Study of antiproton-proton annihilation reaction and experimental contribution to hadron polarimetry

Wang Ying

Supervisors: Egle Tomasi-Gustafsson

Dominique Marchand

Content

Phenomenology

Introduction

Motivation

Effective meson theory and

Crossing symmetry

Results for charged particles

and neutral particles

angular distribution of pion,

kaon, eta pairs.

S–dependence

Summary

Experiment

Introduction

Motivation for ALPOM2 experiment

Comparison of figure of merit for np zero exchange and charge exchange reactions

Polarized protons and neutrons: measure analyzing powers up to 4.2 GeV/c
on C, CH, CH2 targets

Preliminary Results

Summary

PART I

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

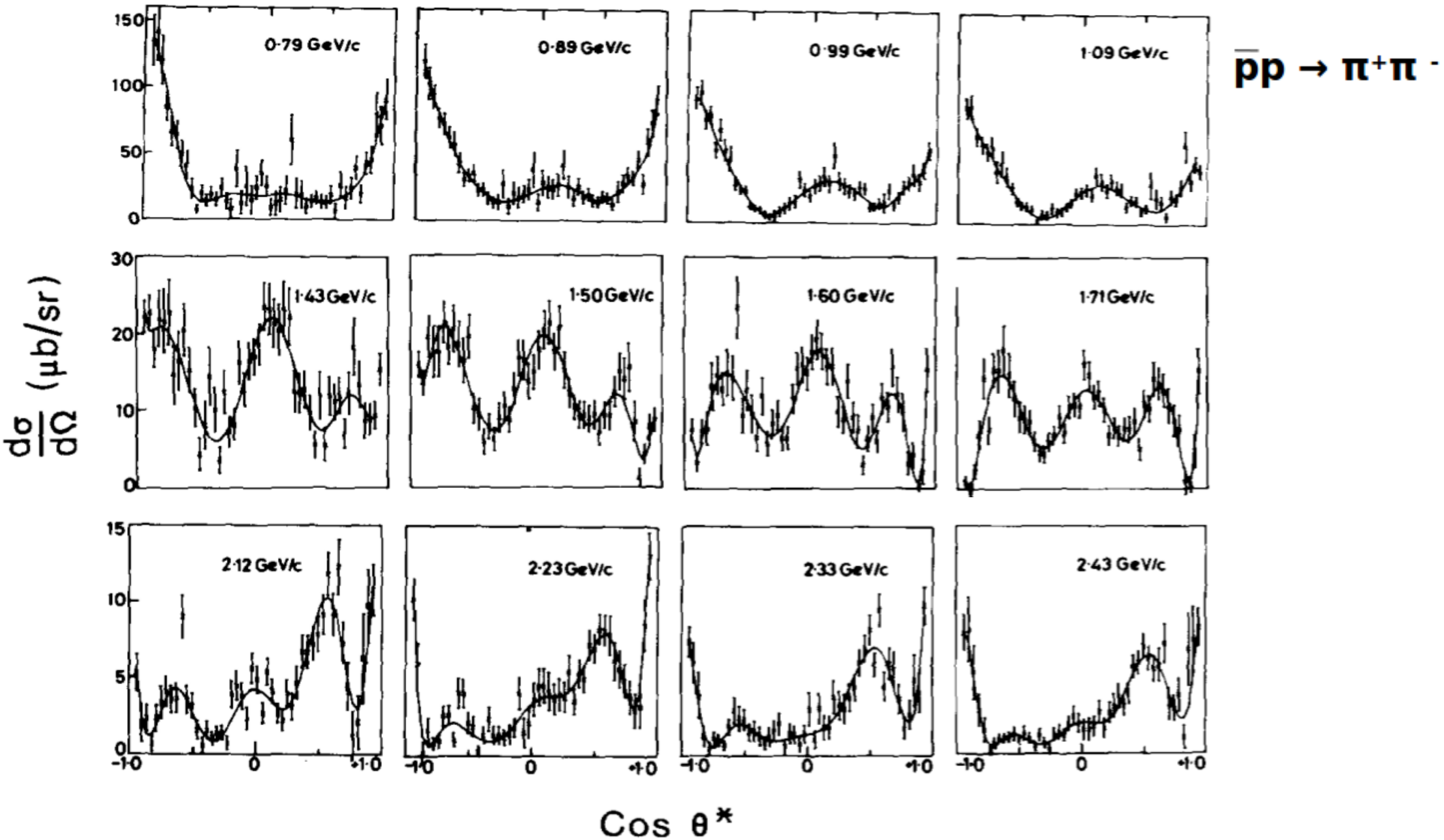
Motivation

- 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

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

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

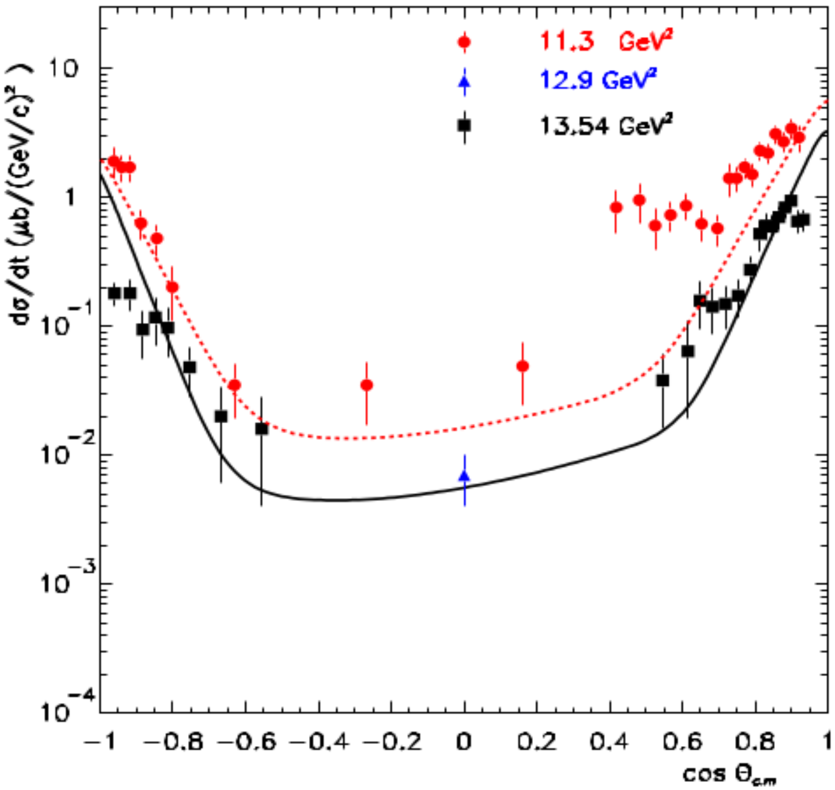
Earlier recent work

Comparison with the model from ref: EPJ A 46 (2010) , 291–298

- With Regge factor

  - well work for the backward region. can be improved in the forward and central regions.

  - the parameters in the Regge factors are not well followed the mass and angular momentum.



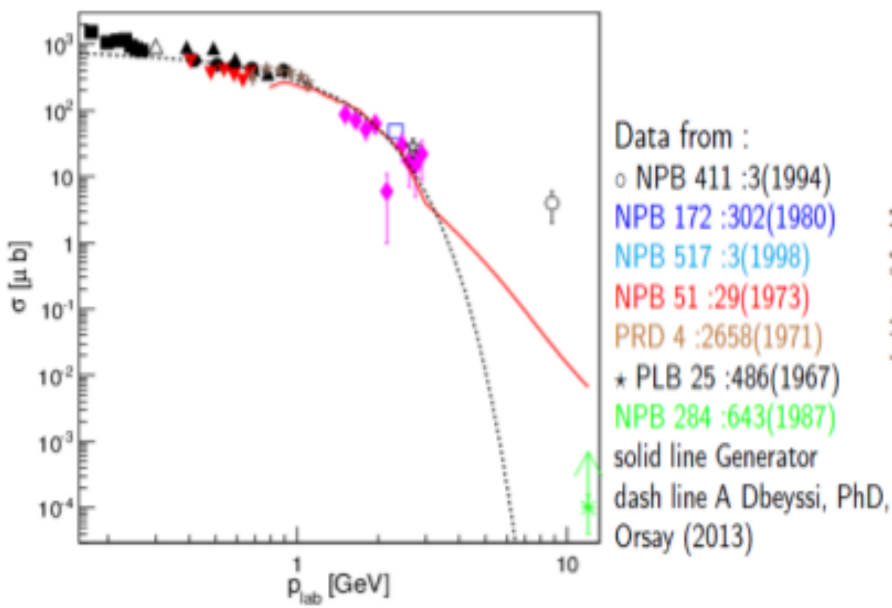
PART I

Motivation

Few experimental data at the PANDA energies to constrain the model

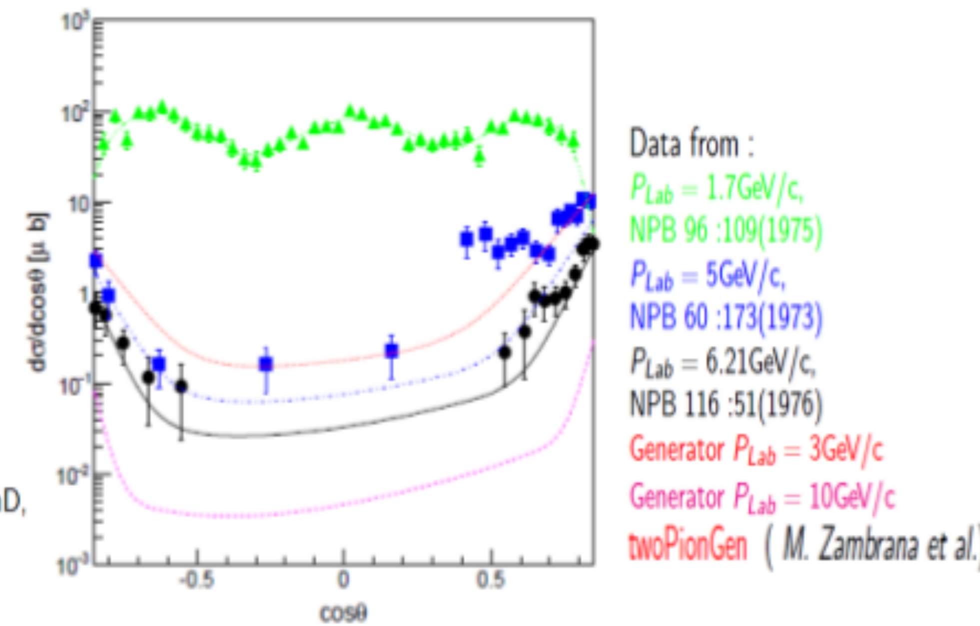
$$\bar{p}p \to \pi^- \pi^+$$

1. Total cross section



Extrapolation of existing models to Panda range is risky

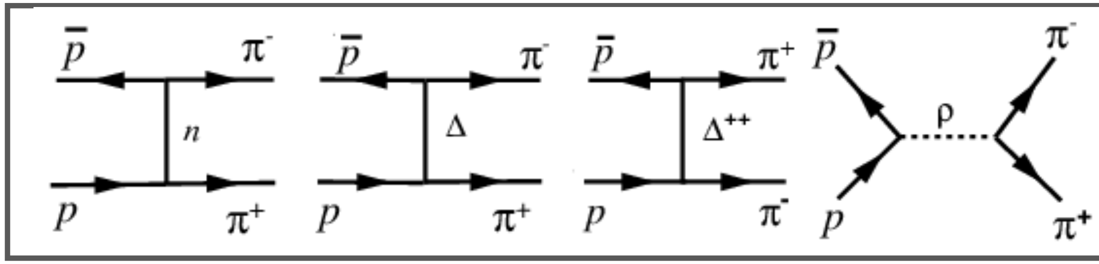
2. Differential cross section



Few and incomplete angular distributions data of annihilation(6 sets of $\pi^+\pi^-$ in panda energy region)

Effective Lagrangian Model

$$\frac{d\sigma}{d\Omega} = \frac{1}{2^8\pi^2}\frac{1}{s}\frac{\beta_\pi}{\beta_p}\overline{|\mathcal{M}|^2}$$



$$\mathcal{M} = \mathcal{M}_n + \mathcal{M}_{\Delta^0} + \mathcal{M}_{\Delta^{++}} + \mathcal{M}_\rho.$$

$$F_{N,\Delta}(x) = \frac{\mathcal{N}_{N,\Delta}\cdot M_0^4}{\left[(x-\Lambda_{N,\Delta}^2)\log\frac{(x-\Lambda_{N,\Delta}^2)}{\Lambda_{QCD}^2}\right]^2},$$

➙ **logarithmic form factors**

➙ **no Regge factors**

- Regge factors not well extrapolation to time like region
- Regge factors give none physic parameters

$$x = s,\ t,\ u$$

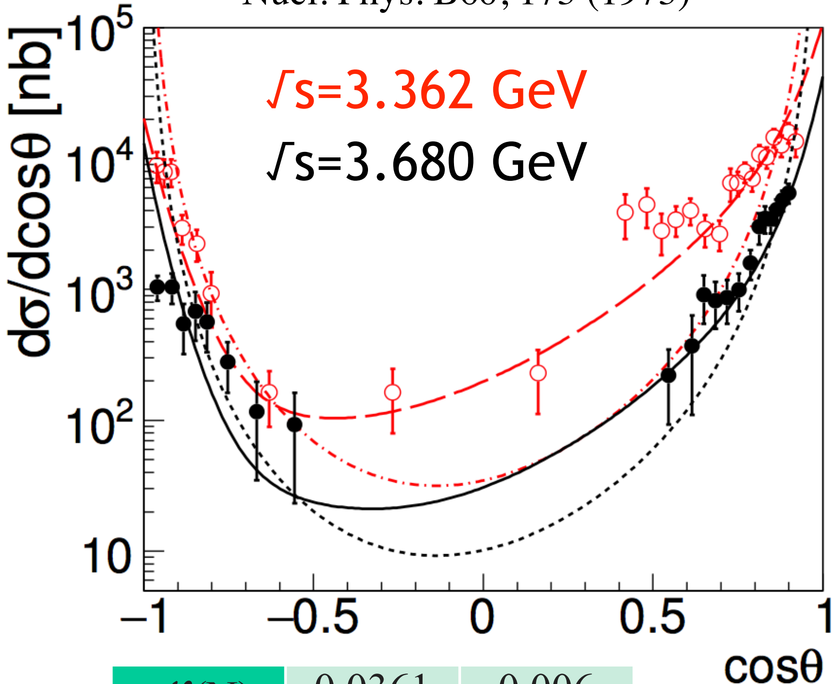
M_0 = 3.86 GeV is a scale parameter

Λ_{QCD} = 0.3 GeV is the QCD scale parameter

Results and Comparison

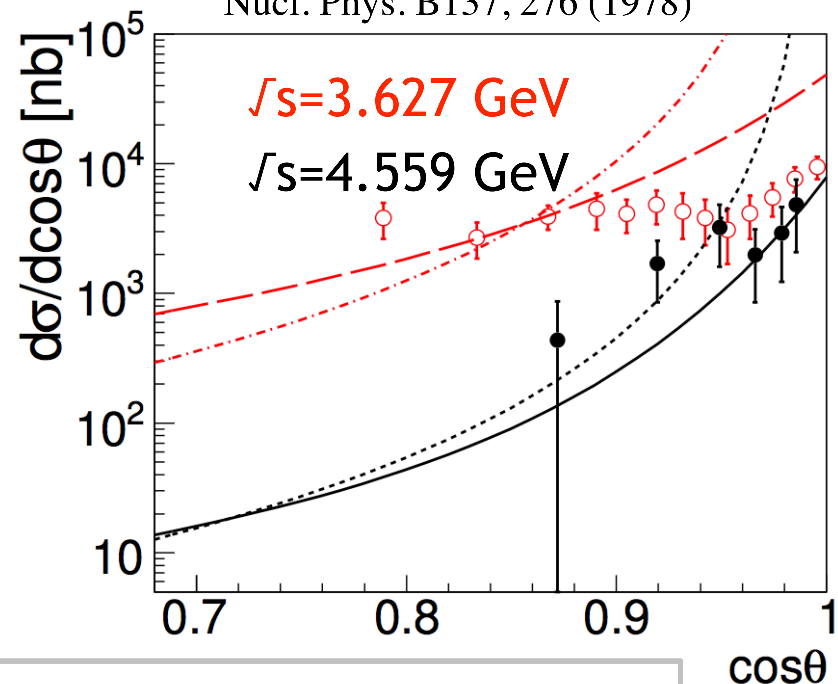
Nucl. Phys. B116, 51 (1976)

