Hadroproduction measurements for simulations of neutrino beams

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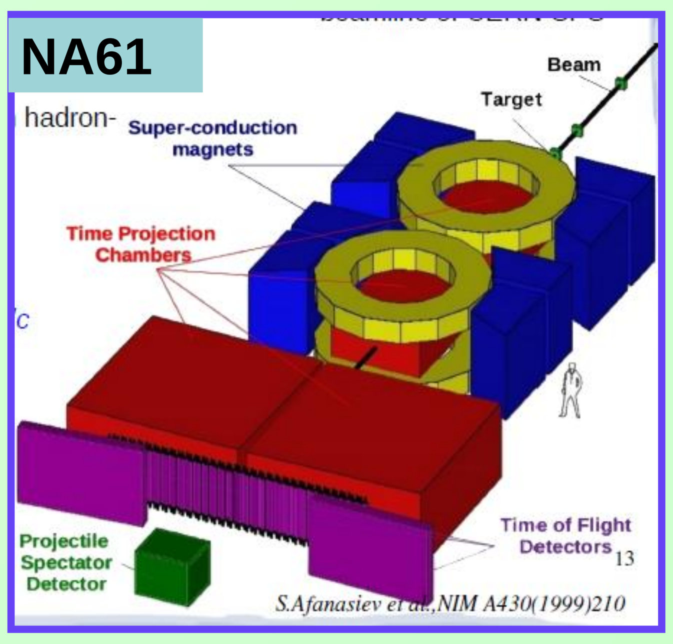
- π and K production in the target are the ultimate source of neutrino flux.
- Knowledge and understanding of this is important for ν oscillation experiments
- Two type of modelling (using experimental data on hadroproduction as input) :
  - **Hadronic cascade Monte Carlo** (MARS, GEANT4, FLUKA) tuned to experimental data. Tend to be black boxes and errors are hard to factorize
  - **Parametrized simulations** based on parametrizations of hadron production data (BMPT, SW, …) . Provide experimenter with functions, errors. They are FAST.

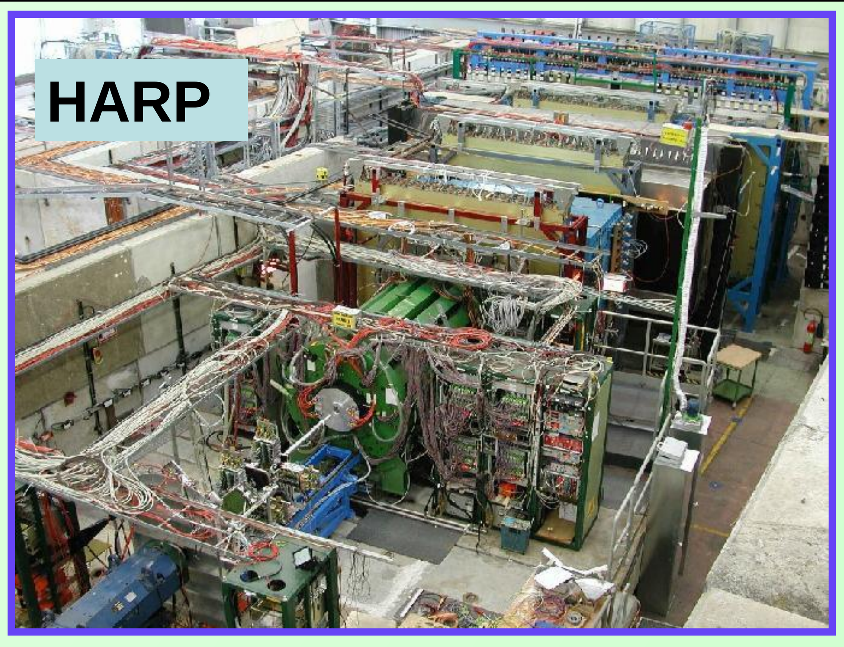
Available data for simulations of neutrino beamlines

