JÜLICH
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Pion production in diproton reactions with polarized beams at ANKE-COSY

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for the ANKE collaboration

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- Double polarized experiment ($A_{x,x}$ and $A_{y,y}$)

Summary and outlook

Introduction: two nucleon systems

Deuteron: bound (p+n) system, very well studied

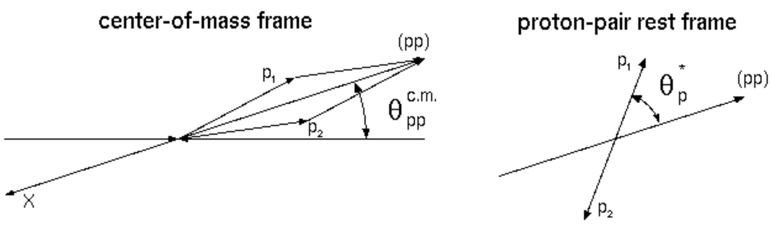
Di-proton $\{pp\}_s$: free {pp}-pair in $^1S_0$ state, $E_{pp} < 3$ MeV

S wave:

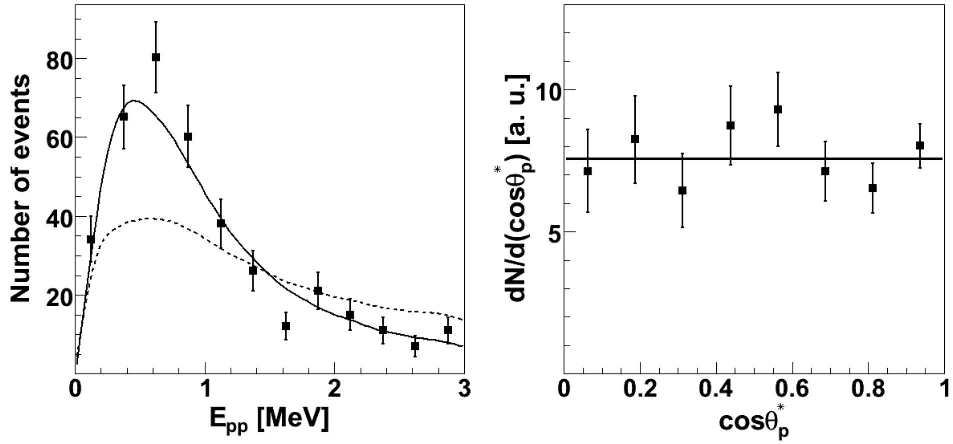
Isotropy in {pp} - rest frame

pp Final State Interaction

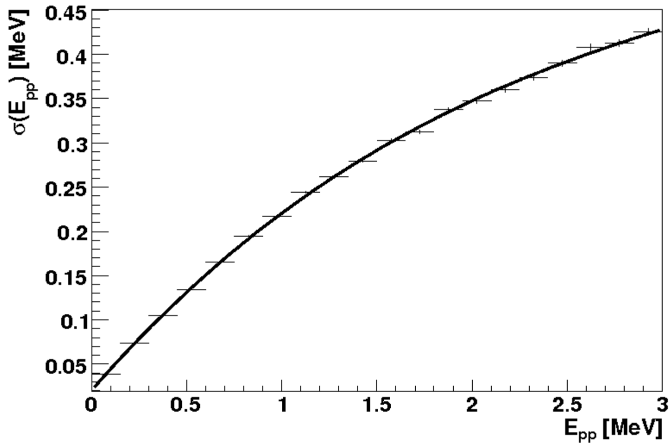
(Migdal-Watson FSI factor)



Example: $pp \rightarrow \{pp\}_s\gamma$ at 500 MeV



Excitation energy resolution



New tool to study hadron interactions

Pion production study at ANKE (1)

- Theoretical description of $pN \rightarrow pp\,\pi$ process is considerably simplified if two final protons are detected at low excitation energy, i.e. such di-protons are predominantly 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 $pp \rightarrow d\pi^+$)

$$\left(\frac{d\sigma}{d\Omega}\right)_0 = \frac{1}{4}(|A|^2 + |B|^2), \qquad A_y^p = A_y^Q = -\frac{2Im(A^*B)}{|A|^2 + |B|^2}$$

$$A_{xx} = -A_{zz} = \frac{|B|^2 - |A|^2}{|A|^2 + |B|^2}, \quad A_{yy} = 1, \quad A_{xz} = A_{zx} = -\frac{2Re(A^*B)}{|A|^2 + |B|^2}$$

From this it follows that the measurement of

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

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

Pion production at 353 MeV

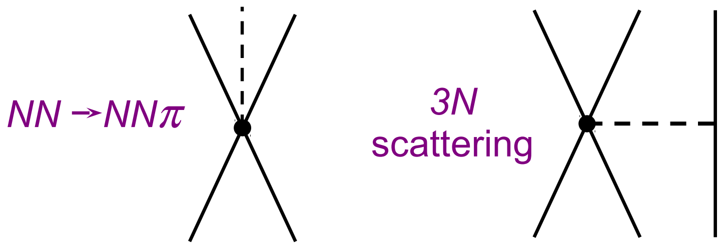
The experiments on $pp \to \{pp\}_s\pi^0$ in the 350 MeV region, taken in conjunction with $np \to \{pp\}_s\pi^-$, are particularly interesting because a valuable test of χPT could be deduced.

- ***Test of χPT predictions:***

A full data set of all observables would give the *partial wave amplitudes*
Transitions up to the pion d wave:
$pp \to \{pp\}_s\pi^0$ includes ${}^3P_0 \to {}^1S_0 s$, ${}^3P_2 \to {}^1S_0 d$ and ${}^3F_2 \to {}^1S_0 d$
$np \to \{pp\}_s\pi^-$ adds ${}^3S_1 \to {}^1S_0 p$ and ${}^3D_1 \to {}^1S_0 p$

- ***Extraction of χPT LEC from pion production***

(short range interactions in χPT)
The p-wave amplitudes give access to the 4Nπ contact operator, controlled by the *low energy constant d*.



