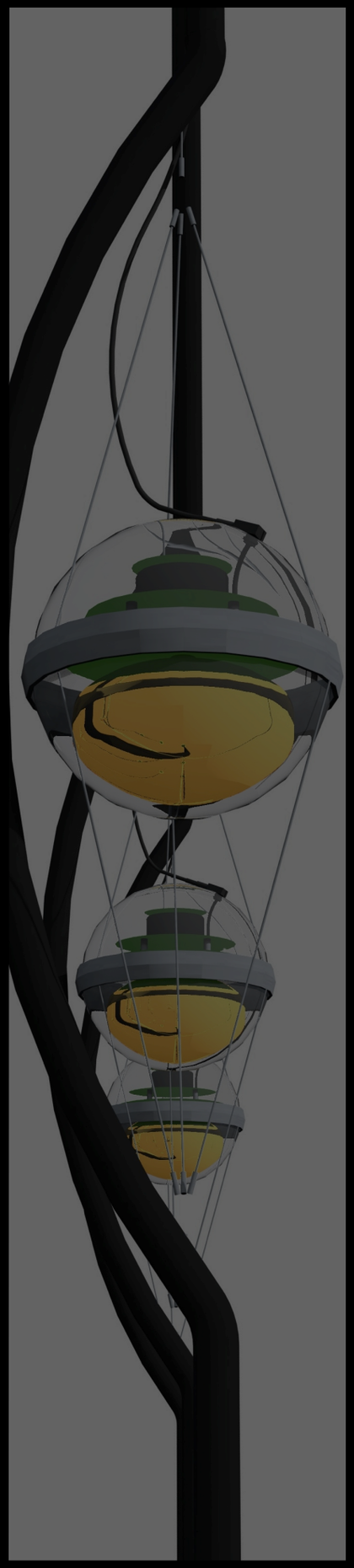


In-situ DOM efficiency with stopped Muons

UNIVERSITY OF ALBERTA

Tania Wood
/J. Feintzig/J.Garb

Motivations.. many.

An example from Atmos nu. analysis

- The Largest systematic uncertainty in the signal prediction comes from light detection efficiency in a DOM in situ (in the Antarctic ice).
- For example, varying the efficiency by 10% in the simulation changes the predicted atmos_nu rate by 11% in this analysis.
- Key is to reduce the systematic
- Challenge, transition from lab to in situ.
- If we have a source we can identify very well then we can identify that energy deposition directly for the DOM in the ice and greatly reduce this systematic.

TABLE II. Systematic uncertainties.

Source of uncertainties	atm. μ	atm. ν_μ	atm. ν_e
Ice properties	8%	6%	2%
DOM efficiency	30%	11%	10%
Cosmic-ray flux	33%	-	-
ν-nucleon cross section	-	6%	6%
Sum	45%	14%	11%

Table taken from '*Measurement of the Atmospheric ν_e flux in IceCube*,' Phys. Rev. Lett. 110 (2013) 151105

General Idea:

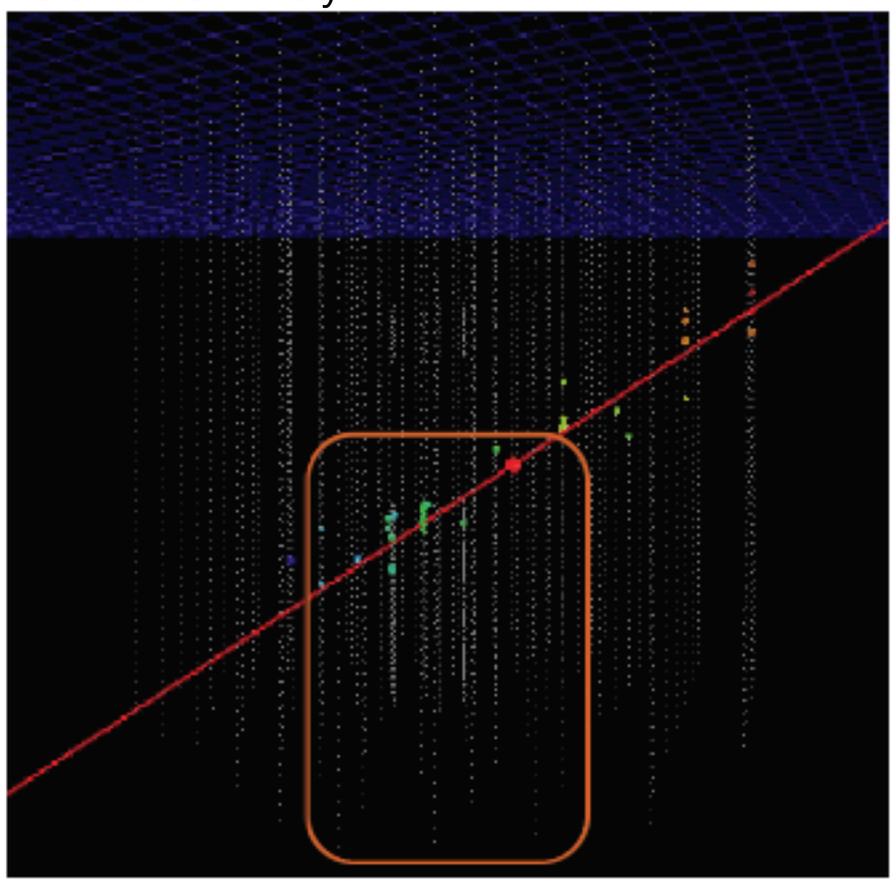
Minimum ionizing muons provide a calibration source

- Have a constant, known light emission
- Are abundant: high statistics
- Can be reconstructed to fairly high precision

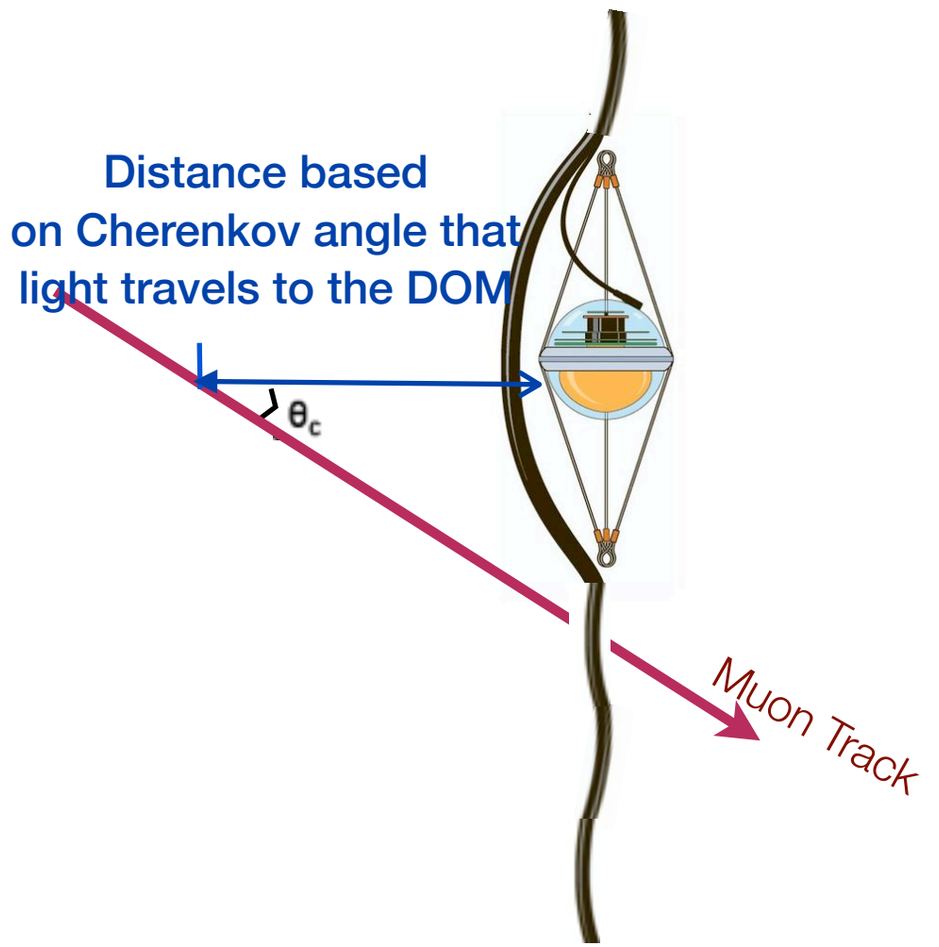
DOM efficiency is calculated using modules in the deep centre of the array

- Use only charge from DOMs in the study region
- Bin collected charge on a given DOM (PMT + DAQ m
  based on the track-to-DOM Cherenkov distance

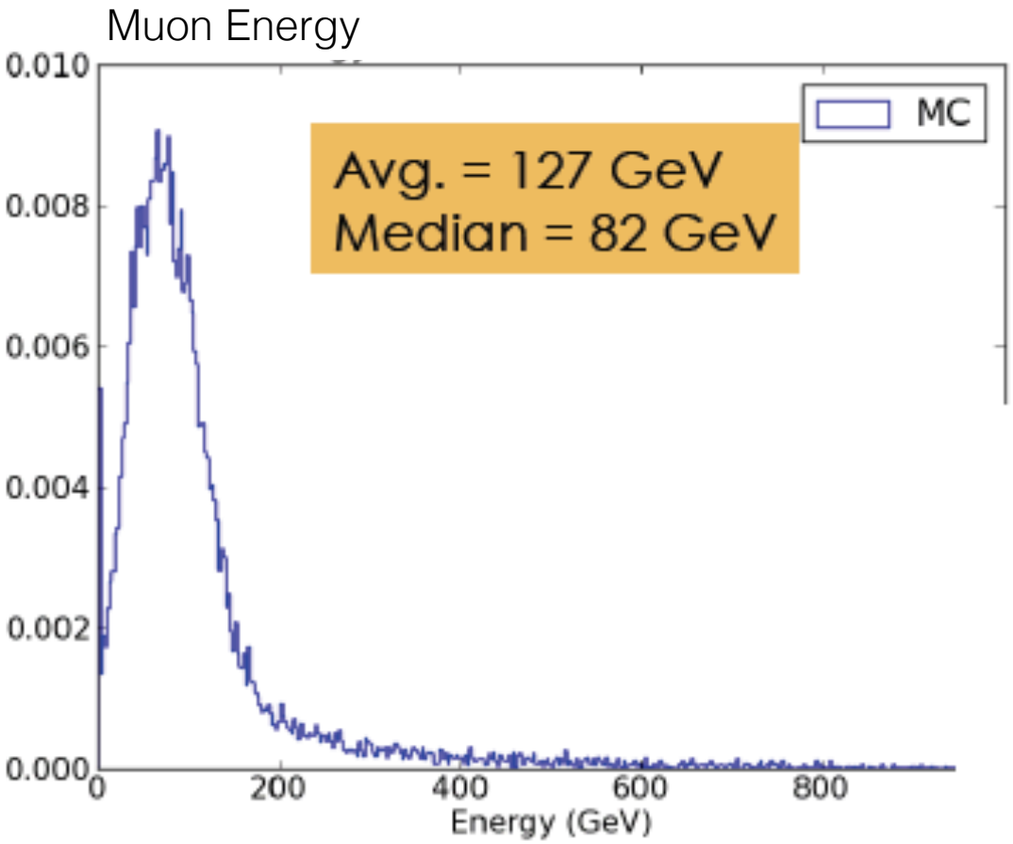
IceCube Array



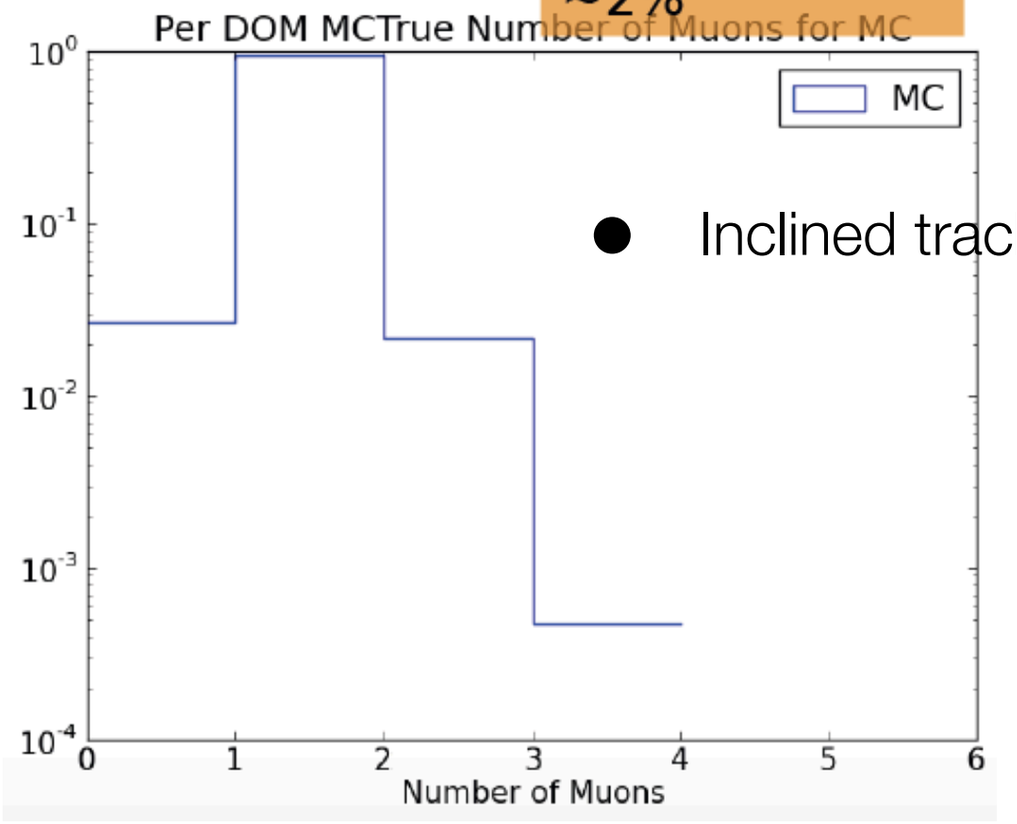
study region



Event selection isolates a sample of minimum ionizing atmospheric muons



Contribution due to muon bundles is ~2%



- Inclined tracks, zenith ~4deg

- Use well reconstructed muons,end point of track within 50m of our detector boarders, ie '***stopping tracks***'

- Systematic effects are a larger issue at lower energy where we have less event information.

