fiTQun Fiducial Volume Studies

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fiTQun! Workshop
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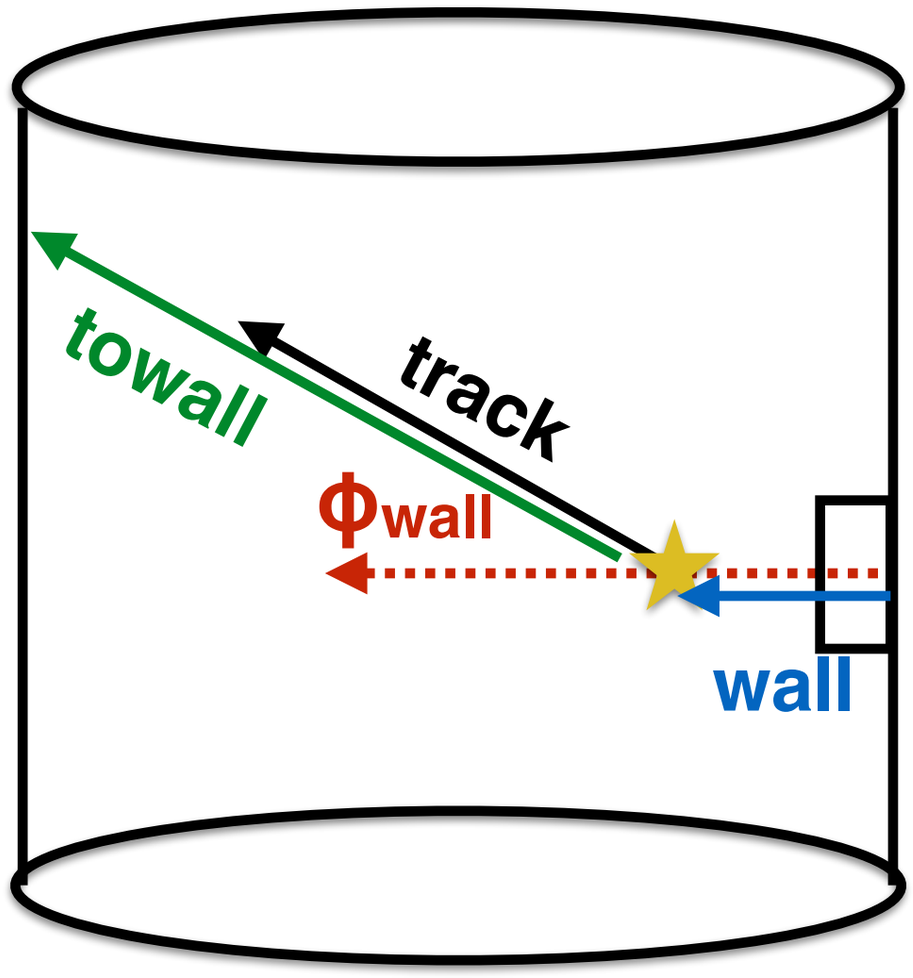
Outline

- **MC Studies**
  - Reconstruction quality near FV boundary
  - T2K cut performance near FV boundary
- **Systematic Error Studies**
  - Systematic error checks using stopping cosmic ray muons and decay electrons
- **Optimization Methods**
  - Metrics for FV cut optimization
  - Incorporating systematics into optimization

Introduction

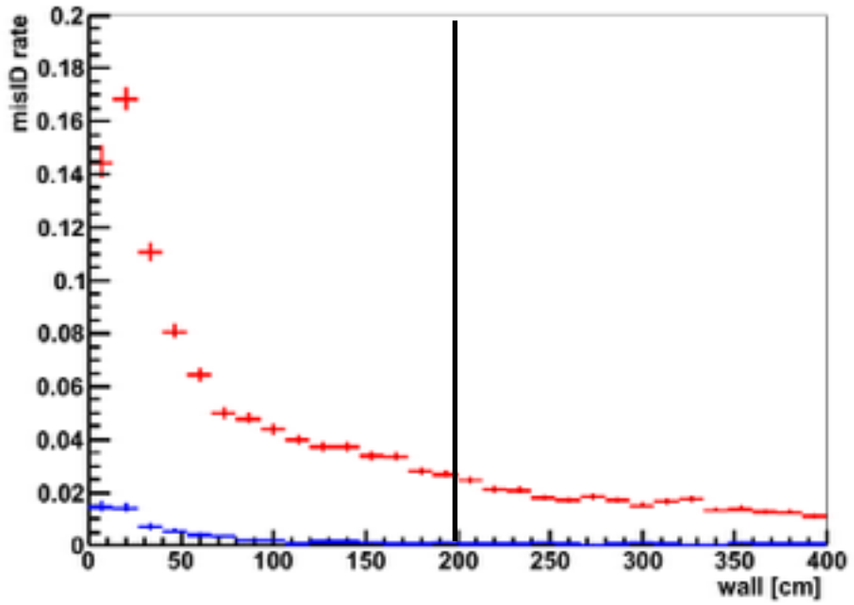
- Fiducial cut variable definitions:
  - Wall - minimum distance from vertex to ID wall
    - Current fiducial cut for T2K is wall > 200 cm
  - Towall - distance to ID wall along the track direction
  - Phiwall - angle between track direction and the norm of the nearest ID wall
- Fiducial volume cut is envisioned as a cut in (wall,towall) or (wall,ϕwall) space



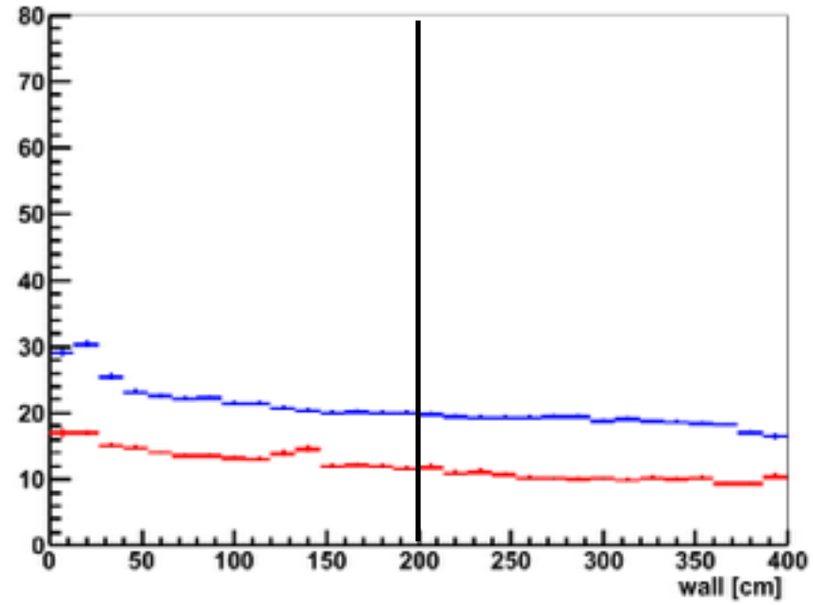
Performance Near ID Wall

misID rate

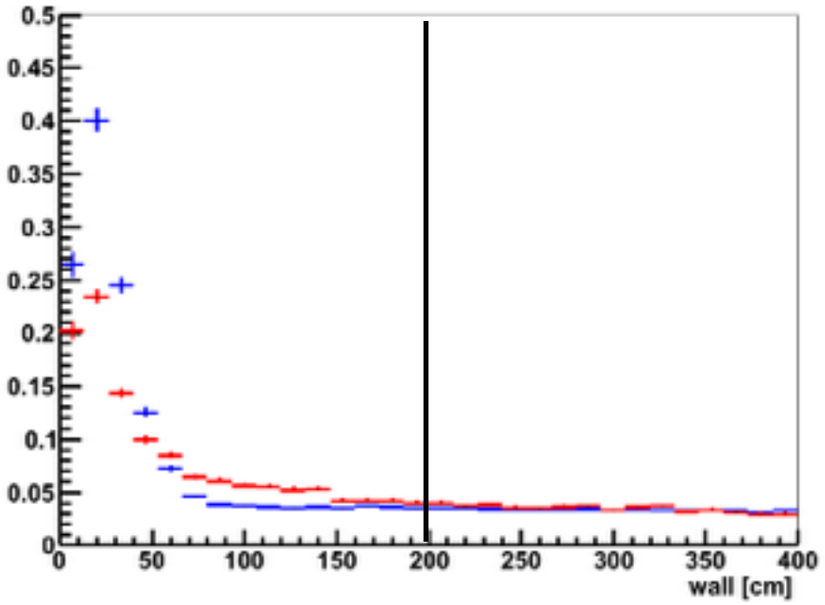
true muon
true electron



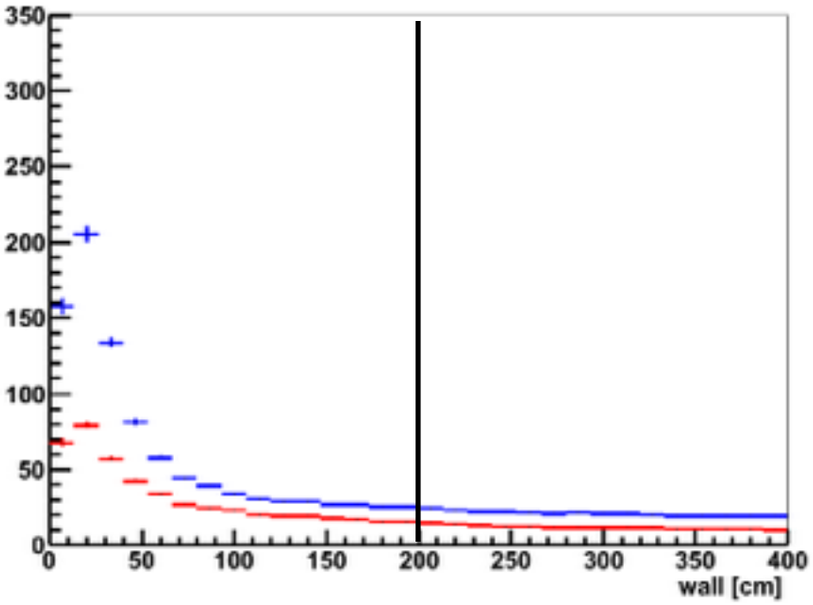
average Δ vtx [cm]



average Δ θ [rad]

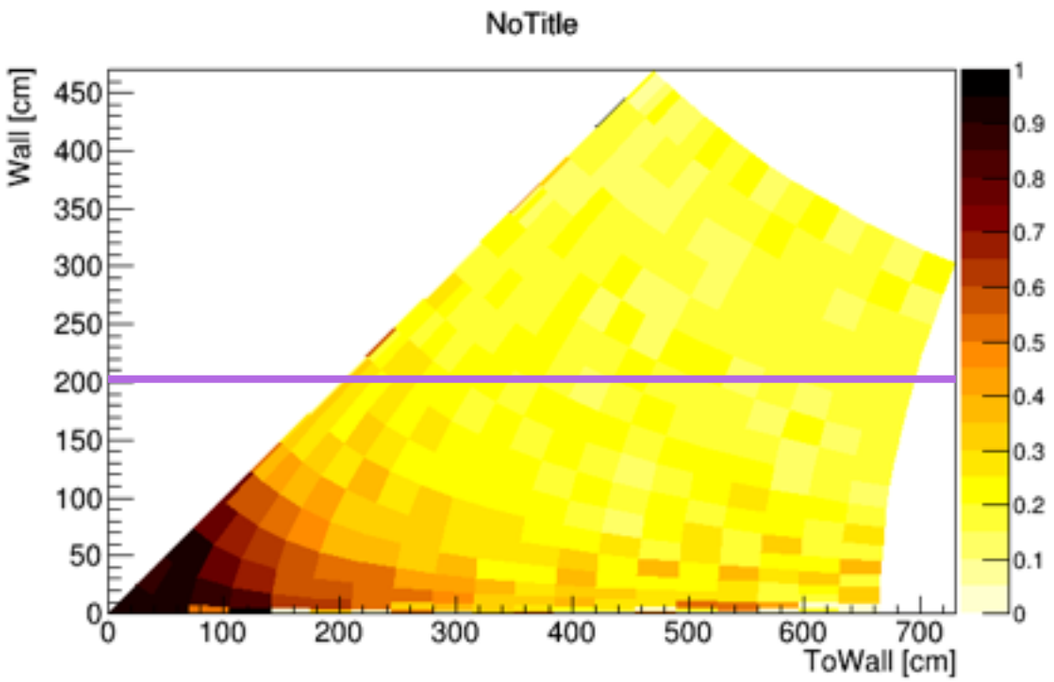


average Δ p [MeV]

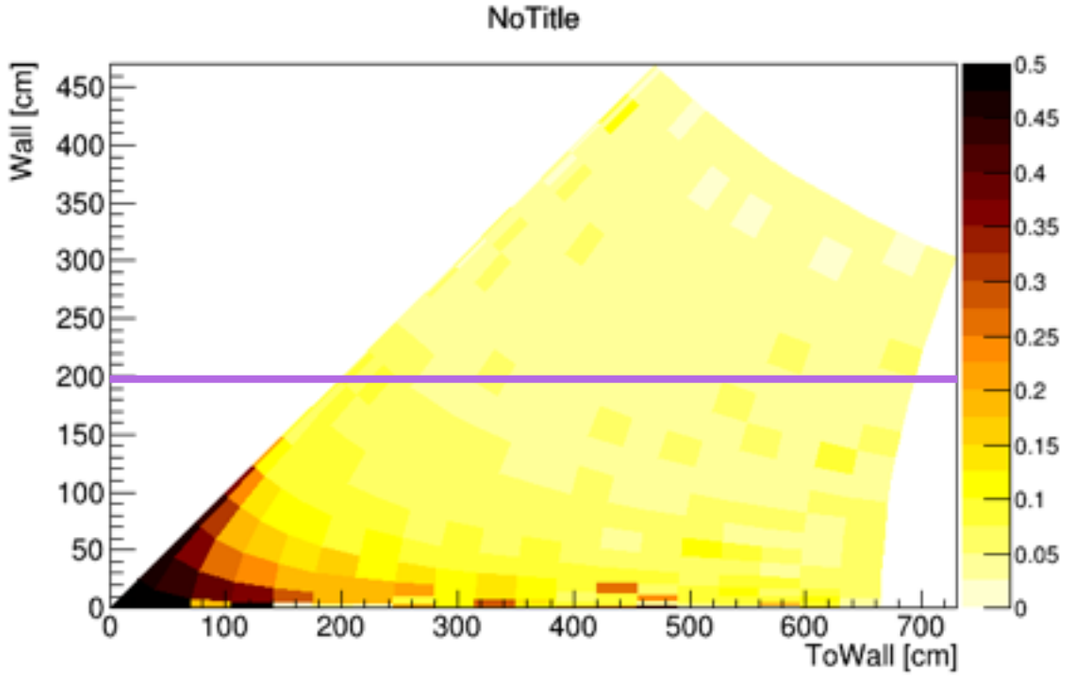


True Wall-Towall

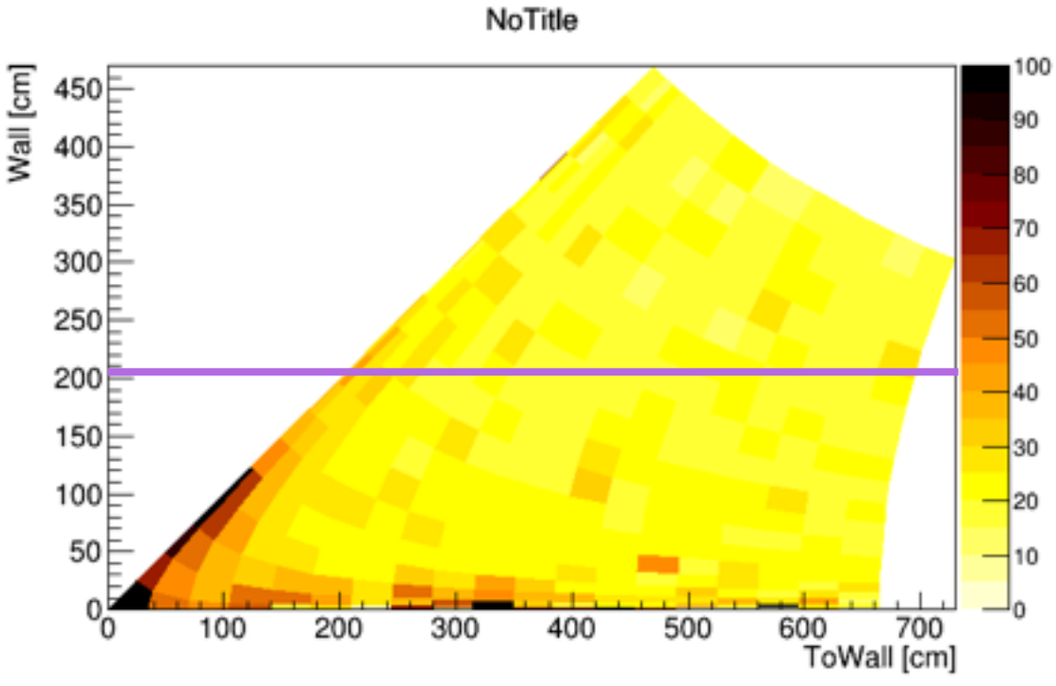
fraction with missed decay e



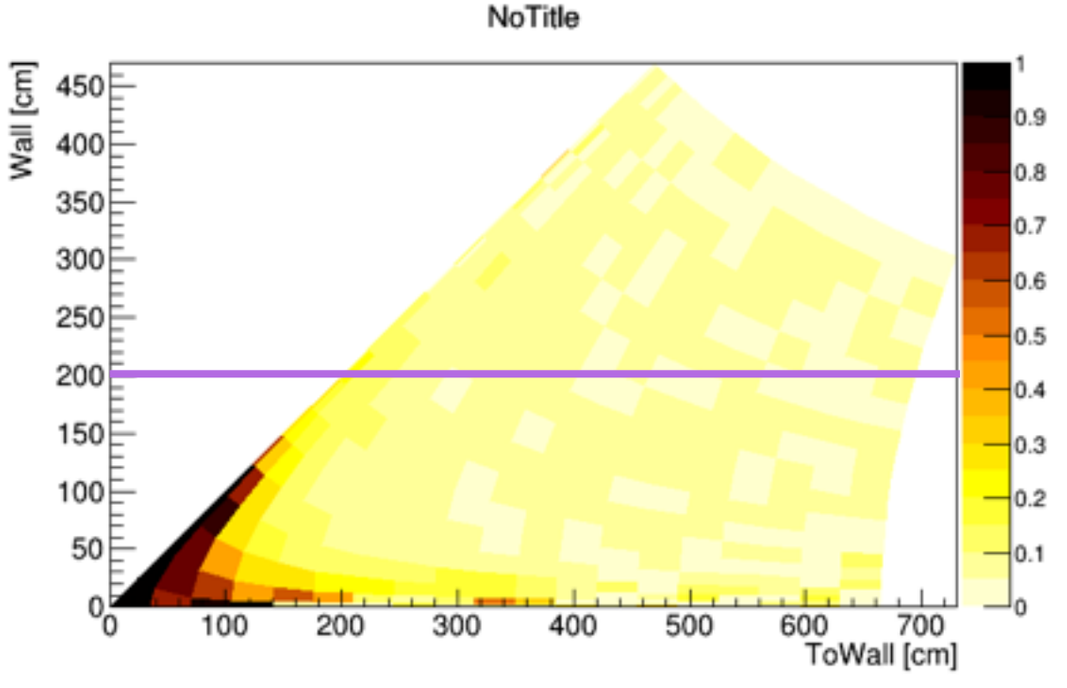
momentum resolution



position resolution

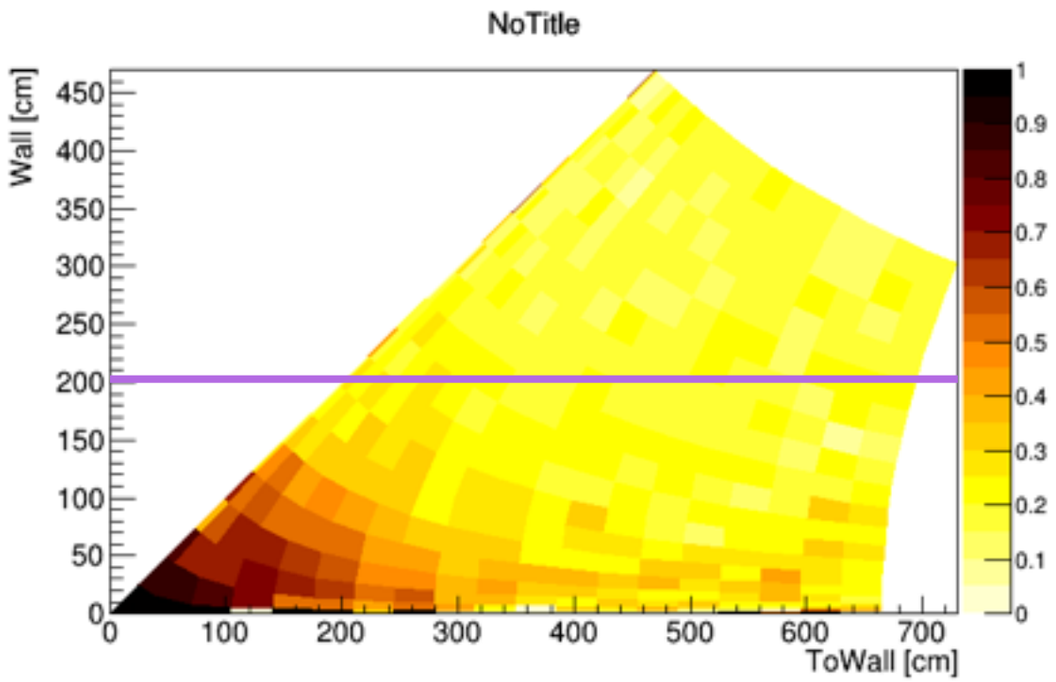


direction resolution

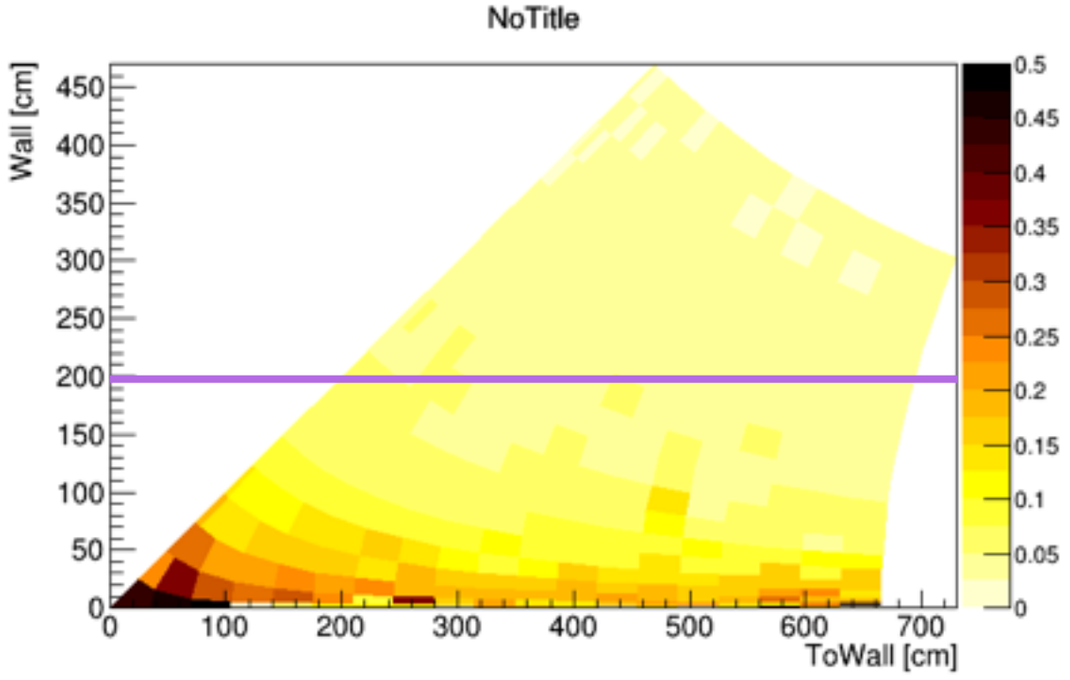


Reconstructed Wall-Towall

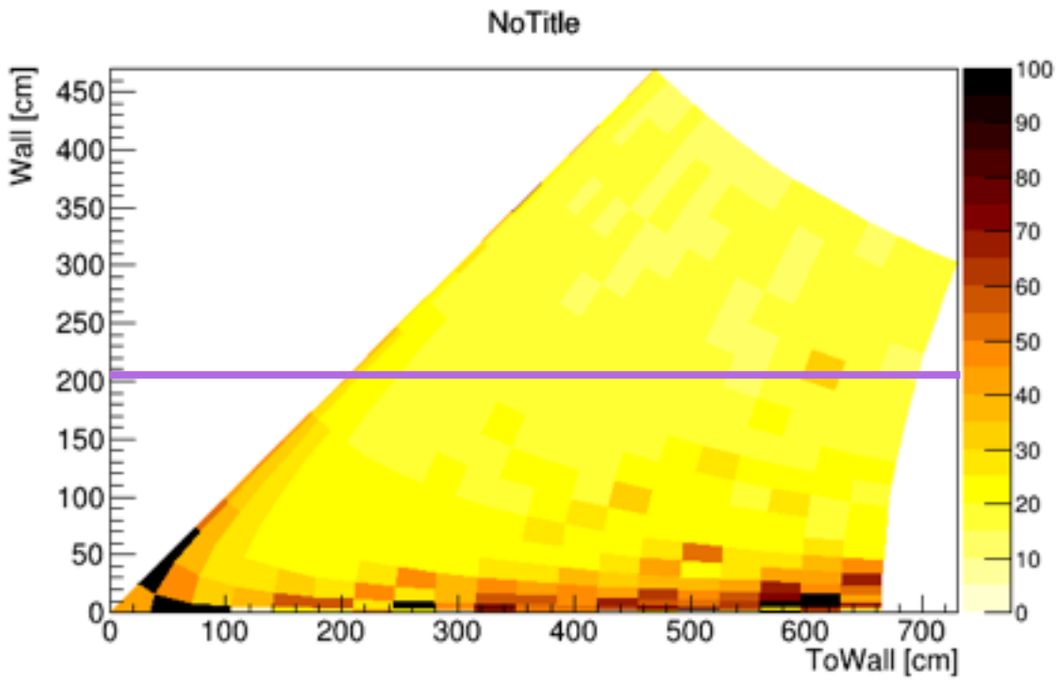
fraction with missed decay e



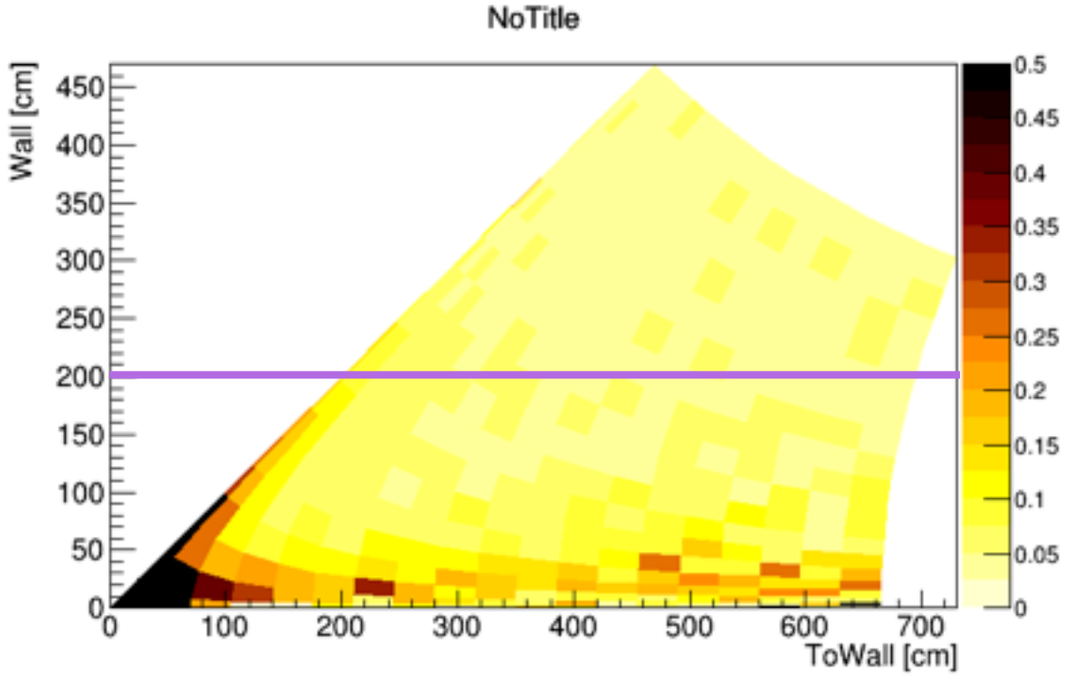
momentum resolution



position resolution



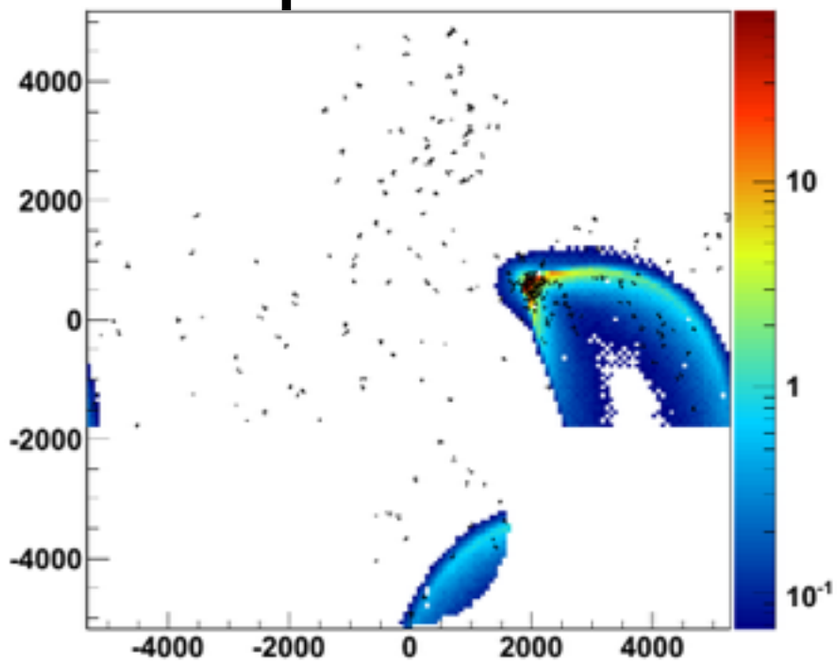
direction resolution



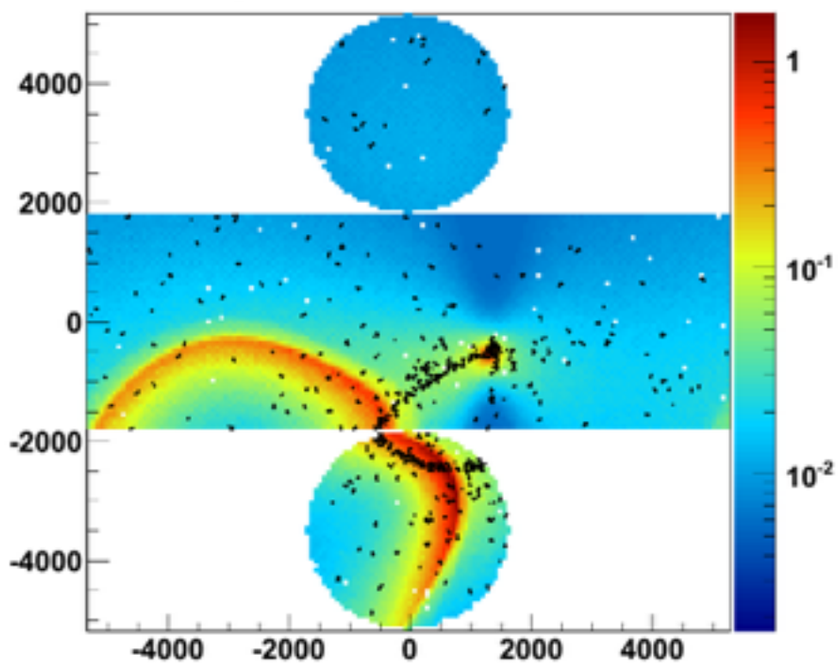
Fit Issues Near ID Wall

- From eye scan of fits, the types of failure modes can be broken down into two categories
  - **spot events** - true track is pointed into ID wall
    - fiTQun reconstructs track in opposite direction
  - **point events** - true track is tangent to the ID wall
    - fiTQun seed cannot reconstruct point feature leads to poor fit results
- Currently, fiTQun uses at 200 cm minimum wall value when finding the seed vertex
  - Reconstruction of “point events” may be improved by lowering minimum wall value for pre fitter (50 cm)

spot event



point event

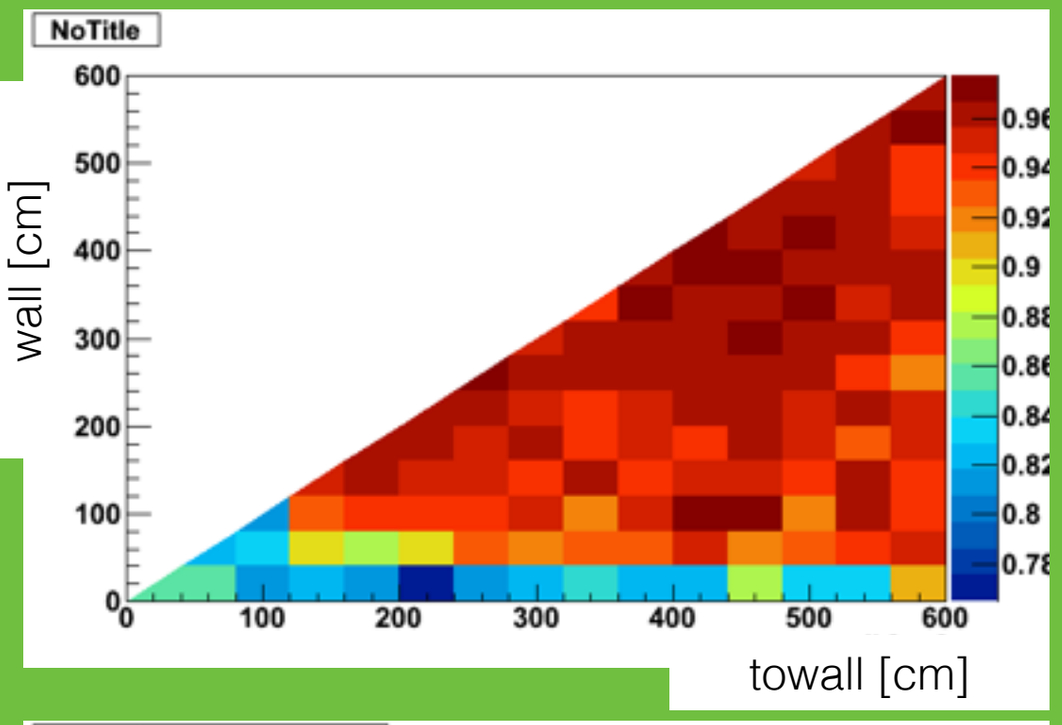


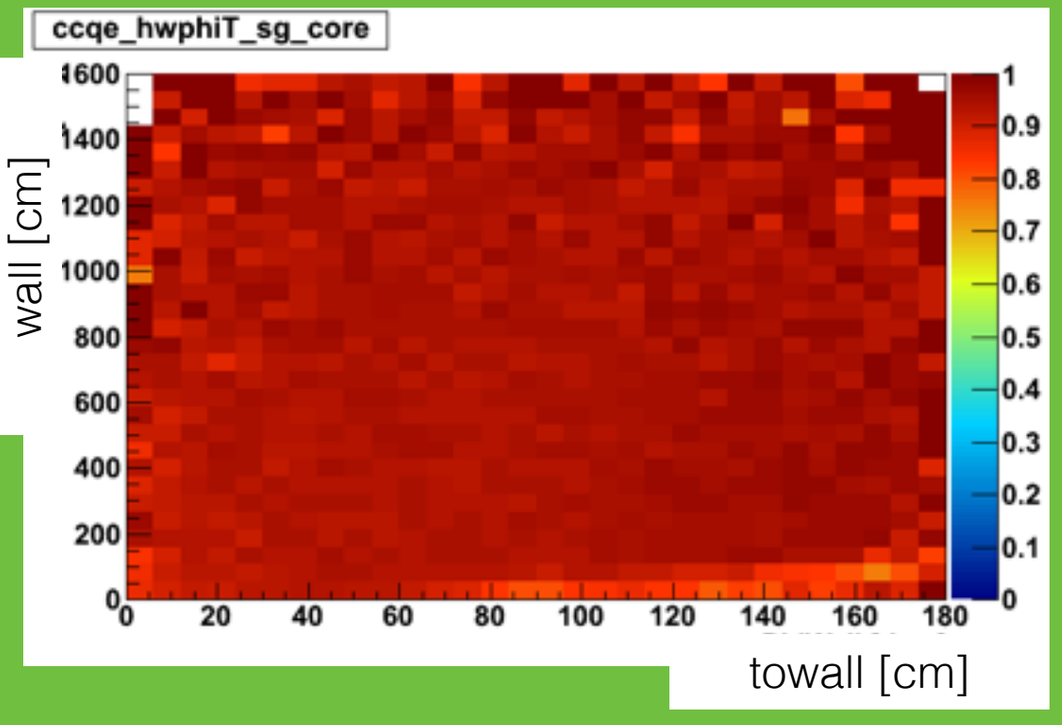
T2K Cut Efficiencies

- Check how the fiTQun ring counting and PID cuts are affected in the fiducial boundary region
- For this study:
    - Using νμ T2K MC
    - Apply successive T2K CCQE cuts and plot efficiency in wall, towall space
        - FC cut: nhitac<16
        - Evis cut: fq1rmom[0][1] > 30 MeV
        - nring cut: fqmrnring[0] =1
        - PID cut: ln(Lμ/Le) = 0.2* fq1rmom[0][1] (from tech. note)
        - fqnse < 2
- I define “signal” and “background” using the visible event topology

