FERMILAB TEST BEAM RESULTS

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GOALS

- Use the Baby BCAL as a proxy of the BIC SciFi
  - Matrix design is mechanically identical
  - Kuraray double-clad fibers
  - Older generation SiPMs

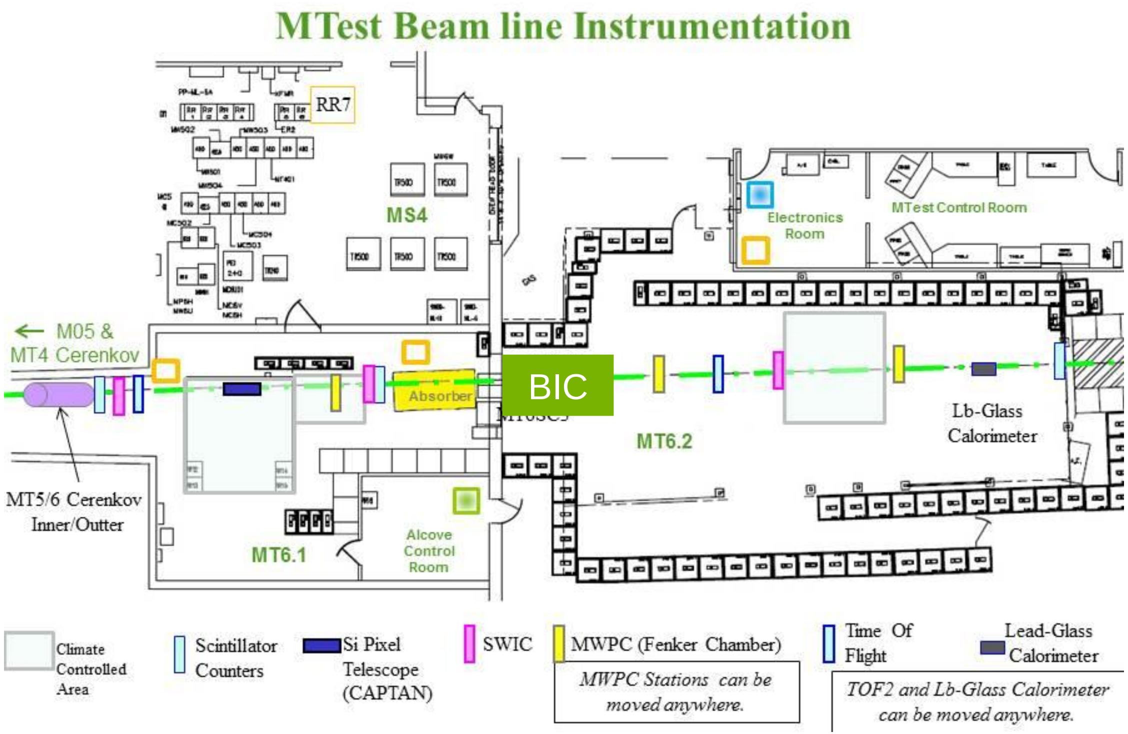
- Verify simulated performance of BIC
  - Particularly hadronic showers, which are often not well simulated

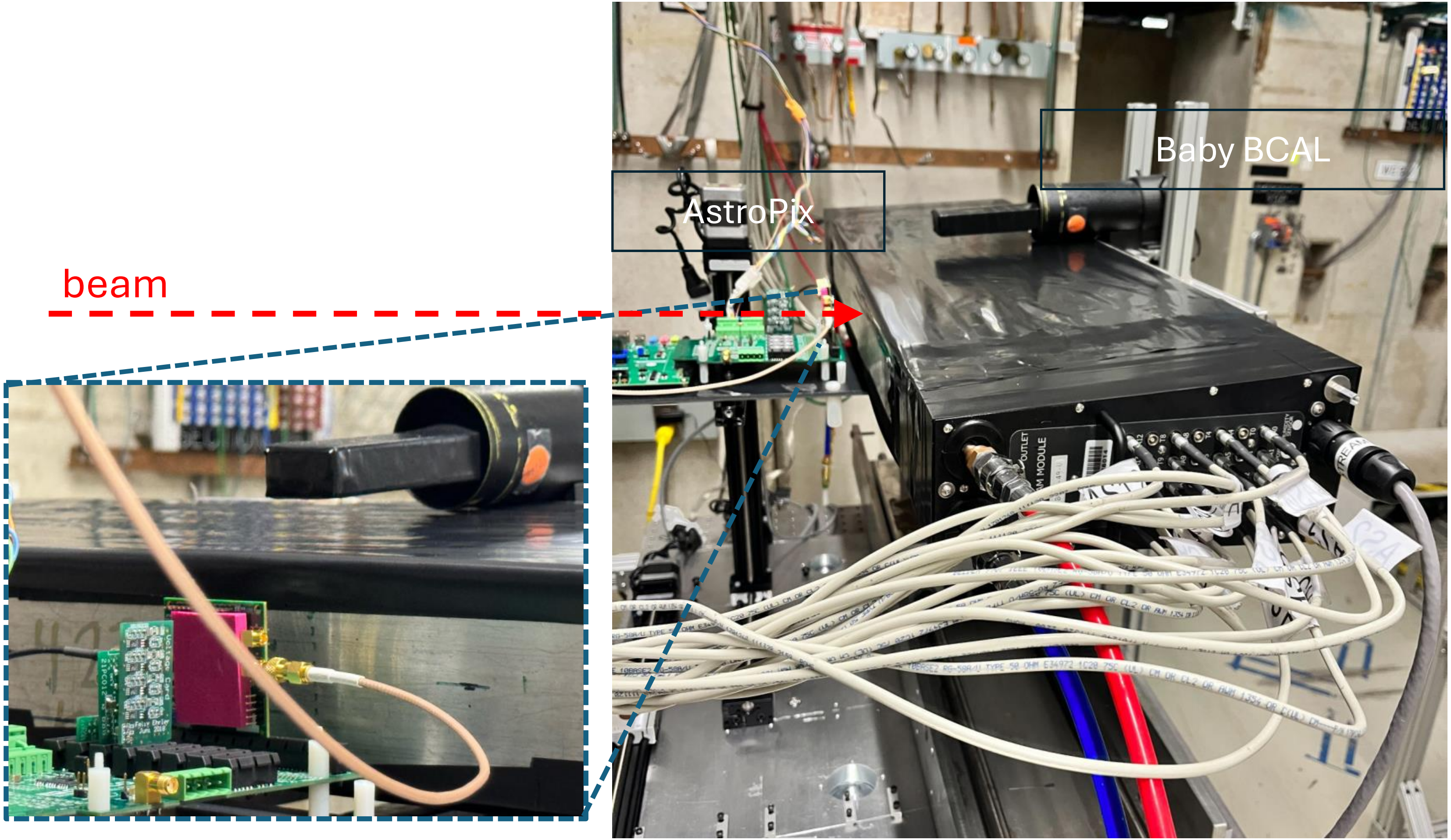
- Extract energy resolution of Baby BCAL

- Measure electron/pion separation capabilities

FERMILAB TEST BEAM FACILITY

- Nominal beam is 120 GeV protons from main injector
- Secondary hadron/electron beam from sending 120 GeV protons on a 30 cm thick aluminum target
- Scintillators provided by FTBF along beamline for trigger
- Two Cherenkovs for PID

