Review on parton fragmentation studies in BABAR

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On behalf of the *BABAR* Collaboration

Workshop on parton fragmentation processes in the vacuum and in the medium

ECT* - Trento

February 25-29, 2008 Trento

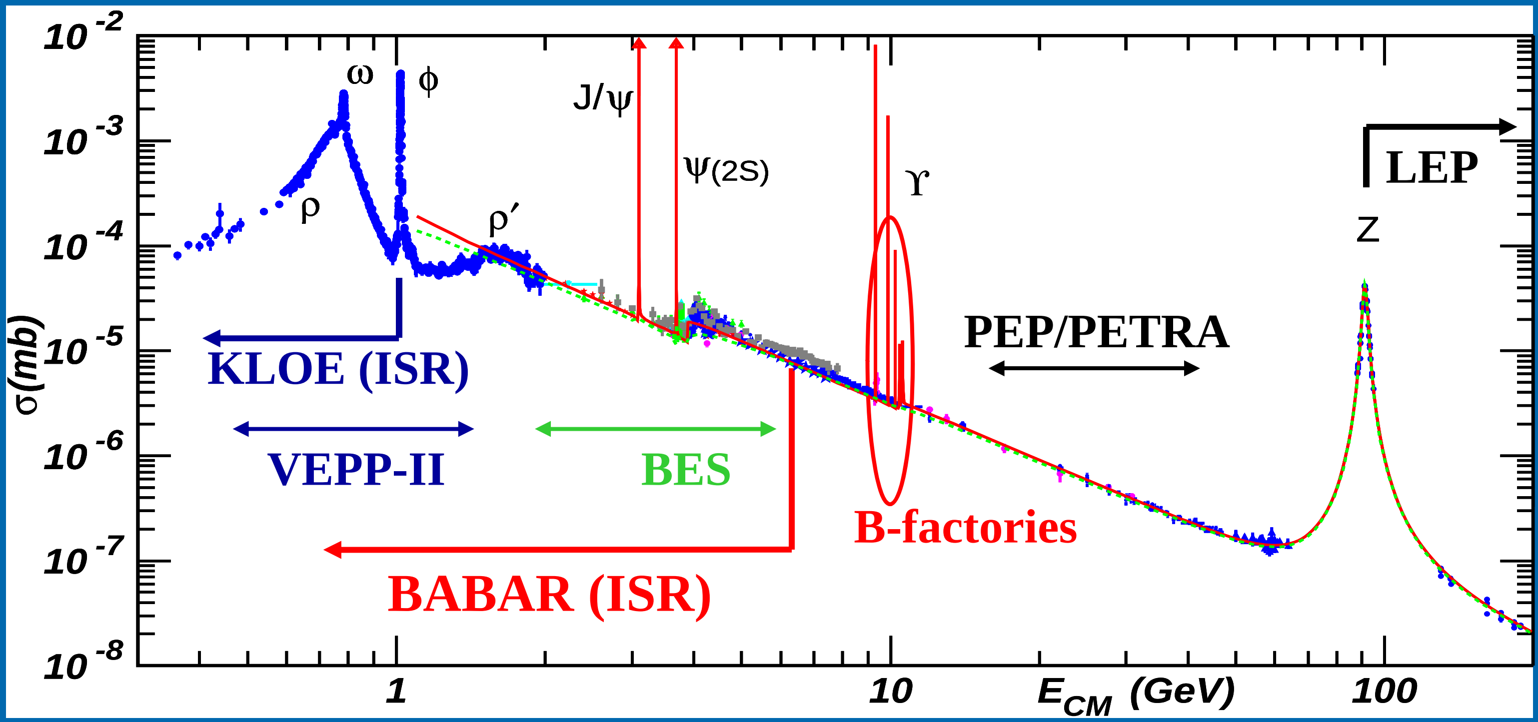
Outline:

- Physics motivation
- BABAR and PEPII

- Inclusive production of light particles at ~10 GeV
- Inclusive studies on charmed baryons at ~10 GeV
  - Inclusive Λ_c and Ξ_c spectra
  - $\Lambda_c^+ \overline{\Lambda}_c^-$ correlated production and popcorn mesons
- Studies of exclusive state at ~10 GeV
  - $e^+e^- \rightarrow p\bar{p}p\bar{p}$
  - $e^+e^- \rightarrow \rho\rho,\ \phi\rho,\ \phi\eta$
- e^+e^- interactions at low energy via Initial State Radiation

- Conclusions

$\sigma(e^+e^- \rightarrow hadrons)$



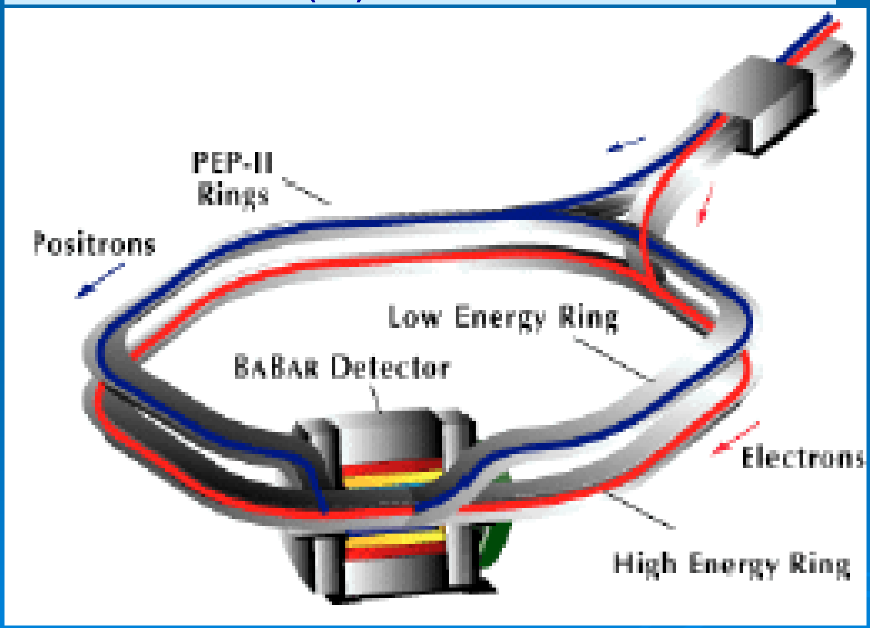
- High E_{cm}: perturbative QCD holds ==> $e^+e^- \rightarrow q\bar{q}(g) \rightarrow jets$
  - QCD predicts energy dependence of "rare" few-body processes
- Low E_{cm}: resonances, *quasi 2-,3-body* processes,…
  - lots of physics: spectroscopy, form factors, QCD tests,…
- the same also at $c\bar{c}$ and $b\bar{b}$ threshold (and at Z^0)
- difficult predictions (and models poorly tested) in the "transition" region
- total σ_{had} is the experimental input for evaluation of hadronic contribution to $(g-2)_\mu$ and $\alpha_{QED}(M_Z)$

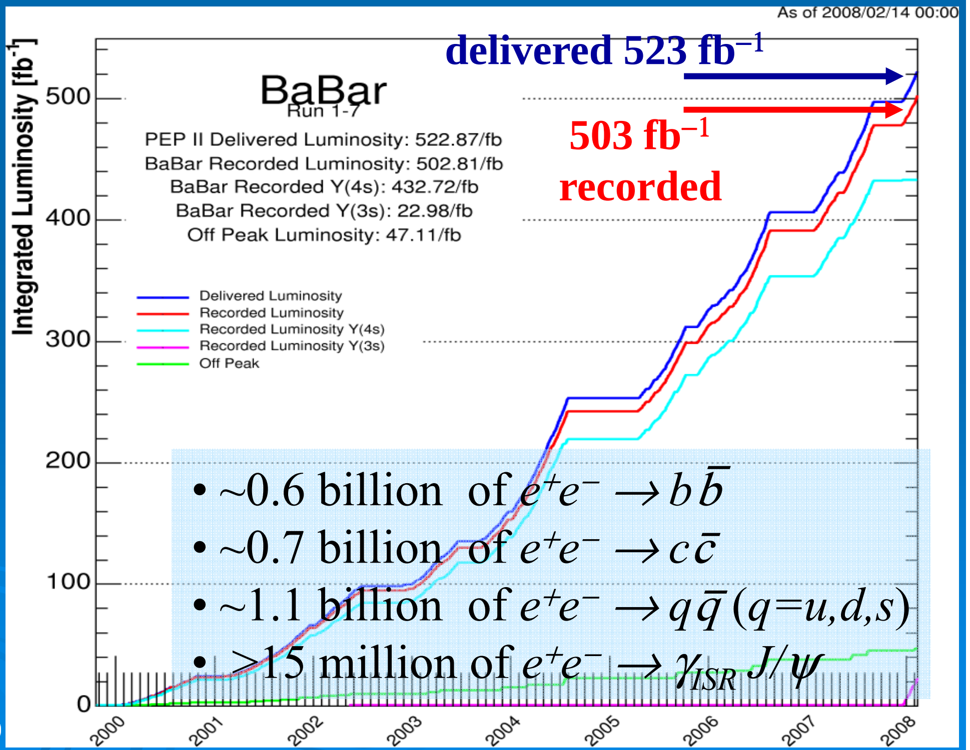
The asymmetric *B*-factory PEP-II

Both machine and detector optimized for study the CP violation in B mesons decays very well suited also for any type of physics at this energy

- PEP-II largely outperformed the design parameters:
  - $L_{peak} = 1.2 \cdot 10^{34}\ \mathrm{cm^{-2}\ s^{-1}}$
  - Best 24h : $L = 910\ \mathrm{pb^{-1}}$
  - logging efficiency >96%

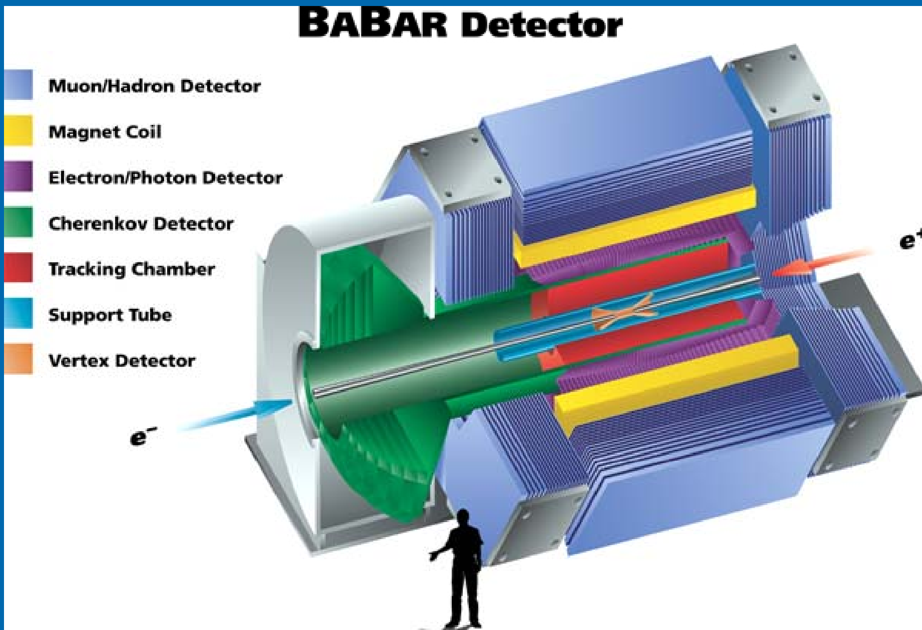
E_{e-} = 9.0 GeV; E_{e+} = 3.1 GeV
$\sqrt{s} \approx M_{\Upsilon(4S)}$ = 10.58 GeV/c²





- ~0.6 billion of $e^+e^- \to b\bar{b}$
- ~0.7 billion of $e^+e^- \to c\bar{c}$
- ~1.1 billion of $e^+e^- \to q\bar{q}\ (q=u,d,s)$
- >15 million of $e^+e^- \to \gamma_{ISR}\ J/\psi$

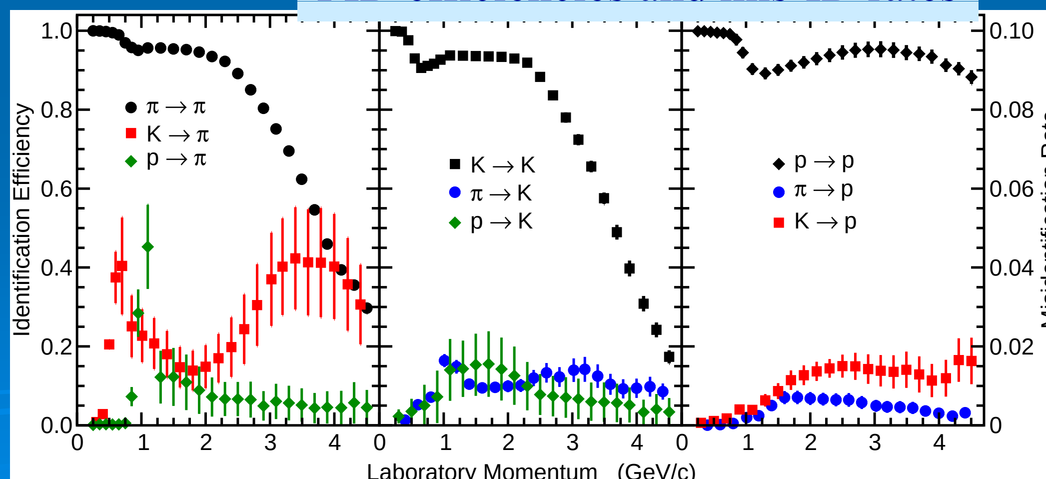
The BABAR detector



Excellent detector performances:

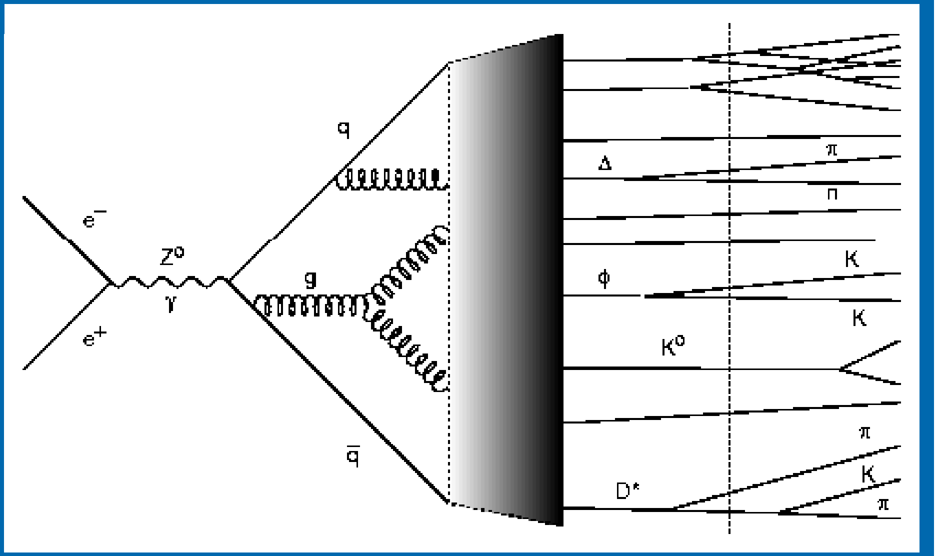
- SVT: $\varepsilon \approx 97\%$, ~15 μm z hit resolution
- Tracking (SVT+DCH): $\sigma(p_T)/p_T \cong (0.13\ \ p_T(\mathrm{GeV}/c) \oplus 0.45)\ \%$
- K-π separation >3 σ (p ~ 4 GeV/c)
- EMC energy resolution: $\sigma(E)/E \approx (2.3\ \ E^{-1/4} \oplus 1.8)\ \%$
- Polar angle coverage in c.m. frame (w.r.t. e^- beam): $0.9 < \cos\vartheta^* < 0.85$

PID efficiencies and mis-ID rates



- Analysis presented here make use of very good PID performances
  - **PID eff > 90% for most of interesting range**
  - **mis-ID < 3% almost everywhere**

Inclusive Hadronic Particle Spectra



- The total fragmentation function for a hadron *h* in e^+e^- annihilation at an energy E_{cm} is:

$$F^h(x, E^2_{cm}) = \frac{1}{\sigma_{tot}} \frac{d\sigma}{dx}(e^+e^- \to V \to hX),$$
$$\textit{where} \quad V = \gamma, Z^0 \quad \textit{and} \quad x = 2E_h / E_{cm}$$