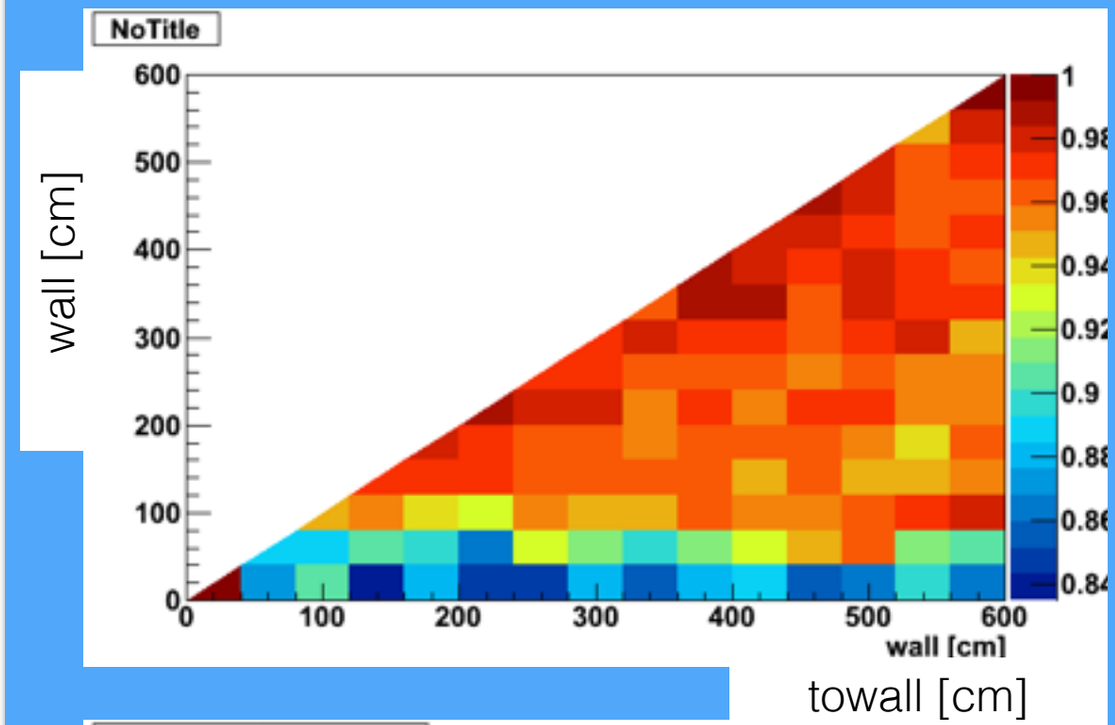
Ring Counting Cut (Signal)

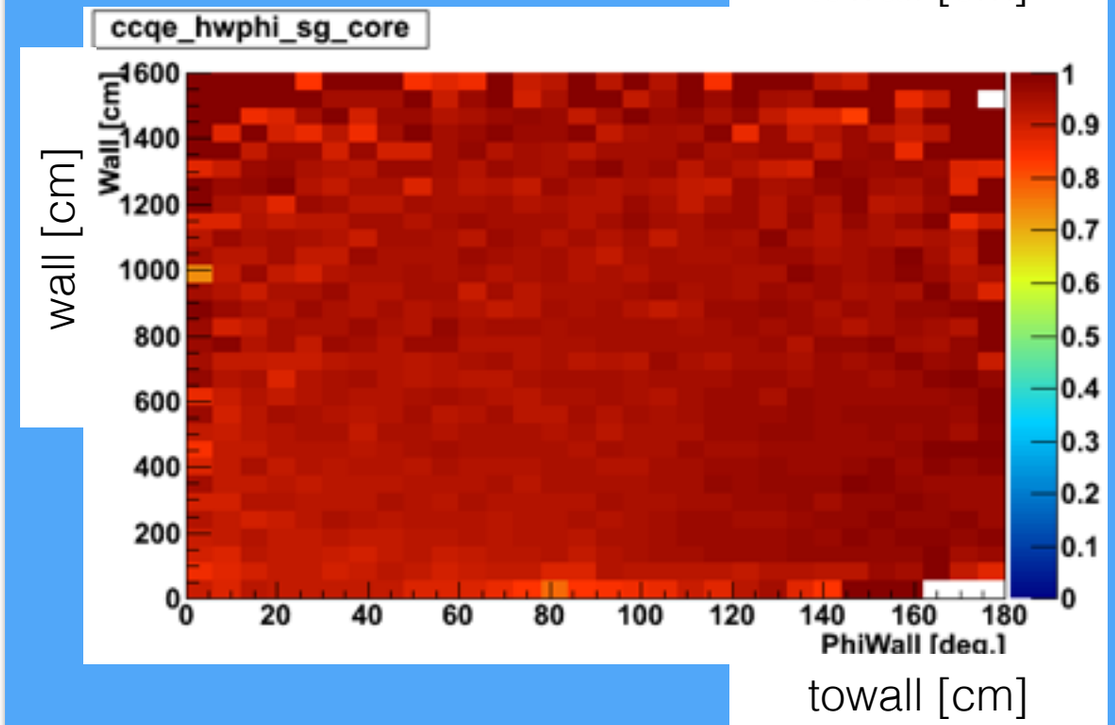
True FV Variables





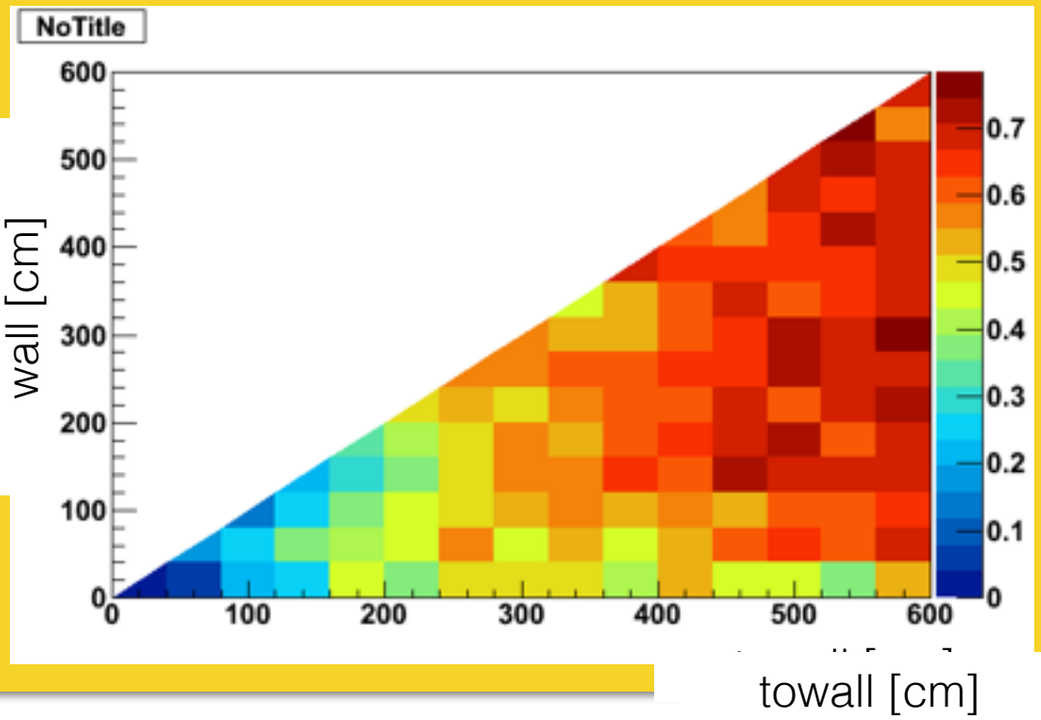
RC FV Variables



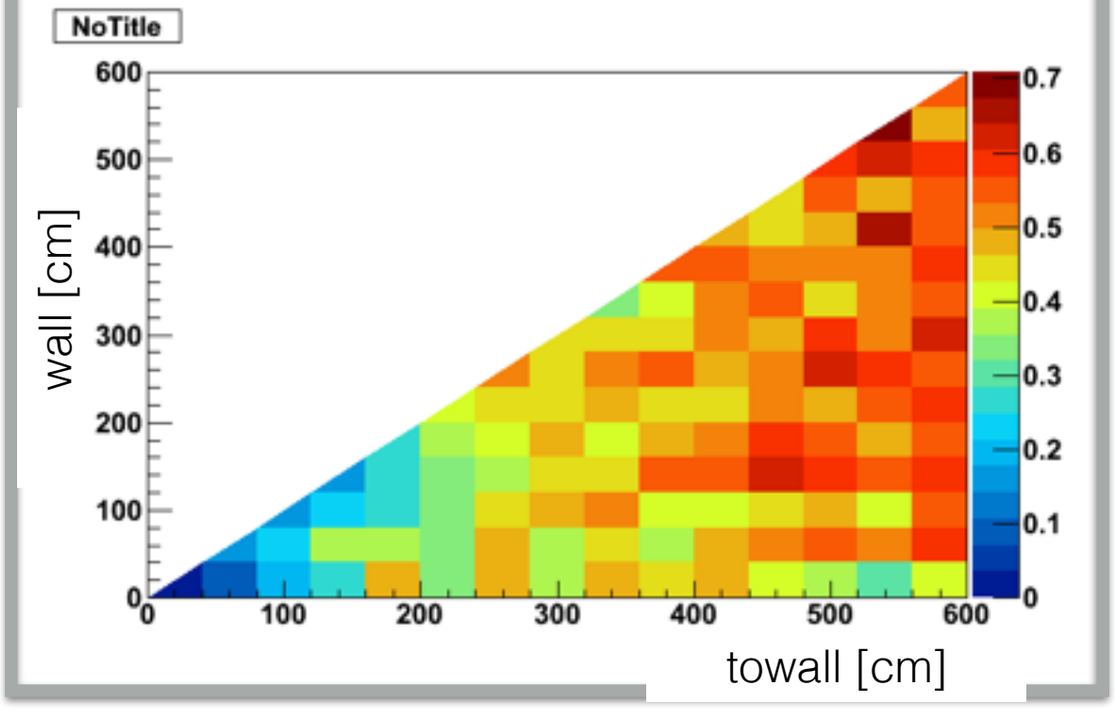


Ring Counting Cut (Background)

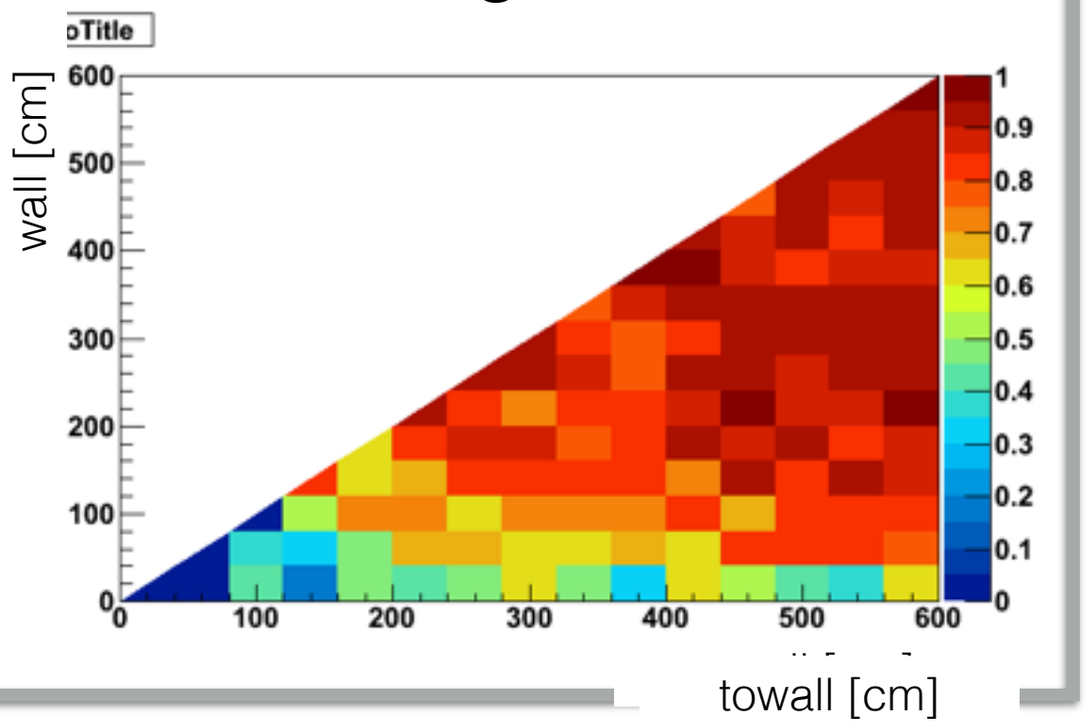
All BG (rejection efficiency)



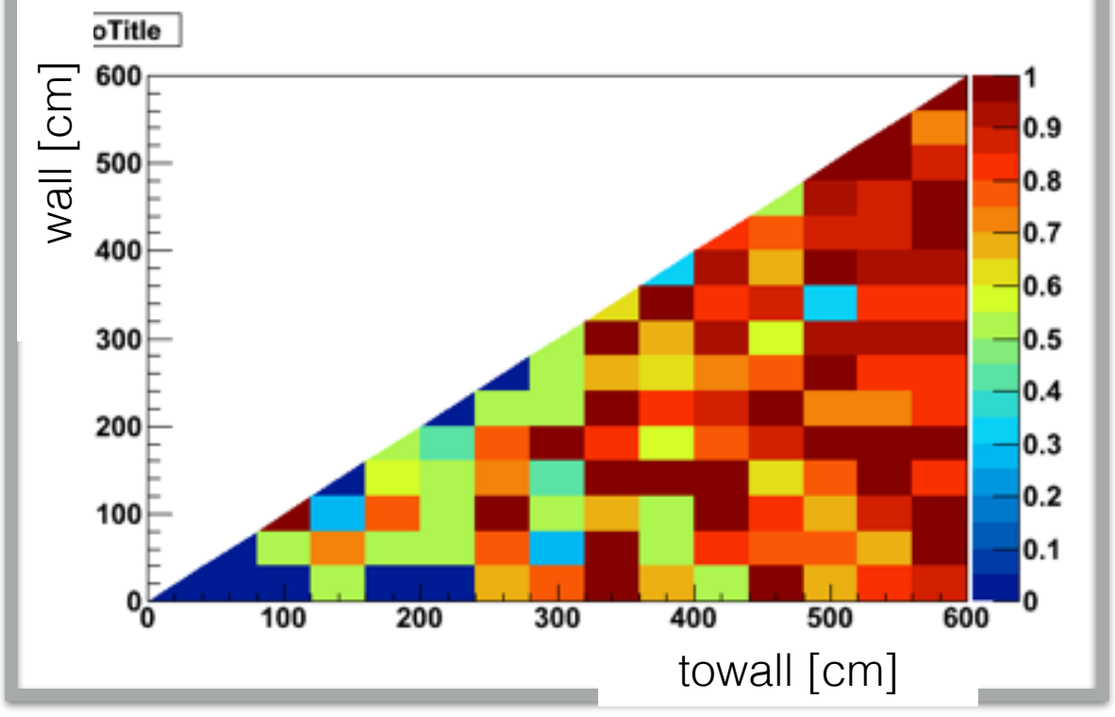
Single π+



Single π0

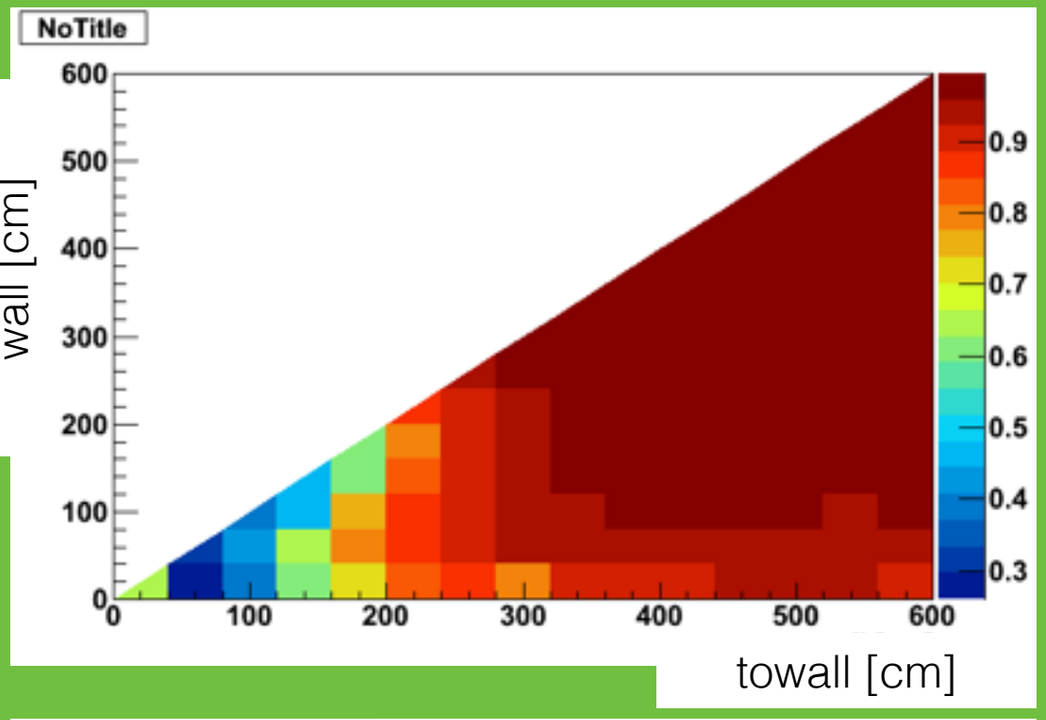


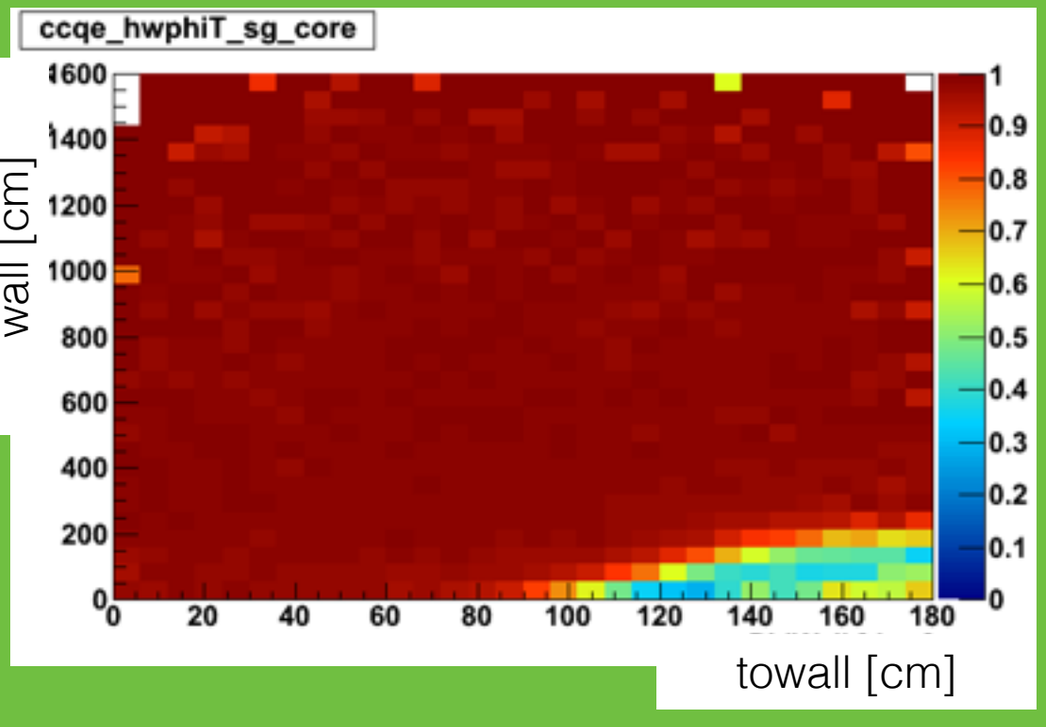
Multi π



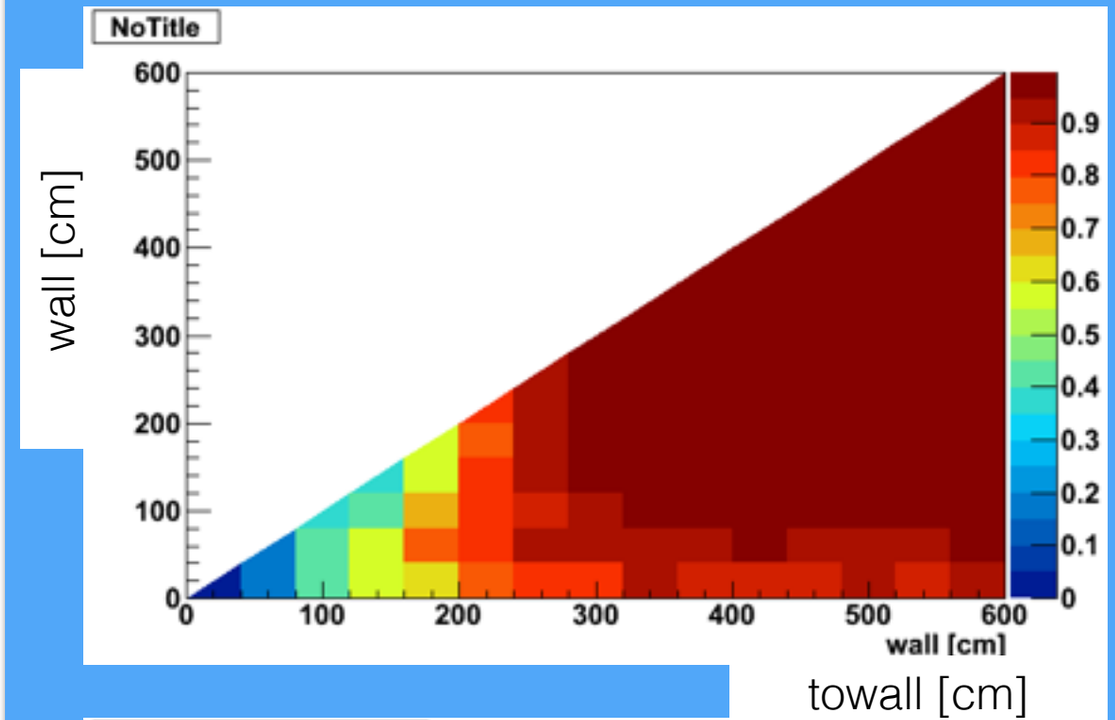
e/μCut (Signal)

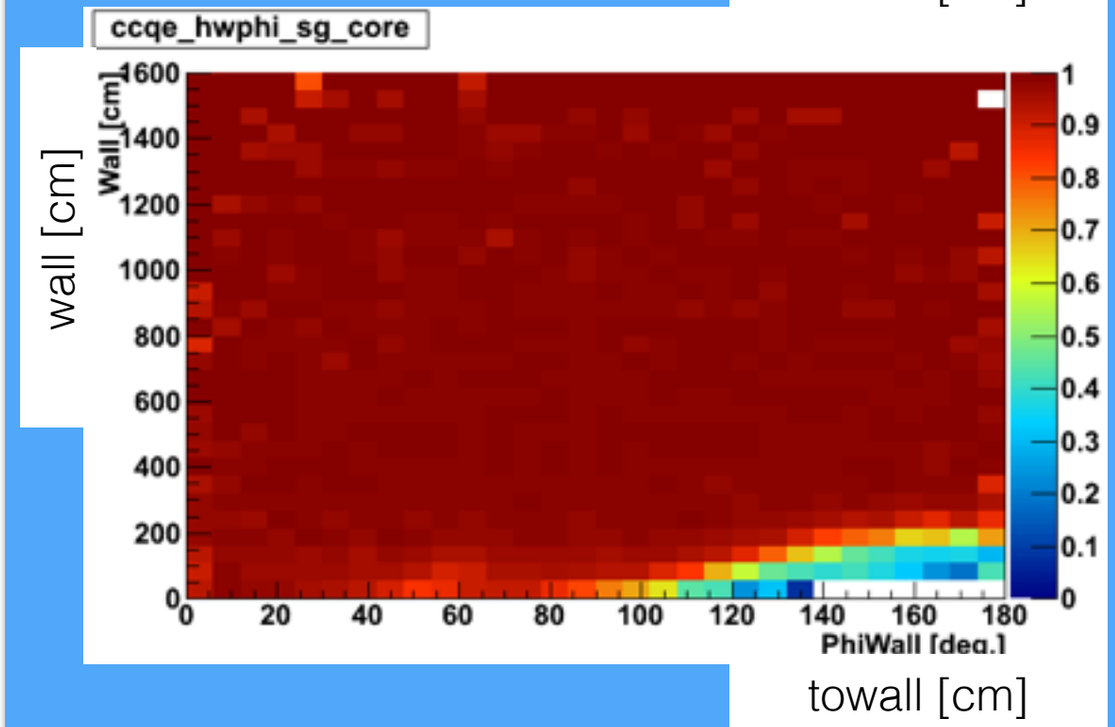
True FV Variables





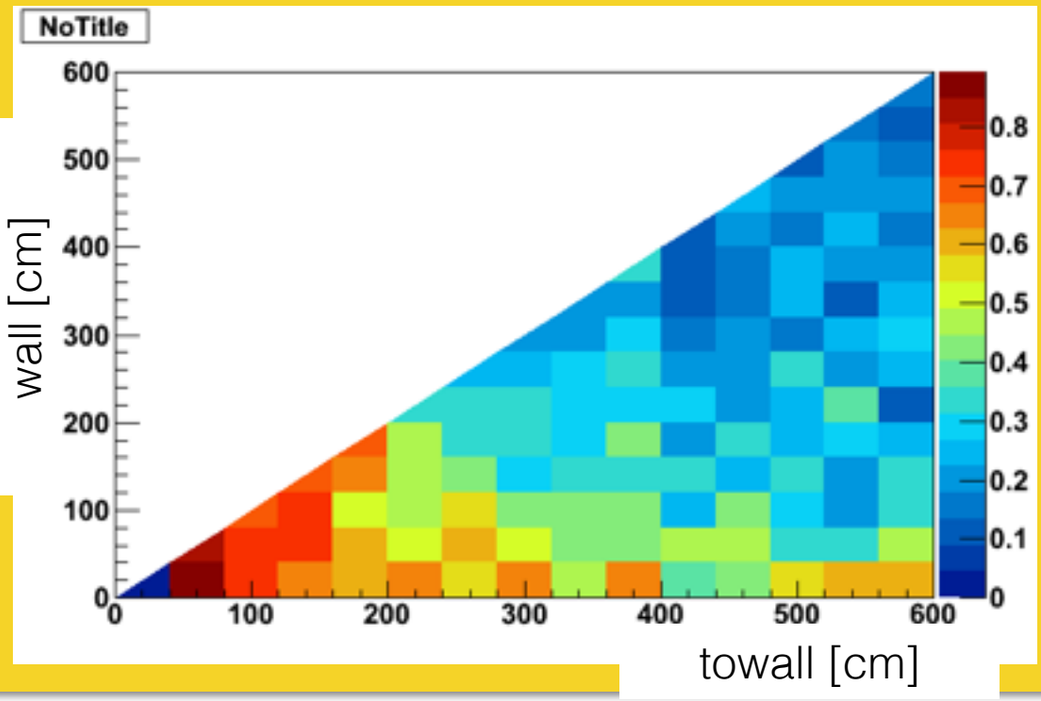
RC FV Variables



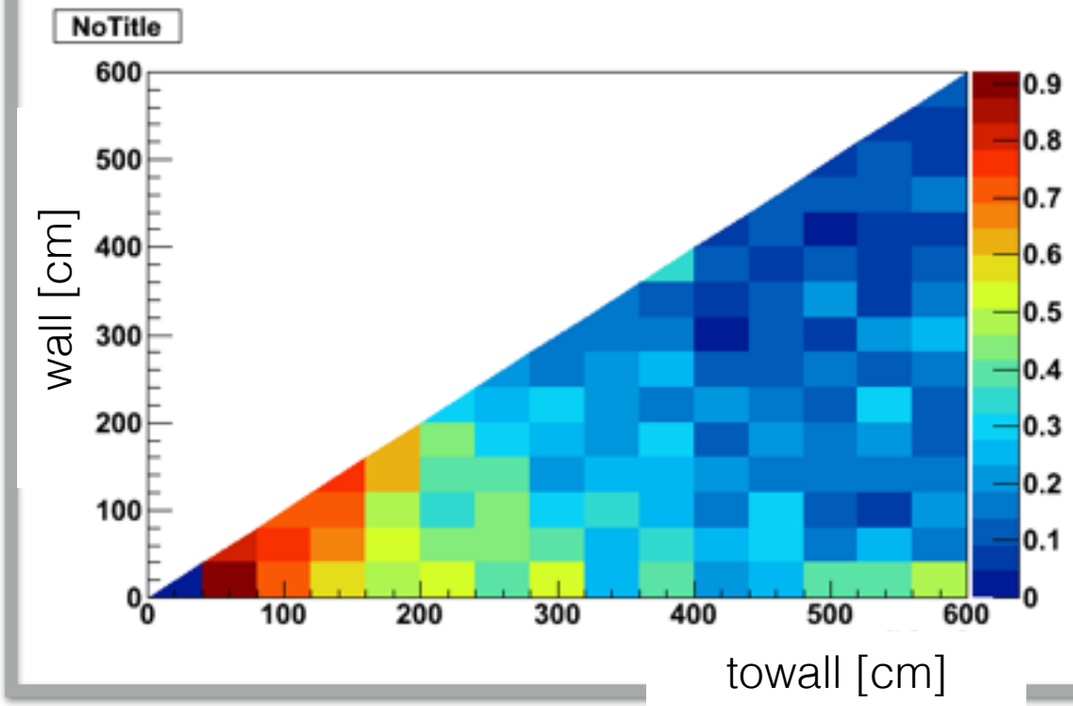


e/μ Cut (Background)

