Wright Laboratory

Impact of DM-Ice17 Muon Data on IceCube Reconstructions

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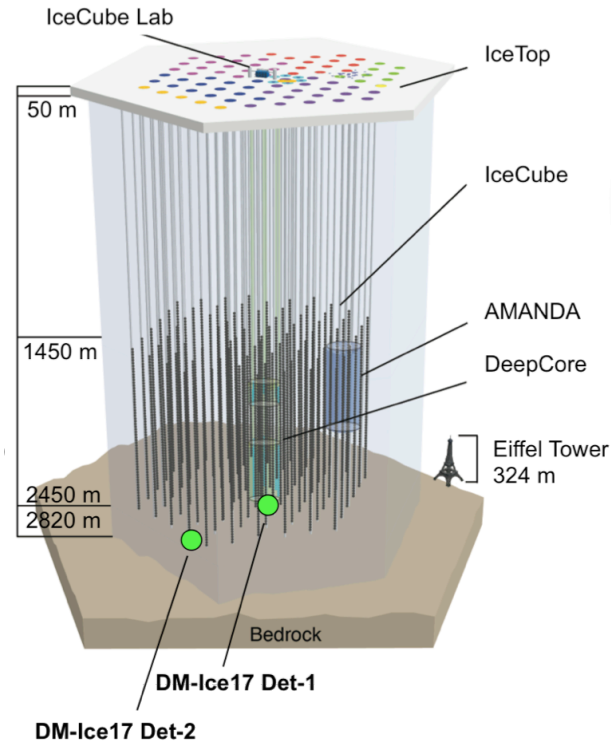
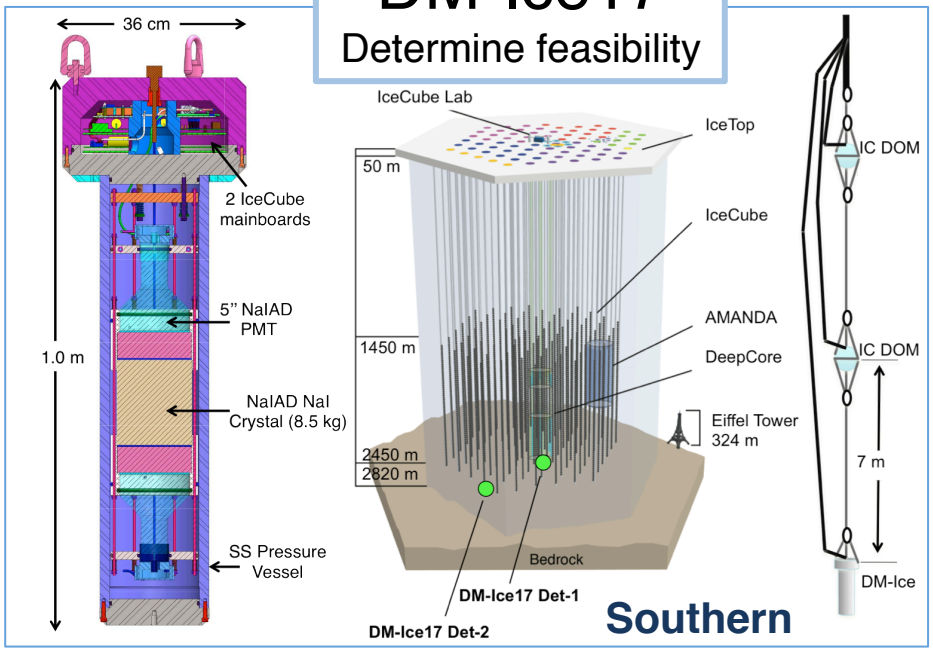
DM-Ice17/IceCube Coincidence

- IceCube: 1 km^3 Cherenkov detector
- DM-Ice17: 14 cm x 16 cm NaI(Tl)
  - 2 detectors on IC strings, 7.5 m below the bottom DOM
- Coincident muons provide:
  - Muon tag verification for DM-Ice17
  - Volume for direct muon path in IceCube
- Identification condition
  - [-1, +6] μs window
  - Synchronized GPS allows time coincidence

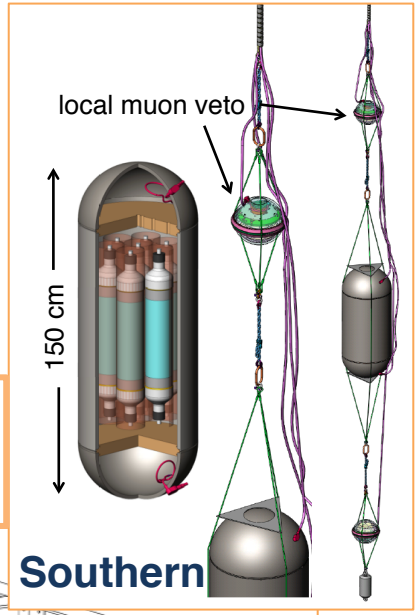


DM-Ice

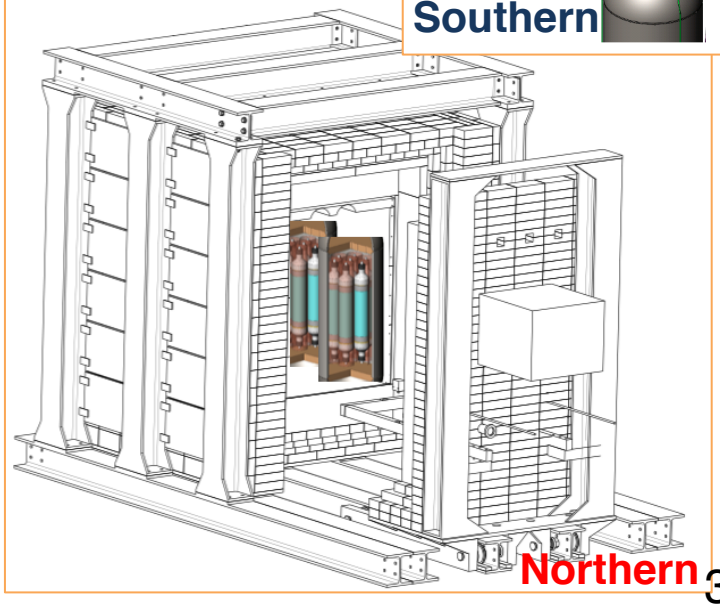
DM-Ice17
Determine feasibility



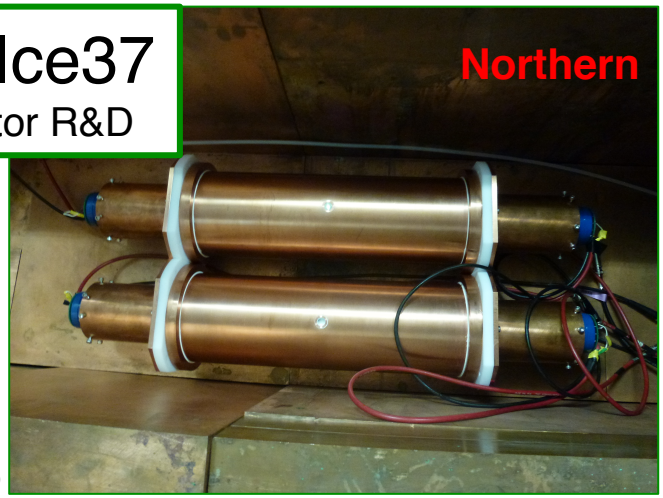
DM-Ice is a phased program that will run in both hemispheres to test the dark matter interpretation of the DAMA modulation



