A study of the decay

\[ \tau^- \rightarrow \pi^- \pi^0 \nu_\tau \]

using the BaBar detector

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1 - Contents

- Motivation for study
- Event selection
- Models of the Hadronic Current
- Smearing
- Results
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2 - Motivation

• Important uncertainty in calculations of \((g_\mu-2)\) arises from hadronic loop corrections:

• Experimentally determined \(\pi\pi\) spectral functions allow us to calculate these corrections.

• CMD-2 experiment measured \(e^+e^- \rightarrow \pi^+\pi^-\) cross section. ALEPH, CLEO and OPAL gave data on \(\tau^- \rightarrow \pi^-\pi^0\nu_\tau\) spectral function \(\rightarrow\) CVC allows us to relate the two results.

• After corrections made for isospin symmetry breaking effects the two data sets were seen to disagree below and around the \(\rho\) mass peak.

\(\tau^- \rightarrow \pi^-\pi^0\nu_\tau\)

BaBar’s high statistics make it ideal for studying \(\tau\) data.
3 - Event Selection

- Use 1-1 topology in CoM
- Require signal in one hemisphere of event and tag in other:

\[ \tau^- \rightarrow \pi^- \pi^0 \nu_{\tau} \quad \text{SIGNAL} \]

\[ \tau^- \rightarrow e^- \bar{\nu}_e \nu_{\tau} \quad \text{TAG} \]

\[ \rightarrow \mu^- \bar{\nu}_\mu \nu_{\tau} \]

**Decay Cuts:**
- \( \pi \) track ID
- Single \( \pi^0 \)
- 0.85 < Thrust < 0.985 (uds, bhabhas)
- \( E_{CM}(\pi) + E_{CM}(\pi^0) < 5.29 \text{GeV} \) (beam bckgnds)
- CMS Tag track momentum < 4 GeV/c (\( \mu \mu \) bckgnds)
- No unused neutrals with lab energy > 0.3 GeV (a\(_1\) tau bckgnds)
- \( E_{CM}(\pi) + E_{CM}(\pi^0) > 0.75 \text{GeV} \) (\( \gamma \gamma \) bckgnds)
4 - Invariant Mass Spectrum

- Form invariant mass of $\pi^{-}\pi^{0}$:

**Electron Tag**

$\epsilon = 1.22\%$

$\tau^{-} \rightarrow \pi^{-}\pi^{0}\nu_{\tau}$
5 - Spectrum II

\[ \tau^- \rightarrow \pi^- \pi^0 \nu_\tau \]

\( \epsilon = 1.13\% \)
6 - Tag comparison

ratio as function of mass

Peak normalised overlay

$\tau^- \rightarrow \pi^- \pi^0 \nu_\tau$
7 - $\tau^{-}\rightarrow\pi^{-}\pi^{0}\nu_{\tau}$

- Main contribution to $\pi^{-}\pi^{0}$ lineshape is from $\rho(770)$
- $\rho(1450)$ and $\rho(1700)$ resonances included in PDG but not precisely measured
- Many theoretical models available allowing fits to $\pi^{-}\pi^{0}$ partial width to determine contribution from each resonance

Perform fit to mass spectrum:

$$\frac{dn}{dm} = Nm \left(1 + \frac{2m^2}{M_{\tau}^2}\right) \left(1 - \frac{m^2}{M_{\tau}^2}\right)^2 \left(1 - \frac{4m_{\pi}^2}{m^2}\right)^{3/2} |F_{\pi}(m^2)|^2$$

- phase space
- pion form factor
8 - Spectral Function

- Model form factor \( F \) with Breit-Wigner functions:

\[
|F_\pi(m^2)|^2 = \left| \frac{B \text{W}_\rho + \beta e^{i\phi_\rho} B \text{W}_{\rho'} + \gamma e^{i\phi_{\rho'}} B \text{W}_{\rho''} + A e^{i\phi}}{1 + \beta + \gamma} \right|^2 + b
\]

- Use various models for the Breit-Wigners:

Kuhn and Santamaria (KS):

\[
\text{BW}_\rho = \frac{M_\rho^2}{(M_\rho^2 - m^2) - i\sqrt{m^2 \Gamma_\rho (m^2)}}
\]

Gounaris and Sakurai (GS):

\[
\text{BW}_\rho = \frac{M_\rho^2 + M_\rho \Gamma_\rho d}{(M_\rho^2 - m^2) + f(m^2) - i\sqrt{m^2 \Gamma_\rho (m^2)}}
\]
9 - Smearing

- The data invariant mass spectrum will be smeared by the detector resolution
  - migration or loss of events
- To account for this smearing use a smeared fit function in the process of making the fit
- Use Monte Carlo to determine the amount of smearing:

For each bin, \( i \), in generator level MC distribution fill a histogram, \( H_{ij} \), with the reconstructed mass of the \( n_i \) entries
10 - Smearing II

- Fit Gaussian to each histogram and plot sigma as a function of mass

\[ \tau^- \rightarrow \pi^- \pi^0 \nu_\tau \]
11 - Smearing III

- Extract $\sigma(m)$ using a linear fit

- Allow amount of smearing to vary in fit using a floating scale factor

$$\sigma(m) = 0.00814 + 0.00857m$$

$$\sigma(m) = (1 + s)(0.00814 + 0.00857m)$$
12 - Smearing IV

- Convolve fit function with a mass dependent Gaussian

$$\frac{1}{\sqrt{2\pi} \sigma(m)} \exp\left(-\frac{(m-m')^2}{2\sigma(m)^2}\right)$$

Calculate unsmeared fit function, multiply each bin by mass dependent Gaussian and re-sum to give smeared function