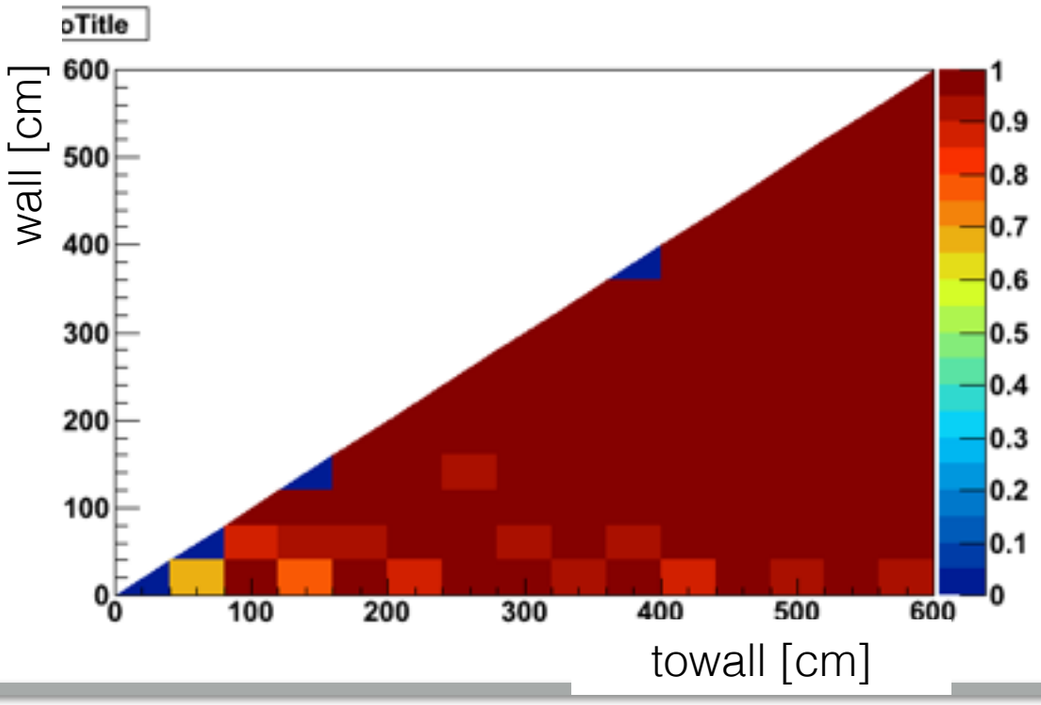
All BG



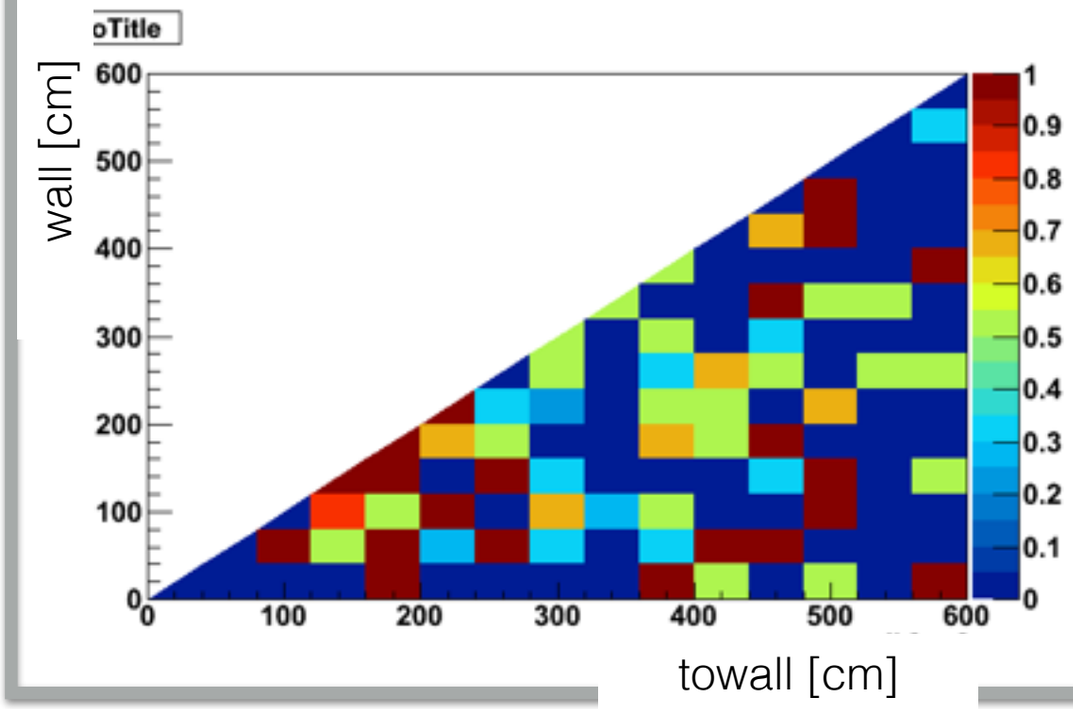
Single π+



Single π0

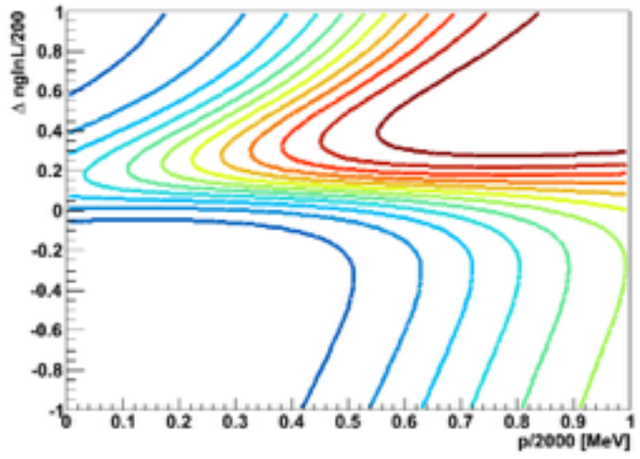


Multi π

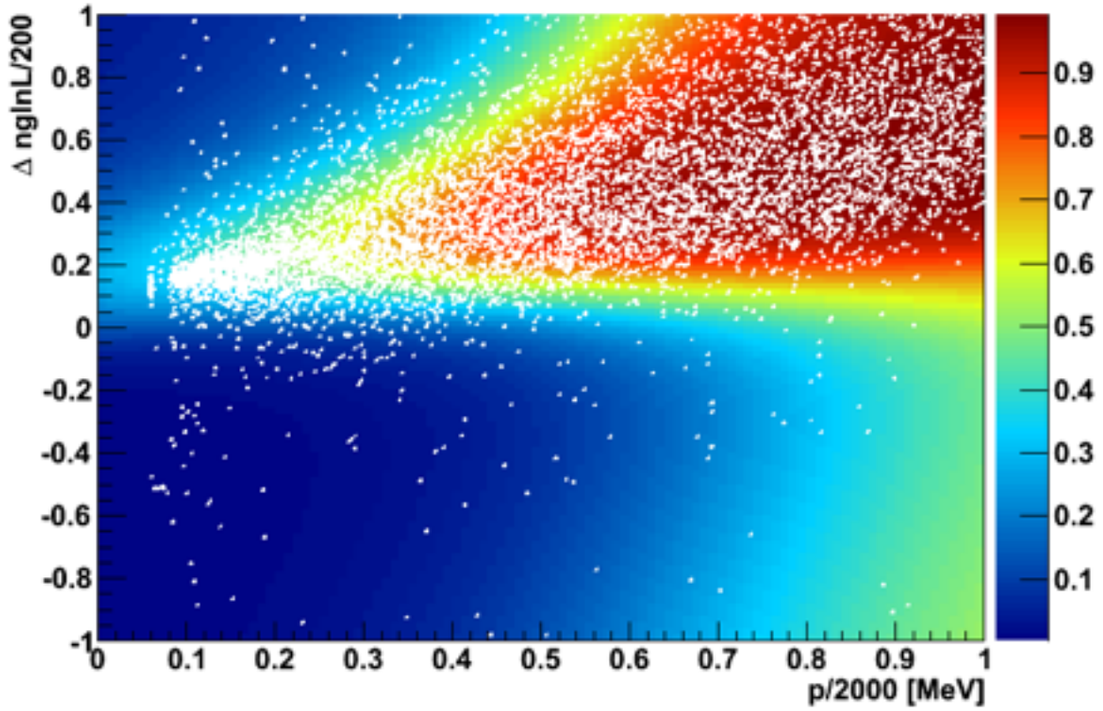


π+ Rejection Cuts

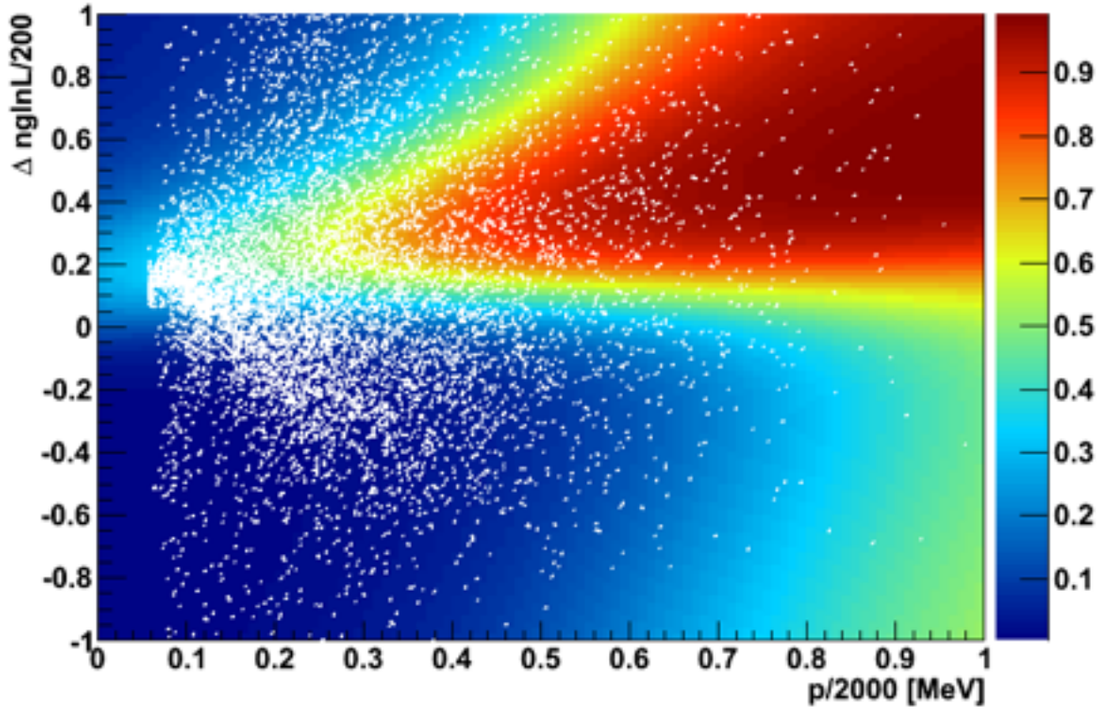
- Also tested neural network cut to check if line cut can be improved
- Neural network with 8 hidden nodes was trained on particle gun data
- Neural network output is just a function that maps to [0,1]
  - values close to 1 are signal-like regions
  - values close to 0 are background-like regions
- Make cuts on contours of this function



Signal μ

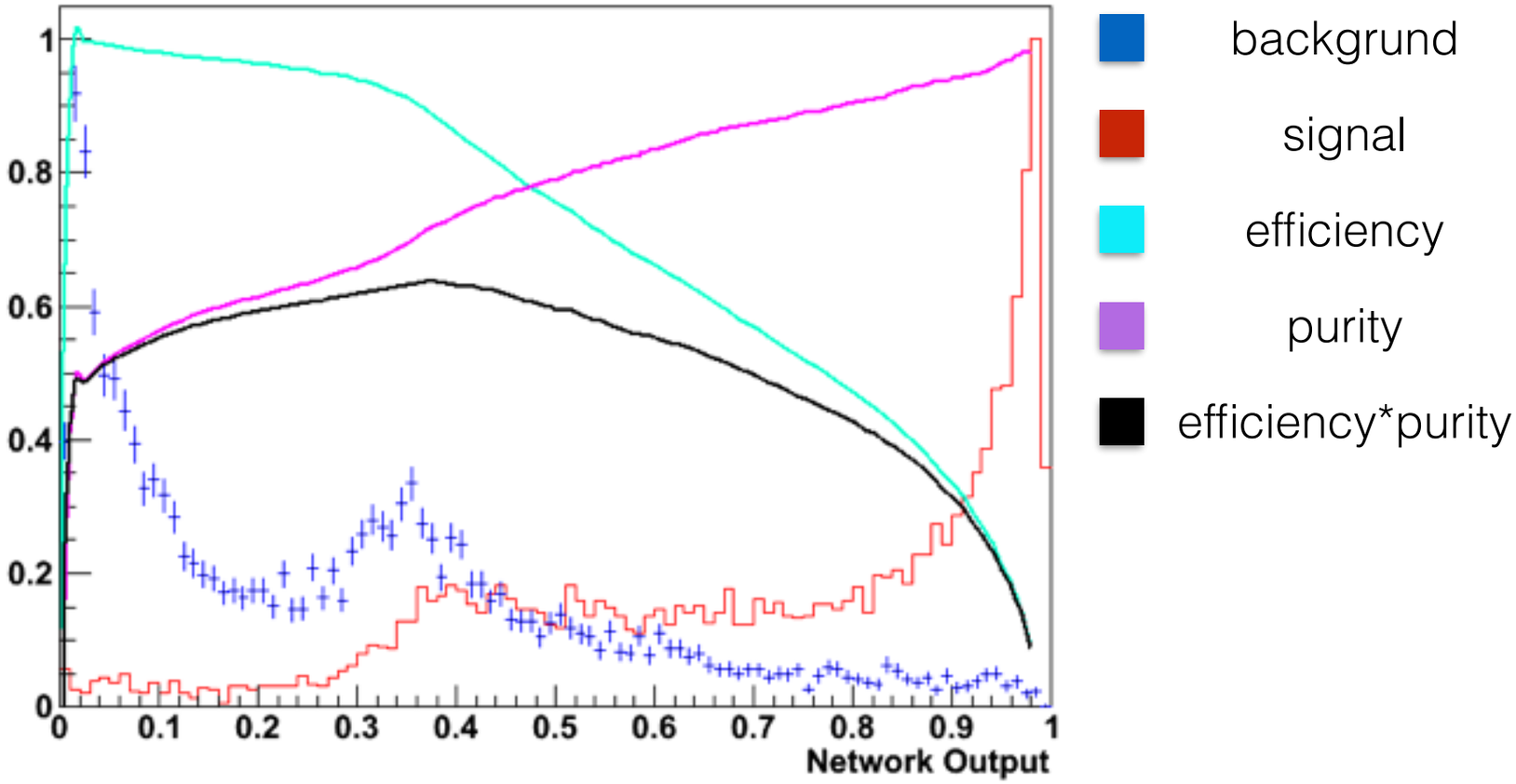


Background π+



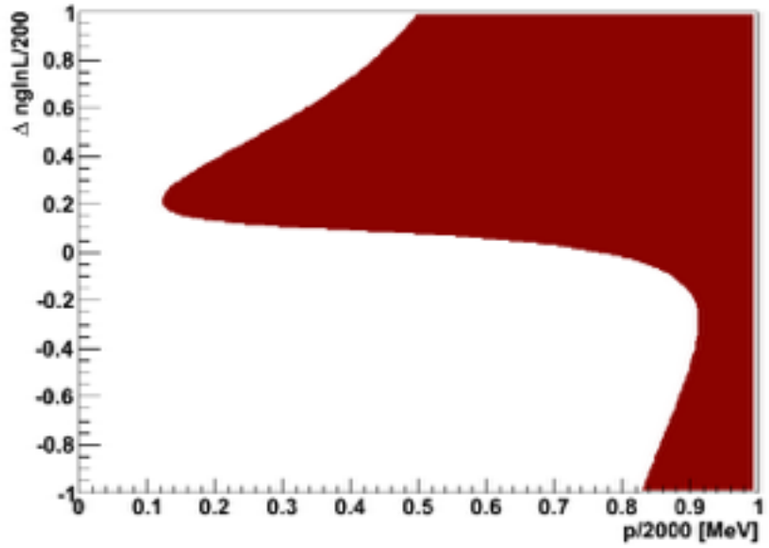
π+ Rejection Cuts

- Neural network slightly outperforms line cut:



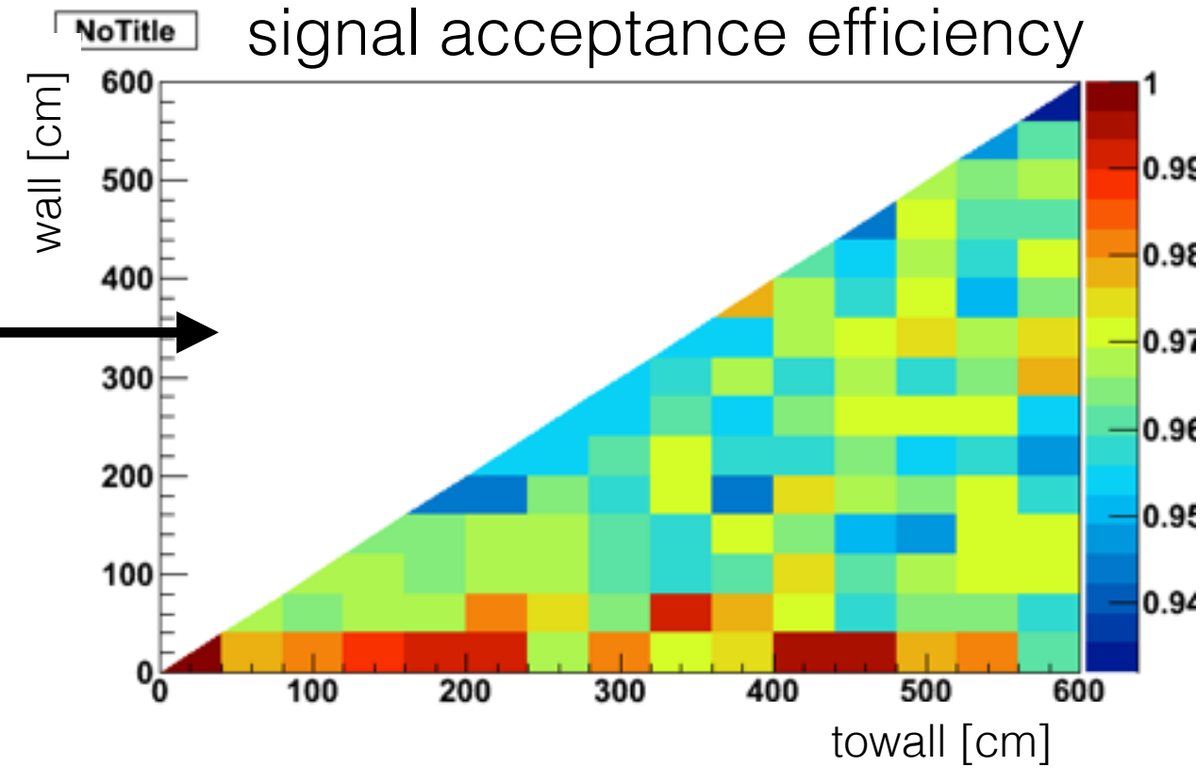
- 93.1% → 95.8% efficiency at 63.4% purity

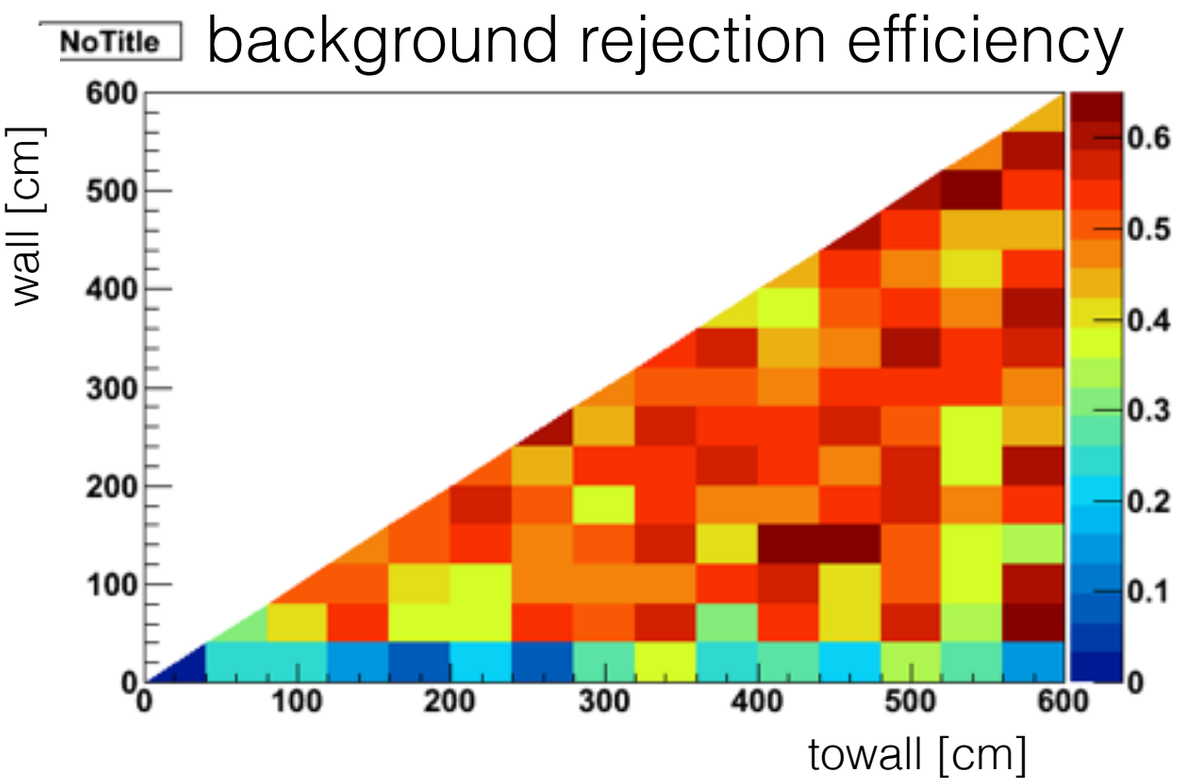
signal selection region at maximum efficiency*purity



π+ Rejection Cuts

π+ rejection cut retains >94% of single ring muon events

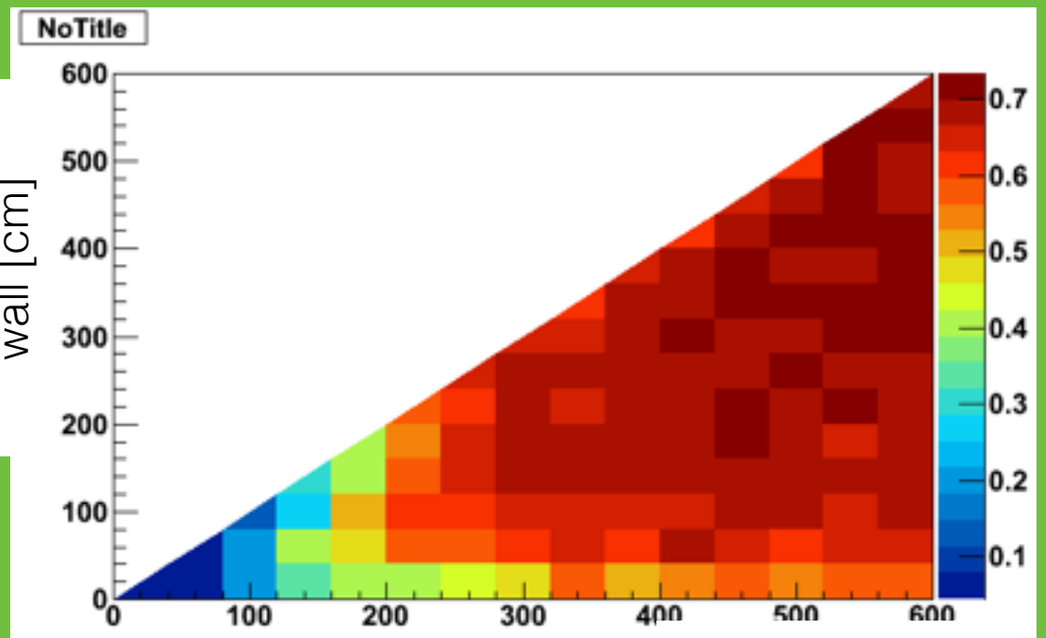


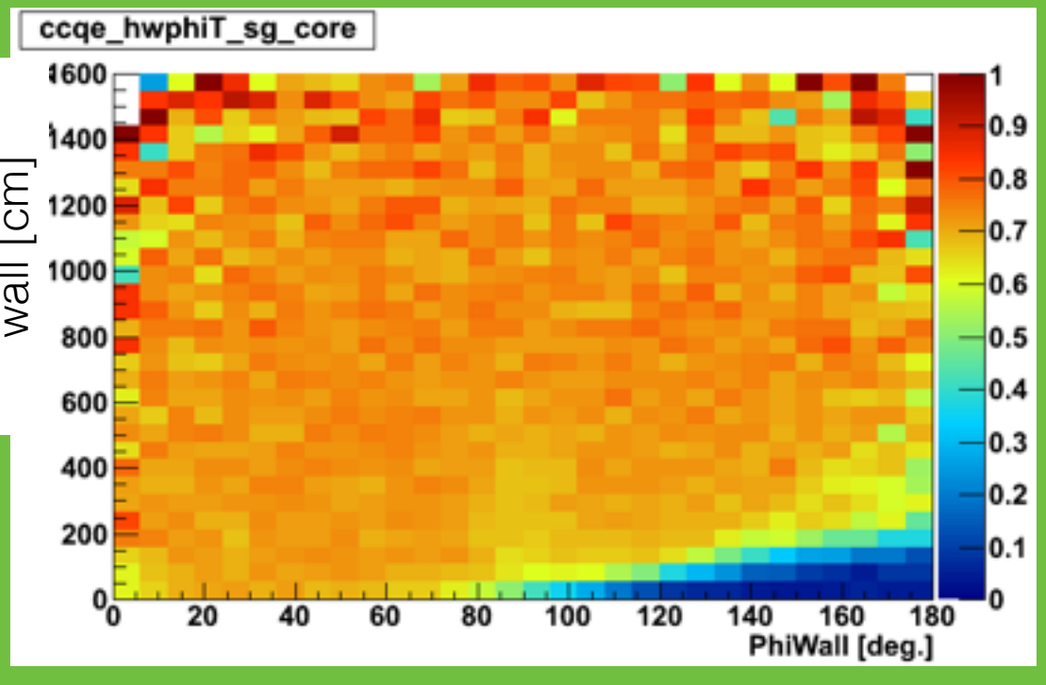


← cut rejects an additional 50% more background (~20% if wall<50cm)

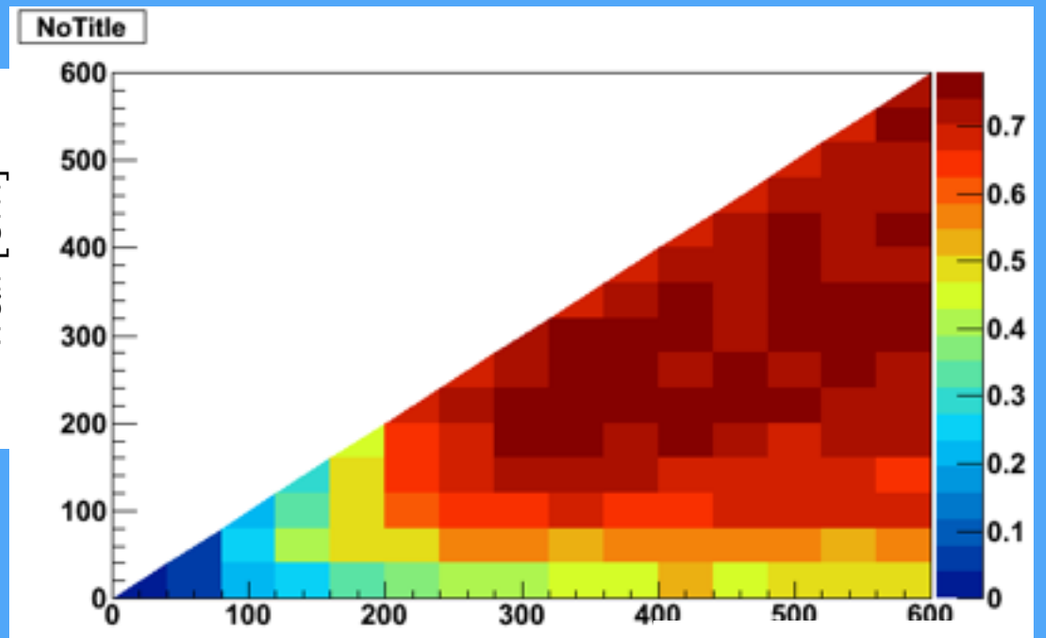
All Cuts (Signal)

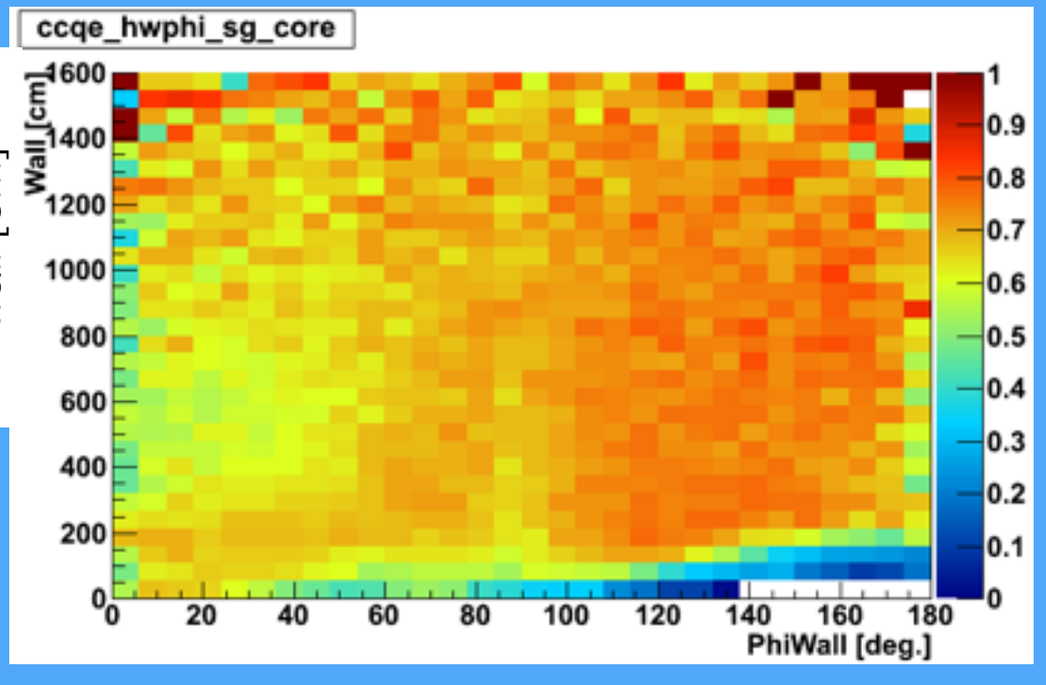
True FV Variables





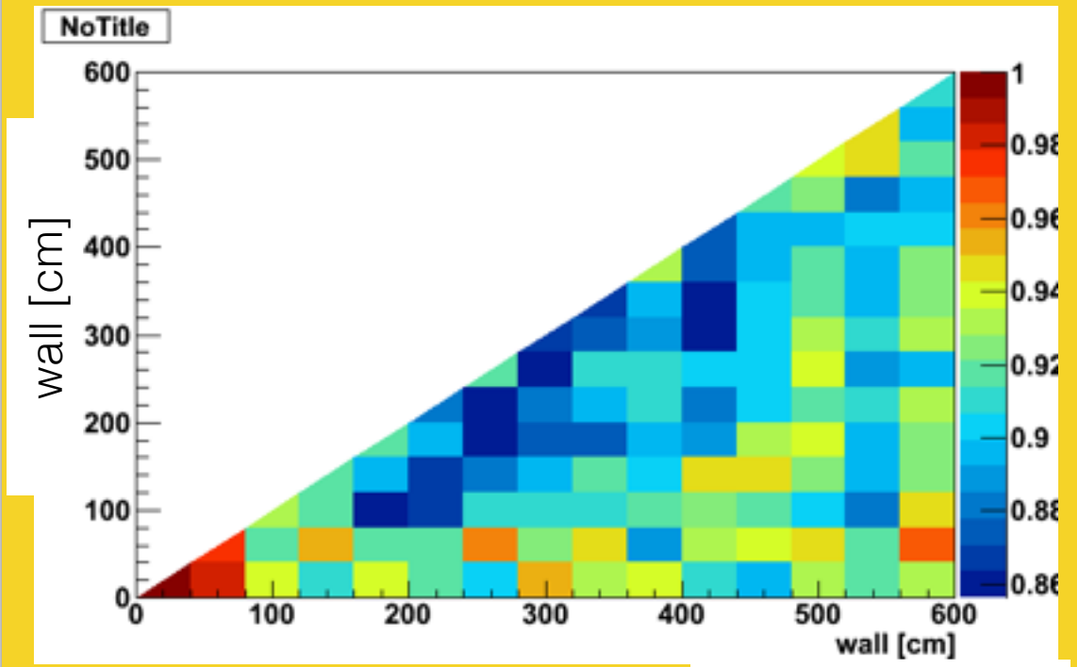
RC FV Variables



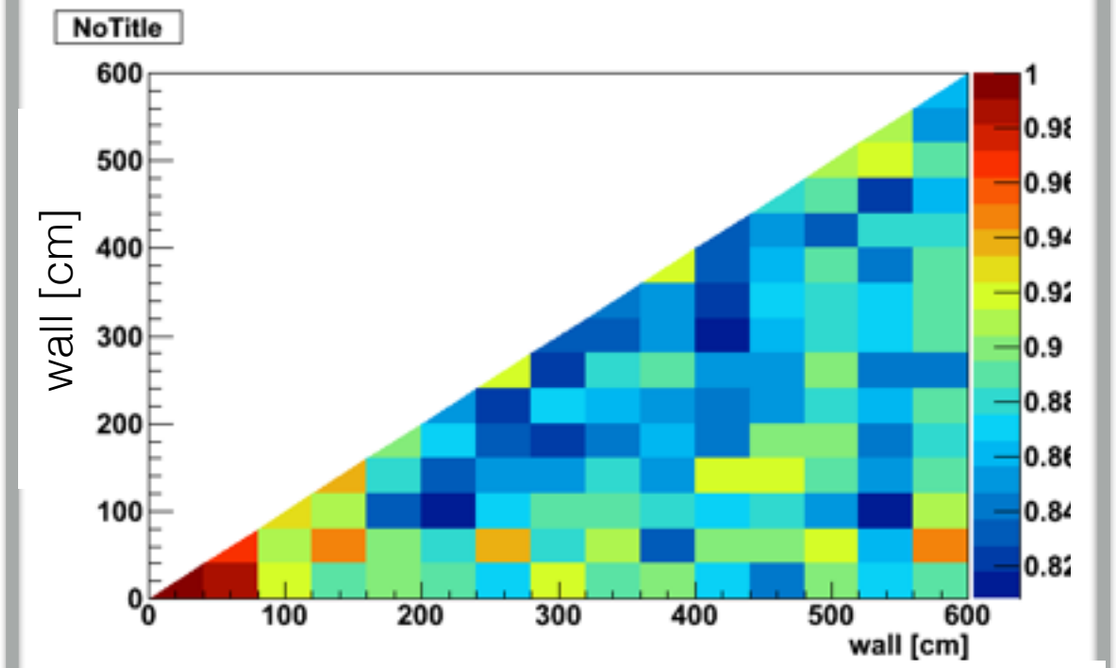


All Cuts (Background)

