α_s *from the (revised) Aleph data for* τ *decay*

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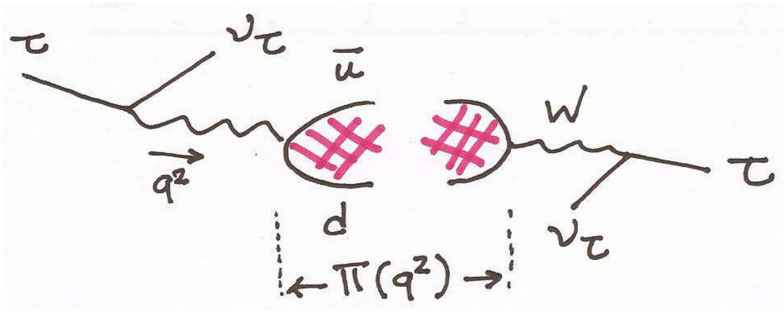
Mainly based on Phys. Rev. **D91**, 034003 (2015) and refs. therein.

See also arXiv:1606.08898 [hep-ph] and 1606.08899 [hep-ph].

QCD in τ decay

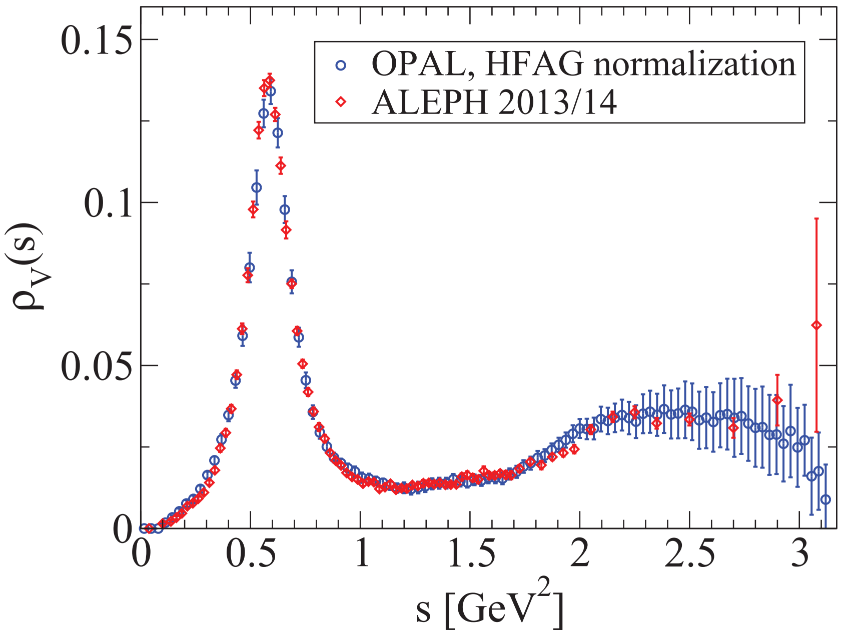


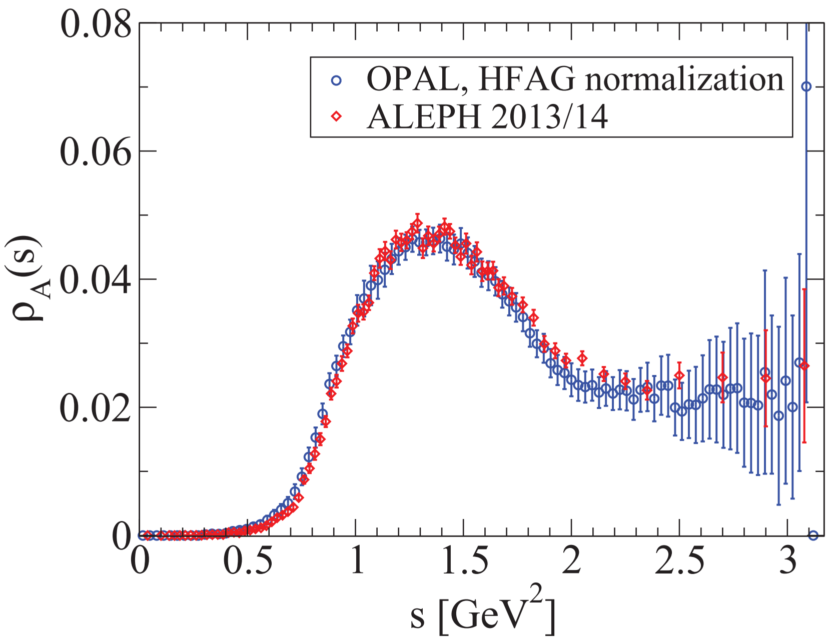
$$w_T(s;s_0) = (1+2\tfrac{s}{s_0})\ \underbrace{(1-\frac{s}{s_0})^2}_{\text{doubly pinched}}$$

$$w_L(s;s_0) = 2(\tfrac{s}{s_0})\ \underbrace{(1-\frac{s}{s_0})^2}_{\text{doubly pinched}}$$

