MATHUSLA General Meeting - Analysis Update

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Follow up points from previous presentation

- Angle of incidence of the predicted tracks is accounted for when computing the radiation length of the scintillator layers for multiple scattering

$$\sigma(\theta_{\mathrm{proj}}) = \frac{13.6}{p}\sqrt{\frac{L_{rad}}{\sin\phi}}\left[1 + 0.038\ln\left(\frac{L_{rad}}{\sin\phi}\right)\right] \qquad L_{rad} \equiv \sum_i \frac{X_i}{X_{0,i}}$$

ϕ is the inclination angle of the track

- P-values (instead of raw χ^2/ndof) have been used at hit dropping stages to slightly improve algorithm efficiency.
- The point was raised that imposing $0.8 \leq \beta \leq 1.2$ at track forming is stricter than our resolution between layers.
    - To clarify; this cut is imposed on a track once all hit information is collected and our beta resolution is much better (ie. during the smoothing stage)

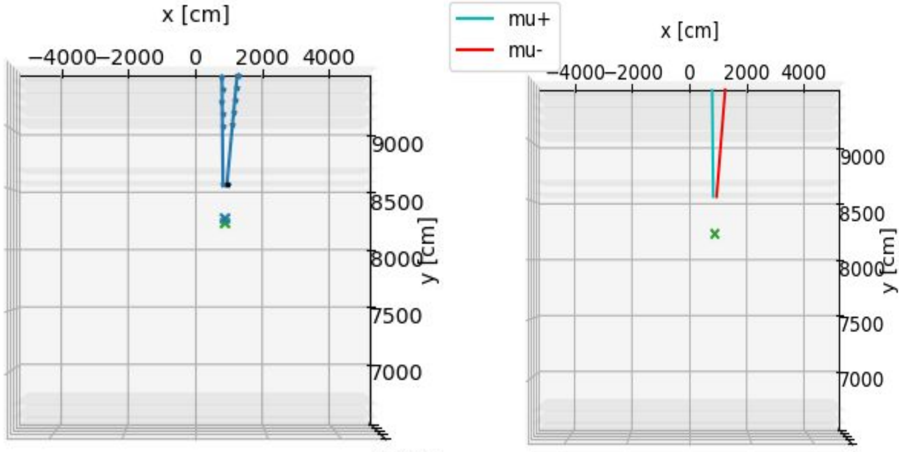
Motivation

- We have a Kalman Filter Tracking algorithm that can account for multiple coulomb scattering
  - Given a dataset of both signal and W background, how well can we use the reconstructions to identify new physics?
  - Our goal is to write a simple and robust algorithm that can reject background events based on features available during the experiment while maximizing the number of surviving signal events
- How does the performance of this analysis algorithm depend on the efficiency in the floor and wall detectors?

List of Cuts - During Tracking

- Tracks
  - Must have hits in at least 4 layers
  - Must have reconstructed $0.8 \leq \beta \leq 1.2$
  - Can't have $\chi^2/\mathrm{ndof} \geq 15$
    - P-value was not helpful for global GOF cuts
- Vertices
  - Can't have $\chi^2/\mathrm{ndof} \geq 15$

List of Cuts - During Analysis

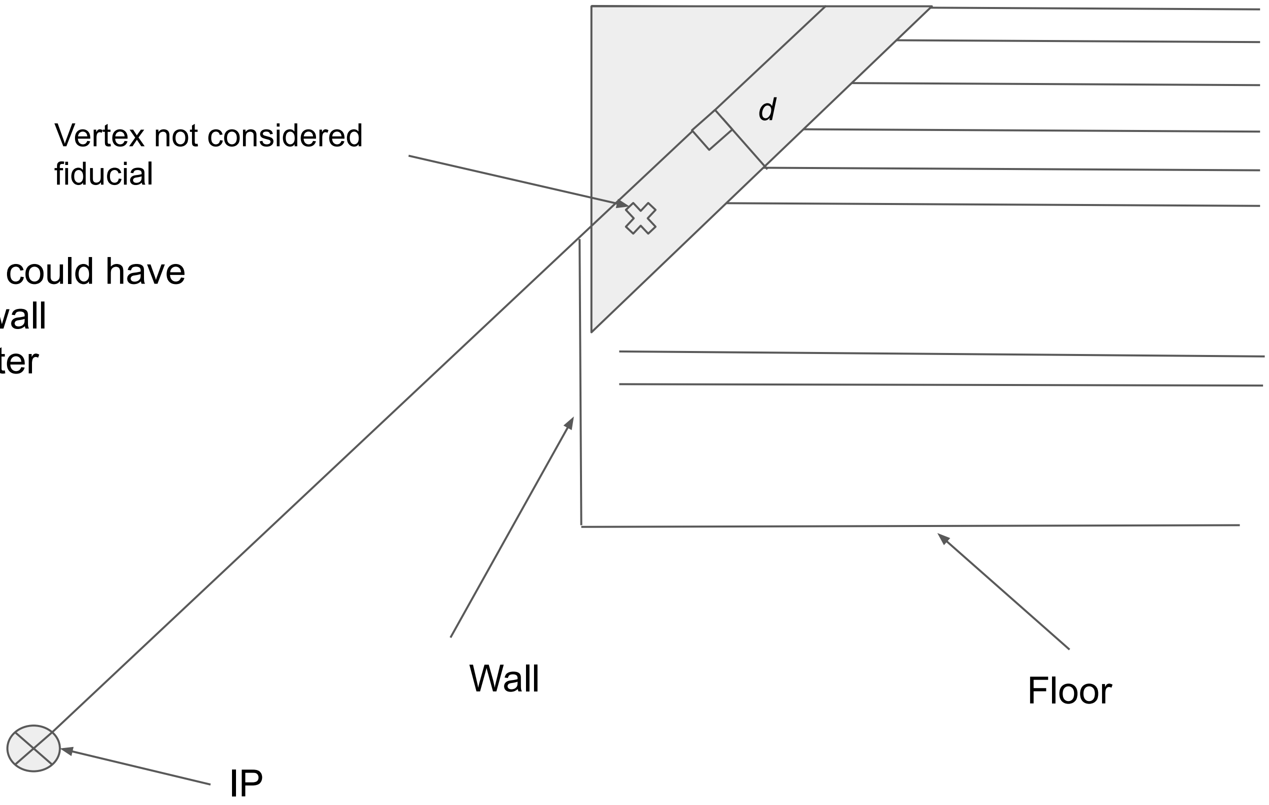


10 GeV Muon Signal

1. 2 or more tracks in the event
2. 1 or more vertex
3. 1 or more fiducial vertex
    - A vertex is fiducial if it is in the detector
4. No hits associated with a track in the floor or wall
5. No vertices in the corner of the detector above the wall
6. No floor or wall hits that could have been added to any vertex tracks
    - If there is a hit in the floor or wall near (within 20 m) to where we expect a track, and it occurred in time before the vertex, cut the event
7. No pseudo-tracks that could have vetoed the event
    - Veto event if a hit in the floor/wall forms a "pseudo-track," i.e. a light-like, pair-wise combinations of hits
8. Angles of two track vertices are consistent with CMS Interaction Point (IP) origin

