Systematic studies for high precision heavy quark analyses

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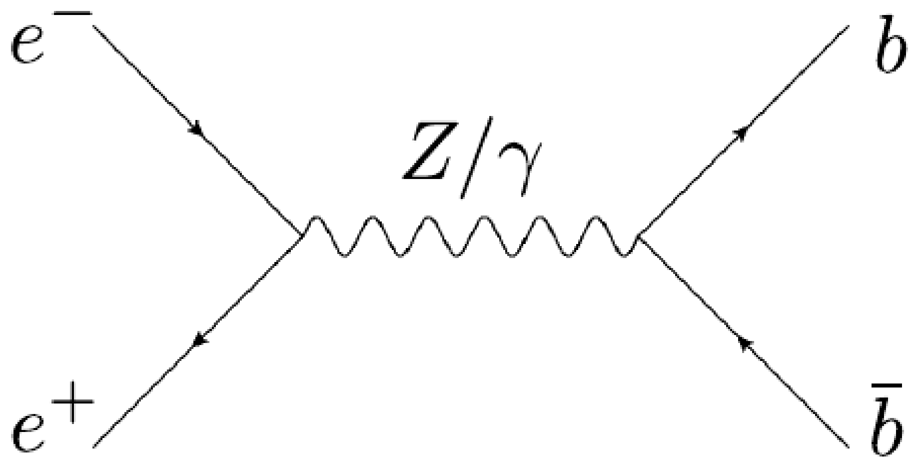
Introduction

$$R_b^0 = \Gamma_{b\bar{b}}/\Gamma_{had}$$

b-quark identification. No need to measure an angular distribution, a priori.



$$\frac{d\sigma}{d\cos\theta}$$

The angular distribution relies on the jet charge measurement

$$A_{FB} = \frac{N_F - N_B}{N_F + N_B}$$

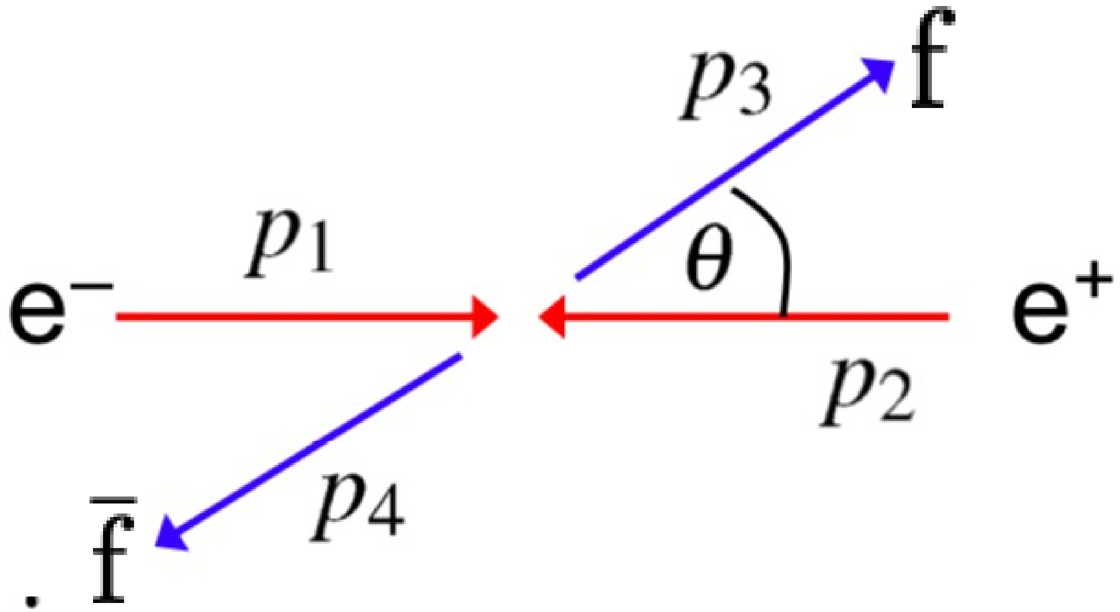
The b-quark polar angle is defined as a polar angle of the vector

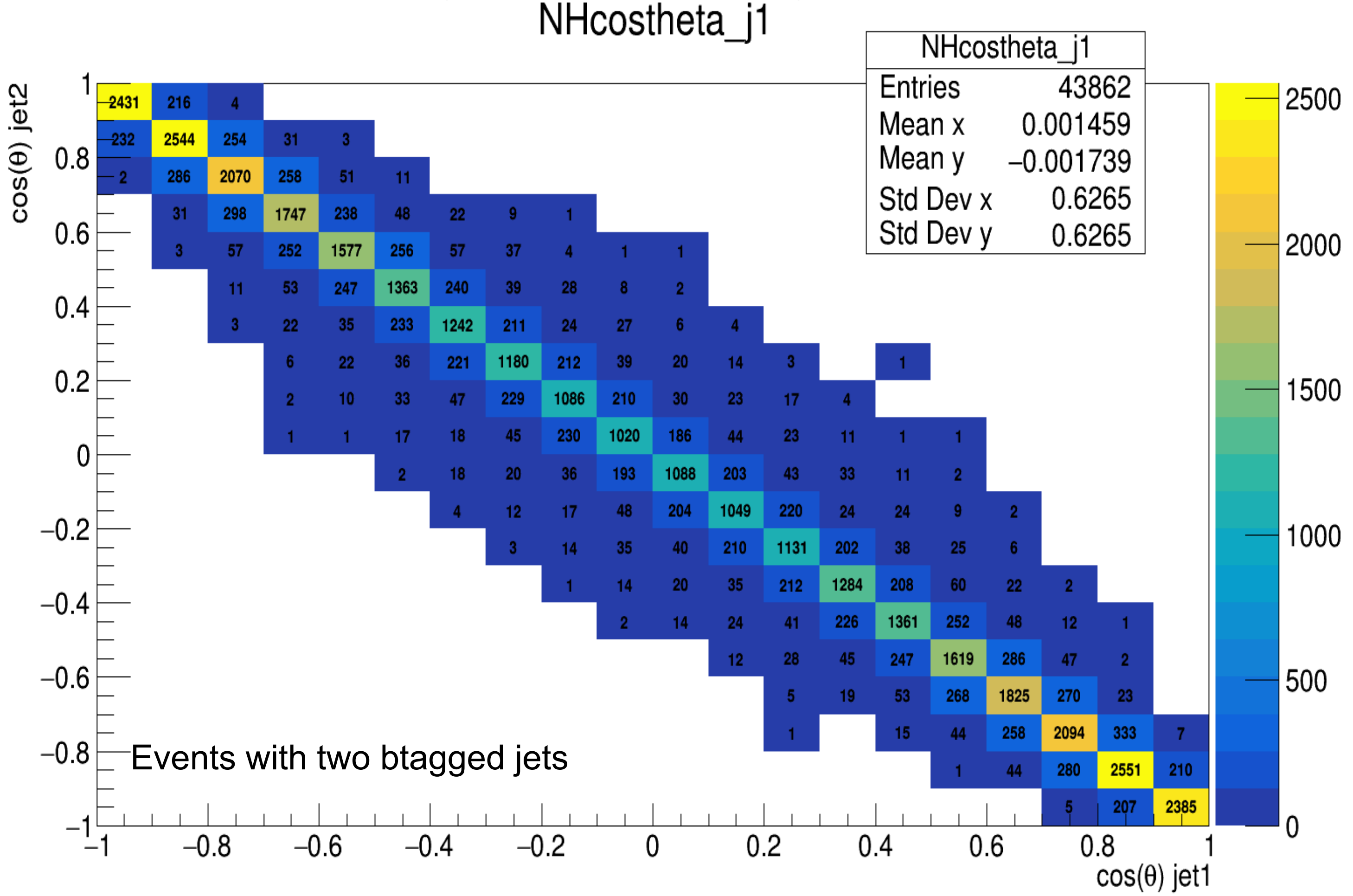
$$\vec{p}_{b\bar{b}} = \vec{p}_b - \vec{p}_{\bar{b}},$$

