INSTITUT DE PHYSIQUE NUCLÉAIRE ORSAY

First results of a global analysis of pion pair production in proton and antiproton annihilation

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Content

Introduction

- Panda experiment
- Motivation

Effective meson theory

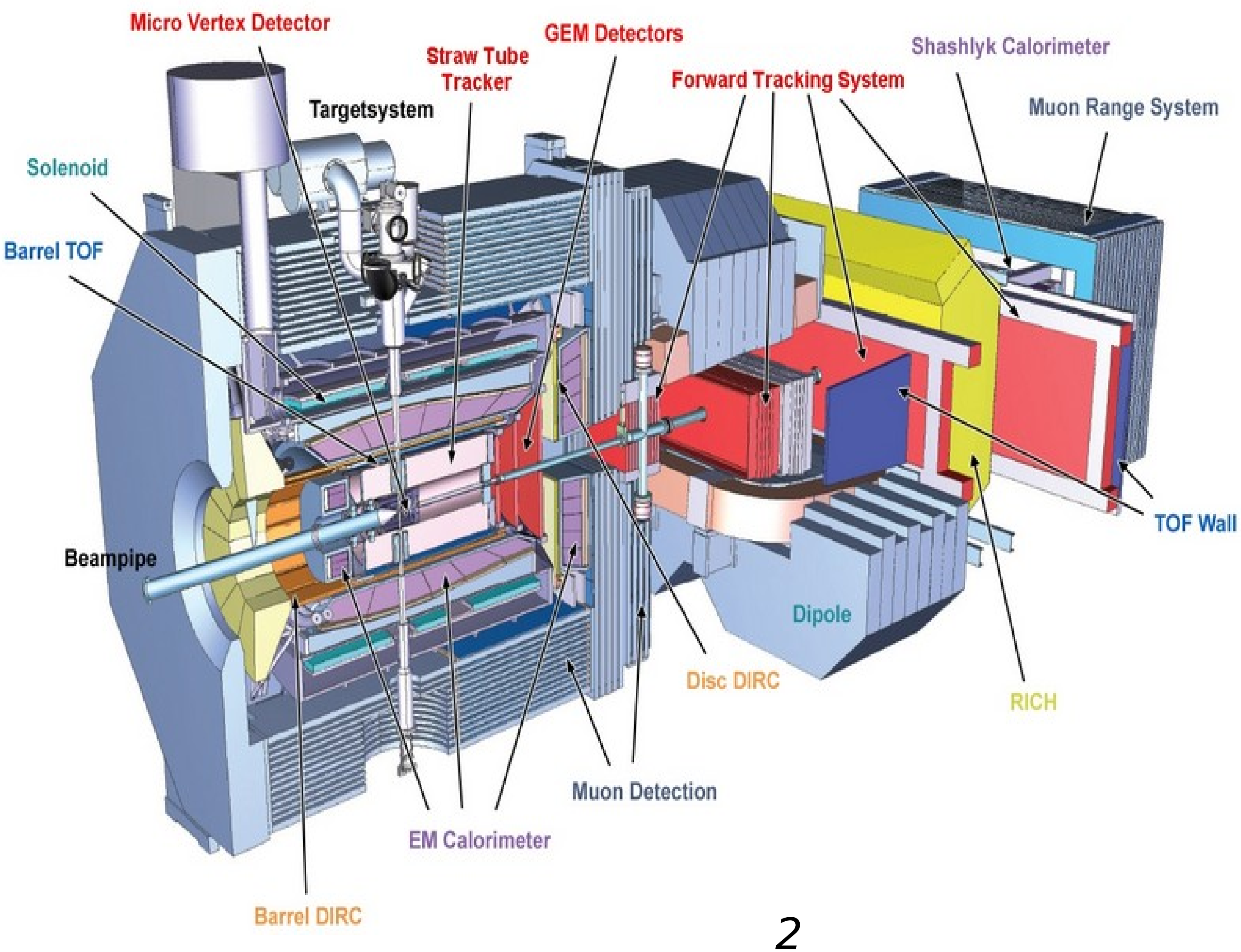
Results

- Neutral particles

  pbar p → $\pi^0\pi^0$, η η, $\eta\pi^0$
- Charged particles
- Crossing symmetry

Summary

Panda Detector



4π acceptance

Tracking momentum resolution 1%

Interaction rate 20MHz

PID
Charge and neutral particles
π , K, e, p, μ

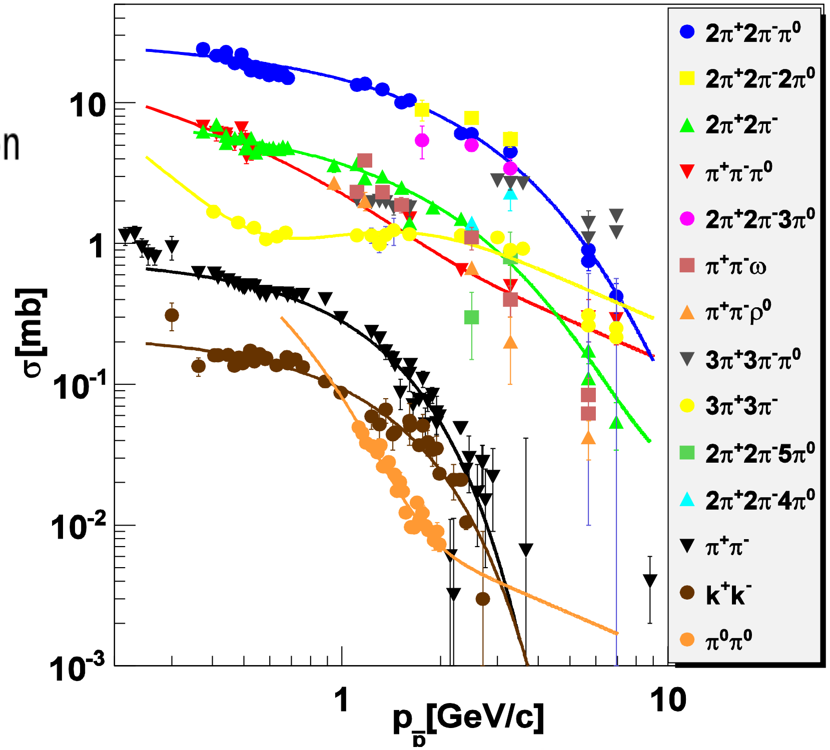
γ detection from 3 MeV - 10 GeV

Motivation of my work

- The reaction $\bar{p}p \to e^+e^-$ allows to measure electromagnetic proton form factors.
- Important simulation work is under way.
- The reaction $\bar{p}p \to \pi^+\pi^-$ is the main background :
  - has a large cross section,
  - contains information on the quark content of the proton
  - allow to test different QCD models

Largest cross sections come from multi-pions

(5 > 4> 2)



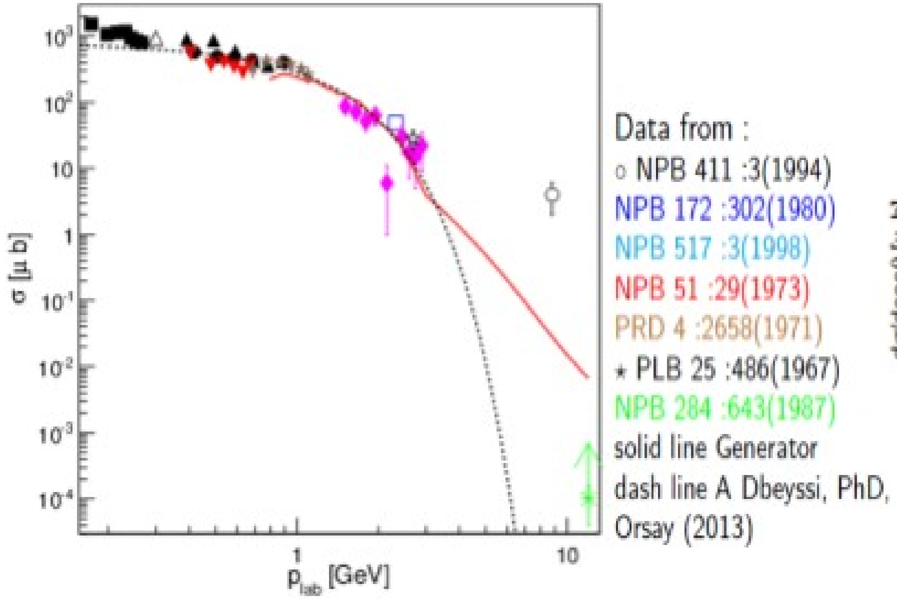
It is necessary to fully understand the process $\bar{p}p \to \pi^+\pi^-$

