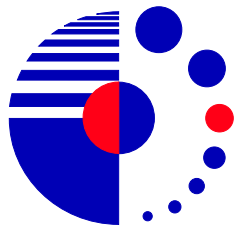


Measurement of the Strangeness Spectral Function and the Mass of the Strange Quark with the OPAL Detector at LEP

Wolfgang Mader
The University of Iowa




bmb+f - Förderschwerpunkt
Elementarteilchenphysik
Großgeräte der physikalischen
Grundlagenforschung





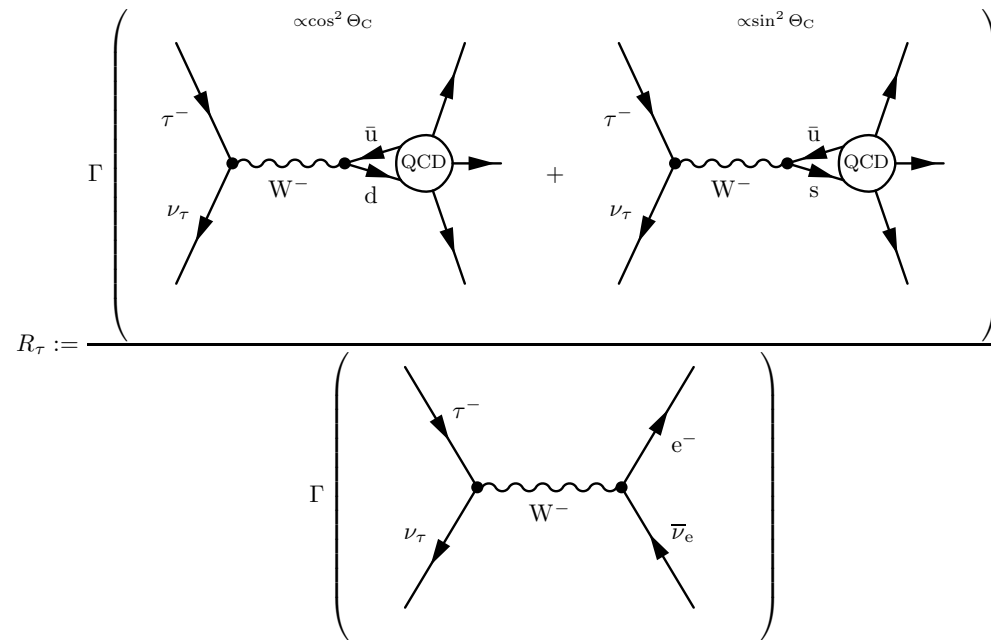
Outline

- Introduction
- Experimental Aspects
- Selection of Signal Channels
- Results
- Conclusion

- 
- Introduction
 - Experimental Aspects
 - Selection of Signal Channels
 - Results
 - Conclusion

- **QCD in τ -Decays**
- **Decay Channels with Net-Strangeness**
- **The OPAL Detector**

QCD and τ -Decays



τ -Hadronic Width R_τ :

- Naïve Parton Model: $R_\tau = 3$
- Measurement:

$$\begin{aligned}
 R_\tau = N_c & \left(|V_{ud}|^2 + |V_{us}|^2 \right) S_{ew} \\
 & \left(1 + \delta_{\text{pert}}(\alpha_s) \right) \quad (\approx 20\%) \\
 & + \delta_{\text{non-pert}} \quad (\approx 2\%) \\
 & + \delta_{ew} \quad (\approx .01\%) \quad) \approx 3.65
 \end{aligned}$$

QCD and τ -Decays

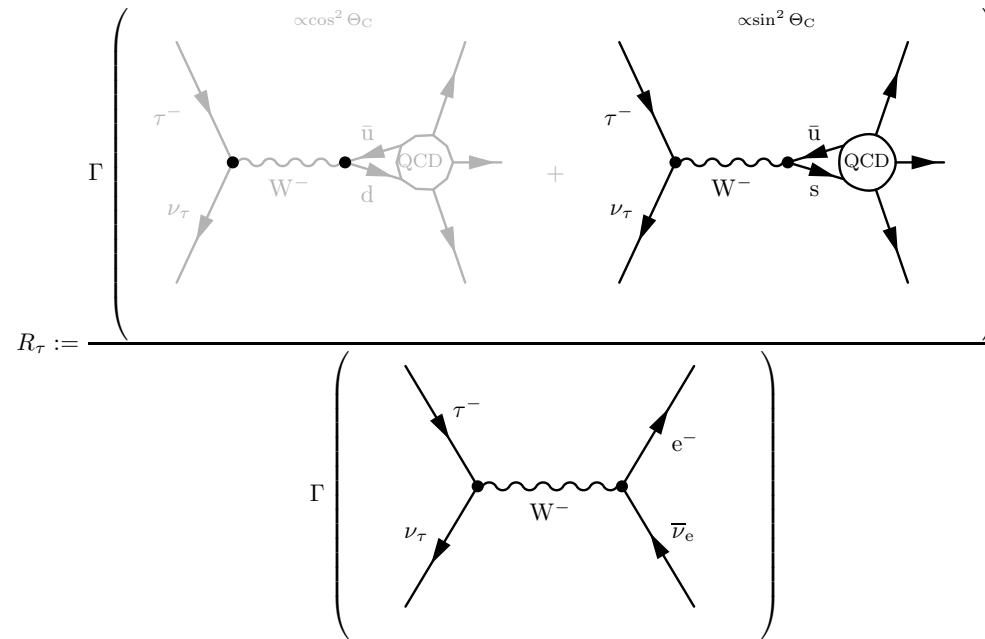
$$R_\tau := \frac{\Gamma \left(\begin{array}{c} \propto \cos^2 \theta_C \\ \tau^- \\ \nu_\tau \\ W^- \\ \bar{u} \\ d \\ \text{QCD} \end{array} \right) + \Gamma \left(\begin{array}{c} \propto \sin^2 \theta_C \\ \tau^- \\ \nu_\tau \\ W^- \\ \bar{u} \\ s \\ \text{QCD} \end{array} \right)}{\Gamma \left(\begin{array}{c} \tau^- \\ \nu_\tau \\ W^- \\ e^- \\ \bar{\nu}_e \end{array} \right)}$$

Input Quantities for QCD Studies:

- Spectral Functions

$$v_J^S(s)/a_J^S(s) = \frac{m_\tau^2}{6|V_{us}|^2 S_{ew}} \left(1 - \frac{s}{m_\tau^2}\right)^{-2} \left(1 + \frac{2s}{m_\tau^2}\right)^{-J} \\ \times \frac{B(\tau \rightarrow (V/A)^{(S=-1)} \nu_\tau)}{B(\tau \rightarrow e^- \bar{\nu}_e \nu_\tau)} \frac{1}{N_{V/A}} \frac{dN_{V/A}}{ds}$$

QCD and τ -Decays



Spectral Function in non-strange τ Decays:

- OPAL: (**Eur.Phys.J.C7:571-593,1999**)

$$\alpha_s(m_\tau^2) = 0.348 \pm 0.010_{\text{exp}} \pm 0.019_{\text{theo}}$$

$$\alpha_s(m_{Z^0}^2) = 0.1219 \pm 0.0010_{\text{exp}} \pm 0.0017_{\text{theo}}$$

- ALEPH: (**Eur.Phys.J.C4:409-431,1998**)

$$\alpha_s(m_\tau^2) = 0.334 \pm 0.022$$

$$\alpha_s(m_{Z^0}^2) = 0.1202 \pm 0.0027$$

QCD and τ -Decays

$$R_\tau := \frac{\Gamma \left(\begin{array}{c} \alpha \cos^2 \theta_C \\ \tau^- \\ \nu_\tau \\ W^- \\ \bar{u} \\ d \\ \text{QCD} \end{array} \right) + \Gamma \left(\begin{array}{c} \alpha \sin^2 \theta_C \\ \tau^- \\ \nu_\tau \\ W^- \\ \bar{u} \\ s \\ \text{QCD} \end{array} \right)}{\Gamma \left(\begin{array}{c} \tau^- \\ \nu_\tau \\ W^- \\ e^- \\ \bar{\nu}_e \end{array} \right)}$$

Spectral Function in strange τ -Decays:

- Existing Measurements
 - OPAL: (**Eur.Phys.J.C35:437-455,2004**)
 - ALEPH: (**Eur.Phys.J.C11:599-618,1999**)
- Depends on, e.g.
 - Measurement of $(\alpha_s)_{\text{strange}}$
 - Determination of the Strange Quark Mass m_s
 - Measurement of the CKM Matrix Element V_{us}

τ -Decays with Net-Strangeness

	Measured			Monte Carlo	
	$B_{\text{total}}/\%$	τ -Decay	$B_{\text{PDG}}/\%$	τ -Decay	$B_{\text{PDG}}/\%$
$(K)^-$	0.686 ± 0.023			$\tau^- \rightarrow K^- \nu_\tau$	0.686 ± 0.023
$(K\pi)^-$	1.340 ± 0.050				
$(K\pi\pi)^-$	0.708 ± 0.068				
$(K\pi\pi\pi)^-$	0.150 ± 0.045				
$\sum B_{\text{strange}}^{\text{total}}$		$\sum B_{\text{strange}}^{\text{meas}}$		$\sum B_{\text{strange}}^{\text{external}}$	

Remarks

- $\tau^- \rightarrow K^- \nu_\tau$ from PDG

τ -Decays with Net-Strangeness

	Measured			Monte Carlo	
	$B_{\text{total}}/\%$	τ -Decay	$B_{\text{PDG}}/\%$	τ -Decay	$B_{\text{PDG}}/\%$
$(K)^-$	0.686 ± 0.023			$\tau^- \rightarrow K^- \nu_\tau$	0.686 ± 0.023
$(K\pi)^-$	1.340 ± 0.050	$\tau^- \rightarrow K^- \pi^0 \nu_\tau$ $\tau^- \rightarrow K^0 \pi^- \nu_\tau$	0.450 ± 0.030 0.890 ± 0.040		
$(K\pi\pi)^-$	0.708 ± 0.068				
$(K\pi\pi\pi)^-$	0.150 ± 0.045				
$\sum B_{\text{strange}}^{\text{total}}$		$\sum B_{\text{strange}}^{\text{meas}}$		$\sum B_{\text{strange}}^{\text{external}}$	

Remarks

- $\tau^- \rightarrow K^- \nu_\tau$ from PDG

τ -Decays with Net-Strangeness

	Measured			Monte Carlo	
	$B_{\text{total}}/\%$	τ -Decay	$B_{\text{PDG}}/\%$	τ -Decay	$B_{\text{PDG}}/\%$
$(K)^-$	0.686 ± 0.023			$\tau^- \rightarrow K^- \nu_\tau$	0.686 ± 0.023
$(K\pi)^-$	1.340 ± 0.050	$\tau^- \rightarrow K^- \pi^0 \nu_\tau$ $\tau^- \rightarrow K^0 \pi^- \nu_\tau$	0.450 ± 0.030 0.890 ± 0.040		
$(K\pi\pi)^-$	0.708 ± 0.068	$\tau^- \rightarrow K^0 \pi^- \pi^0 \nu_\tau$ $\tau^- \rightarrow K^- \pi^+ \pi^- \nu_\tau$	0.370 ± 0.040 0.280 ± 0.050	$\tau^- \rightarrow K^- \pi^0 \pi^0 \nu_\tau$	0.058 ± 0.023
$(K\pi\pi\pi)^-$	0.150 ± 0.045				
$\sum B_{\text{strange}}^{\text{total}}$		$\sum B_{\text{strange}}^{\text{meas}}$		$\sum B_{\text{strange}}^{\text{external}}$	