N.B.: Will focus on b-quarks but same arguments hold of course for c-quarks and other quarks

Back to Back configuration

$$\cos\left(\theta_{\vec{p}_{\vec{b}\vec{\bar{b}}}}\right)=\cos\left(\theta_{b\bar{b}}\right)\approx\frac{\cos\left(\theta_{b}\right)-\cos\left(\theta_{\bar{b}}\right)}{2}\approx\cos\left(\theta_{b}\right)\approx-\cos\left(\theta_{\bar{b}}\right)$$

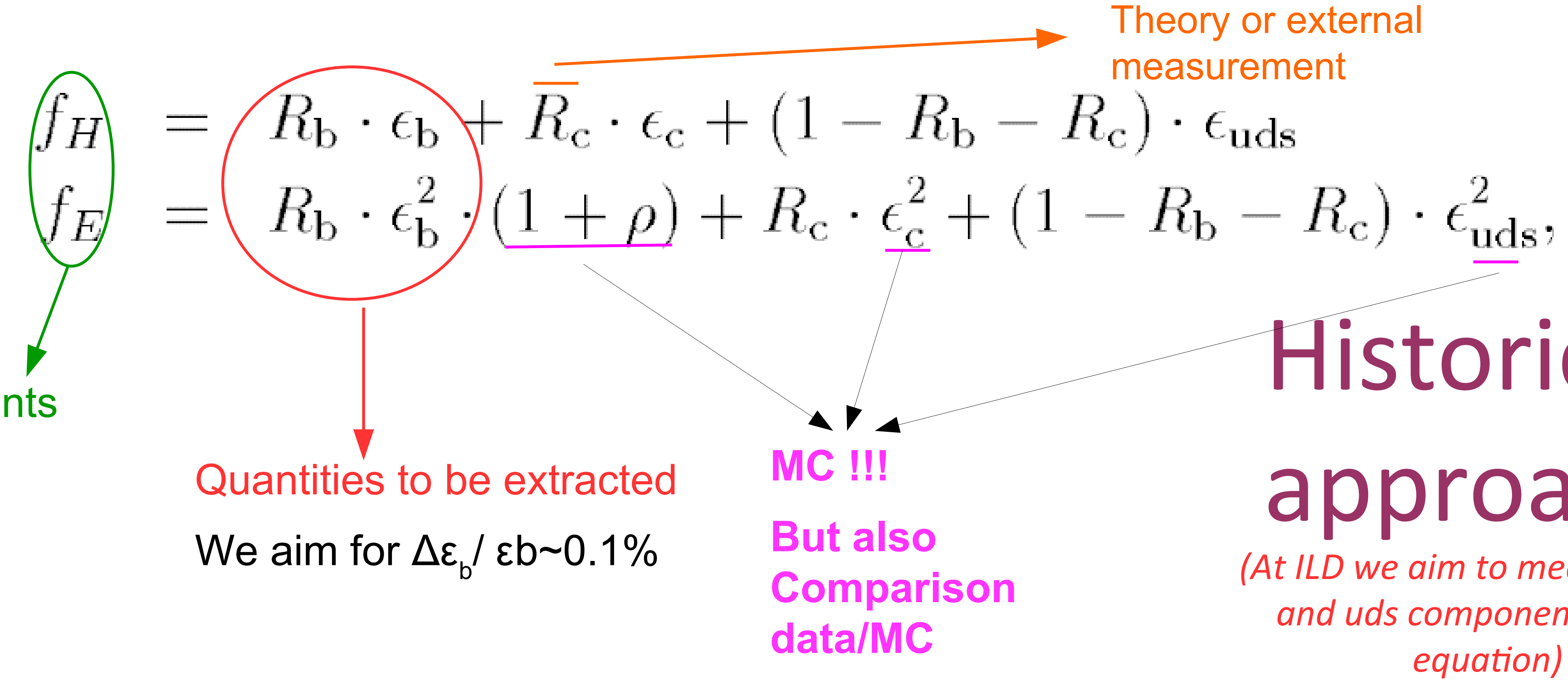




- Jets in different hemispheres of (a priori) symmetric detector
- Jets maximally separated from each other
- Starting point for all correlation studies at LEP/SLC
  - => Safe ground to resume corresponding studies for Linear Collider

Measuring the b-tagging efficiency

- To start with we reproduce LEP/SLD (i.e. Eur.Phys.J. C10 (1999) 415-442)
- We compare single vs double tagged topologies.
  - fH = fraction of events in which we had at least one hemisphere b-tagged
  - fE = fraction of events in which we both hemispheres b-tagged



Theory or external measurement

$$
\begin{aligned}
f_H &= R_b \cdot \epsilon_b + \overline{R_c} \cdot \epsilon_c + (1 - R_b - R_c) \cdot \epsilon_{uds} \\
f_E &= R_b \cdot \epsilon_b^2 \cdot \underline{(1+\rho)} + R_c \cdot \underline{\epsilon_c^2} + (1 - R_b - R_c) \cdot \underline{\epsilon_{uds}^2},
\end{aligned}
$$

measurements

Quantities to be extracted

We aim for $\Delta\epsilon_b / \epsilon_b \sim 0.1\%$

MC !!!

