R. Hahn

Fermilab Main Injector Tunnel

Intensity Frontier Geant4 Requirements

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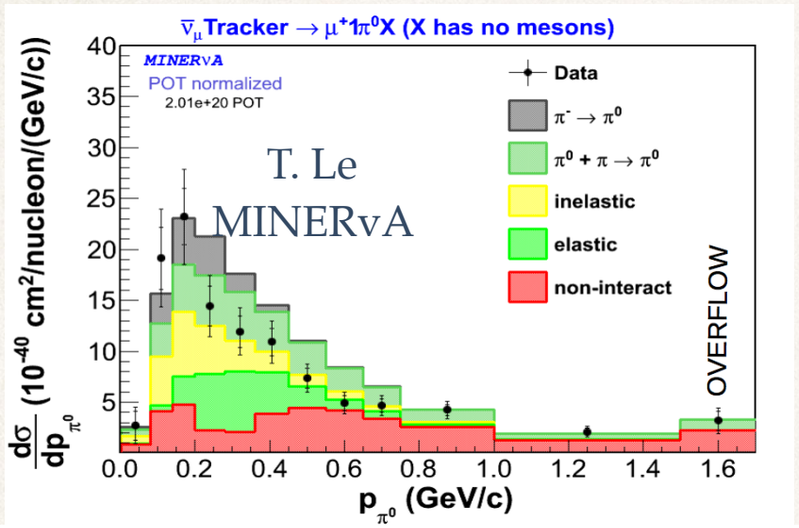
Fermilab

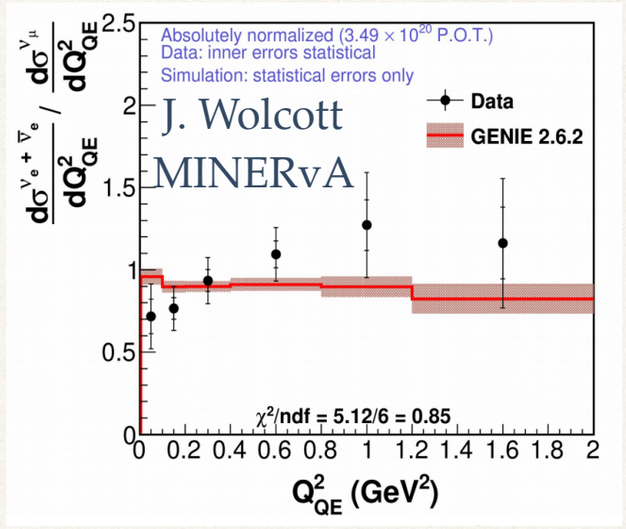
2 October 2015

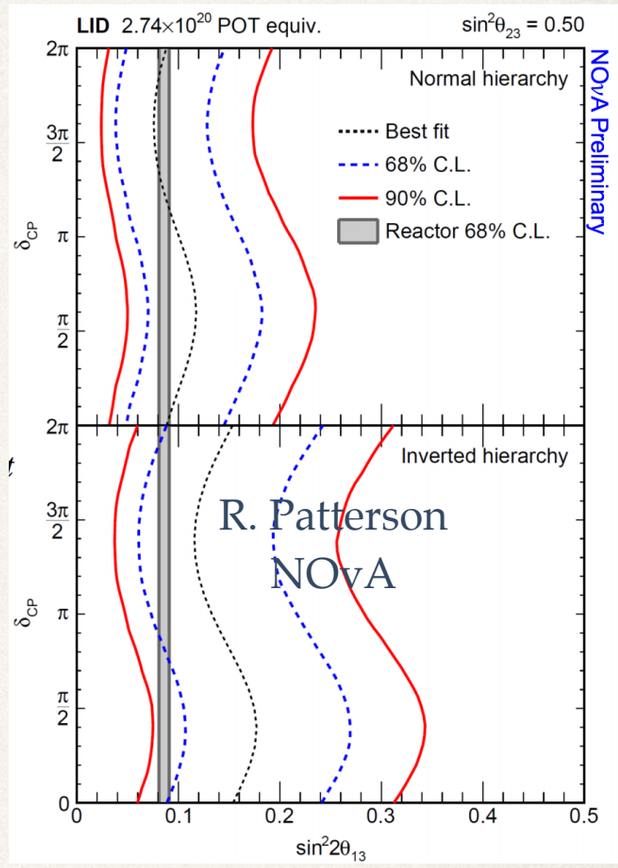
First of All: Thank You!

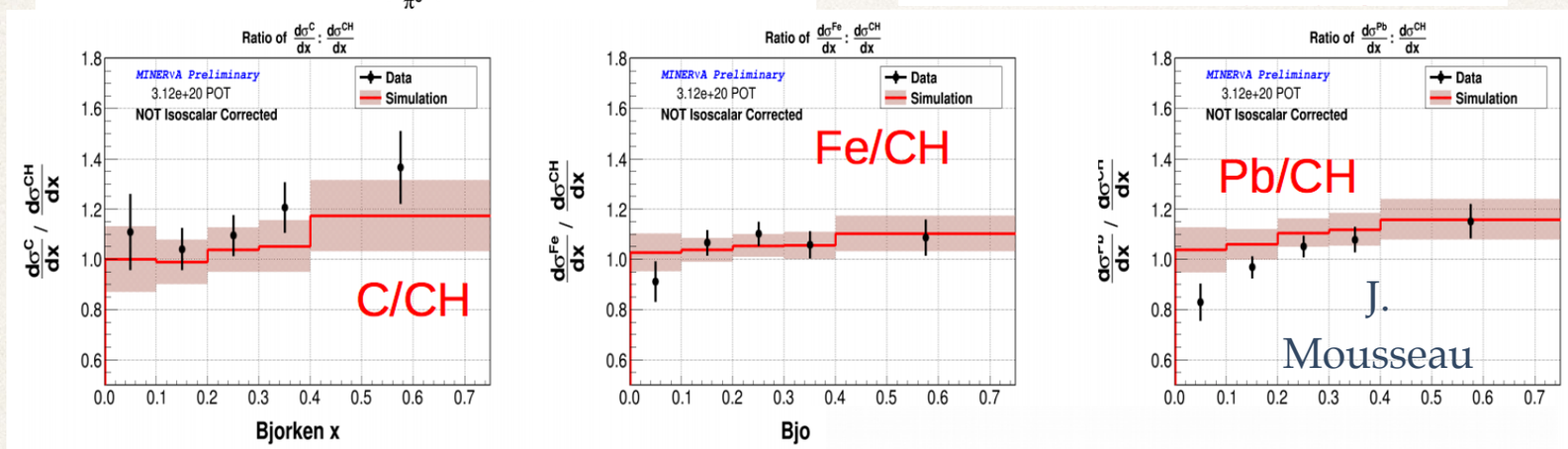
Intensity Frontier results this year that used Geant4 extensively

