Systematic uncertainties on R_b and R_c measurements at an e^+e^- collider

Zhijun Liang
(IHEP, Chinese Academy of Sciences)

中国科学院高能物理研究所
Institute of High Energy Physics
Chinese Academy of Sciences

Branching ratio (R^b): motivation

$$\frac{\Gamma(Z \to b\bar{b})}{\Gamma(Z \to had)}$$

- At LEP measurement 0.21594 ±0.00066
- Fcc-ee and CEPC aim to improve the precision by a factor 10~20 (0.02%)
- R^b measurement is sensitive to New physics models (SUSY)
  - SUSY predicts corrections to Z→ bb vertex
  - Through gluino and chargino loop …

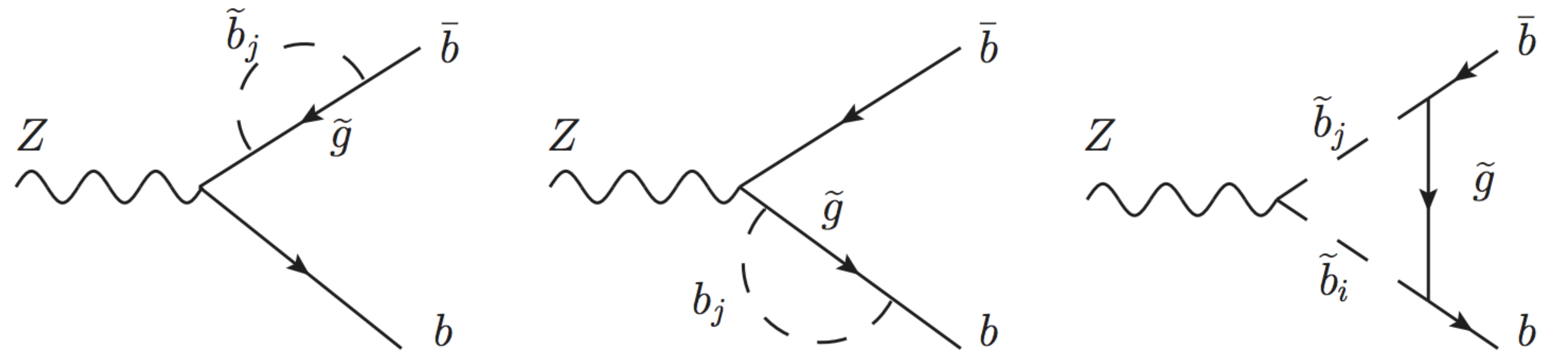


FIG. 1: One-loop Feynman diagrams of gluino correction to $Z \to \bar{b}b$

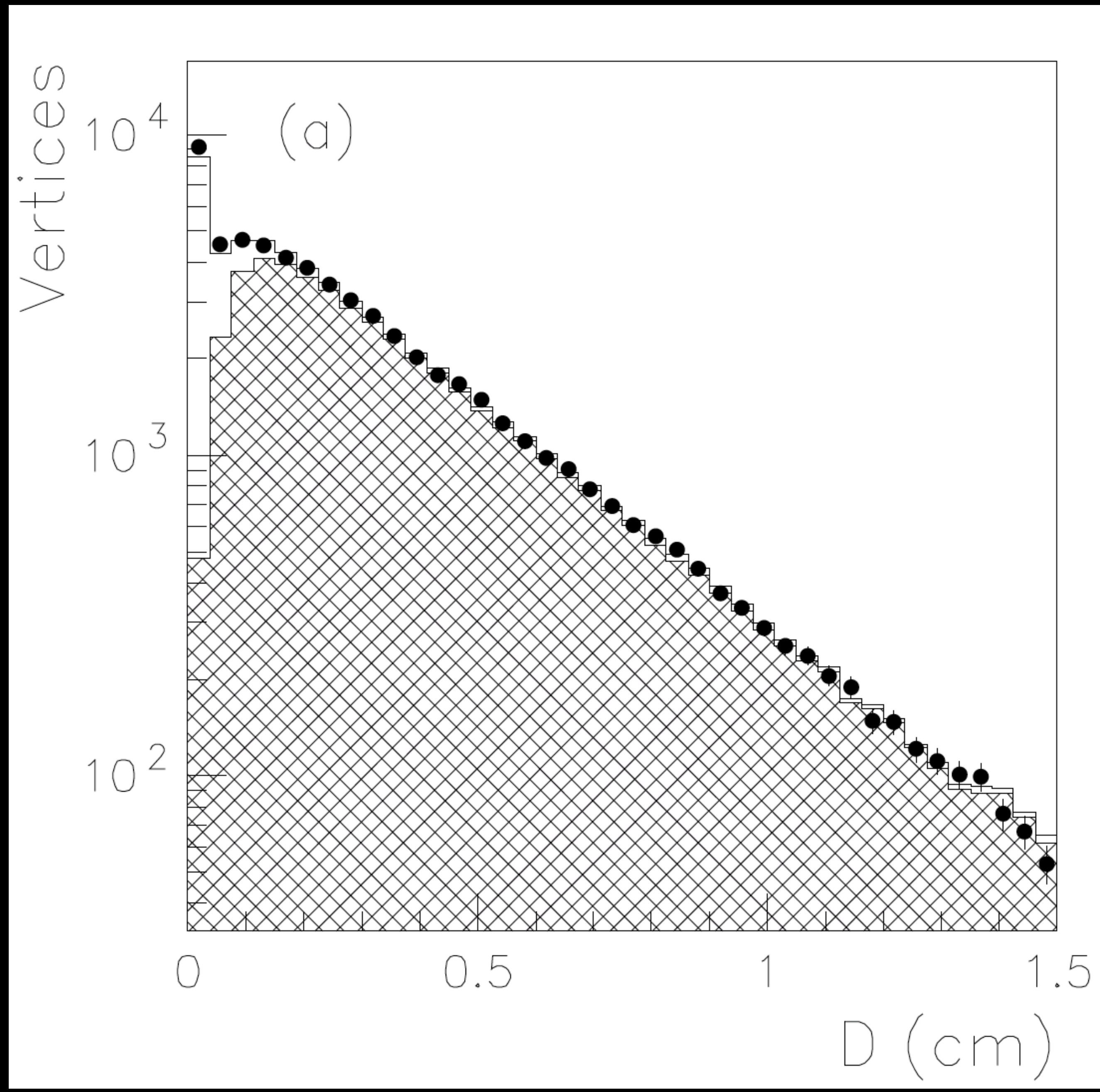
Arxiv:1601.07758v2

Branching ratio (R^b): detector requirement

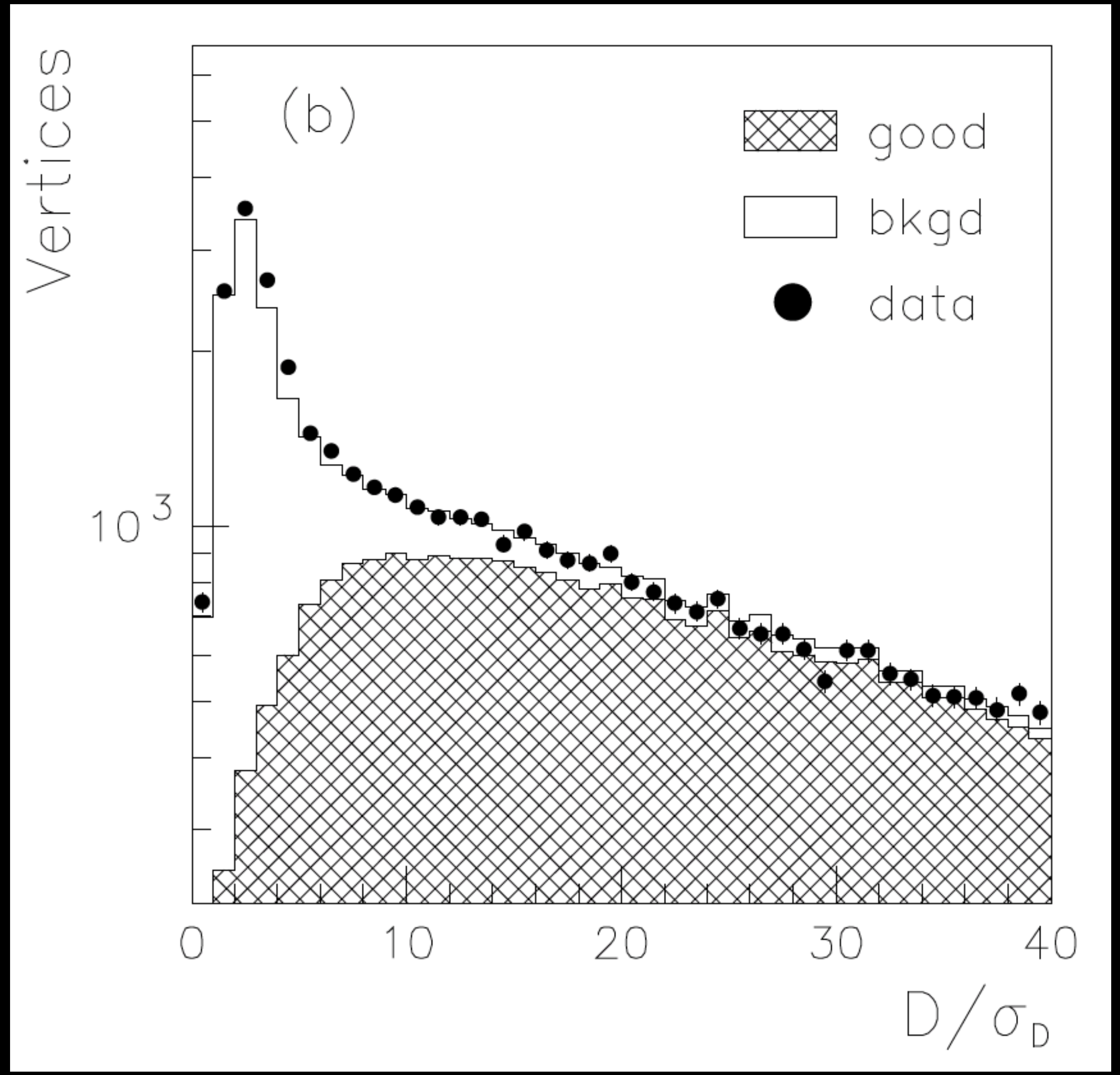
$$\frac{\Gamma(Z \to b\bar{b})}{\Gamma(Z \to had)}$$

