Selected topics in τ physics from BABAR

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(on behalf of the BABAR Collaboration)

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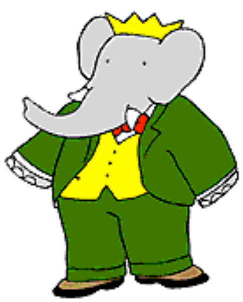

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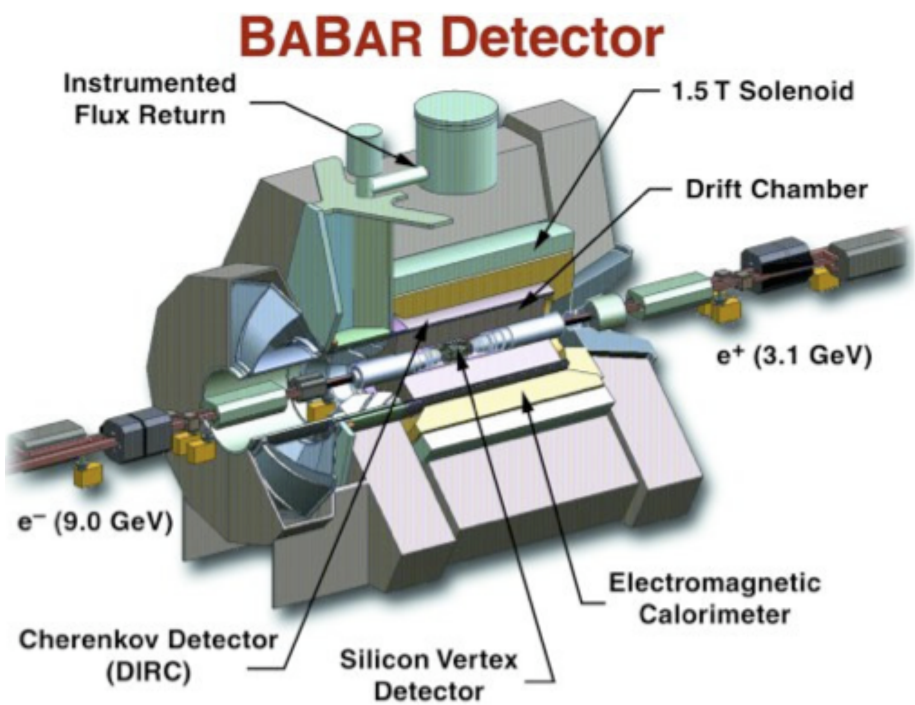
Outline

- Introduction to BaBar detector and dataset
- Selected τ topics
  - Precise measurement of τ mass and $\tau^+ \tau^-$ mass difference
  - Measurement of $B(\tau^- \to \overline{K^0}\pi^-\pi^0\upsilon)$
  - Analysis of $\tau^- \to K_S^0\pi^-\nu$ mass spectrum
- Conclusions

BaBar Detector and Data Sample

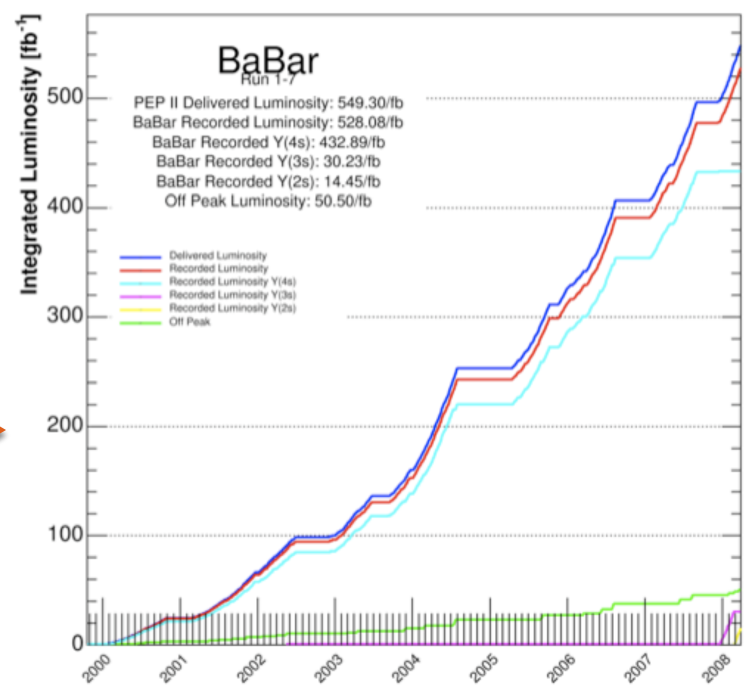


e+e⁻ collide at centre-of-mass energy of 10.58 GeV → Υ(4s)

$$\sigma(e^+e^- \to bb)@\Upsilon(4s) = 1.05nb$$

$$\sigma(e^+e^- \to \tau^+\tau^-)@\Upsilon(4s) = 0.92nb$$

Over 525fb^{-1} of data collected, of which 423fb^{-1} is at the Υ(4s)



τ mass measurement and $\tau^+ \tau^-$ difference: Motivation

- M_τ important for testing lepton universality
- $M(\tau^+) - M(\tau^-)$ important for testing CPT invariance
- Current measurements:
  - $M_\tau = 1776.84 \pm 0.17\ MeV/c^2$
  - **CPT:** $\dfrac{M(\tau^+) - M(\tau^-)}{M_{average}} < 2.8 \times 10^{-4}$ (@ 90% C.L.)