DM-Ice250
Set limits

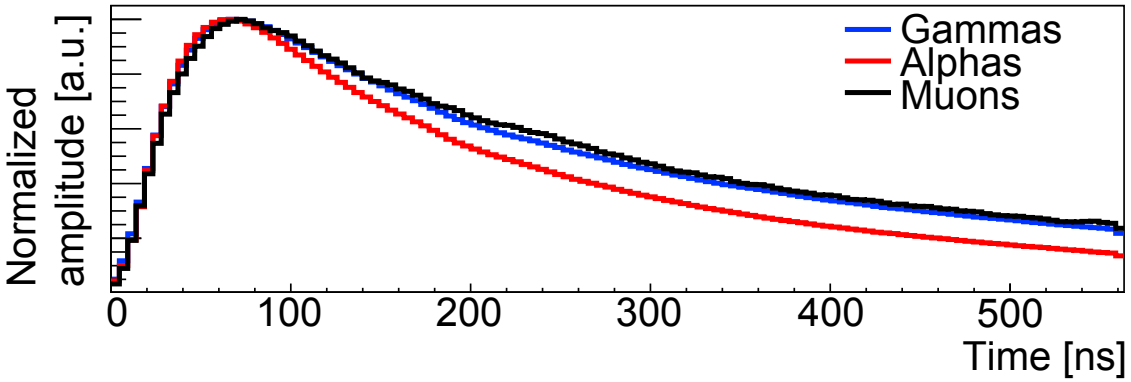


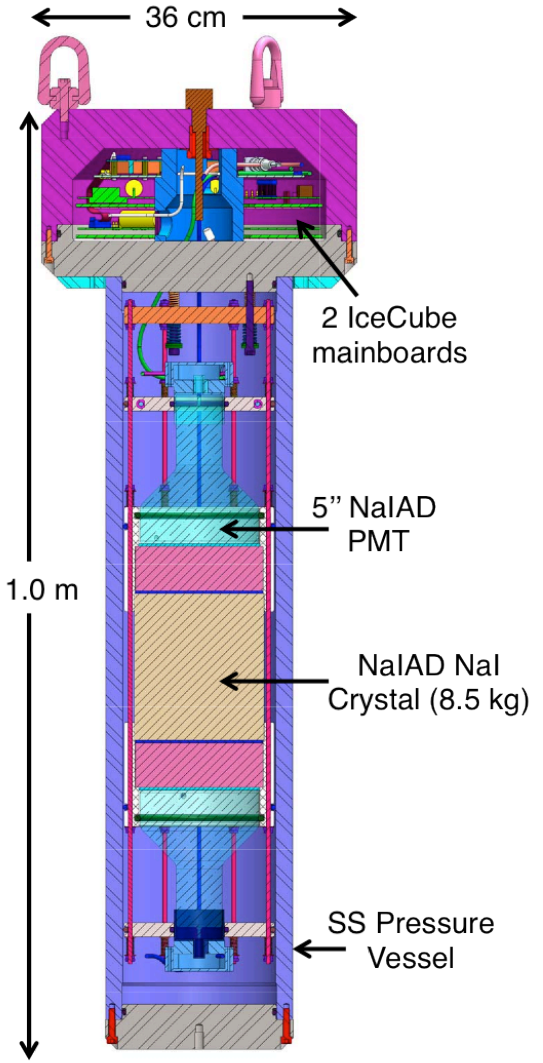
DM-Ice37
Detector R&D



DM-Ice17

- Deployed December 2010
  - 99% uptime after June 2011
- 2 detectors at 2457 m deep
  - Optically isolated from the ice
  - Only sensitive to interactions in the NaI(Tl) crystal
- 14 cm dia. x 16 cm NaI(Tl)

