

# Second Order Corrections to Heavy Quark Decays at Intermediate Recoil

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Loopfest VII

# Outline

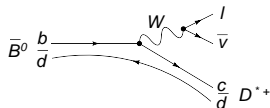
## 1 Semi-leptonic $b$ Decay and $|V_{cb}|$

- Measurement and Calculation
- Previous and Recent Work

## 2 Intermediate Recoil Expansions

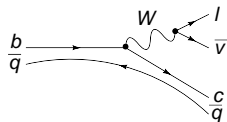
- Method of Calculation
- Results

# Measuring $|V_{cb}|$



Exclusive b Decay

$$\bar{B}^0 \rightarrow D^{*+} l^- \bar{\nu}_l$$
$$|V_{cb}| = (40.9 \pm 1.8) \times 10^{-3}$$

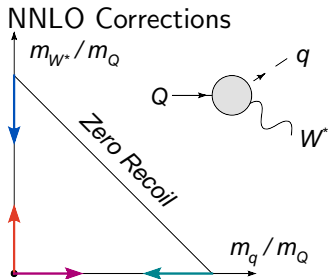


Inclusive b Decay

$$B \rightarrow X_c l \bar{\nu}$$
$$|V_{cb}| = (41.7 \pm 0.7) \times 10^{-3}$$

Difference of  $\approx 2\%$ .

# How to Calculate $\mathcal{O}(\alpha_S^2)$ Corrections

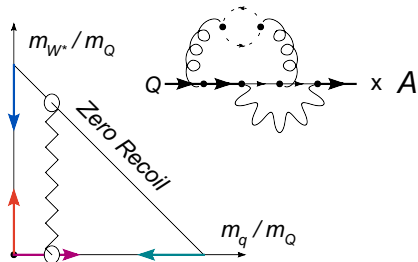


Expansions done by Blokland, Czarnecki, Melnikov, Pak, Slusarczyk, and Tkachov.

- The  $\mathcal{O}(\alpha_S^2)$  corrections are calculated as expansions in various limits of masses of the  $c$ -quark and  $W^*$ .

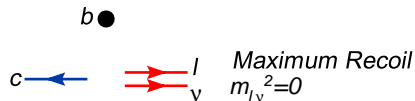
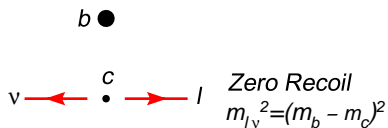
# BLM Estimate

BLM estimate



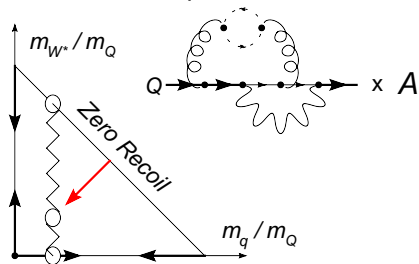
Calculated in 1995 by Luke, Savage and Wise.

The two points on either end of the BLM line are known from



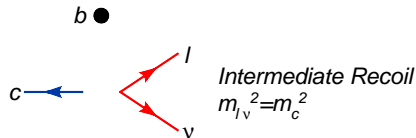
# NNLO Result

## Zero Recoil Expansion



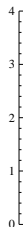
Calculated in 1998 by Czarnecki and Melnikov

Czarnecki and Melnikov were able to expand to another point along this line allowing a polynomial fit to the three known points.



# Previous Estimates

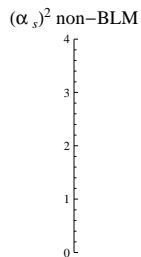
$(\alpha_s)^2$  non-BLM



Czarnecki, Melnikov

- This value has been used in fits done to extract  $|V_{cb}|$ .
- Intermediate Recoil results recalculated using  $\frac{m_c}{m_b} = 0.25$ ,  $\alpha_s(m_b)$ , and  $N_f = 3$  to allow comparison with recent work.

# Recent Work



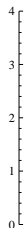
Czarnecki, Melnikov, Melnikov  
(2008)

- Recently Melnikov computed numerical corrections to the full decay  $b \rightarrow c \ell \bar{\nu}$ .



# Recent Work

$(\alpha_s)^2$  non-BLM

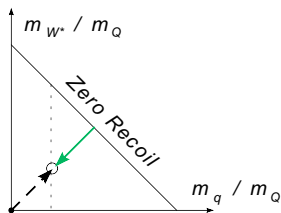
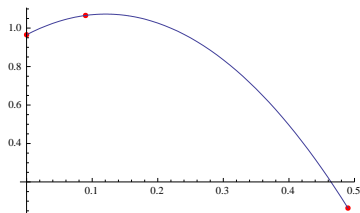


Czarnecki, Melnikov, Melnikov  
(2008), Pak, Czarnecki (2008)

- At the same time, Czarnecki and Pak, have been able to compute an analytical expansion for the full decay.
- Both of these results DO NOT agree with the original polynomial fit.