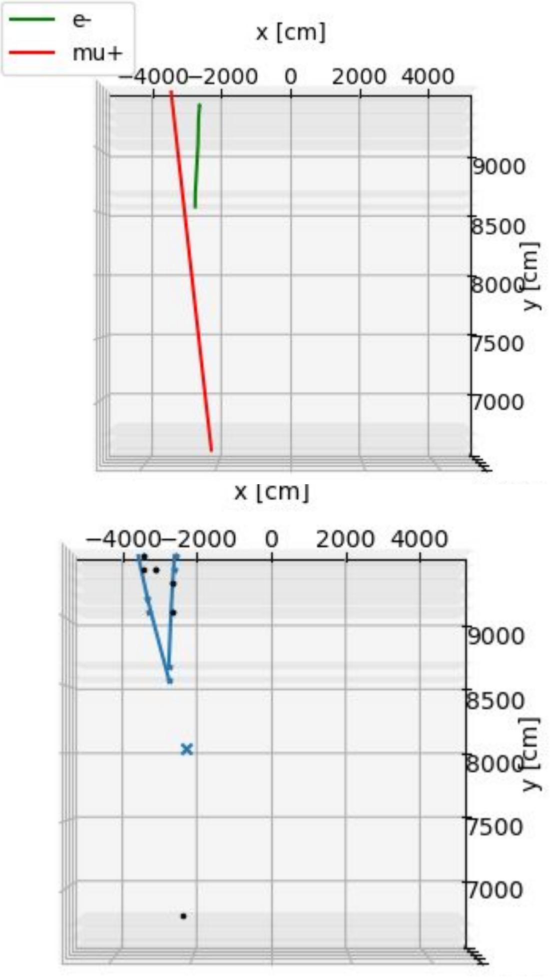
Non-Fiducial Corner Cut Details

- Ignore vertices that could have passed above the wall
- *d* is the cut parameter
    - *d* = 7.5 m



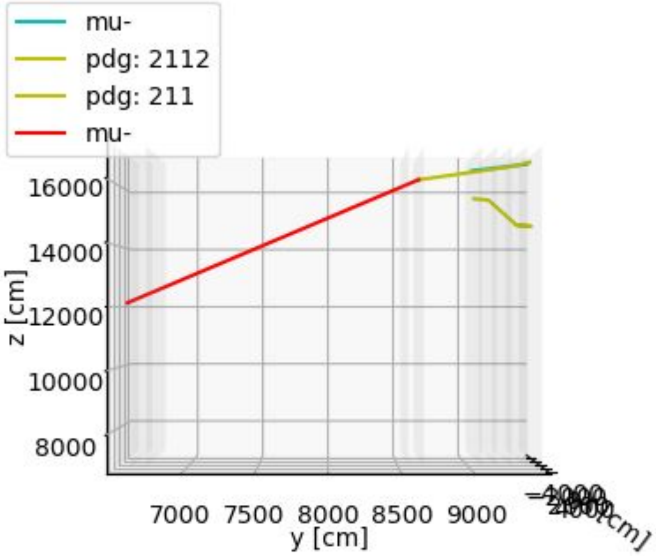
Missed hits in the floor or wall Cut Details

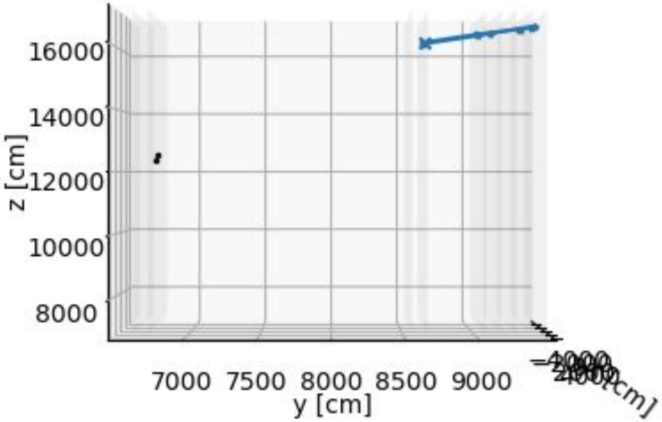
- Propagate vertex tracks backwards into the plane of the floor and wall
  - Compute the distance (in the plane) to all hits before the vertex
- Cut on the minimum distance between a track and a hit
  - Events where this parameter is less than 20 m are cut
    - This value is larger than one might expect primarily from hit selection inaccuracies



Pseudo-Tracks Cut Details

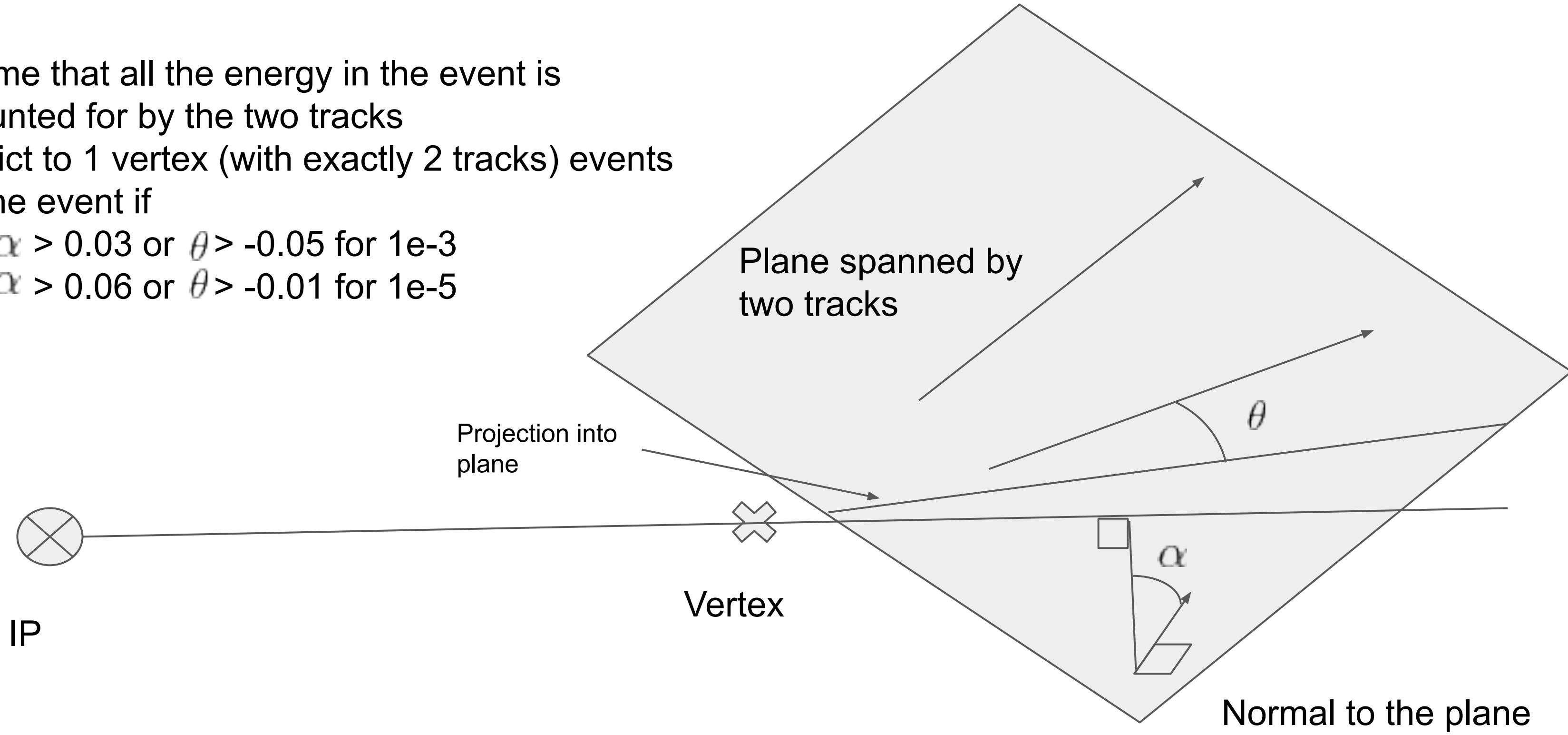
- Collect hits in the floor and wall that happen before the vertex
- Use these to make pseudo-tracks with pairwise combinations of unused hits in the tracking layers
  - Calculate β for each of these tracks
- If $0.8 \leq \beta \leq 1.2$, veto the event
  - Could have been a muon (that wasn't reconstructed) that knocked off electrons to form a fake vertex





