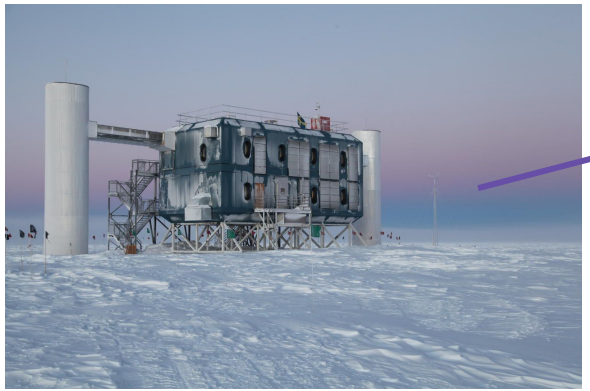
Measuring the inelasticity distribution of neutrino interactions for 100 GeV < E_ν < 1 TeV with IceCube DeepCore

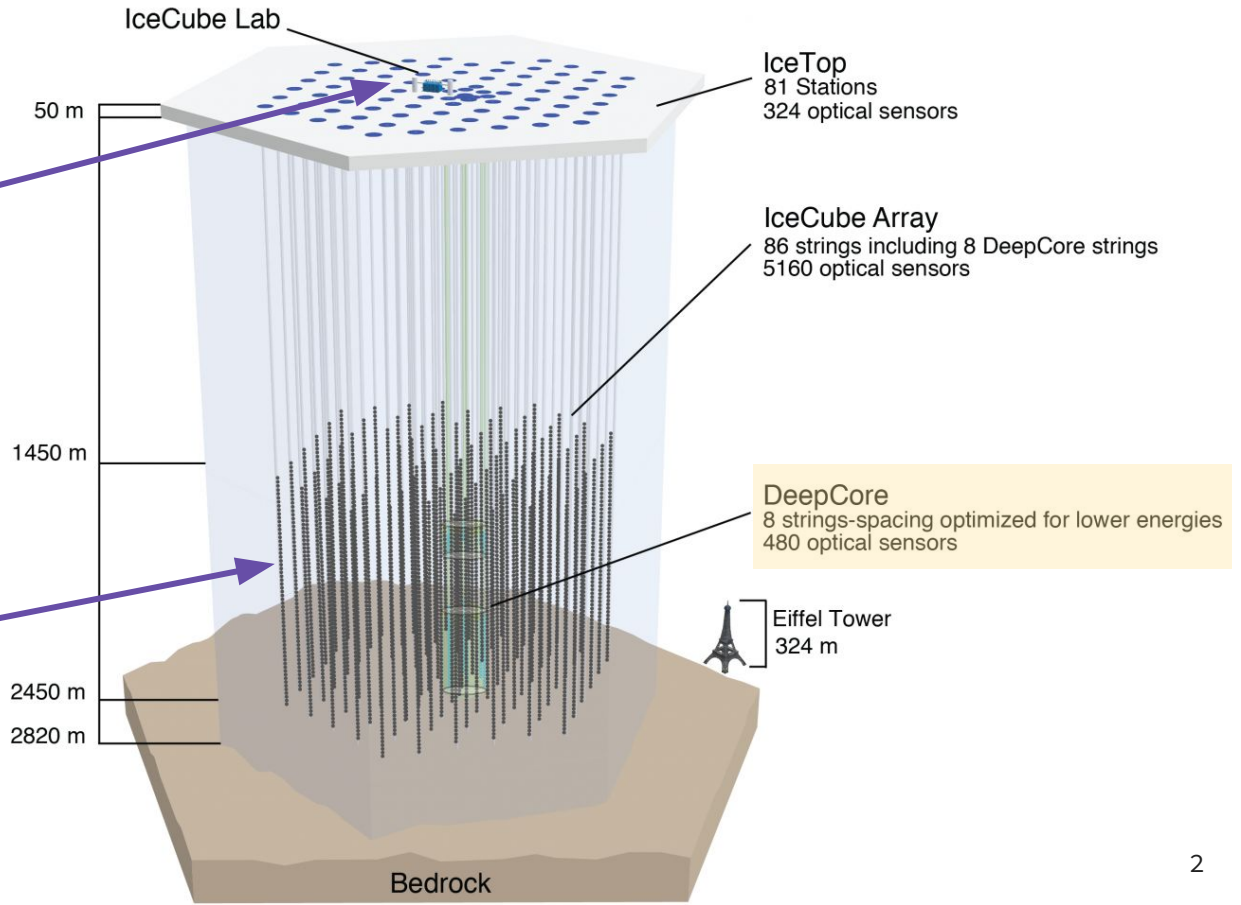
Maria Liubarska

June 8

CAP 2022

IceCube




IceCube Lab
IceTop
81 Stations
324 optical sensors
50 m
IceCube Array
86 strings including 8 DeepCore strings
5160 optical sensors
1450 m
DeepCore
8 strings-spacing optimized for lower energies
480 optical sensors
Eiffel Tower
324 m
2450 m
2820 m
Bedrock

Inelasticity

★ Inelasticity is a fraction of neutrino energy transferred to the hadronic system in an inelastic interaction

$$y = \frac{E_{hadr}}{E_\nu}$$

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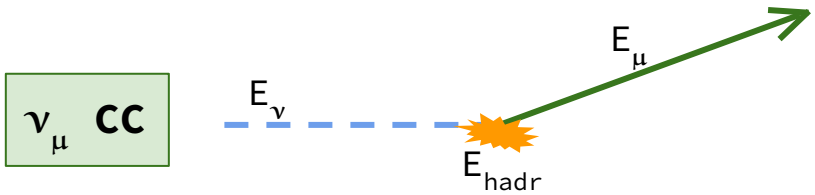
★ Inelastic scattering cross sections depend on inelasticity

✧ **DIS cross section:**

$$\frac{d^2\sigma_{CC}^{\nu N}}{dxdy} = 2x\sigma_0 \left(\sum_{d,s} f_q^N(x) + (1-y)^2 \sum_{\bar{u},\bar{c}} f_{\bar{q}}^N(x) \right)$$

Inelasticity in IceCube

★ In IceCube, inelasticity can be reliably reconstructed for ν_μ CC events



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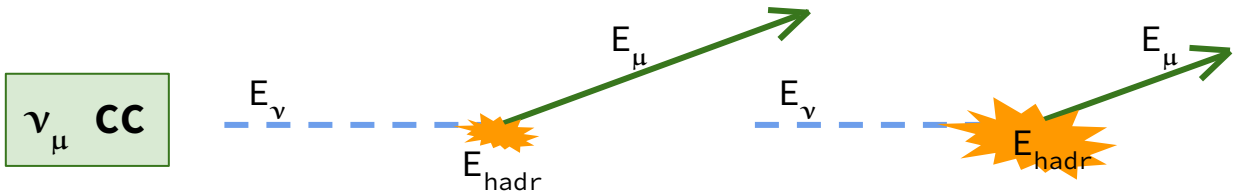

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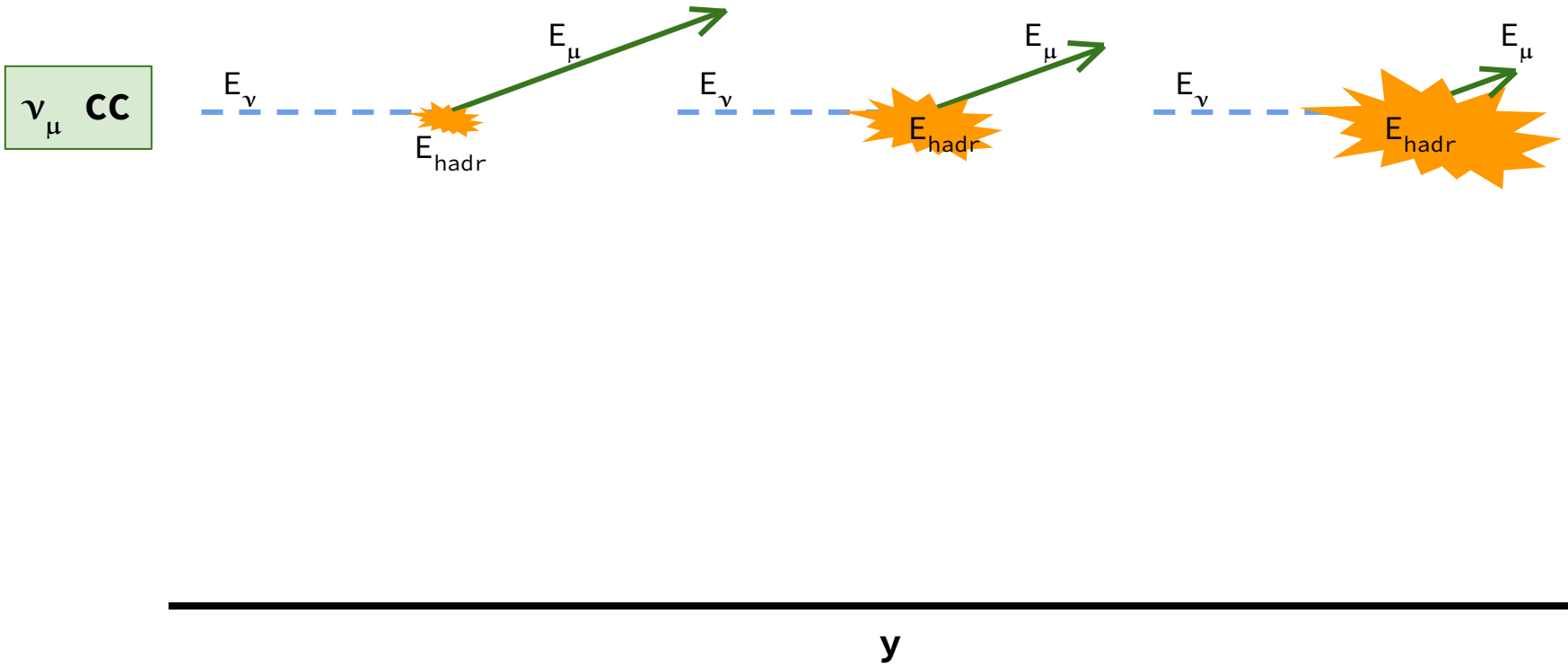