(PDG 08)

τ mass measurement and $\tau^+ \tau^-$ difference: Methodology

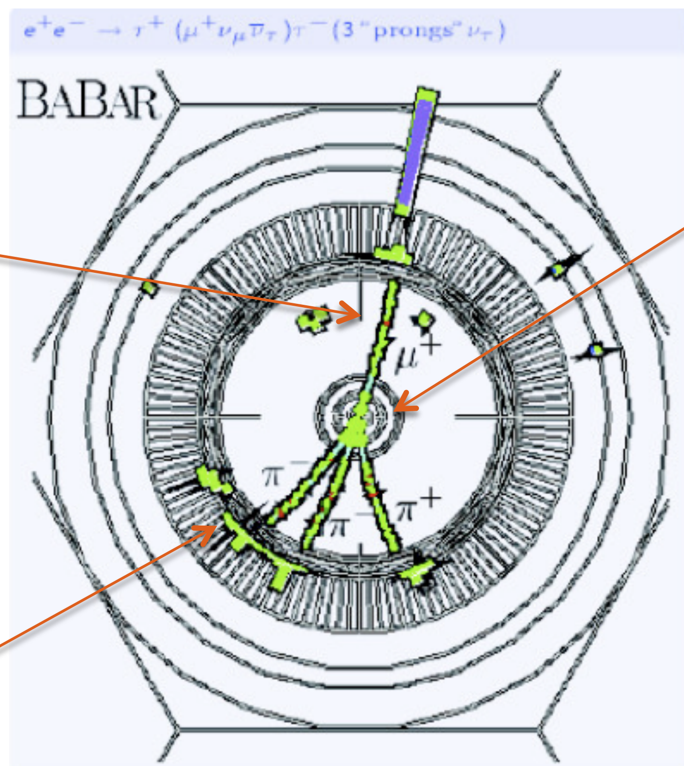
- Use Pseudomass endpoint method (next slide)

  [ARGUS Phys.Lett. B292, 221 (1992)] , [BELLE Phys.Rev.Lett. 99, 011801 (2007)]

- Use decay $\tau^- \to \pi^- \pi^+ \pi^- \upsilon_\tau$ (High branching ratio ~ 8.99%)

Use leptonic tag on one-prong side

3 tracks not identified as lepton on signal side

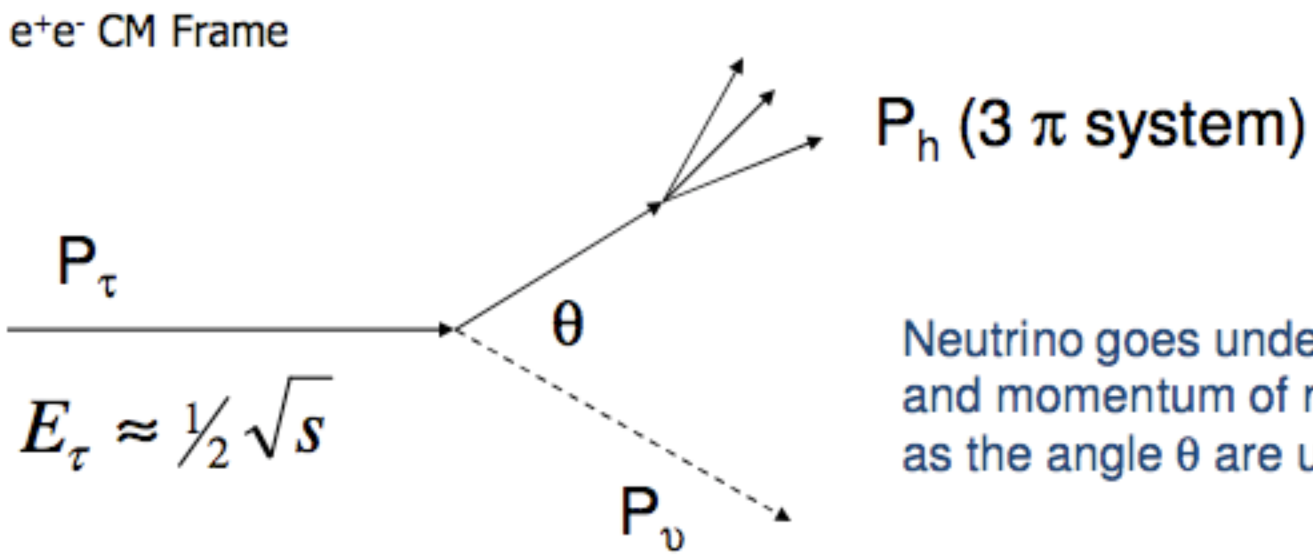


τ leptons decay isotropically in CM frame

- Veto charged/neutral kaons and protons
- Less then 5 photons and neutral energy < 300 MeV
- Purity ~ 96%, Signal Efficiency ~ 2%

τ mass measurement and $\tau^+\tau^-$ mass difference: Methodology

- Psuedomass endpoint method:



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

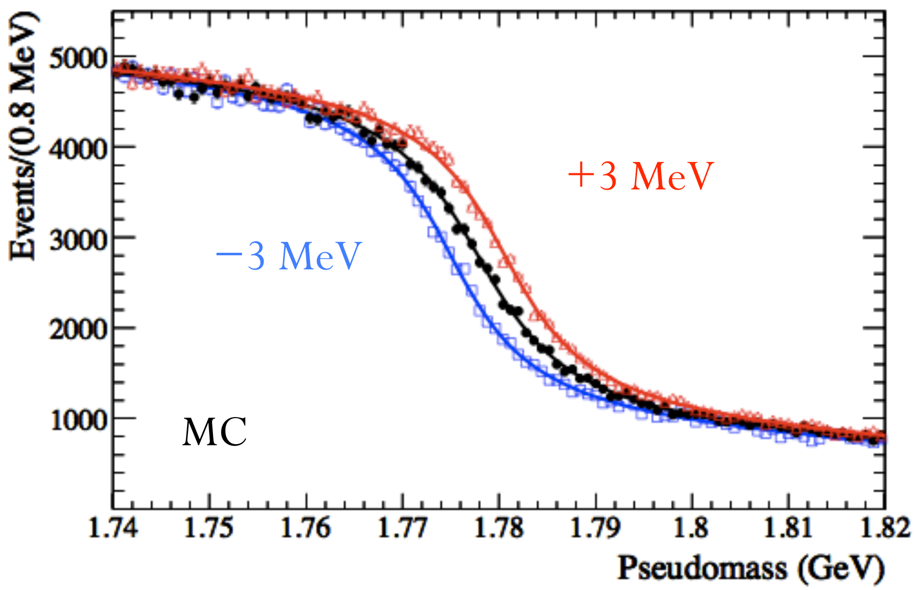
$$M_\tau^2 = M_h^2 + 2(E_\tau - E_h)(E_h - P_h \cos\theta)$$

