Identified Hadron Production at SLD and BABAR

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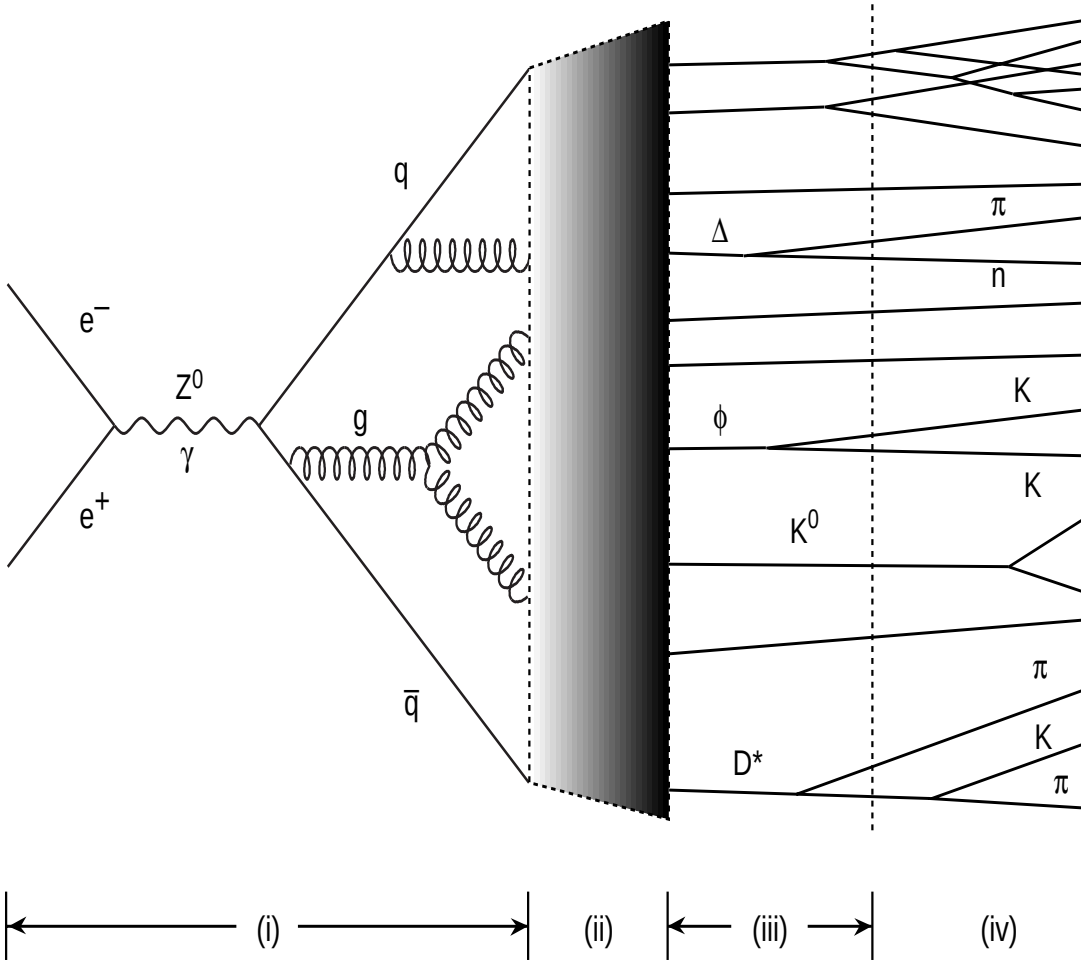
SLAC

- Introduction
- Charged $\pi^{\pm}$, $K^{\pm}$ p/$\overline{p}$ at SLD and BABAR — A641, 684
- $\eta \rightarrow \gamma\gamma$ at BABAR — A641
- Flavor Dependence at SLD — A684
- Leading Particles and Correlations — A684, 685
- Signed Rapidity Correlations — A685

Hadronization

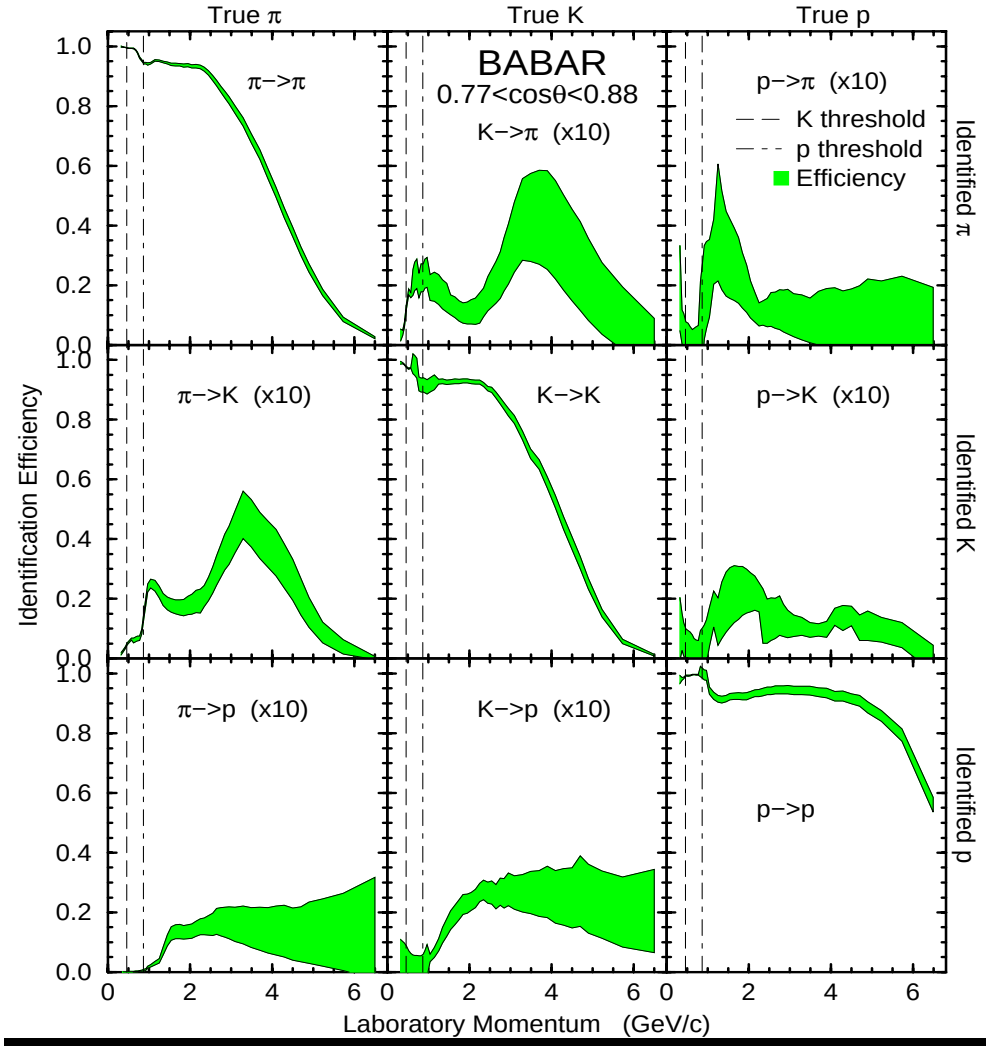
- Remains a 'wild frontier' in particle physics
- Theory/phenomenology:
  - → MLLA, coherent parton shower MCs describe fragmentation (i) well
  - → Models describe hadronization (ii) ... adequately
  - → Little recent progress ....
- Experimental precision:
  - → many inclusive results from e^+e^-, ep, $p\bar{p}$, ...



- New experimental directions:
  - → more and more precise identified/rec'ed particles
  - → Quark flavor dependence
  - → Gluon vs. (light) quark jets
  - → B,D hadrons and other leading particles,
  - → Dependence on c.m. energy

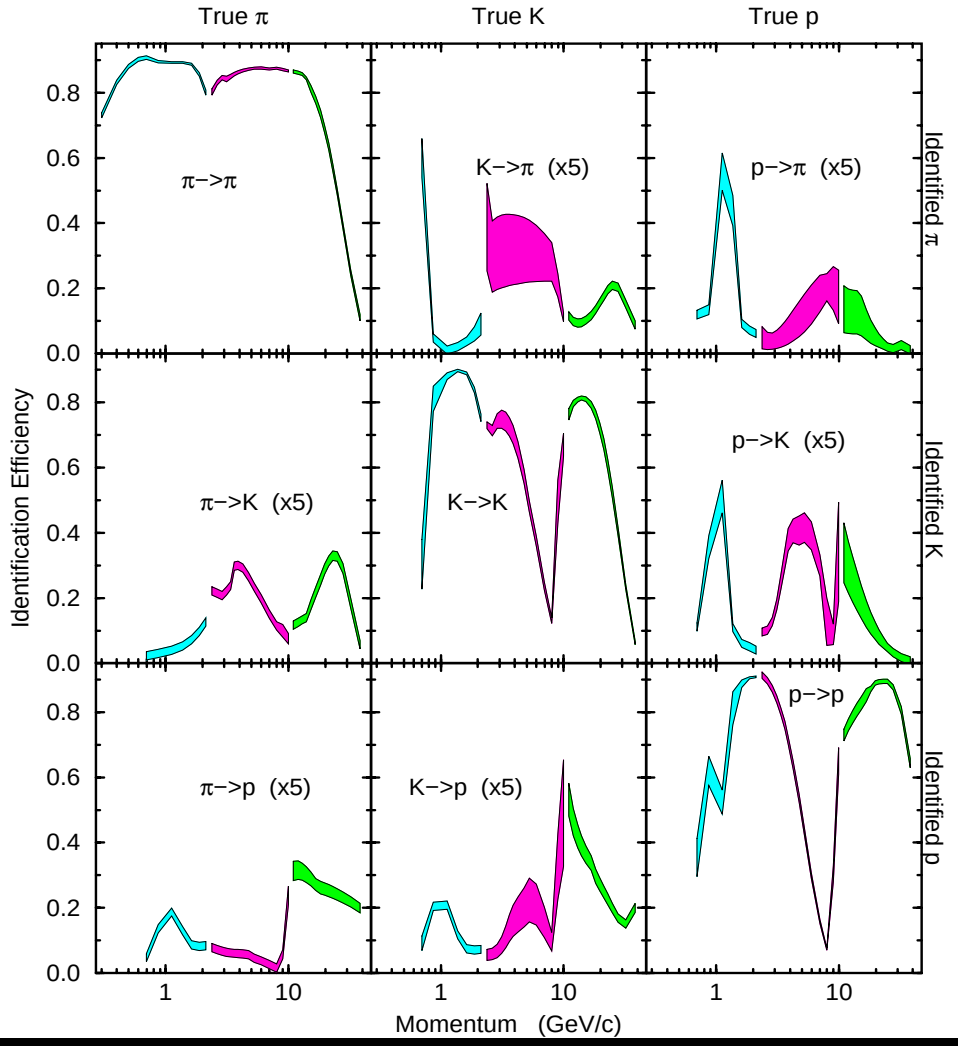
BABAR

- $e^+e^- \rightarrow \gamma \rightarrow q\bar{q}$ at 10.54 GeV
- Charged hadron ID from dE/dx plus internally reflecting imaging Cherenkov detector

