

Project NA61/SHINE (2019 — 2021)

JINR participation. Theme 02-1-1087-2009/20

V. Kireyeu

49th meeting of the PAC for Particle Physics

18/06/2018

Project NA61-SHINE

SHINE – SPS Heavy Ion and Neutrino Experiment

Study of Hadron Production in Hadron-Nucleus and Nucleus-Nucleus Collisions at the CERN SPS

Project leader
Deputy project leader

A.I. MALAKHOV
G.L. MELKUMOV

Project NA61-SHINE



JOINT INSTITUTE FOR NUCLEAR RESEARCH

SEVEN-YEAR PLAN FOR THE DEVELOPMENT OF JINR 2017–2023

(Approved by the Committee of Plenipotentiaries of the Governments of the JINR
Member States at its session held on 21–22 November 2016)

Dubna 2017

pp.17-18

Expected results:

1.The start-up of the BM@N first configuration for high-intensity light-ion beams extracted from the Nuclotron. Obtaining first results in the research programme of the BM@N experiment: study of yields of hadrons, hyperons, and light nuclei -- 2017–2019.

2.Obtaining results at BM@N using high-intensity heavy-ion beams, including ions of gold. Study of elliptic and directed flows, production of hyperons with $S=2$ and hypernuclei -- 2019–2023.

3.The start-up of the MPD Stage I, obtaining first results in the research programme to study the properties of hot and dense baryonic matter in the central rapidity range, to search for phase transitions (observables – particle yields and spectra) including partial restoration of chiral symmetry (observables – yields of di- leptons), and to search for the critical end-point (observables – event- by-event fluctuations, particle correlations) -- 2020–2023.

4.Commissioning of the MPD Stage II. Beginning of the research programme with the MPD detector in the available phase space region -- 2023.

5. Obtaining new results in the energy scan programme in the experiments NA61 (SPS) and STAR (RHIC) -- 2017–2023.

6.Obtaining new results in the femtoscopy programme in the ALICE experiment (LHC), participation in ALICE upgrade -- 2017–2023.

7.Settlement of commitment in the development and commissioning of the CBM set-up under JINR's obligations in accordance with the NICA–FAIR joint research programme -- 2017–2023.

RECOMMENDATIONS

47th meeting, PAC for Particle Physics

The PAC takes note of the reports on the NA61 experiment presented by M. Gazdzicki and V. Kireyev. NA61 is expected to complete the data-taking phase in 2018, and the NA61 collaboration is considering the possibility to extend its programme for the period 2021–2024.

The PAC appreciates the role of the JINR group in data taking, detector and software maintenance but considers that **the impact on physics analyses is not commensurate to the group size and would like to see a larger involvement in leading physics analyses.**

The PAC recommends continuation of the JINR participation in the NA61 experiment with the current group size until the end of the NA61 data-taking phase in 2018. Continuation of the JINR team activities within NA61 on data analysis or R&D beyond 2018 would require submitting a new proposal.

Participants from JINR

- **JINR management**

V.A. Matveev;

- **Veksler and Baldin Laboratory of High Energy Physics**

V.A. Babkin, M.G. Buryakov,

V.A. Kireyeu, V.I. Kolesnikov, V.V. Lenivenko, A.I. Malakhov,

G.L. Melkumov, M.M. Rumyantsev, A.A. Zaitsev

- **Dzelepov Laboratory of Nuclear Problems**

G.I. Lykasov, V.V. Lyubushkin, B.A. Popov, V.V. Tereshchenko

- **Institute Physics and Technology of Mongolian Academy of Science, Ulaanbaatar, Mongolia**

B. Baatar;

- **Sofia University "St. Kliment Ohridski", Bulgaria**

D. Kolev, M. Bogomilov

Participants from JINR

Table 1. LHEP manpower.