$s_0 = m_\tau^2$ $\qquad \rho_{V,A} = \frac{1}{\pi}\mathrm{Im}\Pi_{V,A}$

$$\frac{\Gamma(\tau\to\nu_\tau \mathrm{H}_{ud}(\gamma))}{\Gamma[\tau\to\nu_\tau e\bar{\nu}_e(\gamma)]} = 12\pi^2|V_{ud}|^2 S_{EW}\int_0^{s_0}\frac{ds}{s_0}\left[w_T(s;s_0)\rho^{(1+0)}_{V+A}(s) - w_L(s;s_0)\rho^{(0)}_A(s)\right]$$

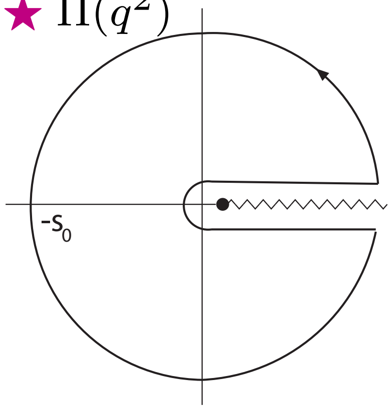




Theoretical Foundations

Shankar '77; Braaten-Narison-Pich '92

★ $\Pi(q^2)$



"Cauchy's Theorem" $\left(z = q^2 \; ; \; \rho(t) = \frac{1}{\pi}\mathrm{Im}\Pi \; ; \; w_n = \text{polynomial}\right)$:

$$\int_0^{s_0} dt\, w_n(t)\, \underbrace{\rho(t)}_{exp.} = \frac{1}{2\, i\pi} \oint_{|z|=s_0} dz\, w_n(z)\, \Pi(z)$$

$$= \frac{1}{2\, i\pi} \oint_{|z|=s_0} dz\, w_n(z) \left[\underbrace{\Pi_{\mathrm{OPE}}(z)}_{\mathcal{O}(\alpha_s^4)} + \underbrace{\Pi(z) - \Pi_{\mathrm{OPE}}(z)}_{\Pi_{DV}(z)} \right]$$

(Cata-Golterman-S.P. '05)

★ $\Pi_{DV} \to 0 \Longleftrightarrow \Pi_{\mathrm{OPE}} \to \Pi.$

However, Π_{OPE} expected **asymptotic**.

