ALEPH τ analysis: sensitivity to MC generators

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τ miniworkshop 3, January 30 2025

- Follow up from November 8 and December 9 meetings
- For details on the ALEPH analysis see my talk posted then

ALEPH: τ Decay channels

Class label	Reconstruction criteria	Generated τ decay	
e	$1\ e$	$\tau \to e^- \overline{\nu}_e\ \nu_\tau$	
μ	$1\ \mu$	$\tau \to \mu^- \overline{\nu}_\mu\ \nu_\tau$	
h	$1\ h$	$\tau \to \pi^-\ \nu_\tau$ $\tau \to K^-\ \nu_\tau$ $\tau \to K^{*-}\ \nu_\tau$	$\tau \to \pi^- K^0 \overline{K}^0\ \nu_\tau$ $\tau \to K^- K^0\ \nu_\tau$
$h\ \pi^0$	$1\ h\ +\ \pi^0$	$\tau \to \rho^-\ \nu_\tau$ $\tau \to \pi^- \pi^0 \overline{K}^0\ \nu_\tau$	$\tau \to K^- \pi^0 K^0\ \nu_\tau$ $\tau \to K^{*-}\ \nu_\tau$
$h\ 2\pi^0$	$1\ h\ +\ 2\pi^0$	$\tau \to a_1^-\ \nu_\tau$ $\tau \to K^{*-}\ \nu_\tau$ $\tau \to K^-\ 2\pi^0\ \nu_\tau$	$\tau \to \pi^- \omega\ \nu_\tau\ ^{(2)}$ $\tau \to \pi^- K^0 \overline{K}^0\ \nu_\tau$ $\tau \to K^- K^0\ \nu_\tau$
$h\ 3\pi^0$	$1\ h\ +\ 3\pi^0$	$\tau \to \pi^- 3\pi^0\ \nu_\tau$ $\tau \to \pi^- \pi^0 \overline{K}^0\ \nu_\tau$	$\tau \to K^- \pi^0 K^0\ \nu_\tau$ $\tau \to \pi^- \pi^0 \eta\ \nu_\tau\ ^{(3)}$
$h\ 4\pi^0$	$1\ h\ + \geq 4\pi^0$	$\tau \to \pi^- 4\pi^0\ \nu_\tau$ $\tau \to \pi^- K^0 \overline{K}^0\ \nu_\tau$	$\tau \to \pi^- \pi^0 \eta\ \nu_\tau\ ^{(4)}$
$3h$	$2-4h$	$\tau \to a_1^-\ \nu_\tau$ $\tau \to K^{*-}\ \nu_\tau$ $\tau \to K^- \pi^+ \pi^-\ \nu_\tau$	$\tau \to K^- K^+ \pi^-\ \nu_\tau$ $\tau \to \pi^- K^0 \overline{K}^0\ \nu_\tau$ $\tau \to K^- K^0\ \nu_\tau$
$3h\ \pi^0$	$2-4h+\pi^0$	$\tau \to 2\pi^- \pi^+ \pi^0\ \nu_\tau\ ^{(5)}$ $\tau \to \pi^- \pi^0 \overline{K}^0\ \nu_\tau$	$\tau \to K^- \pi^0 K^0\ \nu_\tau$
$3h\ 2\pi^0$	$3h+2\pi^0$	$\tau \to 2\pi^- \pi^+ 2\pi^0\ \nu_\tau\ ^{(6)}$ $\tau \to \pi^- K^0 \overline{K}^0\ \nu_\tau$	$\tau \to \pi^- \pi^0 \eta\ \nu_\tau\ ^{(7)}$
$3h\ 3\pi^0$	$3h + \geq 3\pi^0$	$\tau \to 2\pi^- \pi^+ 3\pi^0\ \nu_\tau$	
$5h$	$5h$	$\tau \to 3\pi^- 2\pi^+\ \nu_\tau$	$\tau \to \pi^- K^0 \overline{K}^0\ \nu_\tau$
$5h\ \pi^0$	$5h+\pi^0$	$\tau \to 3\pi^- 2\pi^+ \pi^0\ \nu_\tau$	

- Monte Carlo generator KORALZ 07 with TAUOLA (Z. Was), FSR generated by PHOTOS
- Reconstruction level:
  - paired γ's (π^0 identified)
  - unpaired γ : π^0 with lost γ or radiative photon (LH identified) or merged γ's (π^0 identified)
  - remaining unpaired γ counted as π^0 in classification
  - account of fake γ from hadron interactions in calorimeter (LH identif.)