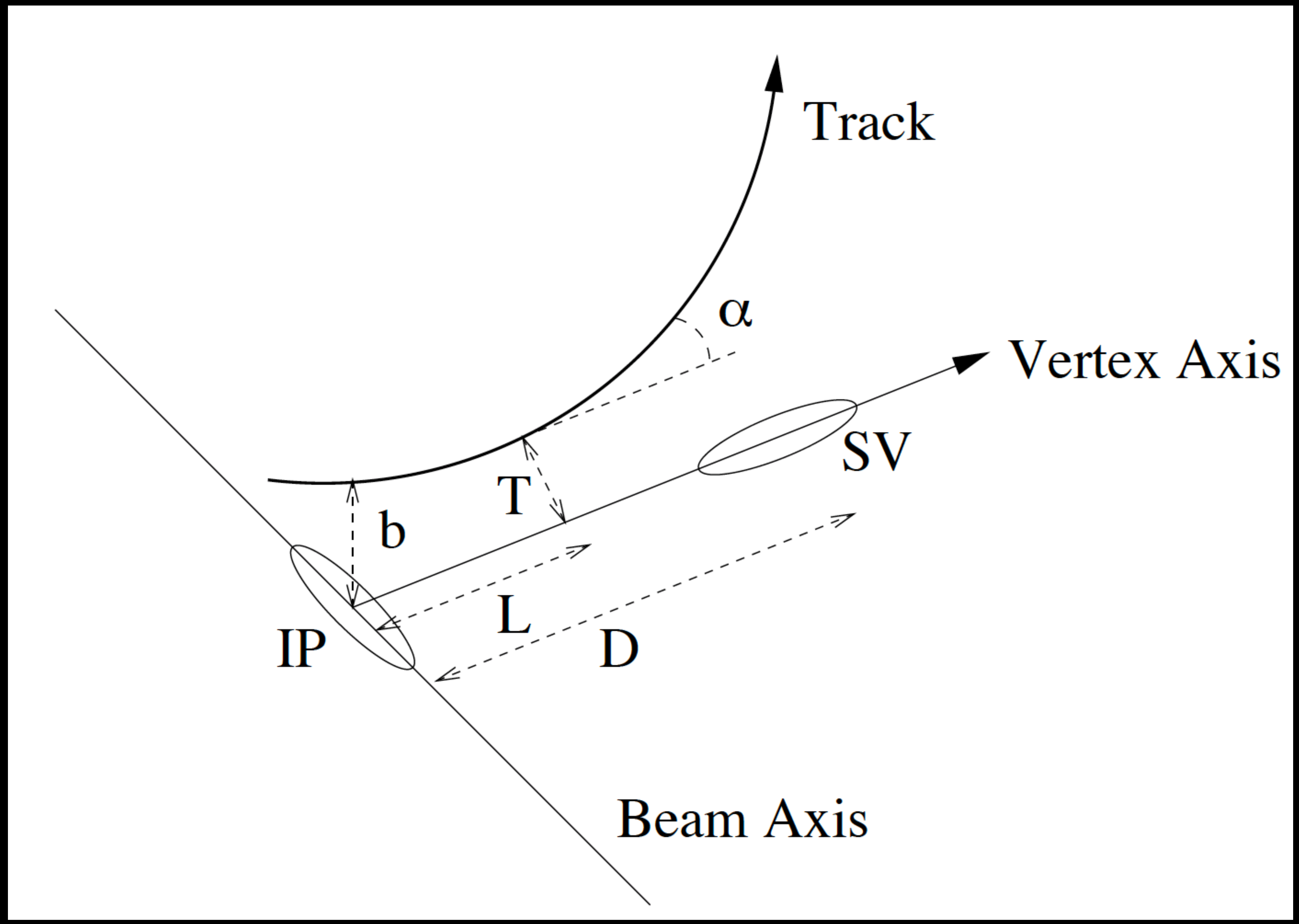
- Two ways to tag the b quarks in Z->qq events
  - Secondary Vertex tag (Average decay length of b meson of 2mm level at Z pole)
    - ➢ Multi-variant analysis : Impact parameter in R/φ and Z , mass of vertex …
  - Lepton tag
  - ➢ High momentum Electron and muon with pT>1GeV in a jet …

Vertex distance to IP



Vertex distance significance





SLD, Ann.Rev.Nucl.Part.Sci.46:395-469,1996

Branching ratio (R^b): systematics

Source	$\Delta\epsilon^c/\epsilon^c$ (%)	$\Delta\epsilon^{uds}/\epsilon^{uds}$ (%)	ΔR_b
Tracking resolution	1.24	4.0	0.00017
Tracking efficiency	0.80	4.0	0.00014
Silicon hit matching efficiency	0.82	2.8	0.00009
Silicon alignment	0.58	2.1	0.00008
Electron identification efficiency	1.11	0.5	0.00015
Muon identification efficiency	0.64	0.2	0.00009
c quark fragmentation	2.26	-	0.00028
c hadron production fractions	3.66	-	0.00046
c hadron lifetimes	0.55	-	0.00007
c charged decay multiplicity	1.09	-	0.00014
c neutral decay multiplicity	2.39	-	0.00030
Branching fraction $B(D \to K^0)$	1.20	-	0.00015
c semileptonic branching fraction	2.44	-	0.00031
c semileptonic decay modelling	2.34	-	0.00029
Gluon splitting to $c\bar{c}$	0.34	6.3	0.00018
Gluon splitting to $b\bar{b}$	0.50	9.3	0.00027
K^0 and hyperon production	-	0.3	0.00001
Monte Carlo statistics (c, uds)	0.66	2.5	0.00010
Subtotal $\Delta\epsilon^c$ and $\Delta\epsilon^{uds}$	6.65	13.3	0.00090
Electron identification background			0.00039
Muon identification background			0.00041
Efficiency correlation ΔC^b			0.00066
Event selection bias			0.00033
Total			0.00129

$$\frac{\Delta R_b}{R_b} = -0.059\frac{\Delta\epsilon^c}{\epsilon^c} - 0.010\frac{\Delta\epsilon^{uds}}{\epsilon^{uds}} + \frac{\Delta C^b}{C^b}$$

Tracker resolution and efficiency(~0.1%)

Lepton identification (~0.1%)

Charm modeling (~0.4%)

Gluon splitting (~0.1%)

Background (~0.2%)

b-tagging corrections (~0.3%)

OPAL collaboration, Eur.Phys.J.C8:217-239,1999

R^b: b tagging hemisphere correlations

- Hemisphere is taken to be tagged
  - if it is tagged by either one or both of the secondary vertex and lepton tags.
- Major systematics: hemisphere correlations
  - The tagging efficiency correlation between the two hemispheres in one event:
    - Angular effects : due to inefficient regions of detector
    - QCD effects (g->bb)
    - Vertex effects : due to vertex fitting

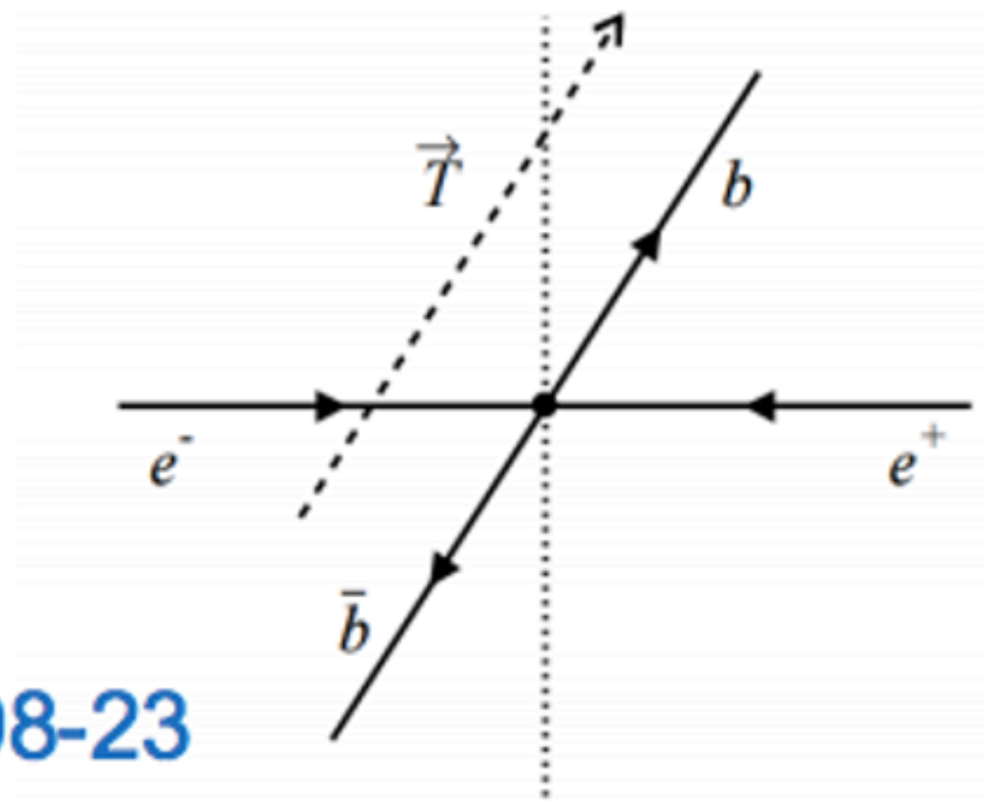
$$C_b = \frac{\varepsilon_{2jet-tagged}}{(\varepsilon_{1jet-tagged})^2}$$