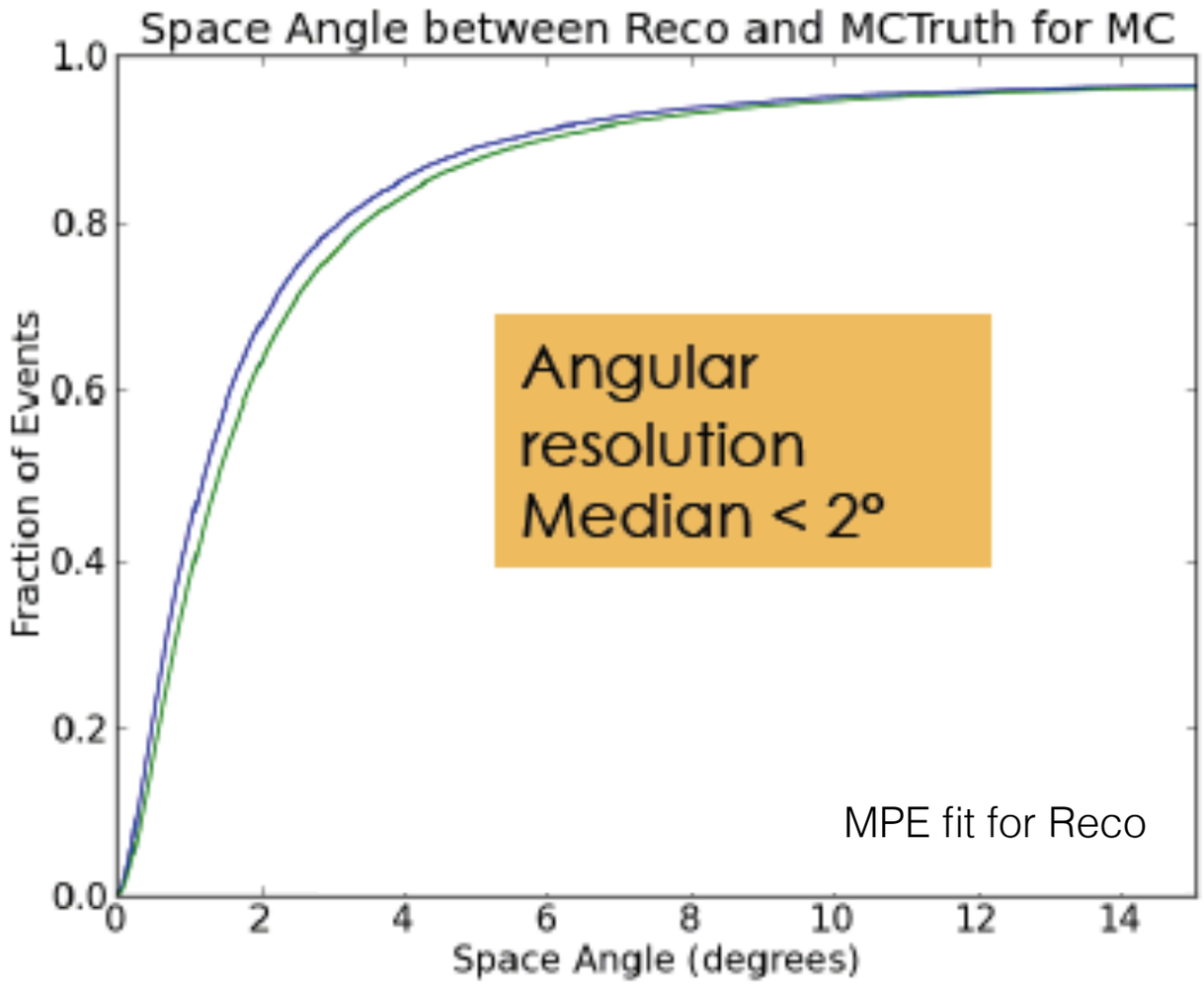
- Use as low an energy as possible a sample which can still take advantage of tools with better(~2deg) track direction resolution

Event selection isolates high-quality, minimum-ionizing, single muons

Cuts:
-SMT8
-At least 1 hit in center strings
-40 < MPEfit_zenith<70
-Rlogl<10, NumberDirectHits>5
-Nchannel >20
-Zend point > -400m
-XY-distance of reconstructed endpoint to detector border> 50m

- **Inclined tracks: zenith ~45°**
- **Well-reconstructed stopping tracks**

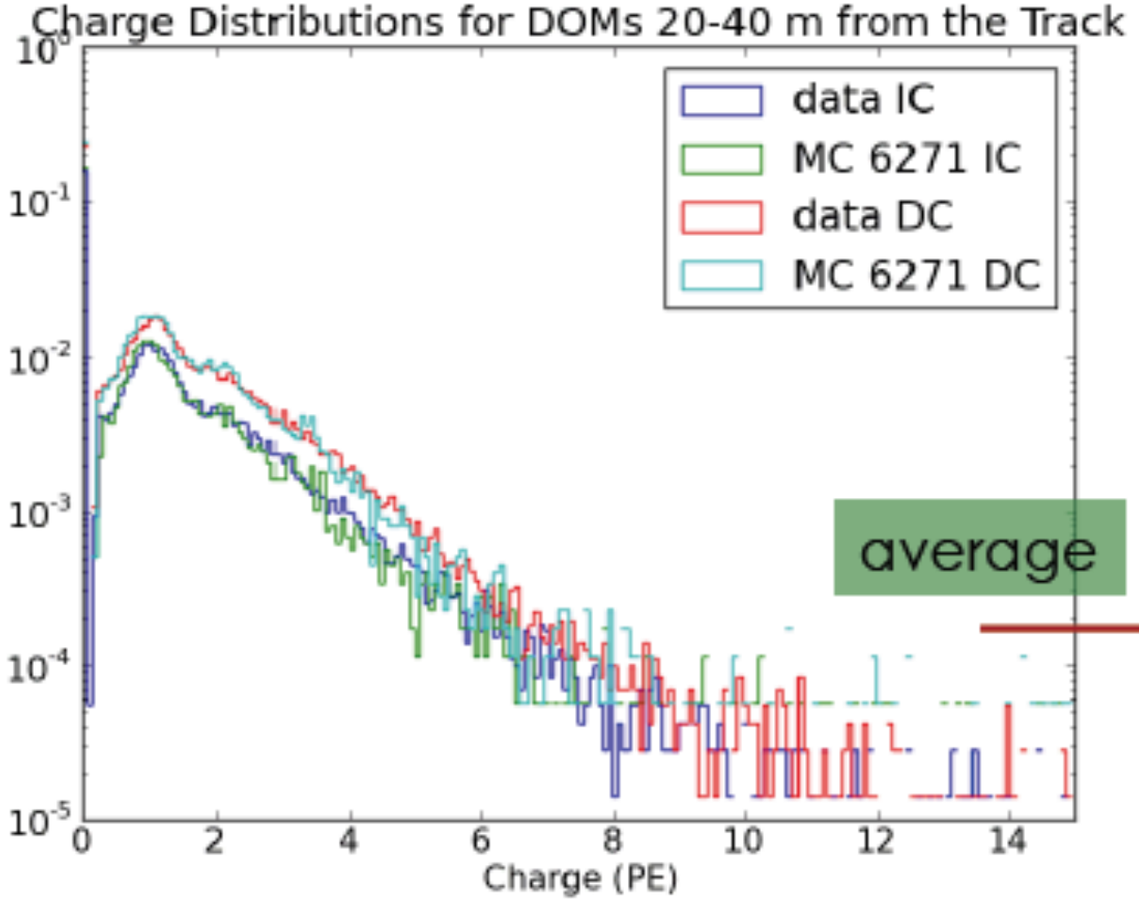
-Inclined tracks: zenith ~45 deg
- Well-reconstructed stopping tracks



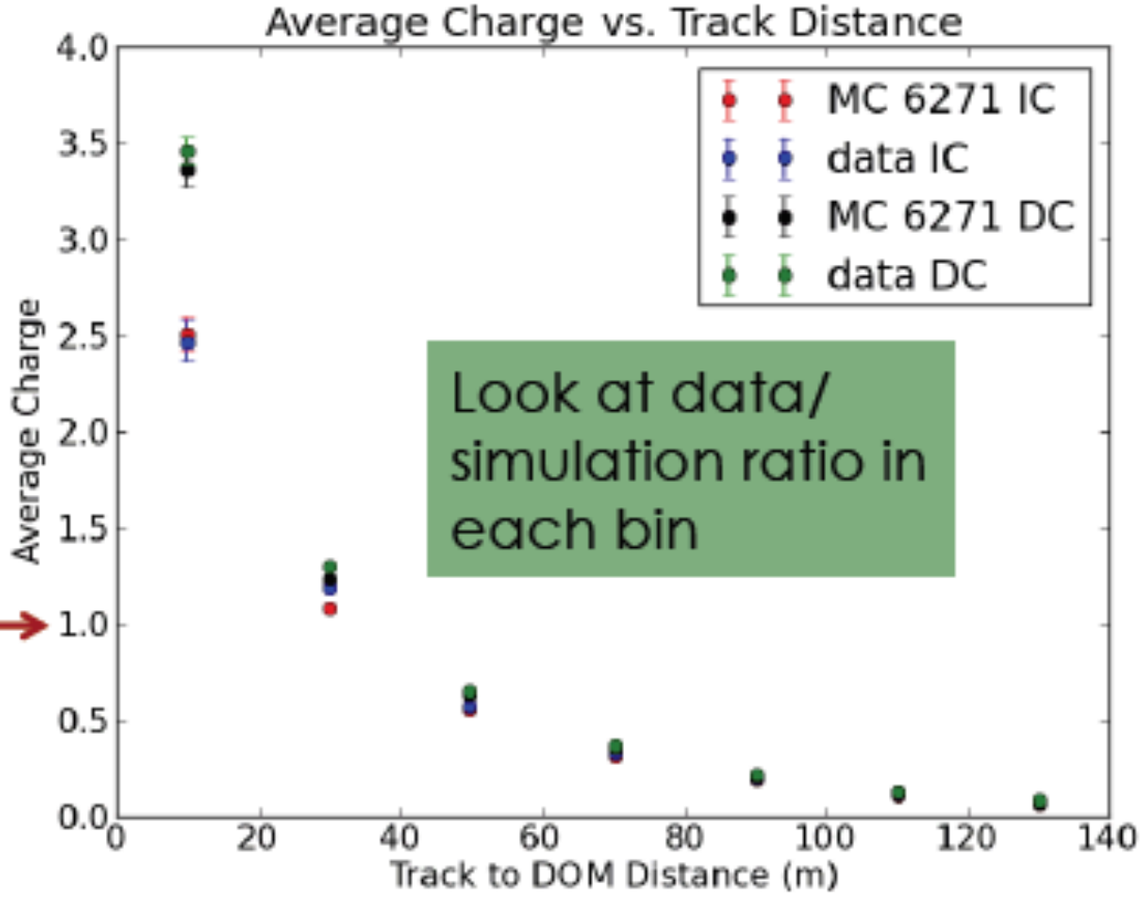
Event DOM efficiency is calculated by comparing charge in data to Monte Carlo

- Only study standard (not highQE) DOMs with specific track topology for the “IceCube” selection (did a separate selection for DeepCore.. results pending)

- Bin collected charge on a given DOM based on the track-to-DOM Cherenkov distance
-Average charge in each distance bin



average

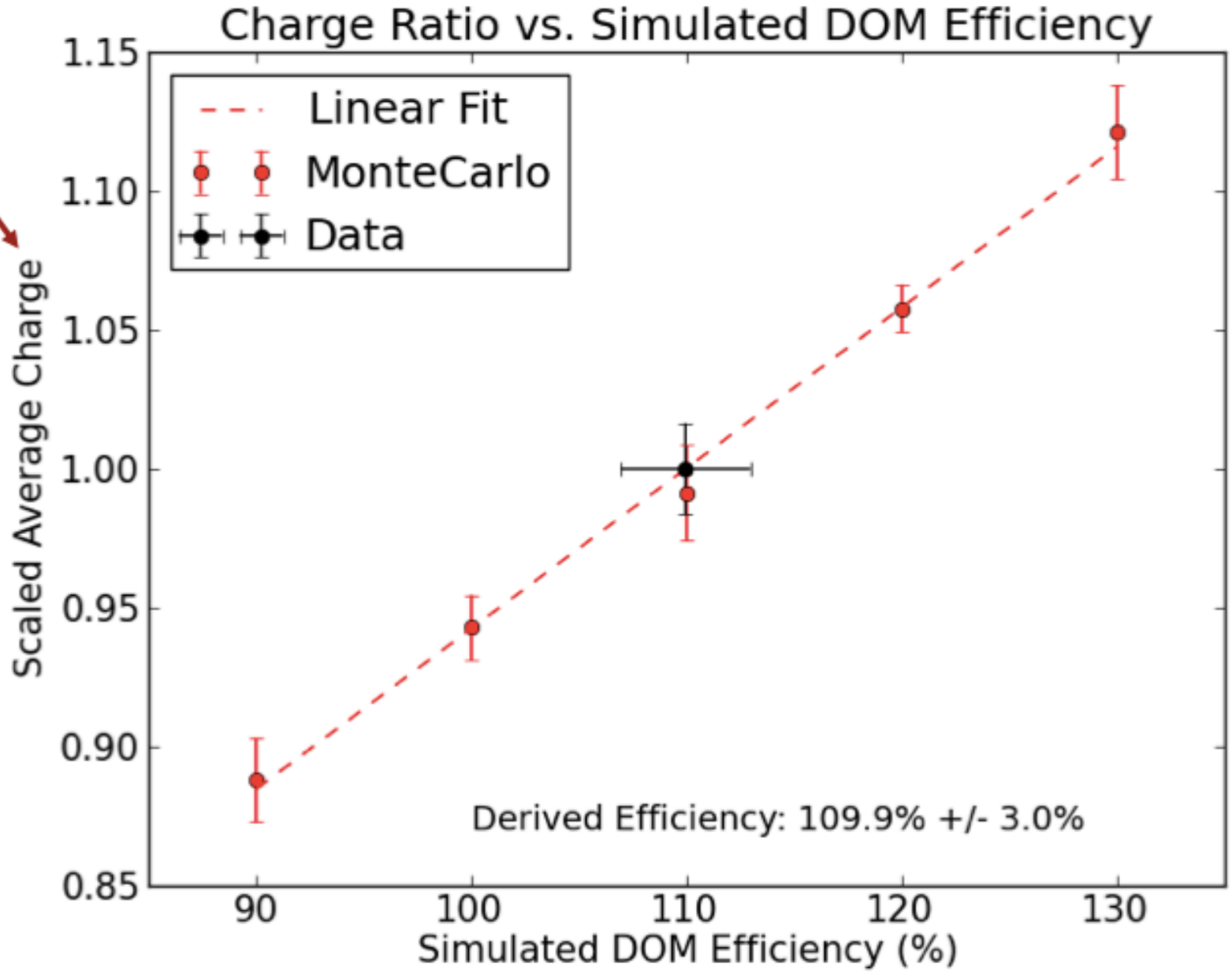


Reminder: deriving the DOM module efficiency with muons and the unknown bias

Average charge of 20-80 m bins

- Analysis response is linear over DOM efficiencies of 90% to 130%
- Derived efficiency is 109.9%
- 3% uncertainty includes statistics and systematics

