Opposite Side B Flavor Tagging at CDF

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Outline:

- Method overview
- Soft Muon Tagging
- Jet Charge Tagging
- Conclusions

Introduction: B Flavor Tagging

B mixing and CP violation analyses:

- flavor: b or $\bar{b}$ quark
- compare B flavor at production and decay
- study observed flavor as a function of *ct*

What is flavor tagging?

- decay flavor: obvious from reconstruction
- a tagger: tool to determine B production flavor
- this talk: Opposite Side Soft Muon and Jet Charge Tagger

Flavor tagging at CDF: CKM matrix measurements

- primary interest:
  1. B_s mixing
  2. CP violation in $B_s \rightarrow J/\psi\ \phi$ and $B^0 \rightarrow h^+h^-$
- also: B^0 mixing and $\sin 2\beta$ in $B^0 \rightarrow J/\psi K_s$

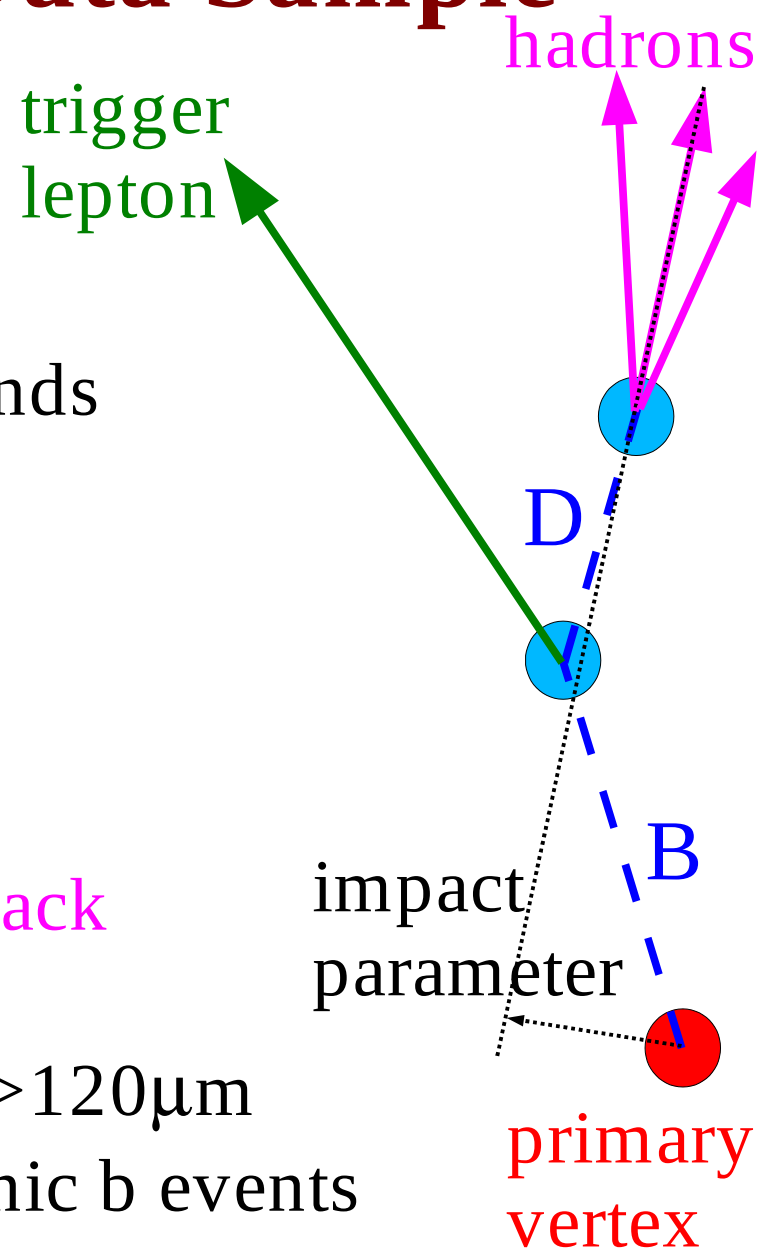
CDF Trigger and Data Sample

Important for any tagger study:

- large data sample of B candidates
- understood and removed backgrounds
- known flavor of the signal B

CDF heavy flavor samples:

- trigger based on displaced tracks
- this study: lepton and a displaced track
  - ➔ lepton: P_T>4 GeV/c
  - ➔ displaced track: P_T>2 GeV/c, I.P.>120μm
- high statistics: O(1M) of semileptonic b events
- lepton charge ⇒ signal B flavor