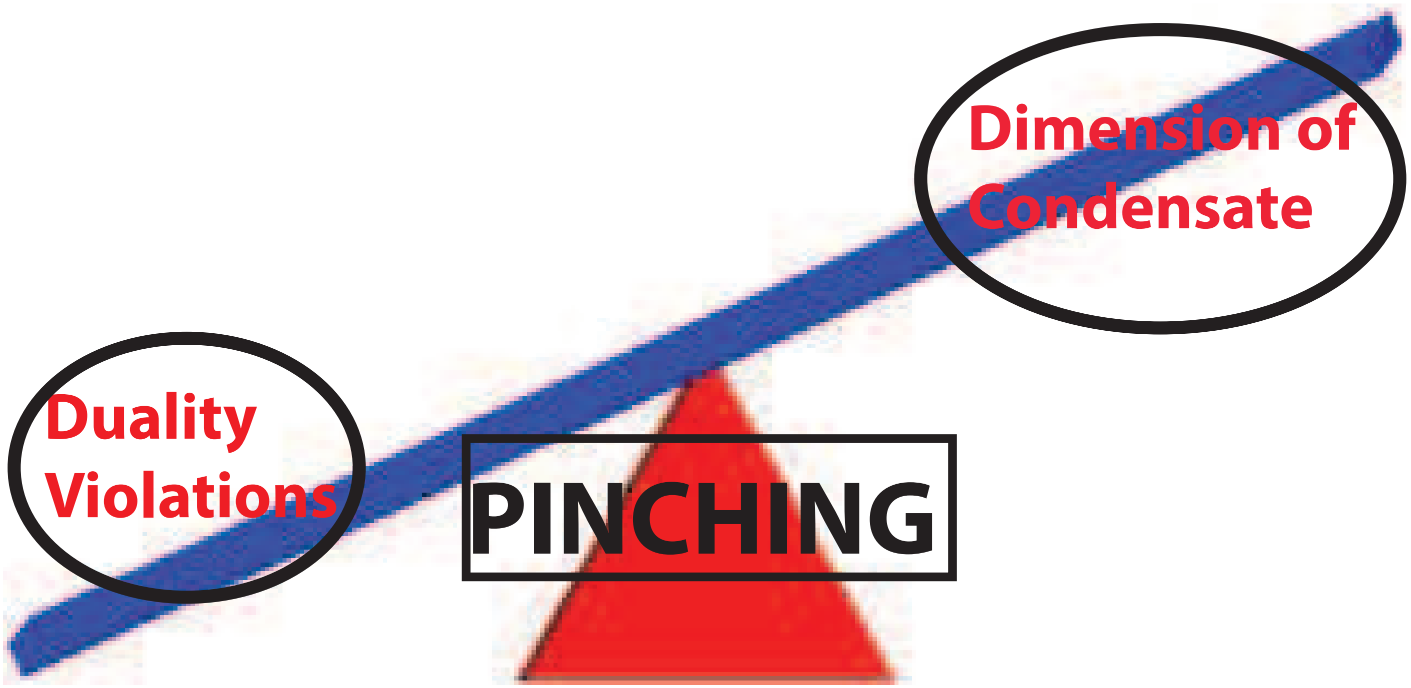
For s_0 large:

$$-\frac{1}{2\pi i} \oint_{|z|=s_0} dz\, w(z)\, \Pi_{DV}(z) = \quad - \underbrace{\int_{s_0}^{\infty}}_{\text{extrapolation!}} ds\;\; w(s)\;\; \underbrace{\frac{1}{\pi}\mathrm{Im}\Pi_{DV}(s)}_{\sim\ \text{exp. damping}}$$

Main Theoretical Message

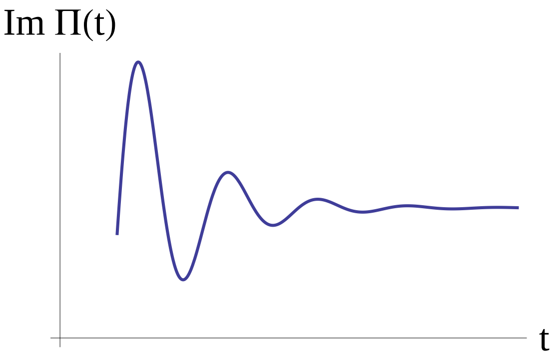
★ “Seesaw” mechanism at work:

Pinching: Not possible to suppress simultaneously DVs and NP condensate contributions.



What is $\mathrm{Im}\Pi_{DV}$?

Asymptotically at large t:



No answer from first principles, yet; just an educated guess.
(to be checked against the data)

- **Oscillation Period**: assume Regge-type spectrum, i.e. $M_n^2 \sim n$;

$$\Rightarrow \mathrm{Im}\delta\Pi \sim \sin(\alpha + \beta\, q^2).$$

- **Amplitude**: Exp. damping from asymptotic expansions and renormalons,

$$\Pi(Q^2) \sim \sum_n n!\,(b\alpha_s)^{n+1} \;\Rightarrow\; \delta\Pi \sim \mathrm{e}^{-1/b'\alpha_s} \sim \frac{\langle \alpha_s G^2 \rangle}{q^4}$$

with the replacement $\alpha_s \to 1/q^2$, i.e. $\delta\Pi \sim \mathrm{e}^{-\gamma\, q^2}$

$$\Rightarrow \mathrm{Im}\delta\Pi \sim \mathrm{e}^{-\gamma\, q^2} \sin(\alpha + \beta\, q^2).$$

These properties can be explicitly verified in a (physically motivated) model.
(Blok, Shifman and Zhang '97)

A Change of Strategy (I)

Old Strategy: (LeDiberder-Pich '92)

- Use 5 pinched weights

$$w_{kl}(y) = (1-y)^2(1+2y)(1-y)^k y^l \quad , \quad y = s/s_0, \quad s_0 = m_\tau^2 \text{ (only)}$$

with $(k,l) = \{(0,0),(1,0),(1,1),(1,2),(1,3)\}$.