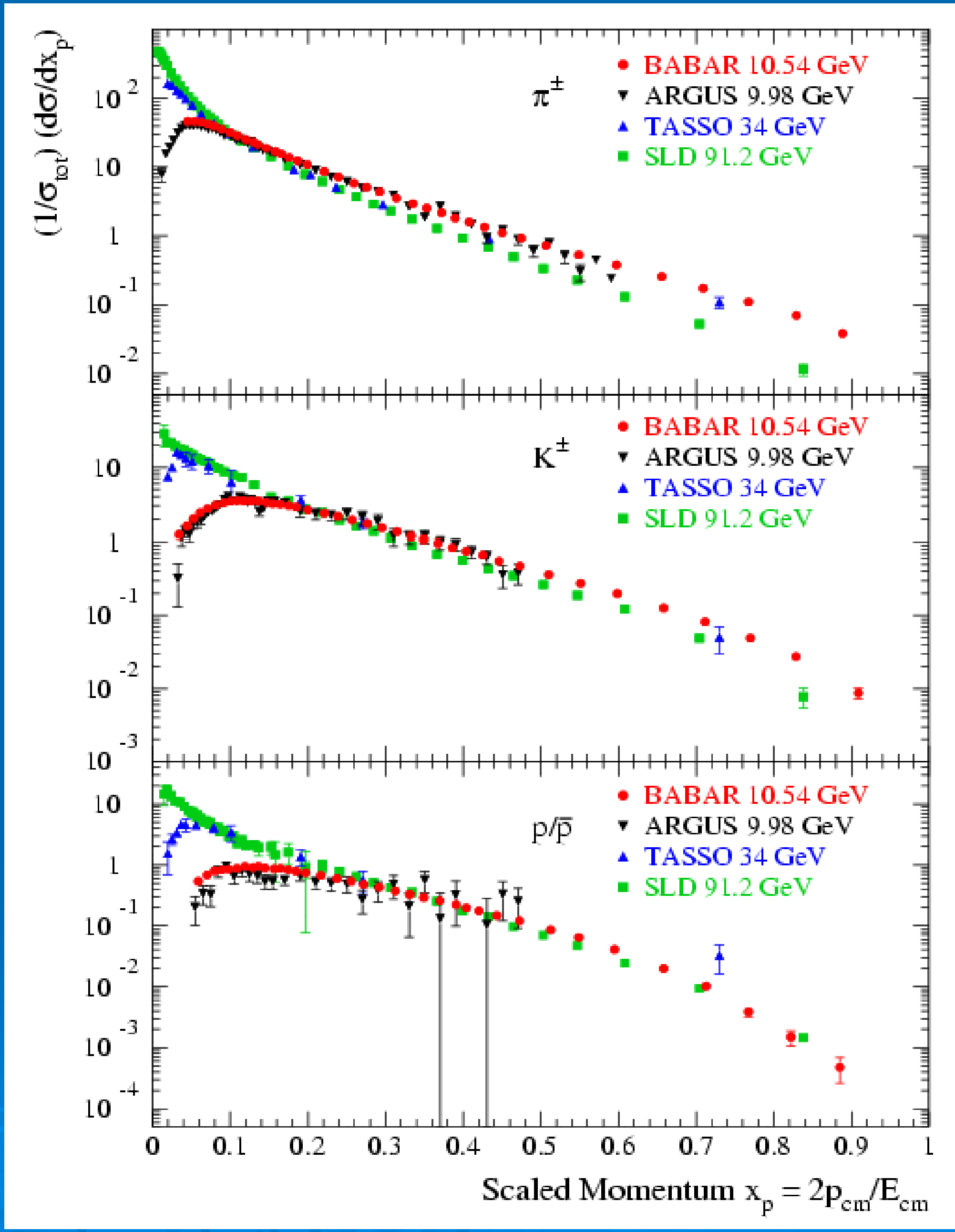
- precise measurements of IPS at different energies needed to:
  - better comprehension of fragmentation processes
  - check consistency with a number of fragmentation models
  - test scaling violation
  - test QCD predictions
- many recent high-energy results
- limited precision measurements at low-energy before *B*-factories

- So far, *BABAR* have measured IS of:
  - 3 light mesons ($\pi^\pm$, $K^\pm$, η)
  - 1 light baryon (p/p̄)
  - 3 Heavy baryons (Λ_c, Ξ_c, Ξ'_c)

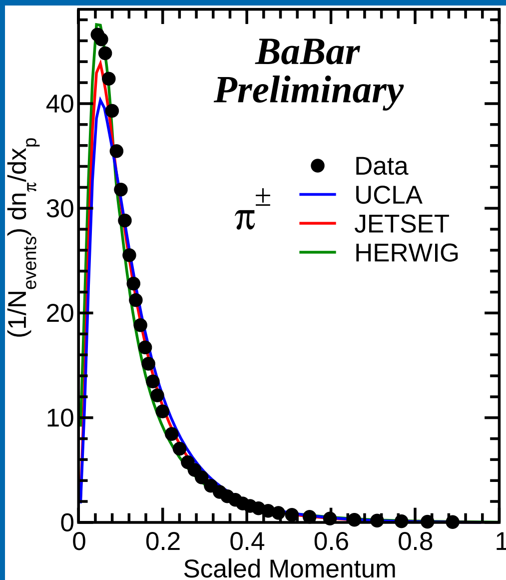
- measurements performed both at $\sqrt{s}$=10.54 GeV and at $\Upsilon(4S)$ mass peak

IHPS: $\pi^+, K^+, \eta, p/\bar{p}$

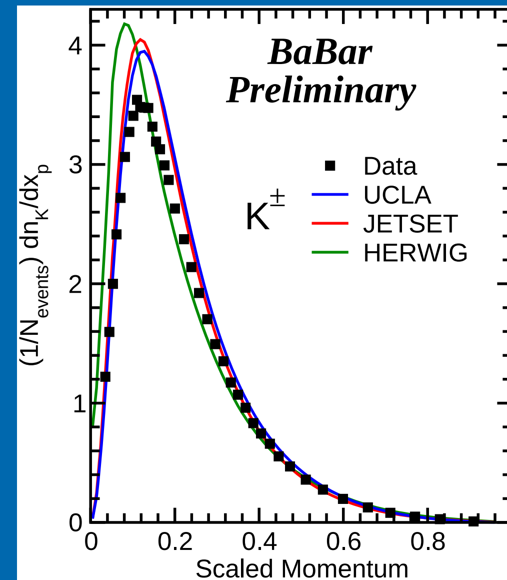
- BABAR measurement based on:
  - 0.9 fb^{-1} off-resonance
  - 3.6 fb^{-1} on-resonance
- plot scaled momentum distribution $x_p = 2p^*/E_{cm}$
- data available at E_{cm} = 10-200 GeV (some example shown here)
- good consistency between *BABAR* and ARGUS data
  - ARGUS extends to lower values
  - BABAR covers the high side of the spectrum
  - precision of data already limited by systematics effects.
- reviewed analysis of BABAR data ongoing

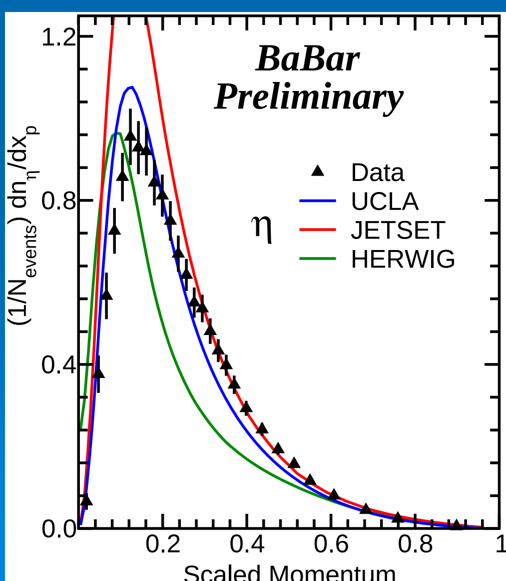


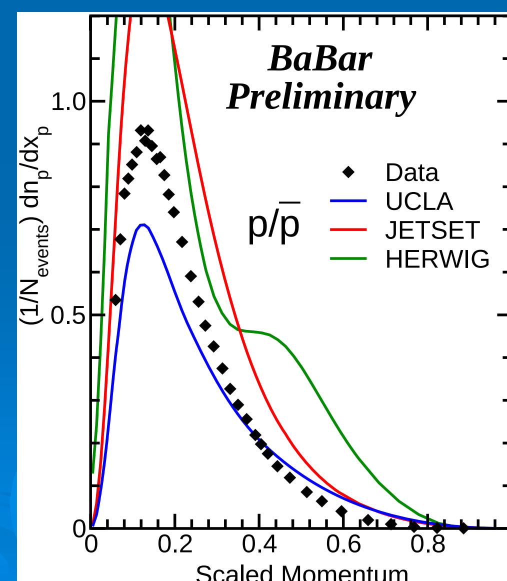
IHPS: π^+, K^+, η, $p/\bar{p}$



- comparison of BABAR data with some models on the market :
  - good consistency for pions
  - reasonable agreement with other scalar mesons, for most of the energy range
  - no model really works with protons (and baryons in general)

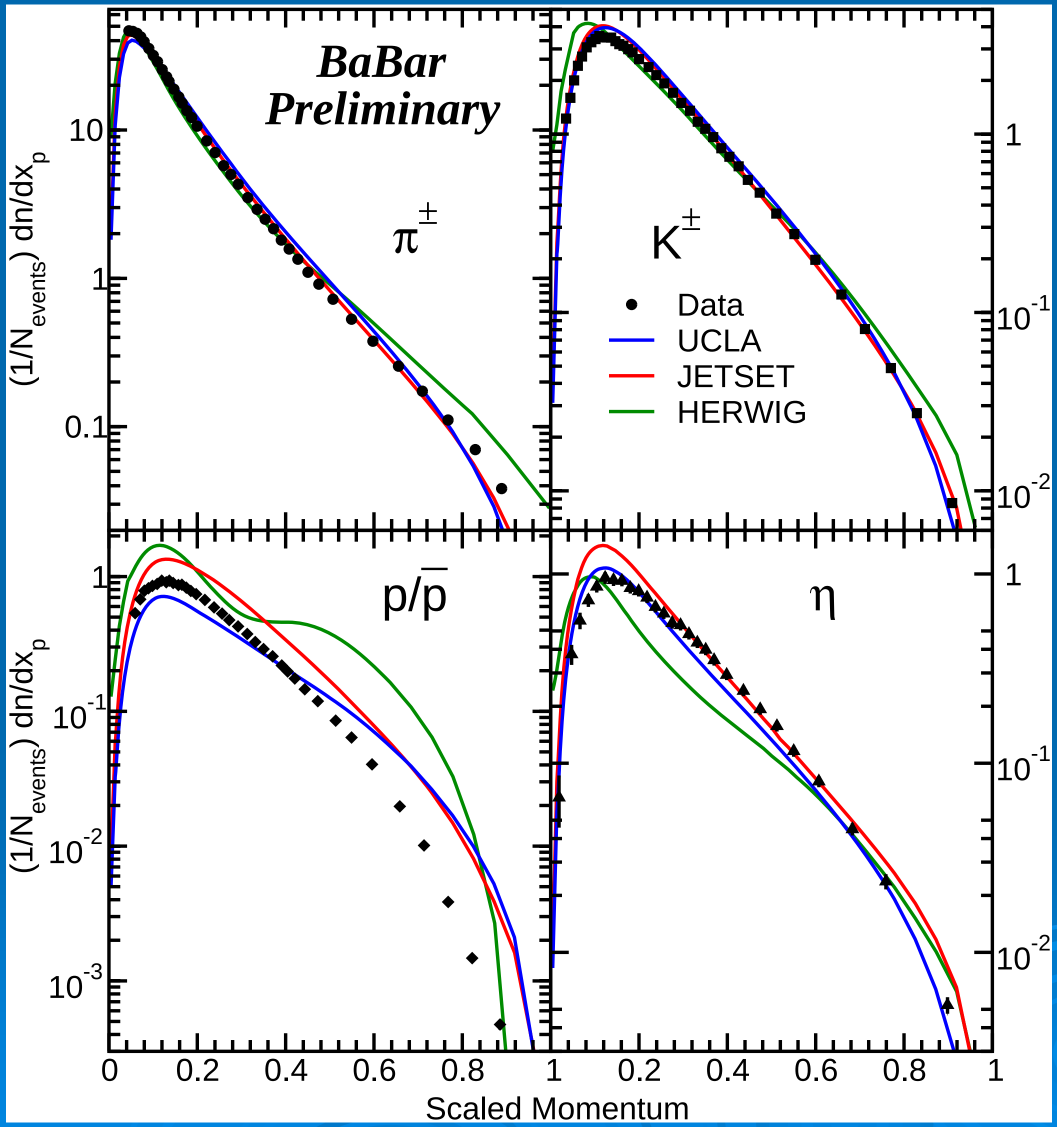




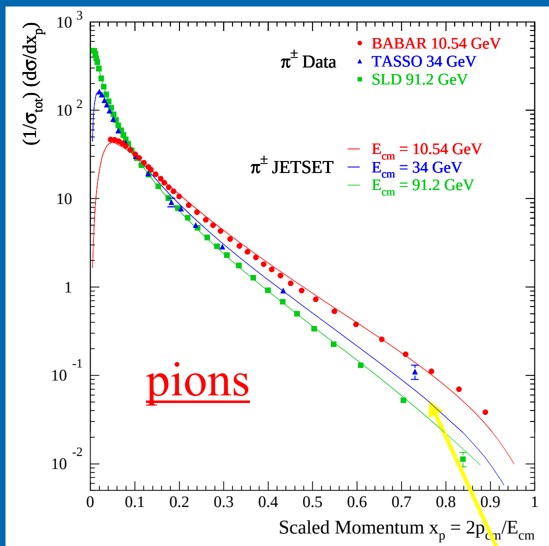


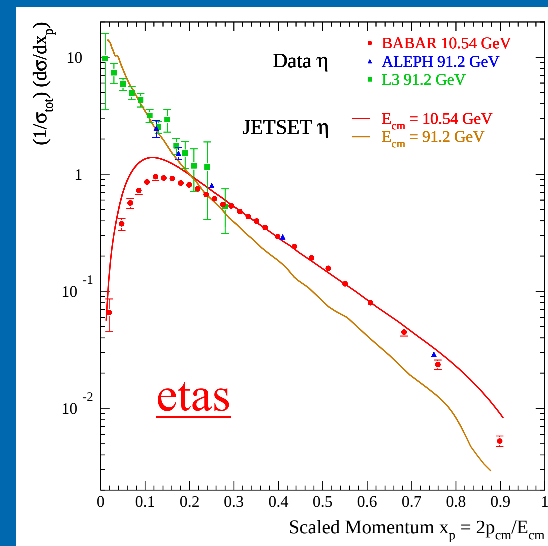
IHPS: π^+, K^+, η, $p/\bar{p}$

- same data shown in previous slide, in log scale

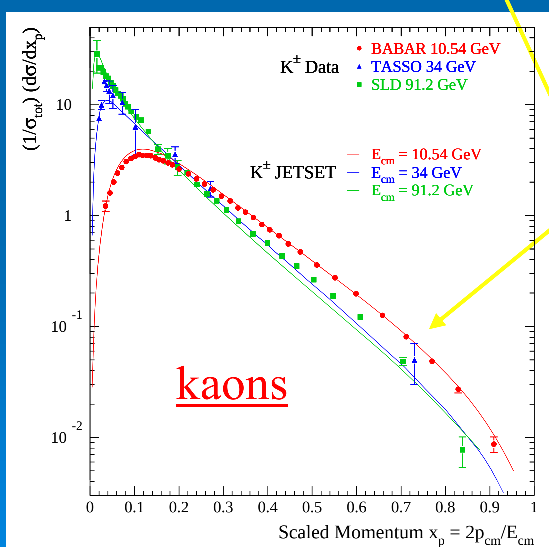


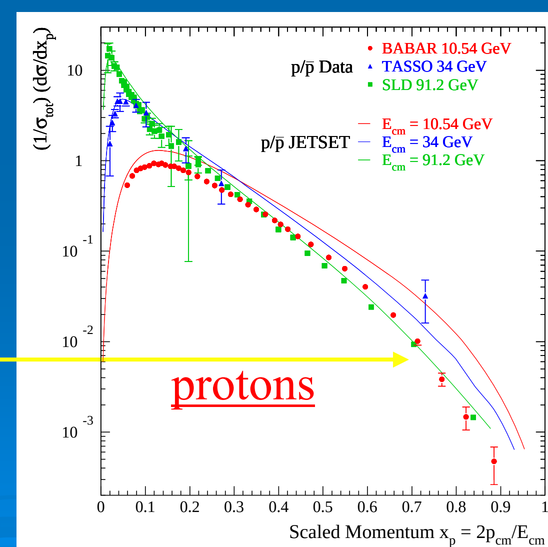
IHPS: cross section scaling





- 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 well known and modeled adequately (here JETSET is shown for comparison)
- expect substantial scaling violations at high x_p
  - seen clearly in π and K data; reproduced by models
  - NOT seen in $p/\bar{p}$ data! Wrong model predictions





$\pi^{\pm}$, $K^{\pm}$, η, $p/\bar{p}$: test QCD predictions

- In the *Modified Leading Logarithmic Approximation* (MLLA), distributions versus $\xi = -\ln(x_p)$ should be Gaussian near the peak.

