Light Flavor Branching Fractions in $e^+e^- \to q\bar{q}$

ILD Software & Analysis Meeting

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Introduction

- Idea: Leading particle flavor content correlated to jet flavor → tag light flavor jets by identifying highest momentum hadrons above a threshold momentum.
- Original method developed for LEP experiments.
- Problem: Tags are not unambiguous due to additional production of u, d and s quarks from the QCD sea.
- Solution: Measure hadrons containing different flavors to resolve ambiguities ($\pi^{\pm}$, $K^{\pm}$, p, K_S^0, Λ).
- Observables: Number of jets N_i tagged with hadron i and number of double tagged events N_{ij}.
- Use standard b and c tagging techniques to determine and subtract heavy flavor content.

$$\frac{N_i}{N_{had}} = 2 \times \sum_q \eta_q^i R_q$$

$$\frac{N_{ij}}{N_{had}} = (2 - \delta_{ij}) \times \sum_q \rho_{ij} \eta_q^i \eta_q^j R_q$$

- $\eta_q^i = \frac{N_{q \to i}}{N_q}$ is the probability that a quark of flavor q creates a leading hadron i.
- $R_q = \frac{\Gamma_{ee \to qq}}{\Gamma_{had}}$ is the branching fraction of $e^+e^- \to q\bar{q}$.
  - Alternative use $R'_q = \frac{R_q}{1 - R_c - R_b}$
- ρ_{ij} are jet correlation factors.
- N_{had} is the total number of $e^+e^- \to q\bar{q}$ events.

Additional Assumptions

- Additional assumptions are required to solve the equation system.
- Hadronization Symmetries (K^0 includes K_S^0 and K_L^0):

$$\begin{aligned} \eta_d^{\pi^\pm} &= \eta_u^{\pi^\pm} \\ \eta_d^{K^0} &= \eta_u^{K^\pm} \\ \eta_u^{K^0} &= \eta_d^{K^\pm} \\ \eta_s^{K^0} &= \eta_s^{K^\pm} \\ \eta_u^{\Lambda} &= \eta_d^{\Lambda} \end{aligned}$$

  - Are broken by < 2%.
- Normalization of branching fractions: $\sum_q R_q = 1$ or $\sum_q R'_q = 1$
- From weak isospin structure: $R_d = R_s$

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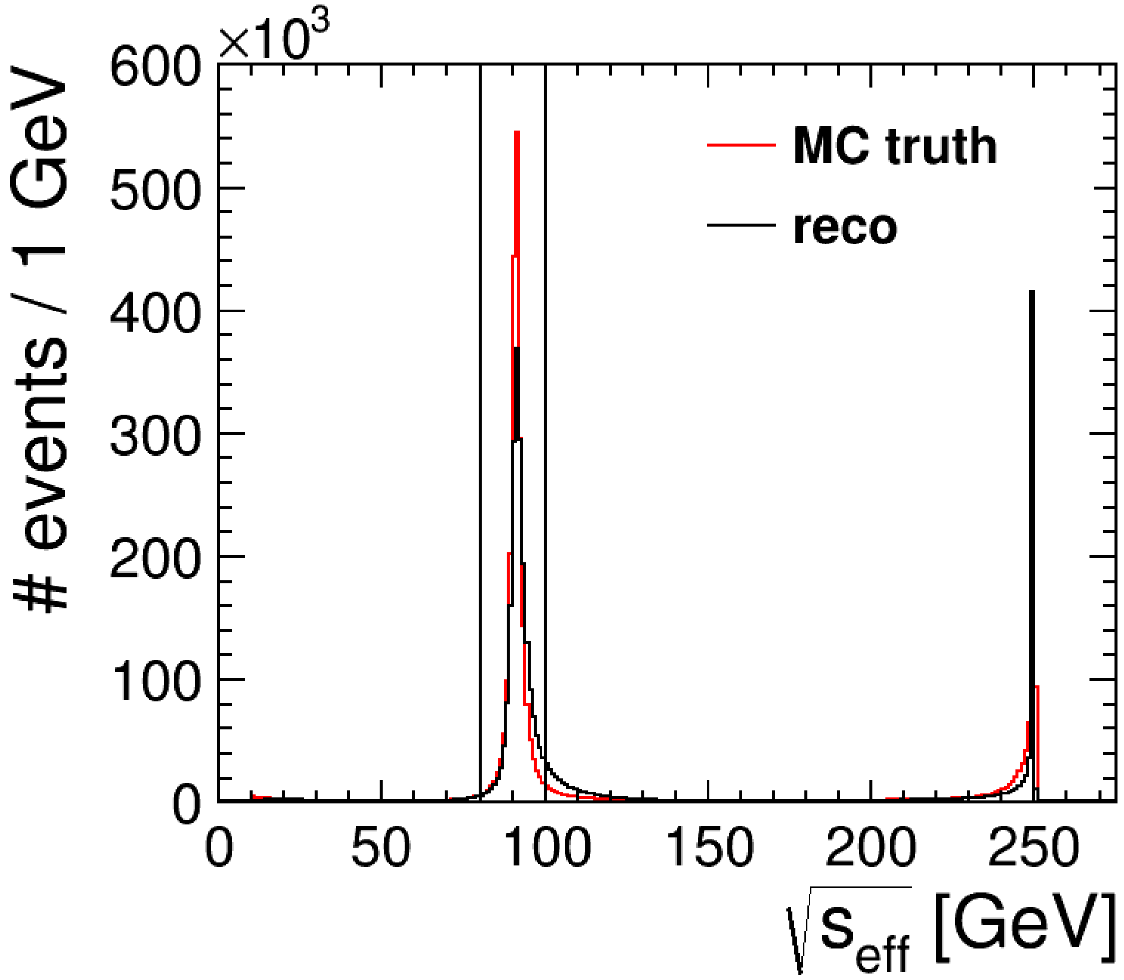
Data & Event Treatment