But also Comparison data/MC

Historical approach

(At ILD we aim to measure the c and uds components of the equation)

Jet correlations

Correlation function used by SLC: arxiv:0503005

$$C = \sum_i \epsilon(\cos\theta_i)\cdot\epsilon(-\cos\theta_i)\, f(\cos\theta_i)/\bar{\epsilon}^2$$

Correlation function used by DELPHI
Eur.Phys.J. C10 (1999) 415-442

$$\rho_\theta = \frac{2\int_0^{z_{max}} dz\, f(z)\epsilon_b(z)\cdot\epsilon_b(-z)}{\left(\int_{-z_{max}}^{z_{max}} dz\, f(z)\epsilon_b(z)\right)^2} - 1 \quad , \; z = \cos\theta .$$

- It is easy to see that both functions are completely equivalent
- Correlation functions measure inhomogeneities in the detector
- Procedure exploits that the value of the test variable is correlated between detector hemispheres
  - i.e. One jet at cosθ means the other at -cosθ

Jet correlations – Quick Review LEP/SLC

	LEP	SLD
	Eur.Phys.J. C10 (1999) 415-442	Phys.Rev. D71 (2005) 112004
ε_b	*29.5 ± 0.18 % (data)* *28.2 % (MC)*	*62.01 ± 0.24 % (data)* *61.78 ± 0.03 % (MC)*
ρ	*3.4 ± 0.5 % (MC, analysis1)* *2.0 ± 0.3 % (MC, analysis2)*	*0.6± 0.4 % (MC, analysis1)* *-0.02± 0.3 % (MC, analysis2)*
ε_c	*0.38 ± 0.03 % (MC)*	*1.19 ± 0.01 % (MC)*
ε_{uds}	*0.052 ± 0.008 % (MC)*	*0.134 ± 0.003 % (MC)*

$|\varepsilon_b(\text{data}) - \varepsilon_b(\text{MC})|/\varepsilon_b \approx 1\%$!! while our goal is

- **$\Delta\varepsilon_b / \varepsilon_b \sim 0.1\%$**

- **ρ plays a main role in the determination of Rb i.e. to correct ε_b for detector inhomogeneities**
- **Main sources of correlations**
  - **Angular correlations: beam spot shape (primary vertex determination!)**, loss of acceptance of the detector, detector inhomogeneities…
  - **QCD effects: gluon emission** that modifies the energy of both quarks.

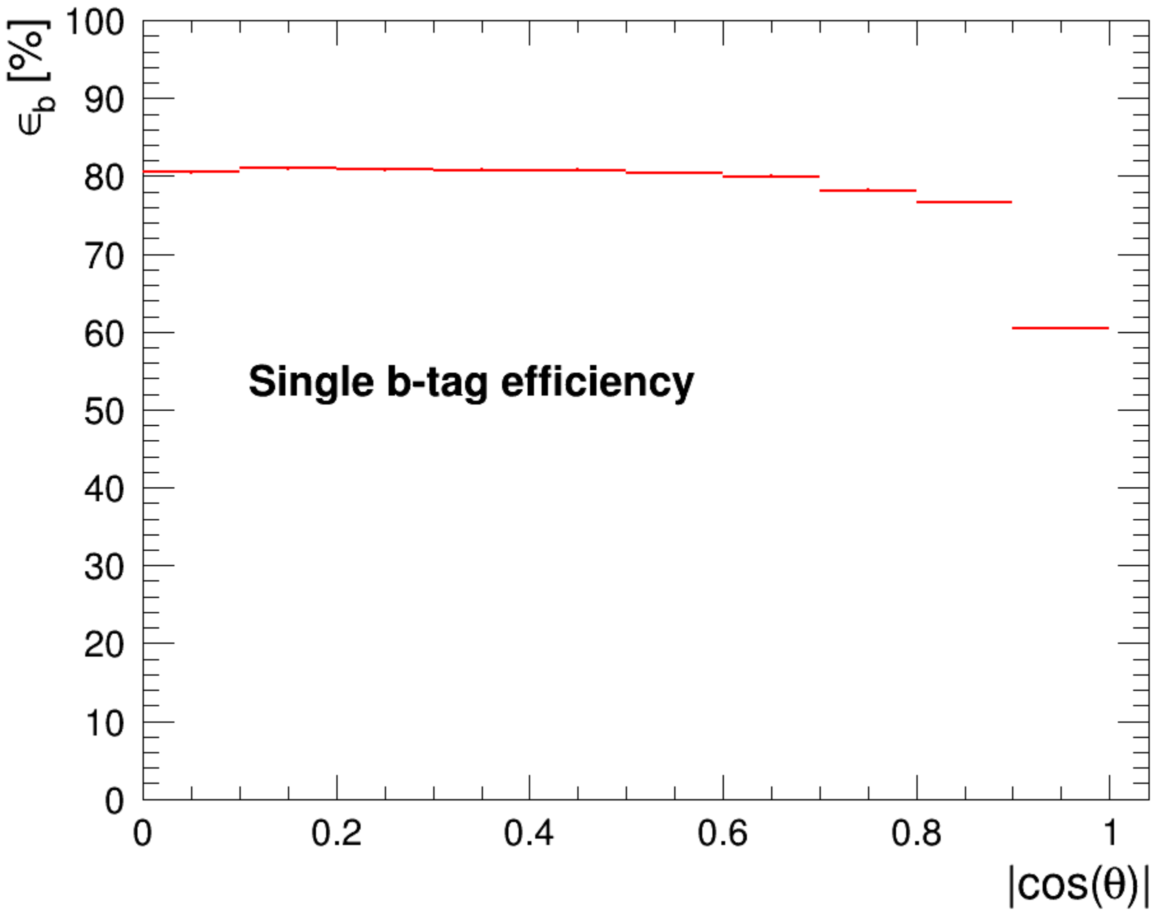
LEP (large beam spot): **ρ** ≈ 2% → $\Delta R_b \approx 0.2\%$