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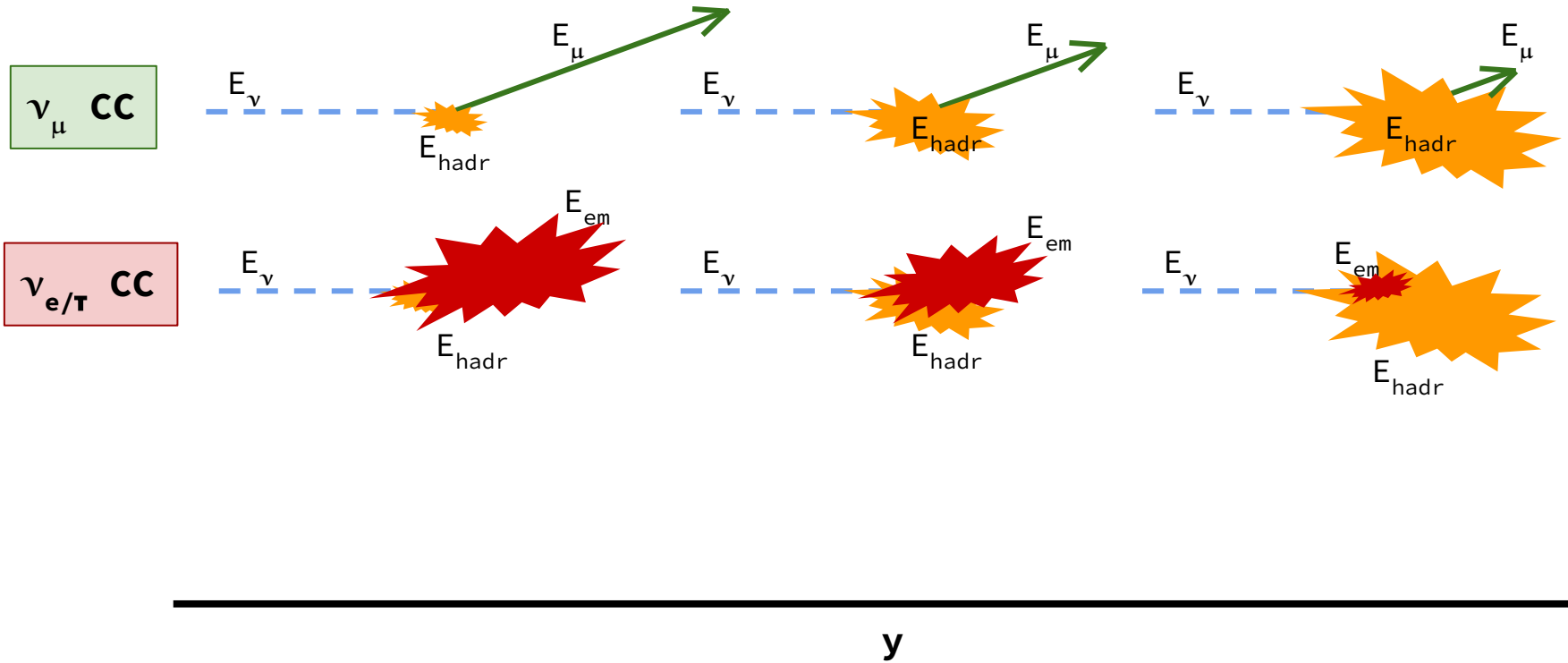

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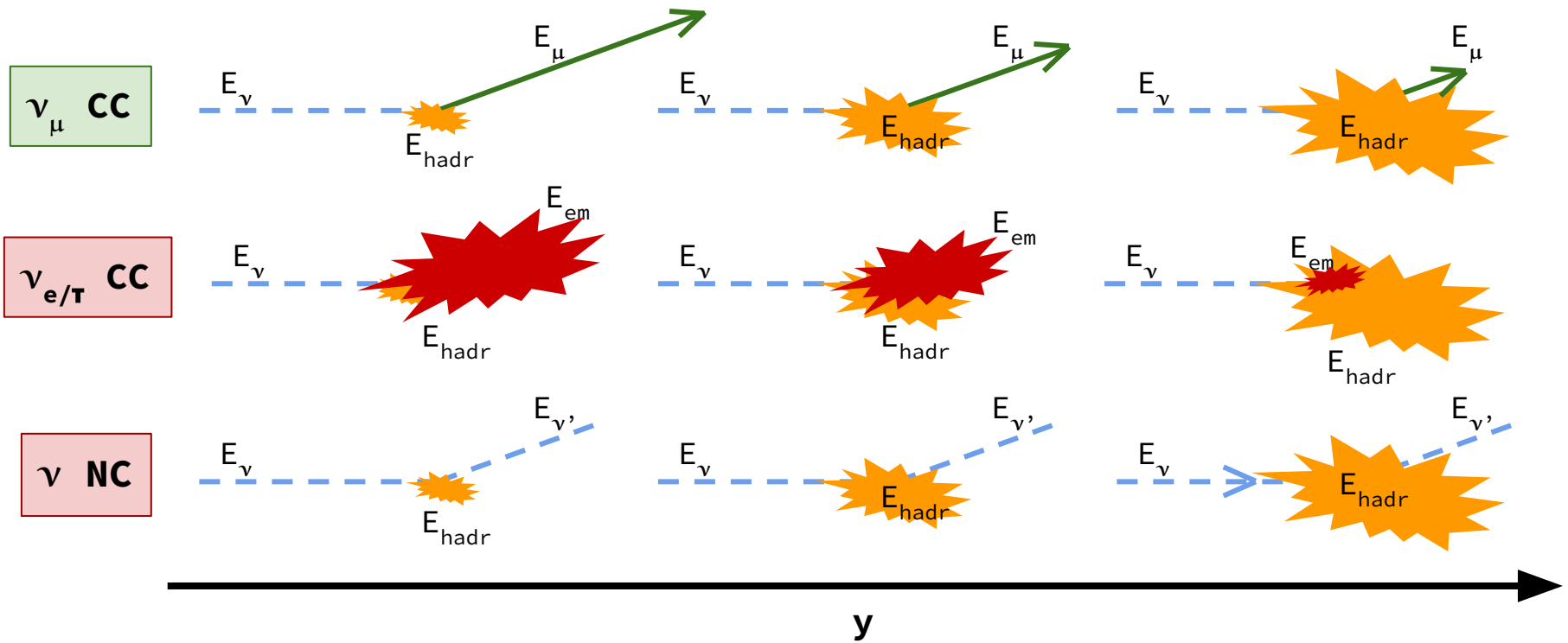
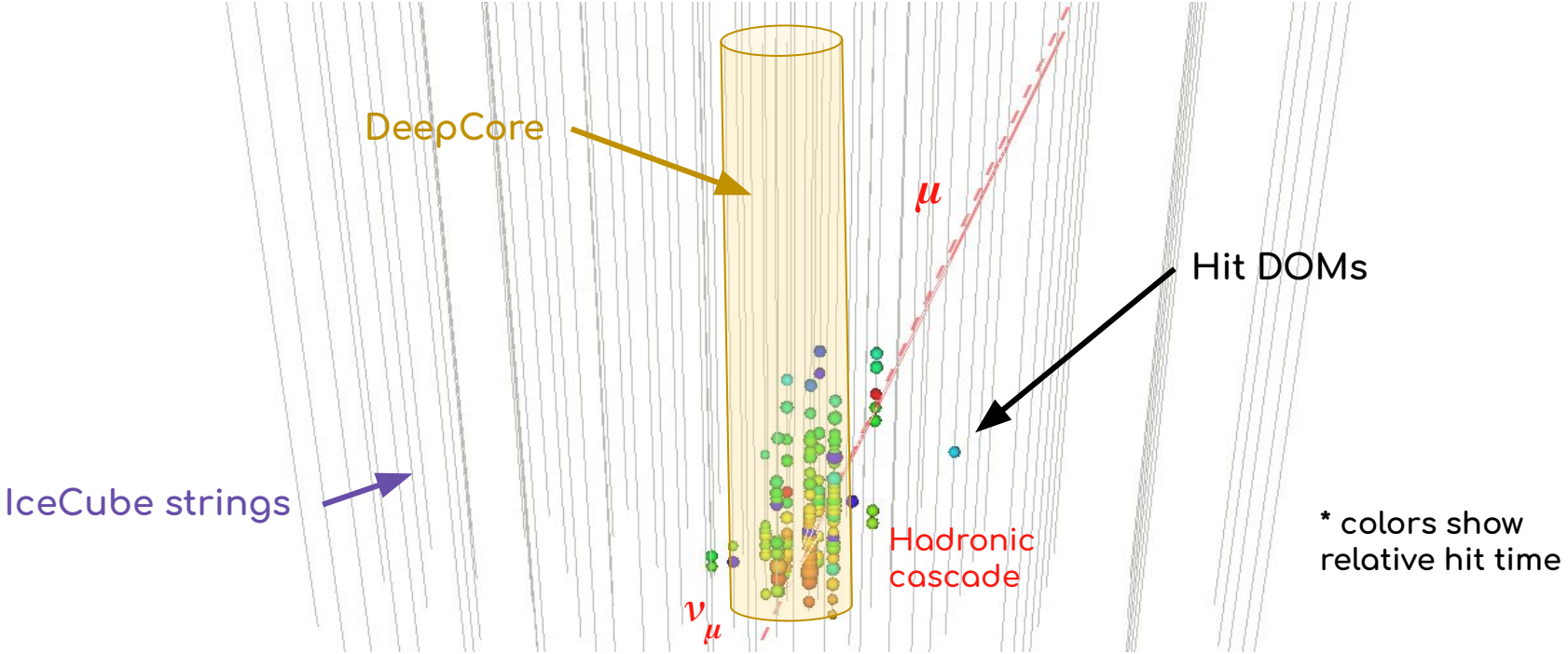


