Tau Mass Measurement

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Representing the BaBar Collaboration

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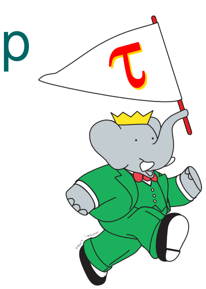


Motivation: Tau Mass

Measuring the Tau Mass (M_τ)

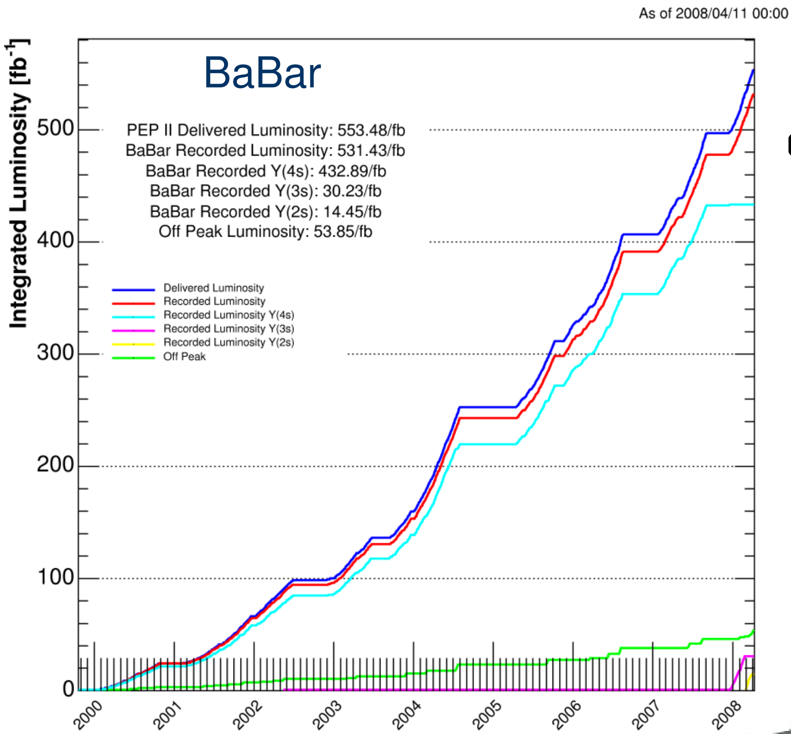
- **Parameter needed to check lepton universality**
- **Current value: 1776.84 ± 0.17 MeV (PDG 2008)**
  - **Dominated by the BES and KEDR measurement at the tau production threshold**
  - **BES result:** $1776.96^{+0.18+0.25}_{-0.21-0.17}$ **MeV**
    [PRD 53, 20 (1996)]
  - **KEDR result:** $1776.81^{+0.25}_{-0.23} \pm 0.15$ **MeV**
    [Nucl. Phys. Proc. Suppl. 169, 125 (2007)]
- **Belle's current result uses a pseudomass endpoint method**
- **Belle result: 1776.61 ± 0.13 (stat) ± 0.35 (sys) MeV**
  [PRL 99, 011801 (2007)]

Motivation: CPT Test

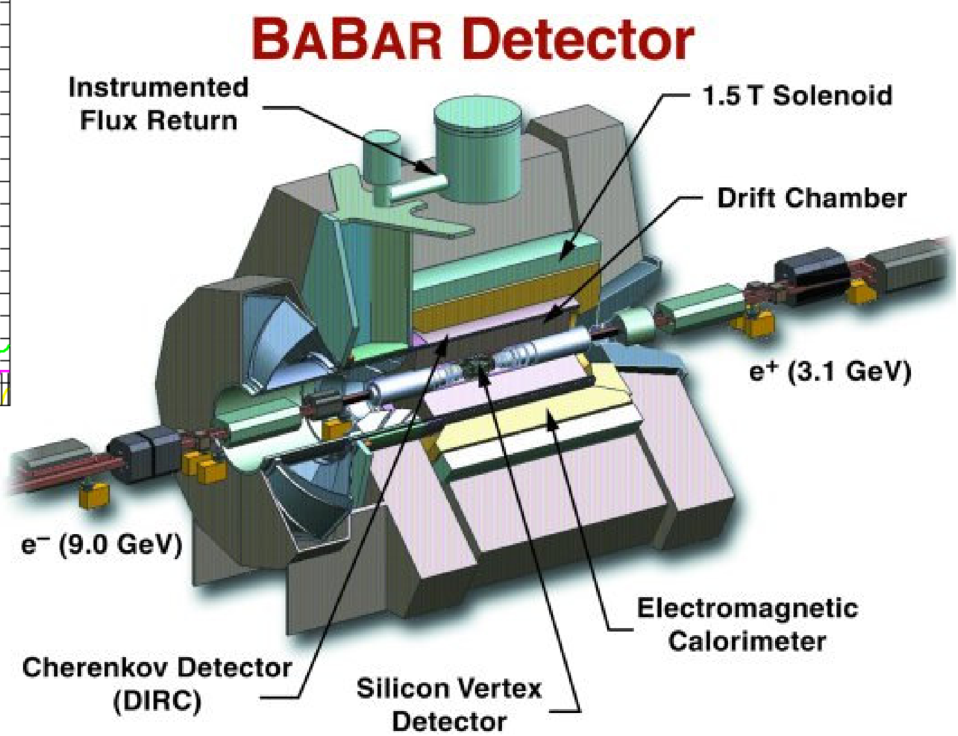
Test CPT Theorem: $\frac{M(\tau^+) - M(\tau^-)}{M_{Average}}$ **= 0**

