Hyperon Polarization in Heavy ion Collisions

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Strangeness in Quark Matter 2013
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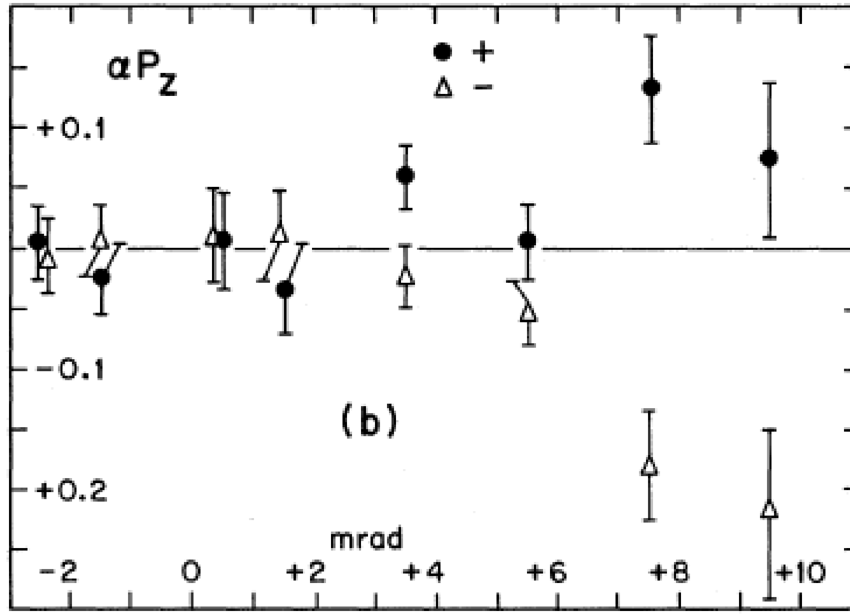
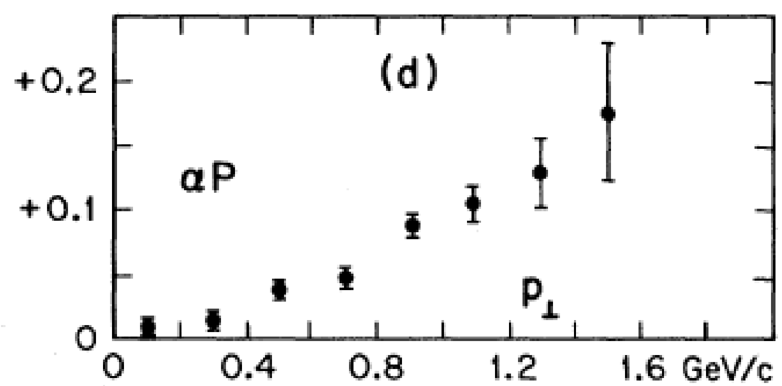
1976 – Bunce et al. (*Phys. Rev. Lett.* 36, 1113)

$$p + Be \rightarrow \Lambda + X$$

300 GeV

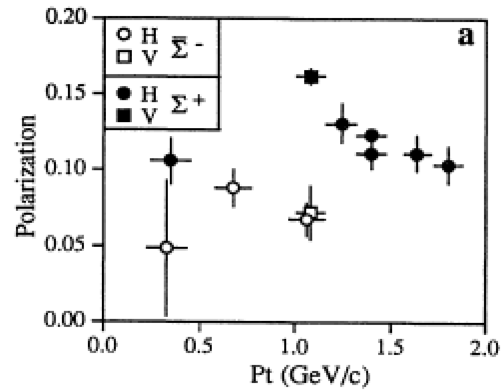


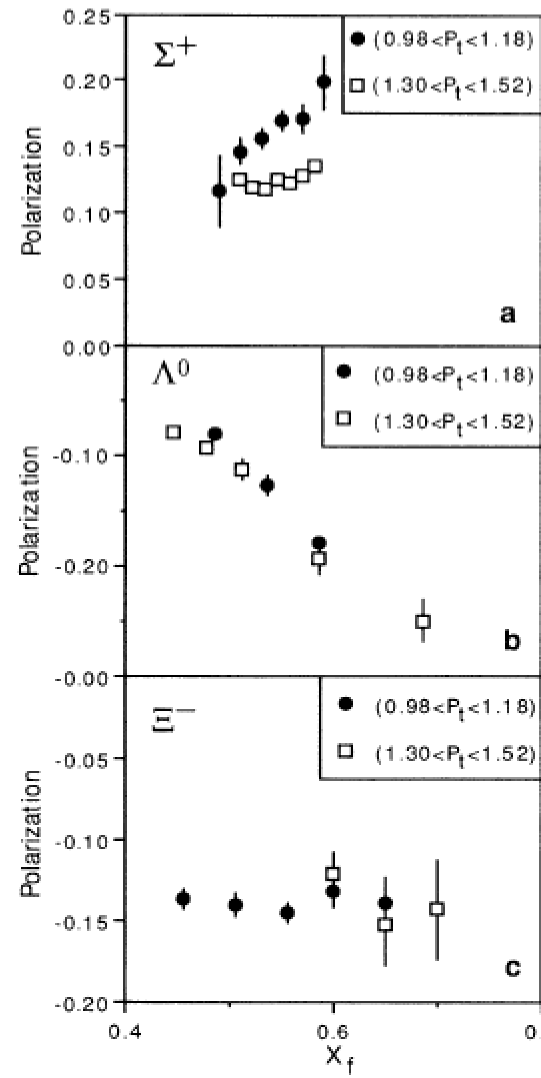


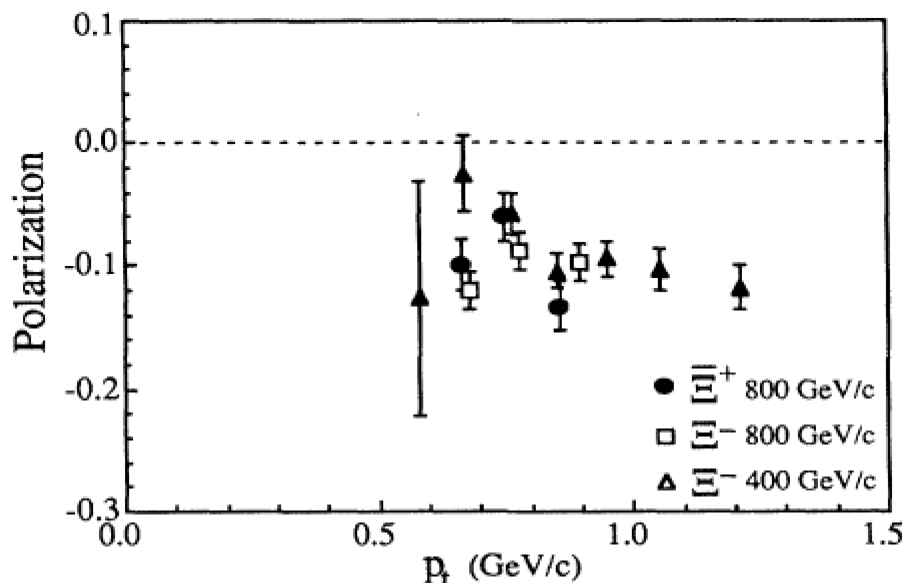
A totally unexpected result –
Polarization effects shoud vanish at
High energies (theoretical and experimental
expectative)

