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Baryons2013

International Conference on the Structure of Baryons
June 24th – 28th 2013, Glasgow

The Hadron Physics Program at COSY-ANKE: selected results

June 26, 2013 | Andro Kacharava (JCHP/IKP, FZ-Jülich)

Outline

- ➢ Introduction
  - Overview of the program
  - Experimental facilities (COSY, ANKE)
- ➢ SPIN physics program: selected results
  - Nucleon-Nucleon scattering
  - Pion production
  - Hyperon-Nucleon interaction
- ➢ Future plans

Introduction: Program overview

Goal:

Study of 3-body final states aiming to extract basic spin-dependent two-body scattering information

Tools:

- Hadronic probes (p,d)
- Double polarization (beam and target)

Topics:

1. NN scattering ↔ pp- and np-amplitudes, nuclear forces
2. Meson production ↔ NNπ amplitudes (ChPT), FSI
3. Strangeness production ↔ YN interaction, SU(3) symmetry

COSY proposal #152
ArXiv:nucl-ex/0511028

Introduction: COSY storage ring

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COSY (COoler SYnchrotron) at Jülich (Germany)

- Hadronic probes: protons, deuterons
- Polarization: beam and targets

- Energy range:

  0.045 – 2.8 GeV (p)

  0.023 – 2.3 GeV (d)
- Max. momentum ~ 3.7 GeV/c
- Energy variation (ramping mode)
- Electron and Stochastic cooling
- Internal and external beams
- High polarization (p,d)
- Spin manipulation

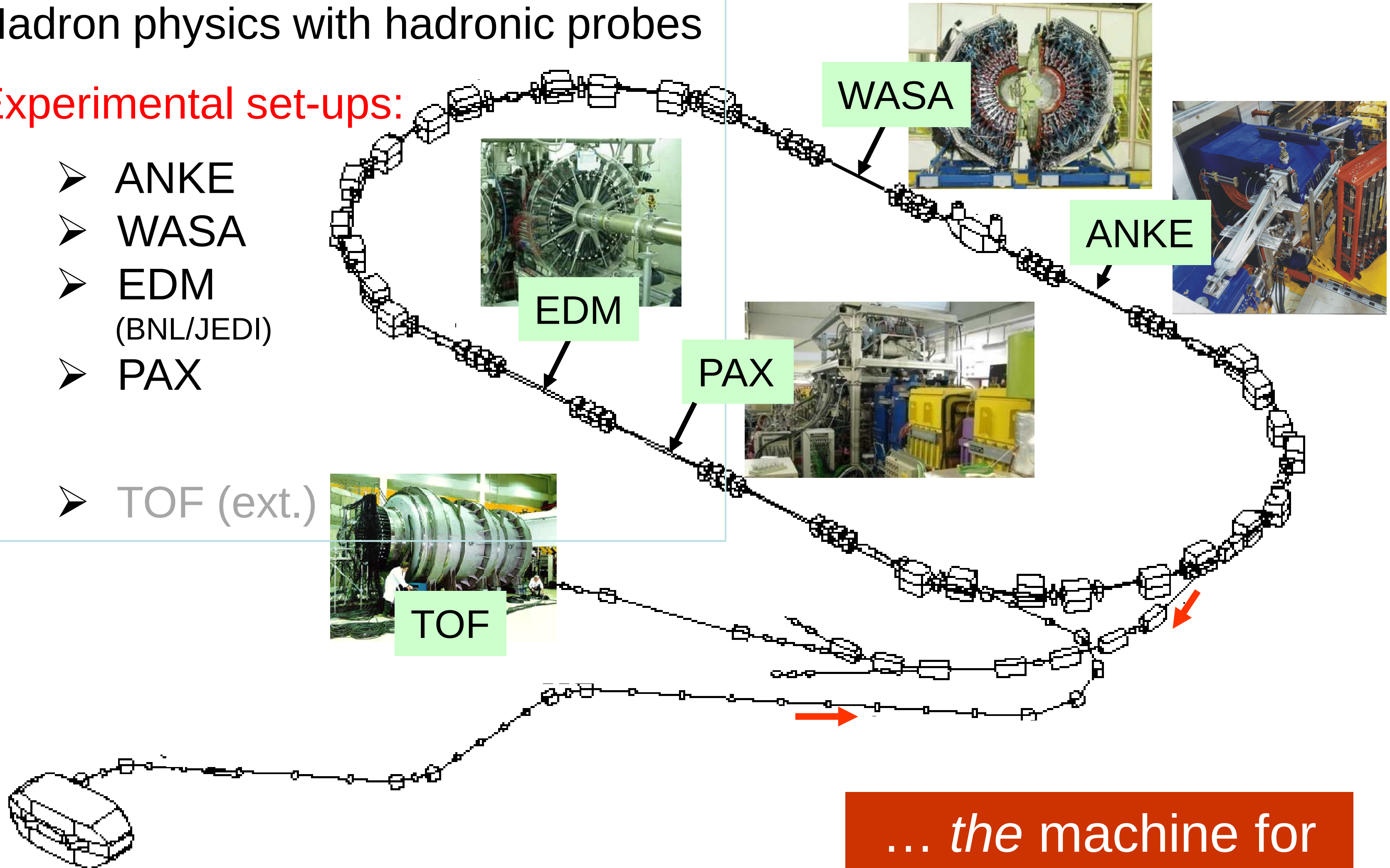
Introduction: COSY overview

Hadron physics with hadronic probes

Experimental set-ups:

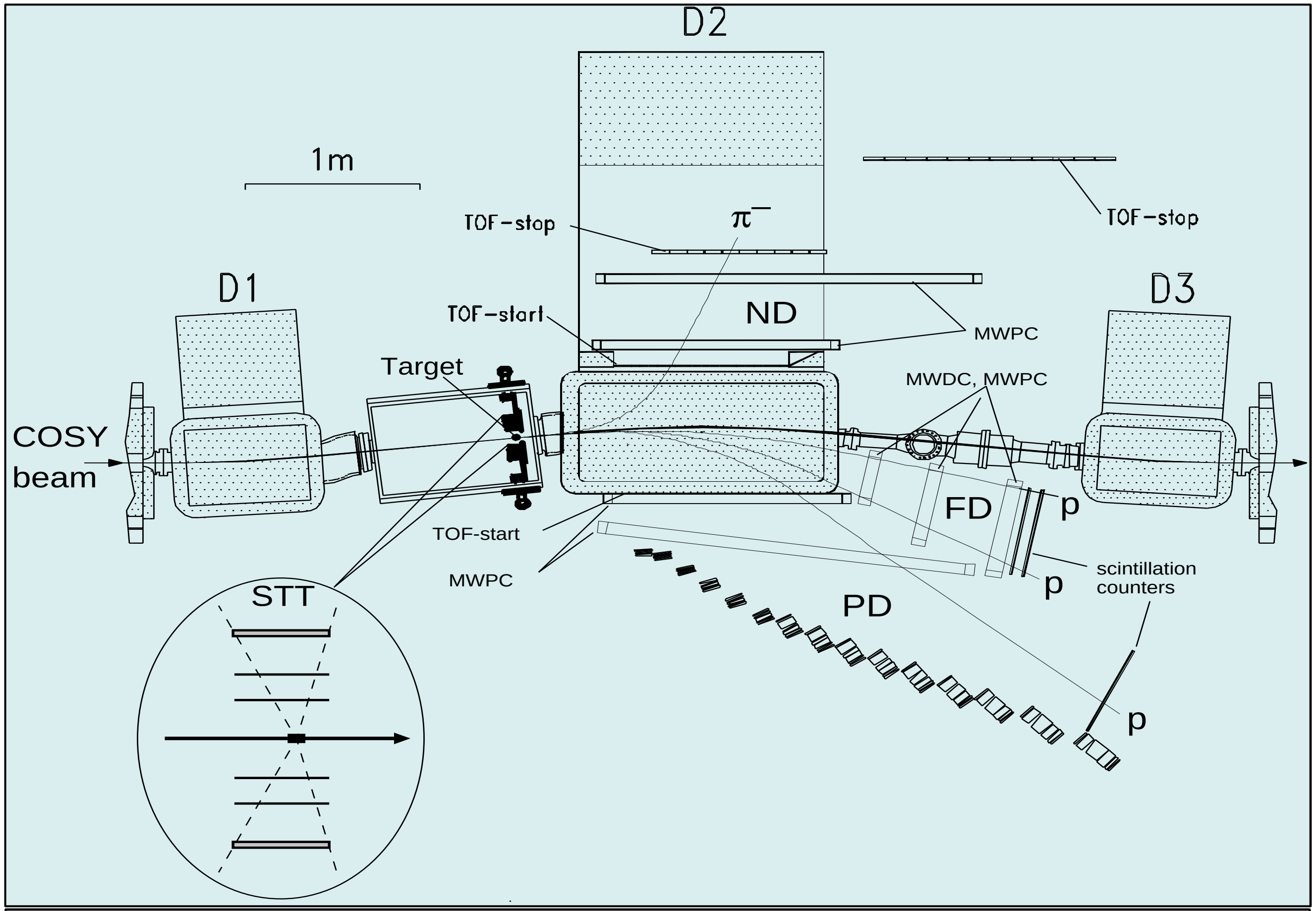
- ANKE
- WASA
- EDM
  (BNL/JEDI)
- PAX

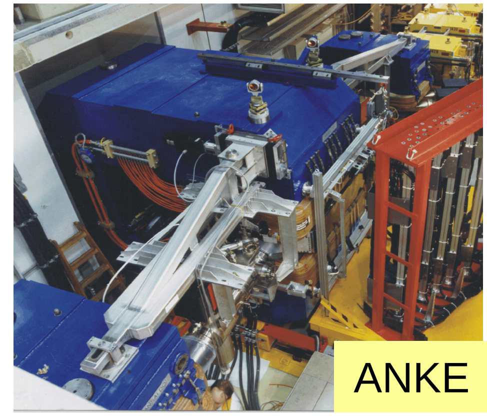
- TOF (ext.)

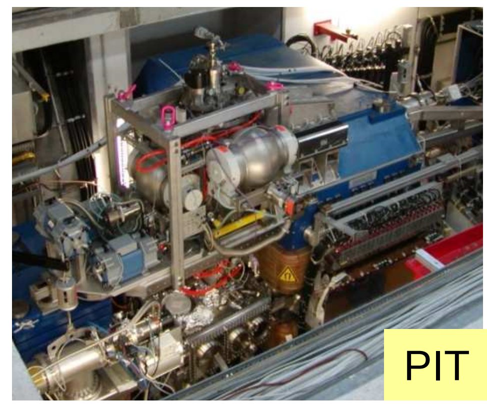


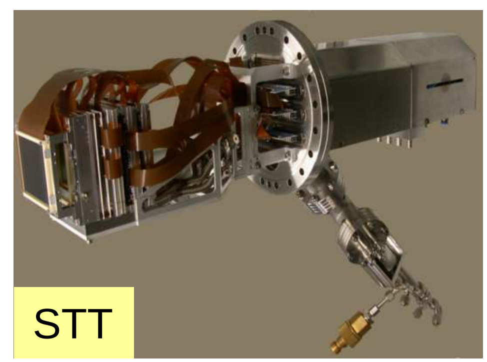
… *the* machine for hadron spin physics

Apparatus: ANKE spectrometer









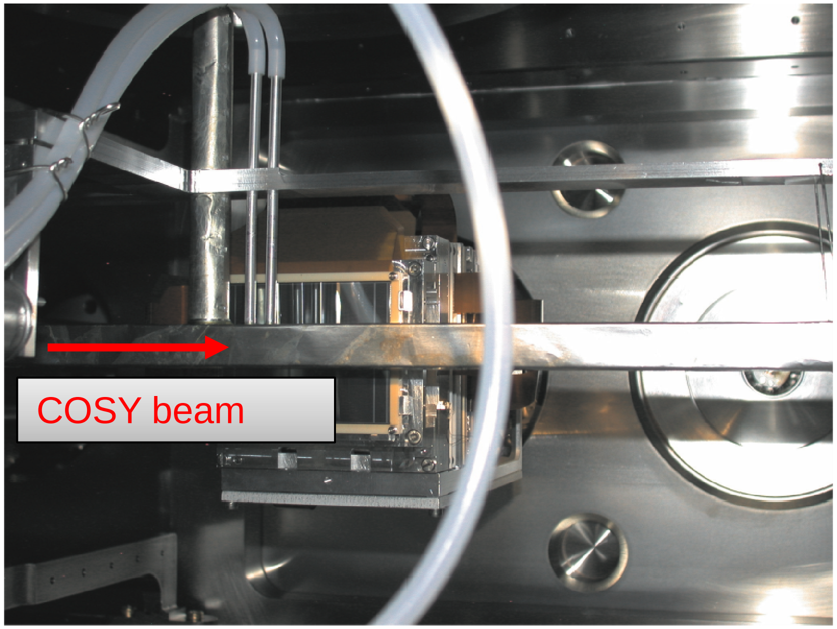
Main features:

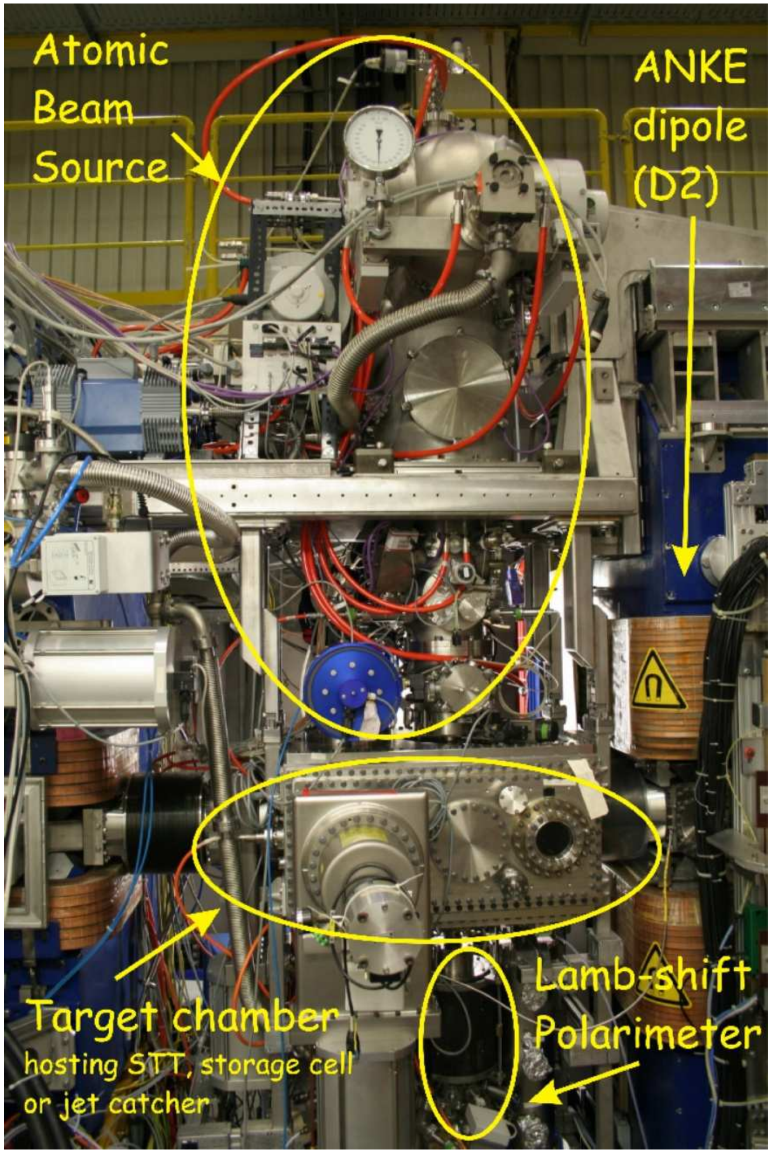
- Excellent Kaon identification (Positive and Negative)
- Low energy proton (spectator) detection (STT)
- Di-proton ($\{pp\}_s$) selection (by FD)
- Polarized (unpolarized) dense targets

Apparatus: PIT at ANKE

Polarized Internal Target (PIT):

- Polarised H (D) gas (ABS) in the cell
  - Q_y = 0, -1, +1, high degree >90%
  - Density ≥ 10^{13} cm^{-2}
- Storage cell: 20 x 15 x 390 mm^3
- Lamb-shift Polarimeter





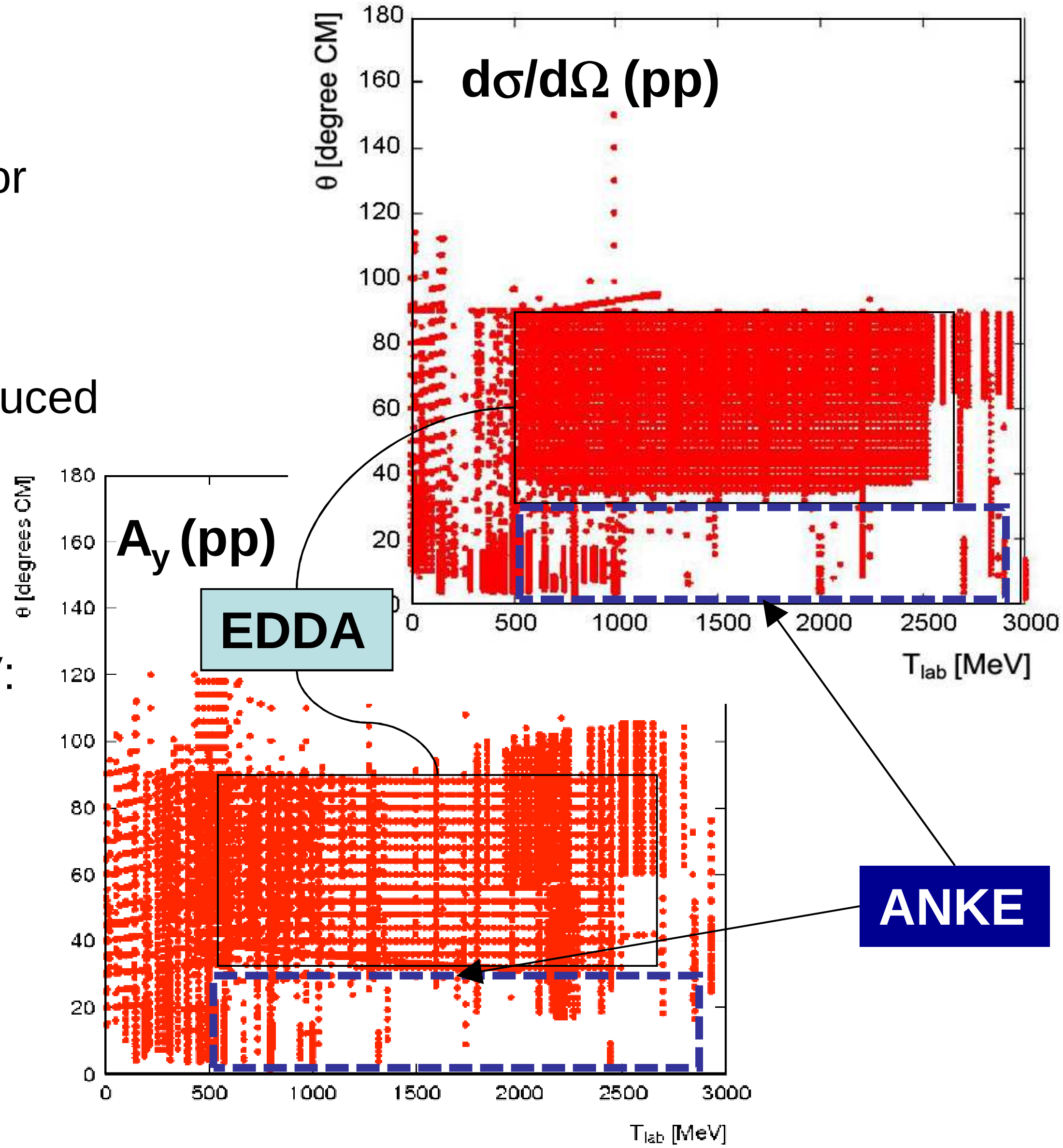
NN scattering: Motivation (pp)

- Description of nucleon-nucleon interaction requires precise data for Phase Shift Analysis (PSA)

- COSY-EDDA collaboration produced wealth of data ($35° < \theta_p < 90°$) for **pp elastic scattering**

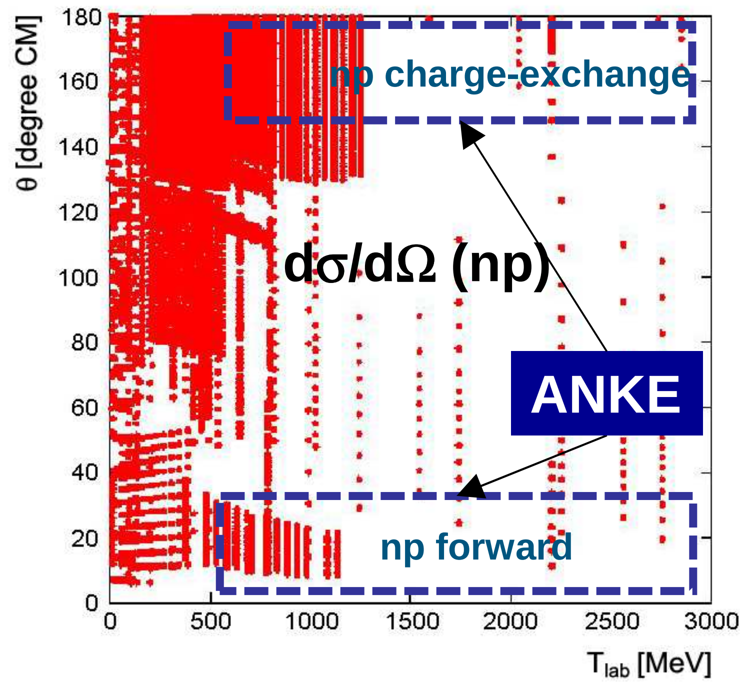
- Large impact on PSA > 0.5 GeV: Significantly reduced ambiguities in I=1 phase shifts

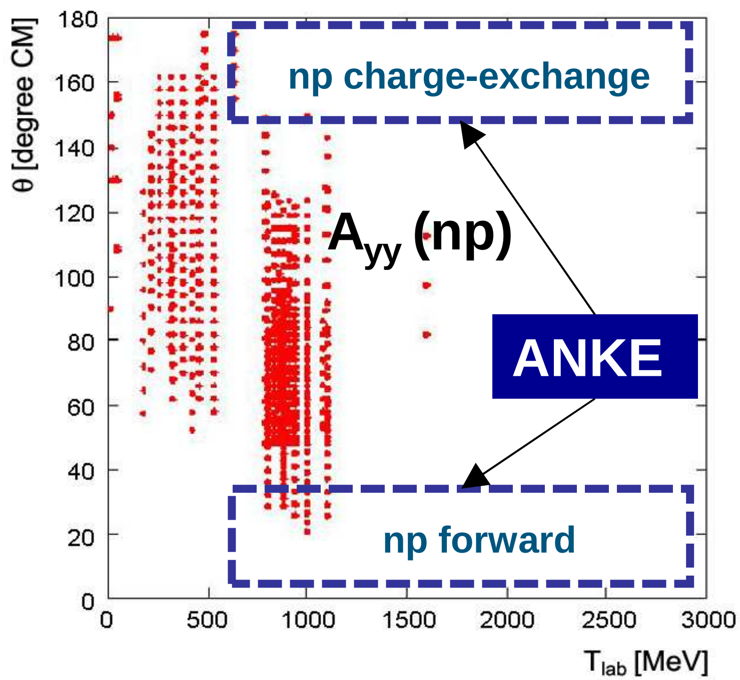
- No exp. data at smaller angles ($\theta_p < 35°$) above T_p=1.0 GeV



NN scattering: Motivation (np)

R. Arndt: *"Gross misconception within the community that np amplitudes are known up to a couple of GeV.* ***np data*** *above 800 MeV is a DESERT for experimentalists."*





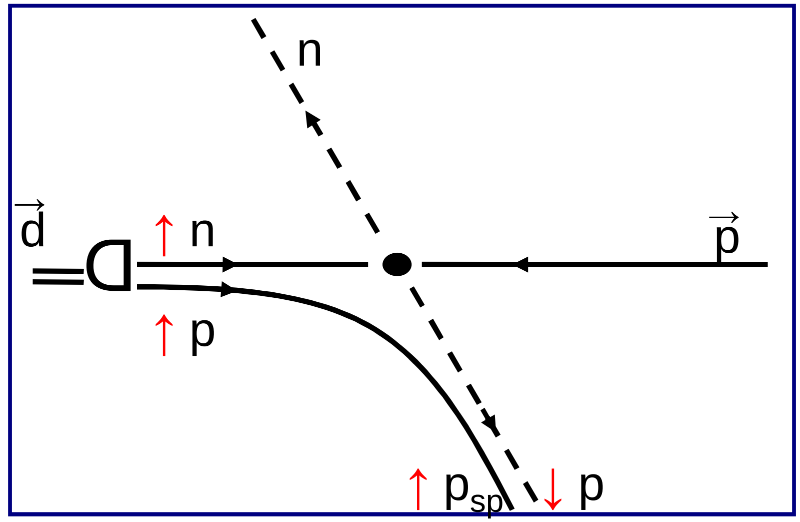
ANKE is able to provide the experimental data for both:
pp and np systems and improve our understanding of NN interaction