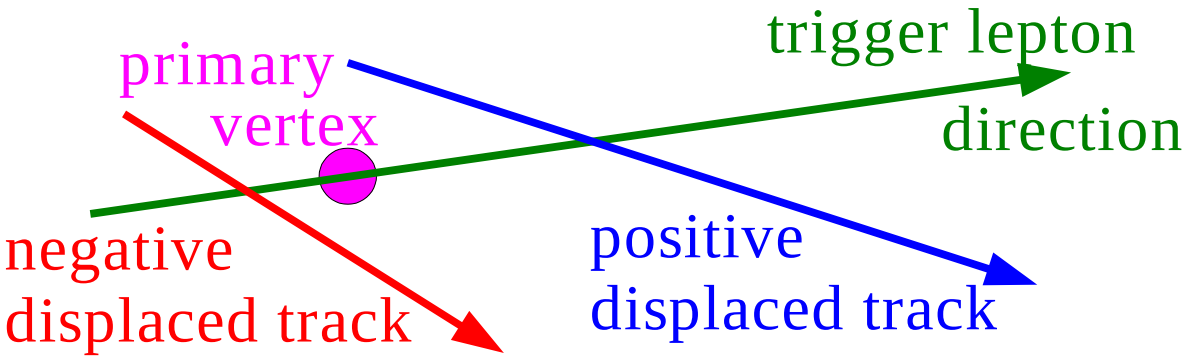


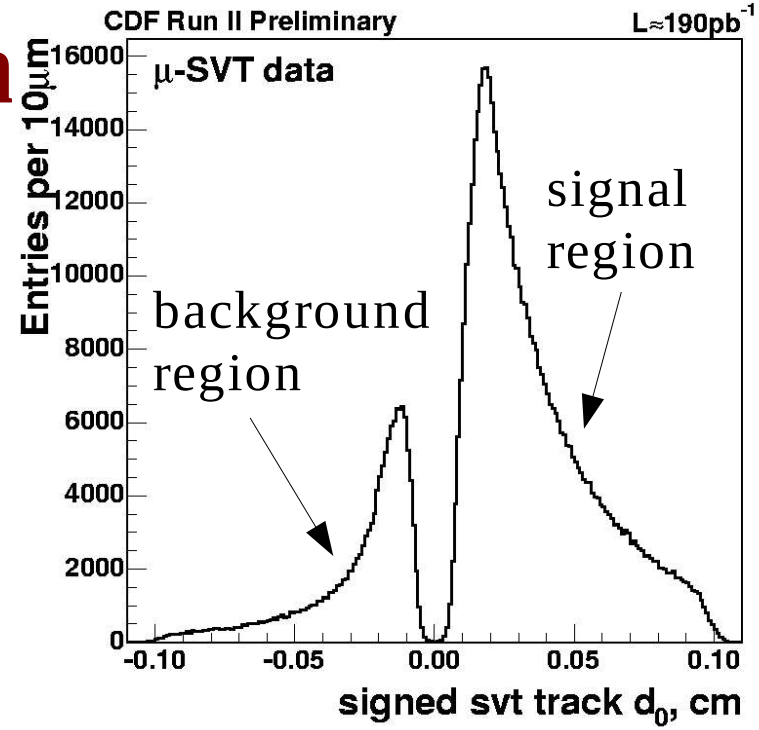
Background suppression

QCD background:

- $pp \rightarrow$ light quark events
- displaced tracks from $K_s/\Lambda/...$
- displaced mismeasured tracks

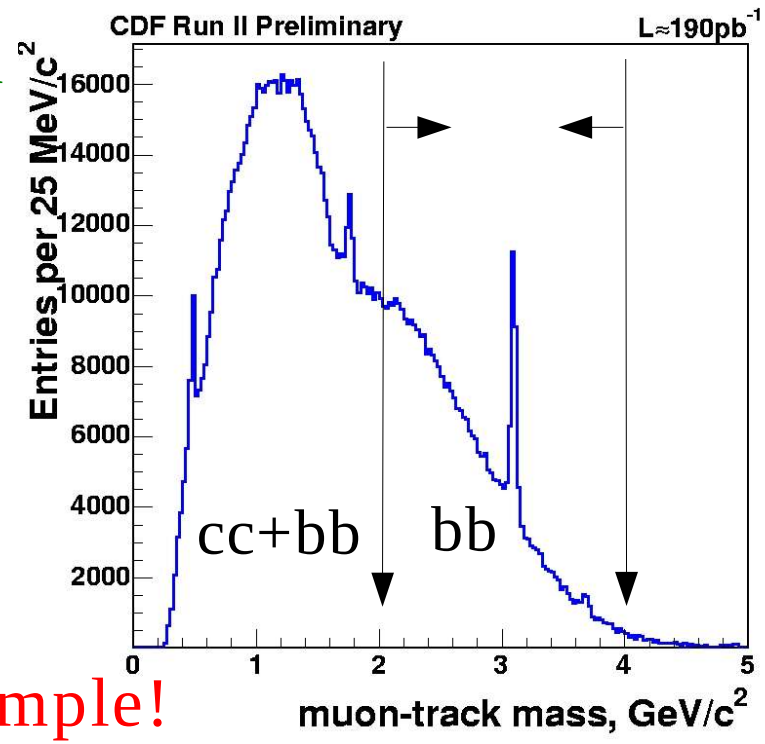
➔ remove by signed IP subtraction





Charm background:

- $pp \rightarrow cc$ events
- remove by: $2 < m_{tr.lep.-h} < 4$ GeV/c



Result: equivalent of 100% pure bb sample!