Nucl. Phys. B60, 173 (1973)



Phys. Rev. Lett. 39, 378 (1977)

Nucl. Phys. B137, 276 (1978)



$\mathcal{N}$(N)	0,0361	0,006
$\mathcal{N}$(Δ)	0,041	0,003
Λ(N)	2,25	0,09
Λ(Δ)	1,05	0,04

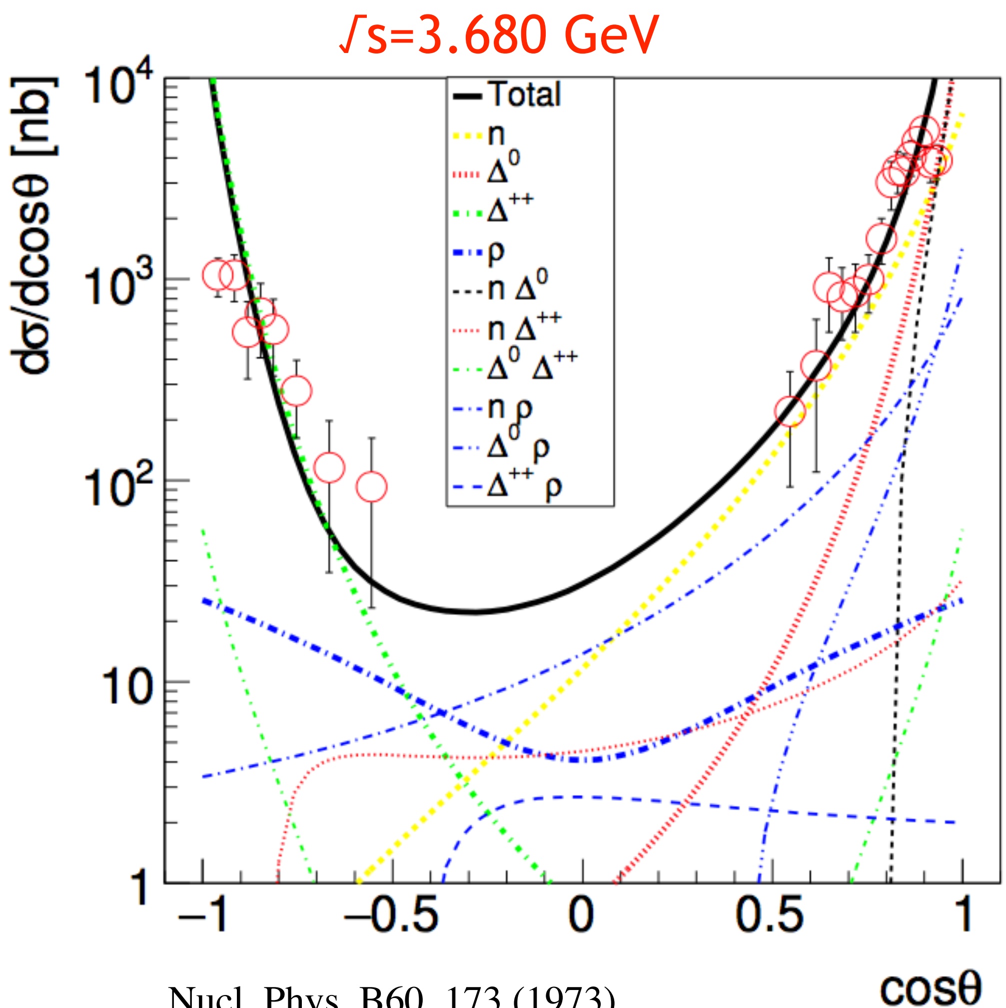
$$\chi^2/ndf = 1.99$$

Our Model

Model from: PRD 8, 287(1973)

quark exchange

Components of our model



Nucl. Phys. B60, 173 (1973)

Forward mainly from
n and Δ0

Backward mainly from
Δ++

s-channel from ρ and
interferences

Crossing symmetry

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

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

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

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

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

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

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

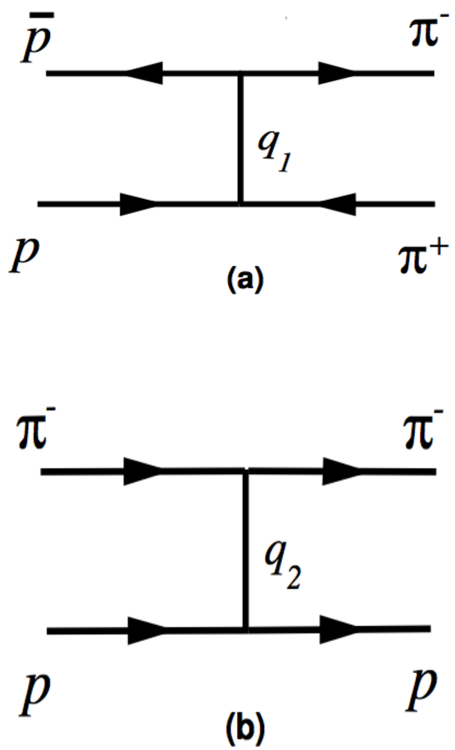
$$\sigma^a = \frac{1}{2}\frac{|\vec{k}_s|^2}{|p_a|^2}\sigma^s = f\sigma^s$$

when t is small,

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

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

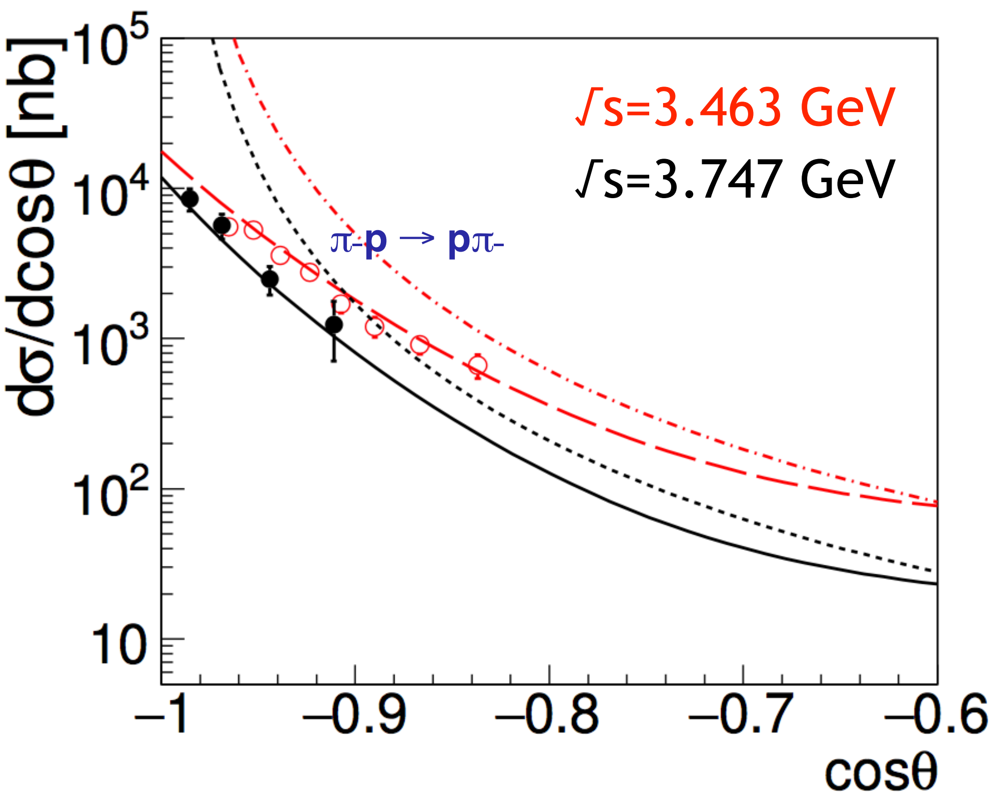
$$\sigma^a(s) = f\sigma^s(s_1) \cdot \frac{s^{-2}}{s_1^{-2}}$$



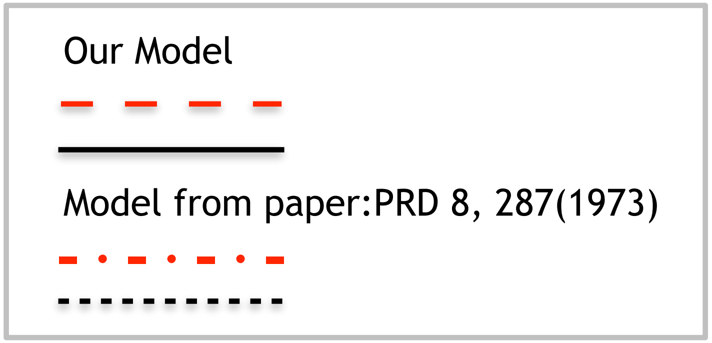
Crossing symmetry of the model

Phys. Rev. 181, 1794 (1969)

Nucl. Phys. B 25, 385(1971)



- using crossing symmetry from pπ- elastic to get more experiment data in the backward region



Quark counting rules:

Hadron-hadron collision at high energies (CMS)

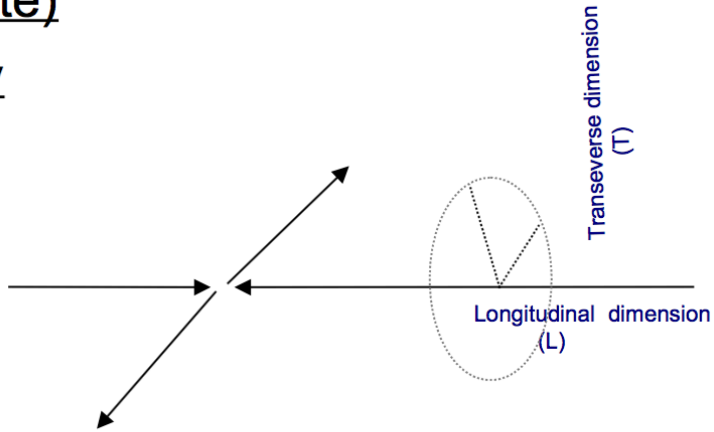
2 experimental rules in the reaction

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

limited T momenta with s increasing (L can be infinite)

average number of particles produced grows slowly when s increases

↓ kinematics is defined by dimensions T and L



- Strong dynamical difference between T-L

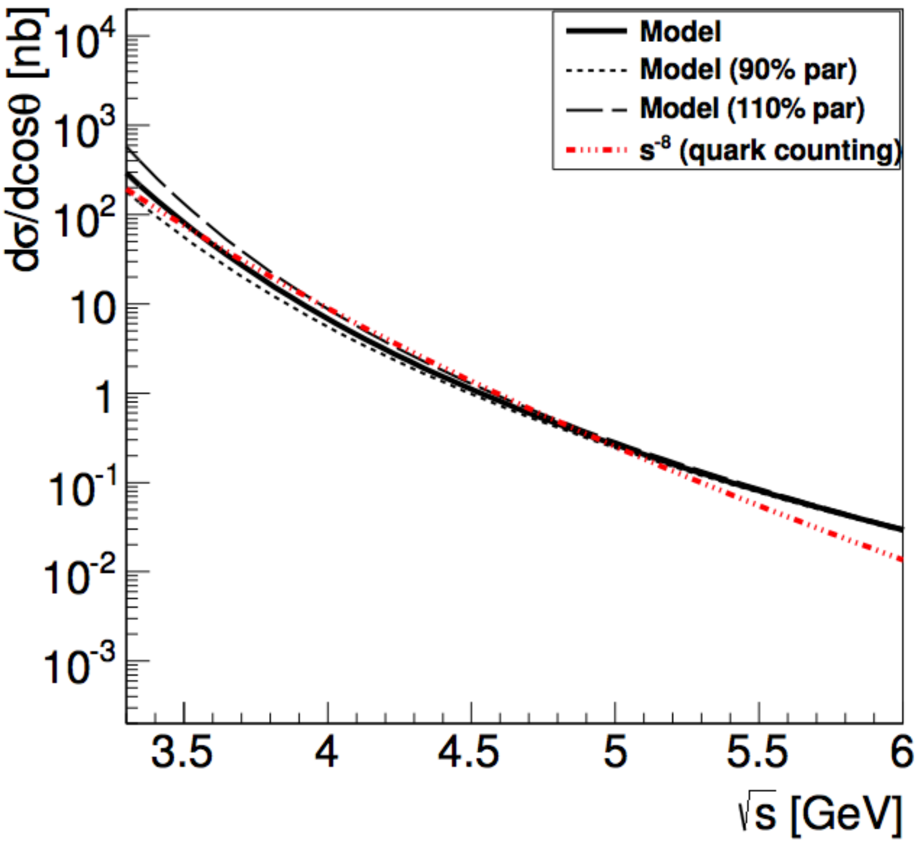
- Essential constants purely related to T

↓

Asymptotically, the average number of particles(mutiplicity), and the average transverse momentum are constant as function of s.

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

Compare to quark counting rules at 90 degree



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.

