The R_b and R_c Measurements at SLD

Sean Walston
University of Oregon
Representing the SLD Collaboration

Frontiers in Contemporary Physics II
March 5−10, 2001, Nashville Tennessee

Improved R_b and R_c Results

- New Winter 2001 R_b Result With Improved Event Selection Bias Correction:

$$R_b = 0.21705 \pm 0.00094 \pm 0.00079$$

- Summer 2000 Result as Reported at ICHEP:

$$R_b = 0.21669 \pm 0.00094 \pm 0.00101$$

- New Winter 2001 R_c Result With Improved Multitag Analysis (Better Statistics):

$$R_c = 0.1757 \pm 0.0032 \pm 0.0024$$

- Summer 2000 Result as Reported at ICHEP:

$$R_c = 0.1732 \pm 0.0041 \pm 0.0025$$

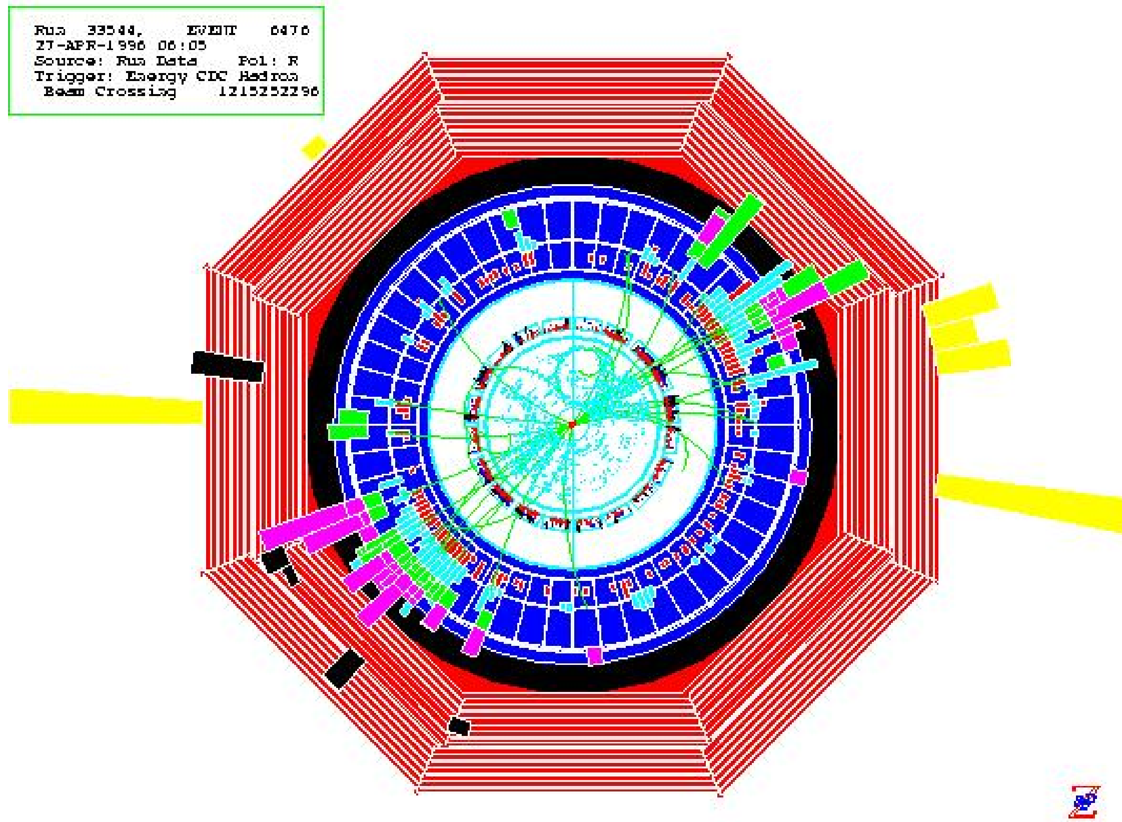
What are R_b and R_c

- Fraction of Hadronic Z_0 Decays producing Bottom or Charm Quarks

$$R_b = \frac{Z_0 \Rightarrow b\,\bar{b}}{Z_0 \Rightarrow Hadrons}$$

$$R_c = \frac{Z_0 \Rightarrow c\,\bar{c}}{Z_0 \Rightarrow Hadrons}$$

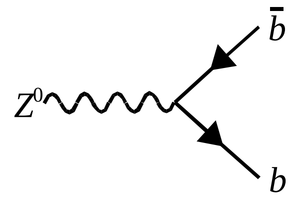
- Must Identify:
  - ✔ Hadronic Events
  - ✔ Bottom Events
  - ✔ Charm Events



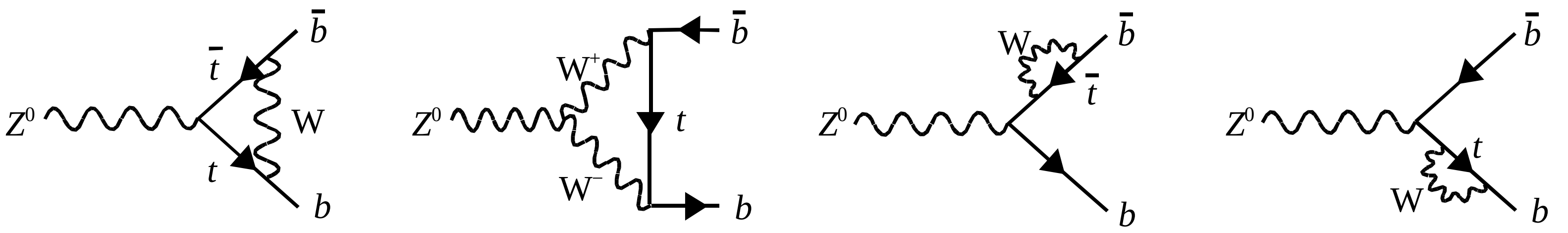
Why Measure R_b?

