Fermilab U.S. DEPARTMENT OF ENERGY Office of Science

Nu Tools for BSM: Outlook

from my point of view as a theorist

Pedro Machado

December, 2022

A vibrant BSM program is crucial for the future of our field

We need to start this program NOW

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Where is the new physics?

There are three main beacons that guide theorists

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Where is the new physics?

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Curiosity

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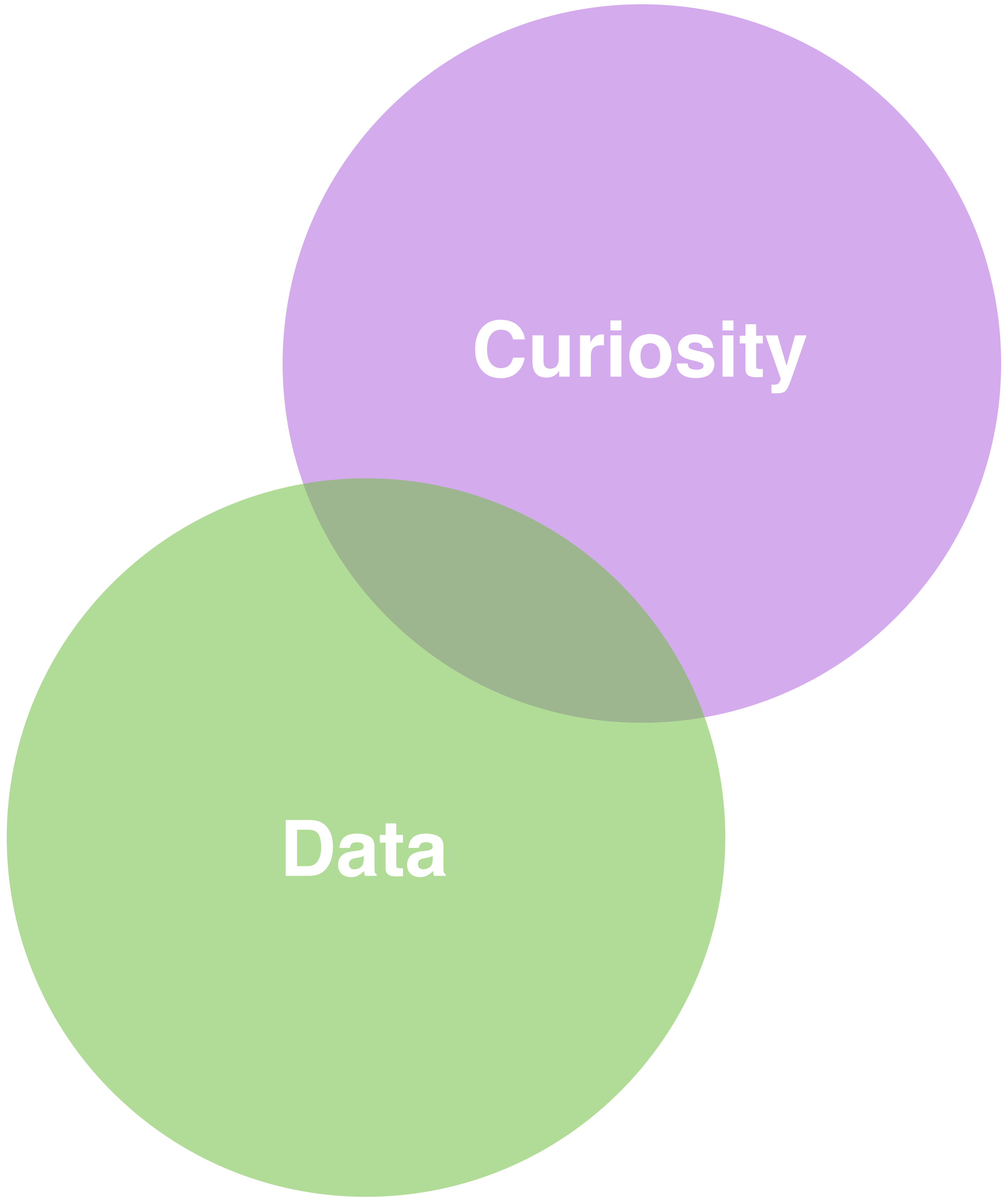
Where is the new physics?

There are three main beacons that guide theorists



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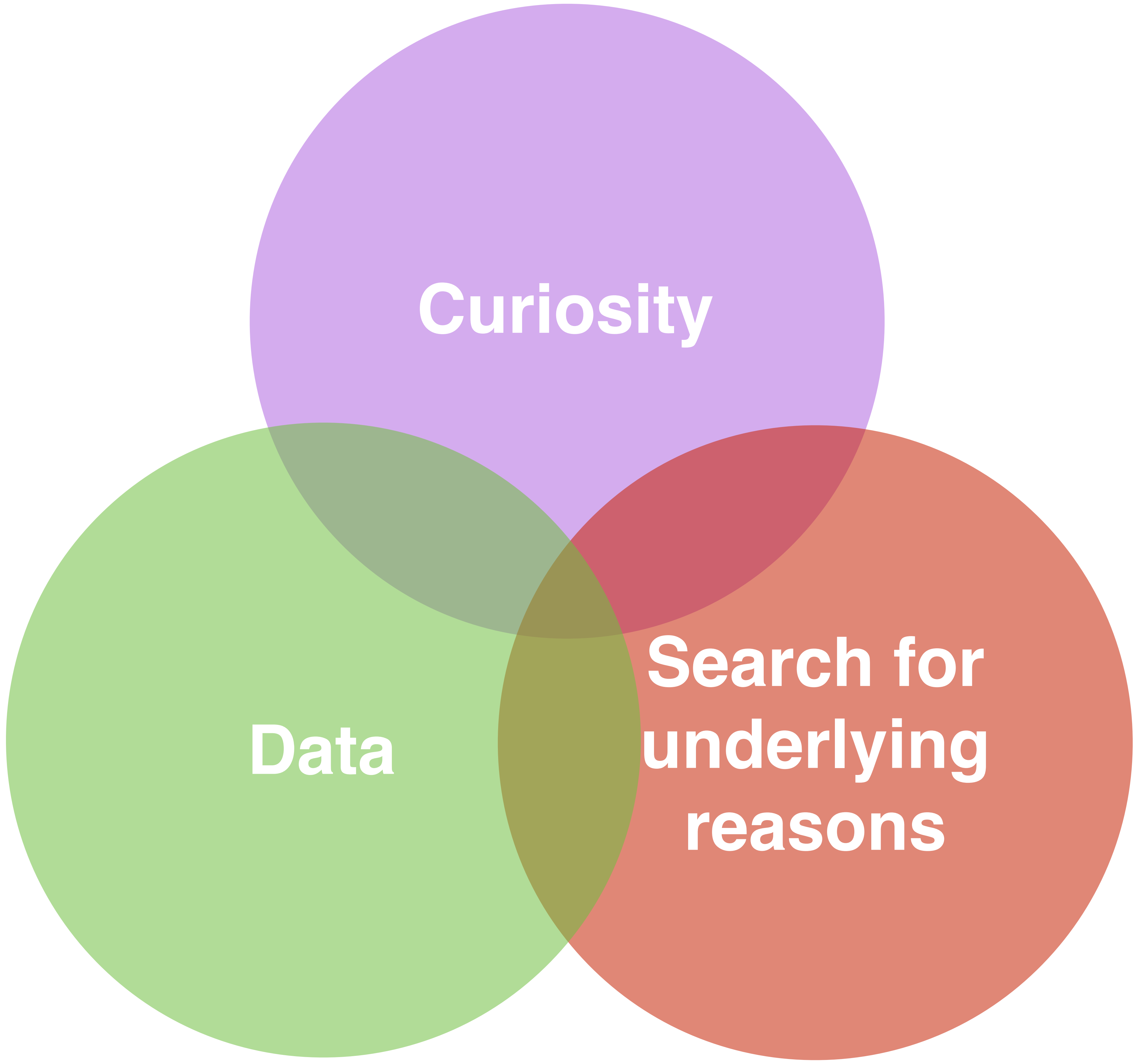
Where is the new physics?

There are three main beacons that guide theorists



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While some of our guides, like naturalness, fine tuning, unification, underlying symmetries and other concepts are still is solid,
the community is much more open to the question of
where is the new physics

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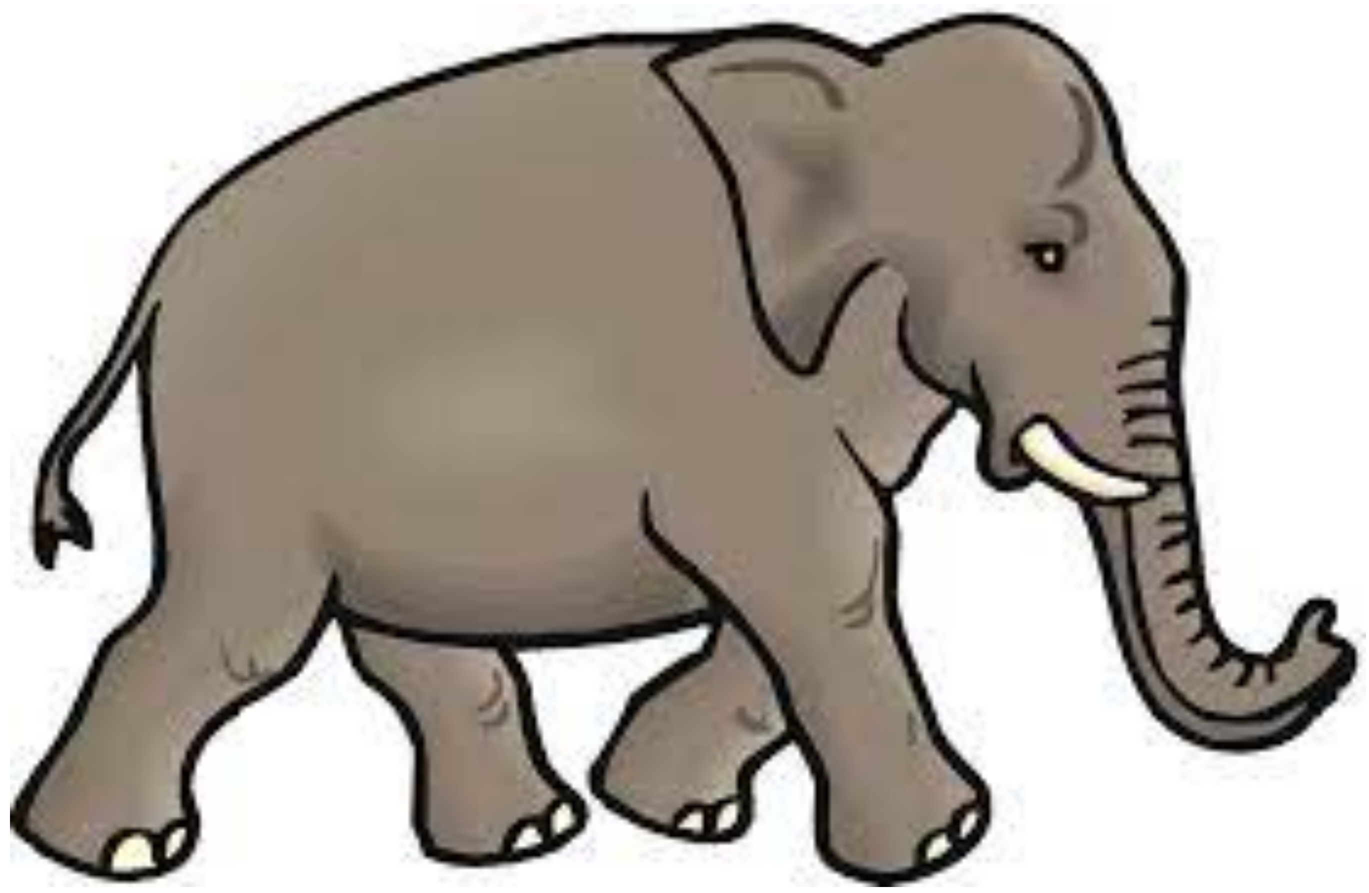
High scale new physics



