# np Charge Exchange Polarimetry in GeV Region

***Measurement of analyzing powers for the reaction***
***p + CH2 up to 7.5 GeV/c***
***and n + CH up to 4.5 GeV/c at the Nuclotron***
***(ALPOM2 proposal)***

N. Piskunov

# ALPOM2 Collaboration


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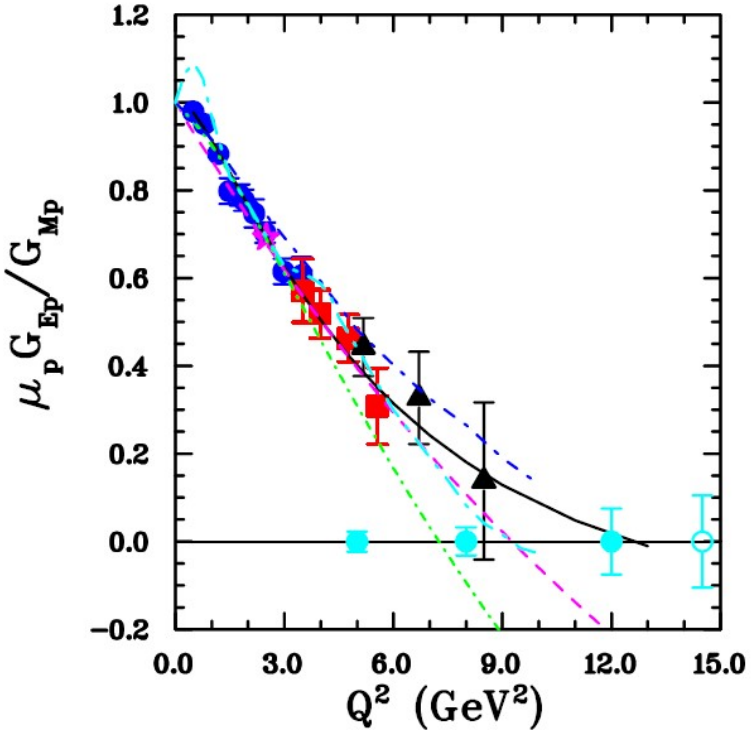
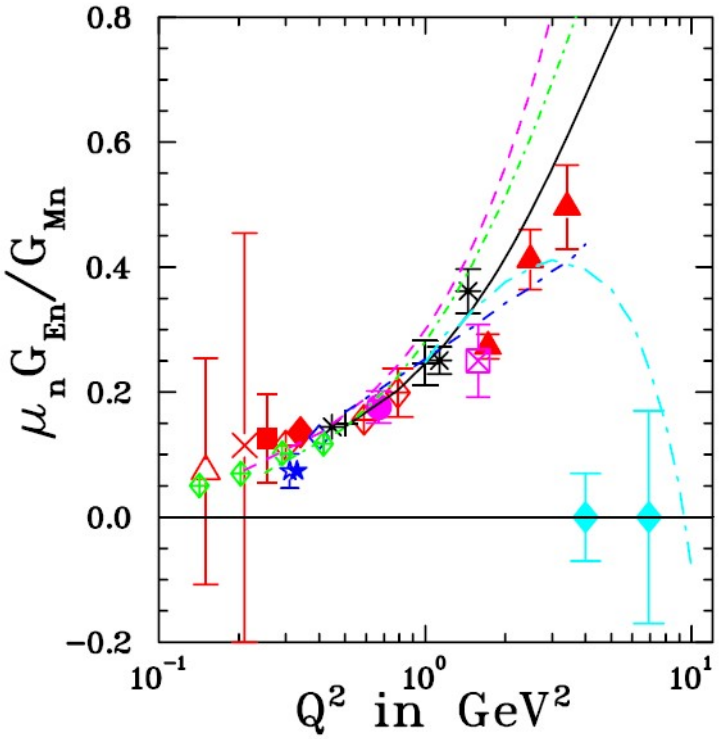
# Current Status and Projected Errors for $G_{Ep}/G_{Mp}$ and $G_{En}/G_{Mn}$

**Anticipated statistical uncertainties for approved experiments to measure $G_{Ep}/G_{Mp}$ and $G_{En}/G_{Mn}$ which will use the recoil polarization method, and CEBAF 12 GeV beam energy at JLab in near future.**

**The statistical uncertainty of the ratio depends directly on optimization of the coefficient of merit is $\eta A_y^2$. For both experiments knowledge of p and n analyzing power proposed here at Nuclotron (JINR) is of great importance.**

**The importance of future experiments which will establish whether either ratio does, or does not cross zero near $Q^2$=10 GeV$^2$.**

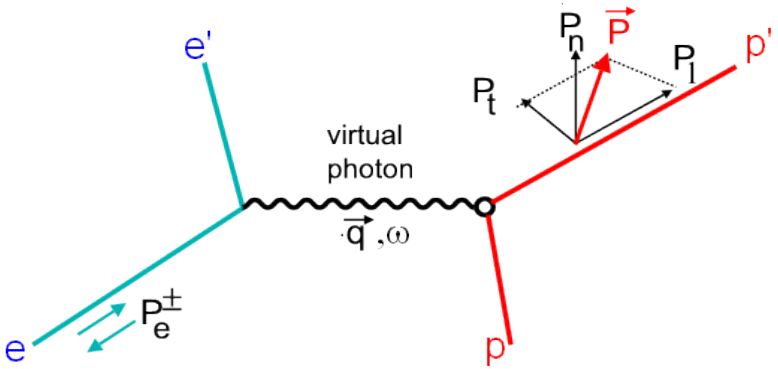


# Double Polarization Method in Elastic $\vec{e}N$ Scattering

**Polarization transfer in $\vec{e}N \rightarrow e\vec{N}$ or spin-target asymmetry $\vec{e}\vec{N} \rightarrow eN$, (N=p or n), two different techniques, which give same information.**

**For recoil polarization, the two polarization components are in the reaction plane, no normal component:**




$$hP_eP_t = -hP_e 2\sqrt{\tau(1+\tau)}G_{Ep}G_{Mp}\tan(\frac{\theta_e}{2})/I_0$$

$$hP_eP_\ell = hP_e\frac{(E_e+E_{e'})}{M}G_{Mp}^2\sqrt{\tau(1+\tau)}\tan^2(\frac{\theta_e}{2})/I_0$$

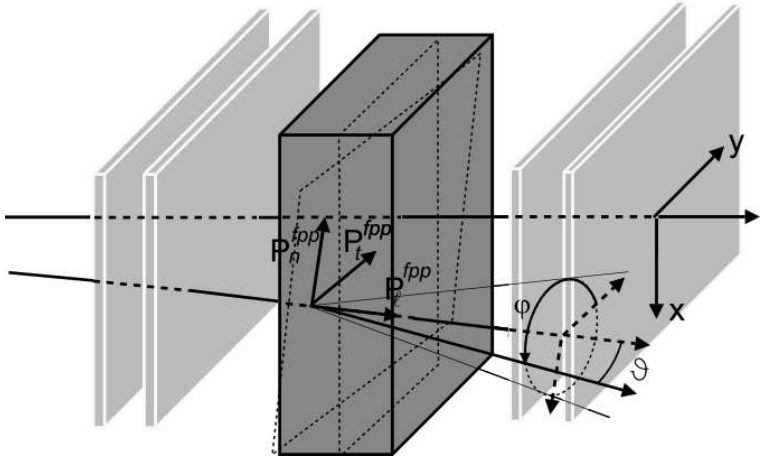
$$\frac{G_{Ep}}{G_{Mp}} = -\frac{P_t}{P_\ell}\frac{(E_e+E_{e'})}{2M}\tan\left(\frac{\theta_e}{2}\right) \quad \text{and} \quad I_o = G_E^2 + \frac{\tau}{\varepsilon}G_M^2$$

**Superior method: " much smaller systematics"**

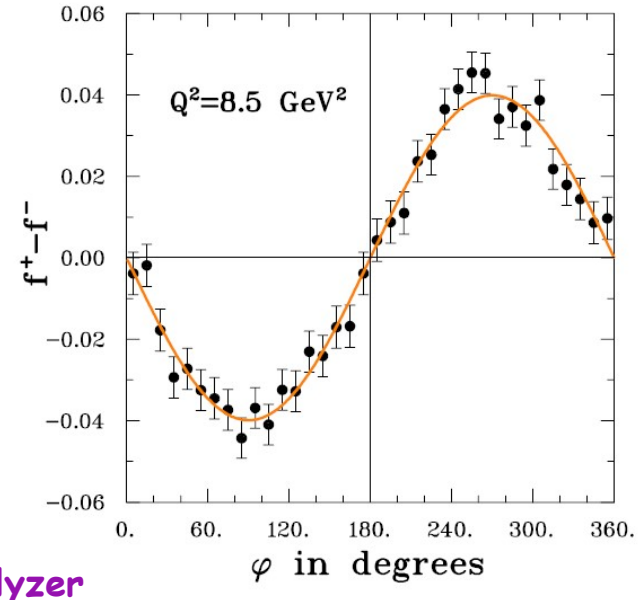
**Form Factor ratio is independent of the electron polarization $P_e$ and of the polarimeter analyzing power $A_y$ (h is beam helicity ±1).**

**Statistical uncertainty depends directly on both $P_e$ and $A_y$.**

# Focal Plane Polarimeter




Front Trackers  $CH_2$ Analyzer  Rear Trackers




Azimuthal distribution of protons after scattering in the analyzer

$$f^{\pm}(\theta,\varphi)=\frac{\varepsilon(\theta,\varphi)}{2\pi}\left(1 \pm \bar{A}_y(\theta)P_t^{fpp}\cos\varphi \mp \bar{A}_y(\theta)P_n^{fpp}\sin\varphi\right)$$

$P_t^{fpp}$ and $P_n^{fpp}$ are the polarization components at the FPP

Physical Asymmetries are obtained from difference distributions

$$D_i=\frac{\left(f_i^{+}-f_i^{-}\right)}{2}=\frac{\varepsilon(\theta,\varphi)}{2\pi}\left[\bar{A}_y P_t^{fpp}\cos\varphi-\bar{A}_y P_n^{fpp}\sin\varphi\right]$$

Sum distribution gives instrumental asymmetries

$$E_i=\frac{(f_i^{+}+f_i^{-})}{2}=\frac{\varepsilon(\theta,\varphi)}{2\pi}$$

The properties of the polarimeter are analyzing power $A_y$, and probability of elastic (or quasi-elastic scattering), $\eta$. The coefficient of merit is $\eta A_y^2$.