Example event view

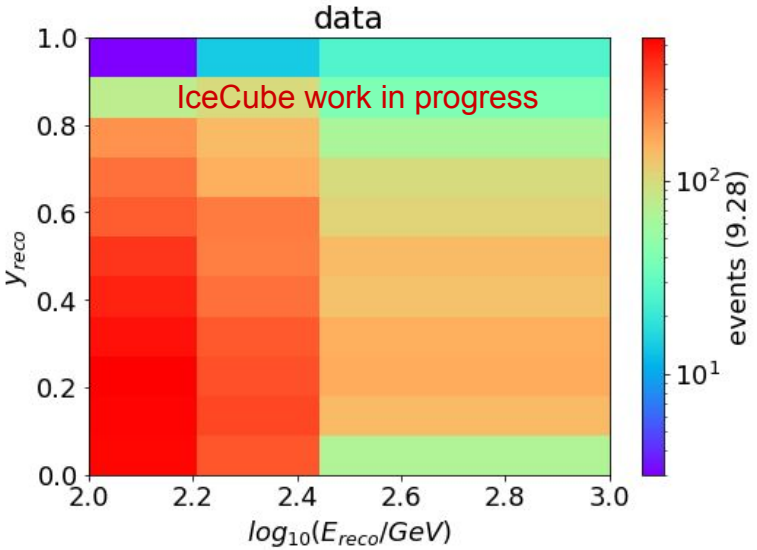
★ Example ν_μ CC interaction in DeepCore

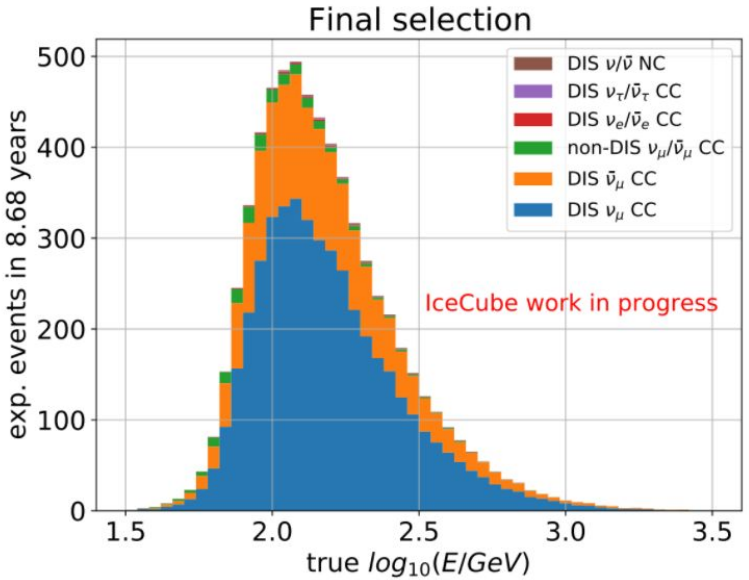


Event sample

★ Well reconstructed ν_μ CC events >100 GeV starting inside DeepCore

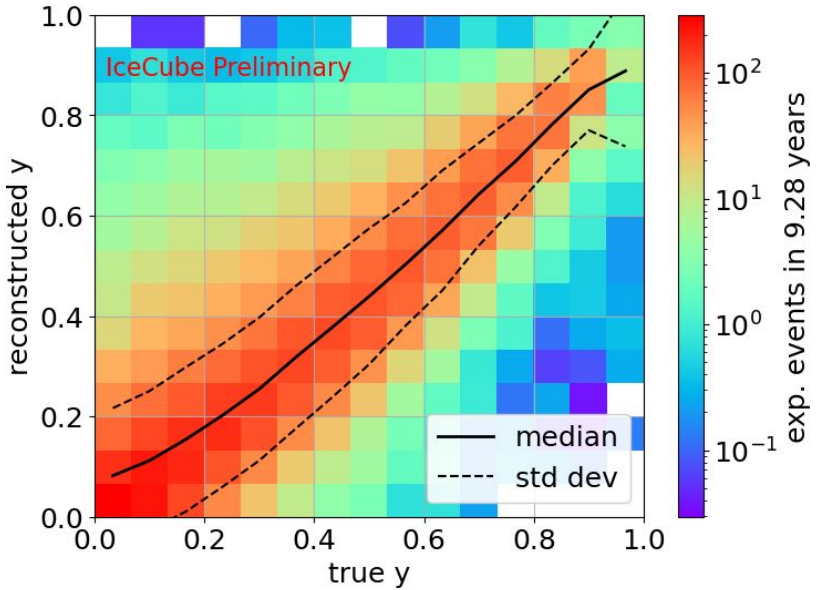
★ 99% pure ν_μ CC sample





Reconstructed inelasticity

- ★ Using new IceCube reconstruction algorithm
- ★ Good correlation between true and reconstructed inelasticity!
  - ✧ Final level resolutions for ν_μ CC events:



Fitting inelasticity distribution

★ Using approximate parametrization for true inelasticity distribution with two independent parameters, **<y>** and **$\log_{10}\lambda$**

$$\frac{dp}{dy}(\langle y\rangle, \lambda) \equiv \frac{1}{\sigma}\frac{d\sigma}{dy}(\langle y\rangle, \lambda) =$$

$$= N(\langle y\rangle, \lambda) \cdot (1 + \epsilon(\langle y\rangle, \lambda) \cdot (1 - y)^2) \cdot y^{\lambda-1}$$

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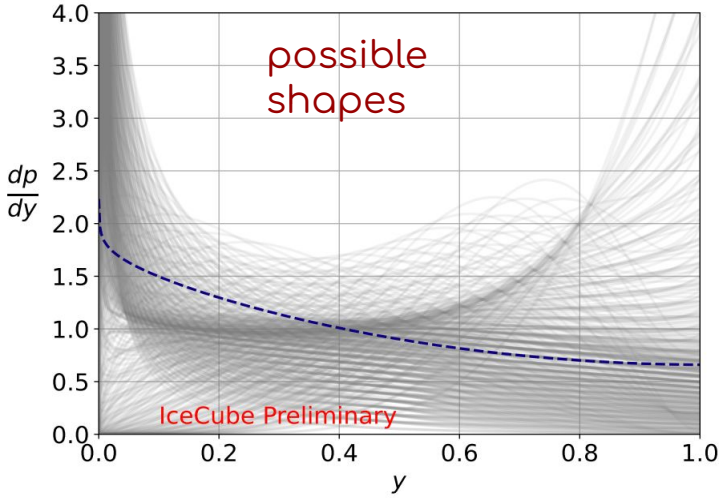