Motivation of my work

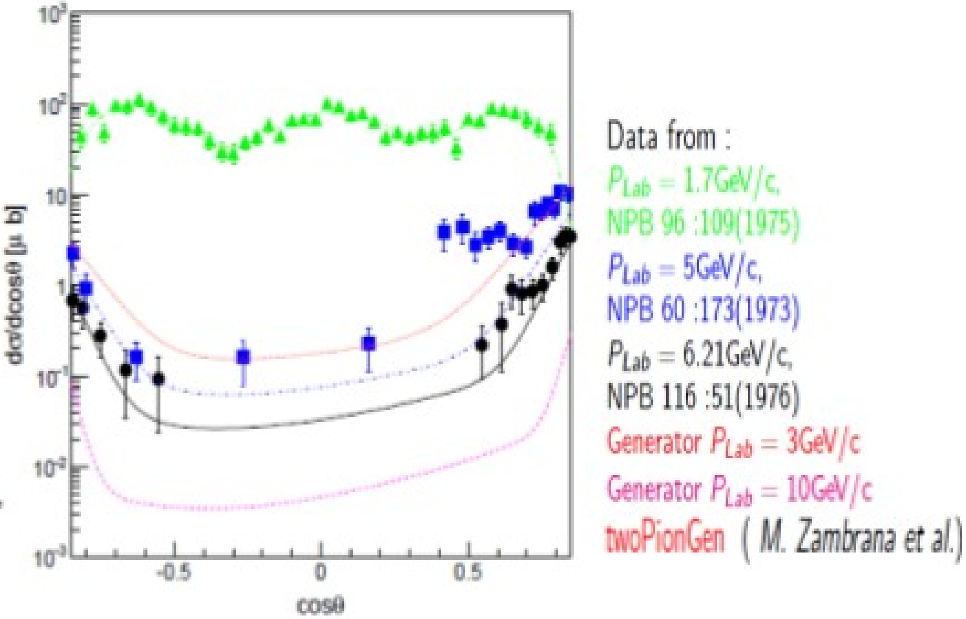
Few experimental data at the PANDA energies to constrain the models

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

Total cross section



Differential cross section



Extrapolation of existing models to Panda range is risky

Few and incomplete angular distributions data of annihilation

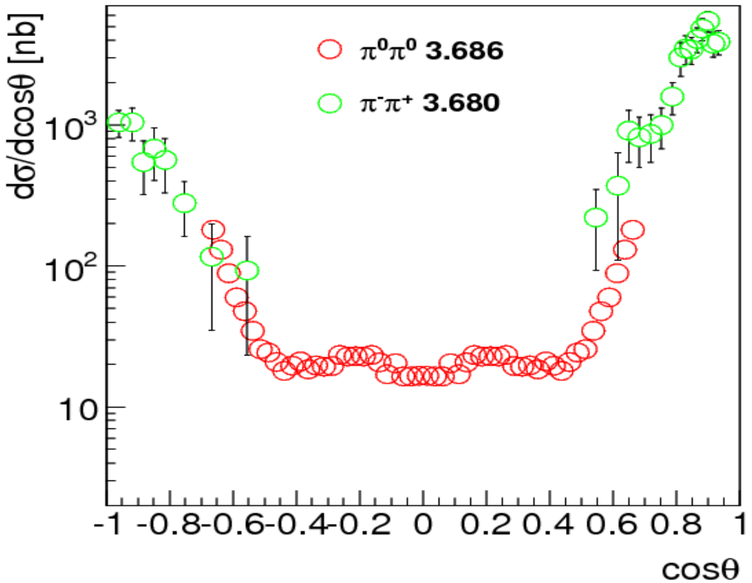
(6 sets of $\pi^+\pi^-$ in panda energy region)

Motivation of this model

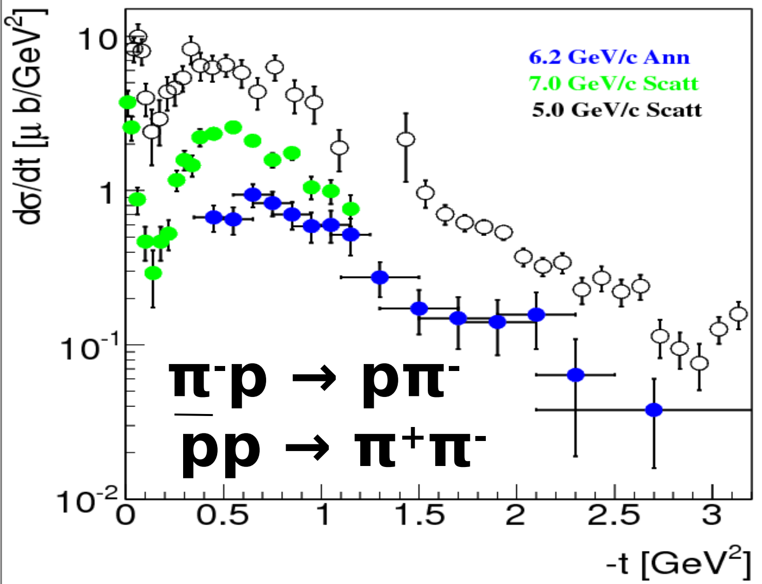
Global description in Panda energy range

Developing an effective Lagrangian model based on Feynman diagrams to describe binary annihilation reactions induced by antiprotons in Panda energy region.

Describe the similar production $\pi^+\pi^-$, $\pi^o\pi^o$ in a coherent way



- using crossing symmetry from pπ^- elastic to get more experiment data
- Getting a reliable s dependence to predict the panda region where there are very few data



Low Energy Model

Low energy $(p_{Lab} < 1\ \mathrm{GeV/c})$

Take into account nucleon and Δ exchange in the Lagrangian

$$L_{pp\pi_0} = \frac{g_{\pi NN}}{2m}\bar{\psi}\gamma^\mu\gamma^5\psi\partial_\mu\phi, \qquad L_{p\Delta_{++}\pi_+} = g_{\pi N\Delta}(\bar{\psi}_\mu\psi\partial^\mu\phi + \mathrm{h.c.})$$

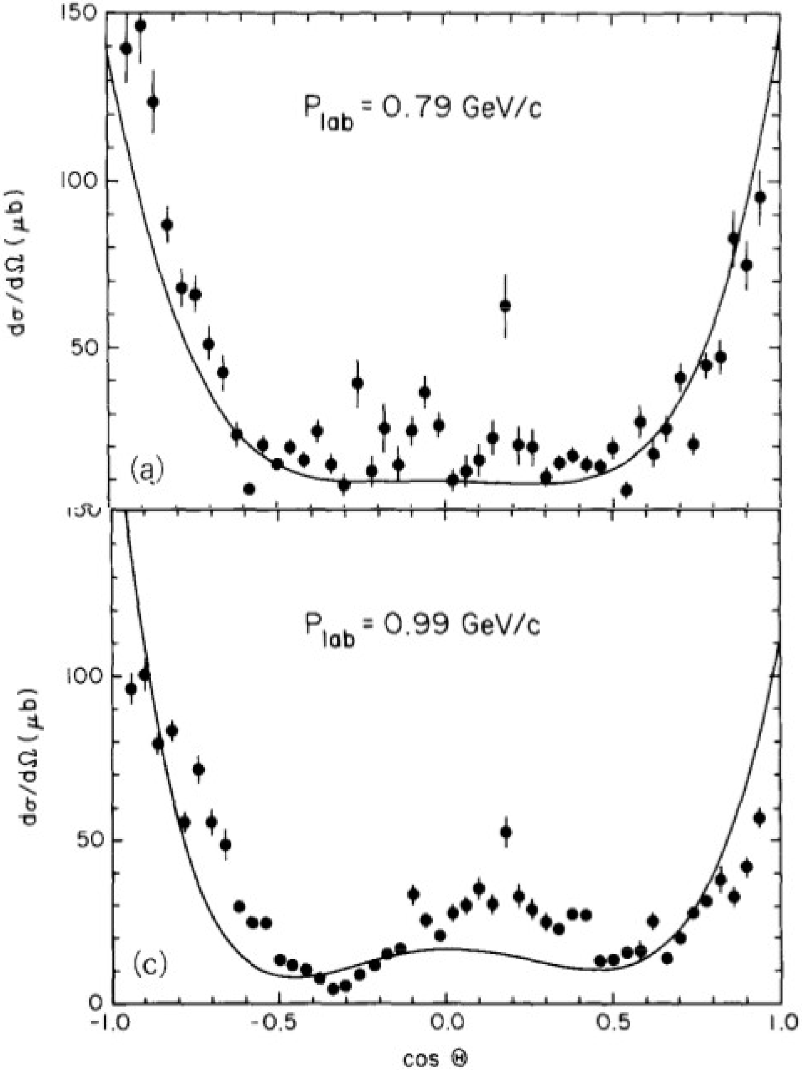
Instead of schrodinger equation, using optical model to generate the initial-state interaction

$$V_{++} = \frac{p}{m}A + q\cos\theta B, \qquad V_{+-} = \frac{q}{m}E_p(-\sin\theta\, e^{i\phi})B$$

With two parameters in vertex form factors,

$$F(p_1, p_2, p_3) = \prod_{i=1}^{3} e^{(p_i^2 - m_i^2)/2\Lambda_i^2}$$

B. Moussallam, NPA 429 (1984)



Intermediate energy Model

p_{Lab} <1.94 GeV/c

Partial wave amplitude $T_{L,J}$ as sums over resonances

$$T_{L,J} = \sum_{i=1} \frac{G_i B_L(p) B_J(q) \exp(i\phi_i)}{M_i^2 - s - iM_i \Gamma_i}$$