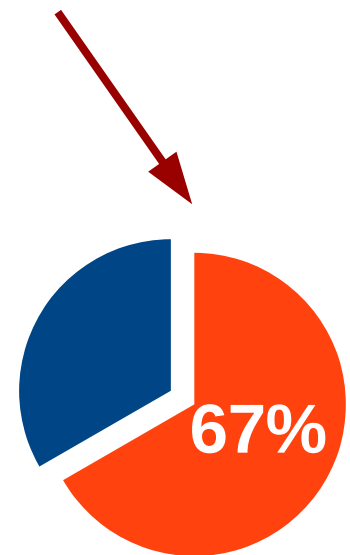
| № | Name | Category | FTE |
|---|---------------|-----------------------|-----|
| 1 | Babkin V. | MRPC | 0.2 |
| 2 | Buryakov M. | MRPC | 0.2 |
| 3 | Kireyeu V. | Analysis, data taking | 0.5 |
| 4 | Kolesnikov V. | Analysis | 0.1 |
| 5 | Lenivenko V. | Analysis, data taking | 0.2 |
| 6 | Malakhov A. | Analysis, data taking | 0.3 |
| 7 | Melkumov G. | Analysis, data taking | 0.8 |
| 8 | Rumyantsev M. | MRPC | 0.2 |
| 9 | Zaitsev A. | Analysis, data taking | 0.8 |
| Σ | | | 3.3 |

Table 2. LNP manpower.

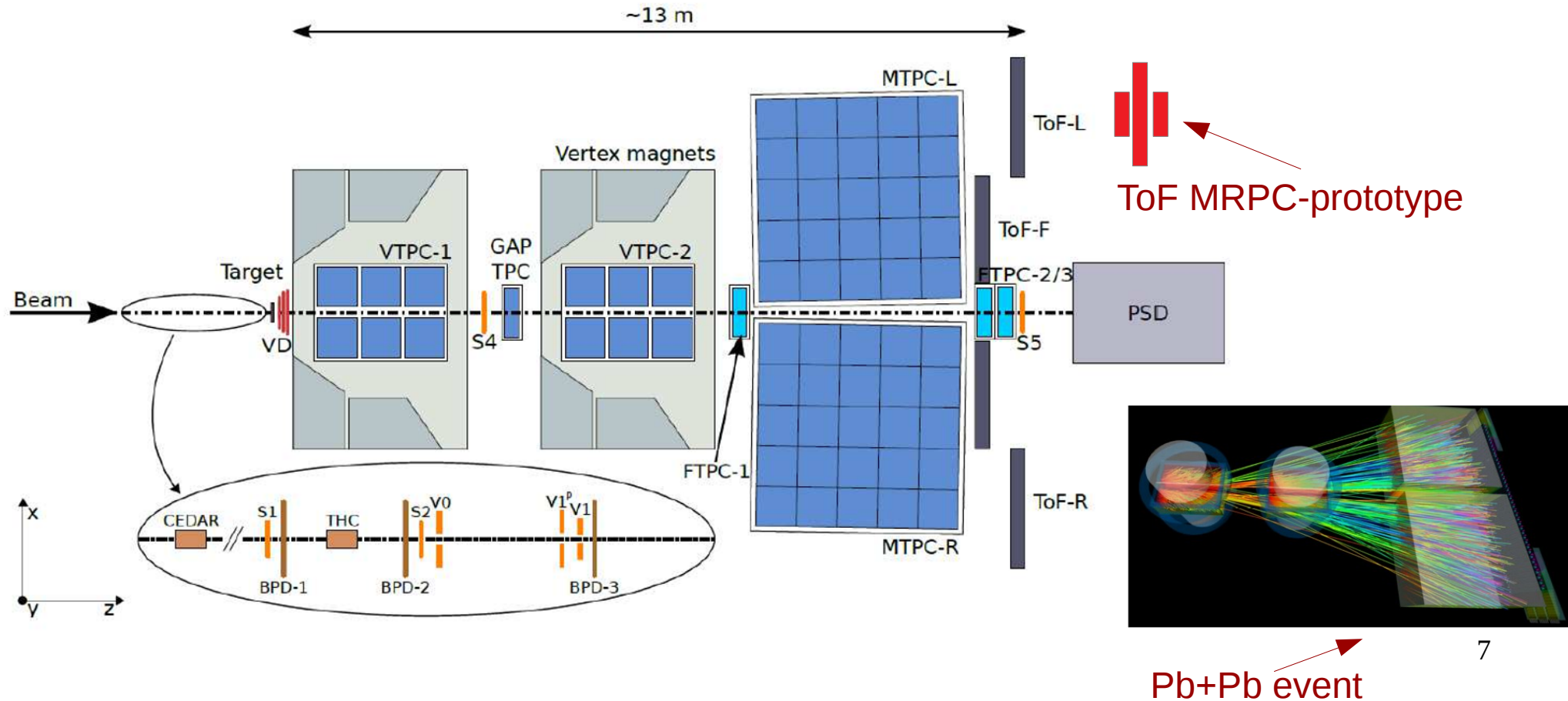
| № | Name | | FTE |
|---|---------------|-----------------------|-----|
| 1 | Lykasov G. | Theory | 0.1 |
| 2 | Lyubushkin V. | Analysis, data taking | 0.2 |
| 3 | Popov B. | Analysis | 1.0 |
| 4 | Tereshenko V. | MRPC, data taking | 0.3 |
| Σ | | | 1.6 |