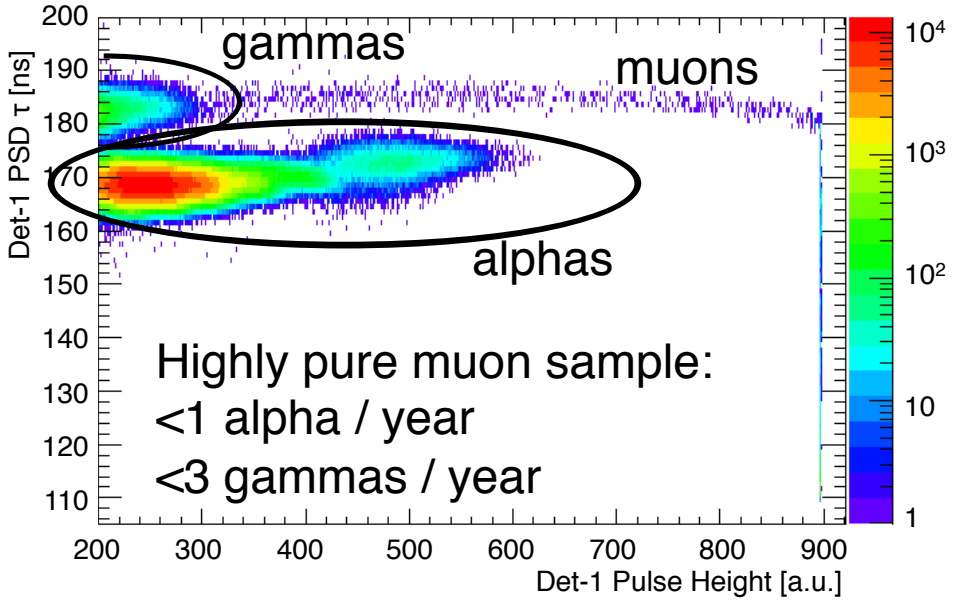


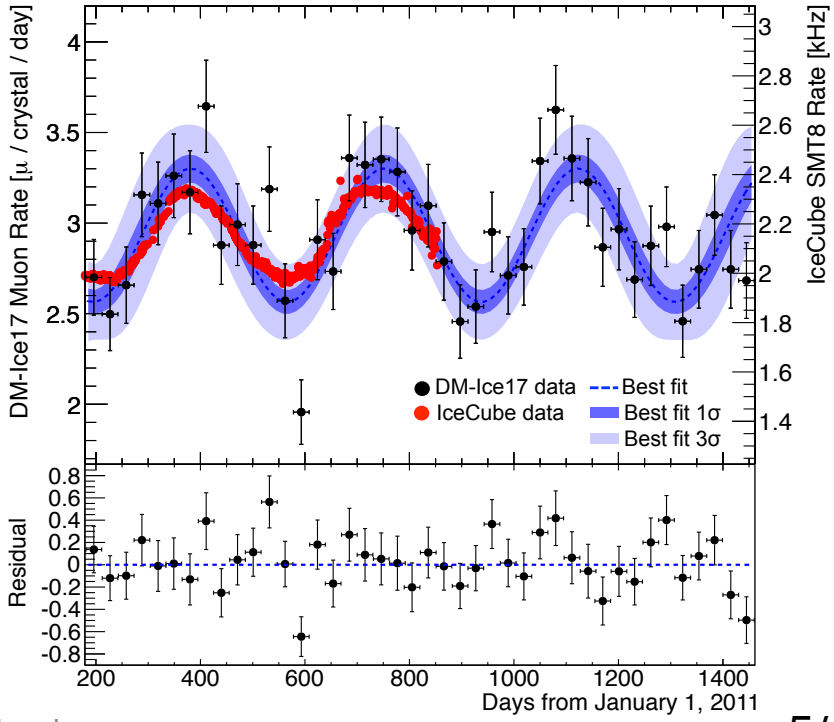


PRD 90, 092005 (2014)

DM-Ice17 Muon Events

- Flux of 2.93 ± 0.04 muons / crystal / day
  - 12.3 ± 1.7% annual modulation amplitude in the muon rate
- Identified via pulse shape and energy deposition
  - Gamma and muon pulses decay faster than alphas
  - MIP energy deposition



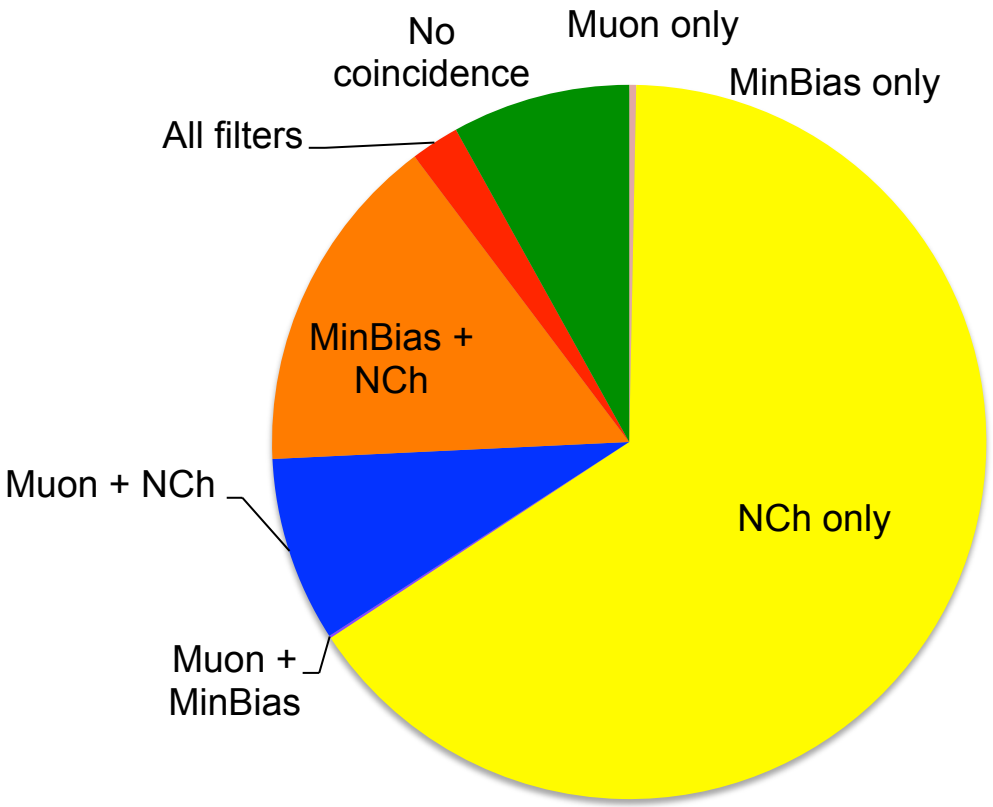


Online IceCube Data Streams

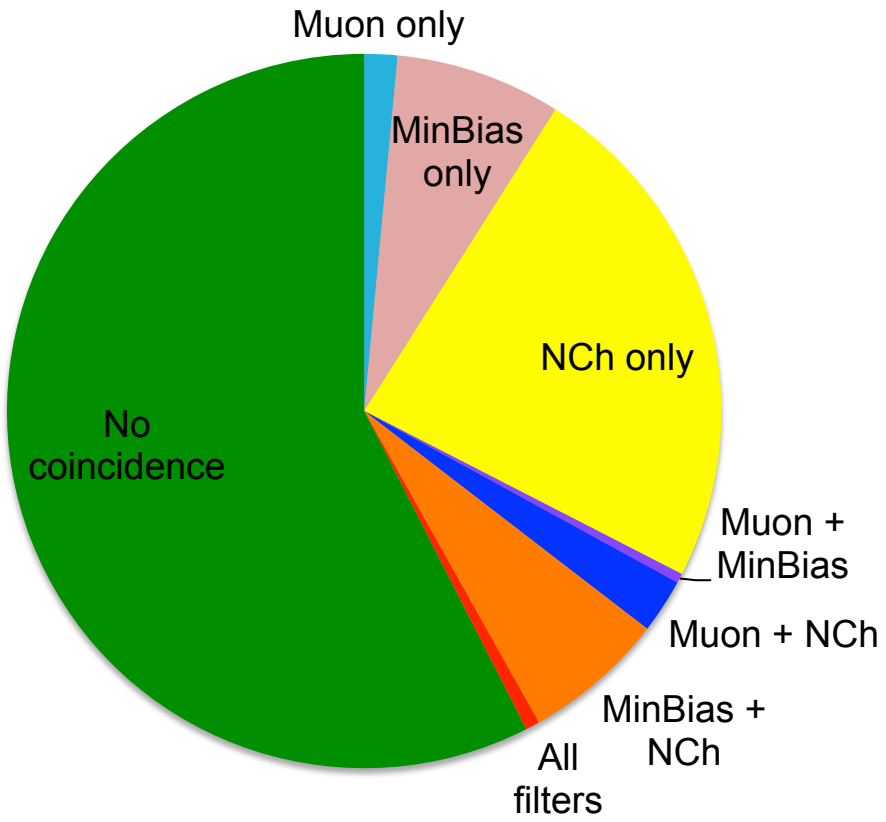
- IC86-1 and IC86-2 study (2012-2014)
  - 3 IC channels selected for muon acceptance and noise rejection
- **Muon Filter**: 34 Hz
  - Higher energy, SMT8 (HLC) events; observe 6.8% coincidence, consistent with expectation
- **sDST MinBias**: 454 Hz
  - Every 5th event; observe 15% coincidence, consistent with expectation
- **sDST NCh**: 432 Hz (2012 only)
  - Events with at least 25 trigger DOMs; expect 90-95% coincidence
  - NCh saw 93(37)% coincidence with Det-1(2)