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

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

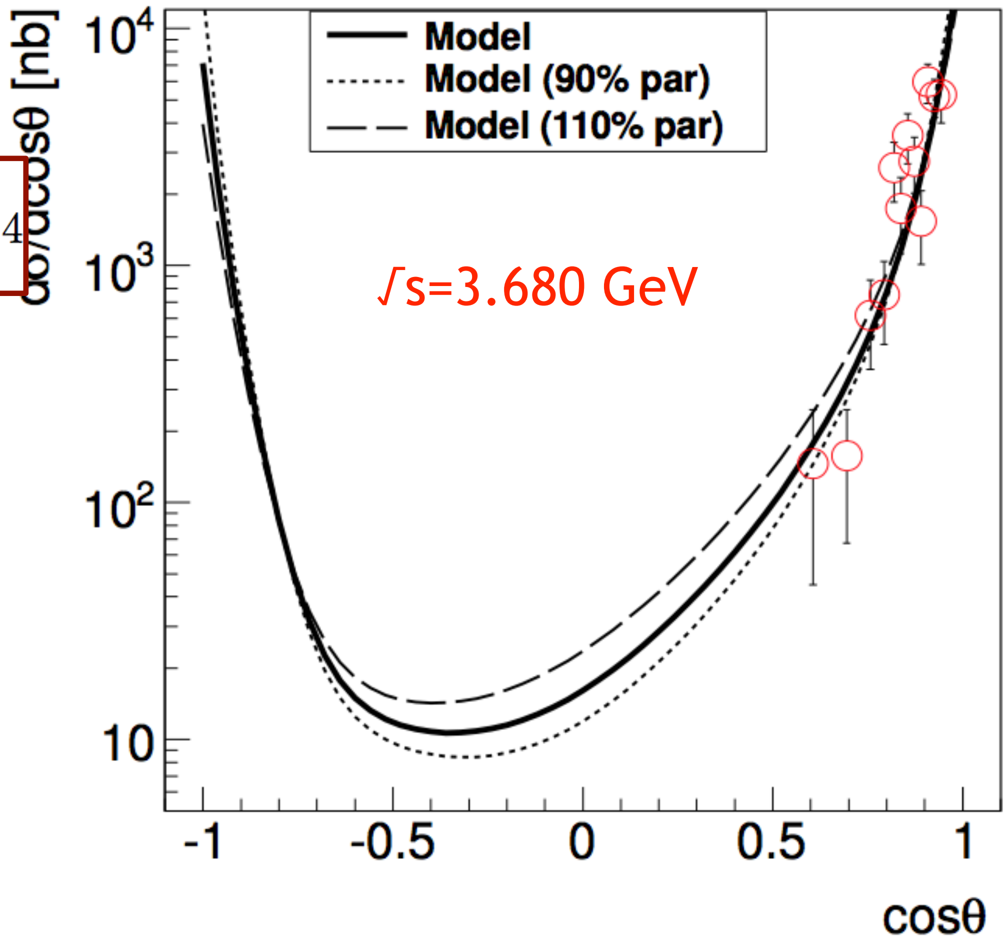
Results and Comparison

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

V. Anisovich, Phys. Lett. B 364, 195 (1995).

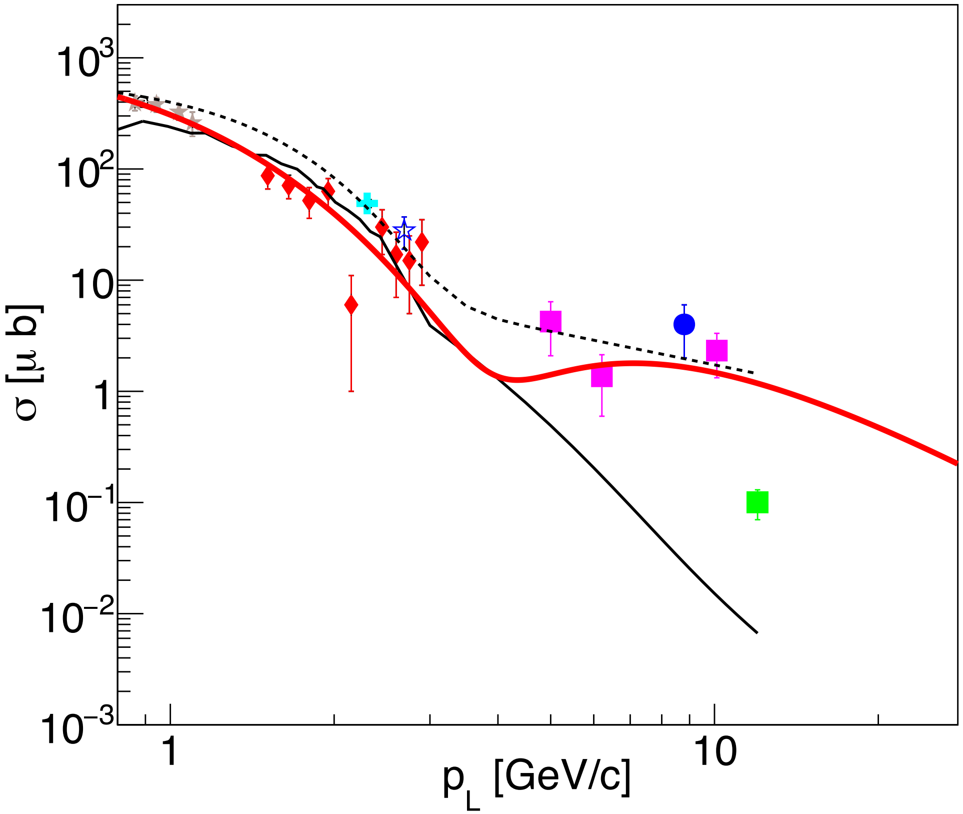
- Prediction through SU3 symmetry with no change of parameters.

$$\sigma(\pi^-\pi^+) : \sigma(K^-K^+) = 1 : \frac{4\lambda}{3}, \text{ where } \lambda = 0.4$$



- Evaluate the total cross section, from the integrated cross section $\sigma(\text{pbar}+p \rightarrow K^+ + K^-) = 2.1 \pm 0.8\text{mb}$.

Total cross section



- Black dashed line modified from A Dbeyssi PhD

$$\sigma = a \cdot e^{-(b \cdot p_{lab} + c \cdot p_{lab}^2 + d)} + \frac{e}{p_{lab}}$$

Added term

- Red solid line - our model
- Black solid line -Mainz generator

pink points from the integration of limited angular distribution.

From pion to eta through SU(3)

Pion and eta 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 $\Theta \approx 45°$

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

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

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

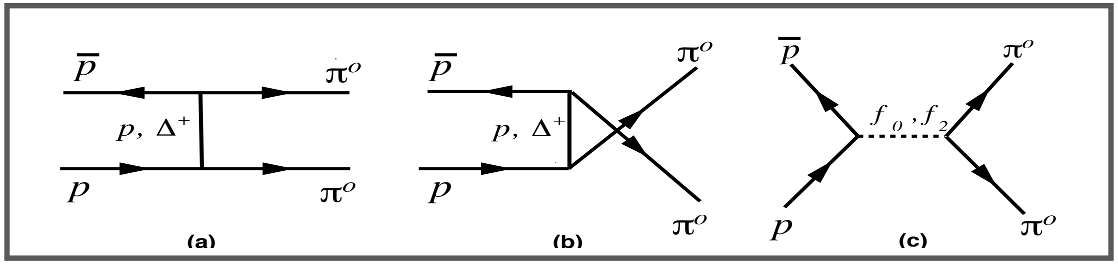
$$|s\bar{s} >= -\sin\Theta|\eta > + \cos\Theta|\eta' >$$

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

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

$\pi^0\pi^0$ production

$$\frac{d\sigma}{d\Omega} = \frac{1}{2^8\pi^2}\frac{1}{s}\frac{\beta_\pi}{\beta_p}\overline{|\mathcal{M}|^2}$$



$$F_{N,\Delta}(x) = \frac{\mathcal{N}_{N,\Delta}\cdot M_0^4}{\left[(x-\Lambda^2_{N,\Delta})\log\frac{(x-\Lambda^2_{N,\Delta})}{\Lambda^2_{QCD}}\right]^2},$$

$$\mathcal{N}(s)_{p,\Delta} \to \mathcal{N}(s)_{p,\Delta} - e^{\frac{p^{\mathcal{N}}_{p,\Delta}(s)}{\sqrt{s}}}$$

$$\Lambda(s)_{p,\Delta} \to \Lambda(s)_{p,\Delta} - e^{\frac{p^{\Lambda}_{p,\Delta}(s)}{\sqrt{s}}}$$

M_0 = 3.86 GeV is a scale parameter

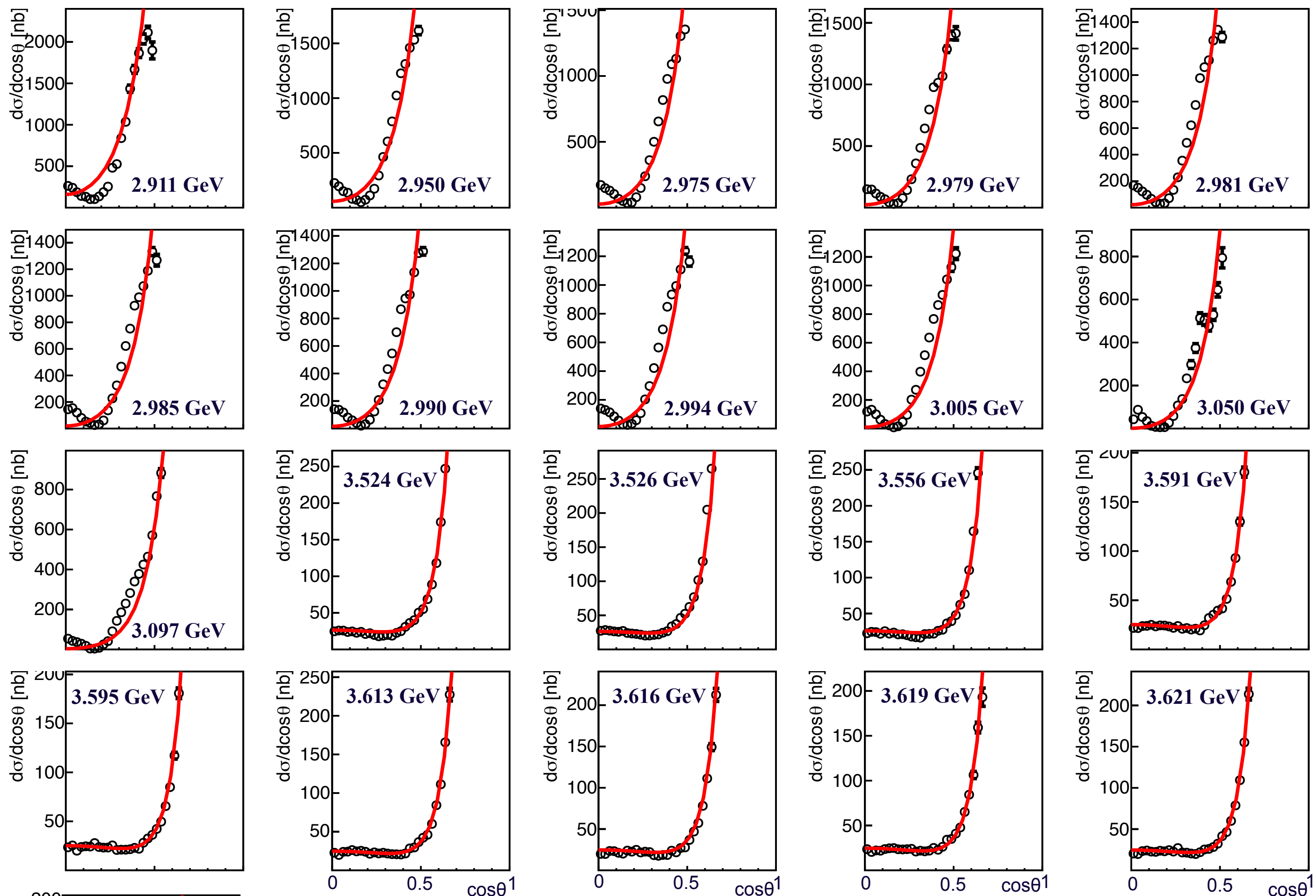
Λ_{QCD} = 0.3 GeV is the QCD scale parameter

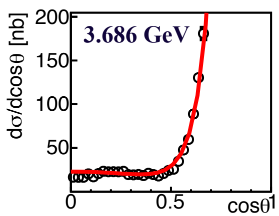
$p^{\mathcal{N}}$(N)	-3,013	0,210
$p^{\mathcal{N}}$(Δ)	-5,959	0,205
p^{Λ}(N)	4,047	0,019
p^{Λ}(Δ)	3,141	0,002

