Mikhail Shifman
William I. Fine Theoretical Physics Institute, University of Minnesota

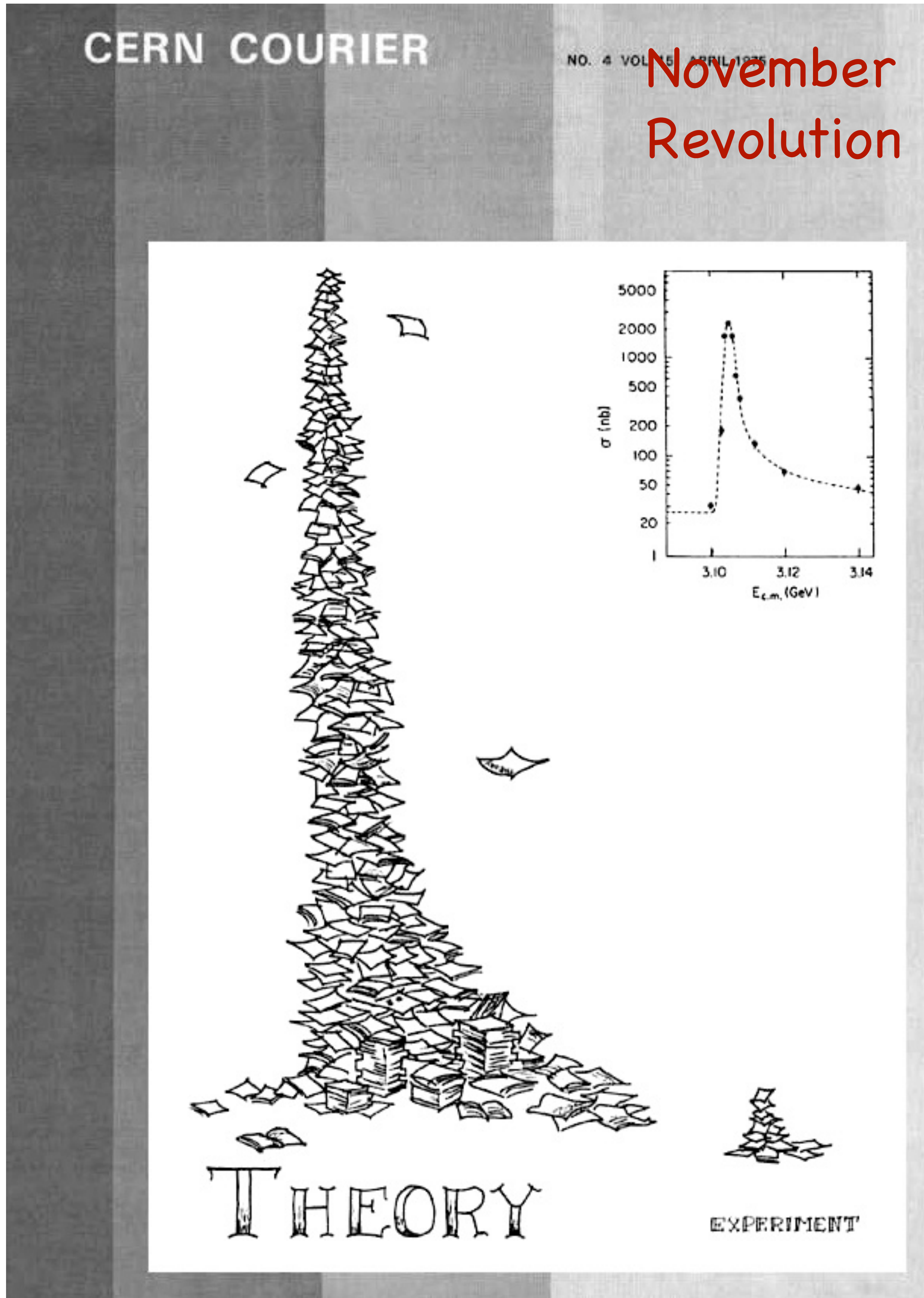
A brief history of lifetimes

Sept. 23, 2025, Siegen, Germany

November Revolution 1974

Discovery of J/ψ

ITEP in winter 1982

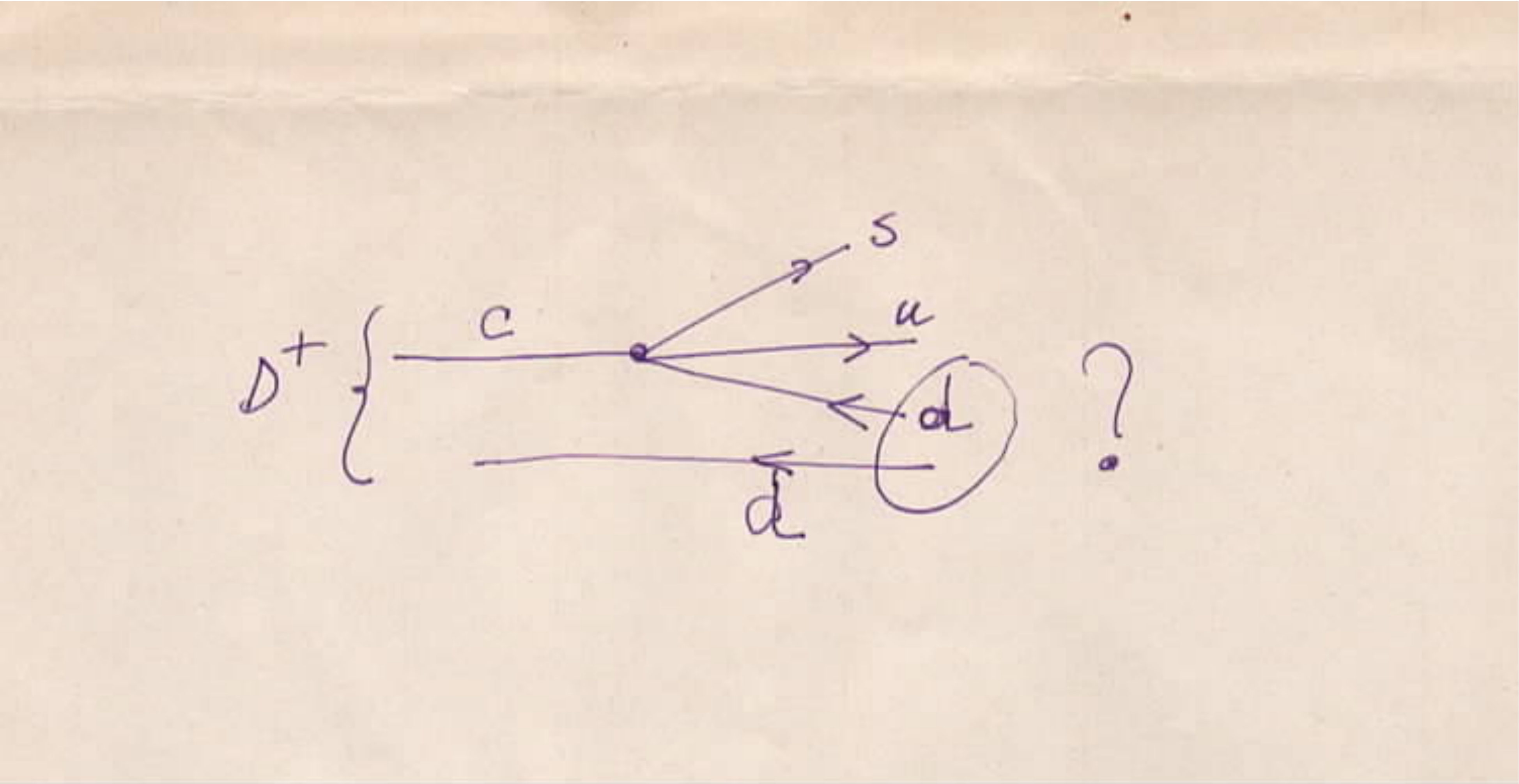


Winter 1982: charmed quark is the only heavy quark known

All c containing hadron widths were estamted as, say,

$$\Gamma(D^+ \to \text{hadrons}) = \Gamma(c \to su\bar{d})$$

No distinctions between various mesons and baryons!