- Window onto the Top Quark ($V_{tb} \sim 1$, ΔR_b proportional to m_t^2)
- R_b is a Precision Test of the Standard Model
- The $Zb\bar{b}$ vertex is sensitive to certain types of new physics which primarily couple to heavy families (Higgs Couplings linear with mass)

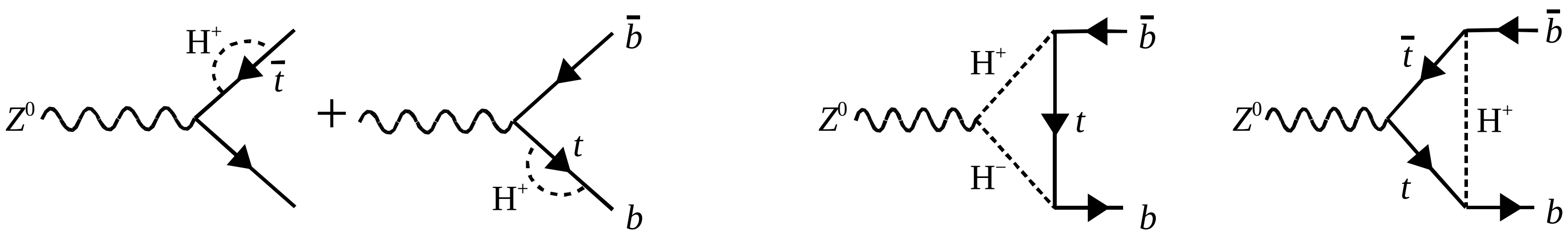
The $Zb\bar{b}$ Coupling



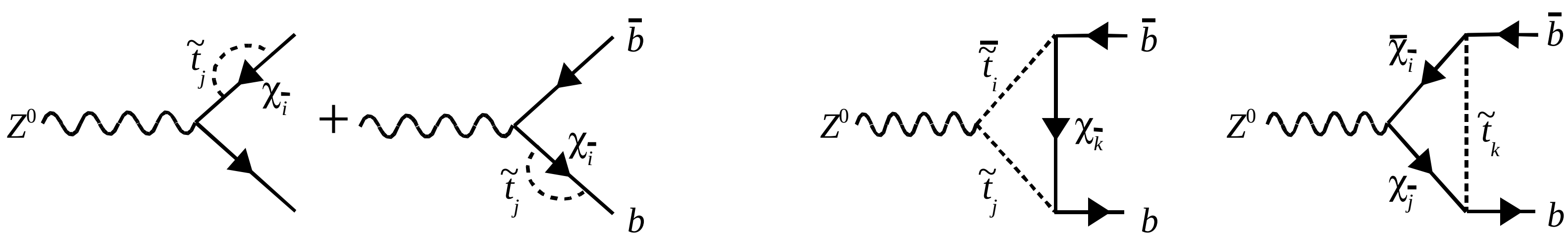
- SM Radiative Corrections: $\Delta R_b^{\,SM\ Rad.\ Cor.} = 0.0035$



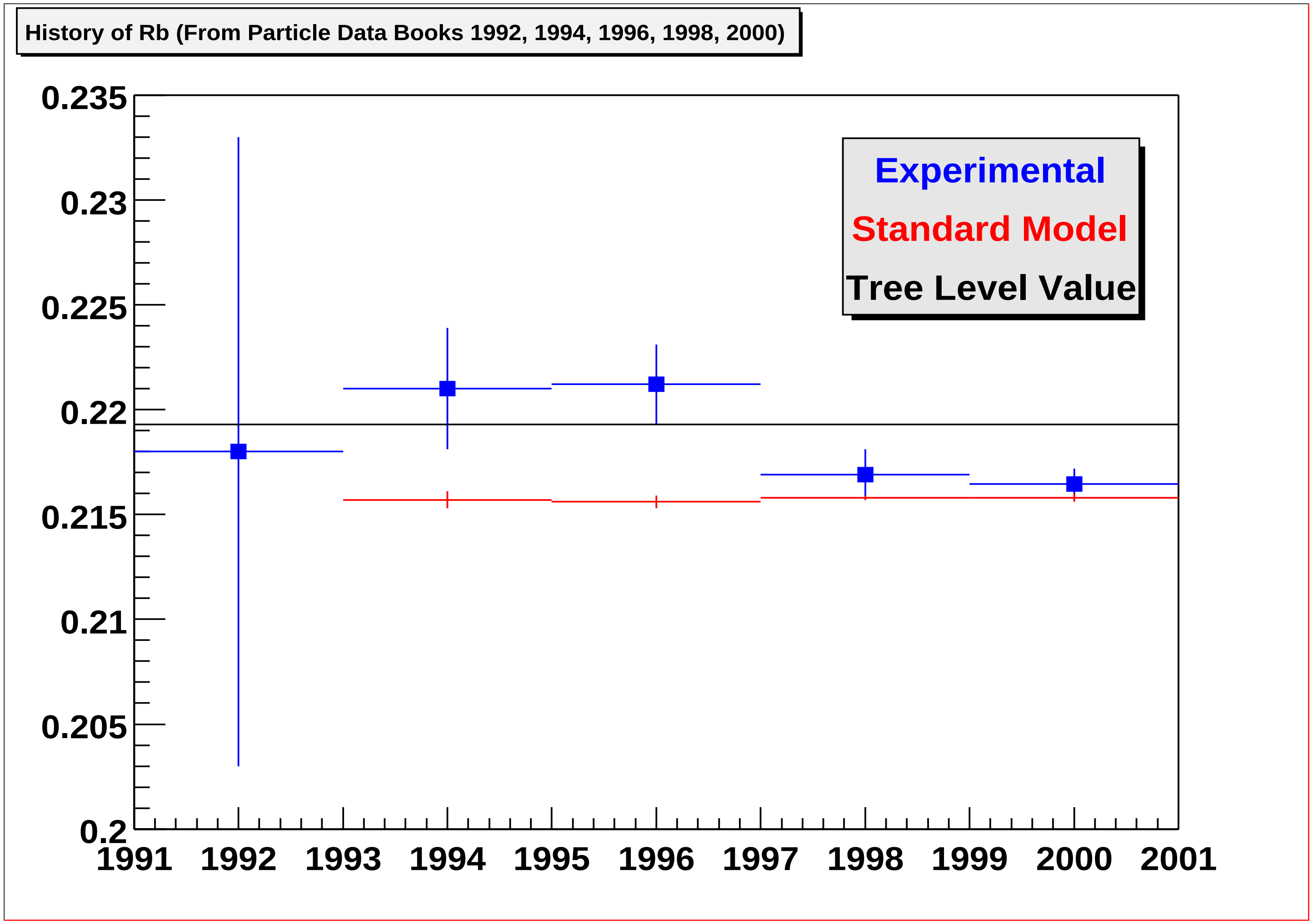
- Corrections from a Second Higgs Doublet



