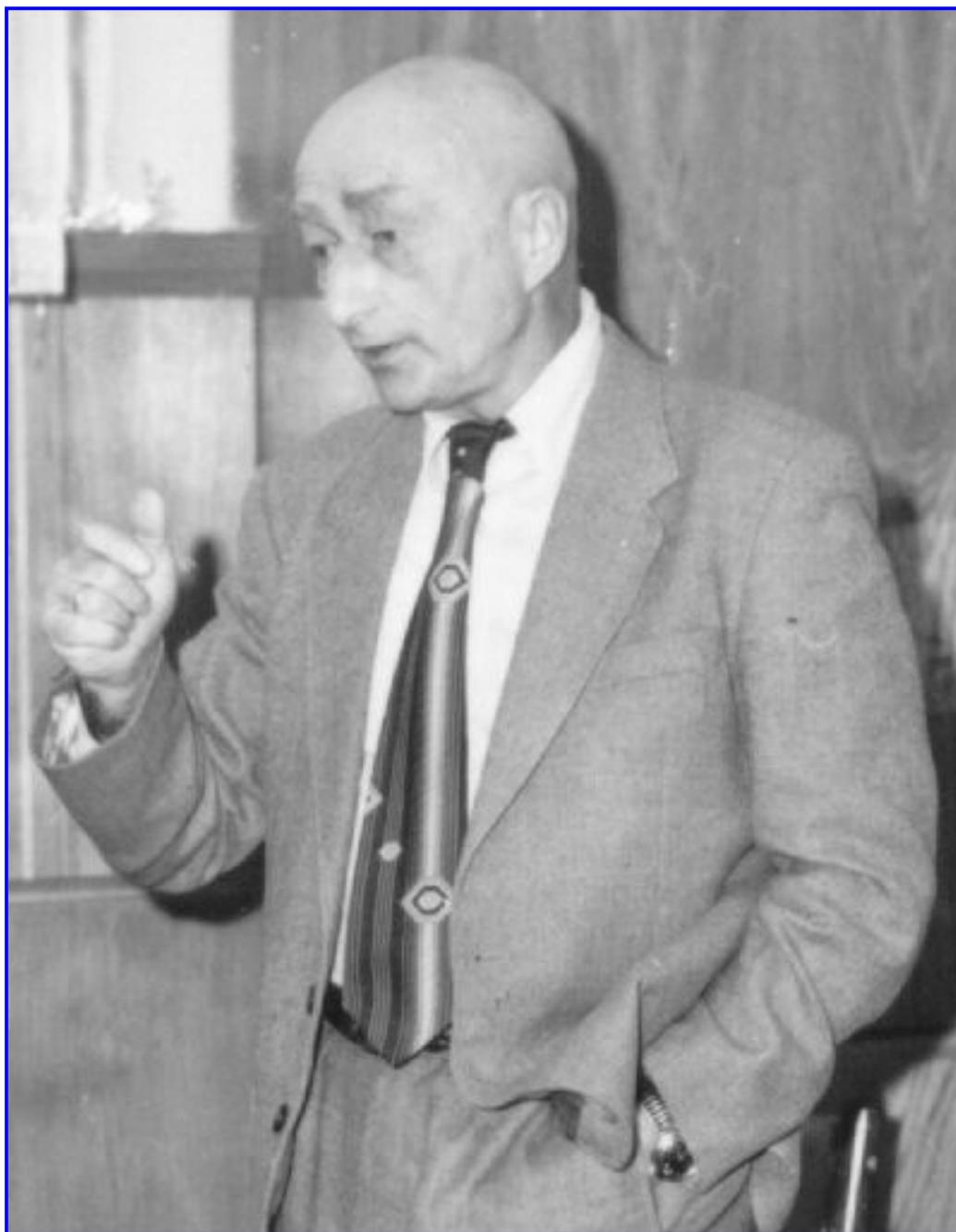


Investigations in Veksler and Baldin Laboratory of High Energies

A.I.Malakhov

*Veksler and Baldin Laboraory of High Energies of
Joint Institute for Nuclear Research, Dubna, Russia*





Investigations in Veksler and Baldin Laboratory of High Energies

- *Development of the Nuclotron
Accelerator Complex*
- *Relativistic Nuclear Physics at VBLHE
Accelerator Complex*
- *Participation in Physics Research at
Other Scientific Centers*



Research Programme of VBLHE in 2005-2007

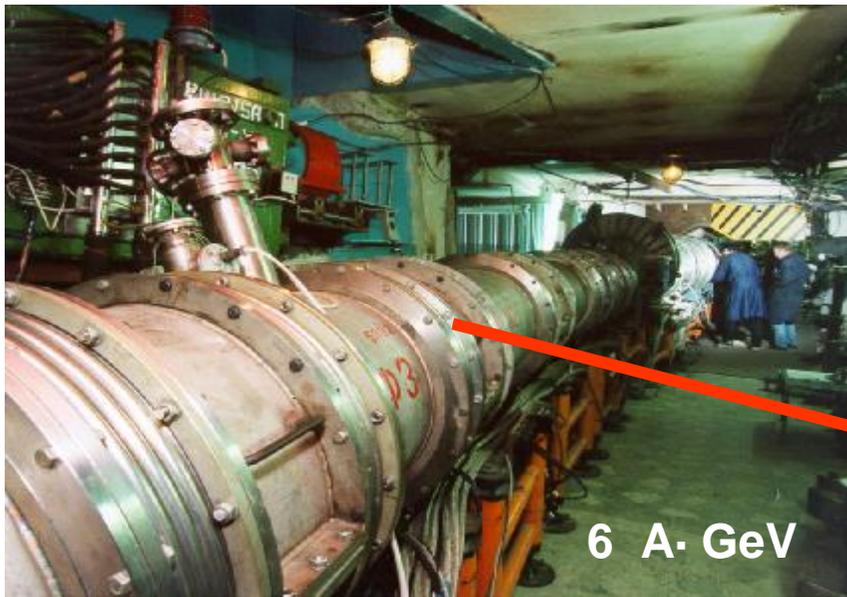
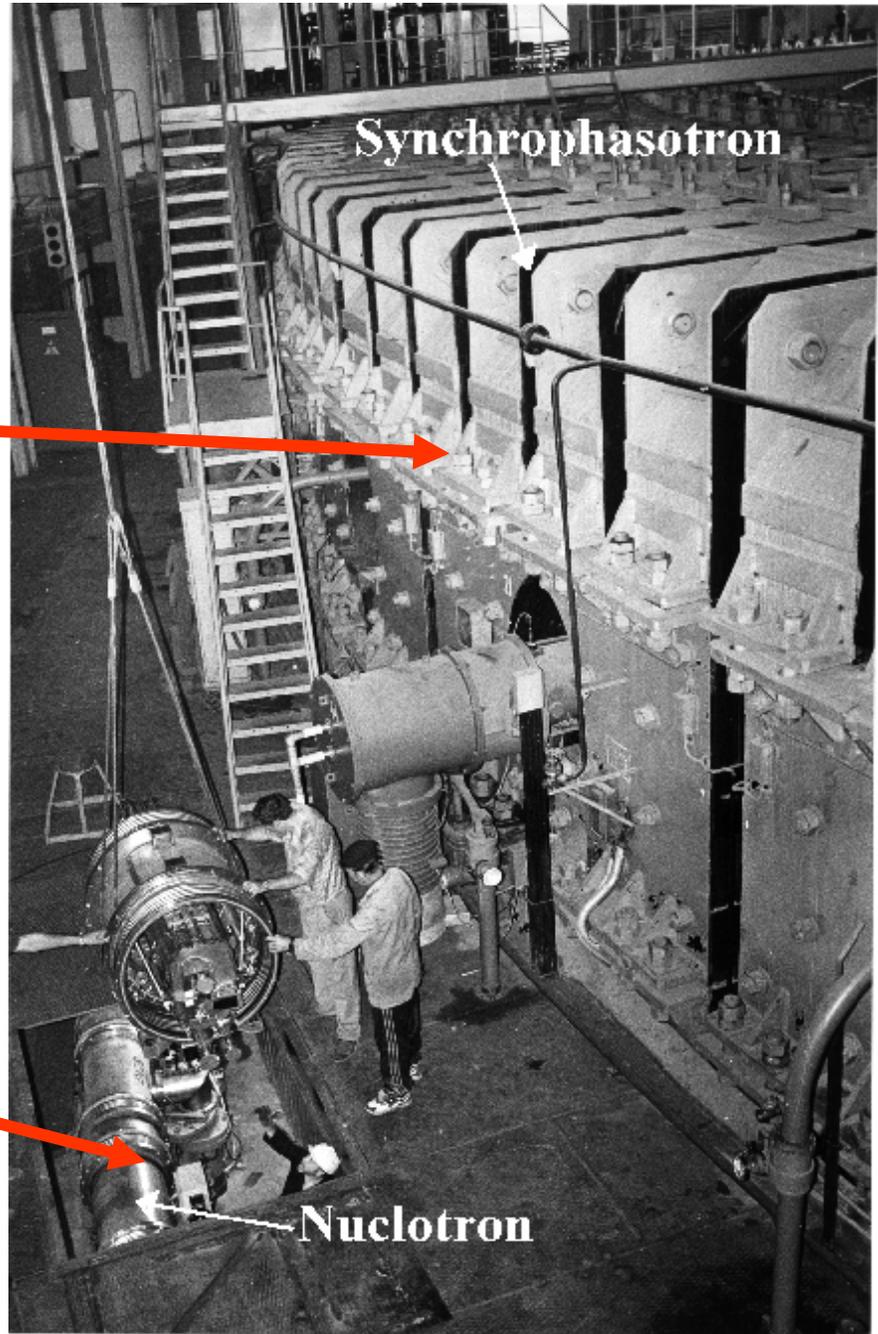
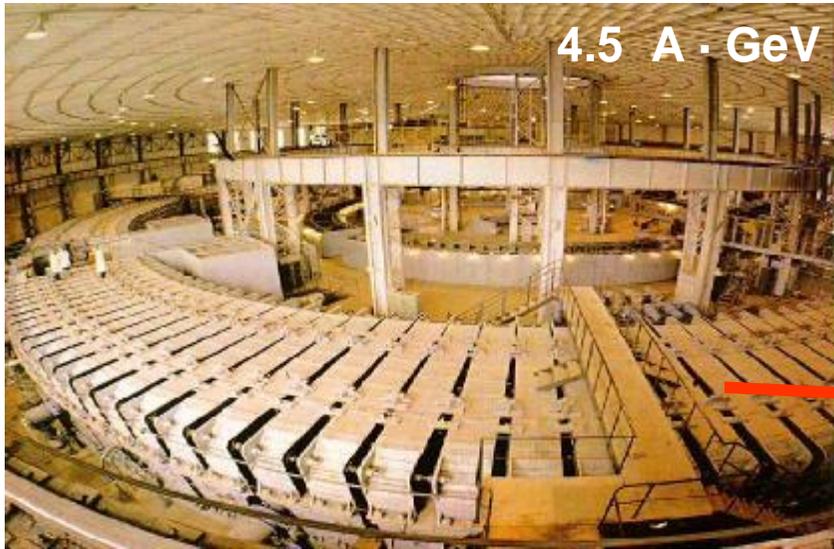
Relativistic Nuclear Physics at VBLHE Accelerator Complex:

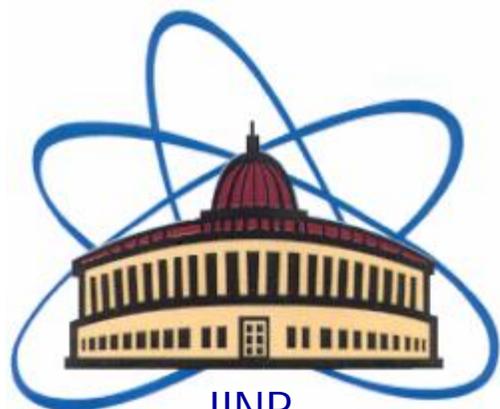
- *Investigations hadron and nuclear structure*
- *Spin Physics at Relativistic Energies*
- *Applied research*



Investigations in Veksler and Baldin Laboratory of High Energies

NUCLOTRON





JINR

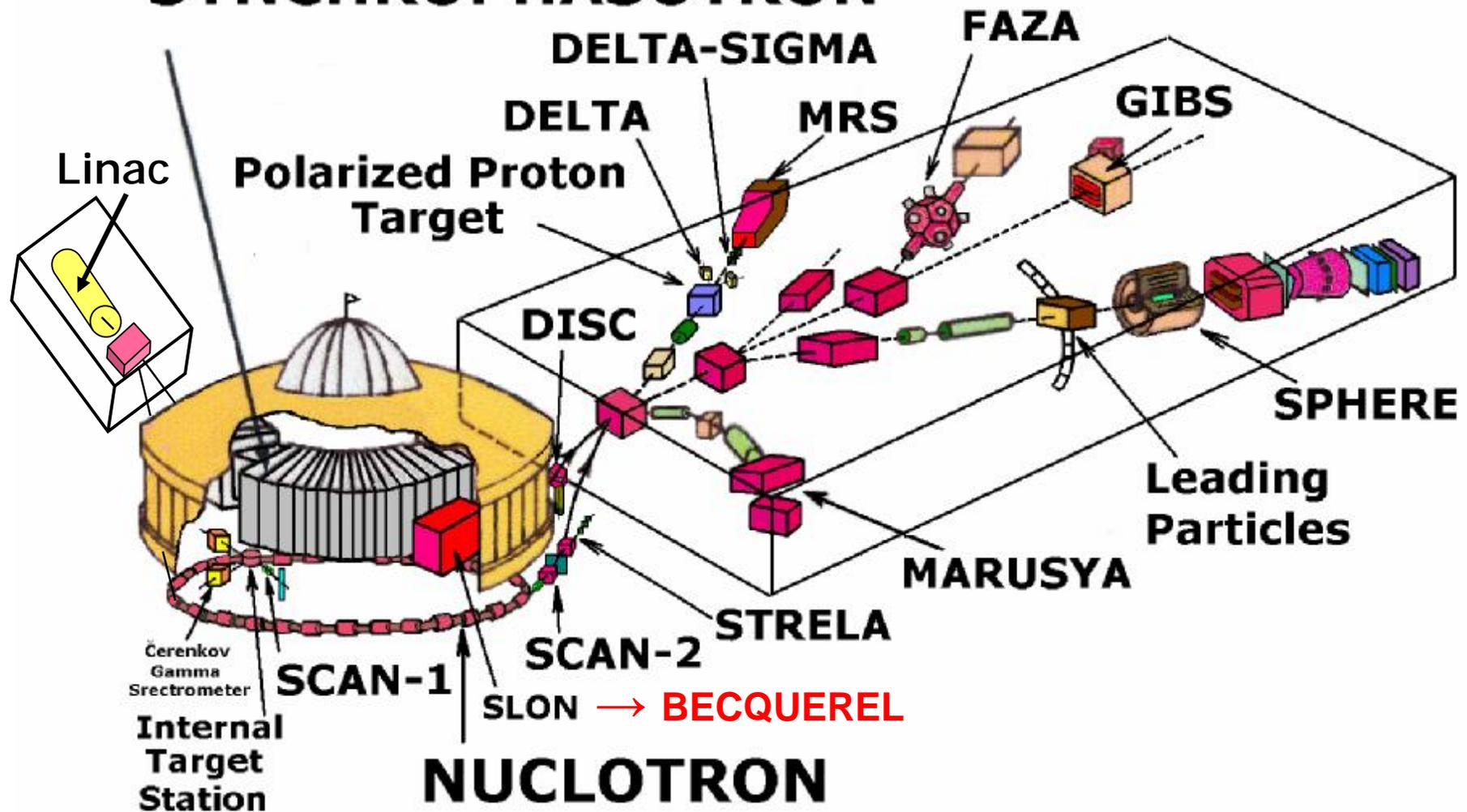
Veksler & Baldin
Laboratory of High
Energies
Dubna



NUCLOTRON

Beam	Nuclotron intensity (particles per cycle)	
	available	have to be (with booster)
p	$2.5 \cdot 10^{10}$	10^{13}
d	$5 \cdot 10^{10}$	10^{13}
d-	$3 \cdot 10^8$	$5 \cdot 10^{10}$
t	$4 \cdot 10^5$	10^{10}
^4He	$8 \cdot 10^8$	$2 \cdot 10^{12}$
^7Li	$2 \cdot 10^9$	$5 \cdot 10^{12}$
^{10}B	$2 \cdot 10^7$	10^{10}
^{12}C	$6.5 \cdot 10^8$	$2 \cdot 10^{12}$
^{24}Mg	$1.2 \cdot 10^8$	$5 \cdot 10^{11}$
^{40}Ar	10^8	10^{10}
^{56}Fe	10^6	10^{11}
^{84}Kr	10^3	$5 \cdot 10^8$