2 With $\omega \to \pi^0 \gamma$
3 With $\eta \to \gamma\gamma$
4 With $\eta \to 3\pi^0$
5 This channel includes $\tau \to \pi\omega\ \nu_\tau$ with $\omega \to \pi^-\pi^+\pi^0$
6 This channel includes $\tau \to \pi\pi^0\omega\ \nu_\tau$ with $\omega \to \pi^-\pi^+\pi^0$
7 With $\eta \to \pi^-\pi^+\gamma$

ALEPH global BR measurement

$$n_i^{obs} - n_i^{bkg} = \sum_j \varepsilon_{ji} N_j^{prod}$$

$$B_j = \frac{N_j^{prod}}{\sum_j N_j^{prod}}$$

- Efficient ττ selector exploiting topology, missing energy
- Efficiency matrix ε_{ji}: decay generated in class j, reconstructed in class i, 13 classes up to 5 charged hadrons, 3 π^0
- Determined with simulation
- Corrected for data/simulation differences (few per mil)
- FSR included for all channels

	e	μ	h	$h\pi^0$	$h2\pi^0$	$h3\pi^0$	$h4\pi^0$	$3h$	$3h\pi^0$	$3h2\pi^0$	$3h3\pi^0$	$5h$	$5h\pi^0$
e	73.26	0.01	0.41	0.45	0.34	0.25	0.74	0.02	0.02	0.05	0.00	0.00	0.00
μ	0.01	74.49	0.63	0.22	0.07	0.21	0.33	0.01	0.01	0.00	0.00	0.00	0.00
h	0.25	0.75	65.03	3.56	0.34	0.06	0.00	1.44	0.10	0.08	0.00	0.80	0.00
$h\pi^0$	1.02	0.26	4.70	68.19	11.31	2.15	0.49	0.48	1.28	0.62	0.05	0.24	0.00
$h2\pi^0$	0.12	0.01	0.33	5.67	57.68	23.13	7.57	0.08	0.39	1.48	0.24	0.04	0.00
$h3\pi^0$	0.01	0.00	0.07	0.41	6.92	43.06	38.15	0.01	0.10	0.37	0.71	0.04	0.00
$h4\pi^0$	0.00	0.00	0.02	0.05	0.67	6.25	25.26	0.00	0.02	0.11	0.19	0.00	0.00
$3h$	0.01	0.02	0.25	0.07	0.03	0.00	0.00	67.98	6.77	0.80	0.03	22.11	2.52
$3h\pi^0$	0.01	0.01	0.22	0.56	0.27	0.06	0.06	7.29	58.90	16.53	4.46	7.07	16.04
$3h2\pi^0$	0.00	0.00	0.04	0.06	0.10	0.08	0.02	0.41	6.02	40.42	25.02	0.28	0.65
$3h3\pi^0$	0.00	0.00	0.00	0.00	0.00	0.01	0.05	0.02	0.41	6.19	28.98	0.00	0.00
$5h$	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.00	38.70	4.58
$5h\pi^0$	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.03	0.08	2.99	38.72
Class 14	3.27	4.17	6.38	0.73	1.08	1.71	1.75	0.80	3.66	9.96	13.87	5.03	9.75
sum	77.06	79.72	78.08	79.97	78.81	76.97	74.42	78.56	77.71	76.64	73.64	77.30	72.26

- Large selection efficiency: overall 78.9%, 91.7% in polar angle acceptance
- Rather independent of decay channel (± 5%)
- Non-τ background (1.2%) subtracted

Sensitivity of ALEPH analysis to $\tau\tau$ generator

- Selection efficiency matrix between generated and reconstructed τ decay modes determined using $\tau\tau$ event generator KORALZ with τ decay library TAUOLA (Z. Was et al.)

