np Charge Exchange Polarimetry in GeV Region

N. Piskunov

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)

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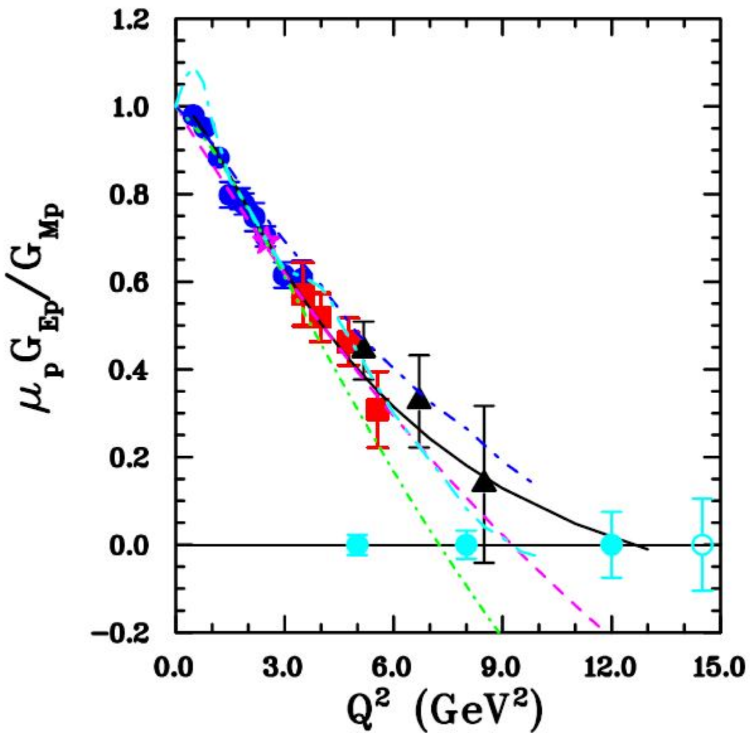
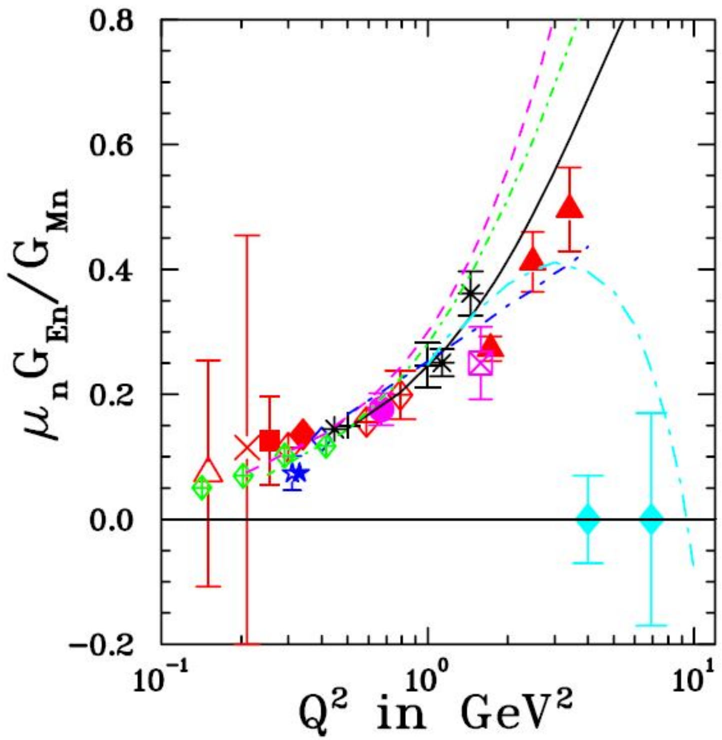
Current Status and Projected Errors for G_{Ep}/G_{Mp} and G_{En}/G_{Mn}

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 ηA_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.

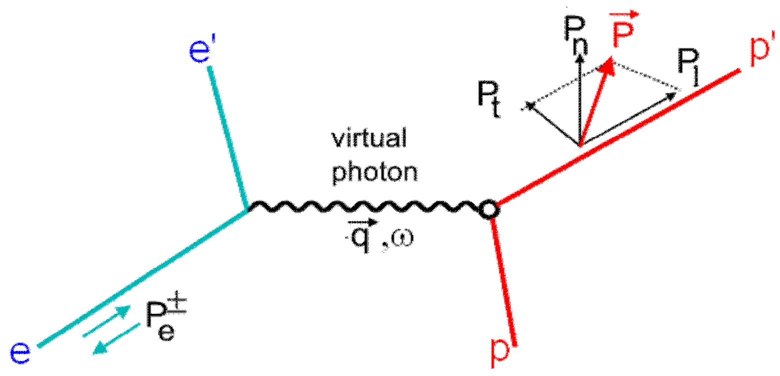




Double Polarization Method in Elastic $\vec{e}N$ Scattering

Polarization transfer in $\vec{e}N \to e\vec{N}$ or spin-target asymmetry $\vec{e}\vec{N} \to eN$, (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:



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

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

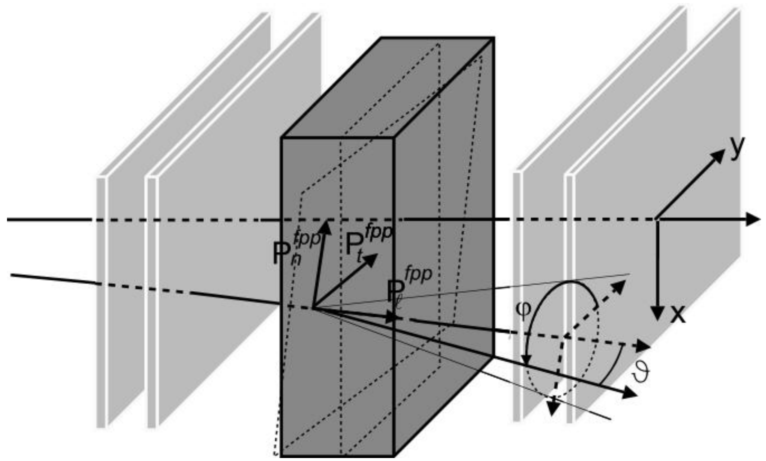
$$\frac{G_{Ep}}{G_{Mp}} = -\frac{P_t}{P_\ell}\frac{(E_e+E_{e'})}{2M}\tan\left(\frac{\theta_e}{2}\right) \text{ and } I_0 = G_E^2 + \frac{\tau}{\varepsilon}G_M^2$$

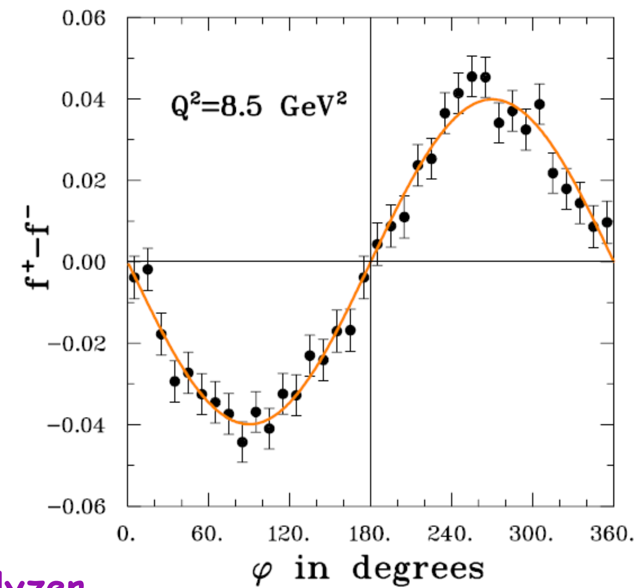
Superior method: " much smaller systematics"

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





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), η. The coefficient of merit is ηA_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** (GeV/c)^2 from the Reaction $^2H(\vec{e},e'\vec{n})^1H$ via Recoil Polarimetry

E12-11-009

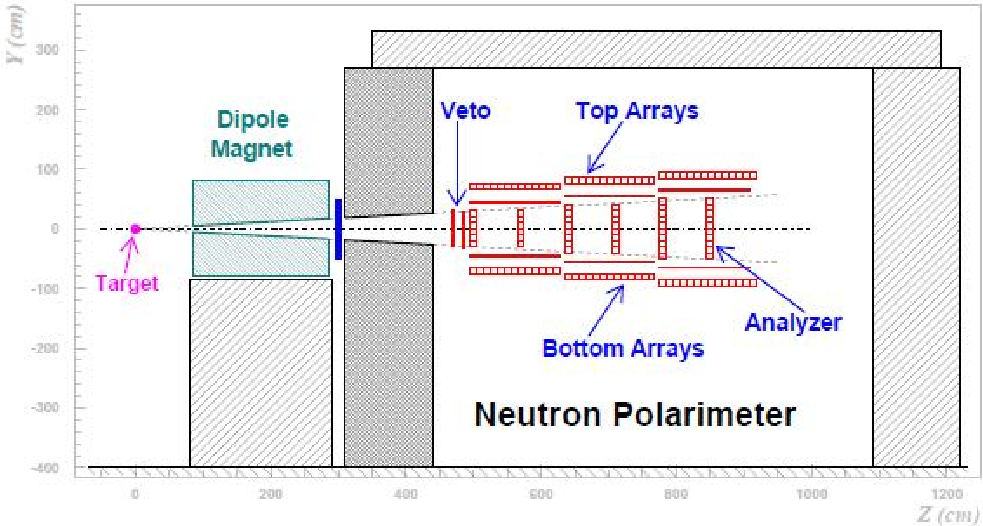
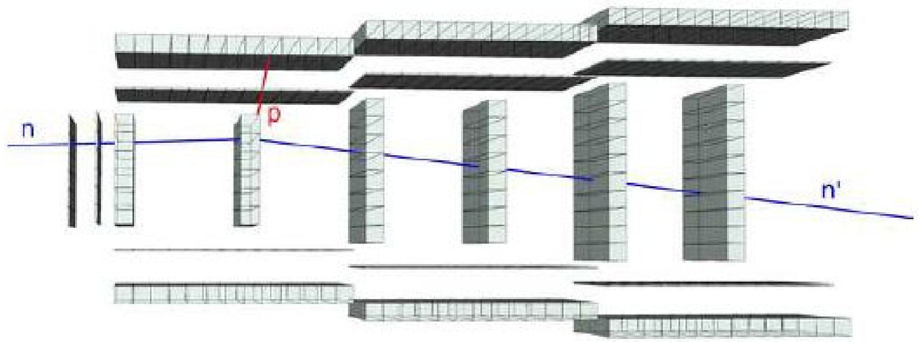