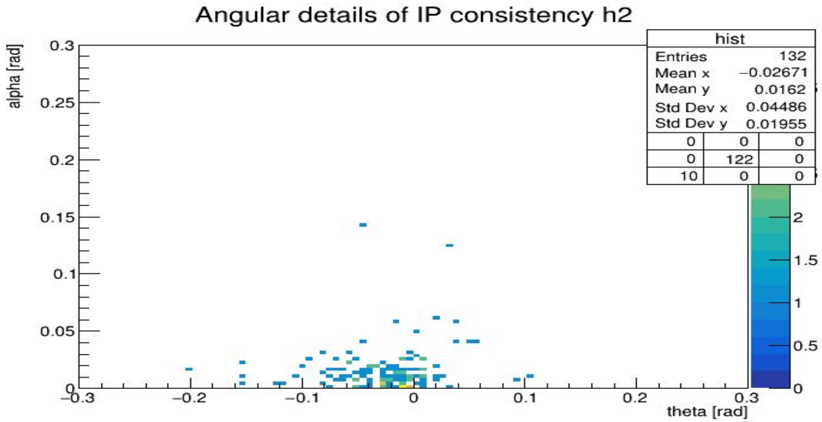
Consistency with IP Cut Details

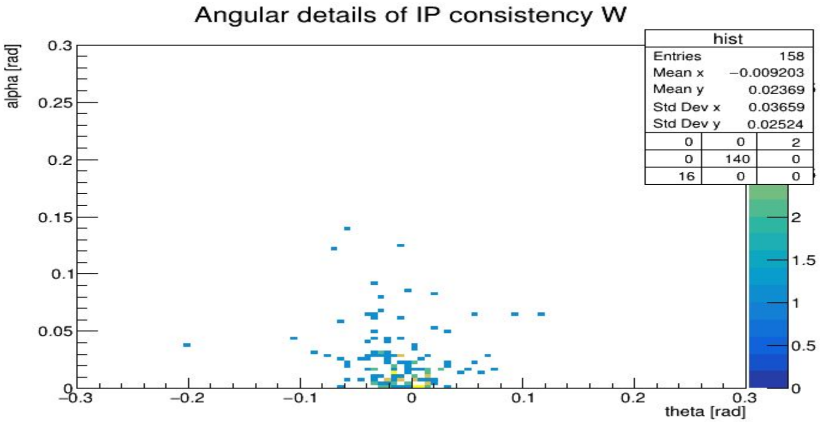
- Assume that all the energy in the event is accounted for by the two tracks
- Restrict to 1 vertex (with exactly 2 tracks) events
- Cut the event if
  - α > 0.03 or θ> -0.05 for 1e-3
  - α > 0.06 or θ> -0.01 for 1e-5

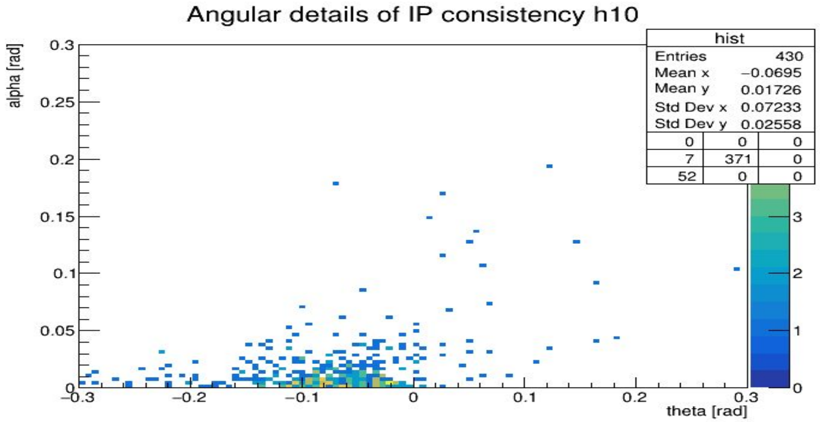


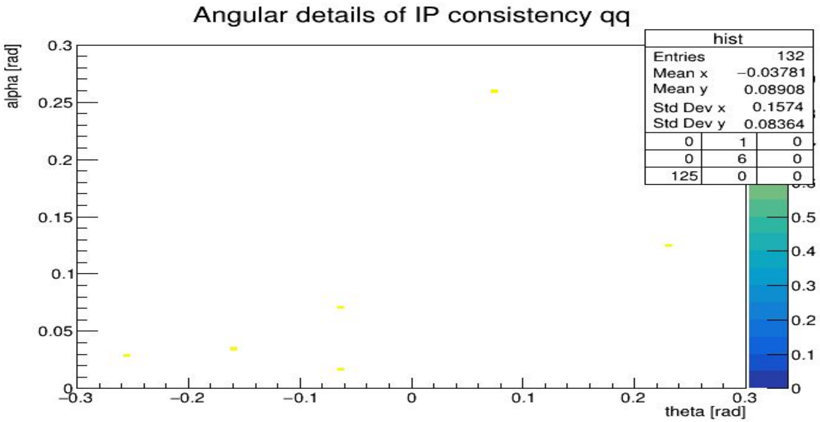
Consistency with IP Cut Distributions - 1e-3

α > 0.03 or
θ > -0.05 for 1e-3



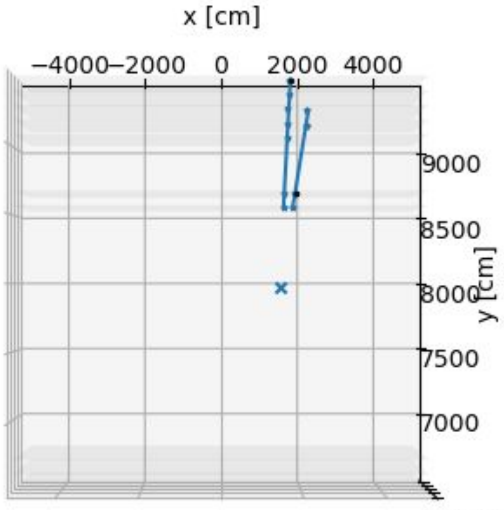


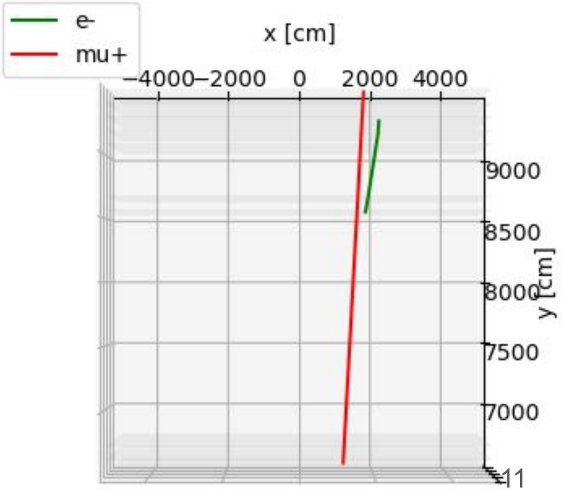




Degraded Efficiency Studies - Motivation

- We randomly drop hits in the floor and wall with probabilities 0, 1e-5, and 1e-3 to simulate detector inefficiencies
- Geometry has 1 Hermetic Floor and Wall
- $c\tau = 50\mathrm{m}$ for signal





