

*Measurement of analyzing powers for the reaction
 $p(\text{pol}) + \text{CH}_2$ up to 7.5 GeV/c
and $n(\text{pol}) + \text{A}$ up to 6.0 GeV/c at the Nuclotron
(ALPOM2 proposal)*

S.N. Basilev, Yu.P. Bushuev, O.P. Gavrishchuk, V.V. Glagolev, D.A. Kirillov, N.V. Kostayeva, A.D. Kovalenko,
K.S. Legostaeva, A.N. Livanov, I.A. Philippov, N.M. Piskunov, A.A. Povtoreiko, P.A. Rukoyatkin, R.A. Shindin,
A.V. Shipunov, A.V. Shutov, I.M. Sitnik, V.M. Slepnev, I.V. Slepnev, A.V. Terletskiy

Joint Institute for Nuclear Research, 141980 Dubna, Moscow region, Russia

C.F. Perdrisat

the College of William and Mary, Williamsburg, VA 23187, USA

V. Punjabi

Norfolk State University, Norfolk, VA 23504, USA

M.K. Jones

Thomas Jefferson National Accelerator Facility, Newport News, VA 23606, USA

E. Brash

Christopher Newport University and TJNAF

G. Martinska, J. Urban

University of P.J. Šafárik, Jesenna. 5, SK-04154 Košice, Slovak Republic

J. Mušinsky

Institute of Experimental Physics, Watsonova 47, SK-04001 Kosice, Slovak Republic

E. Tomasi-Gustafsson

IRFU, DPHN, CEA, Université Paris-Saclay, 91191 Gif-sur-Yvette, France

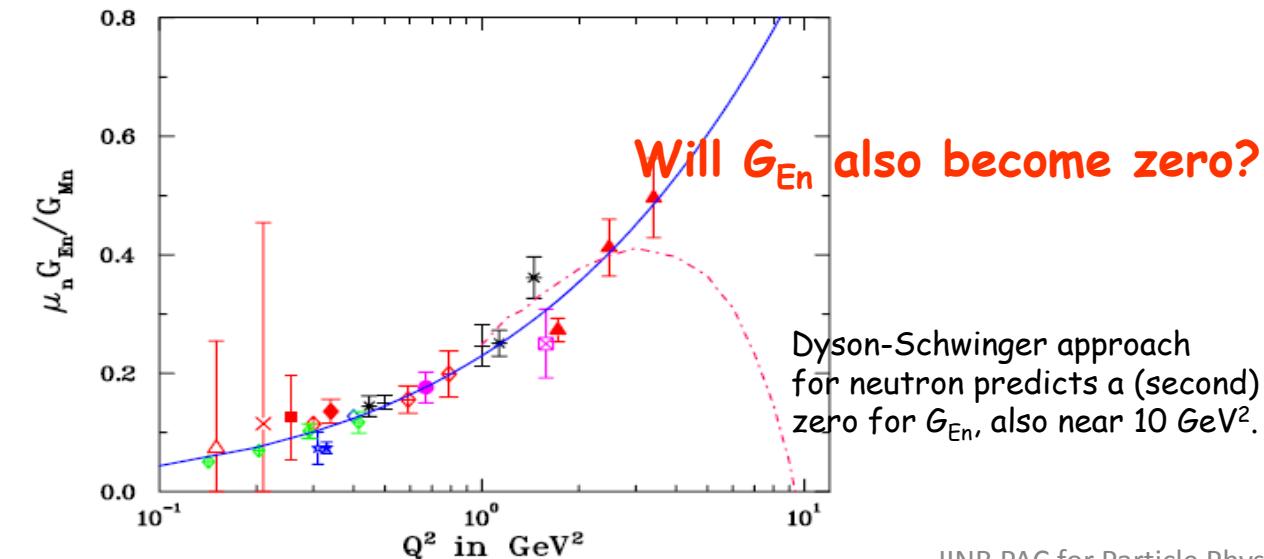
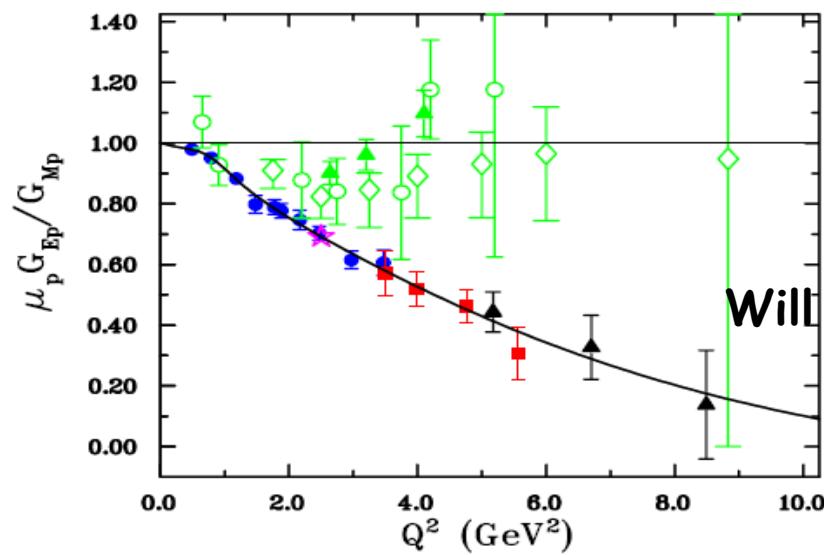
D. Marchand

IPN Orsay, 91406 ORSAY cedex, France

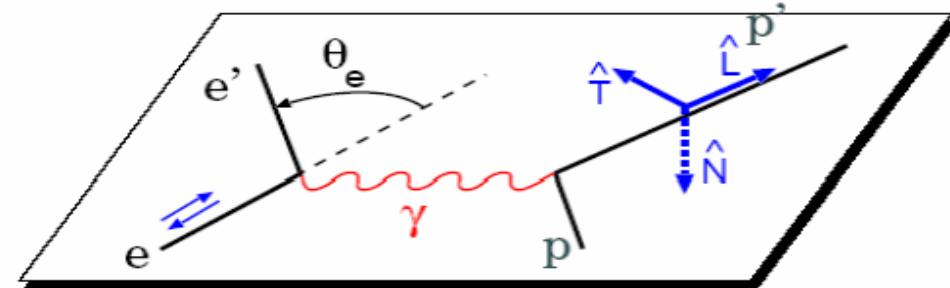
J. R.M. Annand, K. Hamilton, R. Montgomery

University of Glasgow, Glasgow G12 8QQ, Scotland, UK

Nucleon formfactors



Spin Transfer Reaction ${}^1H(\vec{e}, e' \vec{p})$



Transferred polarization is: (Akhiezer & Rekalo)

$$P_n = 0$$

$$\pm h P_t = \mp h 2\sqrt{\tau(1+\tau)} G_E^p G_M^p \tan\left(\frac{\theta_e}{2}\right) / I_0$$

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

Where, $h = |\vec{h}|$ is the beam helicity

$$I_0 = (G_E^p(Q^2))^2 + \frac{\tau}{\epsilon} (G_M^p(Q^2))^2$$

$$\Rightarrow \frac{G_E^p}{G_M^p} = - \frac{P_t}{P_l} \frac{E_e + E_{e'}}{2M} \tan\left(\frac{\theta_e}{2}\right)$$

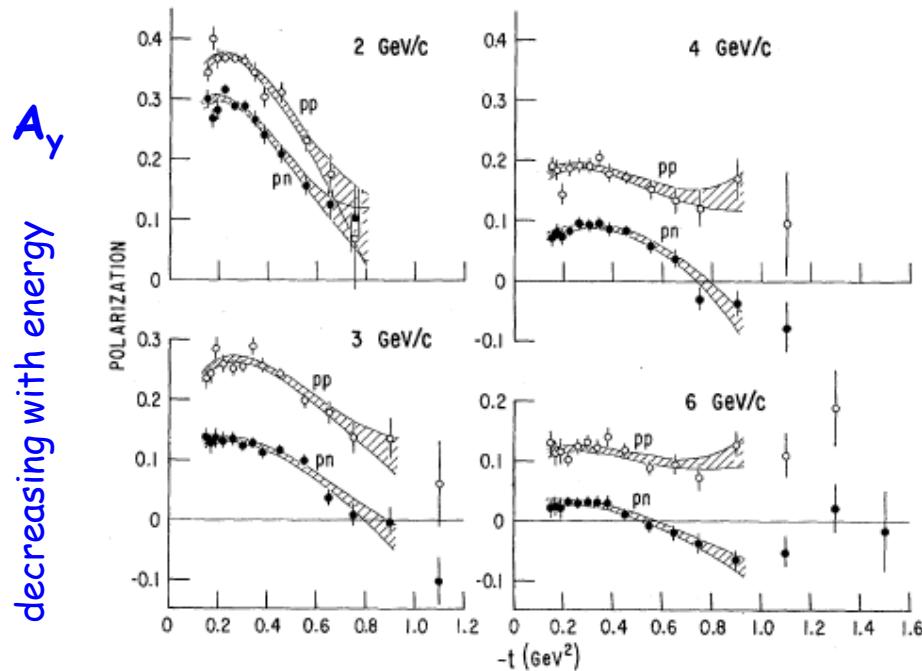
No error contributions from analyzing power and beam polarization measurements

Neutron polarimetry

$pp \rightarrow pp$

$pd \rightarrow pn + (p)$

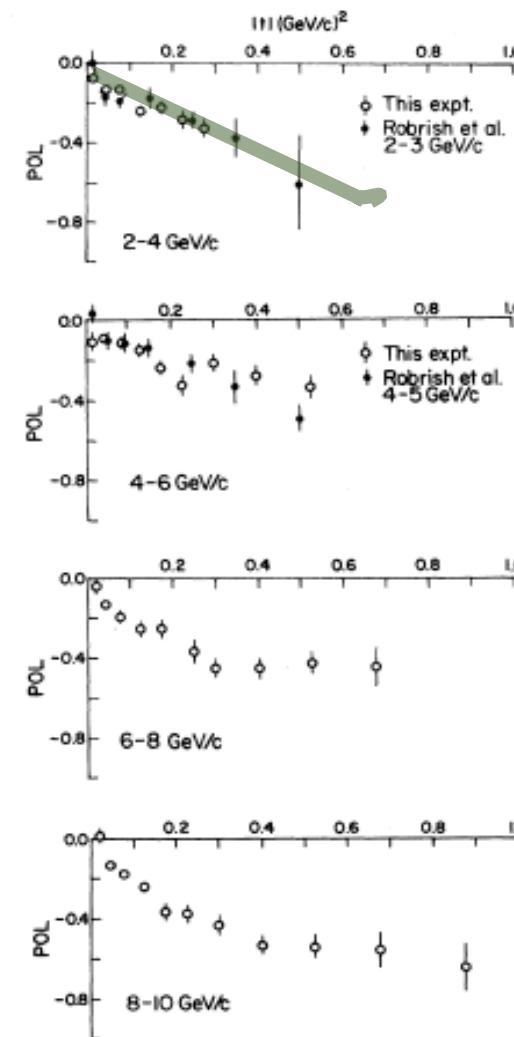
Phys. Rev. Lett 35 (1975) 632



The existing data for A_y in np elastic scattering indicate that the analyzing power decreases faster than the pp analyzing power, becoming very small, then negative around 6 GeV/c neutron momentum.

