bHCAL Meeting – Neutron Calibration Update

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OVERVIEW

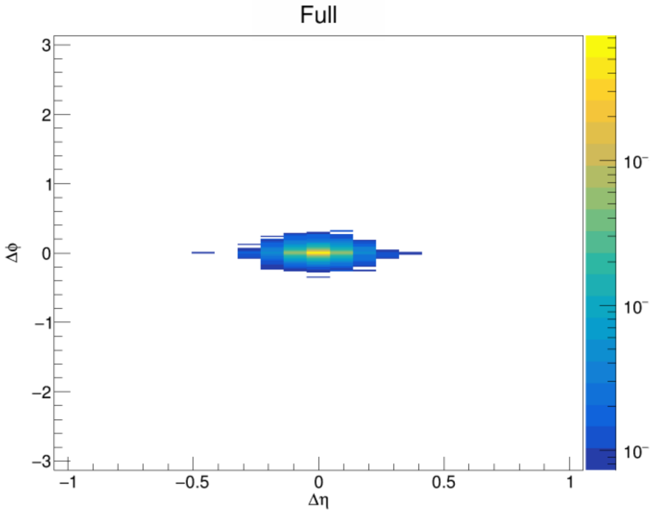
- More detailed look at various energy deposition parameters in bECAL and bHCAL:
  - Shower size in bHCAL in $\Delta\eta$ vs. $\Delta\phi$
    - Updated since last time
  - Various quantities as a function of first hit layer of bECAL (SciFi layers only)
    - To explore if there is any useful dependence on where in bECAL the neutron shower starts

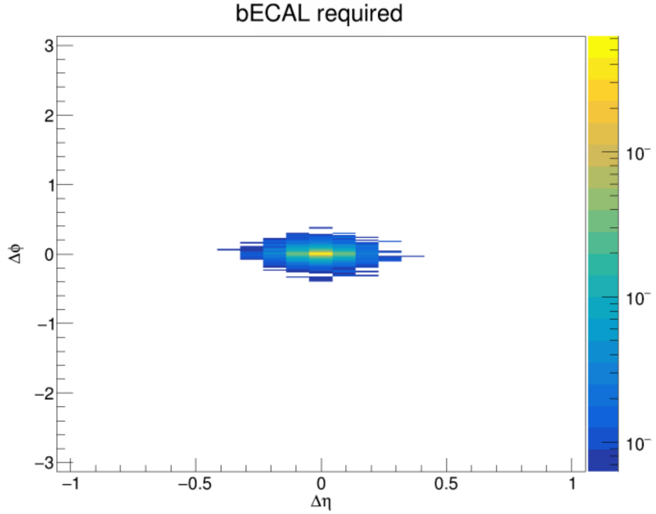
NEW $\Delta\eta$ VS. $\Delta\phi$

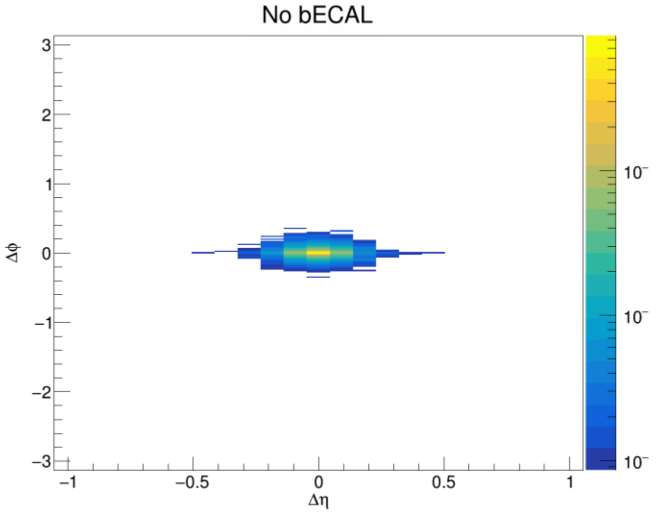
SHOWER TRANSVERSE SIZE IN bHCAL (1 GeV/c)

- Transverse size of shower in bHCAL
  - MC neutron momentum: $1\ \mathrm{GeV}/c$
  - (top left) All hits
  - (top right) Require hits in bECAL
  - (bottom left) Require no hits in bECAL

- $\Delta\eta = \eta_i - \bar{\eta}, \bar{\eta} = \frac{\sum_i \eta_i E_i}{\sum_i E_i}$
  - Index i is for individual tiles with energy deposition E_i at η_i
  - Same method for $\Delta\phi$
  - Bin sizes same as bHCAL tile sizes





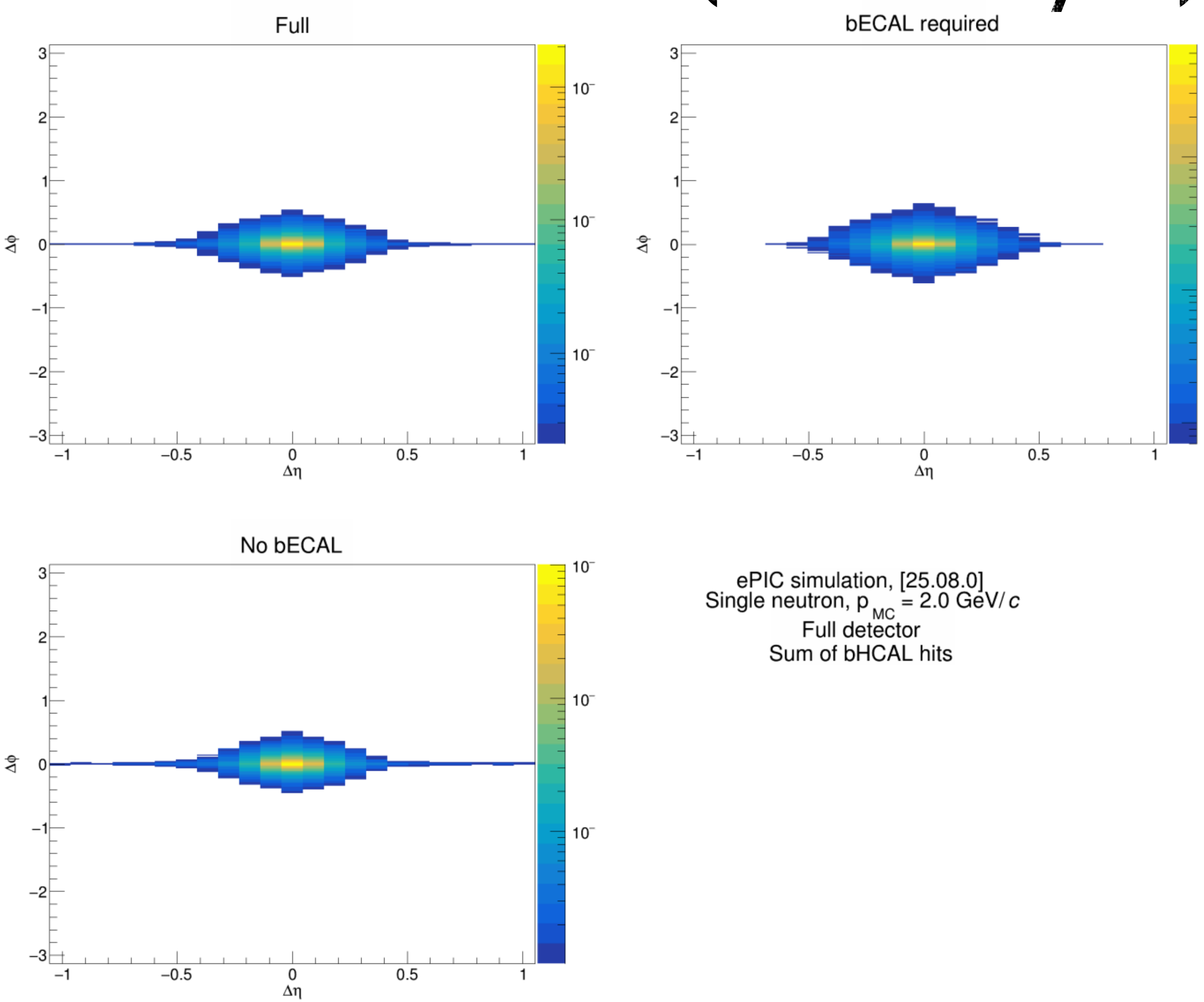


ePIC simulation, [25.08.0]
Single neutron, p_{MC} = 1.0 GeV/c
Full detector
Sum of bHCAL hits

SHOWER TRANSVERSE SIZE IN bHCAL (2 GeV/c)

- Transverse size of shower in bHCAL
  - MC neutron momentum: 2 GeV/c
  - (top left) All hits
  - (top right) Require hits in bECAL
  - (bottom left) Require no hits in bECAL

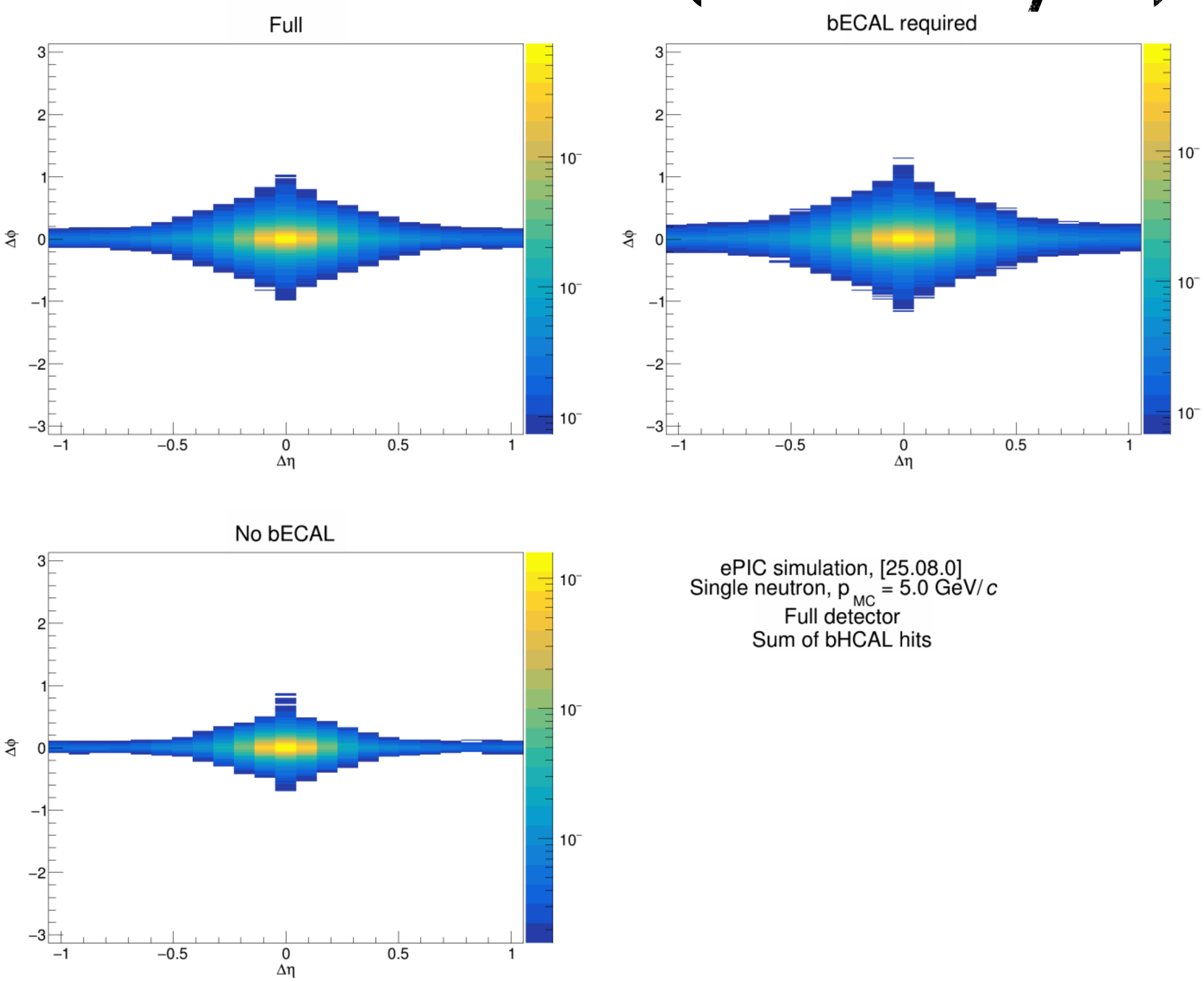
- $\Delta\eta = \eta_i - \bar{\eta}, \bar{\eta} = \frac{\sum_i \eta_i E_i}{\sum_i E_i}$
  - Index i is for individual tiles with energy deposition E_i at η_i
  - Same method for $\Delta\phi$
  - Bin sizes same as bHCAL tile sizes



SHOWER TRANSVERSE SIZE IN bHCAL $(5\ \mathrm{GeV}/c)$

- Transverse size of shower in bHCAL
  - MC neutron momentum: $5\ \mathrm{GeV}/c$
  - (top left) All hits
  - (top right) Require hits in bECAL
  - (bottom left) Require no hits in bECAL

- $\Delta\eta = \eta_i - \bar{\eta}, \bar{\eta} = \frac{\sum_i \eta_i E_i}{\sum_i E_i}$
  - Index i is for individual tiles with energy deposition E_i at η_i
  - Same method for $\Delta\phi$
  - Bin sizes same as bHCAL tile sizes



SECTION SUMMARY

- Updated $\Delta\eta$ vs. $\Delta\phi$ distributions provide a bit better insight into shower size for different neutron energies and different hit requirements in bECAL and bHCAL

- $1\ \mathrm{GeV}/c$: No significant difference between different hit combinations observed
- $2\ \mathrm{GeV}/c$: Shower profile a bit wider when shower starts in bECAL
- $5\ \mathrm{GeV}/c$: Shower profile substantially wider when shower starts in bECAL

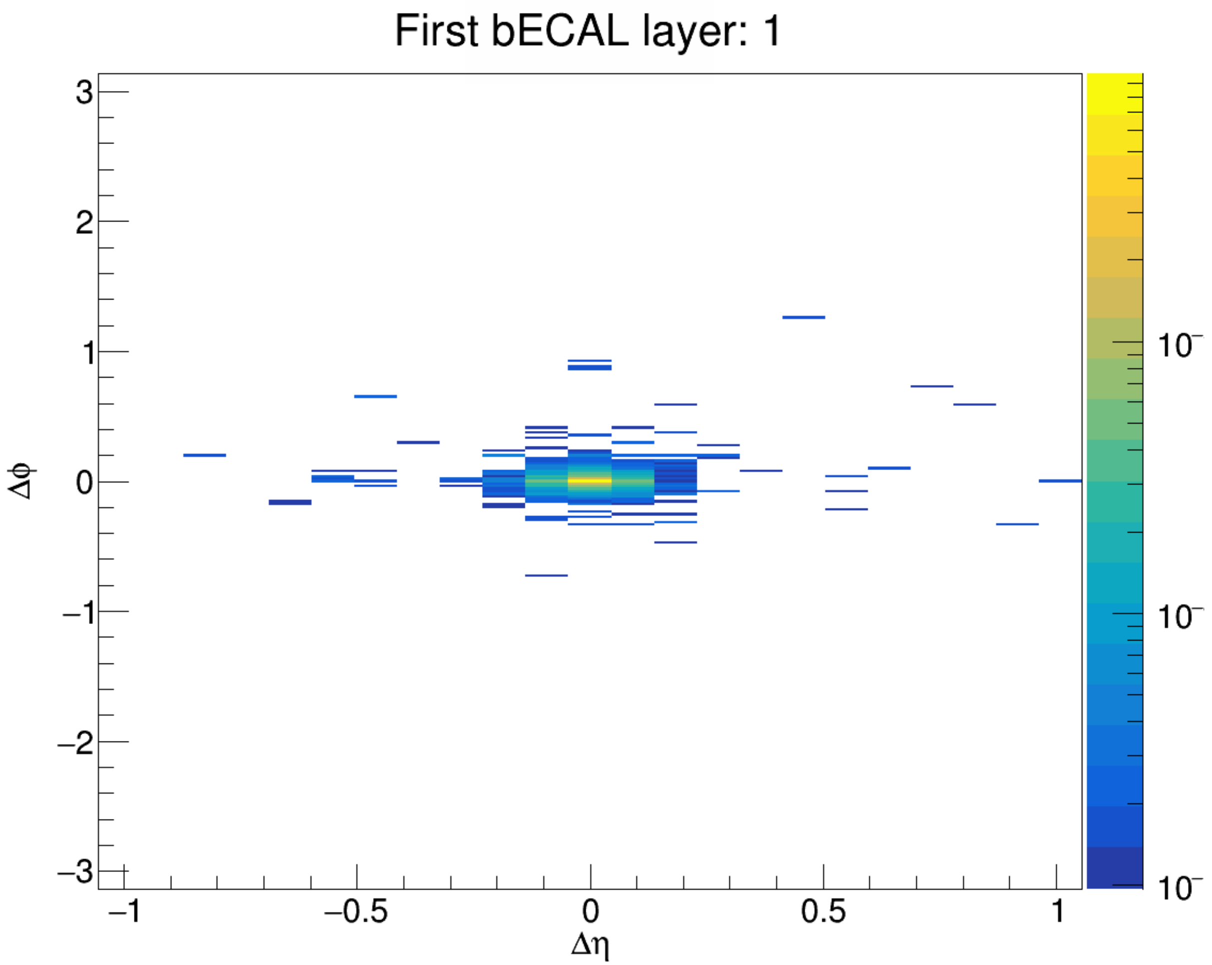
- Only qualitative study for now, will follow with quantitative to double-check

