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Master's Thesis for
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Exact and Natural Science Faculty
Fundamental Physics

SPIN-FILTERING EXPERIMENT AT COSY:
BEAM POLARIMETRY STUDIES

Master's Thesis prepared in Forschungzentrum Jülich

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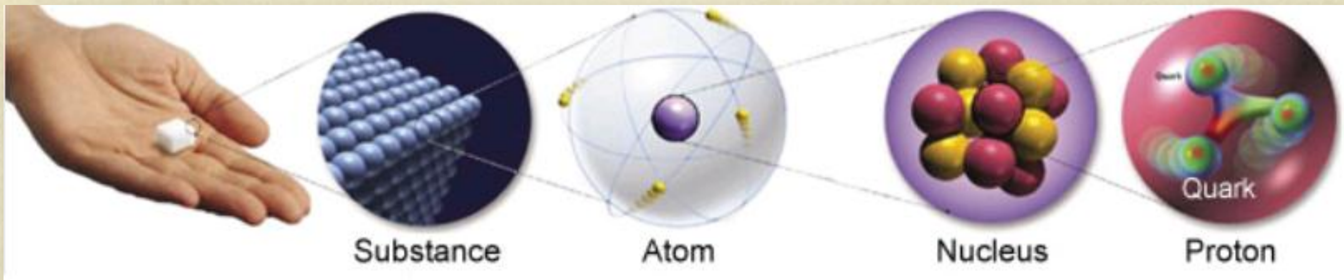
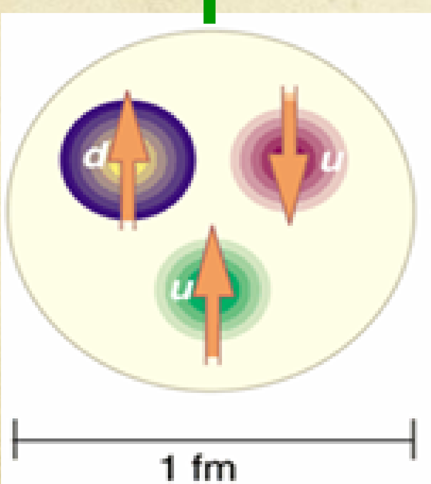
OUTLINE

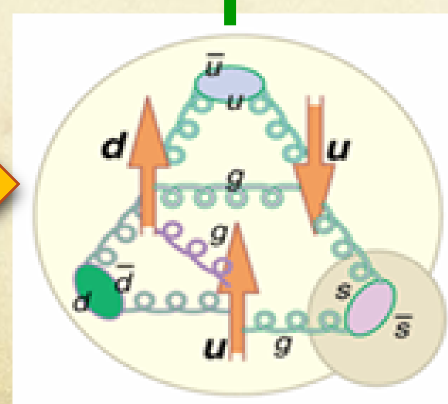
- Motivation
- Spin Filtering
  - Beam polarization lifetime
- Experimental Set-up
- RESULTS:
  - Reaction identification
  - Measurement of the beam polarization lifetime
  - Analyzing power for deuteron break-up reaction

WHAT IS THE WORLD MADE OF?

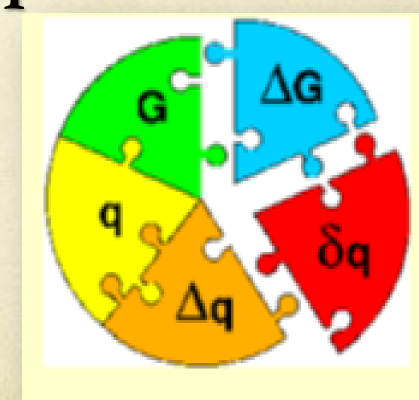


Complex nuclear structure

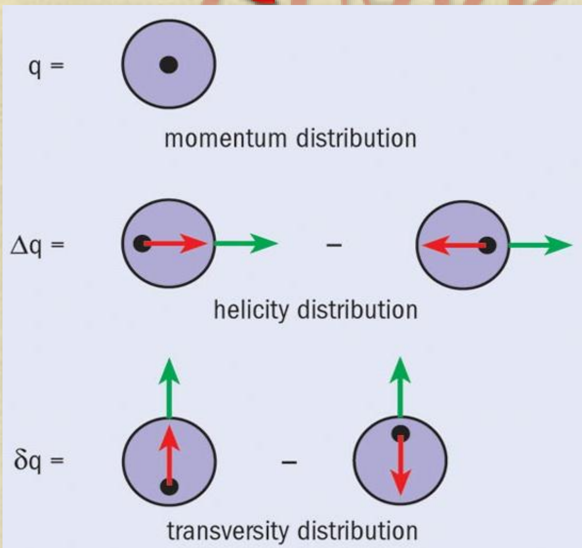




"Spin Crisis"



QUARK DISTRIBUTIONS

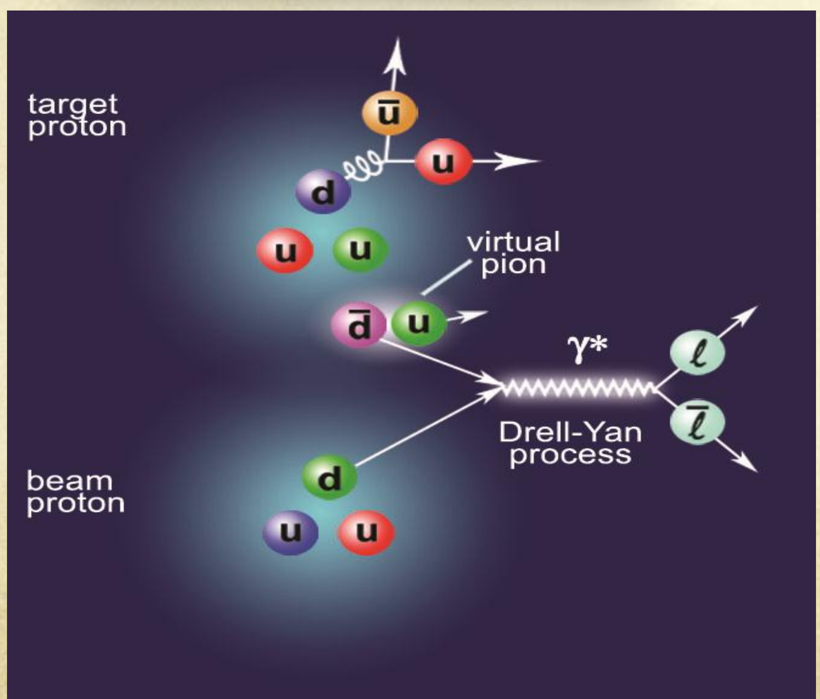


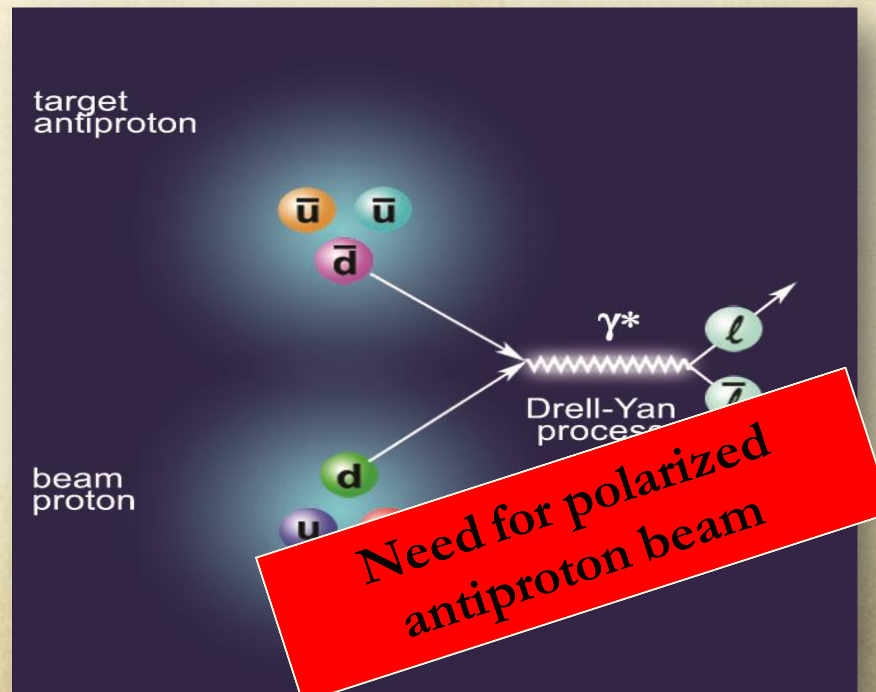
Momentum distribution (well known)

$\Delta q(x)$: helicity distribution (known)

$\delta q(x)$: transversity distribution (not yet directly measured!)