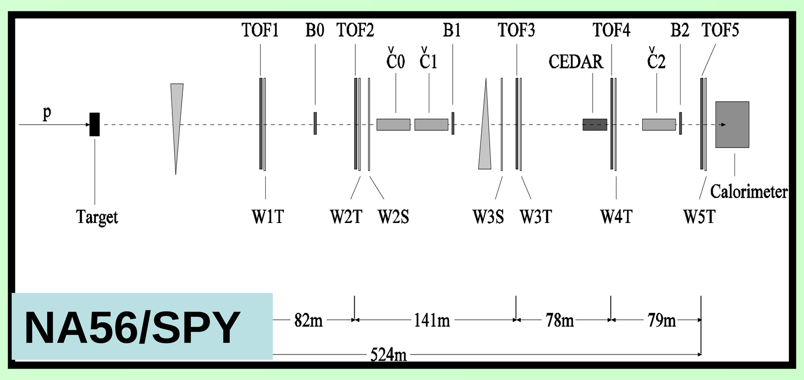
Low energy ν beams (K2K, NUFACT, MiniBooNE, MicroBooNE, SciBooNE); mainly HARP at CERN PS

High energy ν beams (WANF, CNGS, NuMI, T2K..) : NA20, NA56/SPY, MIPP, NA61/SHINE

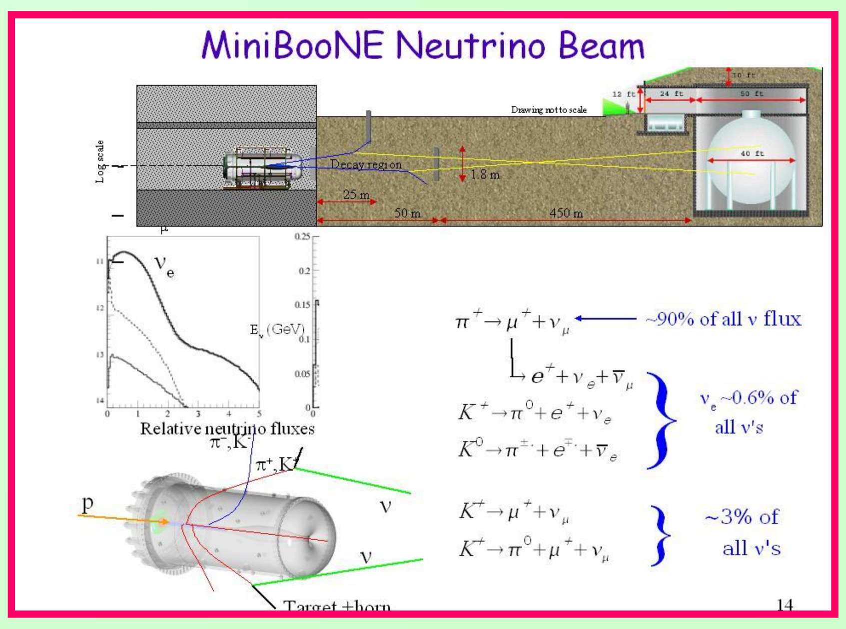
In addition a lot of old non-dedicated experiments with small statistics and high syst errors