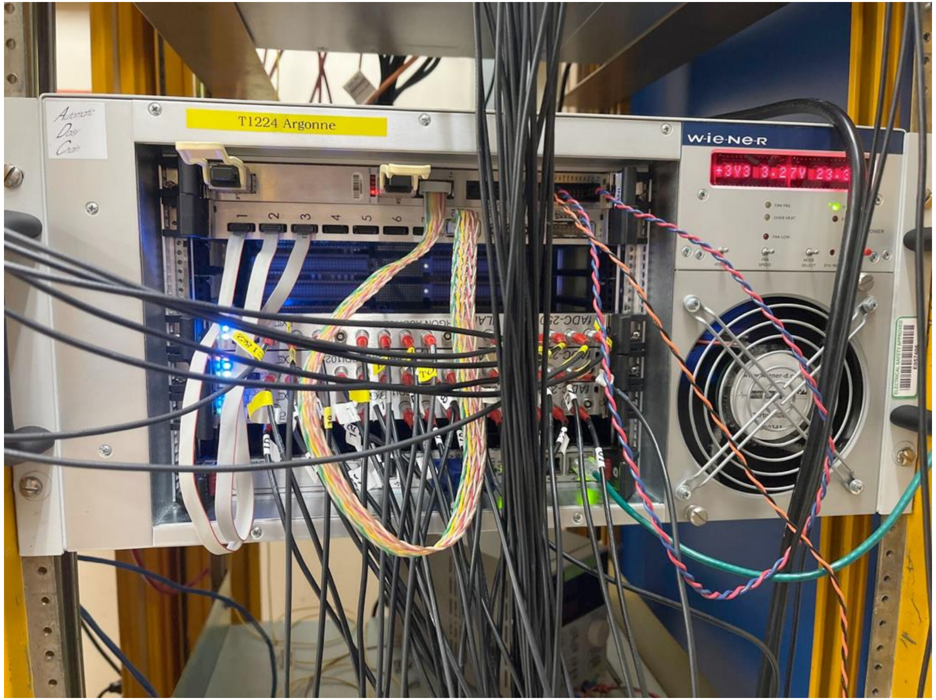



beam
AstroPix
Baby BCAL

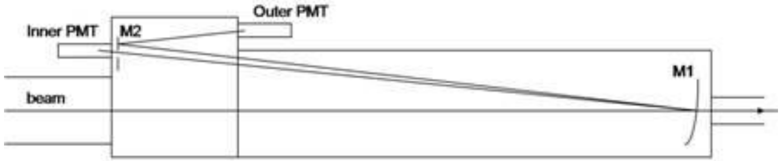
DAQ

- Used 3x 16 channel JLab 250 MHz fADCs in full waveform readout mode

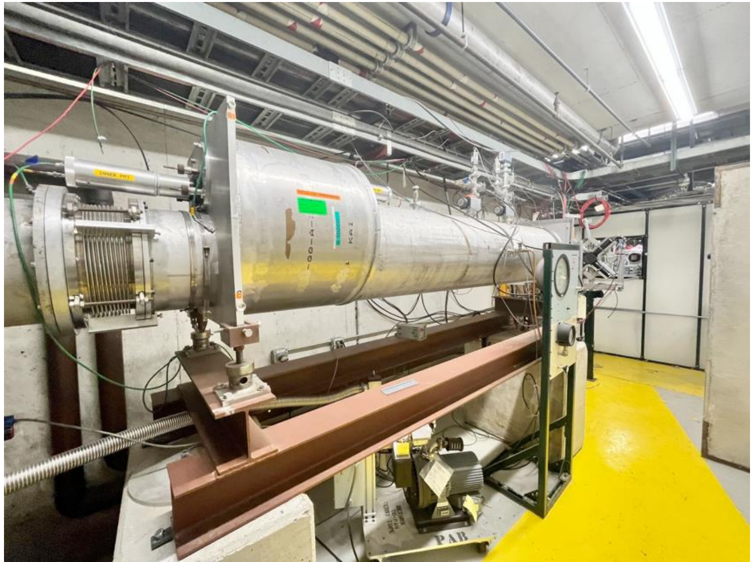
- Sent analog signals from the “north” and “south” sets of 16 baby BCal channels into two blades of fADC, remaining blade used for FTBF detectors, cosmic ray paddles, AstroPix analog signal

