An exact framework for Uncertainty Quantification in Monte Carlo simulation

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Monte Carlo in HEP

cross sections, branching ratios, physics models, physics parameters..

Event generator
(Pythia, Herwig...)

Particle transport
(Geant4, MCNP, MARS...)

How much can we trust the observables produced by MC?

P. Saracco, M.G. Pia, INFN Genova
If the accuracy of observable $A$ is assessed by comparison with experiment, what about observable $B$?

And what about the simulation of detector concepts, which do not exist yet?
And observables which cannot be measured in practice?
Uncertainties

Monte Carlo method

Input with uncertainties

Observable with uncertainties

Validation of MC modeling ingredients

Beware: input uncertainties can be hidden in models and algorithms in the code

Uncertainties deriving from
- input uncertainties
- Monte Carlo algorithm
- simulation model

Uncertainty quantification is the ground for predictive Monte Carlo simulation
Parameter uncertainties

They are the uncertainties of the “**ingredients**” of the simulation engine (**particle transport system, event generator**)

Can they be disentangled from statistical uncertainties associated with the Monte Carlo method?

Can we estimate their effect on the observables produced by the simulation?

**Sensitivity analysis**

**Exact calculation**
Disentangling uncertainties

Algorithmic (statistical) and parameter uncertainties
Sensitivity analysis

Computational cost

- **Input physical data (with uncertainties)**
  - Physical data sample 1
  - Physical data sample 2
  - ... Physical data sample $N_{MC}$
  - Simulation 1
  - Simulation 2
  - ... Simulation $N_{MC}$
  - Observable distribution 1
  - Observable distribution 2
  - ... Observable distribution $N_{MC}$
  - Statistical analysis
  - Observable ± error

- **Mathematical methods**
- **Software toolkits** *(DAKOTA, PSUADE..)*
Uncertainty propagation

Spiegare il concetto
Paolo’s slides go here
Bisogna spiegare quali siano le attuali limitazioni (concettuali e pratiche) del “nostro” UQ, e come intendiamo affrontarle
The validation of the physics “ingredients” of Monte Carlo codes is a (complex, slow) still ongoing process
- at least regarding Monte Carlo particle transport

Quantitative estimates of input uncertainties (cross sections, angular distributions, BR etc.) are necessary for uncertainty propagation
- A qualitative plot is not enough…

Epistemic uncertainties are often embedded in the code, without being documented
Conclusion and outlook

Collaborative contribution from HEP experiments is welcome!
Collezione di immagini utili