Measurement of Inclusive Production of Light Charged Hadrons at BABAR

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On behalf of the BABAR Collaboration

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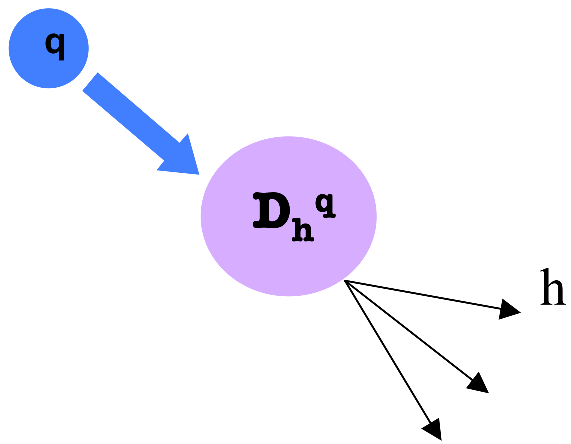
OUTLINE

- Fragmentation Function and Hadronization
- The BABAR experiment
- Pion, kaon, and proton cross sections at BABAR
- BABAR results
  - Test of hadronization models
  - Scaling proprieties and MLLA QCD predictions
- Summary and conclusions

Introduction: What is a Fragmentation Function?



✓ Fragmentation Function (FF) describes the process of hadronization of a parton q

✓ contains non-pertirbative information

✓ "Universal" function

  ✓ The cleanest way to access FF is $e^+e^- \rightarrow q\bar{q}$:

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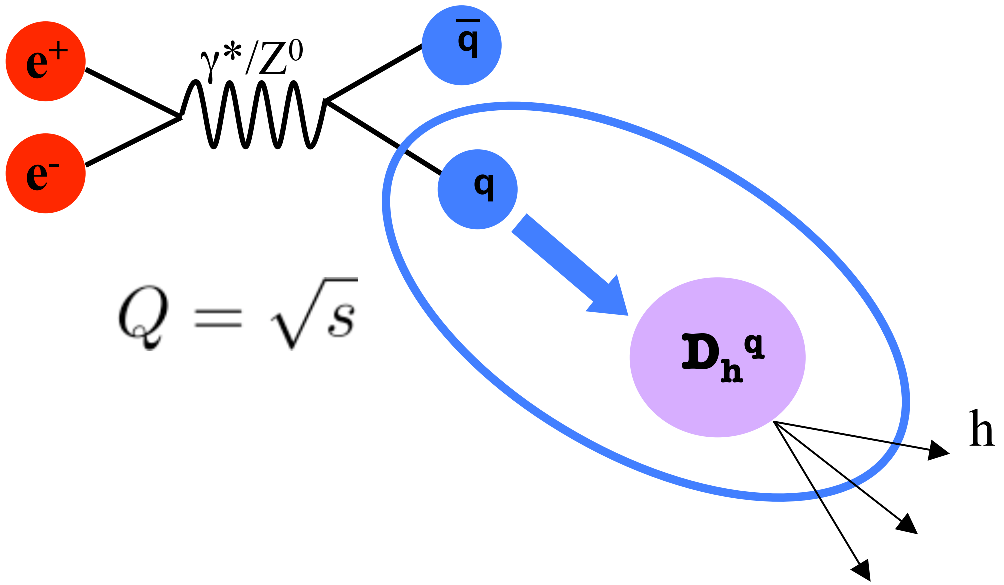


- ✓ Fragmentation Function (FF) describes the process of hadronization of a parton q
- ✓ contains non-pertirbative information
- ✓ "Universal" function
  - ✓ The cleanest way to access FF is $e^+e^- \rightarrow q\bar{q}$:

$$\sigma^{e^+e^-\rightarrow hX} \propto \sum_{i=q,\bar{q}} \sigma^{e^+e^-\rightarrow q\bar{q}} \times D_q^h$$

Ideally, given a (hard) parton q (q=u,d,s,c,b,g), we want to find the **probability**

$$\mathbf{D_h^q(z,Q^2)}$$

that a parton q fragments into a hadron h carrying away a fraction $z=2E_h/\sqrt{s}$ of the parton momentum

What do we Mean by Fragmentation?

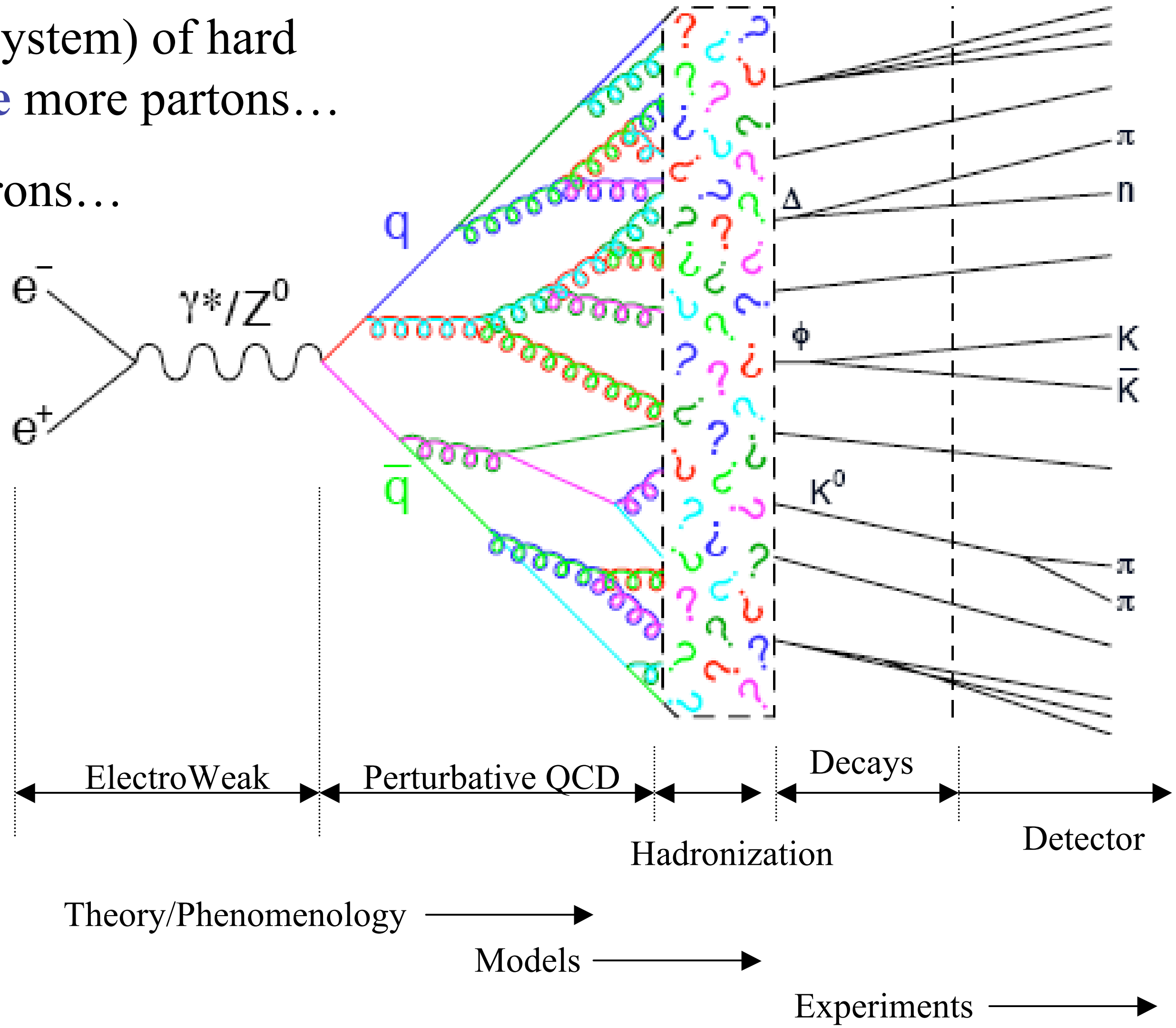
1) The process by which (a system) of hard quarks and/or gluons **radiate** more partons…

