Hadronization tuning in *Genie V3*

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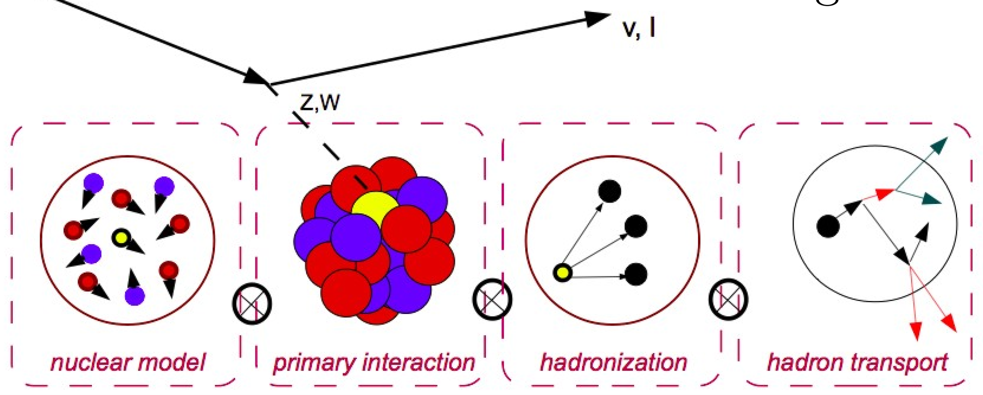
Genie Neutrino Monte Carlo generator

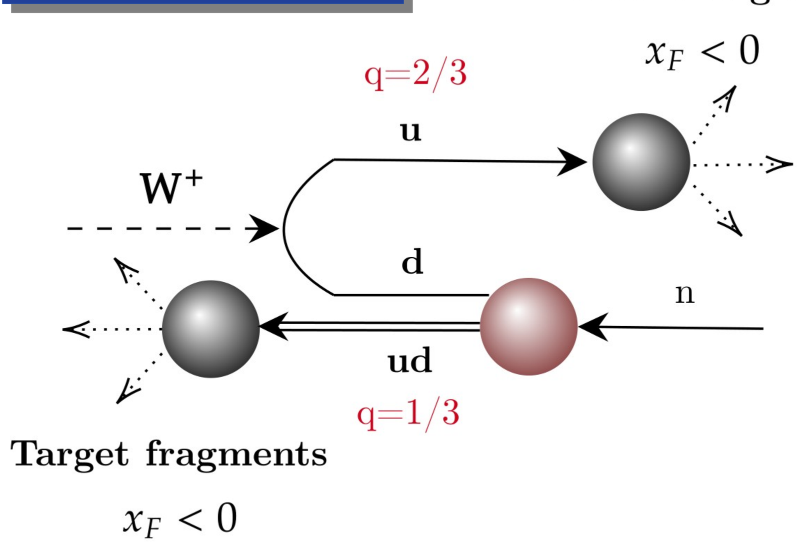
GENIE handles all neutrino flavours and targets, all processes relevant from MeV to PeV energy scales [1].

GENIE v3 offers different sets of comprehensive model configurations (CMC), which will be validated against neutrino scattering data.



Neutrino-Nucleus interactions are simulated by adding different layers on top of ν-nucleon interaction

Hadronization in neutrino interactions



Hadronization models provide information of the final state hadrons after a DIS interaction

It affects:

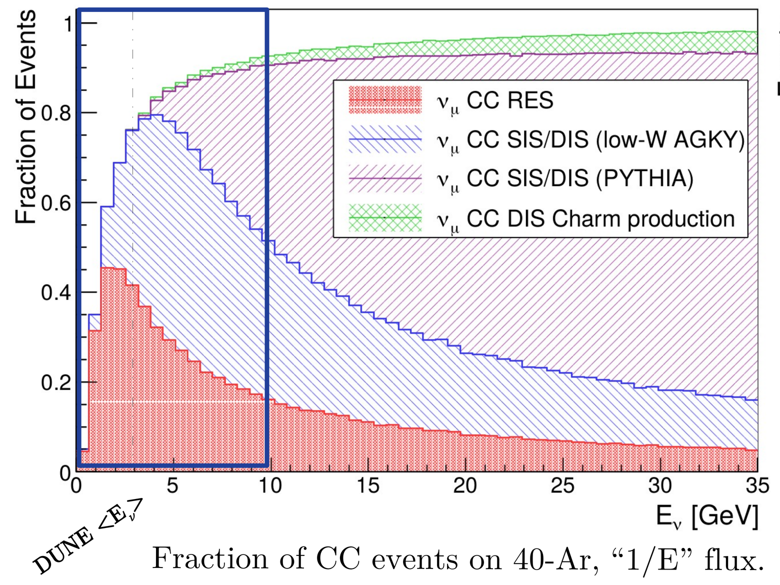
- E_ν reconstruction
- Efficiency to classify NC/CC events
- Estimation of backgrounds