Drell-Yan Process "Golden Channel"





POLARIZATION

For ½ spin particles beam:

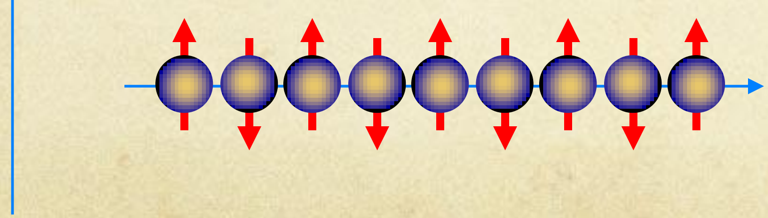
Beam Intensity $\mathbf{I} = N_{\uparrow} + N_{\downarrow}$

Vector Polarization $\mathbf{P_y} = \dfrac{N_{\uparrow} - N_{\downarrow}}{N_{\uparrow} + N_{\downarrow}}$

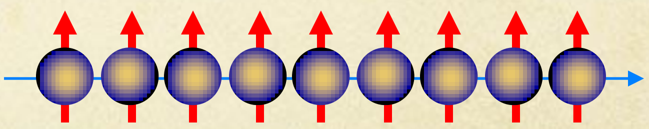
$-1 < P_y < 1$

y

Unpolarized Beam $P_y = 0$



Polarized Beam $P_y = 1$

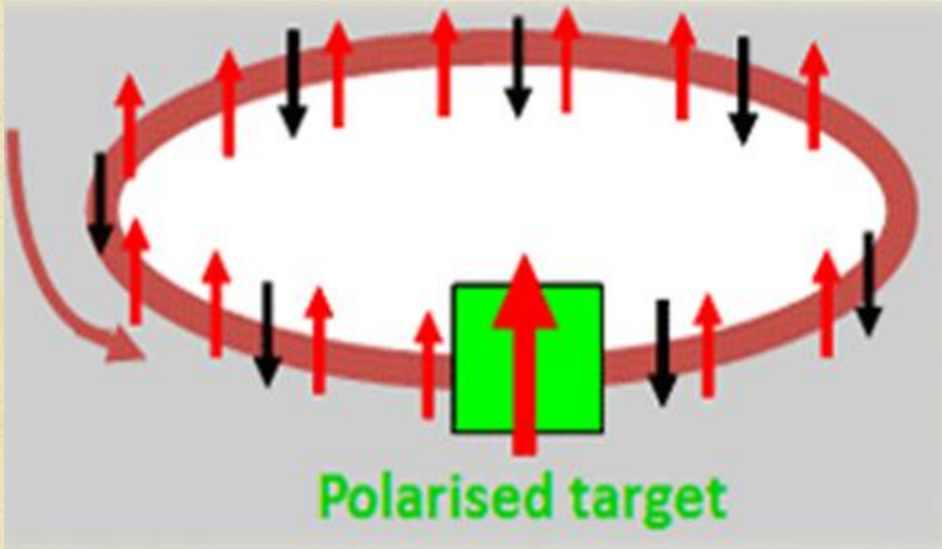


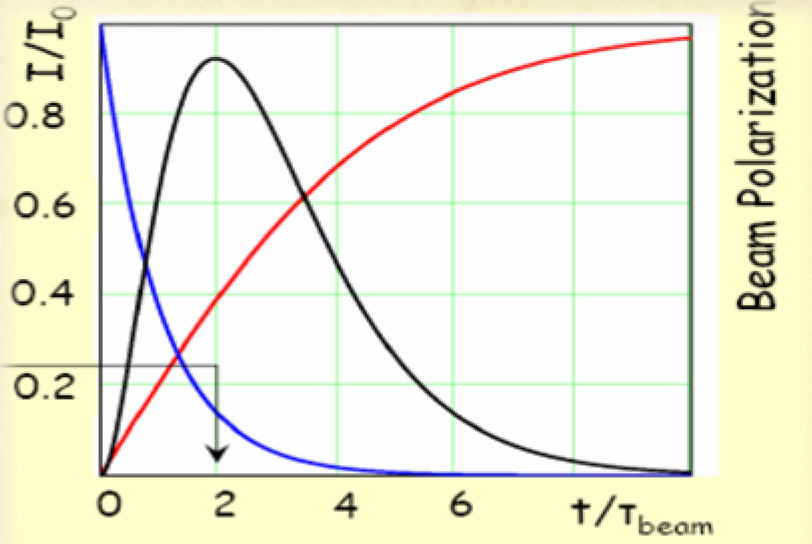
HOW TO POLARIZE ANTIPROTONS? SPIN FILTER

$$\sigma_{tot} = \sigma_0 + \sigma_\perp \cdot \vec{P} \cdot \vec{Q} + \sigma_{||} \cdot (\vec{P} \cdot \vec{k})(\vec{Q} \cdot \vec{k})$$

P beam polarization
Q target polarization
k || beam direction

- Unpolarized beam
- Polarized target
- Discard one substate more than the other based on $\sigma(\uparrow\uparrow) \neq \sigma(\uparrow\downarrow)$