- Fit to extract 4 param. : α_s and $C_{D=4,6,8}$.
- Set (arbitrarily) OPE condensates $C_{D=10,12,14,16} = 0$.
- Set (unknown) Duality Violations =0.
- May use V and A, but assume $V+A$ more reliable.

(Davier et al. '14)

$$\begin{aligned}
\langle \frac{\alpha_s}{\pi} GG \rangle \quad &= \quad (-0.5 \pm 0.3) \times 10^{-2}\ \text{GeV}^4 \,, \qquad \chi^2 = 0.43,\ p = 51\% \qquad V\,, \\
&\quad\ \ (-3.4 \pm 0.4) \times 10^{-2}\ \text{GeV}^4 \,, \qquad \chi^2 = 3.4,\ p = 7\% \qquad A\,, \\
&\quad\ \ (-2.0 \pm 0.3) \times 10^{-2}\ \text{GeV}^4 \,, \qquad \chi^2 = 1.1,\ p = 29\% \qquad V+A\,.
\end{aligned}$$

- Check Weinberg sum rules.

A Change of Strategy (II)

New Strategy (Boito et al. '11 and '12):

- Do not use $w(y)$ with a term linear in y. (Beneke et al. '13)
- Do not assume any condensate is zero. (Let the data speak.)
- Do not assume that Duality Violations are zero. (Let the data speak.)

  For $s \geq s_{min}$ (Regge/asymp. series model assumption):

$$\rho_{DV}^{V,A}(s) = \mathrm{e}^{-\delta_{V,A} - \gamma_{V,A} s} \sin\left(\alpha_{V,A} + \beta_{V,A} s\right)$$

  c.f. old strategy model assumption: $\mathrm{e}^{-\delta_{V,A}} = 0.$

- Fit to $\alpha_s, C_{D=6,8}$ and DV parameters with 3 weights:

$$w_0 = 1, w_2 = 1 - y^2 \quad \text{and} \quad w_3 = (1-y)^2(1+2y)$$

  Use all data for $s_0 \geq s_{min}$, to be determined by the fit as well.

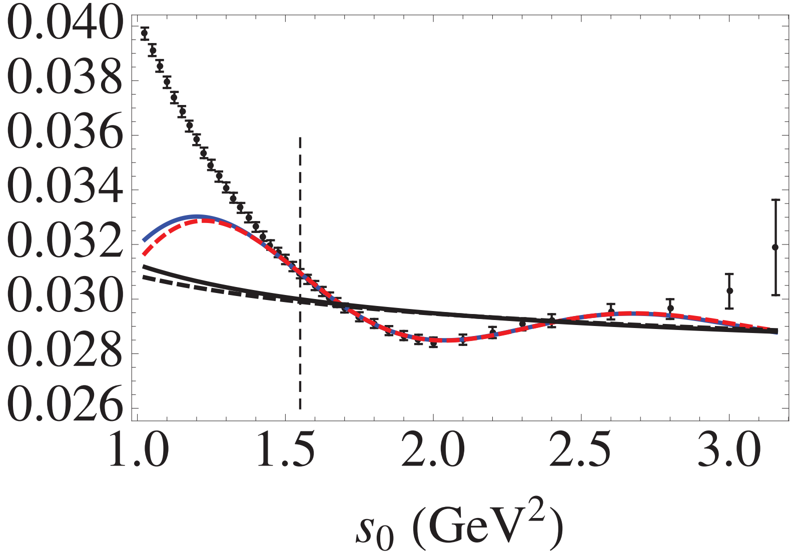
- Use V and A. Check spectral functions.
- Check Weinberg sum rules.

Example: Fit to $w_0 = 1$, V channel (I).