- **Can only be tested where τ^+ and τ^- can be individually reconstructed**
- **Current limit: < 2.8 X 10^{-4} at 90% CL (PDG 2008)**
  - **Belle Collaboration pseudomass end-point measurement [PRL 99, 011801 (2007)]**
  - **First performed by the Opal Collaboration: < 3.0 X 10^{-3} at 90% CL (PDG 2008) [PLB 492, 23 (2000)]**

BaBar Detector



Over 532 fb^{-1} of data collected, of which 432 fb^{-1} is at the Υ(4S) center of mass energy

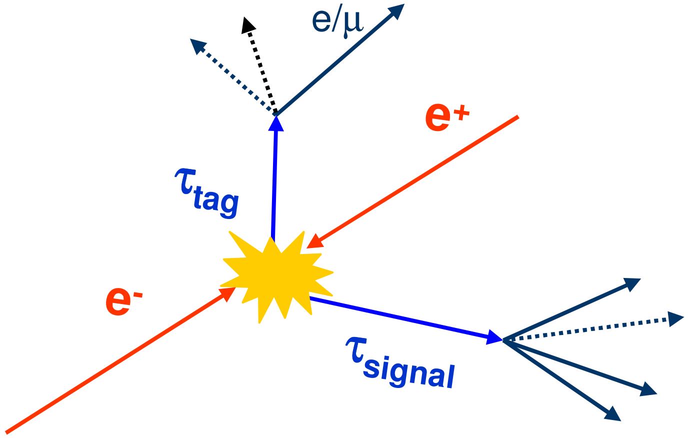


This analysis uses 98% of the available data taken at the Υ(4S) center of mass energy

