Tau decays and the a1-meson

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Motivation

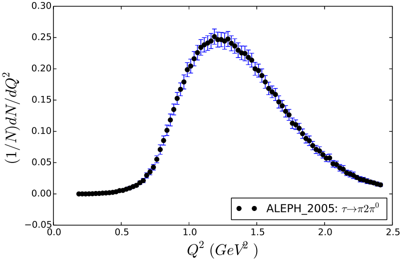
Why is the axial vector current at $E \simeq m_\tau$ interesting?

- discrepancies in $B \to D^* \tau \nu$, $H \to \mu \tau$
- neutrino scattering, muon $g - 2$
- CP-violation $\Rightarrow$ applicable to $\tau \to K\pi\pi$ as well
- current hadronic models (e.g. Dumm, Roig, Pich 2010) not sufficient for recent BABAR tau decay data (Nugent et al. 2013)

$\tau \to 3\pi\nu$: clean separation of weak and strong effects

$\Rightarrow$ great laboratory to examine the pionic strong interaction
$\Rightarrow$ conceptual improvement of models needed for strong interaction amplitudes: include FSI

Experimental information on tau decays?

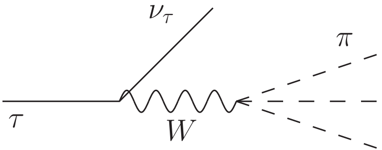


- often fitted by summing overlapping Breit-Wigner lineshapes for 2- or 3-body interaction
- 1-d distribution used for properties of the a_1 meson
- caveat: a_1 properties vary between hadronic channels ($\pi N \to 3\pi N$) and τ decays

Theoretical framework

Basic definitions

More information encoded in structure functions W_X (Kühn, Mirkes, 1992)



$$\mathcal{M} \propto L_\mu H^\mu, \quad H_\mu = \langle \pi\pi\pi | V_\mu - A_\mu | 0 \rangle$$

H_μ: restricted to axial vector current A_μ by G-parity

helicity amplitudes $\mathcal{A}_\lambda = \epsilon_\mu(\lambda) H^\mu$: simple partial wave expansion

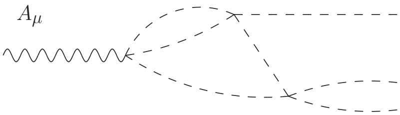
$\epsilon_\mu(\lambda)$: polarization vector of final state system with helicity $\lambda = \pm, 0, t$

W_X: linear combinations of $H^{\lambda\lambda'} = \mathcal{A}_\lambda \mathcal{A}^\dagger_{\lambda'}$

What do we know at the amplitude level?

$\mathcal{A}_\lambda(s,t,u)$ analytic continuation of scattering amplitudes

$Q^2 = s + t + u - 3M_\pi^2$



$$\mathcal{A}_\lambda^{ijmn}(s,t,u) \propto \sum_I \sum_l \sqrt{2l+1}\, a^l_{I,\lambda}(s)\, d^l_{\lambda 0}(\theta_\pi) P_I^{ijmn}$$

P_I^{ijmn}: isospin projection, $\theta_\pi =$ 2-pion angle

Bose symmetry restricts $I + l \stackrel{!}{=}$ even

transverse amplitude: p- and d-wave dominating

Analytic structure

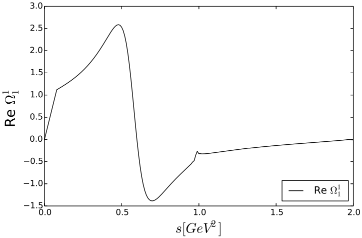
2-pion amplitudes $a_I^l(s)$ partly known from $\pi\pi$-scattering:

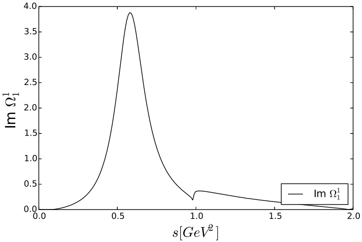
$$a_I^l(s) = \Omega_I^l(s) * G(s), \quad \Omega_I^l = \exp\left(\frac{s}{\pi}\int_{s_0}^{\infty} \frac{ds'}{s'}\frac{\delta_I^l(s')}{s'-s}\right)$$

