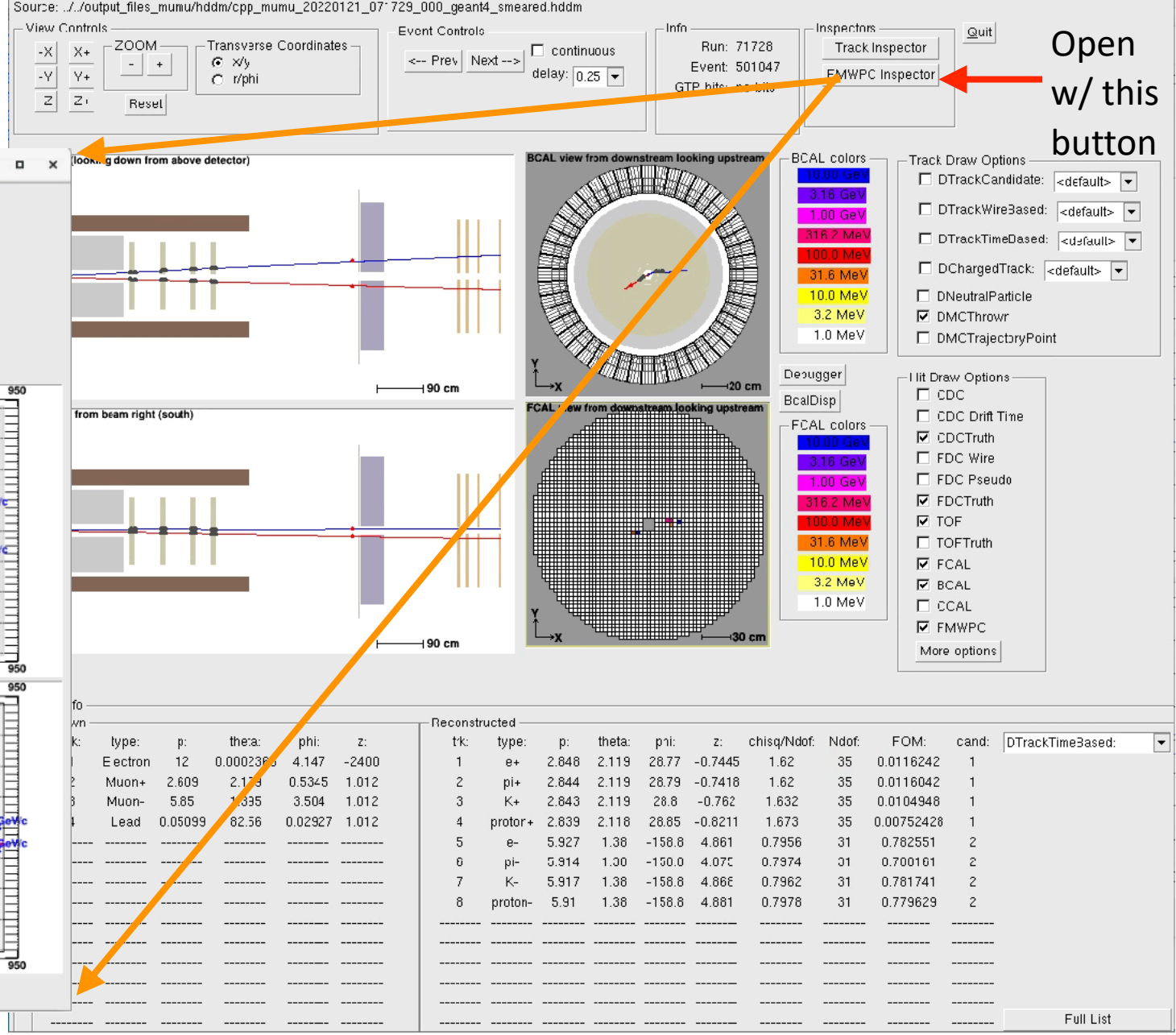


FMWPC Inspector in HDView2

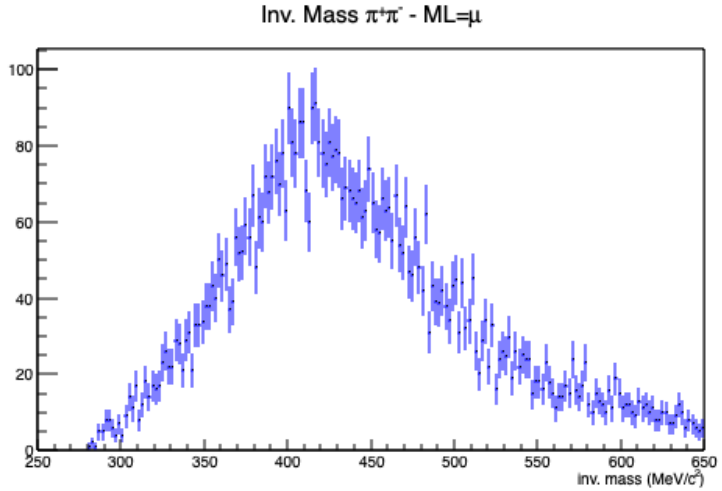


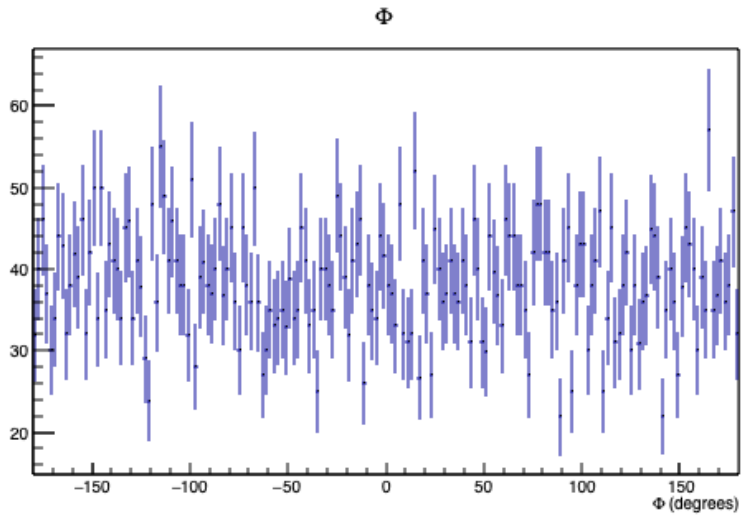
FMWPC Inspector in HDView2