LEC **d** *connects different low-energy reactions*: $pp \to de^+\nu$, $pd \to pd$, $\gamma d \to nn\pi^+$

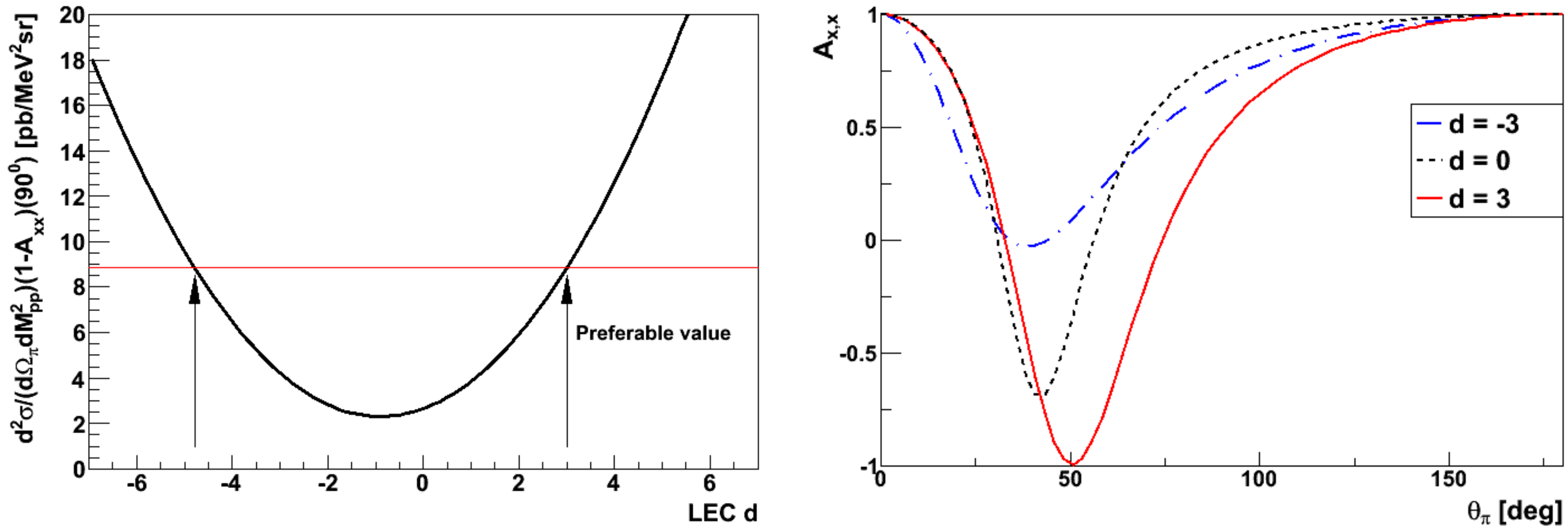
Accessing LEC *d* via $A_{x,x}$ and $d\sigma/d\Omega$

The *direct and most clean* way to access the *LEC d* is to measure *the cross section and the spin correlation coefficient* $A_{x,x}$ in $np \to \{pp\}_s\pi^-$:

$$(1-A_{x,x})d\sigma/d\Omega \sim |\delta|^2 k^2 \sin^2\theta, \qquad A_{y,y}=1$$

where δ is one of the p-wave amplitudes, containing the $4N\pi$ contact term

Only one factor $(1-A_{x,x})d\sigma/d\Omega(90^0)$ has to be extracted from the measurement.

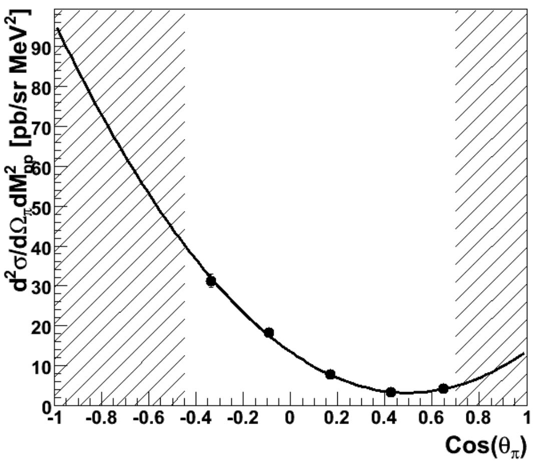


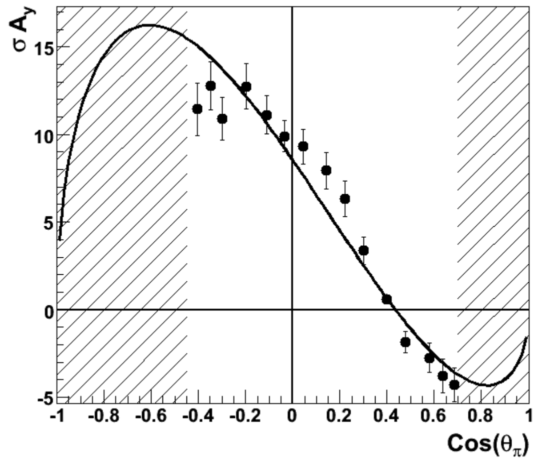
χPT calculation by FZ-Juelich IKP theory (V.Baru et al)

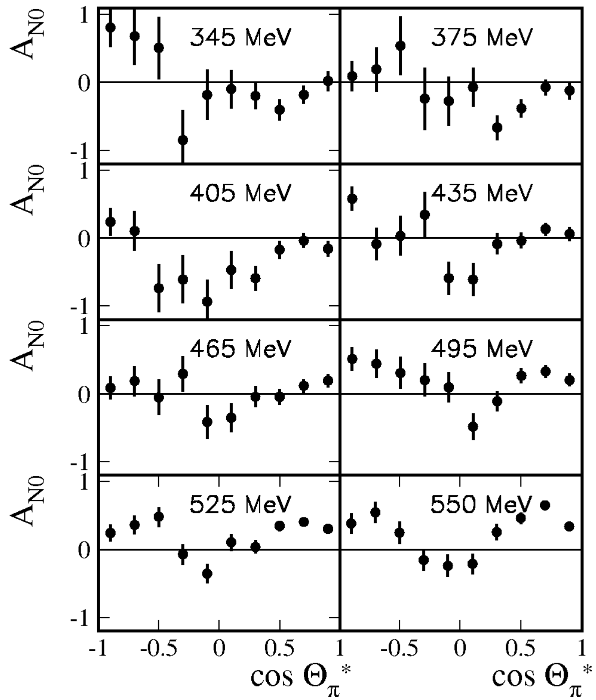
The method does not depend on assumptions about the d-waves or require subtraction of data with different systematic errors.

Available data on $d\sigma/d\Omega$ and A_y^p at 353 MeV

$pn \to \{pp\}_s \pi^-$







TRIUMF data

H. Hahn et al., Phys. Rev. Lett. 82 (1999) 2258,
F. Duncan et al., Phys. Rev. Lett. 80 (1998) 4390
(fits are quadratic over π momentum)

PSI data

M. Daum et al., Eur. Phys. J. C 25 (2002) 55

Problems:

Absence or poor precision of $pn \to \{pp\}_s \pi^-$ data at large and small angles.