- **The widening of shower as it propagates through the bECAL+Magnet+bHCAL system seems to only be visible for high energy neutrons**

- Following slides: $\Delta\eta$ vs. $\Delta\phi$ for different first layers of bECAL

$\Delta\eta$ VS. $\Delta\phi$ VS. FIRST bECAL LAYER

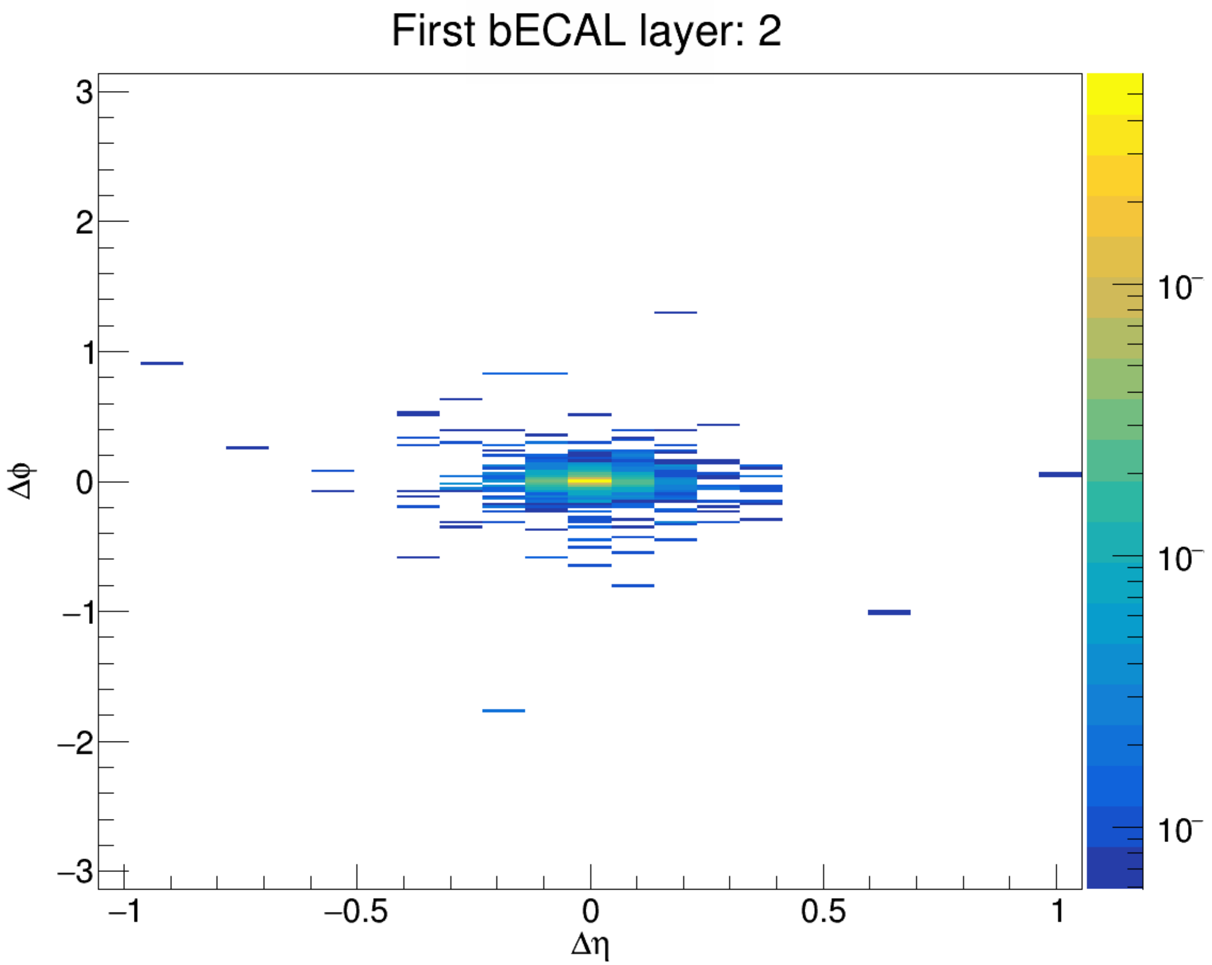
SHOWER TRANSVERSE SIZE IN bHCAL (1 GeV/c)



ePIC simulation, [25.08.0]
Single neutron, p_{MC} = 1.0 GeV/c
Full detector
Sum of bHCAL hits

- Transverse size of shower in bHCAL
  - MC neutron momentum: 1 GeV/c
  - **First hit in bECAL layer 1**
- $\Delta\eta = \eta_i - \bar{\eta}, \bar{\eta} = \frac{\sum_i \eta_i E_i}{\sum_i E_i}$
  - Index i is for individual tiles with energy deposition E_i at η_i
  - Same method for $\Delta\phi$
  - Bin sizes same as bHCAL tile sizes

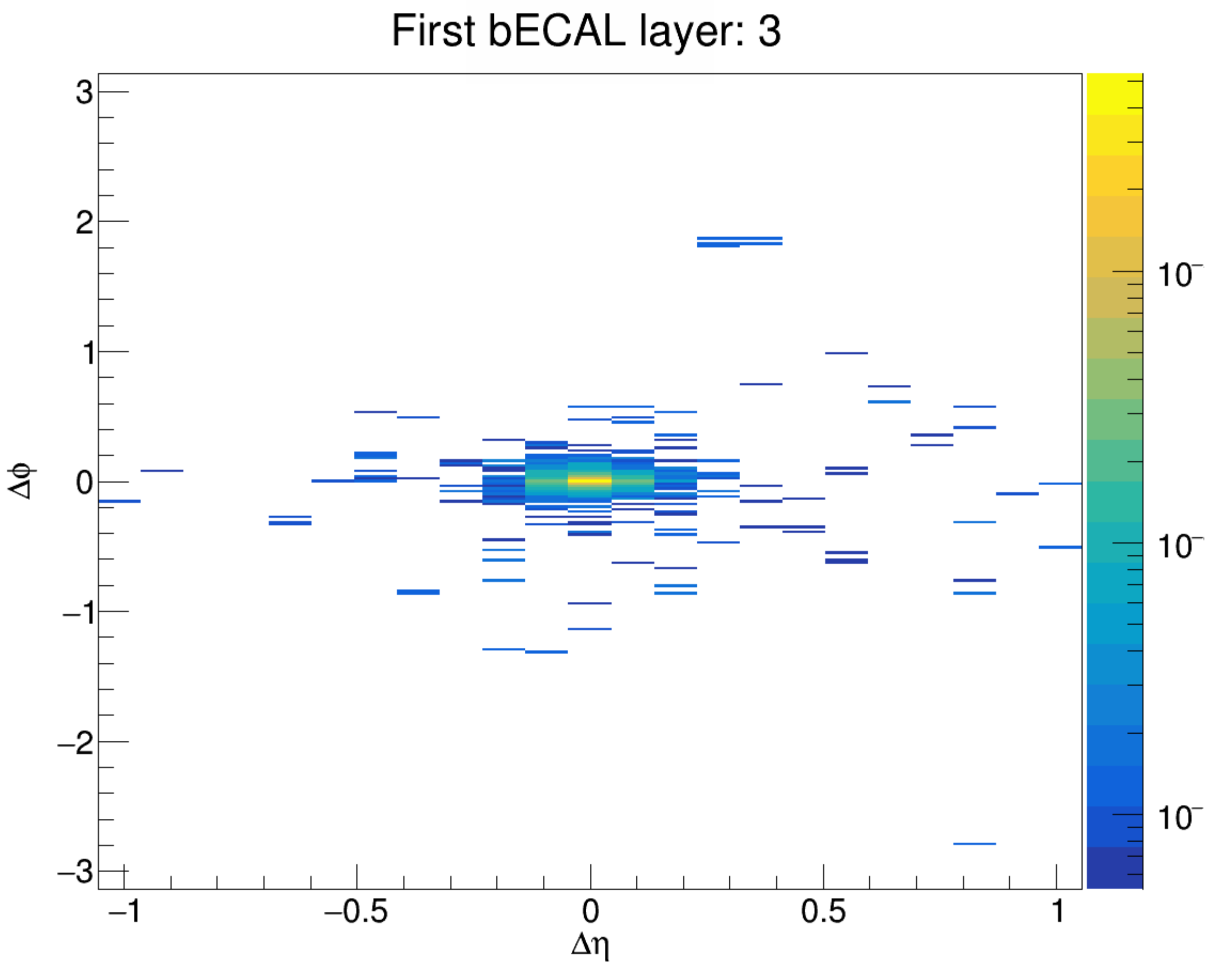
SHOWER TRANSVERSE SIZE IN bHCAL $(1\ \mathrm{GeV}/c)$



ePIC simulation, [25.08.0]
Single neutron, $p_{MC} = 1.0$ GeV/c
Full detector
Sum of bHCAL hits

- Transverse size of shower in bHCAL
  - MC neutron momentum: $1\ \mathrm{GeV}/c$
  - **First hit in bECAL layer 2**
- $\Delta\eta = \eta_i - \bar{\eta}, \bar{\eta} = \frac{\sum_i \eta_i E_i}{\sum_i E_i}$
  - Index i is for individual tiles with energy deposition E_i at η_i
  - Same method for $\Delta\phi$
  - Bin sizes same as bHCAL tile sizes

SHOWER TRANSVERSE SIZE IN bHCAL (1 GeV/c)

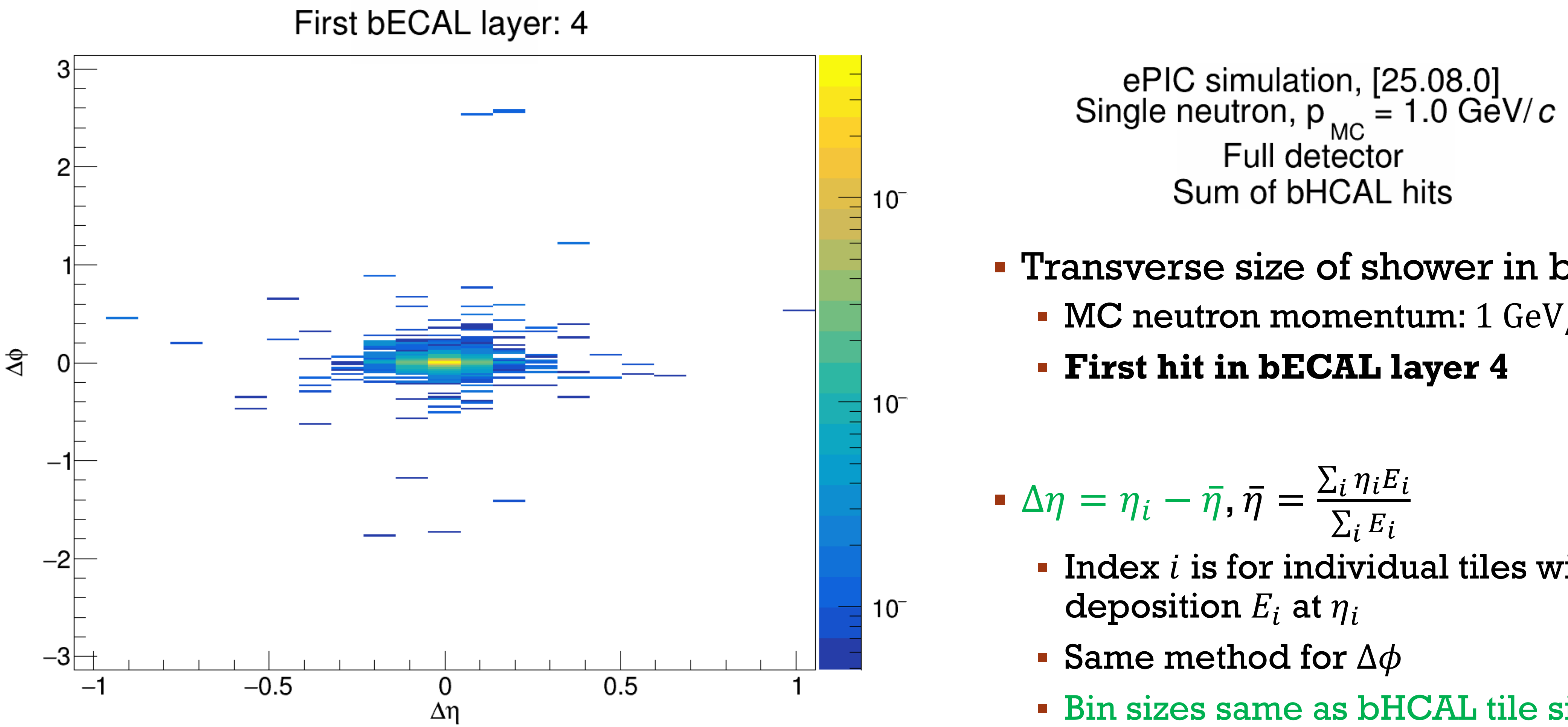


ePIC simulation, [25.08.0]
Single neutron, p_{MC} = 1.0 GeV/c
Full detector
Sum of bHCAL hits

- Transverse size of shower in bHCAL
  - MC neutron momentum: 1 GeV/c
  - **First hit in bECAL layer 3**

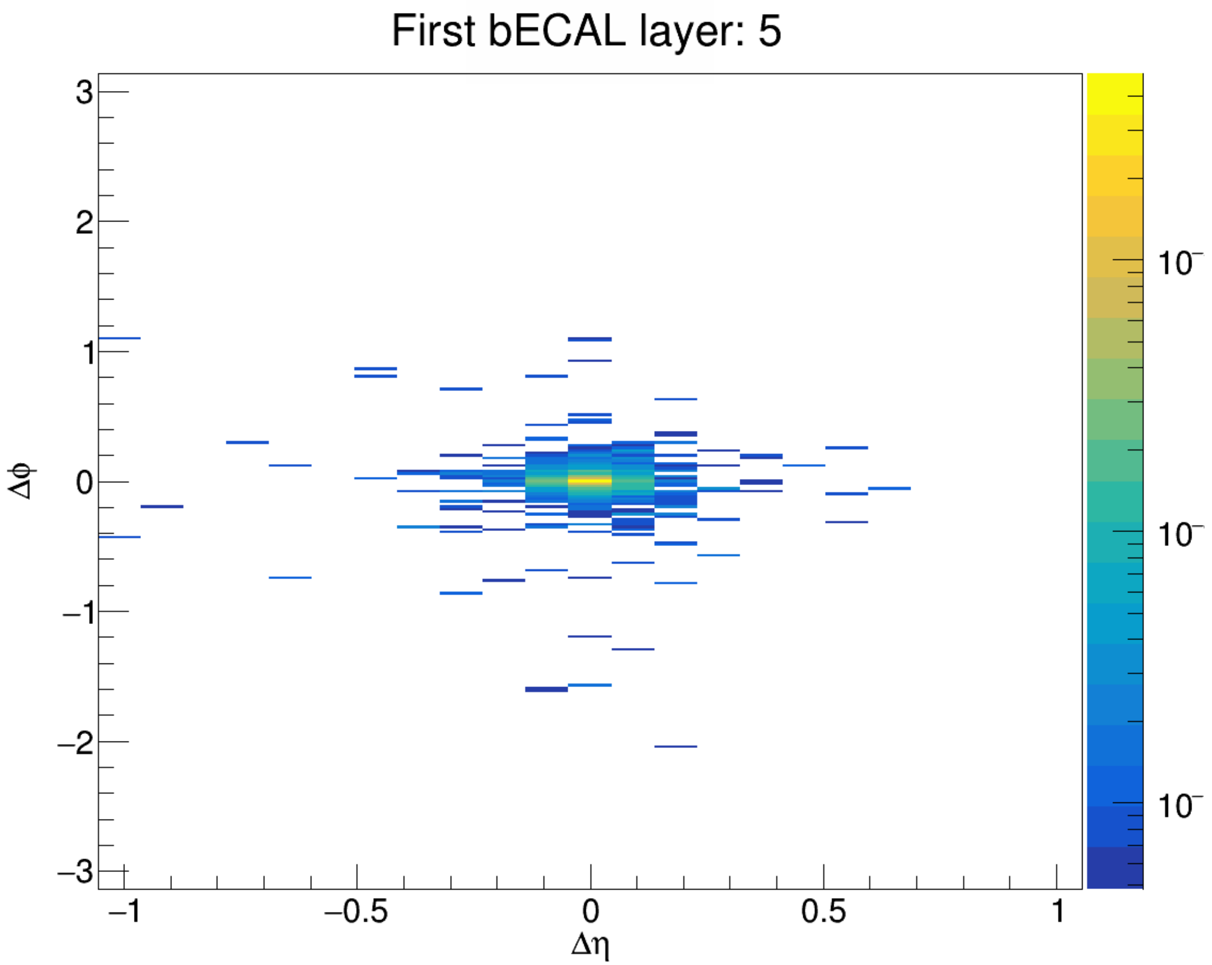
- $\Delta\eta = \eta_i - \bar{\eta}, \bar{\eta} = \frac{\sum_i \eta_i E_i}{\sum_i E_i}$
  - Index i is for individual tiles with energy deposition E_i at η_i
  - Same method for $\Delta\phi$
  - Bin sizes same as bHCAL tile sizes

SHOWER TRANSVERSE SIZE IN bHCAL (1 GeV/c)



- Transverse size of shower in bHCAL
  - MC neutron momentum: 1 GeV/c
  - **First hit in bECAL layer 4**
- $\Delta\eta = \eta_i - \bar{\eta}, \bar{\eta} = \frac{\sum_i \eta_i E_i}{\sum_i E_i}$
  - Index i is for individual tiles with energy deposition E_i at η_i
  - Same method for $\Delta\phi$
  - Bin sizes same as bHCAL tile sizes

