2020 T2K flux prediction file release description

The T2K Collaboration

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Flux predictions for the T2K ND280 (near) and SK (far) detectors used in T2K analyses in 2020 and later are provided. These correspond to T2K internal version number 13av7.1 tuned fluxes.

The original description of the T2K flux prediction is published in Phys. Rev. D 87, 012001 (2013). Since the publication, the flux prediction has been updated with new 2009 thin and 2009 replica target data from the NA61/SHINE experiment, and flux predictions for antineutrino enhanced beam operation have been produced. The NA61/SHINE thin target measurements of $\pi^{\pm}$, $K^{\pm}$, K^0_S, Λ and p production are published in Eur. Phys. J. C (2016) 76: 84. The NA61/SHINE 2009 replica target measurements of $\pi^{\pm}$ are published in Eur. Phys. J. C (2016) 76: 617. This flux release uses tuning to NA61/SHINE 2009 replica target data for all interactions inside of the production target, while interactions not tunable by replica target data are tuned to NA61/SHINE 2009 thin target data and other earlier datasets. Updates to the flux predictions are described in Phys. Rev. D 91, 072010 (2015) and Phys. Rev. D 103, 112008 (2021), while the flux prediction released here corresponds to that used in the T2K 2020 oscillation physics result paper (to be submitted to Eur. Phys. J. C). The provided flux predictions include no neutrino oscillations.

The ND280 flux is calculated as the average flux at a 150×150 cm^2 plane that is centered in the ND280 near detector volume. The plane is at a distance of 284.9 m from the center of the production target. The direction from the center of the production target to the plane is offset from the beam direction by 2.042°. The SK flux is calculated for an infinitesimal angular range in a direction that is offset by 2.506° from the beam direction. The SK flux is calculated at a distance of 295.3 km from the center of the production target. Fluxes are provided for both +250 kA (neutrino enhanced beam) and −250 kA (antineutrino enhanced beam) operation of the T2K magnetic horns. Fluxes are provided for both nominal horn currents and a nominal, Gaussian proton beam centered on the neutrino production target (labeled as "nominal"), as well as for the average measured horn currents and proton beam parameters at the target over the T2K Run 1-10 period (Jan 2010-Feb 2020) (labeled as "runcond"). The "nominal" fluxes should be used for sensitivity estimations, notably for higher statistics projections of T2K data. The "runcond" fluxes should be used to compare predictions to published T2K measurements according to the actual used

data runs. Many T2K cross section measurements have independently released flux predictions for the corresponding data periods, including tuning – those fluxes should be used for measurement comparisons when available.

The flux is provided using a binning scheme optimized to give relatively consistent statistical errors for all bins, and uses 138 bins with bin edges at energies in GeV of:

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bins[138+1] = {0, 0.01, 0.02, 0.03, 0.04, 0.05, 0.06, 0.07, 0.08, 0.09,
0.1, 0.11, 0.12, 0.13, 0.14, 0.15, 0.16, 0.17, 0.18, 0.19, 0.2, 0.21,
0.22, 0.23, 0.24, 0.25, 0.26, 0.27, 0.28, 0.29, 0.3, 0.31, 0.32, 0.33,
0.34, 0.35, 0.36, 0.37, 0.38, 0.39, 0.4, 0.41, 0.42, 0.43, 0.44, 0.45,
0.46, 0.47, 0.48, 0.49, 0.5, 0.51, 0.52, 0.53, 0.54, 0.55, 0.56, 0.57,
0.58, 0.59, 0.6, 0.61, 0.62, 0.63, 0.64, 0.65, 0.66, 0.67, 0.68, 0.69,
0.7, 0.71, 0.72, 0.73, 0.74, 0.75, 0.76, 0.77, 0.78, 0.79, 0.8, 0.82,
0.84, 0.86, 0.88, 0.9, 0.95, 1, 1.05, 1.1, 1.15, 1.2, 1.3, 1.4, 1.5,
1.6, 1.7, 1.8, 1.9, 2, 2.1, 2.2, 2.3, 2.4, 2.6, 2.8, 3, 3.2, 3.4, 3.6,
3.8, 4, 4.5, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20,
21, 22, 23, 24, 25, 26, 27, 28, 29, 30}
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The bins are normalized to show the flux per 50 MeV. All flux predictions are normalized to 1×10^{21} protons delivered to the T2K production target (Protons On Target – POT). Thus, fluxes are given in units of $1/(\text{cm}^2\ 50\text{MeV}\ 10^{21}\text{POT})$. The error bars shown in the histograms are Monte Carlo statistical errors.

