Neutrino Flux Prediction at NOvA

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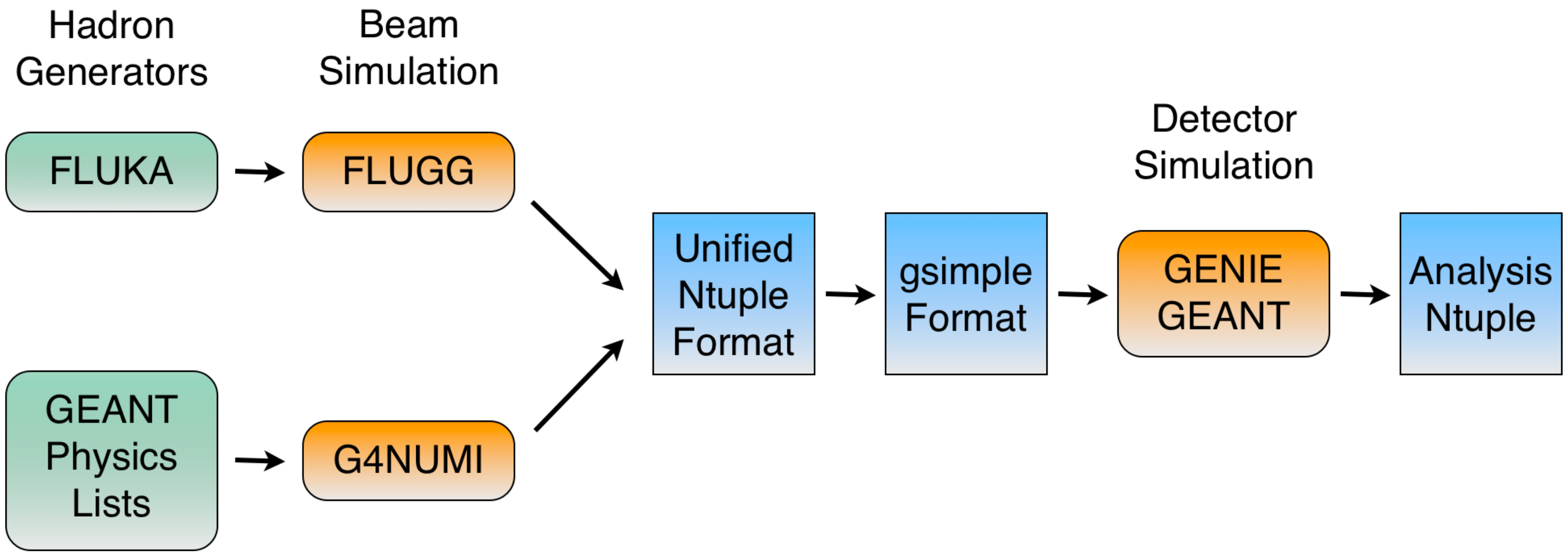
Fermilab

Outline

- The NoVA beam simulation
- Flux uncertainties
- Plans for computing beam systematics in NOvA

