The Λ_b lifetime

Alexander Lenz
CERN Theory Division

Colour meets Flavour — Khodjamirian Fest
University of Siegen — October 13th, 2010

Motivation:

- Most recent paper (= #100) of our *birthday boy* (www.leo.org) deals with heavy baryons

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1. **Form Factors and Strong Couplings of Heavy Baryons from QCD Light-Cone Sum Rules.**
   A. Khodjamirian, Ch. Klein, Th. Mannel, Y.-M. Wang (Siegen U.). SI-HEP-2011-05. Aug 2011. 45 pp.
   e-Print: **arXiv:1108.2971 [hep-ph]**
   References | BibTeX | LaTeX(US) | LaTeX(EU) | Harvmac | EndNote
   Abstract and Postscript and PDF from arXiv.org
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2. **$B \to \pi \ell \nu_l$ Width and $|V_{ub}|$ from QCD Light-Cone Sum Rules.**
   A. Khodjamirian, Th. Mannel (Siegen U.), N. Offen (Regensburg U.), Y.-M. Wang (Siegen U.). SI-HEP-2011-3. Mar 2011. 22 pp.
   Published in **Phys.Rev. D83 (2011) 094031**
   e-Print: **arXiv:1103.2655 [hep-ph]**
   References | BibTeX | LaTeX(US) | LaTeX(EU) | Harvmac | EndNote
   Abstract and Postscript and PDF from arXiv.org
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   Detailed record - Similar records - Cited by 3 records
3. **Hadronic matrix elements with heavy quarks: The charm-loop effect in B ---> K(*) l+ l-.**
   Alexander Khodjamirian (Siegen U.). 2011. 8 pp.
   Published in **AIP Conf.Proc. 1317 (2011) 284-291**
   Prepared for SPIRES Conference C10/06/20.2 (Conference information coming soon)
   References | BibTeX | LaTeX(US) | LaTeX(EU) | Harvmac | EndNote
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   AIP Conference Server
   Detailed record - Similar records
4. **Form Factors and Long-Distance Effects in $B \to V(P)\ell^+\ell^-$ and $B \to V\gamma$.**
   Alexander Khodjamirian (Siegen U.). SI-HEP-2011-01. Jan 2011. 8 pp.
   To appear in the proceedings of SPIRES Conference C10/09/06
   e-Print: **arXiv:1101.2328 [hep-ph]**
   References | BibTeX | LaTeX(US) | LaTeX(EU) | Harvmac | EndNote
   Abstract and Postscript and PDF from arXiv.org
   Detailed record - Similar records - Cited by 1 record
5. **Nonperturbative QCD methods for B-physics: Status and prospects.**
   Alexander Khodjamirian (Siegen U.). 2009. 7 pp.
   Published in **PoS BEAUTY2009 (2009) 045**
   Prepared for 12th International Conference on B Physics at SPIRES Conference C09/09/07 (Conference information

Motivation:

- Most recent paper $(= \#100)$ of our *birthday boy* (www.leo.org) deals with heavy baryons
- Many people in the audience worked on $\tau(\Lambda_b)$
I. Bigi, P. Colangelo, F. deFazio, B. Melic, A. Petrov, M. Shifman, N. Uraltsev, A. Vainshtein
- Several people in the audience (MB, GB, AL, UN) *promised* some years ago to finish the NLO-QCD calculation
- SM4 and B_s-mixing lost a tiny little bit of its extraordinary attraction in the past months due to the results of LHC

Experimental numbers for $\tau(\Lambda_b)$

Year	Exp	Decay	$\tau(\Lambda_b)$ [ps]	$\tau(\Lambda_b)/\tau(B_d)$
2011	HFAG	average	1.425 ± 0.032	0.938 ± 0.022
2010	CDF	$J/\psi\Lambda$	1.537 ± 0.047	1.020 ± 0.031
2009	CDF	$\Lambda_c + \pi^-$	1.401 ± 0.058	0.922 ± 0.038
2007	D0	$\Lambda_c \mu\nu X$	1.290 ± 0.150	$0.849 \pm 0.099*$
2007	D0	$J/\psi\Lambda$	1.218 ± 0.137	$0.802 \pm 0.090*$
2006	CDF	$J/\psi\Lambda$	1.593 ± 0.089	1.049 ± 0.059
2004	D0	$J/\psi\Lambda$	1.22 ± 0.22	0.87 ± 0.17
2003	HFAG	average	1.212 ± 0.052	0.798 ± 0.034
1998	OPAL	$\Lambda_c l$	1.29 ± 0.25	$0.85 \pm 0.16*$
1998	ALEPH	$\Lambda_c l$	1.21 ± 0.11	$0.80 \pm 0.07*$
1995	ALEPH	$\Lambda_c l$	1.02 ± 0.24	$0.67 \pm 0.16*$
1992	ALEPH	$\Lambda_c l$	1.12 ± 0.37	$0.74 \pm 0.24*$

