ISSUES FOR α_s FROM HADRONIC τ DECAY AND ELECTROPRODUCTION DATA

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[With T. Yavin, and ongoing work with D. Boito, O. Cata, M. Golterman, M. Jamin, J. Osborne, S. Peris]

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OUTLINE

- *Basics/generalities*
- α_s *from hadronic* τ *decay data*
- α_s *from electroproduction cross-sections*

BACKGROUND/BASICS

- Basic objects: current-current 2-point functions

  ($J^\mu = J^\mu_{EM}$ or $J^\mu_{V/A;ud}$)

$$\Pi^{\mu\nu}(q^2) \equiv i\int d^4x\, e^{iq\cdot x}\langle 0|T\left(J^\mu(x)J^{\dagger\,\nu}(0)\right)|0\rangle$$
$$= \left(q^\mu q^\nu - q^2 g^{\mu\nu}\right)\Pi^{(1)}(q^2) + q^\mu q^\nu\,\Pi^{(0)}(q^2)$$

- "Spectral functions" $\rho^{(J)}(s) \equiv \frac{1}{\pi} Im\,\Pi^{(J)}(s+i\epsilon)$:

  * $\rho^{(0)}_{EM} = 0$; $\rho^{(0)}_{V;ud} = O[(m_d - m_u)^2]$, hence negligible

  * $\rho^{(0)}_{A;ud} = 2f_\pi^2\delta(s-m_\pi^2) + O[(m_d+m_u)^2]$, hence negligible except for π pole contribution

* $\rho^{(1)}_{EM}(s)$, $\rho^{(1)}_{V/A;ud}(s)$ measurable experimentally from

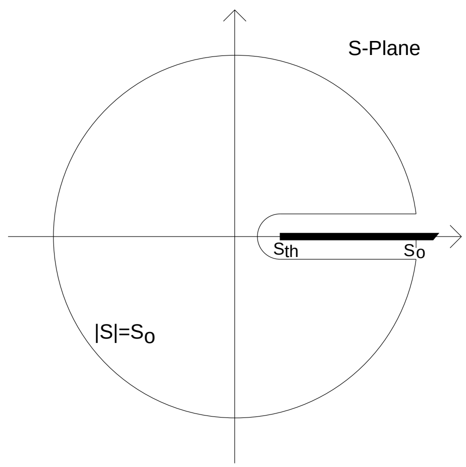
  ◦ EM: $\sigma[e^+e^- \to hadrons] \equiv \sigma_{EM}(s)$

  ◦ ud V/A : $R_{V/A;ud} \equiv \frac{\Gamma[\tau\to\nu_\tau\, \text{hadrons}_{V/A;ud}(\gamma)]}{\Gamma[\tau^-\to\nu_\tau e^-\bar{\nu}_e(\gamma)]}$, $y_\tau = s/m_\tau^2$, $w_T(y) = (1-y)^2(1+2y)$

$$\rho^{(1)}_{EM}(s) = \frac{s\,\sigma_{EM}(s)}{16\pi^3\alpha^2_{EM}}$$

$$\rho^{(1)}_{V/A;ud}(s) = \frac{m_\tau^2\, dR^{(J=1)}_{V/A;ud}/ds}{12\pi^2 S_{EW}|V_{ud}|^2\, w_T(y_\tau)}$$

- $\Pi^{(1)}_{EM}$, $\Pi^{(0+1)}_{V/A;ud}$ satisfy the FESR relation, valid for any s_0, any analytic $w(s)$



$$\int_0^{s_0} w(s)\,\rho(s)\,ds = -\frac{1}{2\pi i}\oint_{|s|=s_0} w(s)\,\Pi(s)\,ds$$

- Basic idea: data on LHS, OPE (hence α_s) on RHS

OPE FEATURES (AND ISSUES)

- Sensitivity to α_s: For $s_0 \gtrsim 2$ GeV^2, strong $D=0$ dominance (and known to 5-loops)