Single (N_t) and double tagged events (N_{tt})

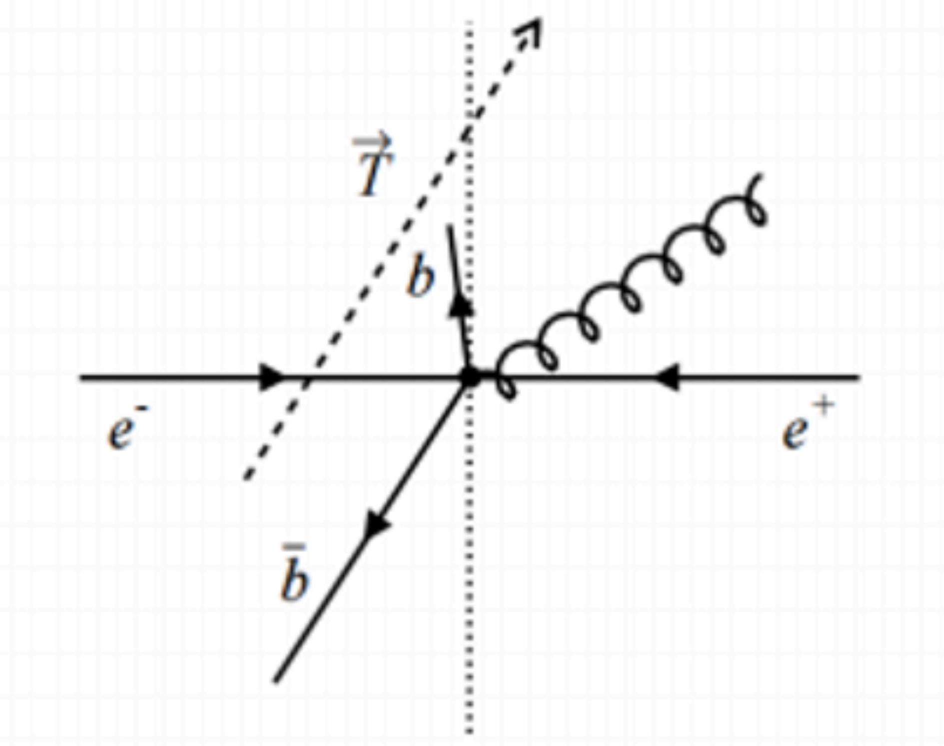
- $$\begin{aligned} N_{\mathrm{t}} &= 2N_{\mathrm{had}}\{\epsilon^{\mathrm{b}}\ R_{\mathrm{b}}\ + \epsilon^{\mathrm{c}}\ R_{\mathrm{c}}\ + \epsilon^{\mathrm{uds}}\ (1 - R_{\mathrm{b}} - R_{\mathrm{c}})\}, \\ N_{\mathrm{tt}} &= N_{\mathrm{had}}\{C^{\mathrm{b}}\ (\epsilon^{\mathrm{b}})^2\ R_{\mathrm{b}} + C^{\mathrm{c}}(\epsilon^{\mathrm{c}})^2\ R_{\mathrm{c}}\ + C^{\mathrm{uds}}(\epsilon^{\mathrm{uds}})^2\ (1 - R_{\mathrm{b}} - R_{\mathrm{c}})\}, \end{aligned}$$

Branching ratio (R^b): theory systematics

- QCD related systematics
  - High order QCD corrections gives impact to hemisphere correlations
  - Impact to Backward-forward asymmetry