- Using DBD data: 2.86×10^6 events.
  - $\sqrt{s} = 250$ GeV, Dijet events
- Weighted to 2 ab^{-1}: 119.45×10^6 events.
  - Split (45%, 45%, 5%, 5%) between (+−, −+, ++, −−).
- ISR is identified by MC truth and removed.
  - Methods like kinematic fits have been shown to reliably recover ISR.
- Rest of event is boosted into CM system after ISR.
- Event is split into hemispheres by projecting particle momenta onto thrust axis.
- In each hemisphere the particle with the highest momentum (leading particle) is identified.

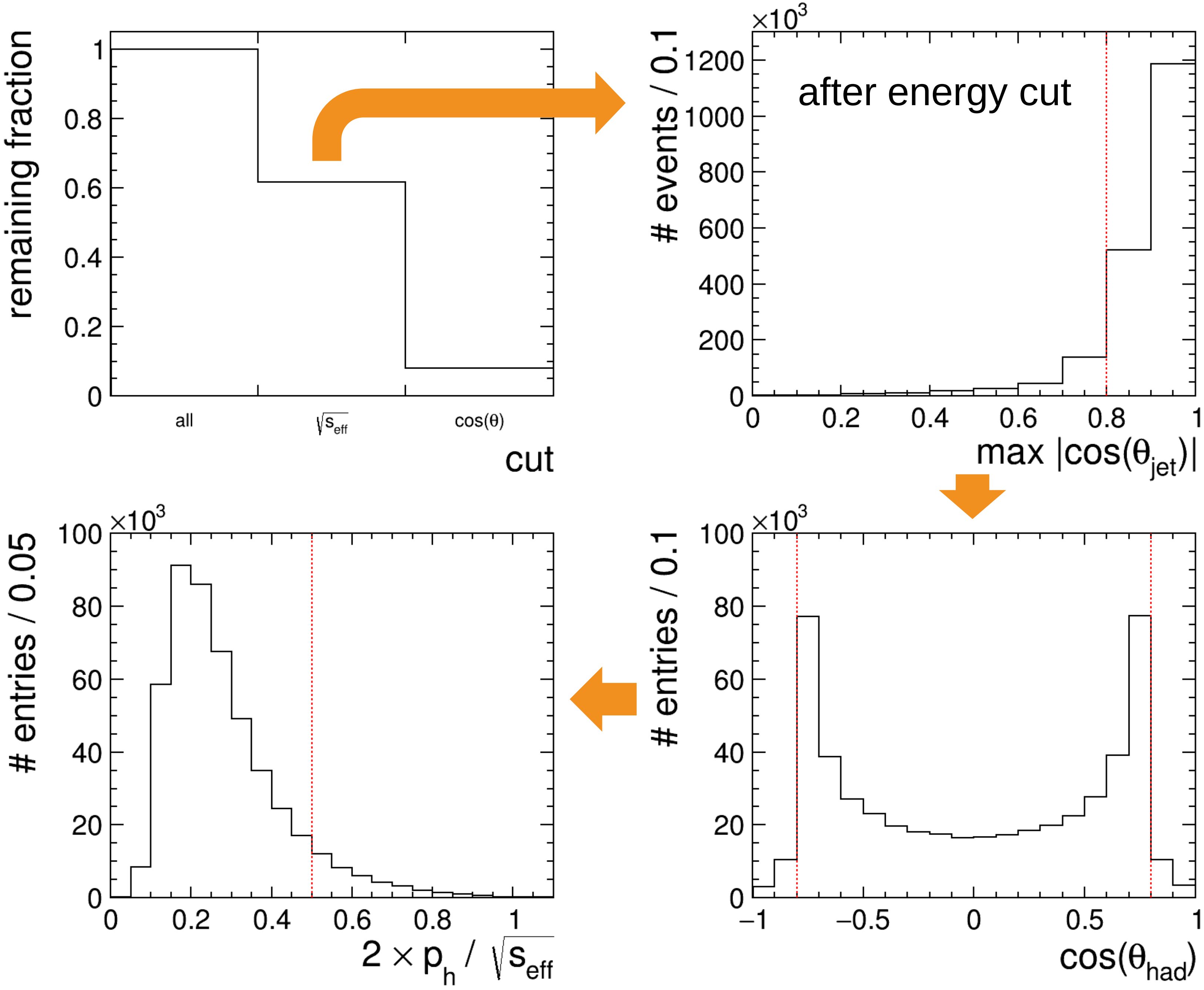


Data

80 GeV $< \sqrt{s_{eff}} <$ 100 GeV

$p_{had} > 0.5 \times \sqrt{s_{eff}}/2$

- Event cuts:
  - 80 GeV $< \sqrt{s_{eff}} <$ 100 GeV
  - $|\cos\theta_{jet}| < 0.8$ for both jets
- Leading particle cuts:
  - $|\cos\theta_{had}| < 0.8$
  - $p_{had} > 0.5 \times \sqrt{s_{eff}}/2$
- Considering $\pi^{\pm}$, $K^{\pm}$, p, K_S^0, Λ

