Moving NRQCD: B mesons at high velocities

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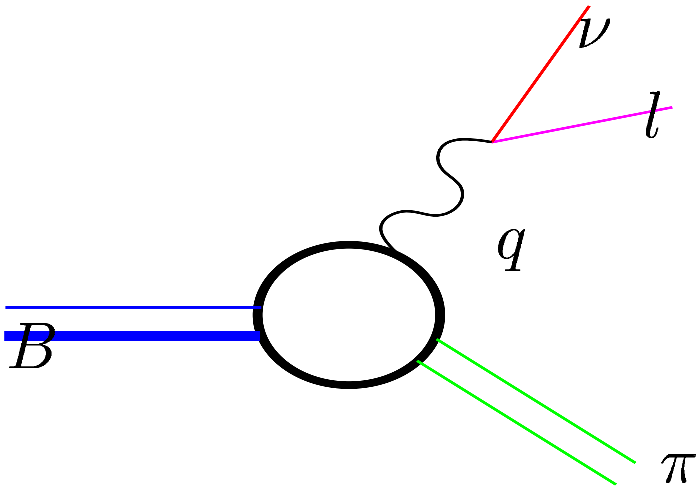
Moving NRQCD: Motivation

Exclusive Semileptonic Decays

Form Factors needed for CKM elements

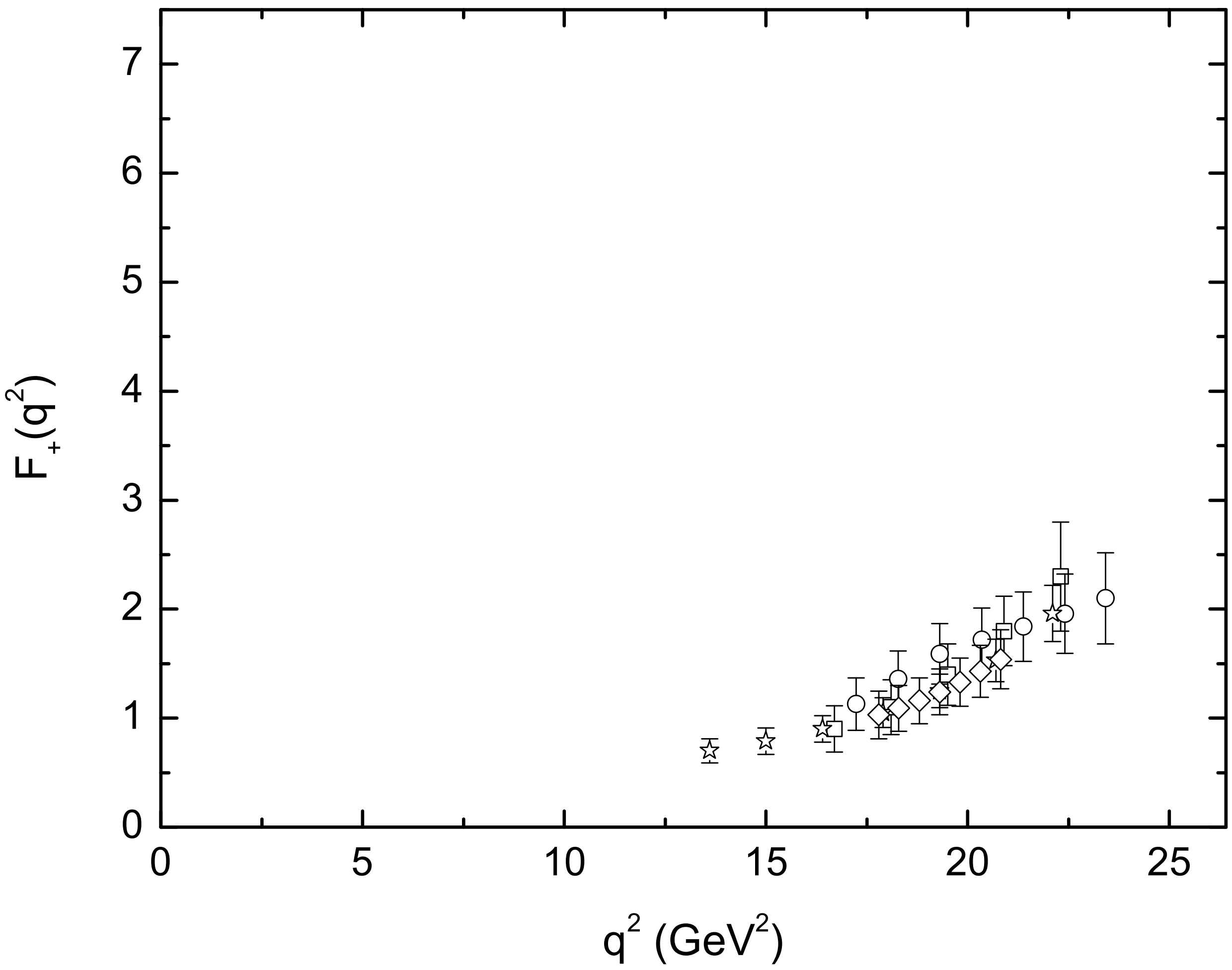


- $B \to \pi l \nu \quad \Rightarrow \quad V_{ub}$
- $D \to \pi l \nu \quad \Rightarrow \quad V_{cd}$
- $B \to D l \nu \quad \Rightarrow \quad V_{cb}$

large mass difference $\Rightarrow$ large recoil momentum likely

$\Rightarrow$ high recoil region (q^2 small)

Lattice Form Factor Results



Why no large recoil values?

