Anti-Hyperon Production ($\bar{\Lambda}, \bar{\Xi}, \bar{\Omega}$)

I. A proposed signal of the QGP (Rafelski + Müller, 1982)

1. $m_s \sim T_c$
2. $gg \to s\bar{s}$
3. $\bar{\Xi}, \bar{\Omega}$ decouple quickly (freeze out early)

Problem: **chemical equilibration is slow**, free fit parameters in AA

II. Presently modelled with

1. Ropes - RQMD

   increase energy density of strings

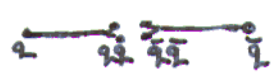
2. Quark-Matter Droplets - NEXUS, VENUS

$P(\frac{s}{u})$ increases with increased energy density (κ)

$$P(\tfrac{s}{u}) \sim e^{-\frac{4\pi}{\kappa}(m_s^2 - m_u^2)} \quad \text{(Schwinger tunneling)}$$

Problem: free fit parameter(s) in AA

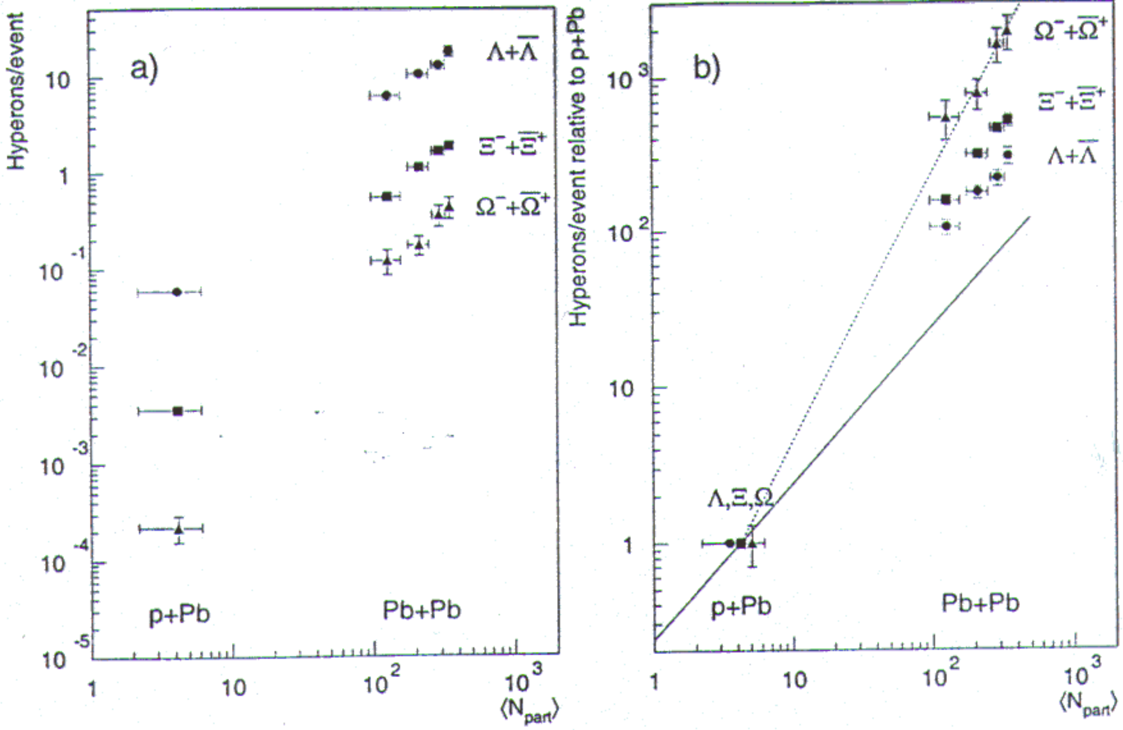
III. Proposed Hadronic Scenario

1. 

2. 

Advantage: Parameters fit by pp and pA data

However: Can only partially reproduce $\bar{\Omega}$ yields (not yet the whole story)



WA97

Phys. Lett. B433 (1998) 209.

Figure 5: a) The Λ, Ξ and Ω yields expressed in units of yields per event. b) The Λ, Ξ and Ω yields expressed in units of yields observed in p-Pb collisions and compared to yield curves proportional to the number of participants $\langle N_{part}\rangle$ (solid curve) and to $\langle N_{part}\rangle^{1.72}$ (dotted curve). The proton points are stacked together on the horizontal scale. See text for details.

NA49 Ξ measurement (preliminary) nucl-ex/9810005

$\frac{dN_{\Xi^-}}{dy} = 2.29$, $\frac{dN_{\bar{\Xi}^+}}{dy} = 0.52$ in 158 GeV/c Pb+Pb

factor of <u>10</u> enhancement over scaled pp collision yields

Ratios (WA97, QM'97)

$\bar{\Lambda}/\Lambda = 0.128 \pm 0.012$

$\bar{\Xi}^+/\Xi^- = 0.266 \pm 0.028$

$\bar{\Omega}^+/\Omega^- = 0.46 \pm 0.15$

(NA49)

$\bar{\Xi}^+/\Xi^- = 0.23 \pm 0.03$

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2. 

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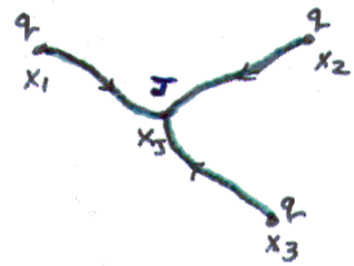
However: Can only partially reproduce $\bar{\Omega}$ yields (not yet the whole story)

Baryon Junction Physics 1

D. Kharzeev, Phys. Lett. **B378** (1996) 238. G.C.Rossi and G. Veneziano, Nucl. Phys. **B123** (1977) 507; Phys. Rep. **63** (1980) 153.

• Baryon Wave Function - QCD

$$B = \epsilon^{j_1 j_2 j_3} \left[P \exp\left(ig \int_{x_1}^{x_J} dx^\mu A_\mu\right) q(x_1)\right]_{j_1} \left[P \exp\left(ig \int_{x_2}^{x_J} dx^\mu A_\mu\right) q(x_2)\right]_{j_2}$$
$$\times \left[P \exp\left(ig \int_{x_3}^{x_J} dx^\mu A_\mu\right) q(x_3)\right]_{j_3}$$



• Junction/Anti-Junction state

$$M_0^J = \epsilon^{j_1 j_2 j_3} \epsilon_{k_1 k_2 k_3} \left[P \exp\left(ig \int_{x_{\bar{J}}}^{x_J} dx^\mu A_\mu\right)\right]_{j_1}^{k_1} \left[P \exp\left(ig \int_{x_{\bar{J}}}^{x_J} dx^\mu A_\mu\right)\right]_{j_2}^{k_2}$$
$$\times \left[P \exp\left(ig \int_{x_{\bar{J}}}^{x_J} dx^\mu A_\mu\right)\right]_{j_3}^{k_3}$$

