Search for CP Violation in $D^+ \rightarrow K^+ K^- \pi^+$

BABAR Experiment

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May 2, 2006
Outline

- Introduction
  - CP Violation
  - Motivation

- The BABAR Experiment
  - Detector

- Analysis
  - Selection Criteria
  - Systematics Studies
  - Results

- Contributions to
  - BABAR
  - MINOS
In the standard model via a complex phase the CKM matrix (V):

$$V = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$

weak eigenstates $\begin{pmatrix} d' \\ s' \\ b' \end{pmatrix} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \begin{pmatrix} d \\ s \\ b \end{pmatrix}$

mass eigenstates

- $V$ is 3x3 unitary matrix: $VV^\dagger$
- $V_{ij}$ strength of the i-j quark coupling
- $V$ can be parametrized with 4 parameters:

$$V \approx \begin{pmatrix} 1 - \frac{1}{2} \lambda^2 & \lambda & A \lambda^3 (\rho - i \eta) \\ -\lambda & 1 - \frac{1}{2} \lambda^2 & A \lambda^2 \\ A \lambda^3 (1 - \rho - i \eta) & -A \lambda & 1 \end{pmatrix} + O(\lambda^4)$$

Wolfenstein parametrization: $A \sim 1, \lambda \sim 0.22$

- Why is important CP Violation:
  - Distinguish between matter and antimatter
  - Is the Universe only made out of matter? (CPV is a condition in Sakharov's model)
  - Very sensitive to new physics models
Three types of CP Violation:

(a) Indirect CPV (in mixing)

\[ \Gamma(D^0 \rightarrow f) \neq \Gamma(D^0 \rightarrow f) \]

In D decays mixing is suppressed (<10^{-2})

(b) Direct CPV (in decay)

\[ \Gamma(D \rightarrow f) \neq \Gamma(D \rightarrow f) \]

(c) Interference (between mixing and decay)
Experimental Observations of CP Violation

→ In K mesons:
  
  ▶ CPV in mixing (1964 using $K_L^0 \to \pi^+ \pi^-$): $\epsilon = 2.3 \times 10^{-3}$
  
  ▶ CPV in decay (1999): $\Re (\epsilon'/\epsilon) = (1.8 \pm 0.4) \times 10^{-3}$

→ In B mesons:
  
  ▶ CPV in mixing (2002 charmonium modes): $\sin (2 \beta) = 0.72 \pm 0.04 \pm 0.02$
  
  ▶ CPV in decay (2004 $B^0 \to K^+ \pi^-$): $A_{K\pi} = -0.133 \pm 0.030 \pm 0.009$

→ In D mesons:
  
  ▶ No CPV observed. No even mixing.

New physics could be hidden in the Charm sector!
Considering a decay amplitude and its conjugate given by

\[ A = |A| e^{i(\delta_1 + \phi_1)} + |B| e^{i(\delta_2 + \phi_2)} \]

and

\[ \bar{A} = |A| e^{i(\delta_1 - \phi_1)} + |B| e^{i(\delta_2 - \phi_2)} \]

The CP Asymmetry is

\[ A_{CP} = \frac{|A|^2 - |\bar{A}|^2}{|A|^2 + |\bar{A}|^2} = \frac{2|A||B|\sin(\phi_1 - \phi_2)\sin(\delta_1 - \delta_2)}{|A|^2 + |B|^2 + 2|A||B|\cos(\phi_1 - \phi_2)\cos(\delta_1 - \delta_2)} \]

where \( A_{CP} \neq 0 \) only if \( A \neq B \) and \( (\phi_1 - \phi_2) \neq (\delta_1 - \delta_2) \neq 0 \)
Possible asymmetry in SCS decays in the interference of tree-level and penguin process

\[ V_{cs}^* \cdot V_{us} \quad \text{different weak phases} \quad V_{cd}^* \cdot V_{ud} \]

\[ \Delta I = 1/2, 3/2 \quad \text{different strong phases} \quad \Delta I = 1/2 \]

\[ A_{CP} \propto \Im \left( V_{cd} V_{ud}^* V_{cs} V_{us}^* \right) \sin \delta \propto A^2 \eta \lambda^4 \sin \delta < 10^{-3} \]
The time-integrated CP asymmetries can be written as

\[ A_{CP} = \frac{\Gamma (D \rightarrow f) - \Gamma (\bar{D} \rightarrow \bar{f})}{\Gamma (D \rightarrow f) + \Gamma (\bar{D} \rightarrow \bar{f})} \]

where \( \Gamma (D \rightarrow f) \) is the decay rate.