1.425 ps is $4.1\sigma(4.1 * 0.052)$ above 1.212 ps

Theoretical numbers for $\tau(\Lambda_b)$

Year	Author	$\tau(\Lambda_b)/\tau(B_d)$
2007	Tarantino	0.88 ± 0.05
2004	Petrov et al.	0.86 ± 0.05
2003	Tarantino	0.88 ± 0.05
2002	Rome	0.90 ± 0.05
2000	Körner,Melic	$0.81...0.92$
1999	Guberina,Melic,Stefanic	0.90
1999	diPierro, Sachrajda, Michael	0.92 ± 0.02
1999	Huang, Liu, Zhu	0.83 ± 0.04
1996	Colangelo, deFazio	> 0.94
1996	Neubert,Sachrajda	” > 0.90”
1992	Bigi, Blok, Shifman, Uraltsev, Vainshtein	$> 0.85...0.90$
x	only$1/m_b^2$	0.98

Colour coding:

- Wilson coefficient
- Matrix element of dimension 6 operator
- Numerical update

Motivation II

- LHCb will soon have quite precise numbers for $\tau(\Lambda_b)$ and resolve the experimental discrepancy

  $$\Lambda_b \to J/\psi \Lambda, \Lambda_c \pi$$

  Probably also CMS

- Test of the HQE see Uli Nierste

  HQE is used to predict Γ_{12}

  - Decay rate difference $\Delta\Gamma$
  - Semi leptonic asymmetries $a_{sl}^{s,d}$
  - Di-muon asymmetry A_{sl}^b

- Non-perturbative parameters are more than 10 years old

Theoretical Framework:

1. Effective Hamiltonian: (see e.g. Buras 1102.5650)
   - Integrating out the W boson
   - Altarelli, Curci, Martinelli, Petrarca (1981)
     Buchalla, Buras, Jamin, Lautenbacher, Weisz (1990 -'95)
     Ciuchini, Franco, Lubicz, Reina, Scimemi, Silvestrini (1993 -'95)
     NNLO: Gorbahn, Haisch 2004,2005
2. Heavy Quark Expansion:
   - Integrating out the final state loop momenta
   - Shifman, Voloshin, Khoze; Bigi, Uraltsev, Vainshtein; (1983 -'92)
     Bagan, Ball, Braun, Fiol, Gosdzinsky: (1994,95); A.L., Nierste, Ostermaier (1997,1998); Greub, Liniger (1999)
     Beneke, Buchalla, Greub, A.L., Nierste; (1998 -. . .); Ciuchini, Franco, Lubicz, Mescia, Tarantino (2001 -. . .) ; Petrov (2003,04)
3. Matrix elements of the local $\Delta B = 0, 2$ operators
   - Calculation of non-perturbative physics with lattice simulations and sum rules
   - Colangelo, De Fazio (1996); Huang, Liu, Zhu (1999)
     DiPierro, Sachrajda, Michael (UK QCD) (1999); Becirevic (2000)

Heavy Quark Expansion I:

The standard expression for the decay rate is

$$\Gamma(B \to X) = \frac{1}{2m_B} \sum_X (2\pi)^4 \delta^{(4)}(p_B - p_X) |\langle X | \mathcal{H}_{eff} | B \rangle|^2$$

The optical theorem gives

$$\Gamma(B \to X) = \frac{1}{2m_B} \langle B | \mathcal{T} | B \rangle$$

with the transition operator

$$\mathcal{T} = \mathrm{Im}\, i \int d^4x T \left[\mathcal{H}_{eff}(x), \mathcal{H}_{eff}(0) \right]$$

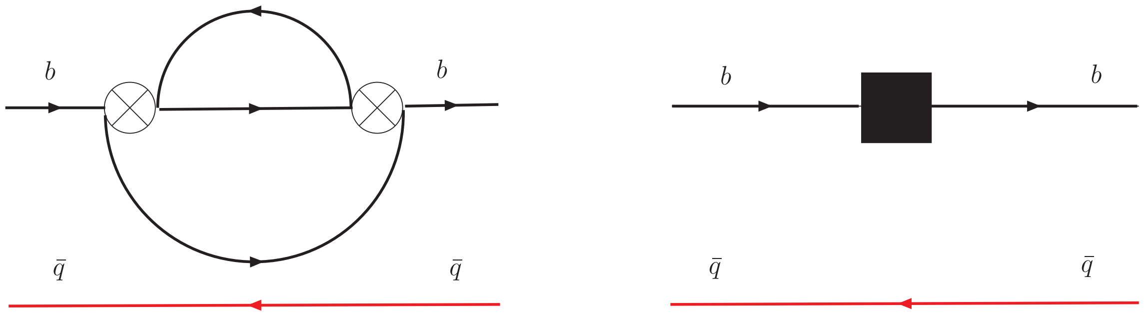
An operator-product-expansion for $\mathcal{T}$ yields

$$\mathcal{T} = c_3 \bar{b} b + \frac{c_5}{m_b^2} \bar{b} g_s \sigma_{\mu\nu} G^{\mu\nu} b + \frac{\tilde{c}_6}{m_b^3} (\bar{b} q)_\Gamma (\bar{q} b)_\Gamma + \ldots$$