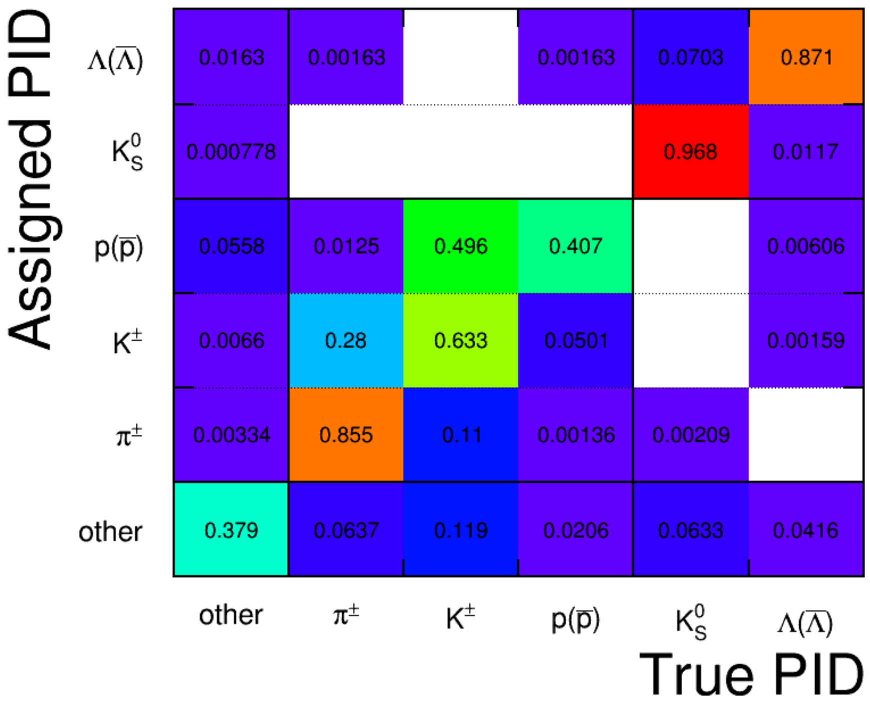


Particle ID

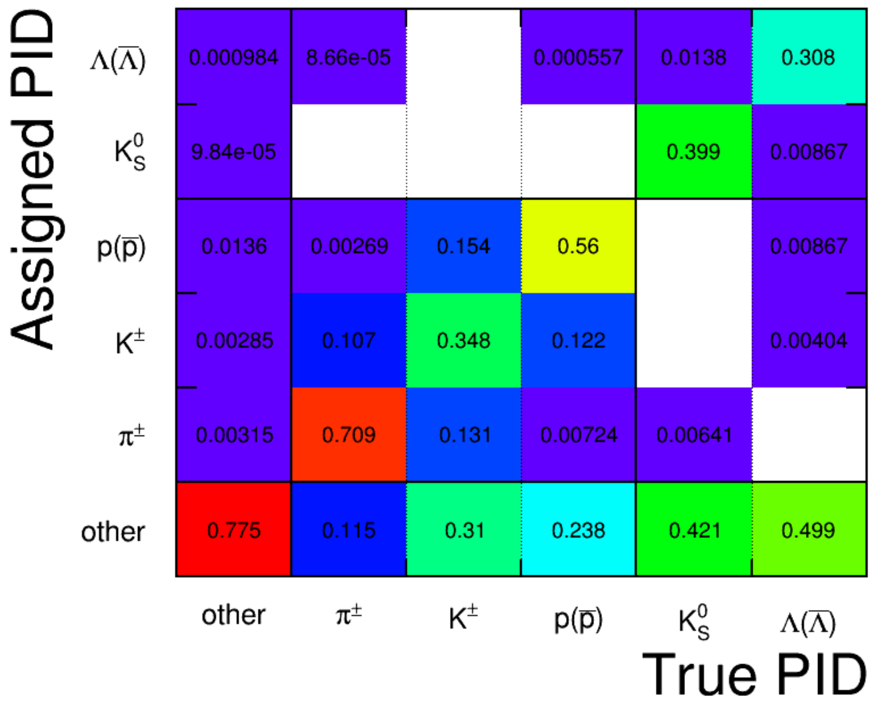
80 GeV $< \sqrt{s_{eff}} <$ 100 GeV, $p_{had} > 0.5 \times \sqrt{s_{eff}}/2$

- K_S^0 and Λ are identified by V0Finder in standard reconstruction.
- No dE/dx PID done in DBD samples.
- Applying toy PID to leading particles based on dE/dx separation power calculated by Uli Einhaus on iLCSoft v01-19-05.