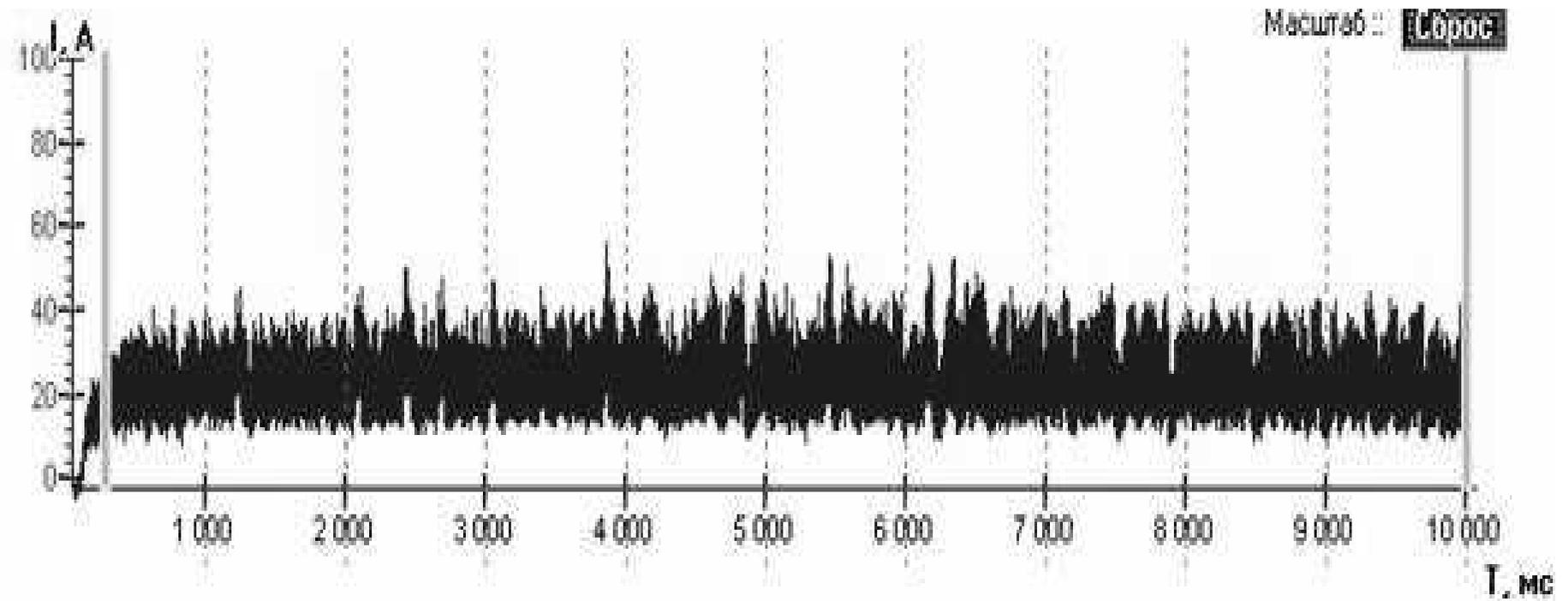
SYNCHROPHASOTRON





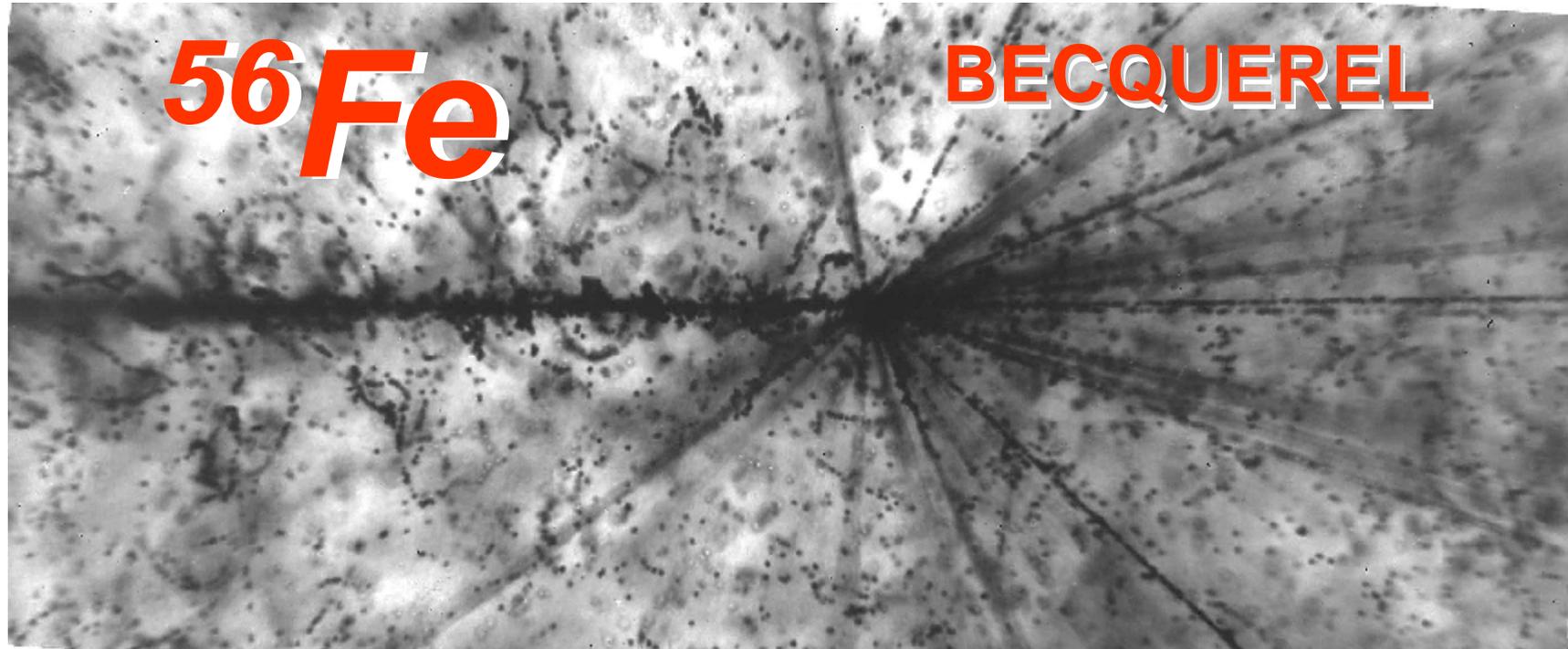
Investigations in Veksler and Baldin Laboratory of High Energies

Nuclotron beam spill up to 10 sec.





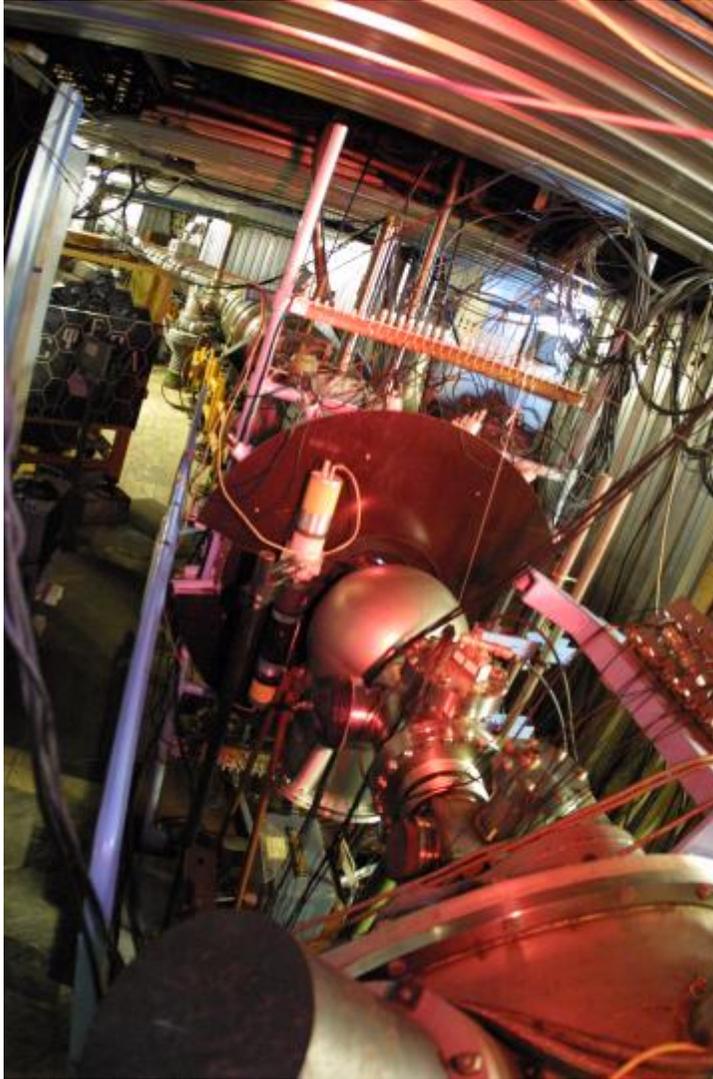
Investigations in Veksler and Baldin Laboratory of High Energies



Interaction of ^{56}Fe ion with $E_{kin} = 1 \text{ A}\cdot\text{GeV}$
from Nuclotron with an emulsion nucleus



Investigations in Veksler and Baldin Laboratory of High Energies



Nuclotron Internal Target Station

Vacuum Prague

Phys.Inst. of SAS, Bratislava

INPNE of BAS, Sofia



Investigations in Veksler and Baldin Laboratory of High Energies

Maximum Nuclotron energy:

Kovalenko A.D., Smirnov A.A.

6 A·GeV

in the end 2005



Investigations in Veksler and Baldin Laboratory of High Energies

$$I_{d-} = 5 \cdot 10^{10} \text{ d/cycle}$$

in 2006



Investigations in Veksler and Baldin Laboratory of High Energies

Relativistic Nuclear Physics at VBLHE



Investigations in Veksler and Baldin Laboratory of High Energies

$$\mathbf{I + II} \text{ (R)} \quad \mathbf{1 + 2 + 3 + \dots}$$

$$b_{ik} = - (u_i - u_k)^2$$

$$u_i = p_i / m_i$$

$$u_k = p_k / m_k$$

$$i, k = \mathbf{I, II, 1, 2, 3, \dots}$$



Investigations in Veksler and Baldin Laboratory of High Energies

Classification of Relativistic Nuclear Collisions on b_{ik}

$$b_{ik} \sim 10^{-2}$$

classic nuclear physics

$$0.1 \leq b_{ik} < 1$$

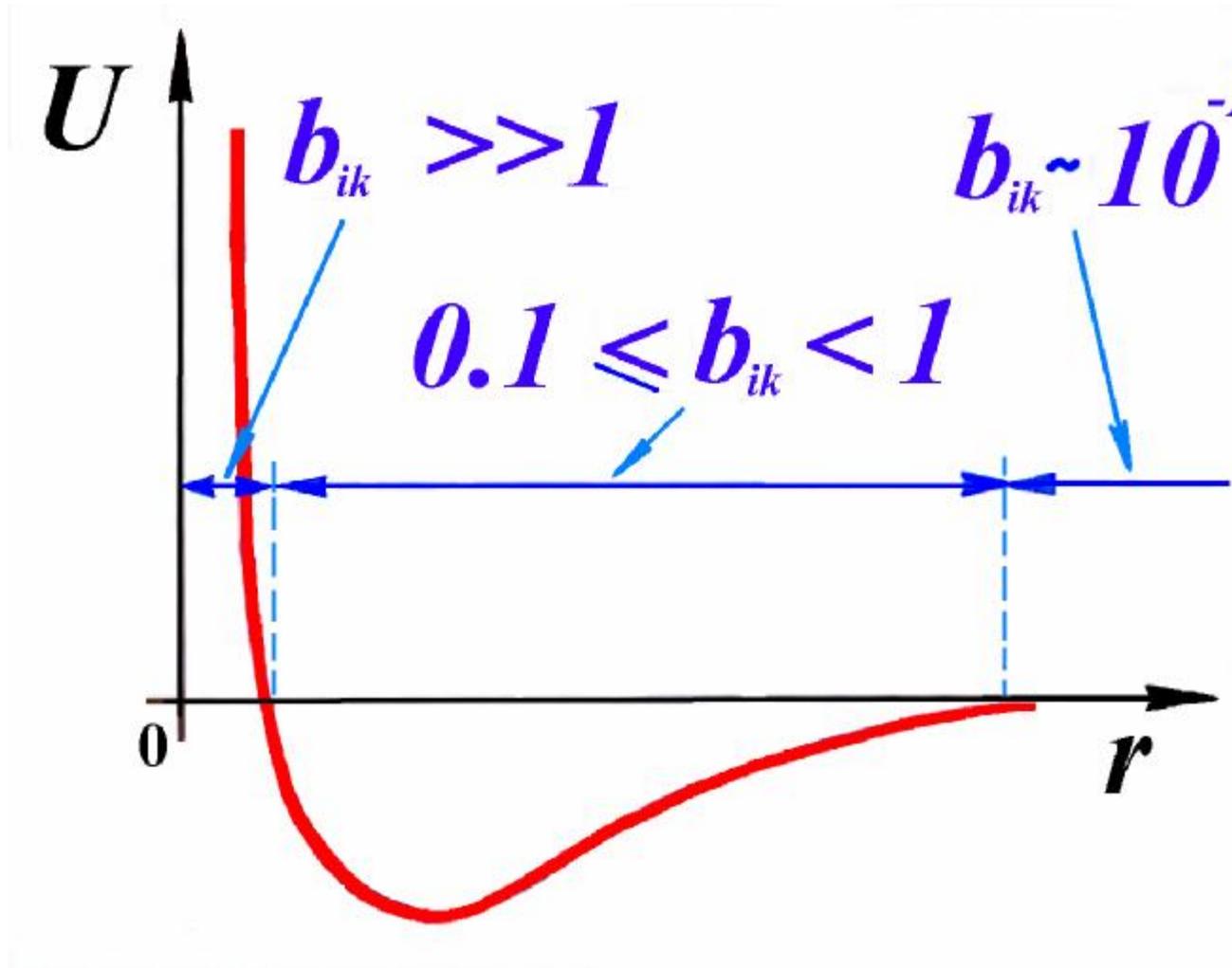
intermediate domain

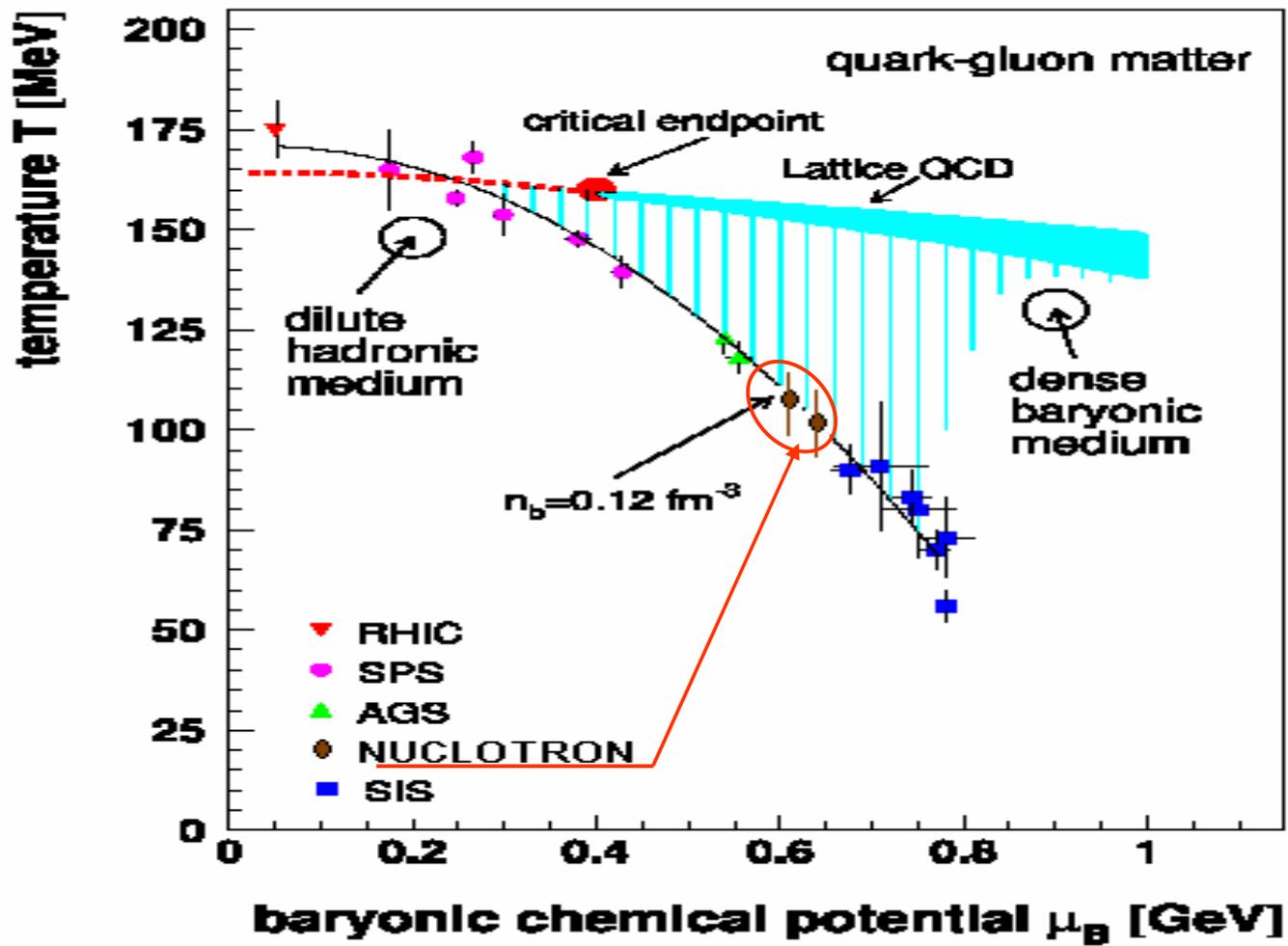
$$b_{ik} \gg 1$$

nuclei should be considered as
quark-gluon systems



Investigations in Veksler and Baldin Laboratory of High Energies







Investigations in Veksler and Baldin Laboratory of High Energies

**Investigations hadron,
nuclear structure and
modification of nuclear
matter**



Investigations in Veksler and Baldin Laboratory of High Energies

Narrow exotic barions (pentaquarks):