• Reggeon Intercept

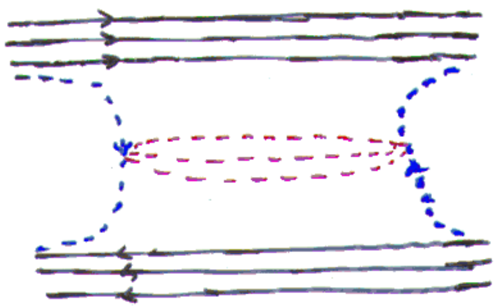
$$\alpha_0^J(0) \simeq 2\alpha_B(0) - 1 + 3(1 - \alpha_R(0)) \simeq \frac{1}{2}$$

where $\alpha_B(0) = 0$ and where $\alpha_R(0) = \frac{1}{2}$

Junctions (Rossi + Veneziano, 1977)

I. Observed that $\bar{n}_{B\bar{B}\,ann} \simeq \frac{3}{2} n_{B\bar{B}\ \text{scattering}}$

II. Annihilation Diagram (3 $q\bar{q}$ jets)



$\sigma \sim s^{\alpha_0^J(0)-1}$

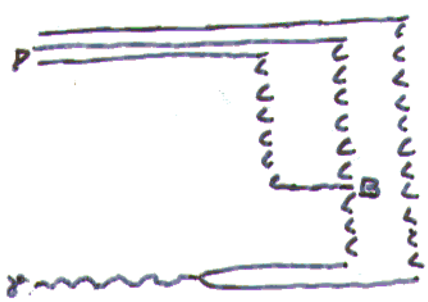
III. $\Delta\sigma \equiv \sigma(p\bar{p}) - \sigma(pp) = 2(\omega + J) \simeq 2J$

or $\Delta\sigma \simeq \sigma_{ann.}$

Data shows that $\Delta\sigma \sim s^{-0.6} \Rightarrow \alpha_0^J(0) \sim \frac{1}{2}$

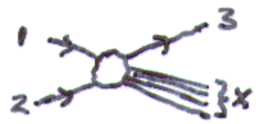
IV. H1 data (ep) (Kopeliovich + Povh, hep-ph/9810530)

$A = \frac{N_p - N_{\bar{p}}}{N_p + N_{\bar{p}}} \simeq 8\%$ W= 200 GeV $|\eta_{lab}| < 1$



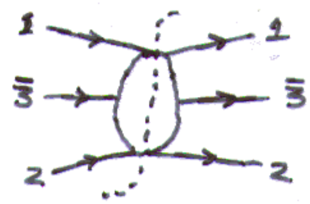
Generalized Optical Theorem + Regge Theory

Inclusive Processes $1+2 \to 3+X$ or $1+2 \to 3+4+X$



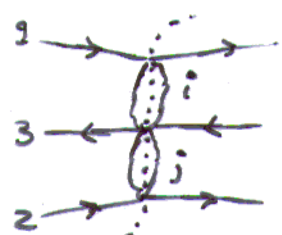
$$E_3 \frac{d^3\sigma}{d^3\vec{p}_3} = \frac{1}{(2\pi)^3\, 2 s_{12}}\, \mathrm{Im}\left\{ M_{12\bar{3}\to 12\bar{3}}(p_1 p_2 p_{\bar{3}} = -p_3) \right\}$$

(assume crossing symmetry $M_{12\to 3X} = M_{12\bar{3}\to X}$)



Example:

$$16\pi^3 E_3 \frac{d^3\sigma}{d^3\vec{p}_3} \xrightarrow[s\to\infty]{} \gamma_{ij}(\mu_3^2) \left|\frac{t}{s_0}\right|^{\alpha_i(0)-1} \left|\frac{u}{s_0}\right|^{\alpha_j(0)-1},$$



Note: $t \xrightarrow[s\to\infty]{} -\sqrt{s}\,\mu_3 e^{-y_3}$, $u \xrightarrow[s\to\infty]{} -\sqrt{s}\,\mu_3 e^{y_3}$,

where $\mu_3^2 = \vec{p}_{3T}^{\,2} + m_3^2$

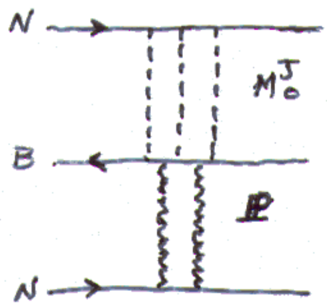
Baryon Junction Physics 2

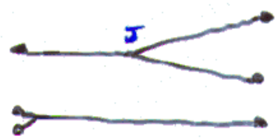
D. Kharzeev, Phys. Lett. **B378** (1996) 238. G.C.Rossi and G. Veneziano, Nucl. Phys. **B123** (1977) 507; Phys. Rep. **63** (1980) 153.

- **One M_0^J Reggeon Exchange**

$$E_B \frac{d^3\sigma^{(1)}}{d^3\mathbf{p}_B} \rightarrow C_B s^{\frac{1}{2}(\alpha_0^J(0)-1)} \left(e^{-(\alpha_0^J(0)-1)y_B} + e^{(\alpha_0^J(0)-1)y_B} \right)$$

$$\simeq C_B s^{-1/4} \cosh(y_B/2)$$

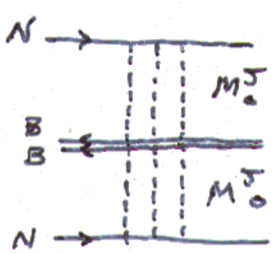


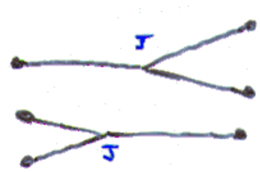


- **Two M_0^J Reggeon Exchange**

$$E_B \frac{d^3\sigma^{(2)}}{d^3\mathbf{p}_B} \rightarrow C_B s^{\frac{1}{2}(2\alpha_0^J(0)-2)}$$

$$\simeq C_B s^{-1/2}$$





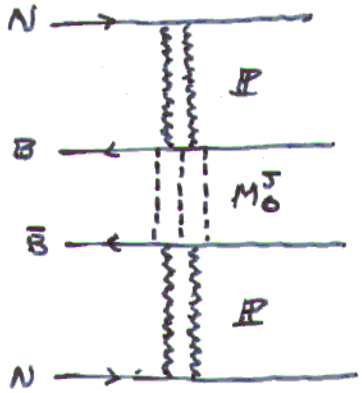
Baryon Junction Physics 3

S.E. Vance and M. Gyulassy, submitted to PRL, nucl-th/9901009

- **Baryon Pair Production**

$$E_B E_{\bar{B}} \frac{d^6\sigma}{d^3\mathbf{p}_B d^3\mathbf{p}_{\bar{B}}} \rightarrow C_{B\bar{B}} e^{(\alpha_0^J(0)-1)|y_B - y_{\bar{B}}|}$$