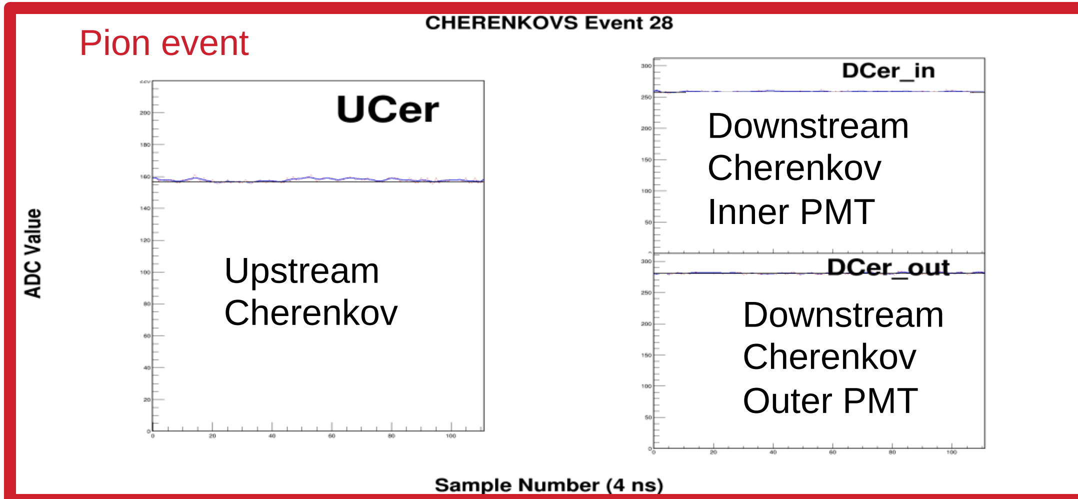


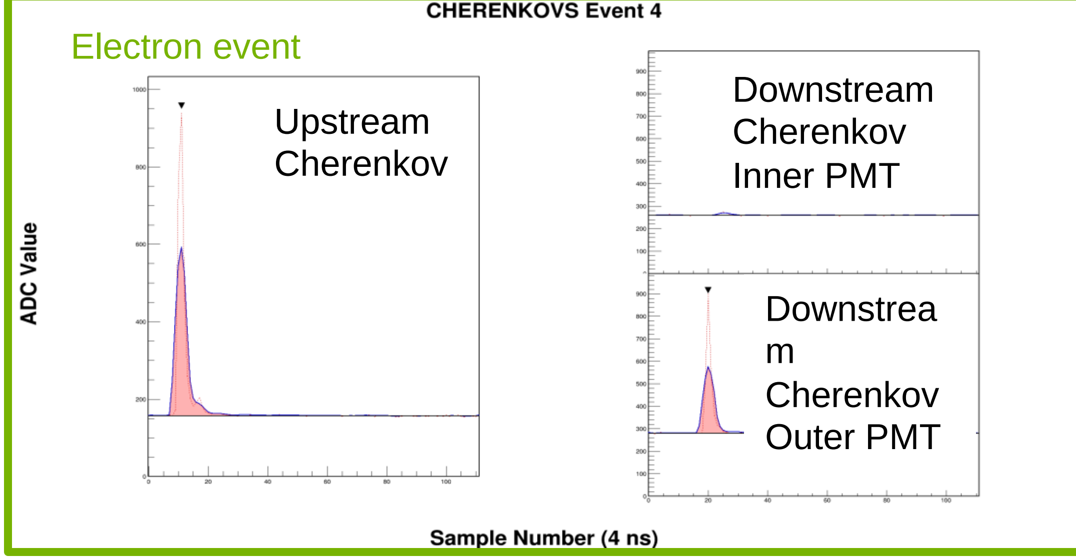
CHERENKOV DETECTORS



Downstream Cherenkov







DATASETS

- Due to heat issues at FNAL, only ran for **~30%** of our allotted week
- DAQ was limited to ~7 kHz due to full waveform readout
- **120 GeV protons**
  - Mostly parasitic overnight
  - Large dataset, few million events
- **10 GeV e/pi**
  - Also large dataset, but mostly taken with FADC jumpers set in the wrong positions, so gain is 2x higher than it should be
- **10 GeV mu/pi**
  - Taken with a lead sheet in the beam to absorb electrons
  - Provides a large MIP calibration dataset
- **Energy scan e/pi**
  - 4 GeV (1.4M), 6 GeV (440K), and 8 GeV (320K)
  - Took a larger 4 GeV because pions are rarer at low energies

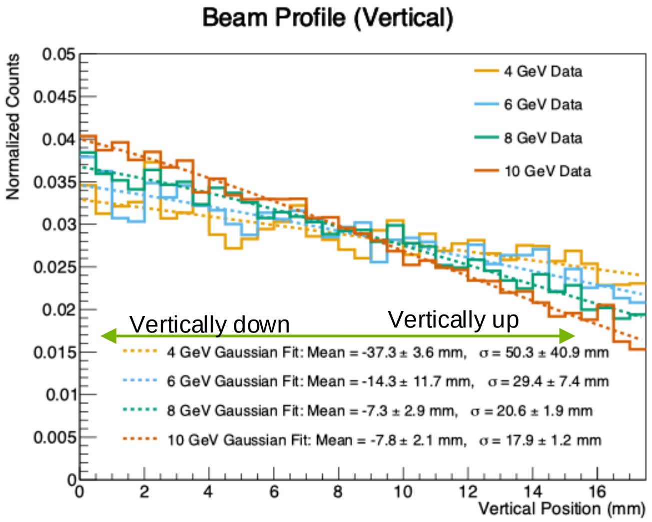
BEAM ΔP

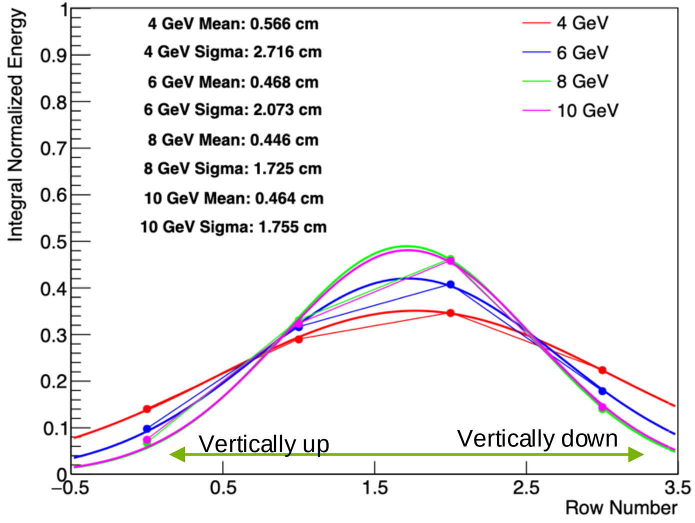
- An important factor in understanding the energy response is the beam momentum spread
- This term enters as a constant term on the energy resolution
- Quoted beam spread is 2.7% at low energies, improving to 2% at 120 GeV
  - However, statement from Joe at FTBF: ”*Every calo group is telling me it looks like the momentum spread is higher than the website indicates it should be.”* – does this tell us something about the beam or the “optimism” of calorimeter experts?
- This number depends on beam tune, which can vary from run to run
- We see the 4 GeV beam is physically wider, which suggests it also has a larger momentum spread

Energy	Mode[1]	Protons	Pions[2]	Highest Intensity[3]	Muons	Kaons	electrons	Spot Size[4]	Δp
10 GeV	LEπ +/-								
8 GeV	LEπ +/-		55%	750,000	98%			12mm	2.3%
6 GeV	LEπ +								
4 GeV	LEπ +/-		31%	400,000	74%			13mm	2.7%
3 GeV	LEπ +/-								2.7%
2 GeV	LEπ +/-		<30%	450,000				13mm	2.7%
1 GeV	LEπ +/-		<30%	69,000					2.7%

BEAM PROFILE

- For calo analysis, want to know the profile of the beam in the vertical direction
  - Determines amount of leakage
- Not much info from FTBF detectors
  - MWPCs were out of gas
  - SWICs showed poor performance for secondary beams
- Have AstroPix & Calo information
  - Thanks to Bobae and Manoj for taking nice AstroPix data for us ☺
- Both detectors agree beam widens at lower energy, both agree the beam center is vertically below the center of the calorimeter





