Multidisciplinary nature of modern HEP

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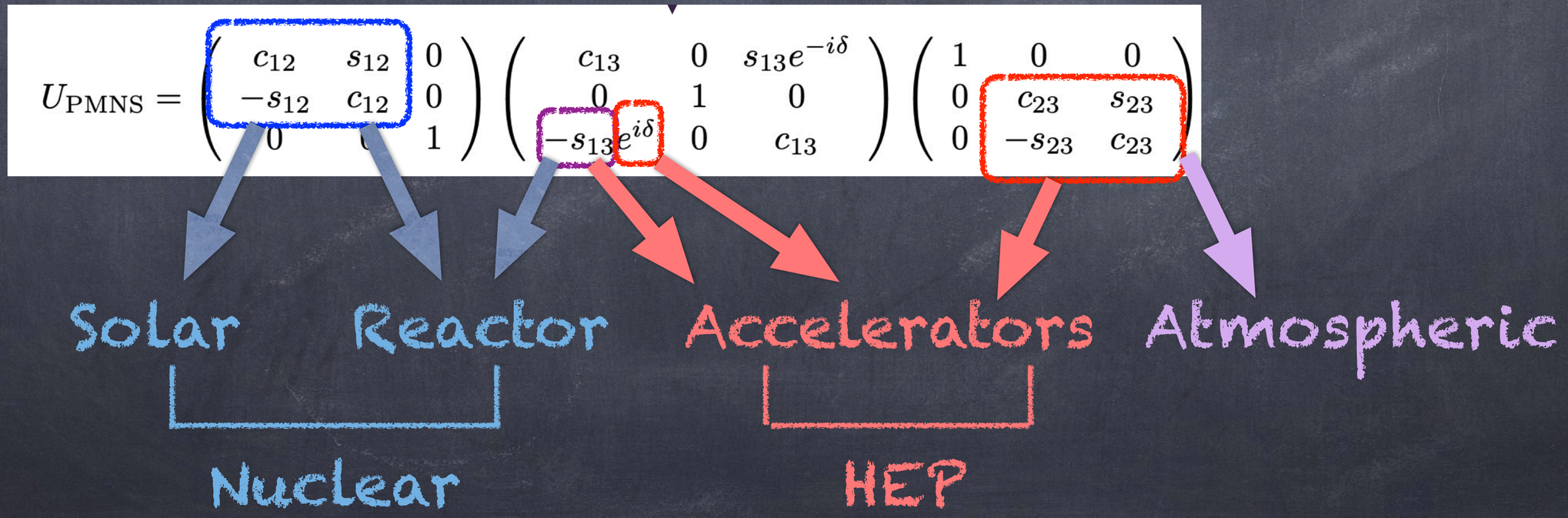
"Where is the boundary of our field?"

H. Murayama (PS talk, APS April Meeting 2023)

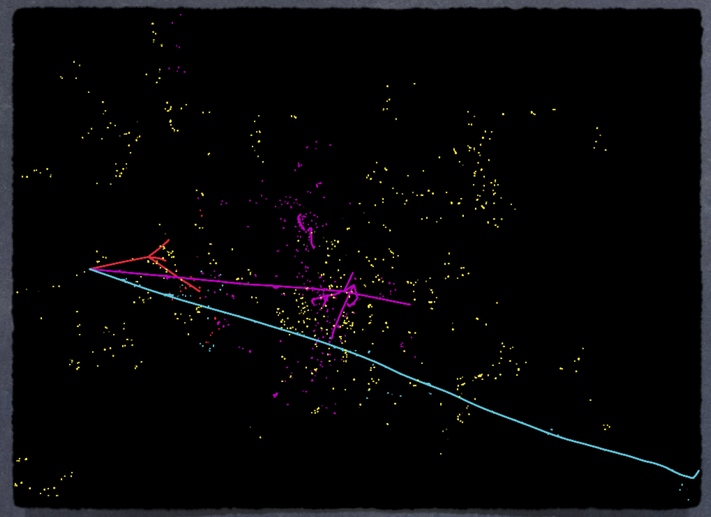
- How do we train the next generation of theorists? How do we assure them a career path?
- I will use neutrino physics + the theory program as an illustration (a few minutes!)
  - Broader implications implied
- Go by energy? While Nuclear physics upgraded JLab to 12 GeV, High Energy Physics is now using neutrino beams of 1-4 GeV

