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

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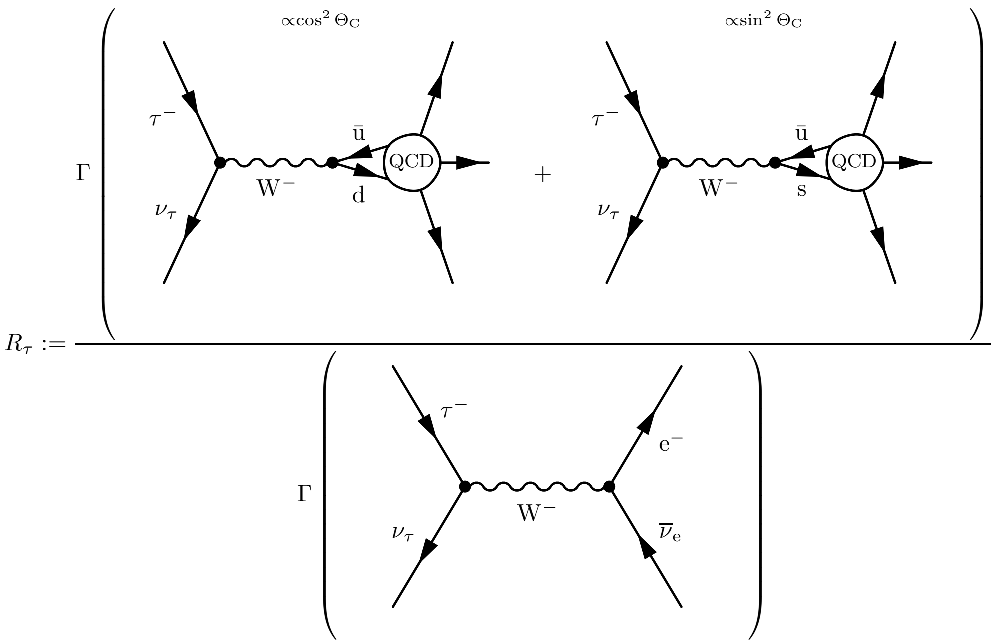
Outline

- 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

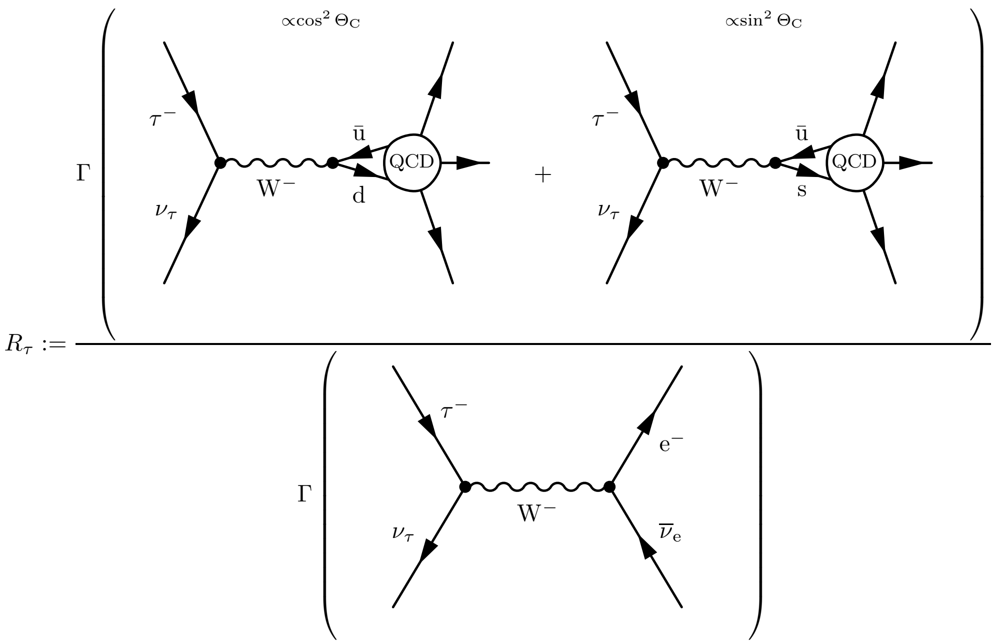


τ-Hadronic Width R_τ:

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

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

QCD and τ-Decays

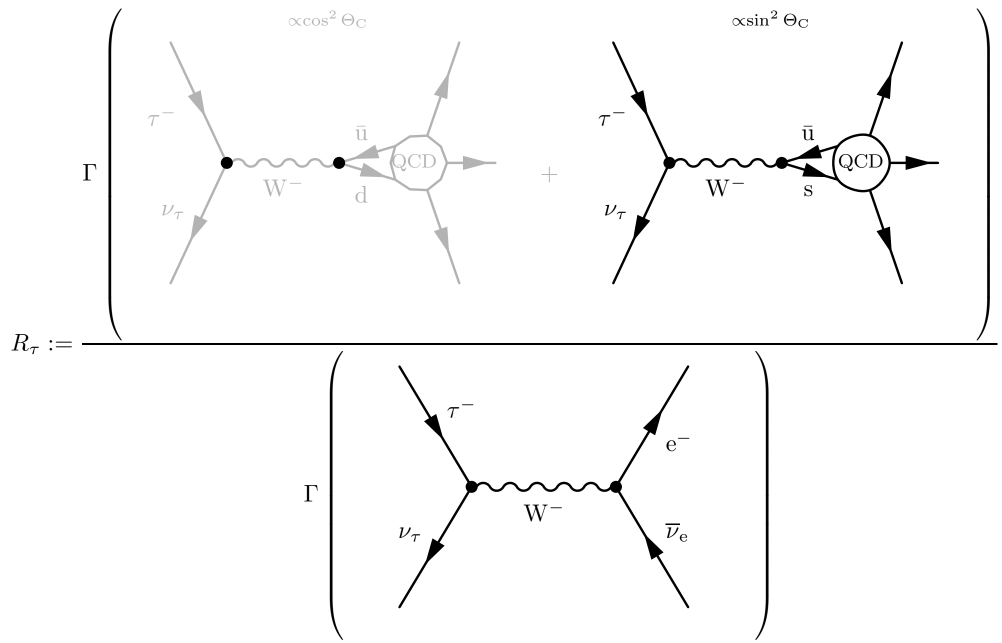


Input Quantities for QCD Studies:

- Spectral Functions

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

QCD and τ-Decays



Spectral Function in non-strange τ Decays:

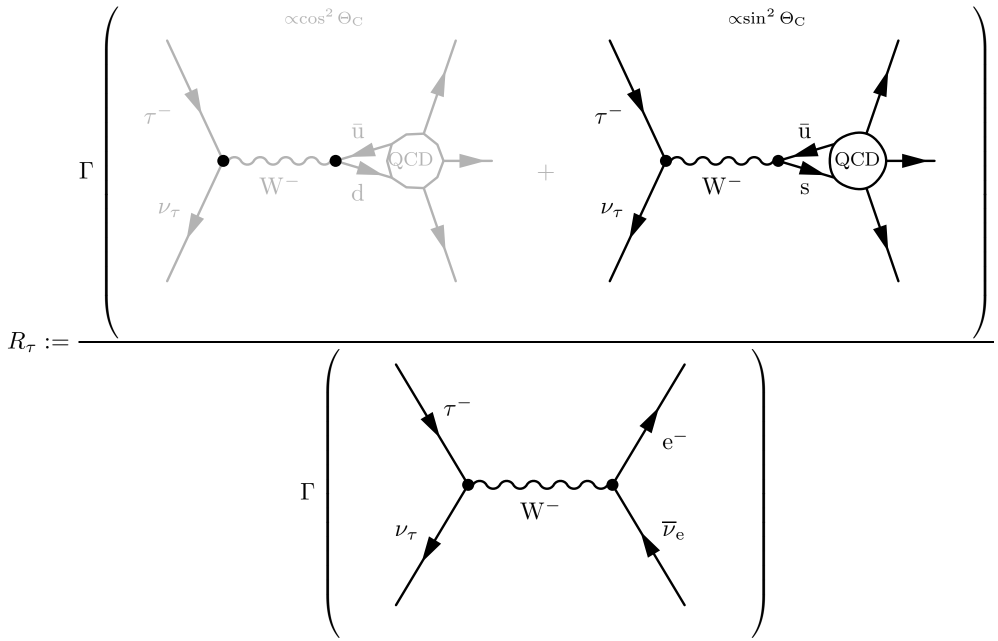
- OPAL: (**Eur.Phys.J.C7:571-593,1999**)

$$\alpha_s(m_\tau^2) = 0.348 \pm 0.010_{\text{exp}} \pm 0.019_{\text{theo}}$$
$$\alpha_s(m_{Z^0}^2) = 0.1219 \pm 0.0010_{\text{exp}} \pm 0.0017_{\text{theo}}$$

- 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



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** $(\alpha_s)_{\mathrm{strange}}$
  - **Determination of the Strange Quark Mass** m_s
  - **Measurement of the CKM Matrix Element** V_{us}

τ-Decays with Net-Strangeness

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

- Remarks
  - $\tau^- \to \text{K}^- \nu_\tau$ **from PDG**

τ-Decays with Net-Strangeness

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

- Remarks
  - $\tau^- \to \mathrm{K}^- \nu_\tau$ **from PDG**

τ-Decays with Net-Strangeness

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$(\mathrm{K}\pi)^-$	1.340 ± 0.050	$\tau^-\to\mathrm{K}^-\pi^0\nu_\tau$ $\tau^-\to\mathrm{K}^0\pi^-\nu_\tau$	0.450 ± 0.030 0.890 ± 0.040		
$(\mathrm{K}\pi\pi)^-$	0.708 ± 0.068	$\tau^-\to\mathrm{K}^0\pi^-\pi^0\nu_\tau$ $\tau^-\to\mathrm{K}^-\pi^+\pi^-\nu_\tau$	0.370 ± 0.040 0.280 ± 0.050	$\tau^-\to\mathrm{K}^-\pi^0\pi^0\nu_\tau$	0.058 ± 0.023
$(\mathrm{K}\pi\pi\pi)^-$	0.150 ± 0.045				
$\sum B^{\text{total}}_{\text{strange}}$		$\sum B^{\text{meas}}_{\text{strange}}$		$\sum B^{\text{external}}_{\text{strange}}$	