Form factor for s-channel

$$FF_f(s) = \frac{F_f^2}{F_f^2 + M_f^2 - s}$$

Results of $\pi^0\pi^0$

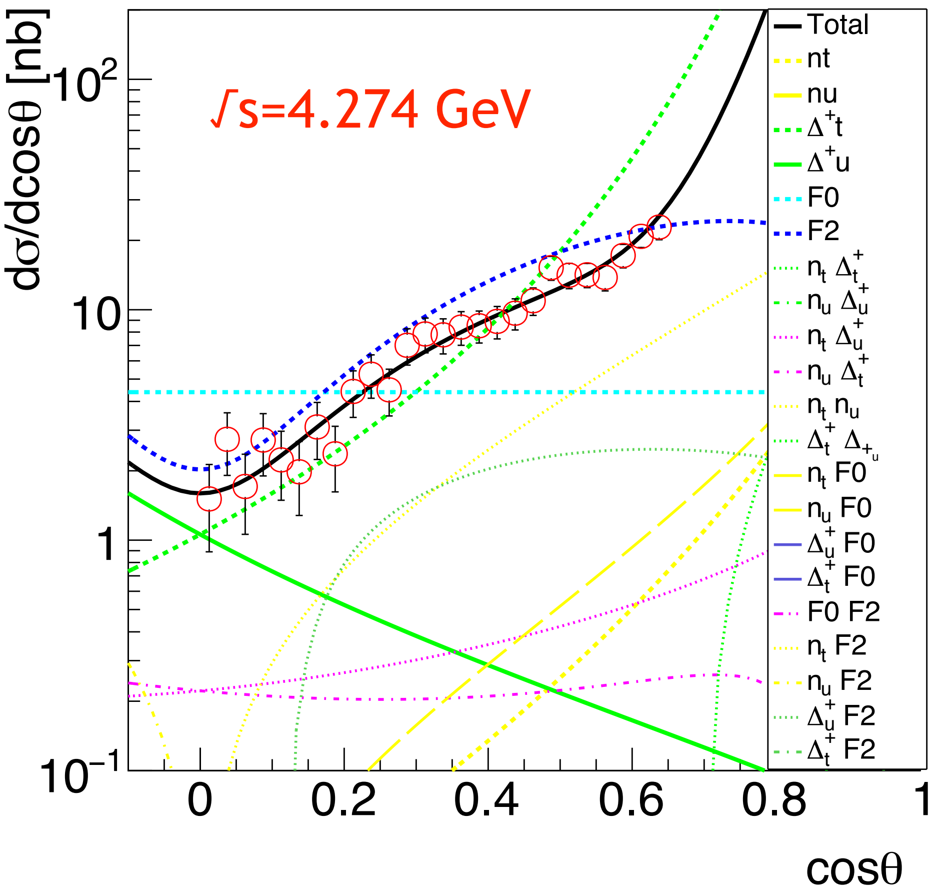




T. Armstrong et al. (Fermilab E760 Collaboration), Phys. Rev. D56, 2509 (1997)

F_{f0}	1,17	0,051
χ^2/ndf	109	

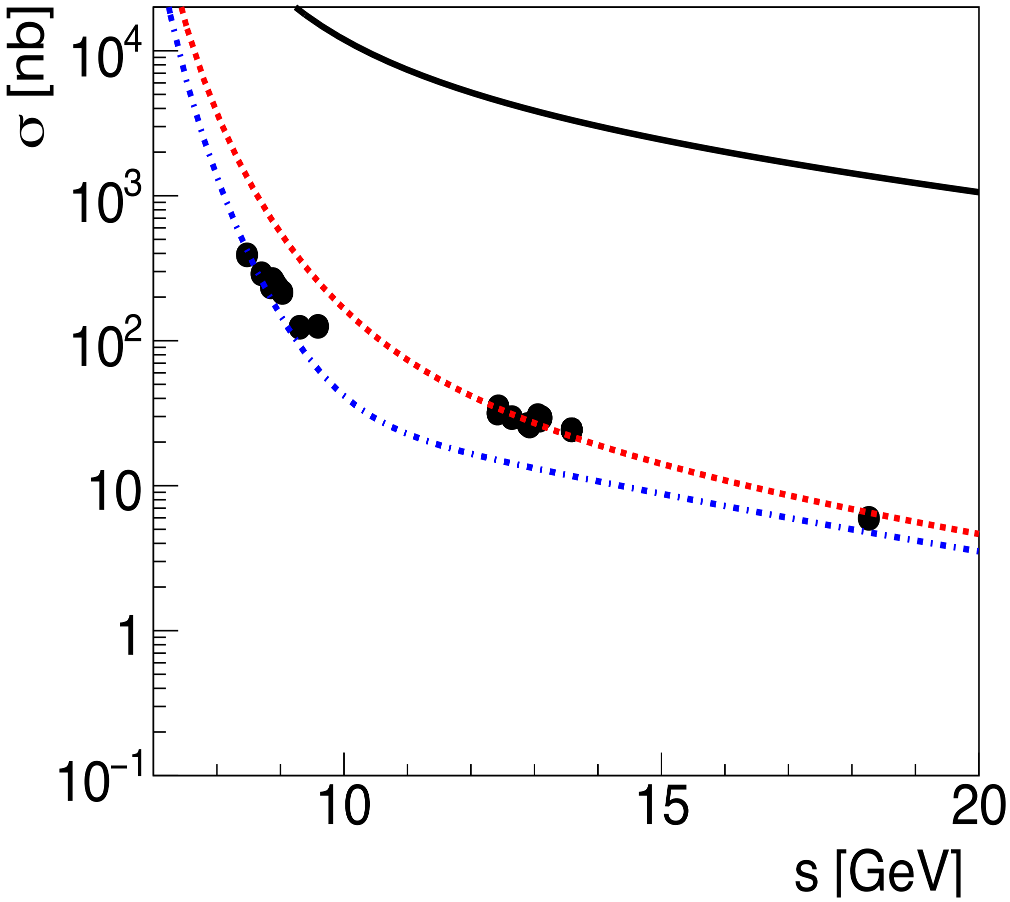
Components for $\pi^0\pi^0$



F_{f0}	0,870	0,014
F_{f2}	0,187	0,001
$\chi 2$/ndf	0,787	

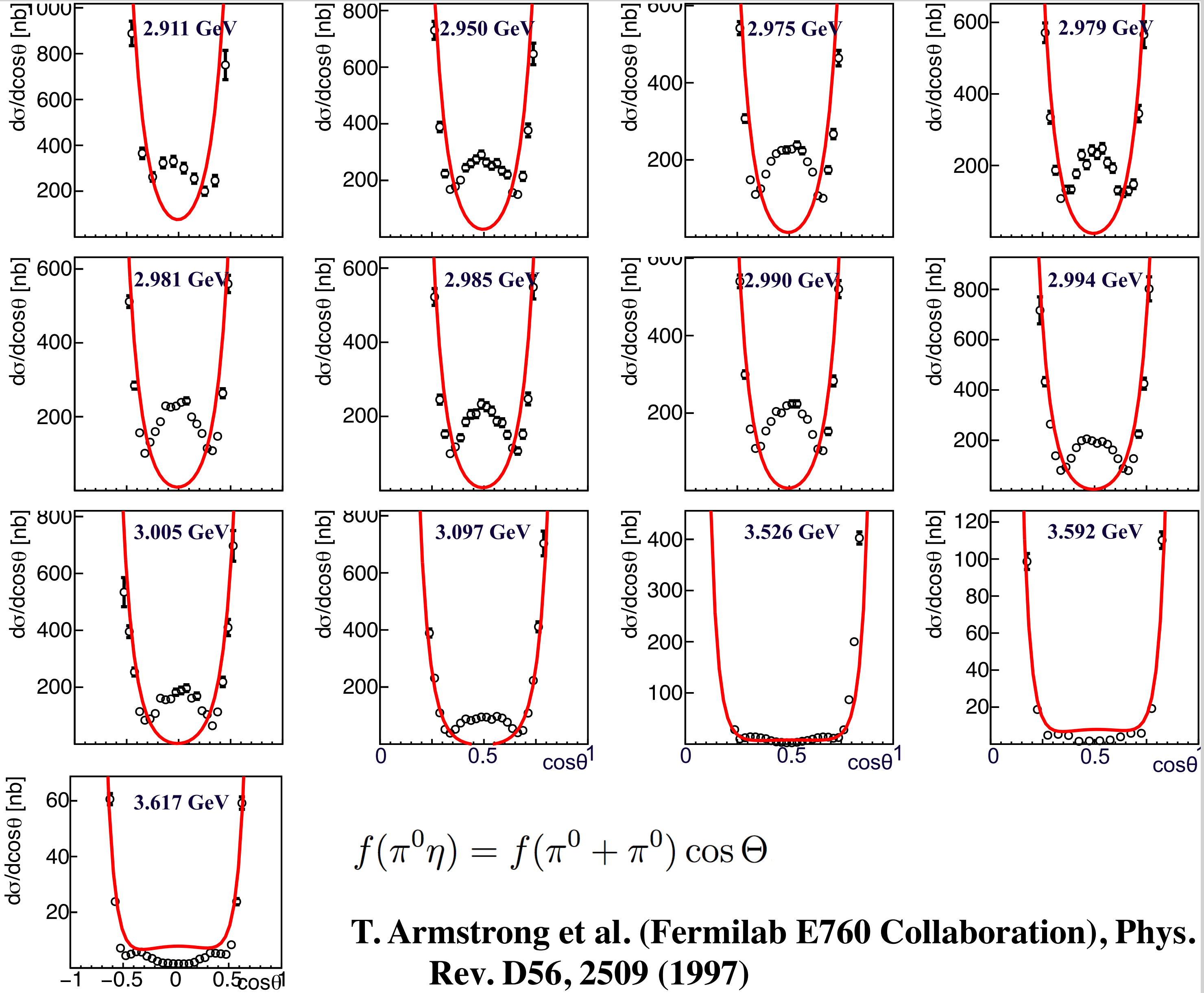
- Black solid line - our model
- **Blue dashed line -f_0.**
- The bump is produced by the J=2 meson f_2.

Integrated cross section of $\pi^0\pi^0$



- black line - full angular range
- Red line - integrated within the region $0 < \cos\theta < 0.66$
- Blue line - integrated within the region $0 < \cos\theta < 0.48$

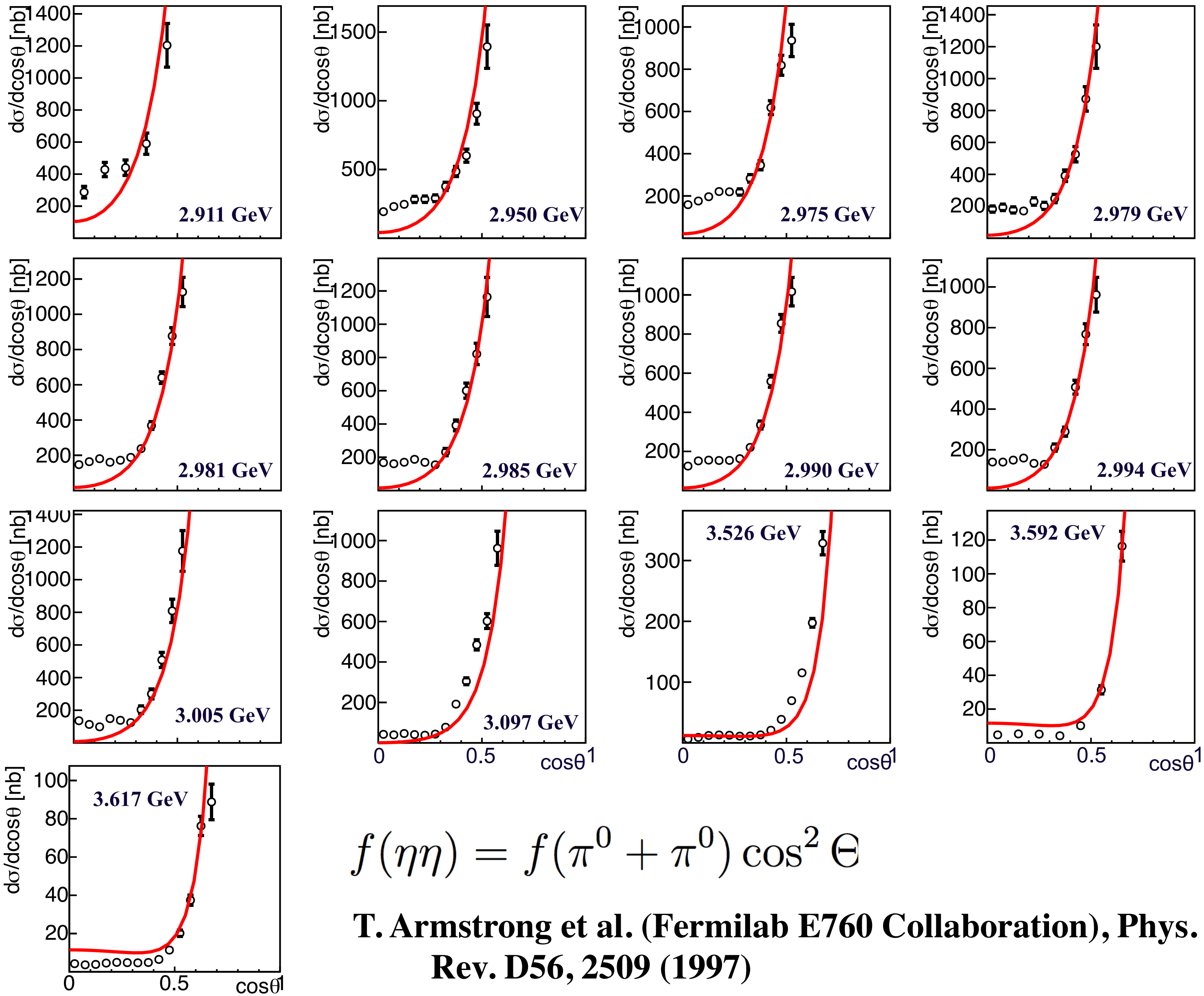
Results of $\eta\pi^0$ with SU(3) symmetry



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

T. Armstrong et al. (Fermilab E760 Collaboration), Phys. Rev. D56, 2509 (1997)

Results of ηη with SU(3) symmetry



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

T. Armstrong et al. (Fermilab E760 Collaboration), Phys. Rev. D56, 2509 (1997)

Summary Part I

A promising model based on effective Lagrangian has been built to describe 2 meson production in pbar p annihilation

- We reproduced existing charged and neutral pion data.
- We reproduced π+p, π-p using crossing symmetry
- Charged kaon channel obtained from SU3 symmetry: K+K-. Neutral production $\eta\eta$,$\eta\pi0$ obtained through SU(3) symmetry from $\pi0\pi0$.
- very good results on angular distributions and the expected s-dependence have been obtained

therefore we can trust the extrapolation of our model in the PANDA energy range.

PART II

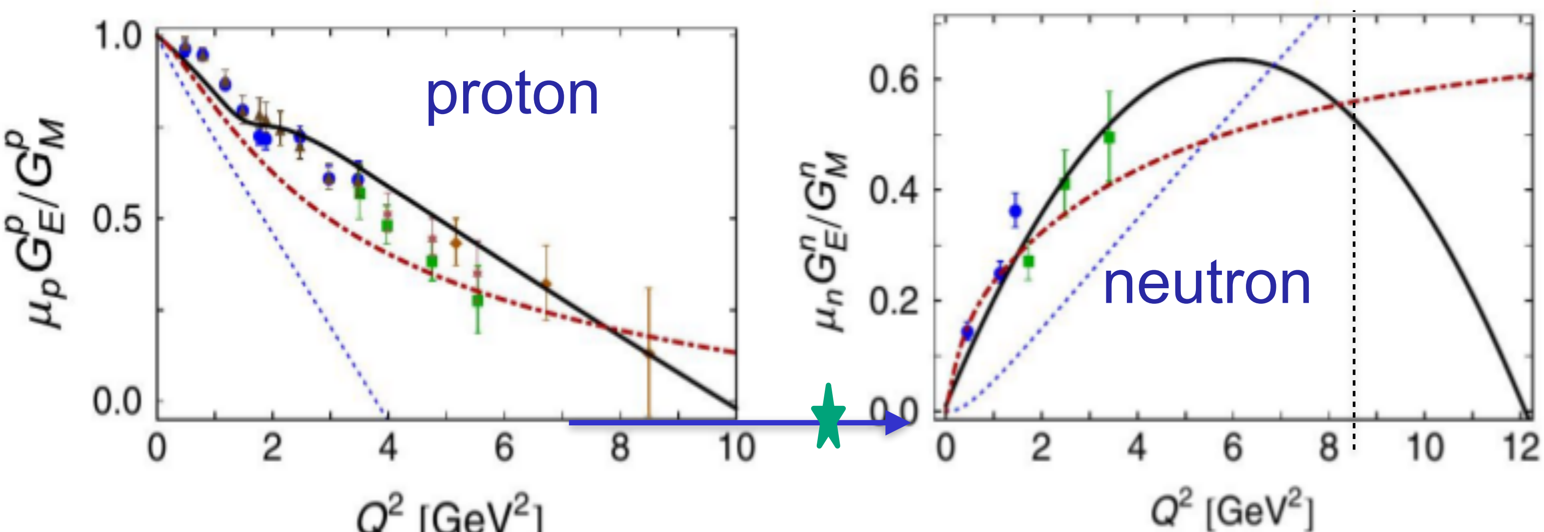
Analyzing powers

- Measuring analyzing powers (ALPOM2) is the first step to conceive and optimize a polarimeter to measure proton (neutron) polarization .

- Polarization experiments are needed for the extraction of electromagnetic form factors (FFs) using polarized eN elastic experiments (Jlab).

Motivation

Jlab proposals (PAC 43) :Proton and neutron FFs with Akhiezer-Rekalo recoil polarization method at Q^2 at 12.4 GeV^2 and 8.4 GeV^2.