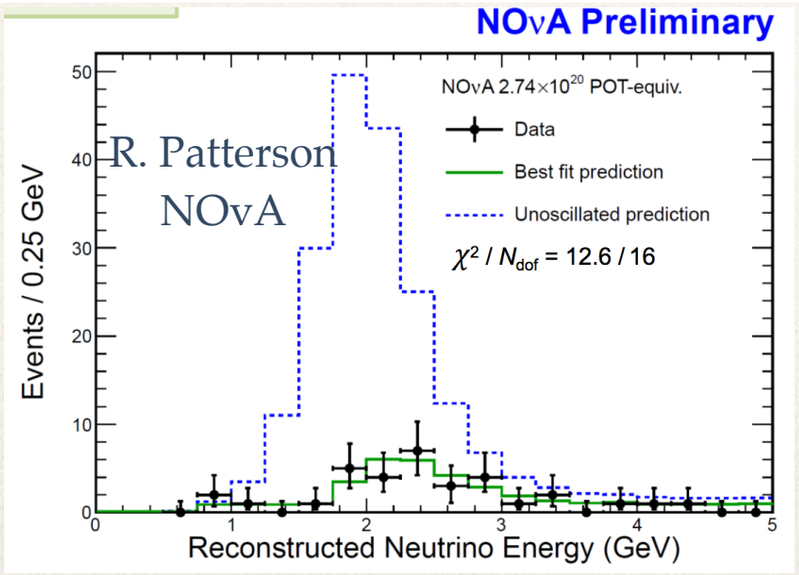
All drawn from FNAL Wine & Cheese Talks

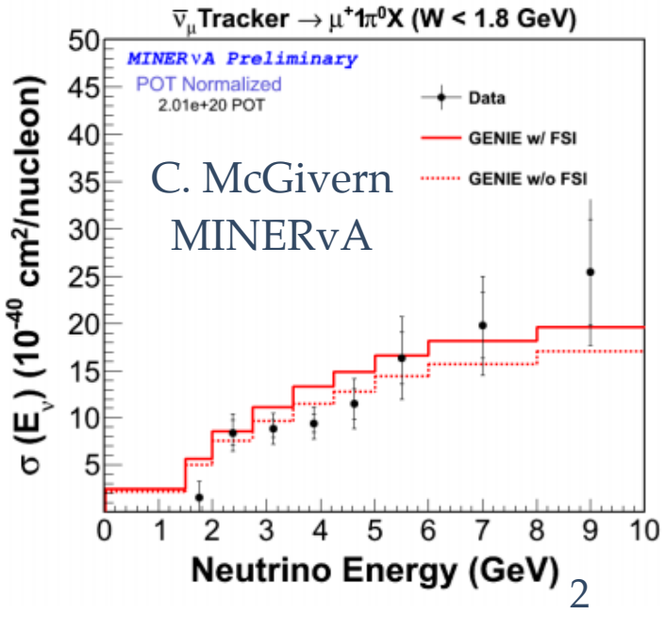






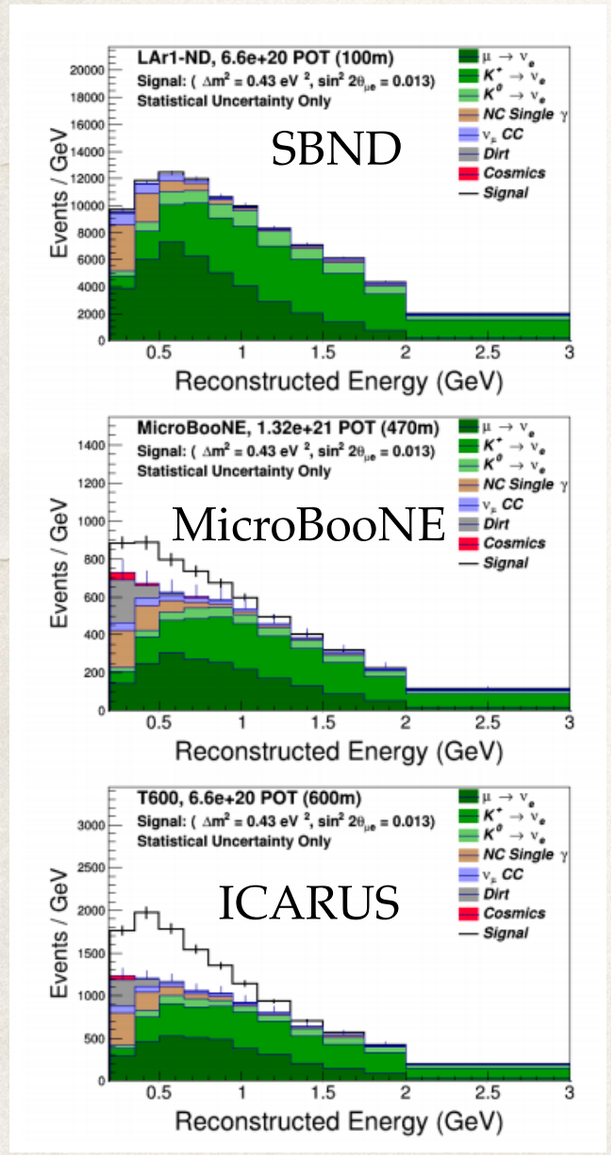


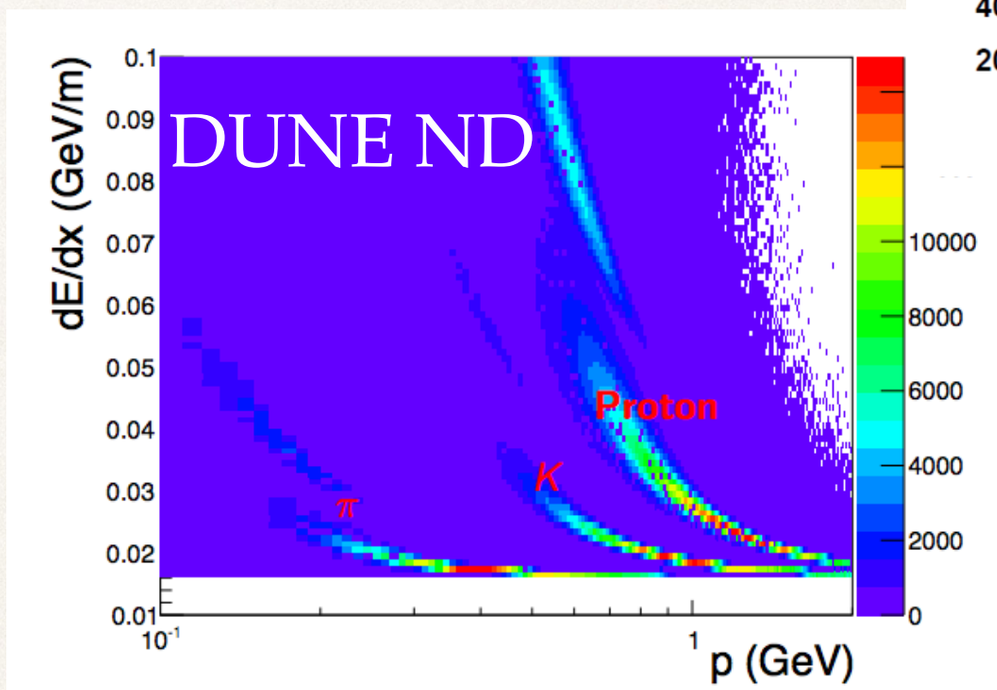


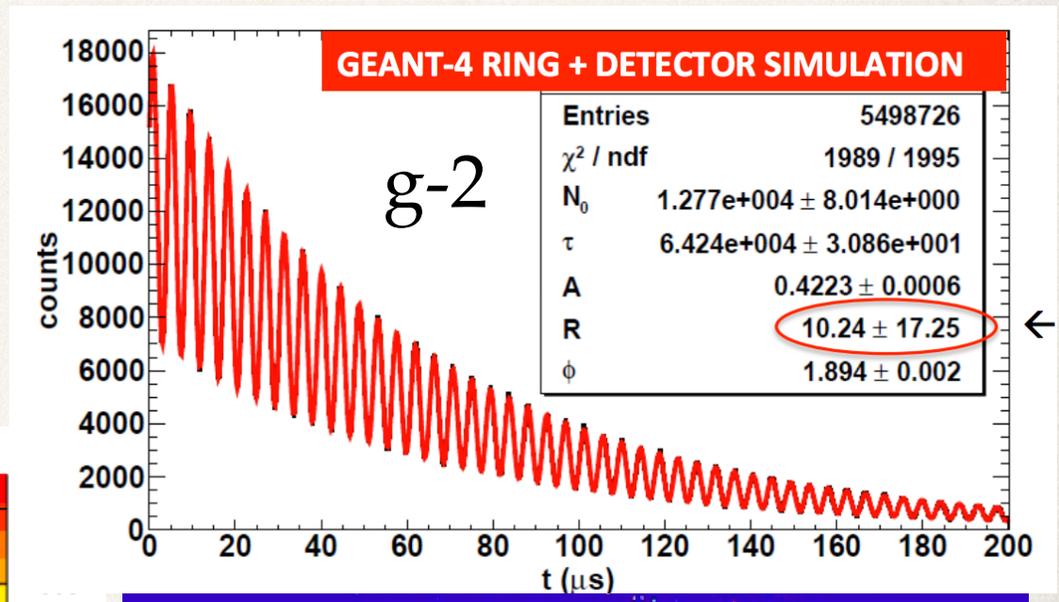


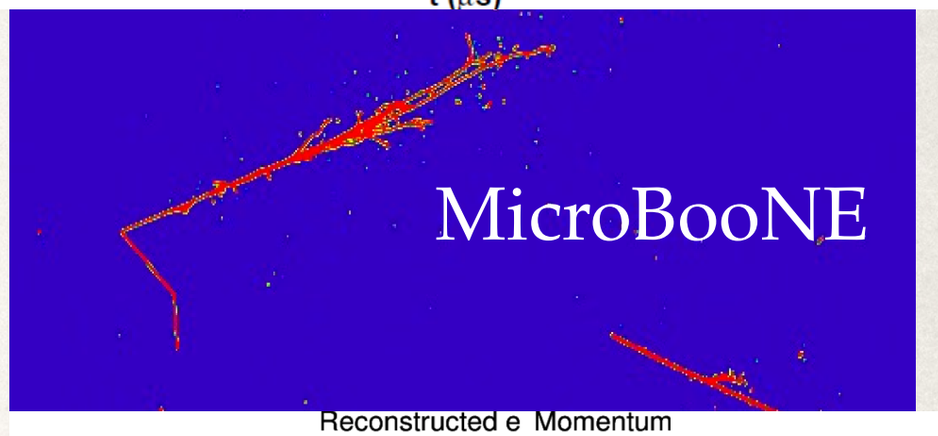
First of All: Thank You!

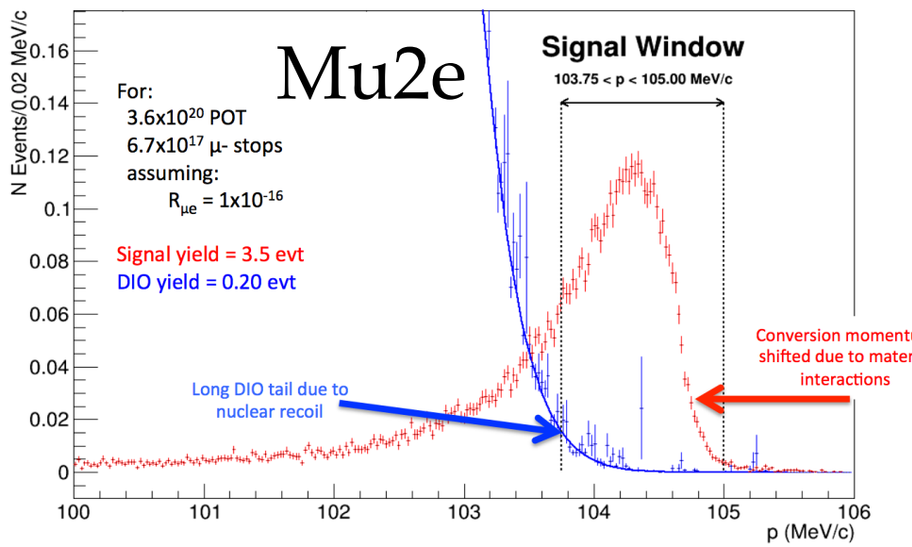
Geant 4 is also giving us an unprecedented ability to design and understand the capabilities of upcoming experiments











Introduction

- Geant 4 is clearly working very well for the Intensity Frontier
- This talk is a list of requests that would make it work even better
- Experiments who have provided input:

Muon	Neutrino	Fixed Target	Test Beam
g-2	DUNE	SeaQuest	LArIAT
Mu2e	MicroBooNE		
	MINERvA		
	MiniBooNE		
	NOvA		

* These experiments have contacted me or the FNAL Geant4 team. Other intensity frontier experiments were not intentionally excluded and will be contacted by the FNAL Geant4 team in the future