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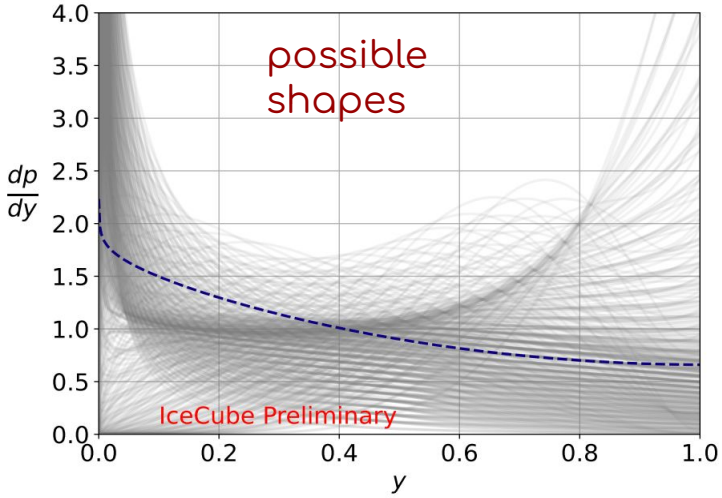


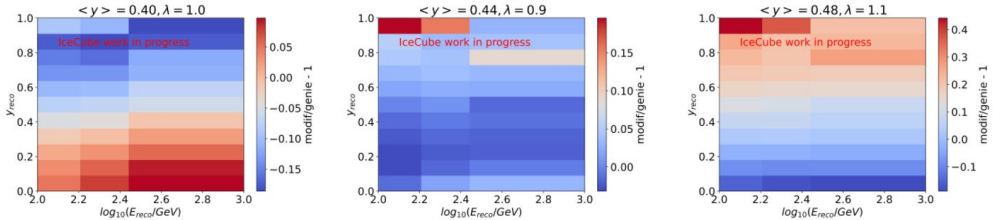
★ Measuring shape of **flux-averaged inelasticity distribution**

$$\frac{dp}{dy}_{fl.\,av.}(E) = \tilde{\Phi}_{\nu}(\Phi, \sigma, sel.; E) \cdot \frac{dp}{dy}_{\nu}(E) + \tilde{\Phi}_{\bar{\nu}}(\Phi, \sigma, sel.; E) \cdot \frac{dp}{dy}_{\bar{\nu}}(E)$$

detected flux

Systematic uncertainties

Modifications from physics parameters



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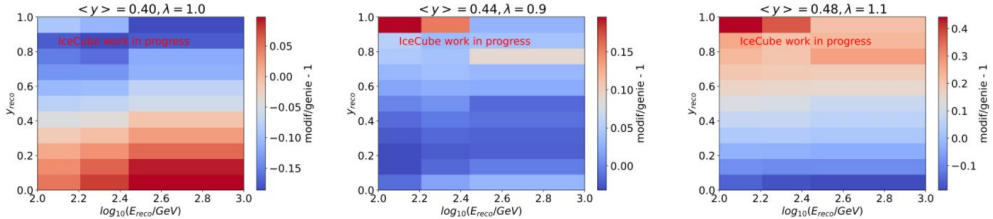
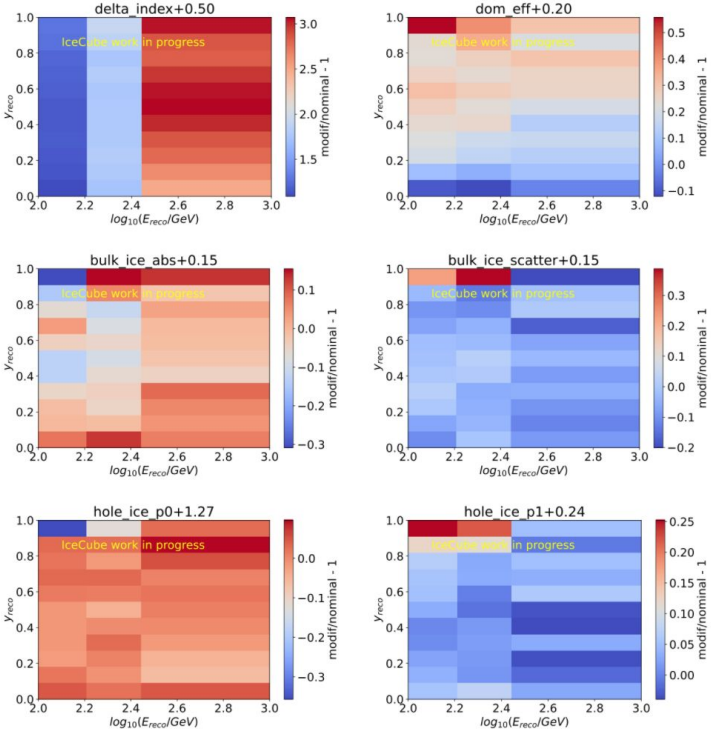


Group	Systematic	Nominal value	Prior	Range
Flux	delta_index	0.0	± 0.1	[-0.5, 0.5]
Detector	dom_eff	1.0	± 0.1	[0.8, 1.2]
	bulk_ice_abs	1.0	uniform	[0.85, 1.15]
	bulk_ice_scatter	1.0	uniform	[0.85, 1.15]
	hole_ice_p0	-0.2674	± 0.6	[-2.0, 1.0]
	hole_ice_p1	-0.04206	± 0.12	[-0.2, 0.2]
Normalization	aeff_scale	1.0	uniform	[0.0, 3.0]

Table 5.1: Summary of the settings for nuisance parameters used in the analysis.

Modifications from nuisance parameters



Results

Measurement results

- ★ Forward folding method
- ★ Fit p-value = 9.5%

Physics parameters

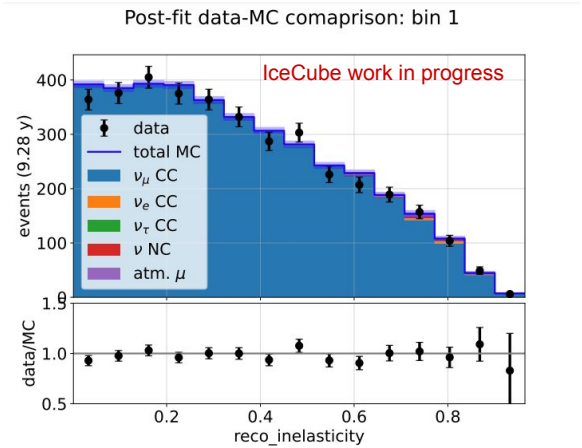
Parameter	Best fit
<y> bin 1	**0.45** ± 0.02 ± 0.005
<y> bin 2	**0.46** ± 0.02 ± 0.004
<y> bin 3	**0.45** ± 0.02 ± 0.006
$\log_{10}\lambda$ bin 1	**0.02** ± (+0.09, -0.12)
$\log_{10}\lambda$ bin 2	**0.10** ± (+0.06, -0.05)
$\log_{10}\lambda$ bin 3	**0.10** ± (+0.05, -0.04)

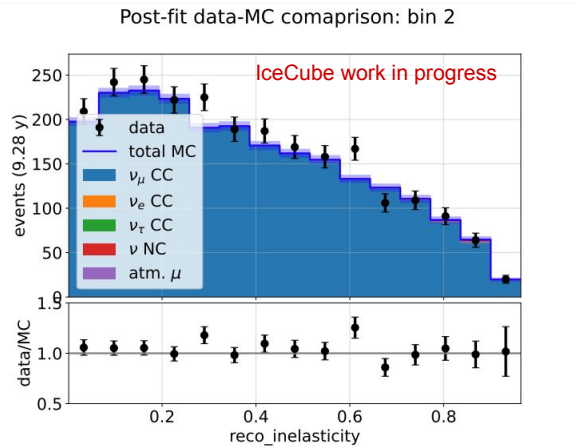
Nuisance parameters

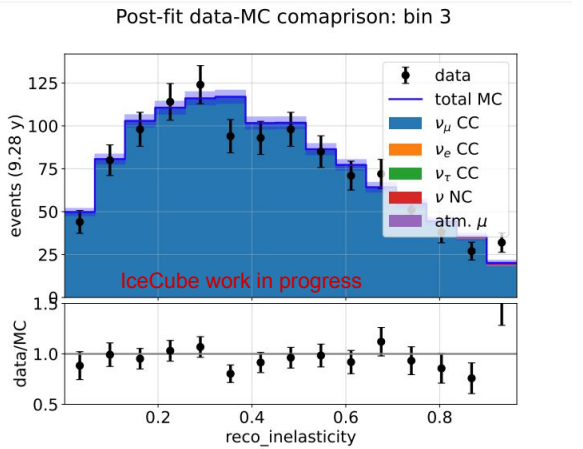
Parameter	Best fit
delta_index	0.114
dom_eff	1.069
bulk_ice_abs	0.999
bulk_ice_scattering	1.014
hole_ice_p0	-0.599
hole_ice_p1	-0.023
aeff_scale	0.777