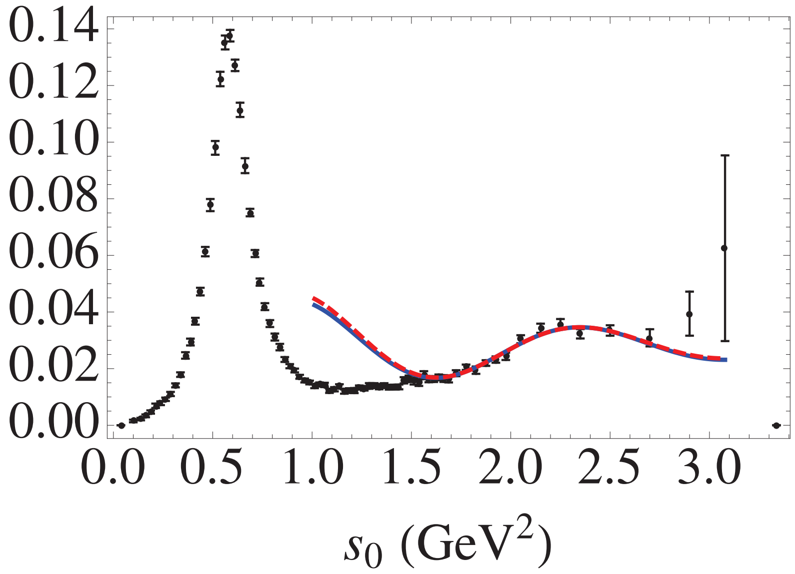
$s_{min} = 1.55\ \mathrm{GeV}^2$, $\chi^2/dof = 24.5/16$ ($p = 8\%$) ($D = 0$ FOPT, CIPT similar)

<u>curves</u>: red=CIPT blue =FOPT black =no DV

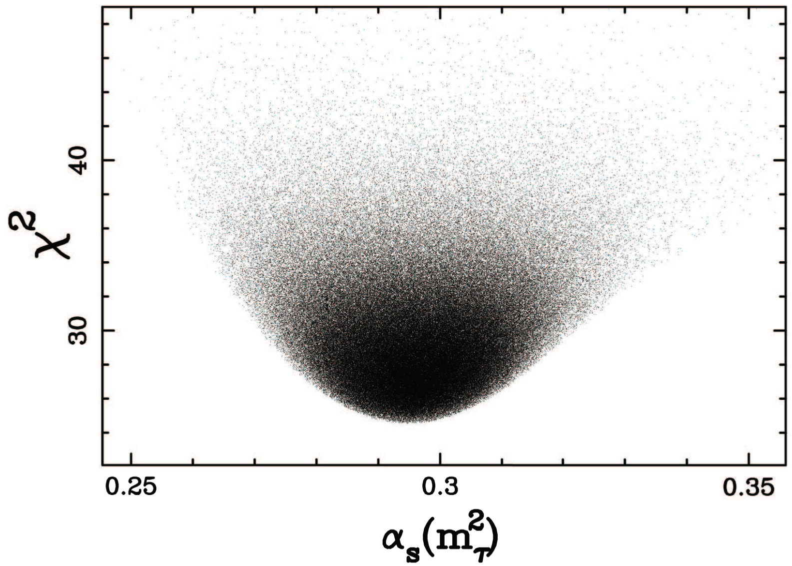
$w_0 = 1$ spectral integral

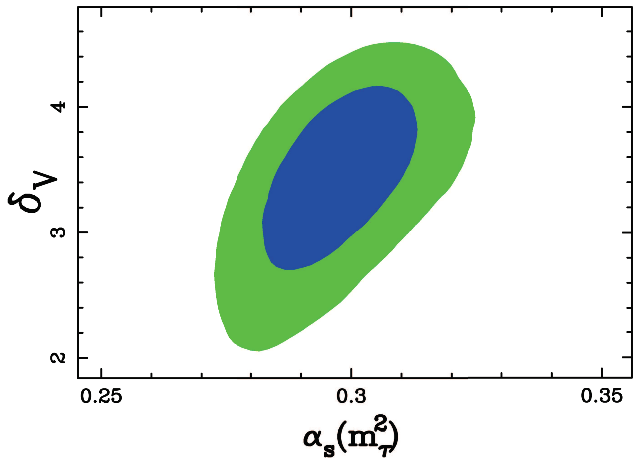


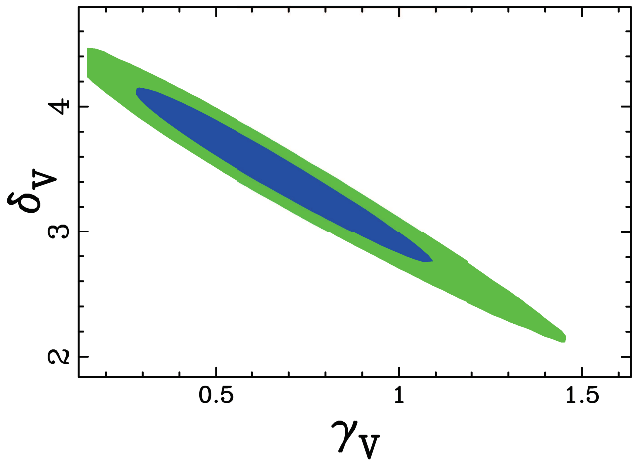
V spectrum



Example: Fit to $w_0 = 1$, V channel (II).