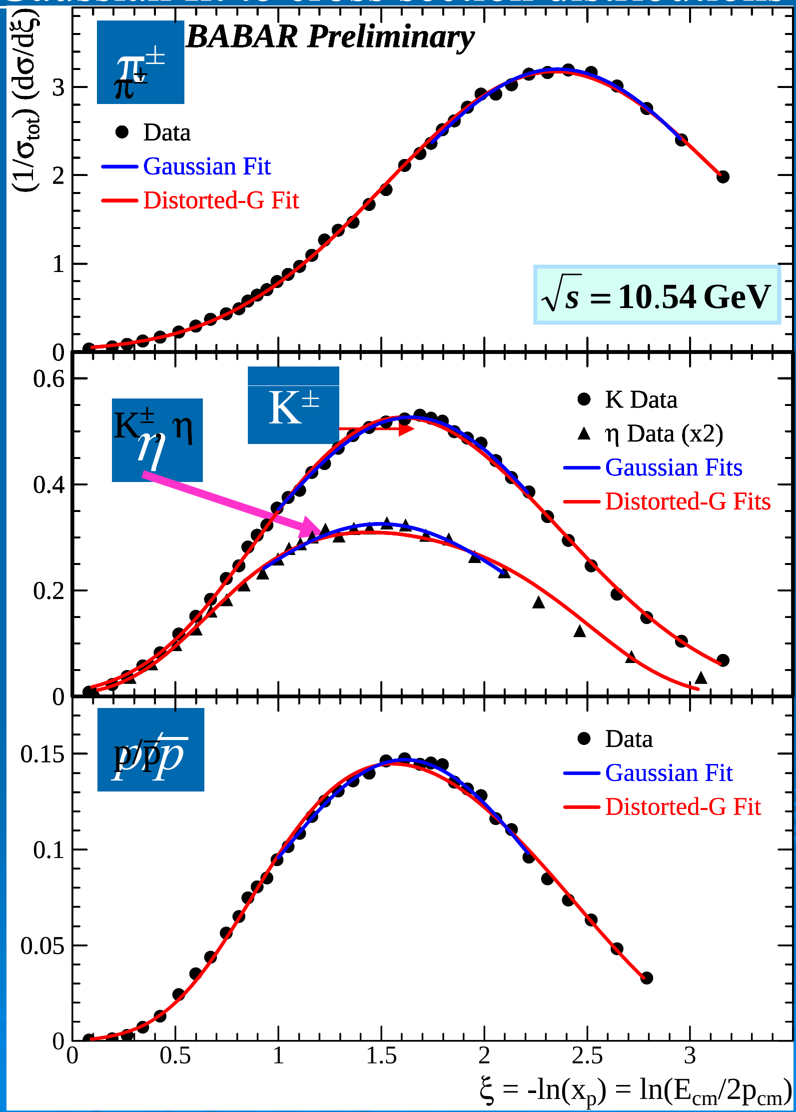
peak position $\xi*$ from symmetric gaussian fits

π^+	**2.36 ± 0.01**
K^+	**1.64 ± 0.01**
p	**1.61 ± 0.01**
η	**1.44 ± 0.02**

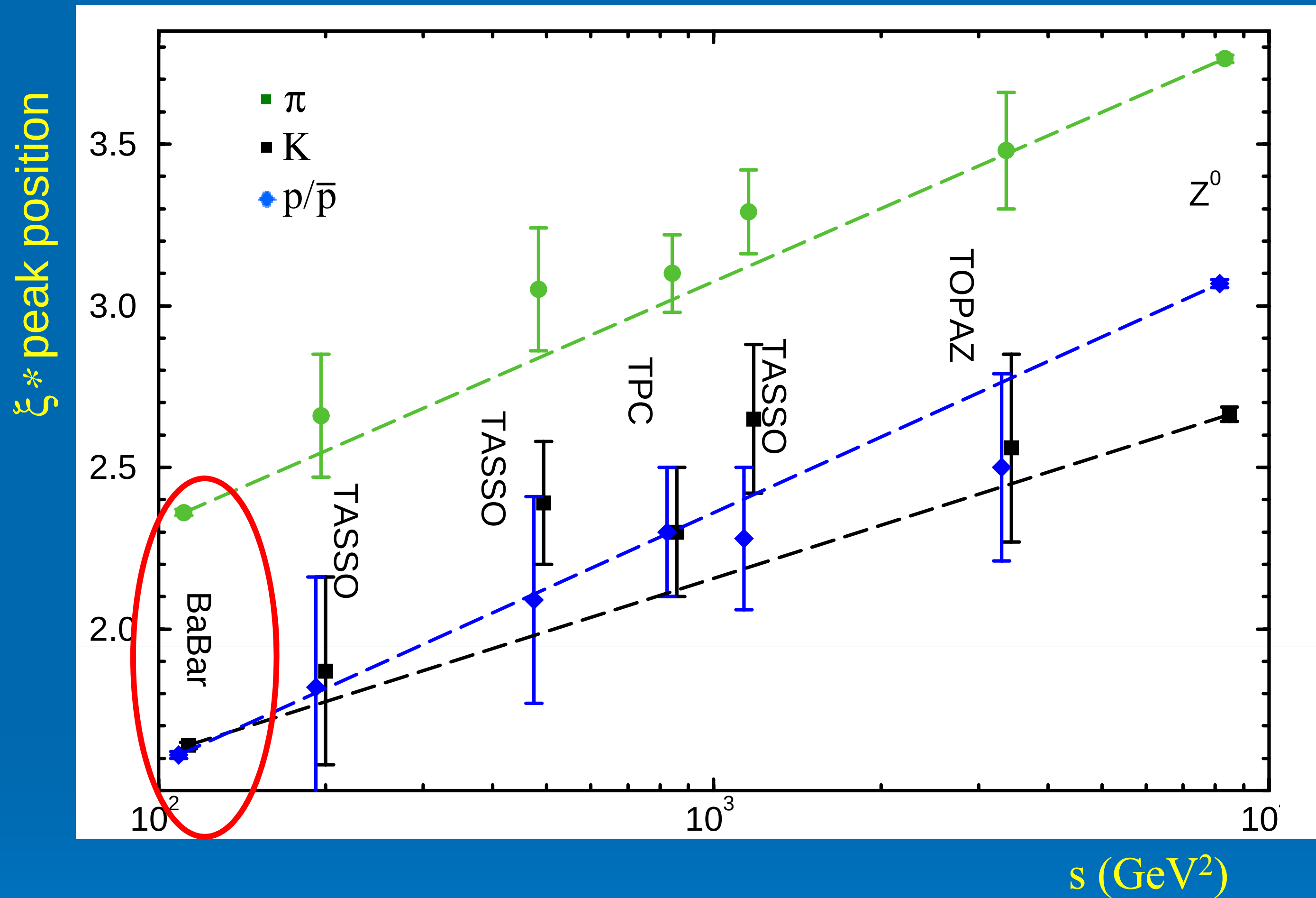
- QCD prediction is that $\xi*$ falls monotonically with increasing particle mass.

while it is observed $\xi*_p \approx \xi*_K$

Gaussian fit to cross section distributions

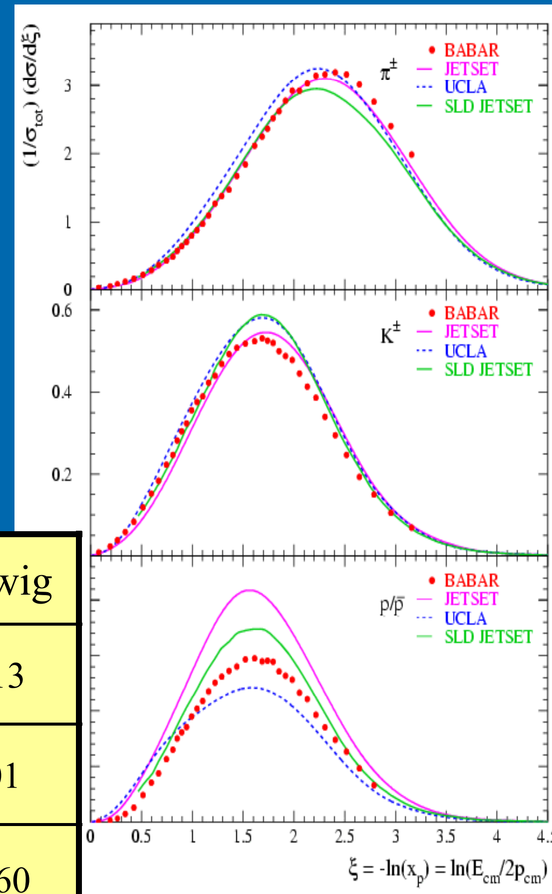


π , K , $p/\bar{p}$: test QCD predictions



- All data are consistent with the expected logarithm dependence with the center-of-mass energy
- but, different slopes, protons data above kaons…

$\pi^{\pm}, K^{\pm}, p/\bar{p}$: production rate



- total number of particles produced per event extrapolated using fit to $d\sigma/d\xi$ distributions

	BABAR	ARGUS	CLEO	JETSET	UCLA	Herwig
π^{+}	6.40 ± 0.17	6.38 ± 0.12	8.3 ± 0.4	6.22	6.44	6.13
K^{+}	0.910 ± 0.018	0.888 ± 0.030	1.3 ± 0.2	0.934	1.01	1.01
$p/\bar{p}$	0.235 ± 0.012	0.271 ± 0.018	0.40 ± 0.06	0.336	0.217	0.460
η	0.276±0.017	0.19±0.04 ±0.04	---	0.410		0.233

Charm production at BABAR

- Heavy hadrons produced in e^+e^- annihilations provide a laboratory for the study of heavy-quark jet fragmentation
- Relevant quantities are
  - Relative production rates for different spin, parity, etc
  - Associated momentum spectra
  - Differences among mesons and baryons

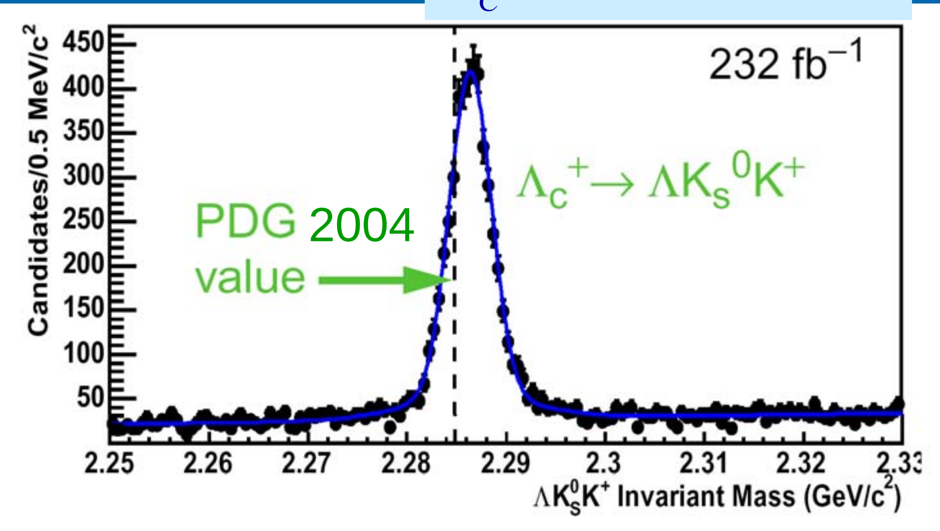
- Measurements at 10.54 GeV, below $B\bar{B}$ production threshold, are the ideal place to study $e^+e^- \to c\bar{c}$ reactions, and test charm fragmentation functions, the charmed hadrons being made of one of the leading quarks
- Large amount of data to study $b \to c$ decays from inclusive measurements at the Υ(4S):
  - *B-mesons* $\to$ *charmed mesons/baryons*

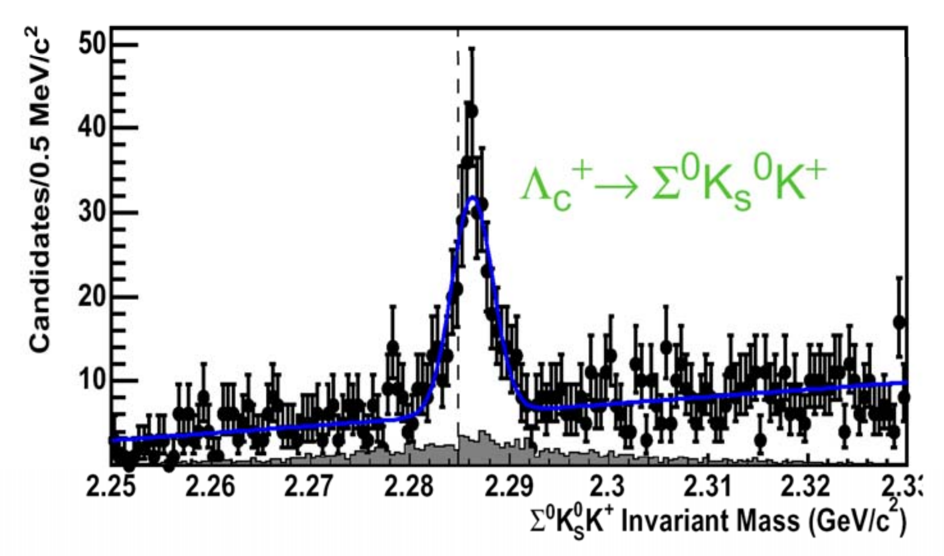
- Great potential for charm spectroscopy (search for new states, precise measurements of fundamental quantities, e.g. masses, spin, I-spin,…) !
  - last results on this topic shown yesterday by S. Pacetti

Inclusive Λ_c studies

- The Λ_c^+ (*cud*) is the lightest c-baryon
- We precisely measured its mass reconstructing two low-Q decays, to minimize systematic uncertainties
- We find (PRD 72, (2005) 052006)
  - $m(\Lambda_c^+) = 2286.46 \pm 0.14$ MeV/c^2
- More precise and 2.5σ higher than the previous PDG value:
  - $m_{PDG}(\Lambda_c^+) = 2284.9 \pm 0.6$ MeV/c^2

Λ_C^+ mass measurement





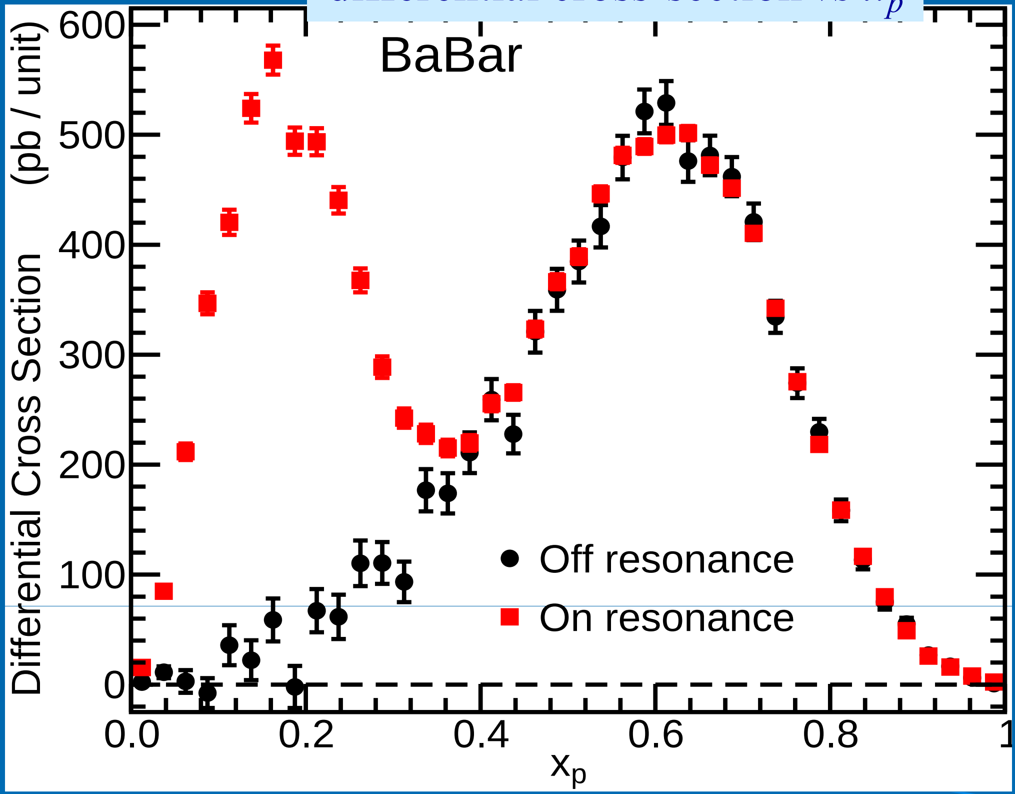
Inclusive Λ_c spectrum measurement

PRD 75, 012003 (2007)

