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QCD Dynamics

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Study of the transition region between quark-gluon and hadronic degrees of freedom.

Topics treated:
- Antihyperon-hyperon production
- Two pion production

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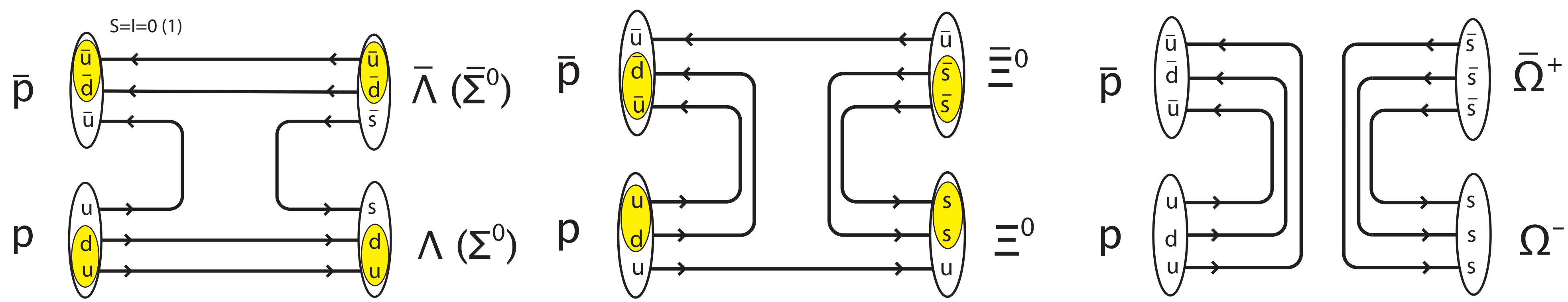
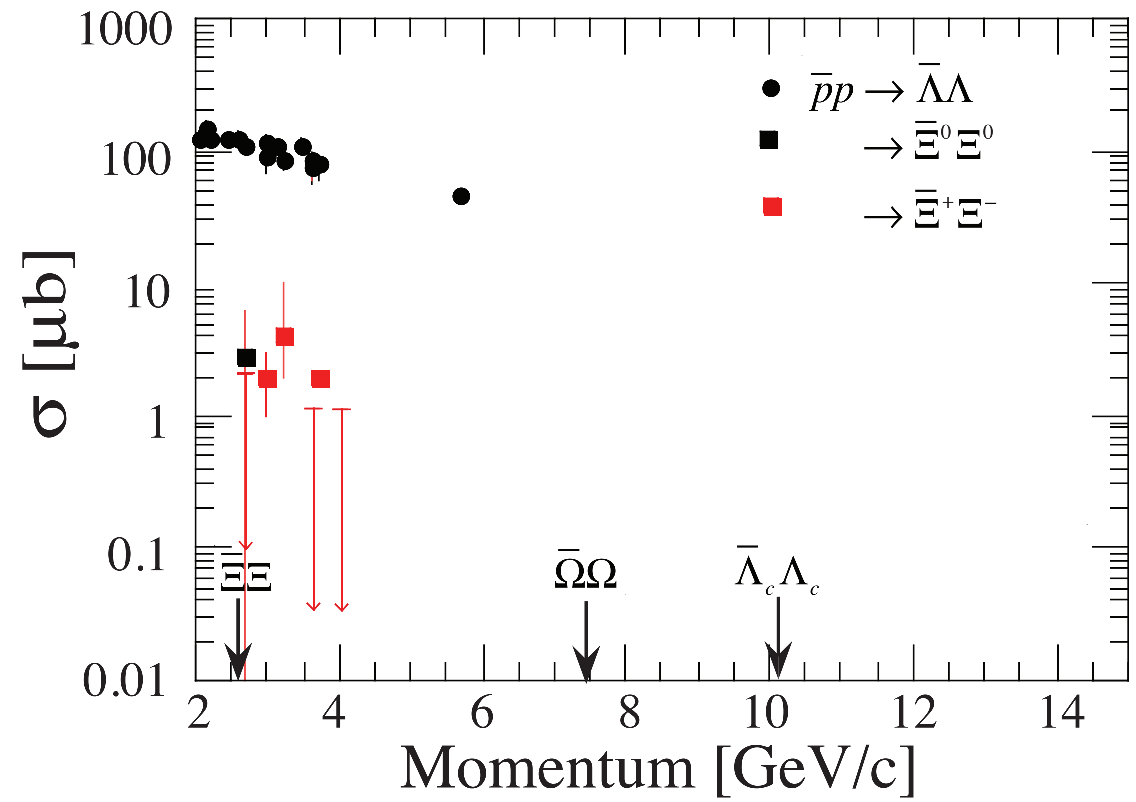
Antihyperon-hyperon production