- **Need to know beam polarization lifetime**

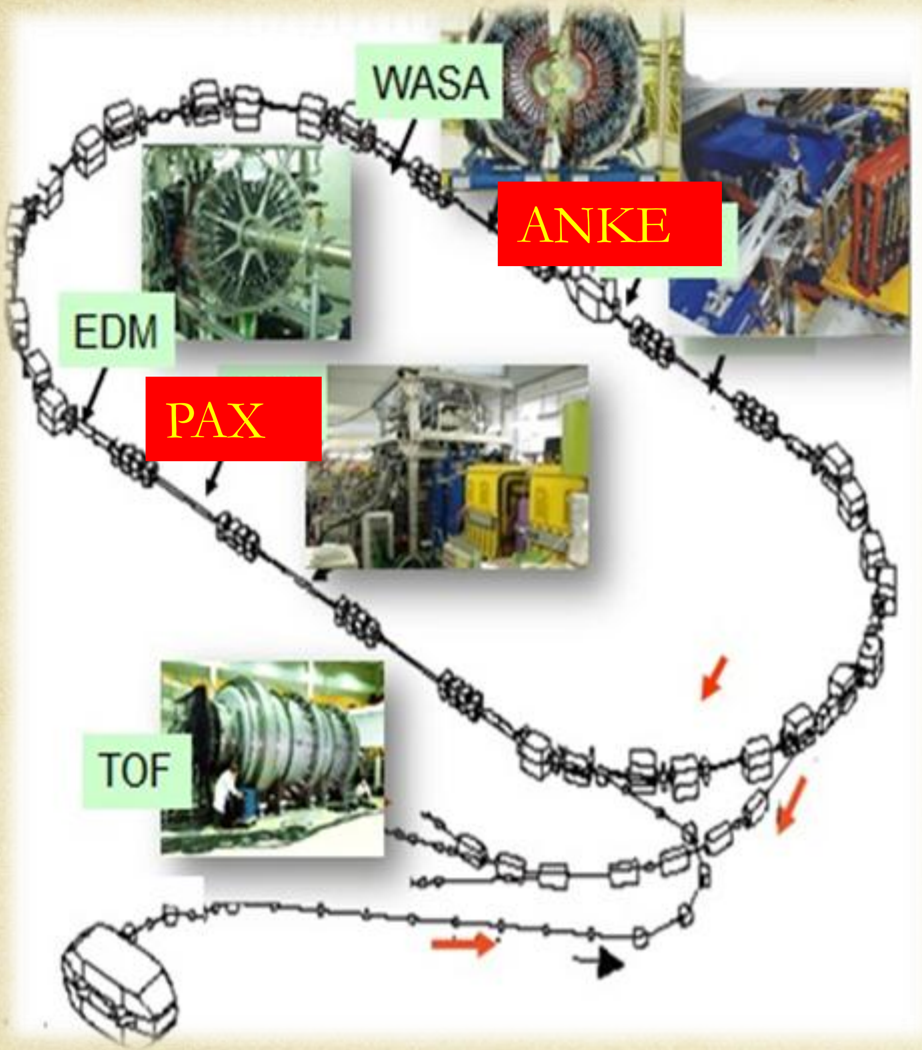
$$FOM(t) = P^2(t)\, I(t)$$

- **Studies on proton beams (COSY, Juelich)**
  - to commission and test the experimental hardware
  - develop dedicated procedures for the analysis

OBJECTIVES OF THE THESIS

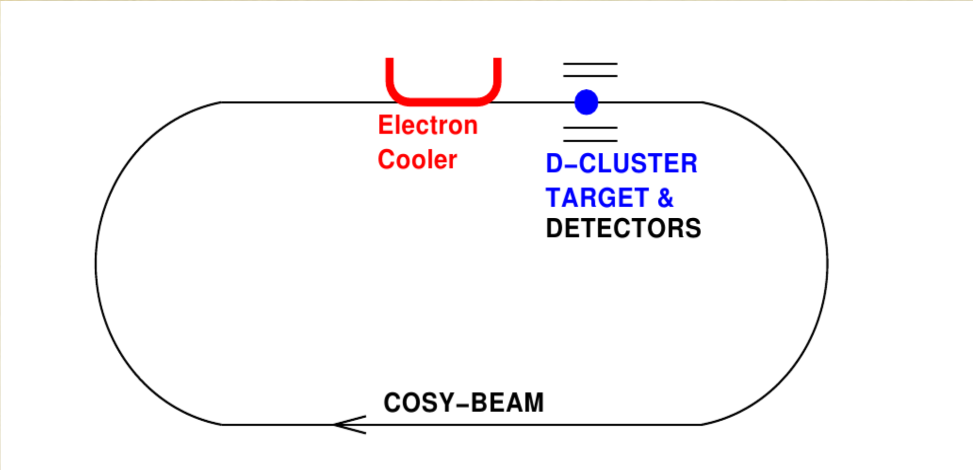
- **Beam Polarization Lifetime:**
  - Polarized Beam
  - Long cycles
  - Elastic Scattering
- **Break-up events**
  - By-product of the main experiment
  - But suitable to be used to extract useful information for Chiral Perturbation Theory
  - 49,3 MeV energy is small enough to use ChPT
  - Large enough to see 3 nucleon forces contributions

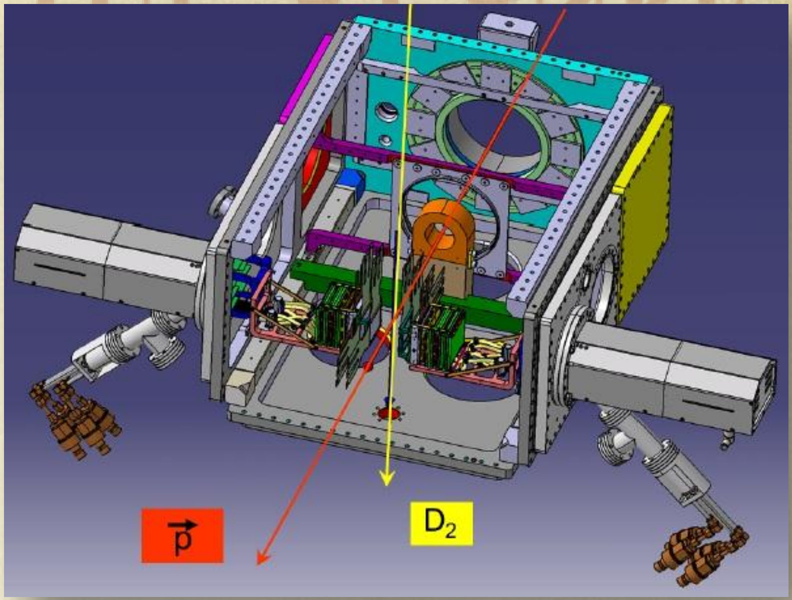
COSY (COOLER SYNCHROTRON)



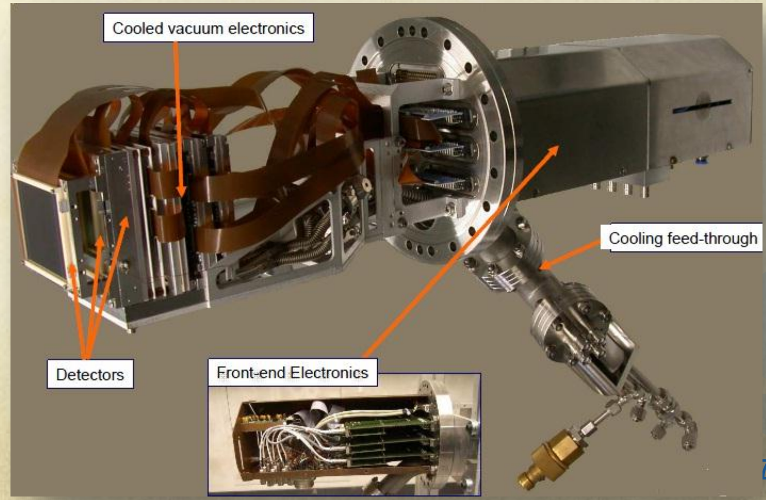
- Unpolarized and transversely polarized proton and deuteron beams
- Momentum range: 300MeV/c - 3.7 GeV/c
- Intenstity $\sim 10^{10}$

EXPERIMENTAL SETUP AT ANKE





- Unpolarized deuteron cluster target
  - Silicon Tracking Telescope



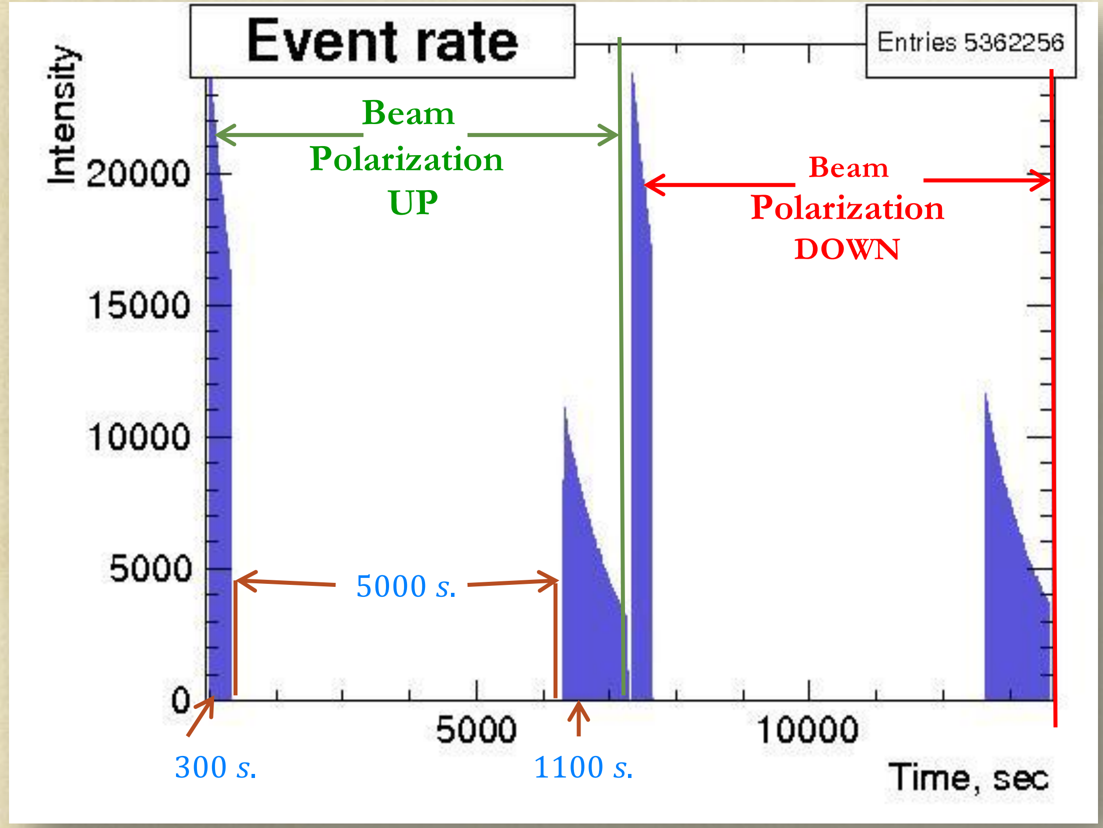
- 3 layers of double – sided silicon-strip detectors