In the following years – many data for *Y (Λ,Σ,Ξ)* and antihyperons (E761,...)

$$p + A \rightarrow Y(\bar{Y}) + X$$

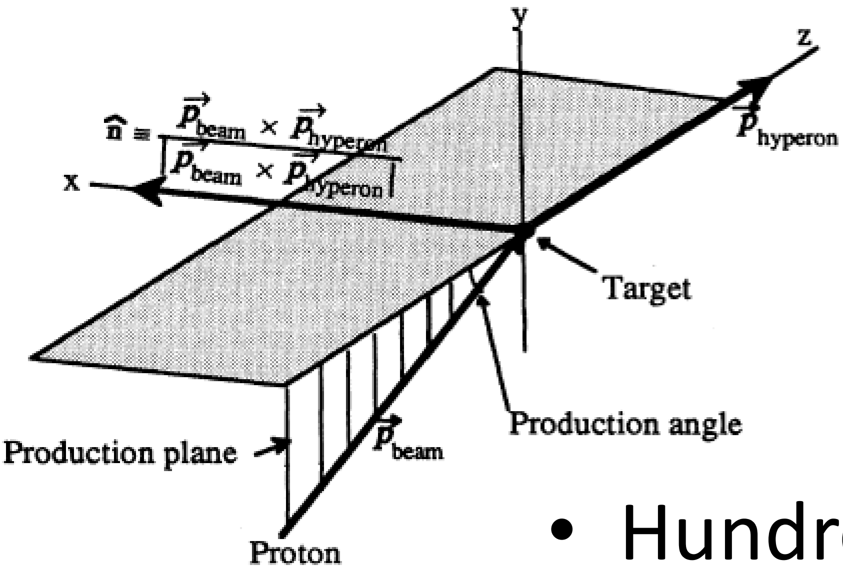






And other...

Polarization in pA Collisions



$$P = \frac{N_{\uparrow} - N_{\downarrow}}{N_{\uparrow} + N_{\downarrow}}$$

- Hundreds of GeV
- Normal to the production plane
- Be, ...
- Hyperon and antihyperon

Polarization in pA Collisions

- A very challenging problem.
- Many models: - OPER

  - Quark recombination

  - Lund strings

  - Constituent quark models...
- Explain the data, but there are problems, specially for the antihyperons (most of these models does not apply)
- Y. Hama, T. Kodama (1993) – Hydrodinamical elements+ optical potential – final state interactions

Collision

↓

Hot expanding Hadronic matter (final stage)

↓

Final particle interactions

(and statistical fluctuations)

The Model

- Hydrodynamical aspects

+

- Low energy πY final-state interactions

(the relative energy is small)

- Most of the produced particles are pions – this is the dominant interaction (for baryons)
- It is a indirect production mechanism

Low Energy πY Interactions

- Few data for these interactoins
- Effective chiral lagrangians – a good choice

(describe quite well πN and NN low energy interactions)

- Tree diagrams + sigma term (loop)
- Many intermediate particles considered (resonances, mesons...)

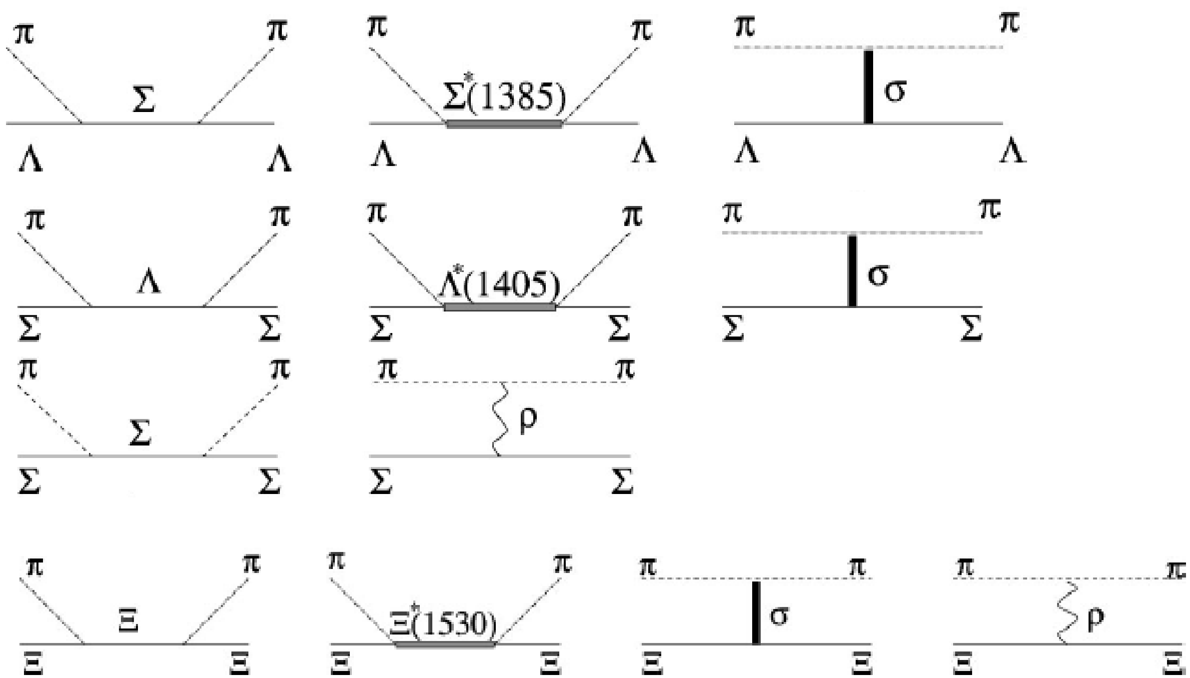
Low Energy πY Interactions

$$\mathcal{L}_{\pi BB'} = \frac{g_A}{2\ f_\pi}\left[B'\gamma_\mu\gamma_5 T^a B\right]\partial^\mu\phi_a + \text{h.c.}$$

$$\mathcal{L}_{\pi BR} = \frac{g_A^*}{2\ f_\pi}\left[\overline{R}_\mu T^a B\right]\partial^\mu\phi_a + \text{h.c.}$$

$$\mathcal{L}_{B\rho B'} = \frac{\gamma_0}{2}\left[\overline{B}'\gamma_\mu T^a B\right]\vec{\rho}^\mu + \frac{\gamma_0}{2}\left[\overline{B}'\left(\frac{\mu_{B'}-\mu_B}{4m_B}\right)i\sigma_{\mu\nu}T^a\ B\right].(\partial^\mu\vec{\rho^\nu} - \partial^\nu\vec{\rho^\mu})$$

$$\mathcal{L}_{\rho\pi\pi} = \gamma_0\vec{\rho}_\mu.(\vec{\phi}\times\partial^\mu\vec{\phi}) - \frac{\gamma_0}{4m_\rho^2}(\partial_\mu\vec{\rho}_\nu - \partial_\nu\vec{\rho}_\mu).(\partial^\mu\vec{\phi}\times\partial^\nu\vec{\phi}) \quad ,$$