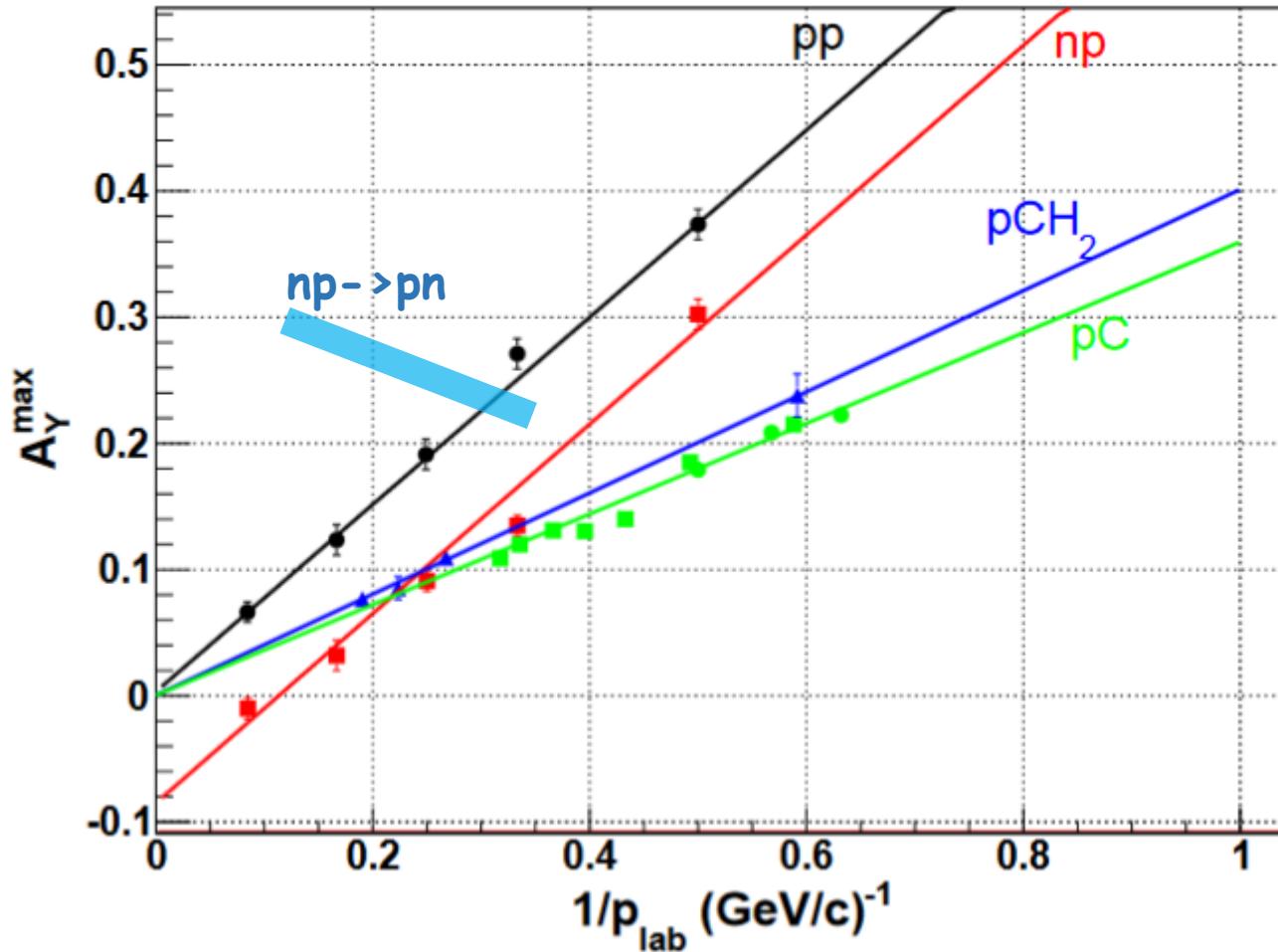
Phys. Rev. Lett 30 (1973) 1183

$np \rightarrow pn$

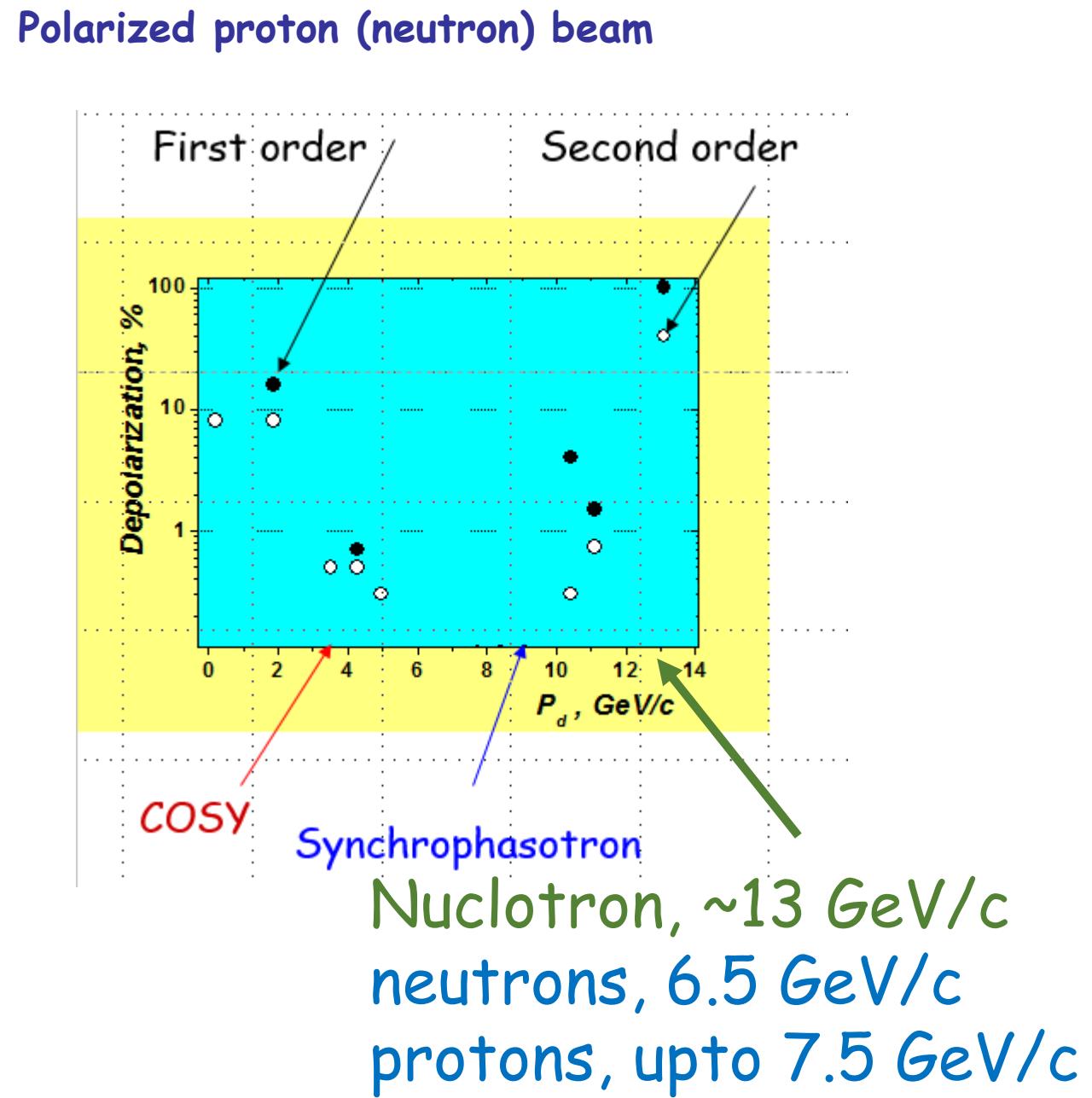
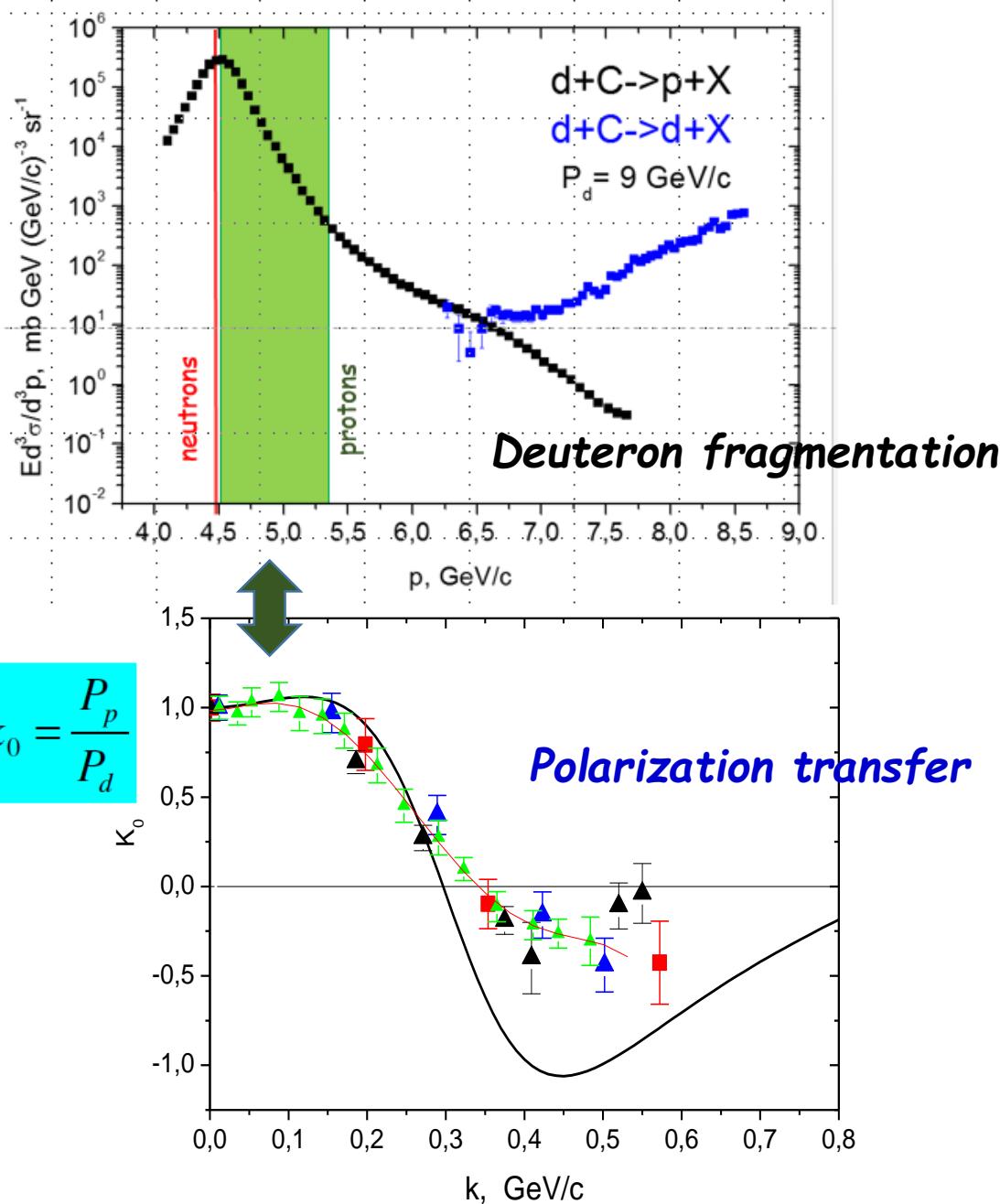


Charge exchange reaction

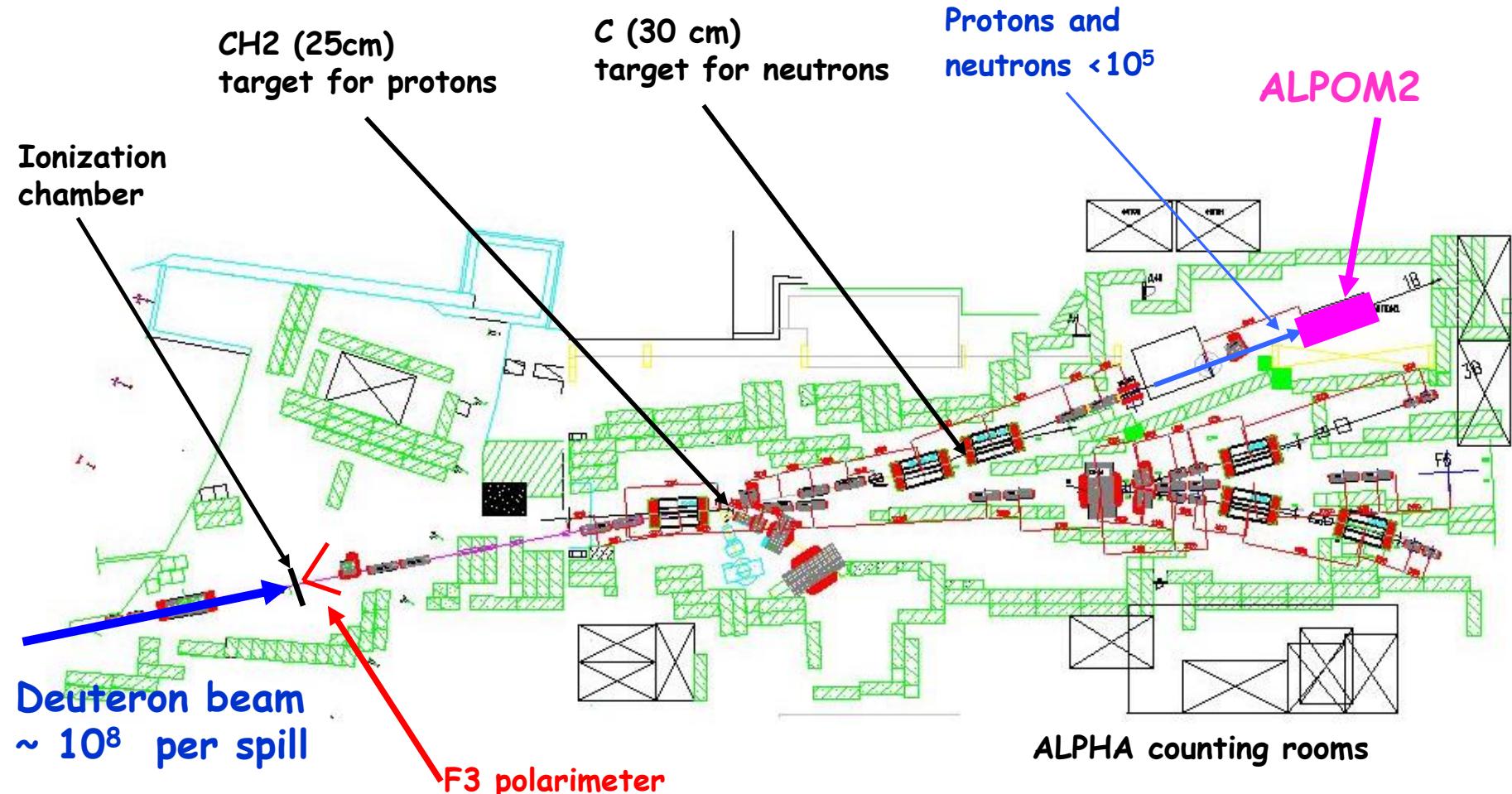
The dependence of the maximum of A_y on $1/p_{\text{lab}}$.



Black circles: ANL d(p,p)n data [29, 30]; black line: linear fit. Red squares: ANL d(p,n)p data [29, 30]; red line: linear fit. Blue triangles [25]: p+ CH₂→charged+X; blue line: linear fit [25]. Green squares [31] and circles [32]: p+ C→charged+X; green line: linear fit [25].