Lack of $pp \to \{pp\}_s \pi^0$ A_y data at the same energy.

Experimental program at ANKE

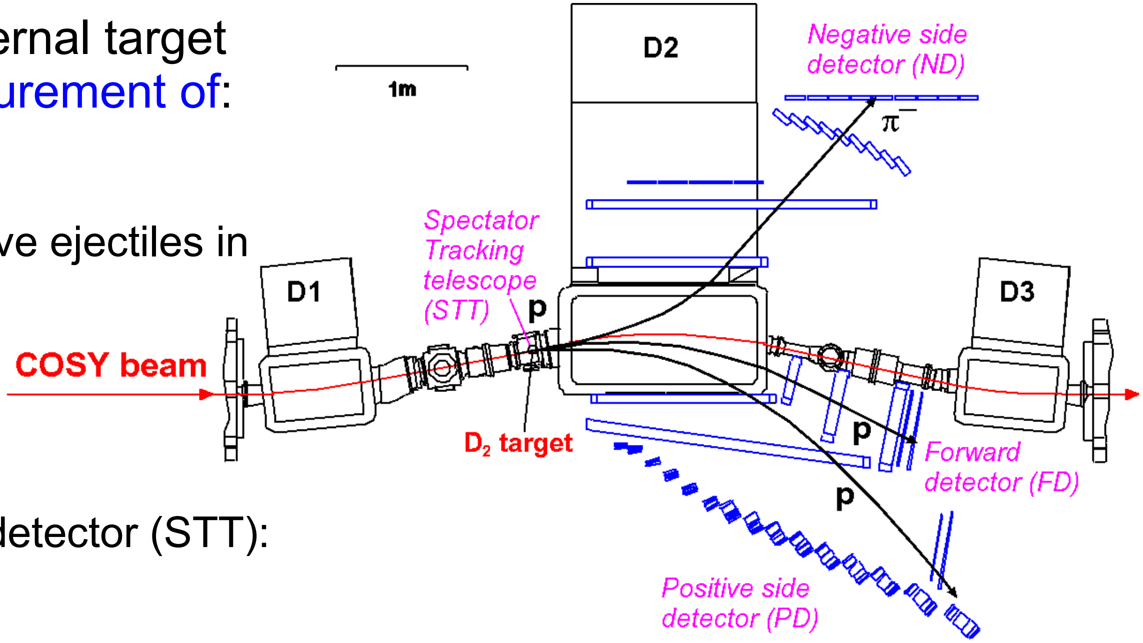
$pN \to \{pp\}_s\pi$ interactions at T_n=353 MeV:

- $d\sigma/d\Omega$ and A_y^p in $\vec{p}p \to \{pp\}_s\pi^0$ measured in 2007, 2009
- $d\sigma/d\Omega$ and A_y^p in $\vec{p}n \to \{pp\}_s\pi^-$ measured in 2009
- $A_{x,x}$, $A_{y,y}$ in $\vec{n}\vec{p} \to \{pp\}_s\pi^-$ measured in 2011

Experiment: ANKE@COSY

Cooler Synchrotron COSY at Juelich provides
polarised proton and *deuteron* beams of 600 – 3700 MeV/c momentum.

The ANKE spectrometer at internal target position of COSY allows measurement of:



- Fast forward positive and negative ejectiles in Forward, Positive and Negative detectors (FD, PD, ND):
  momentum, Id by TOF, dE/dX

- Slow positive ejectiles in Vertex detector (STT):
  energy, tracking, Id by dE/dX

Targets available:

- Cluster jet H_2 and D_2
- Internal polarized (H, D) target (PIT) with a storage cell

ANKE is well suited for the fast proton pairs with low excitation energy

Experiment: scheme of measurement

$d\sigma/d\Omega$ and $A_y^{\vec{p}}$

$\vec{p}d \to \{pp\}_s\pi^- + p_{spec}$ $\vec{p}p \to \{pp\}_s\pi^0$

Polarized proton beam: $P_y = 65\%$

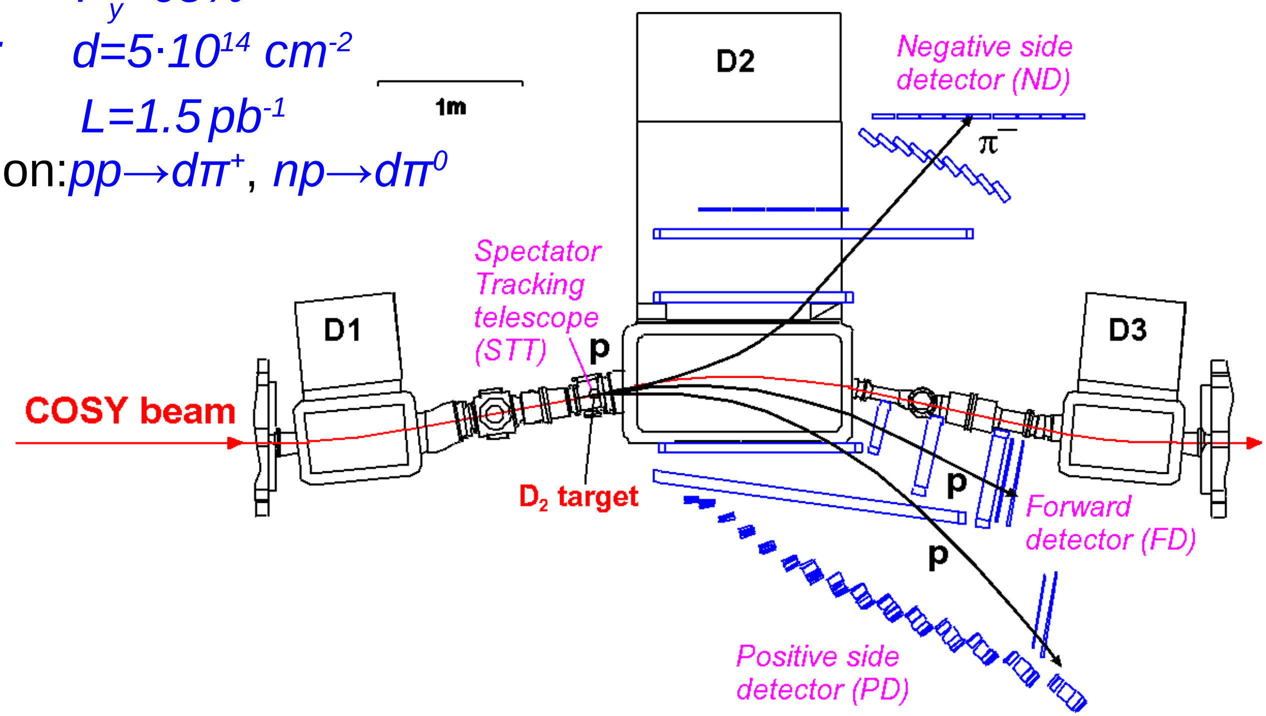
H_2, D_2 cluster jet target: $d = 5\cdot10^{14}\ cm^{-2}$