2) … that **combine** into hadrons…

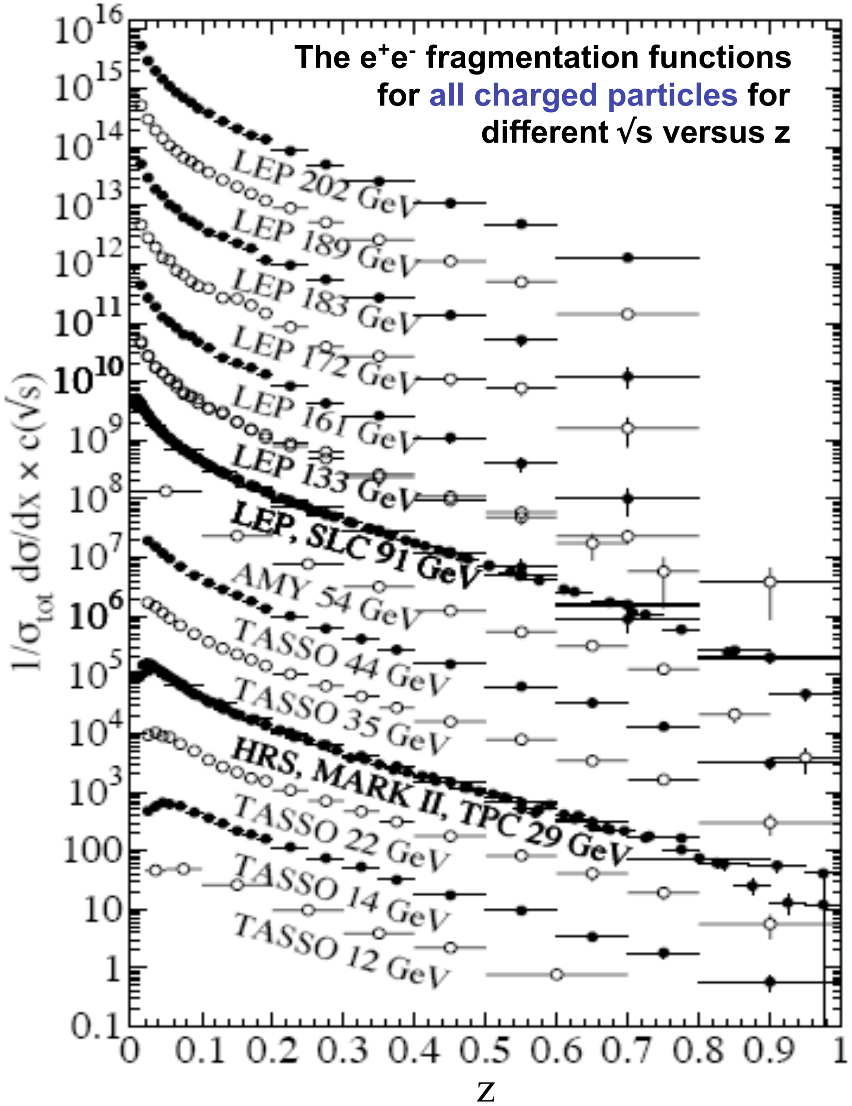
3) … that **decay** into "stable" particles…

…that can be **observed** in a detector…

Experimentally, we push from the right, as example:
- measure all $K^{\pm}$
- then ϕ
- subtracting ϕ daughters gets closer to primary $K^{\pm}$