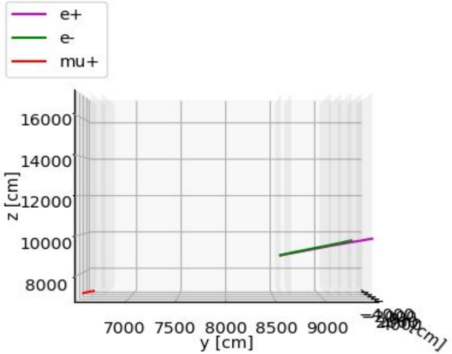
Missed hits can make W background look like signal

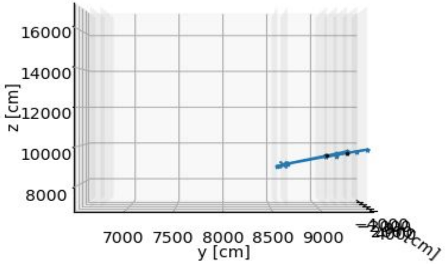
Analysis Performance - W Background

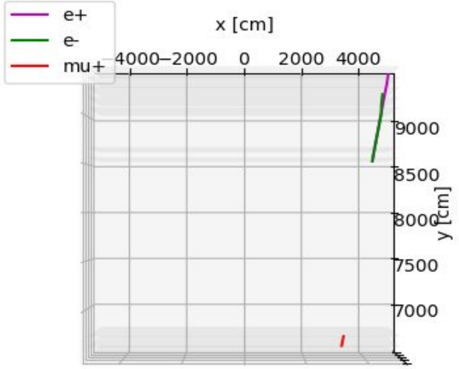
We expect 6e10 W events, (½ of IP induced background). Assuming we get 90% efficiency from CMS, we normalize to ~1e10: we're at about ½ the total rate.

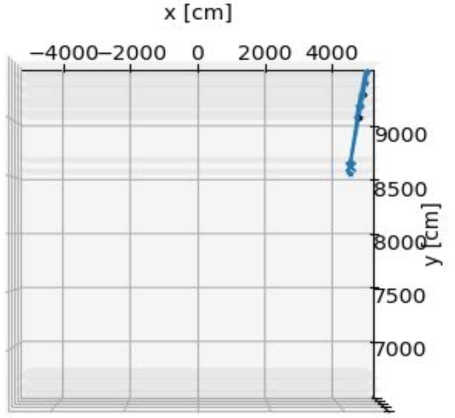
Cuts / Efficiency (Triggered Events) (Simulated Events)	Full Efficiency (41 812 652) (4.41e9)	1e-5 Inefficiency (42 617 875) (4.50e9)	1e-3 Inefficiency (43 179 810) (4.56e9)
Tracks >= 2	698789 (0.0167)	711873 (0.0167)	722108 (0.0167)
Vertices >= 1	320989 (0.00768)	327120 (0.00768)	331997 (0.00769)
Fiducial Vertex	116073 (0.00278)	118707 (0.00279)	120525 (0.00279)
No Track Hits in Floor / Wall	4559 (0.000109)	4685 (0.000110)	4875 (0.000113)
Non-Fiducial Corner Cut	506 (1.21e-5)	493 (1.16e-5)	658 (1.52e-5)
No Floor Wall Hits before Vertex	14 (3.3e-7)	18 (4.20e-7)	174 (4.03e-6)
No Pseudo-Tracks Cut	1 (2.00e-8)	8 (1.90e-7)	158 (3.66e-6)
Angles Consistent with IP	1 (2.00e-8)	2 (5.00e-8)	22 (5.10e-7)