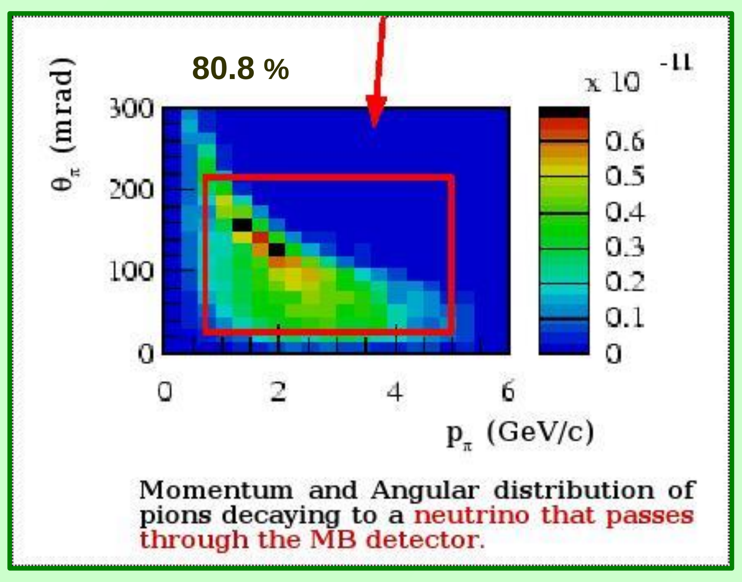


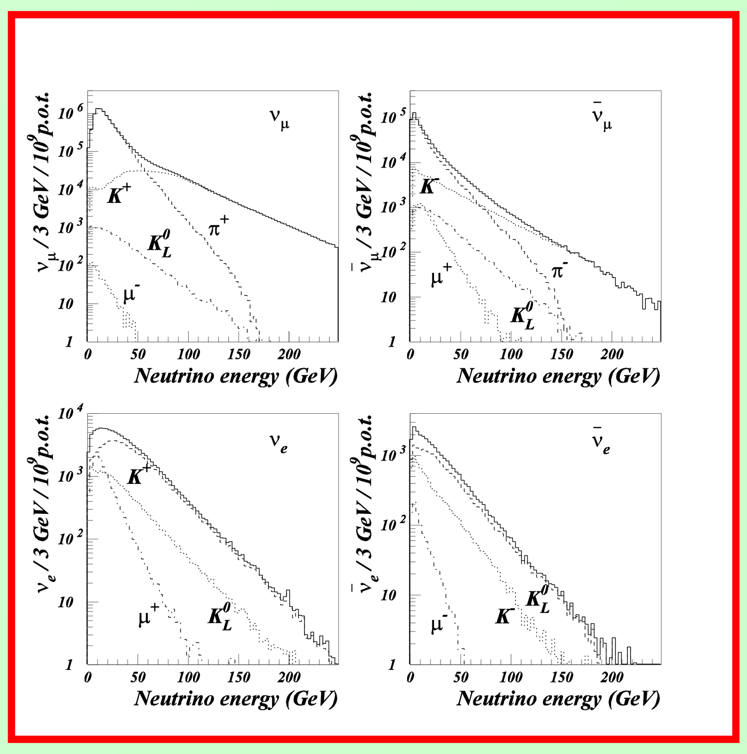


How to simulate a neutrino beam



HARP p-Be-> p+-X data 8.9 GeV/c:
M. G. Catanesi et al., Eur. Phys. J. **C52** (2007) 29
MiniBooNE with Harp input ,
A.A.Aguilar-Arevalo et al., Phys. ReV. Lett. **98** (2007)





Ingredients to compute a ν flux :

π(and k) production cross section (use same target and proton energy as the proton driver of the experiment)