The statistical uncertainty on the form factors is $\frac{1}{\sqrt{N\eta A_y^2}}$ where N is number of events.

# The Neutron Electric Form Factor at $Q^2$ up to 7 $(\mathrm{GeV/c})^2$ from the Reaction $^2H(\vec{e}, e'\vec{n})^1H$ via Recoil Polarimetry

*E12-11-009*

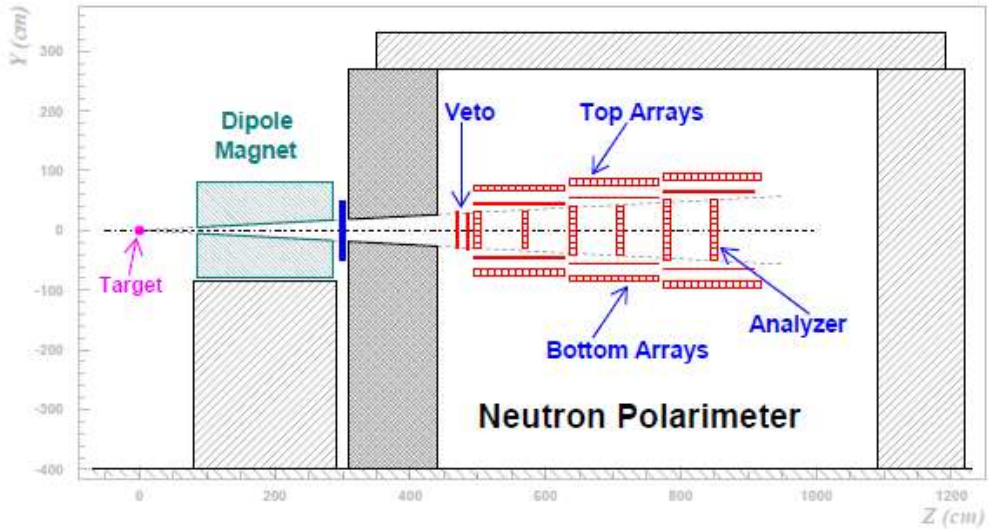
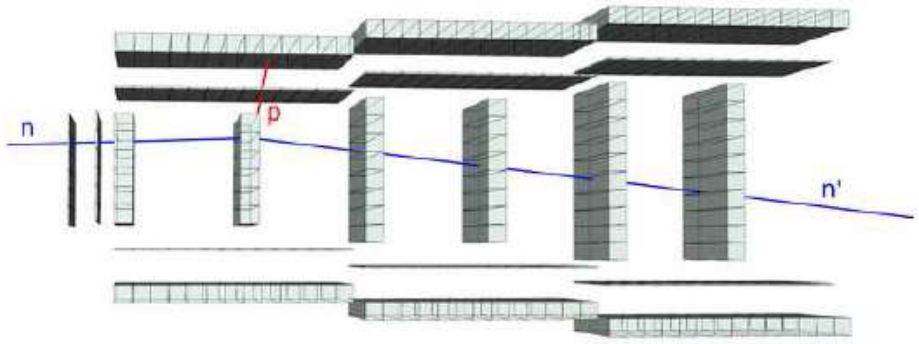



Figure 14: Neutron polarimeter to be used in the measurements.

CH – material

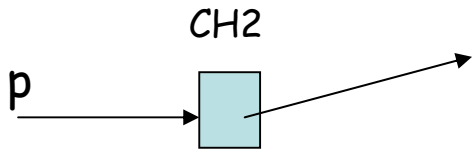
Low neutron detection efficiency



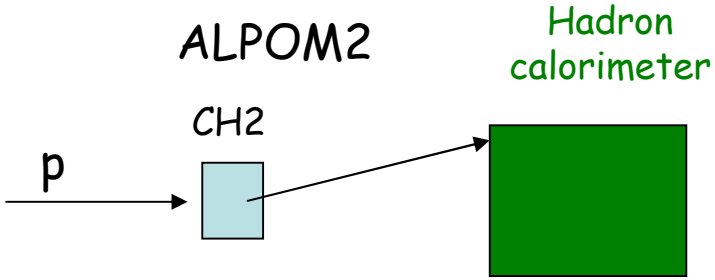

| Neutron Momentum, $P_n$ (GeV/c) | 2.901 | 3.602 | 4.511 |
|---|---|---|---|

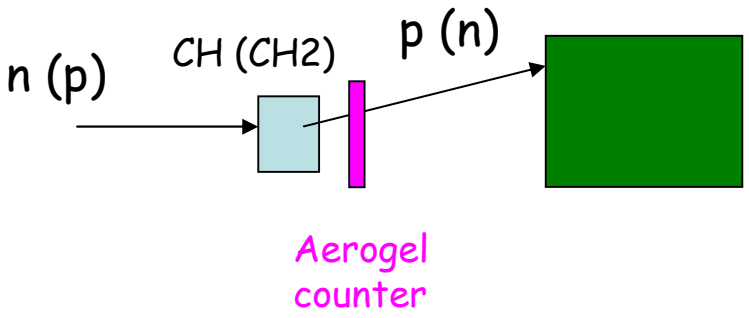
ALPOM

2001




ALPOM2




$$F^2 = \int_\theta \varepsilon(\theta) A_y^2(\theta) d\theta$$

$$\Delta P_y = \sqrt{\frac{2}{N_{inc} F^2}}$$

Proton polarimetry

p + C(CH2) -> charged particle + X

Neutron polarimetry

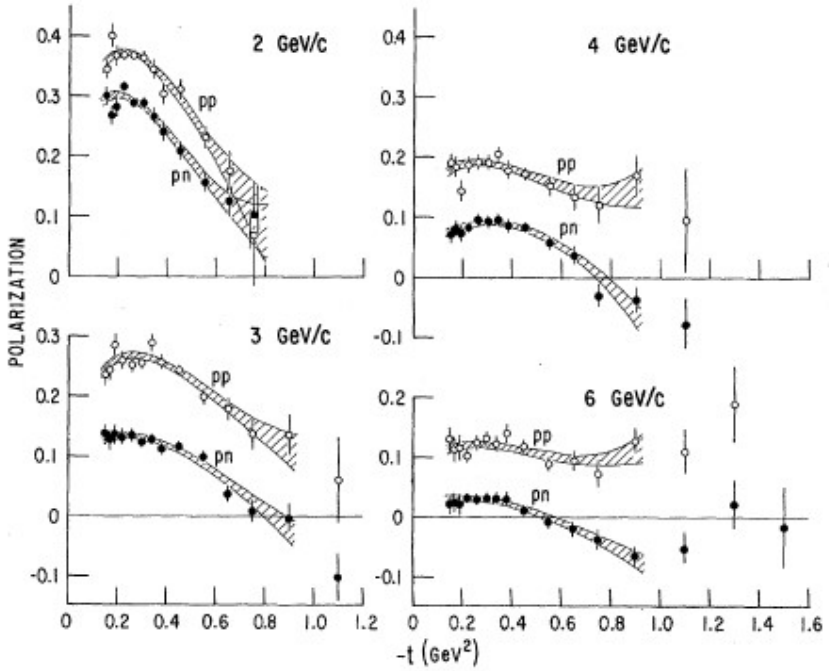
n + p -> n + p , CH - target

New suggestion: n + p -> p + n

Charge exchange reaction

Phys. Rev. Lett 35 (1975) 632

pp -> pp
pd -> pn + (p)