- Lattice calculation done in rest frame of initial meson
- for $B \to \pi l \nu$:

$$q^2 \approx 0 \quad \Rightarrow \quad p_\pi \approx 2.6\mathrm{GeV}$$

- errors $\approx (ap)^2$

$$p_\pi \approx 2.6\mathrm{GeV} \quad \Rightarrow \quad a^{-1} \gg 3\mathrm{GeV}$$

small a computationally unfeasible

Better Reference Frame

(1) Light Quarks:

- better choice of lattice frame: $p_\pi \approx \sqrt{\Lambda_{\mathrm{QCD}} M_B}$
- share momentum between initial and final mesons for $B \to \pi l \nu$:

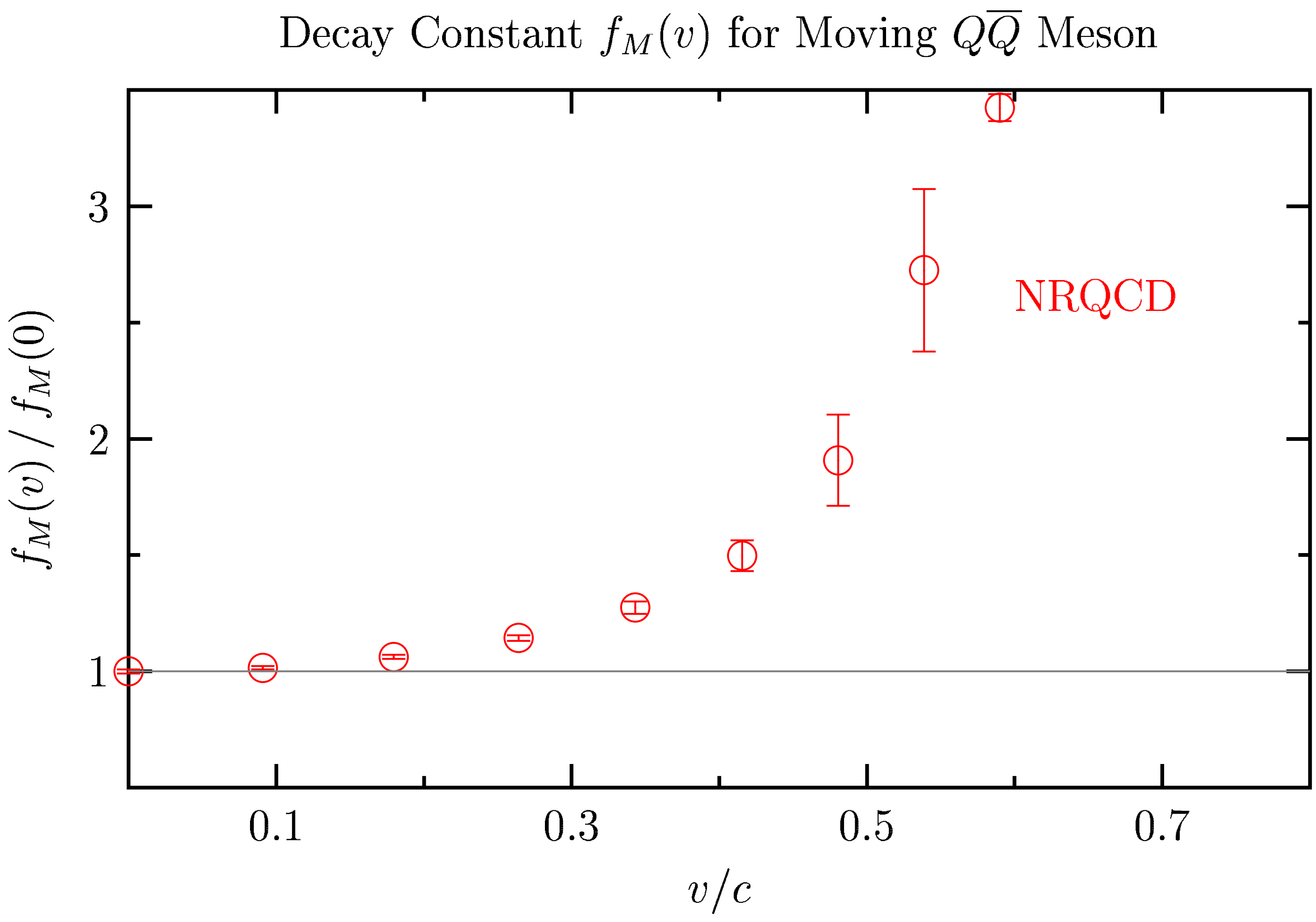
$$p_\pi \approx 800\mathrm{MeV} \quad \& \quad p_B \approx 8.0\mathrm{GeV}$$