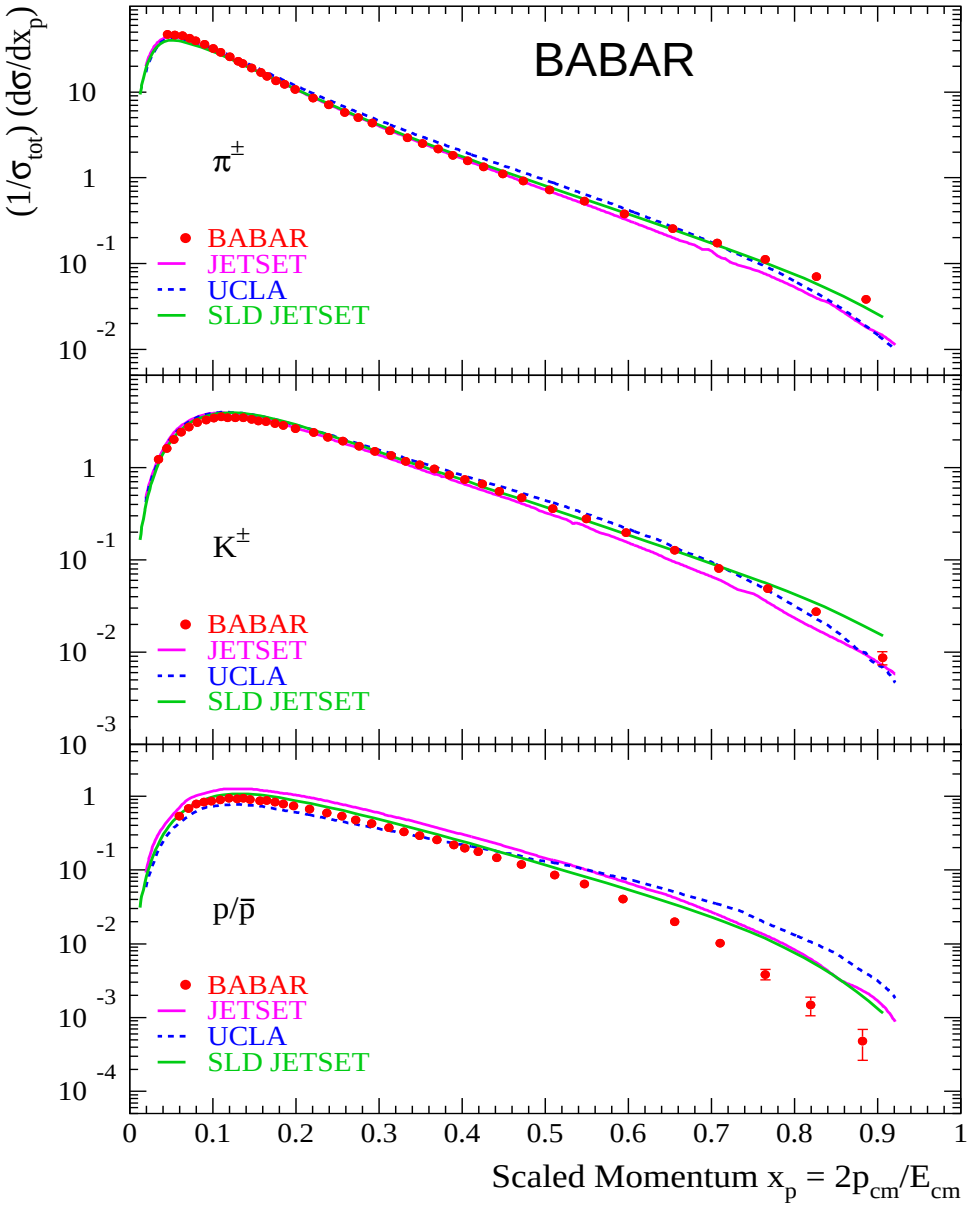


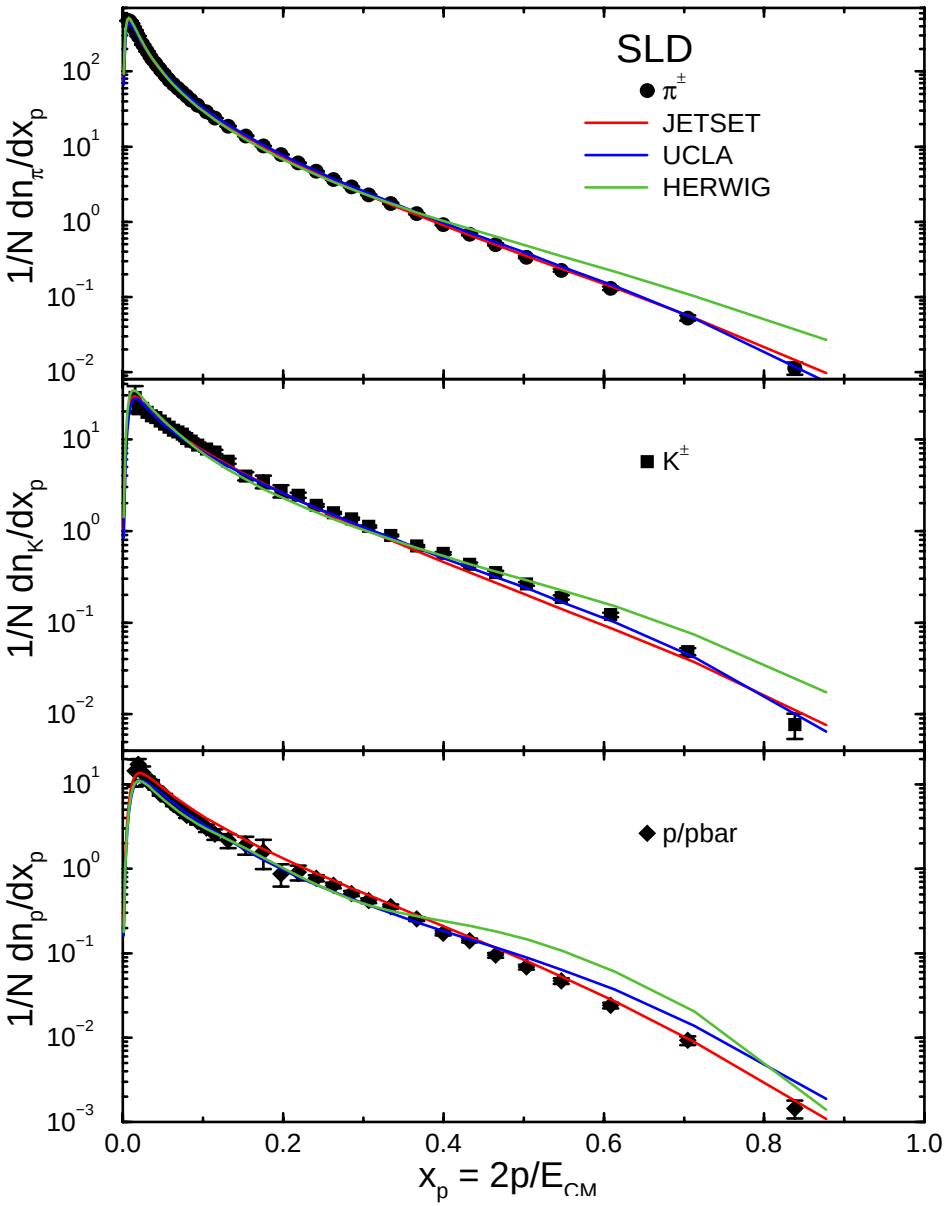
SLD

- $e^+e^- \rightarrow Z^0 \rightarrow q\bar{q}$ at 91.2 GeV
- Charged hadron ID from a dual radiator Cherenkov ring imaging detector