Remarks

- $\tau^- \rightarrow K^- \nu_\tau$ from PDG

τ -Decays with Net-Strangeness

	$B_{\text{total}}/\%$	Measured		Monte Carlo	
		τ -Decay	$B_{\text{PDG}}/\%$	τ -Decay	$B_{\text{PDG}}/\%$
$(K)^-$	0.686 ± 0.023			$\tau^- \rightarrow K^- \nu_\tau$	0.686 ± 0.023
$(K\pi)^-$	1.340 ± 0.050	$\tau^- \rightarrow K^- \pi^0 \nu_\tau$ $\tau^- \rightarrow K^0 \pi^- \nu_\tau$	0.450 ± 0.030 0.890 ± 0.040		
$(K\pi\pi)^-$	0.708 ± 0.068	$\tau^- \rightarrow K^0 \pi^- \pi^0 \nu_\tau$ $\tau^- \rightarrow K^- \pi^+ \pi^- \nu_\tau$	0.370 ± 0.040 0.280 ± 0.050	$\tau^- \rightarrow K^- \pi^0 \pi^0 \nu_\tau$	0.058 ± 0.023
$(K\pi\pi\pi)^-$	0.150 ± 0.045	$\tau^- \rightarrow K^- \pi^+ \pi^- \pi^0 \nu_\tau$	0.064 ± 0.024	$\tau^- \rightarrow K^0 \pi^- \pi^0 \pi^0 \nu_\tau$ $\tau^- \rightarrow K^- \pi^0 \pi^0 \pi^0 \nu_\tau$ $\tau^- \rightarrow K^0 \pi^- \pi^+ \pi^- \nu_\tau$	0.026 ± 0.024 0.037 ± 0.021 0.023 ± 0.020
$\sum B_{\text{strange}}^{\text{total}}$		$\sum B_{\text{strange}}^{\text{meas}}$	2.054 ± 0.085	$\sum B_{\text{strange}}^{\text{external}}$	0.144 ± 0.044

Remarks

- $\tau^- \rightarrow K^- \nu_\tau$ from PDG
- For Final States $(K\pi)^-$, $(K\pi\pi)^-$ and $(K\pi\pi\pi)^-$, 93.4% are Reconstructed

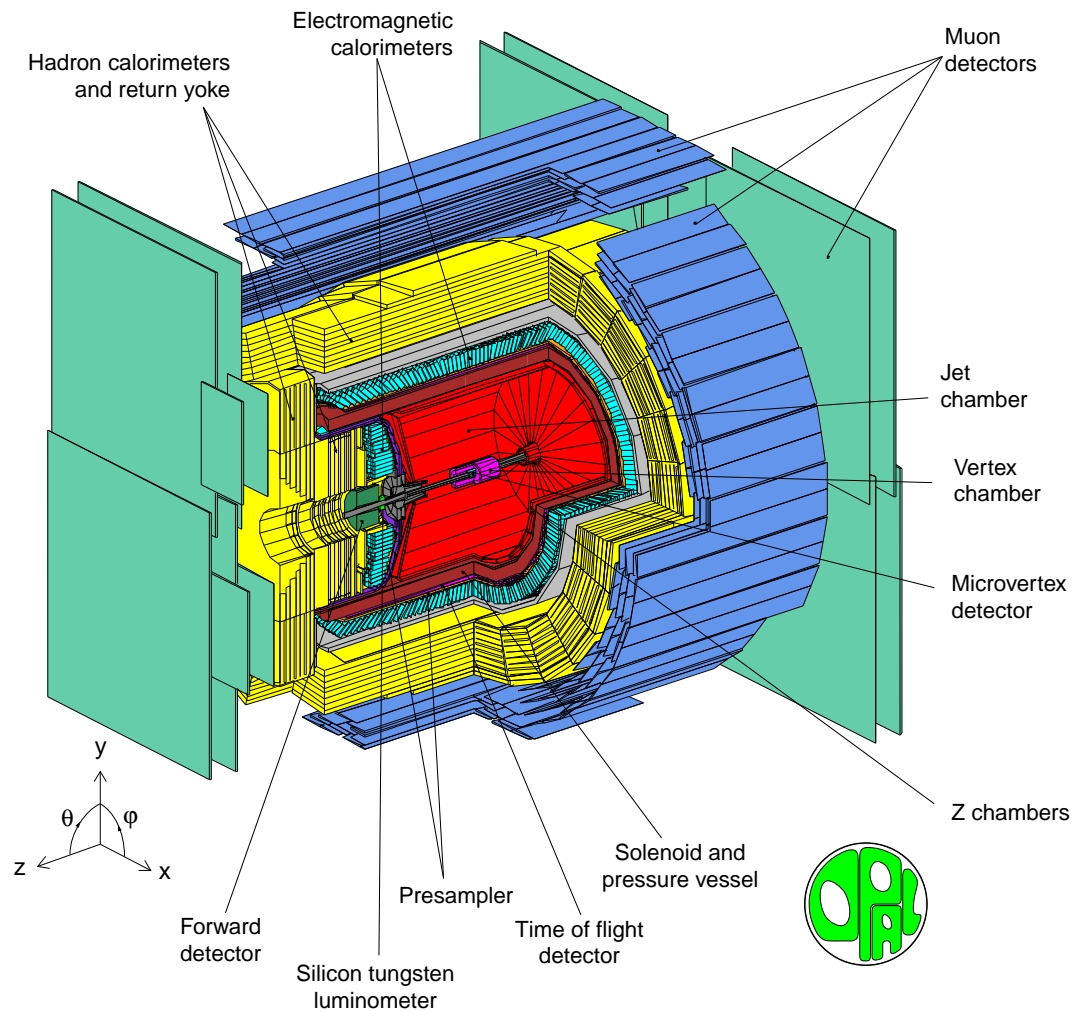
τ -Decays with Net-Strangeness

	$B_{\text{total}}/\%$	Measured		Monte Carlo	
		τ -Decay	$B_{\text{PDG}}/\%$	τ -Decay	$B_{\text{PDG}}/\%$
$(\text{K})^-$	0.686 ± 0.023			$\tau^- \rightarrow \text{K}^- \nu_\tau$	0.686 ± 0.023
$(\text{K}\eta)^-$	0.027 ± 0.006			$\tau^- \rightarrow \text{K}^- \eta \nu_\tau$	0.027 ± 0.006
$(\text{K}\pi)^-$	1.340 ± 0.050	$\tau^- \rightarrow \text{K}^- \pi^0 \nu_\tau$ $\tau^- \rightarrow \text{K}^0 \pi^- \nu_\tau$	0.450 ± 0.030 0.890 ± 0.040		
$(\text{K}\pi\pi)^-$	0.708 ± 0.068	$\tau^- \rightarrow \text{K}^0 \pi^- \pi^0 \nu_\tau$ $\tau^- \rightarrow \text{K}^- \pi^+ \pi^- \nu_\tau$	0.370 ± 0.040 0.280 ± 0.050		
$(\text{K}^*(892)\eta)^-$	0.029 ± 0.009			$\tau^- \rightarrow \text{K}^- \pi^0 \pi^0 \nu_\tau$ $\tau^- \rightarrow \text{K}^*(892)^- \eta \nu_\tau$	0.058 ± 0.023 0.029 ± 0.009
$(\text{K}\pi\pi\pi)^-$	0.150 ± 0.045	$\tau^- \rightarrow \text{K}^- \pi^+ \pi^- \pi^0 \nu_\tau$	0.064 ± 0.024	$\tau^- \rightarrow \text{K}^0 \pi^- \pi^0 \pi^0 \nu_\tau$ $\tau^- \rightarrow \text{K}^- \pi^0 \pi^0 \pi^0 \nu_\tau$ $\tau^- \rightarrow \text{K}^0 \pi^- \pi^+ \pi^- \nu_\tau$	0.026 ± 0.024 0.037 ± 0.021 0.023 ± 0.020
$\sum B_{\text{strange}}^{\text{total}}$	2.940 ± 0.099	$\sum B_{\text{strange}}^{\text{meas}}$	2.054 ± 0.085	$\sum B_{\text{strange}}^{\text{external}}$	0.200 ± 0.045


Remarks

- $\tau^- \rightarrow \text{K}^- \nu_\tau$ from PDG
- For Final States $(\text{K}\pi)^-$, $(\text{K}\pi\pi)^-$ and $(\text{K}\pi\pi\pi)^-$, 93.4% are Reconstructed
- Final States $\text{K}^- \eta \nu_\tau$ und $\text{K}^*(892)^- \eta \nu_\tau$ from Monte Carlo

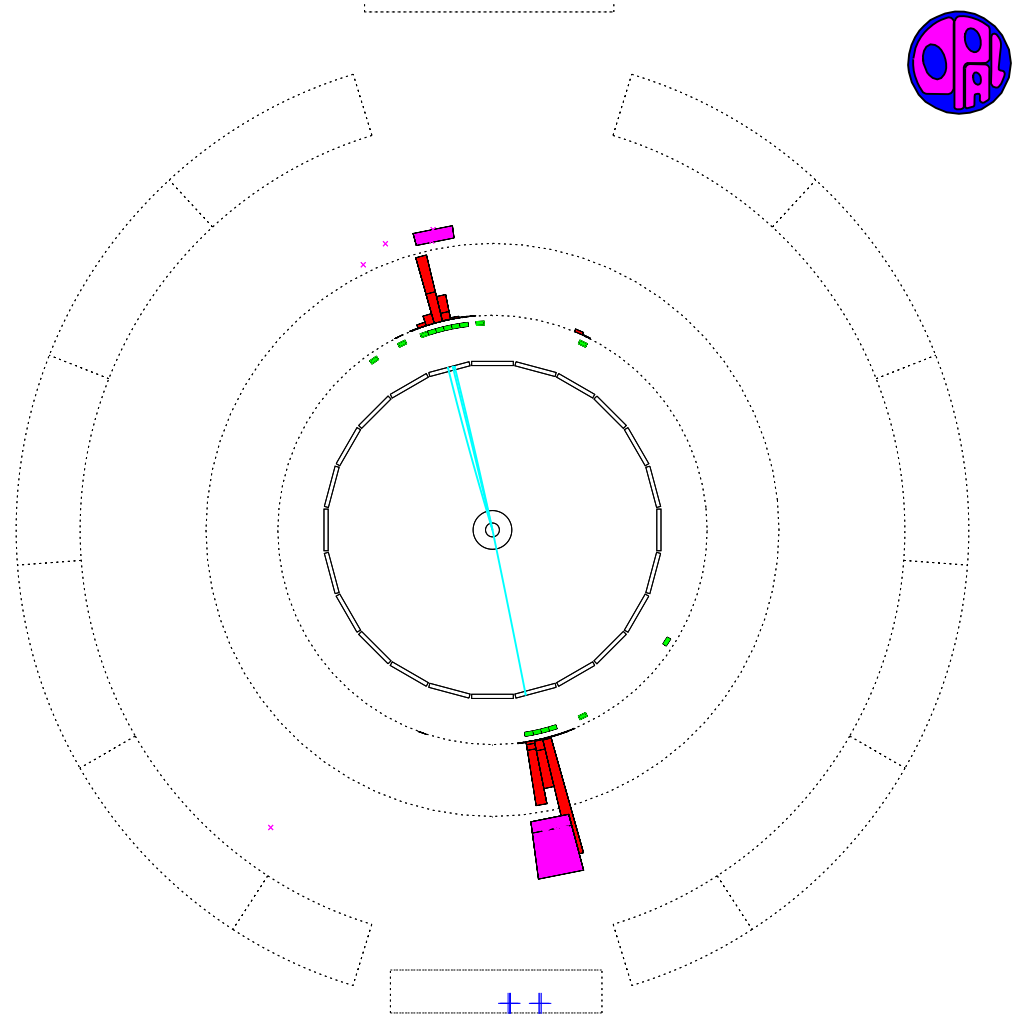
The **O**mni **P**urpose **A**pparatus at **L**EP



- Analysis based on LEP-I DATA (1990-95)
- Number of selected τ Pair Candidates: 162 477

- 
- Introduction
 - Experimental Aspects
 - Selection of the Signal Channels
 - Results
 - Conclusion
- **Identification of K**
(dE/dx Measurement)
 - **Reconstruction of Photonen**
 - **Reconstruction of K_S^0**

