Aspects of Nucleon form factors measurements:

- Phenomenological study of proton anti-proton annihilation into light meson pairs
- Contribution to ALPOM2 experiment

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The electromagnetic FFs: GE and GM
- Inside structure of nucleon
  Spatial distributions of charge and magnetization current inside the nucleon.

How to measure?
Can be approached from two sides within one photon exchange assumption

1. Space-like region (SL)
   \[ ep \rightarrow ep \]

2. Time-like region (TL)
   \[ \bar{p}p \rightarrow e^+ e^- \rightarrow \bar{p}p \]
Content

Time-like region ($\bar{p} p \rightarrow e^+ e^-$)
PANDA experiment

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

Space-like region ($e^- p \rightarrow e^- p$)
Experiment preparation ALPOM2

- Experimental prediction for $np \rightarrow np$ (pn)
Motivation of my work

- The reaction $\bar{p}p \rightarrow e^+e^-$ allows to measure electromagnetic proton form factors.
- Important simulation work is under way.
- The reaction $\bar{p}p \rightarrow \pi^+\pi^-$ 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 $\bar{p}p \rightarrow \pi^+\pi^-$. 
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.

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

\[ p + \bar{p} \rightarrow \pi^0 + \pi^0, \eta + \pi^0, \eta + \eta, \pi^0 + \gamma, \gamma + \gamma \]

Energy under 2.911 GeV

Sum of resonances:

\[ T_{L,J} = \sum_{i=1} G_i B_L(p) B_J(q) \exp(i\phi_i) \frac{M_i^2 - s - iM_i \Gamma_i}{M_i^2 - s} \]
Calculation $pp \rightarrow \pi^0\pi^0$

Differential cross section

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

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

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

Add Regge factors and form factors (compositeness of particles, absorption, ISI, FSI...)

$$R_N(t) = \left( \frac{s}{p_3} \right)^{\frac{1}{2}} P_2 \left( \frac{t - M_p^2}{M_p^2} \right)$$

$$R_\Delta(u) = \left( \frac{s}{p_3} \right)^{\frac{3}{2}} P_4 \left( \frac{t - M_\Delta^2}{M_\Delta^2} \right)$$
our fit of $\pi^0\pi^0$

Data from T. A. Amstrong al. PRD(56) 5 1997
Test of quark counting

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

n total number of leptons, photons and quark components

Reaction \( pp \rightarrow \pi^0\pi^0 \)

\[ n = n_l + n_f = 2 \times (3 + 2) = 10 \]
\[ 2 - n = -8 \]

\[ d\sigma/dt \sim s^{-8} f(t/s) \]
Π and η mesons are pseudoscalar mesons. The decay to ηη can be described from π^0π^0 using the well-known decomposition of singlet and octet states, where the mixing angle is Θ ≈ 40°.

\[ \eta \approx \frac{(u\bar{u} + d\bar{d})}{\sqrt{2}} + s\bar{s} \]

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

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

\[ f(\eta\eta) = f(\pi^0\pi^0) \cos^2 \Theta \]
\[ p p \rightarrow \eta \pi^0 \]
II part
ALPOM2 experiment
Hadron form factor measurement

**Polarized ep elastic scattering**

\[ \frac{G_E}{G_M} = -\frac{P_t}{P_\ell} \left( \frac{E_e + E'_e}{2M_p} \right) \tan \left( \frac{\theta_e}{2} \right) \]

1st step: measure the proton analyzing powers (Ay) in GeV region

*(Analyzing power is the Polarization of the beam)*

ALPOM2 (JINR- Dubna):

p+CH2 → One Charge particle + X

np → p n (np)
Introduction of ALPOM2

- Polarized protons will be produced by the fragmentation of the polarized deuteron beam
- Protons interact with activated target CH2
- Through the drift chambers to reconstruct the trajectories
- Finally the particles will be detected by the hadron calorimeter
Differential cross section of np → np(pn)

Red circles are from experiment, and the red line represents Zero-exchange (ZE) and the blue line is Charge-exchange (CE).

\[
\frac{d\sigma}{dt} = \frac{1}{64\pi s q^2} (|T_\pi(u) + T_\rho(u)|^2 + \frac{1}{4}|T_\pi(t) + T_\rho(t)|^2 + |T_P(t)|^2)
\]
Analyzing power and Figure of Merit

\[ \mathcal{F}^2(\cos \theta) = A_y^2(\cos \theta) \cdot \frac{d\sigma / d\cos \theta}{\sigma_{tot}}. \]

**The statistical error**

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

*Figure of Merit considered both cross section and the analyzing power.*

*It can predict the statistical error when you know the experiment condition.*

*Also it can help to decide which energy which reaction to have better expected data.*
Summary

I) We have built a promising model based on effective lagrangian to describe 2 meson production in pbar p annihilation
- Parameters fixed on π^0π^0
- Neutral channel obtained from SU3 symmetry: η η, η π^0
- Encouraging results on angular distributions and the expected s dependence have been obtained

II) Calculation of Figure of Merit for proton and neutron polarimetry at 7.5 GeV/c momentum and comparison of the elastic and charge exchange reactions np->np(pn) for JLAB experiments.
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!