The AGKY hadronization model

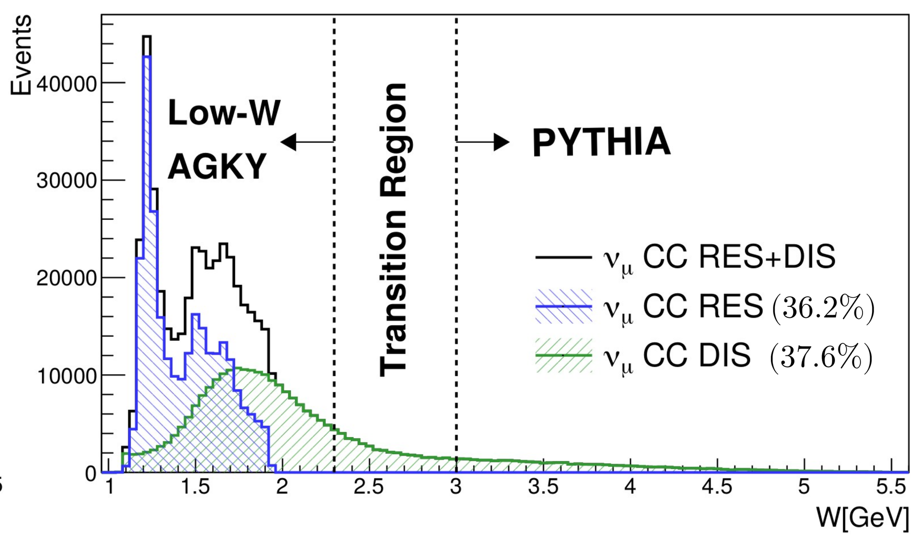
Main AGKY ingredients [2]:

- **Low-W empirical model** for SIS/DIS events at W < 2.3 GeV [4]
- **PYTHIA 6** for events with W > 3 GeV [3]
- **Linear transition** from the low-W empirical model to PYTHIA for 2.3 < W < 3 GeV

The Low-W empirical model plays a central role on accelerator neutrino experiments



Fraction of CC events on 40-Ar, "1/E" flux.



Breakdown of CC RES and DIS events expected for DUNE

Low-W Empirical model

1)Estimate the **averaged charged multiplicity**:

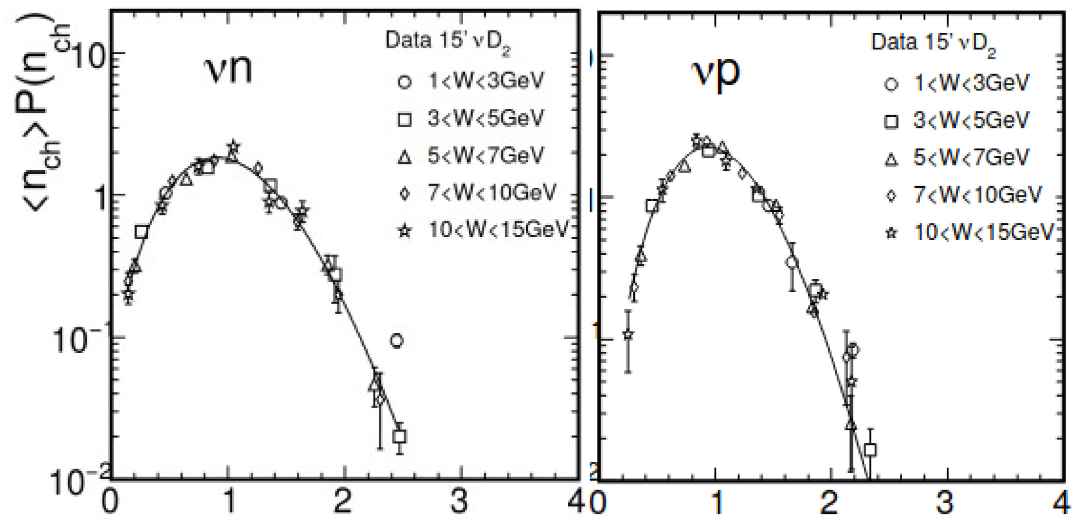
$$\langle n_{ch}\rangle = \alpha_{ch} + \beta_{ch}\ \ln\left(\frac{W^2}{GeV^2/c^4}\right)$$