πΛ Interaction

$$T^{ba}_{\pi\Lambda} = \overline{u}(\boldsymbol{p'})\left\{A + \frac{(\not k + \not k')}{2}B\right\}\delta_{ba}u(\boldsymbol{p})$$

$$A_\Sigma = g^2_{\Lambda\pi\Sigma}(m_\Lambda + m_\Sigma)\left\{\frac{s - m^2_\Lambda}{s - m^2_\Sigma} + \frac{u - m^2_\Lambda}{u - m^2_\Sigma}\right\}$$

$$B_\Sigma = g^2_{\Lambda\pi\Sigma}\left\{\frac{m^2_\Lambda - s - 2m_\Lambda(m_\Lambda + m_\Sigma)}{s - m^2_\Sigma} + \frac{2m_\Lambda(m_\Lambda + m_\Sigma) + u - m^2_\Lambda}{u - m^2_\Sigma}\right\}$$

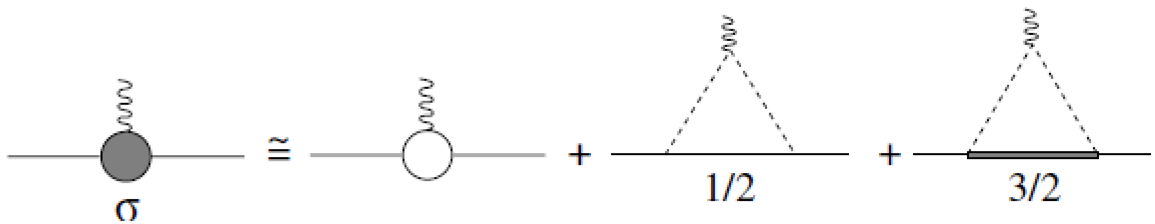
$$A_{\Sigma^*} = \frac{g^2_{\Lambda\pi\Sigma^*}}{3m_\Lambda}\left\{\frac{\nu_r}{\nu_r^2 - \nu^2}\hat{A} - \frac{m^2_\Lambda + m_\Lambda m_{\Sigma^*}}{m^2_{\Sigma^*}} \times \left(2m^2_{\Sigma^*} + m_\Lambda m_{\Sigma^*} - m^2_\Lambda + 2\mu^2\right) + \frac{4m_\Lambda}{m^2_{\Sigma^*}}\left[(m_\Lambda + m_{\Sigma^*})Z + (2m_{\Sigma^*} + m_\Lambda)Z^2\right] k\cdot k'\right\}$$

$$B_{\Sigma^*} = \frac{g^2_{\Lambda\pi\Sigma^*}}{3m_\Lambda}\left\{\frac{\nu}{\nu_r^2 - \nu^2}\hat{B} - \frac{8m^2_\Lambda \nu Z^2}{m^2_{\Sigma^*}}\right\} ,$$

$$\hat{A} = \frac{(m_{\Sigma^*} + m_\Lambda)^2 - \mu^2}{2m^2_{\Sigma^*}}\left\{2m^3_{\Sigma^*} - 2m^3_\Lambda - 2m_\Lambda m^2_{\Sigma^*} - 2m^2_\Lambda m_{\Sigma^*} + \mu^2(2m_\Lambda - m_{\Sigma^*})\right\} + \frac{3}{2}(m_\Lambda + m_{\Sigma^*})t ,$$

$$\hat{B} = \frac{1}{2m^2_{\Sigma^*}}\left[(m^2_{\Sigma^*} - m^2_\Lambda)^2 - 2m_\Lambda m_{\Sigma^*}(m_{\Sigma^*} + m_\Lambda)^2 + 6\mu^2 m_\Lambda(m_{\Sigma^*} + m_\Lambda) - 2\mu^2(m_{\Sigma^*} + m_\Lambda)^2 + \mu^4\right] + \frac{3}{2}t$$

Some loops



$$\sigma_s(t;M)\bar{u}u = \mathrm{i}\mu^2 \left(\frac{g_A}{2f_\pi}\right)^2 (T_a^\dagger T_a) \int [\ldots][\bar{u}\Lambda_s u]$$

$$\int [\ldots] = \int \frac{\mathrm{d}^4 Q}{(2\pi)^4} \frac{1}{[(Q-q/2)^2-\mu^2][(Q+q/2)^2-\mu^2]}$$

Coupling Constants

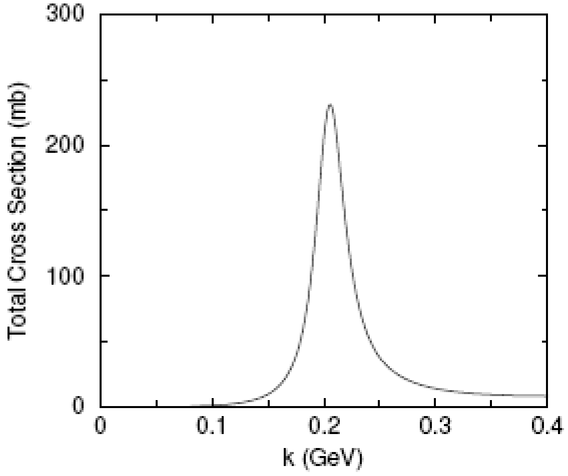
	N	Δ	Λ	Λ^* (1405)	Σ	Σ^* (1385)	Ξ	Ξ^* (1530)
N	1.25	2.82	–	–	–	–	–	–
Λ	–	–	–	–	0.98	1.74	–	–
Σ	–	–	0.98	1.63	0.52	~ 0	–	–
Ξ	–	–	–	–	–	–	0.28	0.84

Sigma term results

	N	Λ	Σ	Ξ
R (fm)	0.58	0.51	0.45	0.35
σ (MeV)	46.0	33.5	29.2	12.0
$\sigma(2\mu^2)$ (MeV)	57.6	39.3	36.2	13.25

$\pi\Lambda$ interactions results

- At low energies the cross Section is dominated by the $\Sigma(1385)$ resonance.
- Similar behavior for the other Hyperons



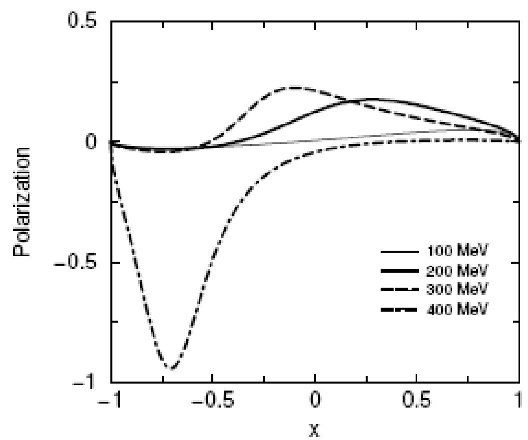


Fig. 4. Polarization in the $\pi\Lambda$ interaction, $x = \cos\theta$.