PID purities



PID efficiencies



Data

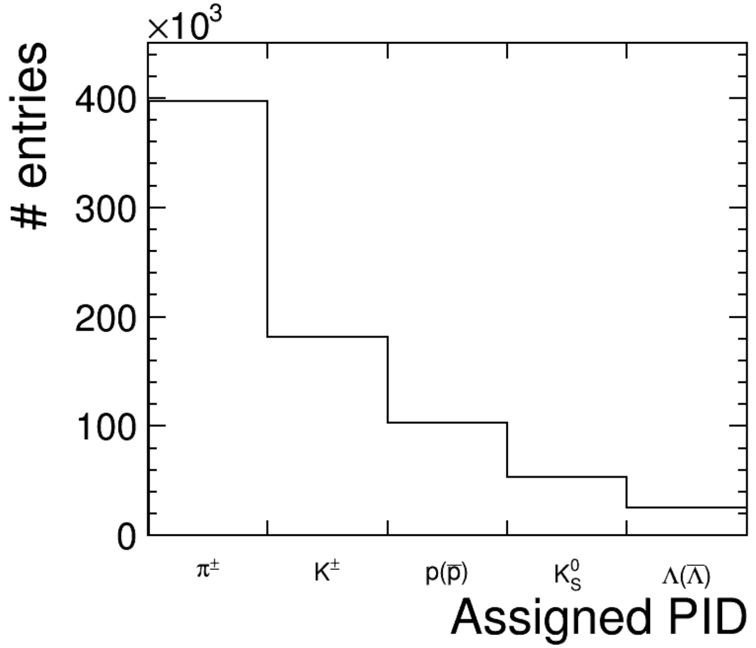
80 GeV $< \sqrt{s_{eff}} <$ 100 GeV

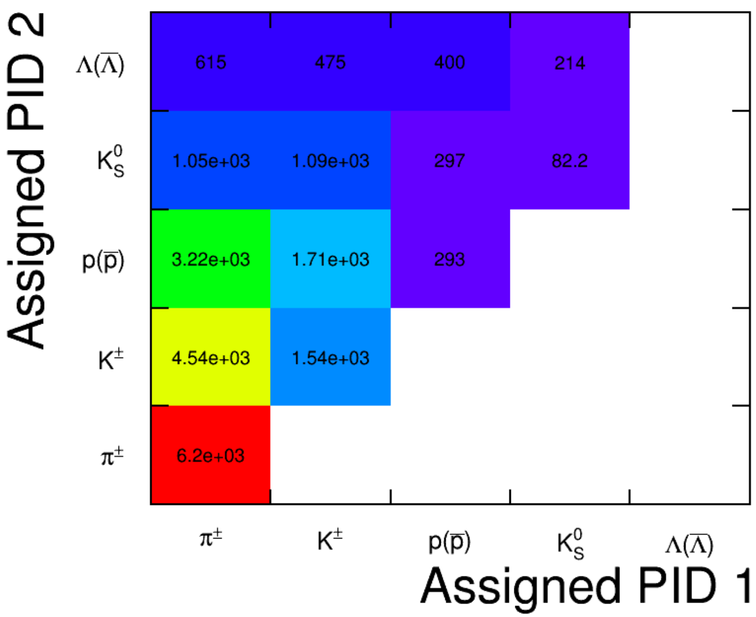
$p_{had} > 0.5 \times \sqrt{s_{eff}}/2$

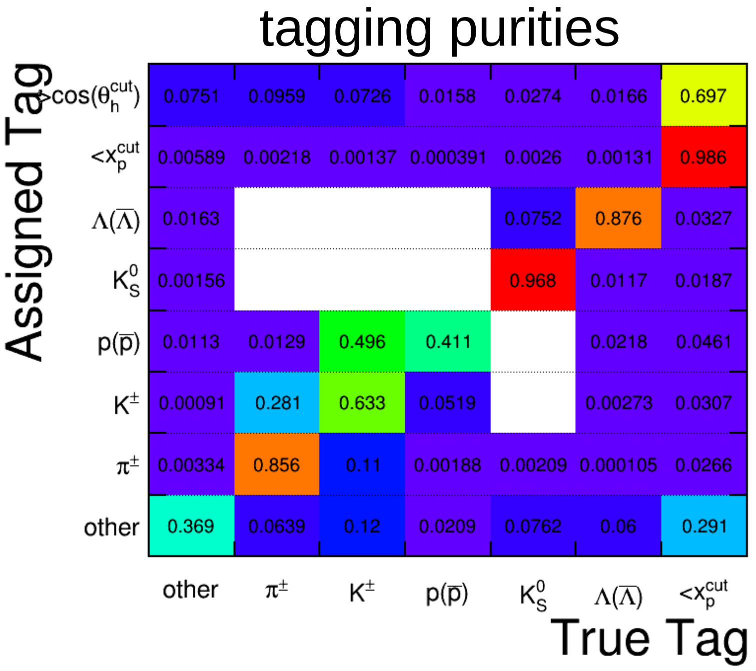
- Considering $\pi^{\pm}$, $K^{\pm}$, p, K_S^0, Λ
- Tagging efficiencies determined from MC.
- Applying tagging efficiencies to reconstructed data:

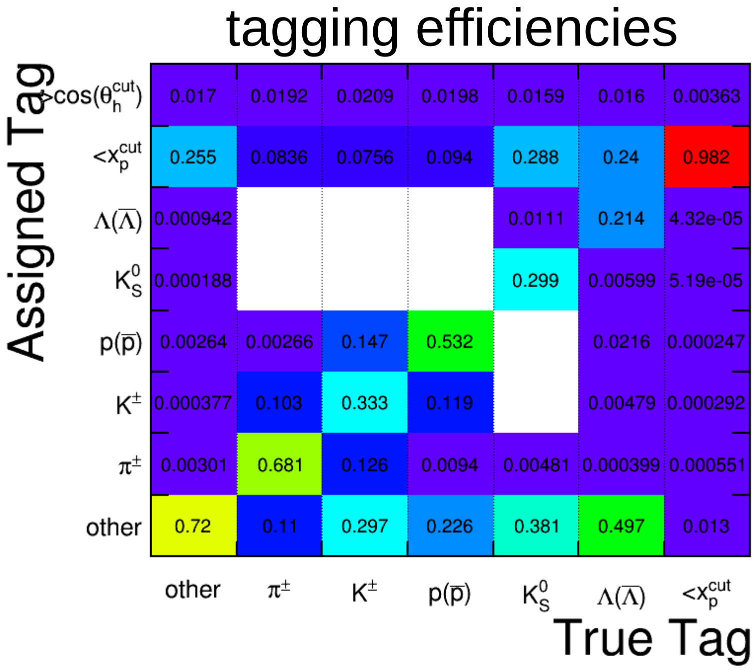
$$\eta_q^{i,exp} = \sum_j \varepsilon_i^j \eta_q^j$$

- Determination of heavy quark contamination in reconstructed samples is cheated with MC truth.









Chi-square Function

The equation system

$$\frac{N_i}{N_{had}} = 2 \times \sum_q \eta_q^{i,exp} R_q$$

$$\frac{N_{ij}}{N_{had}} = (2 - \delta_{ij}) \times \sum_q \rho_{ij} \eta_q^{i,exp} \eta_q^{j,exp} R_q$$

leads to a chi-square function:

$$\chi^2 = \sum_i \left[\frac{\tilde{N}_i - 2N_{had} \times \sum_q \tilde{\eta}_q^i R_q}{\sqrt{\tilde{N}_i}} \right]^2 + \sum_{i,j} \left[\frac{N_{ij} - (2 - \delta_{ij}) \times \sum_q \rho \eta_q^{i,exp} \eta_q^{j,exp} R_q}{\sqrt{N_{ij}}} \right]^2$$

where

$$\tilde{N}_i = N_i - \sum_j (1 + \delta_{ij}) N_{ij}$$

and

$$\tilde{\eta}_q^i = \eta_q^{i,exp} - \sum_j \rho \eta_q^{i,exp} \eta_q^{j,exp}$$

are needed to correct for double counting between the single and double tagged samples.

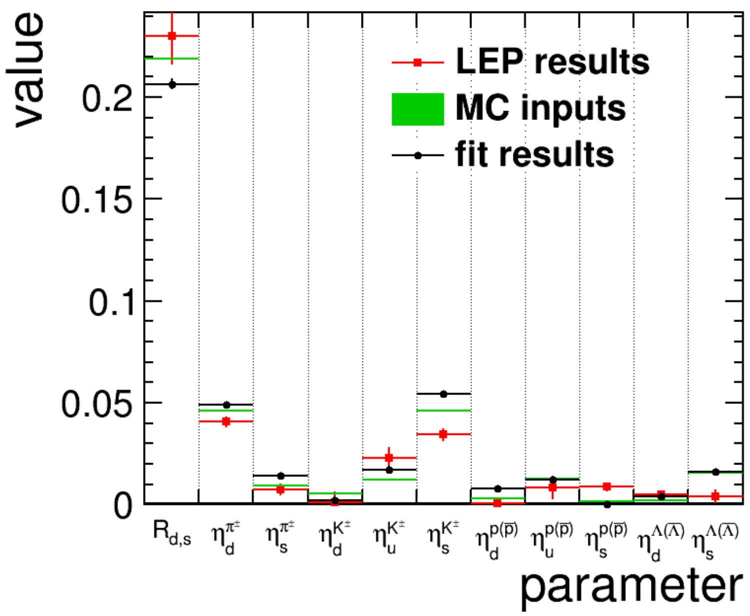
MC shows correlation factors $\rho_{ij} = \rho$ are independent of hadron type for the hadrons used here.