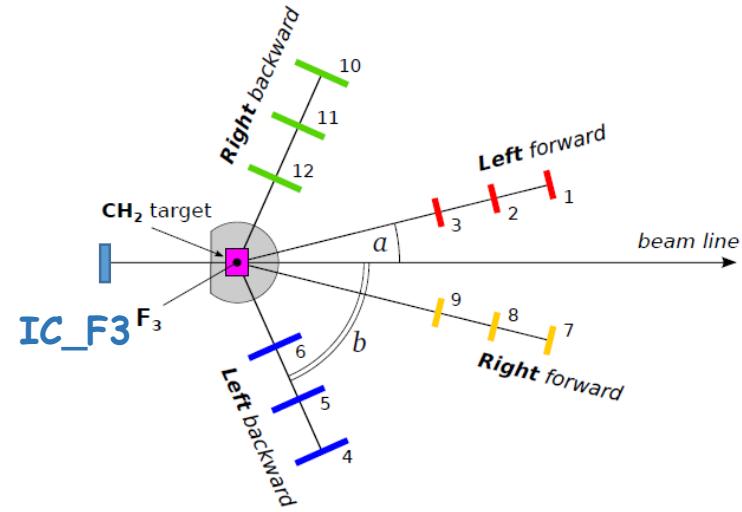


Polarized proton and neutron beams



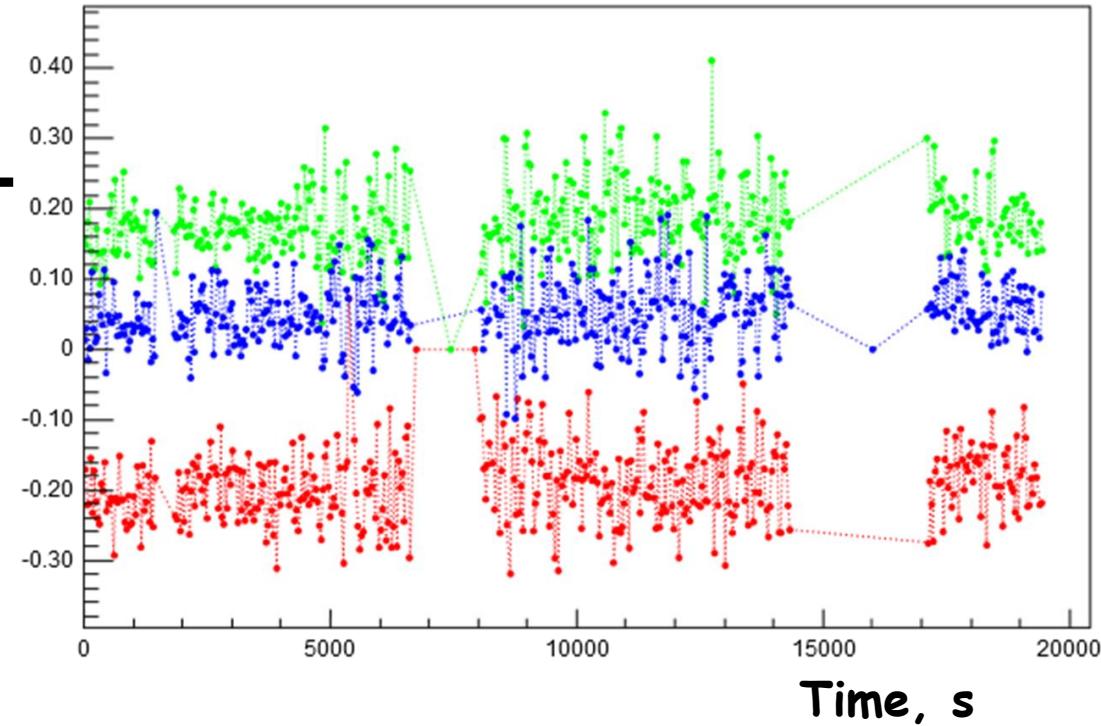
Scheme of transportation polarized beams from Nuclotron to the ALPOM2 setup and the location of F3 polarimeter and production target for proton and neutron beams

Beam polarization measurements



$$P(+)-P(-) = 0.96 \pm 0.05$$

Left-Right
IC_F3

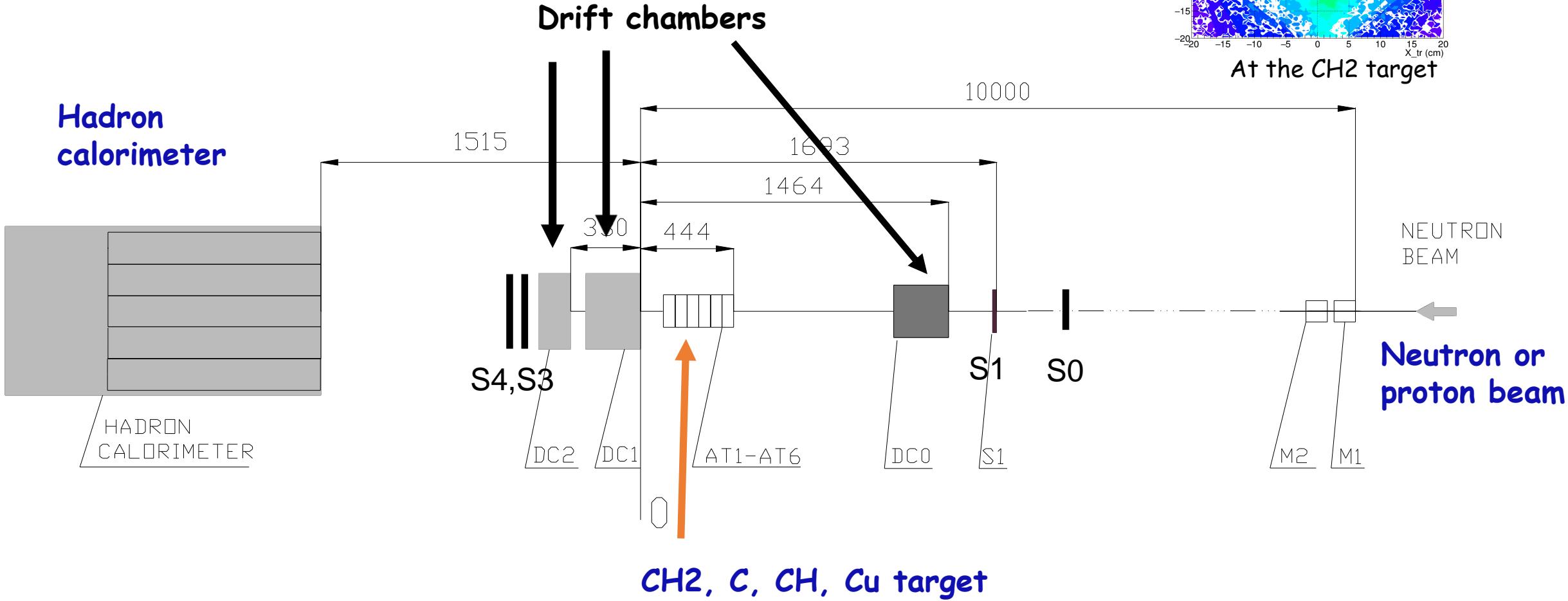


The polarization in one mode
is two times lower than
the other one

About 5 hours

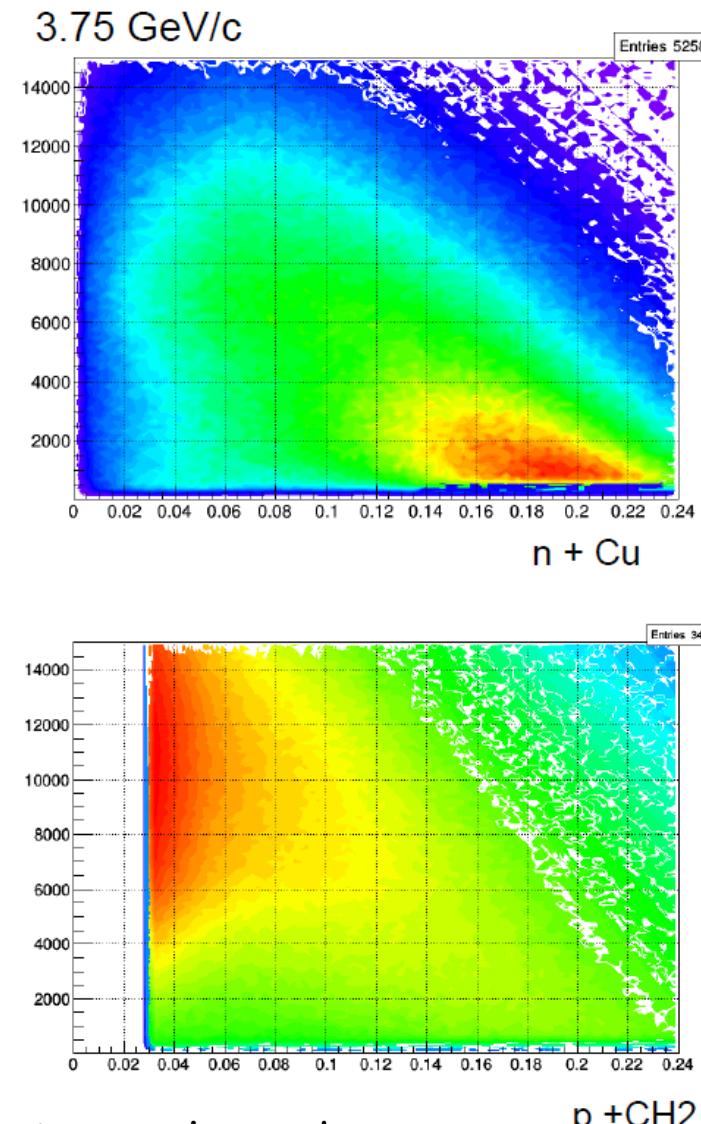
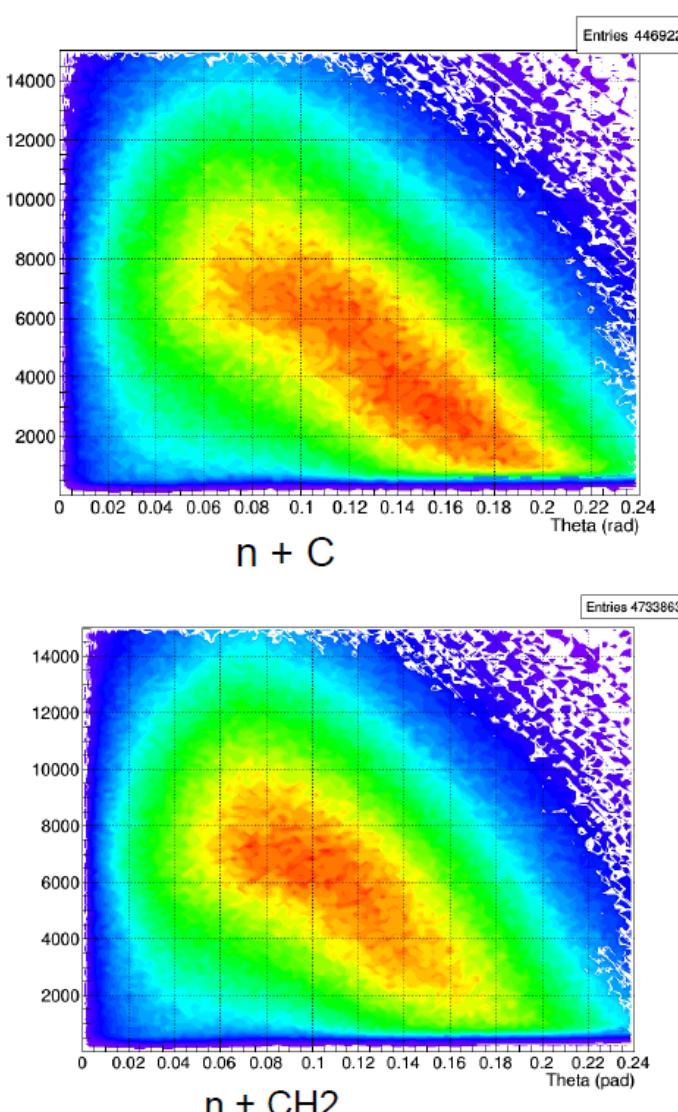
each point corresponds to one spill.