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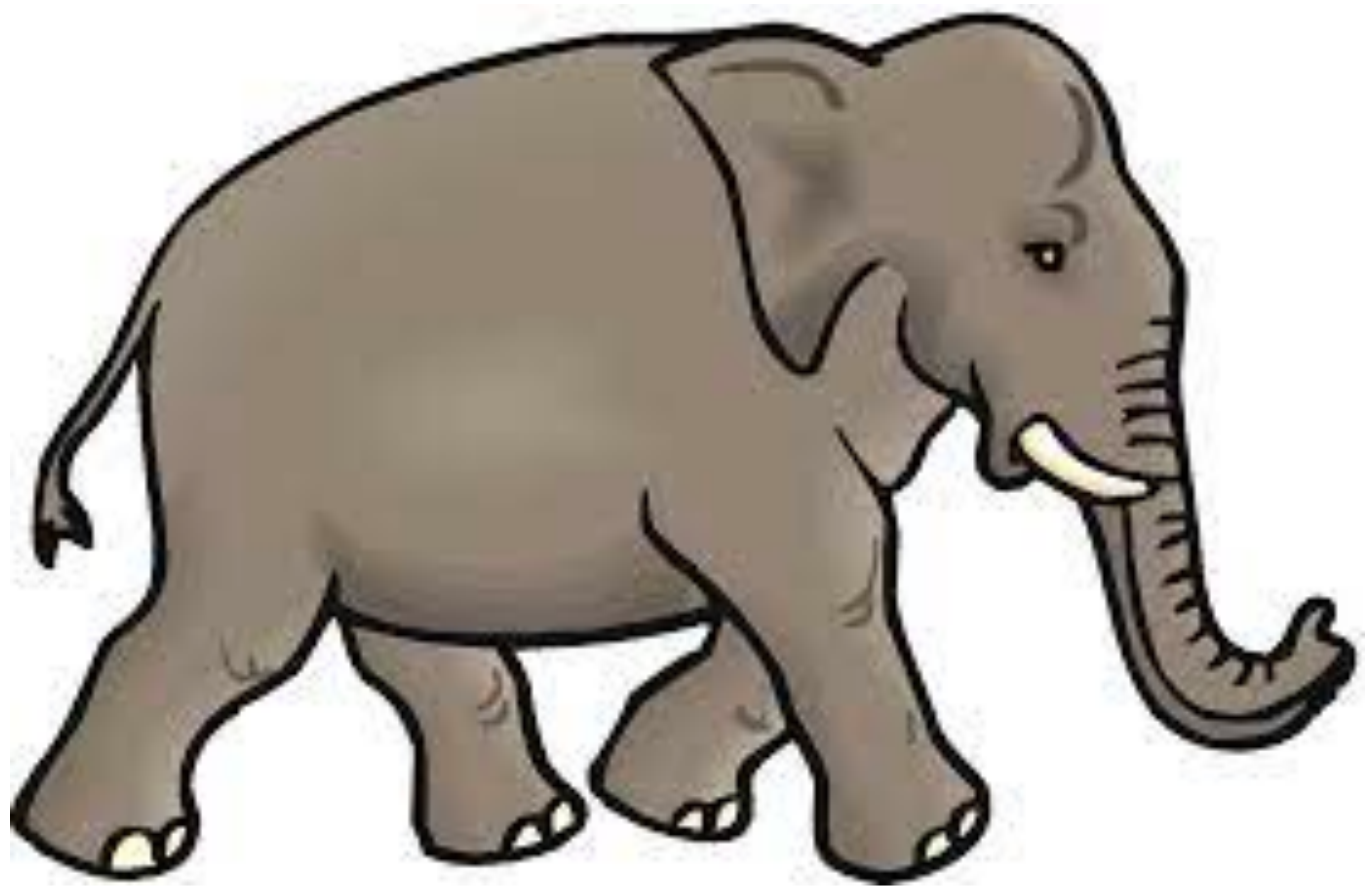

Low scale new physics

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Taking a pragmatic view: there are three classes of BSM that can be searched in neutrino experiments

Same signature as usual neutrinos: sterile neutrinos, NSIs, neutrino decay, …

New neutrino signatures: dark neutrinos, neutrinophilic scalars, …

New particles: dark matter, heavy neutral leptons, axion-like particles, …

Searching for different models will require overcoming different challenges

Let’s look at some examples

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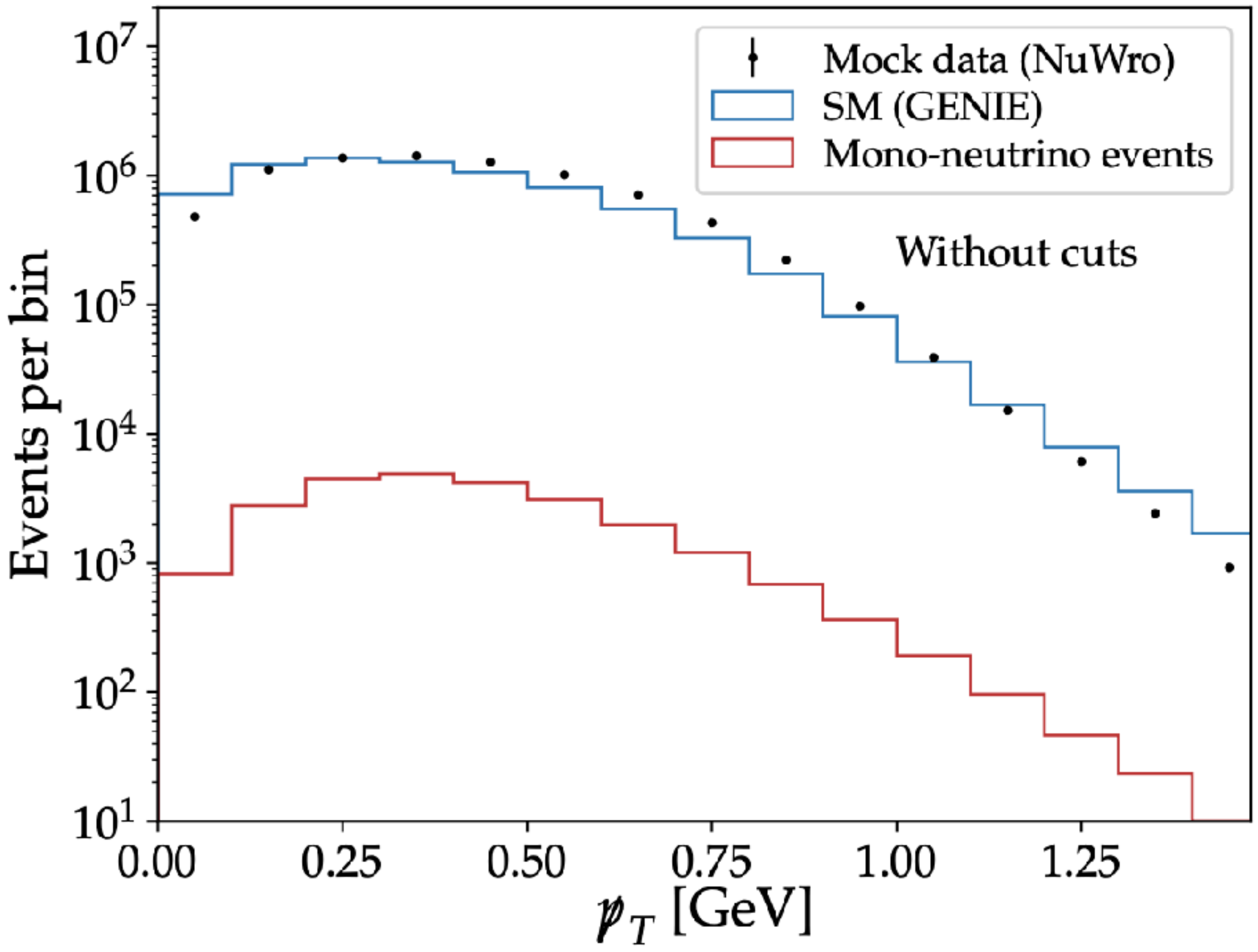
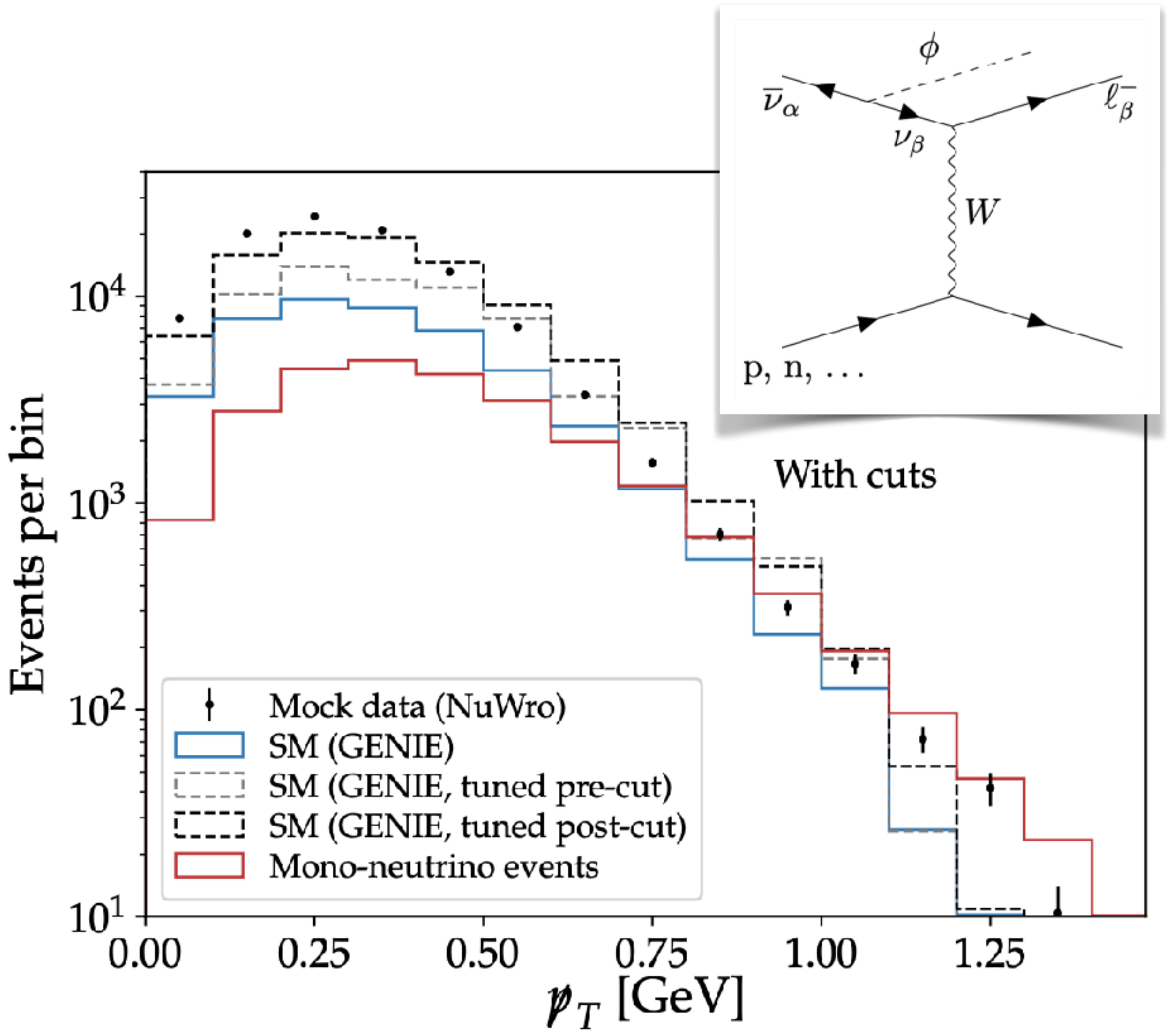
New signatures and BSM << SM: ν-N interaction mis-modeling is a major challenge