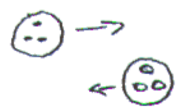
$$\simeq C_{B\bar{B}} e^{-\frac{1}{2}|y_B - y_{\bar{B}}|}$$

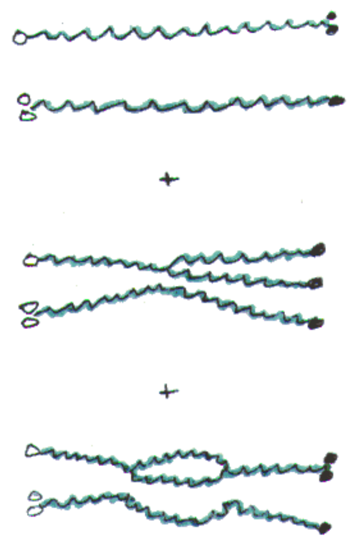


HIJING/B$\bar{B}$

S.E. Vance, M. Gyulassy and X.N. Wang, Phys. Lett. **B**, in press, nucl-th/9806008;
S.E. Vance, M. Gyulassy, submitted to PRL, nucl-th/9901009

I. Soft Physics





a). Background (HIJING)

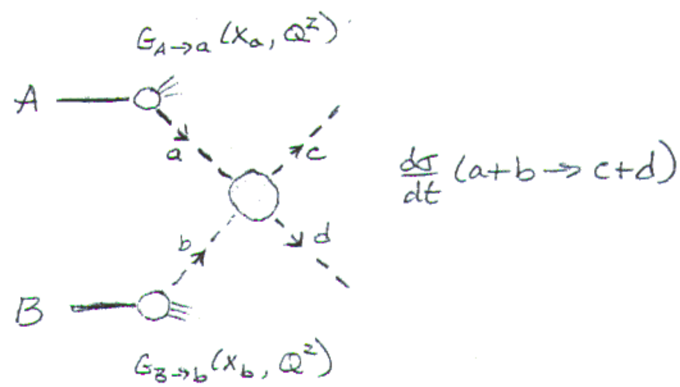
+

b). Baryon Number Transport (**HIJING/B**)

+

c). Baryon Pair Production (**HIJING/B$\bar{B}$**)

II. Hard Physics ($p_T > p_0$)



Minijets, Jet Quenching, Nuclear Shadowing

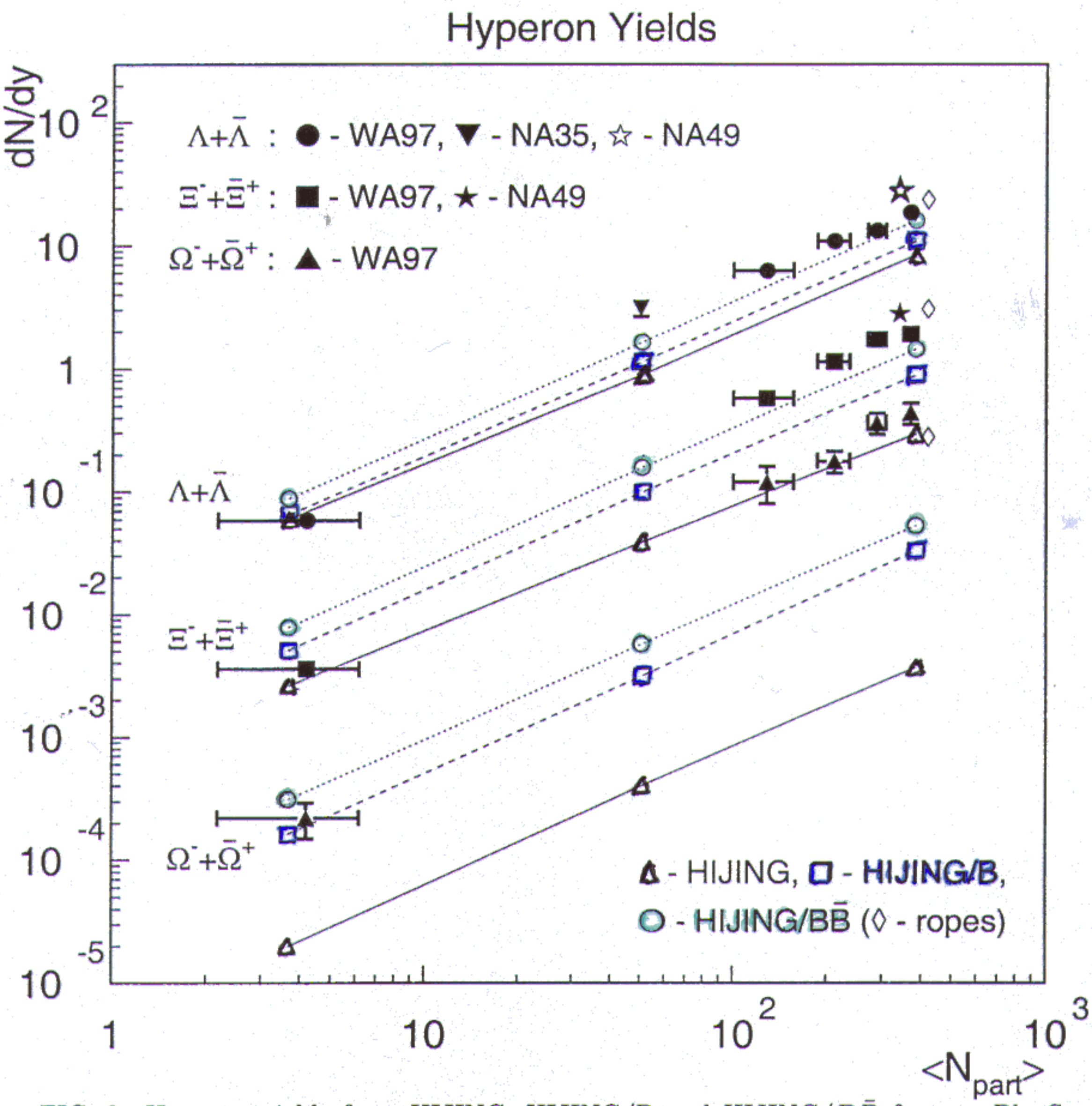


FIG. 2. Hyperon yields from HIJING, HIJING/B and HIJING/$B\bar{B}$ for $p+Pb$, $S+S$ and $Pb+Pb$ at incident momentum $p_{lab} = 160$ AGeV are shown along with data from the NA35 [26], the NA49 [2,3] and the WA97 [1] collaborations.