- Corrections from Supersymmetric Particles: $\Delta R_b^{\,SUSY(max)} = 0.0025$

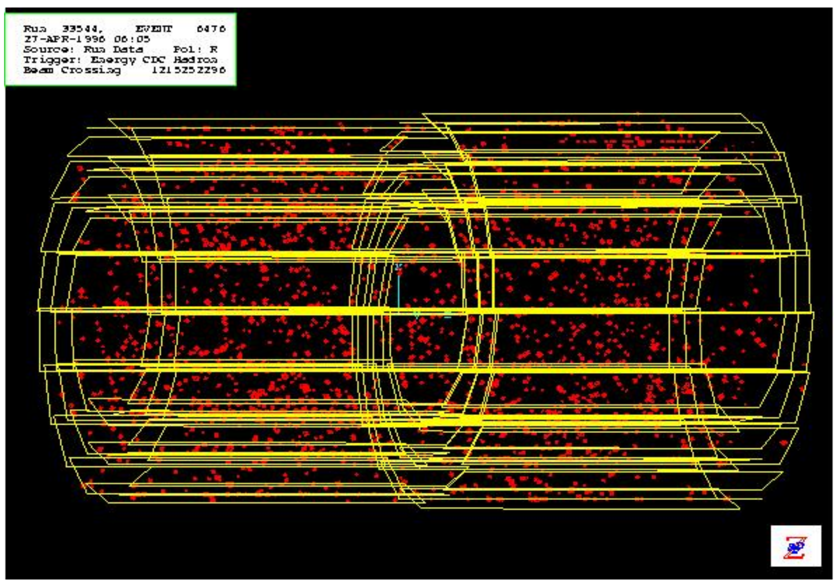


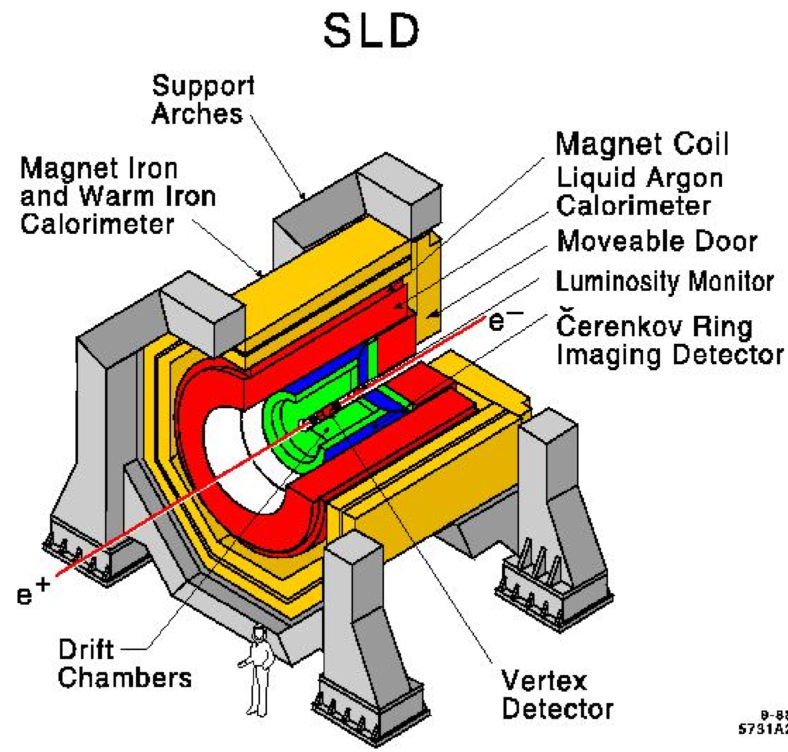
History of the R_b Measurement



Features of SLC/SLD

- Small, Stable Beams:
  - x : < 1.5 μm
  - y : ~ 0.5 μm
  - z : ~ 1.0 mm
- VXD3 CCD Vertex Detector



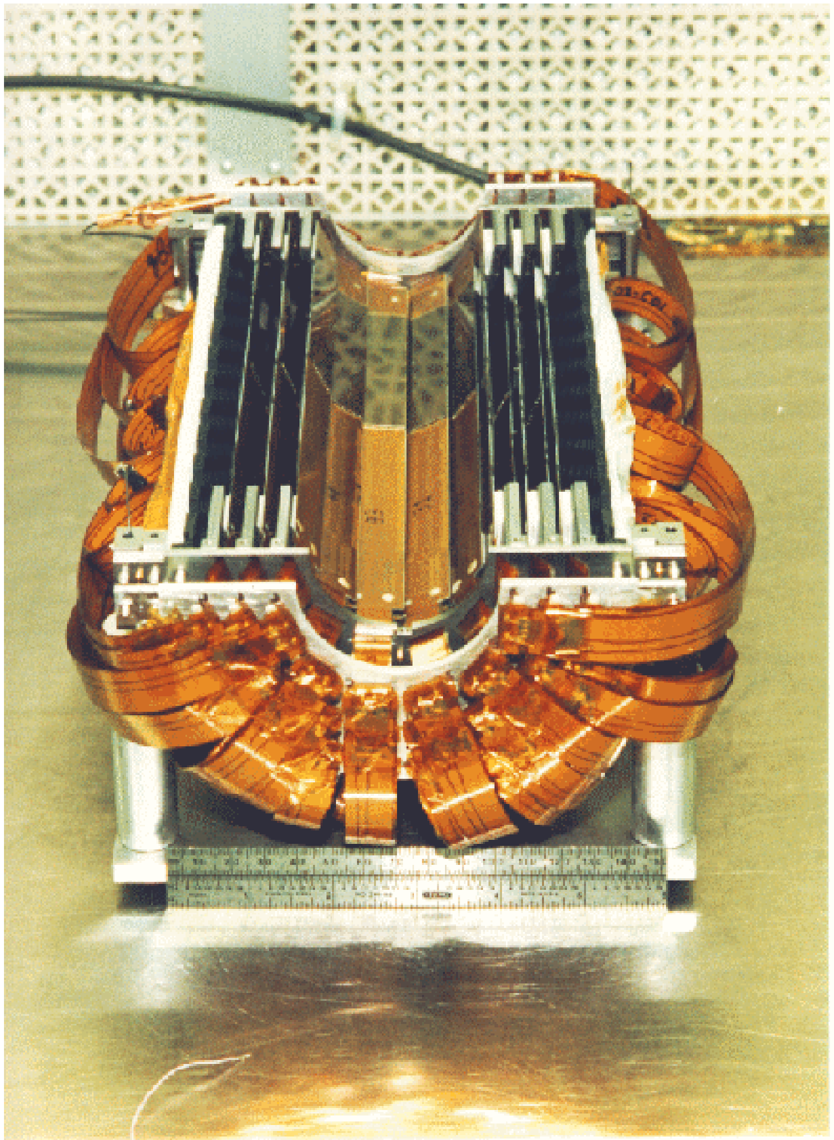


VXD3

- Natural 3−D Space Points from 307,000,000 Pixels!!!
- Pixels 20 x 20 x 20 μm
- Single hit precision < 4 μm
- Radial Lever Arm:
  - Inner Radius = 28 mm
  - Outer Radius = 48 mm
- Impact Parameter Resolution:

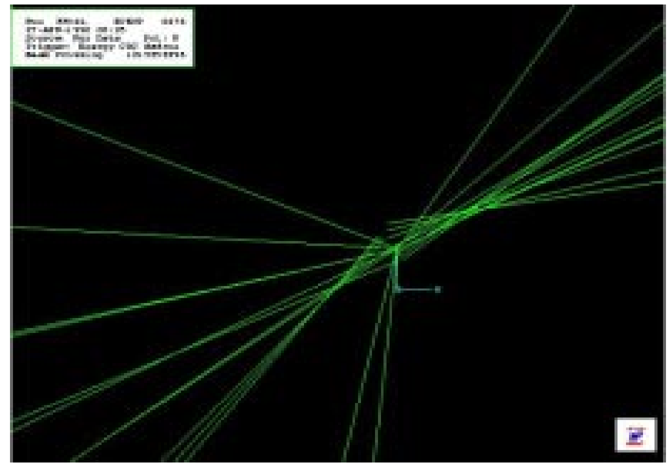
$$\sigma_{r\phi} = 7.8 \oplus \frac{33}{p \sin^{3/2}\vartheta} \ \mu m$$

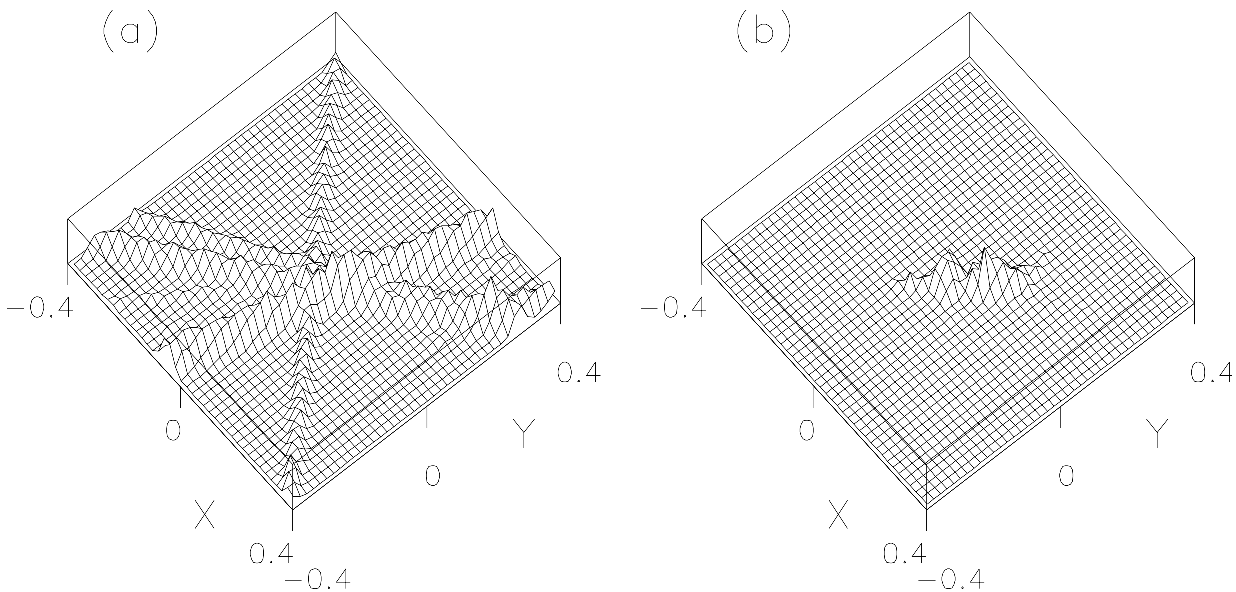
$$\sigma_{rz} = 9.7 \oplus \frac{33}{p \sin^{3/2}\vartheta} \ \mu m$$



Topological Vertexing

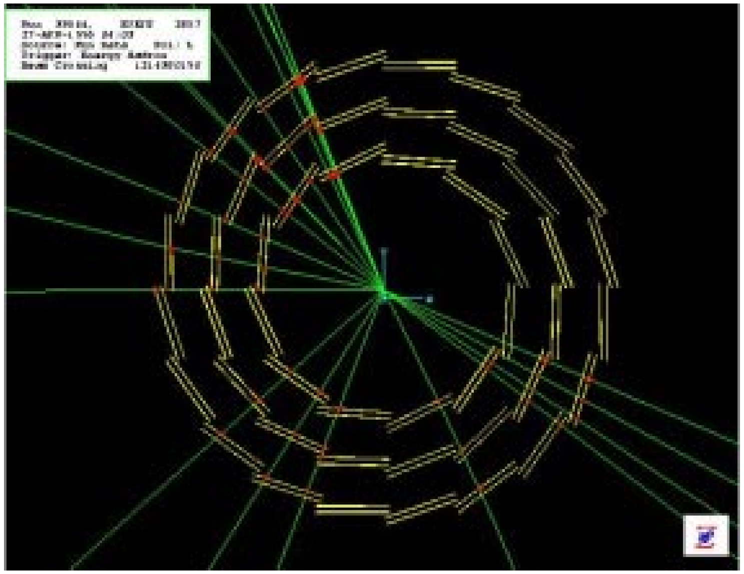
- Tracks Parameterized as Gaussian Probability Tubes in 3D
- Vertices are Regions with High Overlap





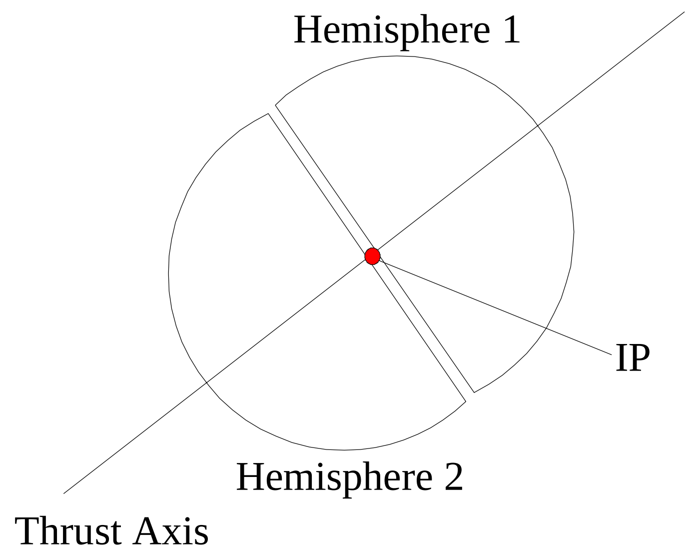
Hadronic Event Selection

- ✔ Visible Energy from Charged Tracks > 18 GeV
- ✔ At least 7 Tracks in the Central Tracking Chamber
  - ✔ Transverse Momentum $p_T > 0.2$ GeV
  - ✔ At least 3 of these Tracks must have links to the Vertex Detector
- ✔ Within Detector Acceptance
  - ✔ $cos\ \theta_{Thrust} < 0.71$
- ✔ 3 Jets or Less ($y_{cut} = 0.02$)