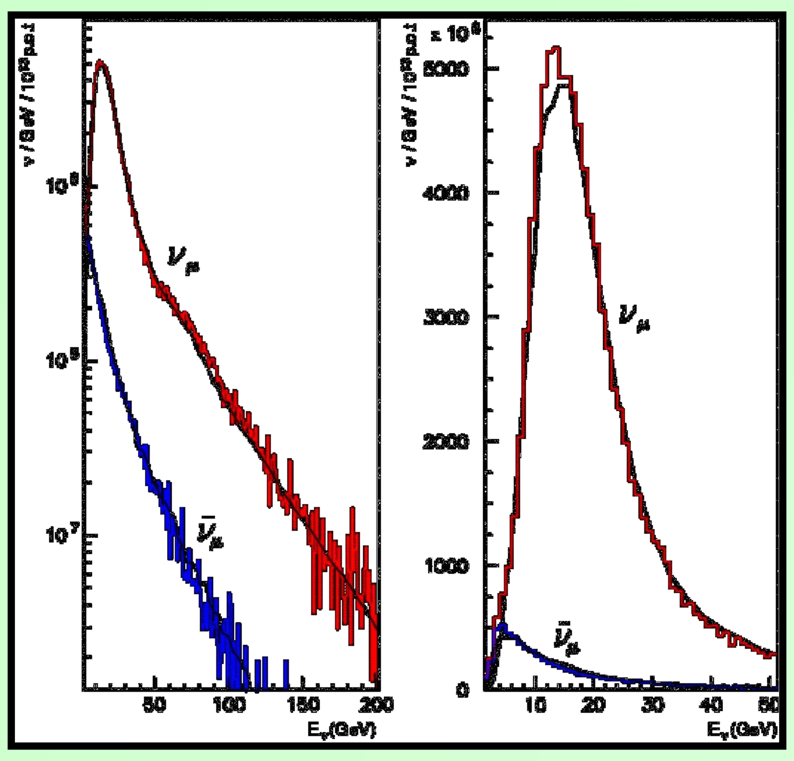
Reinteractions: take data with thin and thick target

All the rest:, simulation of the neutrino beamline: an "easy" problem.

Two approaches: full simulation with hadronic MC (GEANT4, MARS, FLUKA) , fast simulation based on parametrization of hadroproduction data (eg BMPT)

Fluka full simulation (+ reweighting with NA56/SPY data): WANF ν beam for NOMAD

Both approaches needs good hadron production data



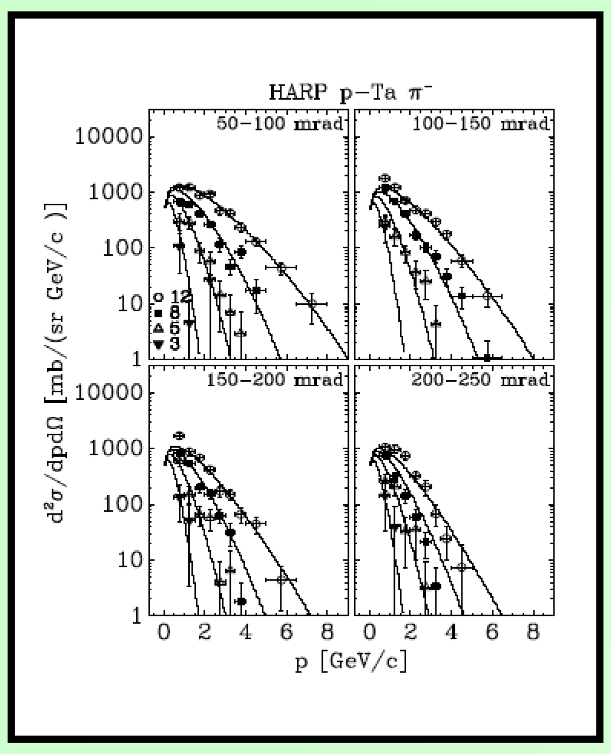
BMPT fast simulation: CHARM II ν beam

Available hadron data parametrizations : SW and BMPT

1) Sanford-Wang empirical parametrization: 8 parameters, used for low energy beams (primary up to 30 GeV/c)

$$\frac{d^2\sigma}{dp\,d\Omega} = c_1 P_\pi^{c_2}\left(1-\frac{P_\pi}{P_p}\right)\times e^{\left(\frac{-c_3 P_\pi^{c_4}}{p_p^{c_5}} - c_6\theta_\pi(P_\pi - c_7 P_p \cos^{c_8}\vartheta_\pi)\right)}$$

HARP data and many others have been parametrized with formulas of this type.
It is only an empirical parametrization.