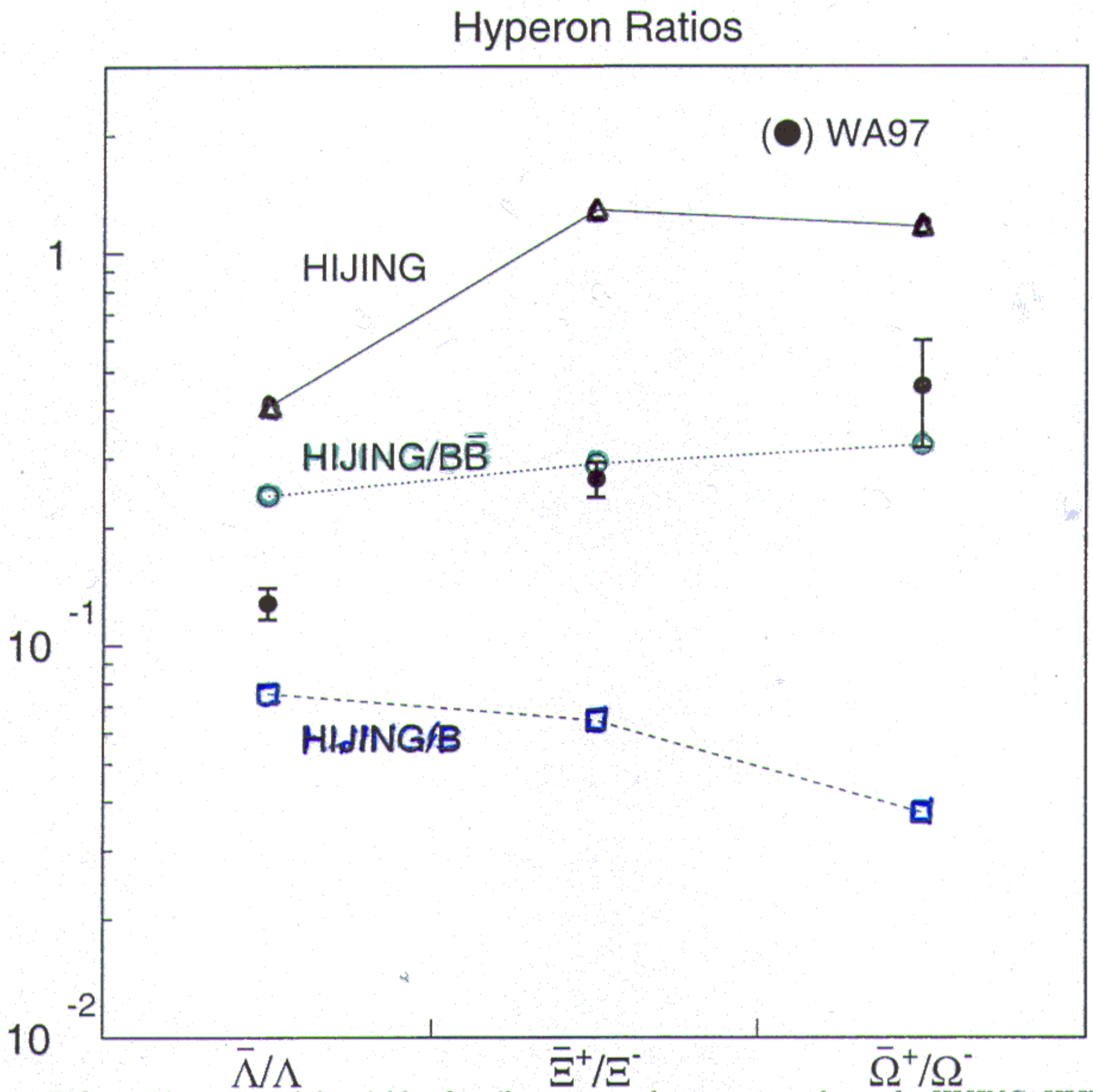
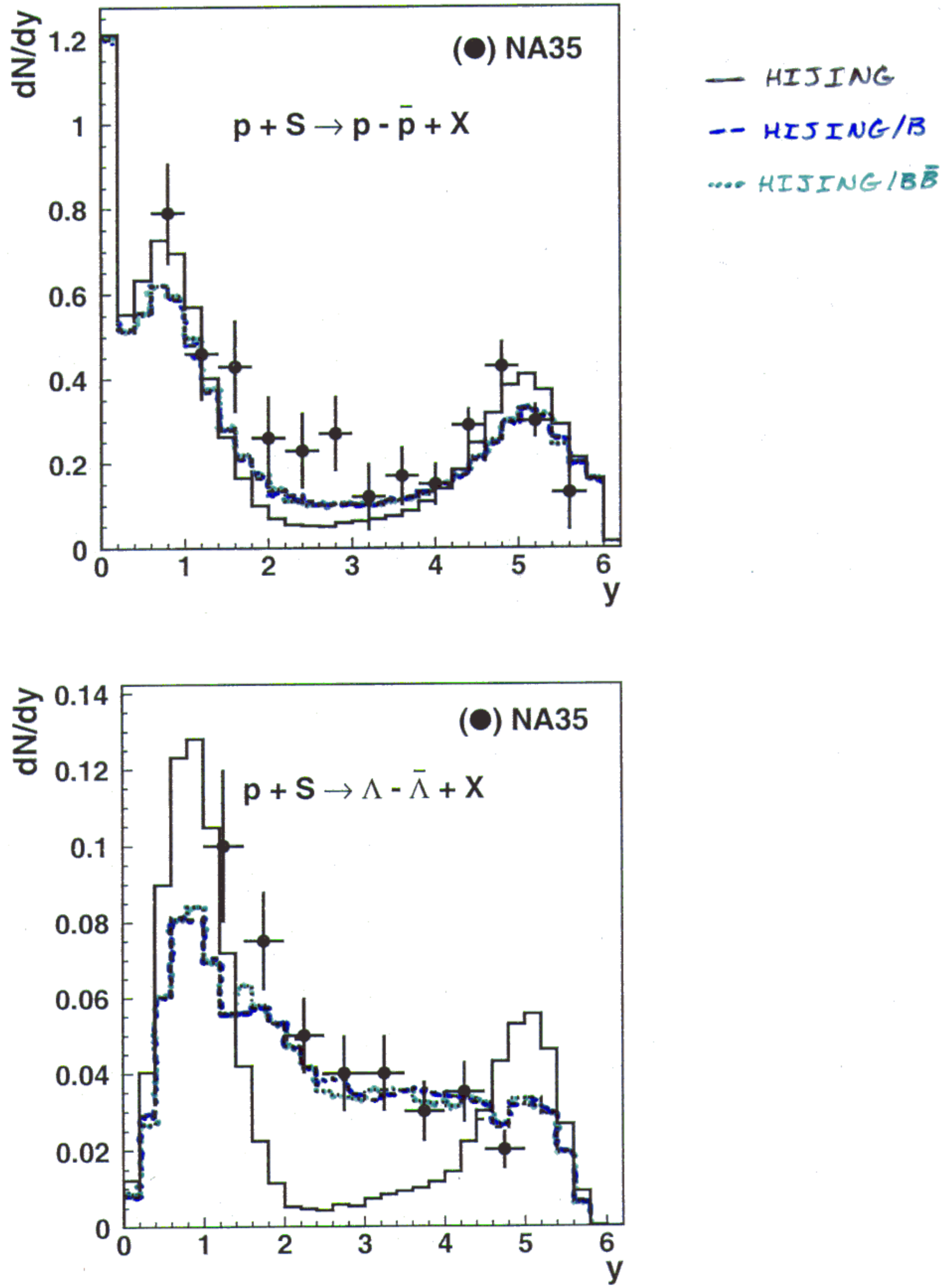
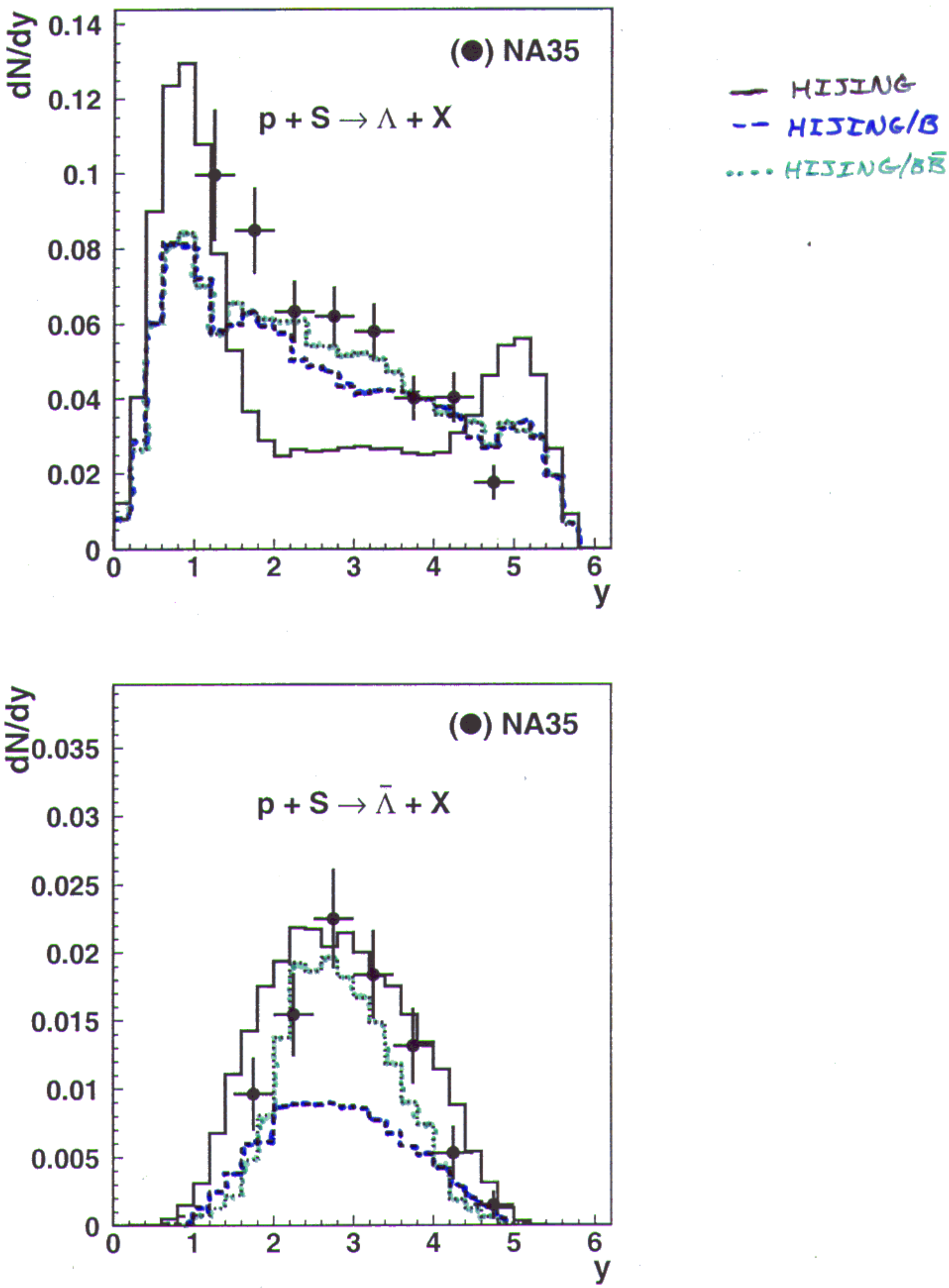