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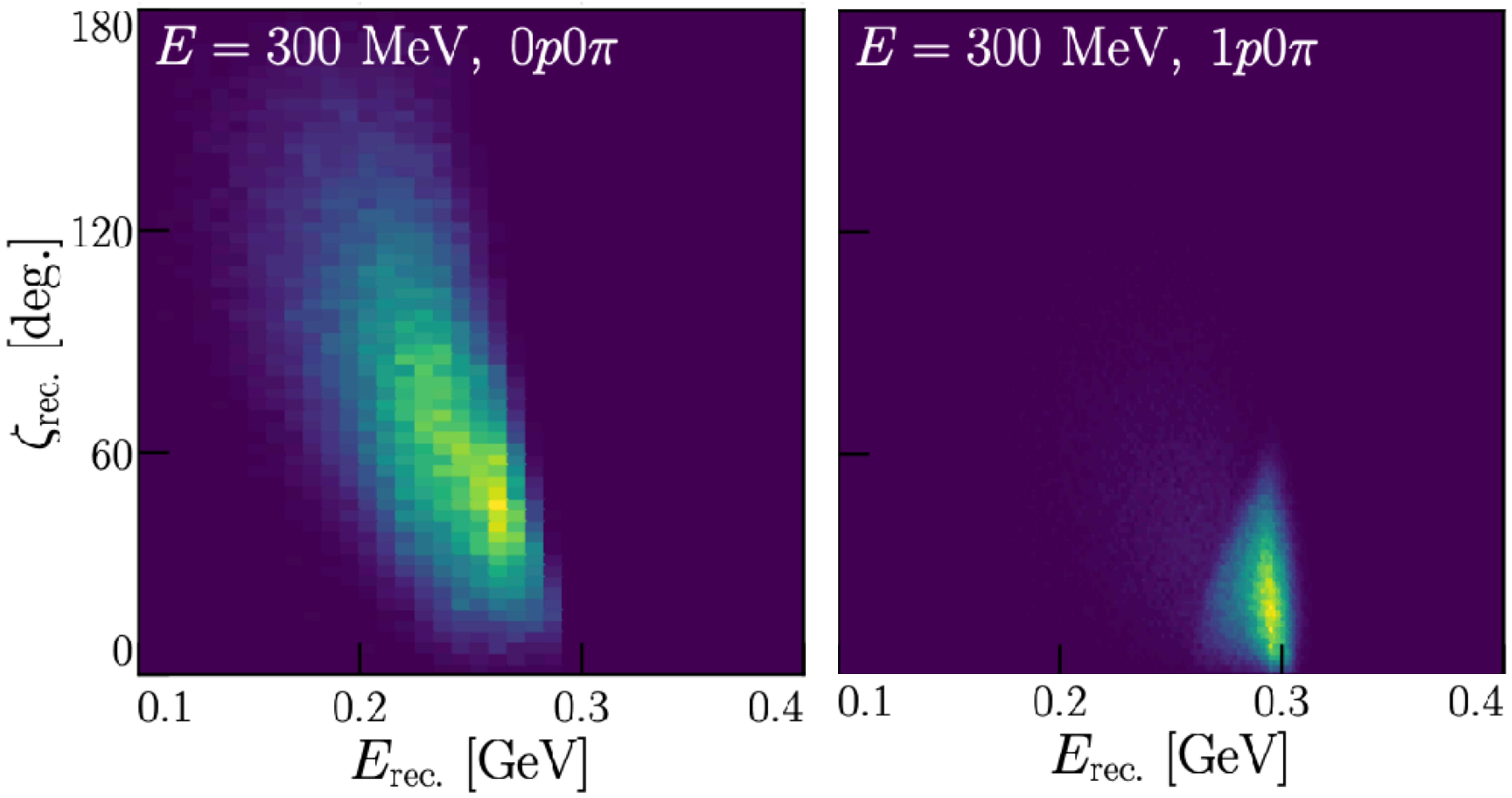
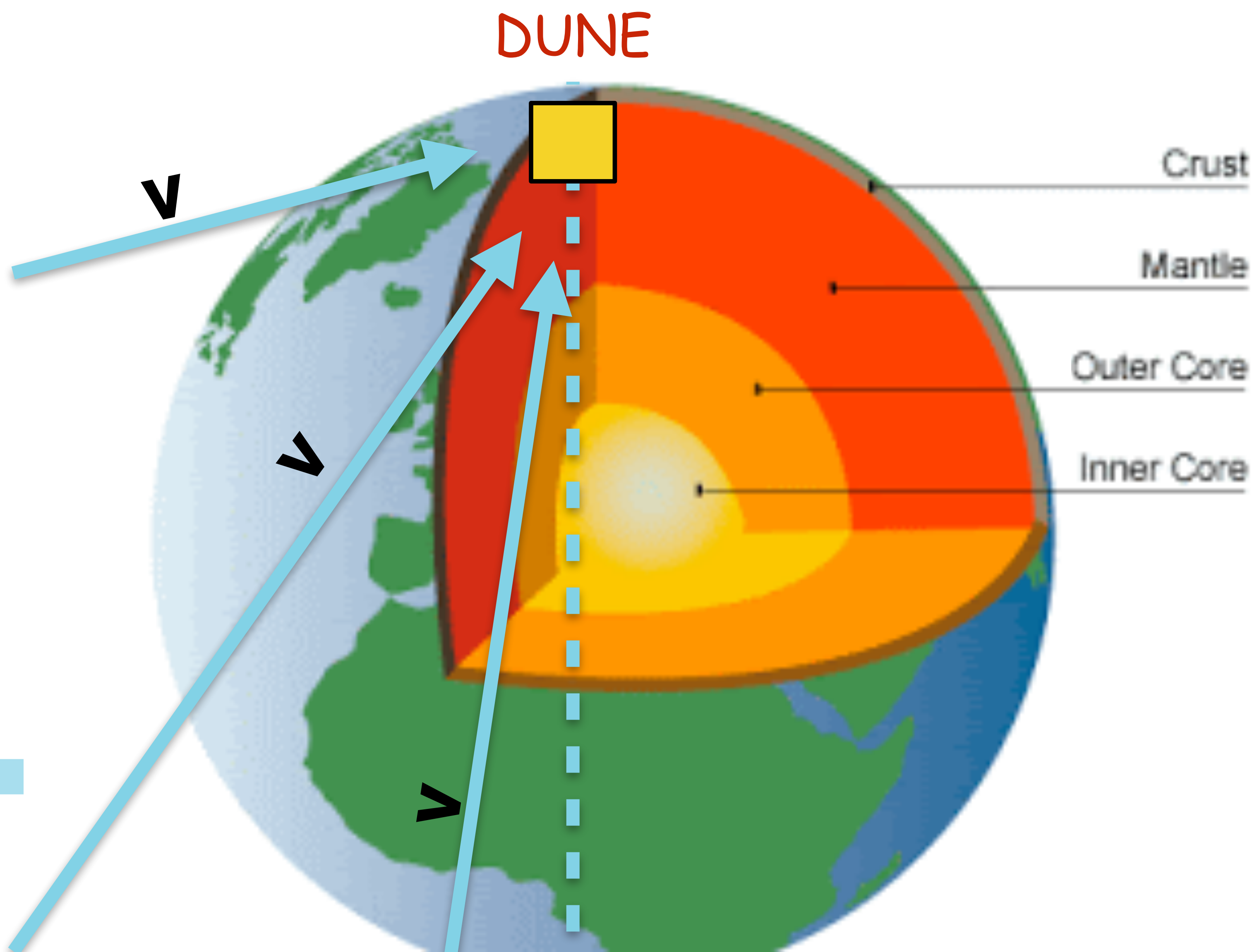
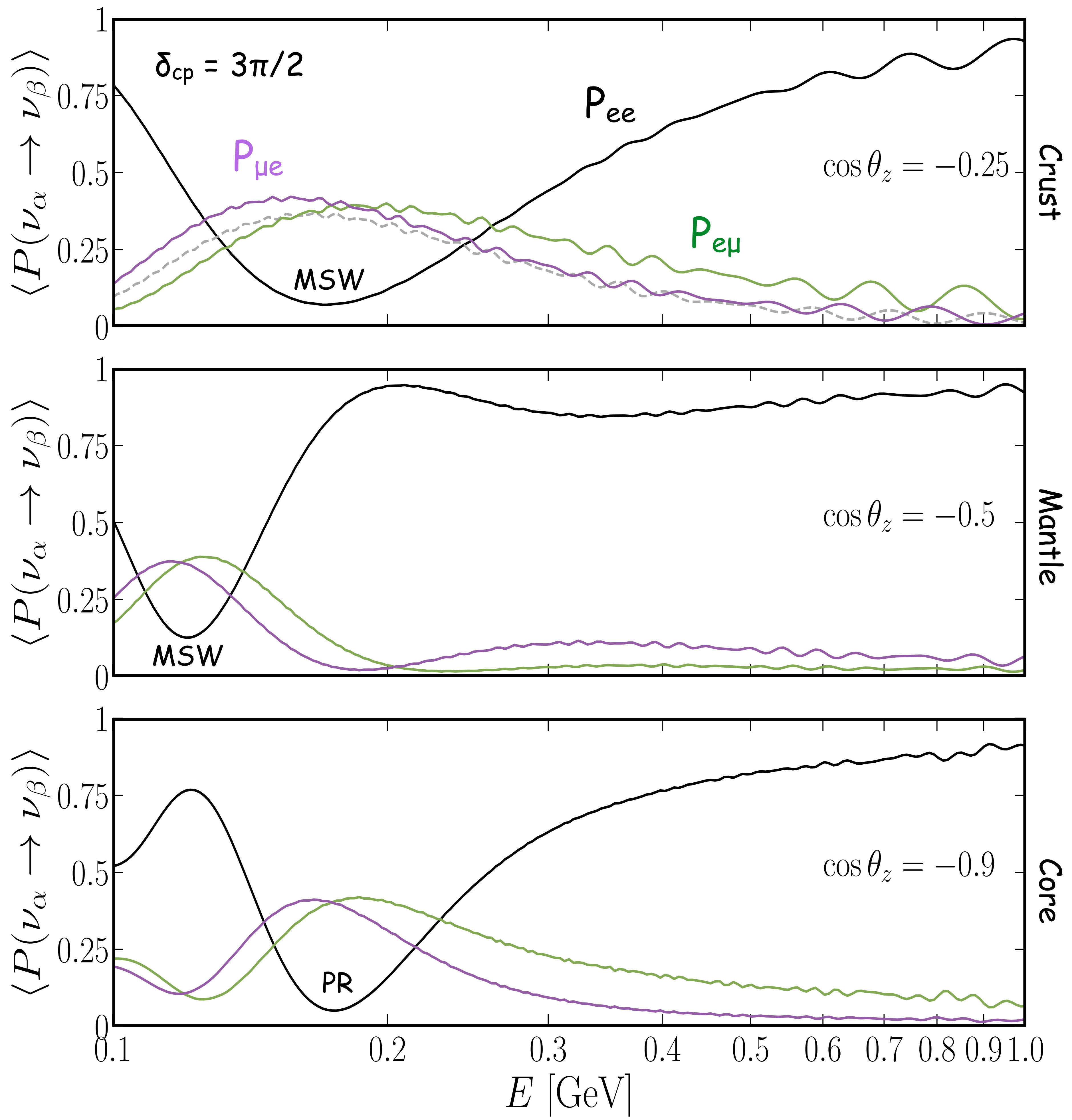
Final state interactions are relevant for direction reconstruction







