

# Hadron physics with di-proton final states

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# Introduction

Two nucleon systems:

- **Deuteron**: very well studied
- **Diproton**:  $\{pp\}$ -pair in  $^1S_0$  state,  $E_{pp} < 3 \text{ MeV}$

## Diproton programme at ANKE

- d-breakup at low and high momentum transfer
- meson production
- inverse diproton photodisintegration

**Pion production** in  $\vec{p}N \rightarrow \{pp\}_s \pi$  interactions:

→  $d\sigma/d\Omega$  and  $A_y^p$  in  $\vec{pp} \rightarrow \{pp\}_s \pi^0$  at  $T_p = 353 - 2400 \text{ MeV}$

*insight into  $\Delta$ -N dynamics in pion production*

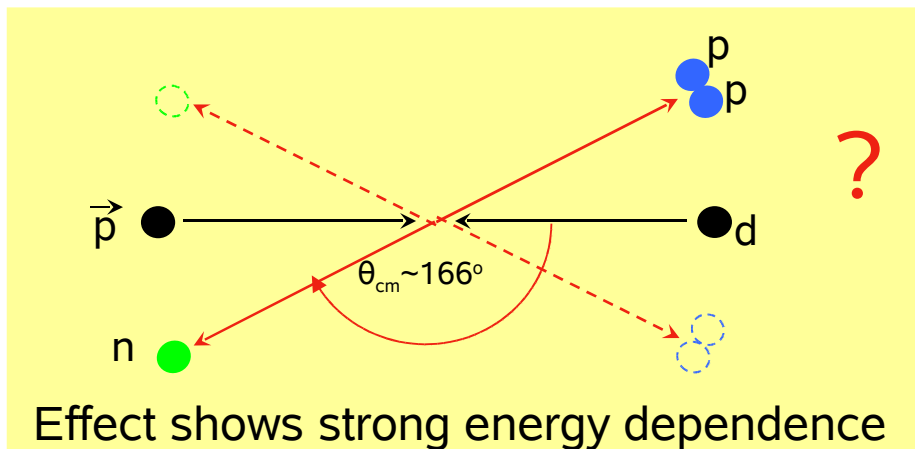
→  $d\sigma/d\Omega$  and  $A_y^p$  in  $\vec{pp} \rightarrow \{pp\}_s \pi^0$  and  $\vec{pn} \rightarrow \{pp\}_s \pi^-$  at 353 MeV