$$\bar{p}p \rightarrow \bar{Y}Y$$



$$\bar{p}p \rightarrow \bar{\Lambda}\Lambda,\ \bar{\Sigma}^{-}\Sigma^{+},\ \bar{\Sigma}^{0}\Sigma^{0},\ \bar{\Sigma}^{-}\Sigma^{+},\ \bar{\Xi}^{0}\Xi^{0},\ \bar{\Xi}^{+}\Xi^{-},\ \bar{\Omega}^{+}\Omega^{-},\bar{\Lambda}_c^{-}\Lambda_c^{+}$$

$\bar{\Lambda}\Lambda$	$\bar{\Sigma}^{-}\Sigma^{+}$	$\bar{\Sigma}^{0}\Sigma^{0}$	$\bar{\Sigma}^{-}\Sigma^{+}$	$\bar{\Xi}^{0}\Xi^{0}$	$\bar{\Xi}^{+}\Xi^{-}$	$\bar{\Omega}^{+}\Omega^{-}$	$\bar{\Lambda}_c^{-}\Lambda_c^{+}$
$\downarrow$	$\downarrow$	$\downarrow$	$\downarrow$	$\downarrow$	$\downarrow$	$\downarrow$	$\downarrow$
$p\pi^{-}$	$p\pi^{0}$	$\Lambda\gamma$	$n\pi$	$\Lambda\pi^{0}$	$\Lambda\pi$	ΛK	$\Lambda\pi$
64%	52%	$\approx$ 100%	$\approx$ 100%	$\approx$ 100%	$\approx$ 100%	68%	$\approx$ 1%



Practically nothing is known about multiple strange and charmed channels

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$\bar{p}p \rightarrow \bar{Y}Y$

- The weak hyperon decay gives access to polarisation and spin correlations.

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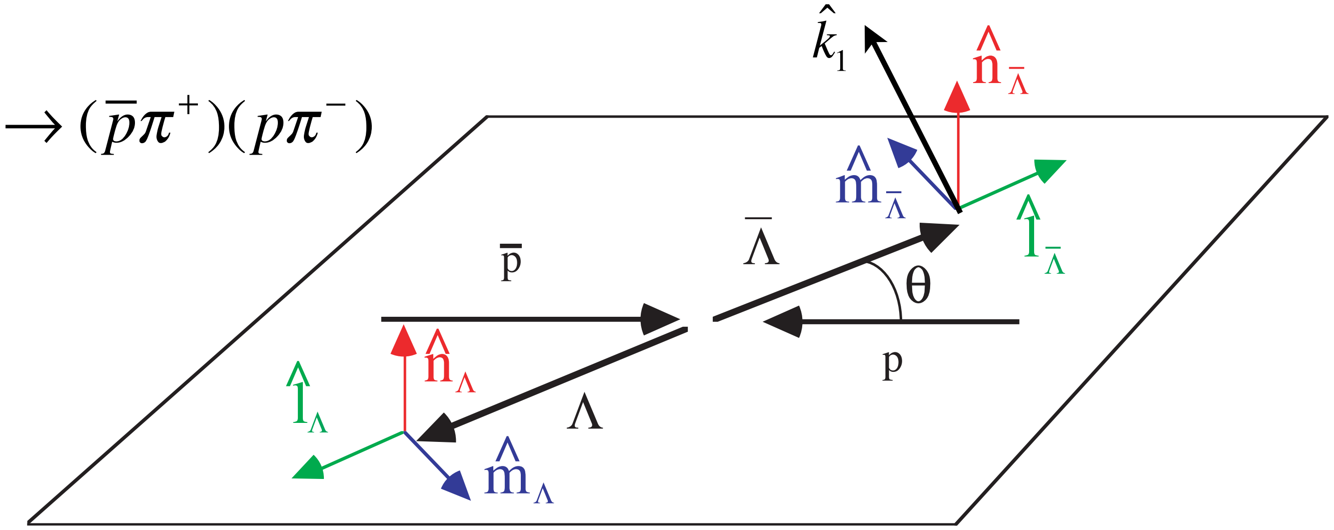
Hyperon	Quarks	Mass [Mev/c^2]	cτ [cm]	α	Decay channel	B.R. [%]
Λ	uds	1116	8.0	+0.64	$p\pi^-$	64
Σ^+	uus	1189	2.4	-0.98	$p\pi^0$	52
Σ^0	uds	1193	2.2x10^{-9}	-	$\Lambda\gamma$	100
Σ^-	dds	1197	2.4	-0.07	$n\pi^-$	100
Ξ^0	uss	1315	8.7	-0.41	$\Lambda\pi^0$	99
Ξ^-	dss	1321	4.9	-0.46	$\Lambda\pi^-$	100
Ω^-	sss	1672	2.5	-0.03	ΛK^-	68
Λ_c^+	udc	2285	6.0x10^{-3}	-.98(19)	$\Lambda\pi^+$	1

