Strange Particle Measurements with the NA61 experiment

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On behalf of the NA61 collaboration
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Importance of the Measurement: Kaon Contribution to the $\nu$ flux in T2K
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![Graphs showing the neutrino flux and error contributions in T2K experiments.](image)

**SK $\nu_e$ Fractional Error**
- Sec. Nucleon Multiplicity
- Pion Multiplicity
- Kaon Multiplicity
- Prod. Cross Sections
- Proton Beam
- Target & Horn Alignment
- Off-axis Angle
- Horn Abs. Current
- Total

**SK $\nu_\mu$ Fractional Error**
- Sec. Nucleon Multiplicity
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Total Error

Kaon Multiplicity

see following talk “Prediction of the Neutrino Flux at T2K” from V. Galymov
Outlook of the Analysis
- K+ Cross Section for 2007 Thin Target data -

- Goal -
  - Cover most of the p-θ phase space relevant for T2K
  - Perform Cross Section measurements with Stat+Syst error below 20%

- Critical Points -
  - Limited Statistics
  - Kaon Decay in Flight
  - PID at higher momentum
Coverage of the T2K Phase Space

$\theta$: [20, 140] mrad
7 bins 0.8 GeV/c wide in the range [1.6, 7.2] GeV/c

$\theta$: [140, 240] mrad
3 bins: 1.6, 2.4, 4.0, 5.6 GeV/c

Positive Reco. Tracks in NA61

$K^+ \rightarrow \nu$ to SK
Track Selections: quality cuts

On the p-θ phase space, acceptance is very sensitive to topology.

The two subsamples treated separately.

On the transverse plane reconstruction, limited by acceptance.

High Reconstruction efficiency Vs number of points.

Efficiency Vs φ

Efficiency Vs Fitted Points
Track Selections: dealing with Kaon DiF

- Decay in Flight of Kaons into $\pi$’s, $\mu$’s
  - ToF and/or dE/dx biased

- Suitable cut: selection of "long tracks"
  - High rejection of DiF Kaons
    - Less statistics
    - High purity
    - Analytical correction can be applied
    - Systematics under control

A ToF hit associated to a decaying-in-flight Kaon

$\sim 13$ m
Combined ToF and $dE/dx$ Information needed for **Particle Identification** in the analysed momentum range.

$$\sigma \left( \frac{dE}{dx} \right) / \langle \frac{dE}{dx} \rangle \approx 3\%$$

$$\sigma(\text{ToF}) \approx 120\,\text{ps}$$
dE/dx Parametrization From Data

Kaon Yield extraction stability critically depends on the constraint on the dE/dx peak position.

- **Low \( \beta \gamma \): \( p/K \) of low-mid momentum
- **Intermediate \( \beta \gamma \): \( K \) of high momentum
- **High \( \beta \gamma \): \( \pi \) whole momentum range

Bethe-Bloch fit to dE/dx measurements in \( \beta \gamma \) regions where peak separation power is maximal.

Precision dE/dx prediction in \( \beta \gamma \) region where peaks overlap.
Kaon Yield extraction stability critically depends on the constraints on the $m^2$ distributions. $m^2$ resolution $\sim p^2$ → high separation power at low momenta.

$m^2$ central value is stable vs mom.

Peak Positions fixed over the whole mom. range.

Resolution function extracted from the data.

Peak Widths extrapolated at higher momenta.

Fit
Kaon Yield Extraction

- Model: Superposition of 4 2D Gaussians $\frac{dE}{dx}$
  - Peak Positions: $<\frac{dE}{dx}>$ calculated from the measured Bethe-Bloch parametrization
  - Peak Width: $\sigma(\frac{dE}{dx})$ same for all the hadrons set as a free fit parameter
    - smearing due to bin size taken into account

ToF
- Peak Positions: $<m^2>$ extrapolated from measured points
- Peak Widths: $\sigma(m^2)$ calculated from the measured resolution function
**MC Correction to Raw Yields**

- **Major Contribution:**
  Correction for the Decay in Flight of the Kaons

- **Others correction:** below 10%
  - **Reconstruction Efficiency** maximized at track selection level
  - **Feed Down** (contamination of K’s from e.g. Weak decays) → negligible
  - **Acceptance** below 90% only in the first bin: optimized with track topology selection

- **Several Unfolding Algorithm Compared:**
  Bin-by-Bin, Bayes, SVD. -> different results are consistent: bin-bin migration effect is under control

- **Unfolding predictions tested on independent MC samples:**
  -> no evidence for biases
Total Error: below 20%