Visualization of Background Survivors - Full Efficiency

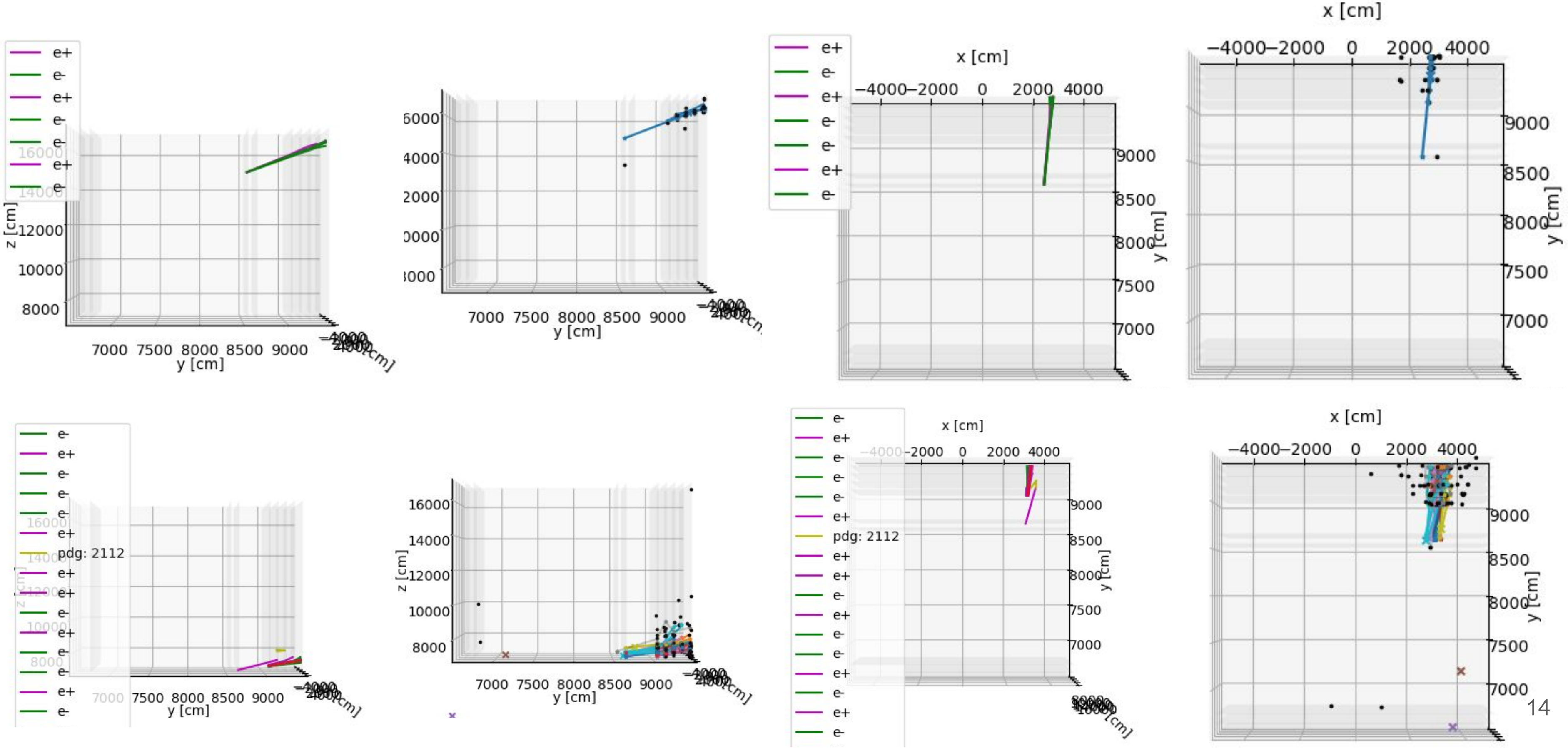








Visualizations of Background Survivors 1e-5



Analysis Performance - 10 GeV Muon Signal

Cuts / Efficiency (Triggered Events)	Full Efficiency (3876)	1e-5 Inefficiency (3876)	1e-3 Inefficiency (3876)
Tracks >= 2	1241 (0.320)	1238 (0.319)	1258 (0.325)
Vertices >= 1	753 (0.194)	744 (0.192)	740 (0.191)
Fiducial Vertex	528 (0.136)	512 (0.132)	554 (0.143)
No Track Hits in Floor / Wall	497 (0.128)	481 (0.124)	504 (0.130)
Non-Fiducial Corner Cut	421 (0.109)	406 (0.105)	431 (0.111)
No Floor Wall Hits before Vertex	420 (0.108)	405 (0.105)	430 (0.111)
No Pseudo-Tracks Cut	420 (0.108)	405 (0.105)	430 (0.111)
Angles Consistent with IP	-	347 (0.0895)	266 (0.0686)

Analysis Performance - 2 GeV Muon Signal

Cuts / Efficiency (Triggered Events)	Full Efficiency (1008)	1e-5 Inefficiency (1008)	1e-3 Inefficiency (1008)
Tracks >= 2	345 (0.342)	357 (0.354)	338 (0.335)
Vertices >= 1	234 (0.232)	238 (0.236)	223 (0.221)
Fiducial Vertex	177 (0.176)	193 (0.192)	170 (0.169)
No Track Hits in Floor / Wall	169 (0.168)	179 (0.178)	156 (0.155)
Non-Fiducial Corner Cut	150 (0.149)	157 (0.156)	132 (0.131)
No Floor Wall Hits before Vertex	150 (0.149)	157 (0.156)	132 (0.131)
No Pseudo-Tracks Cut	150 (0.149)	157 (0.156)	132 (0.131)
Angles Consistent with IP	-	105 (0.104)	37 (0.0367)

Analysis Performance - uubar Signal

One caveat; we can increase quark signal acceptance by tagging high multiplicity events and tuning our cuts accordingly.

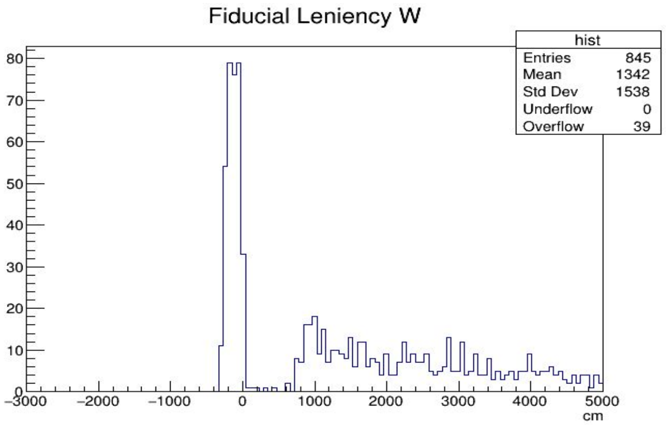
Cuts / Efficiency (Triggered Events)	Full Efficiency (361)	1e-5 Inefficiency (361)	1e-3 Inefficiency (361)
Tracks >= 2	258 (0.715)	252 (0.698)	256 (0.709)
Vertices >= 1	232 (0.643)	236 (0.654)	236 (0.653)
Fiducial Vertex	199 (0.551)	201 (0.557)	205 (0.568)
No Track Hits in Floor / Wall	146 (0.404)	144 (0.399)	150 (0.416)
Non-Fiducial Corner Cut	139 (0.385)	135 (0.374)	139 (0.385)
No Floor Wall Hits before Vertex	136 (0.377)	132 (0.366)	133 (0.368)
No Pseudo-Tracks Cut	134 (0.371)	131 (0.362)	132 (0.366)
Angles Consistent with IP	-	125 (0.346)	127 (0.352)

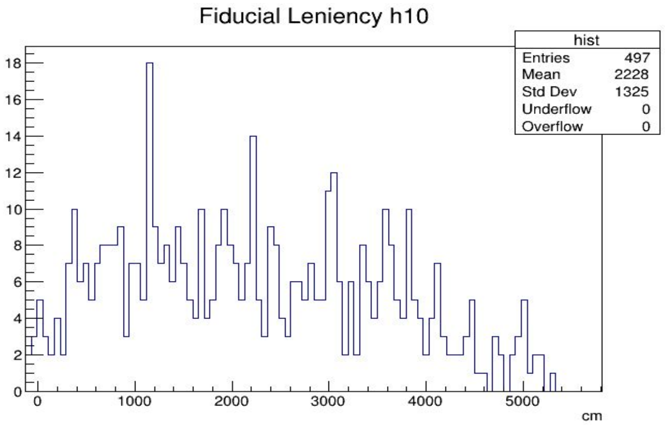
Conclusion and Next Steps

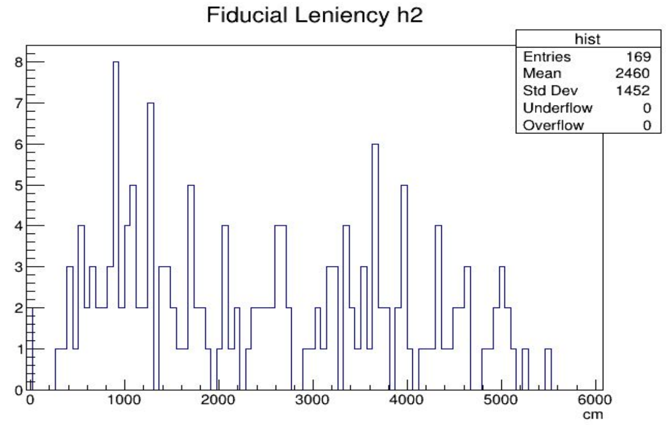
- Our signal acceptance and ability to reject background varies significantly with the efficiency in the floor and wall
  - Hermetic coverage of the decay volume is essential for eliminating W background during analysis
  - Signal acceptance of low mass muon events is severely restricted at 1e-3 inefficiency
- Next we will carry out further studies with the analysis
  - On the effect of noise for the efficacy of the analysis
  - On rejecting K-long background from Cosmic backscatters
  - On the effect of material budget on background rates