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Note: I am a DUNE/MINERvA collaborator. I'm most familiar with their requirements, but have done my best to represent all experiments listed here

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Priority Physics Processes

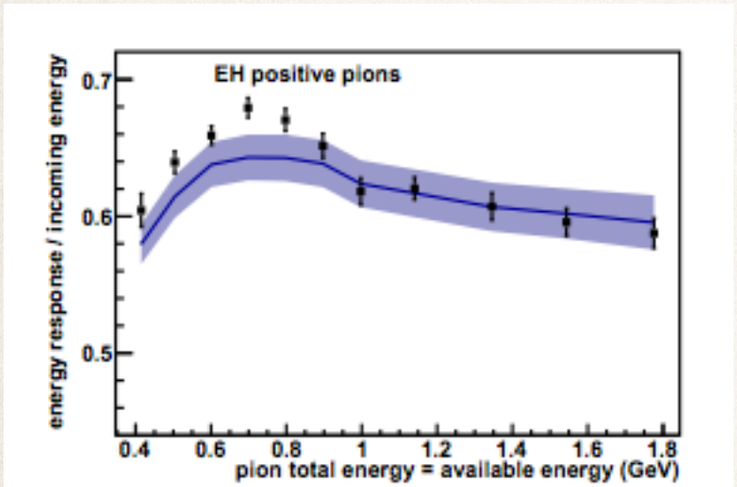
- Physics processes of importance to Intensity Frontier
  - Of general importance:
    - **Hadronic showers** in the range of ~10 MeV to ~10 GeV
      - Key to neutrino energy reconstruction
    - **Low energy electromagnetic showers**
    - **Cosmic rays**: High energy to a few MeV
      - Backgrounds to surface detectors
    - **Muon and antimuon separation** in the absence of a magnetic field
      - Key to separating neutrino background in antineutrino beams
    - **Muon spin tracking and polarization** at point of decay
    - **Muon-nuclear interactions**
    - **Antiproton production** in proton beams

Priority Physics Processes

- Physics processes of importance to Intensity Frontier
  - Of particular interest to Liquid Argon detectors:
    - **Particle ID** via dE/dx in liquid Argon
    - **Proton stopping and dE/dx** profiles in liquid Argon
    - Simulation of **interplay between ionization and scintillation light**
    - **Pion and kaon ID** utilizing specific interaction and decay modes

Systematic Uncertainties

- It is important that Geant4 simulate **physics processes** precisely
  - But **equally important: an estimate of uncertainties** on geant4 simulations and an ability to propagate these to physics measurements



MINERvA testbeam measurement of pion response compared to Geant4

- This is currently done experiment-by experiment, **comparing** key features of **Geant4 simulation to external data**
- Disadvantages:
  - Each experiment is **reinventing the wheel**
  - We are almost certainly **underestimating** geant4-related uncertainties
  - Comparisons typically take years -> makes **upgrading to new versions extremely difficult** (IF collaborations are often small!)

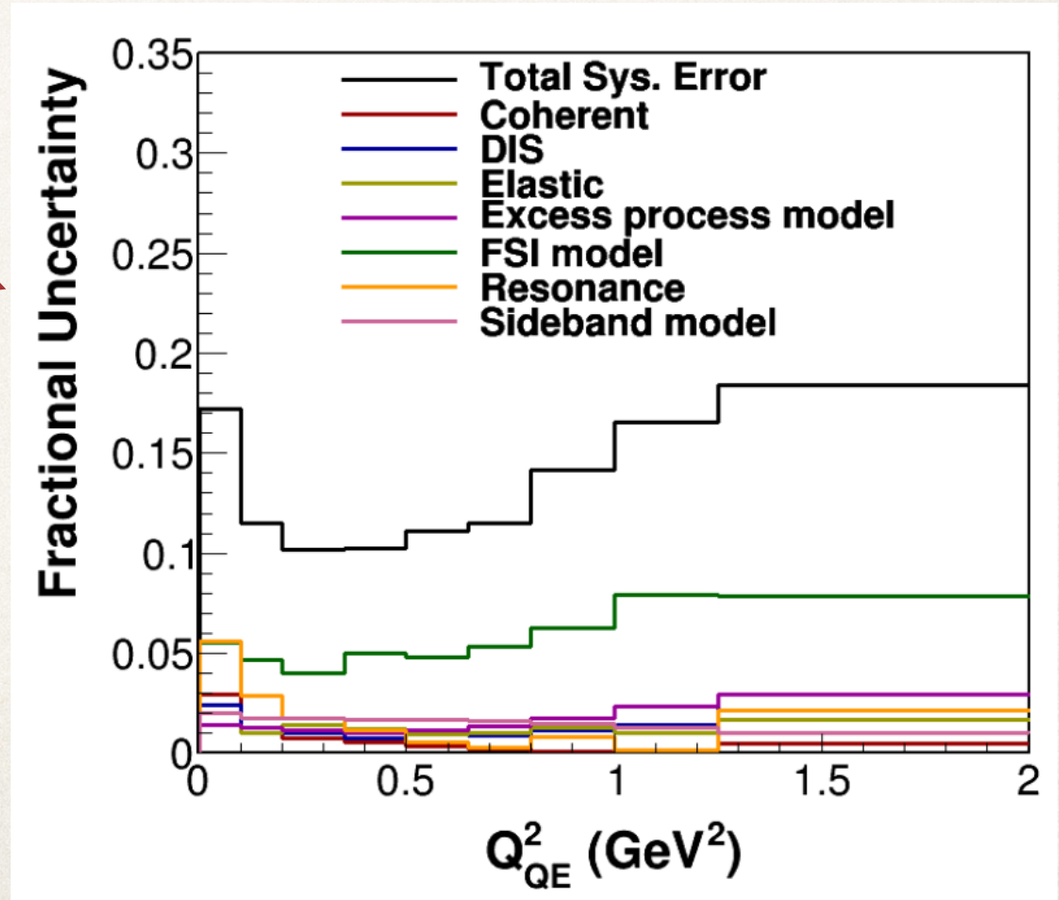
Systematic Uncertainties

- Our request to you: **tools for propagating uncertainties** in Geant4 model parameters to measurements:
  - At a minimum: enable **tunable model parameters** so that users can estimate how much changing parameters changes physics results
  - Our ultimate dream: **a set of parameters, knob turns, and correlations** that we can use to estimate a full Geant4 error band on our results, a la GENIE

GENIE-related and total systematic uncertainties on MINERvA's ν_e CCQE measurement

Very straightforward for new students to use

But never used for final results without considering whether further uncertainties should be assessed