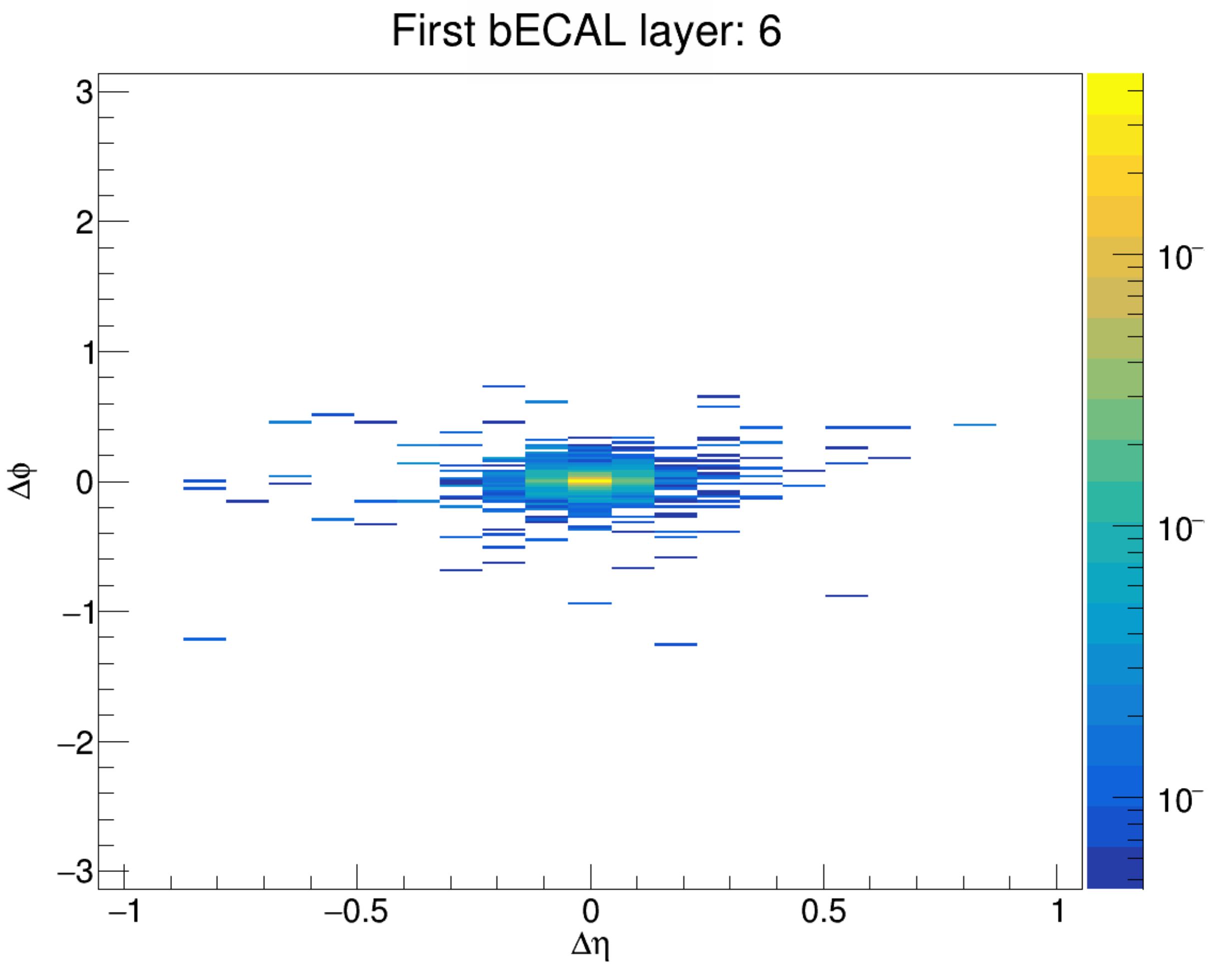
SHOWER TRANSVERSE SIZE IN bHCAL (1 GeV/c)



ePIC simulation, [25.08.0]
Single neutron, p_{MC} = 1.0 GeV/c
Full detector
Sum of bHCAL hits

- Transverse size of shower in bHCAL
  - MC neutron momentum: 1 GeV/c
  - **First hit in bECAL layer 5**
- $\Delta\eta = \eta_i - \bar{\eta}, \bar{\eta} = \frac{\sum_i \eta_i E_i}{\sum_i E_i}$
  - Index i is for individual tiles with energy deposition E_i at η_i
  - Same method for $\Delta\phi$
  - Bin sizes same as bHCAL tile sizes

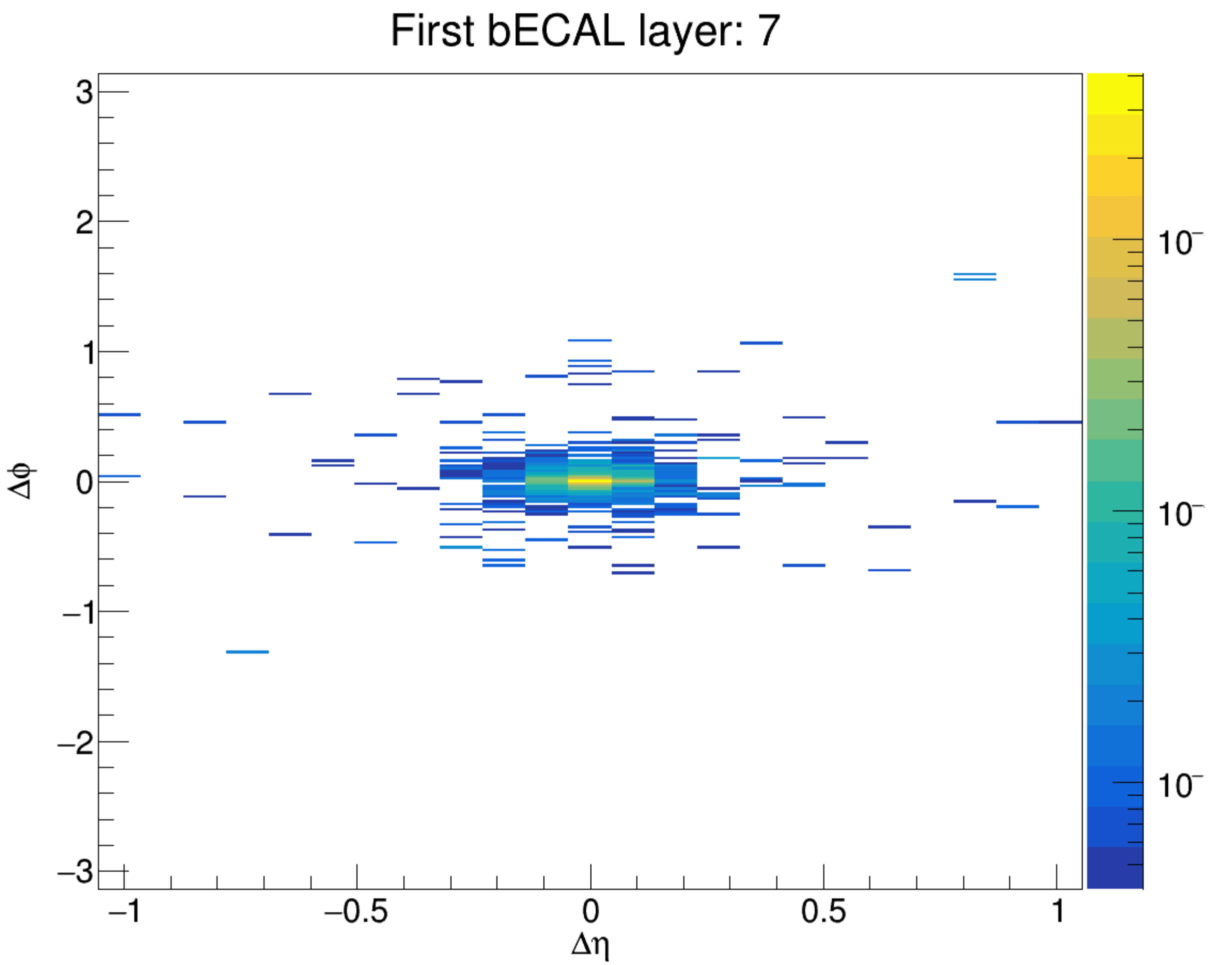
SHOWER TRANSVERSE SIZE IN bHCAL (1 GeV/c)



ePIC simulation, [25.08.0]
Single neutron, p_{MC} = 1.0 GeV/c
Full detector
Sum of bHCAL hits

- Transverse size of shower in bHCAL
  - MC neutron momentum: 1 GeV/c
  - **First hit in bECAL layer 6**
- $\Delta\eta = \eta_i - \bar{\eta}, \bar{\eta} = \frac{\sum_i \eta_i E_i}{\sum_i E_i}$
  - Index i is for individual tiles with energy deposition E_i at η_i
  - Same method for $\Delta\phi$
  - Bin sizes same as bHCAL tile sizes

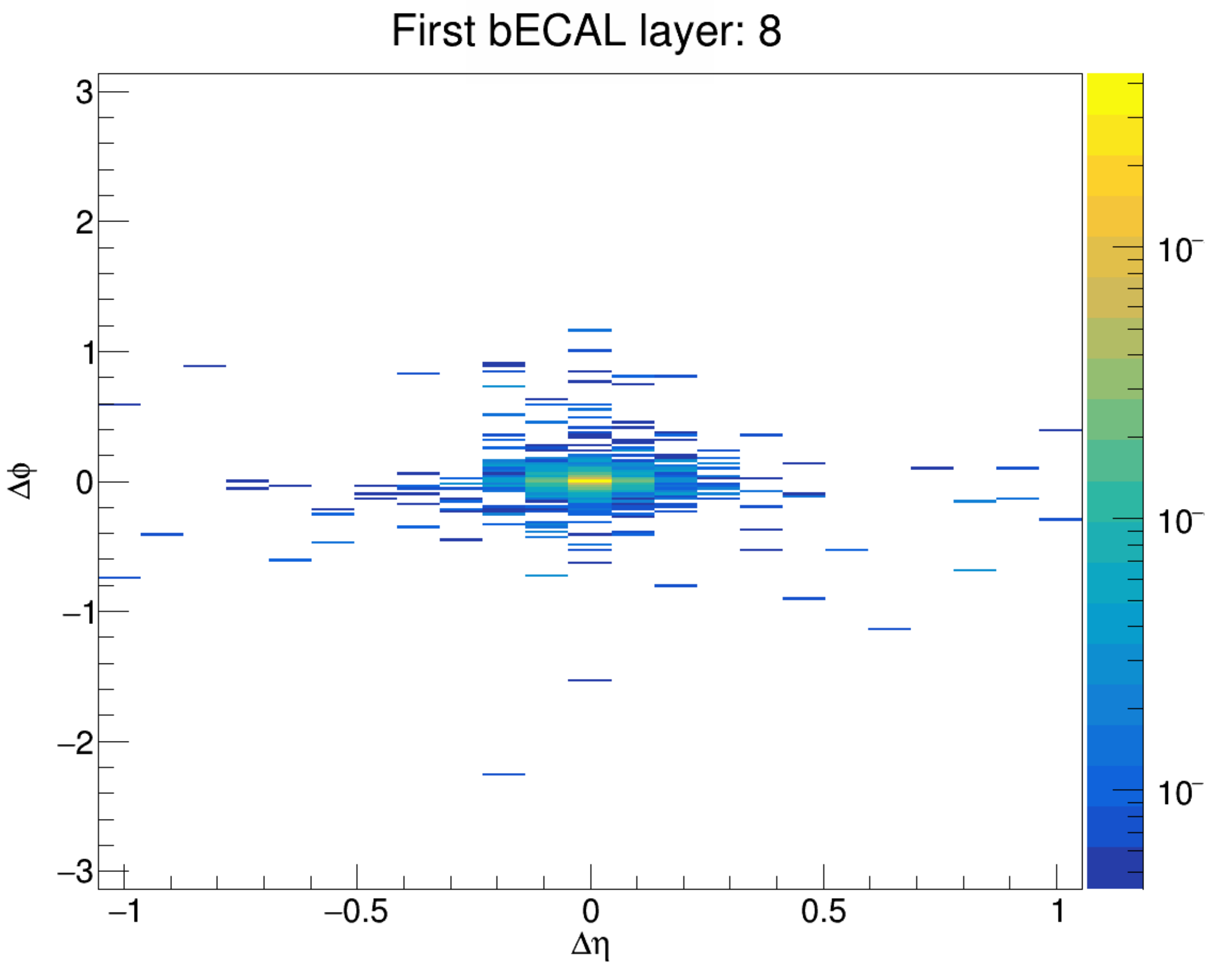
SHOWER TRANSVERSE SIZE IN bHCAL (1 GeV/c)



- Transverse size of shower in bHCAL
  - MC neutron momentum: 1 GeV/c
  - **First hit in bECAL layer 7**

- $\Delta\eta = \eta_i - \bar{\eta}, \bar{\eta} = \frac{\sum_i \eta_i E_i}{\sum_i E_i}$
  - Index i is for individual tiles with energy deposition E_i at η_i
  - Same method for $\Delta\phi$
  - Bin sizes same as bHCAL tile sizes

SHOWER TRANSVERSE SIZE IN bHCAL (1 GeV/c)

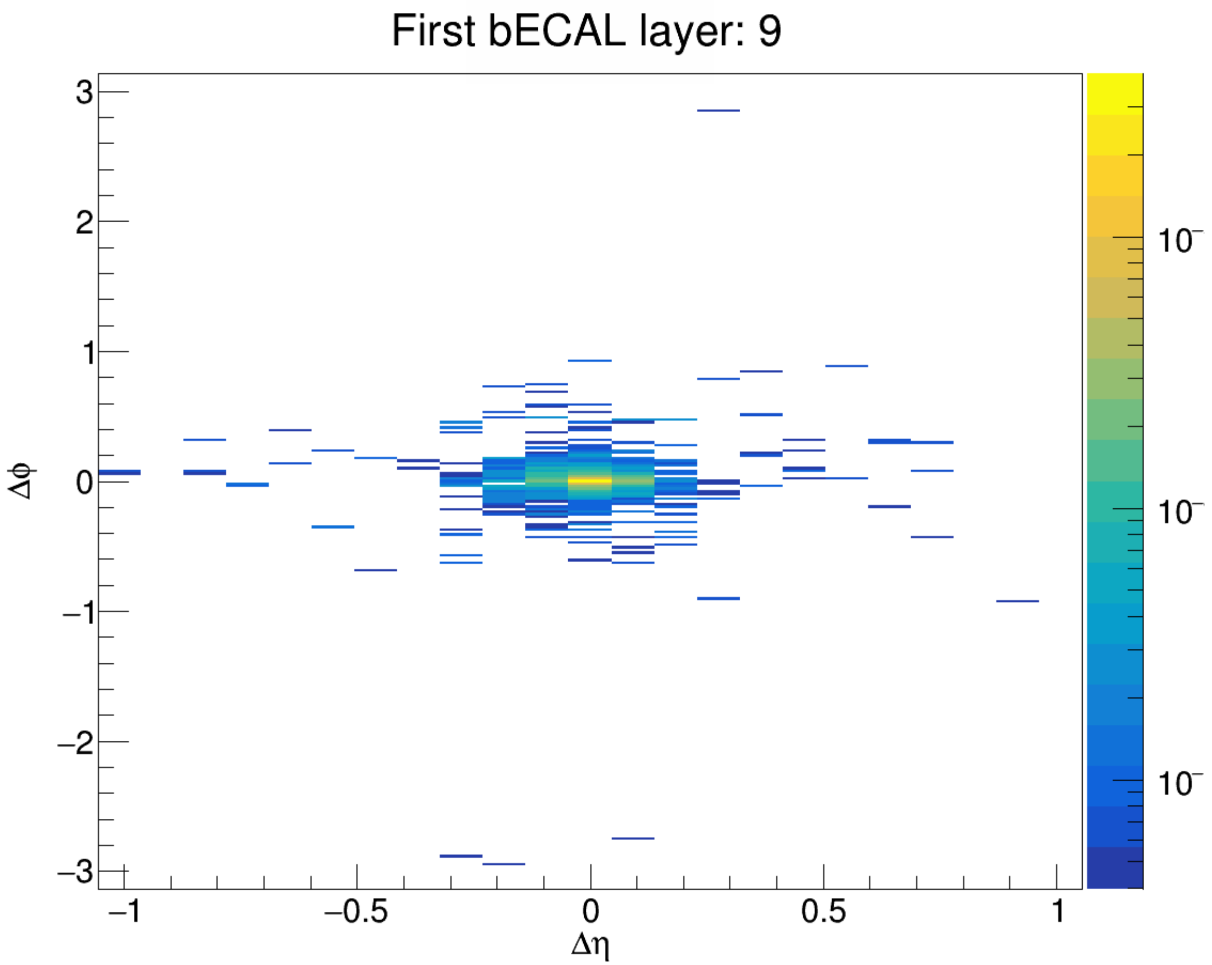


ePIC simulation, [25.08.0]
Single neutron, p_{MC} = 1.0 GeV/c
Full detector
Sum of bHCAL hits

- Transverse size of shower in bHCAL
  - MC neutron momentum: 1 GeV/c
  - **First hit in bECAL layer 8**