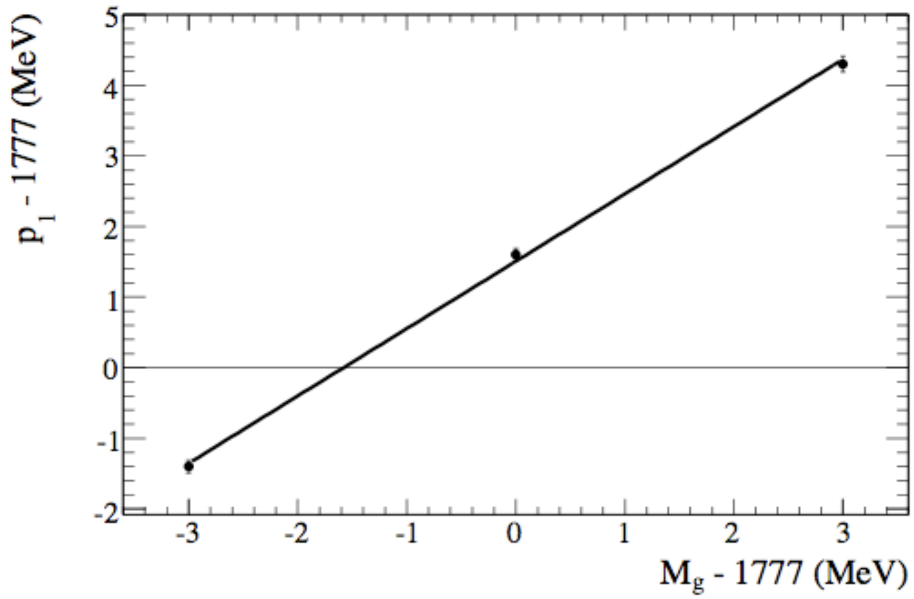
θ is set to zero to get a lower bound on M_τ

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

τ mass measurement and $\tau^+\tau^-$ mass difference: Methodology

- Fit signal region in M_{pseudo} using: $F(x) = (p_3 + p_4 x)\tan^{-1}\left(\frac{x - p_1}{p_2}\right) + p_5 + p_6 x$
- P_1 is the endpoint parameter: can obtain relationship between p_1 and M_τ using MC





Expect slope of unity and y-intercept of zero – however ISR/FSR and imperfect detector resolution lead to a non-zero offset which is used to determine M_τ from the endpoint fit to data

τ mass measurement and $\tau^+ \tau^-$ mass difference: Systematic Uncertainties

- Several sources of uncertainty are considered:

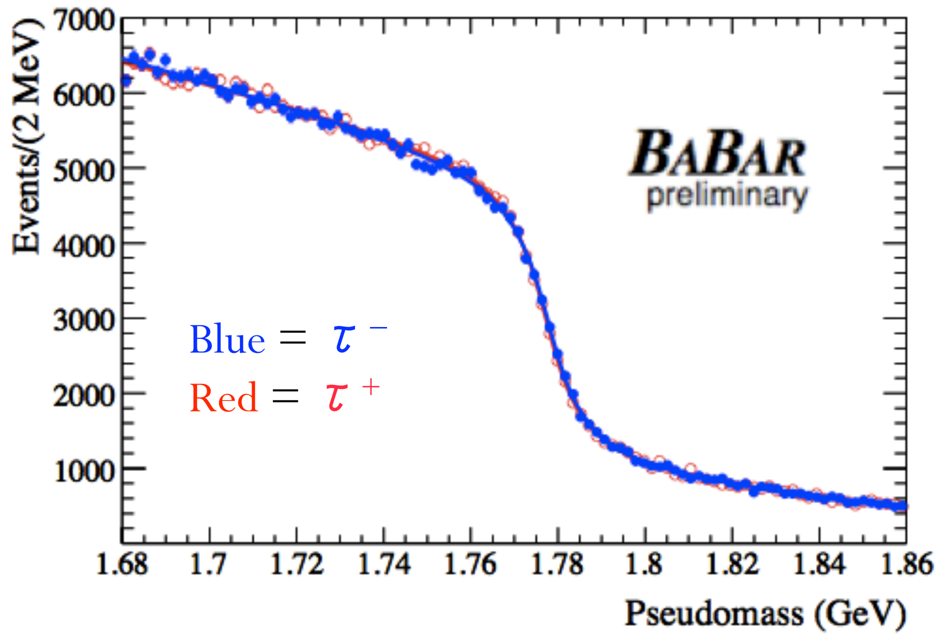
Source	Uncertainty (MeV)
Momentum Reconstruction	0.39
CM Energy	0.09
MC Modeling	0.05
MC Statistics	0.05
Fit Range	0.05
Parameterization	0.03
Total	**0.41**

- Largest uncertainty is due to underestimation of track momenta:

Detector Parameter	M_τ Shift (MeV)
SVT Material +20.0%	+0.31
Solenoid Field +0.02%	+0.11
FBM Field +20.0%	+0.21
Correction	+0.63

τ mass measurement and $\tau^+\tau^-$ mass difference: Results

- Split Data into 2 samples, based on the 3π charge
- Both average and separate measurement of $M(\tau^+)$ and $M(\tau^-)$.

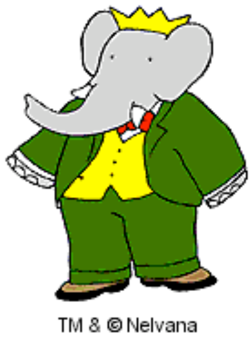


$$M_\tau = 1776.68 \pm 0.12(stat.) \pm 0.41(syst.) MeV/c^2$$

$$\frac{M(\tau^+) - M(\tau^-)}{M_{average}} = -3.4 \pm 1.3(stat.) \pm 0.3(syst.) \times 10^{-4}$$

Strange hadronic τ decays

Measurement of $B(\tau^- \to \overline{K^0}\pi^-\pi^0\upsilon)$ and analysis of $\tau^- \to K_S^0\pi^-\nu$ mass spectrum



Strange hadronic τ decays

Motivation

- τ decays to strange hadronic final states offer a very clean environment to study the weak current ; sensitive to $V_{us.}$
- A fit to the $\tau^- \to K_S^0 \pi^- \nu$ mass spectrum can yield precise values for the mass and width of the dominant K* (892)
- Belle proposed that a scalar resonance, K*(800), was required to fit the the total mass spectrum.
- Their fit yielded values : *(Phys. Lett. B* ***654****, 65, (2007))*

