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Study of the nuclear matter in hard proton-nucleus and nucleus-nucleus collisions at the U70 accelerator (Proposal of experiment "FLUKTON")

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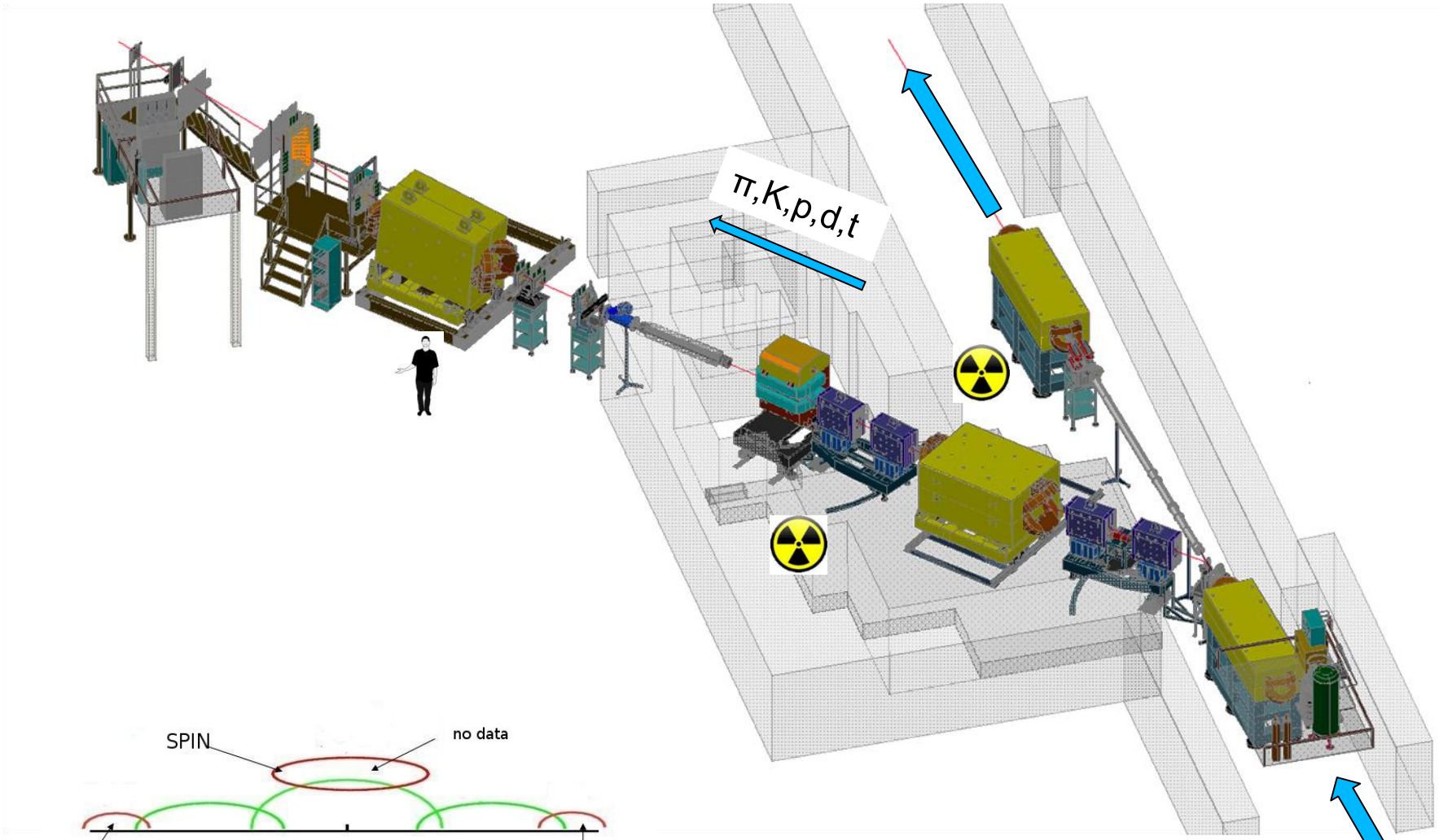
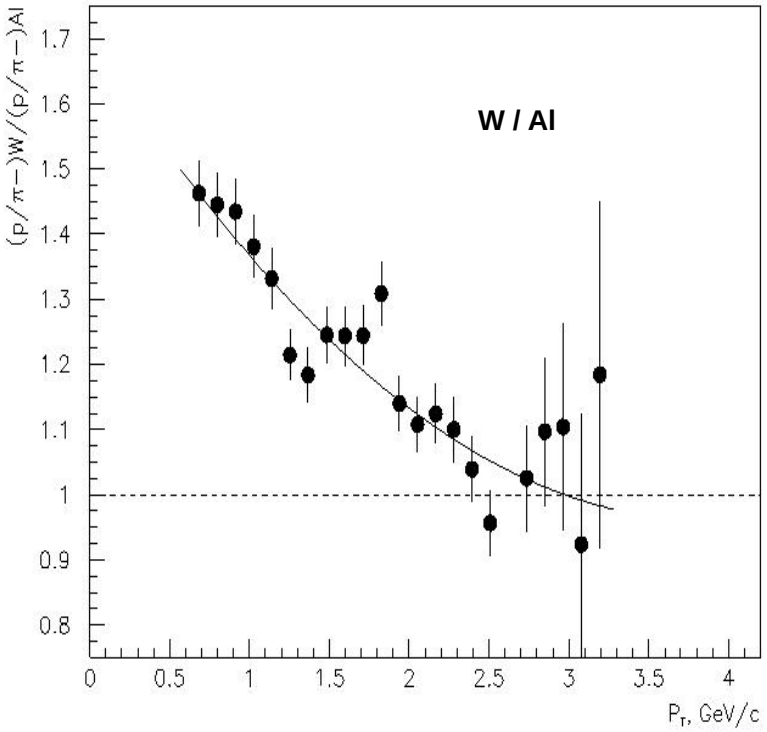
Abstract. A study of relativistic nuclear physics problems with two arms detector "FLUKTON" which can be created on base of already existing SPIN detector (IHEP, Protvino) is proposed. Main goal of the study with FLUKTON will be improvement of our knowledge about cold density baryonic matter (fluctons) inside nuclear matter. For this purpose the high intensive proton and nuclear beams from U70 as well as the liquid hydrogen and nuclear targets will be used.

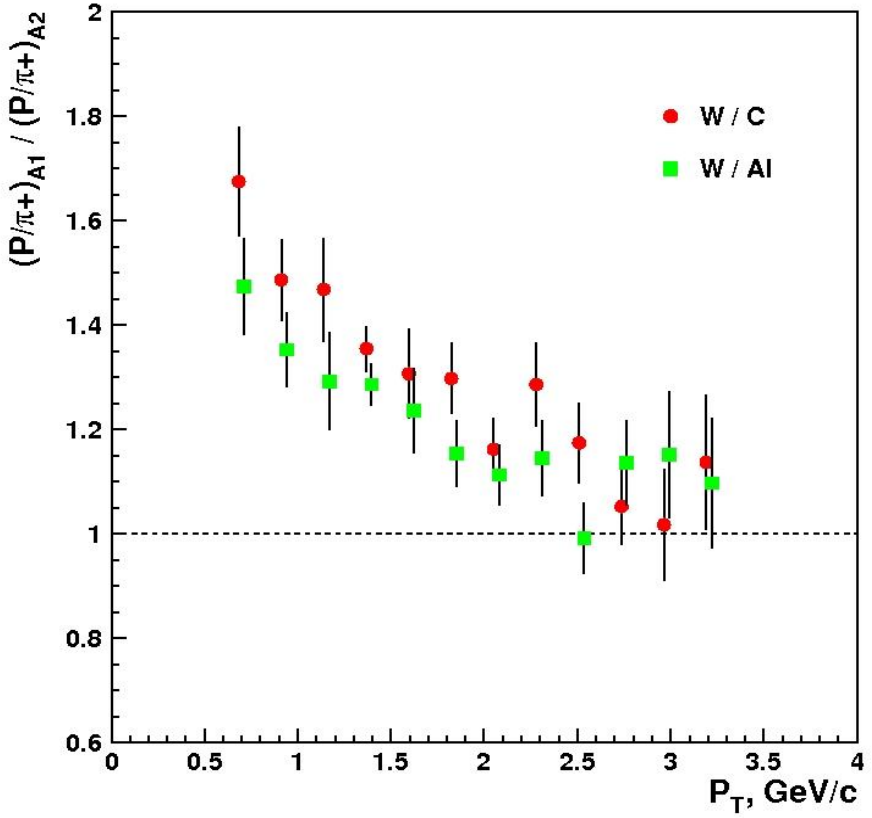
SPIN – narrow acceptance spectrometer, beam line #8