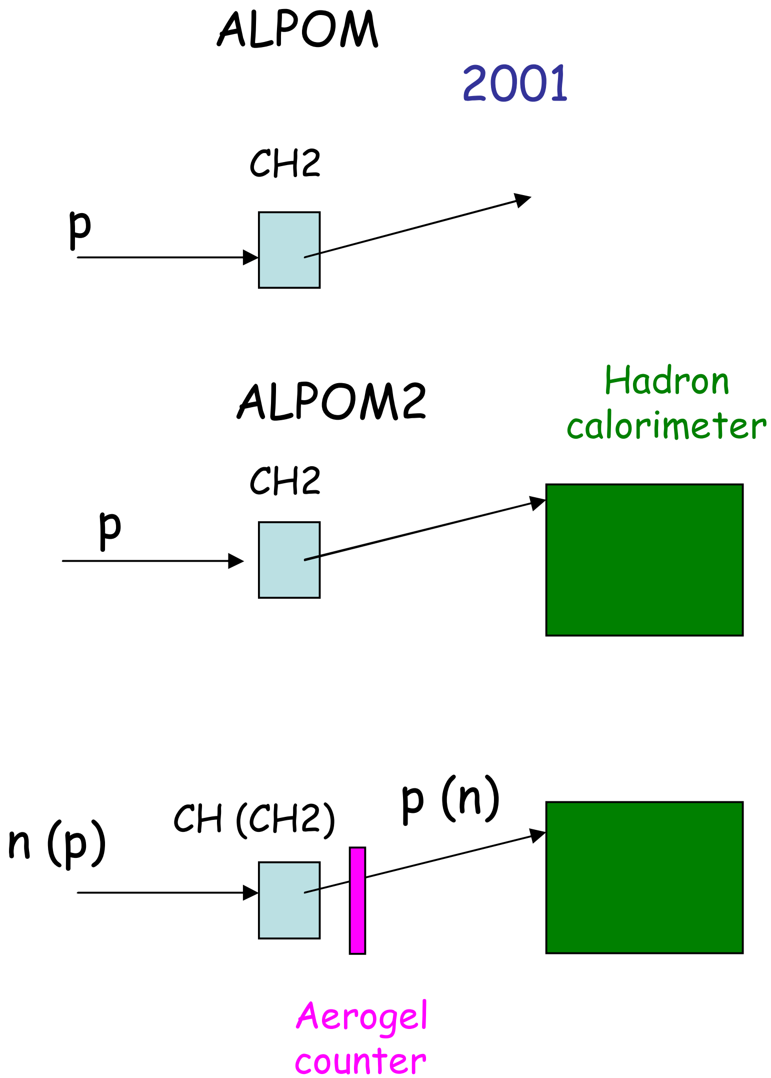
Figure 14: Neutron polarimeter to be used in the measurements.

CH – material

Low detection efficiency



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



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

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

Proton polarimetry

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

Neutron polarimetry

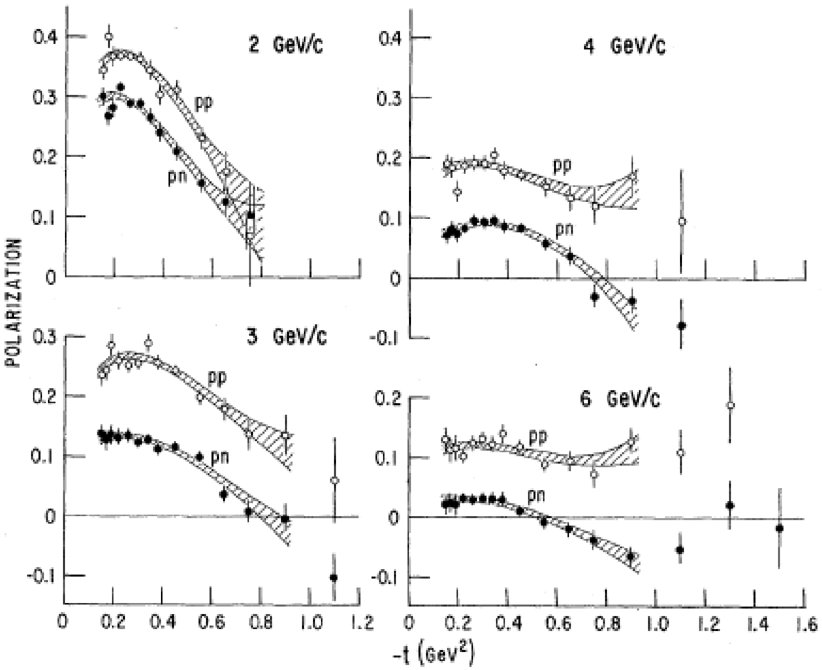
n + p -> n + p , CH - target

New suggestion: n + p -> p + n

Charge exchange reaction

Phys. Rev. Lett 35 (1975) 632

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

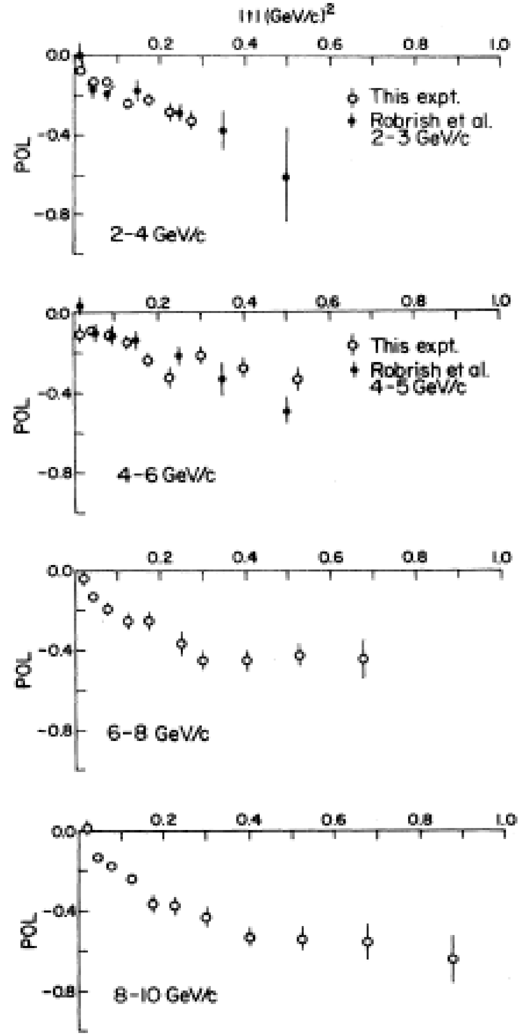


A_y decreasing with energy

Phys. Rev. Lett 30 (1973) 1183

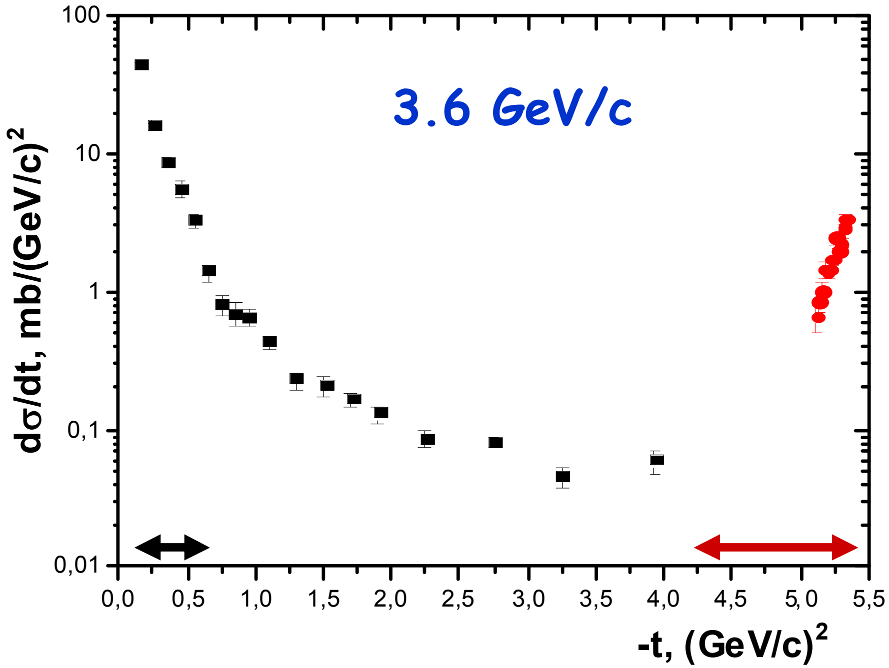
np -> pn

A_y increasing with energy



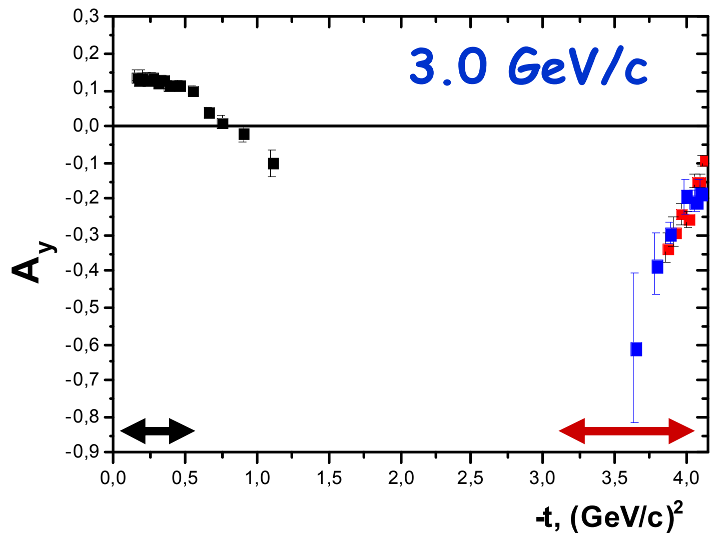
The existing data for A_y in np elastic scattering indicate that the analyzing power decreases faster than the pp analyzing power, becoming very small, then negative around 6 GeV/c neutron momentum.

np -> np   np -> pn



Liquid H2 or D2 target

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



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

$FOM^{el} < FOM^{ce}$

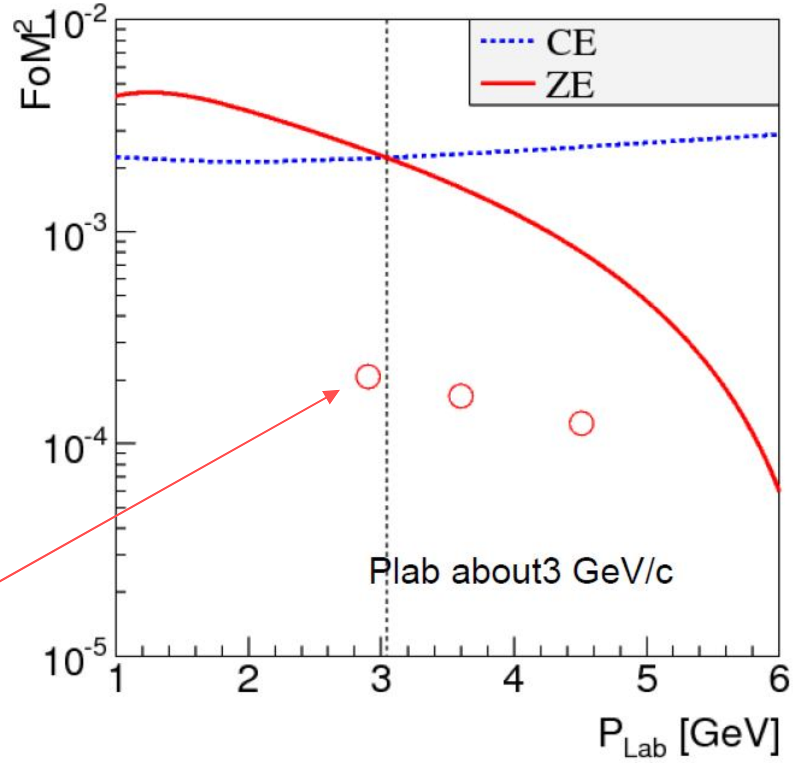
and increasing with energy

From WangYing talk

(for proton as a target)

