CLAS12 Detection Efficiency (Task Force)

CLAS collaboration meeting

Nick Markov for the CLAS Efficiency Task Force

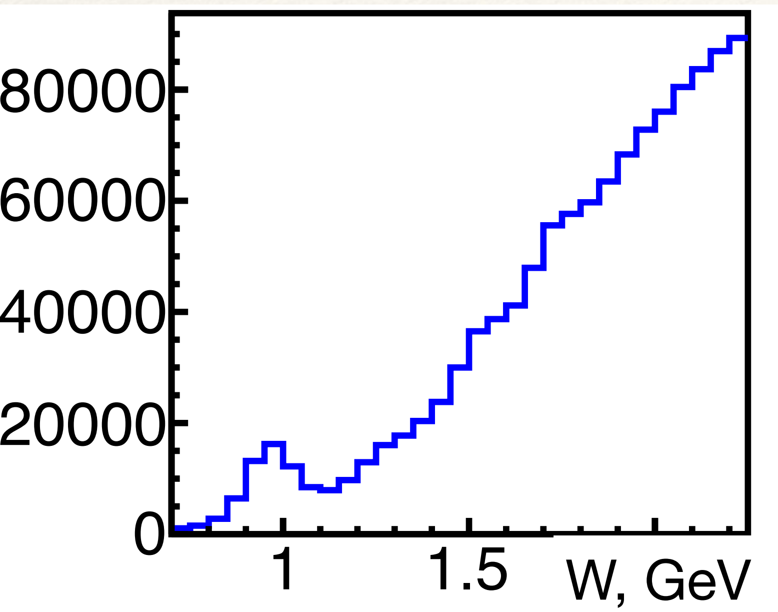
5 March 2021

Outline

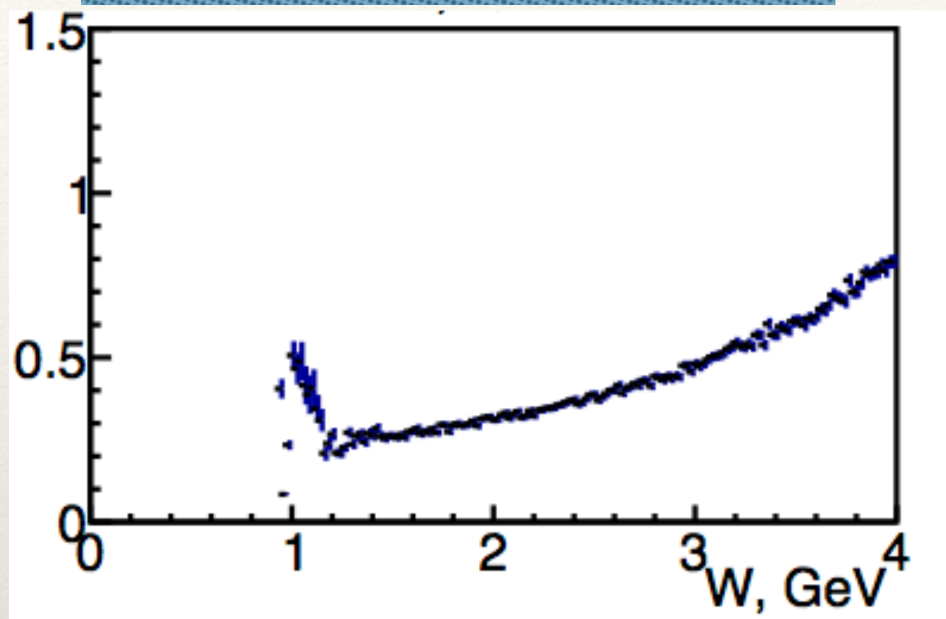
- Introduction;
- Efficiency estimation;
- Efficiency implementation;
- Technical details;
- Future plans.

Cross section, Acceptance Corrections and Efficiency

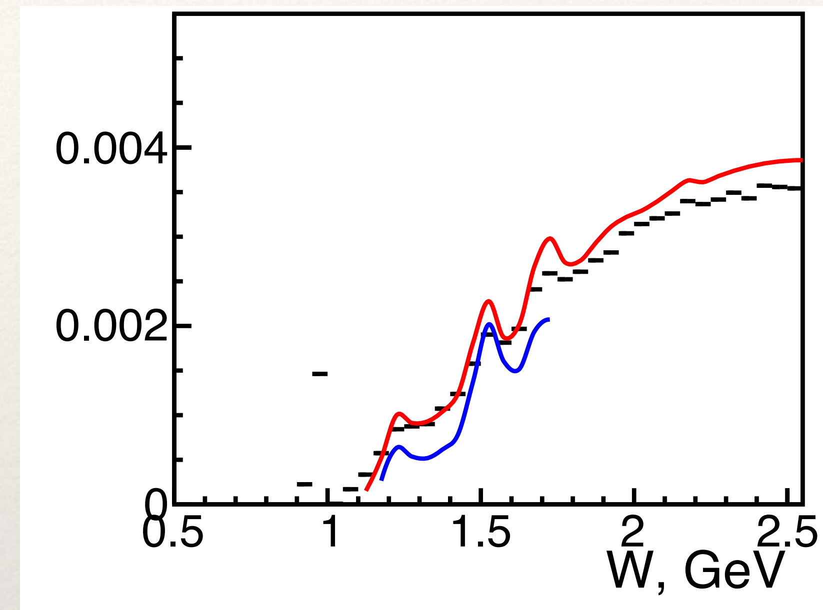
Data



Acceptance Correction from simulation



Cross section



Shown for the inclusive electron scattering):

$$\frac{d\sigma}{dWdQ^2} = N_{ev}\frac{1}{L}\frac{1}{C}\frac{1}{\boxed{Acc}}$$

Luminosity

Rad Corrections
BC corrections

$$\boxed{Acc} = Geom \cdot Eff$$

Our focus

Some questions

Detector efficiency

- Using the default GEMC acceptance we imply that efficiency and geometry are the same in data and MC;
- We either have to prove it to use acceptance from the MC or adjust MC to the data or add a correction;
- **First step is to understand detector efficiency.**

Team

Trigger (Valery Kubarovsky, Rafayel Paremuzyan)

FD

Electrons

- **DC** (Mac Mestayer , Veronique Ziegler, Rafayel Paremuzyan)
- **EC/PCAL** (Cole Smith)
- **FTOF** (Daniel, Raffaella DeVita, Matthew Nicol, Stepan Stepanyan)
- **HTCC** (Youri Sharabian, Nick Markov)

Charged Hadrons

- **DC** (Mac Mestayer, Veronique Ziegler, Rafayel Paremuzyan)
- **FTOF** (Daniel Carman, Stepan Stepanyan)
- **LTCC** (Maurizio Ungaro)
- **RICH** (Valery Kubarovsky)

Neutrals (photons and neutrons)

- **EC/PCAL** (Cole Smith)

FT

Electron

- **FTC** (Raffaella DeVita)
- **TFH** (Raffaella DeVita)

Photons

- **FTC** (Raffaella DeVita)

CD

Charged Hadrons

- **CTOF** (Daniel Carman, Raffaella DeVita, Matthew Nicol)
- **CVT** (Yuri Gotra, Veronique Ziegler, Rafayel Paremuzyan)

Neutrals (photons and neutrons)

- **CND** (Silvia Niccolai)

BAND

Neutrons

- **BAND** (Efrain Segarra)

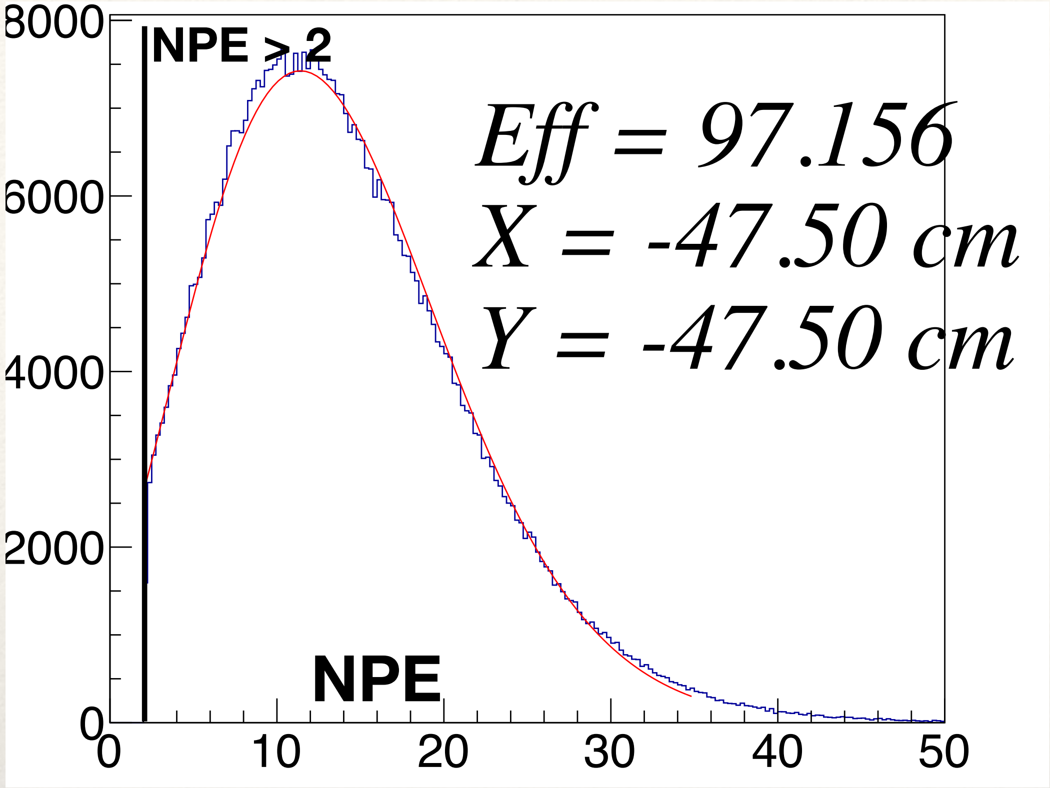
Software Nathan Baltzell, Veronique Ziegler
Simulation Maurizio Ungaro
Validation Harut Avagyan
Background merging Stepan Stepanyan

