ND-GAr Acceptance Studies

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ND-GAr Meeting

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Imperial College London

Overview

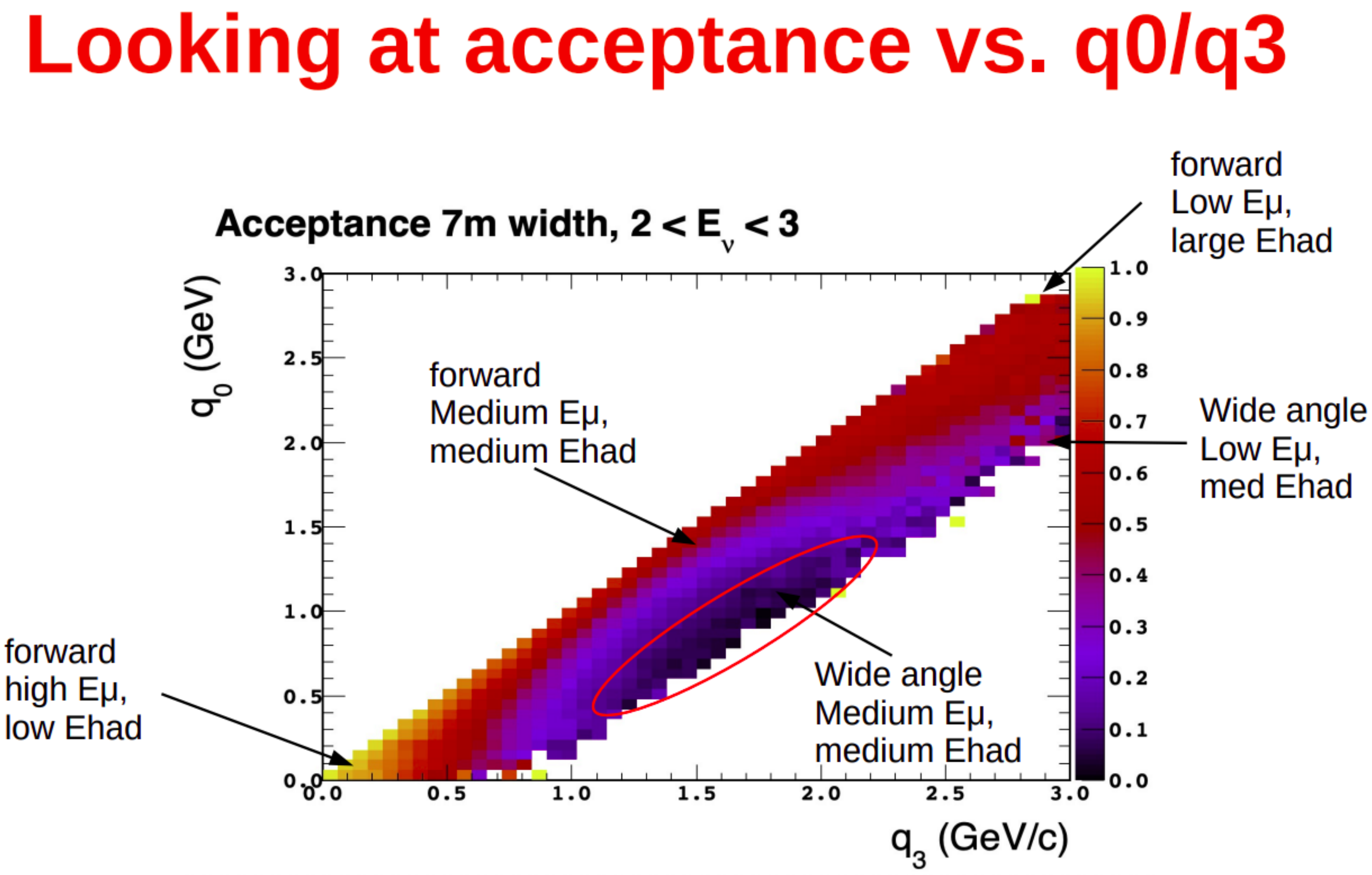
- Motivation for ND-GAr Acceptance Studies
- Method and defining acceptance
- Previous preliminary plots
- Updates to fix bugs/poor estimations
- New Results
  - Understanding these and looking into fiducial volume cuts, PDG of the rejected particles, neutrino energy range cuts, etc.

Motivation

- Chris Marshall's talk
  - FD has 4π acceptance, so ND needs to measure neutrino interactions over the full 4π to match the FD
  - Need to ensure the full phase space has good acceptance so that a reliable correction can be applied
  - However, some regions have very small, or zero, acceptance with ND-LAr + TMS.
  - Events are classed as "accepted" in ND-LAr+TMS if:
    - Hadrons are contained in ND-LAr
    - Muon stops in ND-LAr active volume or TMS instrumented region
  - Some events will be accepted if the vertex is in some region of ND-LAr but the same event can be rejected if it happens elsewhere
  - However, some events are not accepted no matter where the vertex is

Motivation

- [Chris Marshall's talk]
- Study by KiYoung Jung
  - Uses a full Geant4 Simulation of ND-LAr+TMS
  - Region in Q3 vs Q0 phase space that has very low acceptance
    - This is a "blind spot" for the ND



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- Chris Marshall's talk
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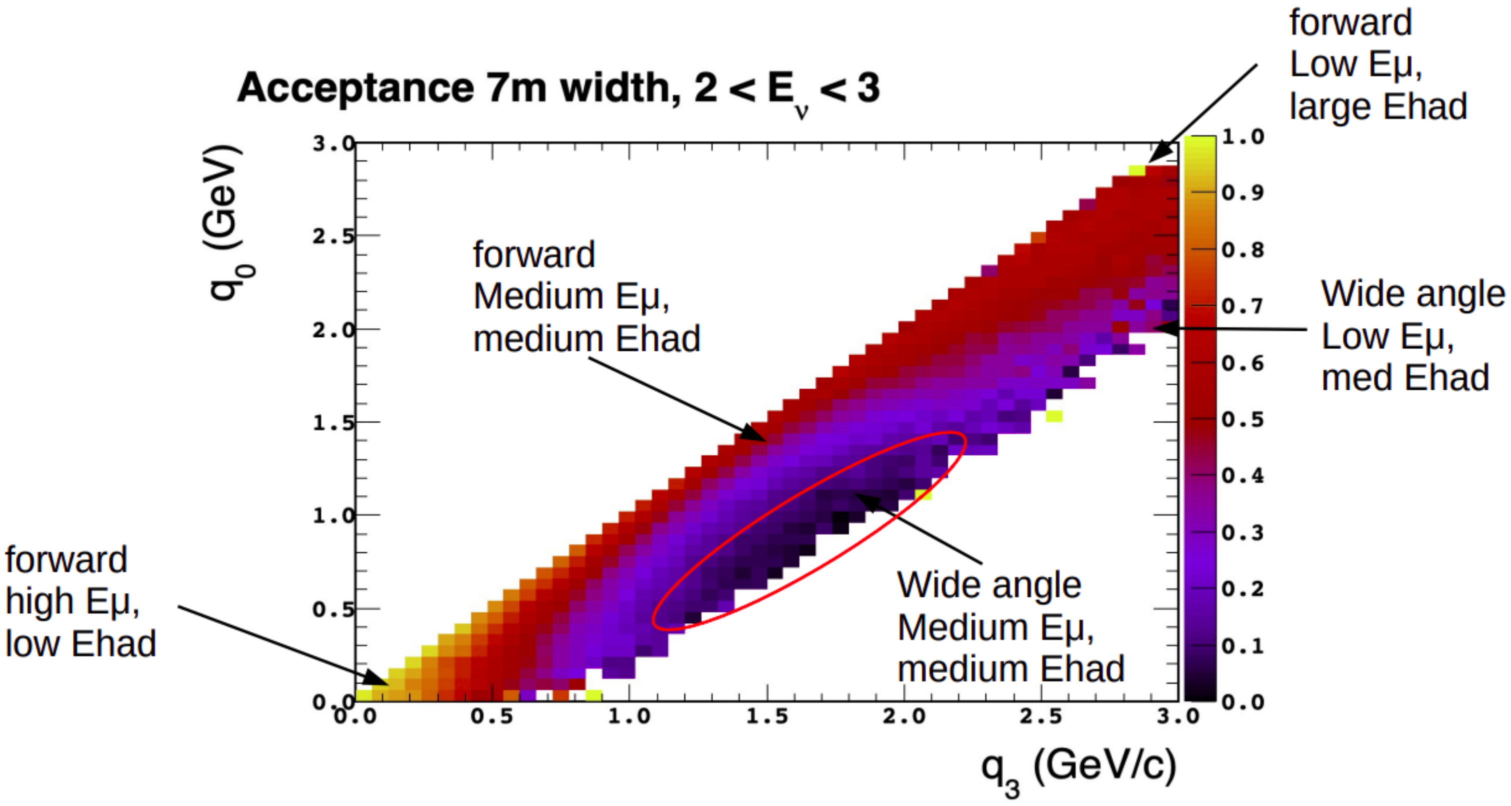
  - Region in Q3 vs Q0 phase space that has very low acceptance
    - This is a "blind spot" for the ND
- **ND-GAr will have full 4π coverage**