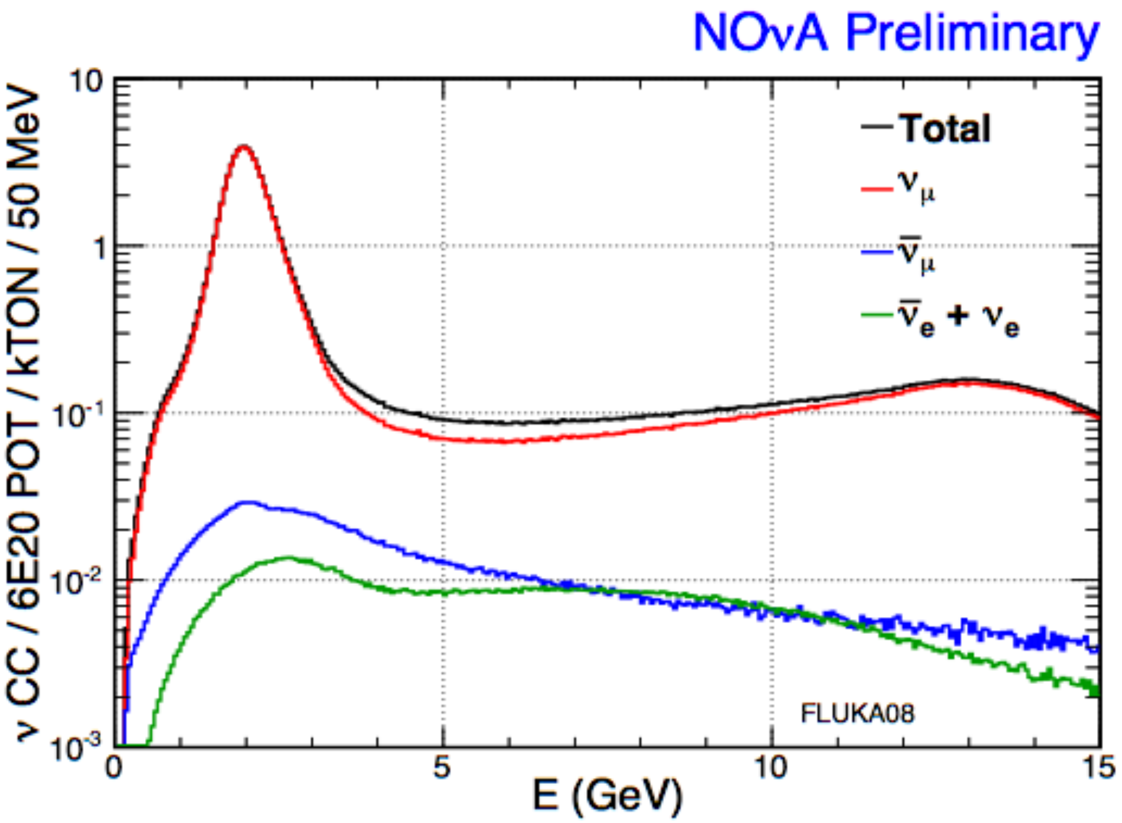
The NOvA Beam Simulation



- FLUKA + FLUGG (primary proton interactions with target + propagation through beamline geometry, out of target interactions)
- G4NuMI (pure G4 simulation)
- See Robert Hatcher's talk for extensive details about the simulation