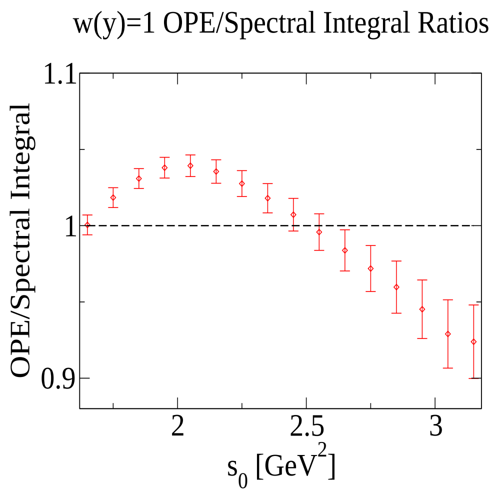
- **HOWEVER** 1% $\alpha_s^{n_f=5}(M_Z^2)$ **requires higher** D **(NP) contributions under control to** $< 0.5\%$ **of** $D=0$

- $w(s) \rightarrow w(y)$, $y = s/s_0$, $w(y)$ polynomial $\Rightarrow$
  - Integrated $D = 2k+2$ OPE scales as $1/s_0^k$
  - $w(y)$ degree $N \Leftrightarrow$ OPE (unsuppressed by α_s factors) up to $D = 2N+2$

- $D > 4$ phenomenologically unknown, must fit to data

- OPE breakdown/duality violation (DV)?

  * Integrated DVs not generally negligible at scales $\sim$ a few GeV^2, even though $>> \Lambda^2_{QCD}$

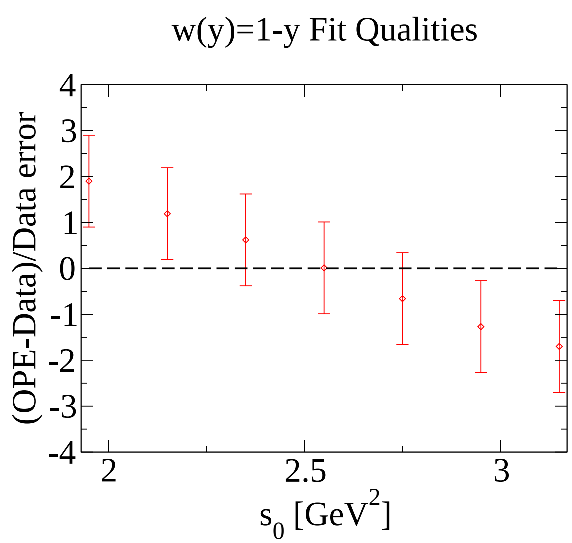


  * Integrated DVs significantly reduced for "pinched" weights ($w(s_0) = 0$), $s_0 \gtrsim 2$ GeV^2

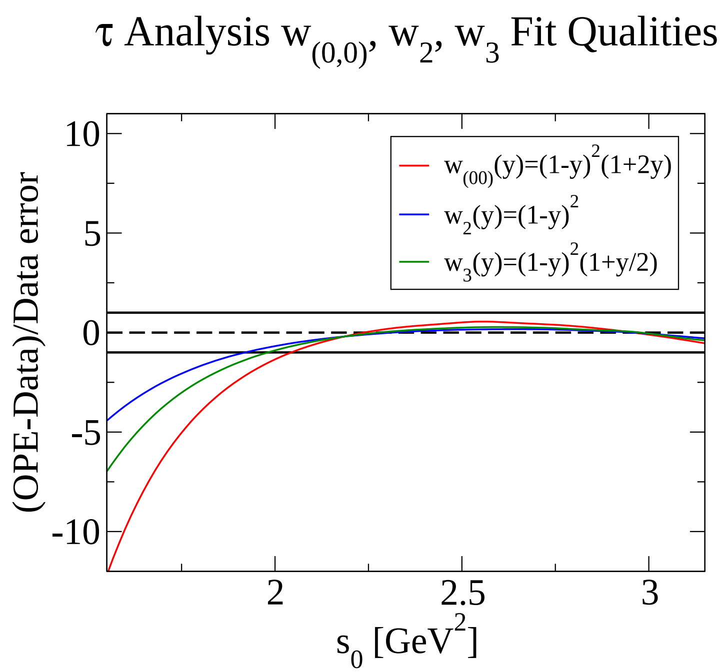
* For display: "fit qualities" from $w(y)$-weighted OPE, spectral integrals, $I_{w;OPE}(s_0)$, $I_{w;spec}(s_0) \pm \delta I_{w;spec}(s_0)$

$$F_J^w(s_0) \equiv \left[I_{w;spec}(s_0) - I_{w;OPE}(s_0) \right] / \delta I_{w;spec}(s_0)$$