*the results will be of relevance for Chiral Perturbation Theory.*

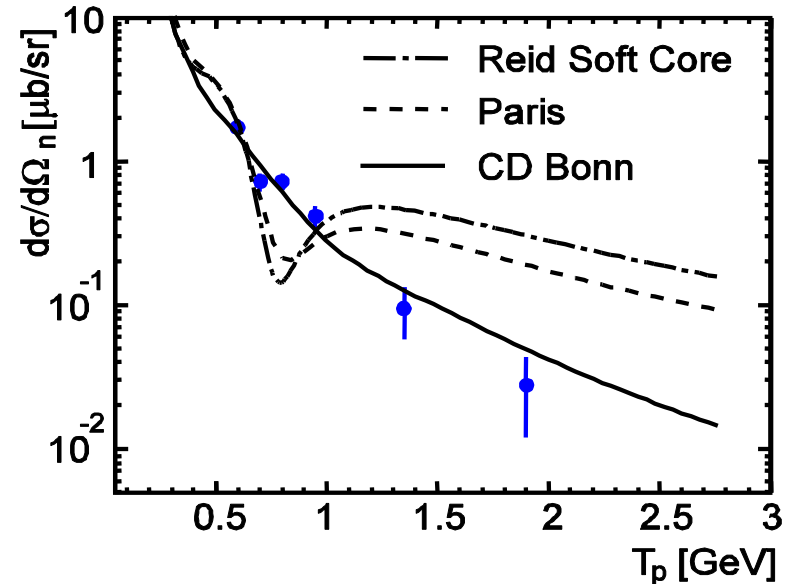
# d-breakup at high momentum transfer

## pd dynamics at high momentum transfer

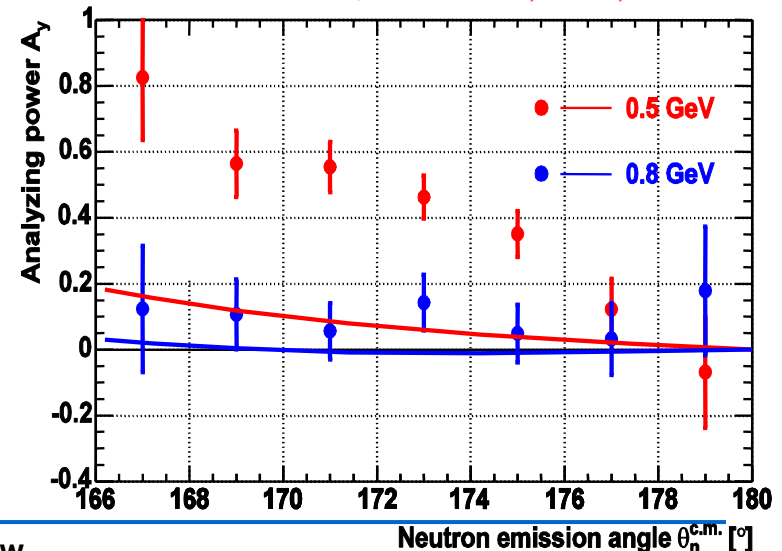
- $pd \rightarrow (pp)_s n$
- Kinematics like pd backward elastic
  - S-wave pp-pairs
  - Suppression of  $\Delta$
- Progress
  - Cross sections (✓)
  - Analyzing power  $A_y^p$  (✓)
  - **Future: Polarized target**
    - Analyzing power  $T_{20}$
    - Spin-Correlation parameters



V. Komarov et al., PL B 553 (2003) 179



S.Yaschenko et al., PRL 94 (2005) 072304



# d-breakup at low momentum transfer

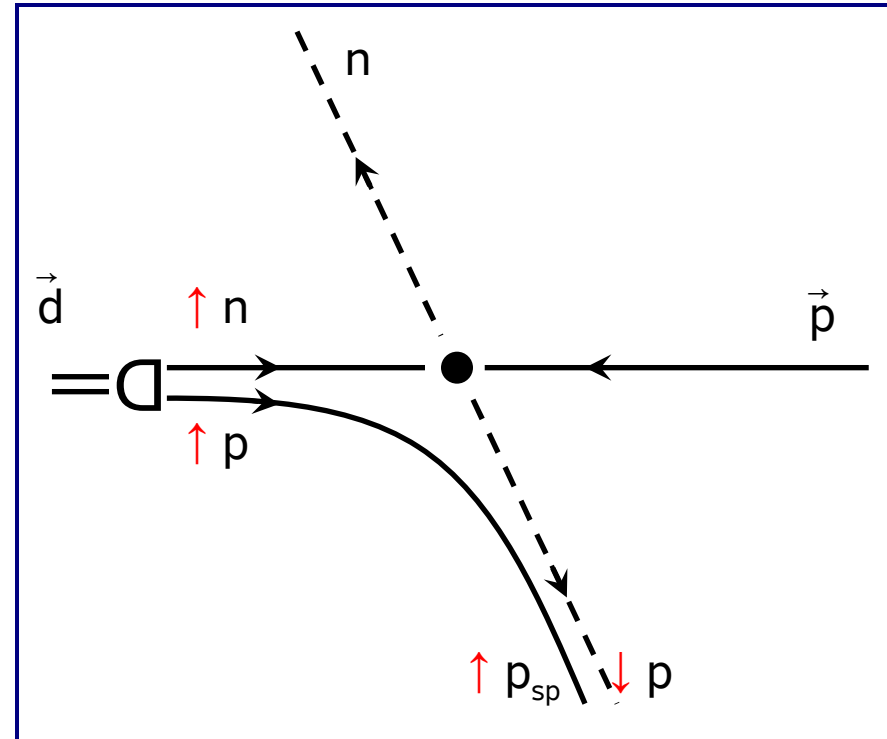
## np charge-exchange

deuteron beam:  $\vec{d}\vec{p} \rightarrow (pp)_{1S_0}n$

deuteron target:  $\vec{p}\vec{d} \rightarrow (pp)_{1S_0}n$

d beam: up to 1.1 GeV for np

d target: up to 2.8 GeV for pn



dp observables:  $d\sigma/d\Omega$ ,  $T_{20}$ ,  $T_{22}$ ,  $A_{y,y}$ , ...