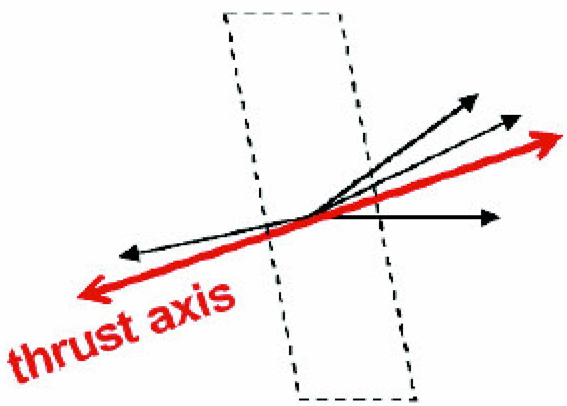
~389 million $\tau^+\tau^-$ pairs

Event Reconstruction

- Well-separated in space

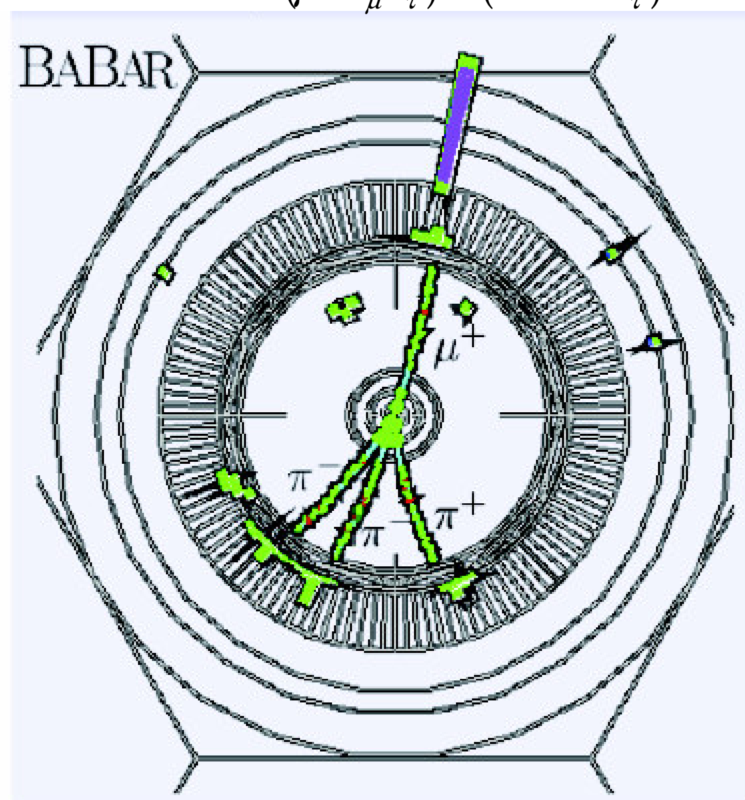


- Divide event into 2 hemispheres in CM frame ⊥ to thrust axis



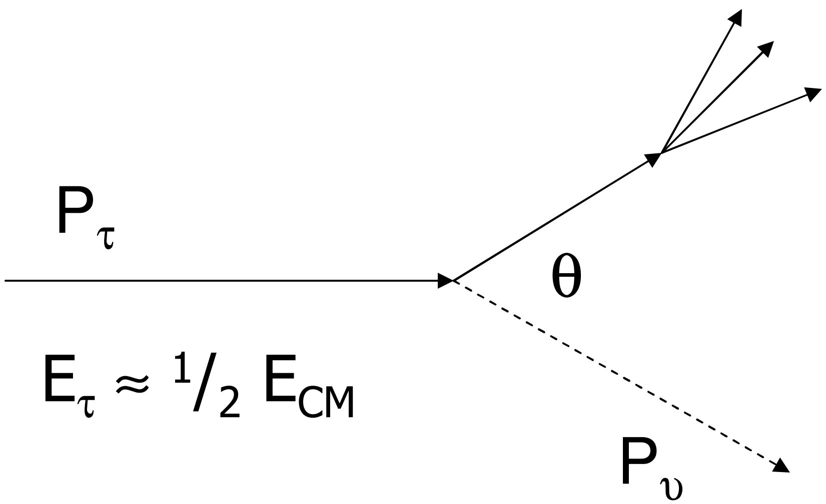
- Unique signature:
  Leptonic + hadronic decay

$$e^+e^- \to \tau^+(\mu^+\nu_\mu\bar{\nu}_\tau)\tau^-(2\pi^-\pi^+\nu_\tau)$$



Kinematics

e^+e^- CM Frame



P_h (3 π system)

$E_\tau \approx {}^1/_2\, E_{CM}$

Neutrino goes undetected. Energy and momentum of neutrino as well as the angle θ are unknown

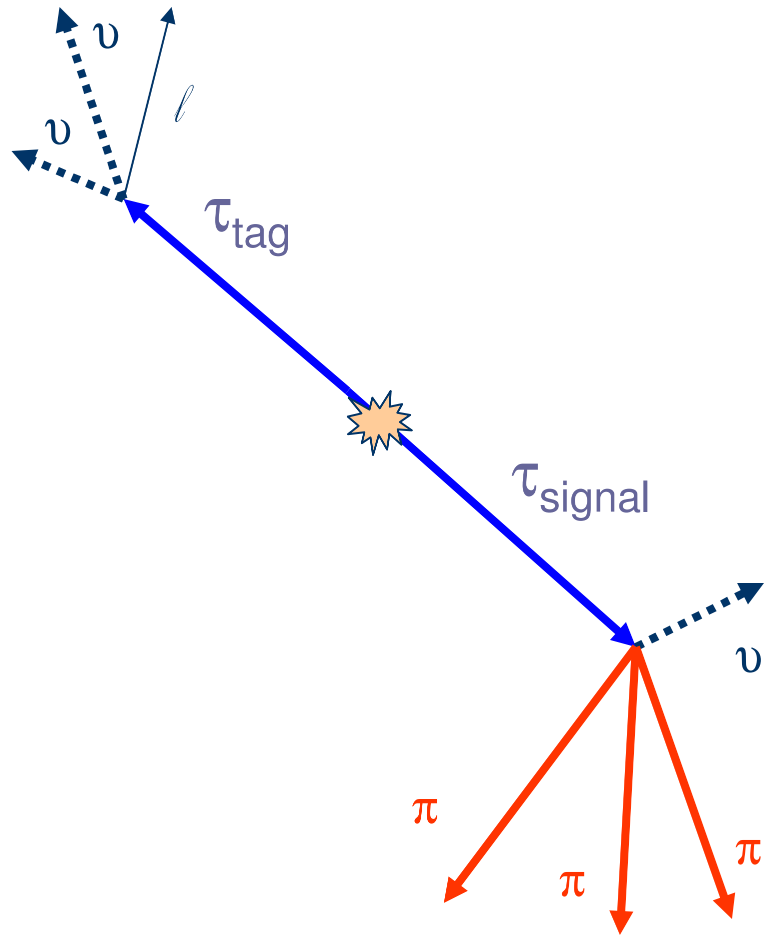
$$M_\tau^2 = M_h^2 + 2(E_\tau - E_h)(E_h - P_h \cos\theta)$$ with $m_\upsilon = 0$