Misha Voloshin and I were having lunch in the ITEP canteen…

I wish you knew the kind of garbage heap

Wild verses grow on, paying shame no heed

Anna Akhmatova

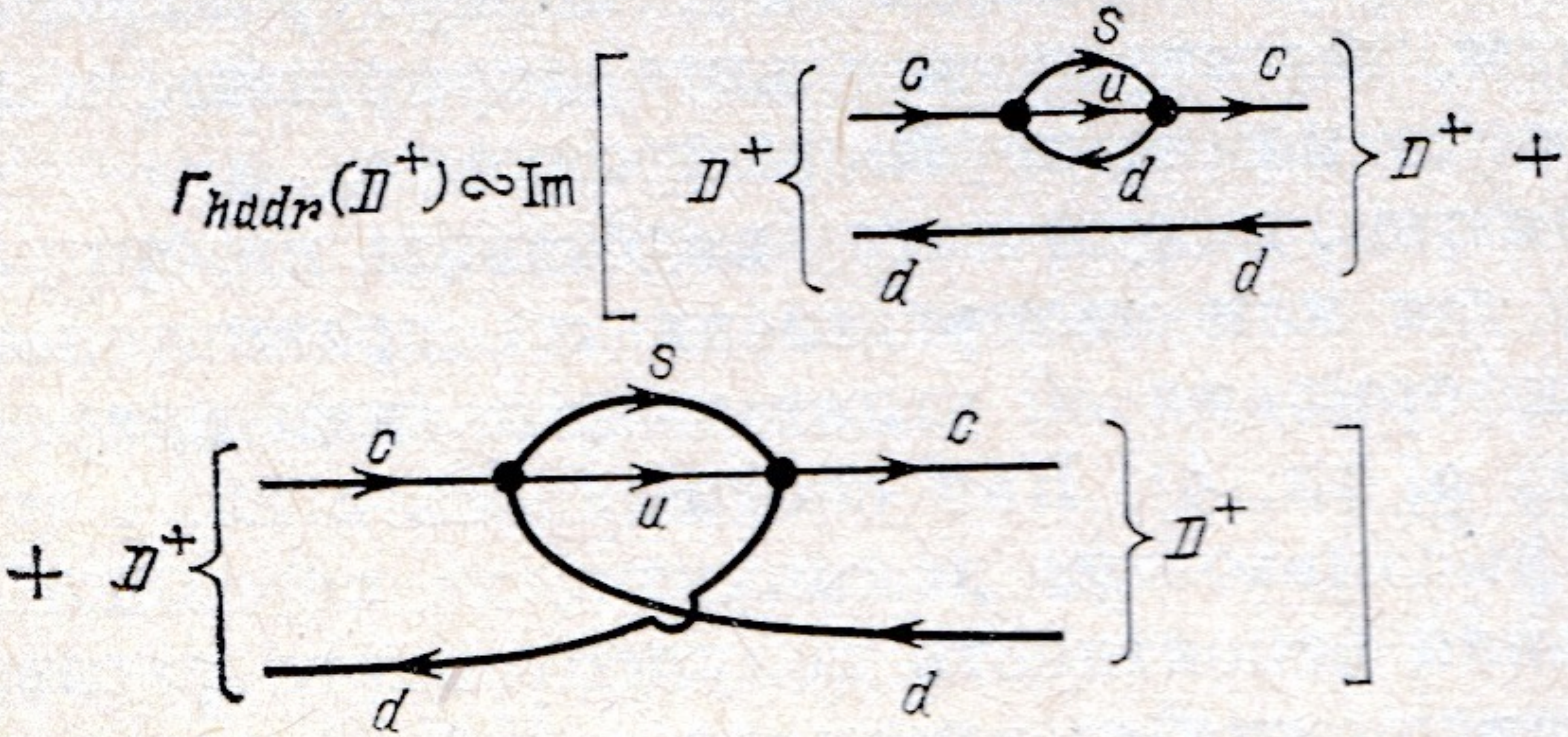
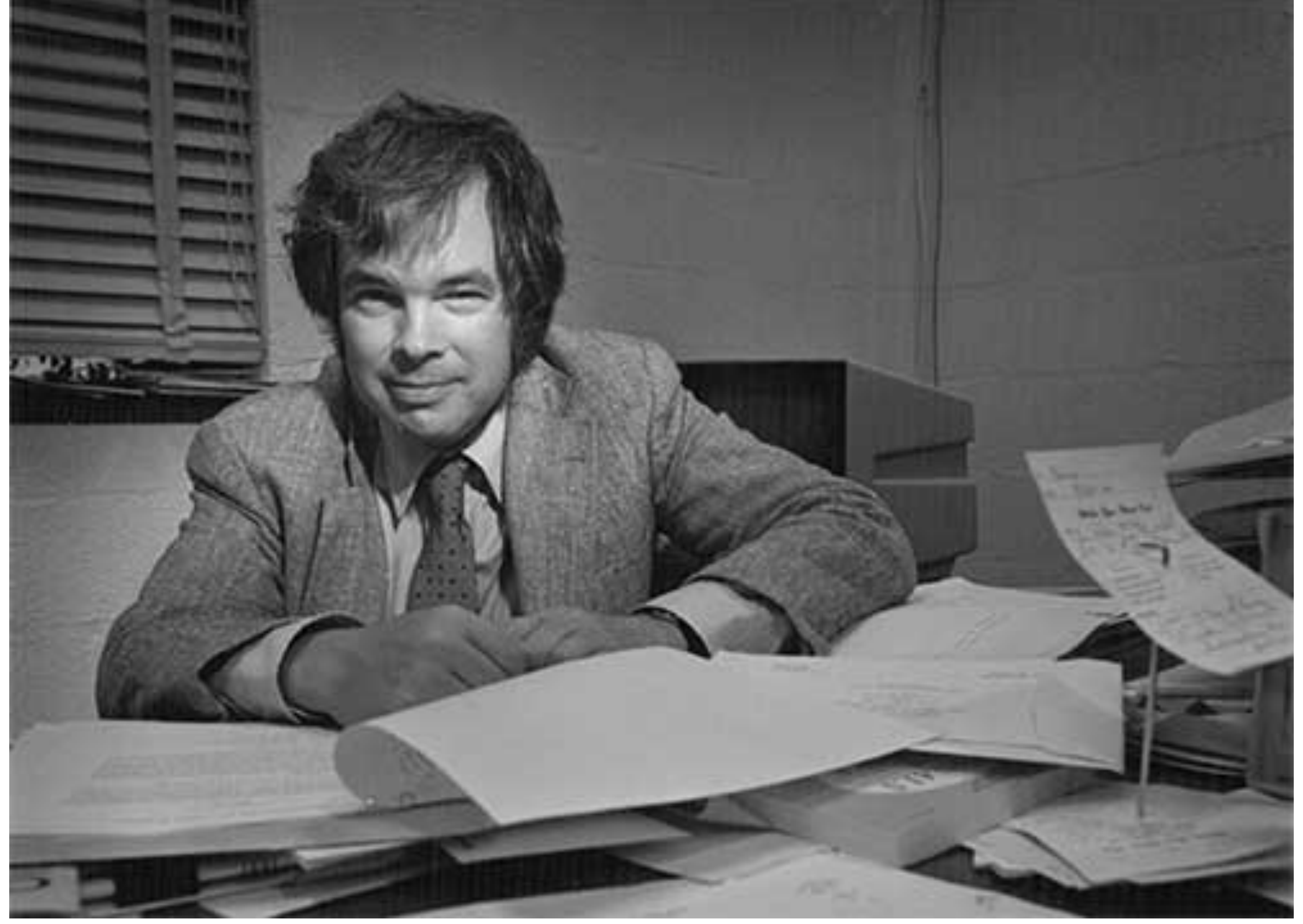


Рис. 22. Интерференционный вклад в адронную ширину распада D^+-мезона.

K. Wilson, Nonlagrangian models of current algebra, Phys. Rev. 179, 1499-1512 (1969)*



Wilson OPE or Wilsonian RG flow from UV to IR grew from

W's framework of separation of scales in QFT was especially suitable for AF theories

GENERAL; Adjustments needed for QCD!

- In QCD fixed point at $\alpha_s = 0$, hence slow logarithmic approach
- Scale Λ is not unique; heavy quark masses m_Q had to be included
- At least some information about IR was needed!

Seemingly the first deliberate decision to build QCD version of Wilson's OPE made in 1974 (penguins): VZ, AV,MS

