Исследование процессов перезарядки на Ускорительном комплексе ЛФВЭ

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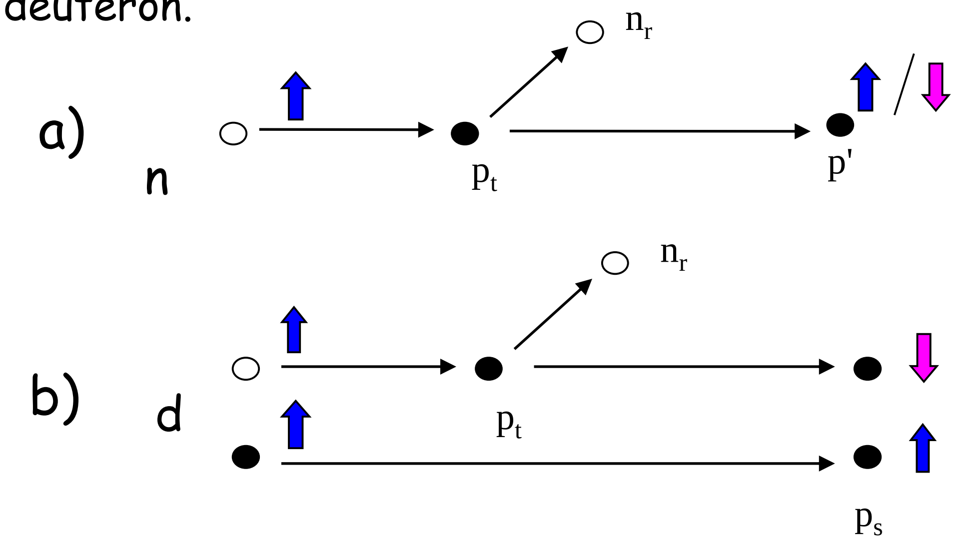
STRELA
ALPOM2 + Jlab experiment
Polarimetry

Several slides will be shown from the meetings in Jlab

Measurement of the charge exchange np→pn reaction by means of the deuteron beam (STRELA setup)

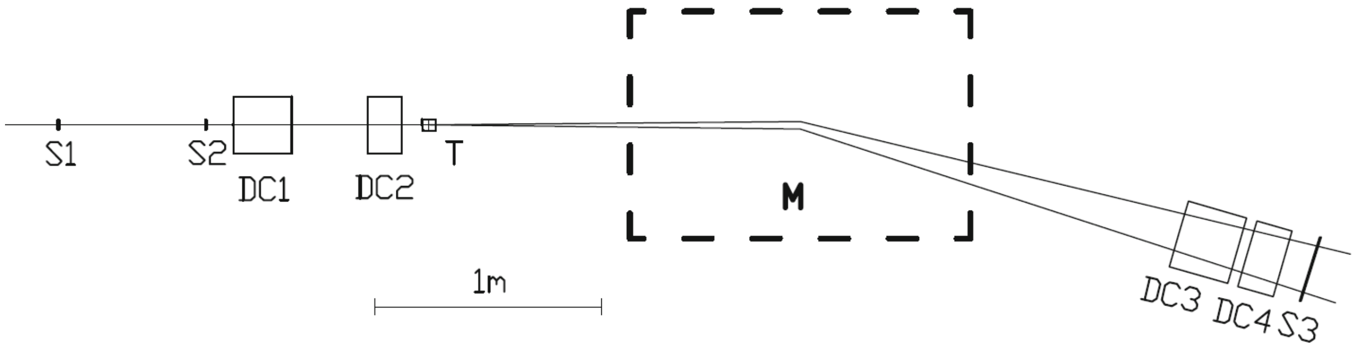
The possibility to get additional information about the amplitude of the elementary charge exchange reaction by means of the charge exchange processes from the experiments with unpolarized deuteron was emphasized by **A.B. Migdal** (ZhETF 28, 1955, p.3)
and **I.Y. Pomeranchuk** (DAN USSR, 1951, LXXVIII, N2, p.249)
in the early fifties.

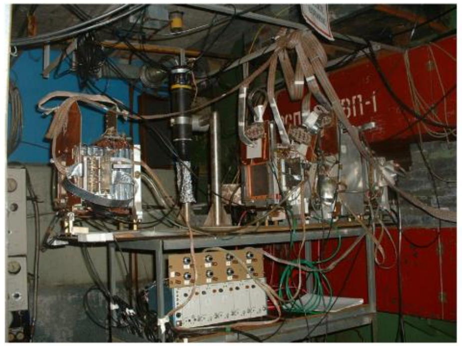
Simplified versions of these two processes in the framework of the Impulse Approximation are shown below;
a) the charge exchange process np -> pn and
b) the reaction dp -> (pp)n, charge-exchange one on the simplest nucleus – the deuteron.



The STRELA setup was built to register two protons at emitted angles less than 3 degree and relative momentum less than 100 MeV/c.

As the detected protons have a momentum close to half of incoming deuteron momentum, there is a big background of stripping protons from fragmentation process.



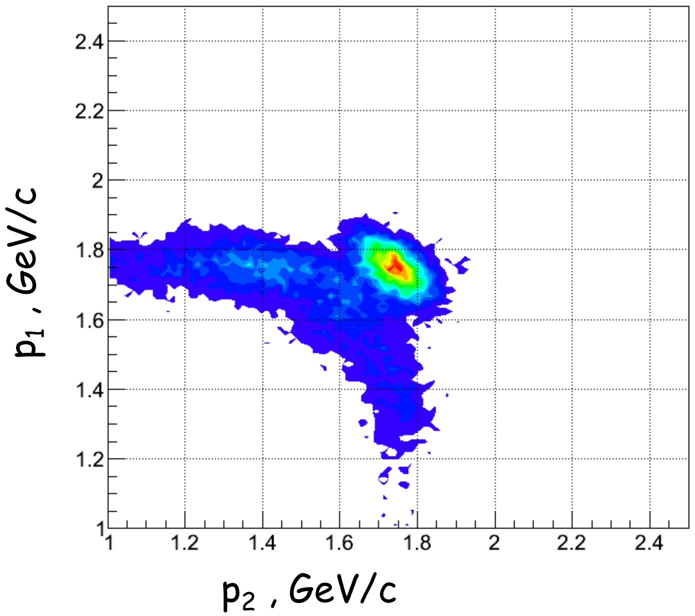


Before the dipole

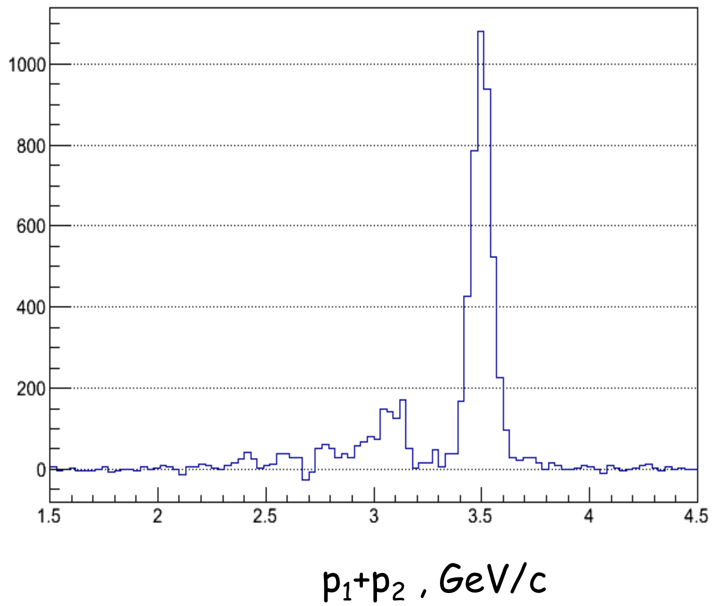
After the dipole

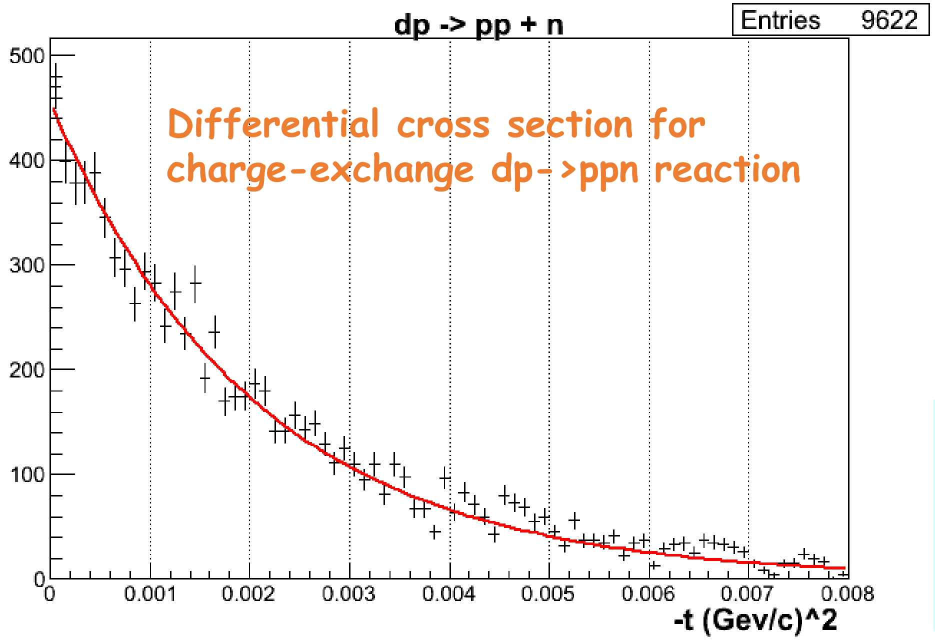
About a billion triggers were received at the Nuclotron run in March, 2014. The efficiency of the accelerator was not less than 96%.

Two proton momenta correlation



CH2-C subtraction



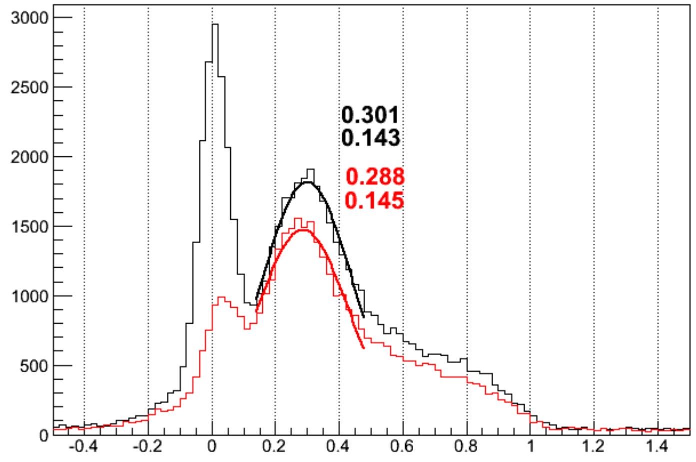


$$R^{ID}_{np} = \frac{(d\sigma/dt)^{SI}_{np}}{(d\sigma/dt)^{SD}_{np}} = \frac{2}{3xR} - 1 = 0{,}047 \pm 0{,}017$$

Thus the charge exchange np amplitude is almost completely spin dependent.