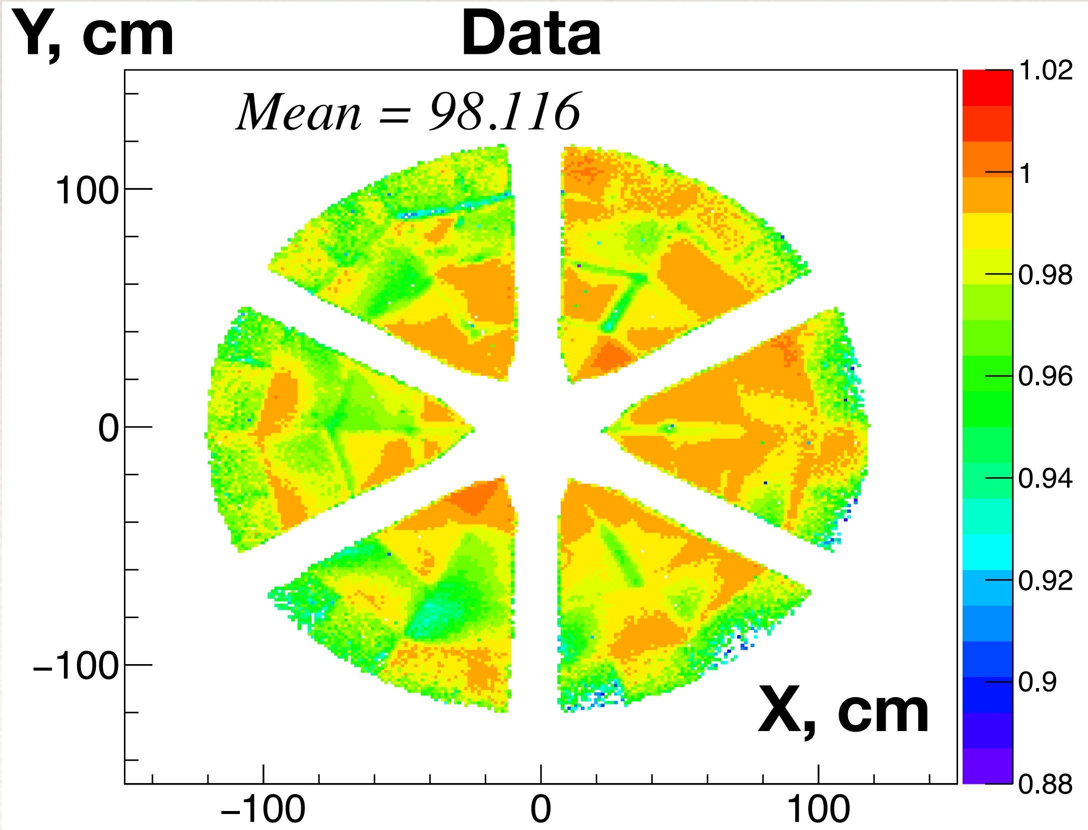
Understanding efficiency

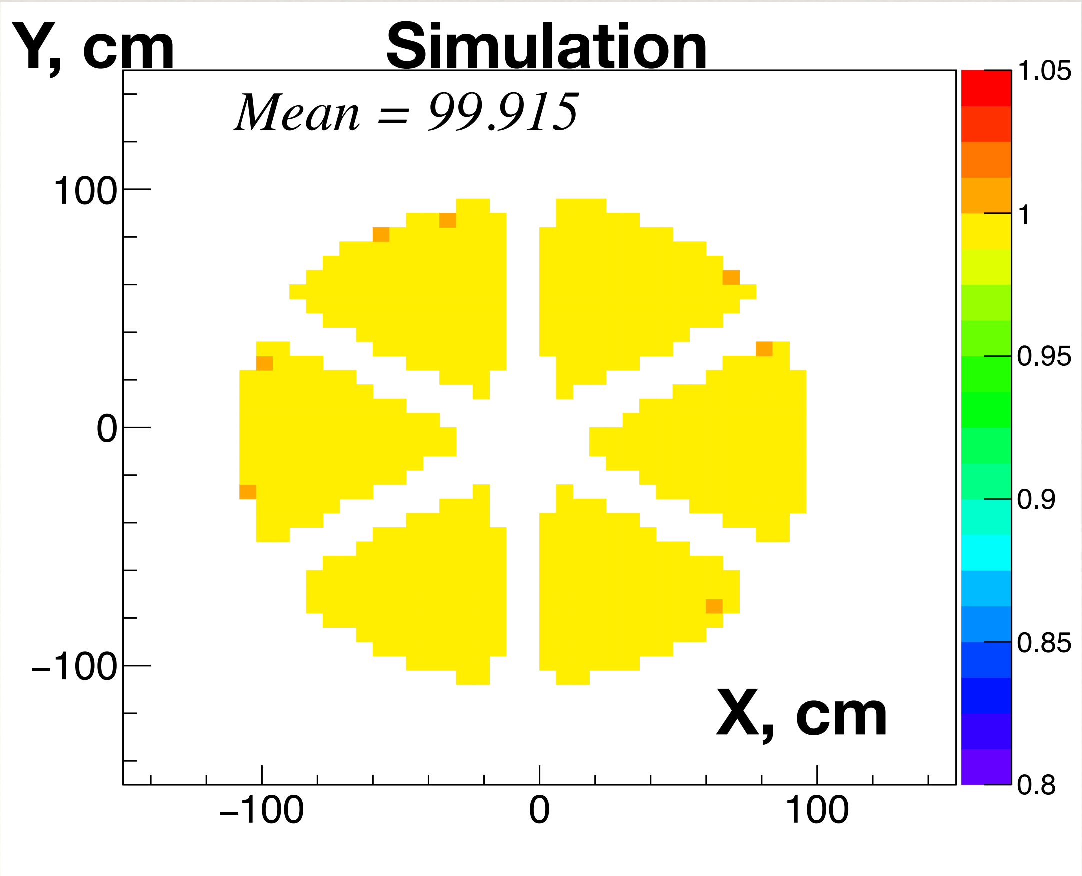
- We need to have an understanding of the detector efficiency for each subsystem;
- Efficiency estimation is not a one time effort;
- Each subsystem should have a software package dedicated to it;
- We should be able to compare data and simulation and adjust simulation or provide correction if needed;
- Efficiency can and most likely will be time-dependent (detector performance can change, GEMC implementation of the detector can change, reconstruction software can change, etc);
- Efficiency estimation should be used during passN preparation;
- Should be used to define and improve detector fiducialization.

HTCC Efficiency

- Map the HTCC response in bins over X and Y (X and Y are coordinates of the intersection of the track with the mirror surface);
- For each X, Y bin (2.5cmx2.5cm) get the spectrum of the NPE;
- Fit individual spectrum in X, Y bin with Poisson;
- Integrate signal under Possion [0, 50] (full signal) and [2, 50] (signal after HTCC electron ID cut);
- Ratio of them is what we lost with the NPE > 2 cut;
- Create the "efficiency map", i.e. calculate the efficiency in each X, Y bin;
- Do all the same steps for the simulation;
- The final, overall efficiency correction to go to cross section calculation will be ratio of the simulation and data efficiency.

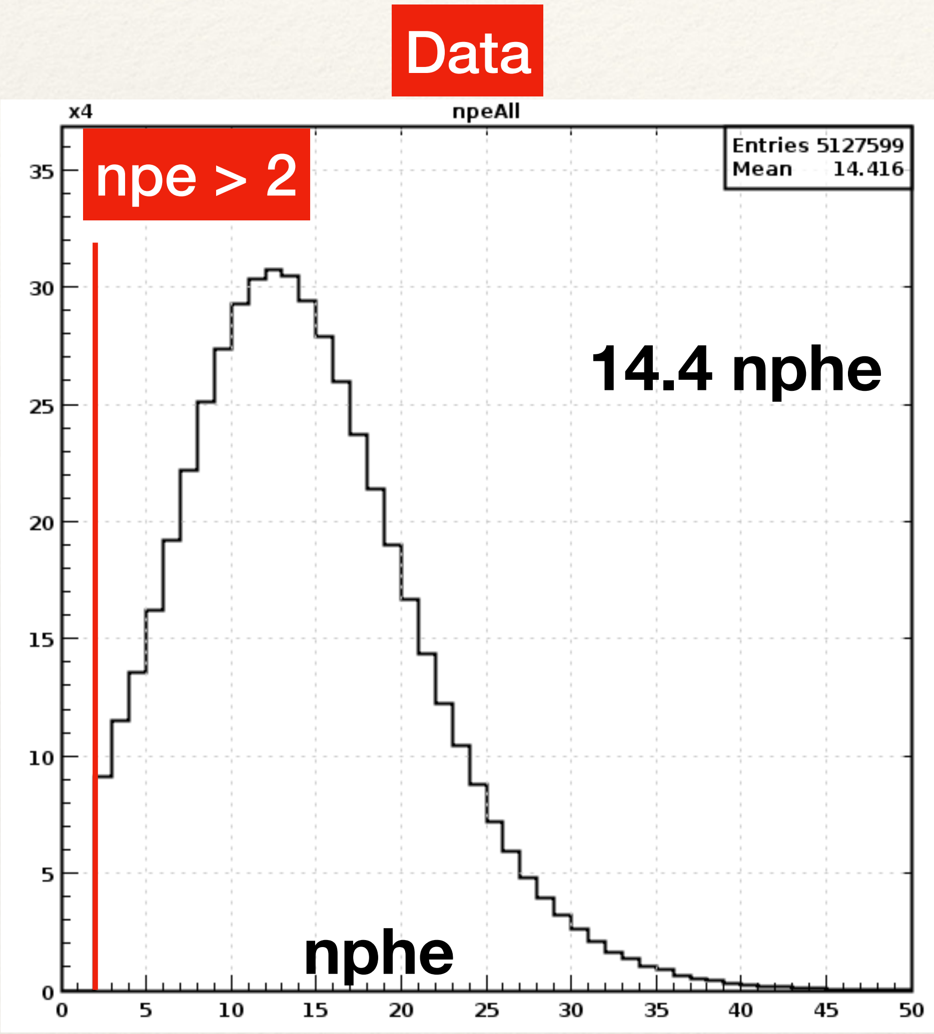






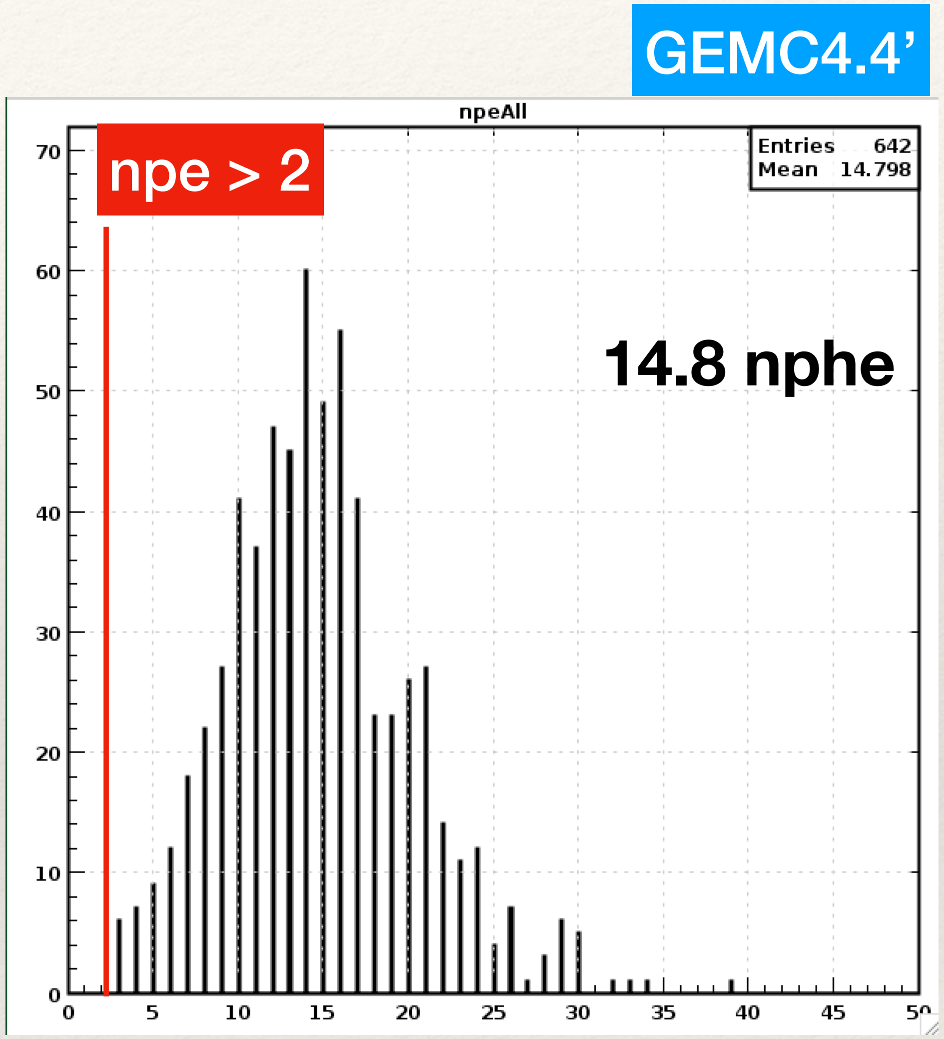
HTCC Efficiency

GEMC Adjustments



nphe

Simulation response scaling and smearing.



nphe

Adjusts width and position of HTCC response in simulation;
Helps with the problem, but requires additional work.