protons
10^{12} - 10^{13} /s

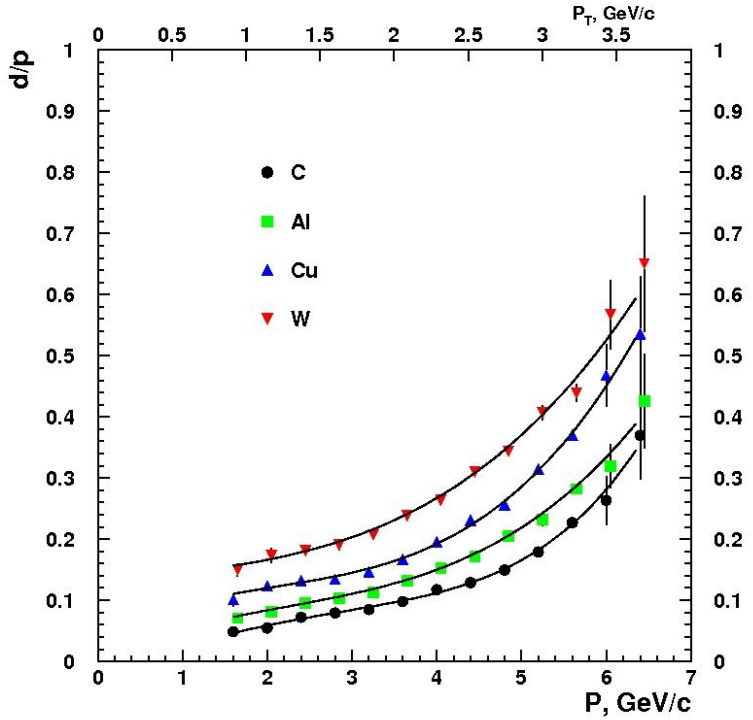
The absence of strong dependence of p/π^- and p/π^+ on atomic mass at high P_T can be interpreted as an indication of a local mechanism of particle production and small contribution of secondary interactions.



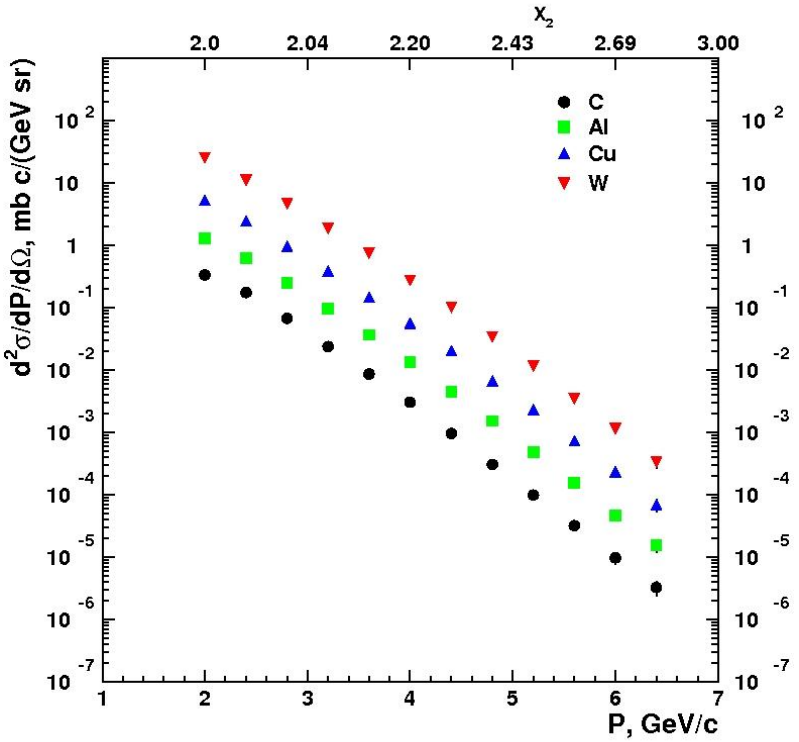


2013, 50GeV/c protons, angle of arm 35^0

d/p ratio



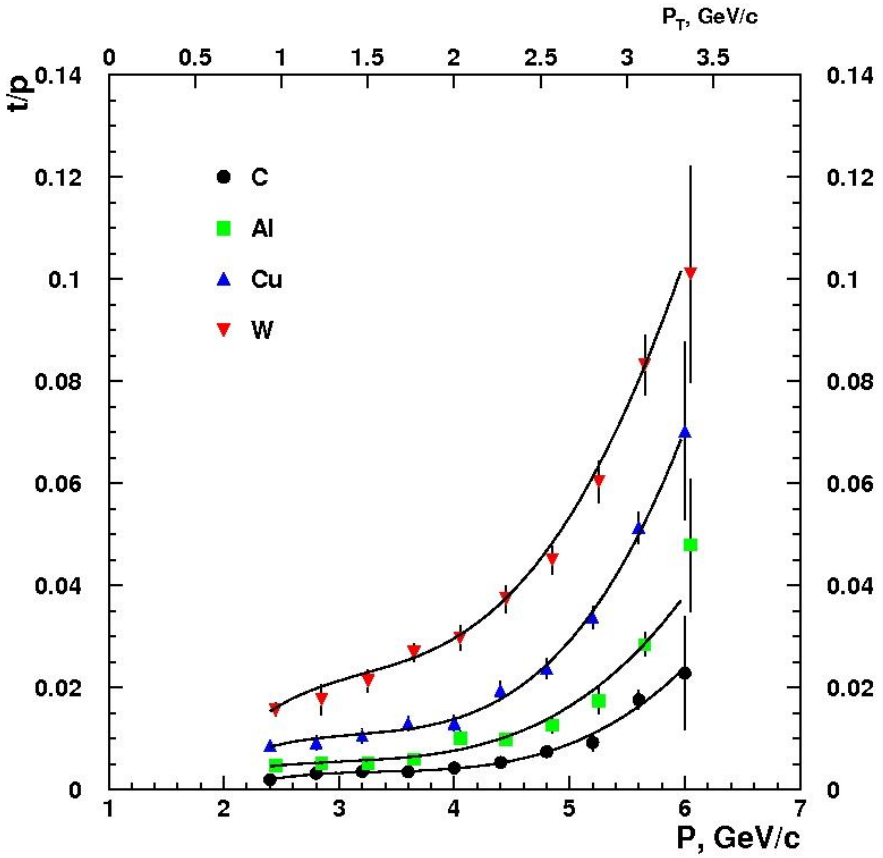
spectra of deuteron dependently on momentum and X_2