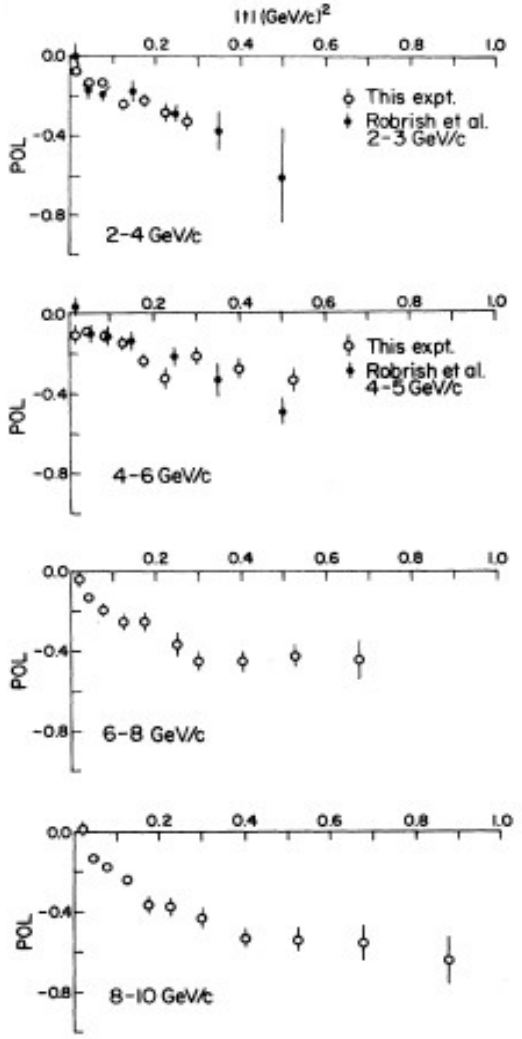



$A_y$ decreasing with energy

Phys. Rev. Lett 30 (1973) 1183

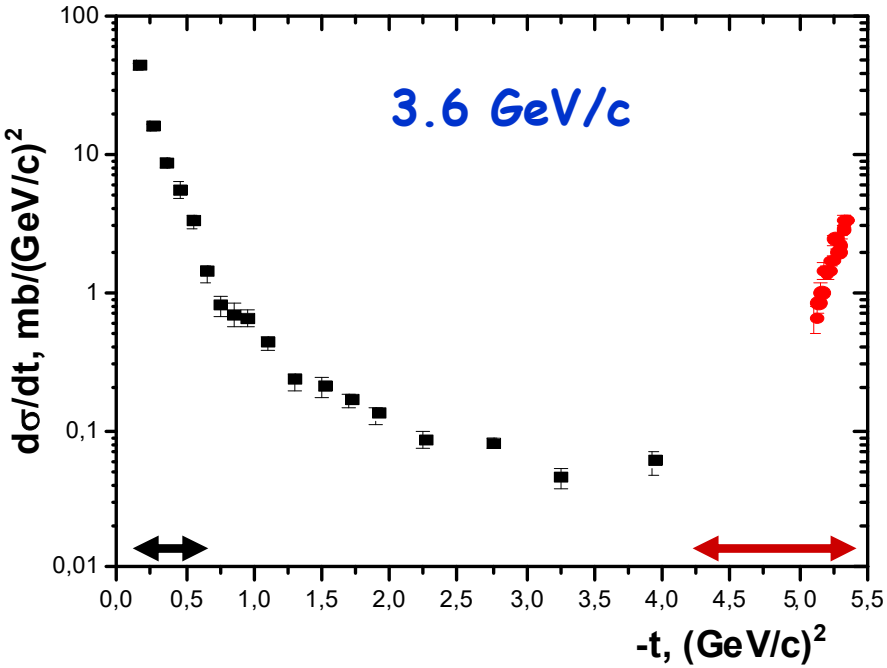
np -> pn

$A_y$ increasing with energy



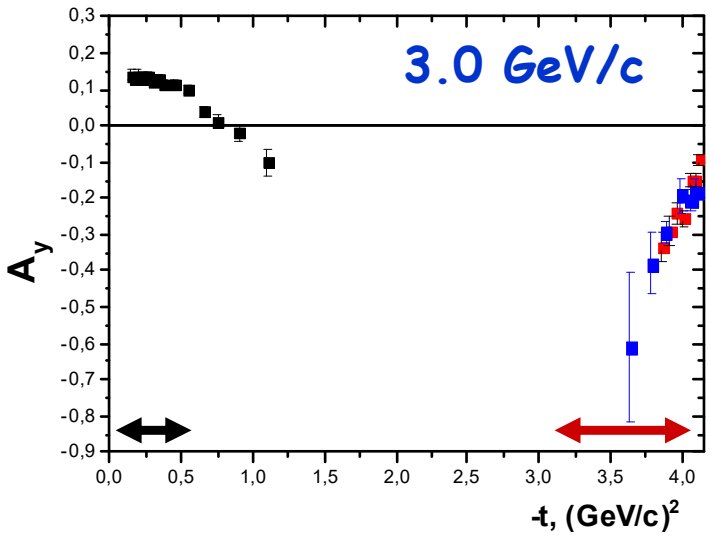

The existing data for $A_y$ in np elastic scattering indicate that the analyzing power decreases faster than the pp analyzing power, becoming very small, then negative around 6 GeV/c neutron momentum.

np -> np  np -> pn




Liquid H2 or D2 target

$d\sigma/dt_{el} > d\sigma/dt_{ce}$




$|A_y^{el}| < |A_y^{ce}|$

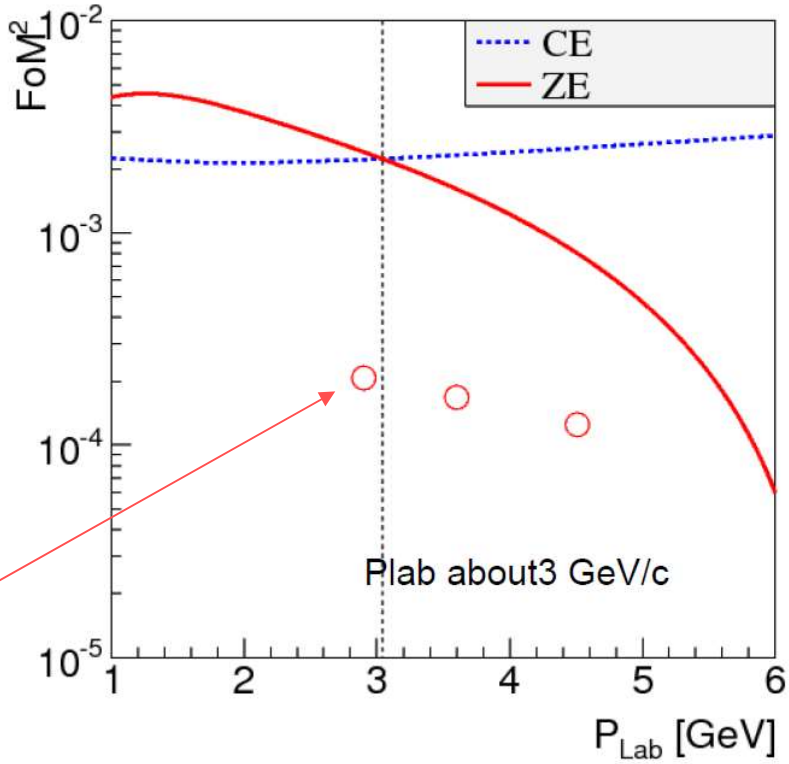
$FOM^{el} < FOM^{ce}$
and increasing with energy

From WangYing talk at ISHEPP23

(for proton as a target)

# Figure of merit

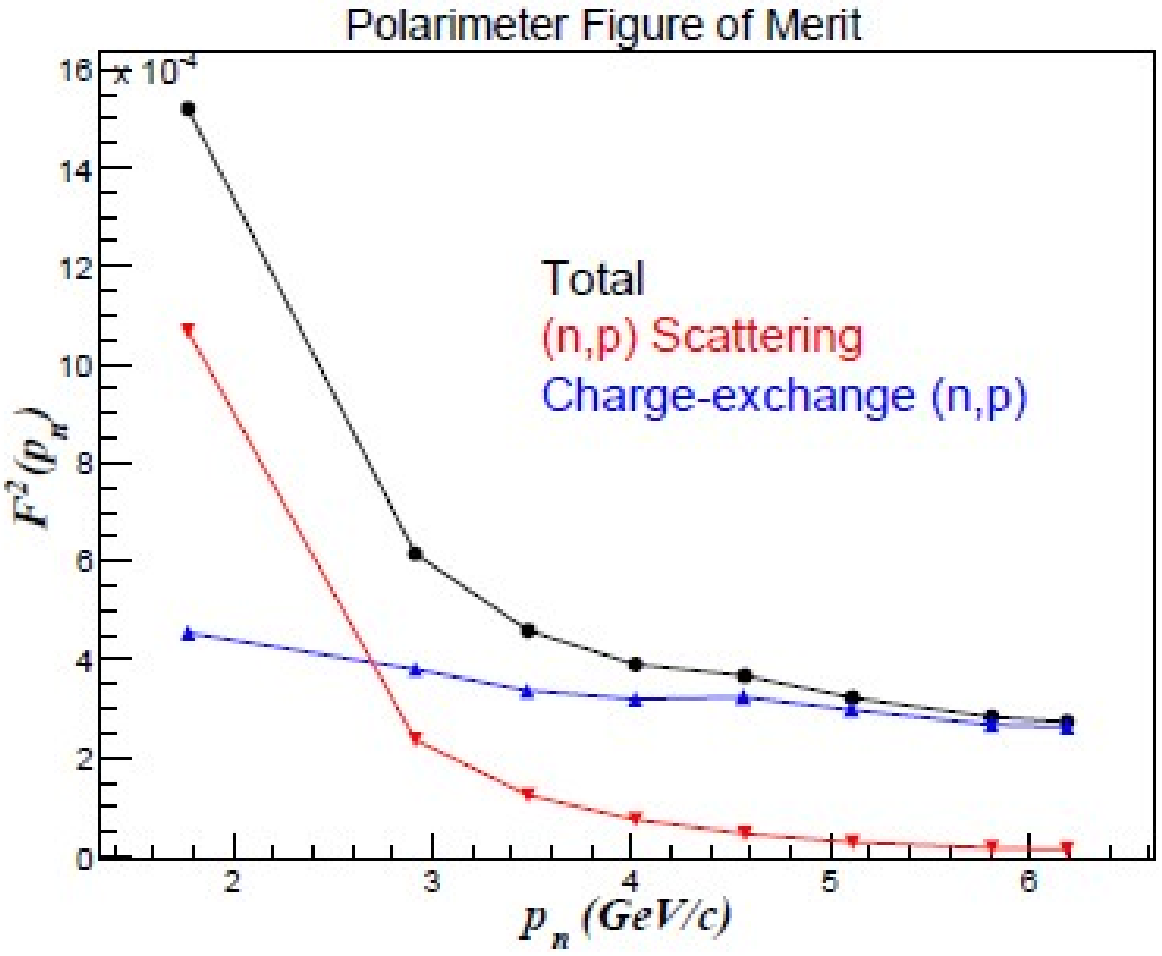
From 1 to 3 GeV/c, ZE has larger Figure of merit due to its larger total cross section. After 3, as cross section becomes really small, figure of merit is dominated by analyzing power, then CE becomes bigger.