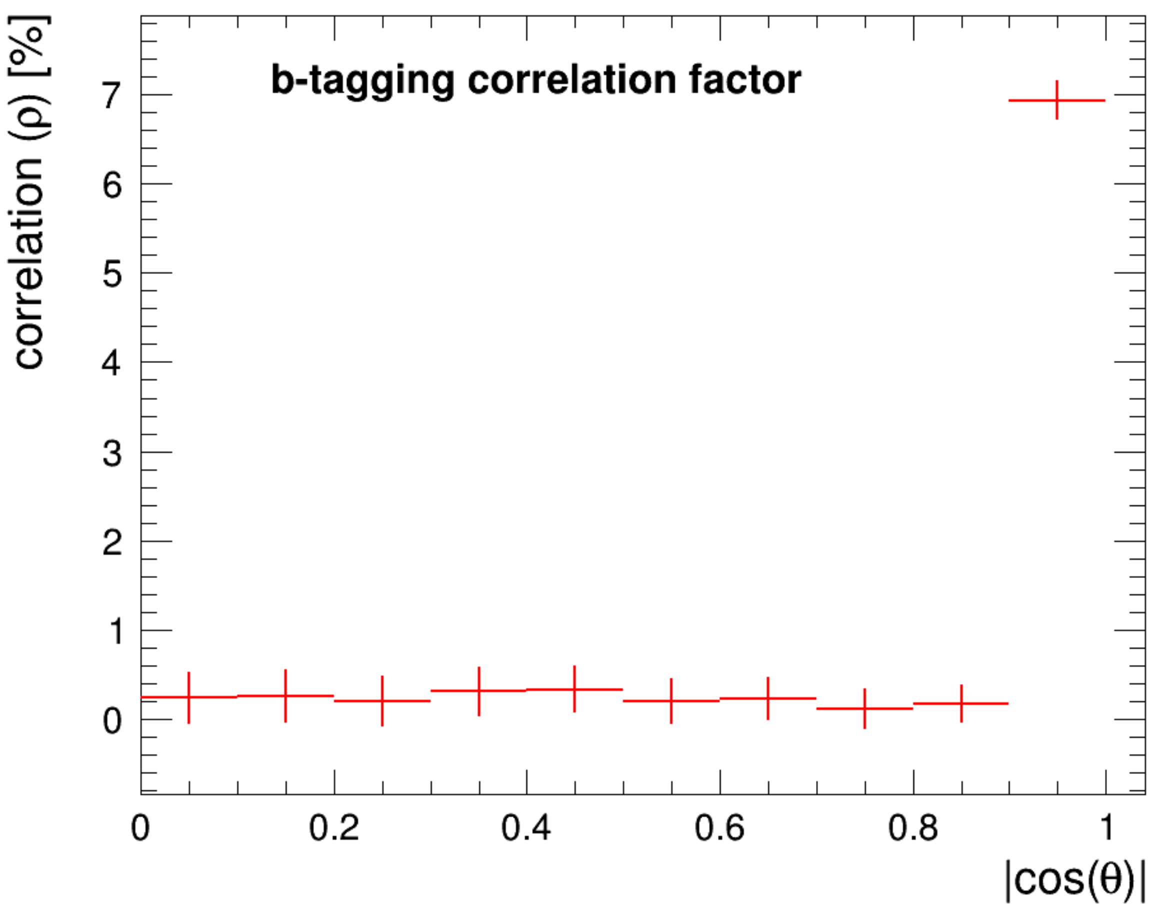
SLC (smaller beam spot): **ρ** < 1% → $\Delta R_b \approx 0.07\%$

- ILD (tiny beam spot): ρ **~0 ?**

b-tagging efficiency and correlation

- As a function of *cosθ*, removing the c and uds components

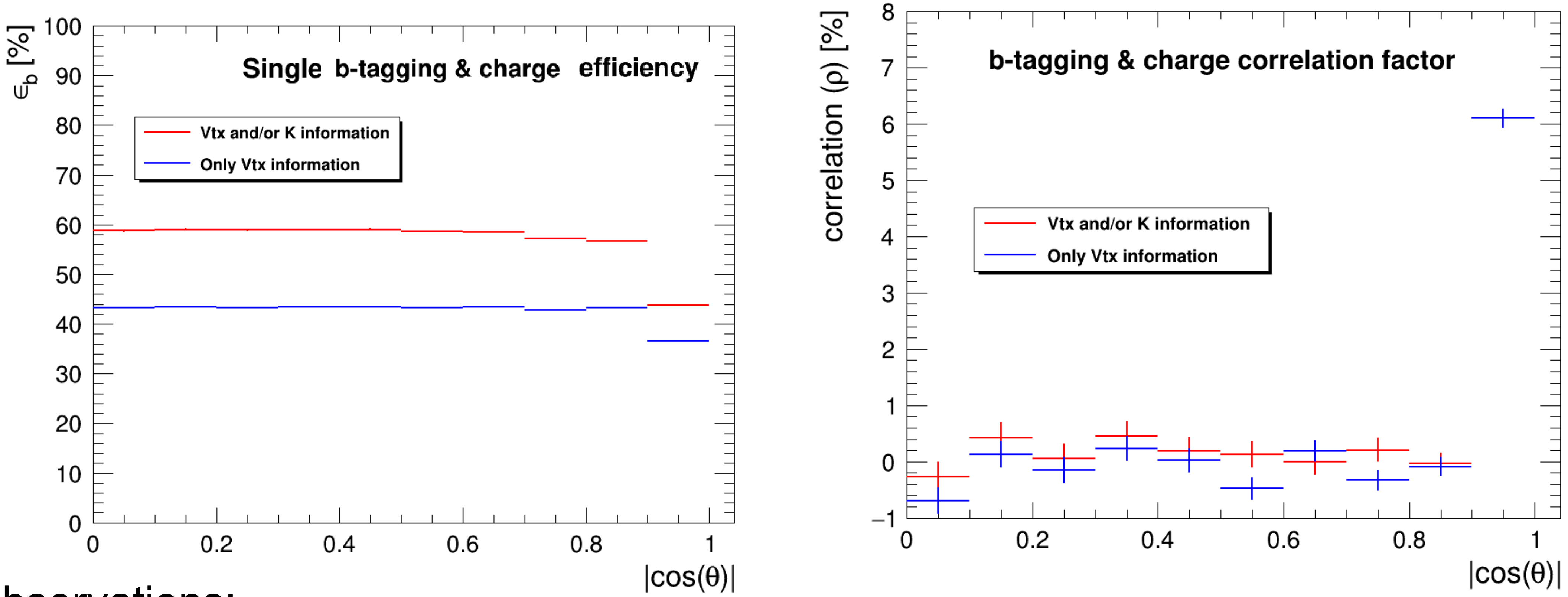




- There is no angular dependence of the correlation factor below *cosθ=0.9*

Applying the same procedure to charge tagging

- LEP & SLD were not able to fully exploit the double tagging potential:
  - Due to the smaller efficiency (w.r.t. ILC) and lack of statistics.
- ILC will also be able to exploit the **double charge measurements** to measure angular spectra.
- Extension of introduced procedure but now also the charge measurement (i.e. using the Vertex charge measurement).



- Observations:
  - About stable efficiency in central region (=full detector acceptance)
  - Small dependence on angle of correlation.