The NOvA Beam - FHC

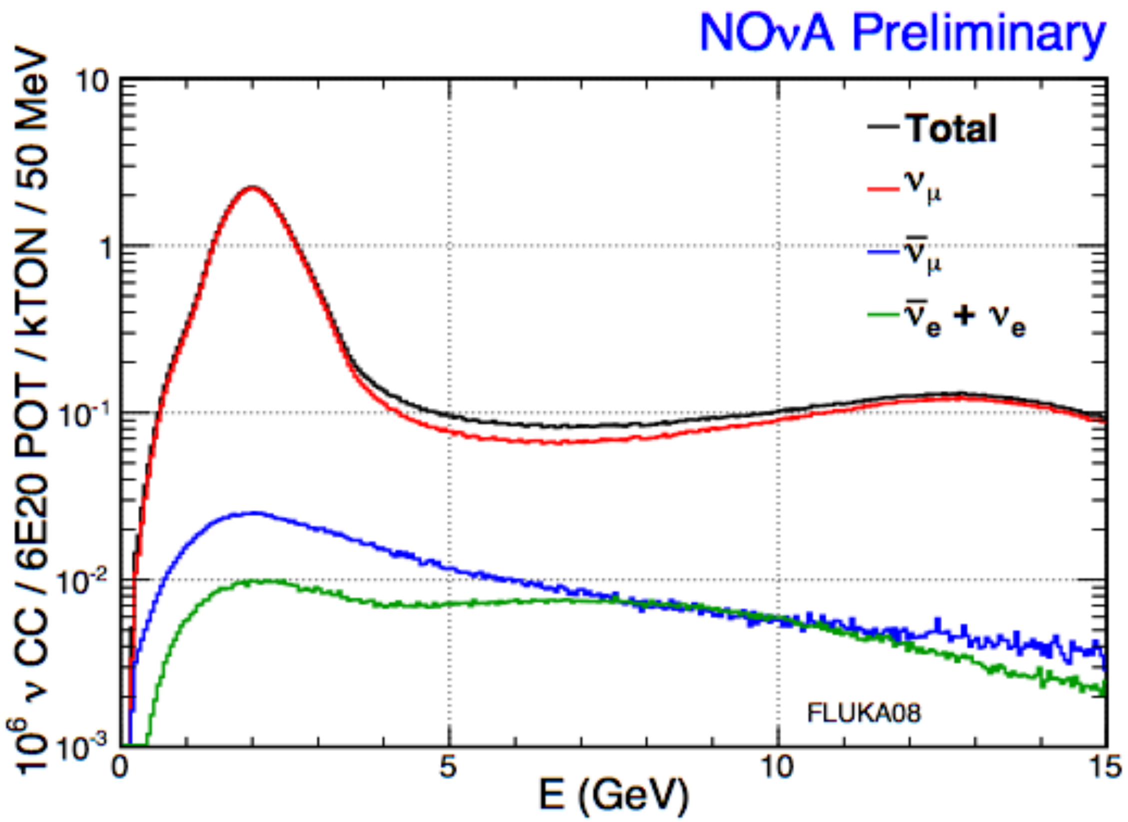
FD



	[1,3]GeV	[0,120]Gev
Total	63.5	103.8
Numu	62.1	97.6
Anti-Numu	1	3.9
Nue+Anti-Nue	0.4	2.3