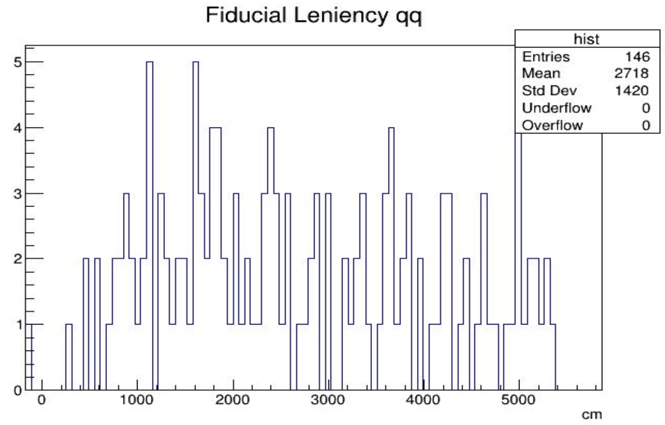
Backup Slides - Non-Fiducial Corner Distributions

Full Efficiency Samples



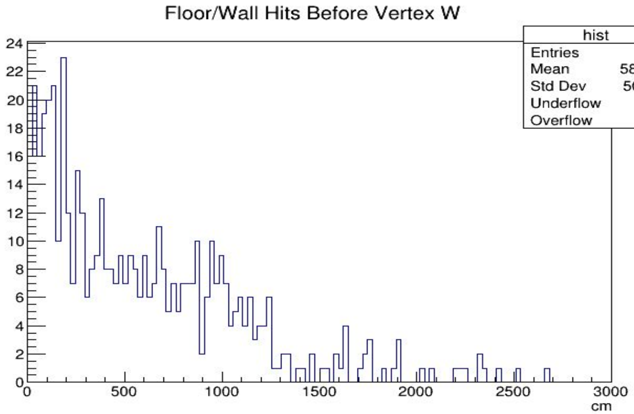


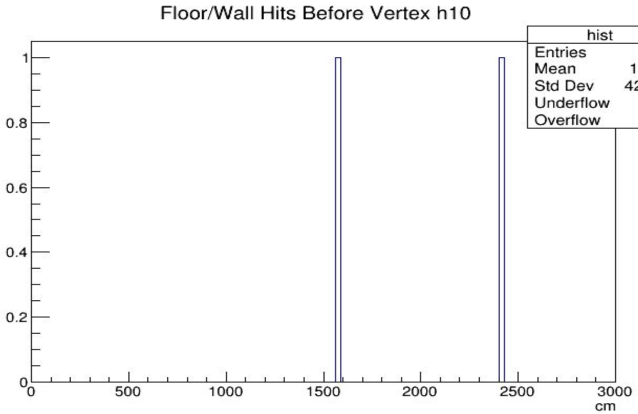


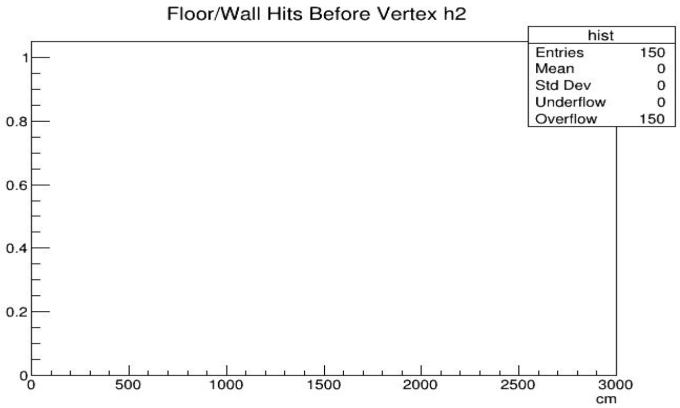


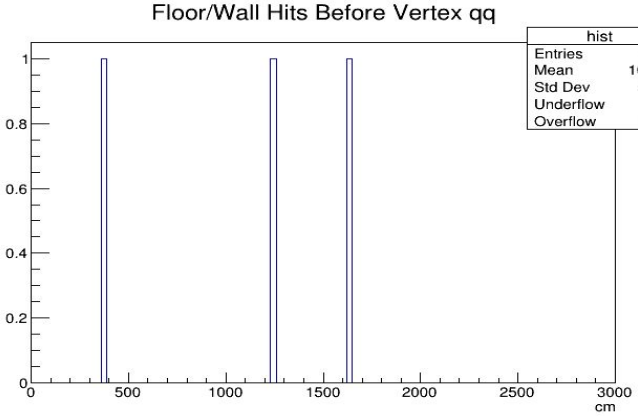
Backup Slides - Floor Wall Hits Before Vertex Distributions