D.V. Bugg.et al, NPB 471 (1996) 59

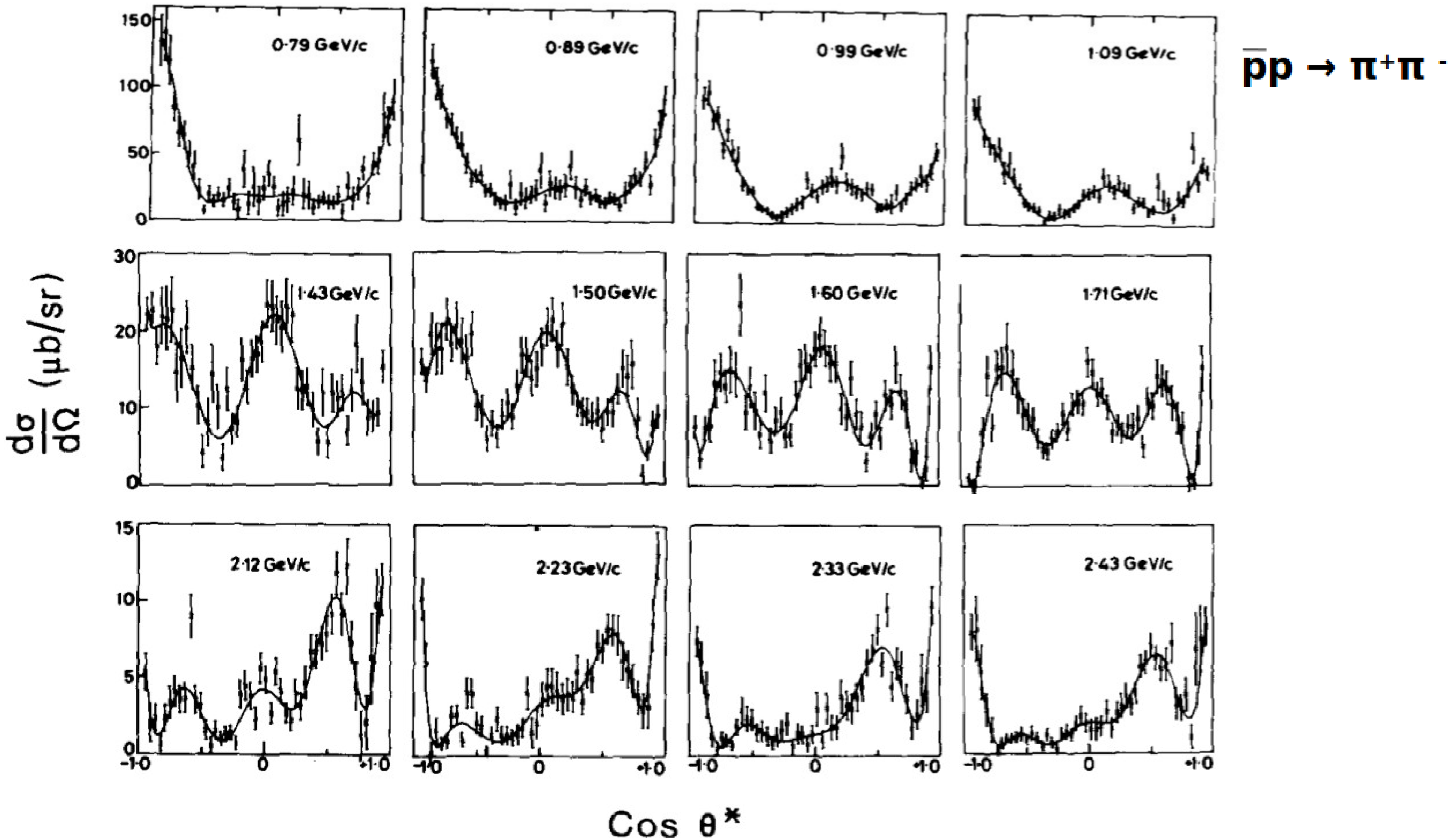
List of Resonances

J^P	Mass M (MeV)	Width Γ (MeV)	$\Delta\chi^2$
6^+	2485 ± 40	410 ± 90	1776
5^-	~ 2500	~ 470	112
5^-	2295 ± 30	235^{+65}_{-40}	2534
4^+	~ 2500	~ 400	1305
4^+	2300 ± 25	270 ± 50	2549
4^+	2020 ± 12	170 ± 15	22382
3^-	2300^{+50}_{-80}	340 ± 150	183
3^-	2210 ± 40	360 ± 55	368
3^-	1960 ± 15	150 ± 25	2957
2^+	~ 2620	~ 430	776
2^+	2300 ± 35	290 ± 50	2879
2^+	2230 ± 30	245 ± 45	2290
2^+	2020 ± 30	275 ± 35	2980
2^+	1910 ± 30	260 ± 40	2286
1^-	2165 ± 40	160^{+140}_{-70}	450
1^-	2005 ± 40	275 ± 75	1341
1^-	(1700)	(180)	8444
0^+	2320 ± 30	175 ± 45	1257
0^+	2105 ± 15	200 ± 25	4030
0^+	2005 ± 30	305 ± 50	370
0^+	(1700)	1000	2844

A.V. Anisovich, et al., PLB 471 (1999) 271–279

Evolution of oscillatory behavior : Sum of resonances

Plab (0.79 – 2.43 GeV/c)



E. Eisenhandler, et al., Nucl. Phys. B 98 (1975) 109

Physics Letters B 471 (1999) 271–279

High Energy Model

High energy (1.5 GeV/c <p_{Lab} <15 GeV/c)

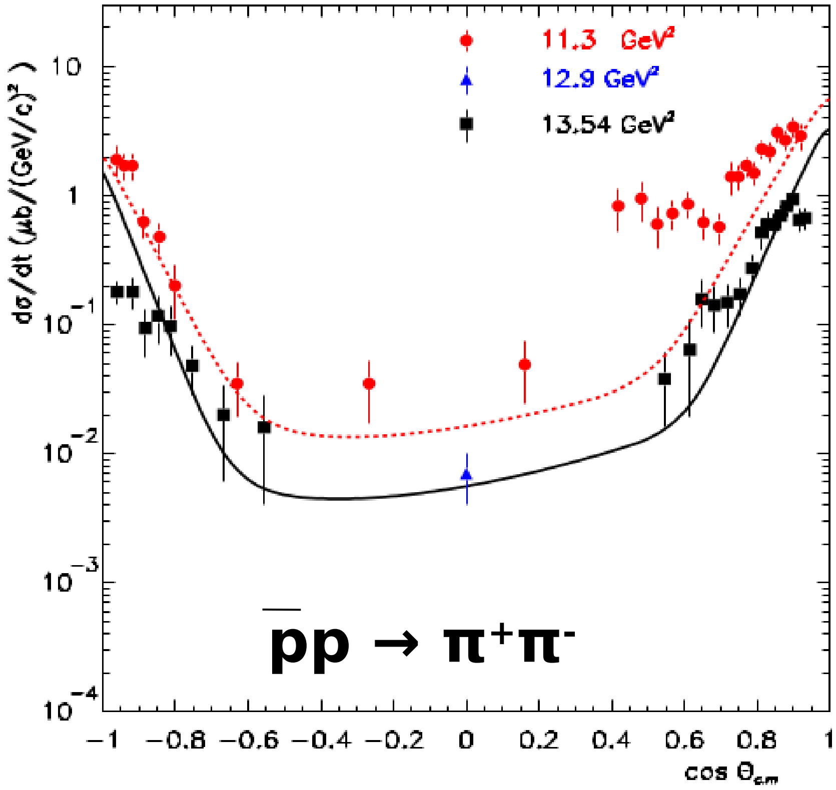
J. Van de Wiele and S. Ong,

EPJ A 46 (2010) , 291–298

Ad-hoc Regge parametrization

Parameters adjusted to the data.

Fails to extrapolate outside range



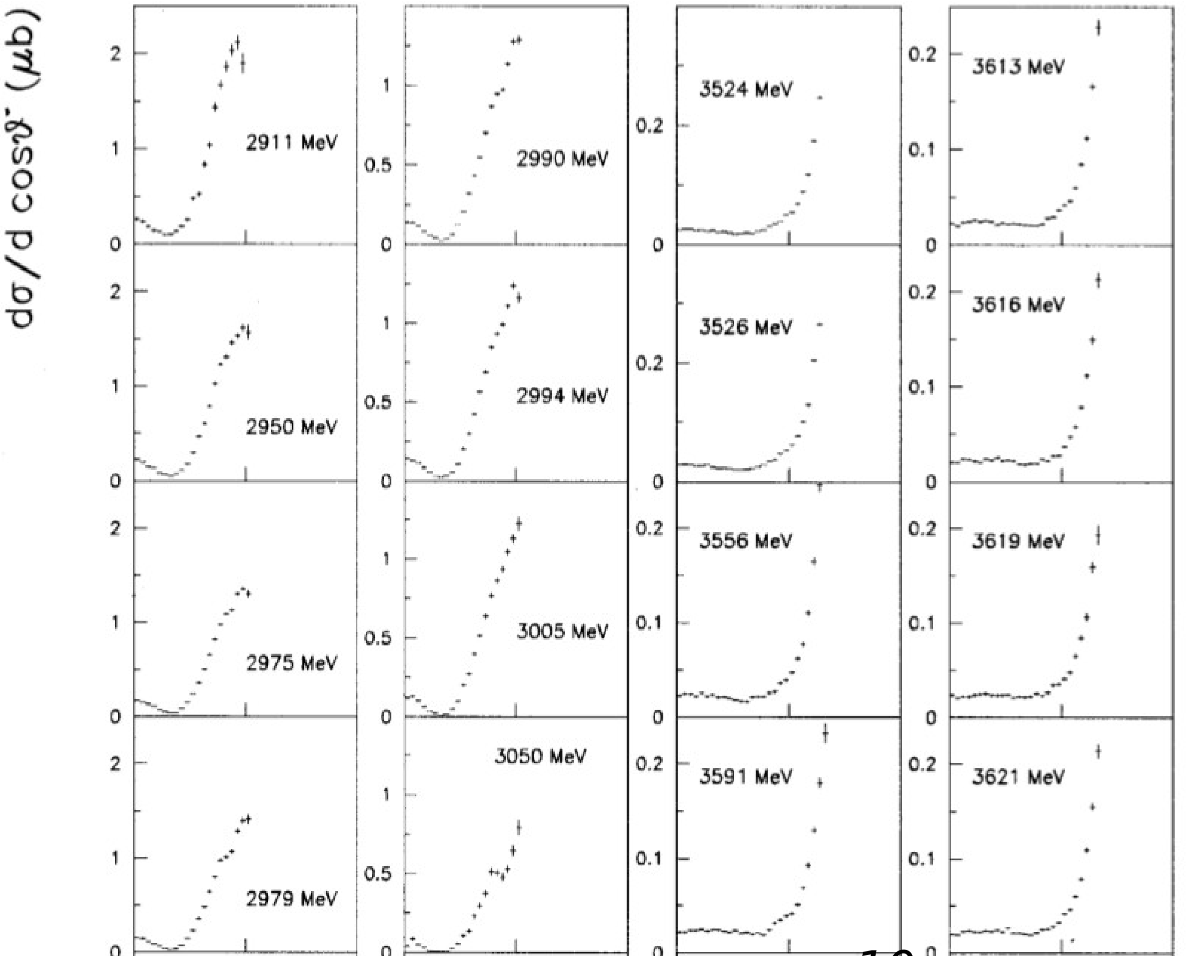
PHYSICAL REVIEW D VOLUME 56, NUMBER 5 1 SEPTEMBER 1997