(black line) J. Segovia *et al.*, Few-Body Syst. 55 (2014), 1185

(red dash) J.J. Kelly, Phys. Rev. C70(2004), 068202.

(blue dotted) D.J. Wilson *et al.*, Phys. Rev. C85(2012),025205.

Points from JLab data

M.K. Jones *et al.* Phys. Rev. Lett. 84(2000), 1398.

O. Gayou *et al.*, Phys. Rev. Lett. 88(2002), 092301.

V. Punjabi *et al.*, Phys. Rev. C71(2005), 055202.

A.J.R. Puckett *et al.*, Phys. Rev. Lett. 104(2010), 242301.

D.J. Wilson *et al.*, Phys. Rev. C85(2012),025205.

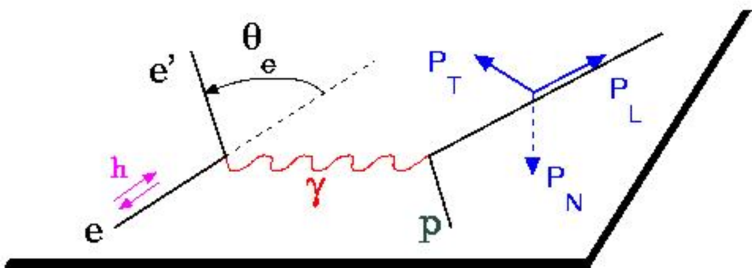
Motivation

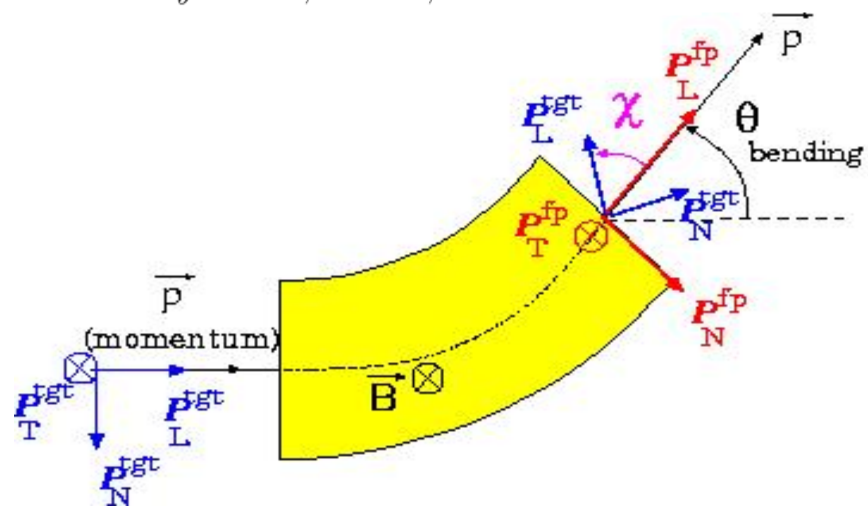
Optimising nucleon polarimetry for high transfer momenta

Akhiezer-Rekalo recoil polarization method

A.I. Akhiezer and Mikhail.P. Rekalo. Polarization phenomena in electron scattering by protons in the high energy region. *Sov.Phys.Dokl.*, 13:572, 1968.

Elastic *ep* reaction (1-γ exchange)





$$\frac{P_{t=x}}{P_{\ell=z}} = -2\cot(\theta_e/2)\frac{M_p}{\epsilon_1+\epsilon_2}\frac{G_E}{G_M}$$

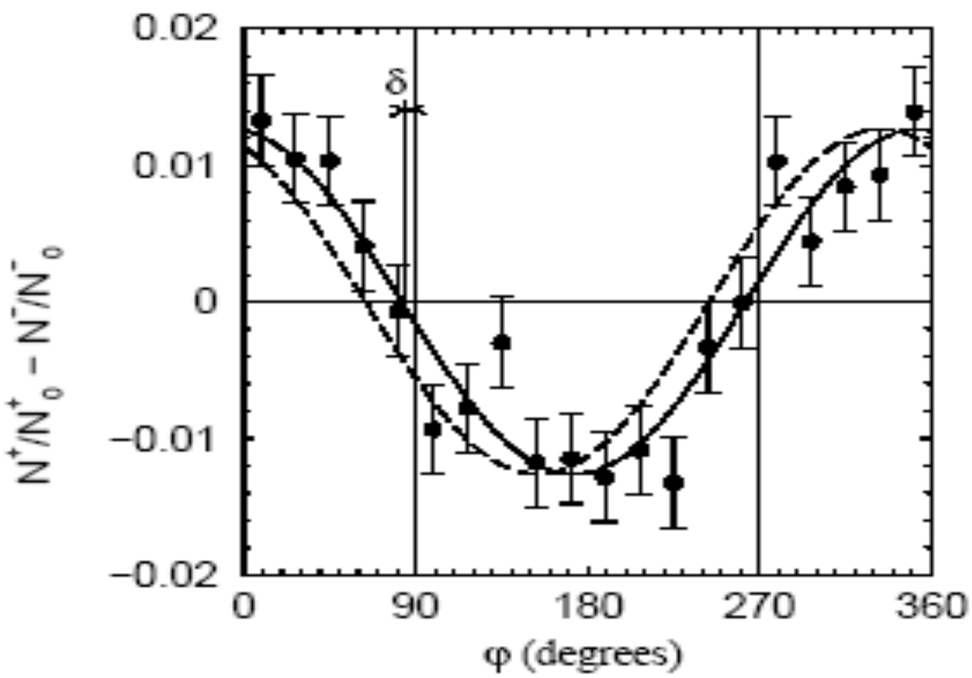
The simultaneous measurement of P_t and P_l reduces systematic errors to achieve more precise ratio of FFs

Principle of polarimetry

Azimuthal distribution of protons after scattering in the analyzer

Q^2=5.6 GeV/c^2

Asymmetry very small, experiment very difficult



M.K. Jones *et al.* Phys. Rev. Lett. 84(2000), 1398.

O. Gayou *et al.*, Phys. Rev. Lett. 88(2002), 092301.

V. Punjabi *et al.*, Phys. Rev. C71(2005), 055202.

A.J.R. Puckett *et al.*, Phys. Rev. Lett. 104(2010), 242301.

Principle of polarimetry

Working principle: measurement of the azImuthal asymmetry in a scattering

Vector polarization: (Proton) inclusive scattering on light targets:

p+C(CH2) → one charged particle +X

(Neutron)

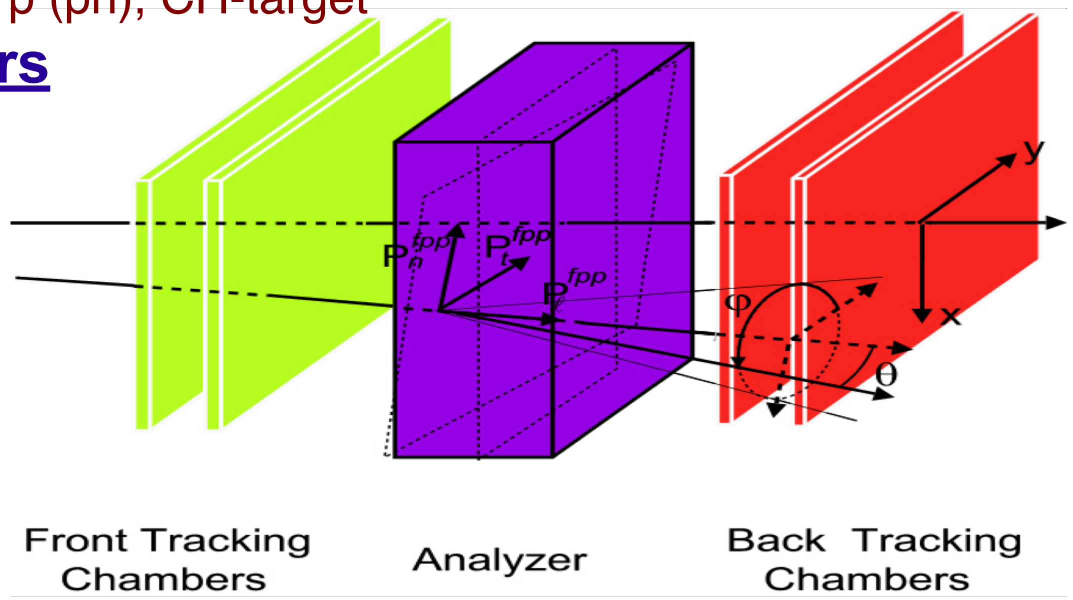
n p → n p (pn), CH-target

- **Calibration: analyzing powers**

$$N^{\pm}(\theta,\phi) = N_0(\theta)(1 \pm P_y A_y(\theta)\cos\phi),$$

$$R(\theta,\phi) = \frac{N^{+}(\theta,\phi) - N^{-}(\theta,\phi)}{N^{+}(\theta,\phi) + N^{-}(\theta,\phi)} = a_1(\theta)\cos\phi$$

$$A_y(\theta) = \frac{a_1(\theta)}{P_y}, \quad \Delta A_y \simeq \frac{1}{P_y}\sqrt{\frac{1}{N_{Incident}}}.$$

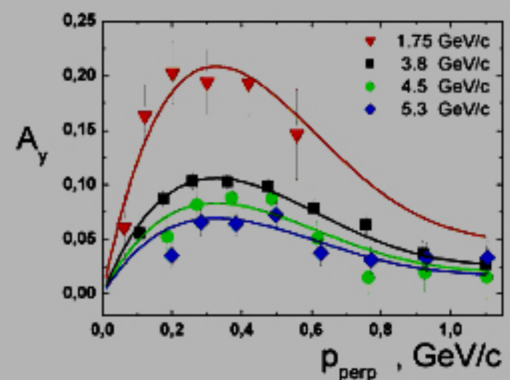


ALPOM II

Upgrade ALPOM (http://lhe.jinr.ru/alpom/)

Pp up to 7.5 GeV/c
Pn up to 5.3 GeV/c

Measurement of the inclisive $\vec{p}CH_2$ analyzing power at high energies (ALPOM-project)



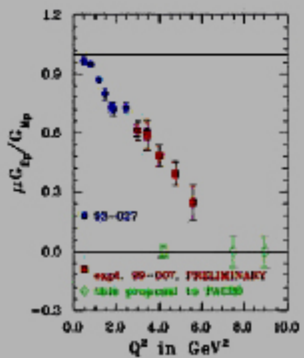


Figure 16: The $\mu_p G_{Ep}/G_{Mp}$ results of experiments 93-027, 99-007 (PRELIMINARY) and proposed 00-111.

The main goal of the project is to obtain the analyzing power for $pCH_2 \to pX$ reaction at large momenta for G_{Ep}/G_{Mp} experiment at JLAB. Also these data are necessary to develop the proton focal-plane polarimetry at hadronic facilities.

Neutron analyzing power measurement: which reaction is better?

Comparison of figure of merit

np → np elastic scattering (zero exchange)

np → pn (charge exchange)

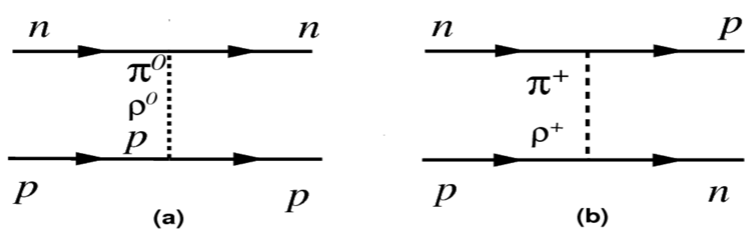
$$\mathcal{F}^2 = \int_\theta \varepsilon(\theta)\ A_y^2(\theta)\ d\theta$$

$$\epsilon(\theta) = \frac{N_{useful}(\theta)}{N_{incident}(\theta)}$$

$$\Delta P = \sqrt{\frac{2}{N_{inc}\mathcal{F}^2}}$$

Pole model for np → np (pn)

Neutron



- Differential cross section

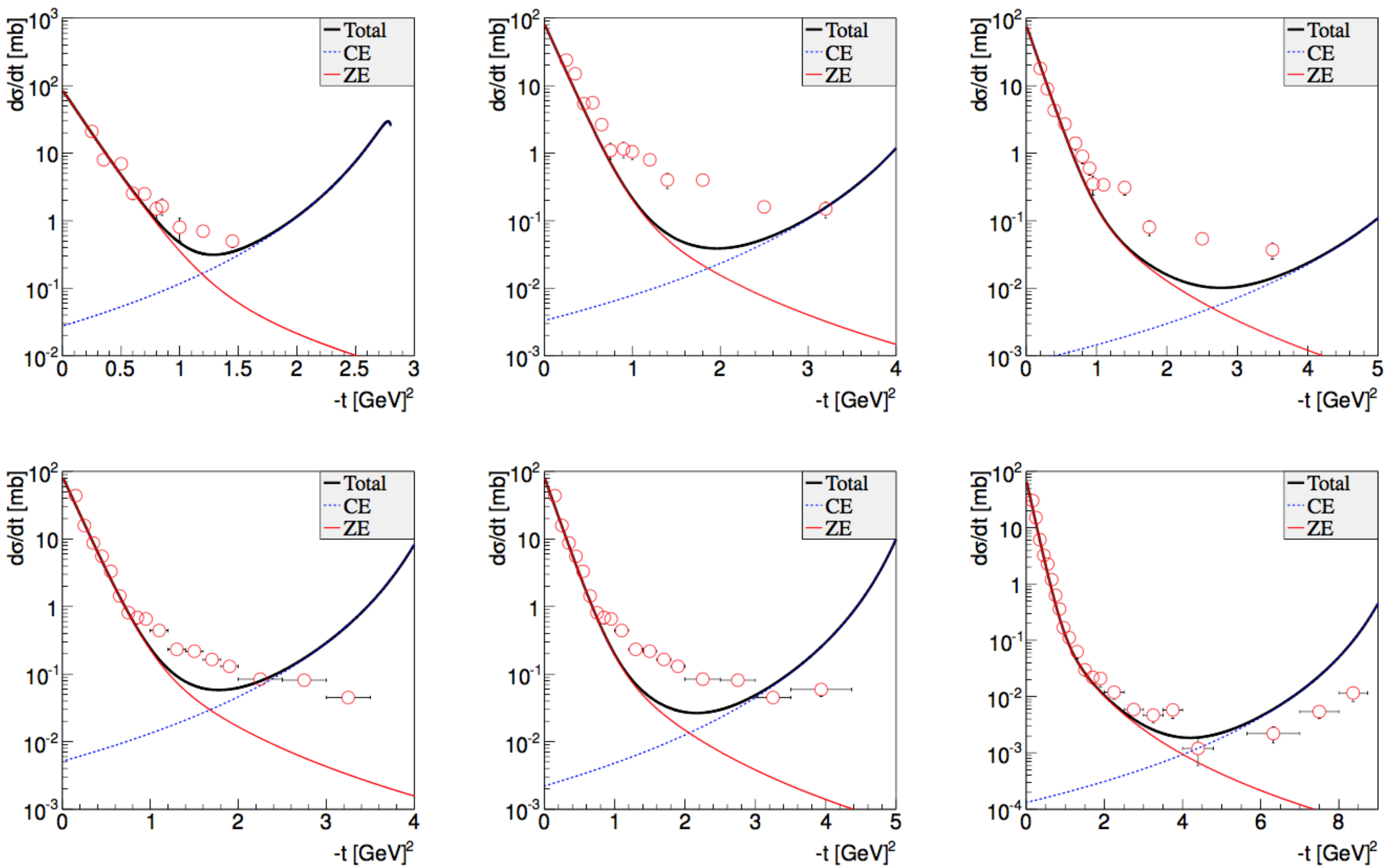
$$\frac{d\sigma}{dt} = \frac{1}{64\pi s q^2}\left(|T_\pi(u) + T_\rho(u)|^2 + \frac{1}{4}|T_\pi(t) + T_\rho(t)|^2 + |T_P(t)|^2\right)$$

$$|T_{CE}(u)|^2 = \left(F_u \frac{uA_\pi}{u - m_\pi^2} F_u\right)^2 + \left|F_u \frac{uA_\rho e^{i\varphi}}{u - m_\rho^2} F_u\right|^2 + 2\left(F_u \frac{uA_\pi}{u - m_\pi^2} F_u\right)\left(F_u \frac{uA_\rho e^{-i\varphi}}{u - m_\rho^2} F_u\right)$$