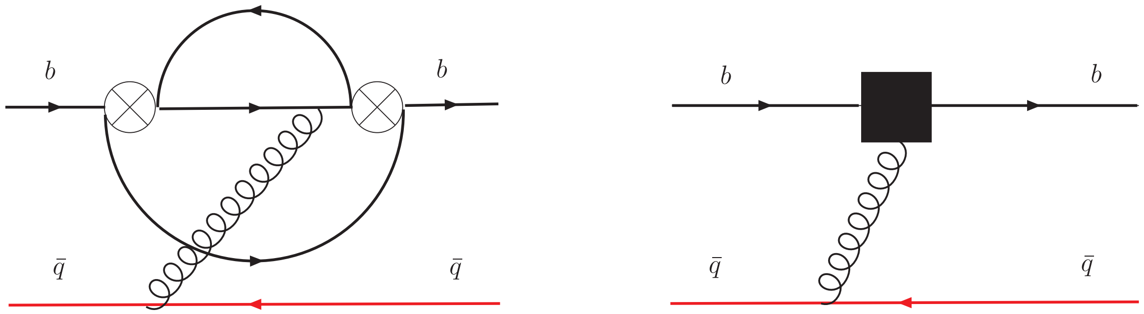
Voloshin, Uraltsev, Khoze, Shifman

Heavy Quark Expansion II:

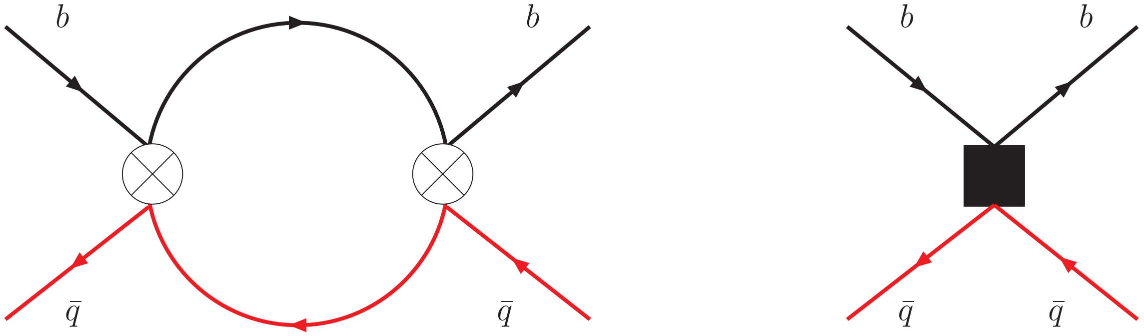
- $\bar{b}b$: Free quark decay (2-loop)



- $\bar{b}g_s\sigma_{\mu\nu}G^{\mu\nu}b$: Chromomagnetic operator (2-loop)



- $(\bar{b}q)_\Gamma(\bar{q}b)_\Gamma$:Spectator effects - weak annihilation (1-loop) $\rightarrow 16\pi^2$



Heavy Quark Expansion III:

The decay rate reads now

$$\Gamma = \Gamma_0 \left[c_3 \langle \bar{b} b \rangle_B + \frac{c_5}{m_b^2} \langle \bar{b} \frac{g_s}{2} \sigma_{\mu\nu} G^{\mu\nu} b \rangle_B \right. \\ \left. + \frac{c_6}{m_b^3} \langle (\bar{b} q)_\Gamma (\bar{q} b)_\Gamma \rangle_B + \mathcal{O}\left(\frac{1}{m_b^4} \right) \right]$$

with

- $\Gamma_0 = (G_F^2 m_b^5)/(192 \pi^3)$
- Wilsoncoefficients c_i;
  calculable in perturbation theory:
  - Renormalization scale dependence $c_i = c_i(\mu)$
  - Renormalization scheme dependence (arises in NLO!)
- Matrix elements of local operators $\langle Q \rangle_B = \langle Q \rangle_B(\mu)$
  Determination via non-perturbative methods

!!!
Unphysical μ- and renormalization scheme dependence
has to cancel
between Wilsoncoefficients and matrix elements

Heavy Quark Expansion IV:

Determination of the matrix elements

- $\underline{\mathcal{O}(1)}$: Non-relativistic expansion

$$\langle \bar{b} b \rangle_B = 1 - \frac{\mu_\pi^2 - \mu_G^2}{2 m_b^2} + \mathcal{O}(m_b^{-3})$$

- $\underline{\mathcal{O}(m_b^{-2})}$: Experiment ($Chromomagnetic\ operator$)

$$\langle \bar{b} \frac{g_s}{2} \sigma_{\mu\nu} G^{\mu\nu} b \rangle_B =: \mu_G^2 + \mathcal{O}\left(m_b^{-1}\right) \approx 0.36 \text{ GeV}^2$$

Sum rules - momentum analysis: ($Kinetic\ operator$)

$$\langle \bar{b} (i \vec{D})^2 b \rangle_B =: \mu_\pi^2 + \mathcal{O}\left(m_b^{-1}\right) \approx 0.450.10 \text{ GeV}^2$$

Ball, Braun; Neubert

- $\underline{\mathcal{O}(m_b^{-3})}$: lattice, sum rules ($Four\ quark\ operator$)

$$\langle (\bar{b} q)_\Gamma (\bar{q} b)_\Gamma \rangle_B =: f_B^2 m_B \sum_\Gamma c_\Gamma B_\Gamma$$

f_B: decay constant, B: Bag-Parameter

UKQCD;JLQCD; Becirevic et al.; Jamin, Lange; Kronfeld

Heavy Quark Expansion V:

Finally one gets:

$$\Gamma = \Gamma_0 \left(1 - \frac{\mu_\pi^2 - \mu_G^2}{2m_b^2}\right) \left[c_3 + 2\frac{c_5}{m_b^2}\mu_G^2 + \frac{16\pi^2 c_6}{m_b^3} f_B^2 m_B \sum_\Gamma c_\Gamma B_\Gamma + \mathcal{O}\left(\frac{1}{m_b^3}\right)\right]$$