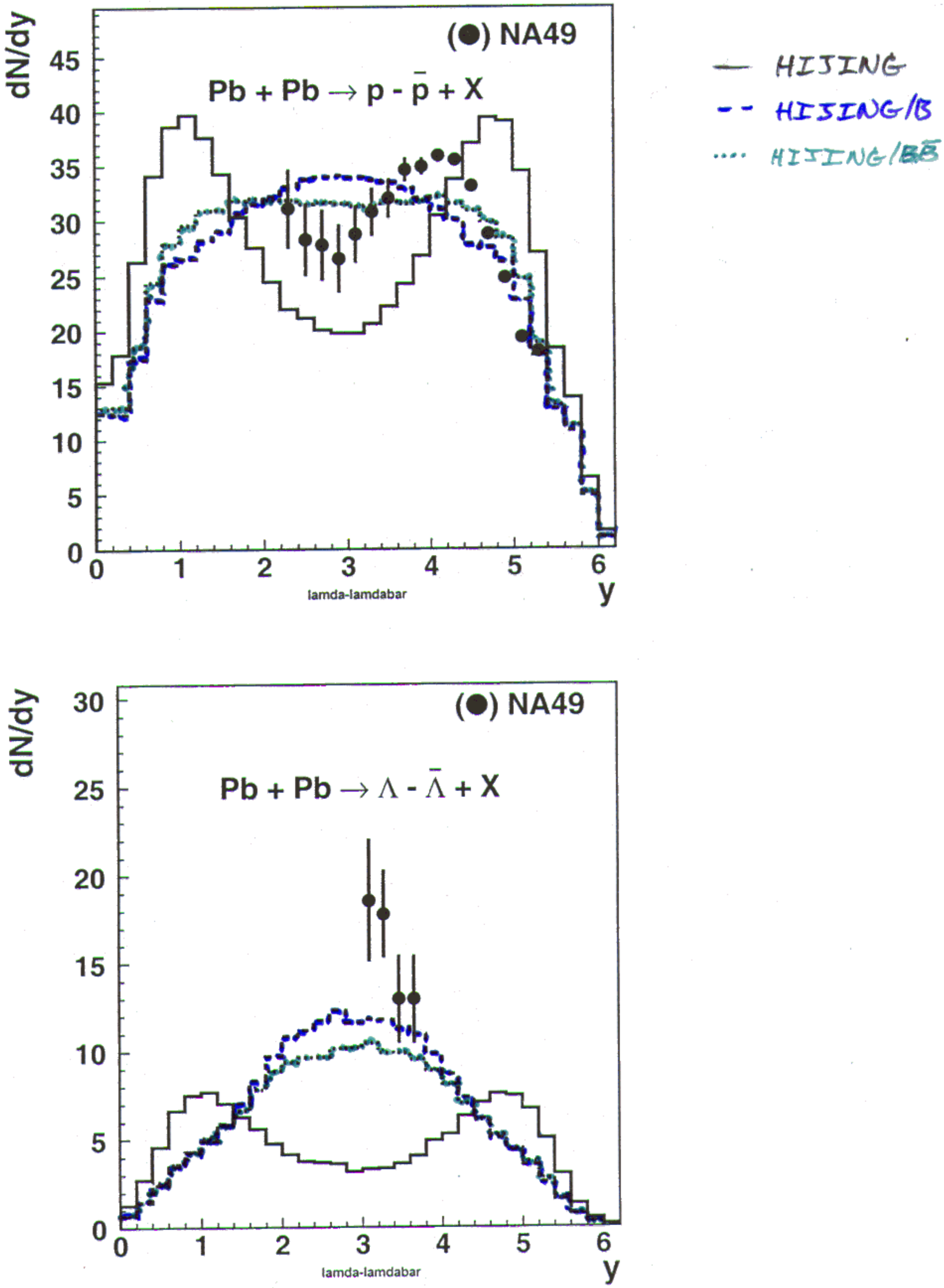
FIG. 3. The ratios of the yields of antihyperons to hyperons are shown for HIJING, HIJING/B and HIJING/$B\bar{B}$ for $p+Pb$, $S+S$ and $Pb+Pb$ at incident momentum $p_{lab} = 160$ AGeV along with data from the WA97 [1] collaboration.