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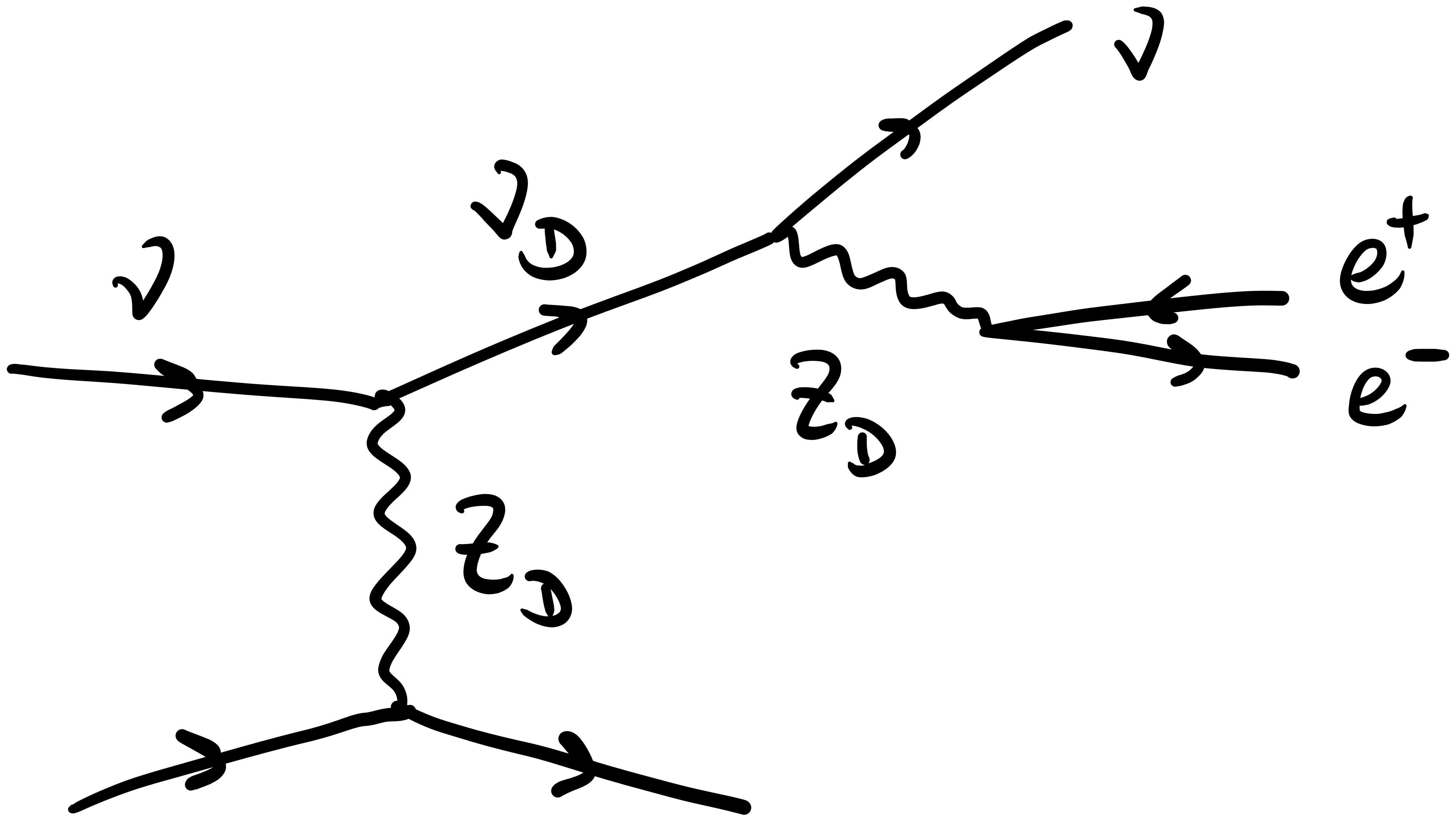
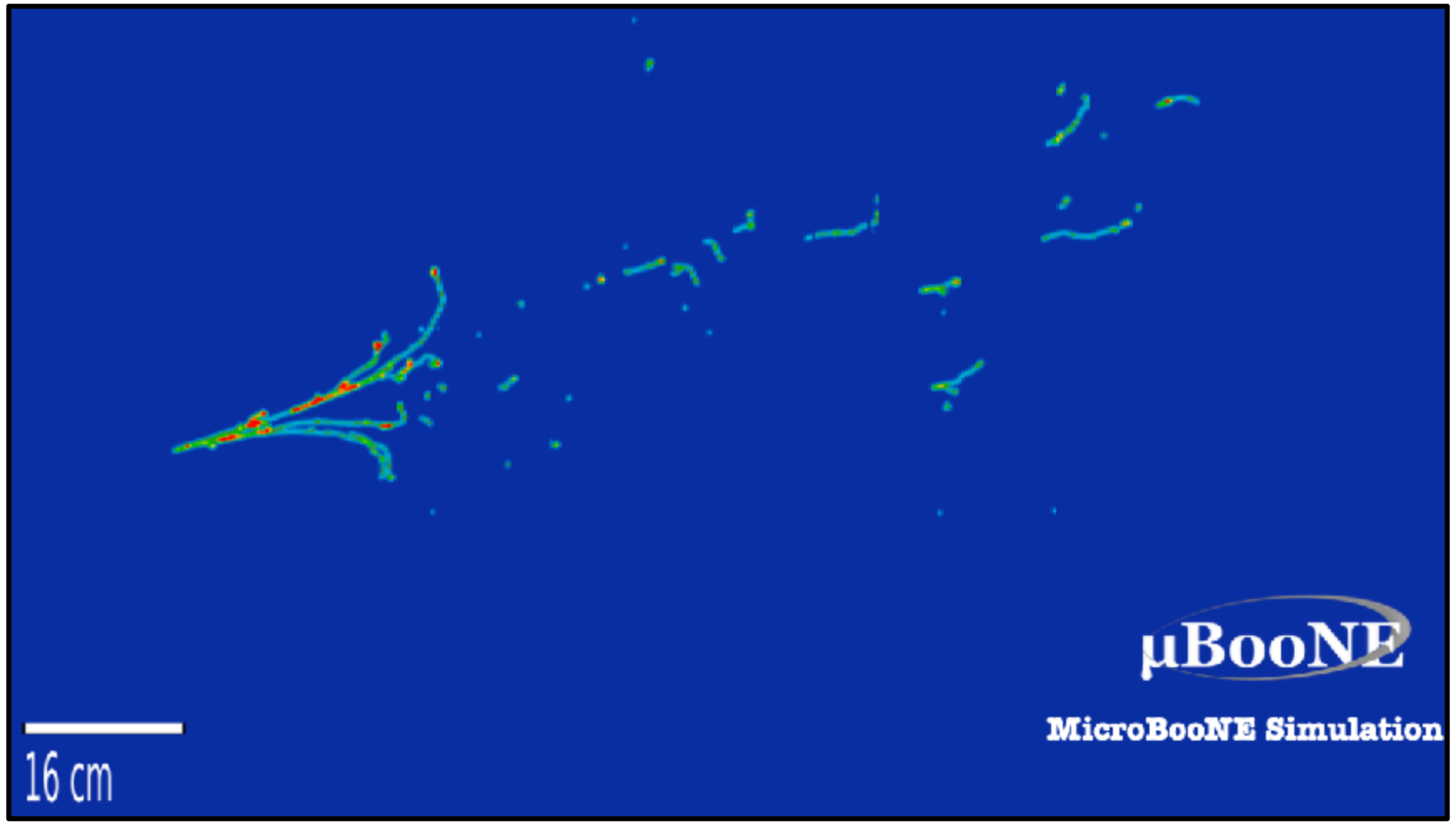
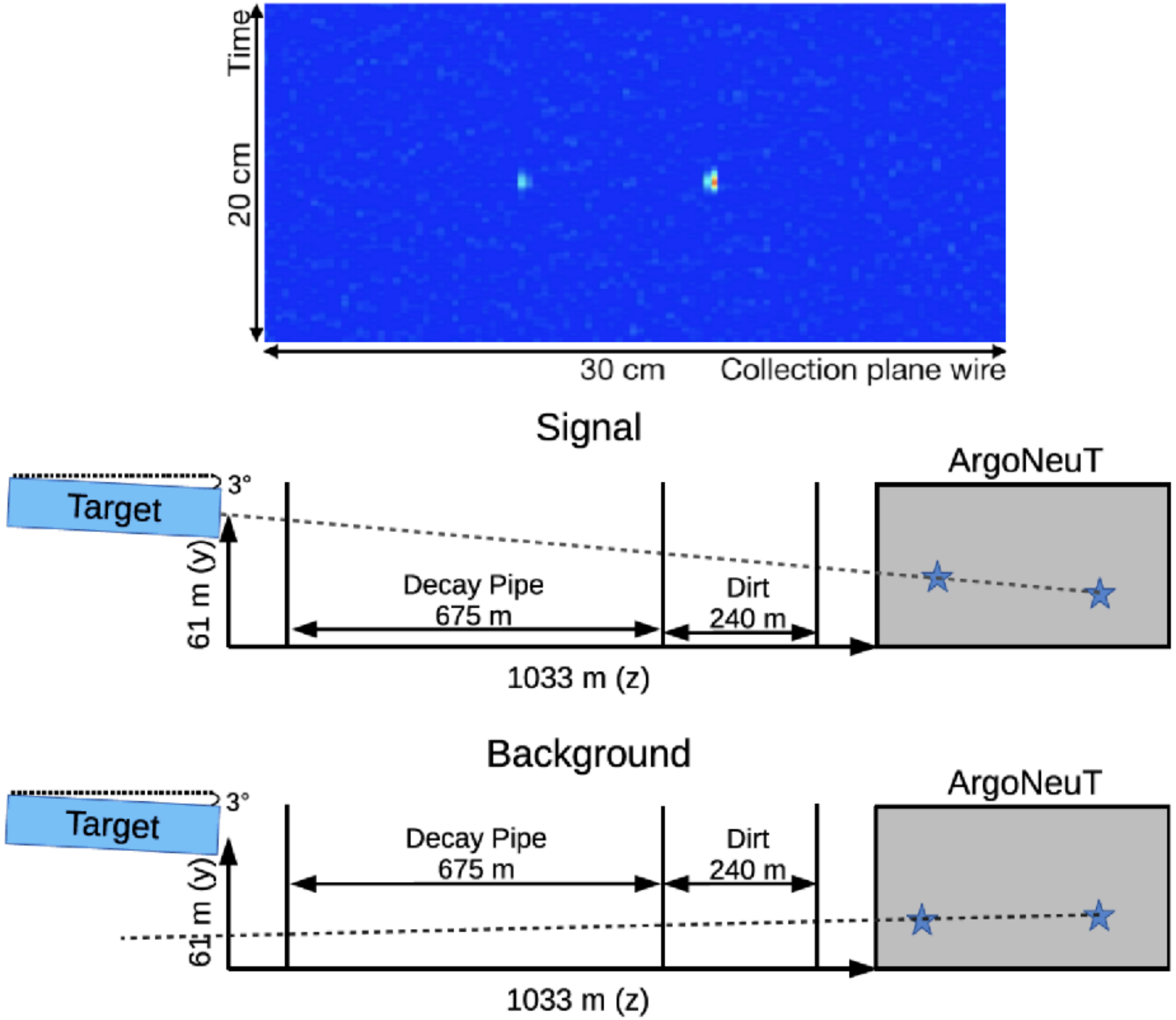
Detector reconstruction is key