`[1,3]GeV: (nue+anue)/numu = 0.6%`

ND

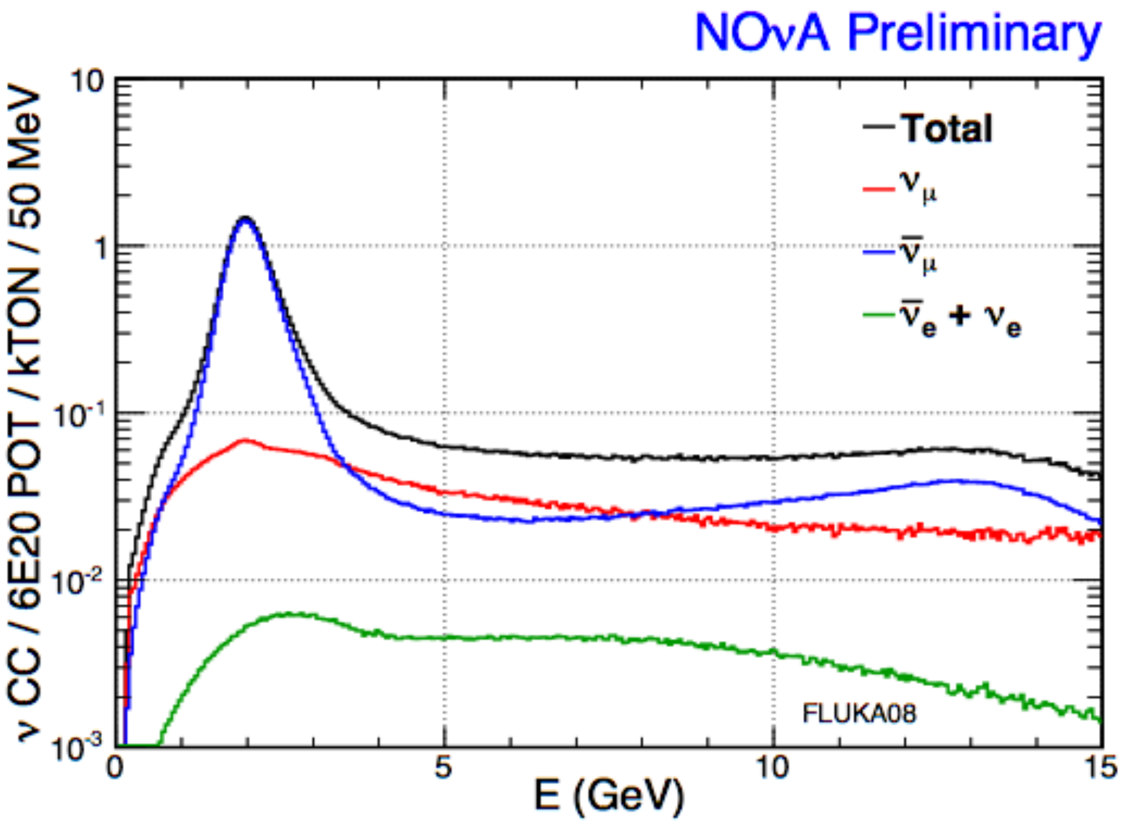


×10	[1,3]GeV	[0,120]Gev
Total	53.9	95
Numu	52.6	89.5
Anti-Numu	0.9	3.5
Nue+Anti-Nue	0.4	2

`[1,3]GeV: (nue+anue)/numu = 0.7%`

The NOvA Beam - RHC

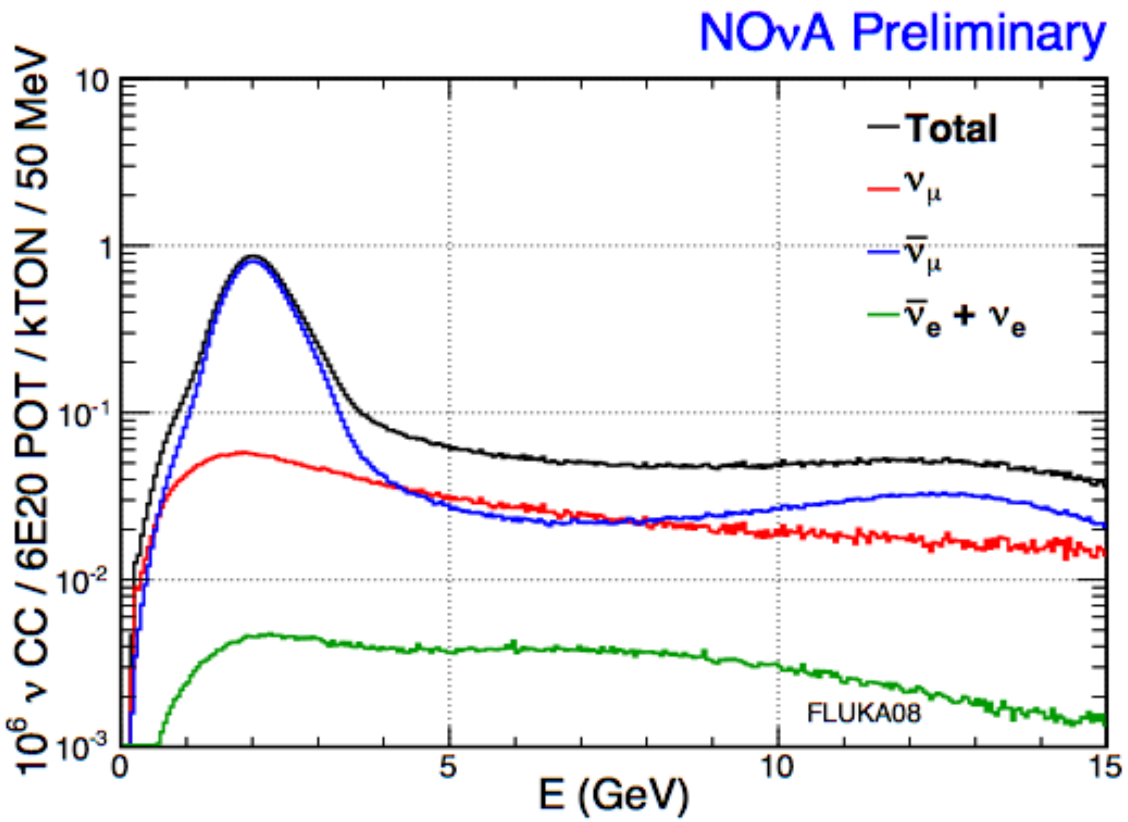
FD



	[1,3]GeV	[0,120]Gev
Total	25.1	46.7
Numu	2.4	13.2
Anti-Numu	22.5	32.2
Nue+Anti-Nue	0.2	1.3

