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Recent results in the deuteron break-up with high momentum transfer at COSY

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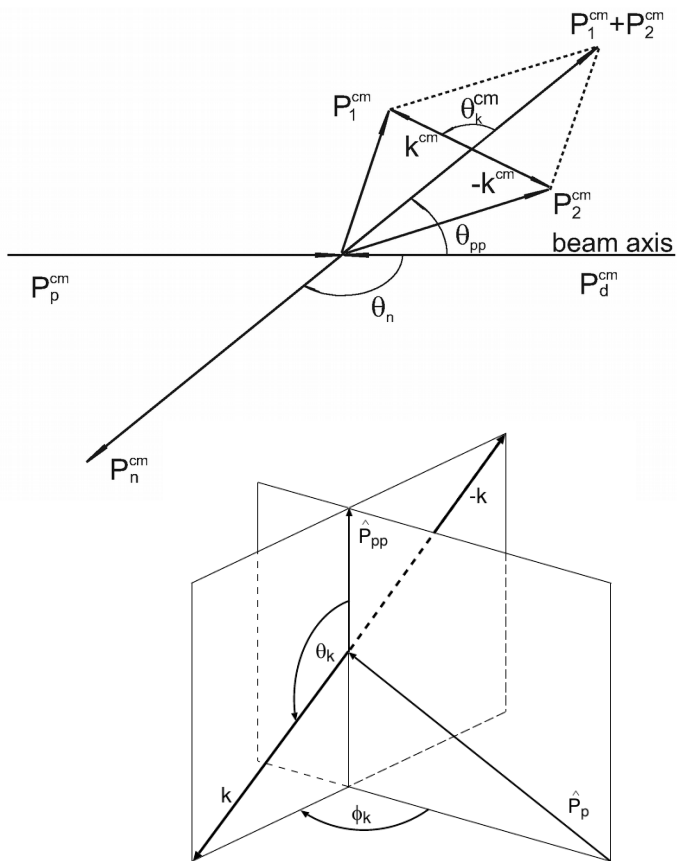
10 September 2018

SPIN 2018, Ferrara

Introduction: two nucleon systems

Deuteron ($pd \rightarrow dp$) : bound (p+n) system, very well studied

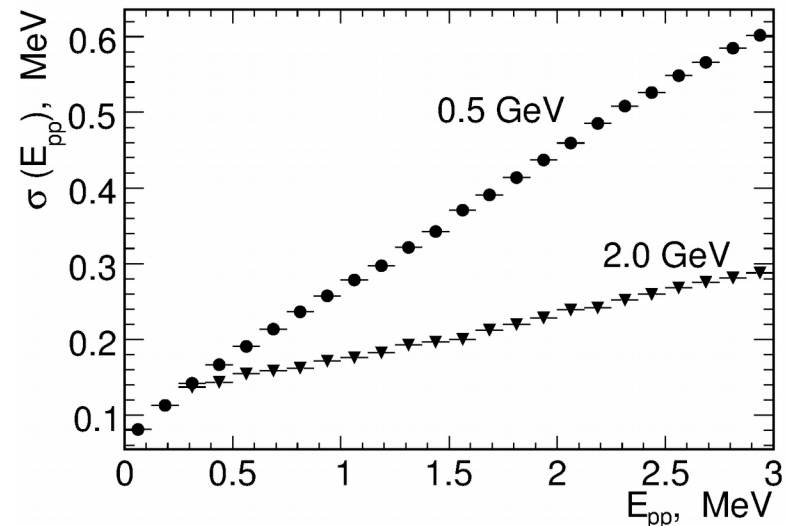
Diproton ($pd \rightarrow \{pp\}_s n$): free $\{pp\}$ -pair in 1S_0 state, $E_{pp} < 3$ MeV



1S_0 state:

- Isotropy in $\{pp\}$ - rest frame
- pp Final State Interaction (Migdal-Watson final state interaction factor)