Looking at acceptance vs. q0/q3



ND-GAr Acceptance Studies

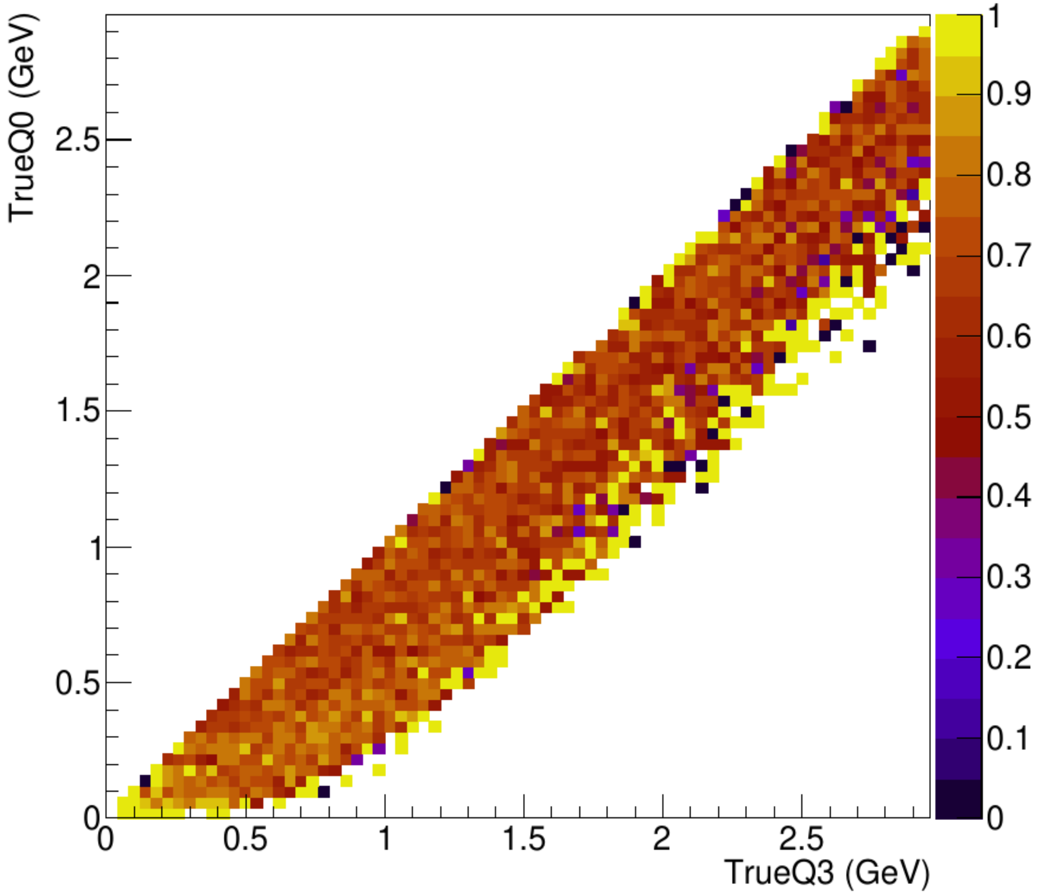
- We want to know what requirements we can put on the design of ND-GAr in order to have a good acceptance in this region that ND-LAr will miss
- We will use the same assumptions as ND-LAr+TMS studies so it is a fair comparison
  - Use the Geant4 Simulation of ND-GAr with GENIE events
  - Using the 100k event sample
  - Using the G18 tune of GENIE

ND-GAr Acceptance Studies

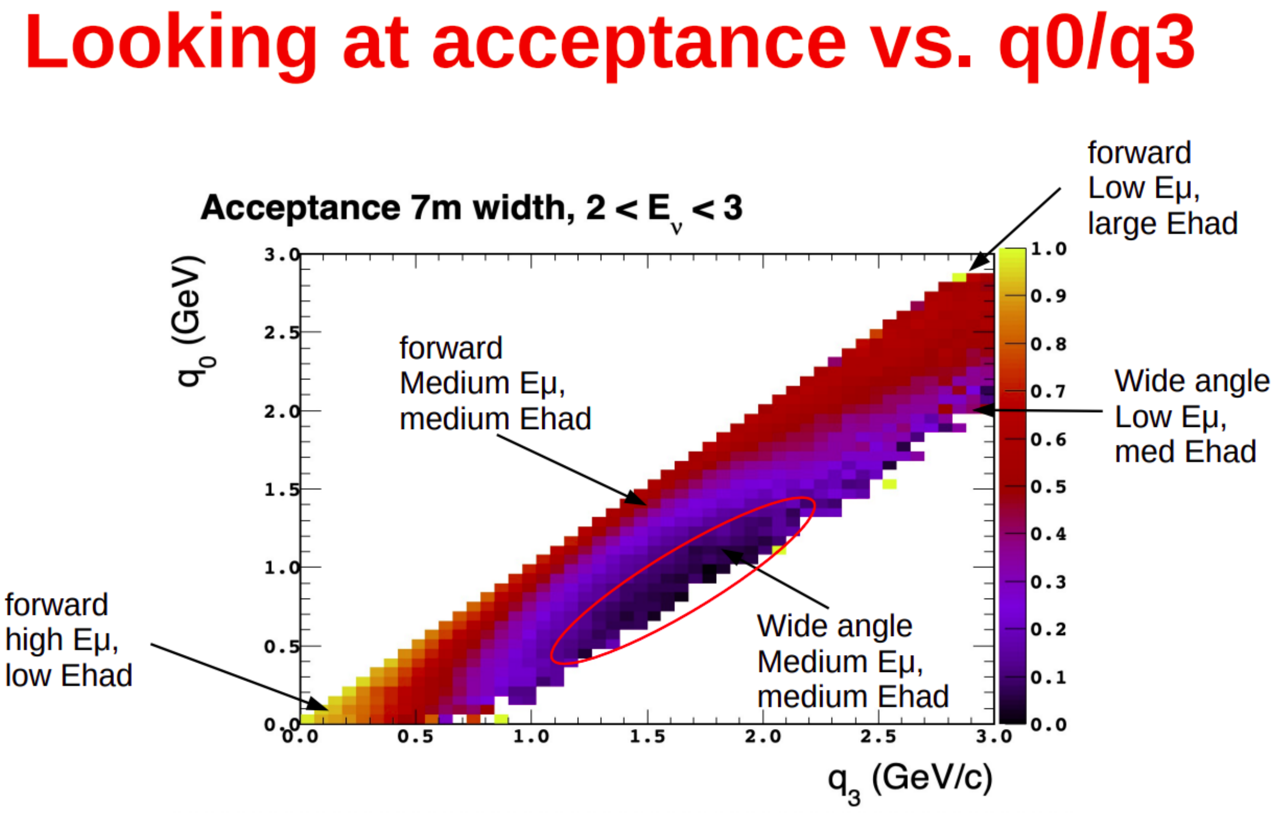
- Define Acceptance as all tracks are either:
  - Contained
  - Better momentum resolution than 5% for any charged particles leaving the TPC
  - Assume Neutral Pions/Photons will be well reco'd in the ECAL
  - Ignore neutrons (as ND-LAr study has ignored these)
- Not accounting for any misreconstruction at the moment