Figure of merit

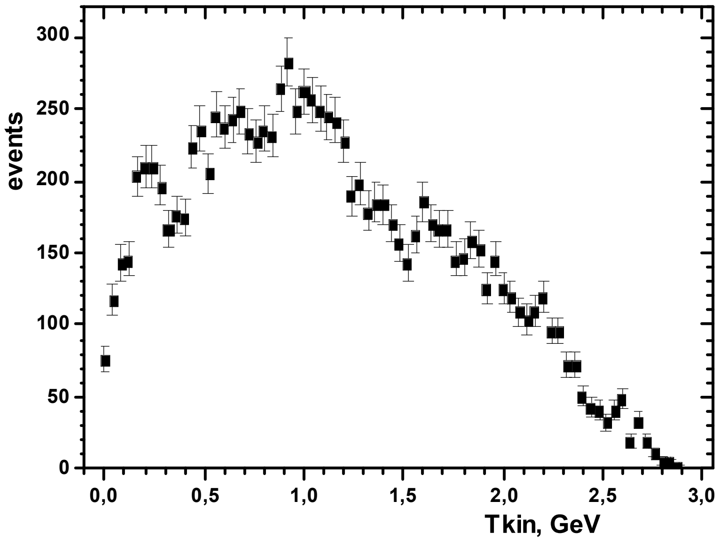
From 1 to 3 GeV/c, ZE has larger Figure of merit due to its larger total cross section. After 3, as cross section becomes really small, figure of merit is dominated by analyzing power, then CE becomes bigger.



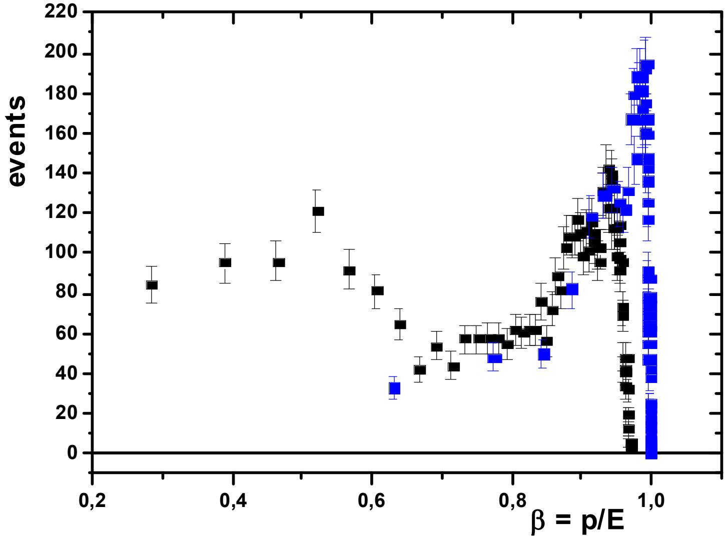
E12-11-009
CH - target

Changing CH to CH2 increases difference FOM twice

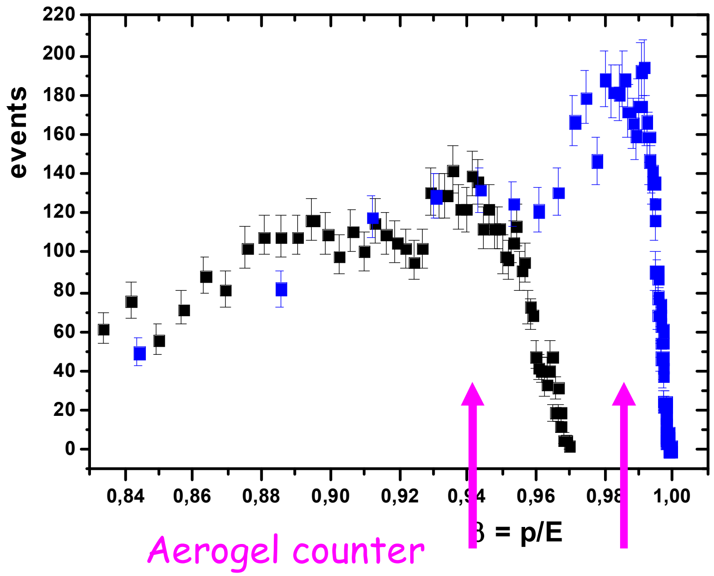
HBC, 3.83 GeV/c protons & pions



5933 protons
5252 pions



Suppression of pions emitted from the target by aerogel counter



R. Asaturyan et al. / Nuclear Instruments and Methods in Physics Research A 548 (2005) 364–374

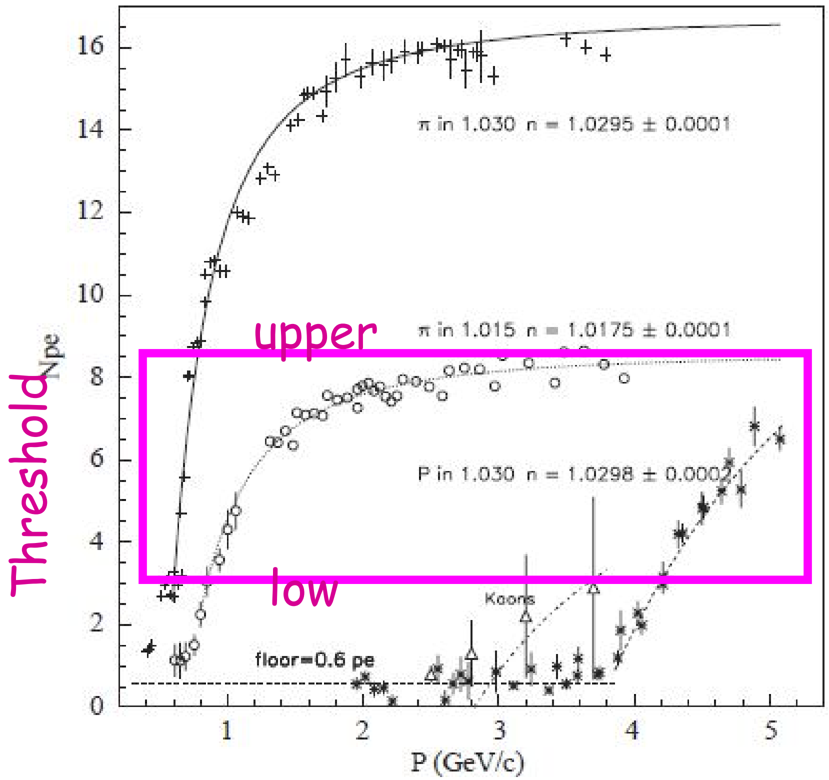


Fig. 7. The momentum dependence of N_{pe} for both types of aerogel material used and for different particles. Both the experimental data and fits to them are shown (compare to Fig. 1).

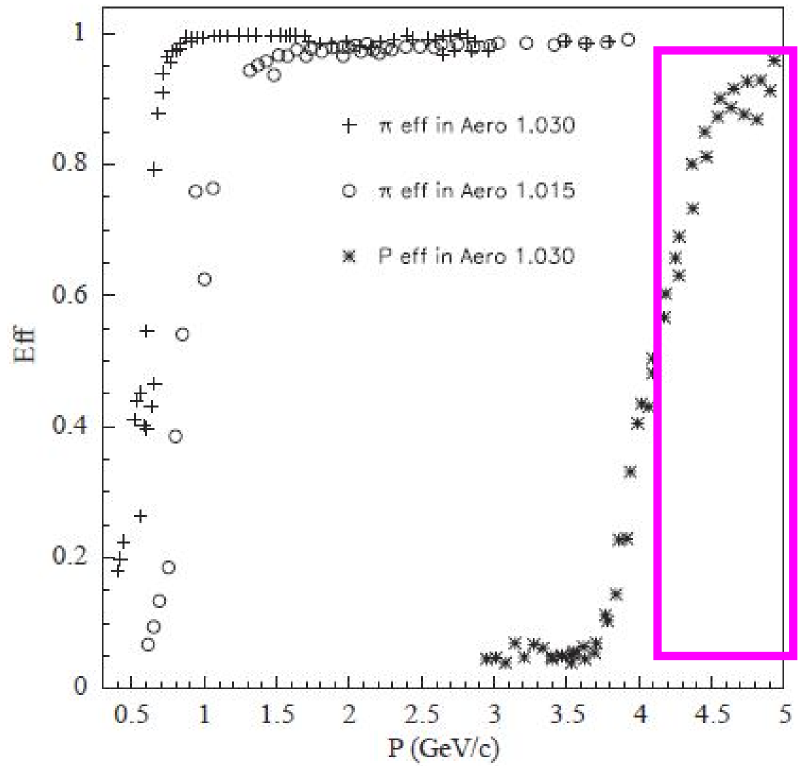
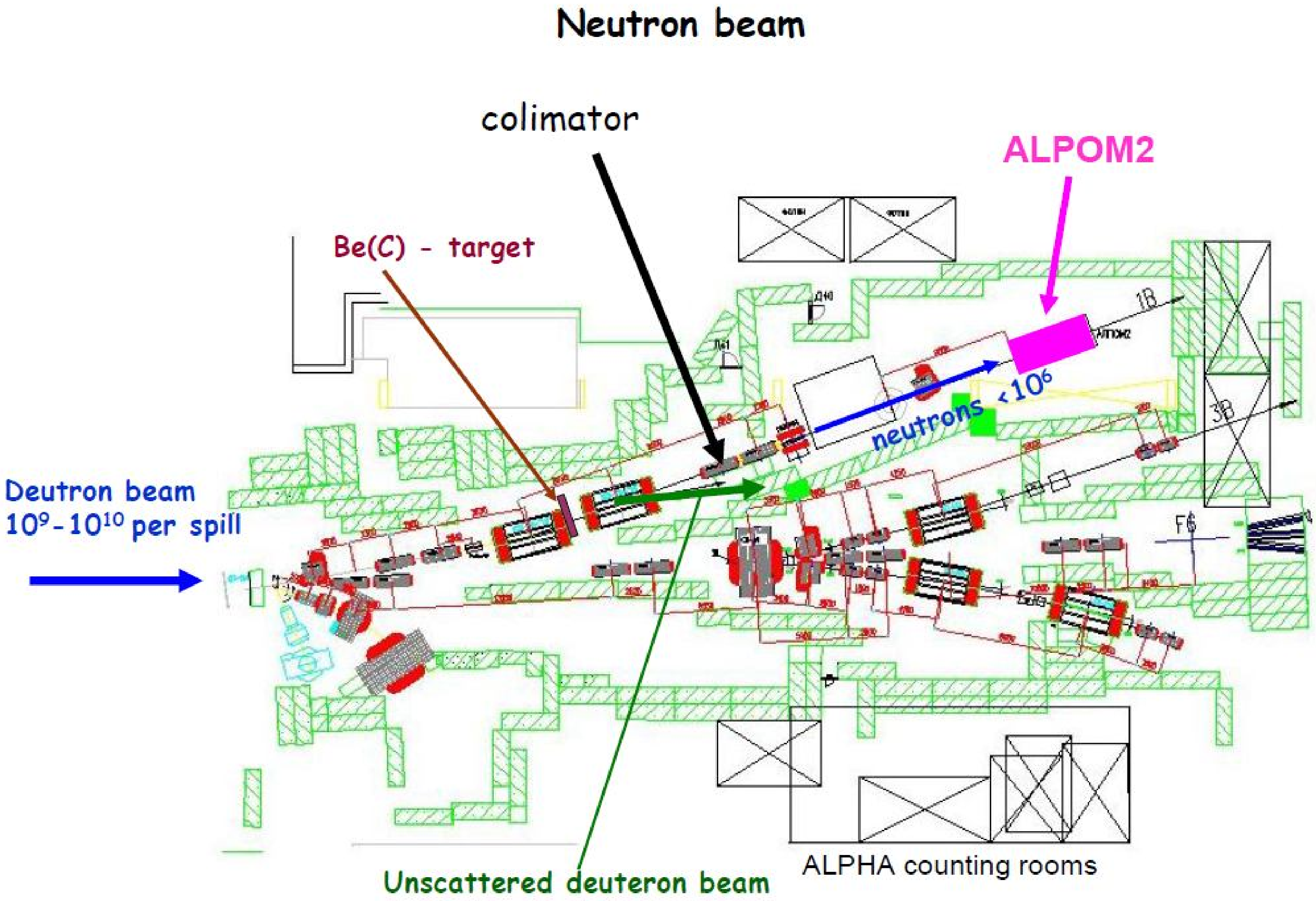