$M(K^*(892)^-) = 895.47 \pm 0.20(\text{stat.}) \pm 0.47(\text{syst.}) \pm 0.59(\text{mod.})$ MeV/c^2

$\Gamma(K^*(892)^-) = 46.2 \pm 0.60(\text{stat.}) \pm 1.0(\text{syst.}) \pm 0.7(\text{mod.})$ MeV

[PDG Values: $M(K^*(892)-) = 891.66 \pm 0.26$ MeV/c^2, $\Gamma(K^*(892)-) = 50.8 \pm 0.9$ MeV]

Strange hadronic τ decays

Motivation

- The branching fraction for $\tau^- \to K_S^0 \pi^- \nu$ was presented at *Tau08, Novosibirsk* (arXiv:0808.1121(hep-ex))

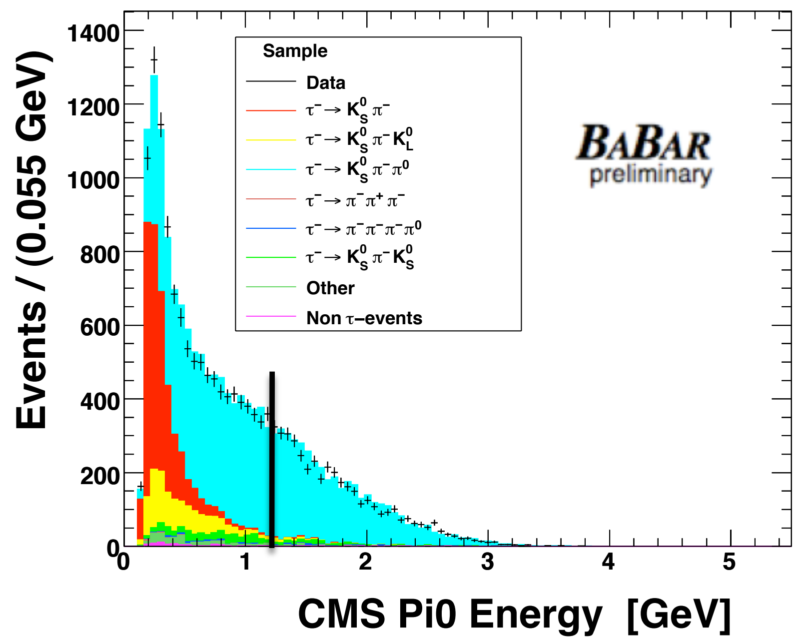
  $$B(\tau^- \to \overline{K}^0 \pi^- \nu_\tau) = 0.840 \pm 0.006(stat.) \pm 0.023(syst.)$$

- Also wanted to consider $\tau^- \to K_S^0 \pi^- \pi^0 \nu$ shape and rate as forms an important component of fitting $\tau^- \to K_S^0 \pi^- \nu$ -large peaking background.
- Measure hadronic distributions in data and use to tune MC

Strange hadronic τ decays: $\tau^- \to K_S^0 \pi^- \pi^0 \nu$

Signal Selection

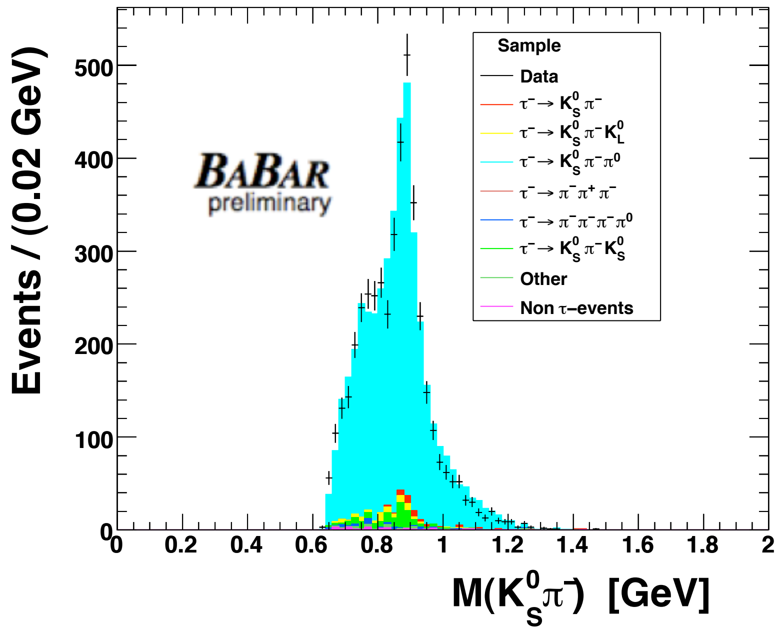
- To obtain high signal purity (~93%) –stringent selection criteria on π^0's were used.
- Exactly one identified π^0
- Trajectory of π^0 to be within 90° of $K_s\pi^-$ momentum vector
- Energy of π^0 to be greater than 1.2 GeV to remove large background below this threshold.



Strange hadronic τ decays:branching fraction

Results

- Using this selection, MC form factors were tuned to that of data:



- Also obtain branching fraction:

$$B(\tau^- \to \overline{K}^0 \pi^- \pi^0 \nu_\tau) = 0.342 \pm 0.006(stat.) \pm 0.015(syst.)$$

Dominant systematic contribution is π^0 efficiency systematic: 3.0% → 0.011(syst.)

Fit to mass spectrum: Methodology

- Using tuned MC form factors a fit is performed to the invariant mass spectrum $\tau^- \to K_S^0 \pi^- \nu$
- A function which reflects the limited resolution and efficiency of the detector is convoluted with the signal PDF
- Terms to include the uncertainty in the rates and shapes of background modes are included in our χ^2 minimisation- background shapes/rates differ in each fit $\longrightarrow$ background subtracted data spectra are different in each fit model
- Several different fit models are investigated

Fit to mass spectrum: Signal PDF

- Use same model Belle used *(Phys. Lett. B **654**, 65, (2007))*:

$$f(m;\vec{\theta}) \propto \frac{1}{s}\left(1-\frac{s}{m_\tau{}^2}\right)\left(1+2\frac{s}{m_\tau{}^2}\right)P\left(P^2|F_V|^2+\frac{3(m_K{}^2-m_\pi{}^2)^2}{4s(1+2\frac{s}{m_\tau{}^2})}|F_S|^2\right).$$