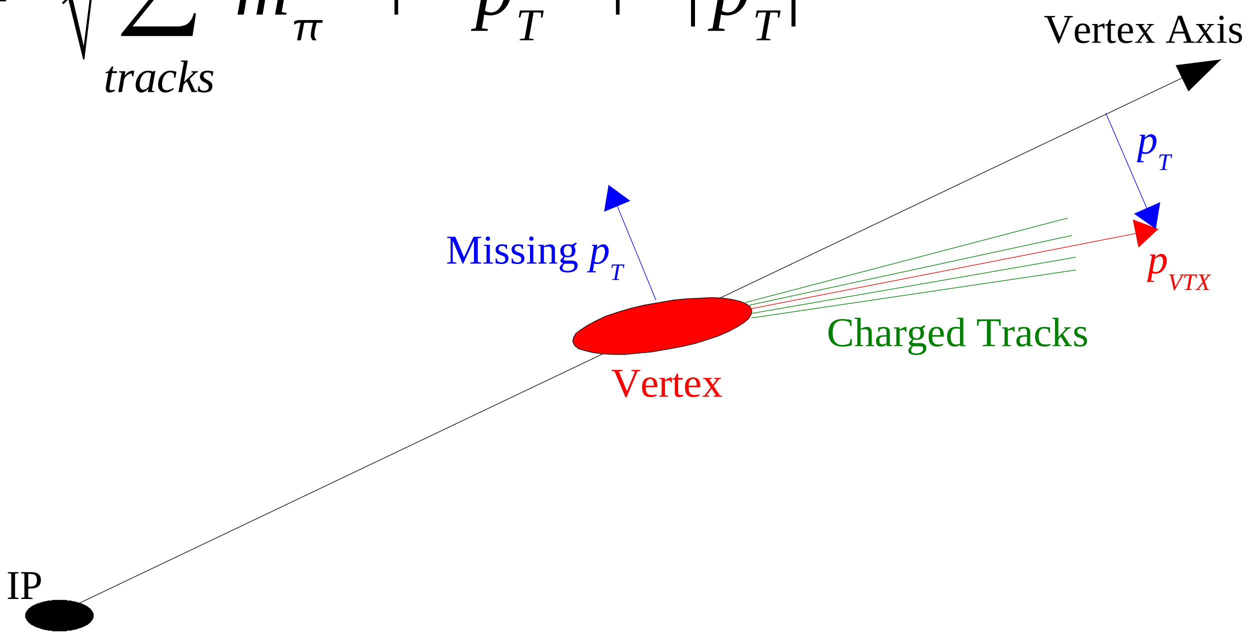
How to Measure R_b

- Separate Hadronic Events into 2 Thrust Hemispheres
- Apply $b-$Tags to each Hemisphere
- Count up the Numbers of:
  - ✔ $b-$Tagged Hemispheres
  - ✔ Double $b-$Tagged Events
- Assume from Monte Carlo mistagging efficiency and Hemisphere Correlation

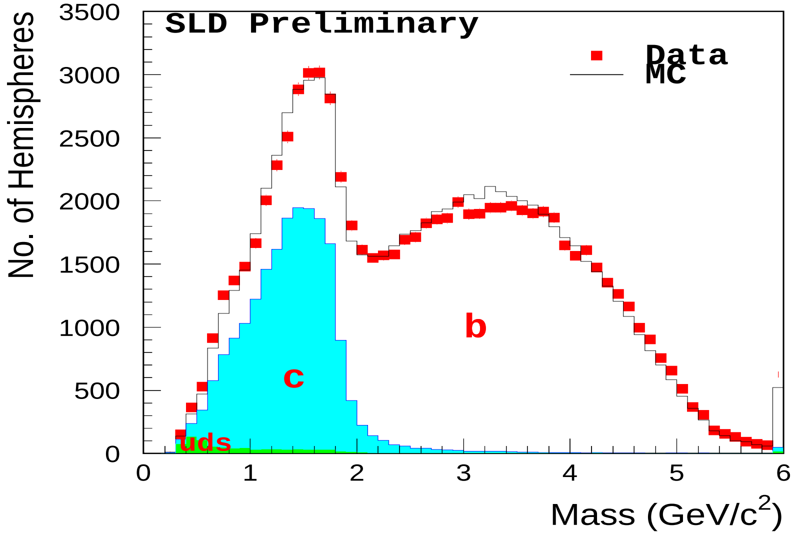


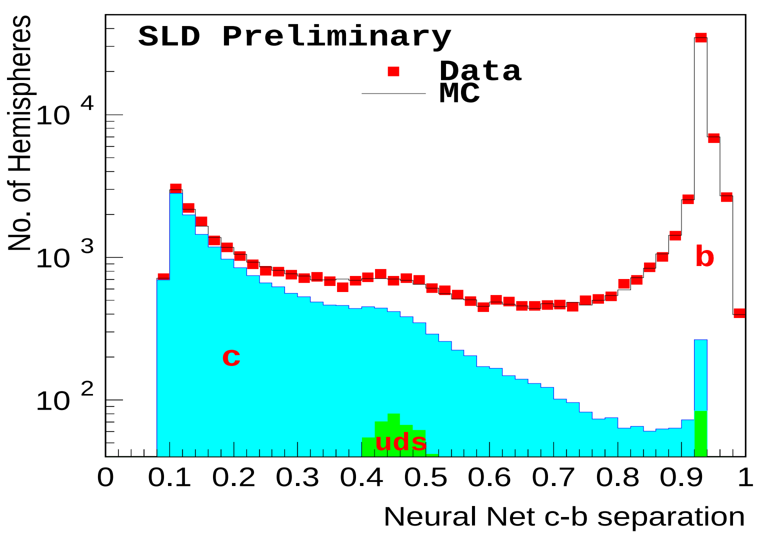
The Vertex Mass Tag

$$M_{VTX} = \sqrt{\sum_{tracks} m_{\pi} + p_T^2} + |p_T|$$



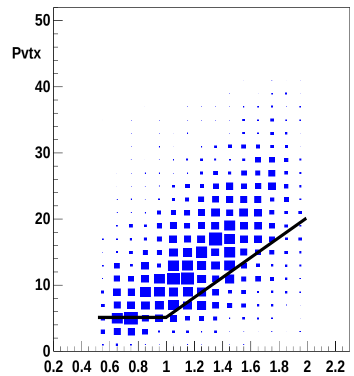
SLD c/b Selection Neural Net



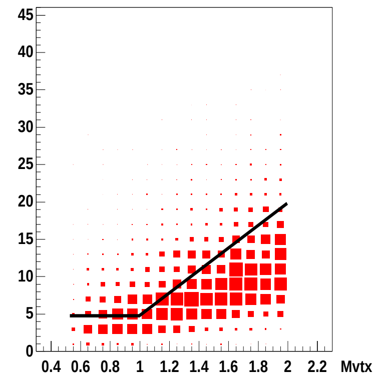


- Vertex Mass
- Vertex Momentum
  - lower for *b* than for *c*
- Decay Length
  - higher for *b* than for *c*
- Track Multiplicity
  - higher for *b* than for *c*