Future studies of charge-exchange processes in *dp*--interactions using polarized deuteron beam, ~ 150 hours of beam time

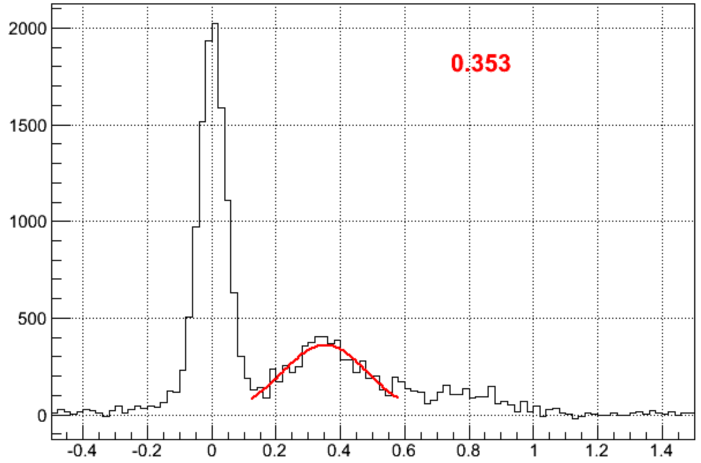
Δ-exitation



CH2

C

$\omega = E_d - E_{p1} - E_{p2}$,   GeV

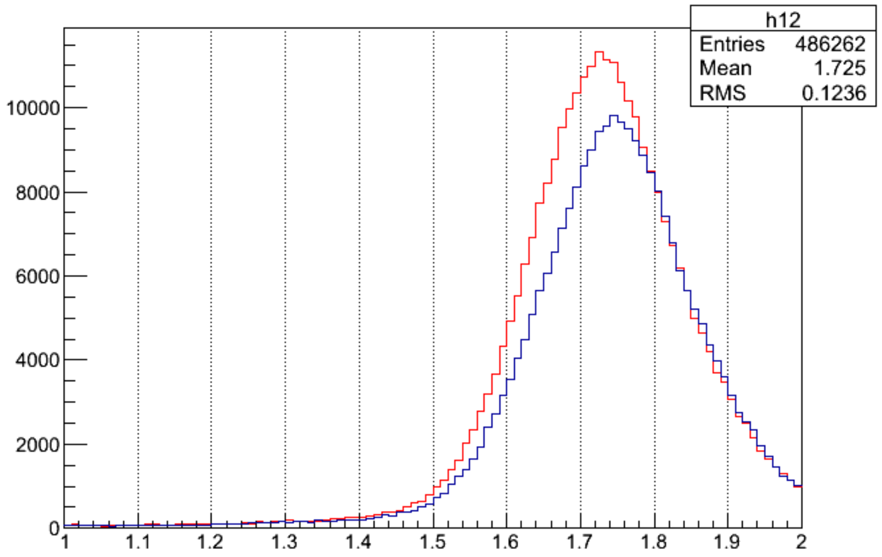


CH2-C

0.353 - 0.288 = 0.065

65 MeV

One charge particles, dA -> pX



p, GeV/c

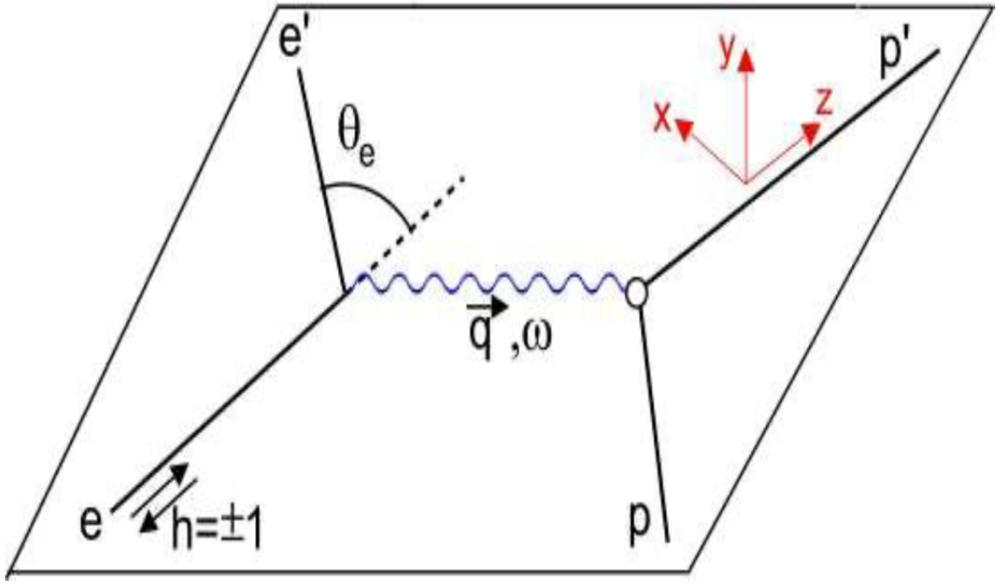
CH2

C

ALPOM2 + Jlab experiment

Formalism: Polarimetry Technique

- Accessing form factors:
  - Polarization transfer method: $\vec{e}N \rightarrow e\vec{N}$
  - Longitudinal (P_l) and transverse (P_t) component of nucleon (no normal component on reaction plane)



$$P_l = \sqrt{\tau(1+\tau)}\frac{E_e + E_{e'}}{M} G_M^2 \tan^2\frac{\theta_e}{2} / I_0$$

$$P_t = -2\sqrt{\tau(1+\tau)} G_E G_M \tan\frac{\theta_e}{2} / I_0$$

$$I_0 \propto G_E^2 + \frac{\tau}{\epsilon} G_M^2$$

$$\frac{G_E}{G_M} = -\frac{P_t}{P_l}\frac{E_e + E_{e'}}{2M}\tan\frac{\theta_e}{2}$$

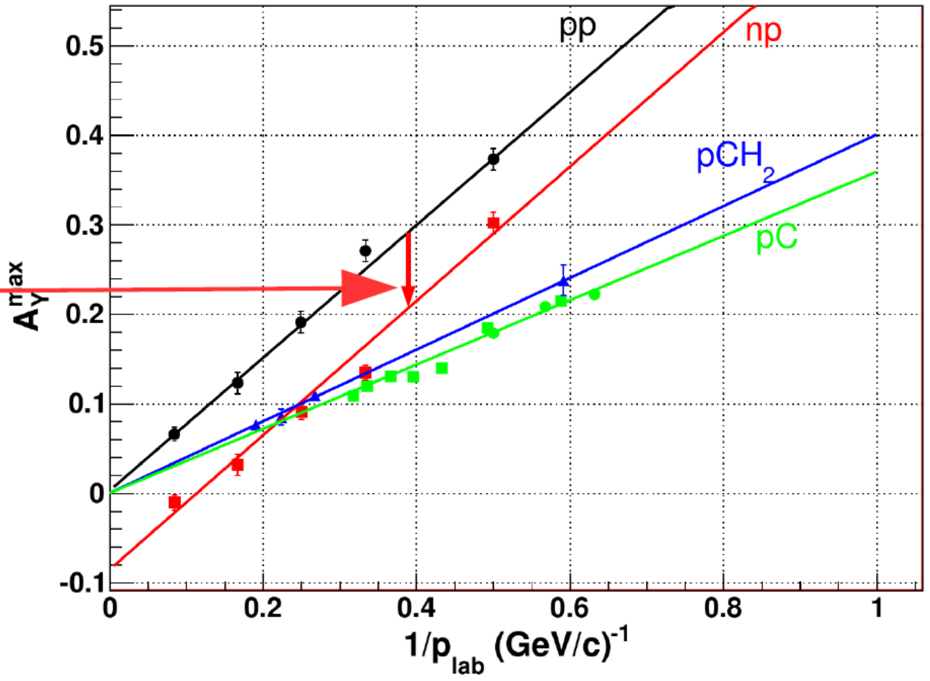
- Form Factor ratio is independent of analyzing power (A_y)

Nucleon Polarimetry:
Analyzing Power for N-N Scattering

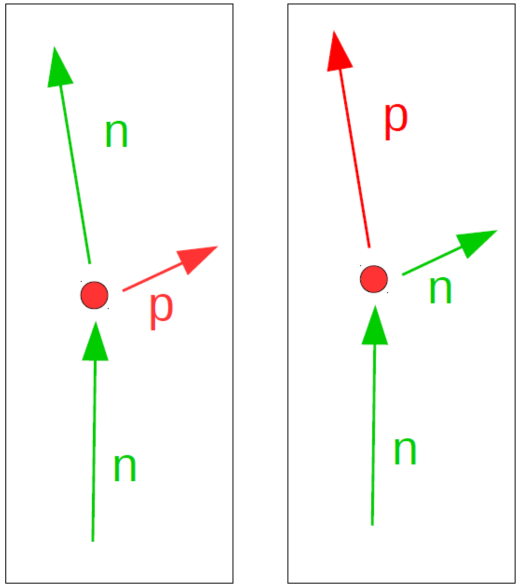
- Elastic np→np or pp→pp for highest A_y value
- Proton A_y measurements C, CH_2:
  - empirical p+C value of A_y **~0.5** of free elastic p+p scattering
  - due to Fermi-motion smearing of the elastic signal and inelastic contamination
- pp→pp scales as $1/p_{lab}$
- np→np has similar slope but negative offset
- Up to now no data on n+C→n+p+X at p_{lab}~ several GeV/c
  (nor for any medium-to-high Z nucleus)

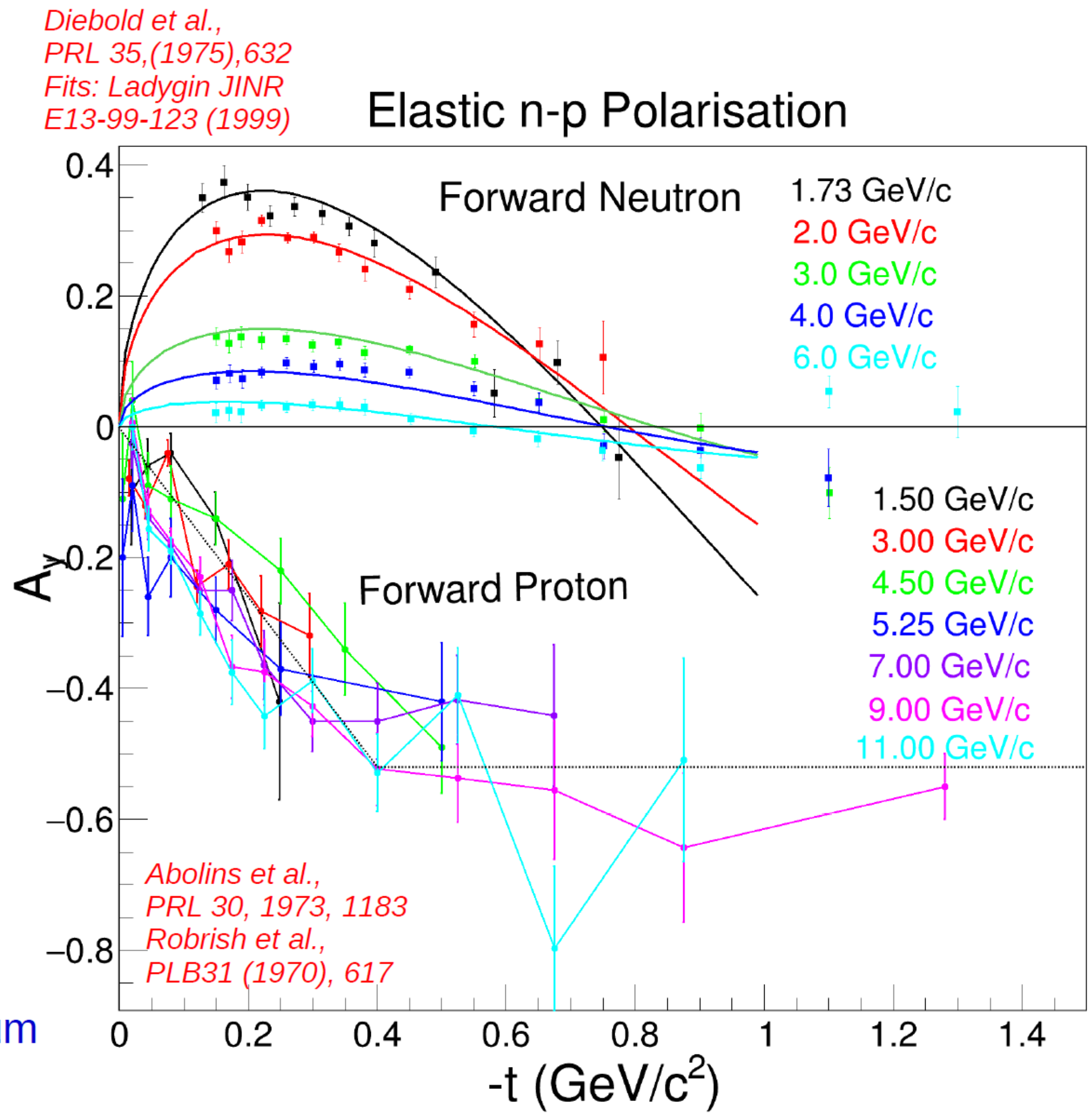
Peak Analysing Power of N-N Scattering
A_y^{max} @ $p_\perp$ ~ 300 - 400 MeV/c

- R. Diebold et al., PR. 35(1975), 632.
  S.L. Kramer et al., PRD17(1978), 1709.
- L.S. Azhgirey et al., NIM A538(2005), 431.
- N.E. Cheung et al., NIM A363(1995), 561.
- I.G. Alekseev et al., NIM A434(1999), 254.