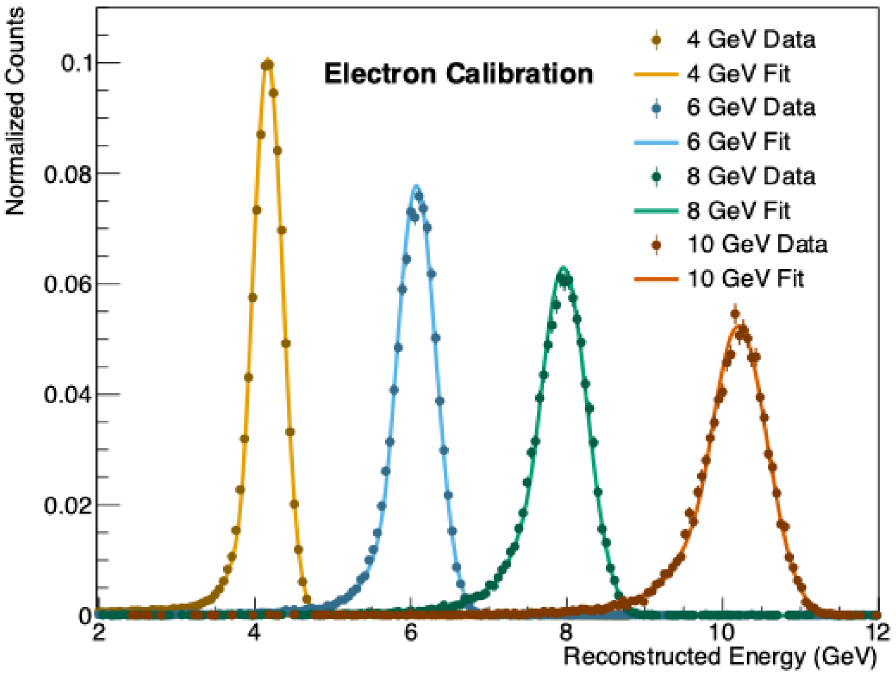
CALIBRATION

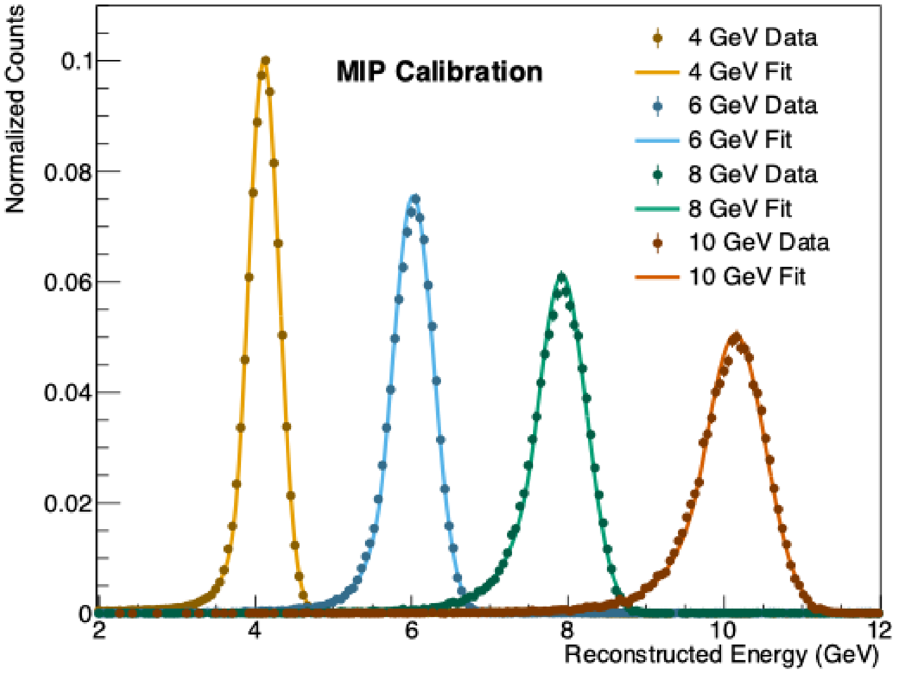
- Employ two complementary calibration techniques

- **MIP technique** – use MIP peak to align all channels
  — Pro: Each channel has an independent calibration constant, one single solution
  — Con: MIP sampling fraction is different from electrons! Needs an additional sampling fraction correction.

- **Electron technique** – minimize difference of sum of all channels with respect to a known input electron energy
  — Pro: Better energy resolution achievable
  — Con: No unique solution, 16 (or 32) unknowns and one known, different combinations of calibration constants can give the same result

ELECTRON ENERGY

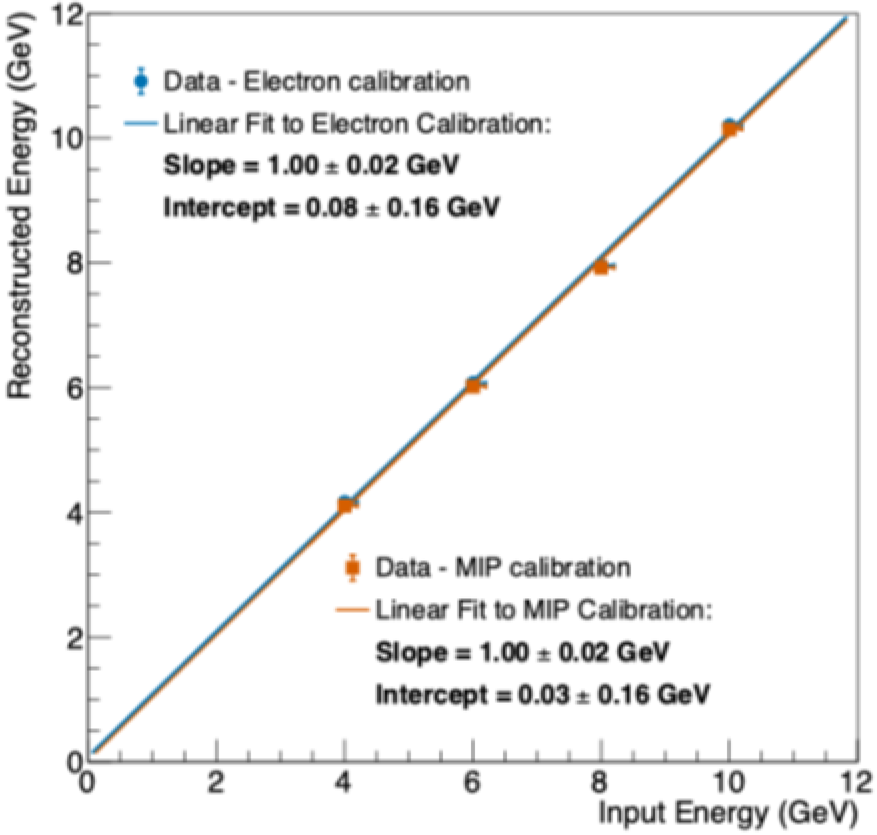




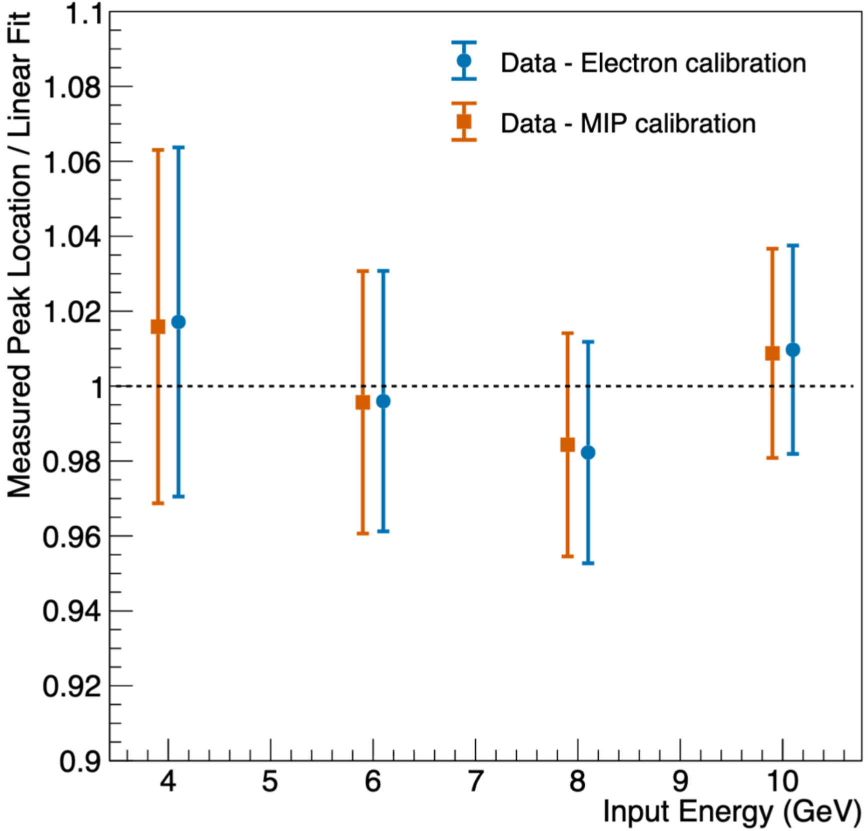
MIP & Electron give very similar results!