Using \( \Gamma_{tot} (D) = \Gamma_{tot} (\bar{D}) \), from CPT conservation

\[ A_{CP} = \frac{B (D \rightarrow f) - B (\bar{D} \rightarrow \bar{f})}{B (D \rightarrow f) + B (\bar{D} \rightarrow \bar{f})} \]

where \( B (D \rightarrow f) \) is the branching fraction.

**Note** that \( A_{CP} \) can be normalized by a CP invariant branching fraction to reduce systematic errors. In the SM, Cabibbo-Favored decays are CP invariant:

\[ B (D \rightarrow f_{CF}) = B (\bar{D} \rightarrow \bar{f}_{CF}) \]
Search for New Physics in Charm CP Asymmetries

→ CPV in charm is expected to first manifest in **Singly Cabibbo Suppress**.

→ In the **standard model**, CPV in SCS decays $\sim 10^{-3}$.

→ **New Physics** can give CPV asymmetries $\sim 10^{-2}$.

→ Experiments reaching limit of $10^{-2}$ providing a window for new discoveries.

We search for the CP asymmetry in SCS decays $D^+ \to K^+ K^- \pi^+$ and in the resonant decays $D^+ \to \phi \pi^+$ and $D^+ \to \bar{K}^*0 K^+$

Use $D^+$ Cabibbo-Favored as normalization to reduce systematics due to PID and tracking.

$A_{CP} = \frac{B(D^+ \to K^+ K^- \pi^+) - B(D^- \to K^+ K^- \pi^-)}{B(D_s^+ \to K^+ K^- \pi^+)} \frac{B(D_s^- \to K^+ K^- \pi^-)}{B(D^+ \to K^+ K^- \pi^+) + B(D_s^- \to K^+ K^- \pi^-)}$

(high statistic analysis (stat. error at 1%) → challenge: tiny systematic errors (sub-% syst. errors))
The BABAR Detector

**BABAR Detector**
- Instrumented Flux Return
- 1.5 T Solenoid
- Drift Chamber
- Cherenkov Detector (DIRC)
- Silicon Vertex Detector
- Electromagnetic Calorimeter

**SLAC**

$Y(4S), 9 \text{ GeV} \ e^- \ 3.1 \text{ GeV} \ e^+$
logged $316 \text{ fb}^{-1}$

$\sigma(e^+e^- \rightarrow cc) \sim 1.3 \text{ nb}$

$\sigma(p_T/E) = 2.3\% E[\text{GeV}/c]^{-1/4} + 1.9\%$

$\sigma(p_T/p_T) = 0.13\% \times p_T[\text{GeV}/c] + 0.45\%$

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CP Violation in D+
May 1, 2006
pg. 10
Data Sample and Selection

\[ 10 \text{ fb}^{-1} \quad \text{randomly} \quad 80 \text{ fb}^{-1} \]

- Same selection criteria applied to CF and SCS modes whenever possible

- Reconstruct decays: \( D^\pm \rightarrow K^- K^+ \pi^\pm \quad D_s^\pm \rightarrow K^- K^+ \pi^\pm \quad D^\pm \rightarrow K^\mp \pi^\pm \pi^\pm \)

  (for branching fraction)

- At least three charged tracks
- Particle identification for kaons
- Pions are tracks that fail a loose kaon PID
- Common vertex. Probability \( \chi^2 > 1\% \)
- Reject D from B decays (background) by \( p_{\text{CM}}(D^+) > 2.4 \text{ GeV/c} \)
- Remaining combinatorial background reduced with a likelihood ratio technique
Discriminating Variables

Construct Probability Density Functions (PDF) for signal and background:

Variables for $D^+$ and $D_s^+$ decays:

- cm momentum ($p_{c.m.}$)
- Vertex-fit probability with beam-spot constraint ($P_{BS}(\chi^2)$)
- Vertex separation (from interaction point) in the X-Y plane ($d_{xy}$)