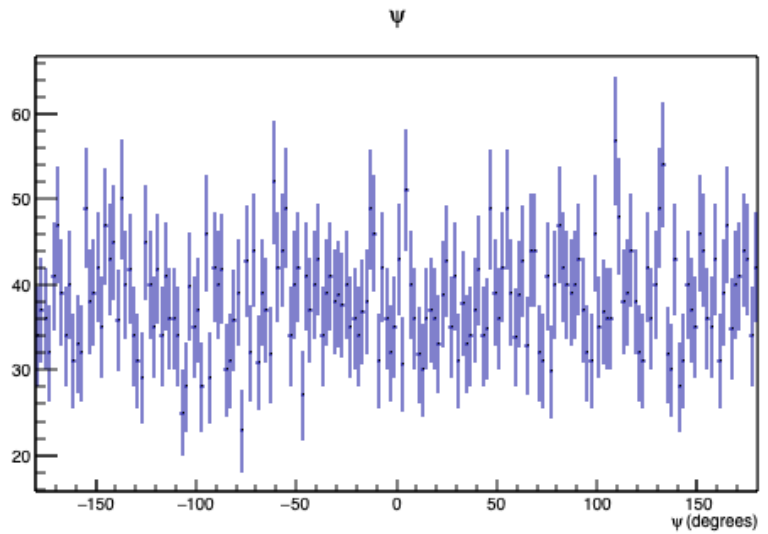


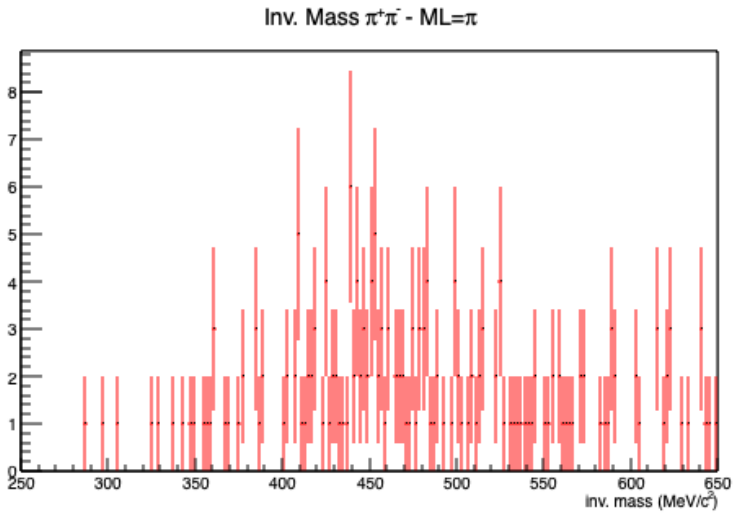


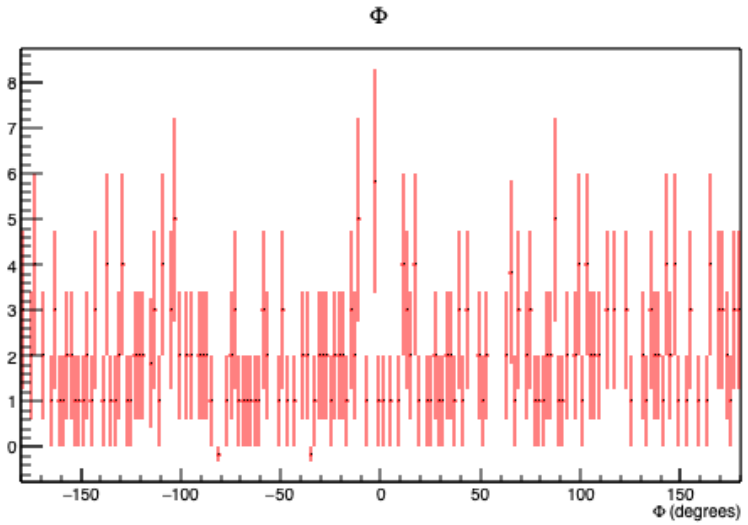
Tensorflow Model in the counting house

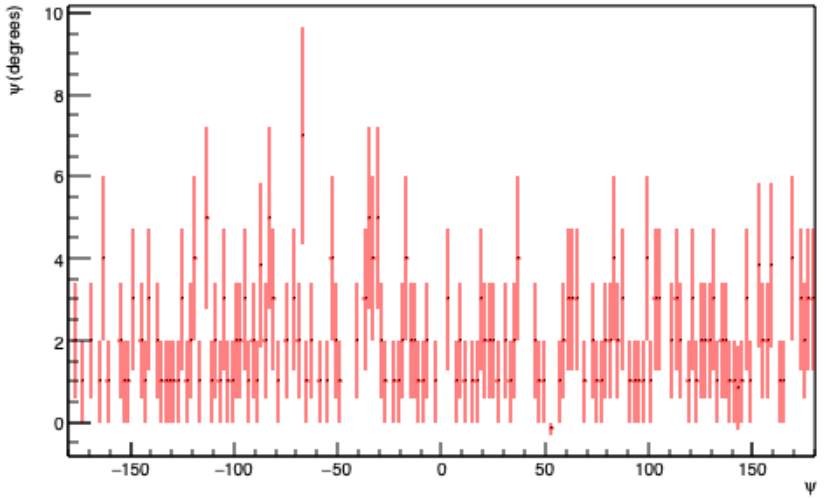