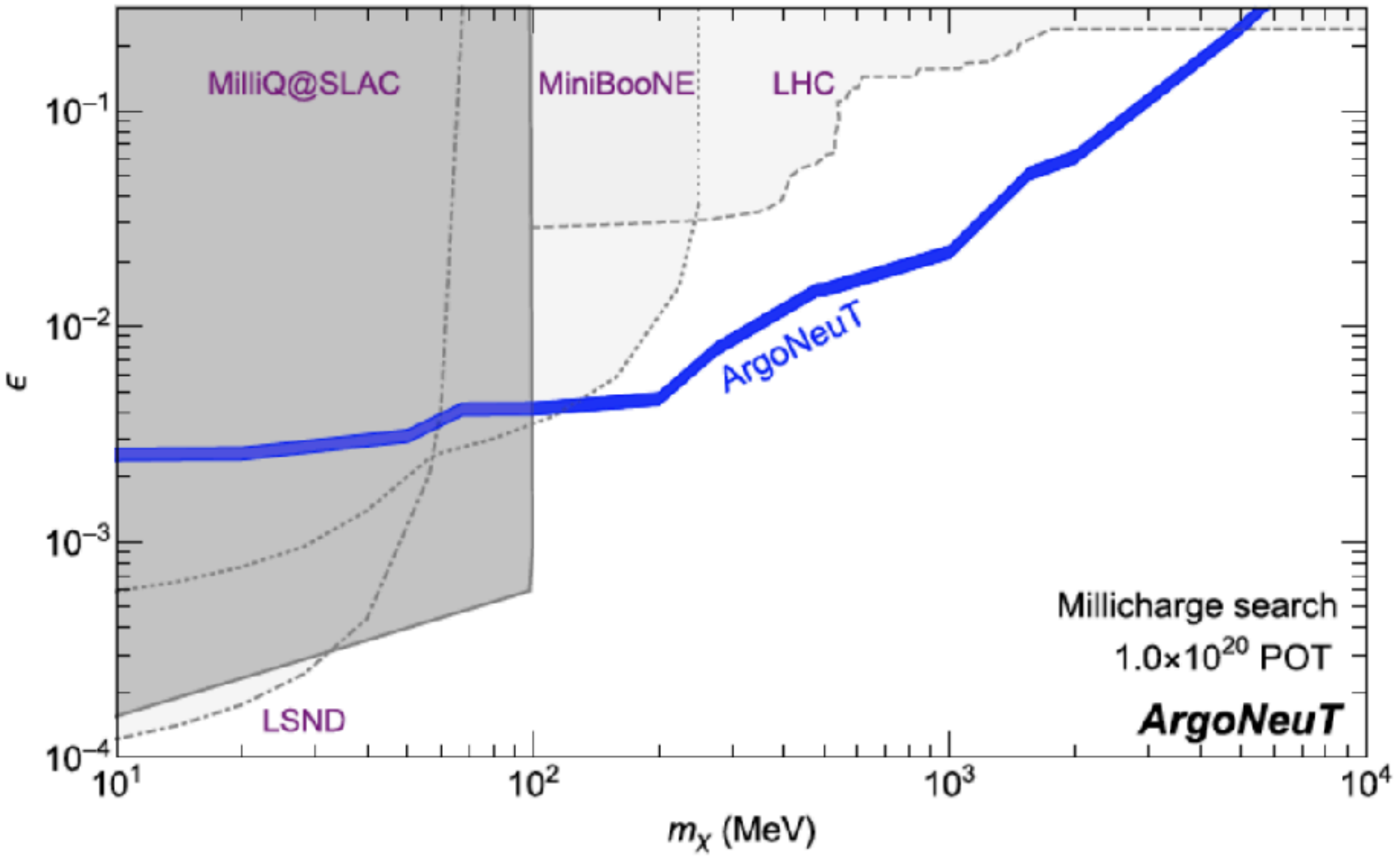




Sometimes, we just need to be smart



ArgoNeuT Collaboration + 2 theorists (R. Harnik and Z. Liu)
R. Acciarri et al., PRL124 131801 (2020)



Leading constraints in unexplored parameter region!

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Overall challenges

Precise description of neutrino-nucleus interaction is hard

Realistic studies need heavy machinery (generators)

Leveraging detector capabilities and doing realistic analyses

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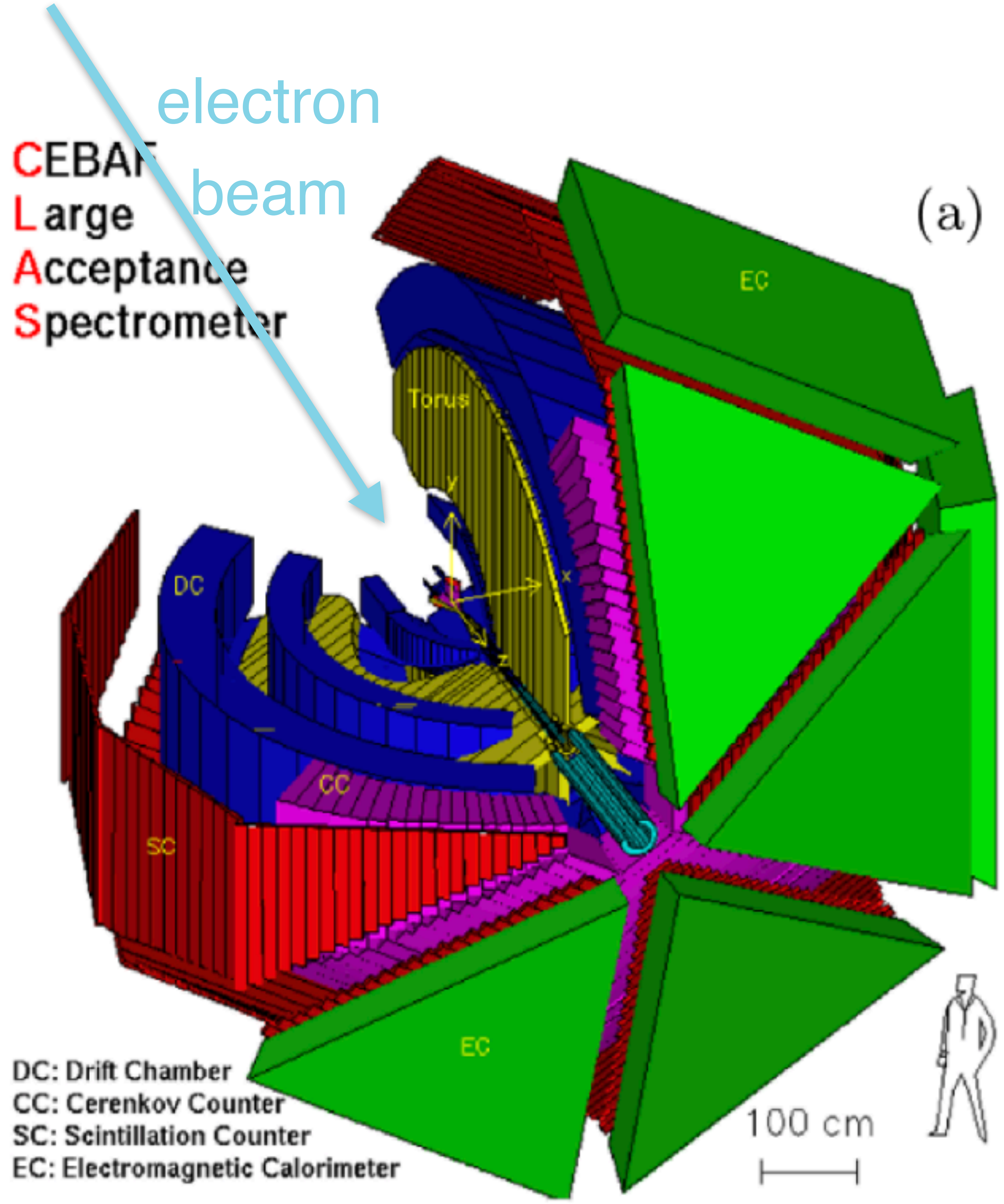
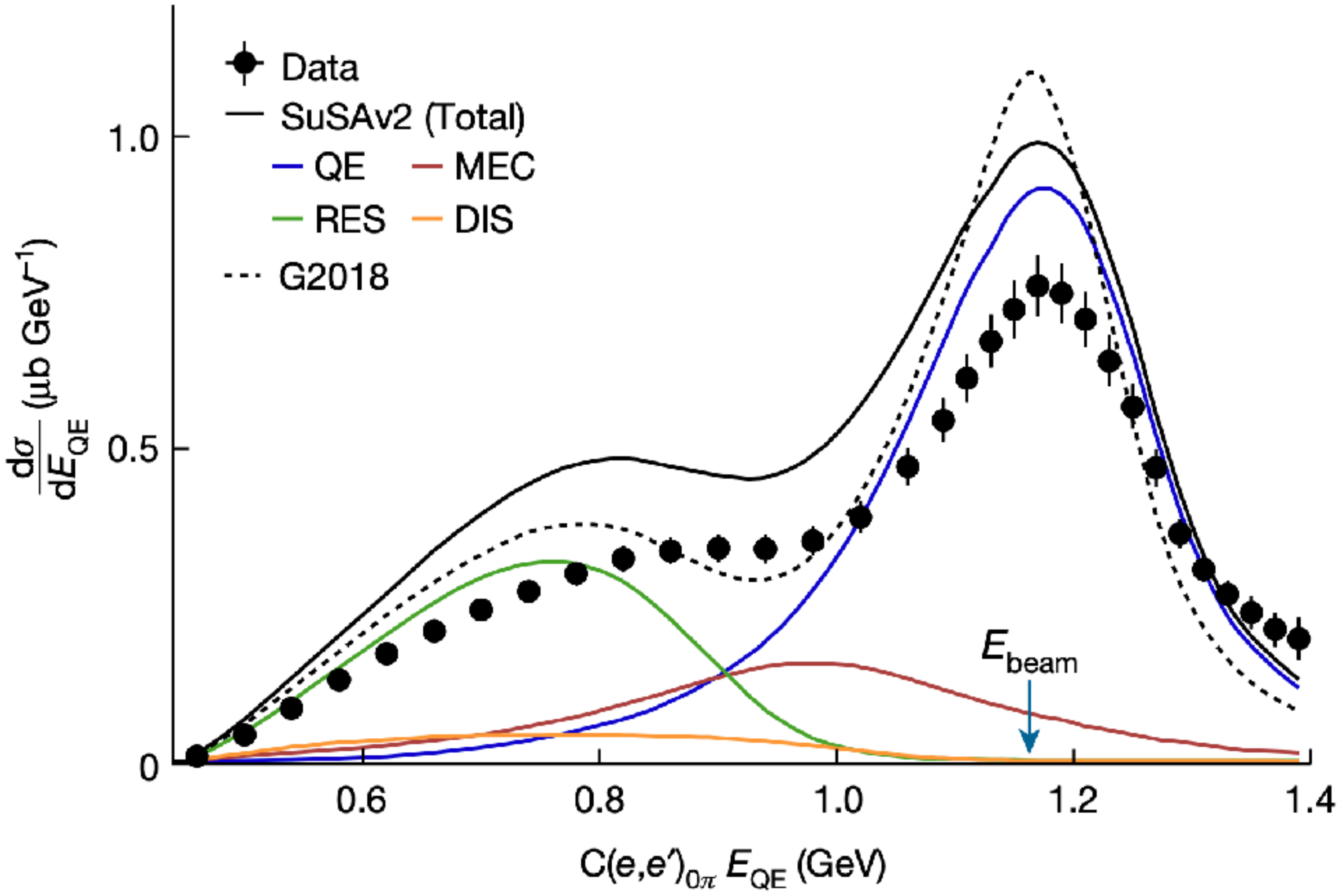
Description of neutrino-nucleus interaction is just hard



CLAS/E4v Nature 599 (2021) 7886, 565-570



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Generators are complex, requiring significant time to be developed and to incorporate new physics

Leveraging detector capabilities and doing realistic analyses

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What do we need to do great physics with our neutrino experiments?

