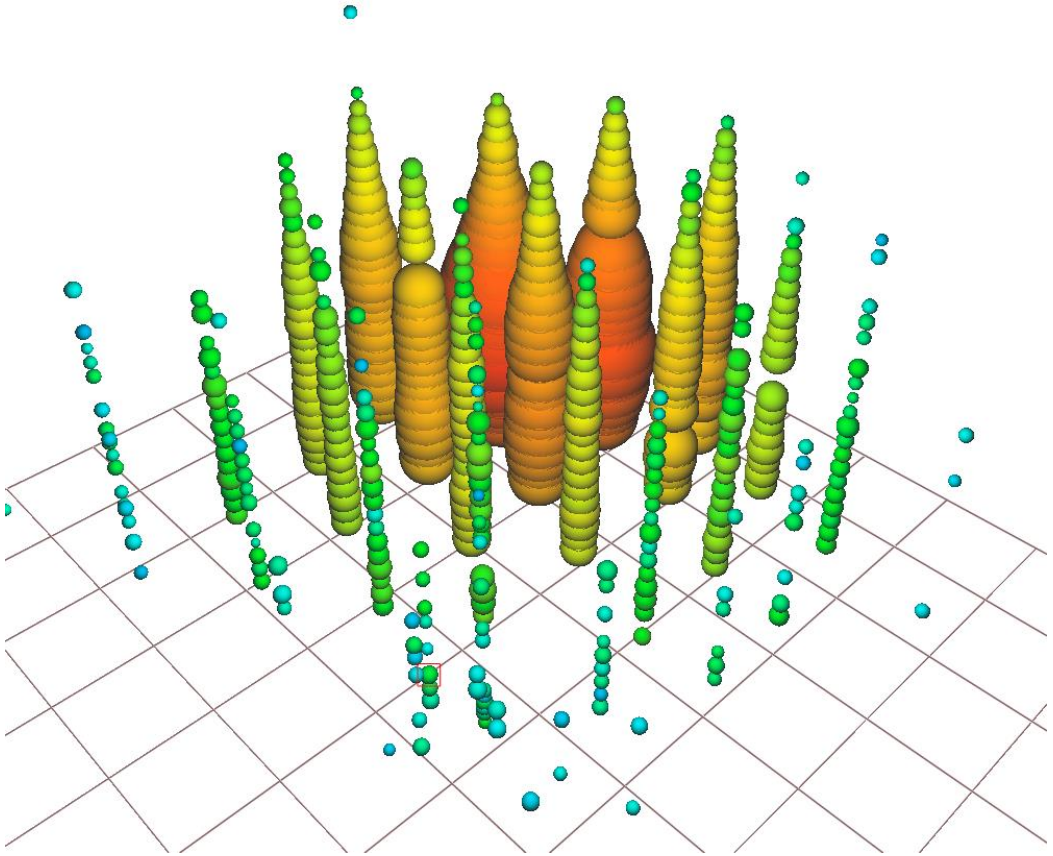
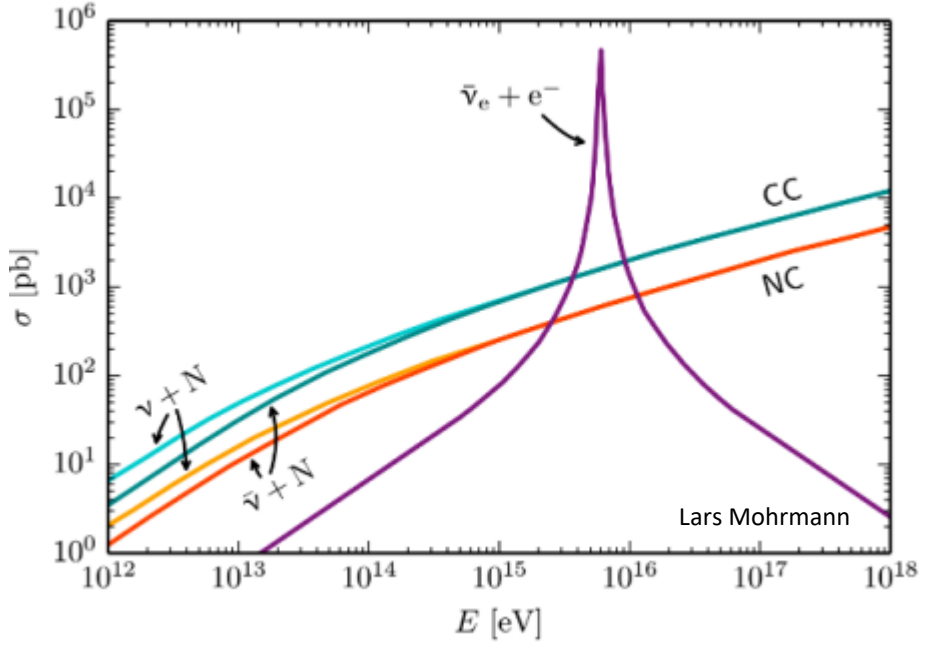
Improving the Angular Resolution of Hadronic Cascades in IceCube

Christian Haack, RWTH Aachen University
Lu Lu, Chiba University
Tianlu Yuan, UW Madison