quasi-free

np observables:  $A_y$ ,  $A_{yy}$ ,  $D_{yy}$ ,  $A_{xy,y}$ , ...

# d-breakup at low momentum transfer: analyzing powers

$$\vec{dp} \rightarrow (pp)_{1S_0} n$$

Transition from deuteron to  $(pp)_{1S_0}$ :

pn  $\rightarrow$  np spin flip

np spin-dependent amplitudes:

$$\frac{d\sigma}{dq}, T_{20}, T_{22} \Rightarrow |\gamma|^2 + |\beta|^2, |\delta|^2, |\epsilon|^2$$

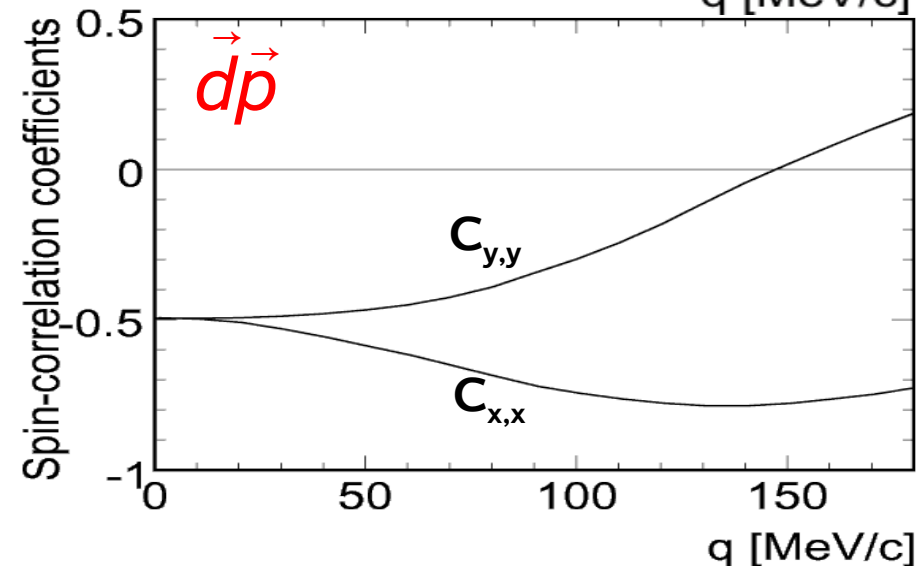
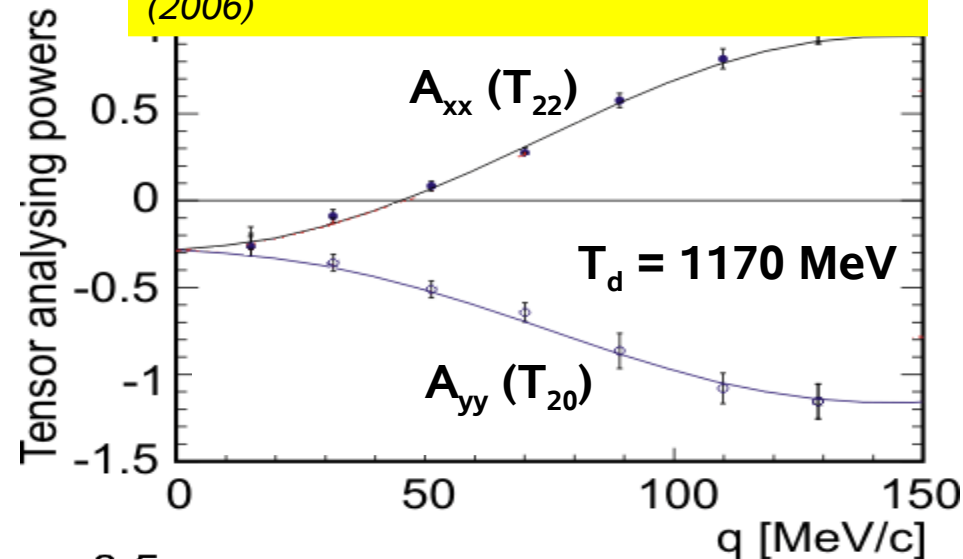
## Results:

- Method works at  $T_n = 585$  MeV
- Application to higher energies
- $T_d = 2.3$  GeV (*in progress*)

## Next step:

- Double polarized  $\rightarrow C_{y,y}, C_{x,x}$   
 $\Rightarrow$  relative phases

D.Chiladze et al. Phys. Let. B 637, 170 (2006)



# Pion production: motivation

- The final **di-protons** in  $pN \rightarrow \{pp\}_s \pi$  are in the  $^1S_0$  state.
- Spin structure of the  $pn \rightarrow \{pp\}_s \pi^-$  (or  $pp \rightarrow \{pp\}_s \pi^0$ ) is  $\frac{1}{2}^+ \frac{1}{2}^+ \rightarrow 0^+ 0^-$   
 only two spin amplitudes (compared to 6 for  $pp \rightarrow d\pi^+$ )

From this it follows that the measurement of

- the differential cross section,
- the analyzing power and
- one spin correlation coefficient

is sufficient to extract magnitudes of the two amplitudes and their relative phase.

## Near threshold region:

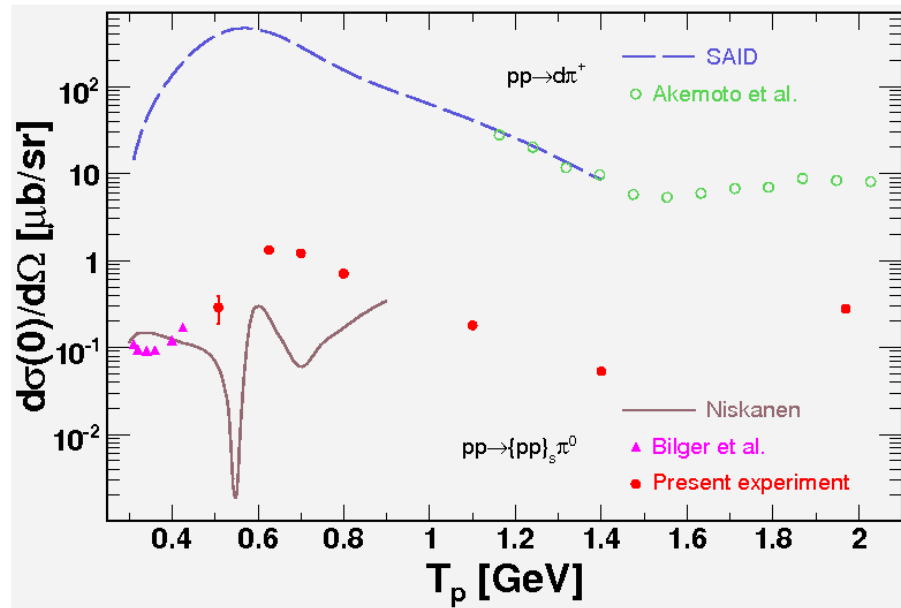
Combined study of several observables in  $pp \rightarrow \{pp\}_s \pi^0$  and  $np \rightarrow \{pp\}_s \pi^-$  could be used to isolate an important *strength parameter  $d$  of four-nucleon contact interaction in ChPT*.