Resolution in $\{pp\}$ excitation energy



Introduction: reactions with diprotons at ANKE

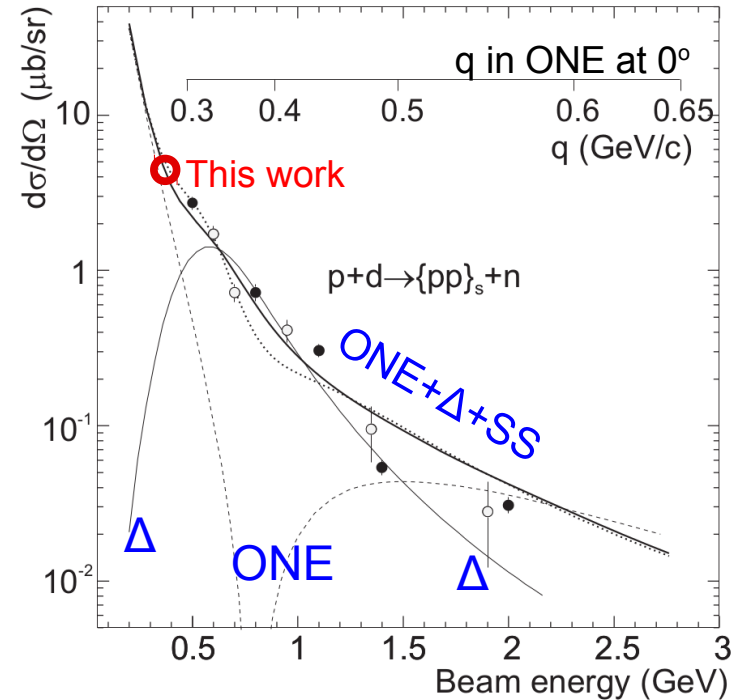
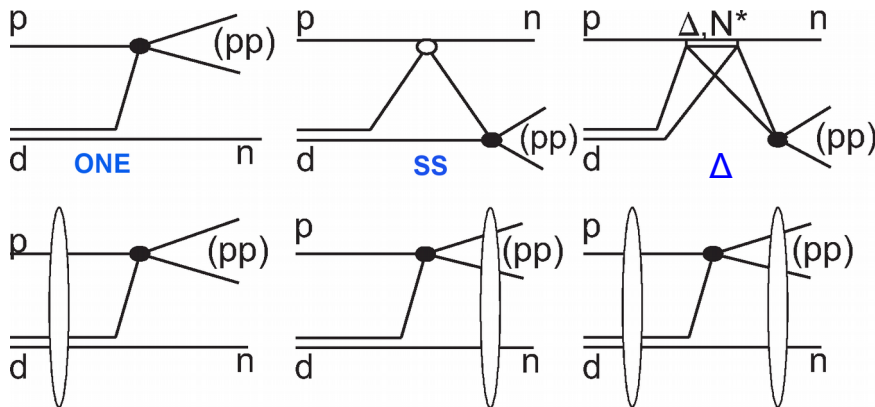
- d-breakup $\vec{p}d \rightarrow \{pp\}_s (0^0) n$ at high momentum transfer (short range NN)
- $\vec{d}p \rightarrow \{pp\}_s (0^0) n$ at low momentum transfer (pn CE amplitudes)
- $dp \rightarrow \{pp\}_s (0^0) \Delta^0$

- meson production in $pN \rightarrow \{pp\}_s X$
 - $X=\pi$
 - $\vec{p}p \rightarrow \{pp\}_s \pi^0$ at $T_p = 0.5 - 2.4$ GeV
 - $\vec{p}N \rightarrow \{pp\}_s \pi$ near threshold (χ PT contact interaction)
 - $X=(2\pi)$ (ABC effect in pp collisions)
 - $X=\eta, \omega$