- Remarks
  - $\tau^- \to \mathrm{K}^-\nu_\tau$ **from PDG**

τ-Decays with Net-Strangeness

		Measured		Monte Carlo	
	$B_{\text{total}}/\%$	$\tau-$Decay	$B_{\text{PDG}}/\%$	$\tau-$Decay	$B_{\text{PDG}}/\%$
$(\mathrm{K})^-$	0.686 ± 0.023			$\tau^-\to\mathrm{K}^-\nu_\tau$	0.686 ± 0.023
$(\mathrm{K}\pi)^-$	1.340 ± 0.050	$\tau^-\to\mathrm{K}^-\pi^0\nu_\tau$ $\tau^-\to\mathrm{K}^0\pi^-\nu_\tau$	0.450 ± 0.030 0.890 ± 0.040		
$(\mathrm{K}\pi\pi)^-$	0.708 ± 0.068	$\tau^-\to\mathrm{K}^0\pi^-\pi^0\nu_\tau$ $\tau^-\to\mathrm{K}^-\pi^+\pi^-\nu_\tau$	0.370 ± 0.040 0.280 ± 0.050	$\tau^-\to\mathrm{K}^-\pi^0\pi^0\nu_\tau$	0.058 ± 0.023
$(\mathrm{K}\pi\pi\pi)^-$	0.150 ± 0.045	$\tau^-\to\mathrm{K}^-\pi^+\pi^-\pi^0\nu_\tau$	0.064 ± 0.024	$\tau^-\to\mathrm{K}^0\pi^-\pi^0\pi^0\nu_\tau$ $\tau^-\to\mathrm{K}^-\pi^0\pi^0\pi^0\nu_\tau$ $\tau^-\to\mathrm{K}^0\pi^-\pi^+\pi^-\nu_\tau$	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

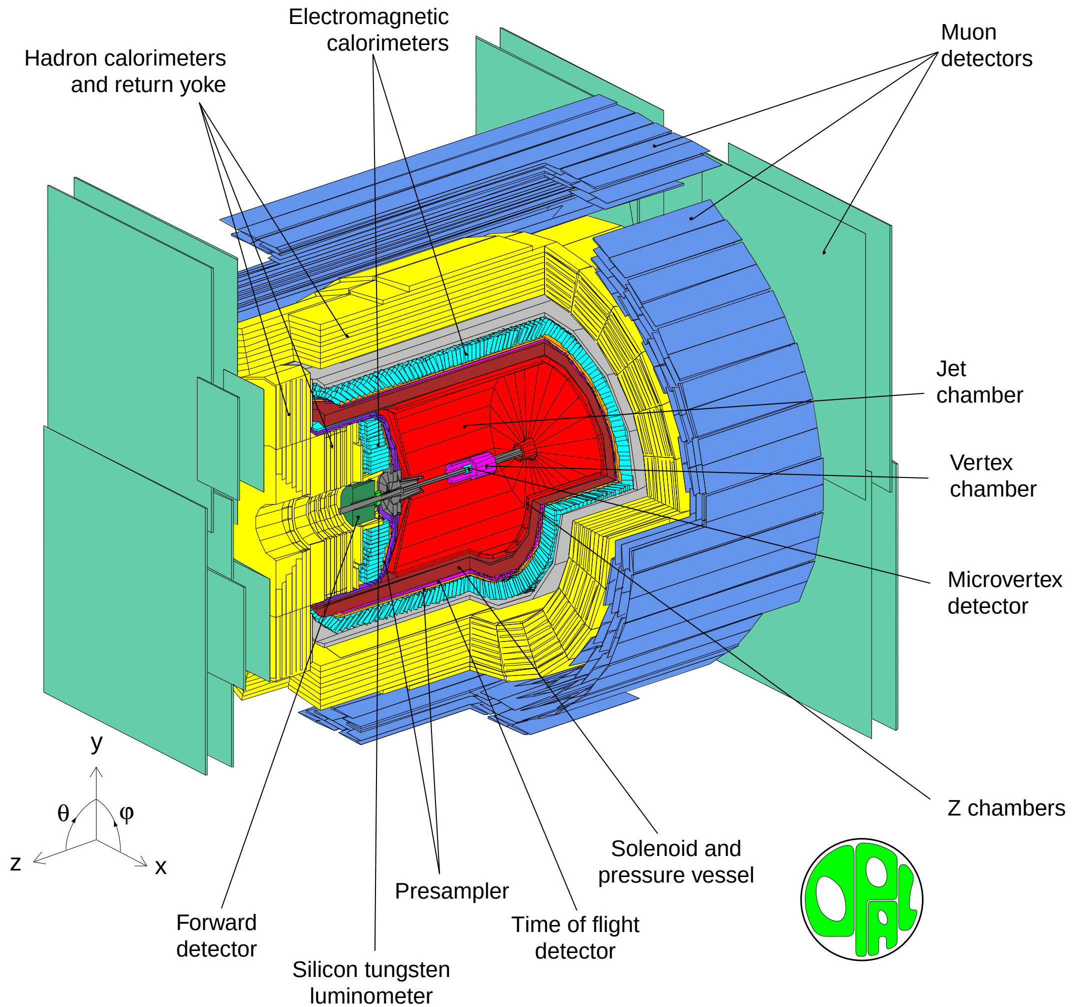
- $\tau^- \to \mathrm{K}^-\nu_\tau$ **from PDG**
- **For Final States** $(\mathrm{K}\pi)^-$, $(\mathrm{K}\pi\pi)^-$ **and** $(\mathrm{K}\pi\pi\pi)^-$, 93.4% **are Reconstructed**

τ-Decays with Net-Strangeness

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

- Remarks
  - $\tau^- \to \text{K}^- \nu_\tau$ **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**

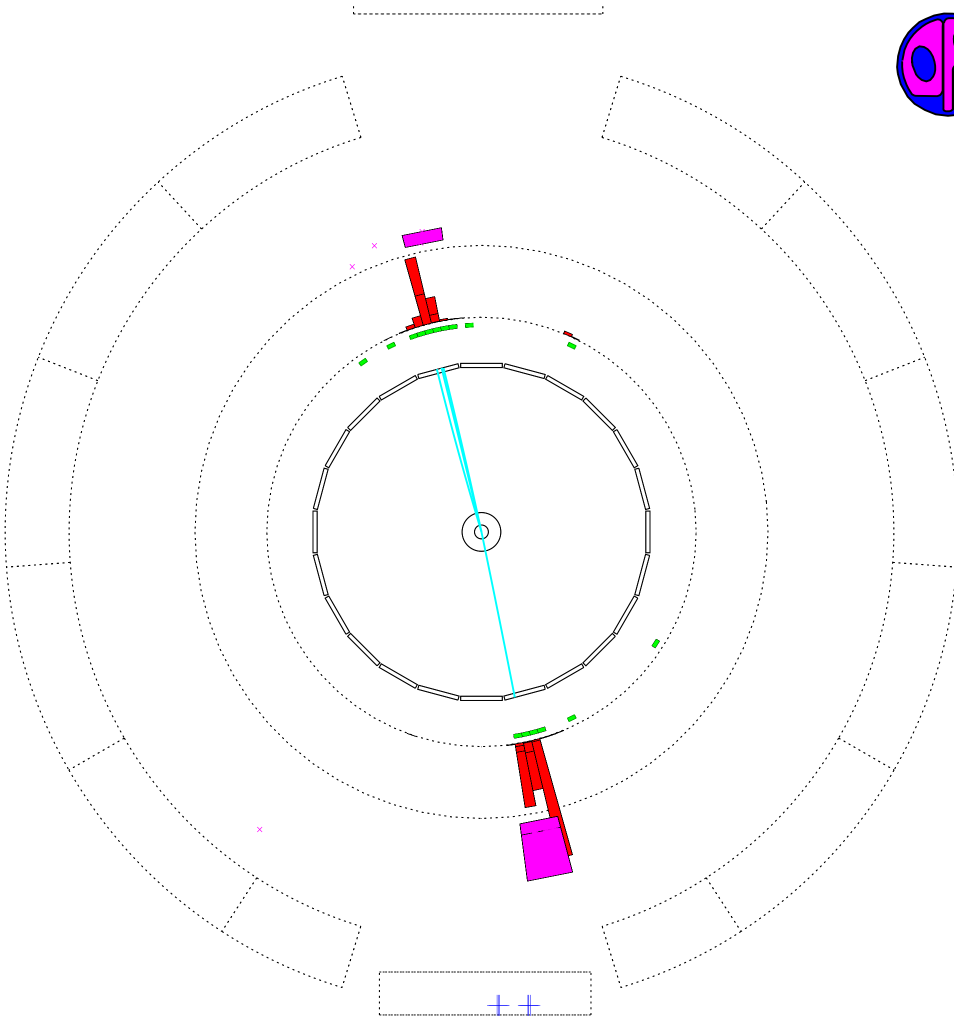
The Omni Purpouse Apparatus at LEP



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

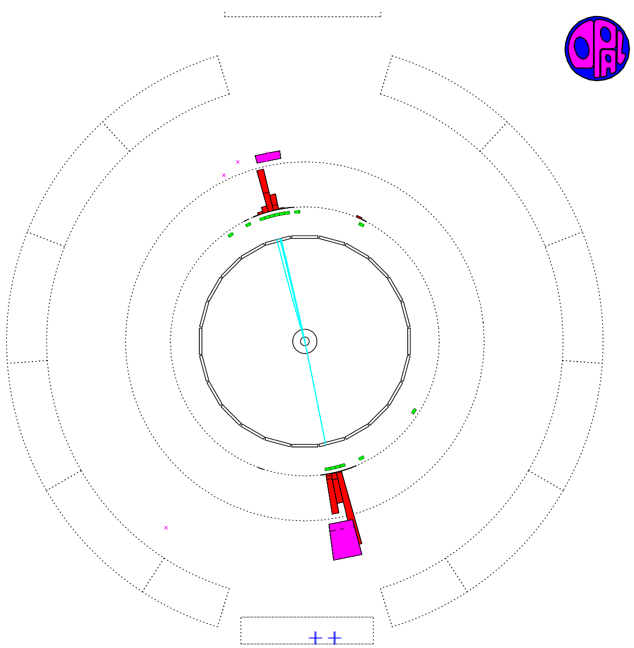
- **Identification of K ($\mathrm{d}E/\mathrm{d}x$ Measurement)**
- **Reconstruction of Photonen**
- **Reconstruction of K^0_S**