Khuri, Treiman (1960)

- Omnes functions $\Omega_I^l(s)$ contain the unitary, right-hand cut in s
- $G(s)$ contains the left-hand cut from the crossed channels

Pelaez et al. (2013): Ω_1^1, Ω_0^2, Ω_2^2





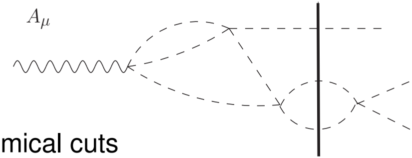
Parametrization

$$G(s) = \int_{s_0}^{s_{in}} \frac{ds'}{\pi} \frac{\text{Im}G}{s'-s} + \sum_i c_i z_i(s),$$

Yndurain (2002), Danilkin et al., JPAC (2015)

$$z(s) = \frac{\sqrt{s_{in}-s} - \sqrt{s_{in}}}{\sqrt{s_{in}-s} + \sqrt{s_{in}}},$$

s_{in} : inelasticity threshold



Redefine $a_{Il,\lambda}$ to contain only dynamical cuts

$\Rightarrow$ relate left- and righthand cuts iteratively:

$$a^{right}(s) = \Omega(s) \int_{s_0}^{\infty} \frac{ds' \sin\delta(s')}{\pi|\Omega(s')|} \frac{a^{left}(s')}{(s'-s)}$$

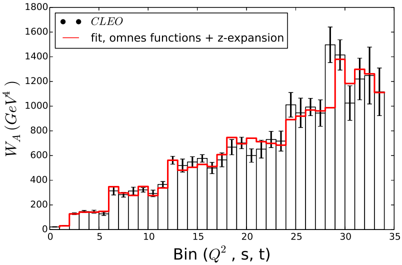
$$a^{left}(s) \propto \int_{-1}^{+1} d\cos\theta_\pi P_l(\cos\theta_\pi) \sum_{I,l} ...a^{right}(s)$$

inversion of partial wave expansion

Results

Structure functions

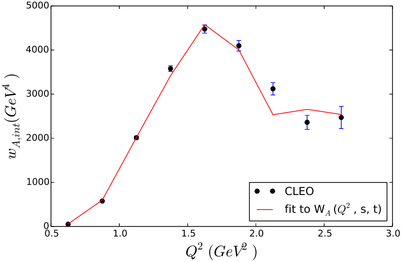
Preliminary:



- $d\Gamma \propto L_{\mu\nu}H^{\mu\nu} = \sum_X^{16} L_X W_X$
- W_A related to all non-zero structure functions, dominates decay rate
- very good description at lower bin numbers: two-pion interactions dominate and Omnes functions are well-known

Integrated structure functions

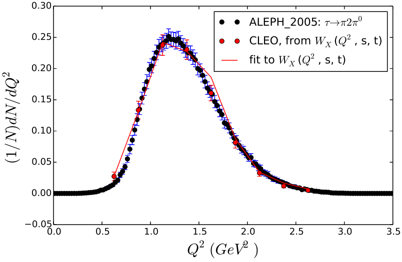
Preliminary:



- low-Q^2 well described
- integration over Dalitz plot invariants yields resonance-like structure

Decay rate

Preliminary:



- Fitting two-body interactions in all channels to CLEO structure functions
- Comparable to decay rate without adding Breit-Wigner by hand

Summary/Outlook

- Conclusion for the a_1: can be dynamically generated by two-pion interactions in all channels
- 'bumps' often interpreted as two-body threshold effects, consider here also three-body interactions
- examine impact of three-body unitarity

Apply this framework to full Dalitz plot distributions from BABAR, Belle(II), COMPASS...

$\Rightarrow$ Implement hadronic currents for TAUOLA

$\Rightarrow$ This better control of strong effects allows tests of the SM