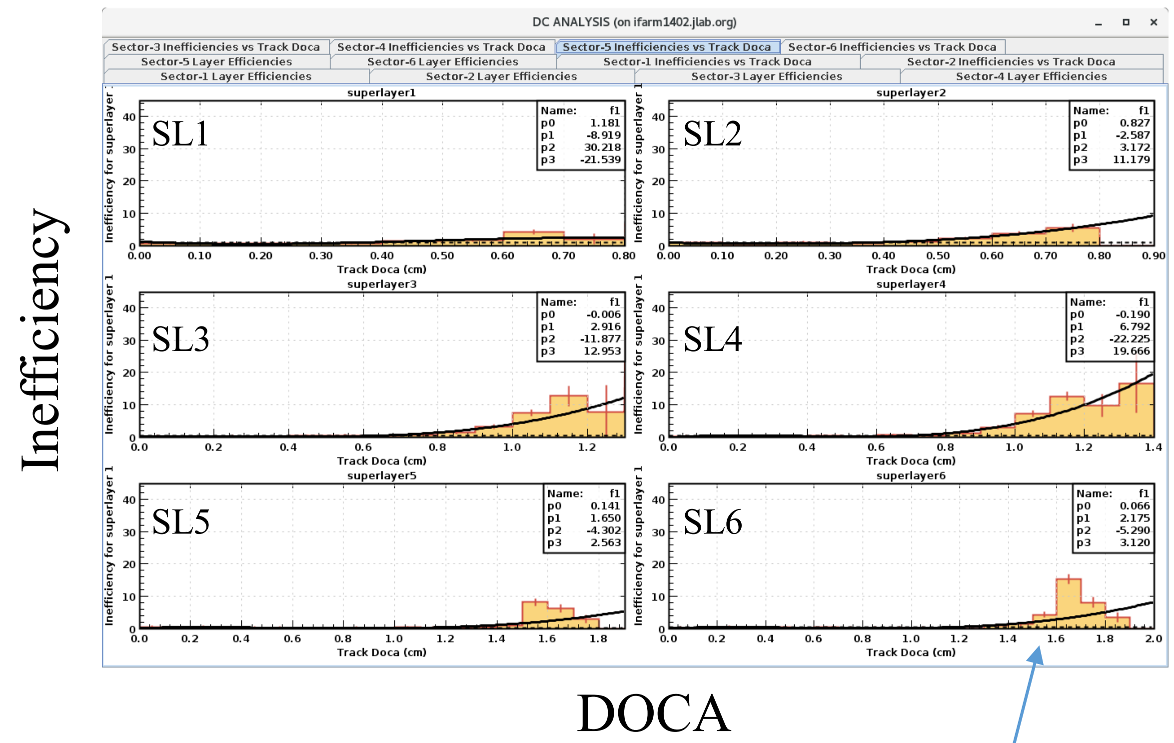
Simulating Intrinsic Inefficiency vs. DOCA

- Run 'layer efficiency' script on data
- ``finds track segment excluding one layer → did that layer fire? "
- fit inefficiency to function
- same function used in GEMC

→ tune GEMC parameters to match data (hit rejected if random number less than function)

✓ already implemented, needs tuning

Run 5443 Sector 5 HV "9 10 10"



Inefficiency is larger far from the wire

- these are 'corner clippers'
- fewer ions → smaller signal

LTCC efficiency

The team of Stefano Migliorati, Valerio Mascagna and Andrea Bianconi is making good progress in having an efficiency table for LTCC as a function of momentum, theta and phi. A preliminary document was written. A few more analysis steps are ongoing.

TOF Efficiency

Daniel Carman, Raffaella De Vita, Stuart Fegan, Matthew Nicol, Rhidian Williams, Nick Zachariou

Group has been meeting weekly since Dec. 2020

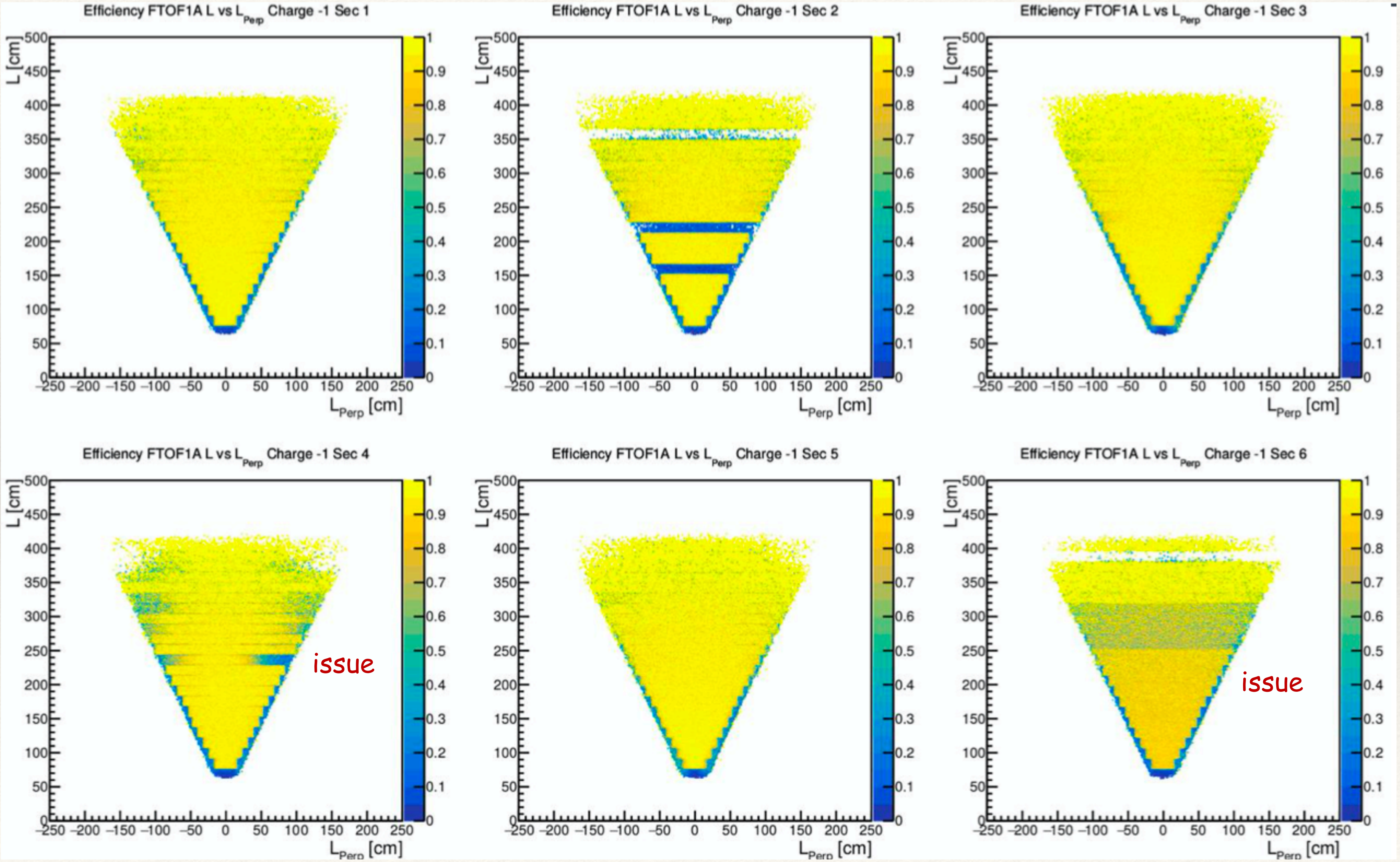
FTOF Efficiency Studies Plan:

- Validate "robust" definition of hit efficiency for each FTOF counter for charged particles
- Continue to study ε vs. hit pos, PID, electric charge, luminosity, threshold, magnetic field, etc. to understand features in data
- Need to separate "intrinsic" counter efficiency from other effects that bias the definition arising from the trigger definition and Event Builder
  - Studies of ε_{FTOF} over past few weeks have revealed subtle biases due to event selection and trigger - while not fully understood, their effect has been mitigated
  - Some issues remain in p1a S4, p1a & p1b S6 – still need to be investigated

FTOF Efficiency

ε_{FTOF} = (FTOF hit & DC track & ECAL hit) / (DC track & ECAL hit)

FTOF – panel-1a negatives



Similar plots exist for

panel-1a positives

panel-1b negative

panel-1b positives

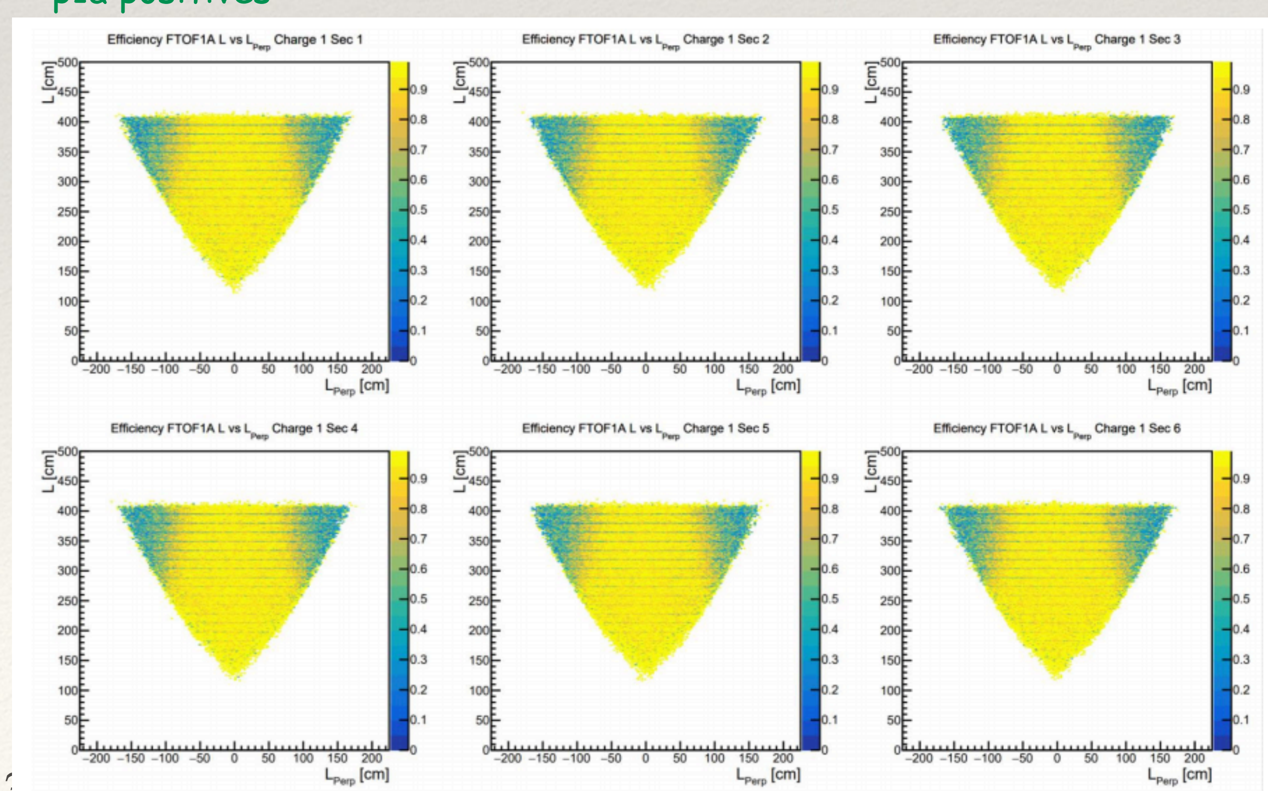
FTOF Efficiency

FTOF Next Steps:

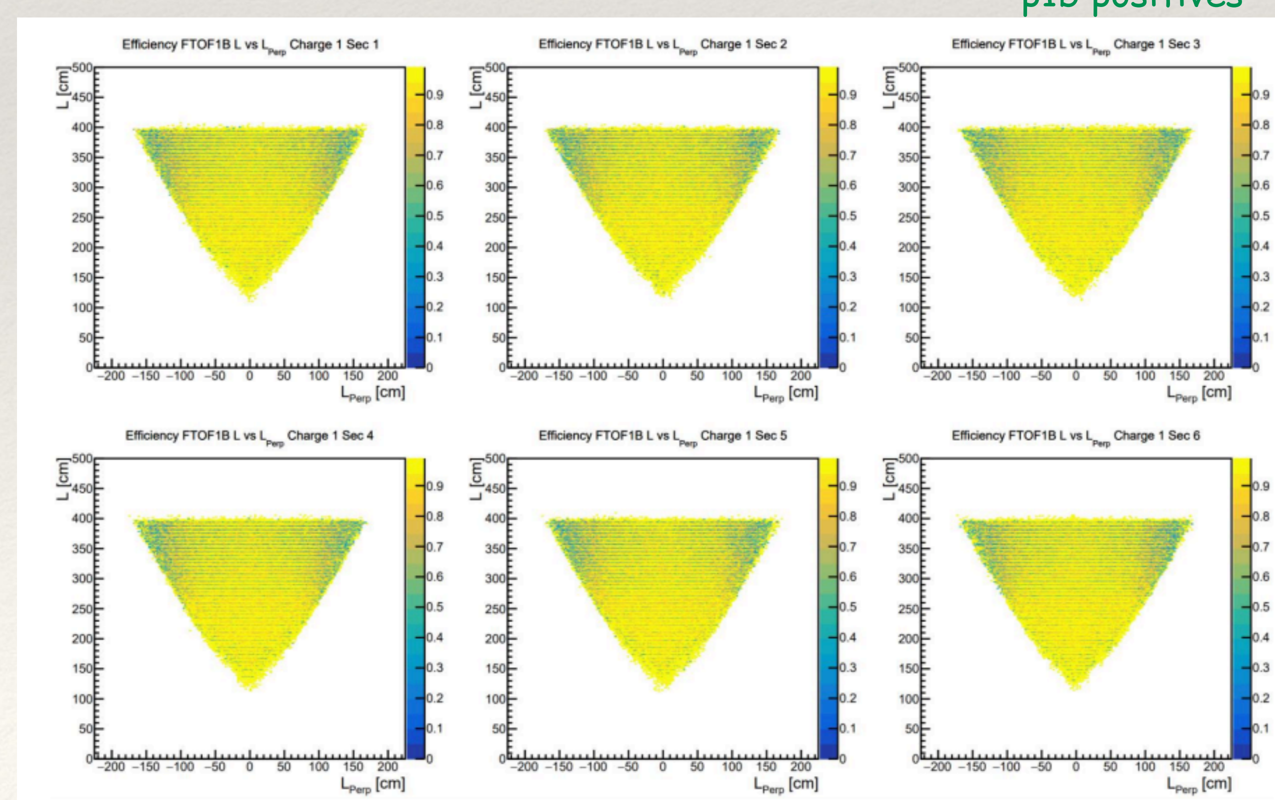
- Investigate S6 issues seen in p1a and p1b
- Eliminate runs with problems from sample
- Derive efficiency table for portion of FTOF in ECAL acceptance
- Use 2π channel to cross-check efficiency table from hit ratios and to extend table to cover full FTOF acceptance – including panel-2
- Advance studies of simulation to compare efficiency derived from data

Crude threshold modeling on MC

p1a positives



p1b positives



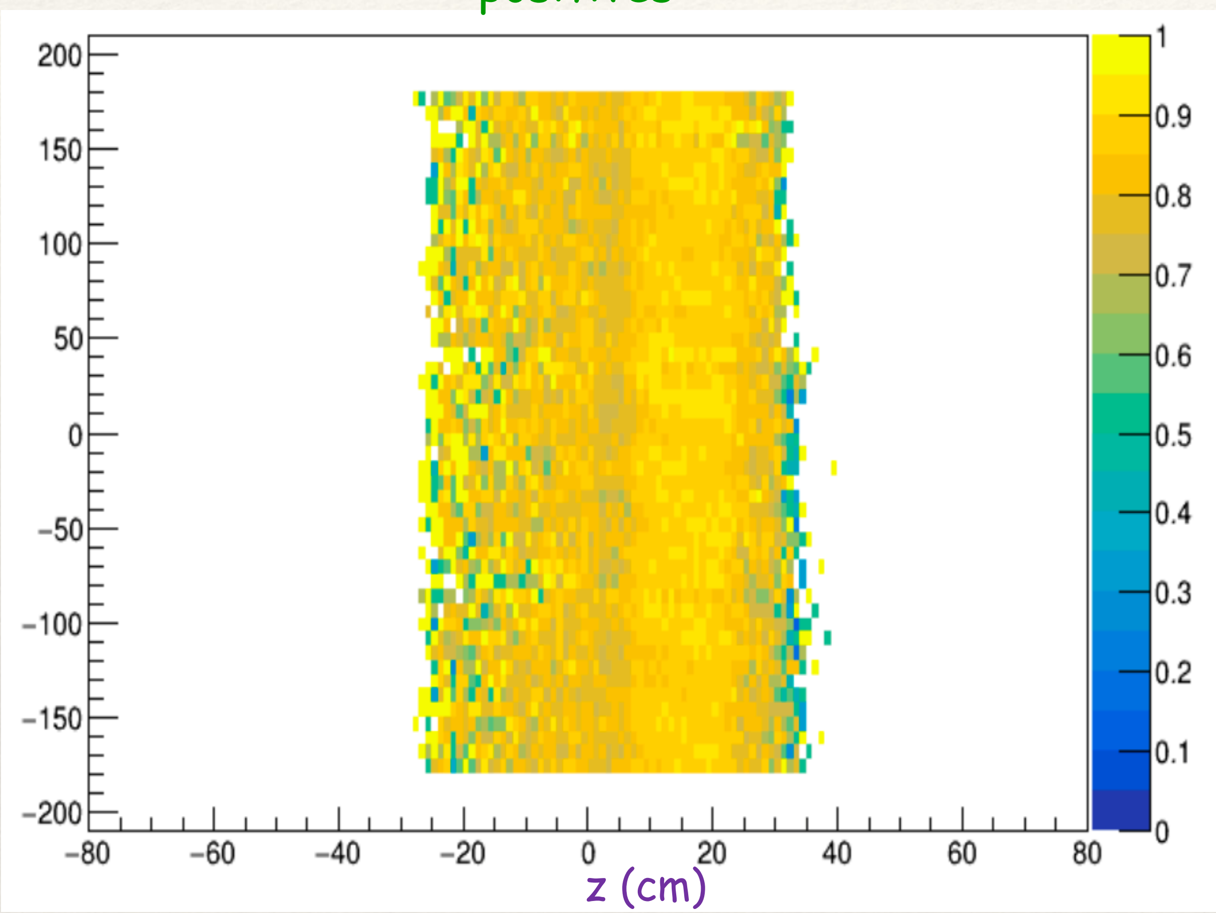
CTOF Efficiency

ε_{CTOF} = (CTOF hit & CVT track & CND hit) / (CVT track & CND hit)

ε_{CTOF} definition with hit in CND

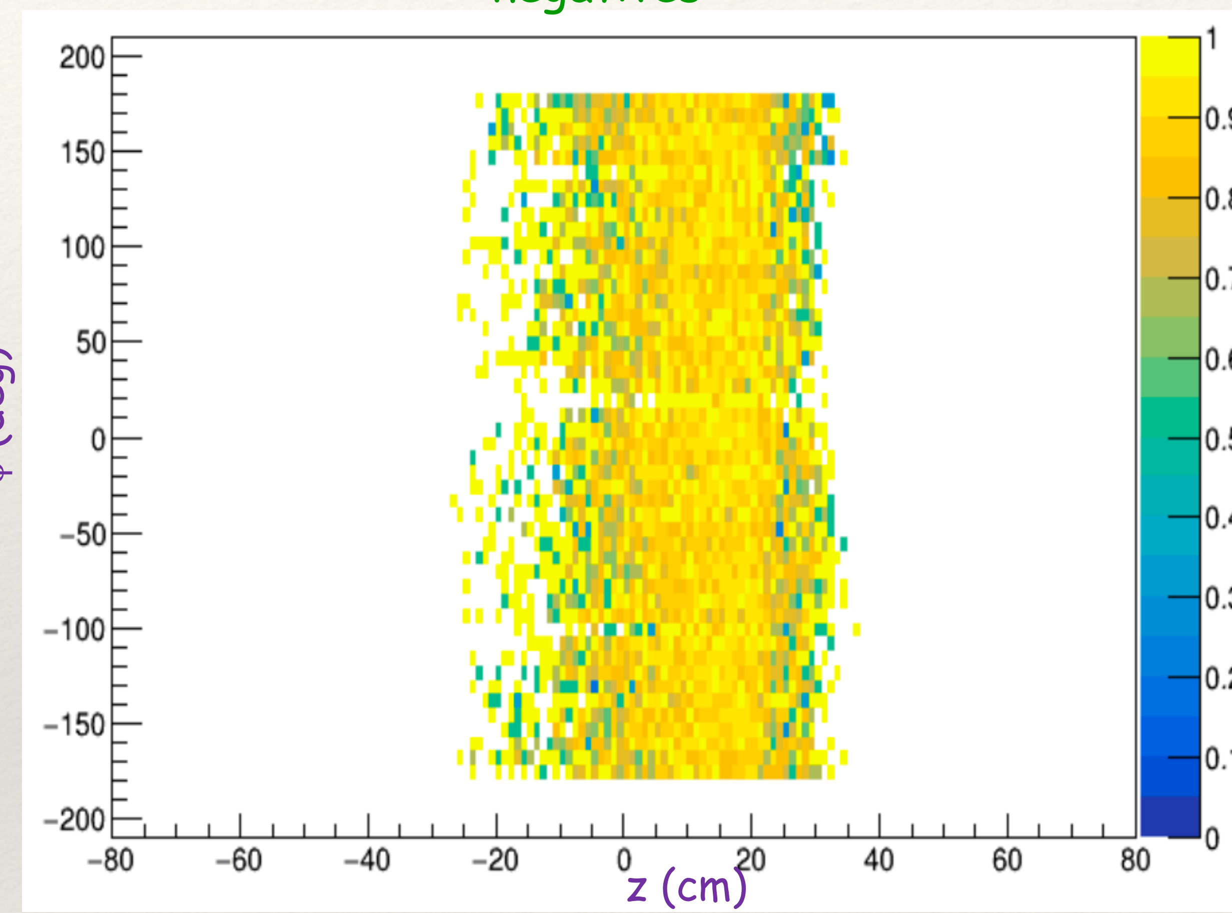
positives

φ (deg)



negatives

φ (deg)



To do:

- Look at event selection with electron in FT as well
- Understand portion of CTOF acceptance "lost" with CND hit requirement (low momentum tracks)
- Understand all "features" in CTOF efficiency plots
- Look at 2π electroproduction as a cross-check

EC/PCAL Efficiency

Electrons

- Absolute efficiency studies so far only with MC and ideal detector (fixed attenuation and gain).
- Random or non-electron triggers may have insufficient yield for detailed 2D efficiency maps.
- Relative efficiency studies planned using radiated photons or CD elastic protons to tag negative tracks with missing PID.