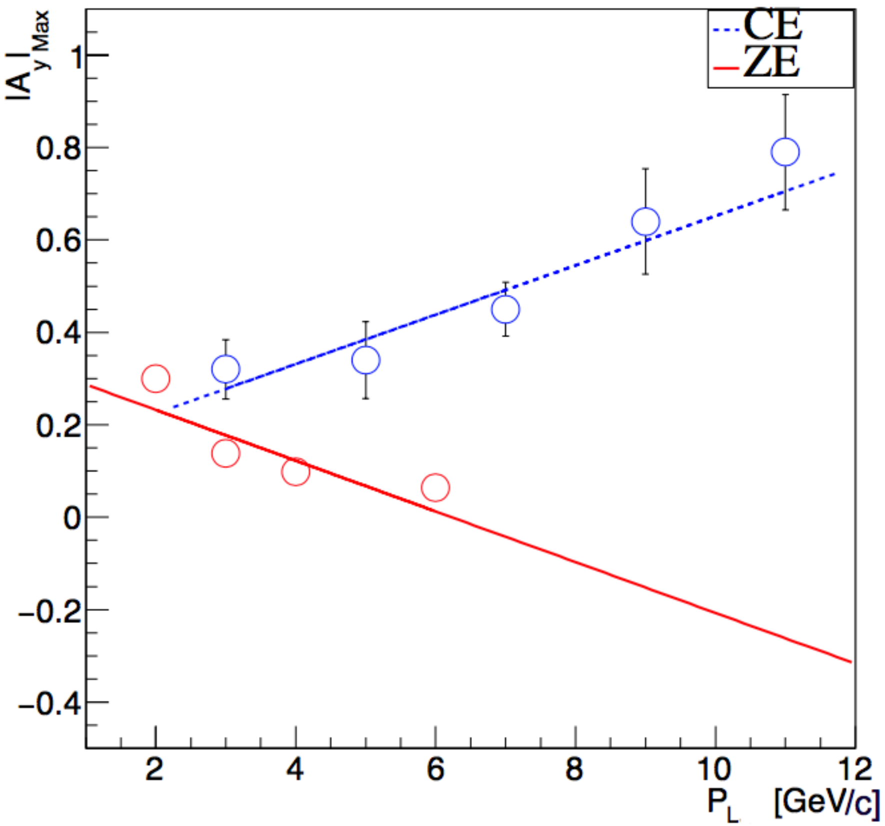
$$|T_{ZE}(t)|^2 = \frac{1}{4}\left[\left(F_t \frac{tA_\pi}{t - m_\pi^2} F_t\right)^2 + \left|F_t \frac{tA_\rho e^{i\varphi}}{t - m_\rho^2} F_t\right|^2 + 2\left(F_t \frac{tA_\pi}{t - m_\pi^2} F_t\right)\left(F_t \frac{tA_\rho e^{-i\varphi}}{t - m_\rho^2} F_t\right)\right] + (A_P e^{-b|t|})^2$$

Yu.A. Troyan, M.Kh. Anikina, A.V. Belyaev, A.P. Ierusalimov, and A.Yu. Troyan. Elastic np np(pn) scattering at intermediate energies. *Physics of Particles and Nuclei Letters*, 11(2):101–108, 2014.

Differential cross section



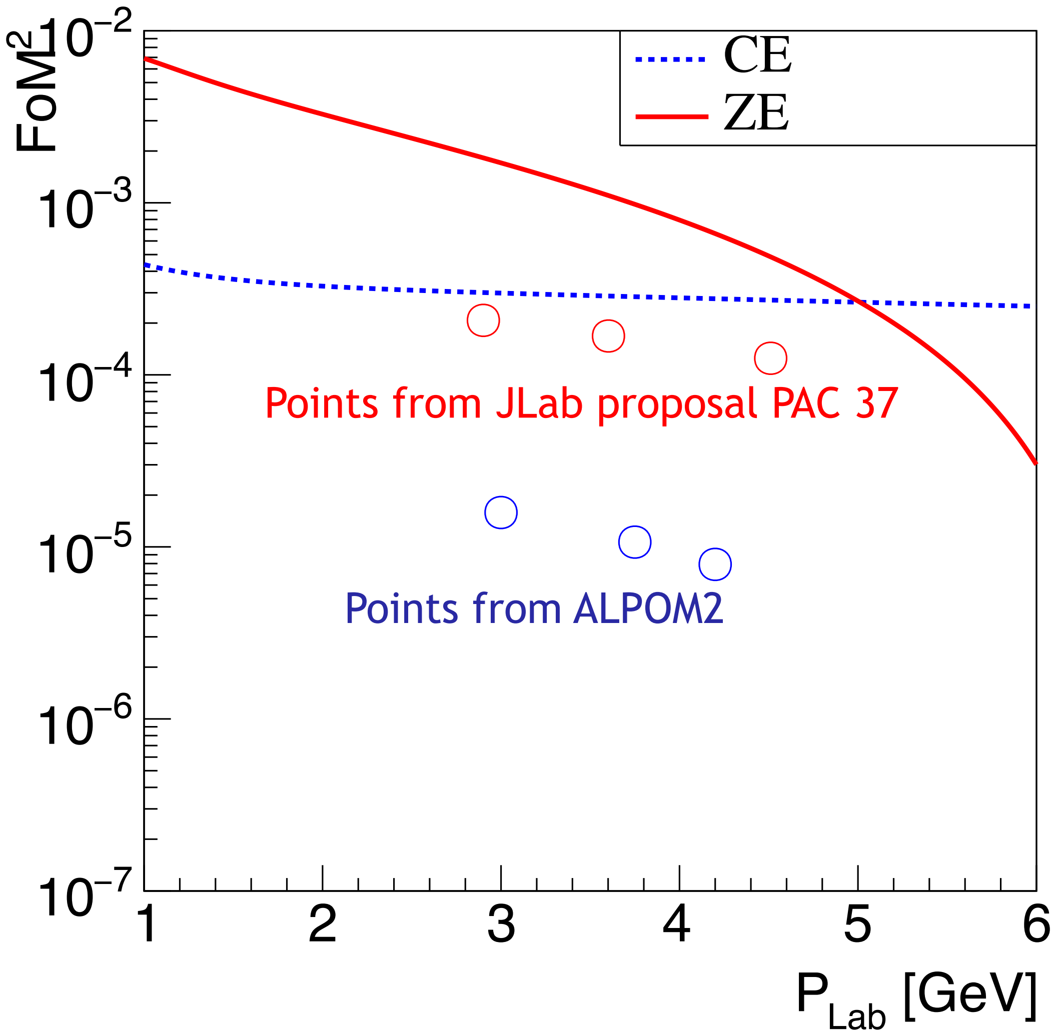
Maximum analyzing powers



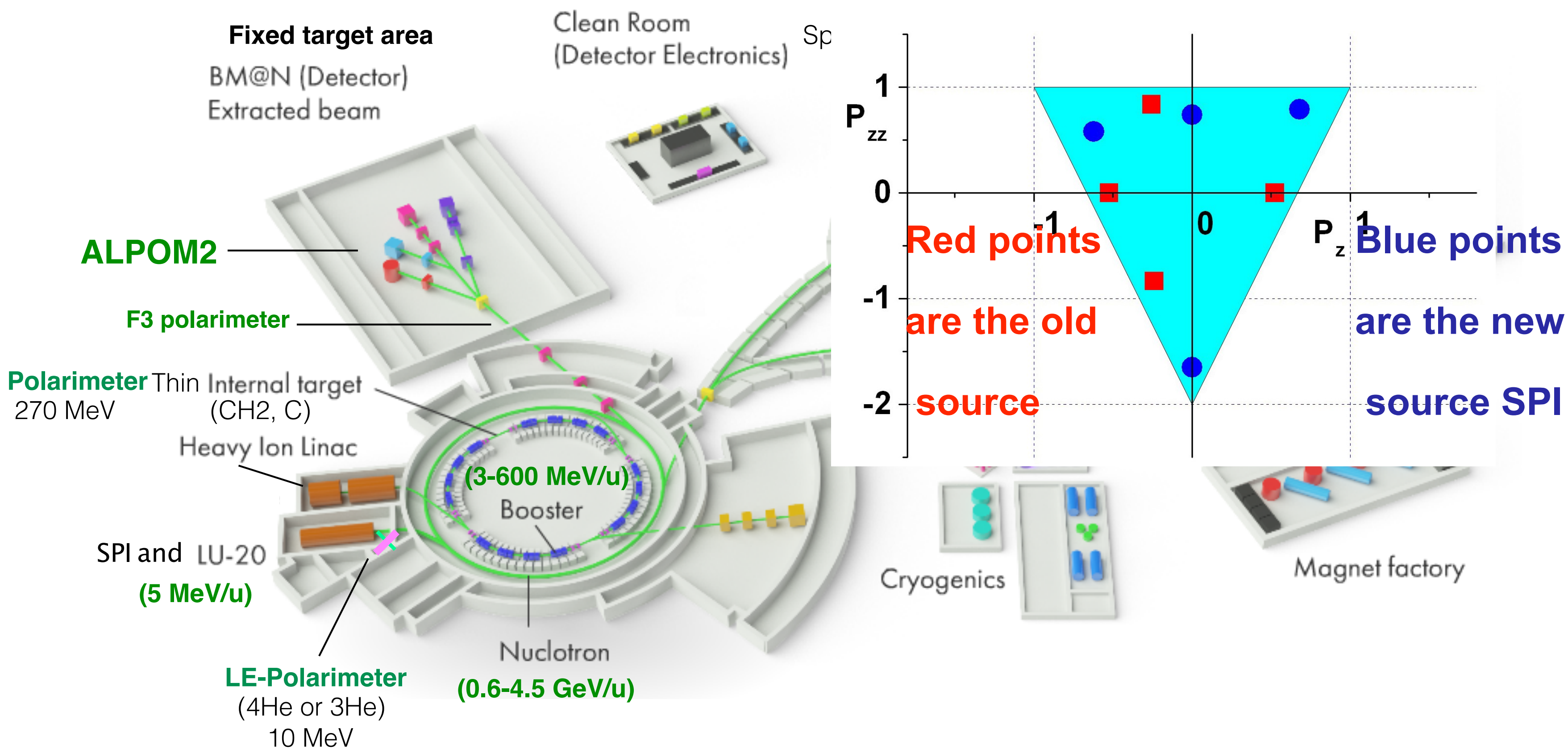
np → np elastic scattering
(zero exchange)
np → pn
(charge exchange)

Figure of merit (100% efficiency)

From 1 to 5 GeV/c, ZE has larger Figure of merit due to its larger total cross section. After 5 GeV, as cross section becomes really small, figure of merit is dominated by analyzing power, then CE becomes bigger.



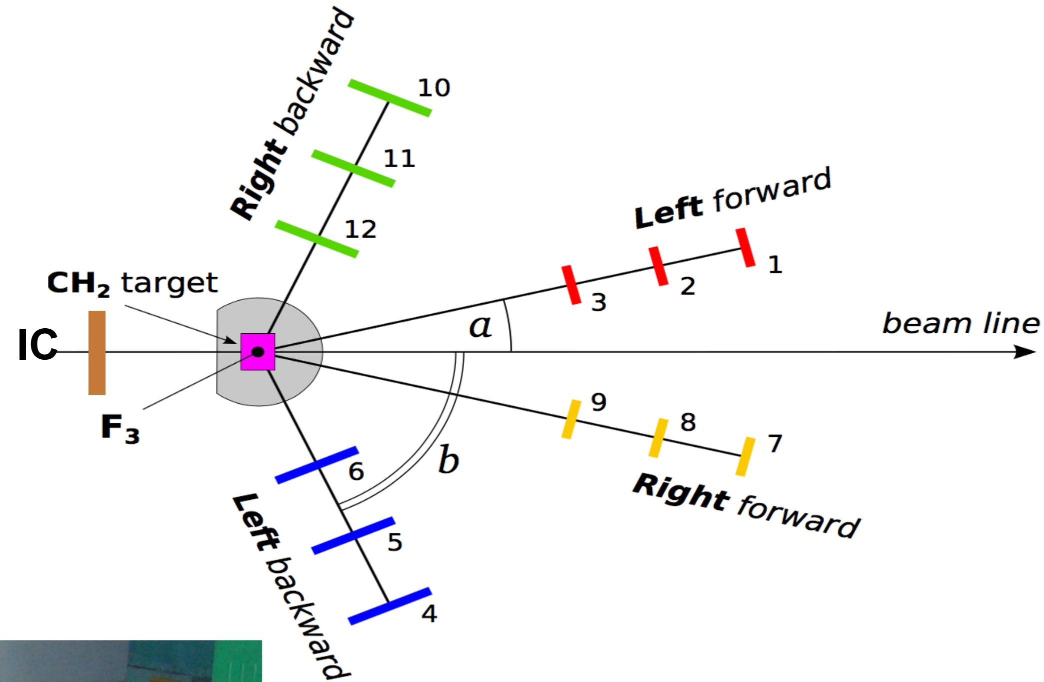
ALPOM2 @Nuclotron



Polarized neutrons and protons are obtained from the Nuclotron deuteron beam with momentum up to 13 GeV/c that undergoes a breakup reaction through a 8 cm thick Be target, installed about 100 m upstream of the polarimeter.