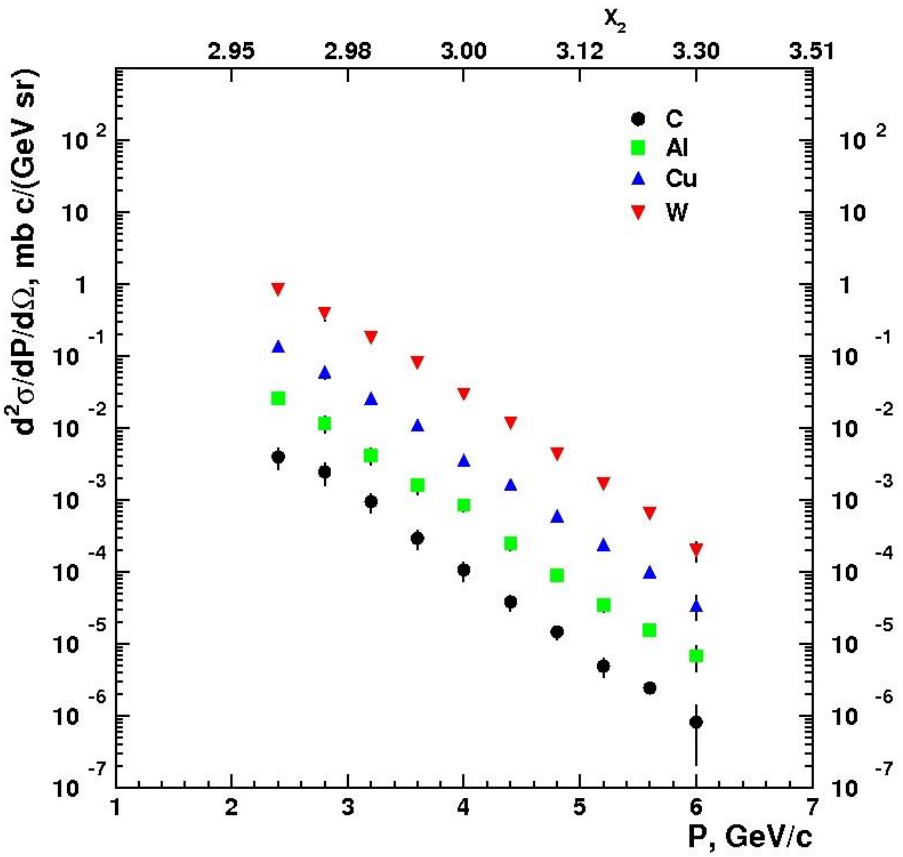
minimal target mass $\geq 2 \times m_n$

2013, 50GeV/c protons, angle of arm 35^0

t/p ratio

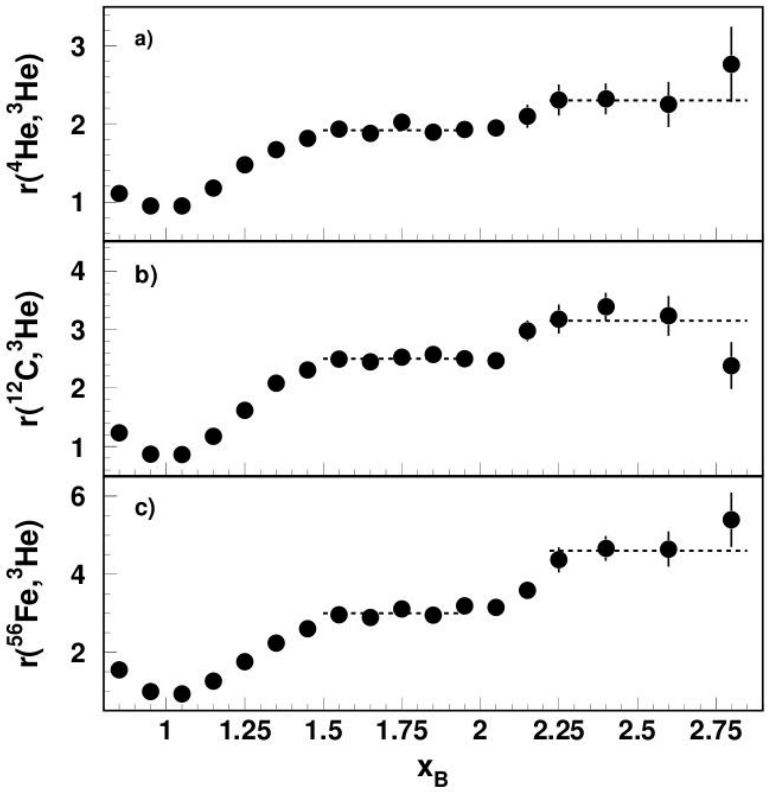


spectra of triton dependently on momentum and X_2



“Measurement of 2- and 3-nucleon short range correlation probabilities in nuclei.”

CLAS Collaboration (K.S. Egiyan et al.) Phys.Rev.Lett.96:082501,2006



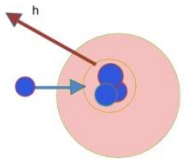
The ratios of inclusive electron scattering cross sections of He4, C12 and Fe56 to He3 have been measured at 1 < x_B < 3. At Q^2 > 1.4 GeV^2, the ratios exhibit two separate plateaus, at 1.5 < x_B < 2 and at x_B > 2.25. This pattern is predicted by models that include 2- and 3-nucleon short-range correlations (SRC). Relative to A=3, the per-nucleon probabilities of 3-nucleon SRC are 2.3, 3.2, and 4.6 times larger for A=4, 12 and 56. This is the first measurement of 3-nucleon SRC probabilities in nuclei.

TABLE I. $a_j(A/^3\mathrm{He})$ and $a_{jN}(A)$ $(j = 2, 3)$ are the per nucleon relative (to ^{3}He) and absolute probabilities of (jN) SRC, respectively. Errors shown are statistical and systematic for a_j and are combined (but systematic dominated) for a_{jN}. The systematic uncertainties due to the Coulomb interaction and SRC c.m. motion are not included. For the $^{56}\mathrm{Fe}/^3\mathrm{He}$ ratio they are expected to be $<2\%$–6% and $<20\%$, respectively, and are somewhat smaller for $^{12}\mathrm{C}/^3\mathrm{He}$ and smaller still for $^4\mathrm{He}/^3\mathrm{He}$ ratios.

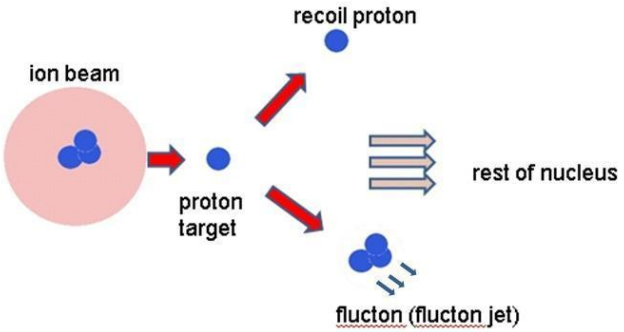
	$a_2(A/^3\mathrm{He})$	$a_{2N}(A)$ (%)	$a_3(A/^3\mathrm{He})$	$a_{3N}(A)$ (%)
^{3}He	1	8.0 ± 1.6	1	0.18 ± 0.06
^{4}He	$1.93 \pm 0.02 \pm 0.14$	15.4 ± 3.3	$2.33 \pm 0.12 \pm 0.19$	0.42 ± 0.14
^{12}C	$2.41 \pm 0.02 \pm 0.17$	19.3 ± 4.1	$3.05 \pm 0.14 \pm 0.21$	0.55 ± 0.17
^{56}Fe	$2.83 \pm 0.03 \pm 0.18$	22.7 ± 4.7	$4.38 \pm 0.19 \pm 0.33$	0.79 ± 0.25

Crazy idea: flucton visualization in Inversed kinematic.
Ion beam interacts with the Liquid Hydrogen Target.
Two-arm detector is needed

- In many previous experiments the inclusive spectra of cumulative particles were measured in region of target fragmentation



- Here we propose to look at properties of a flucton by measurement of whole jet from the its fragmentation will be done.



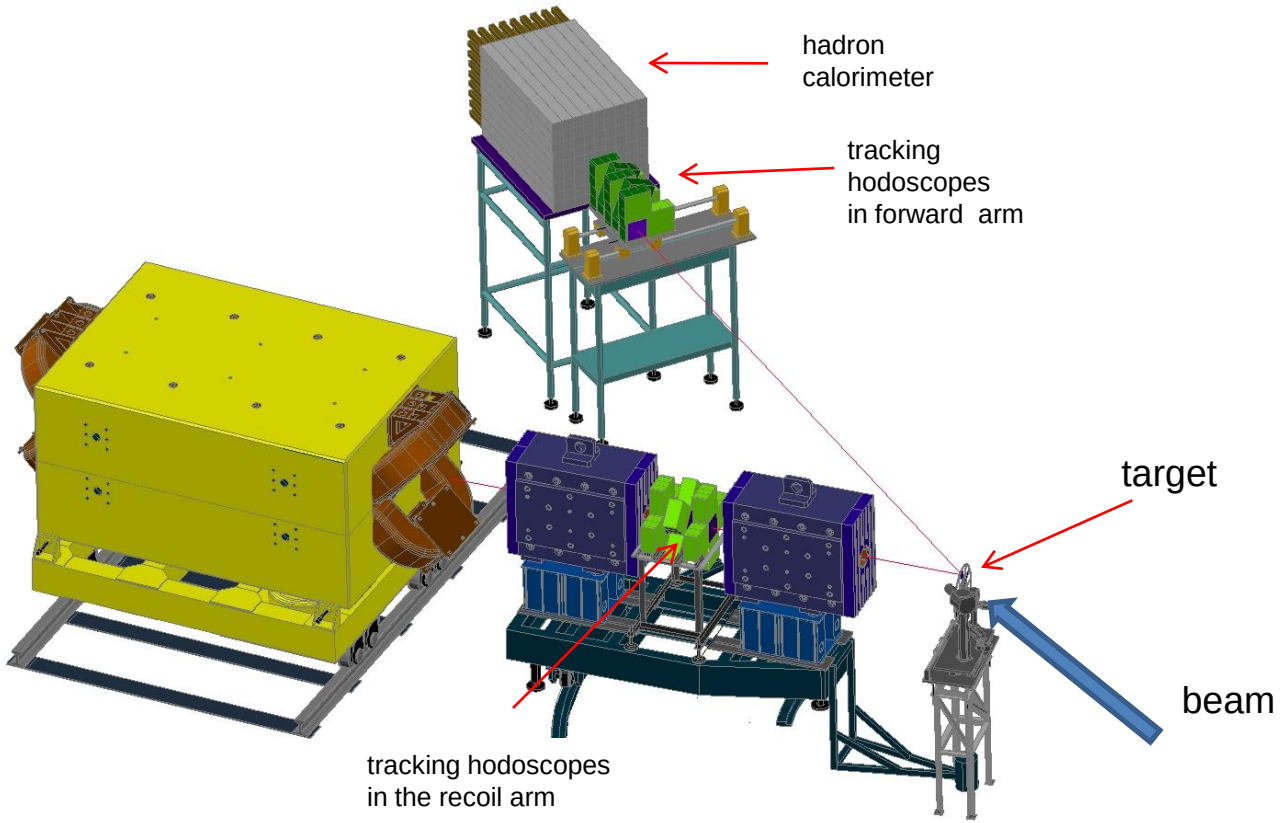
- It is supposed that a rest of nucleus will move along beam direction not affecting a measurements with double arm detector.
Region of high P_T values will be chosen for a study.