ARTICLES

T. A. Amstrong, al

Two-body neutral final states produced in antiproton-proton annihilations at $2.911 \leqslant \sqrt{s} \leqslant 3.686$ GeV

$$p+\bar{p} \to \pi^0+\pi^0, \quad \eta+\pi^0, \quad \eta+\eta, \quad \pi^0+\gamma, \quad \gamma+\gamma$$



We develop effective Lagrangian model based on s,t, u channel Feynman diagrams.

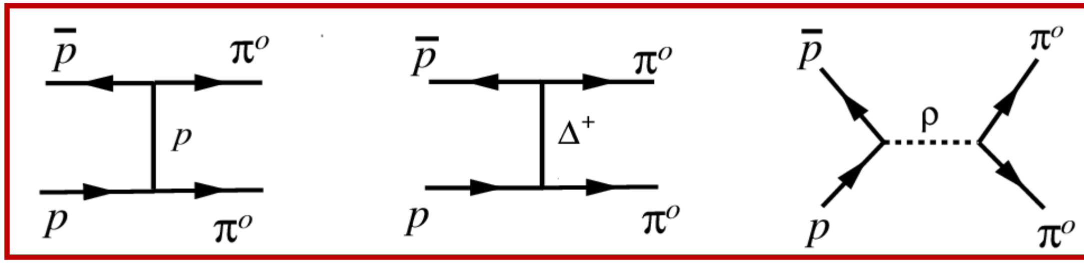
The aim is to reproduce all available data and make reliable predictions at higher energies.

Our model should work in Panda energy region

Calculation $\bar{p}p \to \pi^o\pi^o$

➢ Differential cross section

$$\frac{d\sigma}{d\cos\theta} = \frac{1}{2^7\pi}\frac{1}{s}\frac{\beta_\pi}{\beta_p}|\overline{\mathcal{M}}|^2$$



✓ (e.g.)Nucleon exchange

- Vertex: $-ig_{\pi NN}(i\gamma_5)(2\pi)^4$
- Propagator: $\frac{i}{(2\pi)^4}\frac{\hat{q}_t + M_p}{q_t^2 - M_p^2}$

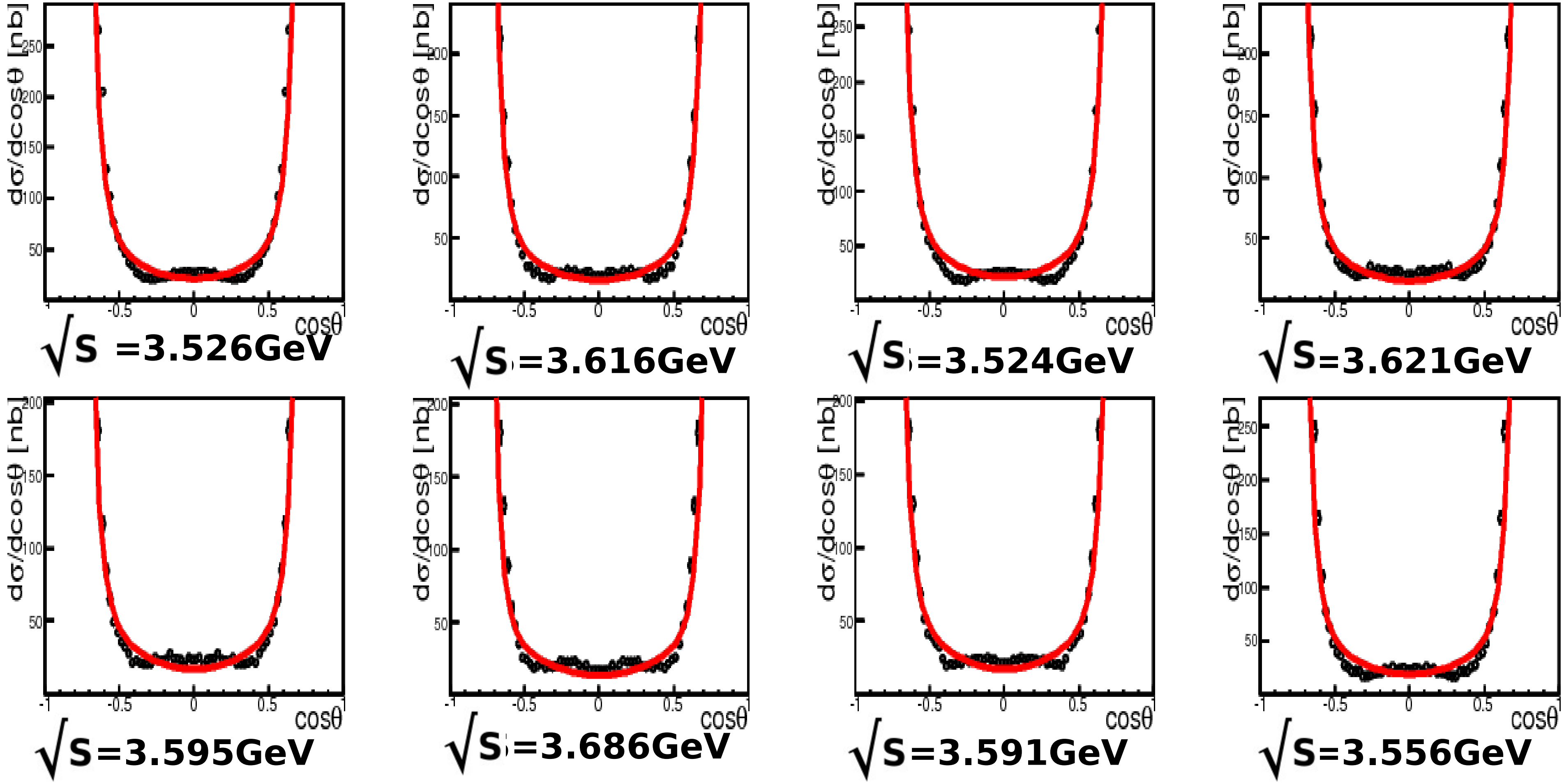
$$|\overline{\mathcal{M}_n}|^2 = \mathcal{M}_n A^*(a) = \frac{g_{\pi NN}^4}{(q^2 - M_p)^2} Tr\left[(\hat{p}_1 - M_p)(\hat{q} + M_p)^2(\hat{p}_2 + M_p)\right]$$

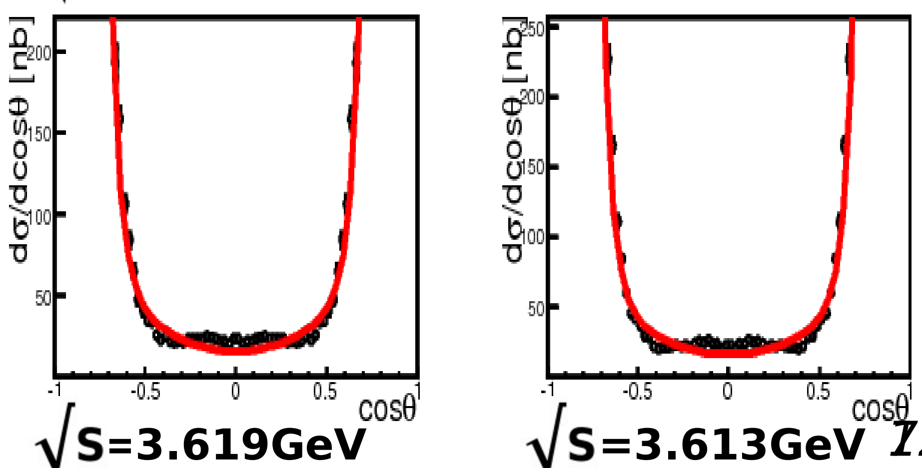
About 10^8 difference
In the absolute value of the differential cross section
(compositeness of particles, absorption, ISI, FSI...)