e^+e^- Data

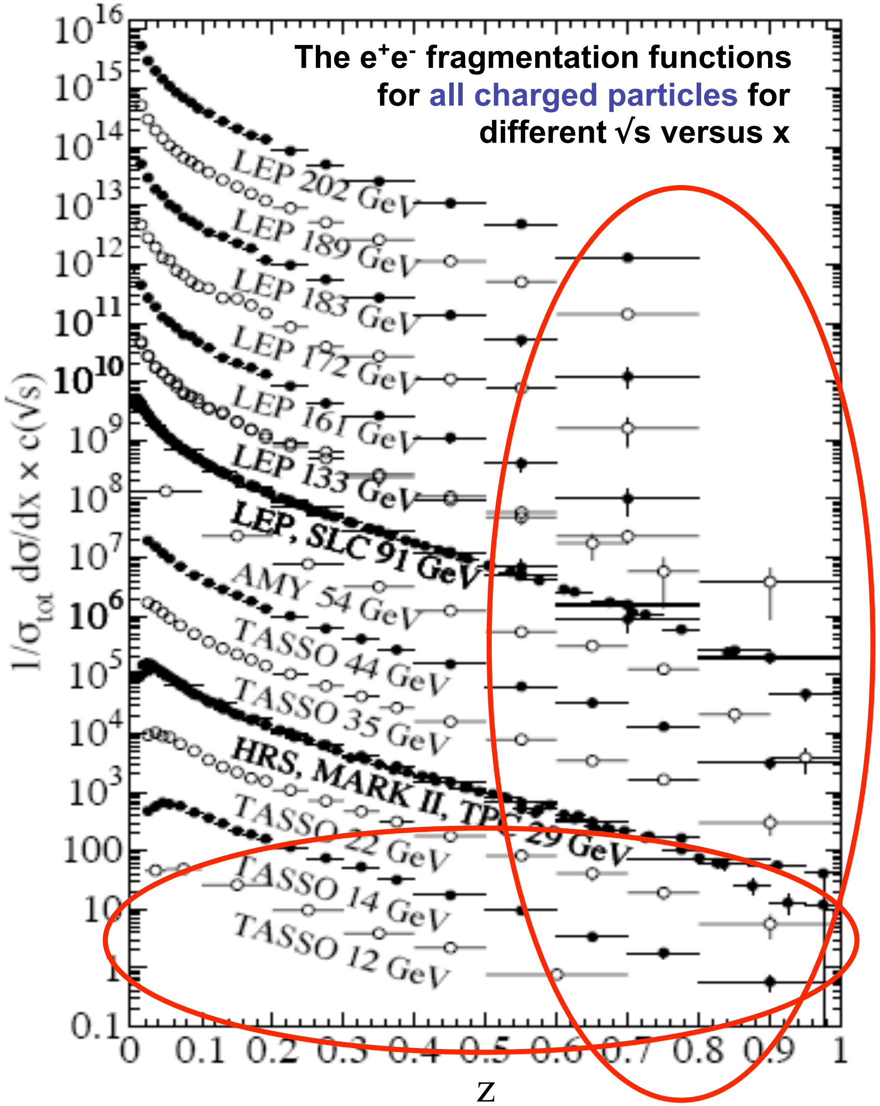


Perturbative QCD corrections lead to logarithmic scaling violations via the evolution equations (DGLAP):

$$\frac{\delta}{\delta ln\mu^2} D_i(x,\mu^2) = \sum_j \int_x^1 \frac{dz}{z} P_{ji}(z, \alpha_s(\mu^2)) D_j(\frac{x}{z}, \mu^2)$$

- Most of data are obtained at LEP energies
- Measurement of both quark and antiquark fragmentation
- The information on how the individual q flavour fragment into h depends on the "tagging techniques"
- 3-jet fragmentation to access gluon FF difficult (not yet well constrained).

e^+e^- Data



- Many attempts to extract FF from e^+e^- data: KKP, AKK, HKNS, Kretzer …

Nucl.Phys.**B725**,181(2006), Nucl.Phys.**B803**,42(2008), Phys.Rev. **D75**,094009(2007), Phys.Rev.**D62**,054001(2000), Nucl.Phys. **B582**,514(2000);

- Global analysis: e^+e^-, SIDIS, and pp

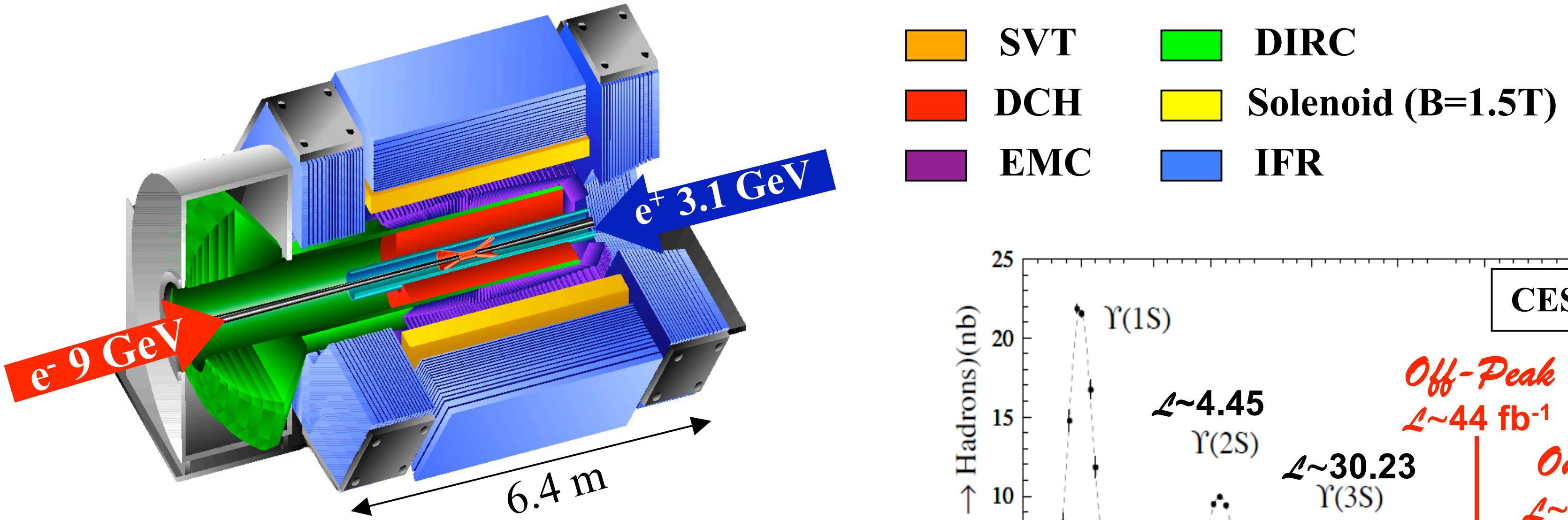
De Florian, Sassot, and Stratmann, Phys.Rev. **D75**,114010(2007), Phys.Rev. **D76**,074033(2007), Epele, Llubaroff, Sassot, Stratmann, arXiv:1209.3240