Minimum Ionizing (pions, muons)

- PCAL efficiency defined relative to DC track projection (pions) or FTOF 1B (cosmic muons).
- ECIN, ECOUT efficiency defined relative to PCAL.
- For pions efficiency losses dominated by nuclear interactions.
- In general MIP efficiency losses affected by light attenuation from longest strips.

Neutrals

- Neutrons: MC efficiencies compared to data using tagged neutrons from $p(e,e'\pi^+)n$.
- Photons: MC studies only with ideal detector.

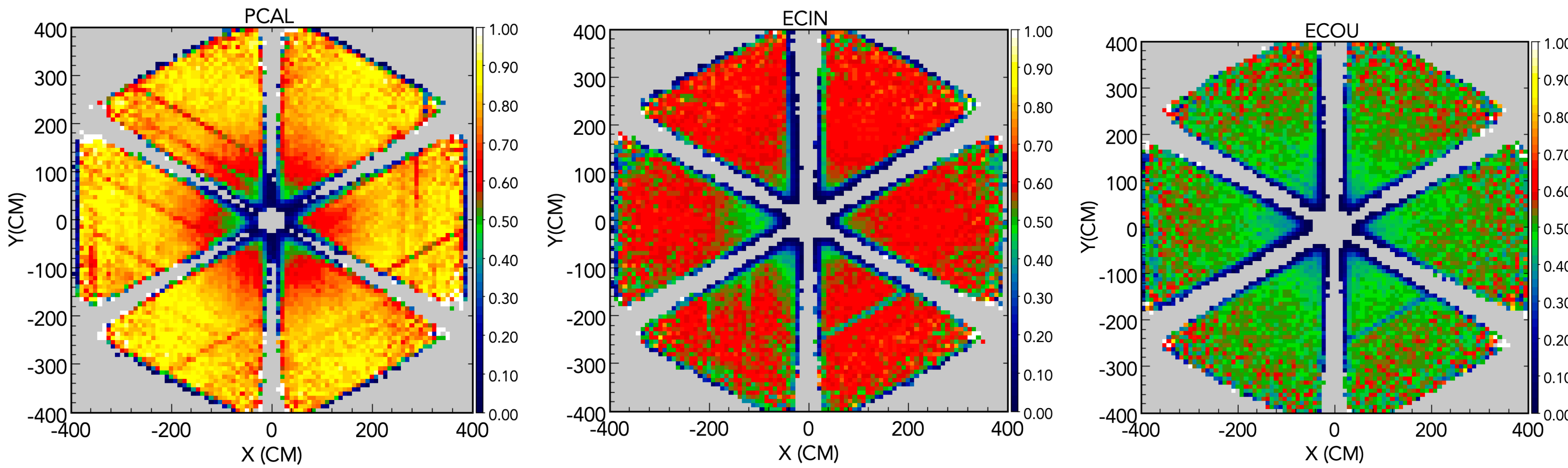
General observations

- Cross check of data/MC derived efficiencies essential to ensure consistency.
- MIP studies offer best opportunity of data/MC comparison with realistic detector.
- Neutral efficiency studies hampered by reconstruction issues (extra, merged clusters, PID).

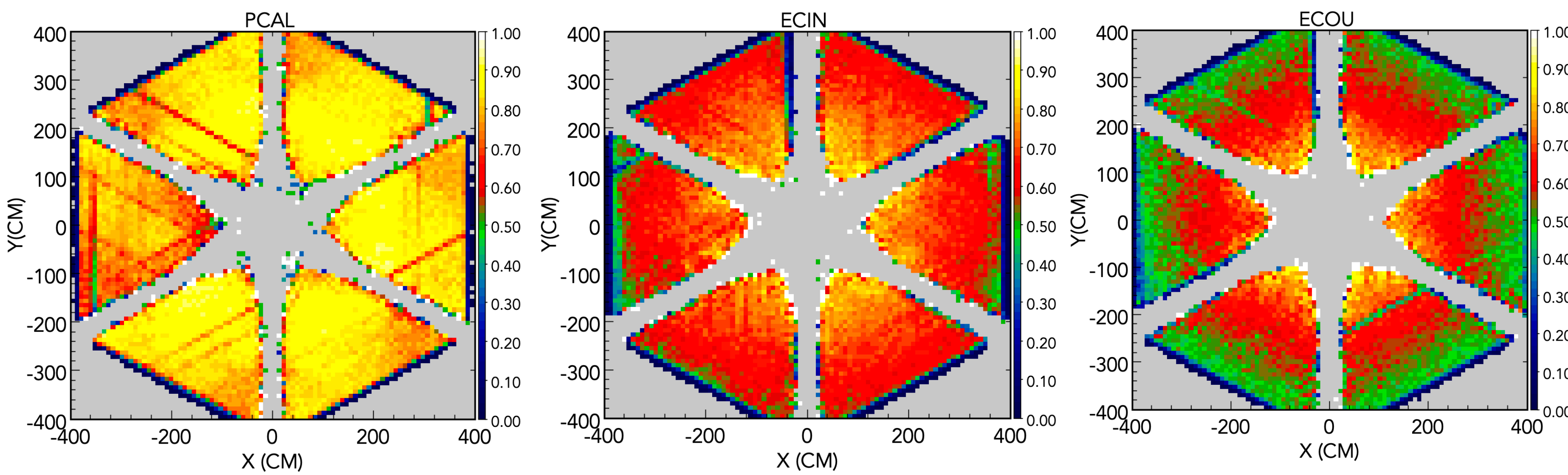
EC/PCAL Efficiency

PION: RGA-F18 ECAL efficiency maps for π^+ and p>0.7 GeV

RUN 5038 INBENDING



RUN 5460 OUTBENDING



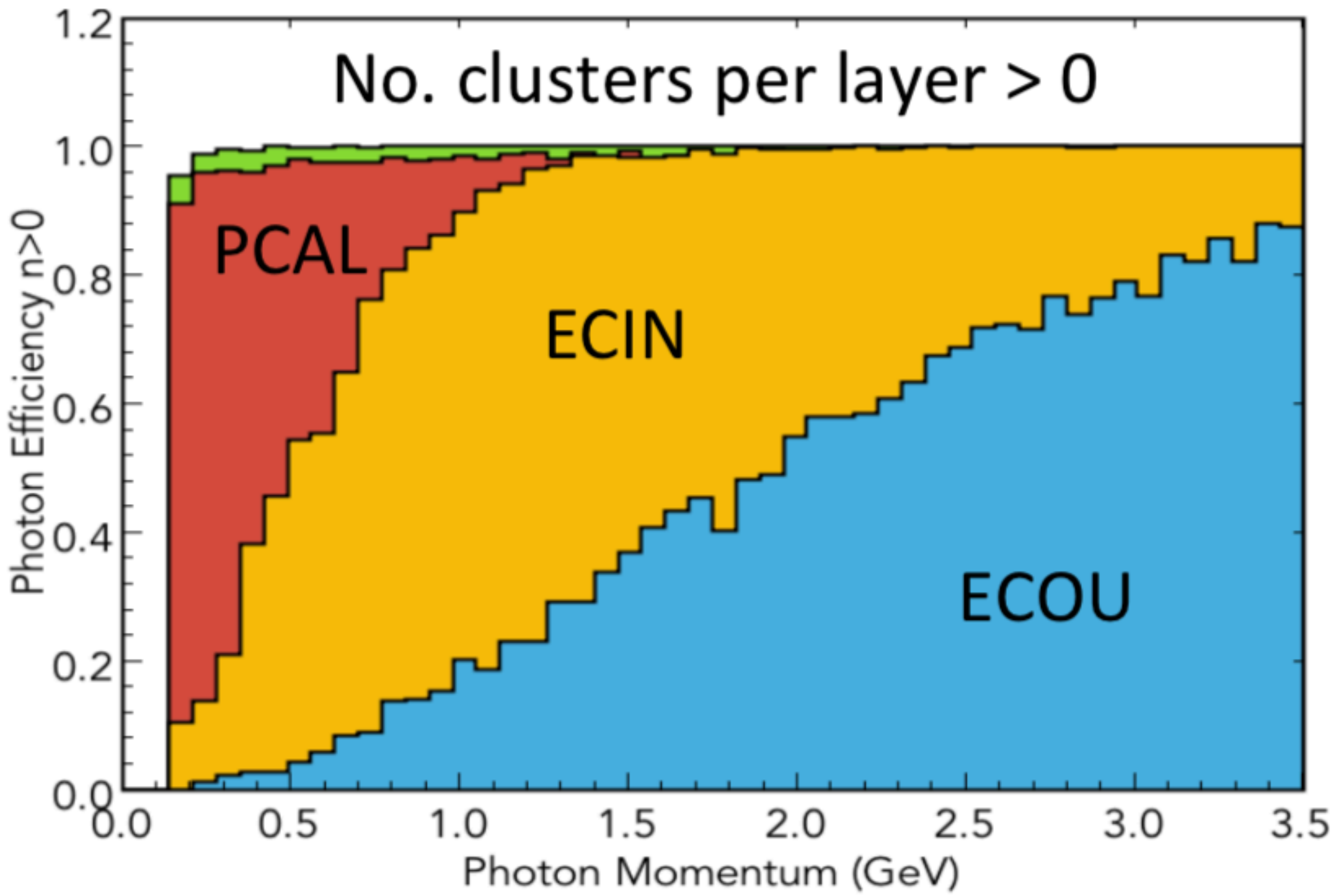
Minimum Ionizing (pions, muons)

- PCAL efficiency defined relative to DC track projection (pions) or FTOF 1B (cosmic muons).
- ECIN, ECOUT efficiency defined relative to PCAL.
- For pions efficiency losses dominated by nuclear interactions.
- In general MIP efficiency losses affected by light attenuation from longest strips.

EC/PCAL Efficiency

PHOTON: MC studies with FTOF + PCAL/EC only

- Efficiency > 95 % for E > 0.2 GeV.
- Upstream photon conversions will impact energy dependence.
- Requires accurate modeling of all radiating surfaces (for both e- and ϒ).