Table 3. The age of young employees.

| № | Name | Age (years) |
|---|---------------|-------------|
| 1 | Babkin V. | 36 |
| 2 | Buryakov M. | 27 |
| 3 | Kireyeu V. | 28 |
| 4 | Lenivenko V. | 27 |
| 5 | Rumyantsev M. | 29 |
| 6 | Zaitsev A. | 26 |



NA61/SHINE general view

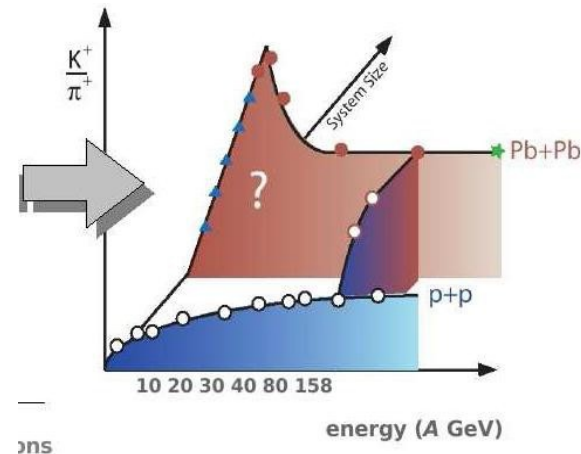
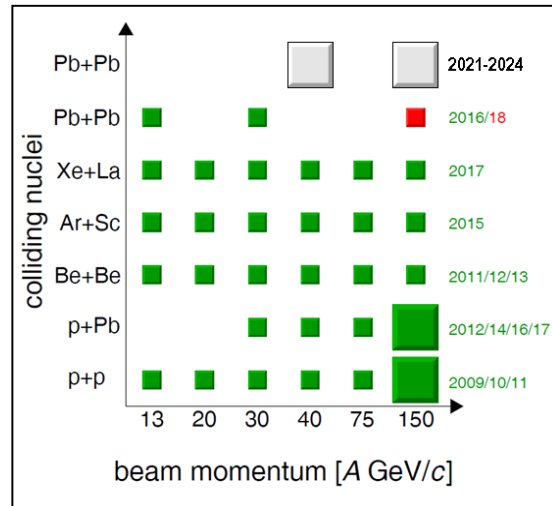


NA61/SHINE physical programme

- Study of nucleus-nucleus collisions with the aim to identify the properties of the onset of deconfinement and to find the evidence for the critical point of strongly interacting matter.
- Study of proton-proton and proton-nucleus collisions as the reference data for better understanding of nucleus-nucleus reactions.
- Measurements of hadron production in hadron-nucleus interactions for neutrino and cosmic ray experiments.

NA61/SHINE experimental strategy

- Perform a 2D (energy-system size) scan with several beam species (p Be, Ar,Xe,Pb) within the energy range from 13 to 158A GeV
- Study as many as possible Event-by-Event fluctuation signals ($\langle p_T \rangle$, mult., ratios, etc.)