$$\bar{p}p \to \bar{\Lambda}\Lambda \to (\bar{p}\pi^+)(p\pi^-)$$



$$I_{\bar{\Lambda}\Lambda}\left(\theta,\hat{\boldsymbol{k}}_1,\hat{\boldsymbol{k}}_2\right)=\frac{I_0^{\bar{\Lambda}\Lambda}}{64\pi^3}\left[\begin{array}{l}1\\+P_n\left(\bar{\alpha}k_{1n}+\alpha k_{2n}\right)\\+C_{nn}\left(\bar{\alpha}\alpha k_{1n}k_{2n}\right)\\+C_{mm}\left(\bar{\alpha}\alpha k_{1m}k_{2m}\right)\\+C_{ll}\left(\bar{\alpha}\alpha k_{1l}k_{2l}\right)\\+C_{ml}\left(\bar{\alpha}\alpha\left(k_{1m}k_{2l}+k_{1l}k_{2m}\right)\right)\end{array}\right]$$

I_0 = σ$_{tot}$

$I(\theta)$ = dσ/dΩ

P_n = Polarisation

C_{ij} = Spin correlations

θ = C.M. scattering angle

$\hat{\boldsymbol{k}}_1,\hat{\boldsymbol{k}}_2$ = directional vectors

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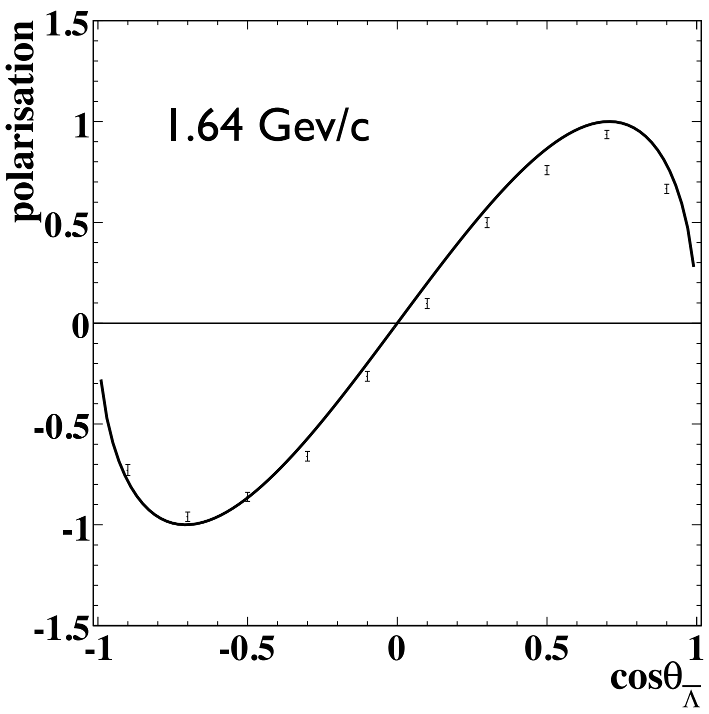