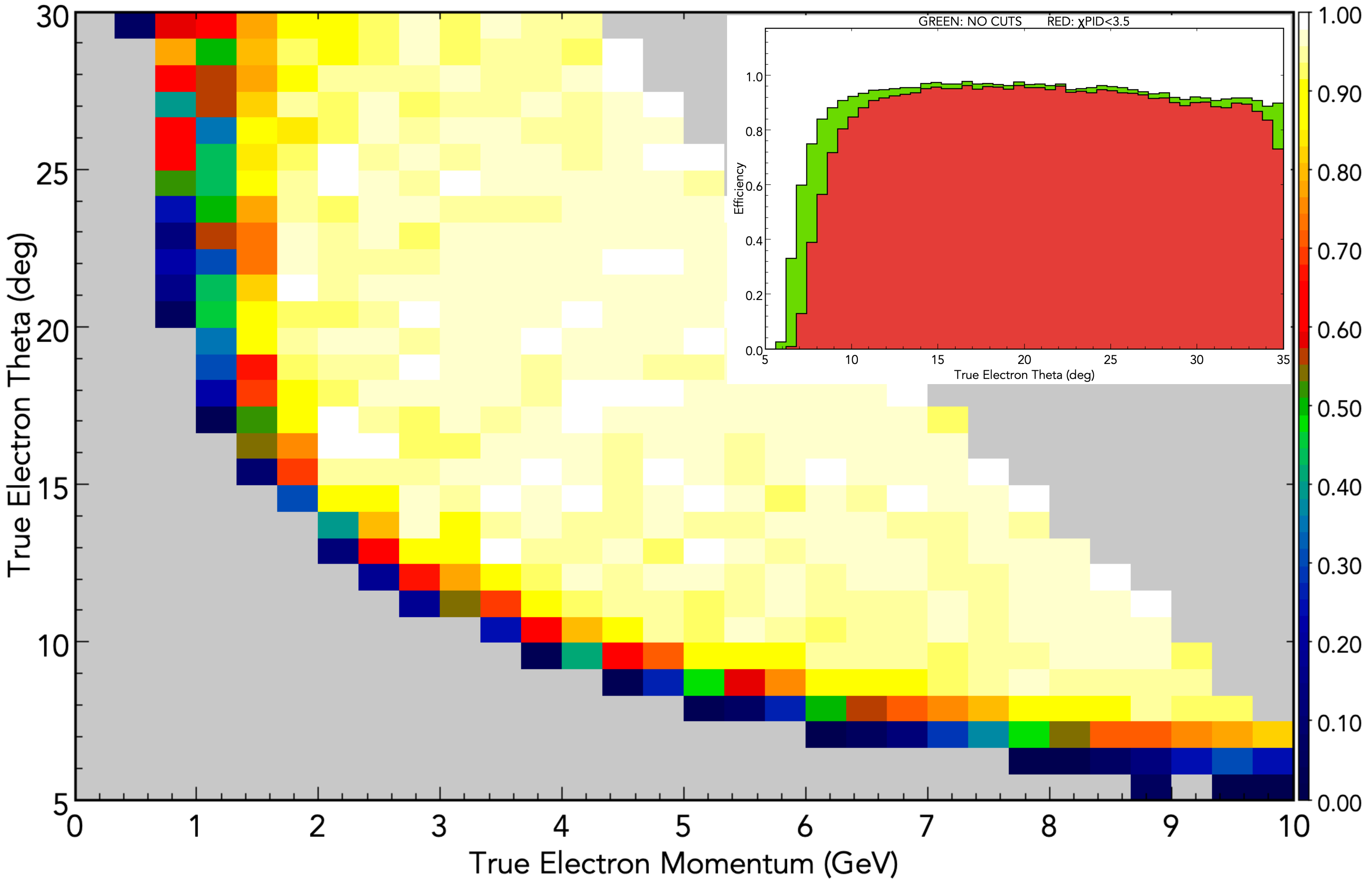
Neutrals

- Neutrons: MC efficiencies compared to data using tagged neutrons from p(e,e'π^+)n.
- Photons: MC studies only with ideal detector.

EC/PCAL Efficiency

ELECTRON: MC studies (inbending) with full RGA-F18 gcard

- Efficiency > 90% away from fiducial boundaries.
- E/P fiducial losses due to reduced PCAL/EC overlap for theta < 10 deg.
- Radiative fiducial losses for for p < 2 GeV and theta > 25 deg.



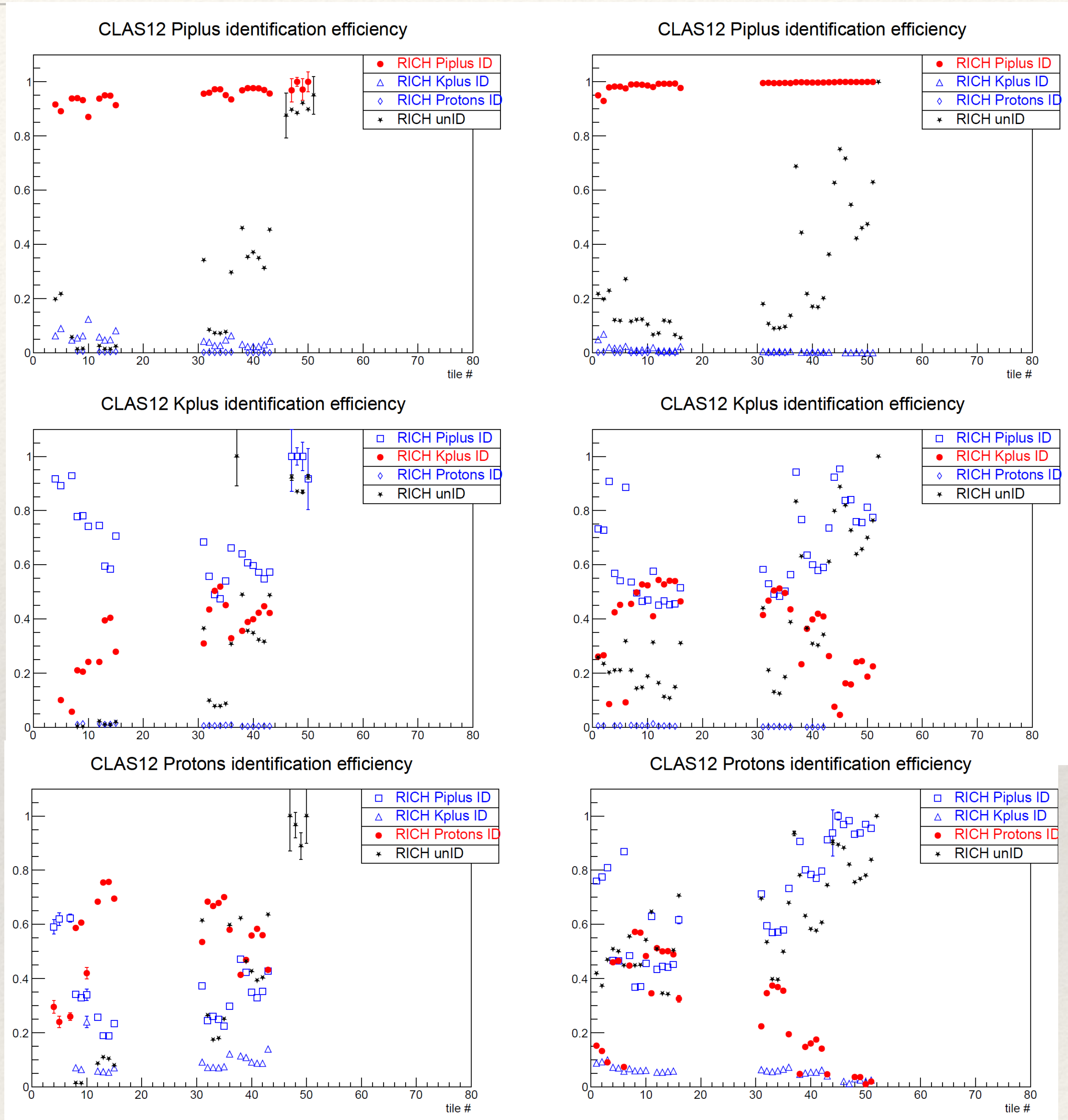
Electrons

- Absolute efficiency studies so far only with MC and ideal detector (fixed attenuation and gain).
- Random or non-electron triggers may have insufficient yield for detailed 2D efficiency maps.
- Relative efficiency studies planned using radiated photons or CD elastic protons to tag negative tracks with missing PID.

CLAS12 PID efficiency: positive hadrons

Left plots: inbending data
Right plots: outbending data

1. **Pions**
   - **CLAS12 and RICH agree 100% for pi+ outbending, around 90% for inbending**
   - **fraction of no RICH ID 10% in forward direction, higher at large angles**
2. **Kaons**
   - **max 50% agreement between CLAS12 and RICH**
   - **largest wrong CLAS12 ID is from pions**
   - **fraction of no RICH ID similar to pions**
3. **Protons**
   - **max 70% agreement between CLAS12 and RICH, large angular variations**
   - **largest wrong CLAS12 ID from pions, but also from kaons**
   - **large fraction of no RICH ID (high Cherenkov threshold)**



	Inbending data		
CLAS12 ID	RICH π^+	RICH K^+	RICH p
π^+	0.9716 ± 0.0001	0.0274 ± 0.0001	0.0010 ± 0.0000
K^+	0.5893 ± 0.0008	0.4040 ± 0.0008	0.0067 ± 0.0001
p	0.2657 ± 0.0013	0.0645 ± 0.0007	0.6697 ± 0.0014

Table 4: CLAS12 particle identification efficiency using the RICH for positive hadrons in inbending data.

red full circles:
fraction of CLAS12 pi+ with same ID in the RICH
empty blue symbols:
fraction of CLAS12 pi+ with different ID in the RICH

FT Efficiency

- Inefficiencies can arise from thresholds or malfunctioning components
- Use exclusive two pion reaction to measure the efficiency:
  - Select events with pi+, pi-, p measured in FD-CD
  - Use missing mass to select events with an electron going in the FT acceptance
  - Check if an electron is detected in the FT
- Perform the study for both data and MC
- Tune MC to properly account for thresholds
- Use status tables to knock-out malfunctioning/dead component
- Need to find suitable reactions to study photon efficiency

CVT Efficiency

- **Tracking:**
  - Algorithm inefficiencies have been addressed, improved Kalman Filter, track seeding and efficiency of reconstruction of low-momenta tracks, ongoing work on removing ghost/split/duplicate tracks
  - Added 2nd algorithm for tracks passing through the BMT sector gaps
  - TracTools-ExLayr branch developed with an option to exclude layer(s) from tracking, latest improvements with helical, straight, and cosmic tracking
  - CVT geometry framework developed to allow tracker rotation/translation in reconstruction
- **MC truth matching:**
  - Algorithm has been validated, banks are used in efficiency studies (no BG)
- **BG merging:**
  - Validated on RG-A (45 nA) and RG-B (50 nA) BG files
  - Issue with BG merging for the CVT zero ADC hits is fixed in TracTools-ExLayr
- **Out-of-time hit rejection:**
  - RG-B 50 nA, hit occupancy reduced from 1.6% to 1.1% while gaining 2% of CTOF+CND matched tracks with 50 nA cut on BMT hit timing; SVT timing studies in progress
- **Detector studies:**
  - Ongoing work on detector calibration, status tables, Lorentz angle calibrations, efficiency maps