Study how the NA49 observables (“Horn”) evolve with system size

Recent physics results (2017 - 2018)

- A. Aduszkiewicz , Y. Ali, E. Andronov, ..., V.I. Kolesnikov, A.I. Malakhov, V. Matveev, G.L. Melkumov, R.Tsenov, et al. Measurements of π^\pm , K^\pm , p and anti- p spectra in proton-proton interactions at 20, 31, 40, 80 and 158 GeV/c with the NA61/SHINE spectrometer at the CERN SPS. Eur. Phys. J. C 77 (2017), 671.
- A. Aduszkiewicz , Y. Ali, E. Andronov, ..., V.I. Kolesnikov, A.I. Malakhov, V. Matveev, G.L. Melkumov, R.Tsenov, et al. Two-particle correlations in azimuthal angle and pseudorapidity in inelastic p+p interactions at the CERN Super Proton Synchrotron. Eur.Phys.J. C77 (2017) no.2, 59.
- V.I. Kolesnikov, ..., A.I. Malakhov, V. Matveev, G.L. Melkumov, R.Tsenov et al. Recent results on light nuclei production from the NA49 experiment. XIII International Baldin Seminar on High Energy Physics Problems Relativistic Nuclear Physics and Quantum Chromodynamics (Baldin ISHEPP XXIII). EPJ Web of Conferences, v. 138, 03001 (2017).
- В.И. Колесников. Изучение рождения $\pi^{+/-}$, $K^{+/-}$, протонов, антипротонов, легких ядер (d , t , ^3He) и антидейтронов в столкновениях Pb+Pb при энергиях от 20 до 158 ГэВ на нуклон. Диссертация на соискание ученой степени доктора физ.-мат. наук. ОИЯИ, Дубна, 2017.
- A. Malakhov and G. Lykasov. Description of nucleon-nucleon and nucleus-nucleus interactions in four-dimensional velocity space, including data of NA61/SHINE. NA61/SHINE & NA49 Collaboration Meeting at MEPhI in Moscow, May 8-12, 2017.
- D.Artemenkov, A.Malakhov and G.Lykasov. Development of the Baldin approach for the relativistic nuclear interactions. EPJ Web of Conferences 138, 01031 (2017).
- A.Aduszkiewicz et al. Measurement of meson resonance production in π^-+C interactions at SPS energies, NA61/SHINE Collaboration. Eur.Phys.J. C77 (2017) no.9, 626.
- A.Aduszkiewicz et al. Report from the NA61/SHINE experiment at the CERN SPS, NA61/SHINE Collaboration. CERN-SPSC-2017-038, SPSC-SR-221.
- G.I. Lykasov, A.I. Malakhov. "Self-consistent analysis of hadron production in pp and AA collisions at mid-rapidity". arXiv:1801.07250v1 [hep-ph] 22 Jan 2018.