*E12-11-009*
*CH - target*

Changing CH to CH2 increases difference FOM twice

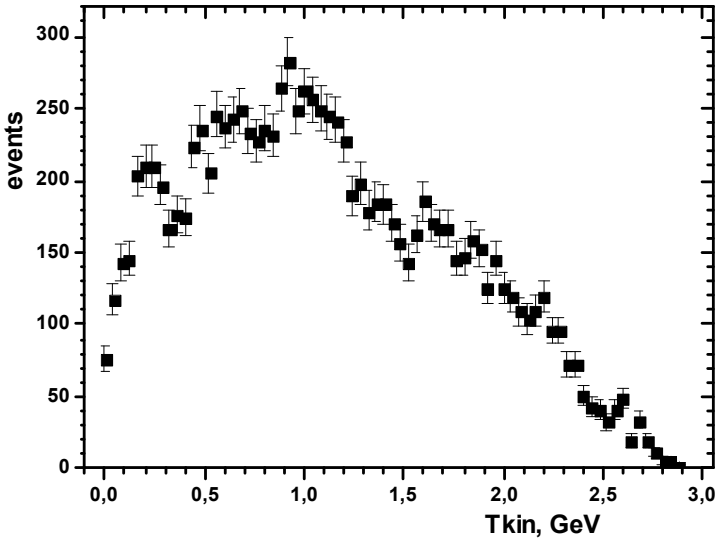

Yu.A. Troyan, M.Kh. Anikina, A.V. Belyaev, A.P. Ierusalimov, and A.Yu. Troyan. Elastic np  np(pn) scattering at intermediate energies. *Physics of Particles and Nuclei Letters*, 11(2):101–108, 2014.



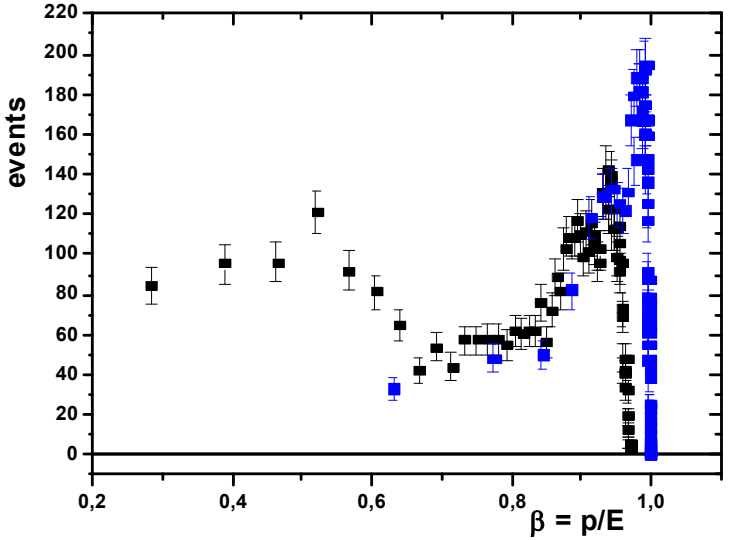

J.R.M. Annand's calculations for CH target

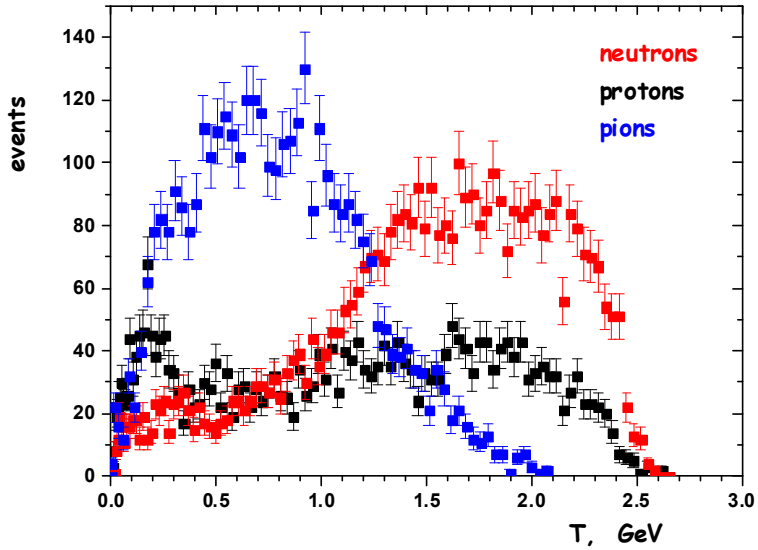
Figure 6: Neutron polarimeter figure of merit as a function of incident neutron momentum. Red: standard $n-p$ scattering, blue: charge-exchange $n-p$ scattering, black: sum of the two scattering channels.

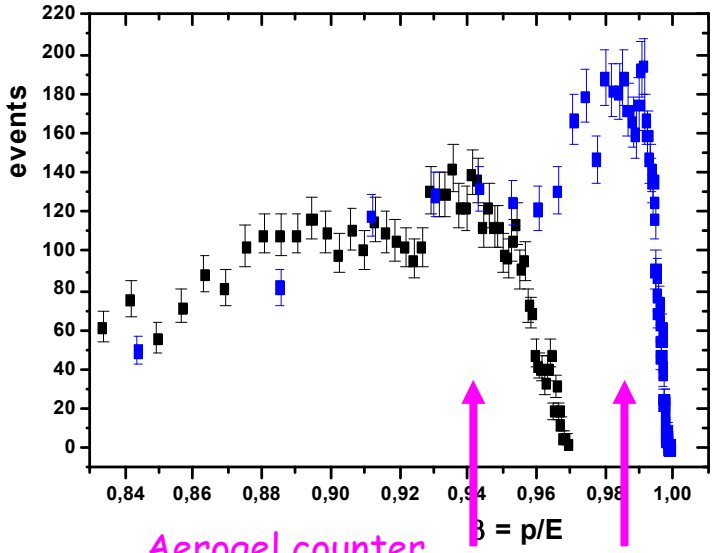
# HBC, 3.83 GeV/c protons & pions




5933 protons
5252 pions




Suppression of pions emitted from the target by aerogel counter

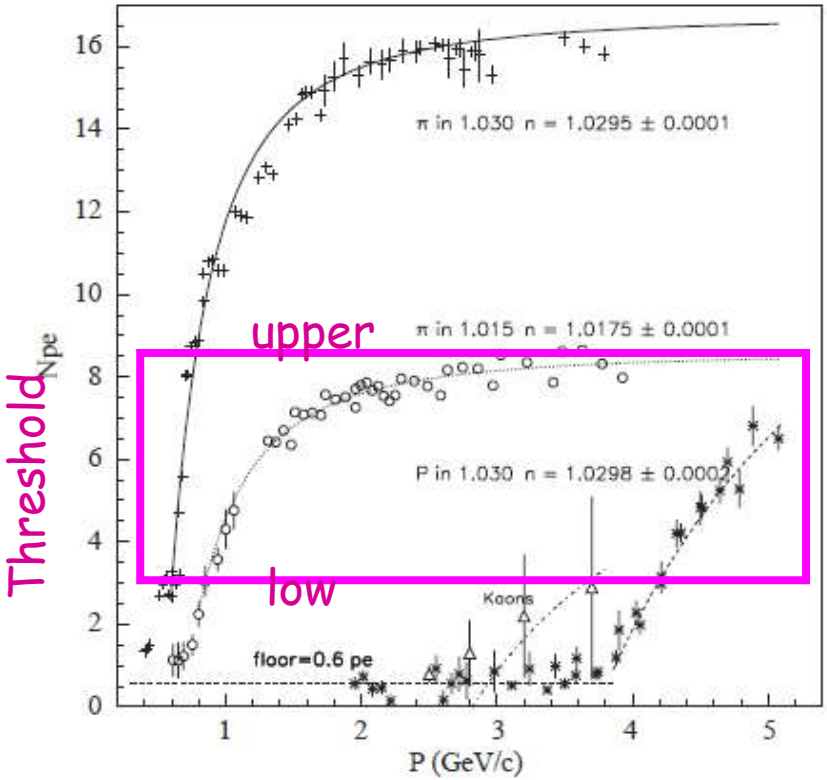



Fig. 7. The momentum dependence of $N_{pe}$ for both types of aerogel material used and for different particles. Both the experimental data and fits to them are shown (compare to Fig. 1).