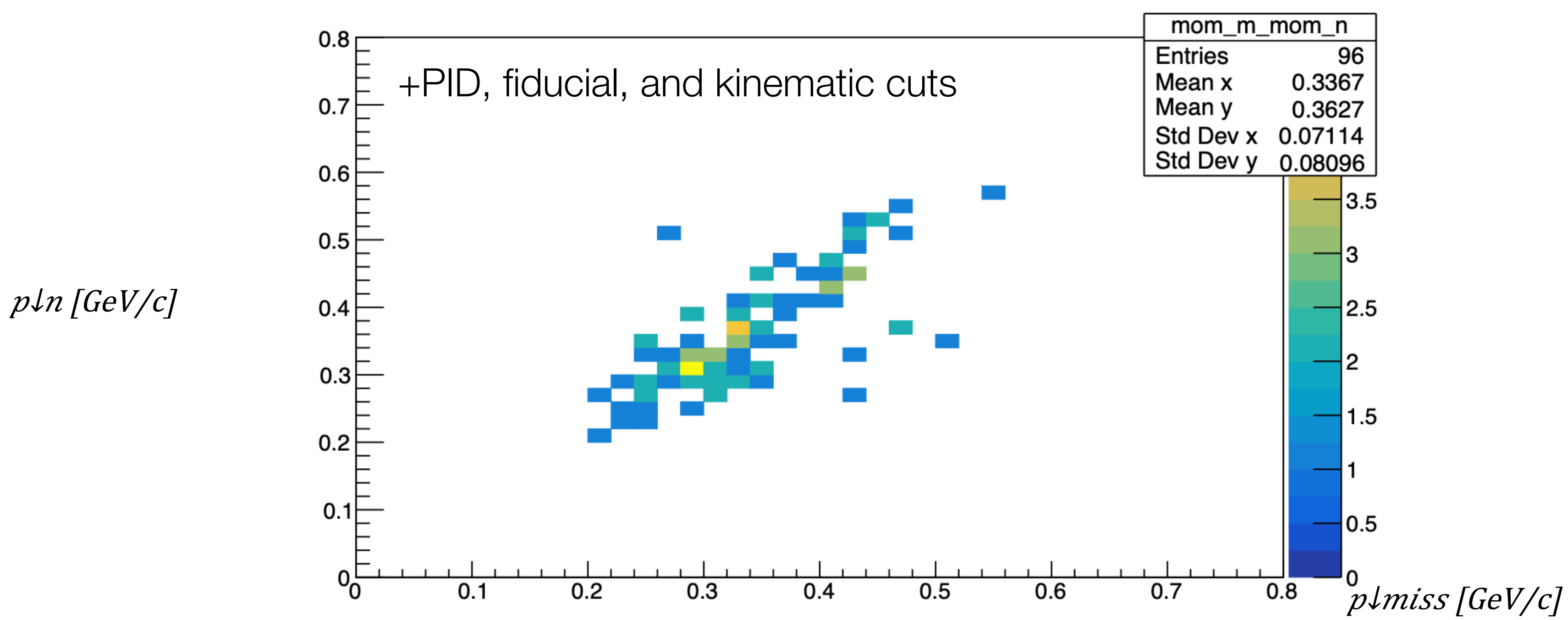
The CVT is not fully aligned yet. Work on extraction of the misalignment constants has higher priority as it affects tracker efficiency.

BAND Efficiency

Extracting efficiency & resolution of BAND

- 2 days@4.2 GeV beam energy
- Torus inbending
- Target: Deuterium
- Trigger: Electron inclusive (mostly w/o sector 4, trigger board problem)
- Run Numbers: 11289 - 11302
- Goal: Measure BAND efficiency (and momentum resolution)

Measured neutron momentum in BAND
vs missing momentum in d(e,e'p)n reaction



- Measure d(e,e'p) reaction using CLAS for the scattered electron and proton, select kinematics for quasi-elastic scattering, and then calculate the "missing-momentum" vector, which is the neutron momentum that is unmeasured.
- Check if this vector points to BAND and that is our denominator for efficiency (# good QE events that point to BAND)
- Then for these events, we look at BAND and, if we have one, reconstruct a neutron vector (our numerator in efficiency)
- On the plot is the correlation between the missing momentum and actual measured momentum
- Lastly, we can bin this efficiency as a function of neutron momentum.

General issues and tools

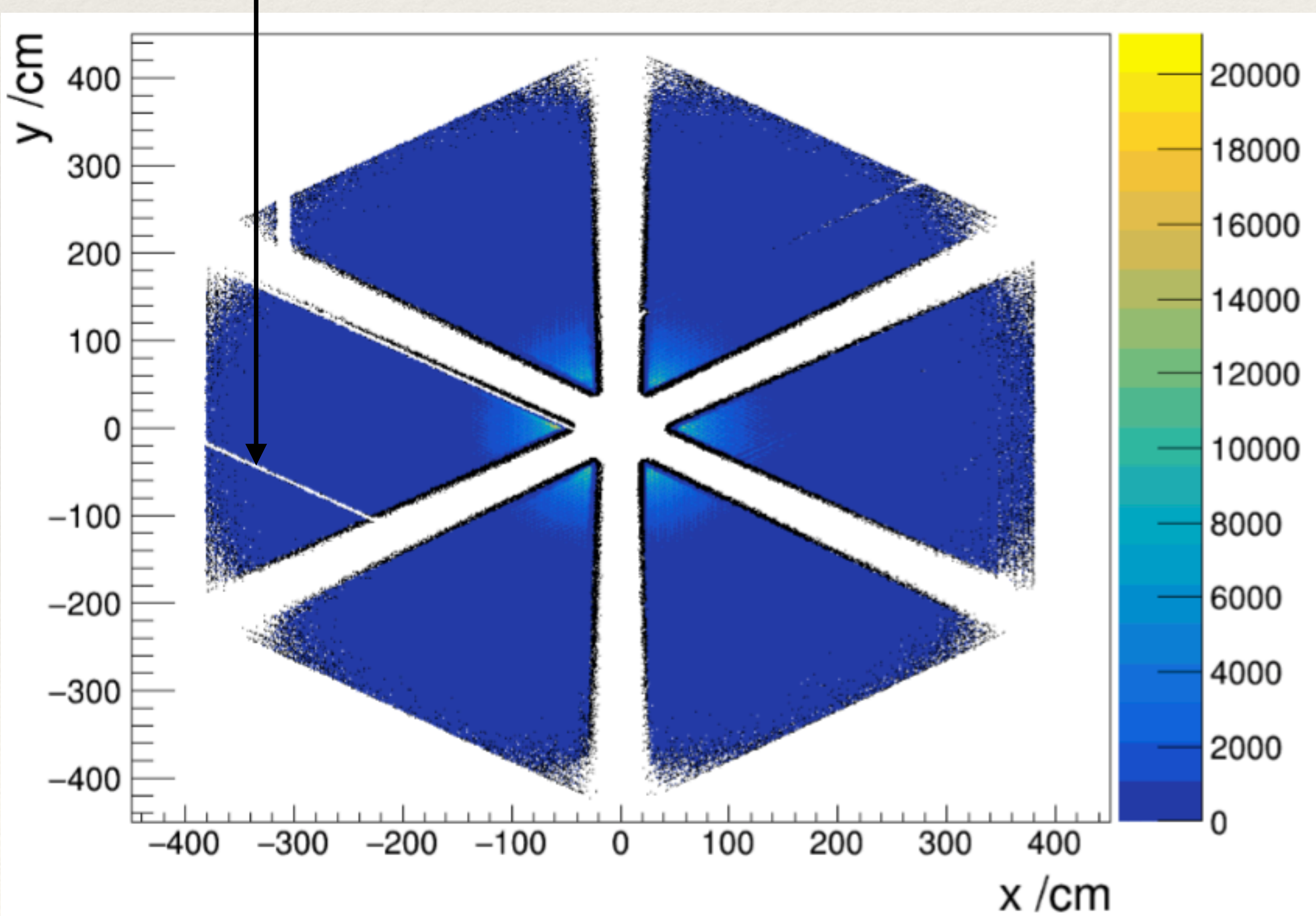
- Malfunctioning detector components and status word implementation
- Thresholds in GEMC
- Possible geometry issues
- Radiative photon and electron efficiency

Status tables

Address hardware problems in simulation;
GEMC remains “perfect”;
Exclude dead or problematic channels in reconstruction to reproduce the losses caused in data by these malfunctioning elements in simulation as well.

Exclude this in both data and simulation

PCAL



Hardware Status Assignments

- 0 - fully functioning
- 1 - no ADC
- 2 - no TDC
- 3 - no ADC, no TDC (PMT is dead)
- 5 - any other reconstruction problem

Threshold in GEMC

Implementing Hardware Thresholds in GEMC

(do we need to do it in GEMC?)

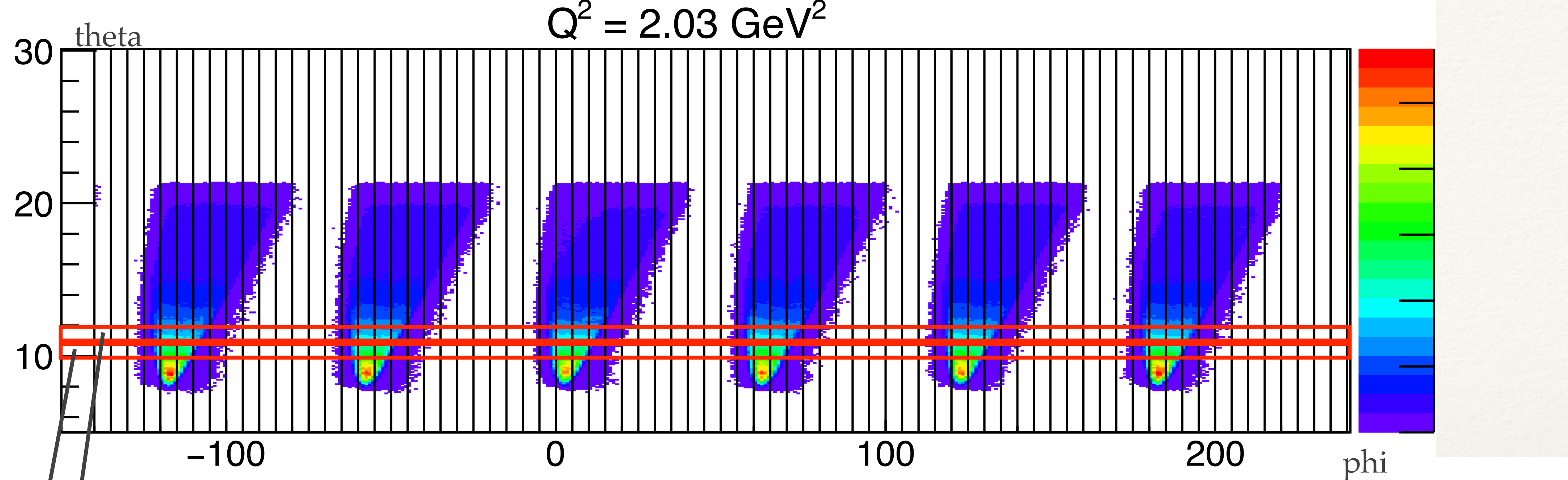
- Use ADC (or energy deposited, or nphe, or…?) integrated value
- Add / Load Thresholds values from CCDB
- Hits are not written in the output if threshold not passed
- Currently threshold would apply to both ADC/TDC. Work could be done in GEMC to have 1 ADC and 1 TDC threshold.