- inverse diproton photodisintegration $pp \rightarrow \{pp\}_s \gamma$

D-breakup at high momentum transfer

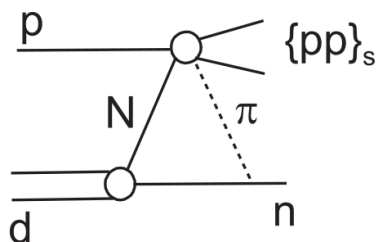
- Motivated by study of short range NN-interactions in backward elastic $pd \rightarrow dp$ scattering
- One nuclear exchange (ONE) + Δ excitation + Single Scattering (SS) model developed for $pd \rightarrow dp$ (Uzikov, Yu. N, *Yad. Fiz.*, 1997, 60, 1603)
- $pd \rightarrow \{pp\}_s(0^\circ)n$ has same kinematics as $pd \rightarrow dp$, same model applied
- Δ contribution suppressed by 1/9 in cross section \rightarrow short range NN



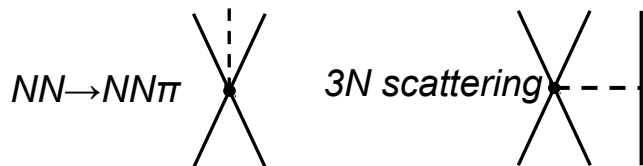
S. Dymov et al., *PRC* 81, 044001 (2010)

Connection with χ PT

D-breakup can be described with triangle diagram with subprocesses $pn \rightarrow \{pp\}_s \pi^-$ and $pp \rightarrow \{pp\}_s \pi^0$



The p-wave amplitudes in $pn \rightarrow \{pp\}_s \pi^-$ give access to the $4N\pi$ contact operator in χ PT, controlled by the *low energy constant d*.



LEC d connects different low-energy reactions:

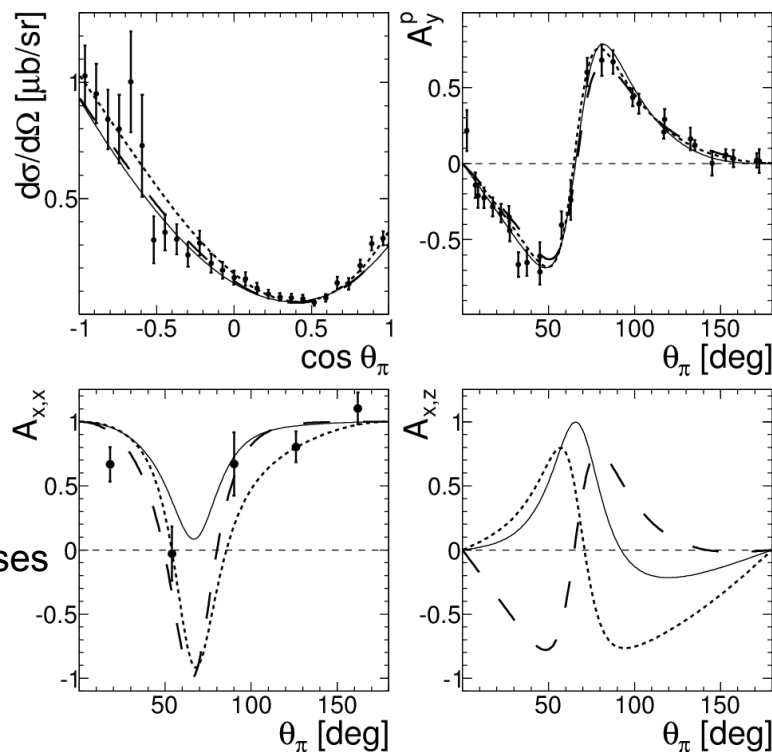
$pp \rightarrow de^+ \nu$, $pd \rightarrow pd$, $\gamma d \rightarrow nn \pi^+$

The goal to compare d extracted from different processes

PWA of ANKE data on $pp \rightarrow \{pp\}_s \pi^0$ and $pn \rightarrow \{pp\}_s \pi^-$ yielded three solutions.