Layout of the setup

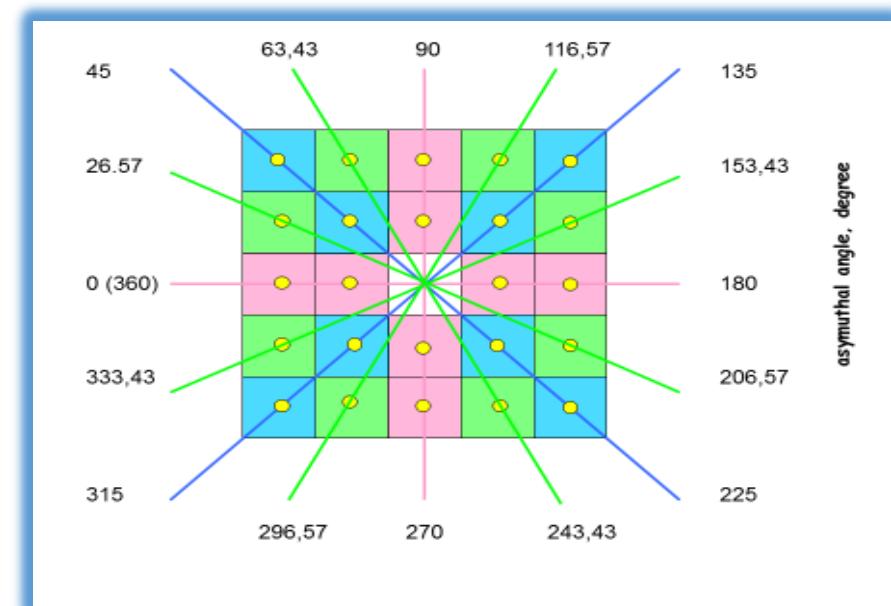


Energy deposit measurements in the hadron calorimeter, 3.75 GeV/c

energy deposit



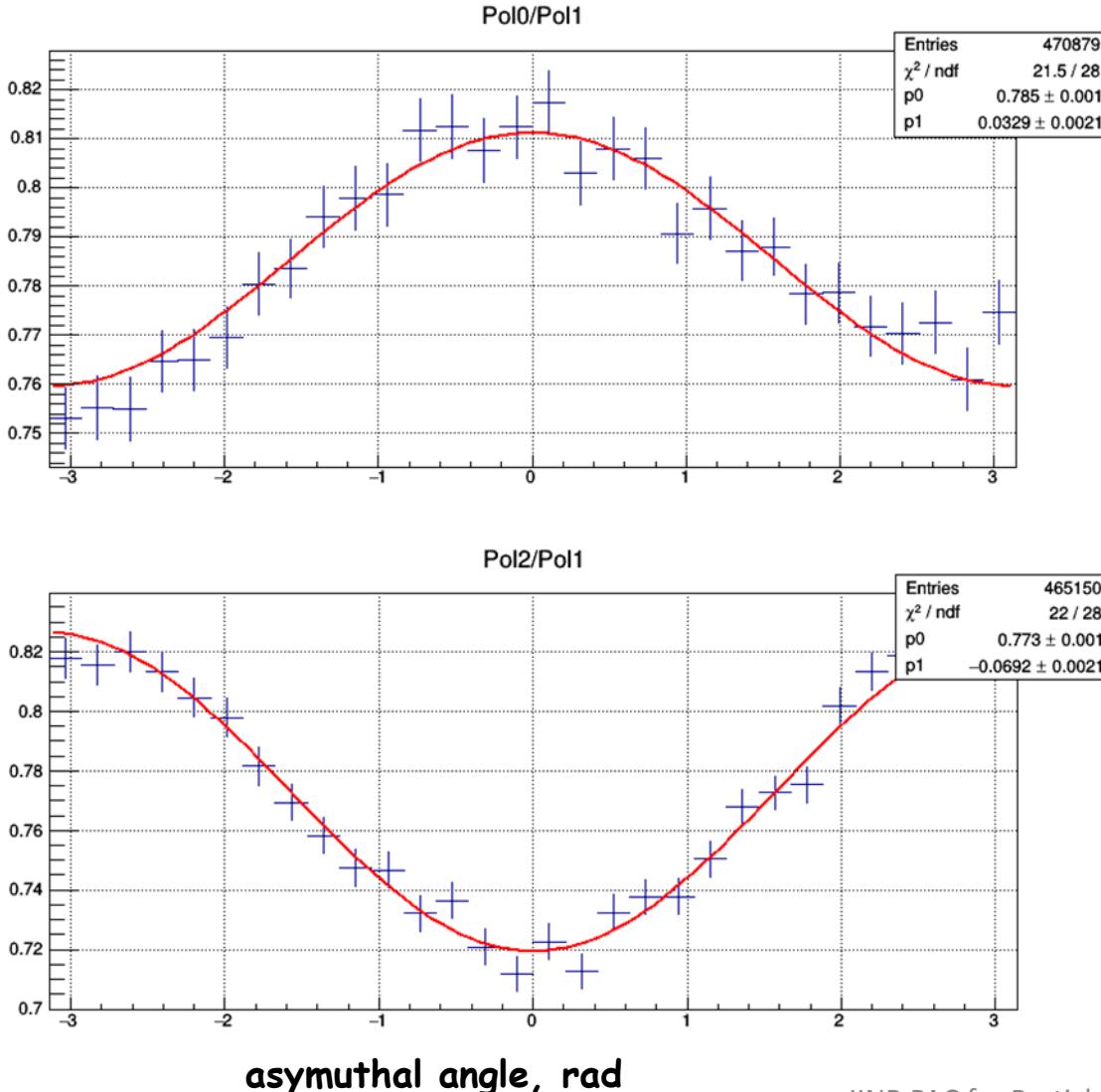
Azimuthal segmentation available
from the hadron calorimeter
for asymmetry measurements



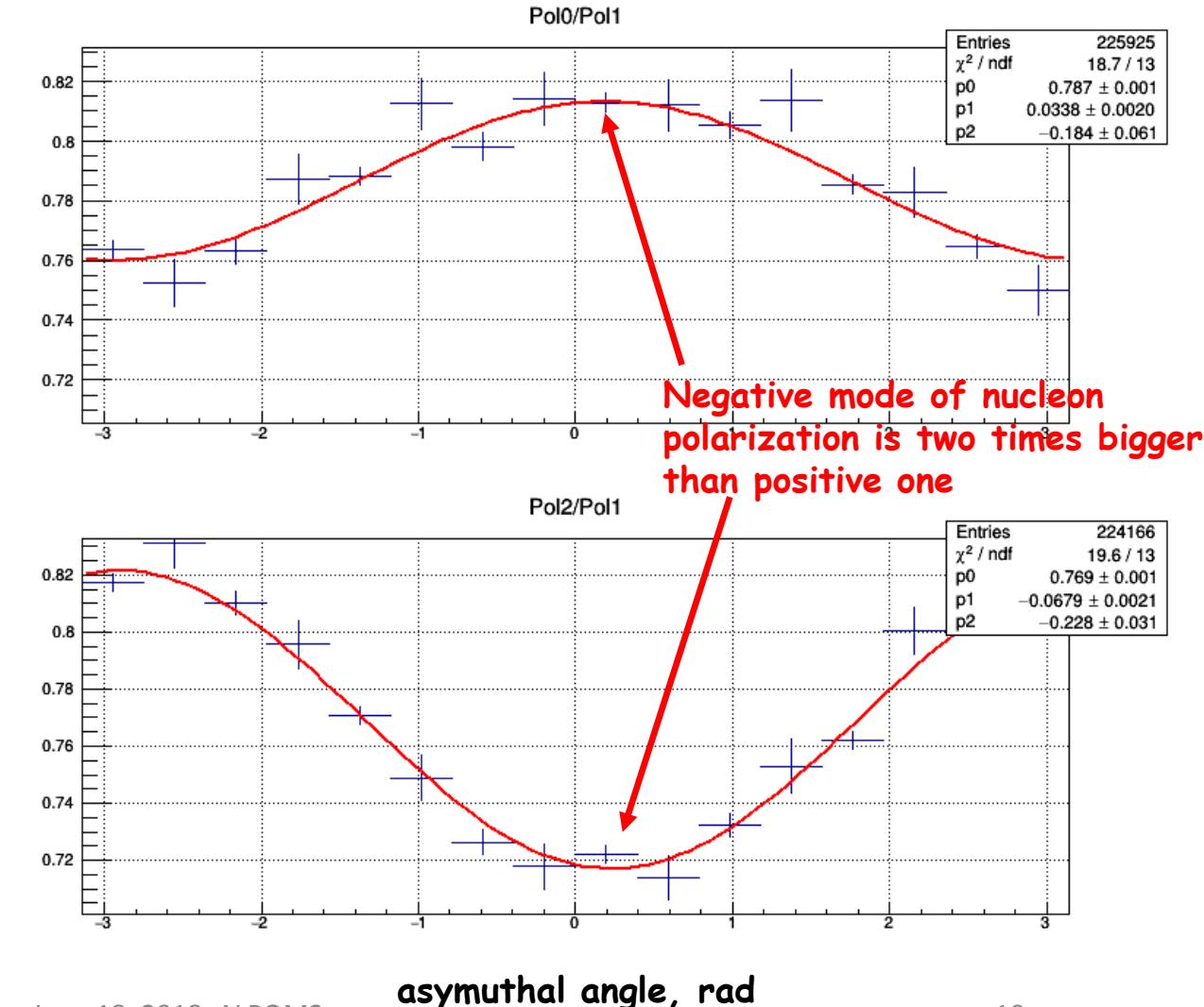
Measured asymmetries

$p+CH_2$, 3.0 GeV/c, tracks,
scattering angles 0.03-0.24 rad

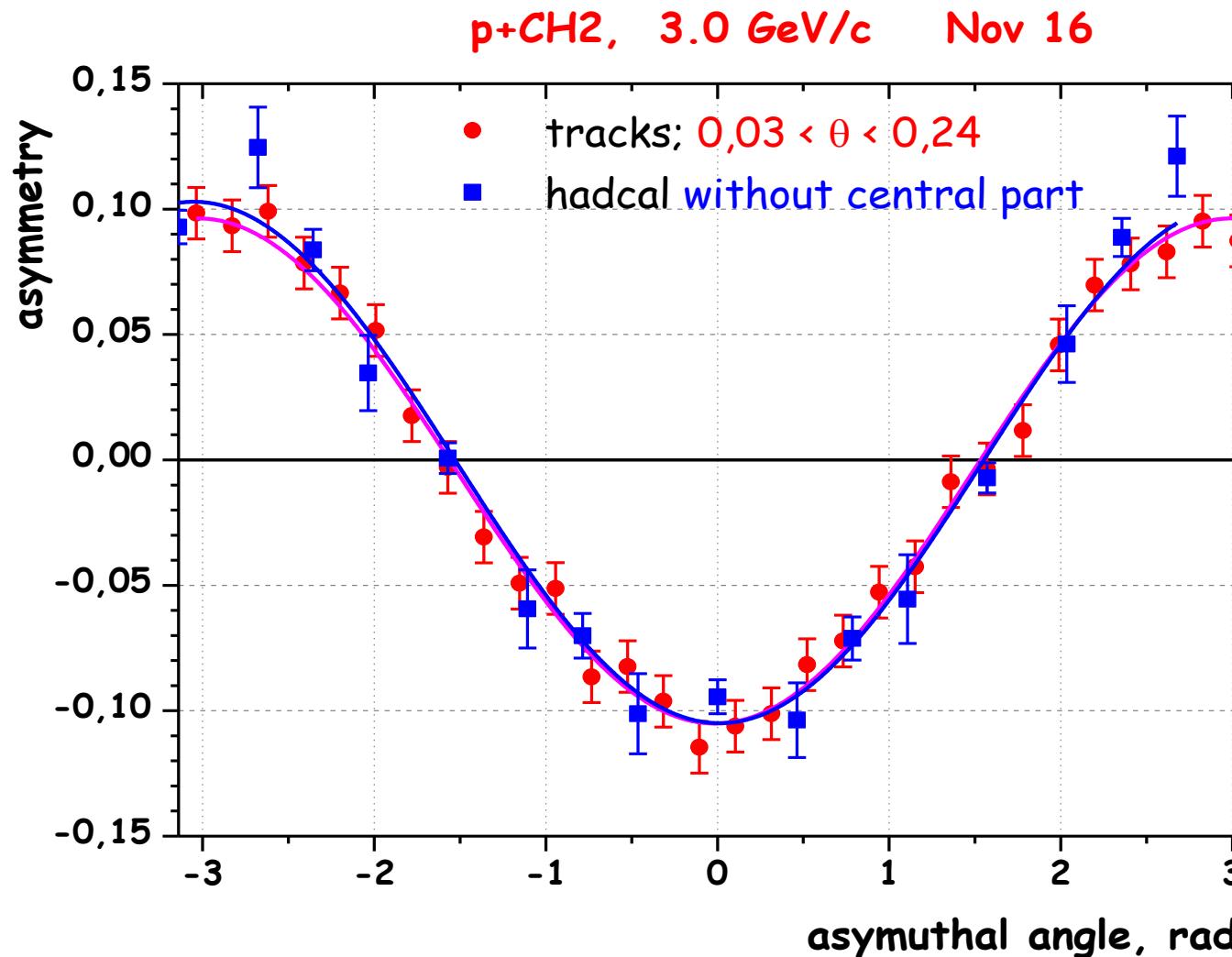
asymmetry



$p+CH_2$, 3.0 GeV/c, hadcal, max amplitude
without the central part



Combining of two polarization modes

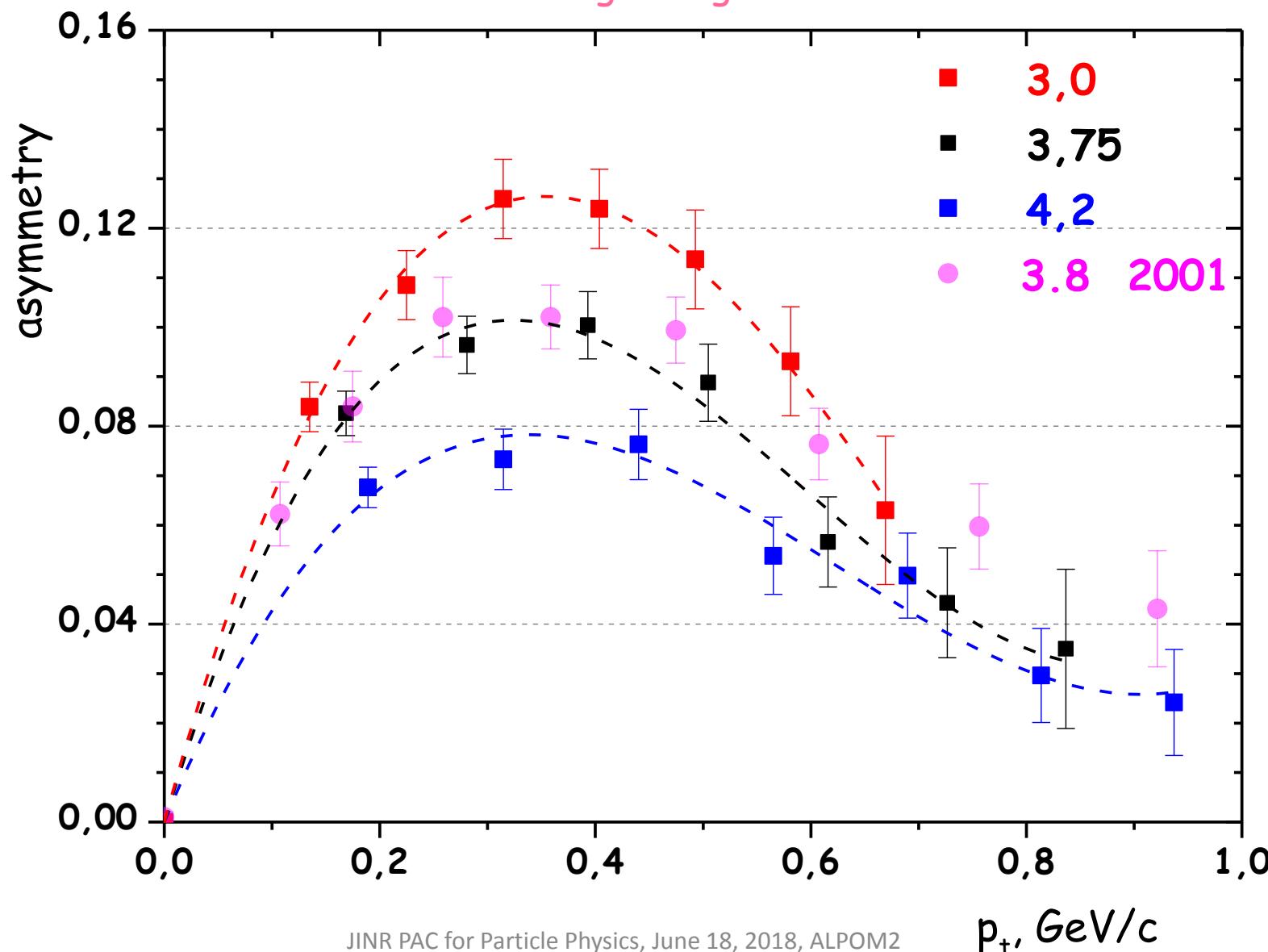


The asymmetry as a function of the azimuthal angle from the calorimeter (blue squares) and from the drift chambers (red circles)