Full Efficiency
Samples



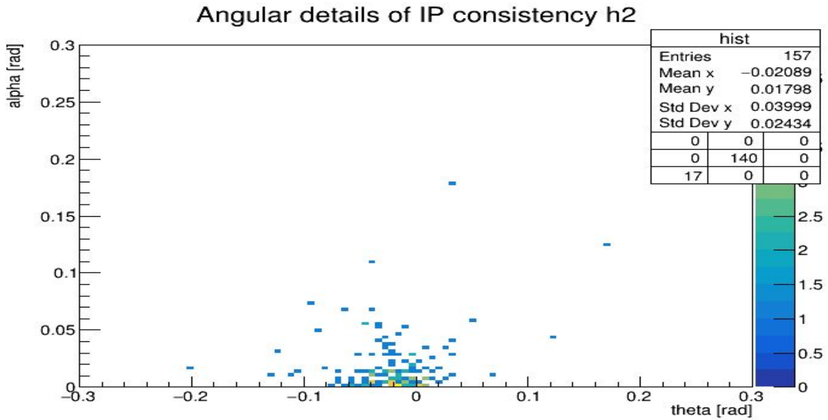


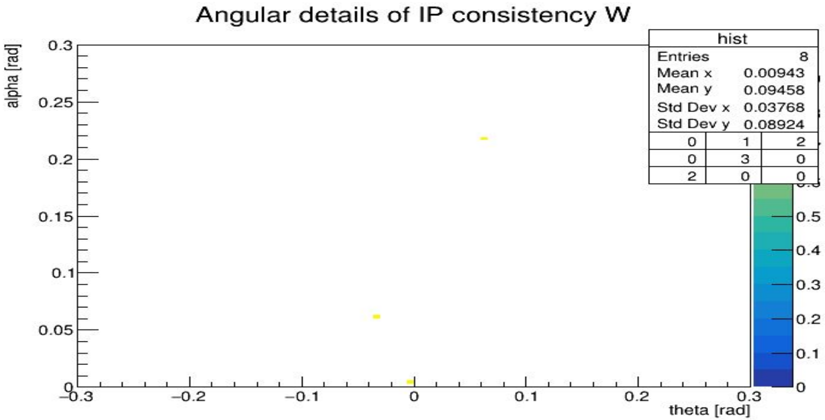


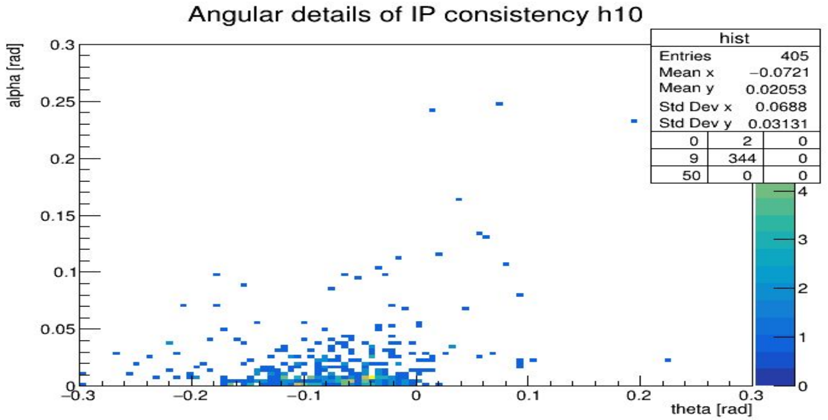


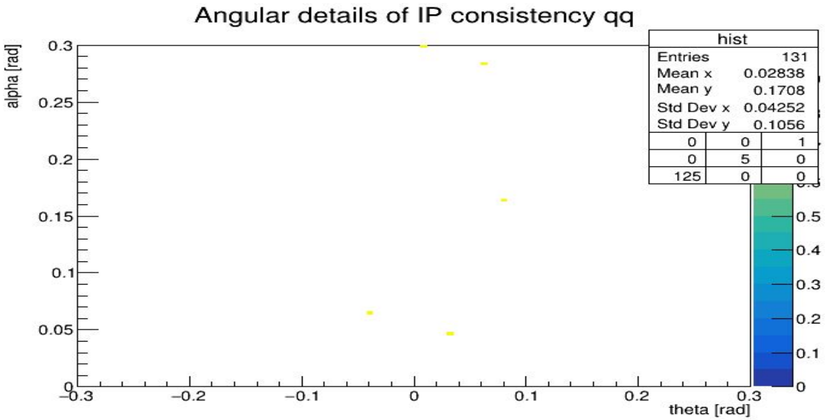
Consistency with IP Cut Distributions - 1e-5

α > 0.06 or
θ > -0.01 for 1e-5



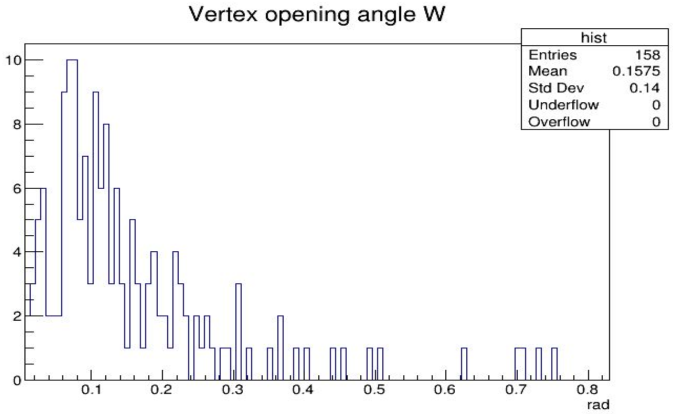


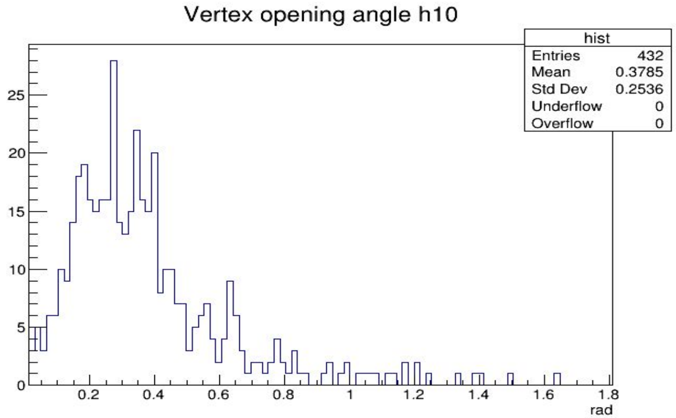


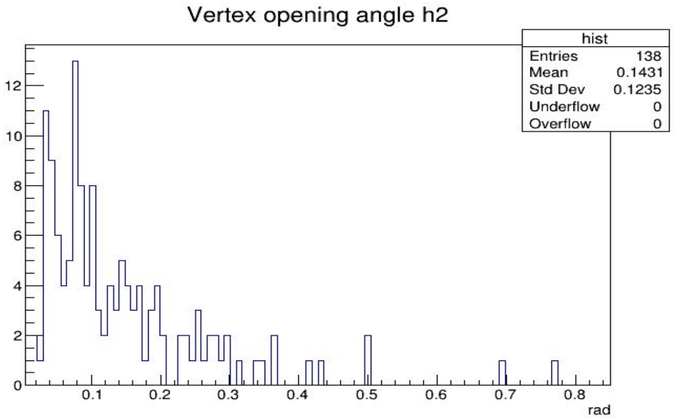


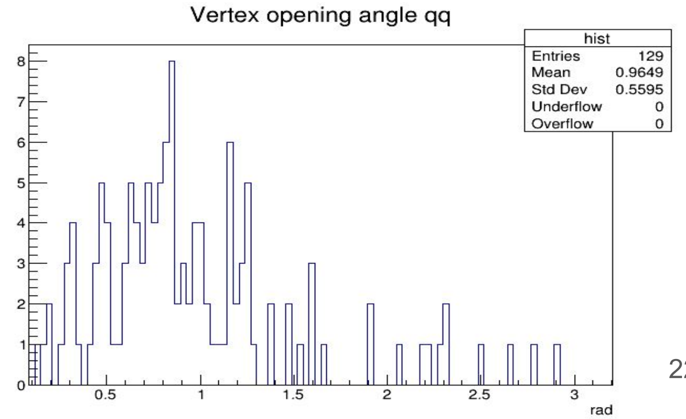
Backup Slides - Minimum Opening Angles of Vertex Tracks