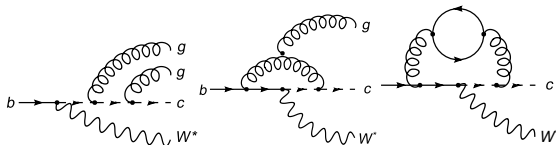
# What We Need

- Reproduce original expansion and generate more orders.
- Expand from opposite side to check consistency of the expansion.



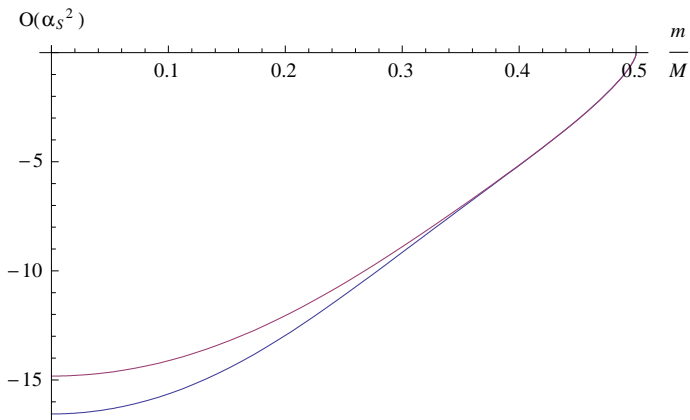
# Expansion From Zero Recoil Line

- More terms have been calculated, again to limits of available computer power.
- Second order diagrams calculated as decays with each cut being computed separately.



Some samples of the diagrams that needed to be calculated.

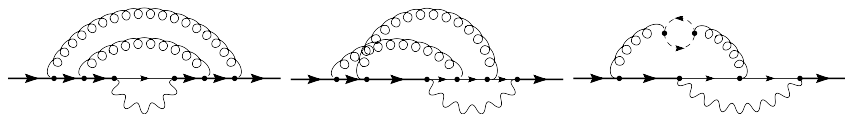
# Results



Old versus new expansion

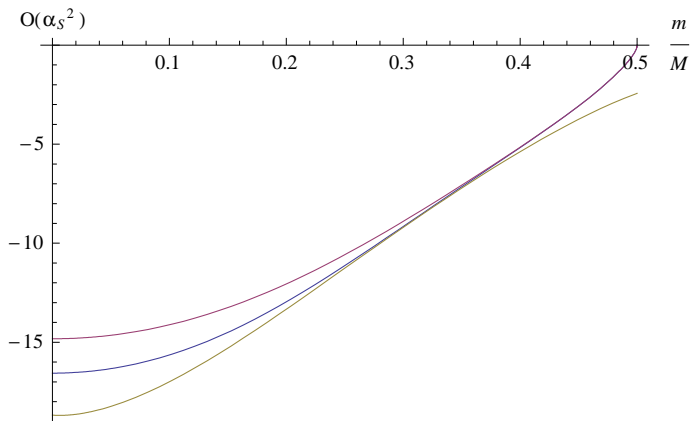
# Expansion From Zero Mass

- Second order contributions calculated using 3-loop diagrams and optical theorem.
- We used asymptotic expansion to treat the 10 topologies that were used to calculate the diagrams.
- Needed to calculate at most 11 asymptotic regions, requiring months of CPU time.



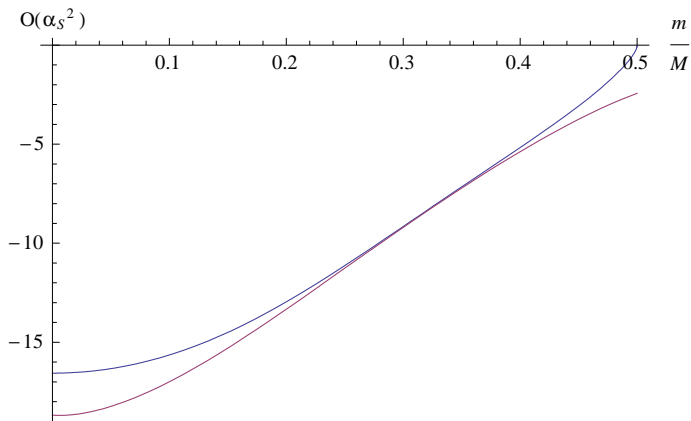
Examples of the diagrams that needed to be calculated for this expansion.

# Matching



Matching of the two diagonal expansions.

# Matching



Matching of the two diagonal expansions.

# Summary

- We have calculated the NNLO of  $b \rightarrow cW^*$  decay with  $m_c = m_{W^*}$ .
- The two expansions agree well showing that the polynomial extrapolation to  $b \rightarrow c\ell\bar{\nu}$  decay does not give a reliable result.
- Estimated change in  $|V_{cb}|$  is  $\approx 0.5\%$  bringing exclusive and inclusive measurements closer together.