- Width of jet from a fuction should be narrow because inclusive spectra of cumulative particles $f = E \cdot d\sigma/d^3p$ can be described
[G. A. Leksin, Phys. At. Nucl. 65, 1985 (2002)]. with $C \cdot exp(-T/T_0)$ at $T_0 \sim 100$ MeV

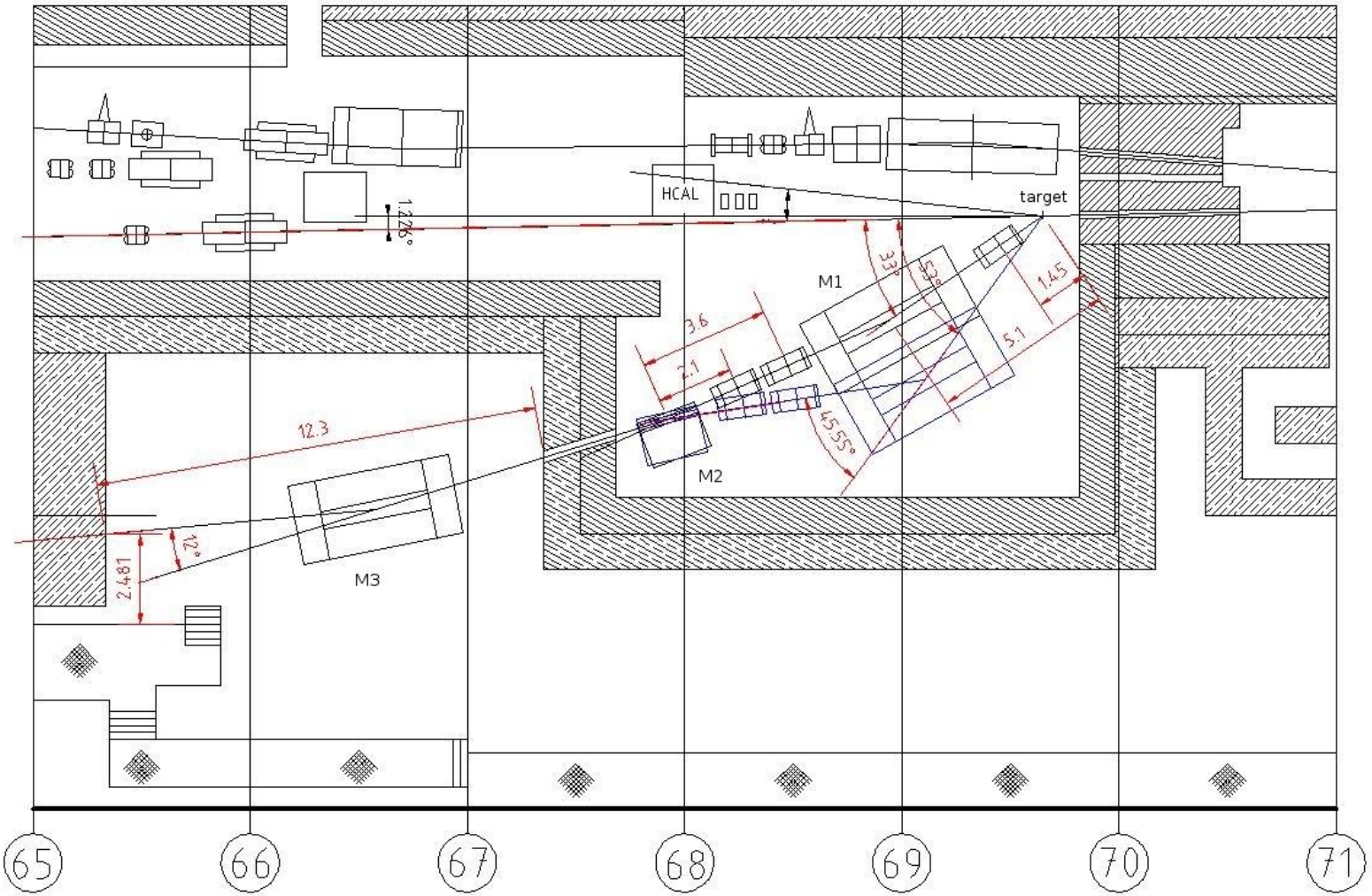
from SPIN to FLUKTON

Recoil arm: almost the same as in SPIN but added with tracking hodoscopes

Forward arm: consists of several hodoscope stations plus 100 modules of hadron calorimeter. Length of the arm – 700 cm



Proposed location of the two arm detector in 23rd beam line at U70



Physical Program for FLUKTON :

1. Correlation measurements using 10-15 A·GeV carbon beam with Liquid Hydrogen and nuclear targets with purpose to visualize a knockout of multinucleons configurations and to study their properties.

2. The colour (nuclear) transparency measurements in *A(p,2p)* reactions at the U70 energies. New information about *A* and angle dependences can be received.

3. More detailed and wider inclusive spectra measurements as continuation of the SPIN study will be provided.

What is different in d+p and p+p elastic processes when angle of recoil proton is fixed?

Table I	d+p-->d+p, 2x10 GeV/c				
№	fixed angle, recoil proton deg	45	48	50	52
1	-t GeV^2	2.91	2.40	2.10	1.84
2	recoil proton, momentum GeV/c	2.30	2.00	1.83	1.67
3	deuteron momentum GeV/c	18.44	18.72	18.87	19.01
4	angle of deuteron deg	5.07	4.57	4.26	3.97
elastic pp at 10 GeV/c					
5	recoil proton, momentum GeV/c	2.06	1.82	1.67	1.53
6	fast proton, mjmentum GeV/c	8.66	8.89	9.02	9.14

t+p→t+p at 3x10 GeV/c

Table II t+p →t+p 3x10 GeV|c				
angle of recoil arm, deg	**45**	**48**	**50**	**52**
-t GeV^2	**3.07**	**2.52**	**2.20**	**1.92**
Momentum of recoil proton ,GeV/c	**2.40**	**2.08**	**1.89**	**1.72**
momentum of tritium, GeV/c	**28.35**	**28.64**	**28.82**	**28.97**
angle of tritium, deg(rad)	**3.43(0.060)**	**3.09(0.054)**	**2.88(0.050)**	**2.69(0.047)**

Cumulative recoil proton can be used as a trigger for an event produced by flucton-proton scattering. Additional sign of such an event will be extra energy measured in forward arm.

Cross-section of elastic p+d scattering

G.Warren et al., Nucl. Phys. B207 (1982) 365-373 "PROTON-DEUTERON ELASTIC SCATTERING FROM 20 TO 210 GeV"

$$\frac{d\sigma}{dt}(t)pd = \frac{I_G^2}{\pi}\left(\frac{d\sigma}{dt}(t/4)\right)^2_{pp}$$

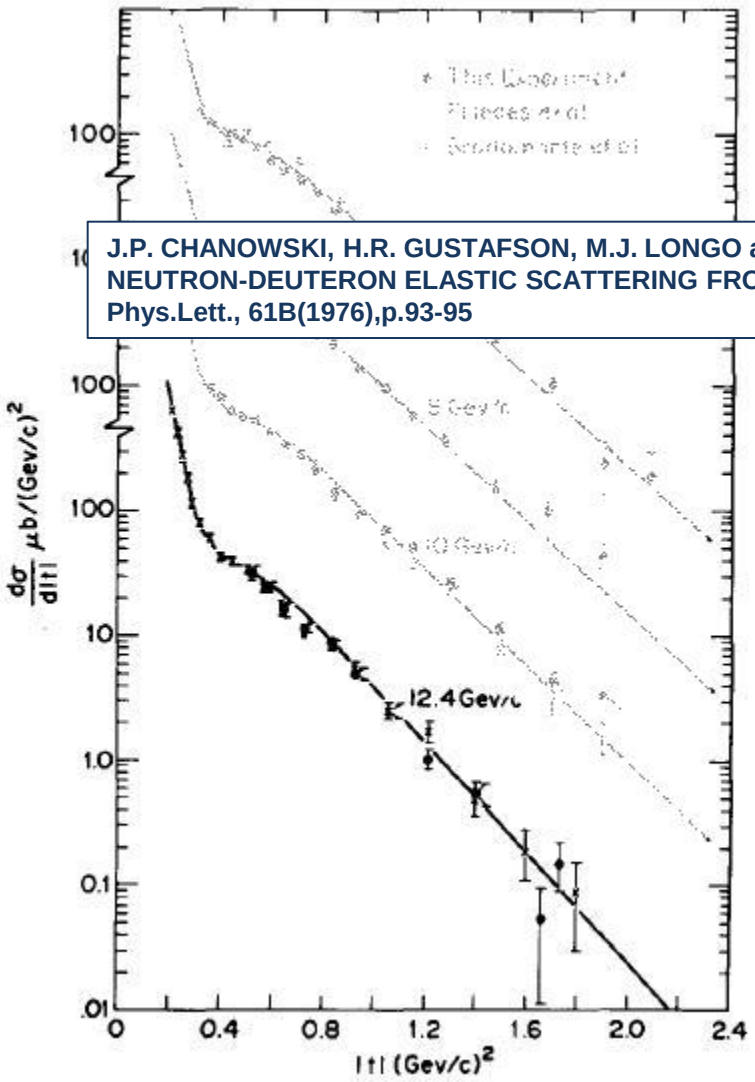
where Glauber integral $I_G = \frac{1}{2}\int_0^\infty S(t)\, e^{b_{pp}t}\, dt$