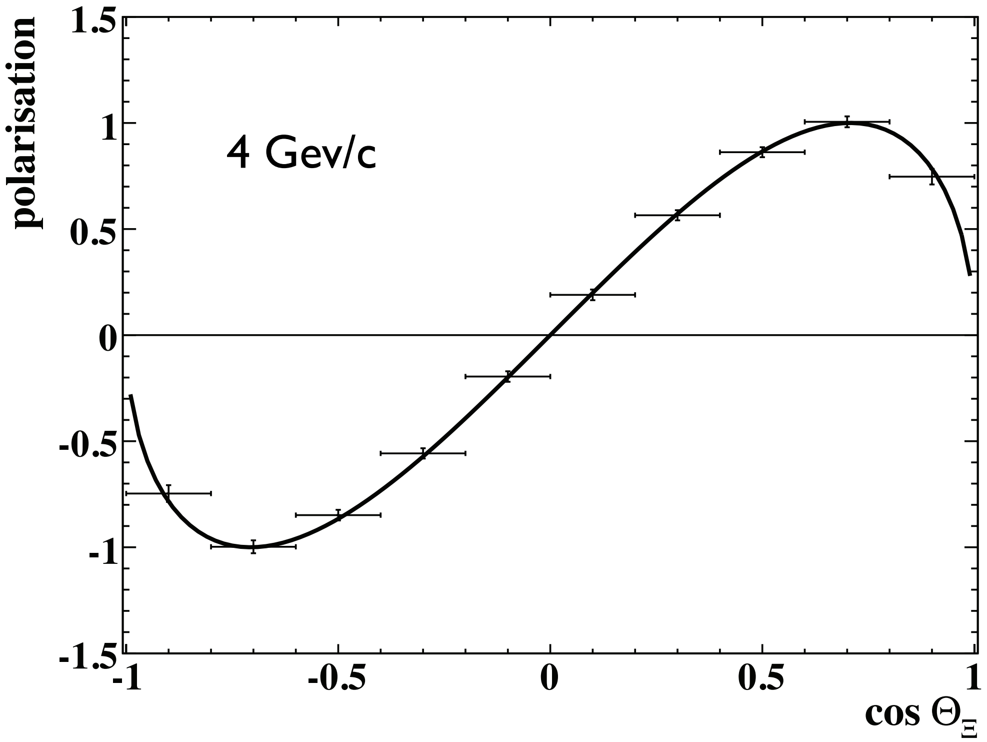
$\bar{p}p \rightarrow \bar{Y}Y$

- The weak hyperon decay gives access to polarisation and spin correlations.
  - ➪ Access to spin degrees of freedom in $\bar{s}s$ and $\bar{c}c$ quark-pair creation.
  - ➪ Many observables
    - ➪ ➪ PWA of the data to extract relevant quantum numbers (resonances)
    - ➪ ➪ high discriminating power between models (hadron or quark-gluon based)
  - ➪ High x-sec for $\bar{p}p \rightarrow \bar{\Lambda}\Lambda$: CP-violation tests
  - ➪ Powerful reactions for Baryon Spectroscopy

Physics Performance Report for PANDA:

- Single and double strange hyperon channels can be well reconstructed.
- Acceptance over the full angular range.





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- Low background and high event rate.