NN scattering: Measurements at ANKE

- np system: different isospin channel
- via Charge-Exchange deuteron breakup:

deuteron beam: $dp \rightarrow \{pp\}_s (0^0) + n$

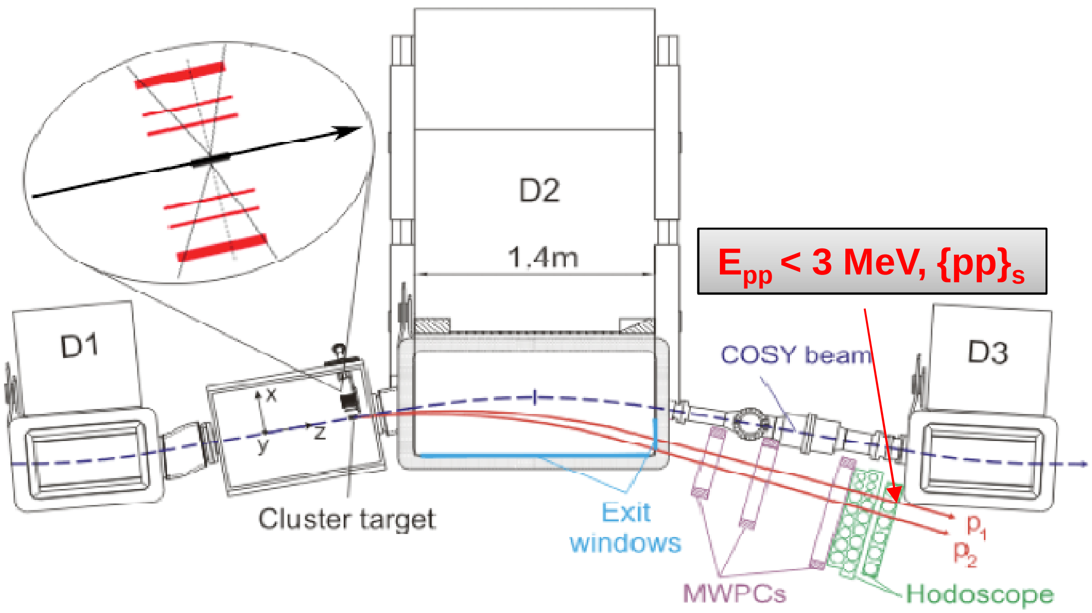
deuteron target: $pd \rightarrow \{pp\}_s (180^0) + n$



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

quasi-free

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



- Transition from $d \rightarrow (pp)^1S_0$: $pn \rightarrow np$ spin flip
- np spin-dependent amplitudes:

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

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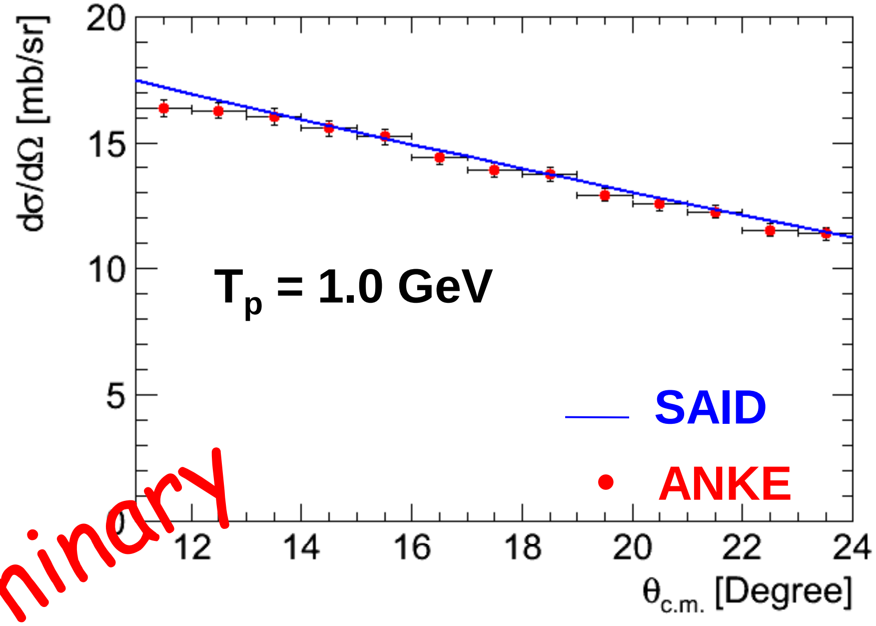
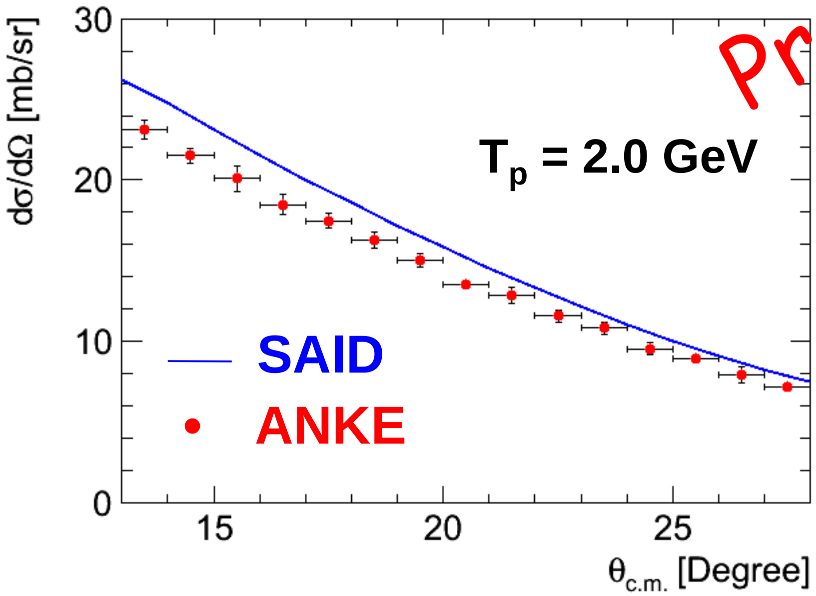
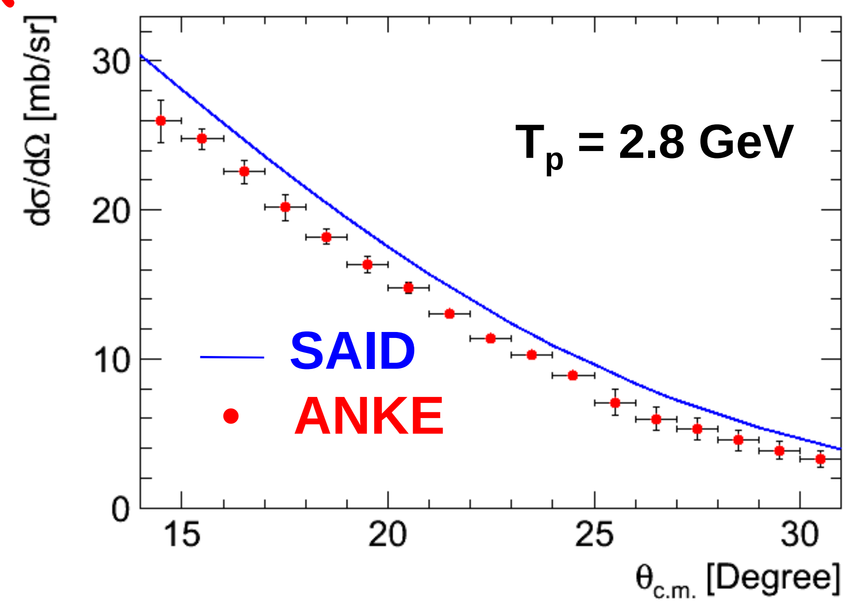
NN scattering: pp elastic

- **dσ/dΩ** at 8 beam energies: Tp = **1.0**, 1.6, 1.8, **2.0**, 2.2, 2.4, 2.6, **2.8**
- Precision measurements:
  - Luminosity by Schottky technique ~ 2%
  - Absolute cross section ~ 5%
- Details: *Stein et al., PR ST-AB 11, (2008)*



Preliminary



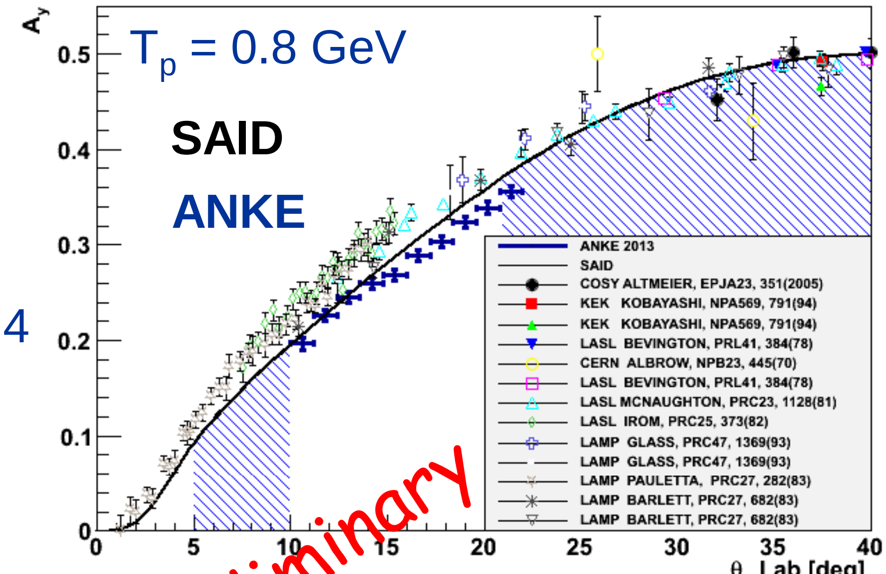


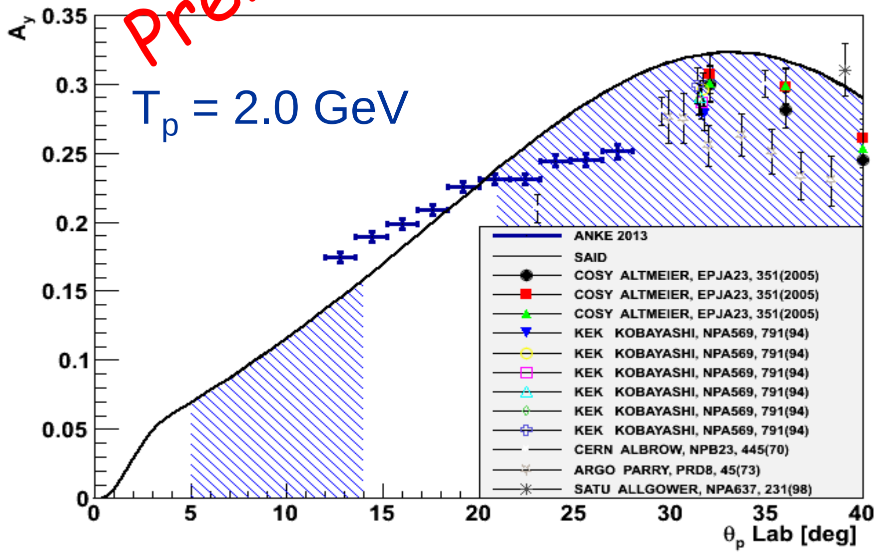
NN scattering: pp elastic (A_y)

ANKE exp., April 2013,
on-line fast analysis

- **Ay** for pp elastic (ANKE) at 6 beam energies: T_p = **0.8**, 1.6, 1.8, **2.0**, 2.2, 2.4
- Only FD system is used (up to now)
- Beam polarization from EDDA
  $\langle P_y \rangle$ ≈ 50 to 65% (Preliminary)

ANKE data shows different shape compared with SAID at higher energies!