Data-MC agreement

★ Observed good post-fit data-MC agreement in all control variables

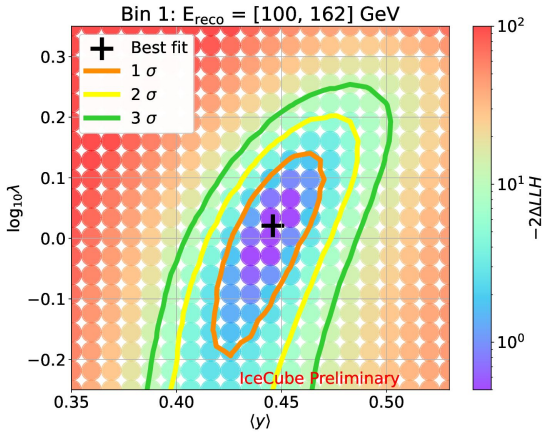


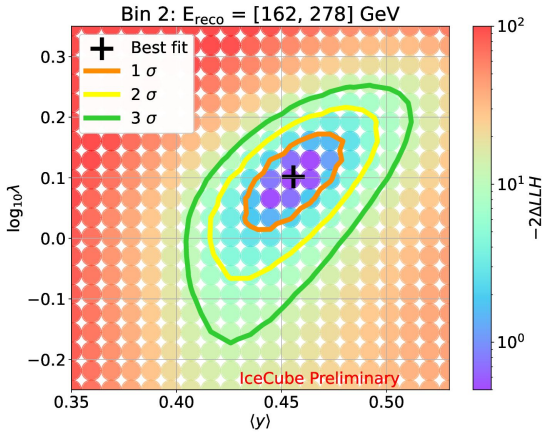


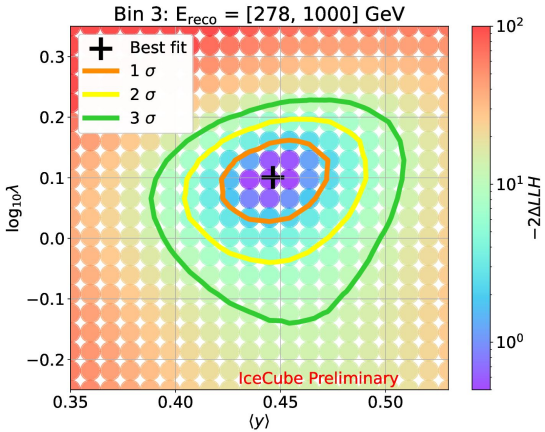


Results in (<y>, λ) space

★ Best fit points for a set of physics parameters in each of three energy bins

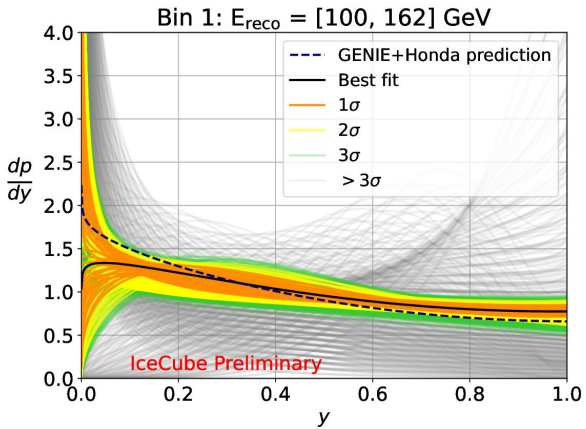


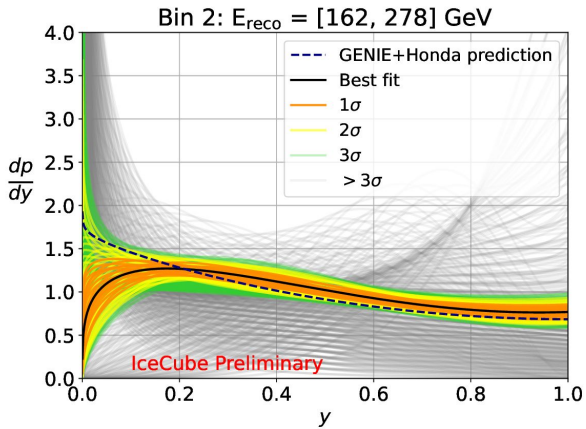


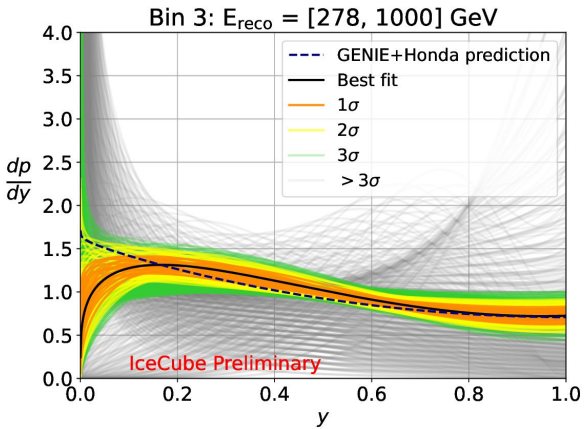


Inelasticity distribution shapes

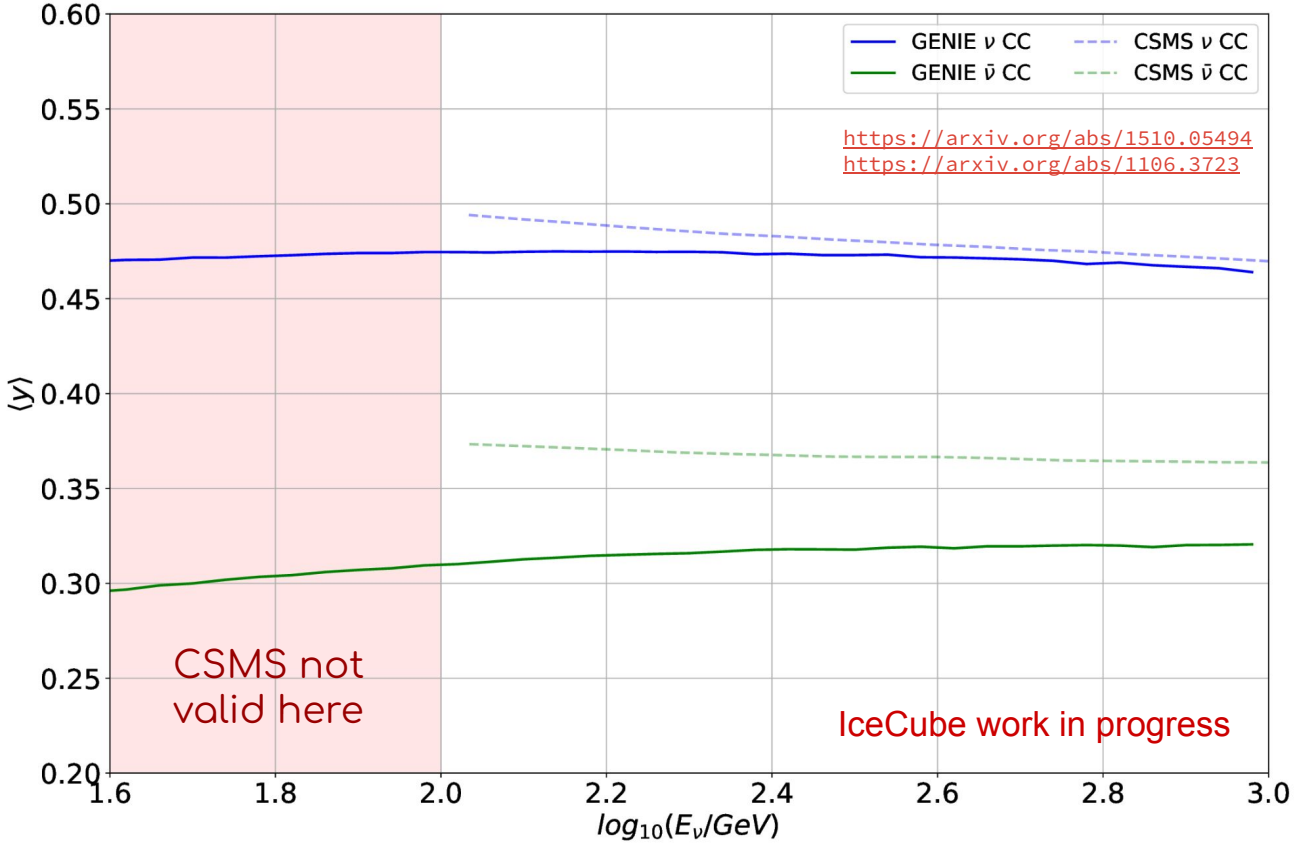
★ Inelasticity distribution shapes corresponding to the best fit values of physics parameters for each of energy bins