Analyzing Power for Elastic n-p Scattering



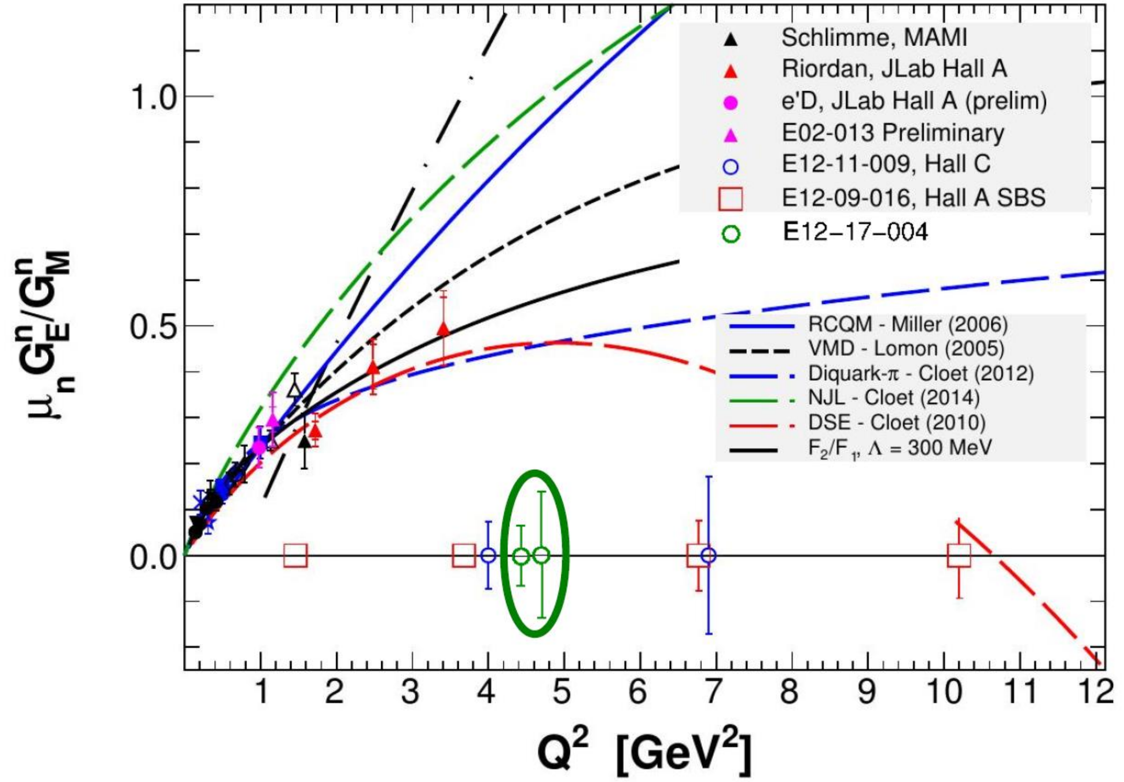


- A_y for n-p (or p-n) falling rapidly with increasing neutron momentum
- A_y for charge-exchange n-p large at sufficiently large t (θ_p ~ few deg.)
- No apparent strong incident momentum dependence for charge-exchange A_y
- $\sigma_{np\rightarrow np}$ factor ~10 higher than $\sigma_{np\rightarrow pn}$

Precision on the Form Factor Ratio

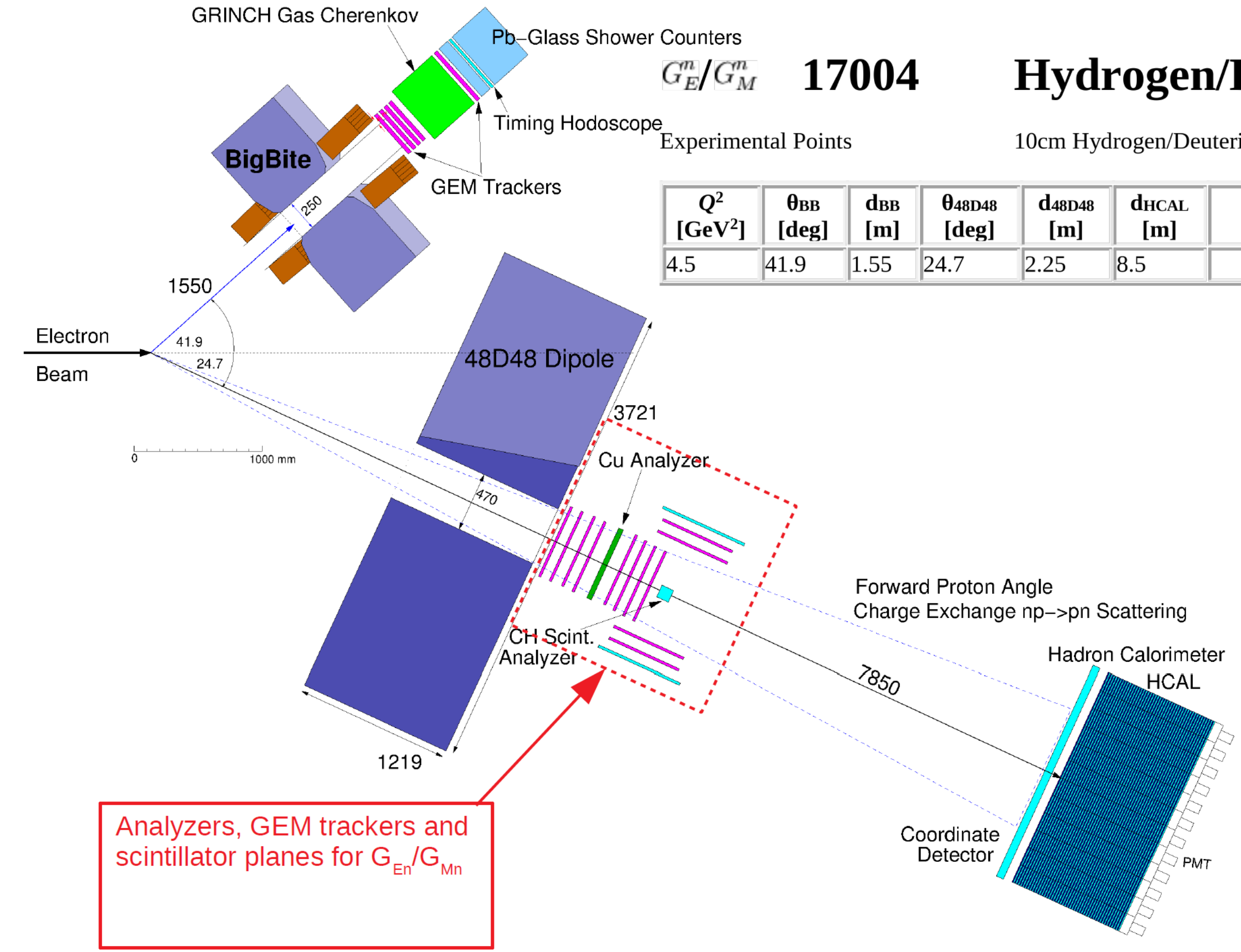
$$\delta P = \sqrt{\frac{2}{N_{inc}\mathcal{F}^2}} \qquad R = \mu_n G_E^n / G_M^n \qquad \left(\frac{\delta R}{R}\right)^2 = \left(\frac{\delta P_x}{P_x}\right)^2 + \left(\frac{\delta P_z}{P_z}\right)^2$$

E_{beam} (GeV)	Q^2 $(GeV/c)^2$	p_n (GeV/c)	Rate (Hz)	Time (hours)	FOM $\times 10^{-4}$	δP (absolute)	δR (absolute)
4.4	4.5	3.15	48.8	120	2.6 (CE)	0.019	0.078
					0.8 (PR)	0.034	0.140
					3.4 (Total)	0.017	0.070



- Estimates from latest g4sbs agree very well with previous simulation studies (in proposal)
- δR based on Galster G_{En} and Kelly G_{Mn} parametrizations
- Expect overall systematic error to be ~3.0%

Experimental Layout



G_E^n/G_M^n **17004** **Hydrogen/Deuterium**

Experimental Points

10cm Hydrogen/Deuterium

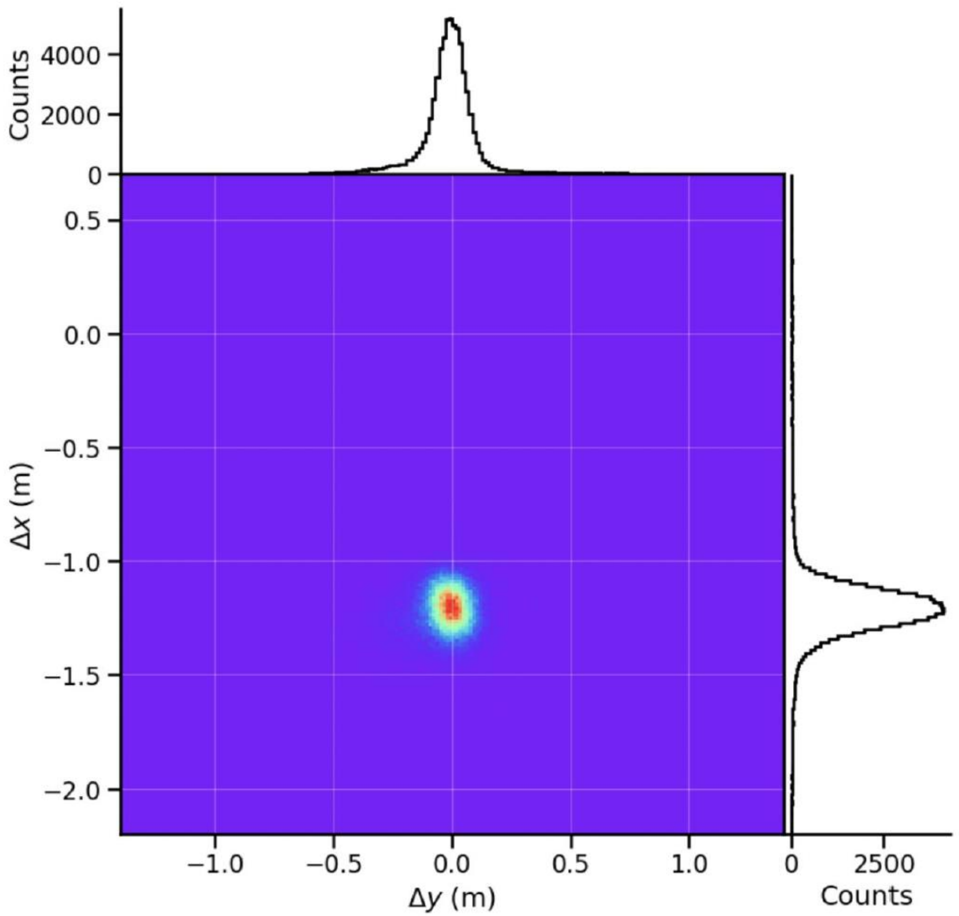
Q^2 [GeV^2]	θ_{BB} [deg]	d_{BB} [m]	θ_{48D48} [deg]	d_{48D48} [m]	d_{HCAL} [m]	Beam Line Configuration #
4.5	41.9	1.55	24.7	2.25	8.5	3