=> add Regge factors and form factors

$$R_N(t) = \left(\frac{s}{p_3}\right)^{\frac{1}{2}+p_2\left(\frac{t-M_p^2}{M_p^2}\right)} \quad F_N(t) = (t - p_0^2)^2$$

$$R_\Delta(u) = \left(\frac{s}{p_3}\right)^{\frac{3}{2}+p_4\left(\frac{t-M_\Delta^2}{M_\Delta^2}\right)} \quad F_\Delta(u) = (u - p_1^2)^2$$

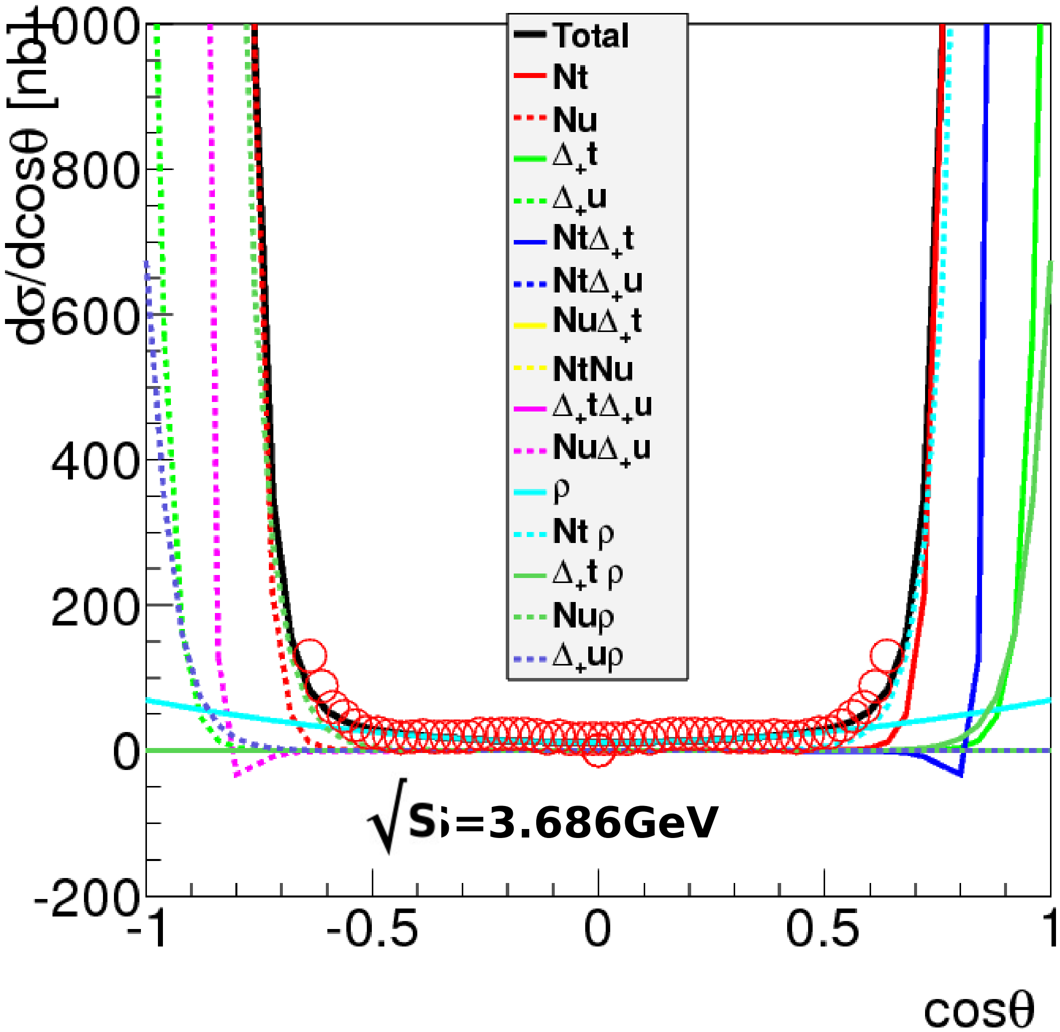




our fit of $\pi^o\pi^o$

Data from T. A. Amstrong al. PRD(56) 5 1997

First results for $\bar{p}p \to \pi^o\pi^o$



- <u>angular dependence</u>

- fully symmetrized components forward and backward

ρ Exchange mainly contributes to central angules (s channel)

- N and Δ mainly contribute forward and backward

S-dependence $\bar{p}p \to \pi^o\pi^o$

Test of quark counting

PRL (1973) 31. 18.
S. J. Brodsky, G. R. Farrar
Scaling Laws at Large Transverse Momentum

LETTERE AL NUOVO CIMENTO (1973) 5 14
V. A. Matveev et al.
Automodelity in Strong Interactions.