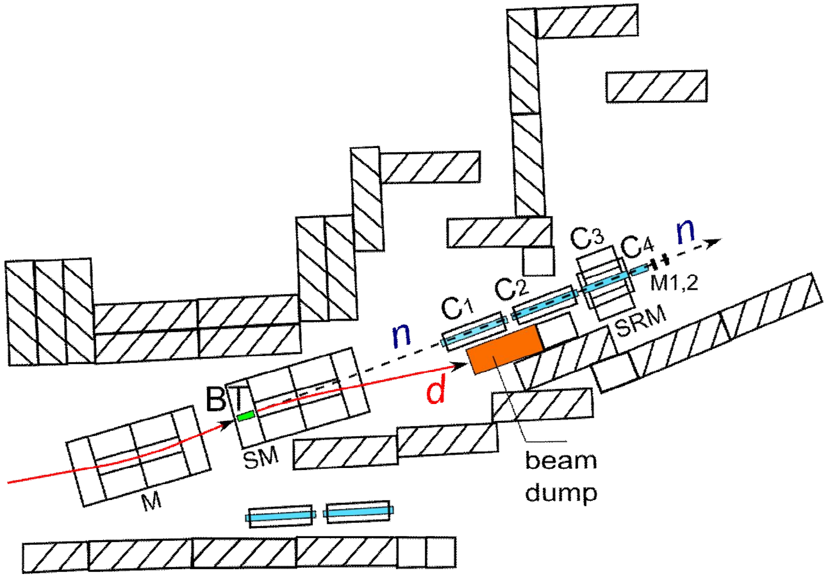
Fig. 8. Particle detection efficiency versus momentum P for the detector with aerogels $n = 1.030$ and $n = 1.015$.

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

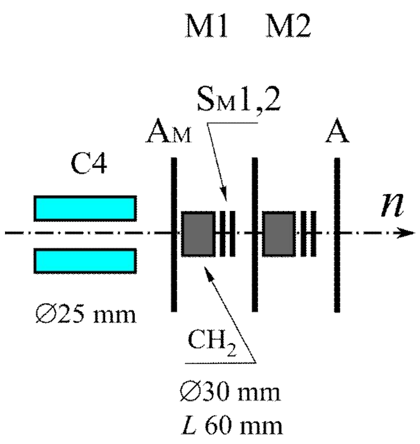
Schematic of Neutron Beam Extraction and Transport

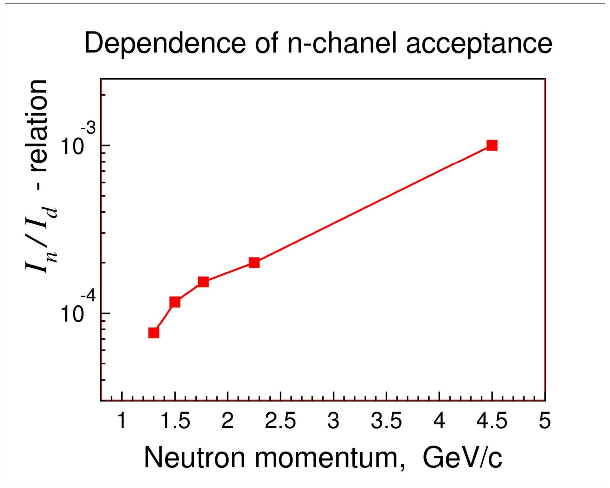


Scheme of both extracted deuteron and free neutron beam lines.
The beryllium target BT for the neutron production,
the collimators C1 – C4, the monitors M1, M2 for estimation of
beam intensity, the SM – magnet for vanishing of the charged deuterons.



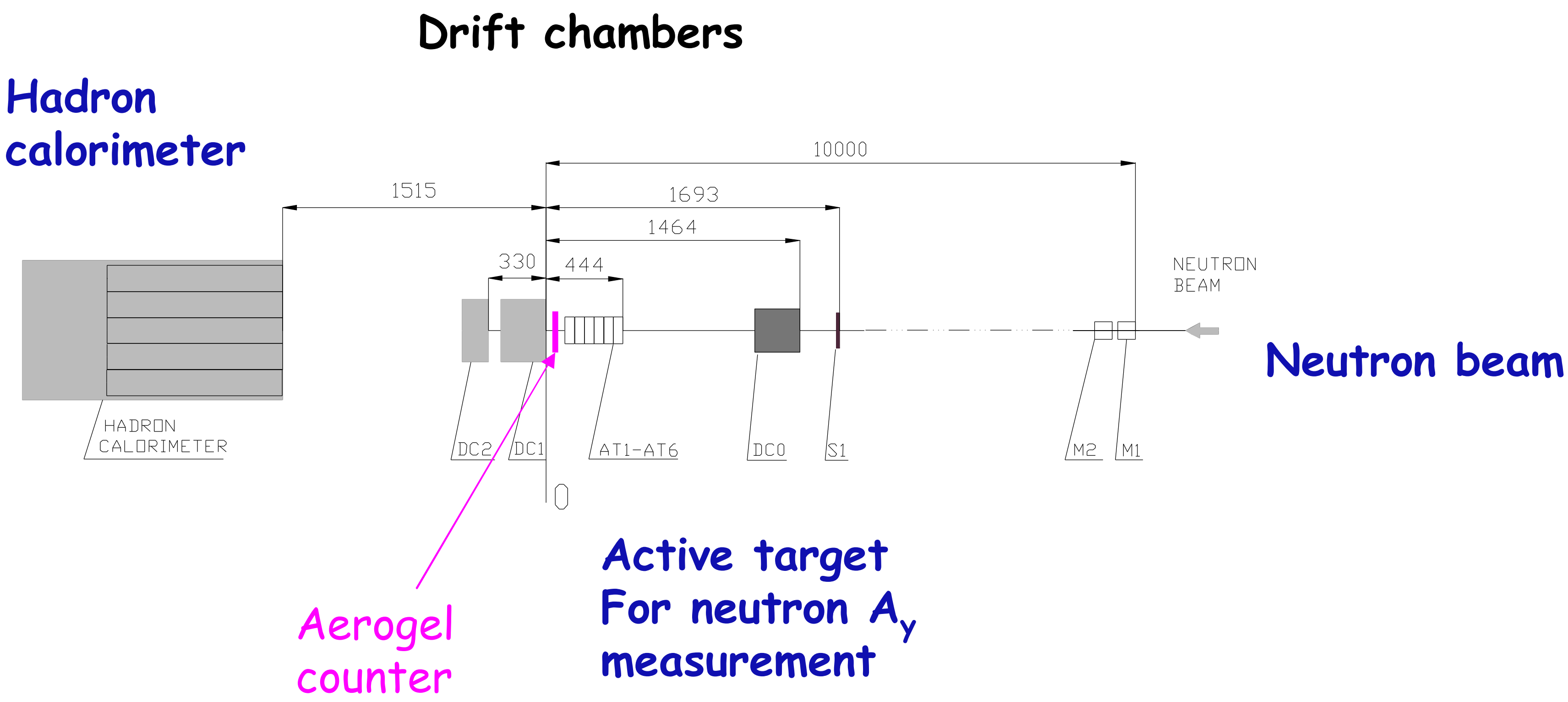
neutron monitors





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

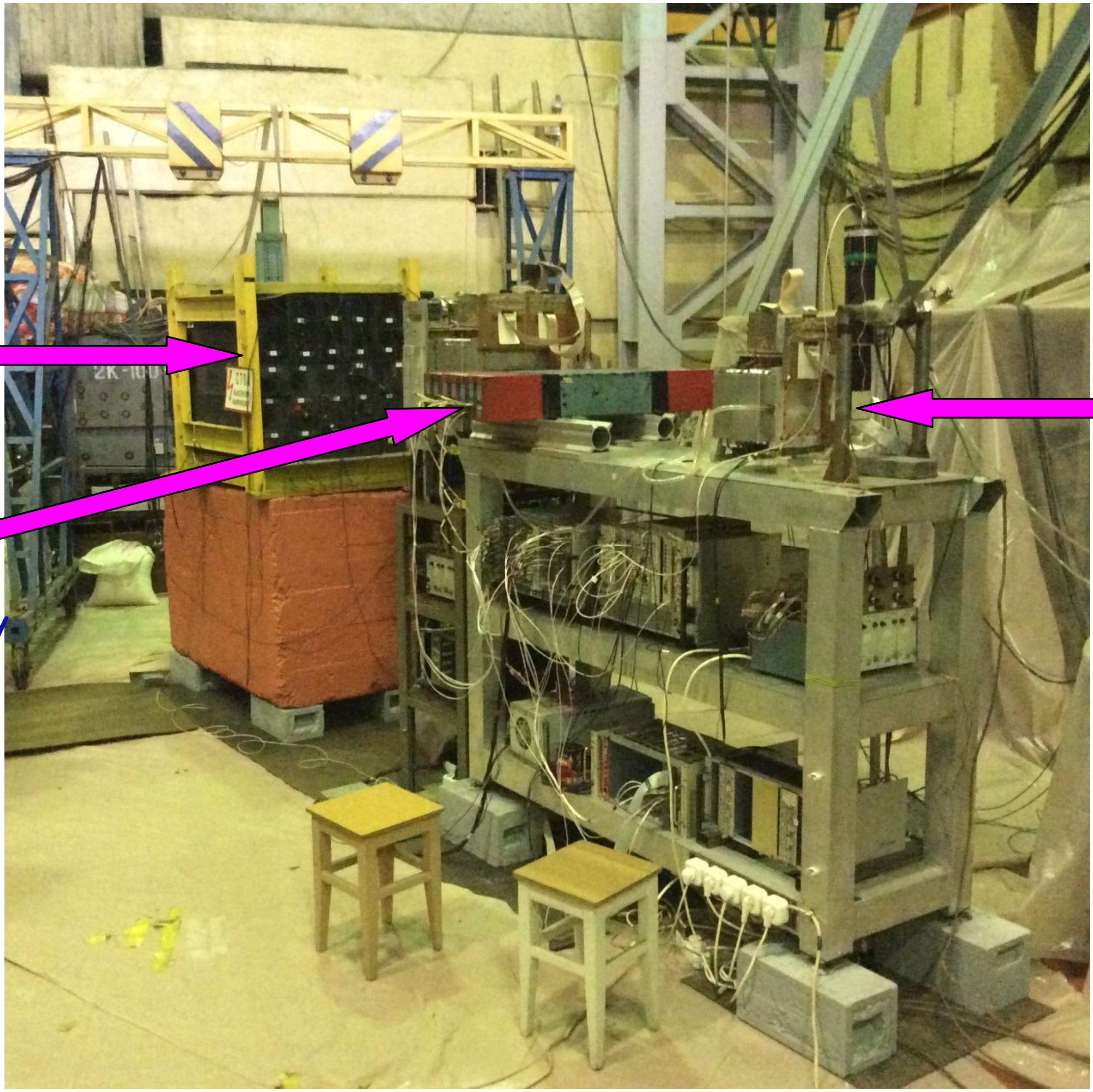
The distance form the BT to the collimator exit is about 12 m
and thus determining the solid angle equal ~ 5 msr.


