Simulations of the NuMI Beam

& General NuMI-X Work

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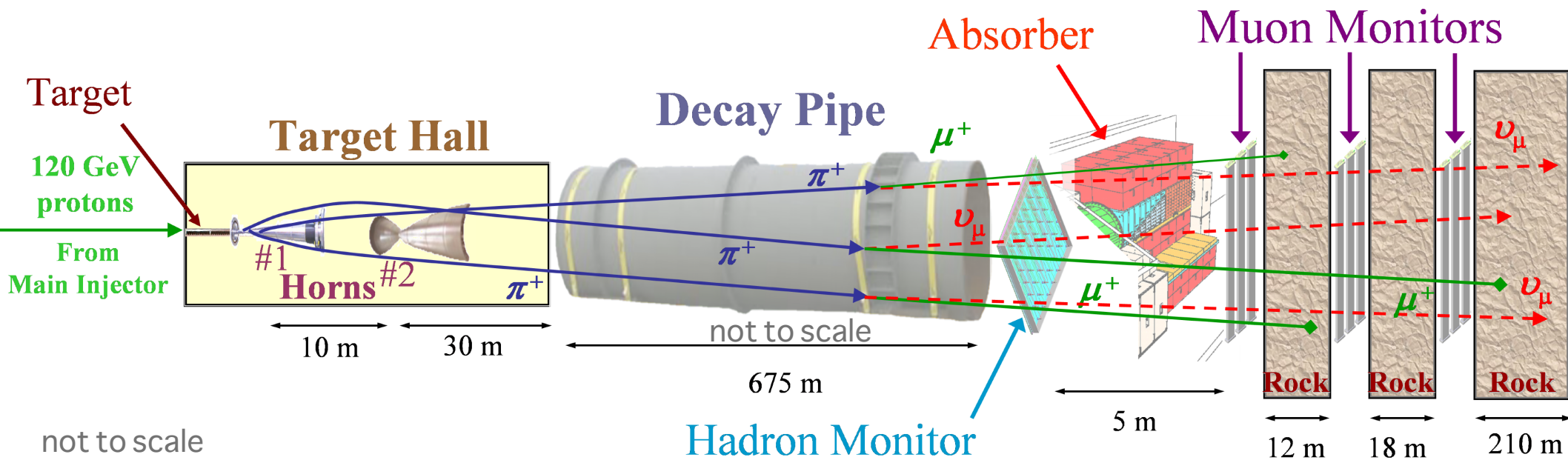
Neutrino Flux Prediction Mtg 2014-09-22

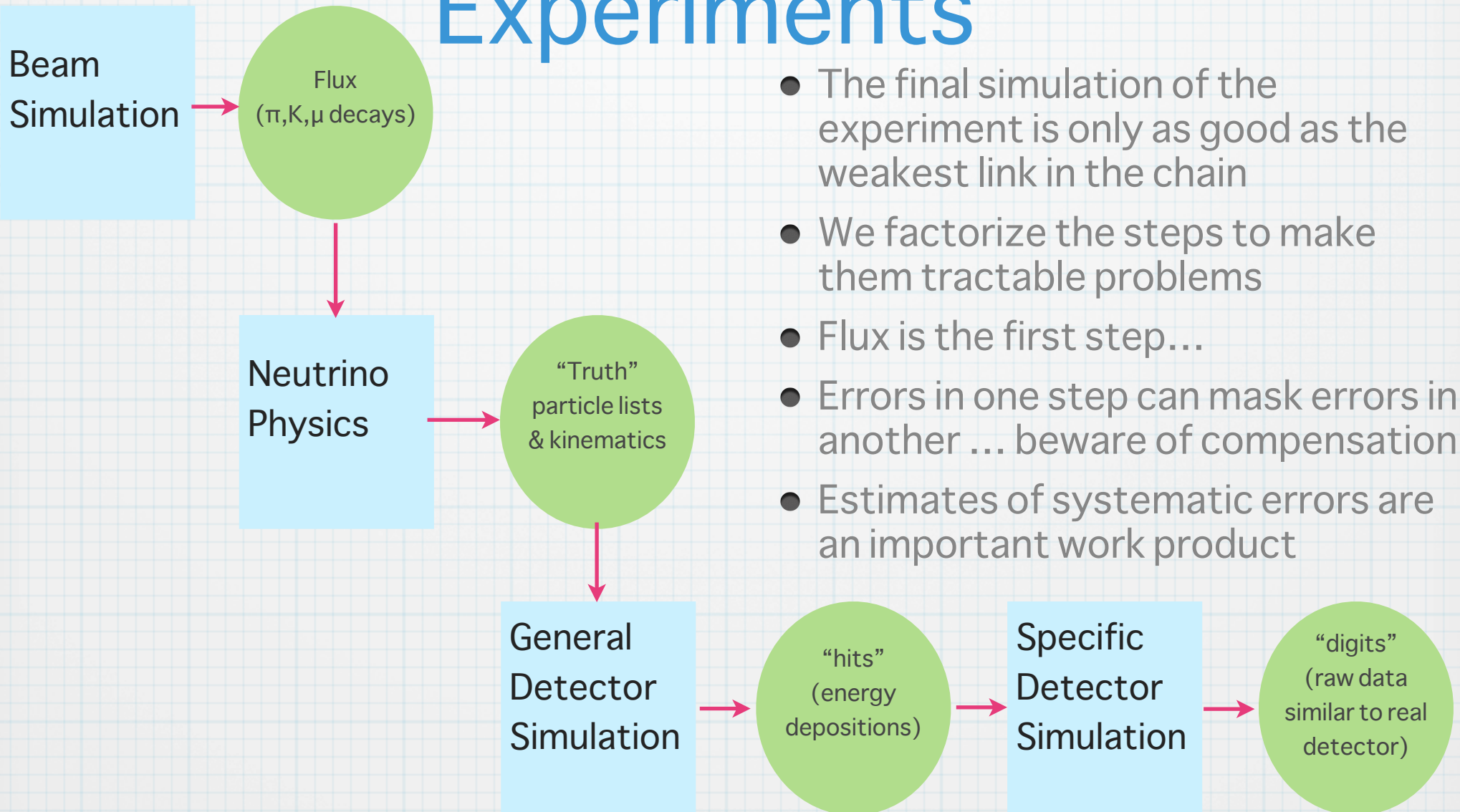# NuMI
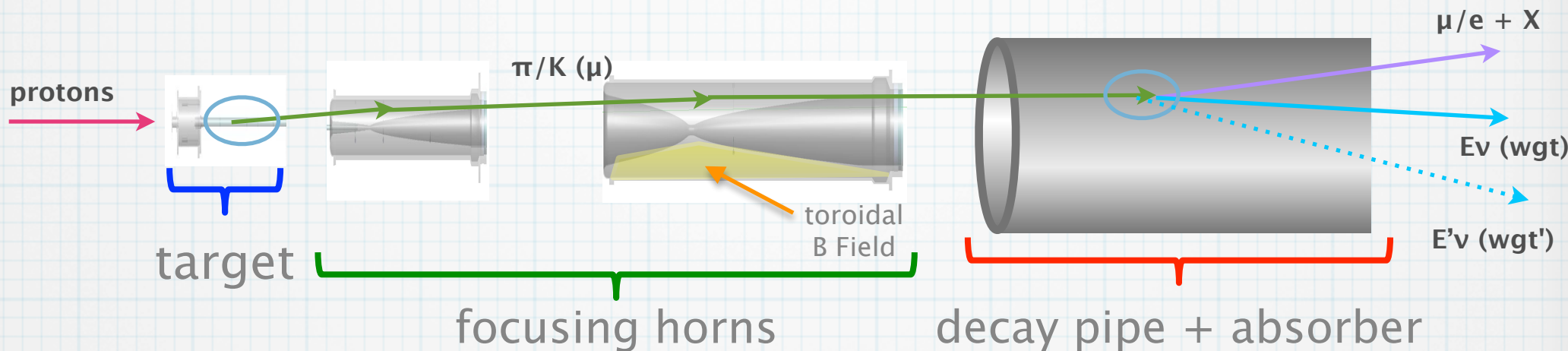
- NuMI = Neutrinos at the Main Injector

