THE STATUS α_s FROM THE LATTICE AND HADRONIC τ DECAYS

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Achievements and New Directions in Subatomic Physics

(Tony 60-Fest)

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OUTLINE

- *Context (including lattice vs. τ decay tension)*
- *Recent updates of UKQCD/HPQCD lattice approach*
- *New results on the hadronic τ decay determination*
- *Propsects/issues*

THANKS/COLLABORATORS

- CSSM version lattice α_s: Derek Leinweber, Peter Moran and Andre Sternbeck

- τ decay α_s: Tzahi Yavin

- work in progress on duality violation in τ α_s (etc.): Maarten Golterman, Santi Peris, Oscar Cata

- CSSM in general for its terrific physics atmosphere!!

CONTEXT ETC.

- HPQCD/UKQCD, PRL95 (2005) 052002: perturbative analysis of UV-sensitive lattice observables [dominant input to PDG08 assessment $\alpha_s(M_Z) = 0.1176(20)$]

$$[\alpha_s(M_Z)]_{latt} = 0.1170(12)$$

- Conventional ALEPH, OPAL [e.g., EPJC56 (2008) 305]: "(k,m) spectral weight" hadronic τ determination as of mid-2008:

$$[\alpha_s(M_Z)]_\tau = 0.1212(11)$$

- c.f. recent experimental determinations

Source	$\alpha_s(M_Z)$
Global EW fit	0.1193(28)
H1+ZEUS NLO inclusive jets	0.1198(32)
H1 high-Q^2 NLO jets	0.1182(45)
Non-singlet structure functions	0.1142(23)
NNLO+NLLA LEP event shapes	0.1224(39)
NNLO+NLLA JADE event shapes	0.1172(51)
NLO inclusive jets, $p\bar{p}$	0.1161(48)
ZEUS NLO inclusive jets, γp	0.1223(38)
NNNLL ALEPH+OPAL thrust distributions	0.1172(21)
$\Gamma[\Upsilon(1s) \to \gamma X]/\Gamma[\Upsilon(1s) \to X]$	0.1190(60)

NOTE: expt'l det'n errors large c.f. nominal lattice, τ

Excluding τ, lattice input, Bethke [0908.1135] average

$$\alpha_s(M_Z) = 0.1184(7) \to 0.1179(13)$$

UPDATES OF HPQCD LATTICE APPROACH

- Based on perturbative analyses of observables, O_k, measured on MILC (asqtad) $n_f = 2+1$ ensembles

- $O(\alpha_s^3)$ $D = 0$ $(m_q = 0)$ expansion

  $$[O_k]_{D=0} = D_k \alpha_T(Q_k) \left[1 + c_1^{(k)} \alpha_T(Q_k) + c_2^{(k)} \alpha_T^2(Q_k) + \cdots \right]$$

  with $Q_k = d_k/a$ the BLM scale for O_k

- D_k, $c_1^{(k)}$, $c_2^{(k)}$, d_k: Q. Mason et al. 3-loop lattice PT

- Original HPQCD/UKQCD analysis [PRL 95 (2005) 052002]: $a \sim 0.18$, 0.12, 0.09 fm ensembles

- HPQCD [PRD78 (2008) 114507], CSSM [PRD78 (2008) 114504] updates add new $a \sim 0.15$, 0.06 fm ensembles, one (am_ℓ, am_s) $a \sim 0.045$ fm ensemble (HPQCD only) (results dominated by finer ensembles)

- m_q-dependent NP contributions: linear m_q extrapolation/subtraction

- m_q-independent NP: estimate/subtract via LO $\langle aG^2 \rangle$ (+ fitted $D > 4$ for more long-distance-sensitive observables in 2008 HPQCD)

Some relevant details

- $D = 0$ to $O(\alpha_s^3)$ insufficient to account for observed scale dependence $\Rightarrow$ MUST fit additional HO term(s)

- 2008 HPQCD, CSSM: different $D = 0$ expansion parameter choices $\Rightarrow$ different (complementary) handling of residual HO perturbative uncertainties

- $m_q \to 0$ extrapolation very reliable:
  - many (am_ℓ, am_s) for $a \sim 0.12$ fm, very good linearity (plus good linearity for other a as well)
  - extrapolation very stable to added non-linear terms

- Re m_q-independent NP subtraction:
  - $\langle aG^2 \rangle = 0 \pm 0.012\ GeV^4$ (HPQCD), with independent fit for each O_k
  - $\langle aG^2 \rangle = 0.009 \pm 0.007\ GeV^4$ (CSSM), common input for all O_k to identify small NP cases
  - estimated $D = 4$ correction tiny for shortest-distance-sensitive observables (e.g., $log(W_{11})$, $log(W_{12})$)
  - After fitted m_q-independent NP subtractions, HPQCD observables with LARGE estimated $D = 4$ corrections yield α_s in good agreement with $log(W_{11})$ etc.

