Precise description of heavy quark decays

Loops and Legs

Eisenach, April 2006

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Outline

Introduction: semileptonic and hadronic decay modes of the b quark;

Theoretical prediction of the SL branching fraction and its conflict with experiment;

New perturbative corrections

Outlook: need to account for the charm mass

50^{th} anniversary of radiative corrections (to charged particle decays)

1956: Behrends, Finkelstein, Sirlin,
`Radiative corrections to decay processes'

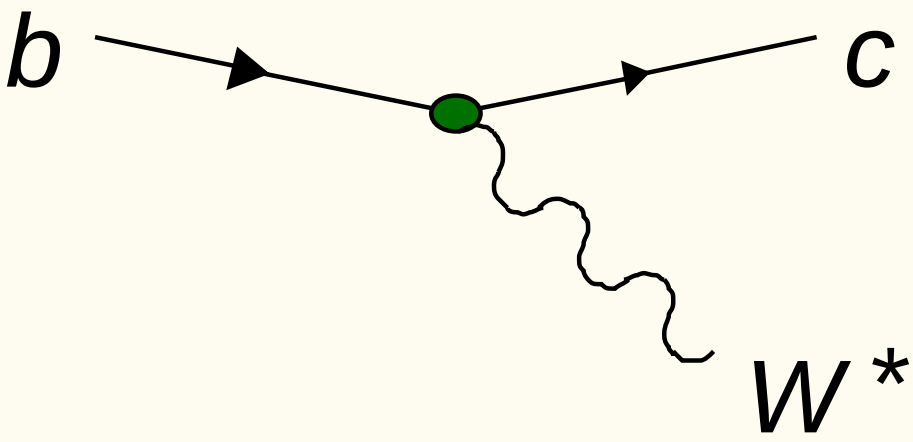
Muon decay: electron spectrum, total rate

1996: first result at two loops (zero recoil)

1999: complete muon lifetime (van Ritbergen, Stuart); b→u (vR)

2005: complete muon spectrum (Anastasiou, Melnikov, Petriello)

How does *b* quark decay?



Semileptonic

$\bar{\nu}_e, \bar{\nu}_\mu, \bar{\nu}_\tau$

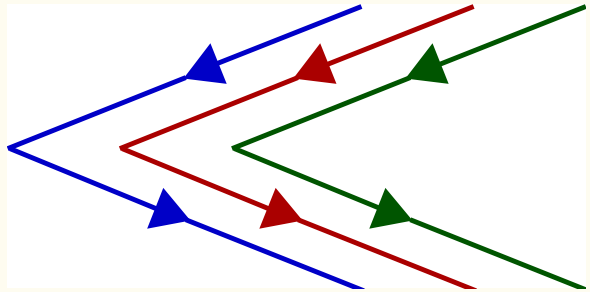
e^-, μ^-, τ^-

Semileptonic branching ratio (parton model without QCD)

$$B_{SL} \approx \frac{1}{3+6} \approx 11\%$$

$$\Delta B_{SL} = \frac{1}{3+6} - \frac{1}{3+6(1+\delta)} \approx \frac{6\delta}{81} = \frac{\delta}{13.5}$$

Nonleptonic



$\bar{u}, \bar{c}$

d, s

8% shift of the NL width shifts B_{SL} by 0.6 percentage points

What do experiments get for B_{SL}?

World average: $(10.76 \pm 0.23)\%$

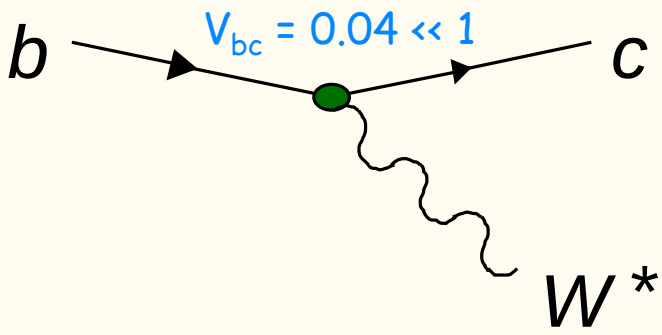
hep-ex/0505100
(without b → u)