We set $\theta = 0$ to get a lower bound on M_τ

$$M_{pseudo} \equiv \sqrt{M_h^2 + (E_{CM} - 2E_h)(E_h - P_h)} \leq M_\tau$$

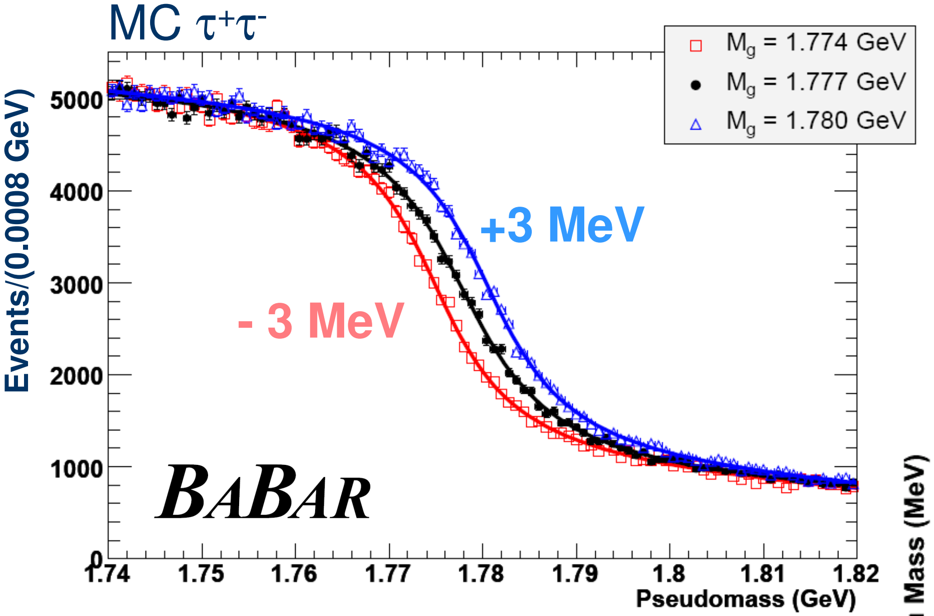
Event Selection

- Require lepton on the tag side
- Require 3 tracks that pass loose pion criteria and are not identified as kaons, protons, or leptons on the signal side
- Require < 5 neutrals and the total neutral energy < 300 MeV, on the signal side, to reduce
  $\tau^- \rightarrow 2\pi^- \pi^+ \pi^0$ background
- Signal Region:
  $1.68 \leq M_{Pseudo} \leq 1.86$ (GeV)
- Signal efficiency ~2.0% in signal region
- Purity ~96% in signal region



Mass Extraction Procedure

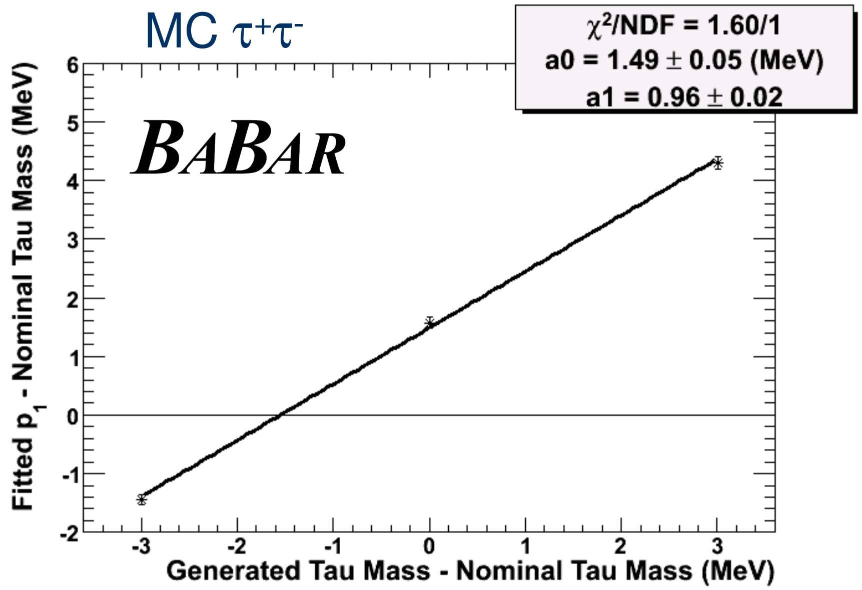
MC $\tau^+\tau^-$



Empirical Fit Function

$$(p_3 + p_4 x)\tan^{-1}\left(\frac{x - p_1}{p_2}\right) + p_5 + p_6 x$$

MC $\tau^+\tau^-$



- p_1 is the effective endpoint parameter
- $p_1 \neq M_\tau$
- Endpoint, and p_1, shift linearly with the generated M_τ
- Use MC to determine relationship between p_1 and M_τ