Signal PDF obtained by

$$F(signal) = \frac{1}{\alpha} F(signal\ region) - \frac{1 - \alpha}{\alpha} F(side\ bands), \alpha = \frac{N_D}{N_{signal\ region}}$$
Signal and Background PDFs

$D^+ \rightarrow K^{\mp} \pi^\pm \pi^\pm$ DECAYS:

Probability to form a vertex within the beam-spot region

small probability for D+ signal
Likelihood Ratios

Construct a likelihood for signal and background:

\[ L_{\text{signal}} = \prod_i L_{\text{signal}}^i(x_i) \quad L_{\text{bkg}} = \prod_i L_{\text{bkg}}^i(x_i) \]

then, the likelihood ratio is

\[ r \equiv \frac{L_{\text{signal}}}{L_{\text{bkg}}} \]

→ About 16% of the events have more than one D+:
   → Select event with highest likelihood ratio.
   → Most of these events are combinatorics
→ Ratio (r) formed using only \( p_{\text{c.m.}} \) and \( P_{\text{BS}}(\chi^2) \)
→ Sensitivity (S/\(\Delta S\)) optimized as a function of ratio:
   → Maximum at \( r \geq 4.3 \)
   → Same criteria applied to both CF and SCS decays
→ Define ratio (\( r_1 \)) by including \( d_{xy} \) PDF in the likelihoods
   → Sensitivity is nearly as good as ratio “r” \([ d_{xy} \) correlated with \( P_{\text{BS}}(\chi^2) \)]
   → Used to measure a systematic uncertainty
\(D^+ \rightarrow \phi \pi^+\) reconstruction:

- Invariant mass within 10 MeV/c\(^2\) of nominal \(\phi\) mass
- Helicity angle cut at maximum sensitivity: \(|\cos(\theta_H)| \geq 0.2\)

\(D^+ \rightarrow K^*0 K^+\) reconstruction:

- Invariant mass within 50 MeV/c\(^2\) of nominal \(K^*0\) mass
- Helicity angle cut at maximum sensitivity: \(|\cos(\theta_H)| \geq 0.3\)
Remove Additional Background

\( D_s^{\pm} \rightarrow K^- K^+ \pi^\pm \) selection:

- Selected by a procedure identical to that of SCS \( D^+ \) decays
- Remove contamination from \( D^{\pm} \rightarrow K^{\mp} \pi^{\pm} \pi^{\pm} \)
  - For all (KK\( \pi \)), the \( K \) with same charge as pion is treated as pion and then the (K\( \pi \pi \)) invariant mass is calculated.
  - \( D^+ \) peak in mass region is removed.
- Contamination from \( D^{*+} \rightarrow D^0 (\rightarrow K^- \pi^+ , K^- K^+) \pi^+ \)
  - Remove events which \( m_{K^- \pi^+} \geq 1.84 \text{ GeV}/c^2 \)

\( D^{\pm} \rightarrow K^\mp \pi^{\pm} \pi^{\pm} \) selection:

- Events removed if either (K\( \pi \)) combination satisfies \( m_{K^- \pi^+} \geq 1.84 \text{ GeV}/c^2 \)

\( D^{\pm} \rightarrow K^- K^+ \pi^\pm \) selection:

- Partially reconstructed \( D^{*+} \rightarrow D^0 (\rightarrow K^- \pi^+ \pi^0) \pi^+ \) misidentify as (KK\( \pi \)), if \( \pi^0 \) missed and pion misidentify as a kaon: Events removed if K track treated as \( \pi \) and \( 0.139 < \left( m_{K^- \pi^+ \pi^+} - m_{K^- \pi^+} \right) < 1.84 \left[ \text{GeV}/c^2 \right] \)
Mass Distributions After Selection – Full Sample