NN scattering: np system

Di-proton program: {pp} in $^1S_0$ state

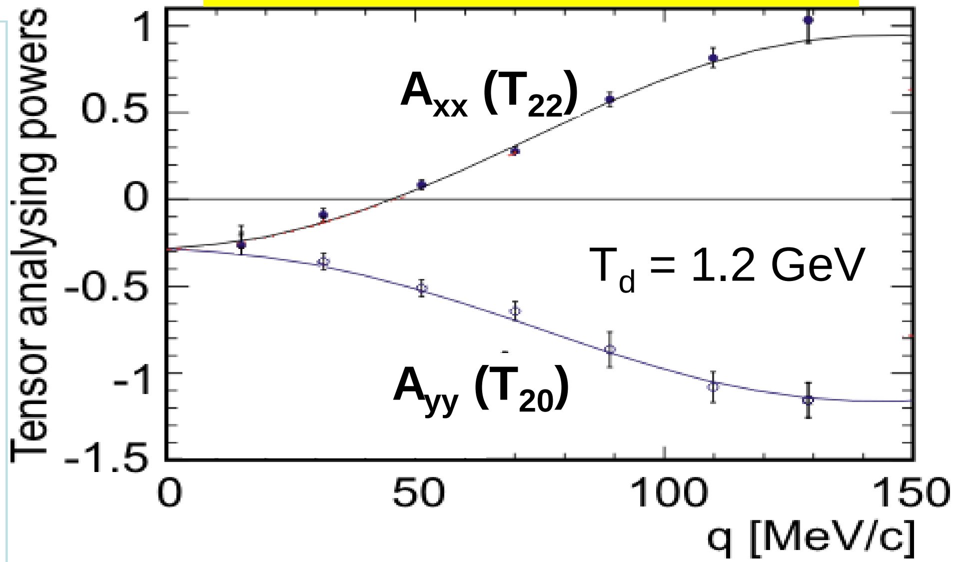
Deuteron breakup: dp → $\{pp\}_s n$
(polarized beam)

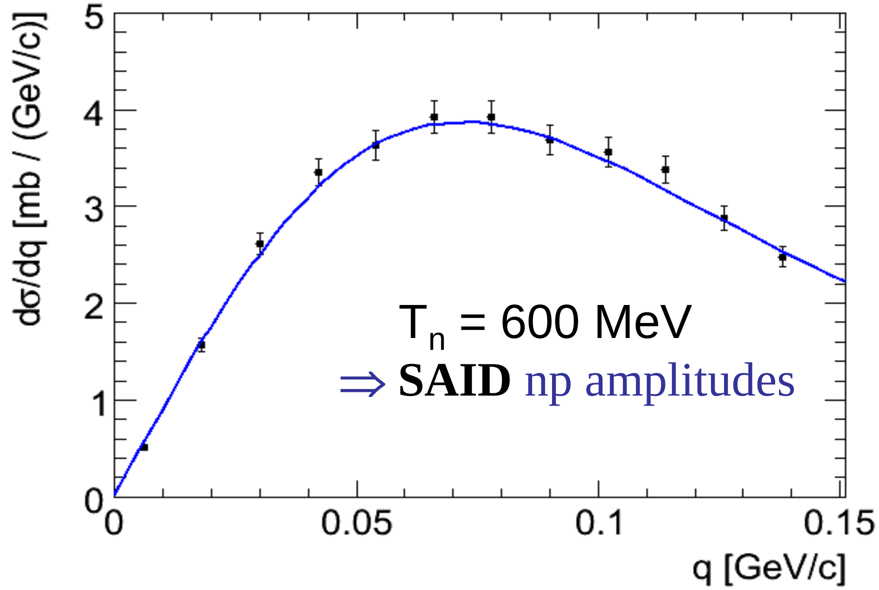
- np-data at T_d = 1.2 GeV:
  Proof of method !
- theory: Impulse approx. with current
  SAID input *(DB&CW, NPA 467, 1987)*

Achievements:

- Method works at T_d = 1.2 GeV
- Application to higher energies
  T_d=1.6, 1.8, 2.27 GeV

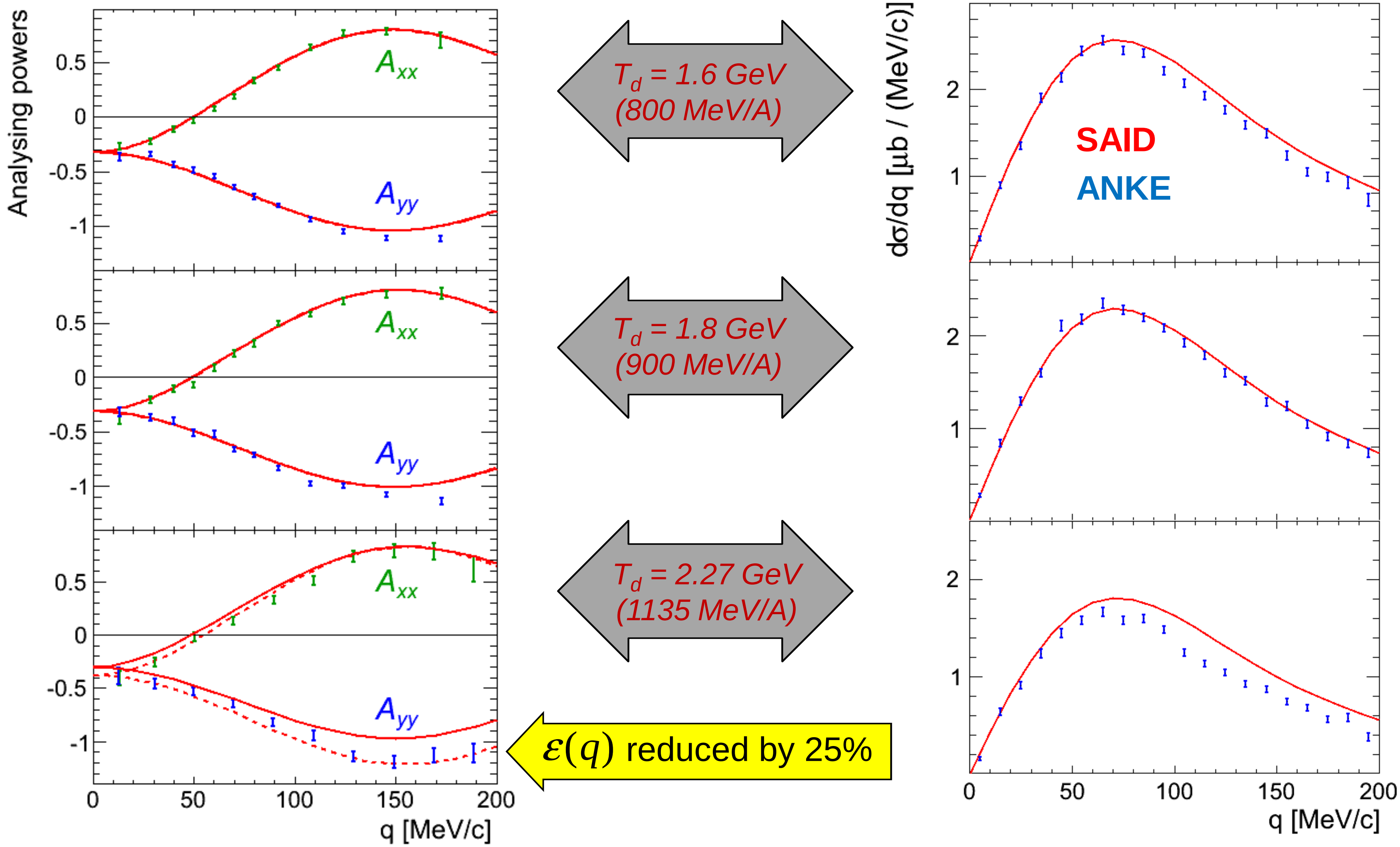
D.Childadze et al. EPJA 40, 23 (2009)





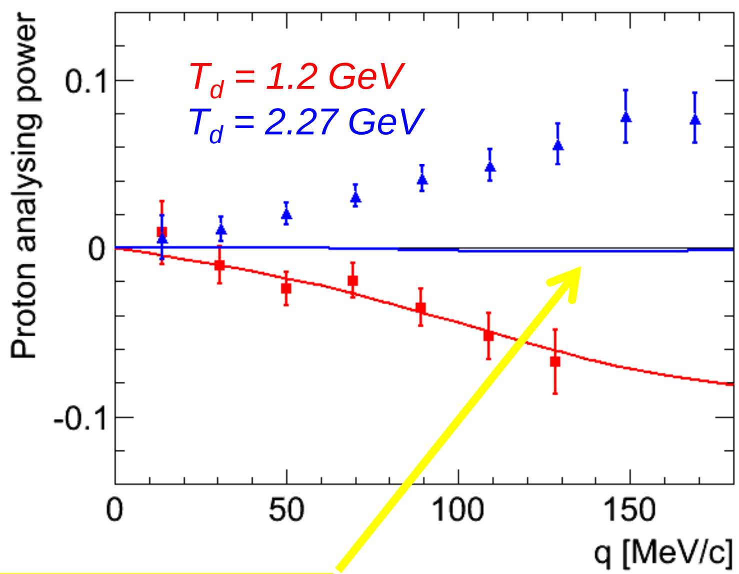
NN scattering: np system ($d\sigma/dq$, A_{ii})

D.Mchedlish. et al., EPJA 49, 49 (2013)



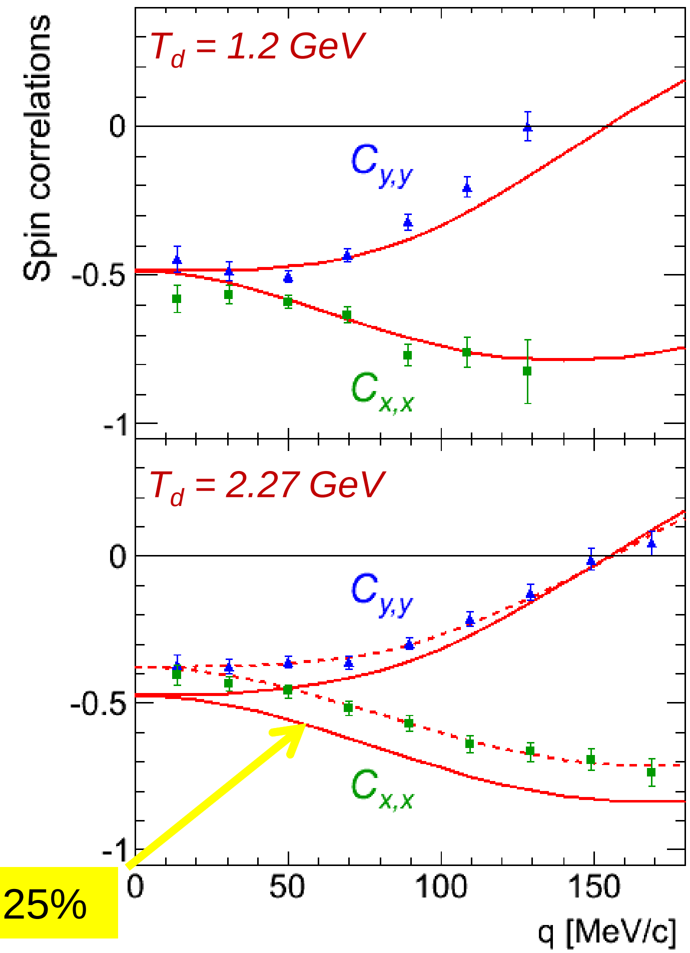
NN scattering: np system (A_y, $C_{i,i}$)

- $\vec{d}\vec{p} \rightarrow \{pp\}_s n$
- $E_{pp} < 3$ MeV
- New: measurement for $C_{x\,x}$ and $C_{y,y}$



Problem with $\gamma(q)$

D.Mchedlish. et al., EPJ A 49, 49 (2013)



$\varepsilon(q)$ reduced by 25%

Challenge: put info (about np spin-dependent amplitudes) into the SAID program !

NN scattering: np with Δ-isobar

Di-proton program: {pp} in $^1S_0$ state (E_{pp} < 3 MeV)

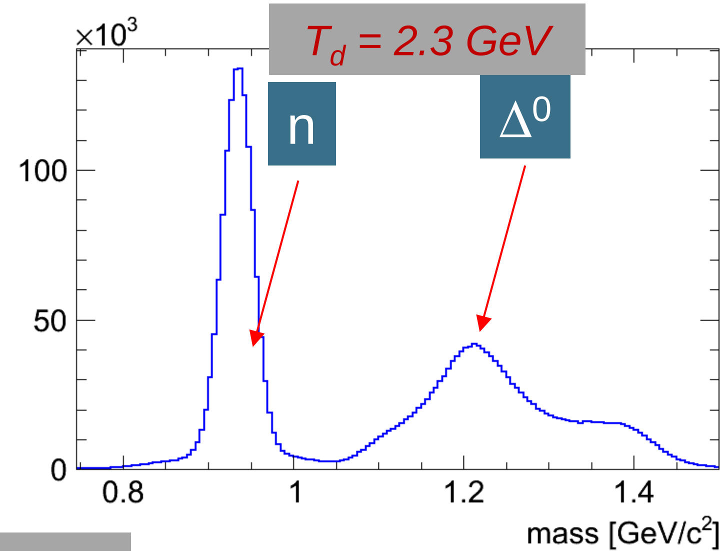
Deuteron breakup: $\vec{dp} \rightarrow \{pp\}_s\, \Delta^0$ (polarized)

$np \rightarrow p\Delta^0$

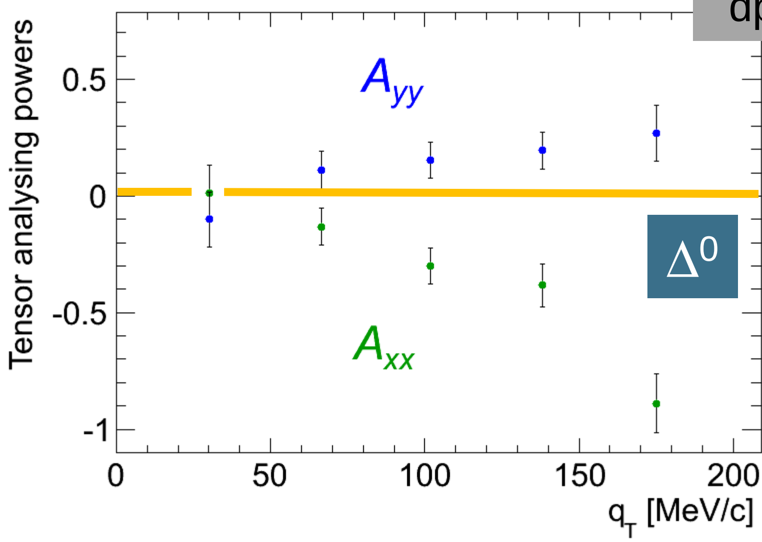
first measurement (at 2.3 GeV)!