Typical τ-Event



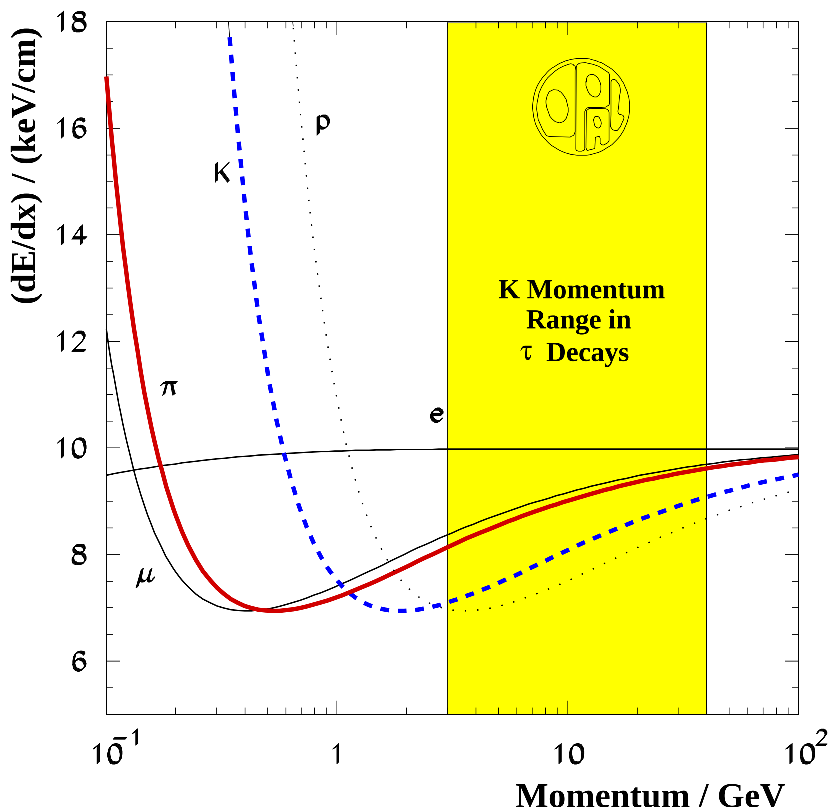
- Event Signature
  - **Back-to-back Jets**
  - **Small Number of Tracks**
  - **Strongly collimated ($\gamma \approx 25$)**
  - **Energy Deposits in ECAL/HCAL**

Typical τ-Event

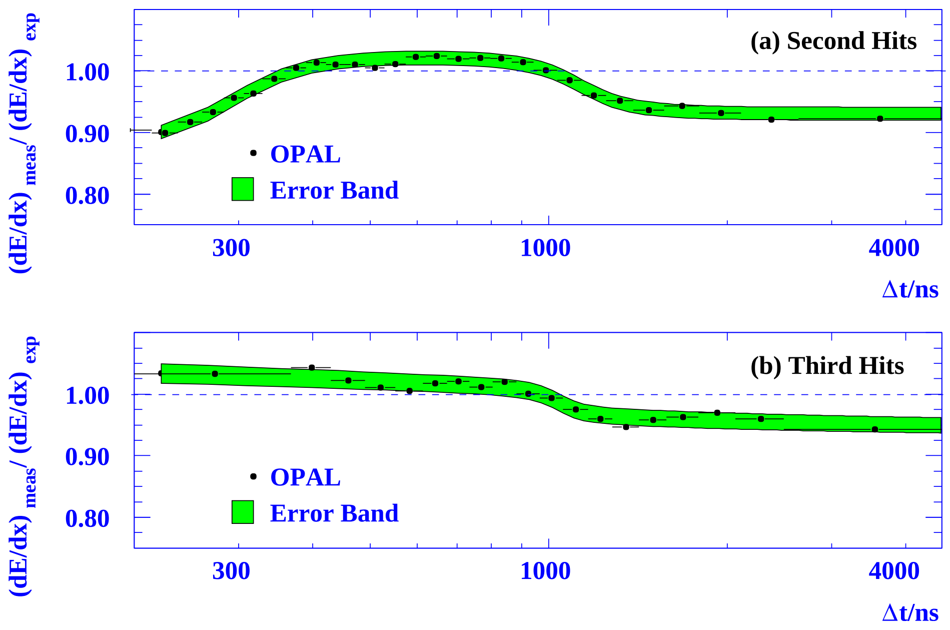


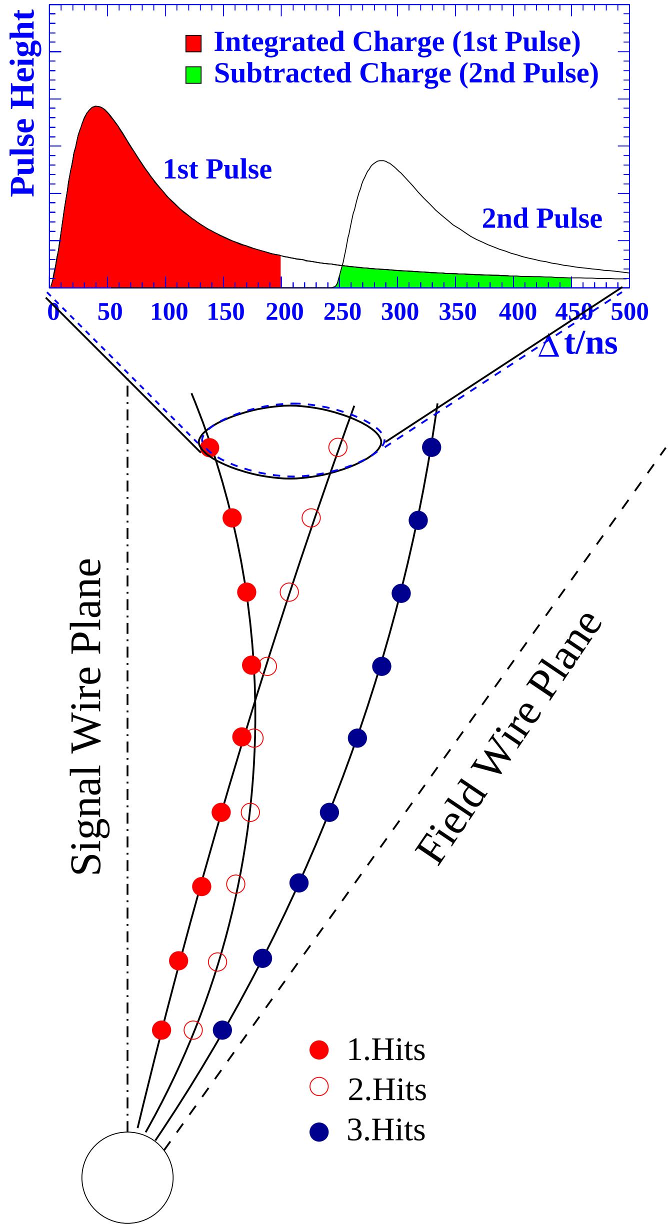
- OPAL Drift Chamber
  - **Optimized for Particle Identification**
  - **Argon/Methan/IsoButan (88.2%/9.8%/2.0%)**
  - **Pressure: 4bar**
  - **159 Measurements/Track (Barrel)**

- K^--π^--Identification
  - **Energy Loss Measurement ($\mathrm{d}E/\mathrm{d}x$)**
  - **Momentum Range $3\,\mathrm{GeV} < p_\mathrm{K} < 35\,\mathrm{GeV}$**
  - **Separation of $> 2\sigma$ (10% absolute)**