- $\Delta\eta = \eta_i - \bar{\eta}, \bar{\eta} = \frac{\sum_i \eta_i E_i}{\sum_i E_i}$
  - Index i is for individual tiles with energy deposition E_i at η_i
  - Same method for $\Delta\phi$
  - Bin sizes same as bHCAL tile sizes

SHOWER TRANSVERSE SIZE IN bHCAL $(1\ \mathrm{GeV}/c)$

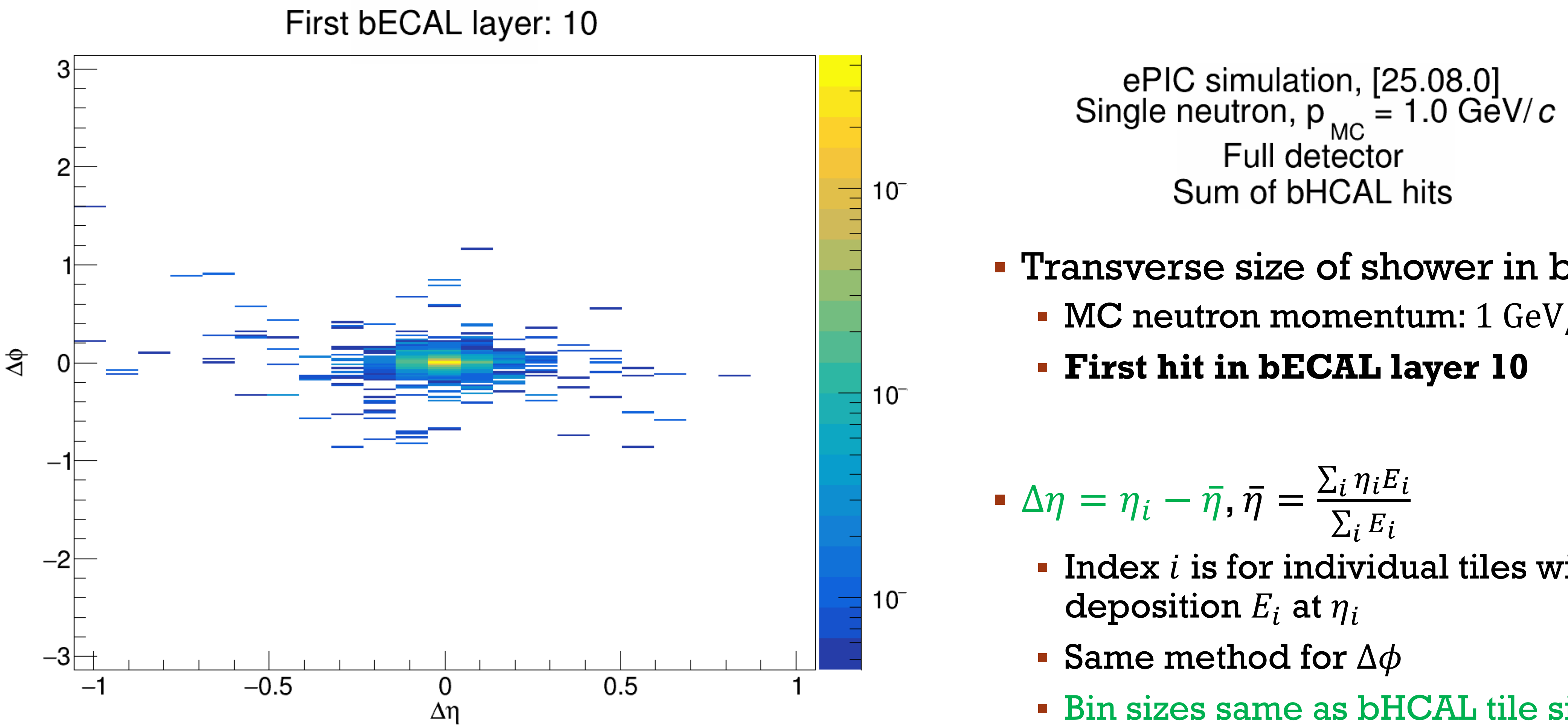


ePIC simulation, [25.08.0]
Single neutron, $p_{MC} = 1.0\ \mathrm{GeV}/c$
Full detector
Sum of bHCAL hits

- Transverse size of shower in bHCAL
  - MC neutron momentum: $1\ \mathrm{GeV}/c$
  - **First hit in bECAL layer 9**

- $\Delta\eta = \eta_i - \bar{\eta}, \bar{\eta} = \frac{\sum_i \eta_i E_i}{\sum_i E_i}$
  - Index i is for individual tiles with energy deposition E_i at η_i
  - Same method for $\Delta\phi$
  - Bin sizes same as bHCAL tile sizes

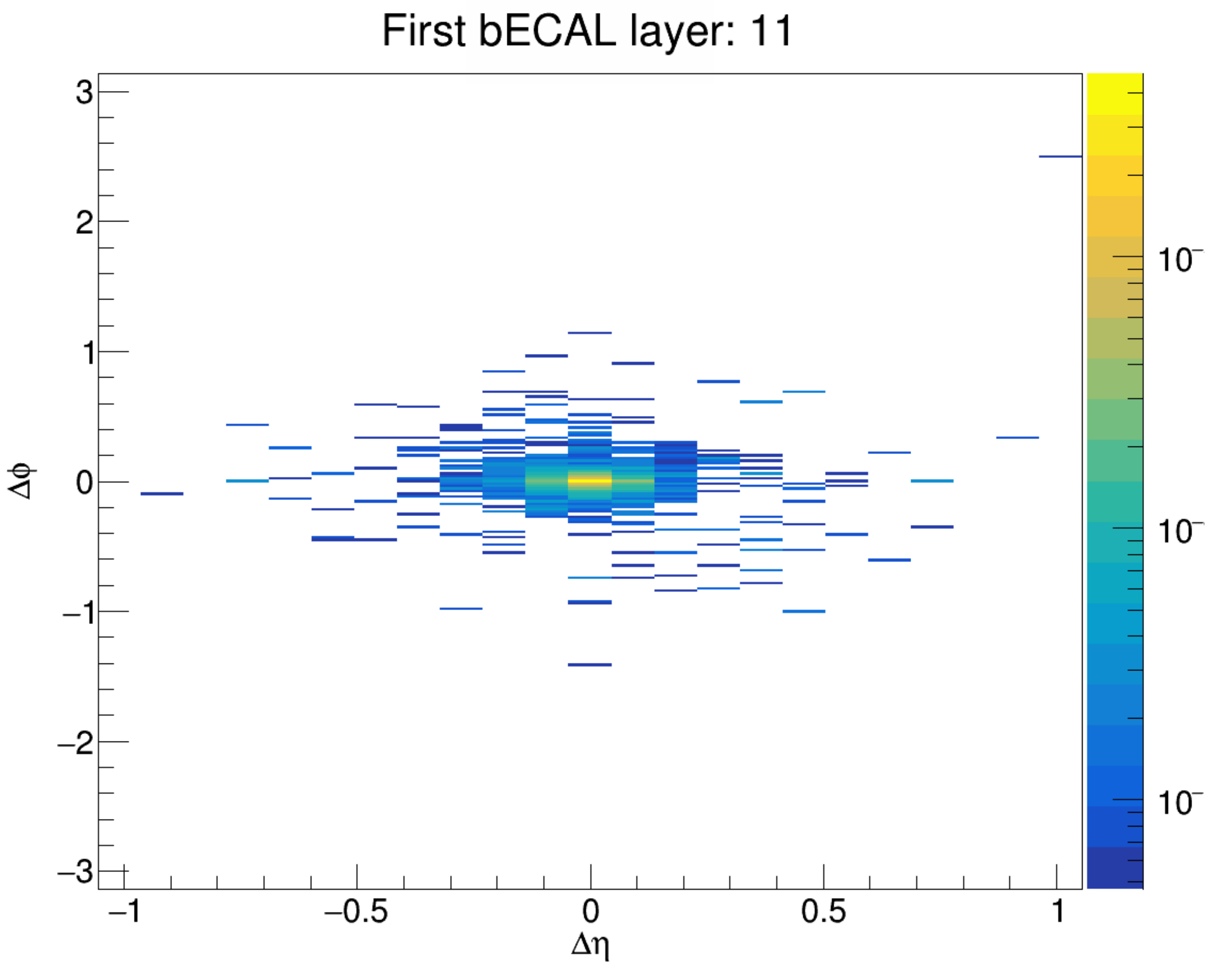
SHOWER TRANSVERSE SIZE IN bHCAL (1 GeV/c)



- Transverse size of shower in bHCAL
  - MC neutron momentum: 1 GeV/c
  - **First hit in bECAL layer 10**

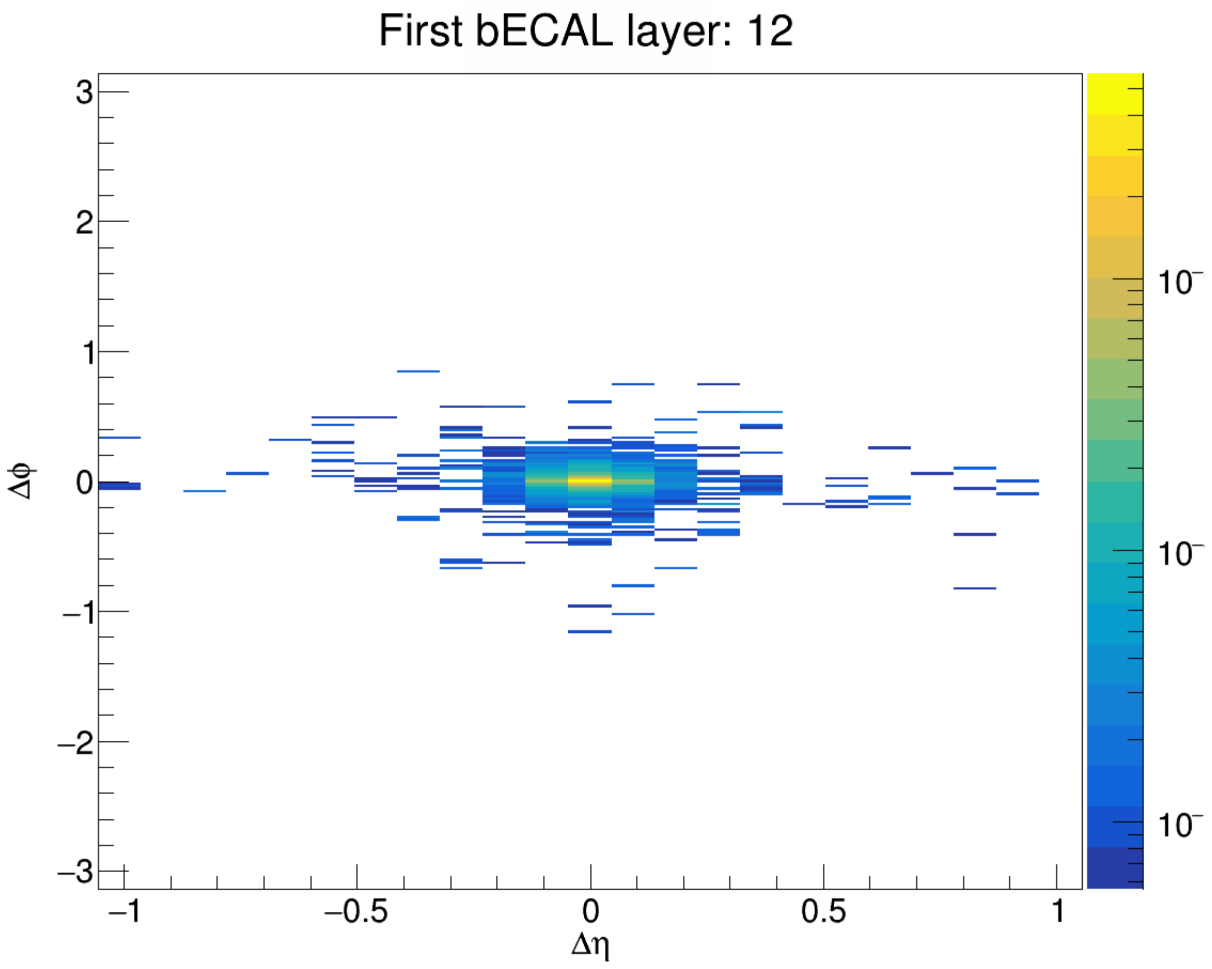
- $\Delta\eta = \eta_i - \bar{\eta}, \bar{\eta} = \frac{\sum_i \eta_i E_i}{\sum_i E_i}$
  - Index i is for individual tiles with energy deposition E_i at η_i
  - Same method for $\Delta\phi$
  - Bin sizes same as bHCAL tile sizes

SHOWER TRANSVERSE SIZE IN bHCAL $(1\ \mathrm{GeV}/c)$



- Transverse size of shower in bHCAL
  - MC neutron momentum: $1\ \mathrm{GeV}/c$
  - **First hit in bECAL layer 11**
- $\Delta\eta = \eta_i - \bar{\eta}, \bar{\eta} = \frac{\sum_i \eta_i E_i}{\sum_i E_i}$
  - Index i is for individual tiles with energy deposition E_i at η_i
  - Same method for $\Delta\phi$
  - Bin sizes same as bHCAL tile sizes

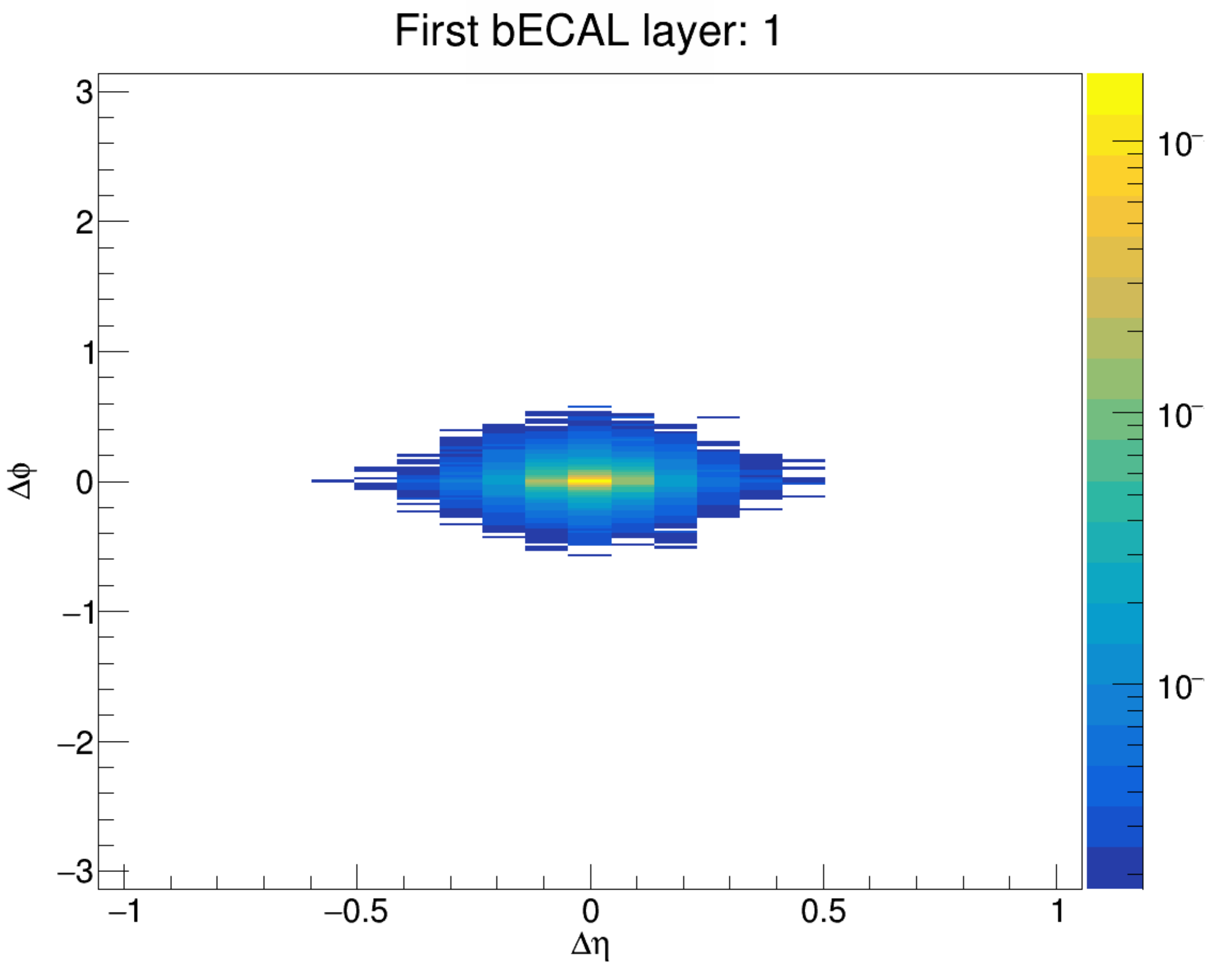
Shower transverse size in bHCAL (1 GeV/c)



ePIC simulation, [25.08.0]
Single neutron, p_{MC} = 1.0 GeV/c
Full detector
Sum of bHCAL hits

- Transverse size of shower in bHCAL
  - MC neutron momentum: $1\ \mathrm{GeV}/c$
  - **First hit in bECAL layer 12**
- $\Delta\eta = \eta_i - \bar{\eta}, \bar{\eta} = \frac{\sum_i \eta_i E_i}{\sum_i E_i}$
  - Index i is for individual tiles with energy deposition E_i at η_i
  - Same method for $\Delta\phi$
  - Bin sizes same as bHCAL tile sizes

SHOWER TRANSVERSE SIZE IN bHCAL (2 GeV/c)