Current results

	LEP	**SLD**	**ILC (only b-tag)**	**ILC (btag & charge)**
	Eur.Phys.J. C10 (1999) 415-442	Phys.Rev. D71 (2005) 112004	*MC (250fb-1 left + 250 fb-1 right)*	*MC (250fb-1 left + 250 fb-1 right)*
ε_b	*29.5 ± 0.18 % (data)* *28.2 % (MC)*	*62.01 ± 0.24 % (data)* *61.78 ± 0.03 % (MC)*	*77.94 ± 0.13 % (« data »)*	*58.55 ± 0.12 % (« data »)*
ρ	*3.4 ± 0.5 % (MC, analysis1)* *2.0 ± 0.3 % (MC, analysis2)*	*0.6± 0.4 % (MC, analysis1)* *-0.02± 0.3 % (MC, analysis2)*	*0.2 ± 0.1 % (MC)*	*0.12 ± 0.1 % (MC)*
ε_c	*0.38 ± 0.03 % (MC)*	*1.19 ± 0.01 % (MC)*	*2.158 ± 0.007 % (MC)*	*1.584 ± 0.007 % (MC)*
ε_{uds}	*0.052 ± 0.008 % (MC)*	*0.134 ± 0.003 % (MC)*	*0.216 ± 0.002 % (MC)*	*0.146 ± 0.001 % (MC)*

Integrating for all angles smaller than cos(theta)=0.8

- **ρ is very small !!**
- Negligible angular dependence of the correlation factor.
- First look at QCD effects seem to be well under control due to the cuts applied against radiation

With 2000fb^{-1}, we can achieve the $\Delta\varepsilon_b/\ \varepsilon_b$~0.1% !!

The uncertainties associated to ρ will have minimal impact in the final observable

Towards the (overall) per-mille level?

$$\begin{aligned} f_H &= R_\mathrm{b}\cdot\epsilon_\mathrm{b} + \overline{R}_\mathrm{c}\cdot\epsilon_\mathrm{c} + (1-R_\mathrm{b}-R_\mathrm{c})\cdot\epsilon_\mathrm{uds} \\ f_E &= R_\mathrm{b}\cdot\epsilon_\mathrm{b}^2\cdot\underline{(1+\rho)} + R_\mathrm{c}\cdot\underline{\epsilon_\mathrm{c}^2} + (1-R_\mathrm{b}-R_\mathrm{c})\cdot\epsilon^2_{\underline{\mathrm{uds}}}, \end{aligned}$$

With standard b-tagging cuts, we get:

ε_b=58.55+-0.06 % (MC)

ρ=0.15+-0.1 % (MC stats, similar than in SLD/LEP in which were dominant)

mistagging c's:

ε_c=1.584+-0.007 % (MC stat, but **$\Delta\varepsilon_c/\ \varepsilon_c$** syst ~1-10% if measured with MC)

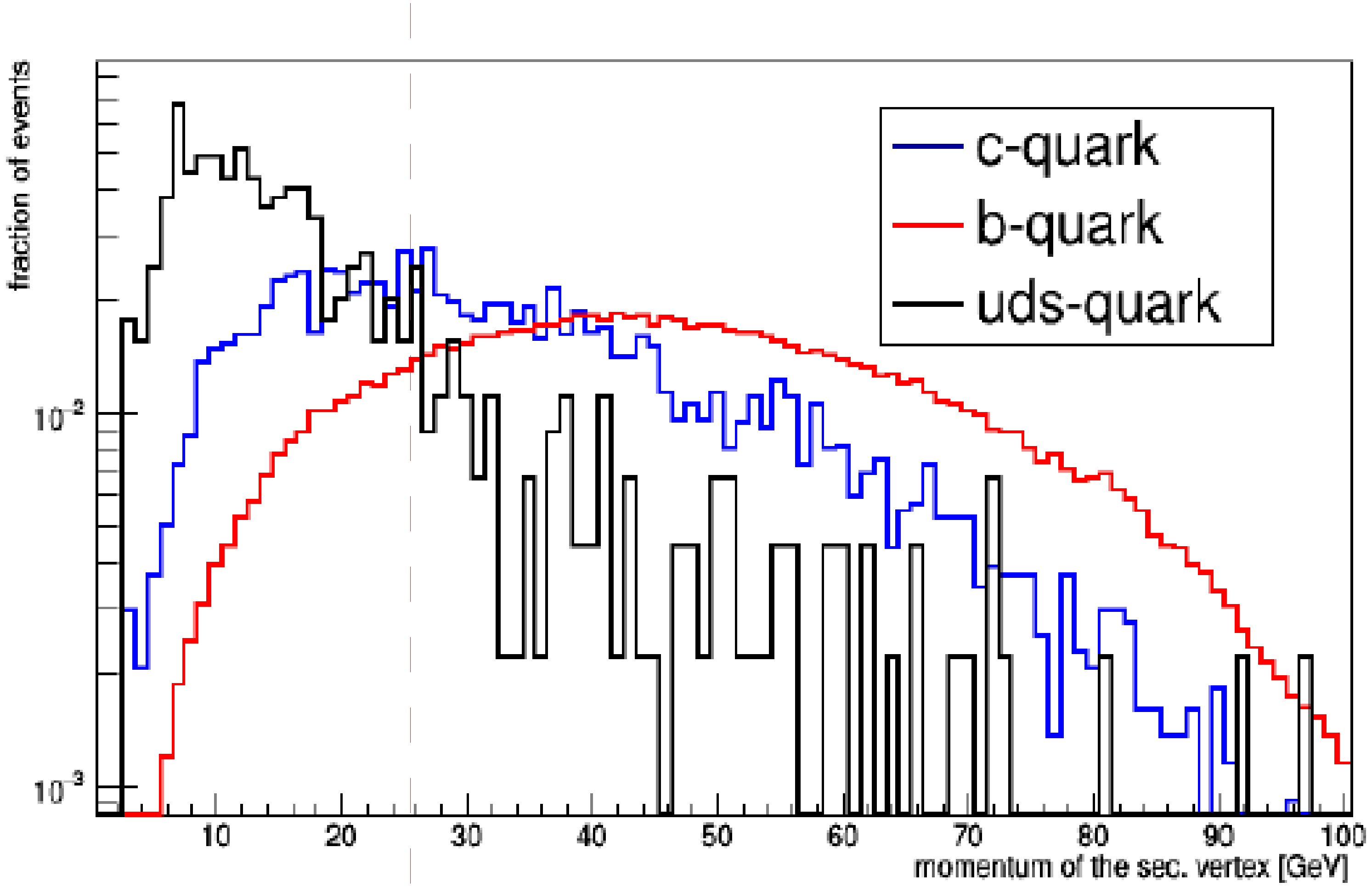
See talk by A. Irles on ee->cc (shows at least that we start to control cc production)

mistagging uds's:

ε_{uds} =0.153+-0.002 % (MC stat but the error associated to **(g→bb) is $\Delta\varepsilon_c/\ \varepsilon_c$ ~ 10%**)