Previous Plots - Acceptance

- ND-GAr



- ND-LAr+TMS



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Issues/Poor Estimations

- Changes made:
  - Had calculated the momentum resolution in the x-direction incorrectly
  - Improved the estimation of track propagation and the length of track within the TPC
  - Gluckstern formula relies on approximation of track as a straight line and therefore invalid for L/R > 0.3 - requires another term
  - Had extended the pixel grid only up to the fiducial volume, fixed this to extend the instrumented region all the way to 2.5m radius
  - Including multiple scattering to the momentum resolution calculation

Updated Momentum Resolution Calculation

- For particles that do not stop in the fiducial volume, we can determine their momentum from track curvature
- Track must be long enough and curved enough to measure momentum with a 5% uncertainty
- Assuming a helix with fixed radius of curvature

$$\left(\frac{\sigma_p}{p}\right)^2 = \left(\frac{\sigma_{p_T}}{p_T}\right)^2 + (\tan(\lambda)\sigma_\lambda)^2$$

R. Kogler

- p is Total Momentum
- pT is Transverse Momentum
- λ is the dip angle of the helix

Updated Momentum Resolution Calculation

- Transverse momentum resolution estimated from the Gluckstern Formula

$$\frac{\sigma_{p_{T_G}}}{p_T} \approx \sqrt{\frac{720}{N+4}} \left(\frac{\sigma_y p_T}{0.3BL^2}\right) \sqrt{1 - \frac{1}{21}\left(\frac{L}{R}\right)^2}$$

A. Karimaki

- N is the number of pixels a track goes through.
  - This is estimated using a pixel grid of 6mm x 6mm pixels.
- B is the magnetic field.
  - Set to 0.5 T , but will be varied and studied
- L is the length of the **chord** of the track in the transverse plane
  - Estimate the track as a circle in the transverse plane and find where the track intersects with the detector edge (intersection of two circles, with the point of intersection that comes first in the track trajectory taken
- σ_y is the spatial resolution in the transverse plane (pixel spacing)

Updated Momentum Resolution Calculation

- Dip Angle Resolution Estimation

$$\tan(\lambda) = \frac{L_x}{L_T} \qquad\qquad L_T = \frac{L_x}{pitch} 2\pi R$$

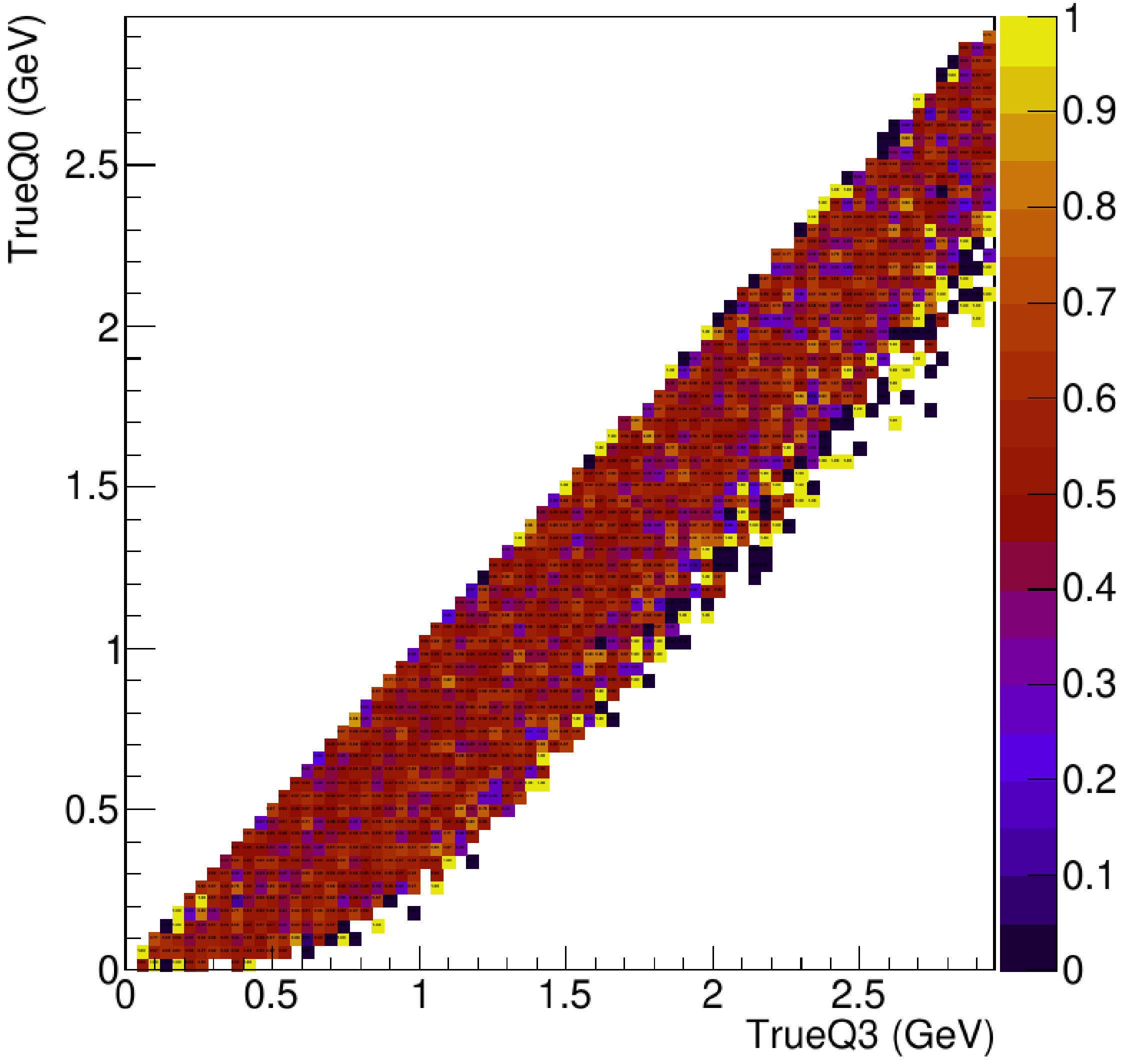
- Lx is the track length in the X-direction (direction of the B-field)
- This gives:

$$\sigma_\lambda = \cos^2(\lambda) \left(\frac{pitch}{2\pi R}\right) \sqrt{\left(\frac{\sigma_x}{L_x}\right)^2 + \left(\frac{\sigma_{p_T}}{p_T}\right)^2}$$

- We take σx to be the spatial resolution in the x-direction (assuming a drift velocity of ~3.011 cm/µs and a Sampling frequency of 20 MHz, which gives a σx = 1.5 mm

What does the Acceptance look like with these changes?

- Including:
  - Improved Gluckstern Formula
  - Fixed momentum resolution for dip angle term
  - Improved track trajectory estimation
  - 6 mm spatial resolution in y-z plane
- This is including every event within the fiducial volume (227 cm rad, 209 cm length)
- Not including:
  - Instrumenting the correct size volume
  - Multiple Scattering



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What does the Acceptance look like with these changes?