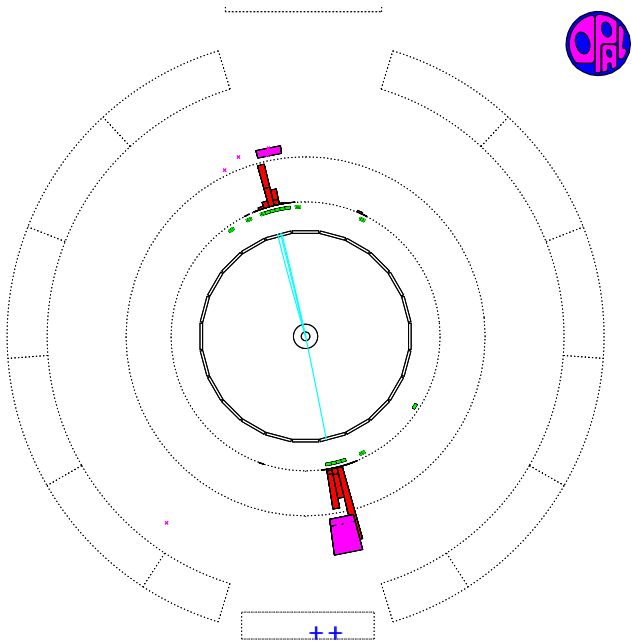
Typical τ -Event



● Event Signature

- Back-to-back Jets
- Small Number of Tracks
- Strongly collimated ($\gamma \approx 25$)
- Energy Deposits in ECAL/HCAL

Typical τ -Event

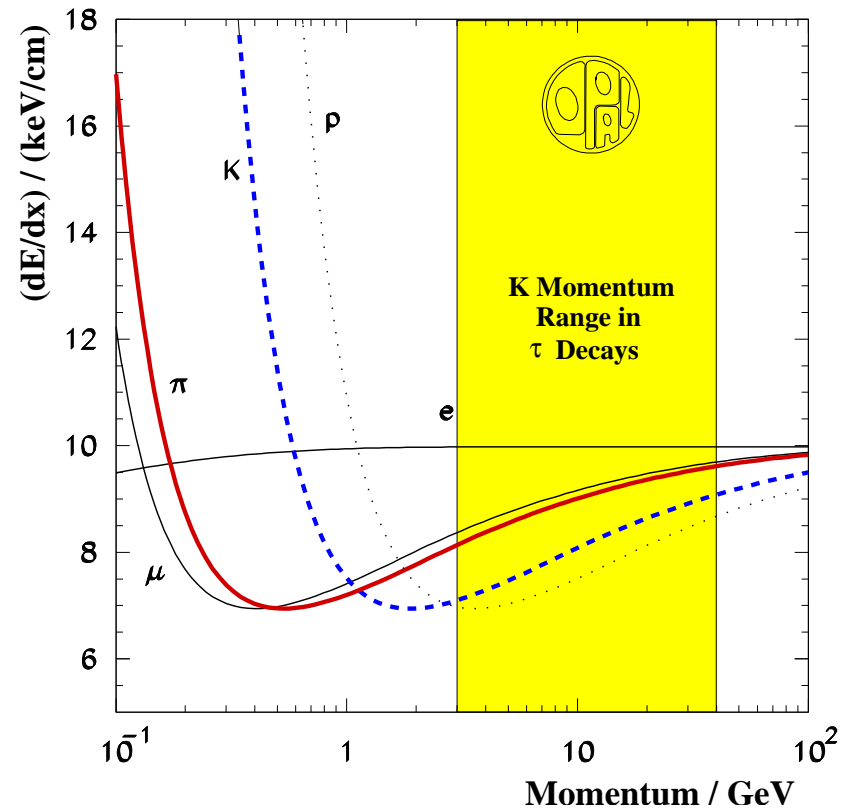


OPAL Drift Chamber

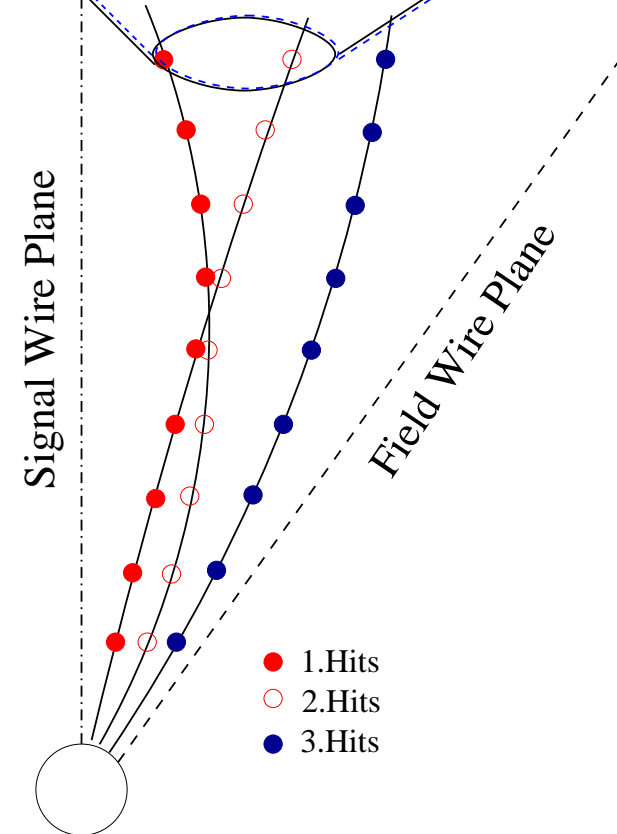
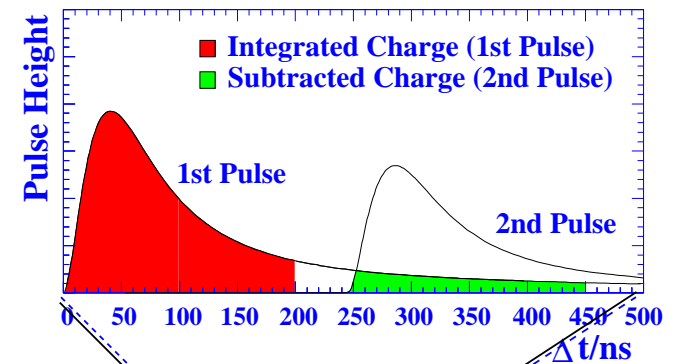
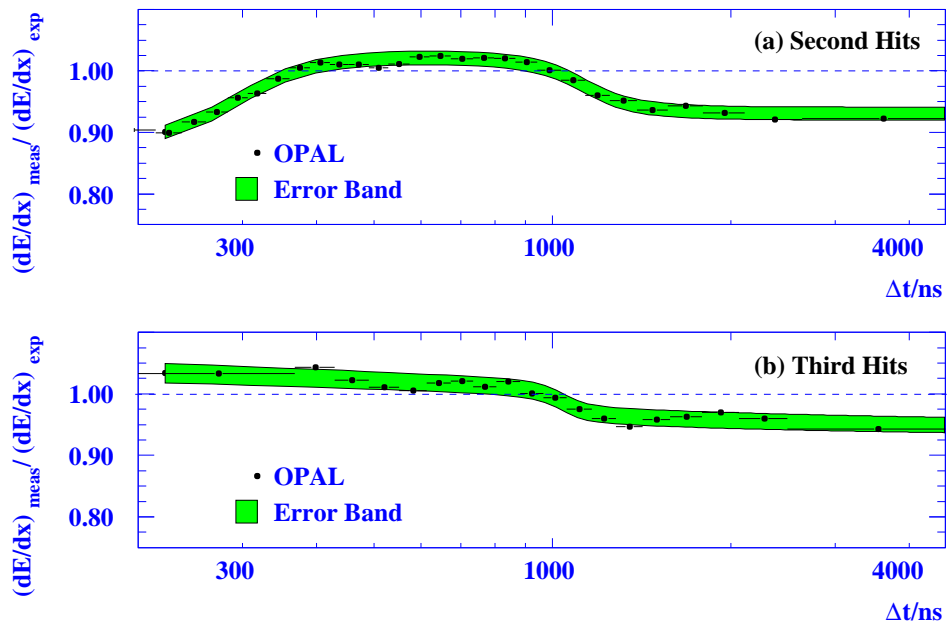
- Optimized for Particle Identification
- Argon/Methan/IsoButan
(88.2%/9.8%/2.0%)
- Pressure: 4bar
- 159 Measurements/Track (Barrel)

● $K^- - \pi^-$ -Identification

- Energy Loss Measurement (dE/dx)
- Momentum Range $3 \text{ GeV} < p_K < 35 \text{ GeV}$
- Separation of $> 2\sigma$ (10% absolute)