Total 43k

Total 11k

Total 10k

<table>
<thead>
<tr>
<th>Parent Charge</th>
<th>$D^\pm \rightarrow K^- K^+ \pi^\pm$</th>
<th>$D^\pm \rightarrow \phi \pi^\pm$</th>
<th>$D^\pm \rightarrow K^{*0} K^\pm$</th>
<th>$D_s^\pm \rightarrow K^- K^+ \pi^\pm$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$21632 \pm 228$</td>
<td>$5452 \pm 87$</td>
<td>$5247 \pm 96$</td>
<td>$23066 \pm 217$</td>
</tr>
<tr>
<td></td>
<td>$20940 \pm 226$</td>
<td>$5327 \pm 86$</td>
<td>$5113 \pm 96$</td>
<td>$22928 \pm 214$</td>
</tr>
</tbody>
</table>
Obtained from a sample of MC generated $c\bar{c}$ events.
- Same selection criteria is applied.
- **Efficiency** = signal MC events / generated events.
- Monte Carlo includes corrections to Particle ID and Tracking.
Cross – Check of CP Asymmetries

(1) Measure CP Asymmetry in Cabibbo-Favored Ds+ decays as a **cross-check** using full sample (80 fb⁻¹)

\[ A_{CP}(D_s^+ \rightarrow KK \pi) = ( +0.64 \pm 0.75 ) \times 10^{-2} \]

asymmetry consistent with zero

(2) Alternative \( A_{CP}^{(2)} \) measure of CP asymmetry **without** using Ds+ decays

<table>
<thead>
<tr>
<th>Decay</th>
<th>( A_{CP} ) [10⁻²]</th>
<th>( A_{CP}^{(2)} ) [10⁻²]</th>
</tr>
</thead>
<tbody>
<tr>
<td>( K^- K^+ \pi^\pm )</td>
<td>+1.36 ± 1.01</td>
<td>+2.07 ± 0.84</td>
</tr>
<tr>
<td>( \phi \pi^\pm )</td>
<td>+0.24 ± 1.45</td>
<td>+0.94 ± 1.33</td>
</tr>
<tr>
<td>( \bar{K}^*0 K^\pm )</td>
<td>+0.88 ± 1.67</td>
<td>+1.58 ± 1.57</td>
</tr>
</tbody>
</table>

(statistic errors only)  \( A_{CP} \) consistent
**Line shape background**
Linearity of the background bands checked with a linear and quadratic functions. Best Probability $\chi^2$ obtained with linear function. (no contribution)

**Peaking backgrounds**
Selection criteria run over generic MC samples: B+B-, B$^0$B$^0$, c$\bar{c}$, uds. (no contribution)

**Momentum dependency**
Probability $\chi^2$ to be constant 32% (no contribution)

**Temporal dependency**
Probability $\chi^2$ to be constant 63% (no contribution)
**MC simulation**
Slightly harder momentum spectrum for Ds+ decay products. (Conservatively) estimated as three times the maximum difference in $\pi$, $K$ asymmetries in the efficiencies from D+ vs Ds+

**Background estimate**
Increase by 50% the widths of the sideband mass regions. Uncertainty is taken to be the resulting difference in the central value of $A_{CP}$.

**Selection criteria**
Estimated with two variants: (1) tightening the LH ratio to produce a 10% change in the yields, and (2) using the LH ratio ($r_1$) in place of $r$. The uncertainty is chosen to be the larger of the two.
### CP Asymmetry Results

<table>
<thead>
<tr>
<th>Decay</th>
<th>$A_{CP} \times 10^{-2}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$K^- K^+ \pi^{\pm}$</td>
<td>$+1.4 \pm 1.0 \text{(stat.)} \pm 0.8 \text{(syst.)}$</td>
</tr>
<tr>
<td>$\phi \pi^{\pm}$</td>
<td>$+0.2 \pm 1.5 \text{(stat.)} \pm 0.6 \text{(syst.)}$</td>
</tr>
<tr>
<td>$\bar{K}^*0 K^\pm$</td>
<td>$+0.9 \pm 1.7 \text{(stat.)} \pm 0.7 \text{(syst.)}$</td>
</tr>
</tbody>
</table>

**Significant improvement in resonant modes**
Construct an adaptive binned Dalitz plot and study the asymmetry in each bin.