- target: so far two distinct styles (MINOS-era [le], NOvA-era [me])
  - both are graphite, but internal structure is different
  - MINOS-era target could be repositioned relative to horn 1
- two "horns" produce magnetic fields that focus secondaries
  - relative positioning affects focussing, and thus the spectrum
- long decay pipe (vacuum or He filled)

General Simulation Workflow & Products in Neutrino Experiments

Beam Simulation → **Flux (π,K,µ decays)**

↓

Neutrino Physics → **"Truth" particle lists & kinematics**

↓

General Detector Simulation → **"hits" (energy depositions)** → **Specific Detector Simulation** → **"digits" (raw data similar to real detector)**

- The final simulation of the experiment is only as good as the weakest link in the chain
- We factorize the steps to make them tractable problems
- Flux is the first step…
- Errors in one step can mask errors in another … beware of compensation
- Estimates of systematic errors are an important work product

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Techniques

protons → target | focusing horns | decay pipe + absorber

π/K (μ) → μ/e + X, Ev (wgt), E'v (wgt')

toroidal B Field

- Keep track of kinematics at key points
  - many π's: toss many (energy dependent); give those that remain an corresponding importance weight
  - hadron production
    - NA49, NA61, MIPP can inform us on adjusting MC yields
  - kinematics of the decay
    - calculate new ν energy and weight for alternative directions
    - not dependent on low efficiency at pointing to a given detector
- Recent: keep track all intermediate stages in ancestry

Weighting
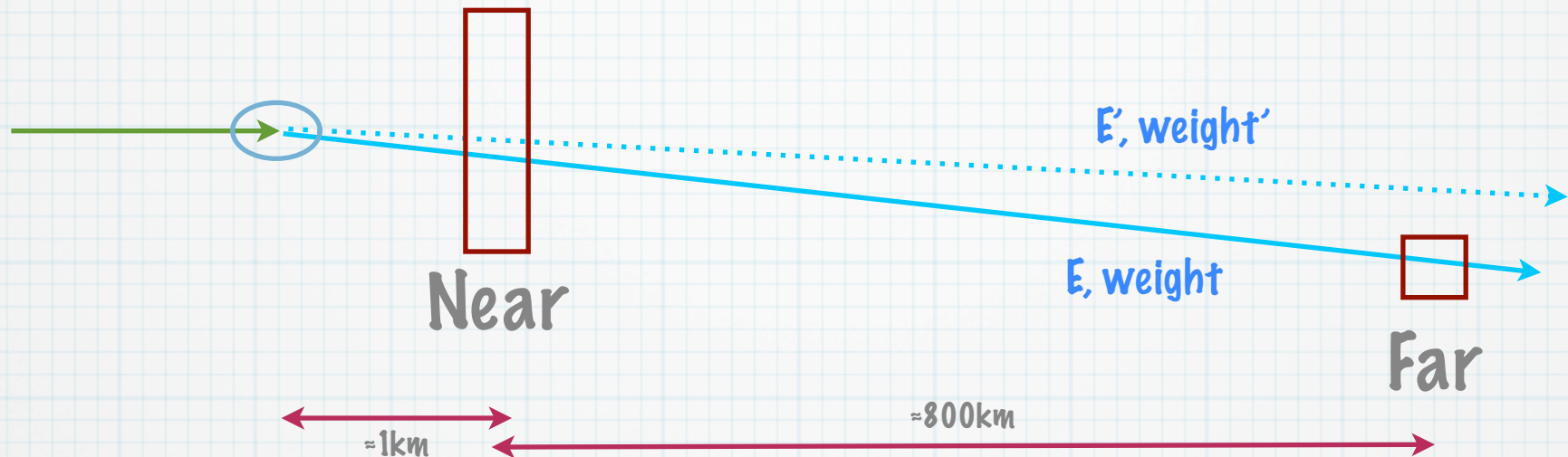
- **Keep track of kinematics at key points** ⬭
  - many π's: toss many (energy dependent); give those that remain an corresponding importance weight
  - initial scatter
    - NA49, NA61, MIPP can inform us on adjusting MC yields
  - **kinematics of the decay**
    - calculate new ν energy and weight for alternative directions
    - not dependent on low efficiency at pointing to detector
- Keep track all intermediate stages in ancestry