The answer depends on which BSM you want to probe

Good news: we do not need to solve all problems at once

But there is no one size fits all

Let’s come up with some wish list, but first let’s get some things straight

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Hard vs. Challenging vs. Burdensome

This is my own personal definition

Hard = we don't know how to do, and it is not clear how much we will progress
Challenging = still needs a lot of work, but we will get there (to a good extent)
Burdensome = we know what to do, we just need to do it

hard Percent-level description of neutrino-nucleus interactions

challenging

- Event reconstruction
- Cosmic ray rejection in SBN detectors
- Electron-photon discrimination
- Pile-up in DUNE ND
- Particle identification

burdensome

- Beam produced dark matter signal
- BSM implementation on generators
- Flux simulation and tracking meson momenta

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My wish list

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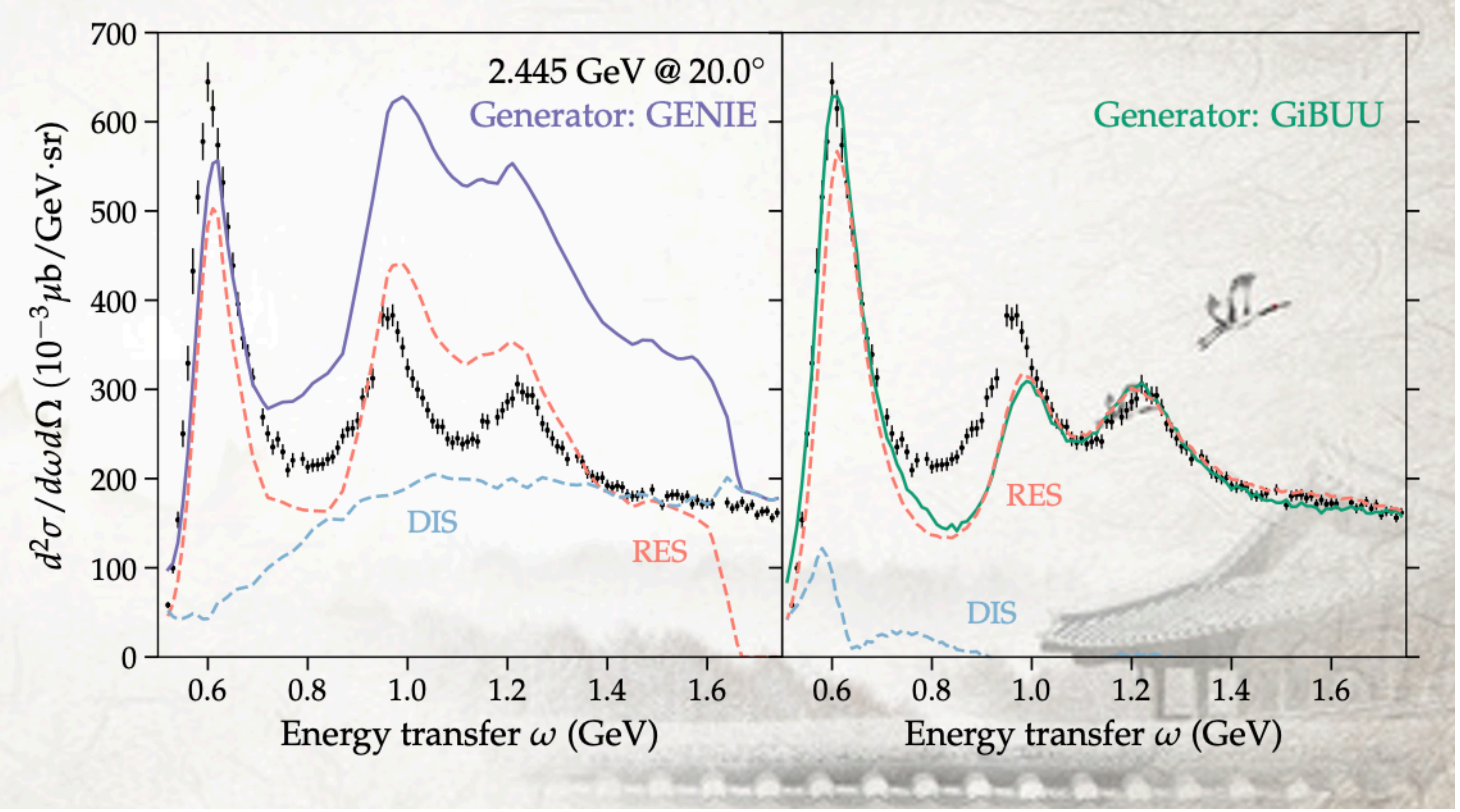
My wish list

Support generator development and theory work on neutrino-nucleus interaction physics

We need a better understanding of neutrino-nucleus interactions

This is relevant for our main goals, but even more relevant to probe light, weakly interacting physics



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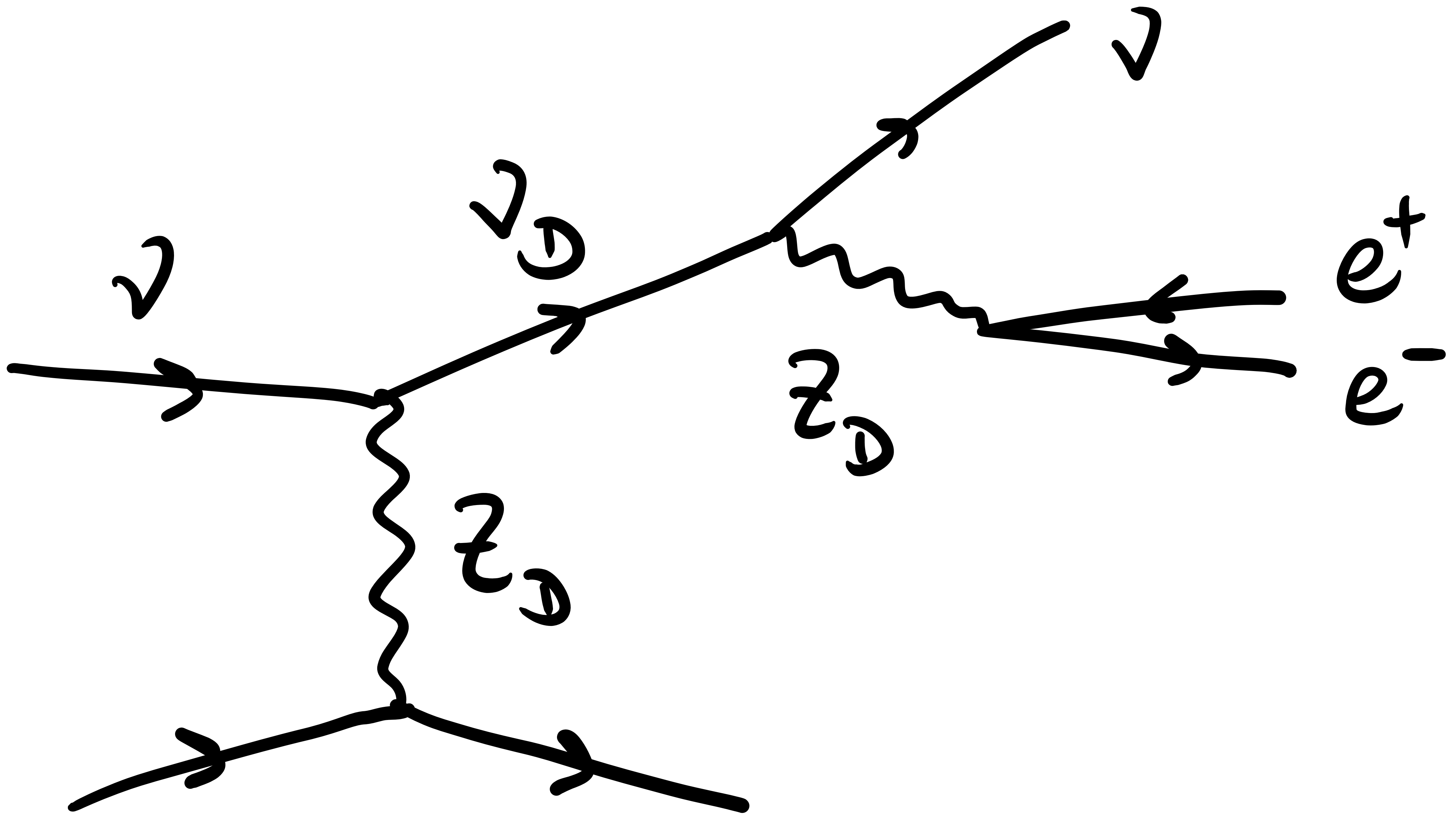
My wish list

Make experimentalist lives easier



Several models, however different they are, may lead to similar final states.
Therefore, a single search may be useful for more than one model, or may easily be recasted/adapted to account for other scenarios

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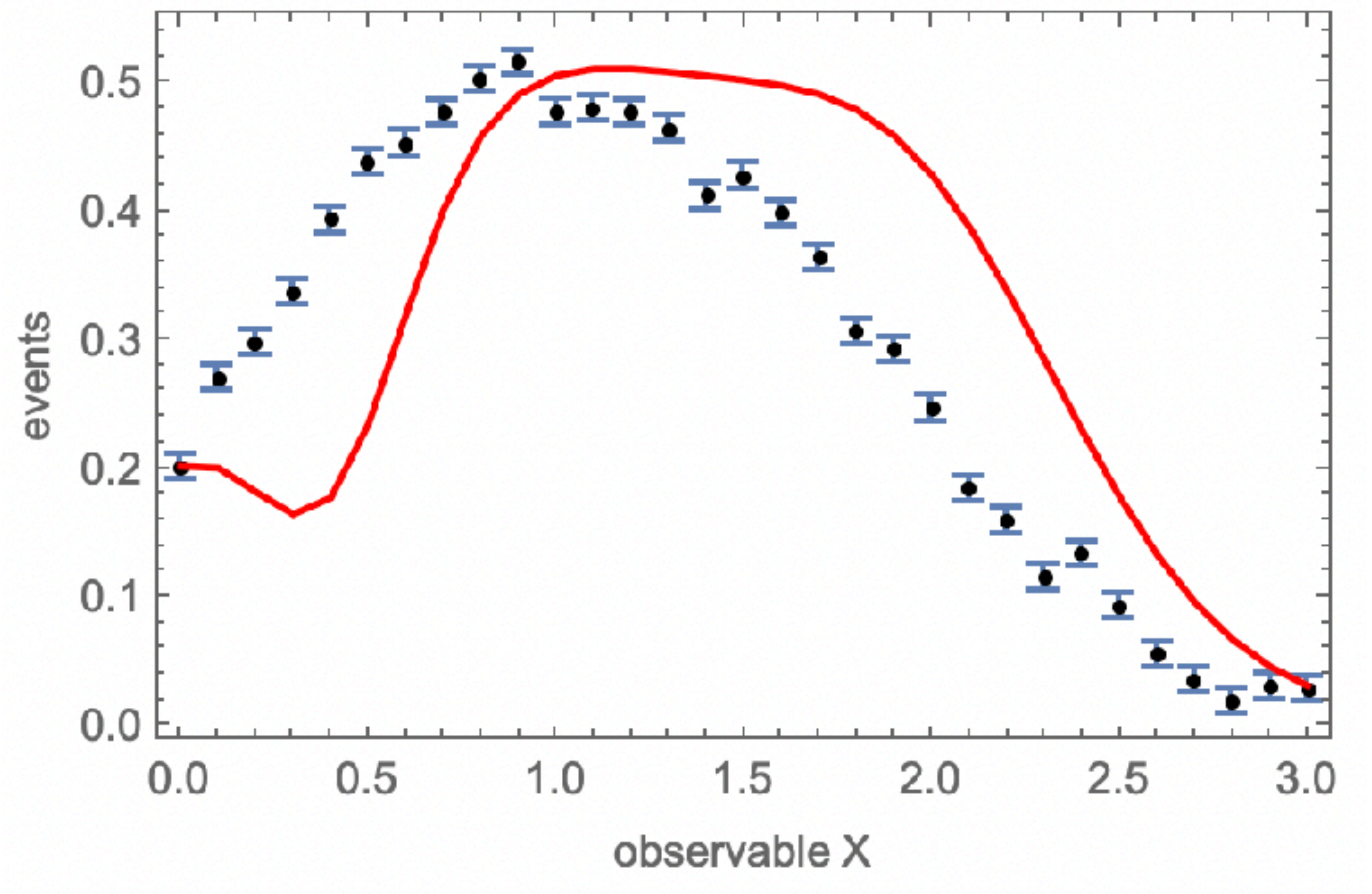
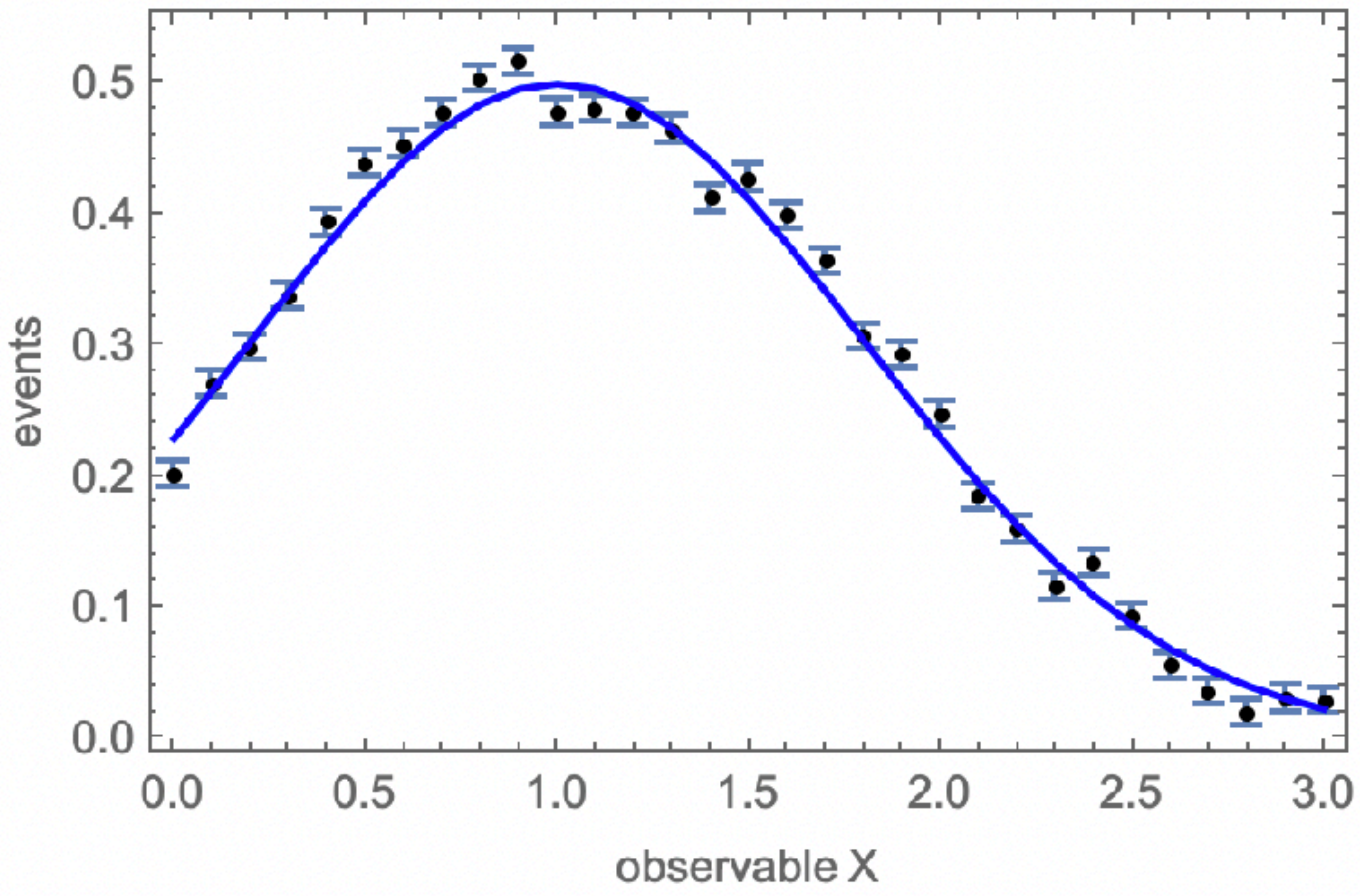
My wish list