9.5 fb^{-1} off-resonance
81 fb^{-1} on-resonance

- reconstruct $\Lambda_c^+ \to pK^-\pi^+$ from tracks consistent from originating from interaction point
- evaluate track efficiencies from data in two-dimensional (p,θ) bins
- weight events according to inverse efficiency matrix
- fit mass peak in each x_p bin

differential cross-section *vs* x_p



- Determine $e^+e^- \to c\bar{c}$ events from off-resonance data (E_{cm}=10.54 GeV)
- Determine $e^+e^- \to B\bar{B}$ events from on-resonance data subtracting the off-resonance cross section scaled by the different c.m. energy

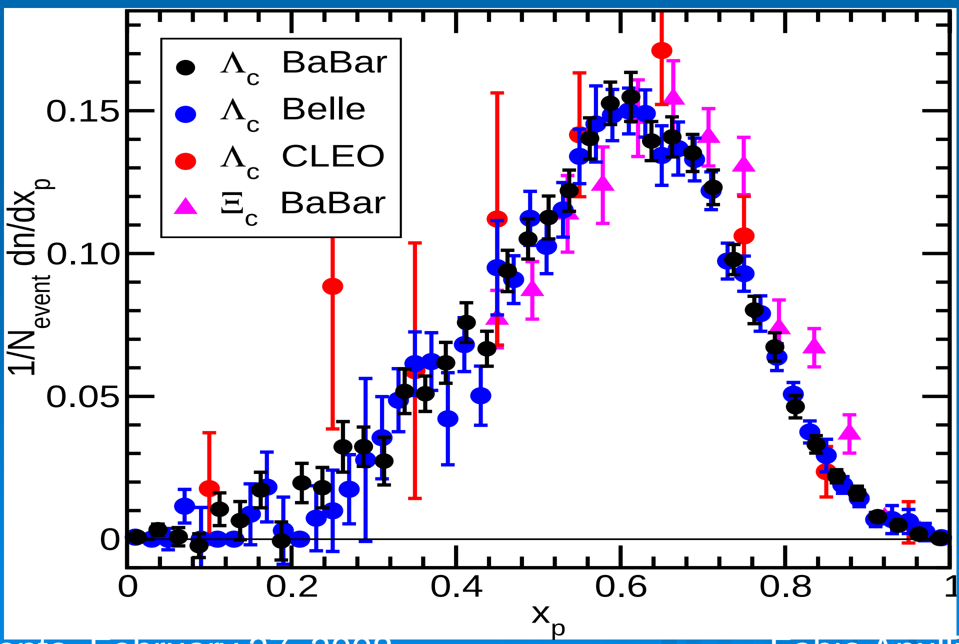
Inclusive Λ_c spectrum measurement

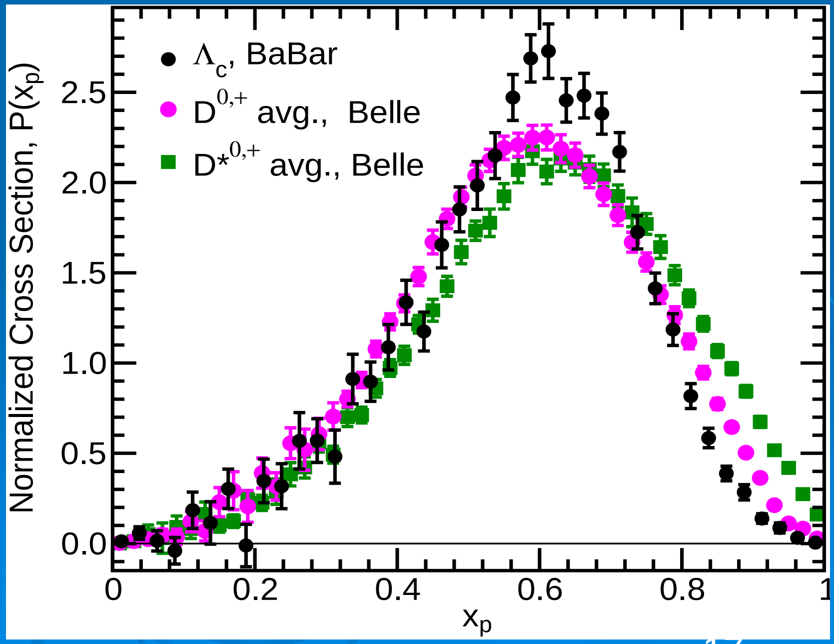
- We measure (at E_{cm}=10.54 GeV):
- $\langle x_p \rangle = 0.574 \pm 0.009$
- Total rate per event:

  $N^{q\bar{q}}_{\Lambda_C} = 0.057 \pm 0.002(\text{exp}) \pm 0.015(\Lambda_C BF)$
- assuming Λ_C^+ from $e^+e^- \to c\bar{c}$ we get a production rate per c-jet of:

  $N^{c-jet}_{\Lambda_C} = 0.071 \pm 0.003(\text{exp}) \pm 0.018(\Lambda_C BF)$
- Result consistent with previous CLEO and Belle measurements

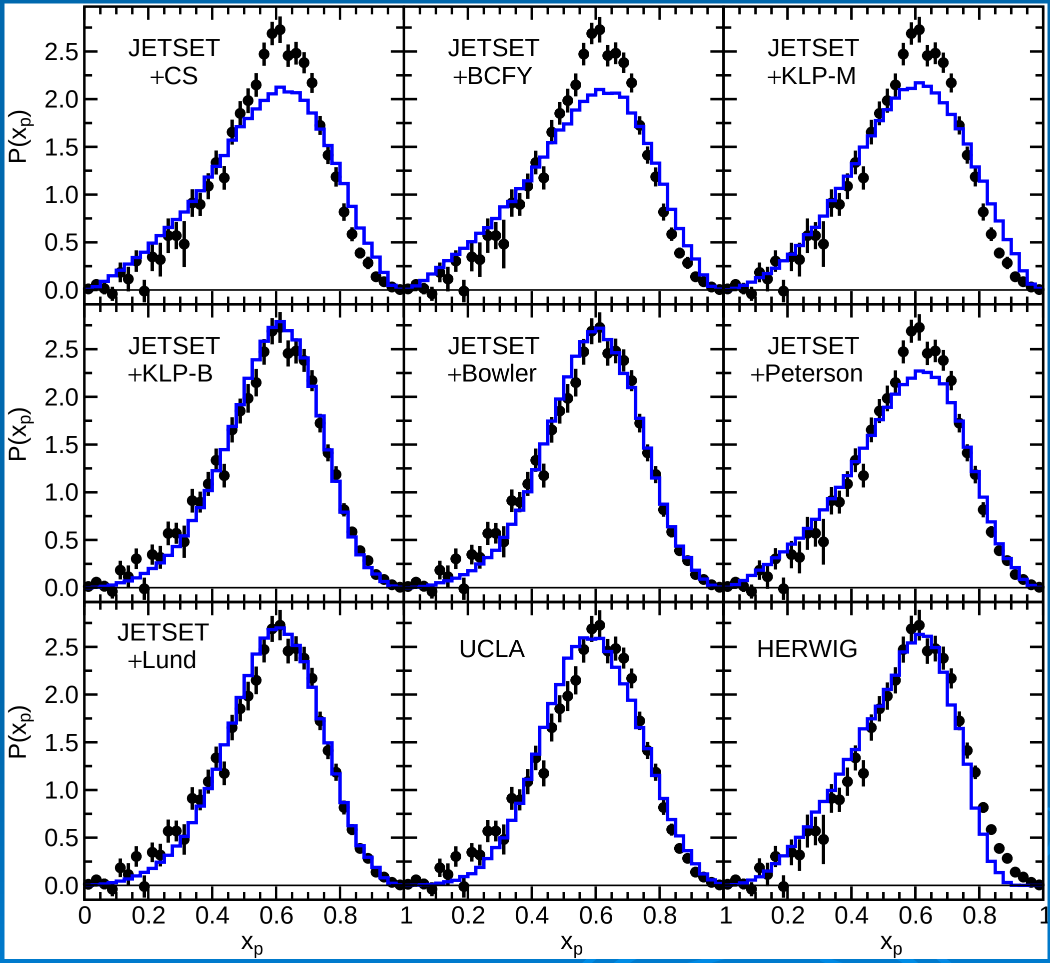
- Compare to other baryons or mesons
- Λ_C peak slightly lower w.r.t. Ξ_c
- D mesons (both PS and V state), show broad peaks and differ significantly for $x_p \sim 1$





Inclusive Λ_c spectrum measurement

- Several fragmentation functions implemented in JETSET generator
  - distributions affected by JETSET simulation of gluon radiation
  - test each models against our data using a binned χ^2



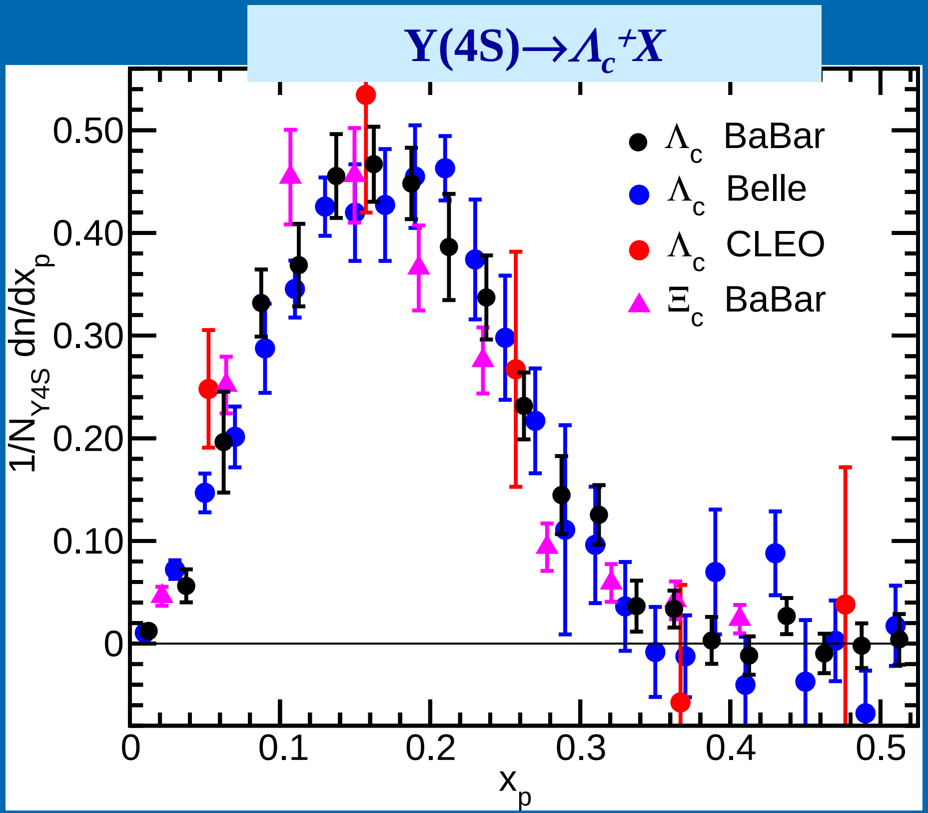
- No model seems to correctly reproduce the data, but
- The fitted values of the free parameters are quite different from those used for light hadrons and charmed mesons
- These results indicate the needs of different functions for baryons and mesons (like in DIS, where there is a dependency on the number of spectator quarks)

Inclusive Λ_c spectrum at the Y(4s)

- Spectrum for Y(4S) decays obtained subtracting the much harder $e^+e^- \to c\bar{c}$ spectrum
- Kinematic limit $x_p = 0.47$
- Shape consistent with previous results
- We measure

$$N^{Y}_{\Lambda_c} = \mathbf{0.091 \pm 0.006\,(exp) \pm 0.024\,(\Lambda_c BF)}$$

- *i.e.* (4.5 ±1.2)% of $B_{u,d}$ decays include a Λ_c



- Data suggest a dominance of quasi-two-body decays like:
  - $B \to (\Lambda_c^+\bar{p},\ \Lambda_c^+\bar{n},\ \Lambda_c^+\Delta,\ \Sigma_c\bar{p}\ ) +\ m\pi$
  - comparing with MC simulations the favorite range for the number of pions is $3 < m < 5$
  - also B decays into 2 charmed baryons seem to contribute significantly

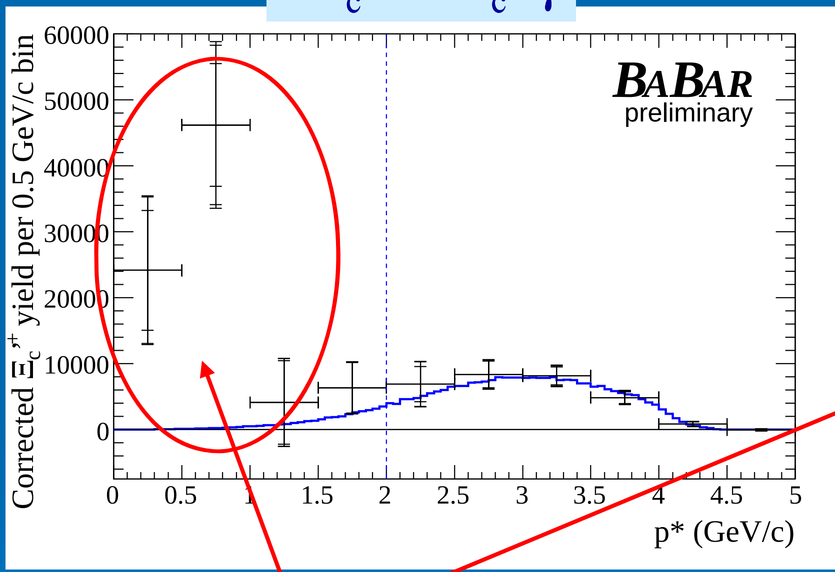
More c-baryons inclusive spectra: Ξ_c'

hep-ex/0607086

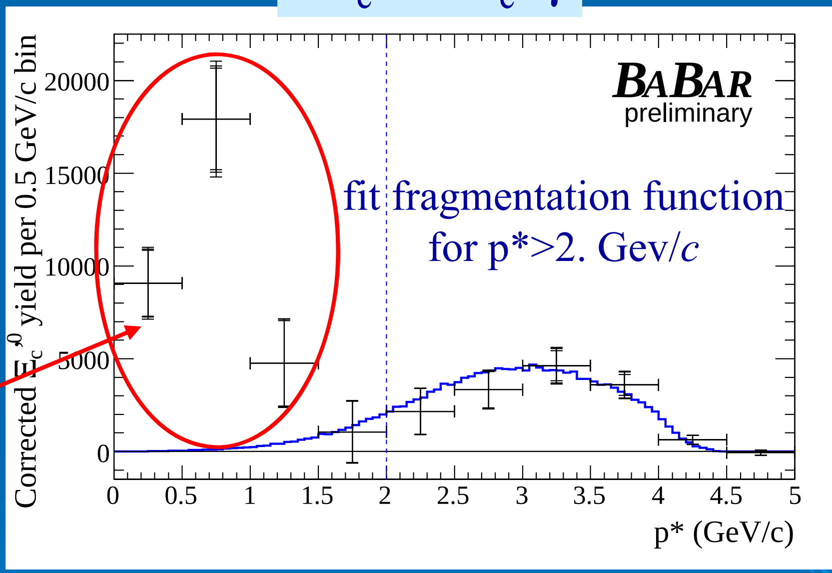
State	Mass (MeV/c^2)	J^P
Ξ_c	2470	$1/2^+$
Ξ_c'	2575	$1/2^+$
Ξ_c^*	2645	$3/2^+$