NuMI Combinatorics

- Multiple detector locations
  - Near vs. Far
    - far detectors see a point source
    - near detectors see a more distributed ("fuzzy") source
  - Angle relative to beam direction
    - on-axis yields a broad spectrum beam
    - off-axis sees a more narrow spectrum
  - Different positions are sensitive to π production in different regions of p_t & p_z
- Multiple target designs
  - MINOS-era target could be repositioned relative to the horn
- Horn current affects focussing
  - "horn off" is valuable running condition

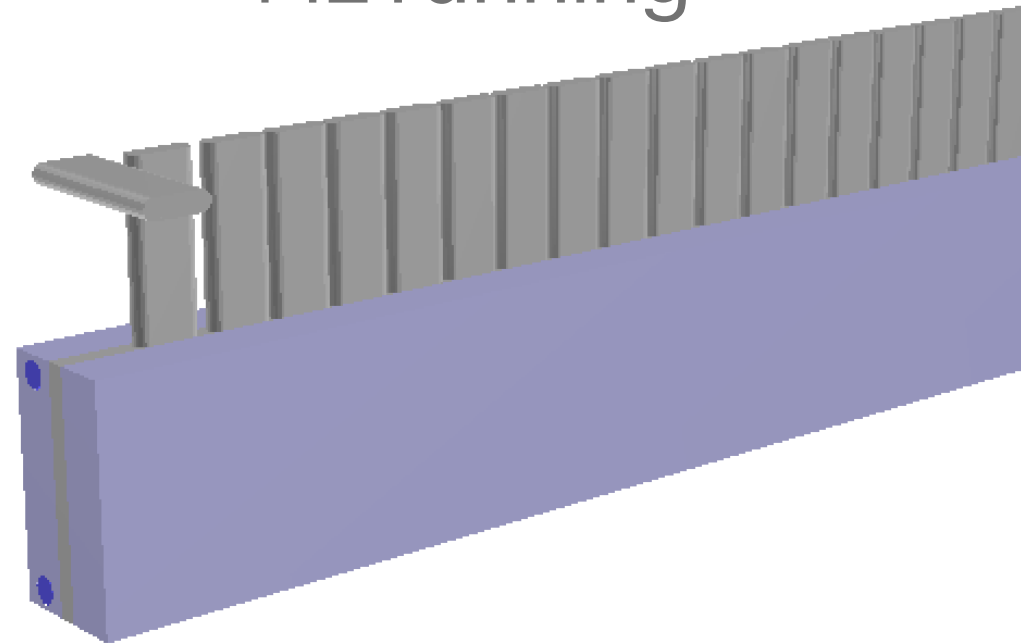- Many "knobs" to turn to get a handle on systematics