Comparison to model predictions



* here GENIE is inclusive cross section and CSMS is DIS-only

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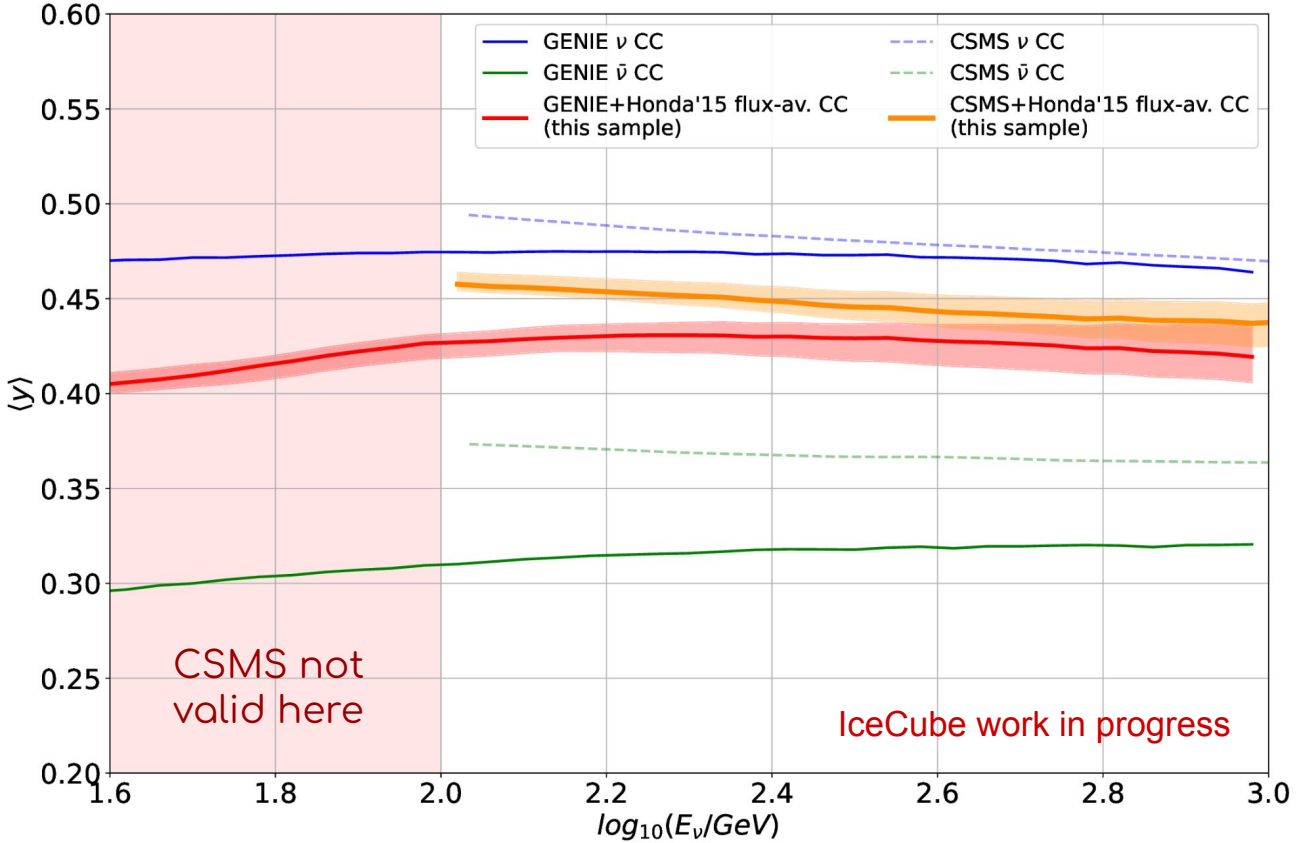

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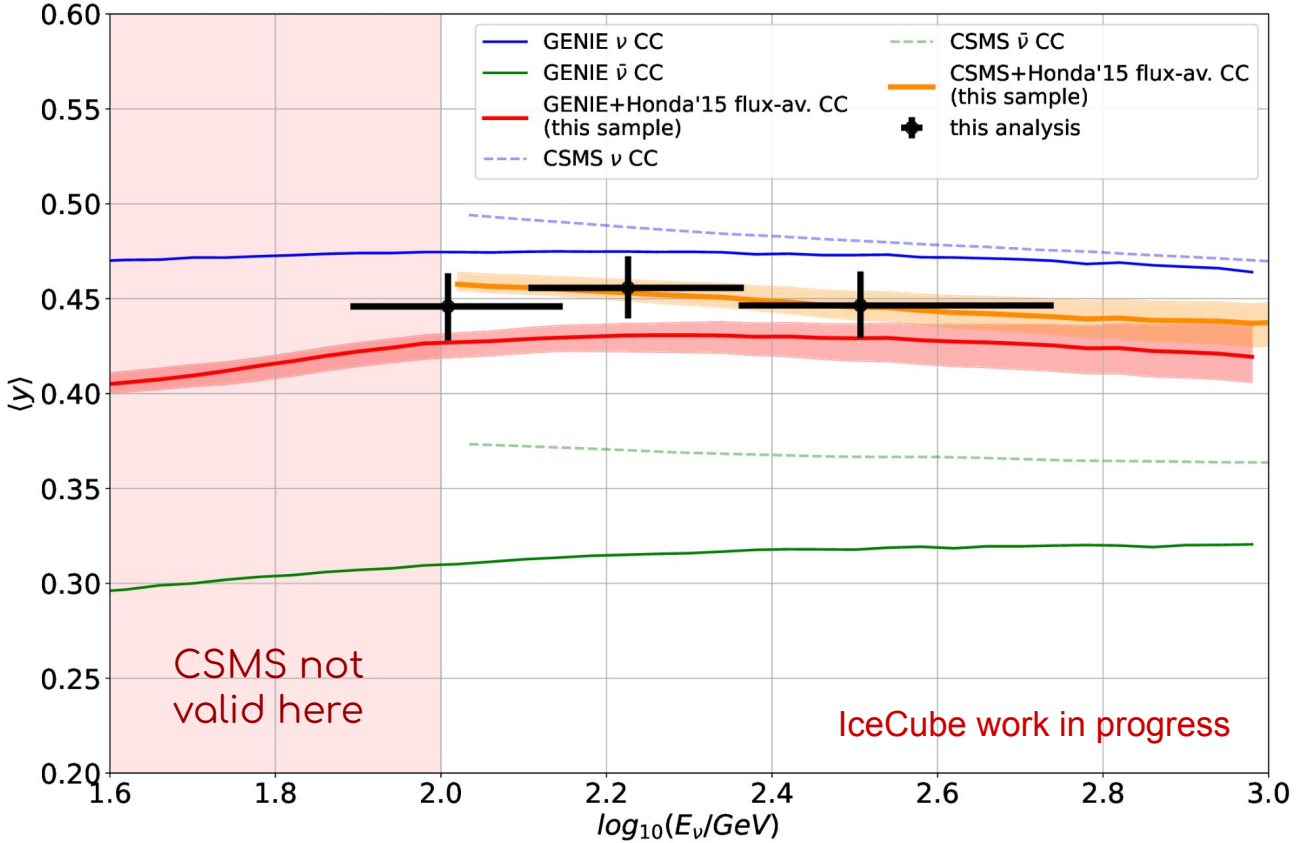