- Ξ'_c first observed by CLEO in 1999
- $\Delta m = m(\Xi'_c) - m(\Xi_c) = 107$ MeV/c^2
  - electromagnetic decay $\Xi'_c \to \Xi_c \gamma$

$\Xi'^{+}_c \to \Xi^{+}_c \gamma$



$\Xi'^{0}_c \to \Xi^{0}_c \gamma$



- first evidence of $B \to \Xi'_c$ decays

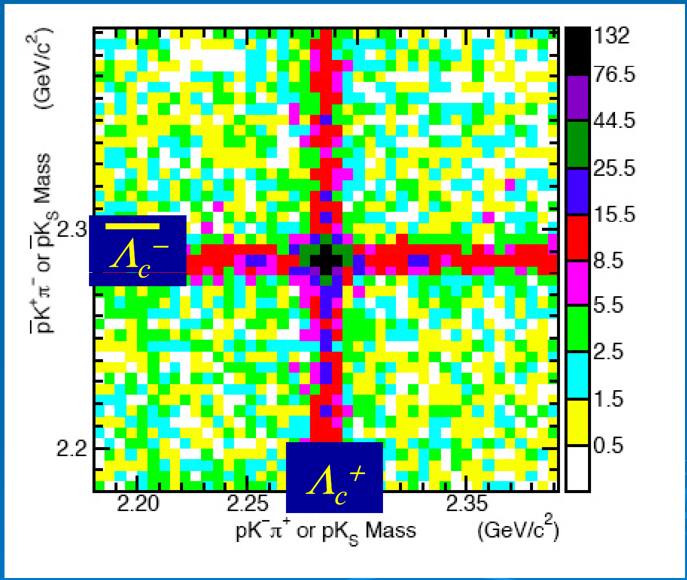
$$\mathcal{B}(B \to \Xi_c'^{+} X) \times \mathcal{B}(\Xi_c^+ \to \Xi^- \pi^+ \pi^+) = (1.69 \pm 0.17(\text{exp.}) \pm 0.10(\text{model})) \times 10^{-4}$$
$$\mathcal{B}(B \to \Xi_c'^{0} X) \times \mathcal{B}(\Xi_c^0 \to \Xi^- \pi^+) = (0.67 \pm 0.07(\text{exp.}) \pm 0.03(\text{model})) \times 10^{-4}$$

Correlated $\Lambda_c^+ \overline{\Lambda}_c^-$ production

- What about baryon number conservation?
  - Measurements at high energies shows small rapidity differences between Baryon-antiBaryon couples ==> "local baryon correlation"
  - if "local" correlation and two charmed baryons produced from leading *c*-quarks, we expect to see two more baryons ==> kinematically suppressed @ E_{cm}~10 Gev
  - CLEO measured $\dfrac{P(\Lambda_c \overline{\Lambda}_c X)}{P(\Lambda_c \overline{D}^{(*)} Y)} \approx 3.5$

PRD 63, 112003 (2001)

- BABAR looks for $e^+e^- \to \Lambda_c^+ \overline{\Lambda}_c^- X$ events
- Observe 649 ± 31 events vs ~150 expected ==> ratio of ~4.2 consistent with CLEO result
- very few additional baryons observed
- most of additional tracks are pions produced at the e^+e^- vertex ==> we measure 2.6 ± 0.3 $\pi^\pm$/event
- there is room for additional ~1.3 popcorn π^0/event
- 2.2 units of rapidity differences observed on average

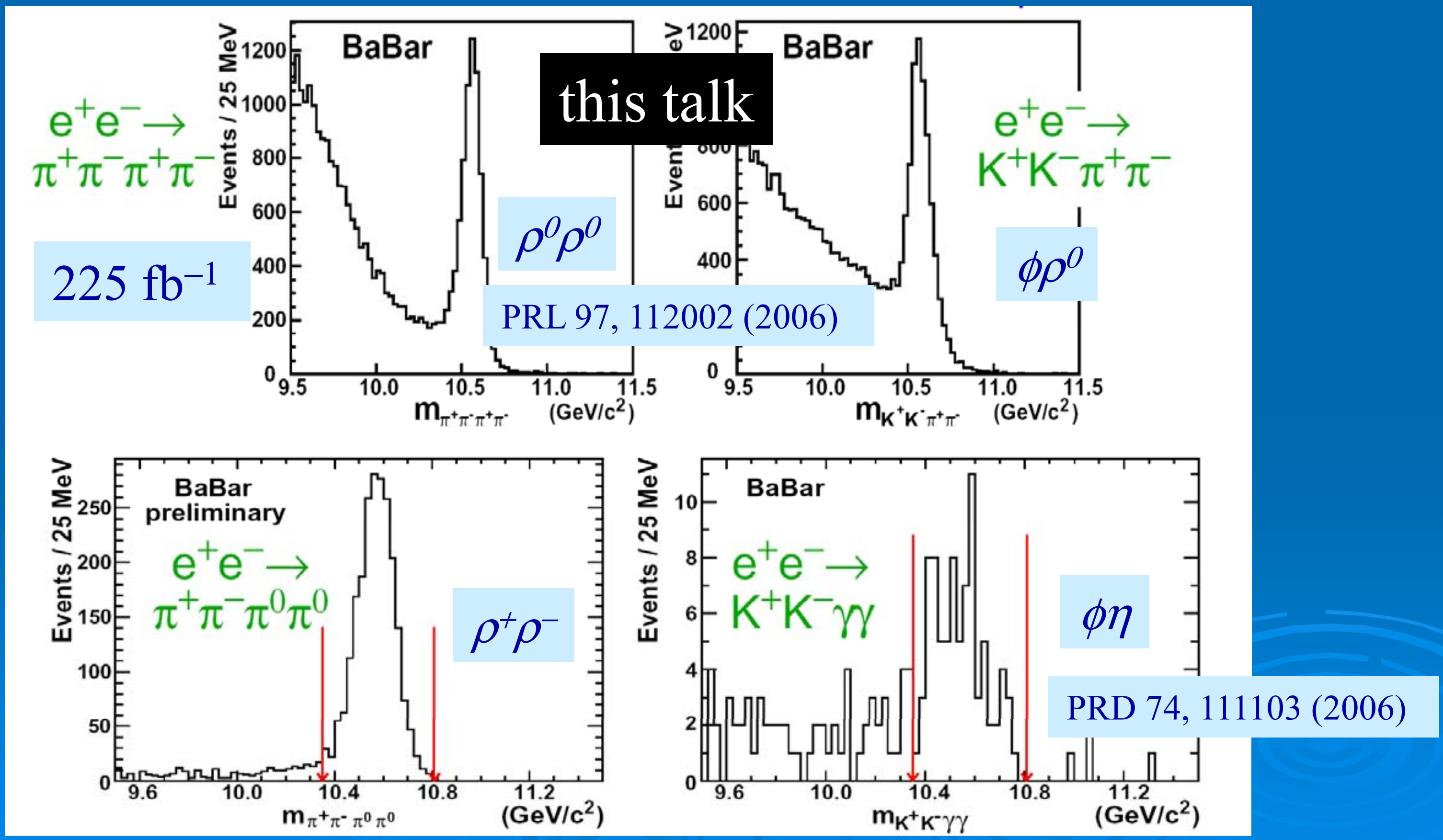


all indicate these are "jetty" events with long-range baryon number conservation !

For details see the talk by S. Pacetti

Exclusive reactions at 10.6 GeV

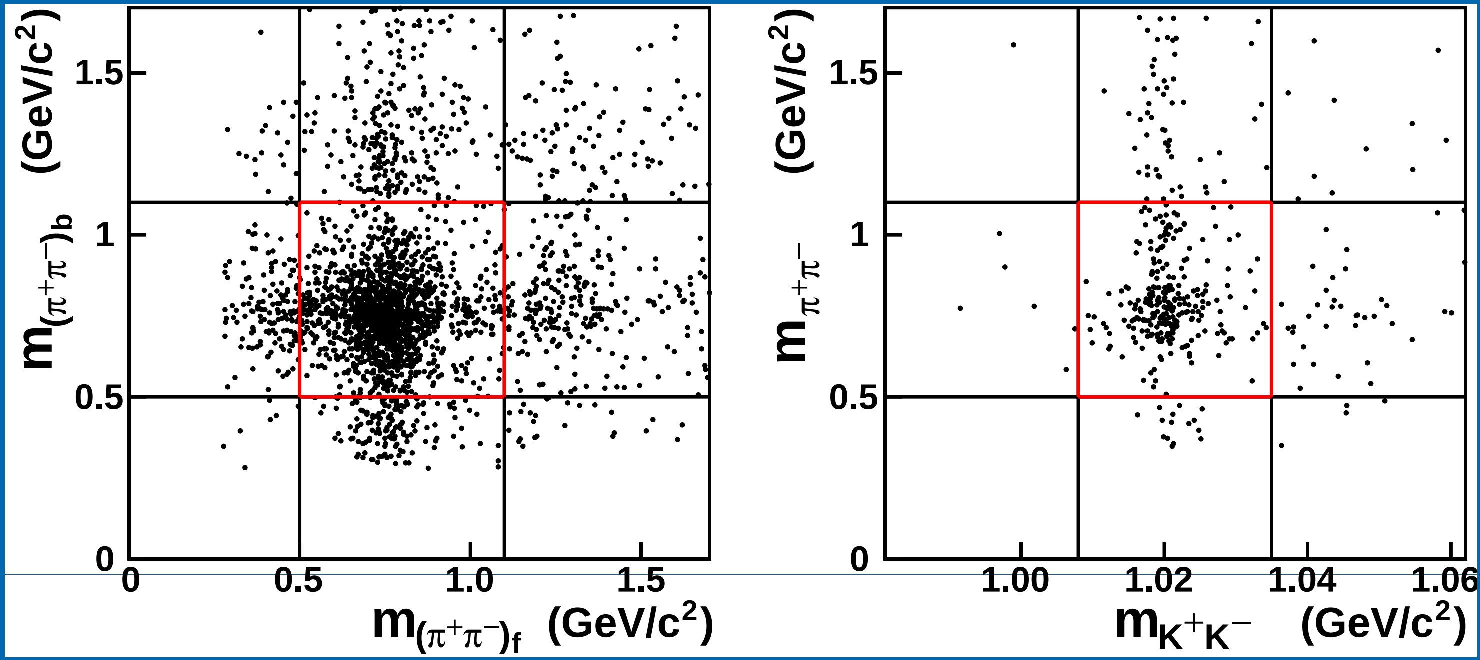
- Very rare final states can be studied with the full BABAR statistics
- Select events with a specific set of identified tracks, reconstructed photons and π^0's, η's
- Look at mass combinations, momentum and angular distributions, etc
- clear signals in each channel ==> interesting features of hadronic interactions can be studied



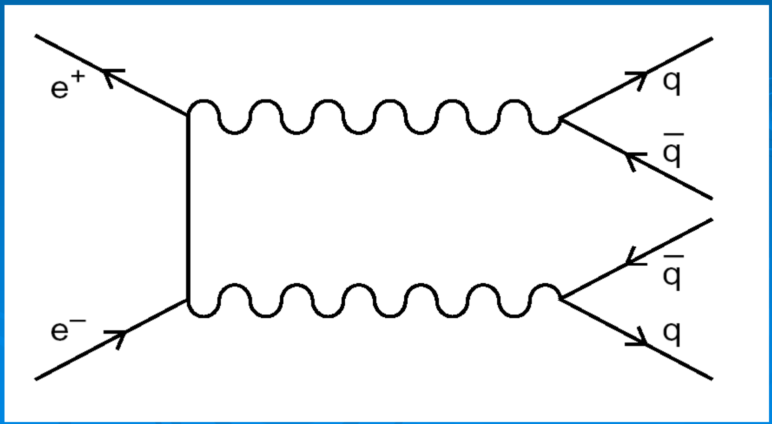
$e^+e^- \to \rho^0\rho^0, \phi\rho^0$

PRL 97, 112002 (2006)

- we observe clear $\rho^0\rho^0$ signal in $\pi^+\pi^-\pi^+\pi^-$ events and $\phi\rho^0$ in $K^+K^-\pi^+\pi^-$

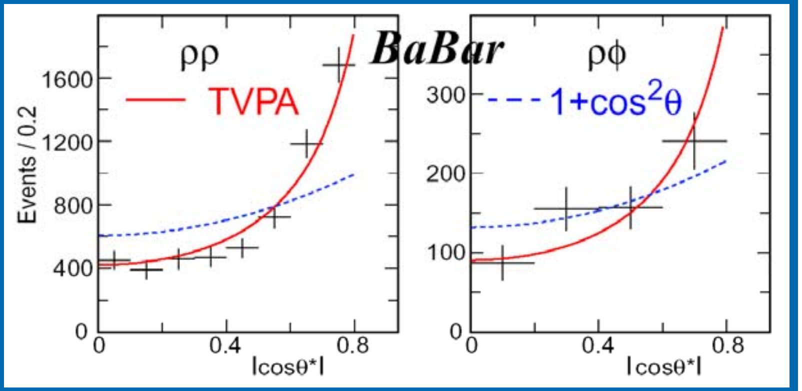


- Both channels have C = +1:
  - ==> forbidden in single γ^* annihilation
  - ==> allowed (and expected ~at this level) in 2-γ^* annihilation (TVPA)
  - ==> check angular distributions….

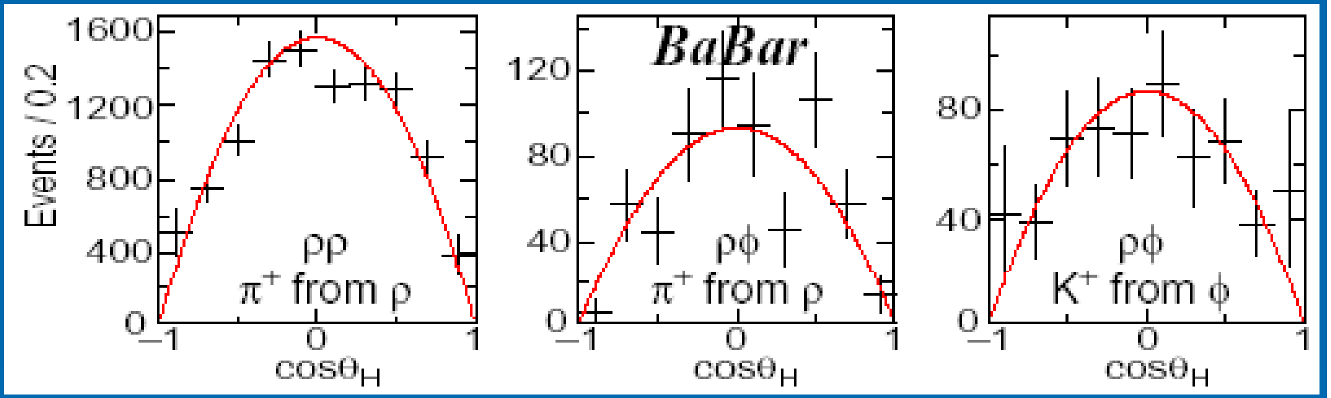


$e^+e^- \to \rho^0\rho^0, \phi\rho^0$ - angular distribution

- ρ^0, ϕ production angle θ^*:
  - TVPA predicts $\dfrac{1+\cos^2\theta^*}{1-\cos^2\theta^*}$
  - other process may give $\sin^2\theta^*$, flat, $1+\cos^2\theta^*$