MC Generators: kk2f & Tauola

Calibration of Track Momentum Reconstruction

- We calibrate the track momentum reconstruction in order to correctly reconstruct some well known reference masses (PDG 2008), following the method developed in the Λ_c mass measurement at BaBar [PRD 72 052006 (2005)]
- We use this method to correct the measured value of p_1 as well as calculate a systematic uncertainty on M_τ
- The reference masses used in this analysis are the K_s^0 and $D^\pm$ masses
- After adjusting the detector material and B-Field to fit the reference masses, we refit the tau event tracks to get a better calibrated momentum measurement which we use to fit for p_1 and therefore M_τ

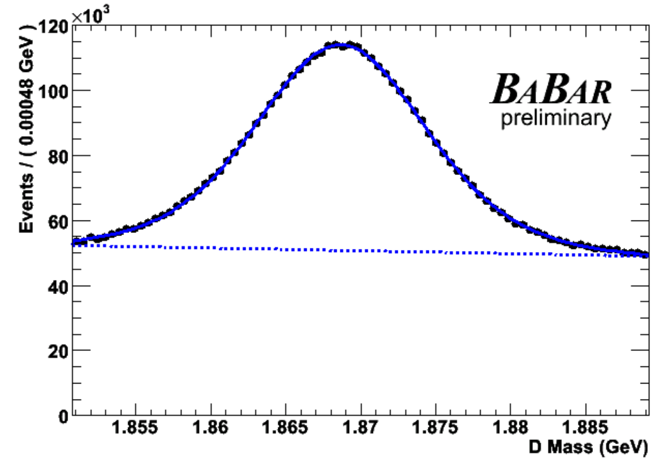
Correction and Systematic Uncertainty of the Momentum Reconstruction

Detector Parameter	ΔM_τ (MeV)
Increased SVT Material	+0.31
Increased Solenoid Field	+0.11
Increased Bending Magnet Field	+0.21
M_τ Momentum Reconstruction Correction	**+0.63**
M_τ Momentum Reconstruction Uncertainty	**0.39**

We sum in quadrature the shift induced separately by the material and B-Field adjustments to determine the uncertainty on M_τ

$D^{\pm}$ Mass Cross Check

Detector Parameter	ΔM_D (MeV)
Increased SVT Material	+0.47
Increased Solenoid Field	+0.30
Increased Bending Magnet Field	+0.30
Momentum Reconstruction Correction	+1.07