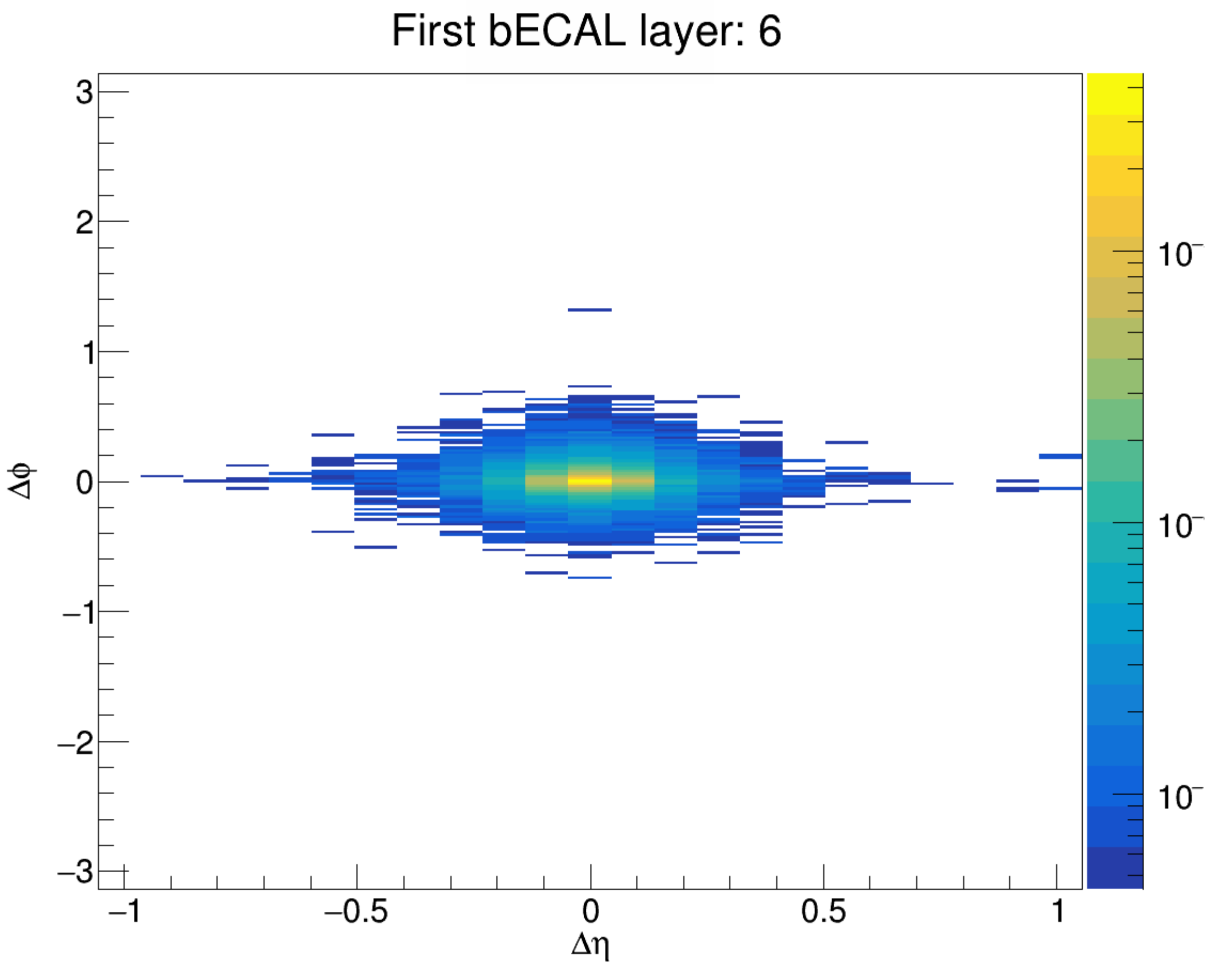


ePIC simulation, [25.08.0]
Single neutron, p_{MC} = 2.0 GeV/c
Full detector
Sum of bHCAL hits

- Transverse size of shower in bHCAL
  - MC neutron momentum: 2 GeV/c
  - **First hit in bECAL layer 1**

- $\Delta\eta = \eta_i - \bar{\eta}, \bar{\eta} = \frac{\sum_i \eta_i E_i}{\sum_i E_i}$
  - Index i is for individual tiles with energy deposition E_i at η_i
  - Same method for $\Delta\phi$
  - Bin sizes same as bHCAL tile sizes

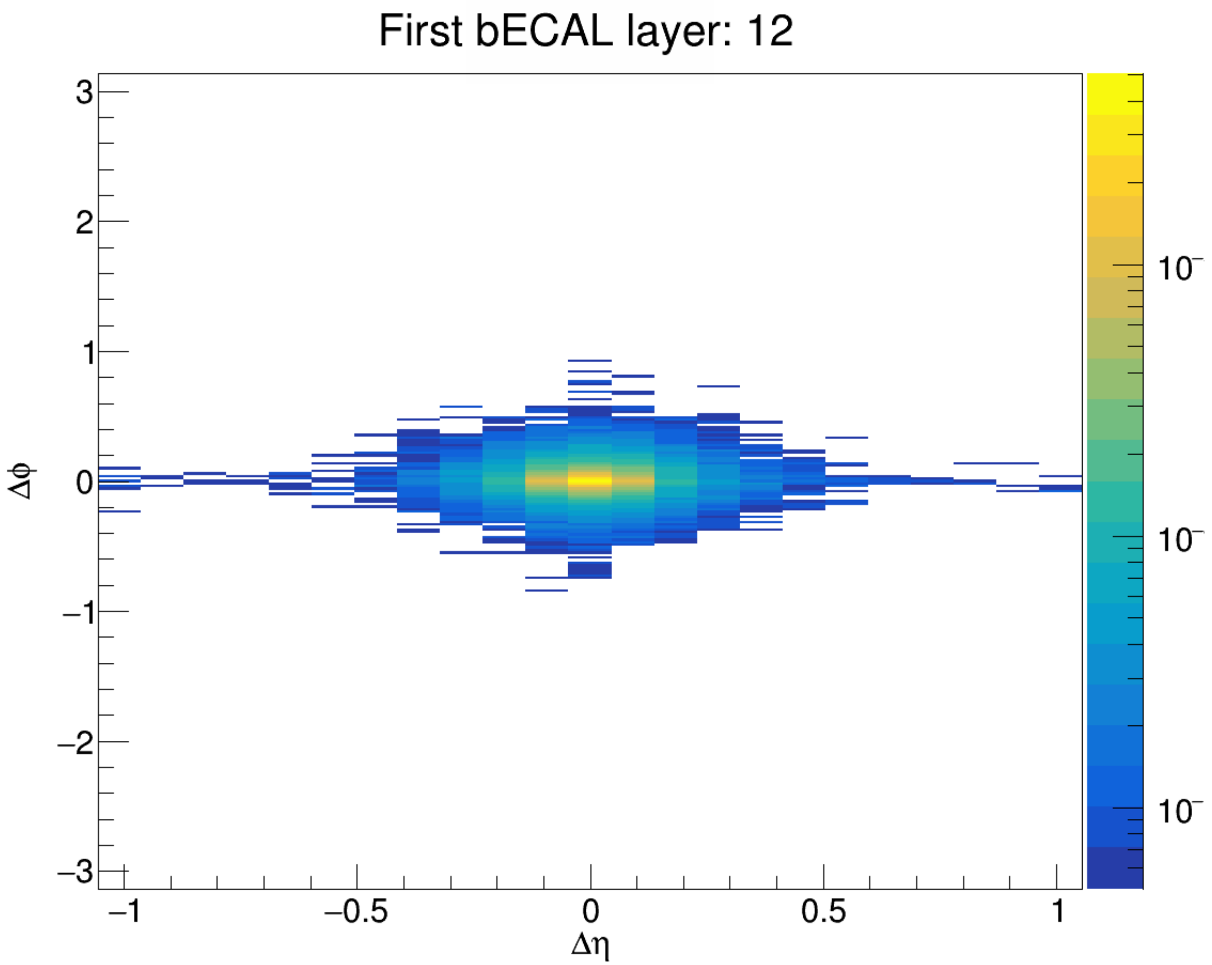
SHOWER TRANSVERSE SIZE IN bHCAL (2 GeV/c)



ePIC simulation, [25.08.0]
Single neutron, p_{MC} = 2.0 GeV/c
Full detector
Sum of bHCAL hits

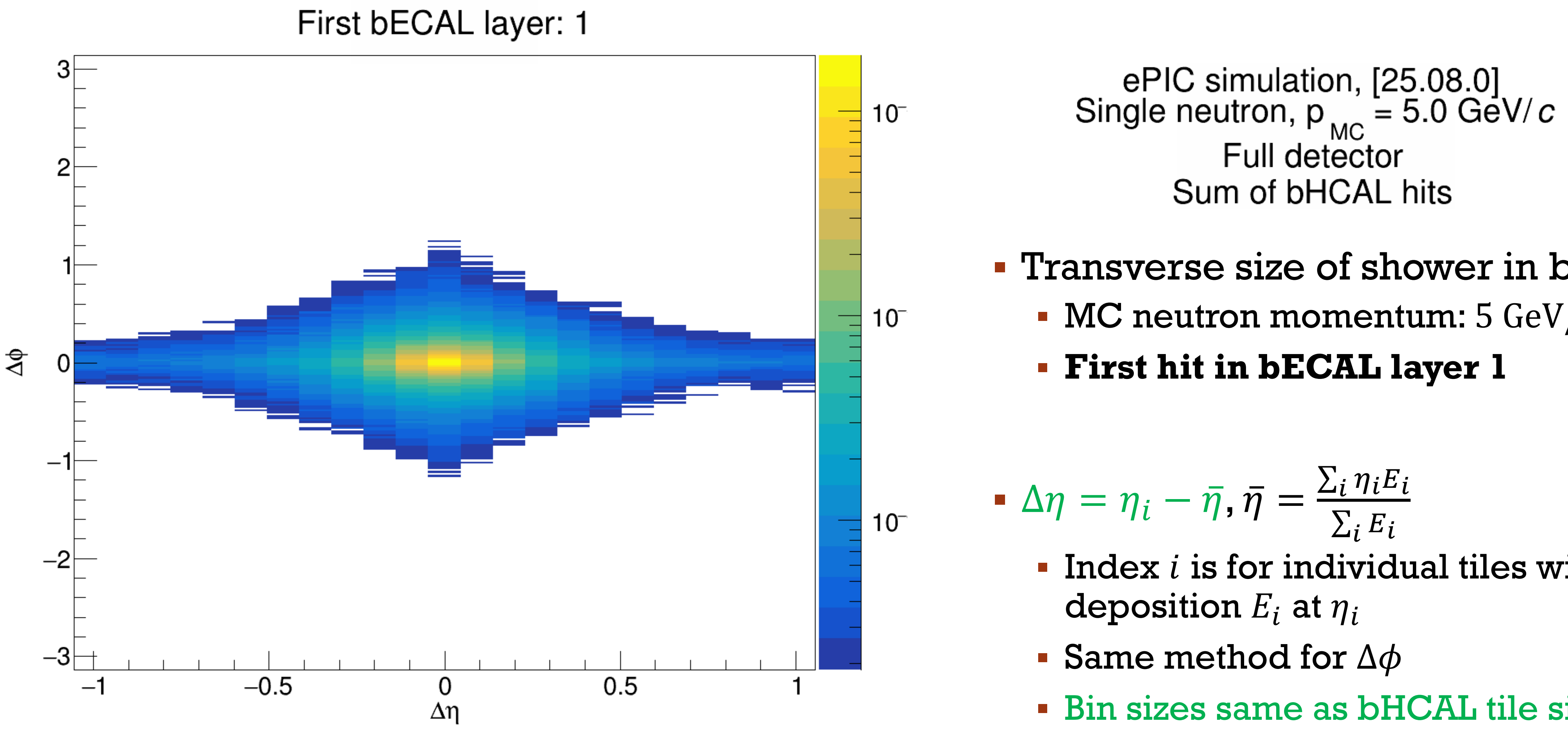
- Transverse size of shower in bHCAL
  - MC neutron momentum: 2 GeV/c
  - **First hit in bECAL layer 6**
- $\Delta\eta = \eta_i - \bar{\eta}, \bar{\eta} = \frac{\sum_i \eta_i E_i}{\sum_i E_i}$
  - Index i is for individual tiles with energy deposition E_i at η_i
  - Same method for $\Delta\phi$
  - Bin sizes same as bHCAL tile sizes

SHOWER TRANSVERSE SIZE IN bHCAL (2 GeV/c)



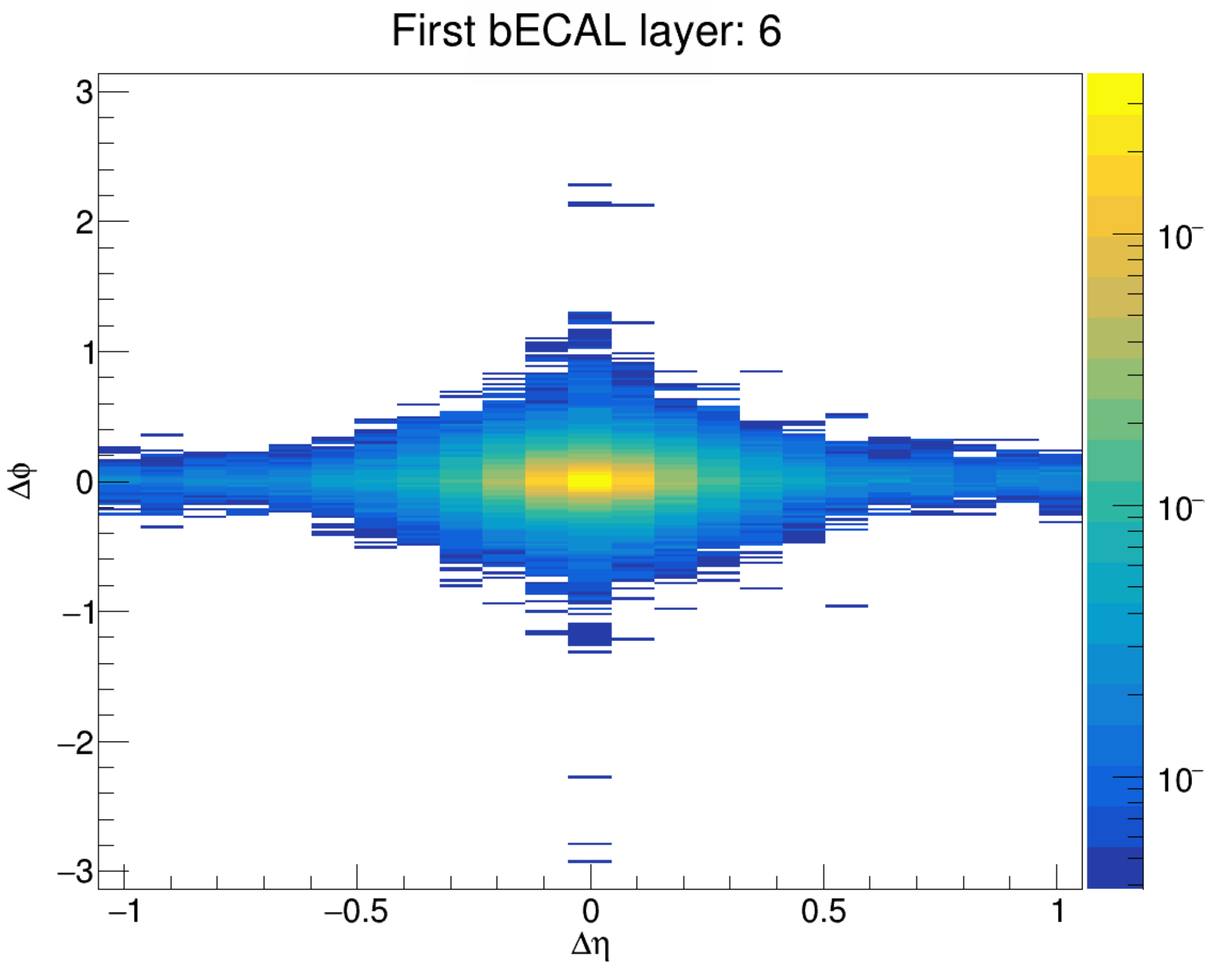
- Transverse size of shower in bHCAL
  - MC neutron momentum: 2 GeV/c
  - **First hit in bECAL layer 12**
- $\Delta\eta = \eta_i - \bar{\eta}, \bar{\eta} = \frac{\sum_i \eta_i E_i}{\sum_i E_i}$
  - Index i is for individual tiles with energy deposition E_i at η_i
  - Same method for $\Delta\phi$
  - Bin sizes same as bHCAL tile sizes

SHOWER TRANSVERSE SIZE IN bHCAL (5 GeV/c)



- Transverse size of shower in bHCAL
  - MC neutron momentum: 5 GeV/c
  - **First hit in bECAL layer 1**
- $\Delta\eta = \eta_i - \bar{\eta}, \bar{\eta} = \frac{\sum_i \eta_i E_i}{\sum_i E_i}$
  - Index i is for individual tiles with energy deposition E_i at η_i
  - Same method for $\Delta\phi$
  - Bin sizes same as bHCAL tile sizes