Preserve experimental data

Today



Tomorrow



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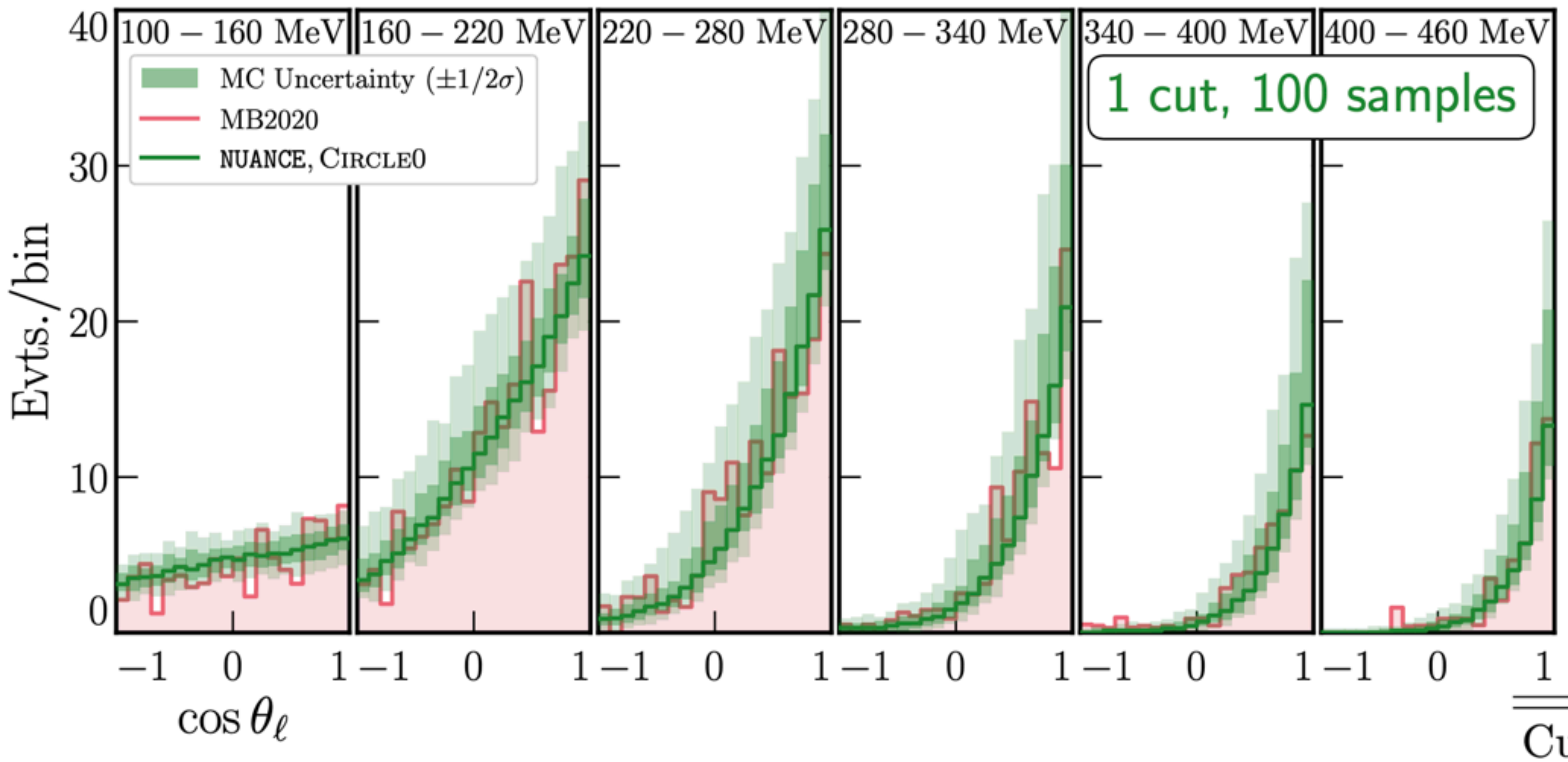
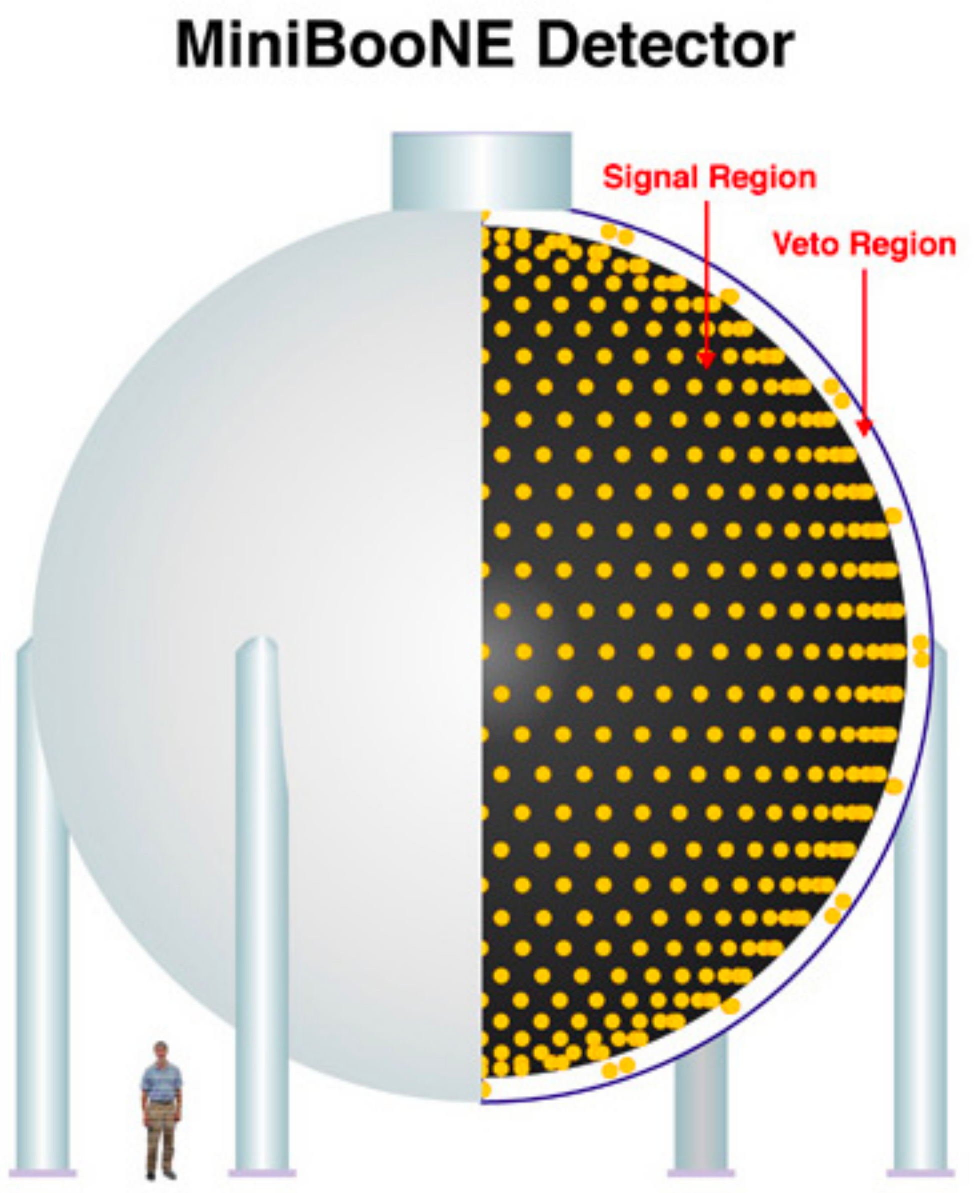
My wish list

Preserve experimental data





Our estimate of the updated MB Significance: $\sim 3\sigma$

Cut Prescription	$NC\pi^0$ background rate (Median $\pm 1\sigma$ range)
1 Cut, 100 Samples	
CIRCLE1	$669.8^{+241.3}_{-51.8}$
CIRCLE0	$664.3^{+255.0}_{-48.3}$
DIAGONAL	$659.9^{+266.2}_{-48.8}$

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My wish list

Please please please explain your analyses in a way we can reproduce them

PS191, Physics Letters B 166, 1986

about one month. The events on tape were subsequently filtered and scanned for decay candidates using a microprocessor [8] developed to suit our requirements. The events retained for further study were a few tens. The latter were subjected to a thorough series of tests, essentially visual, to convince ourselves that they could not possibly satisfy the expected ν-decay topology. None emerged as a credible candidate.

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MicroBooNE HPS search 2021

> After applying the BDT selection, the number of events expected for each background contribution and for several signal definitions are shown in Table II. The table also presents the estimated signal selection efficiency. The total expected background-only prediction is 1.9 ± 0.8 candidate events.