Targets

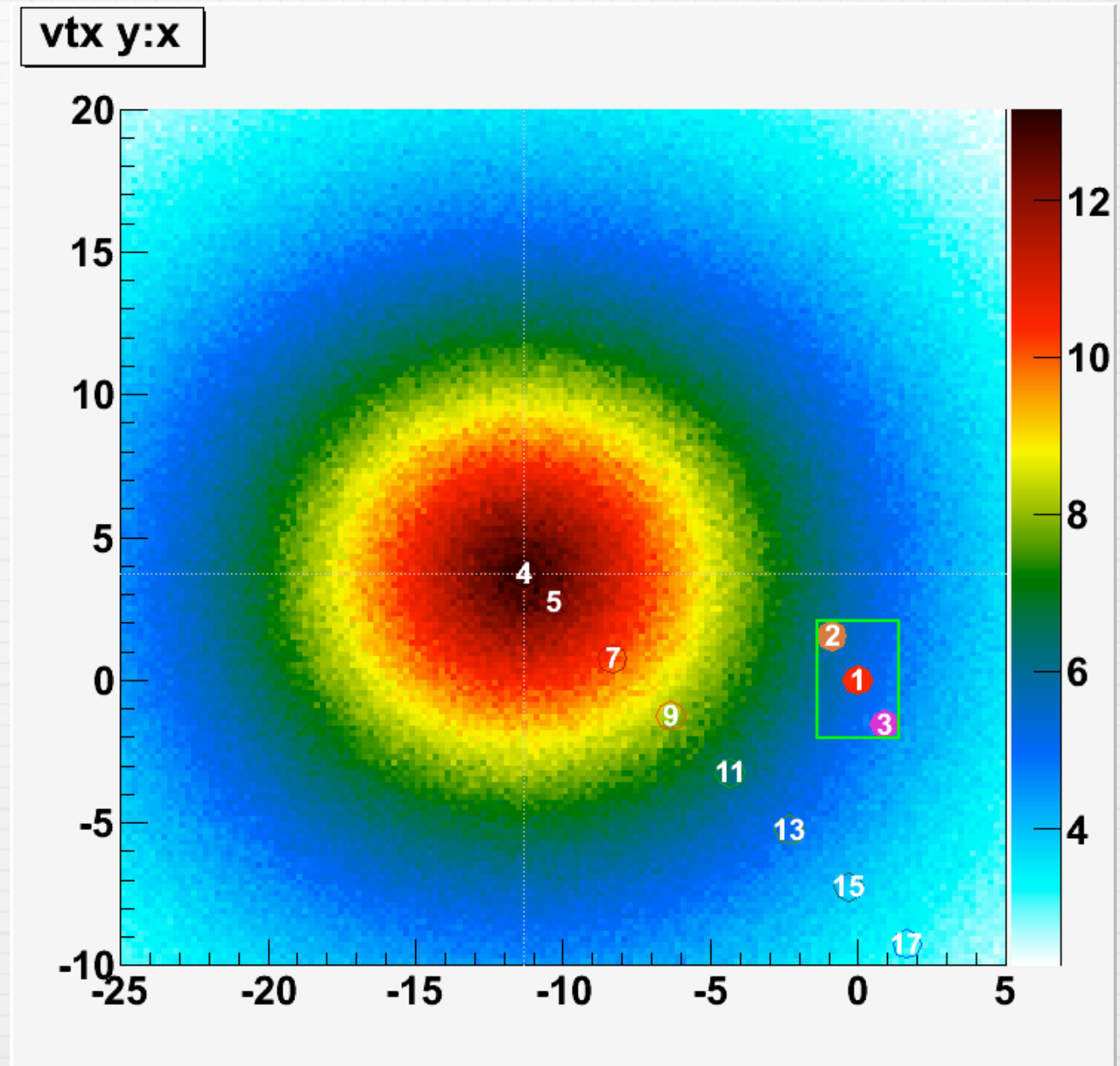MINOS-era
mostly LE running
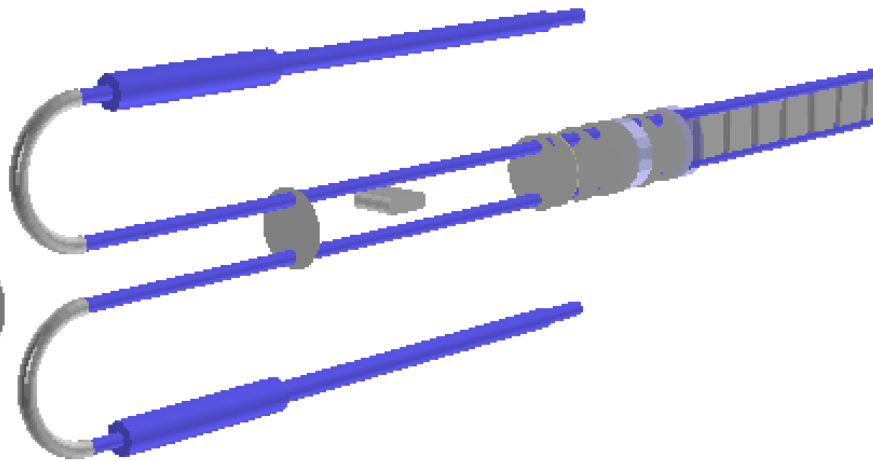