Beam polarization measurement

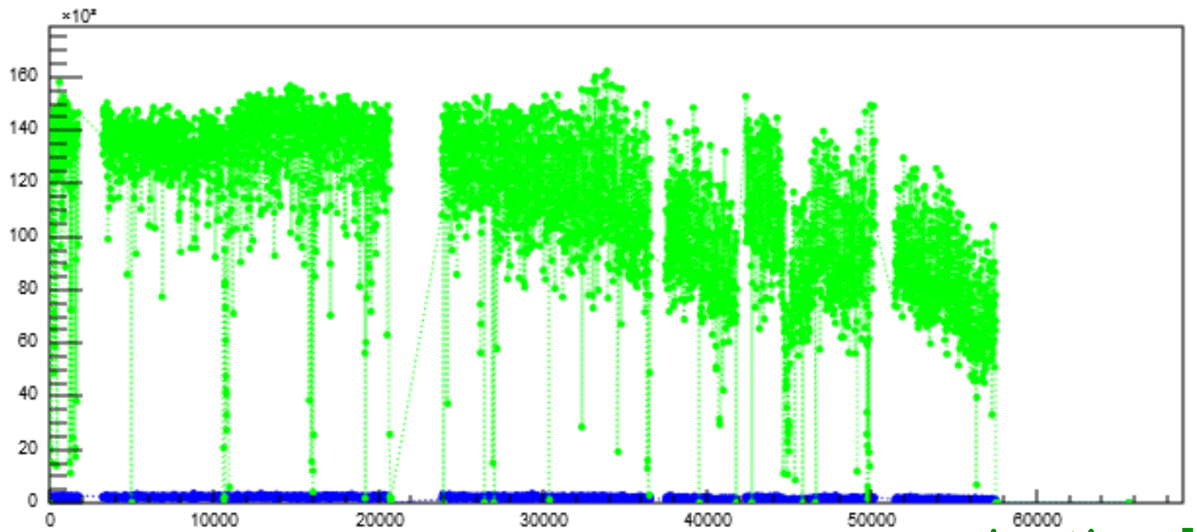
F3 Polarimeter



by Shindin Roman

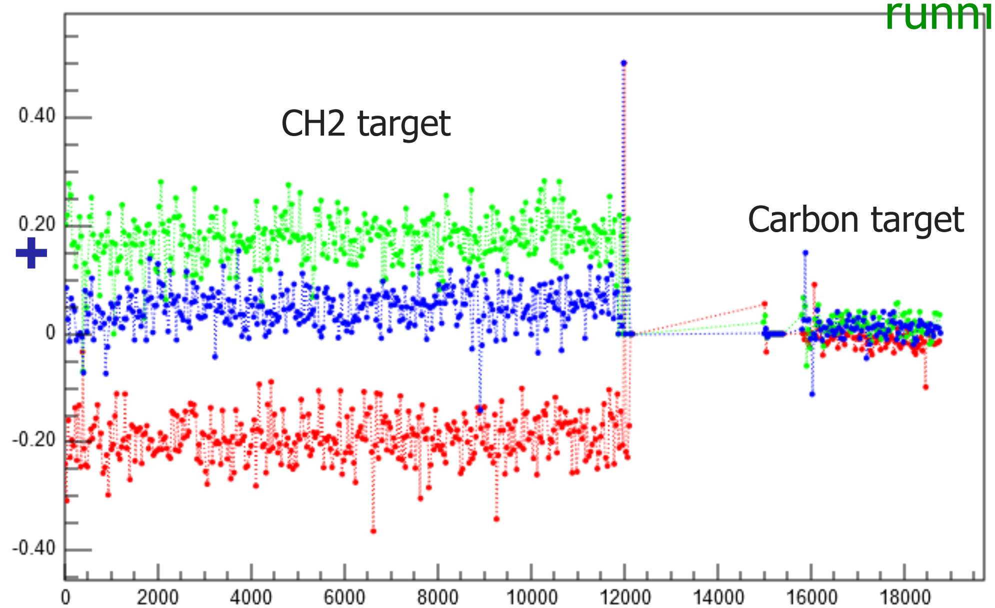
Online Beam monitor

Beam stability



When P=3.75 GeV/c

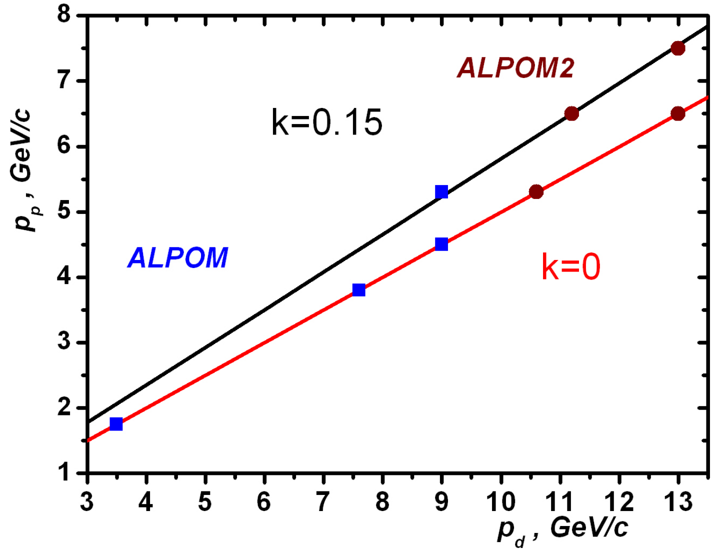
$A_y = 0.2$ +/- 8% **pol +**



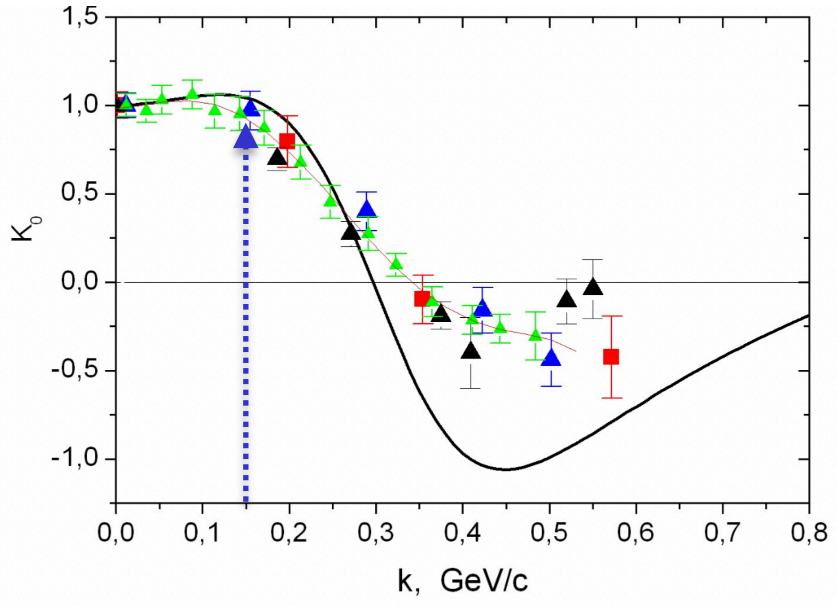
$$P^{+} = 0.593 \pm 0.005 \pm 0.047,$$
$$P^{-} = -0.302 \pm 0.006 \pm 0.024.$$

Beam production from deuteron breakup

Momentum transfer



Polarization transfer coefficient



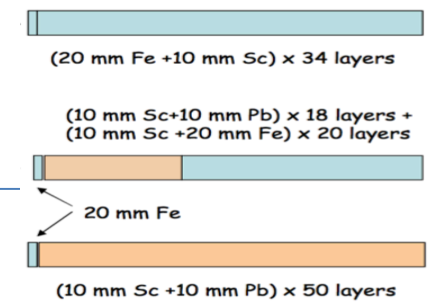
$$\kappa = \sqrt{\frac{m^2}{4\alpha(1-\alpha)} - m^2},$$

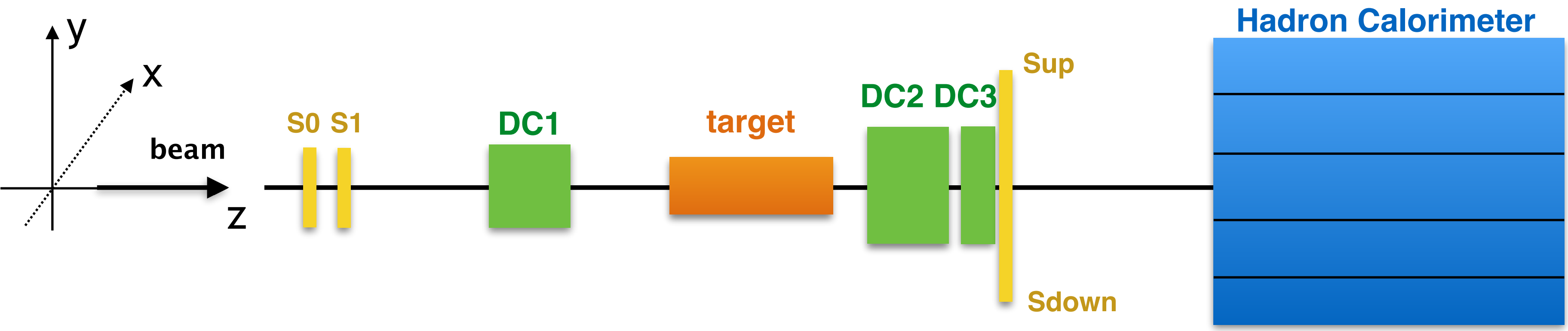
$$\alpha = \frac{E_p + p_{||}}{E_d + p_d},$$

Ep proton energy
pll longitudinal momentum

It is known from previous measurement that the polarization is totally transferred to the proton and neutron from the breakup, even for momenta larger than half of the deuteron momentum.

ALPOM2 setup





Trigger for neutron beam:

active target, Sup, Sdown, and IC.

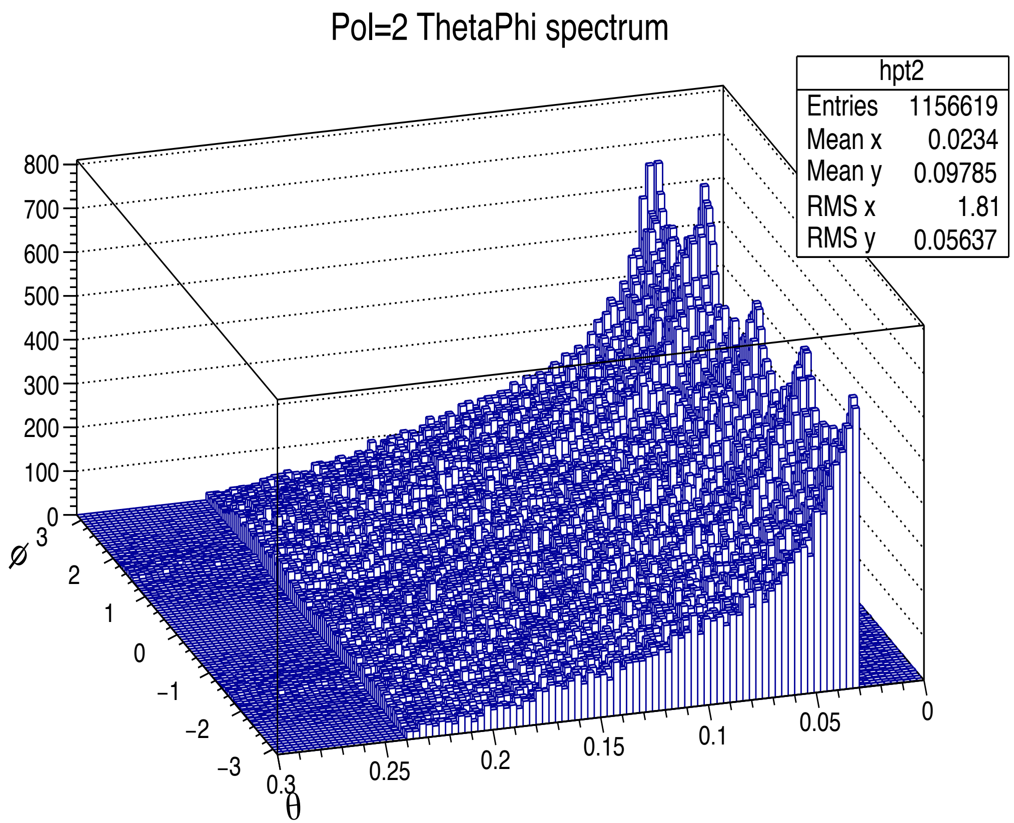
Trigger for proton beam:

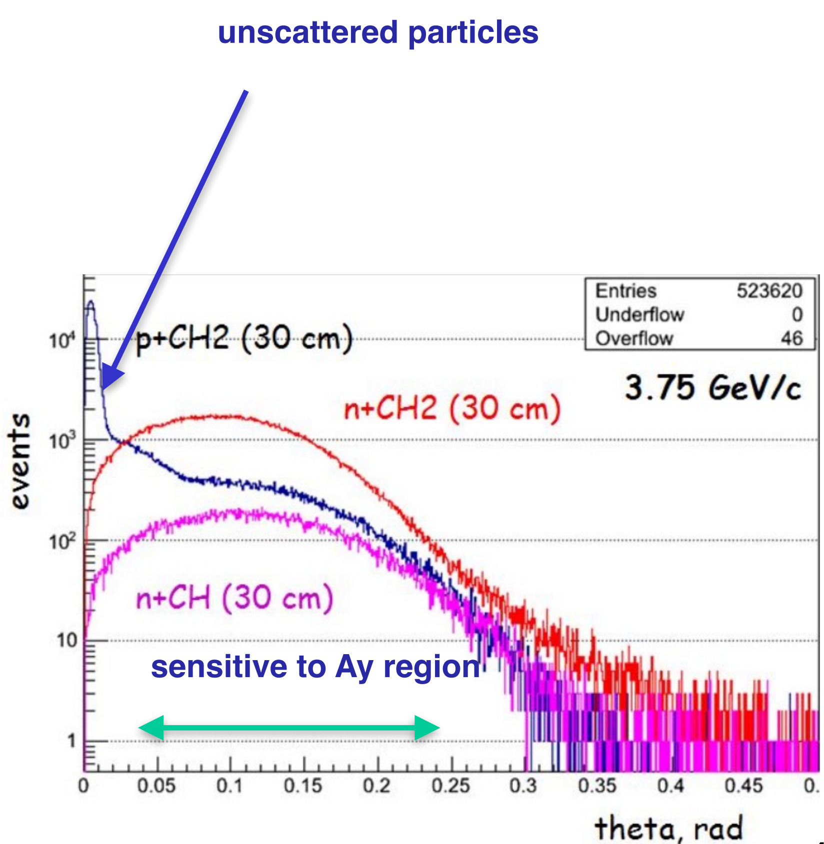
S0, S1, Sup, Sdown.