Luminosity: $L = 1.5\ pb^{-1}$

Polarimetry, normalization: $pp \to d\pi^+$, $np \to d\pi^0$

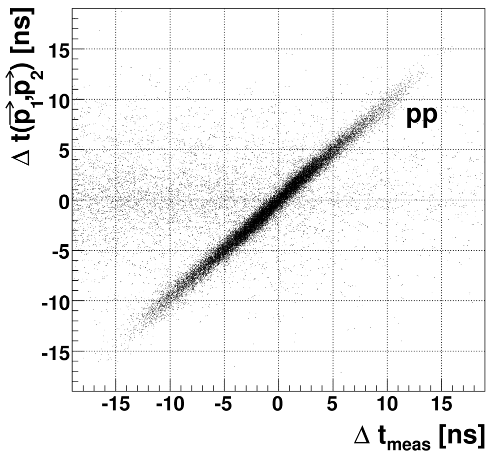
π^0 case: $\{pp\}$ detected

π^- case: + p_{spec} or π^-

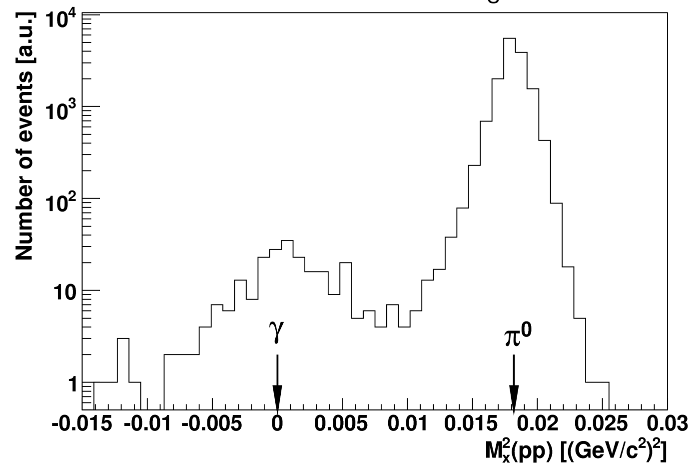


Experiment: Identification of $pn \rightarrow \{pp\}_s \pi^-$ and $pp \rightarrow \{pp\}_s \pi^0$ at 353 MeV

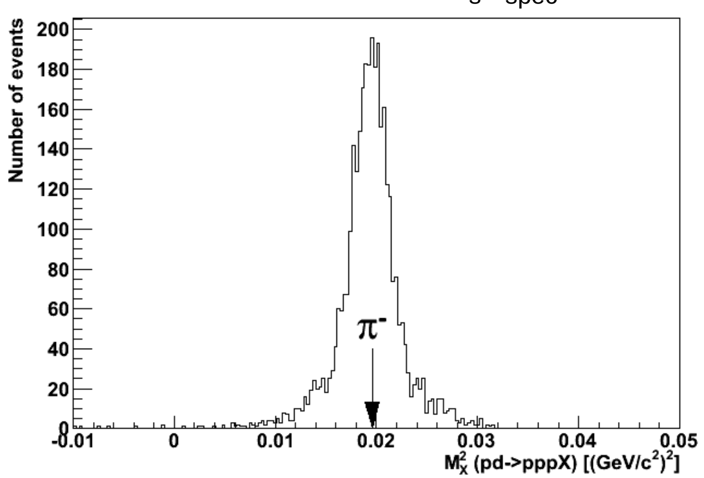
Diproton PID by TOF



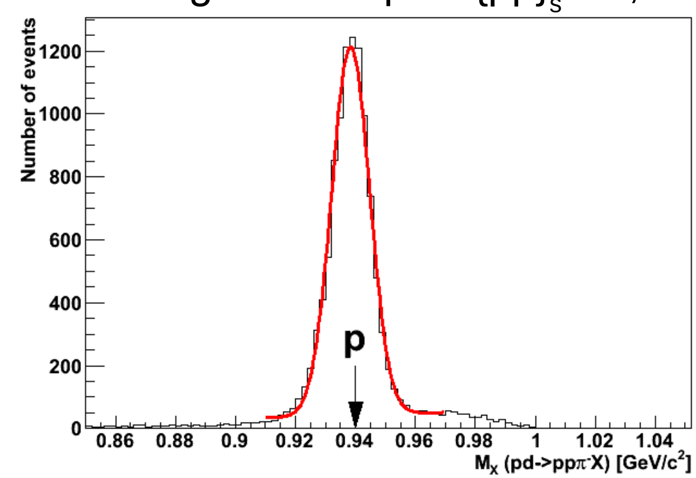
Missing mass in $pp \rightarrow \{pp\}_s X$, $X=\pi^0$