Charged Pion, Kaon, and Proton Cross sections

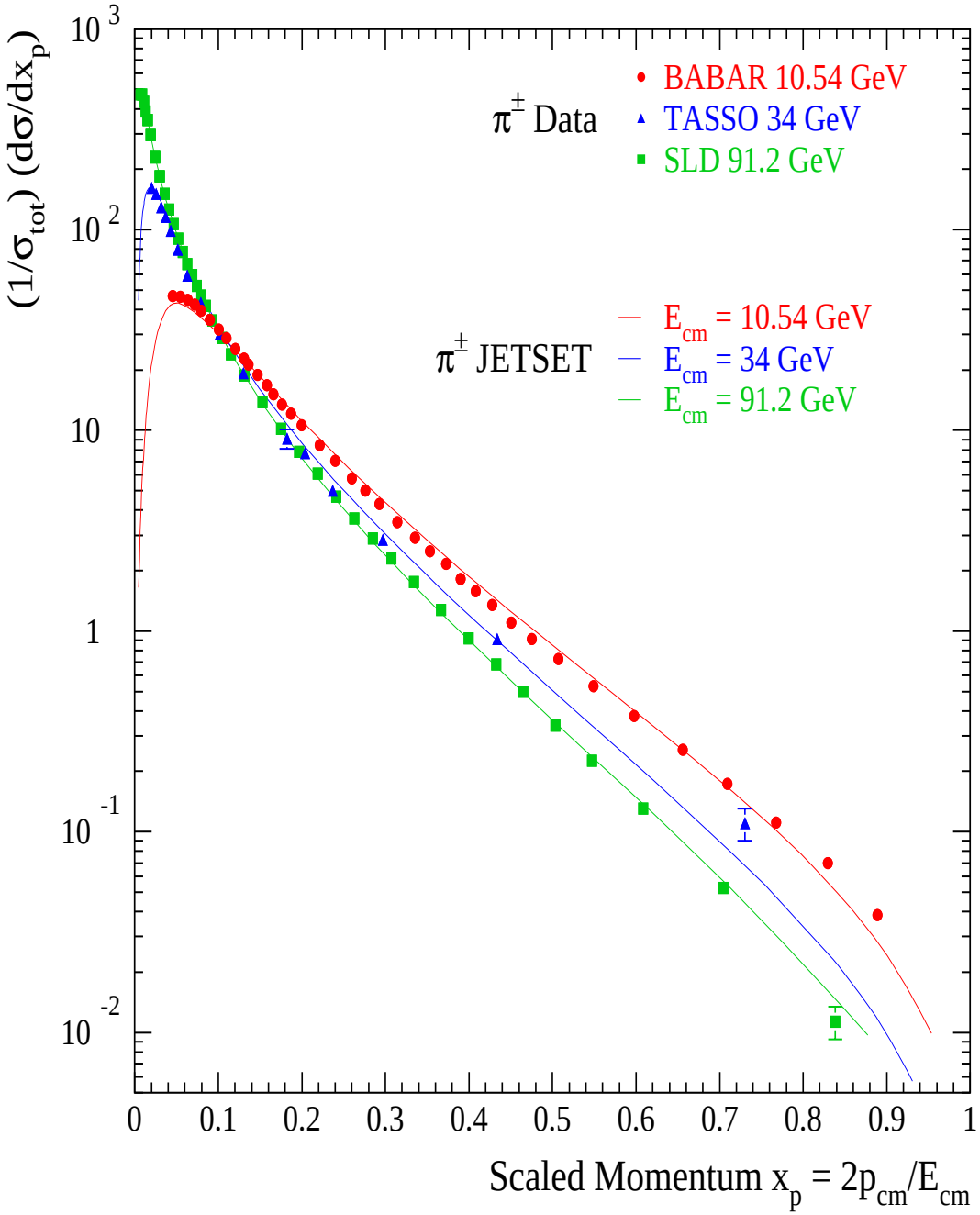


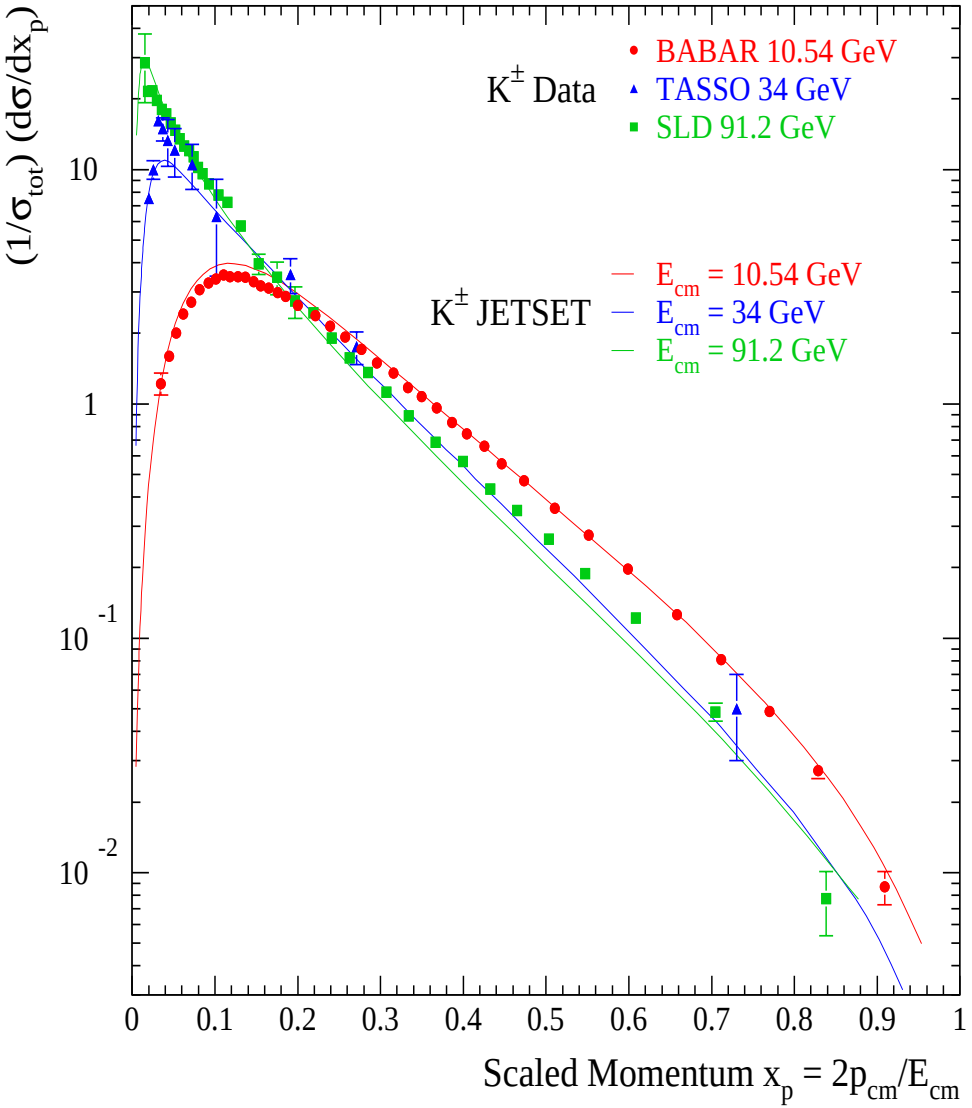


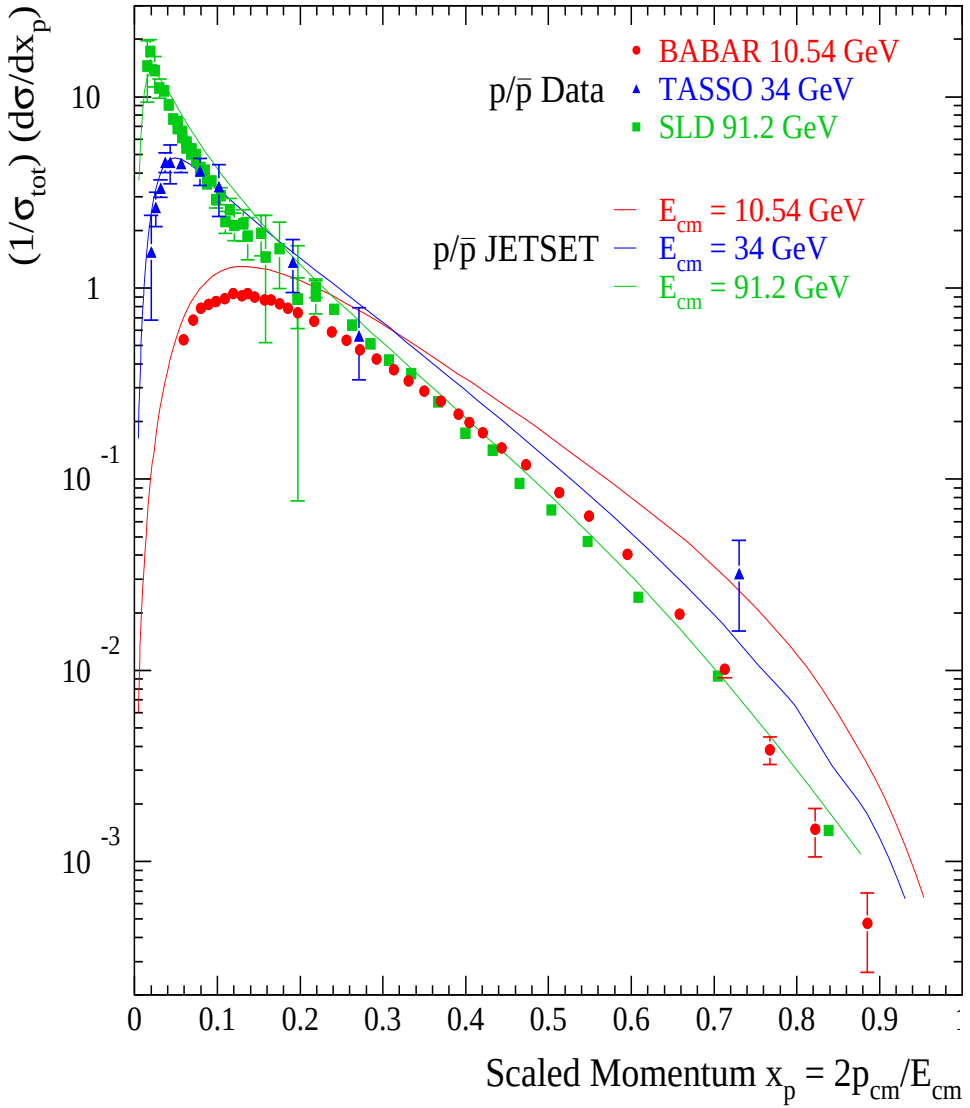
- MCs imperfect, but not too bad at high E_{CM}...
- ...but get a little worse at low E_{CM}, especially for protons

Scaling

- Hadronization should be scale invariant except for 'small' effects of hadron masses, running of α_s, ...
- Scaling violations at low x_p due to masses are familiar, well modelled
- At high x_p scaling violations become very large as E_{CM} gets small
  - → models do a good job for pions (JETSET shown, others similar)
  - → ...and predict similar effects for kaons and protons
  - → ...however, the data...







→ ...show effects only ~half as large for kaons (~10% from flavor composition)...

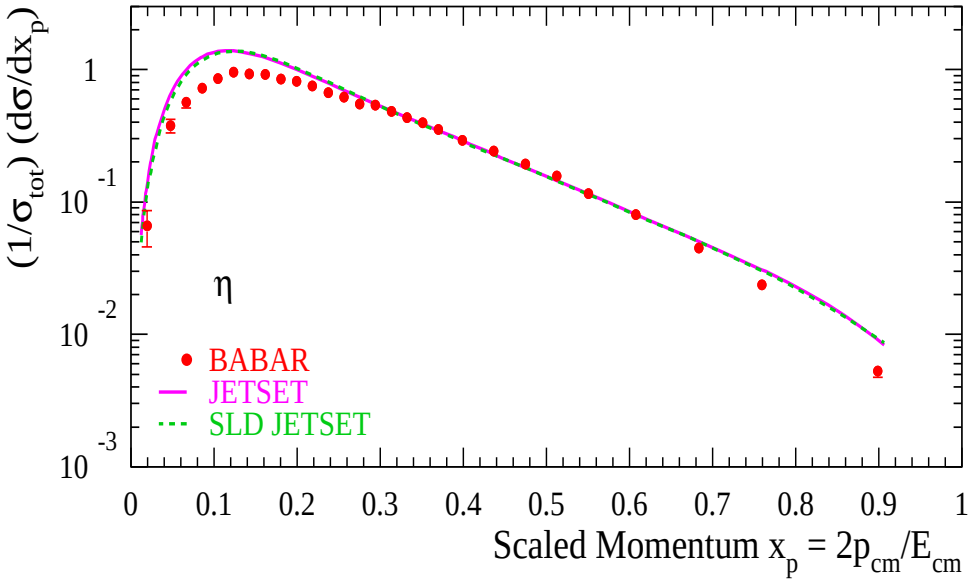
→ ...and very little effect for $p/\bar{p}$

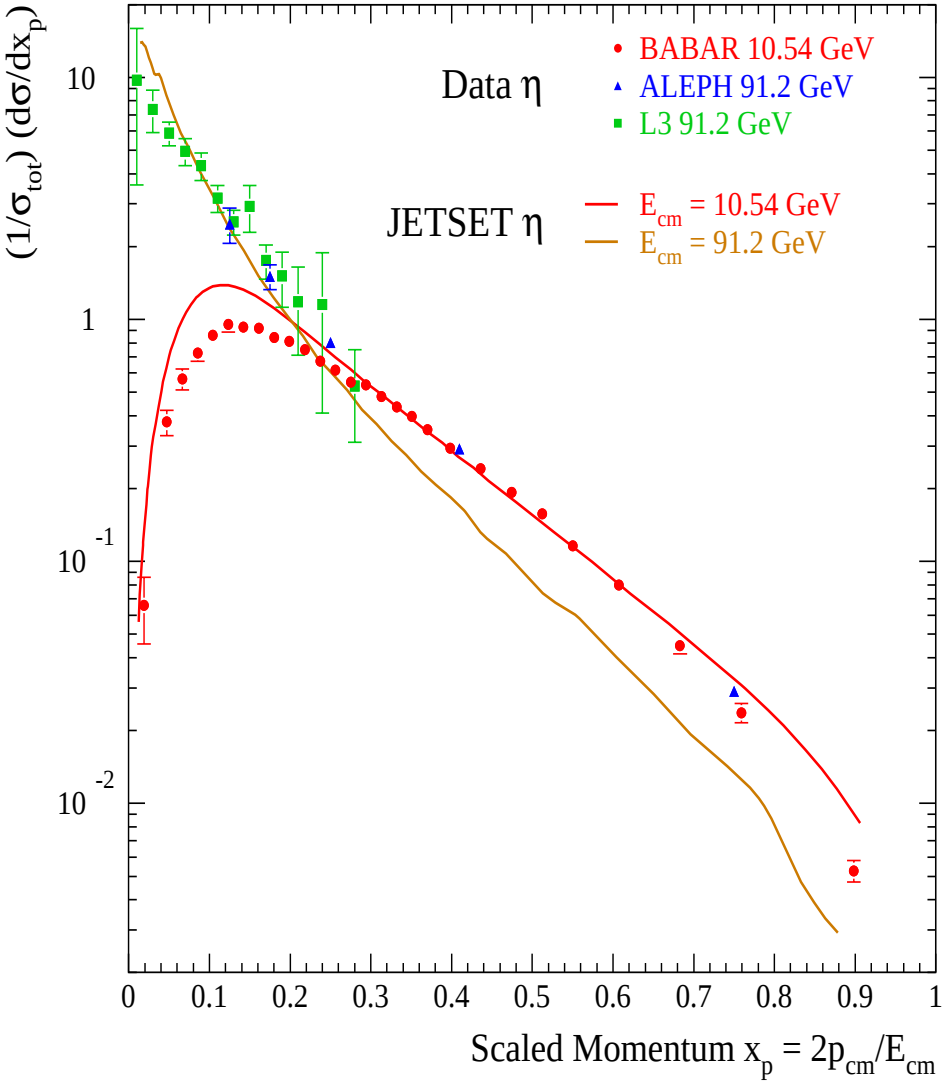
⇒ What's going on here?!?

⇒ Model builders, get back to work!!