Summary 2012

Det-1: 887 coincident/955 μ

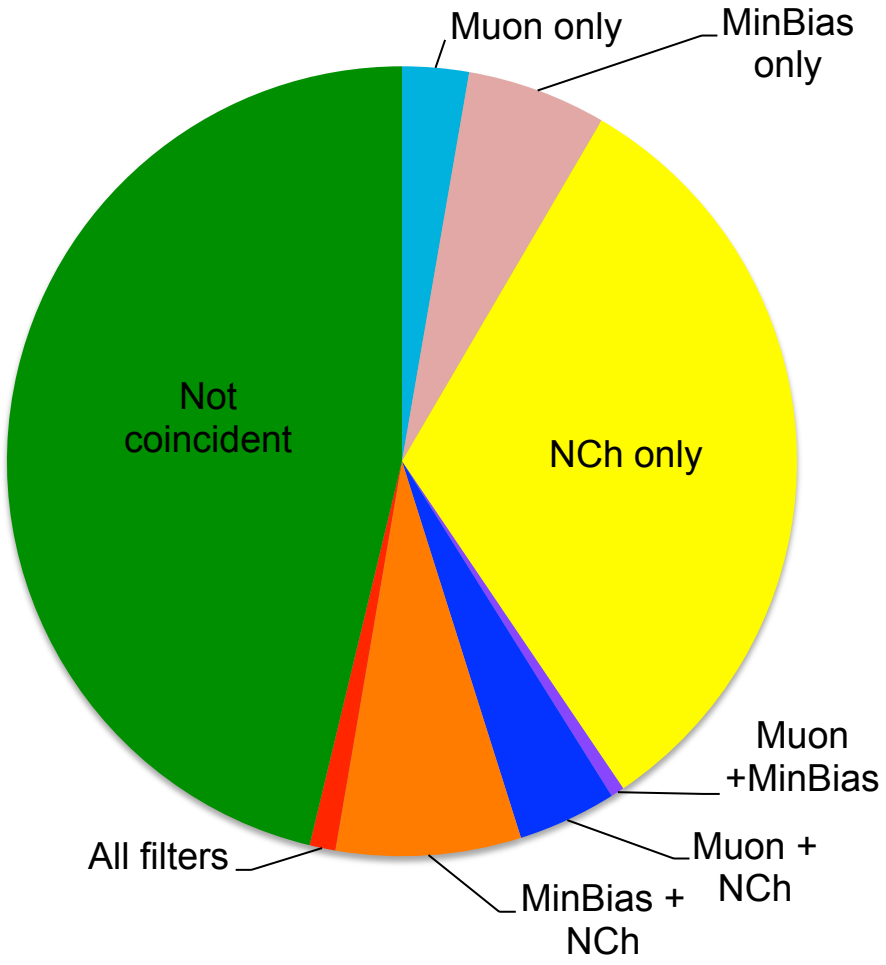


Det-2: 309/934 μ

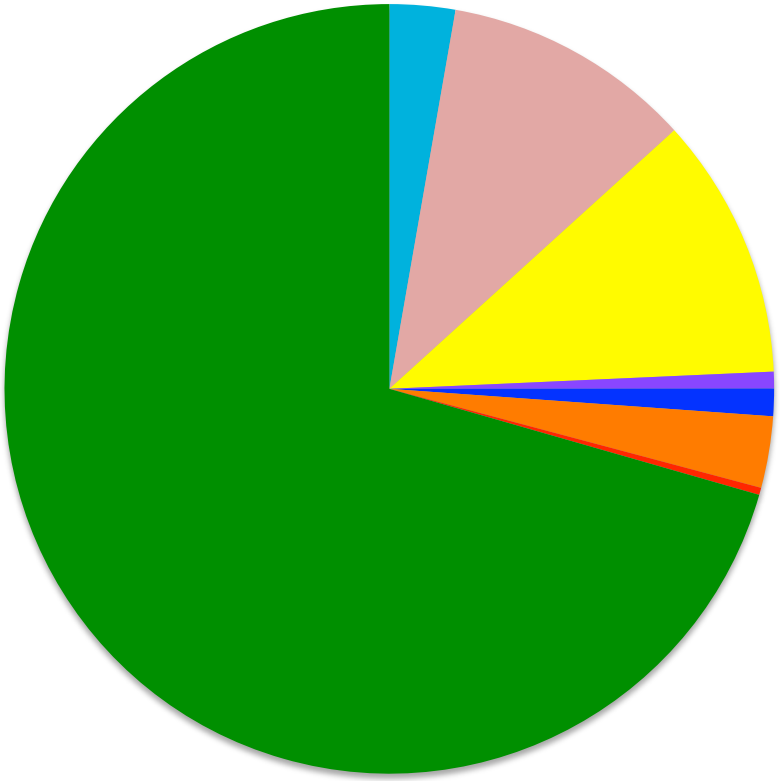


Summary 2012 + 2013

Det-1: 1072 coincident/1981 μ

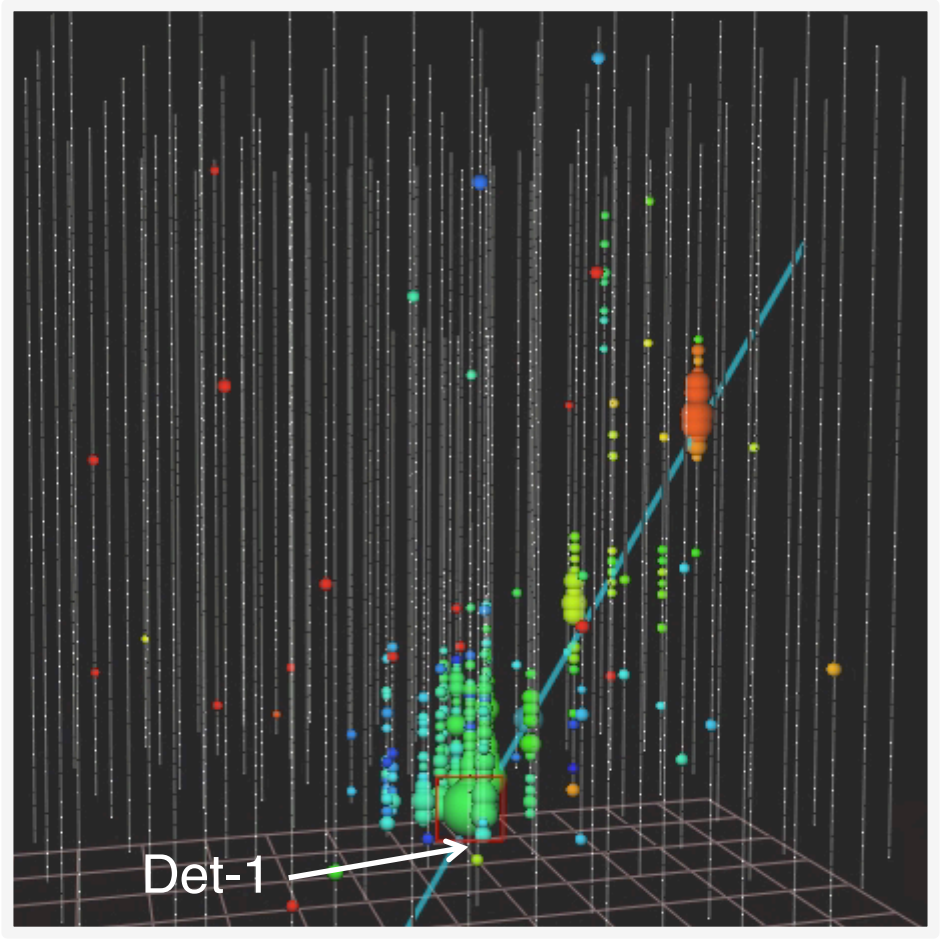


Det-2: 594/1997 μ

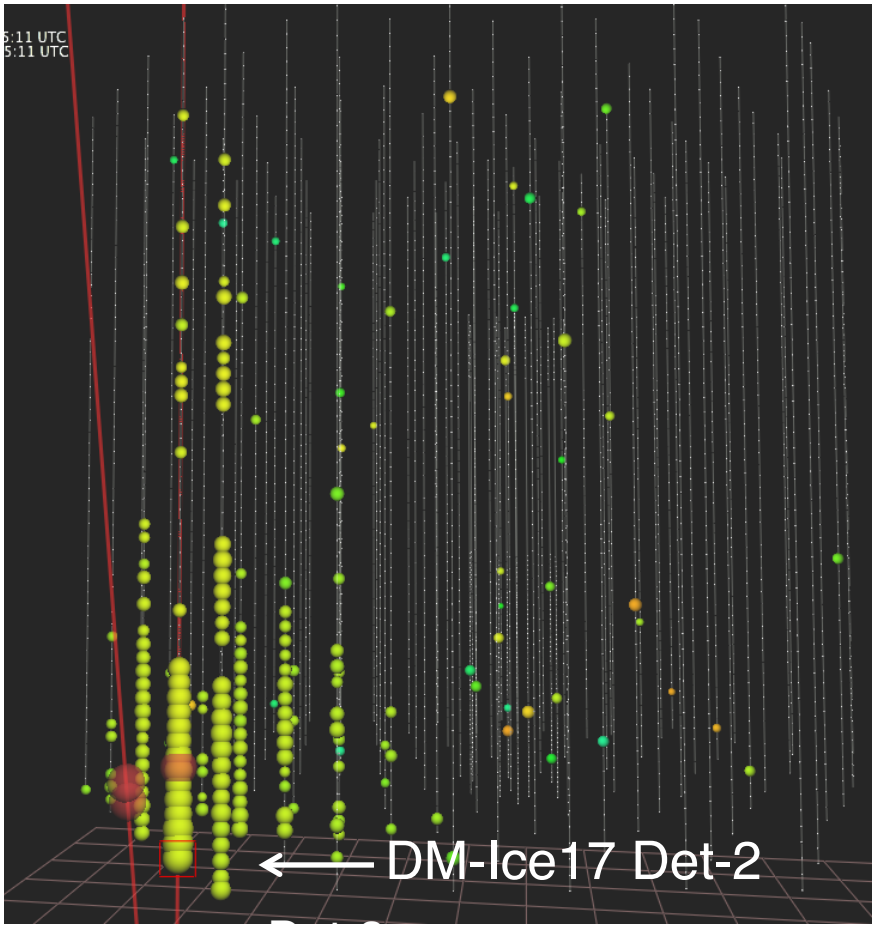


Coincident Events

Det-1



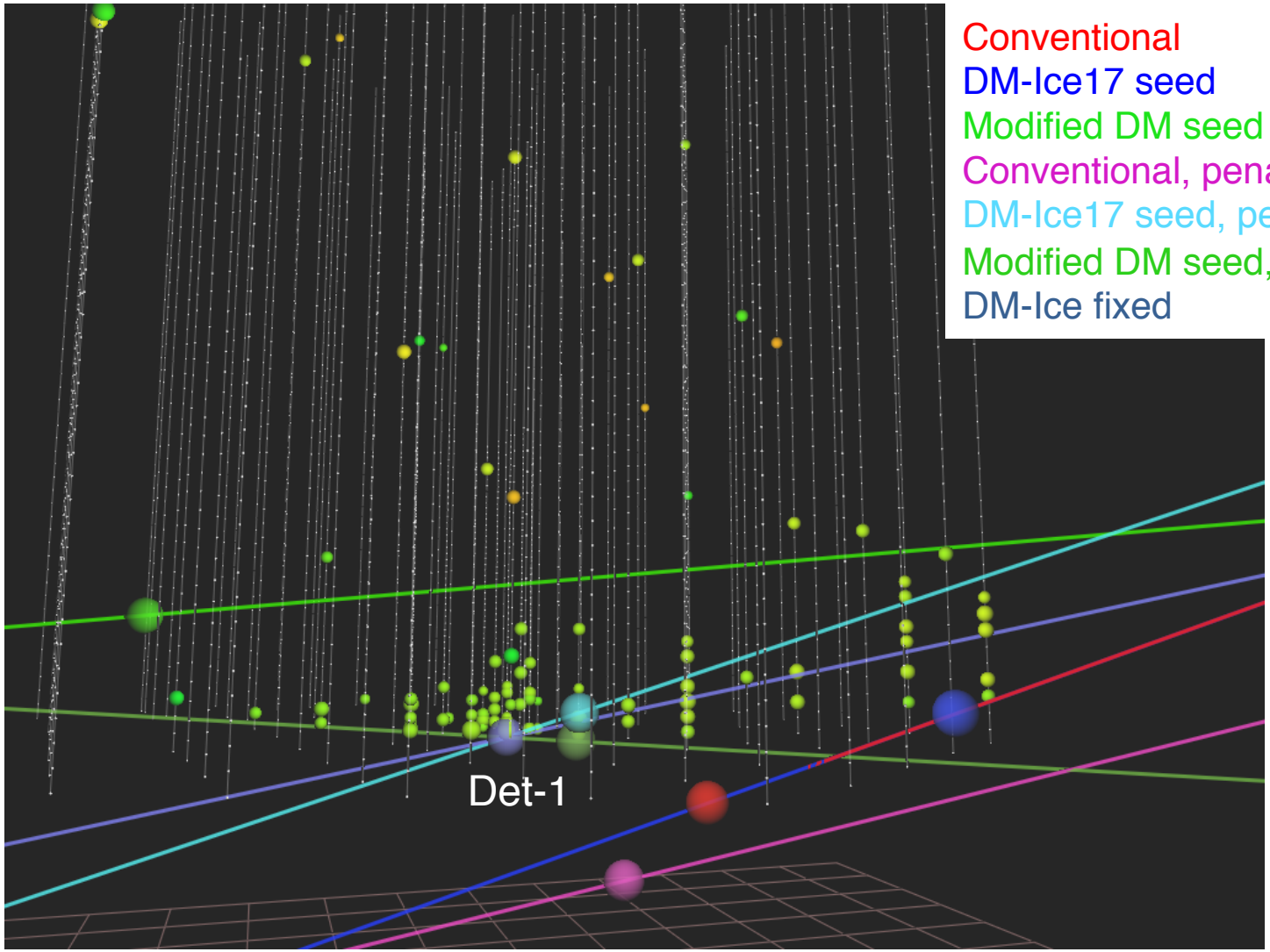
Det-2



Using Coincident Events

- Integrate DM-Ice17 location into IceCube reconstructions
- Reconstruction Methodology
  - Fast reconstructions seed more precise algorithms
    - Seeds: interaction vertex and reconstructed direction
  - Linefit (which DOMs triggered) seeds:
  - SPEFit (first photon arrival times), which seeds:
  - MPEFit (all photons)
- Methods explored in MPEFit:
  - Seeds: conventional, DM-Ice vertex, modified DM-Ice (original vertex with adjusted direction to pass through DM-Ice17)
  - Reconstructions: conventional (no DM-Ice17 information), penalized (by distance of closest approach), forced through DM-Ice17 volume

Seed Comparison



Measuring Improvements

- Study explores both data and simulation
  - Data: Level2 data with basic noise removal
  - Simulation: MuonGun through DM-Ice17
- Metrics of reconstruction quality
  - Number of failed reconstructions (θ_z>90°)
  - Distance of closest approach of the direct track to DM-Ice17
  - Shift in zenith, azimuth, energy between reconstruction results
- Caveats: no additional event splitting or noise removal explored

