UNIVERSITÉ DE GENÈVE
FACULTÉ DES SCIENCES

ECT* 2018 and 2019 workshop

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What is ECT*?

- European Center for Theoretical Studies in Nuclear Physics and Related Areas
- Located in Trento, Italy
- They support research in nuclear physics:
  - **Nuclear Structure** and **Nuclear Reactions**, **Quantum Chromodynamics** and **Hadron Physics**, **Physics of Matter under Extreme Conditions** and **Ultra-relativistic Heavy Ion Collisions**, with related areas including topics in **Astrophysics**, **Particle Physics**, **Condensed Matter Physics**, **Many-Body Theory**, **Bose-Einstein Condensation**, and **Computational Physics**.

- They hosted a workshop on neutrino interaction modeling 9-13 July, 2018 : should add **Electroweak Nuclear Physics** to list

Purpose of the workshops

- To improve the Neutrino-Nucleus event generators used by neutrino experiments

- Steps taken at the workshop:
  - Learn what models nuclear physics community have
  - Tell that community what's in our generators now
  - Tell them how we MODIFY ("tune") what's there now
  - Wait for them to stop laughing
  - Ask for help to put better models in our generators

2018 Topics

- Modeling electron scattering on nuclei and potential impact in ν scattering
- Detailed description of ν event generators : GiBUU, GENIE, NEUT, NuWro (and introduction to FLUKA ν event generator!)
  - Quasielastic
  - Pion production
  - Shallow and deep inelastic interactions
- Inclusive vs. exclusive interaction descriptions and effects on experimental observables.
- Applying advanced mathematical tools: deep learning,
- Experimental approaches to ν interaction modelling: DUNE, T2K, NOvA, MINERvA, etc...

Modelling tools at 2018

- SuperScaling and possible applications in generator models (also shown here, Amaro, Megias)
- Mean Field approximations and potential implementations in generator models
- Cascade and transport models in nuclei
- Nuclear initial state description
- Spectral functions
- Nucleon-nucleon correlations
- Meson exchange currents