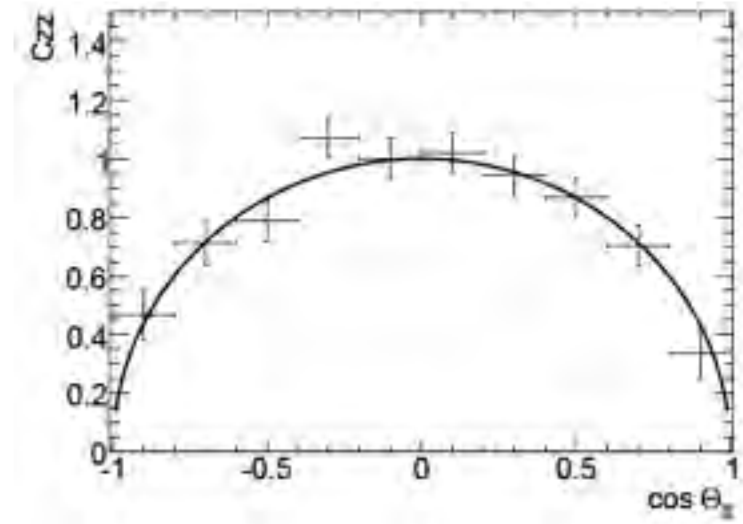
Channel 1.64 GeV/c	Rec. eff.	σ [μb]	Signal
$\bar{p}p \to \Lambda\bar{\Lambda}$	0.11	64	1
$\bar{p}p \to \bar{p}p\pi^+\pi^-$	$1.2 \cdot 10^{-5}$	~ 10	$4.2 \cdot 10^{-5}$
Channel 4 GeV/c			
$\bar{p}p \to \Lambda\bar{\Lambda}$	0.23	~ 50	1
$\bar{p}p \to \bar{p}p\pi^+\pi^-$	$< 3 \cdot 10^{-6}$	$3.5 \cdot 10^3$	$< 2.2 \cdot 10^{-3}$
$\bar{p}p \to \bar{\Lambda}\Sigma^0$	$5.1 \cdot 10^{-4}$	~ 50	$2.2 \cdot 10^{-3}$
$\bar{p}p \to \bar{\Lambda}\Sigma(1385)$	$< 3 \cdot 10^{-6}$	~ 50	$< 1.3 \cdot 10^{-5}$
$\bar{p}p \to \bar{\Sigma}^0\Sigma^0$	$< 3 \cdot 10^{-6}$	~ 50	$< 1.3 \cdot 10^{-5}$
Channel 15 GeV/c			
$\bar{p}p \to \Lambda\bar{\Lambda}$	0.14	~ 10	1
$\bar{p}p \to \bar{p}p\pi^+\pi^-$	$< 1 \cdot 10^{-6}$	$1 \cdot 10^3$	$< 2 \cdot 10^{-3}$
$\bar{p}p \to \bar{\Lambda}\Sigma^0$	$2.3 \cdot 10^{-3}$	~ 10	$1.6 \cdot 10^{-2}$
$\bar{p}p \to \bar{\Lambda}\Sigma(1385)$	$3.3 \cdot 10^{-5}$	60	$1.4 \cdot 10^{-3}$
$\bar{p}p \to \bar{\Sigma}^0\Sigma^0$	$3.0 \cdot 10^{-4}$	~ 10	$2.1 \cdot 10^{-3}$
DPM	$< 1 \cdot 10^{-6}$	$5 \cdot 10^4$	$< .09$
Channel 4 GeV/c	**Rec. eff.**	**σ (μb)**	**Signal**
$\bar{p}p \to \bar{\Xi}^+\Xi^-$	0.19	~ 2	1
$\bar{p}p \to \bar{\Sigma}^+(1385)\Sigma^-(1385)$	$< 1 \cdot 10^{-6}$	~ 60	$< 2 \cdot 10^{-4}$

Momentum [GeV/c]	Reaction	Rate [s^{-1}]
1.64	$\bar{p}p \to \Lambda\bar{\Lambda}$	580
4	$\bar{p}p \to \Lambda\bar{\Lambda}$	980
	$\bar{p}p \to \bar{\Xi}^+\Xi^-$	30
15	$\bar{p}p \to \Lambda\bar{\Lambda}$	120