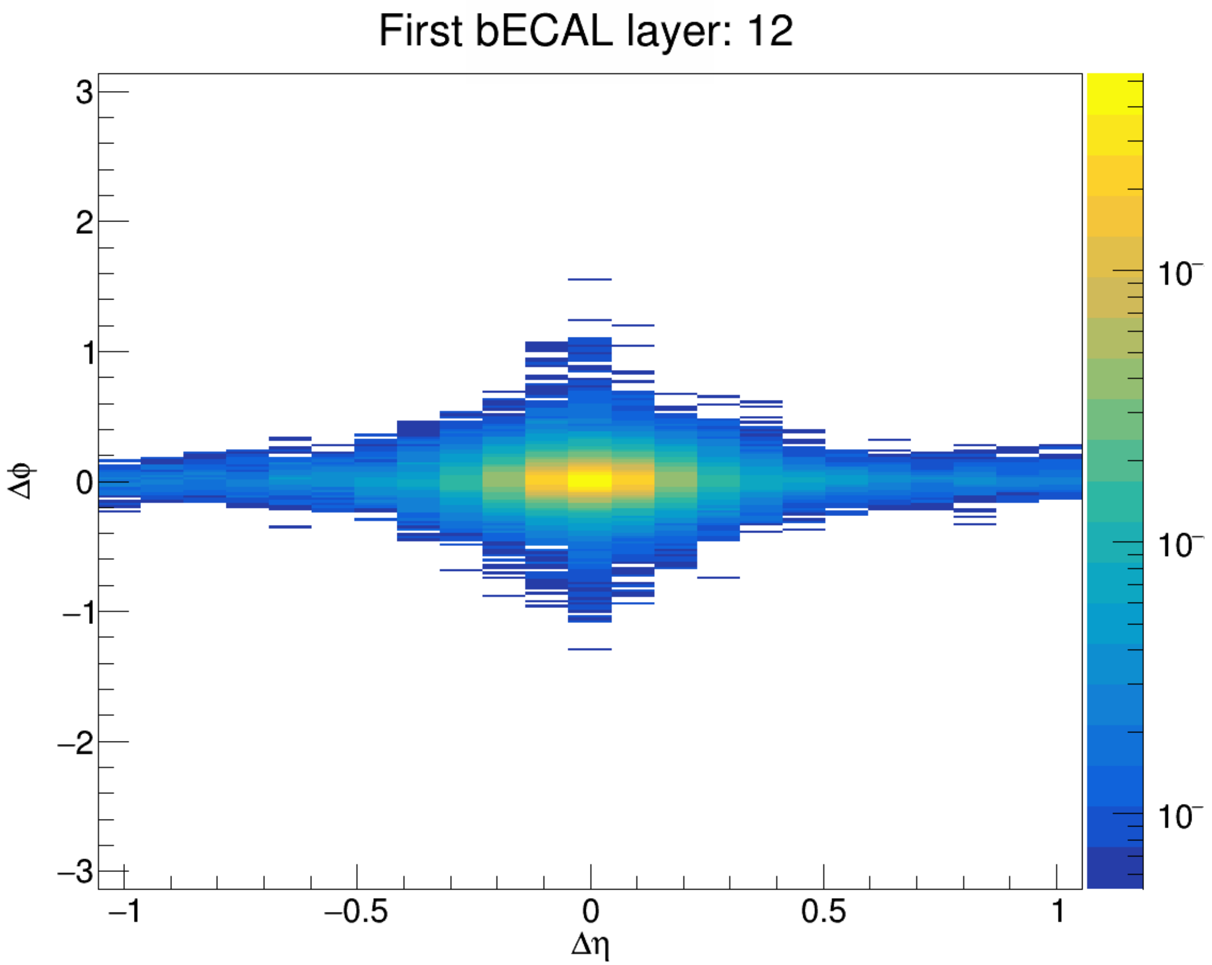
SHOWER TRANSVERSE SIZE IN bHCAL (5 GeV/c)



ePIC simulation, [25.08.0]
Single neutron, p_{MC} = 5.0 GeV/c
Full detector
Sum of bHCAL hits

- Transverse size of shower in bHCAL
  - MC neutron momentum: 5 GeV/c
  - **First hit in bECAL layer 6**
- $\Delta\eta = \eta_i - \bar{\eta}, \bar{\eta} = \frac{\sum_i \eta_i E_i}{\sum_i E_i}$
  - Index i is for individual tiles with energy deposition E_i at η_i
  - Same method for $\Delta\phi$
  - Bin sizes same as bHCAL tile sizes

SHOWER TRANSVERSE SIZE IN bHCAL (5 GeV/c)



ePIC simulation, [25.08.0]
Single neutron, p_{MC} = 5.0 GeV/c
Full detector
Sum of bHCAL hits

- Transverse size of shower in bHCAL
  - MC neutron momentum: 5 GeV/c
  - **First hit in bECAL layer 12**

- $\Delta\eta = \eta_i - \bar{\eta}, \bar{\eta} = \frac{\sum_i \eta_i E_i}{\sum_i E_i}$
  - Index i is for individual tiles with energy deposition E_i at η_i
  - Same method for $\Delta\phi$
  - Bin sizes same as bHCAL tile sizes

SECTION SUMMARY

- Similar conclusion as in section with global $\Delta\eta$ vs. $\Delta\phi$ distribution

- $1\ \mathrm{GeV}/c$: No significant difference between different hit combinations observed
- $2\ \mathrm{GeV}/c$: Shower profile in bHCAL a bit wider when shower starts in early bECAL, but difference is small
- $5\ \mathrm{GeV}/c$: Shower profile in bHCAL substantially wider when shower starts early in bECAL (layer 1) compared to case where it starts late (layer 12)

- The widening of shower as it propagates through the bECAL+Magnet+bHCAL system seems to only be visible for high energy neutrons

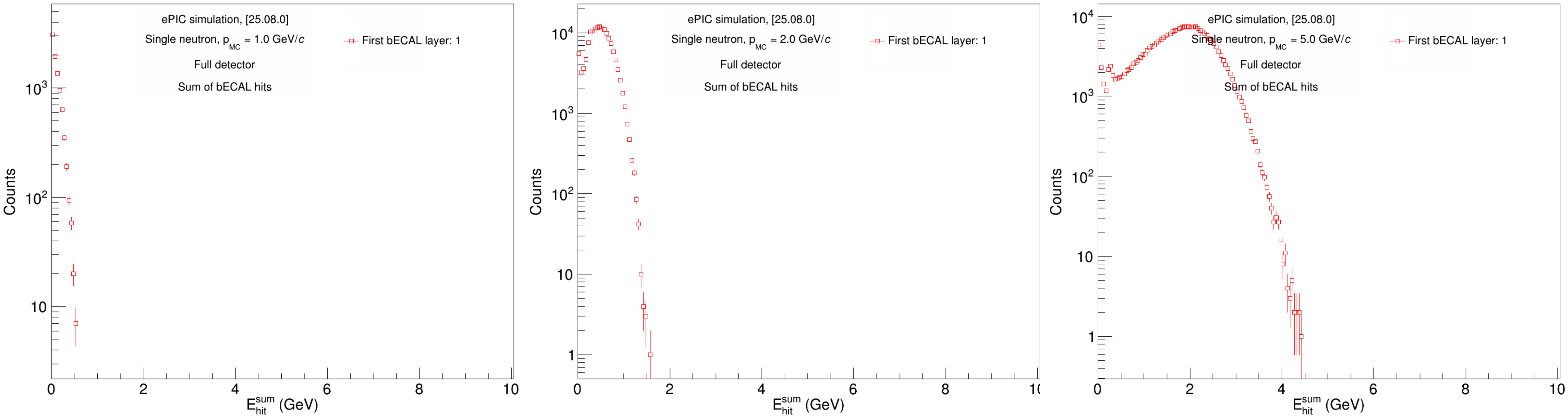
- **Shower profile in bHCAL as a function of first layer in bHCAL does not seem to provide any useful information for manual calibrations of 1 GeV/c (for now)**
  - Might be useful for higher energies

ENERGY DEPOSITION VS. FIRST bECAL LAYER

ENERGY IN bECAL – FIRST LAYER 1

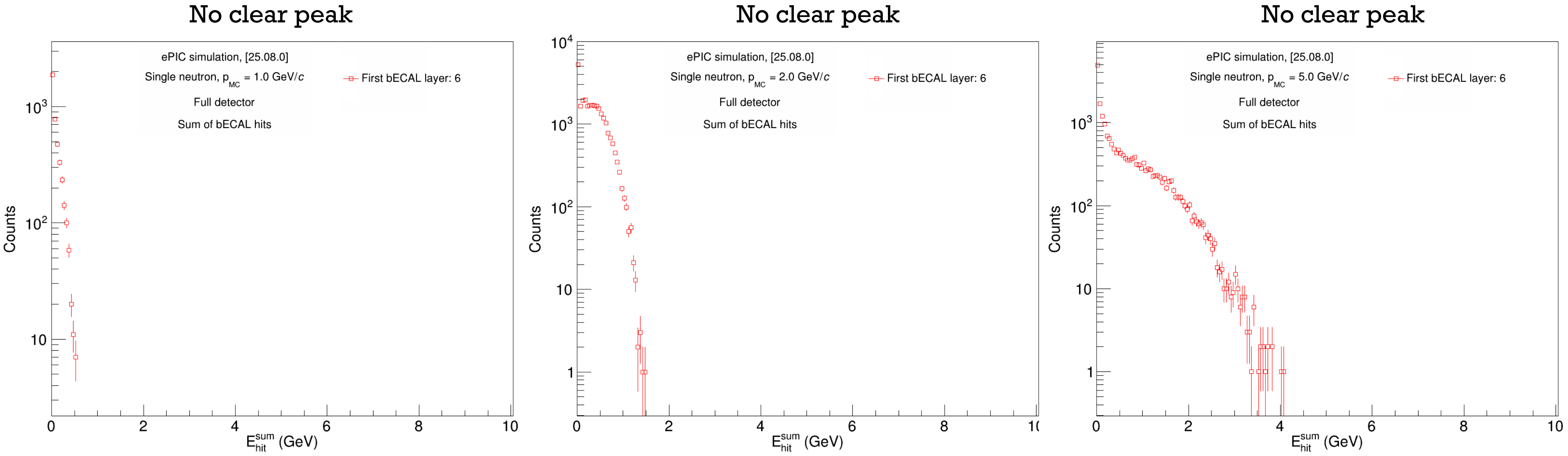
- Energy deposition in **bECAL** for different first layer in bECAL
  - Three MC neutron momenta
    - (left) 1 GeV/c, (middle) 2 GeV/c, (right) 5 GeV/c
  - First bECAL layer 1

No clear peak | Clear peak | Clear peak



ENERGY IN bECAL – FIRST LAYER 6

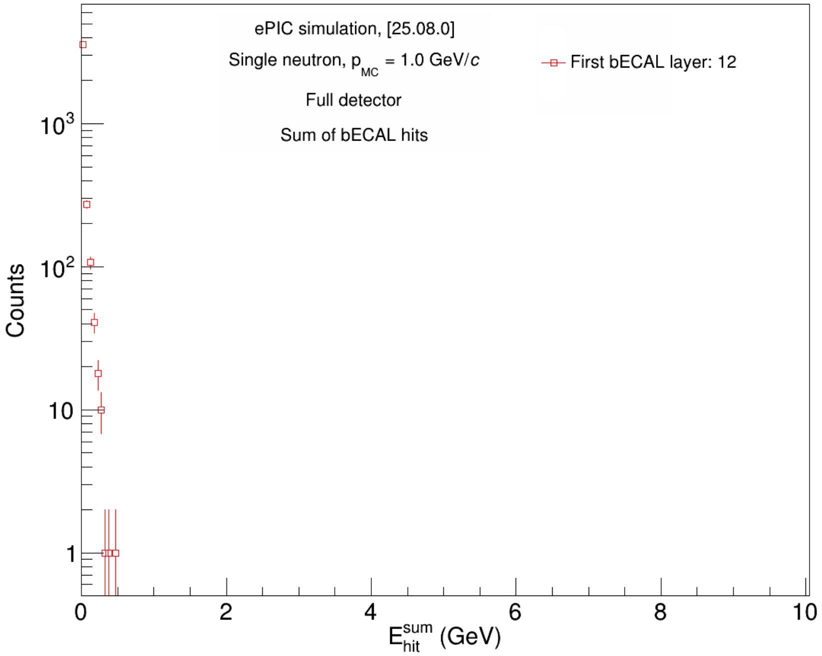
- Energy deposition in **bECAL** for different first layer in bECAL
  - Three MC neutron momenta
    - (left) $1\ \mathrm{GeV}/c$, (middle) $2\ \mathrm{GeV}/c$, (right) $5\ \mathrm{GeV}/c$
  - First bECAL layer 6



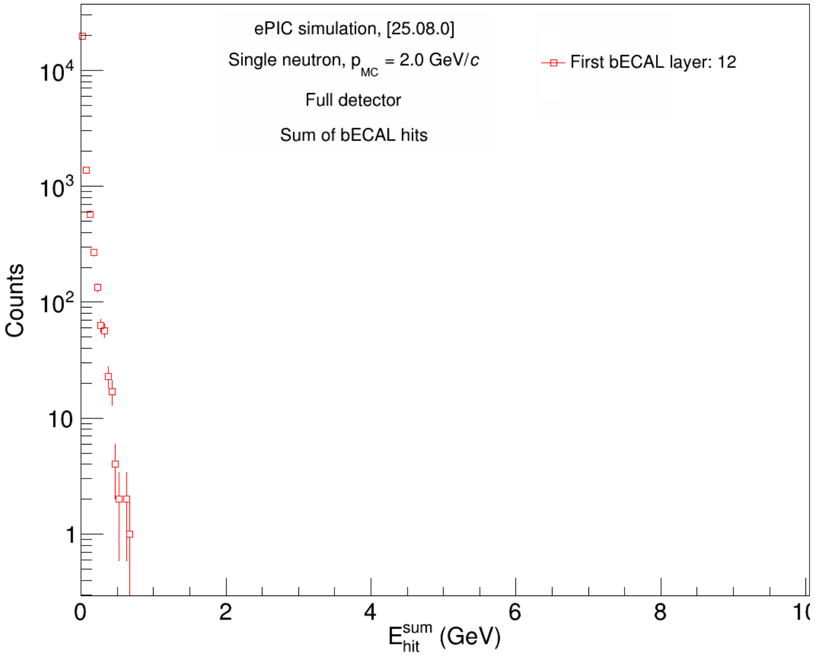
ENERGY IN bECAL – FIRST LAYER 12

- Energy deposition in **bECAL** for different first layer in bECAL
  - Three MC neutron momenta
    - (left) $1\ \mathrm{GeV}/c$, (middle) $2\ \mathrm{GeV}/c$, (right) $5\ \mathrm{GeV}/c$
  - First bECAL layer 12