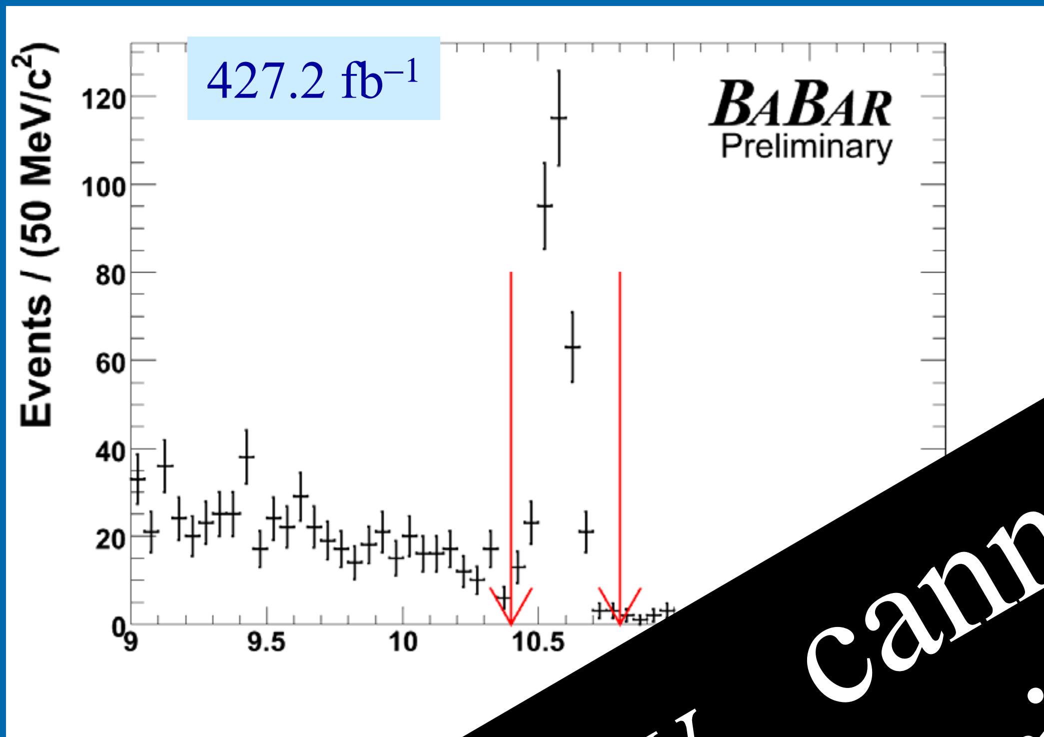


- Decay helicity angles :
  - TVPA predicts transverse ρ,ϕ polarization, *i.e.* $\sin^2\theta_H$ distribution for decay helicity angles



- First observation of TVPA!
- (Fiducial) cross sections:
  - $(20.7 \pm 0.7 \pm 2.7)$ fb for $\rho^0\rho^0$
  - $(\ 5.7 \pm 0.5 \pm 0.8)$ fb for $\phi\rho^0$
  - consistent with vector-dominance two-photon exchange (hep/ph-0606155)

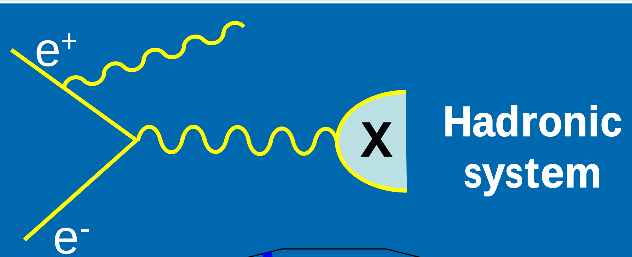
$$e^+e^- \rightarrow p\bar{p}p\bar{p}$$



Sorry, cannot show
wait for Moriond QCD…

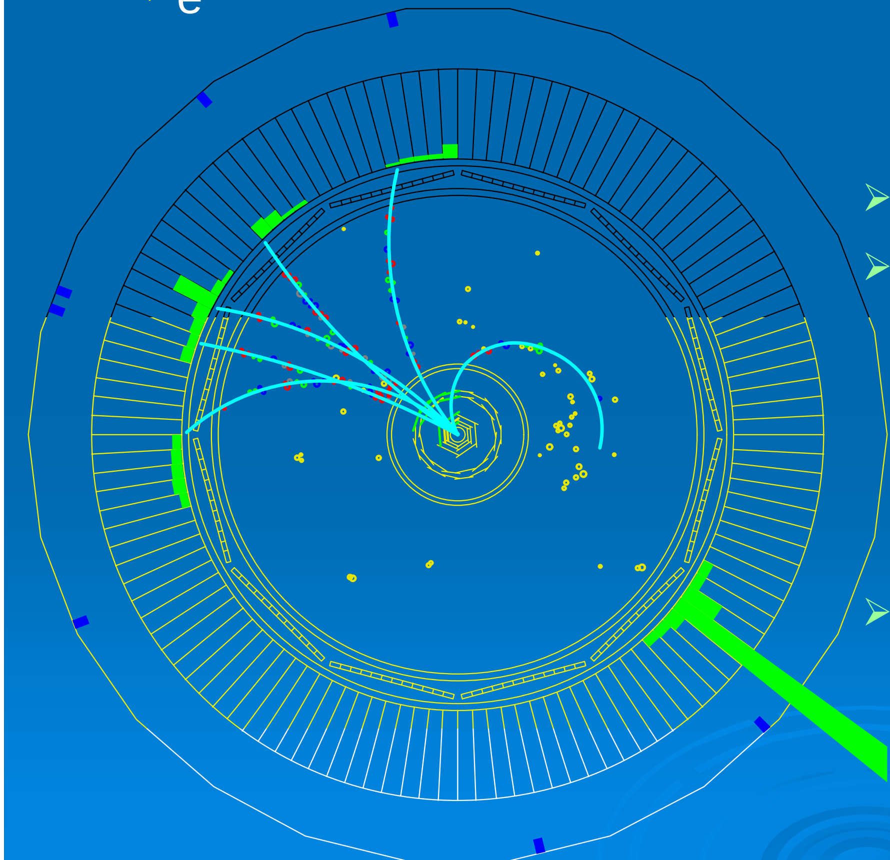
Initial State Radiation essential

ISR studies at the ϒ(4S) yield the same observables as the low energy e^+e^- experiments with enough statistics can probe the transition region from form factors to jets



$$\frac{d\sigma_{e^+e^-\to\gamma X}(s,s',\theta^*_\gamma)}{ds'\,d\cos\theta^*_\gamma} = W(s,s',\theta^*_\gamma)\cdot\sigma_{e^+e^-\to X}(s')$$

$$m_X^2 = s' = s(1-x) \qquad x = \frac{2E^*_\gamma}{\sqrt{s}}$$



- The radiator function W is known at ~ 1% level
- Features :
  - access to wide s' range
  - very small point-to-point systematic errors
  - *c.m.* boost ==> $\varepsilon \neq 0$ at threshold
  - γ_{ISR} detected ==> hadronic system contained
- disadvantages:
  - mass resolution > beam-energy spread
  - required very high luminosity

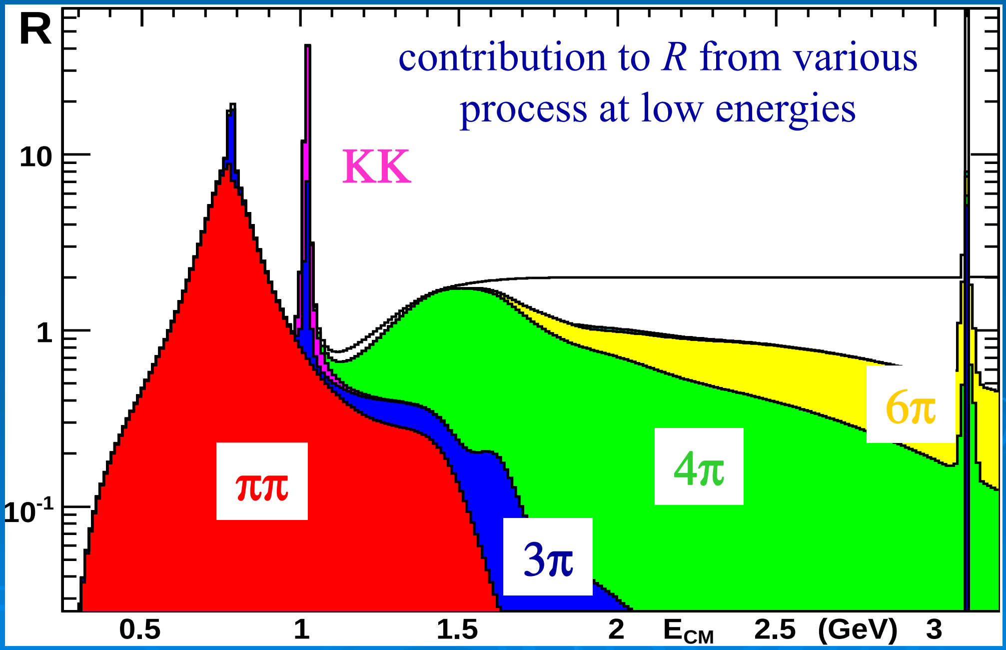
The *BABAR* ISR physics program

- Measure cross section for all significant $e^+e^- \to f$ processes, threshold up to 4-5 GeV
- Purpose:
  - improve understanding of spectroscopy of $J^{PC}=1^{--}$ states, and of resonant sub-structures observable in their decays
  - time-like form factors measurements (e.g. proton,Λ, Σ)
  - improve precision on determination of $R(s) = \sigma_{hadron}(s)/\sigma_{\mu\mu}(s)$ in the energy region $1<E_{cm}<3$ GeV, by summing the measured exclusive cross sections

- Published (or accepted or submitted):

  $\mu^+\mu^-$, $p\bar{p}$, ΛΛ, $\Sigma^0\Sigma^0$, $\pi^+\pi^-\pi^0$, $\pi^+\pi^-\pi^+\pi$, $K^+K^-\pi^+\pi^-$, $K^+K^-\pi^0\pi^0$, $K^+K^-K^+K^-$, $\pi^+\pi^-\pi^+\pi^-\pi^+\pi^-$, $\pi^+\pi^-\pi^+\pi^-\pi^0\pi^0$, $K^+K^-\pi^+\pi^-\pi^+\pi^-$, $K_S^0K^-\pi^+$, $K^+K^-\pi^0$, $K^+K^-\eta$, $J/\psi\, \pi^+\pi^-$, $\psi(2S)\, \pi^+\pi^-$

- Analysis on progress :
  - $\pi^+\pi^-\pi^0\pi^0$, $\pi^+\pi^-\pi^+\pi^-\pi^0$, $\pi^+\pi^-$, K^+K^-, $J/\psi\gamma\gamma$, DD, ISR inclusive,…



shown here as an example, for a general discussion see talk by S. Pacetti

Analysis strategy

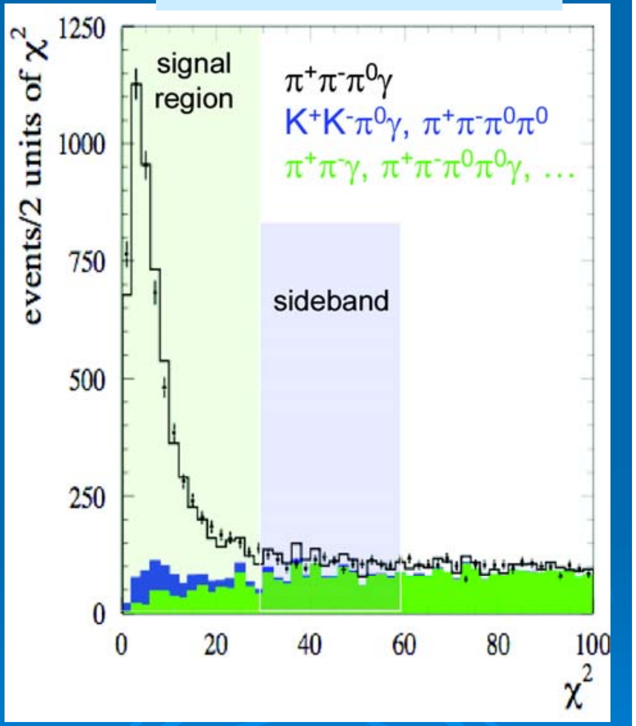
- Events selection:
  - require exact topology: "hard" γ + all particles inside a fiducial volume
  - $\pi/K/p$ discrimination using dE/dx and Cherenkov angle
  - kinematic fit requiring :
    - p and E conservation
    - add mass constraint for each π^0
  - fit result used to select signal events and reject background
- Monte Carlo simulations used for detector acceptances, selection efficiencies and estimates of different background sources:
  - ISR generators based on:

    H.Czyz et al, Eur. Phys. J. C 35(2004)527
  - multiple ISR soft photons:

    M.Caffo et al, N. C. 110A(1997)515
  - final state radiation: (PHOTOS)

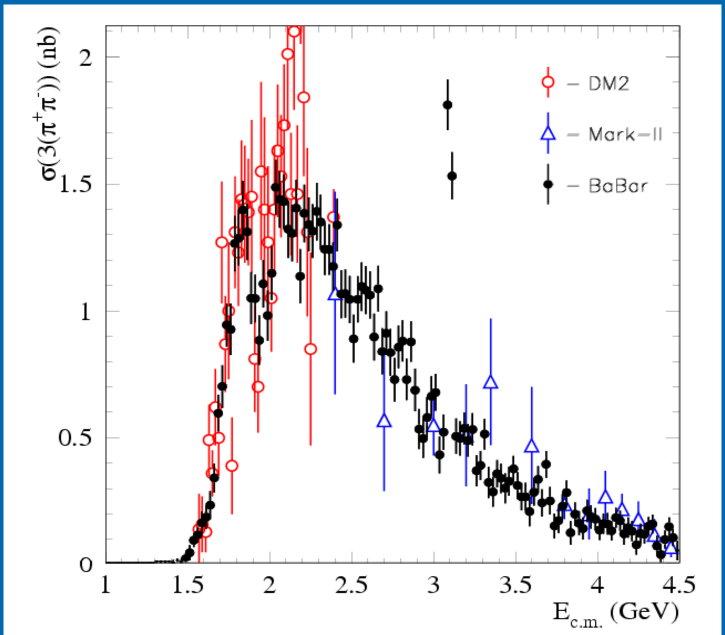
    E. Barberio et al, Comp. Phys Comm. 66(1991)115

event selection for $\pi^+ \pi^- \pi^0$ final state



$e^+e^- \to \gamma + \pi^+ \pi^- \pi^+ \pi^- \pi^+ \pi^-$

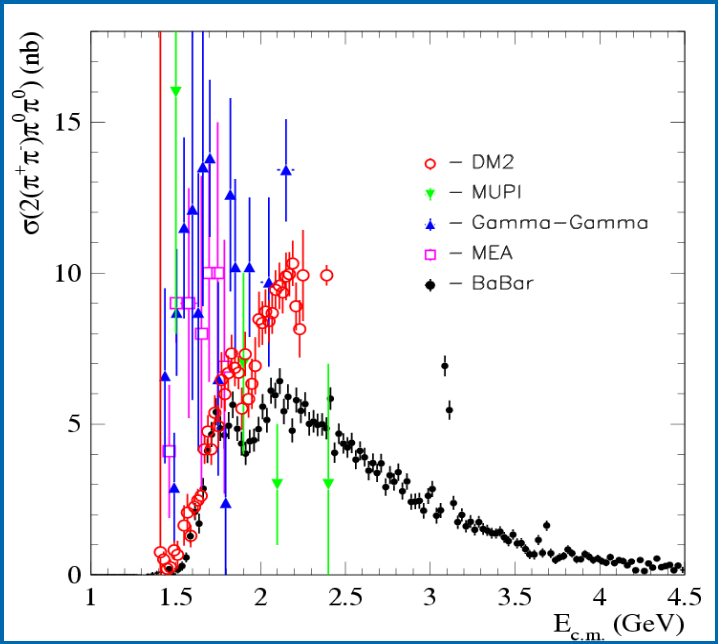
topology
- ISR photon + 6 charged hadrons
- 1C fit in 6π hypothesis. Cut at $\chi^2<20$



- Good agreement with existing data
- Total systematic error ~8%

$e^+e^- \to \gamma + \pi^+ \pi^- \pi^+ \pi^- \pi^0 \pi^0$

- ISR photon + 4 h + 4γ
- 5C fit (constrain π^0 masses) . Cut at $\chi^2<20$

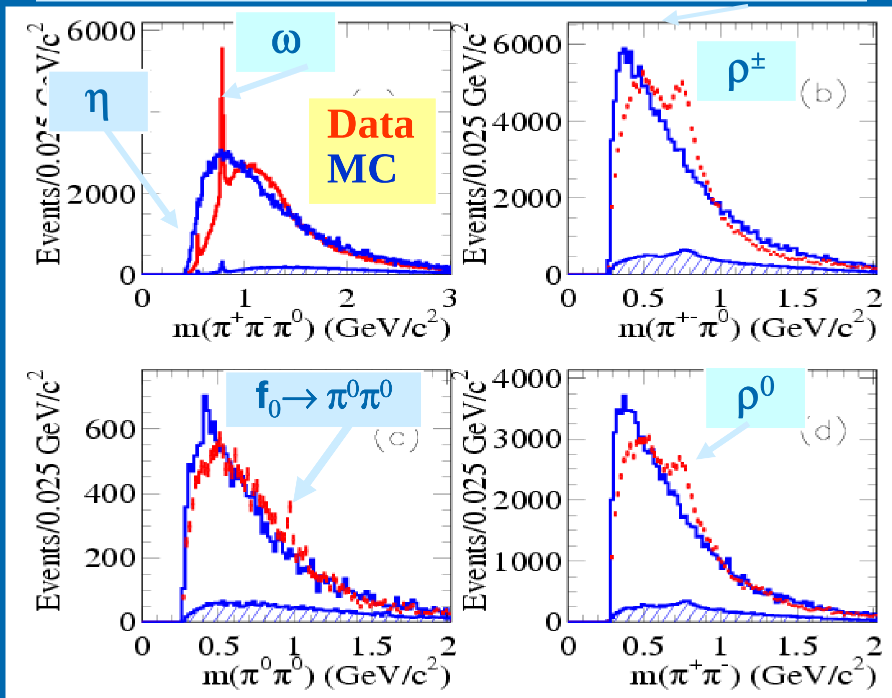


- Agreement with existing data only at low masses
- Total systematic error ~10%

- A structure observed around 1.9 GeV, already seen by DM2 and FOCUS experiments
- … but resonance fit gives inconsistent parameters (?)
- is this the “same dip” visible in $\pi^+\pi^-\pi^0\pi^0$ channel or is it something else?
- is it connected to the observed enhancement of the proton FF at threshold ?