- Non-perturbative parameters μ_π, μ_G, f_B, B
- $\Gamma_0 \propto m_b^5 V_{cb}^2$ cancels in ratios of decay rates
- $1 - \frac{\mu_\pi^2 - \mu_G^2}{2m_b^2}$ cancels in some ratios of decay rates

Heavy Quark Expansion VI:

$$\Gamma \quad = \quad \Gamma_0 + \frac{\Lambda^2}{m_b^2}\Gamma_2 + \frac{\Lambda^3}{m_b^3}\Gamma_3 + \frac{\Lambda^4}{m_b^4}\Gamma_4 + \ldots$$

* Γ_0: *spectator model*: All b-hadrons have the same lifetime!

* There are **no** $1/m_b$ corrections

* Γ_2: *Fermi motion* and *chromomagnetic interaction*:
First corrections due to strong interaction (Isospin):
$->$ $\tau_{B+}/\tau_{B_d} - 1 \approx 0$ and $\tau_{\Lambda_b}/\tau_{B_d} - 1 \approx -2\%$

* Γ_3: *Weak annihilation* and *Pauli interference*:
Spectator quark is first involved at $1/m_b^3$

Lifetime differences test the HQE at the third order

Naive: Γ_3: $16\pi^2 \left(\frac{M_b - m_b}{m_b}\right)^3 \approx 0.16$

$1/N_c\Gamma_3$: ≈ 0.05

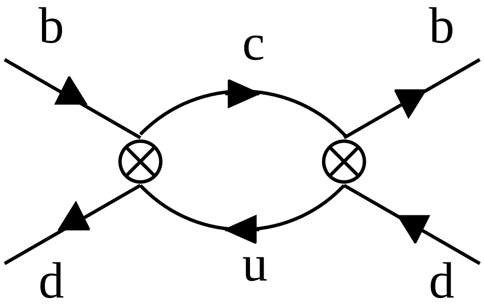
$\alpha_s\Gamma_3$: ≈ 0.03

Γ_4: $16\pi^2 \left(\frac{M_b - m_b}{m_b}\right)^4 \approx 0.02$

Expand each Γ_i in α_s: $\Gamma_i = \Gamma_i^{(0)} + \frac{\alpha_s}{4\pi}\Gamma_i^{(1)} + \ldots$

State of the art:

- To get an idea:
  Calculate the leading term and determine the matrix elements in vacuum insertion approximation (VIA)



$$\langle \bar{B}_s | (\bar{b}_i s_i)_{V-A} (\bar{b}_j s_j)_{V-A} | B_s \rangle \approx f_{B_s}^2 M_{B_s}^2 \cdot color$$

Guberina, Nussinov,Peccei, Rückl (1979)

Bander, Silverman, Soni (1980)

To get a number:

* NLO QCD:
Dress the above diagram with one gluon in all possible ways

* $1/m_b^4$:
Take the momentum of the external d-quark into account:
New operators like $\frac{1}{m_b^2} \bar{b} \overleftarrow{D} \Gamma D s \cdot \bar{b} \Gamma s$ arise

* Non-perturbative evaluation of the matrix elements

$$\langle \bar{B}_s | (\bar{b}_i s_i)_{V-A} (\bar{b}_j s_j)_{V-A} | B_s \rangle \overset{!}{=} f_{B_s}^2 M_{B_s}^2 B \cdot color$$

Evaluation of Bag Parameters

$\tau(\Lambda_b)/\tau(B_d)$ at order $1/m_b^2$

$$\frac{\tau(\Lambda_b)}{\tau(B_d)} = 1 + \frac{\Lambda^2}{m_b^2}\left(\Gamma_2^{(0)} + \ldots\right) + \frac{\Lambda^3}{m_b^3}\left(\Gamma_3^{(0)} + \frac{\alpha_s}{4\pi}\Gamma_3^{(1)} + \ldots\right) + \frac{\Lambda^4}{m_b^4}\left(\Gamma_4^{(0)} + \ldots\right) + \frac{\Lambda^5}{m_b^5}\left(\Gamma_5^{(0)} + \ldots\right) + \ldots$$

Leading Term

$$\begin{aligned}
\frac{\Lambda^2}{m_b^2}\Gamma_2 &= \frac{\mu_\pi^2(\Lambda_b) - \mu_\pi^2(B_d)}{2m_b^2} + c_5\frac{\mu_G^2(\Lambda_b) - \mu_G^2(B_d)}{m_b^2} \\
&= \frac{(0.1 \pm 0.1)\text{GeV}^2}{2m_b^2} + 1.2\frac{0 - 0.33\text{GeV}^2}{2m_b^2} \\
&\approx 0.002 - 0.017 = -0.015
\end{aligned}$$

Numbers from Bigi, Mannel Uraltsev, 2011 *(= update #1)*

$\tau(\Lambda_b)/\tau(B_d)$ at order $1/m_b^3$

$$\begin{aligned}\frac{\tau(\Lambda_b)}{\tau(B_d)} = 1 \quad & - \quad 0.015 \\ & + \quad \frac{\Lambda^3}{m_b^3}\left(\Gamma_3^{(0)} + \frac{\alpha_s}{4\pi}\Gamma_3^{(1)} + \ldots\right) \\ & + \quad \frac{\Lambda^4}{m_b^4}\left(\Gamma_4^{(0)} + \ldots\right) + \frac{\Lambda^5}{m_b^5}\left(\Gamma_5^{(0)} + \ldots\right) + \ldots\end{aligned}$$