Data on $pd \rightarrow \{pp\}_s n$ at 353 MeV may resolve this ambiguity

$pn \rightarrow \{pp\}_s \pi^-$ at 353 MeV (ANKE)



D. Tsirkov et al., PLB 712, 370 (2012)

S. Dymov et al., PRC 88, 014001 (2013)

Experiment

Polarized proton beam: $T_p=353 \text{ MeV}$, $P_y=63\%$, spin flipped every cycle (5 min)

D_2 cluster jet target: $d=5 \cdot 10^{14} \text{ cm}^{-2}$

Luminosity: $L=2.3 \text{ pb}^{-1}$

Polarimetry, normalization: $pn \rightarrow d\pi^0$

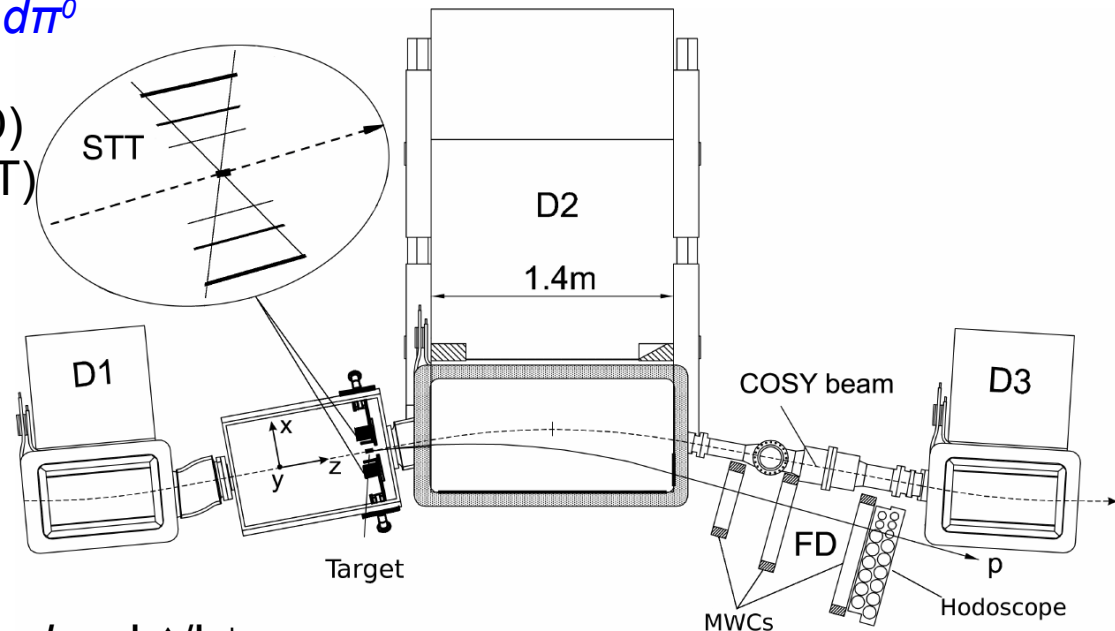
Detectors: Forward detector (FD)
Silicon tracking telescope (STT)

$pd \rightarrow \{pp\}_s n$:

$\{pp\}$ -pairs detected in FD

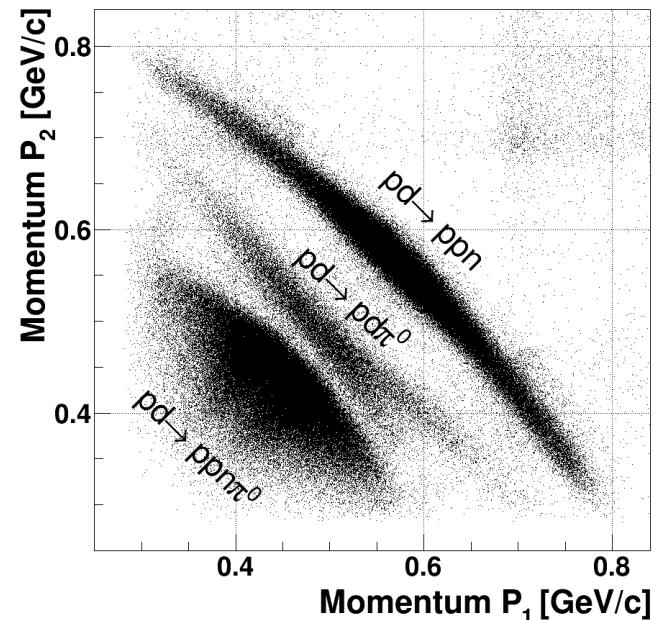
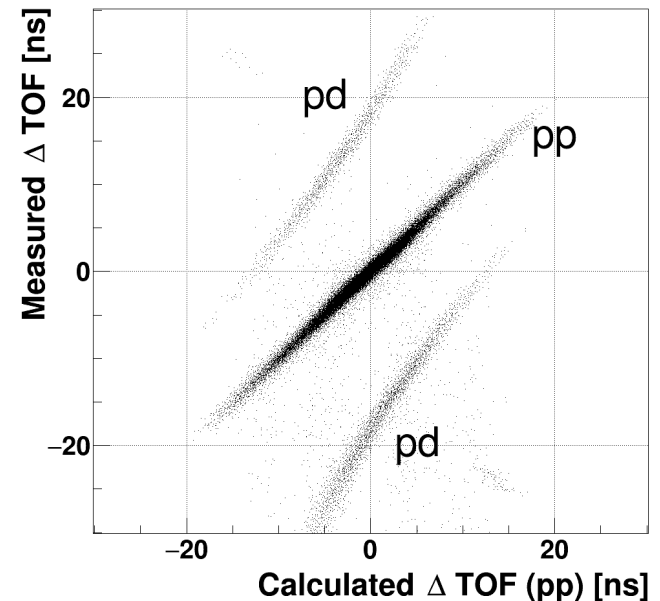
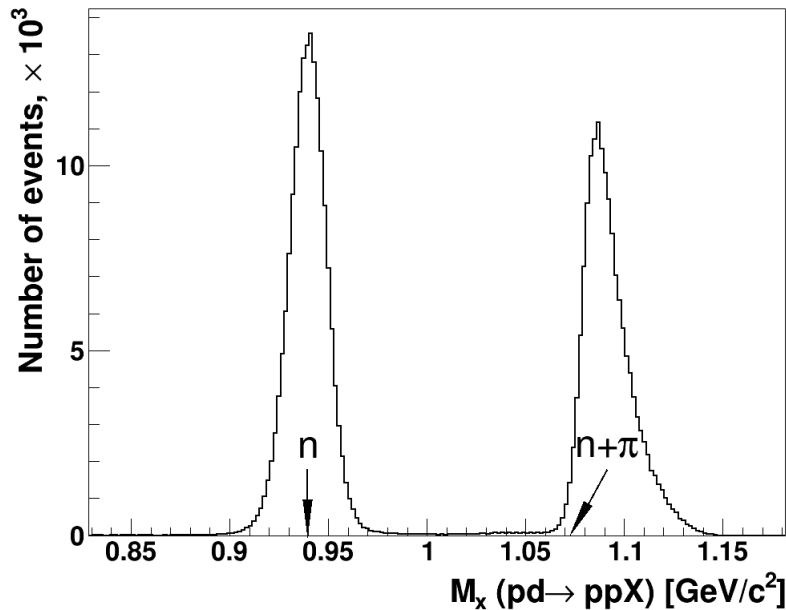
Quasi-free $pn + p_{\text{spec}} \rightarrow d\pi^0 + p_{\text{spec}}$:
deuteron in FD, p_{spec} in STT

Relative normalization of spin modes $L_{\uparrow}/L_{\downarrow}$:
events emitted at $\theta=0^\circ$ or $\varphi=\pm 90^\circ$



Selection of $pd \rightarrow \{pp\}_s n$

- Proton pairs in the forward detector (FD) selected by the difference of arrival times in the hodoscope and by the energy loss
- Two track events in FD show correlation of particle momenta in the narrow forward cone of the FD acceptance
- $pd \rightarrow \{pp\}_s n$ selected among pp -pairs by missing mass $M_x = M_n$
- Cut on excitation energy $E_{pp} < 3$ MeV applied to select 1S_0 $\{pp\}$ state