(68% and 95% contour plots), FOPT. Clearly $DVs \neq 0$.

We did lots of other fits as well...

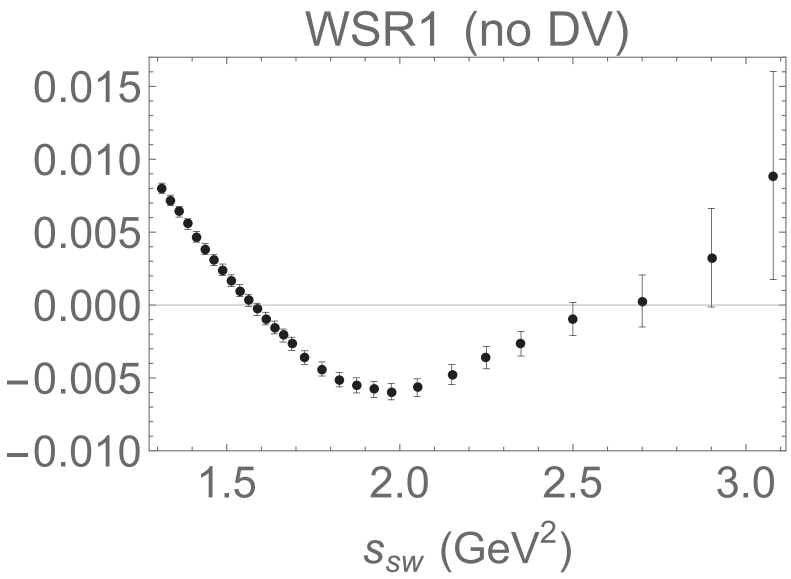
Fits :

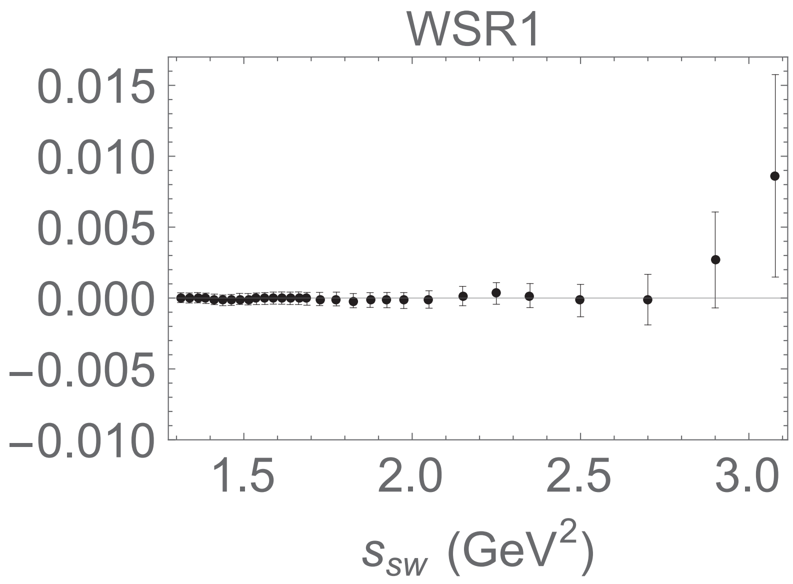
- V channel, $w_0 = 1$.
- V and A channels, $w_0 = 1$.
- V channel, $w_0 = 1$ and $w_2 = 1 - y^2$.
- V and A channels, $w_0 = 1$ and $w_2 = 1 - y^2$.
- V channel, $w_0 = 1, w_2 = 1 - y^2$ and $w_3 = (1 - y)^2(1 + 2y)$.
- V and A channels, $w_0 = 1, w_2 = 1 - y^2$ and $w_3 = (1 - y)^2(1 + 2y)$.

Consistent results in all cases.