η Production at BABAR

- η mesons are reconstructed in the γγ decay mode over the entire kinematic range

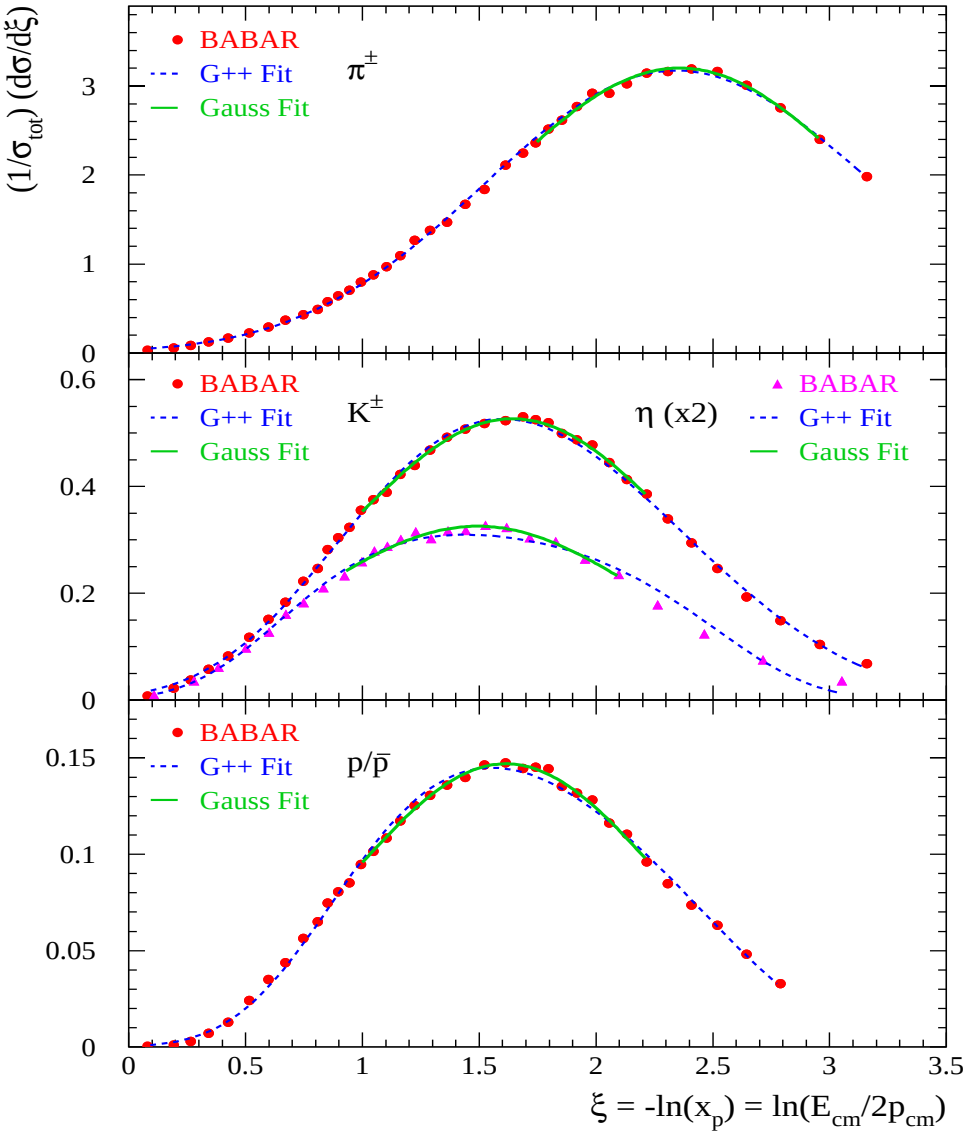


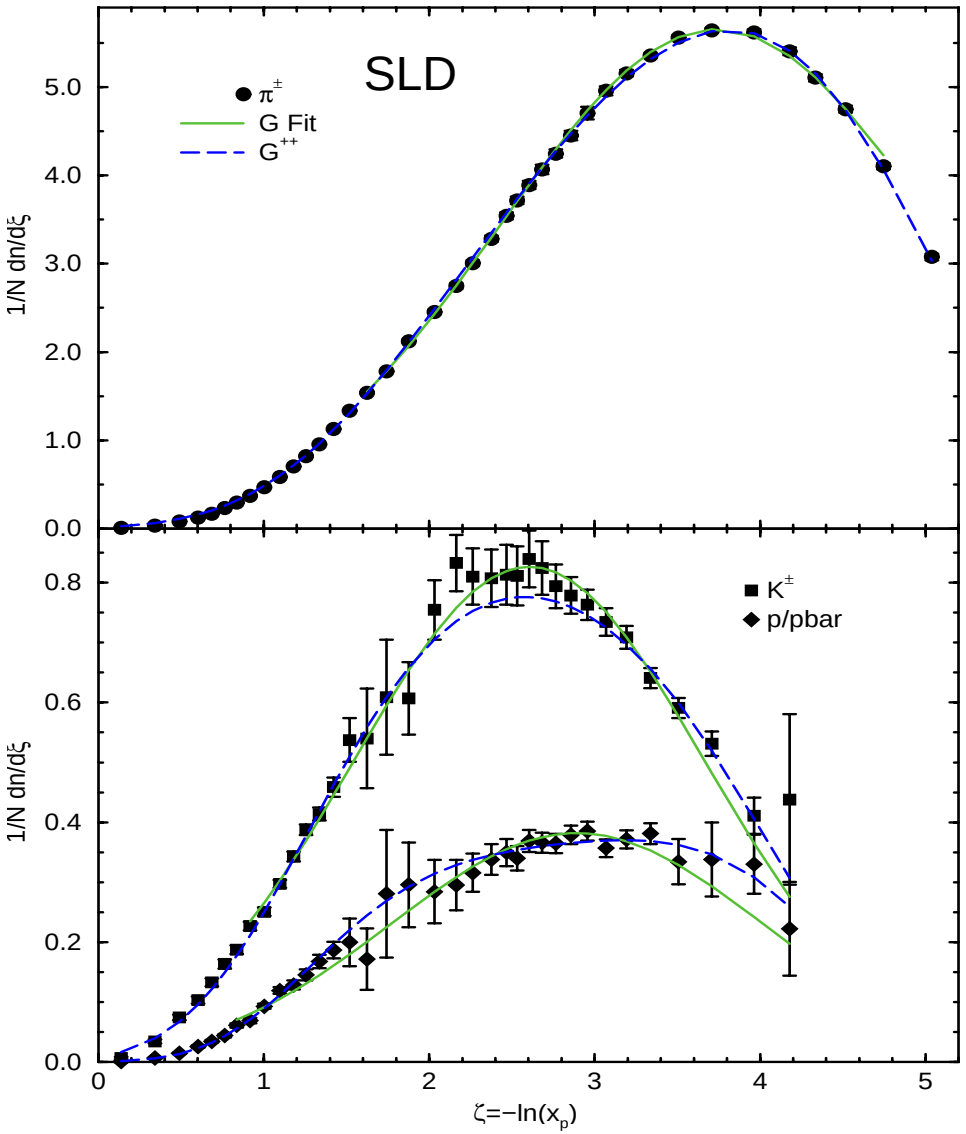


- Models not so good, especially at low x_p
  - → ...not much tuning data...
  - → ...but scaling is again quite different from data

⇒ Another challenge for model builders

Testing MLLA -QCD (+LPHD)

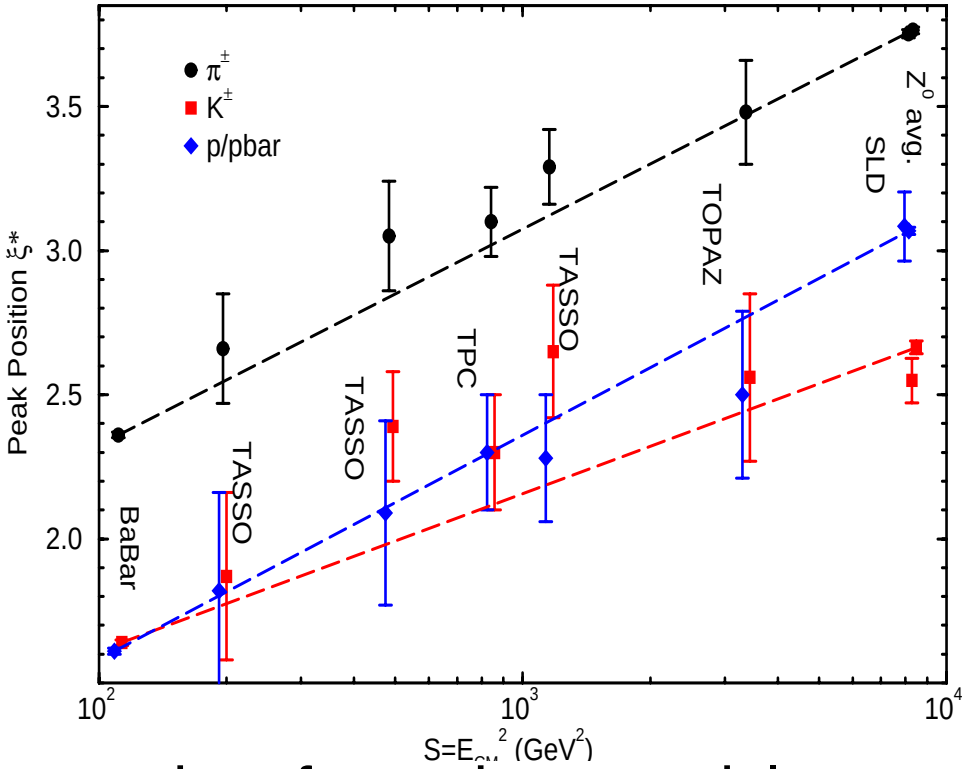




- Remarkably similar at diff. E_{CM}
- Gaussian fit "good" within 1(0.6) units of peak for SLD (BABAR)

- Distorted Gaussian fits over wider range; qualitatively good over full range

- How does the peak position ξ^* depend on energy, ~ln(E_{CM}) ?



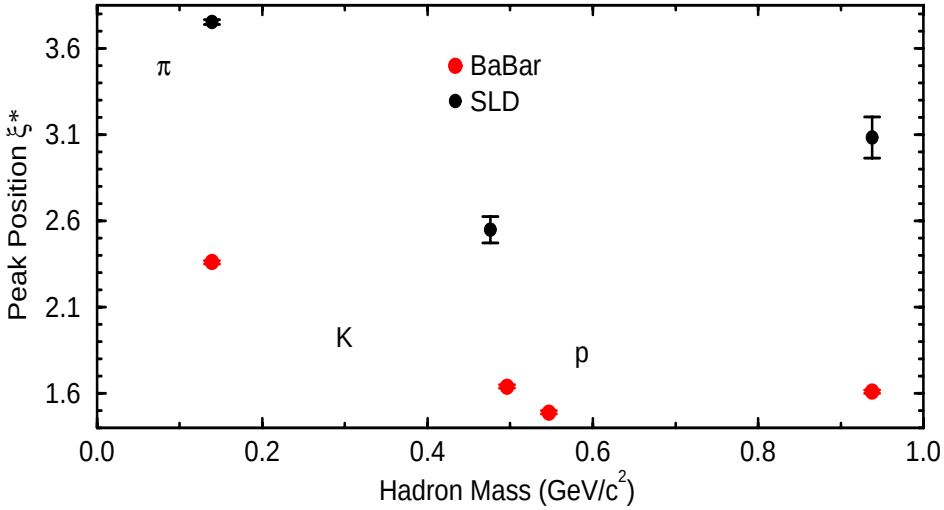
→ data for a given particle are consistent with ln(E_{CM})

→ have very precise slopes

→ ...but should the slopes be so different from each other?

⇒ lets keep the nice new results coming!

- How does ξ^* depend on hadron mass, ~exp(–m) ?