Analyzers, GEM trackers and scintillator planes for G_{En}/G_{Mn}

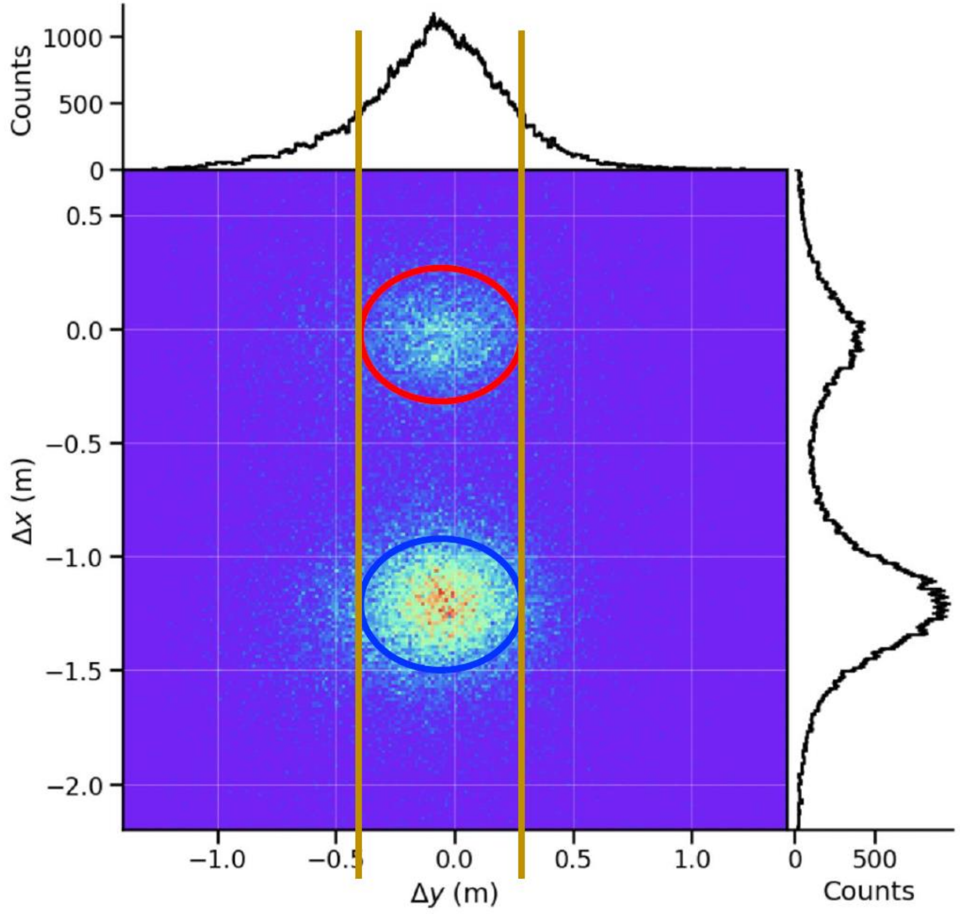
HCAL Δx and Δy Correlation

Q^2 = 3 $(GeV/c)^2$, SBS 50% Field

Elastic Spot (LH_2 Data)

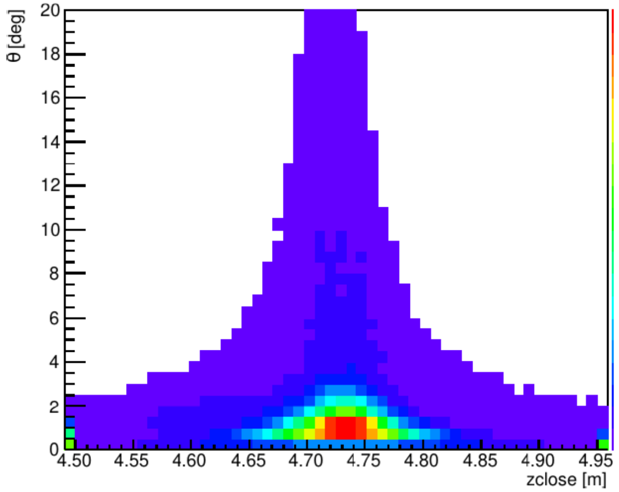


Quasi-Elastic Spots (LD_2 Data)

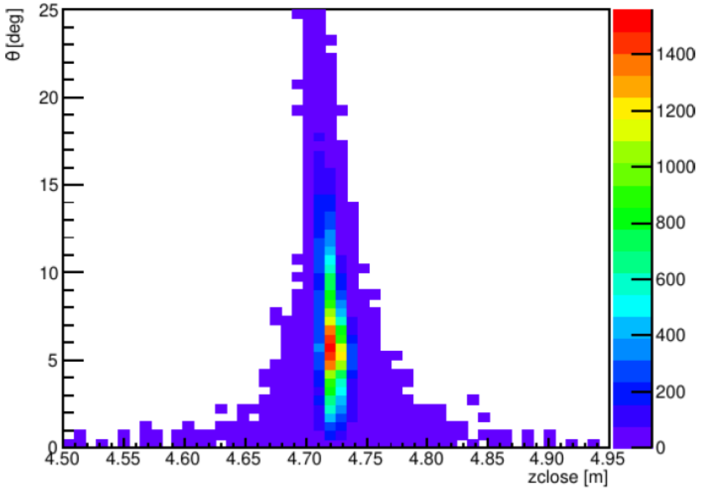


Preliminary Check on GEn-RP Data

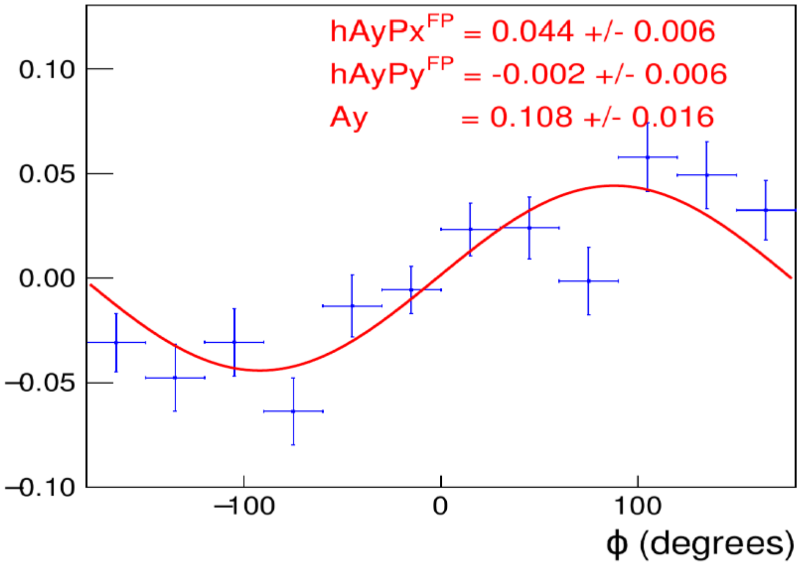
- David Hamilton performed preliminary checks on Gen-RP dataset



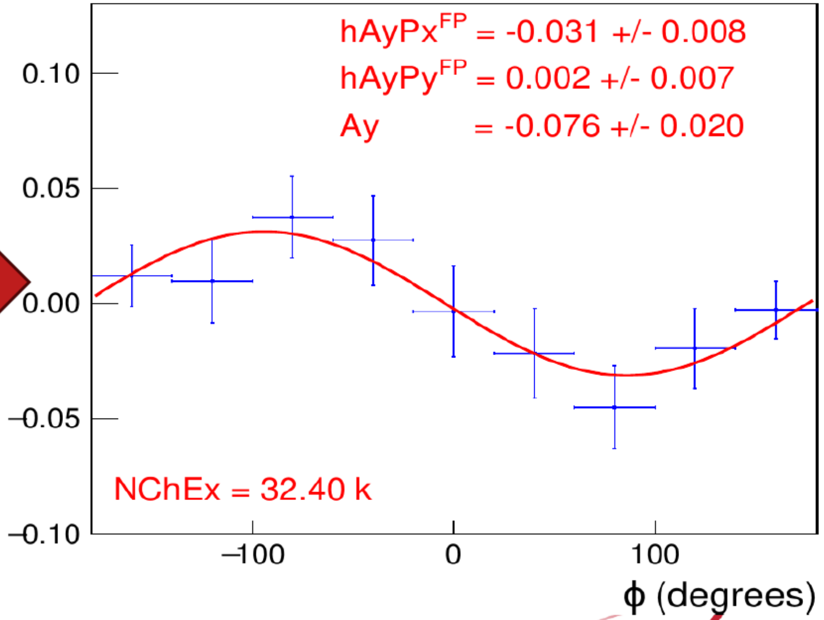
- Analysis based on ~50% of total data collected
- Calibrations and cuts are not optimized
- First GEM Layer at 4.12 m



Proton-> proton channel: Rough estimate of analyzing power as expected (sign and magnitude)