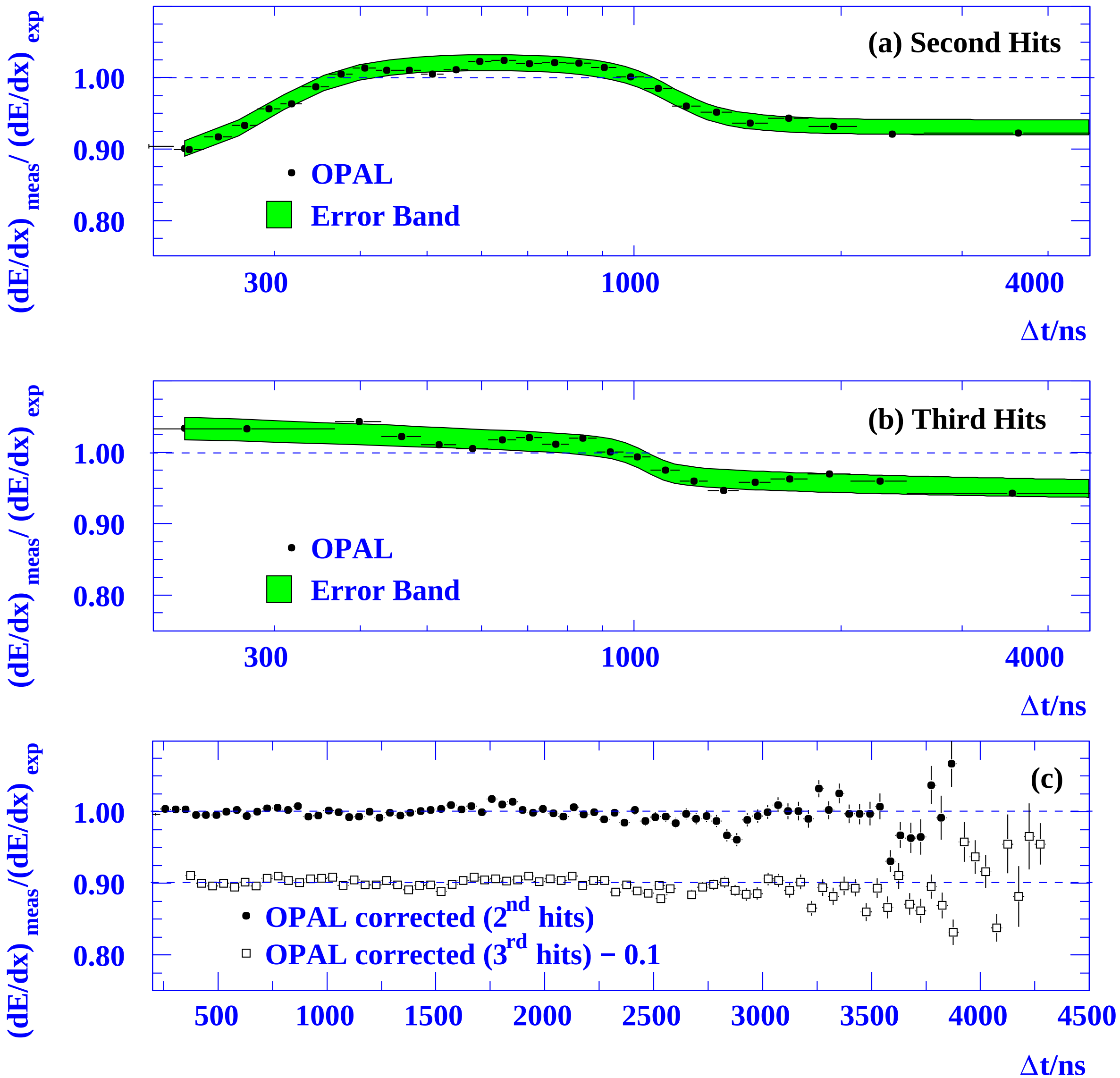
$\mathrm{d}E/\mathrm{d}x$ Calibration



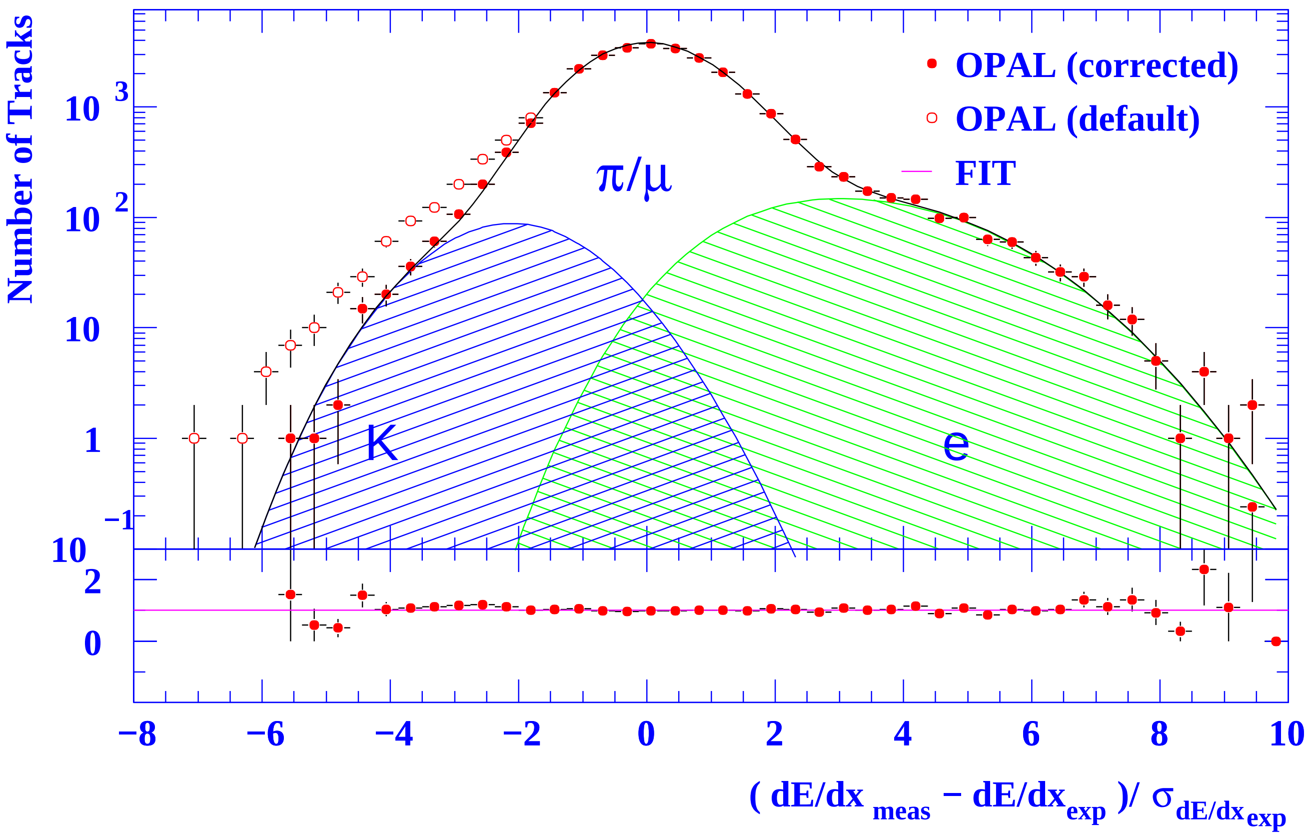


- Correction using Reference Pulse (RP)
- Systematic Deviations
  - $\Delta t = 200\,\mathrm{ns}(\hat{=}1\,\mathrm{cm})$: $\approx 10\%$ **too low**
  - $400 < \Delta t < 1000\,\mathrm{ns}$: $\approx 5\%$ **too high**
  - $\Delta t > 1000\,\mathrm{ns}$: $(7-8)\%$ **too low**
- Improved RP using Tracks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

$\mathrm{d}E/\mathrm{d}x$ Calibration



$\mathrm{d}E/\mathrm{d}x$ Residues



- Events Used:
  - 3-prong τ-Decay **from DATA only**
  - Momentum Range $p > 3\,\mathrm{GeV}$
  - At least $20\;\mathrm{d}E/\mathrm{d}x$ Hits
- New Calibration:
  - Good Agreement between DATA and Prediction
  - Bias $(\mathrm{d}E/\mathrm{d}x)_{\mathrm{meas}}/(\mathrm{d}E/\mathrm{d}x)_{\mathrm{exp}} \approx 1\%$

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

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

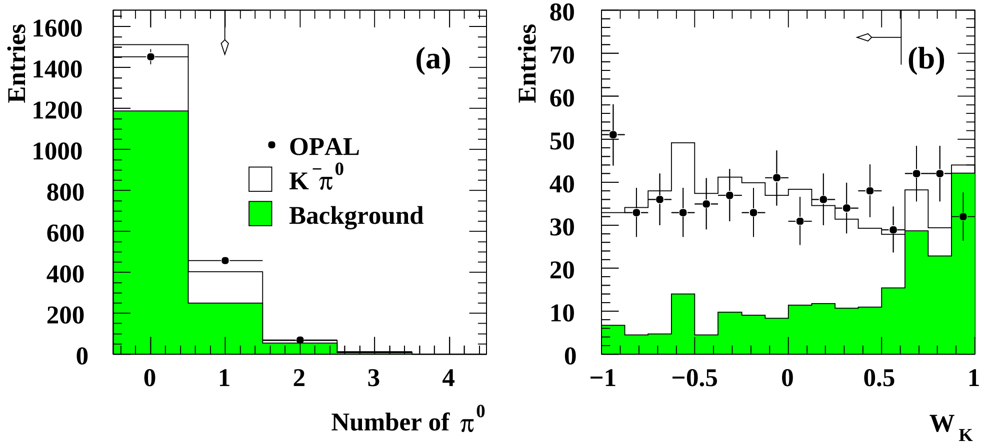
Two-Meson Selection

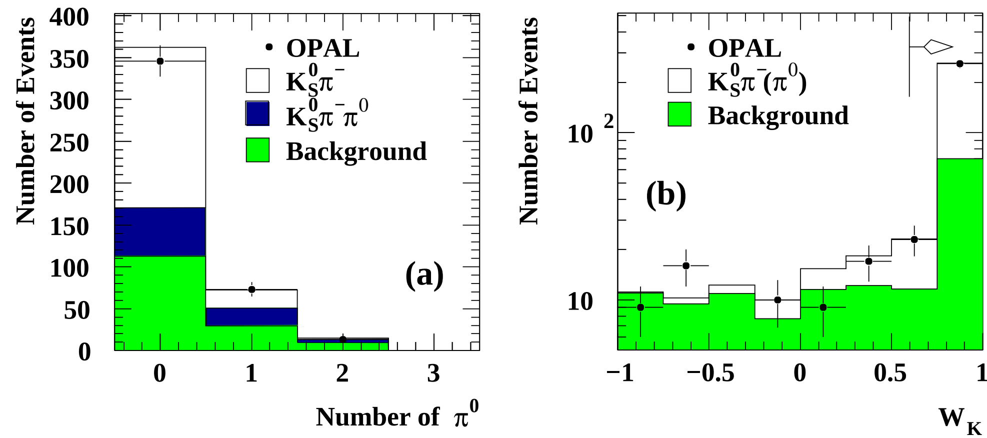
$K^- \pi^0 \nu_\tau$ Selection

- Exactly 1 π^0 Candidate
- Exactly 1 Track
  - # $\mathrm{d}E/\mathrm{d}x$-**Hits** > 20
  - $3\,\mathrm{GeV} < \mathrm{p} < 35\,\mathrm{GeV}$
  - π-**Weight** $W_\pi < 0.98$
  - K-**Weight** $W_\mathrm{K} < 0.8$

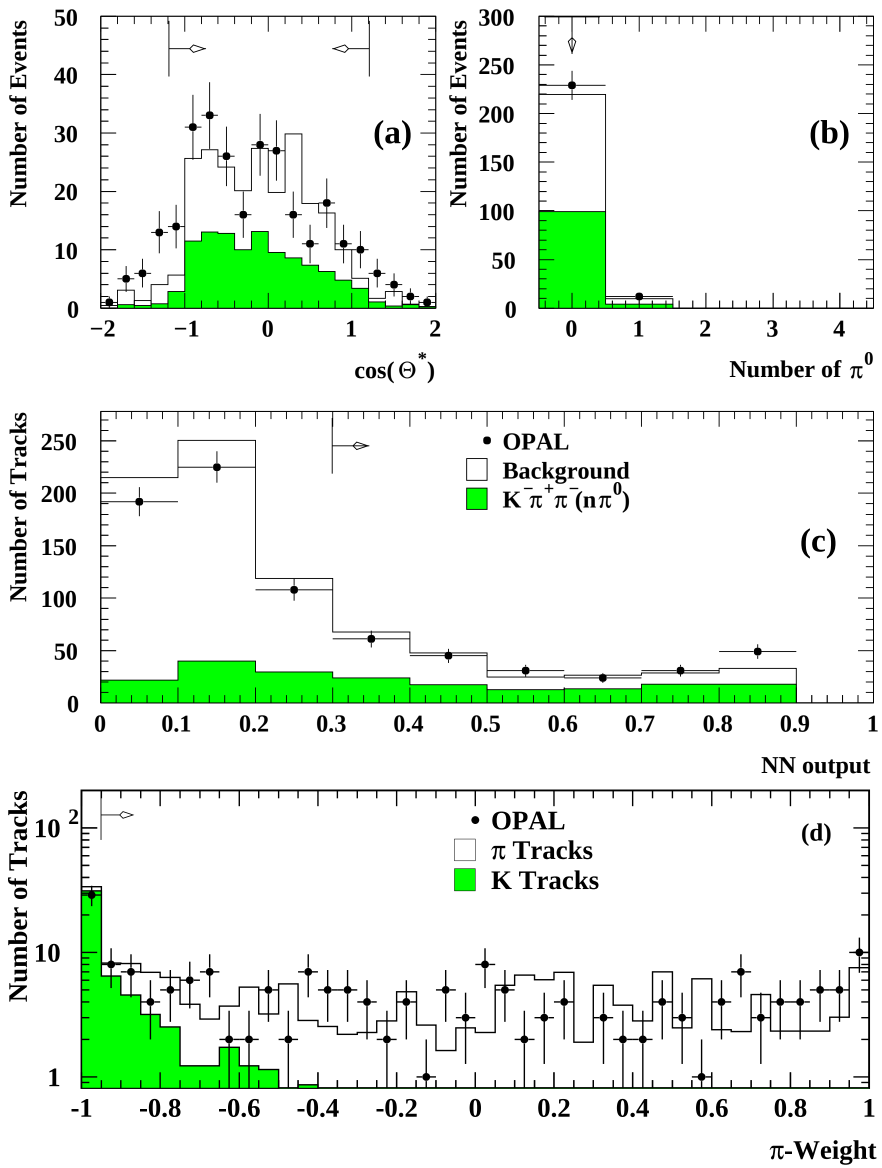
$K^0 \pi^- \nu_\tau (\pi^0)$ Selection

- Exactly 1 K^0_S Candidate
- Momentum $p > 3\,\mathrm{GeV}$ ...
  - # $\mathrm{d}E/\mathrm{d}x$ **Hits** > 20
  - π-**Weight** $W_\pi > 0.98$
- ... or $p < 3\,\mathrm{GeV}$