Particle tracks

Particle Identification by $\frac{\Delta E}{E}$ method

Stopped particles -> Total energy

POLARIZATION LIFETIME CYCLES



- A polarized cooled proton beam at 49.3 MeV.
- Polarization is flipped by RF solenoid
- ANKE unpolarized deuteron target is on only at the beginning and at the end of the cycle.

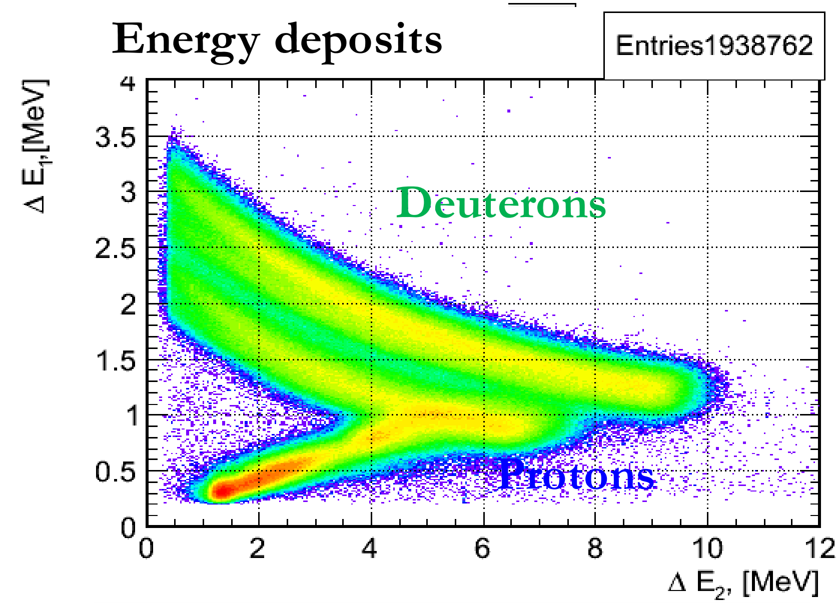
- Between the measurements the cluster target is switched off for about 5000 s
- Polarization is measured using pd elastic scattering

P.S. The time periods are optimized to yield the smallest relative errors in τ_{Pol}

PARTICLE IDENTIFICATION $\frac{\Delta E}{E}$ method

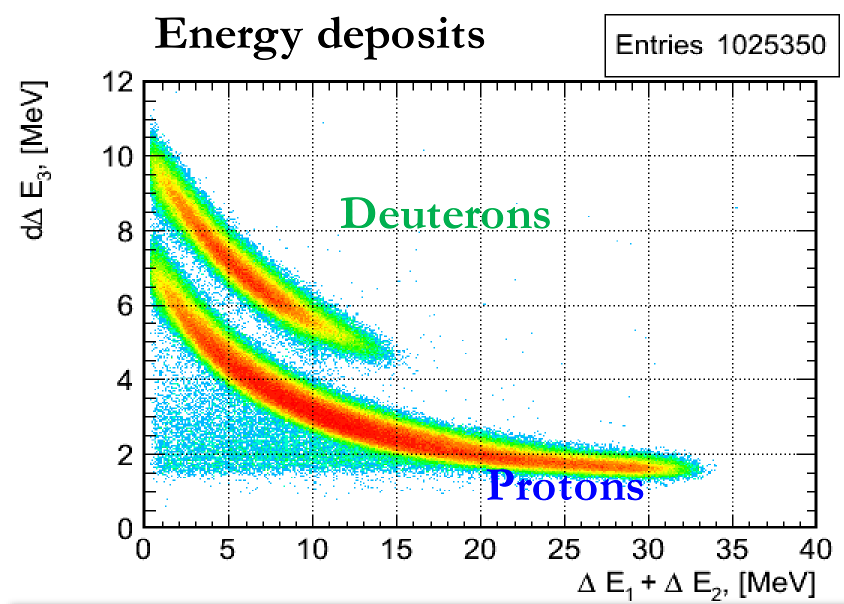
Particles detected only in first two layers:

Energy deposits

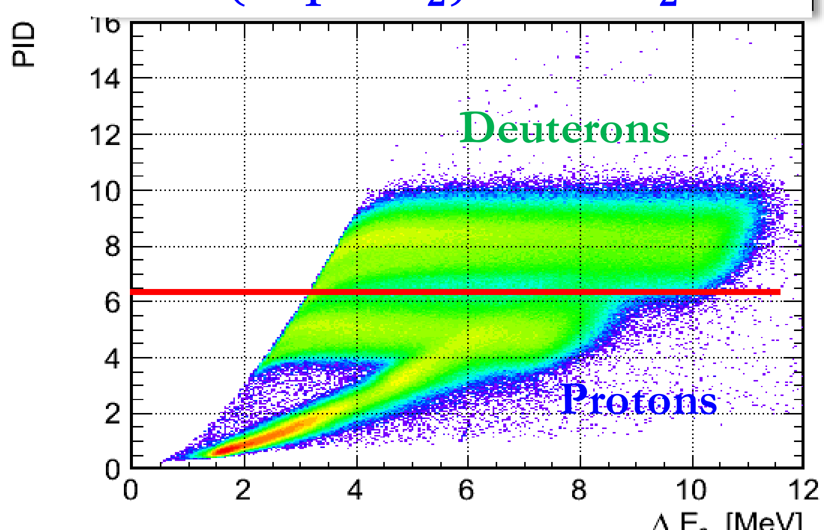


Particles detected in all three layers:

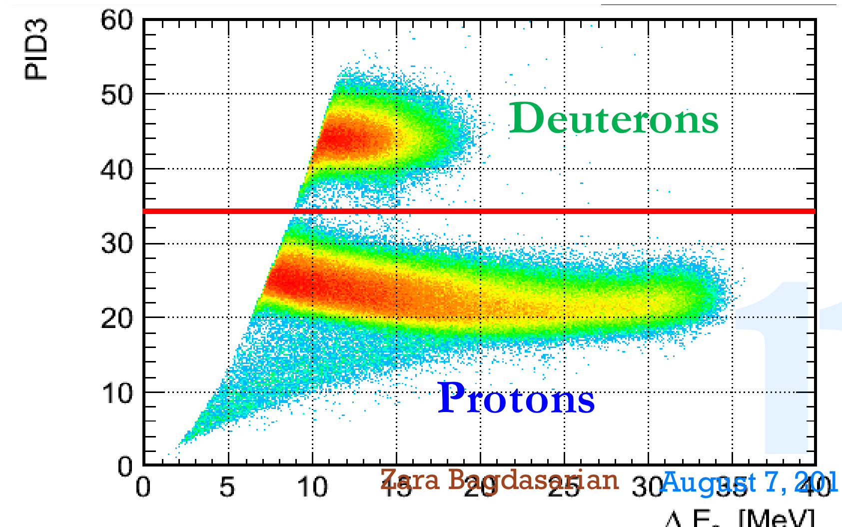
Energy deposits



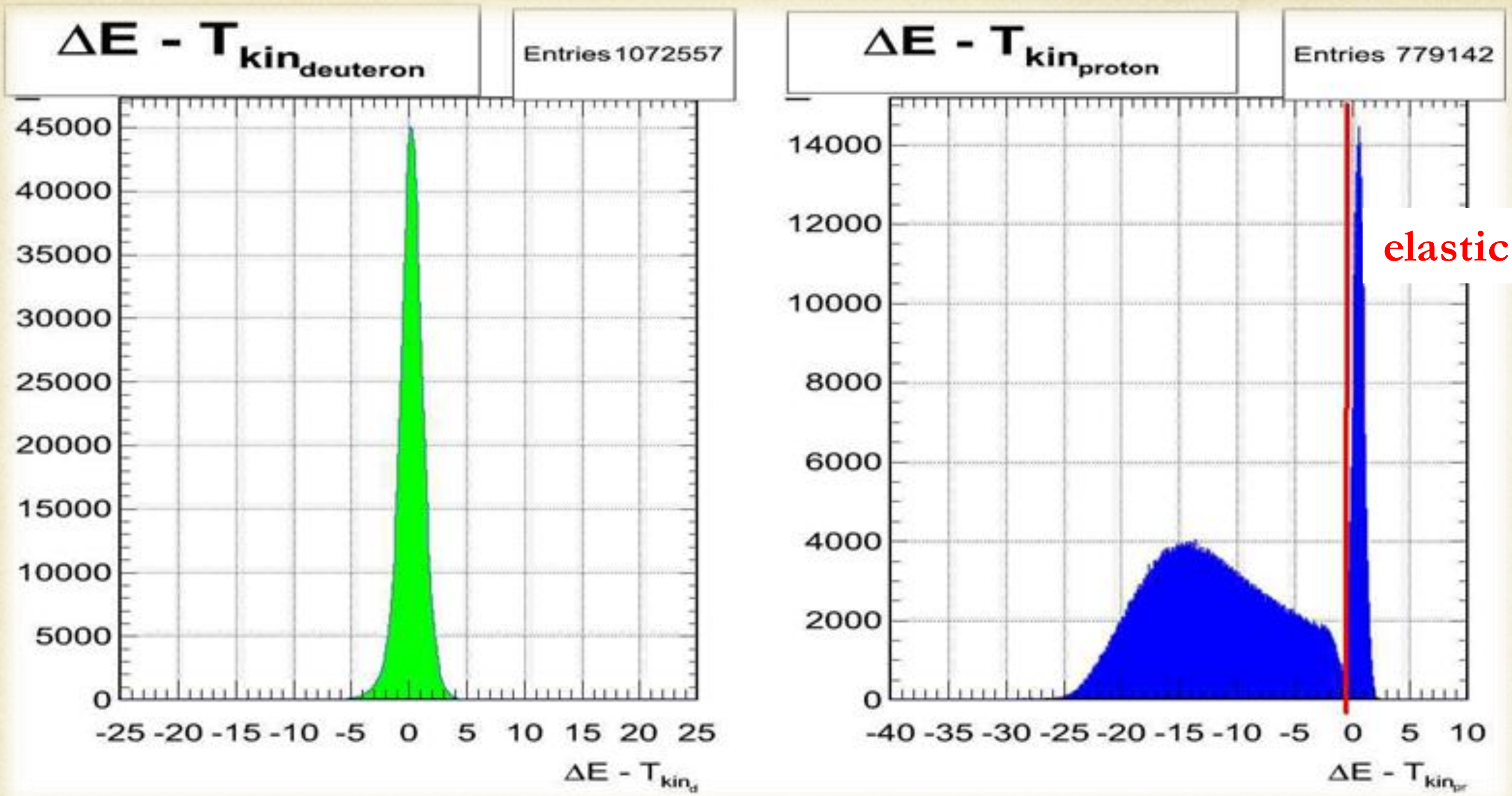
$PID=(\Delta E_1+\Delta E_2)^{1.62}-\Delta E_2^{\ 1.62}$



$PID3=(\Delta E_1+\Delta E_2+\Delta E_3)^{1.62}-\Delta E_3^{\ 1.62}$



PD→PD ELASTIC SCATTERING

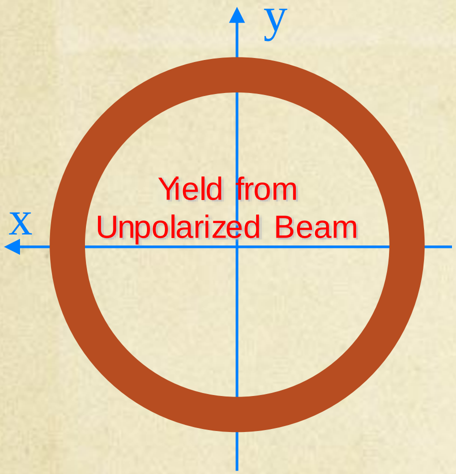


- ✓ Comparison with expected theoretical kinetic energies for deuterons and protons on the given polar angle

  - ✓ Reconstructing deuterons from elastic protons

Missing Mass [MeV]

POLARIZED EXPERIMENTS

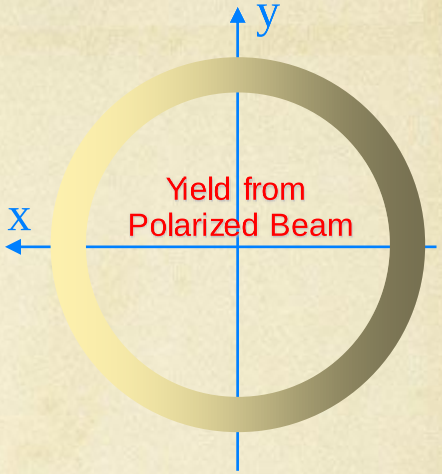


For Transversely polarized beam

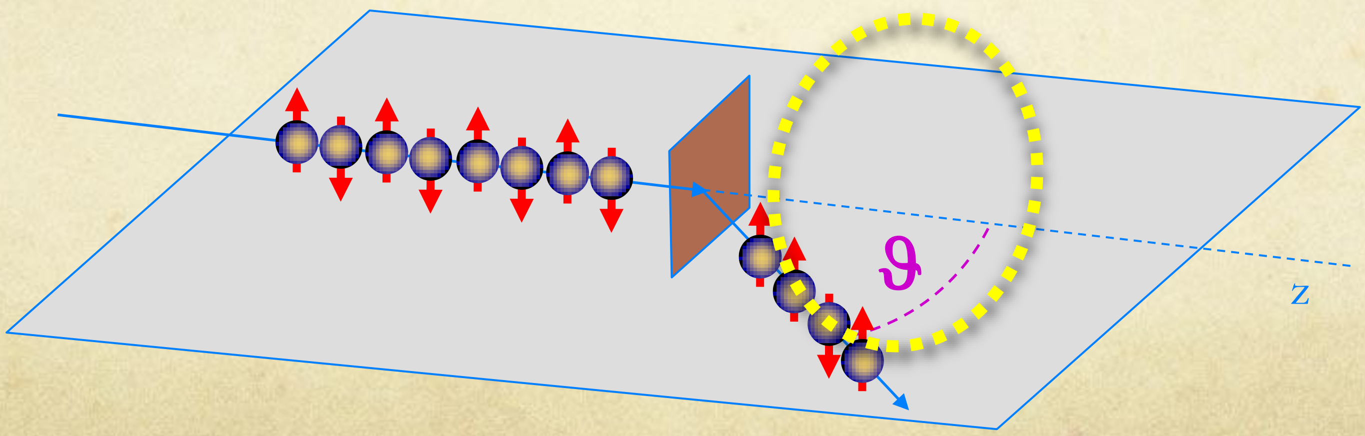
$$\left(\frac{d\sigma}{d\Omega}\right)_{pol}(\vartheta,\varphi)=\left(\frac{d\sigma}{d\Omega}\right)_{0}(\vartheta)\left(1+P_y A_y(\vartheta)\cos\varphi\right)$$