deuteron form-factor [Y.Akimov et al., Phys.Rev. D12(1975)3399]:

$$S(t) = 0.34\, e^{141.5t} + 0.58 e^{26.1t} + 0.08 e^{15.5t}$$

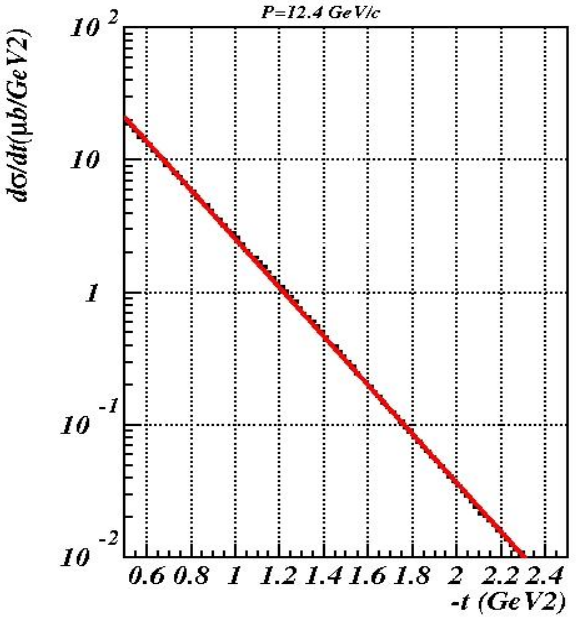
Cross-sections for elastic pp were taken from E.Martynov, Phys.Rev. 76, 074030 (2007)

an example how the calculation can describe existing data



J.P. CHANOWSKI, H.R. GUSTAFSON, M.J. LONGO and J.L. STONE, NEUTRON-DEUTERON ELASTIC SCATTERING FROM 6 TO 12.5 GeV Phys.Lett., 61B(1976),p.93-95

calculated cross-section



$C^{12}+p \rightarrow d+p+X$, expected cross-sections and signal rate

- 10A or 15A GeV carbon beam I=10^9 ions/cycle
- liquid hydrogen target with only 4 cm working length along beam
- luminosity L=10^{32} $cm^{-2}s^{-1}$
- fraction of ***2N***-objects in carbon ≈20%

[K.S. Egiyan *et al.* Phys. Rev. Lett. 96, 082501 (2006)]

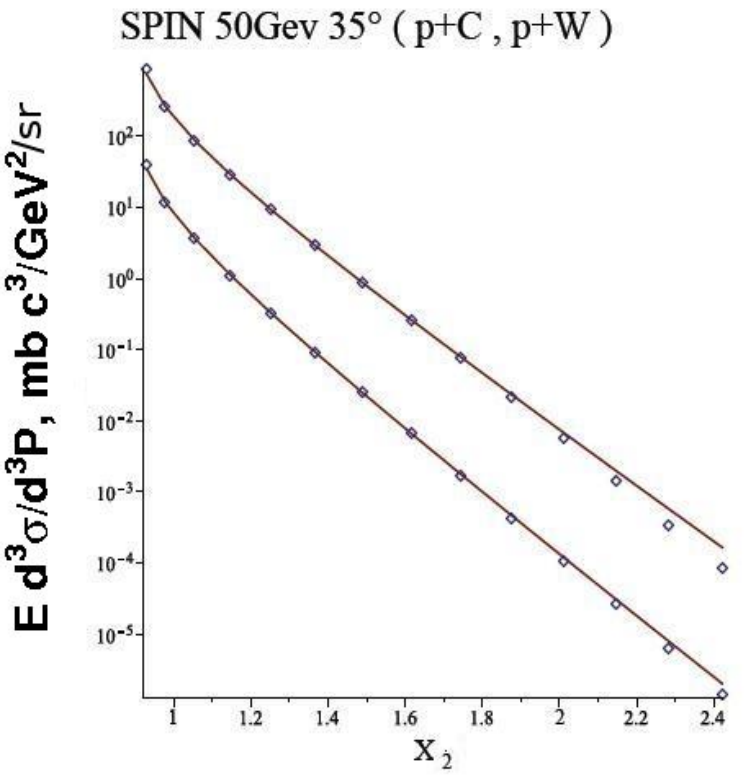
	angle of recoil arm (deg)	45	48	50	52
10A GeV/c	dσ/dt(μb/GeV²)	1.35E-03	9.7E-03	3.4E-02	1.0E-01
	yield/hour	~0.4	3.1	12	33
15A GeV/c	dσ/dt(μb/GeV²)	3.1E-04	3.0E-03	1.1E-02	3.7E-02
	yield/hour	0.1	1	3.5	12

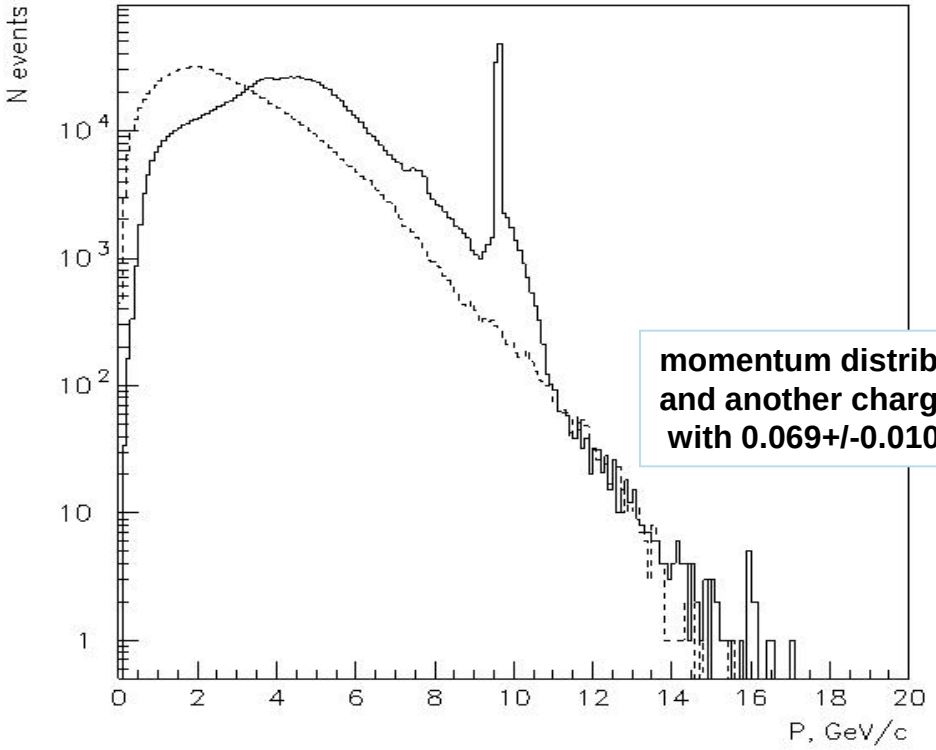
angular acceptance on azimuth and polar angle was taken into account

Background can be due to accidental coincidence between:
cumulative proton production (inclusive) and
prompt .particle produced in few intranuclear rescatterings

Baldin's parameterization was used[A.A. Baldin, brief communication of JINR (Dubna).1992,№3–92. С. 27–37; 1996. № 4–96. С. 61–68; 1999.№2–99. С. 20–29.] to estimate .proton cross-section in cumulative region

An example demonstrating how well Baldin's parameterization describes experimental cross-sections of proton production (SPIN experiment) dependently on Stavinskii variable X2





Simulation of prompt charge particles production with :HIJING vers 1.34(no flucton, no fermi motion) C^{12}+p 10A GeV

momentum distribution for protons(solid) and another charge particle (dashed) emitted with 0.069+/-0.010 polar angle (52^0)

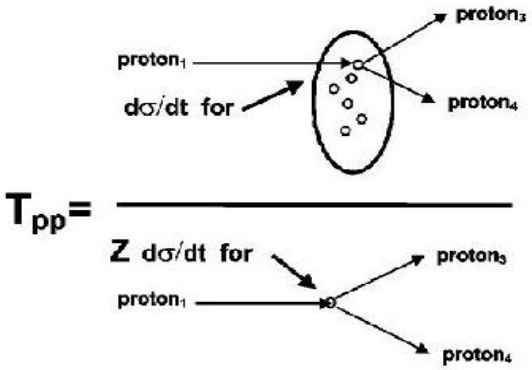
Taking into account that the hadron calorimeter resolution will be not better than 10%, all particles above ~12 GeV were considered as “useful” signal