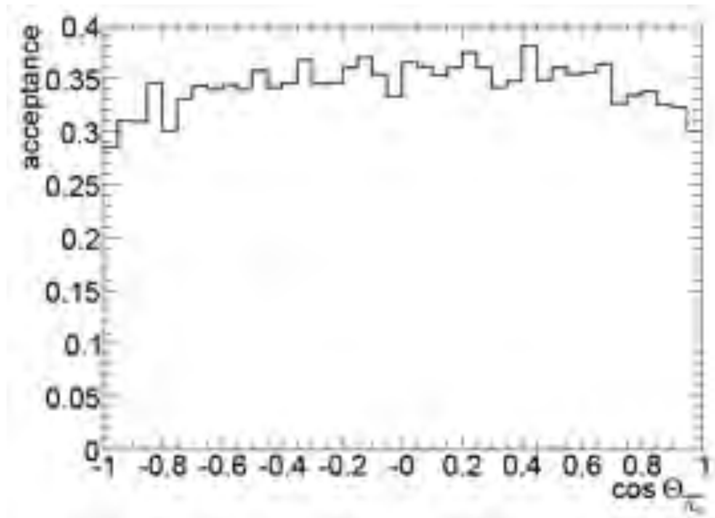
Sophie Grape, Thesis UU, 2009

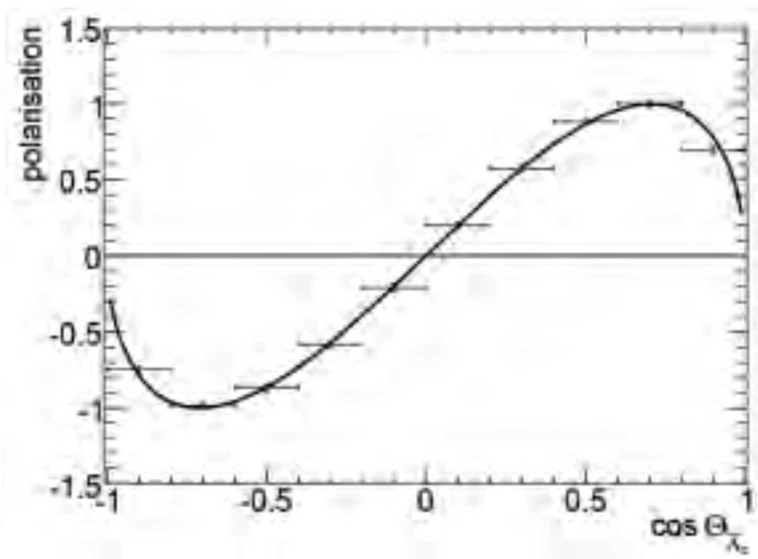
Since Physics Performance Report:

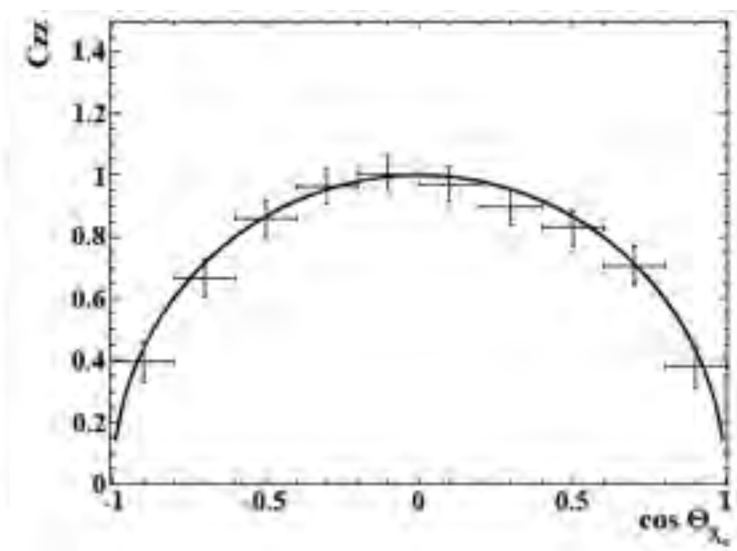
Reconstruction of spin correlations in $\bar{p}p \to \bar{\Xi}^{+}\Xi^{-}$.



$\bar{p}p \to \bar{\Lambda}_c^{-}\Lambda_c^{+} \to \left(\bar{\Lambda}\pi^{-}\right)\left(\Lambda\pi^{+}\right)$ well reconstructed @ 12 GeV/c