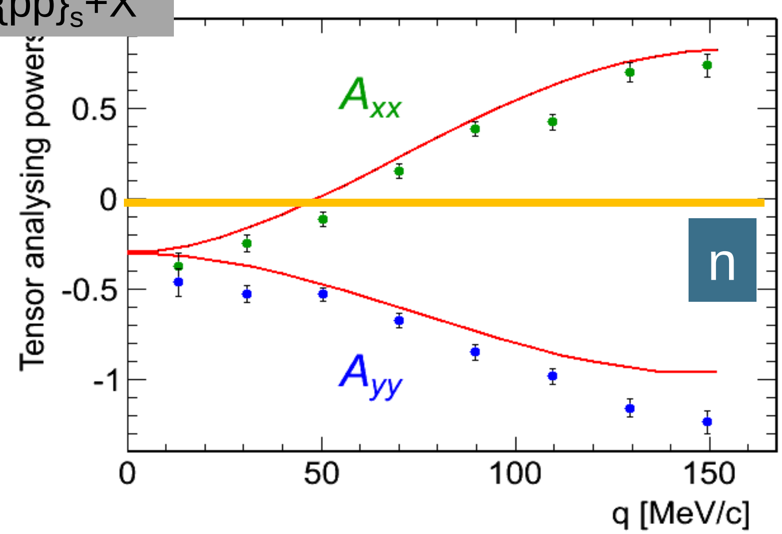
→ significant differences (Δ^0 and n):

- relative sign of A´s interchanged
- A´s ~ 0 for low momentum transfer



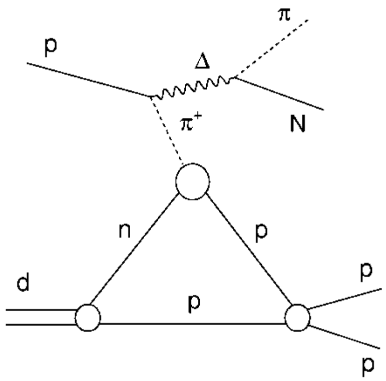
$dp \rightarrow \{pp\}_s + X$





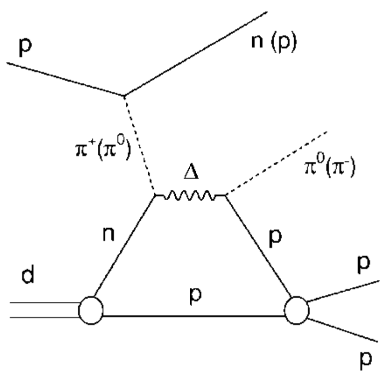
D. Mchedlishvili et al., arXiv:nucl-ex/1305.54

NN scattering: np → pΔ^0 channel



Direct mechanism:

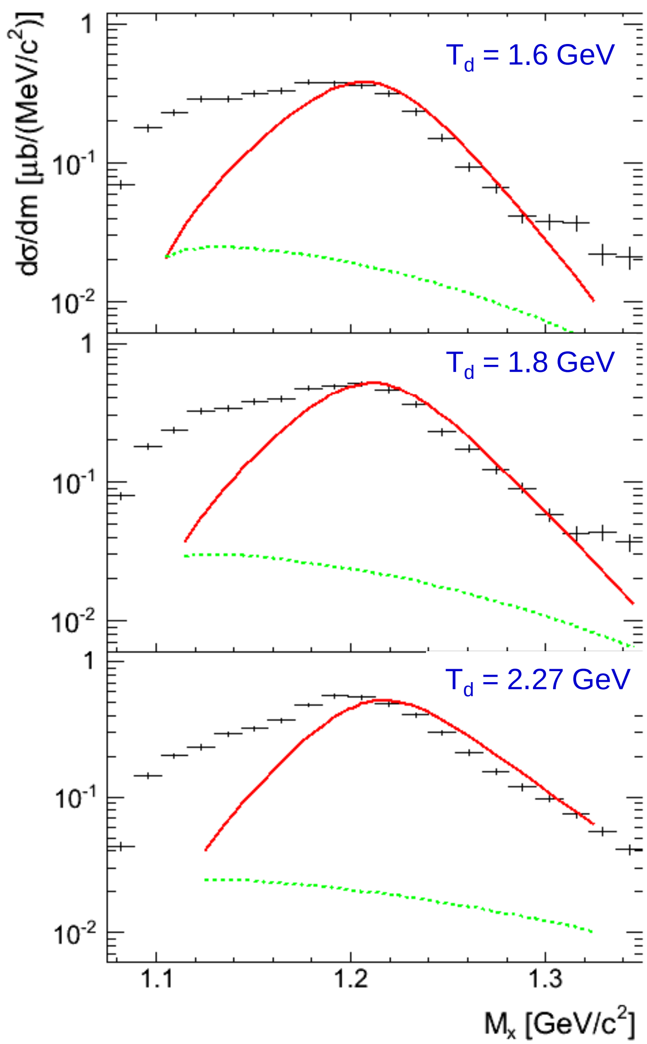
Δ isobar direct production by the one pion exchange



Exchange mechanism:

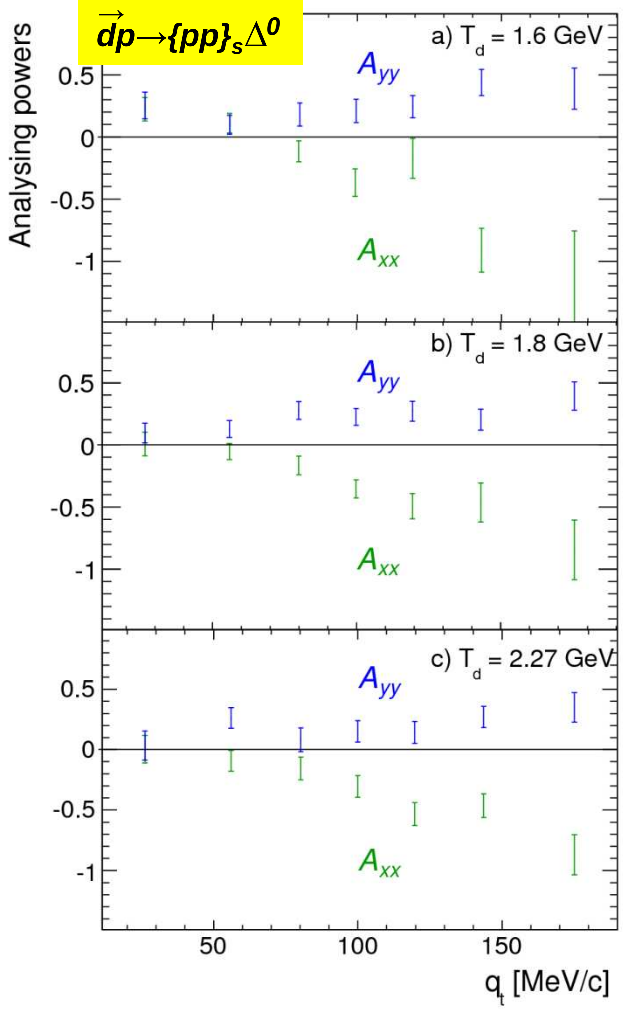
Δ isobar excites inside the projectile deuteron

1. Pion-nucleon are from different vertices
2. I=1/2 and I=3/2 both are allowed



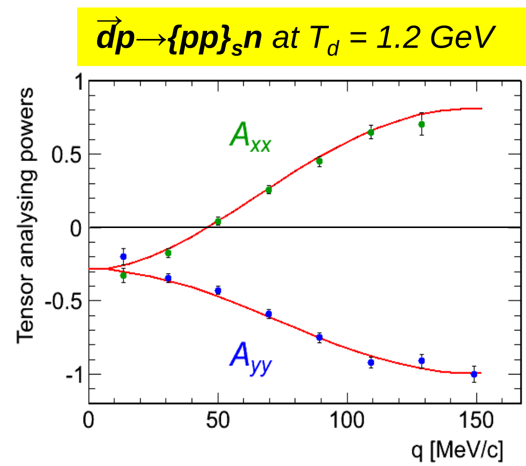
D. Mchedlishvili et al., arXiv:nucl-ex/1305.54

NN scattering: np → pΔ^0 channel



High mass region: $1.19 < M_X < 1.35$ GeV/c^2

COMPARE!



Differences:

- Signs are flipped for all T_d
- A_{xx} and A_{yy} are small at q_t=0

Constraints on the modeling of the $np \to p\Delta^0$ amplitudes !

Pion production: Physics case

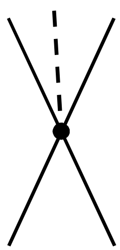
Extension of ChPT to the NN→NNπ process

- A full data set of all observables in $pp \to \{pp\}_s\pi^0$ and $np \to \{pp\}_s\pi^-$
- *Partial wave amplitudes* and test the ChPT predictions.
  (Di-proton $\{pp\}_s$: free {pp}-pair in $^1S_0$ state, $E_{pp} < 3$ MeV)

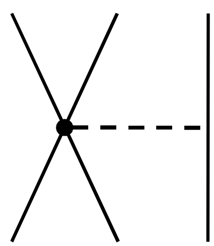
$pp \to \{pp\}_s\pi^0$ includes $^3P_0 \to {}^1S_0\, s$, $^3P_2 \to {}^1S_0\, d$ and $^3F_2 \to {}^1S_0\, d$
$np \to \{pp\}_s\pi^-$ adds $^3S_1 \to {}^1S_0\, p$ and $^3D_1 \to {}^1S_0\, p$

- p-wave amplitudes give access to the 4Nπ contact operator, controlled by the *Low Energy Constant (LEC) d*.

$NN \to NN\pi$



3N scattering



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

Our goal is to establish that the same LEC controls NN→NNπ

Pion production: π^0 channel

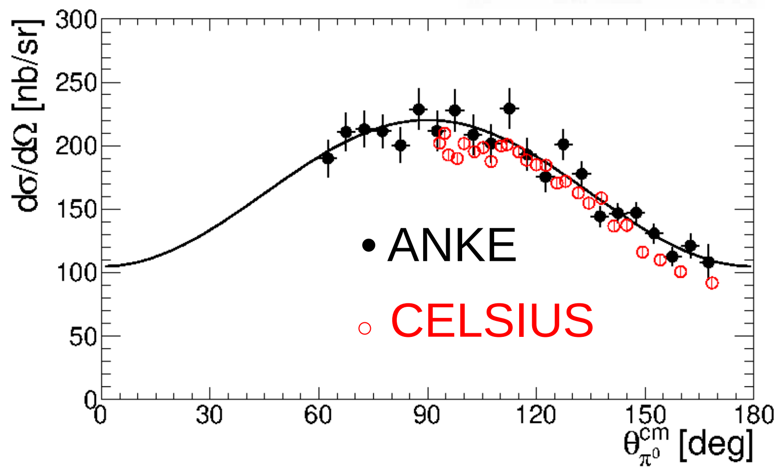
D. Tsirkov et al., PLB, 712, 370 (2012)

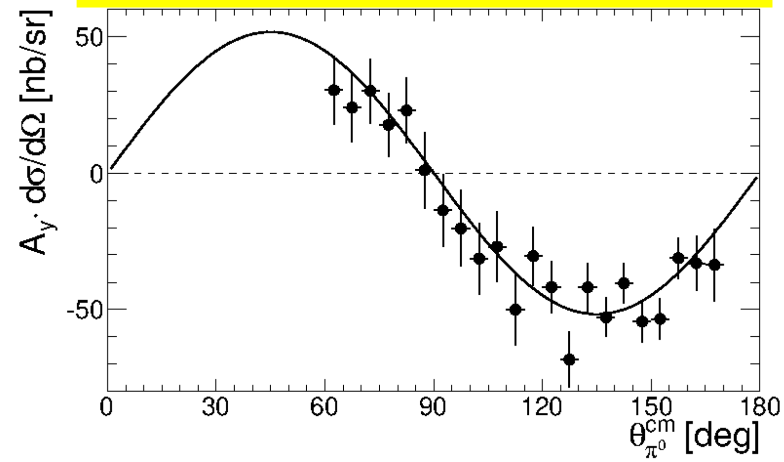
$d\sigma/d\Omega$ and A_y in $pp \to \{pp\}_s \pi^0$