c−events

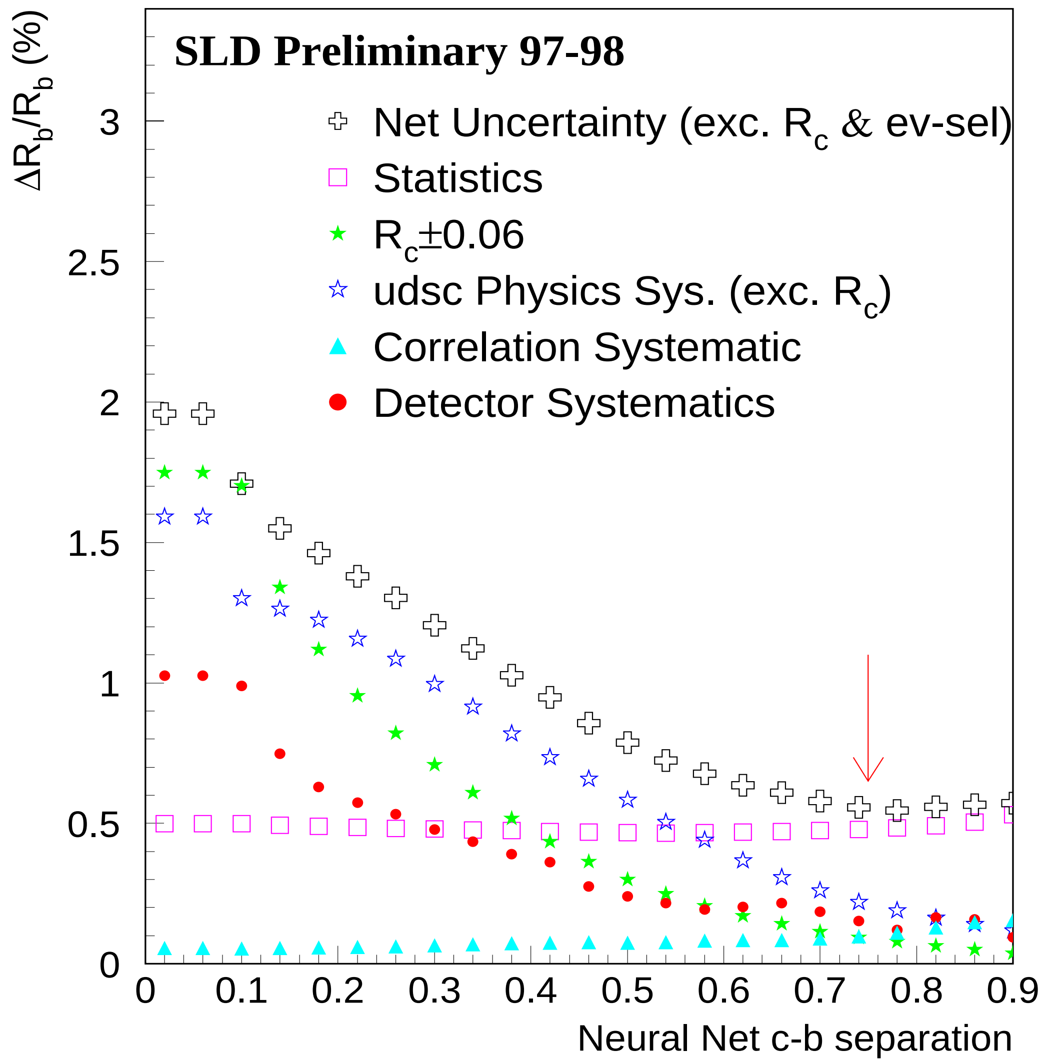


b−events

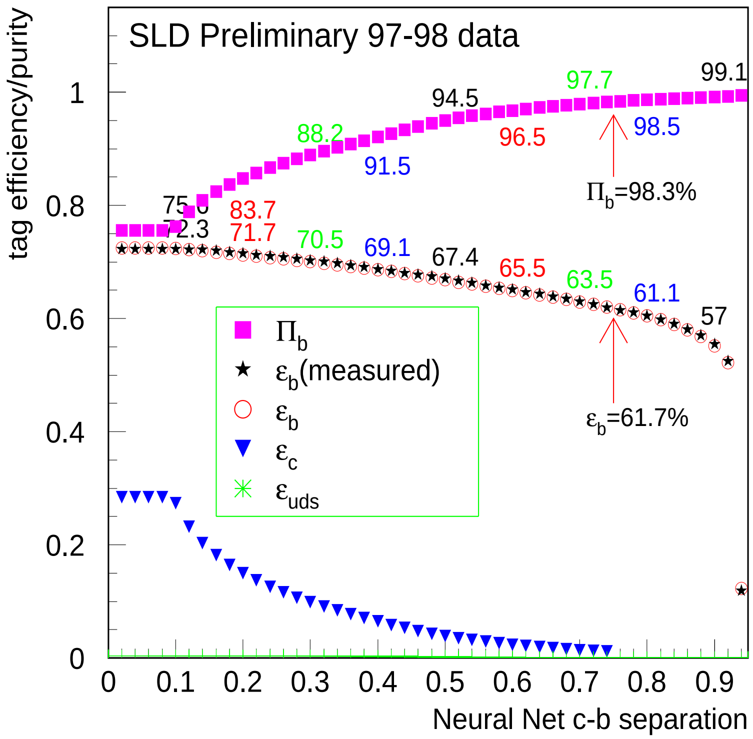


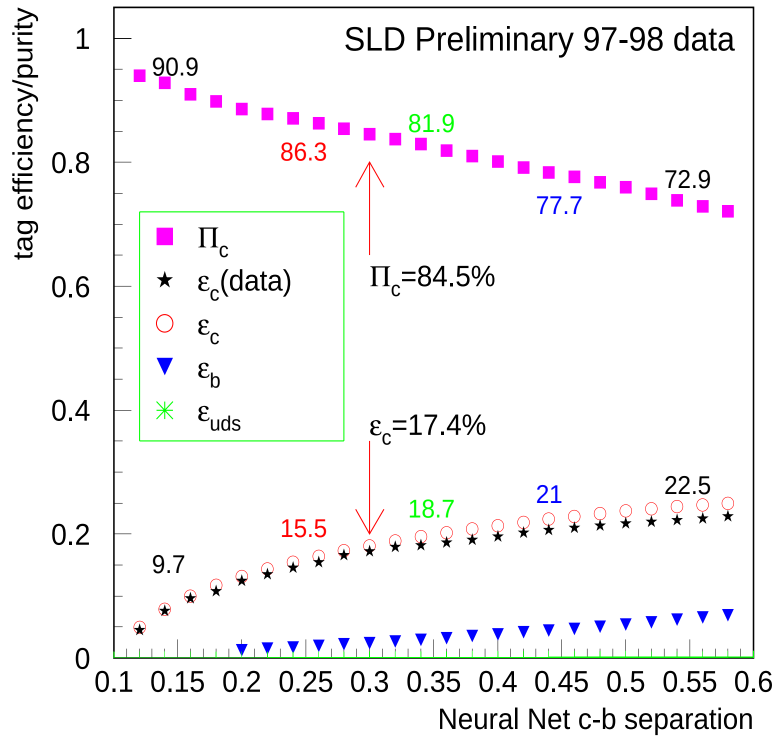
Choice of *c*/*b* Selection Cut

- Pick Cut on *c*/*b* Selection Neural Net Output Such that Overall Uncertainty on R_b is Minimized
- Neural Net *c*/*b* Selection Output > 0.75



Tag Efficiencies and Purities





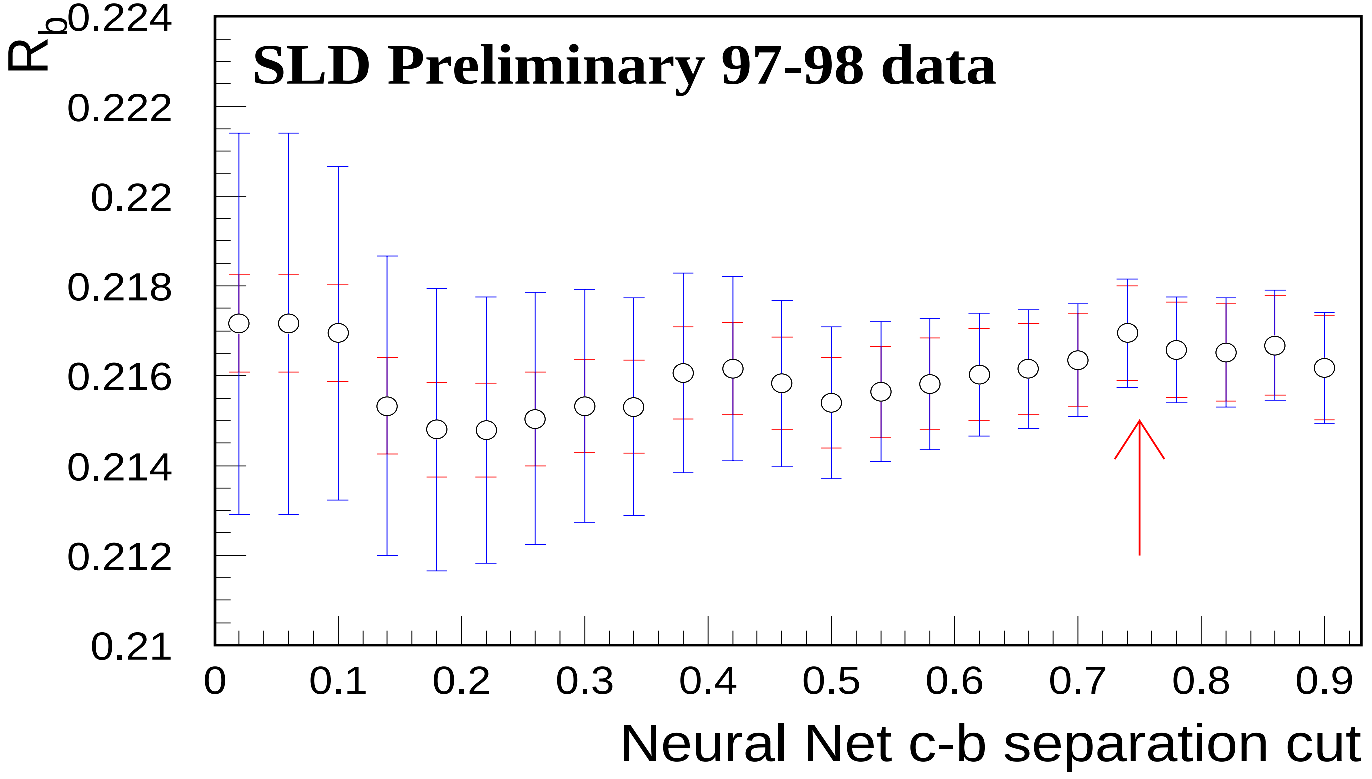
b−Tag Efficiency and Purity

ε_b=61.7% Π_b=98.3%

c−Tag Efficiency and Purity

ε_c=17.4% Π_c=84.5%

R_b vs. *c*/*b* Selection Cut



Event Selection Bias

- Hadronic Event Selection Designed to Include All Hadronic Z_0 Decays
- $N_{Jets} < 4$ removes ~8% of events. According to JETSET, this removes more *udsc*−events than *b*−events

  ➔ Event Selection Bias

- Bias from:

  (1) B−Hadron Decays have wider jets

  ➔ 4 jets not so easily resolved

  (2) Reduced gluon radiation in *b*−events due to large *b*−quark mass

  ➔ Fewer true 4−jet events

- Effect of (1) is reliably estimated using our simulation which is carefully tuned to B−dacay data from ARGUS and CLEO and B−production data from LEP and SLC

$$\delta R_b = -0.00074$$