Free parameters extracted from FNAL bubble chamber data [5]

2)Total averaged multiplicity: $\langle n_{tot}\rangle = 1.5\langle n_{ch}\rangle$

3)The total multiplicity is estimated with the KNO scaling law

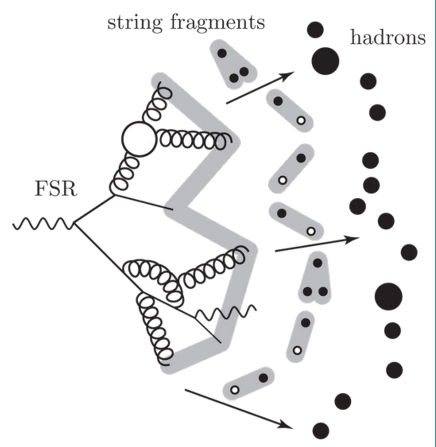
$$<n> P(n) = f\left(\frac{n}{<n>}\right) \dashrightarrow L(z;c) = \frac{2e^{-c}c^{cz+1}}{\Gamma(cz+1)}$$ Levi Function



From fits to data:
c(νp)=7.93 ± 0.34
c(νn)= 5.22 ± 0.15

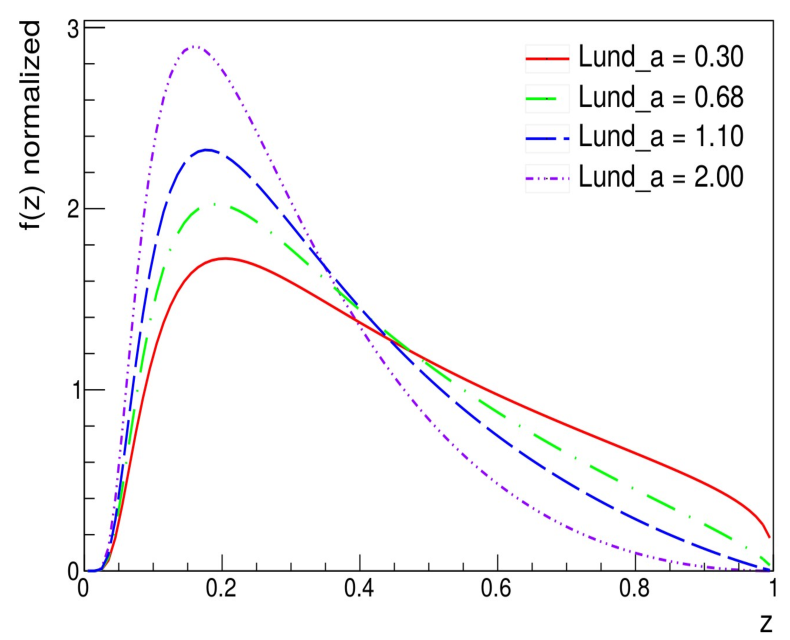
PYTHIA 6 in GENIE

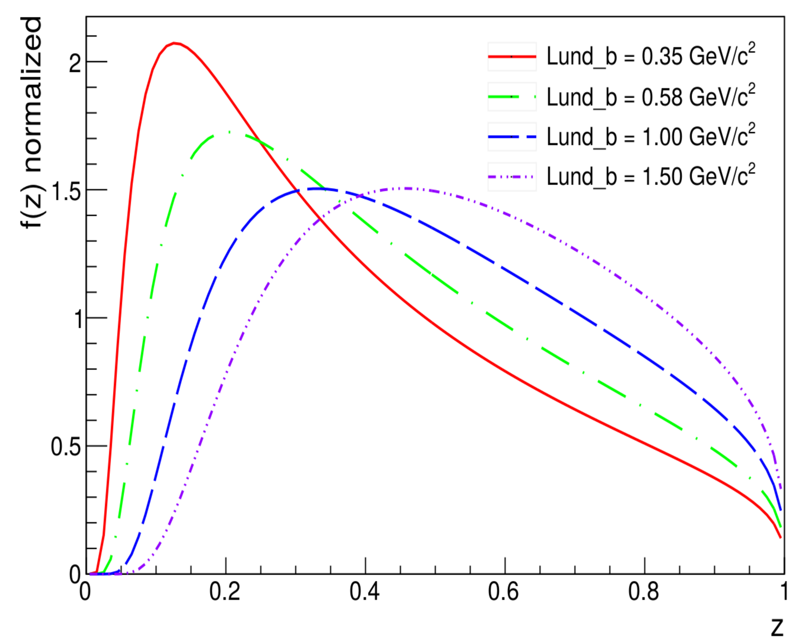
- Based on the **Lund string fragmentation framework**
  - The hadronization is described as break-ups in a string producing $q\bar{q}$ pairs
- The **fragmentation function** gives the probability to produce a hadronic system with a given z:



$$f(z) \propto z^{-1}(1-z)^a \cdot \exp^{\frac{-bm_\perp^2}{z}}$$

$m^2_\perp$ is the transverse mass of the hadron, z =E/ν





Conclusions

The AGKY hadronization model implemented in GENIE has been tuned against charged averaged multiplicity neutrino data. The PYTHIA contribution had never been tuned before against neutrino data and the low-W empirical model only took into account some specific datasets. This new tune incorporates a wider range of historical data and provides a global tune with the first estimation of parameter uncertainties.

Review of charged averaged multiplicity data and AGKY model parametrization

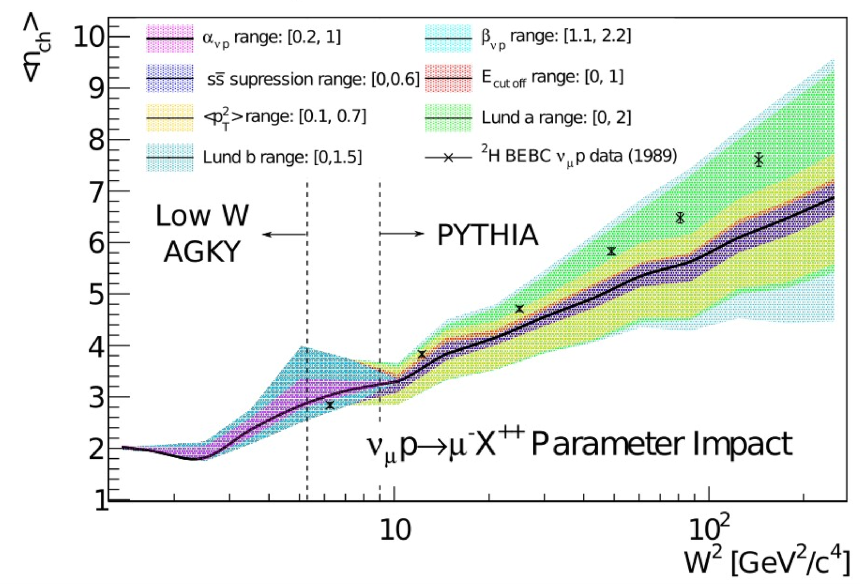
Default low-W AGKY parameters extracted from ^{2}H FNAL 15FT data

- Fits assumed linearity on ln(W^2) for the whole W^2 range
  - In GENIE this is only true at low W
  - Disagreements exist between datasets
- Some of those datasets have been upgraded
- Poor coverage at low-W (W<4-5 GeV/c^2)

The latest analsyis for H and ^{2}H targets for FNAL 15FT and BEBC 12FT are considered to tune the AGKY model

A total of 13 parameters are needed to describe the $<n_{ch}>$:

- At the **low-W region** only the α and β parameters are relevant
- The **transition region** mixes PYTHIA and low-W parameters
- **At high W**, the Lund a and b parameters play a crucial role