Three/Four-Meson Selection

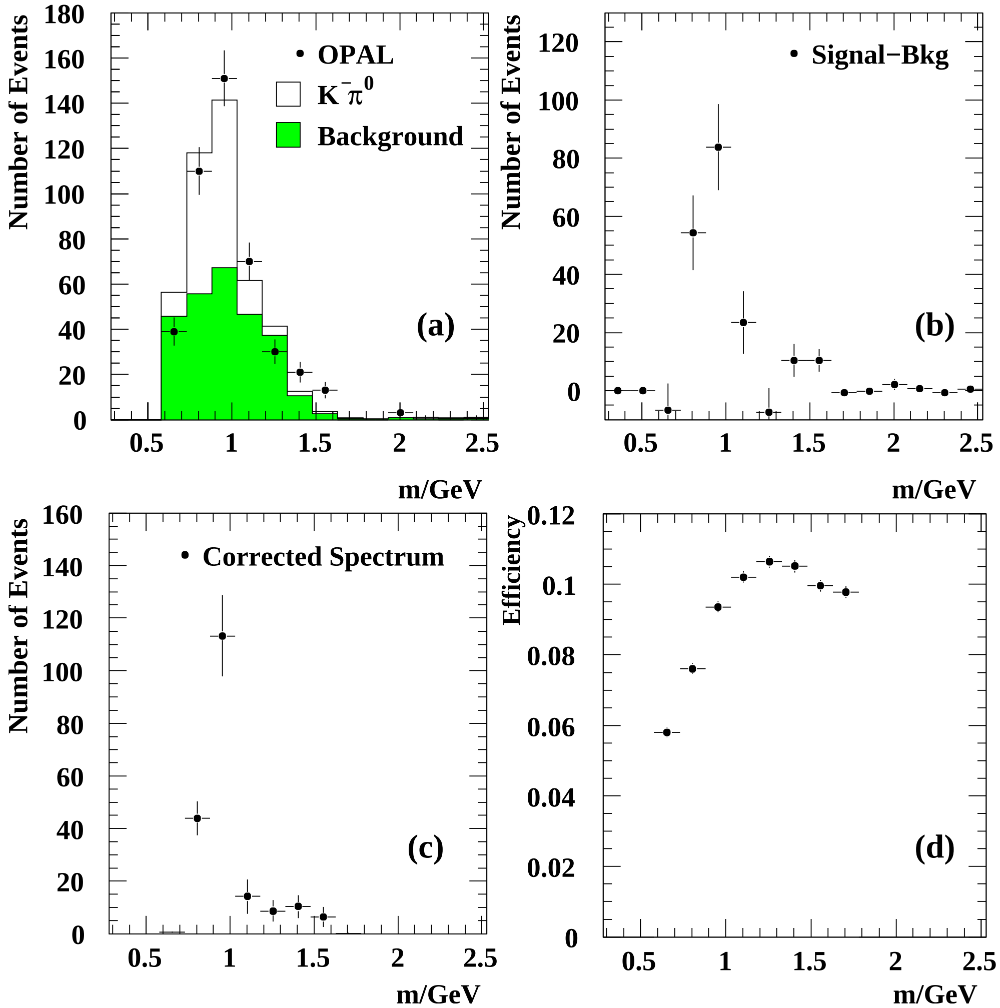


$K^-\pi^+\pi^-\nu_\tau(\pi^0)$-Selection

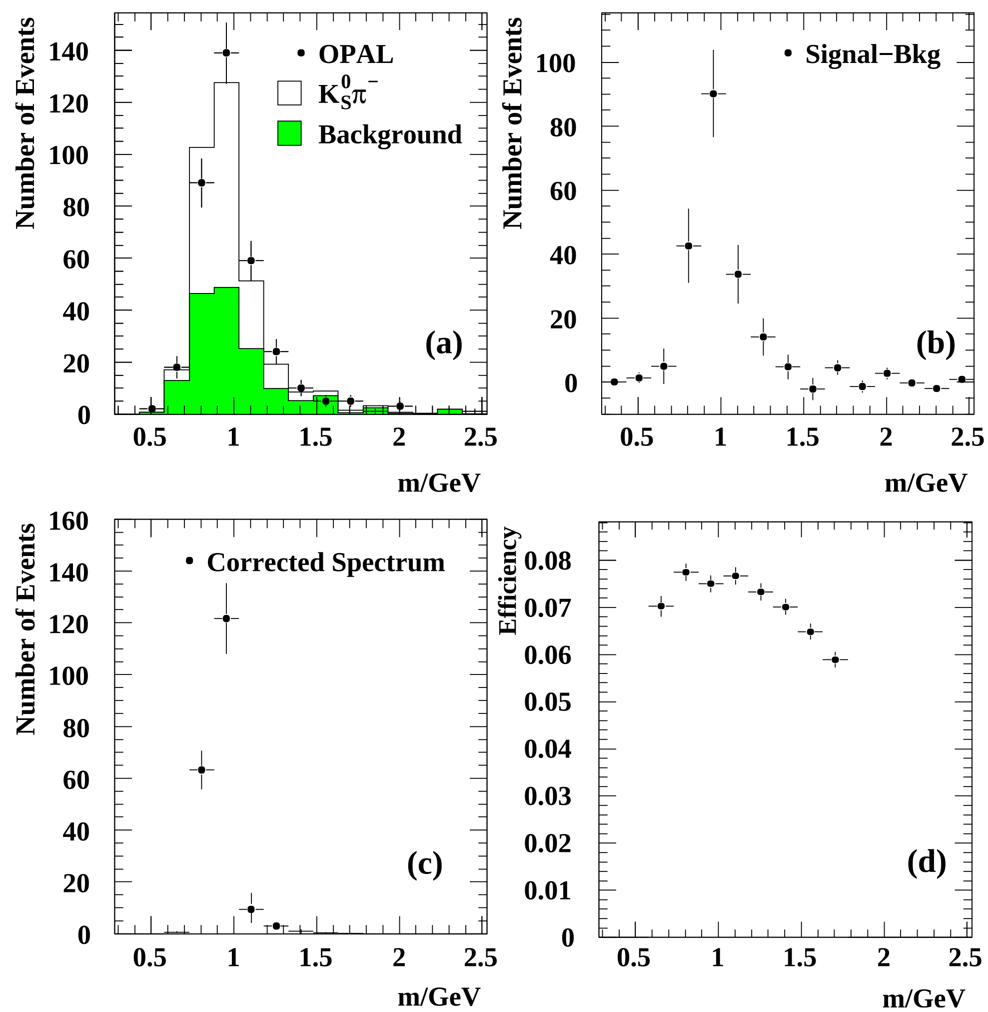
- 3prong-Vertex Fit Probability$> 10^{-7}$
- Exactly 1 K^- Candidate
  - # dE/dxHits > 20
  - $3\,GeV < p < 35\,GeV$
  - **NN-Output** > 0.3
- Exactly 1 π^+ Candidate ($W_\pi > -0.95$)
- GOTTFRIED-JACKSON Angle $|\cos\Theta^*| < 1.2$
- No/One Reconstructed π^0 ($E_{\pi^0} > 2\,GeV$)