- Trojan Yu.A. (LHE bubble chamber)
- Togoo R. (LHE bubble chamber)
- Melkumov G.L. (NA49, SPS CERN)
- Stokovsky E.A. (NIS, Nuclotron)



Investigations in Veksler and Baldin Laboratory of High Energies

Yu. A. Troyan - LHE JINR Hydrogen
Bubble Chamber

$n+p \rightarrow npK^+K^-$ at $P_n = (5.20 \pm 0.12) \text{ GeV}/c$

Narrow exotic barions studied in **K^+n** system

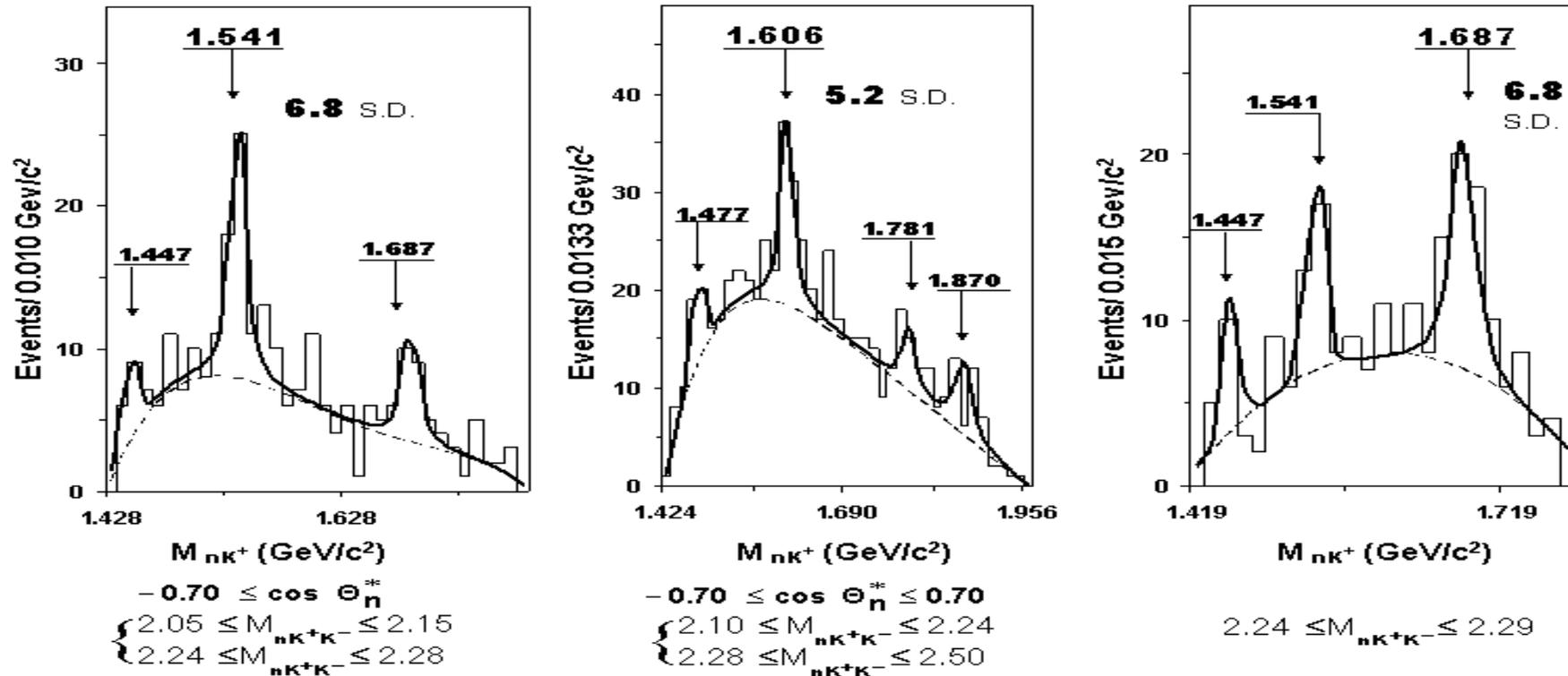
Yu. A. Troyan et al., D1-2004-39, Dubna, 2004;

[hep-ex/0404003](https://arxiv.org/abs/hep-ex/0404003).



Investigations in Veksler and Baldin Laboratory of High Energies

$np \rightarrow npK^+K^-$ $P_n = 5.20 \text{ GeV}/c$

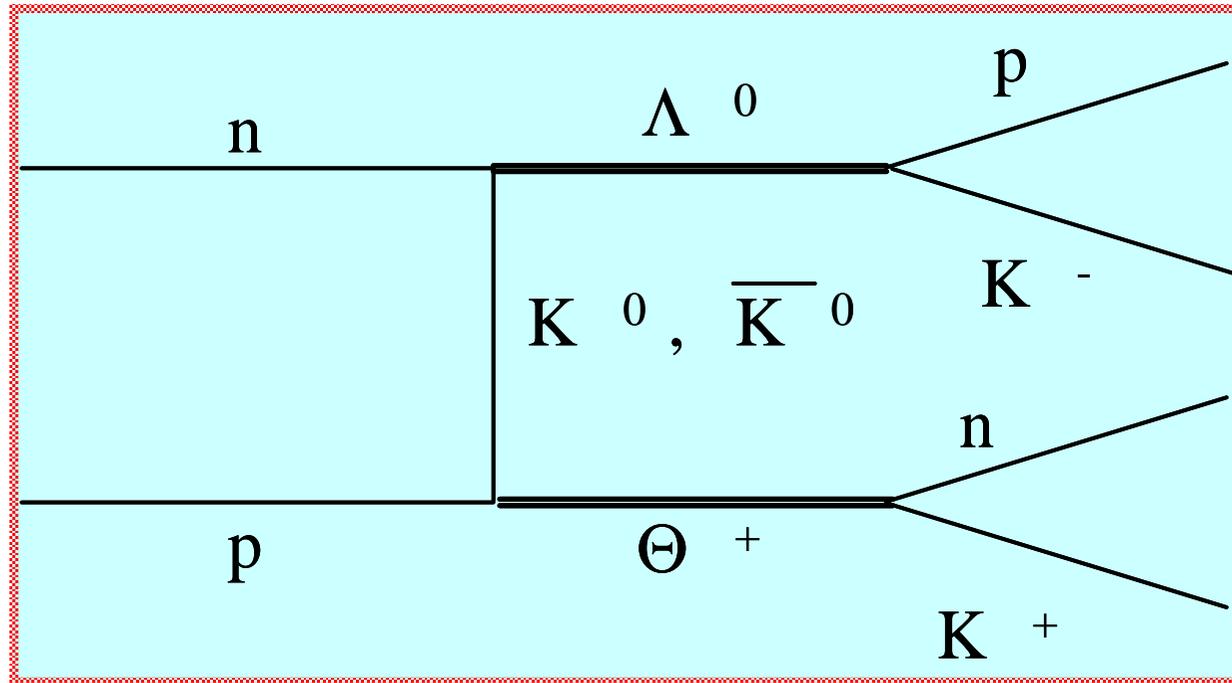


Special Cuts applied to enhance the signal for the resonance at $M = 1.541, 1.606$ and $1.687 \text{ GeV}/c^2$

Three Peaks with Significance $> 5 \sigma$



Investigations in Veksler and Baldin Laboratory of High Energies



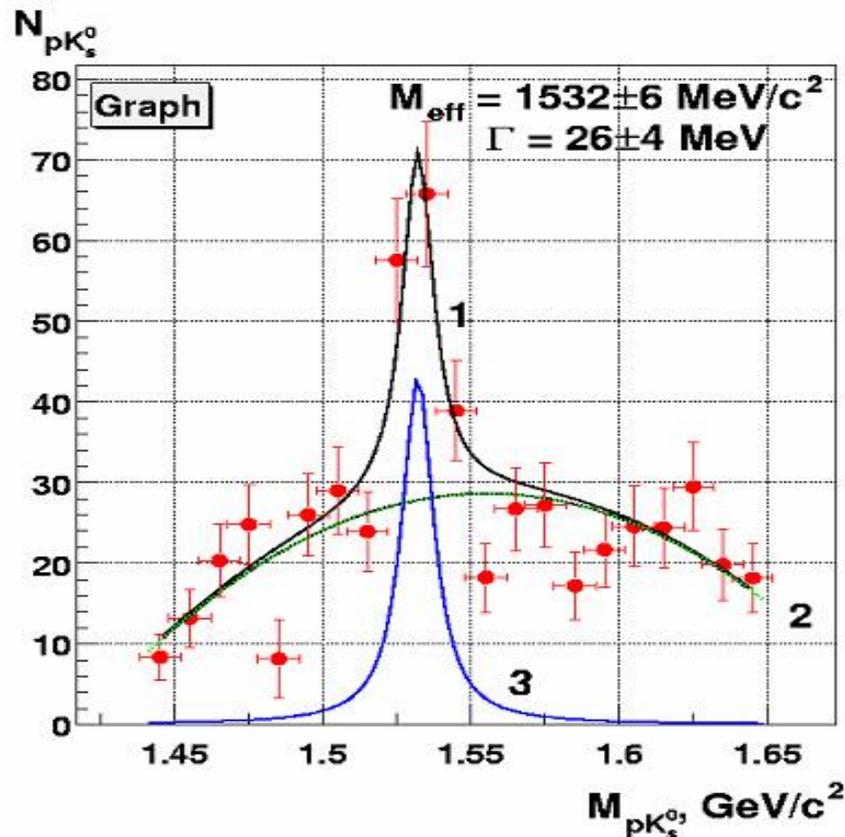
One of the possible mechanism of Θ^+ production

$$\Theta^+ (u u d d \bar{s})$$



Investigations in Veksler and Baldin Laboratory of High Energies

P. Togoo et al. - LHE JINR - 2m Propane Bubble Chamber



$C + C_3H_8 \rightarrow K_s^0 p + X$
 $P_p = 4.2 \text{ A GeV}/c$

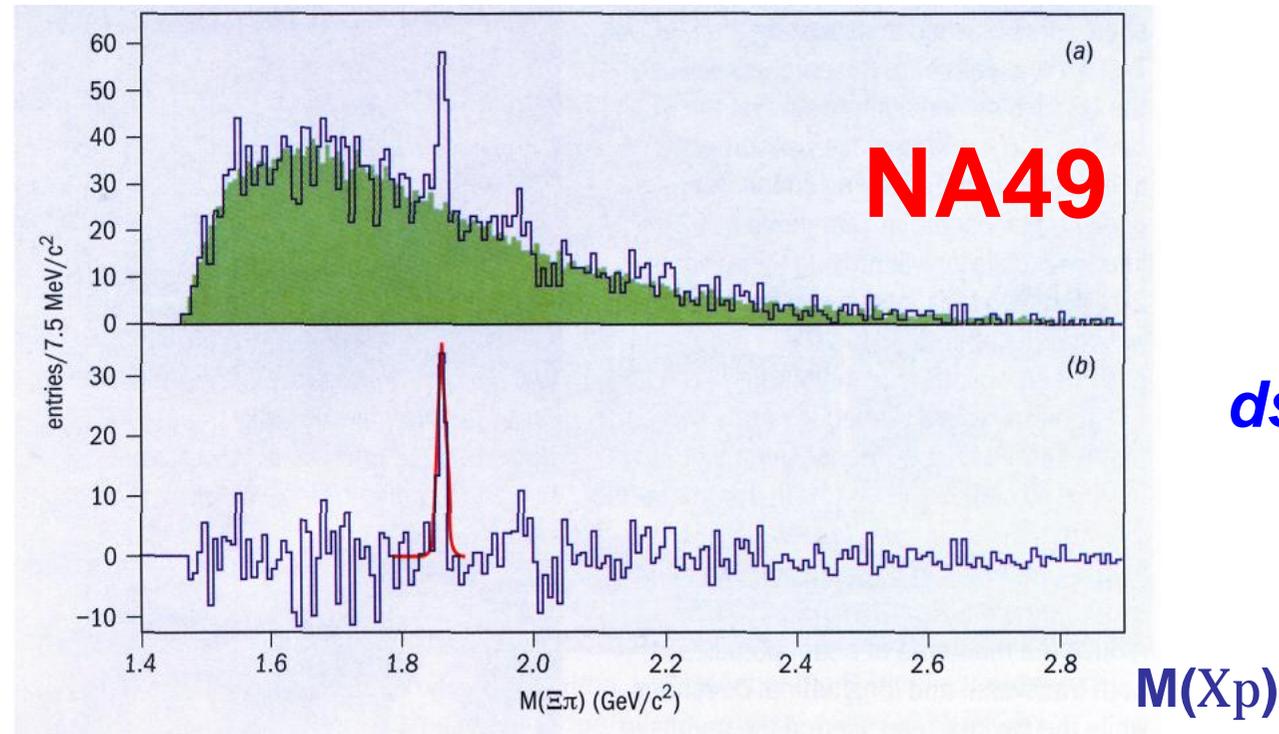
$M = 1532 \pm 6 \text{ MeV}/c^2$

$G \sim 26 \pm 4 \text{ MeV}/c^2$

P. Togoo et al., Proc. of the Mongolian
Academy of Sciences, vol.170, No.4,
p.3, 2003.



Investigations in Veksler and Baldin Laboratory of High Energies



(a) The sum of the $\Xi^- \pi^-$, $\Xi^- \pi^+$, $\Xi^0 \pi^-$ and $\Xi^0 \pi^+$ mass distribution; (b) the mass distribution with combinatorial background subtracted and with a Gaussian fit to the $\Xi \pi$ peak.

C.Alt, T.Anticic, B.Baatar, D.Barna, ..., V.I.Kolesnikov, ..., A.I.Malakhov, G.L.Melkumov et al. (NA49 Collaboration). Evidence for an Exotic $S = -2$ and $Q = -2$ Barion Resonance in Proton-Proton Collisions at the CERN SPS. Phys.Rev.Lett., V.92, No.4, (2004) pp. 042003-1 – 042003-5.