(a) No gluon



(d) Thrust forward, quark backward

CERN-EP/98-23

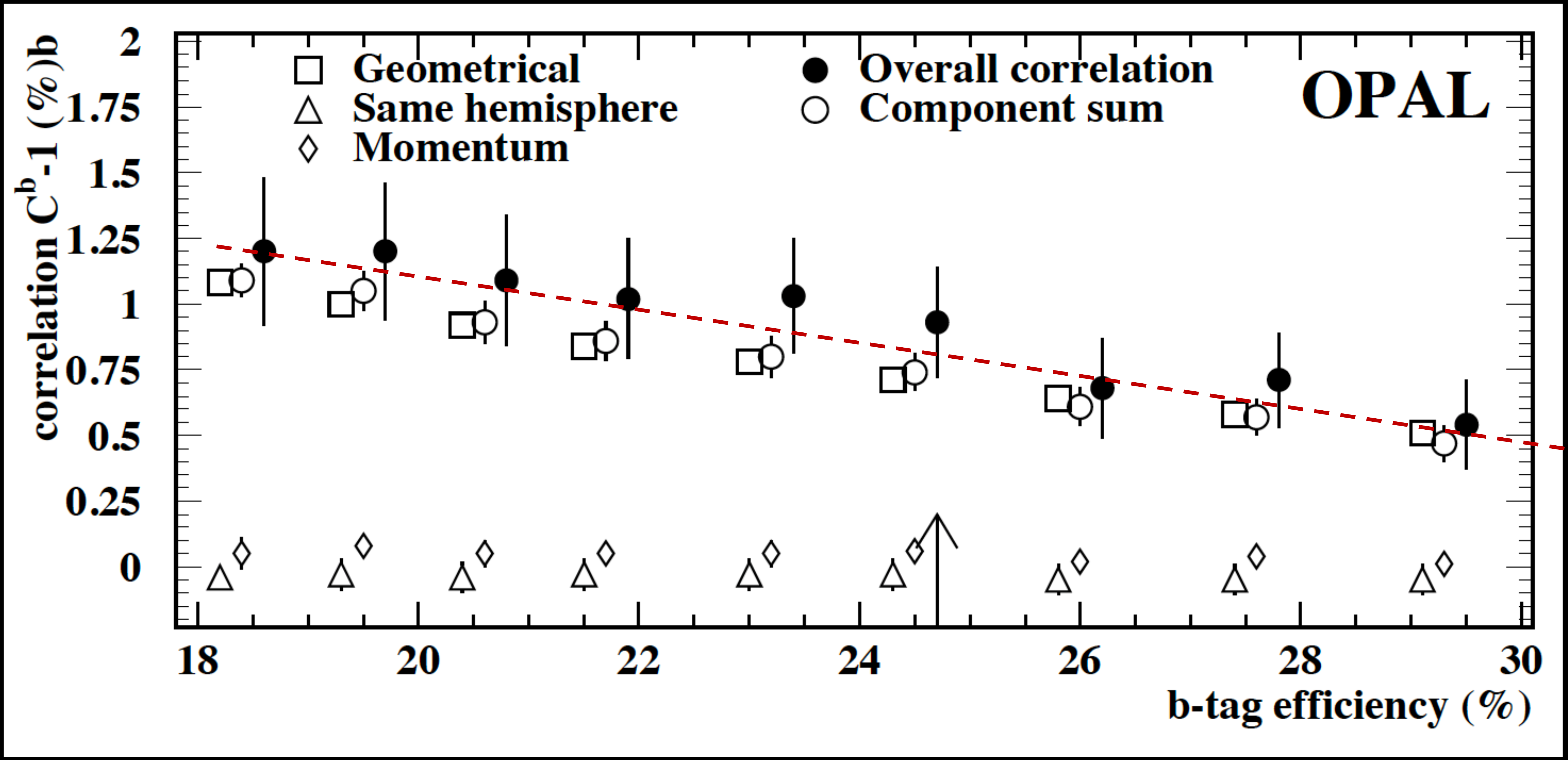
Error source	C^{quark}_{QCD} (%)		$C^{part,T}_{QCD}$ (%)	
	$b\bar{b}$	$c\bar{c}$	$b\bar{b}$	$c\bar{c}$
Theoretical error on m_b or m_c	0.23	0.11	0.15	0.08
$\alpha_s(m_Z^2)$ (0.119 ± 0.004)	0.12	0.16	0.12	0.16
Higher order corrections	0.27	0.66	0.27	0.66
Total error	0.37	0.69	0.33	0.68

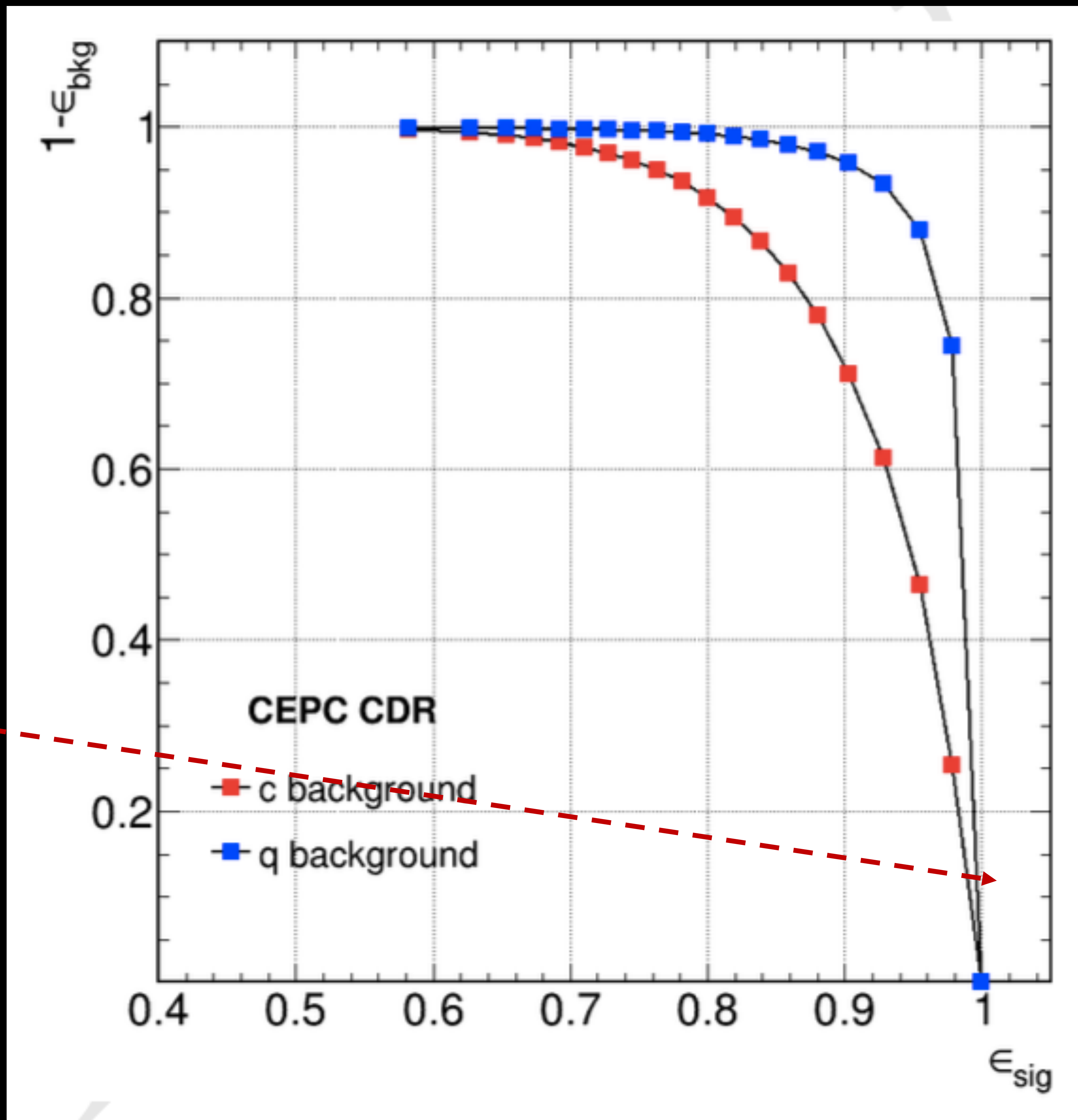
R^b: b tagging hemisphere correlations

- hemisphere correlations depends on b tagging efficiency
  - with 95% purity working points efficiency> 70%
  - This systematics will not be dominated