A very good agreement between tracking and energy deposit data allow us in future experiments used one of these methods

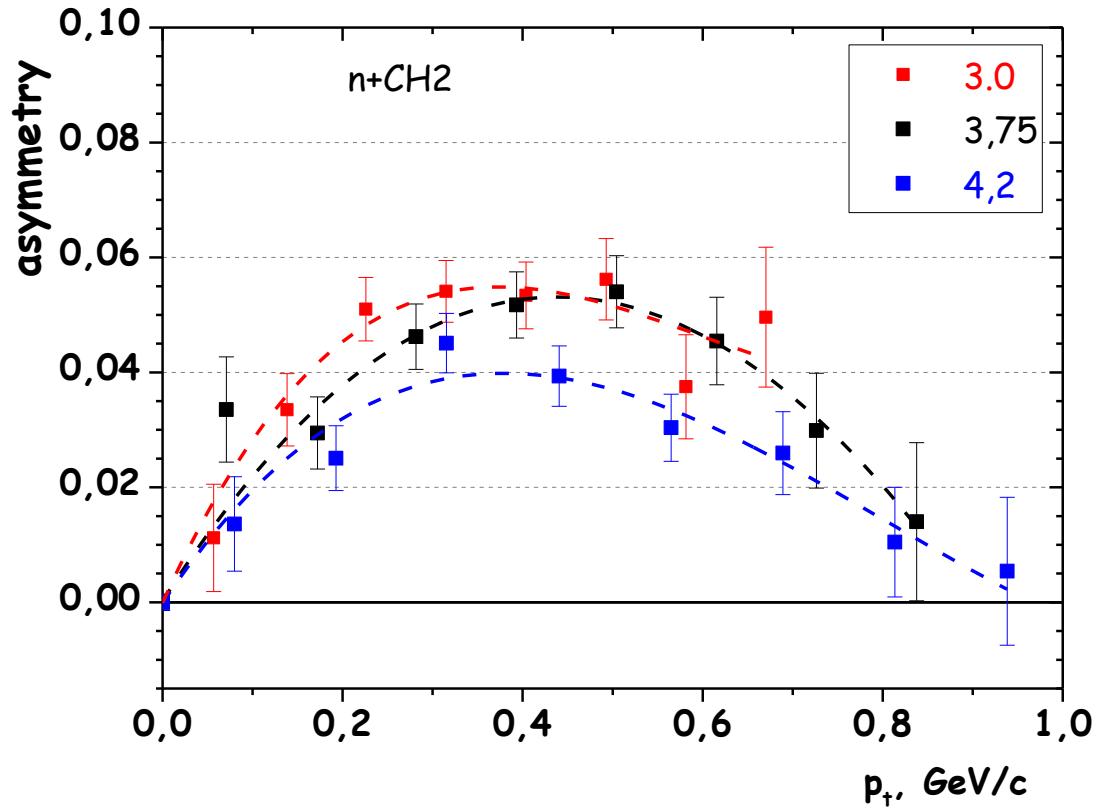
Control measurements, proton beams

good agreement with old data



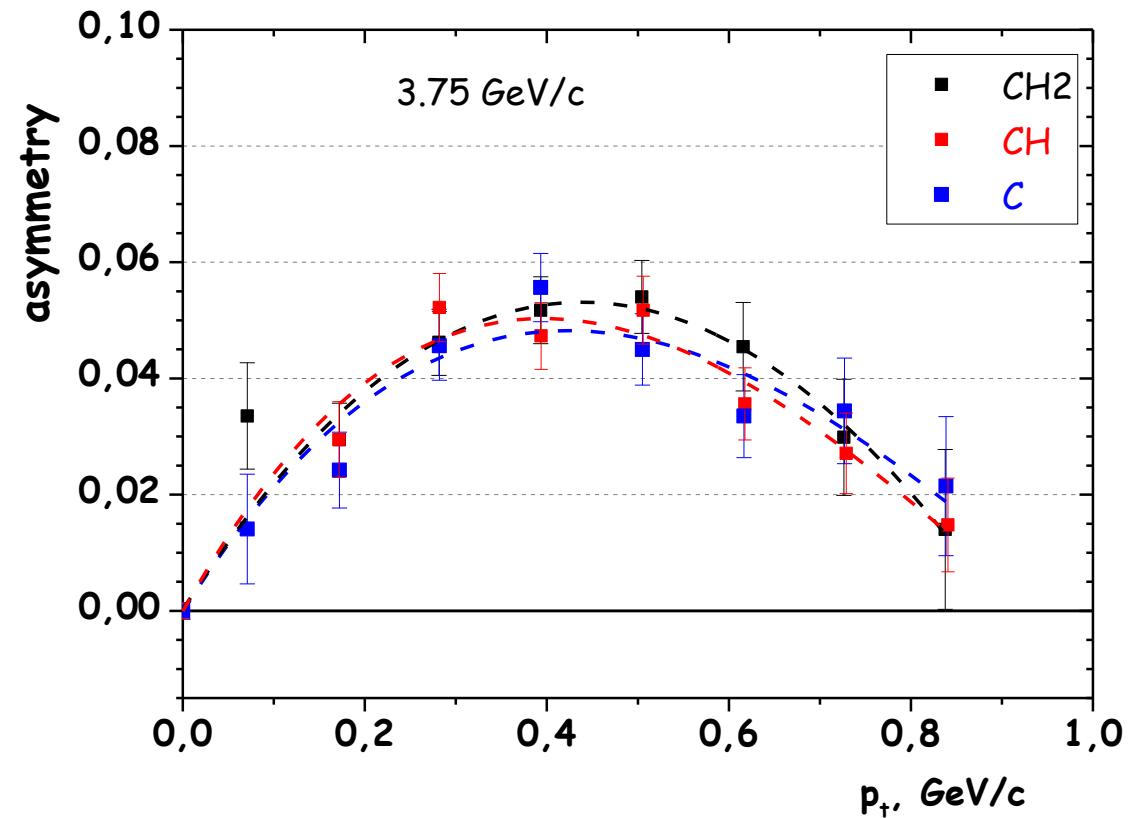
Neutrons

different momenta, CH2 - target



Energy dependence of the neutron
asymmetry on CH₂ target.

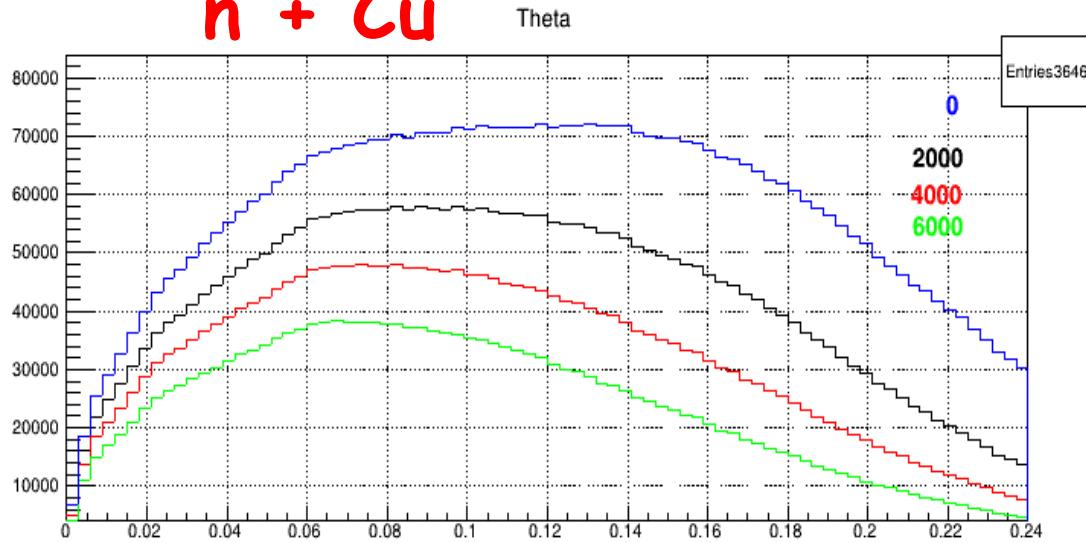
different targets, 3.75 GeV/c



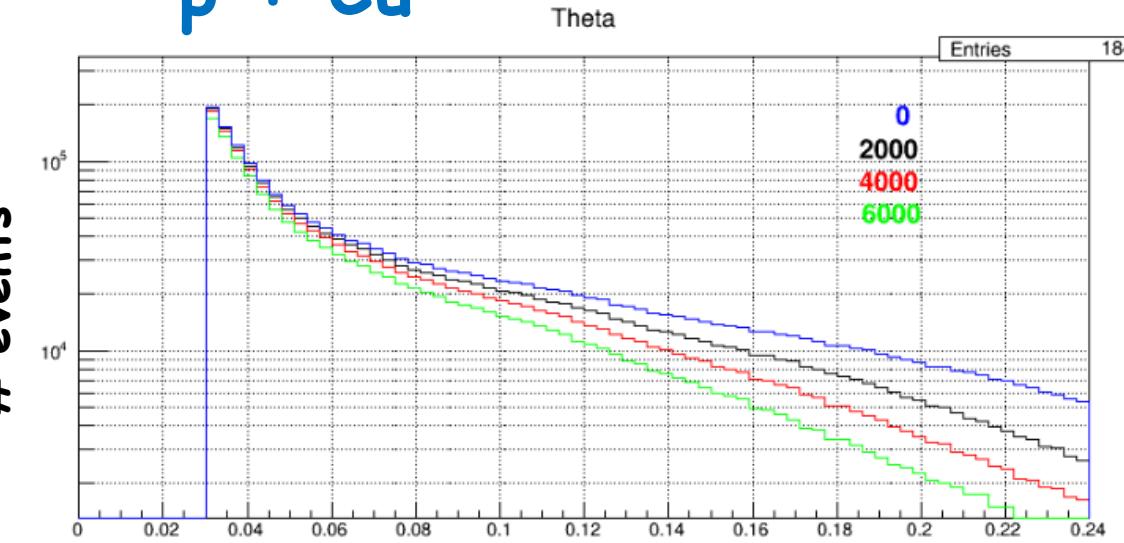
Neutron asymmetry dependence
of different target material