→ the data at a given E_{CM} are inconsistent with e^{-m}

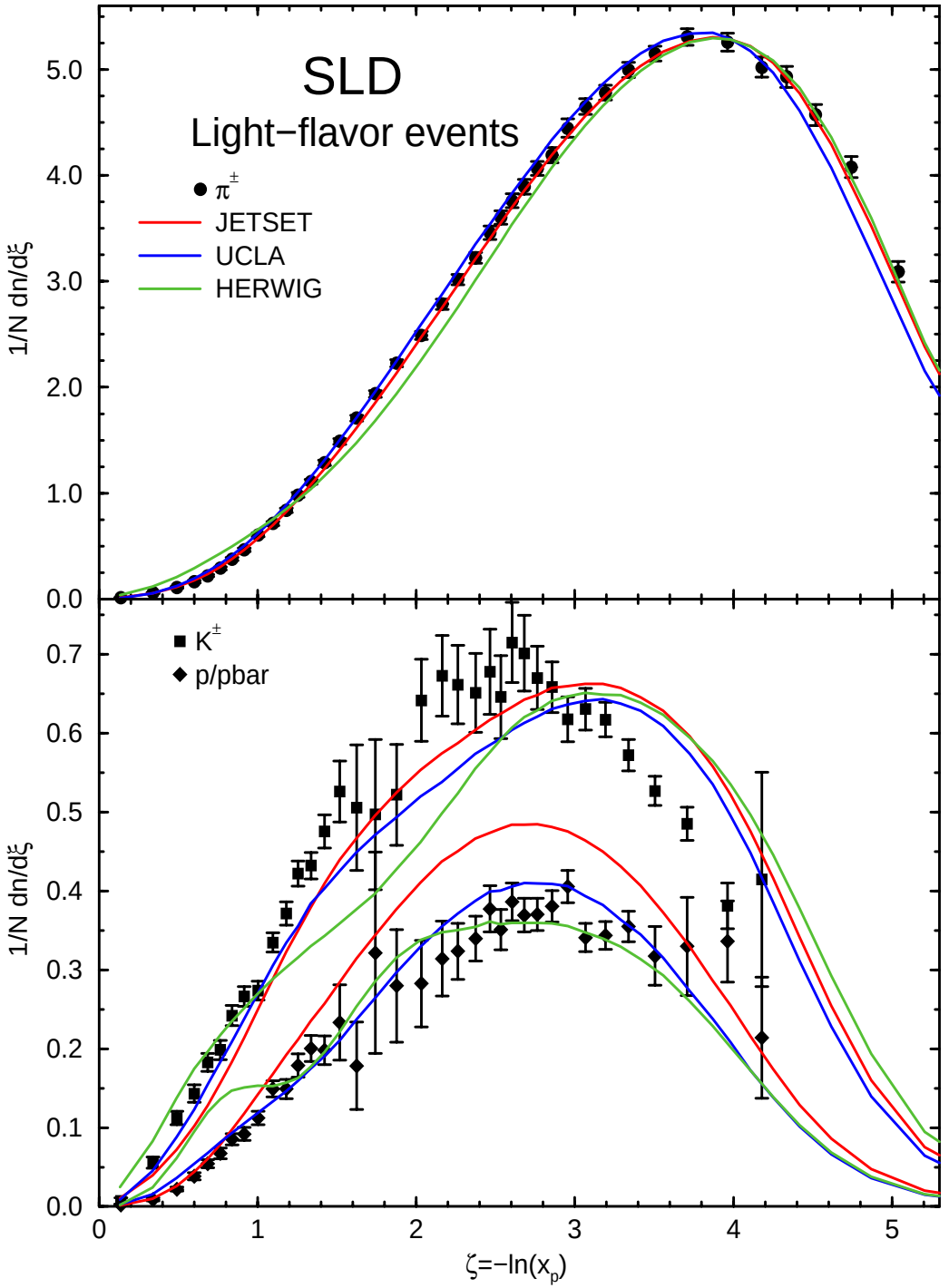
→ similar to results from the Z^0 and other E_{CM}...more later

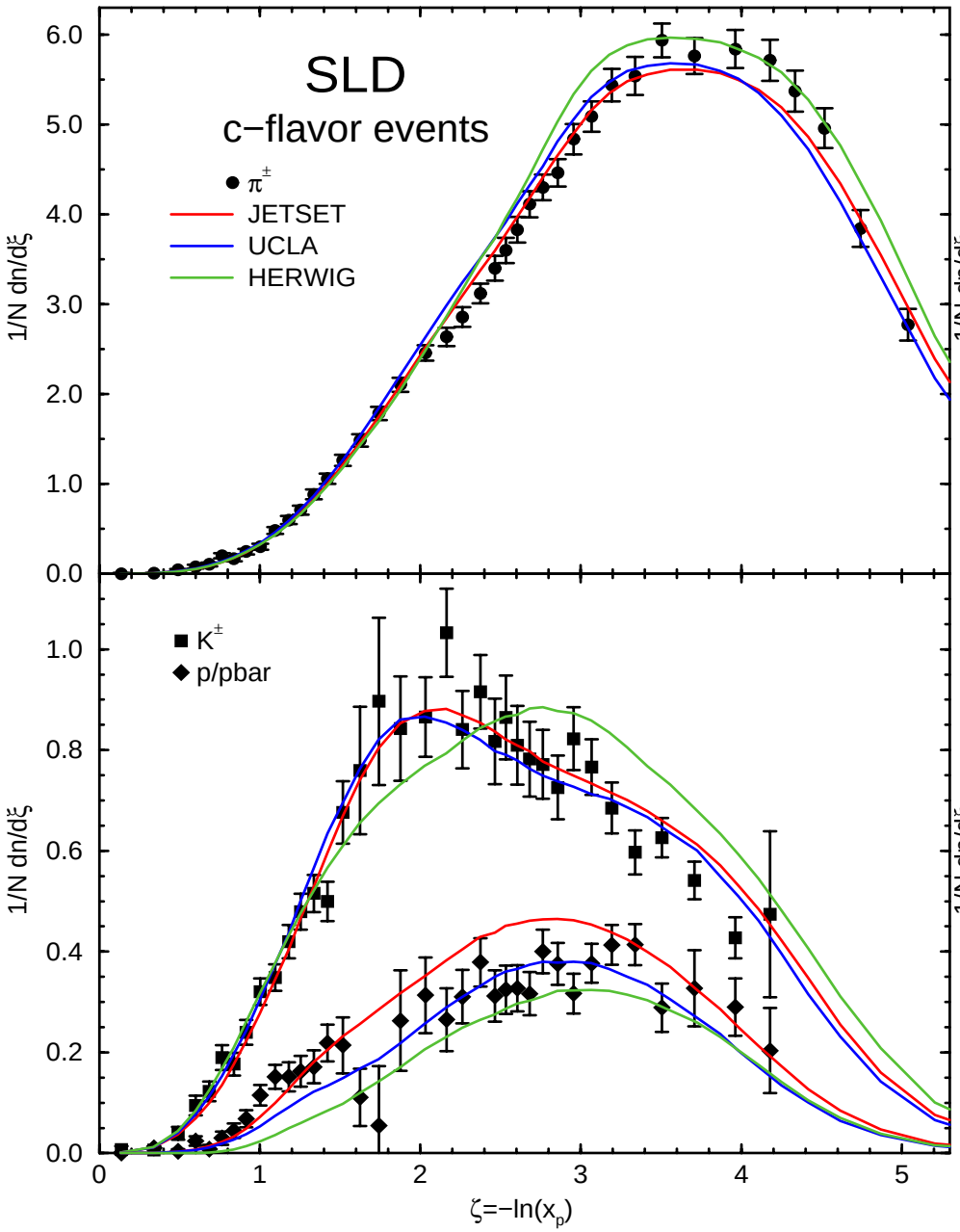
- Integrating ξ^* and extrapolating

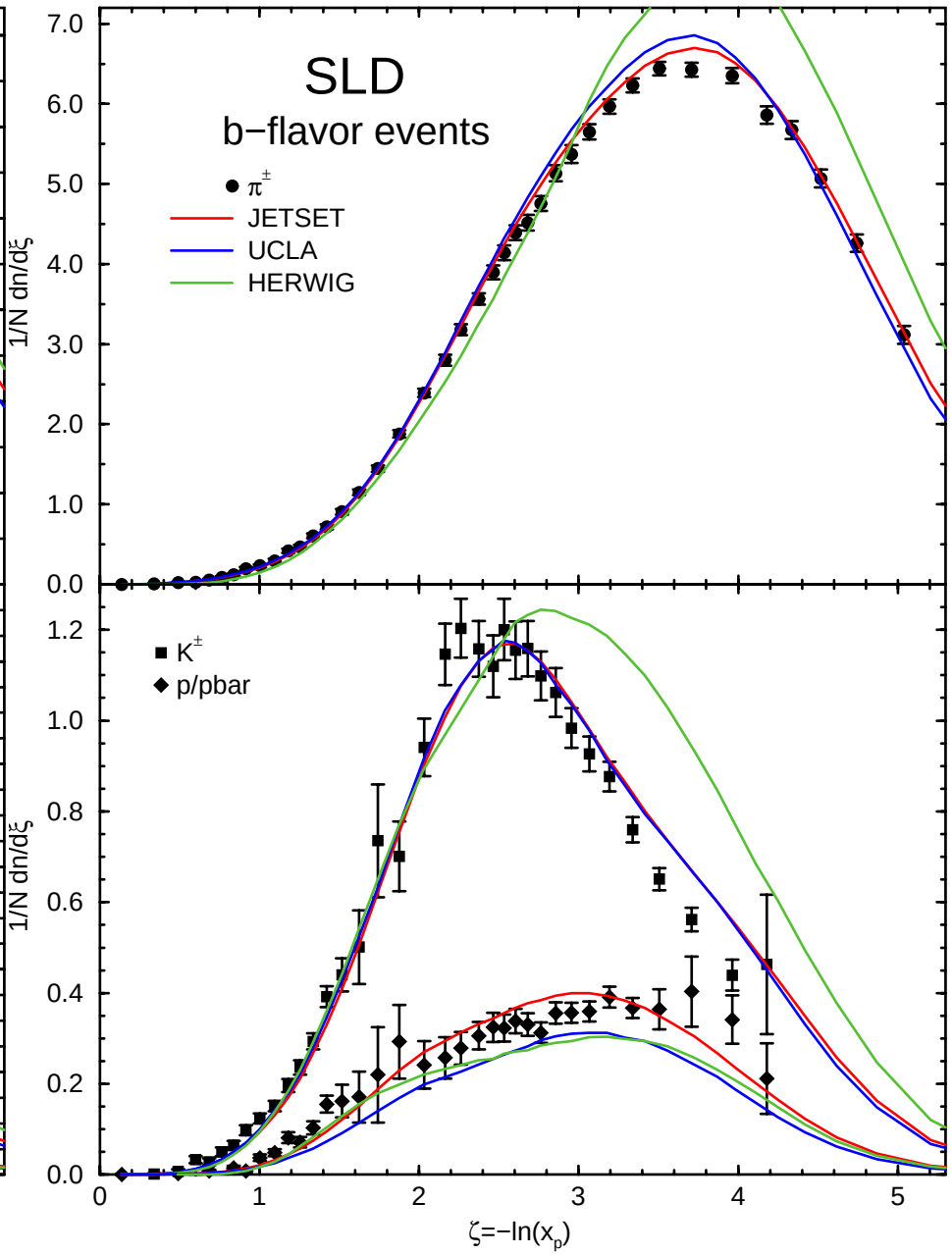
	BABAR	SLD
$\pi^\pm$	6.405±0.172	17.007±0.209
$K^\pm$	0.910±0.018	2.203±0.071
η	0.276±0.017	
$p/\bar{p}$	0.235±0.012	1.054±0.035

Flavor Dependence

- SLD separates $b\bar{b}$, $c\bar{c}$ and light flavors ($u\bar{u}$+$d\bar{d}$+$s\bar{s}$) using high precision vertexing
  - → full unfolding and correction
- Light flavors events "better" for testing QCD, focus on masless stuff in models
  - → results rather similar to those for all flavors
  - → confirm that problems with models are fundamental, not just tails of B,D production
- $b\bar{b}$ and $c\bar{c}$ events expected to look different, due to hard spectrum and decay properties of leading B,D hadrons







