Hadronization Properties of Quark and Antiquark Jets

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Inclusive Identified Hadron Production

- $\pi^{\pm}$, $K^{\pm}$, $p/\overline{p}$ 1_186
- ρ^0, f^0, f^2 1_397

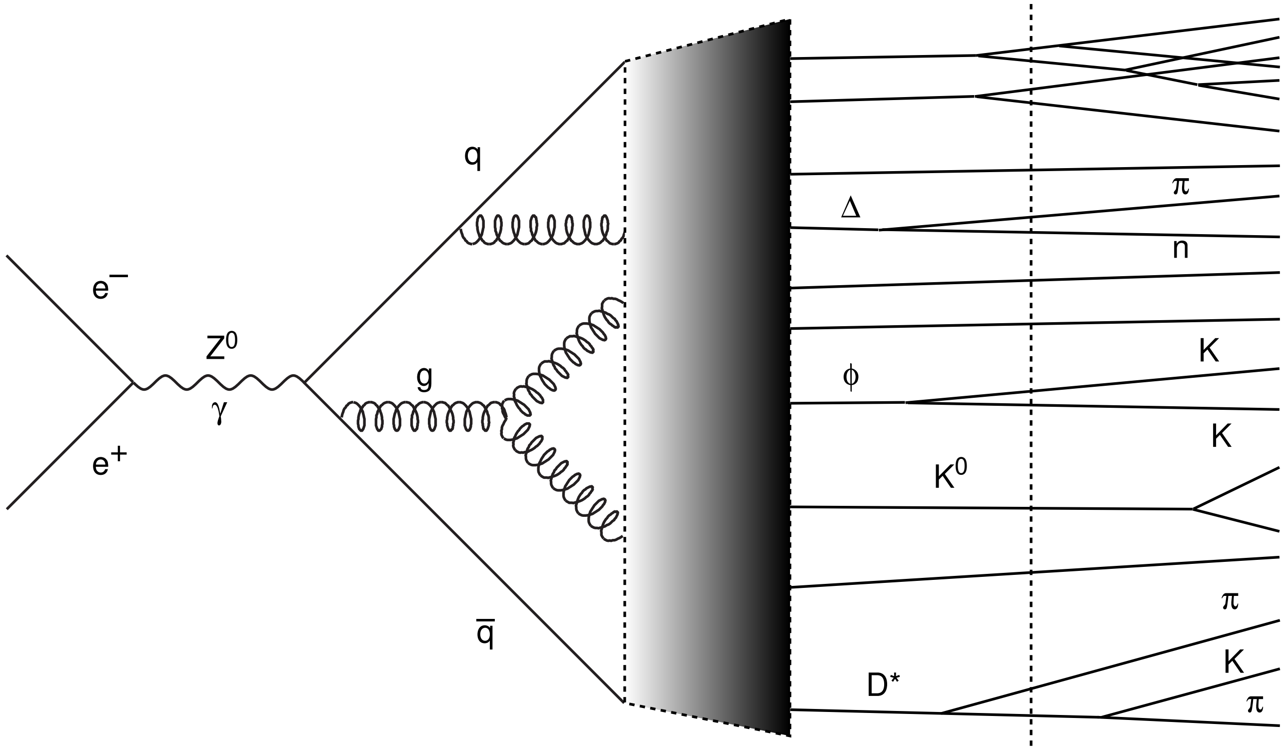
Flavor Dependent Hadron Production

- Inclusive charged tracks 1_220
- $\pi^{\pm}$, $K^{\pm}$, $p/\overline{p}$ 1_186

Leading Particle Production

- $\pi^{\pm}$, $K^{\pm}$, $p/\overline{p}$ 1_186

The hadronization process remains one of the last frontiers in elementary particle physics



Very few theoretical predictions

- left-hand side understood for > 10 years (MLLA, parton showers)

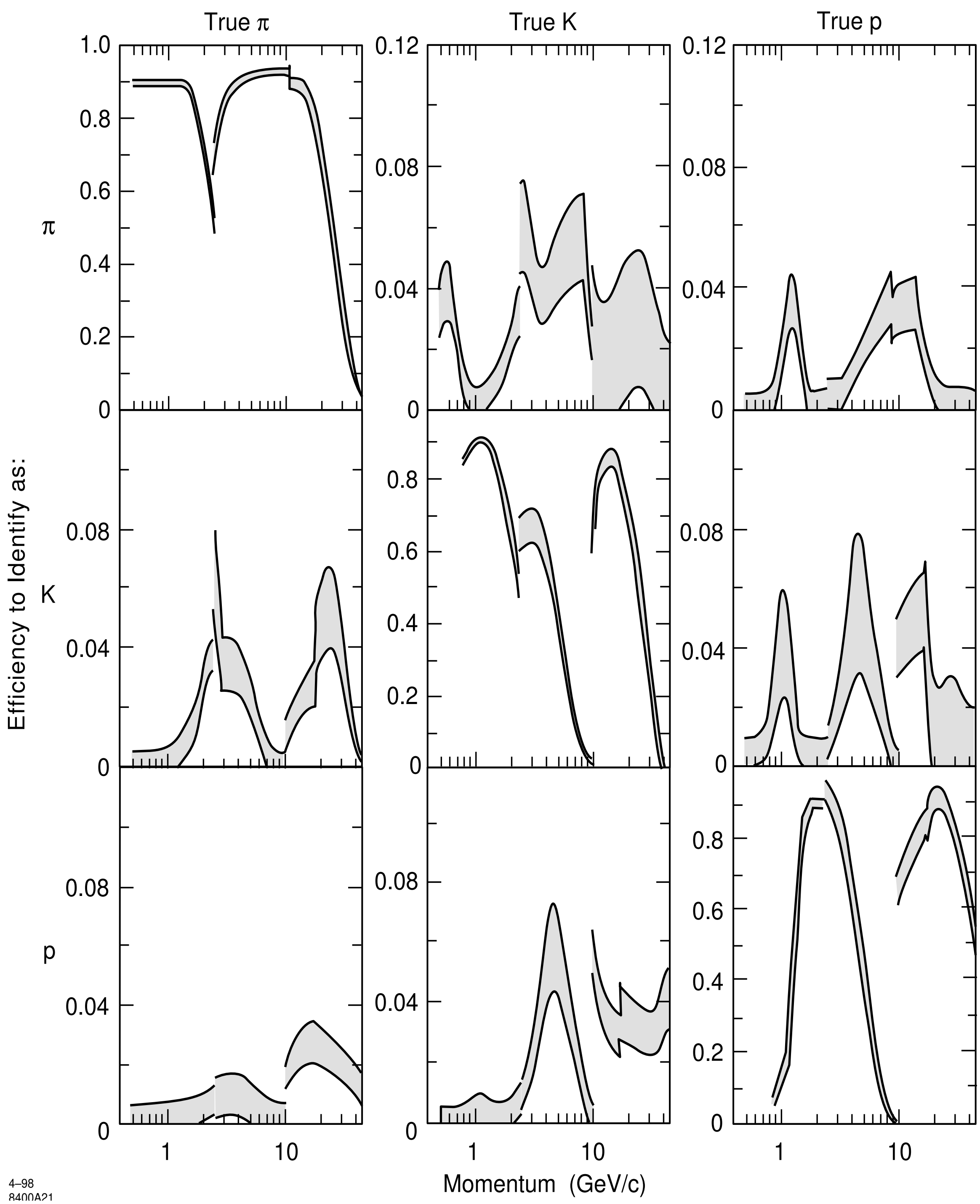
Much recent experimental progress:

- more/heavier particles found in jets
  $\longrightarrow$ pushing in on the right side
- separation of jets of different flavors
- separation of (light) $q/\bar{q}$ from gluon jets
  $\longrightarrow$ see talk by W. Gary
- direct studies of leading particle production
  $\longrightarrow$ separation of (light) q from $\bar{q}$ jets (this talk)
  $\longrightarrow$ see also talk by C. Grandi