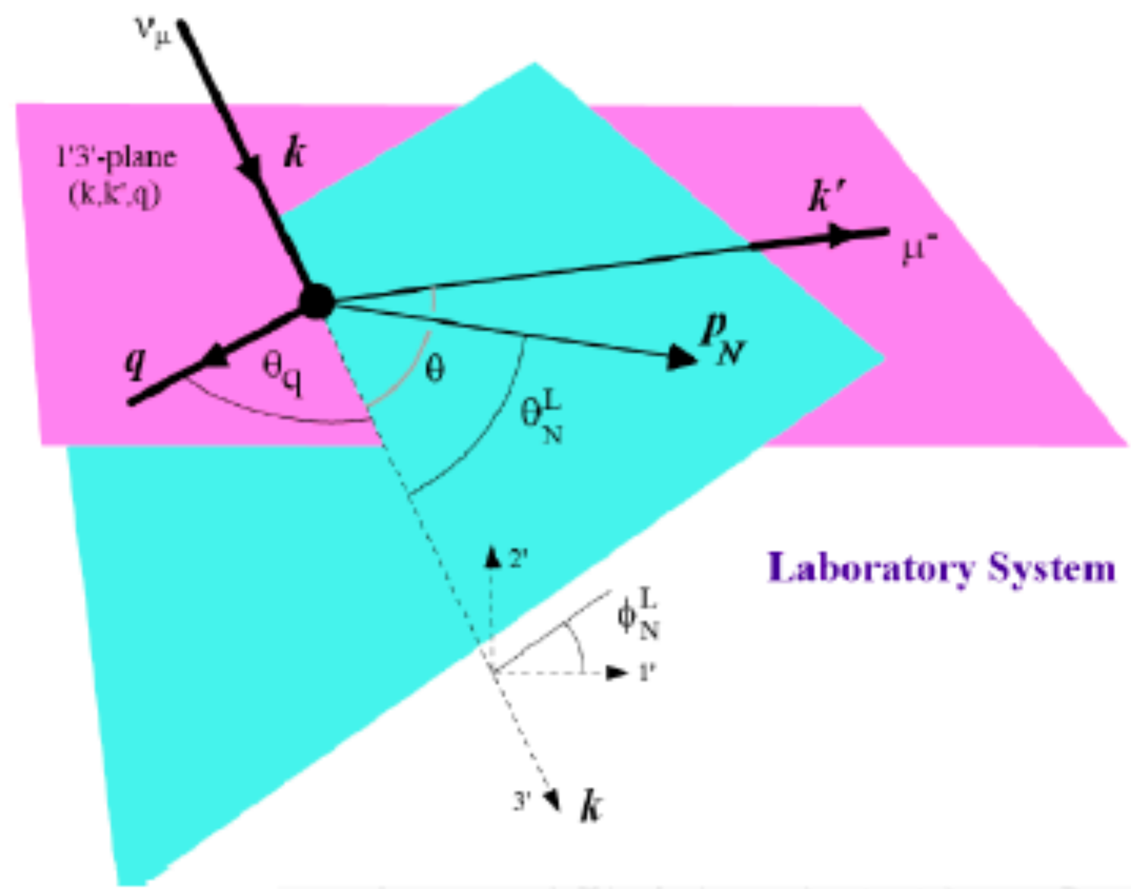
Semi-inclusive reactions

- Are we describing the full degrees of freedom of our system ?
- Poor description has serious implications in:
  - Reconstruction efficiency including vertex activity definition
  - Transverse variables

Semi-inclusive reactions

$$
\begin{aligned}
W^{CC}_{semi} &= \frac{1}{\rho^2}\{\rho^2 X_1 + \rho\nu^2 X_2 + X_3 + 2\sqrt{\rho}\nu X_4 \\
&\quad + H^2 X_5 + 2\sqrt{\rho}\nu H X_6 + 2H X_7\} \\
W^{CL}_{semi} &= \frac{\nu}{\rho^2}\Big\{\rho X_2 + X_3 + \sqrt{\rho}(\frac{1}{\nu} + \nu) X_4 \\
&\quad + H^2 X_5 + \sqrt{\rho}(\frac{1}{\nu} + \nu) H X_6 + 2H X_7\Big\} \\
W^{LL}_{semi} &= \frac{1}{\rho^2}\{-\rho^2 X_1 + \rho X_2 + \nu^2 X_3 + 2\sqrt{\rho}\nu X_4 \\
&\quad + \nu^2 H^2 X_5 + 2\sqrt{\rho}\nu H X_6 + 2\nu^2 H X_7\} \\
W^{T}_{semi} &= -2X_1 + X_5 \eta_T^2 \\
W^{TT}_{semi} &= -X_5 \eta_T^2 \cos 2\phi_N \\
W^{TC}_{semi} &= \frac{2\sqrt{2}}{\rho}\eta_T \{H X_5 + \sqrt{\rho}\nu X_6 + X_7\} \cos\phi_N \\
W^{TL}_{semi} &= \frac{2\sqrt{2}}{\rho}\eta_T \{\nu H X_5 + \sqrt{\rho} X_6 + \nu X_7\} \cos\phi_N \\
W^{T'}_{semi} &= \frac{1}{\sqrt{\rho}}\{Z_1 + H Z_2\} \\
W^{TC'}_{semi} &= \frac{2\sqrt{2}}{\rho}\eta_T \{-(\sqrt{\rho}\nu Y_2 + Y_3)\sin\phi_N + (\sqrt{\rho} Z_2 + \nu Z_3)\cos\phi_N\} \\
W^{TL'}_{semi} &= \frac{2\sqrt{2}}{\rho}\eta_T \{-(\sqrt{\rho} Y_2 + \nu Y_3)\sin\phi_N + (\sqrt{\rho}\nu Z_2 + Z_3)\cos\phi_N\},
\end{aligned}
$$

The ϕ_N dependence can be made explicit, leaving 6 responses, each a function of 5 variables