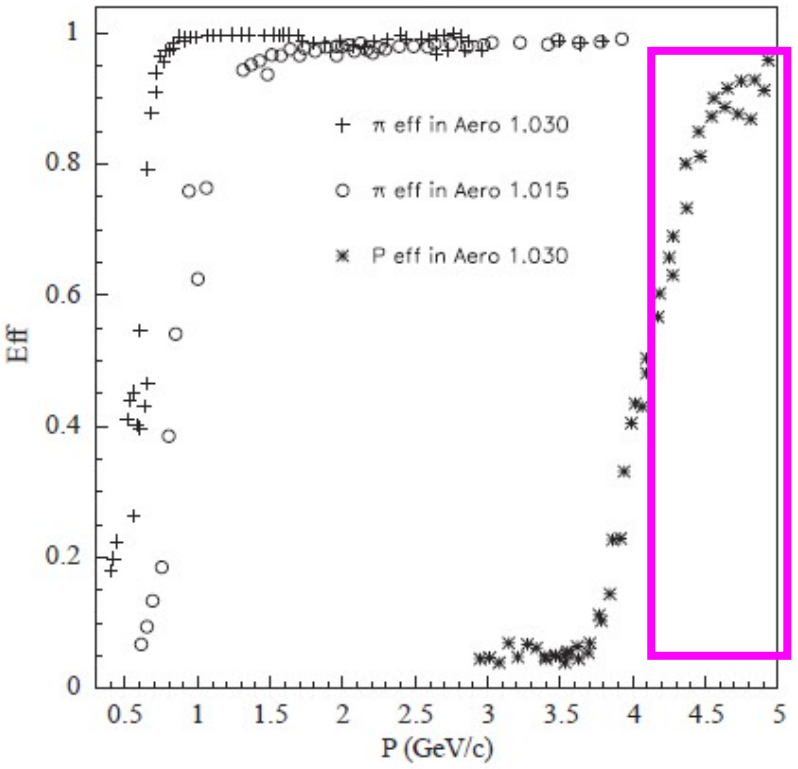
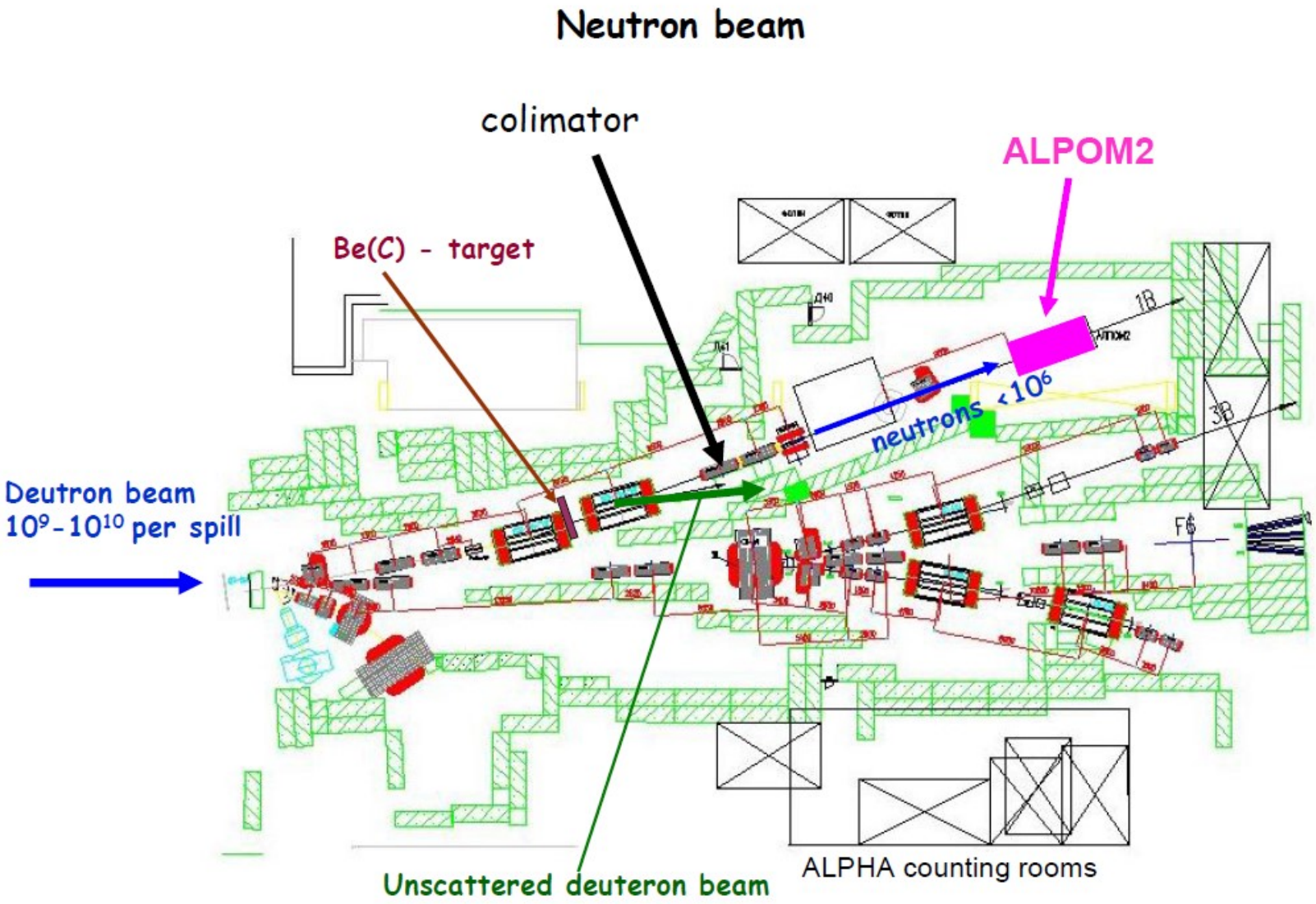



Fig. 8. Particle detection efficiency versus momentum $P$ for the detector with aerogels $n = 1.030$ and $n = 1.015$.

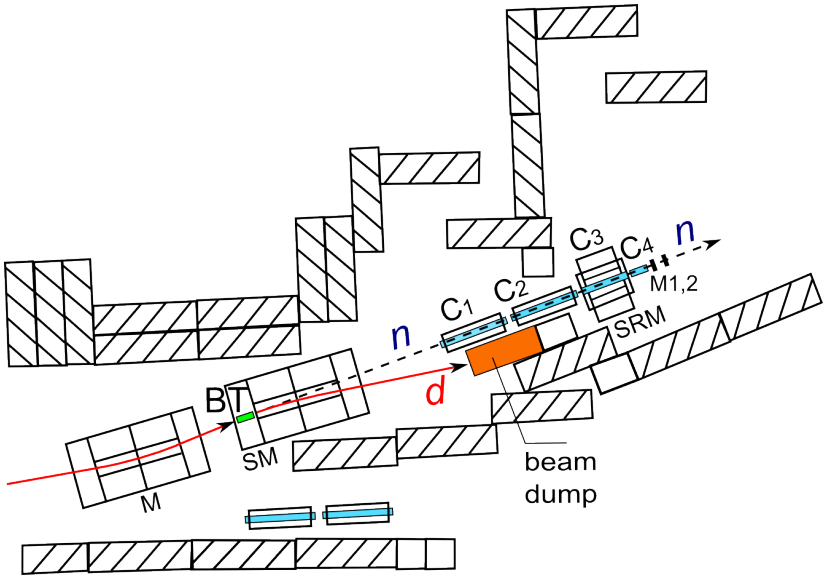
If we use this counter in the differential mode we can detect only protons in our sensitive region

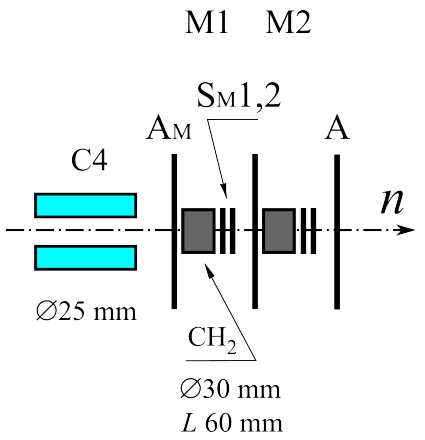
# Schematic of Neutron Beam Extraction and Transport



## neutron monitors

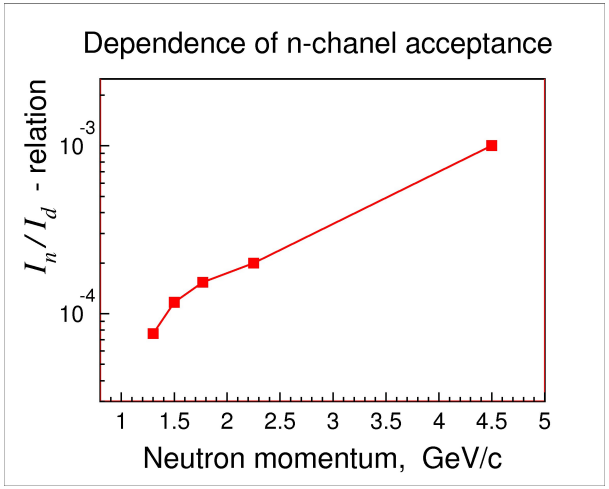
Scheme of both extracted deuteron and free neutron beam lines.
The beryllium target BT for the neutron production,
the collimators C1 – C4, the monitors M1, M2 for estimation of
beam intensity, the SM – magnet for vanishing of the charged deuterons.



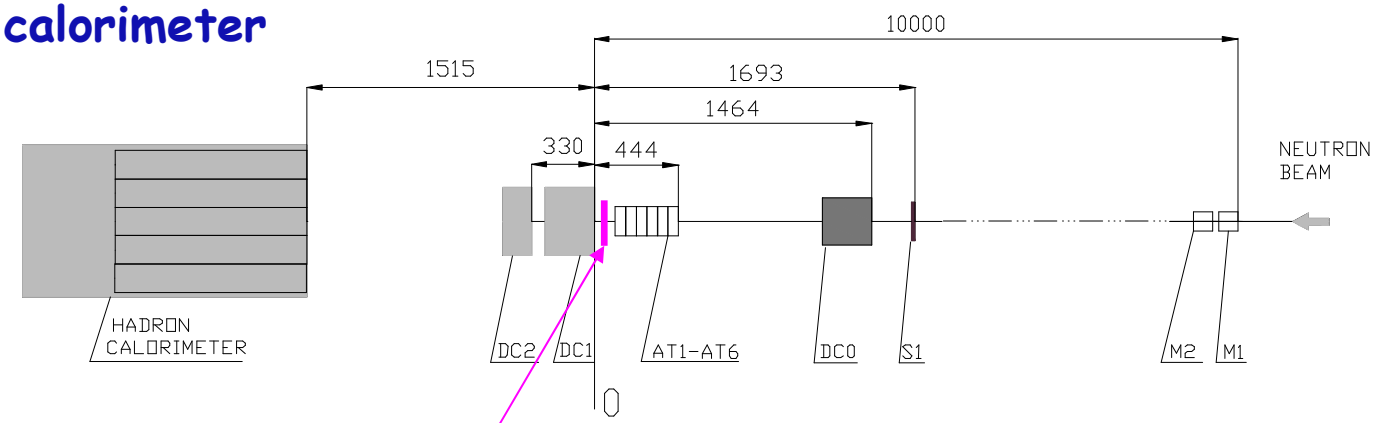

Neutrons have a laboratory momentum $P_n = P_d / 2$
with a gaussian momentum spread of $\sigma P/P \sim 3 \div 4$ %

The distance from the BT to the collimator exit is about 12 m
and thus determining the solid angle equal ~ 5 msr.