Low Energy πY Interactions

HyperCP (2003/2004) - (Ξ decays -Fermilab)

(Chakravorty *et al*. , Phys. Rev. Lett. 91, 031601)

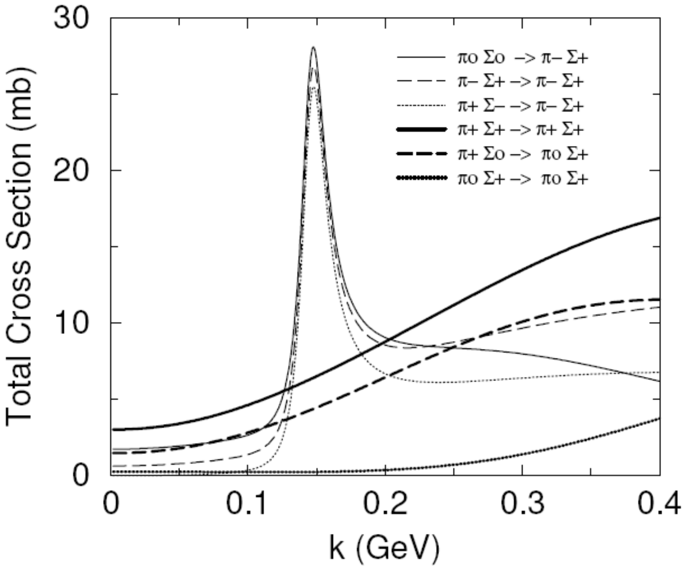
$$\delta_P - \delta_S = (4.6 \pm 1.4 \pm 1.2)^o$$

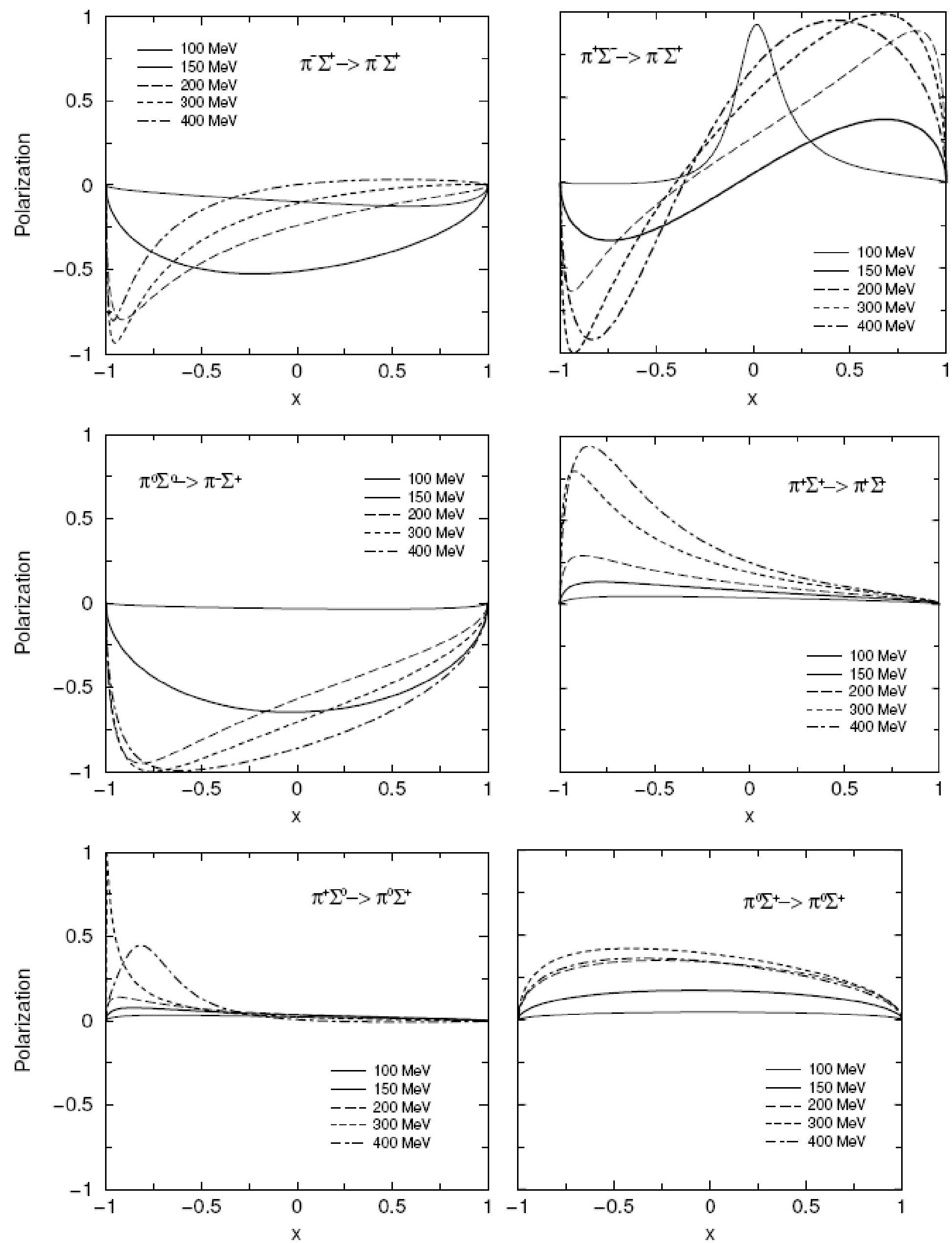
Calculations

(C.C.Barros Jr and Y. Hama, Phys. Rev. C (2001))