Definition of Tagger Quantities

Efficiency ε:

- fraction of events where tagger reaches decision

$$\varepsilon = N_{tagged}/N_{total}$$

Dilution D:

- shows how correct tagger decision is

$$D = 2P - 1,$$

where P is the probability of the correct answer

- when trigger B flavor is known, D is measured as

$$D = (N_{rs} - N_{ws})/(N_{rs} + N_{ws}),$$

where $N_{rs}(N_{ws})$ is the count of correct(wrong) decisions

Tagging power εD^2:

- shows statistical power of the tagger
- improve by binning in discriminating variable: $\varepsilon D^2 = \sum \varepsilon_i D_i^2$

Dilution correction factor

Defining signal *b* flavor via charge of trigger lepton:

- convenient: l^+ comes from B^+,B^0 and l^- from B^-,$\overline{B}^0$
- complication: $l^\pm$ charge shows decay flavor, not production
- sign flips:
  - when a neutral B mixes
  - when lepton comes from sequentials $b \to c \to l$

$\Rightarrow$observed dilution D_{raw} is less than D_{true}

Solution: dilution correction factor

- derive using Monte Carlo simulation
- properly model detector, trigger and decay kinematics

$$N_D \equiv \frac{D_{raw}}{D_{true}} = 0.6412 \pm 0.015(stat)$$

Soft Muon Tagger

The idea of SMT:

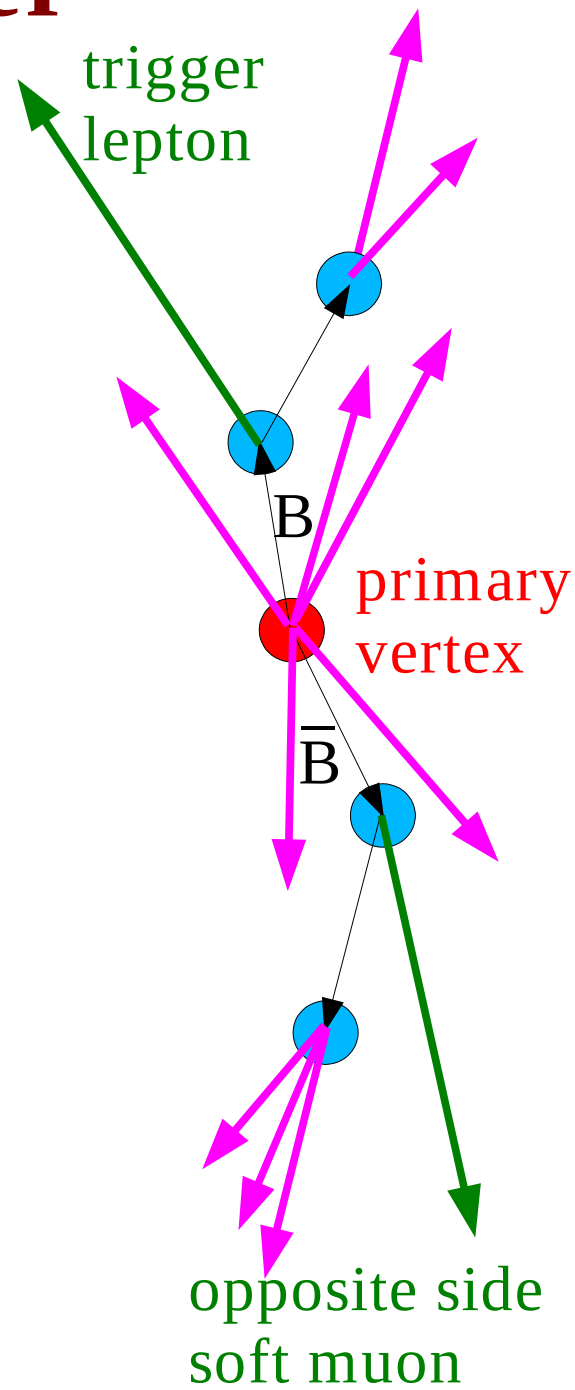
- find events with OS $B \to \mu X$
- OS μ charge gives SMT decision
- same charge trigger μ - OS μ:
  - ➔ wrong sign events
- opposite charge trigger μ - OS μ:
  - ➔ right sign events

SMT qualities:

✔ high purity
  - ➔ a OS μ: almost always from $B \to \mu X$

✗ low efficiency: $Br(B \to \mu X) \sim 10\%$

✗ OS B mixing: reduces performance



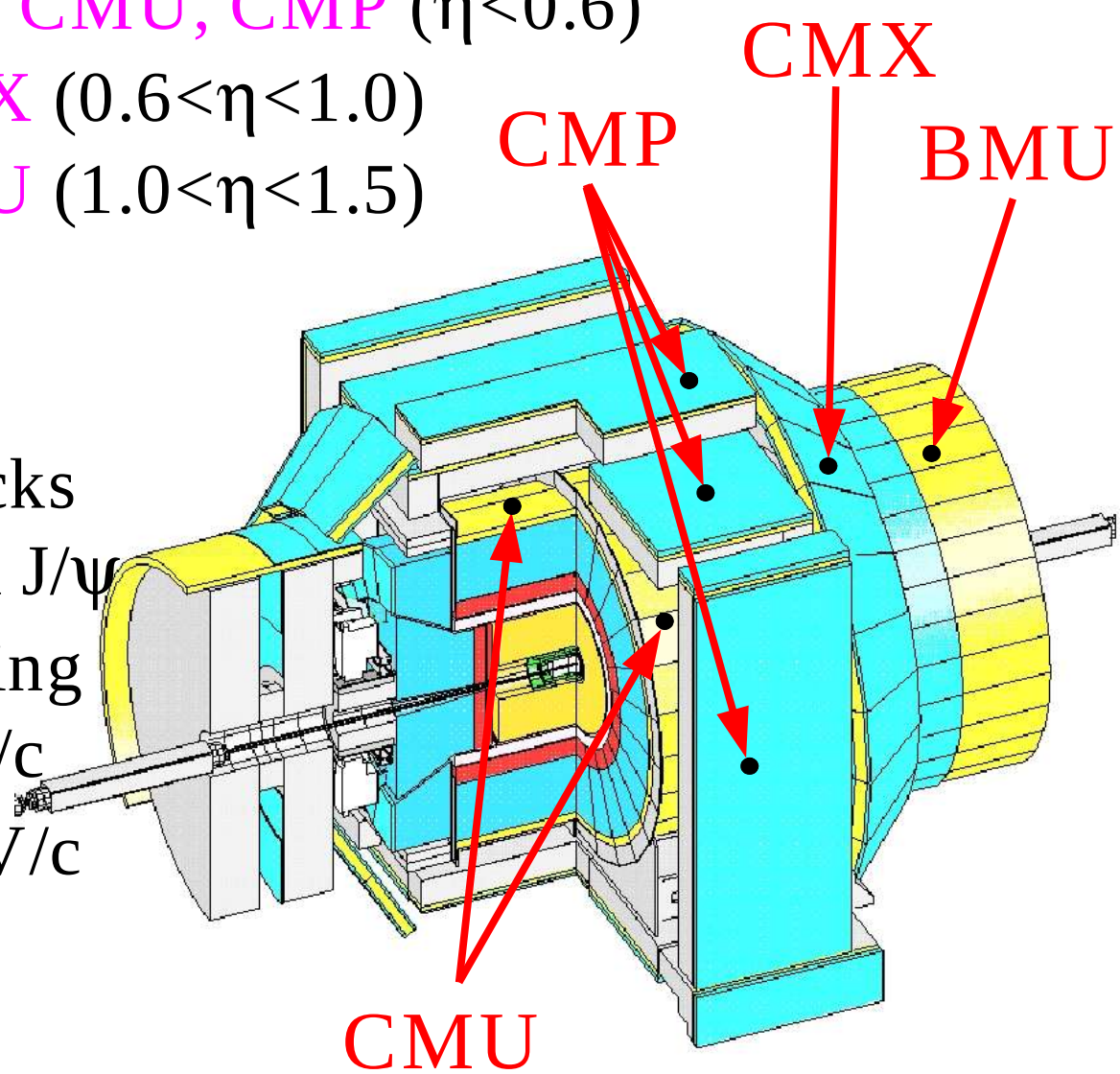
Soft Muons with CDF Detector

Several muon detectors, complex geometry:

- Central muon systems: CMU, CMP ($\eta<0.6$)
- Central extended: CMX ($0.6<\eta<1.0$)
- Forward systems: BMU ($1.0<\eta<1.5$)

Muon selection:

- isolated wrt trigger tracks
- $m_{tr.lep.-\mu}>5$ GeV/c: kill J/ψ
- good track-stub matching
- central μ: $P_T>1.5$ GeV/c
- forward μ: $P_T>2.5$ GeV/c



SMT with different muon systems

Tagger performance:

- averaged between e and μ trigger samples
- uncorrected dilution quoted

Muon Type	D_{raw}, %	ϵ, %	ϵD^2, %
CMUP	34.8±3.9	0.73±0.03	0.098±0.021
CMU only	13.2±3.5	1.23±0.04	0.050±0.017
CMP only	23.9±5.9	0.39±0.02	0.022±0.011
CMX	24.8±3.9	0.74±0.03	0.060±0.016
BMU	31.4±5.8	0.30±0.02	0.034±0.013