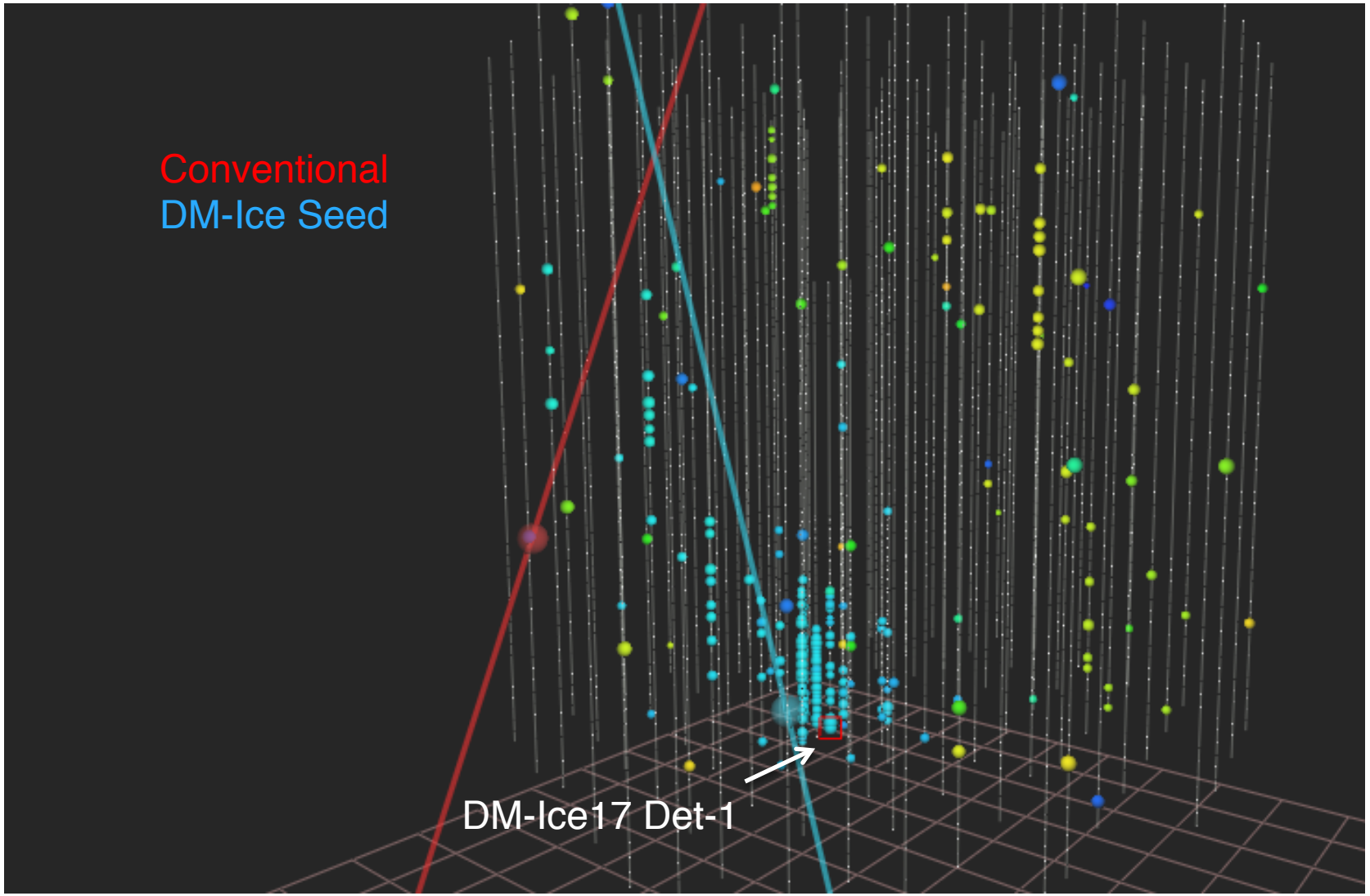
Misreconstruction Rates

Modified DM-Ice17 seed consistently performs the best and is the most physically motivated: it seeds the track as passing through DM-Ice17 without making this the interaction vertex

Reconstruction	Seed	Data Failed [%]	Simulation Failed [%]
Conventional	Conventional	10.8	13.0
	DM-Ice	4.2	9.9
	Modified DM-Ice	3.7	8.1
Weighted	Conventional	3.7	12.1
	DM-Ice	6.0	12.6
	Modified DM-Ice	3.7	9.9
Fixed	DM-Ice	9.8	4.2

Failed tracks are dominated by NCh filter events

Sample Misreconstruction Improvement

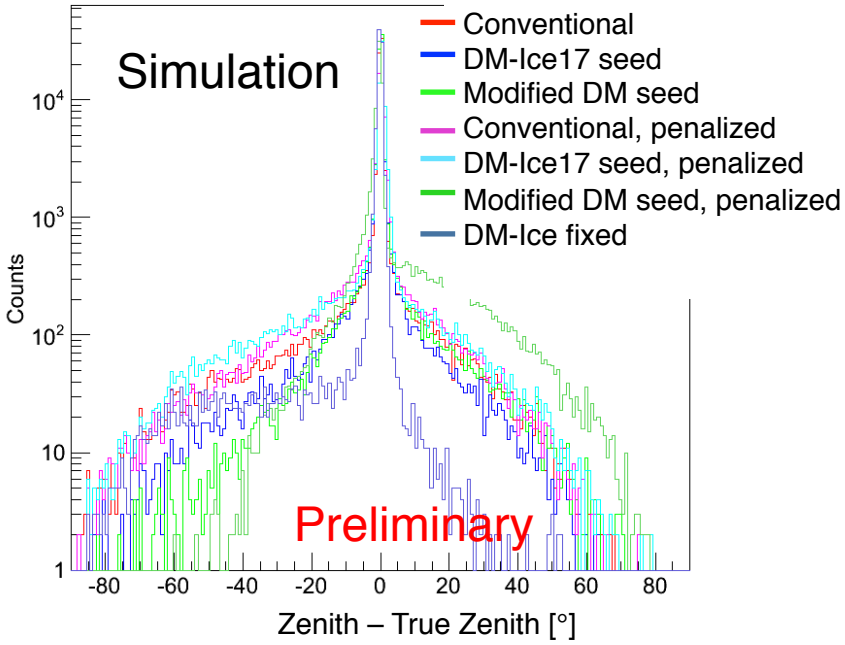


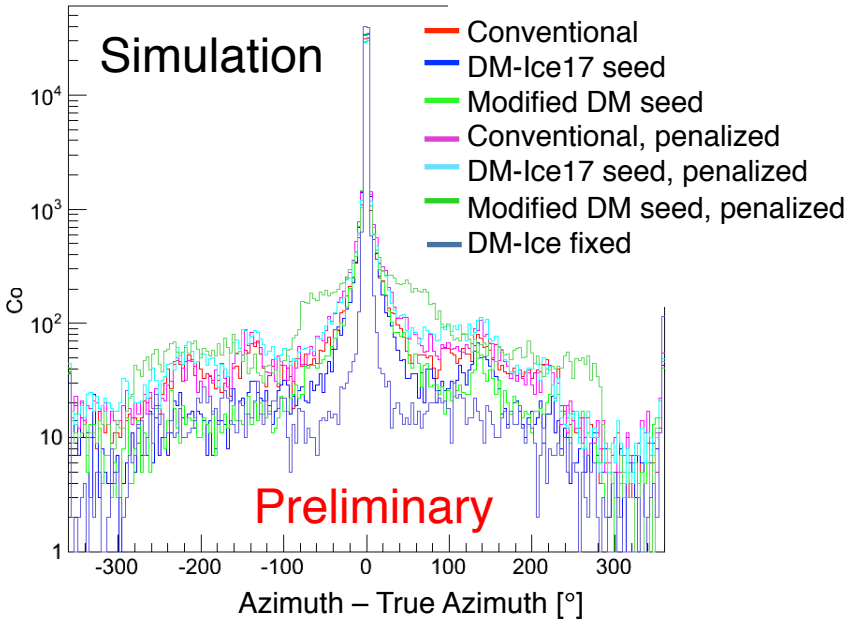
Effect on Reconstruction Parameters

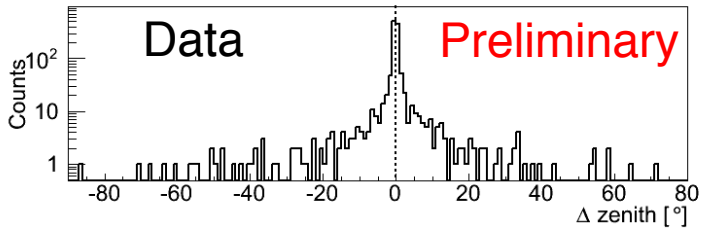
- We examine the effect of DM-Ice17 on reconstructed parameters in data and simulation:
  - Energy: consistent with no change
  - Reconstructed direction: zenith and azimuth
  - Distance of closest approach to DM-Ice17

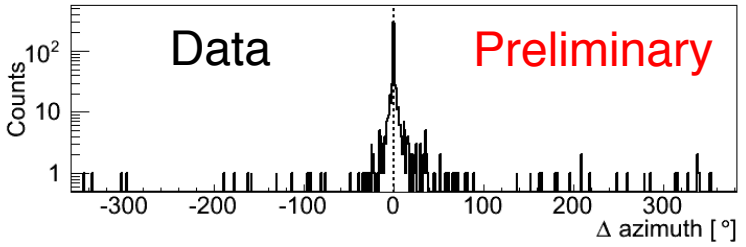
Reconstruction: Zenith & Azimuth

- <2° deviation from truth in simulation for all reconstructions
- <1° width on relative distribution in data