- Including:
  - Improved Gluckstern Formula
  - Fixed momentum resolution for dip angle term
  - Improved track trajectory estimation
  - **Spatial resolution improved to ALICE resolution of 2.5 mm which is better than the 6mm due to charge sharing on the pixels**
- This is including every event within the fiducial volume (227 cm rad, 209 cm length)
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  - Instrumenting the correct size volume
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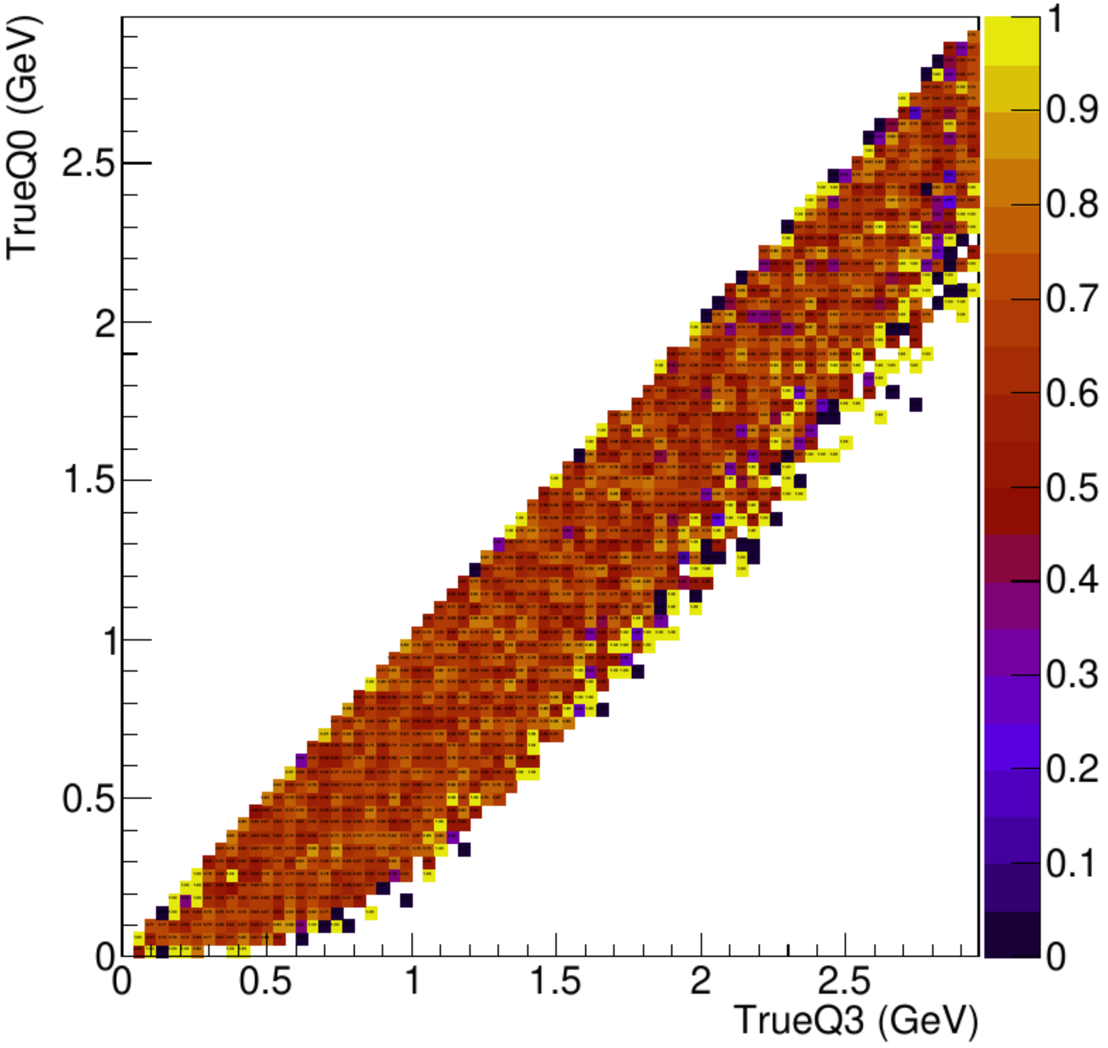

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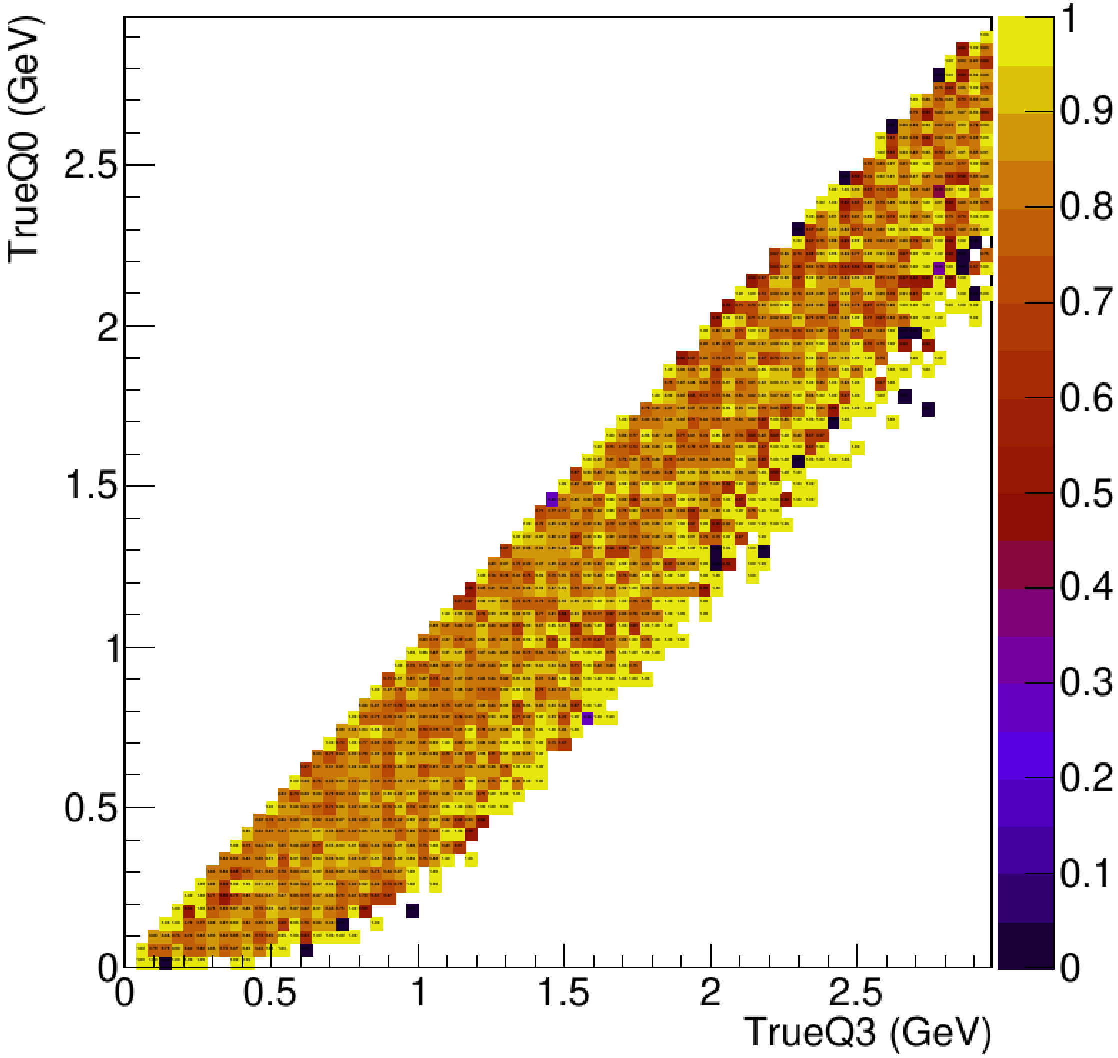
  - **Pixel grid in the fully instrumented region (2.5 m rad)**
- This is including every event within the fiducial volume (227 cm rad, 209 cm length)
- Not including:
  - Multiple Scattering



Updated Momentum Resolution Calculation

- Multiple Scattering contribution to momentum resolution
  - Dominates low momenta particles due to β factor

$$\frac{\sigma_{p_{T_{ms}}}}{p_T} = \frac{0.016}{0.3BL_{tot}\cos(\lambda)\beta}\sqrt{\frac{L_{tot}}{X_0}}$$

- L_{tot} is the total track length in the transverse plane of the helix in the TPC
- X0 is the radiation length of Argon at 10 bar = 1193 cm
- The total momentum resolution in the transverse plane then becomes