System size dependence: onset of fireball

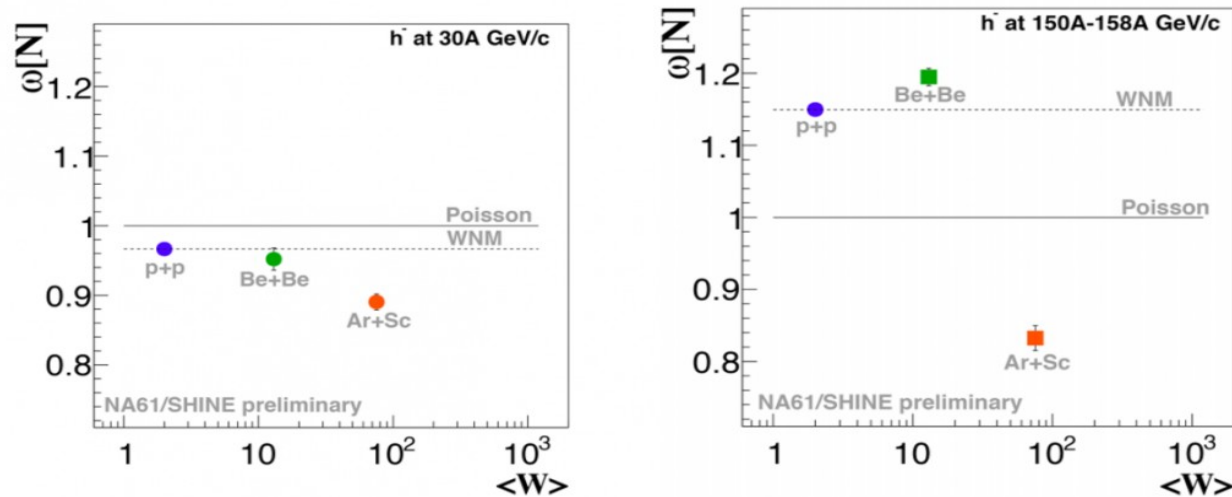
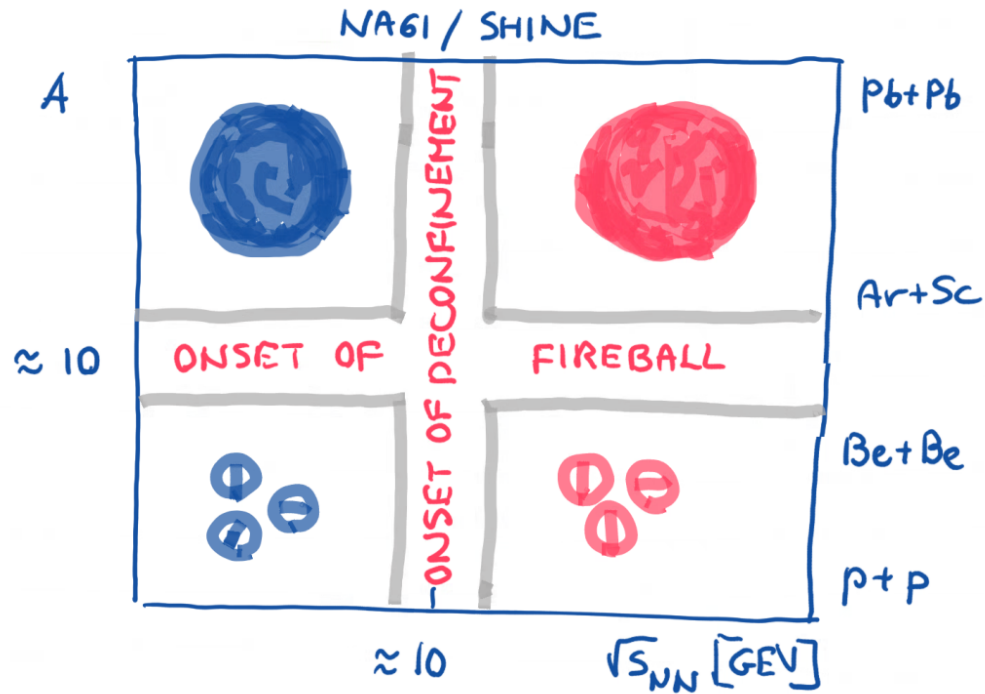


Fig.1 System size dependence of multiplicity fluctuations of negatively charged hadrons at 30 A GeV/c and 158A GeV/c.

The observed rapid change of hadron production properties that start when moving from Be+Be to Ar+Sc collisions can be interpreted as the beginning of creation of large clusters of strongly interacting matter. This phenomenon was referred to as the onset of fireball (the name was proposed by Edward Shuryak during the CPOD 2017 conference).

System size dependence: onset of fireball



The two-dimensional scan conducted by NA61/SHINE by varying collision energy and nuclear mass number of colliding nuclei indicates four domains of hadron production properties separated by two thresholds: **the onset of deconfinement** and **the onset of fireball**.

JINR contributions/responsibilities

- **Data taking**
- **R&D for the future TOF upgrade (MRPC-based)**
- **TOF-L/R response simulation within the SHINE framework**
- **Development and maintenance of the software library (legacy chain)**
- **Raw data reconstruction and DST production**
- **Data analysis**

JINR contributions/responsibilities

G.I. Lykasov, A.I. Malakhov. "Self-consistent analysis of hadron production in pp and AA collisions at mid-rapidity". arXiv:1801.07250v1 [hep-ph] 22 Jan 2018.