- COMPARISON OF HPQCD, CSSM RESULTS
  - Results for a selection of three least-NP and four most-NP observables
  - $\delta_{D=4} \equiv$ fractional change from scale dependence of "raw" observable to that of m_q-independent NP-subtracted version between $a \sim 0.12$ and ~ 0.06 fm ($\langle aG^2 \rangle = 0.009\ GeV^4$ as input)
  - NOTE: re estimated NP $D = 4$ corrections
    - corrections far and away the largest for the 3 HPQCD "outliers"
    - despite *large* corrections, α_s agree with results from observables where NP corrections negligible

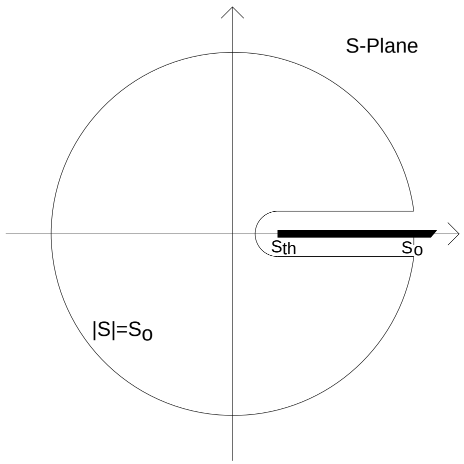
– $\delta_{D=4}$ and resulting $\alpha_s(M_Z)$ values

O_k	$\alpha_s(M_Z)$ (HPQCD)	$\alpha_s(M_Z)$ (CSSM)	$\delta_{D=4}$
$\log(W_{11})$	0.1185(8)	0.1190(11)	0.7%
$\log(W_{12})$	0.1185(8)	0.1191(11)	2.0%
$\log\left(\frac{W_{12}}{u_0^6}\right)$	0.1183(7)	0.1191(11)	5.2%
$log\left(\frac{W_{11}W_{22}}{W_{12}^2}\right)$	0.1185(9)	N/A	32%
$log\left(\frac{W_{23}}{u_0^{10}}\right)$	0.1176(9)	N/A	53%
$log\left(\frac{W_{14}}{W_{23}}\right)$	0.1171(11)	N/A	79%
$log\left(\frac{W_{11}W_{23}}{W_{12}W_{13}}\right)$	0.1174(9)	N/A	92%

THE HADRONIC τ DETERMINATION

- Based on FESRs for $\Pi^{(0+1)}_{T;ud}$, $T = V, A, V + A$

$$\int_0^{s_0} w(s)\,\rho^{(0+1)}_{T;ud}(s)\,ds = -\frac{1}{2\pi i}\oint_{|s|=s_0} w(s)\,\Pi^{(0+1)}_{T;ud}(s)\,ds$$



  - valid for any s_0, analytic $w(s)$
  - LHS: data; RHS: OPE (hence α_s) for $s_0 >> \Lambda^2_{QCD}$

- The spectral integrals

  - V, A, $I = 1$ spectral function $\rho^{(J)=(0+1)}_{V/A;ud}(s)$ from experimental differential decay distributions $\frac{dR_{V/A;ud}}{ds}$, with $R_{V/A;ud} \equiv \frac{\Gamma[\tau\rightarrow\nu_\tau\,\text{hadrons}_{V/A;ud}\,(\gamma)]}{\Gamma[\tau^-\rightarrow\nu_\tau e^-\bar{\nu}_e(\gamma)]}$

  - $\Rightarrow$ experimental access to generic $(J) = (0+1)$; $w(s)$-weighted, $0 < s \leq s_0 \leq m_\tau^2$ spectral integrals

$$I^w_{spec;T}(s_0) = \int_0^{s_0} ds\, w(s)\rho^{(0+1)}_{T;ud}(s)$$

- The OPE side:
  - $D = 0$: fixed by α_s (known to 5 loops); strongly dominant for $s_0 \gtrsim 2$ GeV^2
  - $D = 2$: $\propto (m_d \pm m_u)^2$, hence negligible
  - $D = 4$: fixed by $\langle aG^2 \rangle$, $\langle m_\ell \bar{\ell}\ell \rangle$, $\langle m_s \bar{s}s \rangle$
  - $D = 6, 8, \cdots$:
    - * not known phenomenologically, hence fitted to data (or guesstimated)
    - * for $\sim 1\%$ $\alpha_s(M_Z)$ determination need integrated $D > 4$ to $\lesssim 0.5\%$ of $D = 0$