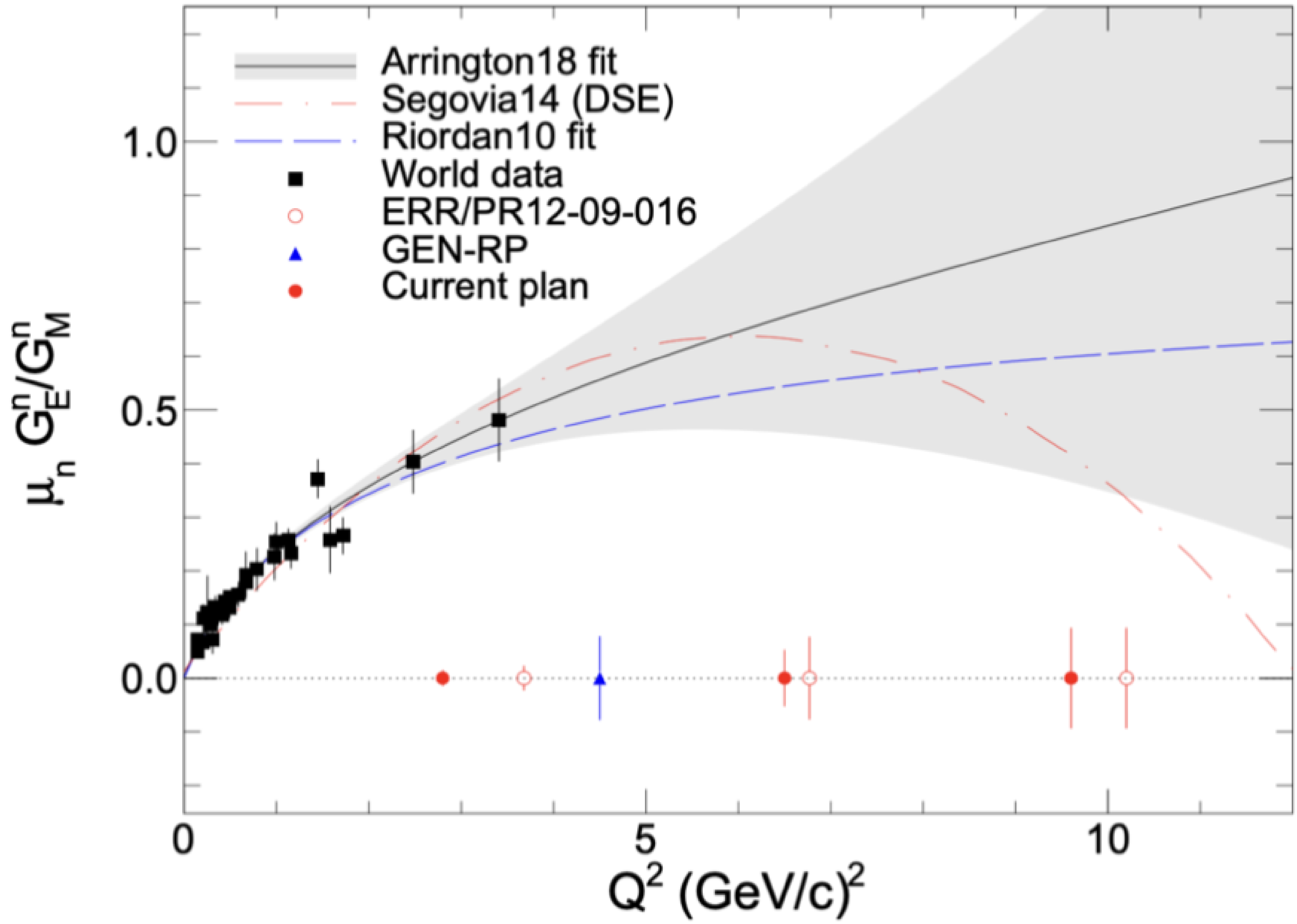


Neutron-> proton channel: Preliminary evidence of non-zero beam spin asymmetry



Summary

- GEn-RP and KLL use the polarization transfer technique to access physics observables
- Gen-PR utilized different polarimeters to access exchange np->pn and large angle elastic np->np interactions
- GEn-RP and KLL experiments successfully completed data taking during April/May run period in the Hall A at Jefferson lab
- Preliminary check shows encouraging result for charge exchange
- Full Analysis is in progress for both Gen-RP and KLL
- GEn-RP, if successful, is a proof of principle for larger analyzing power via charge exchange np->pn interaction which is crucial for expanding the program in future
- KLL along with ALL could provide valuable information on handbag mechanism in wide angle interactions

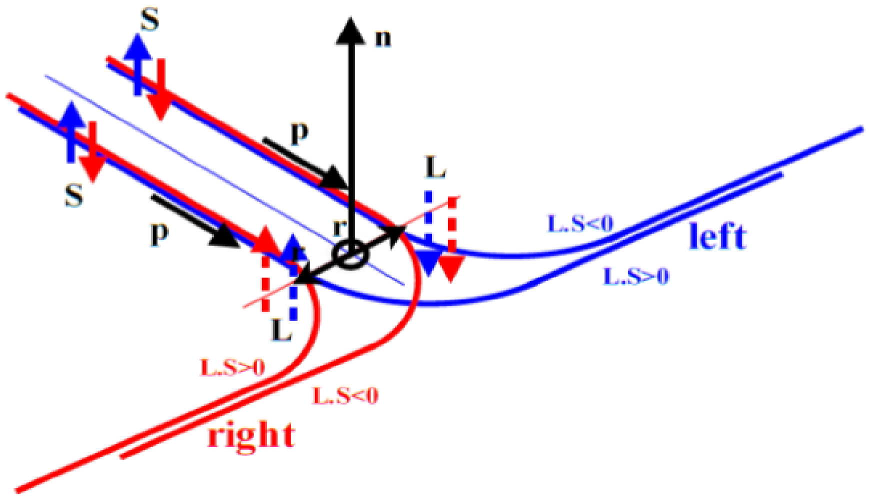


Plot by Andrew (GEn wiki)

POLARIMETRY

$$A_y \bullet P_y = \frac{N_L - N_R}{N_L + N_R}$$

Principle of Polarimetry



Due to **L.S** coupling in NN interaction, incident particle with spin up or spin down relative to scattering plane scatters preferentially left, respectively right.

Azimuthal distribution:

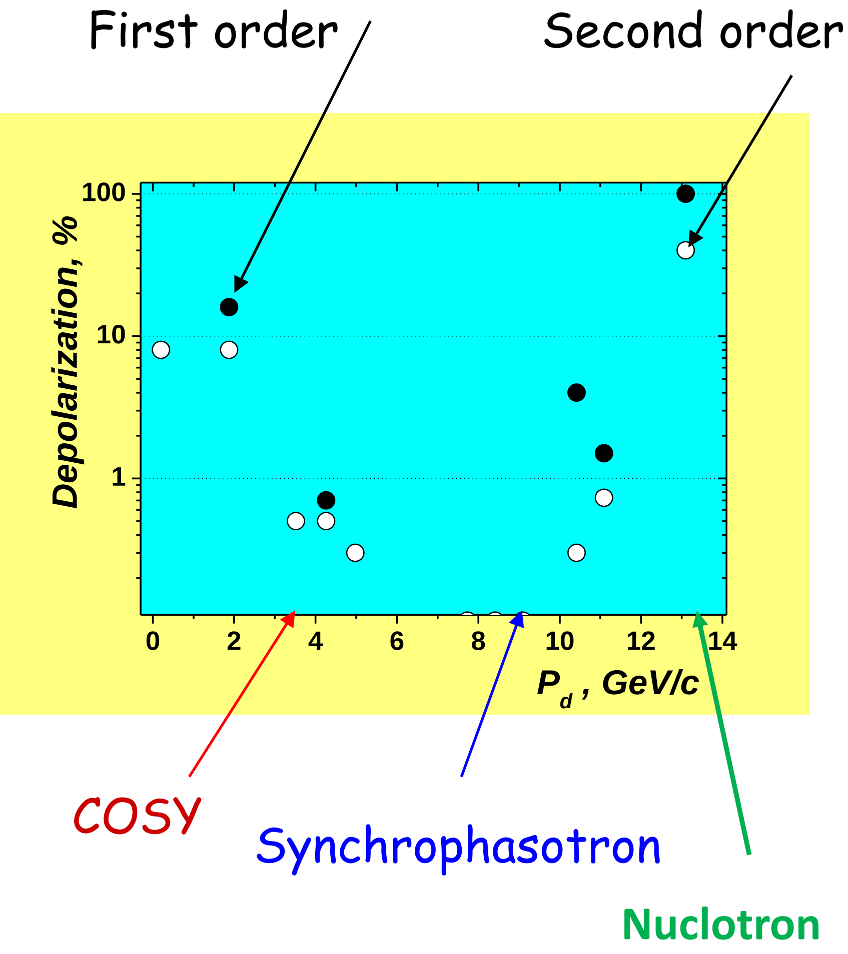
$$I(\vartheta)=I_0[1+A_y(\vartheta)\vec{P}^{fpp}.\vec{n}]$$

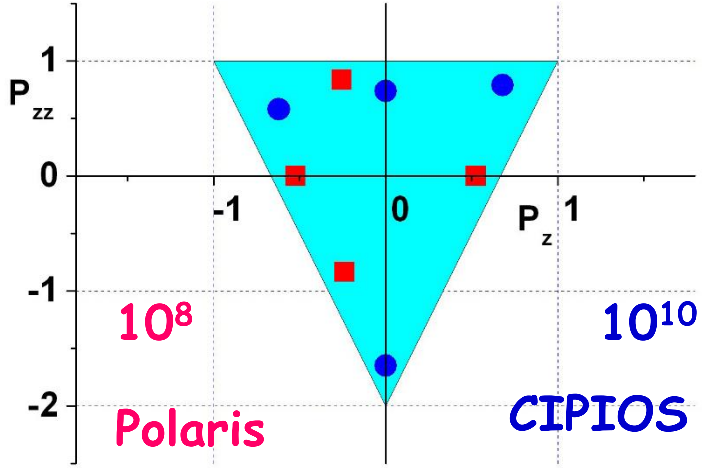
Following Basel convention (1960), spin-$\frac{1}{2}$ particles with spin up scatter preferentially to the left if analyzing power, Ay, is positive

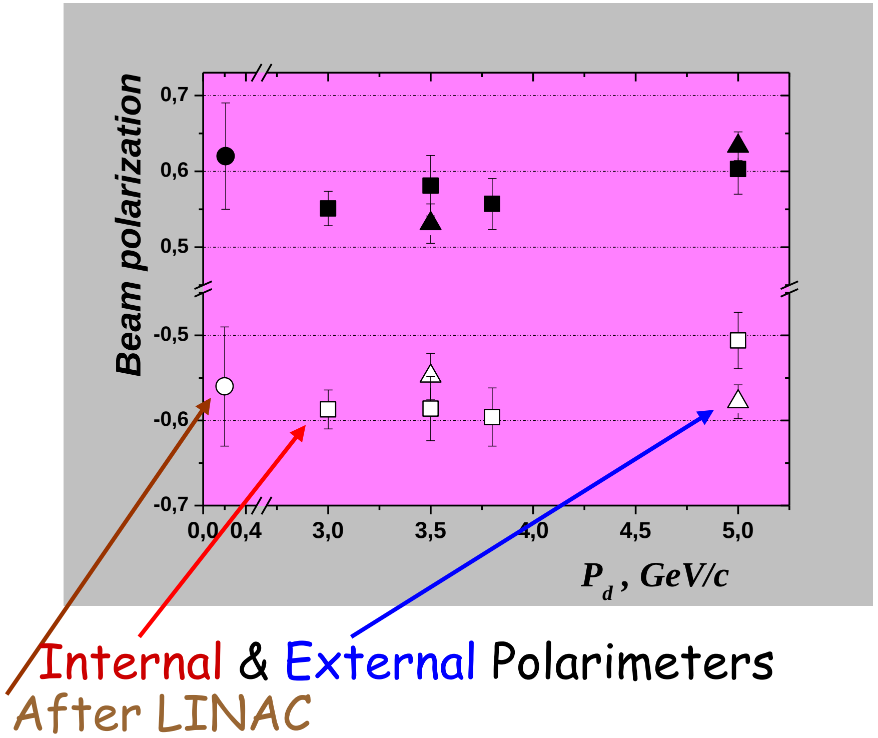
Spin 1/2
$$\frac{d\sigma}{d\Omega}(\Theta,\phi) = \left(\frac{d\sigma}{d\Omega}\right)_0(\Theta)\left[1+\frac{1}{2}p_y A_y(\Theta)\right]$$

Spin 1
$$\frac{d\sigma}{d\Omega} = \left(\frac{d\sigma}{d\Omega}\right)_0\left[1+\frac{3}{2}p_y A_y+\frac{1}{2}p_{zz}A_{zz}+\frac{2}{3}p_{xz}A_{xz}+\frac{1}{6}(p_{xx}-p_{yy})(A_{xx}-A_{yy})\right]$$