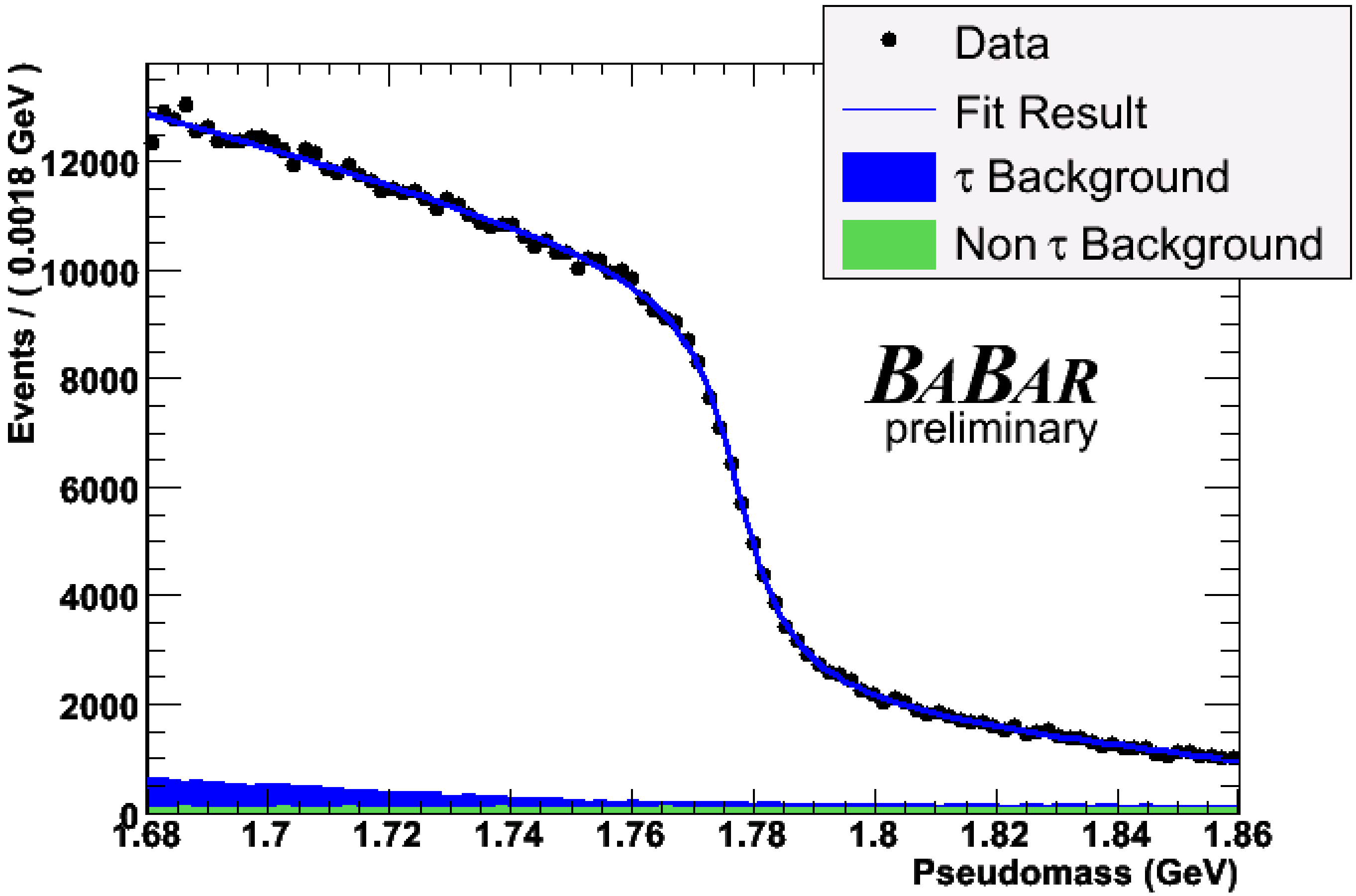


$D^+ \rightarrow K^- \pi^+ \pi^+$

Fit	M_D (MeV)
Uncorrected	1868.70 ± 0.04
Corrected	1869.77 ± 0.04

PDG 2008: 1869.62 ± 0.20

Tau Mass Result

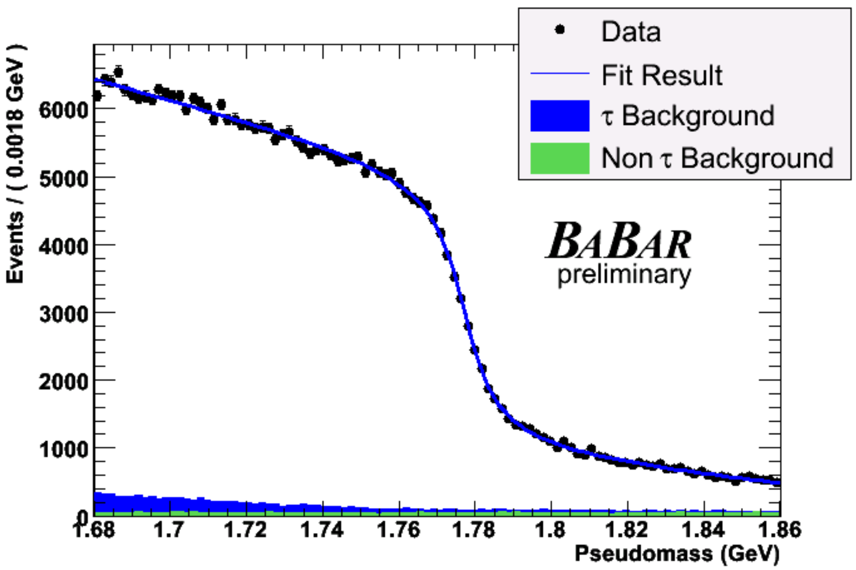


After Corrections

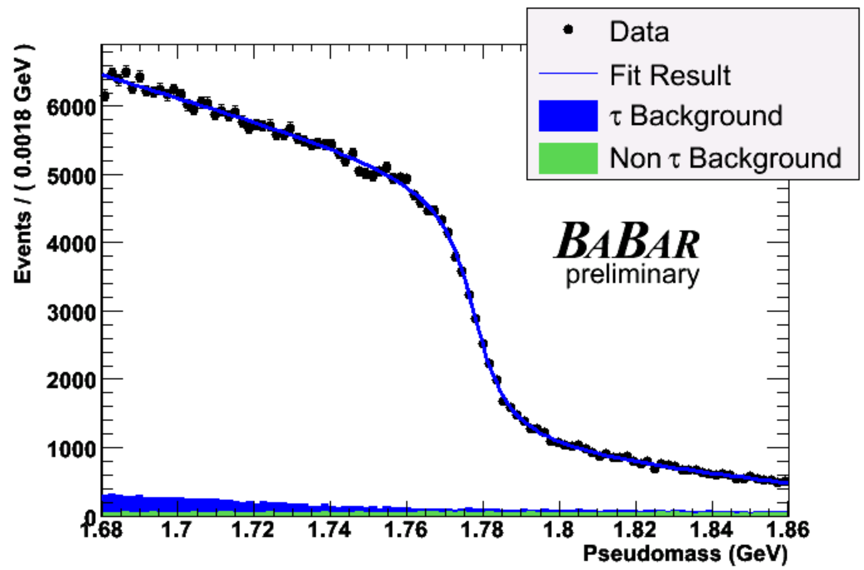
$M_\tau = 1776.68 \pm 0.12$ (stat) MeV

Mass Difference Result

τ^+



τ^-



MC

$\Delta M = M_{\tau+} - M_{\tau-} = 0.05 \pm 0.23$ (stat) MeV

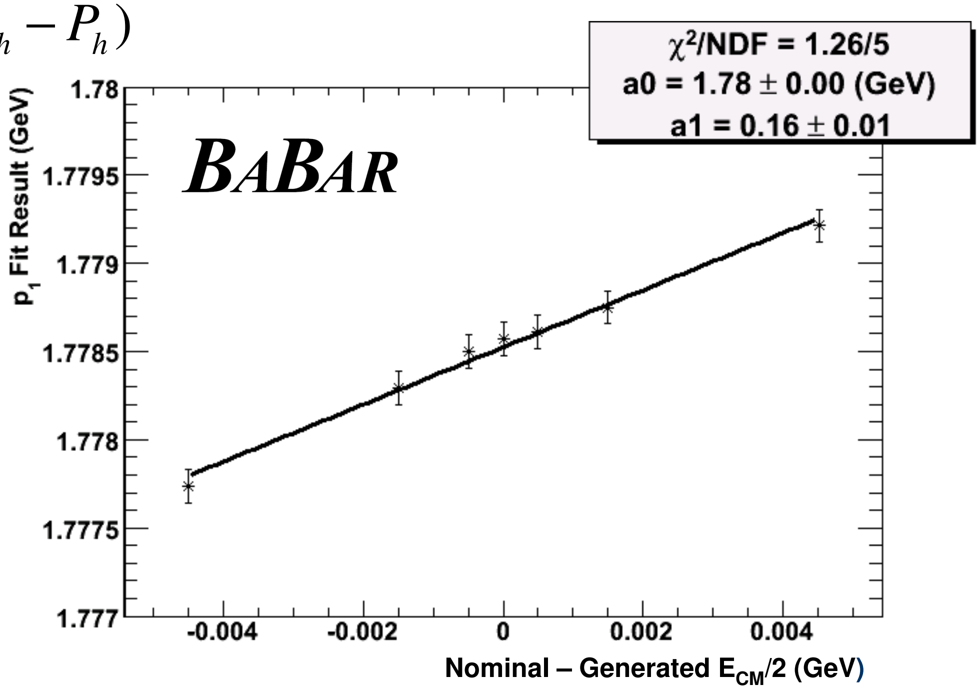
Data

$\Delta M = M_{\tau+} - M_{\tau-} = -0.61 \pm 0.23$ (stat) MeV

Absolute E_{CM} Scale Uncertainty

$$M_{pseudo} \equiv \sqrt{M_h^2 + 2(E_{CM}/2 - E_h)(E_h - P_h)}$$