– More on fitting the $D > 4$ contributions

* $w(y) = \sum_{m=0} b_m y^m$, $y = s/s_0$ to distinguish contribs with different D (differing s_0 dependence)

* integrated $D = 2k + 2 \geq 2$ contribution $\Leftrightarrow b_k \neq 0$ (up to $O[\alpha_s^2(m_\tau^2)]$) $\Rightarrow$ contributions up to $D_{max} = 2N + 2$ for degree N $w(y)$

* integrated $D = 2k + 2$ contributions $\propto 1/s_0^k$

$$\frac{-1}{2\pi i}\oint_{|s|=s_0} ds\, w(y) \sum_{D>4} \frac{C_D}{Q^D} = \sum_{k\geq 2} (-1)^k \frac{b_k\, C_{2k+2}}{s_0^k}$$

Summary of recent τ-based determinations

- Differences in 6-loop $D = 0$ Adler function coeff, d_5; $D = 0$ series integral prescription; $D > 4$ treatment
- Duality violation typically assumed negligible

Source	d_5	$D > 4$ self-consistency	PT scheme	$\alpha_s(M_Z^2)$
BCK08	275	No	$\frac{1}{2}$(FO+CI)	0.1202(19)
ALEPH08	383	No	CI	0.1211(11)
BJ08	283	No	FO	0.1185(14)
	283	No	model	0.1179(8)
MY08	275	Yes	CI	0.1187(16)
N09	0	partly	$\frac{1}{2}$(FO+CI)	0.1192(10)
M09	400	No	$\frac{1}{2}$(RC+CI)	0.1213(11)
CF09	283	No	modified CI	0.1186(13)

THE ALEPH, OPAL (AND RELATED) ANALYSES

- $w_{(00)}(y) = 1 - 3y^2 + 2y^3 \Rightarrow$ OPE up to $D = 6, 8$

- $\Gamma[\tau \rightarrow hadrons_{ud}\, \nu_\tau]$ alone $(\leftrightarrow I^{w_{(00)}}_{spec;V+A}(m_\tau^2))$ insufficient to fix α_s, C_6, C_8

- ALEPH, OPAL approach

  - add $s_0 = m_\tau^2$, $(km) = (10), (11), (12), (13)$ "spectral weight" FESRs $[w(y) \rightarrow y^m\,(1-y)^k\, w_{(00)}(y)]$

  - neglect (in ppl present) $D = 10, \cdots, 16$ contribs

  - α_s, $\langle aG^2 \rangle$, C_6, C_8 fitted to 5 integral set

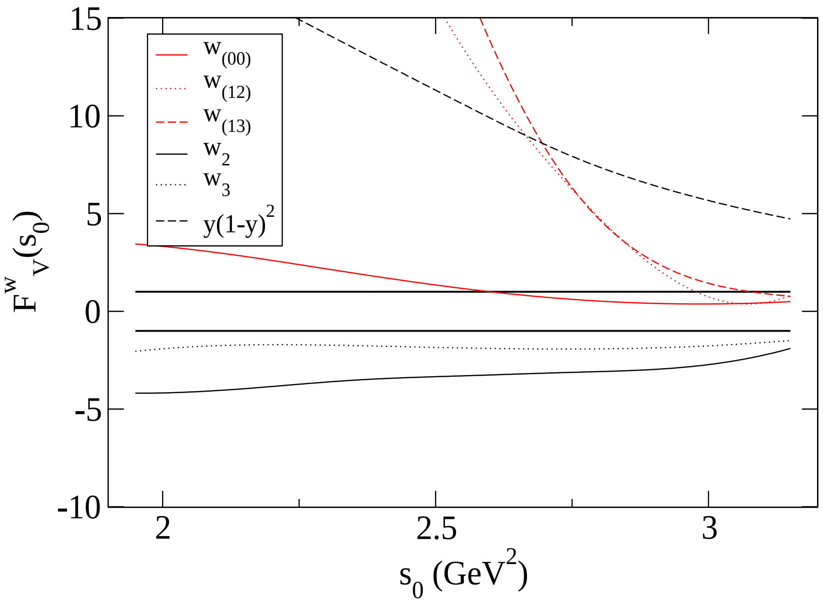
- NOTE: ALEPH C_6, C_8 input to most other analyses