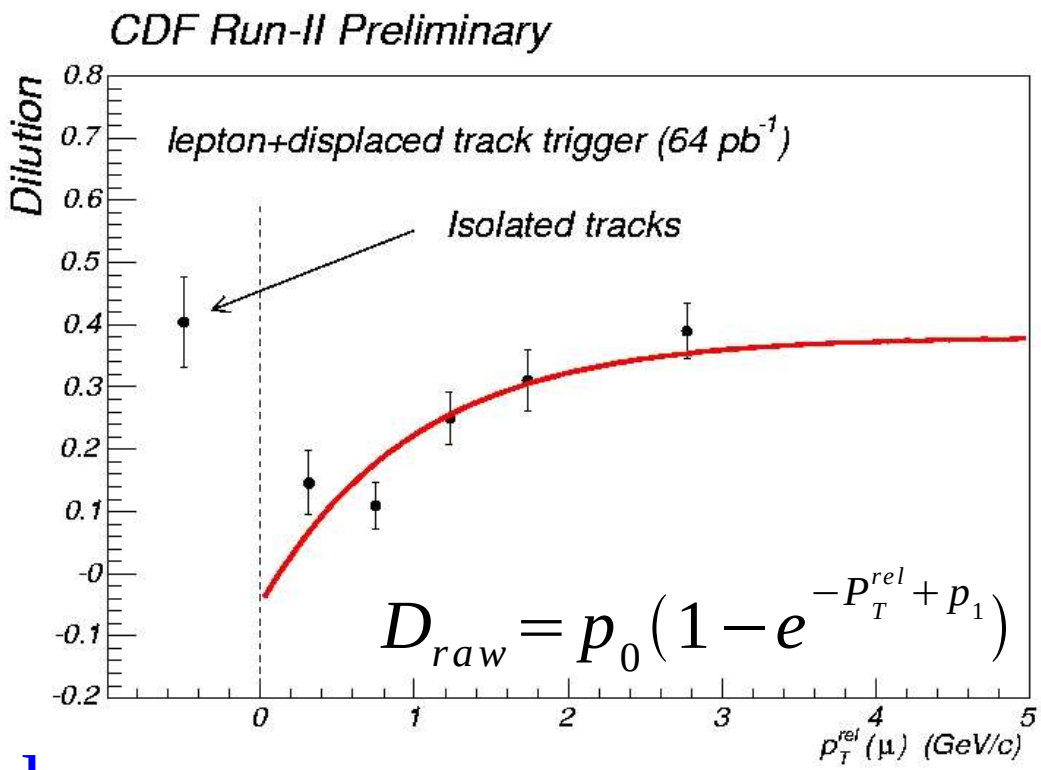
Muon quality:

- Muons with both CMU and CMP are best for tagging
- CMU, CMP, CMX only are worse
- BMU: lowest ε because of forward tracking inefficiency

Dilution dependence on muon P_T^{rel}

Tag quality variable: P_T^{rel}

- find track jet associated with the opposite side soft muon
- calculate transverse momentum relative to jet axis, P_T^{rel}



How it works:

- direct $b \to \mu$: larger P_T^{rel}
- sequential $b \to c \to \mu$ and fake μ: smaller P_T^{rel}

Soft Muon Tagger Performance

Use discriminating variables and split data sample:

- by muon detector: CMU, CMP+CMUP, CMX+BMU
- in 5 bins of P_T^{rel}

The tagging power εD^2 of SMT:

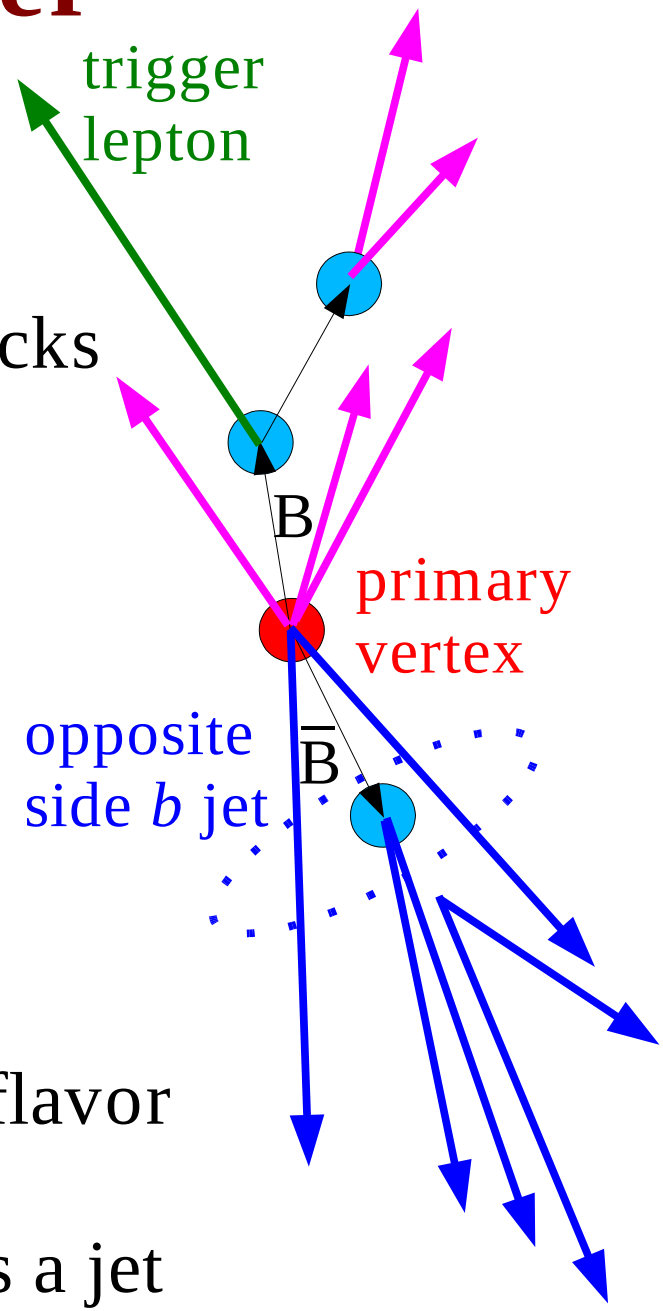
- combined: $\sum \varepsilon D^2$ for all subsamples
- dilution corrected for trigger side mixing and sequentials
- averaged between ***e*** and μ trigger data

$$\varepsilon D^2 = 0.660 \pm 0.193(\text{stat})\%$$

Jet Charge Tagger

The idea of JQT:

- find jet of the OS *b*
- calculate weighted average Q of jet tracks
- Q_{jet} sign gives JQT decision
- same charge trigger μ - Q_{jet}:
  - ➔ wrong sign events
- opposite charge trigger μ - Q_{jet}:
  - ➔ right sign events



JQT qualities:

✗ moderate purity
  - ➔ Qjet is not 100% correlated with *b* flavor

✔ high efficiency:
  - ➔ b in acceptance almost always gives a jet

✗ non-b jets in the event: complicates jet finding

Details of implementation

Find track jets:

- geometrical cone clustering
- seed off high-P_T tracks

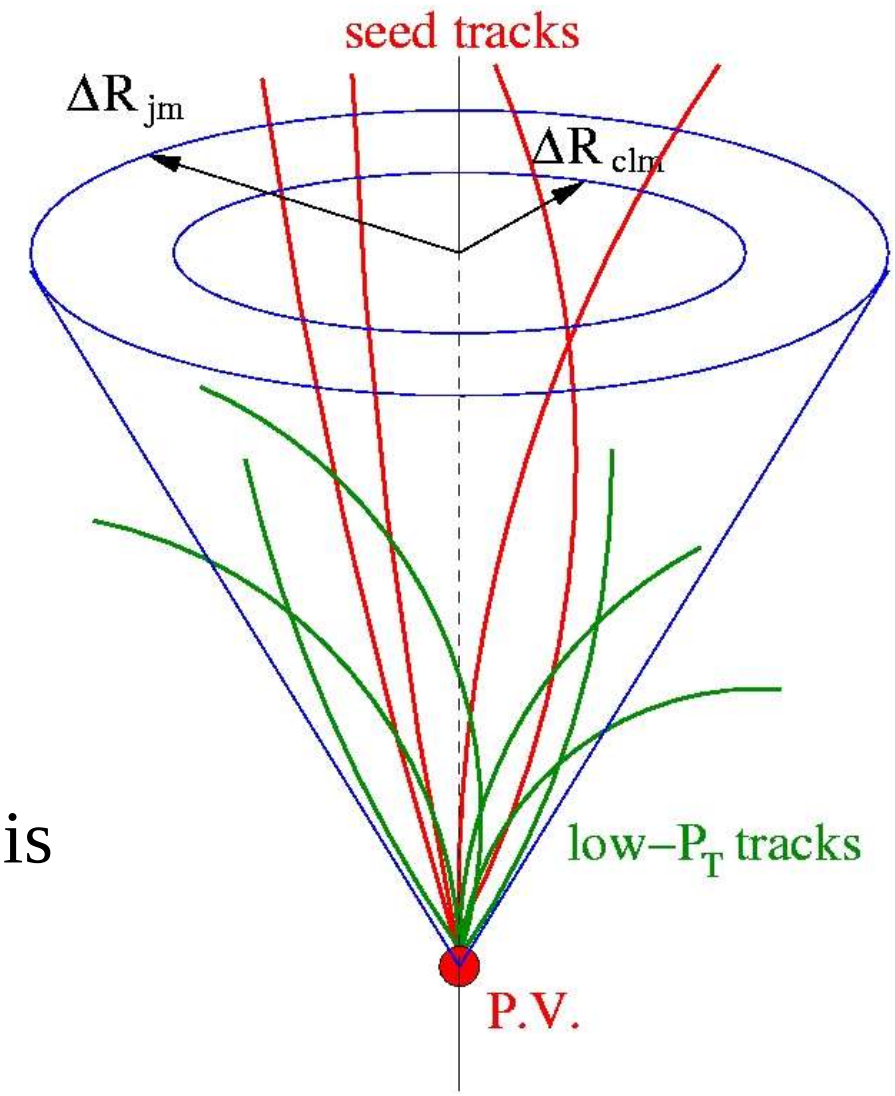
Select the best jet:

- jet with secondary vertex
  - ➔ very likely to be a *b* jet
- otherwise, take highest-P_T jet

Calculate jet charge Q_{jet}:

- weight is $\vec{P}$ projection on jet axis

$$Q_{jet} = \frac{\sum_{tracks} q_i (\vec{P}_i \cdot \vec{P}_{jet})}{\sum_{tracks} (\vec{P}_i \cdot \vec{P}_{jet})}$$