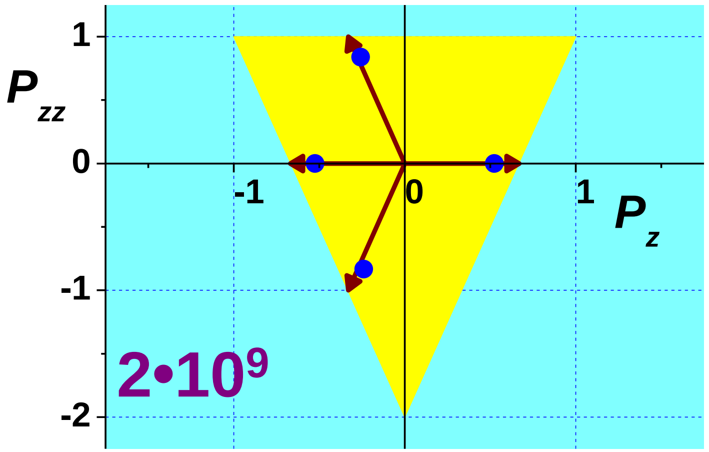
Deuteron polarization at the Nuclotron





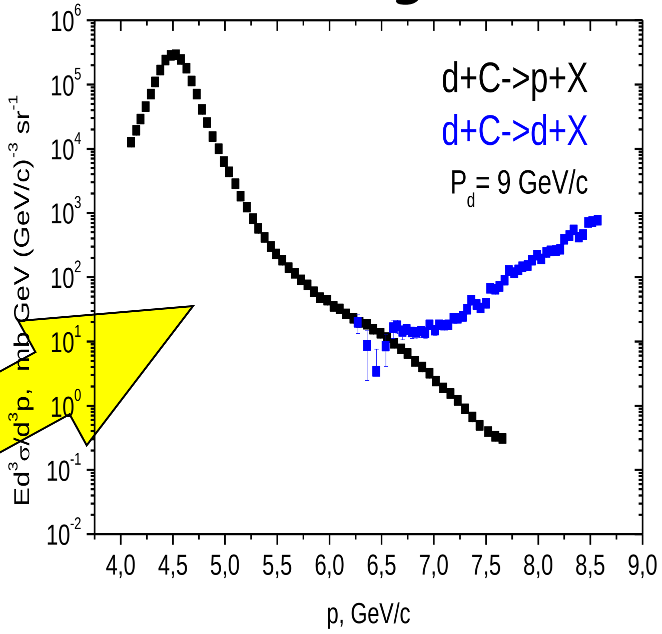


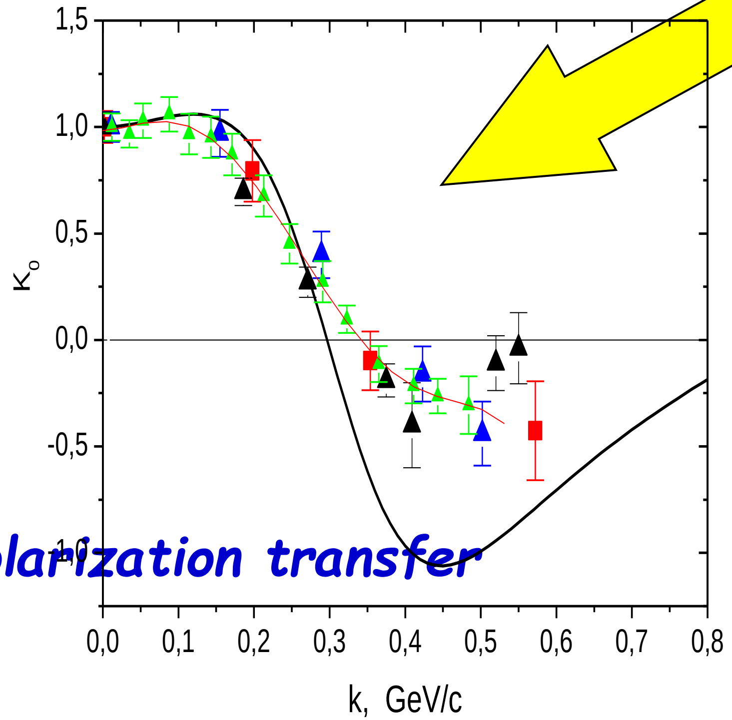
Polarized proton beam



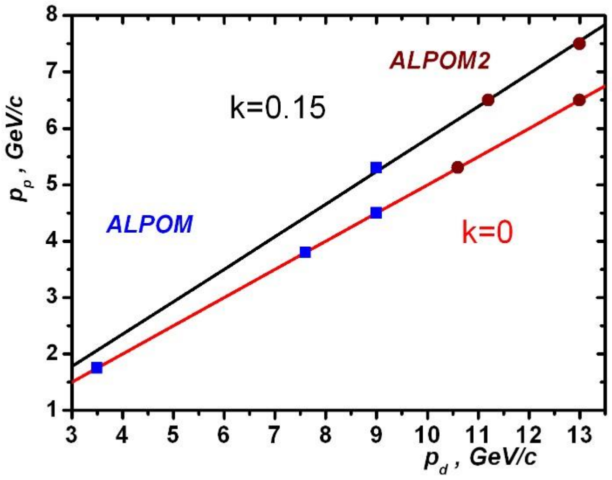
POLARIS

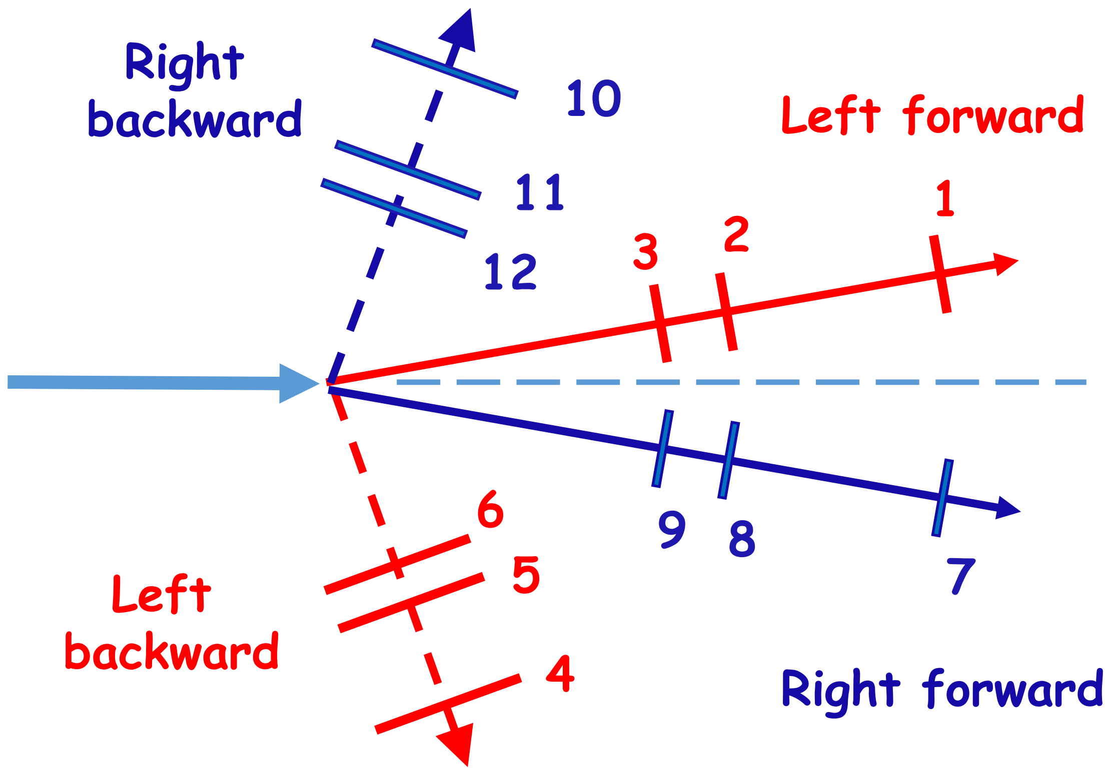
Deuteron fragmentation



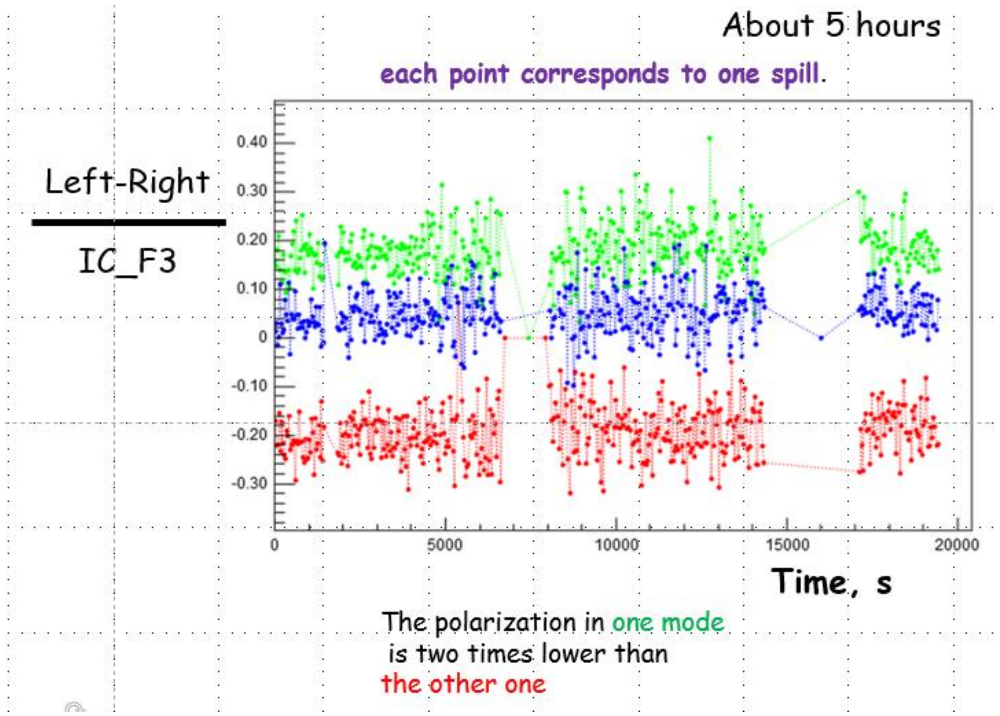


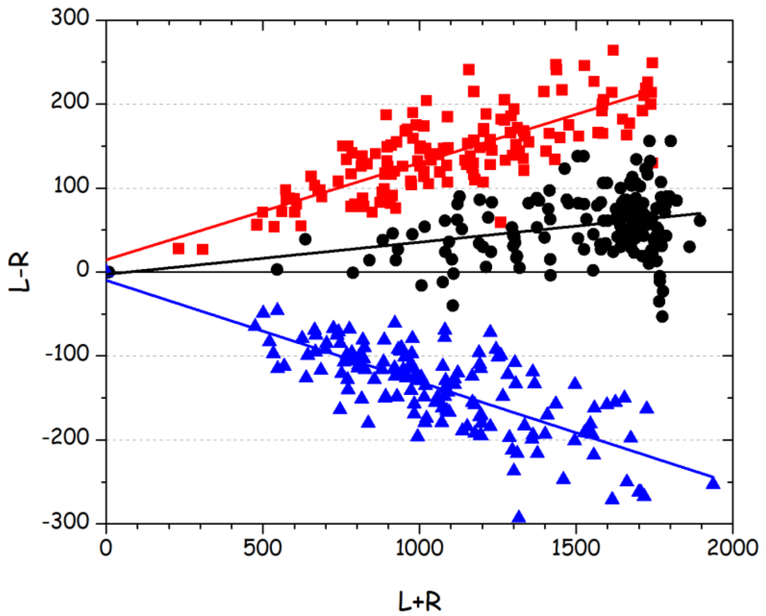
Polarization transfer



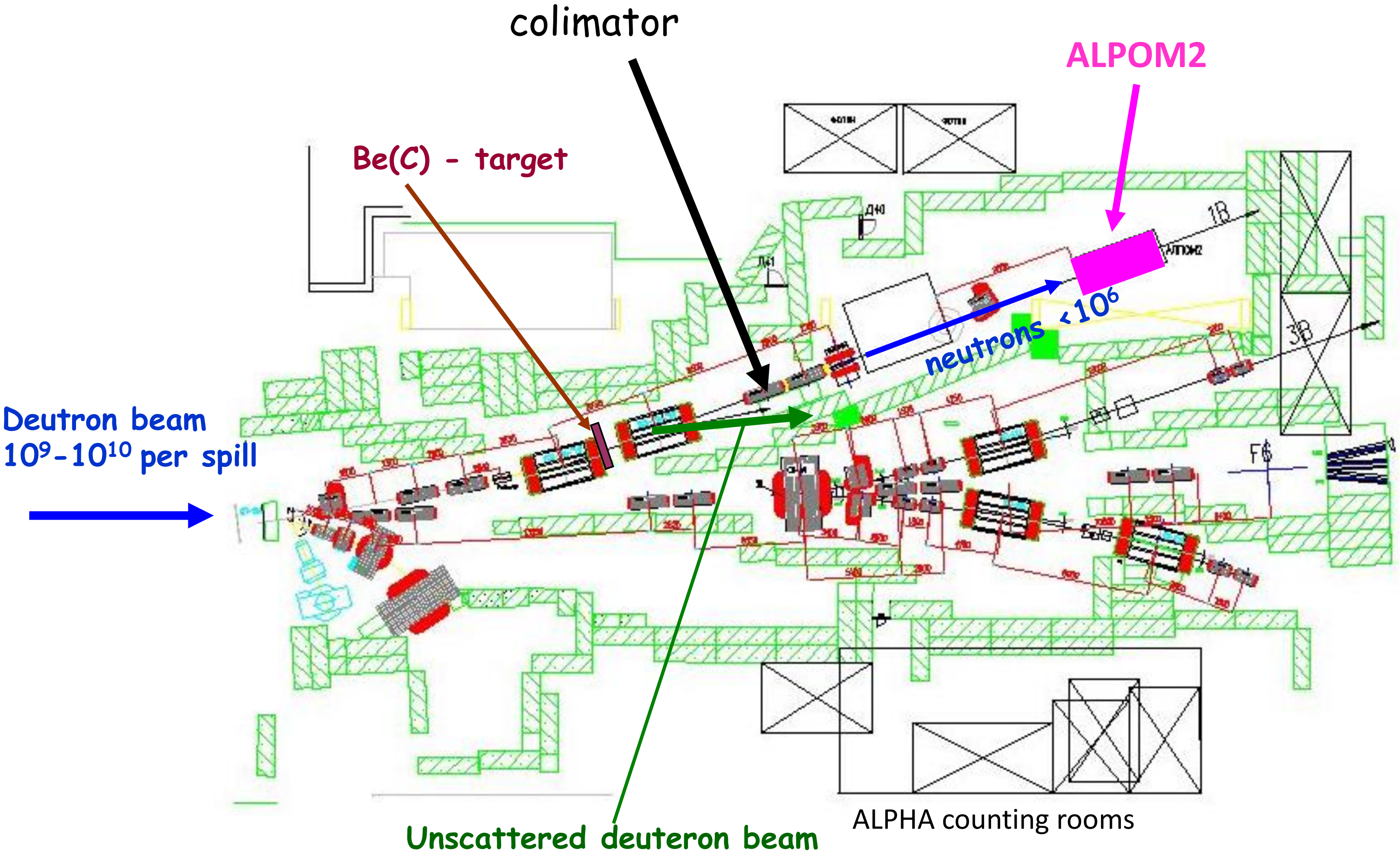


Forward, 8-10⁰ 40x45x5 mm³		Backward, 68-70⁰ 95x150x5 mm³	
#	cm	#	cm
1	185,0	4	99,0
2	121,0	5	67,5
3	96,5	6	55,5
7	185,5	10	100,0
8	120,5	11	66,5
9	96,0	12	56,5





Neutron beam



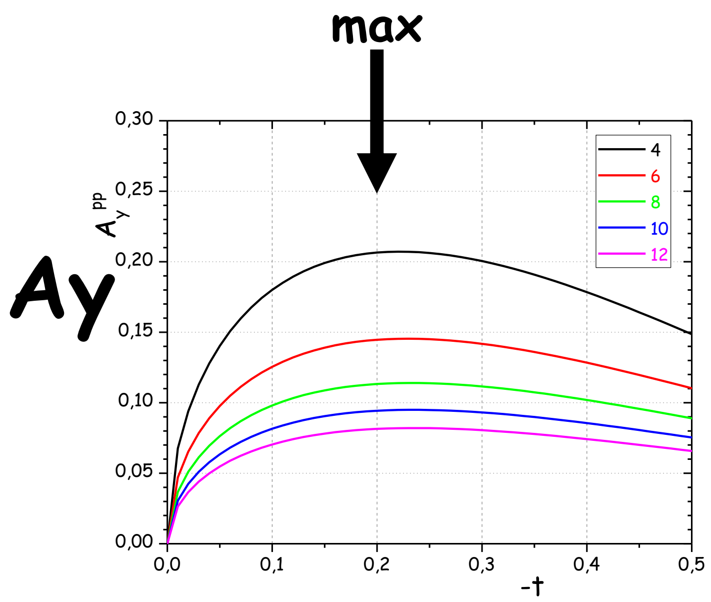
The polarized neutron beam.

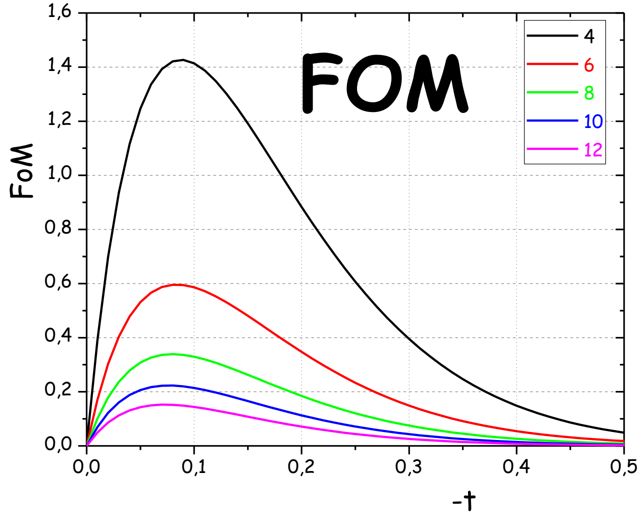
The neutron momentum distribution in the forward break-up reaction, due to the Fermi motion of the nucleons in the accelerated deuterons, has a Gaussian-like shape with FWHM ~5% of the neutron momentum. The production target was positioned close to one focal point of the deuteron beam line. Protons and deuterons were removed from the neutron beam by a bending magnet. Neutrons were collimated by 6 m iron and brass in a path of 17 m upstream from the ALPOM2 set-up. The neutron angular divergence