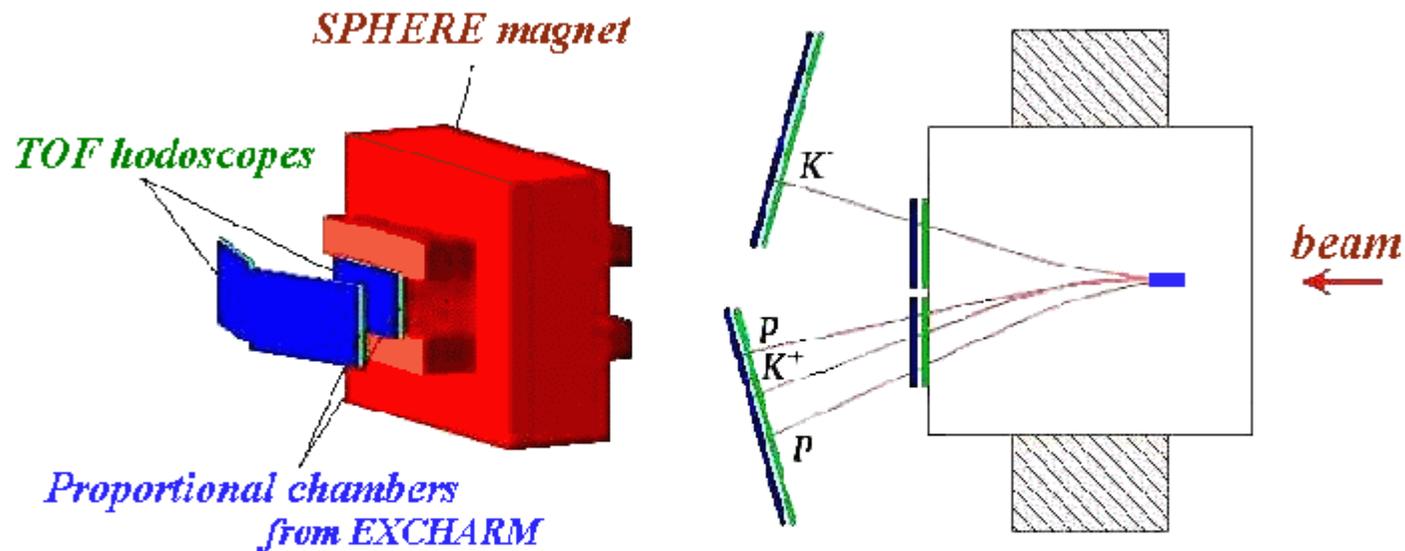


Investigations in Veksler and Baldin Laboratory of High Energies

Project NIS: *Search for effects of Nucleon Intrinsic Strangeness*

E.A.Strokovski

at JINR Nuclotron



Test of OZI rule in

$$p + p \rightarrow p + p + \phi$$

$$p + p \rightarrow p + p + \omega$$

production near threshold

Nucleon intrinsic strangeness should be an additional source of ϕ -mesons

First indication - DISTO: $R(\phi/\omega) = 13R(\phi/\omega)_{OZI}$

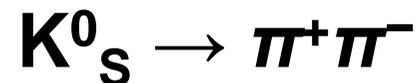


Investigations in Veksler and Baldin Laboratory of High Energies

The physical program of the NIS experiment includes:

(A) Search for effects of nucleon polarized strangeness in production of φ and ω mesons in pp and np scattering close to thresholds (at $\varepsilon \approx 30 \div 100$ MeV above the thresholds).

(B) Search for production of the Θ^+ baryons in pp interactions close to threshold in reactions:



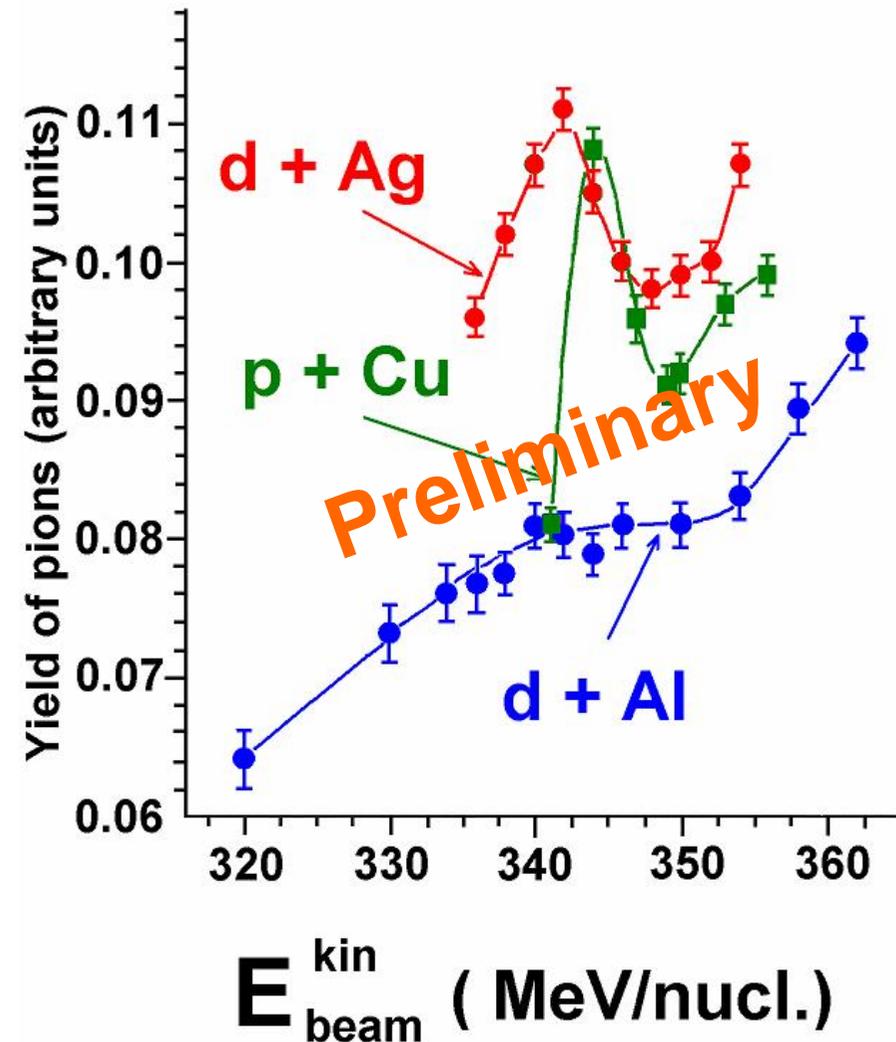


Investigations in Veksler and Baldin Laboratory of High Energies

(DELTA-2)

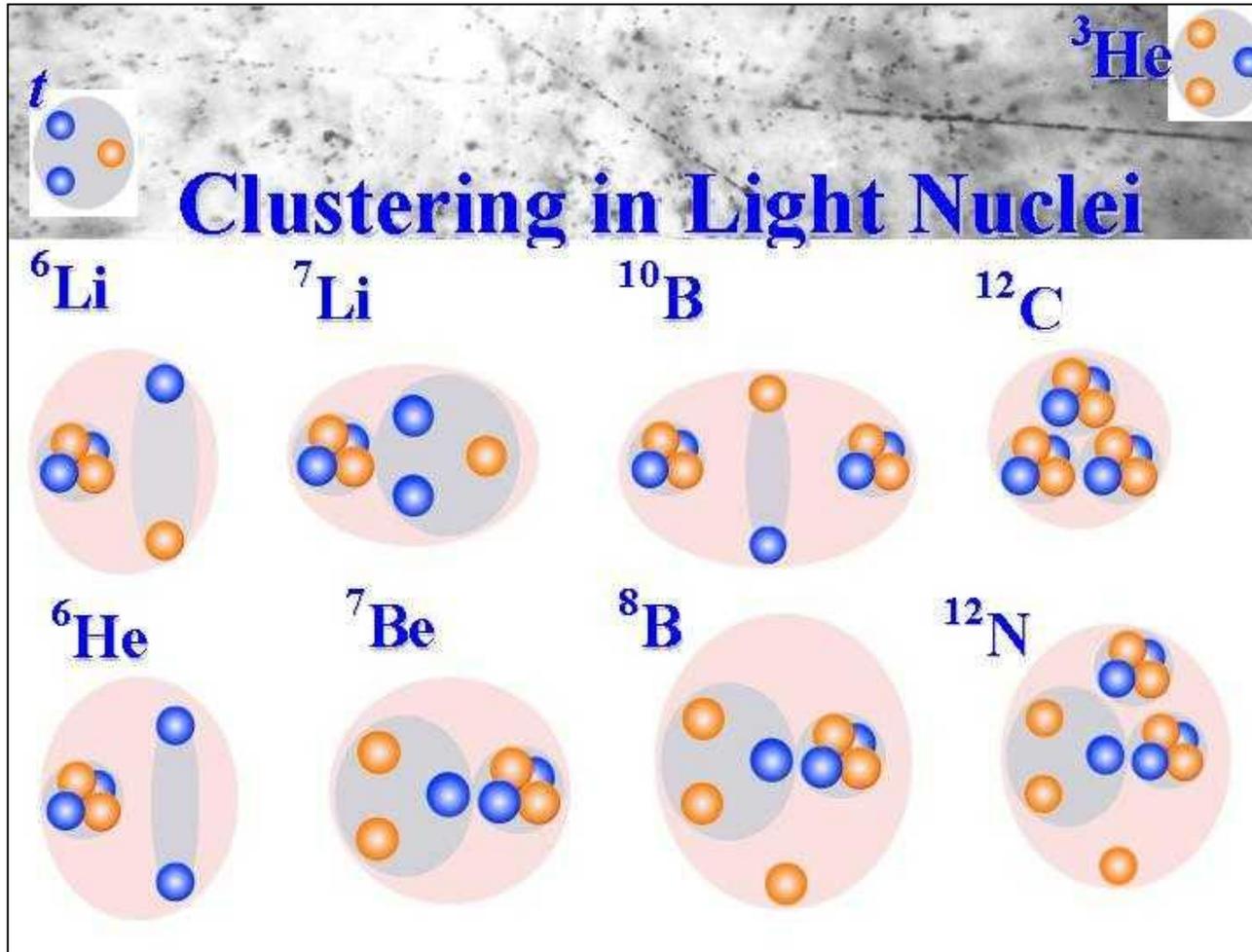
Krasnov V.A.,
Kurepin A.B.

Narrow pion
resonance





Investigations in Veksler and Baldin Laboratory of High Energies



**BECQUEREL
Project**

P.I. Zarubin



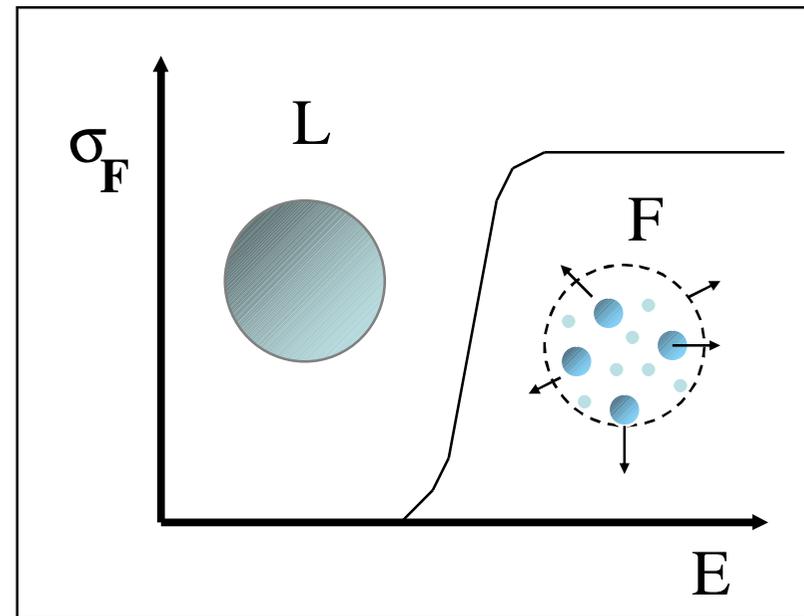
Investigations in Veksler and Baldin Laboratory of High Energies

Modification of nuclear matter

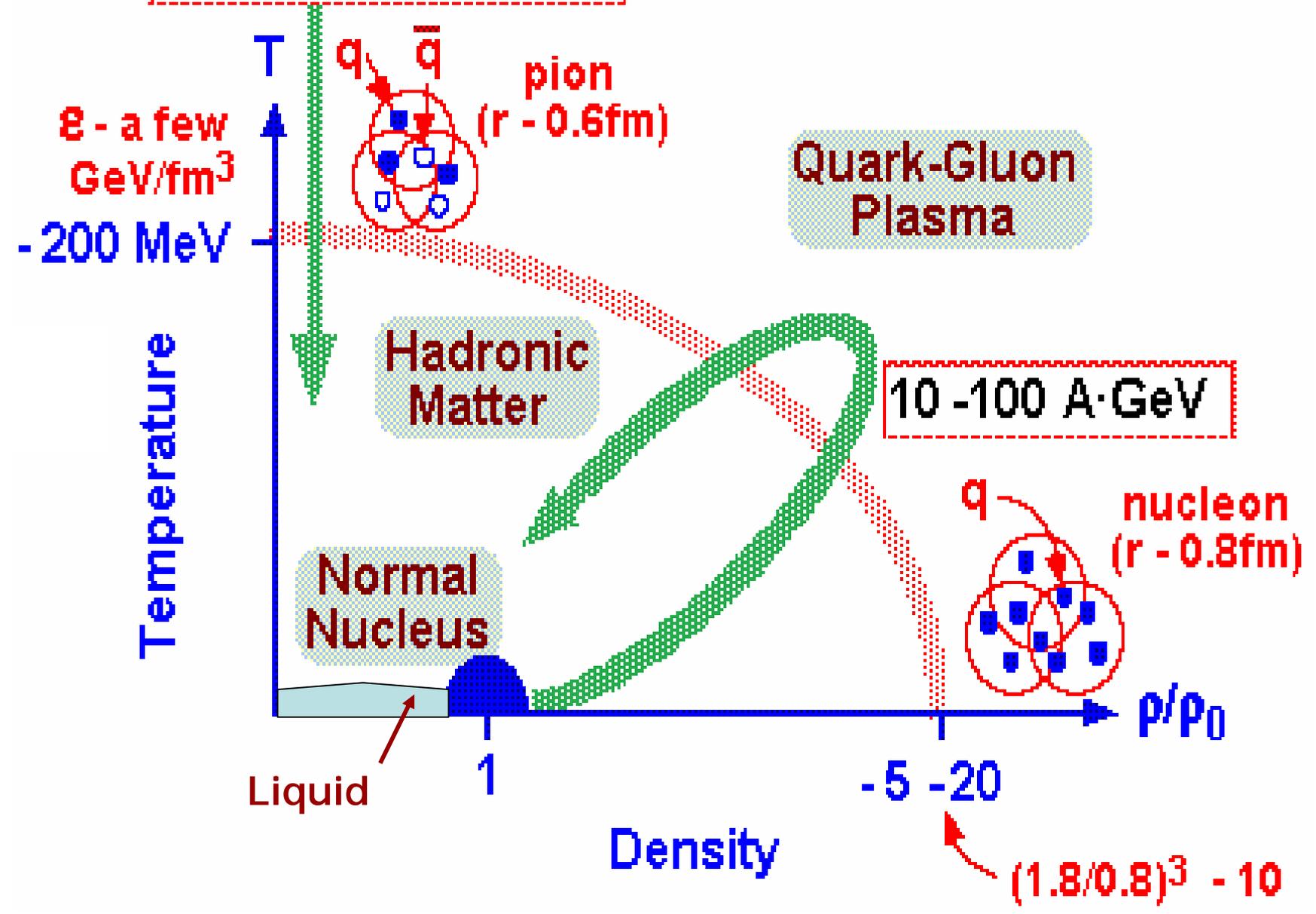
FAZA project (DLNP)

V.A.Karnaukhov

- Hot nuclei
- Thermal multifragmentation
- Liquid-Gas Phase Transition
 $T_c = (17 \pm 2) \text{ MeV}$
- Liquid-Fog Phase Transition
 $T_f = 5 \text{ , } 7 \text{ MeV}$