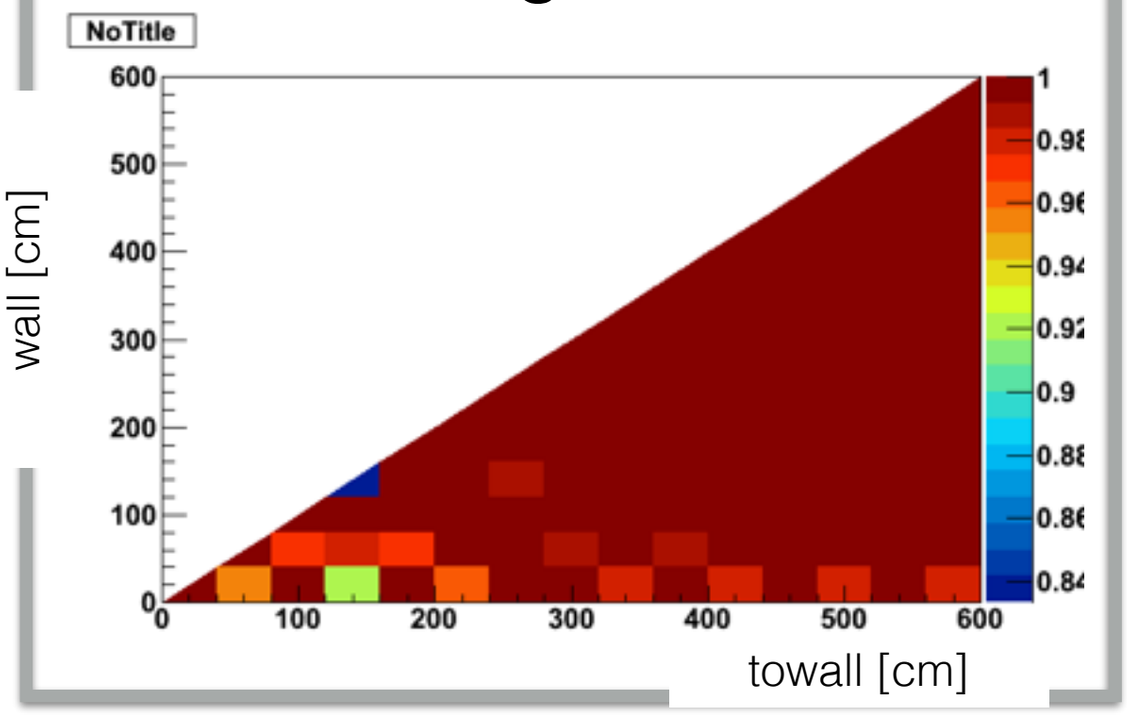
All BG



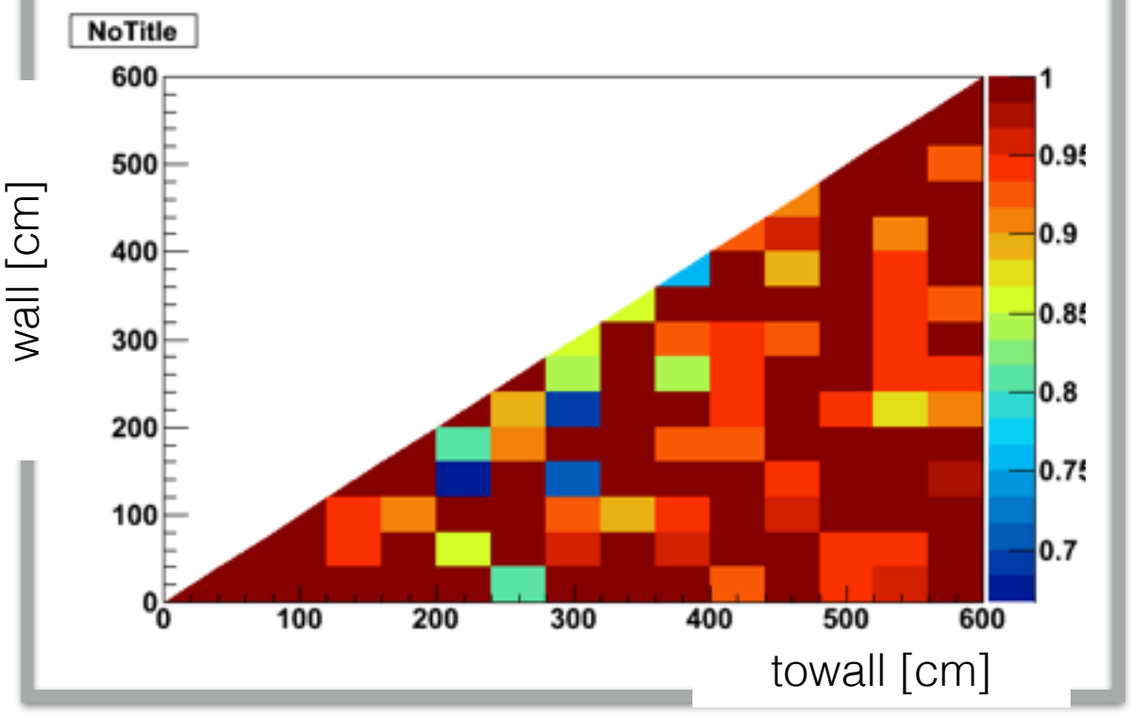
Single π+



Single π0

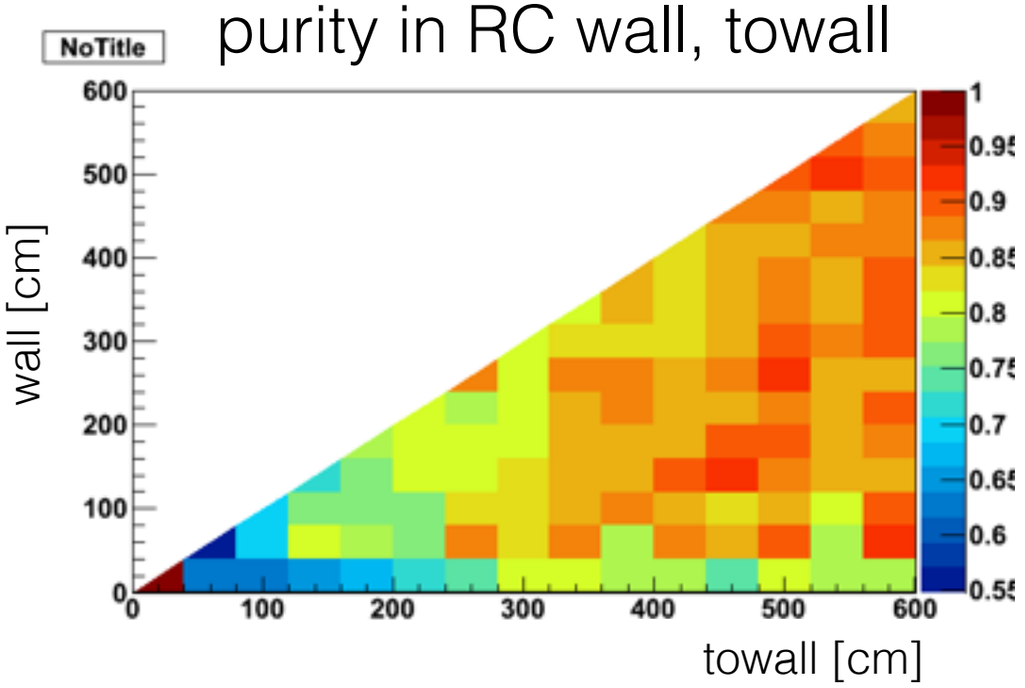


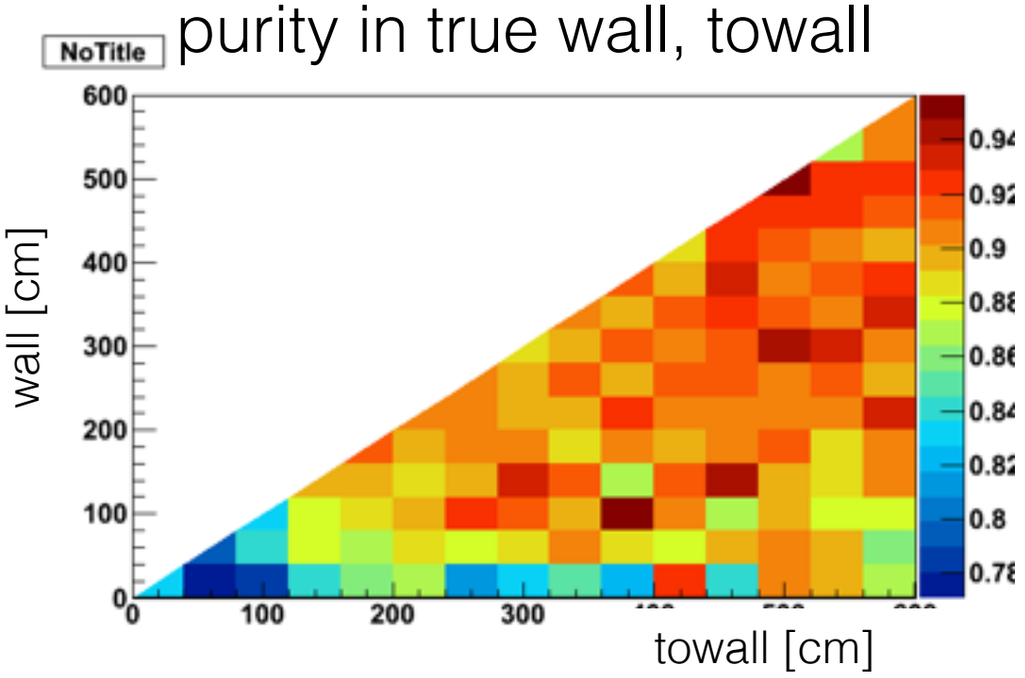
Multi π



T2K Cut Efficiencies

- The results are consistent with studies of fiTQun kinematic reconstruction performance:
    - Cuts efficiency drops sharply at small true wall, towall values
    - Smearing of towall at low wall results in drop in efficiency for wall < 50 at almost all towall values
- A π+/μ cut has been optimized on particle gun samples
    - Rejects an additional ~60% of visible single charged pion events





Cut Optimization

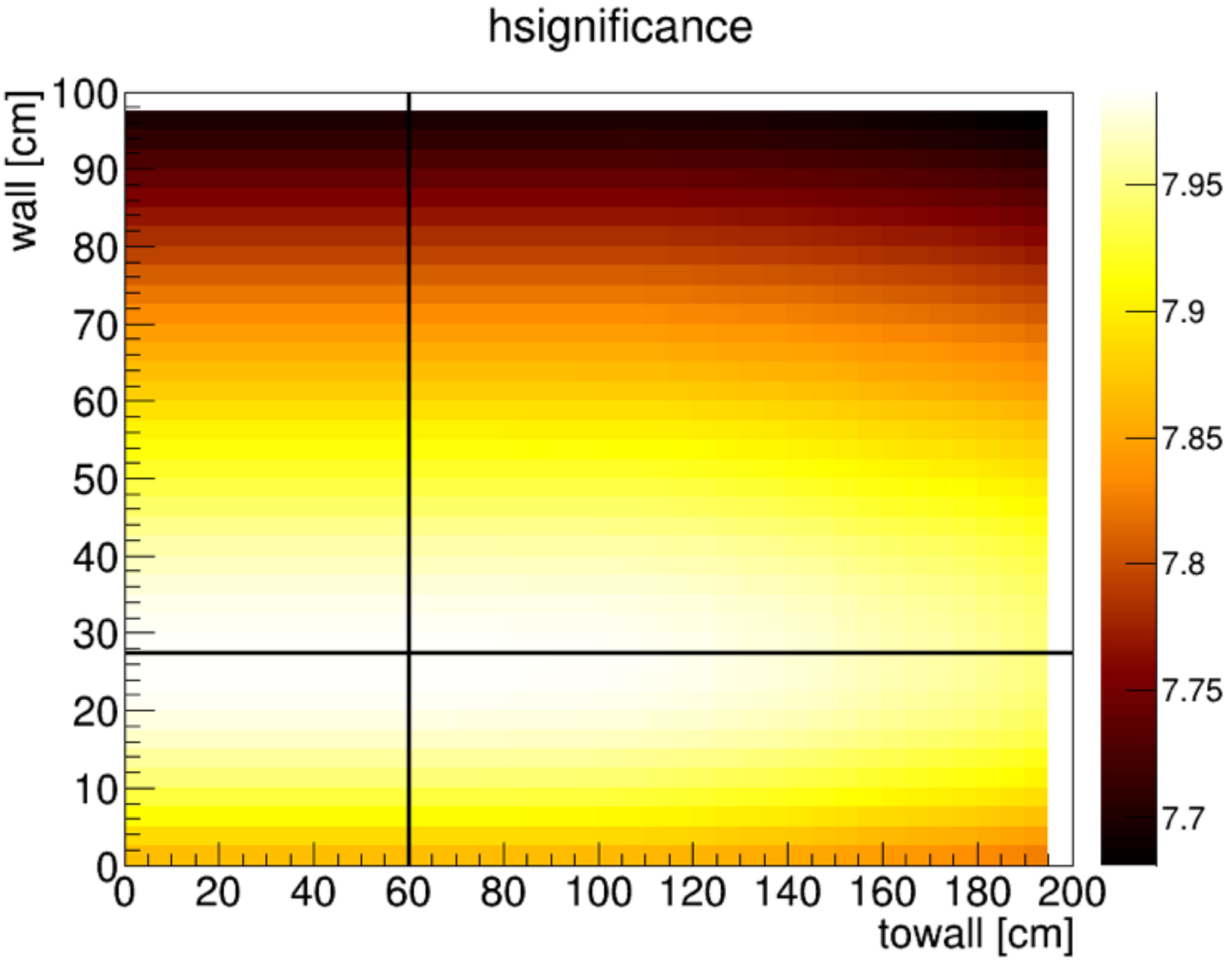
- S/sqrt(S+B) is clearly not the best metric for optimization
  - It is insensitive to kinematic reconstruction problems
- Is there a better metric that is sensitive to the kinematic reconstruction?
  - For now I"m using a "energy bin weighted significance"

$$\overline{S} = \sum_{i=0}^{Nbins} \left(\frac{dn_i}{d\theta}\right) \frac{s_i}{\sqrt{s_i + b_i}}$$

each Enu bin weighted by the derivative of expected number of events w.r.t. the oscillation parameter

for the purpose of this metric, events from true bins !=i are counted as background

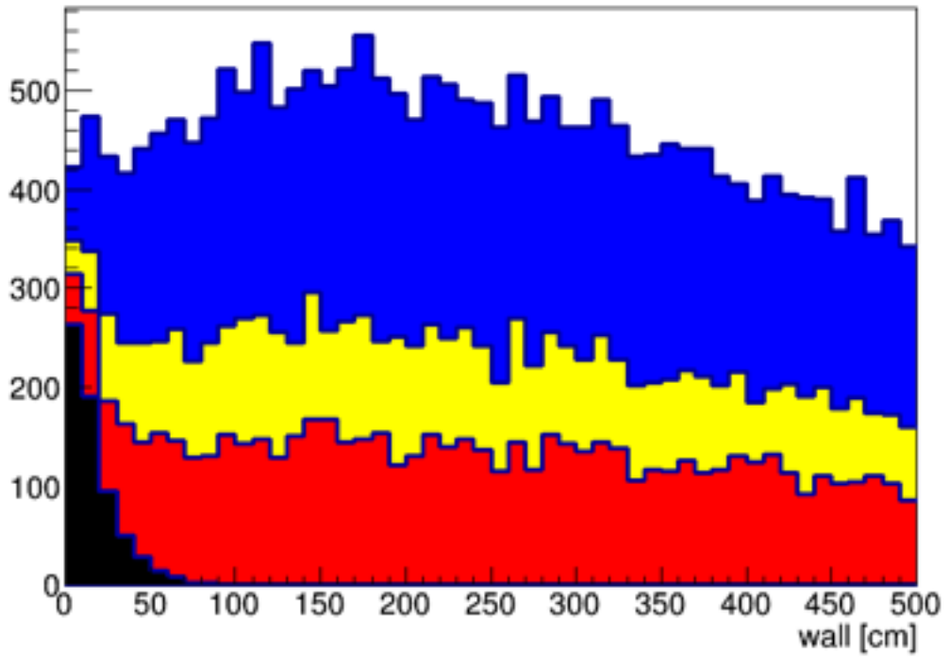
Cut Optimization

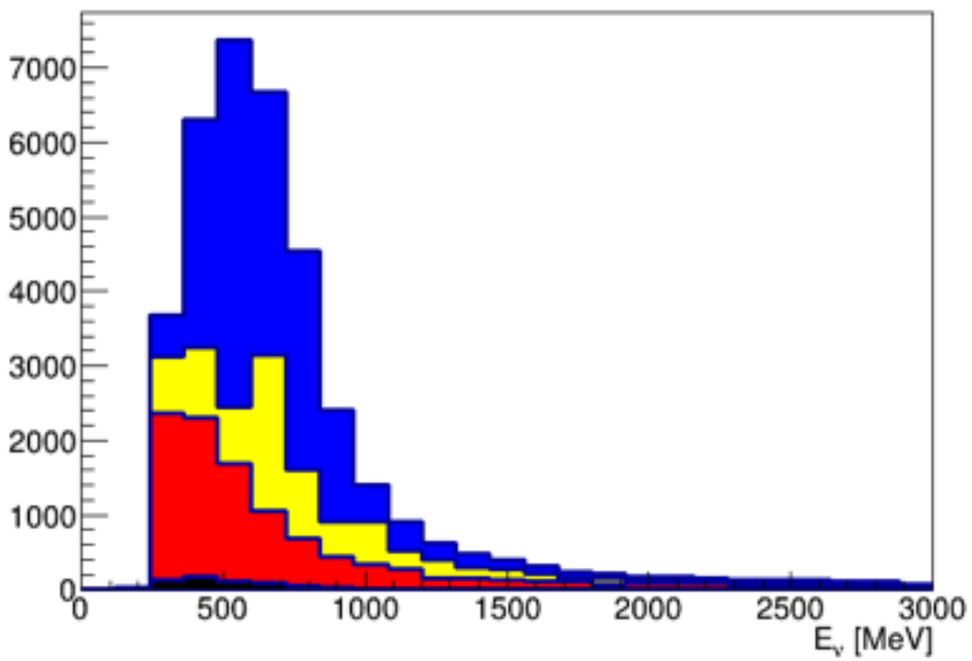


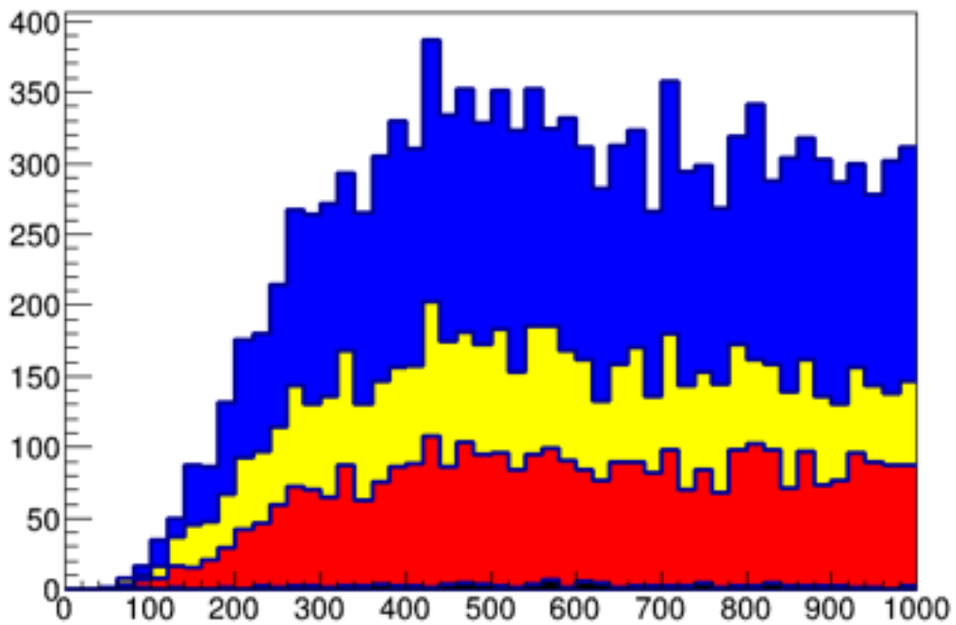
Cut Optimization

before cuts

- CCQE signal
- mis-binned CCQE
- non CCQE
- dead region



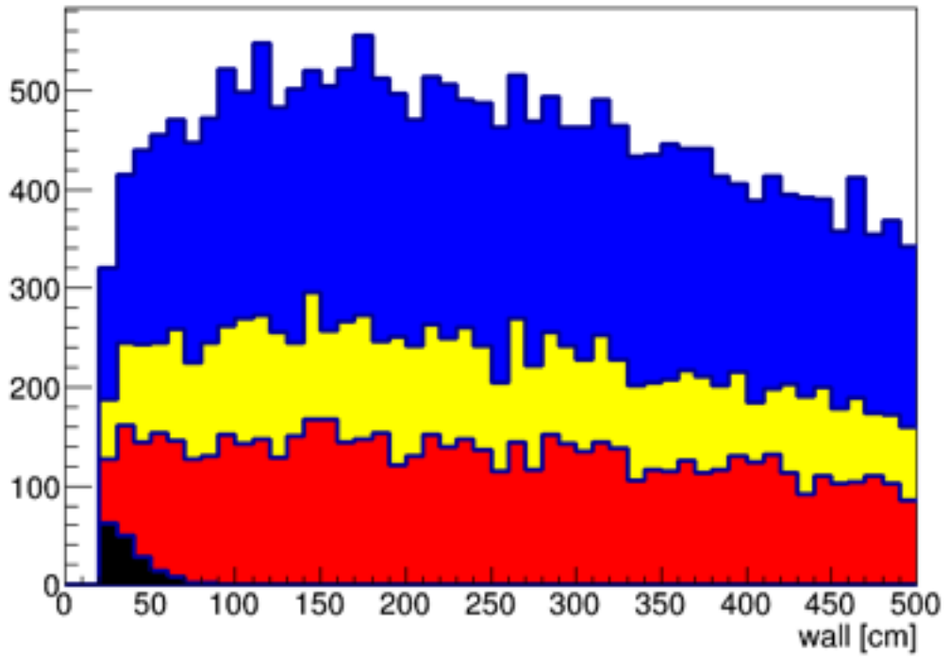


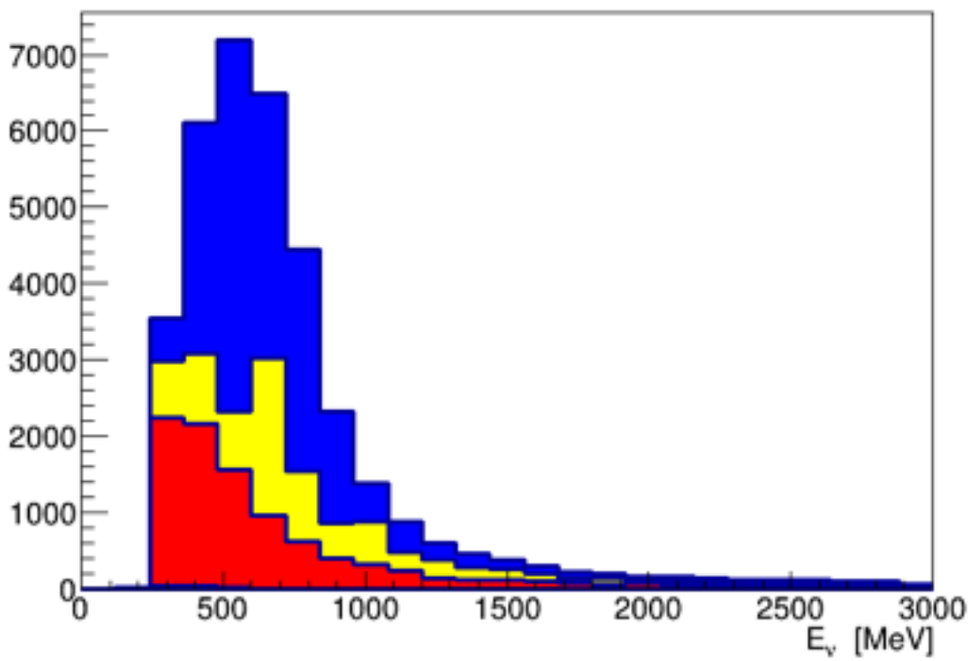


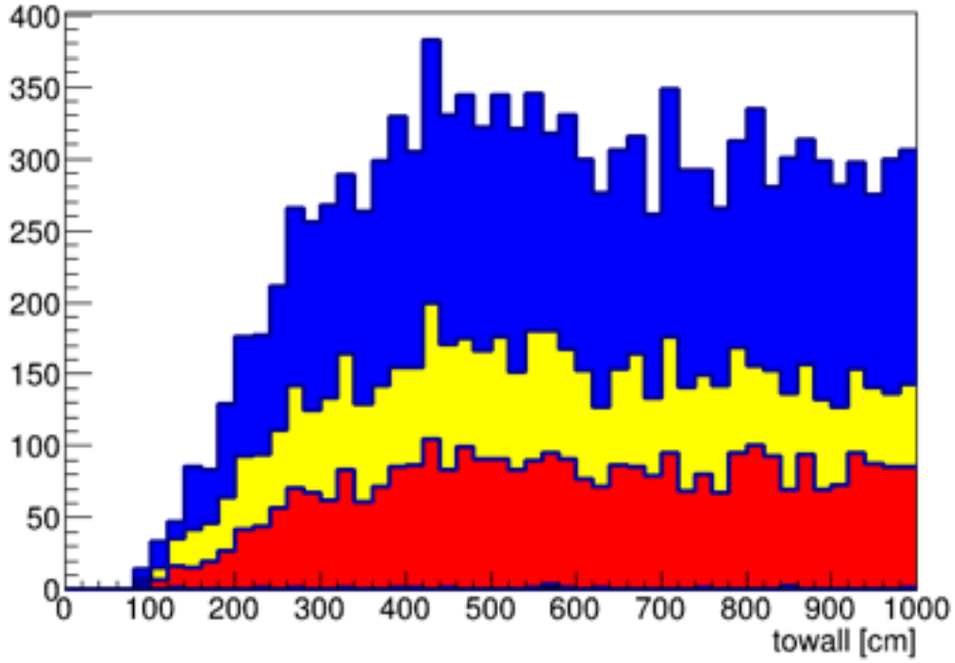
Cut Optimization

after cuts

- CCQE signal
- mis-binned CCQE
- non CCQE
- dead region







Systematics Studies

- fiTQun seems to perform well in some regions outside the current FV cut, but systematics will ultimately determine how far we can push the fiducial boundary.