In 1981 we had all tools at hand. Passing from Euclid → Mink

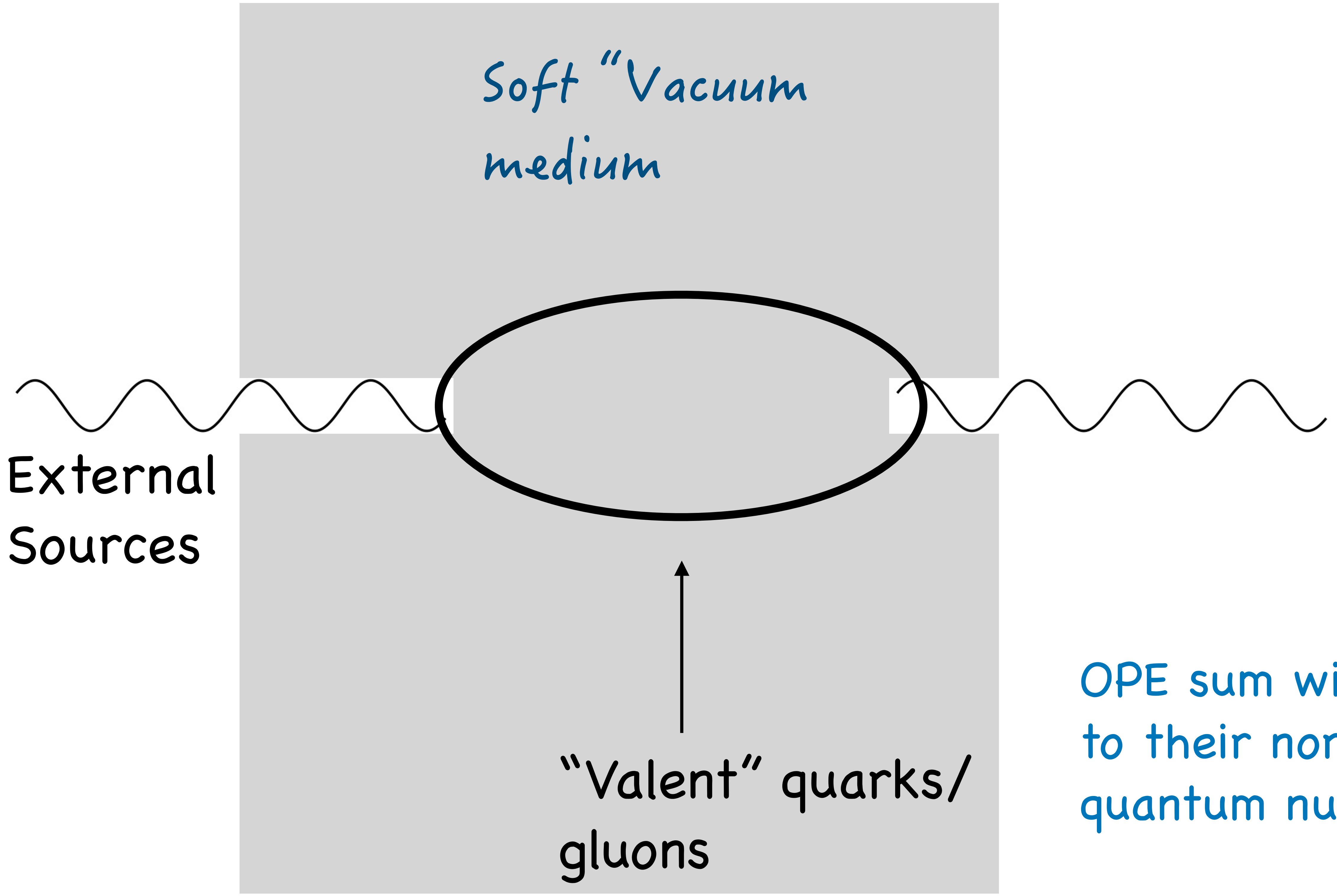
$O_{\text{peng}} = \bar{s}_L \gamma^\mu \mathscr{D}_\nu G^{\mu\nu} d_L \leftrightarrow$ flavor changing . Full class . 6 operators + more if EM is included

VEVs

Table 1 The lowest-dimension operators in OPE. Γ is a generic notation for combinations of the Dirac γ matrices.

Normal dim	3	4	5	6	6
Operator	$O_q = \bar{q}q$	$O_G = G^2_{\mu\nu}$	$O_{qG} = \bar{q}\sigma^{\mu\nu}G_{\mu\nu}q$	$O_{4q} = (\bar{q}\Gamma q)^2$	$O_{3G} = GGG$

Basic Idea



$$= \sum_{\text{dim}_n} C_n(Q,\mu)\langle O_n(\mu)\rangle = \frac{f_0^2}{Q^2 + m_0^2} + \sum_{\text{excit}} \dots$$

OPE sum with a finite number of the lowest-dimension operators ordered according to their normal dimensions (left) . Right: sum over mesons with appropriate quantum numbers. The ground state in the given channel is singled out.

Soviet Physics Uspekhi

REVIEWS OF TOPICAL PROBLEMS

Heavy quarks

V. A. Khoze and Mikhail A. Shifman, Sov. Phys. Usp. **26,** 387 (1983), May issue

Translated

BUT… MIND GLAVLIT

DEUTSCHES ELEKTRONEN-SYNCHROTRON DESY

DESY 83-105

October 1983

HEAVY QUARKS

MV and I figured out how to estimate interference $1/m_Q^2$ effects through the four-fermion operators and designed relevant graphs at ITEP. We actually made an estimate on a napkin, I put it in a review with Khoze, and forgot about this, since at this time I was heavily engaged with SUSY. A few months later, in 1983, Branko Guberina and Neven Bilić from Croatia saw it and detected a wrong sign. They called me (!). ……1984….

Since mid-1980s: $1/m_Q$ expansion in analysis of $Q\bar{q}$ and Qqq

No $1/m_Q$ CGG/BUV th

$$\Gamma(H_Q \to f) = G_F^2 |V_{\rm CKM}|^2 m_Q^5 \sum_i \tilde{c}_i^{(f)}(\mu) \frac{\langle H_Q|O_i|H_Q\rangle_\mu}{2M_{H_Q}}$$

$$\propto \left[c_3^{(f)}(\mu) \frac{\langle H_Q|\bar{Q}Q|H_Q\rangle_{(\mu)}}{2M_{H_Q}} \right.$$

$$+ c_5^{(f)}(\mu) m_Q^{-2} \frac{\langle H_Q|\bar{Q}\frac{i}{2}\sigma G Q|H_Q\rangle_{(\mu)}}{2M_{H_Q}}$$

$$+ \sum_i c_{6,i}^{(f)}(\mu) m_Q^{-3} \frac{\langle H_Q|(\bar{Q}\Gamma_i q)(\bar{q}\Gamma_i Q)|H_Q\rangle_{(\mu)}}{2M_{H_Q}}$$