$$C_b = \frac{\varepsilon_{2jet-tagged}}{(\varepsilon_{1jet-tagged})^2}$$

CEPC b tagging ROC curve

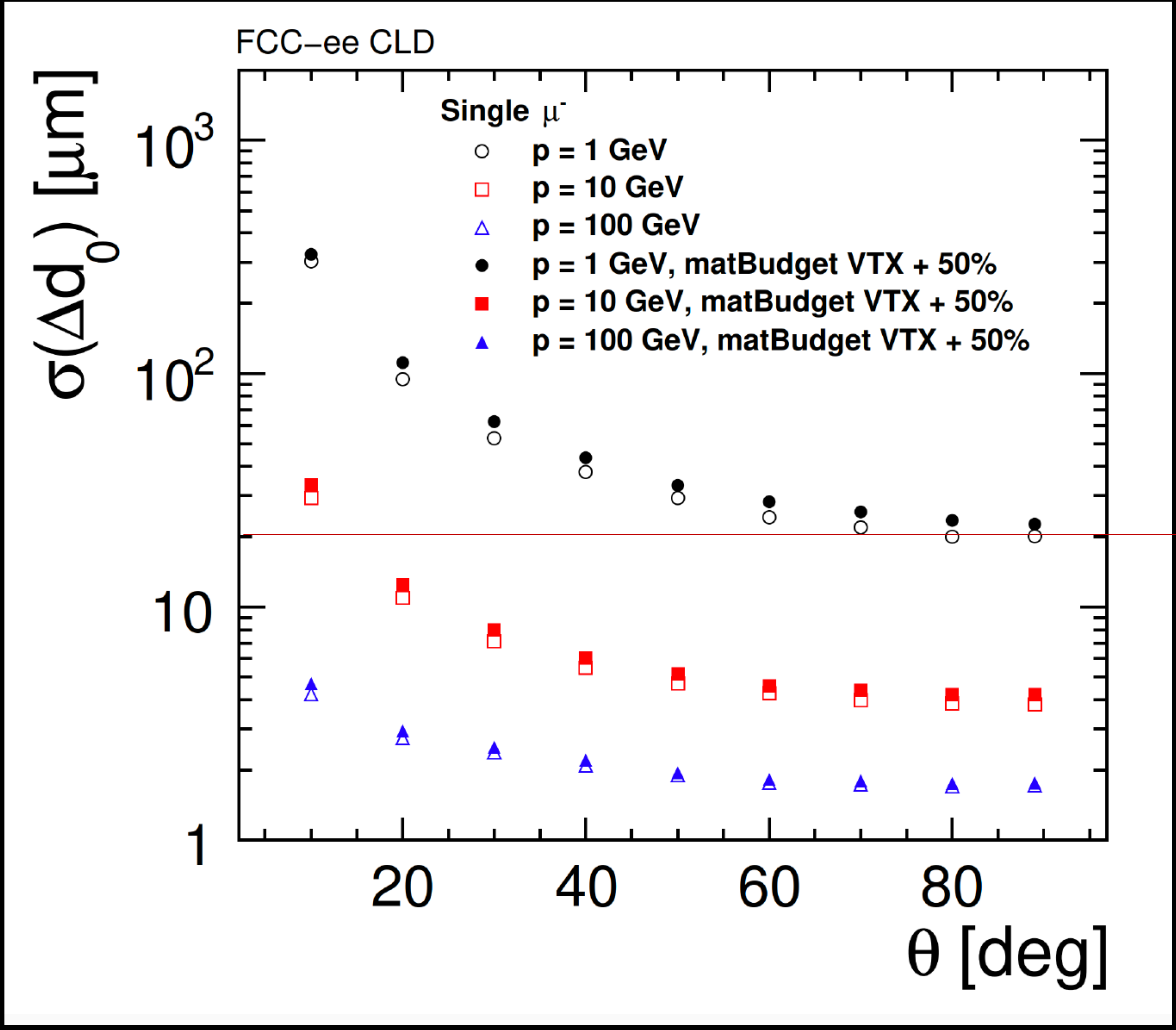




OPAL collaboration, Eur.Phys.J.C8:217-239,1999

R^b: tracker systematics

- Alignment systematics:
  - LEP study : 20µm mis-alignment → 0.04% systematics
  - FCC/CEPC aim for 2um mis-alignment (at least 5µm) → <0.005% syst.
- Hit Efficiency :
  - LEP study 1% syst. → 0.007% syst. In R^b
  - aim for less than 0.5% hit efficiency syst.
- Impact parameter resolutions
  - Should optimize for low pT
  - Aim for 20µm for low pT
- Lepton efficiency
  - LEP: 3% syst. → 0.04% systematics in R^b
  - Should aim for 0.5% syst.