Theoretical lower limit:

$$B_{SL}\left(b \to ce\bar{\nu}_e\right) > 11.5\%$$

Bigi et al, 1994
Voloshin, 2000

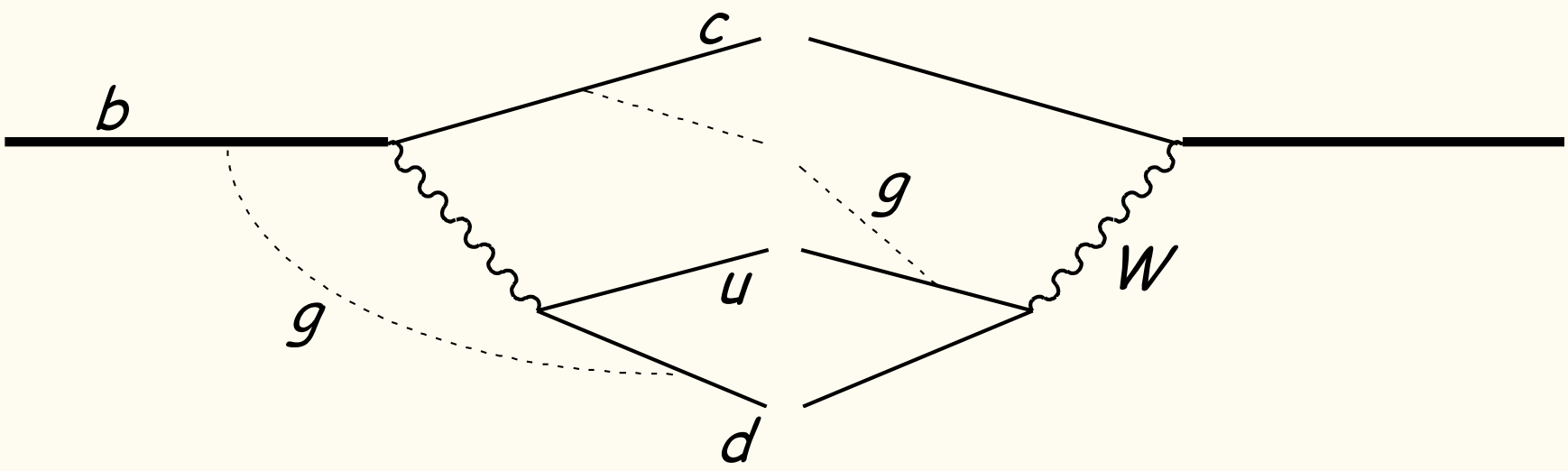
3.2σ difference



Standard Model suppressed:
good place to look for New Physics

Missing in the theoretical bound: NNLO corrections to non-leptonic decays.

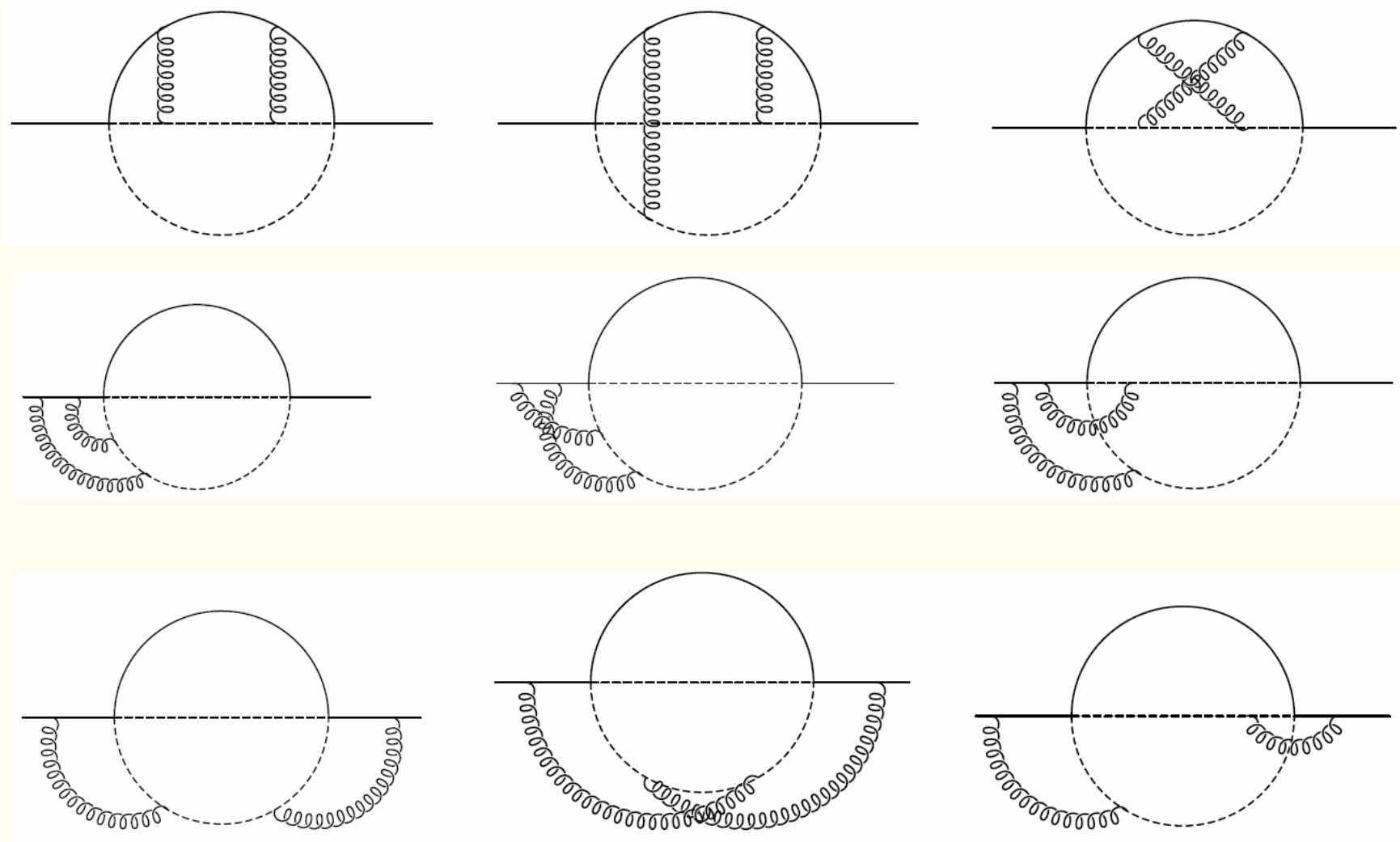
Example:



Four-loop diagrams with masses

Reduction via Laporta algorithm (ordering useful);
Master integrals: recycle as much as possible.

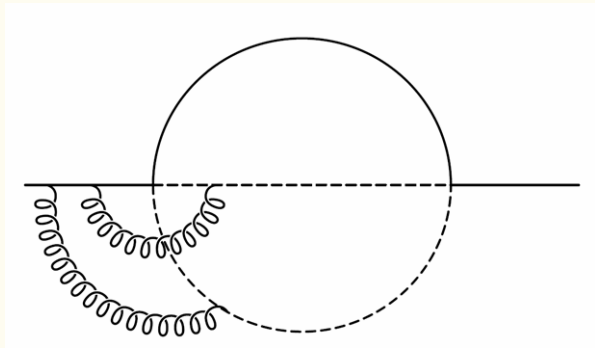
Fortunately: only a dozen `soft' diagrams!



etc.

Results

Example for a single diagram:



$$-\frac{16}{3}\ln^2\frac{M_W}{m_b}+\left(-\frac{311}{18}+\frac{10}{3}\pi^2\right)\ln\frac{M_W}{m_b}+\frac{12287}{324}-\frac{143}{162}\pi^2+\frac{53}{135}\pi^4-\frac{14}{9}\zeta_3$$

(with Maciek Ślusarczyk)

Total correction for the non-leptonic width:

$$\frac{\Gamma(b\to c\bar{u}d)+\Gamma(b\to c\bar{u}s)}{3\Gamma(b\to ce\bar{\nu})}=1+\frac{\alpha_s}{\pi}+\left(\frac{\alpha_s}{\pi}\right)^2\left[4\ln^2\frac{M_W}{m_b}+\frac{15}{2}\ln\frac{M_W}{m_b}+12.4\right]$$

About 5-8% increase of the NL width;
lowers the theoretical lower bound on B_{SL}