Systematic Uncertainties

- A **key point about systematic uncertainties**
  - One reason that GENIE's systematic uncertainties have been so successful is that most of them are **reweightable**
  - We can estimate uncertainties on parameters by reweighing a **single Monte Carlo sample**
  - This **may not be feasible** for most Geant uncertainties
    - But I encourage you to consider whether some parameters are reweightable
    - There is a **vast difference in usability** between reweightable and non-reweightable parameter uncertainties
- Non-reweightable parameters are still much better than nothing!
- **Another option:**
  - A large set of data/MC comparisons with G4 recommended error bands

Custom Features

- Another request related to variable model parameters:
  - **"Custom features"** — e.g. the ability to insert a cross sections extracted from data at key points in the simulation
    - **Hopefully not necessary** in most cases, but **occasionally useful**
      - When an experiment is stuck using an **old version**
      - When some **small corner of phase space** is particularly important to a measurement

Advice on Physics Lists

- Other general requests:
  - Advice on **physics list choice**:
    - Short term: **Validation of current physics list** in phase space of interest to IF experiments
      - An area of importance: **overlap regions** between models
  - Longer term: Development of **new physics lists** designed for intensity frontier needs
  - Also: guidance on constructing **custom physics lists and configurations** that can be shared across experiments

Version Validation

- Other general requests:
  - **Validation of new versions** of Geant4
    - Clear communication about what changes we should expect to see
    - Ideally: tools to understand **differences between any two versions** (not just incremental changes of each release)
- Please **keep old versions of Geant4 available** even if you are no longer supporting them
  - Extremely important when updating **older published results**

Geometry Validation

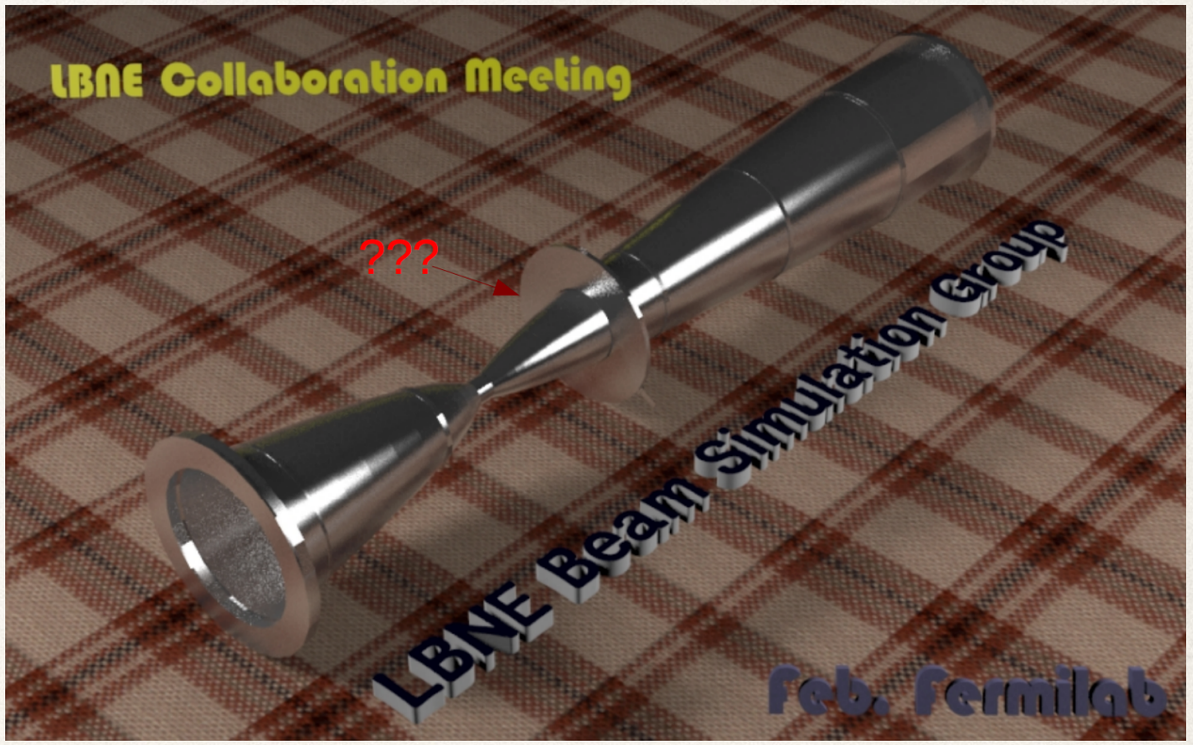
- Tools for **validating and comparing geometries**

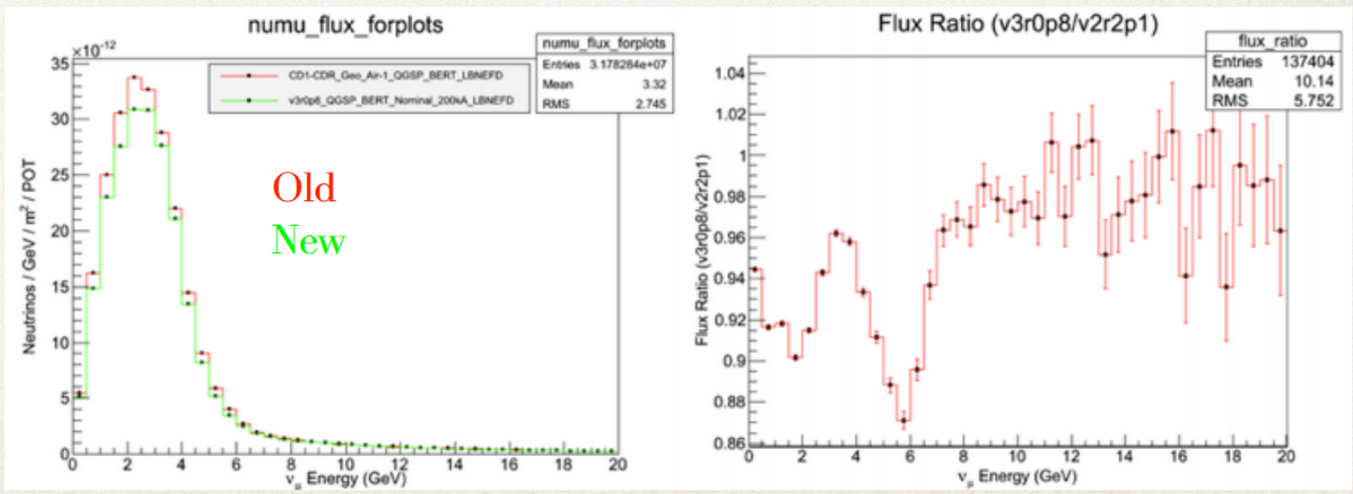
- Also very important: **ensuring that the geometry you want is the geometry you have implemented**