Propagation of errors:
$\sigma(M_\tau) \approx 0.17\sigma\,(E_{CM}/2)$



Generated Toy MC
with different E_{CM}

Beam energy is corrected by comparing m_{ES} peak to B mass.

$$m_{ES} = \sqrt{(E_{CM}/2)^2 - p_B^2}$$

$\sigma(E_{CM}/2) = 0.5$ MeV

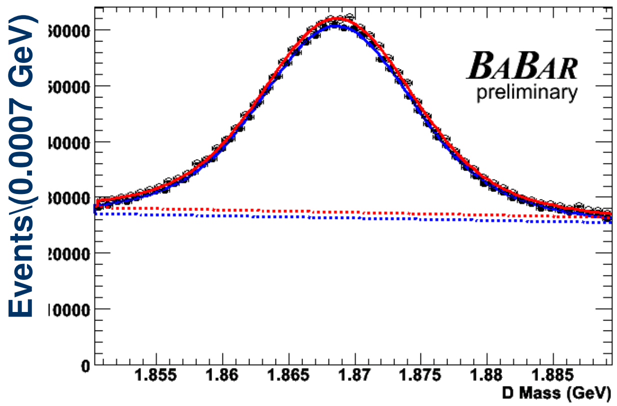
$\sigma(M_\tau) = 0.09$ MeV

Systematic Uncertainties on M_τ

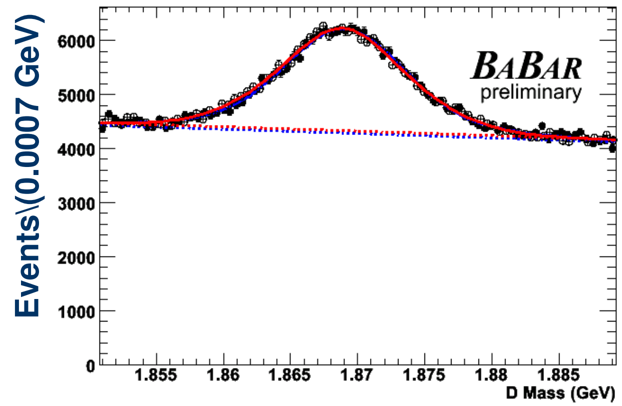
Beam Energy	0.09 MeV
Boost	Negligible
Resolution	Negligible
Fit Range	0.05 MeV
Edge Parameterization	0.05 MeV
MC Modeling	0.05 MeV
Neutrino Mass	Negligible
Limited MC Statistics	0.05 MeV
Momentum Reconstruction Uncertainty	**0.39 MeV**
Total	**0.41 MeV**