Effect of the *b*−Quark Mass

- Previously, JETSET Used to Evaluate a Correction
  - ➔ Full Amount of Correction taken as Systematic Error
- Improved Understanding:
  - ✔ Running *b*−mass measured by Delphi/SLD at $m_b(M_Z) \sim 3$ GeV
  - ✔ LO Calculation of 4−jet rate as a funtion of quark mass
- Scale the Monte Carlo Track Level 4−jet rate difference from the running *b*−mass effect by the theoretical expectation for a running *b*−mass of 3 +/− 1 GeV
- Previous event selection bias correction:
  - ➔ $\delta R_b = -0.00176 \pm 0.00067$
- Improved event selection bias correction:
  - ➔ $\delta R_b = -0.00140 \pm 0.00022$

Latest R_b Result

- Summer 2000 Result as Reported at ICHEP:

$$R_b = 0.21669 \pm 0.00094 \pm 0.00101$$

- New Winter 2001 Result With Improved Event Selection Bias Correction:

$$R_b = 0.21705 \pm 0.00094 \pm 0.00079$$

Brand New Tags for R_c

- b−Tags
  - Standard "Hard" b−tag
    - ➔ NN c/b Selection Output > 0.75
  - "Soft" b−tag, "b−ish"
    - ➔ 0.75 > NN c/b Selection Output > 0.50
- c−Tags
  - Standard "Hard" c−tag
    - ➔ NN c/b Selection Output < 0.30
  - "Soft" c−tag, "c−ish"
    - ➔ 0.30 < NN c/b Selection Output < 0.50