* Residual DVs for only single pinch $[w(y) = 1 - y]$



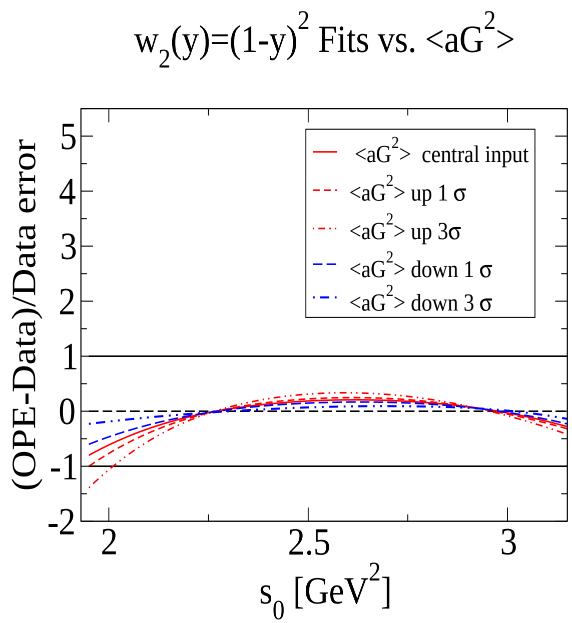
* Double pinch sufficient (within errors) down to ∼ 2 GeV^2, but NOT below



* Limited s_0 window with DV neglect self-consistent

  ◦ $\Rightarrow$ limited number OPE parameters fittable (2 in practice), hence need for external $< aG^2 >$ input

  ◦ $\Rightarrow$ potential additional systematic uncertainties: e.g., $w_2(y)$ fits for various input $< aG^2 >$



REFERENCES FOR A FEW KEY POINTS/ISSUES

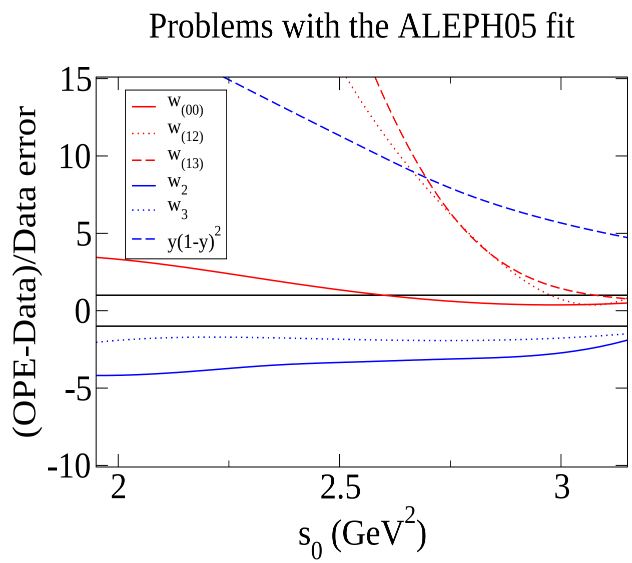
- Baikov, Chetyrkin, Kuhn [PRL 101 (2008) 012002]: the 5-loop $D=0$ Adler function series

- The *conventional* "spectral weight" analyses:
  - ALEPH [Davier et al., EPJ C56 (2008) 305], OPAL [EPJ C7 (1999) 571]
  - $w(s)$ to degree 7, OPE to $D \leq 8$ (consistency?)

- Beneke, Jamin [JHEP 0809 (2008) 044]: FOPT/CIPT

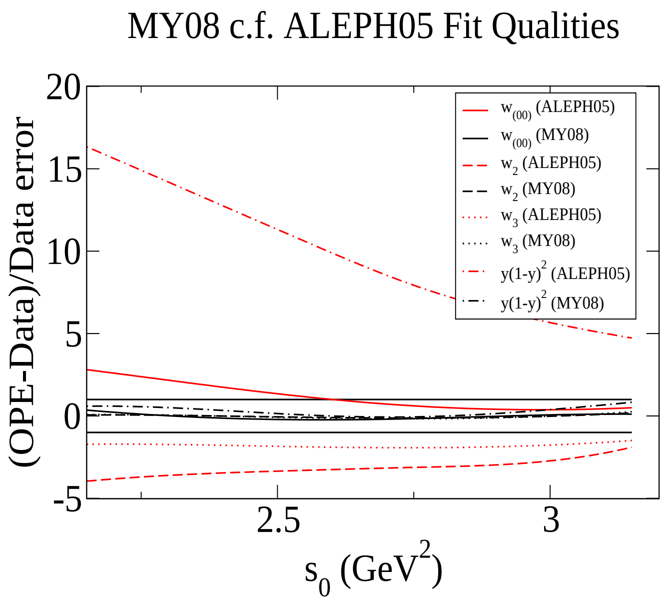
- KM, Yavin [PRD78 (2008) 094020]: self-consistent $w(y)$, OPE D_{max} treatment/issues