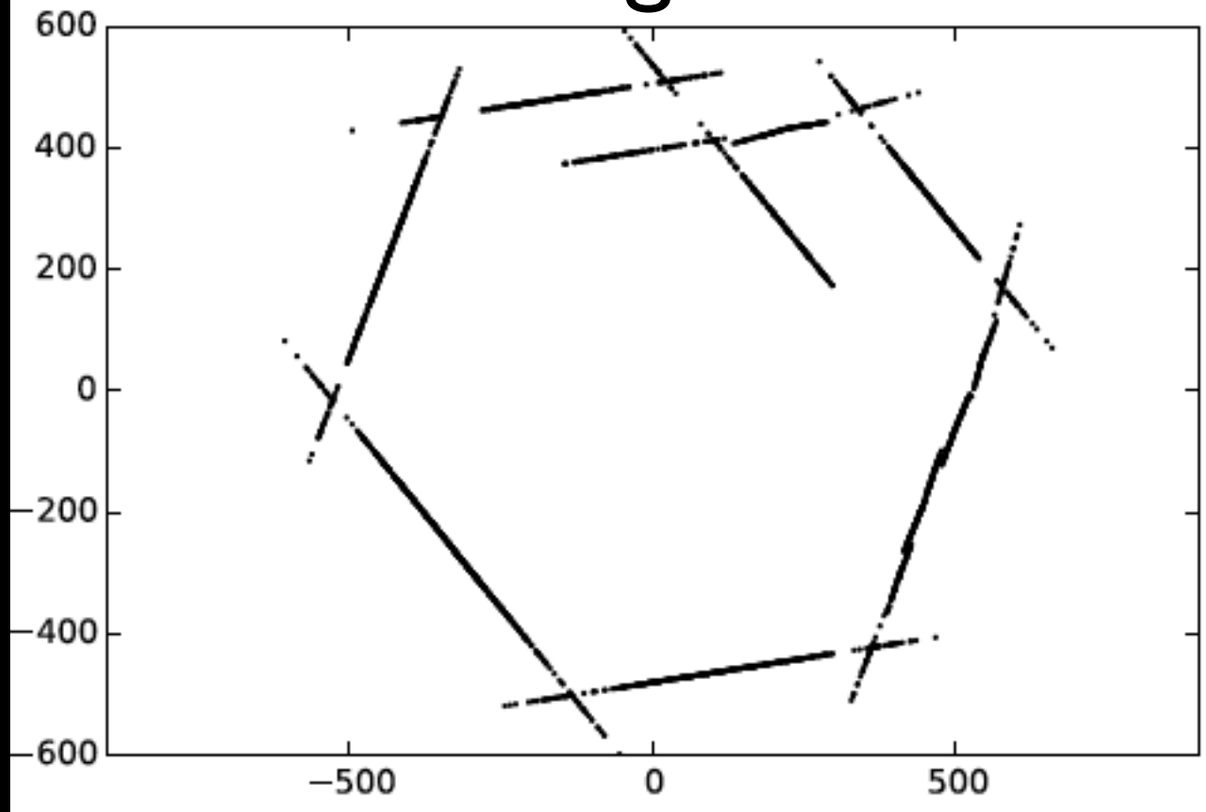
Figure courtesy of J. Feintzig



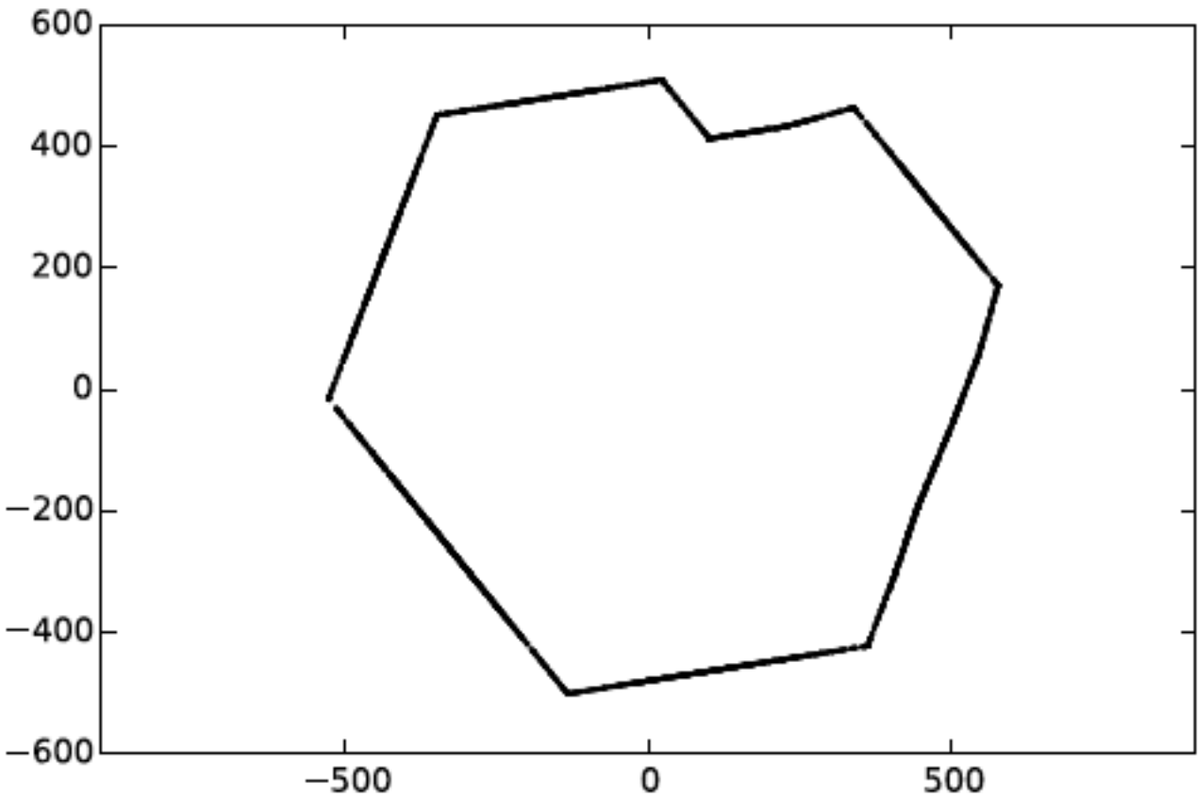
Chasing the bias...

- The selection cuts were re-evaluated following the software re-write and a difference in the geometry selection implemented (distance to border xy cut).

Original



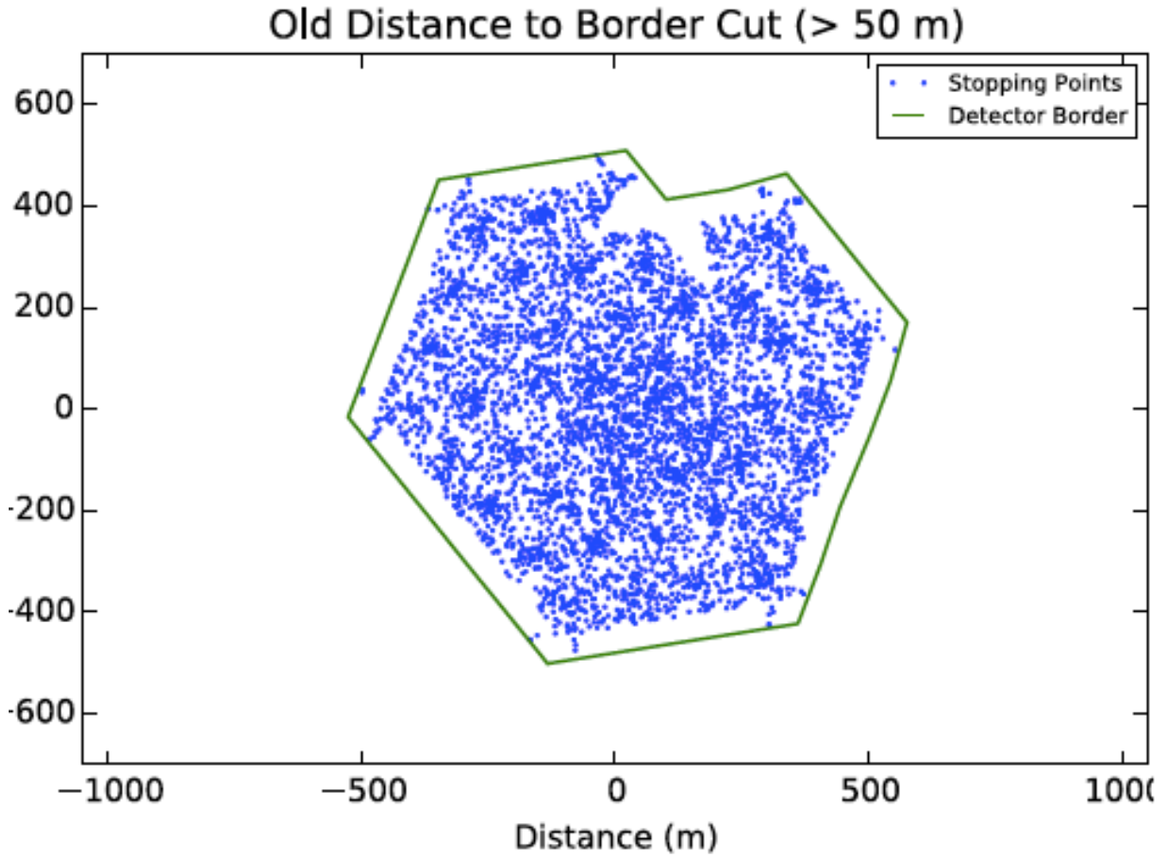
New

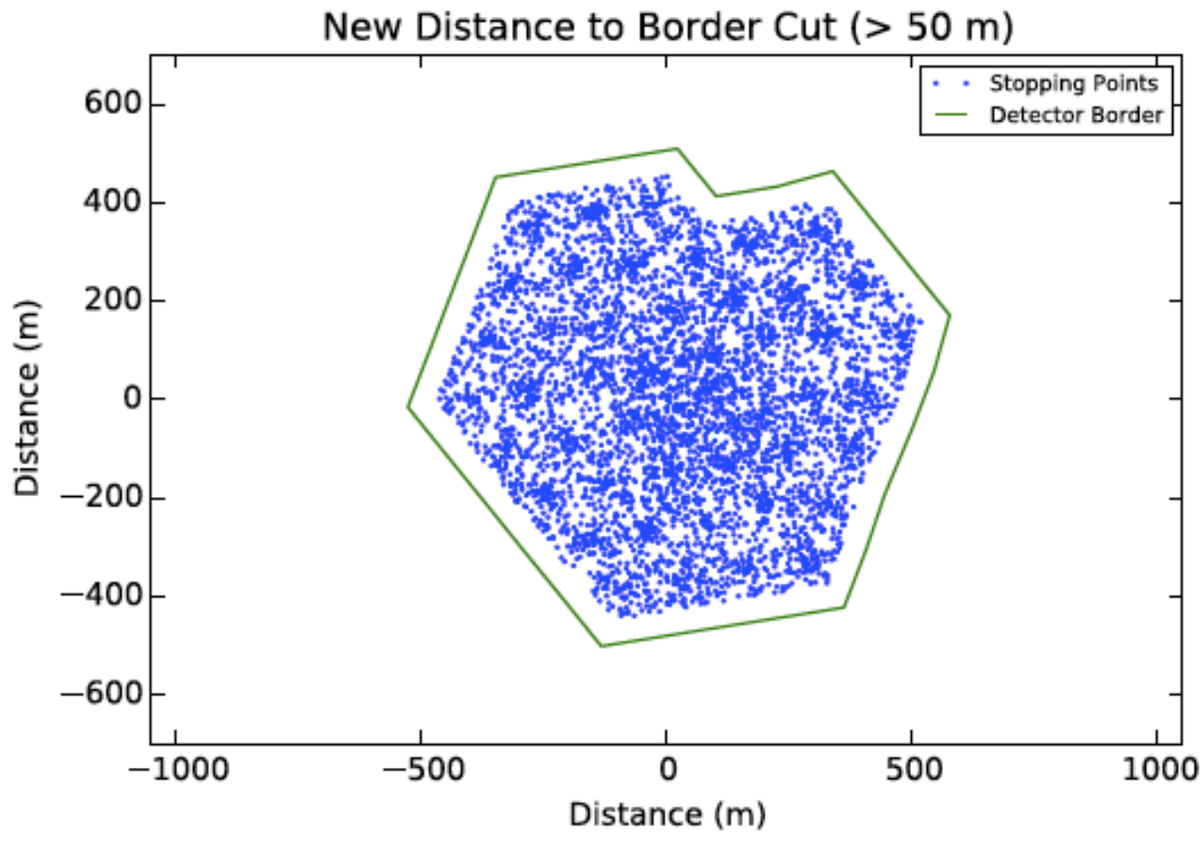


... which provides a difference in the survival probability

Chasing the bias...

- The selection cuts were re-evaluated following the software re-write and a difference in the geometry selection implemented (distance to border xy cut).