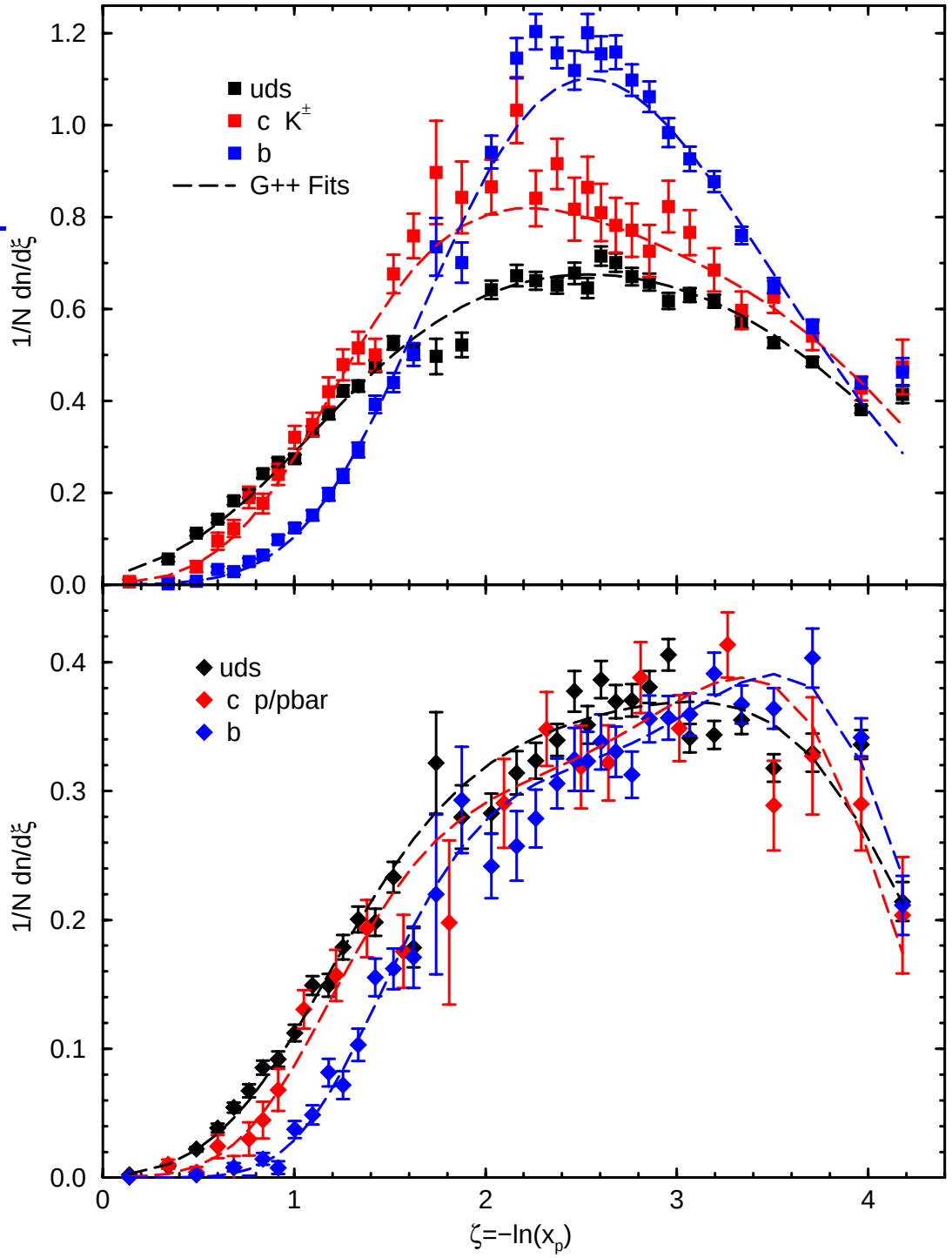
→ ...and they do

→ most models follow ~well

→ B decays need work

More MLLA Fits:

- (Distorted) Gaussian works as well as it did above for pions, and for kaons and protons in uds events
  → still consistent with MLLA
- In $b\bar{b}$ and $c\bar{c}$ events, the kaon and proton distributions are highly distorted
  → probably not inconsistent with theory – these events have a huge contribution from B, D decay products
- The ξ^* in $b\bar{b}$ and $c\bar{c}$ events are hard to define, but very different from uds events
  → do the light flavors behave better in terms of the m or E_{CM} dependence?

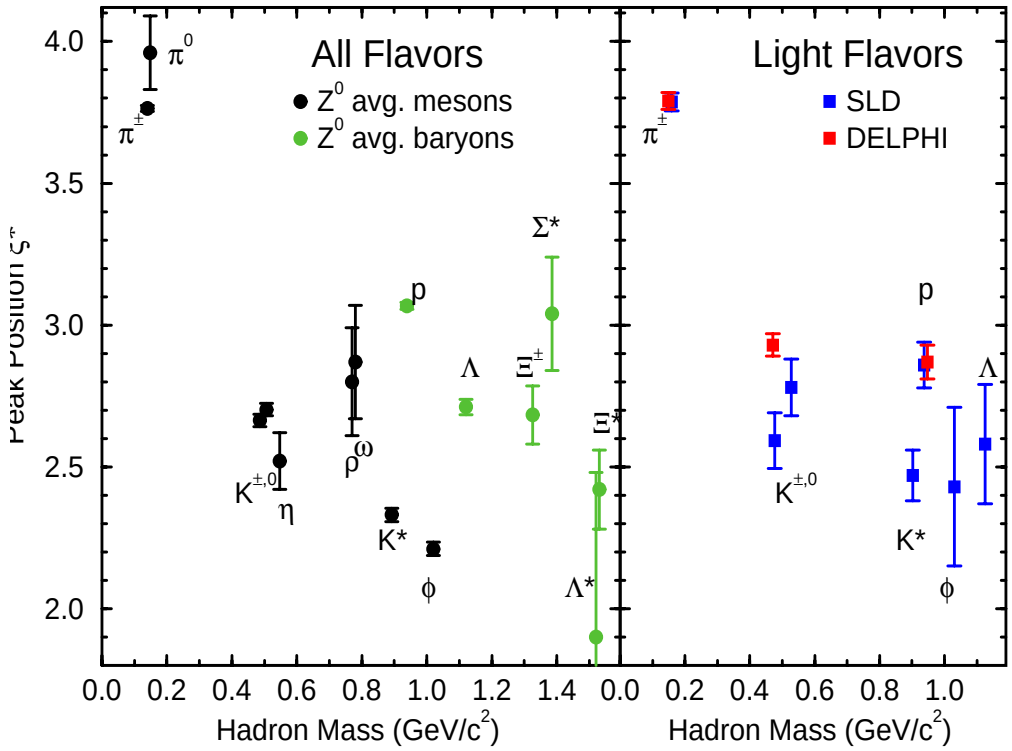


→ ...well, maybe

→ all mass points move in the "right direction" ...

→ ...but do not obviously line up

⇒ Could be more decays that are important; nice to see at least these ones removed



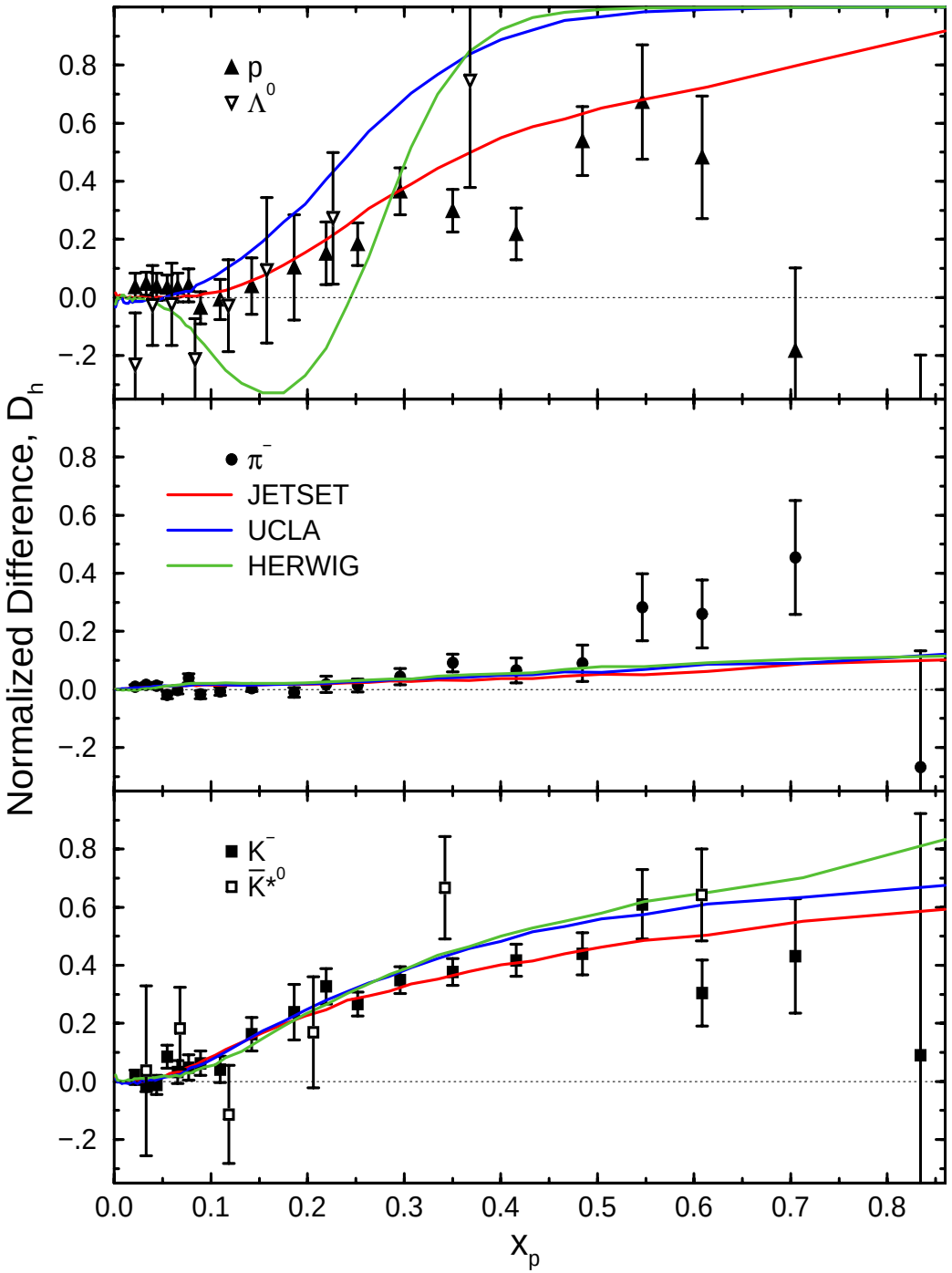
- Integrated spectra show strong flavor dependences

	$\pi^{\pm}$	$K^{\pm}$	$p/\bar{p}$
all	17.01±0.21	2.203±0.071	1.054±0.035
uds	16.58±0.30	2.000±0.068	1.094±0.043
$c\bar{c}$	16.95±0.56	2.427±0.100	1.034±0.077
$b\bar{b}$	18.14±0.33	2.510±0.086	1.004±0.046

	$\pi^{\pm}$	$K^{\pm}$	$p/\bar{p}$
c–uds	0.38±0.59	0.427±0.074	–0.060±0.074
b–uds	1.56±0.23	0.510±0.037	–0.091±0.034
c–b	1.18±0.50	0.083±0.075	–0.031±0.074