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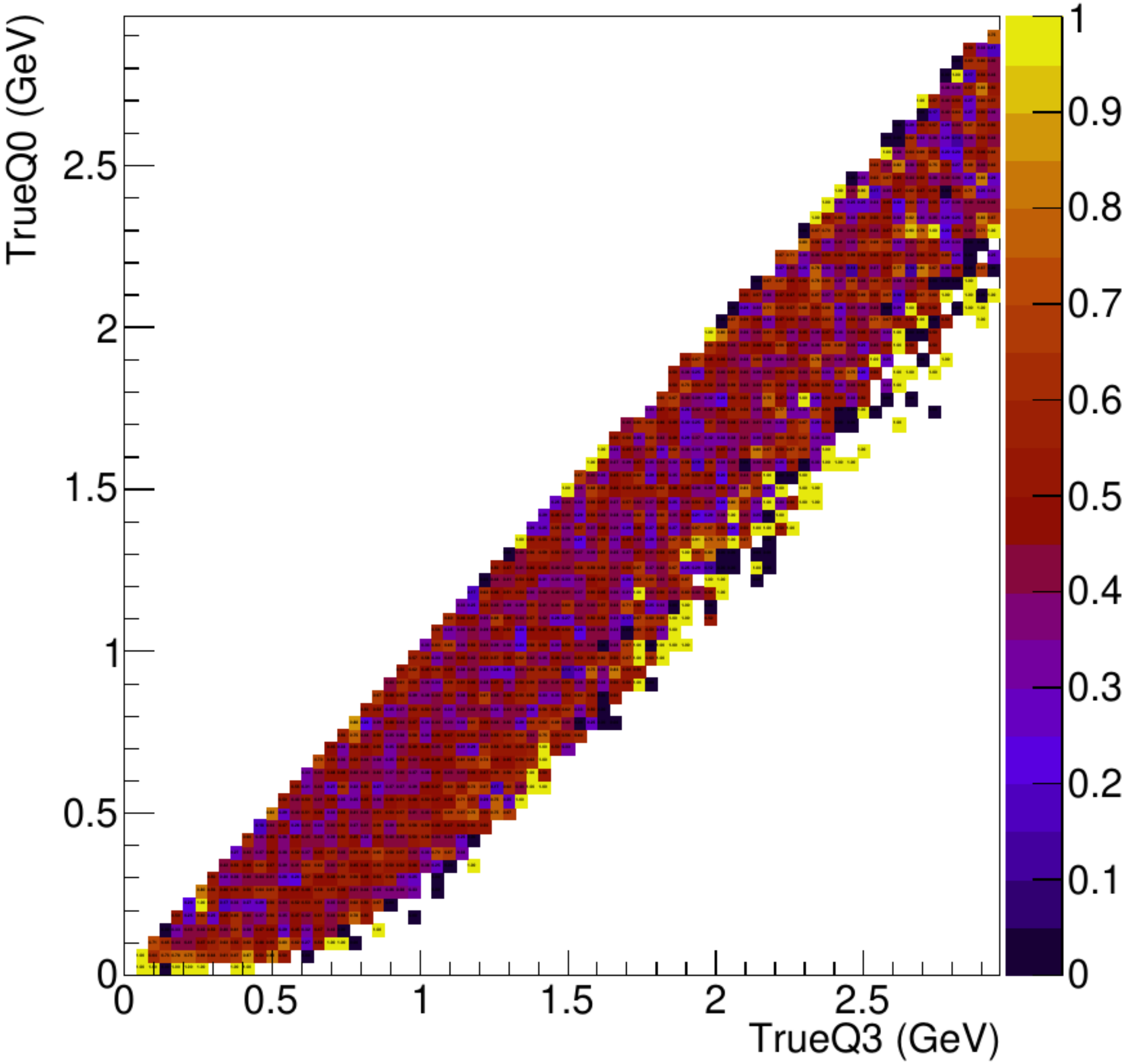
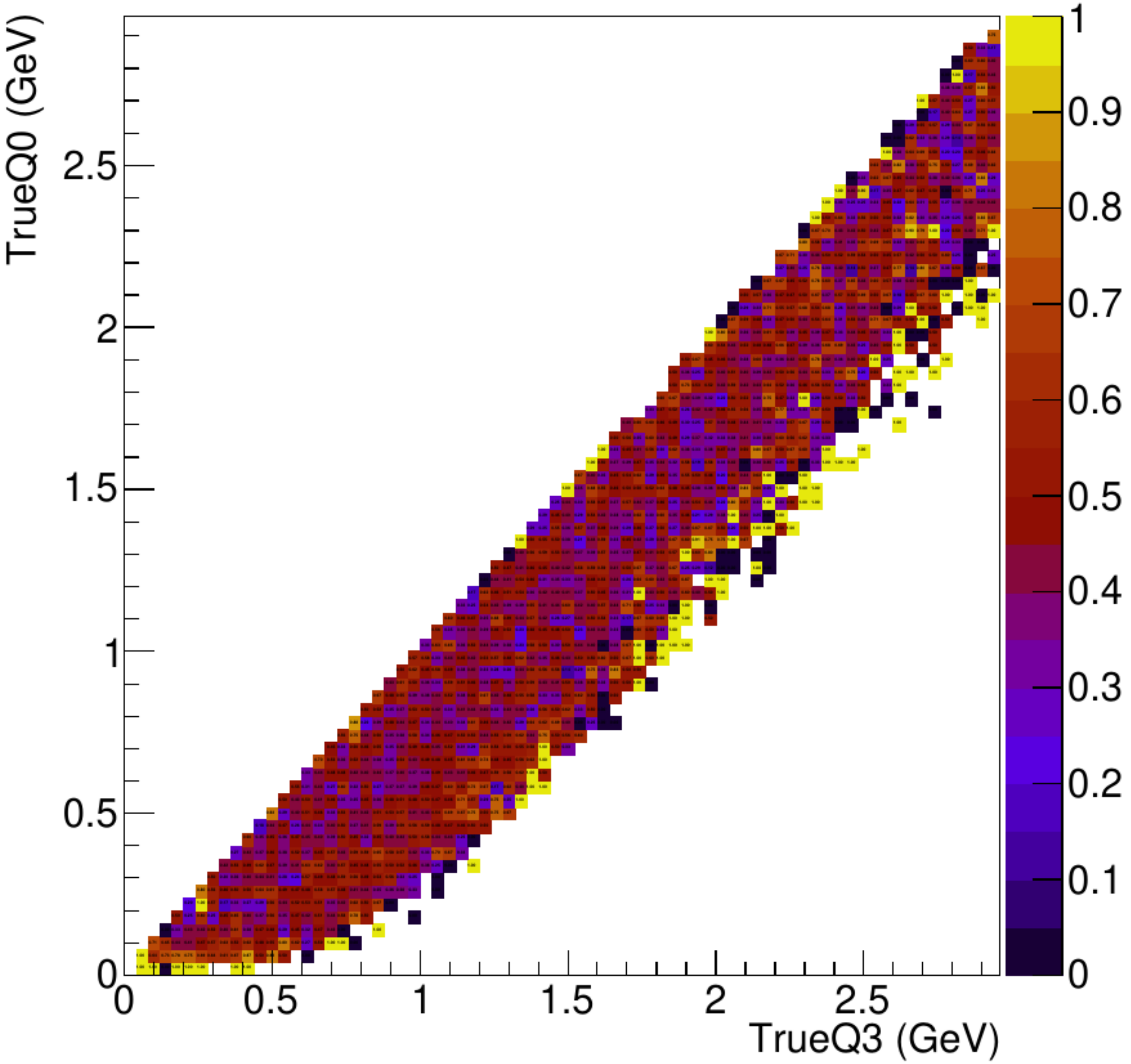
- Including:
  - Improved Gluckstern formula
  - Fixed momentum resolution for dip angle term
  - Improved track trajectory estimation
  - Pixel grid in the fully instrumented region (2.5 m rad)
  - Spatial resolution improved to ALICE resolution of 2.5 mm which is better than the 6mm due to charge sharing on the pixels
  - **Multiple Scattering term in momentum resolution formula**

- This is including every event within the fiducial volume (227 cm rad, 209 cm length)