$$\left. + \mathcal{O}(1/m_Q^4) + \ldots \right] . \qquad (8.2)$$

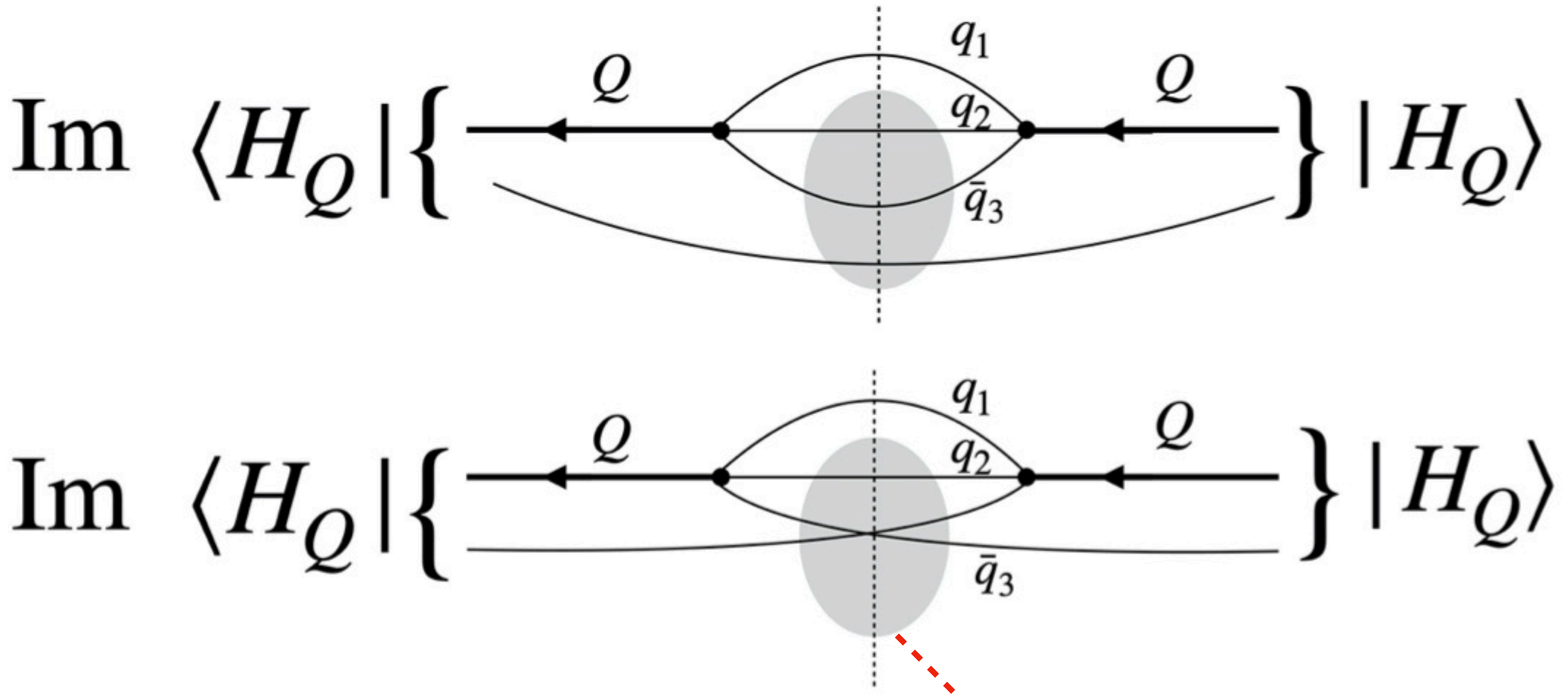
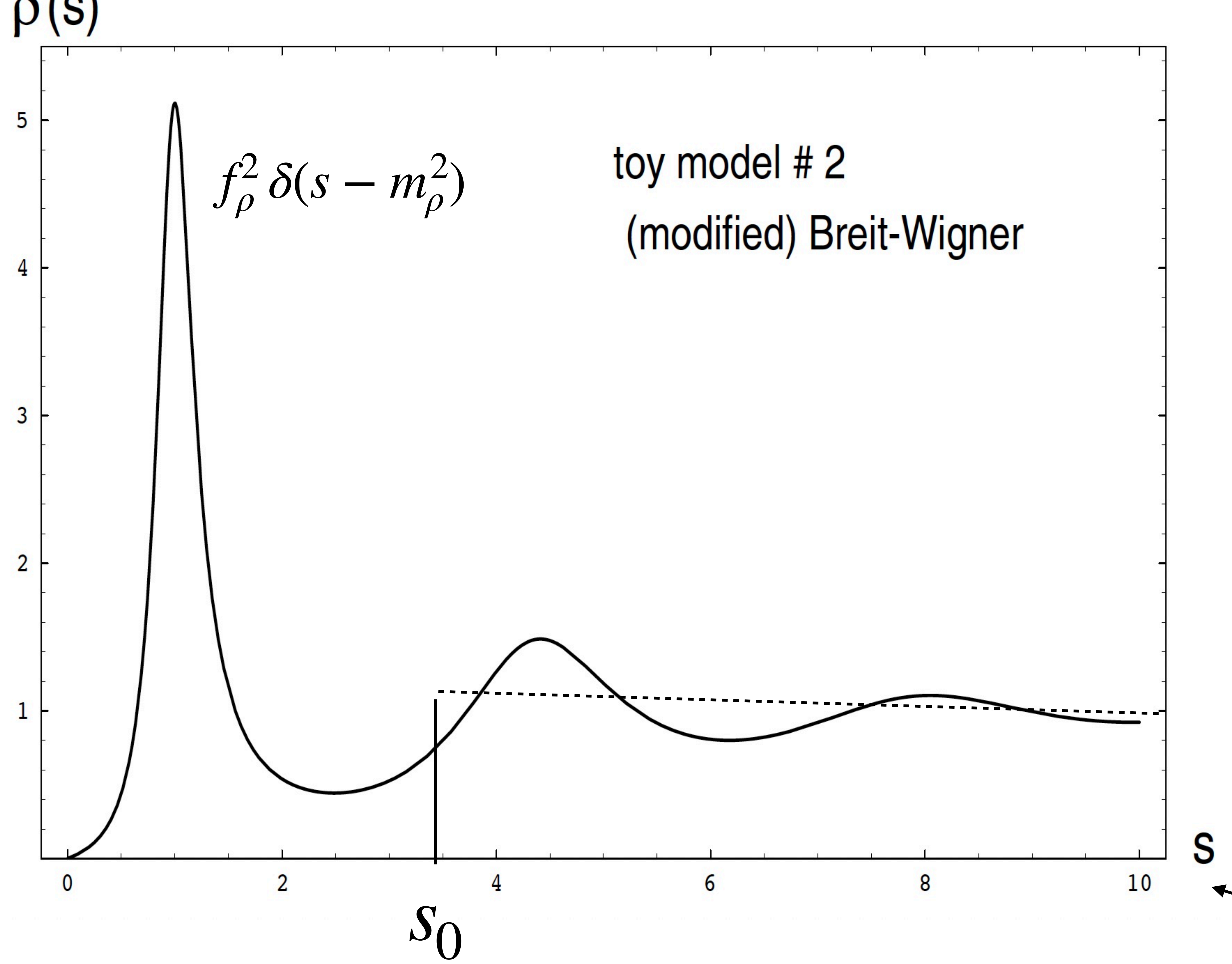