- Data samples available for systematics studies:

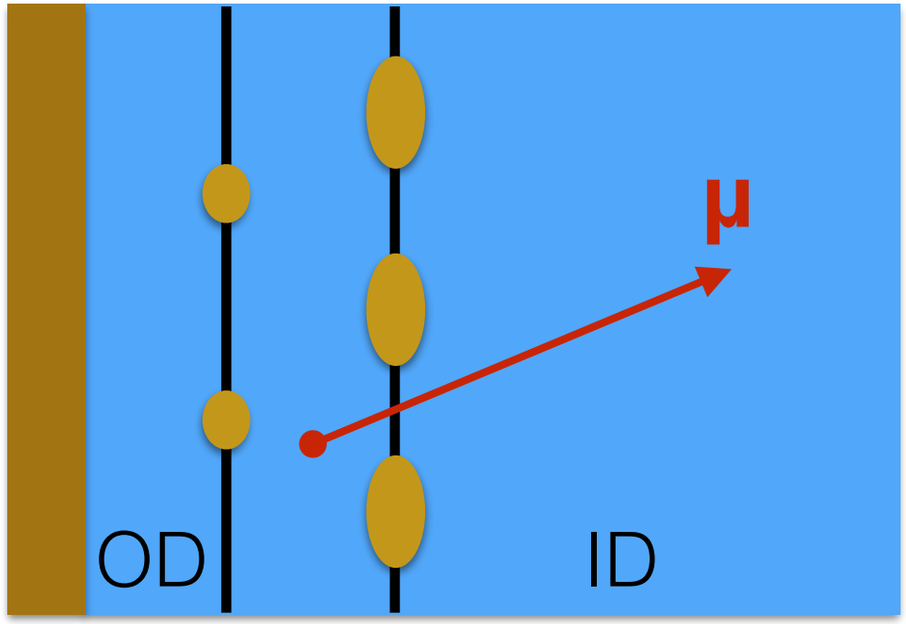
  - **stopping cosmic muons**
  - **hybrid π^0s**
  - **atmospheric neutrinos**

focus of current studies

for future studies (talk on this tomorrow)

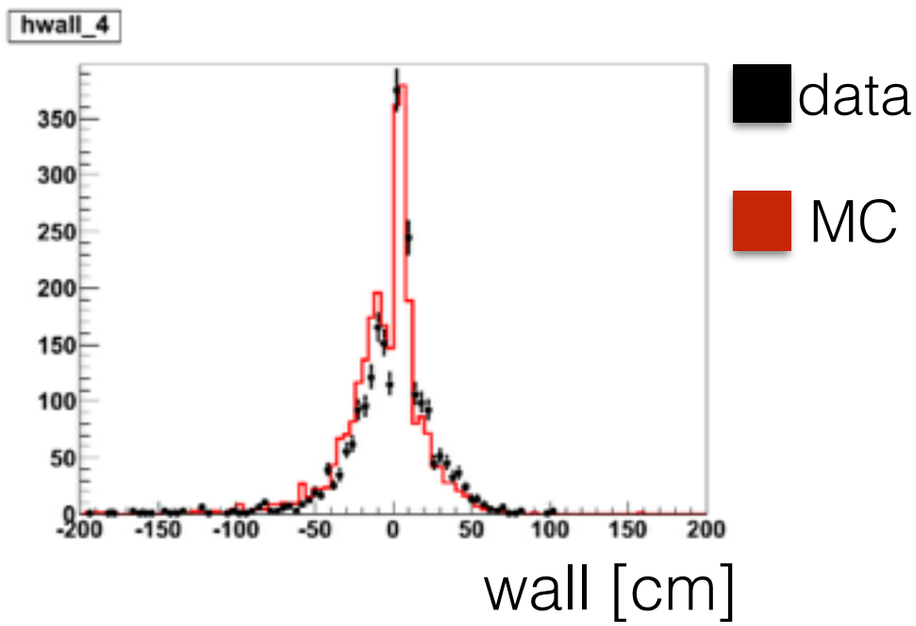
Cosmic Muon Studies

- An important background near the ID wall are “dead region” events
  - These events are produced in the 55cm region between the inner and outer detectors

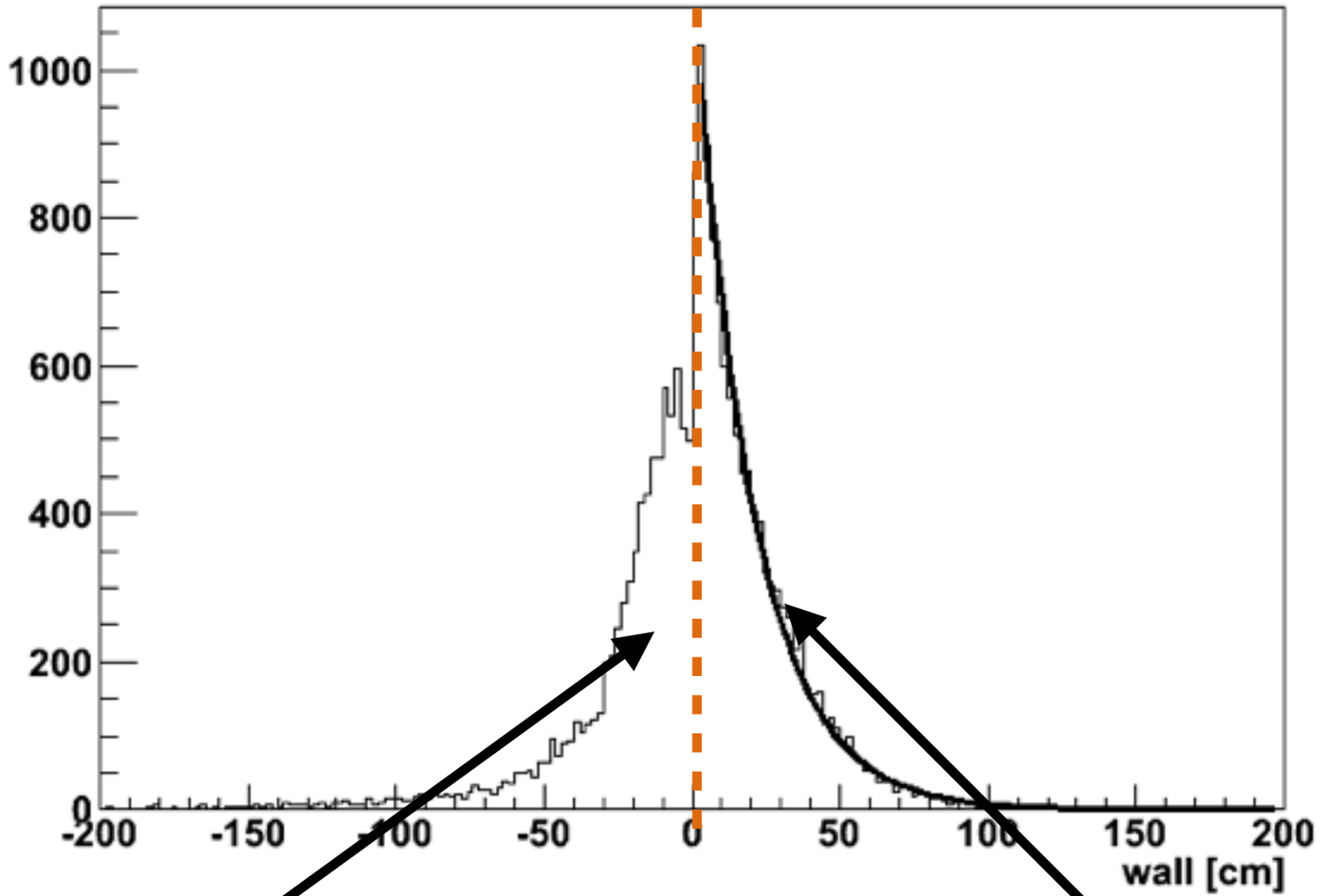


- Can check data/MC differences in how fiTQun reconstructs entering muons using cosmic sample
- This data/MC difference has been parameterized and incorporated into a toy MC

cosmic muon wall distributions



Parameterizing Wall Distribution

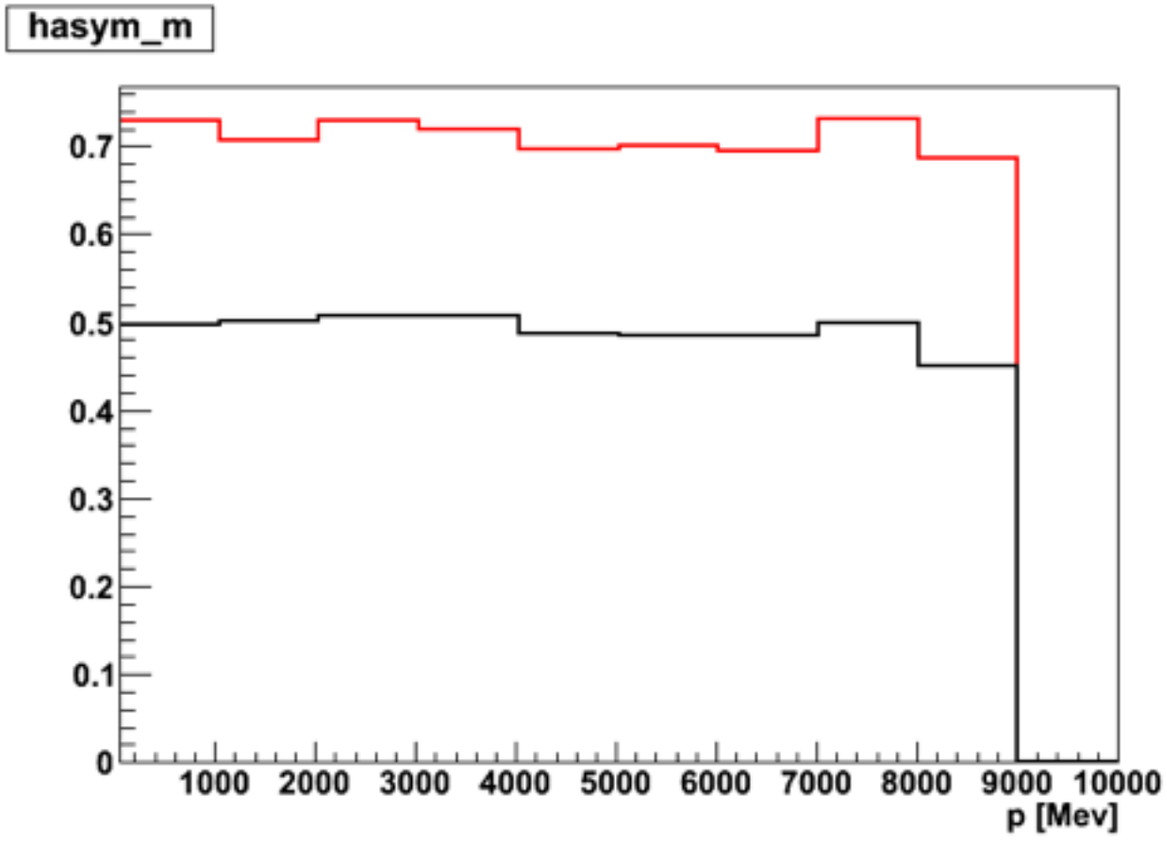


"asymmetry" parameter - the ratio between the number events with positive wall values to the number of events with negative wall values

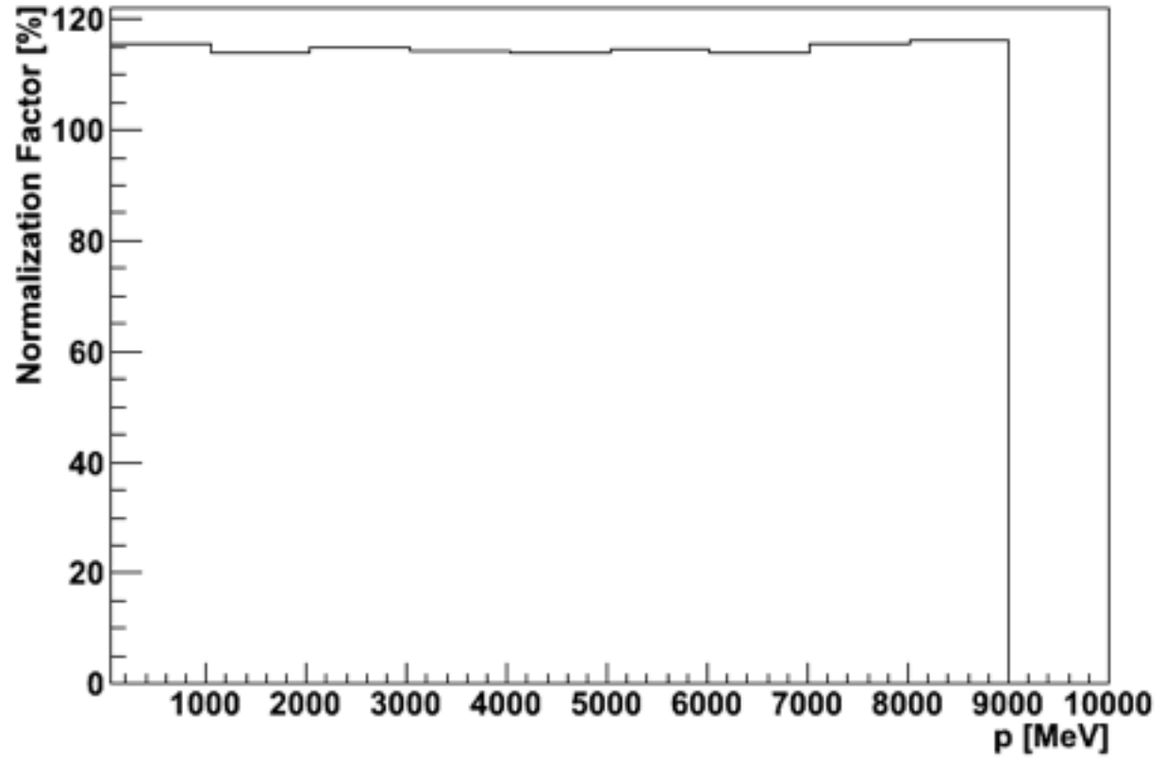
"width" parameter - decay constant from exponential fit

Parameterizing Wall Distribution

Asymmetry parameter vs. momentum



Data/MC differenc [%] vs momentum

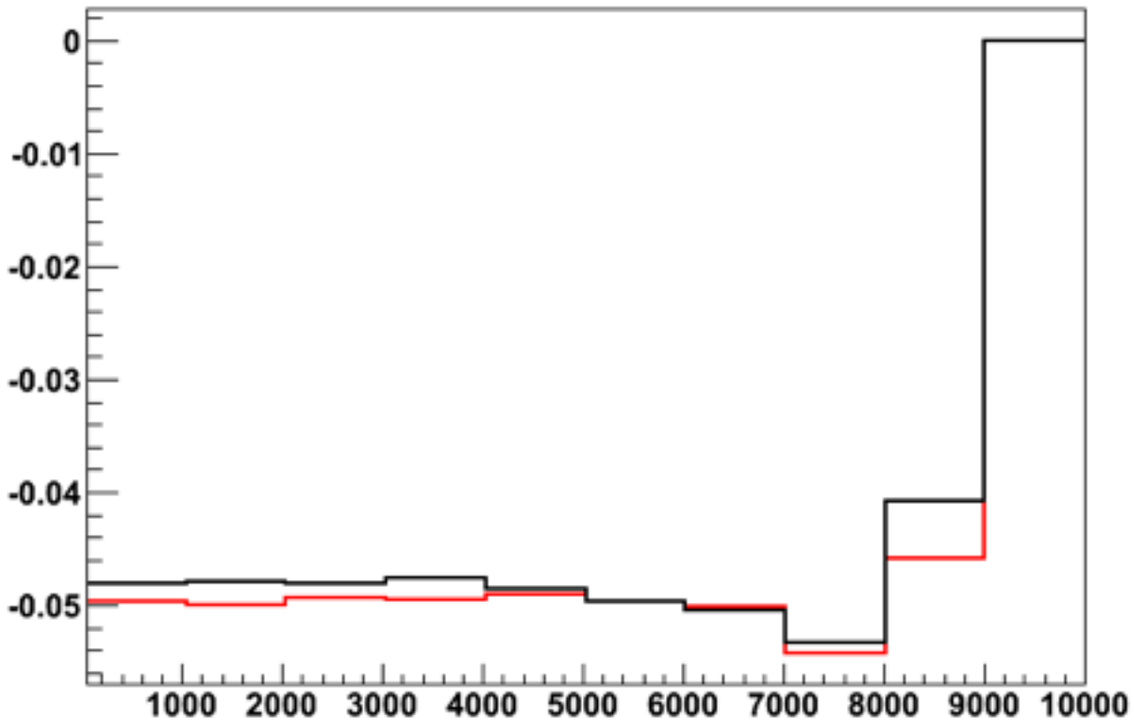


MC

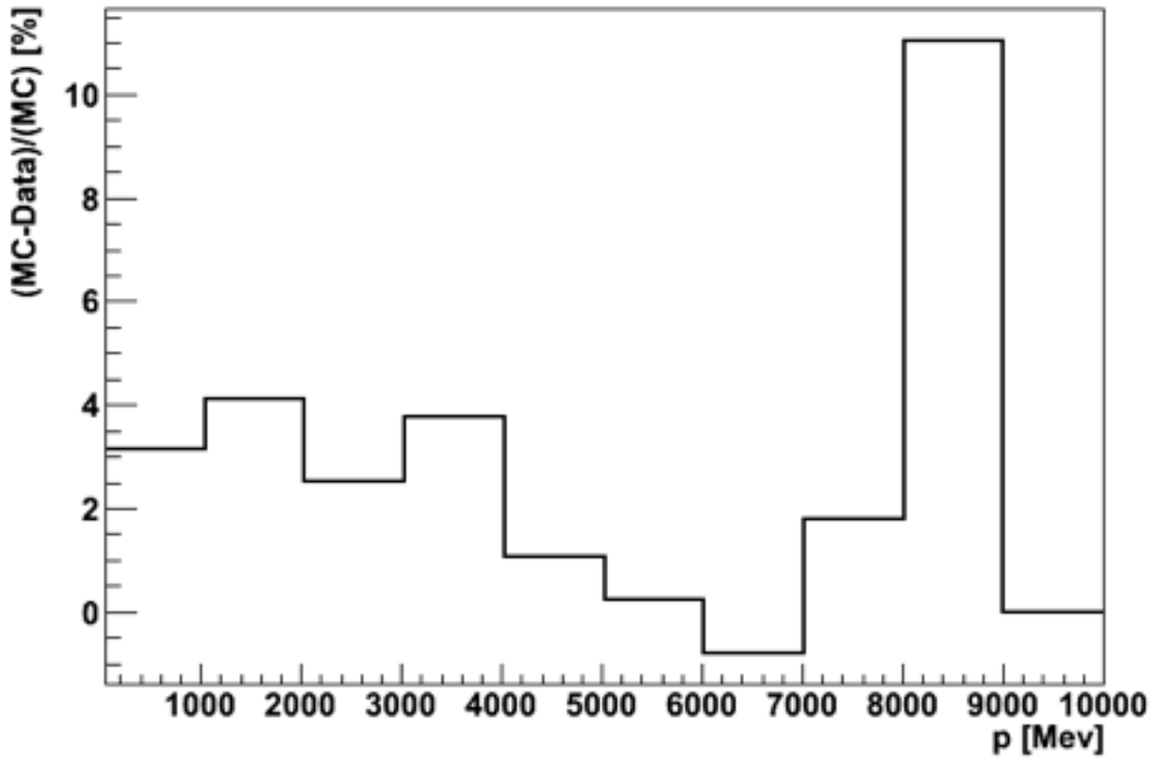
data

Parameterizing Wall Distribution

width parameter vs. momentum



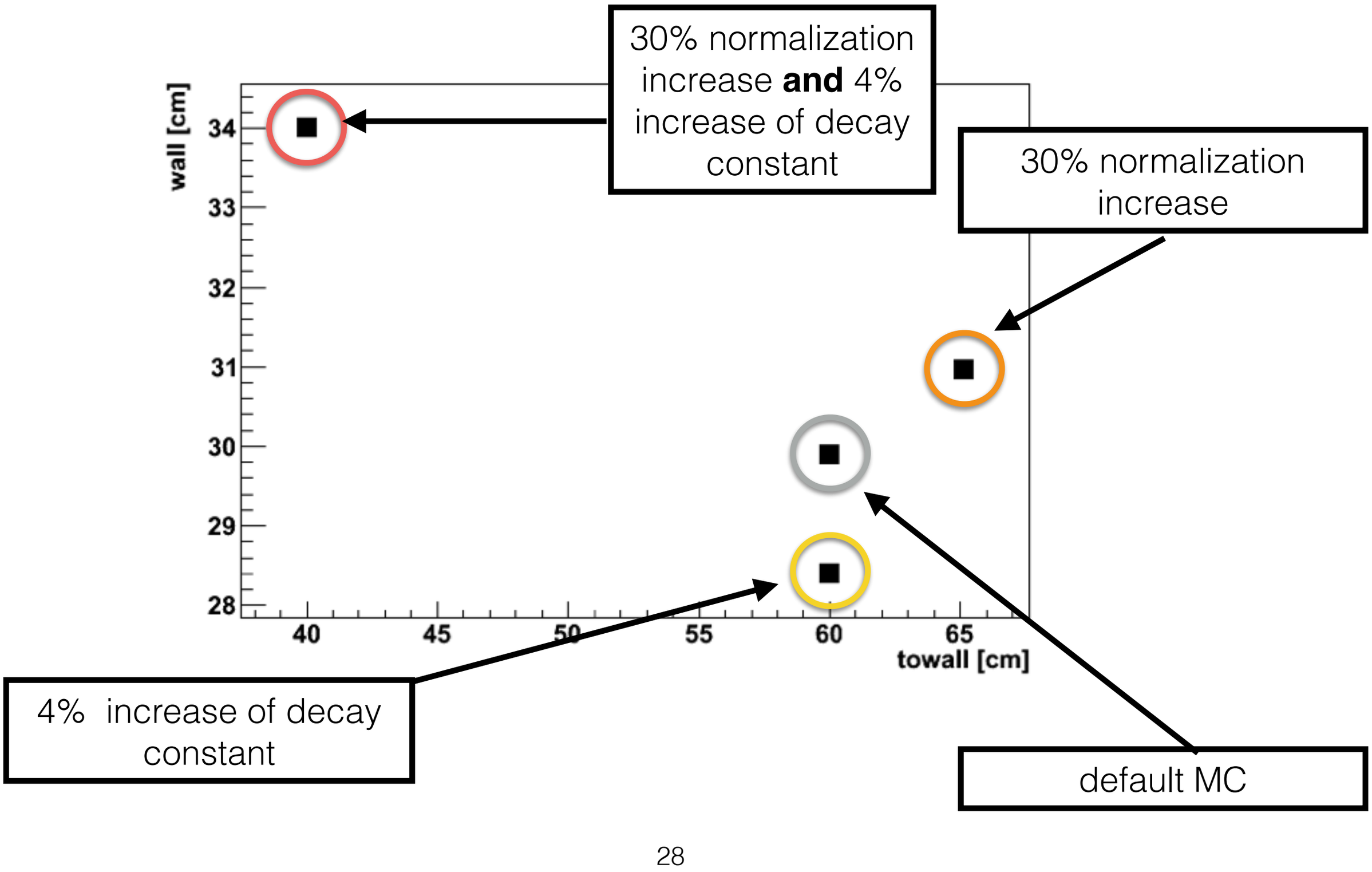
Data/MC differenc [%] vs momentum



MC

data

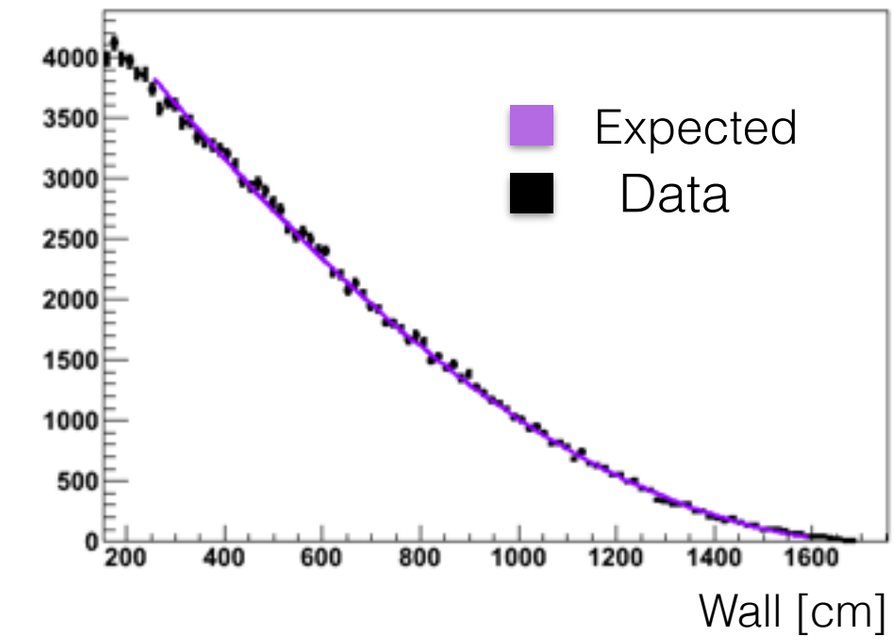
Effect on FV Optimization



Decay Electron Studies

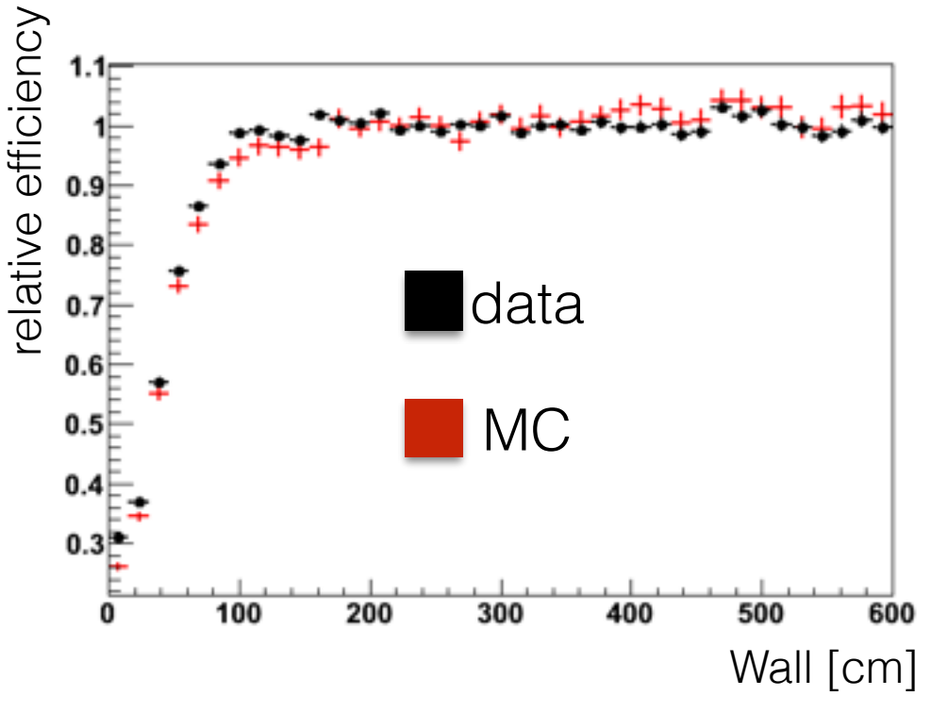
- Michel electrons from the stopping cosmic muons are also an important data sample

- The expected distribution of the wall variable for decay electrons can be derived from the detector geometry



- Comparison between the observed number of events at a given wall value and the expectation gives the efficiency relative to the center of the tank

- ~5% difference between data and MC in the relative efficiency as a function of wall.



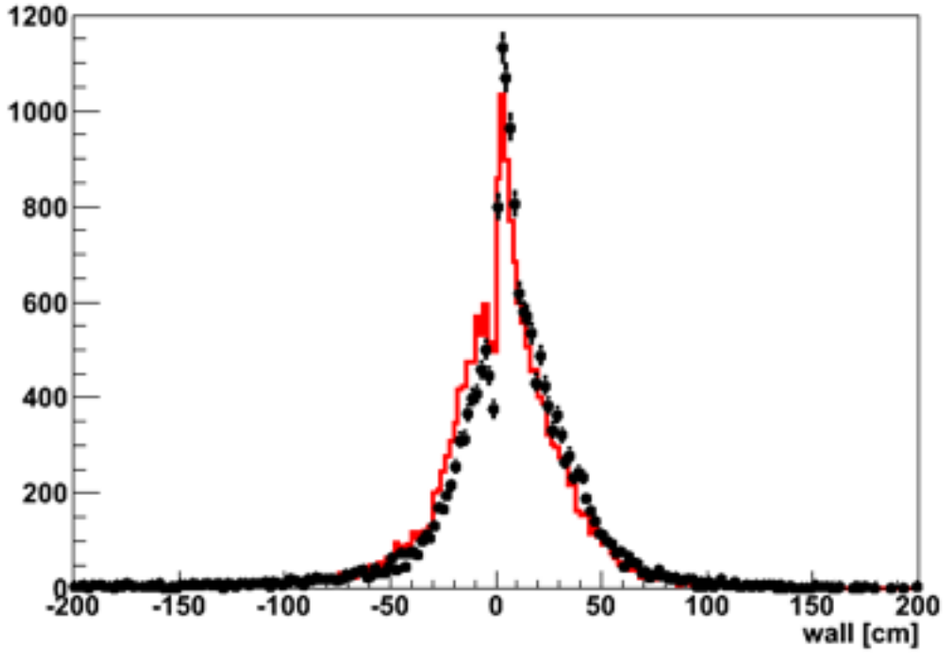
Summary

- MC studies using particle gun and T2K MC have mapped out fiTQun performance near ID wall
  - Significant degradation of reconstruction performance occurs with true towall < 200 cm
  - Poor direction reconstruction smears poor performance to higher reconstructed towall values when wall<50cm
- Effect on T2K cut efficiencies has also been studied and mapped in wall, towall space
- Some systematics studies using stopping cosmic muon data have been performed
  - Data/MC differences in wall distribution used to constrain entering dead region backgrounds
  - Decay electrons from stopping cosmic muons used to map data/MC difference in detection efficiency
- Framework has been developed to optimize fiducial cuts
  - More work to be done toward finding an optimal metric for optimization
- Future work:
  - Develop strategy for confronting systematic errors using atmospheric data.