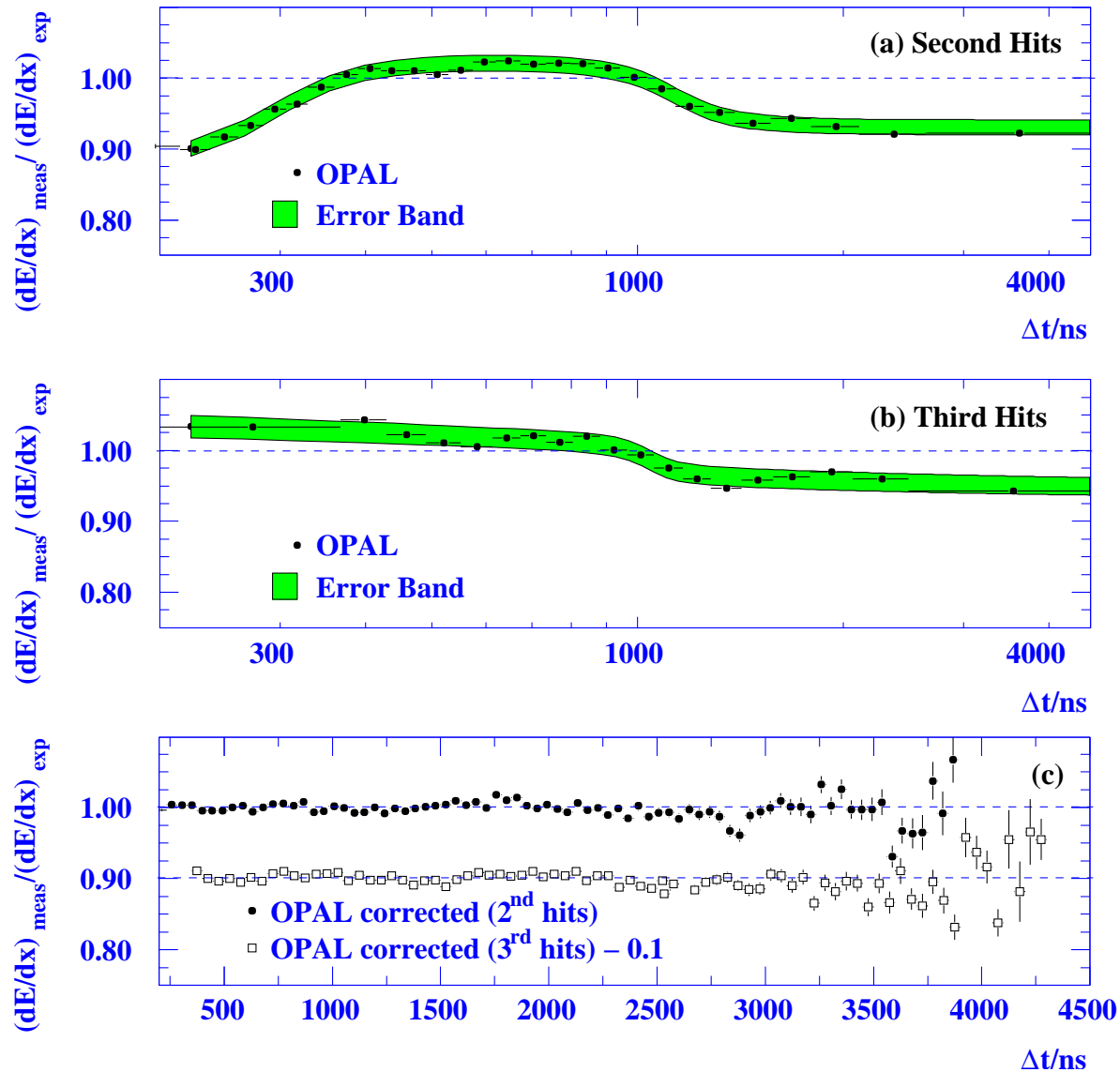


dE/dx Calibration

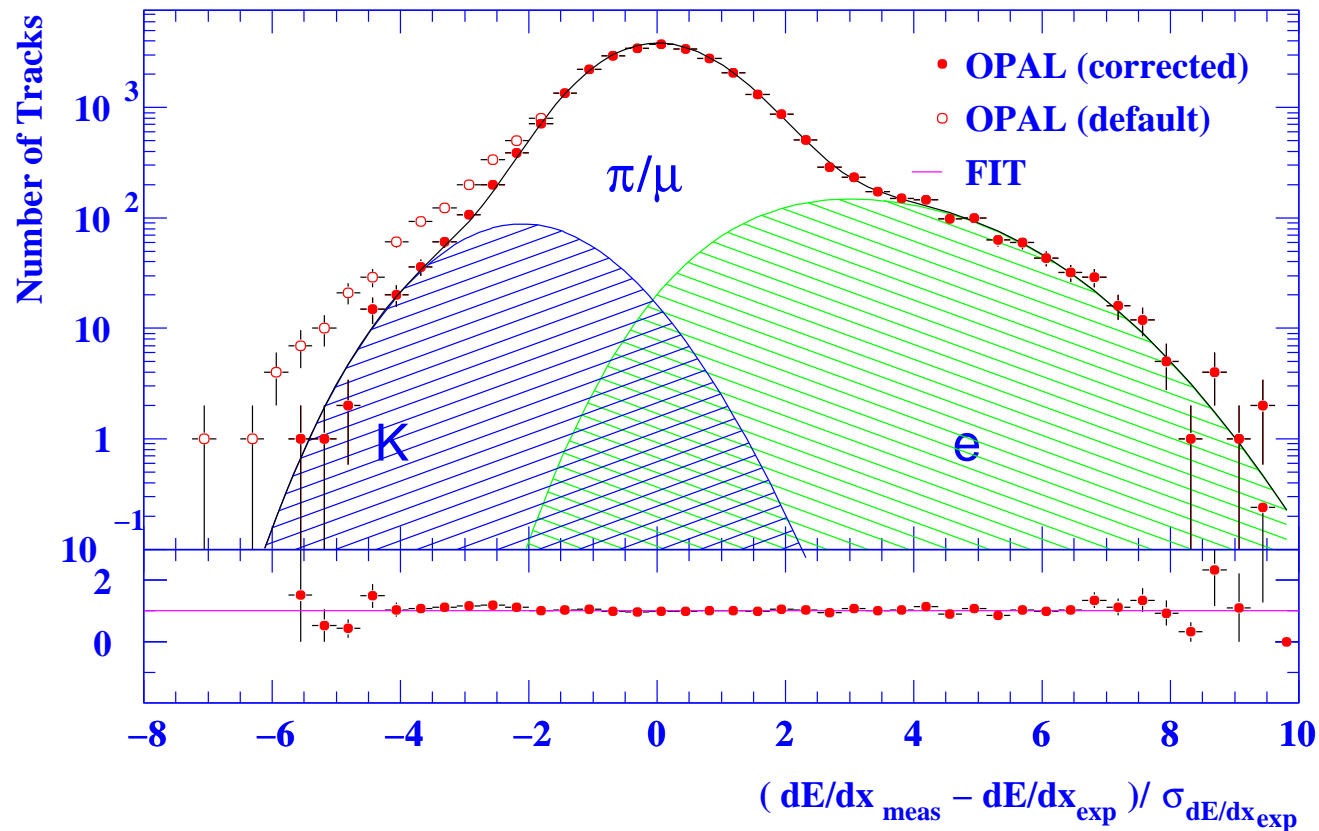


- Correction using Reference Pulse (RP)
- Systematic Deviations
 - $\Delta t = 200$ ns ($\hat{=}$ 1 cm): $\approx 10\%$ too low
 - $400 < \Delta t < 1000$ ns: $\approx 5\%$ too high
 - $\Delta t > 1000$ ns: (7 – 8)% too low
- Improved RP using Tracks with 1st and 2nd Hits

dE/dx Calibration



dE/dx Residues




● Events Used:

- 3-prong τ -Decay **from DATA only**
- Momentum Range $p > 3 \text{ GeV}$
- At least 20 dE/dx Hits

● New Calibration:

- Good Agreement between DATA and Prediction
- Bias $(dE/dx)_{\text{meas}} / (dE/dx)_{\text{exp}} \approx 1\%$

- 
- Introduction
 - Experimental Aspects
 - Selection of the Signal Channels
 - Results
 - Conclusion

- **2-Meson Final States**
- **3-Meson Final States**
- **4-Meson Final States**

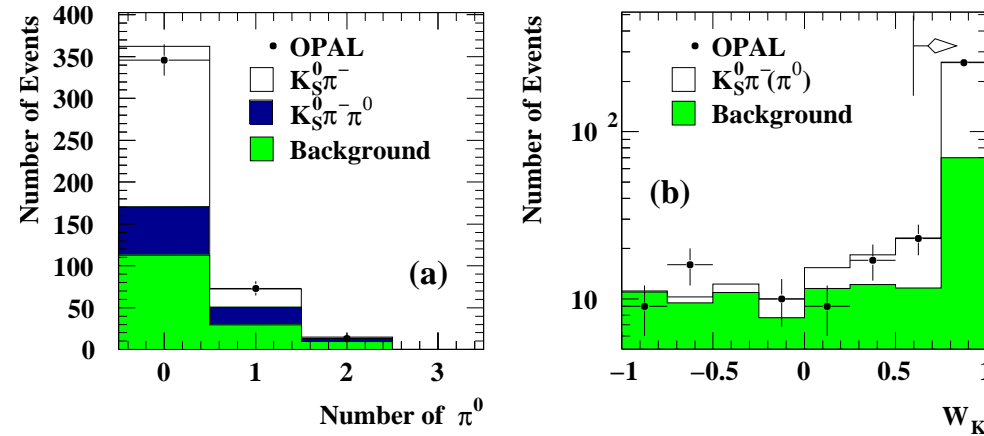
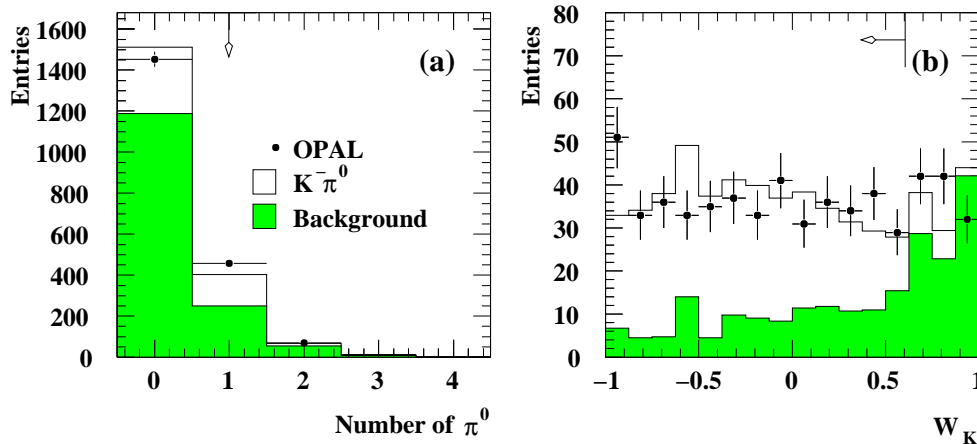
Two-Meson Selection

$K^- \pi^0 \nu_\tau$ Selection

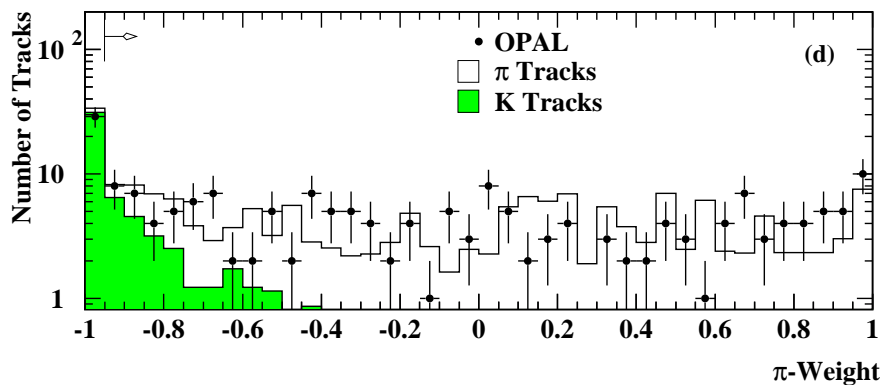
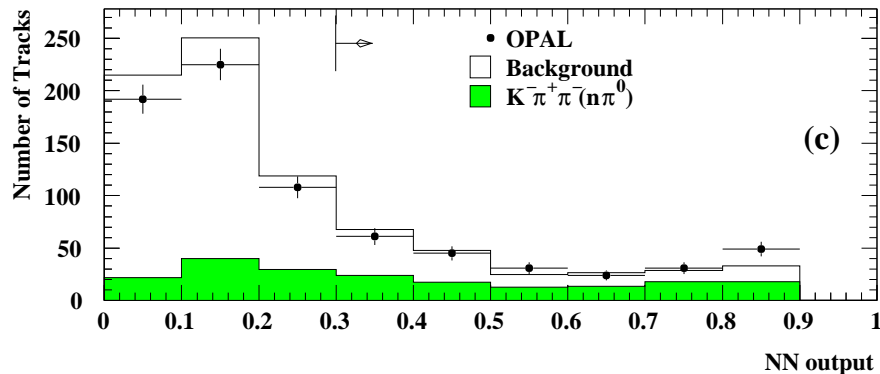
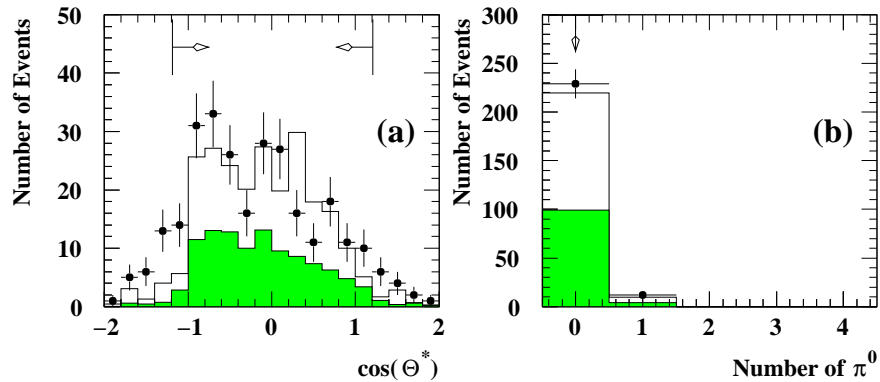
- Exactly 1 π^0 Candidate
- Exactly 1 Track
 - # dE/dx -Hits > 20
 - $3 \text{ GeV} < p < 35 \text{ GeV}$
 - π -Weight $W_\pi < 0.98$
 - K-Weight $W_K < 0.8$

$K^0 \pi^- \nu_\tau (\pi^0)$ Selection

- Exactly 1 K_S^0 Candidate
- Momentum $p > 3 \text{ GeV} \dots$
 - # dE/dx Hits > 20
 - π -Weight $W_\pi > 0.98$
- ... or $p < 3 \text{ GeV}$