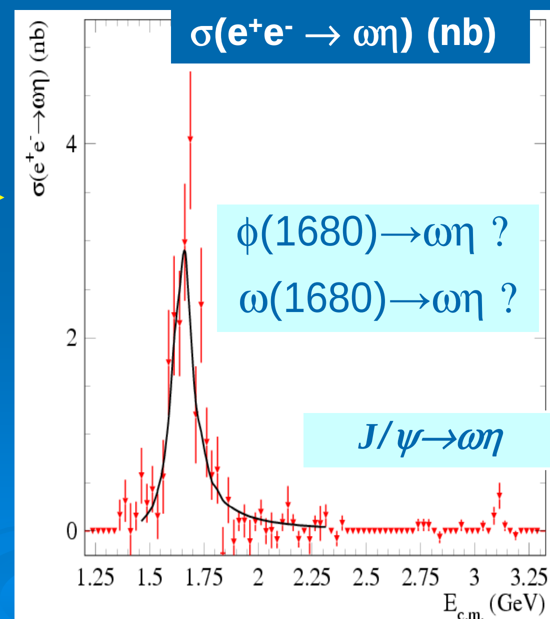
$e^+e^- \rightarrow \gamma + \pi^+\pi^-\pi^+\pi^-\pi^0\pi^0$

substructures in $2(\pi^+\pi^-)\pi^0\pi^0$ final state



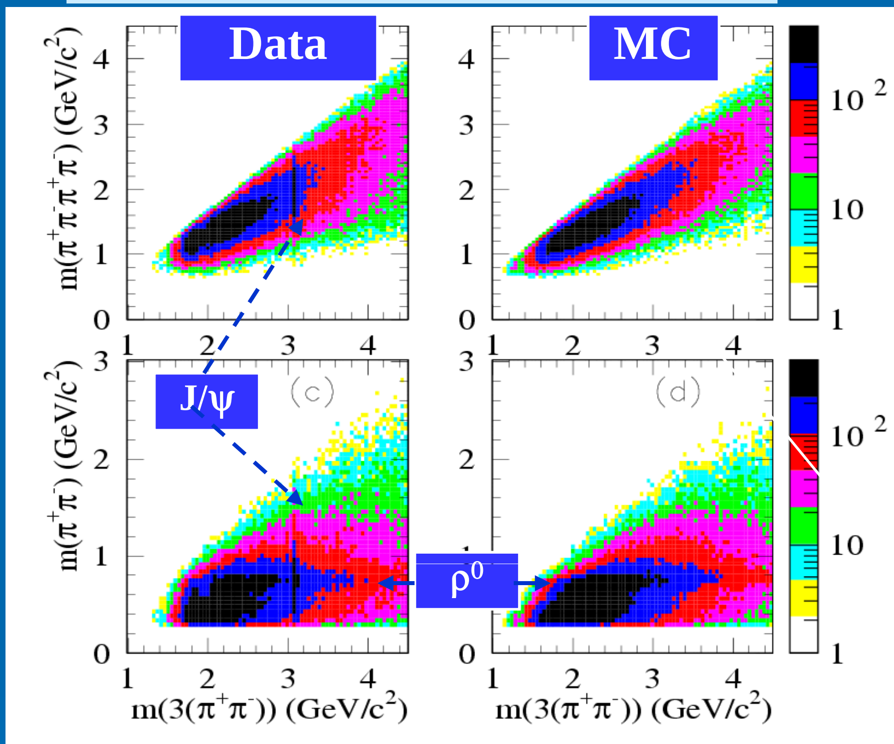
- Very rich resonance structure:
  - $\eta,\omega \rightarrow \pi^+\pi^-\pi^0$
  - $f_0 \rightarrow \pi^+\pi^-$
  - $f_2(1270)/f_0(1370) \rightarrow \pi^0\pi^0$?
  - $J/\psi \rightarrow 2(\pi^+\pi^-)\,\pi^0\pi^0$

- Observed submode $e^+e^- \rightarrow \omega(\pi^+\pi^-\pi^0)\,\eta(\pi^+\pi^-\pi^0)$
- J/ψ peak clearly visible (measure the decay rate)
- Fit the large peak to a resonant shape, we find:
  - $m = 1645 \pm 8$ MeV/c^2
  - $\Gamma = 114 \pm 14$ MeV
- is the ω(1650) (Γ=315), or the φ(1680) (Γ~50) ?
- ….. or something new…?

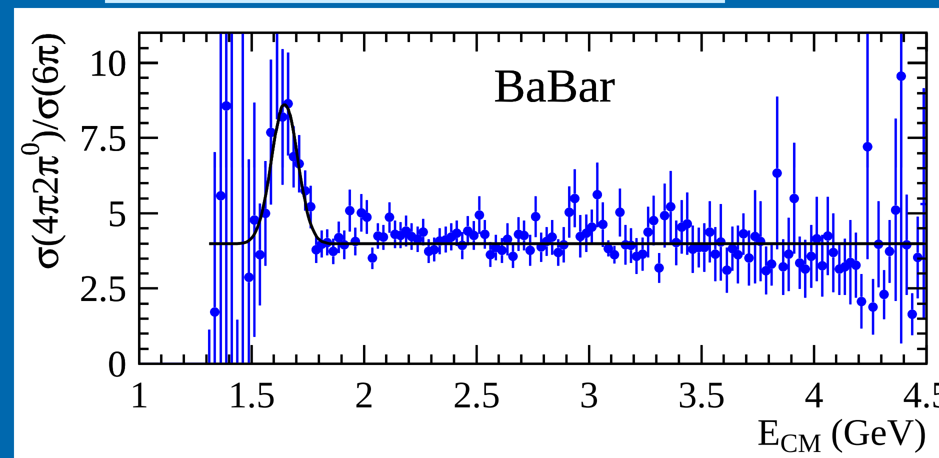


$e^+e^- \rightarrow \gamma + \pi^+ \pi^- \pi^+ \pi^- \pi^+ \pi^-$

substructures in $3(\pi^+\pi^-)$ final state



$(4\pi\ 2\pi^0)/(6\pi)$ production ratio



- The only structure observed in 2/3 π combinations is the ρ(780)
- data consistent with $e^+e^- \rightarrow \rho\pi^+\pi^-\pi^+\pi^-$

- The $2(\pi^+\pi^-)\pi^0\pi^0 / 3(\pi^+\pi^-)$ production ratio is flat and ~4
  - except where the $\omega\eta$ submode contribute
- difficult to explain, also because the former has a much richer substructure
- inclusive distribution of $3(\pi^+\pi^-)$ somewhat consistent with "jetty" behavior, but… hard to make any guess at this energy

Summary

- PEP-II is not only a *B*-factory, but also a $q\bar{q}$-factory ($q=u,d,s,c$)
- The large amount of data make possible stringent test on hadronic reactions at low energies, with unprecedented accuracy

- IS measured for light mesons ($\pi^{\pm}, K^{\pm}, \eta$), for proton, and for some charmed baryons (Λ_c^+, $\Xi^{(')}_c$) covering most of the scaled momentum range

- Jets in the "extreme" region studied:
  - $e^+e^- \to \Lambda_c^+\Lambda_c^-\ X$ ==> long range baryon number conservation
  - $e^+e^- \to p\bar{p}p\bar{p}$ ==> first observation, consistent with "jetty" behavior

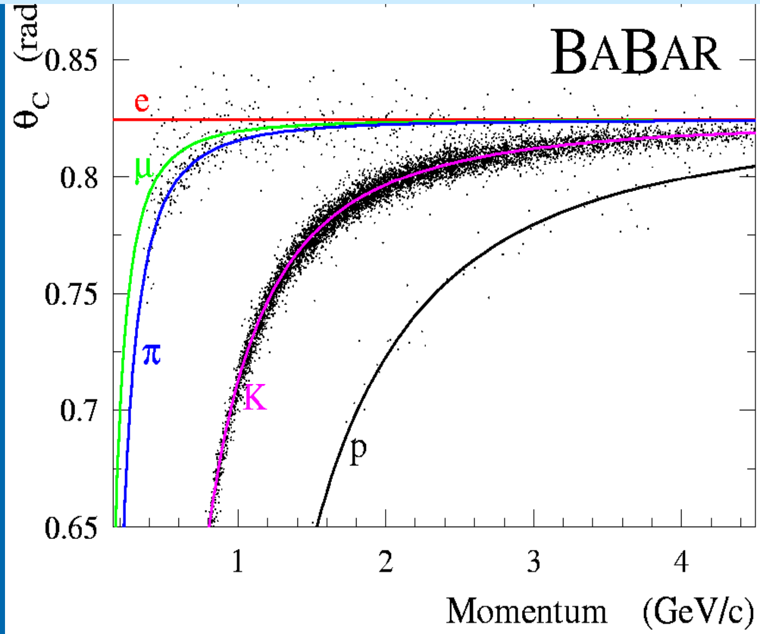
- exclusive reactions studied both at 10 GeV and at lower energies via ISR
- Many new charmed states discovered and studied with inclusive measurements at $\Upsilon(4S)$ energy

- *PEP-II* shutdown on April 6th, 2008 after an exciting journey lasted 9 years
- This would not be the end of the story: expect many more results from analysis of BABAR data for the years to come!

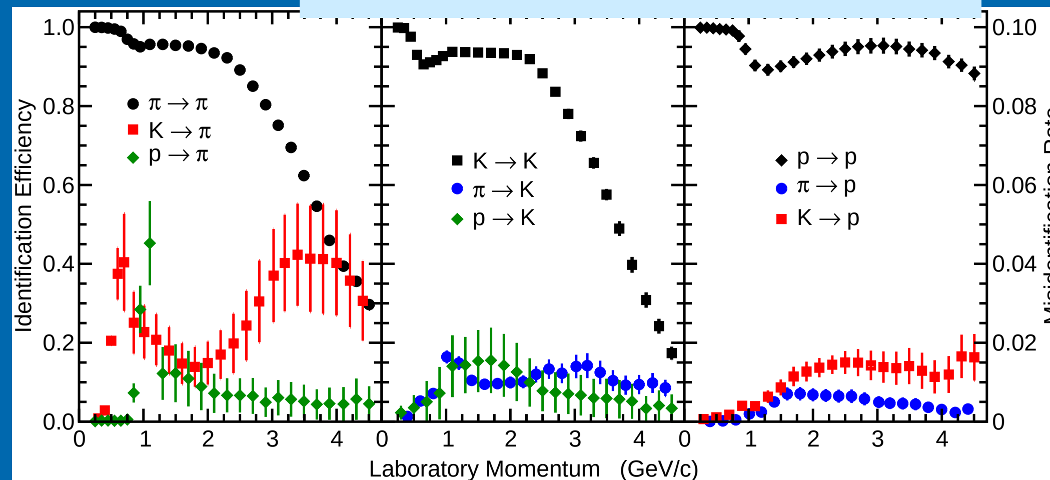
BACKUP SLIDES

PID performances

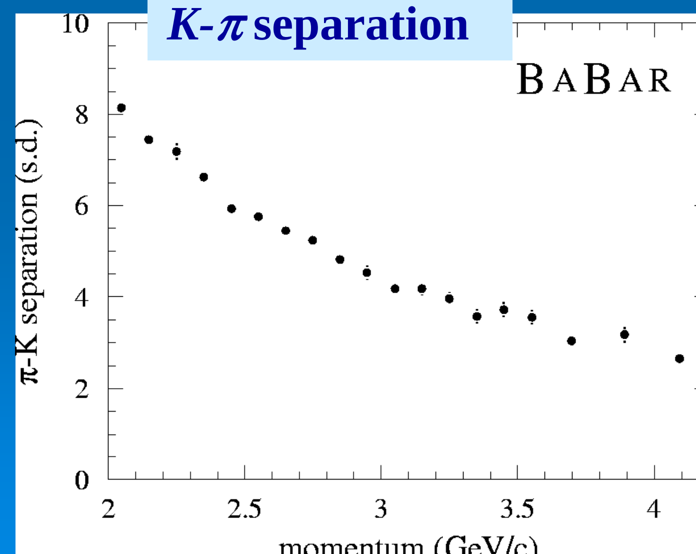
Cherenkov angle for different particle types