Drift chambers
Hadron calorimeter
10000
1515
1693
1464
330
444
NEUTRON BEAM
Neutron beam
HADRON CALORIMETER
DC2
DC1
AT1-AT6
DC0
S1
M2
M1
0
Active target For neutron A_y measurement
Aerogel counter

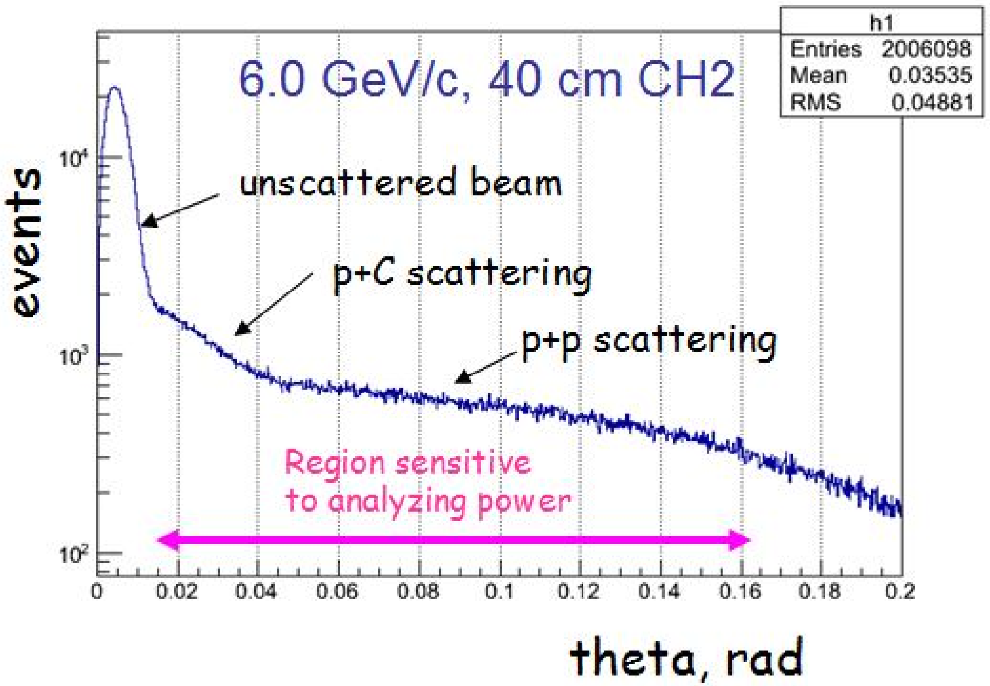
Picture of the ALPOM2 Setup

Hadron calorimeter

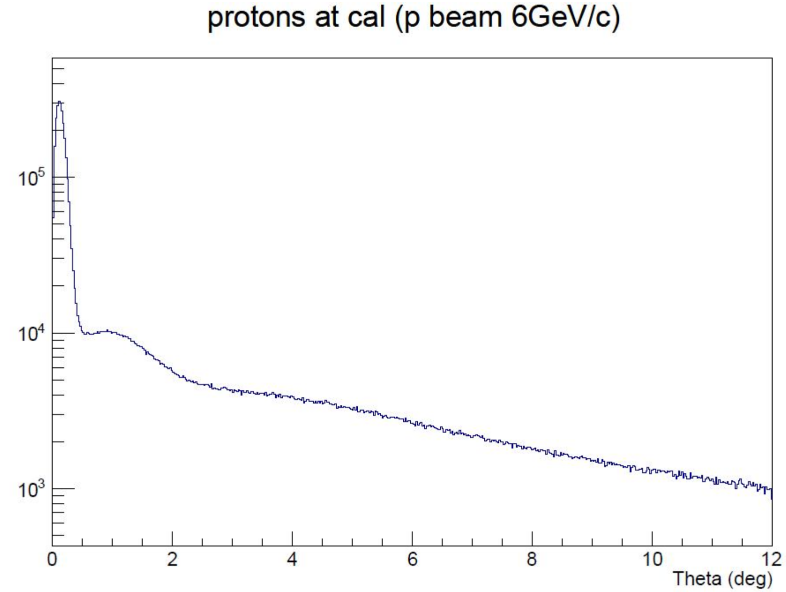
Neutron beam



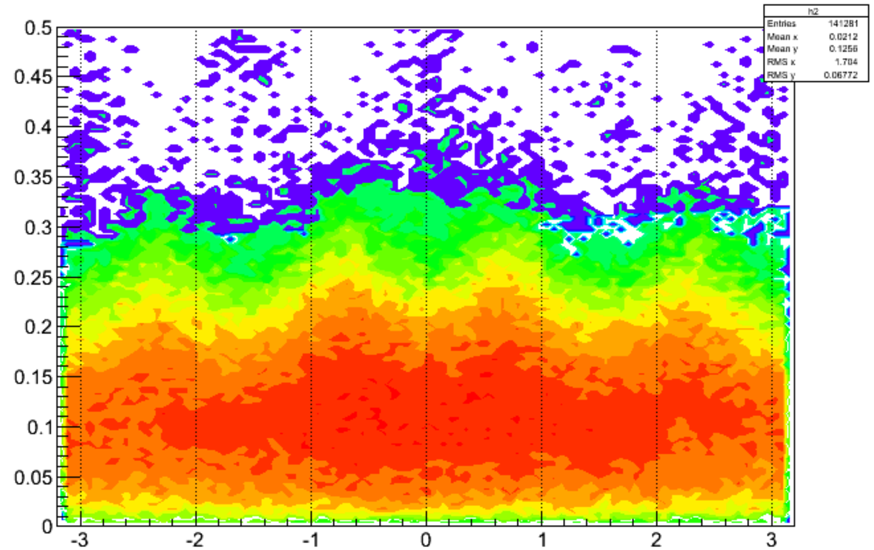
Active target For neutron A_y measurement



MC simulation result

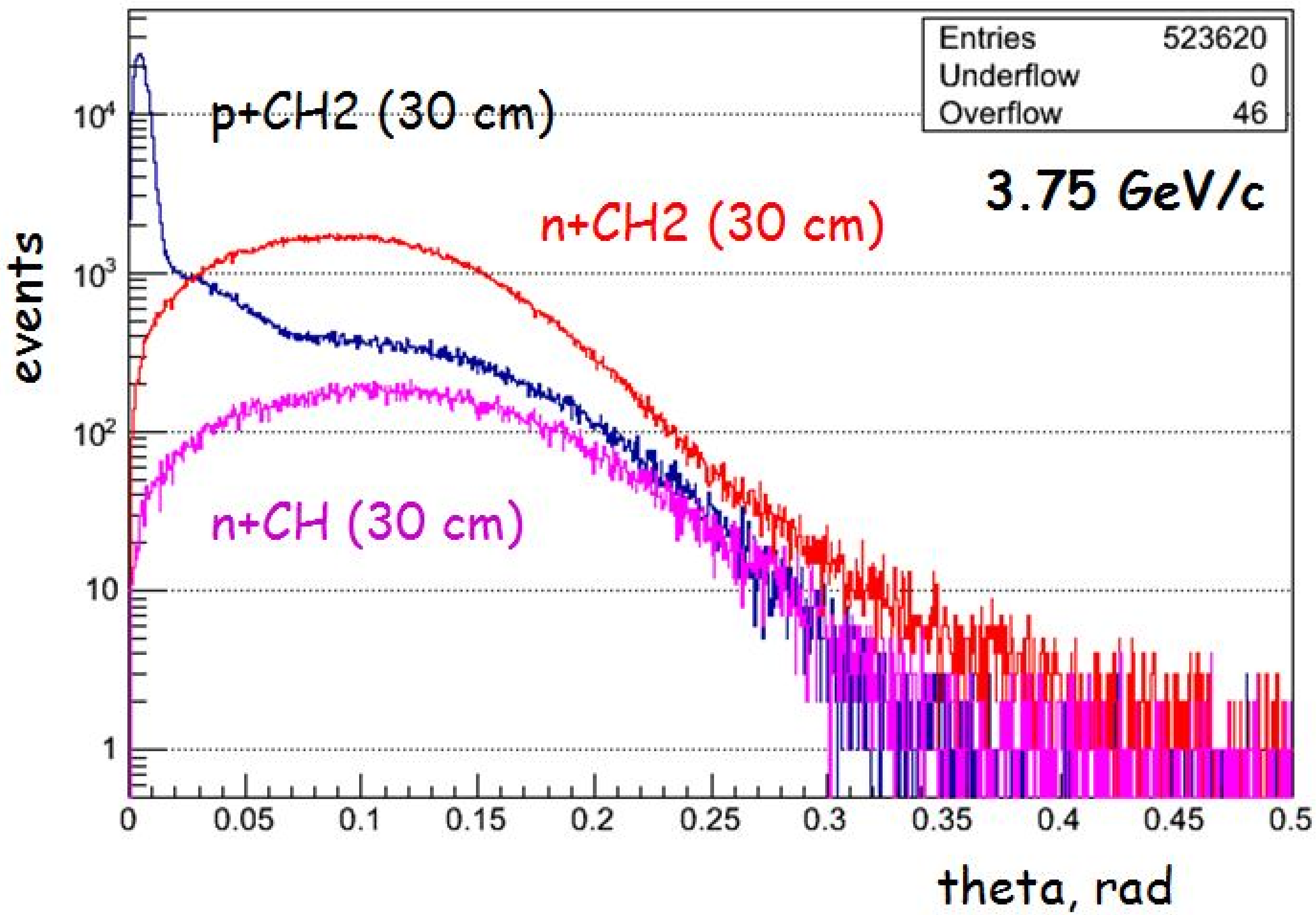


The angular distribution of charged particles after the target.