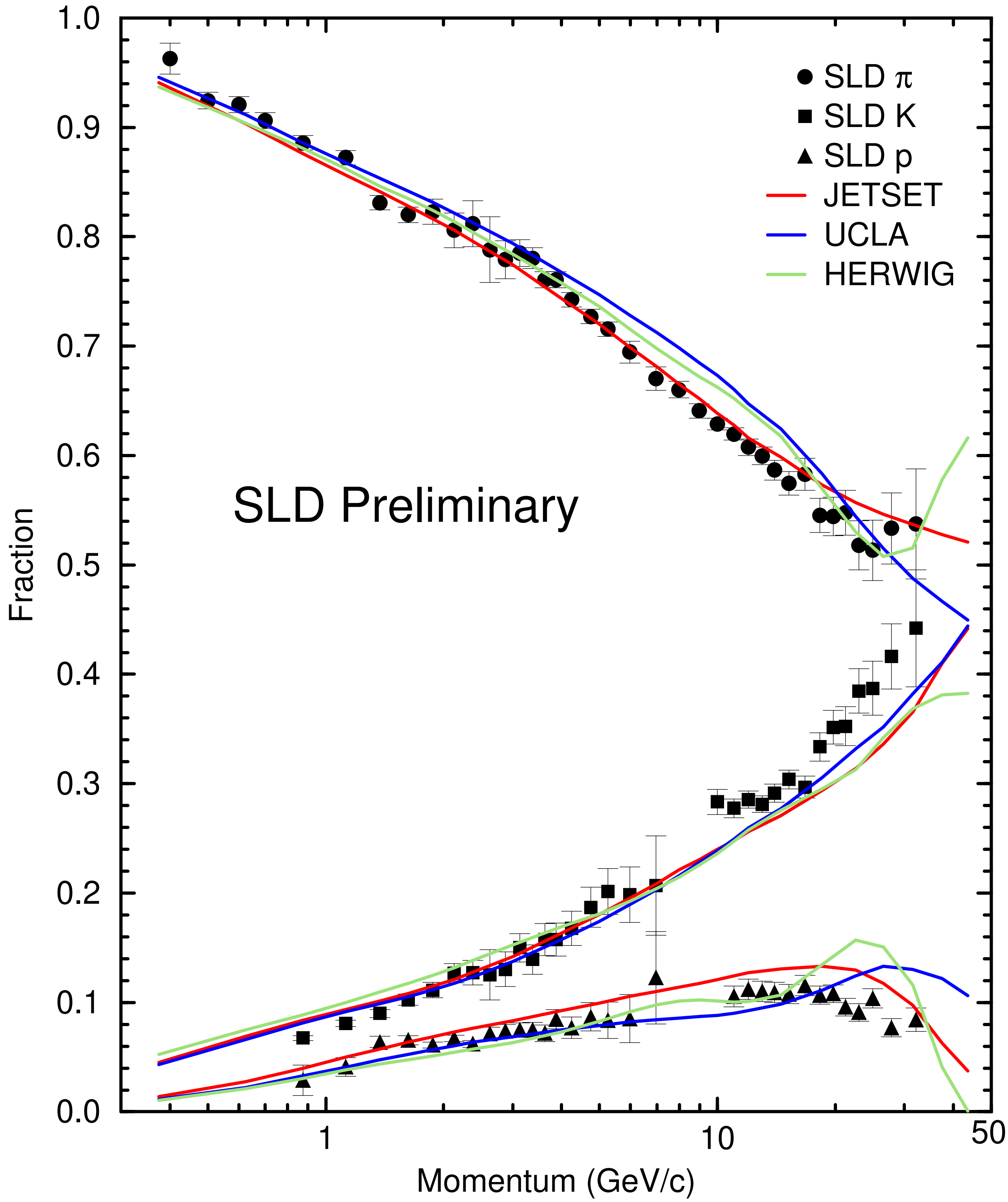
Inclusive Identified Hadrons

1) Charged $\pi^{\pm}$, $K^{\pm}$, $p/\overline{p}$

Updated result from SLD (1_186) using Cherenkov Ring Imaging to select clean samples of these hadrons



→ Precise measurements over wide p-range



→ increased lever arm for frag. model tests

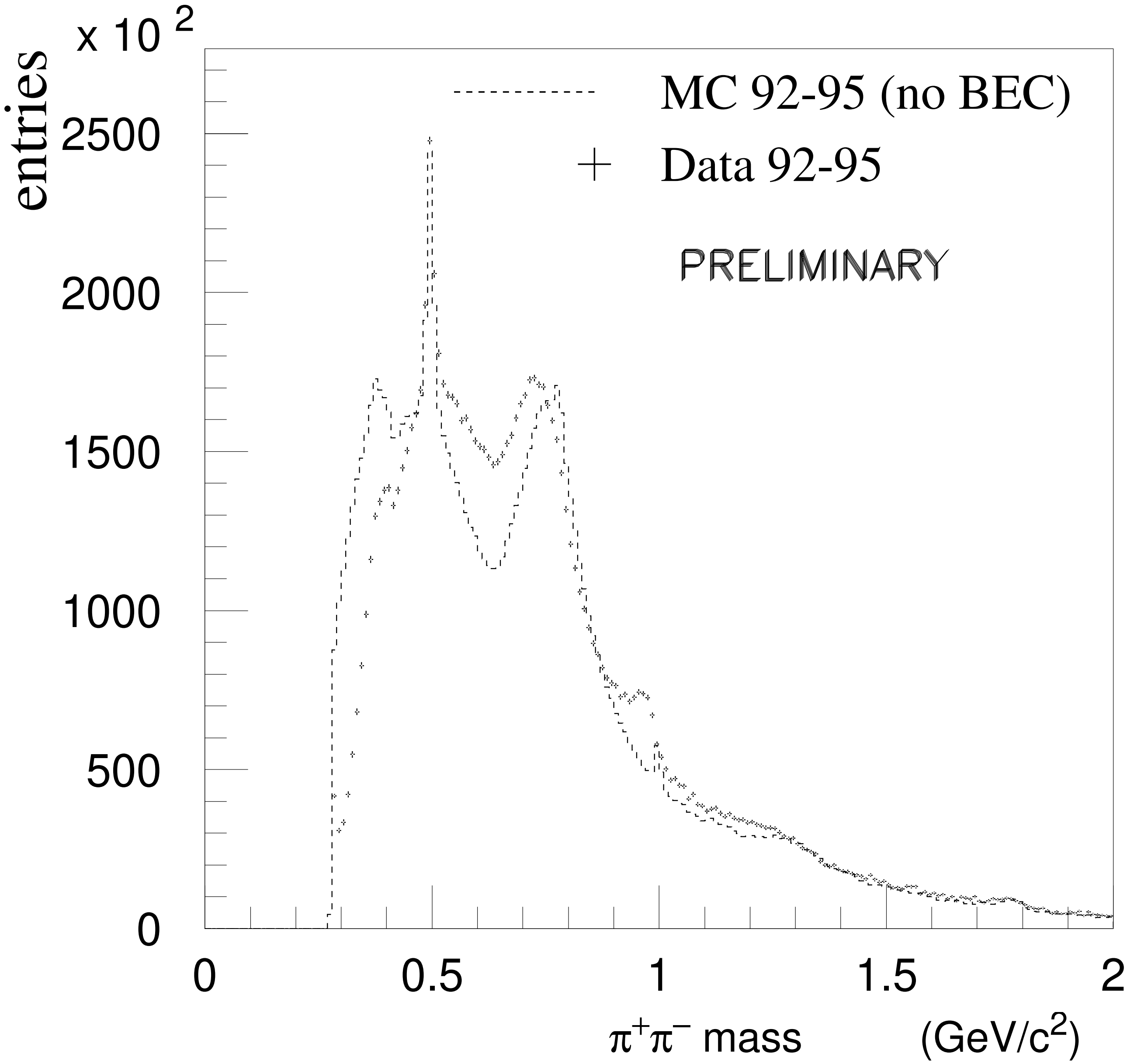
→ may models reproduce data qualitatively

→ no model reproduces all details

2) ρ^0, $f_0(980)$, $f_2(1270)$

New measurement from ALEPH (1_397)