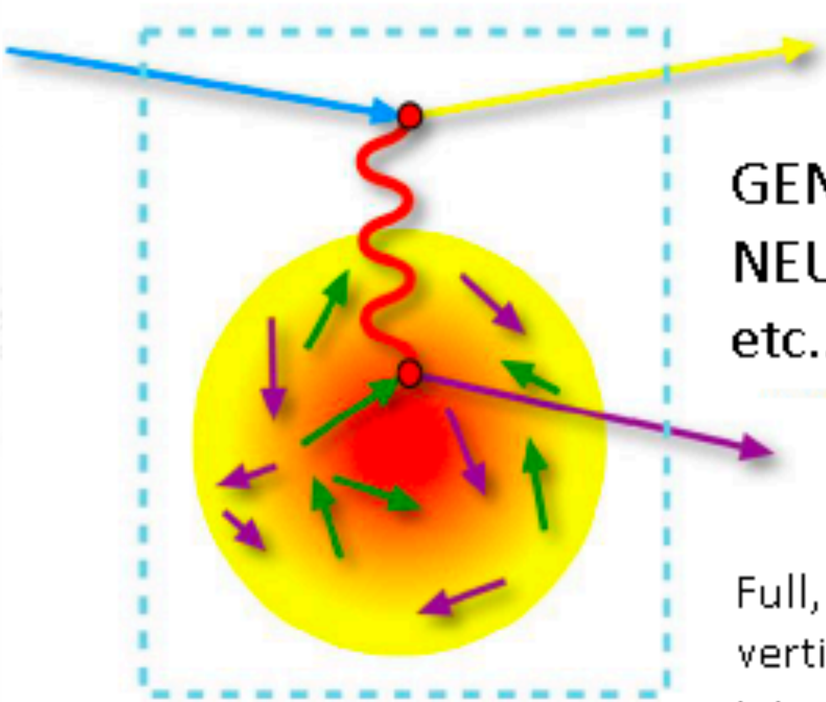
Donnely. B

Efficient monte carlos

- Neutrino experiments require millions of events to be generated:
  - Simulation of passive material around the active fiducial volume.
  - Several model simulations
    - Sometimes done through reweighting techniques.
  - More and more complex models:
    - Fully exclusive models requires also a large face space to cover.
- New MC techniques might help in speeding up the simulations, allowing them to become more complex.

Learning from other communities

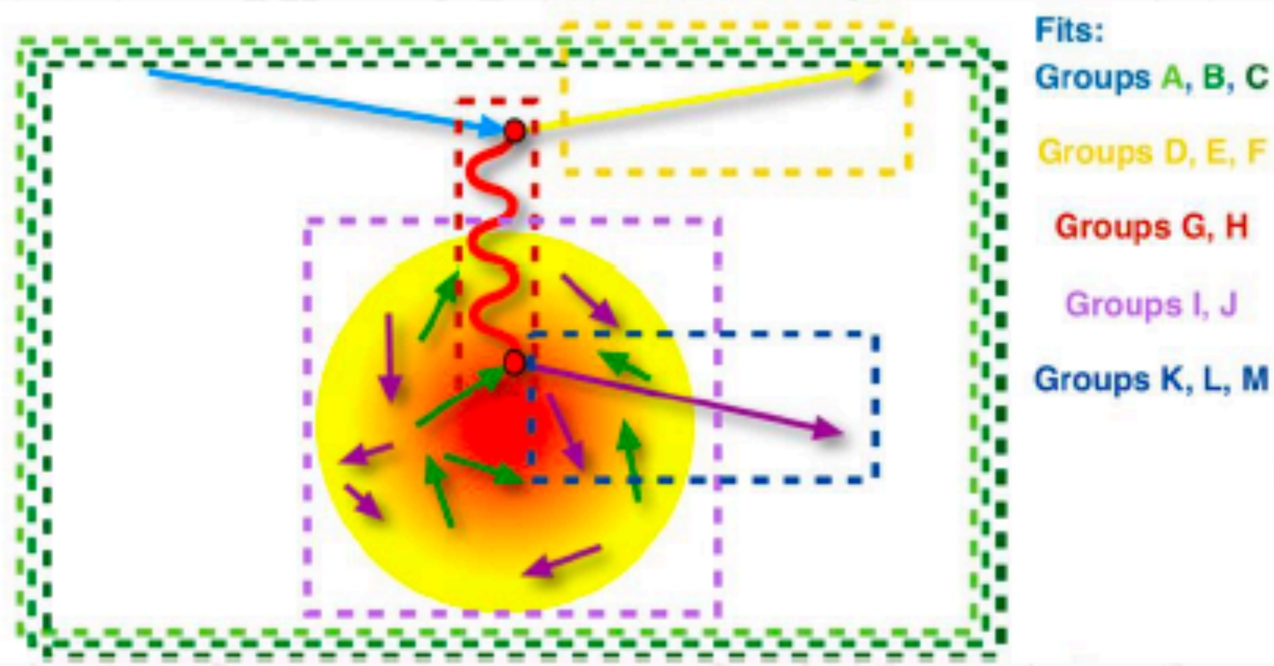
What we look like:



GENIE, NEUT, etc...

Full, vertical integrated solution

How we would look if we were at the LHC



G. Perdue, ECT

- Also many examples in business world...(remember how Amazon started as a place to buy books?)