Mass Difference Systematic

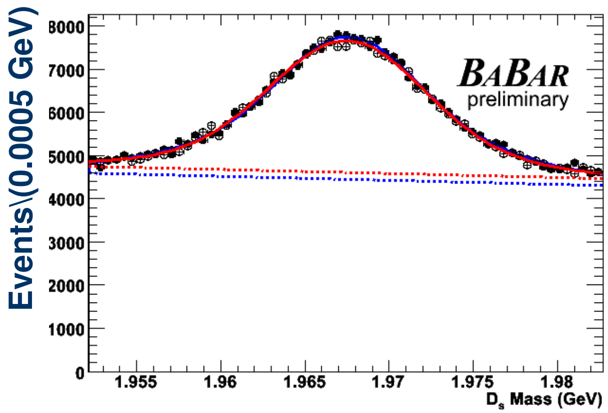
$D^+ \to K^- \pi^+ \pi^+$



$D^+ \to \phi \pi^+$



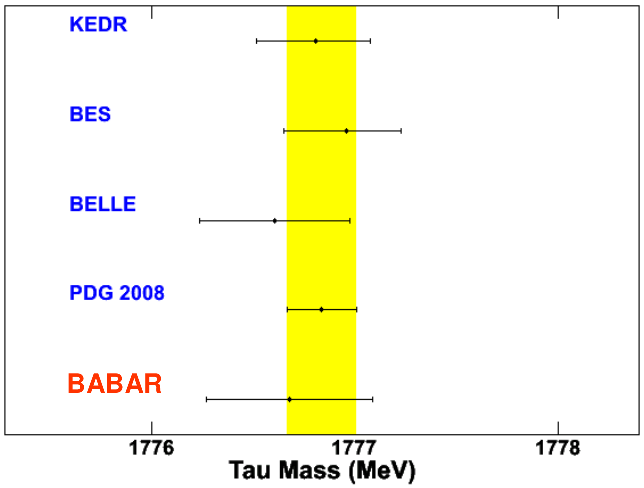
$D_s^+ \to \phi \pi^+$

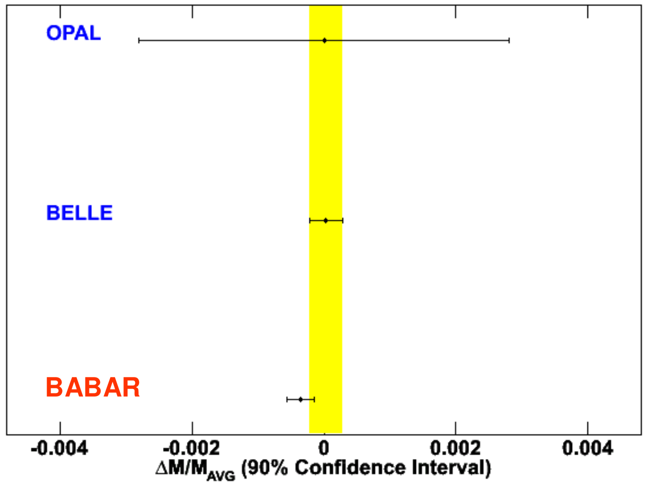


Measured the mass difference between D masses
Take the weighted average as the uncertainty

Mode	Mass Difference (MeV)
$D^+ \to K^- \pi^+ \pi^+$	-0.04 ± 0.03
$D^+ \to \phi \pi^+$	-0.09 ± 0.14
$D_s^+ \to \phi \pi^+$	+0.10 ± 0.07
Mass Difference Systematic	0.05 ± 0.03

Summary





- M_τ = 1776.68 ± 0.12 (stat) ± 0.41 (syst) MeV
- Largest source of uncertainty is that associated with the momentum reconstruction correction
- $\frac{M(\tau^+)-M(\tau^-)}{M_{Average}}$ = $(-3.5 \pm 1.3) \times 10^{-4}$
- 90% Confidence Interval for the mass difference

  $-5.6 \times 10^{-4} < \frac{M(\tau^+)-M(\tau^-)}{M_{Average}} < -1.4 \times 10^{-4}$

Backups

Edge Parameterization

Alternate fit functions

$$F_1(x) = (p_3 + p_4 x)\frac{x - p_1}{\sqrt{p_2 + (x - p_1)^2}} + p_5 + p_6 x$$

$$F_2(x) = (p_3 + p_4 x)\frac{-1}{1 + \exp^{x - p_1 / p_2}} + p_5 + p_6 x$$

Fit	ΔM_τ (MeV)
F1	+0.02
F2	-0.02