- All parameters allowed to float in turn

Norm. = N
masses = $M_\rho$, $M_\rho'$, $M_\rho''$
widths = $\Gamma_\rho$, $\Gamma_\rho'$, $\Gamma_\rho''$
phases = $\phi_\rho$, $\phi_\rho'$, $\phi_\rho''$
couplings = $\beta$, $\gamma$, $A$
Smearing scale factor = $s$
Bkgrd = $b$
Mass dependent width exponent = $\lambda$
### 13 – KS Fit

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>( N )</td>
<td>20297 ± 49.423</td>
<td></td>
</tr>
<tr>
<td>( M_\rho )</td>
<td>0.75539 ± 0.00039053</td>
<td></td>
</tr>
<tr>
<td>( M_\rho' )</td>
<td>1.2964 ± 0.0059416</td>
<td></td>
</tr>
<tr>
<td>( M_\rho'' )</td>
<td>1.6402 ± 0.0074653</td>
<td></td>
</tr>
<tr>
<td>( \Gamma_\rho )</td>
<td>0.14287 ± 0.00018715</td>
<td></td>
</tr>
<tr>
<td>( \Gamma_\rho' )</td>
<td>0.52167 ± 0.0052295</td>
<td></td>
</tr>
<tr>
<td>( \Gamma_\rho'' )</td>
<td>0.18733 ± 0.0047002</td>
<td></td>
</tr>
<tr>
<td>( \beta )</td>
<td>0.21593 ± 0.0010583</td>
<td></td>
</tr>
<tr>
<td>( \gamma )</td>
<td>-0.0534 ± 0.00131</td>
<td></td>
</tr>
<tr>
<td>( \lambda )</td>
<td>2.3396 ± 0.028196</td>
<td></td>
</tr>
<tr>
<td>( s )</td>
<td>0.14956 ± 0.021997</td>
<td></td>
</tr>
<tr>
<td>( b )</td>
<td>2.6797 ± 5.4526</td>
<td></td>
</tr>
</tbody>
</table>

\( \chi^2 = 1.814 \)

Fit range (0.4, 2)
<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value with Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>$N$</td>
<td>$16900 \pm 45.196$</td>
</tr>
<tr>
<td>$M_\rho$</td>
<td>$0.74359 \pm 0.00017781$</td>
</tr>
<tr>
<td>$M_\rho'$</td>
<td>$1.1060 \pm 0.0063427$</td>
</tr>
<tr>
<td>$M_\rho''$</td>
<td>$1.5673 \pm 0.0047170$</td>
</tr>
<tr>
<td>$\Gamma_\rho$</td>
<td>$0.15825 \pm 0.00025341$</td>
</tr>
<tr>
<td>$\Gamma_\rho'$</td>
<td>$0.83960 \pm 0.013740$</td>
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<tr>
<td>$\Gamma_\rho''$</td>
<td>$0.49216 \pm 0.010036$</td>
</tr>
<tr>
<td>$\beta$</td>
<td>$0.22196 \pm 0.0011434$</td>
</tr>
<tr>
<td>$\gamma$</td>
<td>$-0.22577 \pm 0.0010546$</td>
</tr>
<tr>
<td>$\Lambda$</td>
<td>$-0.22146 \pm 0.0057674$</td>
</tr>
<tr>
<td>$\phi_\rho'$</td>
<td>$103.19 \pm 2.9447$</td>
</tr>
<tr>
<td>$\phi_\rho''$</td>
<td>$109.66 \pm 0.68011$</td>
</tr>
<tr>
<td>$\phi$</td>
<td>$-137.97 \pm 0.069106$</td>
</tr>
<tr>
<td>$\lambda$</td>
<td>$3.1479 \pm 0.0086927$</td>
</tr>
<tr>
<td>$s$</td>
<td>$-0.017598 \pm 0.021912$</td>
</tr>
<tr>
<td>$b$</td>
<td>$-2.8277 \pm 7.2601$</td>
</tr>
</tbody>
</table>

Fit range (0.3,2) 

$\chi^2 = 1.383$
15 – Comments on fit

• KS model fits well to spectrum, but it is only a parameterisation
  - don’t expect a perfect fit to this high precision data over so many orders of magnitude.

• Scale factor to smearing is around 15%
  - parameters are correlated so fit can favour narrow resonances with higher smearing scale, or the opposite
  - this scale factor is just a temporary measure - not claiming MC smearing is 15% too low, just that our parameterisation of the smearing histograms needs to be improved = double Gaussian?

• Problems with fits
  - some convergence problems, and inconsistent fit parameters with unreliable errors.
16 - Conclusions

- Selection procedure developed to give high purity sample of $\tau^-\rightarrow\pi^-\pi^0\nu_\tau$ candidates
- Smearing technique developed to account for detector resolution effects and integrated into fitting procedure
- Invariant mass spectrum fitting procedure implemented giving good fit over 5 orders of magnitude
- Ongoing work to improve fits and determine $\rho$, $\rho'$ etc. parameters
  - validating smearing technique and testing different fit functions
Extra Slides
1 - AWG Pi0 Selection

- $pi0AllLoose$
- No merged $\pi^0$s
- No dead/noisy channels
- Photon energy deposited in $\geq 2$ crystals
- Lat 0.001–0.05
- $E_\gamma > 50$ MeV
- Split-off energy cut: 110 MeV
- Split-off distance cut: 25 cm
- Fit probability: $\chi^2 < 5.0$
- Combinatorics: keep best fit $\pi^0$
FCN = 68.92403
num fit points = 54
Num fit params = 16
DOF = 54 – 16 = 38
CHISQUARE = 1.814