Requested Beam Energy (GeV)	Peak $_{MIP}$ (GeV)	σ_{MIP} (GeV)	Peak $_{Ele.}$ (GeV)	$\sigma_{Ele.}$ (GeV)
4.0	4.11	0.20	4.16	0.19
6.0	6.02	0.26	6.07	0.25
8.0	7.92	0.31	7.96	0.30
10.0	10.14	0.38	10.21	0.35

LINEARITY



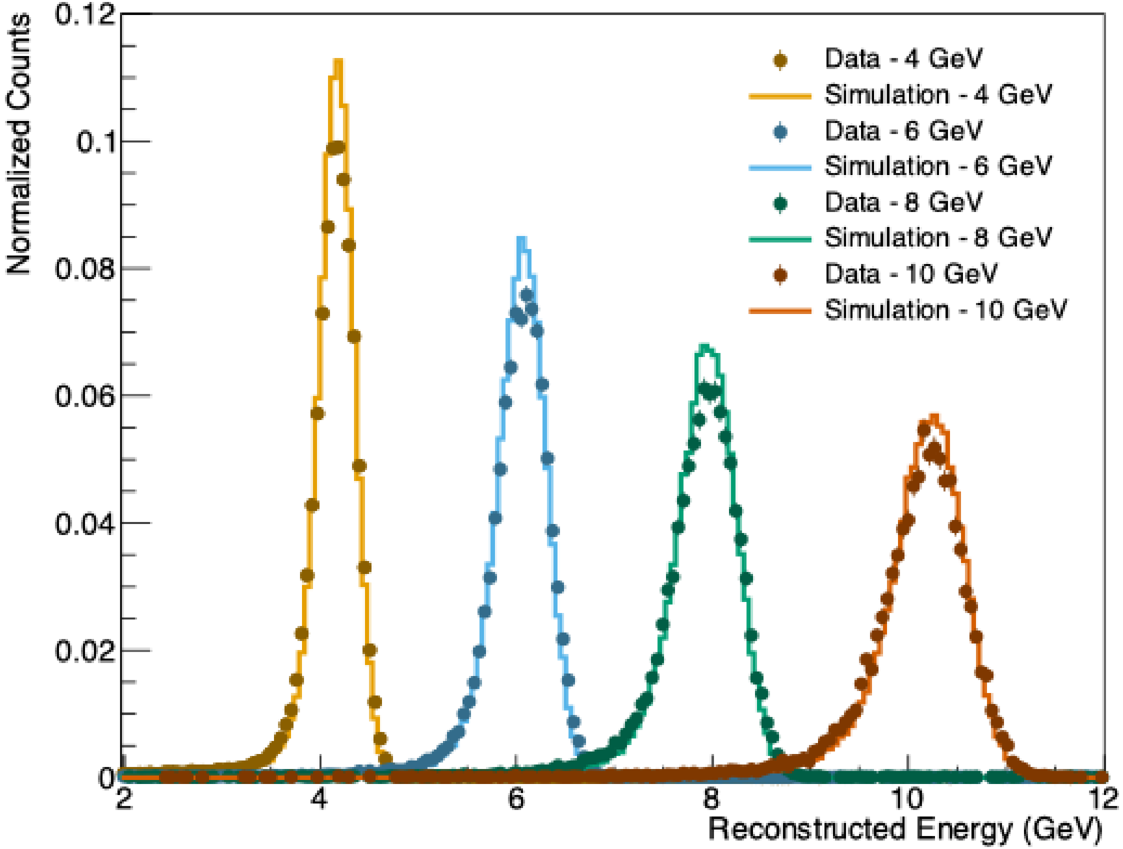
Data - Electron calibration
Linear Fit to Electron Calibration:
Slope = 1.00 ± 0.02 GeV
Intercept = 0.08 ± 0.16 GeV
Data - MIP calibration
Linear Fit to MIP Calibration:
Slope = 1.00 ± 0.02 GeV
Intercept = 0.03 ± 0.16 GeV
Reconstructed Energy (GeV)
Input Energy (GeV)

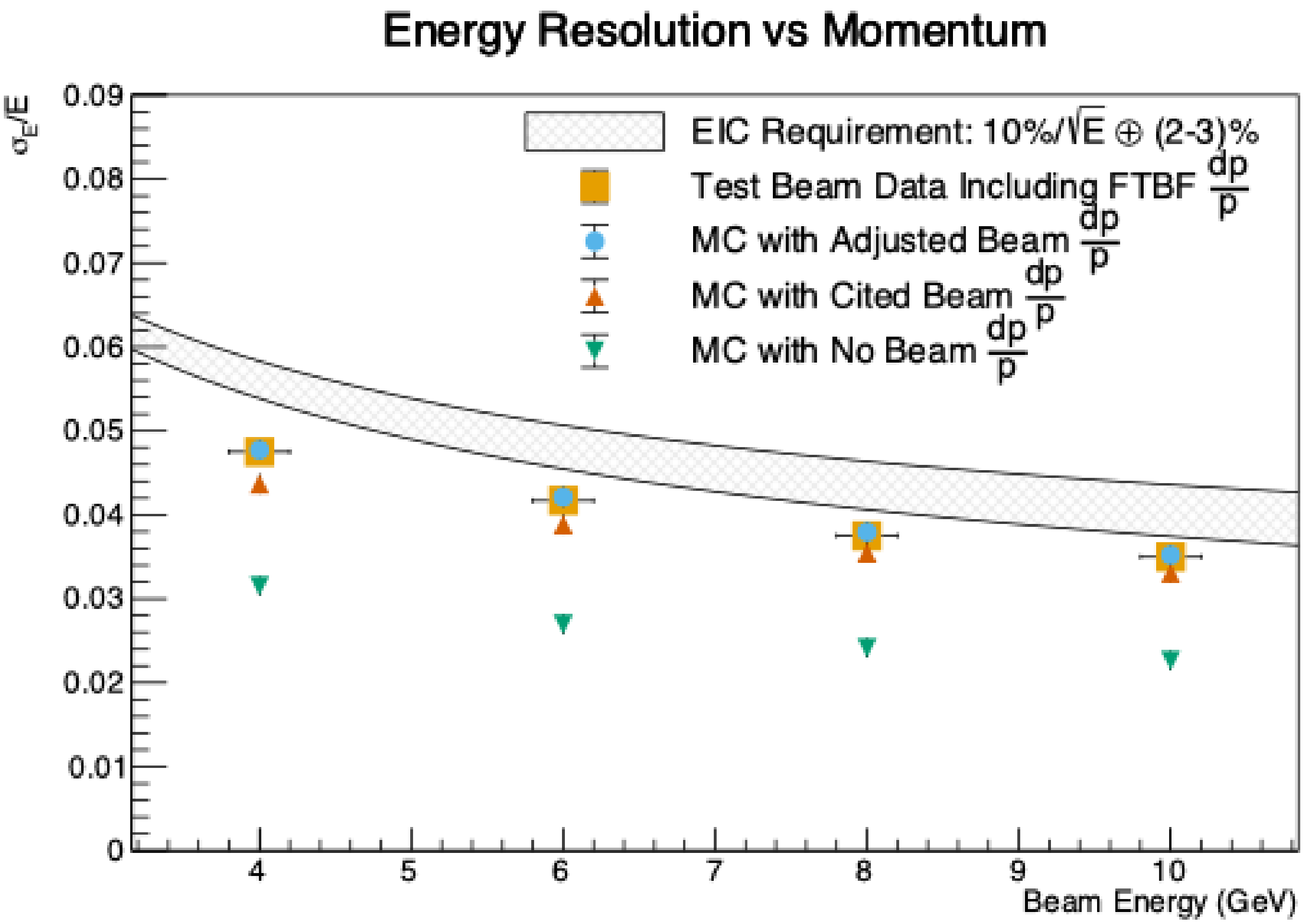


Data - Electron calibration
Data - MIP calibration
Measured Peak Location / Linear Fit
Input Energy (GeV)