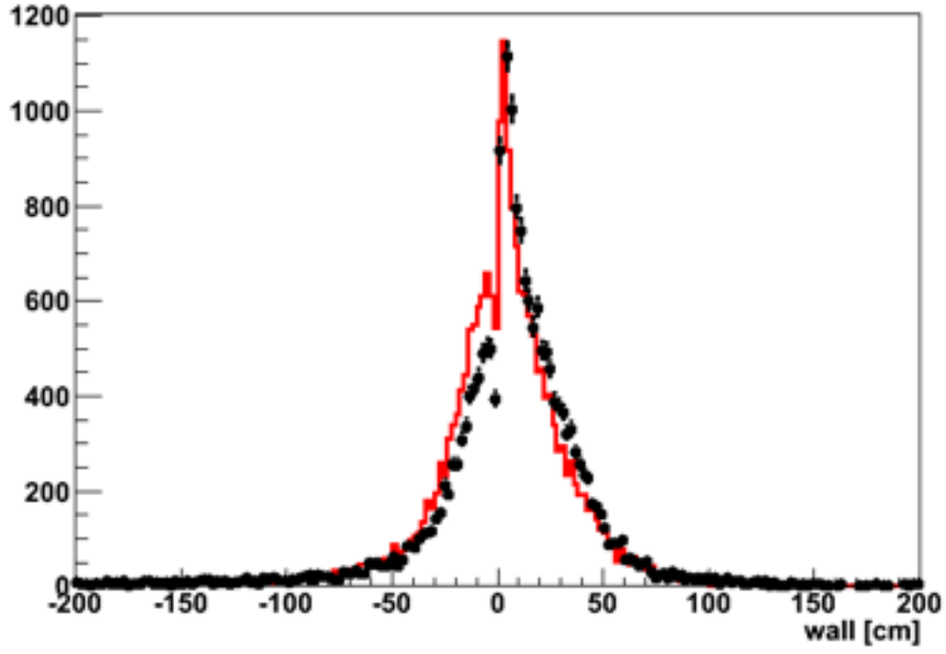
Supplemental Slides

Data/MC Comparison

0-1 GeV



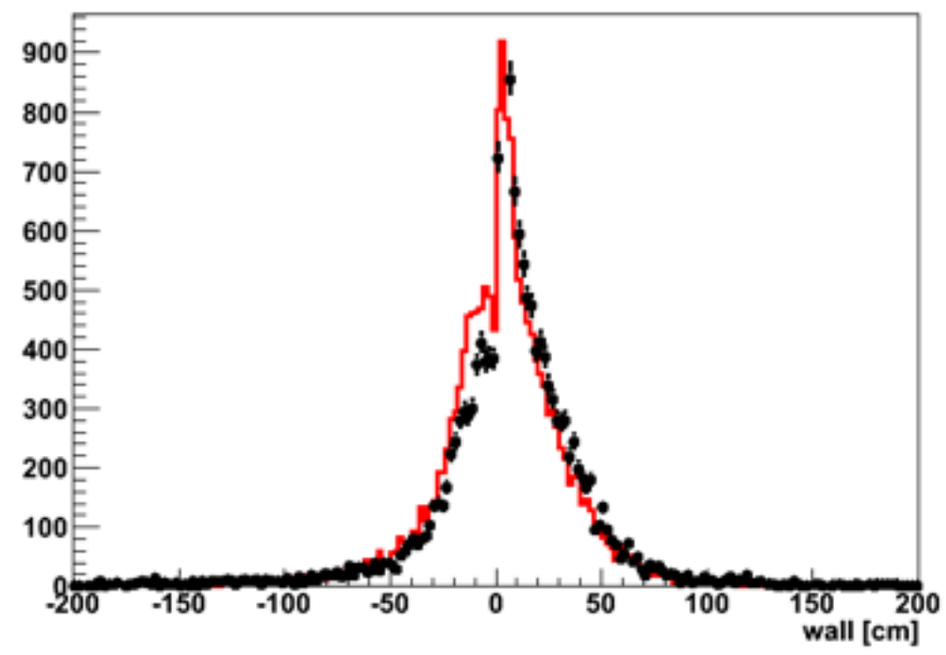
1-2 GeV



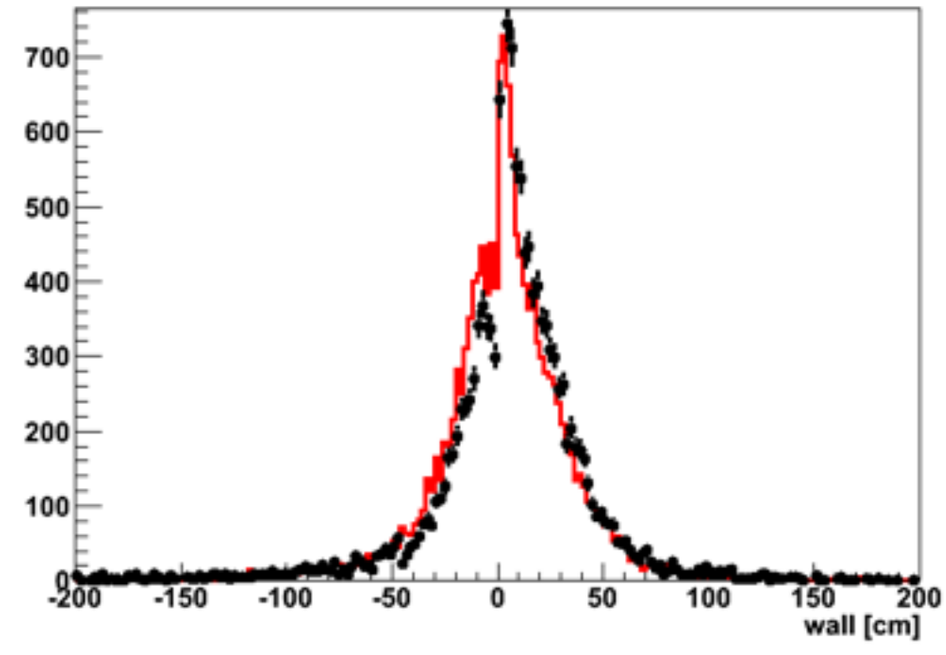
MC

data

2-3 GeV

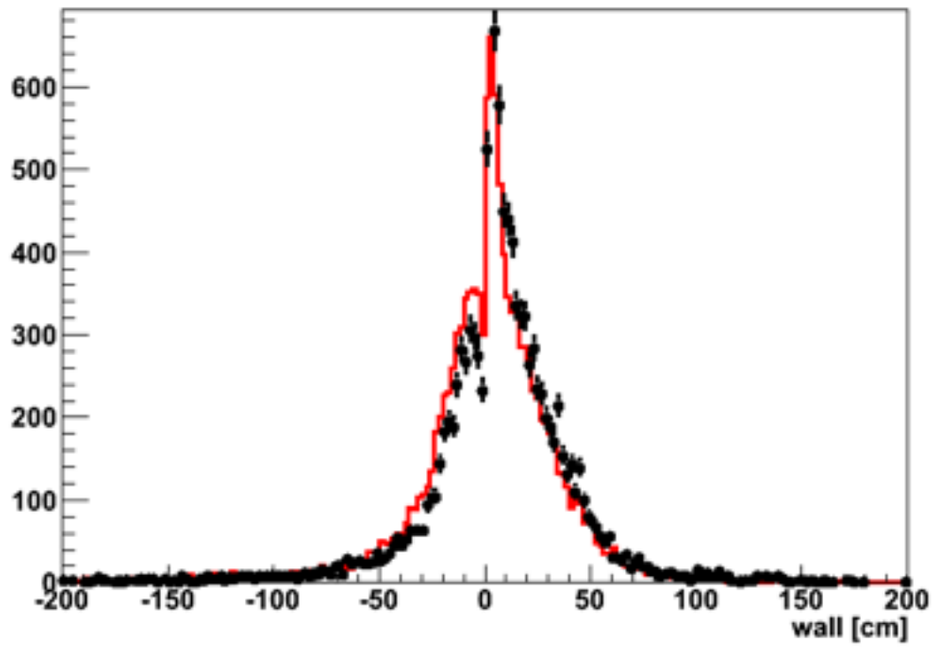


3-4 GeV

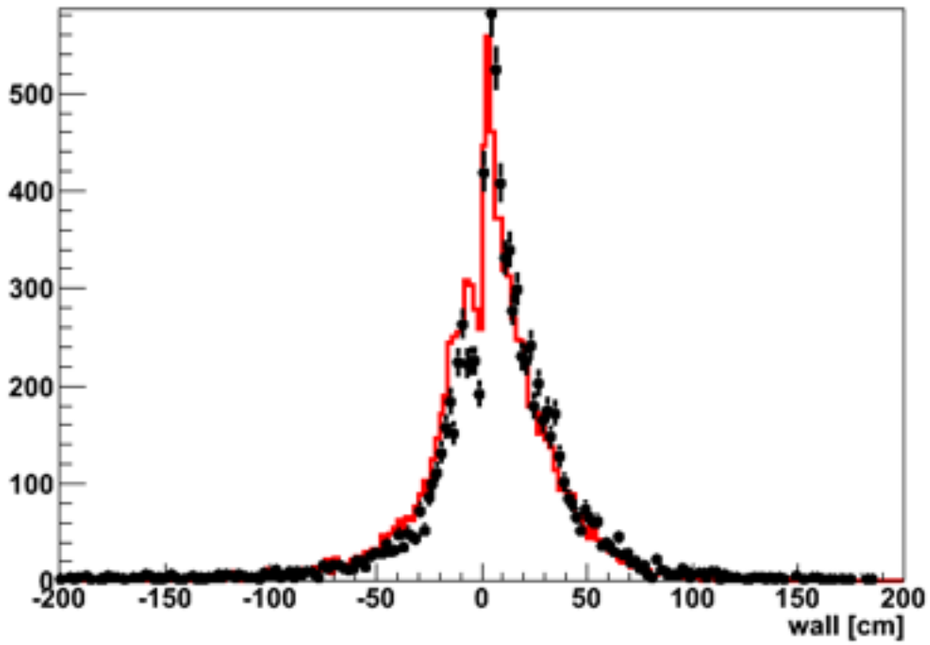


Data/MC Comparison

4-5 GeV



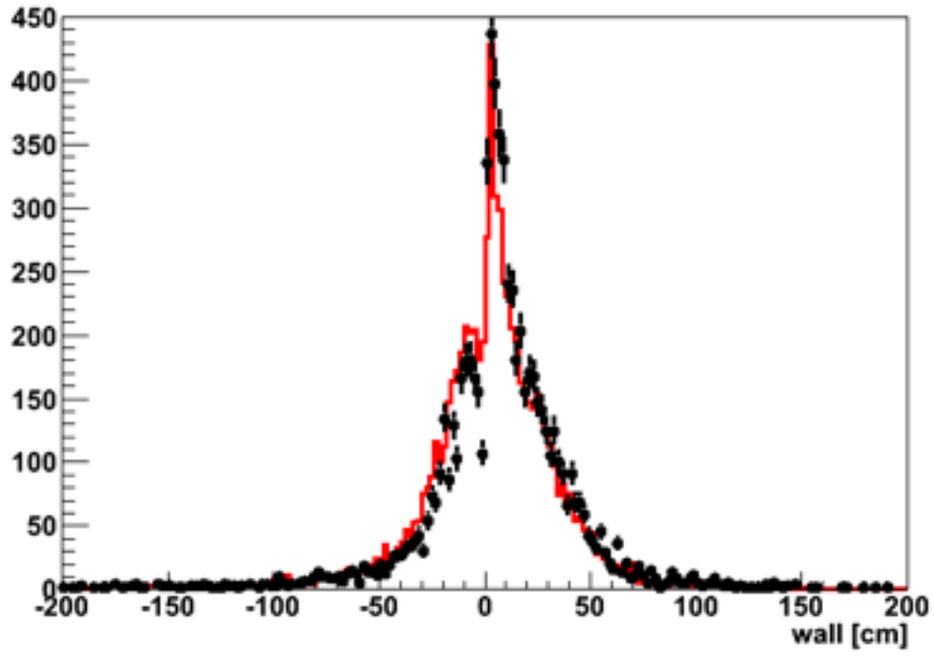
5-6 GeV



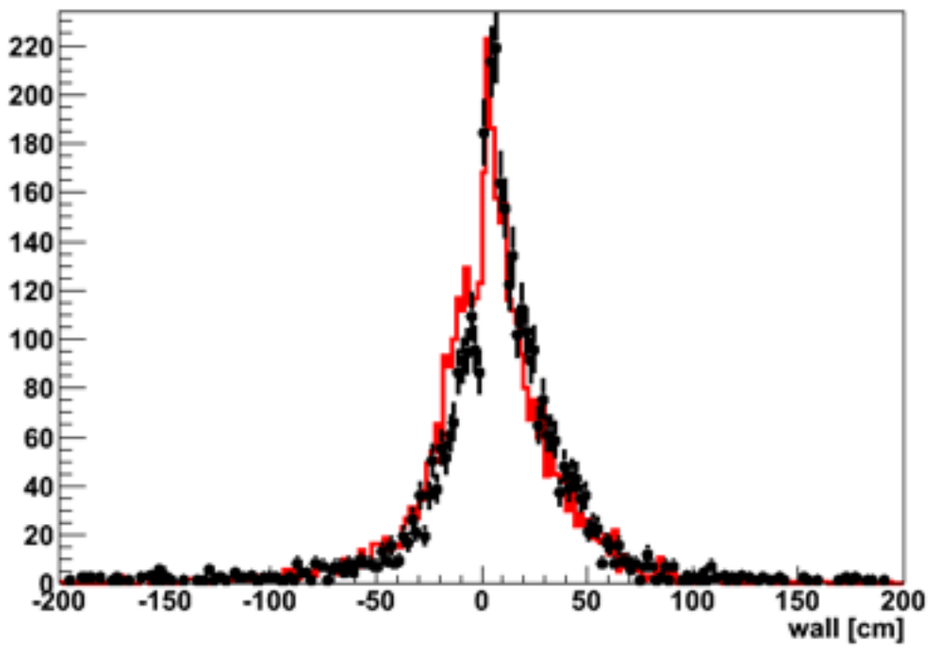
MC

data

6-7 GeV

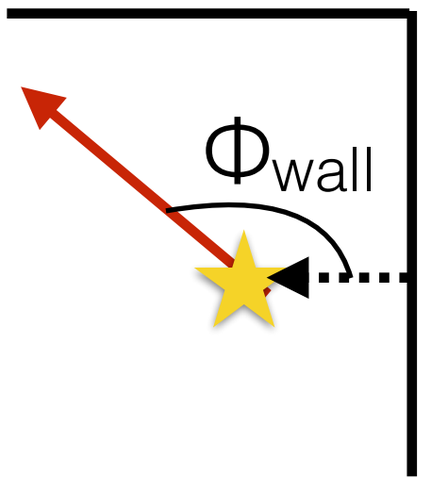


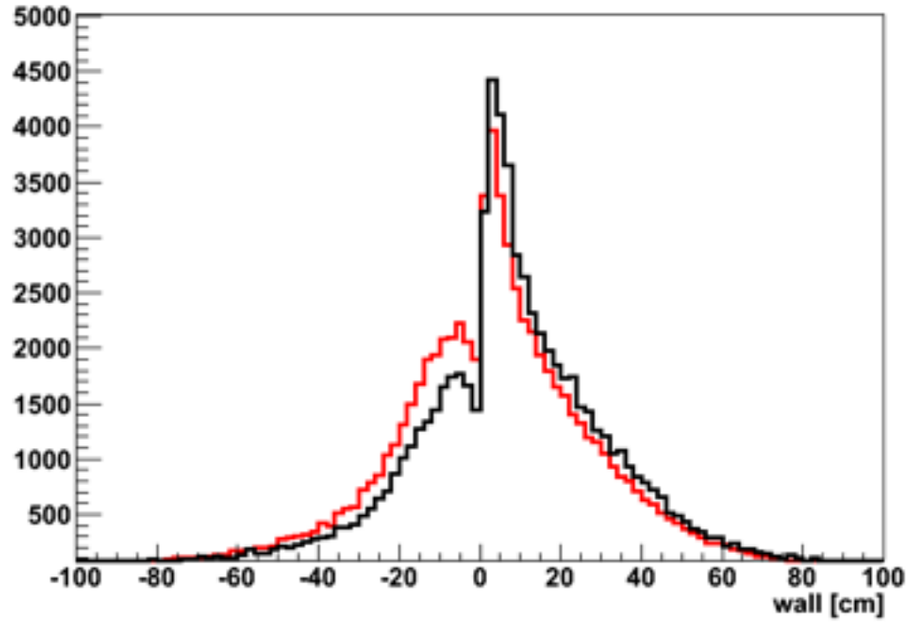
7-8 GeV



Outline

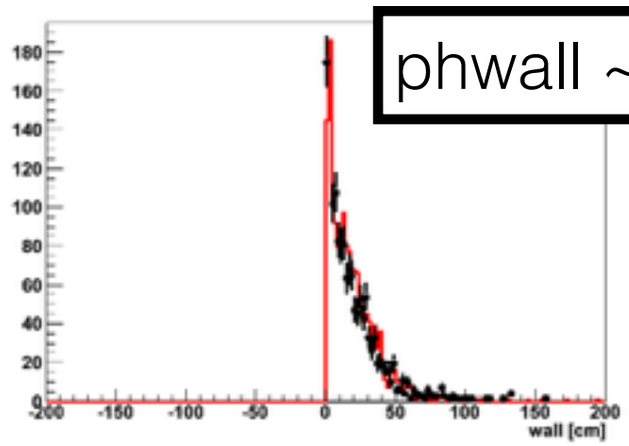
- From last week
  - **wall** distributions for cosmics have a distinct two-peaked shape.
  - I mentioned last week that the angle between in reconstructed direction and and the wall norm. seemed to determine which peak the event ended up in
  - let's call this variable **phiwall**

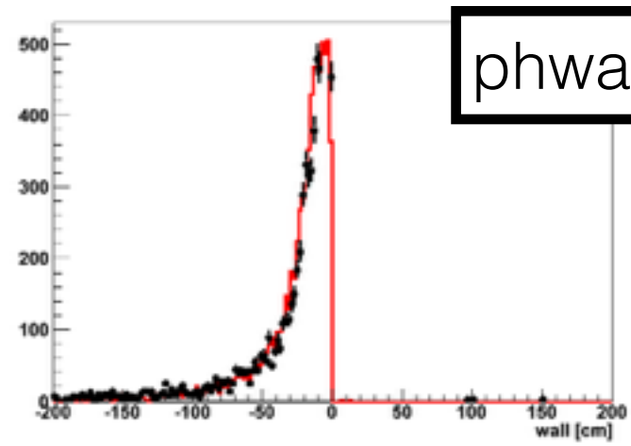




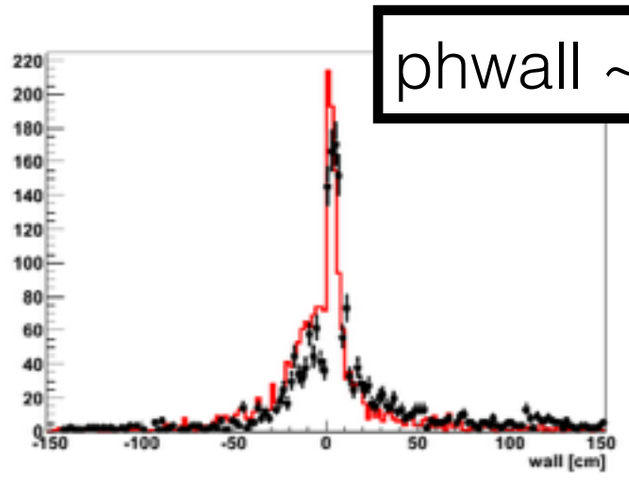
Outline

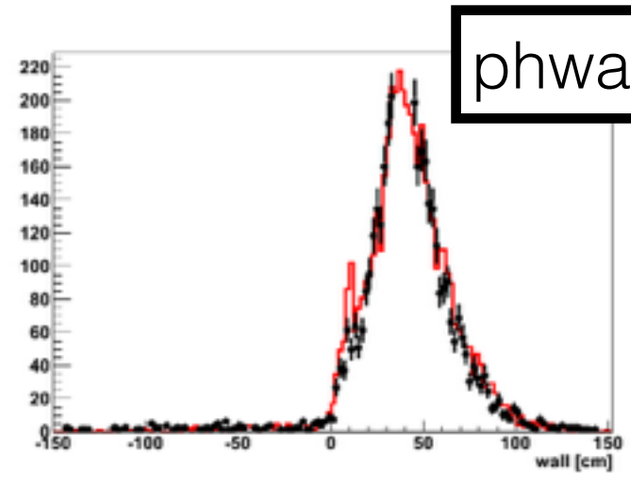
- Unfortunately the variable **phiwall** doesn't depend on wall as much as I initially thought. (Bug in calculating phi wall where the norm changes direction outside the ID.)





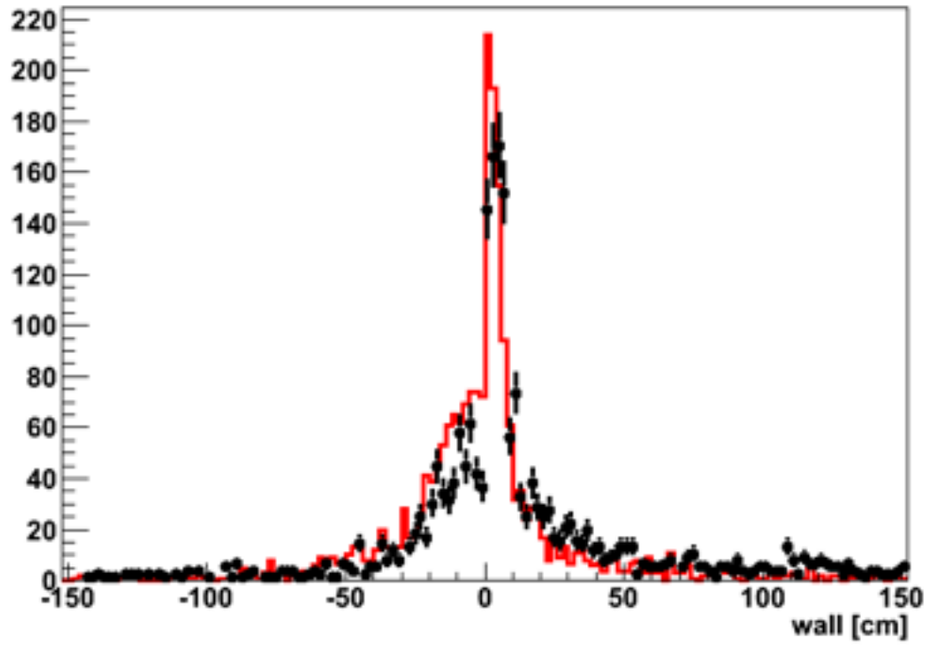
- But when I calculate **phiwall** correctly, there is still some dependance



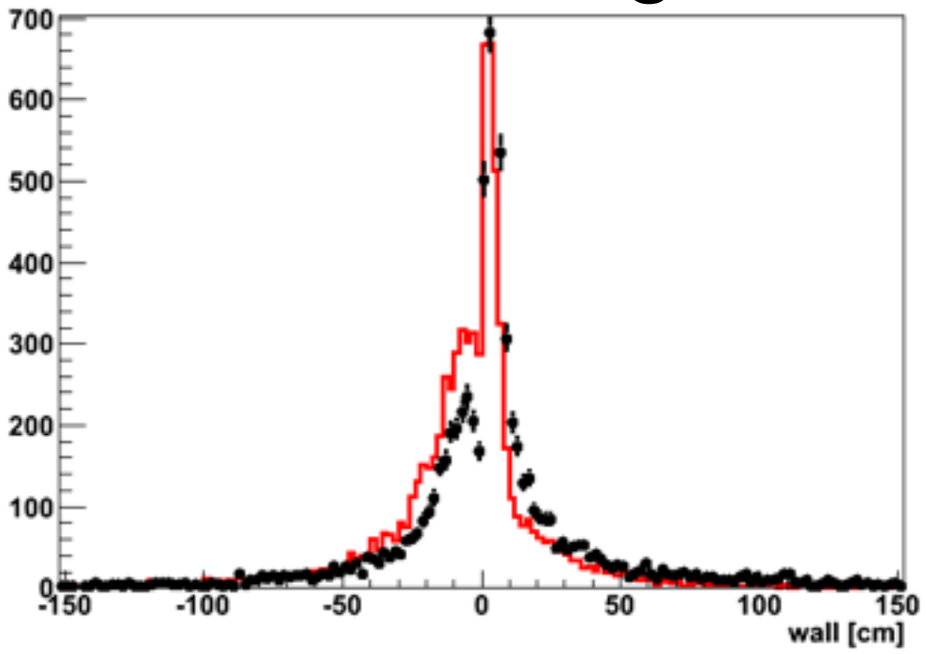


Data/MC Comparison

0-10 deg.



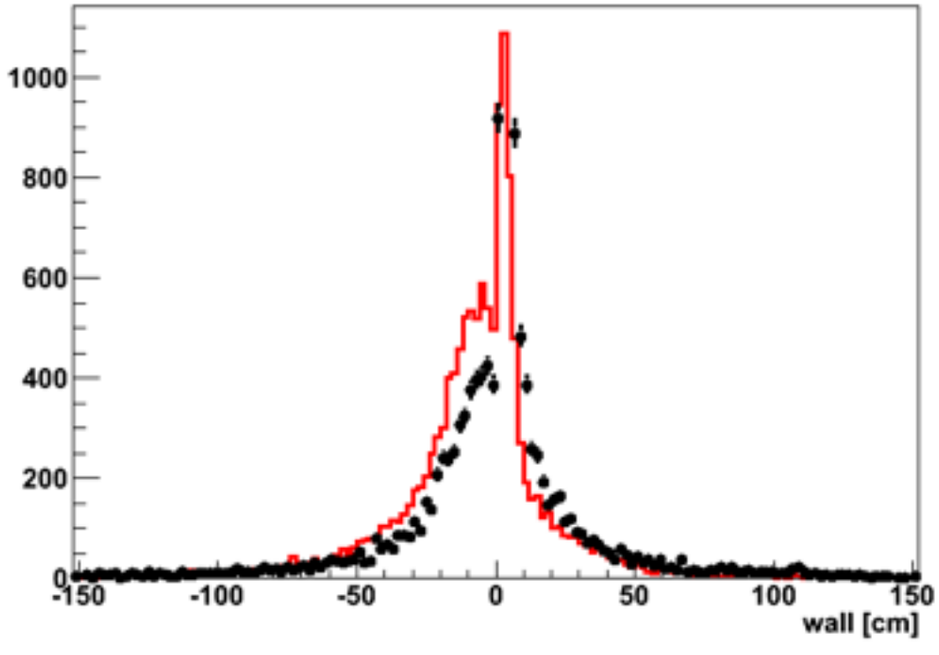
10-20 deg.



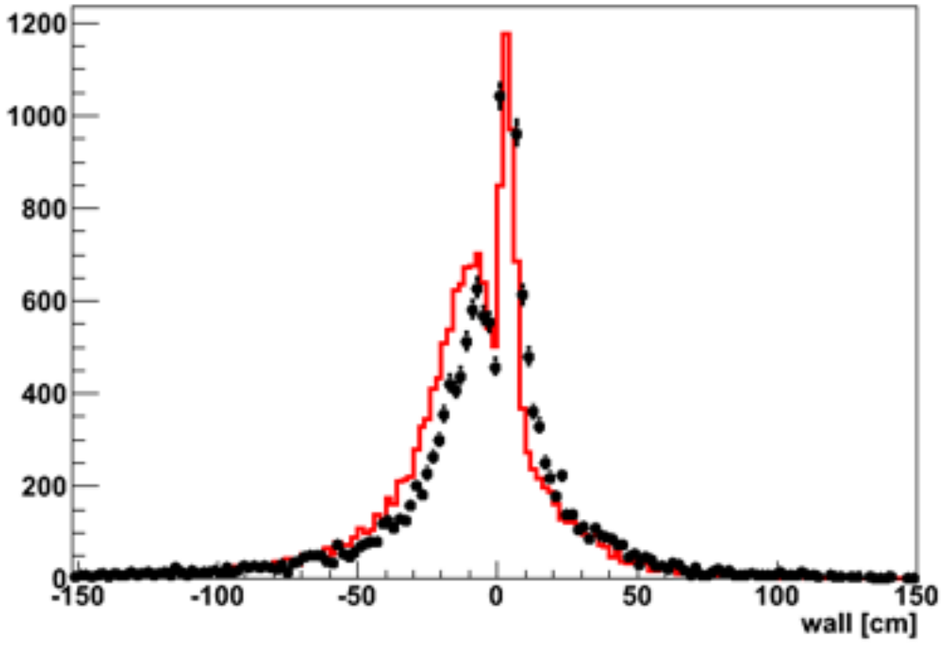
MC

data

20-30 deg.

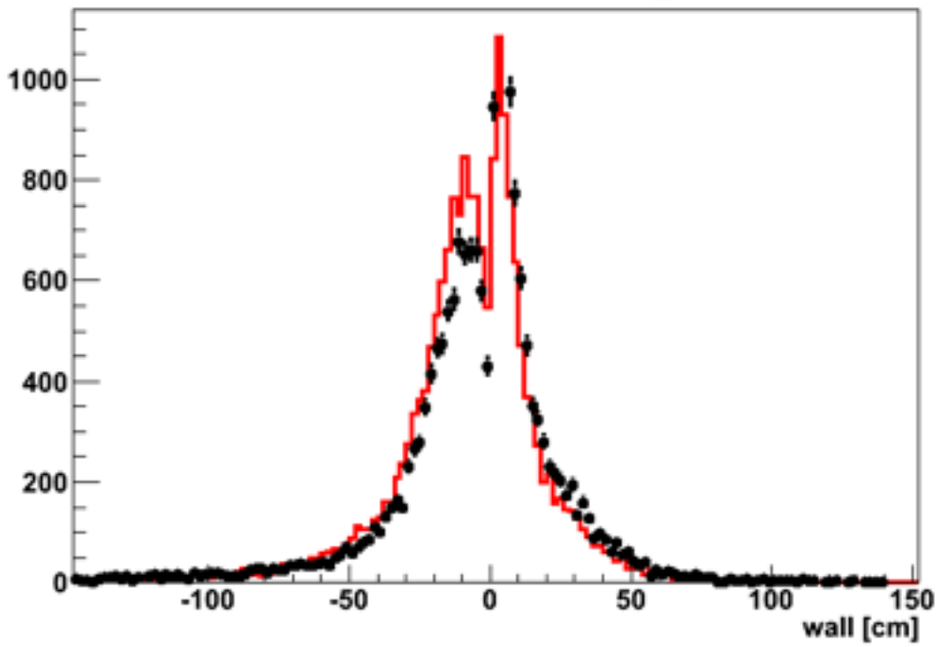


30-40 deg.

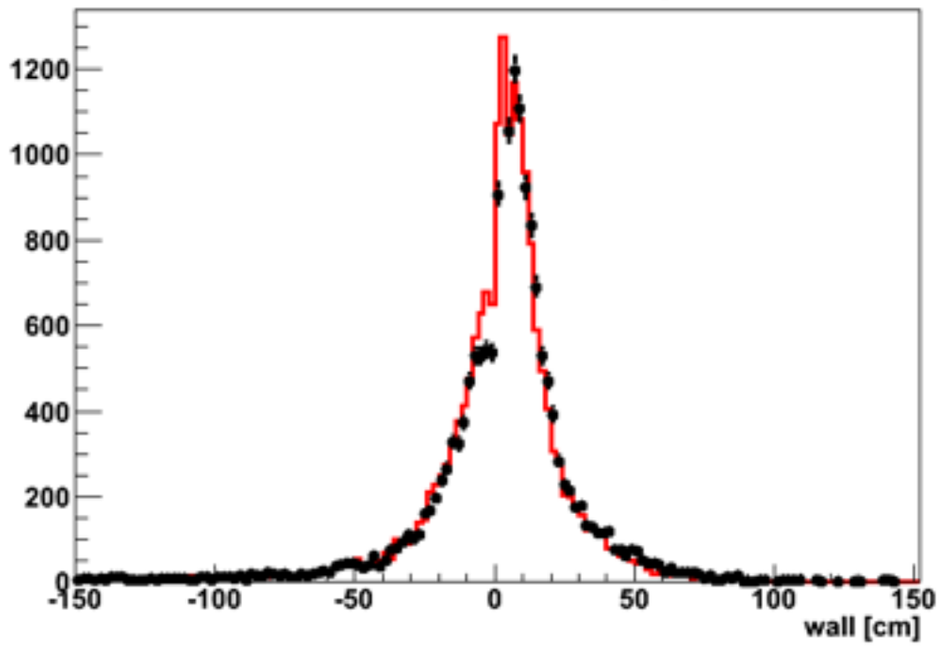


Data/MC Comparison

40-50 deg.



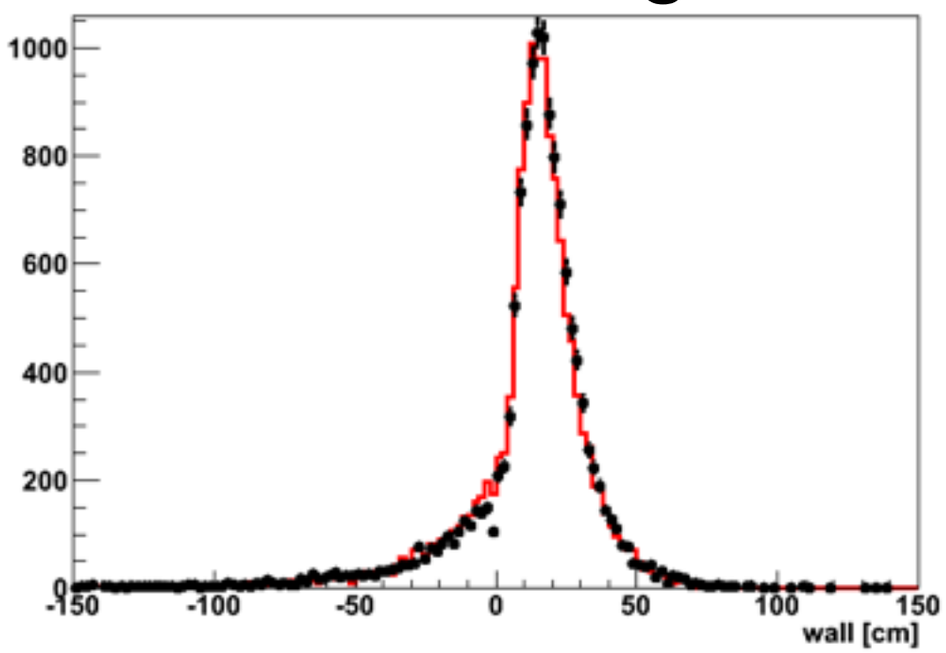
50-60 deg.



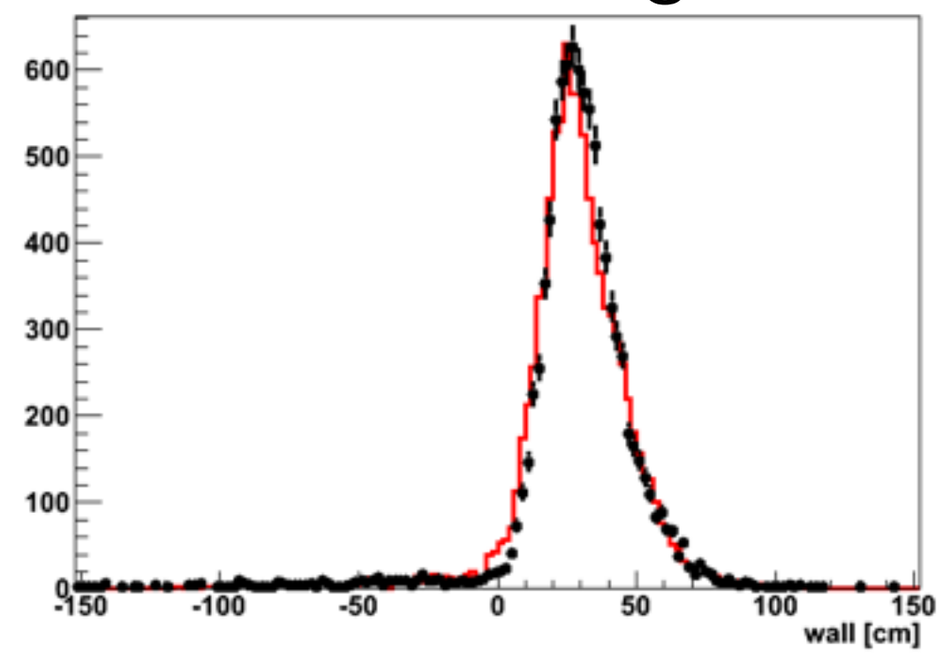
MC

data

60-70 deg.

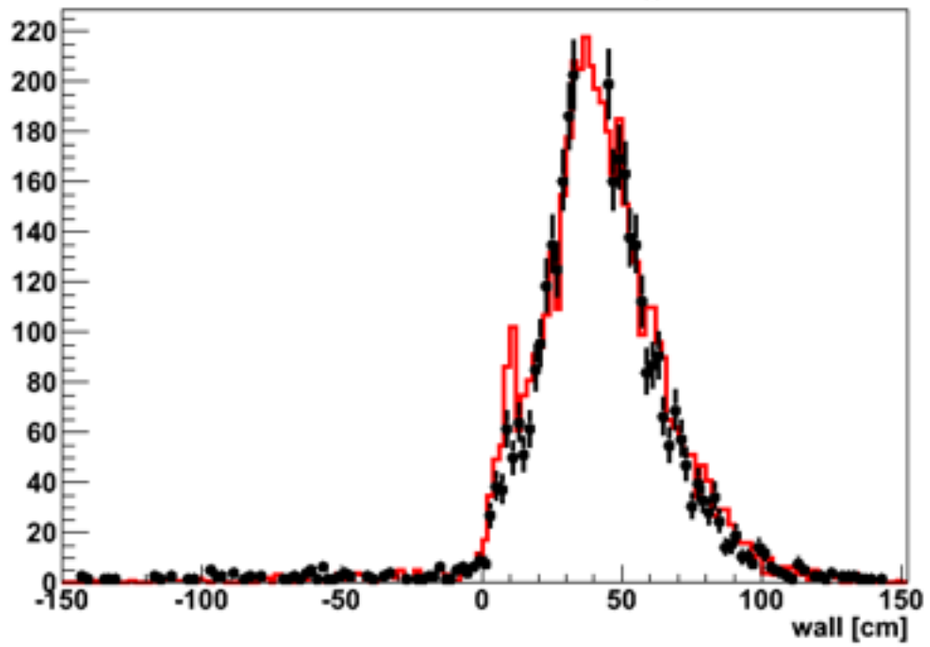


70-80 deg.

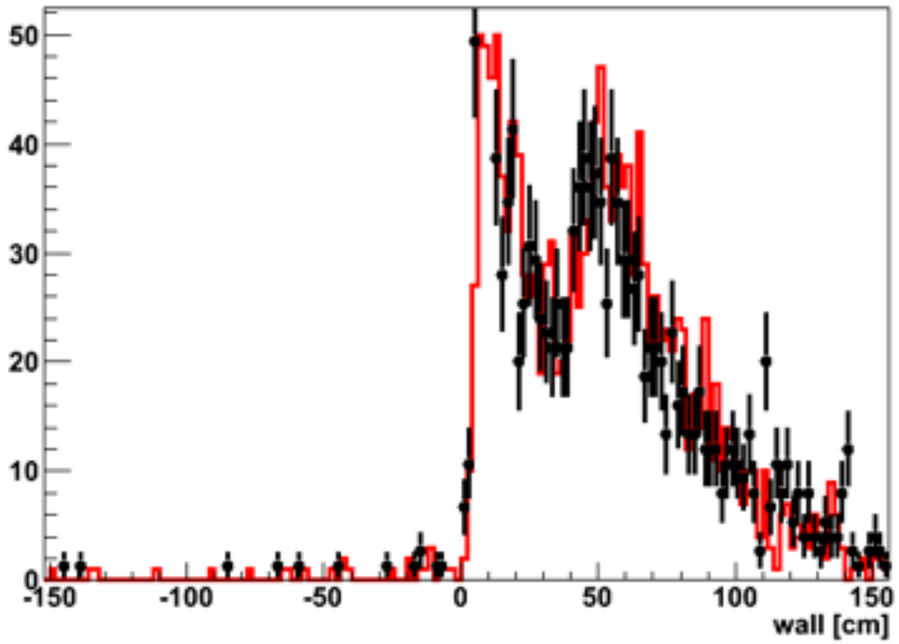


Data/MC Comparison

80-90 deg.



90+ deg.