- discretization errors of all light quarks under control

(2) heavy quarks:

- b quark has velocity $v \approx 0.8c$

Decay Constants: Limits of current methods



moving NRQCD

Heavy b Quark momentum:

$$P_b^\mu = M_b u^\mu + k^\mu$$

- $u^\mu =$ 4-velocity of B meson

$\Rightarrow$ $k^\mu \sim \Lambda_{QCD} u^\mu \ll M u^\mu$

- treat $M_b u^\mu$ exactly
- discretize k^μ
- All quarks (heavy and light) have same size errors!

moving NRQCD Lagrangian

$$\mathcal{L}_{\text{quark}} = \psi_Q^\dagger \left(iD_t + i\boldsymbol{v}\cdot\boldsymbol{D} + \frac{\boldsymbol{D}^2}{2\gamma m} - \frac{(\boldsymbol{v}\cdot\boldsymbol{D})^2}{2\gamma m} \right) \psi_Q + \mathcal{L}_{Q,K} + \mathcal{L}_{Q,E} + \mathcal{L}_{Q,B}$$

$$\mathcal{L}_{Q,K} = \psi_Q^\dagger \left(\frac{i\{\boldsymbol{D}^2, \boldsymbol{v}\cdot\boldsymbol{D}\}}{4\gamma^2 m^2} - \frac{i(\boldsymbol{v}\cdot\boldsymbol{D})^3}{2\gamma^2 m^2} + \frac{\boldsymbol{D}^4}{8\gamma^3 m^3} - \frac{3\{\boldsymbol{D}^2, (\boldsymbol{v}\cdot\boldsymbol{D})^2\}}{8\gamma^3 m^3} + \frac{5(\boldsymbol{v}\cdot\boldsymbol{D})^4}{8\gamma^3 m^3} \right) \psi_Q$$