Background rate (low line) in comparison with d+p → d+p rate for four angles of recoil arm

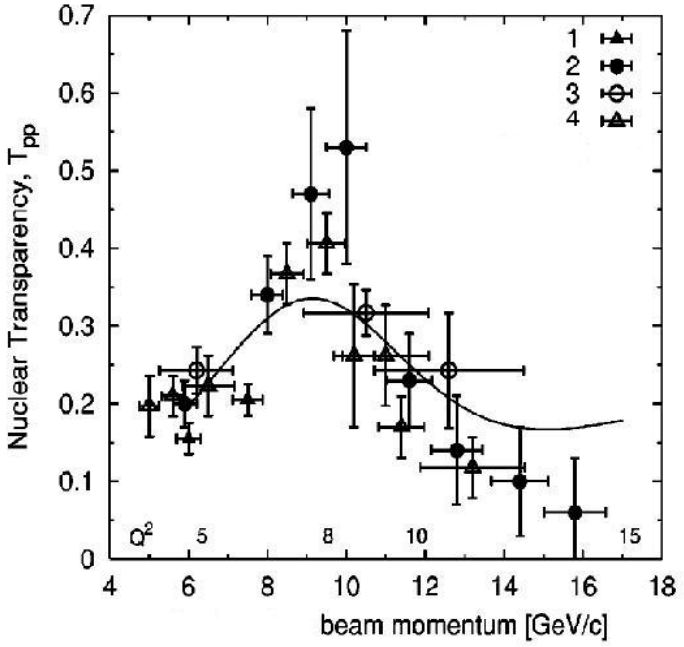
	angle (deg)	45	48	50	52
10A GeV/c	signal/hour	0.4	3.1	12	33
	backgrnd/hour	0.005	0.025	0.06	0.15

Another possible application of the FLUKTON detector – to measure nuclear transparency at U70 energy

Color transparency was predicted on base of QCD ideas in 1982
[S.J.Brodsky, Proc. of the XIII Intern.Symp. on Multi-particle Dynamics, 1982]
[A.Mueller, Proc.of the XVII Recontre de Moriond, 1982]
In exclusive A(p,2p) scattering at high Q^2 momentum transfer a stable point-like state of proton can be produced. It was supposed that this object exists during enough long time for to leave nucleus without interaction. The nuclear transparency is defined as the ratio of the quasi-elastic cross section in a nuclear target to the free elastic pp cross section.



According to QCD the transparency must be small at small Q^2 and rise with growth of momentum.
Traditional Glauber calculations predict transparency to be energy independent.



The measured results showed a rise in Tpp with the beam momentum up to ~9.5GeV/c, which was consistent with expectations coming from the QCD theory. However, this rise was surprisingly followed by a drop at higher momenta. Several experiments in BNL confirmed the same.

Gerald A. Miller,2012 arXiv:1208.3668 : "**Color transparency is an expected, but not certain, consequence of QCD…..Evidence at medium energy is piling up. It seems that PLC formation is an important part of (single) meson production at large values of Q2, but has not yet been observed for the nucleon."**

John P.Ralston (2006):

"An experiment with a 50-70 GeV beam is quite ambitious. It is clear that the whole range of angles 15-40 degrees you cite should test the different models in a completely new regime. It would be straightforward to extend our method and confront such data quantitatively."

In case of FLUKTON the Tpp values will be measured by comparison of cross-sections for quasi-elastic proton- nuclei scattering with cross-section of elastic pp scattering using high intensive proton beam

Liquid Hydrogen Target is supposed to be used to measure pp scattering/ parameters of elastic scattering at different angles of the “recoil” arm

recoil, angle(degree)	50.	46.4	42.0	38.5	36.
Δt, GeV^2	0.13	0.16	0.22	0.28	0.33
t, GeV^2	2.33	2.98	4.00	5.07	6.01
P_{rec}, GeV/c	1.93	2.30	2.92	3.51	4.03

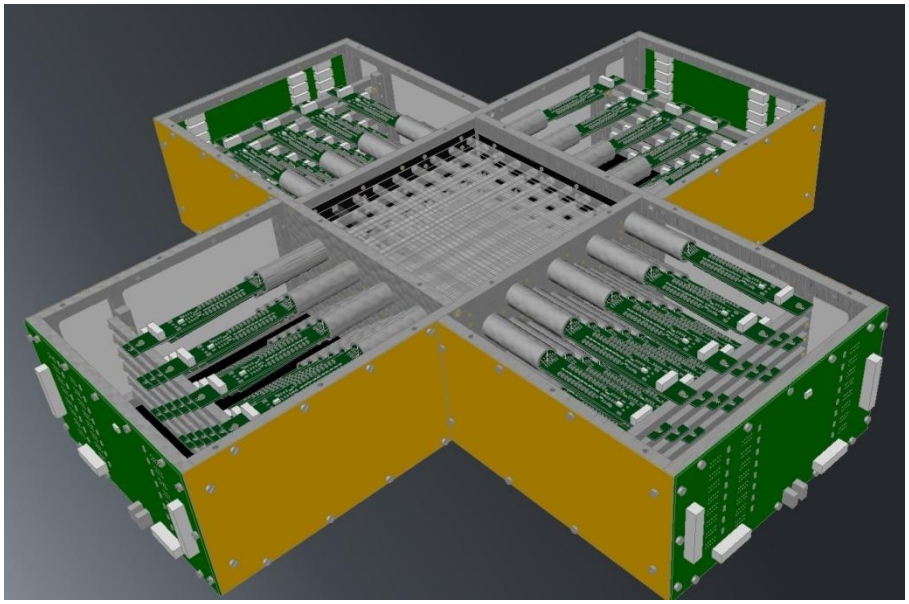
expected rate of elastic scattering events

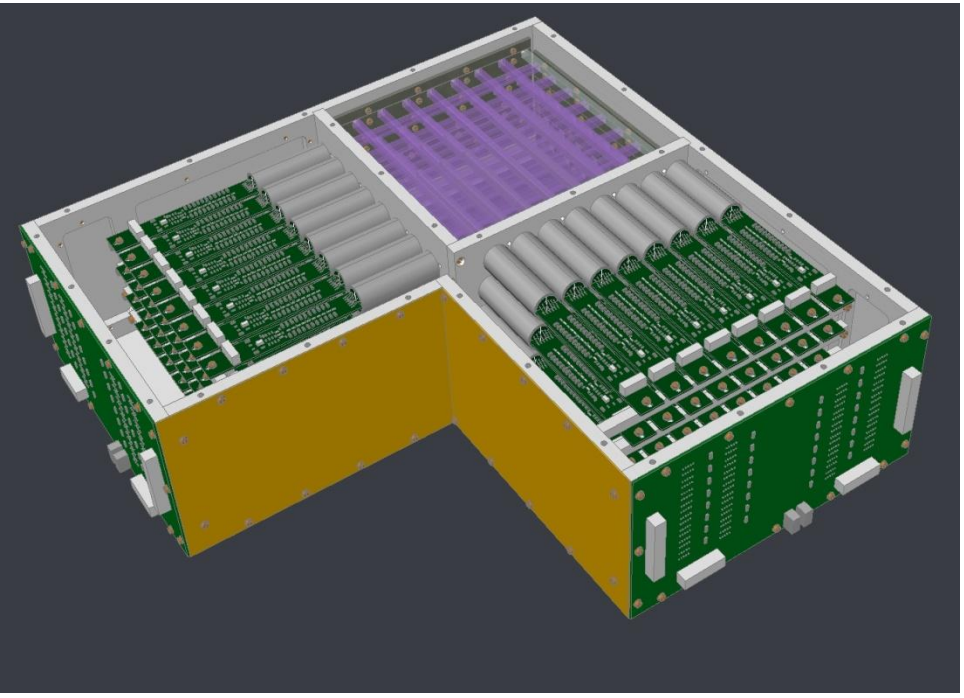
recoil agle	50.	46.4	42.0	38.5	36.
dσ/dt,nb/GeV^2	132.4	34.8	4.96	0.664	0.112
rate	2560/h	828/h	162/h	27.7/h	5.4/h

Steps already done towards FLUKTON

HODOSCOPES

Double-coordinate **hodoscope** stations are multichannel scintillating counters.
Step of scintillators in a forward arm station is 6mm, step in a recoil arm -2 mm