Classic Tests

1st Weinberg sum rule: $\int_0^\infty ds\, \left(\rho_V^{(1)}(s) - \rho_A^{(1)}(s)\right) - 2f_\pi^2 = 0$





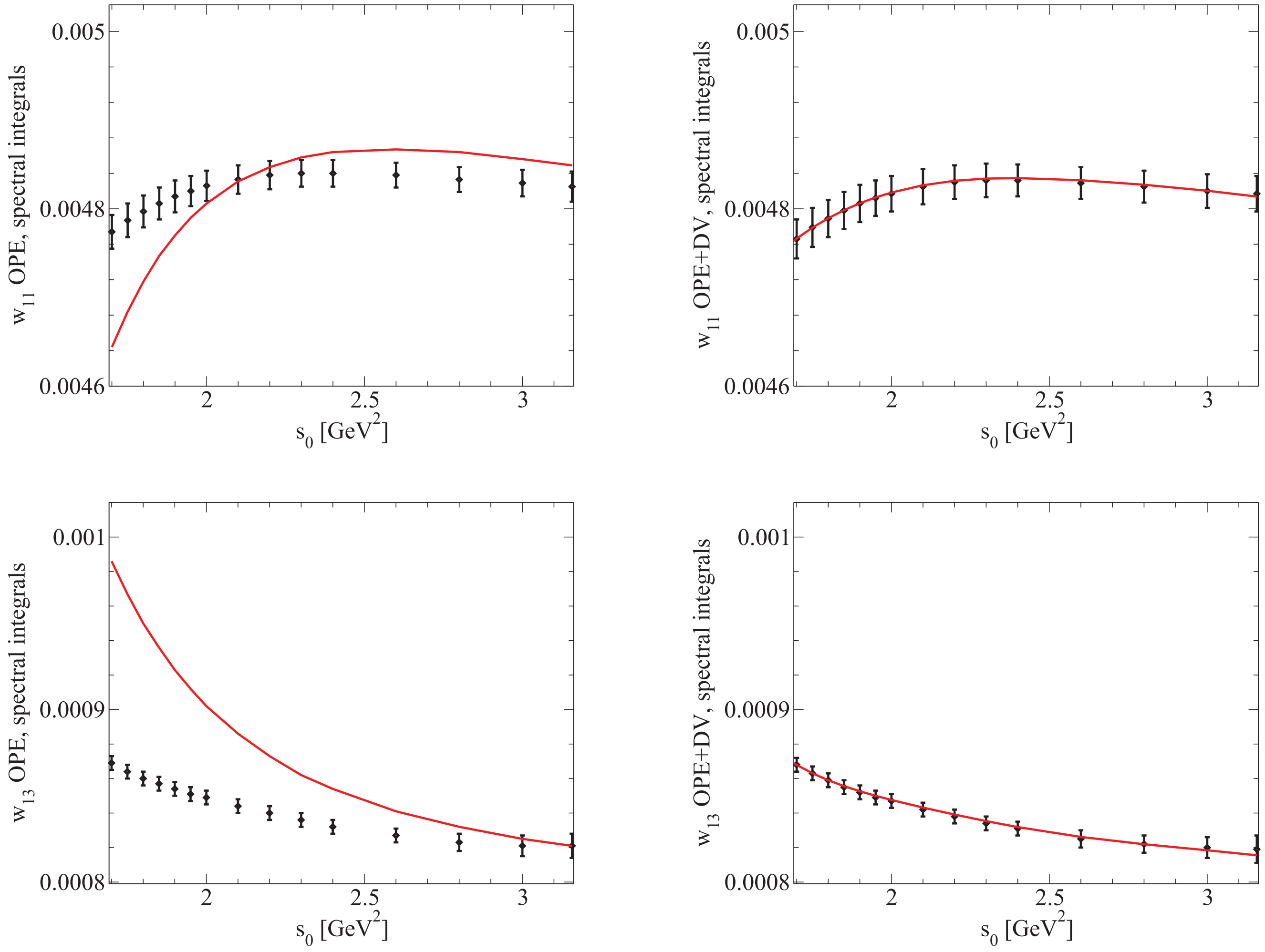
We also checked the 2nd Weinberg sum rule and the pion EM splitting sum rule.

Further Tests

(Maltman-Yavin '08)

"Old vs. New" Strategy in other FESRs: w_{11}, w_{13}, etc...

Old **New**



Results

Aleph:

(FOPT) $\alpha_s(m_\tau) = 0.296 \pm 0.010 \longrightarrow \alpha_s(m_Z) = 0.1155 \pm 0.0014$

(CIPT) $\alpha_s(m_\tau) = 0.310 \pm 0.014 \longrightarrow \alpha_s(m_Z) = 0.1174 \pm 0.0019$

- N.B. "Old Strategy" produces a shift, i.e.