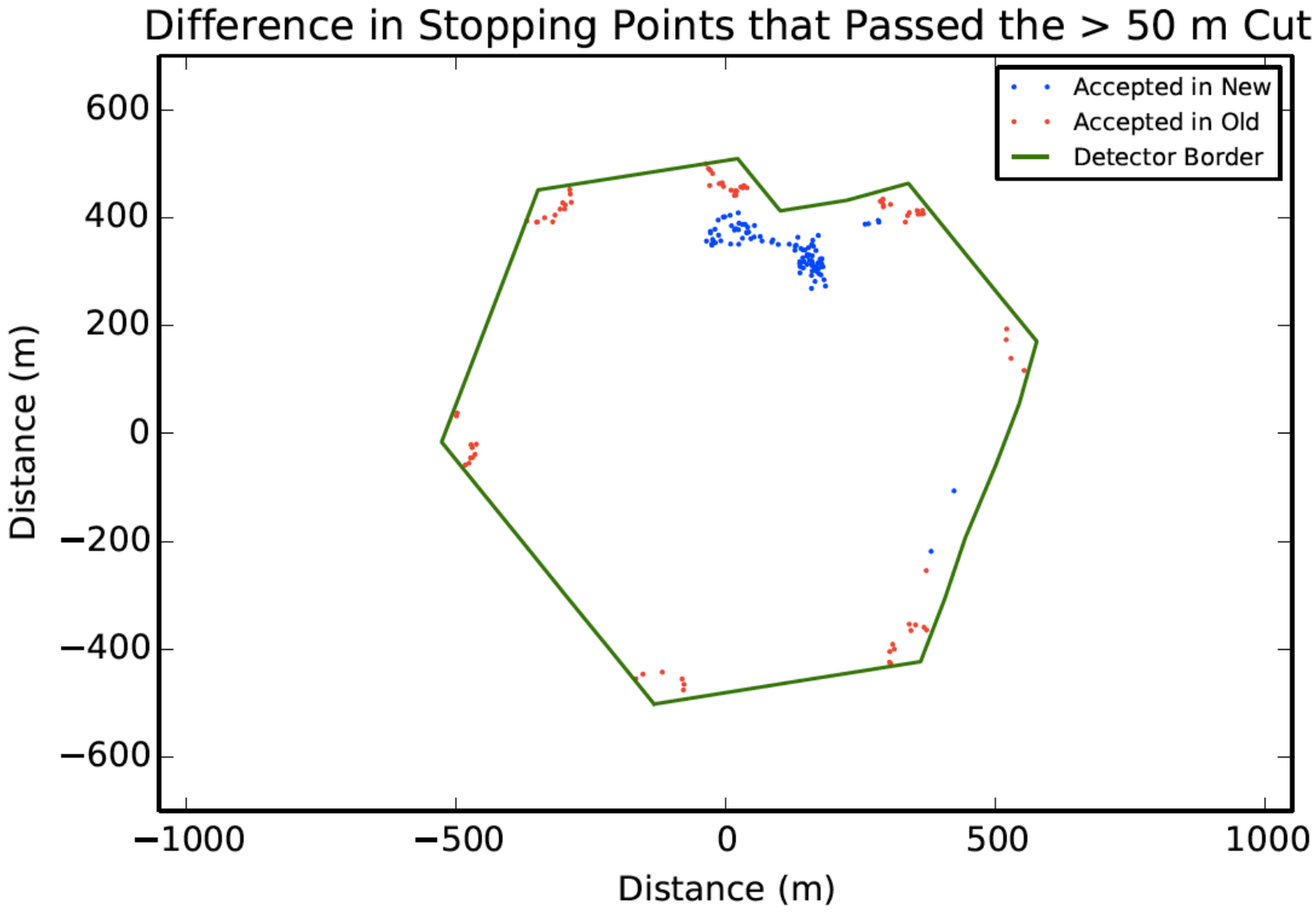




... which provides a difference in the survival probability

Chasing the bias...

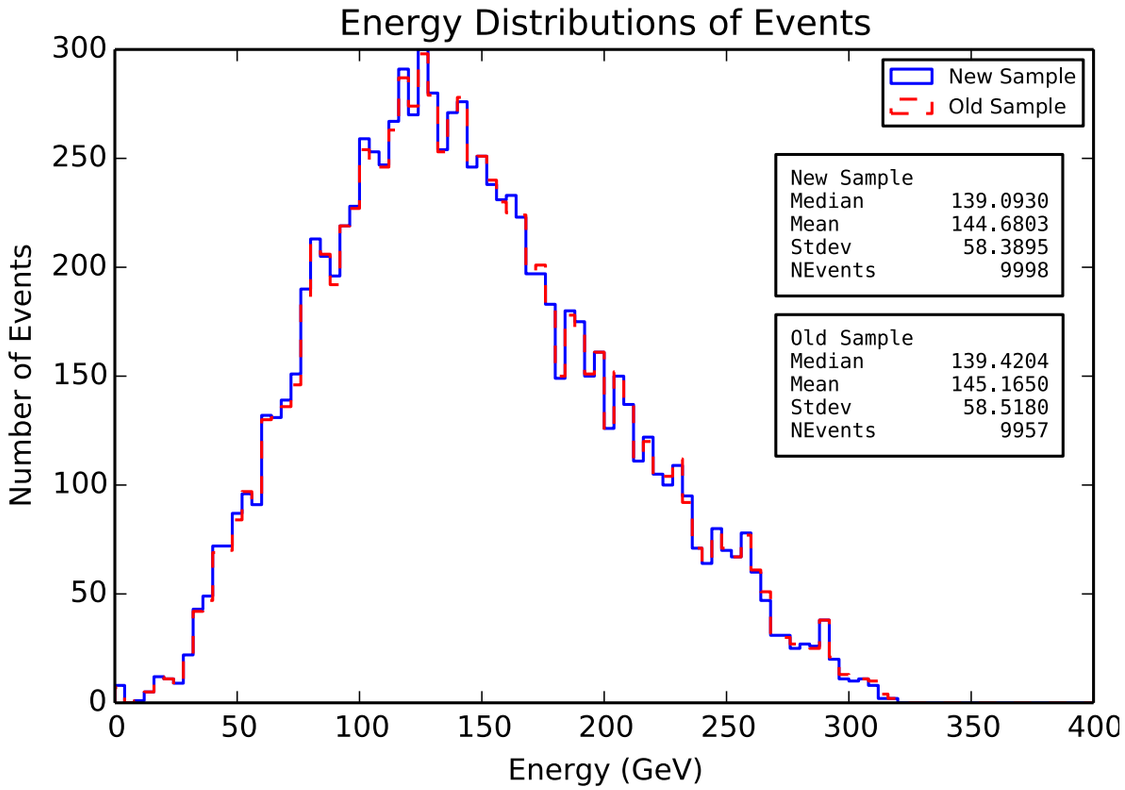
- The selection cuts were re-evaluated following the software re-write and a difference in the geometry selection implemented (distance to border xy cut).

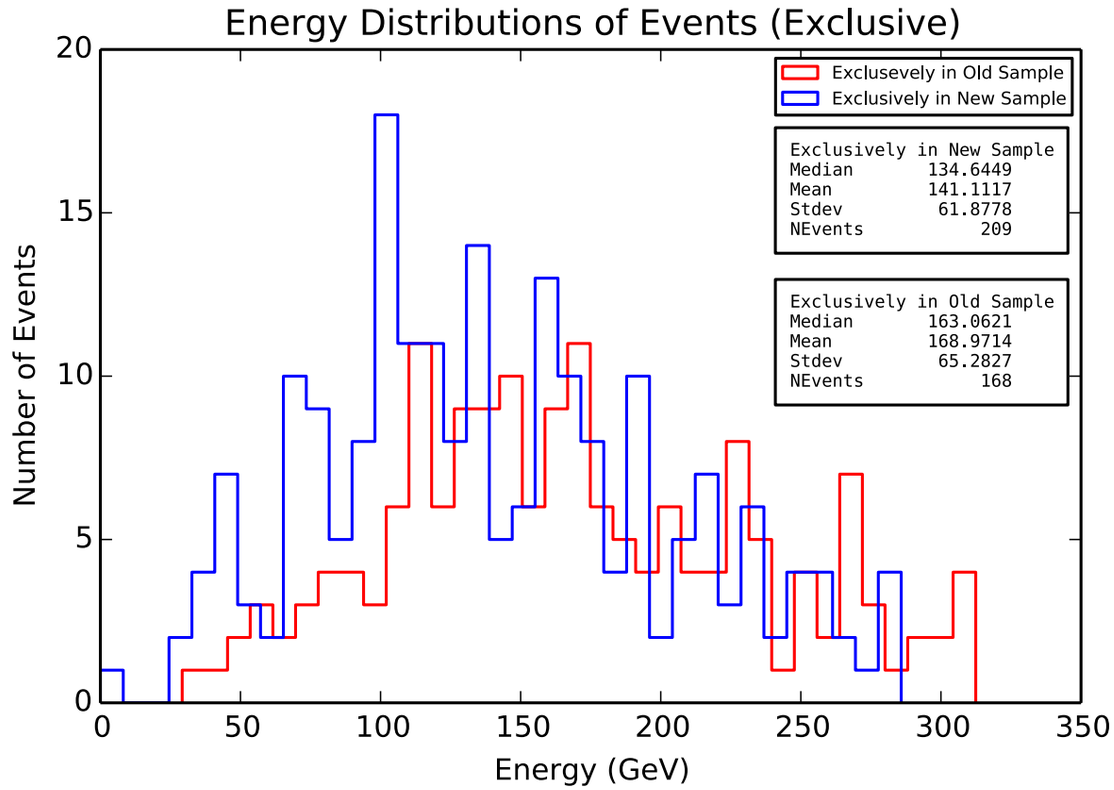


... which provides a difference in the survival probability

Chasing the bias...

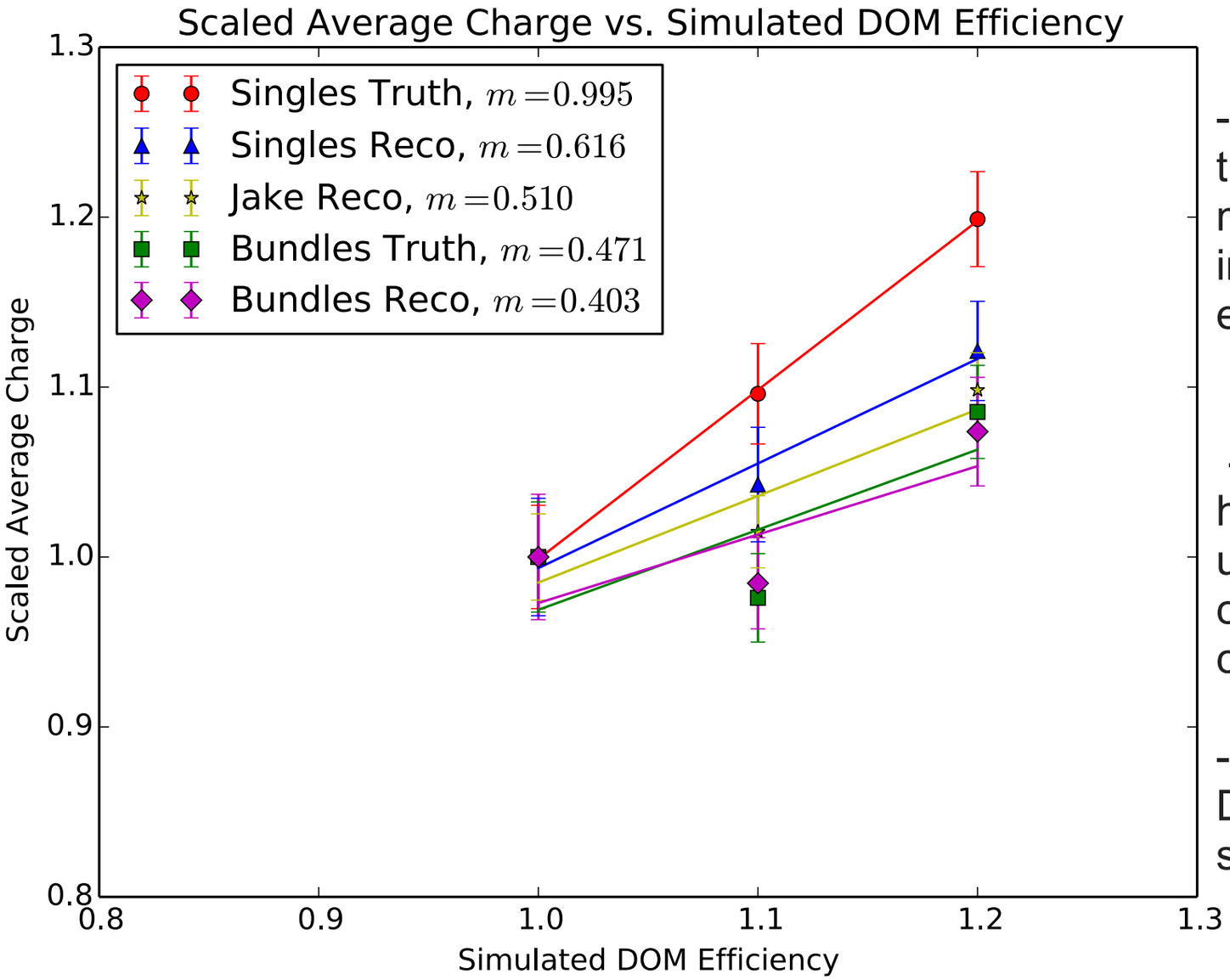
- The selection cuts were re-evaluated following the software re-write and a difference in the geometry selection implemented (distance to border xy cut).





- ran on 20 files of 8316 (120% Dom Eff systematic set)
- events in new sample that were not in old and vis vera is ~2% of the events ... but have an ~20GeV difference of mean energy..
- this turns out to be not much difference to event distribution overall
- may make a difference given we only use certain bins of distance
- checking the effect on the average charge as a function of DOM distance

Chasing the bias... a possible source - reconstruction and muon multiplicity



-The singles-truth (best case scenario) returns the response we all have anticipated for the muon efficiency study, ie. slope near 1 for the increased average charge with increased DOM efficiency.

-It appears the cause of the persistent bias has been identified (a combination of the uncertainty from the reconstruction and contamination of the singles sample); comments are welcome.

-Note there is still an issue with DeepCore DOMs - they do not return the same value for single-truth and we need to understand this.