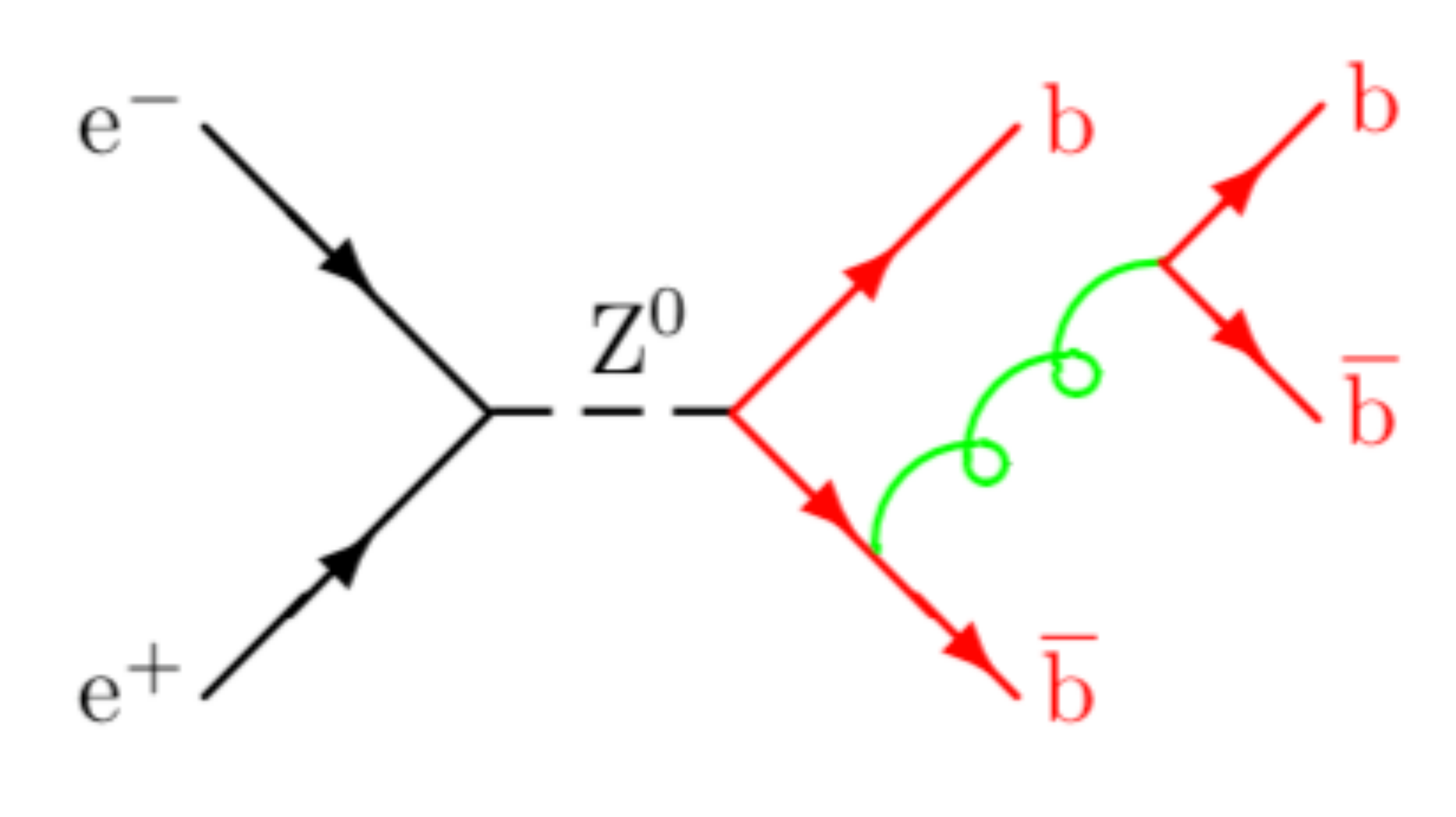
R^b: charm modelling and lepton ID

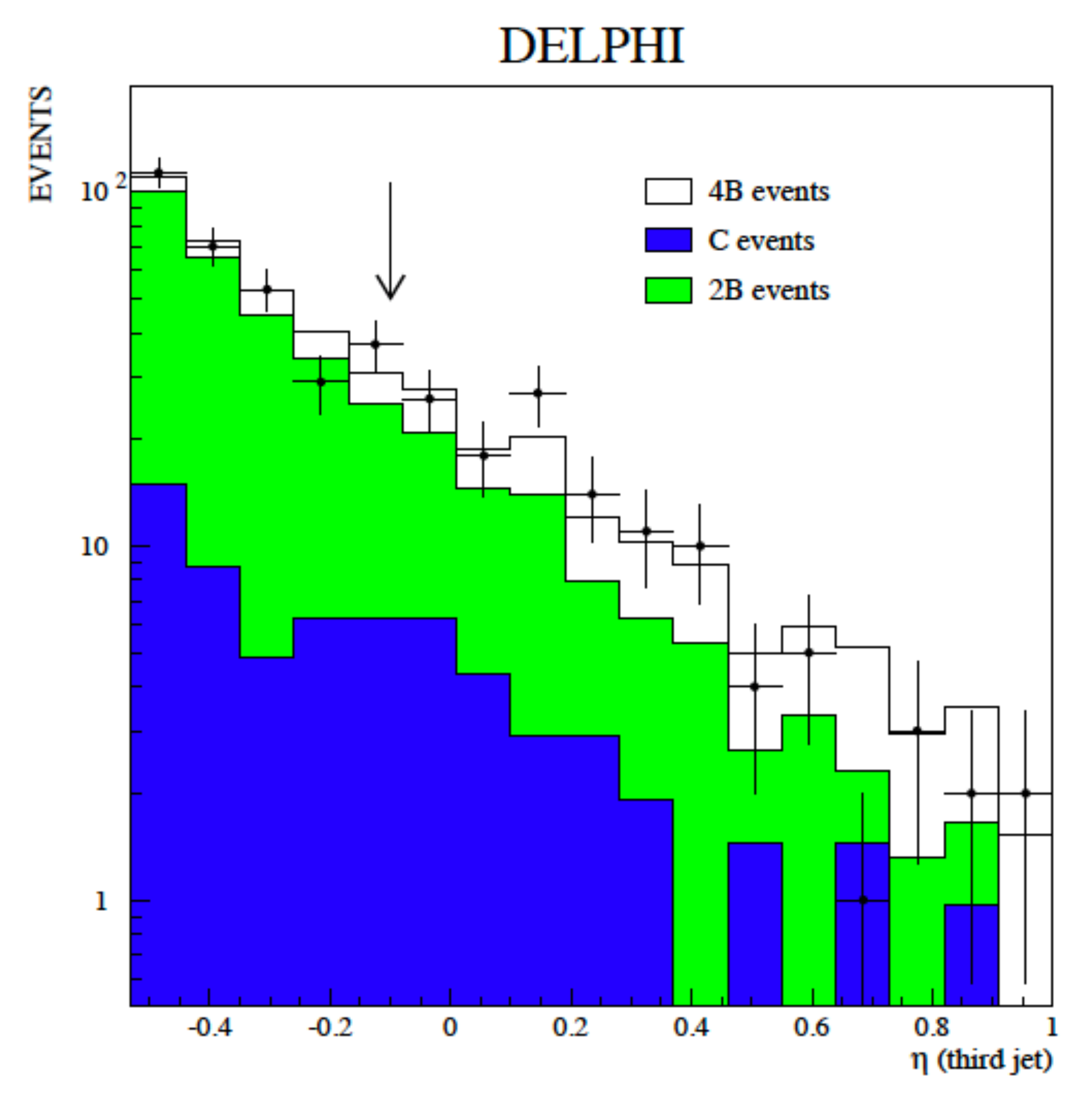
- Charm modelling : depends on input from flavor experiments (BELLEII…)
  - C hadron fractions (factions of D^+, D^0, D^+_s) → 0.2% syst. In R^b
  - LEP: Tagging efficiency for D+ is three times higher than D0
  - Need more study to check D meson tagging efficiency in Fcc-ee/CEPC