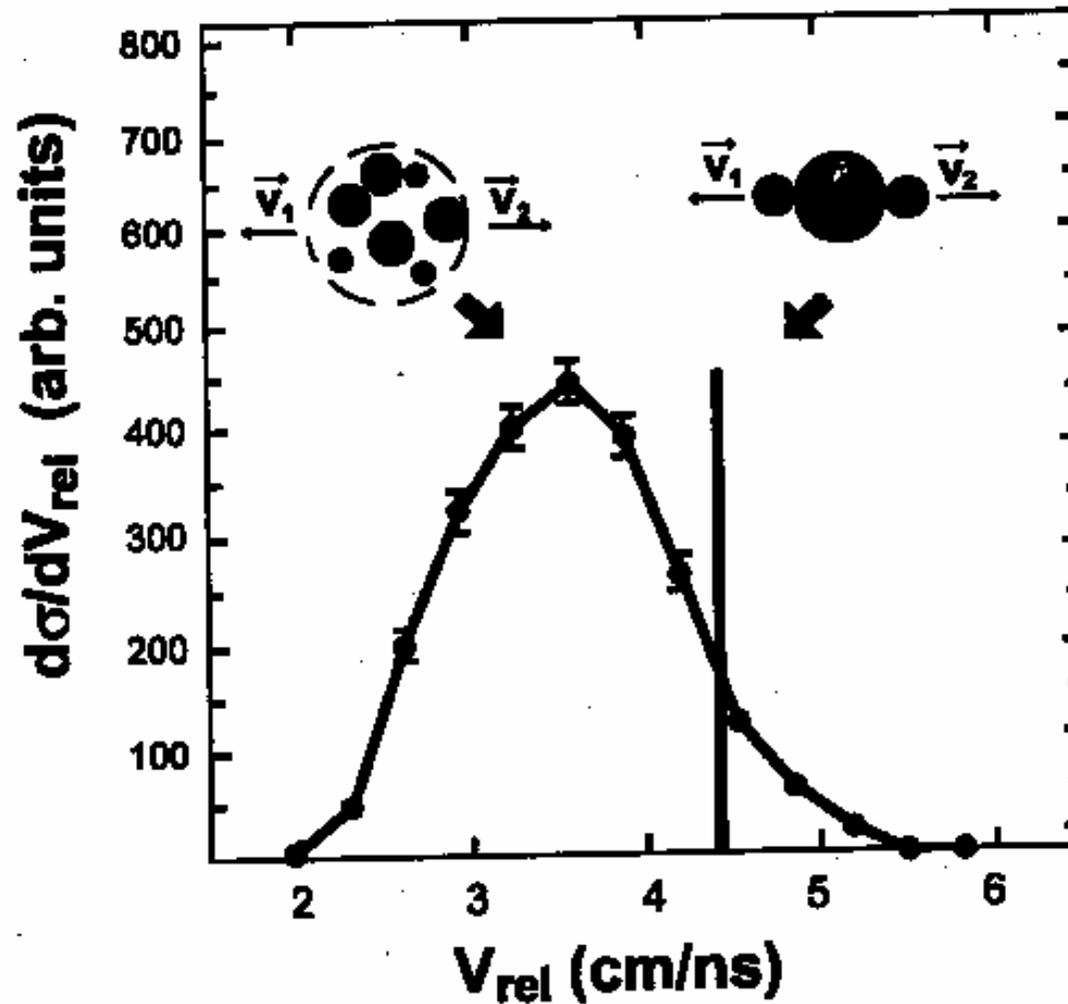


100 A-GeV Collider





Investigations in Veksler and Baldin Laboratory of High Energies

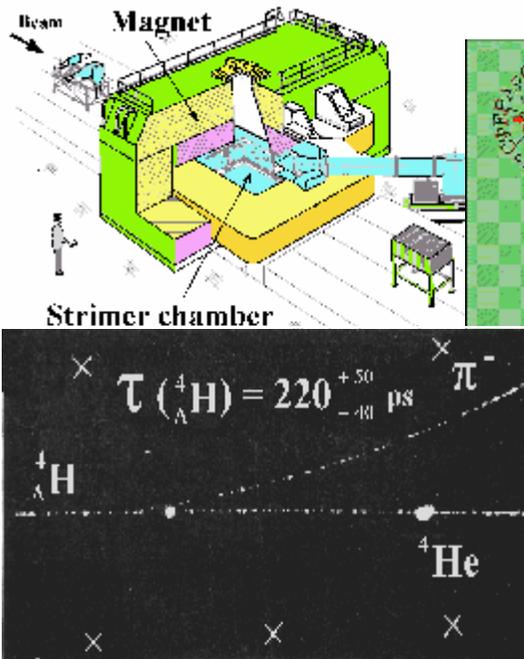


Experiments with relativistic nuclei

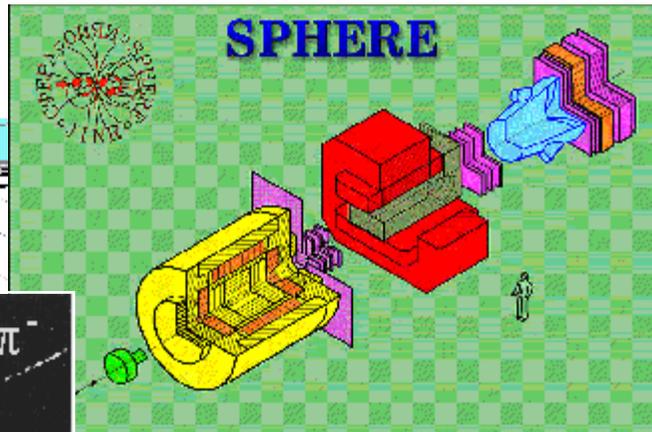
Hypernuclei

Yu. Lukstinsh

GIBS project



SPHERE project



h nuclei

G.Sokol

DELTA project (INR)

DELTA

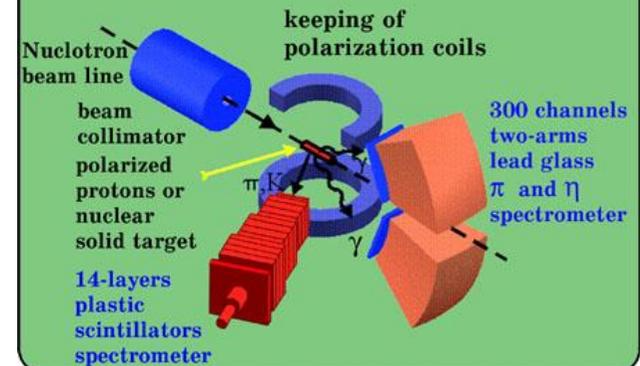
Study of near-threshold η and K -meson production in AA and NN collisions.

$$A+A \rightarrow K^+ + X$$

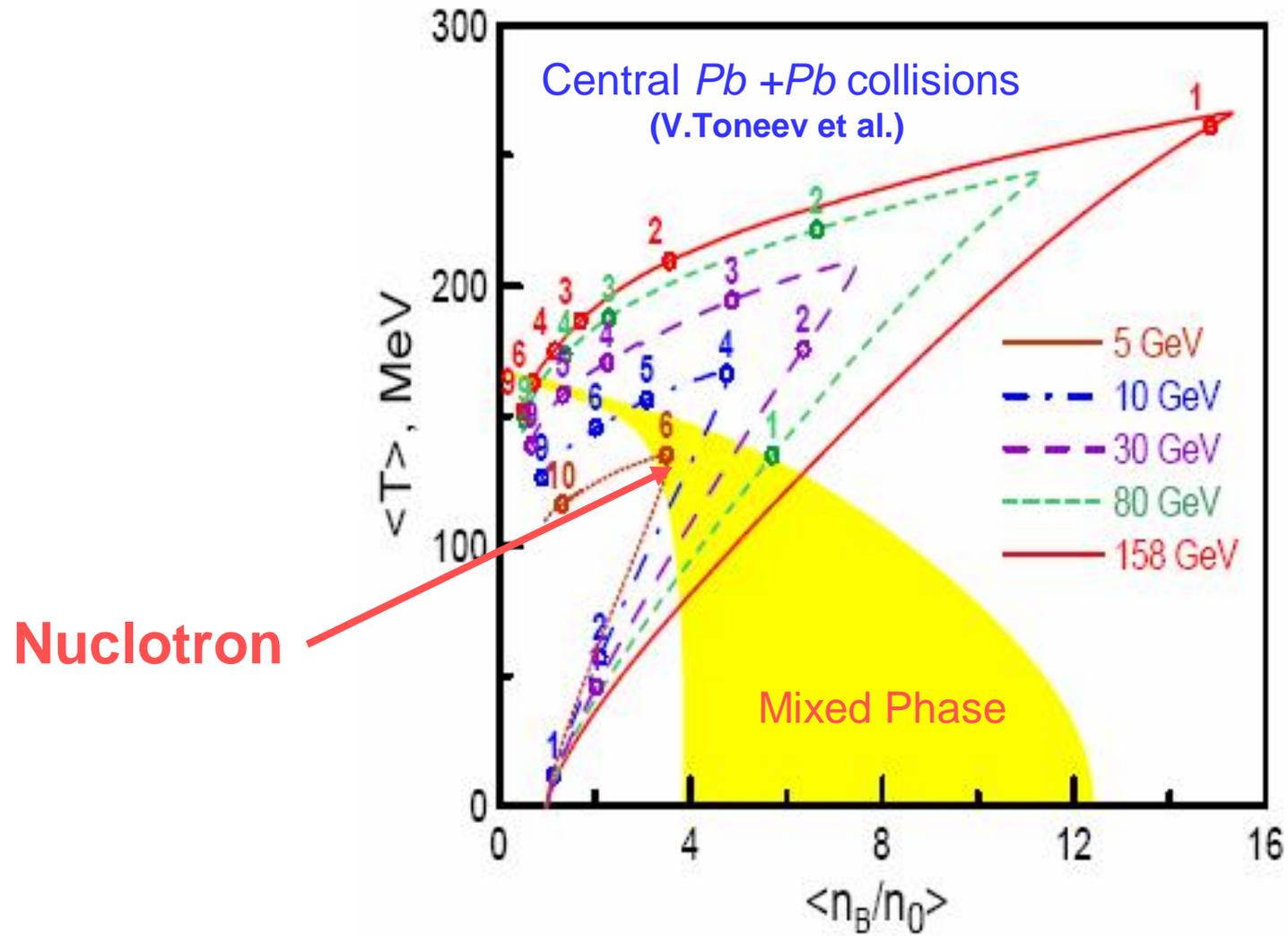
$$\bar{N} + \bar{N} \rightarrow \eta(\pi^0) + X$$

$$\bar{N} + \bar{N} \rightarrow \eta(\pi^0) + d$$

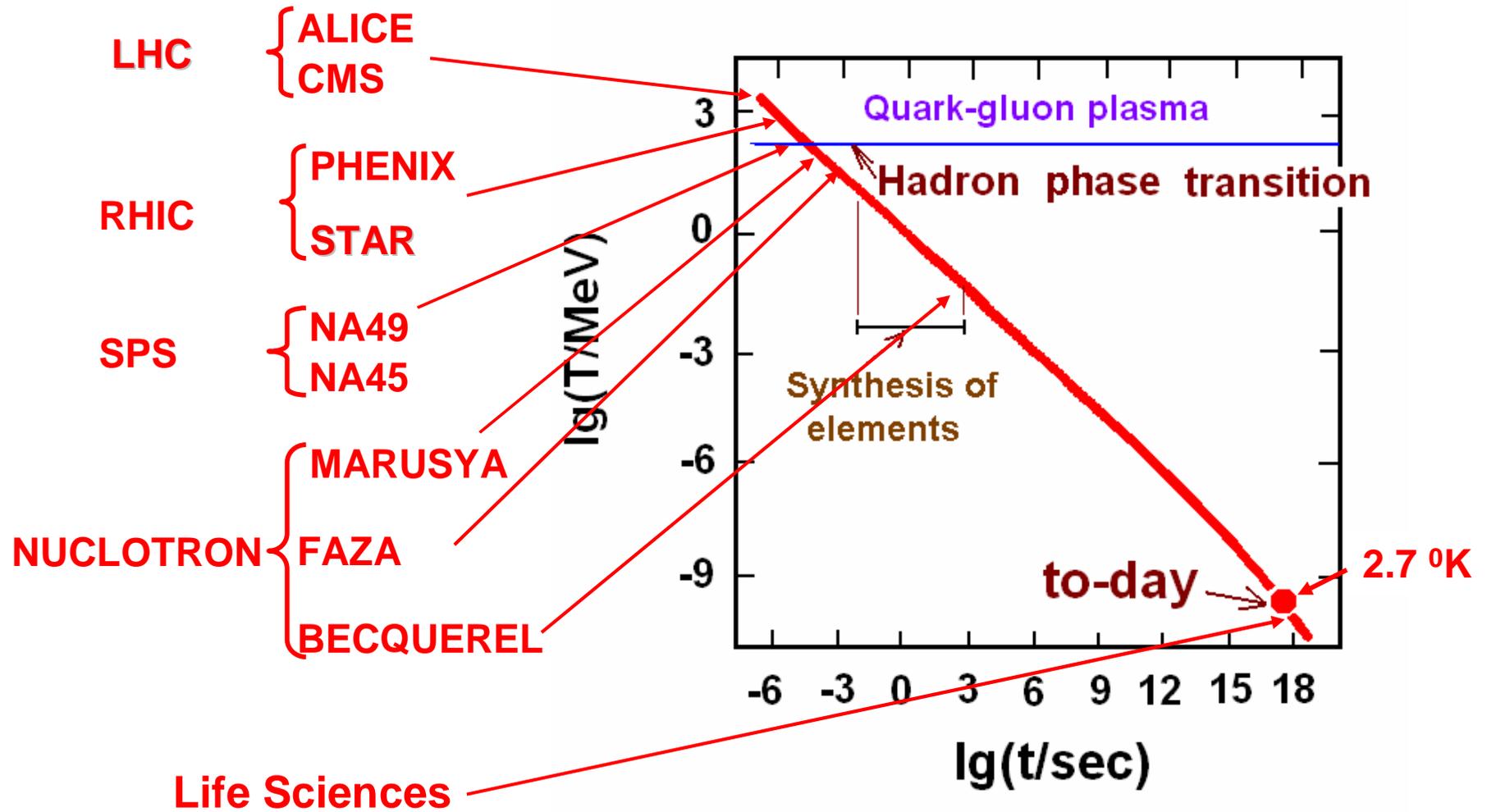
$$T_{\text{beam}} = (0.5-2.0) \cdot A \text{ GeV}$$



Mixed Phase of Nuclear Matter



Thermal history of the Universe





Investigations in Veksler and Baldin Laboratory of High Energies

POLARIZATION INVESTIGATIONS



Investigations in Veksler and Baldin Laboratory of High Energies

DELTA-SIGMA Project

The Aim of the Project

L.N.Strunov, V.I.Sharov

Study of the NN interactions over a new higher energy region of free polarized neutron beams, provided at present **only by the JINR VBLHE accelerator**.

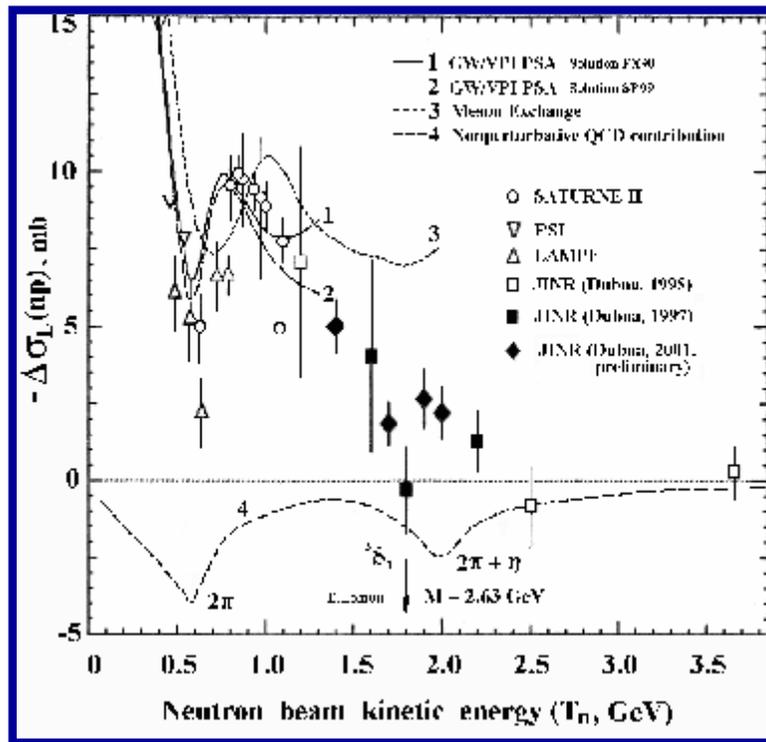
Measurements of the **energy dependence** of $Ds_L(np)$ and $Ds_T(np)$ at the same neutron energies with longitudinal and transverse polarized beam neutrons and target protons.