Excellent b-uds separation required

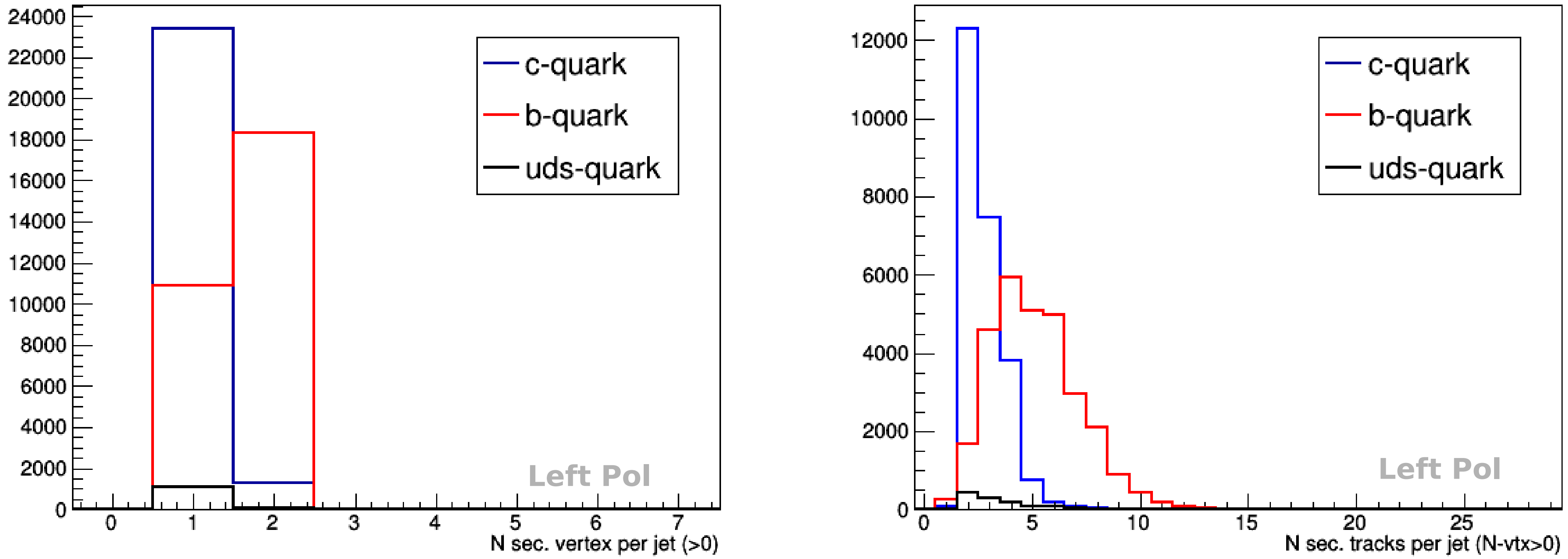
b/c-uds separation I



- Vertex momentum seems to be efficient cut against uds w/o sacrifying too much signal

b/c-uds separation II

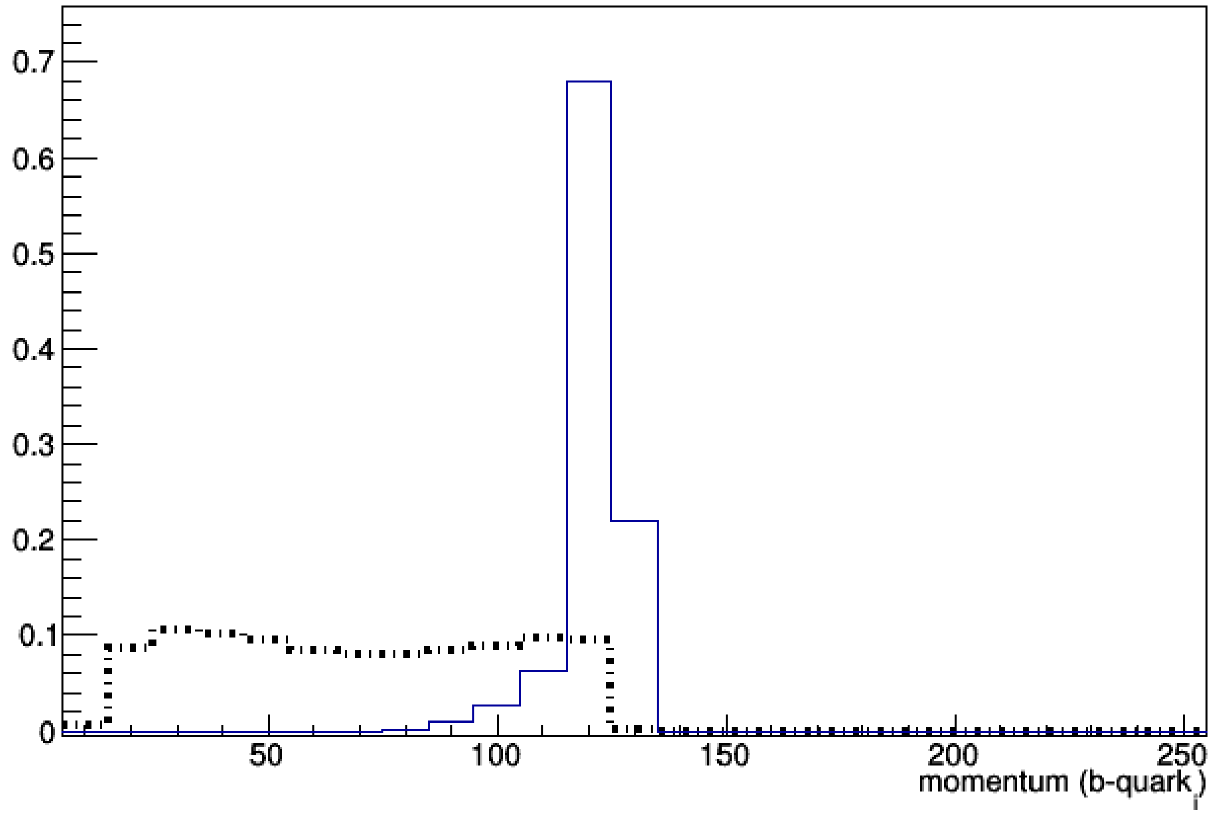
- Vertex tracks?