Two-Meson Spectra

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

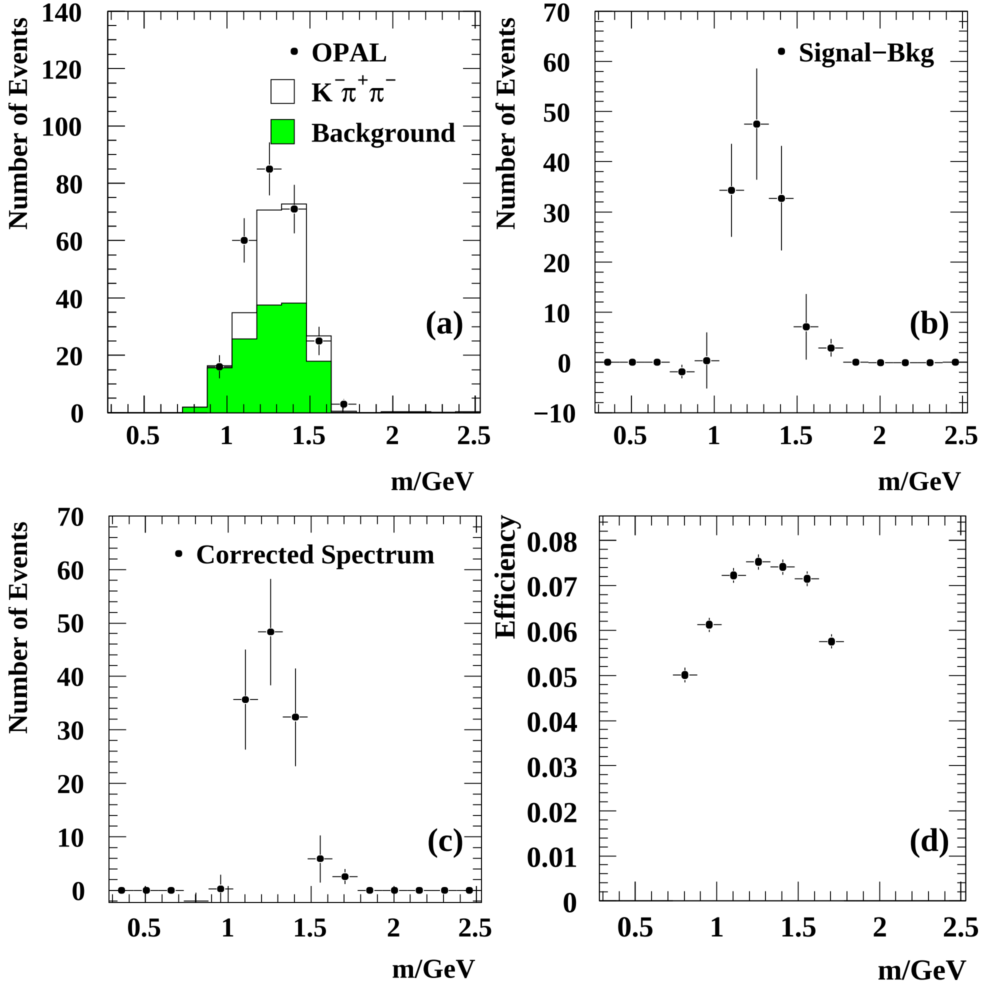


$K^0 \pi^- \nu_\tau$

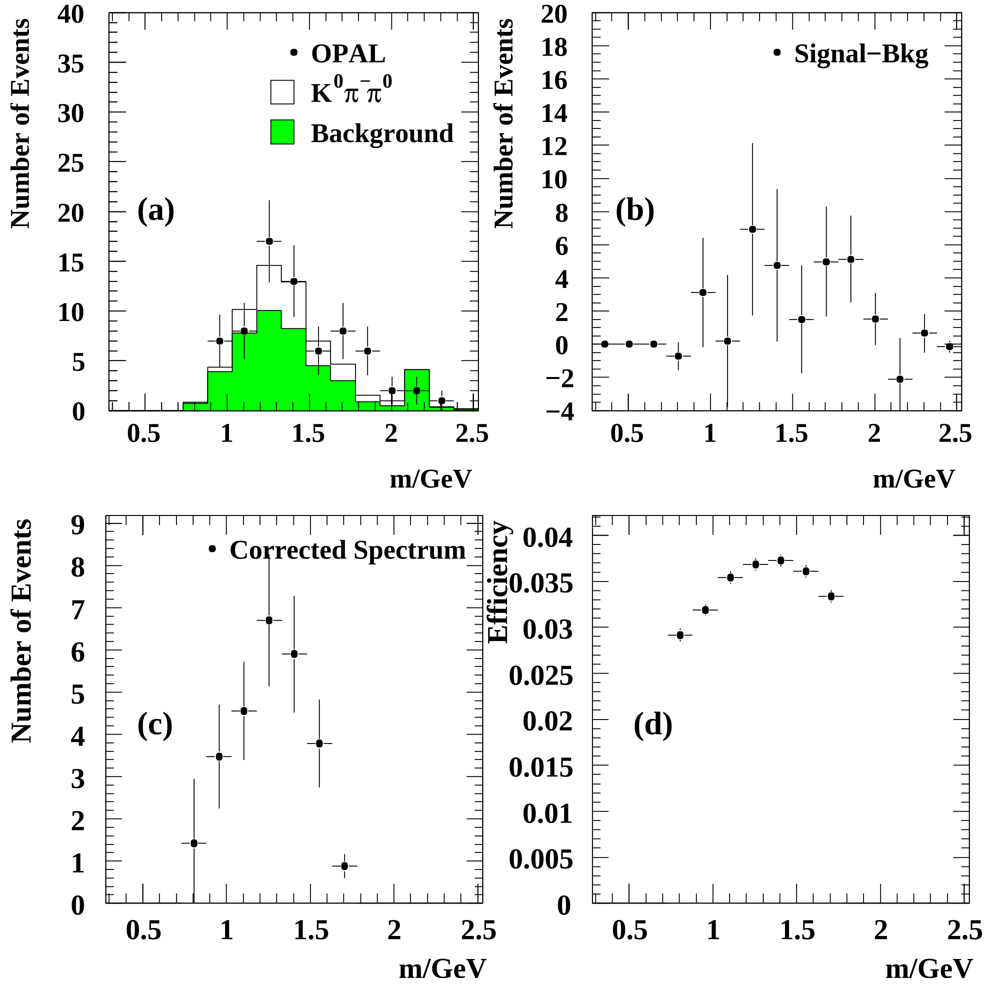


Three-Meson Spektren

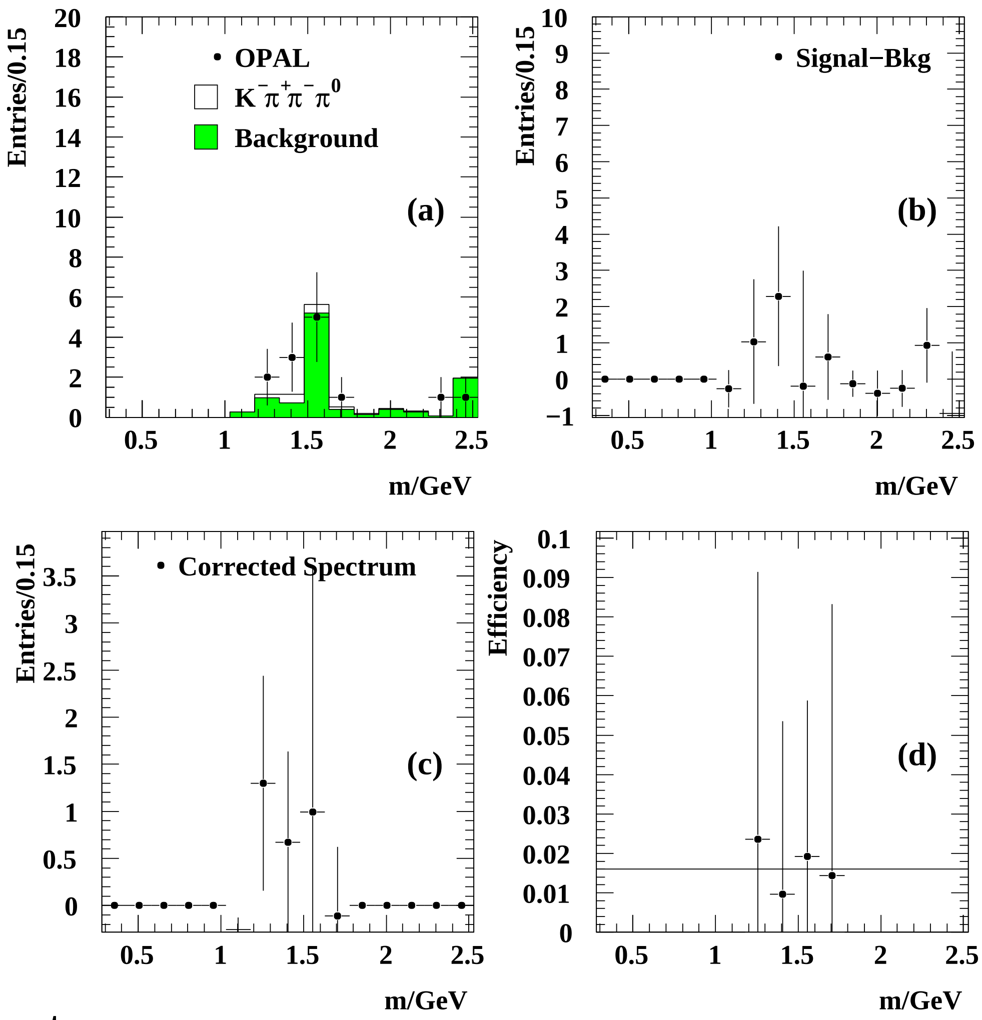
$K^-\pi^+\pi^-\nu_\tau$



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



Four-Meson Spectra



- Statistically not Significant
- Replaced with Monte Carlo Prediction

Branching Fractions

- Number of Expected Events

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

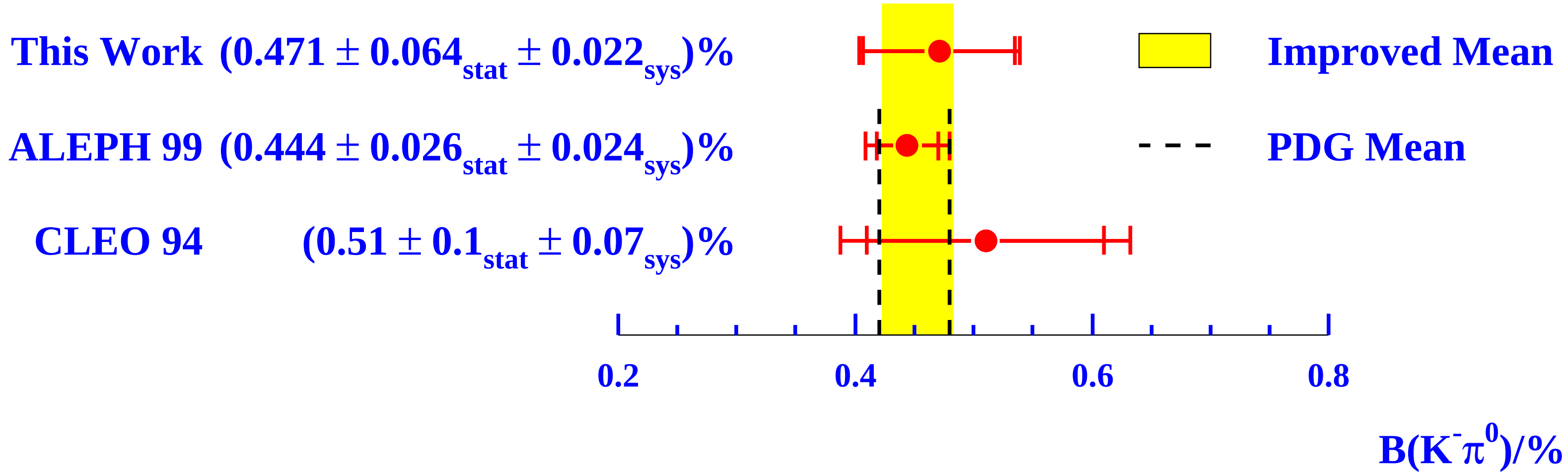
  - $N_i^{\not\tau}$: **non-τ Background**
  - $f_{\rm bkg}^{\not\tau}$: **Fraction of non-τ Background**
  - N^{τ}: **Number of τ-Events**
  - ε_{ij}: **Efficiency**
  - $F_j^{\rm Bias}$: **Bias Factor**
  - B_j: **Branching Fraction**

- Simultaneous χ^2-Fit:

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

  - **Other Channels Consistent with PDG**

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

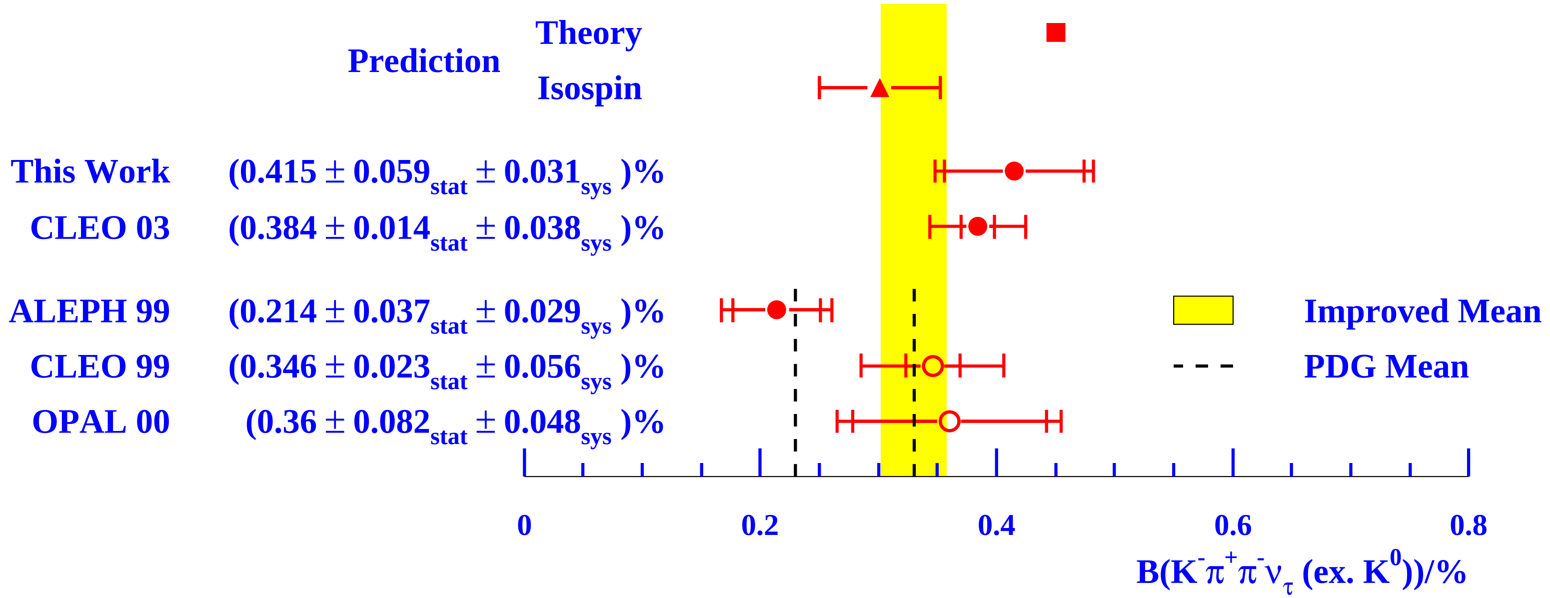


- First OPAL Measurement
- Good Agreement with PDG Average
- Use new Average for Spectral Function/Moments

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

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

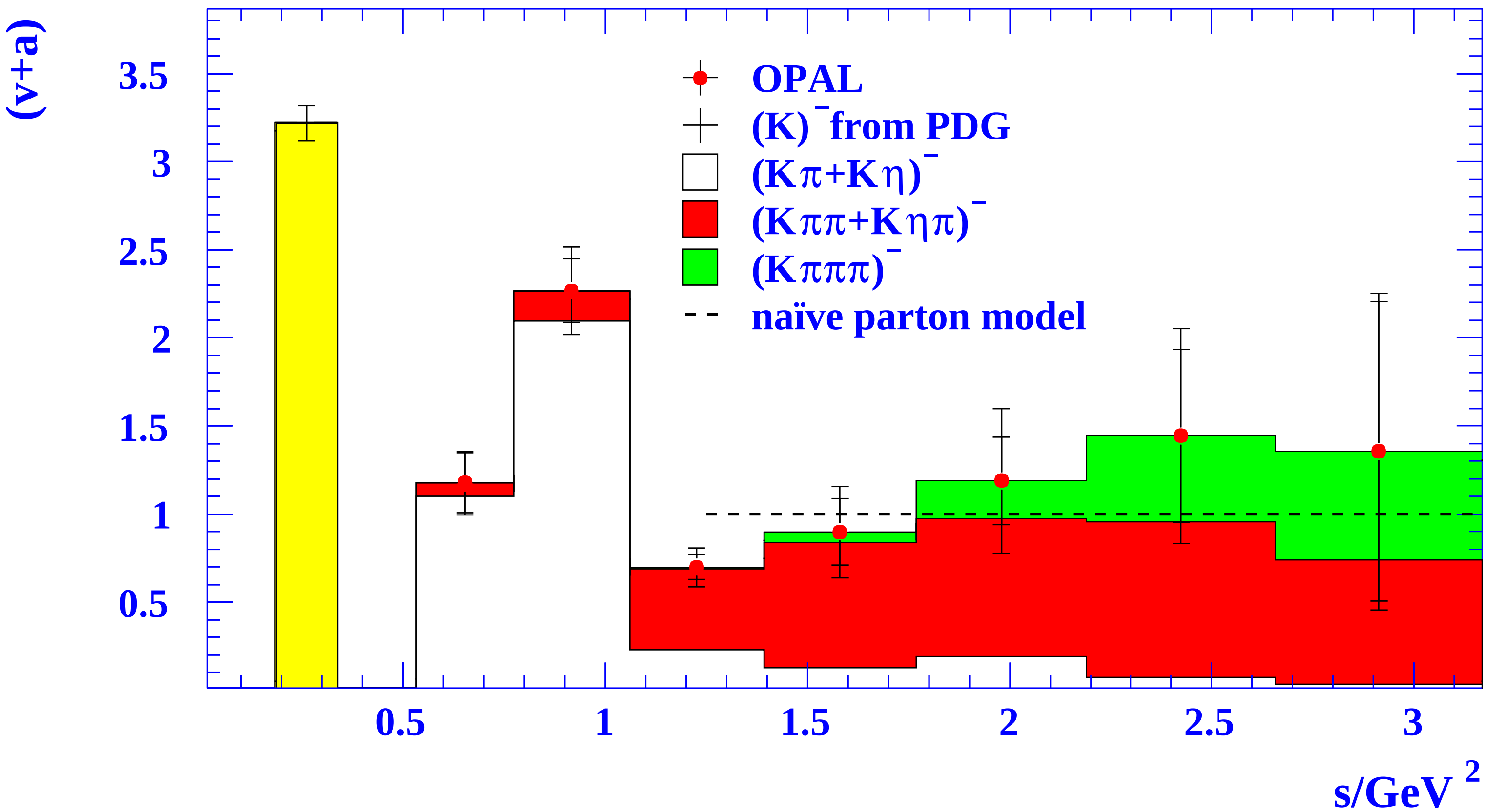
Branching Fraction $K^-\pi^+\pi^-\nu_\tau$



- 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

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

The Strangeness Spectral Function



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

Systematic Uncertainties

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

$(\mathbf{s}-\mathrm{range})/\mathrm{GeV}^{\mathbf{2}}$	Δ_{B}	$\Delta_{\mathrm{d}E/\mathrm{d}x}$	$\Delta_{\mathrm{K_S^0}}$	Δ_{E}	Δ_{p}	Δ_{mcorr}	$\Delta_{\mathrm{sys}}^{\mathrm{tot}}$	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

$$R^{kl}_{\tau,\,\mathrm{S}} = \int_0^{m_\tau^2} \mathrm{d}s \left(1 - \frac{s}{m_\tau^2}\right)^{\mathbf{k}} \left(\frac{s}{m_\tau^2}\right)^{\mathbf{l}} \sum_{\tau^- \to \nu_\tau X_\mathrm{s}^-} \frac{B(\tau \to (\mathrm{V/A})^{(S=-1,J=0/1)} \nu_\tau)}{B(\tau^- \to e^- \bar{\nu}_e \nu_\tau)} \frac{\mathrm{d}N_{\mathrm{V/A}}}{\mathrm{d}s} \frac{1}{N_{\mathrm{V/A}}}$$

- B: **Branching Fractions**
- $\mathrm{d}N_{\mathrm{V/A}}/\mathrm{d}s$: **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

$$R^{kl}_{\tau,\mathrm{S}} = \int_0^{m_\tau^2} \mathrm{d}s \left(1 - \frac{s}{m_\tau^2}\right)^k \left(\frac{s}{m_\tau^2}\right)^l \sum_{\tau^- \to \nu_\tau X_\mathrm{s}^-} \frac{B(\tau \to (\mathrm{V/A})^{(S=-1,J=0/1)}\nu_\tau)}{B(\tau^- \to e^- \bar{\nu}_e \nu_\tau)} \frac{\mathrm{d}N_{\mathrm{V/A}}}{\mathrm{d}s} \frac{1}{N_{\mathrm{V/A}}}$$

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

kl	$R^{kl}_{\tau,\mathrm{S}}$	Δ_{stat}	$\Delta_{\mathrm{d}E/\mathrm{d}x}$	$\Delta_{\mathrm{K}^0_\mathrm{S}}$	Δ_E	Δ_p	Δ_{mcorr}
00	$\mathbf{0.1677 \pm 0.0050}$	0.0050	$--$	$--$	$--$	$--$	$--$

The Spectral Moments

$$R^{kl}_{\tau,\,\mathrm{S}} = \int_0^{m_\tau^2} \mathrm{d}s \left(1-\frac{s}{m_\tau^2}\right)^{\mathbf{k}} \left(\frac{s}{m_\tau^2}\right)^{\mathbf{l}} \sum_{\tau^- \to \nu_\tau X_\mathrm{S}^-} \frac{B(\tau \to (\mathrm{V/A})^{(S=-1,J=0/1)}\nu_\tau)}{B(\tau^- \to e^-\bar{\nu}_e\nu_\tau)} \frac{\mathrm{d}N_{\mathrm{V/A}}}{\mathrm{d}s} \frac{1}{N_{\mathrm{V/A}}}$$

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

kl	$R^{kl}_{\tau,\mathrm{S}}$	Δ_{stat}	$\Delta_{\mathrm{d}E/\mathrm{d}x}$	$\Delta_{\mathrm{K^0_S}}$	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

$SU(3)_{\text{Flavor}}$ Symmetry Breaking

CKM Weighted Difference of strange and non-strange Moments

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

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

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

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

kl	OPAL $\delta R_{\tau,\,\text{S}}$	OPAL Δ_{exp}	OPAL $\Delta_{\|V_{\text{us}}\|}$	ALEPH $\delta R_{\tau,\,\text{S}}$	ALEPH Δ_{exp}	ALEPH $\Delta_{\|V_{\text{us}}\|}$
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

