Prospects for the measurement of b-quark mass at the ILC

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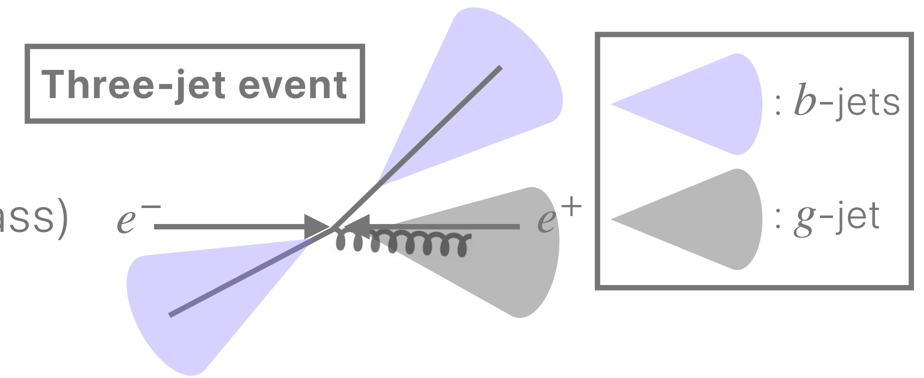
PANIC 2021 Conference

1. Running b-quark mass

- Quarks can not be observed
  → "Single" quark masses are not observables, and they are observed as running parameters(running mass)
- Running mass is described by RGE:

$$\mu^2 \frac{\partial m_q(\mu)}{\partial \mu^2} = -\gamma\left(\alpha_s(\mu)\right) m_q(\mu)$$

μ : renormalization scale
$\gamma\left(\alpha_s(\mu)\right)$: Perturbative function



2. Inferring of running b-quark mass

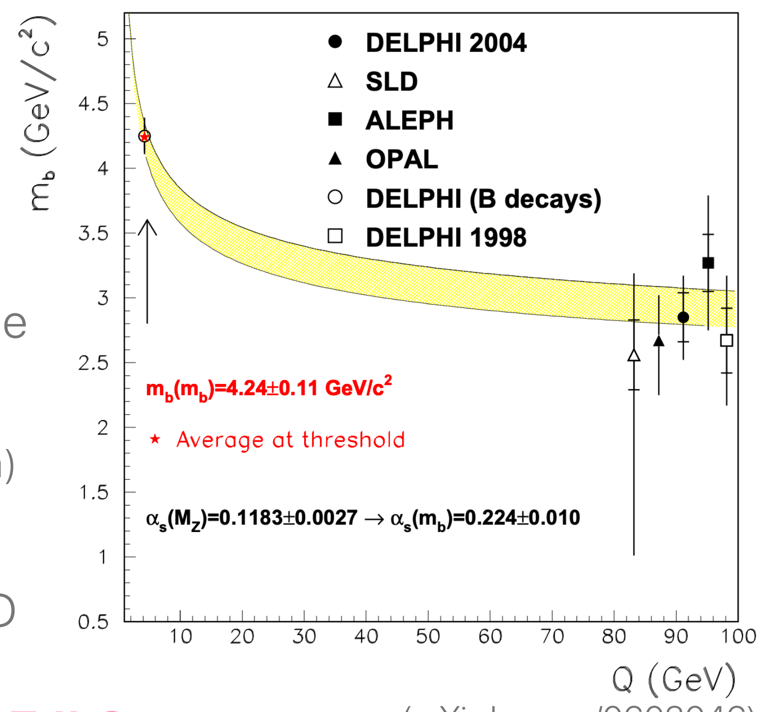
- Quarks and gluons appear as jets
  →running quark masses are obtained from hadronic observables
  Exclusive observables(e.g. three jet rates) have better sensitivity(by a factor of 10 @Z-pole) of quark mass
- Jet should be defined so that avoid infrared(soft/collinear) divergence
  →Jet-Clustering algorithm (JADE, DURHAM, CAMBRIDGE…)

$$R_3^f = \frac{\Gamma_{3j}^f(y_c)}{\Gamma^f}$$

$\Gamma_{3j}^f(y_c)$: $e^+e^- \to f\bar{f}g \to$ 3-jet xsect (y_c : resolution parameter from algorithm)
Γ^f : Total width for $e^+e^- \to f\bar{f}$

- The b-quark mass at Z-pole has been measured precisely at LEP/SLD
  →**b-quark mass at higher energies at the ILC?**
  Estimate dominant systematic errors at 250GeV ILC and Giga-Z ILC

b-quark mass evolution



(arXiv:hep-ex/0603046)