A peculiar arrangement

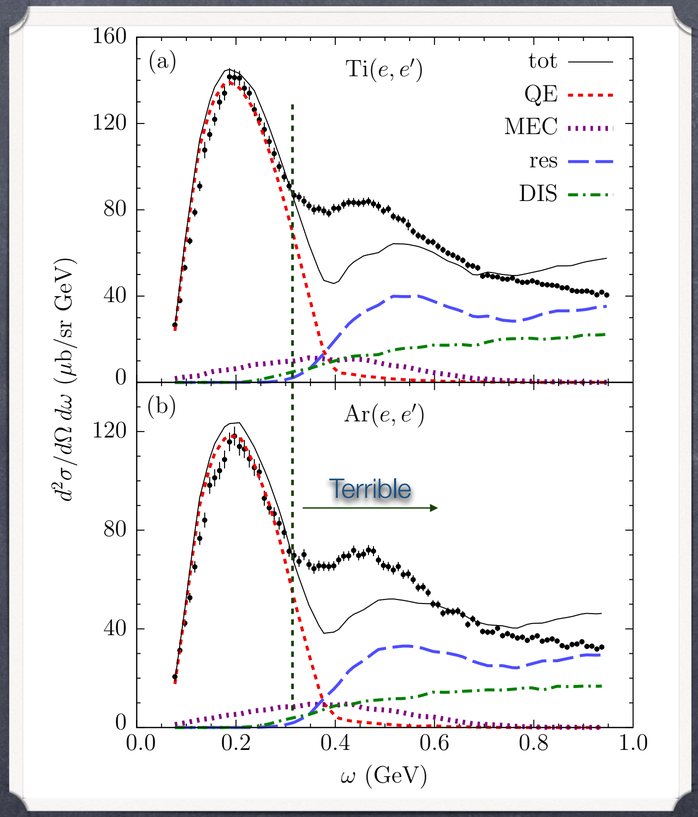
- Neutrinos are notorious for completely disrespecting our carefully crafted partitions between DOE Offices, Frontiers, etc
- Even the 3x3 neutrino mixing matrix has been split between DOE offices



Let's talk about δ_{CP} (DUNE)

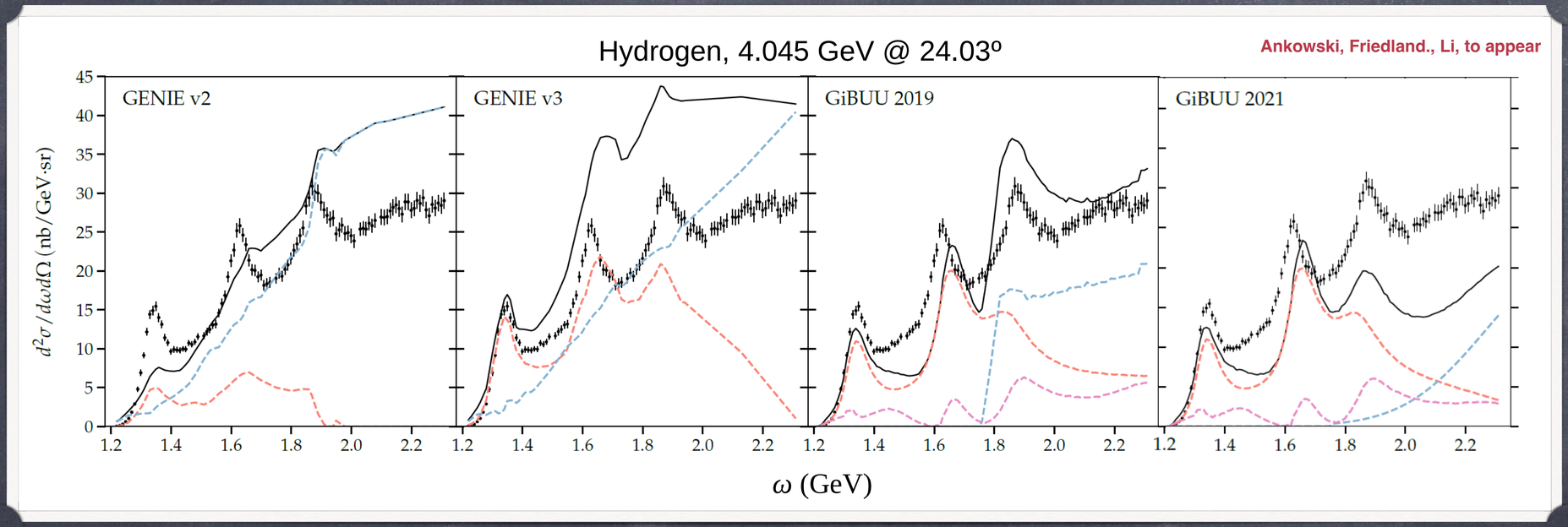


- $P(E_\nu)$ -> We need to reconstruct neutrino energy -> some of it is going to be missing in LArTPC (neutrons, mis-IDed charged particles) -> must rely on the generators to fill in missing info.
- Very nontrivial in GeV regime!