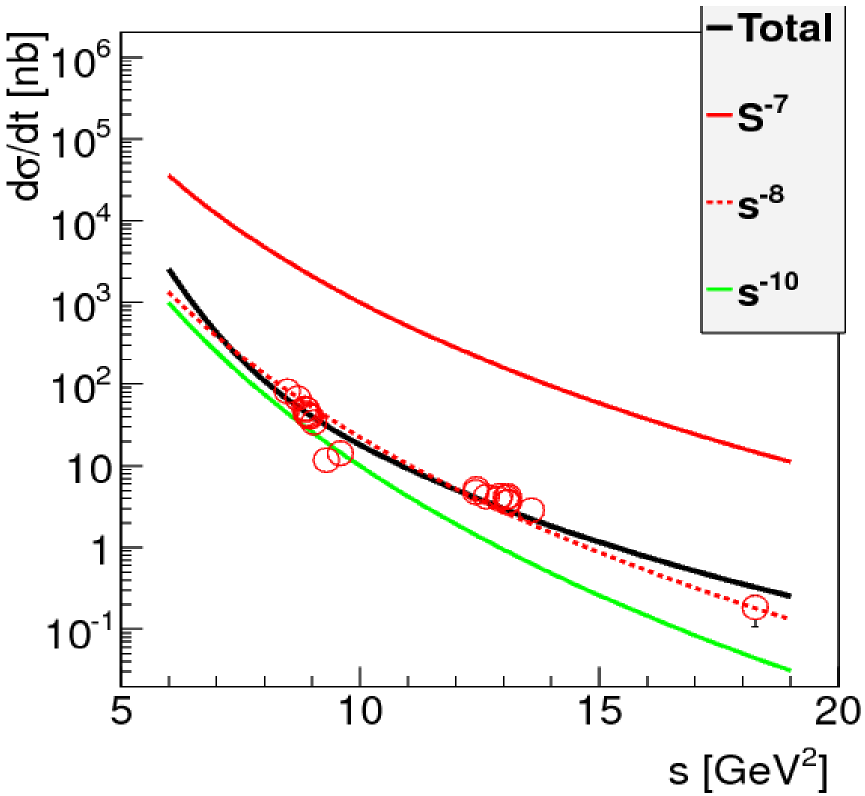
$d\sigma/dt \sim s^{2-n} f(t/s)$

n total number of leptons, photons and quark components

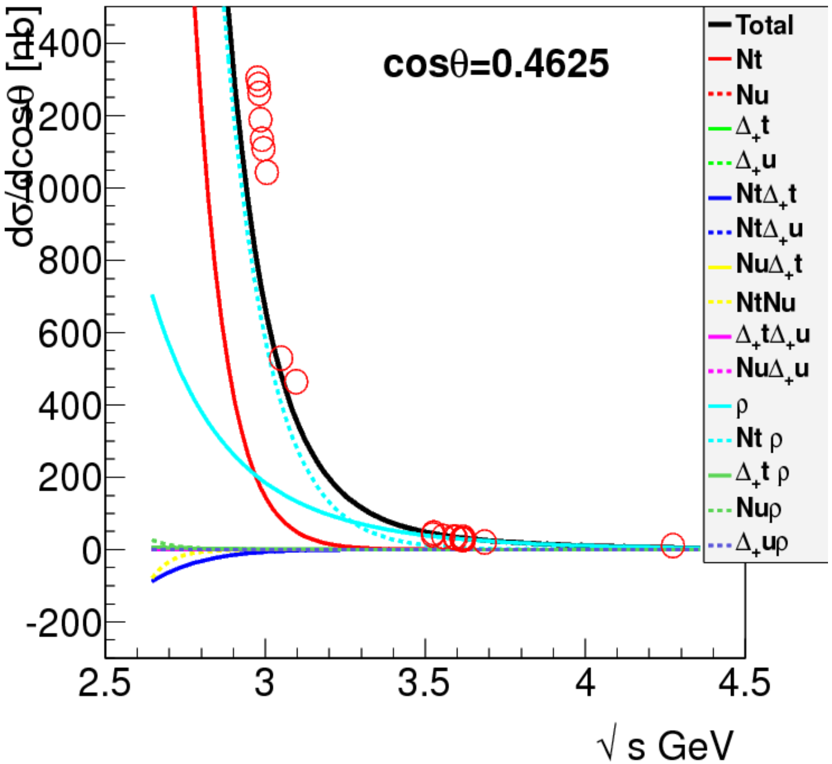
Reaction $\bar{p}p \to \pi^o\pi^o$

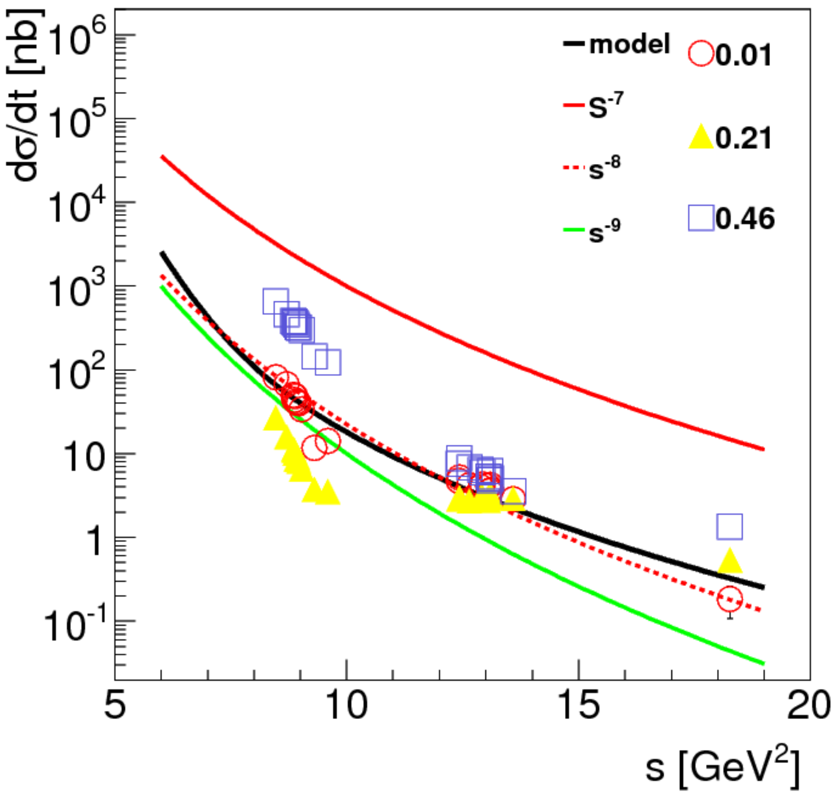
$n = ni + nf = 2x(3+2) = 10$
$2 - n = -8$

$d\sigma/dt \sim s^{-8} f(t/s)$



S-dependence $\bar{p}p \rightarrow \pi^o\pi^o$





Π and η mesons are pseudoscalar mesons.
The decay to ηη can be described from $\pi^0\pi^0$ using the well-known decomposition of singlet and octet states,
where the mixing angle is Θ ≈ 40°

$$\eta \approx (u\bar{u} + d\bar{d})/\sqrt{2} + s\bar{s}$$

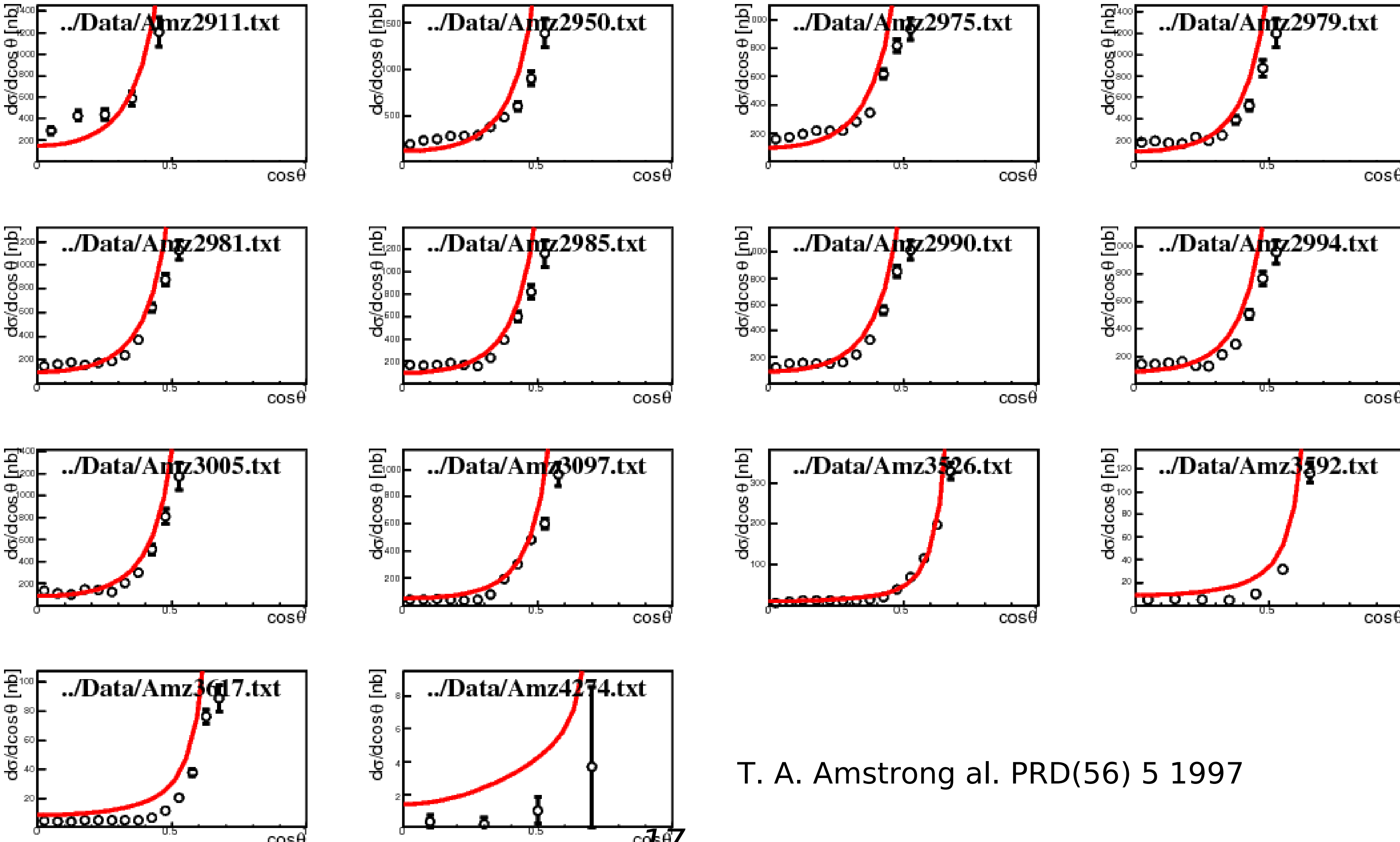
$$(u\bar{u} + d\bar{d})\sqrt{2}$$

$$|q\bar{q}> = \cos\Theta|\eta> + \sin\Theta|\eta'>$$

$$|s\bar{s}> = -\sin\Theta|\eta> + \cos\Theta|\eta'>$$

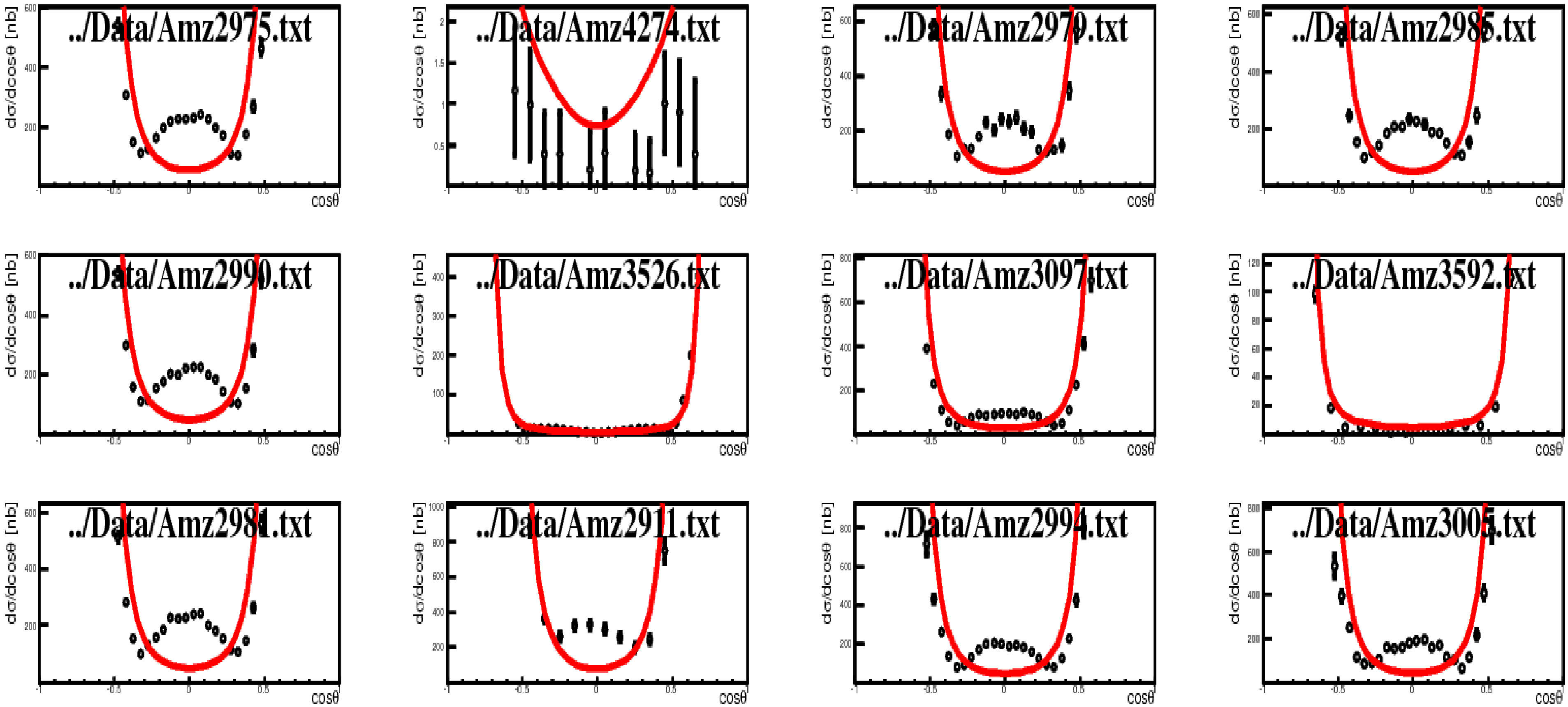
$$f(\eta\eta) = f(\pi^0\pi^0)\cos^2\Theta$$