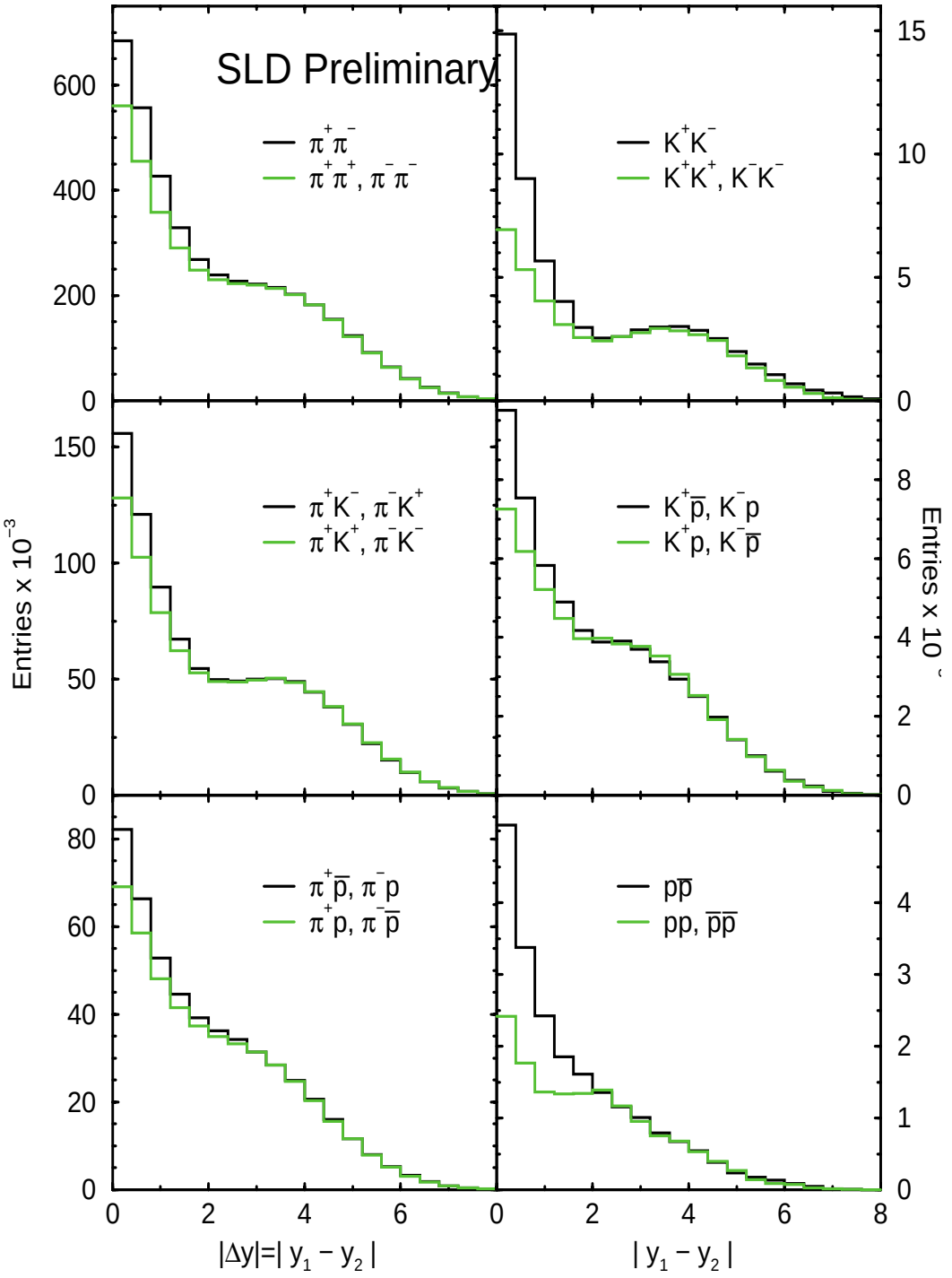
Light Leading Particles (I)

- The initial q or $\bar{q}$ should be "contained" in some particle
  - → ...as a valence constituent
  - → ...of a high-x_p particle
  - → well established for b ,c
- SLD used their polarized e^- beam to tag the q (rather than $\bar{q}$) jet in each event (73%)
  - → measure spectra of + and – tracks; take difference/sum
- Clear evidence for leading
  - → protons in u,d and/or s jets
  - → π^- in d and $\bar{u}$ jets
  - → K^- predominantly in s jets
- New model tests
  - → they work for π,K, but p...

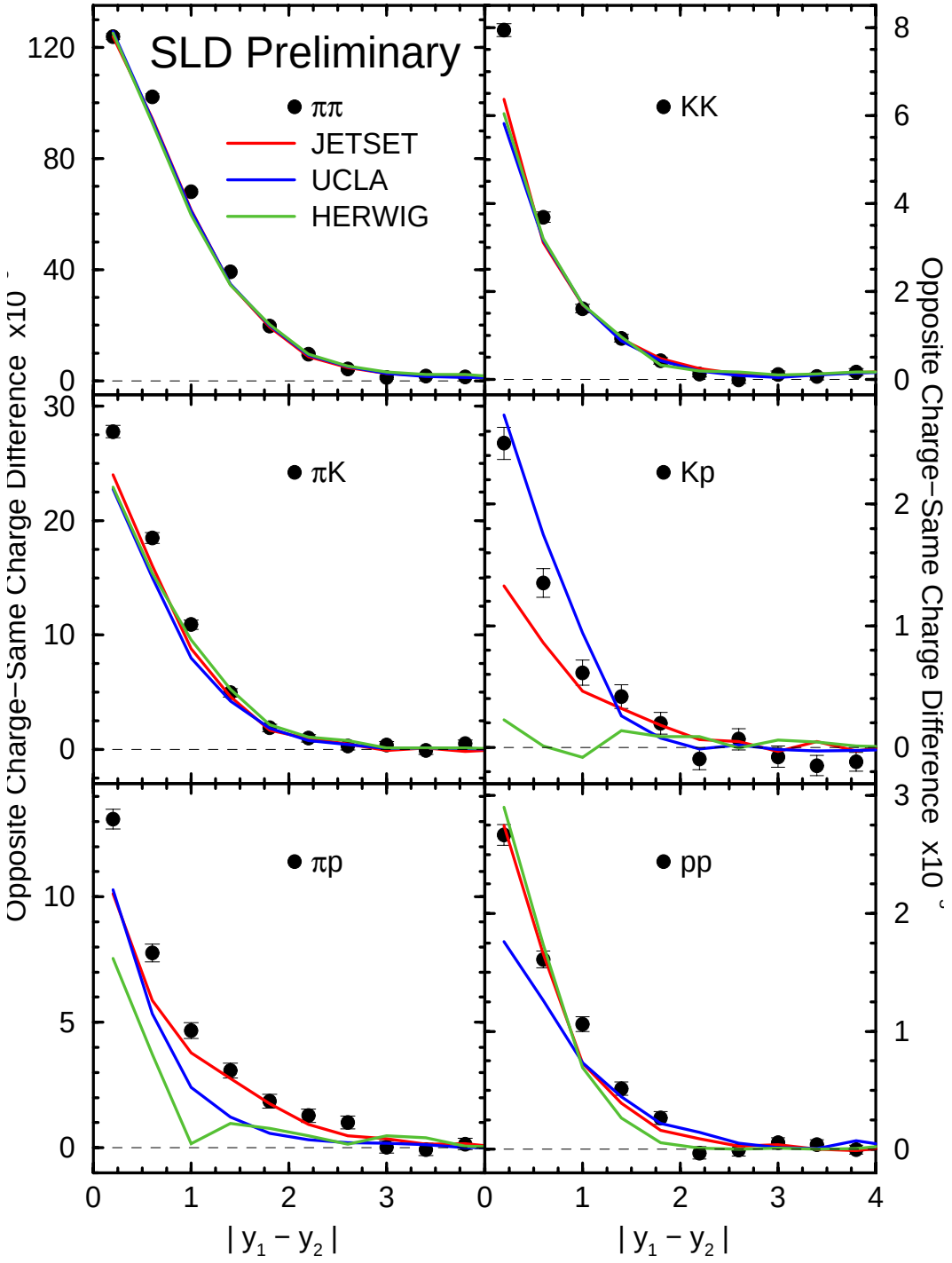


Rapidity Correlations

- $q\bar{q}$ pairs are expected to be "shared" between "nearby" particles in the event
  - → more $h_1^+h_2^-$ than $h_1^\pm h_2^\pm$
  - → for $h_1=h_2$ and $\pi K, \pi p, Kp$
- Rapidity $y=\ln((E+p_{||})/(E-p_{||}))/2$ is a ~scale invariant variable
  - → the difference $\Delta y=|y_1-y_2|$ is a convenient measure of "nearness" of a pair
- Excesses near $\Delta y=0$
  - → local conservation of strangeness, charge, baryon number (known)
  - → and local charge cons. for strange–nonstrange and also meson–baryon pairs

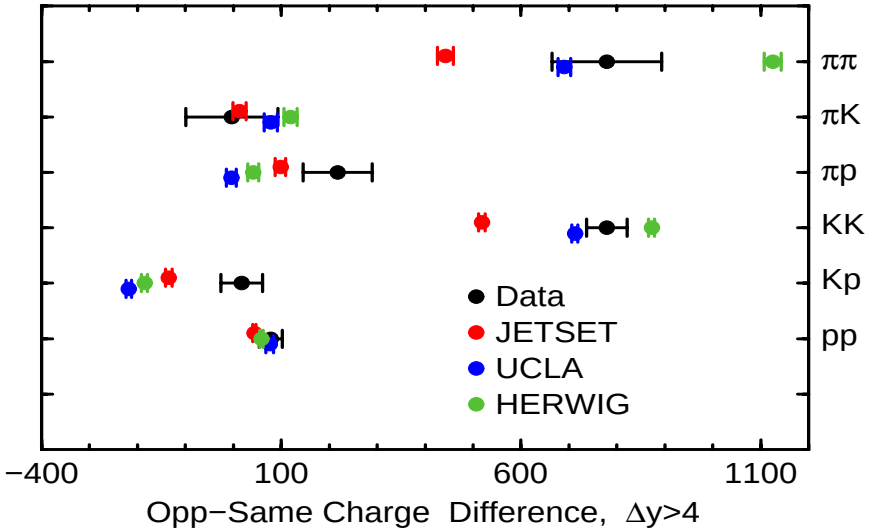


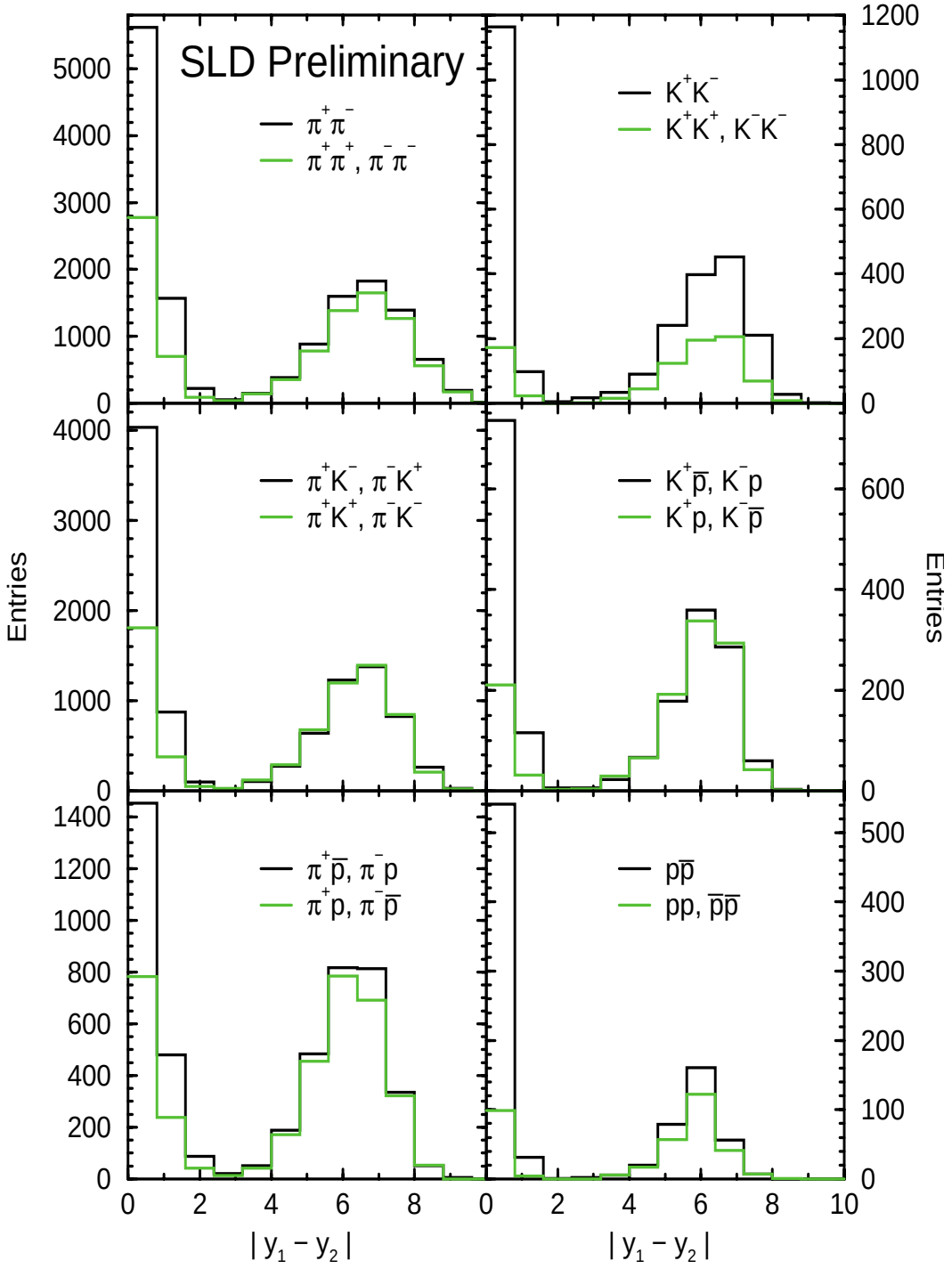
- differences n^{+-}–$n^{\pm\pm}$ between oppositely charged and same charged pairs probe
  - → the effective range of the correlation
  - → frequency of each pair type
- Affected by
  - → characteristic hadronization range?
  - → heavier (primary) decays
  - → "popcorn" mesons
- Nice model tests:
  - → all models not bad ...
  - → ...but wild variations in Kp, πp, pp