Few data at high z

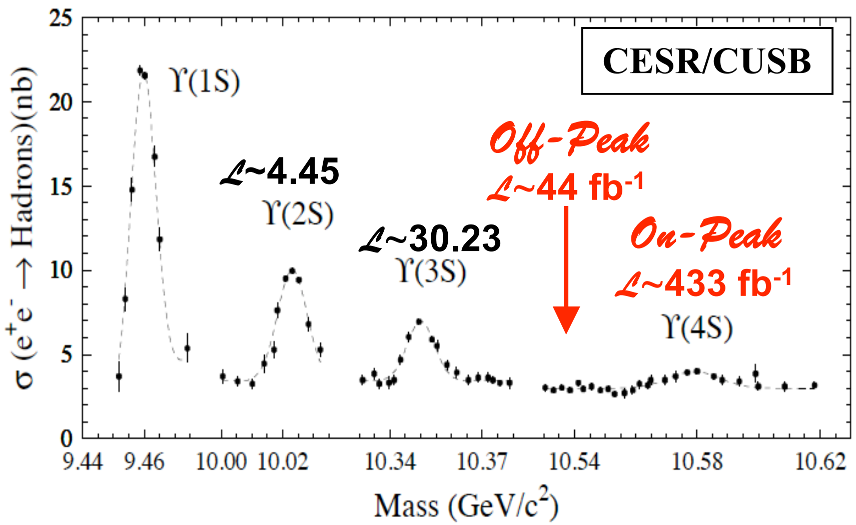
Few data at low energy

Fewer information for identified charged particles

The BaBar Experiment



- $\beta\gamma$=0.56 (c.m. boosted in the lab frame)
- excellent tracking and particle identification



✓ Update on previous preliminary results (Moriond 2004)
⇒ to be submitted to PRD soon

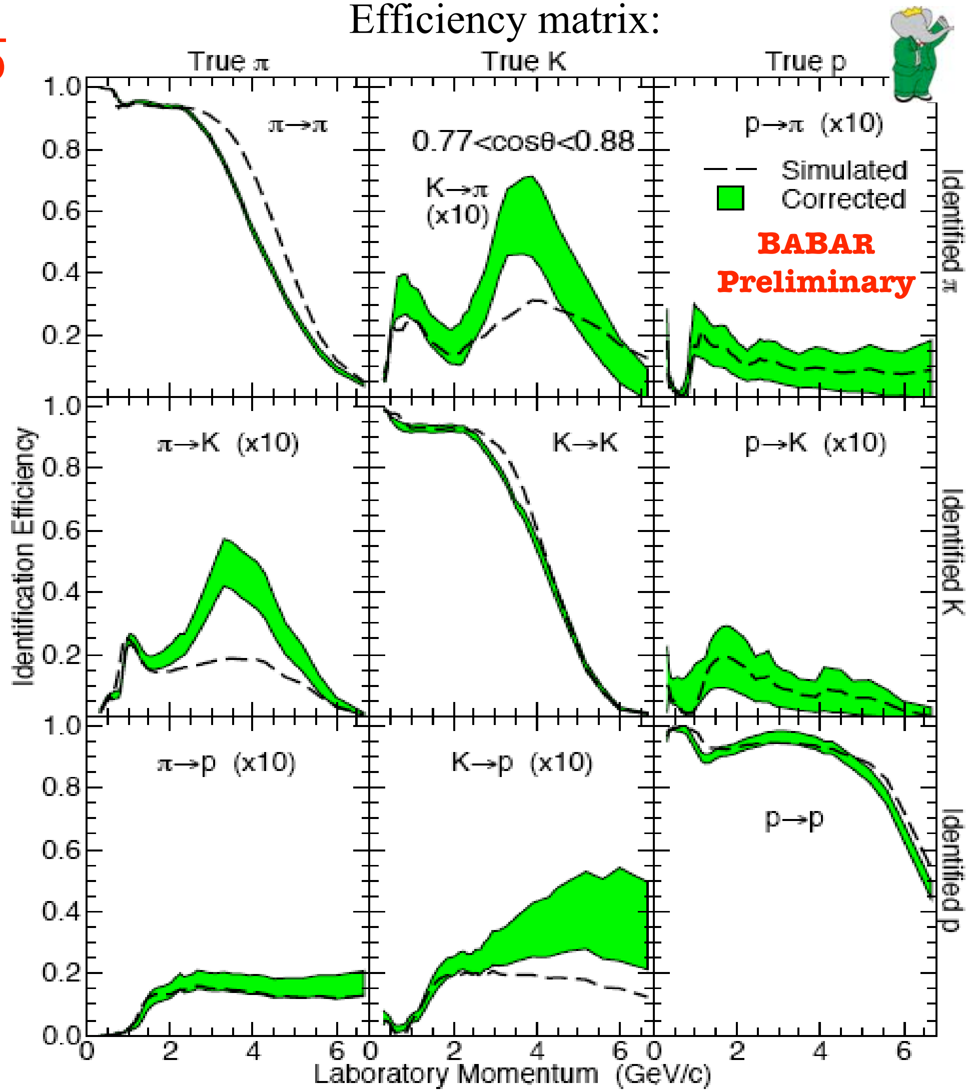
✓ Data samples used: 0.91 fb^{-1} off-peak + 3.61 fb^{-1} on-peak for checks and calibrations

✓ Precision dominated by systematic effects

Charged Hadron Identification

- Excellent identification of $\pi^{\pm}$, $K^{\pm}$, and $p/\bar{p}$
  - DIRC detector plus dE/dx → efficiency matrix:
    - very good at low p_{lab} (good dE/dx)
    - plateau for p_{lab} where DIRC provides good separation
    - fall off at highest p_{lab}, where the Cherekov angles for different particles converge
  - calibrated using data control samples → we derive corrections to the simulated efficiency matrix (green band)
  - large efficiency over much of the momentum range
  - few-% mis-identification

Efficiency matrix:



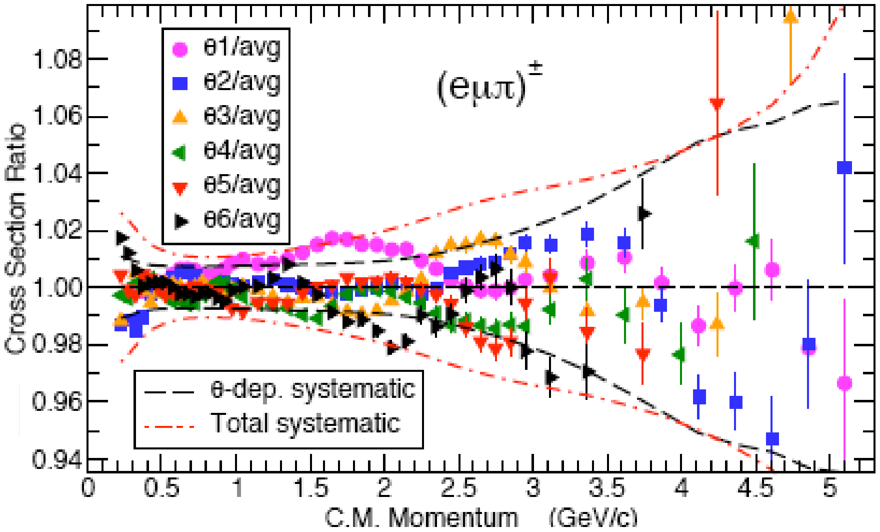
Selection, Corrections, and Systematic Checks