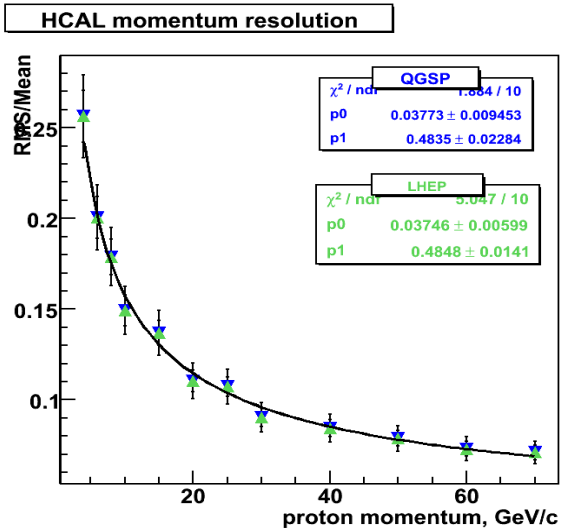




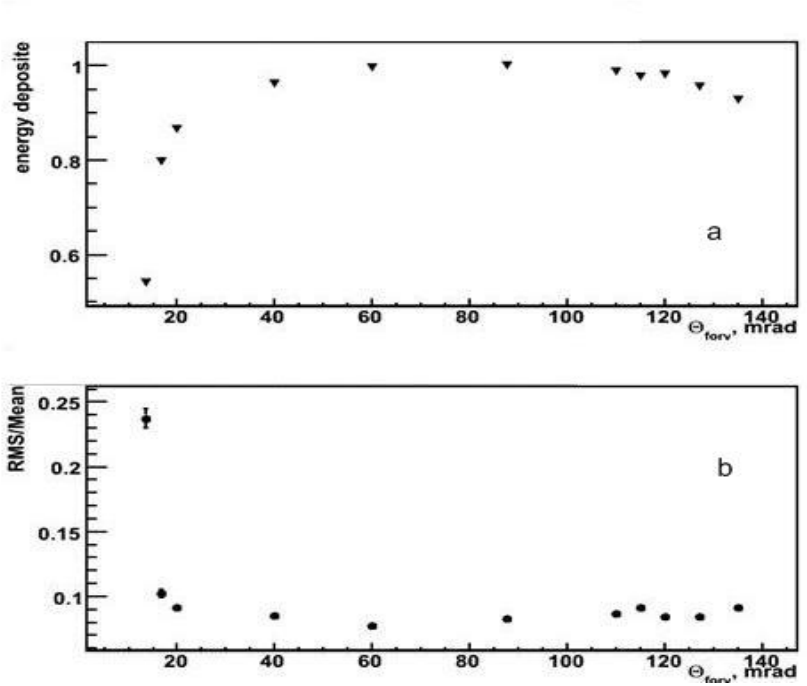
Hadron calorimeter.Computations

Calorimeter: compensating lead/plastic-scintillator sampling calorimeter. Each module is composed with 6mm lead and 1.5 mm plastic. Total length is 6.5 interaction length. Calorimeter consists of 100 modules so its transverse size is about 1x1 m2 (10x10 tower structure)

simulation with GEANT4

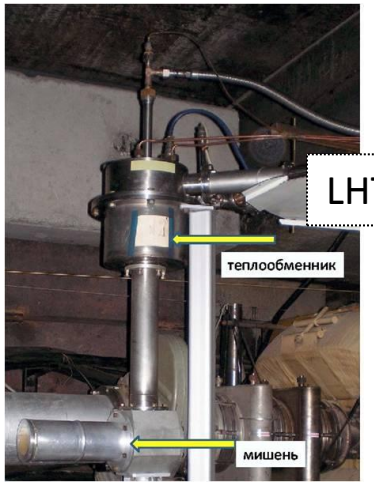


resolution vs momentum

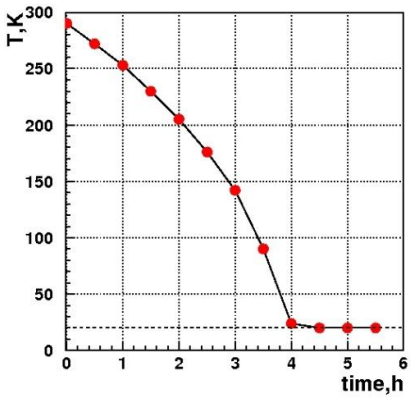


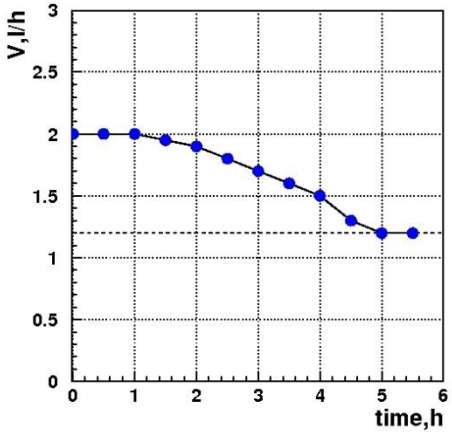
fraction of energy deposited in calorimeter and the resolution dependently on polar angle

Liquid Hydrogen Target (LHT) . Produced for SPIN and tested with beam in 2010



LHT mounted in SPIN area





Stabilization of the LHT temperature (left) and liquid helium flux (right) during ~5 hours past after start

What done, what to be done and its cost

	element	state	readiness	cost estimation million rubles
1	magnets of recoil arm	from SPIN	100%	
2	tracking system in recoil arm	PCs from SPIN +new electronics	100%	0.5
3	TOF RPC+ FEE+HPTDC	from SPIN but new HPTDC needed	90%	0.5
4	scintillating counters+ trigger system	from SPIN	100%	
5	cerenkov detector	from SPIN	100%	
6	automatic target station including Liq.Hydr.Target	from SPIN	100%	
7	hodoscopes of recoil arm	produced, tested	90%	
8	hodoscopes of forward arm	produced, tested	90%	
9	FEE and DAQ for hodoscopes	designed and partially produced	85%	0.2
10	hadron calorimeter, 100 modules	to be designed, to be produced	0%	12
11	FEE and DAQ for calorimeter	to be designed, to be produced	0%	0.6
12	mechanical support for magnets support for calorimeter	to be designed, to be produced	0%	?

BACKUP

Г.А. Лексин, Яд.Физ. т.65 (2002) 2042

Начиная с некоторой энергии E0 величина эффекта не зависит от энергии.
E0 зависит от типа частицы и от ядра.

Инвариантная функция f=Cexp(-T/T0)

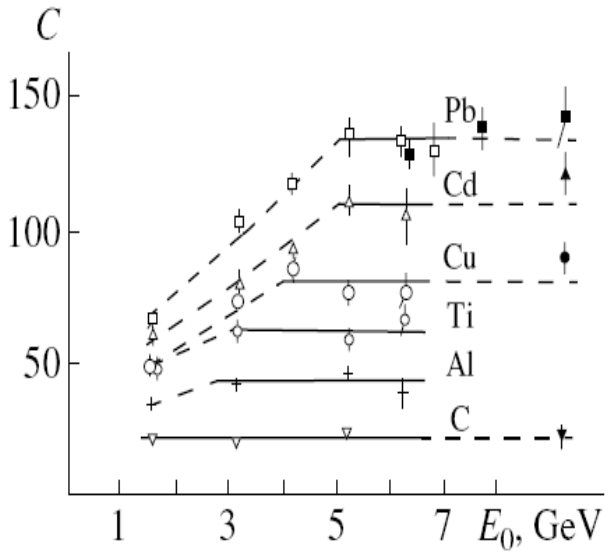


Fig. 3. The coefficient $C(T_0 = 125$ MeV) in the parametrization of the invariant function $f = C\exp(-T/T_0)$ in the reaction pA(C, Al, Ti, Cu, Cd, Pb) $\rightarrow pX$ for a proton escape angle of 120° in the laboratory frame versus the incident-proton energy. The filled circles refer to the initial energy of 400 GeV.

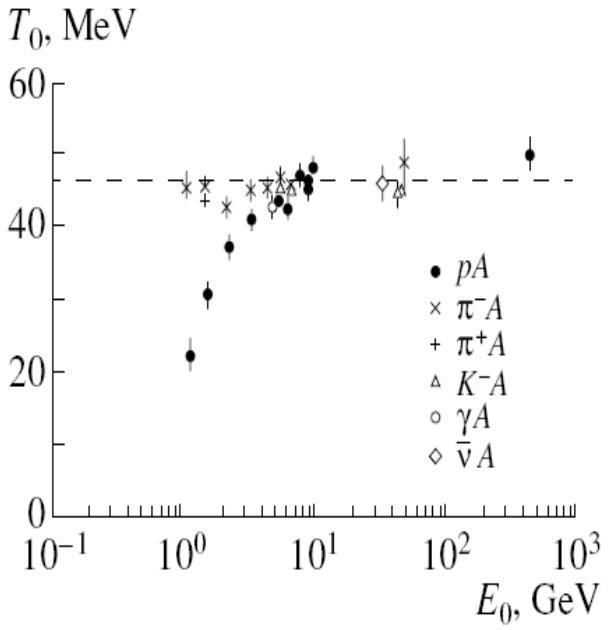


Fig. 5. Dependence of the slope parameter T_0 for the invariant function of the protons escaping under the action of $p, \pi^{\pm}, K^-, \gamma, \bar{\nu}$ with various energies E_0; the escape angle is 120° in the laboratory frame.