$SU(3)_{\mathrm{Flavor}}$ Symmetry Breaking

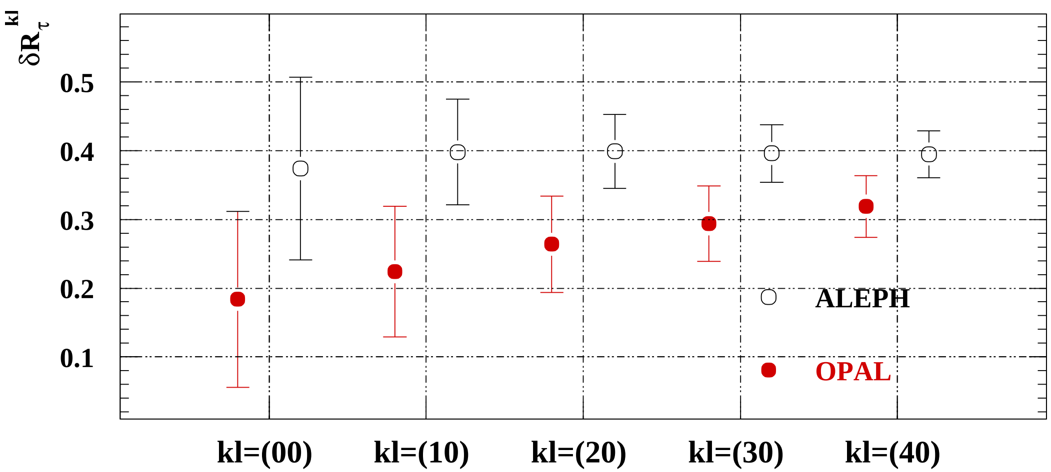
CKM Weighted Difference of strange and non-strange Moments

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

- $R^{kl}_{\tau,\,\mathrm{non-S}}$ updated from **Eur.Phys.J.C7:571-593,1999**
- CKM Inputs

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

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



$SU(3)_{\mathrm{Flavor}}$ Symmetry Breaking

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

- δR_τ^{kl}: Weighted Difference of Moments
- S_{ew}: Electroweak Correction
- $\Delta_{kl}^{(2)}/Q_{kl}$: Pert. Correction dim-2/4
- ϵ_d: $m_d/m_s = 0.053 \pm 0.002$
- $\langle \delta O_4(m_\tau^2)\rangle = (1.5 \pm 0.4) \times 10^{-3}\,\mathrm{GeV}$ Quark-Condensate

kl	m_s / MeV	σ / MeV			Korrelationen / %				
		σ_{theo}	$\sigma_{\lvert V_{us}\rvert}$	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

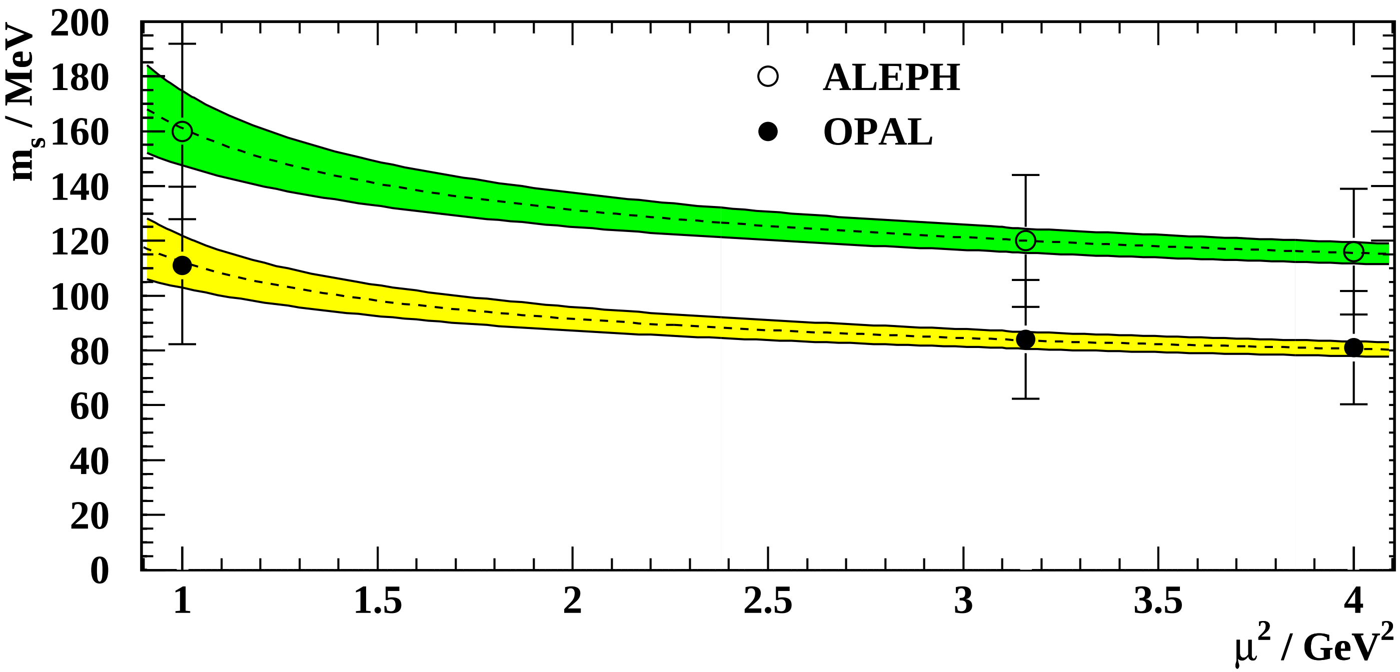
- Strange Quark Mass at $\mu^2 = m_\tau^2$:

$$m_s(m_\tau^2) = (84 \pm 14_{\mathrm{exp}} \pm 6_{V_{us}} \pm 17_{\mathrm{theo}})\,\mathrm{MeV}$$

$$= (84^{+20}_{-26})\,\mathrm{MeV}$$

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

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



- Opal

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

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

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

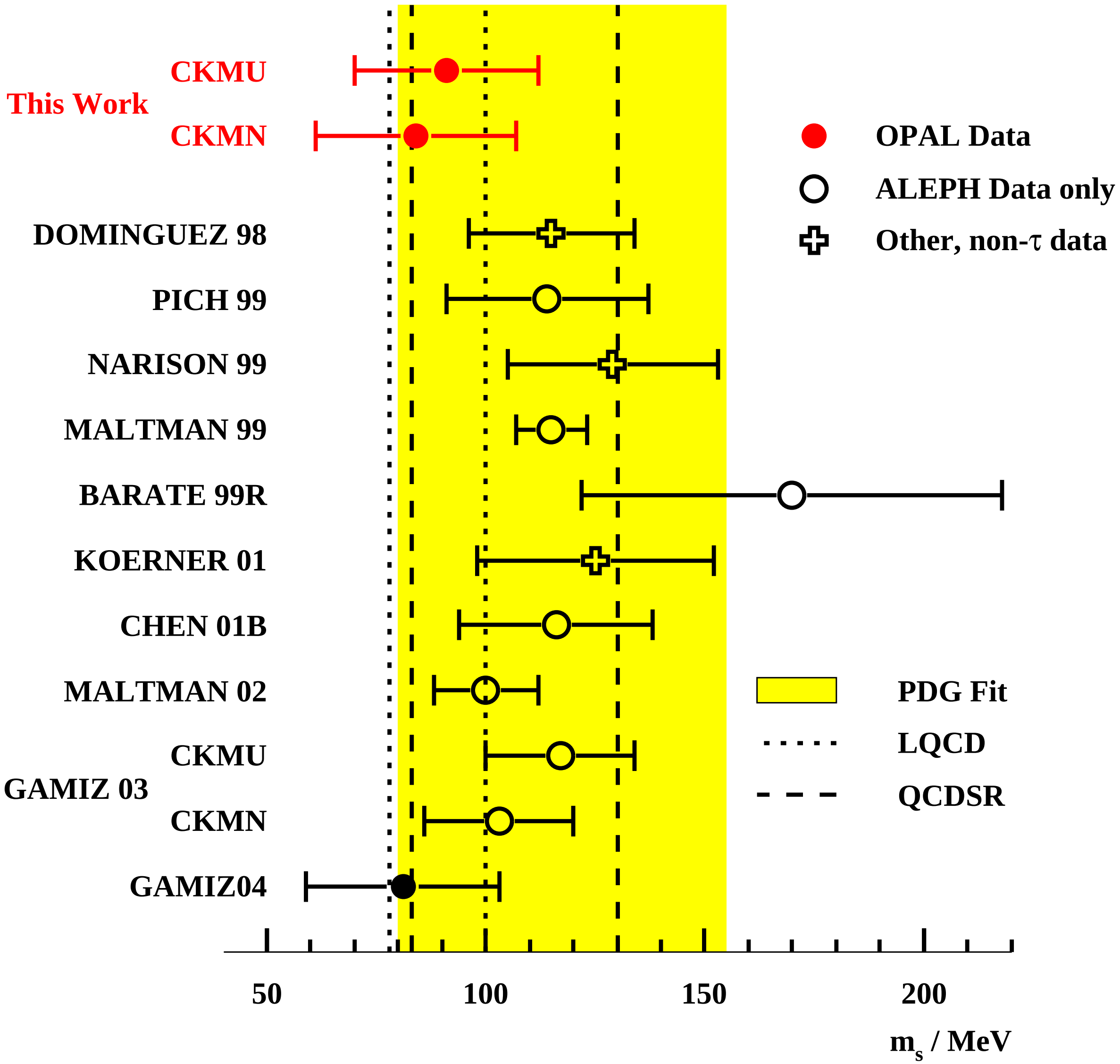
- ALEPH

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

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

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

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



- Matrix Elements
  - w/o CKM Unitarity (CKMN)

$$V_{ud}^{CKMN} = 0.9734 \pm 0.0008$$
$$V_{us}^{CKMN} = 0.2196 \pm 0.0023$$
$$V_{ub}^{CKMN} = (3.6 \pm 0.7) \cdot 10^{-3}$$

  - w/ CKM-Unitarity (CKMU)

$$V_{ud}^{CKMU} = 0.9749 \pm 0.0004$$
$$V_{us}^{CKMU} = 0.2225 \pm 0.0019$$
$$V_{ub}^{CKMU} = (3.604 \pm 0.7) \cdot 10^{-3}$$

Summary

- Experimental Aspects
- Selection of the Signal Channels
- Results
  - **Branching Fractions**

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

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

  - **The Strangeness Spectral Function**
  - **Spectral Moments**
  - **Mass of the Strange Quark**

$$m_{\rm s}(1\,{\rm GeV}^2) = (111^{+26}_{-35})\ {\rm MeV}$$

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

$$m_{\rm s}(4\,{\rm GeV}^2) = (82^{+19}_{-25})\ {\rm MeV}$$

- Thanks to Norbert Wermes and Achim Stahl