Γ_3 is a linear combination of perturbative Wilson coefficients and non-perturbative matrix elements

- Wilson coefficient of $\Gamma_3^{(0)}$ with full m_c dependence:
  1996 Neubert and Sachrajda
- Matrixelement
  HQET: only two different matrix elements (instead of four)

$$\frac{1}{2m_{\Lambda_b}}\langle\Lambda_b|\bar{b}_L\gamma_\mu q_L \cdot \bar{q}_L\gamma^\mu b_L|\Lambda_b\rangle =: -\frac{f_B^2 m_B}{48} r$$

Matrix elements for the Λ_b baryon I

Values for r:

$r \approx 0.2$	*Bag model*	Guberina, Nussino, Peccei, Rückl, 1979
$r \approx 0.5$	*NR quark model*	–"–
$r = 0.9 \pm 0.1$	*spectroscopy*	Rosner, 1996
$r = 1.8 \pm 0.5$	*spectroscopy*	–"–
$r = 0.2 \pm 0.1$	*QCD sum rules*	Colangelo, de Fazio, 1996

Neubert, Sachrajda: $\frac{\tau(\Lambda_b)}{\tau(B_d^0)}$ " > 0.9"

$r = 1.2 \pm 0.2 \pm ?$	*lattice*	di Pierro, Sachrajda, Michael 1999
$r = 2.3 \pm 0.6$	*QCD sum rules*	Huang, Liu, Zhu, 2000
$r = 6.2 \pm 1.6$	*QCD sum rules*	–"–

$$!!! \quad \frac{\tau(\Lambda_b)}{\tau(B_d^0)} - 1 \propto r \quad !!!$$

Matrix elements for the Λ_b baryon II

1996 Rosner

$$r = \frac{4}{3}\frac{m^2_{\Sigma_b^*} - m^2_{\Sigma_b}}{m^2_{B^*} - m^2_B}$$

In 1996 b-baryon masses were hardly known

- $m^2_{\Sigma_b^*} - m^2_{\Sigma_b} \approx m^2_{\Sigma_c^*} - m^2_{\Sigma_c} = (0.384 \pm 0.035)$GeV^2

$$\Rightarrow r = 0.9 \pm 0.10$$

- $m_{\Sigma_b^*} - m_{\Sigma_b} = (56 \pm 16)$ MeV

$$\Rightarrow r = 1.8 \pm 0.5$$

- Use the values from PDG 2011

$$\boxed{\Rightarrow r = 0.68 \pm 0.10}$$

(= update #2)

Matrix elements for the Λ_b baryon III

1999 DiPierro, Sachrajda, Michael:
currently the only lattice determination

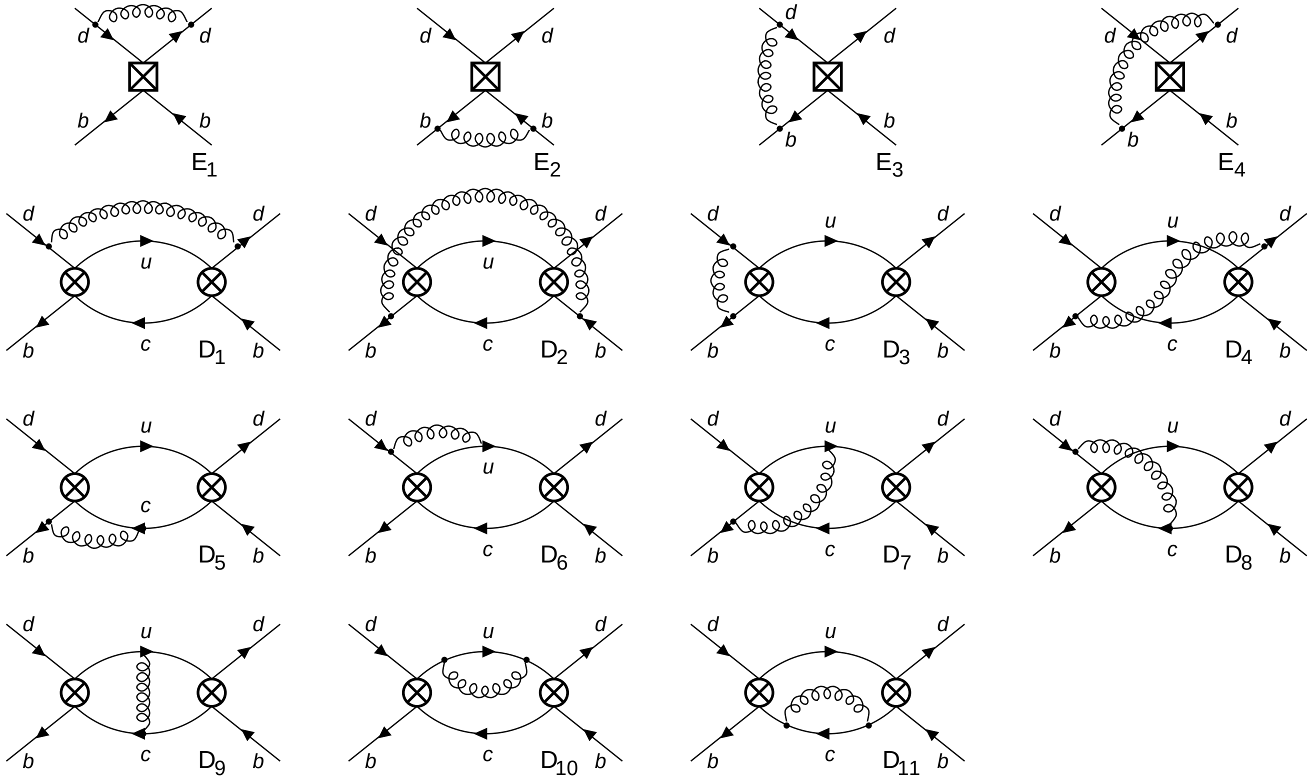
- 12 years old
- The authors call their study *exploratory*
  - Larger lattice should be used
  - Larger sample of gluon configurations should be used
  - Matching to continuum only at leading order
  - No chiral extrapolation attempted
  - Penguin contractions are missing - see below