Summary

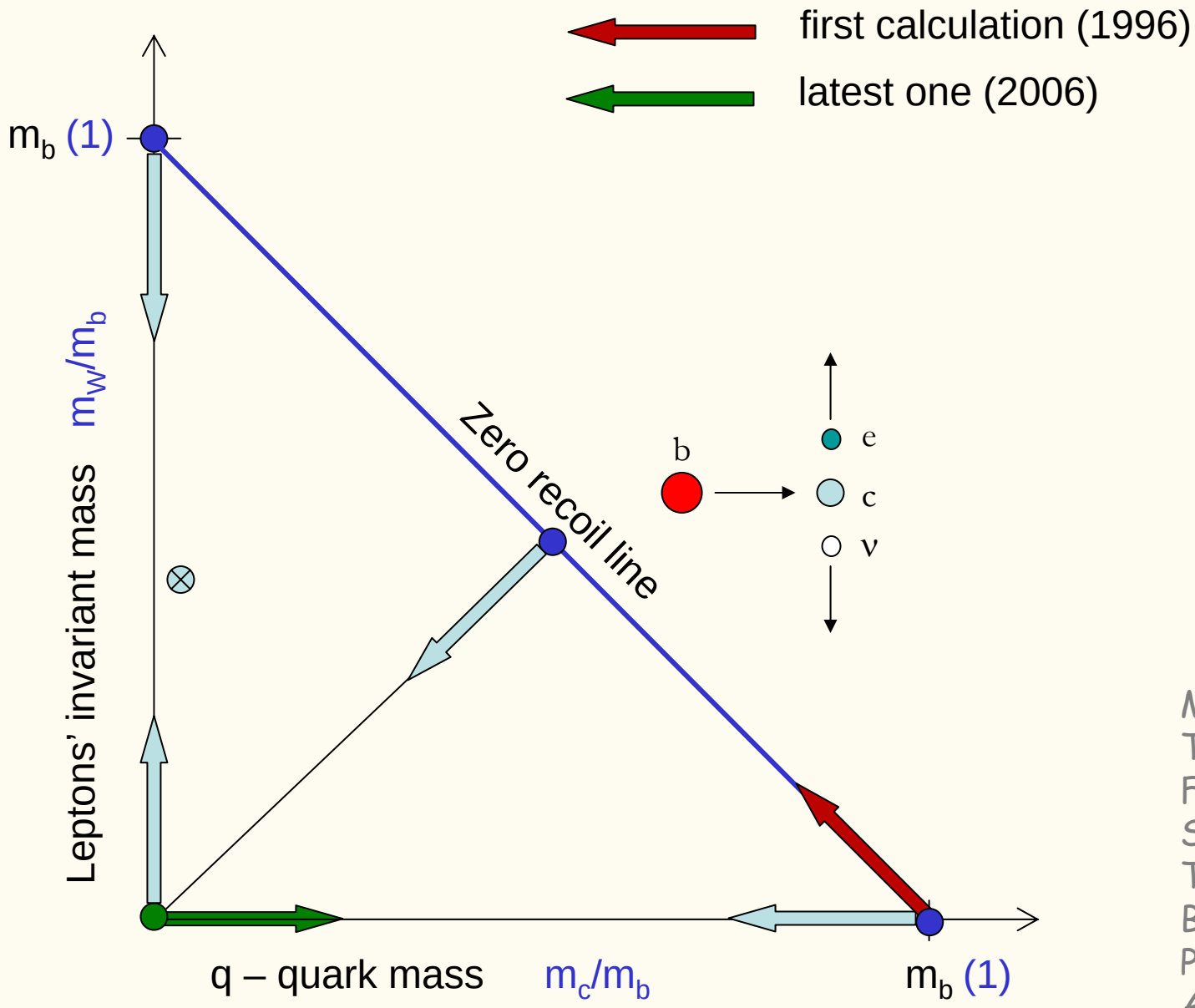
"Fair agreement" reached between theory and experiment;

More important: one can further improve the theoretical prediction (account for charm mass);

Charm mass effects may be very large – a new type of threshold phenomenon?

With new data forthcoming, will we discover competitors to W bosons?

Known two-loop corrections on the *bc* line



Melnikov,
Tausk,
Franzkowski,
Slusarczyk,
Tkachov,
Blokland,
Pak,
AC

Status of perturbative corrections to B_{sl}

- $b \to x l \nu$ known exactly at NLO, many results at NNLO (limit of massless quarks in the final state, …)

- $b \to c\bar{c}s$ known at NLO

  charm counting ⟹ cannot explain B_{sl} discrepancy

- dominant decay channels $b \to c\bar{u}d, \quad b \to c\bar{u}s$ should be studied at NNLO

The puzzle of the low semileptonic branching

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Inconclusive inclusive nonleptonic B decays

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PHYSICS LETTERS B

The baffling semileptonic branching ratio of B mesons

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the expected value for the semileptonic branching ratio of B mesons has become
improved quality of the data and to the increasing maturity of the theoretical
discuss various theoretical options to reduce the semileptonic B branching ratio;
apparent puzzle is the possibility of an unorthodox enhancement in nonperturba-
"New Physics". Phenomenological implications of such scenarios are pointed out.