Vector form factor

$$F_V=\frac{1}{1+\beta+\gamma+\cdots}[BW_{K^1}(s)+\beta BW_{K^2}(s)+\gamma BW_{K^3}(s)+\cdots].$$

Scalar form factor

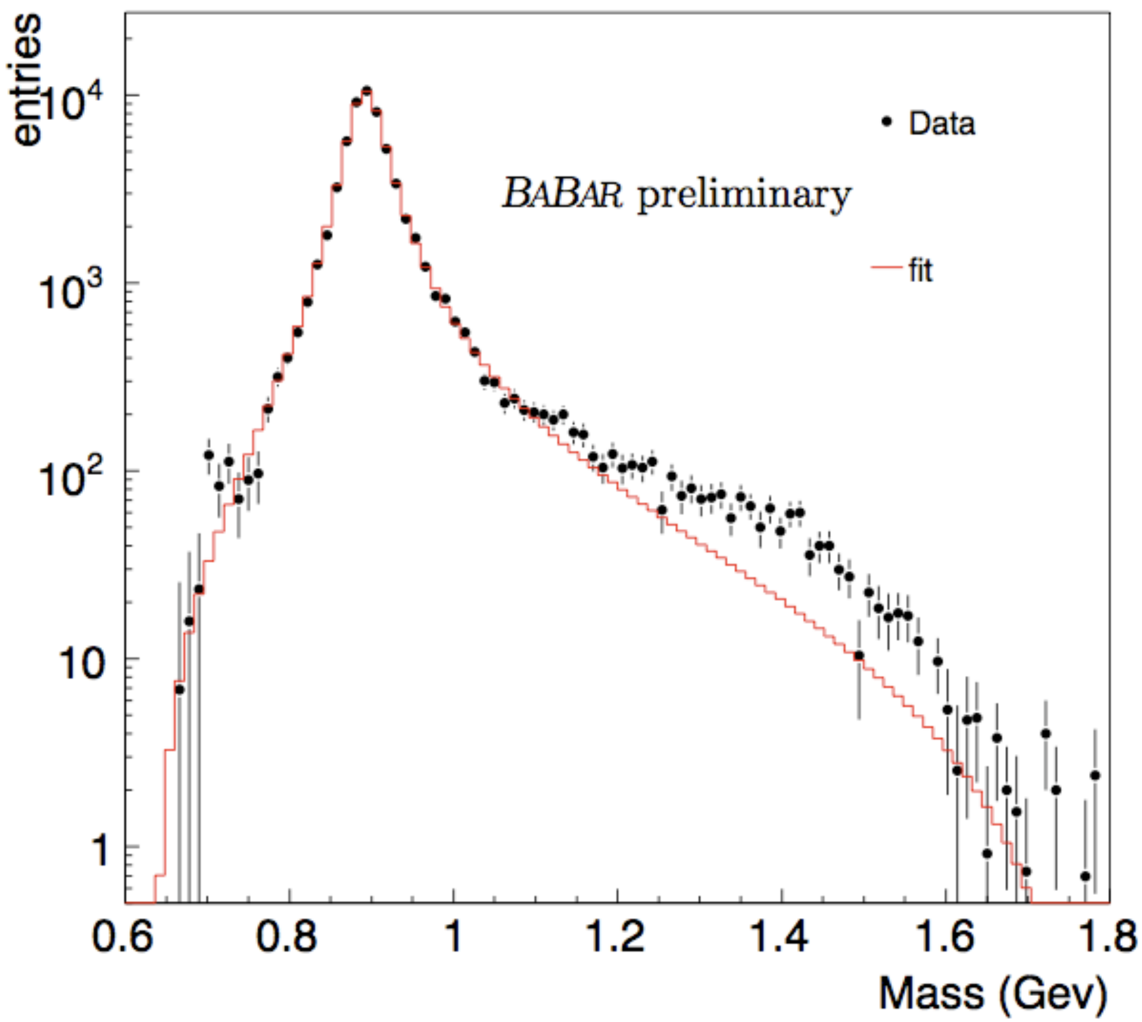
$$F_S=\varkappa\frac{s}{M^2_{K*(800)}}BW_{K*(800)}(s)+\lambda\frac{s}{M^2_{K*(1430)}}BW_{K*(1430)}(s).$$

Also try LASS scalar form factor

$$F_S=\lambda A_s, A_s=\frac{\sqrt{s}}{P}(\sin\delta_B e^{i\delta_B}+e^{2i\delta_B}BW_{K*(1430)}),$$