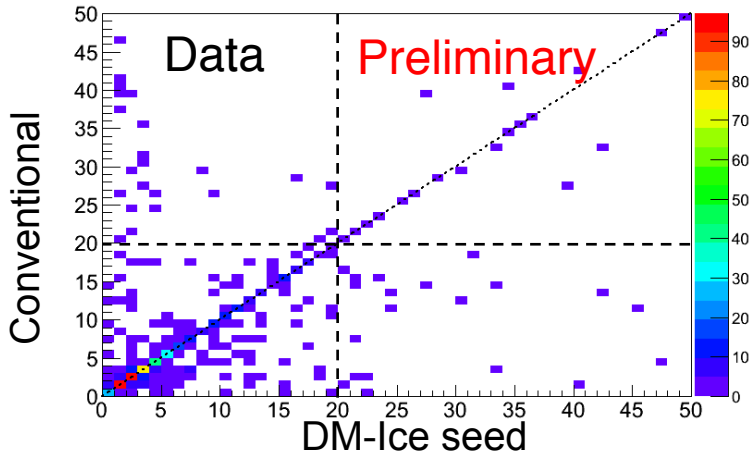


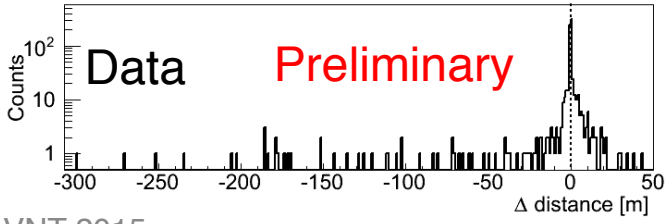


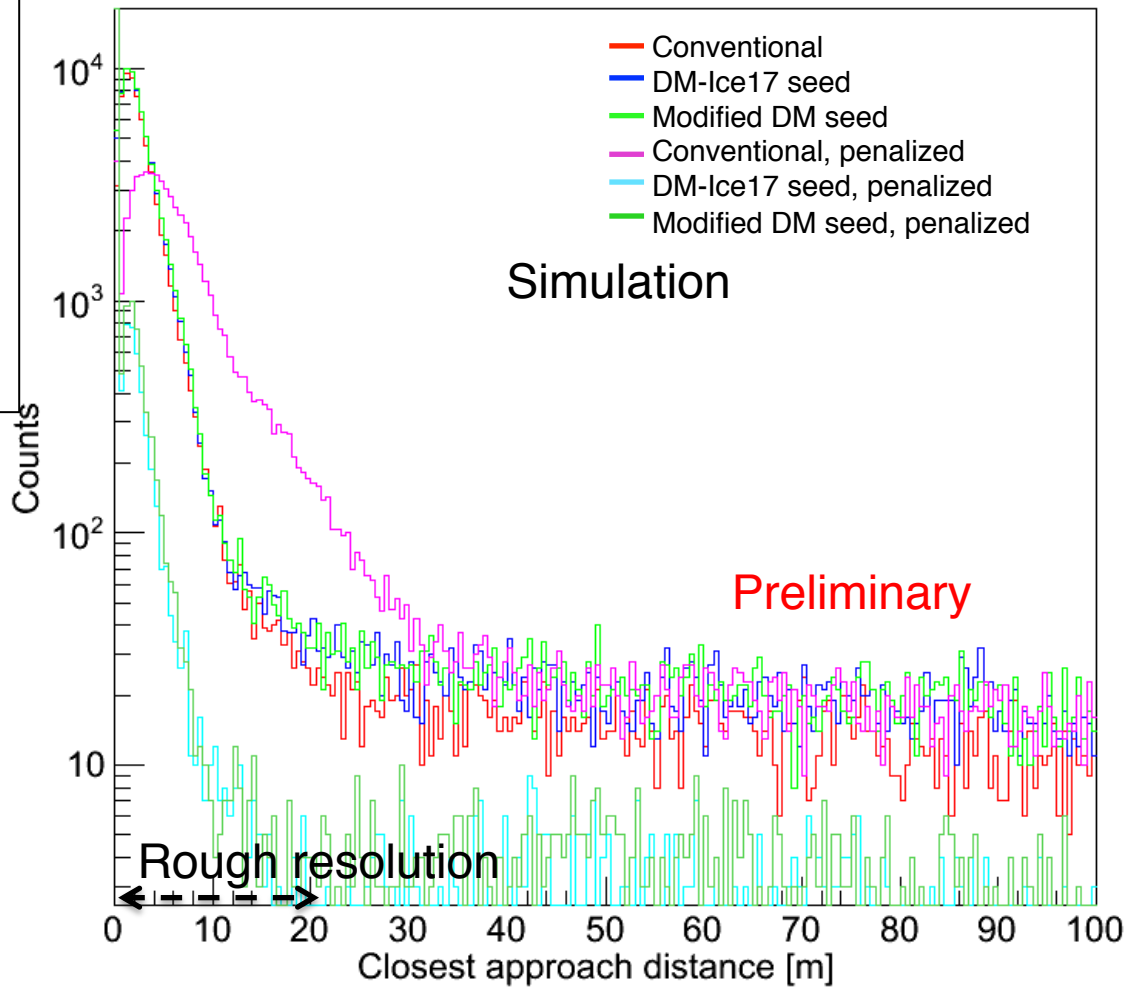
DM-Ice seed
-
Conventional

Reconstruction: Closest Approach

Maximum improvement for penalized reconstructions with either penalized DM-Ice17 seed:
- **simulation:** >90% get closer by >10% and 96% at >20m go <20m
- **data:** 53% of data gets closer with DM-Ice seed







Conclusions

- Scintillators and Cherenkov detectors mutually beneficial!
  - Successful coincidence demonstrated
  - IceCube verifies the DM-Ice17 muon tag and provides muon information, and DM-Ice17 offers a unique calibration tool for IceCube
- Improvements in seeding and reconstruction methodology have been made for these events
  - Rate of misreconstruction improves, and while angular reconstructions of passing events are not significantly altered, the track of the particle in the detector improves
- Future of coincidence
  - IceCube: DM-Ice17 online muon tagging
    - Statistics will increase, allowing for more studies (e.g., DOM efficiency)
  - PINGU
    - DM-Ice250 (14 crystals) on a compatible timescale
    - Plastic scintillators (mTOMs) under investigation: 100s across array