Leading Particles (II)

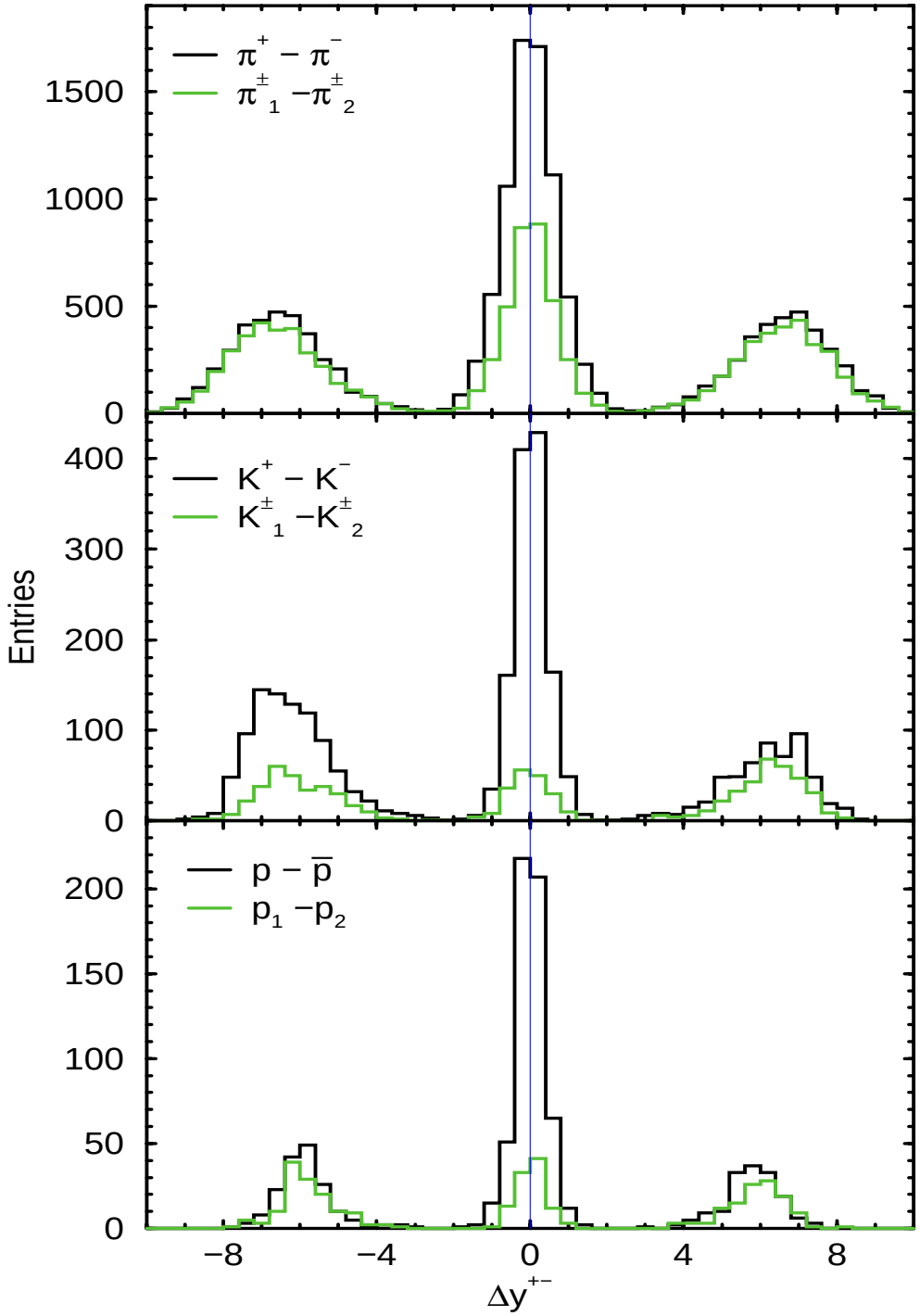
- Leading particles should give "long range" correlations
- Isolate using high-momentum tracks, p>8 GeV/c
  - → huge diff for KK (from $s\bar{s}$)
  - → others diluted by the short range correl. btw leading and subleading particles
  - → significant diffs for ππ,pp
- Diffs at high Δy vs. models





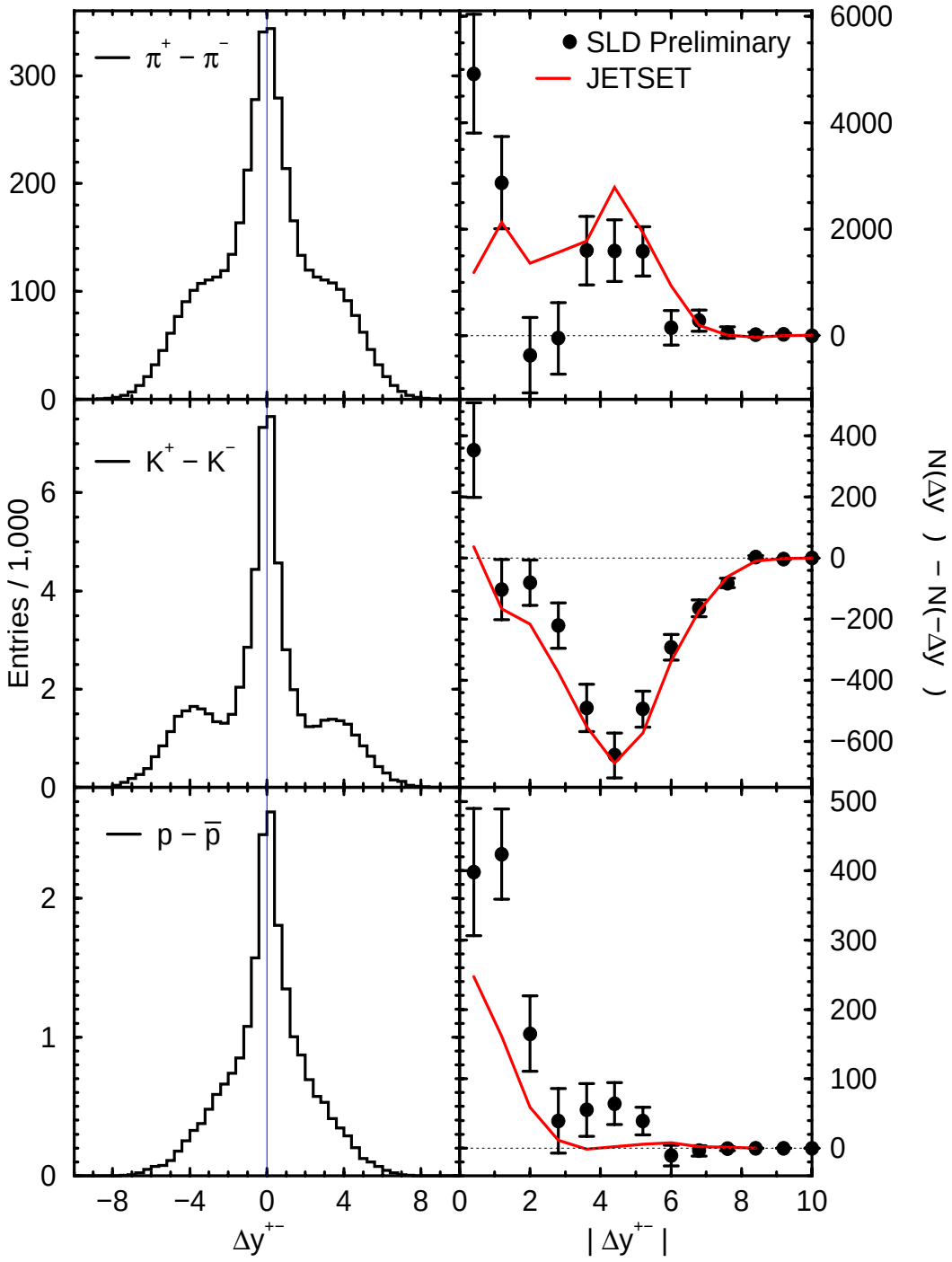
Leading Particles (III)

- Now combine with the beam polarization to give a sign to the rapidity, $y>0 \leftrightarrow q$ direction
- Define $\Delta y^{+-} > y_+ - y_-$, compare with randomly signed $\Delta y^{\pm\pm}$
  - $\rightarrow$ the excess in KK is ~from $s\bar{s}$ for $\Delta y^{+-}<0$, and $u\bar{u}$ for $\Delta y^{+-}>0$
  - $\rightarrow$ similarly $\pi\pi$ from $u\bar{u}$ ($d\bar{d}$) have $\Delta y^{+-}>0$ ($\Delta y^{+-}<0$)
  - $\rightarrow$ ...but $u\bar{u}$ also give sub-leading pairs with $\Delta y^{+-}<0$
  - $\rightarrow$ would have expected pp excess entirely in $\Delta y^{+-}>0$
- With enough such data (other particles) can learn to identify the flavor of light jets



Signed y at Short Range

- Using the same definition on tracks of all momenta
  - → can look for shifts of the short range peaks
- Asymmetries at long range are just higher statistics leading particle studies
- Asymmetries at short range indicate "alignments" of the pairs along the $q \rightarrow \bar{q}$ axis
  - → clear effect for $p\bar{p}$; positive sign indicates p prefers $\bar{q}$ over q direction
  - → hint of an effect for K^+K^-?
  - → apparent effect in pions due to charm decays
- Many more combinations to look at, test models, ...



Summary

- Precise spectra of $\pi^{\pm}$, $K^{\pm}$, η, $p/\bar{p}$ at high and very low energy
  - $\rightarrow$ nice new input to theory, models
  - $\rightarrow$ interesting scaling properties for K, η, p
  - $\rightarrow$ ...though MLLA QCD still works

- Flavor dependent measurements at the Z^0
  - $\rightarrow$ clear differences, as expected
  - $\rightarrow$ heavy flavors inconsistent with MLLA
  - $\rightarrow$ light flavors may be closer to MLLA mass dependence

- Lots of information on leading particles at the Z^0
  - $\rightarrow$ ~expected effects seen in all particles studied
  - $\rightarrow$ still much work to be able to tag the flavor of light jets

- New information in (signed) short range correlations
  - $\rightarrow$ charge ordering among disparate particles
  - $\rightarrow$ $p\bar{p}$ alignment along $q\bar{q}$ axis