was ~1.5 mrad. The deuteron beam intensities and corresponding neutron fluxes are listed in Table 1. The collimators and efficient shielding of the experimental area decreased the low energy tail of the neutron spectrum to about 1%.

Table 1. Averaged deuteron beam intensities and neutron fluxes at three energies

$T_{kin}(d)$ (GeV) accelerator	$T_{kin}(d)$ (GeV) target center	$T_{kin}(n)$ (GeV) mean	Deuterons per spill	Neutrons per spill (PPT)
2.40	2.38	1.19	5.3×10^8	2.7×10^4
5.00	4.98	2.49	6.1×10^8	2.0×10^5
7.32	7.30	3.65	6.4×10^8	4.7×10^5

The polarization of incident deuterons is oriented perpendicularly with respect to the beam momentum, along the vertical axis. The polarization of the produced neutrons has the same direction and the same value as the vector deuteron polarization.

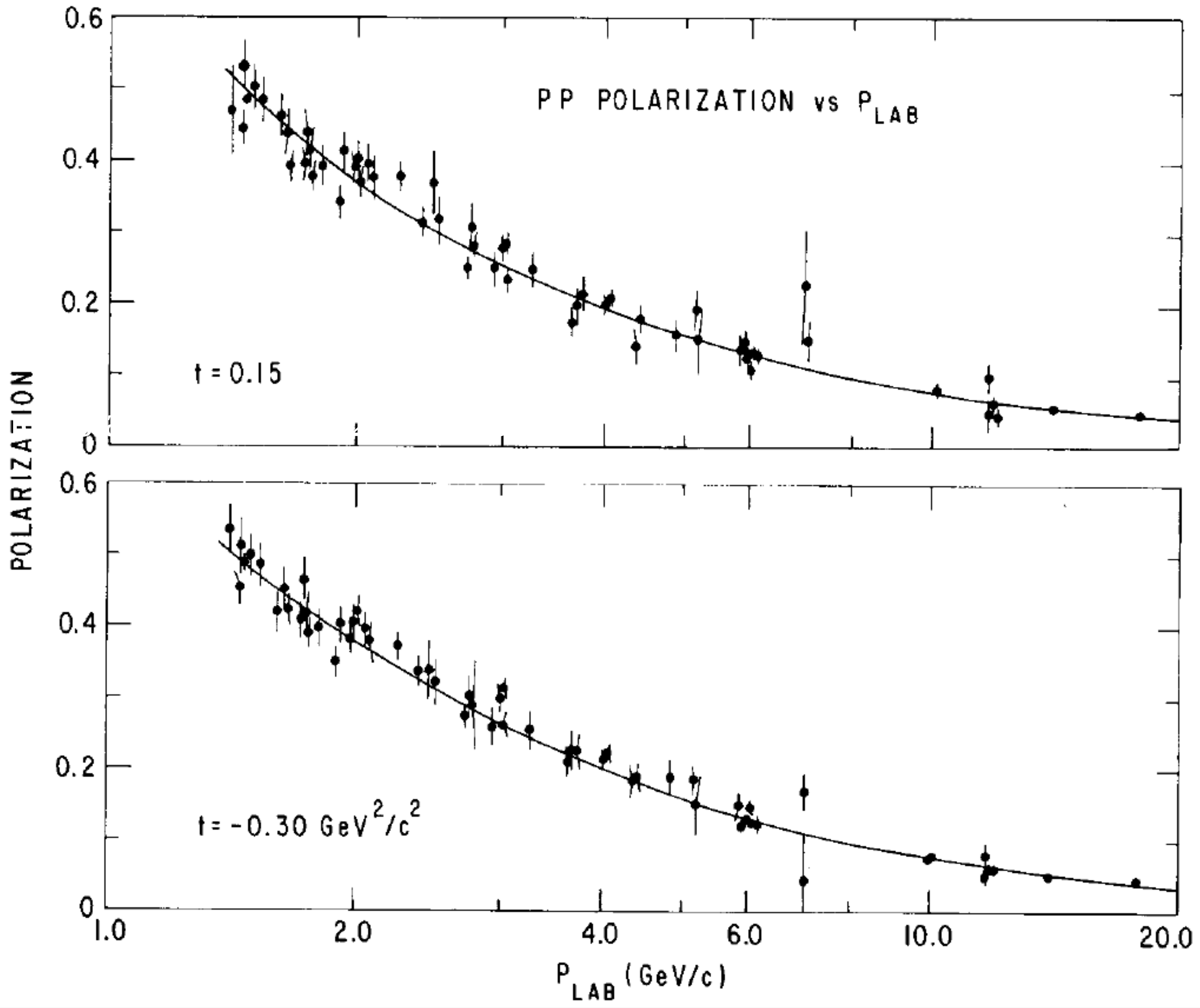




-t, (GeV/c)^2

Nuclear Instruments and Methods 211 (1983) 239-261

H.Spinka, 40 years ago



D. Albers et al.: A Precision Measurement of pp Elastic Scattering Cross Sections at Intermediate Energies

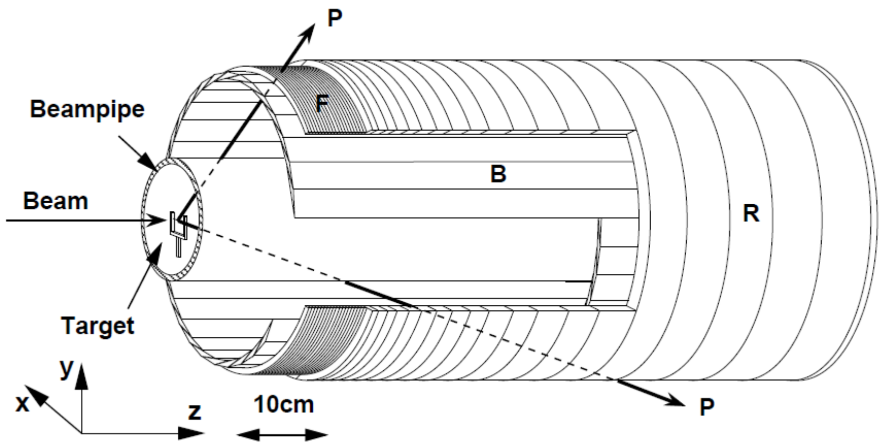


Fig. 1. The EDDA detector (not to scale): target: fiber (CH_2 or C); B: scintillator bars; R: scintillator semi-rings; F: semi-rings made of scintillating fibers.