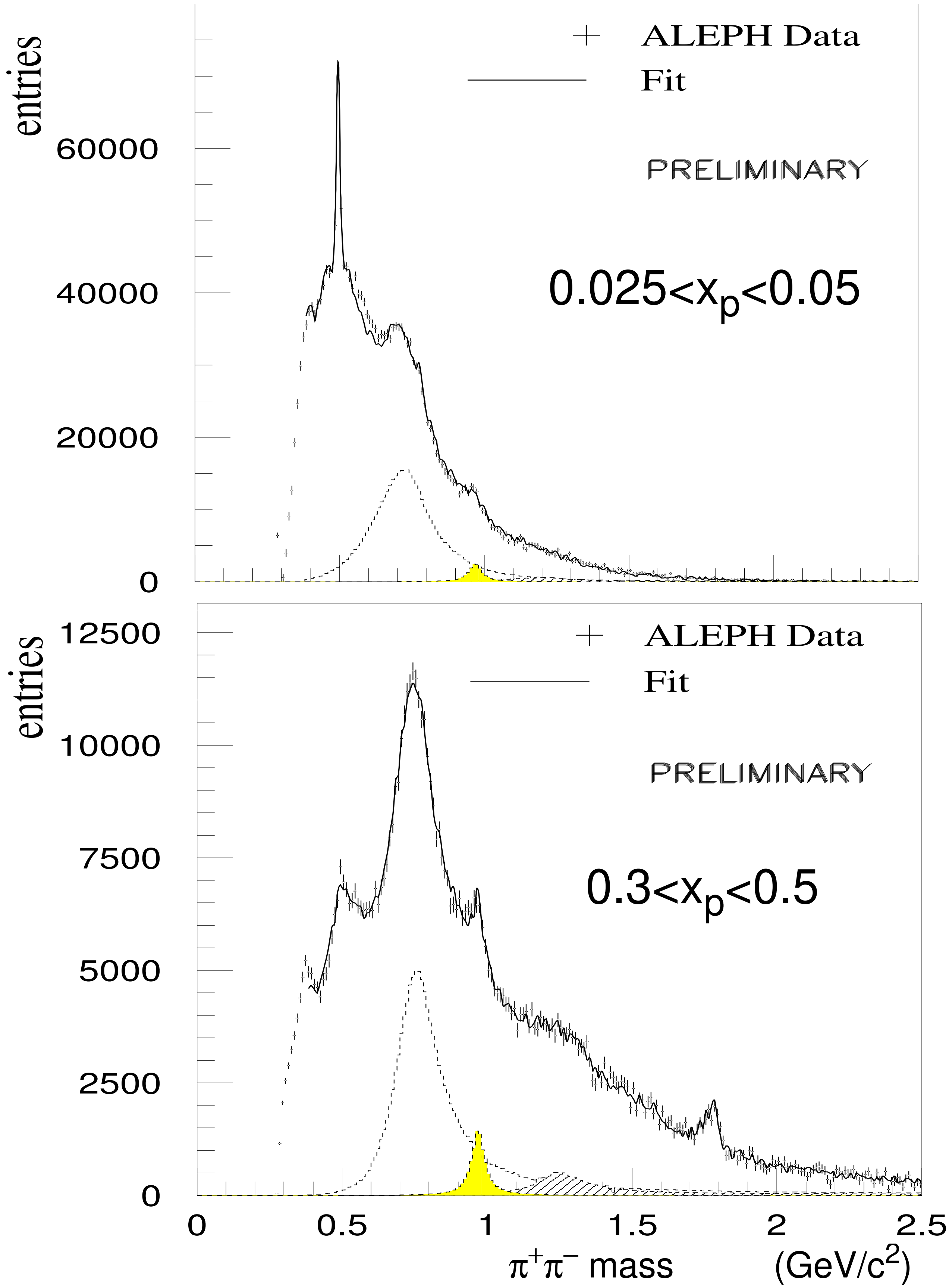
- $\pi^+\pi^-$ pairs with loose dE/dx $K^\pm$,p rejection
- Invariant mass spectrum inconsistent w/ MC



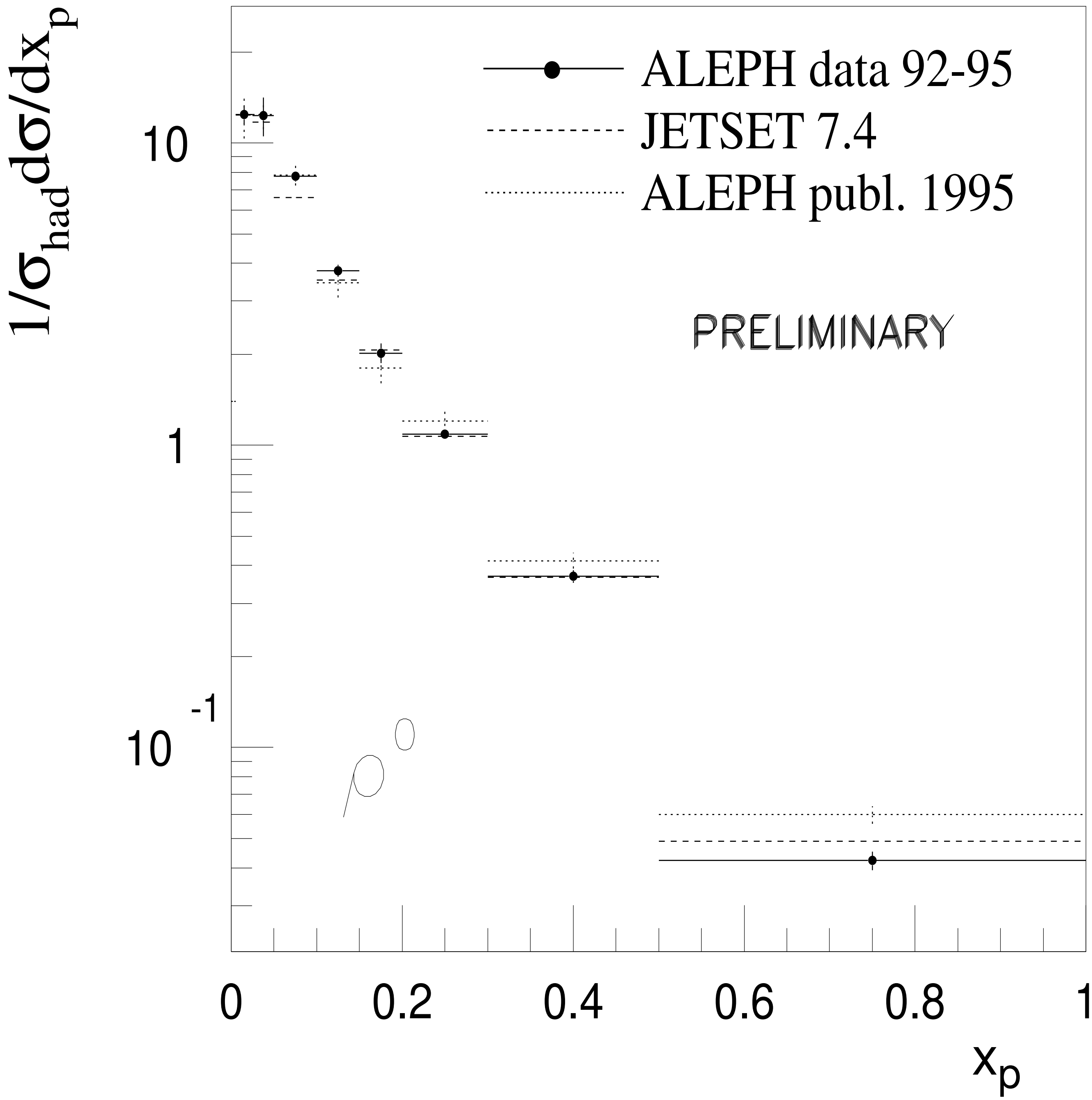
→ no Bose-Einstein correlations in MC

→ problems in $\eta/\eta'/\omega$ region

- fit the data in each x_p-bin using a function that includes resonances, reflections, BE effects