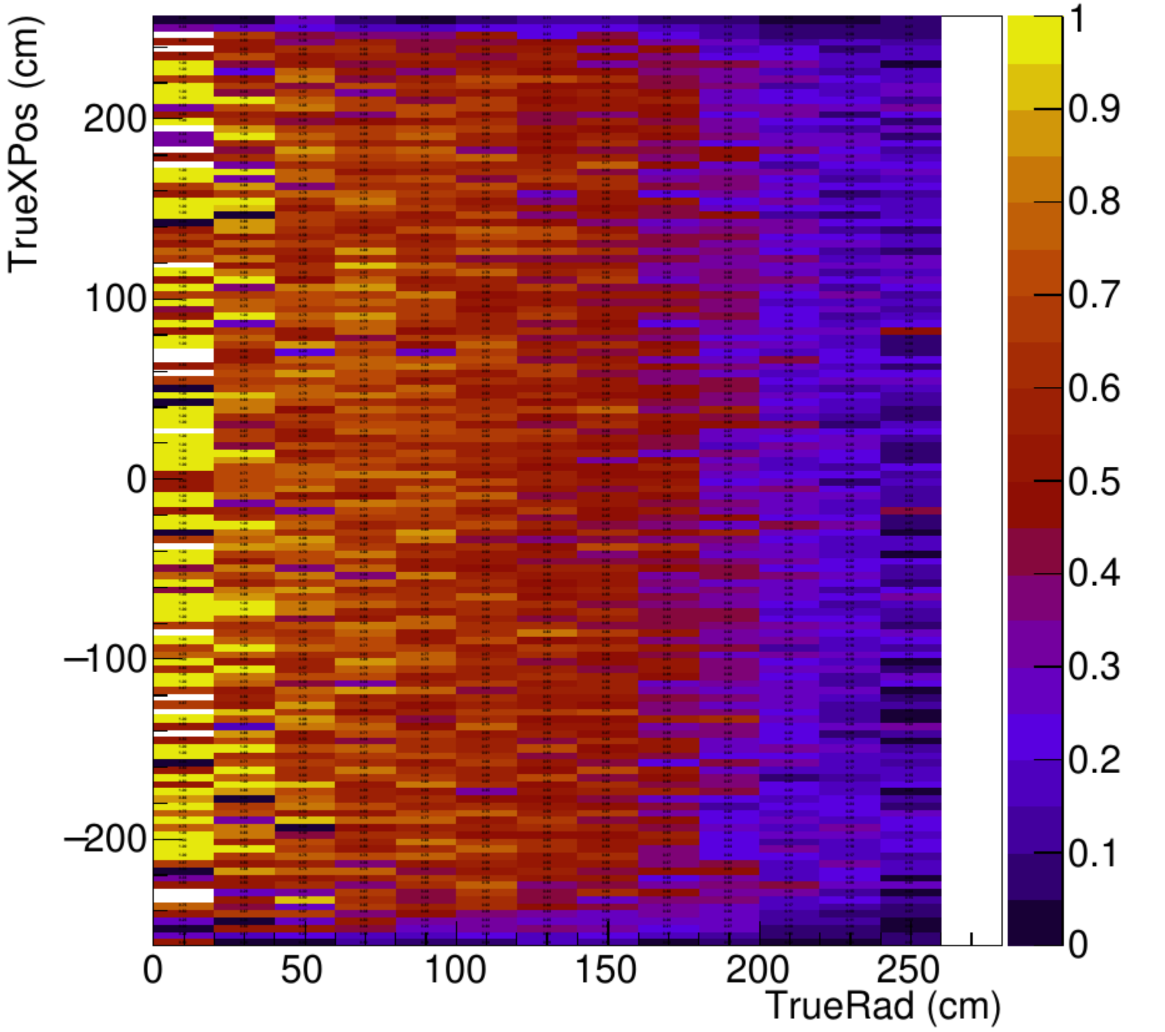
Understanding these plots

- Multiple scattering dominates for very low momenta particles which leave the TPC instrumented region
- We need to find a good cut for the fiducial volume which optimises this acceptance
- We haven't yet restricted the energy range – very high momenta particles will also be rejected as Gluckstern formula would dominate



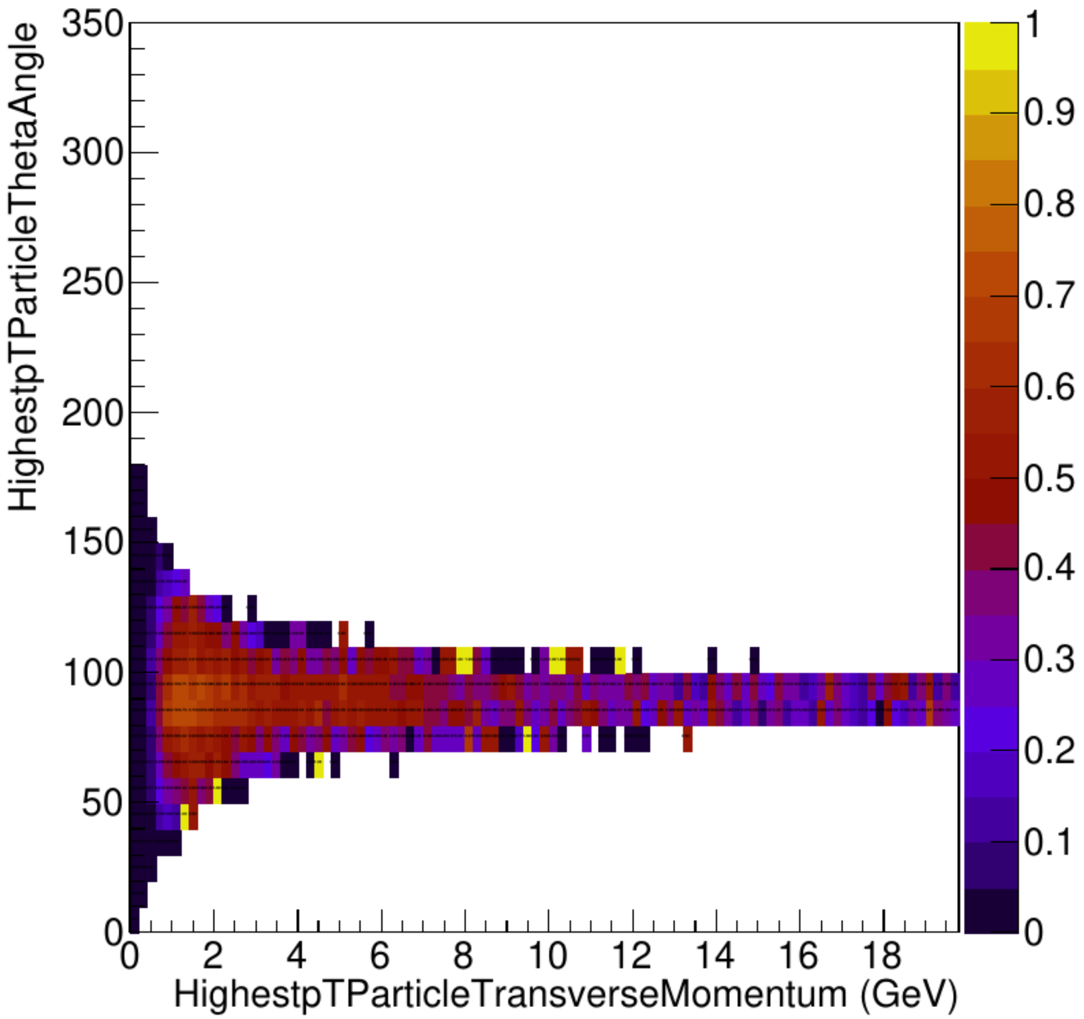
Fiducial Volume Cuts

- Can see that the acceptance depends a lot on where the fiducial volume cut is placed
- Very poor acceptance near the edges of the TPC
- The current fiducial volume used in GArSoft is 209.0 cm in Length and 227.02 cm in radius
  - This should probably be smaller in radius
  - Have tried placing the cut at 180cm radius
- The number of events in our fiducial volume ~ $r^2 L$
  - This means with the cuts shown here we have ~42% of the total events in the TPC instrumented region (34% of the events in the full TPC volume)
  - If we shift the fiducial radius to 160 cm then we reduce the number of events to 33% of the total events in the TPC instrumented region



Neutrino Energy Range

- Low momenta particles have very low acceptance
  - Can't improve that by adding an energy range cut as these will exist in most interactions
- However, high momenta particles also have worse acceptance and those will go away when we place a cut on true neutrino energy
- This is plot has no cuts on fiducial volume
- Here the angle is the angle between the B-field and Track