FAS@ITEP pCu, 10 GeV

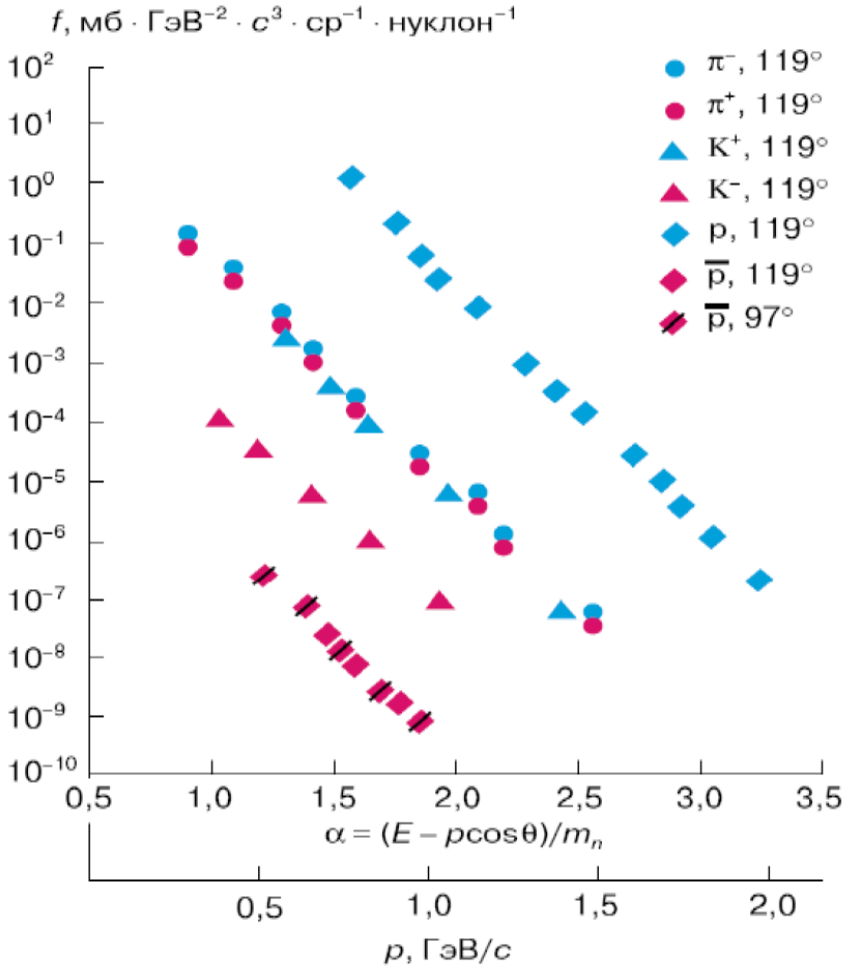
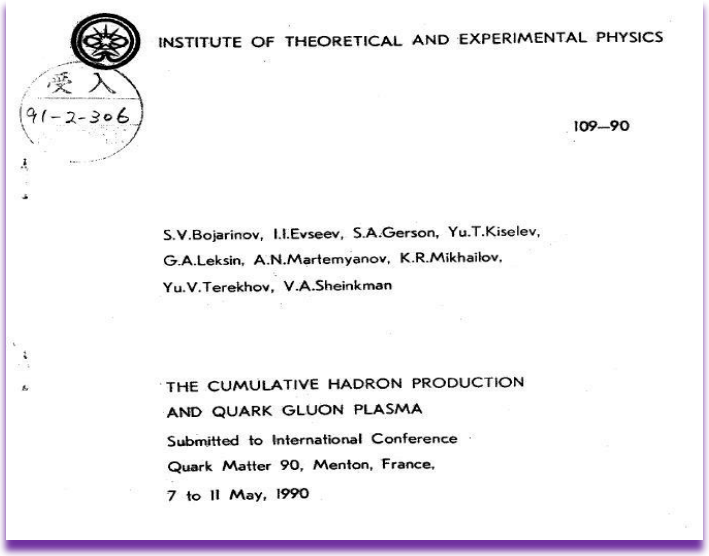


Рис. 2. Зависимость инвариантных функций различных кумулятивных частиц от их величин α. Нижняя шкала абсцисс – импульс кумулятивных протонов при соответствующем α.



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THE CUMULATIVE HADRON PRODUCTION
AND QUARK GLUON PLASMA

Submitted to International Conference
Quark Matter 90, Menton, France,
7 to 11 May, 1990

- T0 не зависит от типа вылетающей частицы
- Выходы π^+ и π^- частиц одинаковы
- Выходы K^+ и π^+ близки

$$K-/K+ \approx \overline{d}/u$$

$$K-/\pi- \approx s/d$$

$$K+/\pi+ \approx \overline{s}/\overline{d}$$

This supports a model of fluctons as multiquark bag and not a short range nucleon correlation

n-p Short-Range Correlations from (p,2p + n) Measurements

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We studied the ^{12}C(p,2p+n) reaction at beam momenta of 5.9, 8.0 and 9.0 GeV/c. For quasielastic (p,2p) events we reconstructed $\mathbf{p}_f$ the momentum of the knocked-out proton before the reaction; $\mathbf{p}_f$ was then compared (event-by-event) with $\mathbf{p}_n$, the measured, coincident neutron momentum. For $|\mathrm{p}_n| > \mathrm{k}_F = 0.220$ GeV/c (the Fermi momentum) a strong back-to-back directional correlation between $\mathbf{p}_f$ and $\mathbf{p}_n$ was observed, indicative of short-range n-p correlations. From $\mathbf{p}_n$ and $\mathbf{p}_f$ we constructed the distributions of c.m. and relative motion in the longitudinal direction for correlated pairs. After correcting for detection efficiency, flux attenuation and solid angle, we determined that 49 ± 13 % of events with $|\mathrm{p}_f| > \mathrm{k}_F$ had directionally correlated neutrons with $|\mathrm{p}_n| > \mathrm{k}_F$. Thus short-range 2N correlations are a major source of high-momentum nucleons in nuclei.

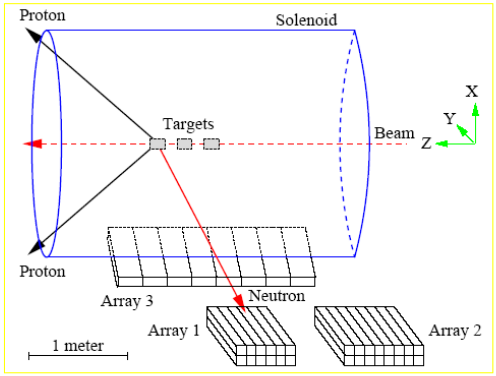

Figure I.3: A schematic view of the EVA solenoid and the neutron counters in the 1998 measurement.

Г.А.Лексин, ЯФ т.65,2002,с.2042

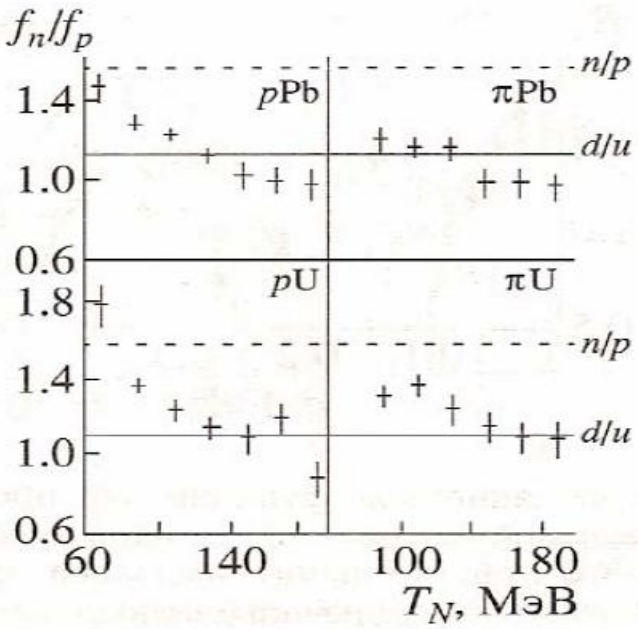

Рис. 12. Отношение выходов нейтронов к протонам из изонесимметричных ядер Pb и U в зависимости от кинетической энергии вылетающих нуклонов; угол вылета 120°, начальная энергия протонов 7.5 ГэВ и пионов 5 ГэВ. Данные, полученные под действием $\pi^{\pm}$-мезонов, усреднены. Штриховые линии — отношение нейтронов к протонам в ядрах мишени, сплошные — отношение d/u-кварков в ядрах Pb и U.