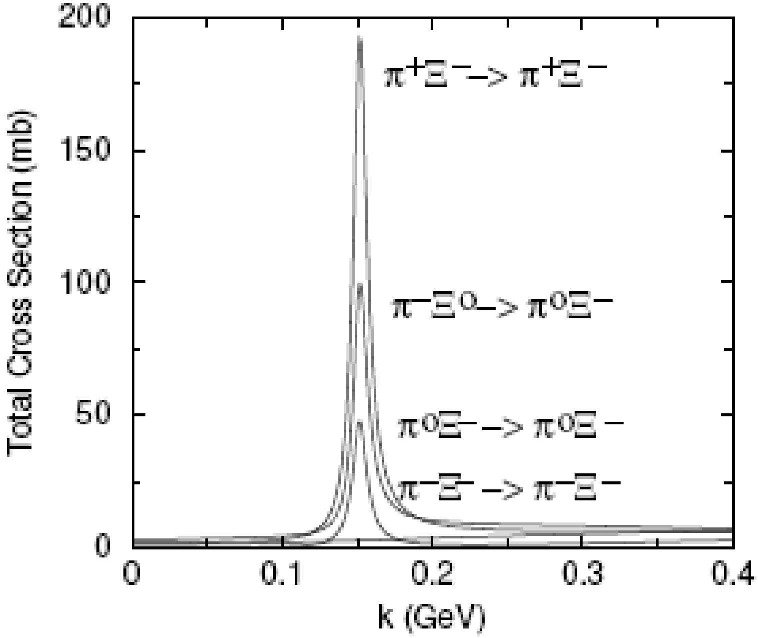
$$\delta_P - \delta_S = 4.3^o$$

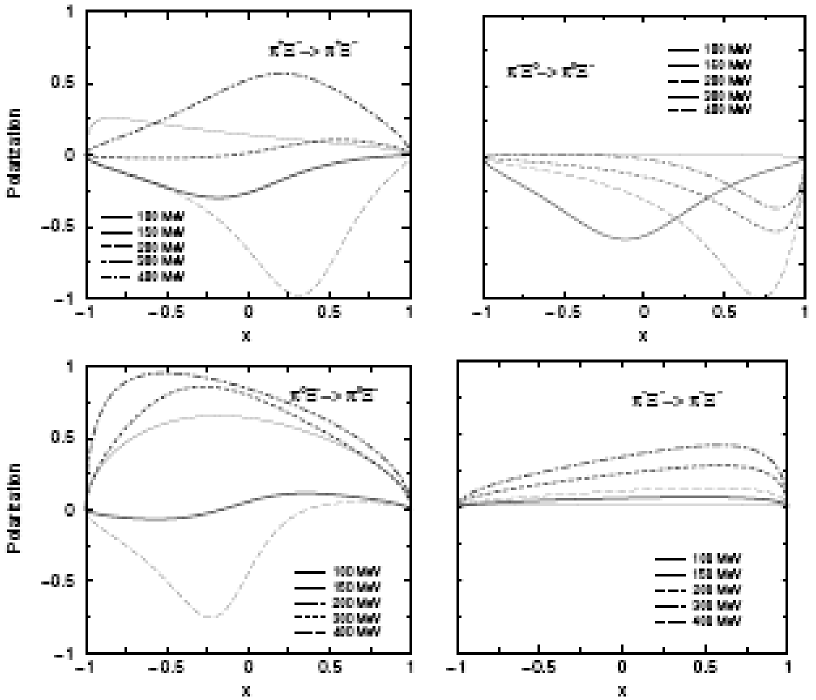
πΣ Interaction





$\pi\Xi$ Interaction





Rapidity Distribuitions

Produced pions
(inside the fluid)

$$\frac{d\sigma}{d\boldsymbol{p}'_\pi} = \frac{1}{E'_\pi}\frac{d\sigma}{dy'd\boldsymbol{p}'_t} = \frac{1}{e^{\frac{E'_\pi}{T}} - 1}$$

$$\frac{d\sigma}{dy'} \sim Ce^{-\beta' y'}$$

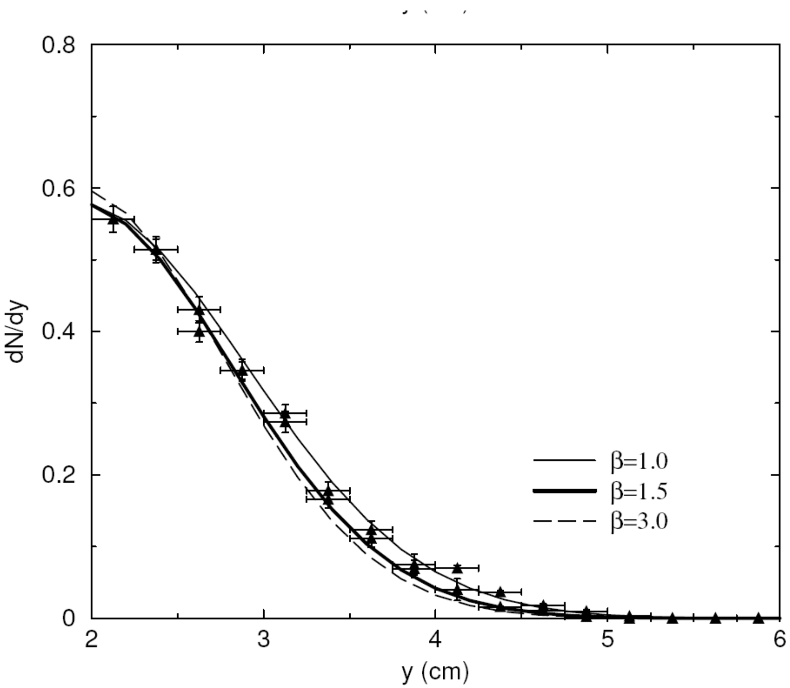
$$T \sim m_\pi \qquad \beta' \sim 0.98$$

Fluid

$$\frac{d\sigma}{d\alpha} = A'[e^{-\beta(\alpha-\alpha_0)^2} + e^{-\beta(\alpha+\alpha_0)^2}]$$

Rapidity distributions

$$\frac{d\sigma}{dy} = \int \frac{d\sigma}{d\alpha}(\alpha)\ \frac{d\sigma}{dy'}(y-\alpha)\ d\alpha$$



Data – W. Bell *et al*., Z Phys, C 27, 191 (1985)

Reactions

$$\pi^+\overline{\Lambda} \to \pi^+\overline{\Lambda}$$
$$\pi^-\overline{\Lambda} \to \pi^-\overline{\Lambda}$$
$$\pi^0\overline{\Lambda} \to \pi^0\overline{\Lambda}$$

$$\pi^-\overline{\Xi}^+ \to \pi^-\overline{\Xi}^+$$
$$\pi^0\overline{\Xi}^+ \to \pi^0\overline{\Xi}^+$$
$$\pi^+\overline{\Xi}^+ \to \pi^+\overline{\Xi}^+$$
$$\pi^+\overline{\Xi}^+ \to \pi^-\overline{\Xi}^+$$