Fig. 4 $1/m_Q$ expansion for a H_Q weak inclusive decay rate (see Eq. (8.2)). Depicted are two operators, the leading $\bar{Q}Q$ and a subleading $(\bar{Q}q_3)(\bar{q}_3 Q)$. Both are sandwiched between the heavy hadron states $\langle H_Q|$ and $|H_Q\rangle$ and the decay rate is determined by the imaginary part. The grey area depicts the soft quark-gluon cloud. Adapted from Ref. [34].

Soft Cloud
instead of
vacuum medium



Mink Very Important !!!

- Quark-Hadron Duality (oscillations!)

ADS/QCD model

Instanton model; qualitatively the same

$$\frac{1}{Q^2+m_n^2} \to \frac{1}{Q^2+m_n^2-im_n\Gamma_n} \to \frac{1}{Q^2+m_n^2-im_n^2B/N_c} \to$$

$$\frac{1}{Q^2+m_n^2-\gamma Q^2\ln Q^2} \to \frac{1}{(Q^2)^{1-\gamma}+m_n^2}\,,$$

$$\gamma = \frac{B}{\pi N_c}\,,$$

$$\Gamma_n \sim \frac{1}{N_c} L\Lambda^2, \quad L \sim m_n \Lambda^{-2}$$

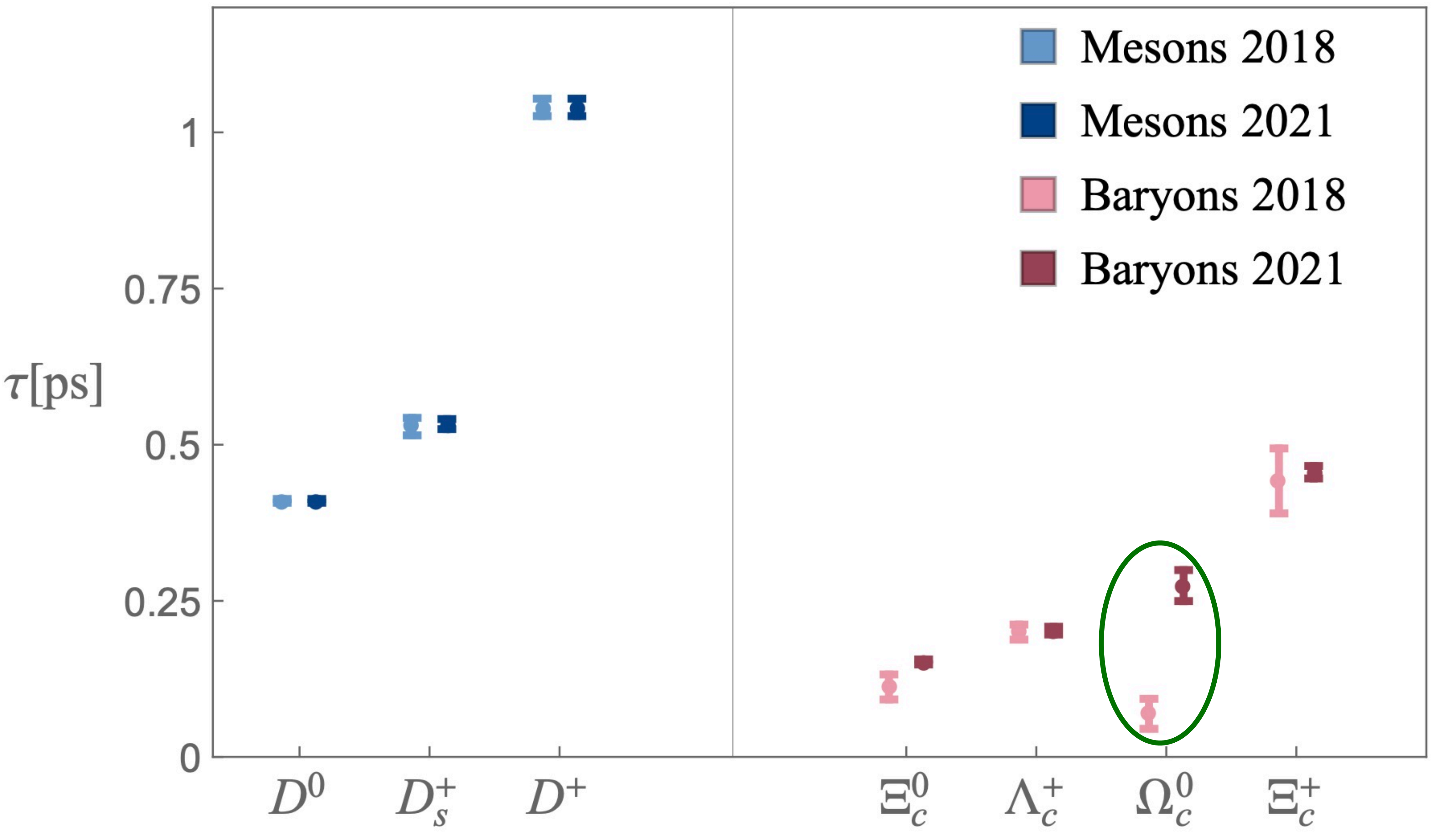
Oscillation in incl H_Q suppressed by M_Q^{-4} (inst) or weakly exponentially