$$\varepsilon(\vartheta) \sim P_y \cdot A_y(\vartheta)$$

$$-1 < A_y < +1$$

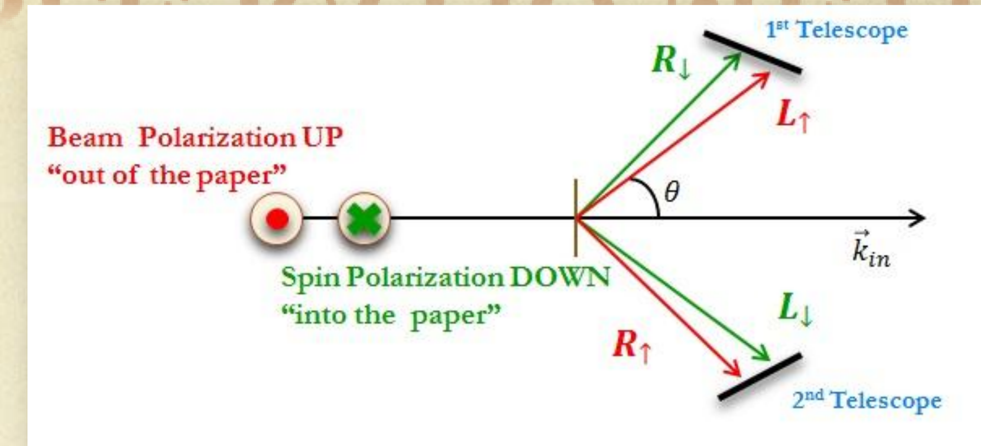


where, ***Ay*** is Analyzing Power of the <u>reaction</u>:
the polarization, obtained in the reaction, initiated with an unpolarized beam.



Zara Bagdasarian August 7, 2012

DOUBLE RATIO METHOD



$$L_\uparrow(\theta,0) = n d_t \Delta\Omega_1 E_1 \sigma_0(\theta)[1+ pA_y(\theta)]$$

$$R_\uparrow(\theta,180) = n d_t \Delta\Omega_2 E_2 \sigma_0(\theta)[1- pA_y(\theta)]$$

$$L_\downarrow(\theta,0) = n' d'_t \Delta\Omega_2 E_2 \sigma_0(\theta)[1+ pA_y(\theta)]$$

$$R_\downarrow(\theta,180) = n' d'_t \Delta\Omega_1 E_1 \sigma_0(\theta)[1- pA_y(\theta)]$$

$$\mathrm{L}\,(\theta) = \sqrt{L_\uparrow(\theta) L_\downarrow(\theta)}$$

$$\mathrm{R}\,(\theta) = \sqrt{R_\uparrow(\theta) R_\downarrow(\theta)}$$

- $$\varepsilon(\theta) = \frac{L(\theta) - R(\theta)}{L(\theta)+R(\theta)} = \frac{2pA_y(\theta)\cancel{\sqrt{n d_t \Delta\Omega_1 E_1 n' d'_t \Delta\Omega_2 E_2 \sigma_0(\theta)}}}{2\cancel{\sqrt{n d_t \Delta\Omega_1 E_1 n' d'_t \Delta\Omega_2 E_2 \sigma_0(\theta)}}}$$
  - count-rate-asymmetry

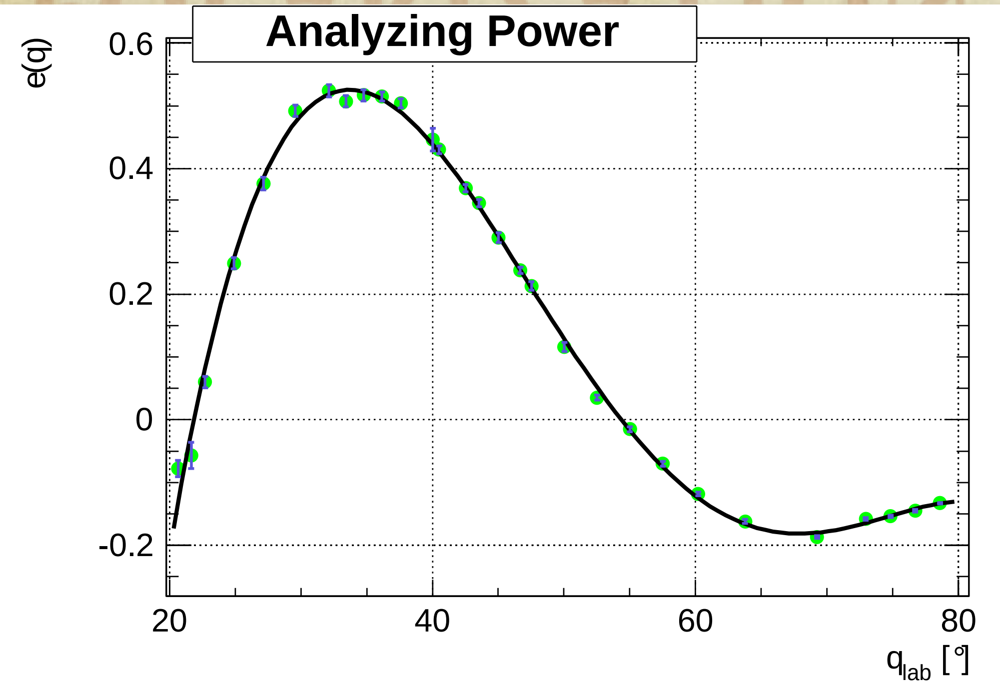
$$\boldsymbol{\varepsilon(\theta) = \frac{L(\theta)-R(\theta)}{L(\theta)+R(\theta)} = pA_y(\theta)^*}$$

d_t, d'_t - *target densities*
n, n' – *beam intensities*
E_1, E_2 - *detectors' efficiencies*
$\Delta\Omega_1$, $\Delta\Omega_2$ -*detectors' geometrical factors*

Independent of relative detector effeciencies and solid angles,
As well as relative integrated charge and of target thickness variations

*In the experimental data only minor $< cos\varphi >$ correction factor had to be considered

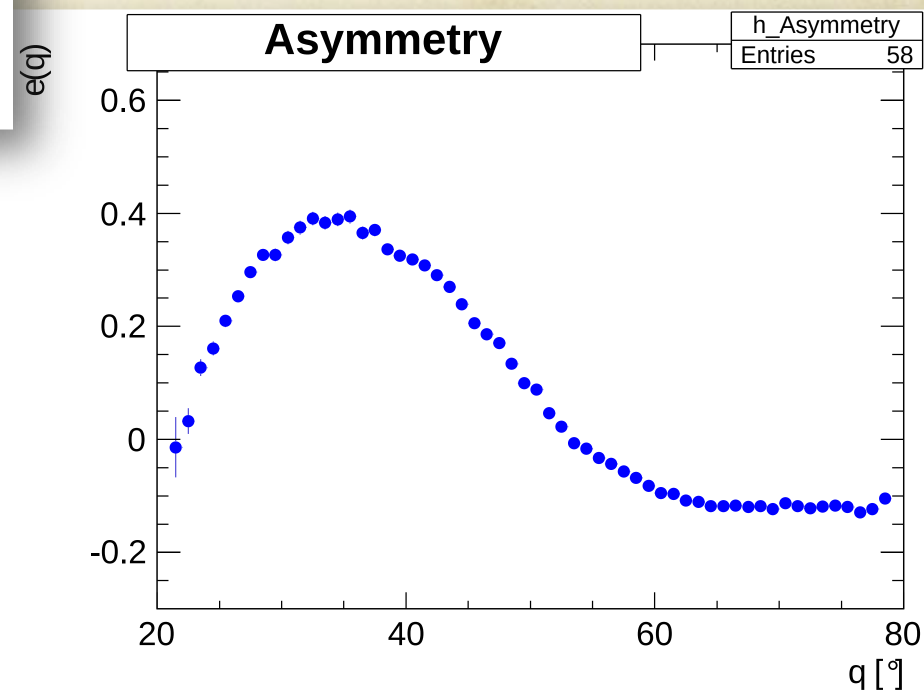
POLARIZATION CALCULATION



King's Data
Approximation Function [King]