Limited Statistics: 1-3x10^3 tracks per bin.
- Statistical Error ~ 12%

Systematics: 3-7% dominated by
- PID: bias on the fit to particle yield
- Correction for Decay in Flight

Estimation of Systematics
- PID: fit systematics calculated from the sensitivity to the input dE/dx and m² parameter setting
- Decay:
  - Effect of mis-reconstructed kink topologies.
  - Effect of model dependent momentum distribution
Comparison to MC Predictions

$K/\pi$ ratio

$\theta: [20, 140]$
K⁰s’ and Lambda’s with 2009 data

- The 4.5 M events of the 2009 (Thin Target) dataset have been processed.
  - K⁰s and Λ signals extracted with a B-W + Polynomial fit to invariant mass distributions.
  - No PID.

General Selections
- Event Quality Cut -> Good Fitted Primary Vertex
- Acceptance and Efficiency -> Cut on Decay Angle
- Presence of a displaced V0 vertex -> cut on vertex longitudinal position
Conclusions

- **Measurement of the Charged Kaon Differential Cross Section**
  - important for the determination of the high energy tail of the neutrino flux in the Long Baseline Neutrino Exp. T2K
  
  (→ talk “*Predicting the Neutrino Flux at T2K*” from V. Galymov)

- **Kaons from Low Statistics Pilot-Run**
  - K+ production Cross Section results released
  - Coarse p-θ binning
  - Statistical error below 15%.
  - Systematic error below 10%, dominated by PID
  - Paper in preparation

- **Ongoing Analysis on the High Statistics (x10) Dataset**
  - Calibration almost finalized
  - Whole dataset (~5M events) processed
  - First K⁰s and Λ mass spectra very promising
  - Perform K+ Cross Section Analysis with
    - Refined Binning
    - Improved Errors
backup
dE/dx-m² correlation in Raw Data

First Angular Bin
θ: [20,140] mrad

p: [1.6,2.4] GeV/c

p: [5.6,6.4] GeV/c

p: [6.4,7.2] GeV/c
dE/dx-m² correlation in Raw Data

Q:1 P:[1.6,2.4] θ:[140,240] 

Entries 1399

p: [1.6,2.4] GeV/c

Second Angular Bin
θ: [140,240] mrad

Q:1 P:[2.4,4] θ:[140,240] 

Entries 1340

p: [2.4,4.0] GeV/c

Q:1 P:[4,5.6] θ:[140,240] 

Entries 529

p: [4.0,5.6] GeV/c
PID: Extraction of the Signal Yield

Bidimensional $dE/dx-m^2$ fit: superposition of 4 2D Gaussians

**dE/dx Projection**

- **RMS**: $0.0897 \pm 0.0013$
- **Mean**: $1.0981 \pm 0.0018$
- **Entries**: 2395
- **nE**: 106 ± 10
- **nK**: 55.9 ± 7.5
- **nP**: 366 ± 19
- **nP**: 1867 ± 43

**m^2 Projection**

- **RMS**: $0.3025 \pm 0.0044$
- **Mean**: $0.1508 \pm 0.0062$
- **Entries**: 2395
- **nE**: 106 ± 10
- **nK**: 55.9 ± 7.5
- **nP**: 366 ± 19
- **nP**: 1867 ± 43
Fit $p: [6.4, 7.2]$  
$\theta: [20, 140]$
Systematics: detector response uniformity

- Selection of tracks laying in the upper or lower side of the TPC = selection of tracks with short or long drift distance hits
  - consistent Kaons Yield -> detector response is uniform along the whole drift distance

**Upper Side**

- $\theta: [20, 140]$:
  - $nE = 14.0 \pm 3.7$
  - $nK = 66.6 \pm 8.5$
  - $nP = 263 \pm 16$
  - $nP\pi = 761 \pm 28$

**Lower Side**

- $\theta: [140, 240]$:
  - $nE = 15.0 \pm 3.9$
  - $nK = 63.6 \pm 8.3$
  - $nP = 291 \pm 17$
  - $nP\pi = 788 \pm 28$

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**Upper Side**

- dE/dx Projection

**Lower Side**

- dE/dx Projection

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**Kaons, $\theta: [20, 140]$**

- $\theta: [20, 140]$
  - $p_y > 0$ Up
  - $p_y < 0$ Down

**Kaons, $\theta: [140, 240]$**

- $\theta: [140, 240]$
  - $p_y > 0$ Up
  - $p_y < 0$ Down