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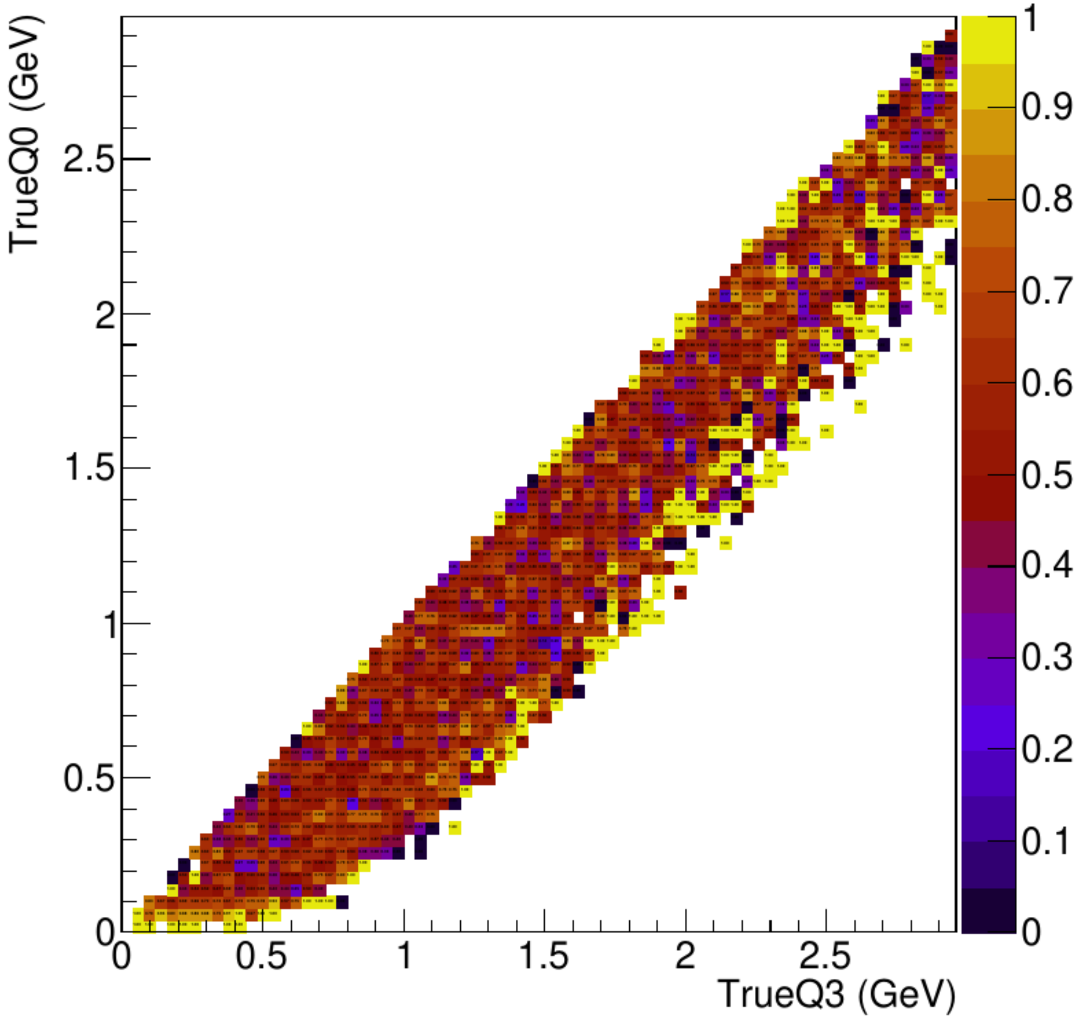
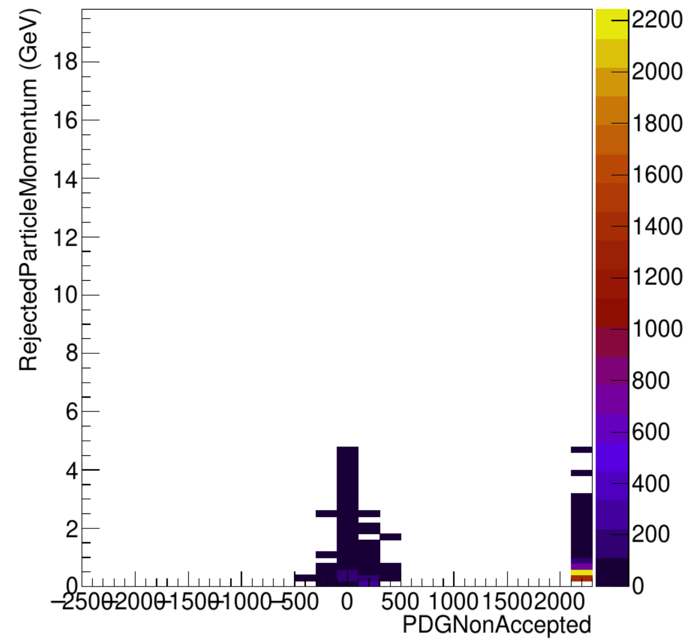
Cut on Fiducial Volume and E_nu

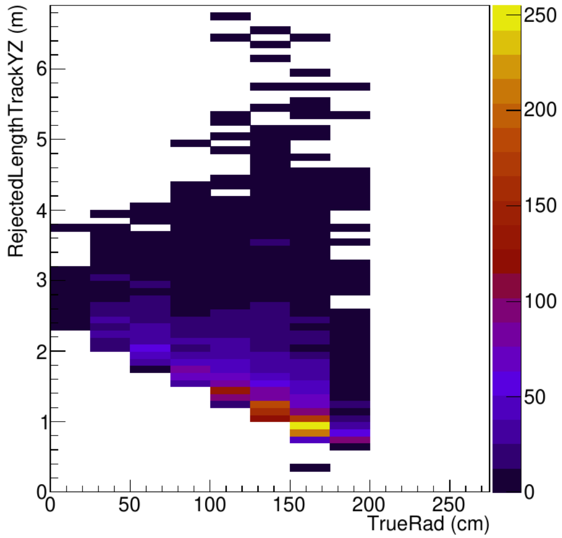
- 1GeV<E_nu<5GeV
  - Ideally would want to cut between 2 to 3 GeV as this is what the ND-LAr+TMS study has done
    - Not enough stats for that at the moment
- Fiducial radius cut of 180 cm and length 209 cm
  - The radius could be a little smaller to optimise acceptance