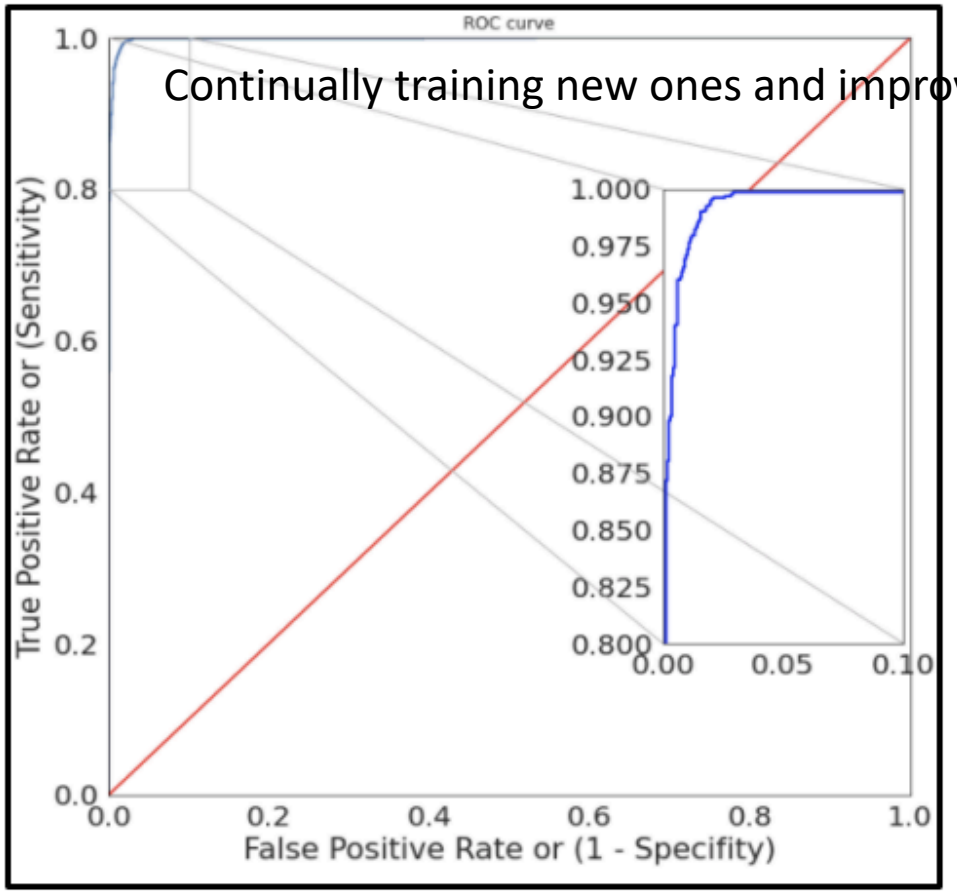






Multivariate Analysis for μ/π

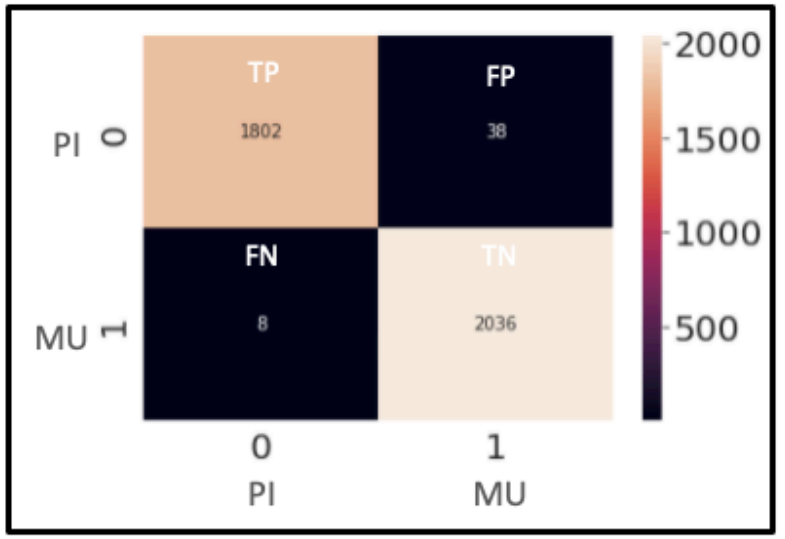
Roc curve



Continually training new ones and improving things

Classification report

	classification_ report			
	precision	recall	f1-score	support
0.0	0.98	0.99	0.99	1887
1.0	0.99	0.98	0.99	1997
accuracy			0.99	3884
macro avg	0.99	0.99	0.99	3884
weighted avg	0.99	0.99	0.99	3884