For the ith-bin:

\[
A_{CP}^{i} = \frac{S_{i}^{+}/\epsilon_{i}^{+} - S_{i}^{-}/\epsilon_{i}^{-}}{S_{i}^{+}/\epsilon_{i}^{+} + S_{i}^{-}/\epsilon_{i}^{-}}
\]

Asymmetry consistent with being constant (with a probability of 51%) and zero
Relative Branching Fraction

- Same selection criteria for CF D+ decays
- Equally populated bins
- Average efficiency = 10.03 ± 0.01 %

\[
\frac{\Gamma(D^+ \rightarrow K^+ K^- \pi^+)}{\Gamma(D^+ \rightarrow K^- \pi^+ \pi^+)} = \frac{\sum_i S_{K K \pi}^i / \epsilon_{K K \pi}^i}{\sum_j S_{K \pi \pi}^j / \epsilon_{K \pi \pi}^j}
\]
Relative Branching Fraction

<table>
<thead>
<tr>
<th>Source</th>
<th>Uncertainty [10^{-2}]</th>
</tr>
</thead>
<tbody>
<tr>
<td>PID + tracking</td>
<td>0.22</td>
</tr>
<tr>
<td>Background estimate</td>
<td>0.05</td>
</tr>
<tr>
<td>Selection criteria</td>
<td>0.02</td>
</tr>
<tr>
<td>Total</td>
<td>0.23</td>
</tr>
</tbody>
</table>

\[
\frac{\Gamma(D^+ \rightarrow K^+ K^- \pi^+)}{\Gamma(D^+ \rightarrow K^- \pi^+ \pi^+)} = (10.7 \pm 0.1 (\text{stat}) \pm 0.2 (\text{syst})) \times 10^{-2}
\]

Significant improvement
Other Contributions to BABAR

- Search for rare $D^0 \rightarrow l^+l^-$ decay
- Particle Identification:
  - Electron control sample
  - Data/MC corrections
  - User support
In the standard model, **Flavor Changing Neutral currents** (FCNC) are very rare (BR $\sim 10^{-13}$) and **Lepton Number Violations** (LNV) are strictly forbidden.

Observation of such decays would be sign of physics beyond the SM, for example R-parity violating SUSY can increase BR by

$$B(D^0 \to e^+ e^-) \sim 10^{-10}$$
$$B(D^0 \to \mu^+ \mu^-) \sim 10^{-6}$$

Branching ratio:

$$B(D^0 \to l^+ l^-) = \left( B(D^0 \to \pi^+ \pi^-) \cdot \frac{1}{N_{\pi\pi}} \cdot \frac{\epsilon_{\pi\pi}}{\epsilon_{ll}} \right) \cdot (N_{\text{obs}} - N_{\text{bkg}})$$

<table>
<thead>
<tr>
<th>Decay</th>
<th>$N^{hh}$</th>
<th>$N^\text{comb}$</th>
<th>$N^\text{bg}$</th>
<th>$S$ $[10^{-7}]$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$D^0 \to e^+ e^-$</td>
<td>0.02</td>
<td>$2.21 \pm 0.38$</td>
<td>$2.23 \pm 0.38$</td>
<td>$2.25 \pm 0.12$</td>
</tr>
<tr>
<td>$D^0 \to \mu^+ \mu^-$</td>
<td>$3.34 \pm 0.31$</td>
<td>$1.28 \pm 0.32$</td>
<td>$4.63 \pm 0.45$</td>
<td>$4.53 \pm 0.30$</td>
</tr>
<tr>
<td>$D^0 \to e^\pm \mu^\mp$</td>
<td>0.21</td>
<td>$1.93 \pm 0.36$</td>
<td>$2.14 \pm 0.36$</td>
<td>$3.27 \pm 0.20$</td>
</tr>
</tbody>
</table>

| $N_{\text{obs}}$ | 3 | 1 | 0 |
| $\text{UL obtained}$ | $1.2 \times 10^{-6}$ | $1.3 \times 10^{-6}$ | $8.1 \times 10^{-7}$ |

Limits improved by 5 2 10 times

Production of pure particle control samples
  - optimize particle selectors
  - calculate efficiencies and misidentification of PID selection

Develop of pure electron control sample

Develop and maintain of tools for reducing data/MC PID discrepancies

Analysis software
Contributions to MINOS

- Magnetic Field Simulation and Calibration
- Neutrino Beam simulation
- Off-axis far detector cross-check
- MC neutrino beam and detector generation
Current Projects – Modeling of Magnetic Fields

- Modeling of end-of-toroid effects for near and far coils.
- Implementation of maps in the reconstruction code.