Quark-hadron duality, MS, hep-ph/0009131

In the mid-1980s predicted $\tau(\Lambda_b)/\tau(B_d) = 0.9 \pm 0.03$

In the late 1990's $\tau(\Lambda_b)/\tau(B_d)_{\text{exp}} = 0.77 \pm 0.05$

In the late 2010's $\tau(\Lambda_b)/\tau(B_d)_{\text{exp}} = 0.93 \pm 0.05$



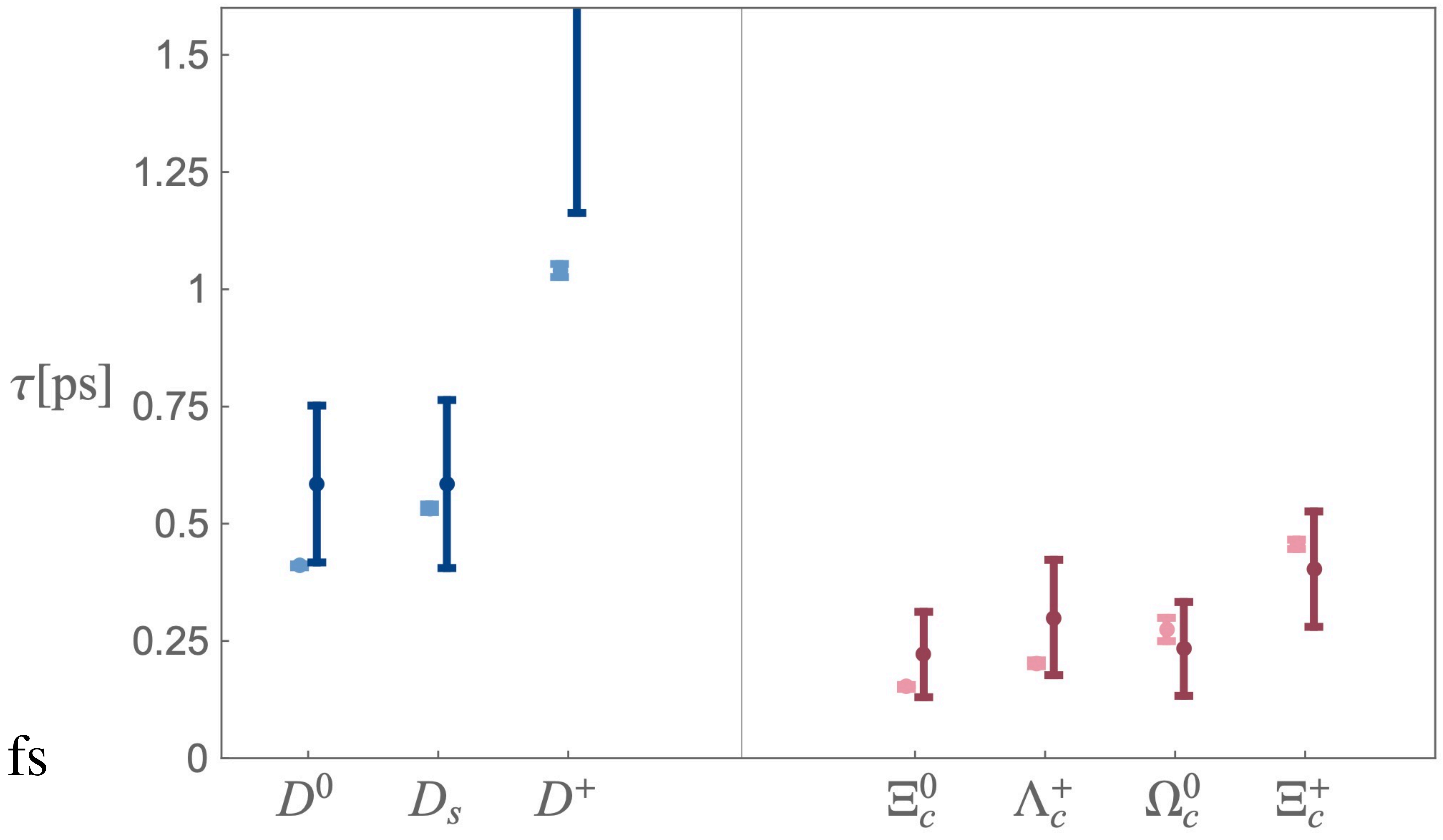
$m_c \approx 1.3\,\mathrm{GeV}$; Expansion parameter $\sim \frac{1}{3}$

For b quark expansion parameter $\sim \frac{1}{10}$

Changes in experimental lifetime averages for mesons (blue, on the left) and baryons (red, on the
018 (light) and 2021 (dark) owing to the recent LHCb results. Recent Belle II results [24] support
$_c$ lifetime measurement. Note that the error bars indicate 2σ uncertainties in all cases.

$$\underline{2018\ \mathrm{PDG}: \tau(\Omega_c^0) = 69 \pm 12\,\mathrm{fs},} \quad 2020\ \mathrm{PDG}: \tau(\Omega_c^0) = 268 \pm 24 \pm 10\,\mathrm{fs}$$