Investigations in Veksler and Baldin Laboratory of High Energies

Spin structure of the np forward scattering amplitude

DELTA-SIGMA project



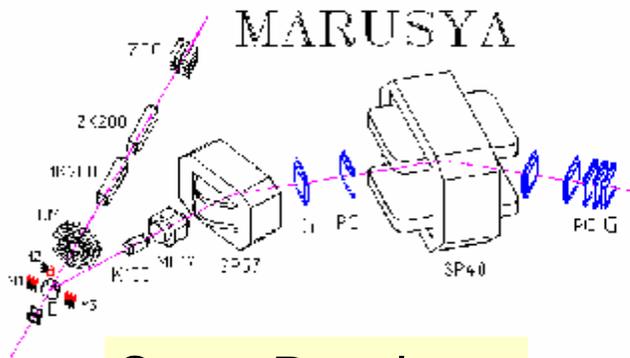
$$- \Delta\sigma_L = \sigma_{\text{tot}}(\Rightarrow) - \sigma(\Leftarrow)$$

$$- \Delta\sigma_T = \sigma_{\text{tot}}(\Uparrow) - \sigma(\Downarrow)$$

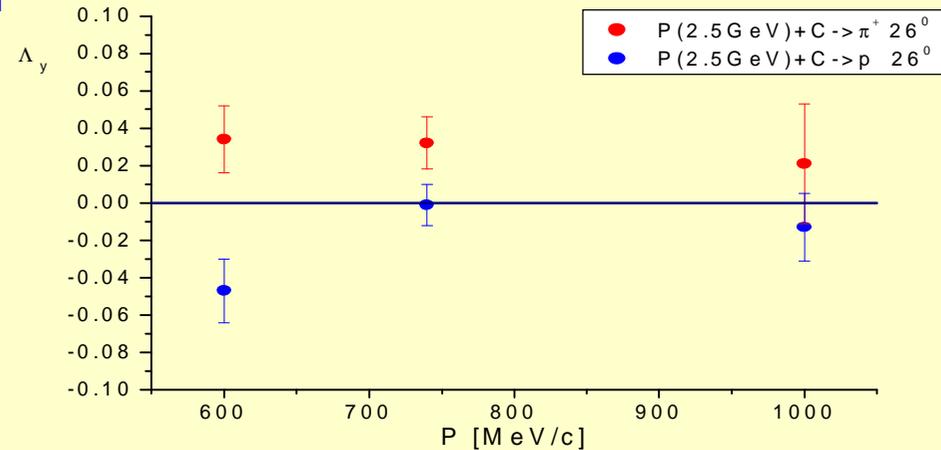


Investigations in Veksler and Baldin Laboratory of High Energies

MARUSYA A.A.Baldin



MARUSYA 2002



Some Results

- Analyzing powers A_y in production of p and π in the interaction of the polarized protons (2.5 GeV/c) with carbon nuclei were measured in the momentum range of the registered particles 0.6 - 1.2 GeV/c at the angle of 26 deg. In this momentum range the A_y tends to decrease for p^+ and to increase for protons with the increasing particle momentum. Further research with polarized beams of the Nuclotron are feasible.



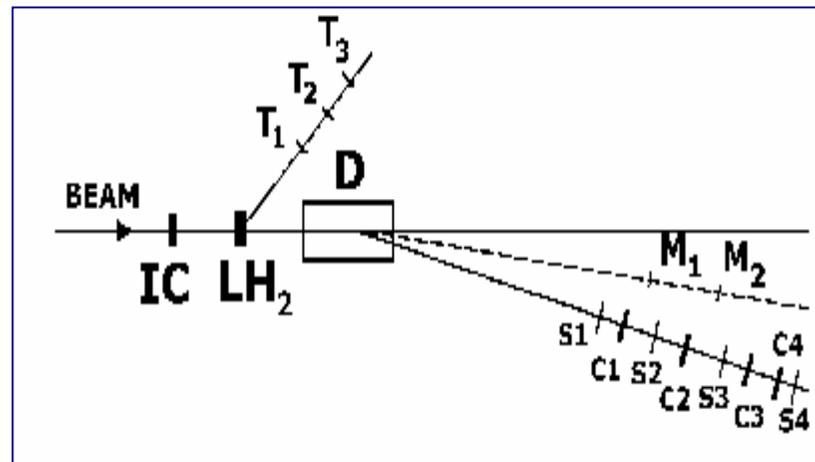
Investigations in Veksler and Baldin Laboratory of High Energies

STRELA project

V.V.Glagolev, N.M.Piskunov

Study of the spin-dependent component of the nucleon scattering amplitude in the charge-exchange process $np \rightarrow pn$ in a deuteron beam extracted from the Nuclotron

Plan – Measurements of the production cross section of two protons at a small momentum transfer in the region of $P_d = 3.0 - 4.0$ GeV/c





Investigations in Veksler and Baldin Laboratory of High Energies

Experiment PIKASO

L.S.Zolin

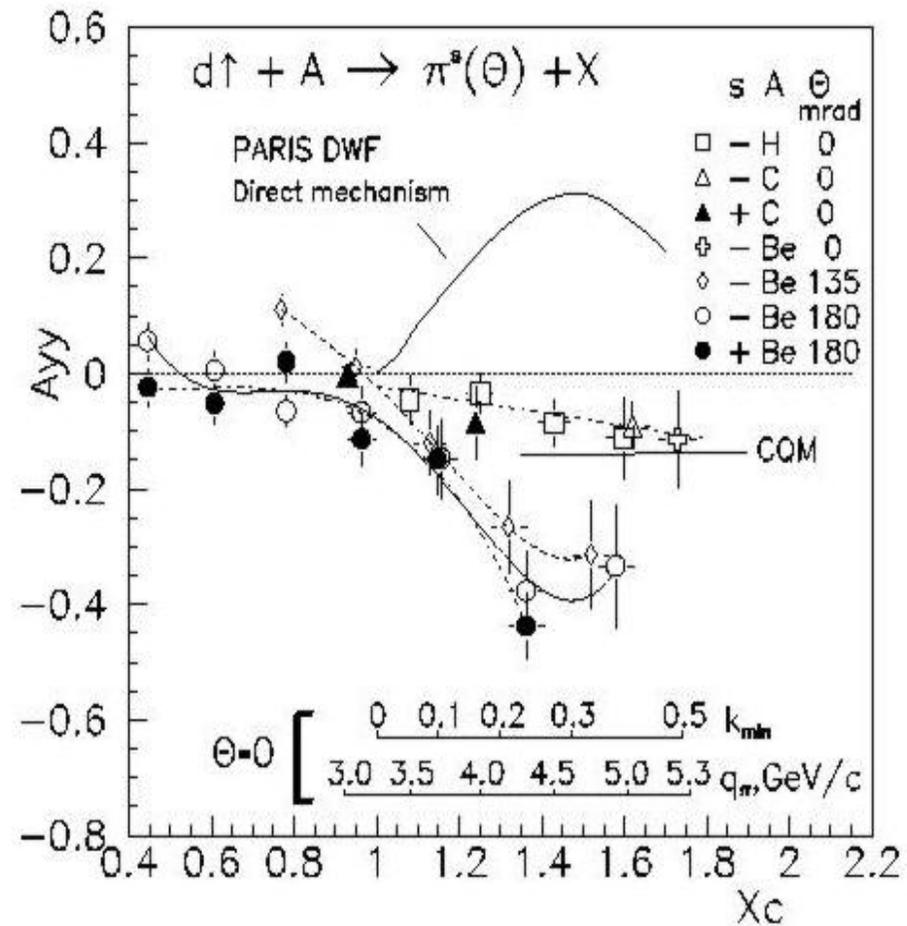
Tensor Analyzing Power A_{yy} in $A(d,p)$

The sign of A_{yy} in the cumulative region ($x_c > 1$) is **negative** at all angles of pion emission (contrary to IA-predictions).

Magnitude of A_{yy} increases with rise of Q_p

A_{yy} reaches a value of **-0.4** at $x_c \sim 1.5$ where D/S-ratio in DWF is close to its maximum.

Large D-state effects are revealed at fragmentation of 9 GeV tensor polarized deuterons into cumulative pions.



LNS project

V.P.Ladygin

Light Nuclei Structure
investigations at LHE
and RIKEN

pHe3 project

V.P.Ladygin, T. Uesaka



$$E_d = 1.0 - 1.75 \text{ GeV}$$

Physics of LNS and pHe3 projects

Both LNS and pHe3 projects are devoted to the study of the spin structure of deuteron and 3-nucleon forces with the use of polarized deuteron beam of Nuclotron

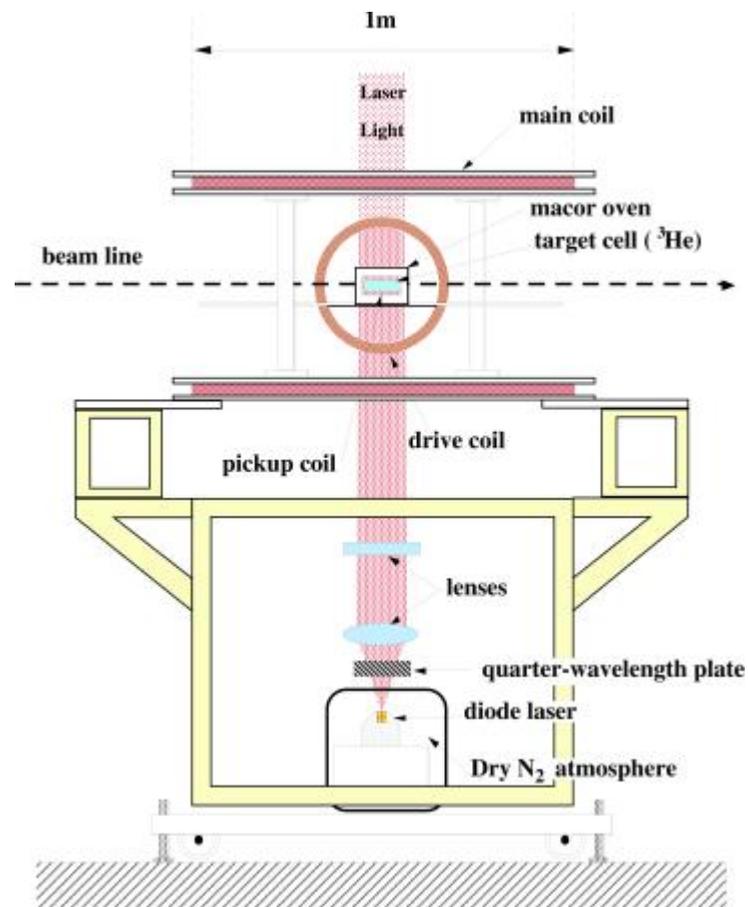
LNS project assumes to measure the tensor A_{yy} and A_{xx} and vector A_y analyzing powers in deuteron-proton elastic scattering and deuteron breakup between 300 and 500 MeV using Internal Target Station

pHe3 project is devoted to the measurement of the tensor analyzing power T_{20} and spin-correlation C_{yy} in the reaction $d + {}^3\text{He} \rightarrow \text{p} + {}^4\text{He}$ at the energies between 1.0 and 1.75 GeV with the use of extracted polarized deuteron beam of Nuclotron and polarized ${}^3\text{He}$ target developed in Japan

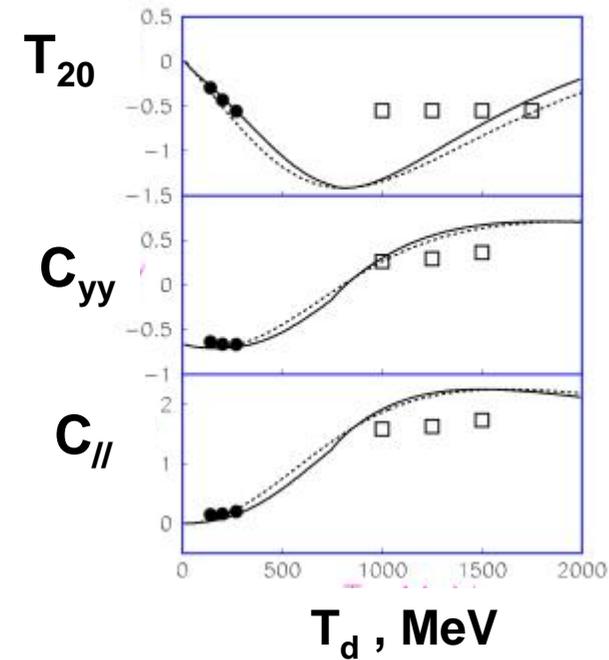


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PHe3



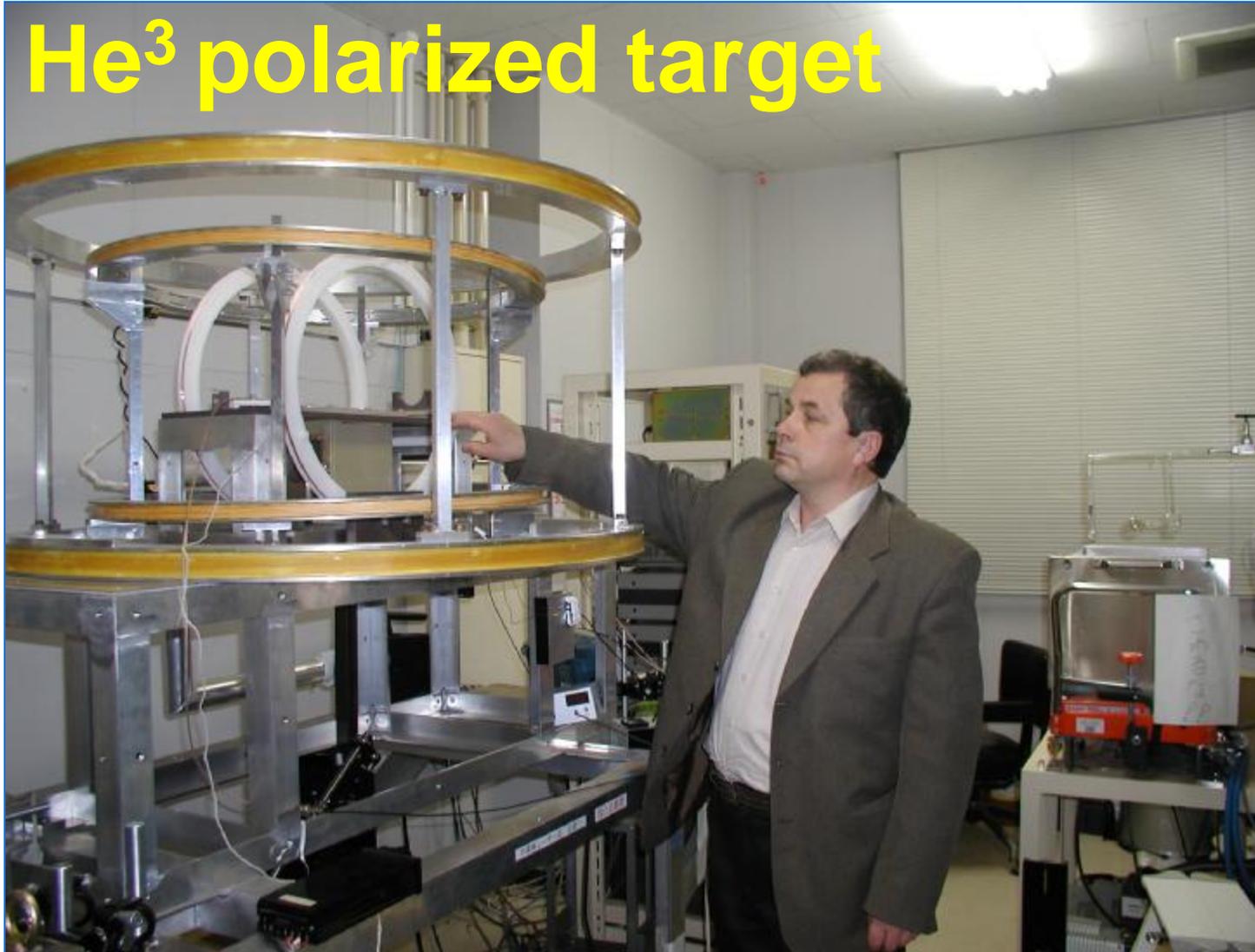
Measurements of the power T_{20} and spin-correlation $C_{y,y}$ in the $d^- + ^3\text{He} - \text{p} + ^4\text{He}$ reaction at Nuclotron





Investigations in Veksler and Baldin Laboratory of High Energies

He³ polarized target





Investigations in Veksler and Baldin Laboratory of High Energies

APPLIED RESEARCH



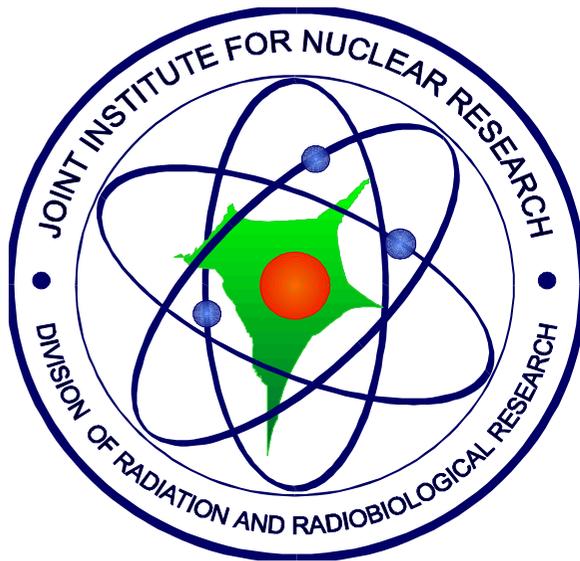
Investigations in Veksler and Baldin Laboratory of High Energies