A matrix which encodes the covariance between different energy bins of the fluxes at the near and far detectors for both horn operation modes is also provided. The binning of the covariance matrix is coarser than the binning of the provided fluxes, and the covariance matrix binning definition is also provided. The ordering of the bins in the covariance matrix is:
ND280 +250 kA ν_μ, $\bar{\nu}_\mu$, ν_e, $\bar{\nu}_e$; ND280 −250 kA ν_μ, $\bar{\nu}_\mu$, ν_e, $\bar{\nu}_e$;
SK +250 kA ν_μ, $\bar{\nu}_\mu$, ν_e, $\bar{\nu}_e$; SK −250 kA ν_μ, $\bar{\nu}_\mu$, ν_e, $\bar{\nu}_e$

ROOT and text files are provided:

- t2kflux_2020_plus250kA_nominal.root
  ROOT histograms of the ND280 and SK flux for +250 kA horn operation and nominal proton beam conditions

- t2kflux_2020_minus250kA_nominal.root
  ROOT histograms of the ND280 and SK flux for −250 kA horn operation and nominal proton beam conditions

- t2kflux_2020_plus250kA_runcond.root
  ROOT histograms of the ND280 and SK flux for +250 kA horn operation and measured proton beam conditions

- t2kflux_2020_minus250kA_runcond.root
  ROOT histograms of the ND280 and SK flux for −250 kA horn operation and measured proton beam conditions

- t2kflux_2020_covariance.root
  ROOT TMatrixT containing the total ND280 and SK flux covariance, and ROOT TAxis with the binning definition for the covariance matrix

- t2kflux_2020_plus250kA_nominal_nd280.txt
  Text table of ND280 flux for +250 kA horn operation and nominal proton beam conditions

- t2kflux_2020_minus250kA_nominal_nd280.txt
  Text table of ND280 flux for −250 kA horn operation and nominal proton beam conditions

- t2kflux_2020_plus250kA_nominal_sk.txt
  Text table of SK flux for +250 kA horn operation and nominal proton beam conditions

- t2kflux_2020_minus250kA_nominal_nd280.txt
  Text table of SK flux for −250 kA horn operation and nominal proton beam conditions

- t2kflux_2020_plus250kA_runcond_nd280.txt
  Text table of ND280 flux for +250 kA horn operation and measured proton beam conditions

- t2kflux_2020_minus250kA_runcond_nd280.txt
  Text table of ND280 flux for −250 kA horn operation and measured proton beam conditions

- t2kflux_2020_plus250kA_runcond_sk.txt
  Text table of SK flux for +250 kA horn operation and measured proton beam conditions

- t2kflux_2020_minus250kA_runcond_nd280.txt
  Text table of SK flux for −250 kA horn operation and measured proton beam conditions

The histograms in the flux ROOT files are:

- enu_sk_numu:
  The SK ν_μ flux prediction in bins of neutrino energy

- enu_sk_numub:
  The SK $\bar{\nu}_\mu$ flux prediction in bins of neutrino energy
- enu_sk_nue:
  The SK ν_e flux prediction in bins of neutrino energy
- enu_sk_nueb:
  The SK $\bar{\nu}_e$ flux prediction in bins of neutrino energy
- enu_nd280_numu:
  The ND280 ν_μ flux prediction in bins of neutrino energy
- enu_nd280_numub:
  The ND280 $\bar{\nu}_\mu$ flux prediction in bins of neutrino energy
- enu_nd280_nue:
  The ND280 ν_e flux prediction in bins of neutrino energy
- enu_nd280_nueb:
  The ND280 $\bar{\nu}_e$ flux prediction in bins of neutrino energy

The contents of the covariance matrix ROOT file are:

- total_flux_cov:
  TMatrixT with the total flux covariance in bins of:
  ND280 +250 kA ν_μ, $\bar{\nu}_\mu$, ν_e, $\bar{\nu}_e$; ND280 −250 kA ν_μ, $\bar{\nu}_\mu$, ν_e, $\bar{\nu}_e$;
  SK +250 kA ν_μ, $\bar{\nu}_\mu$, ν_e, $\bar{\nu}_e$; SK −250 kA ν_μ, $\bar{\nu}_\mu$, ν_e, $\bar{\nu}_e$
- nd280_numode_numu_bins:
  TAxis with the ND280 ν_μ binning for +250 kA horn current
- nd280_numode_numub_bins:
  TAxis with the ND280 $\bar{\nu}_\mu$ binning for +250 kA horn current
- nd280_numode_nue_bins:
  TAxis with the ND280 ν_e binning for +250 kA horn current
- nd280_numode_nueb_bins:
  TAxis with the ND280 $\bar{\nu}_e$ binning for +250 kA horn current
- nd280_anumode_numu_bins:
  TAxis with the ND280 ν_μ binning for −250 kA horn current
- nd280_anumode_numub_bins:
  TAxis with the ND280 $\bar{\nu}_\mu$ binning for −250 kA horn current

- nd280_anumode_nue_bins:
  TAxis with the ND280 ν_e binning for -250 kA horn current
- nd280_anumode_nueb_bins:
  TAxis with the ND280 $\bar{\nu}_e$ binning for -250 kA horn current
- sk_numode_numu_bins:
  TAxis with the SK ν_μ binning for $+250$ kA horn current
- sk_numode_numub_bins:
  TAxis with the SK $\bar{\nu}_\mu$ binning for $+250$ kA horn current
- sk_numode_nue_bins:
  TAxis with the SK ν_e binning for $+250$ kA horn current
- sk_numode_nueb_bins:
  TAxis with the SK $\bar{\nu}_e$ binning for $+250$ kA horn current
- sk_anumode_numu_bins:
  TAxis with the SK ν_μ binning for -250 kA horn current
- sk_anumode_numub_bins:
  TAxis with the SK $\bar{\nu}_\mu$ binning for -250 kA horn current
- sk_anumode_nue_bins:
  TAxis with the SK ν_e binning for -250 kA horn current
- sk_anumode_nueb_bins:
  TAxis with the SK $\bar{\nu}_e$ binning for -250 kA horn current