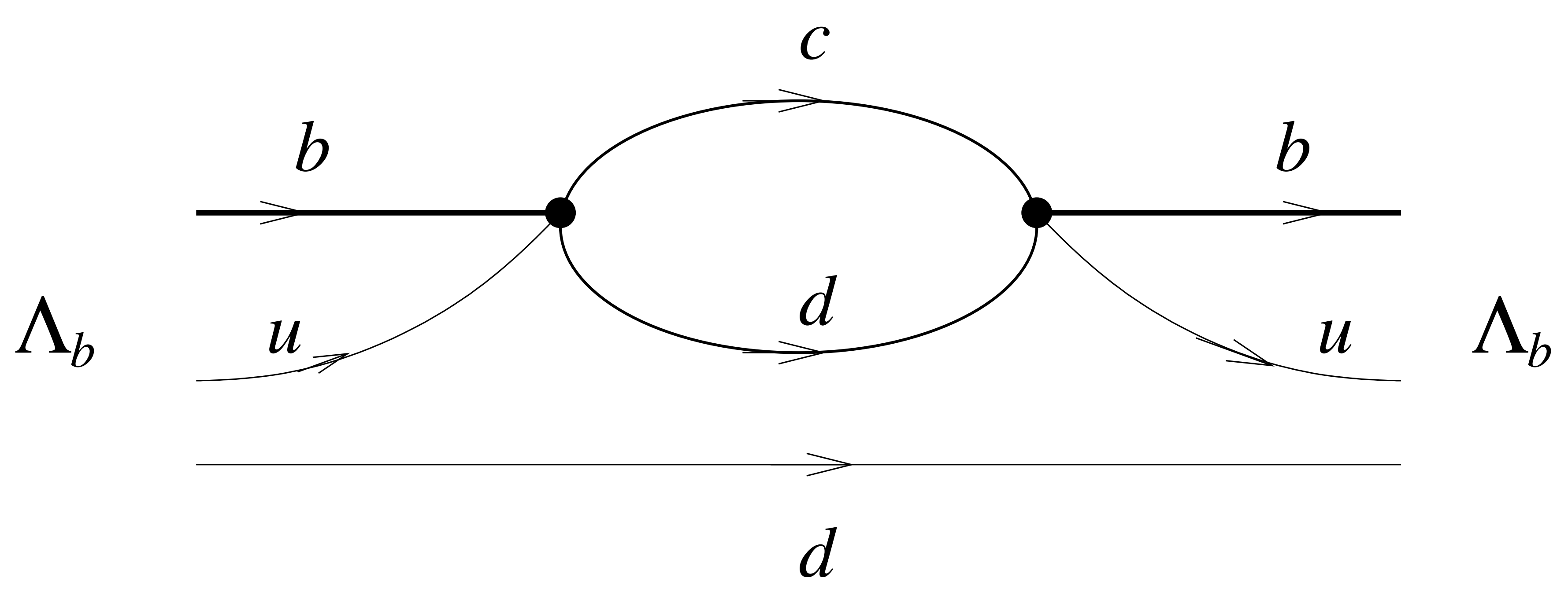
LHCb



$$\tau(\Xi^0) < \tau(\Lambda_c^+) < \tau(\Omega_c^0) < \tau(\Xi^+)$$

Figure 4: Hierarchy of lifetimes of charmed mesons (left, in blue) and singly charmed baryons (right, in red). Our predictions, in the kinetic scheme, are compared to the latest experimental values (left of each pair of values) [1, 11]. © B. Melic

In 1993 Blok+MS argued that Ω_c^0 is likely to be the most long-living



Qq
weak
scatter

Figure 3: Preasymptotic m_b^{-3} corrections: the weak scattering mechanism giving rise to the four-quark operator (13) in the OPE for $\tau(\Lambda_b)$.

For weak scattering we deal with $O_- = 2 j_k^\dagger j_k$ where $j_k = \varepsilon_{kji} b^j C \frac{1-\gamma^5}{2} u^i$

If bu good diquark (à la Wilczek) existed, then the contribution of O_- in weak scattering would significantly increase, shifting $\tau(\Lambda_b)/\tau(B_d)_{\text{theor}}$ back to its 1990s measurement away from the more precise 2020 measurement. NO bu **good diquark!**

PREASYMPTOTIC EFFECTS IN INCLUSIVE WEAK DECAYS OF CHARMED PARTICLES, with M.B. Voloshin, Sov. J. Nucl. Phys. 41 (1985) 120.

HIERARCHY OF LIFETIMES OF CHARMED AND BEAUTIFUL HADRONS, with M.B. Voloshin, Sov. Phys. JETP 64 (1986) 698.

ON INCLUSIVE HADRONIC WIDTHS OF BEAUTIFUL PARTICLES, with V.A. Khoze, N.G. Uraltsev, M.B. Voloshin, Sov. J. Nucl. Phys. 46 (1987) 112.

A QCD "MANIFESTO" ON INCLUSIVE DECAYS OF BEAUTY AND CHARM, with I. Bigi, B. Blok, N. Uraltsev and A. Vainshtein, The Fermilab Meeting, Proc. of the 1992 DPF Meeting of APS, C.H. Albright et al., Eds., World scientific, Singapore 1993, vol.1, page 610. arXiv:hep-ph/9212227.

LIFETIMES OF CHARMED HADRONS REVISITED, Invited Talk, Spain, 1993, with B. Blok, arXiv:hep-ph/9311331 Proc. of the Third Workshop on the Tau-Charm Factory, Ed. J. Kirkby and R. Kirkby, Editions Frontiers, Gif-sur-Yvette, 1994, page 247.

NONLEPTONIC DECAYS OF BEAUTY HADRONS - FROM PHENOMENOLOGY TO THEORY, with I. Bigi, B. Blok, N. Uraltsev and A. Vainshtein, hep-ph/9401298; S. Stone, Ed., B Decays, Second Edition World Scientific, 1994, page 132.

ASPECTS OF HEAVY QUARK THEORY, with I. Bigi and N. Uraltsev, hep-ph/9703290, Ann. Rev. Nucl. Part. Sci. 47 (1997) 591.

Quark-Hadron Duality, 2000, hep-ph/0009131

We live in a New Era of qualitative understanding! And still…

Pioneers of heavy quarks physics – OPE-based Methods (ITEP, now non-existent)

M. Voloshin, 1953-2020

(Since late 1970s)

N. Uraltsev, 1957-2013

(Since mid-1980s)

Photos mine