Legend

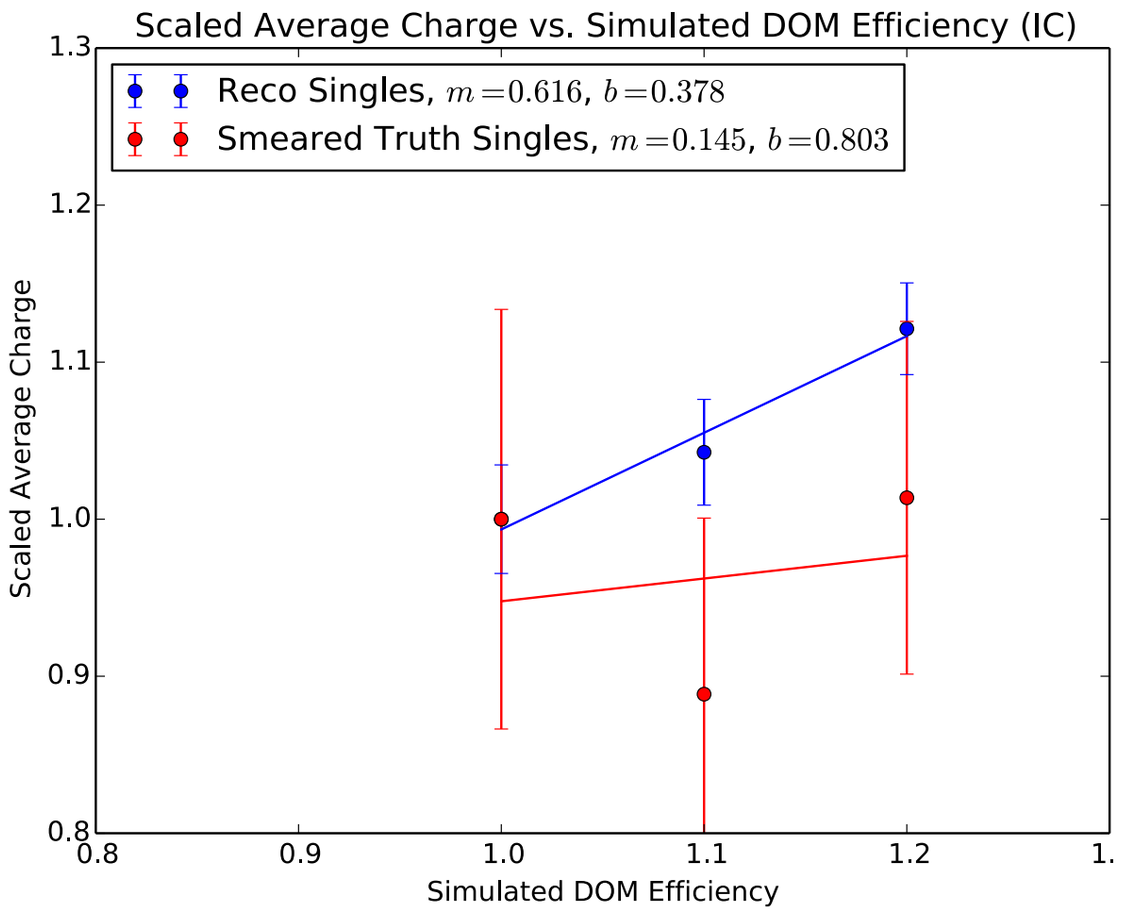
Singles-truth: single muon events using the true track information

Singles-reco: single muon events using reconstructed track information

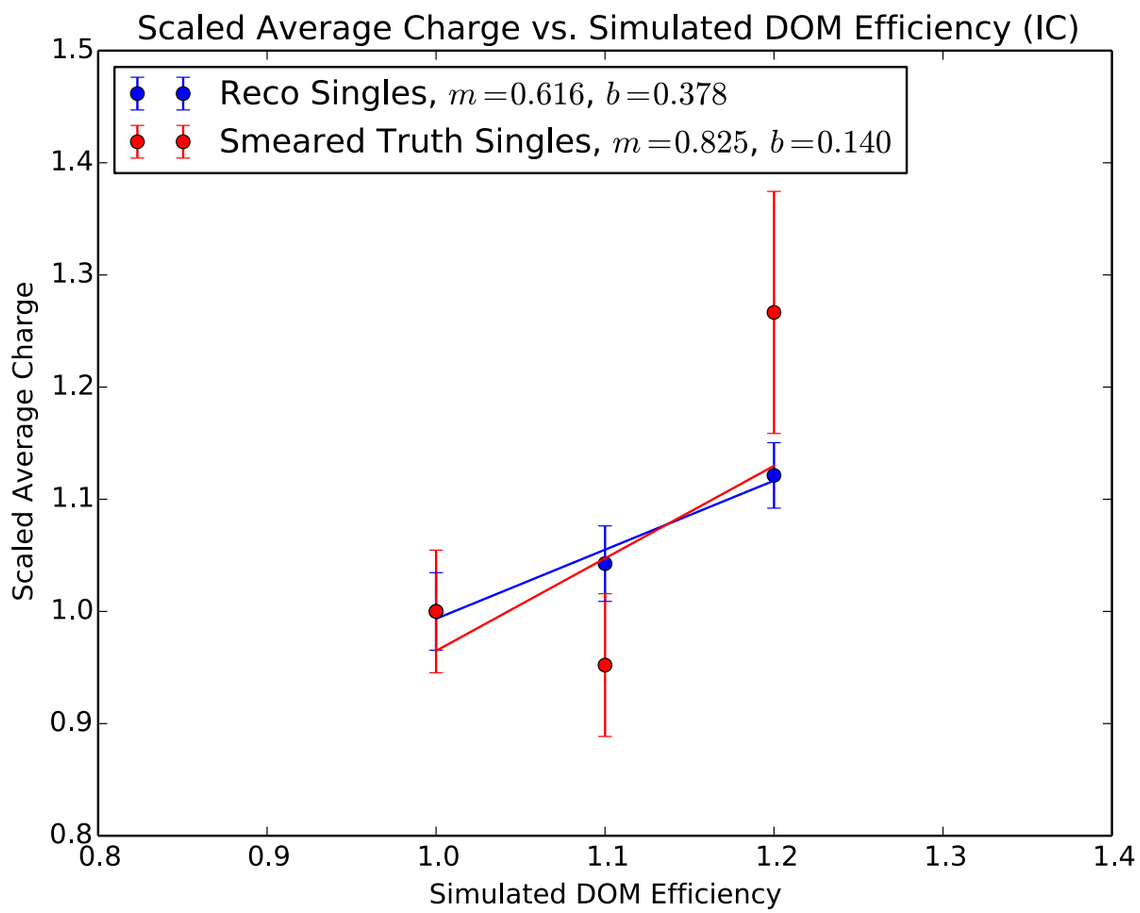
Jake-reco: Jake's event selection which provides a combination of singles and some multiple muon events using reconstructed track information bundles-truth: non-single muon events using true track information

Chasing the bias... a possible source - reconstruction and muon multiplicity

-Chris Wendt “If this is uncertainty from the reconstruction we would expect if one just smeared the "truth" quantities by some typical uncertainties and then reimplemented the cuts, you would see the same thing as in the "singles-reco" plot? “



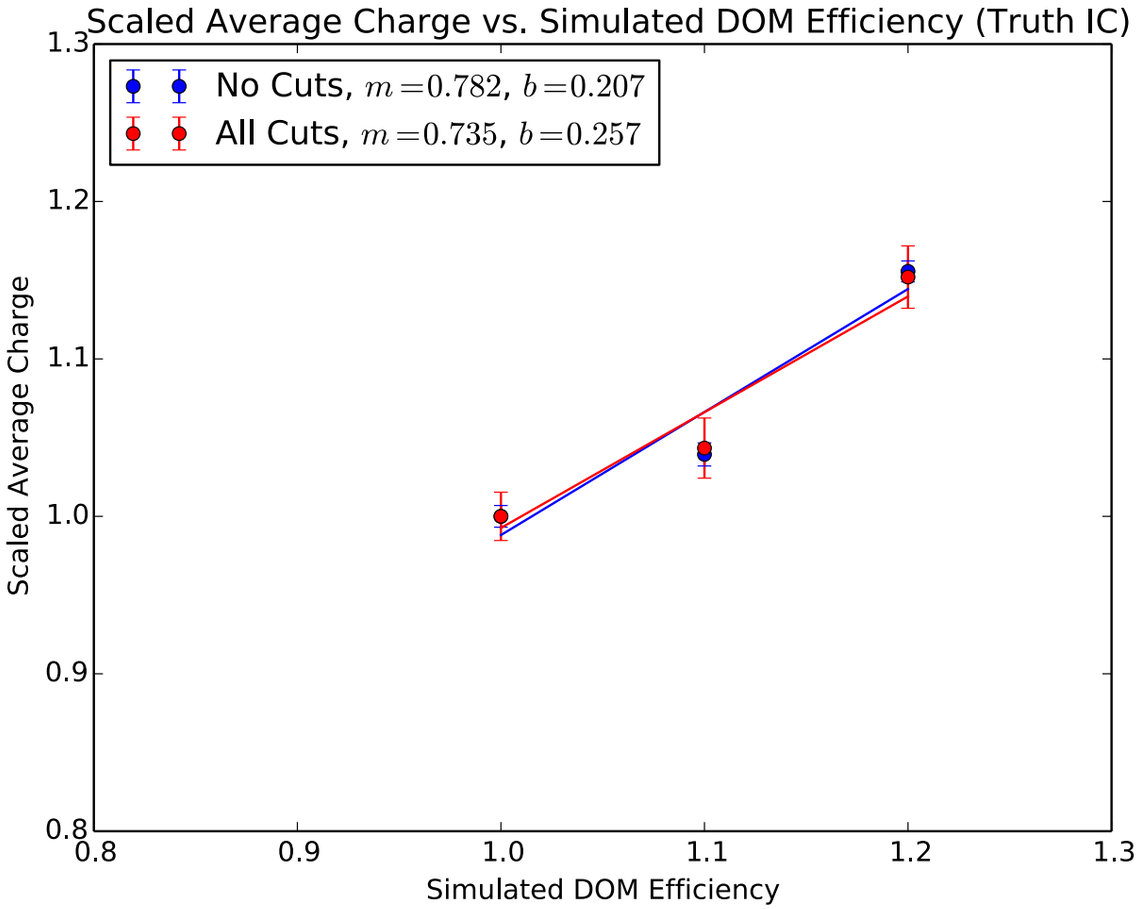
50 m smearing for x, y, z, azimuth, zenith and length (which is how we calculate endpoint)

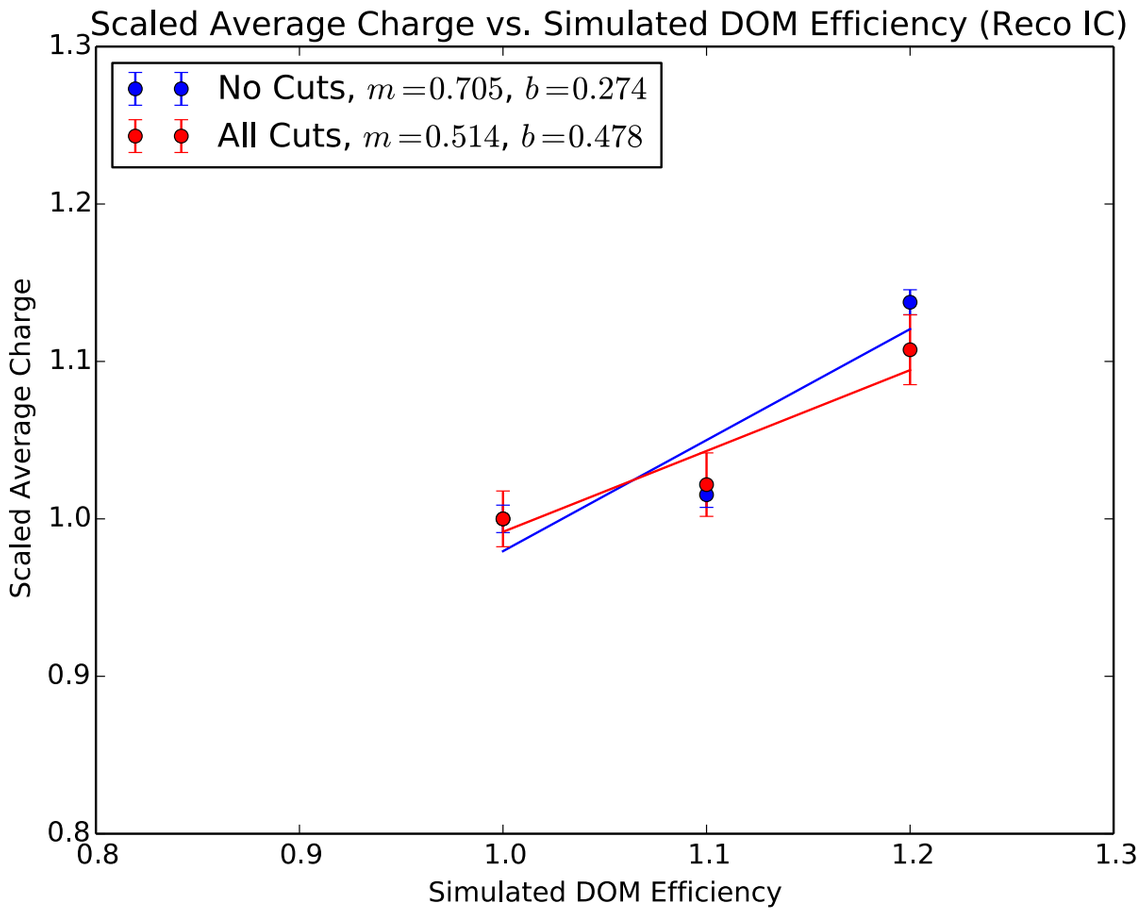


25 m smearing for x, y, z, azimuth, zenith and length (which is how we calculate endpoint)

Chasing the bias... a possible source - reconstruction and muon multiplicity

- it doesn't appear to be a cause of the cuts...