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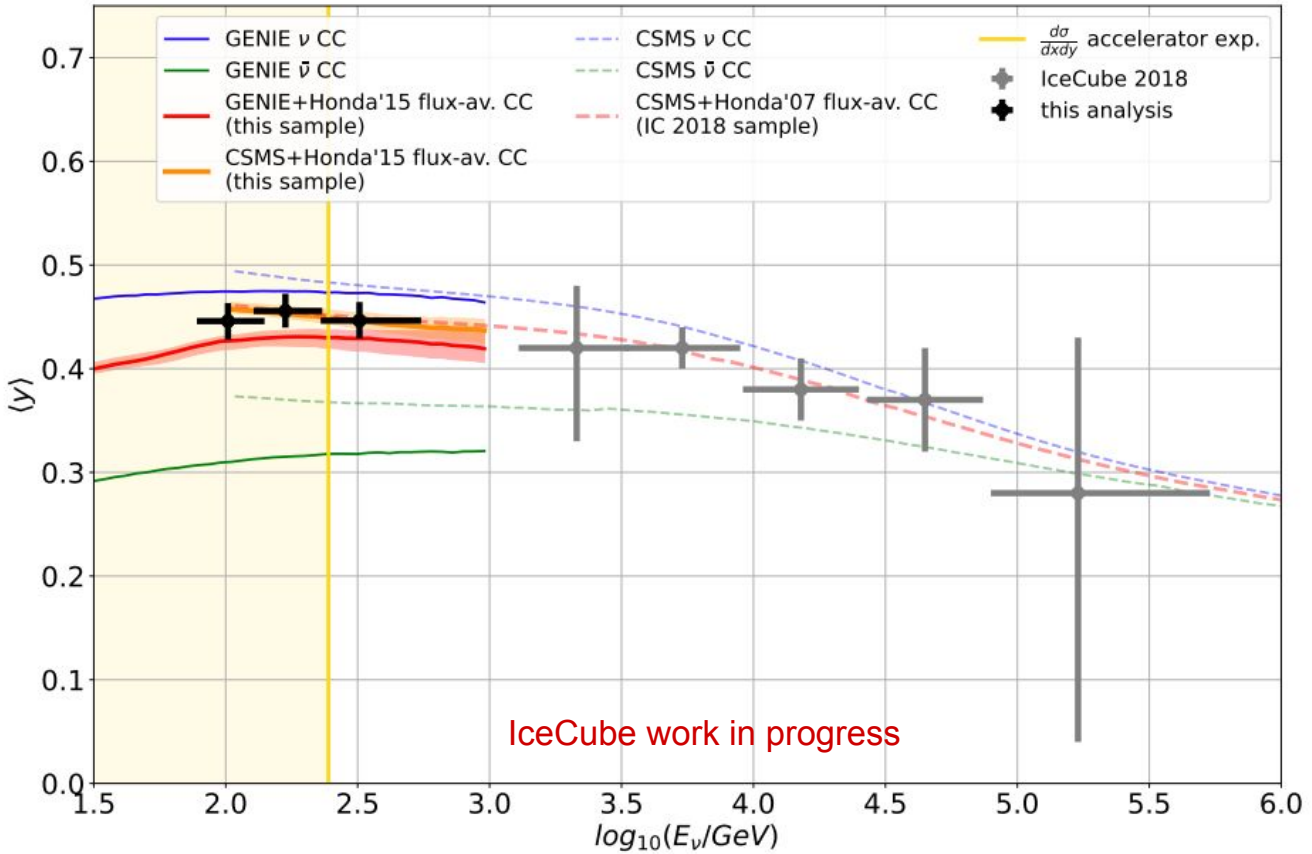
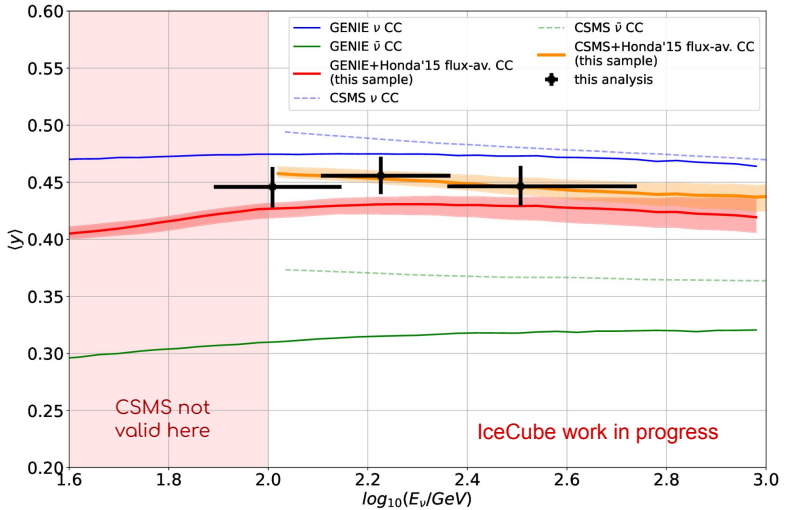


https://arxiv.org/abs/1808.07629

Summary

- ★ New measurement of flux-averaged inelasticity distribution at neutrino energies from 100 GeV to 1 TeV
- ★ Our data favors CSMS+Honda prediction and we see a ~1**σ** tension with GENIE+Honda prediction



Thank you!

Backup

Results - best fit values & λ

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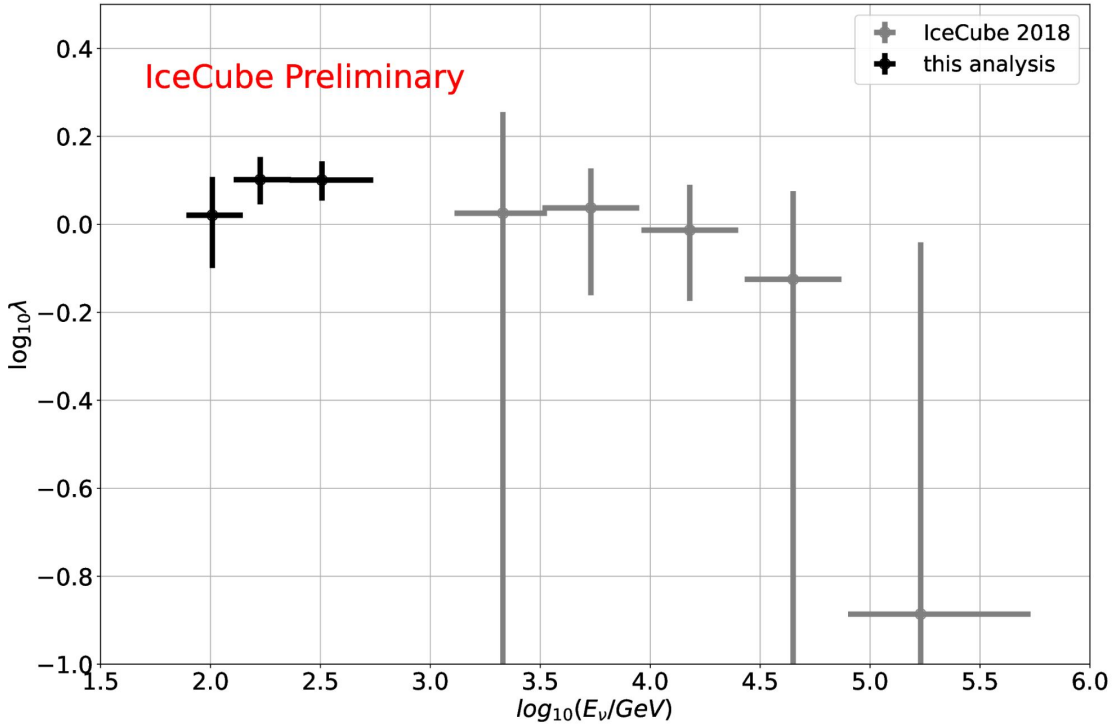
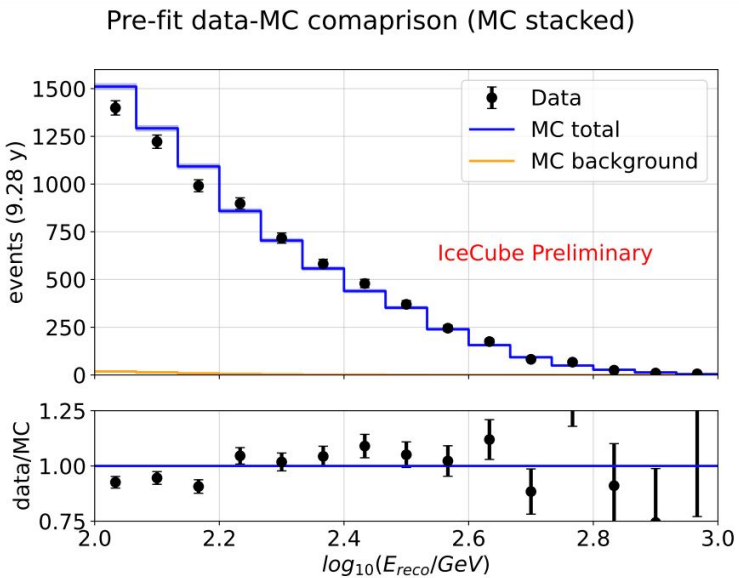
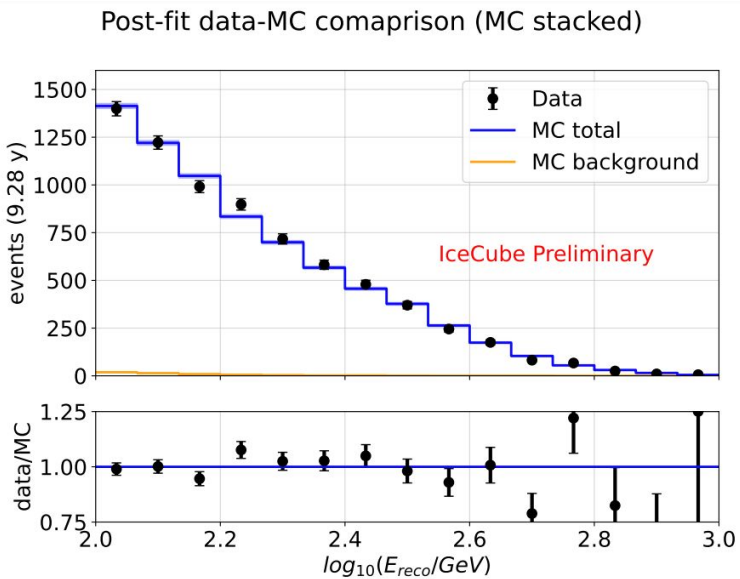
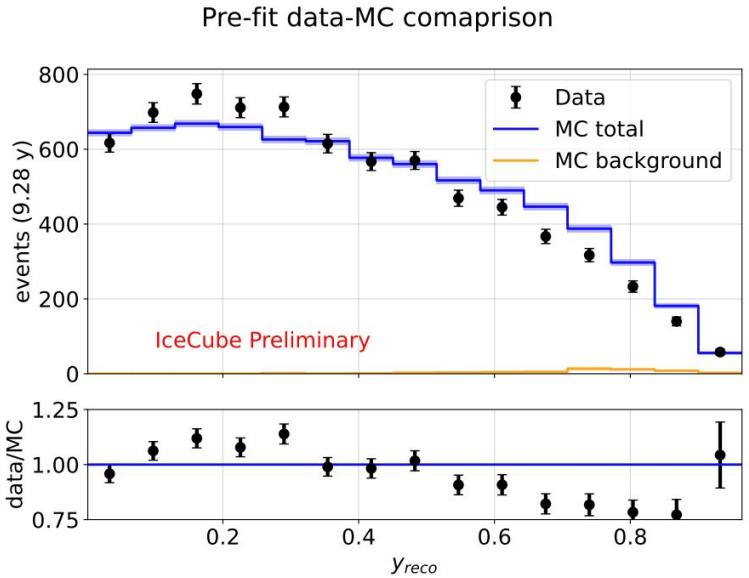


