Uncertainties in experimental results come from various sources, including but not limited to event generation, detector simulation, reconstruction, etc.

Detector simulation toolkits, e.g. Geant4, simulate particles passing through and interacting with matter by employing a collection of models that cover a wide range of interactions types and energies

- Model: set of rules/algorithms aiming to describe/simulate physics processes/events; includes hypotheses and parameters
- All models have room for what we do not know:
  “Reality” = Prediction + Δstat + Δparams + Δmodel

The challenge: what uncertainties are associated with the models and how they translate into simulated observables
Systematic Effects in Detector Simulations (II)

• In recent releases, Geant4 extended configuration interfaces to several physics models, including hadronic ones
• This opens possibilities to extract optimal values of parameters and to determine their uncertainties and ranges, using (e.g. thin target) data and tuning tools
  – E.g. Professor tuning toolkit https://professor.hepforge.org
• One can estimate the uncertainties of Geant4 predictions using tuned parameters, their uncertainties and correlations

Data from Yu.D.Bayukov et al., Preprint ITEP-148-1983 are compared with default Geant4 Bertini model simulation (v4.10.4) and the global Professor fit; green band is uncertainty propagated from the fit results
Significant steps have been made by e.g. Geant4 collaboration towards understanding uncertainties in the simulated results, but a number of challenges remain, including:

- Models involved in detector simulation typically rely on many parameters; estimating their uncertainties and correlations among them through fitting techniques requires FTE’s and CPU
  - Only a fraction of Geant4 model parameters has been explored so far
- Simulating thin target data (i.e. single interaction) and estimating uncertainties is CPU expensive already. Propagating such knowledge to the full-scale detector simulation, e.g. hadronic showers, etc., is very computationally demanding

Further exploration of efficient methods to estimate uncertainties in simulated results is needed (this may include other tuning techniques if/where applicable)