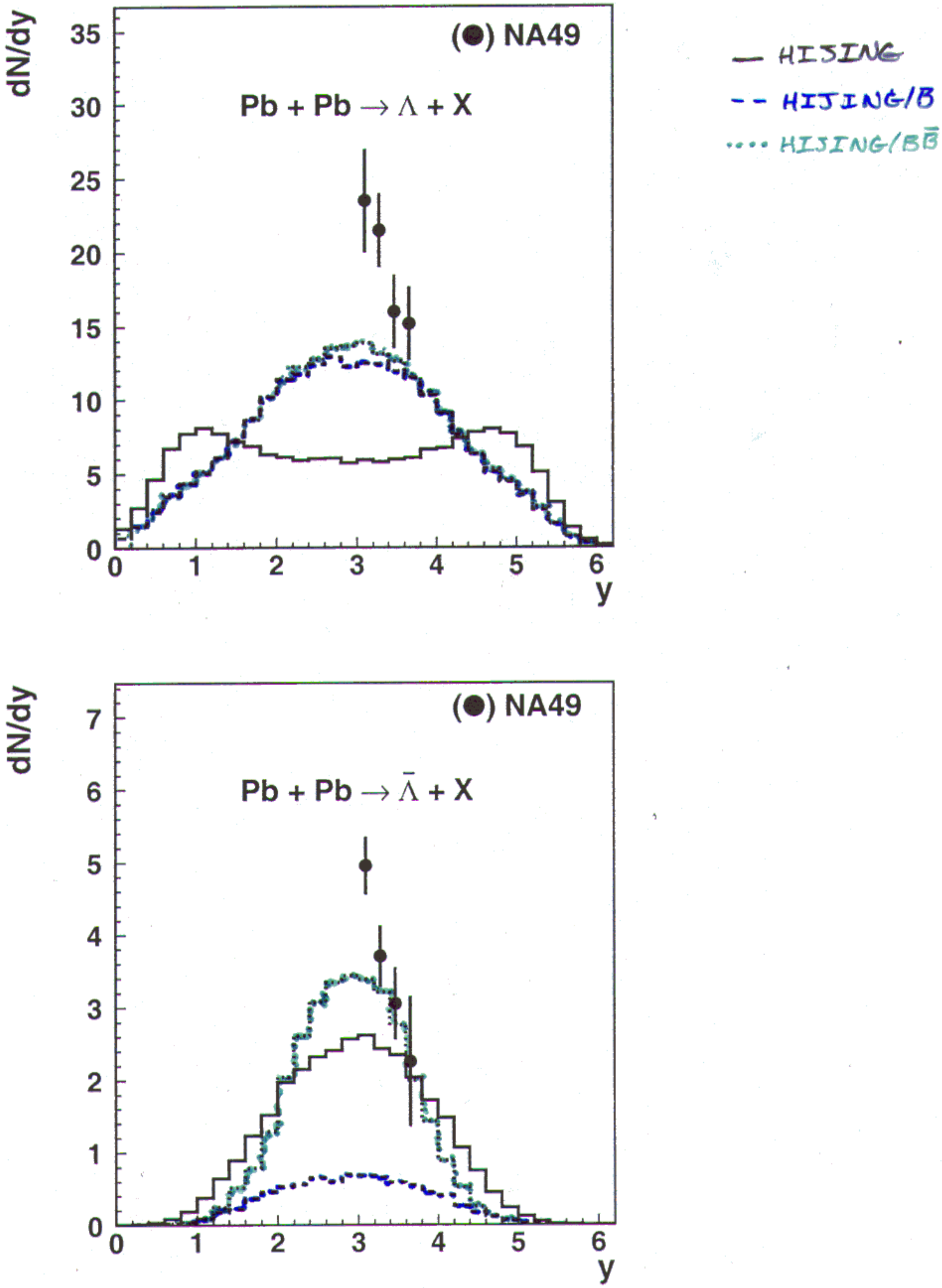
dN/dy
(●) NA35
p + S → p - p̄ + X
y
— HIJING
-- HIJING/B
···· HIJING/BB̄
dN/dy
(●) NA35
p + S → Λ - Λ̄ + X
y