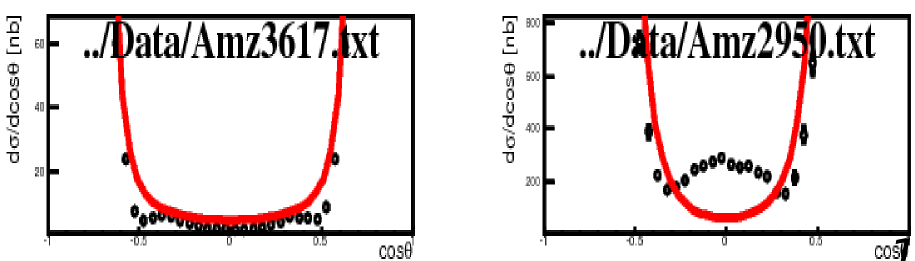
$\bar{p}\, p \rightarrow \eta\, \eta$



T. A. Amstrong al. PRD(56) 5 1997

$\bar{p}\, p \rightarrow \eta\, \pi^0$



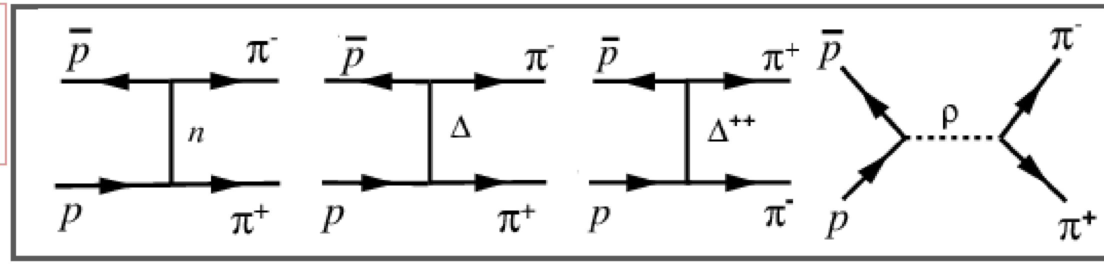


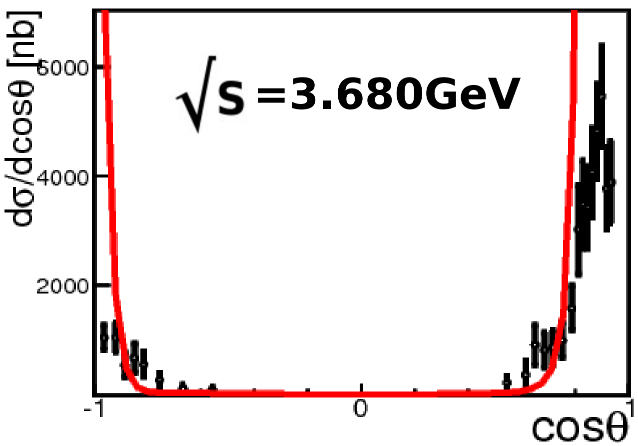
T. A. Amstrong al. PRD(56) 5 1997

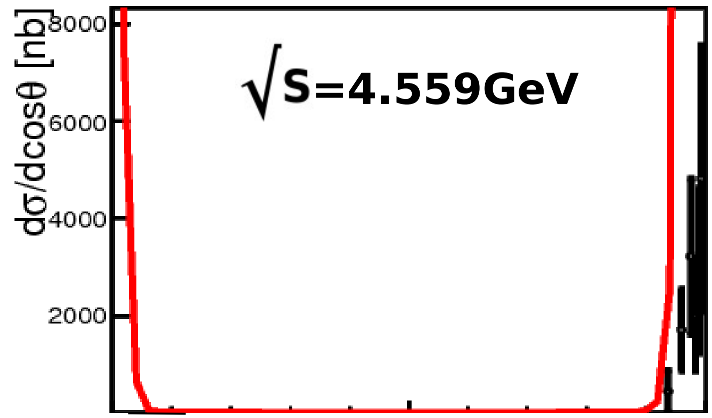
Calculation $\bar{p}p \to \pi^+\pi^-$

Add u-channel Δ^{++}

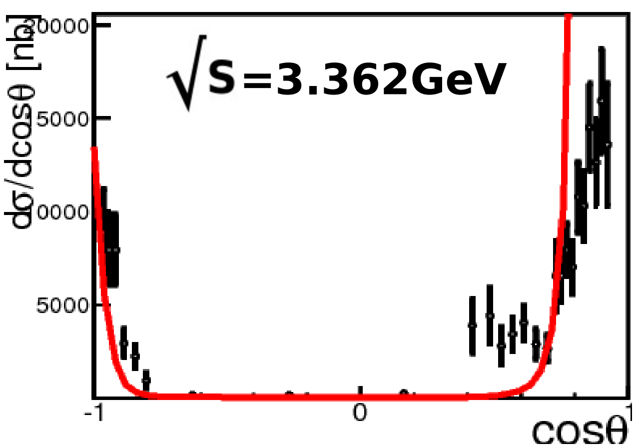
keep same parameters as π^0

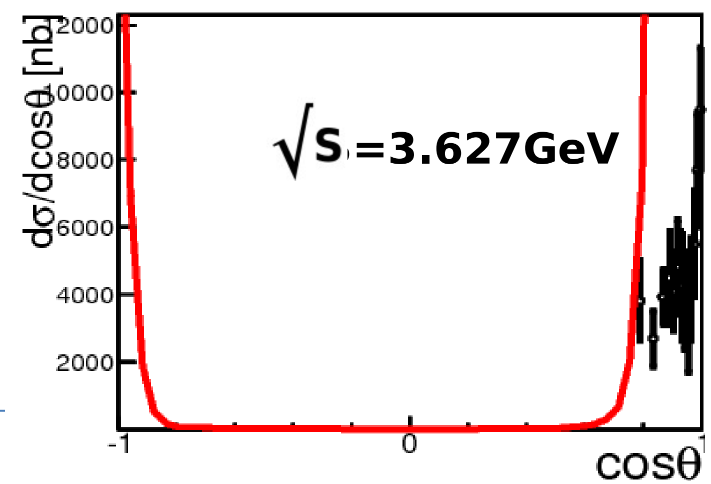






$\bar{p}p \to \pi^+\pi^-$

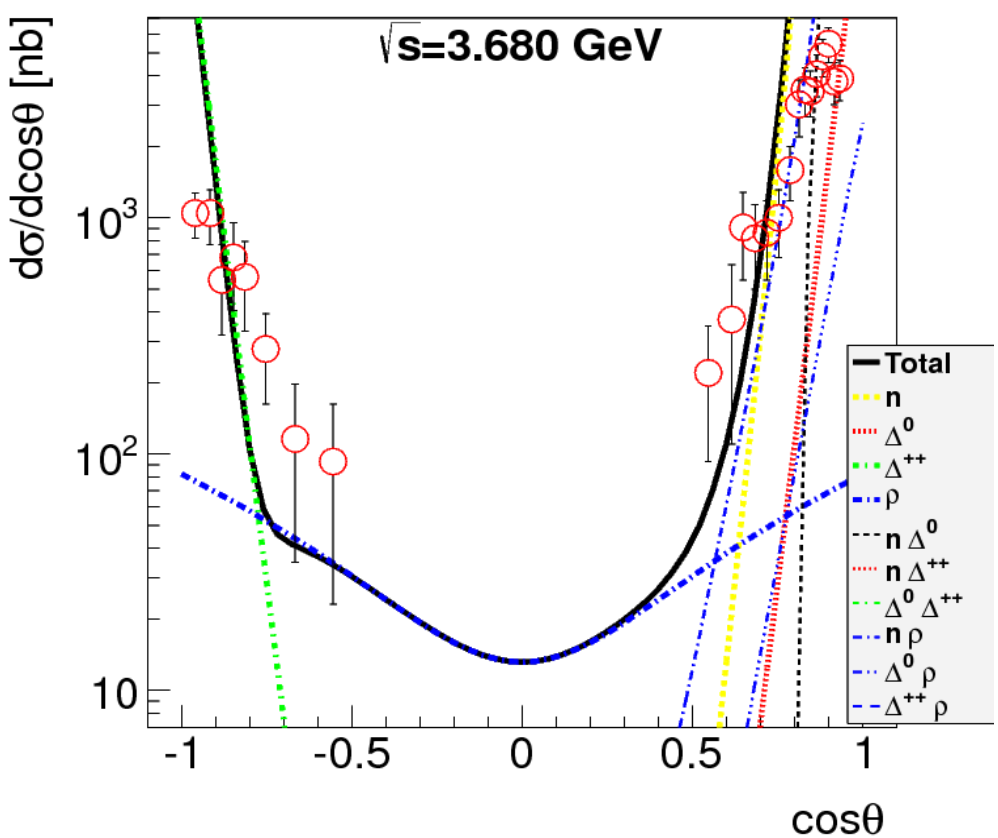




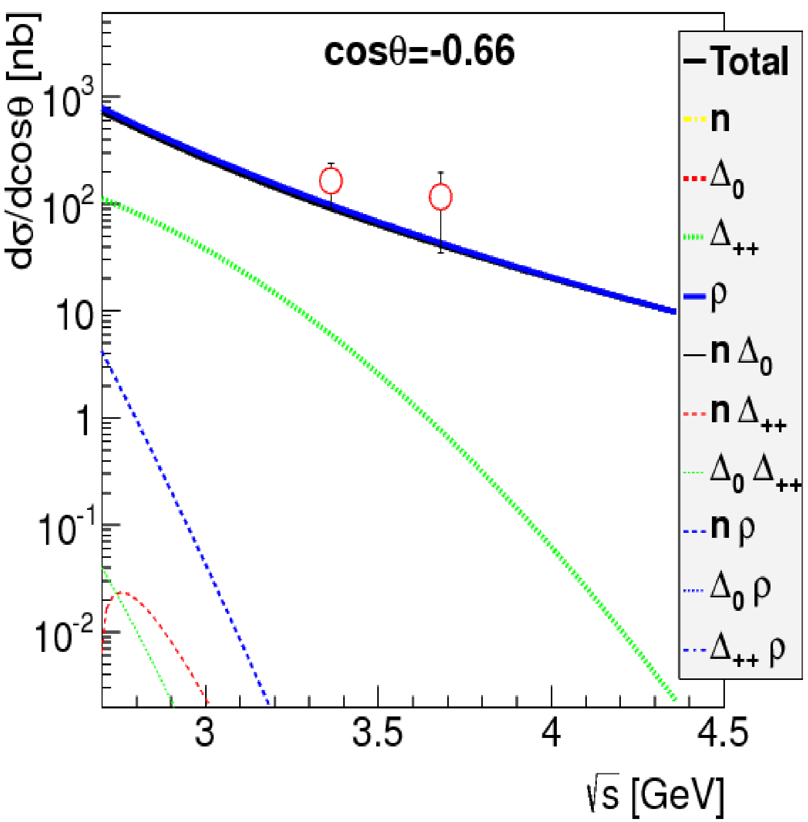
Calculation $\bar{p}p \rightarrow \pi^+\pi^-$

Add u-channel Δ^{++}
keep same parameters as π^0

- Angular distribution



- s-dependence



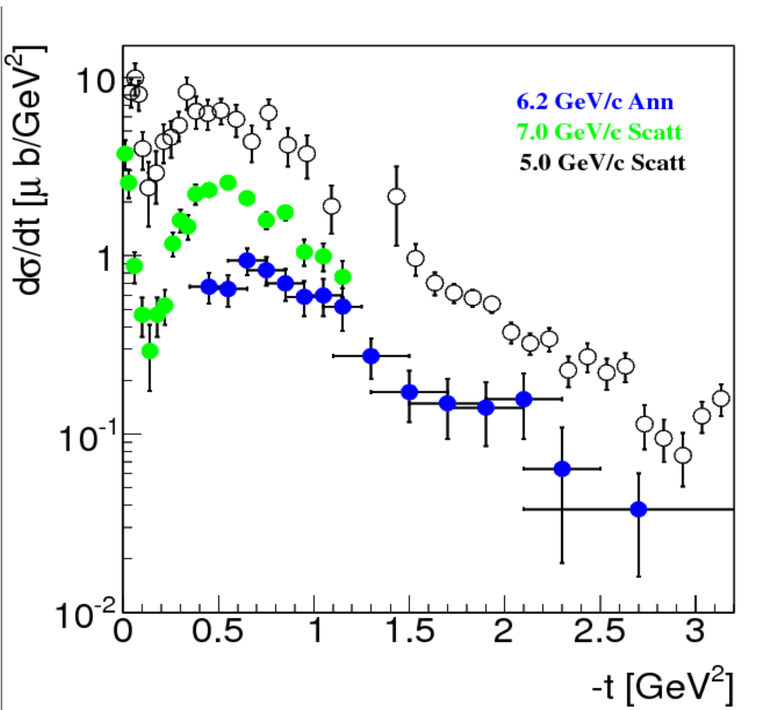
$\pi^- p \to \pi^- p$ & $\bar{p}p \to \pi^+\pi^-$ crossing symmetry

$\bar{p}(p_1)+p\,(p_2)\to \pi^-(k_1)+\pi^+(k_2)$

Annihilation (a)

$\pi^-(-k_2)+p\,(p_2)\to \pi^-(k_1)+p(-p_1)$

Elastic scattering (s)



$$s_s = (-k_2+p_2)^2 \to t_a$$

$$t_s = (-k_2-k_1)^2 \to s_a$$

$$u_s = (-k_2+p_1)^2 \to u_a$$

$$\sigma^a = \frac{1}{2}\frac{|\vec{k}_s|^2}{|p_a|^2}\sigma^s = f\sigma^s$$

when t is small,