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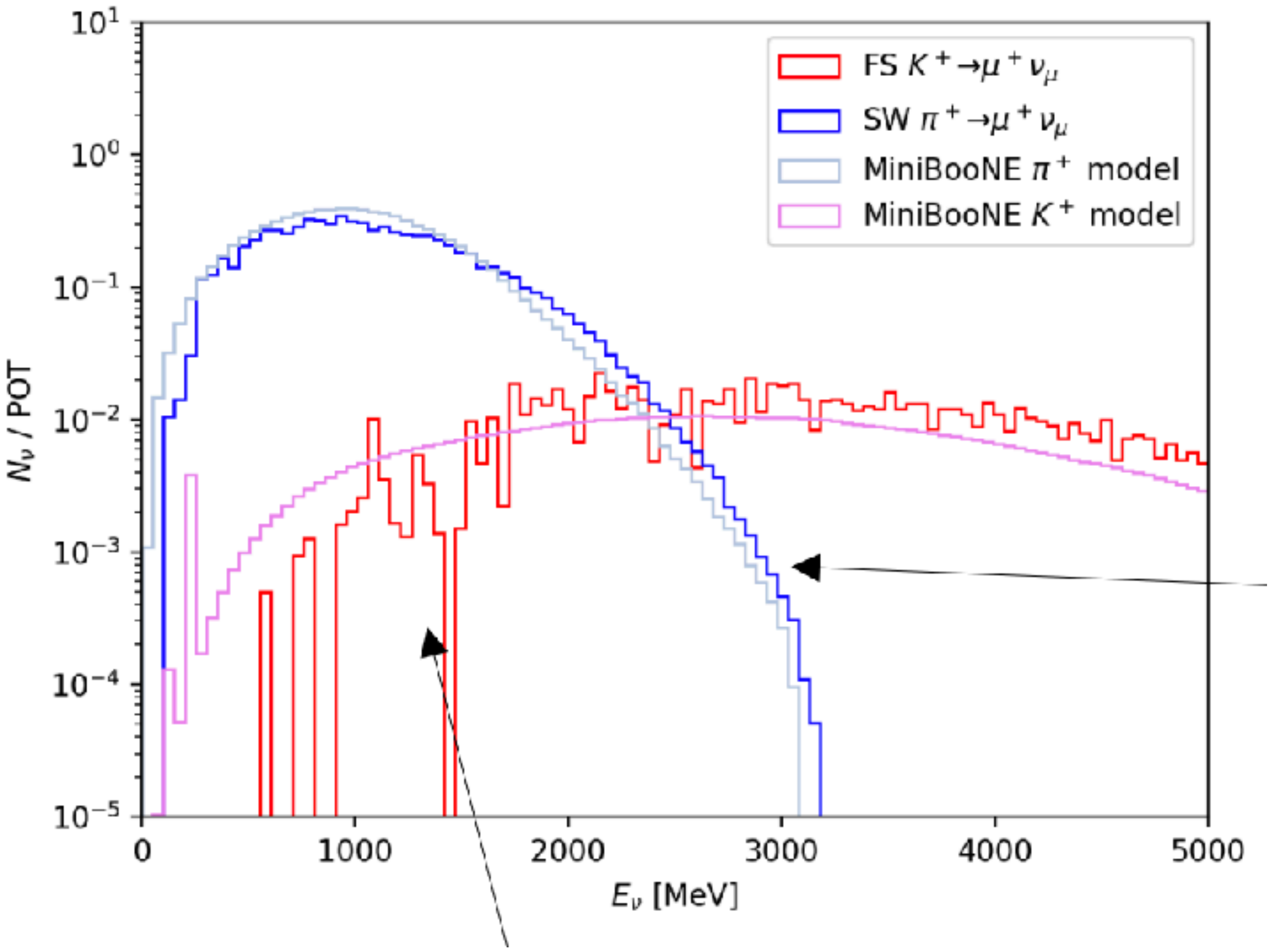
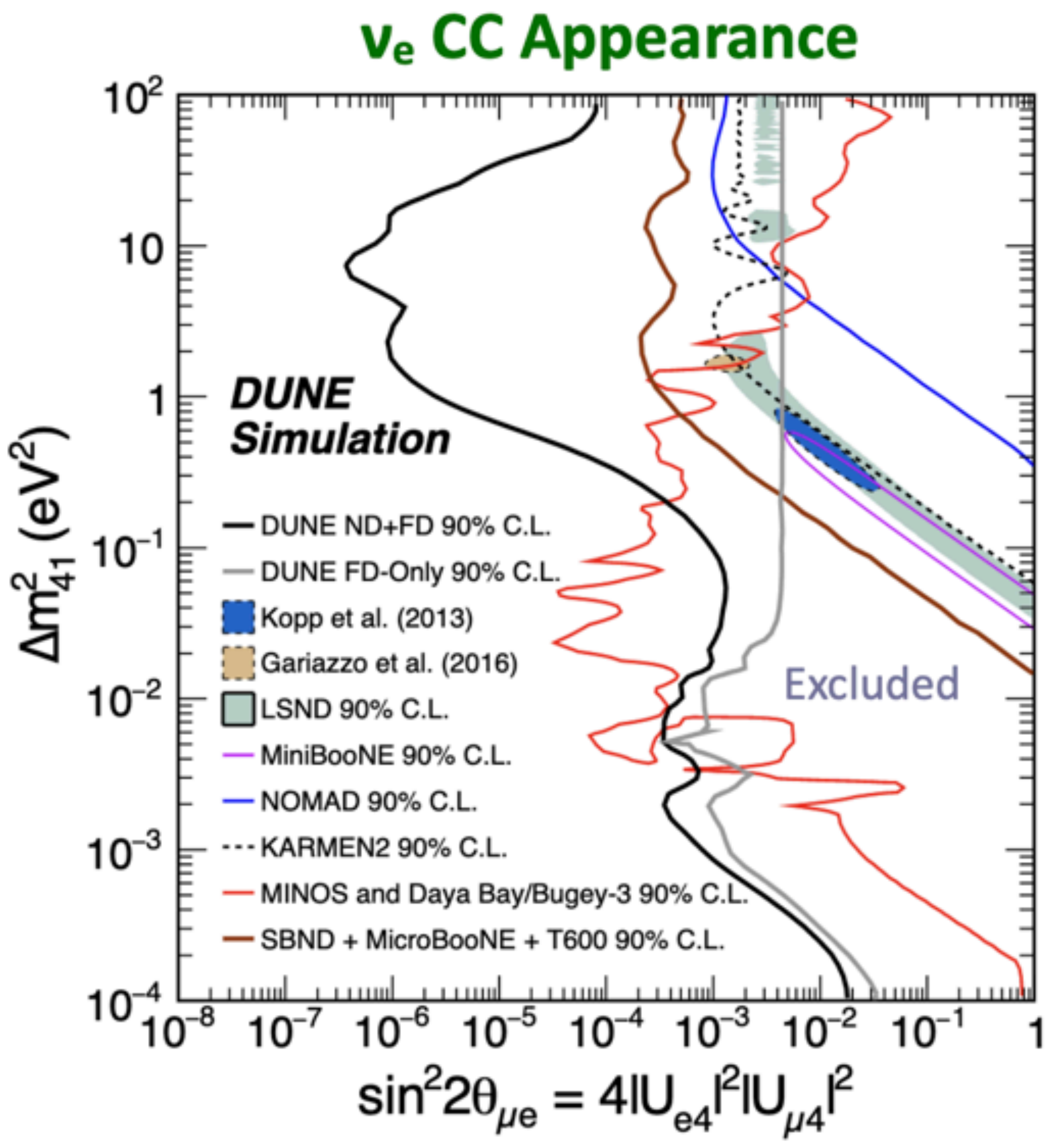
My wish list

Make it easy to make some key information public





Fluxes with info from mesons
Energy reconstruction
Covariance matrices
Efficiencies
Cuts
…

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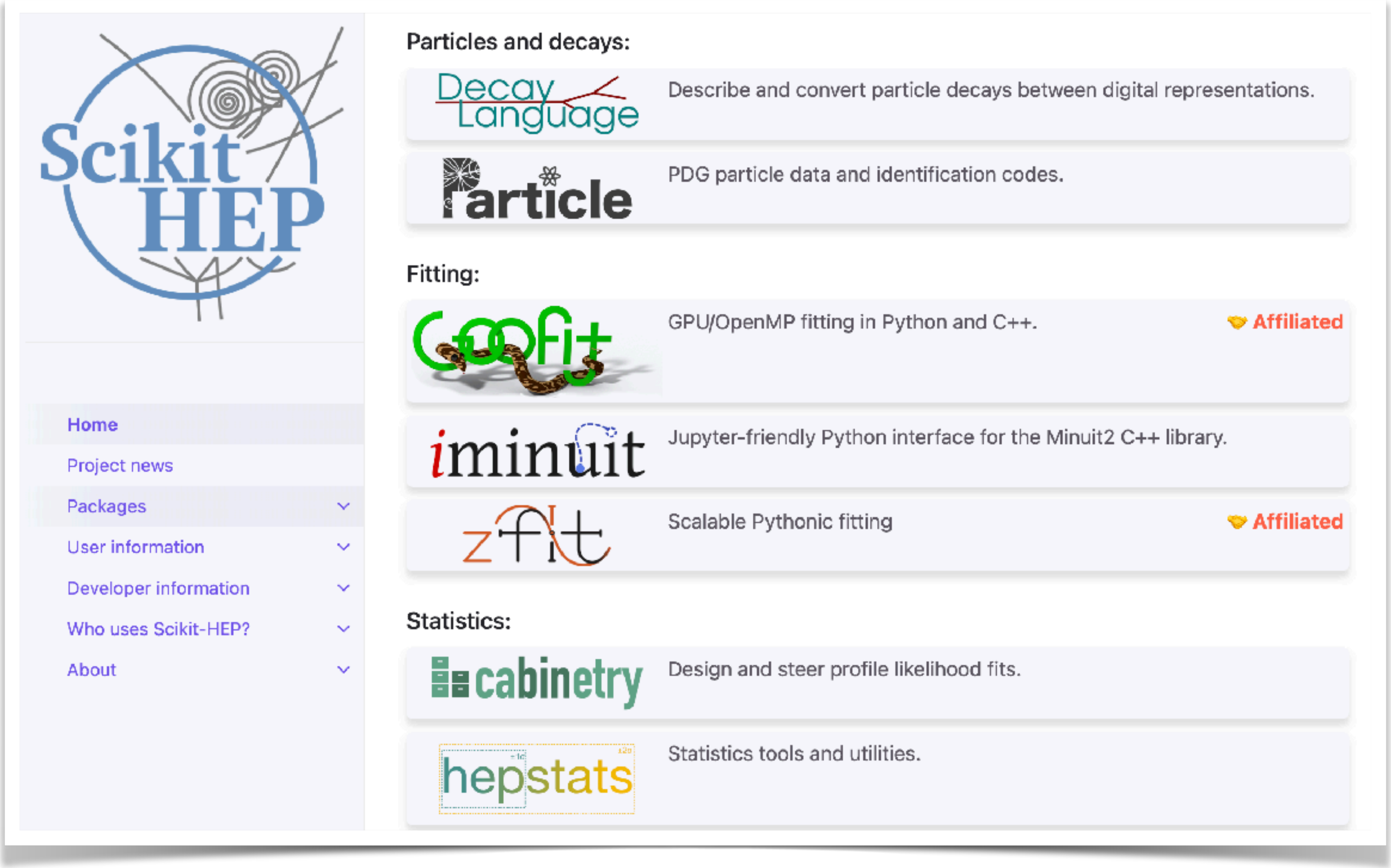
My wish list

Make tools publicly and easily available



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Action items:

- Create a living document with our community guidance
- Create the snapshot document of the summary of the workshop
- Mini-Workshop on data preservation/data release
  - Focus on smaller experiment
  - Involve the right people
  - Discuss in advance to arrive with a plan at the workshop
  - Invite representatives of experiments who did data preservation (IceCube, ATLAS/CMS, MINERvA, …)
  - Wishlist for data release
  - Database for fluxes (beam lines, particles, …)
- Start overleaf, collect wish lists, assign tasks
- Contact NTN PI and establish a network for TH+EXP+Nuc to communicate
- Topical schools/workshops?
- Neutrino Olympics?
- What have we learned from previous experiments?
- What do we want from generators?
- Categorization of models based on observables
- Fast simulation tools
- Pipeline to get experimental information
- Framework development best practices
- Timeline to accomplish action items
- Fast track from Lagrangian to observables