3. Definition of the Observable

- Consider double-ratio R_3^{bl} as the observable
  Cancel or reduce EW corrections and systematic uncertainties (hadronization effect)

$$R_3^{bl} = \frac{\Gamma_{3j}^b(y_c)/\Gamma^b}{\Gamma_{3j}^l(y_c)/\Gamma^l} = 1 + \frac{\alpha_s(\mu)}{\pi} a_0(y_c) + \bar{r}_b(\mu)\left(b_0(\bar{r}_b, y_c) + \frac{\alpha_s(\mu)}{\pi} b_1(\bar{r}_b, y_c, \mu)\right)$$

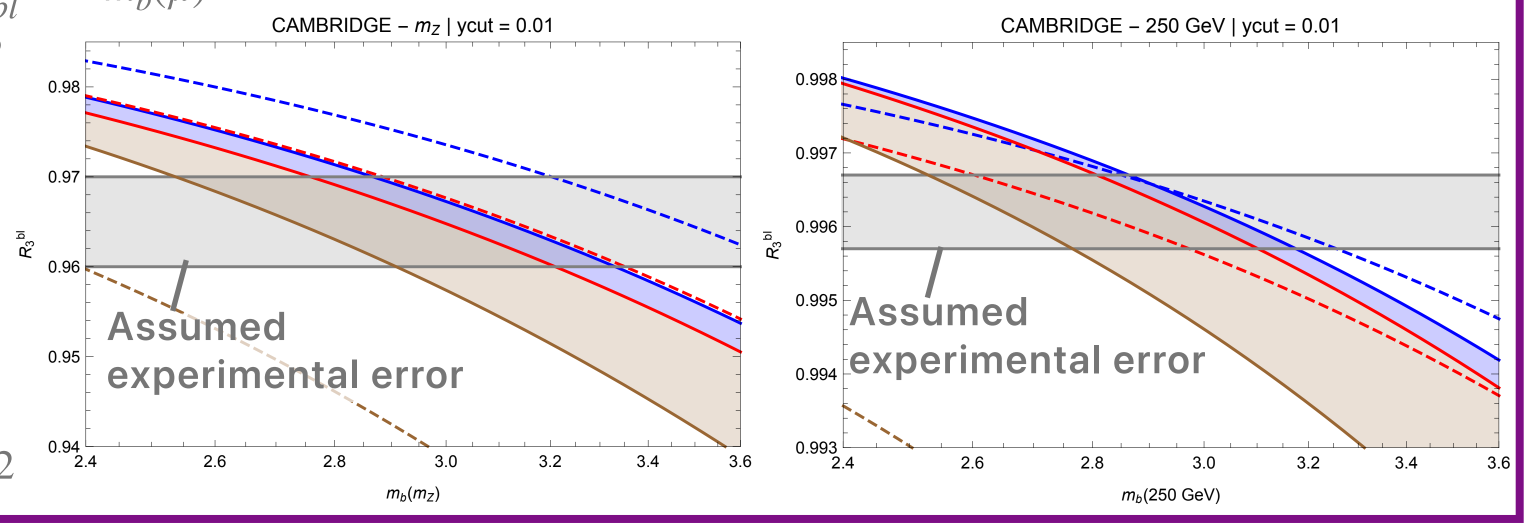
$(l = u, d, s)$

(massless correction; massive LO correction; massive NLO correction)

$$\bar{r}_b(\mu) = m_b^2(\mu)/s$$
$$\bar{b}_1 = b_1 + 2b_0\left(4/3 - \log \bar{r}_b + \log\left(\mu^2/s\right)\right)$$

4. Sensitivity of b-quark mass at high energies

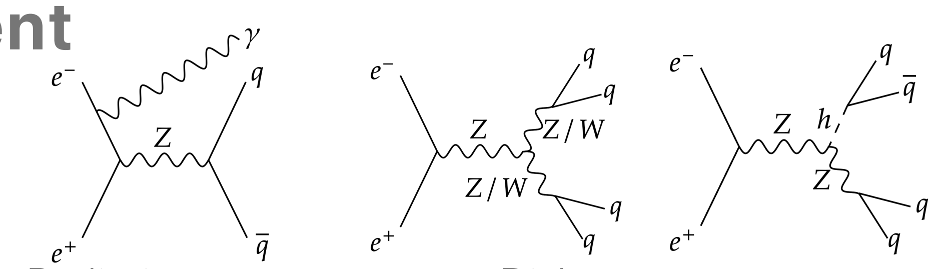
- Sensitivity of b-quark mass for R_3^{bl} is given by $\Delta R_3^{bl} \sim \frac{2\left(1 - R_3^{bl}\right)}{m_b(\mu)} \Delta m_b(\mu)$ (e.g. CAMBRIDGE predictions are given below)
  If we want $\Delta m_b = 0.4$ GeV, we need to measure R_3^{bl} with a precision of 1% (for Z-pole) and 0.1% (for 250 GeV)
  →**The sensitivity at 250 GeV is ~5 times deteriorated**