NOvA-era
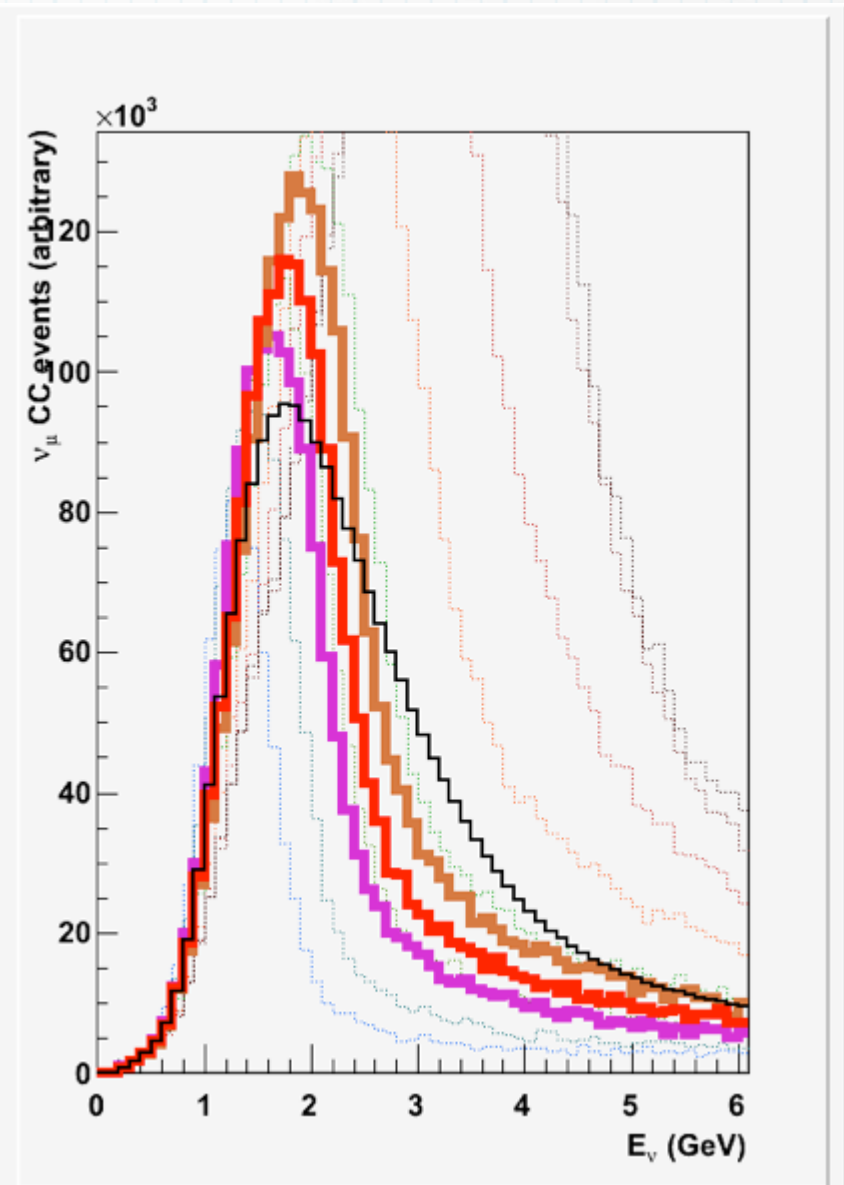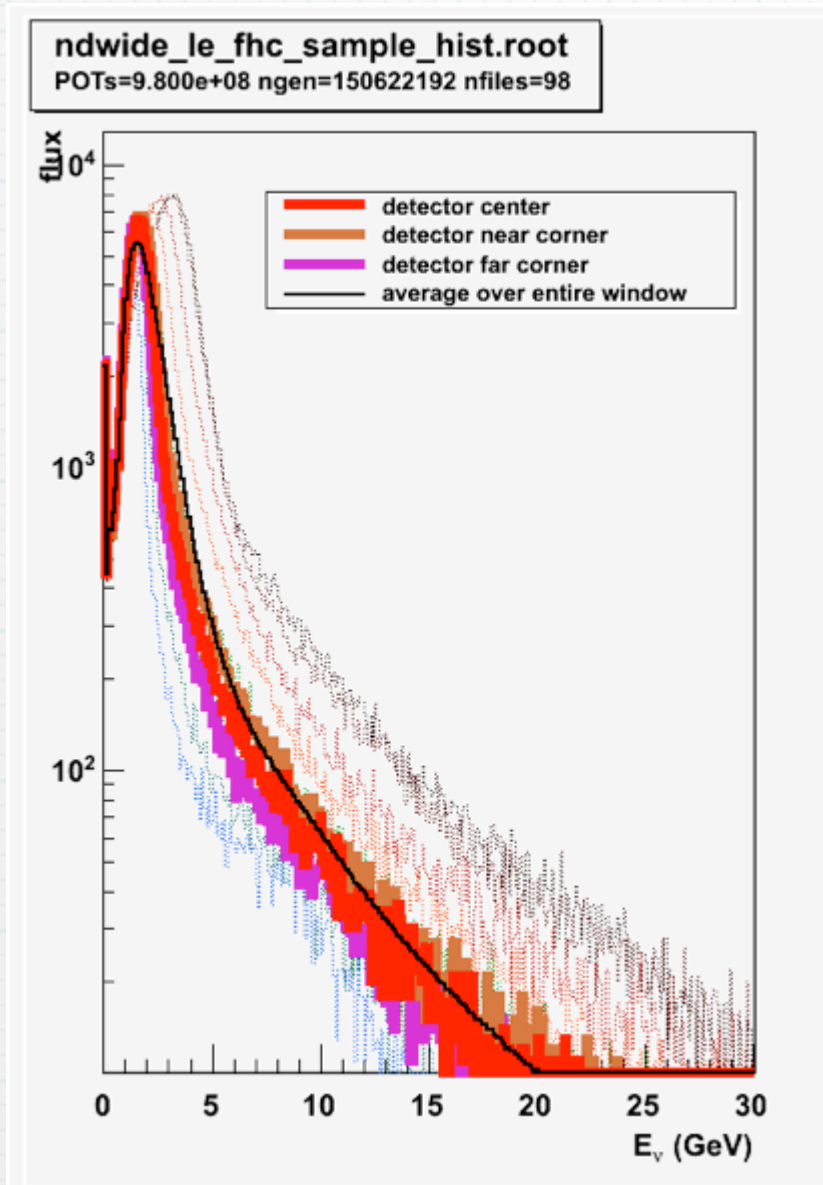ME running