Three/Four-Meson Selection

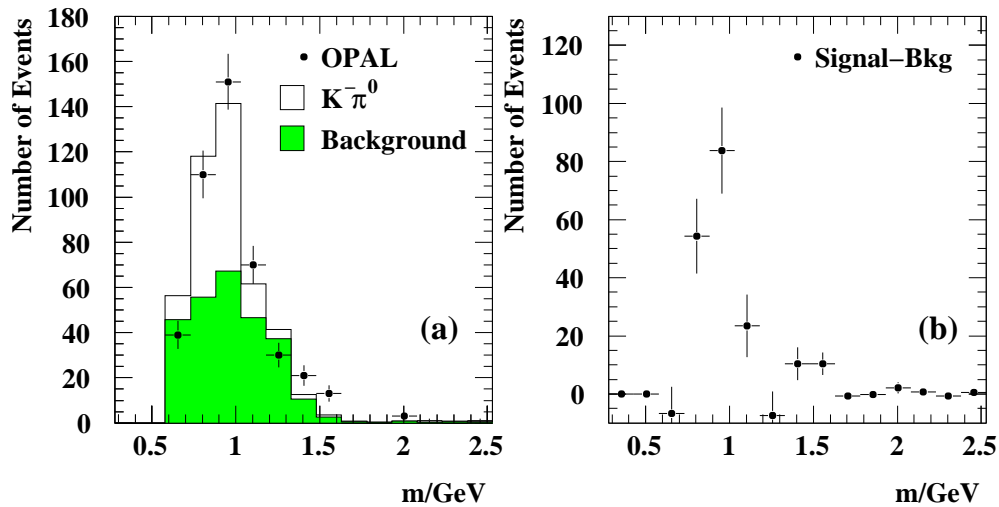


$K^- \pi^+ \pi^- \nu_\tau (\pi^0)$ -Selection

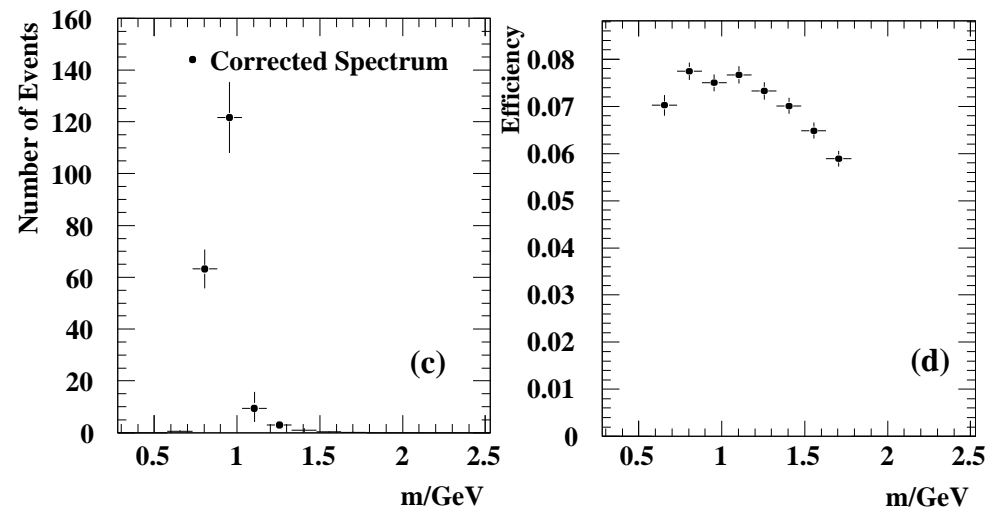
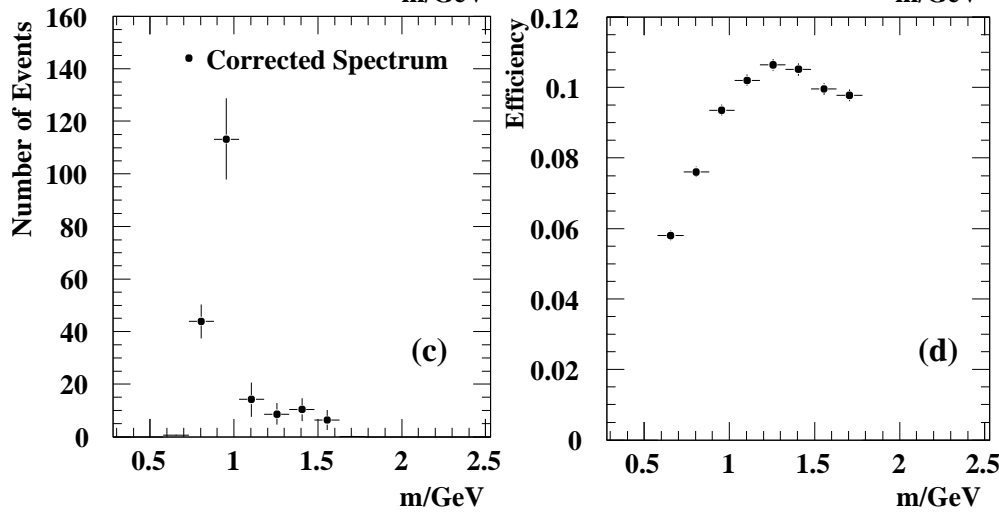
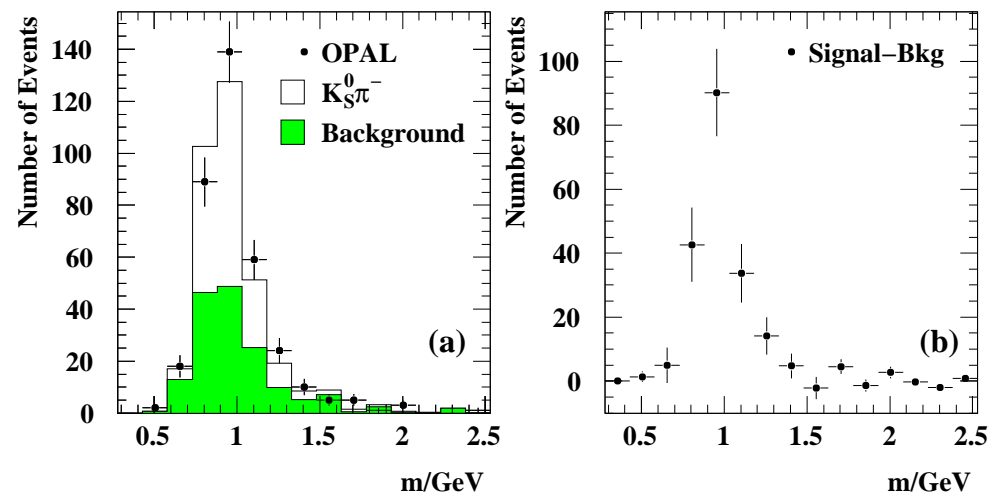
- 3prong-Vertex Fit Probability $> 10^{-7}$
- Exactly 1 K^- Candidate
 - $\# dE/dx \text{ Hits} > 20$
 - $3 \text{ GeV} < p < 35 \text{ GeV}$
 - NN-Output > 0.3
- Exactly 1 π^+ Candidate ($W_\pi > -0.95$)
- GOTTFRIED-JACKSON Angle $|\cos \Theta^*| < 1.2$
- No/One Reconstructed π^0 ($E_{\pi^0} > 2 \text{ GeV}$)

Two-Meson Spectra

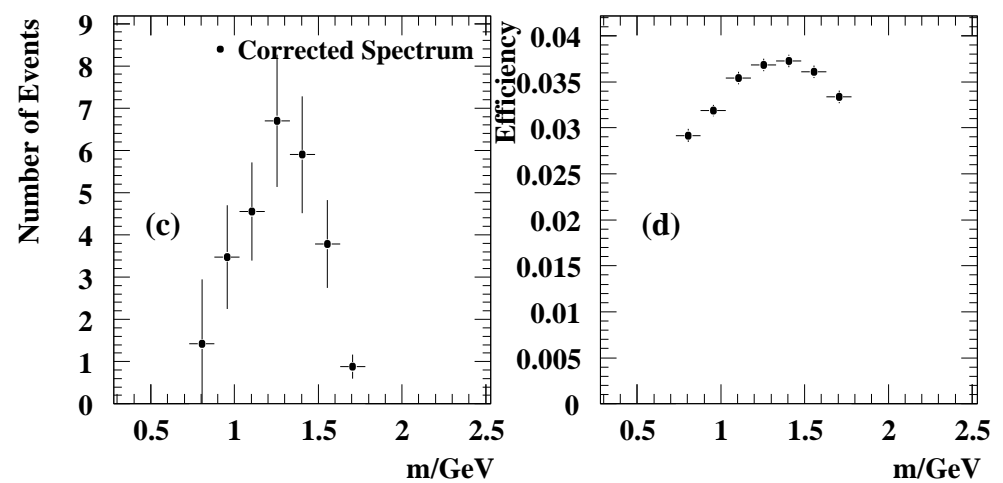
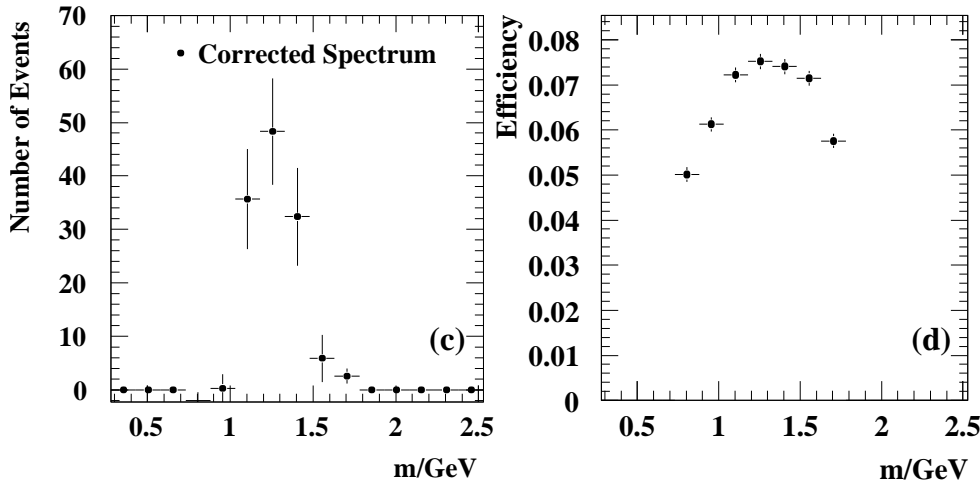
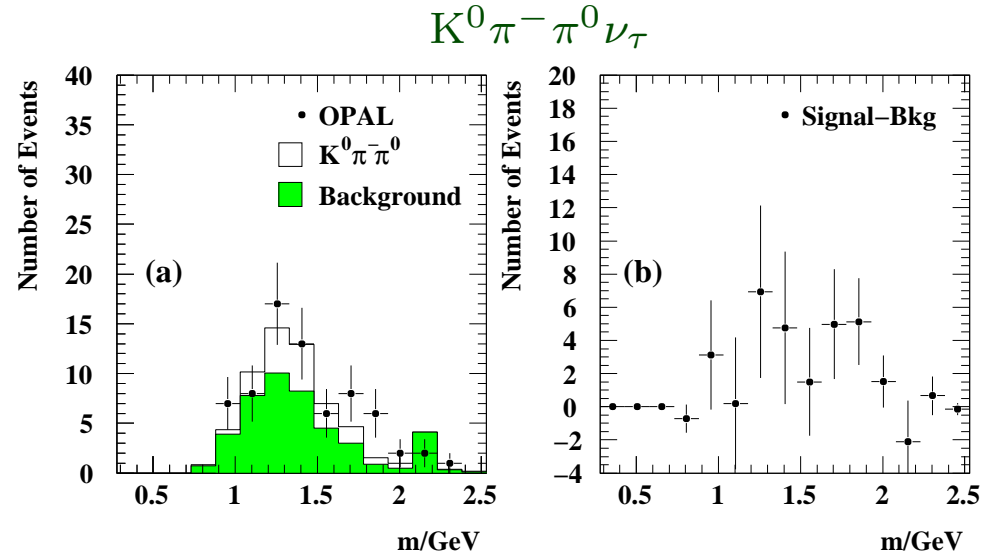
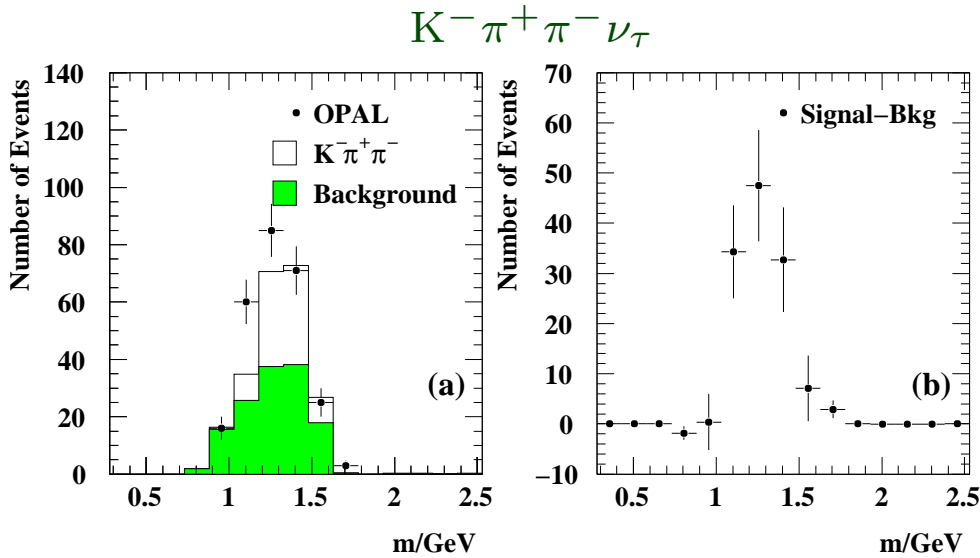
$K^- \pi^0 \nu_\tau$