Strange hadronic τ decays

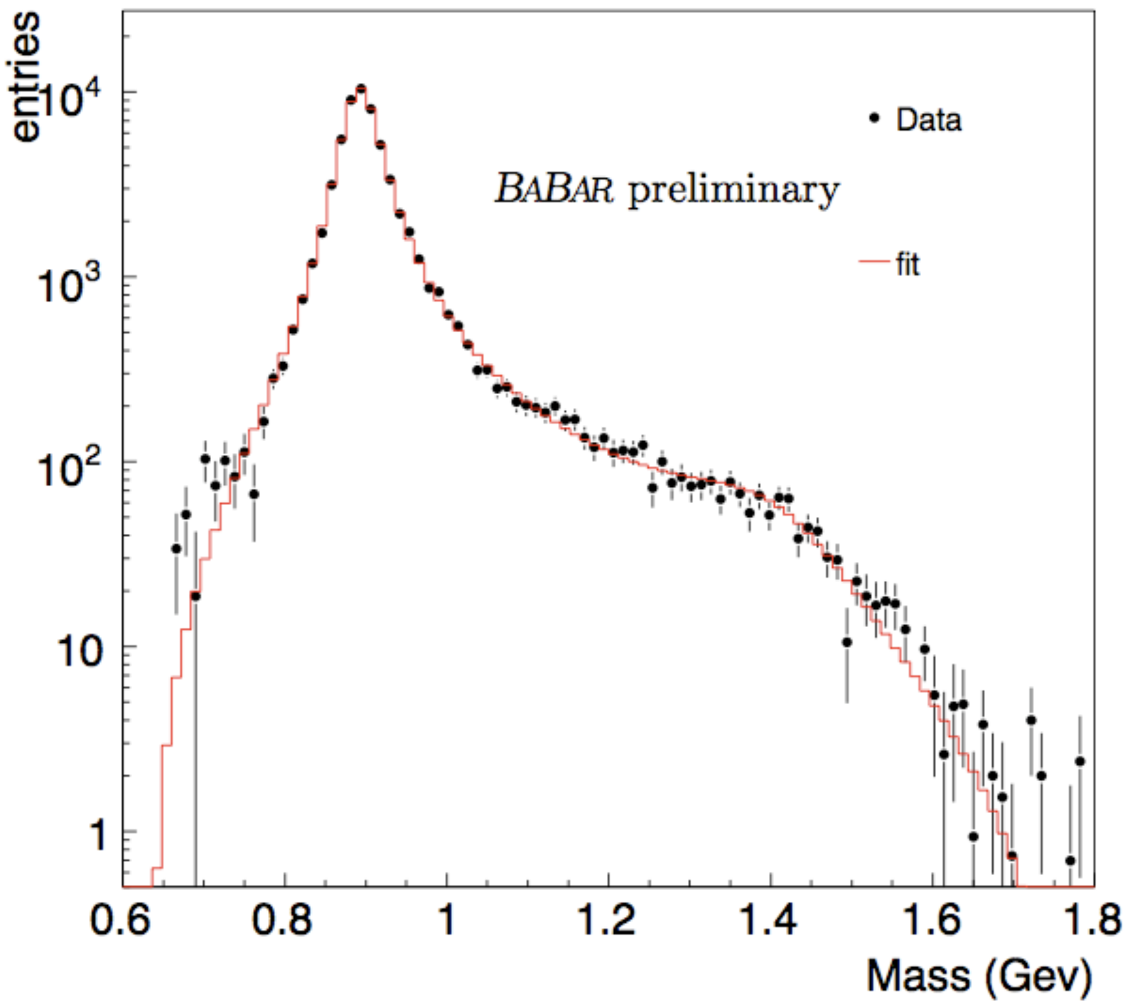
Fit to mass spectrum: Using only K*(892)



$\chi^2/\text{dof} = 399.8/97$

Strange hadronic τ decays

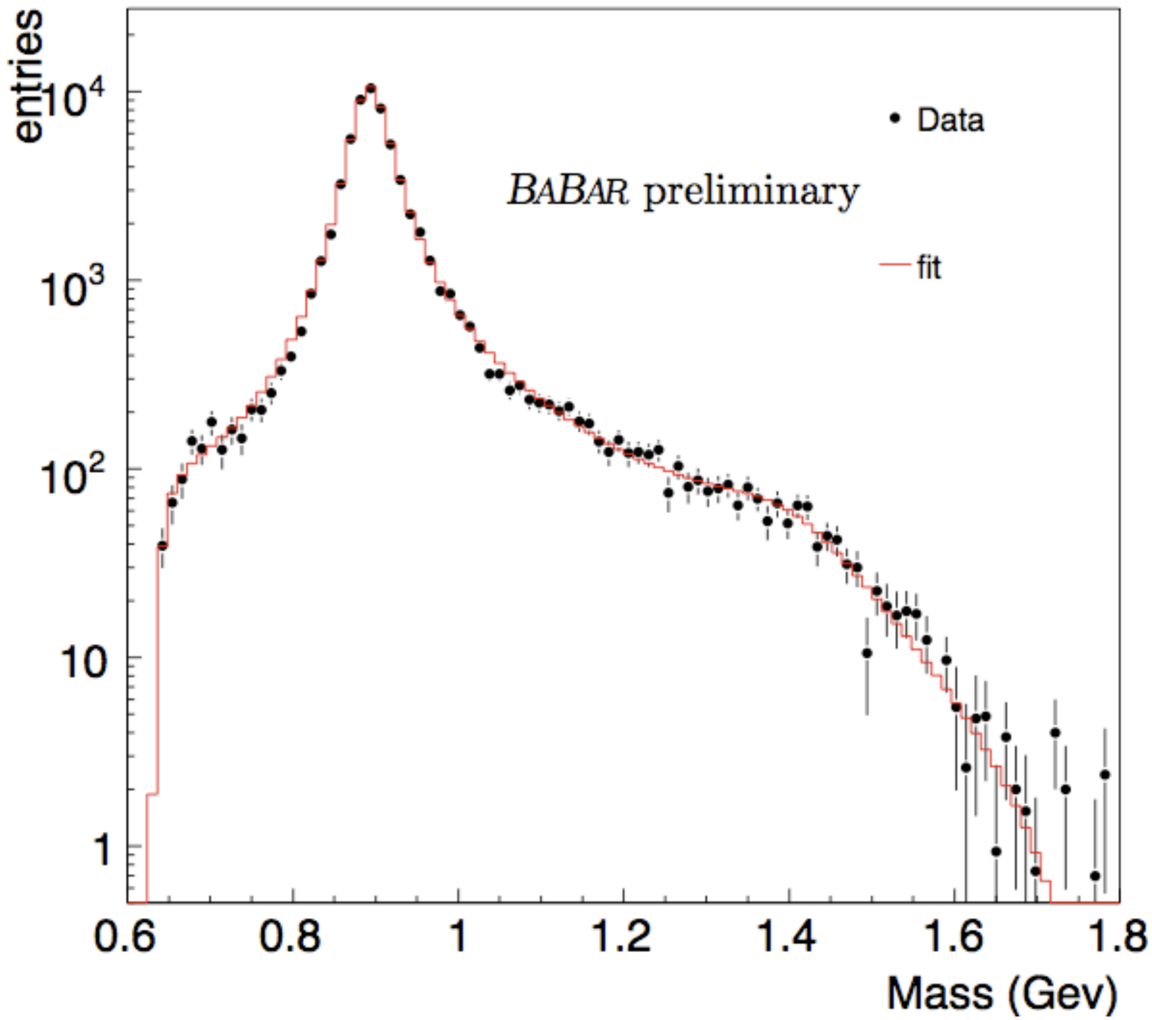
Fit to mass spectrum: Using K*(892)+K*(1410)



$\chi^2/\text{dof} =$ 130.0/95

Strange hadronic τ decays

Fit to mass spectrum: Using K*(800) + K*(892)+K*(1410)