Undergraduate students involved in this work
Current Projects – *Magnetic Field Calibration*

- BH curve of steel samples.
- BH curves from steel planes.

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students involved in this work
Simulation of the Beam Flux

Hadronic production simulated with a detailed target model in FLUKA'05 + Particle Transport and decays with GEANT3

- Cooling pipes
- Graphite fins
- Be window

Low E(-10cm,185kA)

$\nu_\mu$ CC Events/GeV x $10^{20}$ POT/kt

$\nu_\mu$ Energy [GeV]
Current Projects – *Hadron Production*

- Improving modeling of hadron production:
  - Accurate target geometry in the simulation
  - Checking models in the simulation

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**NA49 data (158 GeV/c)**

**FLUKA Simulation**

**FLUKA Simulation**
Current Projects – *Beam Simulation*

- Improving the beam simulation:
  - Detailed modeling of the beam line in GEANT4
  - Validation and implementation

students involved in this work
Current Projects – *Off-Axis Analysis*

**VERY PRELIMINARY**

- Cross-check of an off-axis detector analysis

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![Graphs showing event distribution vs. reconstructed energy](image)

*Reconstructed $E_\nu$ [GeV]*

- Data:
- Best Fit:
- No Oscillations:

![Graph showing data/MC ratio vs. reconstructed energy](image)

*Reconstructed $E_\nu$ [GeV]*

Best fit: $1.5 \pm 1.3$ km
Produced more than 50% of the MINOS MC samples

Steps:
- (FLUKA) Hadron production
- (Particle transport) Neutrino flux
- (near detector) Rock events
- Detector events
- (near) Rock and detector event overlaid

Tools:
- Submitting jobs
- Monitoring jobs
- MC samples status
Summary and Conclusions

- Detector asymmetries understood at the sub-percent level

- CP Asymmetries consistent with zero observed for:
  \[ D^\pm \rightarrow K^- K^+ \pi^\pm \quad D^\pm \rightarrow \phi \pi^\pm \quad D^\pm \rightarrow K^{*0} K^\pm \]

- CP Asymmetry across the phase space of D+ Dalitz plot is consistent with zero

- Significant improvement in the asymmetries has been achieved reducing errors at 1%

- Relative branching fraction improved by more than 4 times

- Published Phys. Rev. D 71, 091101 (2005)
FIN
Backup slides
→ **Charge Conjugation (C):** Transform particle into its antiparticle

\[ C \psi(t, x) C = -i (\bar{\psi} \gamma^0 \gamma^2)^T \]

No conserved in weak interactions (no observed left-handed antineutrinos)

→ **Parity (P):** Space mirror operation

\[ P \psi(t, x) P = \gamma^0 \psi(t, -x) \]

No conserved in weak interactions observed in beta decays (Co$^{60}$)

→ **Charge – Parity (CP):**

→ CP Violation discovered in neutral kaon decays (1964)
→ CP Violation: Decay rate of particle ≠ rate of antiparticle

![Diagram showing CP Violation in K mesons](image)
Previous Hadron Production Data

Near Detector - pions

- LE10/185kA Beam
- Atherton
  - 400 GeV/c p-Be
- Barton
  - 100 GeV/c p-C
- SPY
  - 450 GeV/c p-Be

- Little data
  - Never been measured for a thick C-target (MIPP)
  - Little data to constraint high energy tail
Improvements between data and beam MC were obtained by tuning MC by fitting to hadronic $x_F$ and $p_T$ distributions.

Weights applied as a $f(x_F, p_T)$.
Current best measurements of $\Delta m_{23}^2$ and $\sin^2 2\theta_{23}$ are provided by Super-Kamiokande (atmospheric neutrino analysis) and K2K ($9 \times 10^{19}$ pot)

The limits (at 90% C.L.) are:
- $\sin^2 2\theta > 0.9$
- $1.9 < \Delta m^2 < 3.0 \times 10^{-3}$ eV$^2$

The analysis presented in this talk, which is for $9.3 \times 10^{19}$ pot, should provide a measurement of the mixing parameters that is competitive with these results.
First direct results on neutrino/anti-neutrino oscillations using atmospheric neutrinos