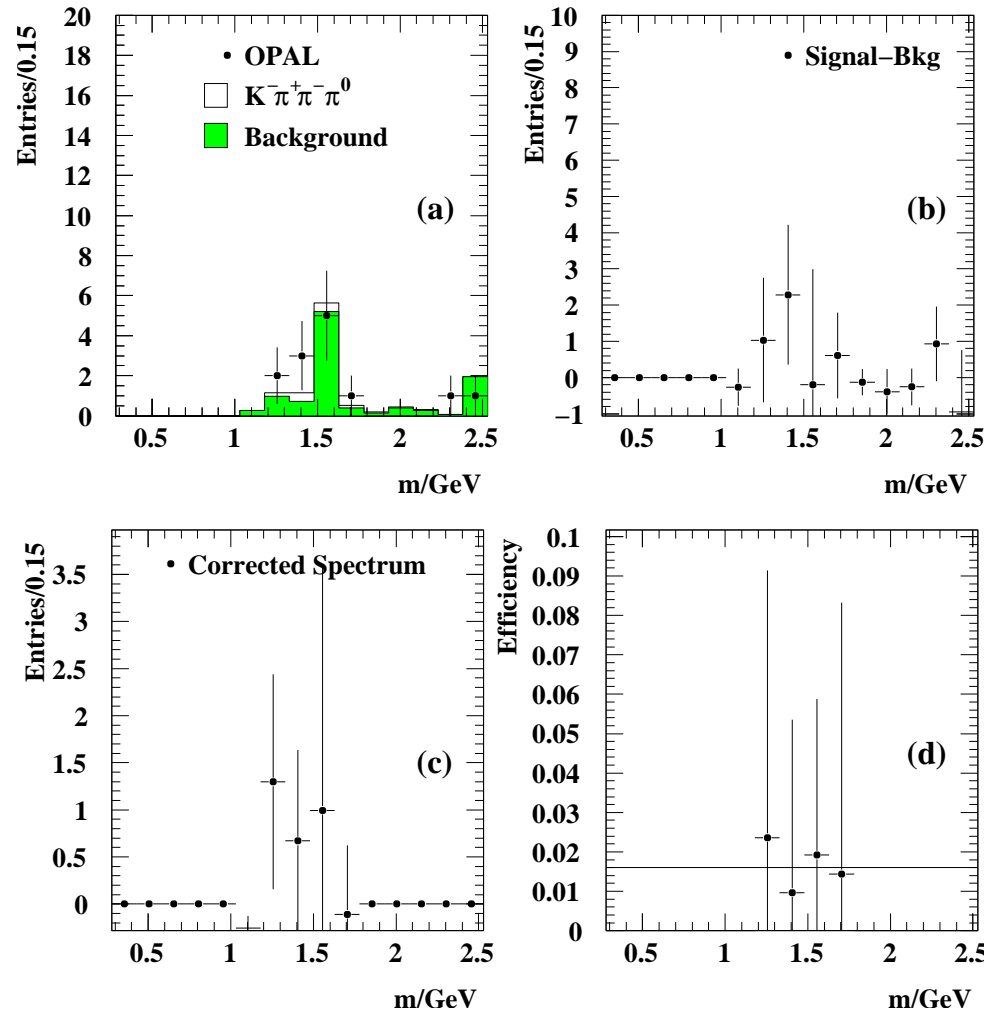
$K^0 \pi^- \nu_\tau$




Three-Meson Spektren



Four-Meson Spectra



- Statistically **not** Significant
- Replaced with Monte Carlo Prediction

- 
- Introduction
 - Experimental Aspects
 - Selection of the Signal Channels
 - Results
 - Conclusion

- **Branching Fractions**
- **Spectral Function**
- **Spectral Moments**
- **Mass of the Strange Quark**

Branching Fractions

- Number of Expected Events

$$N_i = N_i^{\not{\tau}} + (1 - f_{\text{bkg}}^{\not{\tau}}) \cdot N^{\tau} \sum_j \varepsilon_{ij} B_j F_j^{\text{Bias}}$$

- $N_i^{\not{\tau}}$: non- τ Background

- $f_{\text{bkg}}^{\not{\tau}}$: Fraction of non- τ Background

- N^{τ} : Number of τ -Events

- ε_{ij} : Efficiency

- F_j^{Bias} : Bias Factor

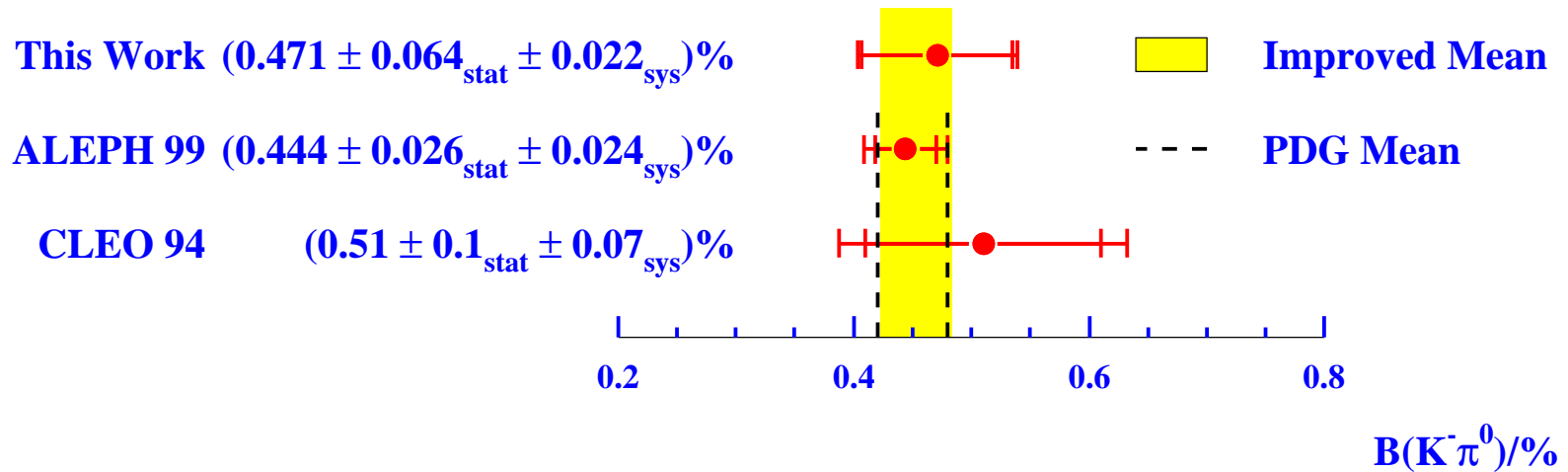
- B_j : Branching Fraction

- Simultaneous χ^2 -Fit:

$$\chi^2 = \sum_{\text{K}^- \pi^0 \nu_{\tau} \text{ K}^- \pi^+ \pi^- \nu_{\tau}} \left(\frac{N_{\text{meas}} - N_{\text{exp}}}{\sigma} \right)^2 + \sum_{j \in \text{Other}} \left(\frac{B_j - B_{j, \text{PDG}}}{\sigma_j} \right)^2$$

- Other Channels Consistent with PDG

Branching Fraction $K^- \pi^0 \nu_\tau$

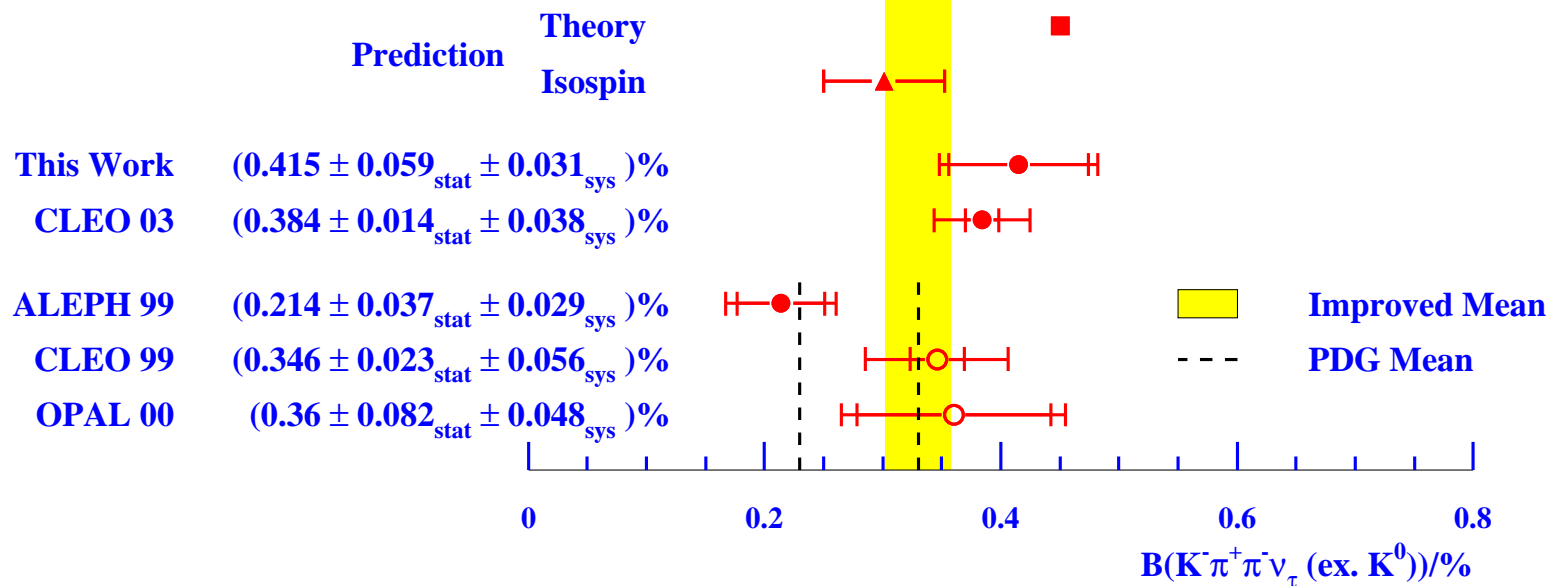


- First OPAL Measurement
- Good Agreement with PDG Average
- Use new Average for Spectral Function/Moments

$$B_{\text{av}}(\tau^- \rightarrow K^- \pi^0 \nu_\tau) = (0.453 \pm 0.030)\%$$

BaBar 2004: $B(\tau^- \rightarrow K^- \pi^0 \nu_\tau) = 0.438 \pm 0.004_{\text{stat}} \pm 0.022_{\text{sys}}$ (see Fabrizio's Talk)