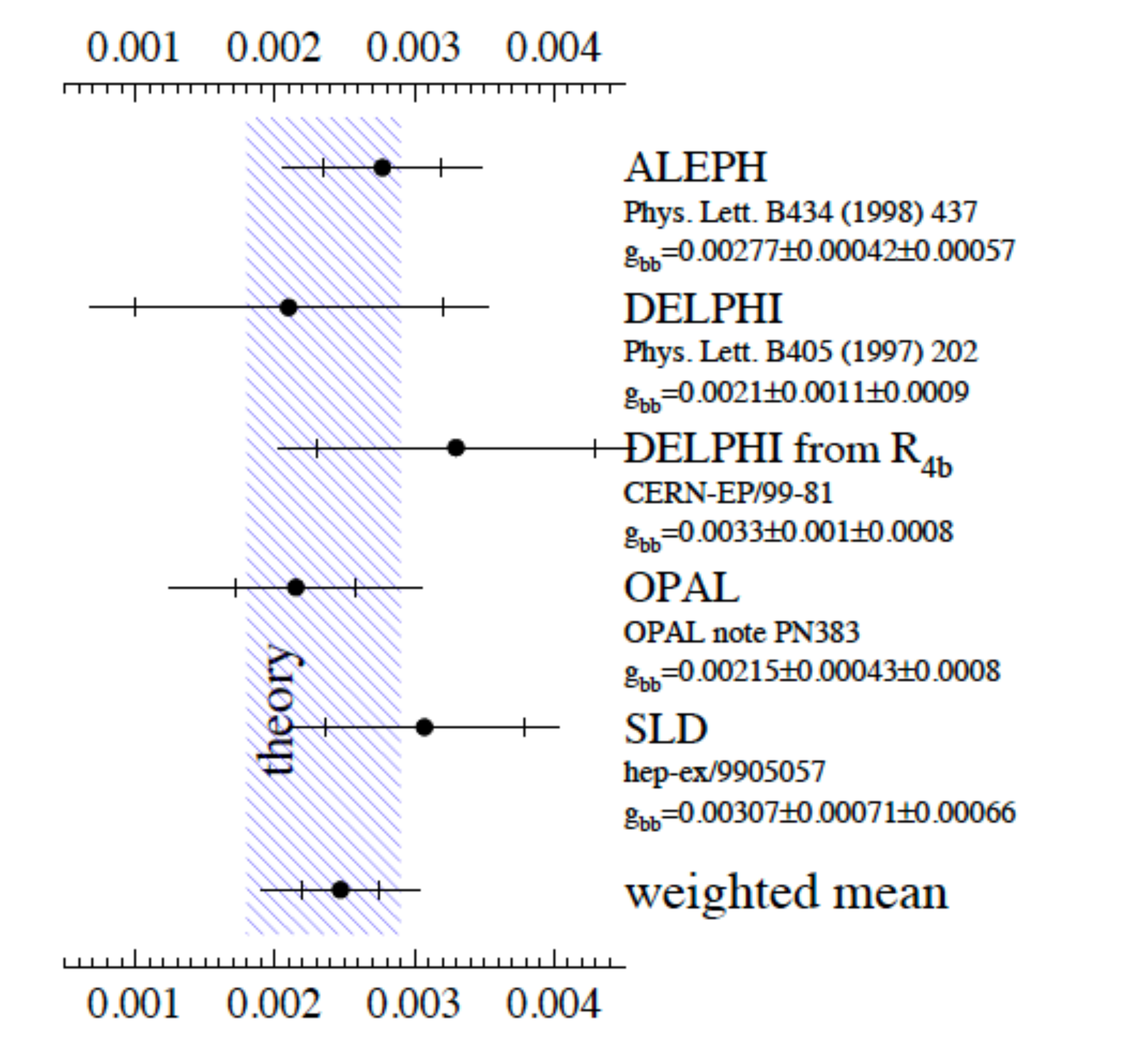
Source	$\Delta\epsilon^c/\epsilon^c$ (%)	$\Delta\epsilon^{uds}/\epsilon^{uds}$ (%)	ΔR_b
c quark fragmentation	2.26	-	0.00028
c hadron production fractions	3.66	-	0.00046
c hadron lifetimes	0.55	-	0.00007
c charged decay multiplicity	1.09	-	0.00014
c neutral decay multiplicity	2.39	-	0.00030
Branching fraction $B(D \to K^0)$	1.20	-	0.00015
c semileptonic branching fraction	2.44	-	0.00031
c semileptonic decay modelling	2.34	-	0.00029

R^b: gluon splitting

- Gluon splitting systematics is estimated by comparing data and MC simulation







$g_{bb} = 0.00247 \pm 0.00028\ (\mathrm{stat}) \pm 0.00048\ (\mathrm{syst})$

DELPHI Z->4b analysis
Gluon splitting measurements

Summary

- **R_b/R_c measurements are well motivated**
- **Need more dedicated study**
- **use R_b/R_c measurements as benchmark for detector optimization**
- **Need external input**
- **Charm modelling systematics (input from BELLEII …)**
- **Higher order QCD calculation**
- **Gluon splitting modelling**