[1,3]GeV: (nue+anue)/anumu = 0.8%

ND



×10	[1,3]GeV	[0,120]Gev
Total	21.4	42.3
Numu	2.1	11.9
Anti-Numu	19.1	29.3
Nue+Anti-Nue	0.2	1.1

[1,3]GeV: (nue+anue)/anumu = 1.0%

Flux Uncertainties

- Uncertainties on the flux prediction obtained by varying the underlying inputs to the flux simulation and evaluate their effect on the predicted flux.
- Two approaches are typically used:
    1. When error sources include a number of correlated underlying parameters
    2. Uncertainties represented by variations of the flux due to the changes in a single underlying parameter
- Different uncertainties coming from: target and horn positions, primary hadron production, downstream “tertiary” production, POT count.

Flux Uncertainties: Correlated Underlying Parameters

- Re-weighting method
- Underlying parameters varied according to their covariance, flux re-weighted with each of N sets of the parameter values
- Effect on the flux evaluated by constructing a covariance matrix from the N re-weighted versions of the flux prediction:

$$V_{ij} = \frac{1}{N} \sum_{k=1}^{k=N} (\phi^i_{nom} - \phi^i_k)(\phi^j_{nom} - \phi^j_k)$$

  where ‘i’ specifies the neutrino energy bin, neutrino flavor, detector at which the flux is evaluated

- The covariance used directly in extrapolation method, uncertainty on a far-to-near ratio.

Flux Uncertainties: Correlated Underlying Parameters

- This method is used for:
  - Hadron production - includes uncertainties associated with experimental data (MIPP, NA61…), different incident proton momenta, target material, production cross section, particle re-interaction within the target, region of phase space not covered by experimental data, etc.
  - Downstream tertiary production - re-weighting of tertiary pion production from nucleon interactions can be done by extrapolating external data sets (NA61/HARP) to lower incident nucleon momentum and other target materials as tertiary production can happen in the horns (aluminum)

Flux Uncertainties: Single Underlying Parameter

- Re-simulation of the flux variating the parameters at typically one sigma or by changing a single option in the simulation (hadron generator, FLUKA/G4 version, etc)
- This method applies to:
  - Target and horn position but also beam direction, horn current, magnetic field uncertainties.
  - Hadron production: ‘model spread’ method to study the impact on the flux when using different hadron production generators in the simulation (G4 physics lists, FLUKA, etc.)