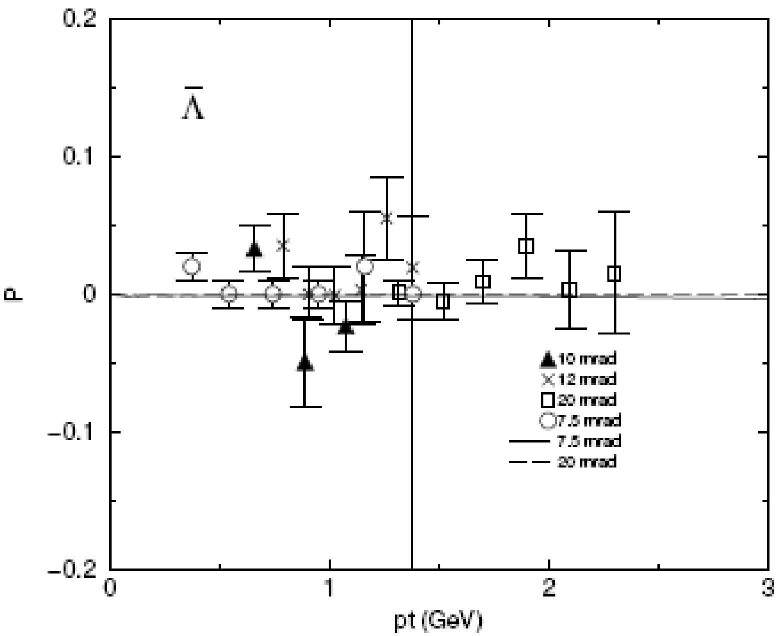
$$\pi^-\overline{\Sigma}^- \to \pi^-\overline{\Sigma}^-$$
$$\pi^0\overline{\Sigma}^- \to \pi^0\overline{\Sigma}^-$$
$$\pi^+\overline{\Sigma}^- \to \pi^+\overline{\Sigma}^-$$
$$\pi^-\overline{\Sigma}^- \to \pi^+\overline{\Sigma}^-$$
$$\pi^-\overline{\Sigma}^- \to \pi^0\overline{\Sigma}^-$$
$$\pi^0\overline{\Sigma}^- \to \pi^+\overline{\Sigma}^-$$

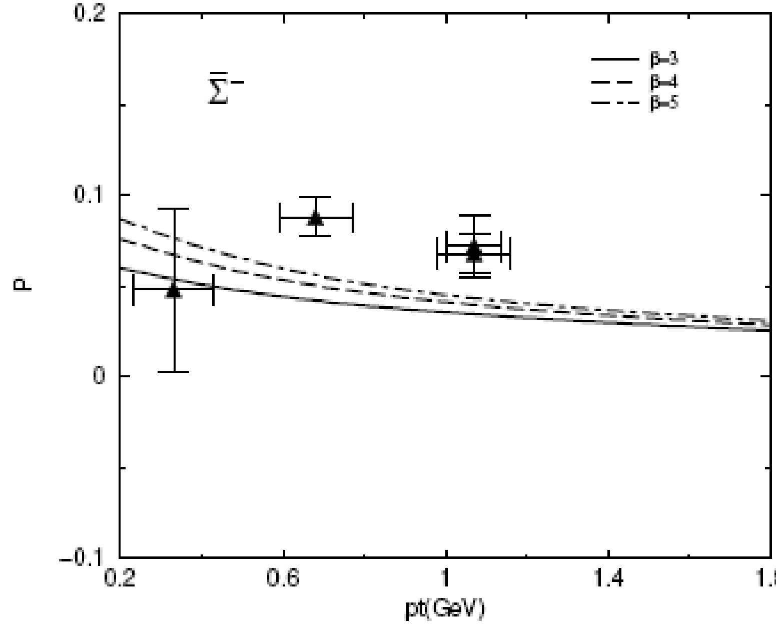
Final Polarization

$$\langle\vec{P}\rangle = \frac{\int\left\{(\vec{P}d\sigma/dt)_{R_1} + (\vec{P}d\sigma/dt)_{R_2} + ... + (\vec{P}d\sigma/dt)_{R_N}\right\}\mathcal{G}d\tau}{\int\left\{(d\sigma/dt)_{R_1} + (d\sigma/dt)_{R_2} + ... + (d\sigma/dt)_{R_N}\right\}\mathcal{G}d\tau}$$

$$\mathcal{G} = \frac{(dN/d\alpha)}{(\exp(\frac{E'_{\pi_0}}{T}) - 1)(\exp(\frac{E'_0}{T}) + 1)}\Lambda_0'^2\pi_0'^2\delta(E'_0 + E'_{\pi_0} - E' - \sqrt{m_\pi^2 + (\vec{\pi}'_0 + \vec{\Lambda}'_0 - \vec{\Lambda}')^2})$$

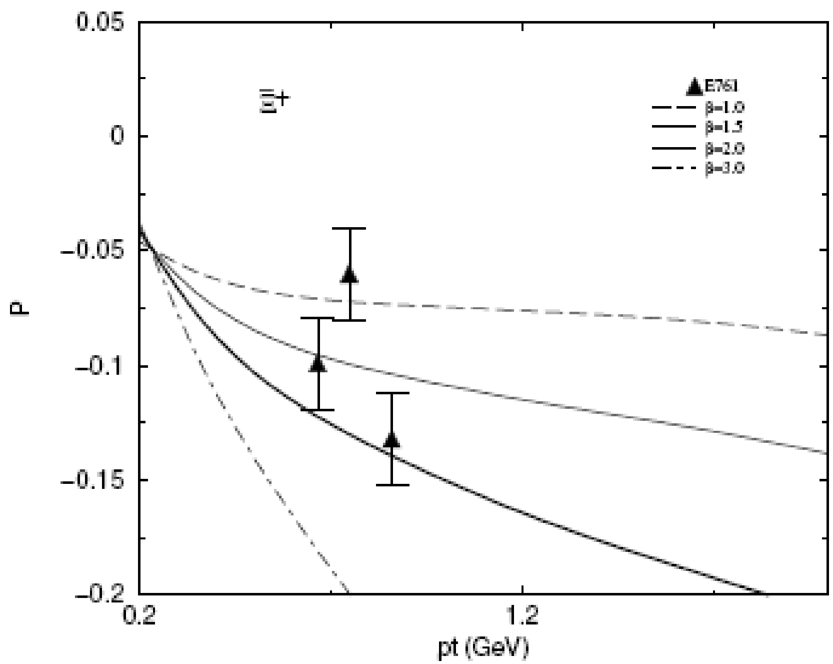
$$d\tau = d\alpha d\vec{\Lambda}'_0 d\vec{\pi}'_0$$