- Potential problem: single s_0 $(= m_\tau^2) \Rightarrow D > 8$ (if non-negligible) distort $D = 0, 4, 6, 8$ fit parameters

- Test for possible symptoms (systematic s_0-dependence problems) using "fit qualities"

$$F_T^w(s_0) \equiv \left[I^w_{spec;T}(s_0) - I^w_{OPE;T}(s_0)\right] / \delta I^w_{spec;T}(s_0)$$

- FIGURE: $F_V^w(s_0)$ for ALEPH data, OPE fit, and 3 $w_{(k,m)}$ used in ALEPH/OPAL fit, PLUS 3 other degree 3 $w(y)$ (to provide independent $C_{6,8}$ tests)



- OPE-spectral mismatch $\Rightarrow$ either a problem with assumption that $D > 8$ negligible, or OPE breakdown (either way a problem for extracted α_s)

A MODIFIED ANALYSIS

- V, A and V+A, $w_N(y) \equiv 1 - \frac{N}{N-1}y + \frac{1}{N-1}y^N$ FESRs

  [KM,T. Yavin, PRD78 (2008) 094020 (arXiv:0807.0650)]

- single unsuppressed $D = 2N + 2 > 4$ contrib ($N \geq 2$), $(-1)^N C_{2N+2}/\left[(N-1)s_0^N\right]$

- $1/s_0^{N+1}$ scaling c.f. $D = 0 \Rightarrow$ joint α_s, C_{2N+2} fit

- $1/(N-1)$ $D = 2N + 2$ suppression, no $D = 0$ suppression $\Rightarrow$ MUCH better α_s emphasis than $w_{(k,m)}$ set

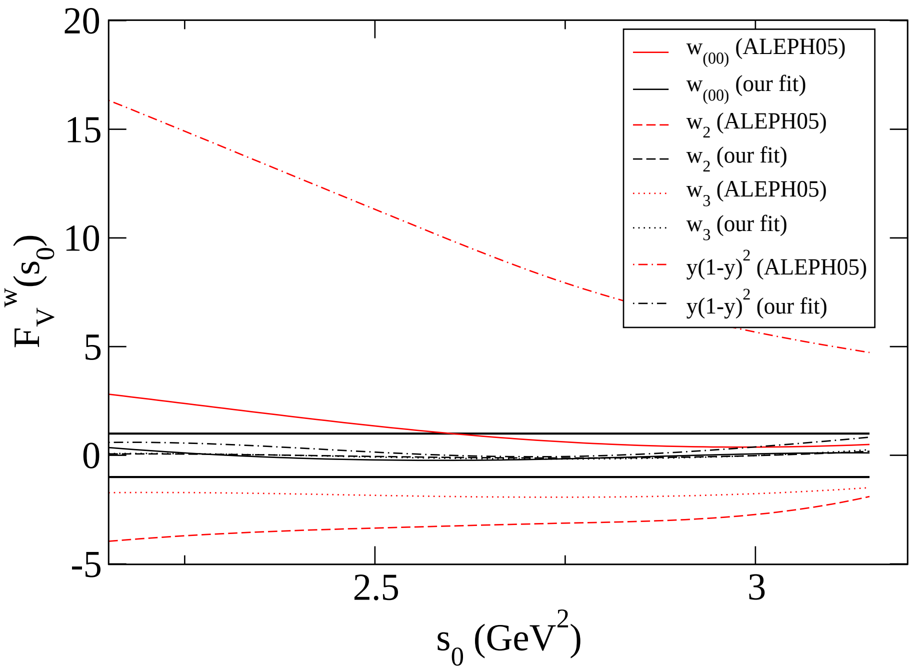
RESULTS

- Results for $\alpha_s(m_\tau^2)$ using the CIPT $D = 0$ prescription

$w(y)$	ALEPH V+A	OPAL V+A
w_2	0.320(5)(12)	0.322(7)(12)
w_3	0.320(5)(12)	0.322(7)(12)
w_4	0.320(5)(12)	0.322(7)(12)
w_5	0.320(5)(12)	0.322(7)(12)
w_6	0.320(5)(12)	0.322(8)(12)

$w(y)$	ALEPH V	ALEPH A	ALEPH V+A
w_2	0.321(7)(12)	0.319(6)(12)	0.320(5)(12)
w_3	0.321(7)(12)	0.319(6)(12)	0.320(5)(12)
w_4	0.321(7)(12)	0.319(6)(12)	0.320(5)(12)
w_5	0.321(7)(12)	0.319(6)(12)	0.320(5)(12)
w_6	0.321(7)(12)	0.319(6)(12)	0.320(5)(12)