1999 Huang, Liu, Zhu:
QCD sum rule result, which is up to a factor of 31 larger than the one by Colangelo and DeFazio

$\tau(\Lambda_b)/\tau(B_d)$ **at order** $\alpha_s 1/m_b^3$

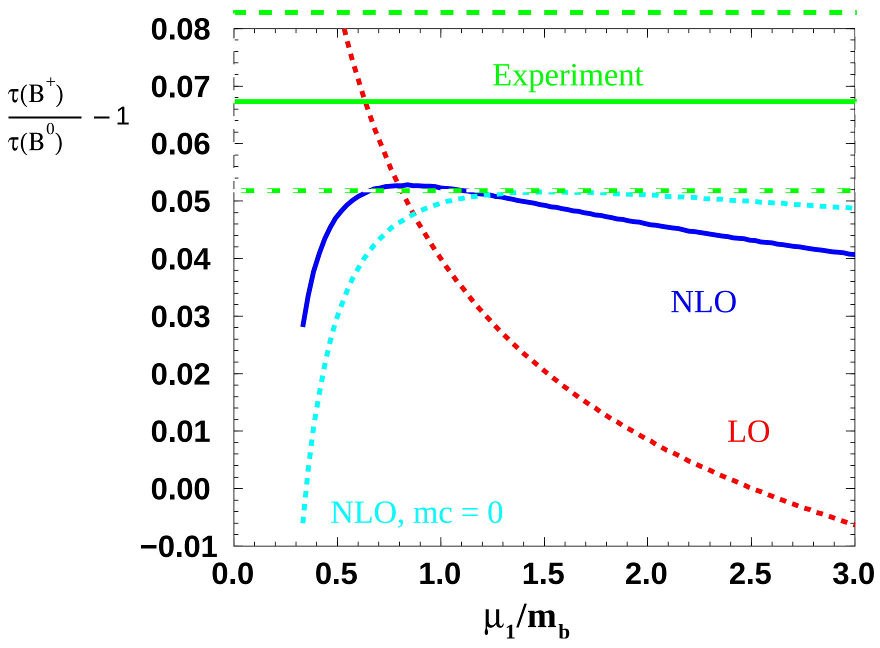
$$
\begin{aligned}
\frac{\tau(\Lambda_b)}{\tau(B_d)} = 1 \quad & - \quad 0.015 \\
& + \quad \frac{\Lambda^3}{m_b^3}\left(\Gamma_3^{(0)} + \frac{\alpha_s}{4\pi}\Gamma_3^{(1)} + \ldots\right) \\
& + \quad \frac{\Lambda^4}{m_b^4}\left(\Gamma_4^{(0)} + \ldots\right) + \frac{\Lambda^5}{m_b^5}\left(\Gamma_5^{(0)} + \ldots\right) + \ldots
\end{aligned}
$$

Ciuchini, Franco, Lubicz, Mescia, Tarantino 2001, 2002; Beneke, Buchalla, Greub, A.L., Nierste 2002



Why do we calculate up to NLO?

- Test of expansion in α_s and m_b^{-1}
- Reduction of theoretical error - μ-dependence



- Renormalization scheme dependence - matching to lattice
- Proper use of $\Lambda_{\overline{MS}}$
- Definition of quark masses $m_{pole} \leftrightarrow m_{\overline{MS}}$
- up to 30 % correction expected
- LO coefficients for lifetime predictions are anomalously small

- Verify IR-safetey of QCD-corrections to Weak Annihilation and Pauli interference diagrams

$\tau(\Lambda_b)/\tau(B_d)$ **at order** $\alpha_s 1/m_b^3$

2002 Franco et al.

$$\frac{\tau(\Lambda_b)}{\tau(B_d)} = \quad 0.90 \pm 0.05$$
$$+ \quad \frac{\Lambda^4}{m_b^4}\left(\Gamma_4^{(0)} + \ldots\right) + \frac{\Lambda^5}{m_b^5}\left(\Gamma_5^{(0)} + \ldots\right) + \ldots$$

Remarks:

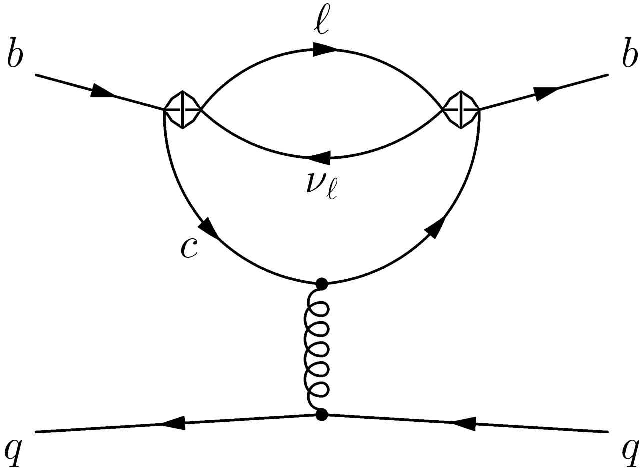
- with $r = 1.67$ (1/3 ... 5/3 ...5 2/3)
  (naive: central value 0.93 with $r = 1.2$ vs. scan?)

- Penguin contributions are missing - see below

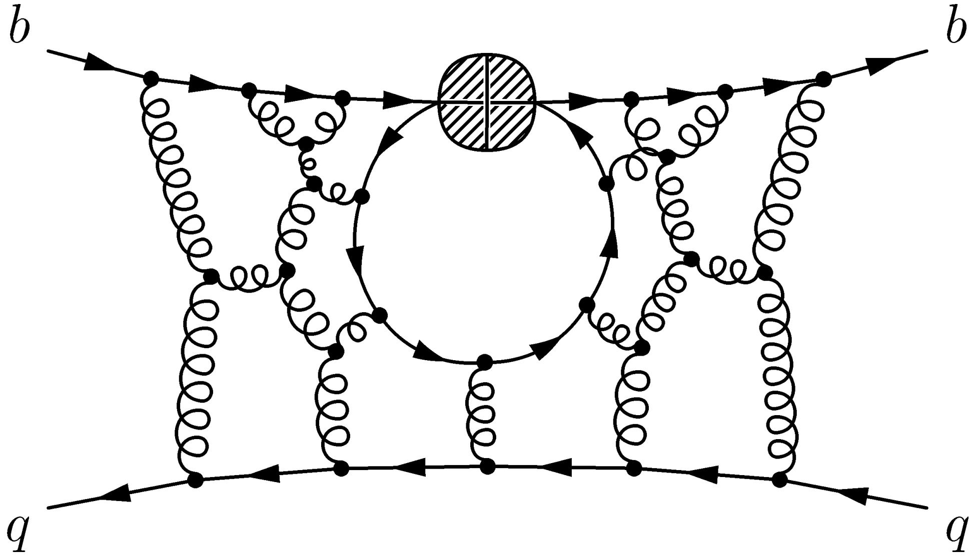
Penguin effects I

Besides the calculated diagrams, **penguin effects** contribute to the lifetime of b-hadrons.

1. Perturbative Penguins:



2. Non-perturbative analogue: **Eye contractions**



Difficult to calculate on the lattice due to mixing with lower dimensional operators!

Penguin effects II

Penguin effects cancel in $\Gamma(B^+) - \Gamma(B_d)$ and in $\Gamma(\Xi_b^0) - \Gamma(\Xi_b^-)$ due to isospin, **but not** between Λ_b and B_d

$$\begin{aligned}
\langle \mathcal{T} \rangle_{B_d} &= \langle B_d | F^u Q_d + F^d Q_u | B_d \rangle \\
&= \langle B_d | F^u Q_d^{(0)} + F^u Q_d^{(P)} + F^d Q_u^{(P)} | B_d \rangle \\
\langle \mathcal{T} \rangle_{B^+} &= \langle B^+ | F^d Q_u^{(0)} + F^d Q_u^{(P)} + F^u Q_d^{(P)} | B^+ \rangle \\
\text{Isospin:} \quad & \langle Q_{d,u} \rangle_{B_d} = \langle Q_{u,d} \rangle_{B^+} \\
\Rightarrow \Gamma_{B_d} - \Gamma_{B^+} \propto \; & (F^u - F^d) \langle (Q_u^{(0)} - Q_d^{(0)}) + (Q_u^{(P)} - Q_d^{(P)}) \rangle_{B^+}
\end{aligned}$$

$\Downarrow$	$\Downarrow$
perturbative	non-perturbative
penguins	penguins
cancel	cancel

These two penguin contributions are still missing in any calculation of $\tau(\Lambda_b)$

$\tau(\Lambda_b)/\tau(B_d)$ **at order** $\alpha_s 1/m_b^4$

$$\frac{\tau(\Lambda_b)}{\tau(B_d)} = \quad 0.90 \pm 0.05$$
$$+ \quad \frac{\Lambda^4}{m_b^4}\left(\Gamma_4^{(0)} + \ldots\right) + \frac{\Lambda^5}{m_b^5}\left(\Gamma_5^{(0)} + \ldots\right) + \ldots$$

Idea: Take the diagrams of $\Gamma_3^{(0)}$ and expand to first order in the momentum of the light *spectator quark*
Operators of the following form appear

$$\begin{aligned}
P_1 &= \frac{m_{d,s}}{m_b} \bar{b}_i(1-\gamma_5)d_i \; \bar{d}_j(1-\gamma_5)b_j \\
P_2 &= \frac{m_{d,s}}{m_b} \bar{b}_i(1+\gamma_5)d_i \; \bar{d}_j(1+\gamma_5)b_j \\
P_3 &= \frac{1}{m_b^2} \bar{b}_i \overleftarrow{D}_\rho \gamma_\mu(1-\gamma_5)D^\rho d_i \; \bar{d}_j\gamma^\mu(1-\gamma_5)b_j \\
P_4 &= \frac{1}{m_b^2} \bar{b}_i \overleftarrow{D}_\rho (1-\gamma_5)D^\rho d_i \; \bar{d}_j(1+\gamma_5)b_j
\end{aligned}$$

which were estimated in VIA for mesons, more difficult for baryons!