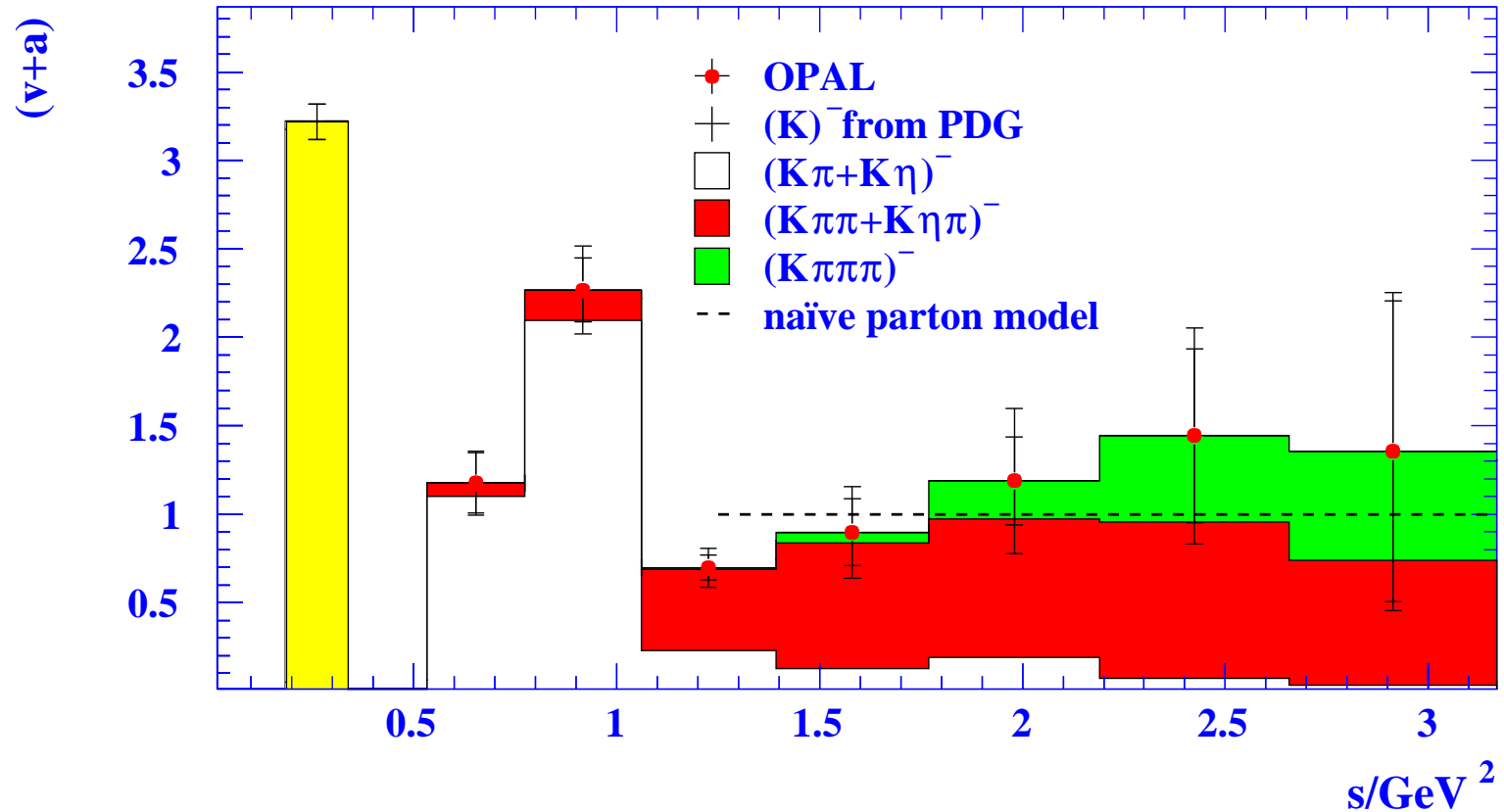
Branching Fraction $K^- \pi^+ \pi^- \nu_\tau$



- Result Consistent with
 - Previous OPAL Measurement
 - CLEO Measurement
- PDG Average Dominated by ALEPH-Measurement (Discrepancy $\sim 3\sigma$)
- Use new Average for Spectral Function/Moments

$$B_{\text{av}}(\tau^- \rightarrow K^- \pi^+ \pi^- \nu_\tau) = (0.330 \pm 0.028)\%$$

The Strangeness Spectral Function



$$v_J^S(s)/a_J^S(s) = \frac{m_\tau^2}{6|V_{us}|^2 S_{ew}} \left(1 - \frac{s}{m_\tau^2}\right)^{-2} \left(1 + \frac{2s}{m_\tau^2}\right)^{-J} \\ \times \frac{B(\tau \rightarrow (V/A)^{(S=-1)} \nu_\tau)}{B(\tau \rightarrow e^- \bar{\nu}_e \nu_\tau)} \frac{1}{N_{V/A}} \frac{dN_{V/A}}{ds}$$

Systematic Uncertainties

- PDG Branching Fractions Δ_B
- K- π Separation $\Delta_{dE/dx}$
- Identification of neutral Kaons $\Delta_{K_S^0}$
- Energy/Momentum Scale Δ_E/Δ_p
- Mass Correction Procedure Δ_{mcorr}

$(s\text{-range})/\text{GeV}^2$	Δ_B	$\Delta_{dE/dx}$	$\Delta_{K_S^0}$	Δ_E	Δ_p	Δ_{mcorr}	$\Delta_{\text{sys}}^{\text{tot}}$	Δ_{stat}	V+A
(0.18, 0.34)	0.10	--	--	--	--	--	0.10	--	3.22±0.10
(0.53, 0.77)	0.04	0.006	0.006	0.007	0.003	0.06	0.07	0.17	1.17±0.18
(0.77, 1.06)	0.13	0.011	0.011	0.014	0.001	0.11	0.17	0.18	2.27±0.25
(1.06, 1.39)	0.08	0.003	0.003	0.004	0.001	0.03	0.09	0.07	0.69±0.11
(1.39, 1.77)	0.18	0.005	0.005	0.005	0.002	0.05	0.18	0.19	0.90±0.26
(1.77, 2.19)	0.32	0.006	0.007	0.007	0.003	0.06	0.33	0.25	1.22±0.41
(2.19, 2.66)	0.35	0.007	0.009	0.009	0.003	0.07	0.36	0.49	1.44±0.61
(2.66, 3.17)	0.30	0.007	0.008	0.008	0.003	0.07	0.31	0.85	1.35±0.90

The Spectral Moments

$$R_{\tau, S}^{kl} = \int_0^{m_\tau^2} ds \left(1 - \frac{s}{m_\tau^2}\right)^k \left(\frac{s}{m_\tau^2}\right)^l \sum_{\tau^- \rightarrow \nu_\tau X_S^-} \frac{B(\tau \rightarrow (V/A)^{(S=-1, J=0/1)} \nu_\tau)}{B(\tau^- \rightarrow e^- \bar{\nu}_e \nu_\tau)} \frac{dN_{V/A}}{ds} \frac{1}{N_{V/A}}$$

- B : Branching Fractions
- $dN_{V/A}/ds$: Invariant Mass Spectrum
- $\left(1 - \frac{s}{m_\tau^2}\right)^k \left(\frac{s}{m_\tau^2}\right)^l$: Weighting Function

The Spectral Moments

$$R_{\tau,S}^{kl} = \int_0^{m_\tau^2} ds \left(1 - \frac{s}{m_\tau^2}\right)^k \left(\frac{s}{m_\tau^2}\right)^l \sum_{\tau^- \rightarrow \nu_\tau X_S^-} \frac{B(\tau \rightarrow (V/A)^{(S=-1, J=0/1)} \nu_\tau)}{B(\tau^- \rightarrow e^- \bar{\nu}_e \nu_\tau)} \frac{dN_{V/A}}{ds} \frac{1}{N_{V/A}}$$

- **B : Branching Fractions**
- **$dN_{V/A}/ds$: Invariant Mass Spectrum**
- **$\left(1 - \frac{s}{m_\tau^2}\right)^k \left(\frac{s}{m_\tau^2}\right)^l$: Weighting Function**

kl	$R_{\tau,S}^{kl}$	Δ_{stat}	$\Delta_{dE/dx}$	$\Delta_{K_S^0}$	Δ_E	Δ_p	Δ_{mcorr}
00	0.1677 ± 0.0050	0.0050	---	---	---	---	---

The Spectral Moments

$$R_{\tau,S}^{kl} = \int_0^{m_\tau^2} ds \left(1 - \frac{s}{m_\tau^2}\right)^k \left(\frac{s}{m_\tau^2}\right)^l \sum_{\tau^- \rightarrow \nu_\tau X_S^-} \frac{B(\tau \rightarrow (V/A)^{(S=-1, J=0/1)} \nu_\tau)}{B(\tau^- \rightarrow e^- \bar{\nu}_e \nu_\tau)} \frac{dN_{V/A}}{ds} \frac{1}{N_{V/A}}$$

- B : Branching Fractions
- $dN_{V/A}/ds$: Invariant Mass Spectrum
- $\left(1 - \frac{s}{m_\tau^2}\right)^k \left(\frac{s}{m_\tau^2}\right)^l$: Weighting Function

kl	$R_{\tau,S}^{kl}$	Δ_{stat}	$\Delta_{dE/dx}$	$\Delta_{K_S^0}$	Δ_E	Δ_p	Δ_{mcorr}
00	0.1677 ± 0.0050	0.0050	---	---	---	---	---
10	0.1161 ± 0.0038	0.0035	0.0006	0.0006	0.0005	0.0002	0.0011
11	0.0298 ± 0.0012	0.0011	0.0001	0.0001	0.0001	0.0001	0.0004
12	0.0107 ± 0.0006	0.0005	0.0002	0.0002	0.0002	0.0001	0.0002
13	0.0048 ± 0.0004	0.0002	0.0002	0.0002	0.0002	0.0001	0.0001
20	0.0862 ± 0.0028	0.0025	0.0006	0.0006	0.0006	0.0002	0.0008
21	0.0191 ± 0.0007	0.0006	0.0001	0.0001	0.0001	0.0001	0.0002
30	0.0671 ± 0.0022	0.0020	0.0005	0.0005	0.0004	0.0002	0.0006
40	0.0539 ± 0.0018	0.0016	0.0003	0.0003	0.0003	0.0001	0.0005

SU(3)_{Flavor} Symmetry Breaking

CKM Weighted Difference of strange and non-strange Moments

$$\delta R_{\tau}^{kl} = \frac{R_{\tau, \text{non-S}}^{kl}}{|V_{ud}|^2} - \frac{R_{\tau, S}^{kl}}{|V_{us}|^2}$$

• $R_{\tau, \text{non-S}}^{kl}$ updated from **Eur.Phys.J.C7:571-593,1999**

• CKM Inputs

$$|V_{us}| = 0.2196 \pm 0.0023$$

$$|V_{ud}| = 0.9734 \pm 0.0008$$

kl	OPAL			ALEPH		
	$\delta R_{\tau, S}$	Δ_{exp}	$\Delta V_{us} $	$\delta R_{\tau, S}$	Δ_{exp}	$\Delta V_{us} $
00	0.262 ± 0.117	0.102	0.058	0.374 ± 0.133	0.118	0.062
10	0.278 ± 0.088	0.078	0.040	0.398 ± 0.077	0.065	0.042
20	0.304 ± 0.065	0.058	0.030	0.399 ± 0.054	0.044	0.031
30	0.325 ± 0.051	0.046	0.023	0.396 ± 0.042	0.034	0.024
40	0.344 ± 0.042	0.037	0.019	0.395 ± 0.034	0.028	0.020

SU(3)_{Flavor} Symmetry Breaking

CKM Weighted Difference of strange and non-strange Moments

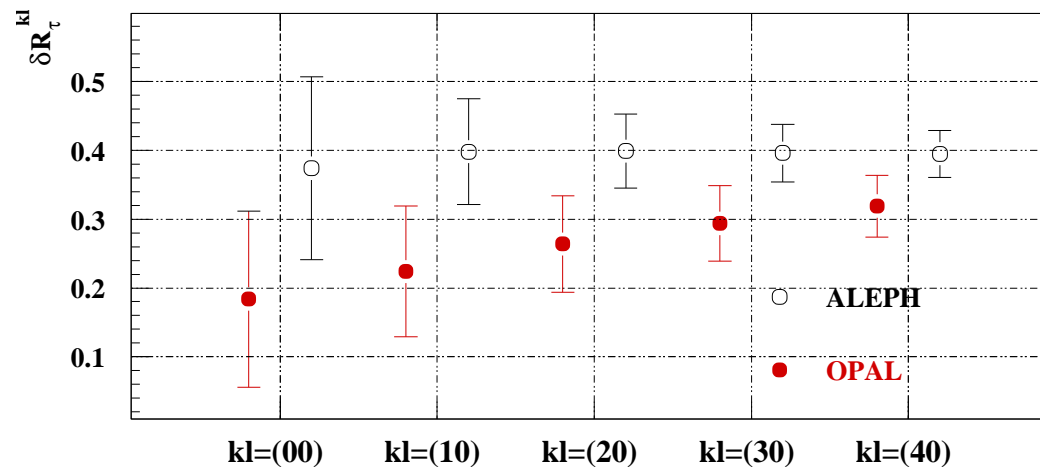
$$\delta R_{\tau}^{kl} = \frac{R_{\tau, \text{non-S}}^{kl}}{|V_{ud}|^2} - \frac{R_{\tau, S}^{kl}}{|V_{us}|^2}$$