GENIE predictions beyond the quasielastic peak disagree with JLab e-N data

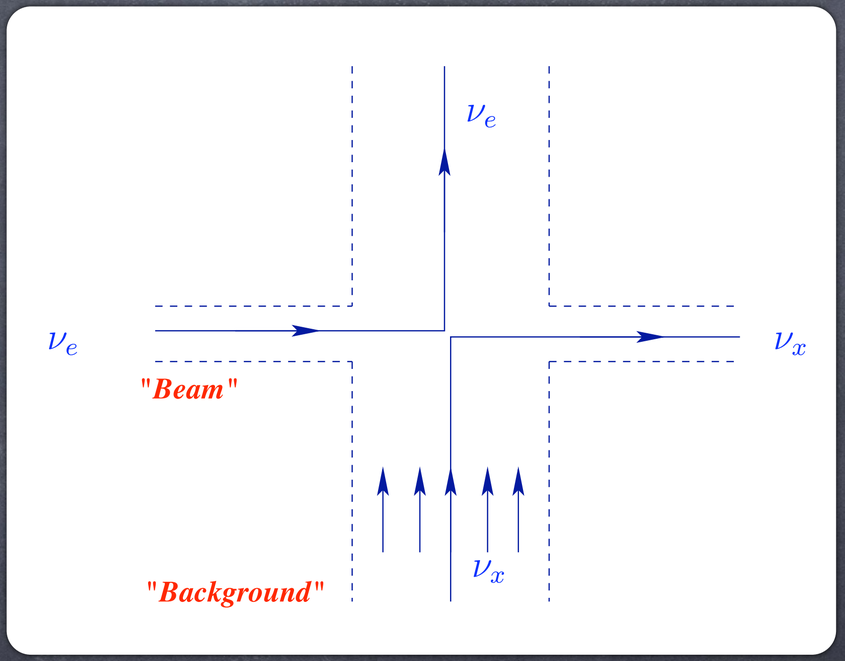
Large discrepancies for all generators



- Won't be solved by blind tuning, need sound physics (theoretical framework).
- The GeV range is the transition regime between nuclear physics and QCD -> need expertise in hadronic physics and nuclear effects + Nucleon axial form-factor from LQCD

More DUNE physics: supernova neutrinos

- Collective flavor oscillations. Just above the collapsed core the number density of streaming neutrinos is 10^8 moles/cm^3. Their flavor evolution is coupled. One has to evolve neutrino ensemble as a whole.
- Rich many-body quantum system, with many regimes (lost of work since 2005)
- Connections to QIS



Getting physics out of the DUNE supernova signal

- If we understand how to read the SNB signal, it may tell us:
  - How the explosion develops in real time
  - Whether the conditions are right for different types of nucleosynthesis
  - Quantum dynamics in dense neutrino gas
  - The EOS of nuclear matter
  - Many probes of new particle physics, at conditions that cannot be reproduced on Earth

Skills we need for the next generation of neutrino theorists

- To sum up: to make the DUNE program a success, need to bring together a lot of exciting physics:
  - Lattice QCD, hadronic physics, nuclear physics, SN explosion astrophysics, collective oscillations and QIS connections, BSM physics, nuclear EOS, nucleosynthesis, ...
- Numerous other examples exist beyond DUNE, e.g.:
  - Reactor antineutrino spectra, cosmological constraints on BSM neutrino scenarios, next-gen solar neutrinos, atmospheric and UHE neutrinos at IceCUBE, $0\nu\beta\beta$ nuclear matrix elements, etc

Skills we need for the next generation of neutrino theorists

- We don't need to preempt or subsume those other disciplines, but we must have enough expertise inside the HEP program to build the bridges, understand their literature, setup meaningful collaborations, etc
- People with these new skills need clear career paths. This situation is not going to solve itself, needs to be addressed thoughtfully and deliberately
- Question appropriate for P5.