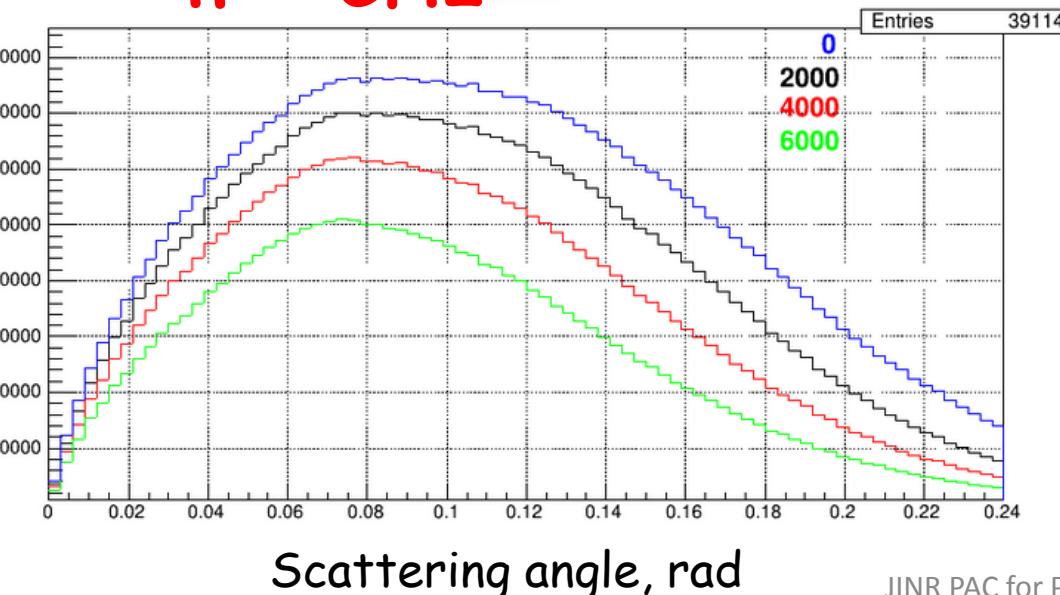
n + Cu



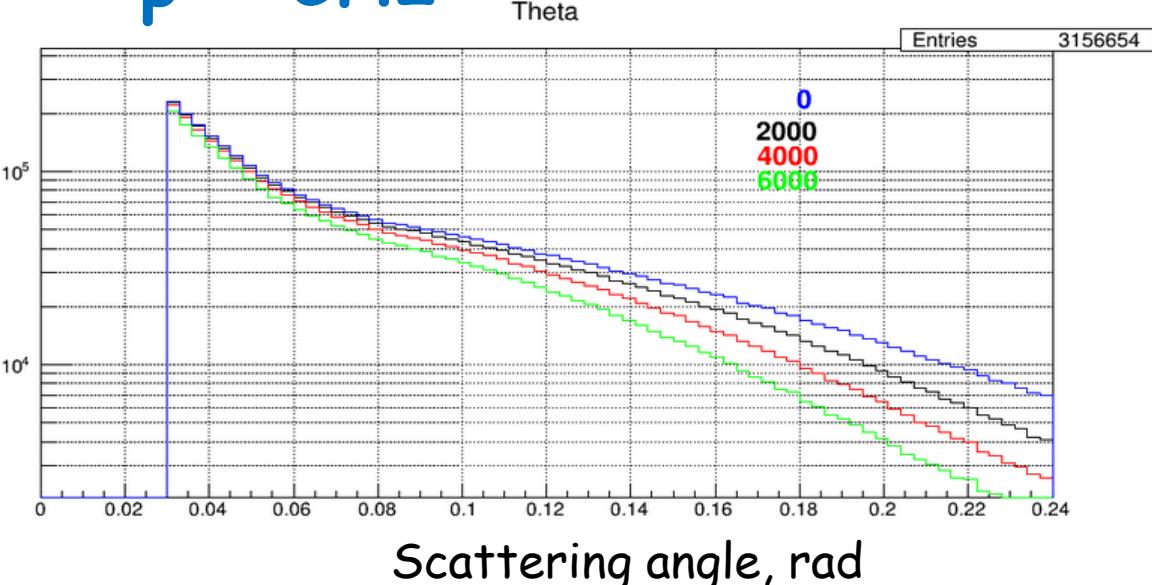
p + Cu



n + CH₂

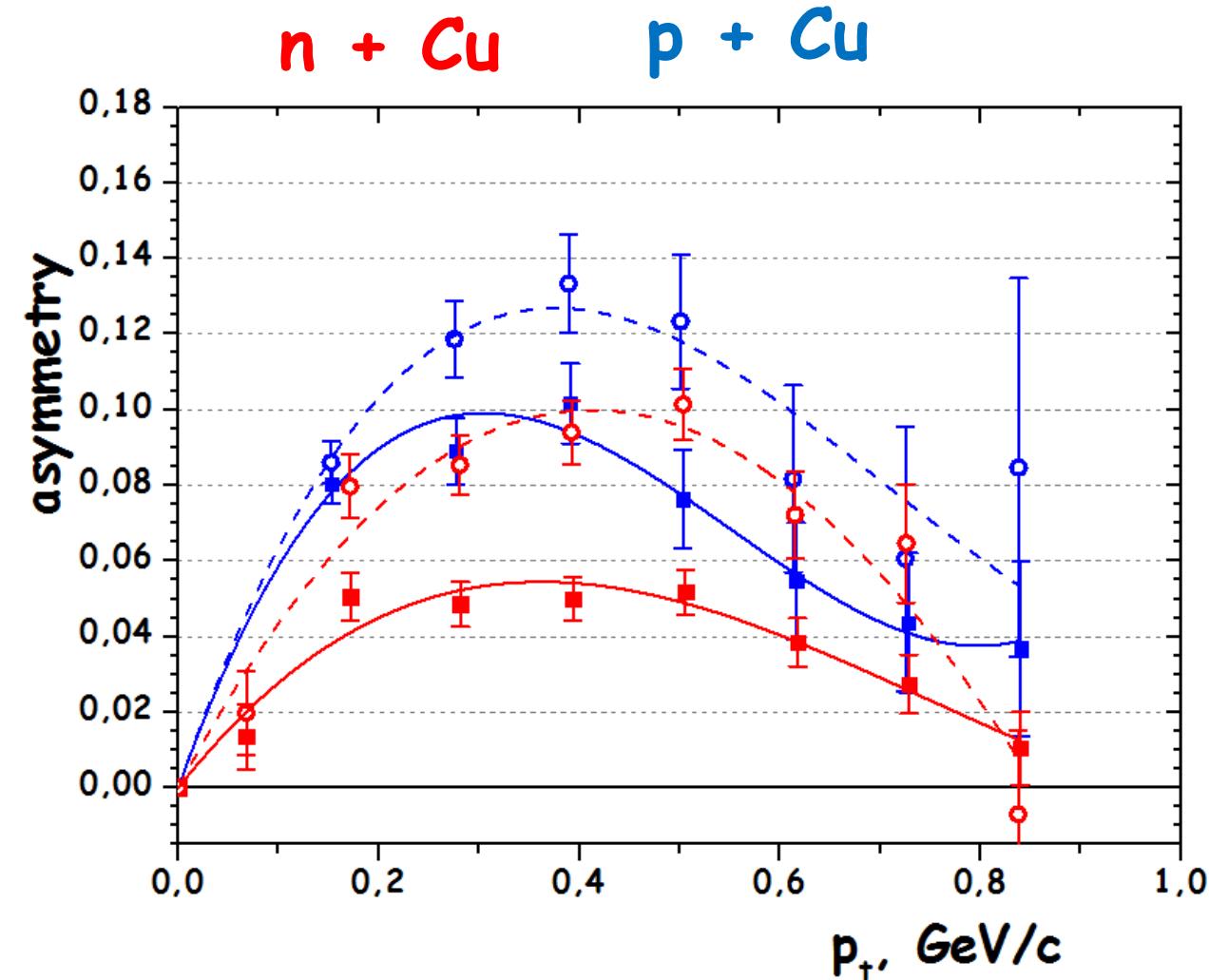
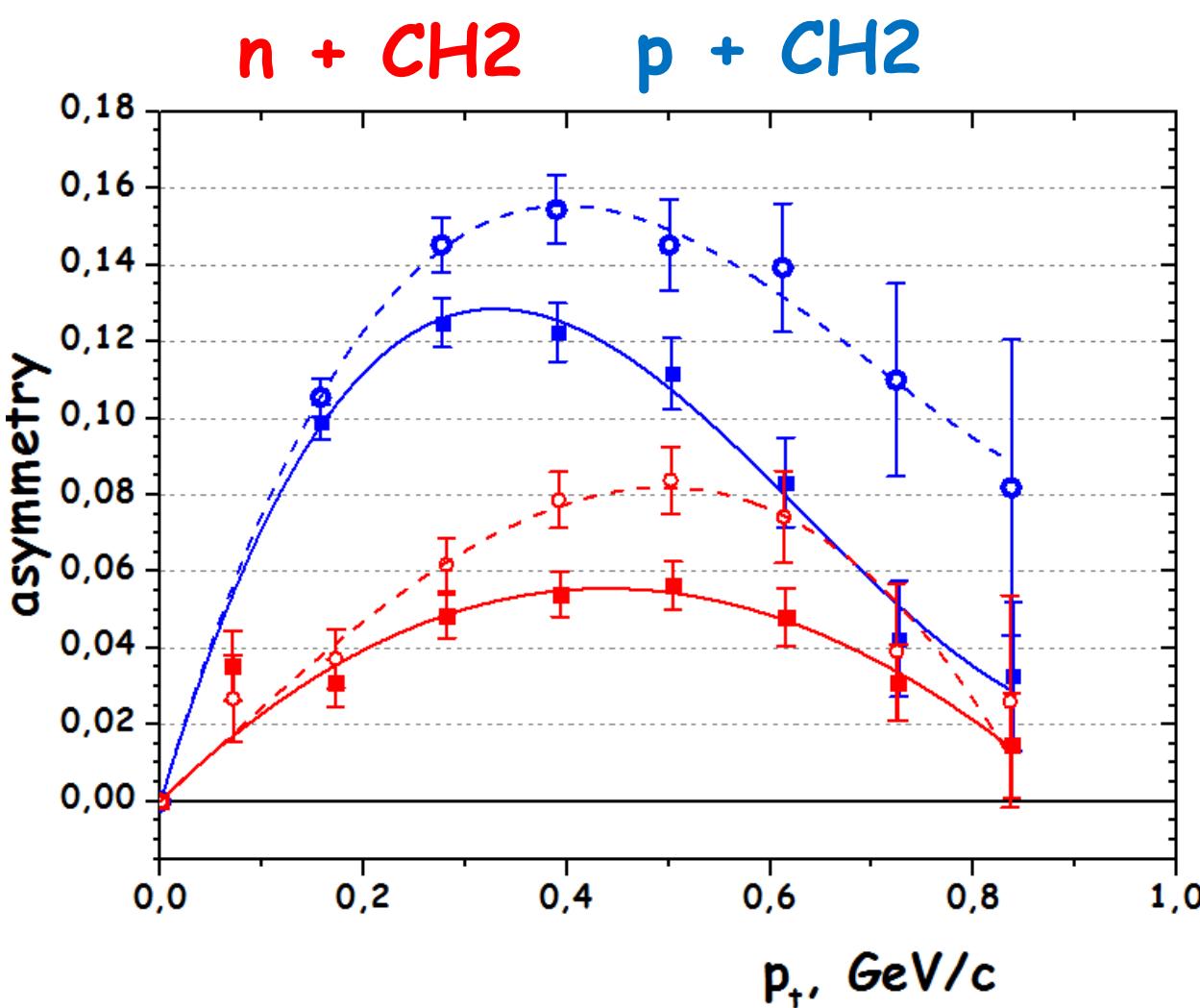


p + CH₂





3.75 GeV/c

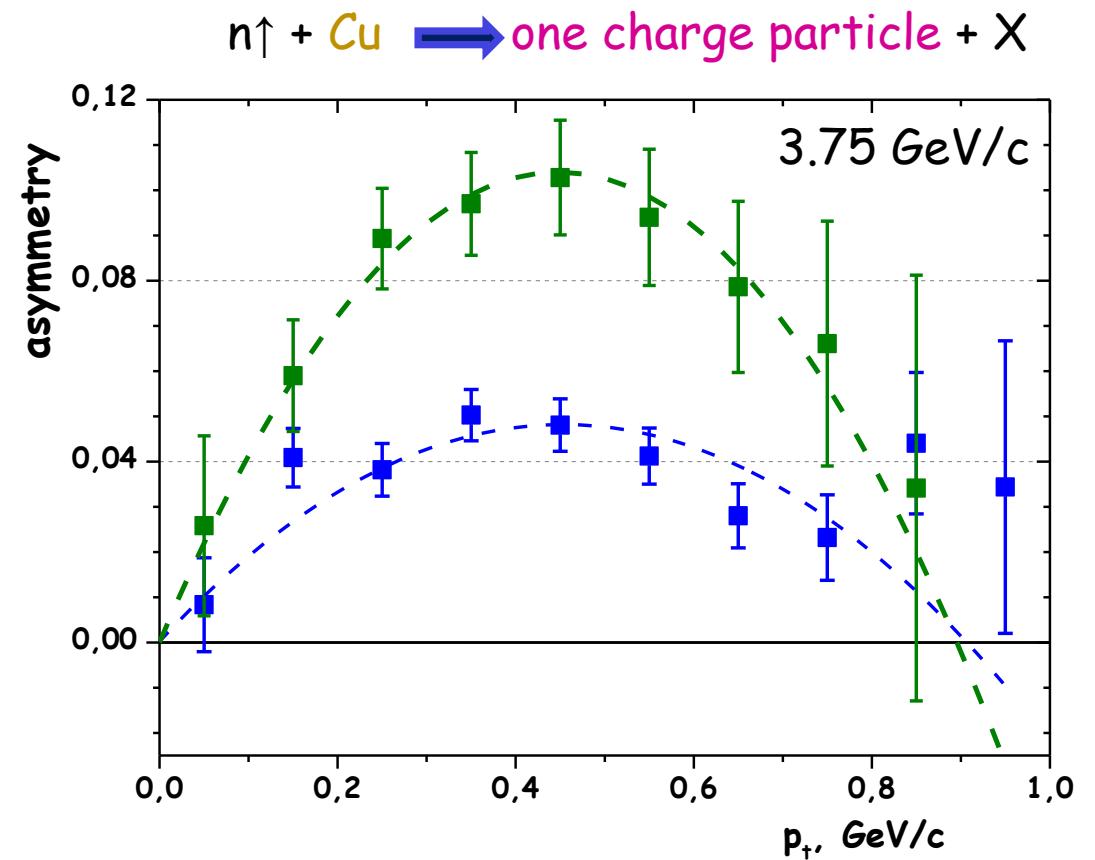


Full squares - no cut; open circles - energy deposit cut, 6000.

Advantage of a copper target as an analyzer one

- 1) The observed asymmetry is unpredictably bigger than in np elastic scattering that usually used for neutron polarimetry
- 2) The length of the copper target is only 4 cm in comparison with the CH one (> 30 cm) used in the elastic np scattering, which makes it possible to improve the accuracy of determining the interaction vertex and the scattering angle.
- 3) Registration of charged particles moving forward is much easier than detection the recoil proton in np elastic scattering

The inverse reaction $p+Cu$ (W) with detection neutron in forward direction by the hadron calorimeter can be used for measurement of the proton polarization at the NICA collider.