Confusion_Matrix

David Lawrence, Malachi Schram, Nikhil Kalra

Time estimates for Run Plan

Activity	Duration (PAC Days)	Duration (hours)	Current	Target	Collimator	Radiator	Contact	Comment
Full target (Production)	20	960	27 nA	Pb (0.3 mm)	3.4 mm	JD70-103 or JD70-107		Alternate 0,0,90,90 deg diamond configuration (90%) with amorphous data (10%)
TOF, CDC HV Scans	0.2	10	27 nA	-	3.4 mm	AMO (1x10-4)	Beni, Naomi	Need time to assess data before updating settings. FCAL/BCAL trigger
Empty Target	1.5?	72	27 nA	-	3.4 mm	JD70-103 or JD70-107	Rory, Ilya, Andrew	Run at higher current?
Diamond Alignment	0.5?	24	20 nA	Pb (0.3 mm)	3.4 mm	JD70-103 and JD70-107	Hovanes	
Trigger Commissioning	1?	48	100 nA?	Pb (0.3 mm)	3.4 mm	JD70-103 or JD70-107	Sasha	
Lead Shield Alignment	0.2	10	30-100 nA	Pb (0.3 mm)	3.4 mm	JD70-103 or JD70-107	Ilya	
Beam Energy Calibration	0.1?	5	100 nA	Pb (0.3 mm)	3.4 mm	JD70-103 or JD70-107	Alexandre	Collimator Blocking for 5 min, periodically
Straight Track (Solenoid off)	0.5?	24	100 nA?	Pb (0.3 mm)	3.4 mm	JD70-103 or JD70-107	Simon, Lubomir	Ramping magnet takes about a shift.
PS magnet at GlueX nominal current	0.1?	5	27 nA?	Pb (0.3 mm)	3.4 mm	JD70-103 or JD70-107	Sasha?	
TAC Runs	1.5?	72	<2 nA	-	3.4 mm	AMO (2x10-5)	Sasha	
All Non-production total	5.6	269	-	-	-	-		-