$\chi^2/\text{dof} = 113.1/94$

Strange hadronic τ decays

Fit to mass spectrum: Alternate resonance models

- K*(800) + K*(892) + K*(1430) – $\chi^2/dof = 114.1/94$
- K*(800) + K*(892) + K*(1680) – $\chi^2/dof = 144.71/94$
- K*(892) + LASS – $\chi^2/dof = 148.38/94$

Strange hadronic τ decays

Fit to mass spectrum: Systematic uncertainties

- Several sources of systematic uncertainty:
  - Vary response function parameters
  - Check dependence on model by fitting signal MC –apply additive correction – use statistical errors as contribution to systematic (dominant contribution for Mass)
  - Check dependence on different resonance models (dominant contribution for Width)
- Systematic uncertainties also enter through statistical error on fit by including adjustable parameters in model:
  - Uncertainty in background rates
  - Shape parameters for $\tau^- \to K_S^0 K_L^0 \pi^- \nu$

Strange hadronic τ decays

Conclusions

- Using K*(800) + K*(892) + K*(1410) as nominal fit yields:

$$M(K^*(892)^-) = 894.30 \pm 0.19(stat.) \pm 0.19(syst.) MeV/c^2$$

$$\Gamma(K^*(892)^-) = 45.56 \pm 0.43(stat.) \pm 0.57(syst.) MeV$$

World's most precise measurements from τ decays

- Most accurate fit includes K*(800) but further study is ongoing to see if background processes are well understood
- Have measured:

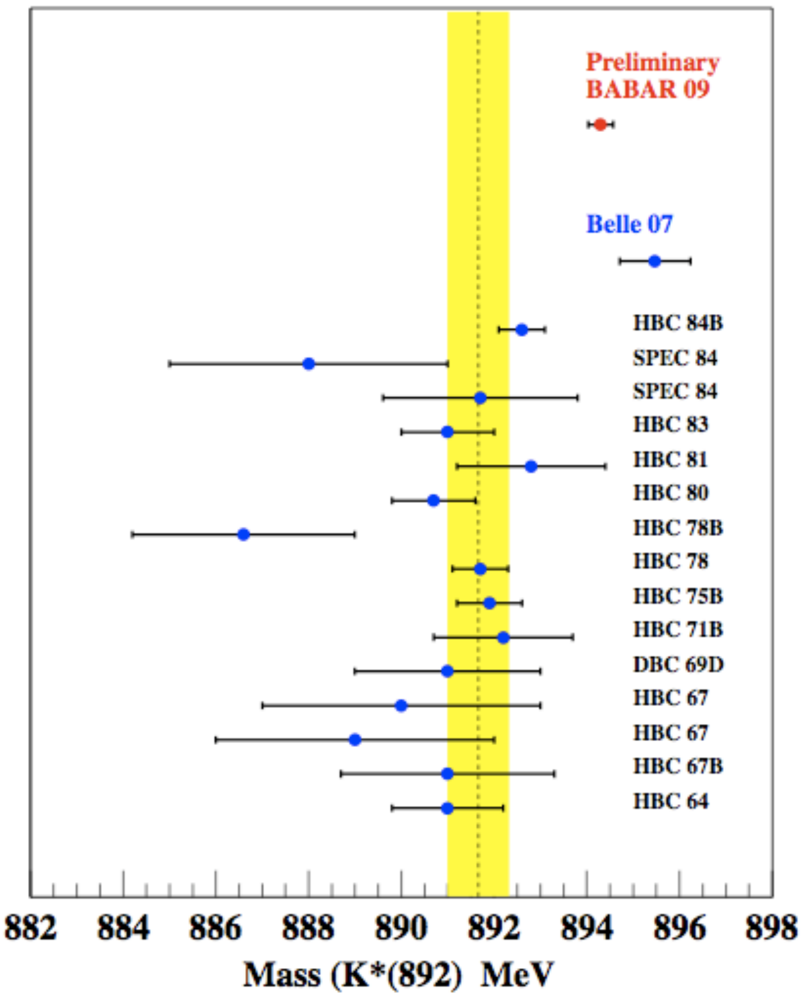
$$B(\tau^- \to \overline{K^0}\pi^-\pi^0\nu_\tau) = 0.342 \pm 0.006(stat.) \pm 0.015(syst.)$$