COMPARISON TO SIMULATION

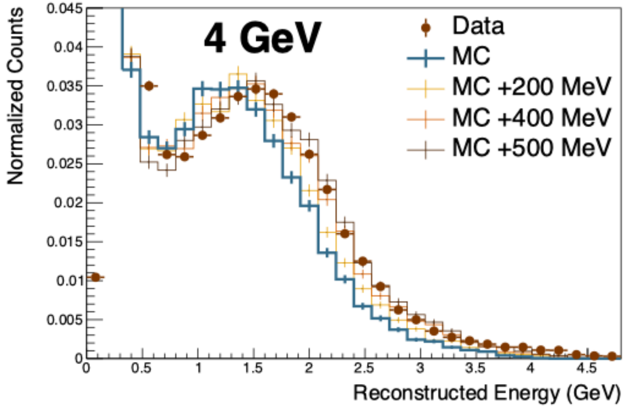
- Simulation using FTBF cited beam momentum smearing
  - Peaks are narrower than data
  - Shapes of distributions are similar
  - Tail in data is well-reproduced by simulation

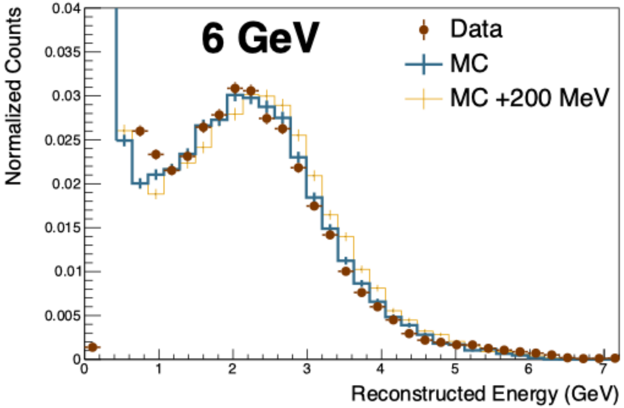


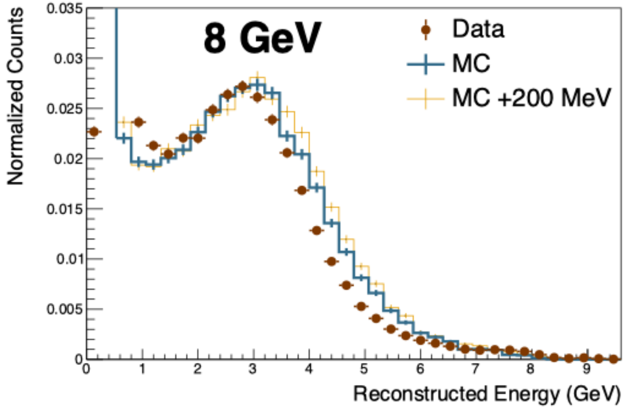

Energy Resolution vs Momentum
σE/E
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
4
5
6
7
8
9
10
Beam Energy (GeV)
EIC Requirement: 10%/√E ⊕ (2-3)%
Test Beam Data Including FTBF dp/p
MC with Adjusted Beam dp/p
MC with Cited Beam dp/p
MC with No Beam dp/p

PION DATA

- Compare data to simulation
  - Observed offset in beam energy, attempt to include in simulation
- Data and simulation agree for 6 GeV pions
  - 4 GeV pions in data deposit more energy than simulation, 8 GeV pions in data deposit less than simulation