VLVnT, Dubna, 2018

A Multi-PeV Uncontained Cascade





Most probable neutrino energy: ~6PeV

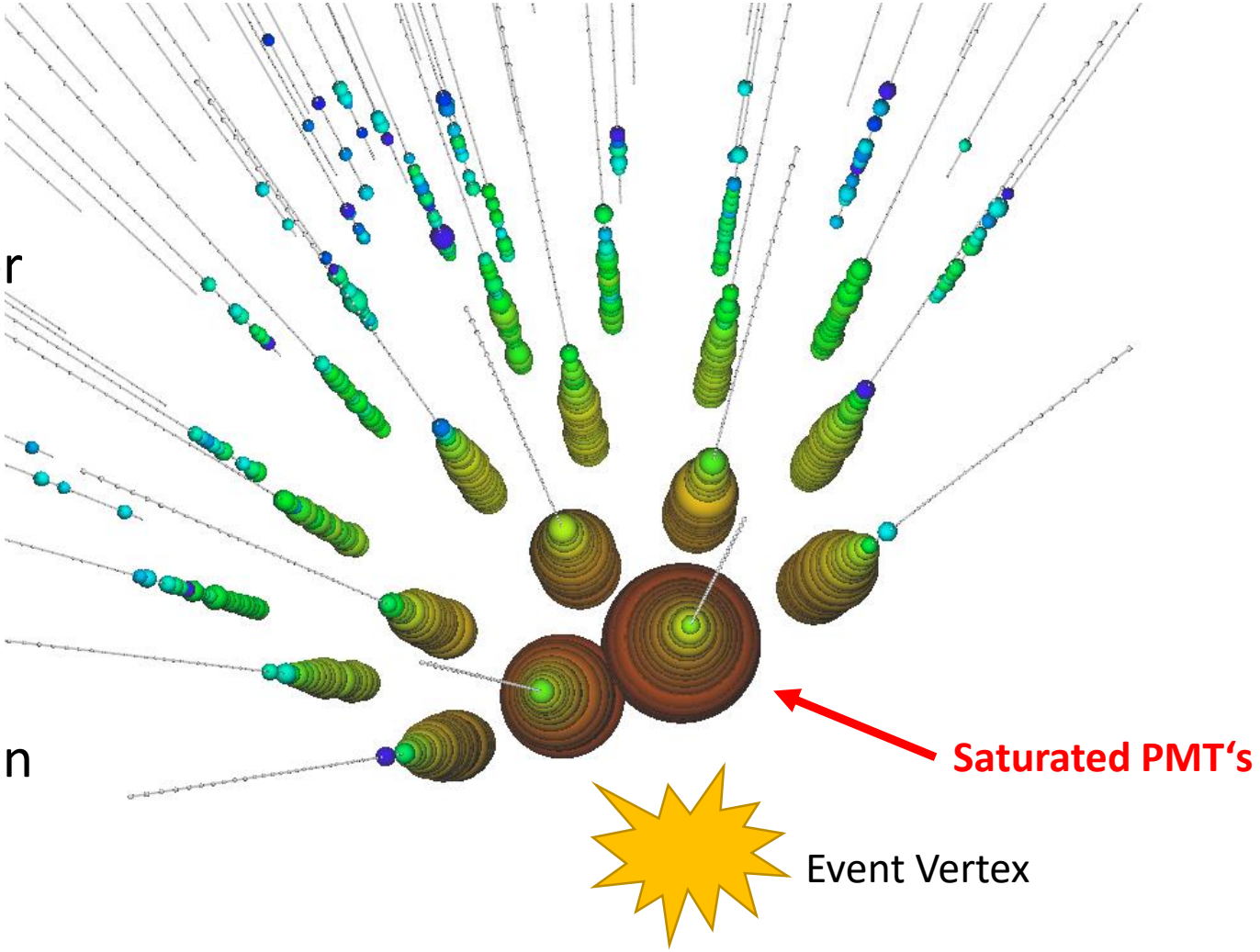
Stay tuned for presentation at UHECR!

A Multi-PeV Uncontained Cascade

The event vertex is outside the detector and the PMT‘s closest to the vertex are saturated.

⇒ **Challenging Reconstruction**

Best angular resolution achieved by *DirectFit,* an ABC (Approximate Bayesian Computing) method.