$d\sigma/d\Omega$  in  $pp \rightarrow \{pp\}_s \pi^0$  measured at 353 MeV (Oct. 2007)

$d\sigma/d\Omega$  and  $A_y$  in  $pn \rightarrow \{pp\}_s \pi^-$  and  $pp \rightarrow \{pp\}_s \pi^0$  at 353 MeV  
are scheduled for 2009

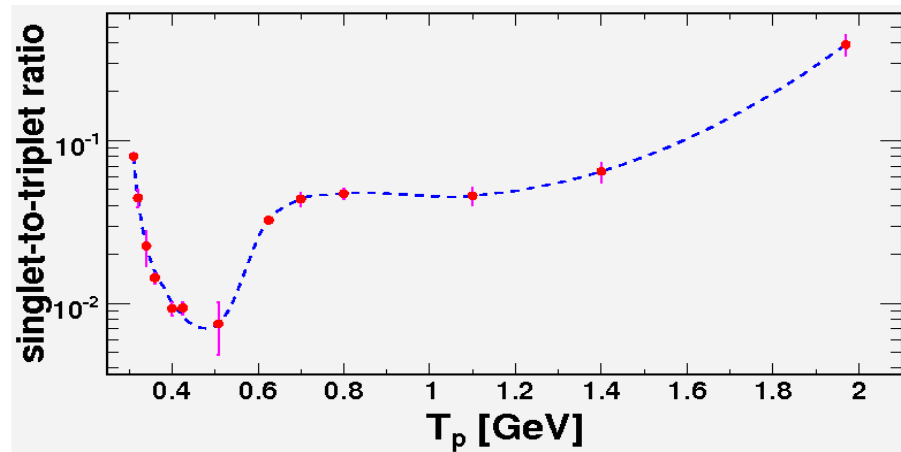
Next step: double-polarized experiment for  $A_{yy}, A_{xx}$

# Pion production in 0.5 – 2.0 GeV region



Forward cross-section extracted at  $T_p = 0.5, 0.6, 0.7, 0.8, 1.4$  and  $2$  GeV

*V. Kurbatov et al., PLB 661, 22-27 (2008)*

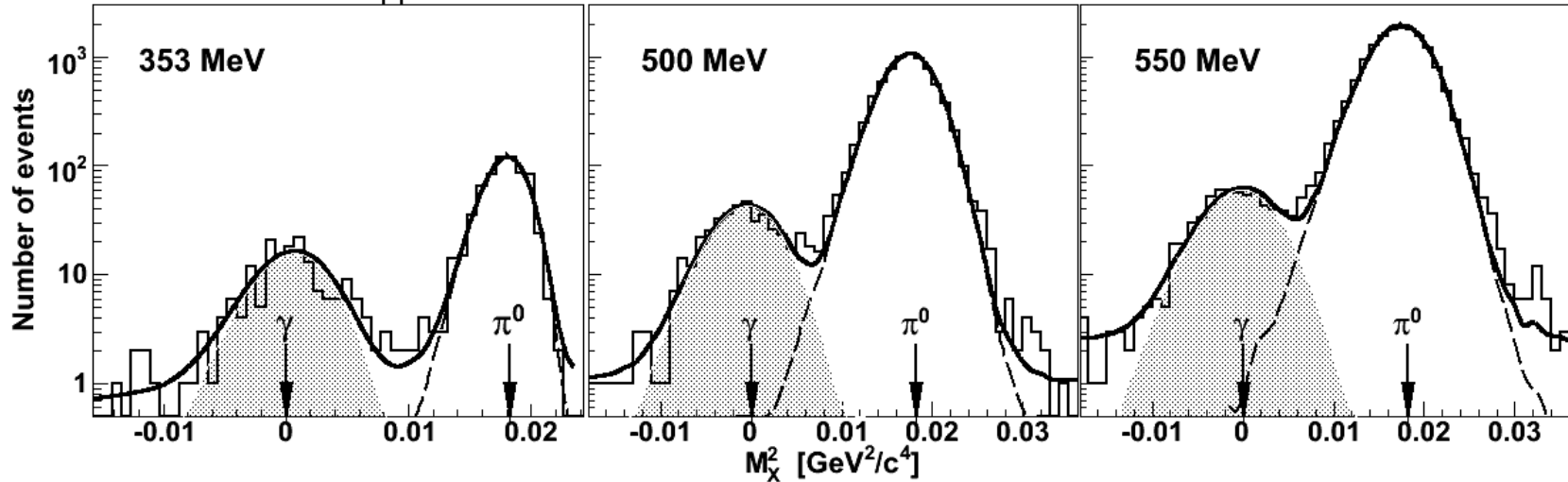


- FSI theory links  $pp \rightarrow d\pi^+$  to  $pp \rightarrow \{pn\}_t \pi^+$  at low  $E_{pn}$
- $\Delta N$  is suppressed for  $pp \rightarrow (pp)\pi^0$
- change of reaction mechanism above 1.5 GeV