Talk Overview

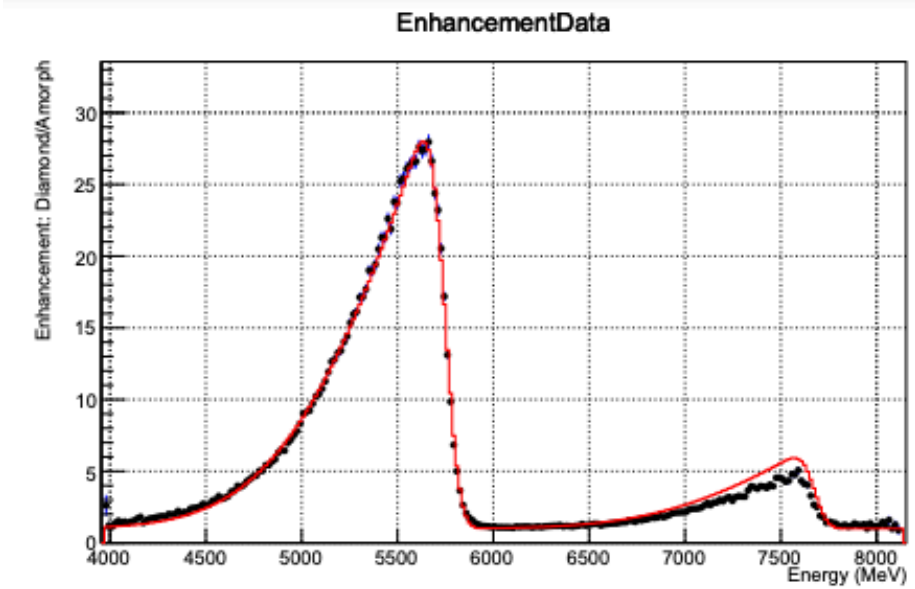
Hardware

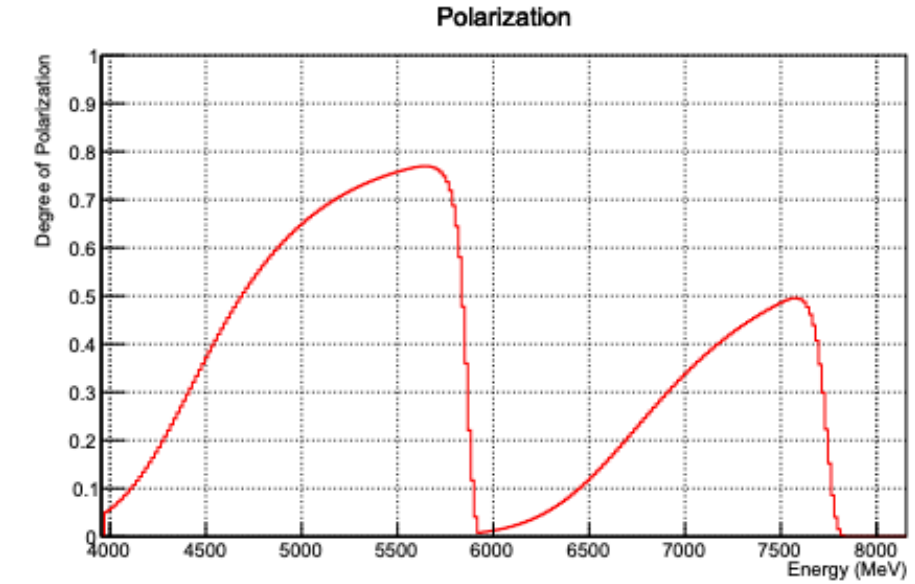
- Muon detector: Forward Multi-Wire Proportional Chambers and CTOF
  - Description of FMWCP and CTOF for Shift Takers
- Tagger Microscope moved to cover 6 GeV coherent peak: GlueX-doc-5420-v1
- Target and modifications to target area to use solid Pb target
- Trigger
  - CPP will use a trigger based on the TOF (new)
  - NPP will use the FCAL/BCAL trigger with a high threshold
- CDC AI

Software

- FMWPC Library
  - DFMPWCHit_Factory, DFMPWCMatchedTrack_Factory, DCPPEpEm_Factory
  - Event viewer
- Monitoring Plots for CPP and NPP

Commissioning and Run plan


EnhancementData
Enhancement: Diamond/Amorph
30
25
20
15
10
5
0
4000
4500
5000
5500
6000
6500
7000
7500
8000
Energy (MeV)


Polarization
Degree of Polarization
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
4000
4500
5000
5500
6000
6500
7000
7500
8000
Energy (MeV)

Draft Commissioning Steps

1. Setup photon beam operation at 50 nA.
2. Check microscope and hodoscope operation in new configuration
3. Align diamond to 6 GeV coherent edge
4. Check rates in microscope in new position
5. Check radiation and backgrounds rates in Hall D with Pb target
   - Check rates and beam stability at 30 nA
   - Check currents and hit distributions in the MWPCs
6. Complete a HV scan for the TOF and CDC. Adjust voltages accordingly, especially those of the TOF in advance of trigger studies.
7. Take data for adjustment of the FCAL PMT gains.
8. Optional: Check rates for two collimator configurations (5 and 3.4 mm) ? Use profiler to stabilize the beam during test.
9. Compare empty vs full target rates
10. Adjustable Pb absorber (upstream of muon detector)
    - Proposal (Ilya)
11. Commission trigger
    - Charged Trigger (TOF)
    - Neutral Trigger (FCAL/BCAL)
    - Calibration triggers (CTOF, random, PS)
    - Compare empty/full trigger rates
12. PS Magnet
    - Set nominal value for CPP = 2/3 * nominal GlueX. Take some data at the nominal GlueX setting for reference.
13. Beam energy calibration
    - May need to repeat periodically