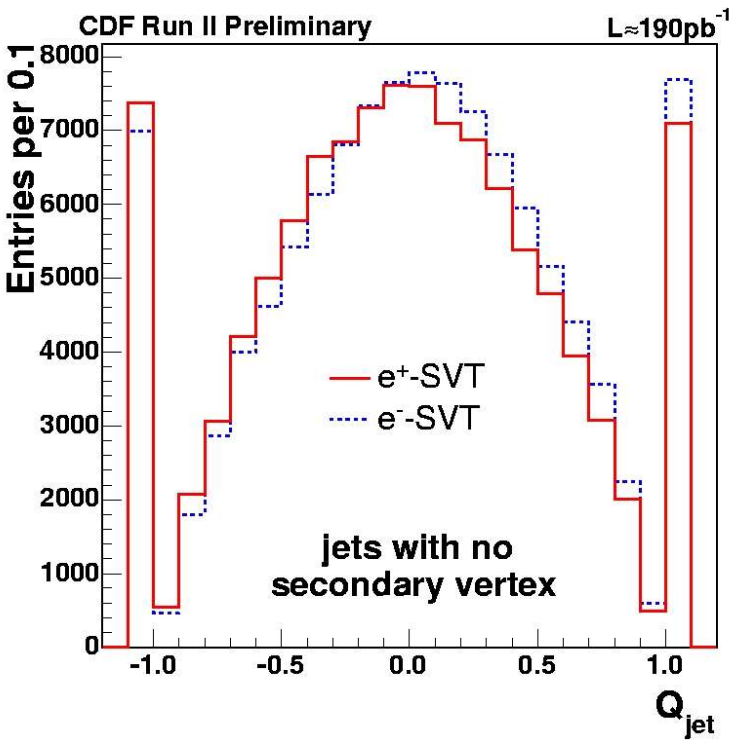
JQT algorithm parameters

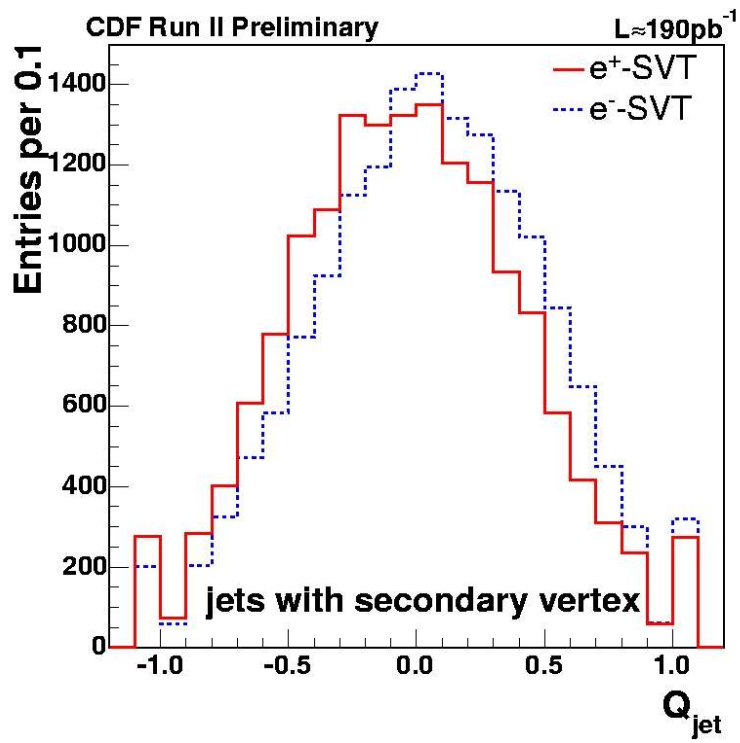
Choice of algorithm parameters:

- optimize algorithm parameters on μ trigger data
- measure JQT performance on independent ***e*** trigger data

Jet charge:

- shift in Q_{jet} for trigger l^+ vs l^- demonstrates tagging quality
- jets with secondary vertex have higher ± separation