Where the "ν" are

- plot of flux intensity
  - irrespective of energy spectrum

- numbered circles represent sample locations
- proposed NOvA-ND 2x3 = ~green box
- gray crosshairs at beam center

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Effect of Position on Spectrum

NuMI Simulation Effort

- GEANT3, MARS, pbeam — tools used in the early days
  - not used for NuMI experiment analysis any more
- g4numi_flugg = fluka physics + G4 geometry + flugg "glue"
  - all (recent) MINOS and NOvA analyses to date have used flugg
    - historically it seemed to better represent what was seen in data when used "out of the box"
  - but it is "problematic" code
    - a bit of a black box & persnickety about input specification
    - can be frustrating to get a coherent stable build w/ our own code
- g4numi = pure Geant4
  - primarily used by Minerva
    - interesting new development work being done here
  - more choices of physics models
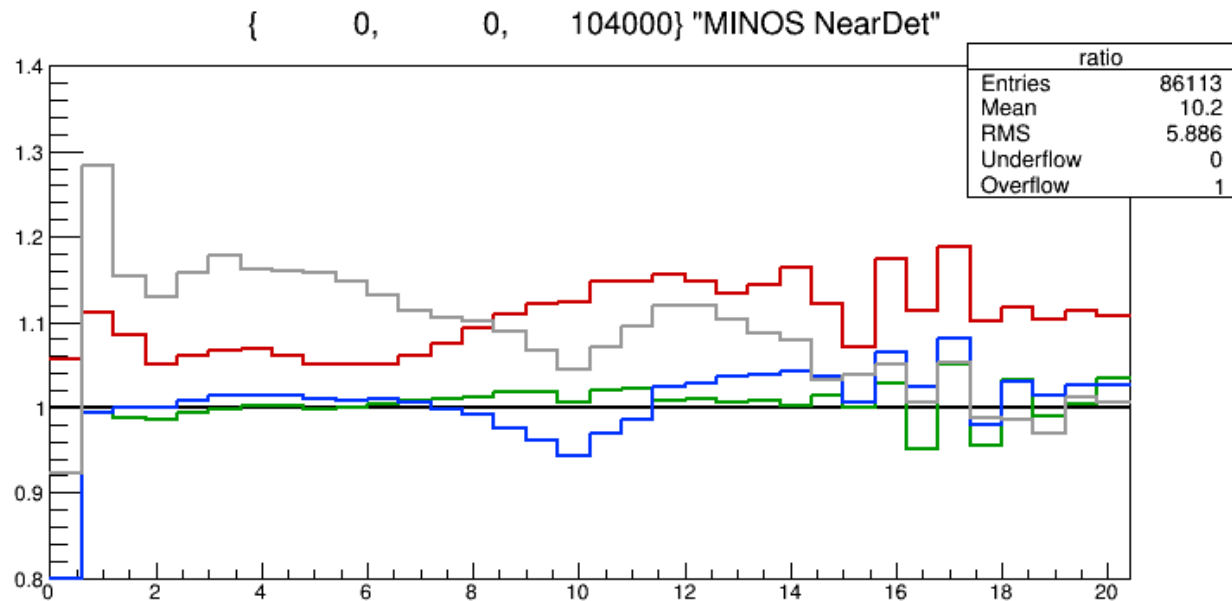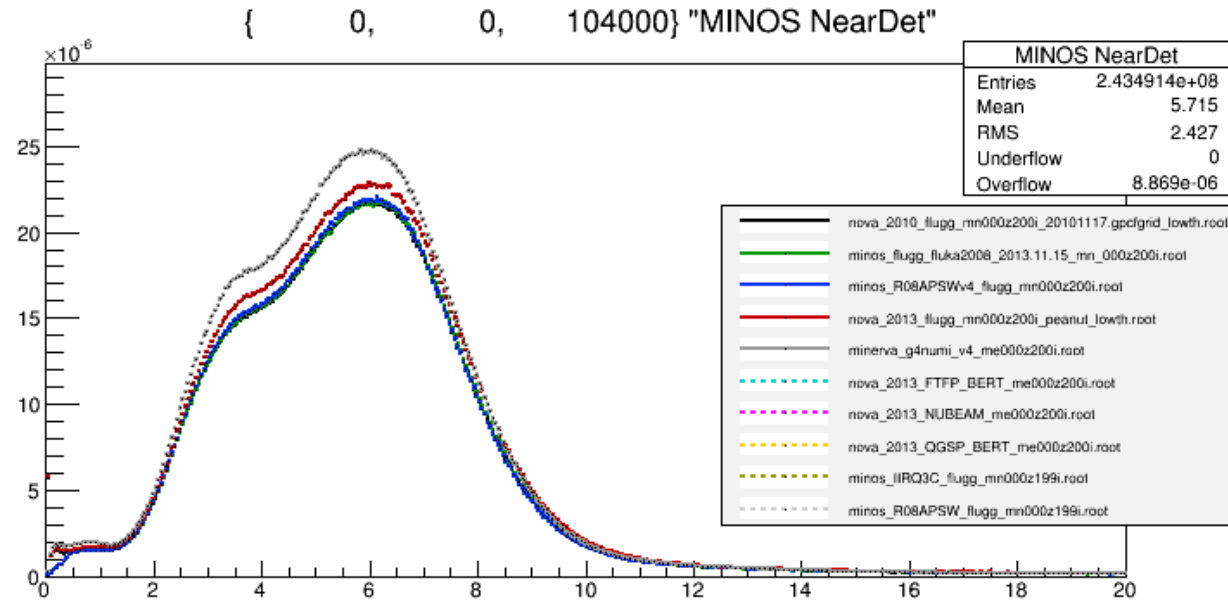 - local experts/development of G4
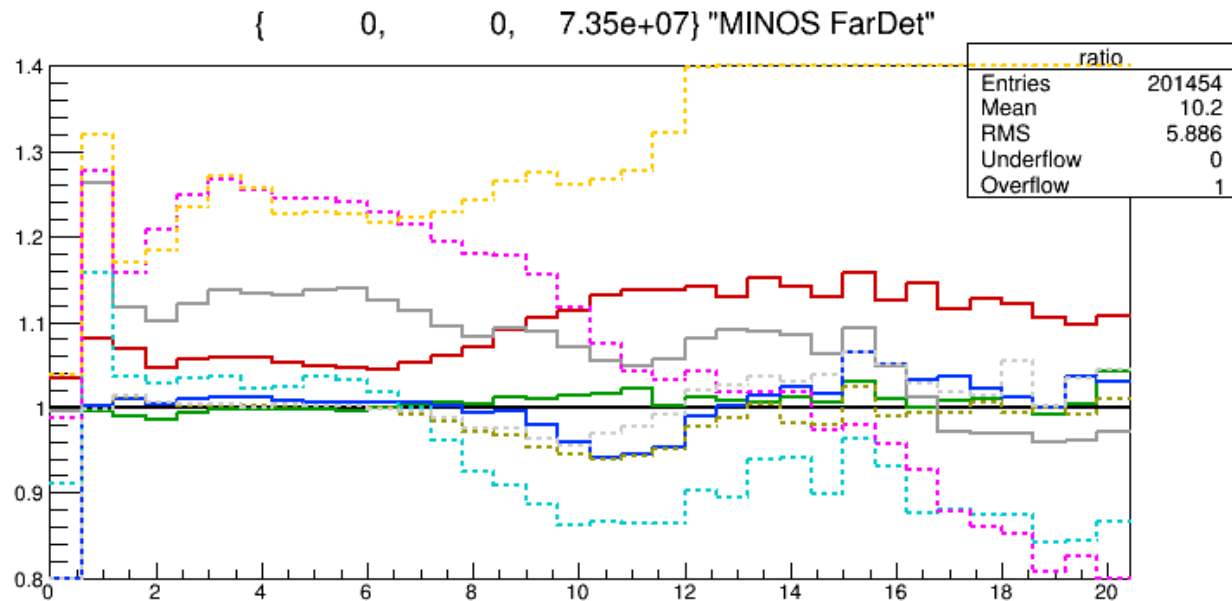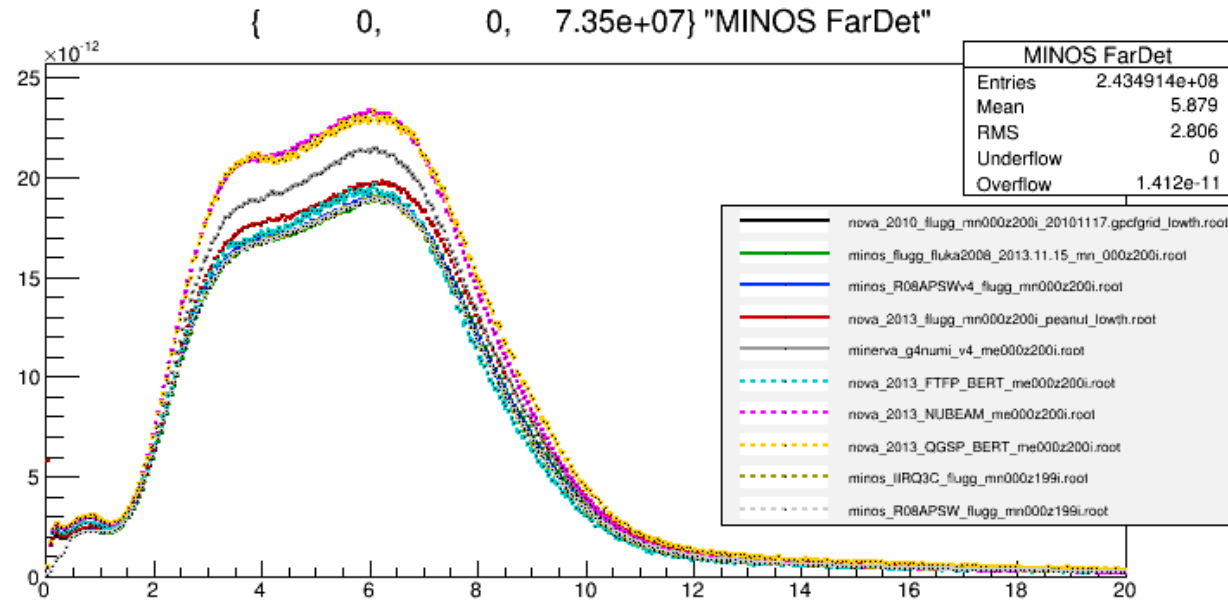
Too Many Choices?