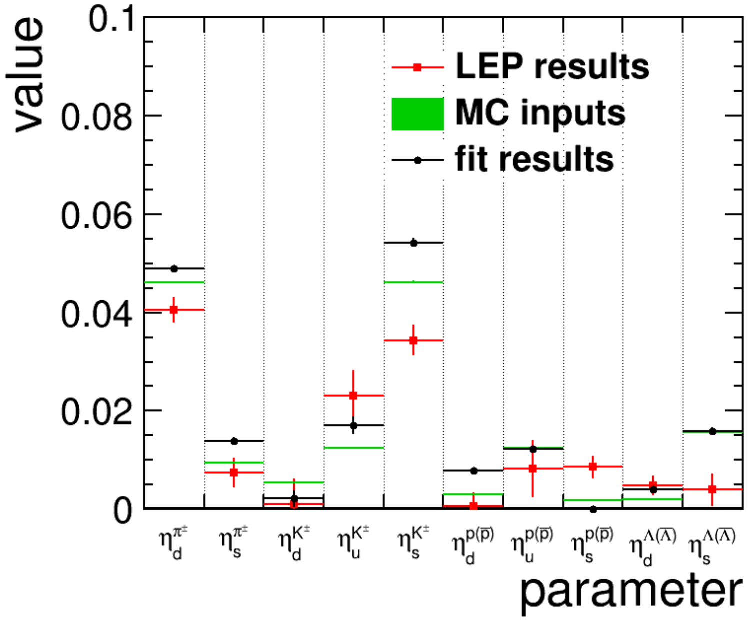
Results

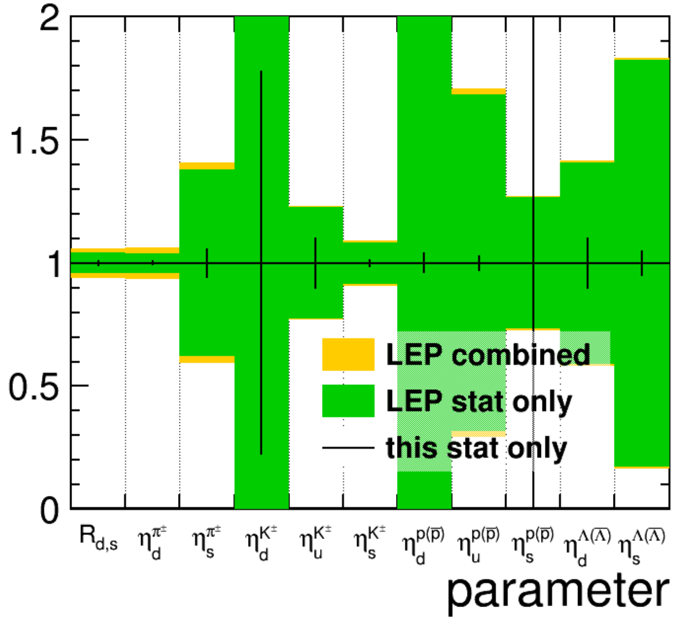
80 GeV $< \sqrt{s_{eff}} <$ 100 GeV

$p_{had} > 0.5 \times \sqrt{s_{eff}}/2$

- $\chi^2/ndf = 496.28/7$ with an average event weight of 41.35
  - Effective $\chi^2/ndf = 12.00/7$
  - Unweighted $\chi^2/ndf = 9.37/7$
- Statistical errors only.
- LEP (OPAL) results for comparison (full errors)