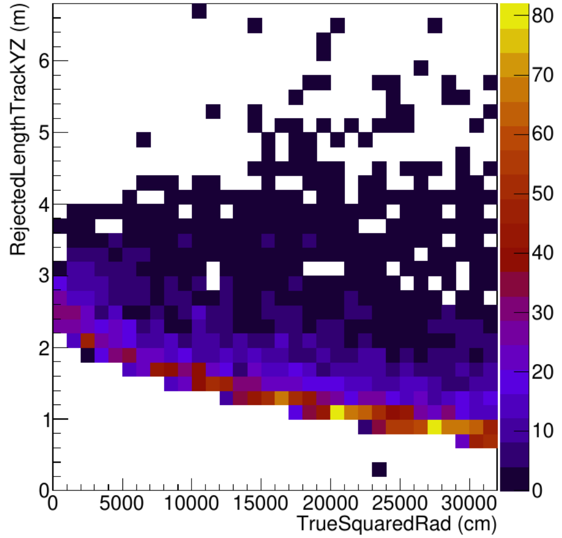


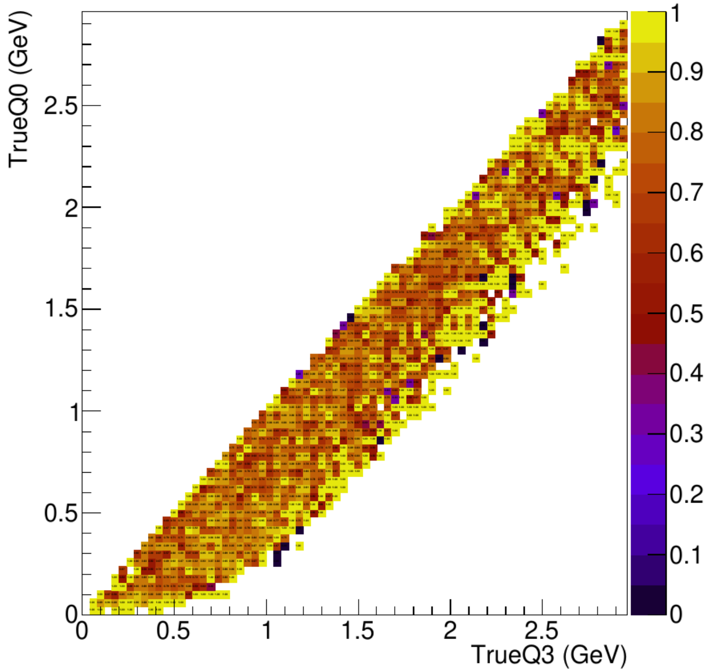
What is getting rejected

- We can see that low momenta protons are mostly getting rejected (top right)
  - This is because protons have higher mass the β value is lower at the same momentum compared to pions
  - The protons will scatter more
  - Federico saw similar when testing the Kalman Filter, and found low momenta protons (< 1 GeV) had ~8% momentum resolution
    - Setting the momentum resolution threshold to 8% (bottom right)
  - Looking just at protons (Rad vs Track length) can see most are near the edge of the FDV









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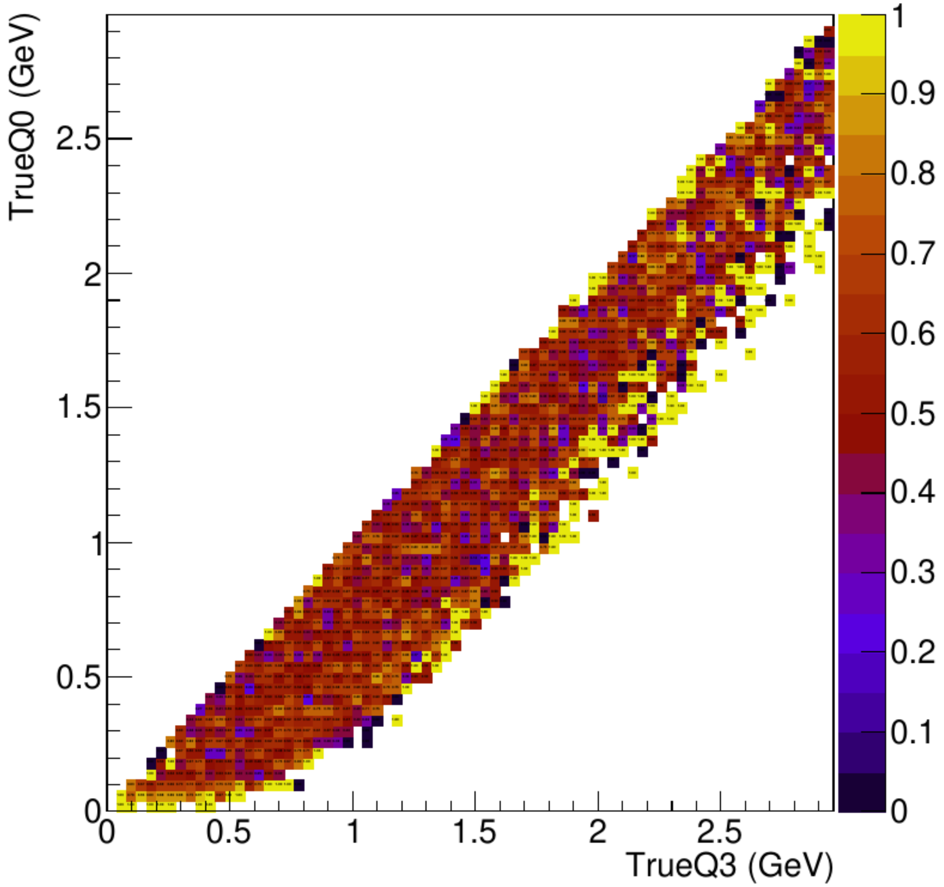
Updated Plots - Acceptance

- ND-GAr plot (left) made using 1GeV < E_{nu} < 5GeV , Fiducial Radius = 180 cm, Fiducial Length = 209 cm
- Total number of events with these cuts = 14695, Accepted Events = 8547, giving overall ~58% acceptance



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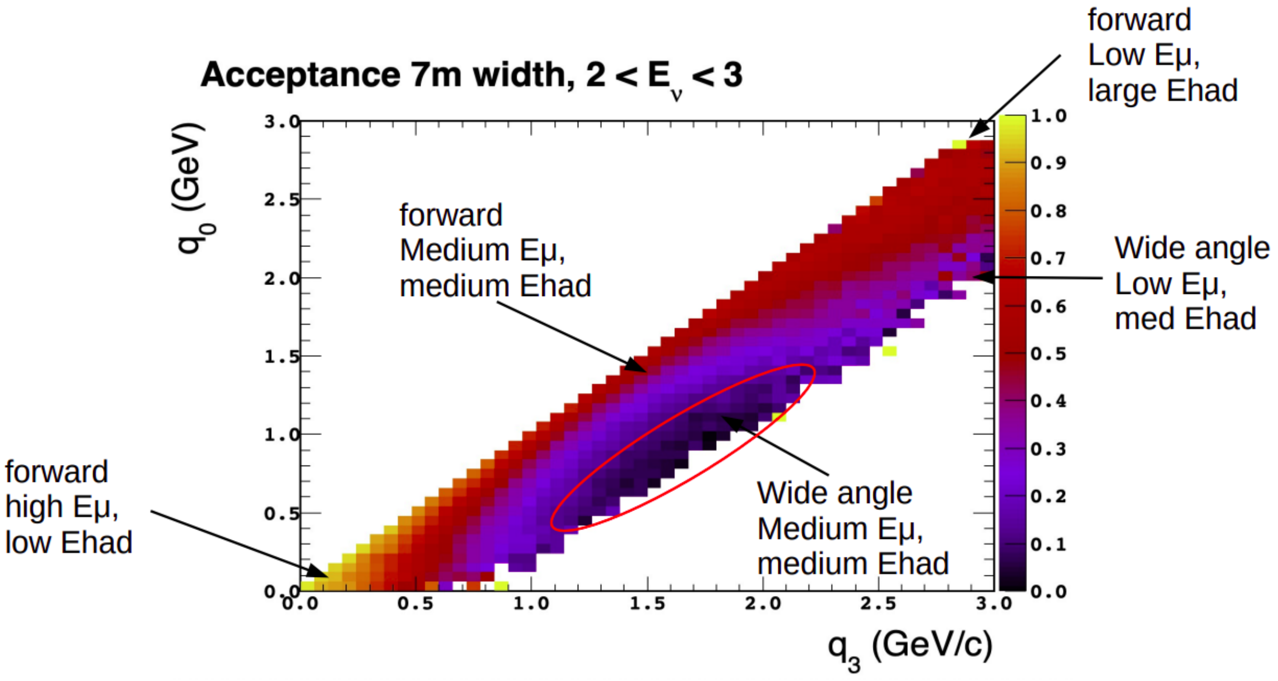

Conclusions

- These early studies are aiming to determine the impact ND-GAr will have on the ND acceptance correction.
- Want to reach a good acceptance in the low acceptance regions of ND-LAr
- Can then vary fiducial volume, pixel spacing, B-field etc. and see what we **require** for ND-GAr to see enough events in this region of phase space
  - Written in an easily configurable way, planning to scan over these variables to optimise
- As this still uses 100k events, we should confirm if the plots show the same thing with a larger sample
  - Looking to also set up running productions on the Imperial Clusters
- Input from this group:
  - Do these look reasonable/intuitive?
  - Approximation for spatial resolution – is there a good approximation for the resolution we'd achieve with GEMs?
- We have tried to keep the assumptions similar to those used in the ND-LAr+TMS study so we can make fair comparisons
  - Plan to show these studies to wider audiences e.g. LBL, ND-Sim/Reco for input