Missing mass in $pd \rightarrow \{pp\}_s p_{spec} X$, $X=\pi^-$

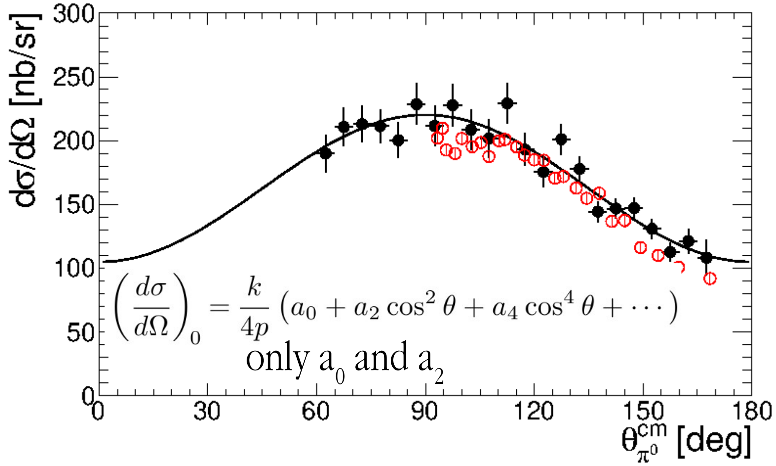


Missing mass in $pd \rightarrow \{pp\}_s \pi^- X$, $X=p_{spec}$

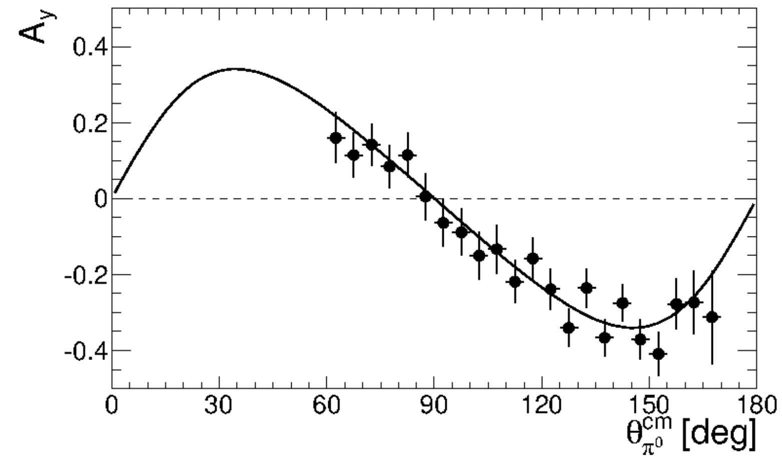


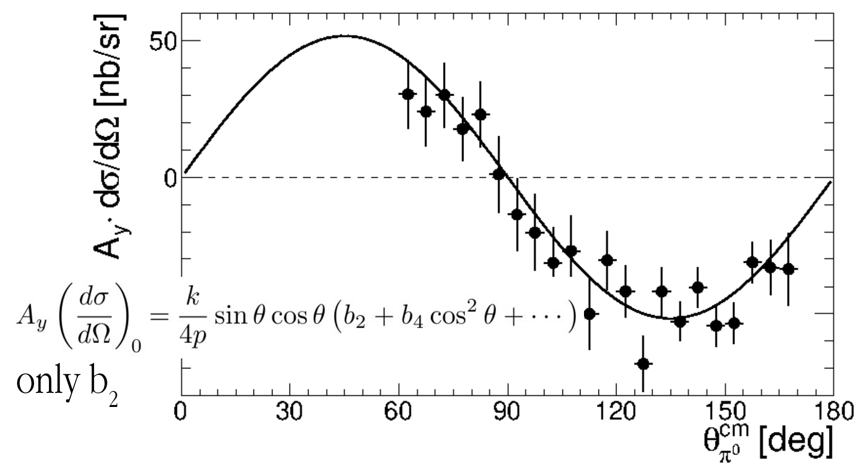
ANKE preliminary results (1)

dσ/dΩ and A_y in $pp \to \{pp\}_s \pi^0$



ANKE (black) compared to CELCIUS (red) at 360 MeV
(R. Builger et al, NPA 663 (2001) 633)



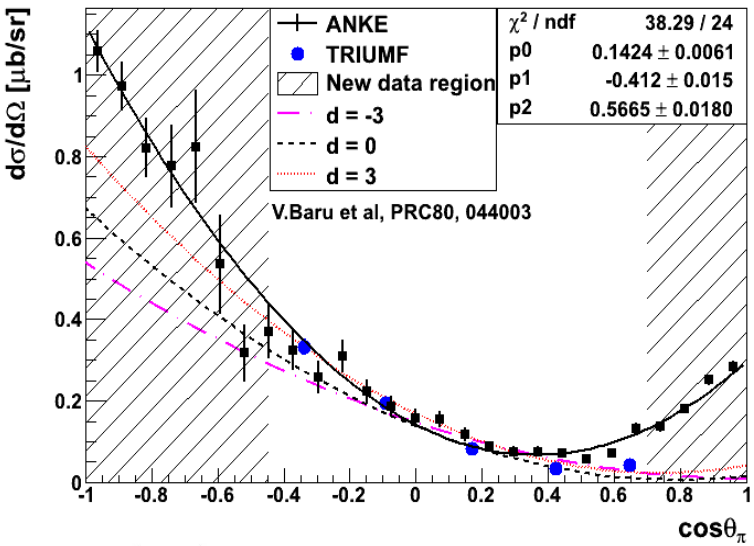


A_y in $pp \to \{pp\}_s \pi^0$ arises due to *s-d* interference ➡ Importance of *d*-waves

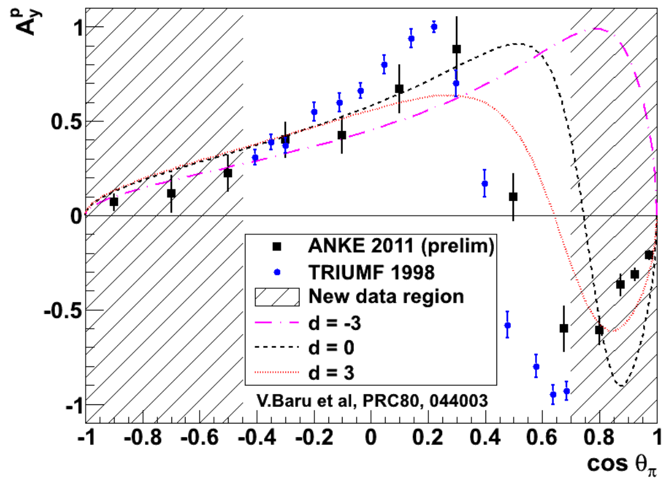
Theoretical interpretation is ongoing

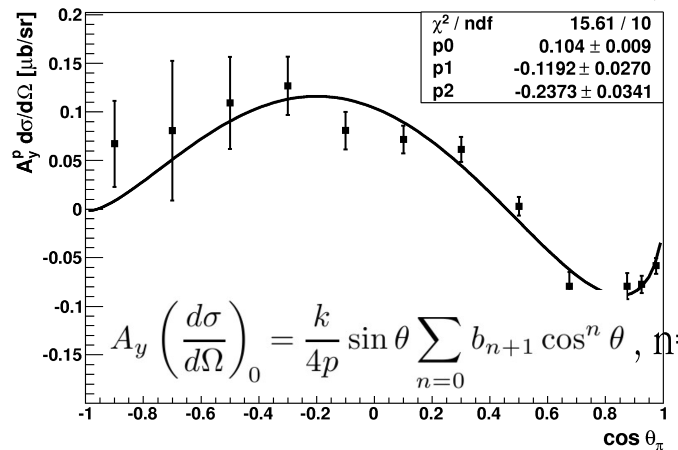
ANKE preliminary results (2)

dσ/dΩ and A_y in $pn \rightarrow \{pp\}_s \pi^-$



$$\left(\frac{d\sigma}{d\Omega}\right)_0 = \frac{k}{4p}\sum_{n=0} a_n \cos^n\theta \quad \text{, n=0-2}$$





$$A_y \left(\frac{d\sigma}{d\Omega}\right)_0 = \frac{k}{4p}\sin\theta \sum_{n=0} b_{n+1} \cos^n\theta \quad \text{, n=0-2}$$