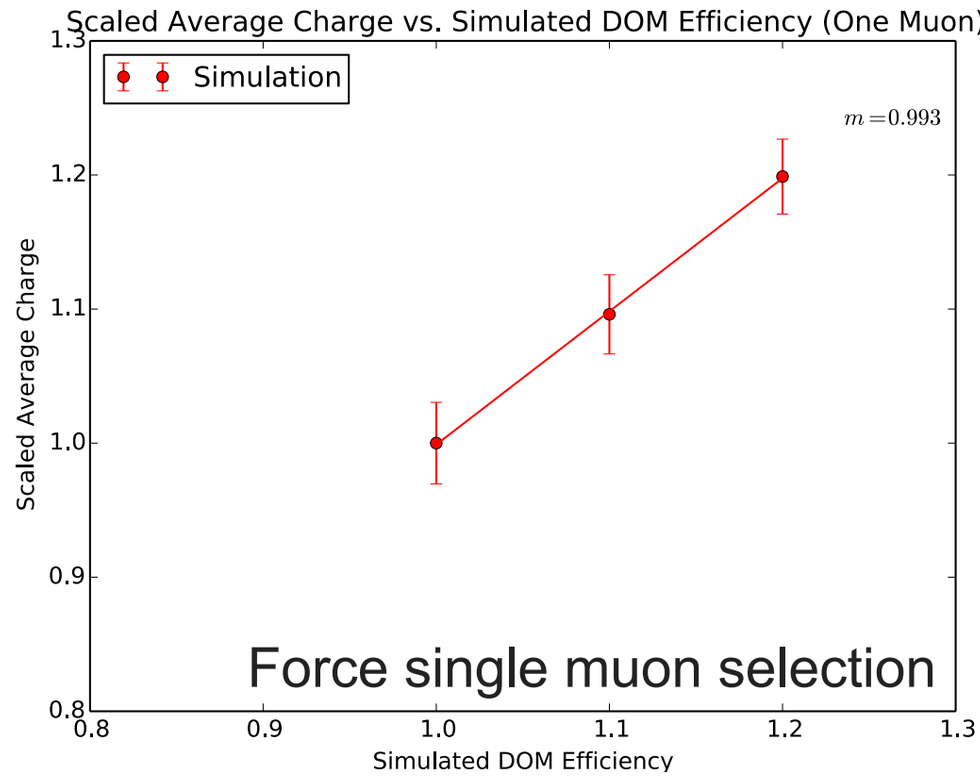


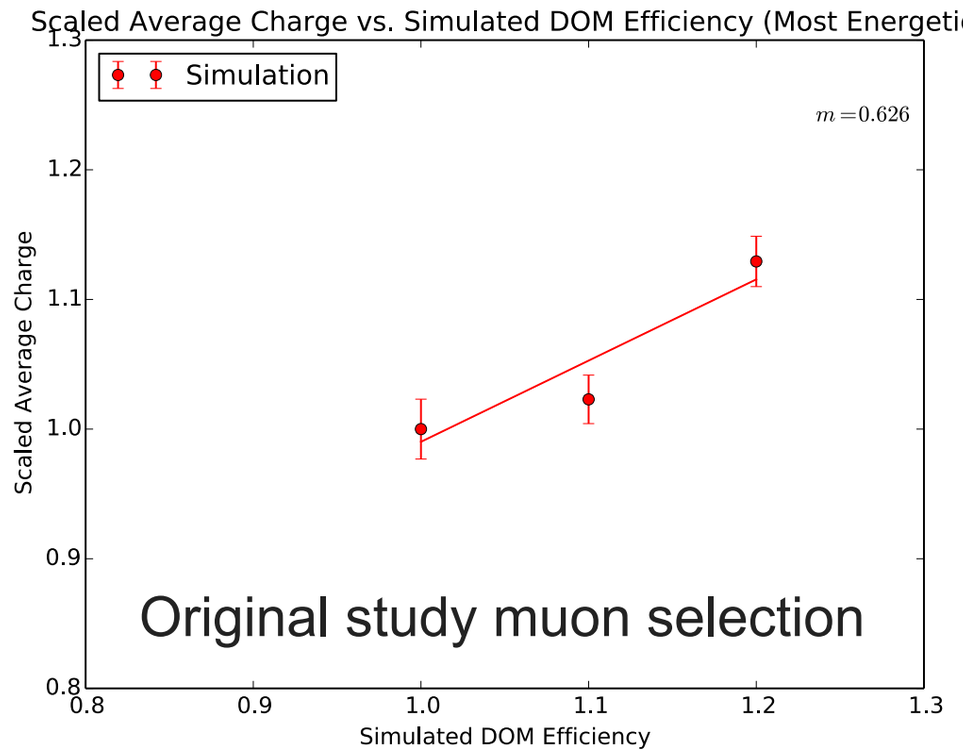


Chasing the bias... a possible source - reconstruction and muon multiplicity

- possibly related to the choice of muon...

- Hypothesis is that the bias is some combination of using reconstructed information AND the assumption that we indeed have single muons is incorrect.. perhaps even if a second muon is not near the DOM, light may reach the DOM and biases the sample.





No reconstructions in these plots (Using MC_truth)

Completing this study...

- Finished the truth smearing study

- Double check the difference in multiplicity reported by the original study vs. this study

- Finish other sanity checks requested

- Execute the method for DeepCore DOMs to extract the in situ efficiency --

See below for code and further details
https://wiki.icecube.wisc.edu/index.php/User:Trwood (contains link to github working version of this code and the static releases in svn (http://code.icecube.wisc.edu/svn/sandbox/trwood/DOM_EFF_MUONS/)

Production Status:
New DOM Efficiency CORSKIA sets

- After various errors and false starts, we have NEW(!! No known bugs ;)) CORSIKA-in-ice, finished during the meeting.

- Metaproject: icerec releases.IC2011-L2_V12-08-00_IceSim4compat_V4
  Metaproject simulation releases: V04-01-11

- This simulation release includes the the new DOMLauncher release and does **not** have the 'DOMLauncher run with DOMSimulator baseline' Bug.

- Benedikt is ran 90%, 100%, 110%, 120% and a small amount of 130% DOM Efficiency sets with this configuration. (**Level2 IC86.2011 CORSIKA-in-ice 5-component model with weighted spectrum of E^-2.6, DOMeff 0.99, using SPICELea ClSim. Angular range of 0deg < theta < 89.99deg and energy range of 600GeV < Eprim < 1e5GeV.)**

- The sets can be found at http://internal.icecube.wisc.edu/simulation/dataset/11690 , 11689, 11691, 11692 11693.

Completing this study...

Execute the method for DeepCore DOMs to extract the in situ efficiency

Update:

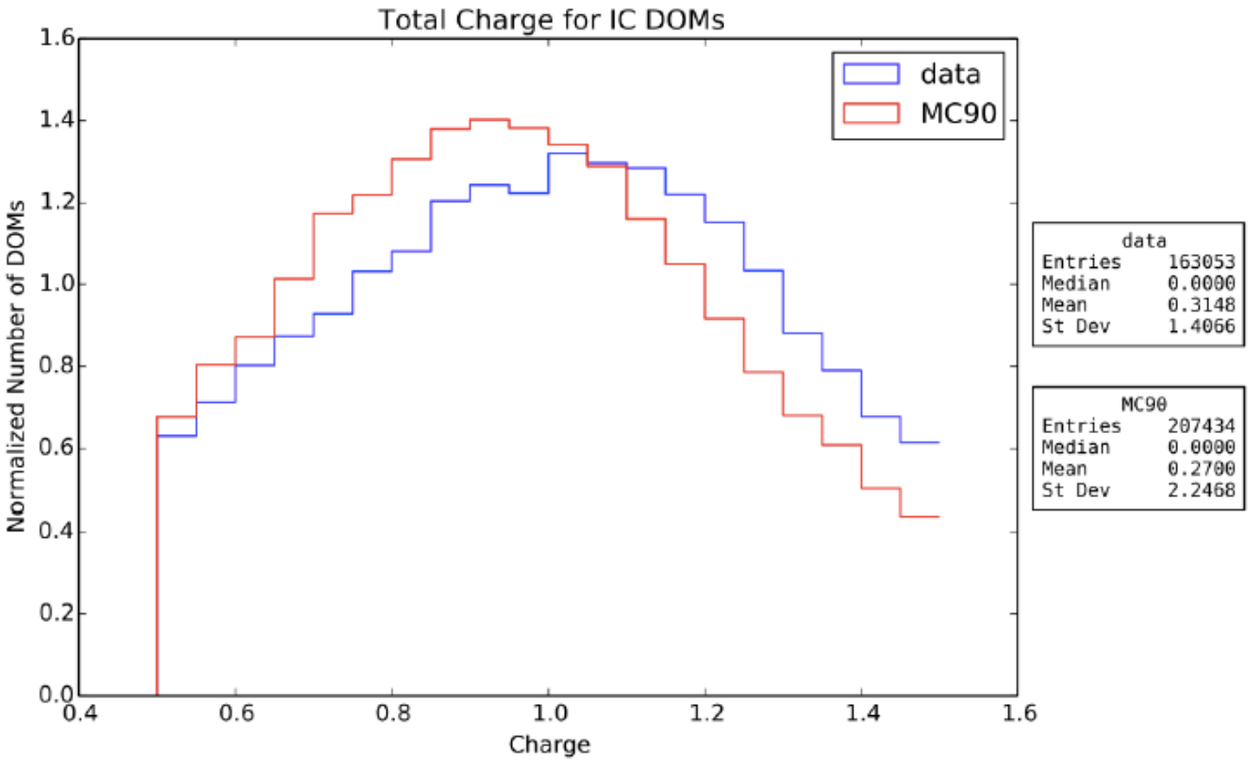
-Found DeepCore had approximately twice the resolution for azimuth and zenith .. tried half the smearing to test this.

- Found that we are now suffering from limited statistics, due to the much reduced detector volume, now that we are only considering DeepCore.
    - Had to put this on hold to have more statistics produced (more CORSIKA). Benedict finished simulating this and I am currently processing it.

See below for code and further details
https://wiki.icecube.wisc.edu/index.php/User:Trwood (contains link to github working version of this code and the static releases in svn (http://code.icecube.wisc.edu/svn/sandbox/trwood/DOM_EFF_MUONS/)

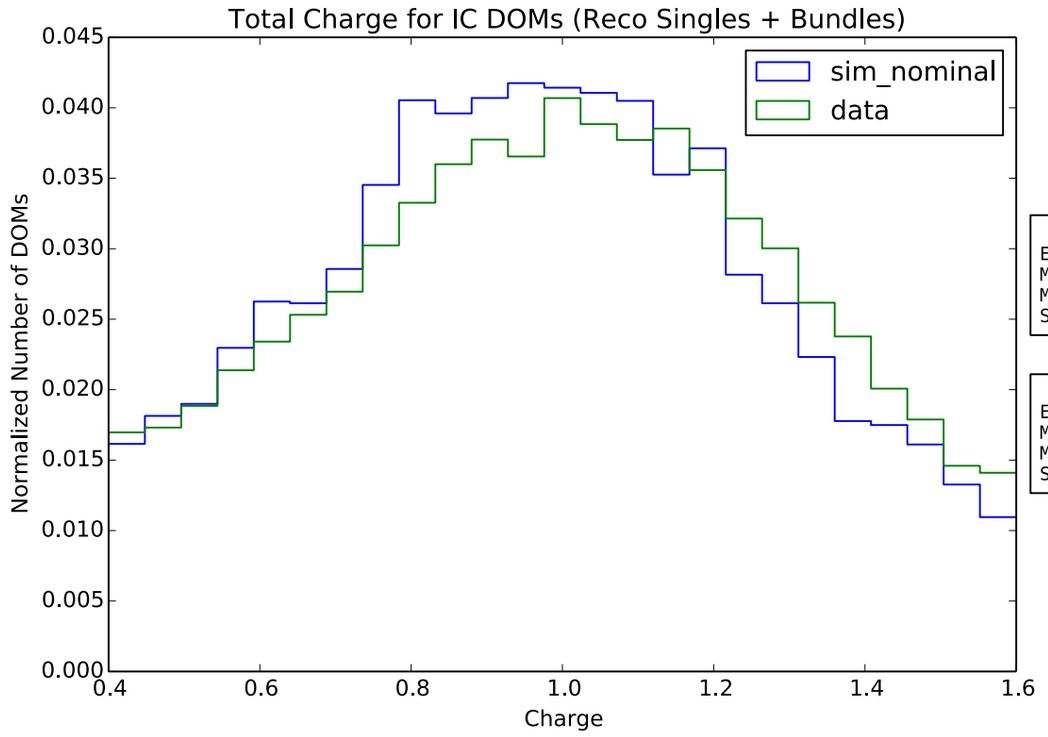
ICESIM 4

Charge distributions: data/sim



Underlying charge distributions look different in data and simulation

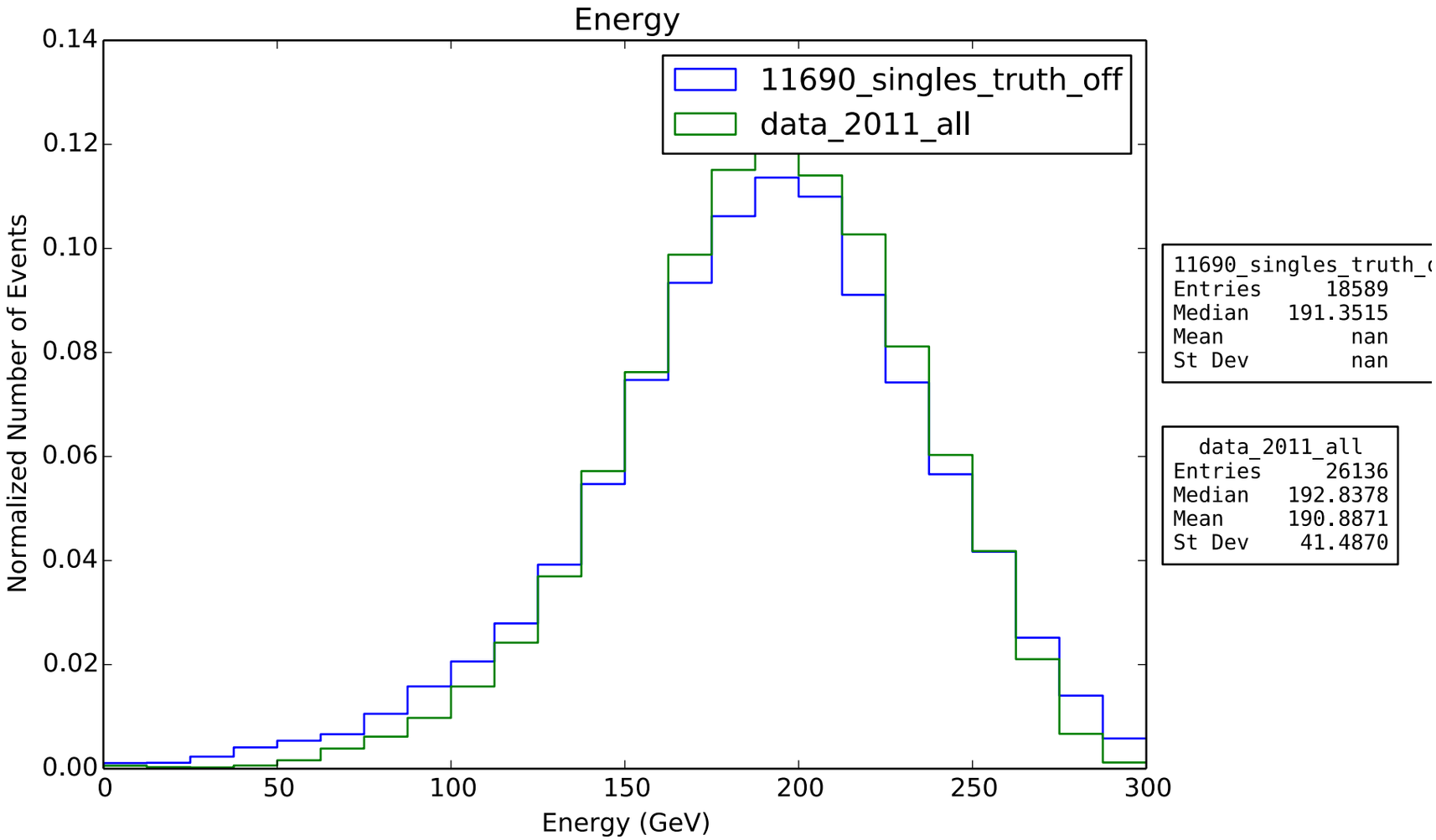
V4 with DomLauncher template mismatch



V4 with DomLauncher corrected

(all know bugs corrected,thanks for simulating it Benedikt!)