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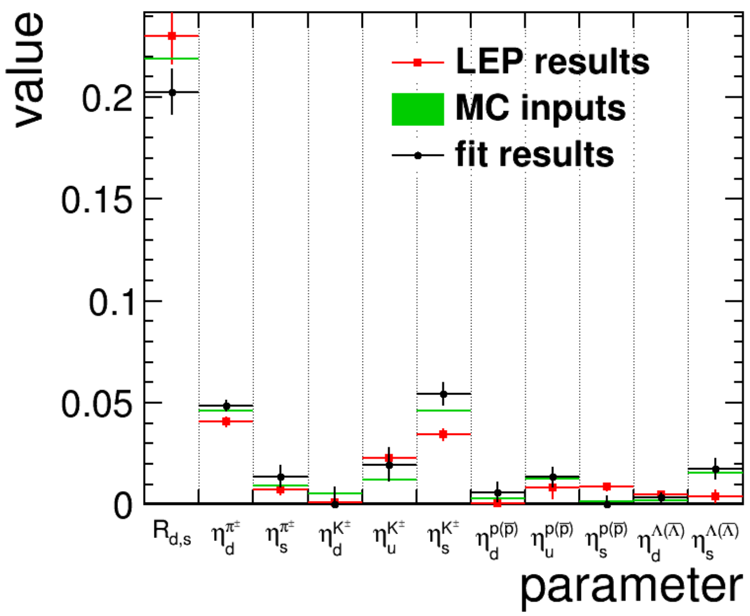

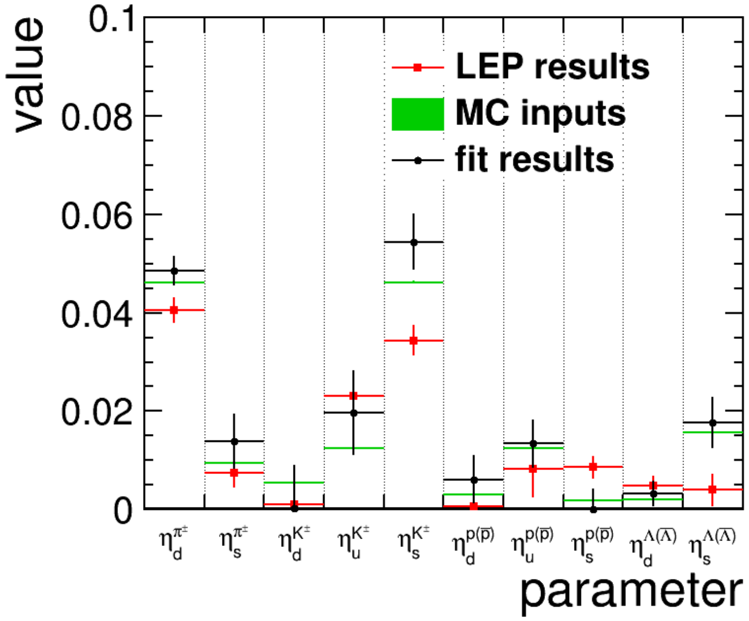

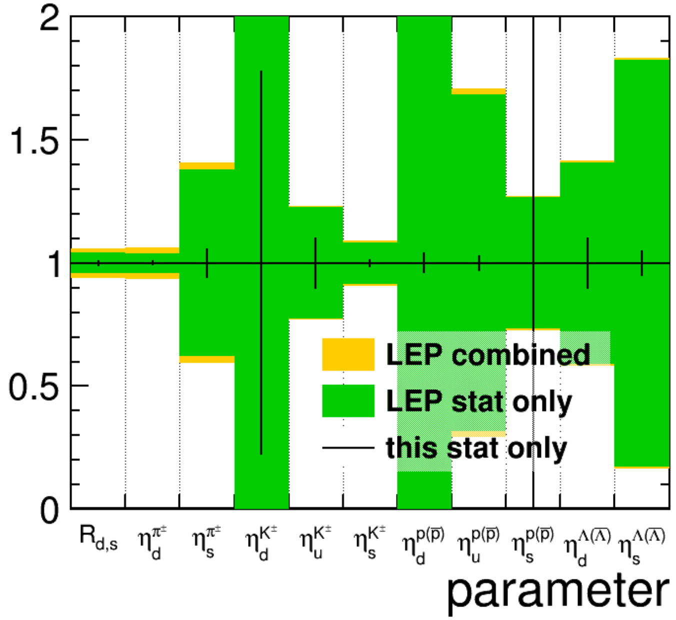

Summary

- Measurement of light quark branching fractions was implemented.
- Statistical errors significantly improved over corresponding OPAL analysis.
  - Factor ~3-4 for $R_{d,s}$.
- Major difficulties to be expected at ILC over LEP:
  - Reconstruction of ISR / effective center of mass.
  - dE/dx PID of high momentum leading particles.