- **Radiobiology and space biomedicine**
- **The impact of nuclear beams on the microelectronic components**
- **The transmutation of radioactive waste**
- **Accelerator driven energy production**
- **Med - Nuclotron**

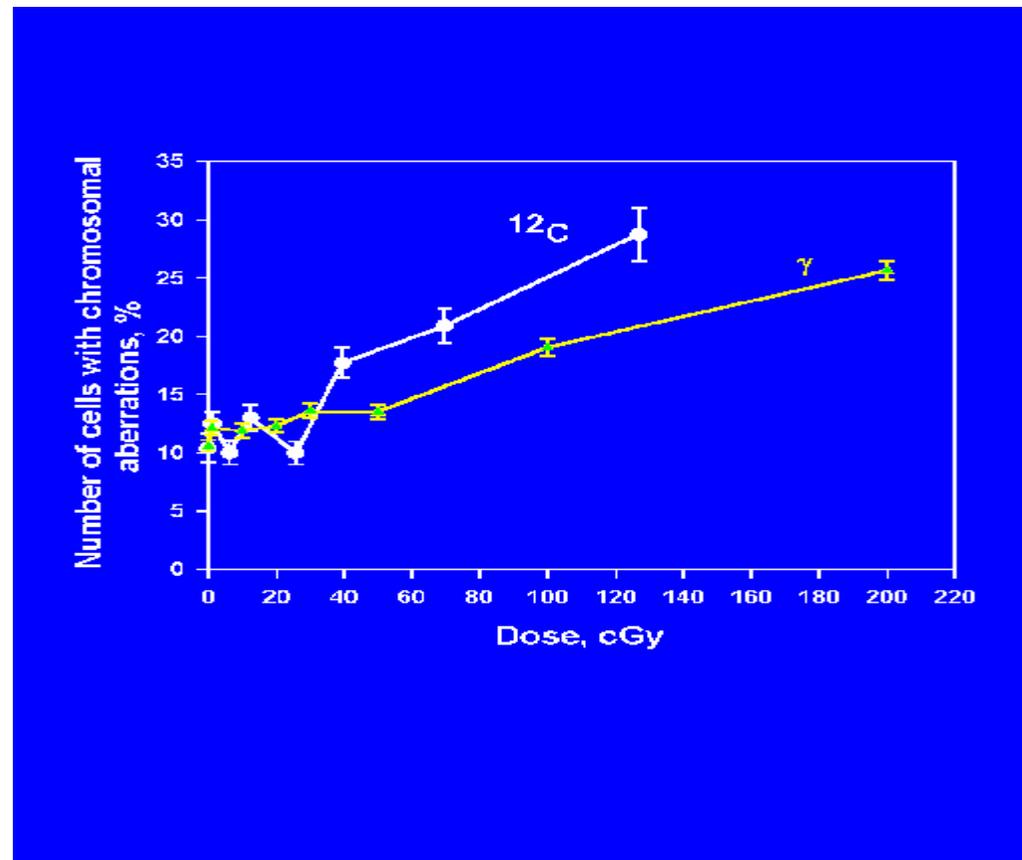


Investigations in Veksler and Baldin Laboratory of High Energies

Radiobiology and space biomedicine



E.A.Krasavin





Investigations in Veksler and Baldin Laboratory of High Energies

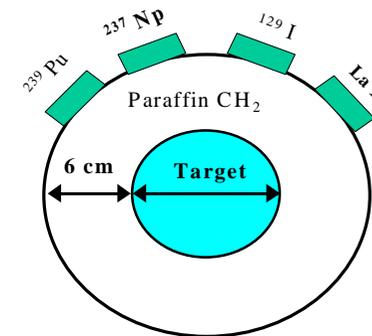
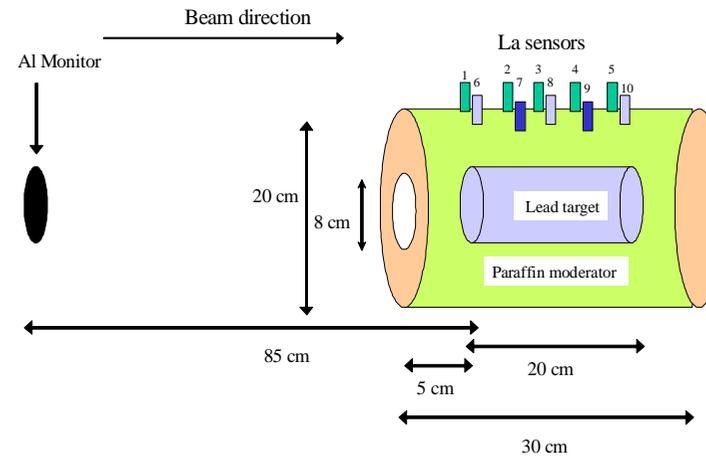
Gamma2 Project

V.M. Golovatyuk

- *Elimination of radioactive waste*
- *Accelerator driven energy production*

Goal

Measuring of the neutron yield as a function of beam energy, type of the particles in the beam, and the target material





Investigations in Veksler and Baldin Laboratory of High Energies

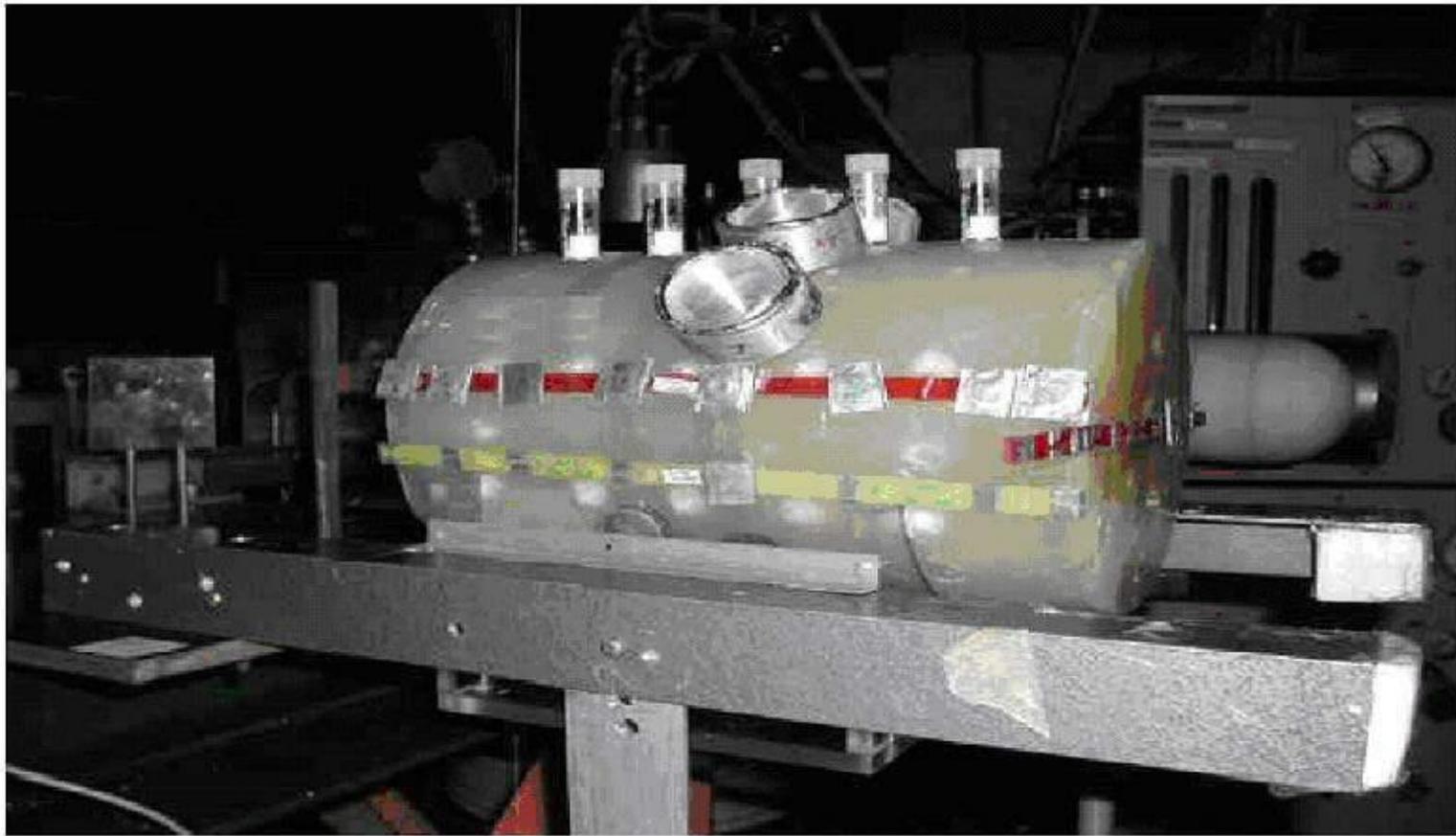


Fig. 2-6 Photography of the experimental set-up GAMMA-2 with the position of the of ^{139}La sensors and transmutation samples (^{129}I , ^{237}Np and ^{239}Pu) at the top surface of paraffin moderator