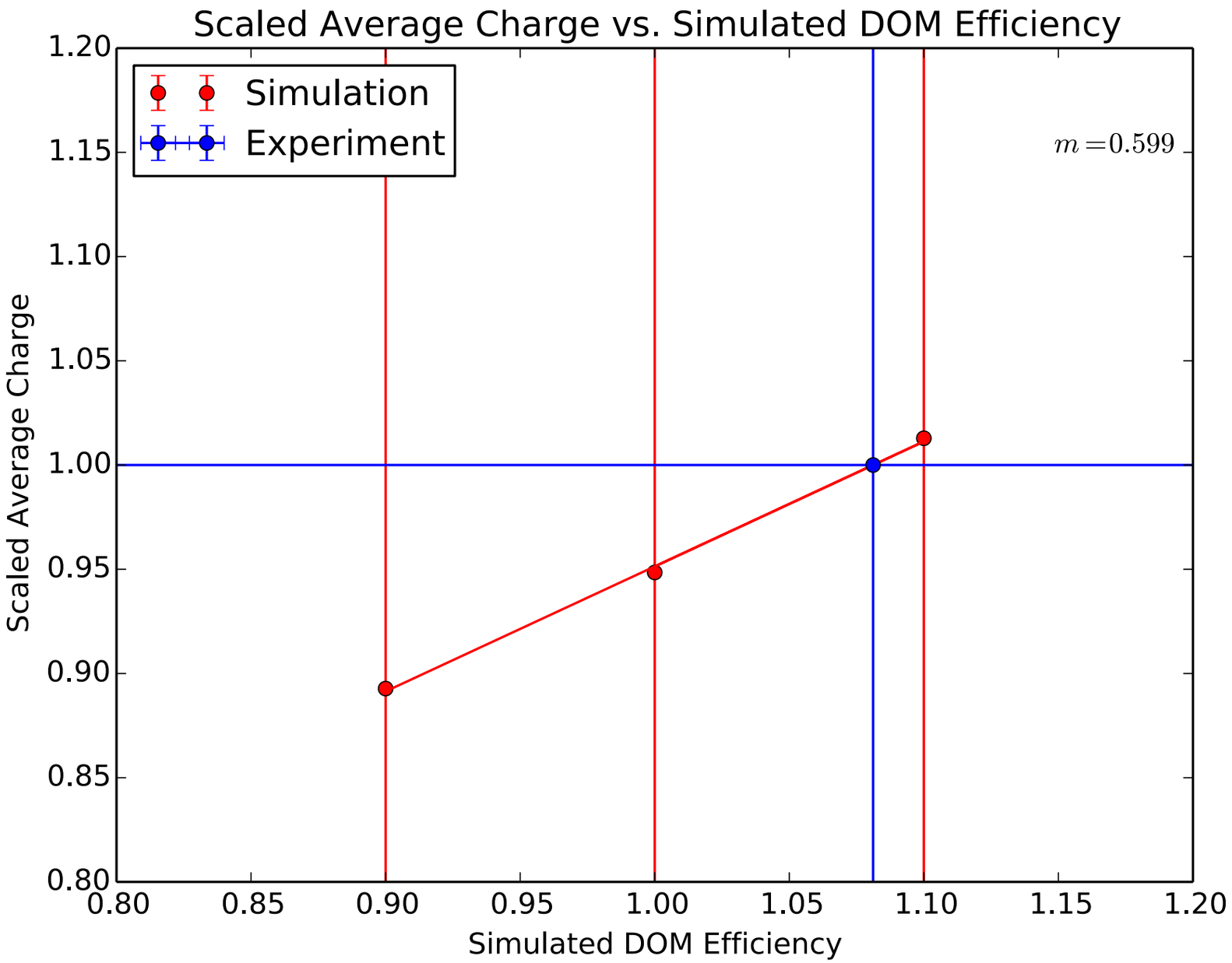
Early Results with ClSim, clean v4



-Here sample is E-2.6, currently redoing with Giasser3a spectrum (reweighting)

-Sample has higher mean energy than previous study ....

Early Results with ClSim, clean v4 (SPICE Lea)



-Previous iteration of this study was with photonics and then scaled to ppc

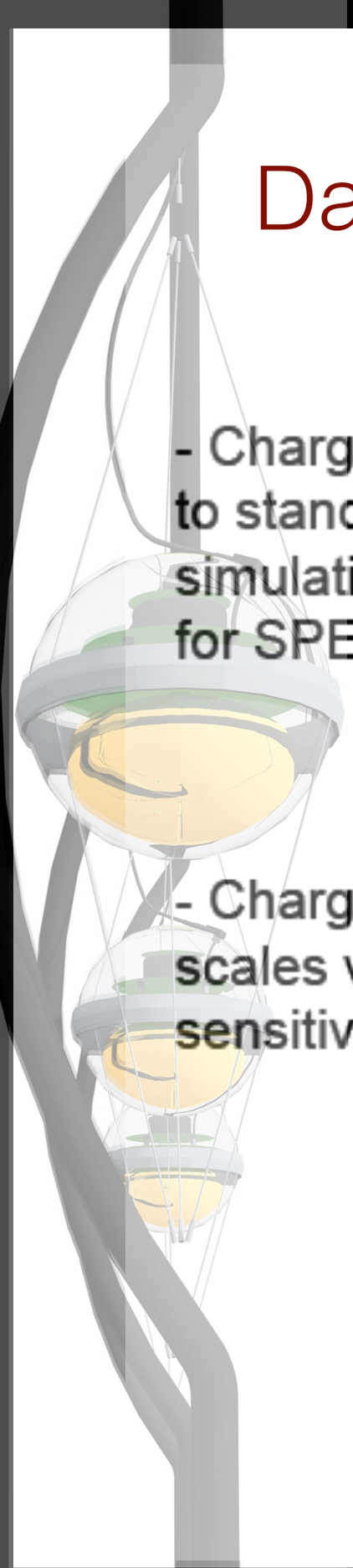
-Have similar statistics (~ 10,000 events), lines guide to the eye

-Preliminarily this suggests an additional ~7.5 % shift compared to the current 0.99 value... careful work on this is ongoing .. two more points to add to this at 120 and 130..we will see if they match the trend.

Thanks!

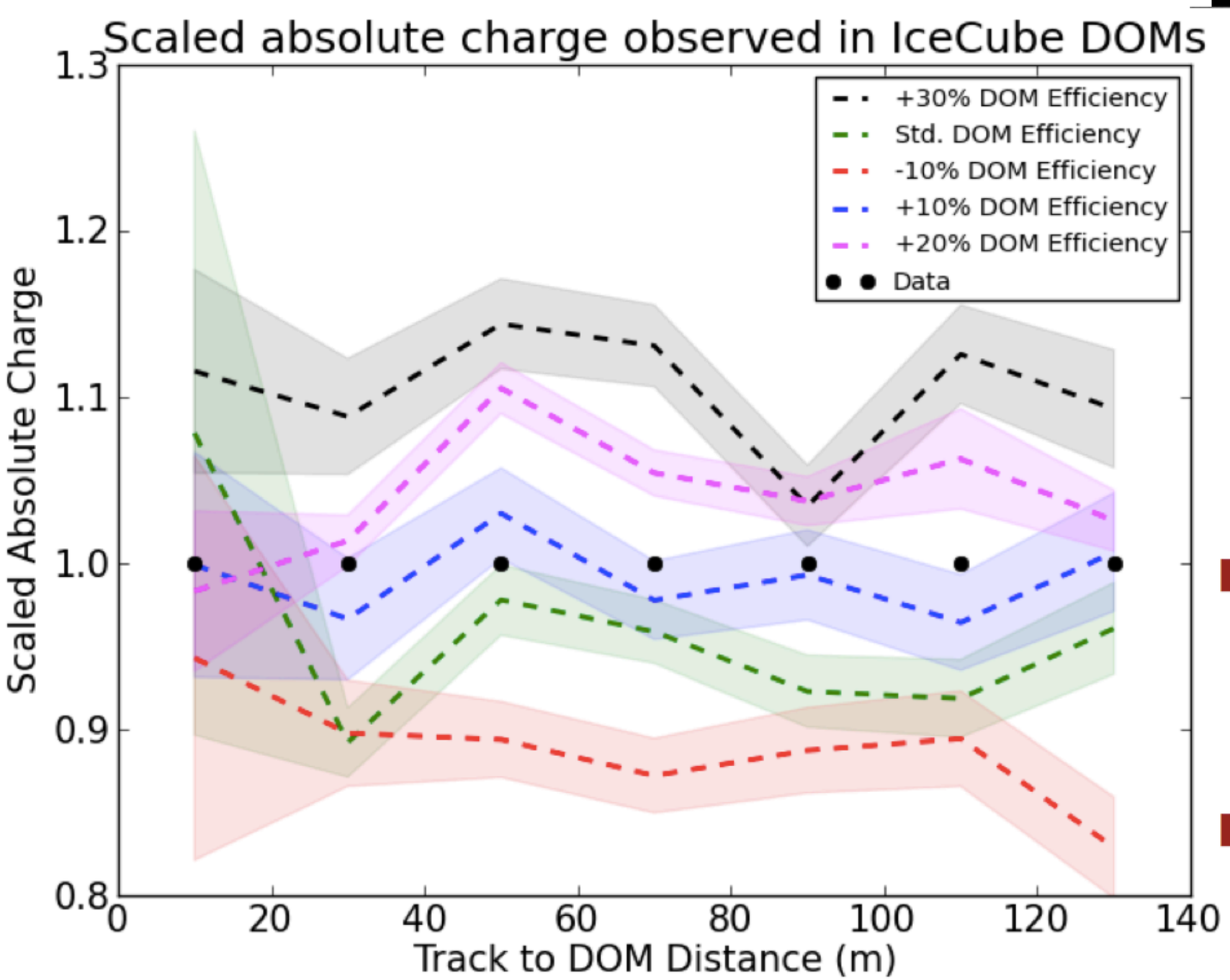
Backup Slides

Data has more charge than simulation:



- Charges are scaled to standard simulation, corrected for SPE peak offset

- Charge roughly scales with the DOM sensitivity

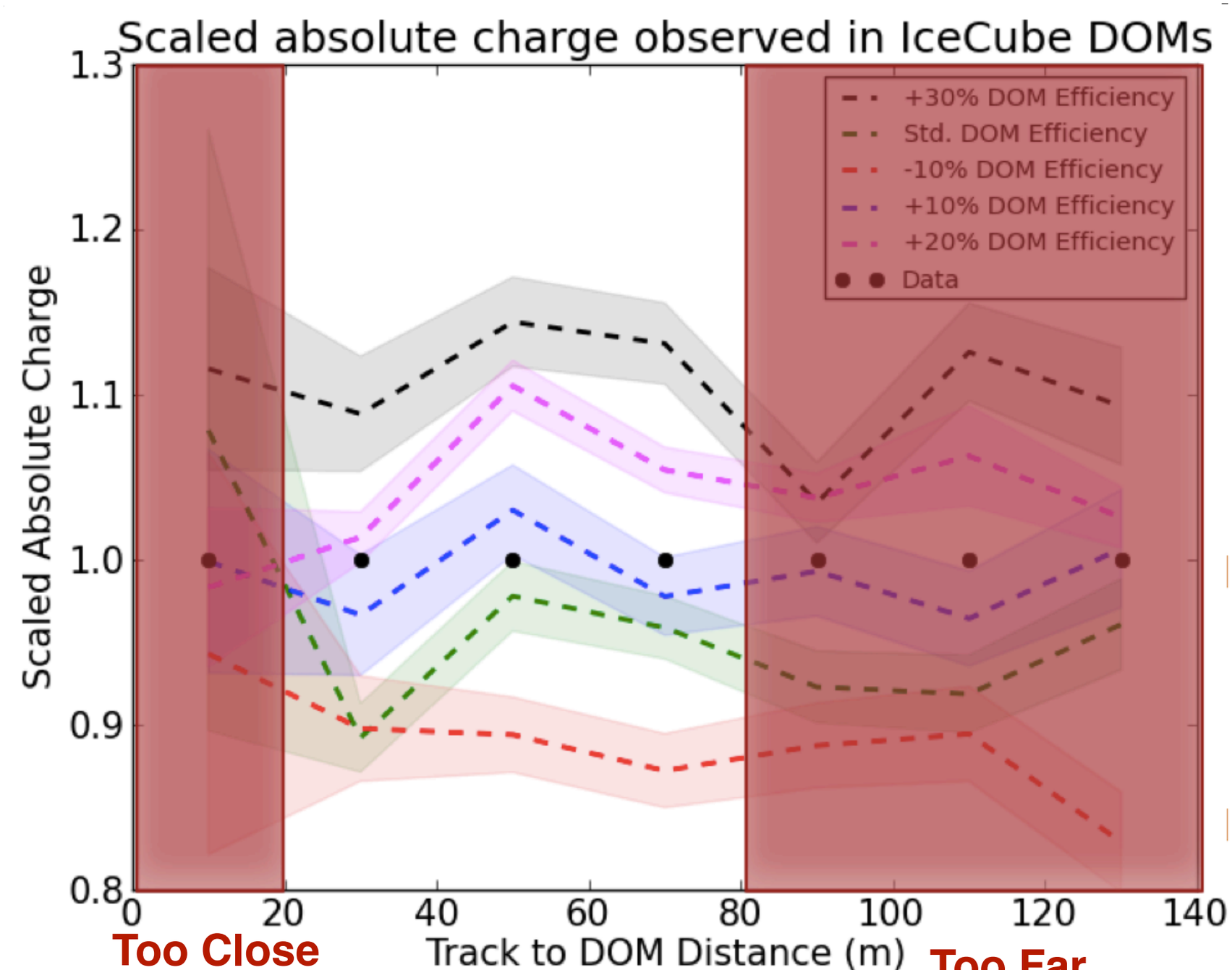


Data has more charge than simulation:

- Charges are scaled to standard simulation, corrected for SPE peak offset

- Charge roughly scales with the DOM sensitivity

Average and analyze 20-80m bins

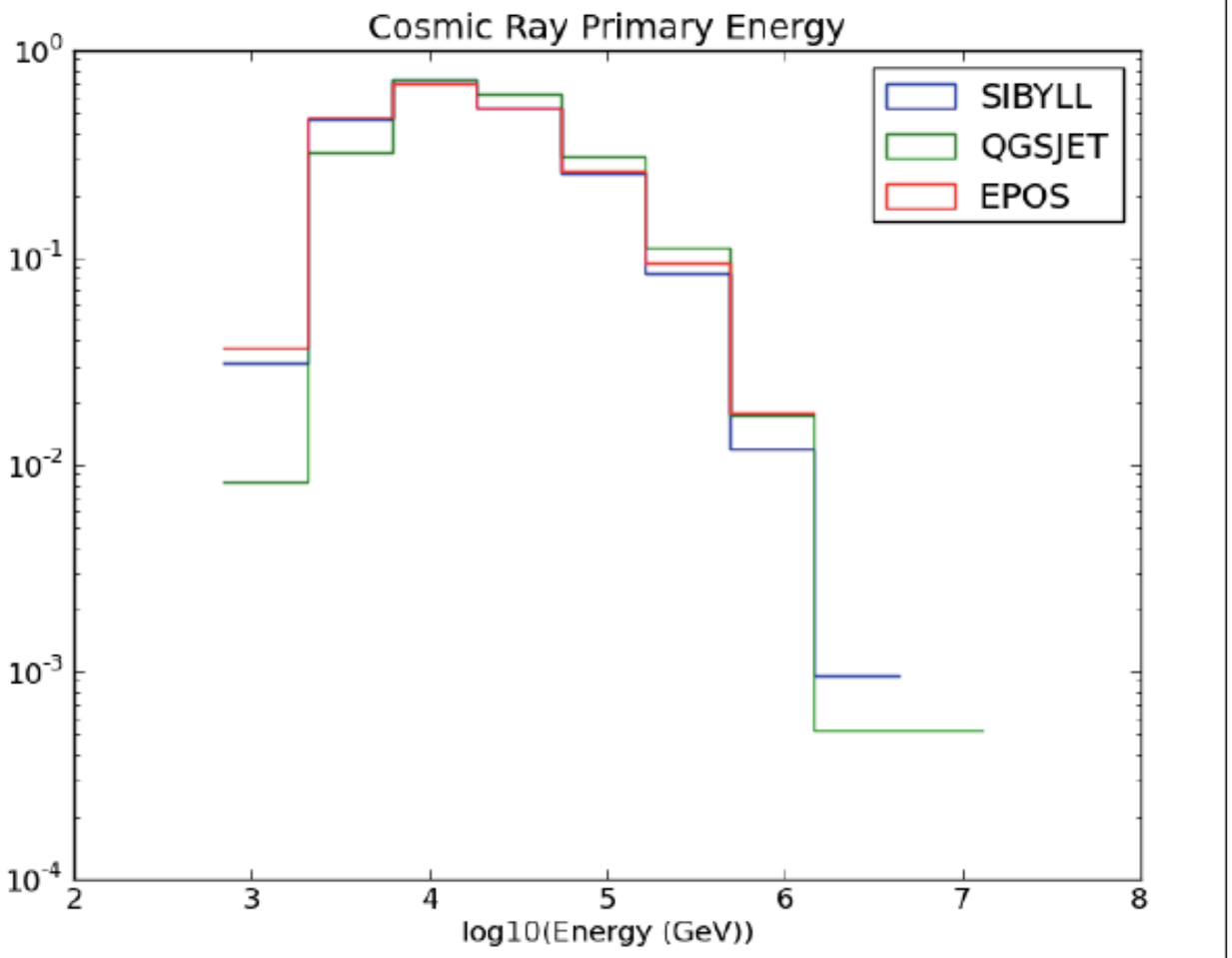


Reconstruction errors, questionable simulation, bigger fluctuations

Ice properties play a bigger role

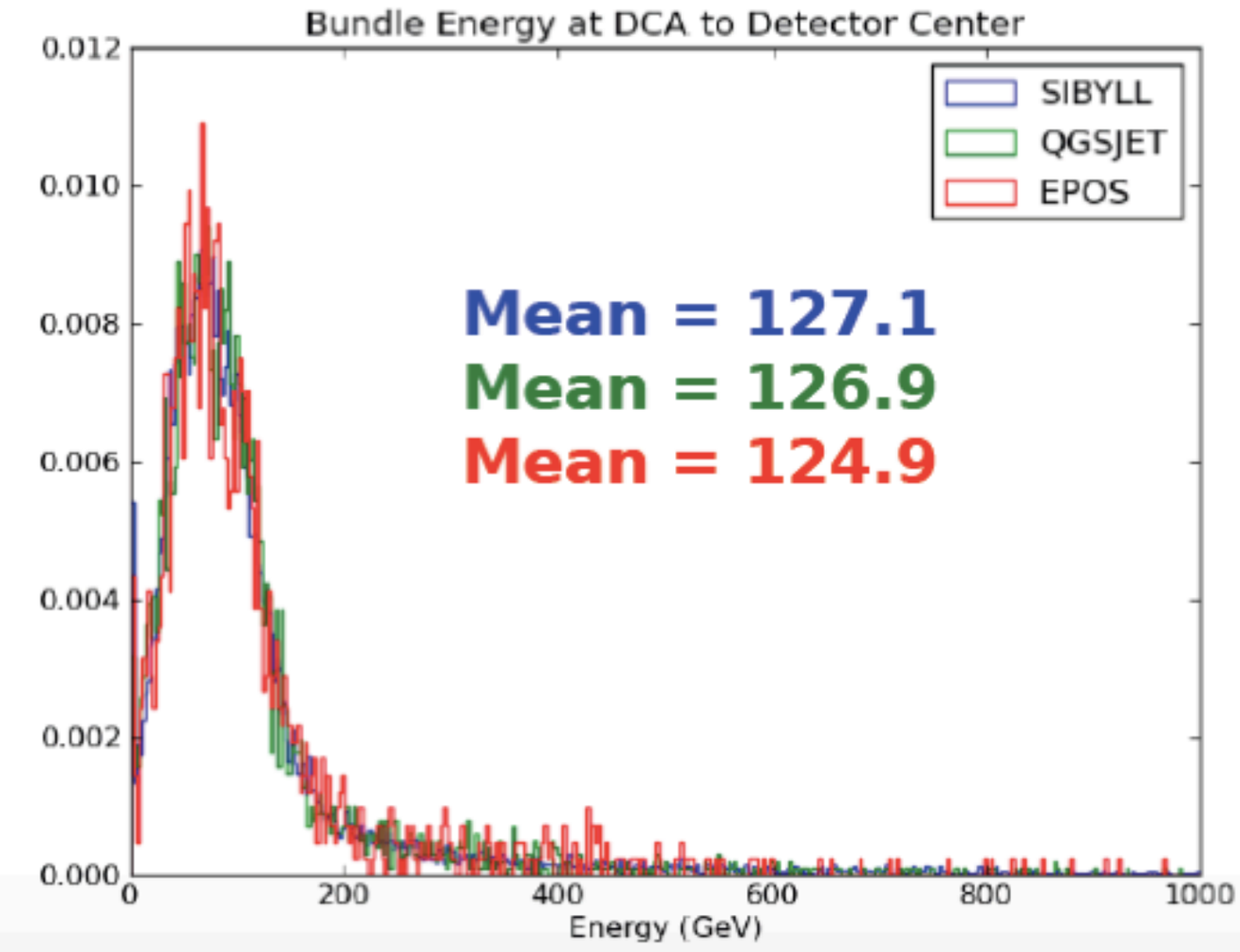
Events originate from cosmic ray primaries around 10 TeV

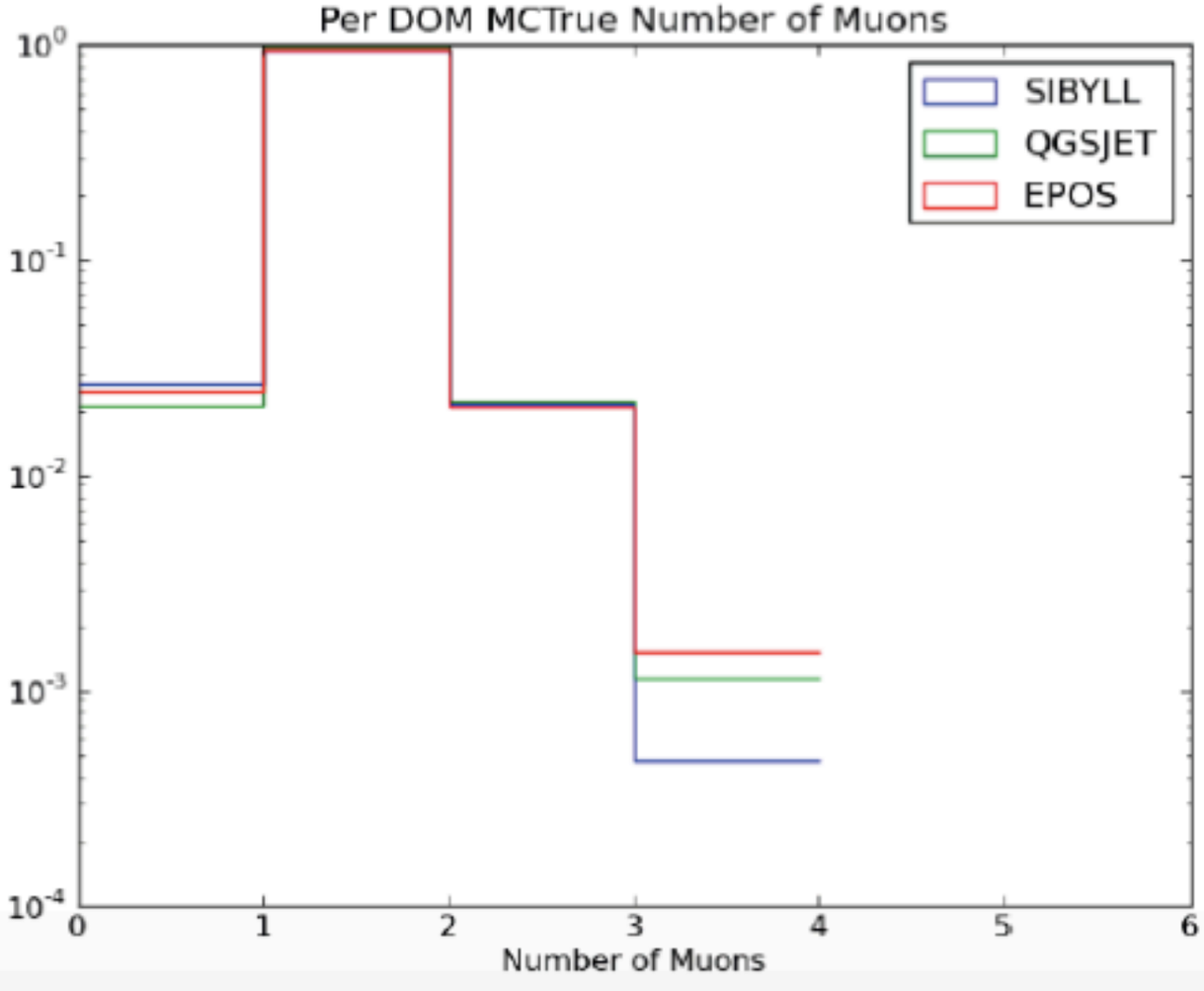
- Sibyll is the standard hadronic interaction model used in this analysis. QGSJET and EPOS are used to evaluate systematic uncertainties
- Uncertainties in CR spectrum/composition are small at these energies



Different hadronic interaction models lead to the same in-ice muon distributions

- Muon multiplicity and total energy spectra are extremely similar





Error on noise rate

- Uncertainty in noise rate is ~25%
- 500 Hz → 10^{-4}/μs x 1 PE/hit x .25 / 0.7 (avg. charge for my study) = 0.018 % uncertainty on charge ratio

Error on afterpulse rate

- Requiring time residual < 1000 ns removes most afterpulses
- There is one afterpulse population at ~500 ns, gives 0.0023 PE for every primary PE
- Uncertainty is ~15%, divide by 0.7, gives 0.05% uncertainty on charge ratio

Uncertainty on derived efficiency is 3.0%

Source of Error	Uncertainty in charge ratio	Uncertainty in derived sensitivity
Hole ice	1.6%	2.8%
Linear Fit (Data and MC statistics)	---------	0.94%
Bundle Uncertainty	0.3%	0.5%
Afterpulses	0.05%	0.09%
Noise Rate	0.02%	0.03%
Total		**3.0%**

- Changes since last fall:
  - PPC correction factor removed, since we're now using PPC directly
  - Hole ice included