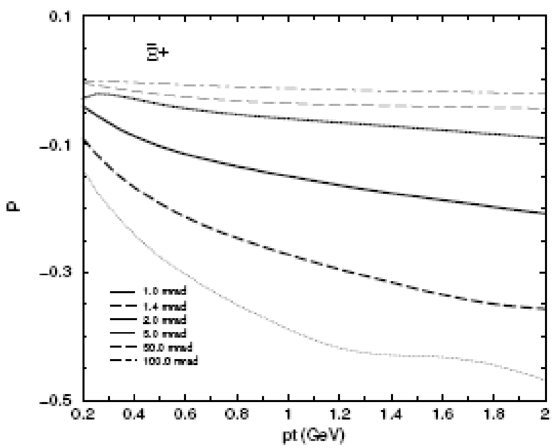


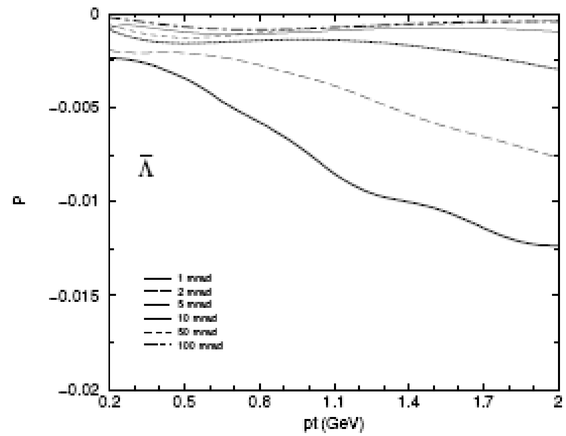
Final

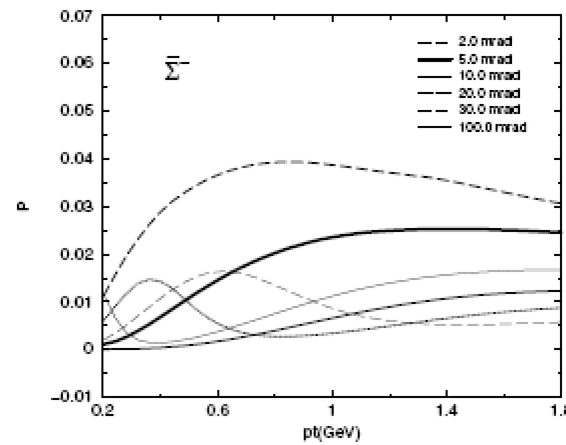
Polarizations



p_t dependence

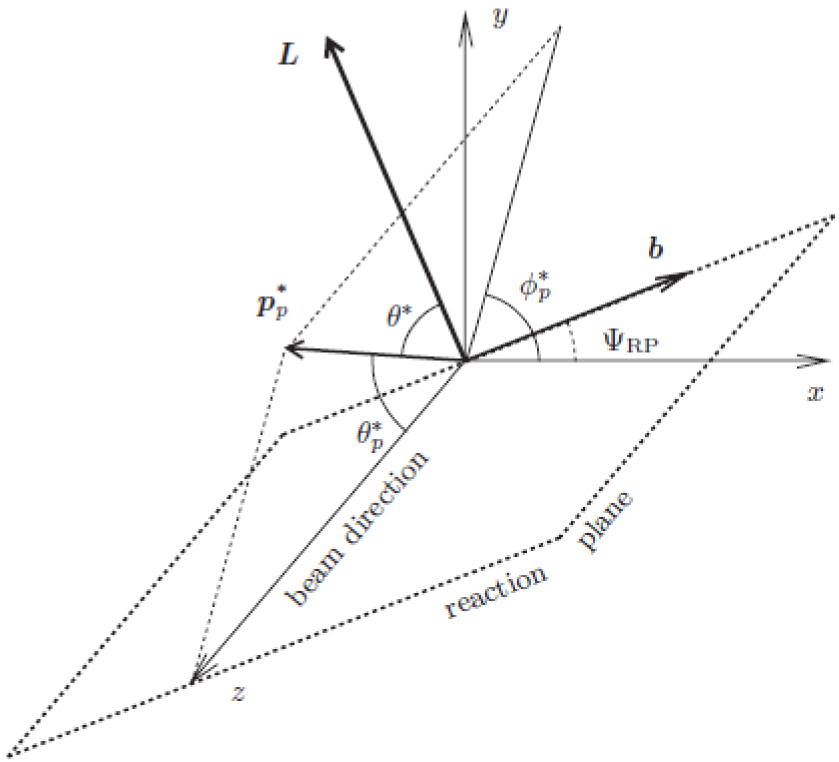






AA Collisions

- STAR data (Abelev et al. 2007) – Global polarization



Noncentral relativistic nucleus-nucleus collisions possesses large angular momentum

Angular momentum of the system, **L**, is Defined normal to the reaction plane

Reaction plane is determined by the beam direction and the impact parameter **b**

AA Collisions

- Some models are availabe (previous talks, for example)
- These system is a interesting place to apply the model
- BRHAMS pseudorapidity distributions are used to determine the fluid propreties and hydrodinamical parameters

$$u^0 \frac{d\rho}{d^3u} = A \left[e^{-\beta(\alpha-\alpha_0)^2} + e^{-\beta(\alpha+\alpha_0)^2} \right] e^{-\beta_t \xi^2}$$

Velocity distribution - Fluid

(longitudinal and transversal expansion)

$$\frac{dN}{d\vec{p}_0} = \frac{N_0}{\exp(E_0/T) - 1}$$

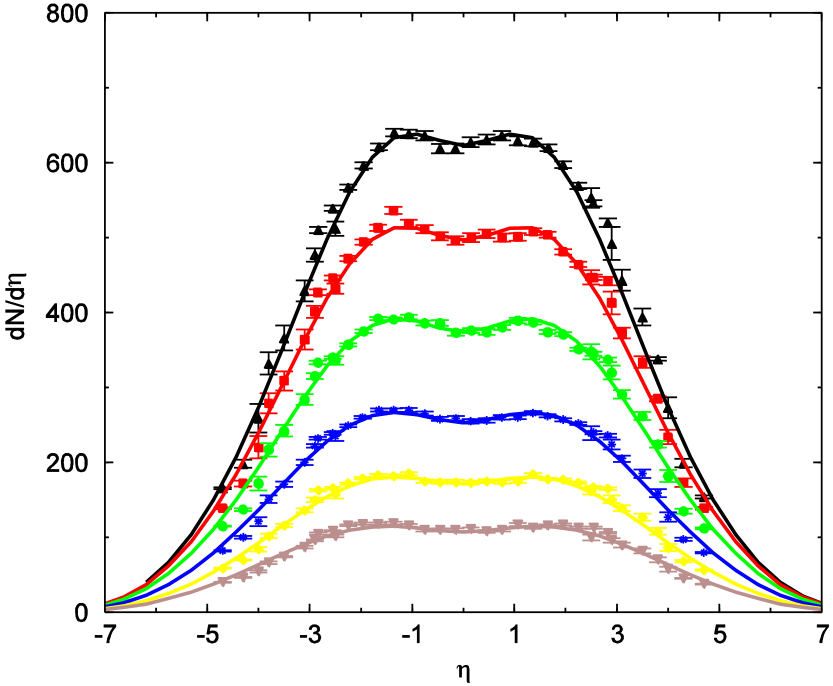
Particles inside the Fluid (pions)

$$E\frac{dN}{d\vec{p}} = C \int \left[e^{-\beta(\alpha-\alpha_0)^2} + e^{-\beta(\alpha+\alpha_0)^2} \right] e^{-\beta_t \xi^2}$$
$$\times \frac{E_0(\alpha,\xi,\phi)}{\exp(E_0(\alpha,\xi,\phi)/T) - 1} \sinh\xi \ \cosh\xi \ \mathrm{d}\alpha \ \mathrm{d}\xi \ \mathrm{d}\phi \quad ,$$