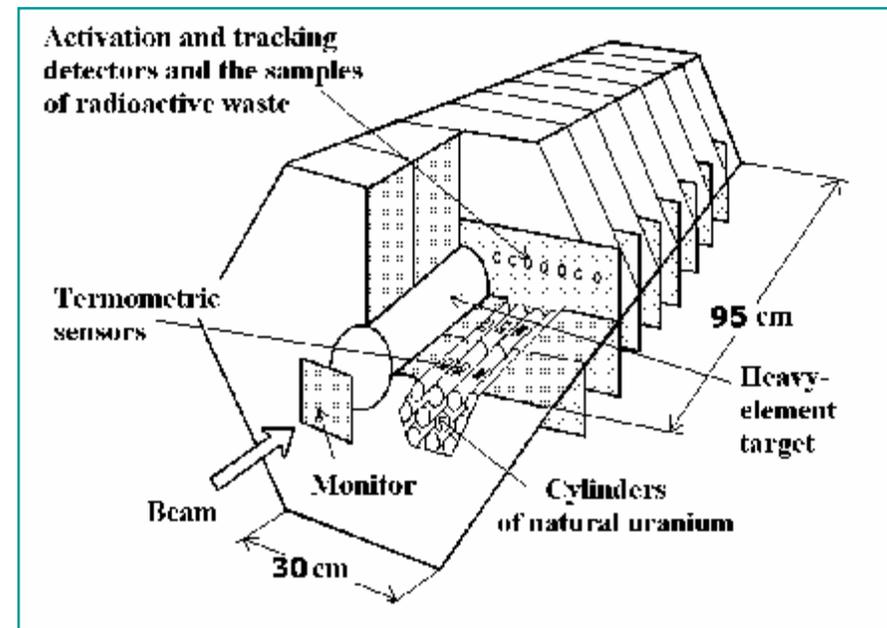


Investigations in Veksler and Baldin Laboratory of High Energies

- The transmutation of radioactive waste
- Accelerator driven energy production

Energy + Transmutation project

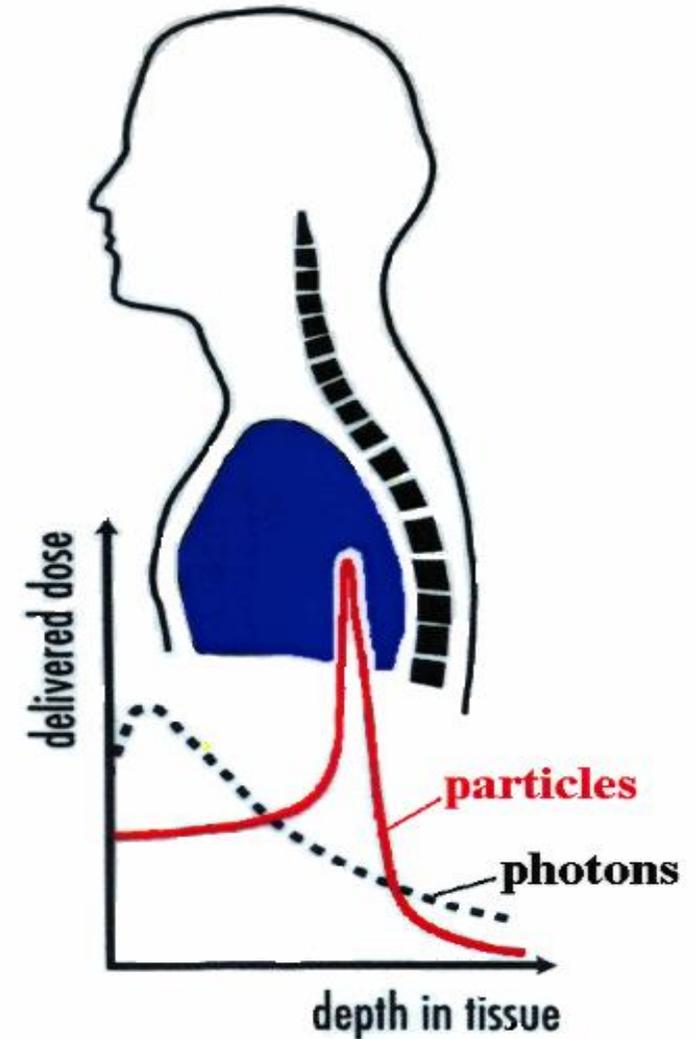
M.I.Krivopustov





Investigations in Veksler and Baldin Laboratory of High Energies

MED- NUCLOTRON





Investigations in Veksler and Baldin Laboratory of High Energies

MED-NUCLOTRON

Ja.Ruzhichka

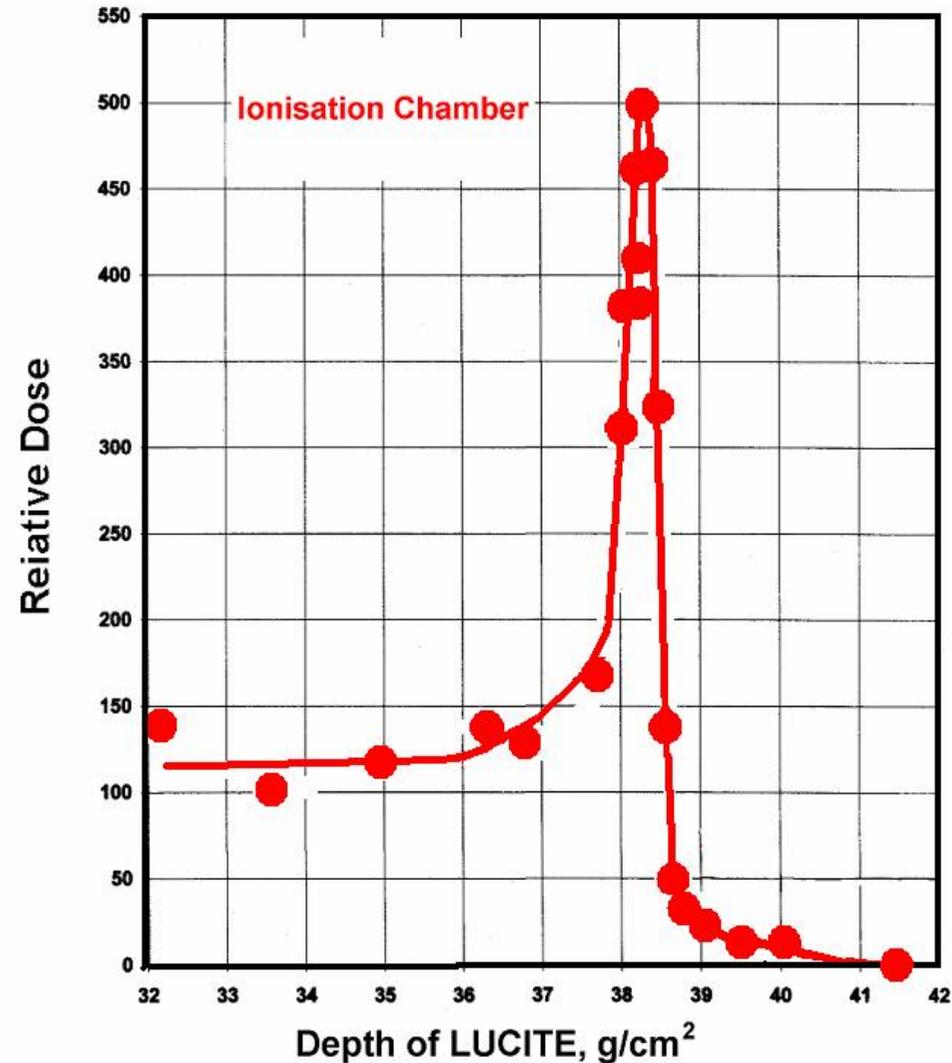
V.M.Golovatyuk

The Bragg peak of ^{12}C ions

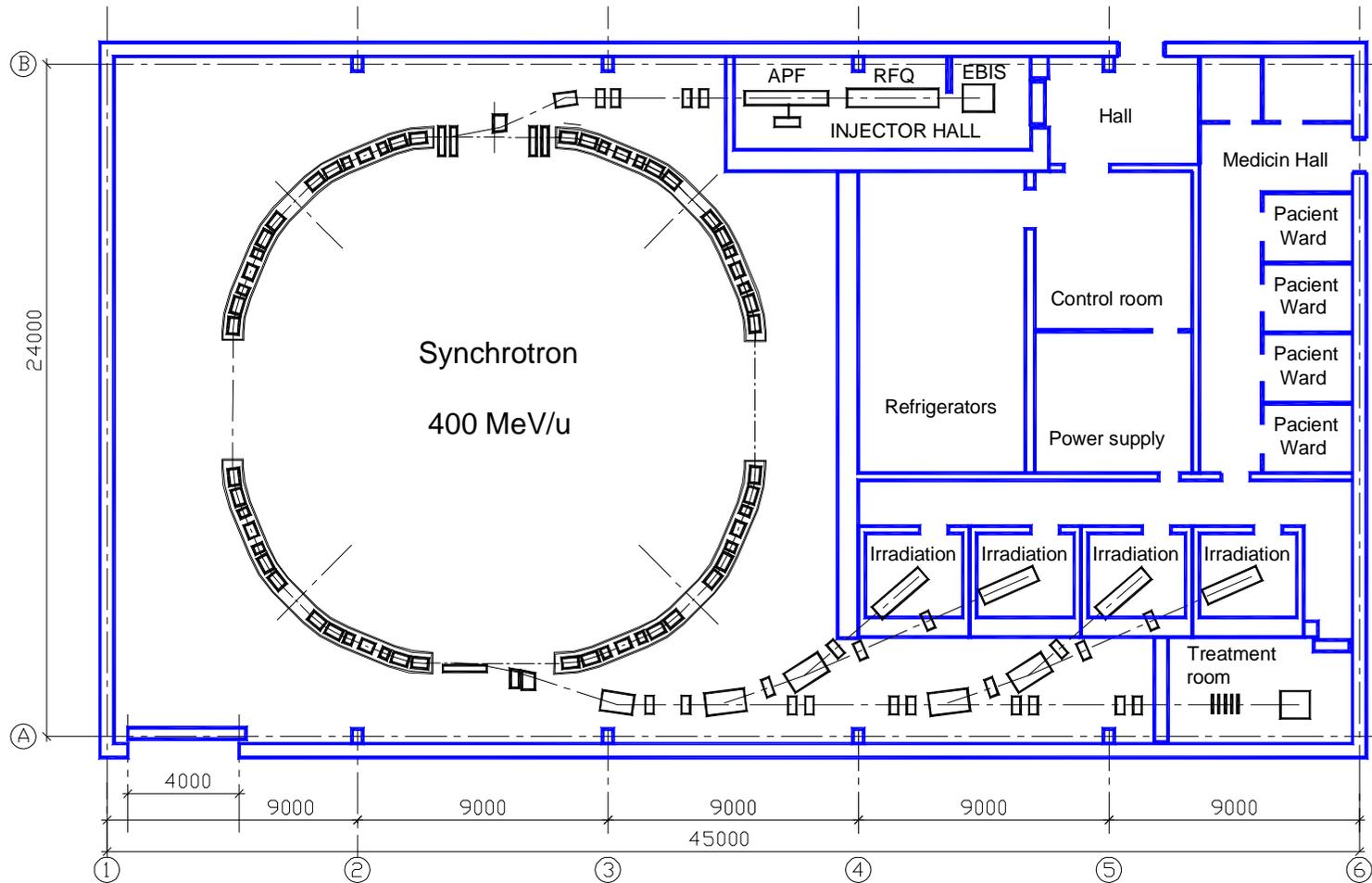
JINR NUCLOTRON

500 A-MeV

20.03.2004



New Medical Superconducting Synchrotron



New medical accelerator will be very similar to the model shown in the picture



NUCLOTRON Users



Bulgaria: Institute for Nuclear Research and Nuclear Energy of BAS, University of Chemical Technology and Metallurgy (UCTM) (Sofia) ...

Belarus: The Institute of Radiative Physical-Chemical Problems of NASB, The Academy of Scientific and Engineering Complex 'SOSNY', (Minsk) ...

Czech Republic: Nuclear Physics Institute (Řež), Charles University, Czech Technical University (Prague) ...

Greece:
Aristotle University of Thessaloniki (Thessaloniki)

Italy: Istituto Nazionale di Fisica Nucleare. Sezione di Firenze (Florence) ...

Germany: Technische Hochschule Darmstadt – Institut für Kernphysik (Darmstadt), Universität (Siegen, Karlsruhe), Philipps-Universität Marburg (Marburg), Forschungszentrum Jülich GmbH (Jülich) ...

Mongolia: Institute of Physics and Technology of MAS, National University of Mongolia (Ulaanbaatar)

Slovak Republic: Institute of Experimental Physics, P.J. Šafárik University (Košice), Institute of Physics SAS, Comenius University (Bratislava) ...

Poland: Niewodniczanski Institute of Nuclear Physics (Cracow), The Andrzej Soltan Institute for Nuclear Studies (Otwock, Warsaw) ...

Russia: Institute for Nuclear Research of RAS (Troitsk), Lebedev Physical Institute of RAS (FIAN), Skobeltsyn Research Institute of Nuclear Physics at the Moscow State University, Russian Nuclear Research Institute of Experimental Physics (Sarov), Institute of Atomic Energy (Obninsk) ...

And the Scientific Centers in Armenia, Georgia, Egypt, Kazakhstan, Romania, USA, Uzbekistan, Ukraine, France, Japan

Australia:
The University of Sidney



Investigations in Veksler and Baldin Laboratory of High Energies

**Participation of the
Laboratory of High Energies
in the other scientific centers**



Heavy Ion Physics



SPS Pb + Pb , 158 GeV/u

NA45

- Detectors
- Data taking & analysis
- New magnet

Yu.A.Panebratsev

NA49

- 900 channel TOF
- Data taking & analysis

G.L.Melkumov



LHC Pb + Pb, 2.76 TeV/u

ALICE

- Muon arm magnet
- TRD
- Simulation
- Photon Spectrometer (PHOS)

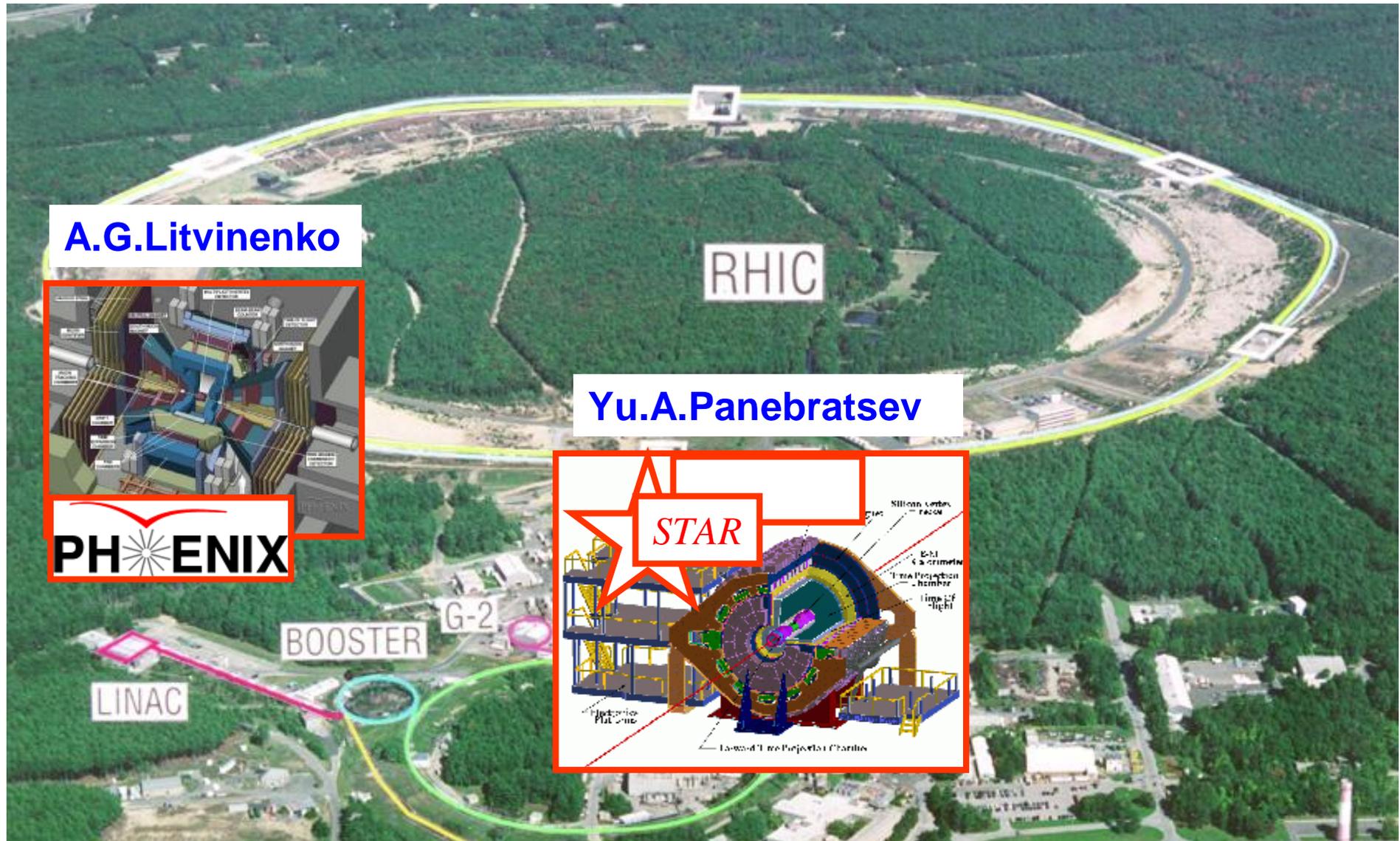
A.S.Vodopianov

CMS

- Heavy Ion Program
- Muon chamber test
- Front-end electronics for HCAL
- Simulation



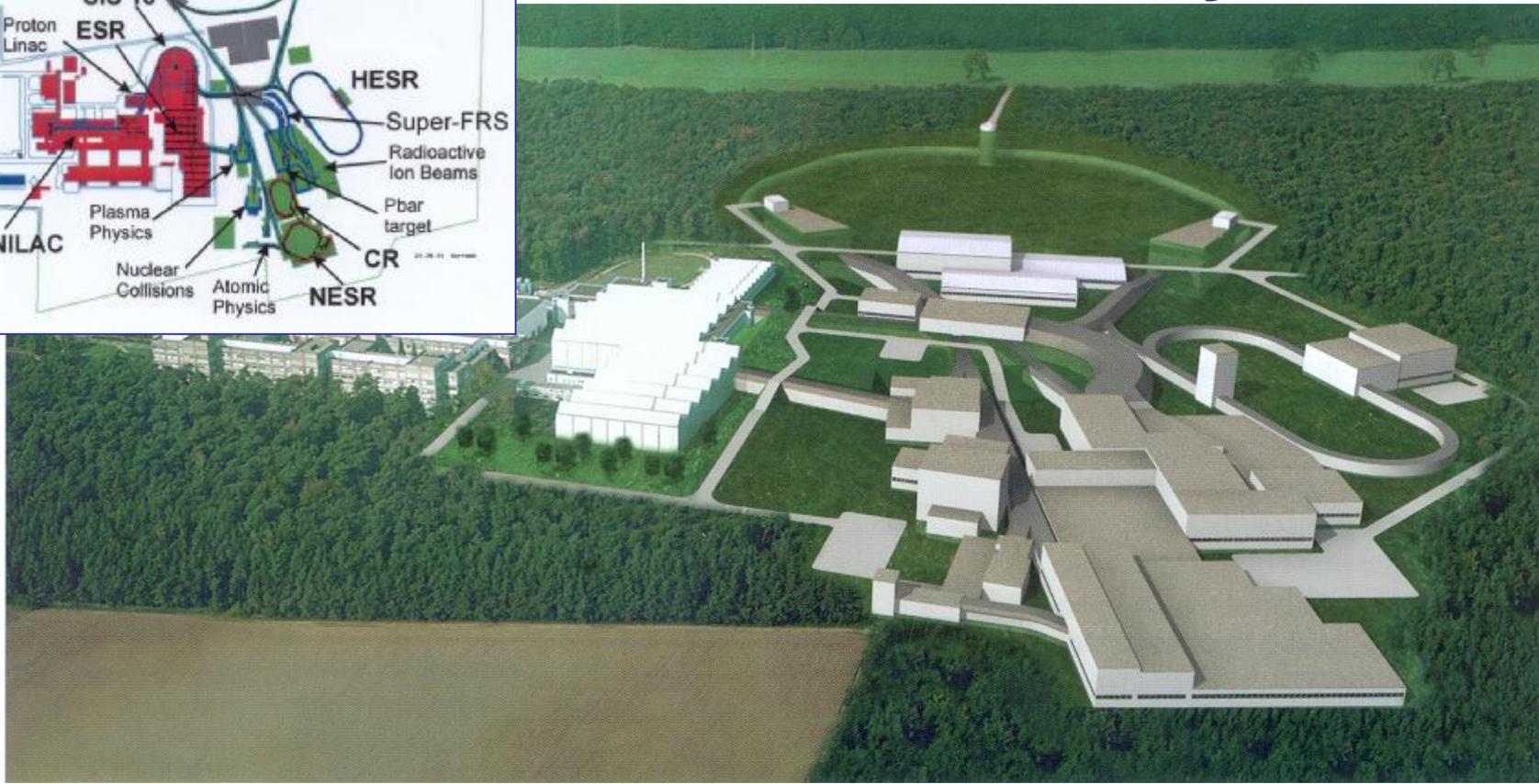
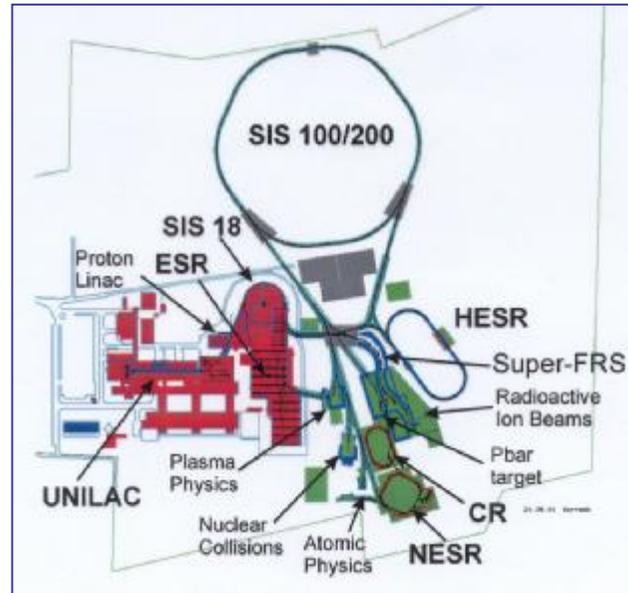
RHIC's Experiments





Investigations in Veksler and Baldin Laboratory of High Energies

Future GSI Accelerator Facility





Investigations in Veksler and Baldin Laboratory of High Energies

Participation in GSI New Project (FAIR):

- Magnets for SIS100 (Nuclotron type)
- CBM experiment (Physics, SC Magnet, TRD, Simulation)
- PANDA (Physics, Simulation, Magnet)

Conclusions

- A wide range program of research with Nuclotron relativistic ions and polarized deuterons is going on in VBLHE with the active participation of researchers from JINR member states and other countries
- The VBLHE scientists active participate in research programs of CERN, scientific centers in USA, Germany, France, Japan and other countries