$$\sigma^a = \frac{1}{4}\frac{|\mathcal{M}_{(a)}|^2}{64\pi^2 s}\frac{|\vec{k}_a|}{|\vec{p}_a|}$$

$$\sigma^s = \frac{1}{2}\frac{|\mathcal{M}_{(s)}|^2}{64\pi^2 s}\frac{|\vec{k}_s|}{|\vec{p}_s|}$$

$$\sigma^s \simeq const \cdot s^{-2}$$

$$\sigma^s(s) = \sigma^s(s_1)\cdot\frac{s^{-2}}{s_1^{-2}}$$

$$\sigma^a(s) = f\sigma^s(s_1)\cdot\frac{s^{-2}}{s_1^{-2}}$$

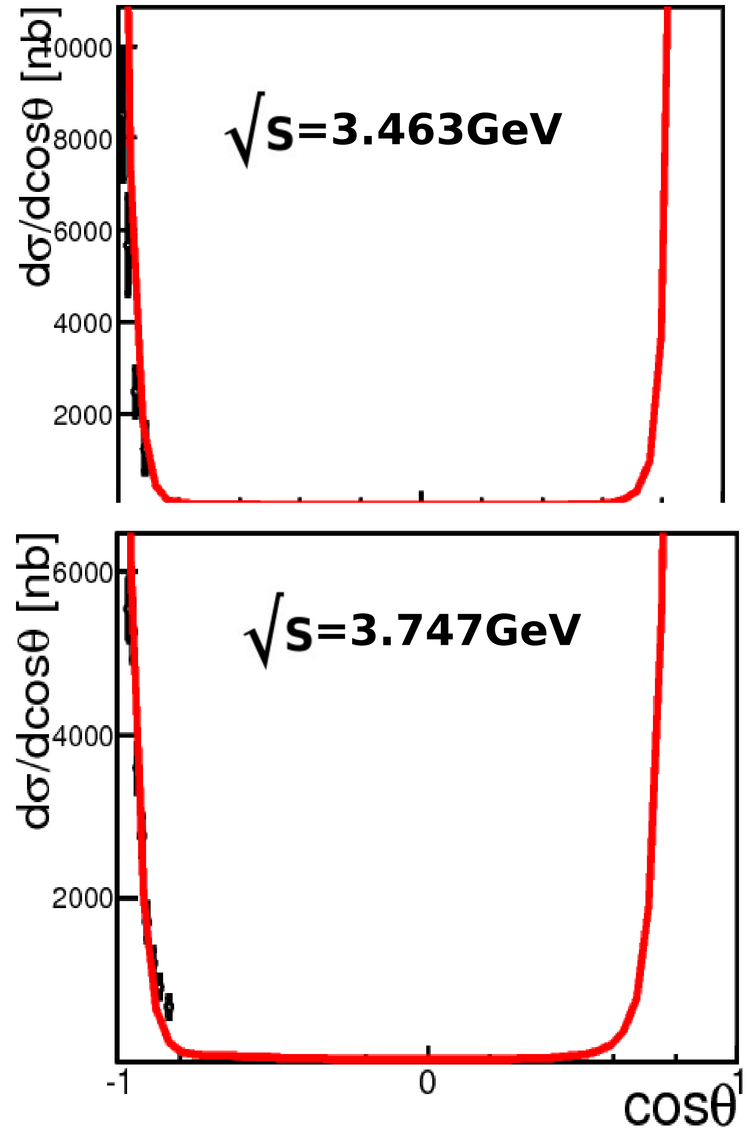
$\pi^- p \to p \pi^-$

$p(p_1) + p\,(p_2) \to \pi^-\,(k_1) + \pi^+\,(k_2)$ (a)

$\pi^-\,(-k_2) + p\,(p_2) \to \pi^-\,(k_1) + p(-p_1)$ (s)

$$\sigma^a(s) = f\,\sigma^s(s)$$

$$f = \frac{1}{2}\frac{|\vec{k}_s|^2}{|p_a|^2}$$



Summary

- We have built a promising model based on effective lagrangian to describe 2 meson production in pbar p annihilation

- Parameters fixed on $\pi^0\pi^0$

- neutral channel obtained from SU3 symmetry: $\eta\ \eta$, $\eta\ \pi^0$

- We reproduced $\pi^+\pi^-$

- We reproduced π^+p, π^-p using crossing symmetry

- Encouraging results on angular distributions and the expected s dependence have been obtained

Perspectives

Optimize the parameters to improve charged pion description at small angles

Apply similar formalism to other channels:

$\gamma\,\gamma$, $\gamma\,\pi^0$, KK

Goal:

To build a generator based on our model

Thank you!