LO calculation; NLO calculation; Pole mass, $\mu = \sqrt{s}$; Running mass, $\mu = 2\sqrt{s}$; Running mass, $\mu = \sqrt{s}/2$

5. Environment of 250GeV measurement

- Signal event: $e^+e^- \to q\bar{q}$ $(q = u, d, s, b)$
- BKG events:
  1. Radiative return (w/ <50 GeV ISR γ)
  2. Di-boson events



- Luminosity: 2ab⁻¹ with two polarizations $\left(P_{e^-}, P_{e^+}\right) = (-0.8, +0.3)$ and $(+0.8, -0.3)$
- Used old DBD sample → event generated by LO for massless quarks in WHIZARD
  Mass effects are only implemented in PYTHIA(PS+Hadronization)
- Situation is completely different from LEP's Z-pole measurement

6. Event selection

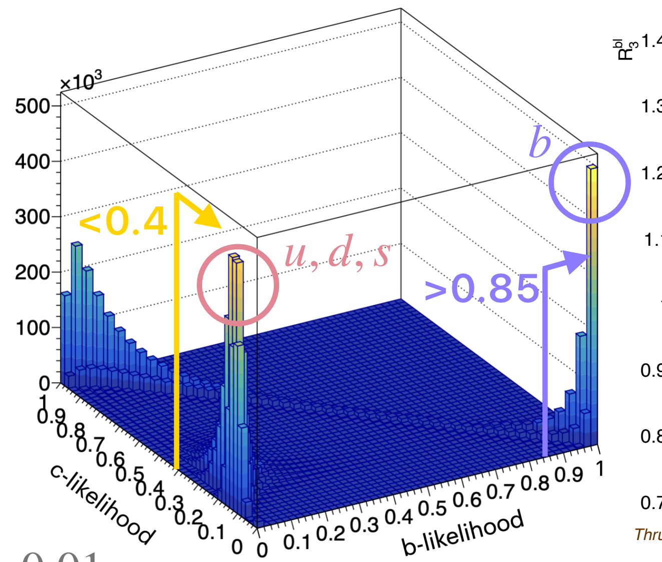
- Radiative return cut
  Construct ISR energy from 2-jets kinematically and remove invisible γs

$$K_{reco} = \frac{250\text{ GeV} \sin \psi_{acol}}{\sin \psi_{acol} + \sin \theta_1 + \sin \theta_2}$$

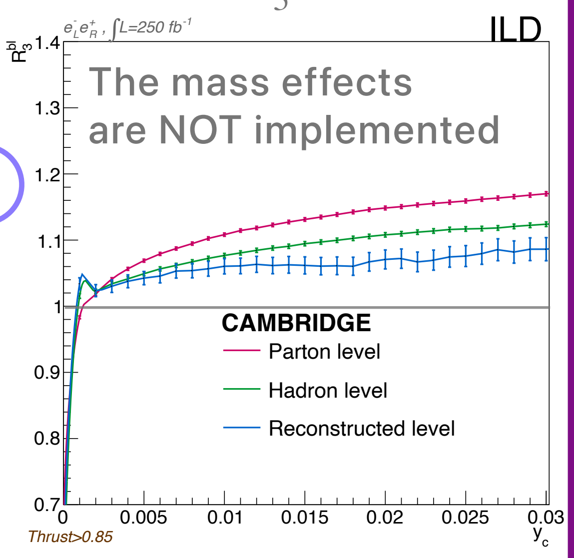
ψ_{acol} : angle of btw 2 jets
θ_i : polar angle of each jet

  Visible γs are removed by neutral PFO information
- Di-boson events cut: use Thrust>0.85
- Flavor-tagging
  Efficiency: 80%(for b), 58%(for uds)
  Purity: 98.7%(for b), 96.1%(for uds)
- Jet-reconstruction: CAMBRIDGE algorithm w/ $y_c = 0.01$