## Drift chambers

Hadron calorimeter

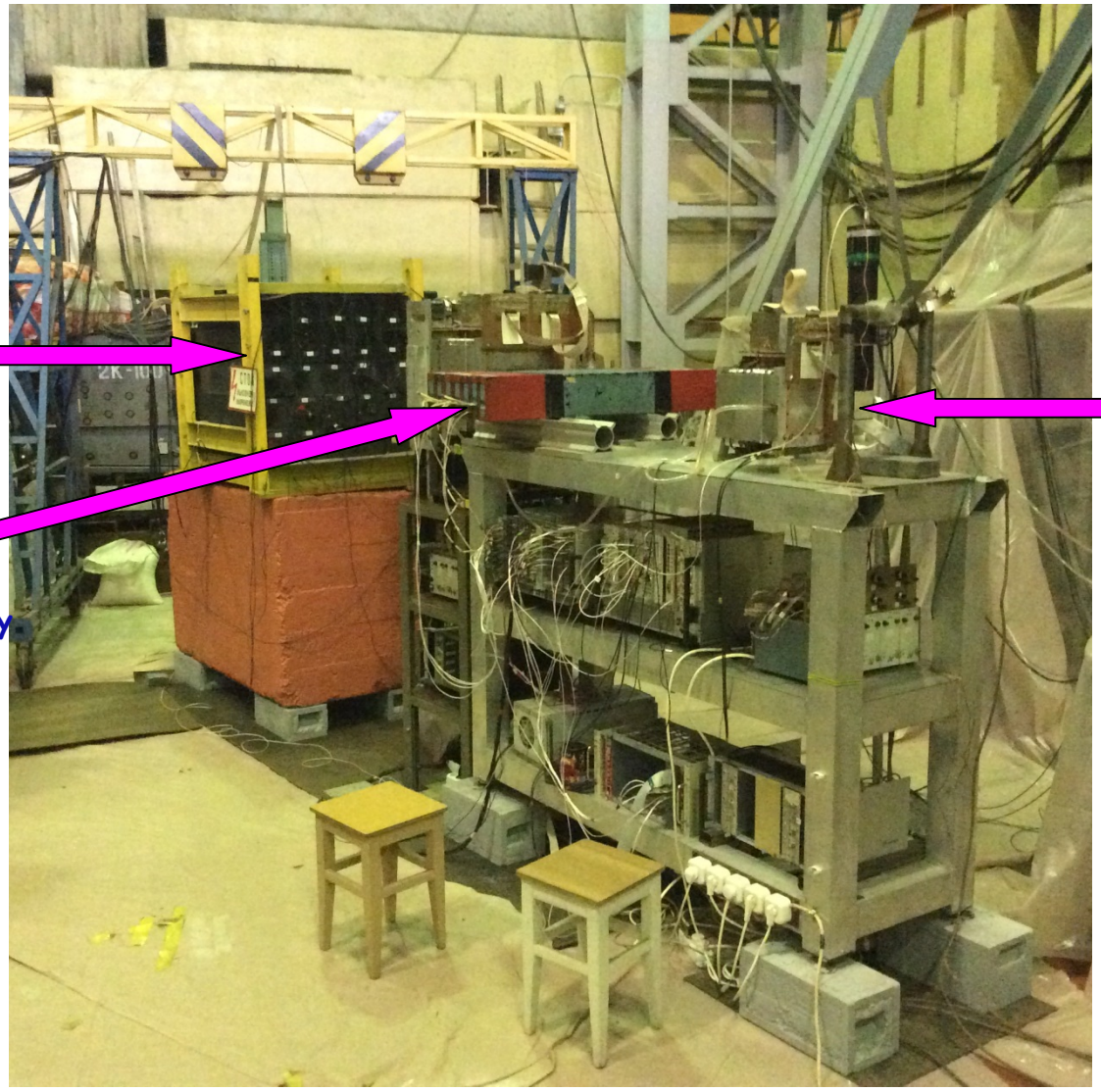


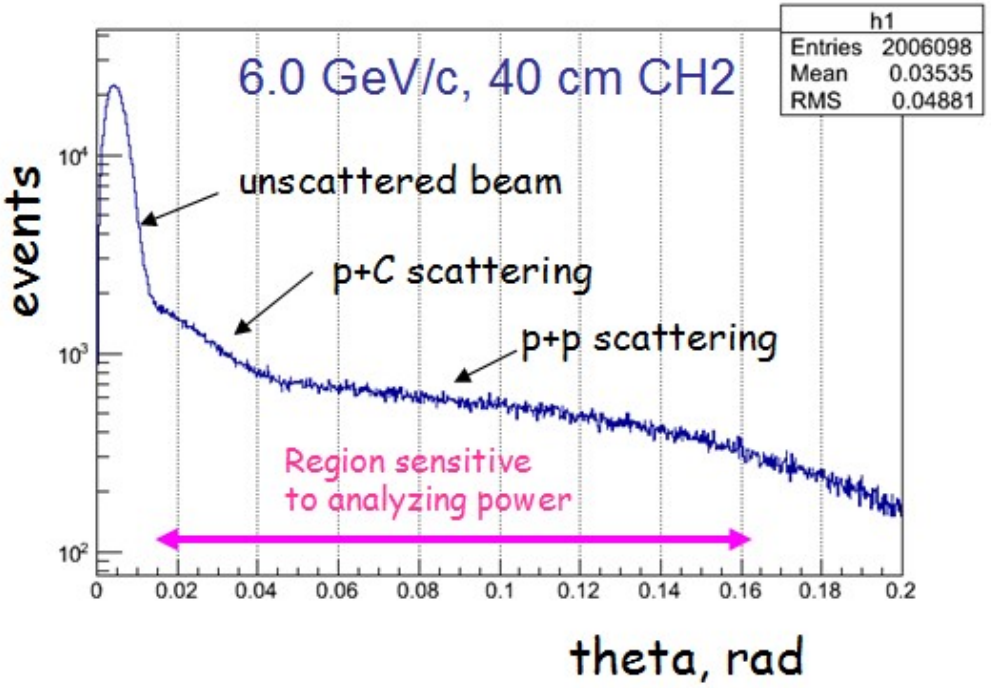

Neutron beam

Aerogel counter

Active target For neutron $A_y$ measurement

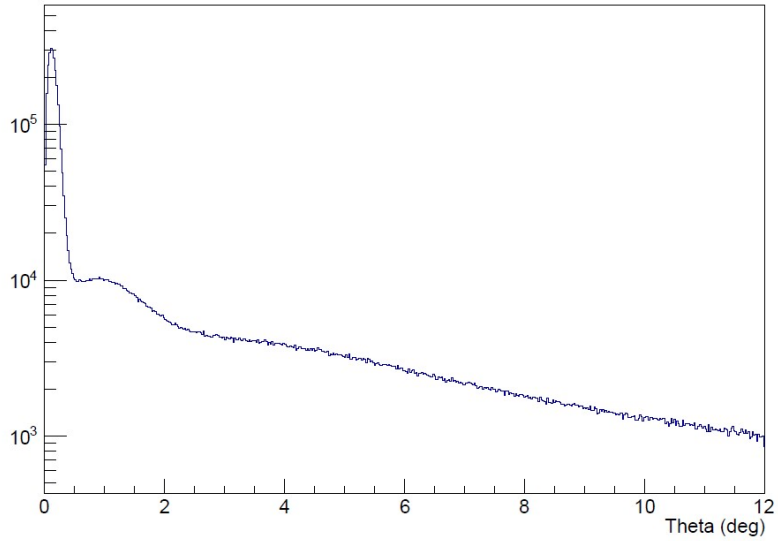
# Picture of the ALPOM2 Setup



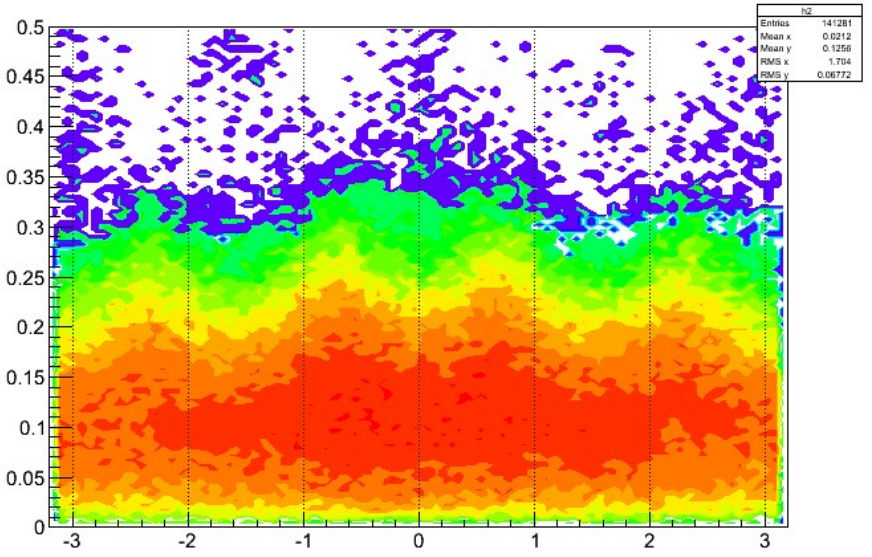



## MC simulation result

protons at cal (p beam 6GeV/c)