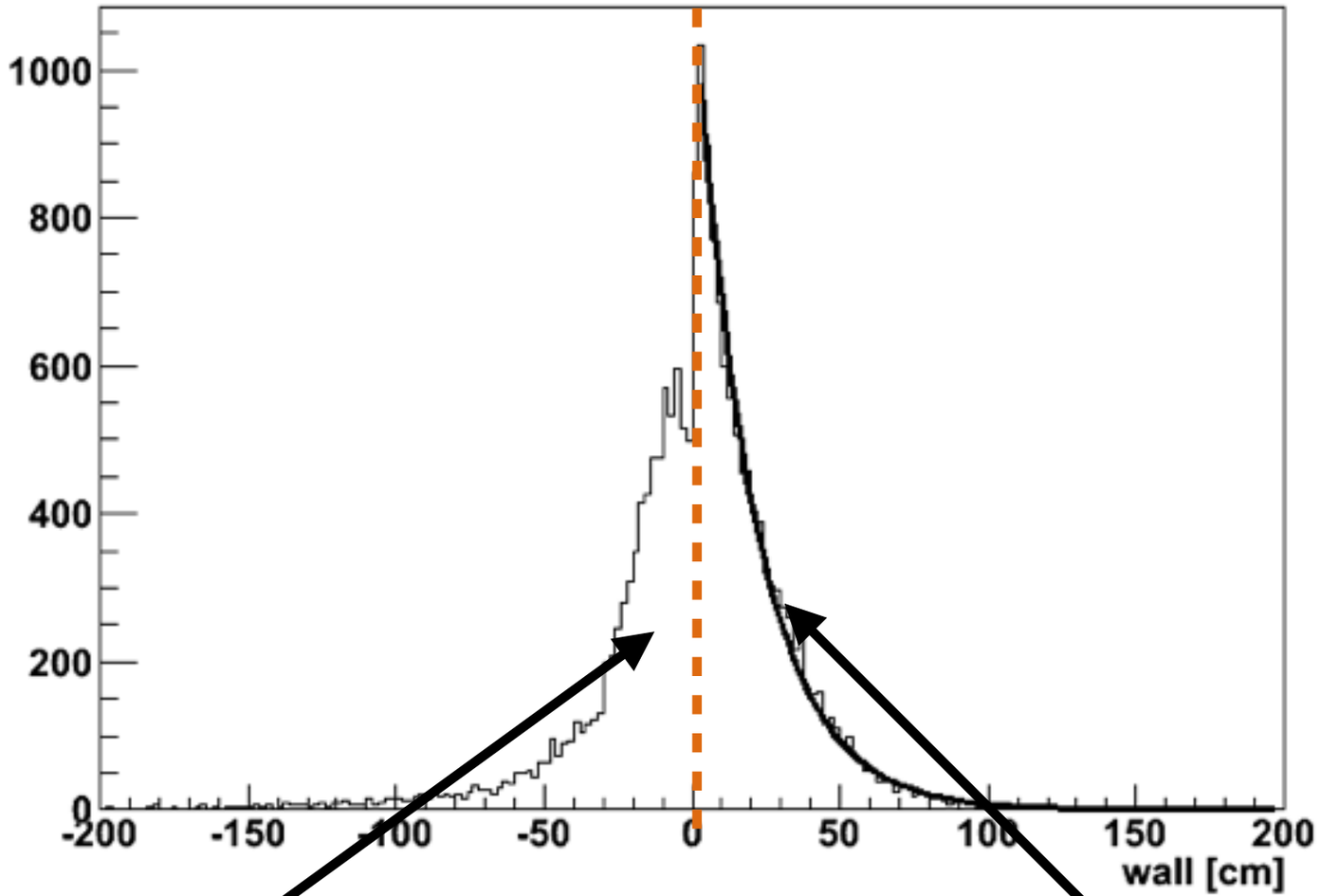


MC

data

- As phiwall increases over ~45 degrees or so, the event in much more likely to be reconstructed inside the ID.
- some data/MC difference in which peak is the largest

Parameterizing Wall Distribution

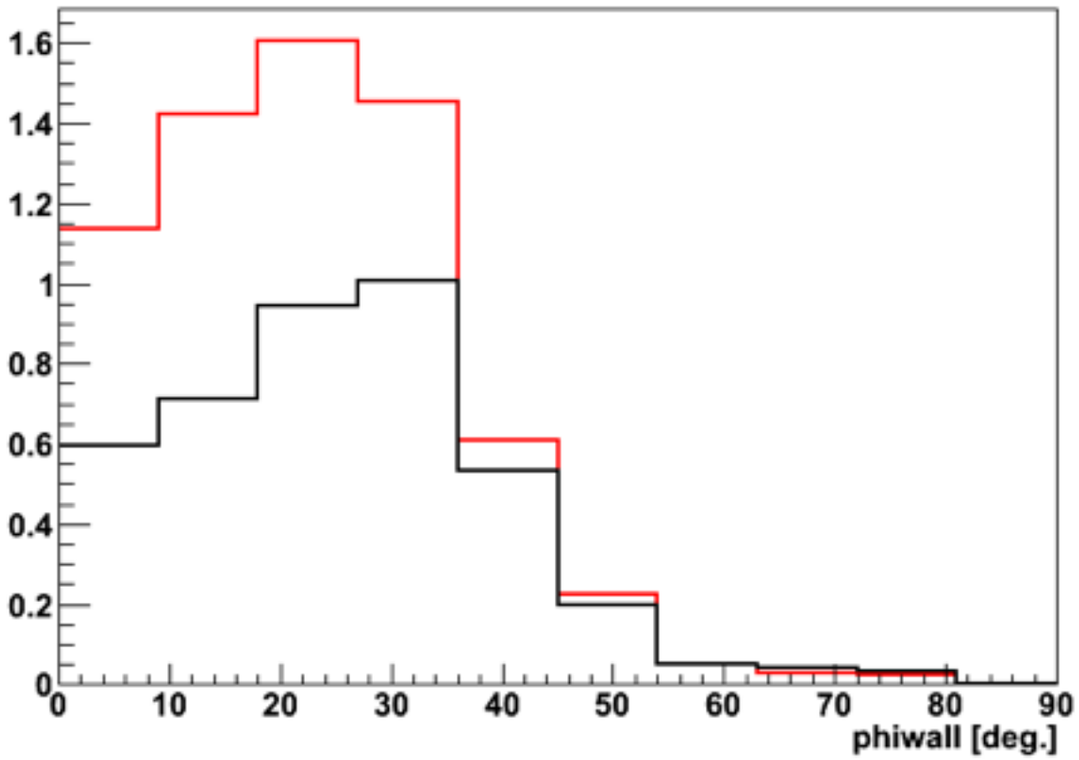


asymmetry parameter - the ratio between the number events with positive wall values to the number of events with negative wall values

decay parameter - decay constant from exponential fit

Parameterizing Wall Distribution

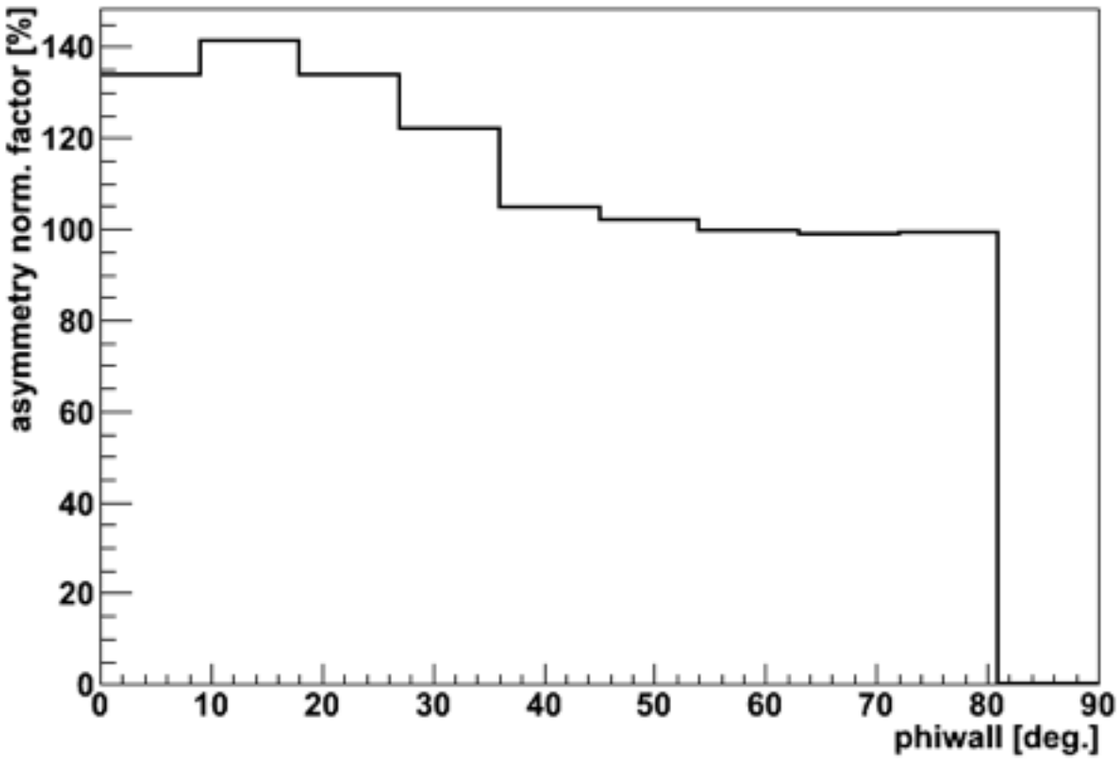
Asymmetry parameter vs. momentum



MC

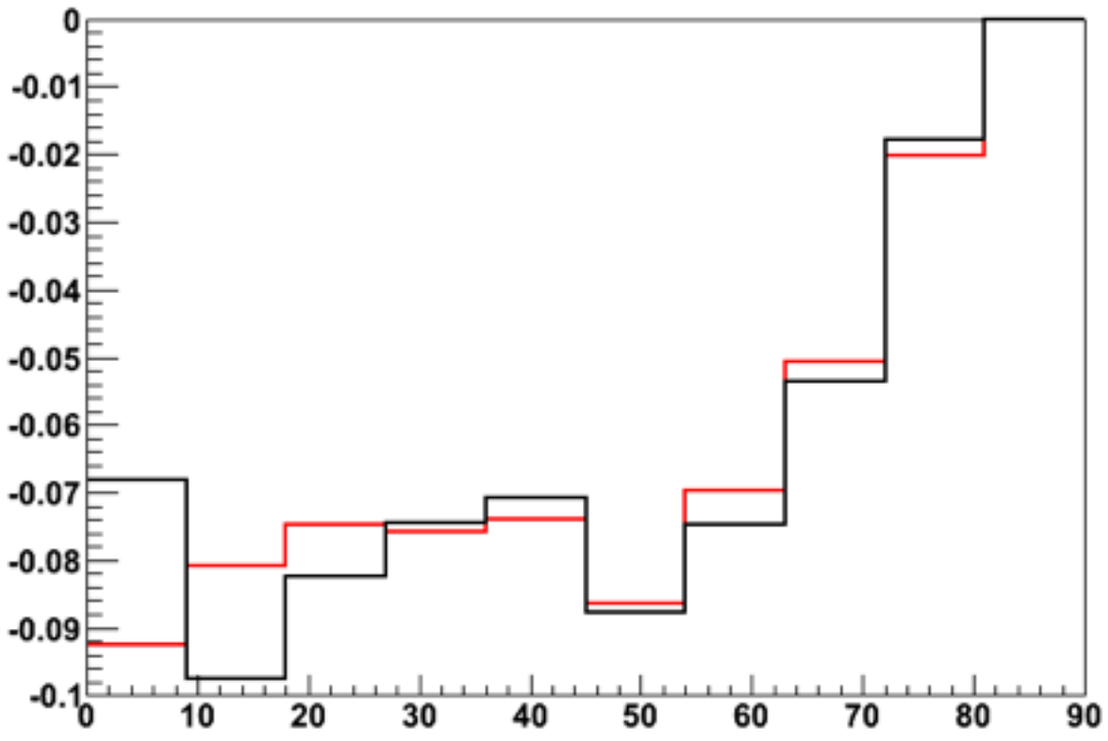
data

Data/MC differenc [%] vs momentum

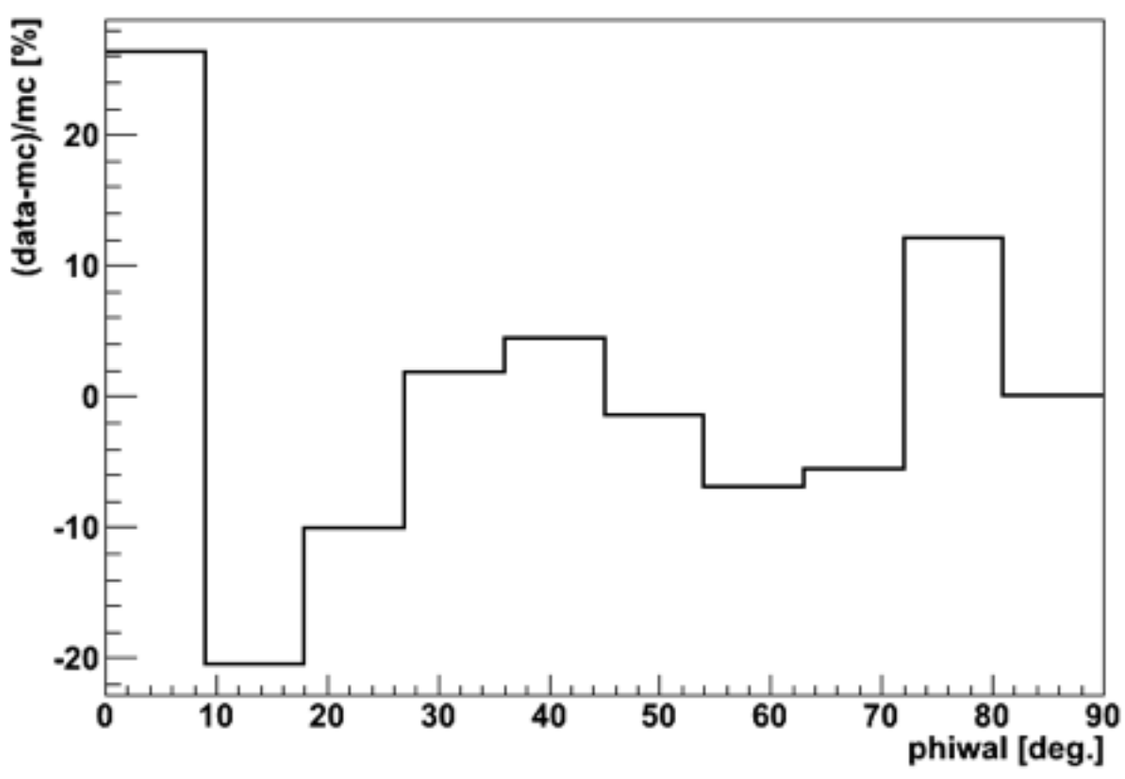


Parameterizing Wall Distribution

decay parameter vs. momentum



Data/MC differenc [%] vs momentum



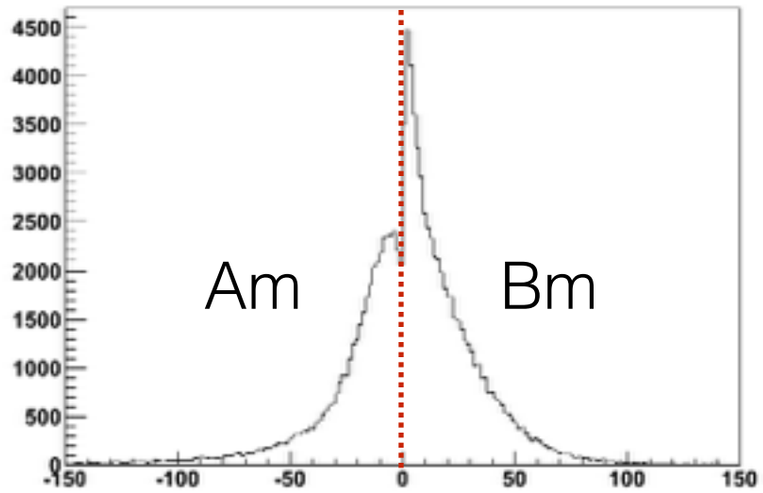
MC

data

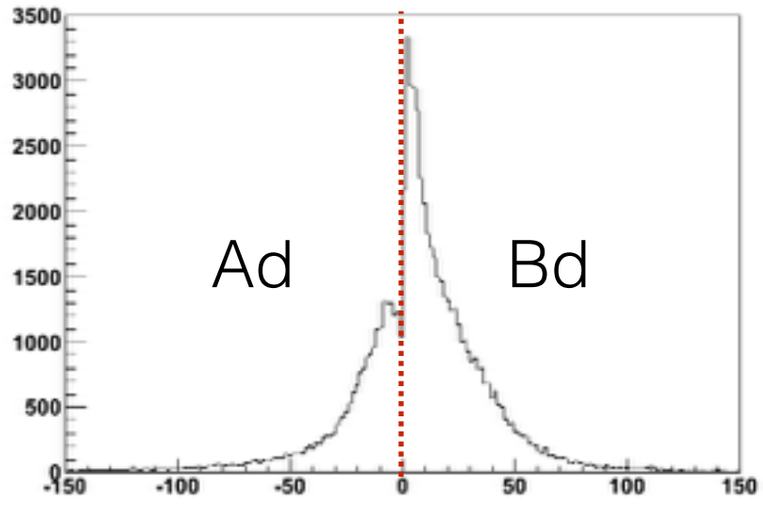
Asymmetry Parameter and T2K MC reweighing

- The asymmetry parameter is the ratio between the # of events with negative wall values to the # of events with positive wall values
- We see that for cosmics, there is disagreement between data and MC.
- What does this mean for T2K MC?
    - We assume that it's reasonable to expect a difference in the wall distribution for muon events between data and M
- How can we account for the uncertainty in this distribution when determining the optimal fiducial cut?
    - We tweak the MC distribution and re-evaluate the optimal cuts using this tweaked MC
- How do I tweak the MC distribution?
    - I use the worst case scenario: the asymmetry in the data is due to events migrating from the negative peak to the positive peak.
        - So I want to change the normalization of the positive peak to look more like the data, while keeping the over normalization the same
- Normalization factor: **α = (Rd +(Rd/Rm)) / (1+Rd),** where **Rd = (Ad/Bd), Rm = (Am/Bm)**

MC:

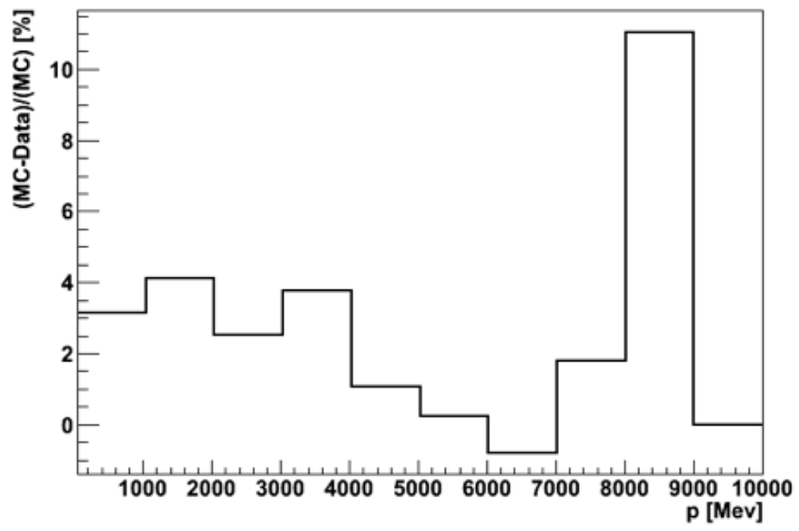


Data:

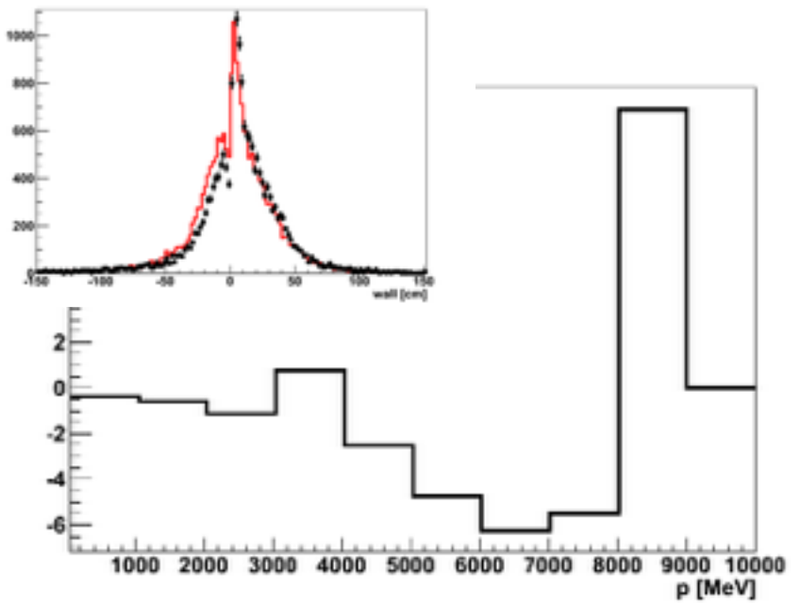


Decay Parameter and T2K MC reweighing

- We also see some data/MC discrepancy in the decay parameter for cosmics
- Once again, we assume that a similar discrepancy should exist in the T2K muon data.
- How do I tweak the MC to account for the discrepancy in the decay of the wall distribution?
  - For each event in the T2K MC, I multiply the reconstructed wall value for dead region events by some factor.
  - This effectively “stretches out” the wall distribution, so its fitted decay constant more closely resembles the data
- I then re-optimize the FV cuts using the T2K MC with the tweaked wall values

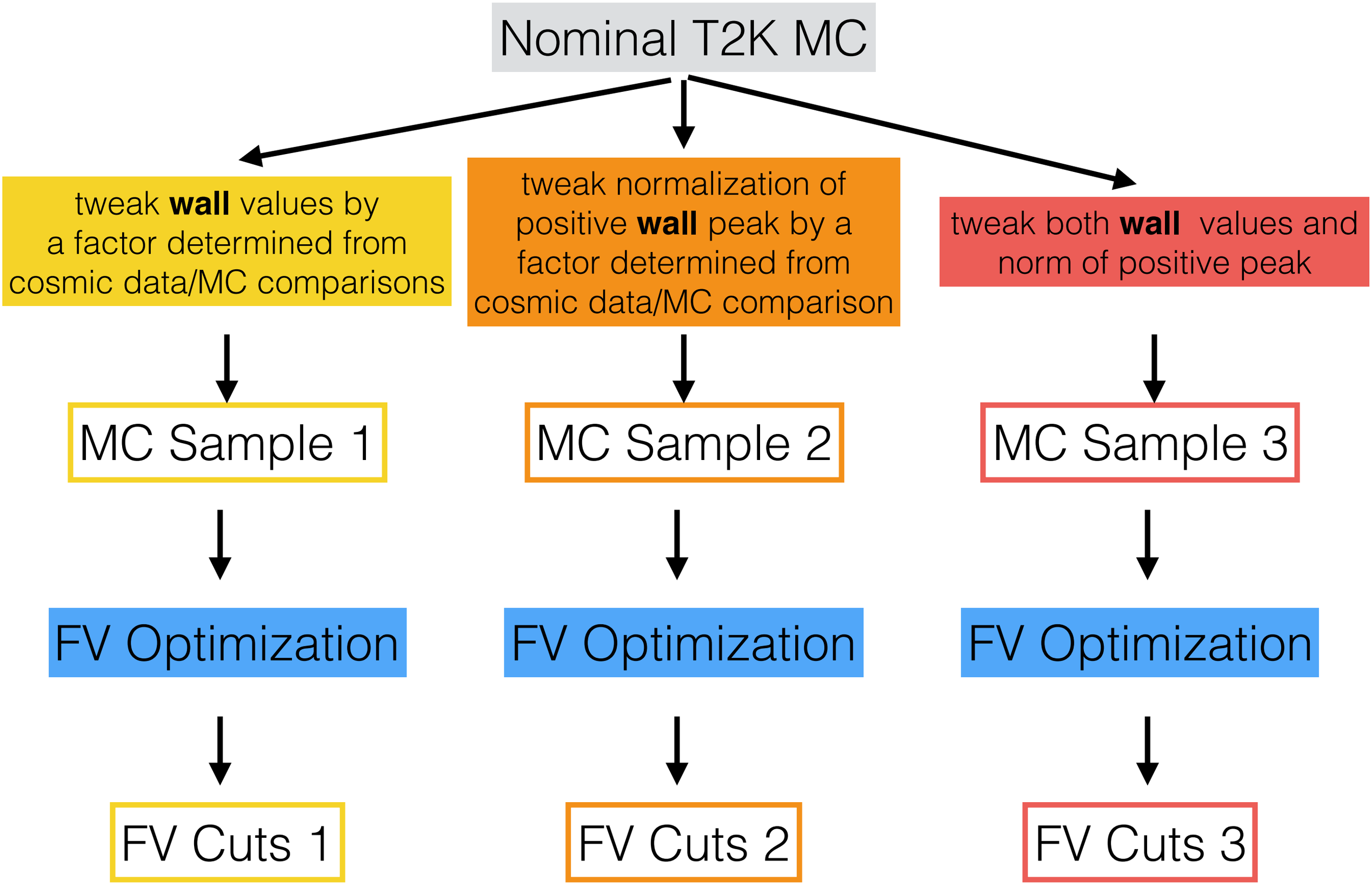


tweak **wall** values



Effect on FV Optimization

- From the shape analysis of the data and MC **wall** distributions, we find the following discrepancies
  - a ~30% difference in the asymmetry parameter
  - a ~4% difference in the decay parameter
  - a negligible difference in the peak location
- How do these discrepancies effect the FV optimal point?
- Check by adjusting the MC distribution and running the FV optimization on the modified MC.
  - for the asymmetry discrepancy, just adjust the normalization since we don't really care about how the negative **wall** distribution is modeled at this time.
  - for the decay discrepancy, modify the **wall** value by some factor


Nominal T2K MC
tweak **wall** values by a factor determined from cosmic data/MC comparisons
tweak normalization of positive **wall** peak by a factor determined from cosmic data/MC comparison
tweak both **wall** values and norm of positive peak
MC Sample 1
MC Sample 2
MC Sample 3
FV Optimization
FV Optimization
FV Optimization
FV Cuts 1
FV Cuts 2
FV Cuts 3

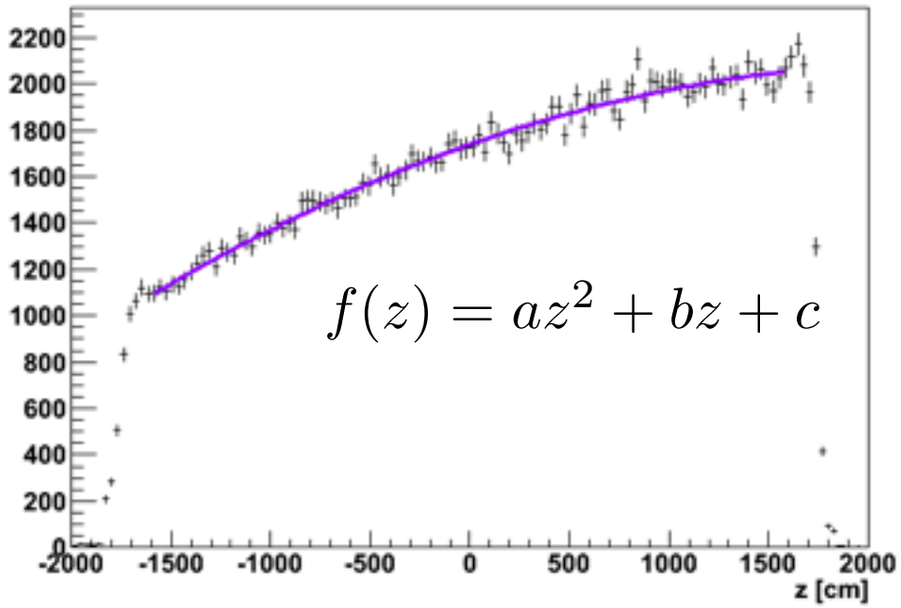
Expected Wall Distribution

- The Michel vertex and direction distribution is (almost) uniform, we can figure out the expected PDF of the wall variable

$$PDF(w) \propto \frac{d}{dw}[\ \pi(R-w)^2(Z-w)] \propto w^2$$

  - assuming uniform density:

- The vertex distribution for cosmics is a slowly varying (w.r.t the scale of the detector)function of z, so we can approximate with a parabola



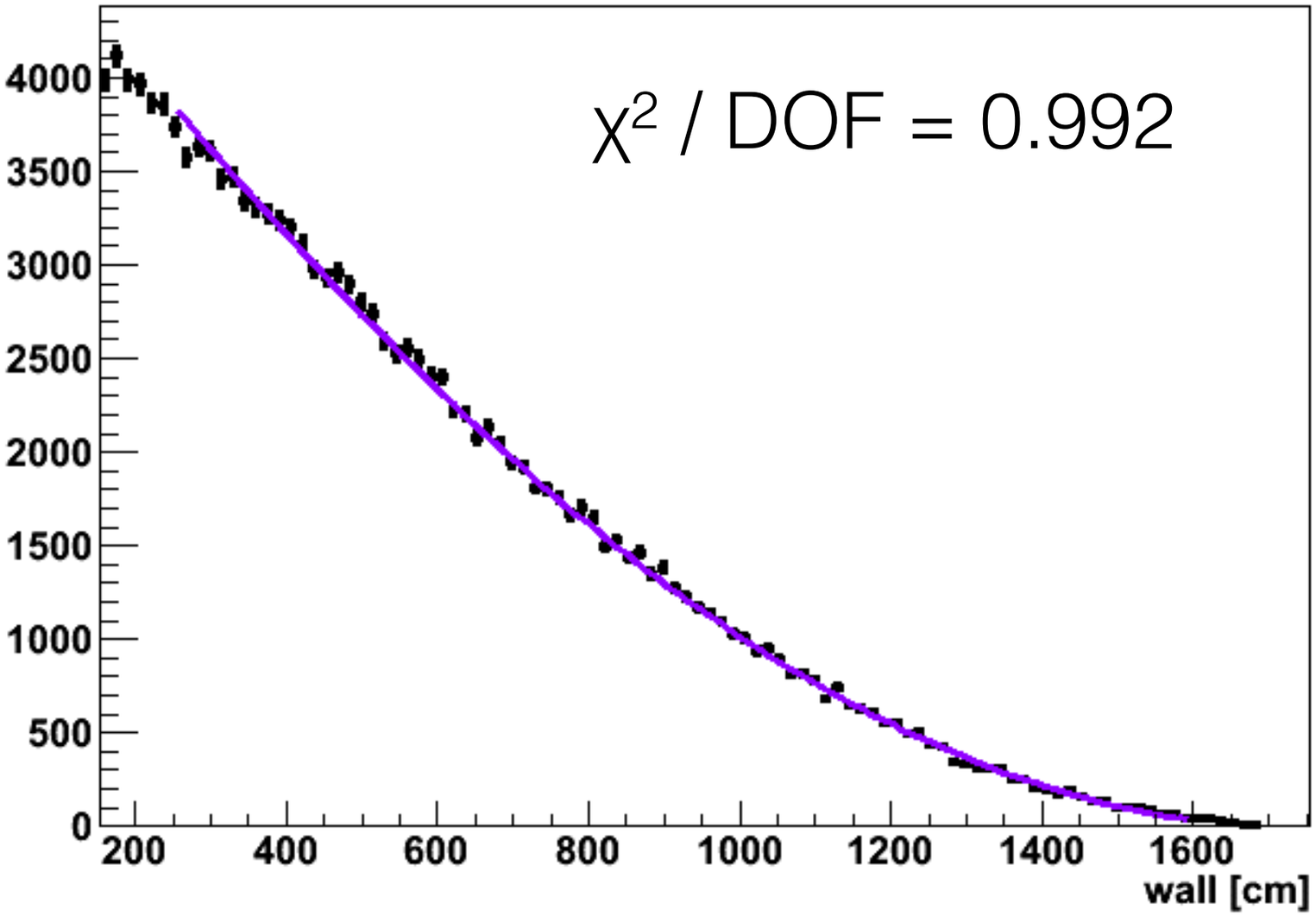
- One can then solve analytically for the expected wall PDF:

- By building this expected PDF (histogram shape) for data and MC, we can compare the Michel efficiency with reduced dependance on flux

$$PDF(w) = \frac{d}{dw}CDF(w) \propto \frac{d}{dw}[\ \pi(R-w)^2 \int_{-z+w}^{z-w} f(z)dz]$$

$$PDF(w) \propto 2(R-w)[\frac{a}{3}(Z-w)^2 + c(Z-w)] + a(R-w)^2(Z-w)^2 + w$$

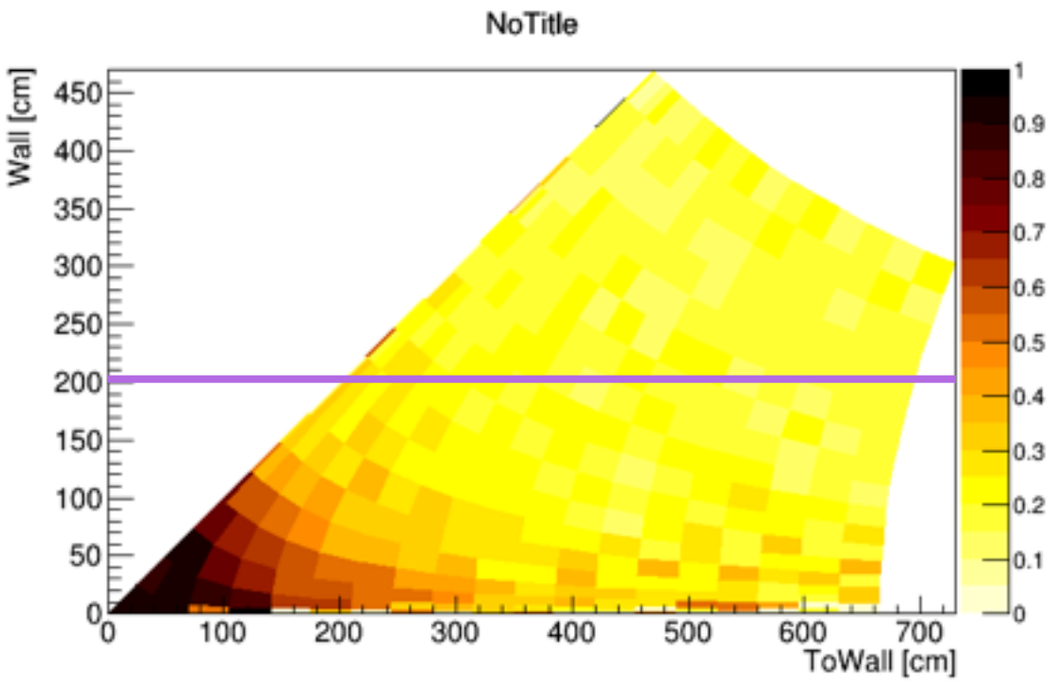
Expected Wall Distribution



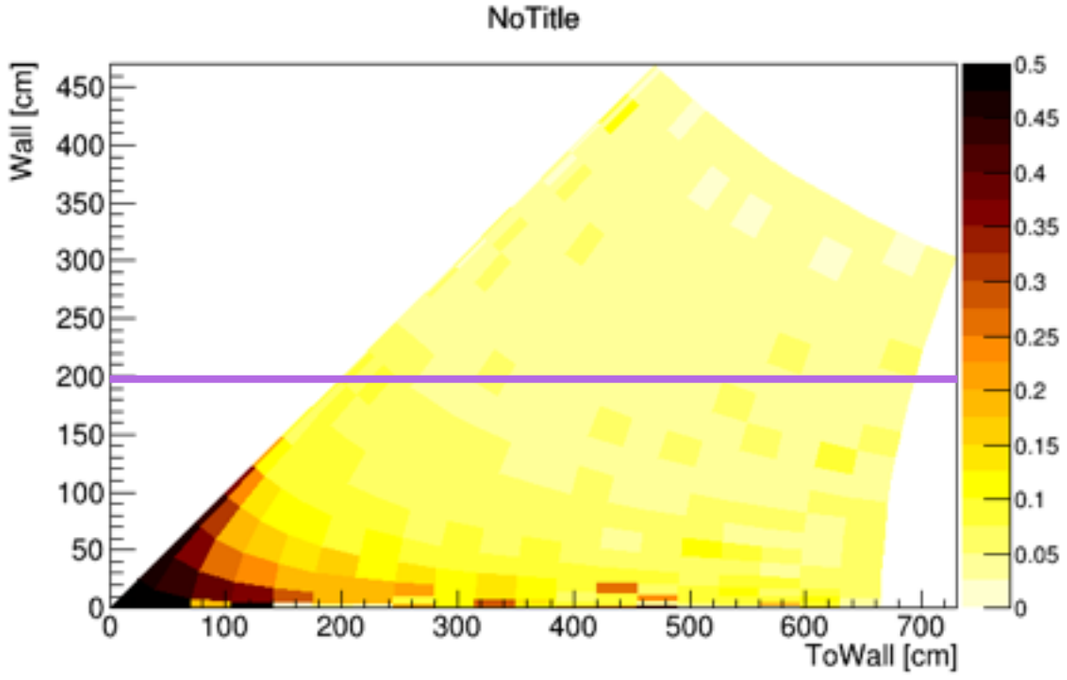
$$PDF(w) \propto 2(R-w)[\tfrac{a}{3}(Z-w)^2 + c(Z-w)] + a(R-w)^2(Z-w)^2 + w$$

True Wall-Towall

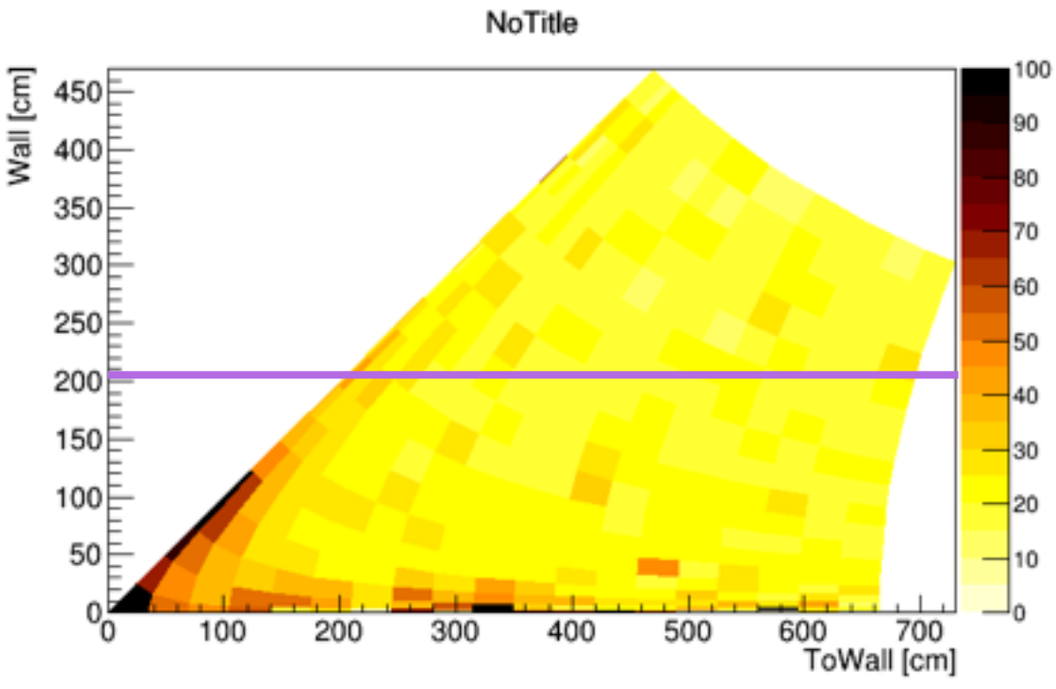
fraction with missed decay e



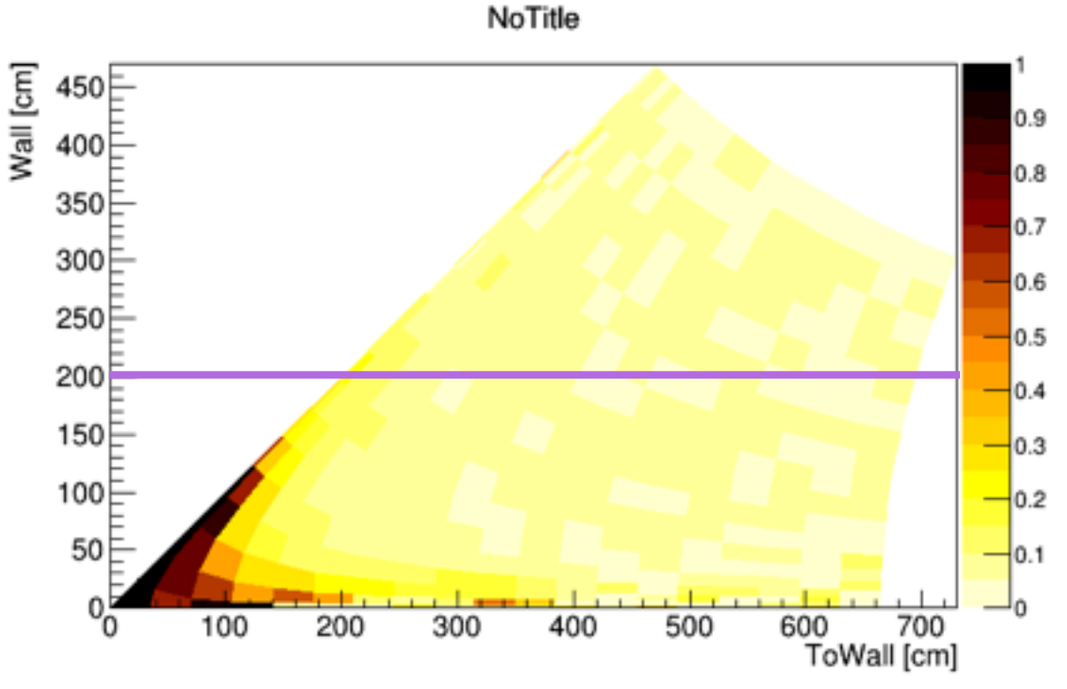
momentum resolution



position resolution

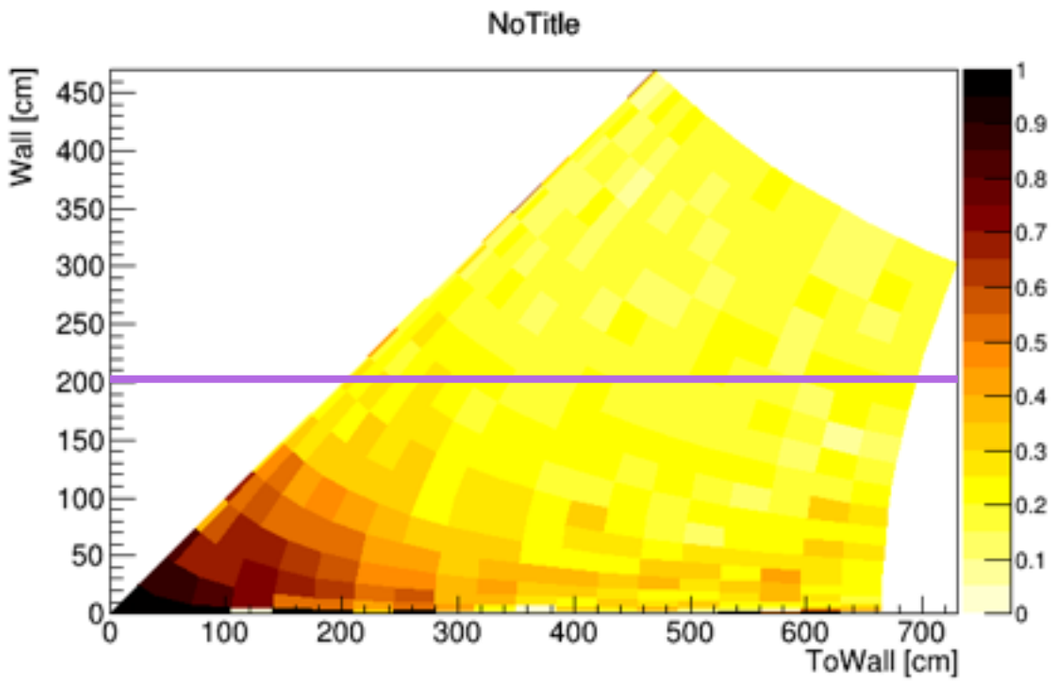


direction resolution

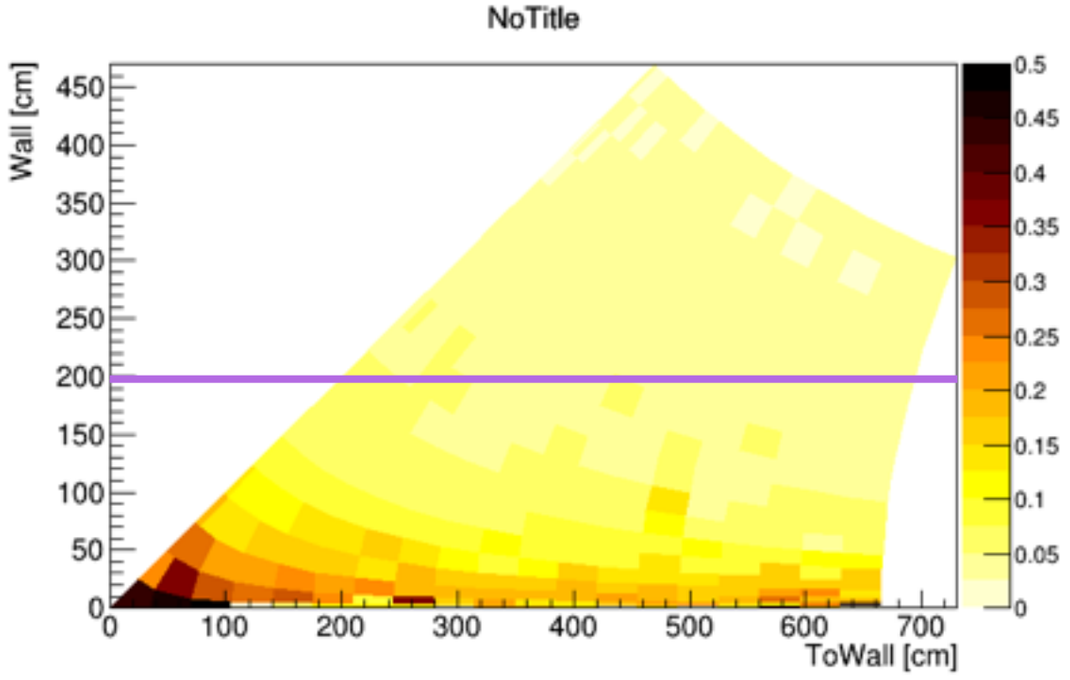


Reconstructed Wall-Towall

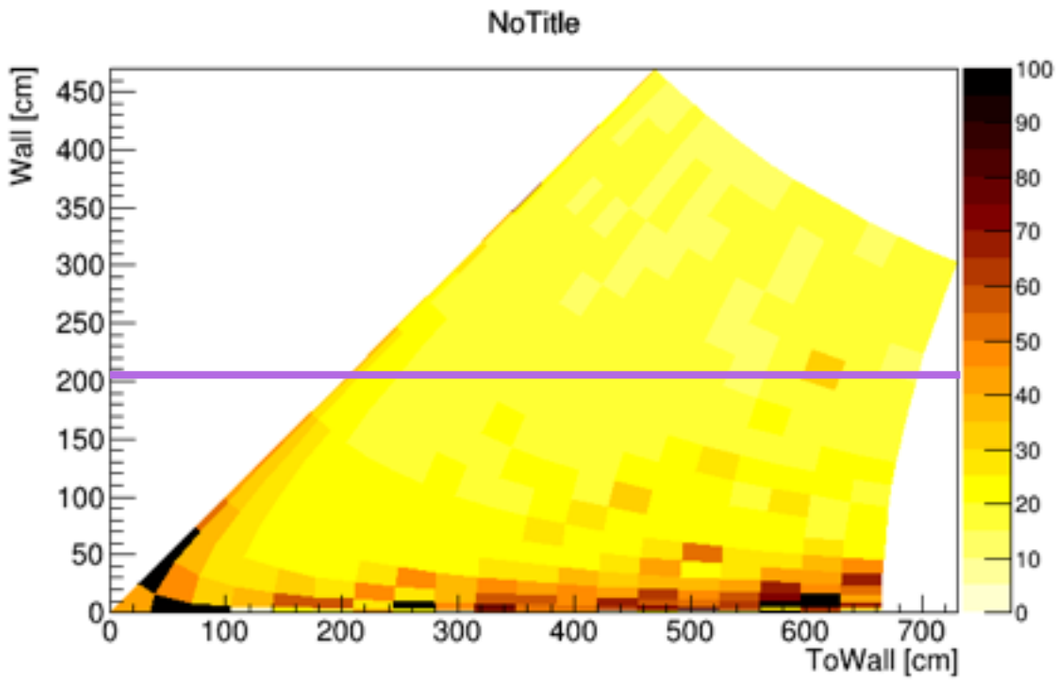
fraction with missed decay e



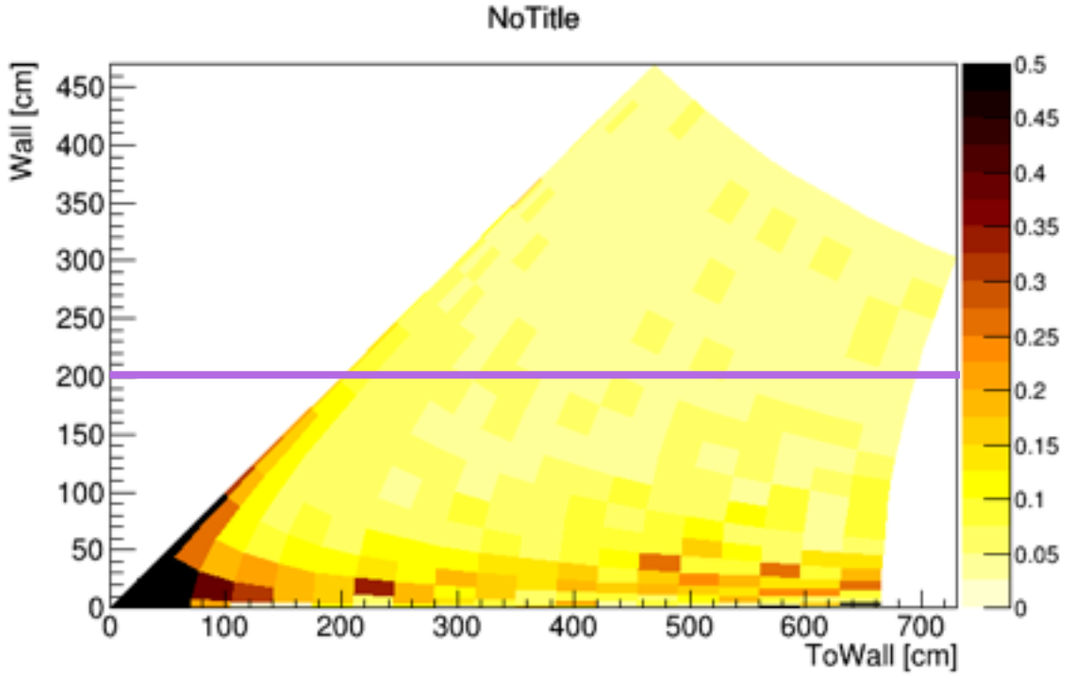
momentum resolution



position resolution

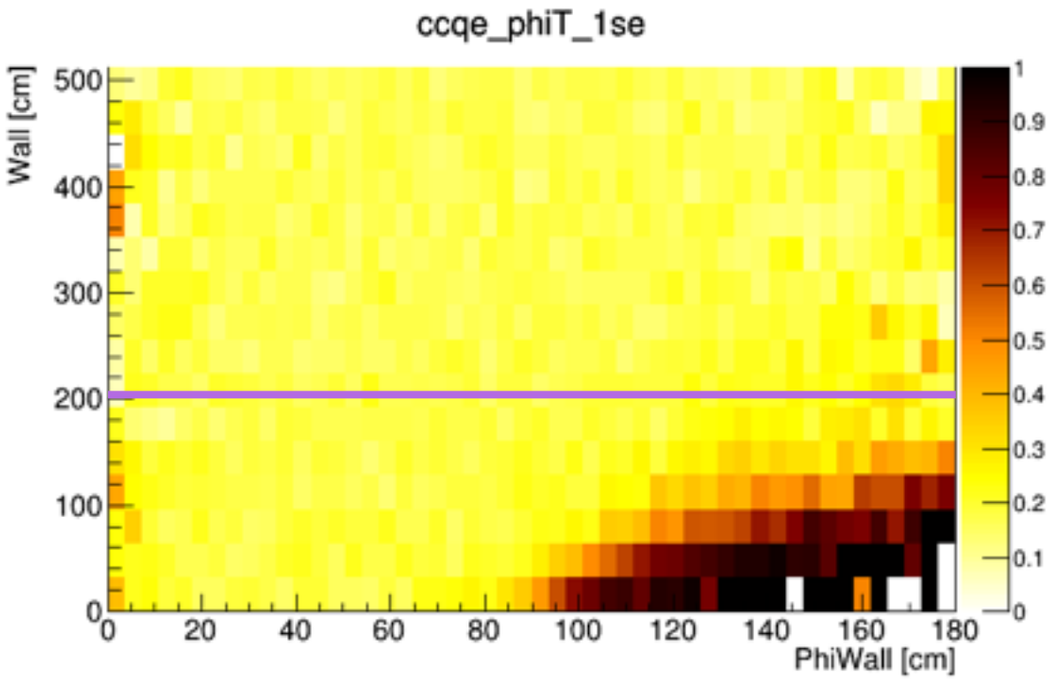


direction resolution

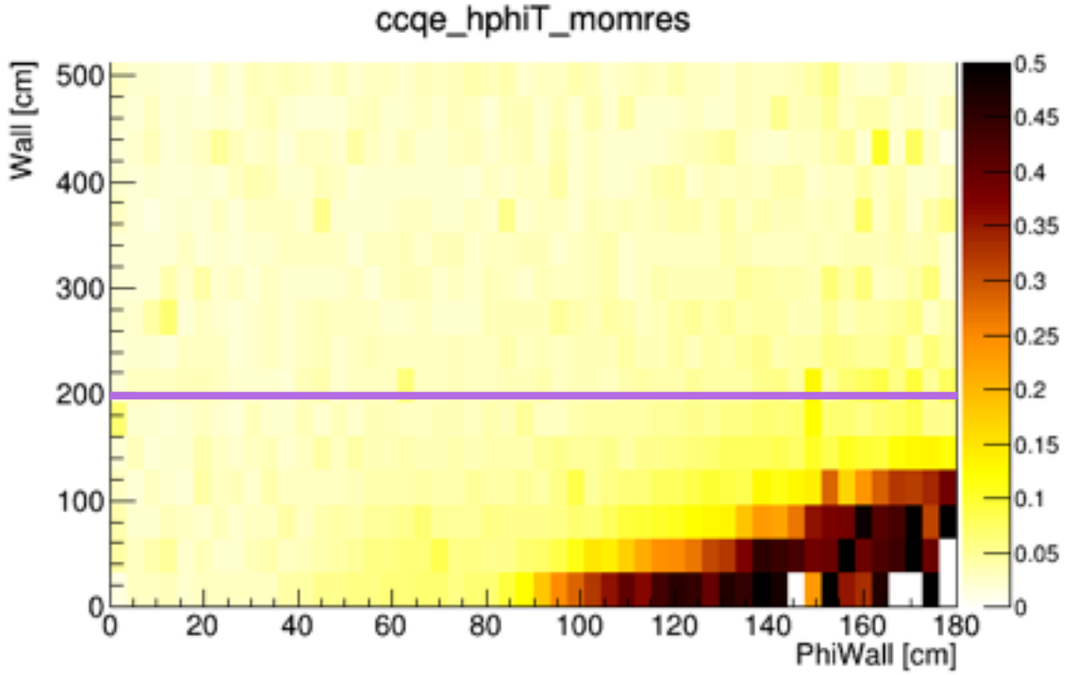


True Wall-Phiwall

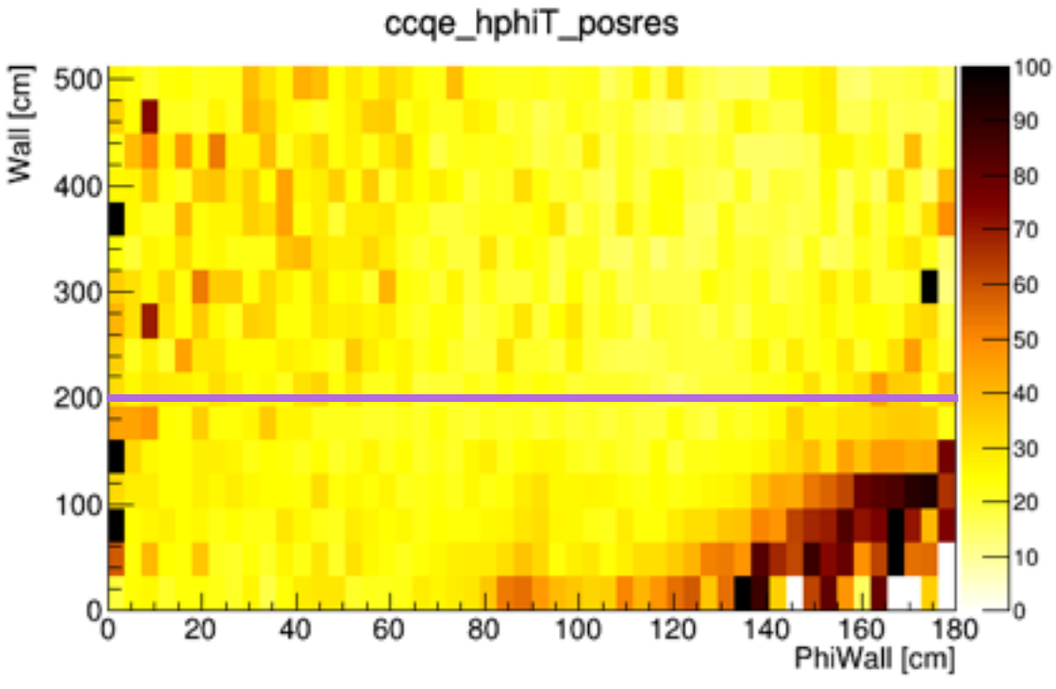
fraction with missed decay e



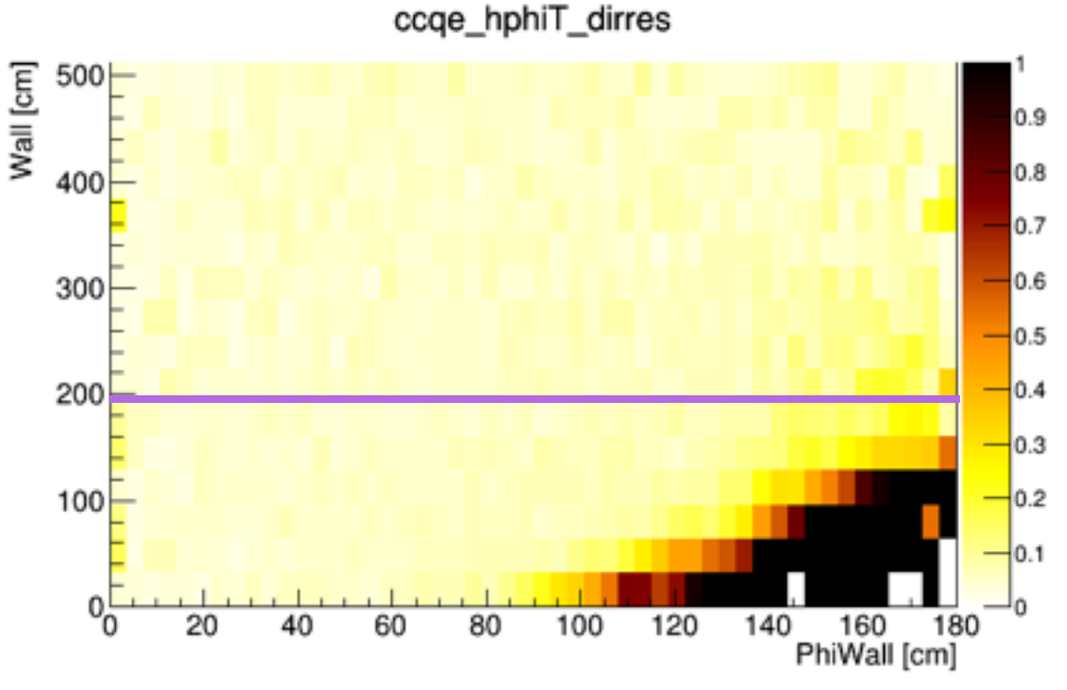
momentum resolution



position resolution

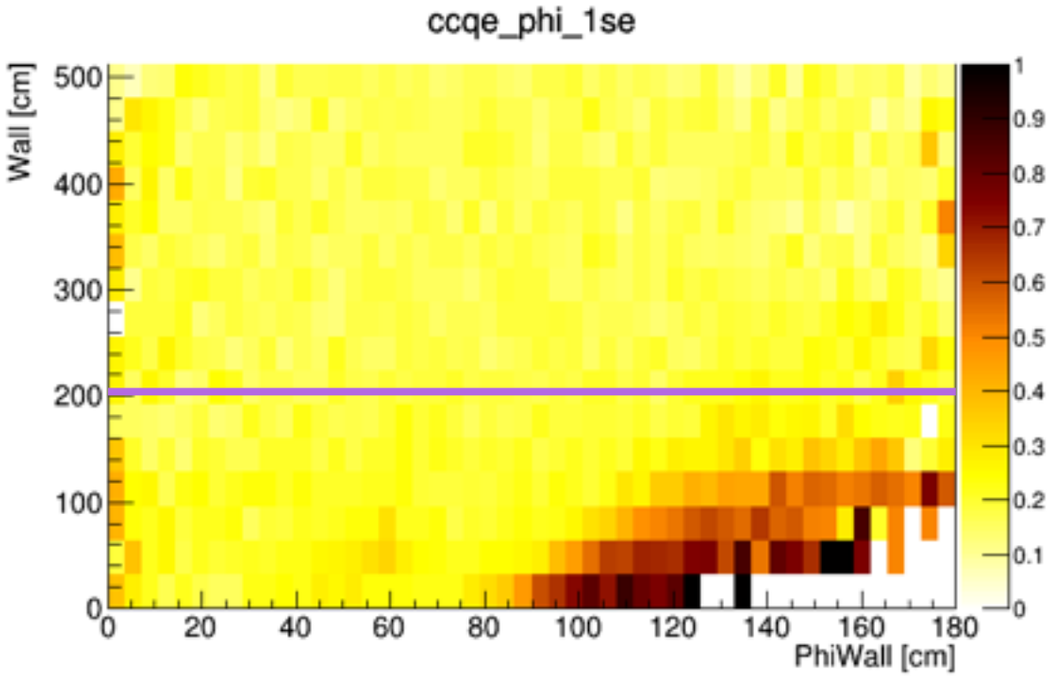


direction resolution

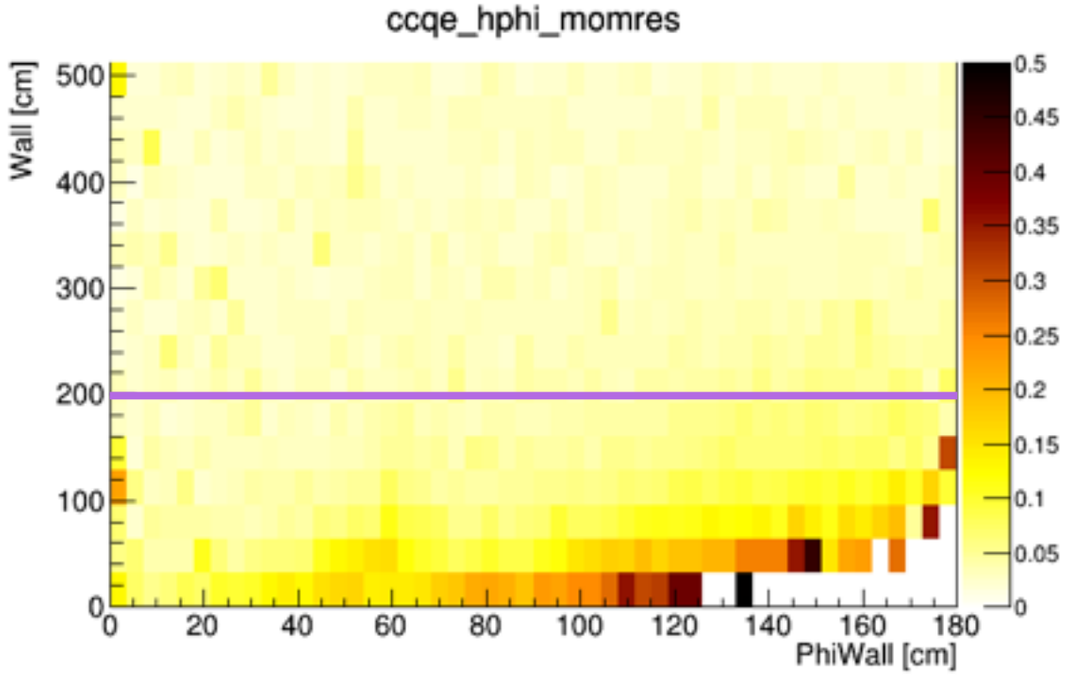


Reconstructed Wall-Phiwall

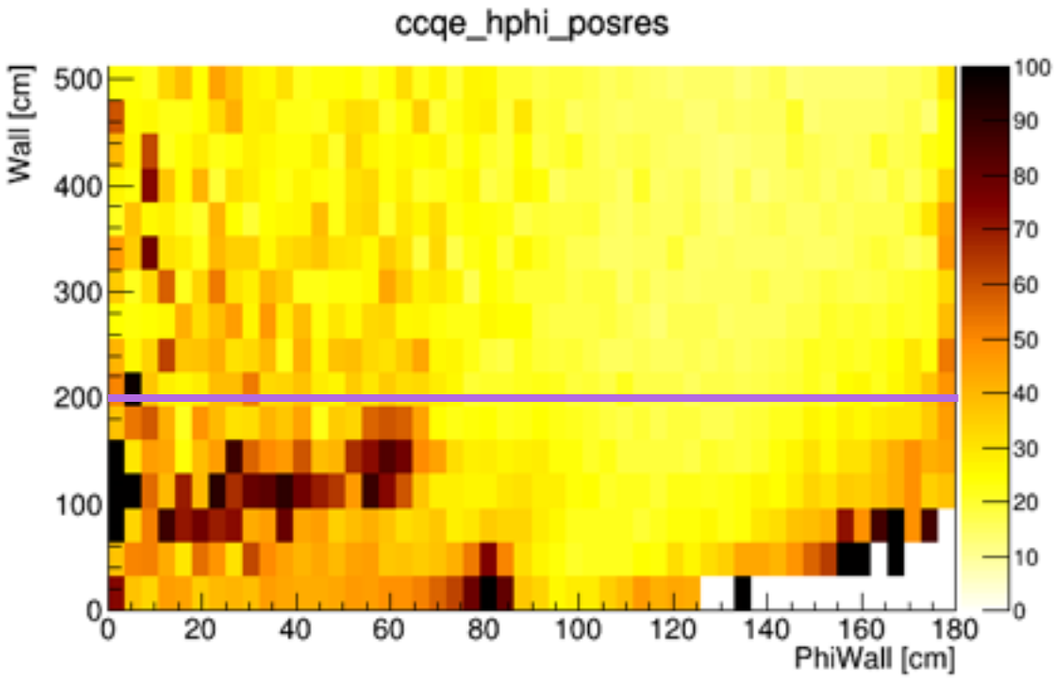
fraction with missed decay e



momentum resolution



position resolution



direction resolution