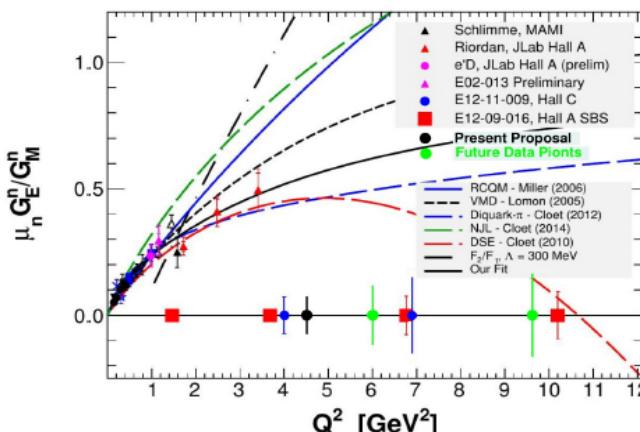
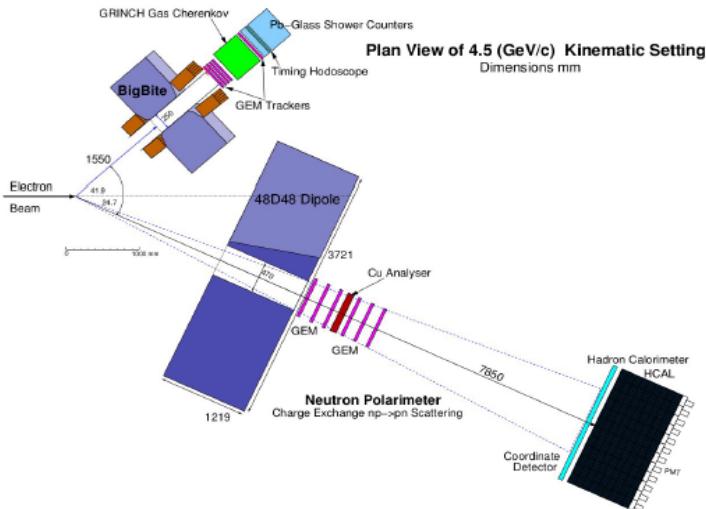
Measurement of the Ratio G_E^n/G_M^n by the Double-polarized ${}^2H(\vec{e}, e' \vec{n})$ Reaction

Neutron Form Factor Ratio G_E^n/G_M^n - 3

- E12-17-004 in Hall A (Annand, Bellini, Kohl, Piskunov, Sawatzky, Wojtsekhowski).
- Polarization transfer using ${}^2H(\vec{e}, e' \vec{n})p$:

$$\frac{G_E^n}{G_M^n} = -\frac{P_t}{P_I} \frac{E + E'}{2M} \tan\left(\frac{\theta_e}{2}\right)$$

- Electron arm: Super Big Bite Spectrometer.
- Neutron arm: HCal, neutron polarimeter, CDet coordinate detector, scintillation counter.
- Kinematics: $Q^2 = 4.5 \text{ (GeV/c)}^2$.
- Beamtime: 5 days.
- Systematic uncertainties about 3%.
- Statistical uncertainties about 8%.
- Will test extension of neutron polarimetry to high Q^2 .
- Expected in the next 2-3 years.



Summary of measurements

The ALPOM2 setup was designed to measure analyzing powers from different analyzer targets, for protons and neutrons. It includes a large size calorimeter to help eliminate multi-particle final states, and correspondingly increase the analyzing power. So far protons and neutrons of 3.0, 3.75 and 4.2 GeV/c momentum have been used. Polarized protons of up to 7.5 GeV/c should become available in the near future.

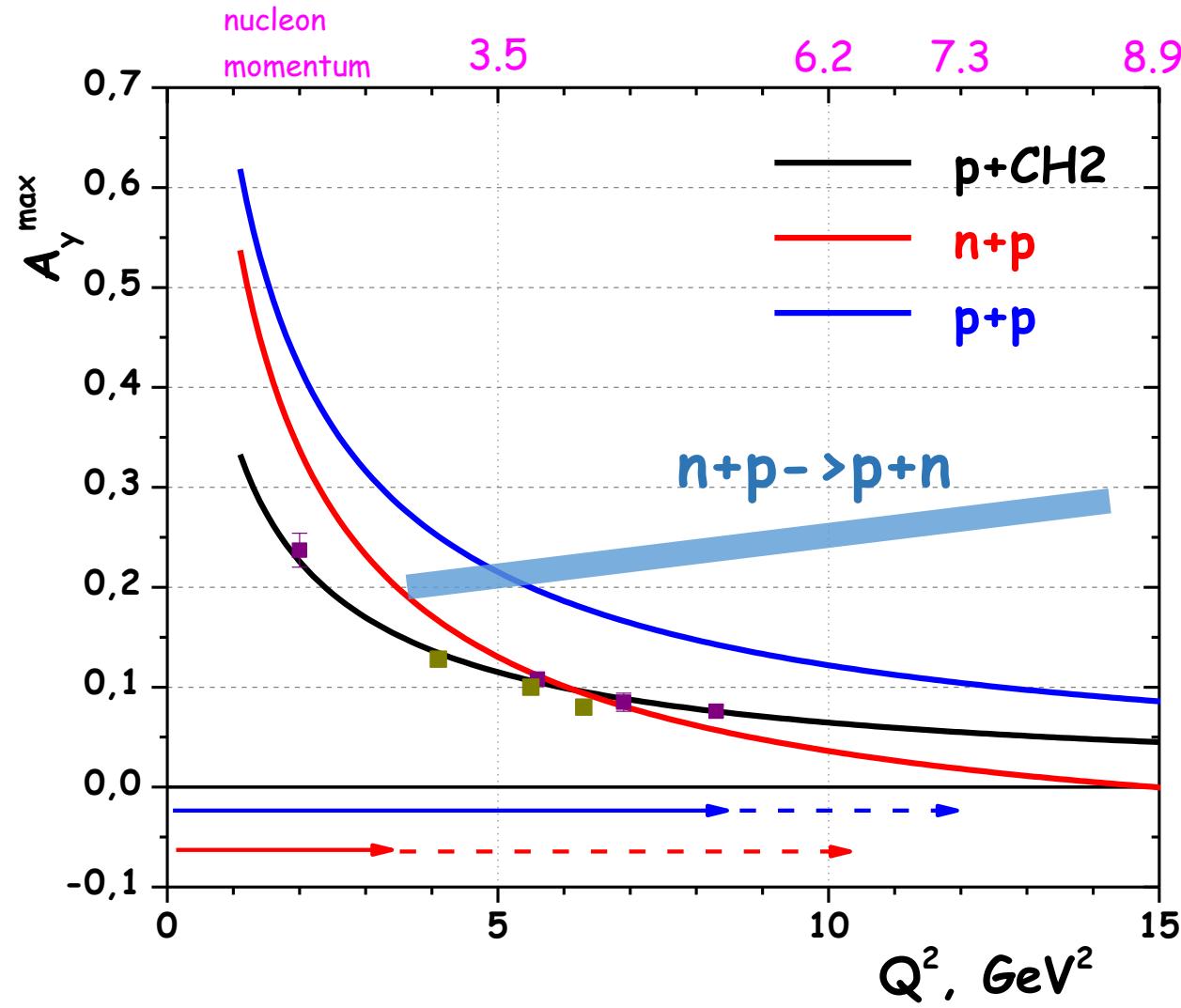
The proton data in the momentum range available at this point in time are in general agreement with data from various laboratories.

We now have, for the first time, analyzing power data for the charge exchange (pol) $n+CH_2 \rightarrow n+X$ reactions, as well as for C, CH (scintillator) and Cu analyzers. Based on the available (and ancient) **charge exchange analyzing power data for $np \rightarrow pn$** , the expectation was that the same reaction channel for the complex target available (C, CH, CH_2 and Cu) would be significantly larger than for the forward process, $np \rightarrow np$. The new data fully support this expectation.

The consistency of these data clearly indicates that the experimental setup is adapted to the challenge, that the beam polarization, intensity and stability are appropriate for this

All data shown are preliminary

Asymmetries vs Q^2



Future runs

End of 2019

Protons, 7,5 GeV/c

Neutrons, 5 & 6 GeV/c

Exp data: 2001 & 2016

Schedule of the experiment:

2019 year	Modification of neutron channel upto 6 GeV/c
2020-2021 years	<p>Data taking during 336 hours.</p> <p>It includes: for proton beam 168 hours</p> <ul style="list-style-type: none">a) measurement A_y at proton momentum of 5.3 GeV/c (control point)b) two measurements of transfer polarization, check conservation polarization at $k=0.15$ GeV/c at deuteron momentum of 11.2 GeV/c (proton momentum 6.5 GeV/c) and deuteron momentum of 13.0 GeV/c (proton momentum 6.5 GeV/c)c) measurement at deuteron momentum of 13.0 GeV/c (proton momentum 7.5 GeV/c) for neutron beam 168 hours <p>measurement A_y at neutron momenta of 5.0 and 6.0 GeV/c .</p>
2021 year	Data analyzes and publication of the results.

Expenses

The following expenses are requested:

Modernization of the neutron channel	22 k\$
Constructing of mechanical support, gases	5 k\$
Reception and sending of the experts	15 k\$
Total:	42 k\$

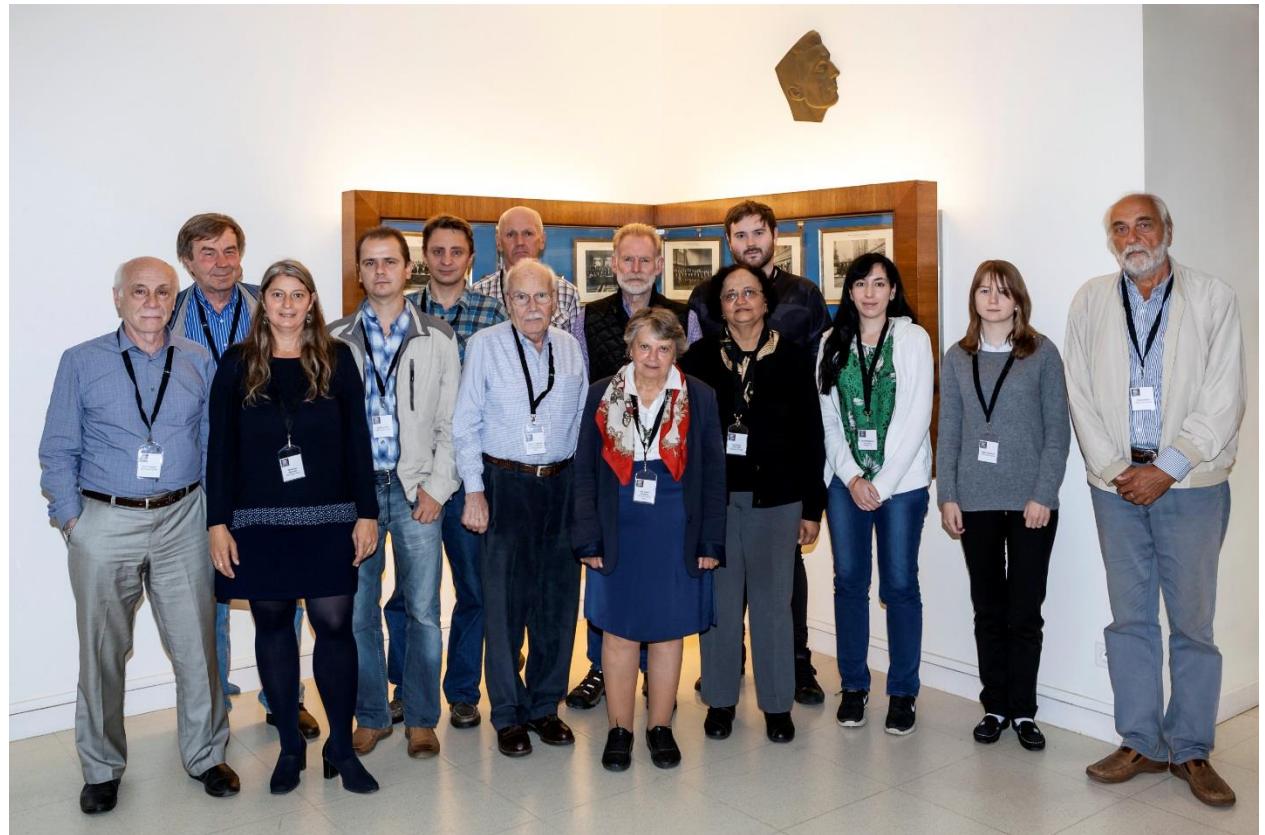
Contributions in previous years from collaborators

USA side - crate VME - 8.5 k\$; HV supply - 2 k\$, .2 TQDC - 8 k\$, hadcal modules - 10 k\$, HV system SY5527 (Caen) - 14.6 k\$

French side - PM XP2020 - 2 items and several electronic modules - 5 k\$

Slovak Republic grants - 22 k\$, HV supply, computers, electronic modules

We are planning to continue the measurements at higher proton and neutron energies



JINR PAC for Particle Physics, June 18, 2018, ALPOM2

Thank you for your attention!