- Select hadronic events:
  - require 3 or more reconstructed charged tracks, thrust axis well within DIRC detector acceptance region ($|\cos\theta^*_{thrust}|<0.8$)
- Select good reconstructed tracks from the primary interaction point, and identify charged particles
- Correct these spectra for:
  - physics background: few-% (mostly $\tau^+\tau^-$), interaction in the detector material (up to 4% al low momentum)
  - efficiency, resolution, transform to c.m. frame

} **corrected cross section**

- extensive systematic cross checks:

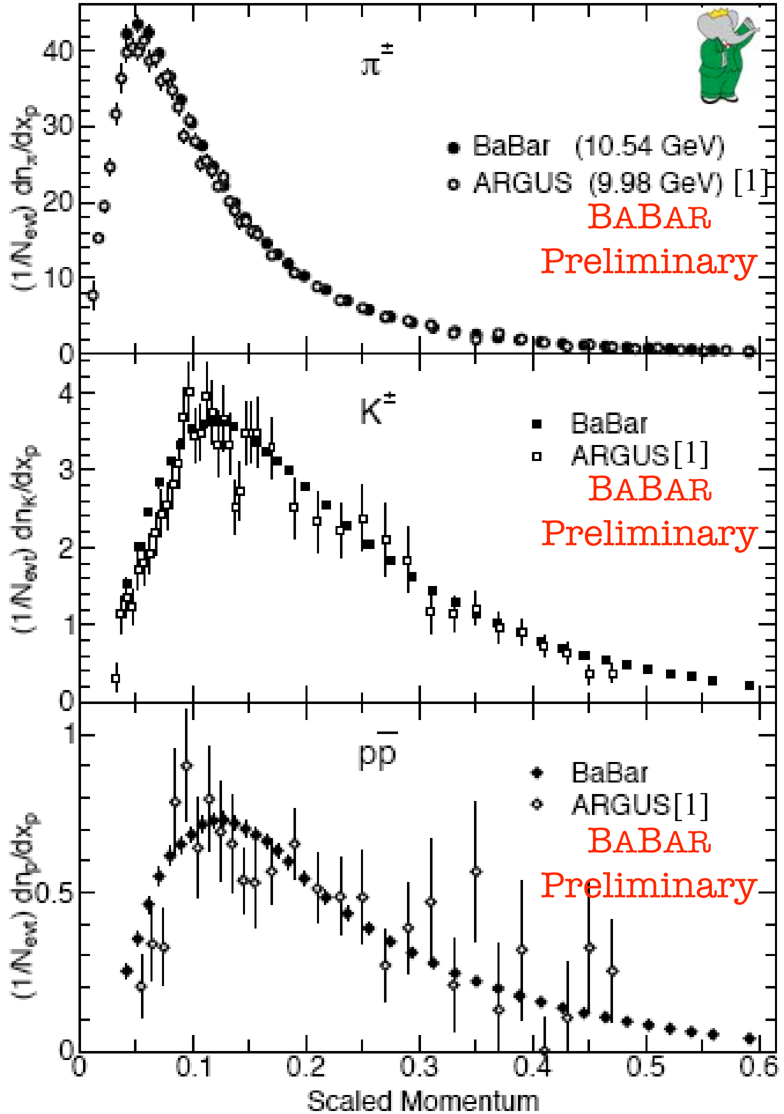
data-MC comparison, check for θ, ϕ,… dependence, compare positive and negative charged tracks,…
  - largest contribution from particle identification and tracking efficiencies



BABAR Results

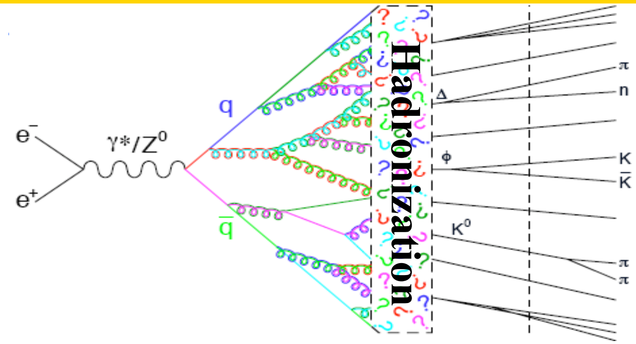
- **Averaged results over θ, in term of scaled momentum $x_p = 2p^*/E_{cm}$**
  - coverage from 0.2 GeV/c to the kinematic limit of 5.27 GeV/c

- **Compare nicely with previous data from ARGUS**
  - consistent everywhere for $x_p > 0.1$
  - mass driven scaling violation for $x_p < 0.1$: ARGUS data systematically below
  - (BABAR) more precise
  - (BABAR) better coverage at high x_p
  - (ARGUS) extends to low momentum for $\pi^\pm \rightarrow$ complementary information



[1] H. Albrecht *et al.* (ARGUS Collaboration) Z. Phys. C **44**, 547 (1989).

Test of Hadronization Models



We compare our cross section with the predictions of three hadronization models:

JETSET model:

- represent the color field between the parton by a "string", and according to an iterative algorithm breaks the string into several pieces, each corresponding to a primary hadron
- **large number of free parameters** (models many hadron species)

HERWING model:

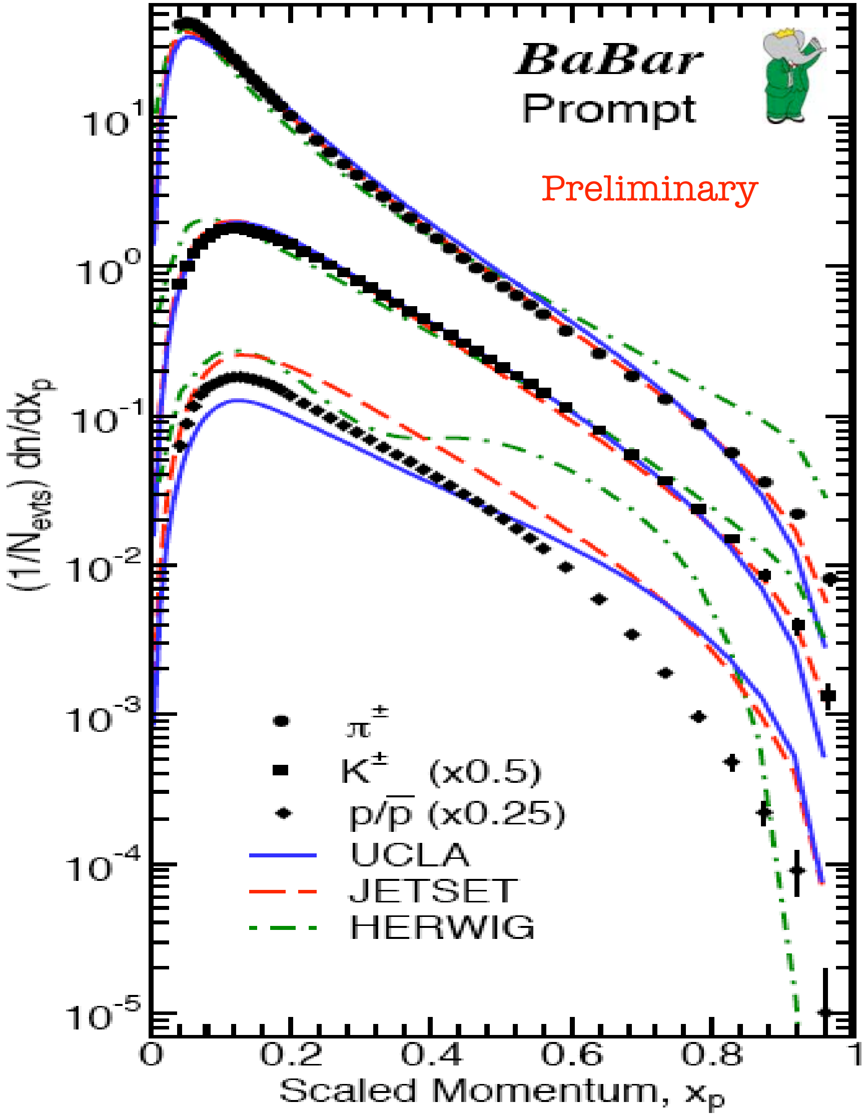
- splits the gluons produced into $q\bar{q}$ pairs, combines these quark and antiquark locally to form colorless "clusters", and decay these "clusters" into primary hadrons
- **few free parameters**

UCLA model:

- generates whole events according to weights derived from phase space and Clebsch-Gordan coefficients
- **few free parameters**

Test of Hadronization Models

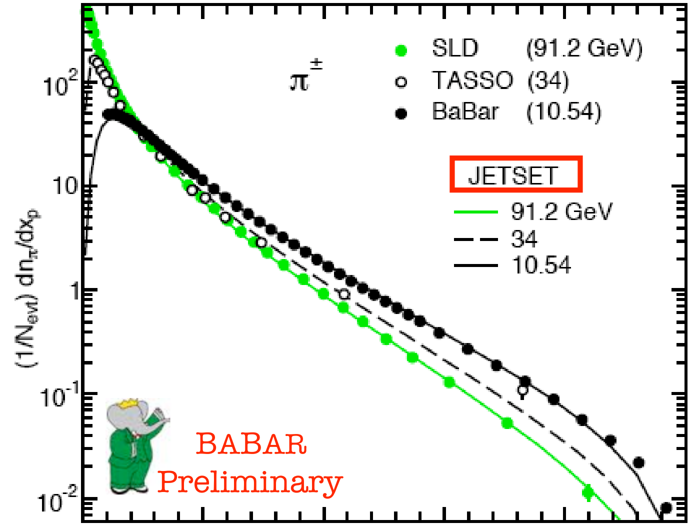
- **Default parameters used**: (based on previous data: higher energies plus ARGUS data)
- **Large discrepancies in general**
  - all the models qualitatively describe the bulk of the spectra
  - no model describes any spectrum in detail
- **Peak positions consistent with data** (except for the HERWIG $K^{\pm}$)
- **Similar discrepancies observed at higher energies**
  - often of the same sign
  - the models do a reasonable job of describing the scaling properties?

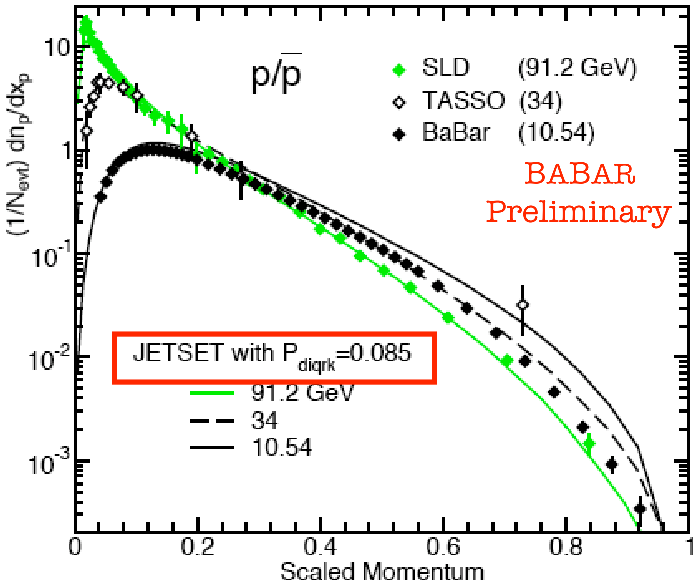


Scaling Properties

Consider π, K, and p from BABAR, TASSO and SLD

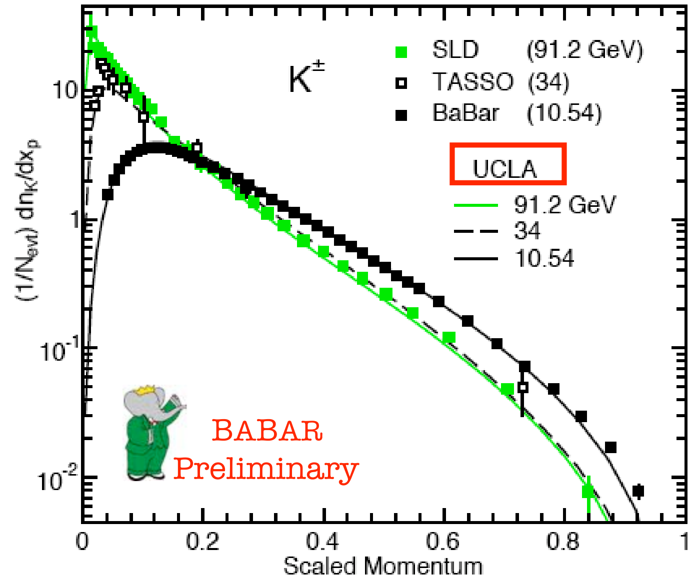
- **Strong scaling violation** at **high x_p** (running of α_s) and at **low x_p** (pion mass)
- **K±**: the different flavor composition of the three samples modifies the expected scaling violation
  - models predict about 10%-15% more scaling violation than is observed





- $p/\bar{p}$: the scaling prediction for 10.54 GeV is consistent with data for x_p<0.07, but exceeding it by as much as a factor 3 at x_p=0.8

Is there something missing?