- Particularly critical for **neutrino beam simulations**, where very subtle differences in geometry can produce big differences in neutrino flux predictions

- **Visualizations** are our main tool (e.g. HepRApp, Paraview, OpenInventor), but freuqently work on some platforms but not on others (OSX, SL6)

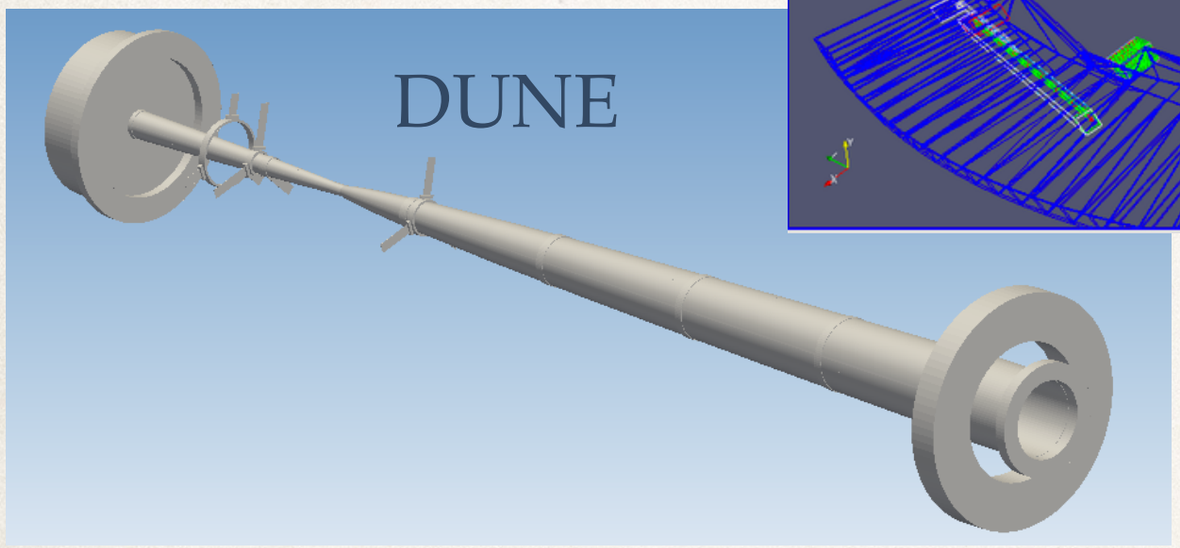
- **Cross checking with other simulations** (e.g. MARS) also very helpful, but differences in GDML writers/readers have slowed these efforts