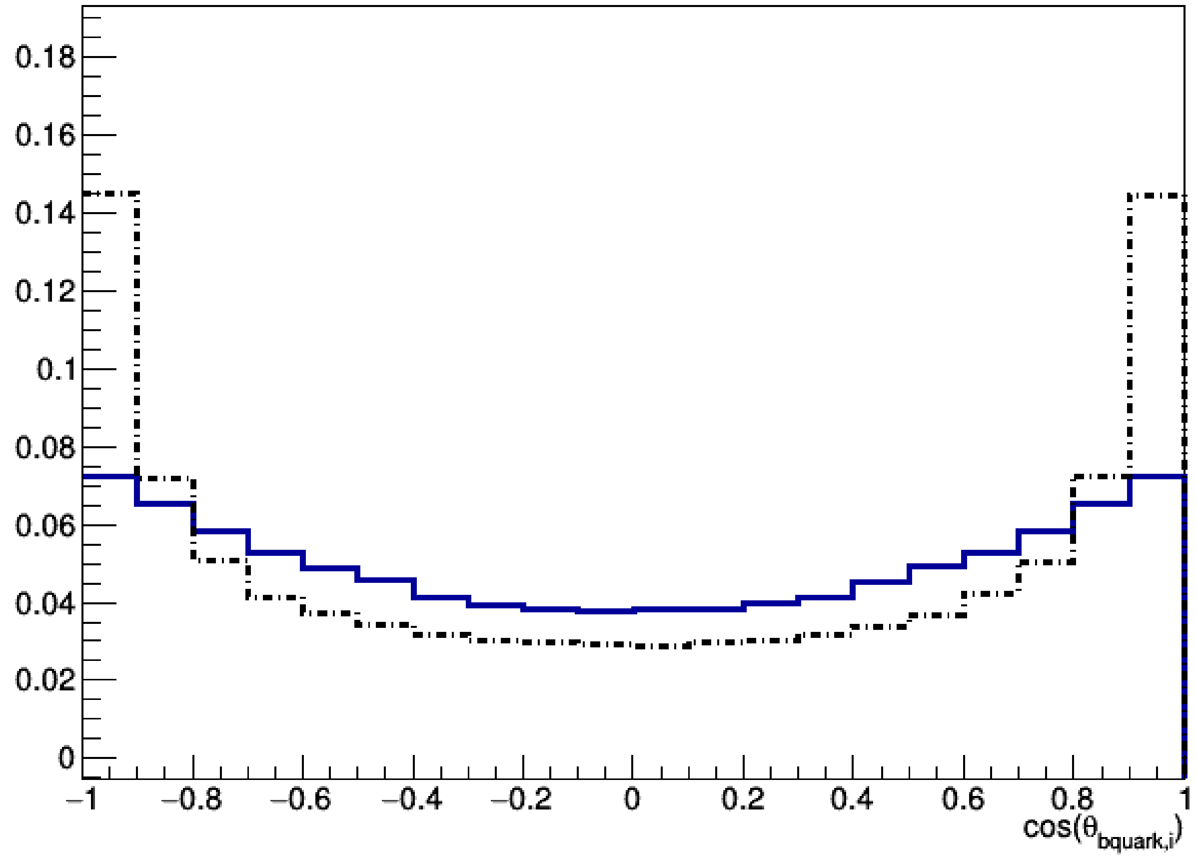


- **Requiring at least 1 secondary vertex mostly suppresses all uds background.**
- Requiring less than 2 secondary vertexes will kill 60% of the b-quark background.

A quick look a radiative return events

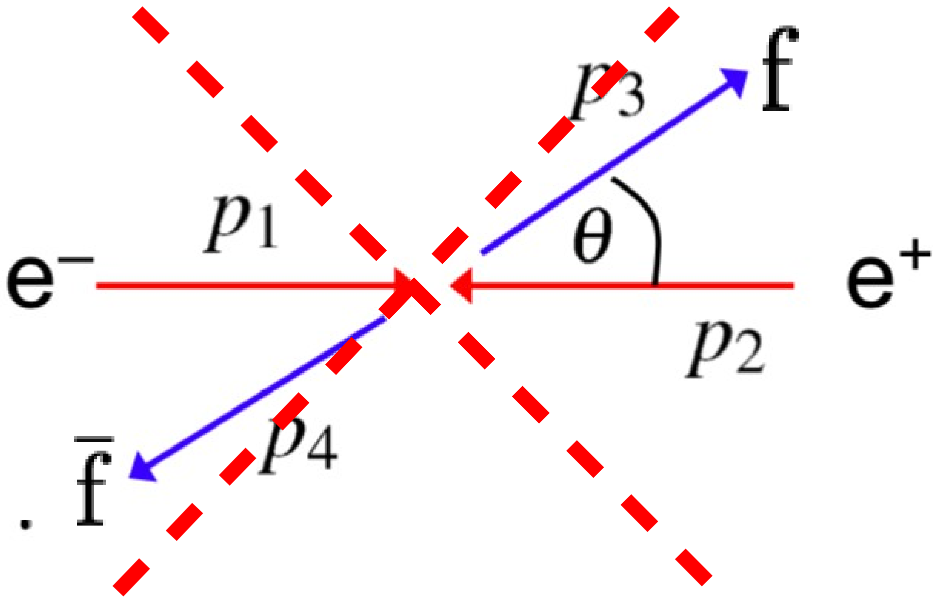
- **Black = radiative**
- **Blue = non radiative**