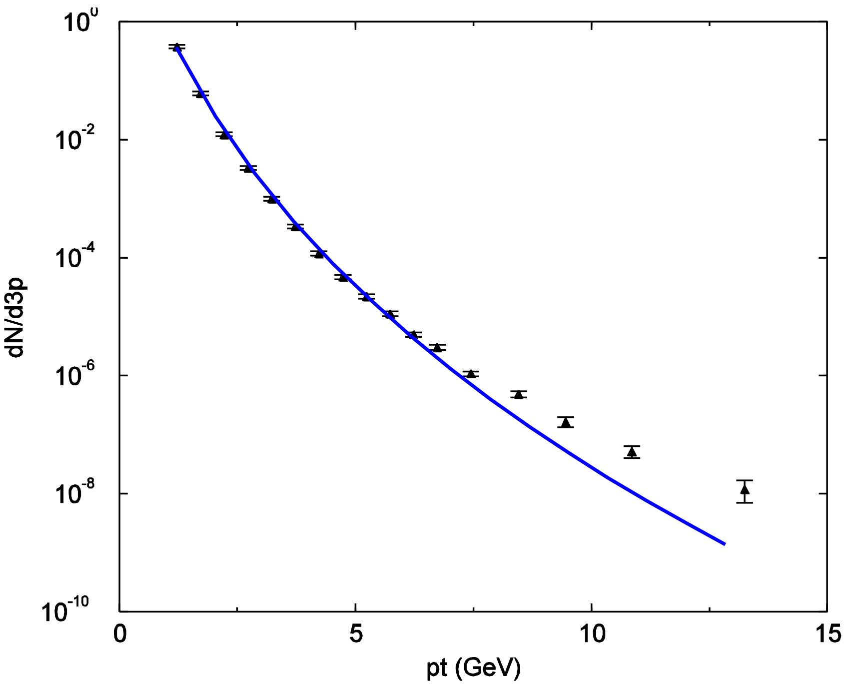
Observed particles Distribution

RHIC

$$\frac{d\sigma}{d\eta} = A\ \mathrm{sech}^2\eta \int_0^\infty \left\{ e^{-\beta(y_L(p,\eta)-y_0)^2} + e^{-\beta(y_L(p,\eta)+y_0)^2} \right\} \frac{p^2 e^{-\gamma(p^2\ \mathrm{sech}^2\eta+\mu^2)^{1/2}}}{\sqrt{p^2+\mu^2}} dp$$



BRHAMS data
200 GeV Au-Au

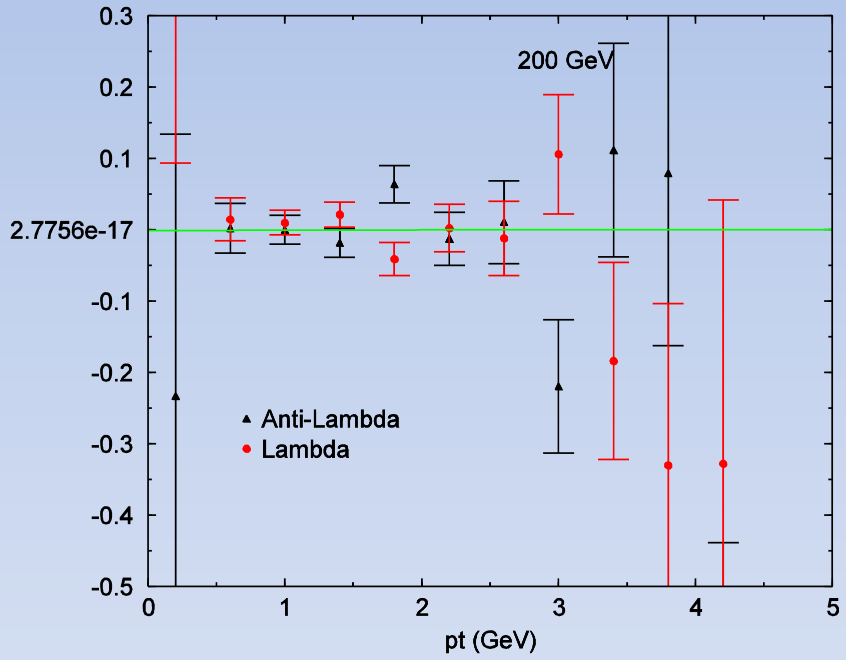


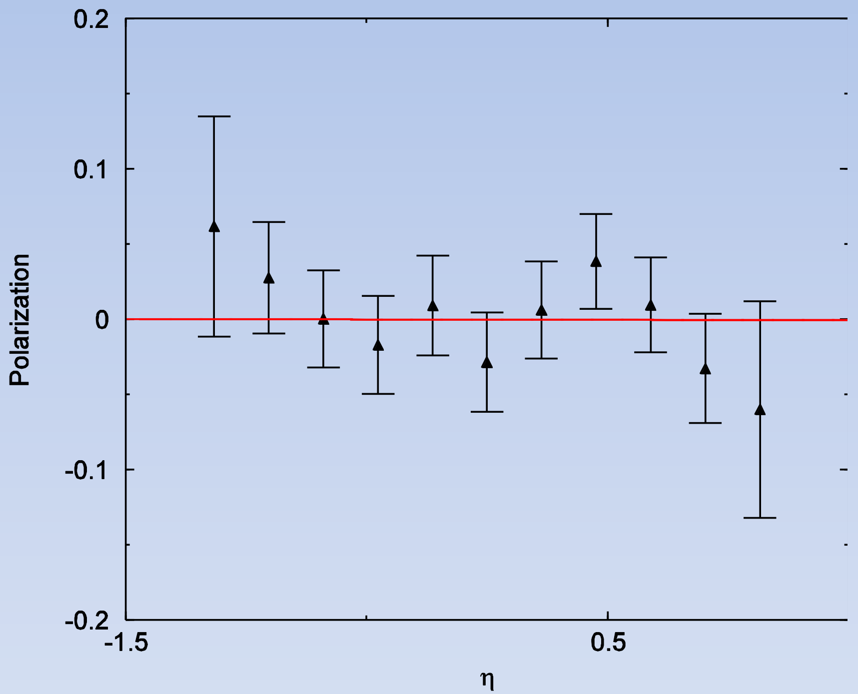
PHENIX data

It is possible to obtain quite well the parameters

Polarization

(the effect of final-state interactions)





STAR data – Abelev *et al*. Phys. Rev. C 76 024915 (2007)

One more time shows that the results are consistent

LHC Perspectives

- With the presented mechanism, for LHC systems, for all Hyperons and Antihyperons the Global polarization

$$P \cong 0$$

(for many reasons, β, incoherent processes...)

Large angular momentum effect?

LHC Perspectives

- *pA* collisions?
- It could be possible to find a small polarization, in the production plane
- At the moment it is just a conjecture, the calculations are not ready yet...

Conclusions

- A model that works to produce polarization in *pA* collisions is considered (hydro+final-state interactions)
- Significant in “old” *pA* collisions
- Global Polarization is almost totally washed out in *AA* collisions – compatible with the RHIC data
- LHC *pA* collisions?
- Where to find? Normal to production plane at small angles (a possibility)