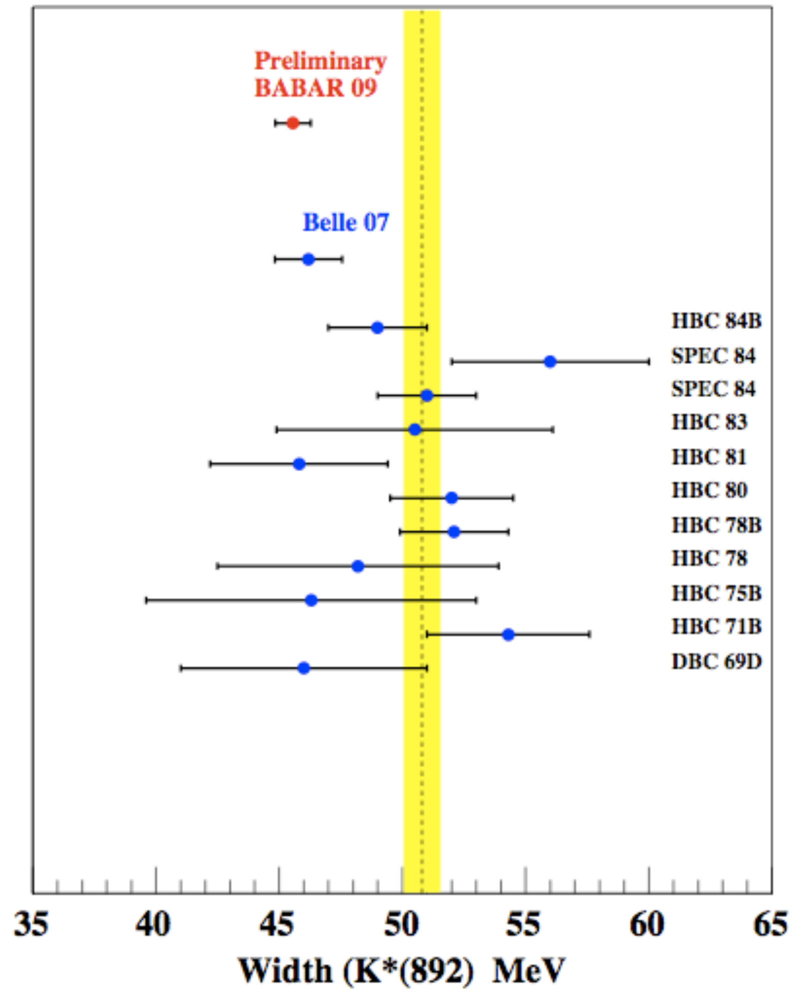
World's most precise measurement

Preliminary results

Strange hadronic τ decays

Summary

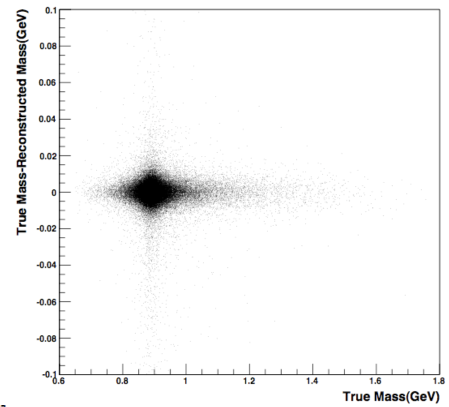




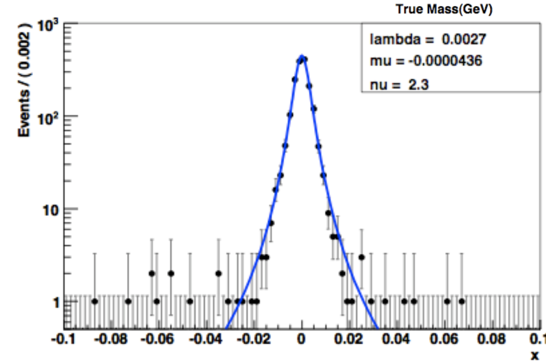
BACKUP SLIDES

Fit to mass spectrum:Response function

- Obtain a 2D figure from MC showing Measured – True mass Vs True Mass

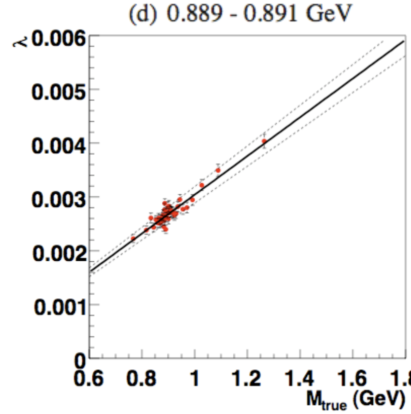


- Split into 1D 'slices' and project onto True mass axis
- Fit each 1D histogram with same parametric form



(d) 0.889 - 0.891 GeV

- Fit parameters obtained above to linear relationship



Strange hadronic τ decays

Fit to mass spectrum: All fit results

Scenario	a	b	c	d	e	f
Resonances	K*(892)	K*(892) ⊕ [K*(1410)]	[K*(800)] ⊕ K*(892) ⊕ {K*(1410)}	[K*(800)] ⊕ K*(892) ⊕ [K*(1430)]	[K*(800)] ⊕ K*(892) ⊕ [K*(1680)]	K*(892)⊕ LASS
$M(892)$ (MeV/c^2)	894.544±0.171	894.412±0.187	894.565±0.193	894.673±0.193	894.393±0.184	894.855±0.196
$\Gamma(892)$ (MeV)	47.673±0.437	46.206±0.455	45.893±0.434	45.834±0.426	45.491±0.392	47.022±0.452
$\|\beta\|$	N/A	0.095±0.006	0.075±0.007	N/A	N/A	
$\arg(\beta)$	N/A	1.983±0.139	1.747±0.18	N/A	N/A	
$M(1410)$ (MeV/c^2)	N/A	{1434.23±11.19 (PDG)}	{1425.55±12.47 (PDG)}	N/A	N/A	N/A
$\Gamma(1410)$ (MeV)	N/A	{253.80±17.68 (PDG)}	{238.76±18.85 (PDG)}	N/A	N/A	N/A
$\|\lambda\|(1430)$	N/A	N/A	N/A	5.059±0.311		N/A
$\arg(\lambda)(1430)$	N/A	N/A	N/A	8.670±0.244		N/A
$M(1430)$ (MeV/c^2)				[1425±50(PDG)]		
$\Gamma(1430)$ (MeV)				[270±80(PDG)]		
$\|\gamma\|(1680)$					0.199±0.016	
$\arg(\gamma)(1680)$					3.559±0.184	
$M(1680)$ (MeV/c^2)	N/A	N/A	N/A	N/A	[1717±27 (PDG)]	
$\Gamma(1680)$ (MeV)	N/A	N/A	N/A	N/A	[322±110 (PDG)]	
$M(800)$ (MeV/c^2)	N/A	N/A	[$841\pm30^{+81}_{-73}$ (BES)]	[$841\pm30^{+81}_{-73}$ (BES)]	[$841\pm30^{+81}_{-73}$ (BES)]	
$\Gamma(800)$ (MeV)	N/A	N/A	[$618\pm90^{+96}_{-144}$ (BES)]	[$618\pm90^{+96}_{-144}$ (BES)]	[$618\pm90^{+96}_{-144}$ (BES)]	
$\varkappa$	N/A	N/A	1.938±0.11	0.255±0.019	2.237±0.101	
χ^2	399.778	130.044	113.049	114.151	144.711	148.375
# d.o.f.	97	95	94	94	94	94
χ^2/# d.o.f.	4.121	1.369	1.203	1.214	1.539	1.579
Prob.(χ^2)	<0.0001	0.0098	0.0880	0.0772	0.0006	0.0002

Strange hadronic τ decays

Fit to mass spectrum:systematics

Table 5: Table of systematic uncertainties in the mass and width of the K*(892) (see text).

	M(K*(892))	Γ(K*(892))
Response matrix width ($\pm 5\%$ variation of λ)	0.023	0.180
Response matrix tails ($\pm 10\%$ variation of ν)	0.030	0.280
Statistical error on fit to reconstructed MC	0.143	0.326
Without using K*(800)	0.118	0.330
Total systematic (quadratic sum)	0.189	0.571