Brand New Improved R_c Scheme

- Analogous to Double Tag method used in R_b, but worse! 4 Tags this time!
- A Hard Tag in one hemisphere yields very high purity in the opposite hemisphere (kind of like MC Truth). In this way, the hard tags can calibrate the soft tags
- Assume from Monte Carlo:
  - ✔ *uds*−Mis−Tagging Efficiencies
  - ✔ *c*−Mis−Tagging Efficiency for the Hard *b*−Tag
  - ✔ Correlations
- Calculate From Data:
  - ✔ Tagging Efficiency for each Tag
  - ✔ Mis−Tagging Efficiencies for all but the Hard *b*−Tag
  - ✔ R_b and R_c
- Weight each Tag by Statistical and Systematic Errors. Softer Tags have:
  - ✔ Lower Statistical Errors
  - ✔ Higher Systematic errors
- Fit the Weights to Minimize the Net Error

Latest R_c Result

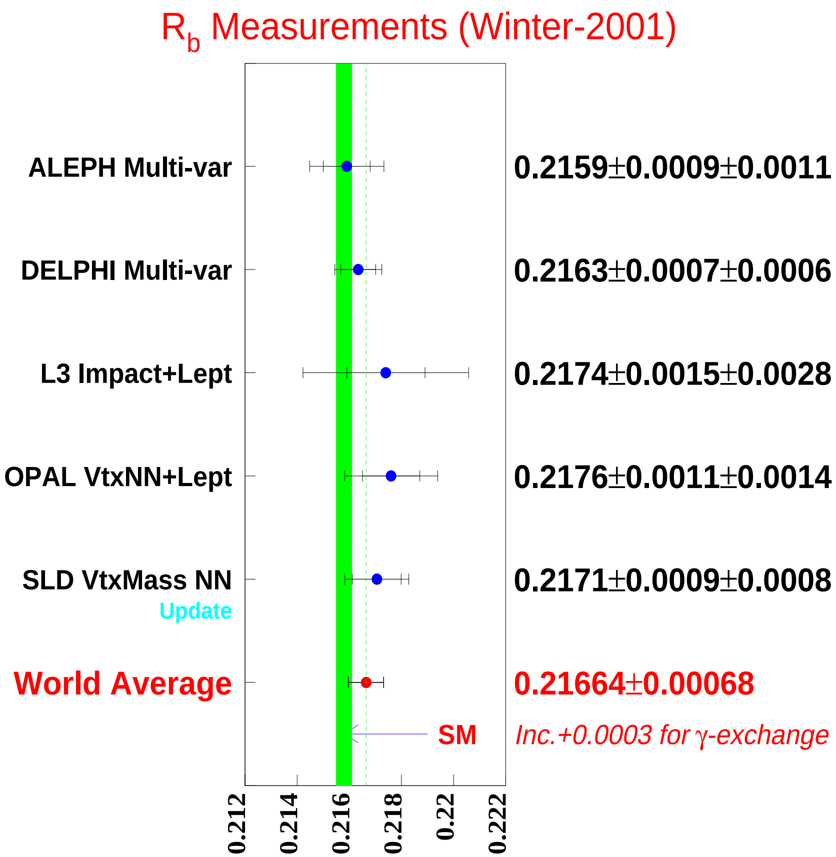
- Summer 2000 Result as Reported at ICHEP:

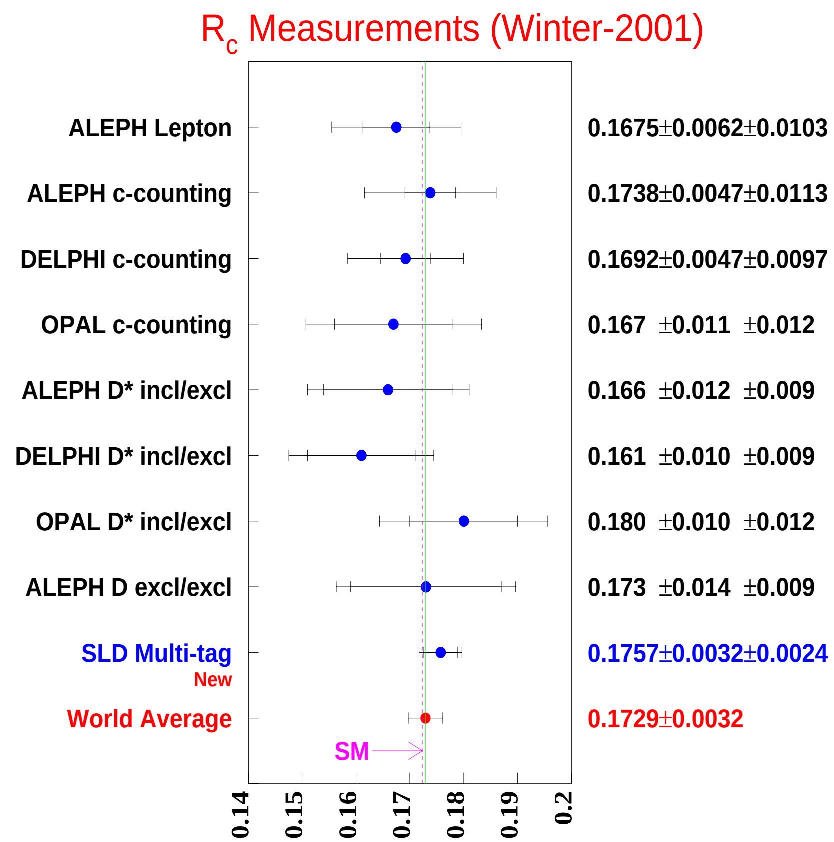
$$R_c = 0.1732 \pm 0.0041 \pm 0.0025$$

- New Winter 2001 Result With Multitag Analysis:

$$R_c = 0.1757 \pm 0.0032 \pm 0.0024$$

R_b and R_c Measurements





Conclusions

- Both R_b and R_c are Consistent with the Standard Model for m_t = 175 GeV
- R_b Measured to Level of 0.3%

$$R_b^{SLD} = 0.2171 \pm 0.0009 \pm 0.0008$$
$$R_b^{World\ Average} = 0.21664 \pm 0.00068$$
$$R_b^{Standard\ Model} = 0.2158 \pm 0.0002$$

- R_c Measured to Level of 1.9%

$$R_c^{SLD} = 0.1757 \pm 0.0032 \pm 0.0024$$
$$R_c^{World\ Average} = 0.1729 \pm 0.0032$$
$$R_c^{Standard\ Model} = 0.1723 \pm 0.0001$$