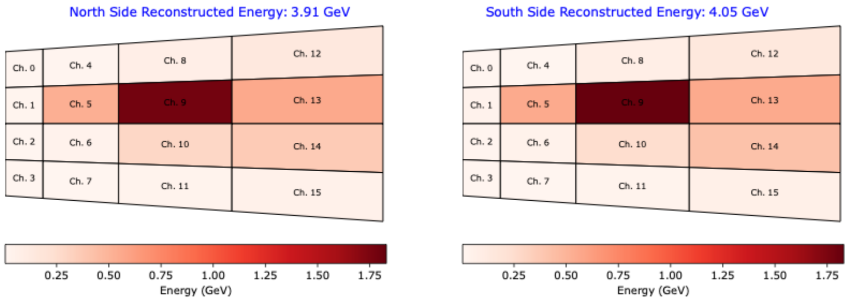


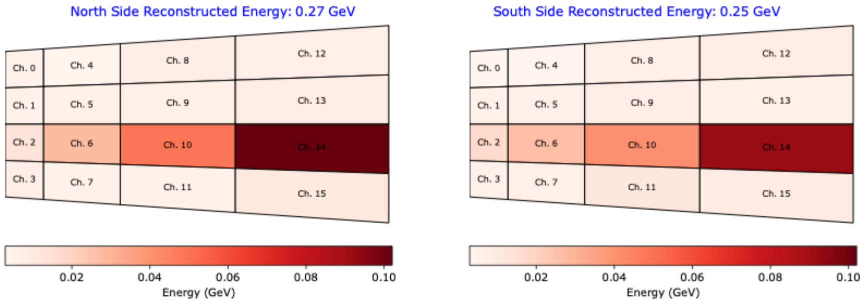


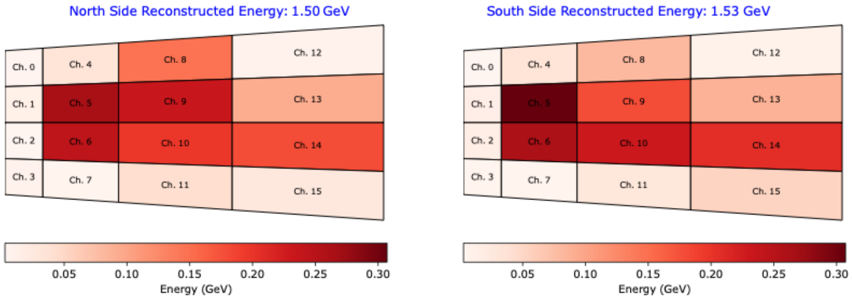


e/π SEPARATION – GUESSING GAME

One of these events is an electron
One is a MIP
One is a showering pion

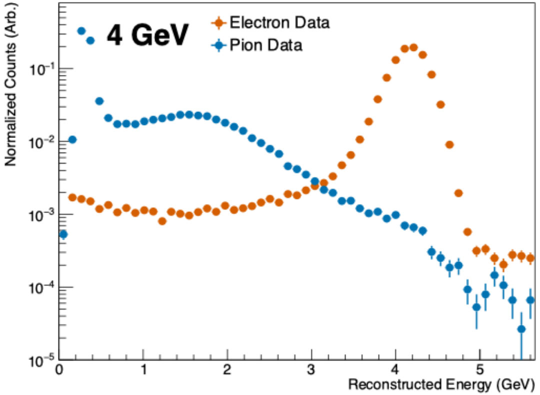


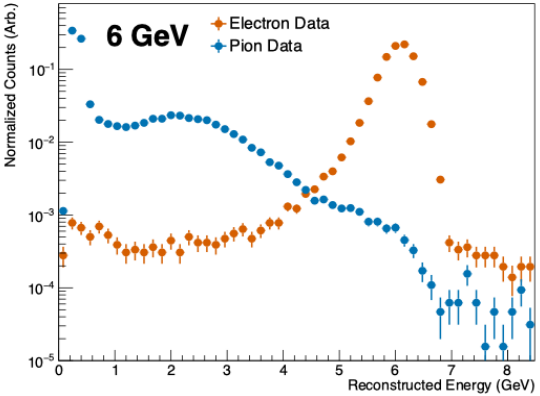


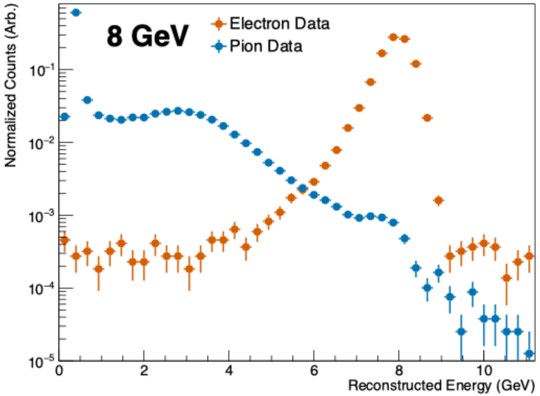


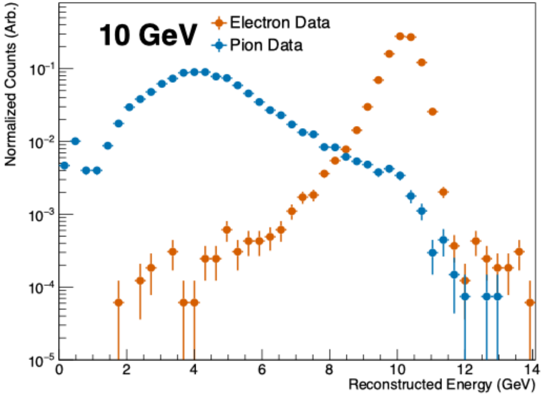
e/π SEPARATION

- Measured energy distributions of events with Cherenkovs firing (electrons, orange) and Cherenkovs not firing (pions, blue)
- Electrons and pions well separated, but both have tails
  - Electron tail – showers upstream, horizontal leakage
  - Pion tail – electron misID, pileup