- Importance of consistent OPE truncation/$w(y)$ choice



$F_V^w(s_0)$ from ALEPH OPE fits: selected "(km) spectral weights" (degree $= 3 + k + m$) (red lines); additional degree ≤ 3 $w(y)$ ($D_{max} \leq 8$) (blue lines)

- Analogous MY08 results with self-consistent degree/OPE D_{max} treatment (V channel degree ≤ 3 $w(y)$ examples)



V channel fit qualities, $F_V^w(s_0)$, for MY08 (black lines), ALEPH05 (red lines) fits

CURRENT STATUS OF τ DECAY RESULTS

- Quote OPAL-based only, pending ALEPH covariance matrix re-analysis/correction

- With DVs neglected, self-consistency (within errors)
  - ∗ MY08 OPAL-based, multiple $w(y)$, V+A
  - ∗ FOPT-CIPT difference included in theory error
  - ∗ Systematic from neglected residual DVs absent (requires DV model to quantify)

$$\alpha_s^{(n_f=3)}(m_\tau^2) = 0.322(7)_{exp}(12)_{th}$$
$$\alpha_s^{(n_f=5)}(M_Z) = 0.1188(3)_{evol}(6)_{exp}(15)_{th}$$

- **PRELIMINARY** analysis including DVs
  - ∗ Physically motivated DV model (large N_c, Regge spacing of resonances)
  - ∗ Based on earlier work by Cata, Golterman, Peris [PRD77 (2008) 093006; D79 (2009) 053002]
  - ∗ Resonance structure ⇔ natural channel-dependence
  - ∗ Work ongoing; see M. Jamin talk for details, results

SOME PRELIMINARY EM ANALYSIS EXPLORATIONS

- $\rho_{EM}(s)$ to ~ 4 GeV^2 from sum over exclusive modes
- New exclusive mode σ_{EM} results (known VP correction status, smaller errors) replace old where old have uncertain/unknown VP corrections (where possible)
- To be specific, BaBar 2009 cross-sections, covariances for $\pi^+\pi^-$
- Preliminary 2007 Lepton-Photon BaBar $\pi^+\pi^-\pi^0\pi^0$ (still significantly below τ+CVC expectations)

- Features/issues for the EM approach

  * Advantage: s_0 not limited by kinematics $\Rightarrow$ c.f. τ, can use higher s_0, wider s_0 fit window (reduced higher D OPE, integrated DV contributions; improved higher D OPE fitting)

  * Disadvantage: expect different DV parameters for $I=0$, $I=1$ (4 per channel for CGP DV model) $\Rightarrow$ almost certainly have to take $I=1$ DVs (and perhaps also fitted higher D $I=1$ OPE condensates) from τ (a problem at present, given the current 4π puzzle/discrepancy)

  * Disagreements between results for some modes from different experiments still to be resolved [BaBar, Belle, VEPP2000 should help here]

- Plunging ahead despite the problems

  * A preliminary $w(y) = 1 - y$ analysis with $I = 1$ DV input and (weakly constrained) $< aG^2 >$ range from τ OPE+DV fits [BCGJMOP approach]

  * Assume $SU(3)_F$ to get $I = 0$ integrated DVs from $I = 1$ (a bit dicey, but s_0 large enough so integrated $I = 1$ DVs fairly small)