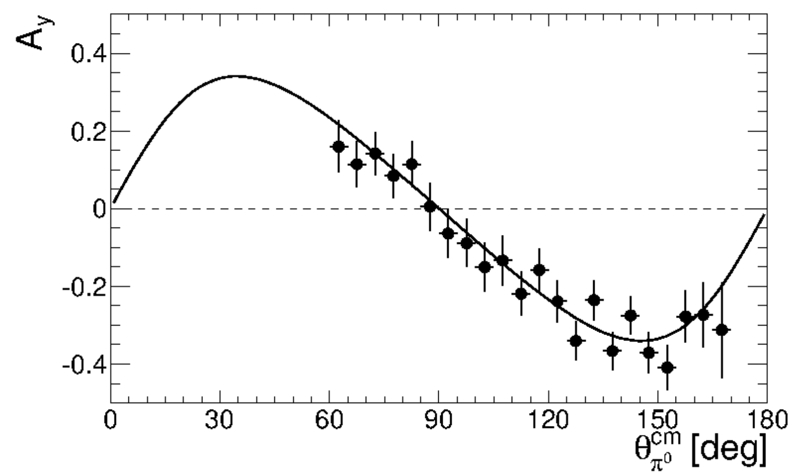
Near threshold at Tp=353 MeV

$$\left(\frac{d\sigma}{d\Omega}\right)_0 = \frac{k}{4p}\left(a_0 + a_2 \cos^2\theta_\pi + a_4 \cos^4\theta_\pi + \cdots\right)$$

$$A_y \left(\frac{d\sigma}{d\Omega}\right)_0 = \frac{k}{4p} \sin\theta_\pi \cos\theta_\pi \left(b_2 + b_4 \cos^2\theta_\pi + \cdots\right)$$







A_y is large in $pp \rightarrow \{pp\}_s\pi^0$

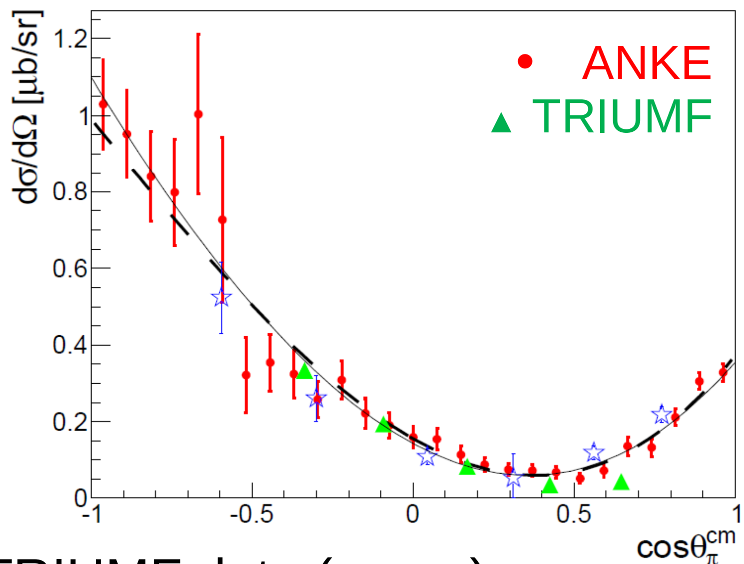
due to s-d interference !

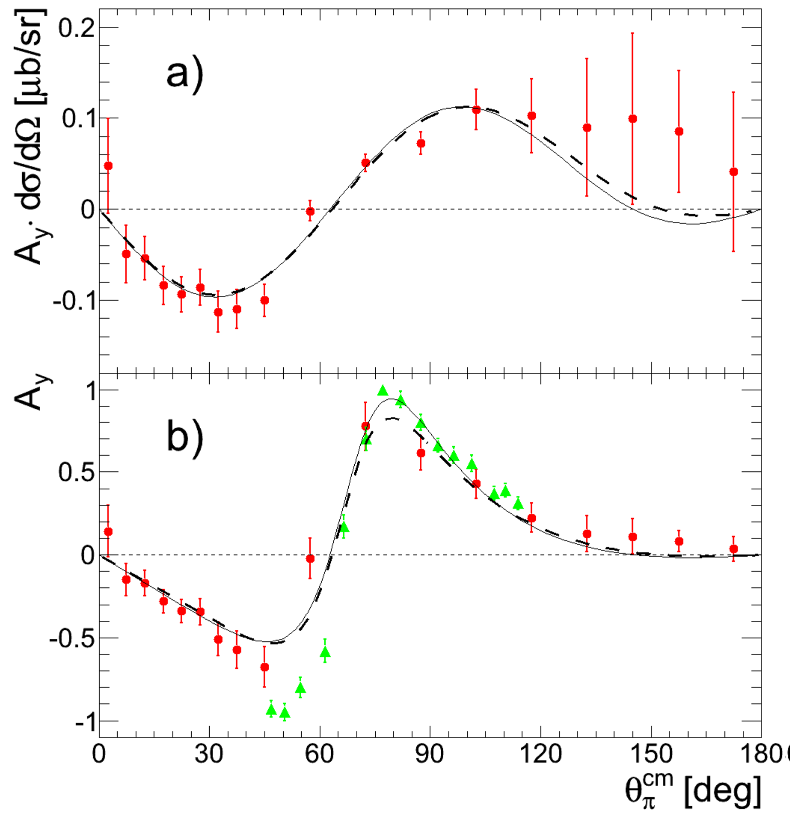
Pion production: π^- channel

$d\sigma/d\Omega$ and A_y in $pn \rightarrow \{pp\}_s \pi^-$ T_p=353 MeV

$$\left(\frac{d\sigma}{d\Omega}\right)_0 = \frac{k}{4p} \sum_{n=0} a_n \cos^n \theta_\pi,$$

$$A_y \left(\frac{d\sigma}{d\Omega}\right)_0 = \frac{k}{4p} \sin\theta_\pi \sum_{n=0} b_{n+1} \cos^n \theta_\pi$$





TRIUMF data (green)

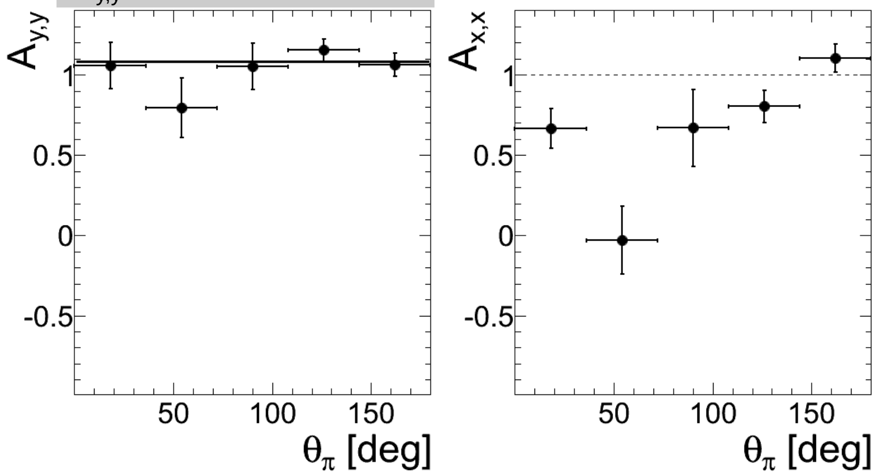
H. Hahn et al., Phys. Rev. Lett. 82 (1999) 2258,
F. Duncan et al., Phys. Rev. Lett. 80 (1998) 4390

S. Dymov et al., PLB, 712 , 375 (2012)

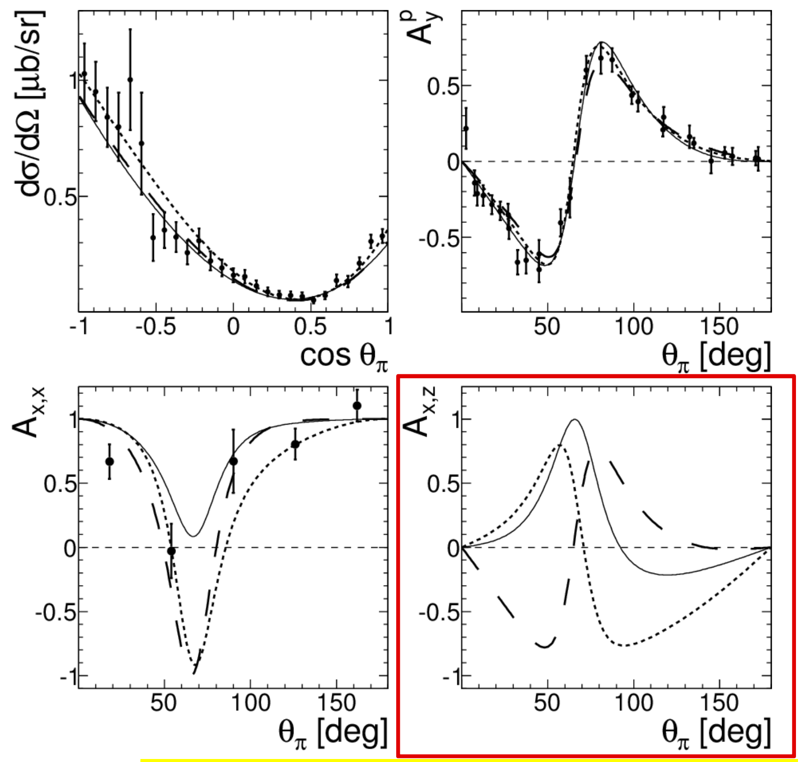
Pion production: π^- channel

$A_{x,x}$ and $A_{y,y}$ in $\vec{n}\vec{p}\to\{pp\}_s\pi^-$ (T_p=353 MeV)

$A_{y,y} \equiv 1$ conservation laws



All Observables in $pn\to\{pp\}_s\pi^-$ (ANKE data)



S. Dymov et al., arXiv:nucl-ex/1304.36

$A_{x,z}$ *measurement in:*

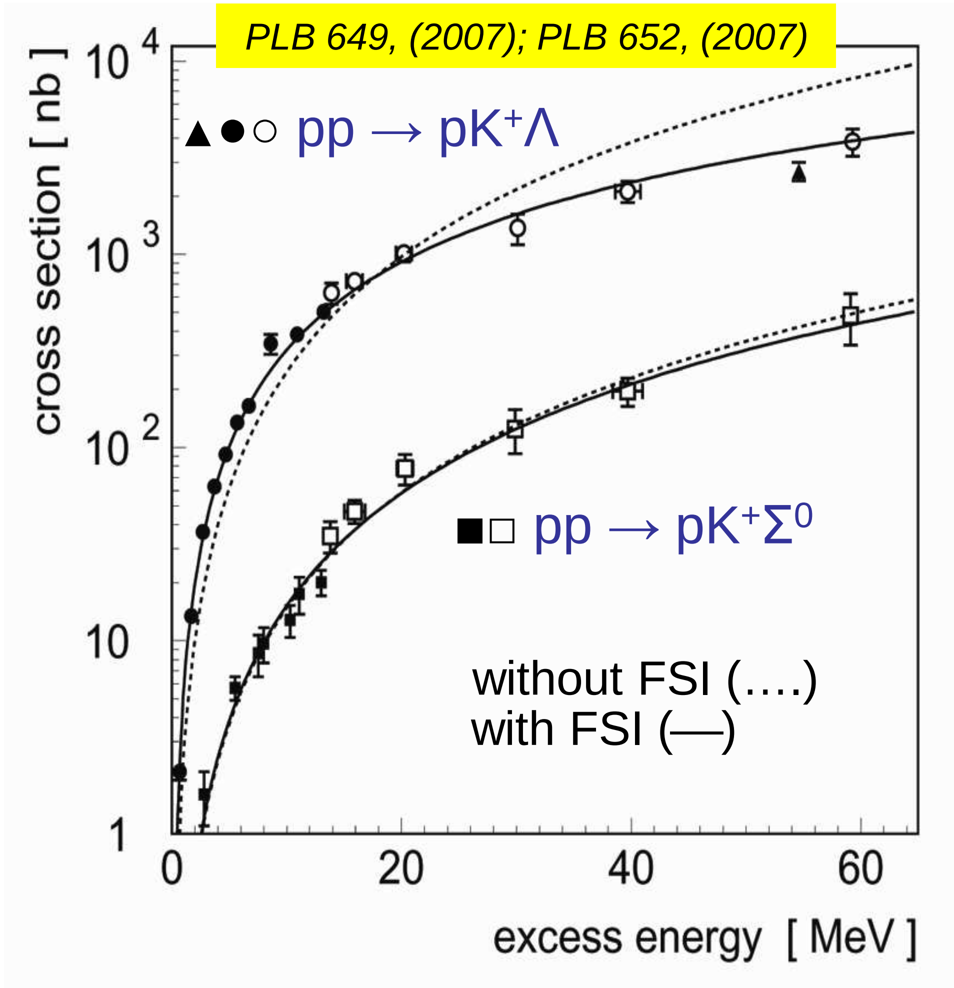
- *$pp\to\{pp\}_s\pi^0$ will test the PWA assumptions*
- *$pn\to\{pp\}_s\pi^-$ will choose between the solutions*

Data will allow a full PWA and determine relevant pion p-wave production strength making contact with ChPT theory !