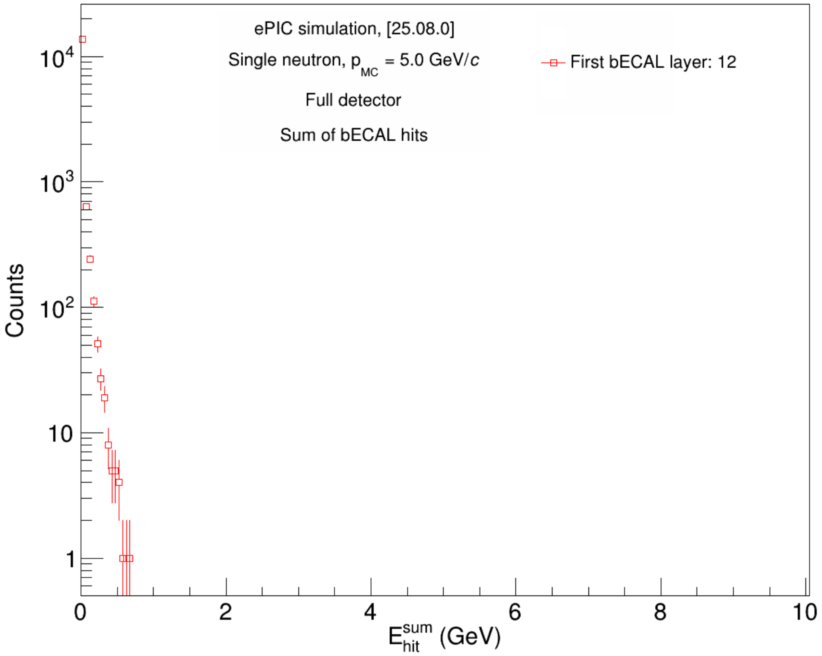
No clear peak



No clear peak



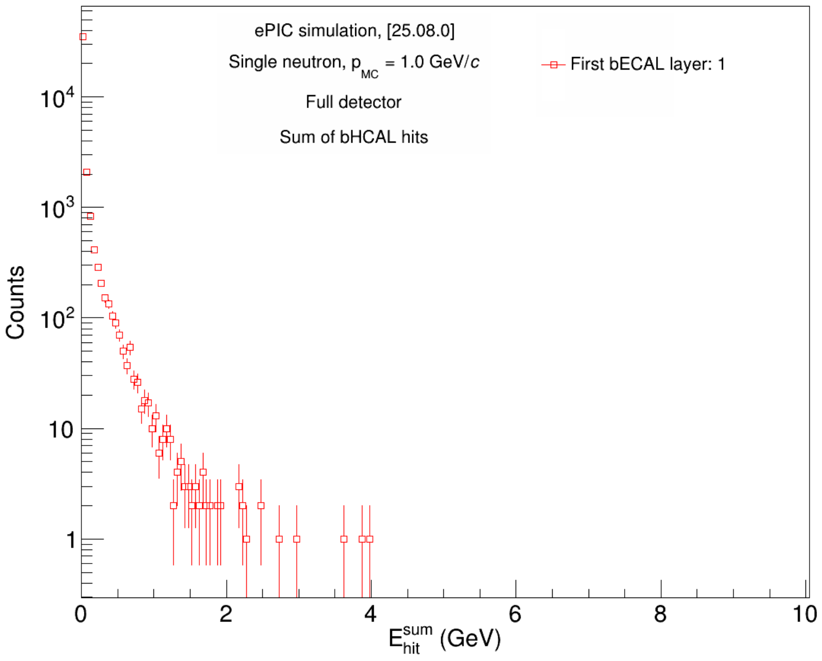
No clear peak



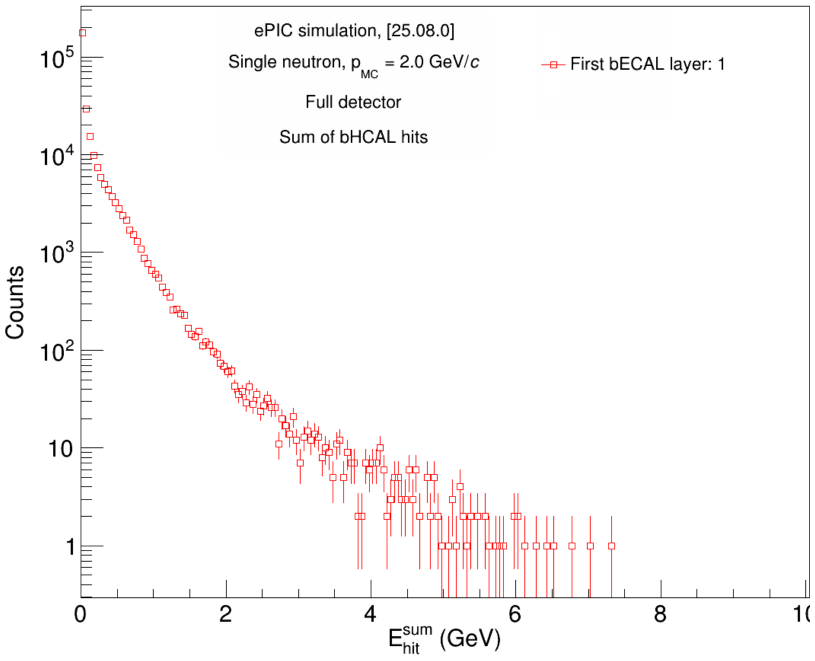
ENERGY IN bHCAL – FIRST LAYER 1

- Energy deposition in **bHCAL** for different first layer in bECAL
  - Three MC neutron momenta
    - (left) $1\ \mathrm{GeV}/c$, (middle) $2\ \mathrm{GeV}/c$, (right) $5\ \mathrm{GeV}/c$
  - First bECAL layer 1

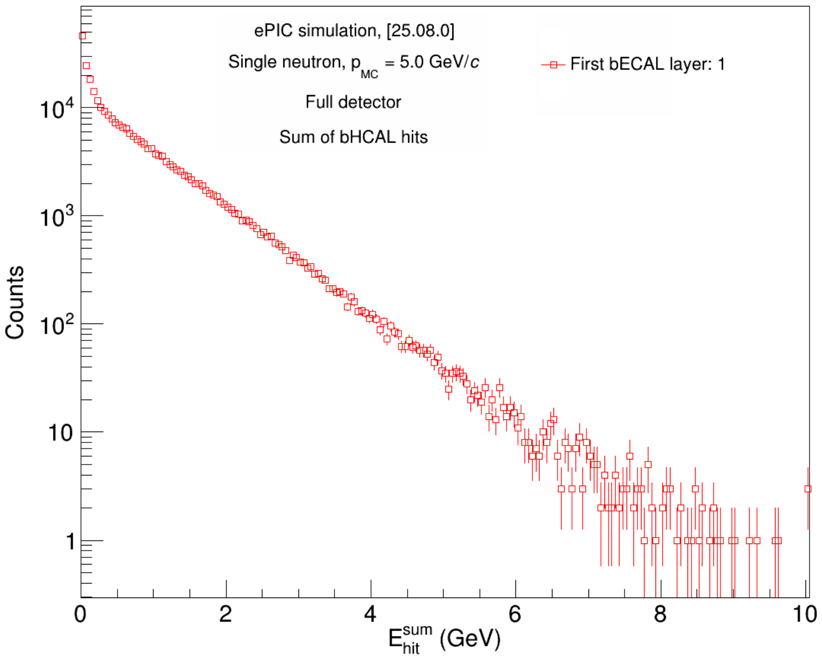
No clear peak



No clear peak



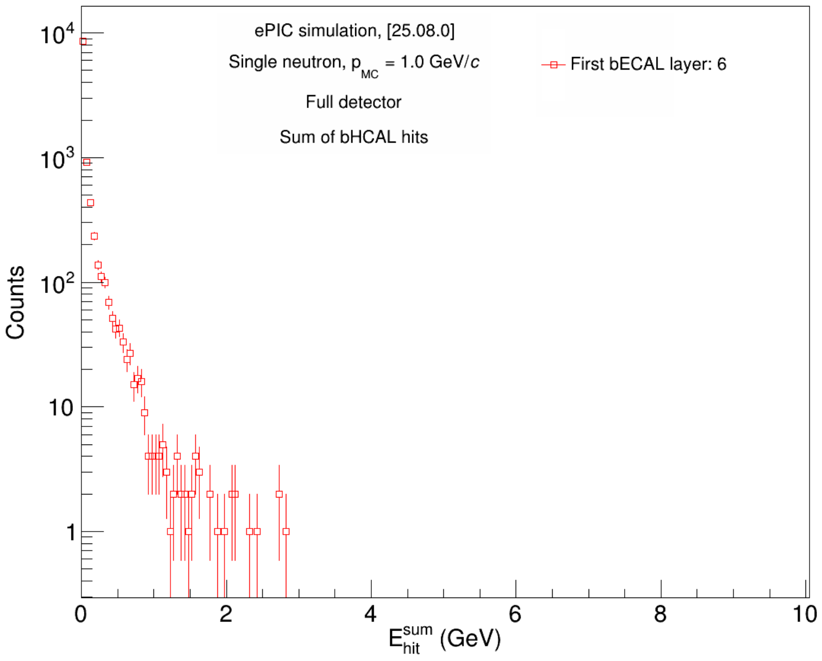
No clear peak



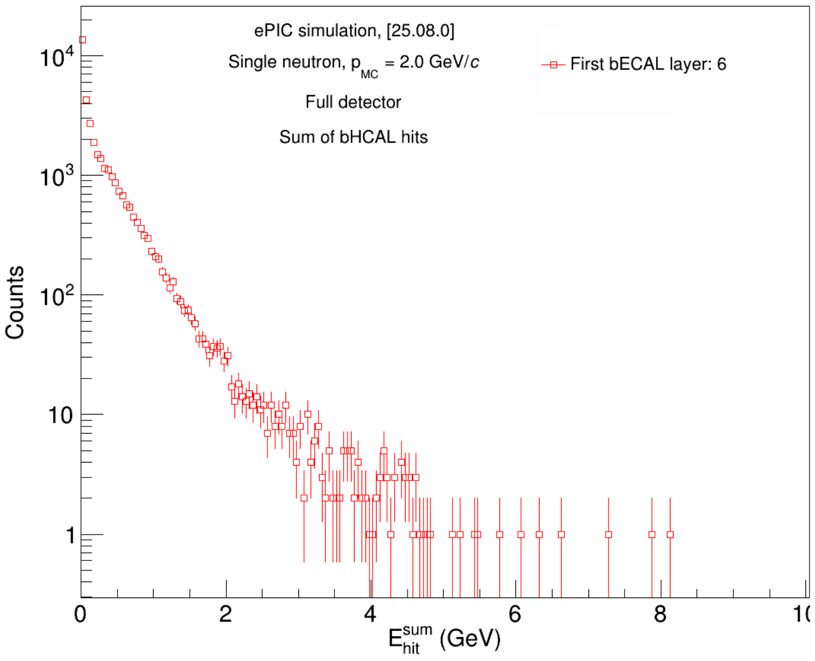
ENERGY IN bHCAL – FIRST LAYER 6

- Energy deposition in **bHCAL** for different first layer in bECAL
  - Three MC neutron momenta
    - (left) 1 GeV/c, (middle) 2 GeV/c, (right) 5 GeV/c
  - First bECAL layer 6

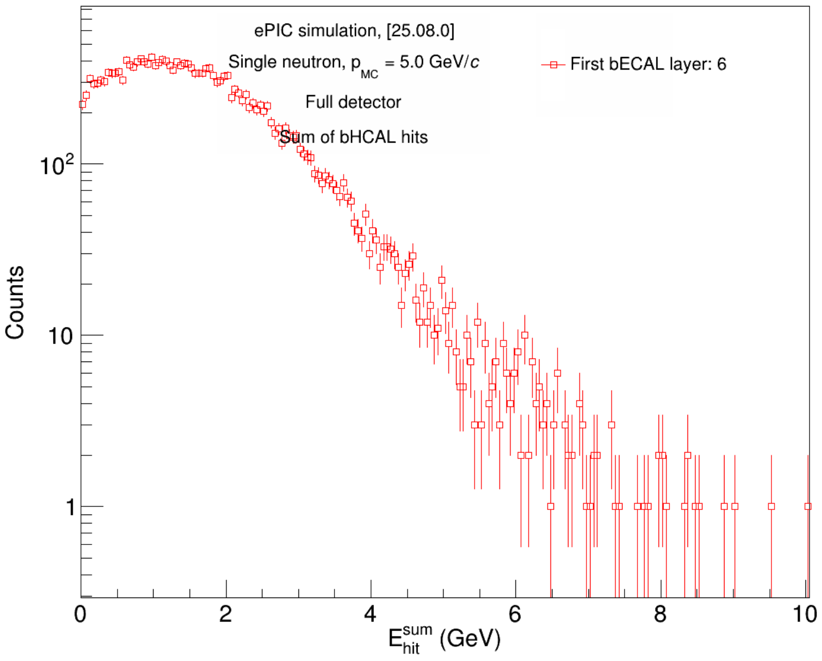
No clear peak



No clear peak



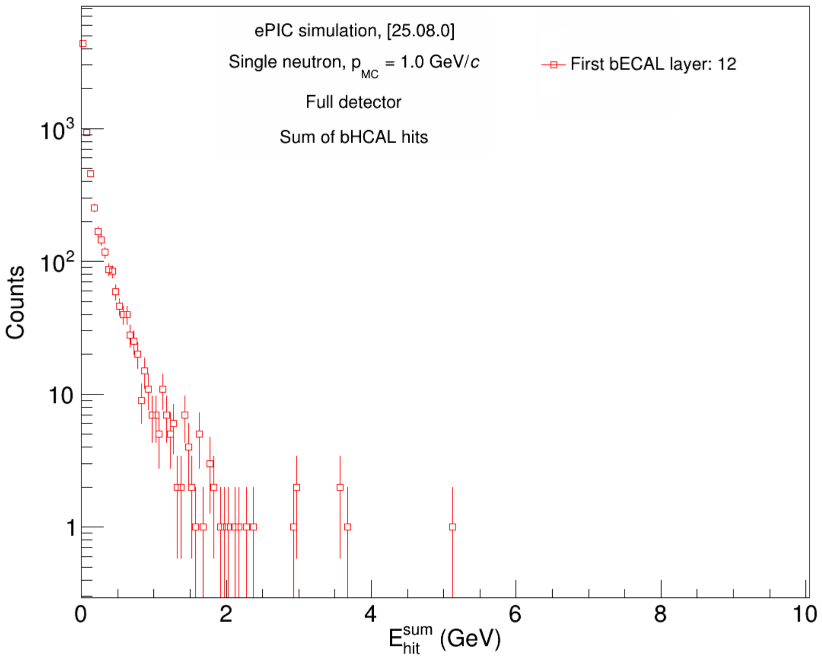
Peak starts to appear



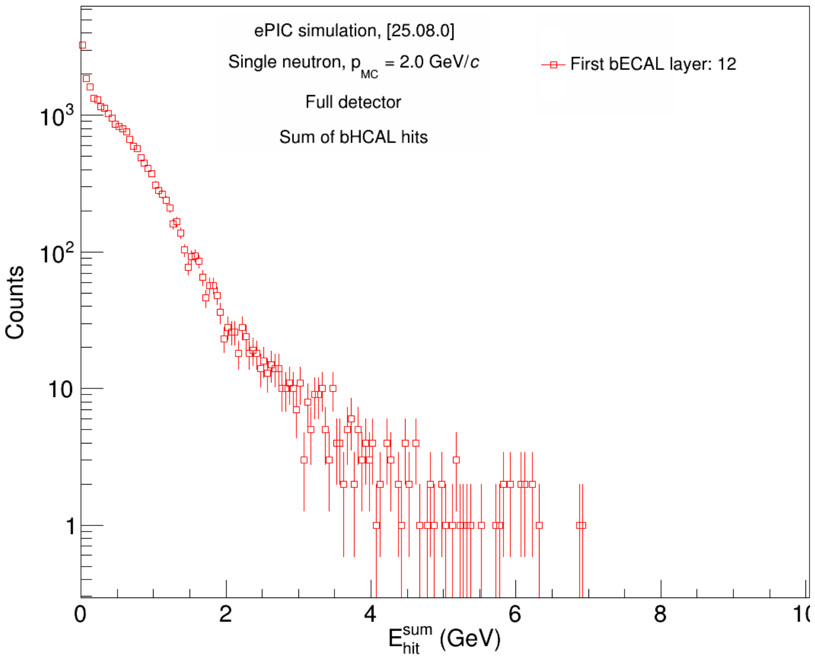
ENERGY IN bHCAL – FIRST LAYER 12

- Energy deposition in **bHCAL** for different first layer in bECAL
  - Three MC neutron momenta
    - (left) 1 GeV/c, (middle) 2 GeV/c, (right) 5 GeV/c
  - First bECAL layer 12

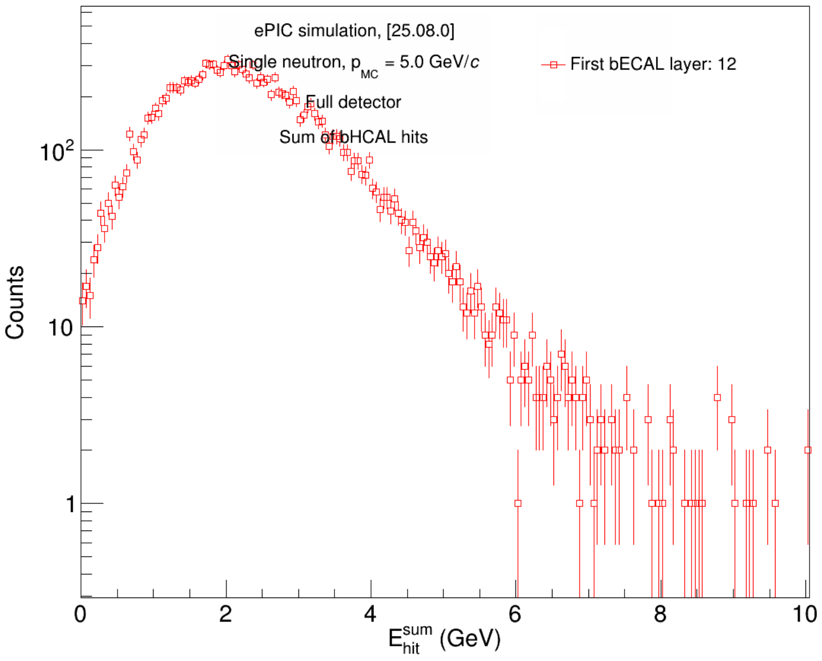
No clear peak



No clear peak



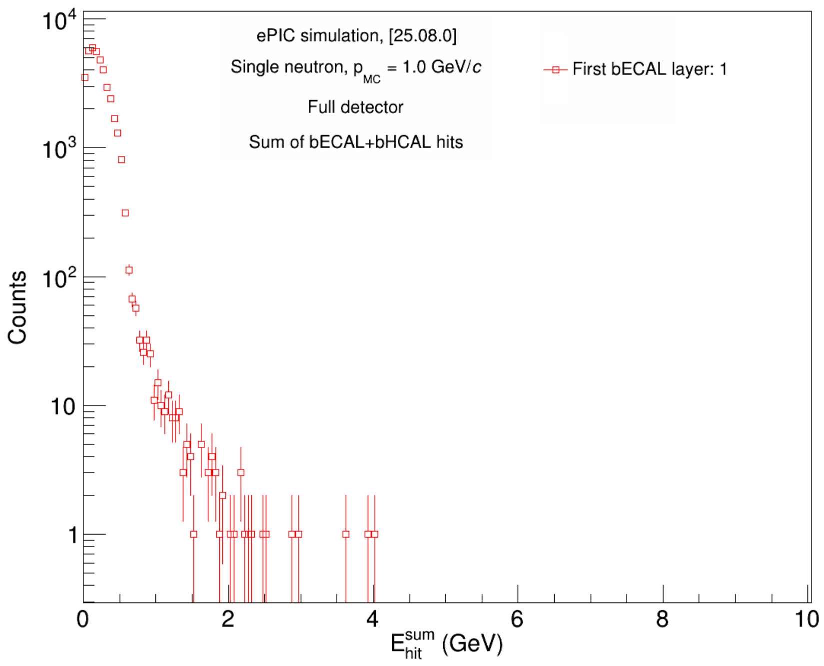
Clear peak



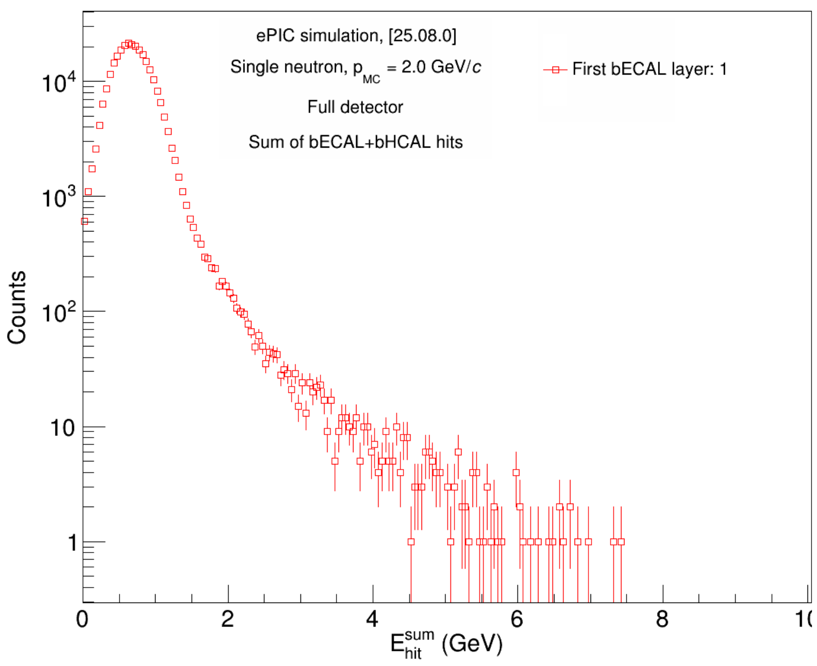
ENERGY IN bECAL+bHCAL – FIRST LAYER 1

- Energy deposition in **bECAL+bHCAL** for different first layer in bECAL
  - Three MC neutron momenta
    - (left) 1 GeV/c, (middle) 2 GeV/c, (right) 5 GeV/c
  - First bECAL layer 1