$$\varepsilon(\theta) = \frac{L(\theta) - R(\theta)}{L(\theta) + R(\theta)}$$

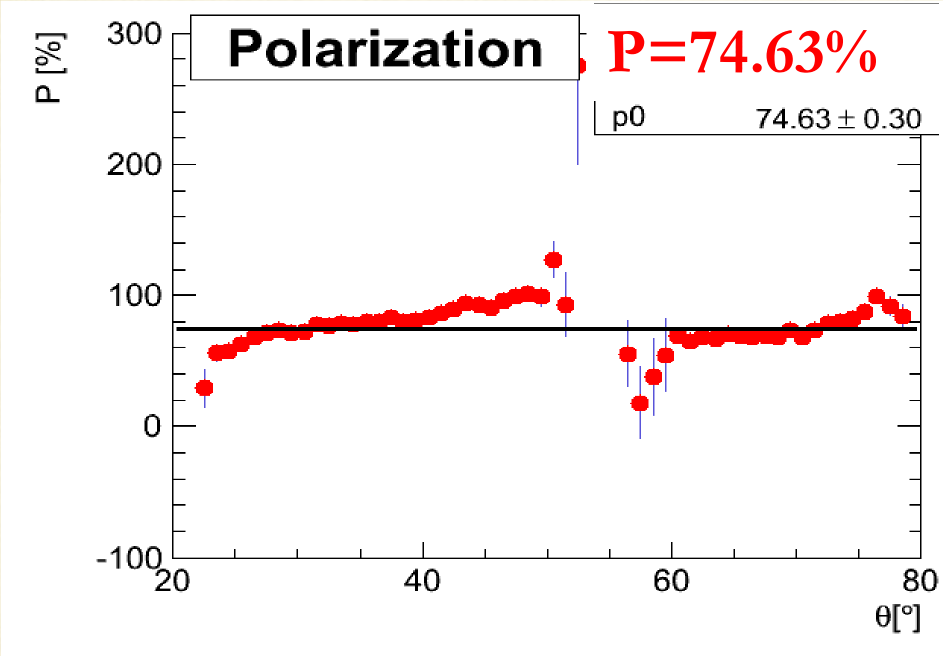
Experimental polar angle asymmetry

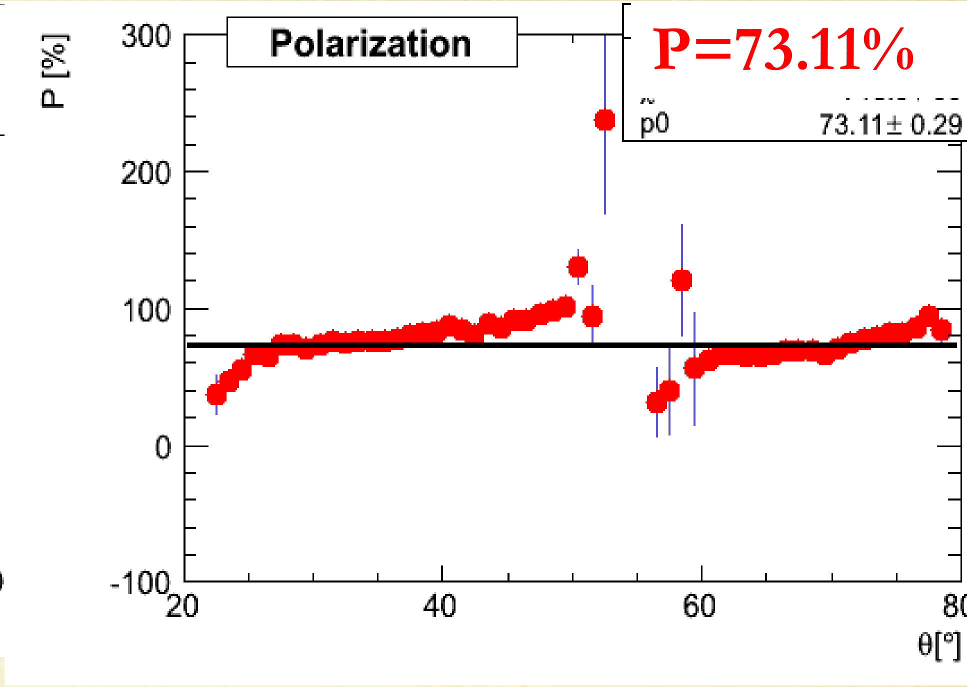


$$\varepsilon(\theta) = pA_y(\theta) < cos\varphi >$$

[King] N.S.P.King et al. Polarization in proton-deuteron scattering at 50 mev. Physics Letters, 69B (2):151-153, August 1977.

BEAM POLARIZATION LIFETIME





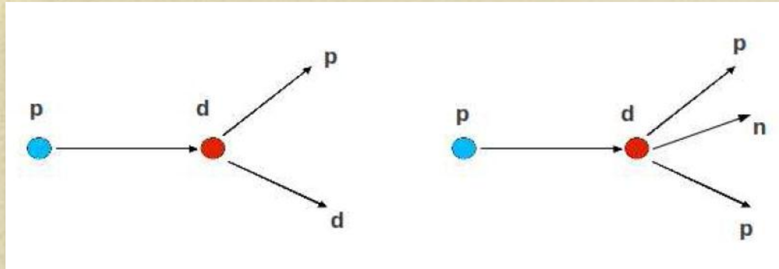
Polarization at the beginning of the cycle

