My presentation today is based on the following topics

1. Introduction to CP violation
2. Details of Belle detector
3. Physics goals
4. $K_L^0$ detection at Belle
5. Toy Monte Carlo study of $D^0 \rightarrow K_L^0 \pi^0$
6. Calibration and resolution study
7. Conclusion
The Belle experiment intends to investigate Kobayashi-Maskawa mechanism for CP violation.

The Cabibbo Kobayashi Maskawa (CKM) matrix

\[
\begin{pmatrix}
{d'} \\
{s'} \\
{b'}
\end{pmatrix} =
\begin{pmatrix}
V_{ud} & V_{us} & V_{ub} \\
V_{cd} & V_{cs} & V_{cb} \\
V_{td} & V_{ts} & V_{tb}
\end{pmatrix}
\cdot
\begin{pmatrix}
d \\
s \\
b
\end{pmatrix}
\]

The Cabibbo Kobayashi Maskawa unitarity triangle

\[
\begin{pmatrix}
V_{ub} & V_{cd} & V_{td} \\
V_{cb} & V_{cs} & V_{ts} \\
V_{tb}
\end{pmatrix}
\]
The Belle detector shown in side view consists of the following subdetectors with the stated functions:

- Vertex measurement by SVD
- Charged particle tracking by CDC
- Particle identification by dE/dX in CDC and measurements in ACC and TOF
- Electromagnetic showers by ECL and EFC
- Muons and $K_L^0$ detection by KLM
- 1.5 T super conducting solenoid
Version 1.x of silicon vertex detector or SVD consists of 3 layers, measures Z-vertices of B and D-mesons and $\tau$’s.

Z-vertex of B/Bbar pair important for time dependent CP violation.

Innermost layer very close to beam pipe wall.
Version 2.0 of SVD consisting of 4 layers has better resolution and was installed in summer 2003

The innermost layer is closer to Interaction Point (IP)
The central drift chamber or CDC reconstructs charge tracks and 3-momentum with precision. 

z asymmetry to cover $17^0 < \theta < 150^0$

Precise $dE/dX$ measurement for particle identification
The aerogel cherenkov counter or ACC helps in particle identification especially $\pi^\pm$ from $K^\pm$.
Time of flight or TOF consists of TOF & TSC (trigger scintillator counters) and helps in particle identification.

TOF and TSC counters in the time of flight detector.

Particle identification by TOF.
The electromagnetic calorimeter or ECL detects photons and electrons with high efficiency and resolution.

Fine grained segmented CsI crystal, silicon photodiode readout.

Tower like crystals pointing towards interaction point of $e^+e^-$. 
The extreme forward calorimeter or EFC increases polar angle coverage and hence experimental sensitivity

Covers polar angle region \(6.4^0 < \theta < 11.5^0\) and \(163.3^0 < \theta < 171.2^0\)

Consists of BGO(bismuth germanate)
The $K_L^0$ and muon detector or KLM identifies $K_L^0$ and muons and consists of alternate iron and RPC layers

Alternate iron and RPC layers in barrel KLM (octagon shaped region)

RPC super layer in KLM detects charge through ionization
The Physics goals of this analysis is to measure the decay asymmetry in $D^0 \rightarrow K_L^0 \pi^0$ and $D^0 \rightarrow K_S^0 \pi^0$.

Doubly Cabibbo Suppressed decay

\[
\frac{\mathcal{B}(D^0 \rightarrow K_L^0 \pi^0)}{\mathcal{B}(D^0 \rightarrow K_S^0 \pi^0)} = \frac{N(K_L^0 \pi^0)/N(K_S^0 \pi^0)}{N((K_L^0 \pi)\pi)/N((K_S^0 \pi)\pi)}
\]

$K_L^0/K_S^0$ reconstruction efficiency from $D^{*+} \rightarrow D^0 \pi^+, D^0 \rightarrow K^{*-} \pi^+, K^{*-} \rightarrow (K_L^0/K_S^0)\pi^-$ reduces systematics.
The decay asymmetry in $D^0 \rightarrow K_L^0 \pi^0$ and $D^0 \rightarrow K_S^0 \pi^0$ is very important for study of $D^0$-$\bar{D}^0$ bar mixing.

The decay asymmetry constrains $\delta_{K\pi}$ which is important for $D^0$-$\bar{D}^0$ bar mixing.
A $K_L^0$ is reconstructed by information from 2 detectors: ECL and KLM

$K_L^0$ is reconstructed by rejecting charged tracks in a 15° cone of $K_L^0$ cluster direction

ECL has better directional resolution for those $K_L^0$ s that interact in the ECL
While $K_L^0$ direction is reconstructed from detector momentum magnitude is obtained from kinematic constraints.

Only direction information for $K_L^0$.