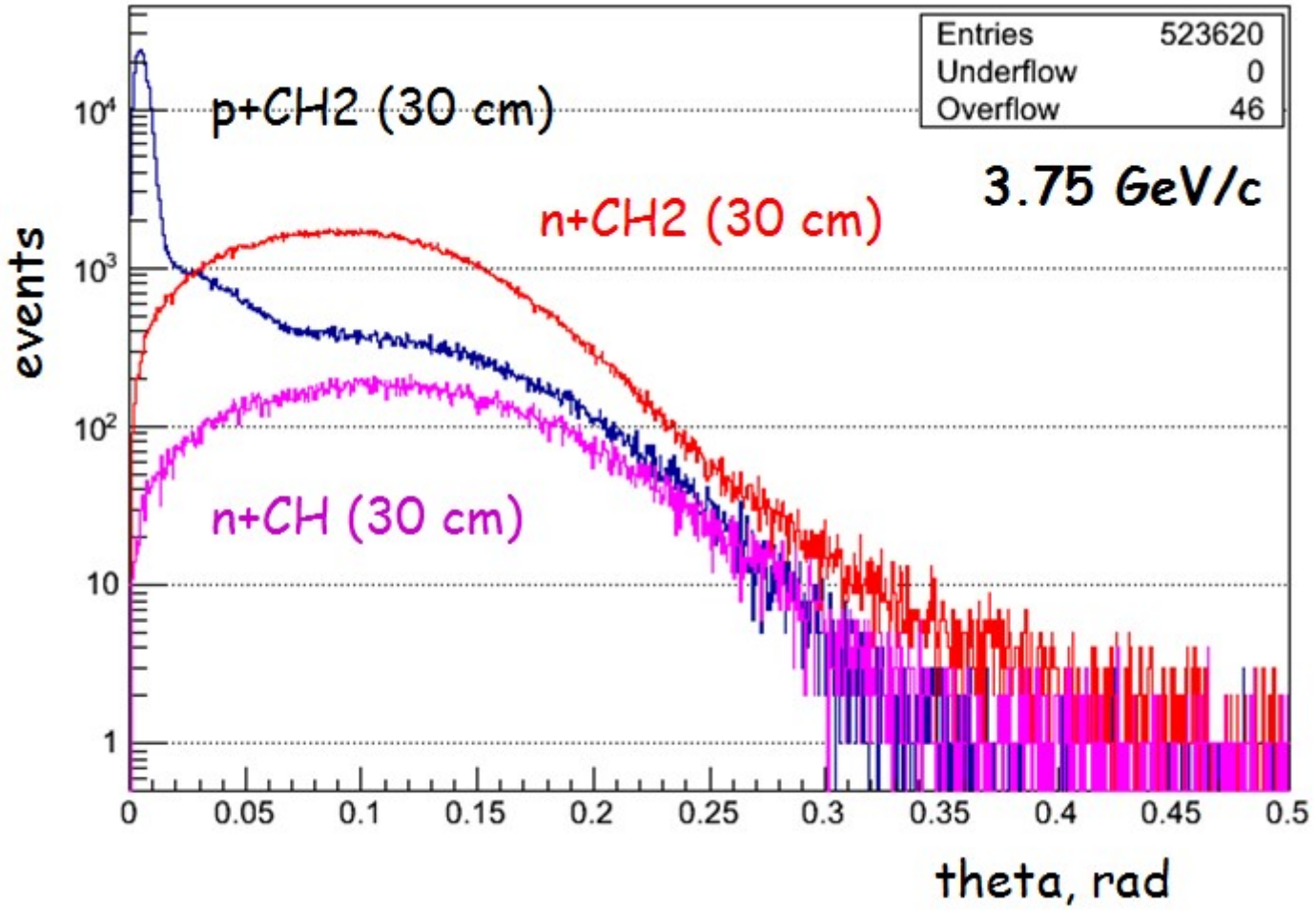



The angular distribution of charged particles after the target.



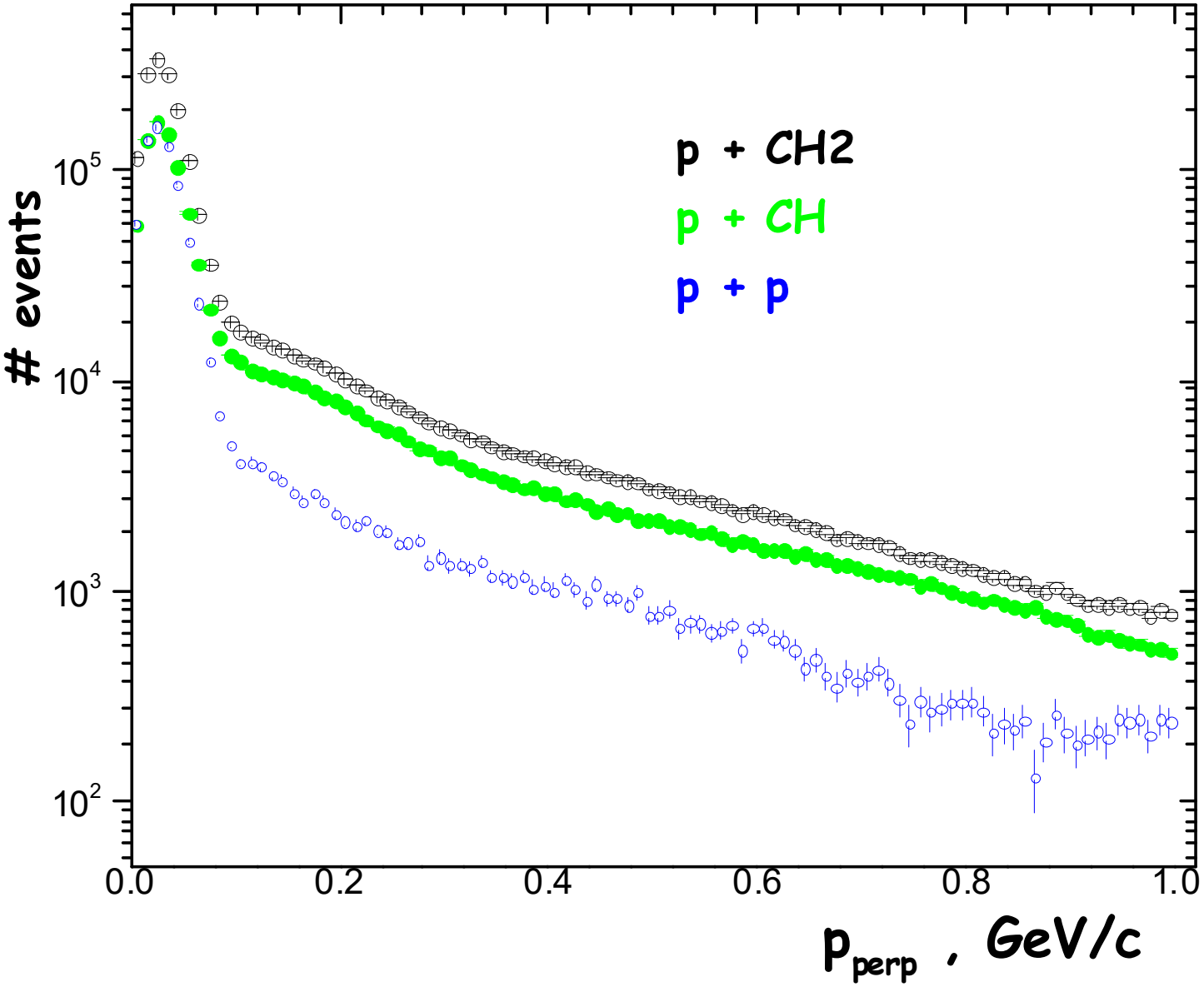
Theta-phi correlation plot.

**The angular distributions of neutrons and protons with the momentum of 3.75 GeV/c for CH and $CH_2$ targets, compared with the distribution for incident protons.**



3.75 GeV/c June 2016

About $10^6$ tracks



# Conclusion

Charge-exchange np reaction is preferable over np elastic scattering in GeV region