$\tau(\Lambda_b)/\tau(B_d)$ **at order** $\alpha_s 1/m_b^4$

2003, 2004 Gabbiani, Onishchenko, Petrov:
Estimate Γ_4 and Γ_5

$$\frac{\tau(\Lambda_b)}{\tau(B_d)} = \quad 0.86 \pm 0.05$$

Remarks

- with $r = 1.2$
- Should error be increased?

Status of the Λ_b-lifetime

- reliable matrix elements of the 4-quark operators
- non-perturbative penguin matrix elements
- perturbative penguins in $\Gamma_3^{(1)}$

are still missing in any calculation of $\tau(\Lambda_b)$!

How to treat dim 7,8, operators?

$$\frac{\tau(\Lambda_b)}{\tau(B_d^0)} - 1 \quad = \quad 0.14 \pm 0.05 + penguin \pm ??$$

Status of the baryon lifetime II

But one can do $\Gamma(\Xi_b^-) - \Gamma(\Xi_b^0)$
visible at LHC!

Here penguin contributions cancel as in $\Gamma(B_d) - \Gamma(B^+)$

$$\frac{\overline{\tau}(\Xi_b^0)}{\overline{\tau}(\Xi_b^-)} - 1 \quad = \quad 0.59 \left(\frac{|V_{cb}|}{0.04}\right)^2 \left(\frac{m_b}{4.8\,\text{GeV}}\right)^2 \left(\frac{f_B}{200\,\text{MeV}}\right)^2 \frac{\overline{\tau}(\Xi_b^0)}{1.5\,\text{ps}}$$

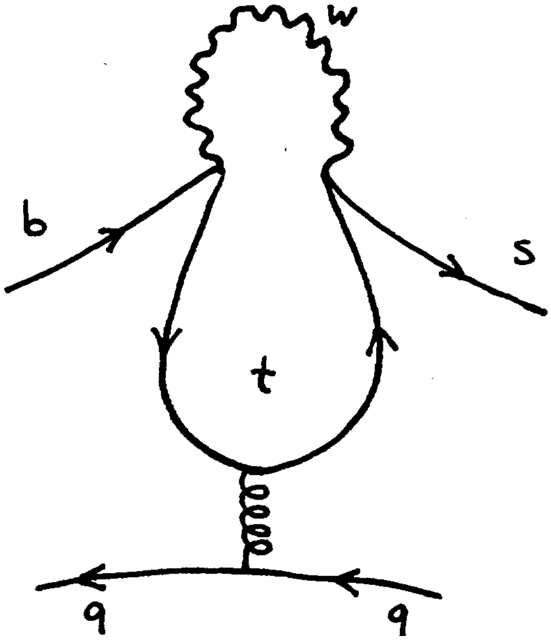
$$\left[(0.040.01)\, L_1 \; - \; (1.000.04)\, L_2 \right]$$

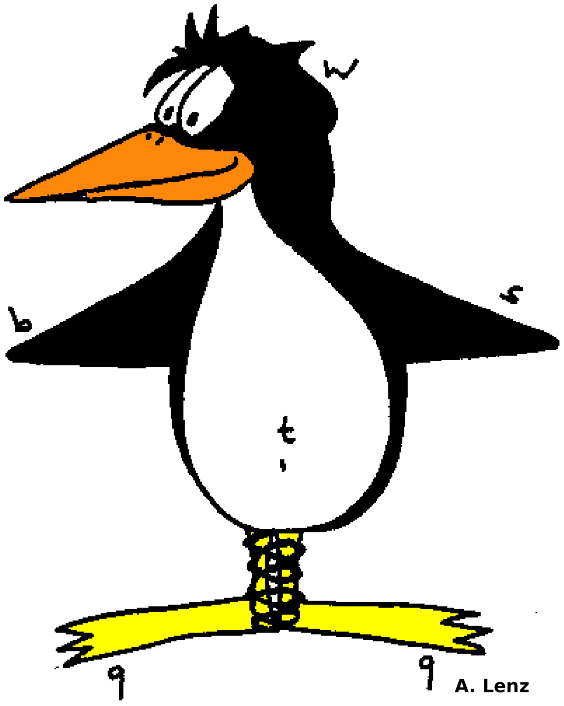
Beneke, Buchalla, Greub, A.L., Nierste

with $\tau(\Xi_b^0) \approx \tau(\Lambda_b)$

$$\frac{\overline{\tau}(\Lambda_b)}{\overline{\tau}(\Xi_b^-)} \quad \approx \quad 0.88$$

BTW: Penguin diagrams look like penguins





Vainshtein, Zakharov, Shifman