Strangeness: YN interaction

p p → K^+ Y N (mostly COSY data)

- Importance of Final State Interaction
- Incoherent sum of $^3S_1$ and $^1S_0$
- FSI with unknown relative strengths
- Spin dependence of FSI unknown



Strangeness: spin-singlet/triplet Λp interaction

Separation of spin-singlet ($\boldsymbol{a_s}$) and triplet ($\boldsymbol{a_t}$) Λp amplitudes and FSI

through the measurement of :

$$p^{\uparrow}p^{\uparrow} \rightarrow K^{+}(\Lambda p) \text{ spin correlation } C_{NN}$$

Experimental information:

- Some data on low energy spin-averaged Λp cross sections;
- Binding energies of hypernuclei suggest $\boldsymbol{a_s}$ (Λp) is more attractive than $\boldsymbol{a_t}$;
- Λp FSI in $K^- d \rightarrow \pi^-$ (Λp) is purely S-wave spin-triplet;
- FSI of $pp \rightarrow K^+(\Lambda p)$ is unknown mixture of $\boldsymbol{a_s}$ and $\boldsymbol{a_t}$;
- Precise (inclusive) measurements carried out at SATURNE and HIRES/COSY;
- HIRES: global fit of all relevant data gave best fit with purely singlet (Λp) amplitude

➢ Better to measure in a single experiment !

COSY proposal #219 (2013)

Strangeness: spin-singlet/triplet Λp interaction

Further information:

- COSY-TOF has clearly shown dominance of N* prodiction in pp → K⁺(Λp): suggests S-wave final state dominance;
- There are two pp → K⁺(Λp) final S-wave production amplitudes:

$$M_1 = [\, W_{1,s}\, \eta_f\, p \bullet \varepsilon_i + i\, W_{1,t}\, p \bullet (\varepsilon_i \times \varepsilon_f)]\;\; X_f \bullet \;\; X_i$$

- The unpolarized cross section is proportional to:

$$I\,(pp \rightarrow K^+\Lambda p) = ¼\,(|W_{1,s}|^2 + 2\,|W_{1,t}|^2)$$

- The spin-correlation picks out purely the singlet:

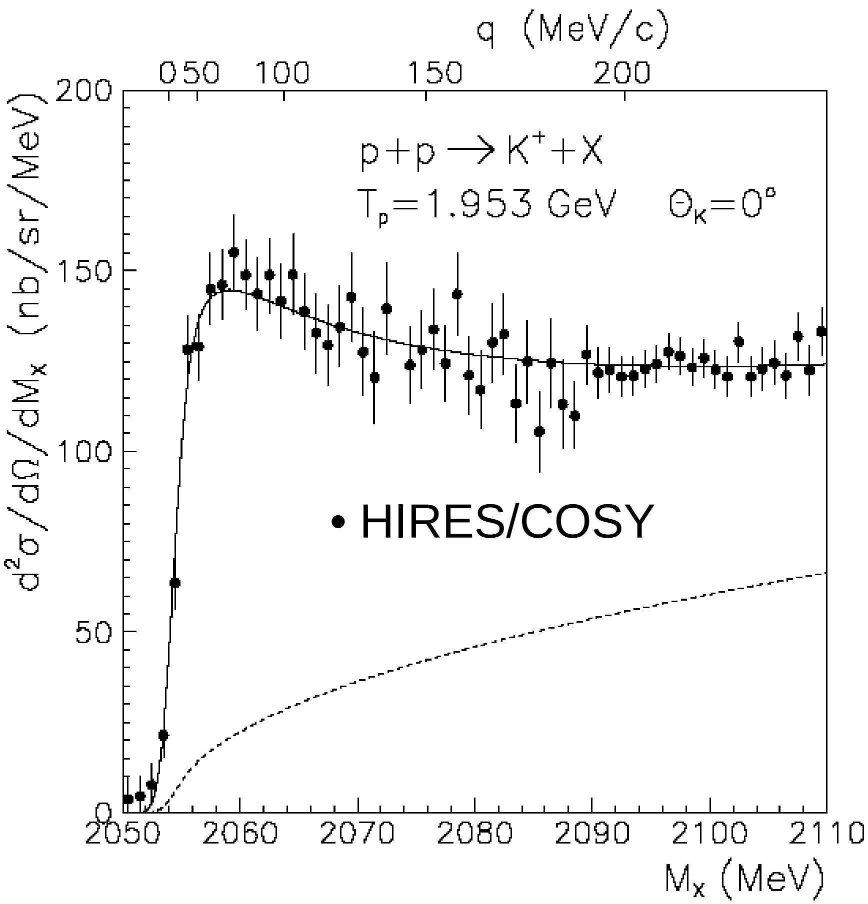
$$I\,(pp \rightarrow K^+\Lambda p)\; C_{NN}\,(pp \rightarrow K^+\Lambda p) = \;¼\,|W_{1,s}|^2$$

➢ The ratio of spin-triplet to spin-singlet is fixed completely by spin-correlation:

$$[\,1 - C_{NN}\,(pp \rightarrow K^+\Lambda p)\,] \,/\, 2 \cdot C_{NN} = |W_{1,t}|^2 / \,|W_{1,s}|^2$$

S. Abd El-Samad et al., PLB 688, 142 (2010)
G. Fäldt and C. Wilkin, EPJ A 24, 431 (2005)

Strangeness: proposed measuremnets at ANKE



A. Budzanowski et al., PLB, 687, 31 (2010)

- Each of the $W_{1,t}$ and $W_{1,s}$ will have own FSI factor, depending on spin-triplet/singlet scattering lenghts;
- We want to measure C_{NN} as a function of the kaon momentum of the Λp invariant mass;
- Simple $\pi^+ \rho$ exchange model near threshold suggests that singlet production is 5 times stronger than triplet.

This will give globally $C_{NN} \approx 0.84$!

- ANKE has considarable experience in detecting K^+p correlations and able to measure such an observable !

Future measurements: ANKE experiments

Double polarization:

(i) $\vec{p}\vec{n} \rightarrow np$ (spin observables)

(ii) $\vec{n}\vec{p} \rightarrow \{pp\}_s\pi^-$ (A_{xz} parameter)

(iii) $\vec{p}\vec{p} \rightarrow K^+\Lambda p$ (C_{NN} coefficient)

All experiments are approved and scheduled for 2013/14 !

Summary

- COSY - unique opportunities for hadron physics with polarized hadronic probes (beam & target) – High precision + Spin
- ANKE state-of-the art facility to investigate a broad and exciting field of physics
- Physics: “NN interaction, ChPT, FSI ” – selected examples and further plans at ANKE
- New opportunities to explore longitudinal polarization using Siberian Snake at COSY

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The END

Many thanks to the conference organizers !

Physics at COSY using longitudinally polarized beams: Snake Concept

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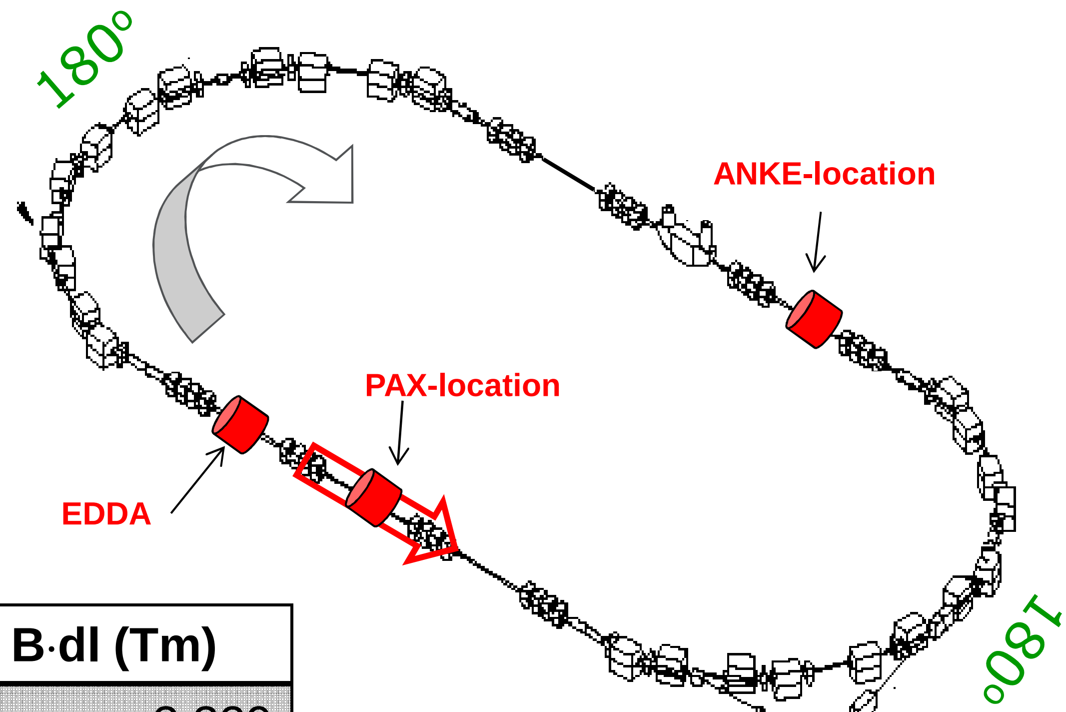
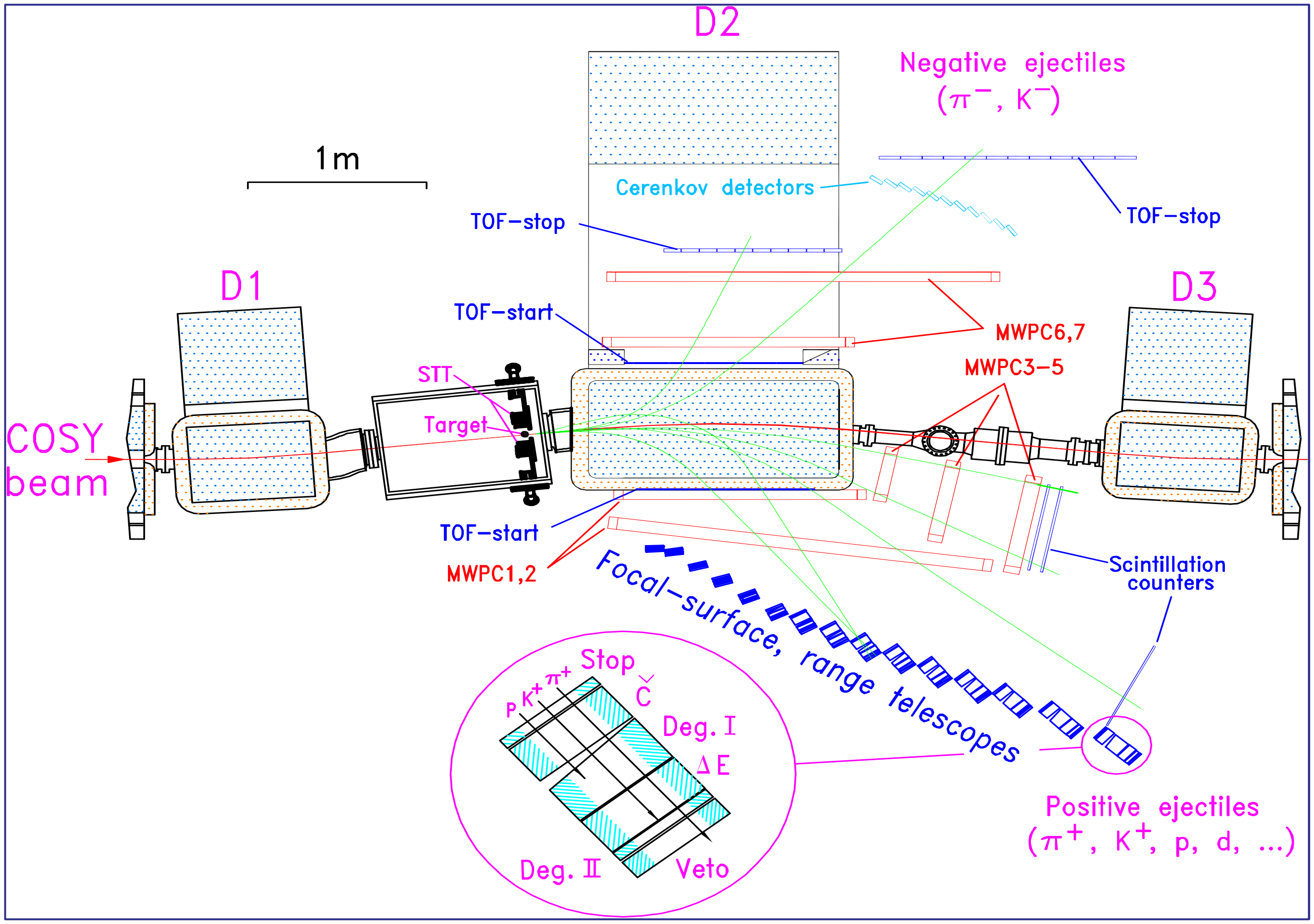
- Should allow for flexible use at two locations
- Fast ramping (< 30s)
- Cryogen-free system