- By construction matrix independent of BR used in the MC generator

- MC dependence only through assumed final-state dynamics in each decay mode

- For feedthrough affecting the $\pi\,\pi^0$ mode, dominant contributions from π and $\pi\,2\pi^0$

- π mode is model-independent, except for FSR : PHOTOS tests by Z. Was
- $\pi\,\pi^0$ mode: rates for $\tau\to\nu_\tau\pi^-\pi^0\gamma$ in KORALZ and radiative calculation (Cirigliano et al))

  E_γ>350 MeV $(2.91 \pm 0.04) \times 10^{-3}$ 2.9×10^{-3}

- $\pi\,2\pi^0$ depends on a_1 decay dynamics (mostly $\rho\pi$): studies performed with different final-state dynamics leading to a systematic uncertainty of 0.04% on BR($\pi\,2\pi^0$), similar tests done for higher multiplicity modes, albeit with smaller contributions

- Syst uncertainty on BR($\pi\,\pi^0$) from $\pi\,2\pi^0$ feedthrough is one order of magnitude smaller

- Conclusion: systematic effects from imperfect knowledge of dynamics is negligible compared to experimental systematics

Sensitivity of ALEPH analysis to detector effects

- Feedthrough originates from detector effects

- Loss of tracks (tracking inefficiency, secondary interactions, acceptance edges)

- Mostly photon/π^0 book-keeping
- Corrections to MC obtained through detailed comparisons between data and MC
- Separation between real/fake γ with multivariate likelihood
- data/simulation rate of fake γ studied and correction applied
- Likelihood separation between radiative and π^0-produced single photons
- Complete π^0 reconstruction: $\gamma\gamma$ invariant mass, overlapping γ showers (unresolved high-energy π^0, signal from mass obtained through transverse shower extent), single unpaired γ (loss of low-energy second γ below detection threshold)
- Studies and systematic uncertainties well documented (54 pages in hep-exp/0506072)
- Made possible by the unique properties of the ALEPH EM calorimeter for τ decays
  - transverse granularity: pointing towers 0.9^ox0.9^o (OPAL 3^ox3^o)
  - longitudinal segmentation: 3 sections (OPAL no segmentation)

- Consistency check of BR unitarity using class 14 (3.7%, hemispheres with PID problems or rejected by cuts for high multiplicity): BR_{14} indeed consistent with 0, (0.058 ± 0.039)%

Systematic uncertainties on measured branching ratios

- Summary of detailed studies on the possible sources of systematic biases
- Dominated by γ/π^0 reconstruction, MC uncertainties sub-dominant
- Systematic and statistical uncertainties comparable
- Absolute uncertainties in %

Topology	π^0	sel	bkg	pid	int	trk	dyn	mcs	total
e	0.011	0.021	0.029	0.019	0.009	0.000	0.000	0.015	0.045
μ	0.004	0.020	0.020	0.021	0.008	0.000	0.000	0.015	0.039
h	0.071	0.016	0.010	0.022	0.022	0.014	0.000	0.019	0.083
$h\pi^0$	0.063	0.027	0.019	0.011	0.045	0.009	0.000	0.027	0.090
$h2\pi^0$	0.089	0.021	0.014	0.004	0.007	0.003	0.040	0.028	0.105
$h3\pi^0$	0.056	0.012	0.015	0.000	0.008	0.001	0.008	0.030	0.068
$h4\pi^0$	0.029	0.005	0.011	0.000	0.015	0.000	0.000	0.019	0.040
$3h$	0.047	0.021	0.018	0.004	0.012	0.014	0.006	0.015	0.059
$3h\pi^0$	0.033	0.017	0.029	0.002	0.041	0.009	0.007	0.018	0.066
$3h2\pi^0$	0.027	0.008	0.015	0.000	0.009	0.003	0.012	0.014	0.038
$3h3\pi^0$	0.010	0.012	0.002	0.000	0.002	0.001	0.010	0.006	0.019
$5h$	0.002	0.000	0.002	0.000	0.000	0.001	0.000	0.003	0.004
$5h\pi^0$	0.002	0.000	0.006	0.000	0.000	0.000	0.000	0.002	0.007
Class 14	0.013	0.003	0.022	0.002	0.024	0.000	0.000	0.011	0.037