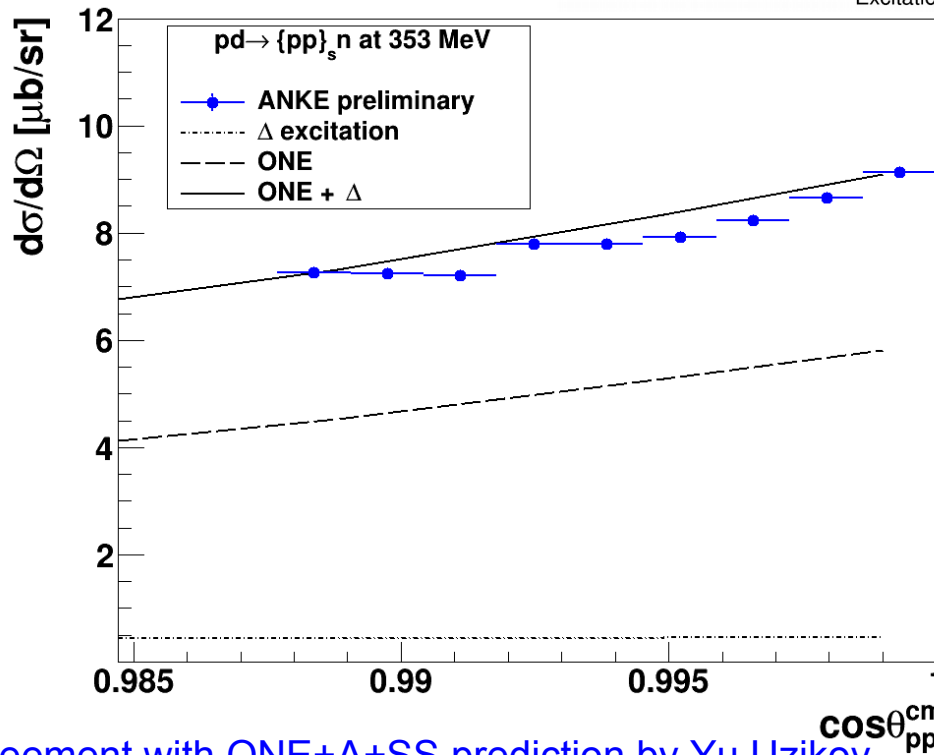
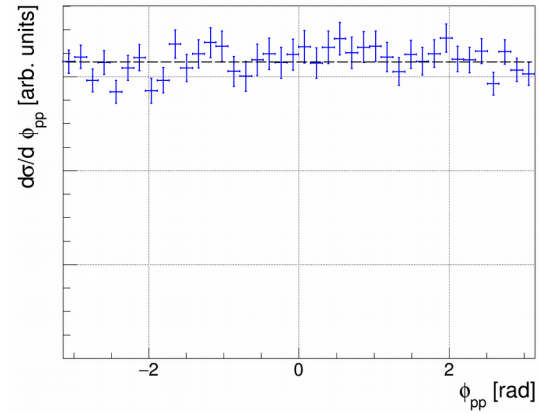
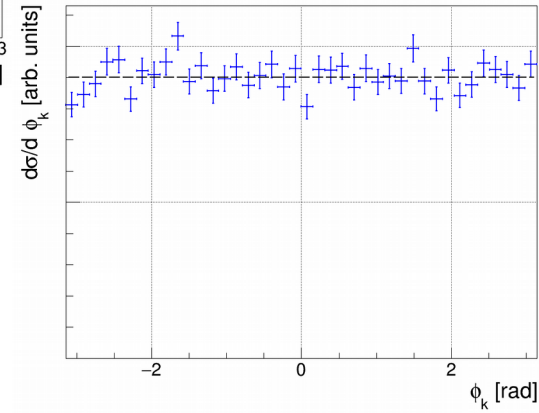
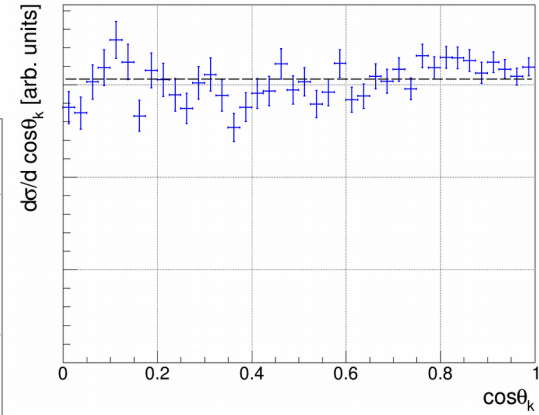
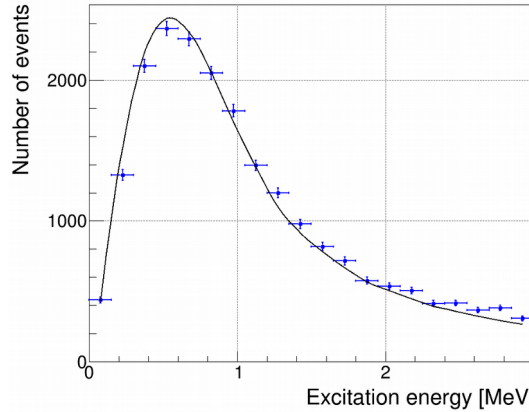