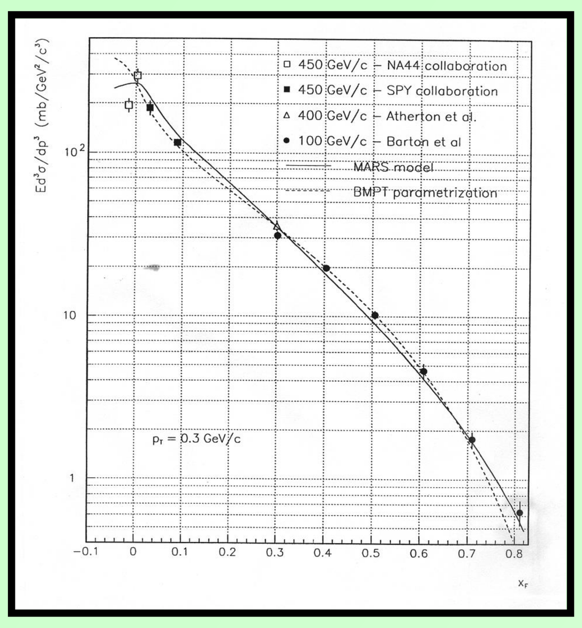
2) The BMPT parametrization : empirical formula based on general physical argument, for high energy beams (primary down to ~30 GeV)

$$E\frac{d^3\sigma}{dp^3} = A(1-x_R)^\alpha(1+Bx_R)x_R^{-\beta}\times\left[1+\frac{a}{x_R^\gamma}p_T+\frac{a^2}{2x_R^\delta}p_T^2\right]e^{-a/x_R^\gamma p_T}$$

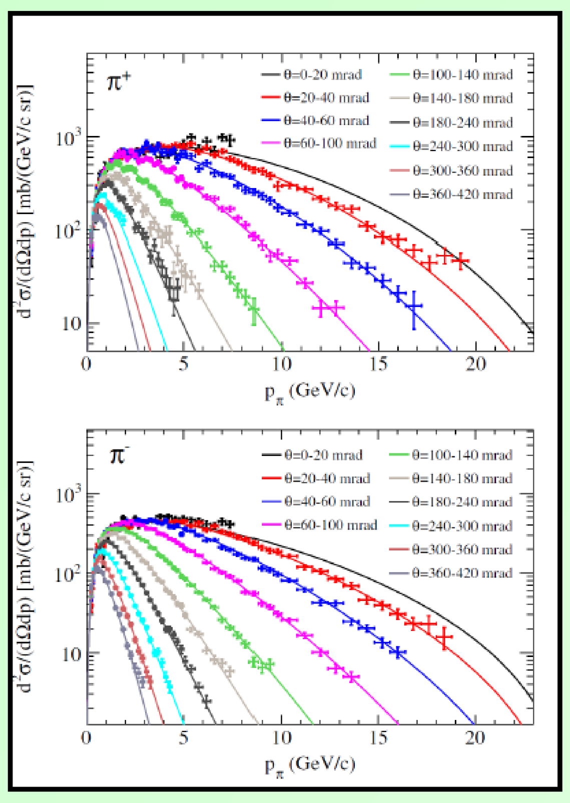
- Approximate factorization in x and p_t
- $(1-x)^a$ behavior in the forward direction for $x \to 1$ (quark counting rule)
- x^{-b} behavior in for $x \to 0$ (non direct hadron formation mechanism)
- Exponential fall in p_t for soft interaction
- to go from original p_{beam} ~400 GeV/c to much lower momenta best refit parameters