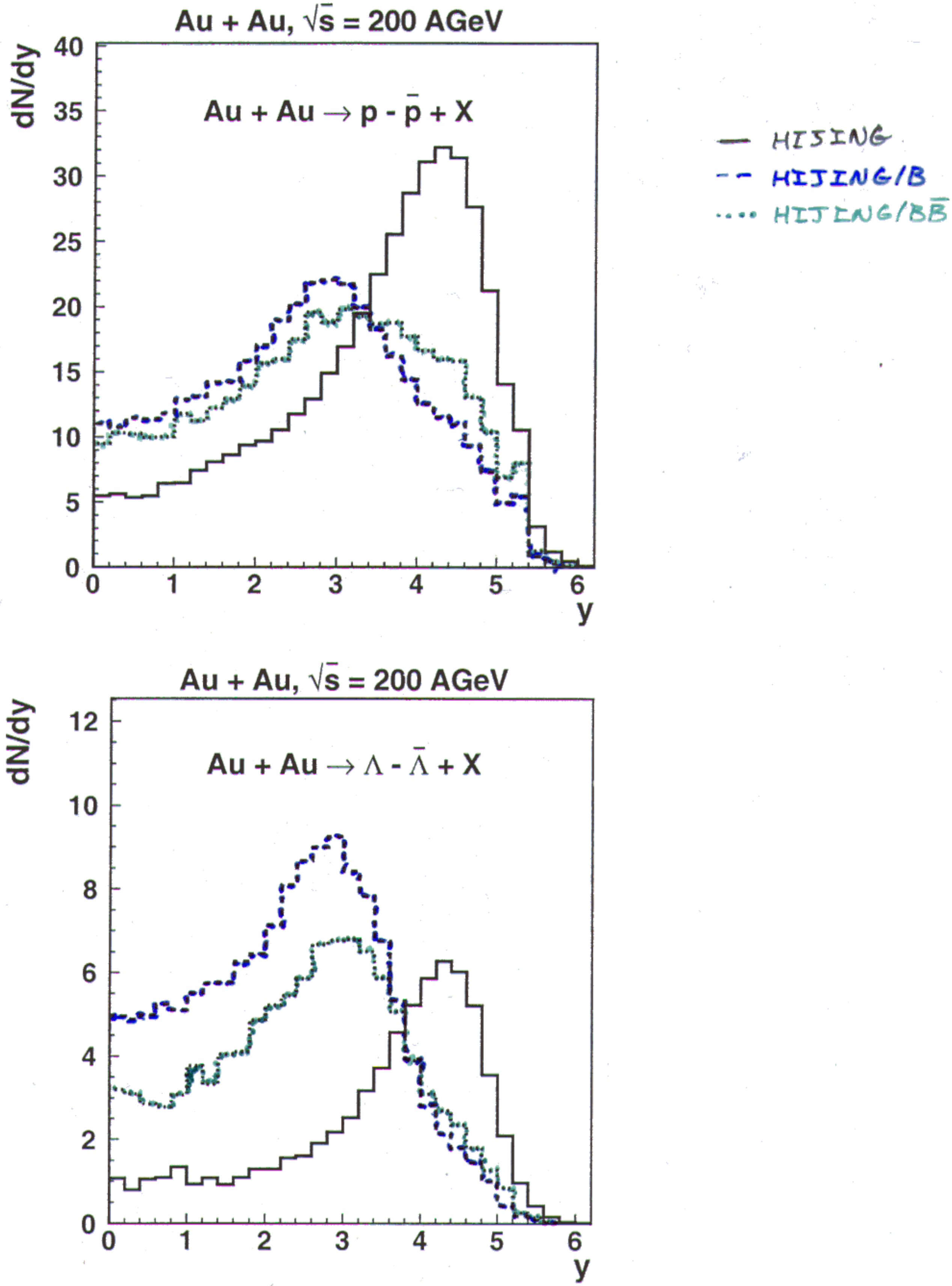
dN/dy
(●) NA35
p + S → Λ + X
y
HIJING
HIJING/B
HIJING/BB̄
dN/dy
(●) NA35
p + S → Λ̄ + X
y