$\alpha_s(m_\tau) \sim +0.03$ higher, (and $\sim$ half errors) (Davier et al. '14)

- Using **Aleph + Opal** data, we get:

$\alpha_s(m_Z) = 0.1165 \pm 0.0012$ (FOPT) $\alpha_s(m_Z) = 0.1188 \pm 0.0015$ (CIPT)

(Current PDG world average: $\alpha_s(m_Z) = 0.1181 \pm 0.0013$)

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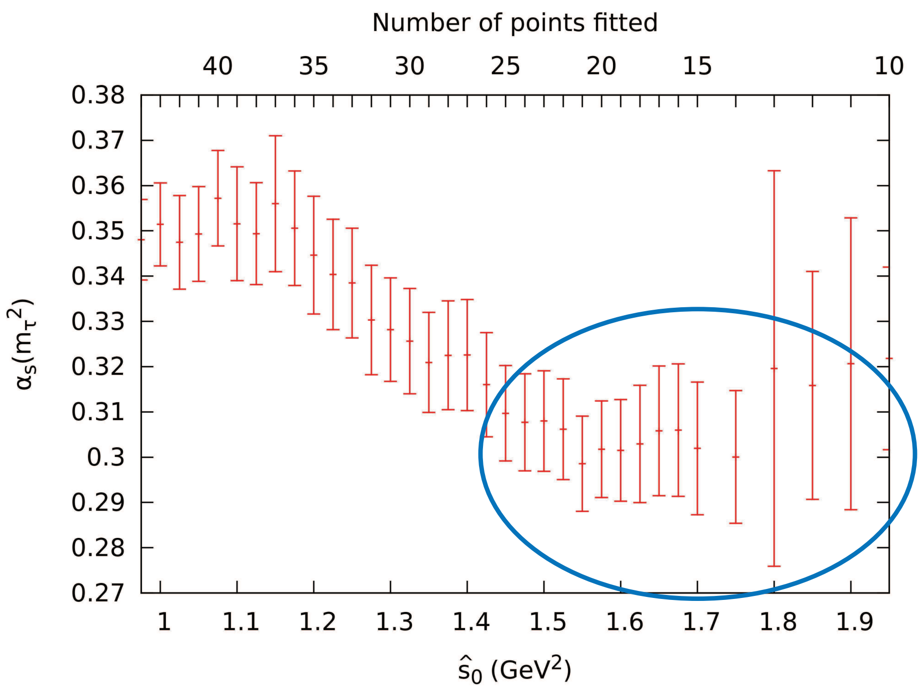
Pich and Rodriguez-Sanchez '16

- New reanalysis with the Old Strategy $\Rightarrow$ same conclusions (not a surprise).
  (and same s_0 dependence problems)

- Criticism: when DVs are included they obtain



$\Leftarrow$ Stability as $\hat{s}_0 = s_{min}$ increases,
as expected for the DV ansatz.
(So this is actually nice...)

Question of Principle:

If modeling DVs is useful for determining condensates in $V - A$

(as, e.g., in Glez-Alonso, Pich, Rguez-Sanchez '15,'16)

why wouldn't it be useful for α_s in $V + A$ as well ?

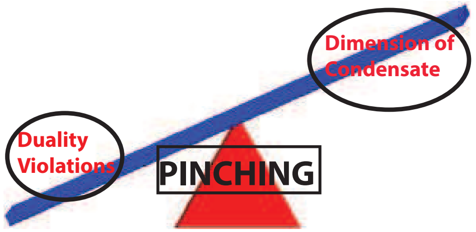
Conclusions and Outlook

- DVs are clearly visible in the τ data.

(DVs are not a question of principle, they exist in practice.)

- Pinching does not allow a simultaneous reduction of DVs **and** higher-dim condensates

(unlike what has been assumed so far in the “Old Strategy" Method).



This introduced an unquantified systematic error, and an s_0-dependence mismatch.

- I see no way to make progress without a better understanding of DVs and/or the OPE as a series expansion.

Resurgence ? (Shifman ’14)

Functional Analysis Methods ? (Caprini, Golterman, S.P. ’14)

Conclusions and Outlook (II)

- We have introduced a new strategy based on an educated guess for DVs which allows the data to determine both the contribution from DVs and condensates.

- The new strategy passes all known tests, experimental and theoretical, performing better than the "Old Strategy".

N.B. The "Old Strategy" also uses **a model**:

$$\mathrm{DVs} = 0 \Leftrightarrow \mathrm{e}^{-\delta} = 0 \quad \text{and} \quad \langle O_{10,12,14,16} \rangle = 0.$$

Not favored by data/present theoretical knowledge.

- Better data (Babar and Belle) will help significantly.
  (We are very excited about A. Lusiani's future spectral functions analysis...)