- 1e-3 inefficiency
- Before Angular Consistency Cut

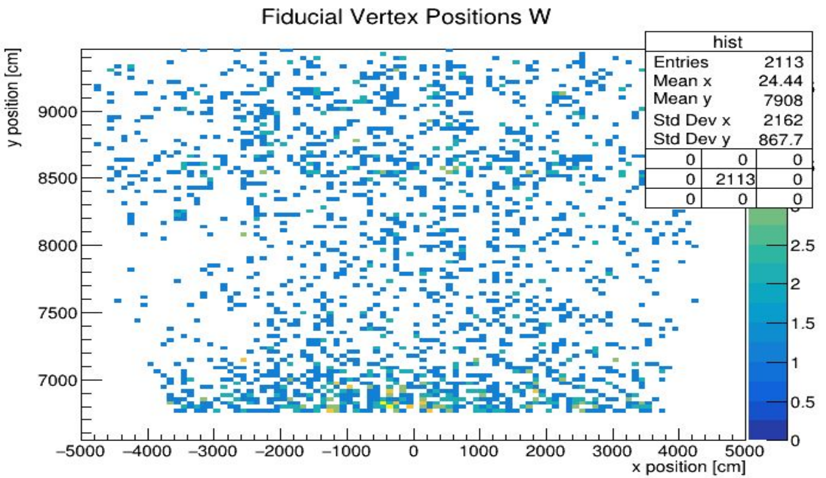


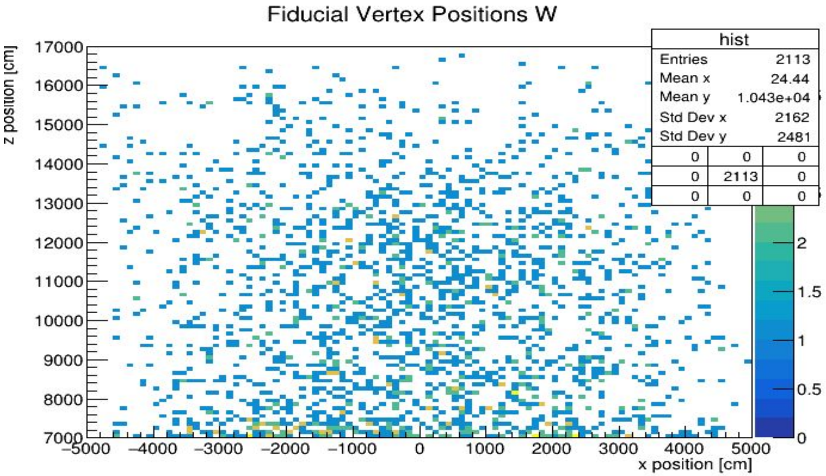




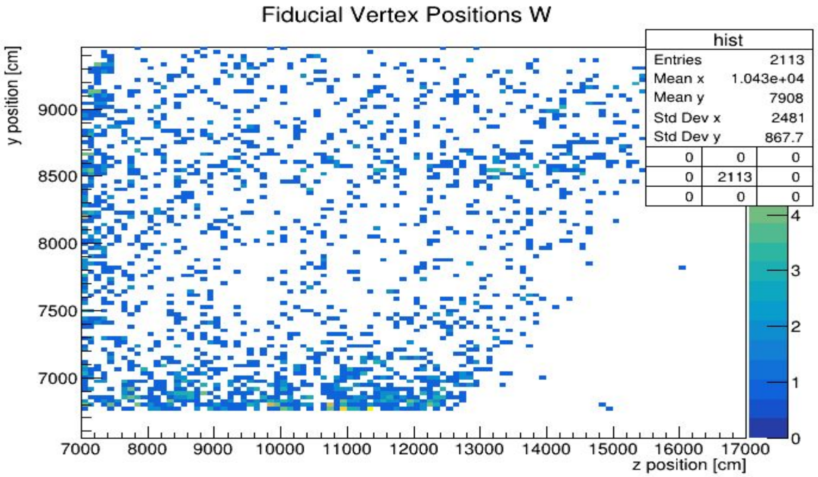


Backup Slides - Vertex Position Plots W

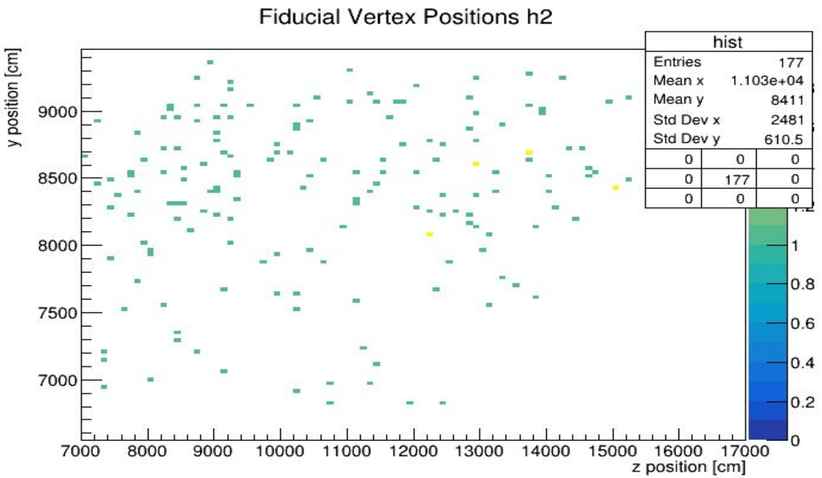


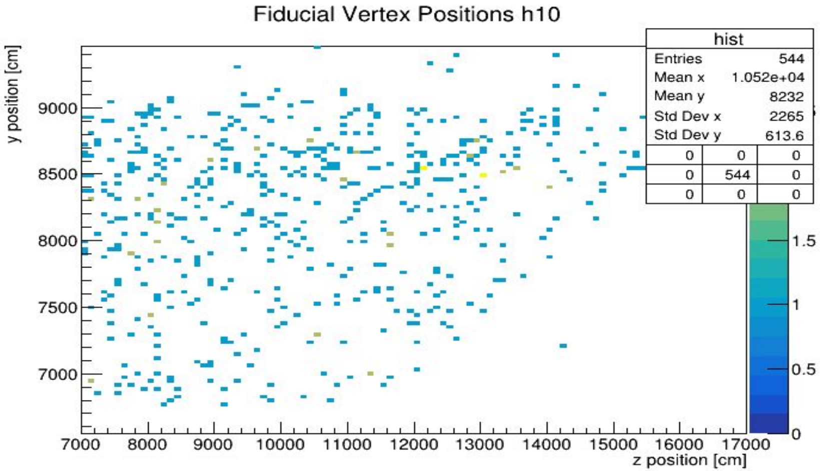


Full Efficiency Samples

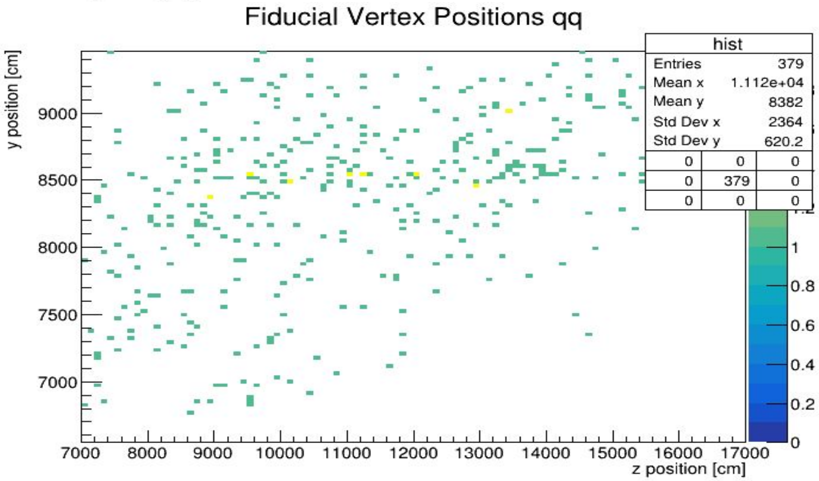


Backup Slides - Vertex Position Plots Signal





Full Efficiency Samples



Backup Slides - Vertexing Algorithm Details

- **VERTEXER** used is a Maximum Likelihood fitter (unchanged)
  - Only use lowest hit and velocity to represent the track
  - **SEED** with pairs of tracks that have a closest approach distance $\leq 100\mathrm{cm}$
    - The seed vertex position is taken to be the midpoint of the particle positions at the time of closest approach
  - **FIT** for vertex position using closest approach position
    - Closest approach cut is $100\mathrm{cm}$, add any other tracks that make the cut
    - **VETO** the vertex if the $\chi^2/\mathrm{ndof} \geq 15$

Backup Slides - Floor Wall Hits Before Vertex Distributions

- Full Efficiency Samples
- From Previous Iteration of Analysis

Falling distribution for correct hit selection + distribution with long tail for incorrect selection