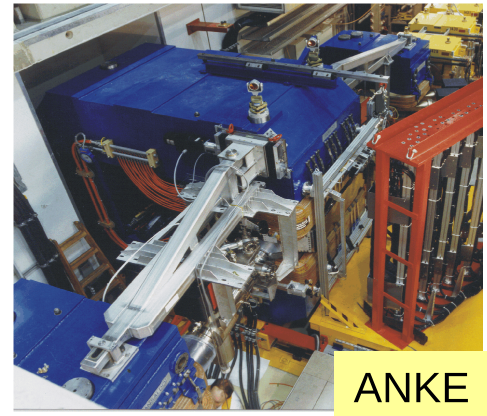


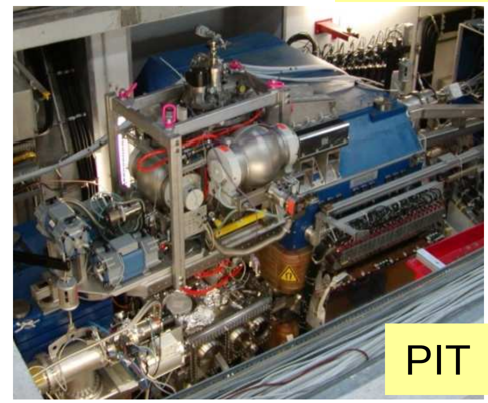
	B·dl (Tm)
pn→{pp}$_s\pi^-$ at 353 MeV	3.329
PAX at COSY 140 MeV	1.994
BUP at COSY 30-50 MeV	1.165
T_{max} at COSY 2.88 GeV	13.887

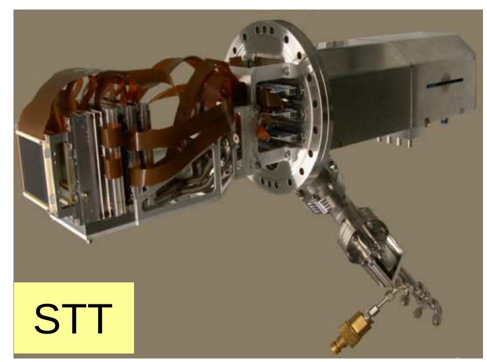
Facilities: ANKE apparatus



- Excellent Kaon identification (Positive and Negative)
- Low energy proton (spectator) detection (STT)
- Di-proton ({pp}) selection (by FD)
- Polarized (un-polarized) dense targets



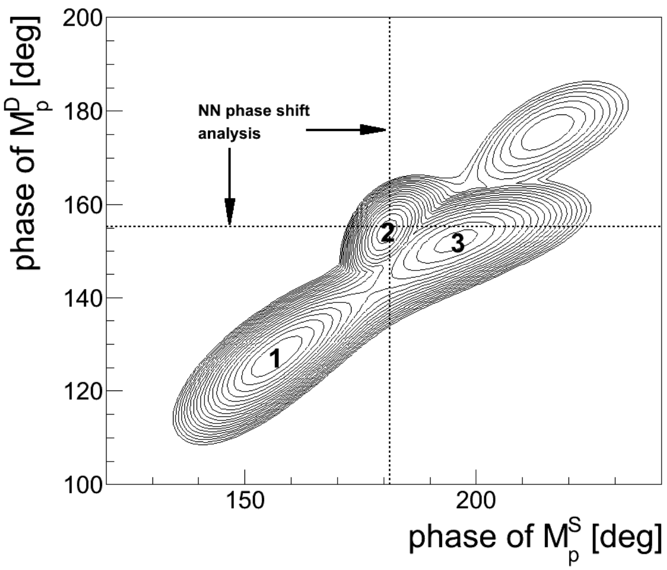




Pion production: π^- channel

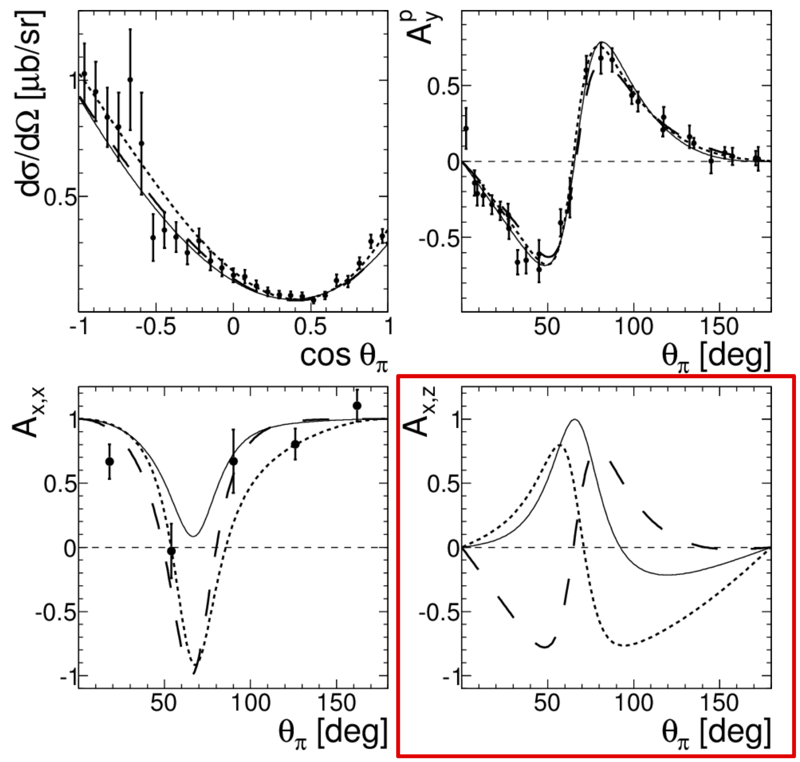
Three minima with close χ^2

Solutions 2 and 3 have close phases but very different magnitudes!



χPT calculation predicts the phases close to the free NN scattering in spite of strong coupling

Observables in $pn \to \{pp\}_s \pi^-$ (ANKE data)

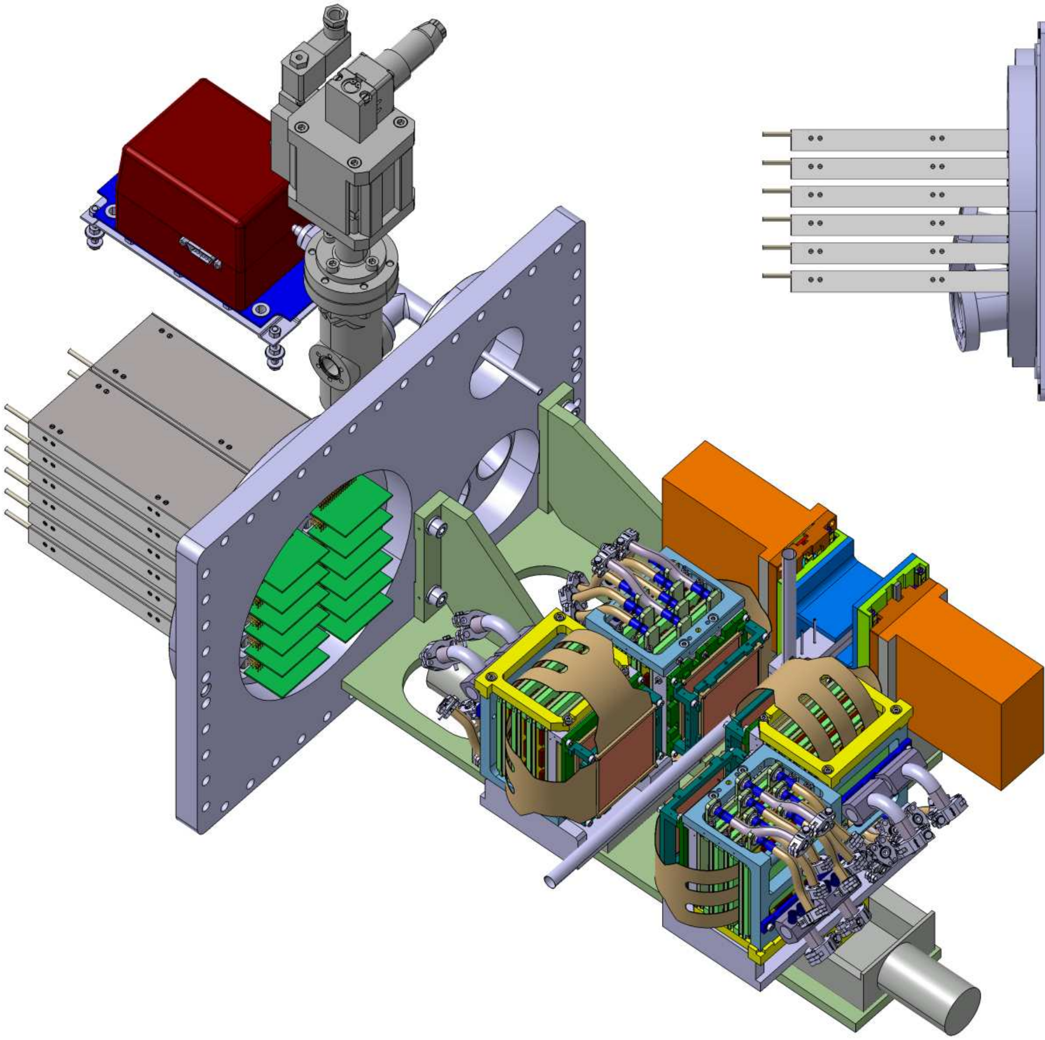


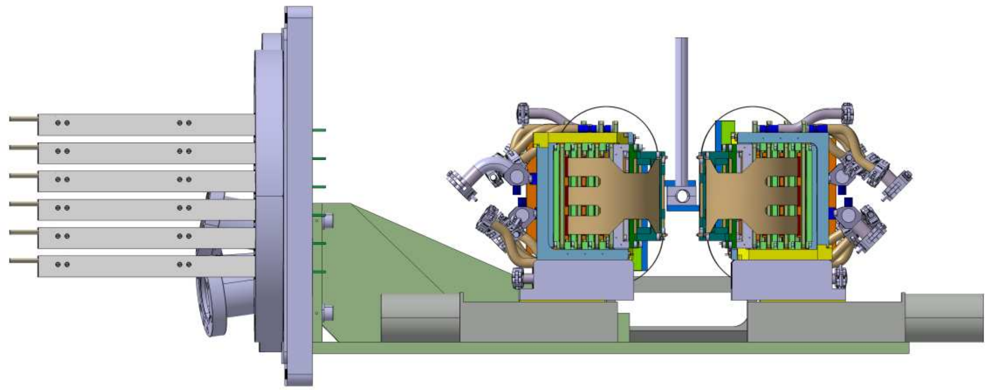
$A_{x,z}$ measured in

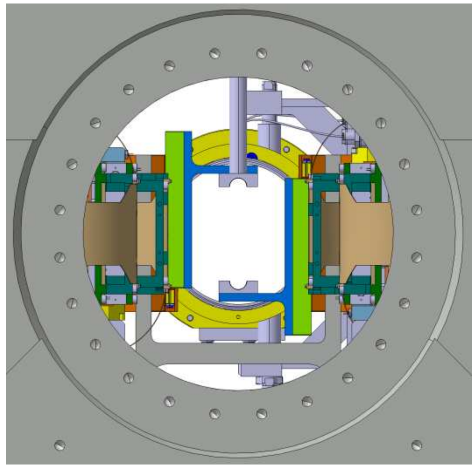
- *$pp \to \{pp\}_s \pi^0$ will test the PWA assumptions*
- *$pn \to \{pp\}_s \pi^-$ will choose between the minima*

S. Dymov et al., arXiv:nucl-ex/1304.36

ANKE Silicon Tracking Telescopes:







ANKE Target Rail System