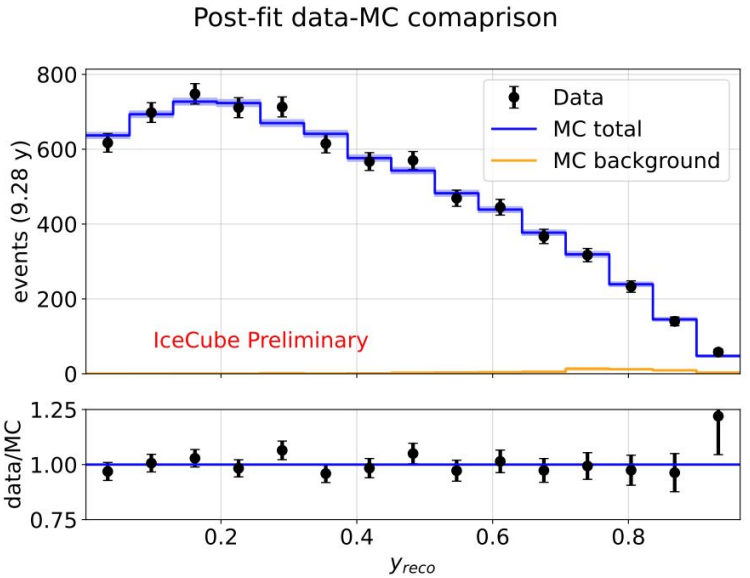
Data-MC comparisons for reco energy





Data-MC comparisons for reco inelasticity





Analysis implementation

- Inelasticity parametrization implemented in PISA4
  - Analysis framework used in Oscillations WG for oscillation and other low-energy analyses
- Measurement is based on the shape of the distribution
- Fitting inelasticity distribution in all bins simultaneously
- Nuisance parameters shared between all bins

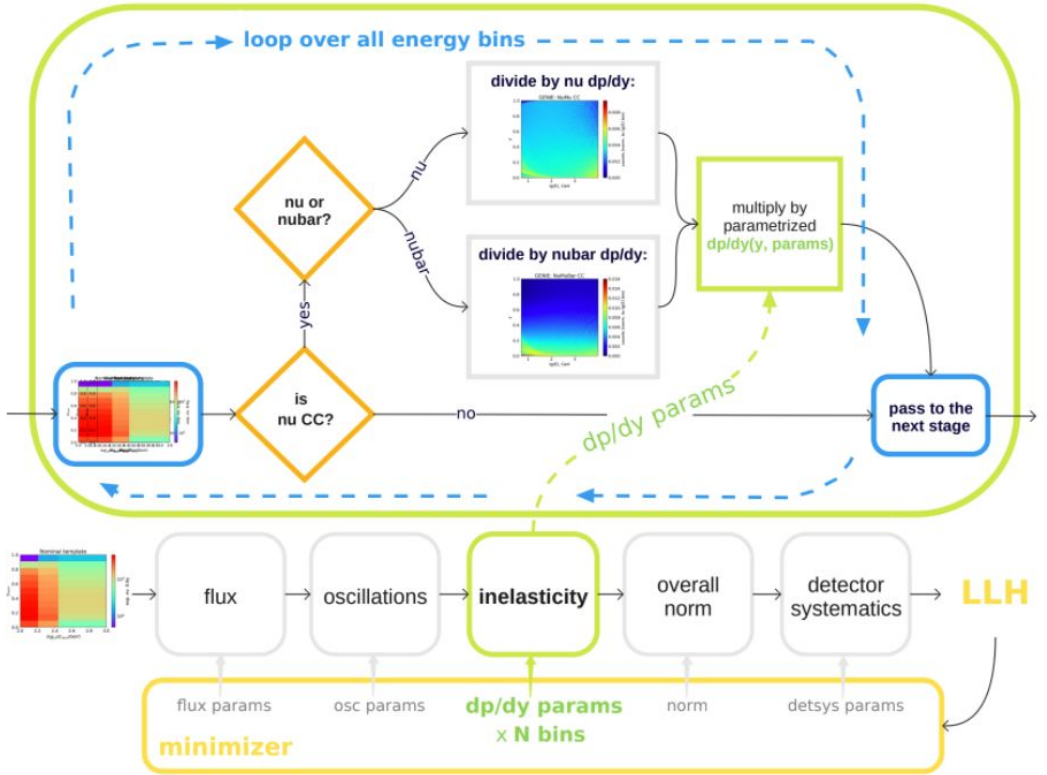


Figure 4.8: Flowchart of the analysis and inelasticity distribution reweighting (reweighting of the muon component is omitted for the simplicity).

Allowed physics parameter space

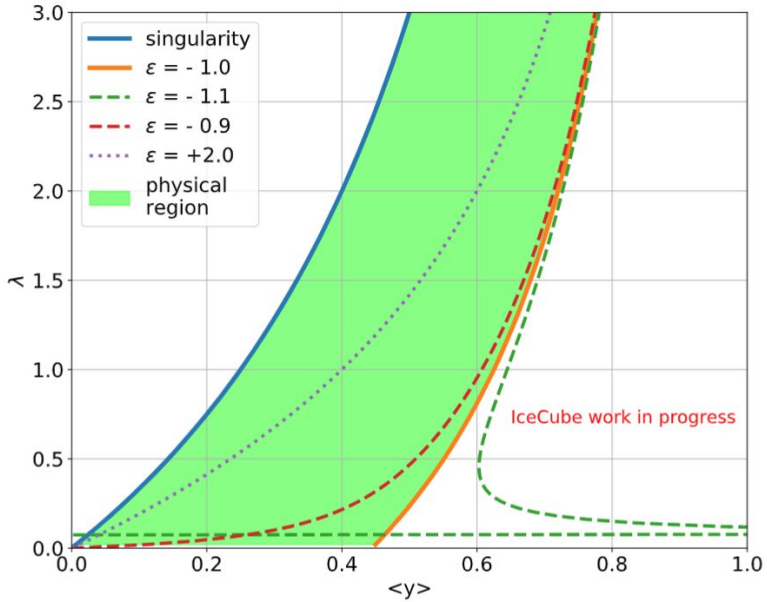


Figure 4.6: Physically allowed region in $(\langle y \rangle, \lambda)$ space (shaded in green) with physics boundaries (solid lines).