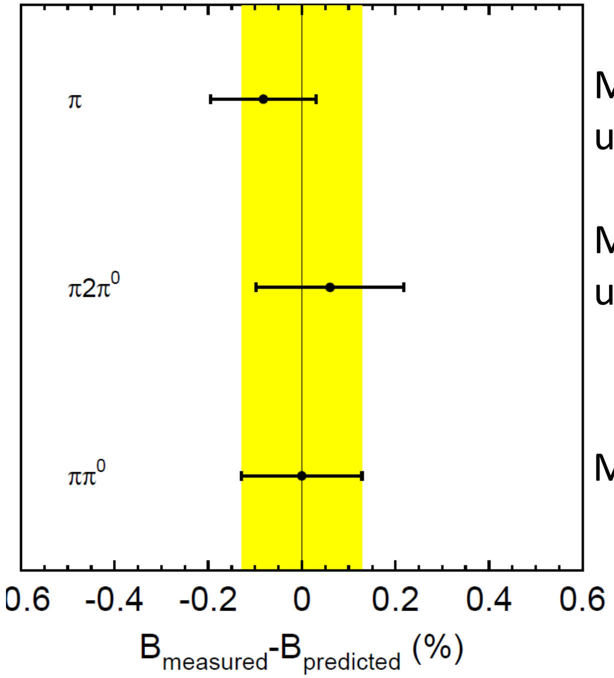
A posteriori checks of the feedthrough treatment

- Compare measurements of 'adjacent' channels $\tau \to \pi^- \nu_\tau$, $\tau \to \pi^- 2\pi^0 \nu_\tau$ with predictions based on lepton universality and isospin, respectively
- Test of feedthrough in the classification according to number of γ/π^0
- Consistent within uncertainties (0.1%)