New workshop

- Approved by ECT*
- Takes place in Trento from the 3rd to the 7th of June.
- Assistance only by invitation.
- The idea is to focus more on technical issues.
- It will be more technical combining talks with actual work.
- We will request work to be prepared in advance to optimize the meeting.
- We might consider to apply for 2020 depending on the outcome of the 2019 meeting.

sketch of program

Organizing event generator work

1. **Collider community model contributions to neutrino generator**
    1. **What it is:** discussion of how we could restructure generators to be contributed parts, rather than the current “all inclusive” model
    2. **Work goals:** toy implementation based on example components
    3. **Work goals, part II:** work on interface design for wrapper code - how can we package theory models (in Fortran, C++?, Python?) such that code may be used with minimal adaptation on the generator side? How do we work with multiple different generator architectures and methods for factoring the physics computations?
2. **Going to more exclusive final state descriptions**
    1. **What it is:** how we could implement Â multidimensional initial and final state interactions such as MEC in our generators including both leptonic and hadronic final states.
    2. **Work goals:** come up with an strategy to attack this problem in 2p2h and similar multidimensional cases.
3. **Design of an universal interface for theorists to provide models.**
    1. **What it is:** can we define an universal interface for all the possible model generators such that the integration with different generators is simple ?
    2. **Work goals:** analyse the requirements from the different MC and define an universal minimal interface.

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sketch of program

Comparisons of different models and generators

1. **Comparison of ab initio calculations to neutrino data and generators**
    1. **What it is:** how the work from the Argonne/Torino/LANL groups can be put into such a comparison
    2. **Work goals:** arrive with an implementation of at least some components for a leptonic observable, i.e., flux averaging for relevant neutrino datasets, identification of what other processes need to be included to make a meaningful comparison
2. **Comparison of FSI models**
    1. **What it is:** Is it possible to compare the different FSI models for different particles and momenta independently of neutrino interactions by using particle guns.
    2. **Work goals:** understand the contribution of the FSI models in different generators independent of their neutrino-nucleus interaction models.
3. **Comparison of Pion production contributions to 0pi final states.**
    1. **What it is:** Neutrino data to probe quasielastic and dip region response are necessarily contaminated with pion production where the pion is absorbed or otherwise stuck inside the nucleus and does not appear in the final state.
    2. **Work goals:** understand specifically how the convolution of primary pion production processes and FSI models in different generators results in different predictions. Â Discuss ways to improve the reliability of this prediction.
4. **Low momentum transfer vs high momentum transfer consistency in, model implementations**
    1. **What it is:** what is the right way to merge low energy and high momentum transfer models in an unique quasi-consistent model.
    2. **Work goals:** discussion of possible venues and options to be explored.
5. **comparison of RFG, LFG and Spectral Functions**
    1. **What it is:** attempt to understand the effect of the different Initial States in the interaction dynamics.
    2. **Work goals:** understand the effects on final and initial state kinematics of the different interactions by fixing the interaction kinematics to avoid contaminations from neutrino-nucleon.
6. **Shallow inelastic region and transition to DIS**
    1. **What it is:** Understanding of the different models implementation of the Shallow Inelastic region.
    2. **Work goals:** understand the systematic differences and work in a direction of a more universal, theory driven model.

sketch of program

Implementation of specific theory models into generators for quasielastic and pion production: Nuclear models, Nucleon models and “Inseparable” nuclear+nucleon models

1. **SuSA**
    1. **What it is:** Implementation of SuSA model in generators and comparison with electron and neutrino scattering data within a generator. Â Best practices for comparing SuSA model against neutrino observables. Next steps.
    2. **Work goals:** Show these comparisons. Discussion of points where generator comparison has uncertainties, needs refinement, e.g., the hadronic final state, single pion model, etc.
2. **Implementation of Â Spectral Functions**
    1. **What it is:** what is the right way to implementing spectral functions in the models and possible differences between generators ?
    2. **Work goals:** understand the different implementations, the treatment of the Pauli blocking and the different results.
3. **Implementation of Â Mean Field calculations in generators**
    1. **What it is:** discussion on the attempts to include MF calculations in generators.
    2. **Work goals:** understand the implementation methods, identify weak points and unify the criteria among generators, consistency issues
4. **Coulomb/Optical potentials implementation on generators (s-called FSI by theorists)**
    1. **What it is:** review of implementations in generators and models and discussion on possible consistent implementations in generators.
    2. **Work goals:** come up with a consistent method to implement coulomb corrections in MC.

sketch of program

Maintaining unified models for neutrino and electron scattering in generators

1. **Neutrino and electron scattering generators**

    1. **What it is:** are we testing our neutrino scattering with their brother electron scattering implementations ?
    2. **Work goals:** define a minimum set of conditions to claim that an electron scattering model implementation is actually a good test of the neutrino scattering and discussion on potential experimental issues in the comparisons. How can we ensure that this consistency is kept in subsequent evolutions of the code ?