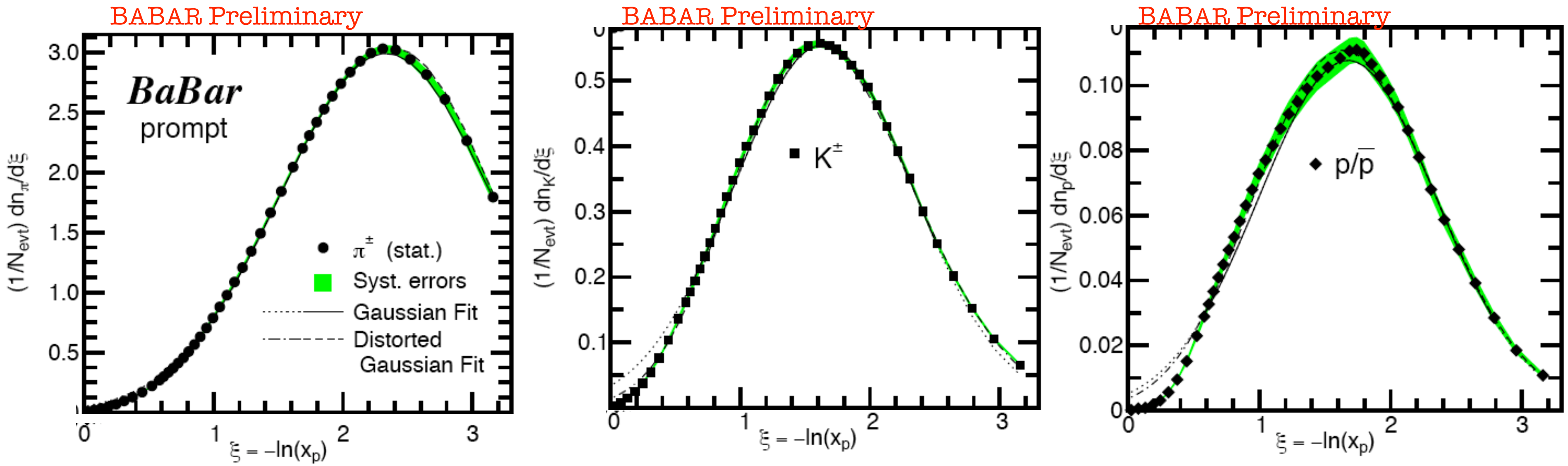
Test of MLLA+LPHD QCD

- Transform our cross section into the variable $\xi=-\ln(x_p)$

Test of QCD prediction

Modified Leading Algorithm Approximation (MLLA) with Local Parton-Hadron Duality (LPHD) ansatz ==> a Gaussian function should provide a good description of these spectra

- Fit the spectra with a (distorted) Gaussian function

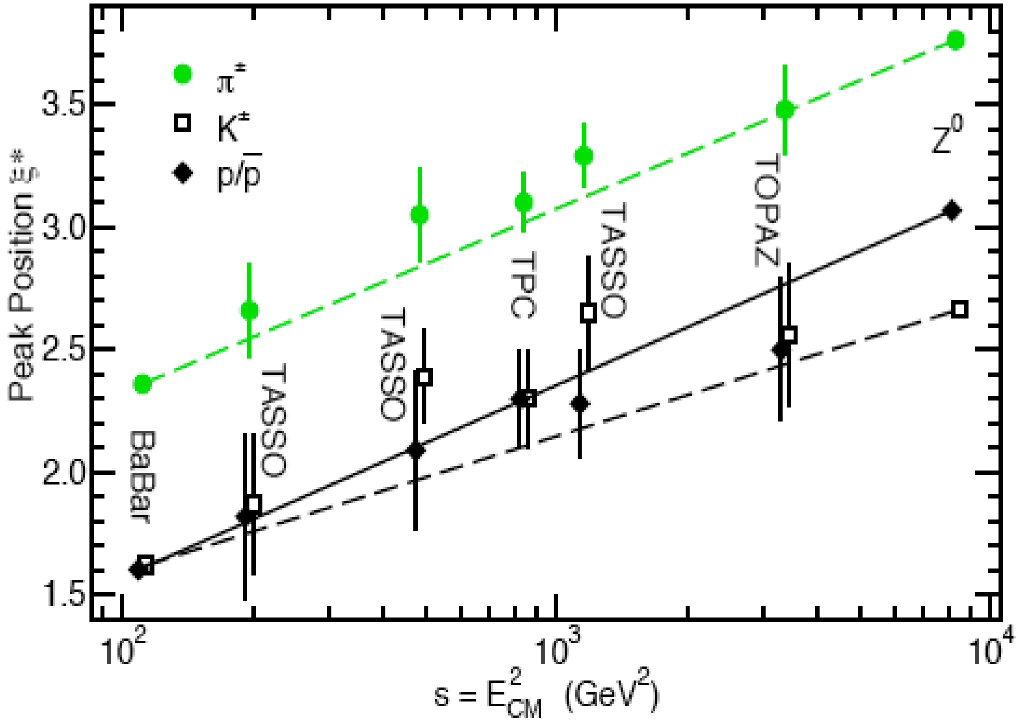


Reasonable description of the data

Test of MLLA+LPHD QCD: Peak Position

→ MLLA predicts that the peak position ξ^*
- should **decrease exponentially with increasing hadron mass at a given E_{cm}**
- should **increase logarithmically with E_{cm} for a given hadron type**