The structure and granularity of the scintillator hodoscope reflect the signature of pp elastic scattering events, namely (i) coplanarity

$$|\phi_2 - \phi_1| = 180° \quad (1)$$

and (ii) kinematic correlation of scattering and recoil angle, viz

$$\tan\theta_{\text{lab},1} \cdot \tan\theta_{\text{lab},2} = \frac{1}{\gamma^2_{\text{c.m.}}}, \quad (2)$$

where $\gamma_{\text{c.m.}} = \sqrt{1 + T_p/2m_pc^2}$ denotes the Lorentz factor of the pp center–of–mass motion as a function of beam kinetic energy T_p. Both conditions are used to define a fast online trigger.

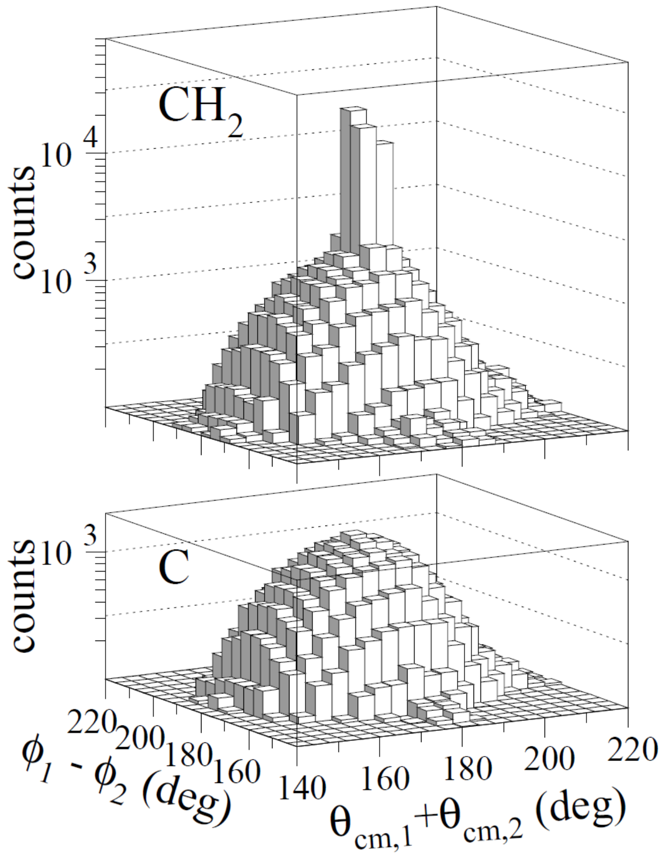


Fig. 8. Distribution of angle integrated events obtained with a CH_2 (top) and carbon (bottom) fiber target at $p = 2.25$ GeV/c. Note the logarithmic scale.

EDDA, COSY, 2004

CONCLUSION

Elastic pp scattering with detecting scattered and recoil protons is the best reaction for proton polarimetry in momentum interval from 1 to 13 GeV/c

A cluster target (protons or deuterons or Argon) should be installed in NICA ring

Thank you!

Extraction of the analyzing powers

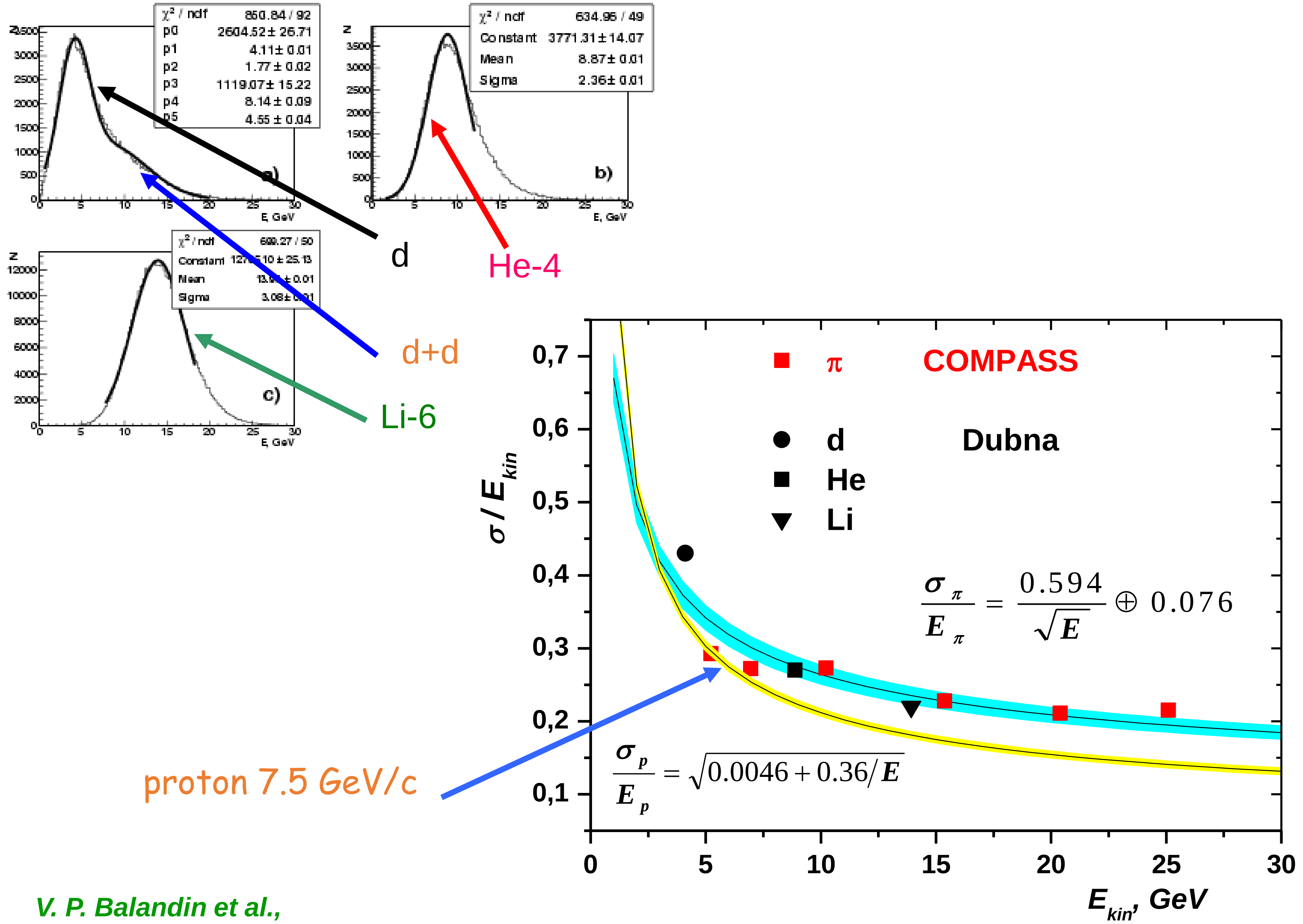
$$\frac{d\sigma}{d\Omega}(\theta,\varphi)=\frac{d\sigma}{d\Omega}(\theta)_{unpol}\left(1+A_y P_y\cos\varphi\right)$$

$(\theta,\varphi)-bin$ $\quad$ $N(\theta,\varphi)^{\pm}$

$$N^{\pm}(\theta,\varphi)=N_0(\theta)\left(1\pm A_y(\theta)P_y\cos\varphi\right)$$

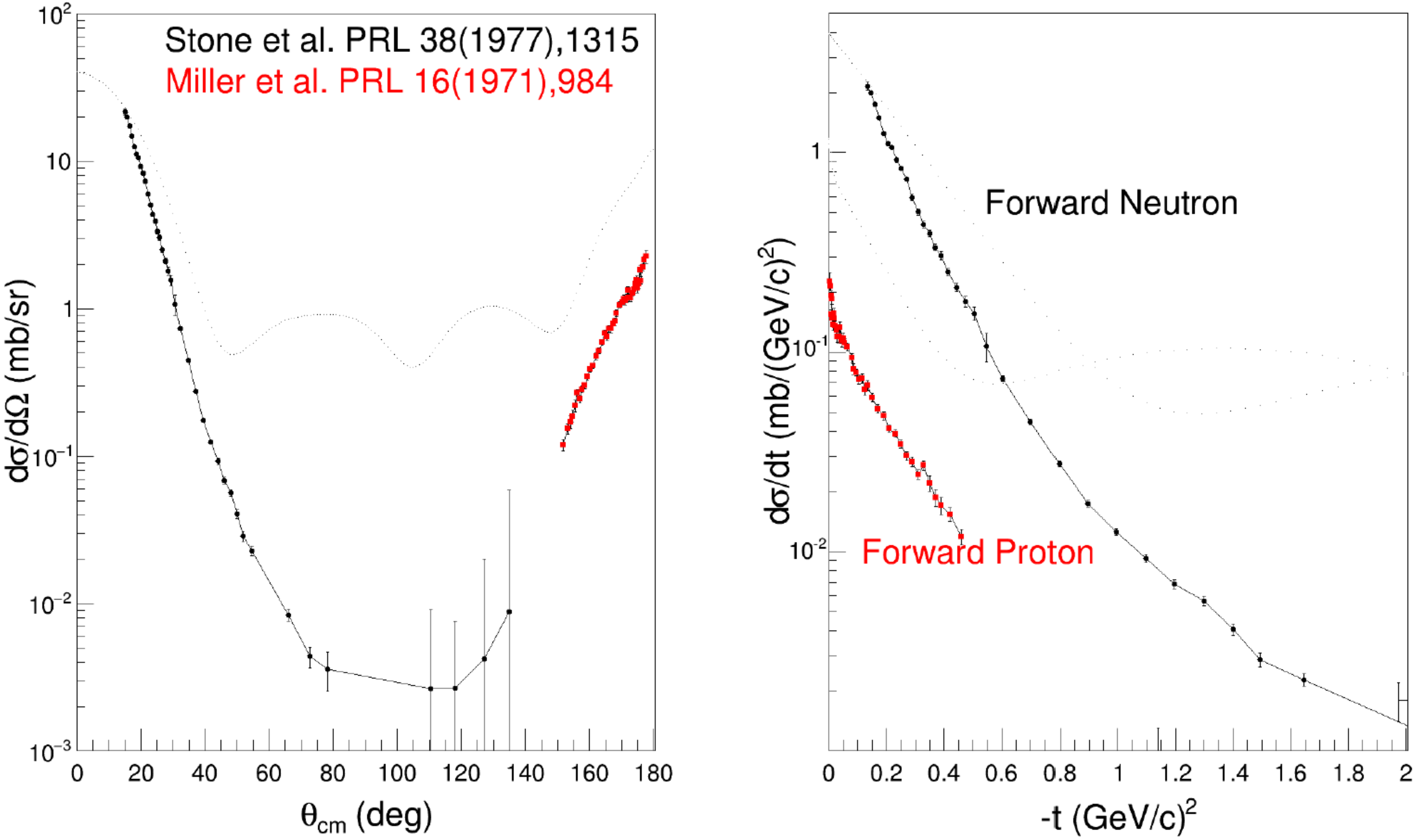
$$R(\theta,\varphi)=\frac{N^+-N^-}{N^++N^-}=P_yA_y(\theta)\cos\varphi$$

$$\Delta A_y=\frac{1}{P_y}\sqrt{A_y^2\Delta P_y^2+\frac{4N^+N^-}{\left(N^++N^-\right)^3}}$$



V. P. Balandin et al.,
JINR Communication P13-2008-196

p_{lab} = 5 GeV/c



Stone et al. PRL 38(1977),1315
Miller et al. PRL 16(1971),984
dσ/dΩ (mb/sr)
θcm (deg)
Forward Neutron
Forward Proton
dσ/dt (mb/(GeV/c)²)
-t (GeV/c)²