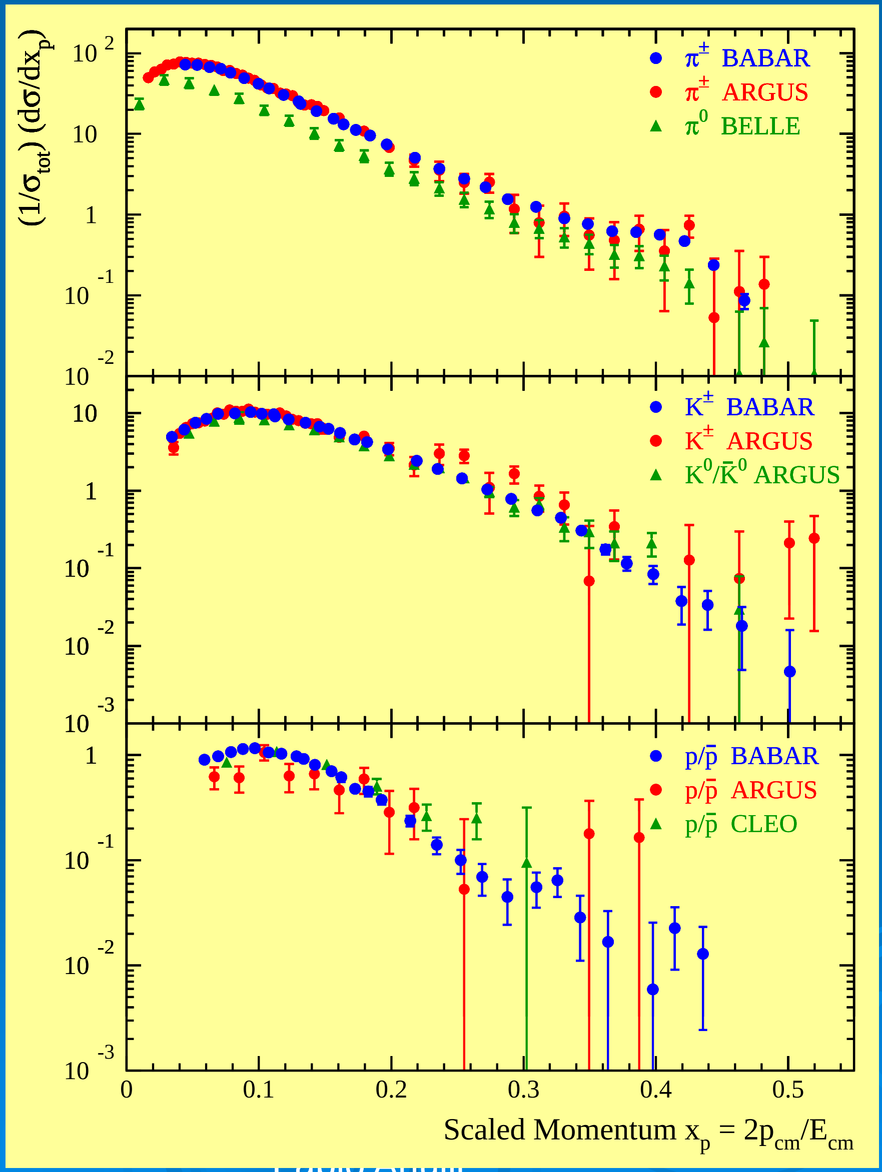
PID efficiencies and mis-ID rates



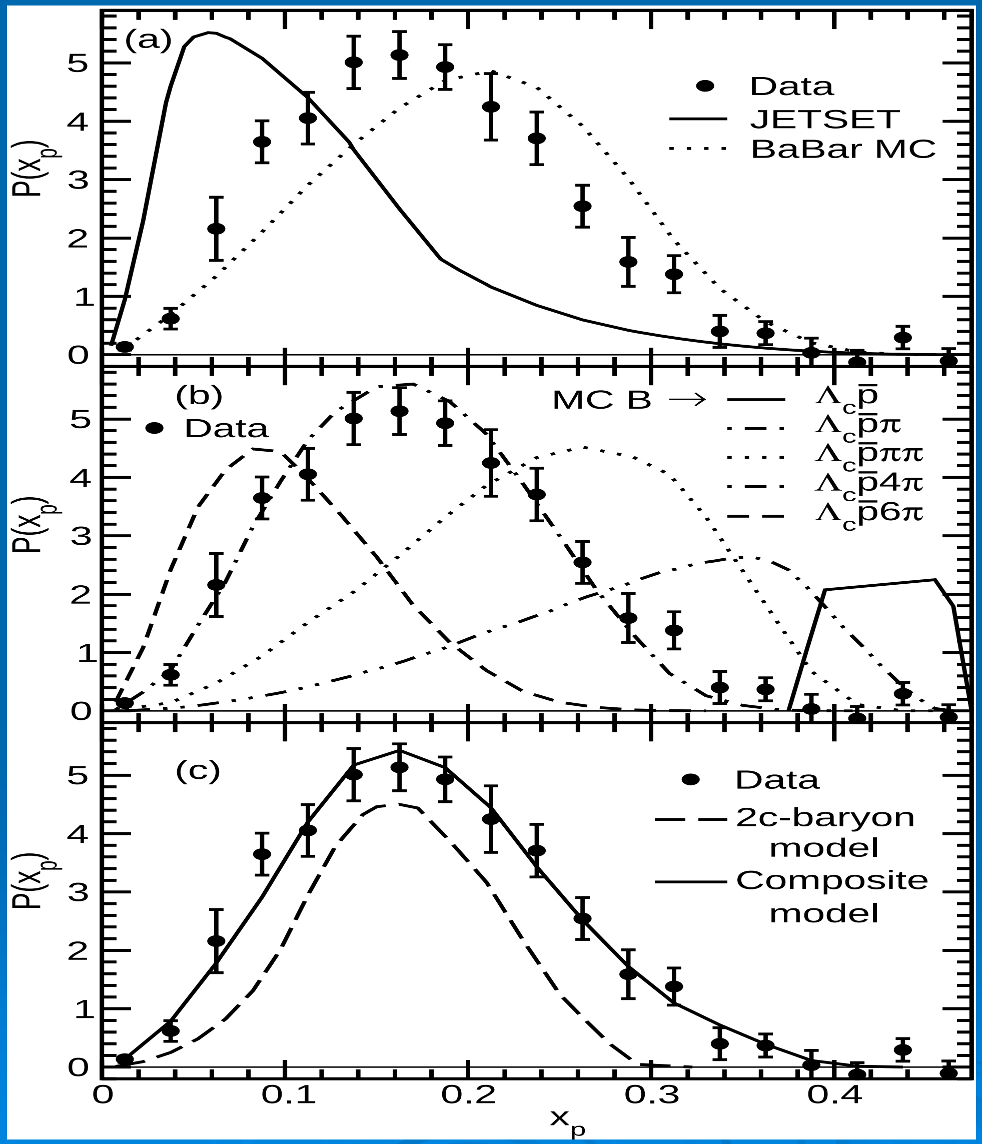
***K-π* separation**



IHPS: $\pi^+, K^+, p/\bar{p}$ from Y(4S) decays

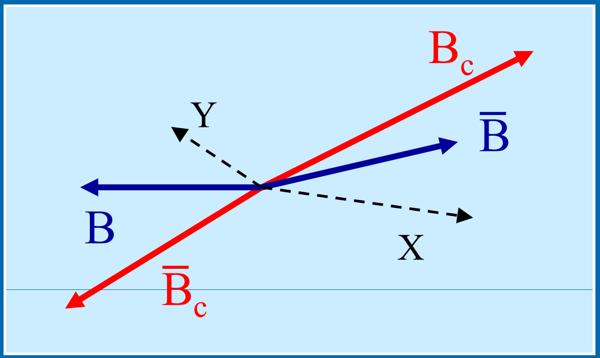


Inclusive Λ_c spectrum



Correlated $\Lambda_c^+ \Lambda_c^-$ production

- What about baryon number conservation?
  - Measurements at high energies shows small rapidity differences between Baryon-antiBaryon couples ==> "local baryon correlation"
  - if "local" correlation and two charmed baryons produced from leading *c*-quarks, we expect to see two more baryons



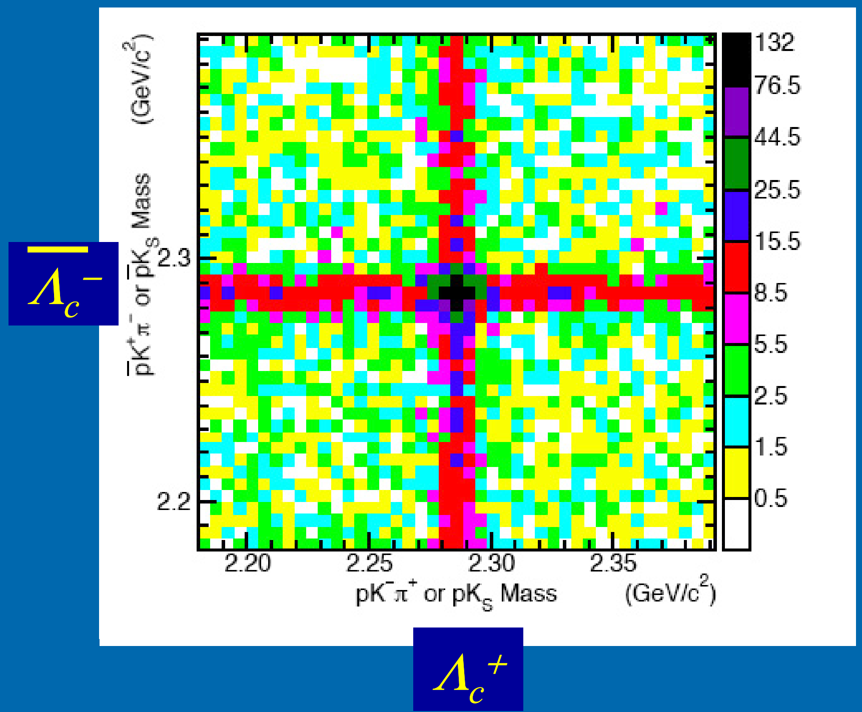
- @ E_{cm}~10 GeV, $m(B_c+\overline{B} + \overline{B}_c+B) > 6.5$ GeV/c2
  - kinematically suppressed
- CLEO measured $\dfrac{P(\Lambda_c\overline{\Lambda}_c X)}{P(\Lambda_c\overline{D}_c^{(*)}Y)} \approx 3.5$

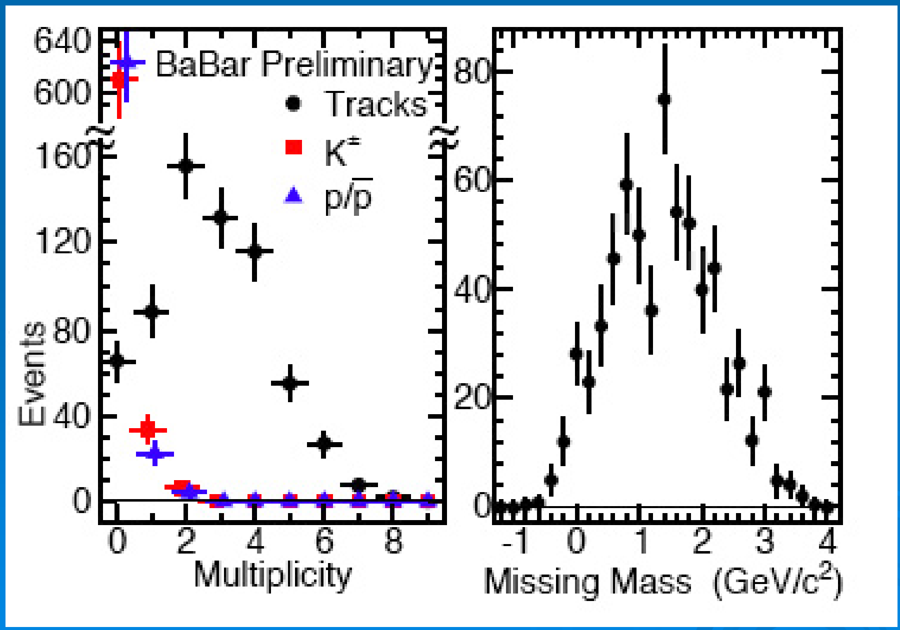
PRD 63, 112003 (2001)

primary *c*-quarks do not fragment independently !

Correlated $\Lambda_c^+ \Lambda_c^-$ production

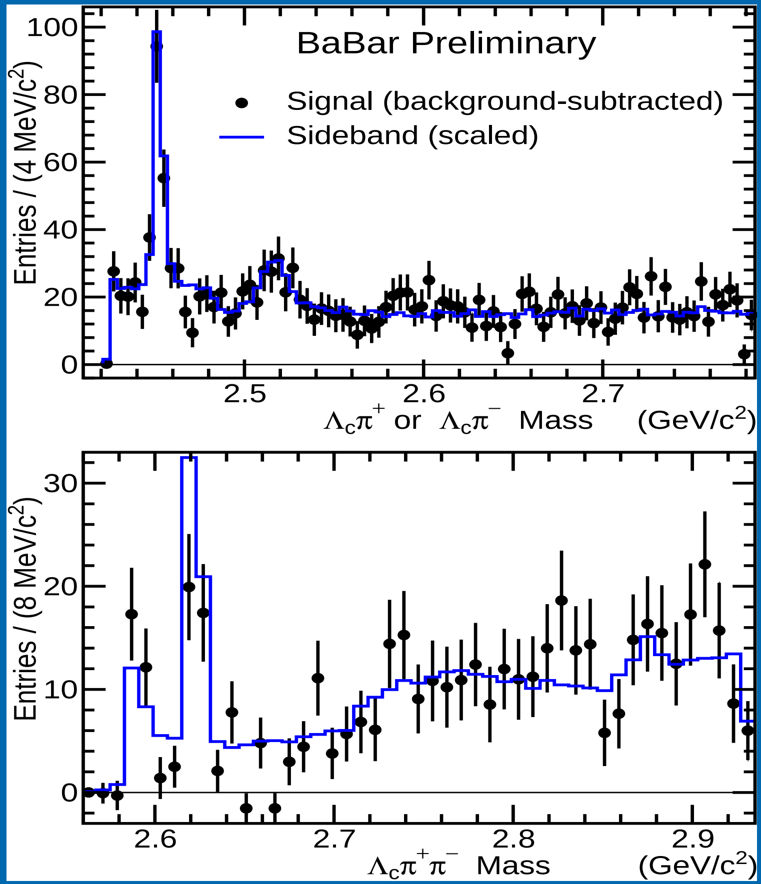
- BABAR looks for $e^+e^- \to \Lambda_c^+ \Lambda_c^- X$ events
- Analysis strategy:
  - reconstruct Λ_c in pK-KS
  - reject Y(4S) decays by p^*_Λ >2.3 GeV/c
- Observe 649 ± 31 events
  - ~150 expected (based on single Λ_c rate)
  - ratio of ~4.2 consistent with CLEO result





- very few additional baryons (13 ± 8 events compatible with 4 baryons)
- very few additional $K^\pm$, K_S, ρ, K^* mesons observed
- most of additional tracks are pions produced at the e^+e^- vertex

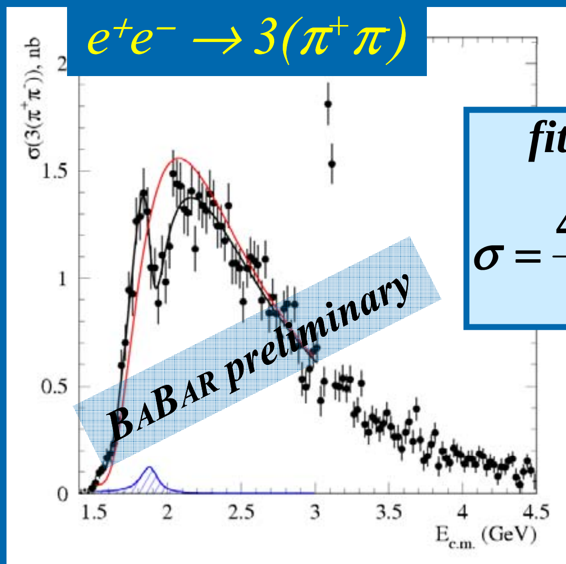
Correlated $\Lambda_c^+ \Lambda_c^-$



- Very few two-body or quasi-two-body events observed
  - no evidence for $e^+e^- \to \Lambda_c^+\Lambda_c^-$
  - small fraction of additional mesons coming from heavier baryons decays
  - no evidence for unknown baryons
- we measure $2.6 \pm 0.3\ \pi^{\pm}$/event
- there is room for additional ~1.3 popcorn π^0/event
- 2.2 units of rapidity differences observed on average
- measurements indicate these are jetty events with long-range baryon number conservation

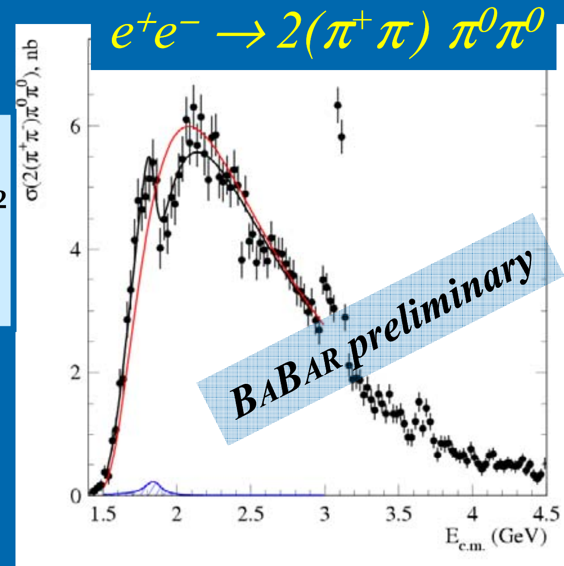
  ==> new type of events
- among the various models, only UCLA is able to qualitatively produce these type of events:
  - production rate too high
  - suppression of kaons and vector mesons production
  - π multiplicity distribution broad, with peak at 1 and average of 1.8

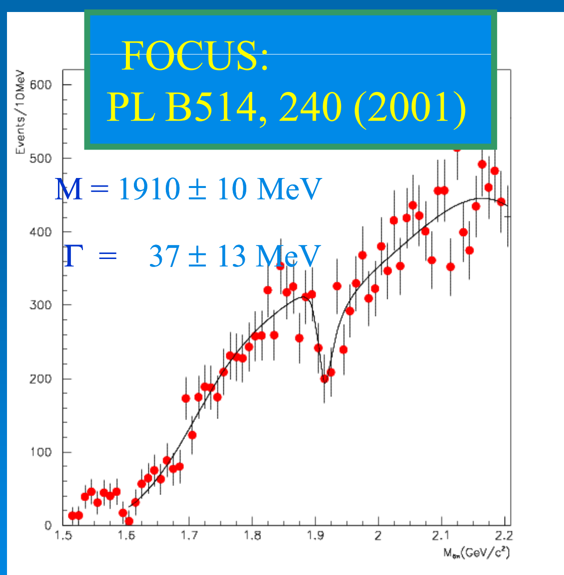
Fit of $e^+e^- \to 6\pi$ cross sections



fit cross section to:

$$\sigma = \frac{4\pi\alpha^2}{s^{3/2}}\left|\frac{gm^2e^{i\phi}}{s - m^2 + i\sqrt{s}\Gamma} + A_{cont}\right|^2$$





Dip of cross section near 1.9 GeV is confirmed, but wider than in DM2 (e^+e^-) and in FOCUS *(diffractive photoproduction)*

	M(GeV/c^2)	Γ(GeV)	phase
BABAR $3(\pi^+\pi^-)$	**1.88 ± 0.03**	**0.13 ± 0.03**	**20 ± 40**
BABAR $2(\pi^+\pi^-)\pi^0\pi^0$	**1.86 ± 0.02**	**0.16 ± 0.02**	**−3 ± 15**
FOCUS $3(\pi^+\pi^-)$	**1.91 ± 0.01**	**0.037 ± 0.013**	**10 ± 30**