→ ξ^*_π is higher than ξ^*_K in agreement with the predicted drop, but ξ^*_p is not lower than ξ^*_K (or seems to follow different trajectories at higher energies)



→ **BABAR and Z^0 data provide precise slope**
→ The other data are consistent with the line that joins BABAR and Z^0 data
→ **Similar slopes of the lines for pions and protons; different for kaons ==> <u>changing flavor composition</u>** with increasing E_{CM}

Summary and Conclusions

• We measured the inclusive spectra for $\pi^\pm$, $K^\pm$, and $p/\bar{p}$ hadrons in e^+e^- annihilation at the center of mass energy of about 10.54 GeV at BABAR

- **precise data at high x_p**
- **consistent with, improvement upon, measurements from ARGUS**
- **can be used to test and tune the models of hadronization** (JETSET, HERWIG, and UCLA)
    - $\pi^\pm$, and $K^\pm$ spectra reproduced within 15% over most p^* range
    - $p/\bar{p}$ poorly described

• Scaling property:

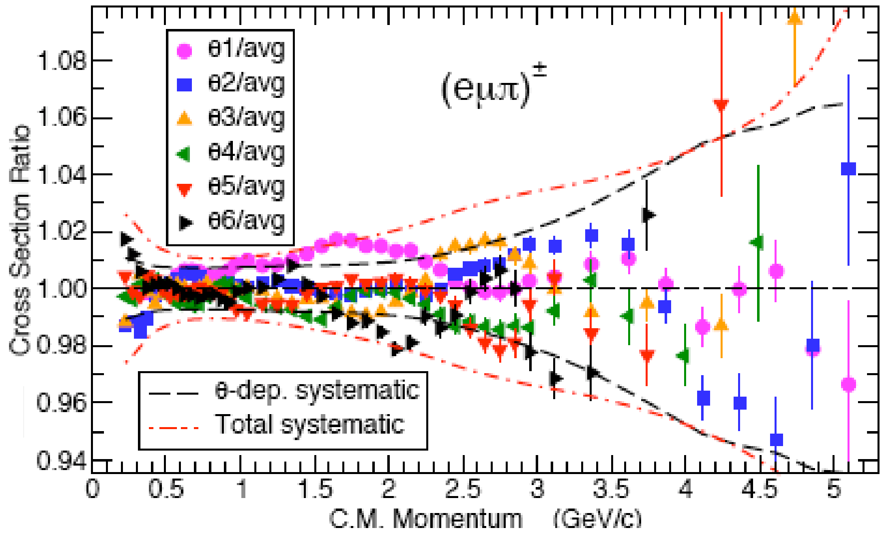
- **no models predict the correct scaling properties for protons**, even though they describe the properties of pions well
- **MLLA is consistent with our data**
- **ξ^* is lower for $K^\pm$ than $\pi^\pm$, as predicted, but ξ^* $p/\bar{p}$ is not lower than that of $K^\pm$**
    - consistent with the behavior observed at higher energies
    - similar slope for $\pi^\pm$ and $p/\bar{p}$
    - lower slope for $K^\pm$, perhaps due to the changing flavor composition

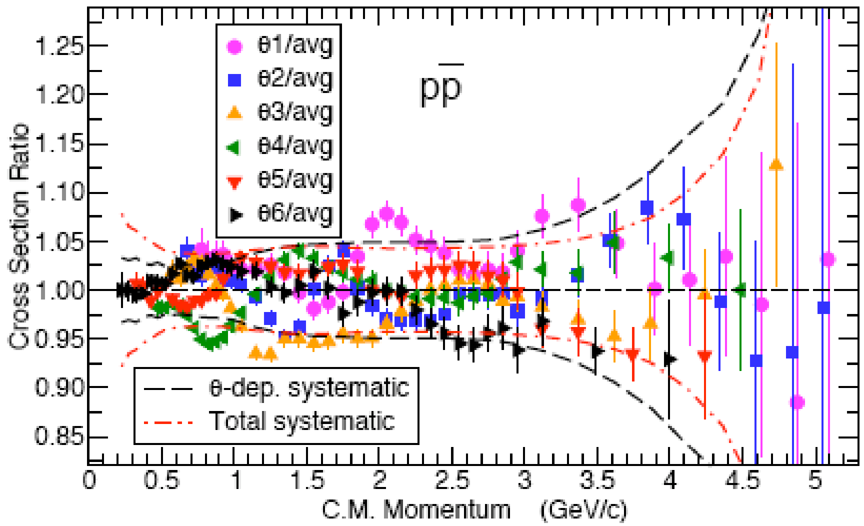
BACKUP SLIDES

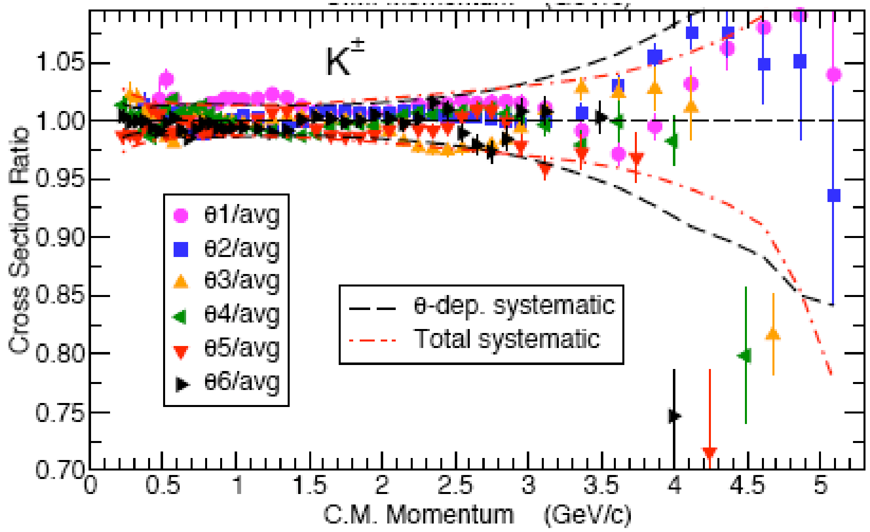
$\pi^{\pm}$, $K^{\pm}$, and $p/\bar{p}$ Analysis

- **extensive systematic cross checks:** data-MC comparison, check for θ, φ,… dependence, compare positive and negative charged tracks,…

Ratio of fully corrected cross sections to their average value from each $\cos(\theta_{lab})$ region







Test of MLLA+LPHD QCD: Peak Position (II)