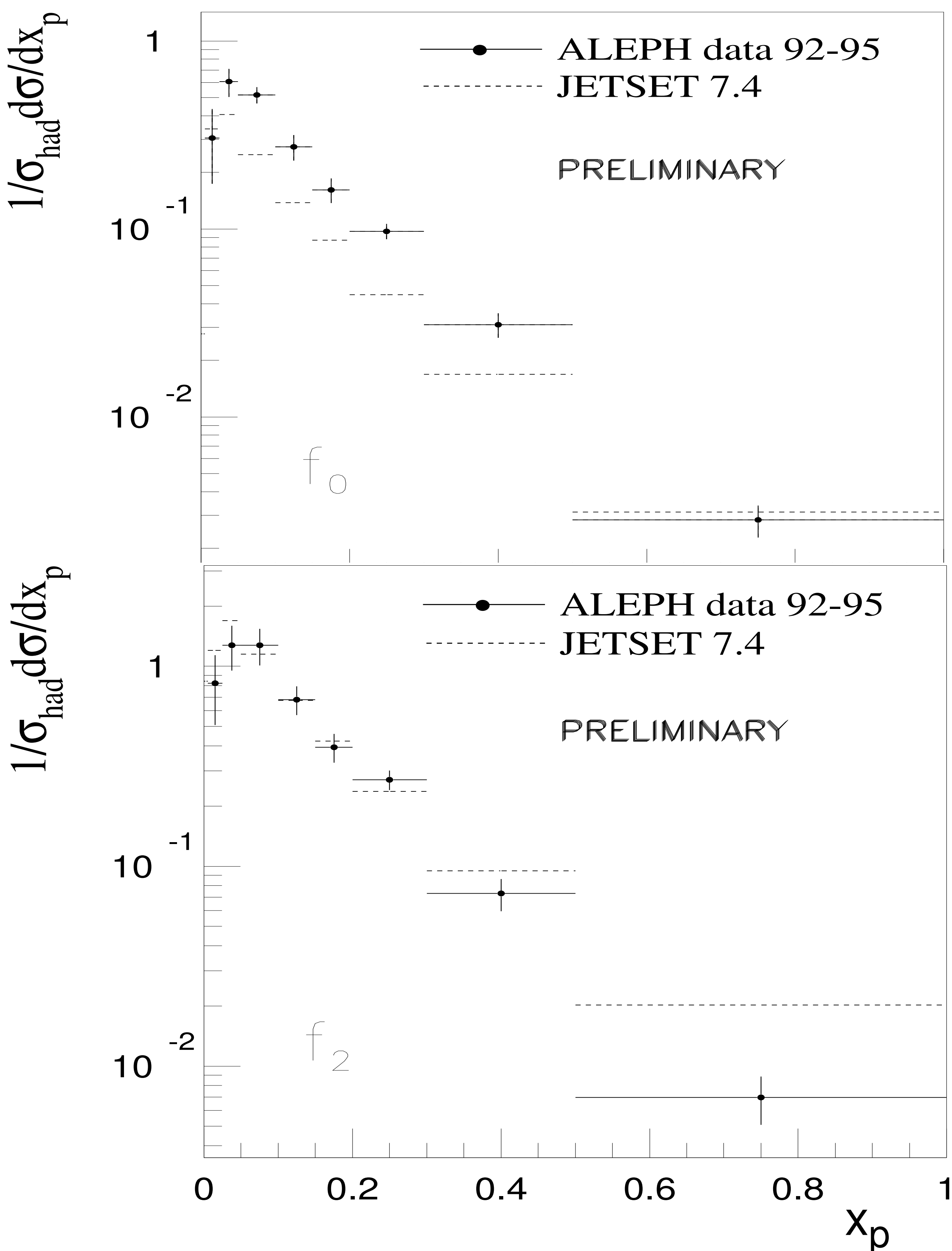


- from fitted signals, compute production cross sections per hadronic event



→ result for ρ^0 supersedes, changes prev. result

→ JETSET prediction consistent with data



→ JETSET OK for f_2 but very low for f_0

→ f_2:f_0 ratio inconsistent with spin counting

Examples of particles observed in Z^0 decays

slight update of Vancouver talk by P. Abreu

Hadron	<n>	Expts.	Hadron	<n>	Expts.
$\pi^\pm$	16.96±0.27	DOS	$f_2(1270)$	0.185±0.015	ADO
π^0	9.76±0.26	ADLO	$f_2(1525)$	0.012±0.006	D
η	0.95±0.07	LO	$K^\pm$	2.25±0.06	DOS
ρ^0	1.44±0.06	ADO	K^0	2.02±0.02	ADLOS
ω	1.08±0.09	ALO	K^{*0}	0.74±0.02	DOS
η'	0.17±0.05	LO	$K_2(1430)$	0.073±0.025	D
$f_0(980)$	1.54±0.07	ADO	p	1.05±0.04	DOS
$a_0(980)$	0.27±0.11	O	Λ^0	0.374±0.007	ADLOS
$\phi(1020)$	0.098±0.006	ADOS	$\Lambda(1520)$	0.023±0.004	DO

Hadronization is now known to produce pseudoscalar, vector, tensor, scalar mesons, octet, decuplet, excited baryons

What else? Does a jet typically comprise only a few primary resonances?

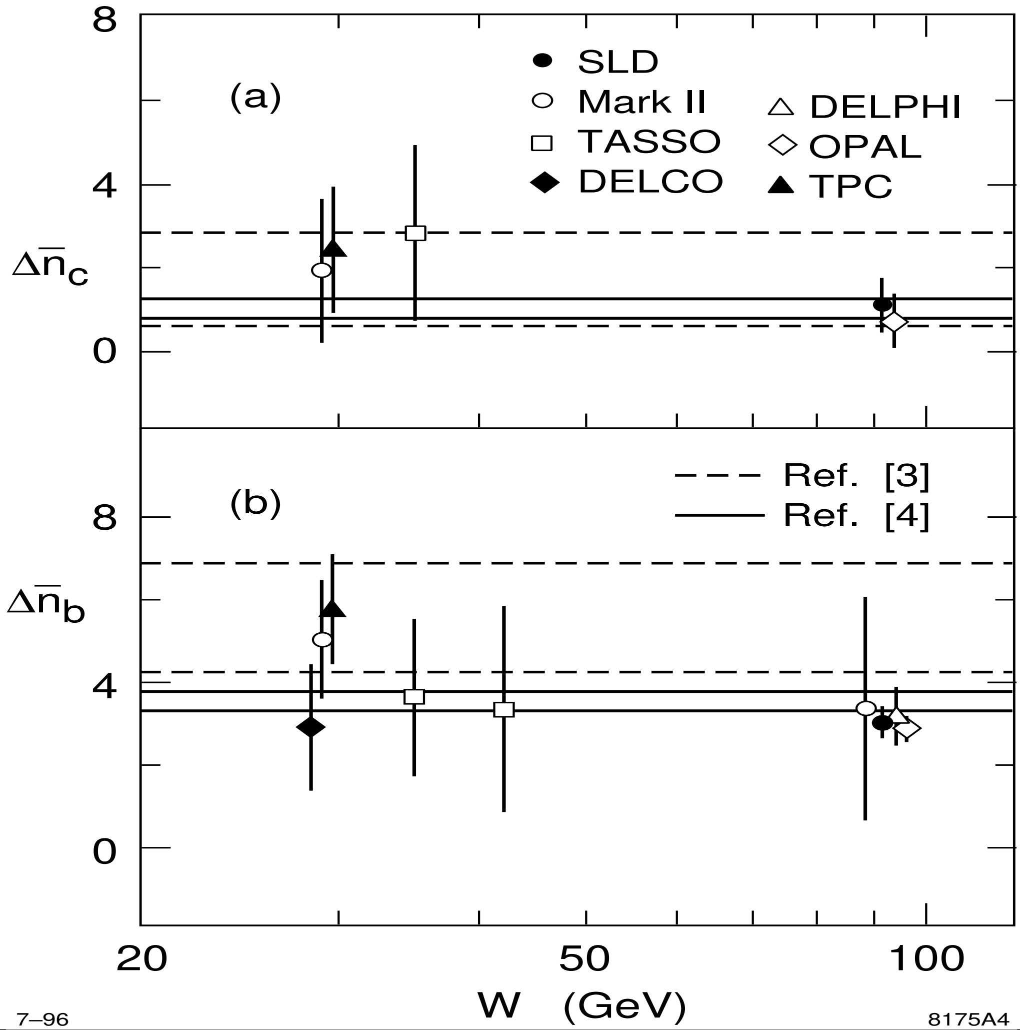
Flavor Dependent Hadron Production

1) Average charged multiplicity, 29-189 GeV

- There are very few precise, testable theoretical predictions for hadronization
- MLLA calcs for suppression of soft, collinear gluons from a massive quark are one
- With LPHD: the $\langle n_{ch} \rangle$ difference between events of two flavors is independent of E_{CM}:

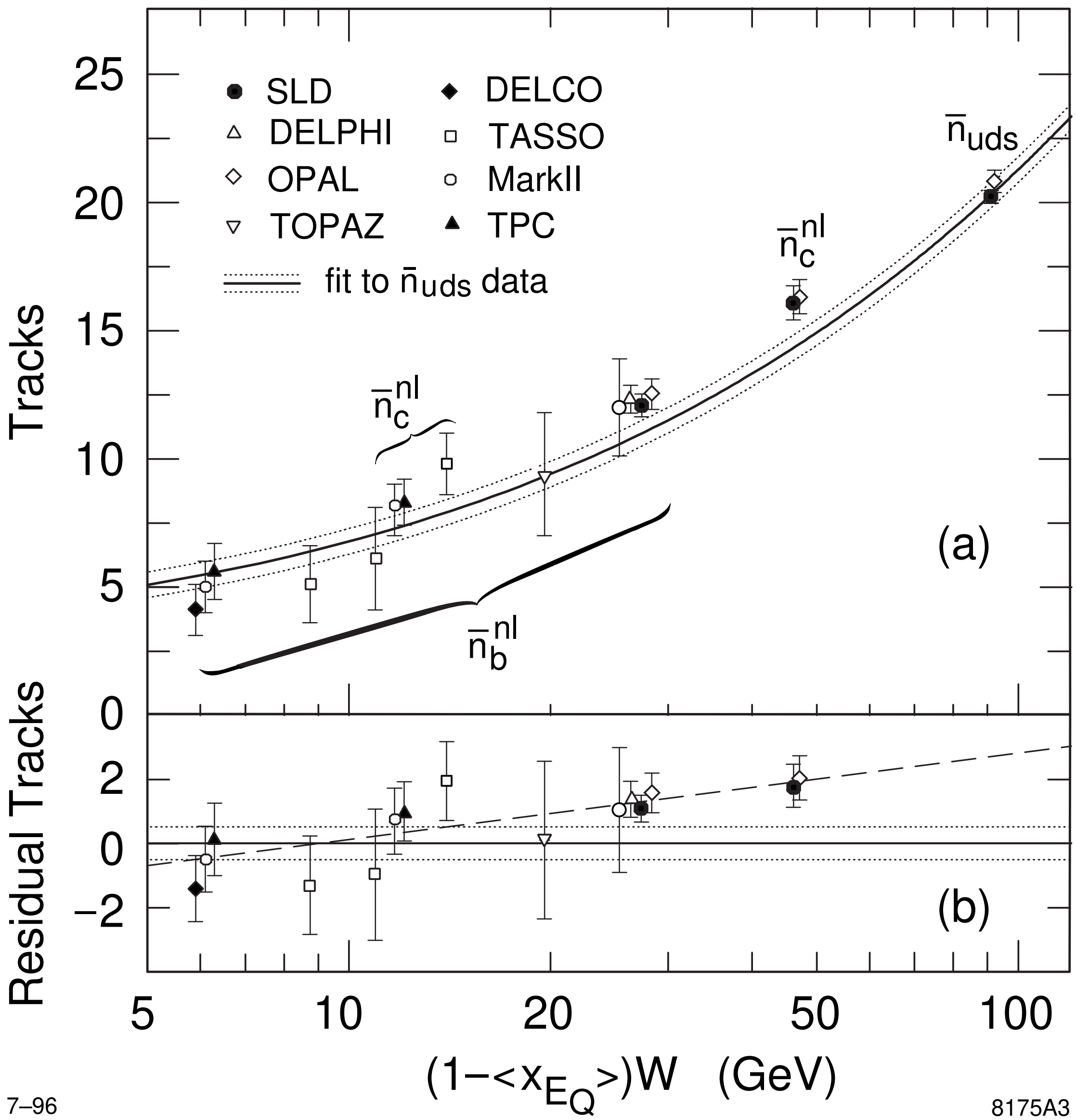
$\langle n_{ch} \rangle_b - \langle n_{ch} \rangle_{uds} = 3.5$, $\langle n_{ch} \rangle_c - \langle n_{ch} \rangle_{uds} = 1.0$

- Many measurements at the E_{CM} up to m_Z



→ Results consistent with theory predictions

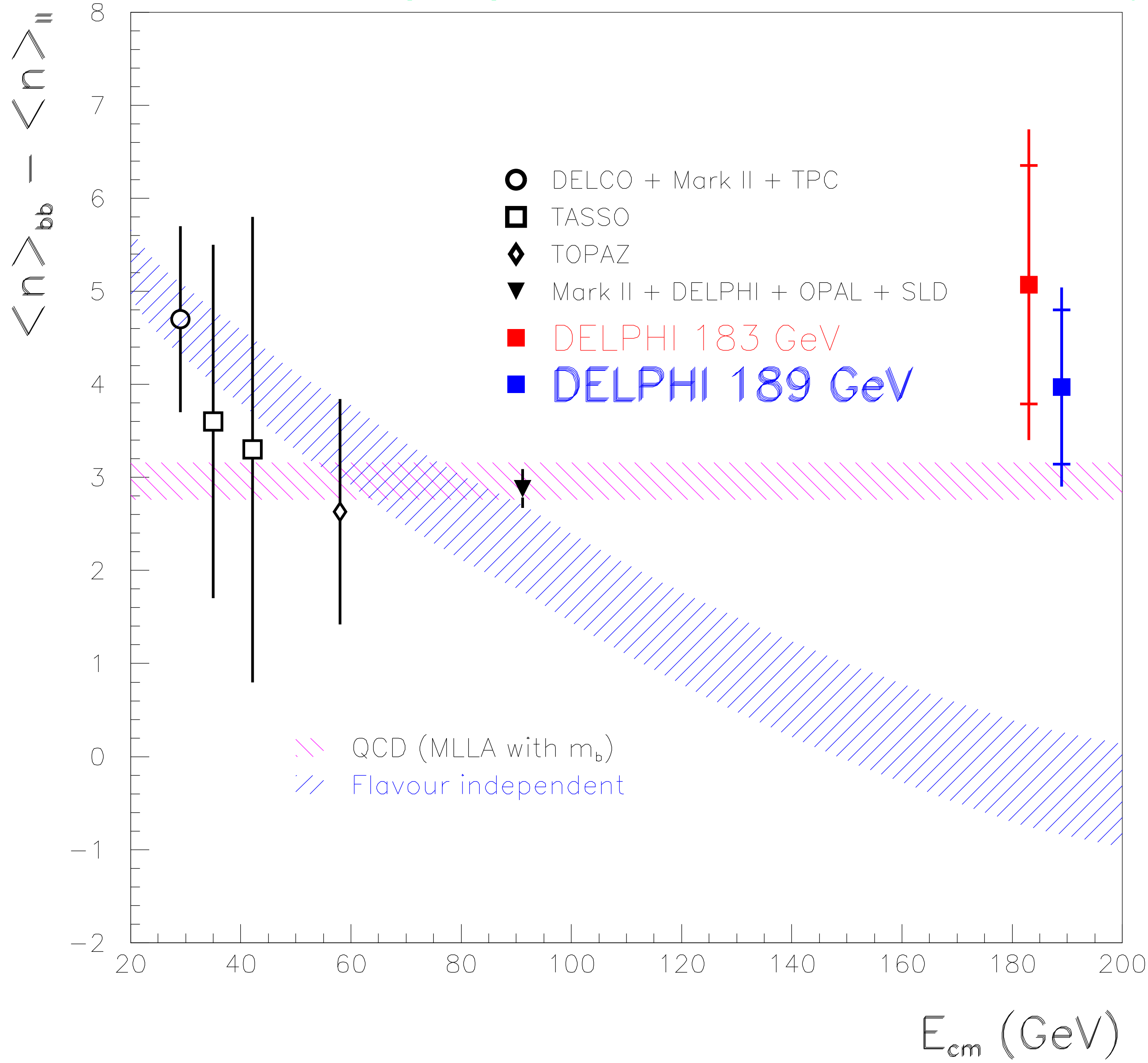
→ ...and with a number of other models, e.g. flavor-independent fragmentation:



New analysis by DELPHI (1_220) LEPII

- tag samples of $b\bar{b}$ and light-flavor events using an optimized combination of lifetime, event shape information

- measure $\langle n_{ch} \rangle$ in each tagged sample, and the inclusive hadronic sample
- unfold for sample purities, correct for efficiency



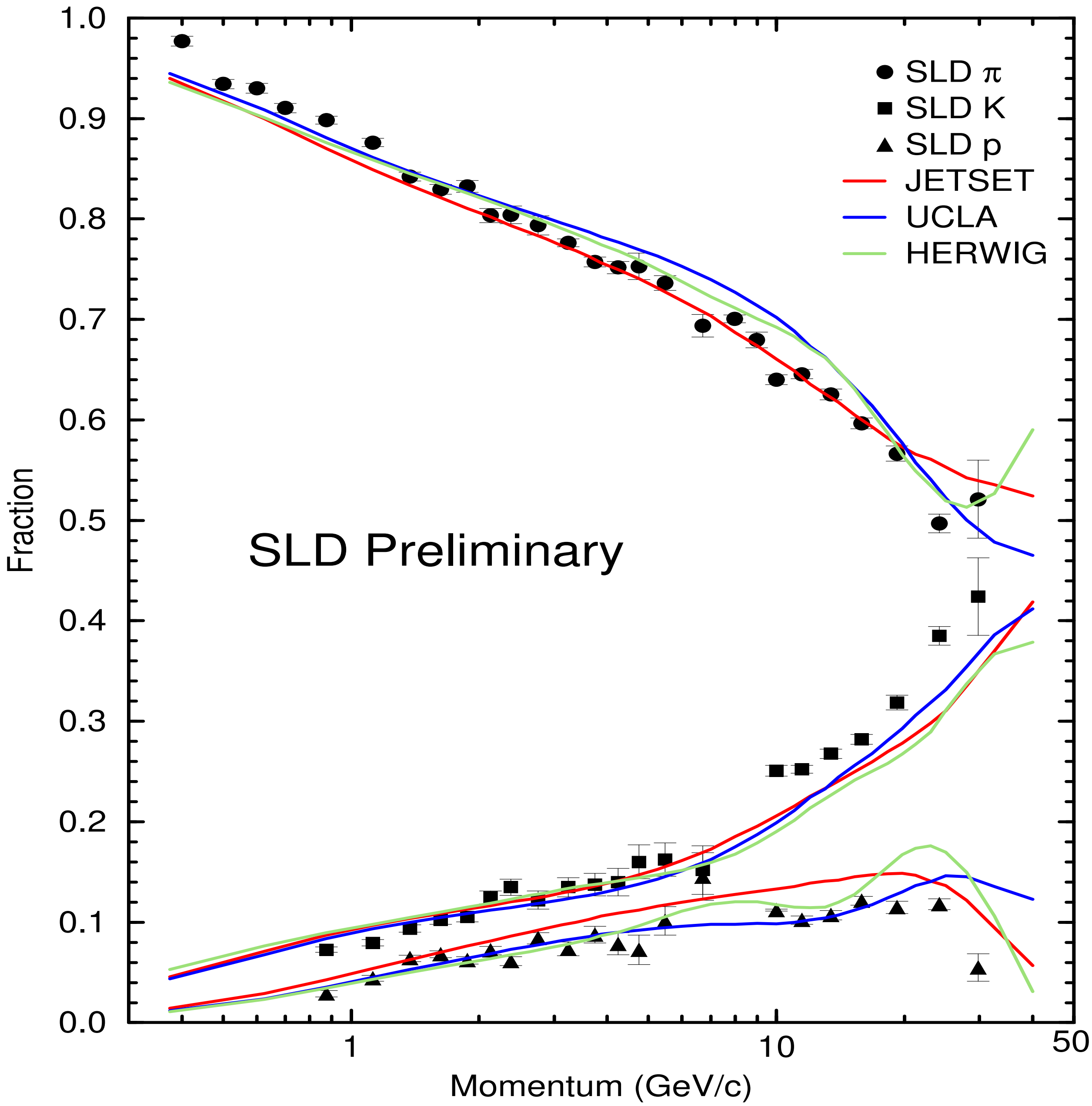
→ consistent with QCD prediction

→ clearly inconsistent with the hypothesis of flavor-independent fragmentation

2) $\pi^{\pm}$, $K^{\pm}$, $p/\overline{p}$ production at 91 GeV

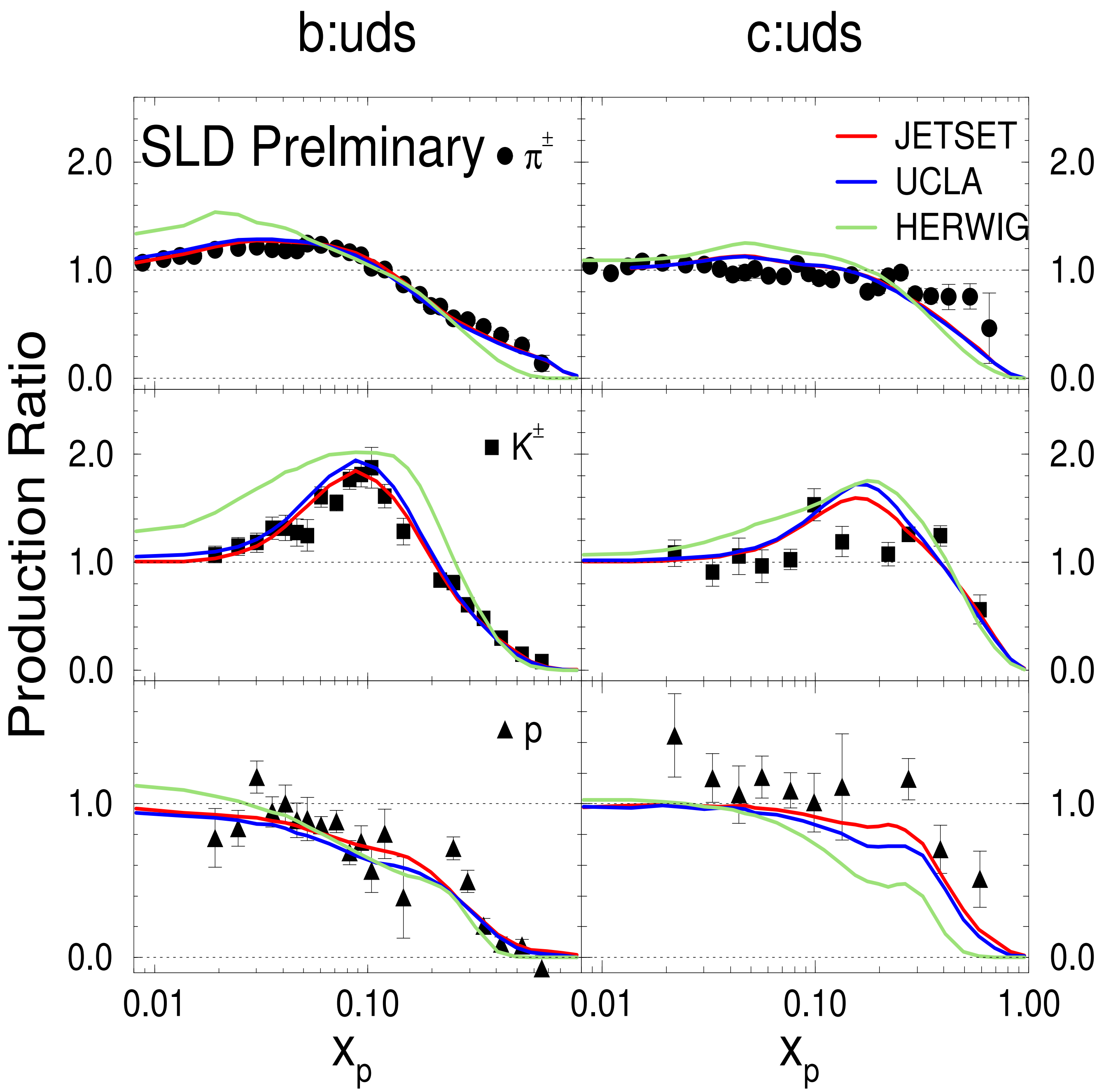
Updated analysis by SLD (1_186)