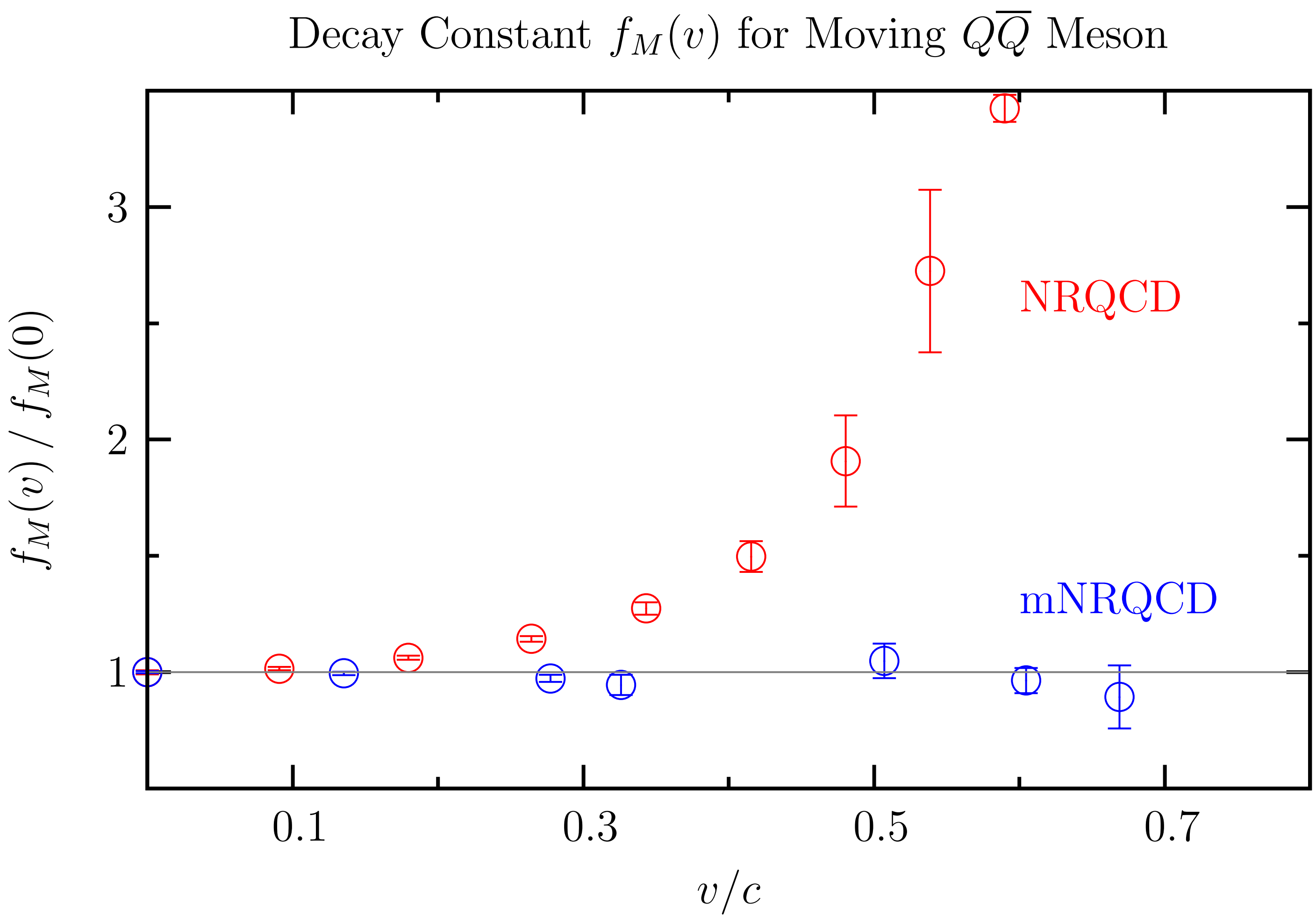
$$\mathcal{L}_{Q,E} = \psi_Q^\dagger \left(\frac{[\boldsymbol{D}\cdot\boldsymbol{E}]}{8\gamma m^2} - \frac{2-\boldsymbol{v}^2[\boldsymbol{v}\cdot\boldsymbol{D}, \boldsymbol{v}\cdot\boldsymbol{E}]}{16 m^2} - \frac{i\{\boldsymbol{v}\cdot\boldsymbol{D}, \boldsymbol{\sigma}\cdot\boldsymbol{v}\times\boldsymbol{E}'\}}{\gamma(\gamma+1)m^2} \right.$$
$$\left. + \frac{i\boldsymbol{\sigma}\cdot(\boldsymbol{D}\times\boldsymbol{E}' - \boldsymbol{E}'\times\boldsymbol{D})}{8\gamma m^2} \right) \psi_Q$$

$$\mathcal{L}_{Q,B} = \psi_Q^\dagger \left(\frac{\boldsymbol{\sigma}\cdot\boldsymbol{B}'}{2\gamma m} + \frac{i\{\boldsymbol{v}\cdot\boldsymbol{D}, \boldsymbol{\sigma}\cdot\boldsymbol{B}'\}}{4\gamma^2 m^2} - \frac{\boldsymbol{v}^2[\boldsymbol{v}\cdot\boldsymbol{D}\times\boldsymbol{B}]}{16 m^2} \right) \psi_Q$$