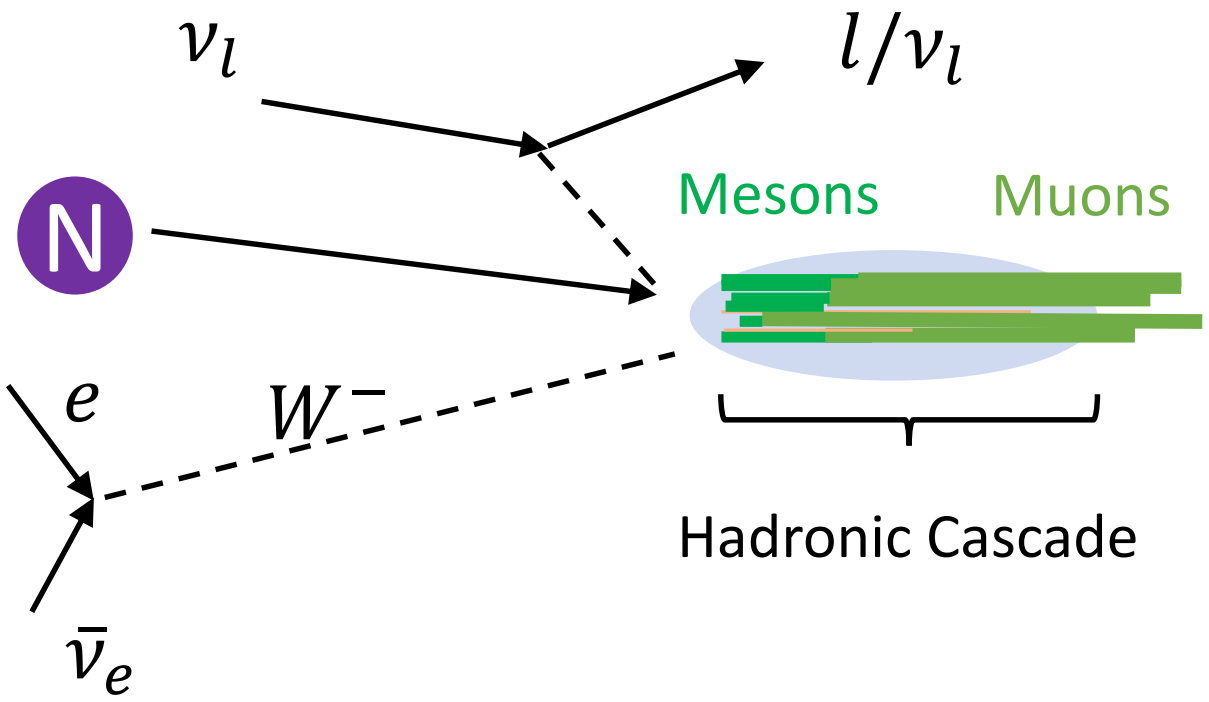


Muon Production in Hadronic Cascades

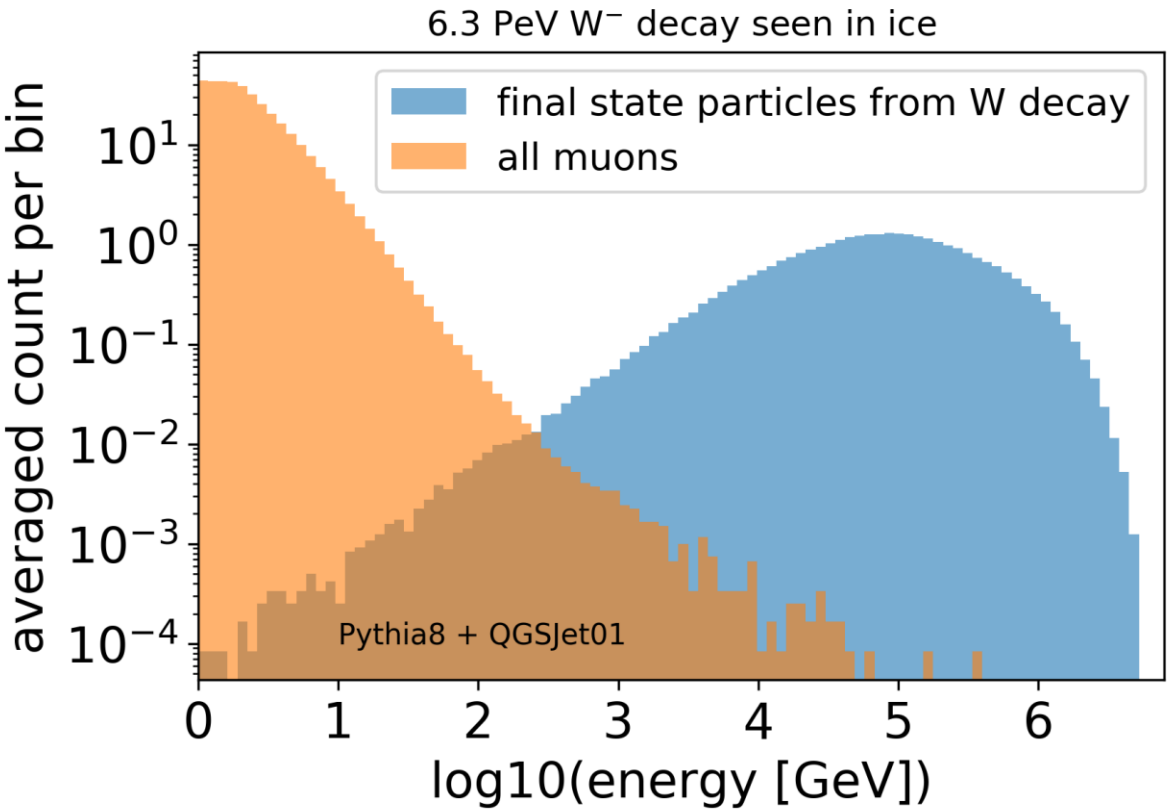
Neutrino DIS

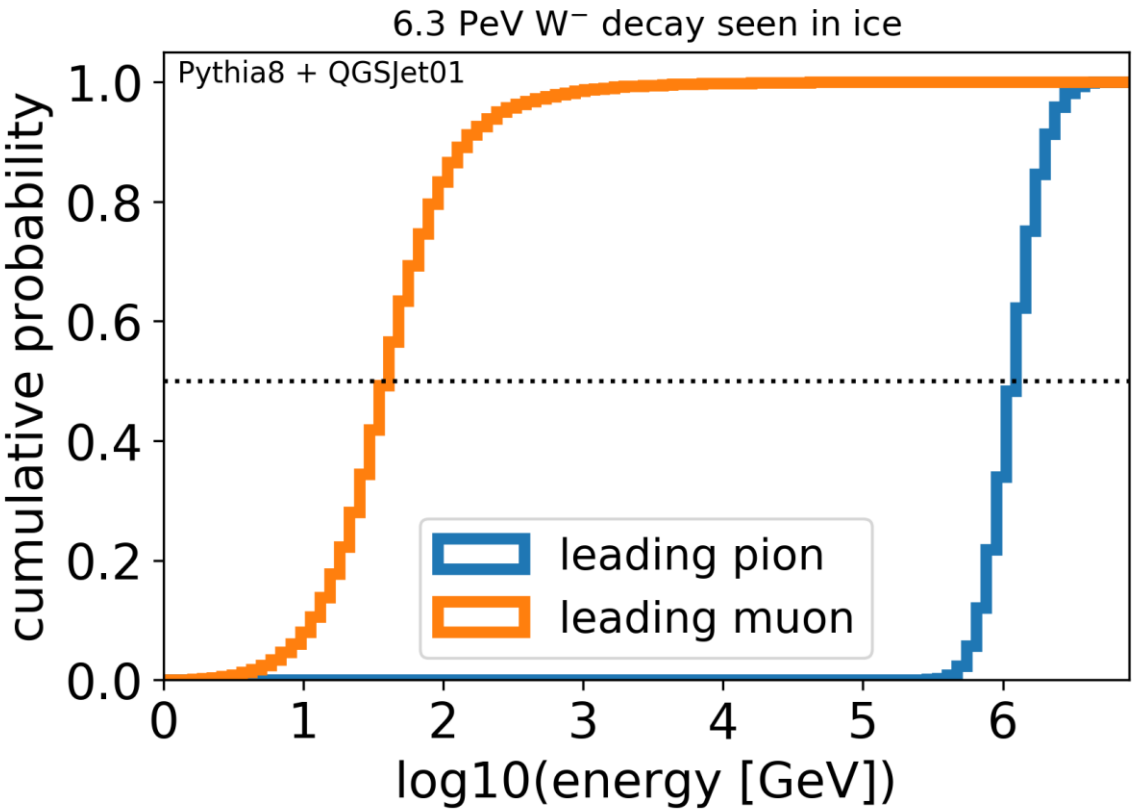
OR

Glashow Resonance

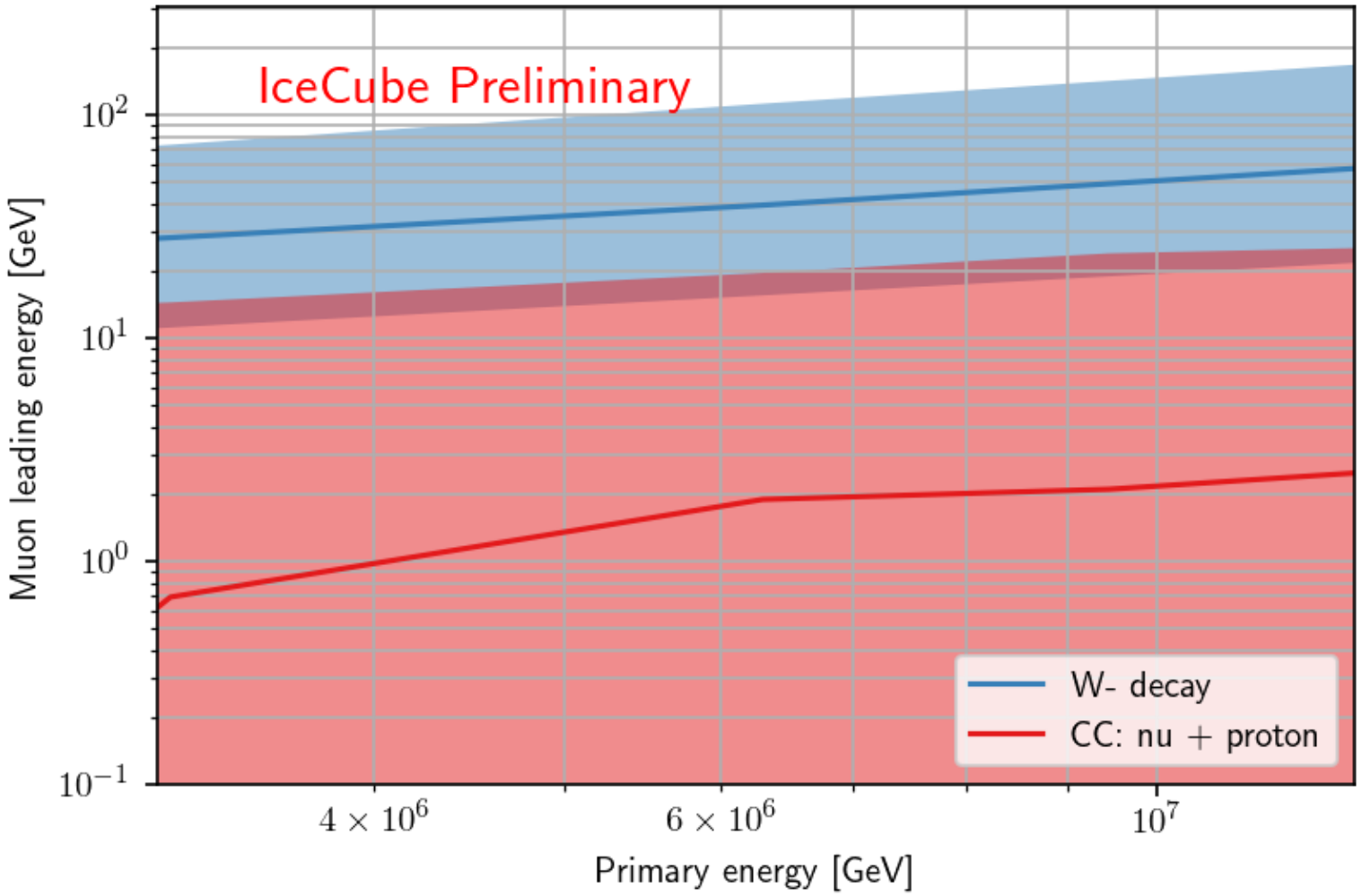