Flavor-tagging likelihoods



Measured R_3^{bl} for each level



7. Assessment of uncertainties

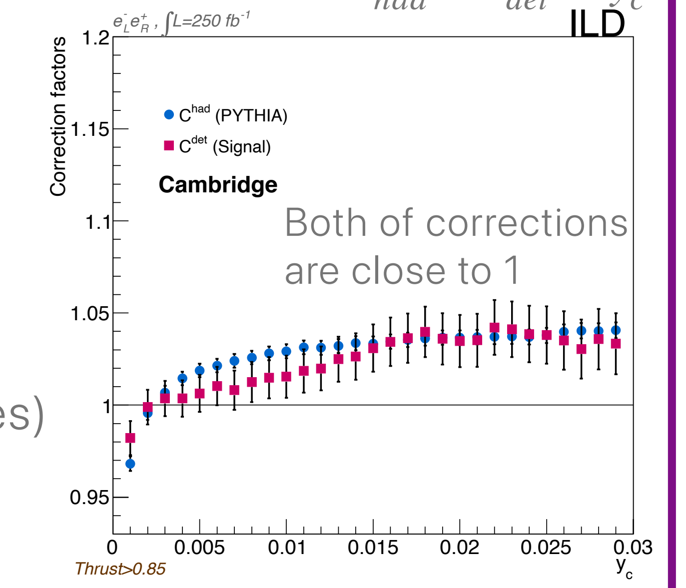
- The mass effects are not implemented in the current MC, but corrections between different levels are worthful:

$$R_3^{bl}\Big|_{parton} = C_{had} \times C_{det} \times R_3^{bl}\Big|_{reco}$$

Hadronization correction $C_{had} = \frac{R_3^{bl}\big|_{parton}}{R_3^{bl}\big|_{hadron}}$

Detector correction $C_{det} = \frac{R_3^{bl}\big|_{hadron}}{R_3^{bl}\big|_{reco}}$

Correction factors C_{had} & C_{det} vs y_c

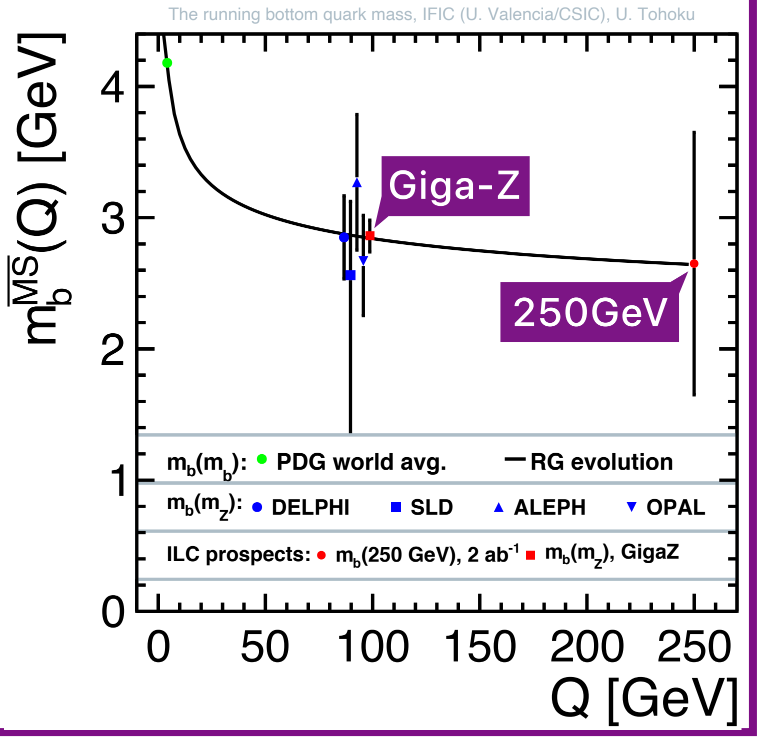


- Estimate systematic uncertainties from these corrections:
  - Hadronization model
    LEP's time: 0.2% uncertainty on C_{had} (Compare different hadronization models and tunes)
    → assumed its half thanks for higher energy B-hadrons and more data
  - Detector
    Propagated flavor-tagging efficiency(0.1-0.5%) and BKG contaminations(O(1%)) to C_{det} through Toy-MC
- Statistical uncertainty is estimated at 2ab⁻¹ H20 scenario
- b-quark mass precision for $R_3^{bl} = 0.996$, $m_b = 2.75$ GeV:

$$\Delta m_b(250) = 0.76(stat.) \pm 0.59(exp.) \pm 0.34(had.) \pm 0.07(theo.)\text{ GeV}$$

- Giga-Z ILC gives better precision thanks for 100times larger statistics, superior flavor-tagging :
  DELPHI: $\Delta m_b(m_Z) = 0.18(stat.) \pm 0.13(exp.) \pm 0.19(had.) \pm 0.12(theo.)$ GeV
  ILD: $\Delta m_b(m_Z) = 0.02(stat.) \pm 0.02(exp.) \pm 0.09(had.) \pm 0.06(theo.)$ GeV

Updated b-quark mass evolution



8. Conclusion and Prospects

- ILC 250GeV measurement has limited b-quark mass sensitivity, but it will add a new point at never proved energies
- Giga-Z ILC will provide superior result at Z-pole than LEP and better QCD test