- single first order time derivative $\Rightarrow$ FAST

see also: Sloan; Hashmoto & Matsufuru; Mandula & Ogilvie

Decay Constant: Comparison of mNRQCD & NRQCD



Velocity Renormalization

New feature of moving NRQCD

- input v not necessarily simulated meson v_R

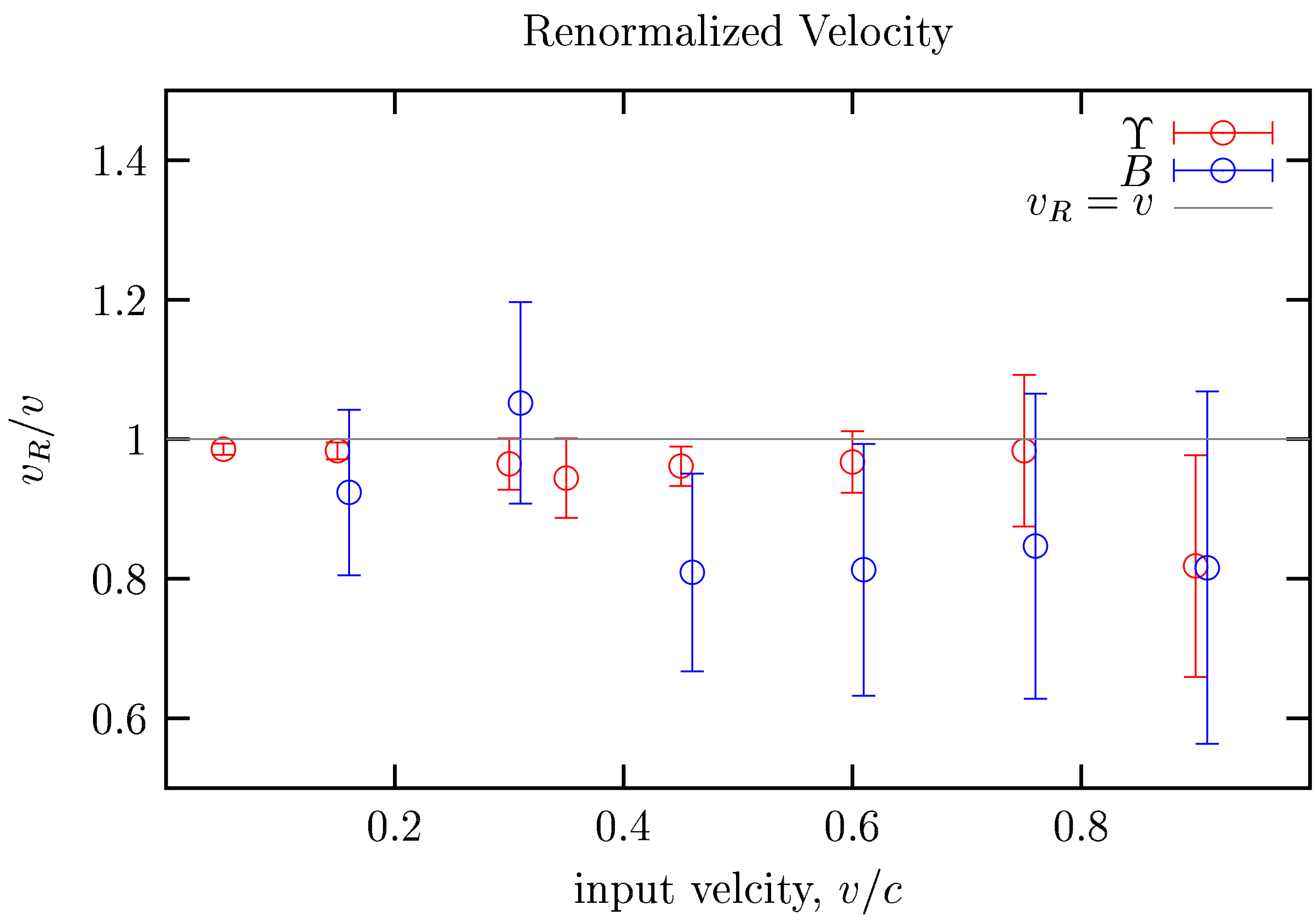
  $\Rightarrow$ due to breaking Lorentz invariance

- Must find renormalized velocity
  - perturbatively
  - non-perturbatively

    same in both Υ and B systems

    use Υ to tune

Velocity Renormalization Results



Conclusions

Calculation of high recoil form factors now possible (add to list of high precision results)

- B and Υ mesons have been analyzed
  - velocity renormalization
  - kinetic energy
  - ground state energy
- 1-loop perturbative results (Next talk!)

In Progress:

- optimized “magic” smearing

  $\Rightarrow$ improve statistics at large v
- Form factors at high recoil in near future!