- tag pure samples of uds, c, b events using vertex information
- unfold measured π,K,p fractions for sample purities, bias uds $\rightarrow$ 'pure' frag. tests:



$\rightarrow$ same problems as in all-flavor events

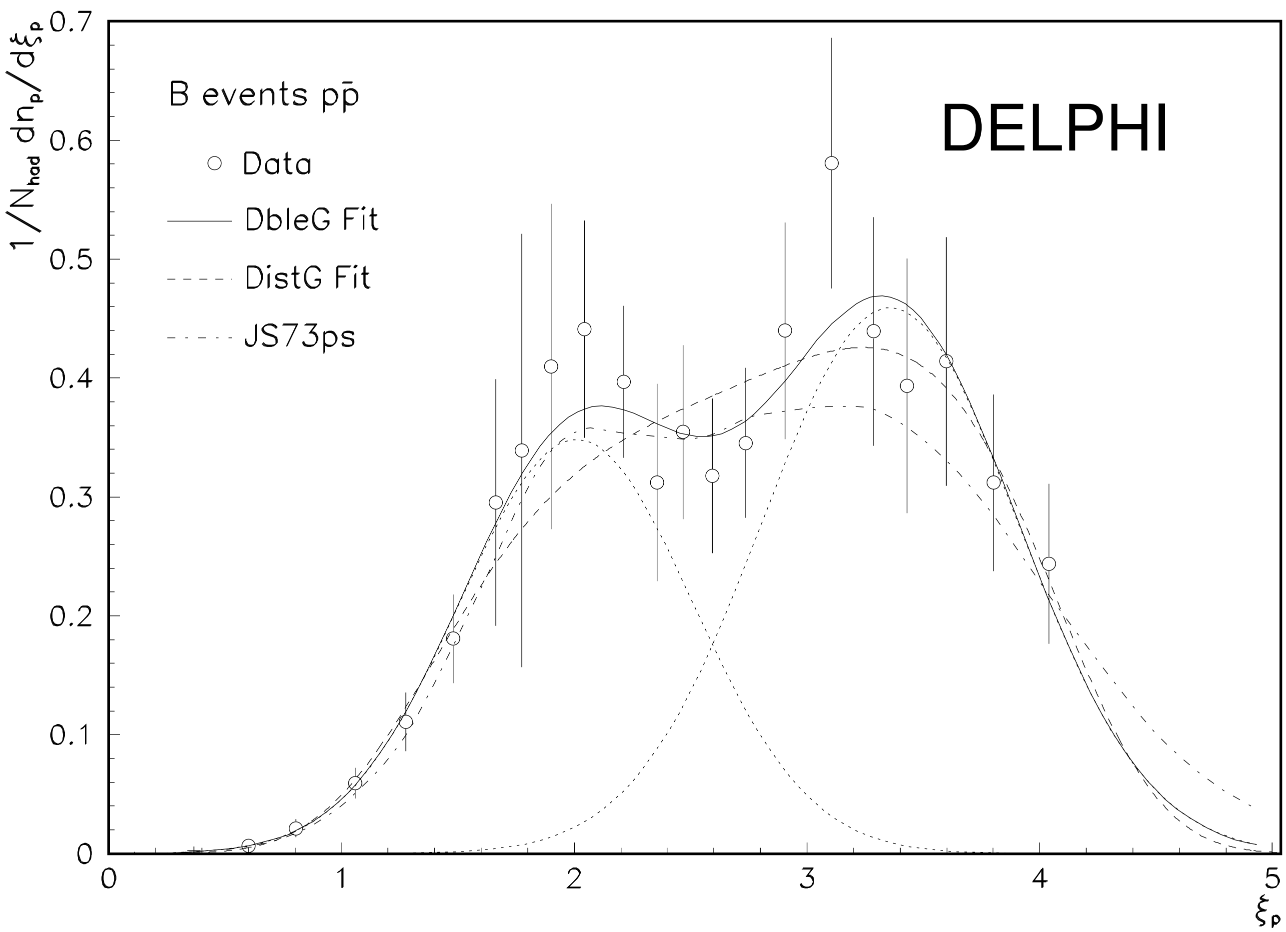
• B D hadrons have a large effect on the inclusive production properties:



→ qualitative features expected from hard frag., high decay multiplicity of B,D hadrons

→ precise model tests for B,D prod. & decay
problems with HERWIG π, K
all models suspect for high-x $p/\bar{p}$

- There are now several results on flavor-dependent hadronization from ALEPH, DELPHI, OPAL, SLD
- A number of known problems with fragmentation models for light flavors still exist, including the difference between $K^{\pm}$ and $K^0/\overline{K}^0$ production
- Some distributions of $\zeta = -\ln x_p$ are measured with sufficient precision in heavy flavor events to see that they are not Gaussian



Leading Particle Production

Updated analysis from SLD (1_186)

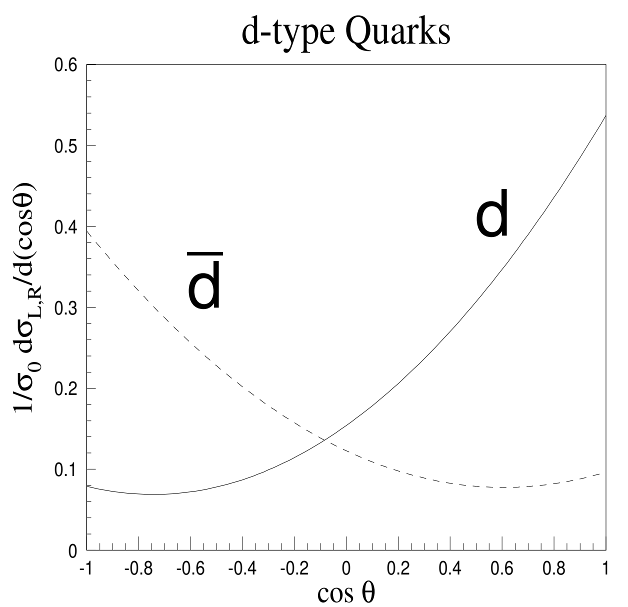
- Use uds-tagged events

- Select quark jets:

$|\cos\theta_{thrust}| > 0.2$

tag forward (backward) hemi. for LH (RH) beam

SM: 73% q, 27% $\bar{q}$

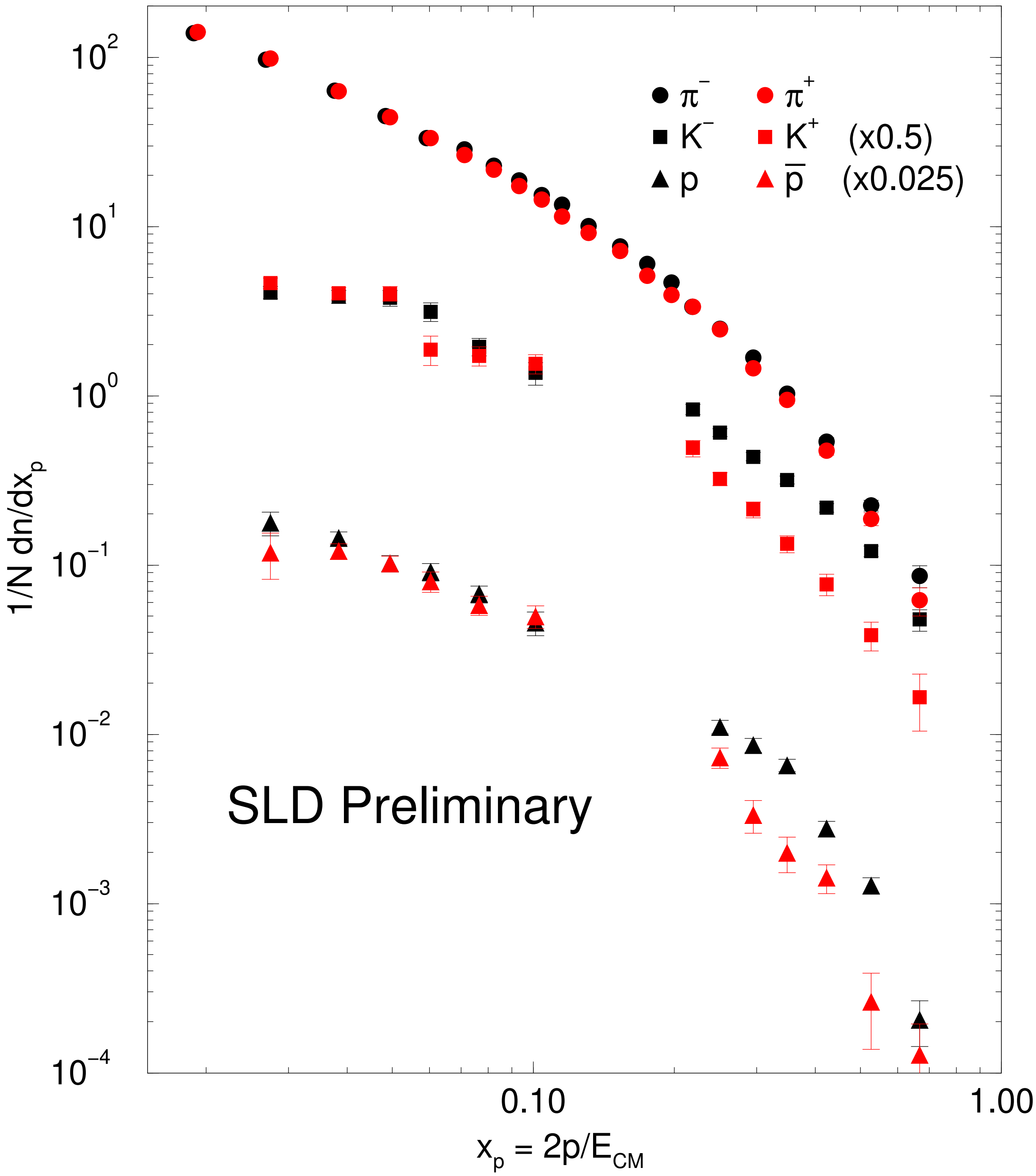


- Measure prod. of π^+ K^+ p Λ^0 separately
  π^- K^- $\bar{p}$ $\bar{\Lambda}^0$

- Subtract (small) heavy quark background and correct for quark sample purity

- Compare $q \rightarrow \pi^+$ with $q \rightarrow \pi^-$, etc.

Hadron and Antihadron production in uds jets

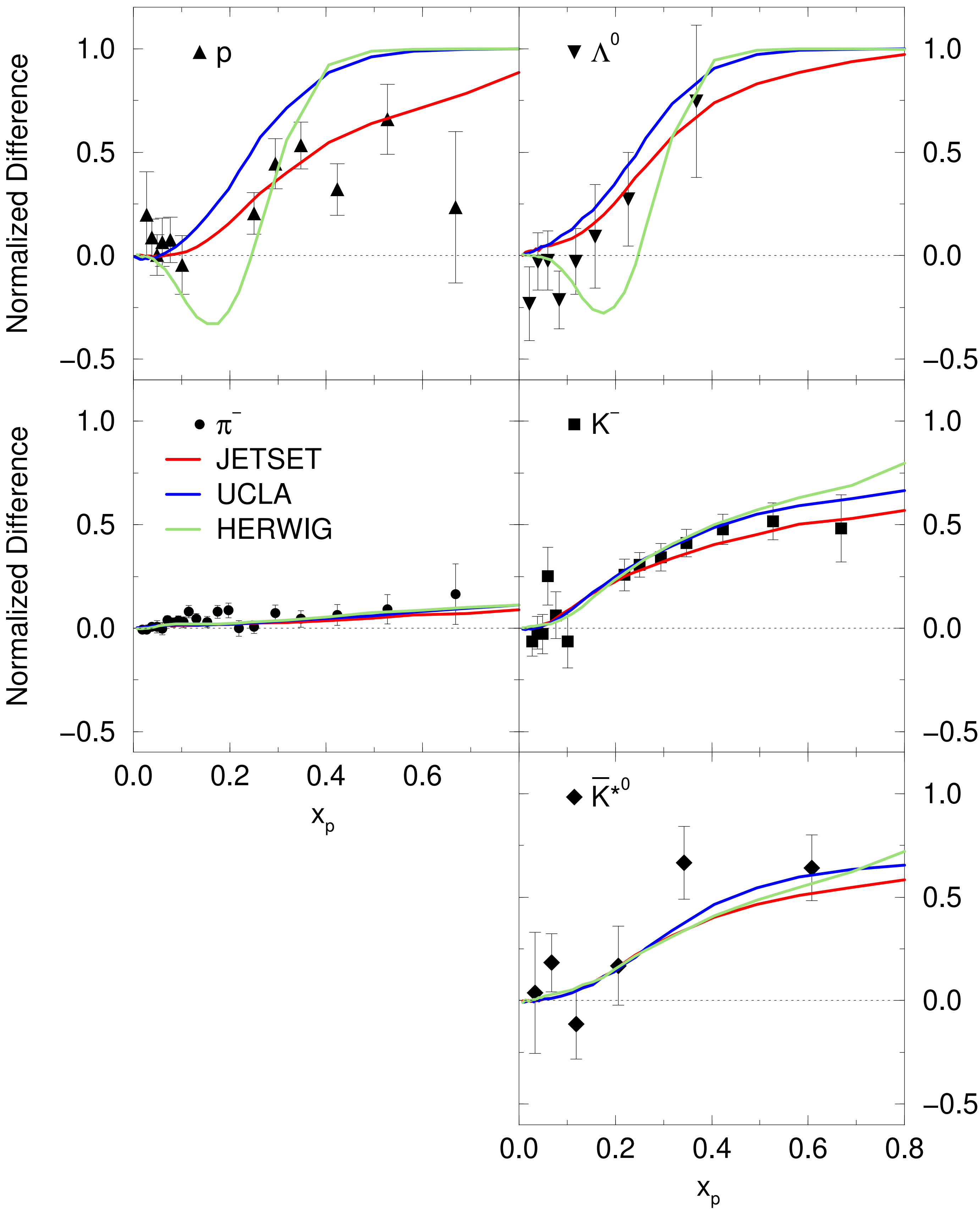


→ no differences at low momentum

→ large excess at high x of p over $\overline{p}$, K^- over K^+

→ significant excess at high x of π^- over π^+

A nice variable: the difference over the sum



→ Large signals for leading baryons, kaons

→ Direct observation of leading pions

→ New, precise tests of fragmentation models:

JETSET, UCLA, HERWIG reproduce the data for mesons well

JETSET reproduces the baryon data

UCLA, HERWIG overestimate the proton data at high x_p

Along with other recent measurements (see talk by C. Grandi), we are beginning to understand leading particle production in detail

Summary

- Hadronization is still an exciting field of study

- Much recent experimental progress:
  - → Observation of tensor, scalar mesons
    excited baryons
  - → effects of large quark masses
  - → energy dependence
  - → quarks vs. gluons
  - → leading particles

- Still much more of this field to explore
  at the Z0
  at LEPII
  as a future e^+e^- collider