$$r(\pi) = r_0(1+x_R)^{r_1}$$
$$r(K) = r_0(1-x_R)^{r_1}$$

Positive to negative ratio

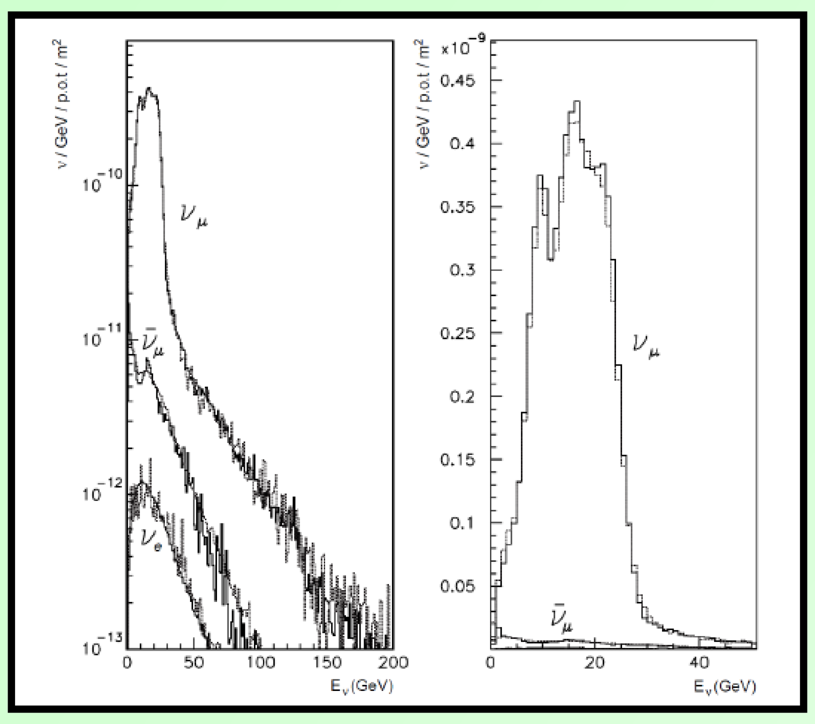


Comparison with Barton et al. (100 GeV/c) with original BMPT parameters

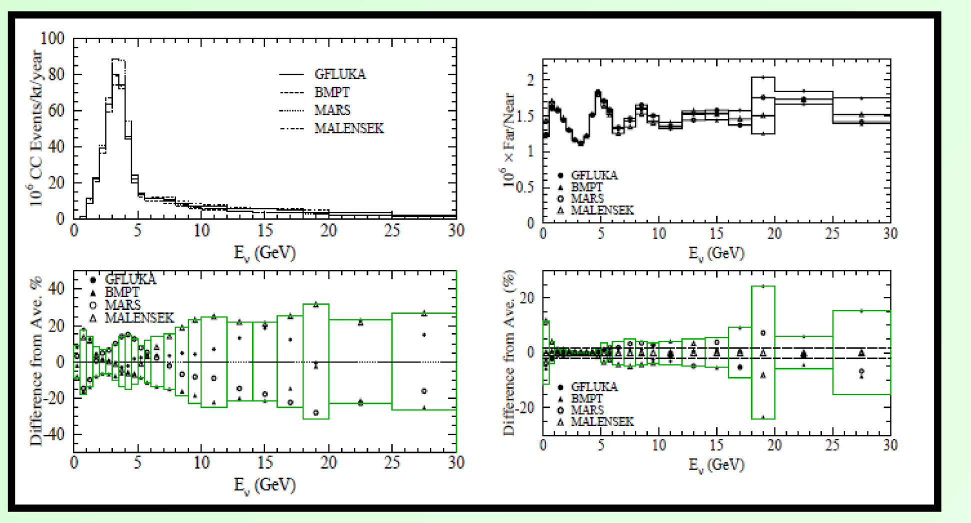


Fit with BPMT parametrization of NA61/SHINE data, used for T2K fllux predictions (from ref. 4)

Applications: two examples



Comparison MC vs BMPT parametrization for CNGS



NUMI long baseline beam (BMPT)

Useful references

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2. *M,. Apollonio et al. (HARP Coll.)* Phys. ReV. **C80** (2009) 065
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4. *K. Abe et al. (T2K Coll*.), Phys. ReV. D87 (2013) 012001
5. *M. Bonesini, A. Marchionni, F. Pietropaolo, T. Tabarelli de Fatis*, Eur. Phys. J. C20 (2001) 13
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