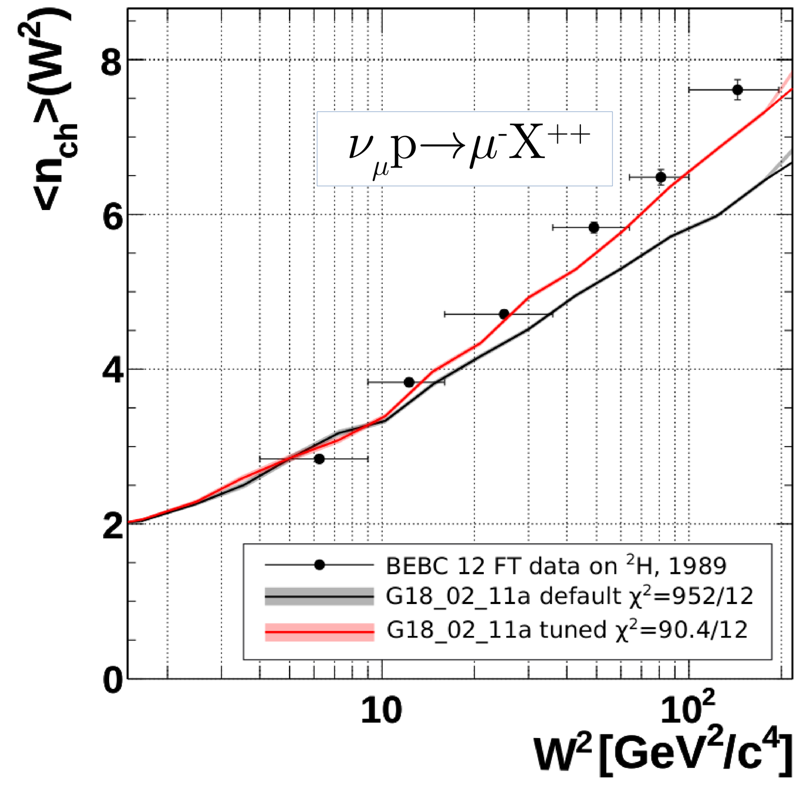
Global fit of the AGKY model against Hydrogen and Deuterium data

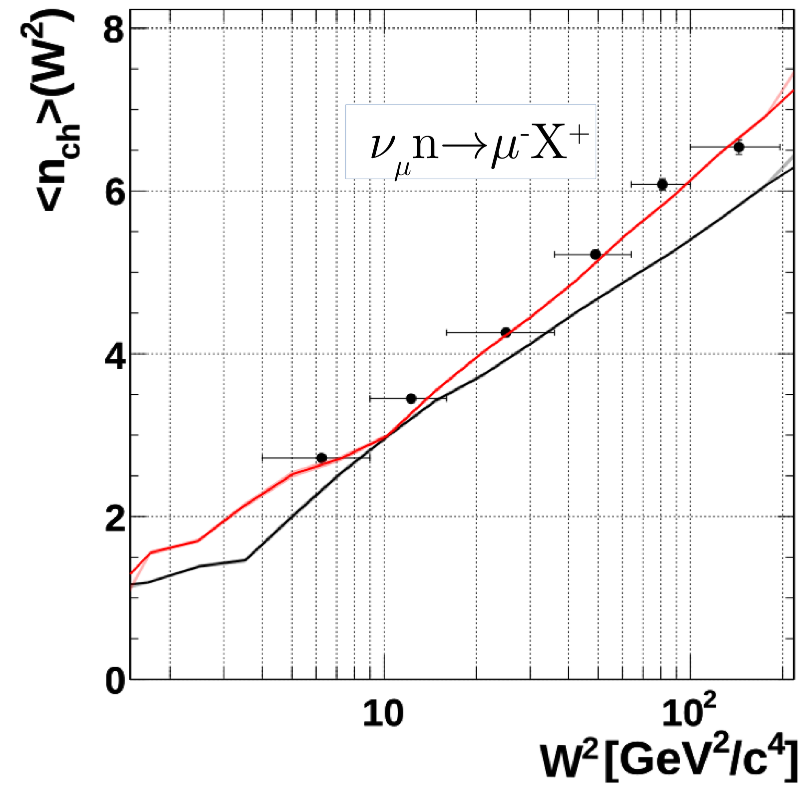
Preliminary

KNO Parameter	Default value	Best fit result
α(νp)	0.40	0.98±0.02
α(νn)	-0.20	1.1±0.1
α(anti-νp)	0.02	-0.20±0.05
α(anti-νn)	0.80	1.17±0.03
β(νp)	1.42	1.02±0.07
β(νn)	1.42	1.04±0.05
β(anti-νp)	1.28	1.6±0.2
β(anti-νn)	0.95	0.73±0.04

PYTHIA Parameter	Default value	Best fit result
$s\bar{s}$ supression	0.30	0.21±0.04
Gaussian $<p_t^2>$	0.44	0.47±0.04
$E_{Cuttoff}$	0.20	0.30±0.09
Lund a	0.30	1.4±0.2
Lund b	0.58	0.86±0.07

χ^2= 196/90 DoF





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