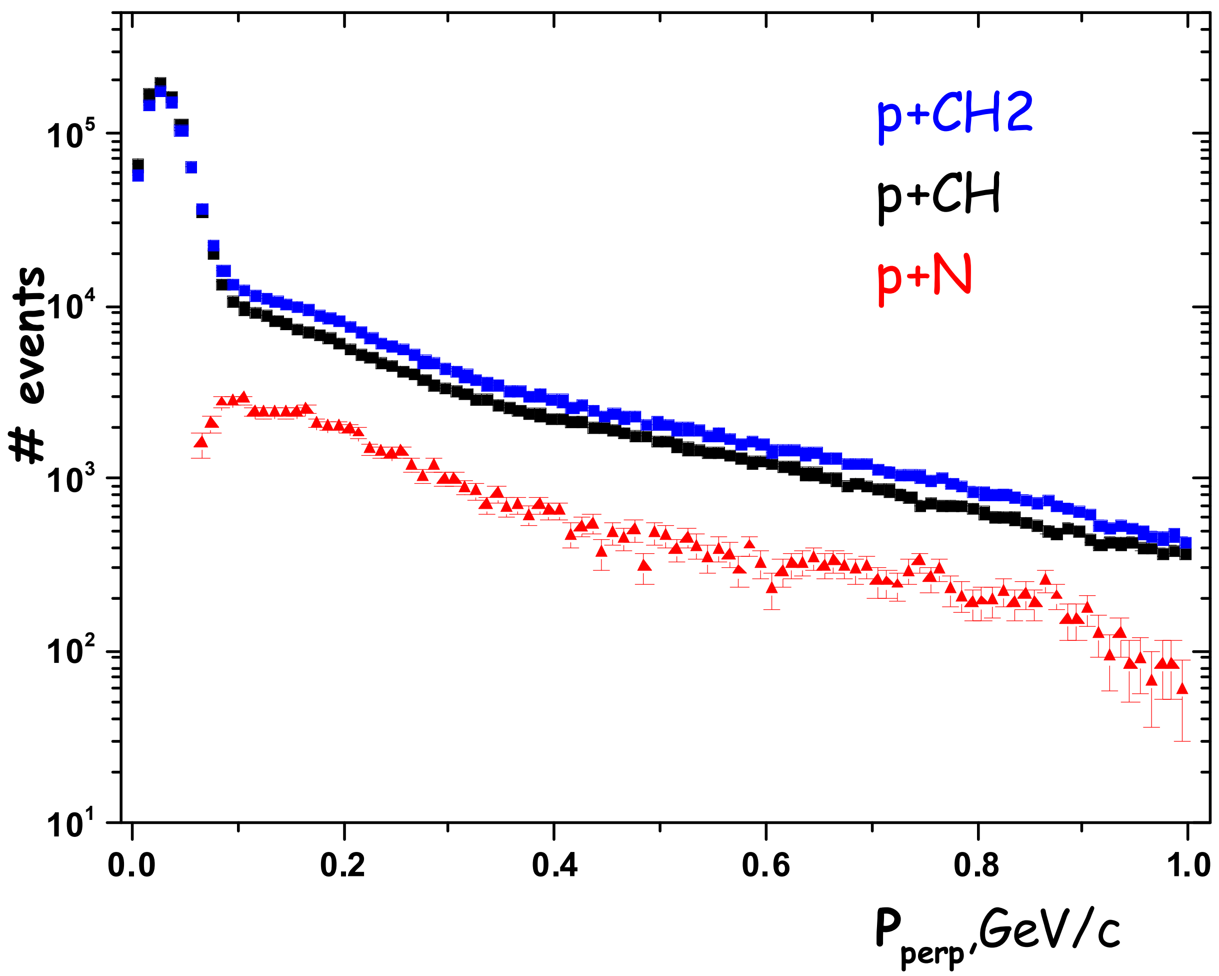


Theta-phi correlation plot.

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.



About 10^6 tracks



Conclusion

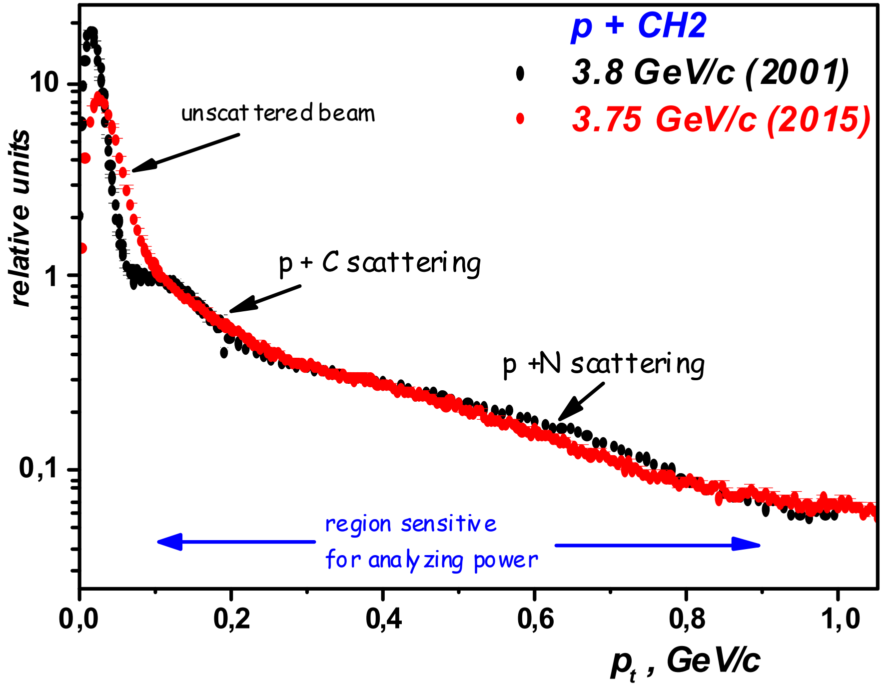
Charge-exchange np reaction is preferable over np elastic scattering in GeV region

A new polarized source is under testing

The setup has been tested

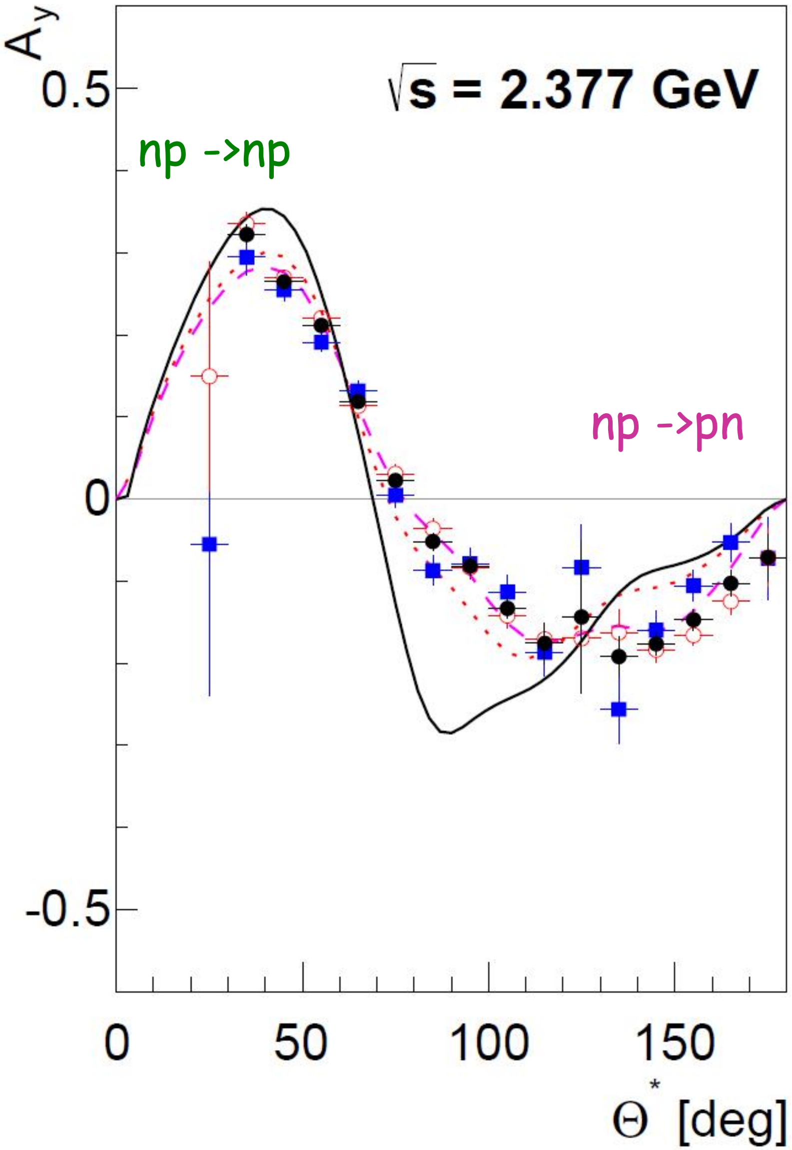
We hope that the measurements be done in 2016

Thank you for your attention


p + CH2
3.8 GeV/c (2001)
3.75 GeV/c (2015)
unscattered beam
p + C scattering
p +N scattering
region sensitive
for analyzing power
relative units
10
1
0,1
0,0
0,2
0,4
0,6
0,8
1,0
p_t , GeV/c

1.1 GeV

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



np ->np

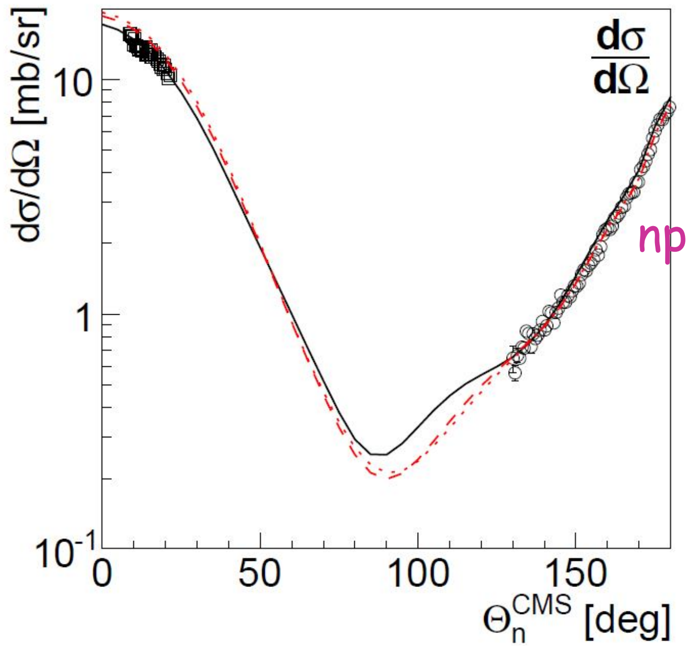
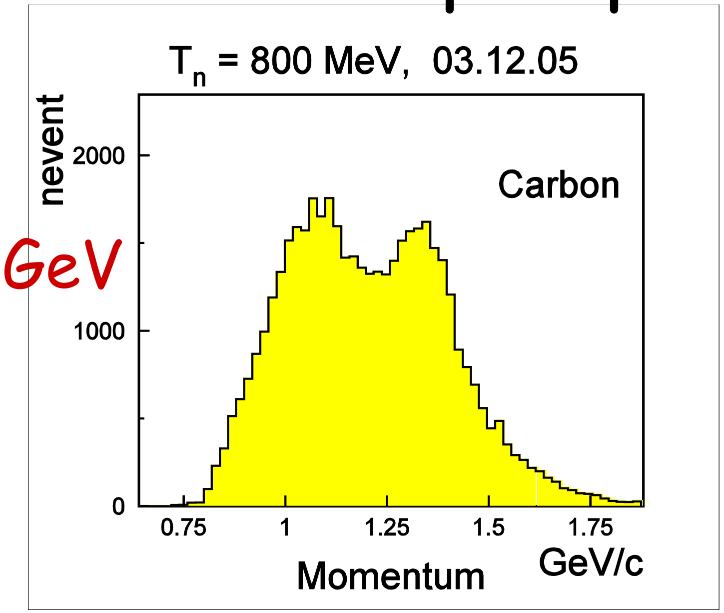