• $R_{\tau, \text{non-S}}^{kl}$ updated from **Eur.Phys.J.C7:571-593,1999**

• CKM Inputs

$$|V_{us}| = 0.2196 \pm 0.0023$$

$$|V_{ud}| = 0.9734 \pm 0.0008$$



SU(3)_{Flavor} Symmetry Breaking

$$m_s^2(m_\tau^2) \Big|_{kl} \simeq \frac{m_\tau^2}{(1 - \epsilon_d^2) \Delta_{kl}^{(2)}(a_\tau)} \left(\frac{\delta R_\tau^{kl}}{24 S_{ew}} + 2\pi^2 \frac{\langle \delta O_4(m_\tau^2) \rangle}{m_\tau^4} Q_{kl}(a_\tau) \right)$$

- δR_τ^{kl} : Weighted Difference of Moments

- S_{ew} : Electroweak Correction

- $\Delta_{kl}^{(2)}/Q_{kl}$: Pert. Correction dim-2/4

- ϵ_d : $m_d/m_s = 0.053 \pm 0.002$

- $\langle \delta O_4(m_\tau^2) \rangle = (1.5 \pm 0.4) \times 10^{-3} \text{ GeV}^4$
Quark-Condensate

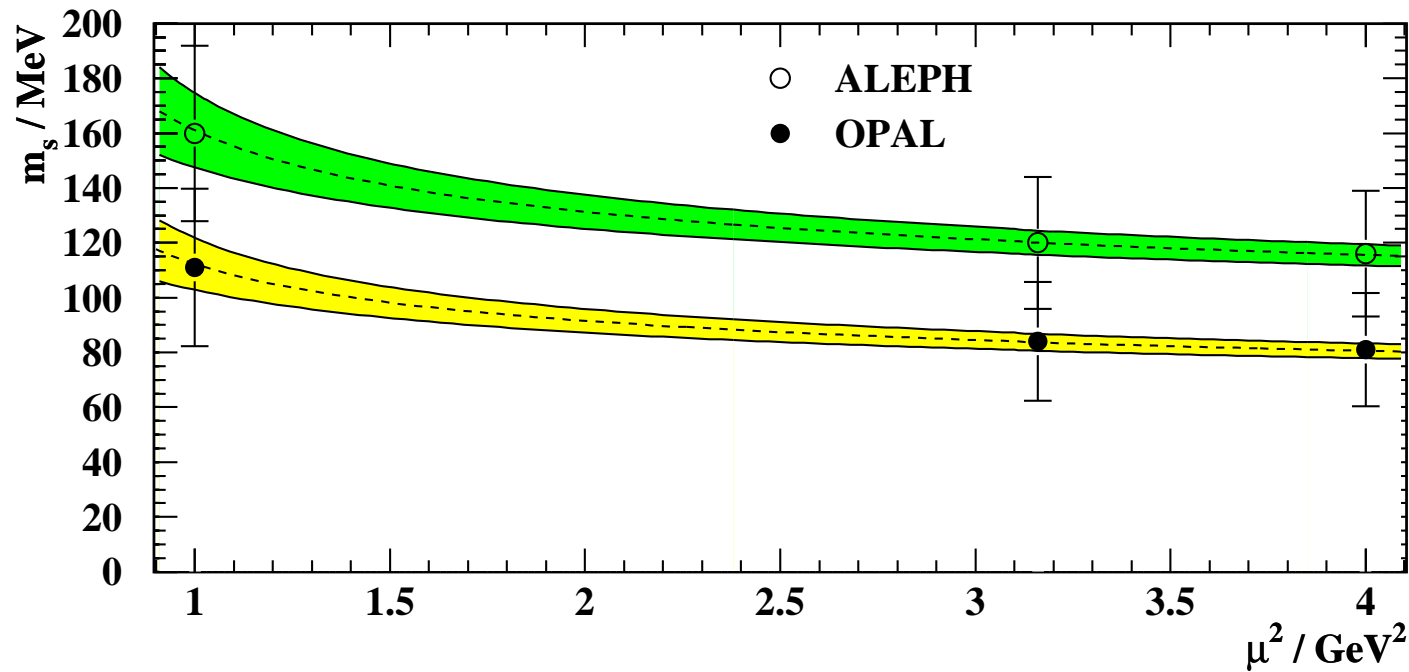
kl	m_s / MeV	σ / MeV			Korrelationen/%				
		σ_{theo}	$\sigma_{ V_{us} }$	σ_{exp}	00	10	20	30	40
00	79.5 ± 49.7	10.0	27.3	39.4	100	59	46	31	22
10	76.0 ± 34.7	12.0	16.7	26.7		100	53	38	29
20	82.4 ± 29.5	16.2	12.4	19.7			100	37	29
30	91.1 ± 32.3	24.0	10.7	17.1				100	24
40	85.6 ± 30.9	25.2	8.3	13.5					100

- Strange Quark Mass at $\mu^2 = m_\tau^2$:

$$\begin{aligned} m_s(m_\tau^2) &= (84 \pm 14_{\text{exp}} \pm 6_{V_{us}} \pm 17_{\text{theo}}) \text{ MeV} \\ &= (84_{-26}^{+20}) \text{ MeV} \end{aligned}$$

m_s at $\mu^2 = 1 \text{ GeV}^2$ and $\mu^2 = 4 \text{ GeV}^2$

- Using Runge-Kutta Procedure
- Use 4-loop β and γ Function



Opal

$$m_s(1 \text{ GeV}^2) = (111^{+26}_{-35}) \text{ MeV}$$

$$m_s(m_\tau^2) = (84^{+20}_{-26}) \text{ MeV}$$

$$m_s(4 \text{ GeV}^2) = (82^{+19}_{-25}) \text{ MeV}$$

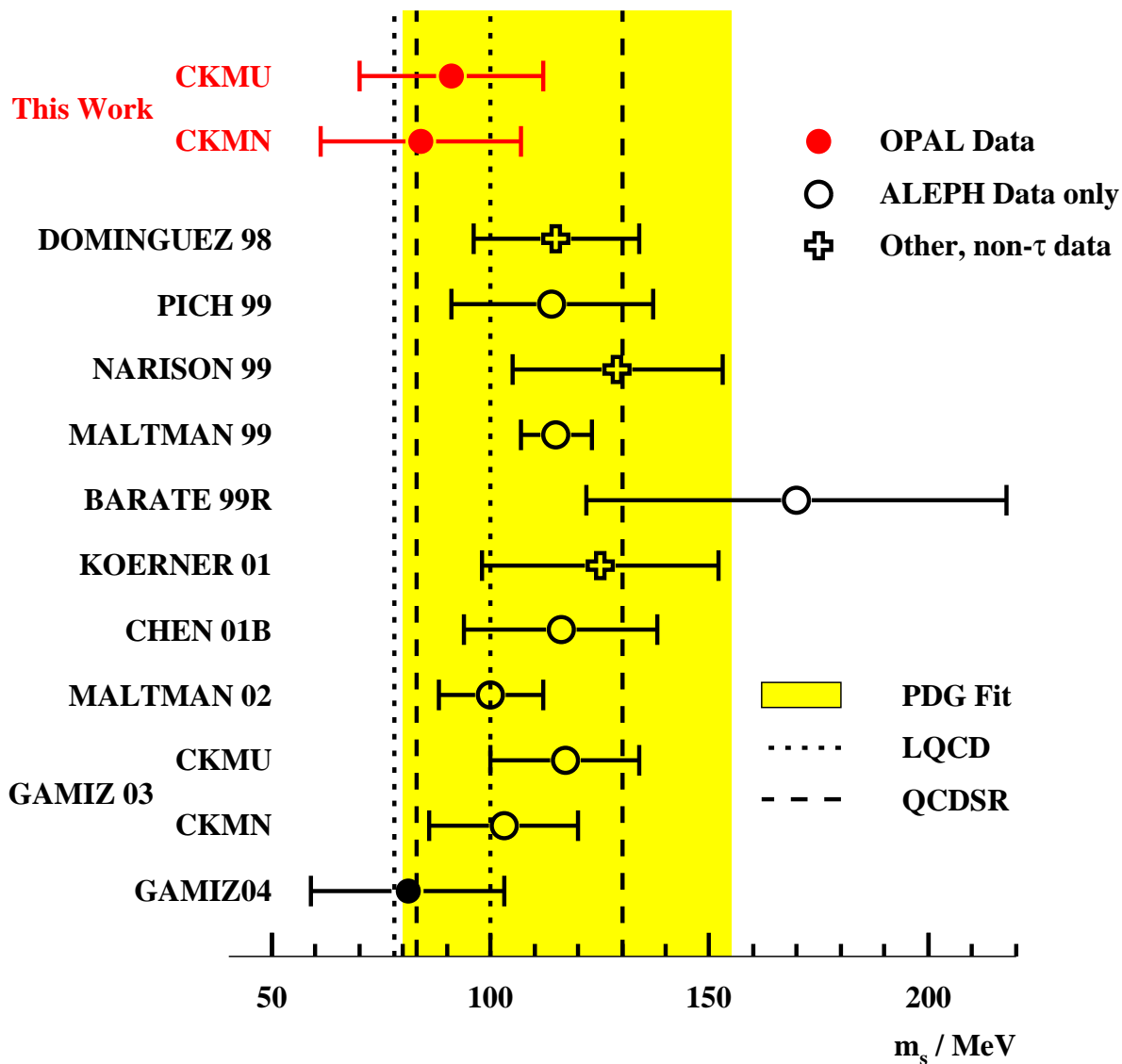
ALEPH

$$m_s(1 \text{ GeV}^2) = (160^{+28}_{-35}) \text{ MeV}$$

$$m_s(m_\tau^2) = (120^{+21}_{-26}) \text{ MeV}$$

$$m_s(4 \text{ GeV}^2) = (116^{+20}_{-25}) \text{ MeV}$$

m_s Comparison ($\mu^2 = 4 \text{ GeV}^2$)



Matrix Elements

● w/o CKM Unitarity (CKMN)

$$V_{ud}^{\text{CKMN}} = 0.9734 \pm 0.0008$$

$$V_{us}^{\text{CKMN}} = 0.2196 \pm 0.0023$$

$$V_{ub}^{\text{CKMN}} = (3.6 \pm 0.7) \cdot 10^{-3}$$

● w/ CKM-Unitarity (CKMU)

$$V_{ud}^{\text{CKMU}} = 0.9749 \pm 0.0004$$

$$V_{us}^{\text{CKMU}} = 0.2225 \pm 0.0019$$

$$V_{ub}^{\text{CKMU}} = (3.604 \pm 0.7) \cdot 10^{-3}$$

Summary

- Experimental Aspects
- Selection of the Signal Channels
- Results

- **Branching Fractions**

$$B(\tau^- \rightarrow K^- \pi^0 \nu_\tau) = (0.471 \pm 0.064_{\text{stat}} \pm 0.021_{\text{sys}})\%$$

$$B(\tau^- \rightarrow K^- \pi^+ \pi^- \nu_\tau) = (0.415 \pm 0.059_{\text{stat}} \pm 0.031_{\text{sys}})\%$$

- **The Strangeness Spectral Function**

- **Spectral Moments**

- **Mass of the Strange Quark**

$$m_s(1 \text{ GeV}^2) = (111^{+26}_{-35}) \text{ MeV}$$

$$m_s(m_\tau^2) = (84^{+20}_{-26}) \text{ MeV}$$

$$m_s(4 \text{ GeV}^2) = (82^{+19}_{-25}) \text{ MeV}$$

- Thanks to Norbert Wermes and Achim Stahl