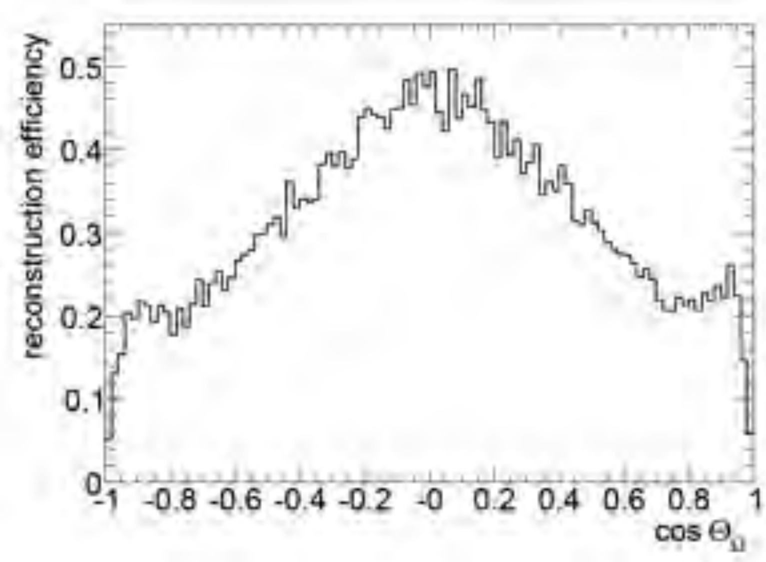




Reconstruction efficiency: 0.35

Event rate: ≈ 25/day (100 nb x-sec assumed)

$\bar{p}p \to \bar{\Omega}^+\Omega^-$ well reconstructed:



Reconstruction efficiency: 0.30

Event rate: ≈ 80/h

(2 nb x-sec assumed)

Expressions for extracting polarisation parameters derived using the spin density formalism. 7 non-zero parameters:

3 parameters from the $\Omega \to \Lambda K$ decay

4 parameters from combined $\Omega \to \Lambda K$ and $\Lambda \to p\pi$ angular distributions.

The total Ω polarisation can be obtained by summing the square of these 7 parameters.

Erik Thomé, Thesis UU, 2012

Spin determination of Ω ?

To be done:

- Verify the findings for $\bar{p}p \to \bar{Y}Y$ using PANDAroot

- Background studies for $\bar{p}p \to \bar{\Omega}^+\Omega^-$ and $\bar{p}p \to \bar{\Lambda}_c^-\Lambda_c^+$

Strategy for data taking (in sequence):

1. Verify PS185 results: $\bar{p}p \to \bar{\Lambda}\Lambda$ @ 1.64 GeV/c
2. Double strangeness production: $\bar{p}p \to \bar{\Xi}^+\Xi^-$
3. Triple charm production: $pp \to \bar{\Omega}^+\Omega^-$
4. Charm production $\bar{p}p \to \bar{\Lambda}_c^-\Lambda_c^+$

Remarks:

- $\bar{p}p \to \bar{\Lambda}\Lambda$ is an excellent reaction to verify tracking.
- A good understanding of $\bar{p}p \to \bar{Y}Y$ reconstruction is a "*sine qua non*" for Baryon Spectroscopy.
- 7 theory papers published on $\bar{p}p \to \bar{Y}Y$ because of the prospects at PANDA

Two-pion production in $\bar{p}p$ annihilation at large angles

Data are needed to test constituent quark counting rules of pQCD [1] and “Landsoff indepedant scattering mechanism” [2].

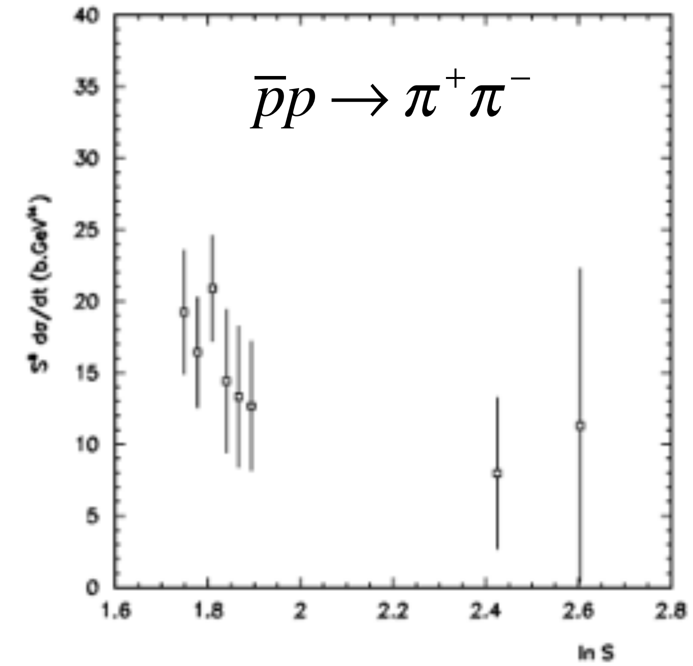
There is lack of large angel scattering data for a conclusive comparison to these approaches.