FIG. 11: (Color online) Angular distribution of the differential cross section $d\sigma/d\Omega$ at $T_n = 1.135$ GeV corresponding to the resonance energy $\sqrt{s} = 2.38$ GeV. For the meaning of the curves see caption of Fig. 4. The plotted data are from Ref. [41] ($T_n = 1.135$ GeV) and Ref. [42]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

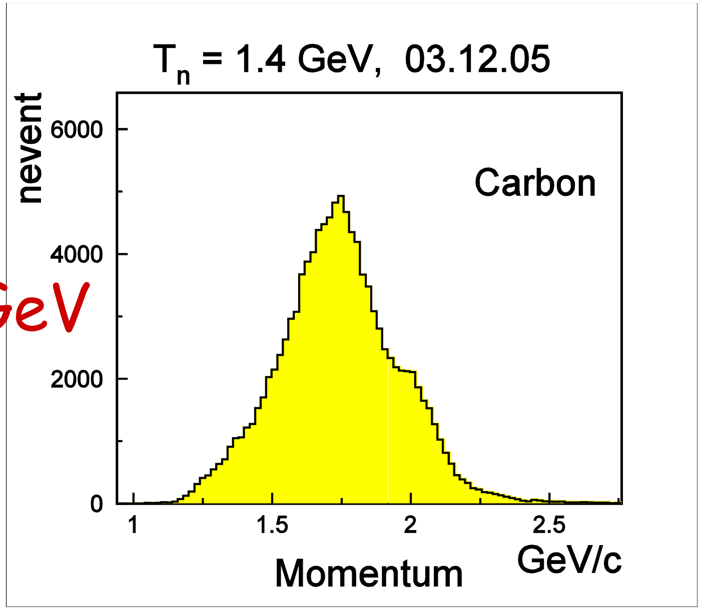
Carbon contribution

Delta-sigma setup np -> pn

0.8 GeV



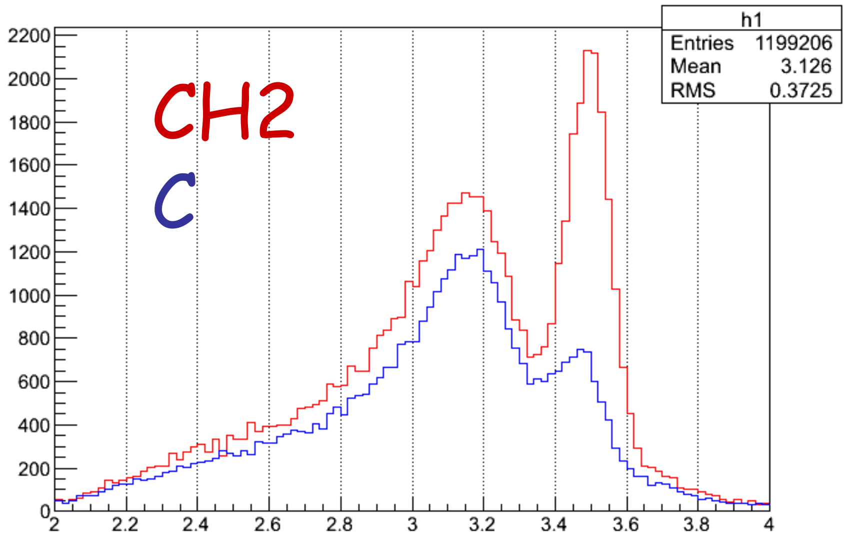
1.4 GeV



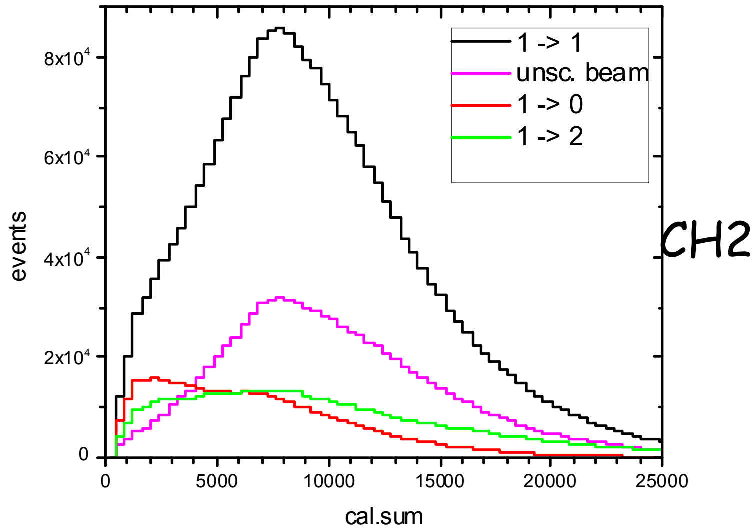
Strela setup

dp -> (pp) n

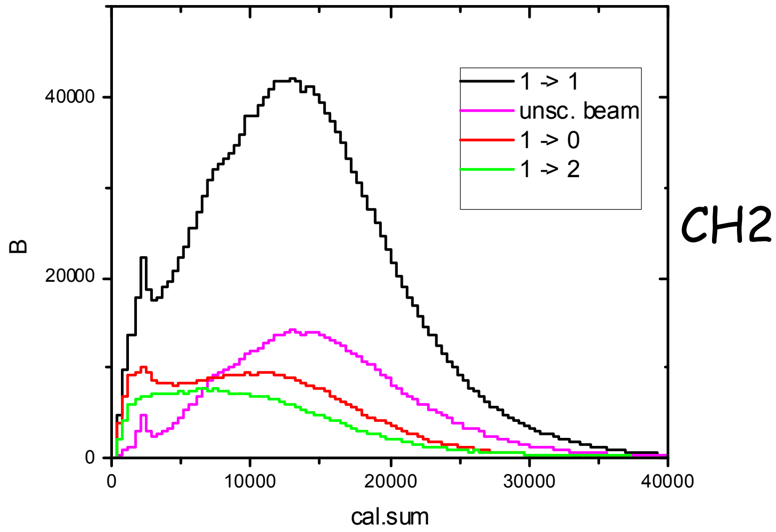
1.05 GeV



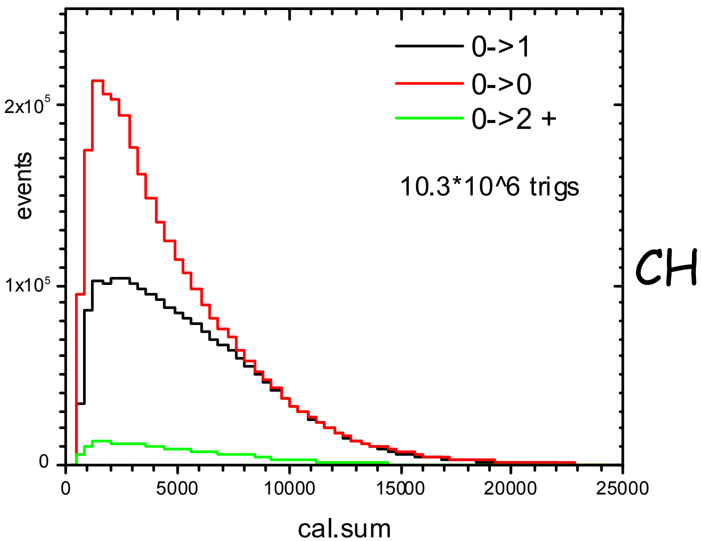
3.75 GeV/c protons



6.0 GeV/c protons

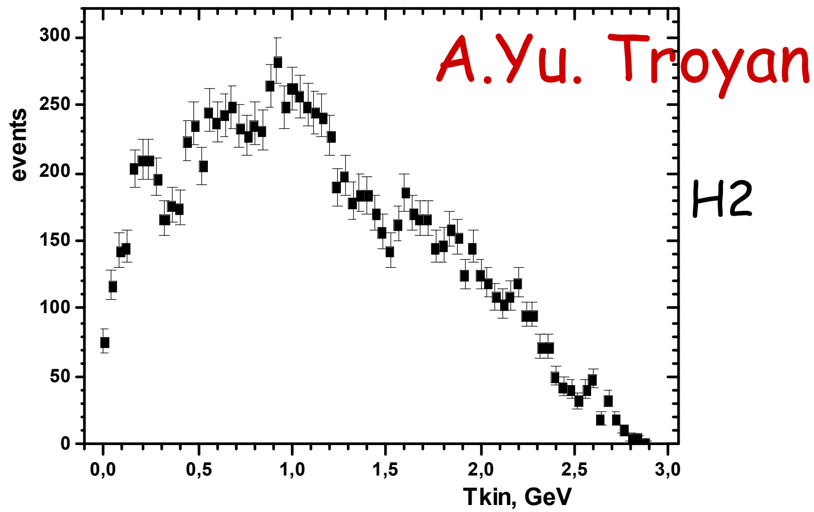


3.75 GeV/c neutrons



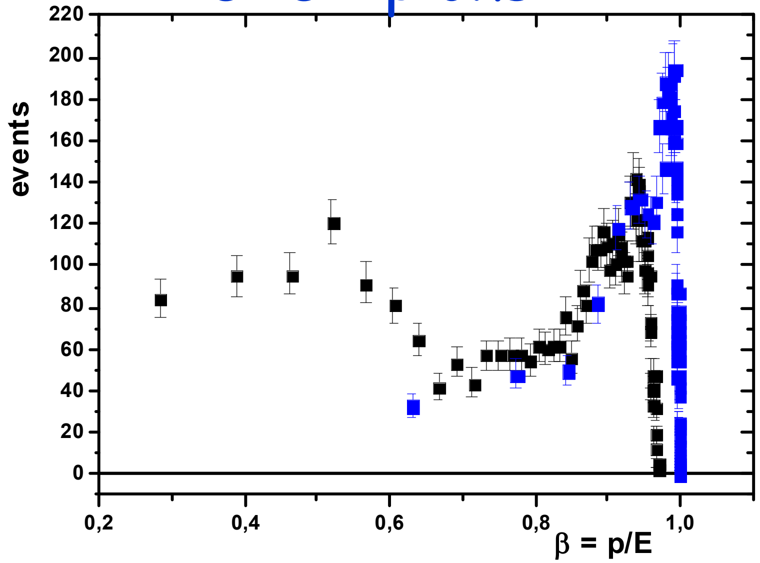
HBC, 3.83 GeV/c

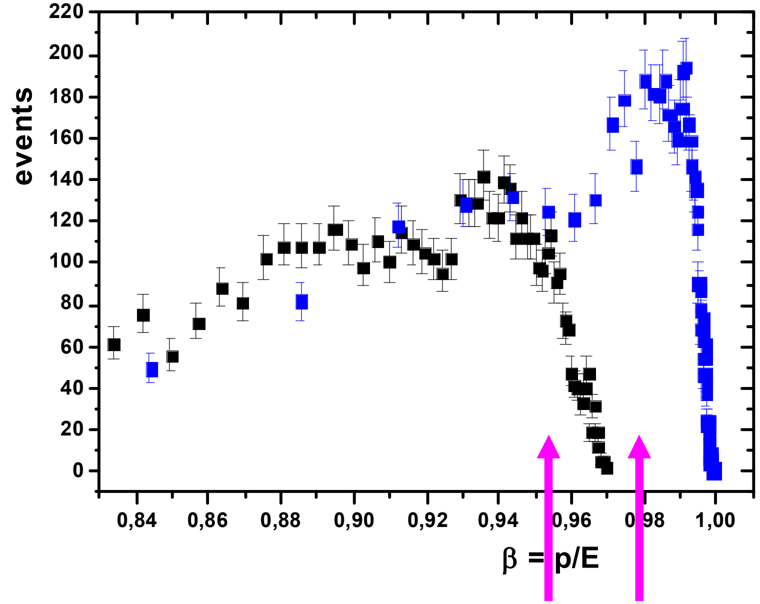
protons & pions



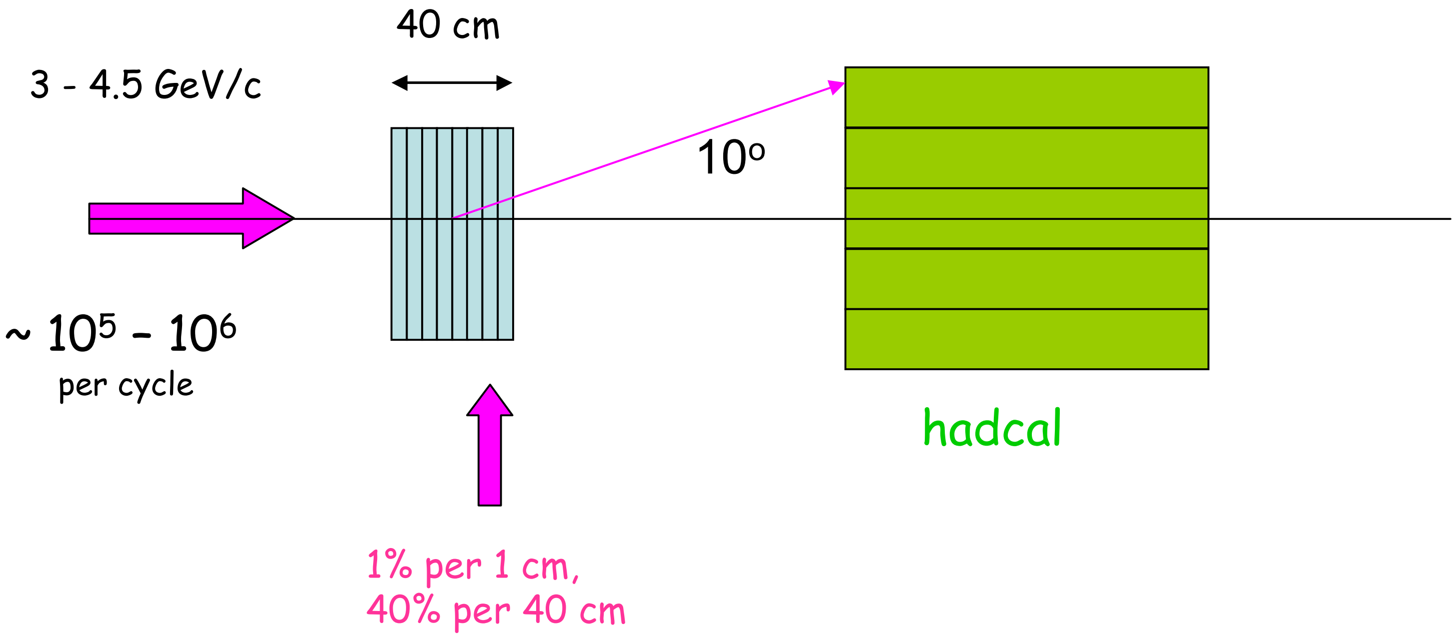
HBC, 3.83 GeV/c
protons & pions

5933 protons
5252 pions





Aerogel counter



Dead time of the data acquisition ~ 30 μs ⇒ (15-20) 10^3 events per second

$5 * 10^5$ ⇒ $2 * 10^5$

We can take the data ~ 10 s

⇓

Really (now) ~ 3-4 s, so $7*10^4$ events per cycle
For 5 cycles per min = $35*10^4$

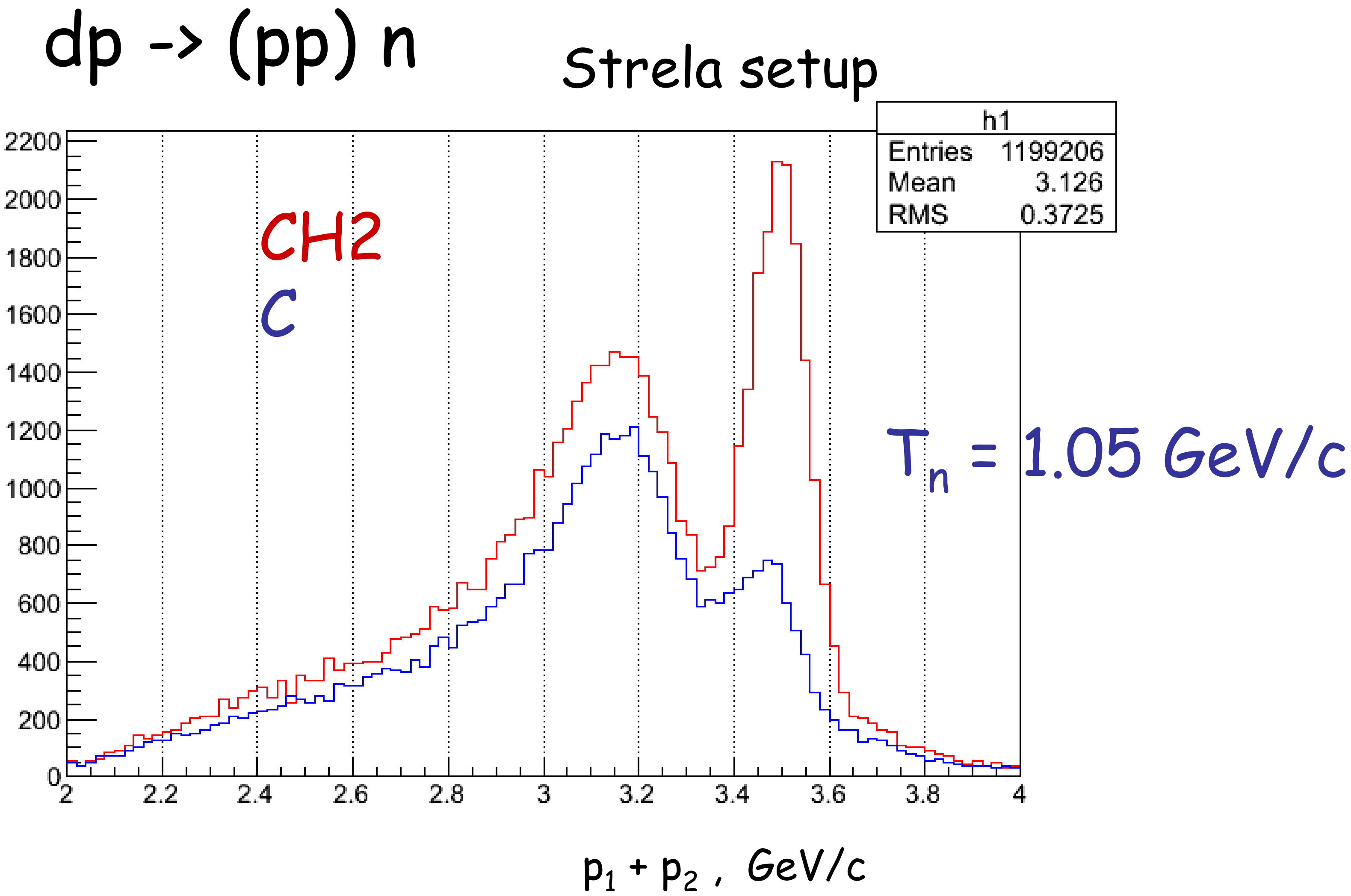
⇓

Elastic np cross section (<10^0) ~ 2 mb