Muon Energy Spectrum from GR

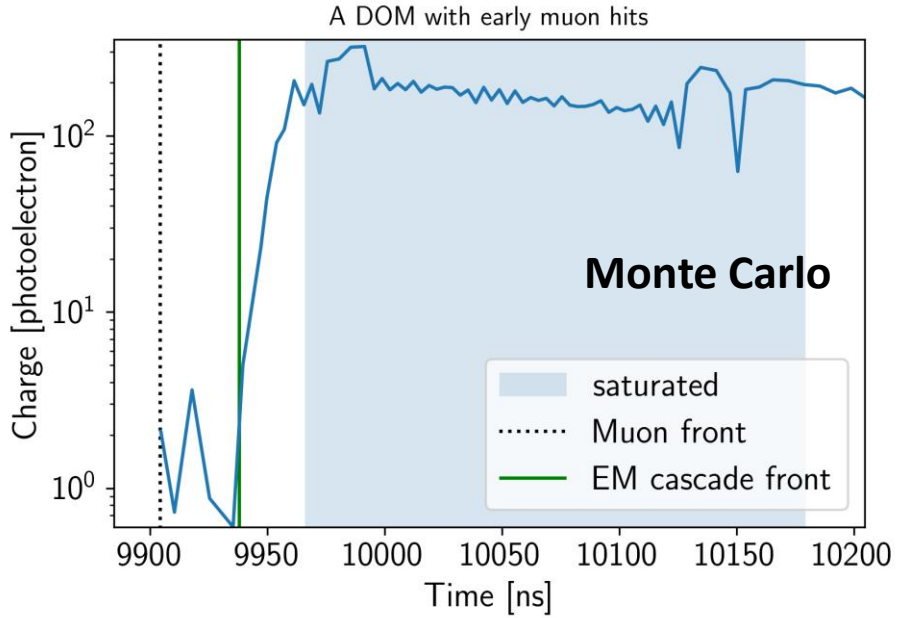


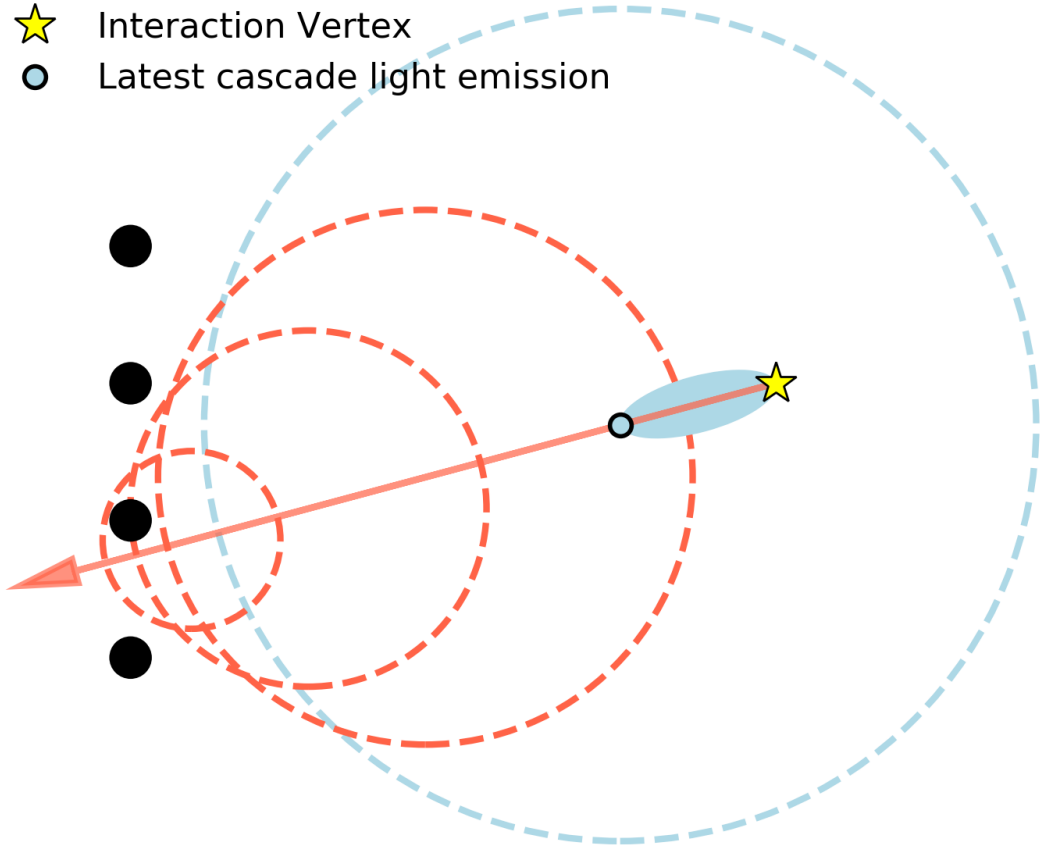


Leading Muon Energies CC/GR



Early Muon Hit Reconstruction (Lollipop)

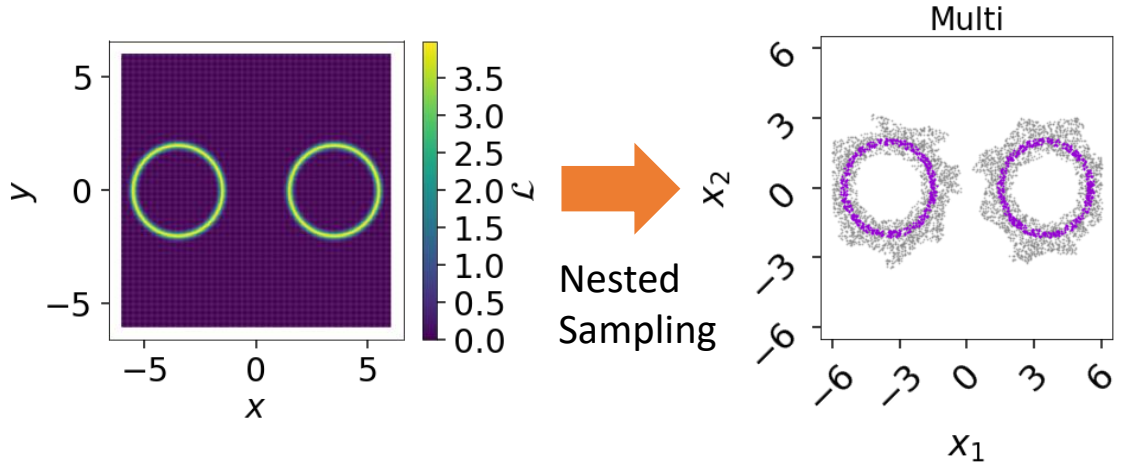




$$t_{\mathrm{casc}} = t_{\mathrm{vertex}} + \frac{|\vec{x}_{\mathrm{DOM}} - \vec{x}_{\mathrm{vertex}}|}{c_{\mathrm{Ice}}}$$

$$t_{\mu} = t_{\mathrm{vertex}} + \frac{|\vec{x}_{\mathrm{DOM}} - \vec{x}_{\mathrm{vertex}}|}{c}$$