Segal's law is an adage that states:

"A man with a watch knows what time it is. A man with two watches is never sure."
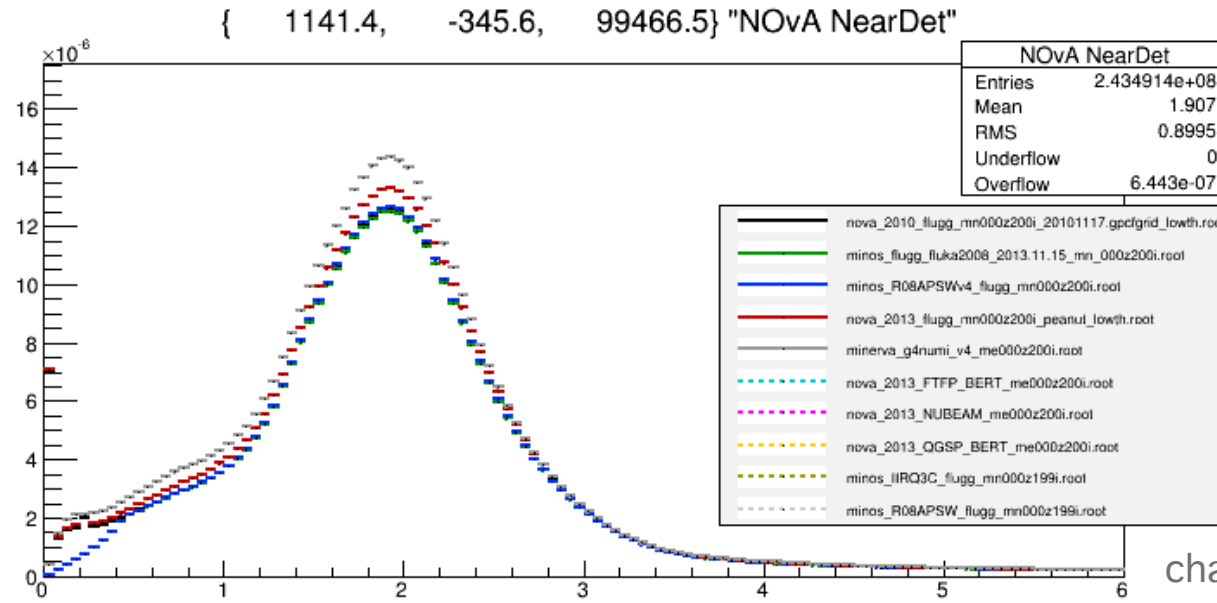
Also, working with physicists is like herding cats.

ME Beam @ MINOS Near

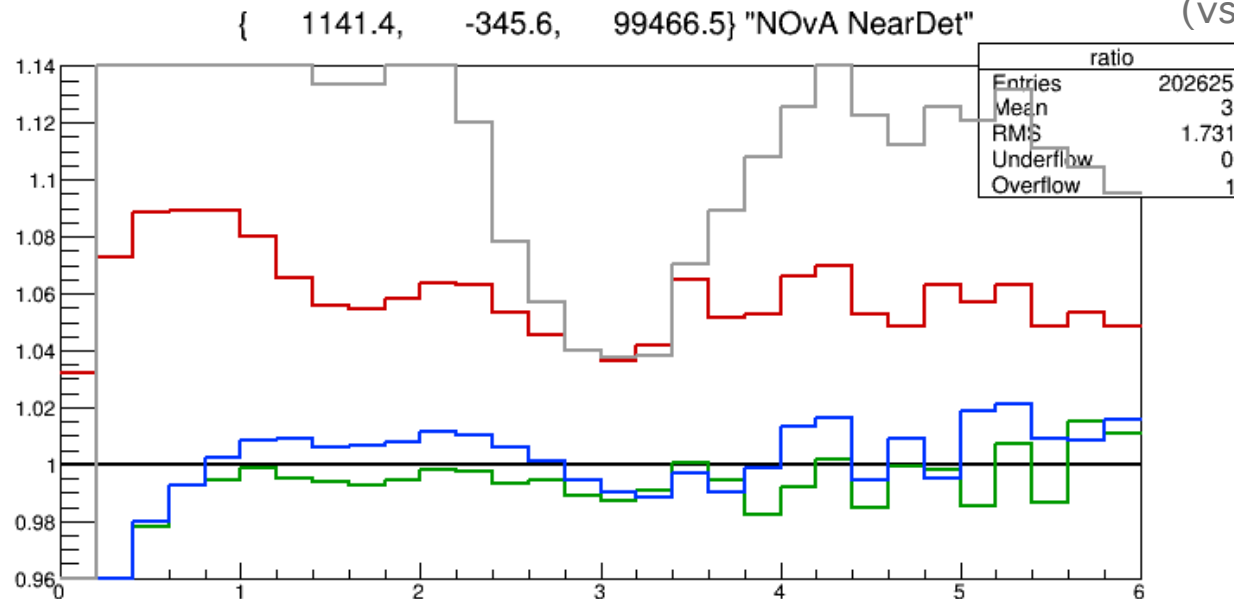# ME Beam @ MINOS Far

ME Beam @ NOvA Near

change of x scale
$E_{max} = 6$ GeV
(vs. previous 20)

The NuMI-X Effort

- One Beamline – Many Experiments
  - MINOS (+):   steel & plastic scintillator sandwich (Near + Far)
  - MiniBooNE: liquid scintillator, off-axis
  - ArgoNeuT: small liquid Ar TPC
  - Minerva: fine grained calorimeter w/ variety of nuclear targets
  - NOvA: large segmented liquid scintillator (off-axis Near + Far)
  - other soon to exist experiments (e.g. off-axis microBooNE)
- The Problem
  - lots of duplicative work was going on concerning the beam
  - people were often confused about the state of our knowledge
  - different experiments put different constraints on the beam
    - needed a means to share data prior to full public release
- Goal: Get all the NuMI experiments "on board" to work on
  - Beam Simulation
 - Beam Analysis (including hadron production studies)