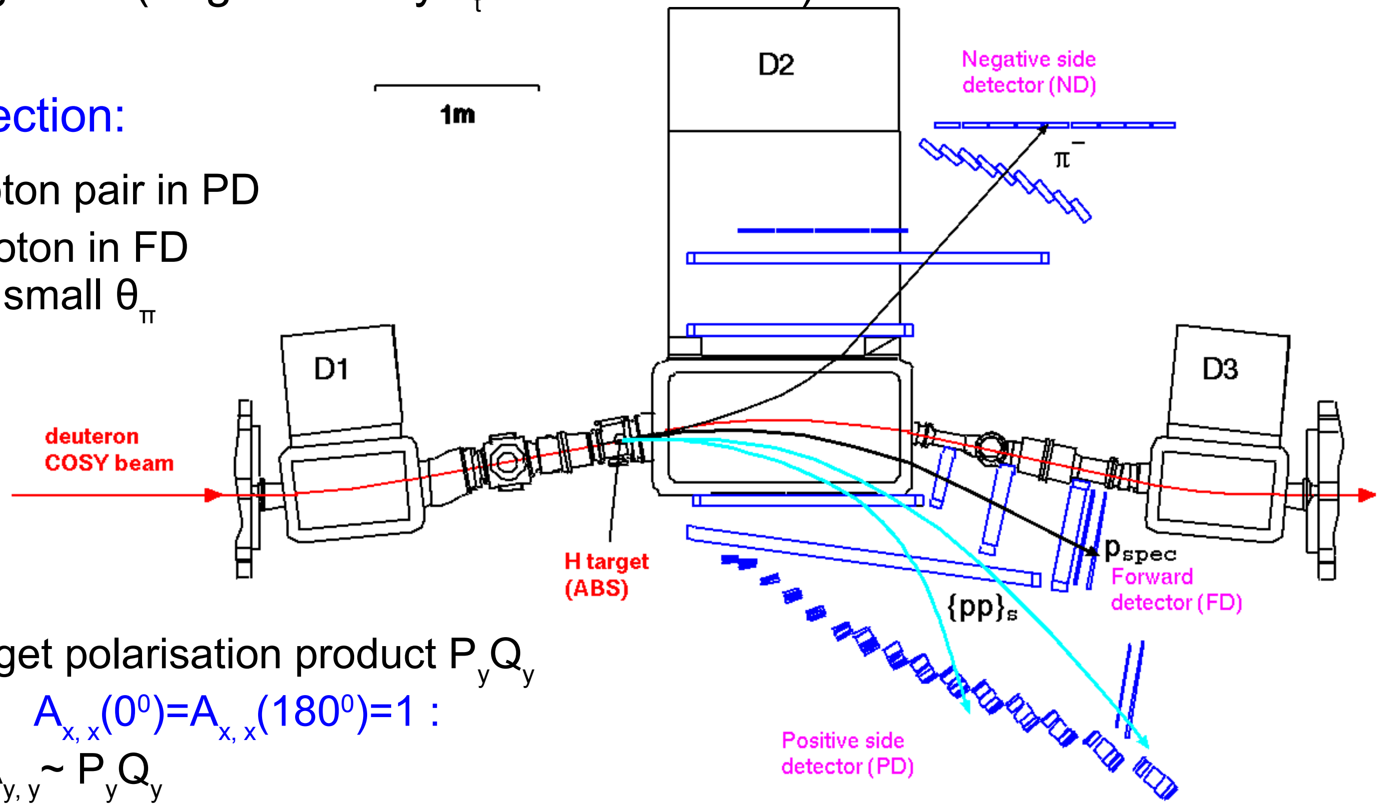
χPT predictions (dσ/dΩ are A_y) are for *s* and *p* pion waves only

Measurement of $A_{x,x}$ in $\vec{d}\vec{p} \to p_{sp}\{pp\}_s\pi^-$ at T_d=706 MeV

Vector polarized deuteron beam (P=50%)
+ hydrogen polarized internal target (Q=60-70%)
with a storage cell (target density $d_t = 1.34 \times 10^{13}\ cm^{-2}$)

Particle detection:

- The $\{pp\}_s$ proton pair in PD
- Spectator proton in FD
- π^- in ND at small θ_π



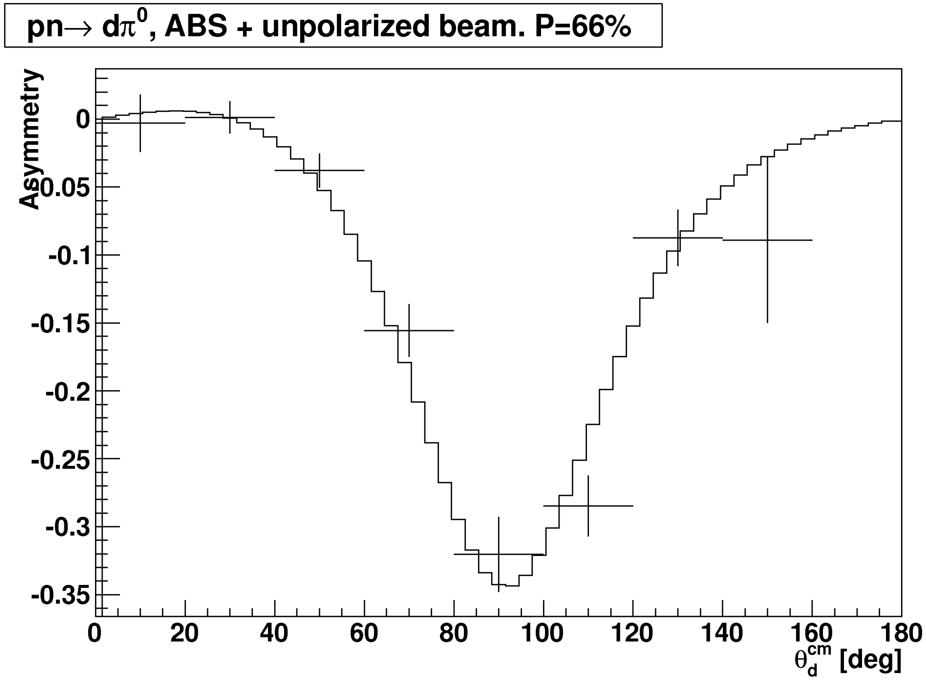
Polarimetry:

- $np \to d\pi^0$
- beam and target polarisation product P_yQ_y

from $A_{y,y}=1$, $A_{x,x}(0^0)=A_{x,x}(180^0)=1$:
$A_{x,x} \sim P_yQ_y$, $A_{y,y} \sim P_yQ_y$

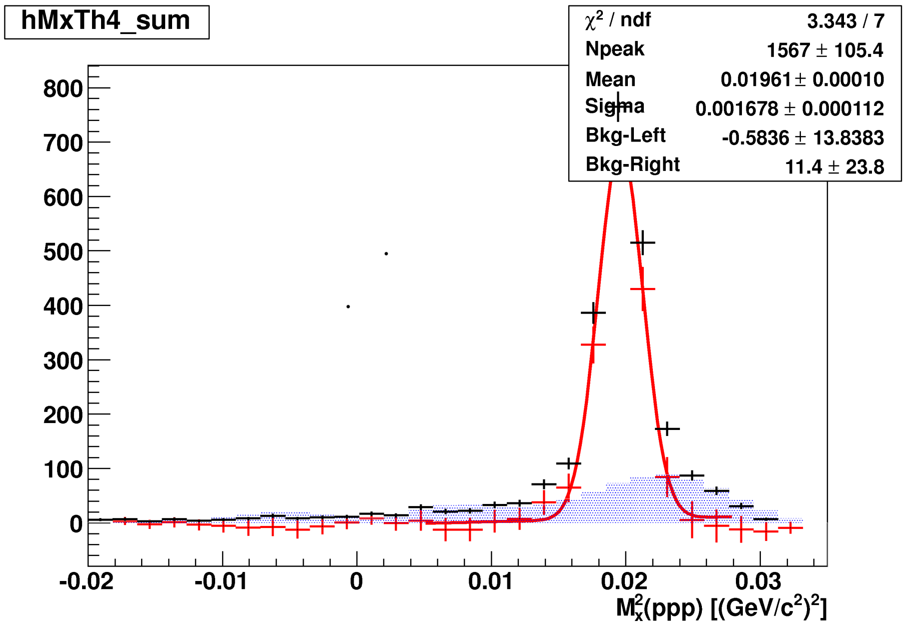
Polarimetry with np→dπ^0

- Final d, spectator p are detected in FD
- Identified by TOF, Mx
- Backgroung shape from measurements with N2
- Polarimetry for beam and target

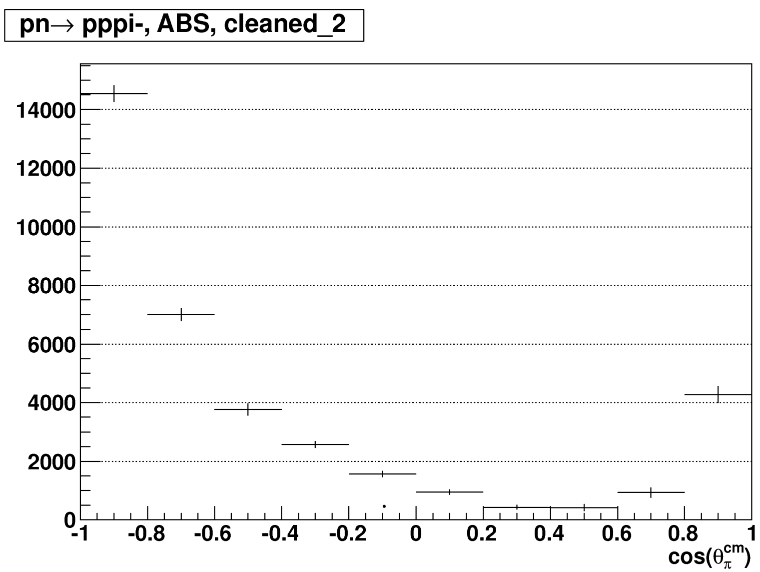


Selection of $dp \to p_{sp}\{pp\}_s \pi^-$

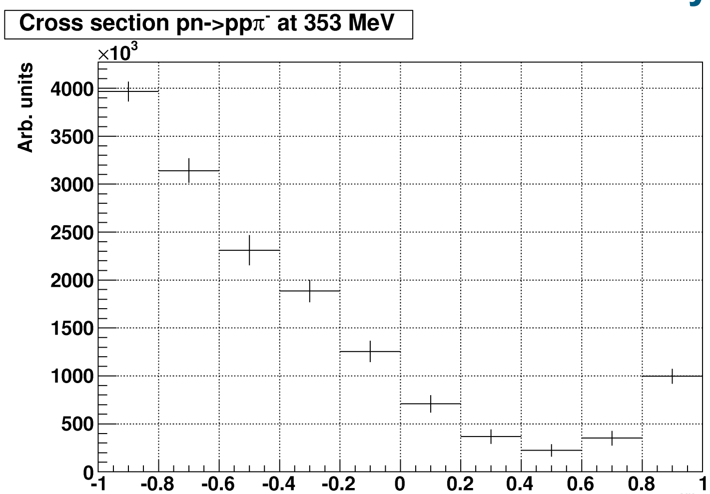
Background subtraction in Mx spectra with N2 data (shaded)