Active target CH (CH2, Cu)
For neutron (proton) Ay measurement

Hadron calorimeter with the scintillator uses moduli of different size and composition at different distance around the beam axis

Particle distribution (θ, φ)

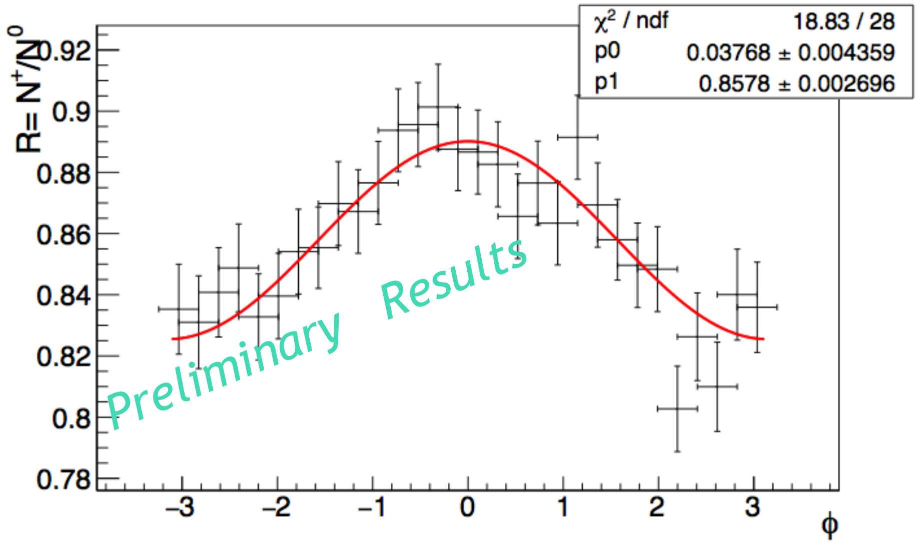




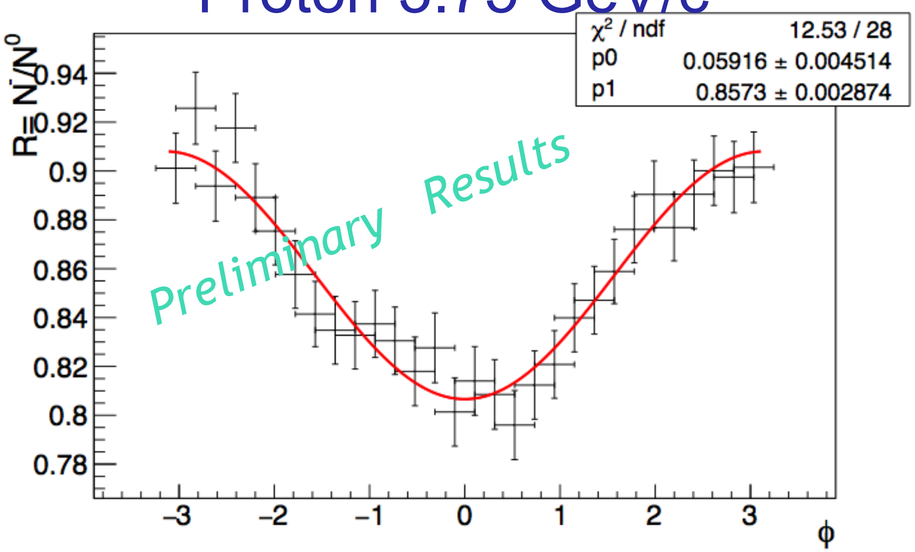
So cut off the region

θ <0.03 and θ>0.24.

Extraction of Analyzing power



Proton 3.75 GeV/c



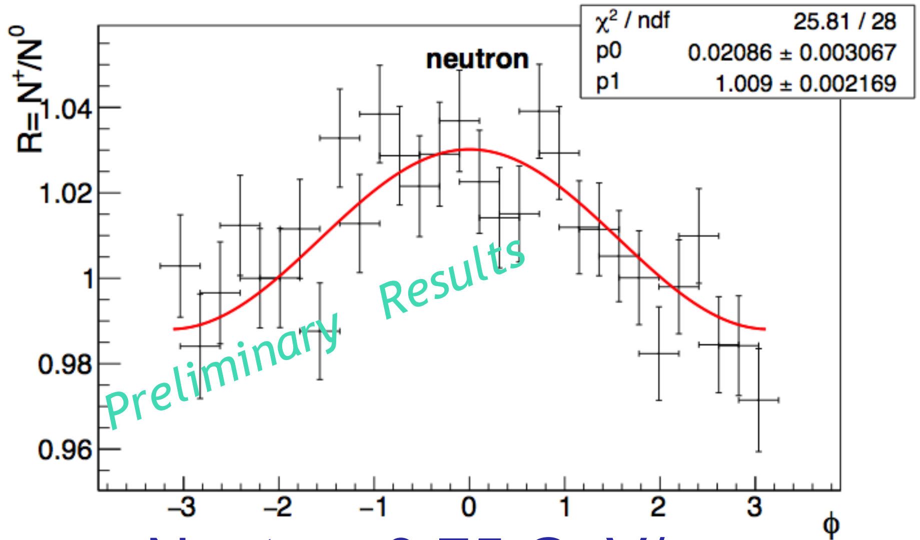
$$\frac{N^+}{N_0} = \frac{N_0^+}{N_0}(1 + |P^+| A \cos\phi),$$
$$\frac{N^-}{N_0} = \frac{N_0^-}{N_0}(1 - |P^-| A \cos\phi),$$

$$\Delta R = \frac{\sqrt{N^\pm \cdot (N^\pm / N_0 + 1)}}{N^\pm}.$$

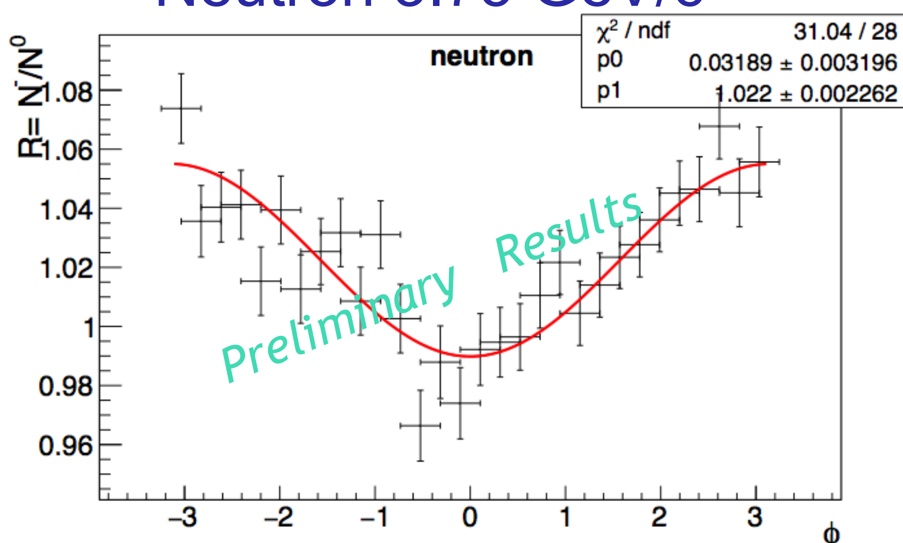
Extraction of Analyzing power

$$\frac{N^+}{N_0} = \frac{N_0^+}{N_0}(1 + |P^+|A\cos\phi),$$
$$\frac{N^-}{N_0} = \frac{N_0^-}{N_0}(1 - |P^-|A\cos\phi),$$

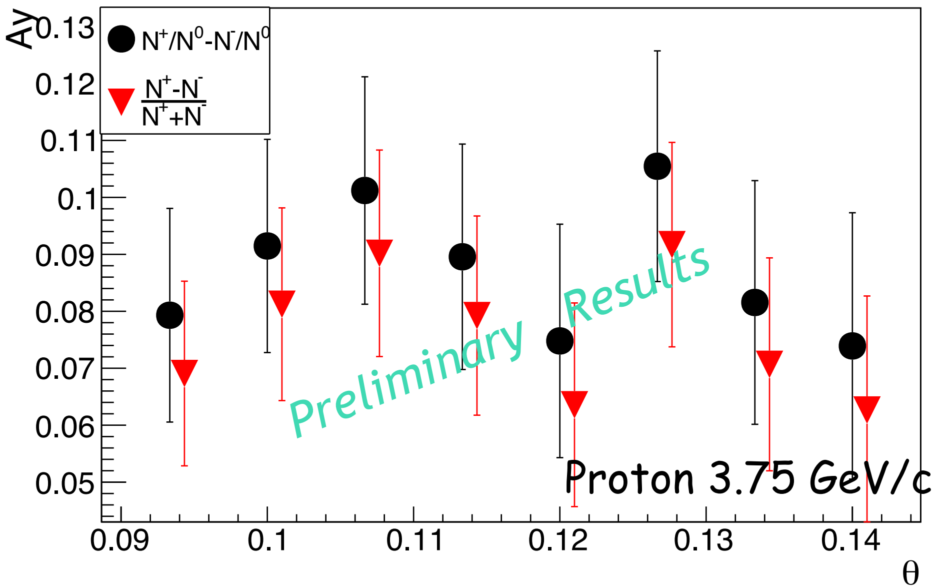
$$\Delta R = \frac{\sqrt{N^\pm \cdot (N^\pm/N_0 + 1)}}{N^\pm}.$$

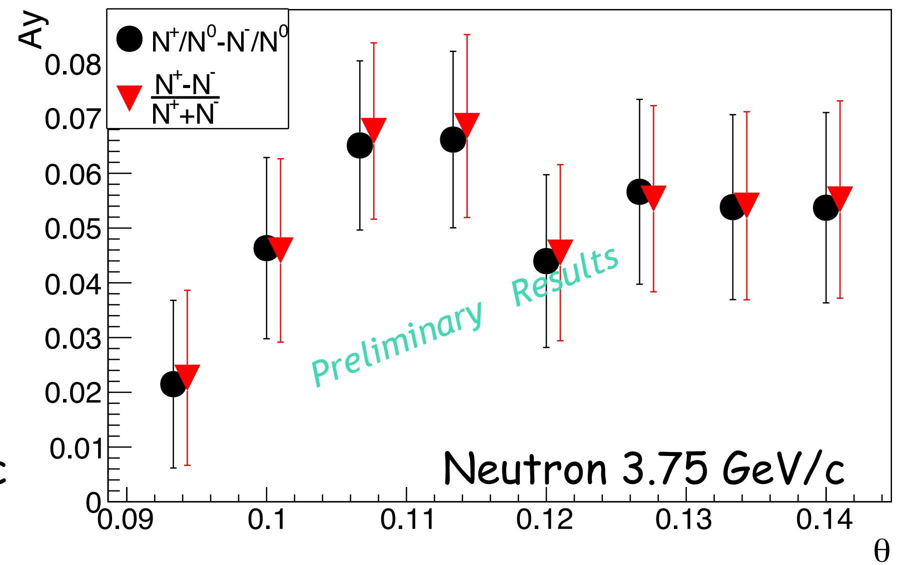


Neutron 3.75 GeV/c



Analyzing power





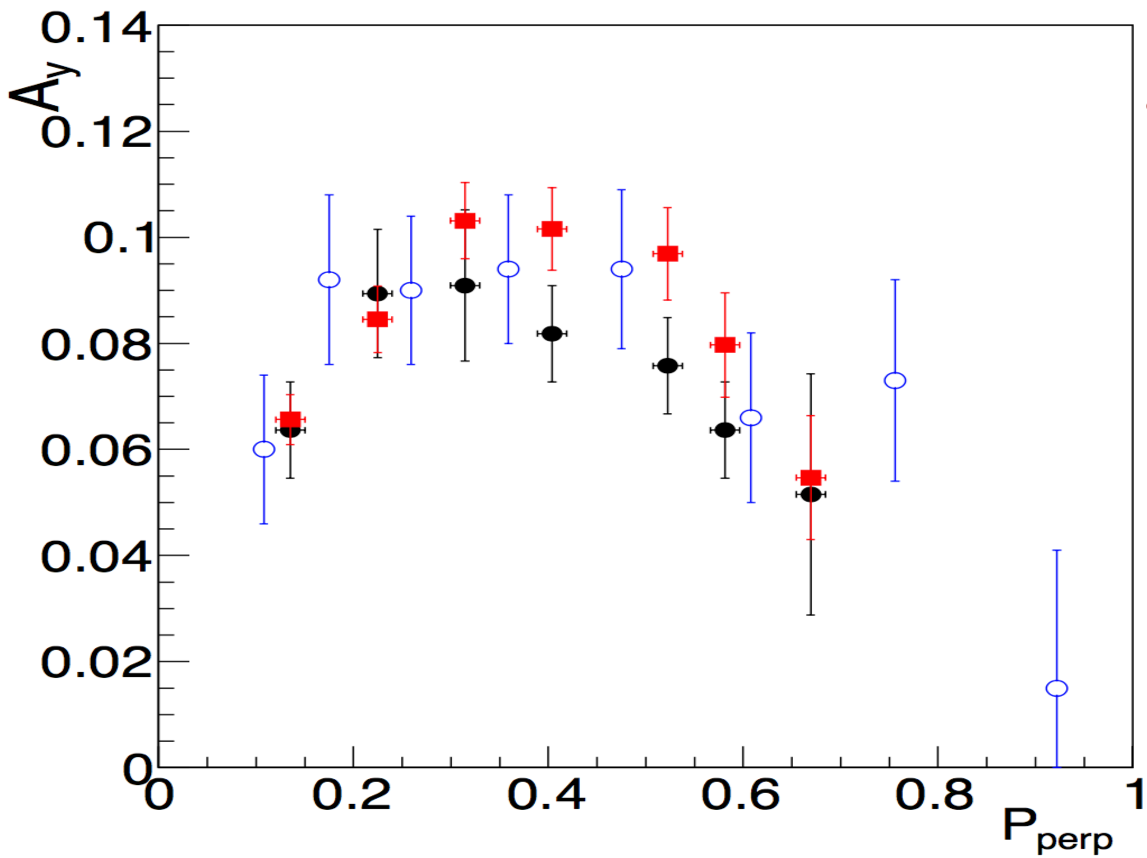
$$R_1 = \frac{a-b}{c} = \frac{N^+ - N^-}{N_0} = A\cos\phi(|P^+| + |P^-|)$$

$$R_2 = \frac{a-b}{a+b} = \frac{N^+ - N^-}{N^+ + N^-} = \frac{A\cos\phi(|P^+| + |P^-|)}{2 + A\cos\phi(|P^+| - |P^-|)}$$

$$\begin{aligned}\Delta R_1 &= \sqrt{(\frac{\partial R_1}{\partial a})^2 \cdot \Delta a^2 + (\frac{\partial R_1}{\partial b})^2 \cdot \Delta b^2 + (\frac{\partial R_1}{\partial c})^2 \cdot \Delta c^2} \\ &= \sqrt{\frac{a+b}{c^2} + \frac{(-a+b)^2}{c^3}}\end{aligned}$$

$$\begin{aligned}\Delta R_2 &= \sqrt{(\frac{\partial R_2}{\partial a})^2 \cdot \Delta a^2 + (\frac{\partial R_2}{\partial b})^2 \cdot \Delta b^2} \\ &= \sqrt{\frac{4ab}{a+b} \cdot \frac{1}{a+b}}\end{aligned}$$

Comparison of analyzing powers from ALPOM2 and ALPOM



- The full symbols from ALPOM2
- The empty symbols from ALPOM

Summary Part II

- We have done the measurement of proton and neutron analyzing power at 3.0, 3.75, and 4.2 GeV/c

  Proton: more precise results have been achieved

  Neutron: the analyzing power on C, CH has been measured for the first time.

Next:

Measurement for higher momenta up to 7.5 GeV/c proton and 5.3 GeV/c neutron has required in the proposal will be performed soon.

Thank you!