BR

2005 Phys.Rep.

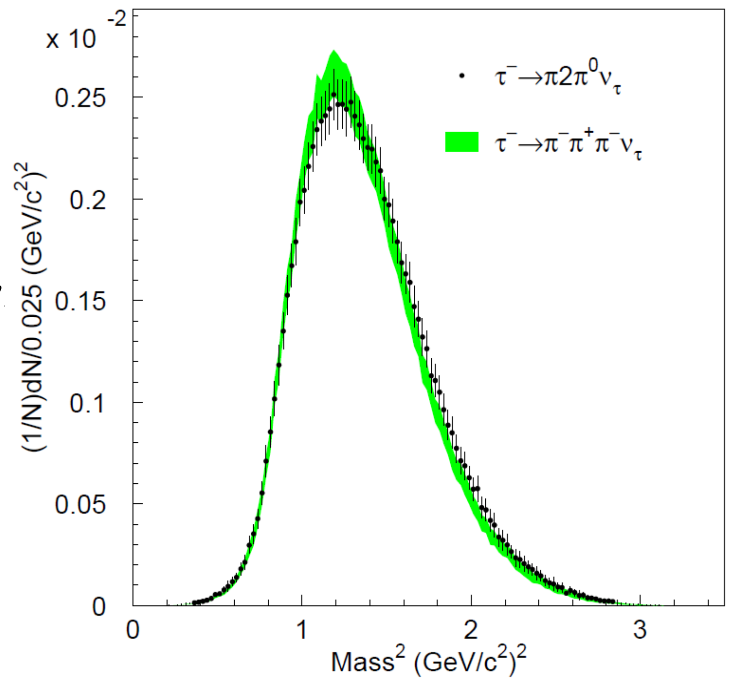
3π spectral functions



Measurement – prediction using leptonic universality

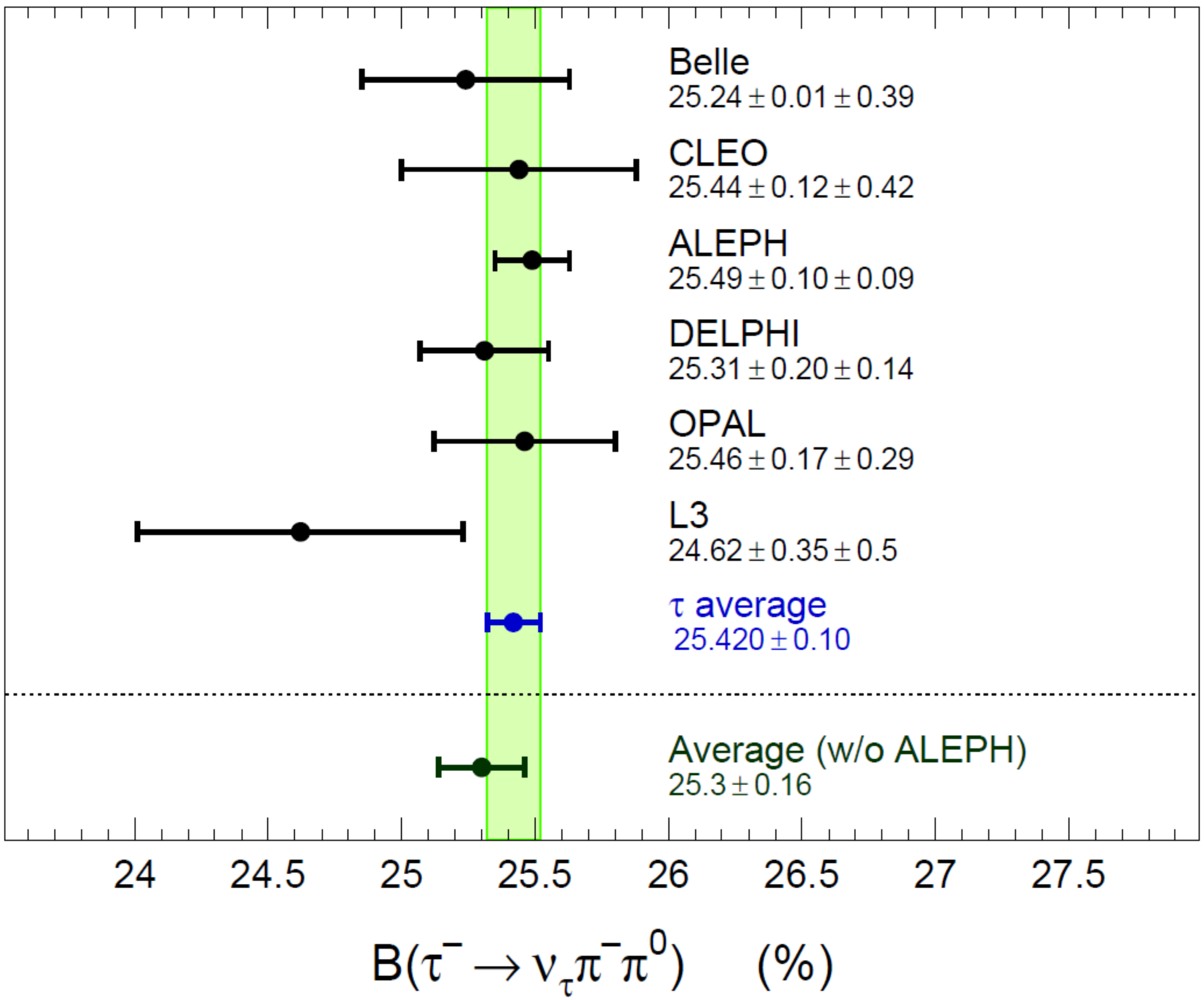
Measurement – prediction using isospin + BR $\tau \to \pi^- \pi^+ \pi^- \nu$ + π mass corrections

Measurement



BR measurements

- $B_{\pi\pi 0}$ strongly dominated by ALEPH
- However average of other measurements consistent with ALEPH with comparable accuracy



2005 Phys.Rep. plot updated

Consistency ALEPH vs average w/o ALEPH
χ^2 = 0.85 (NDF=1)

BR uncertainty contributions:
$B_{\pi\pi 0}$ 3.9 per mil
$B_{e\ uni}$ 1.8 per mil using only ALEPH BRs and WA τ_τ <2017 conservative

Further tests of PHOTOS

- Difficult to test directly in ALEPH data
- small signal: $\pi\pi^0\gamma$ has to be separated from $\pi 2\pi^0$ with one lost γ which is dominant
- E_γ > 350 MeV   x >~0.035 PHOTOS and CEN predict 1.14% x $B_{\pi\pi 0}$=0.29% compared to the total uncertainty of 0.14%

- Much easier in e+e-: already in BABAR09, much more detailed in BABFSRAR23 NLO/NNLO
- E_γ > 200 MeV   x >~0.05 NLO FSR (1.00 $\pm$ 0.16)%
- Good agreement with AfkQed (PHOTOS) data/PHOTOS = 1.08 $\pm$ 0.10