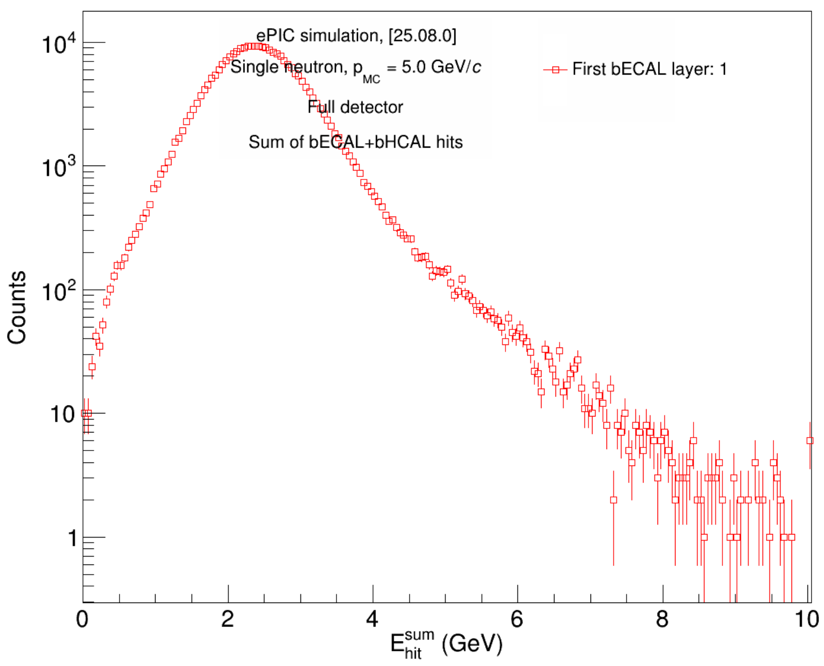
Somewhat clear peak



Clear peak



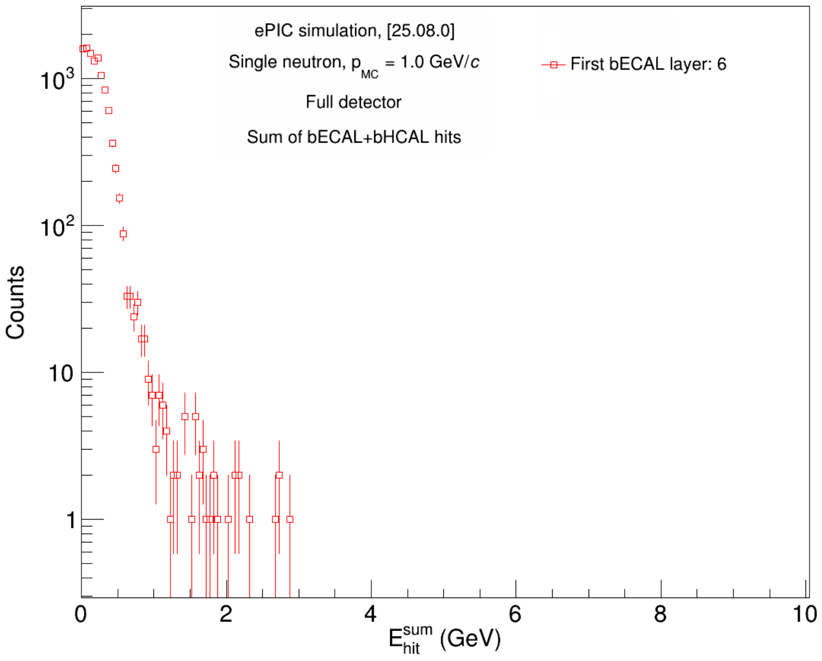
Clear peak



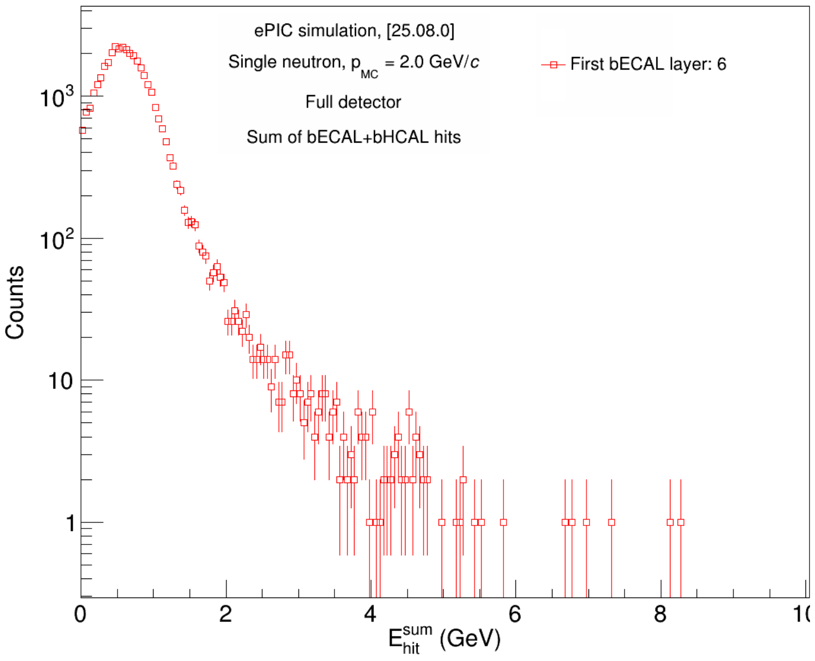
ENERGY IN bECAL+bHCAL – FIRST LAYER 6

- Energy deposition in **bECAL+bHCAL** for different first layer in bECAL
  - Three MC neutron momenta
    - (left) 1 GeV/c, (middle) 2 GeV/c, (right) 5 GeV/c
  - First bECAL layer 6

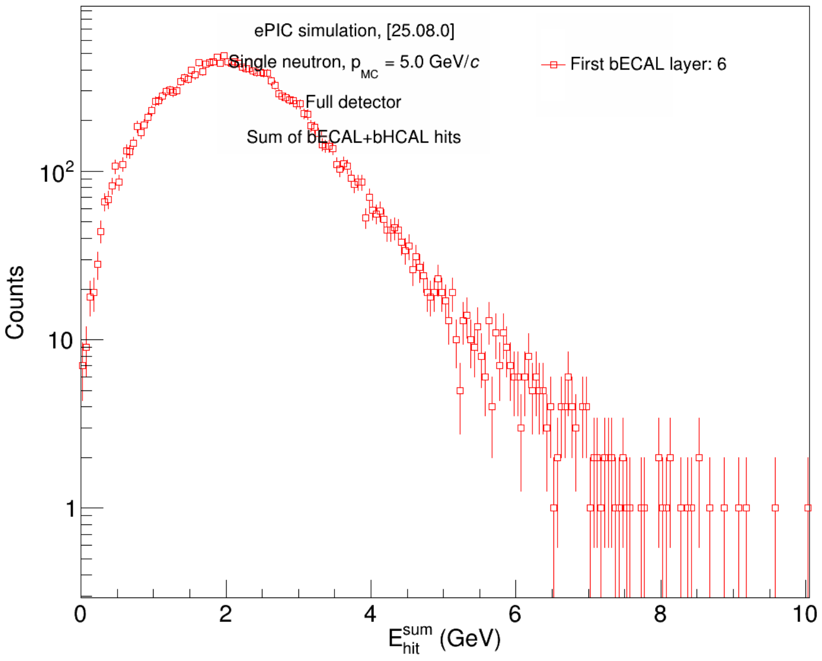
No clear peak



Clear peak



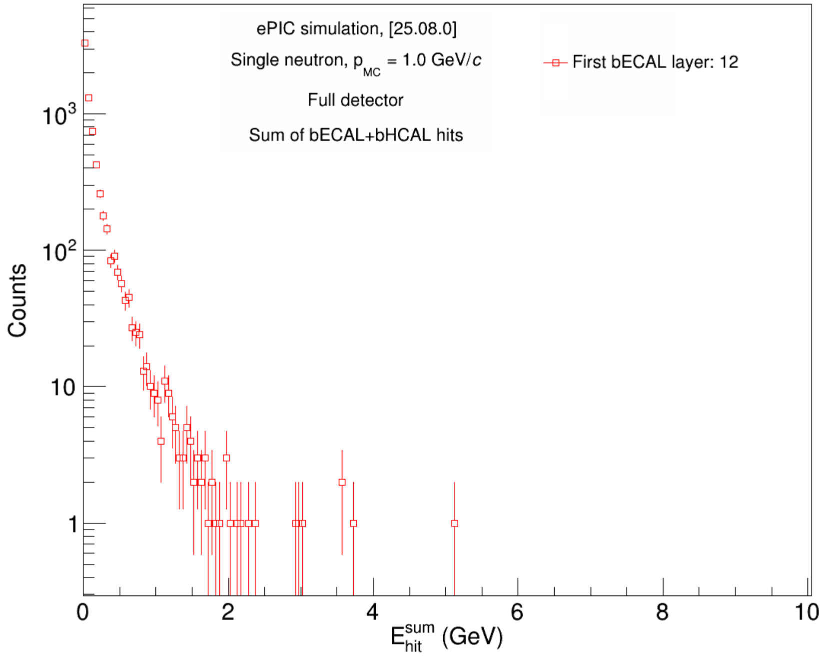
Clear peak



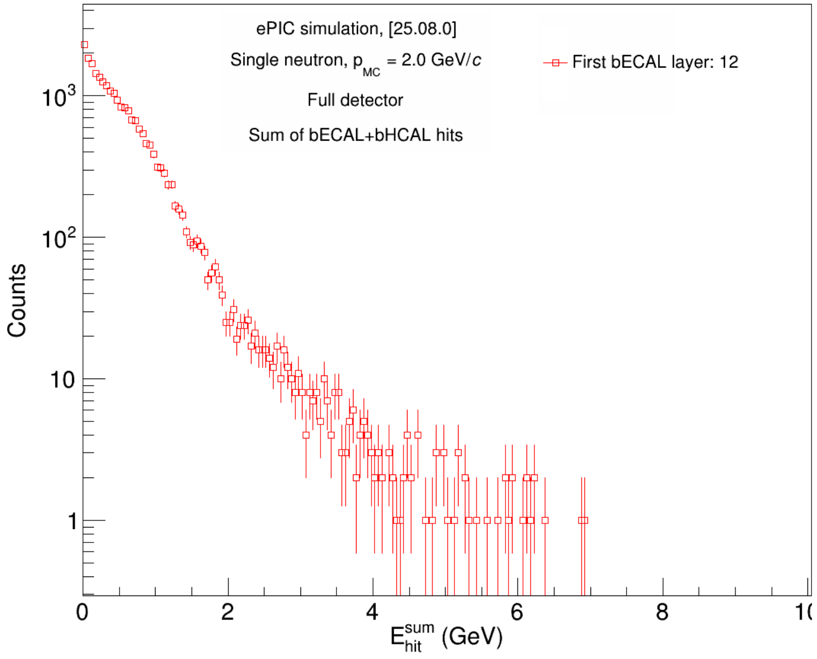
ENERGY IN bECAL+bHCAL – FIRST LAYER 12

- Energy deposition in **bECAL+bHCAL** for different first layer in bECAL
  - Three MC neutron momenta
    - (left) 1 GeV/c, (middle) 2 GeV/c, (right) 5 GeV/c
  - First bECAL layer 12

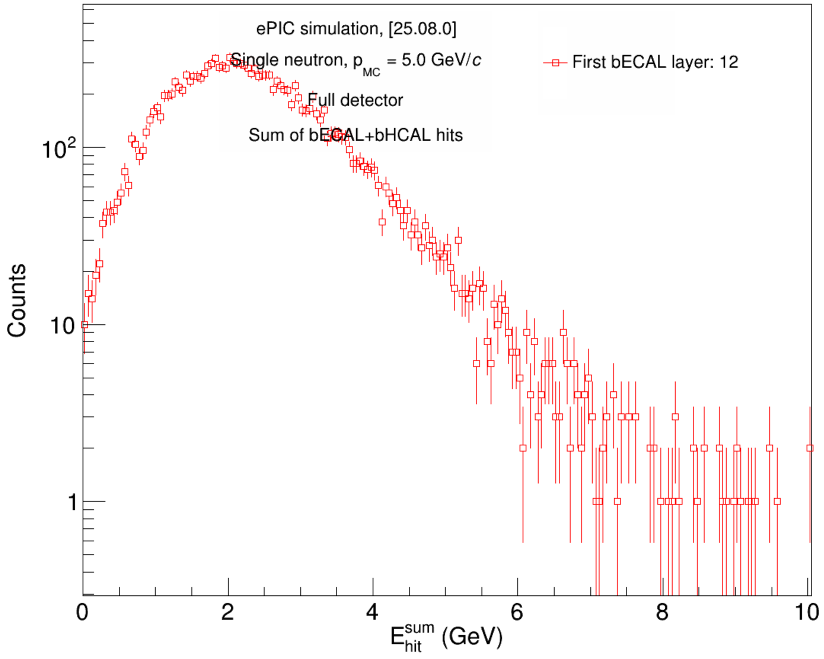
No clear peak



No clear peak



Clear peak



SECTION SUMMARY

- The energy deposition in bECAL and bHCAL has clear and predictable structure depending on first layer in bECAL

- $1\ \mathrm{GeV}/c$: Peak visible for total energy deposition in bECAL+bHCAL only somewhat visible when shower starts early in bECAL (layer 1)
- $2\ \mathrm{GeV}/c$: Peak structure visible even for showers that start in the middle of bECAL (around layer 6)
- $5\ \mathrm{GeV}/c$: Peak structure generally well visible for total energy deposition

- **Peak structure important as its mean can tell us about how far we are from the expected MC particle momentum**
- **This is problem for the lowest energy, as peak structure is generally not visible**

SUMMARY

- The widening of shower as it propagates through the bECAL+Magnet+bHCAL system seems to only be visible for high energy neutrons

- Shower profile in bHCAL as a function of first layer in bHCAL does not seem to provide any useful information for manual calibrations of $1\ \mathrm{GeV}/c$ (for now)
  - Might be useful for higher energies

- Peak structure in total energy deposition is important as its mean can tell us about how far we are from the expected MC particle momentum
  - Problem for the lowest energy, as peak structure is generally not visible

OUTLOOK

- Try using only events that have showers start early in bECAL for calibration
  - Those provide the fullest possible information on energy deposition
  - Try to use those to estimate the energy loss in the magnet
  - Idea is to use modified Method 2:
    - $E_{calib} = A(E_{EMCAL} + BE_{bHCAL} + \boldsymbol{C})$
    - $\boldsymbol{C}$ – additional term to quantify the energy loss in magnet
    - Want to try to set limits on $\boldsymbol{C}$:
      - Based on geometry (thickness of magnet vs. bECAL vs. bHCAL)?
      - Based on actual radiation length?

- Make magnet a sensitive volume in simulation
  - In parallel to above
  - Already talked to Dima and I might be able to do this myself
    - Requires a bit of time to implement and double check functionality

THANK YOU FOR ATTENTION

BACKUP

MANUAL CALIBRATION METHODS

- Simple neutron calibration for bHCAL

- Method 1
  - $E_{calib} = A(E_{EMCAL} + E_{bHCAL})$
  - Plot $(E_{EMCAL} + E_{bHCAL})/E_{par,MC}$
    - A is set as 1/mean of this distribution

- Method 2
  - $E_{calib} = A(E_{EMCAL} + BE_{bHCAL})$
  - Plot $(E_{EMCAL} + BE_{bHCAL})/E_{par,MC}$
    - First find B for which the distribution above has the smallest σ/μ
    - A is set as 1/mean of the distribution with optimal B