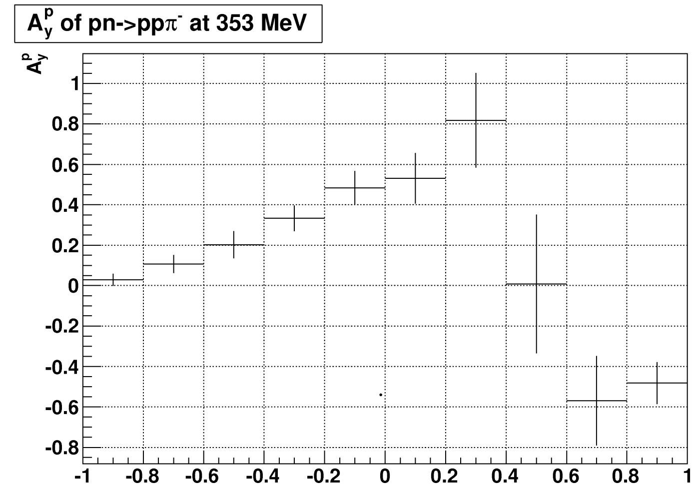


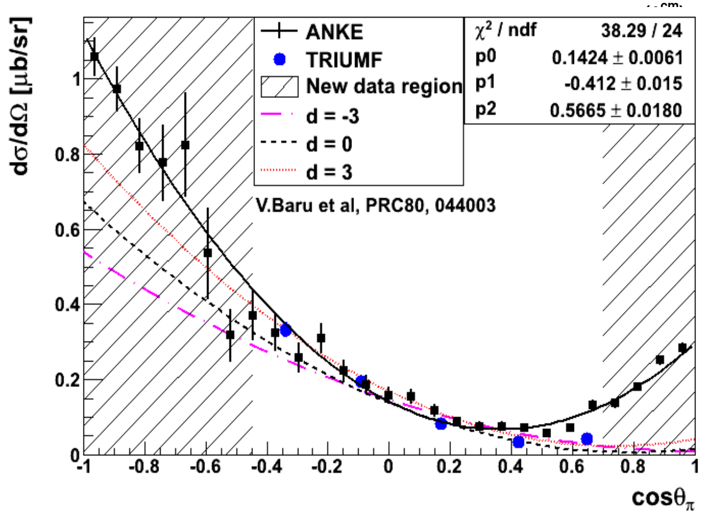
Total useful statistics

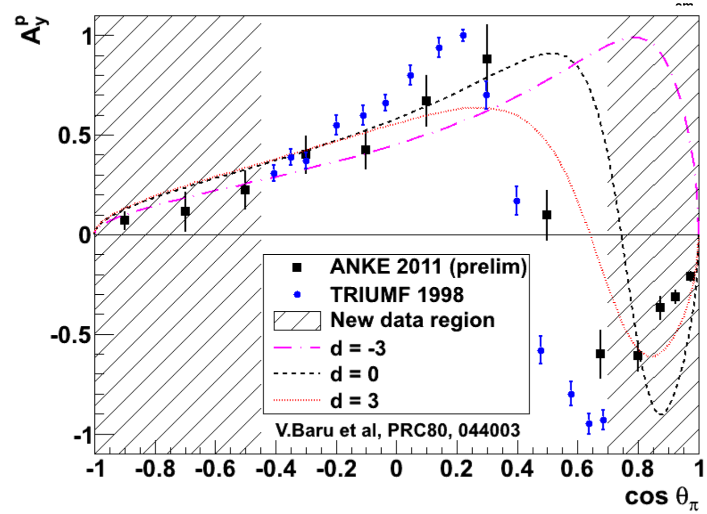


Cross section and A_y from the new data









Summary

- Di-proton final state provides a new tool to study hadron interactions

- Further development of ChPT requires new data on
  the $pp \to \{pp\}_s \pi^0$ and $pn \to \{pp\}_s \pi^-$ processes near the threshold:
  ➡ unpolarized, single and double polarized measurements at ANKE

- $d\sigma/d\Omega$ and A_y in the two processes has been measured at 353 MeV.
  The first results show importance of the pion D-waves,
  LEC d=3 value is favored

- Double polarisation measurement of $A_{x,x}$ in $pn \to \{pp\}_s \pi^-$, done
  in 2011, provides new information on the 4Nπ contact term in ChPT

Outlook

- To fix the d-waves contribution and get second p-wave amplitude
  we need to know $A_{x,z}$ in $pn \to \{pp\}_s \pi^-$
  ➡ Siberian snake is needed at COSY

Additional slides

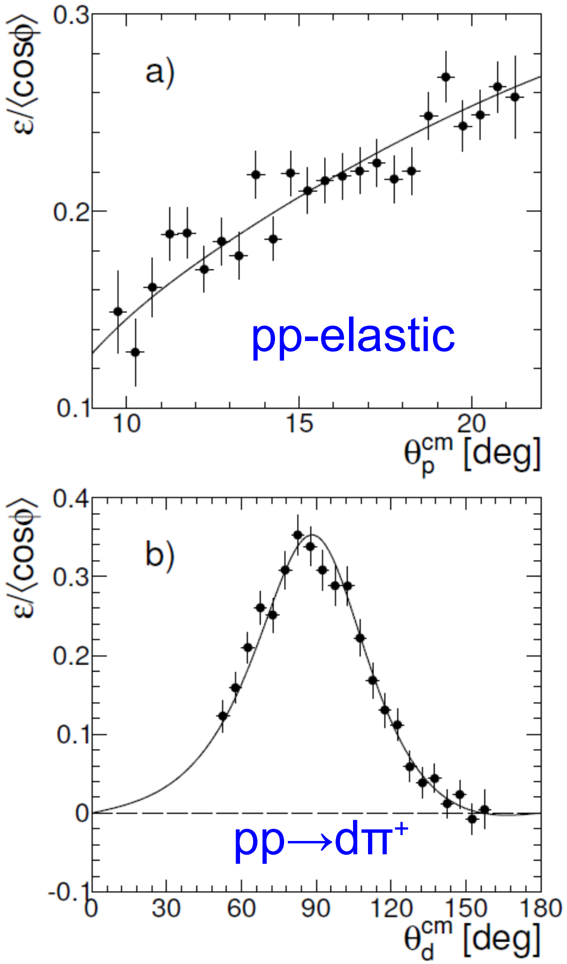
Di-proton program at ANKE-COSY

- d-breakup $\vec{p}d \to \{pp\}_s (0^0)\, n$ at high momentum transfer
- $\vec{d}\vec{p} \to \{pp\}_s (0^0)\, n$ at low momentum transfer (pn CE amplitudes)
- $\vec{d}\vec{p} \to \{pp\}_s (0^0)\, \Delta^0$
- meson production in $pN \to \{pp\}_s X$
  - $X=\pi$
    - $pp \to \{pp\}_s \pi^0$ at T_p = 0.5 -2.4 GeV
    - $\vec{p}\vec{N} \to \{pp\}_s \pi$ near threshold
  - $X=(2\pi)$ (ABC effect in pp collisions)
  - $X=\eta, \omega$
- inverse diproton photodisintegration $pp \to \{pp\}_s \gamma$

Beam polarisation and luminosity at T_n = 353 MeV

- Using (quasi-) free $pp \to d\pi^+$ and $np \to d\pi^0$

  $d\sigma/d\Omega$ and A_y^p available from the SAID database



Example:

Determination of the beam polarization for

$pp \to pp\pi^0$ measurement:

Consistent results P=0.68 from elastic and $pp \to d\pi^+$