Total (np+nC) ~ 350 mb

⇒

Half reaches hadcal, so $175*10^3$ per min
10^7 events per 1 hour

$175*10^3 * 2 / 350 = 2000$ np events per min


dp -> (pp) n
Strela setup
h1
Entries 1199206
Mean 3.126
RMS 0.3725
CH2
C
T_n = 1.05 GeV/c
0
200
400
600
800
1000
1200
1400
1600
1800
2000
2200
2
2.2
2.4
2.6
2.8
3
3.2
3.4
3.6
3.8
4
p_1 + p_2 , GeV/c

Beam Time Request

2015-2016

Test the polarimeter using the polarized proton beam of 7.5 GeV/c 48 hours.

2016-2017

Total Data taking time 240 hours.

for proton beam 120 hours
a) measurement of A_y at proton momentum of 5.3 GeV/c (control point)
b) two measurements to check polarization of breakup proton, at k=0.15 GeV/c with deuteron momentum of 11.2 GeV/c (proton momentum 6.5 GeV/c) and at k = 0 GeV/c with deuteron momentum of 13.0 GeV/c (proton momentum 6.5 GeV/c)
c) measurement of A_y at proton momentum of 7.5 GeV/c

for neutron beam 120 hours
measurement A_y at neutron momenta of 3.0, 3.75 and 4.5 GeV

ALPOM2 setup

Nuclotron run	Date	Deuteron energy	Beam on the target	Target
47	25.03.13 27.03.13	4.5 GeV/n 4.8 GeV/n	Protons 5.66 GeV/c	CH2, 40 cm Empty
48	13.12.13	5.15 GeV/n	Protons ???	CH2, 40 cm Empty
49	21.02.14	2.94 GeV/n	Deuterons 7.5 GeV/c	CH2, 20 cm 40 cm, Empty
50	15.06.14	2.94 GeV/n	Deuterons 7.5 GeV/c Neutrons 3.75 GeV/c	CH, 6x5 cm