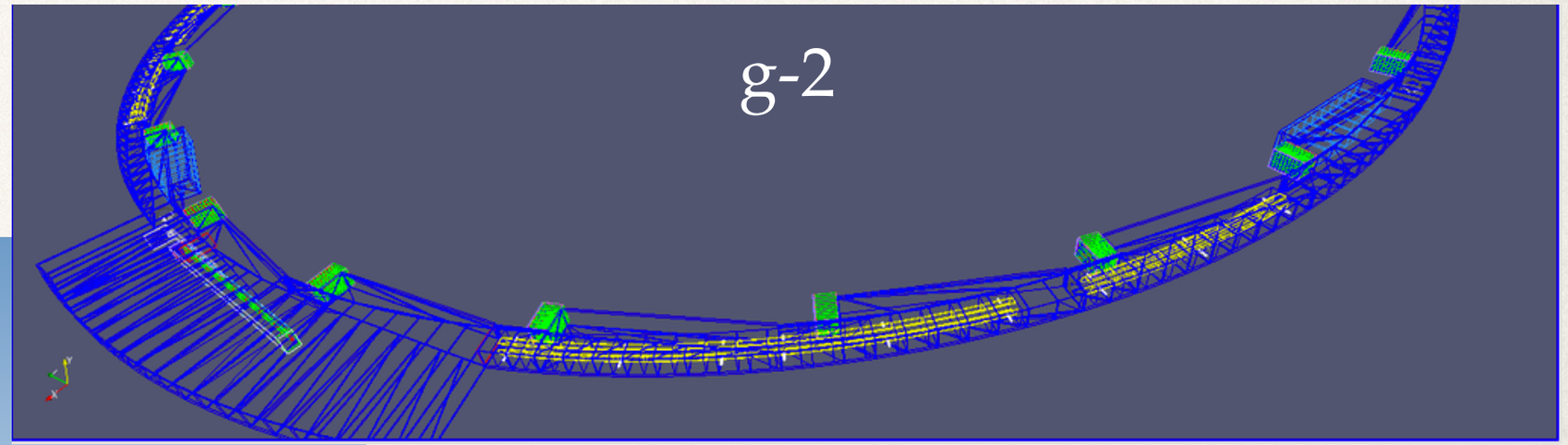




Geometry Validation

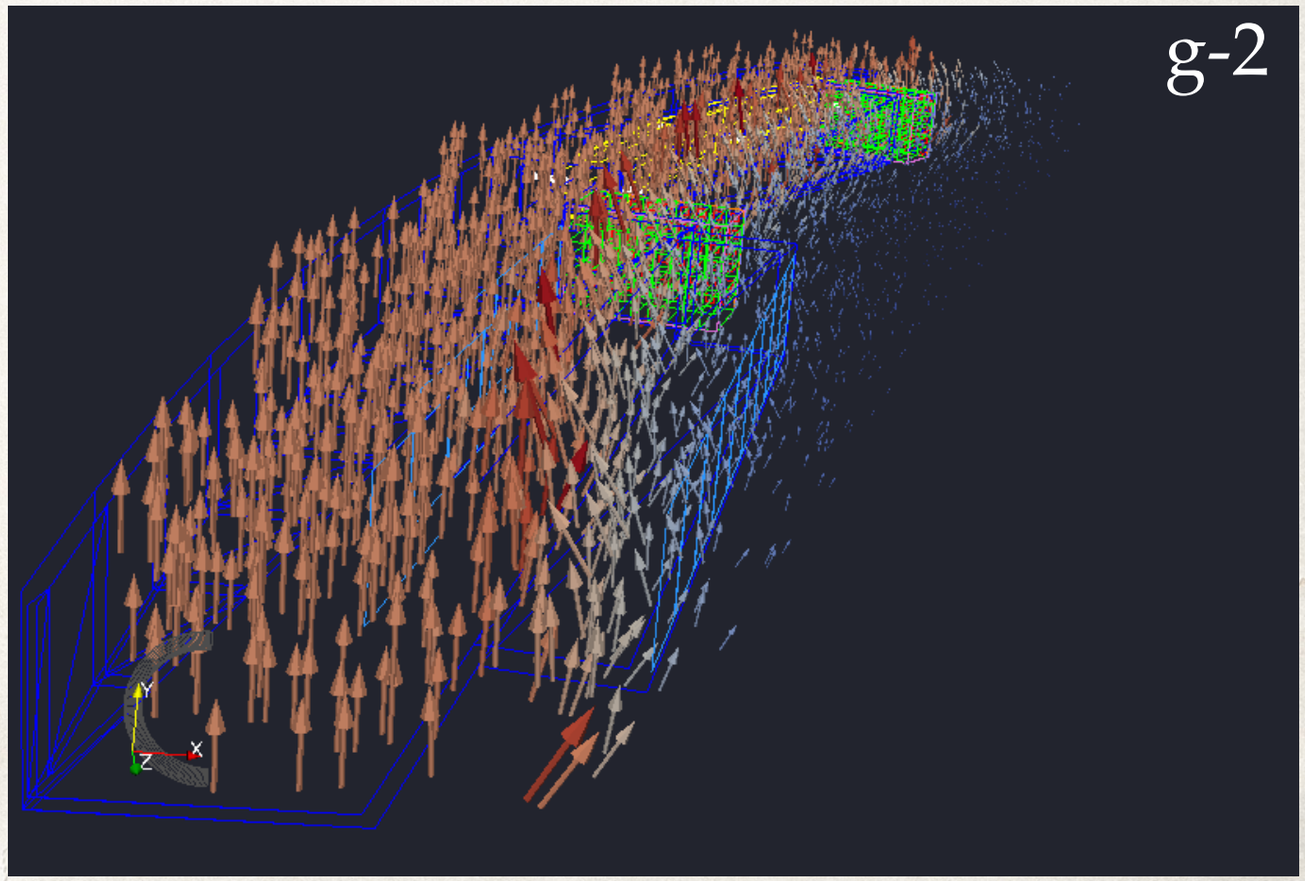
- A tool that has proven useful to Intensity Frontier Experiments: Paraview





- Made with GEANT heprep output using Paraview + Geanttovtk Plugin

- Not well validated on non-Mac platforms



MicroBooNE Requests

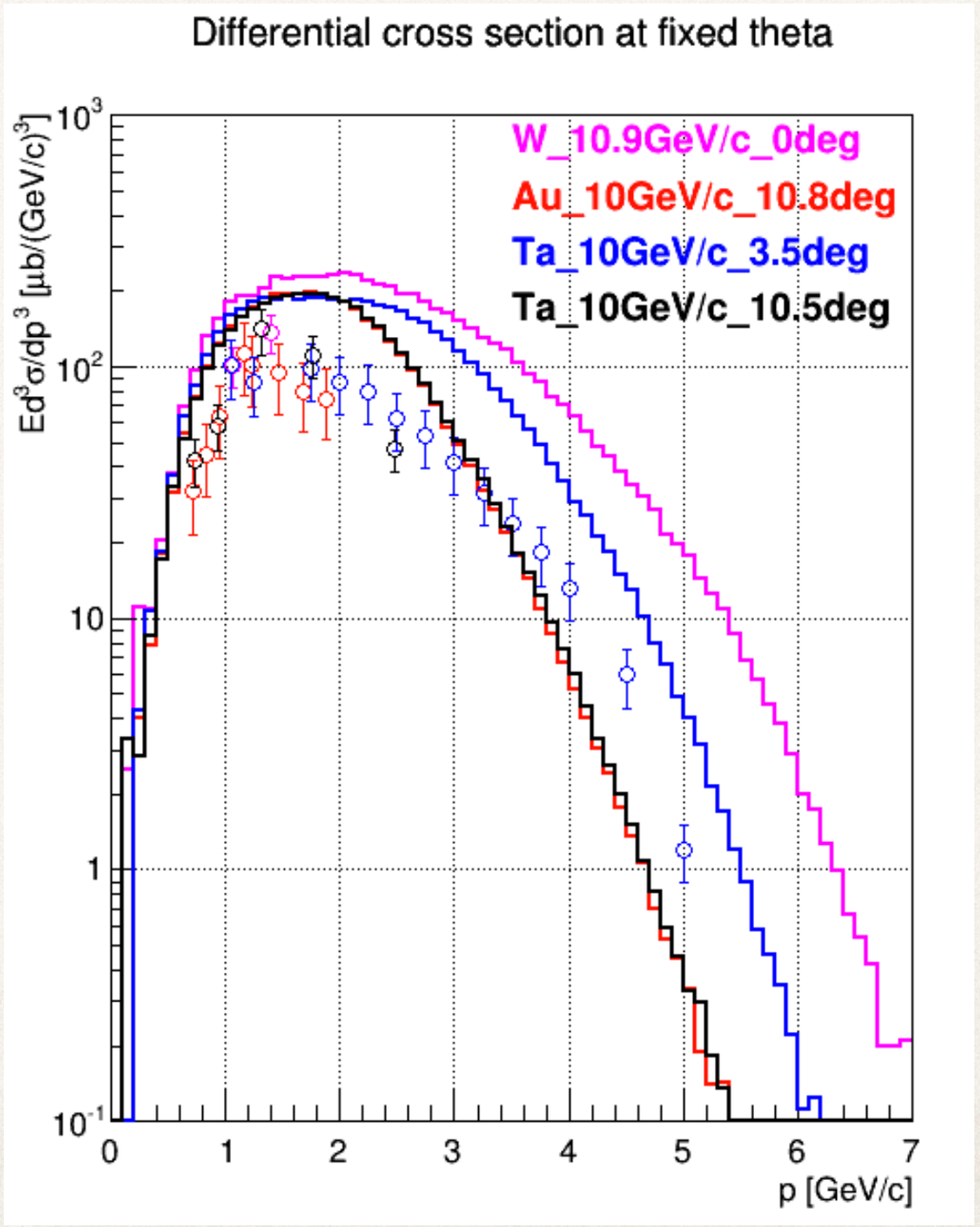
- **Guidance** on using Geant4.10.1's **multi-threaded capabilities**
  - When you have a machine with N processing queues, **how many jobs should be submitted?**
    - N? N/X (X = ?)? 1, and let G4 populate the cores?
      - Event if the answer depends on the use case, guidance is still needed
- **Advice on using G4Py**
  - Would like to use for "quick and dirty" simulations on laptops
  - But i**nstallation on laptops is currently difficult**