Results: cross section

Confirmation of 1S_0 $\{pp\}$ -pair state:

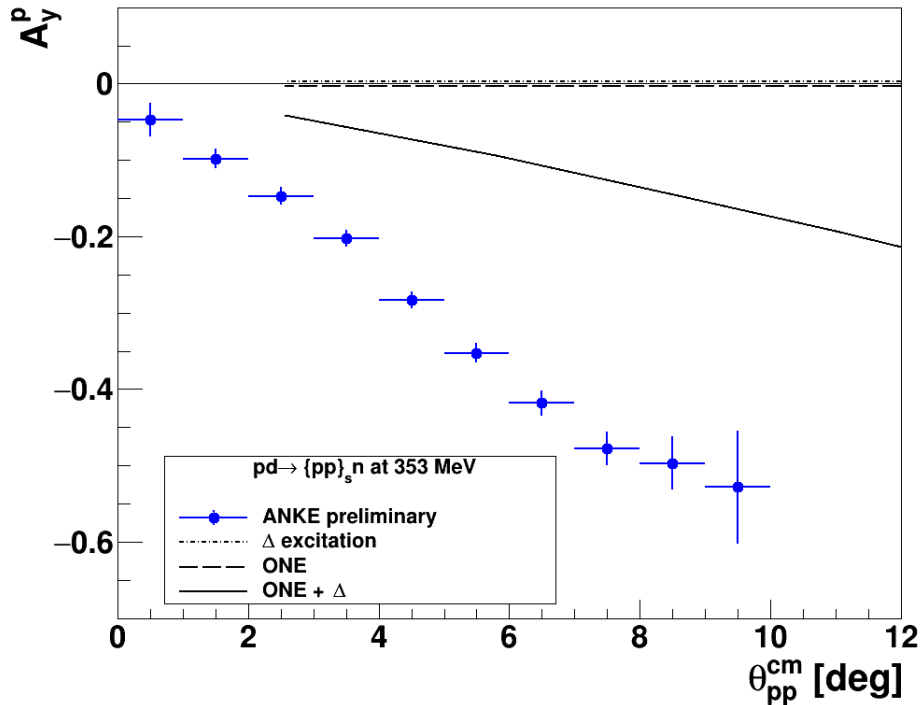
- E_{pp} distribution follows *Migdal-Watson factor* of pp FSI in S-wave
- Isotropy in pp rest frame: flat $\cos\theta_k, \phi_k$