  * EM data as indicated above

  * τ constraints (including weak $< aG^2 >$ constraint) turn out to be needed

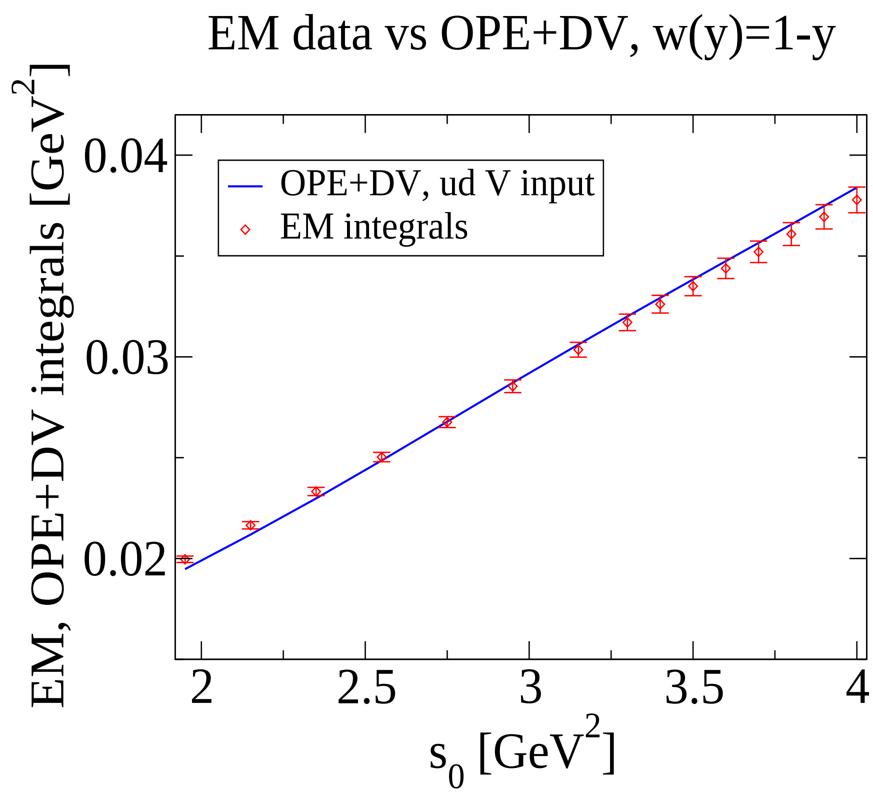
  * No combined multi-weight analysis yet

  * **PRELIMINARY** α_s range allowed by τ constraints: $\alpha_s(m_\tau^2) = 0.286 \pm 0.024 \Rightarrow \alpha_s(M_Z^2) = 0.1140(37)$

* Central EM spectral integrals currently prefer low α_s, but 4π important so significant change possible

* Preliminary analysis with $w(y) = 1-2y^2+y^4$ (strongly suppressed $D = 4$, fitted $D = 6, 10$) confirm preference for low α_s

* FIGURE for $w(y) = 1-y$ OPE+DV versus EM spectral integrals for central α_s from range above



EM data vs OPE+DV, w(y)=1-y
EM, OPE+DV integrals [GeV^2]
0.04
0.03
0.02
2
2.5
3
3.5
4
s_0 [GeV^2]
OPE+DV, ud V input
EM integrals

Comparison with selected other recent high-precision results

Source	$\alpha_s^{(n_f=5)}(M_Z)$
Global EW fit	0.1185(26)
Lattice $\bar{c}c$ correlators	0.1183(7)
UV sensitive lattice observables	0.1186(6)
Lattice VV, AA correlators	$0.1181(3)\left({}^{+13}_{-4}\right)$
SCET NNNLL thrust	0.1135(10)
τ, no DVs	0.1188(16)
τ, with DVs (preliminary)	0.1189(32) (CIPT)
	0.1170(25) (FOPT)
PRELIMINARY low-E EM	$\sim$ 0.1140

COMMENTS/CONCLUSIONS/OPINIONS

- Precision determination from τ decays still feasible, even with DVs incorporated (see M. Jamin talk for details)

- Careful treatment and fitting of $D > 4$ contributions *mandatory*

- Current τ, precision lattice results in agreement

- Central **preliminary** EM determinations low c.f. precision lattice (but further detailed studies required)

- **Theorists' wish list (directed to experimentalists)**
  - τ data (BaBar, Belle):
    - 4π branching fractions/distributions, discrepancy with EM
    - Full ud V, A spectral distributions (fit parameter covariances in analysis including DVs (M. Jamin talk) scale linearly with data covariances)
    - $K\bar{K}\pi$: (relatively simple (?)) angular analysis, would remove dominant V/A separation ambiguity in kinematically accessible regime
    - *The τ vs EM+CVC 4π issue*

– EM data:

  * More ISR exclusive mode cross-sections from B-factories (especially awaiting $\sigma[\pi^+\pi^-\pi^0\pi^0]$)

  * The BaBar vs KLOE/SND/CMD2 $\pi\pi$ issue

  * VEPP2000 exclusive mode cross-sections, $E_{CM} \sim 1.4 \to 2$ GeV eagerly awaited

  * *The EM vs* τ+*CVC* 4π *issue*