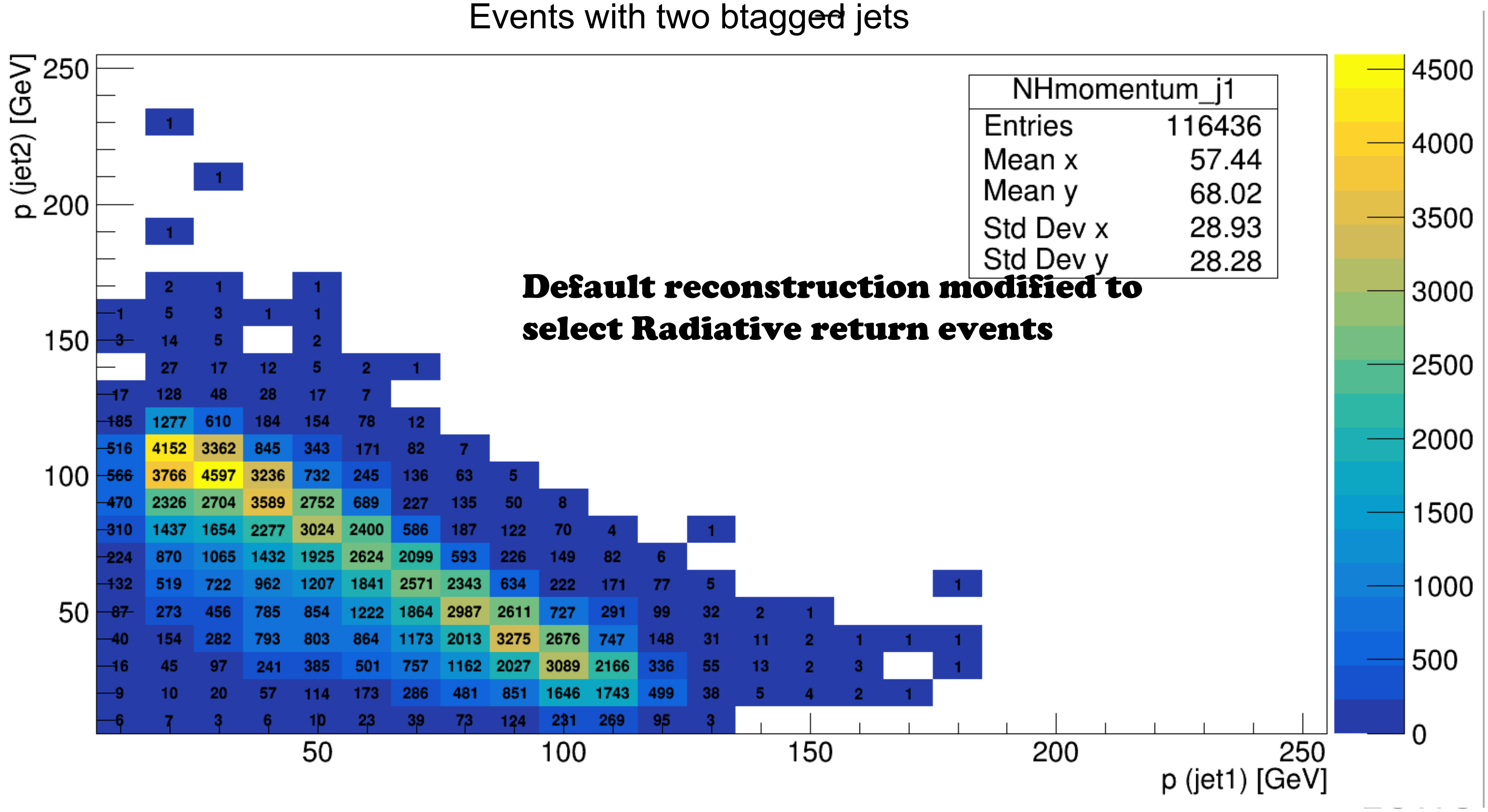




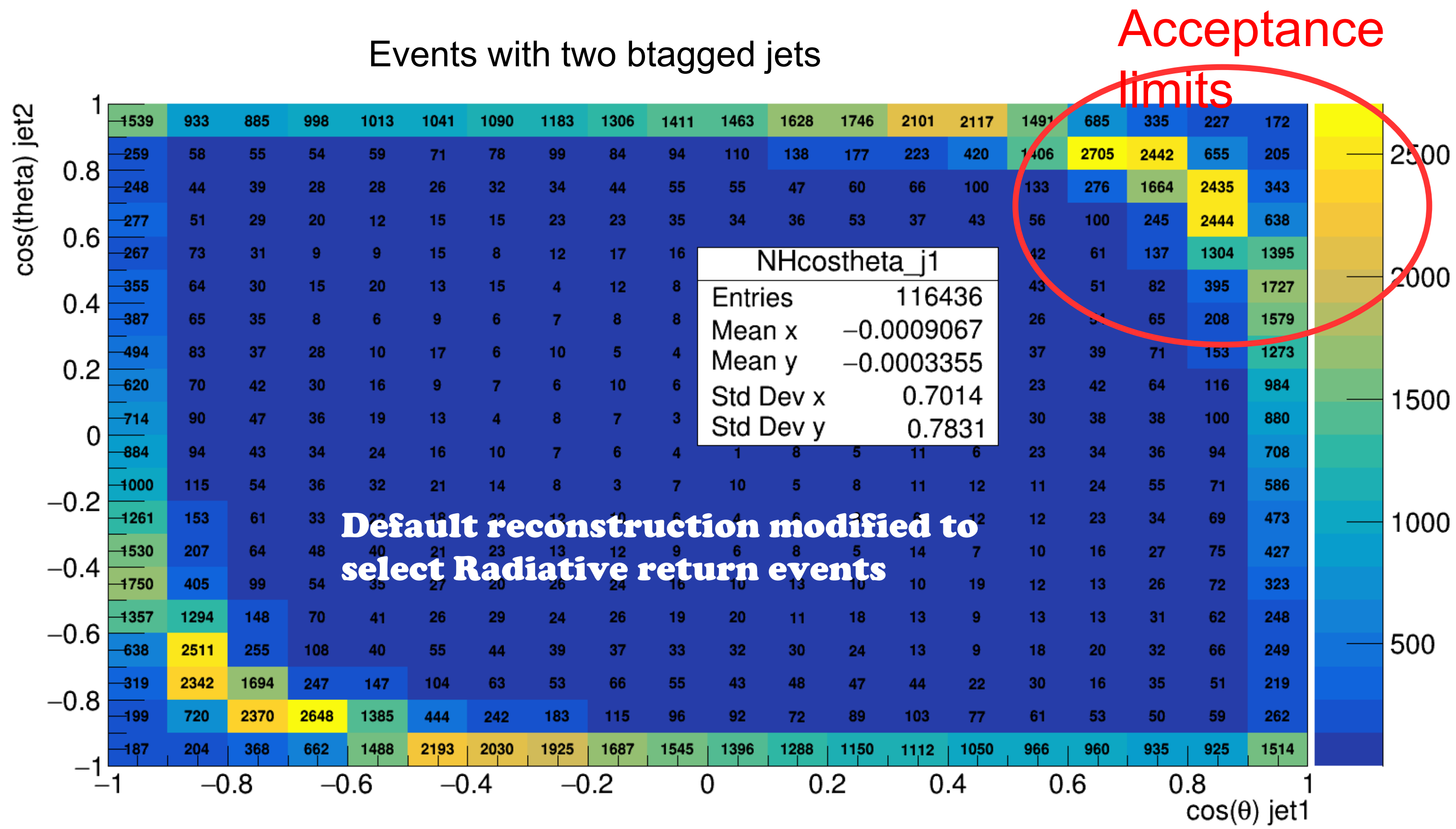
- Sizeable differences in event topology
- Events are more pushed towards detector limits of acceptance
- No monochromatic b energy peak

A quick look a radiative return events





Default reconstruction modified to select Radiative return events



Acceptance limits

Default reconstruction modified to select Radiative return events

- Present topologies:
  - Back to back jets, for |cosθ|>0.9
  - Two forward jets “together” for |cosθ|>0.7
  - One jet very forward and the other in the barrel.
- LEP/SLC Strategy cannot be applied for determination of efficiencies

Summary and outlook

- First steps towards systematic study of error sources for high precision heavy quark measurements

- Starting with reanimation of LEP/SLC Methods
  - Jet correlation one main source of uncertainties at LEP/SLC
  - Introduction of jet correlation parameter ρ
  - Methods rely on back-to-back topologies
  - ILD should think to use ρ as figure ot merit for detector optimisation

- Need to control flavor tagging/separation to the ulmost precision
  - Strategies proposed

- This is just the beginning on the quest to control systematics of the 1‰

Backup