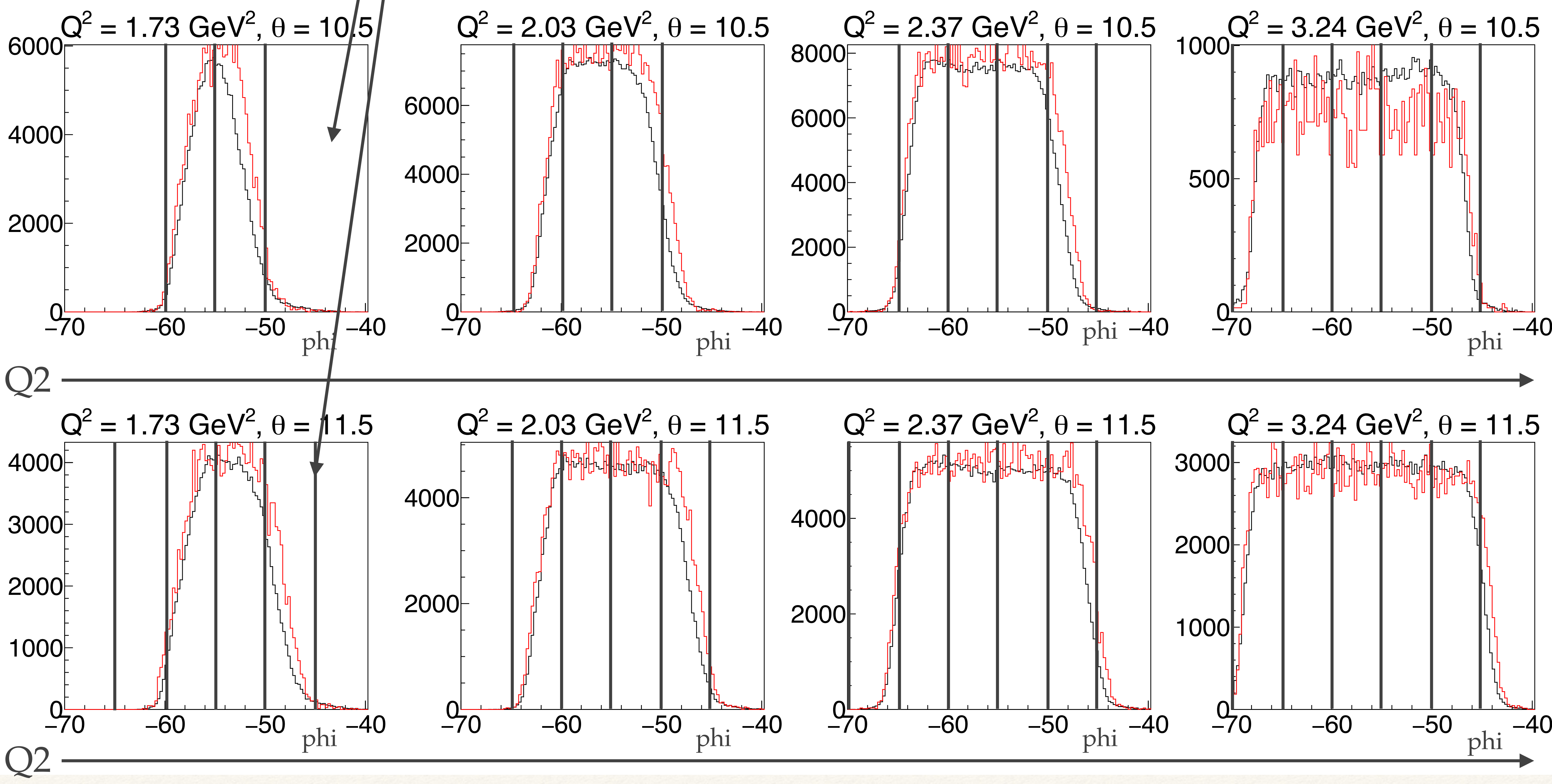
Geometry

1D projections, data and simulation

Data

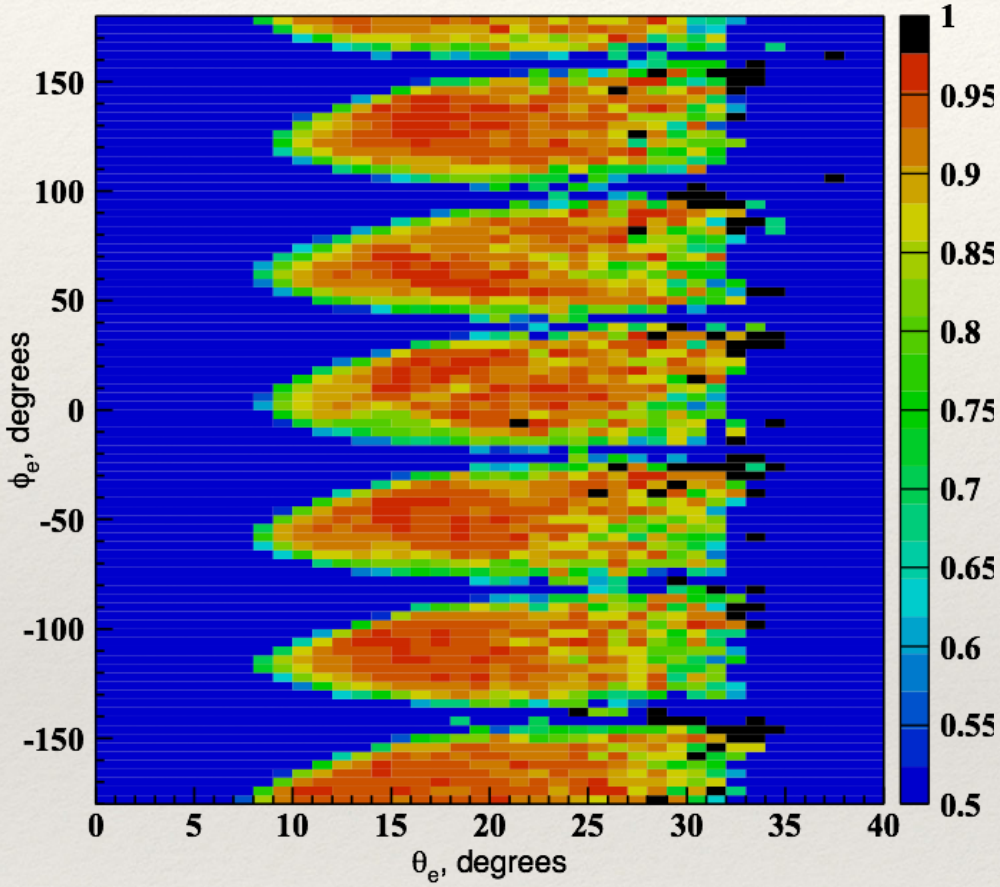
Simulation

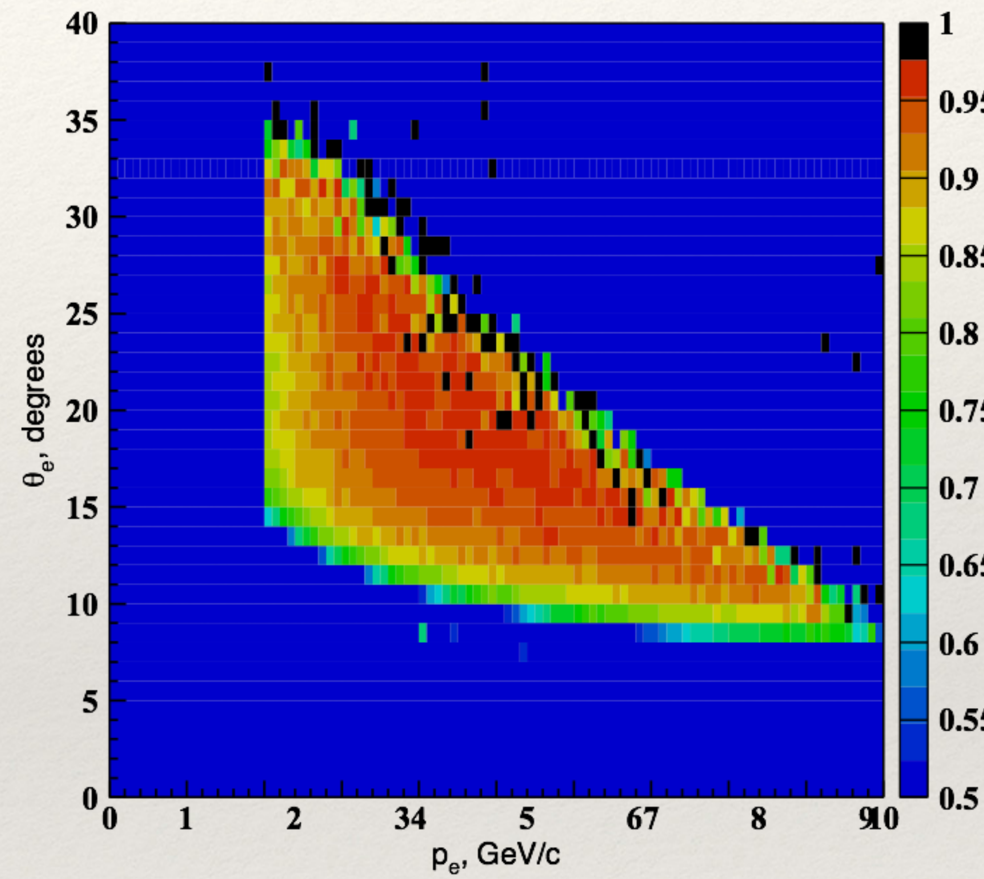




Electron Efficiency

$$Eff. = \frac{N(PID = 11 \left| \chi^2 PID \right| < 3, p > 2 \text{ GeV/c})}{N(PID = 11 \left| \chi^2 PID \right| < 3, p > 2 \text{ GeV/c}) + N(h^- \gamma_R)}$$





- A radiated photon accompanying the scattered electron in ECal has been observed by many
- The radiated photon has the same angles as the electron at the point of the radiation
- In the longitudinal field of the solenoid, at the point of the radiation, the polar angle of the electron is the same as at the production vertex. The azimuthal angle, on other hand, depends on the electron 3-momentum and the distance from the production vertex.

Final check

- Successfully measure well known cross sections in the region of overlap with the world data;
- Different channels available: elastic (in progress from 6.5 GeV RGK data), elastic with proton detected, inclusive electron (in progress from RGA Fall18, advanced stage), single pion;
- Different run groups might be better suited for different channels.

Summary and Future Plans

- Develop algorithms to determine efficiency of every subsystem (different for different particles);
- Develop and validate software packages to extract efficiency for each detector from data and simulation;
- Find relevant GEMC parameters and tune GEMC to match efficiency between data and simulation as much as possible;
- Design, fill and apply status tables (bad, ineffective, nonfunctional elements) in reconstruction;
- Implement thresholds in GEMC;
- Design and implement efficiency tables in the workflow (if required);
- Extract relevant cross section (starting from 10.6 GeV RGA data inclusive cross section and 6.5 GeV RGK data elastic cross sections).