Beam spin averaging: flat ϕ_{pp}



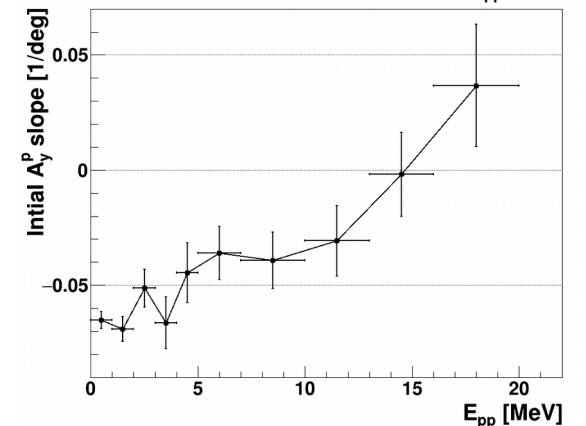
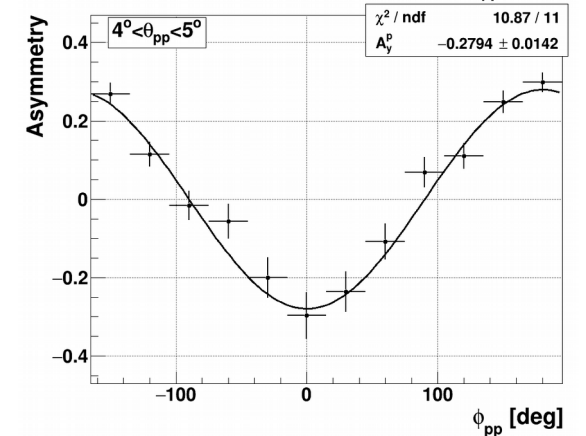
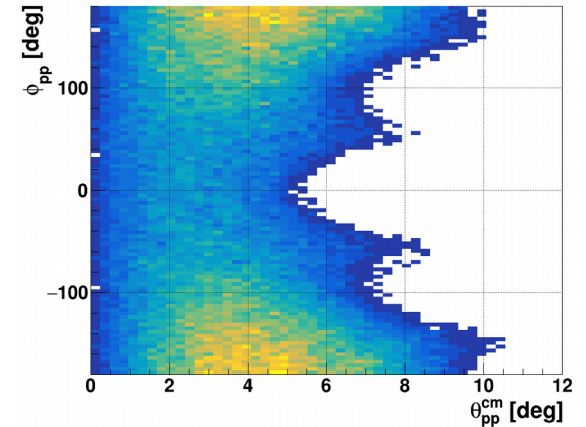
Good agreement with ONE+ Δ +SS prediction by Yu.Uzikov

Results: proton analyzing power



- Data show a very fast rise of A_y^p in forward direction
- Initial A_y^p slope is constant at $E_{pp} < 5$ MeV, increases as higher partial waves added
- Both ONE and Δ separately produce nearly zero A_y^p
- Sizable values appear only due to their interference
- Deviation from data due to uncertainty in the spin structure of Δ contribution

Model calculations: Yu. Uzikov



Summary

- $d\sigma/d\Omega_{pp}$ and A_y^p measured in $\vec{p}d \rightarrow \{pp\}_s n$ at 353 MeV in the range $\theta_{pp} < 10^\circ$
- 1S_0 state of pp -pair at excitation energy $E_{pp} < 3$ MeV is confirmed
- $d\sigma/d\Omega_{pp}$ agrees with prediction of ONE+ Δ +SS model, dominance of ONE at 353 MeV is confirmed
- Very large signal of A_y^p observed at forward θ_{pp}^{cm} , the model describes the sign of A_y^p but diverges in the value
- The new data may resolve ambiguity in the PWA of $pp \rightarrow \{pp\}_s \pi^0$ and $pn \rightarrow \{pp\}_s \pi^-$ near the threshold

Outlook

- Combined analysis of d-breakup and pion production within pion exchange diagram
- T_{20}, T_{22} from $\vec{d}p \rightarrow \{pp\}_s (180^\circ)n$ ANKE measurements at $T_d = 1.2-2.27$ GeV

Thank you!

Contents

Introduction

- ANKE @ COSY
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Near threshold pion production at ANKE

- Motivation for $pN \rightarrow pp \pi$ with diproton FS from ChPT
- ANKE exp. program for $pn \rightarrow \{pp\}_s \pi^-$ and $pp \rightarrow \{pp\}_s \pi^0$
- Preliminary results for $d\sigma/d\Omega$ and A_y^p
- Future measurement of $A_{x,x}$ and $A_{y,y}$

Summary