Polarization at the end of the cycle

$$P(5000) = P(0)e^{-5000/\tau_{pol}}$$

$$\boldsymbol{\tau_{Pol} = 2.3\ 10^5 s.}$$

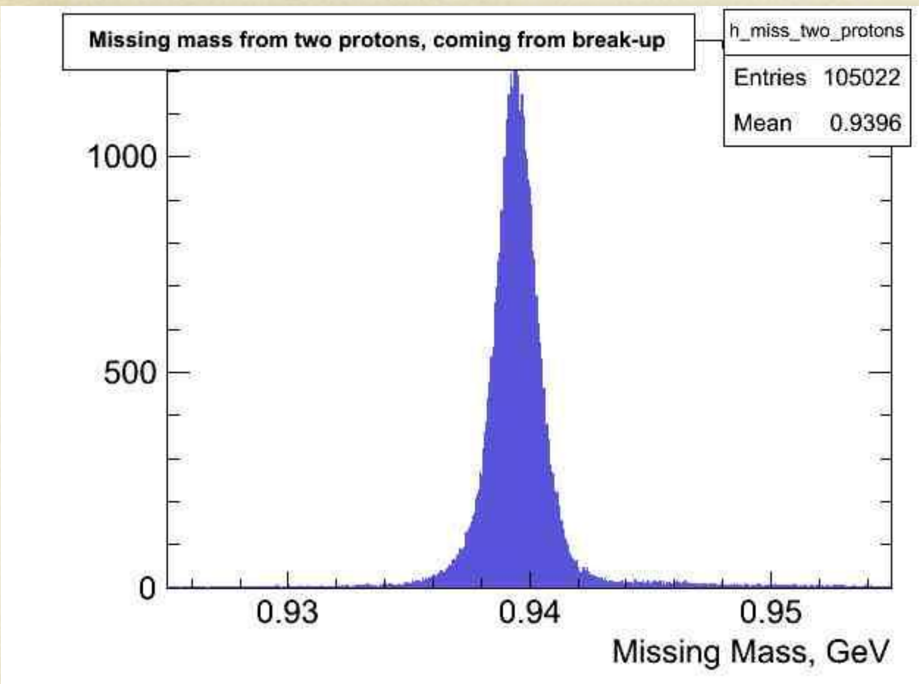
BREAKUP REACTION

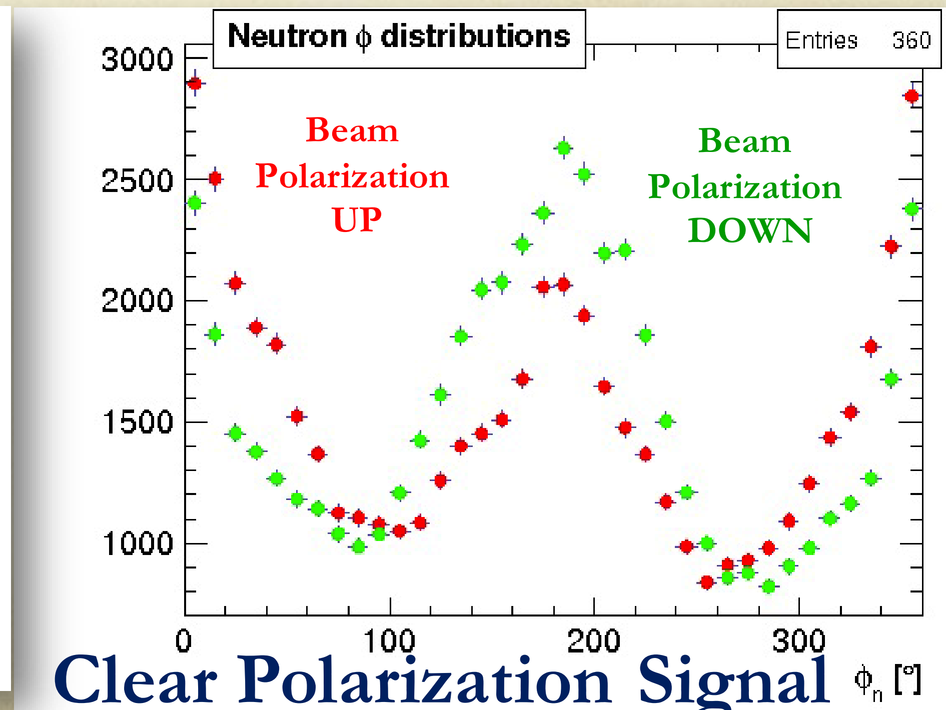


Invisible neutron-> need to detect two protons

- ✓ Need two stopped protons, coming from deuteron break-up
- ✓ From 4-momentum conservation we reconstruct neutron

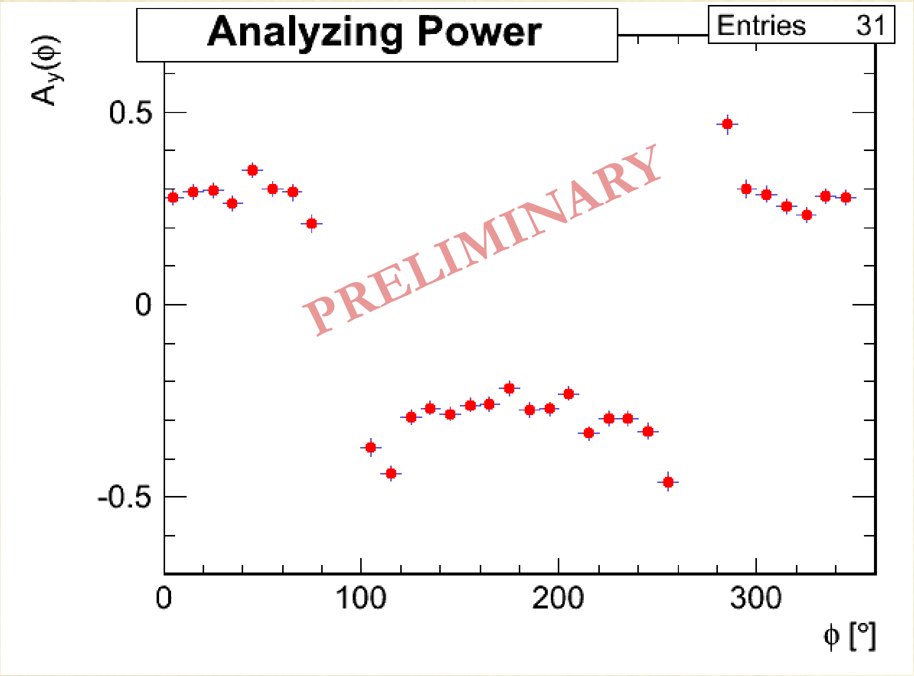
$$n^{\mu} = \vec{p}^{\mu} + d^{\mu} - p^{\mu}{}_{det} - p^{\mu}{}_{det}$$

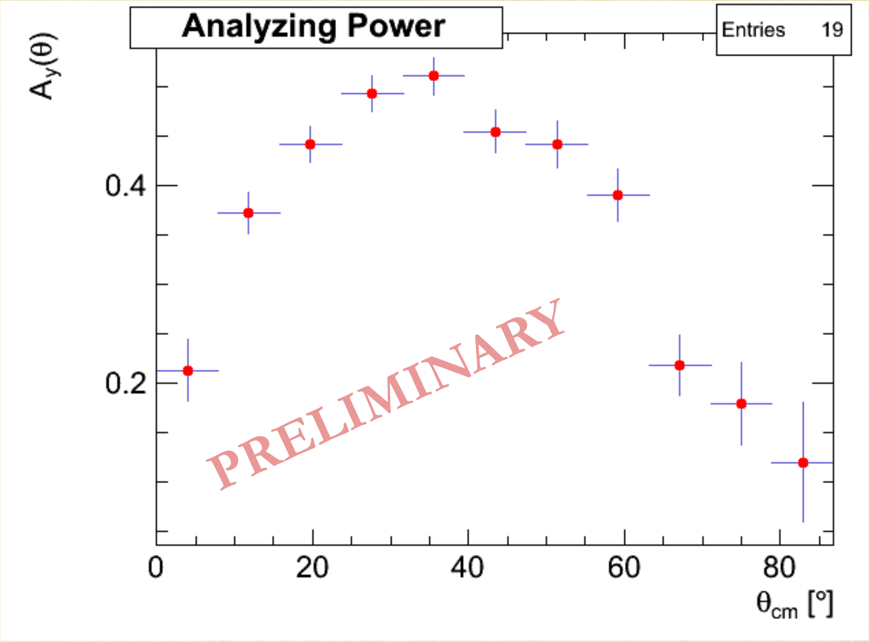




Clear Polarization Signal in ϕ distributions

ANALYZING POWER OF BREAKUP REACTION





$$A_y(\varphi) = \frac{\varepsilon(\varphi)}{p\cos\varphi} \text{ where } \quad \varepsilon(\varphi) = \frac{N_\uparrow(\varphi) - N_\downarrow(\varphi)}{N_\uparrow(\varphi) + N_\downarrow(\varphi)}$$

This experimental data can be used as the input for Chiral Perturbation Theory to understand the contributions of three-nucleon forces

SUMMARY

- Participation in the data taking of Spin-Filtering Experiment
- Code for identification of elastic scattering and break-up reactions has been developed in C++ under ROOT package
- Code for calculating polarization was developed in C++ under ROOT package.
- Polarization values for polarization lifetime runs were measured separately for the beginning of the cycles (74.63%) and end of the cycles (73.11%).
- Beam polarization lifetime value is $\tau_{pol} = 2.3\ 10^5 s$
- Asymmetry of pd →ppn break-up reaction as the function of neutron azimuthal angle was calculated
- Preliminary results for pd →ppn break-up Analyzing Power value

as the function of azimuthal and polar angles

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PhD Susanna Bertelli

My professors from TSU

My parents and friends