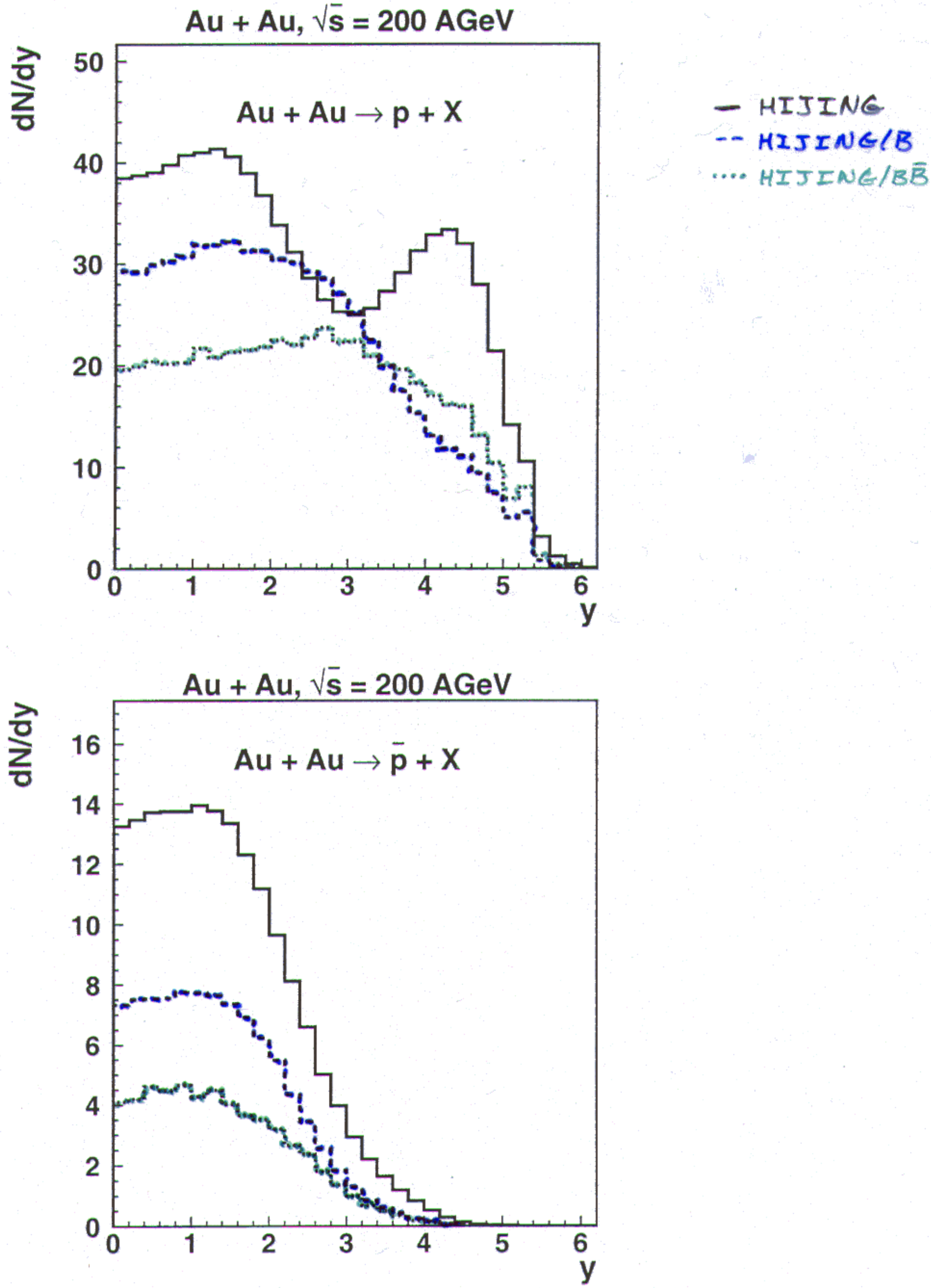


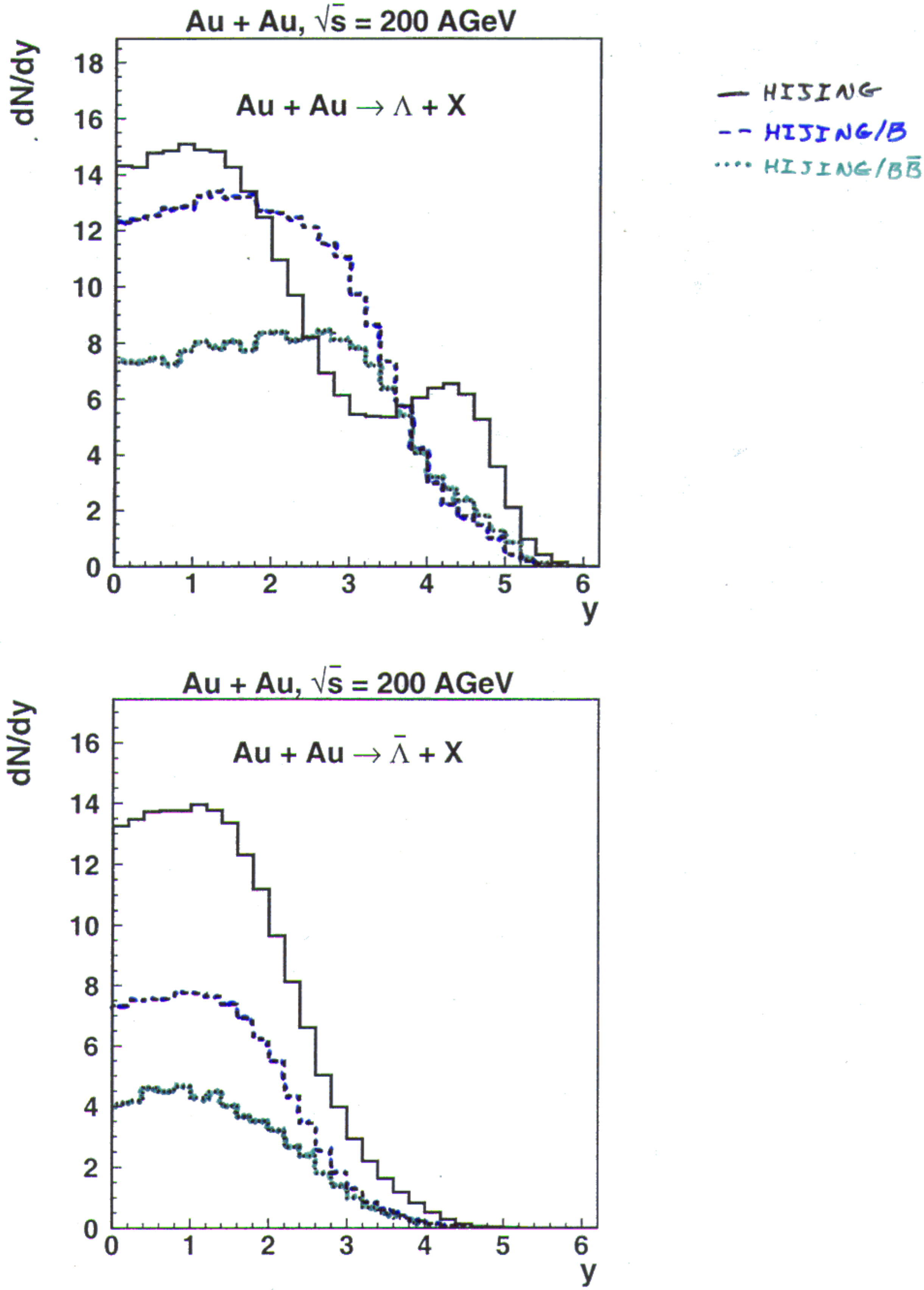
dN/dy
(●) NA49
Pb + Pb → p - p̄ + X
lamda-lamdabar
y
HIJING
HIJING/B
HIJING/BB
dN/dy
(●) NA49
Pb + Pb → Λ - Λ̄ + X
lamda-lamdabar
y



dN/dy
(●) NA49
Pb + Pb → Λ + X
y
dN/dy
(●) NA49
Pb + Pb → $\bar{\Lambda}$ + X
y
— HIJING
-- HIJING/B
···· HIJING/B$\bar{B}$

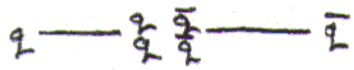

Au + Au, √s = 200 AGeV
dN/dy
Au + Au → p - p̄ + X
y
HIJING
HIJING/B
HIJING/BB̄
Au + Au, √s = 200 AGeV
dN/dy
Au + Au → Λ - Λ̄ + X
y


Au + Au, √s = 200 AGeV
dN/dy
Au + Au → p + X
y
Au + Au, √s = 200 AGeV
dN/dy
Au + Au → p̄ + X
y
— HIJING
-- HIJING/B
···· HIJING/BB̄

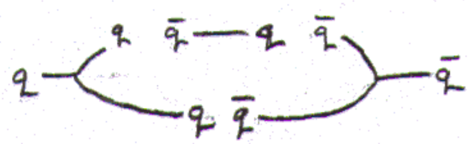

Au + Au, √s = 200 AGeV
Au + Au → Λ + X
dN/dy
y
HIJING
HIJING/B
HIJING/BB̄
Au + Au, √s = 200 AGeV
Au + Au → Λ̄ + X
dN/dy
y

$B_a\bar{B}_b$ Production Mechanisms

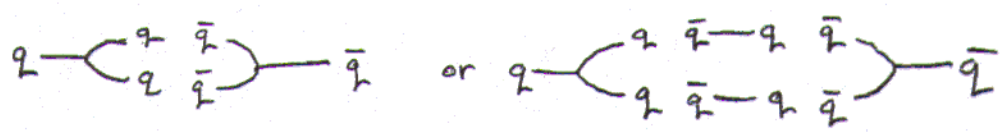
I. Schwinger tunnelling (rigid diquarks)



II. "popcorn" (needed for e^+e^- $\sqrt{s} \approx 29$ GeV)



III. $J\bar{J}$ (RHIC ?!)



Conclusions

I. Hadronic mechanism (parameters fit by pp & pA data) which naturally enhances strangeness (i.e. $\Omega\bar{\Omega}$ production)

II. Interesting rapidity correlations testable at RHIC

$$\sim e^{-\frac{1}{2}|y_B - y_{\bar{B}}|}$$

III. Needed along with baryon junction exchange (diquark breaking) to describe anti-hyperon to hyperon ratios.

IV. Raises the question of more complicated $J\bar{J}$ loop configurations that can further enhance $\Omega\bar{\Omega}$ production which can then explain the large observed enhancements (WA97, NA49)
(Question of initial string configurations at RHIC)