- Much improved $F_V^w(s_0)$ for $w = w_N$ c.f. $w = w_{(k,m)}$



- CIPT $w_2, \cdots, w_6$ fit values consistent to ± 0.0001

- Averaging ALEPH and OPAL based results with non-normalization component of error $\Rightarrow$

$$\alpha_s^{(n_f=3)}(m_\tau) = 0.3209(46)_{exp}(118)_{th}$$

- standard self-consistent combination of 4-loop running, 3-loop matching at flavor thresholds $\Rightarrow$

$$\alpha_s^{(n_f=5)}(M_Z) = 0.1187(3)_{evol}(6)_{exp}(15)_{th}$$

CONCLUSIONS/SUMMARY/PROSPECTS

- Lattice ($log\,(W_{11})$ to be specific) and τ determinations now in excellent agreement

$$[\alpha_s(M_Z)]_{latt} = 0.1185(8),\ 0.1190(11)$$
$$[\alpha_s(M_Z)]_\tau = 0.1187(16)$$

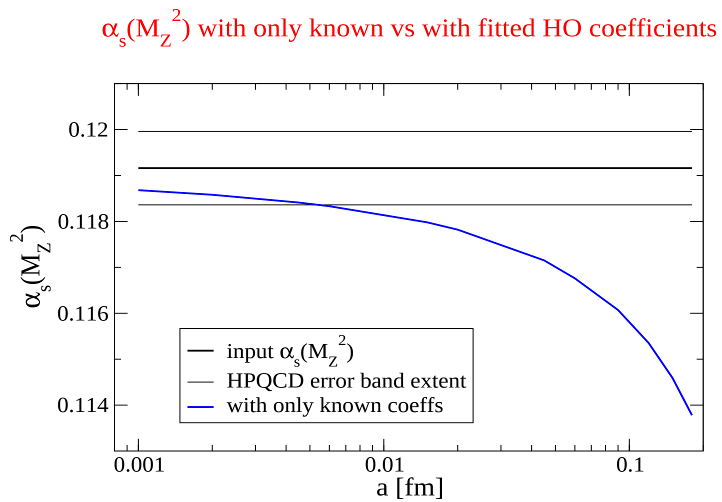
- Future prospects:

  – Significant improvement to lattice errors difficult

  – Some improvement in τ decay analysis probable

MORE ON FUTURE PROSPECTS

- The lattice analysis case:
  - further self-consistency checks from additional $a \sim$ 0.045 fm MILC ensembles, BUT a small enough to avoid fitting HO $D = 0$ coefficients impractical



- dominant overall scale-setting error, residual HO $D=0$ issues hence difficult to improve significantly

- The τ decay analysis case:

  Significant improvement requires better understanding of $D=0$ truncation uncertainty and residual duality violation (if any)

  - Theory error currently dominant ($\sim$ 2.5 times expt'l)

  - $D=0$ truncation largest theory error source (for $|FOPT-CIPT|\oplus O(a^5)$ estimate $\sim$ 0.010 of 0.012 total) $\Rightarrow$ important bottleneck for future improvements (though reducible by suitable weight choice)

- Recent explorations *a la* Beneke-Jamin, Caprini-Fischer (taking into account divergent nature of $D = 0$ series) promising for eventual reduction of $D = 0$ truncation uncertainty

- Constraining duality violation, and related issues:

  * Further constraints on Regge-inspired Cata, Goltermann, Peris DV model now demonstrated [KM+CGP], with simultaneous $\langle aG^2 \rangle$ determination

  * $\langle aG^2 \rangle$ determination relevant because

    · $\langle aG^2 \rangle$ determination proved NOT feasible using $w(y)$ with integrated DV sufficiently suppressed to neglect

- · Second largest theory error source in MY08 from input $\langle aG^2 \rangle$

- · $\langle aG^2 \rangle$ renormalon ambiguity $\Rightarrow$ should be determined simultaneously with corresponding truncated $D = 0$ series

- $*$ Preliminary results [KM+CGP] show additional constraints push maximum DV impact on α_s determination to low end of former CGP range ($\sim$ 0.0004 on $\alpha_s(M_Z)$)

– Non-trivial error reduction thus appears feasible, though not yet explicitly demonstrated

HAPPY BIRTHDAY TONY!

(Canadian English version)

HAPPY BIRTHDAY TOYNY!

(SA English version, to the Canadian ear)

GREAT TO SEE YOU BACK HERE AT THE CSSM!