Lollipop Reconstruction



$$\mathcal{L}(\vec{x_0}, t_0, \vec{d}) = \prod_{Early\ Pulses\ t_i} P(t_i - t_{geo}, \vec{x}_{DOM} | H(\vec{x_0}, t_0, \vec{d}))$$

Flat prior for direction: $\pi(\vec{d})$

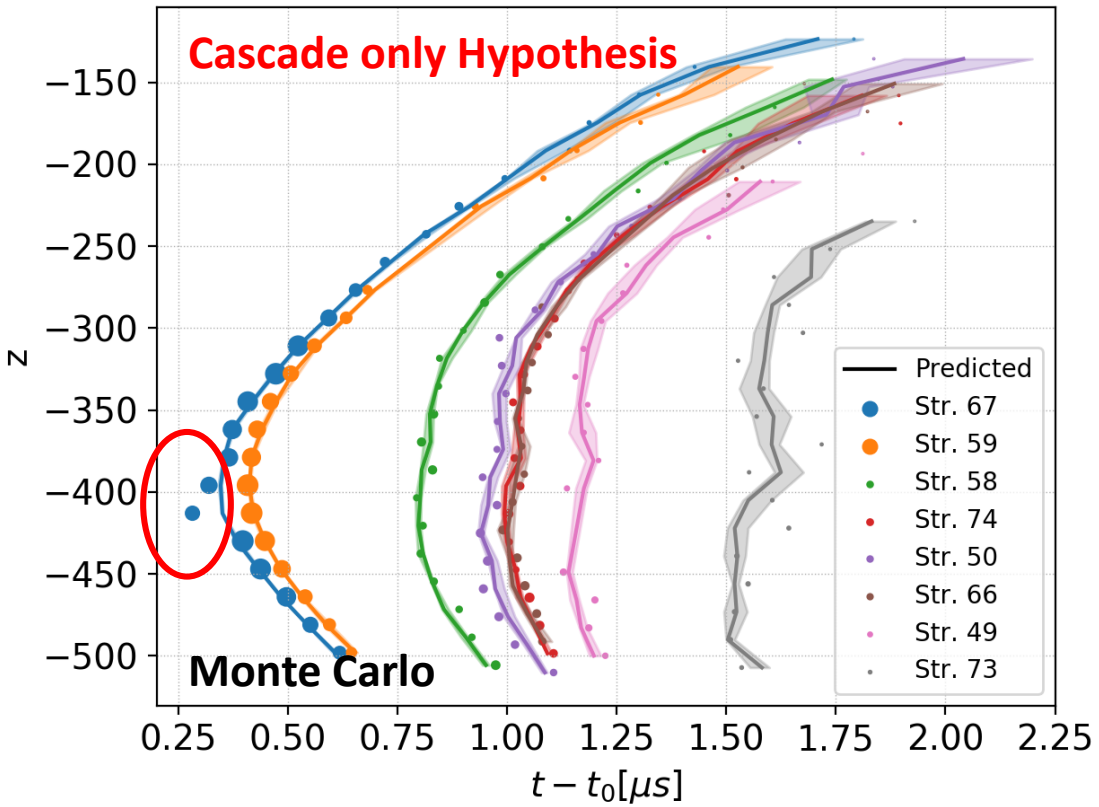
Gaussian prior for time: $\pi(t_0) = N(\mu = 0\,\mathrm{ns}, \sigma = 10\,\mathrm{ns})$

Gaussian prior with cov. from DirectFit for vertex: $\pi(\vec{d}) = N(\mu = \vec{d_{\mathrm{DF}}}, \Sigma = \Sigma_{\mathrm{DF}})$

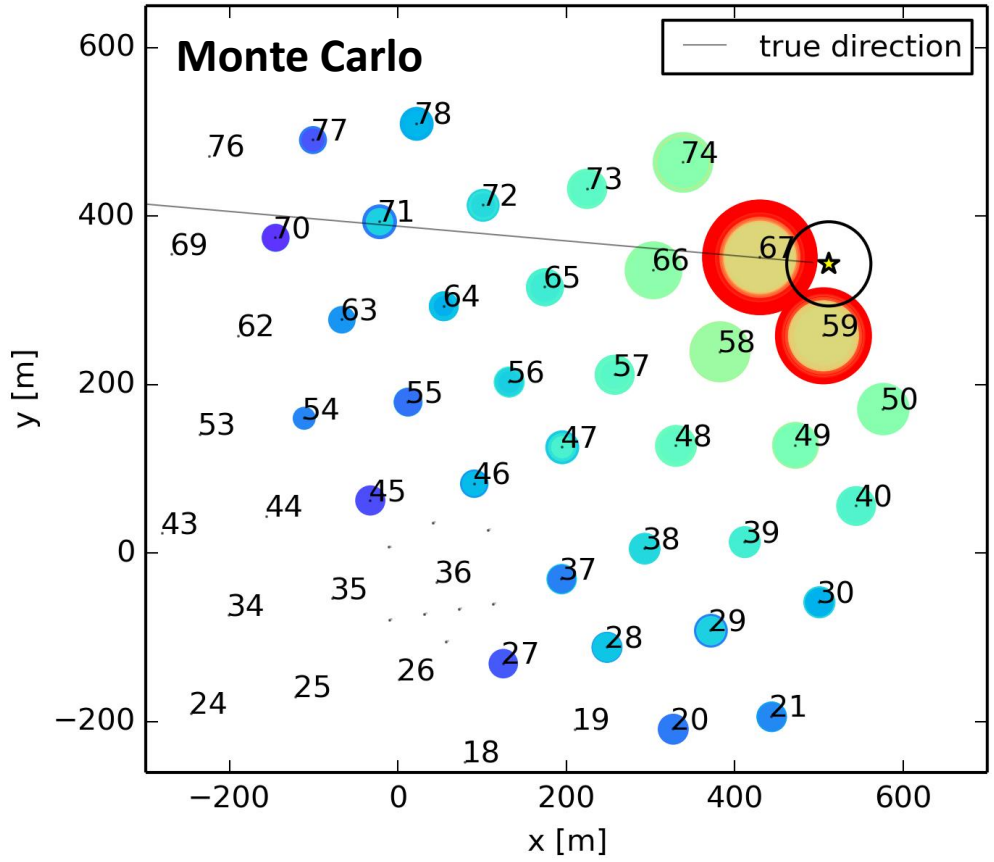
Sample from posterior with nested sampling algorithm:

$$P(t_0, \vec{x}_0, \vec{d} | \text{Early Pulses}) \propto \mathcal{L}(t_0, \vec{x}_0, \vec{d}) \cdot \pi(t_0) \cdot \pi(\vec{x}_0) \cdot \pi(\vec{d})$$

Testing the Reconstruction

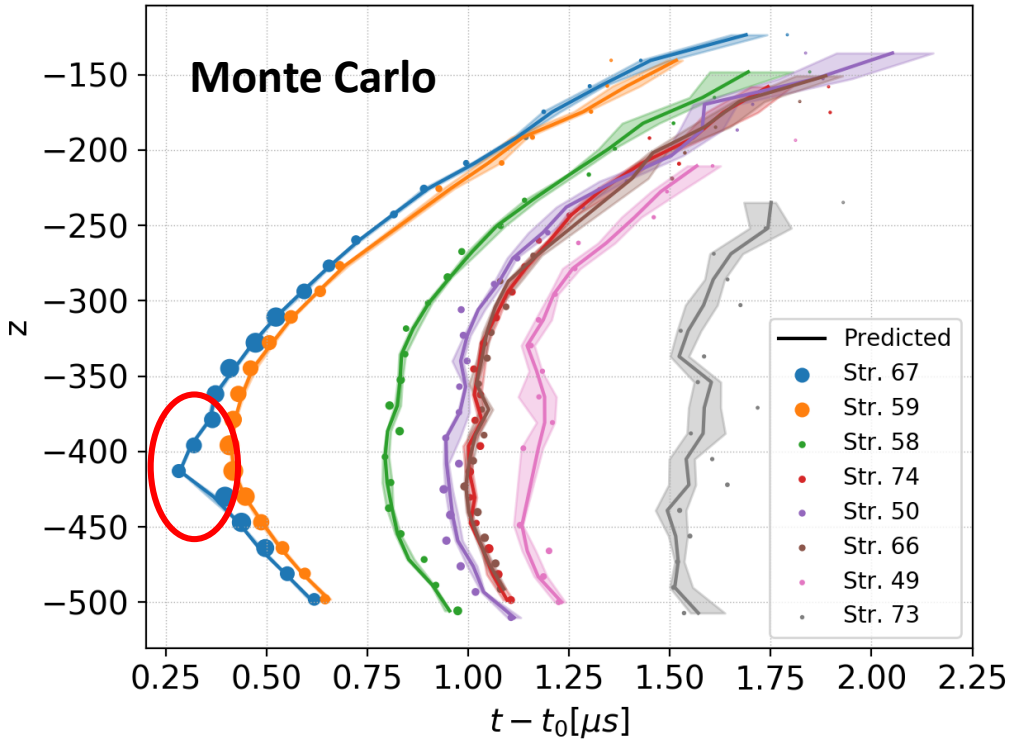


Simulation of a 6PeV hadronic cascade

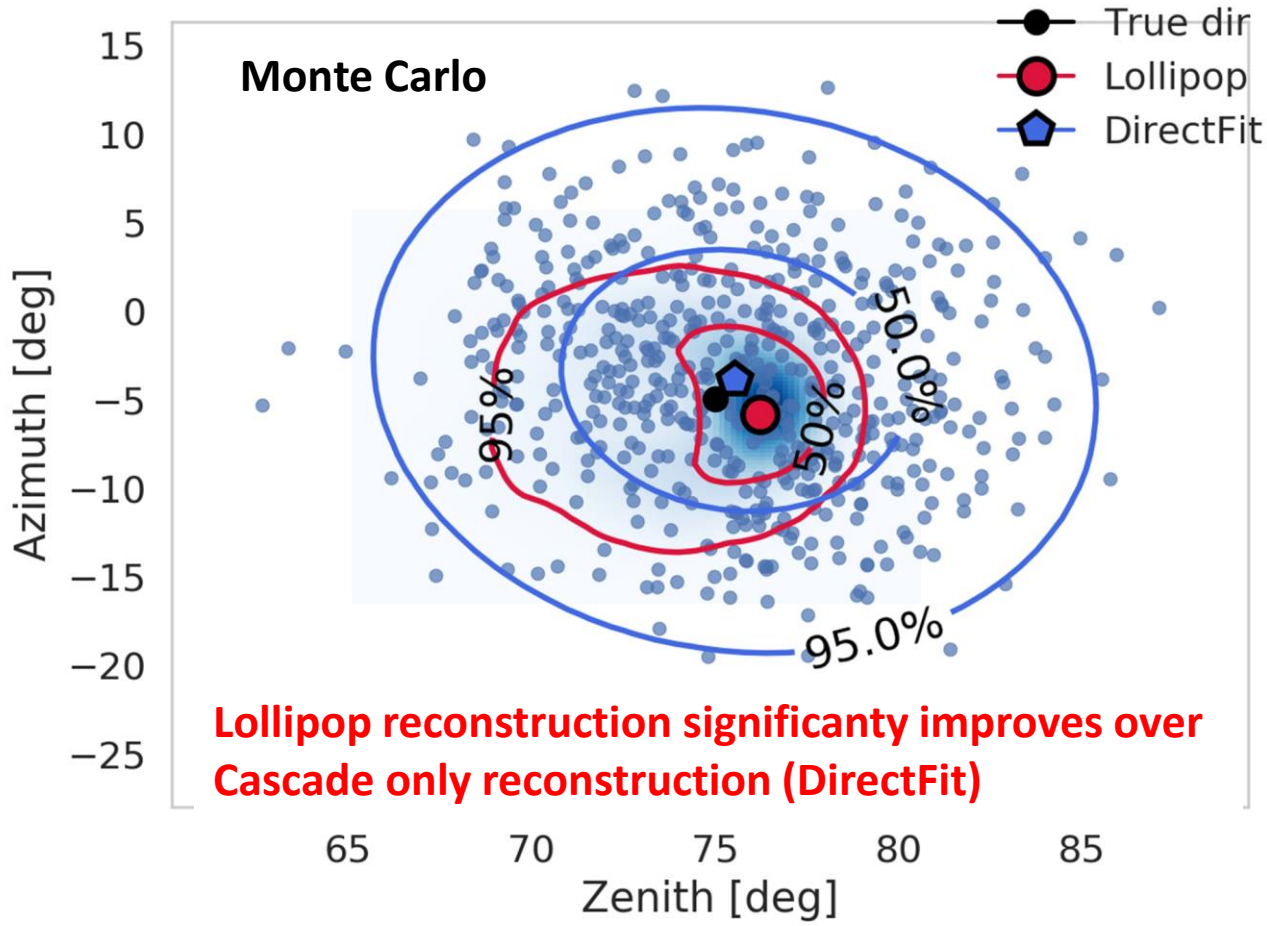


Signature of muonic component clearly visible on closest string

Example Reconstruction Results



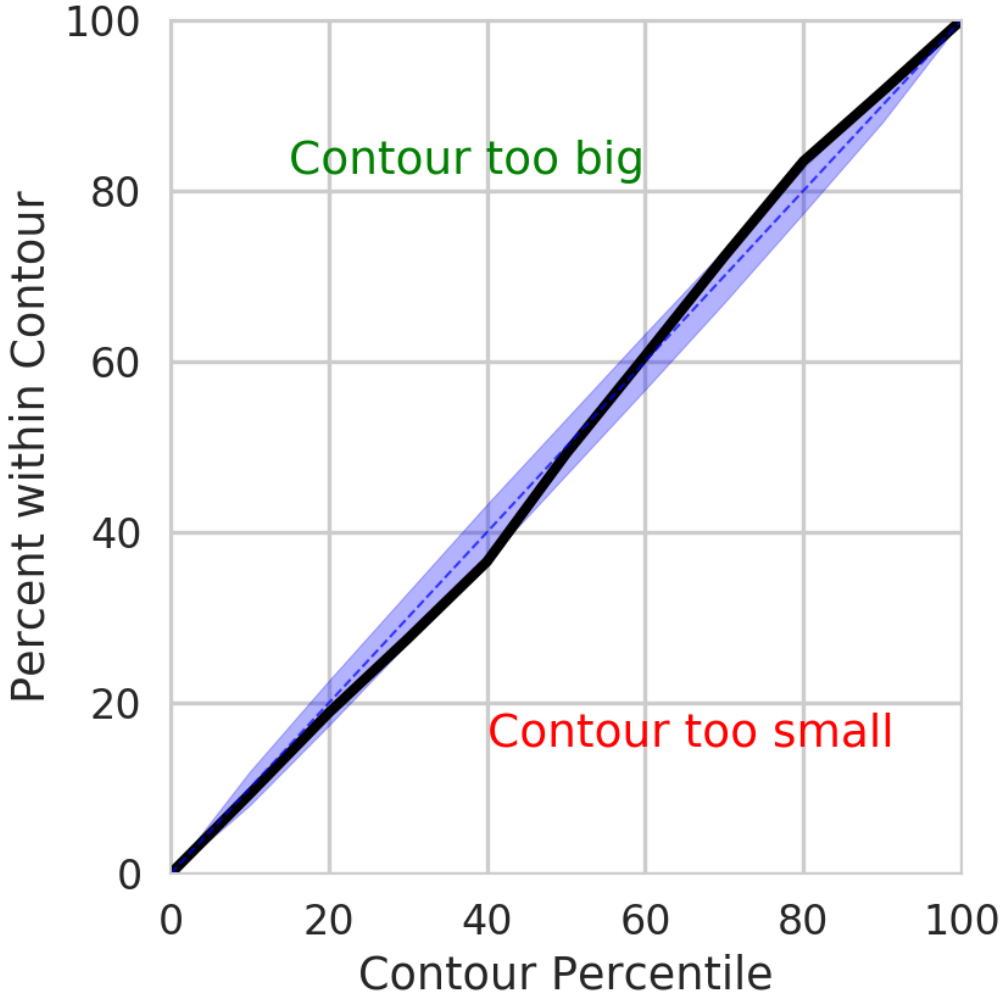
Addition of muonic component describes the early signal



Lollipop reconstruction significanty improves over Cascade only reconstruction (DirectFit)

Contour Coverage

The coverage of the contours obtained from Nested Sampling has been tested by counting how often the true direction lies in a certain contour percentile.



Summary & Outlook

- We have developed a reconstruction technique to specifically reconstruct the faint muonic component in hadronic cascades.
- By using the additional information, we can significantly improve the directional resolution with respect to the cascade-only fit.
- For Glashow-resonance events, the median leading muon energy is ~40GeV
- IceCube has measured a multi-PeV uncontained cascade; results of the reconstruction will be presented next week at UHECR