Recent NuMI-X Efforts

- Unifying disparate code bases
  - baby steps taken … still work to be done
  - `g4numi` and `g4numi_flugg` should use the same geometry
    - — but, sadly, they currently don't
- Unifying the output format — Dk2Nu
  - more structured; standardized naming conventions; flexibility for storing pre-calculated detector location energies and weights
  - carry on Minerva's addition of recording full ancestry
  - non-NuMI specific; LBNE & Booster adoption in progress
- Unifying tools for analysis — FluxReader
  - fast analysis of Dk2Nu files; plotting, × GENIE x-sec, etc
- Studying effects of hadron production models
- Working on more sensible scripts and instructions for building and running the codes
- Working on standardization of file naming + file sharing amongst the experiments

NuMI-X Code Base

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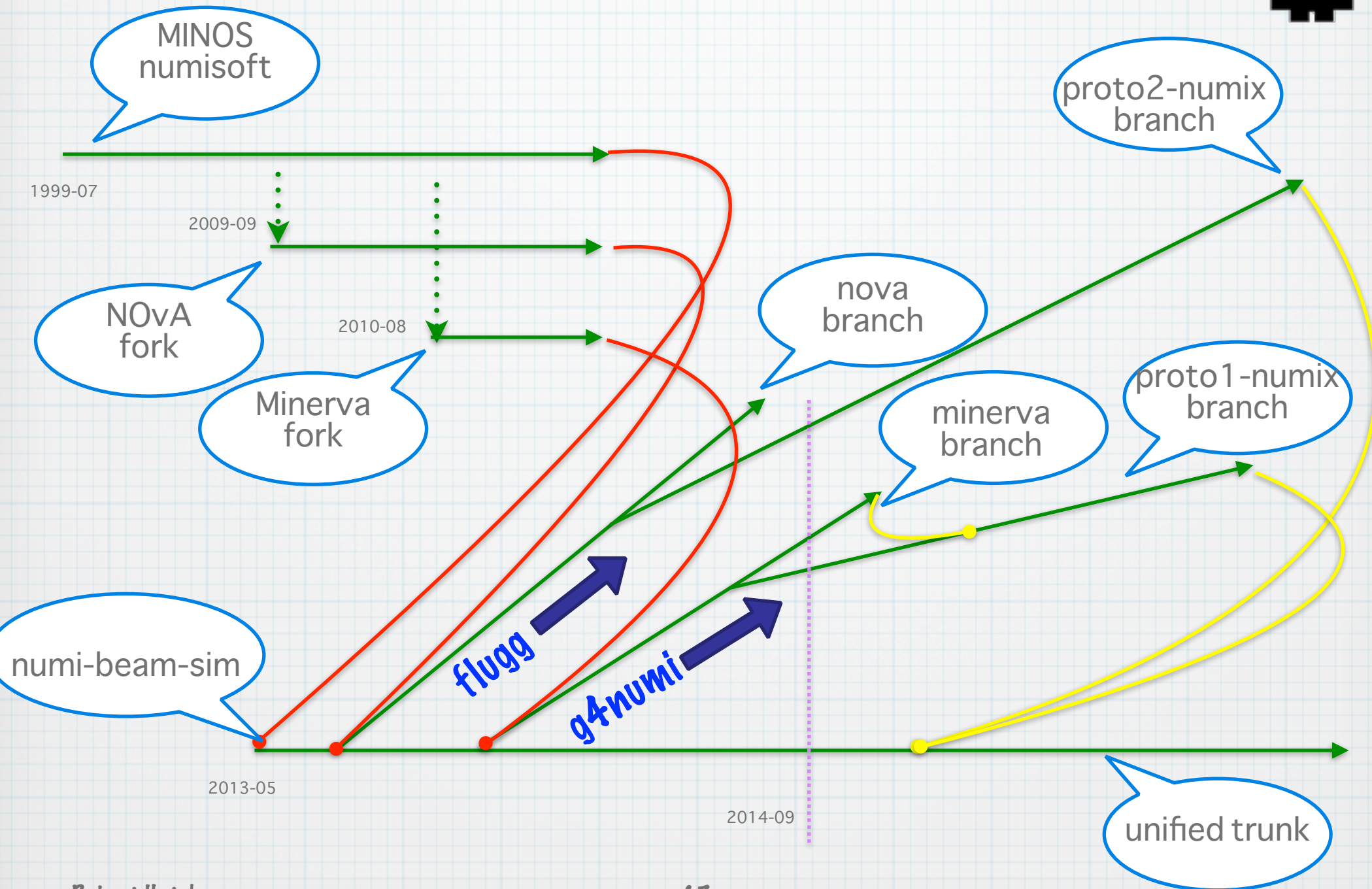
Sign up now!

- Be a NuMI-X member!
- Once you've signed off on the rules print out this card and put it in your wallet:

I,_____, do acknowledge that I am bound by the NuMI-X rules and receive all associated benefits therein.

expiration:
20__-__-__.
yy mm dd

NuMI-X

Punch one square for every CVS or doc-db commit

Questions?

NuMI-X scripts

- Standardize script to build g4numi_flugg
  - avoid confusion about build which requires copying "le" or "me" version of files into place before building
  - build records information about how it was built (fluka, flugg, geant4 versions, scripted modifications)

- Standardize script to run g4numi_flugg
  - command line switches for:
    - horn current (target position for MINOS-era target)
    - beam spot size (x & y)
    - "peanut", "lowth", "stepl" ("stepm")

- https://cdcvs.fnal.gov/redmine/projects/numi-beam-sim/wiki/How_to_build_the_FLUGG_code

Events in Surround Rock

- Illustrative pictures from Matt Strait (MINOS-6643)

- These are the origin of reconstructed particles that enter the front face of the FarDet

- In the FarDet the beam points 3° up (in contrast to down in the NearDet)

- dE/dx ~ 4.2 MeV/cm in the rock
    - 1 GeV μ ~ 2.5m