Strategy

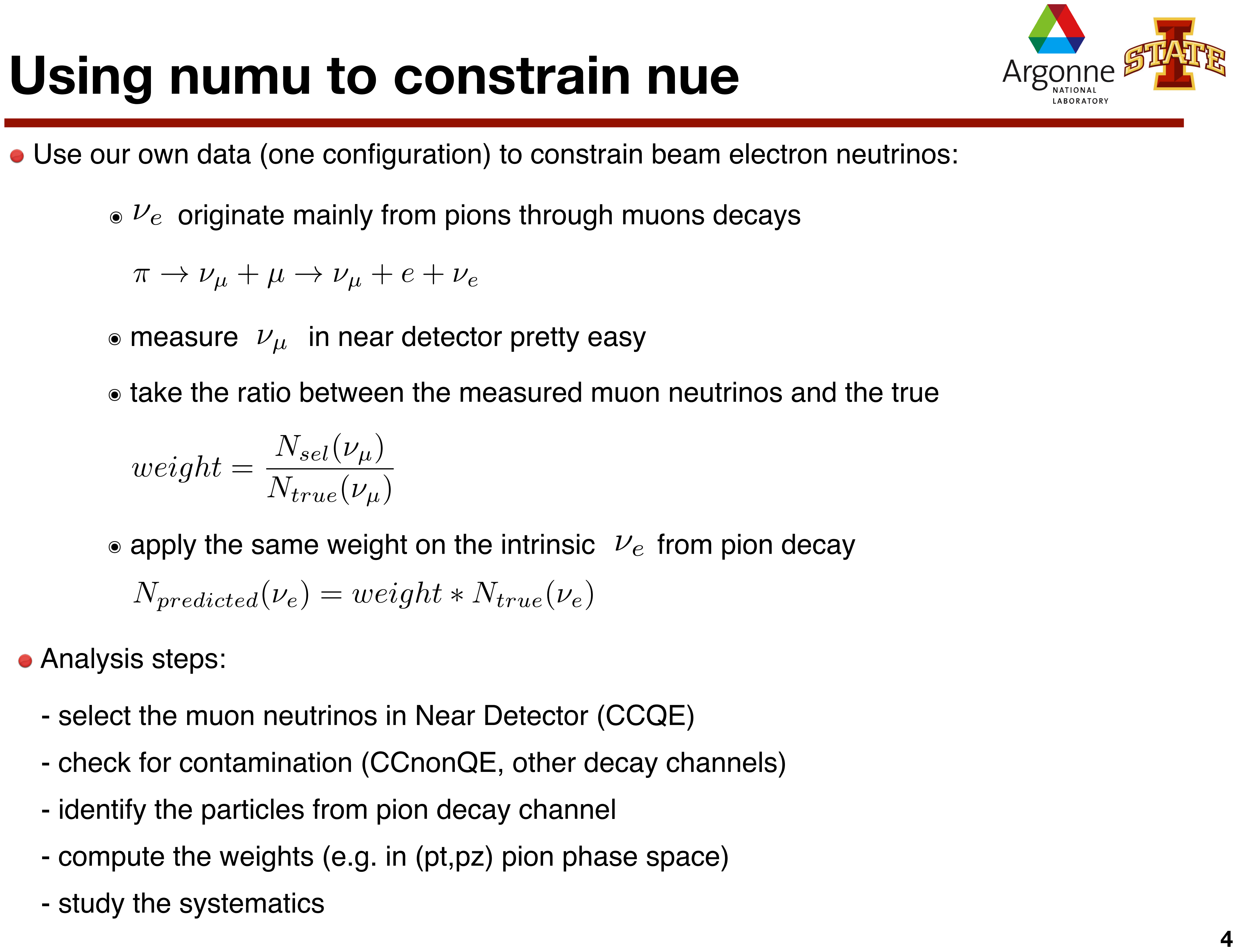
- Short term :
    - Model spread method using latest FLUKA (2011) and different G4 physics lists.
    - Comparing FLUKA/G4NuMI to external data such as MIPP, NA49/61 as a simple way to attribute a systematic error coming from hadron production.
    - Simplified correlation matrix method that takes into account hadron production uncertainties by comparing FLUKA to NA49 data, shift of beam parameters such as horn current and target position.
    - Comparing NA61 (or other) thin/thick target data to FLUKA can help with estimation of uncertainty due to tertiary production.
    - Use data driven techniques to constrain beam nu_e (ND nu_mu data).

Strategy

- Medium/longer term:
  - Cross section re-weighting using beam fit algorithms (SKZP, BMPT parametrization) on ND data, access to full ancestor information in both the FLUGG and G4NuMI simulations possible with new ntuple format.
  - Beam fits combining different NuMI near detector data.
  - Covariance matrix method, taking into account full list of uncertainties such as tertiary production, proton momenta, target material, etc

Backup

Beam Nu_e



Using numu to constrain nue

- Use our own data (one configuration) to constrain beam electron neutrinos:
    - ν_e originate mainly from pions through muons decays

      $$\pi \rightarrow \nu_\mu + \mu \rightarrow \nu_\mu + e + \nu_e$$

    - measure ν_μ in near detector pretty easy
    - take the ratio between the measured muon neutrinos and the true

      $$weight = \frac{N_{sel}(\nu_\mu)}{N_{true}(\nu_\mu)}$$

    - apply the same weight on the intrinsic ν_e from pion decay

      $$N_{predicted}(\nu_e) = weight * N_{true}(\nu_e)$$

- Analysis steps:

  - select the muon neutrinos in Near Detector (CCQE)
  - check for contamination (CCnonQE, other decay channels)
  - identify the particles from pion decay channel
  - compute the weights (e.g. in (pt,pz) pion phase space)
  - study the systematics