A new polarized source is under tuning now

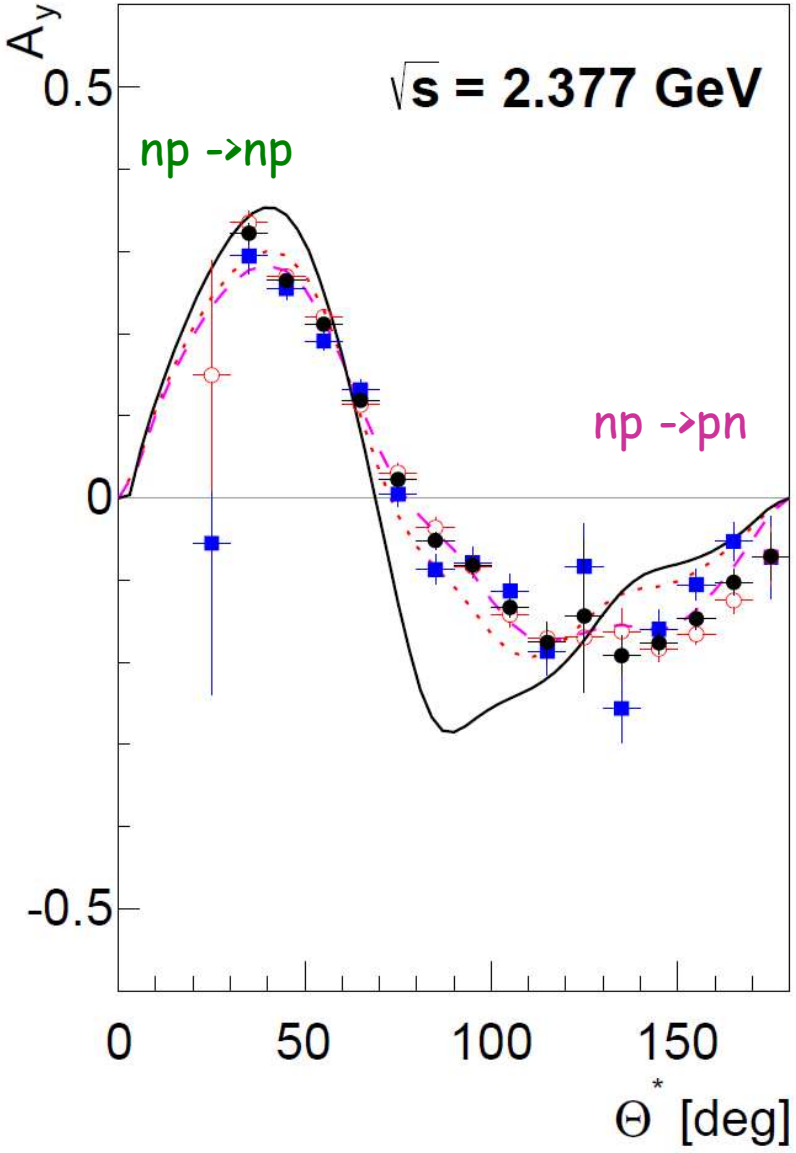
The setup has been tested

We hope that the measurements be done in 2016

Thank you for your attention

# 1.1 GeV

arXiv:1408.4928v1 [nucl-ex] 21 Aug 2014




np ->np

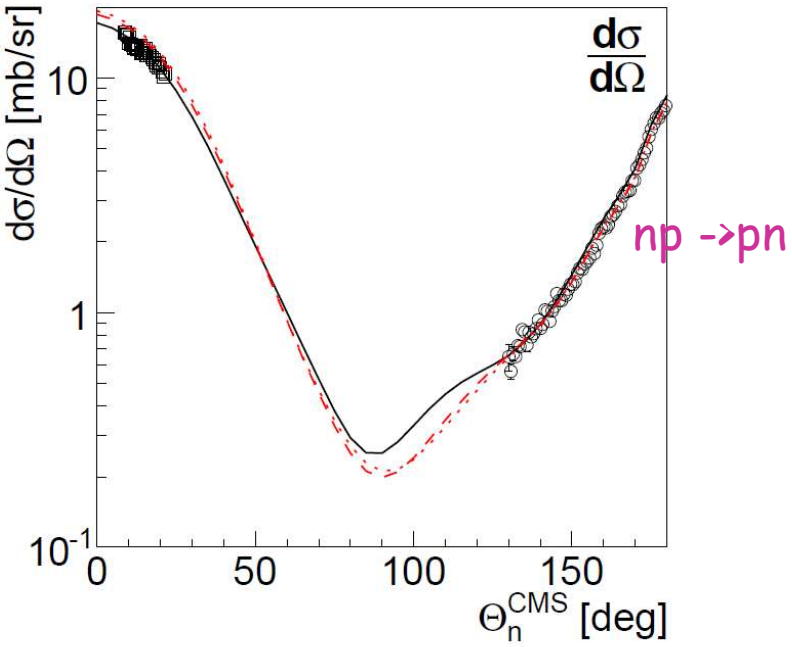
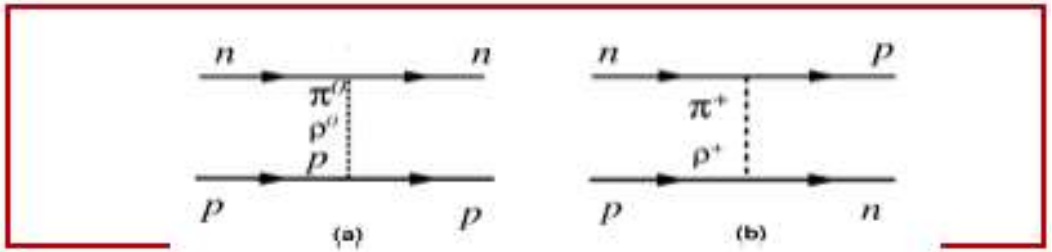



FIG. 11: (Color online) Angular distribution of the differential cross section $d\sigma/d\Omega$ at $T_n = 1.135$ GeV corresponding to the resonance energy $\sqrt{s} = 2.38$ GeV. For the meaning of the curves see caption of Fig. 4. The plotted data are from Ref. [41] ($T_n = 1.135$ GeV) and Ref. [42] ($T_n = 1.118$ GeV).

# Pole model for reactions np → np (pn)

## Neutron




- Differential cross section

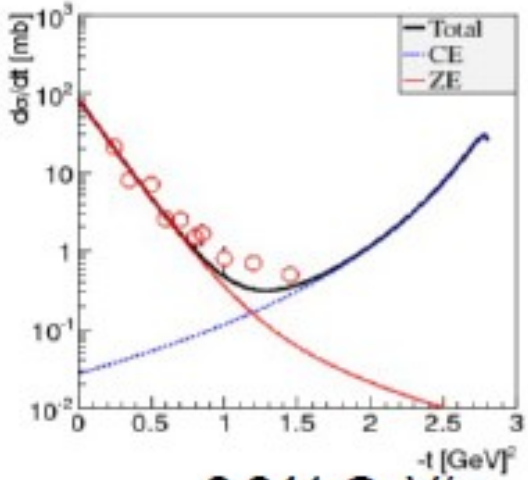
$$\frac{d\sigma}{dt} = \frac{1}{64\pi s q^2}\left(|T_\pi(u) + T_\rho(u)|^2 + \frac{1}{4}|T_\pi(t) + T_\rho(t)|^2 + |T_P(t)|^2\right)$$

$$|T_{CE}(u)|^2 = \left(F_u \frac{uA_\pi}{u-m_\pi^2} F_u\right)^2 + \left|F_u \frac{uA_\rho e^{i\varphi}}{u-m_\rho^2} F_u\right|^2 + 2\left(F_u \frac{uA_\pi}{u-m_\pi^2} F_u\right)\left(F_u \frac{uA_\rho e^{-i\varphi}}{u-m_\rho^2} F_u\right)$$

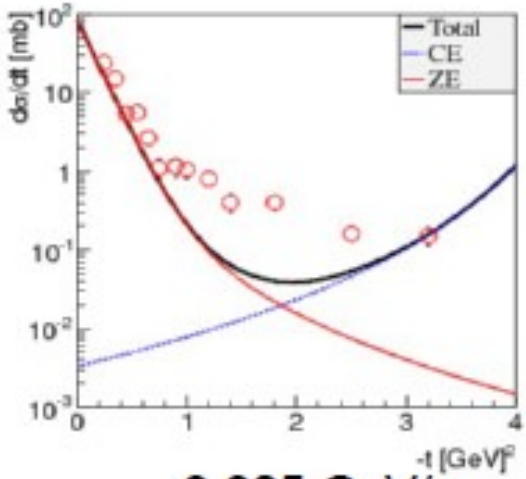
$$|T_{ZE}(t)|^2 = \frac{1}{4}\left[\left(F_t \frac{tA_\pi}{t-m_\pi^2} F_t\right)^2 + \left|F_t \frac{tA_\rho e^{i\varphi}}{t-m_\rho^2} F_t\right|^2 + 2\left(F_t \frac{tA_\pi}{t-m_\pi^2} F_t\right)\left(F_t \frac{tA_\rho e^{-i\varphi}}{t-m_\rho^2} F_t\right)\right] + (A_P e^{-b|t|})^2$$

Yu.A. Troyan, M.Kh. Anikina, A.V. Belyaev, A.P. Ierusalimov, and A.Yu. Troyan. Elastic np  np(pn) scattering at intermediate energies. *Physics of Particles and Nuclei Letters*, 11(2):101–108, 2014.

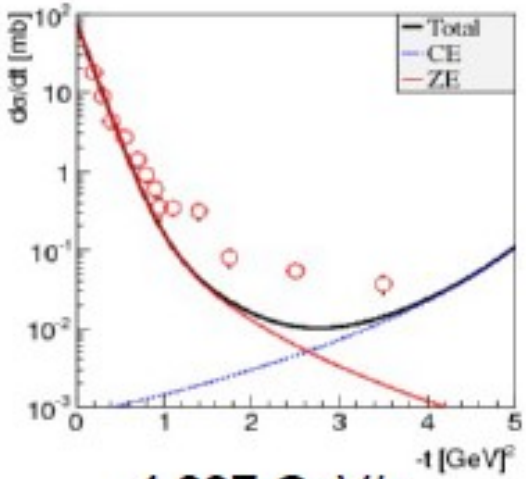
# Differential cross section



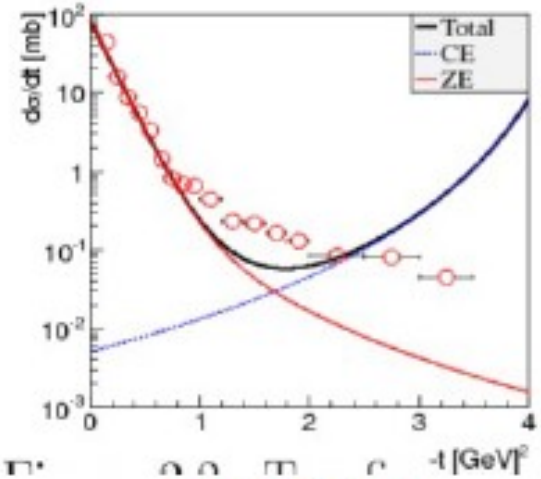

2.241 GeV/c



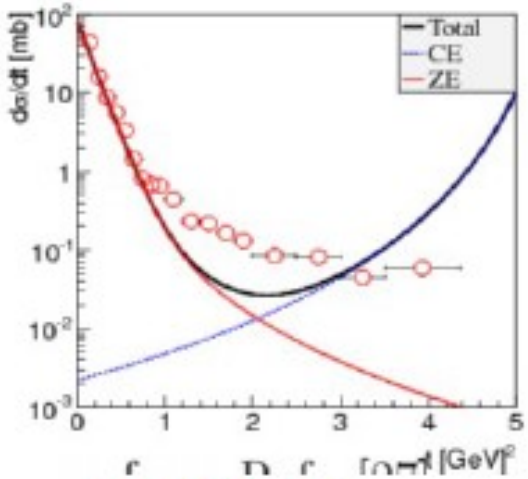

3.305 GeV/c



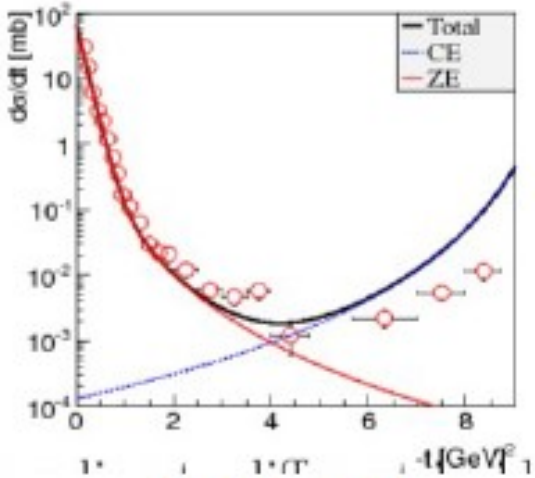

4.337 GeV/c




3.05 GeV/c




3.570 GeV/c




6.120 GeV/c