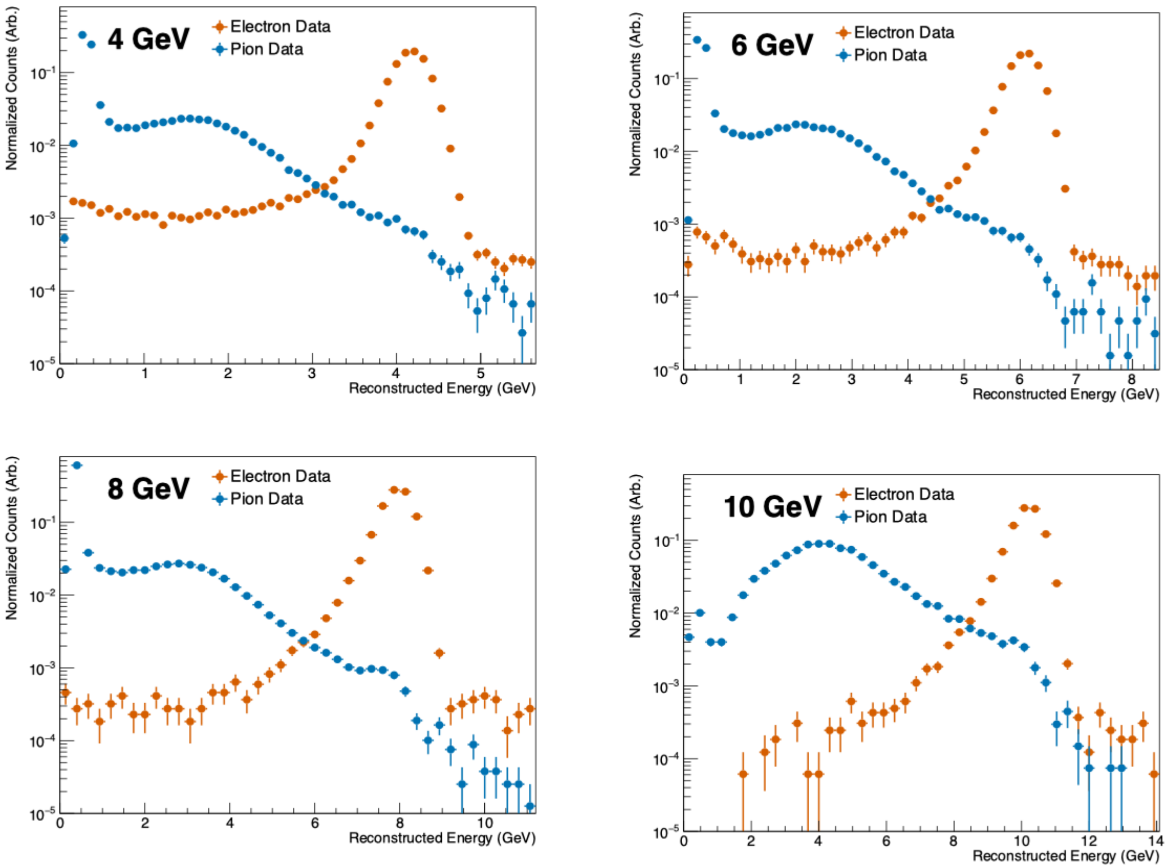






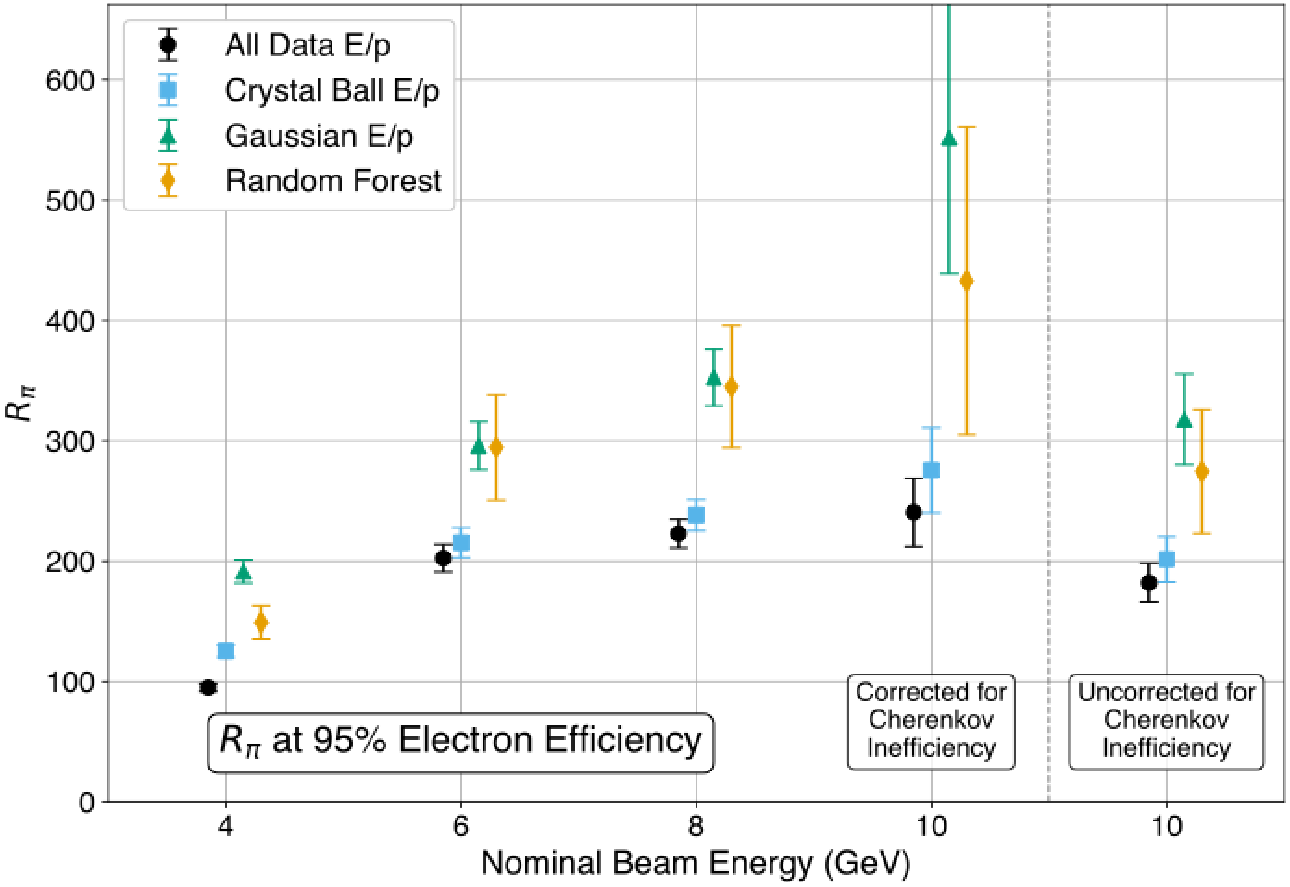
e/π SEPARATION

- The tail of the electron distribution is an artifact of the measurement setup
  - Predict the true performance by fitting crystal ball or gaussian to the electron peak



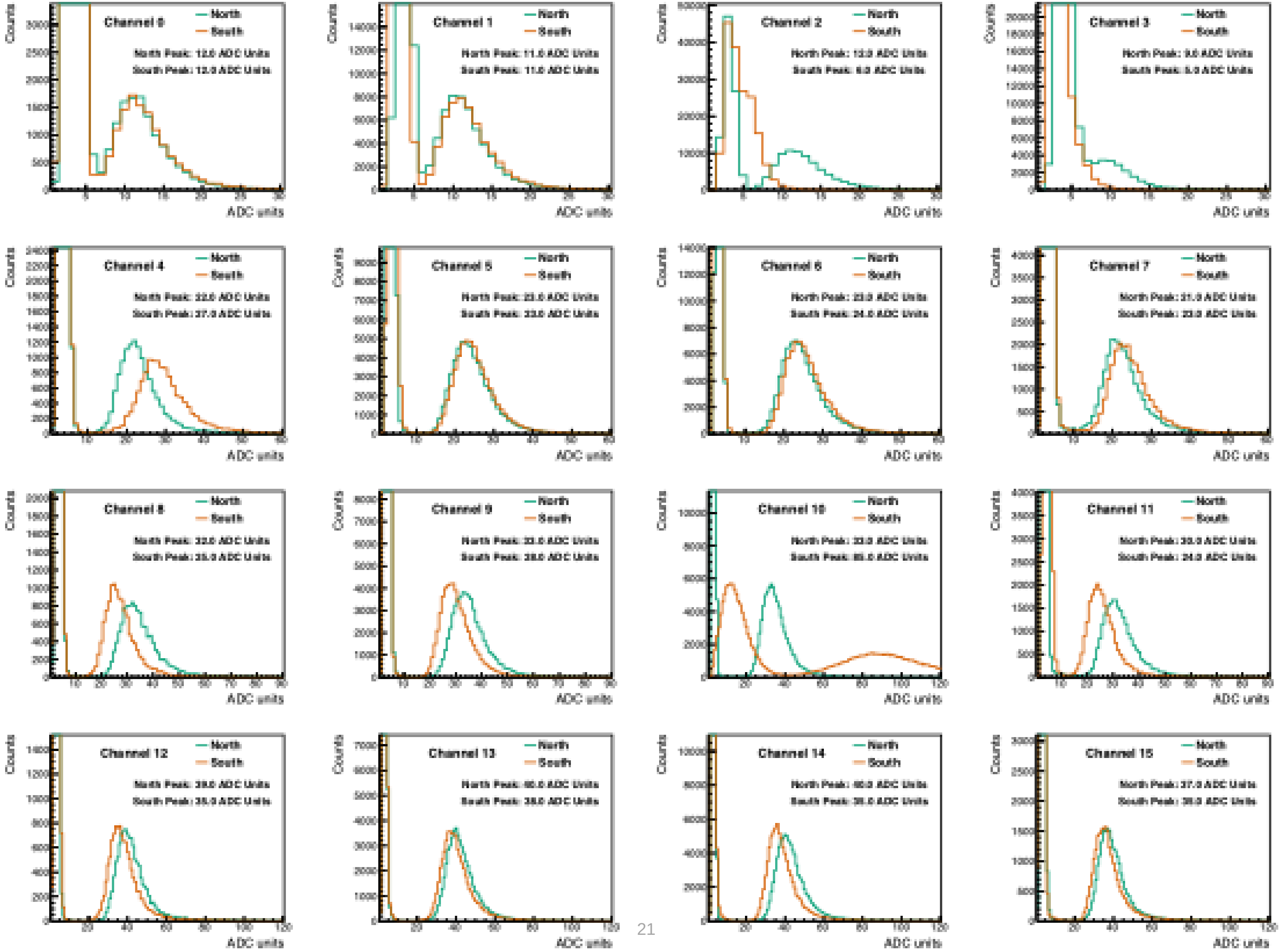
e/π SEPARATION

All things considered, separating electrons and pions is pretty easy in this detector! (even with beam momentum spread & some leakage)



CONCLUSION

- Detector is good!
  - Impressive performance despite complications from beam uncertainty
  - Honestly didn't expect to be able to get all of these results from such a short beam time
- Thanks to everyone who made our test beam campaign successful!


Channel 0
Channel 1
Channel 2
Channel 3
Channel 4
Channel 5
Channel 6
Channel 7
Channel 8
Channel 9
Channel 10
Channel 11
Channel 12
Channel 13
Channel 14
Channel 15
North
South
Counts
ADC units