$D^0$ mass constraint for assumed two-body decay.
A simple toy Monte Carlo study of $D^0 \rightarrow K_L^0 \pi^0$ is done to see how well $D^0$ mass constraint works.

A signal is generated for the decay by simulating $\theta$ and $\varphi$.

Generated and reconstructed momentum for $K_L^0$ match exactly.
Reconstruction of $D^{*+} \to D^0 \pi^+$, $D^0 \to K^* \pi^+$, $K^* \to K_S^0 \pi^-$ from signal Monte Carlo

Track cuts shown in picture (quality cuts) have been applied $z_{\text{dist}} < 1$, $d_r > 0.25$, $d_{\phi} < 0.1$

Following invariant mass cuts have been applied
20 MeV on $K_S^0$, 150 MeV on $K^*$, 60 MeV on $D^0$ and $D^{*+}$

A $K_S^0$ reconstructed by $D^0$ mass constraint and whose direction distribution is smeared to match $K_L^0$ resolution is called a pseudo $K_L^0$
Direction resolution for $K_L^0$ and $K_S^0$ has been studied in signal Monte Carlo

<table>
<thead>
<tr>
<th></th>
<th>$\sigma_\theta$</th>
<th>$\sigma_\varphi$</th>
<th>REMARK</th>
</tr>
</thead>
<tbody>
<tr>
<td>$K_S^0$</td>
<td>0.002</td>
<td>0.002</td>
<td></td>
</tr>
<tr>
<td>$K_L^0$</td>
<td>0.016</td>
<td>0.018</td>
<td>$K_S^0$ resolution is ~10 times better than $K_L^0$ resolution</td>
</tr>
<tr>
<td>KLM $K_L^0$</td>
<td>0.022</td>
<td>0.028</td>
<td></td>
</tr>
<tr>
<td>ECL $K_L^0$</td>
<td>0.012</td>
<td>0.014</td>
<td>ECL $K_L^0$ resolution is better than KLM $K_L^0$ resolution</td>
</tr>
</tbody>
</table>
How many reconstructed $D^{*+} \rightarrow D^0\pi^+, D^0 \rightarrow K^*^-\pi^+, K^*^- \rightarrow K_S^0\pi^-$ in signal Monte Carlo are real?

The decay is compared to generator level information to check if it has been reconstructed correctly.

$D^{*+}$ Mass for correctly reconstructed events in green.
How good is D0 mass constraint in $D^{*+} \rightarrow D^0 \pi^+$, $D^0 \rightarrow K^{*-} \pi^+$, $K^{*-} \rightarrow K_S^0 \pi^-$ signal Monte Carlo?

Mass constraint technique works well is seen by the correlation in momentum reconstructed in two ways.
\( \Delta M = (D^{*-} - D^0) \) mass is a good cut in reducing fake reconstruction and useful in analyzing experimental data.

Correctly reconstructed events from Monte Carlo peak at \( \Delta M = 0.145 \text{ MeV} \) which corresponds to the slow pion from \( D^{*-} \).
Reconstruction of $D^{*+} \rightarrow D^0 \pi^+$, $D^0 \rightarrow K^*^- \pi^+$, $K^*^- \rightarrow K_L^0 \pi$ from signal Monte Carlo

The decay was reconstructed by applying $3\sigma$ mass cuts on $K^*$- and $D^{*+}$ candidates

Good correlation in generated and reconstructed $D^{*+}$ momentum, reconstruction efficiency $= 28\%$
$D^{*+} \rightarrow D^0\pi^+$, $D^0 \rightarrow K^*-\pi^+$, $K^- \rightarrow K_S^0\pi^-$ was reconstructed from skimmed experimental data

Experiment 7 (~6.5 million B/Bar events) was skimmed by applying 3σ mass cuts on the candidates

Reconstruction done from skimmed data using quality cuts, 2σ mass cuts on candidates and a ΔM window (0.143,0.147) on $D^{*+}$
The analysis $D^0 \rightarrow K_L^0 \pi^0$ of is ongoing and I will conclude the same with the following roadmap in mind

We have $\sim 175 \text{ fb}^{-1}$ of experimental data at Belle at the end of 2003

The previous analysis at Belle was based on a data sample of $\sim 23 \text{ fb}^{-1}$, decay rate asymmetry $= 0.88 \pm 0.09$

We expect to see $33005/12,873$ # of $D^0 \rightarrow K_L^0 \pi^0$/$D^0 \rightarrow K_S^0 \pi^0$ events in the larger data sample

I expect to finish the calibration analysis by next 2 months

Once $K_S^0/K_L^0$ relative reconstructive efficiency is calculated in the calibration study I’ll start decay asymmetry analysis in $D^0 \rightarrow K^0 \pi^0$