➪ 2π production at large angles can provide this test.

Predicts a s^{-n} scaling

n + 2 = # of elementary constituents in initial + final state [1]

➪ s^{-8} scaling for 2π production



An observation of an oscillatory pattern angle could signal of an interference between the two mechanisms (seen in the energy dependence of p-p scattering at a fixed backward angle).

[1] S. Brodsky, G. Farrar, Phys. Rev. Lett. 31 (1973) 1153
V.A. Malteev, R.M. Muradian, A.N. Tavkhelidze, Nouv. Cim. 7 (1972) 713
[2] P. Landshoff, Phys. Rev. D10 (1974) 1024

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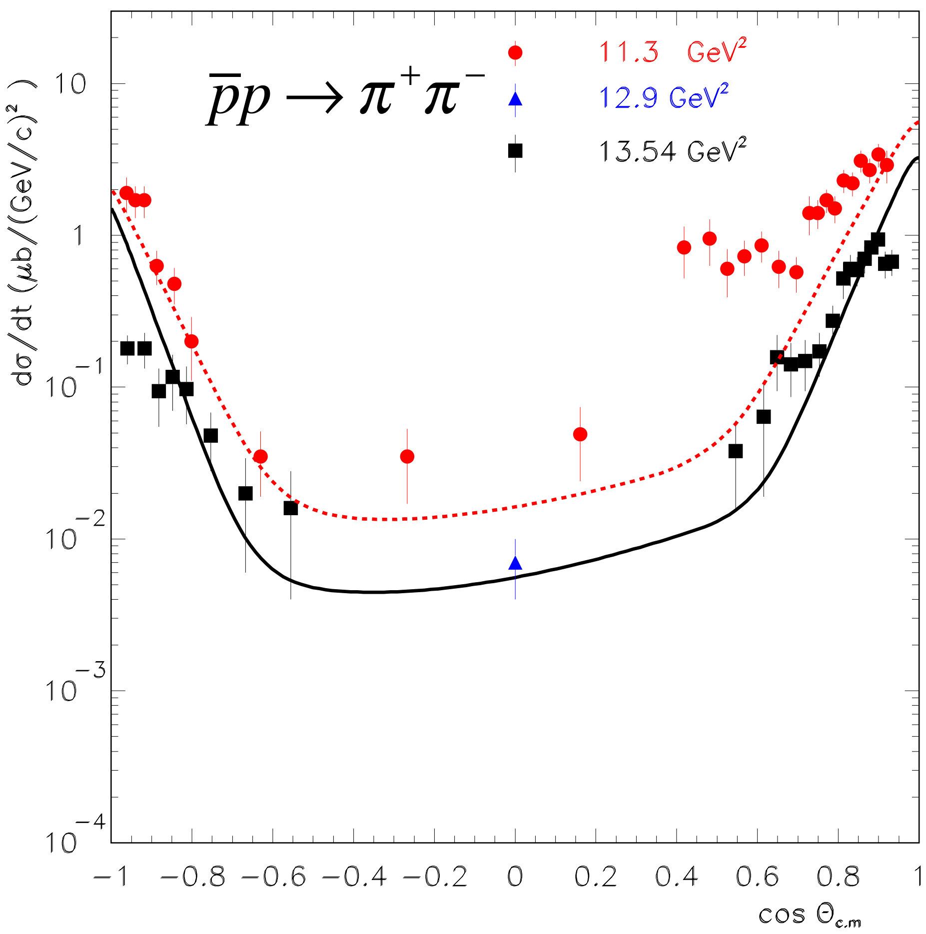
- An event generator for this 2π channel, based on a Regge approach, has been implemented in PANDAroot.

≈ 1 week at full luminosity at s = 13.5 GeV^2 required.



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The uniqueness of the antiproton beam at HESR makes these proposed measurements unique.