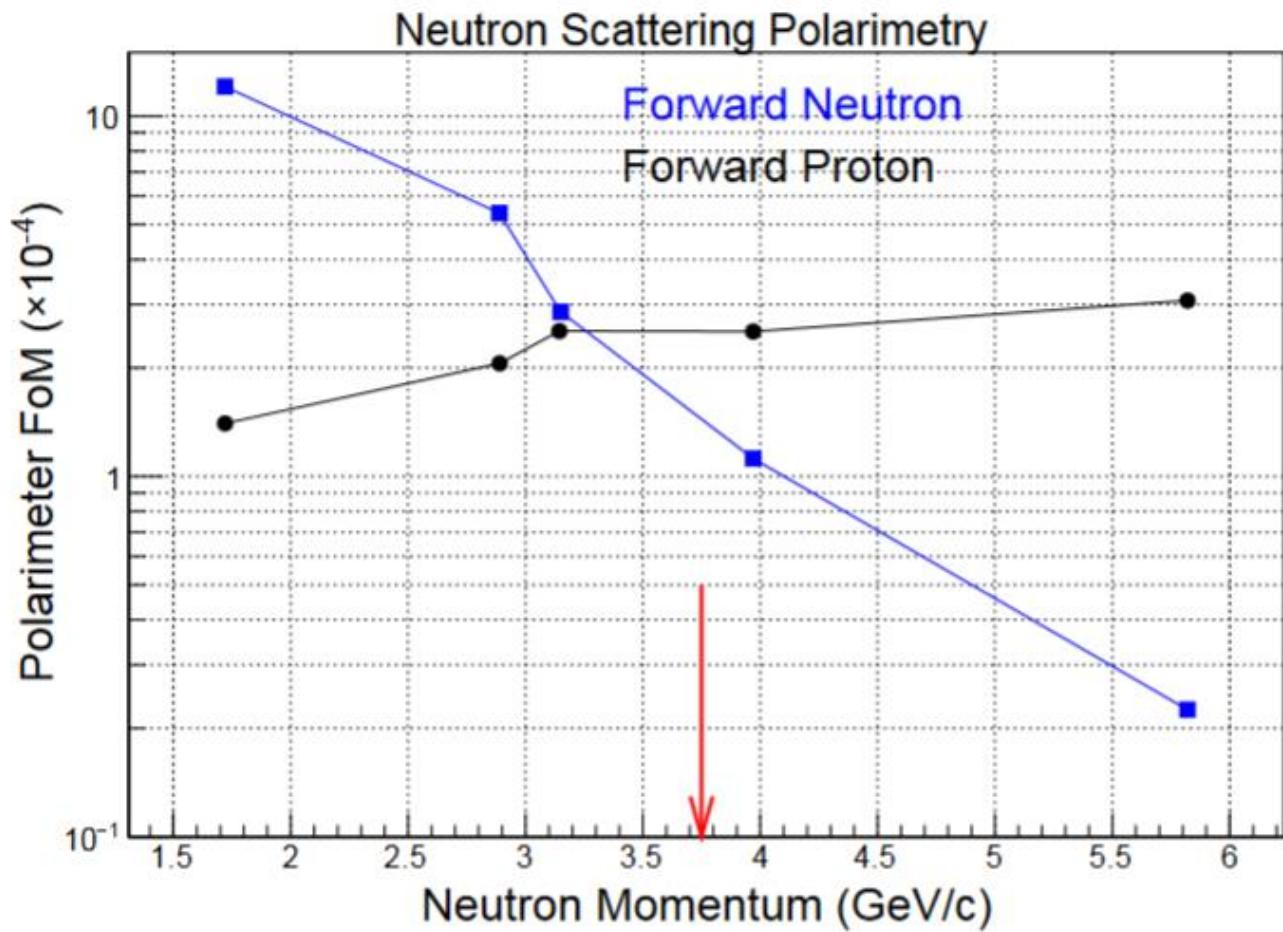
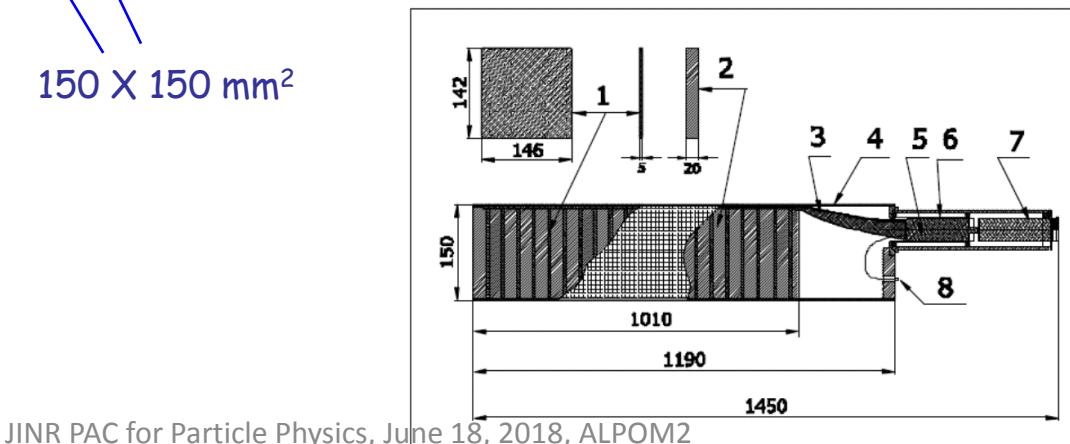
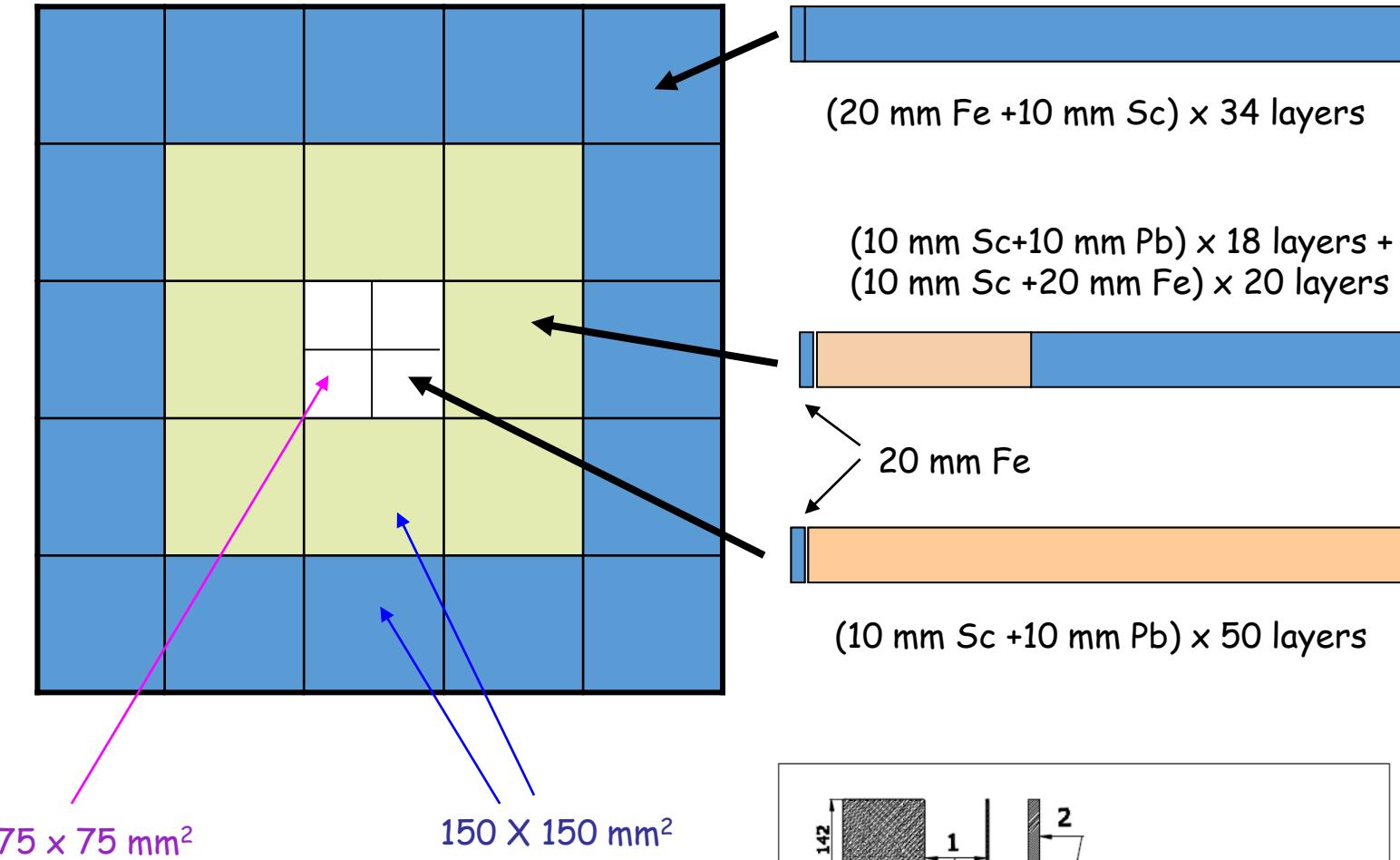
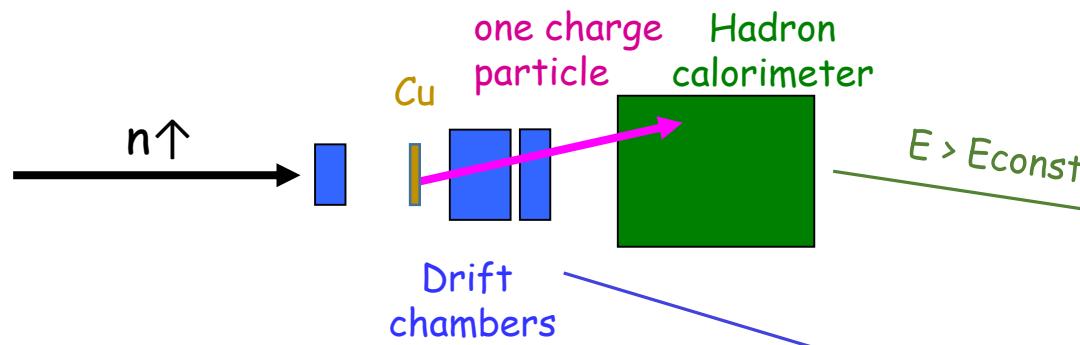


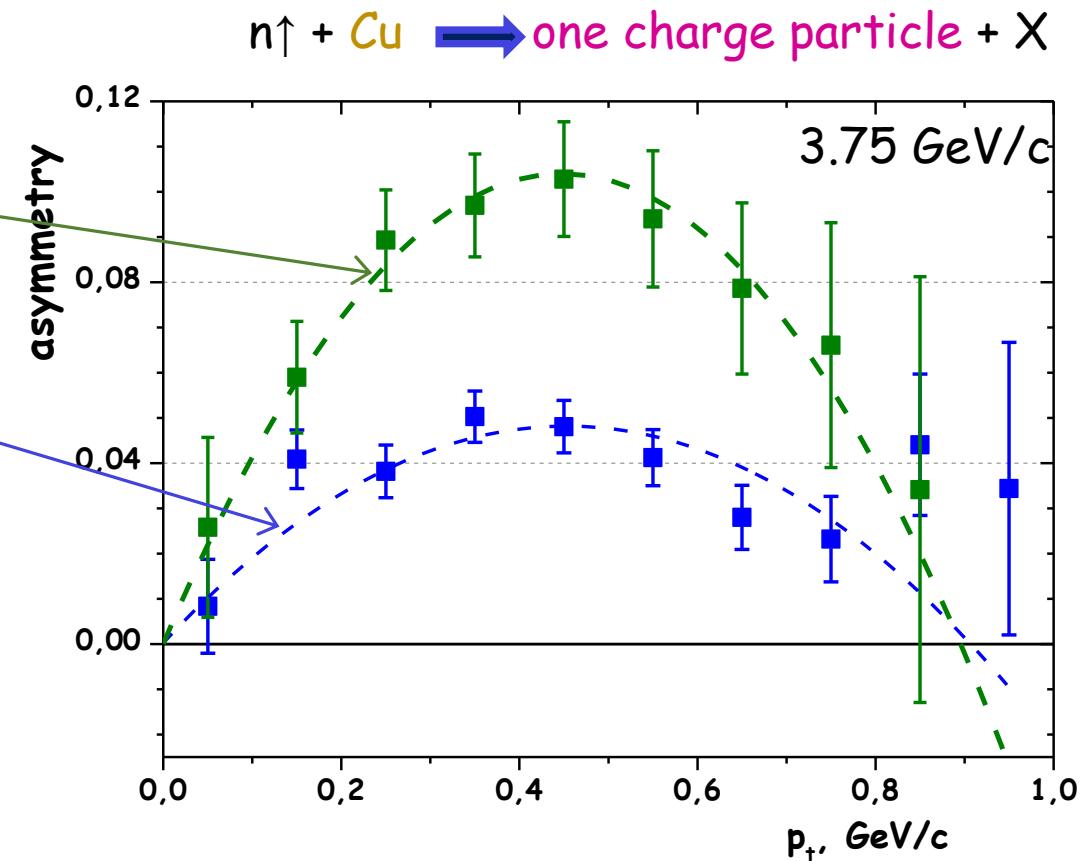
Figure 8: Neutron polarimeter figure of merit as a function of incident neutron momentum for two styles of polarimeter within the SBS apparatus using preliminary data from the recent Dubna measurement. Blue squares: standard $n - p$ scattering from CH scintillator, black circles: charge-exchange $n - p$ scattering from Cu. The red arrow marks the neutron momentum at which a charge-exchange measurement of the analyzing power of Cu was made at Dubna.

Hadron calorimeter





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- 2) The length of the copper target is only 4 cm in comparison with the CH one (> 30 cm) used in the elastic np scattering, which makes it possible to improve the accuracy of determining the interaction vertex and the scattering angle.
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The inverse reaction $p + \text{Cu}$ (W) with detection neutron in forward direction by the hadron calorimeter can be used for measurement of the proton polarization at the NICA collider.

target	Z/A	g/cm ³	L, cm	N _A /cm ³	GeV/c
CH2	0,57034	0,919	30 (40)	15.75	3,0; 3,75; 4,2
CH	0,53768	1.06	30	17.09	3,75
C	0,49955	1.68	20	16.8	3,75; 4,2
Cu	0,45636	8,96	4	16.36	3,75