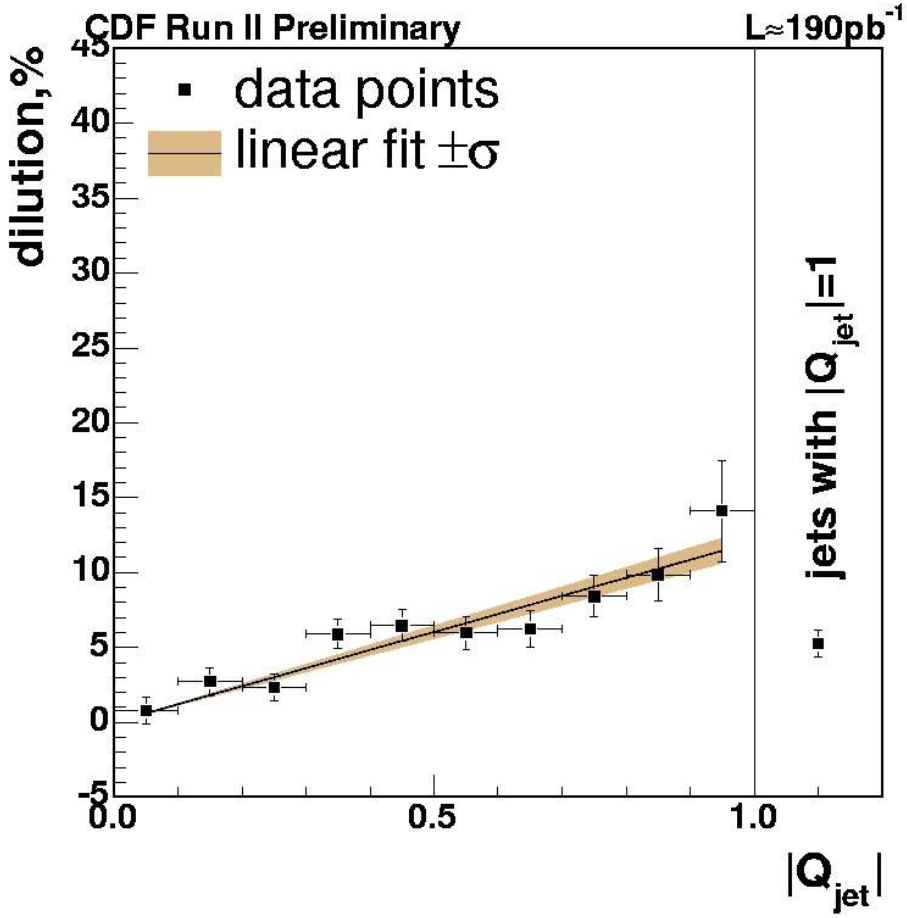


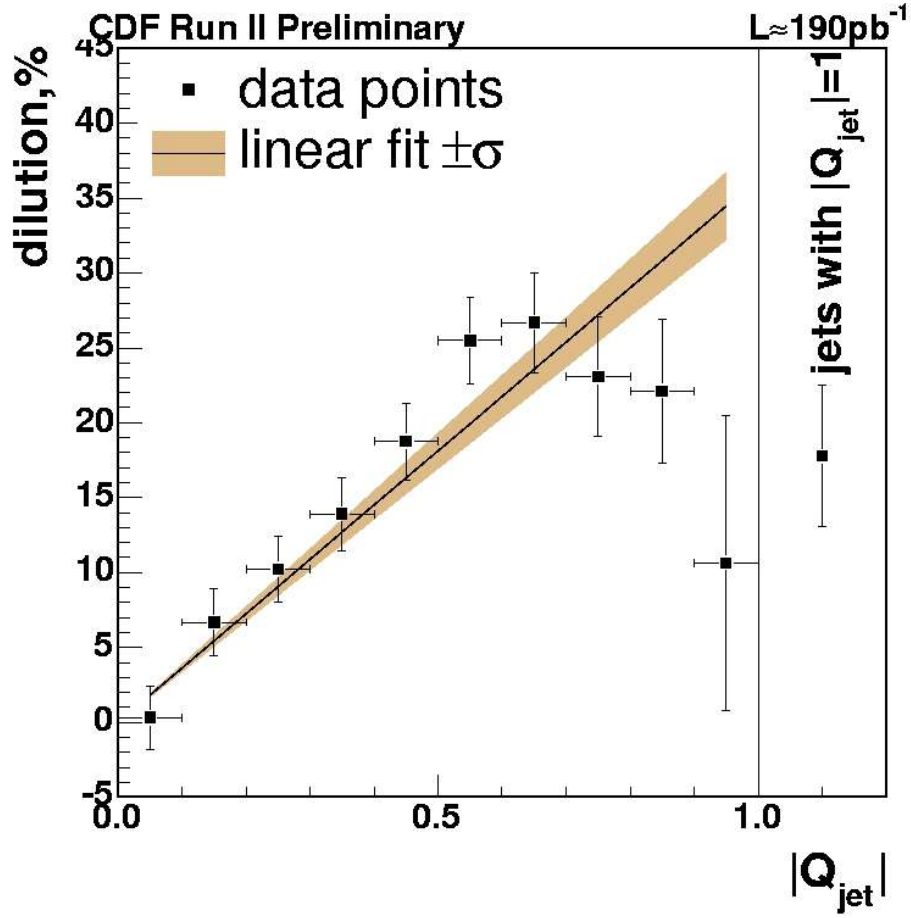


Dilution dependence on Q_{jet}

Tag quality variable: Q_{jet}

- higher Q_{jet} ⇒ higher dilution
- dependence is roughly linear





Jet Charge Tagger Performance

Use discriminating variables and split data sample:

- by jet type: jets with and without secondary vertex
- in 11 bins of $|Q_{jet}|$

The tagging power εD^2 of JQT:

- combined: $\sum \varepsilon D^2$ for all subsamples
- dilution corrected for trigger side mixing and sequentials
- measured on unbiased ***e*** trigger data

$$\varepsilon D^2 = 0.415 \pm 0.017(\text{stat})\%$$

Summary

On a large sample of semileptonic b decays:

- Soft Muon Tagger performance is measured at

$$\varepsilon D^2 = 0.660 \pm 0.193(\text{stat})\%$$

- Jet Charge Tagger performance is measured at

$$\varepsilon D^2 = 0.415 \pm 0.017(\text{stat})\%$$

JQT/SMT upgrades and studies of Soft Electron and Kaon taggers are under way at CDF