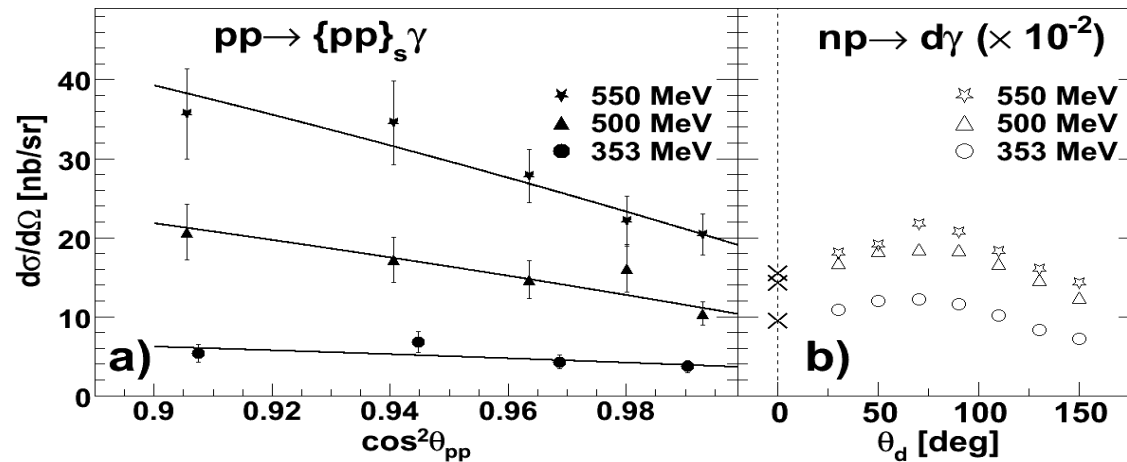
*The ratio is very low in 0.3 – 1.5 GeV range*

# New results: study of $pp \rightarrow \{pp\}_s \gamma$

$pp \rightarrow ppX$ ,  $E_{pp} < 3$  MeV



Extracted cross-section of  $pp \rightarrow \{pp\}_s \gamma$  (arXiv *nucl-ex/0806.0648*)



- rise with energy ( $\Delta$  ?)
- forward dip
- ratio  $\{pp\}/d$   $10^{-3} - 10^{-2}$

# Summary

- Selection of di-proton final state with  $E_{pp} < 3 \text{ MeV}$  gives  
*a new tool to study hadron interactions.*

- Results obtained include:

$d\sigma/d\Omega$  and  $A_y$  in high momentum transfer d-breakup

$A_y$ ,  $T_{20}$ ,  $A_{xx}$  and  $A_{yy}$  in charge-exchange d-breakup

energy dependence of  $d\sigma/d\Omega$  of  $pp \rightarrow \{pp\}_s \pi^0$

$d\sigma/d\Omega$  of  $pp \rightarrow \{pp\}_s \gamma$

published

submitted

- Future measurements and planned results:

$d\sigma/d\Omega$  in charge-exchange d-breakup

$T_{20}$  in high momentum transfer d-breakup

$d\sigma/d\Omega$  of  $pp \rightarrow \{pp\}_s (2\pi)$  (ABC effect)

analysis  
in progress

$d\sigma/d\Omega$ ,  $A_y$  and  $A_{yy}$  in  $pn \rightarrow \{pp\}_s \pi^-$  and  $pp \rightarrow \{pp\}_s \pi^0$  at 353 MeV

$A_y$  in  $pp \rightarrow \{pp\}_s \gamma$ , study of  $pp \rightarrow \{pp\}_s \eta$

scheduled

planned