A g-2 Request

- A crucial component of simulation for g-2: **decay of particles with spin**
  - Requests:
    - **More emphasis on spin** aspects of decay
    - **Easier to enable** decay w/ spin in simulations
    - **Fix to two bugs** in G4DecayWithSpin reported in Bugzilla report 1783 (http://bugzilla-geant4.kek.jp/show_bug.cgi?id=1783)
- Experiment is currently working on designing and understanding detectors — spin issues not critical here
  - But absolutely vital for eventual analysis

A Mu2e Request

- Improved simulation of antiproton production by proton beam
  - Proton beam induced antiproton production; Geant4 9.6.p03 (FTFP_BERT) simulation compared to data from various experiments (Data compiled by S. Striganov; Geant4 simulation by Z. You)
    - Amann et al - 0 degree, 1 and 1.4 GeV/c, tungsten, 10 GeV/c
    - Sibirtsev et al – 3.5 degree, 1.25 – 5 GeV/c, tantalum,10 GeV/c
    - Barabash et al - 10.8 degree, 0.72-1.85 GeV/c, gold, 10 GeV/c
    - Averichev et al – 61 and 90 degree, 0.5 GeV/c, lead, 8.9 GeV/c
    - Boyarinov et al – 97 and 119 degree, 0.6-1.207 GeV/c, tantalum, 10 GeV/c
    - Kiselev et al - 10.5 and 59 degree, 0.58-2.5 GeV/c, tantalum, 10 GeV/c



Conclusion

- Geant4 is helping the intensity frontier to do great things!
  - **We really cannot thank you enough!**
- Our simulations cover a huge array of phase space
- In many cases, our needs are **quite different than** that of **the energy frontier**
- Some of our key requests to you:
  - Physics lists validation and development **focused on the intensity frontier**
  - A framework for evaluating **systematic uncertainties**
    - Assessing uncertainties on a model is just as important as having an accurate model

Thank you for listening!

The End

A Mu2e Request

- Improved simulation of antiproton production by proton beam
  - One of the **larger background sources** are antiprotons which can enter the fiducial area, annihilate and produce electrons with the momentum in the signal window
  - Plot on next page right shows **comparison of proton beam induced antiproton** production from various experiments with Geant4 simulations
  - Simulation was performed using **FTFP_BERT** physics list
  - The **Geant4/data ratio** of differential cross section is **between 1.3 and 3**
  - Given the impact and importance of the antiproton background **the request would be to improve the agreement of the simulation with the data**

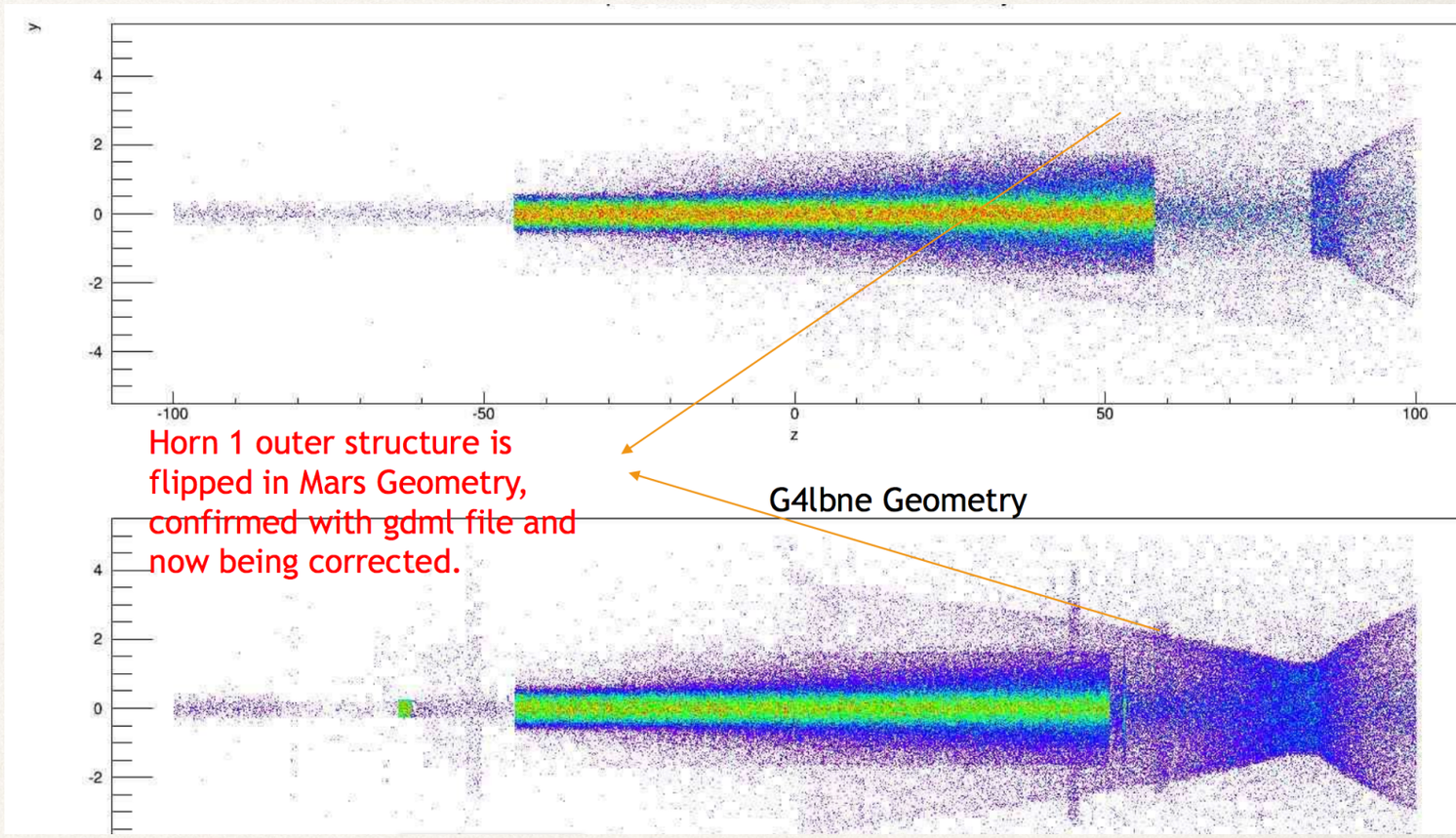
Details on GDML File Conversion

- MARS -> GDML -> Geant4 Conversion Problems

- Various volumes flipped

- Many material densities set to 1 g/cm3

- Attempting to produce heprep file caused jobs to hang



Details on GDML File Conversion

- Geant4 -> GDML -> MARS Conversion Problems

- GDML->Root conversion produced warnings

- Last 100 cm of horn 1 missing

- Could likely have been solved with more iterations, but time constraints necessitated implementing the geometry in root directly

- Problems not seen with similar conversion for BNB beamline simulation (simpler geometry than DUNE)