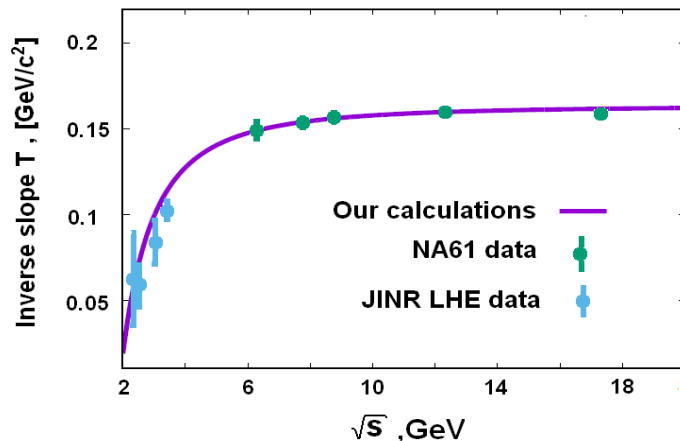


Fig.3. Dependence of the inverse slope parameter T from energy ($pp \rightarrow \pi + \dots$).

Three PhD and two doctoral dissertations have been successfully defended on the NA61 results by the JINR employees and more than three PhD dissertations are planned to be prepared

ОБЪЕДИНЕННЫЙ ИНСТИТУТ ЯДЕРНЫХ
ИССЛЕДОВАНИЙ

На правах рукописи

КОЛЕСНИКОВ
Вадим Иванович

ИЗУЧЕНИЕ РОЖДЕНИЯ $\pi^{+/-}$, $K^{+/-}$, ПРОТОНОВ, АНТИПРОТОНОВ,
ЛЕГКИХ ЯДЕР (d, t, ^3He), И АНТИДЕЙТРОНОВ В СТОЛКНОВЕНИЯХ
 $Pb+Pb$ ПРИ ЭНЕРГИЯХ ОТ 20 ДО 158 ГэВ НА НУКЛОН.

Специальность: 01.04.16 — физика атомного ядра
и элементарных частиц

АВТОРЕФЕРАТ
диссертации на соискание ученой степени
доктора физико-математических наук

Дубна 2017

Plans for 2019 - 2021

Hardware & data taking

- TOF-L/R maintenance : Data taking : shifts, TOF on-line monitoring
- R&D for NA61 TOF upgrade

Software development & reconstruction

- TOF simulation tools within the SHINE framework
- DST production

Plans for 2019 - 2021

Data analysis

- **VBLHEP**

Nuclear-nuclear collisions:

Three young employees (V.Kireyeu, A.Zaitsev, and V.Lenivenko) will focus on the following physics cases:

- study of the production of light nuclei (d, t, ^3He) in nucleus-nucleus interactions
(*continuation of the tradition of the group analysis participation*);
- investigation of the hadron flow in nucleus-nucleus interactions (*jointly with MEPhI*);
- study of hyperon production and search for hypernuclei in Ar +Sc, Xe+La and Pb+Pb collisions (*important for NICA!*);

- **DLNP**

Hadro-production for the Fermilab neutrino program.

Estimate of the JINR budget expenses for the NA61 project

| № | Name of the items cost | full cost (k\$) | | 2019 | | 2020 | | 2021 | |
|-------------------------------|--------------------------------------|-----------------|------------|------------|------------|------------|------------|------------|------------|
| | | Theme 1087 | Theme 1124 | Theme 1087 | Theme 1124 | Theme 1087 | Theme 1124 | Theme 1087 | Theme 1124 |
| 1. | <u>Accelerator (Nuclotron), hour</u> | - | - | - | - | - | - | - | - |
| 2. | Computer communications | 15 | - | 5 | - | 5 | - | 5 | - |
| 3. | LHEP Design bureau | - | - | - | - | - | - | - | - |
| 4. | LHEP Workshop | - | - | - | - | - | - | - | - |
| 5. | Materials | 30 | - | 12 | - | 12 | - | 6 | - |
| 6. | Equipment | 20 | - | 8 | - | 8 | - | 4 | - |
| 7. | <u>Payment research</u> | - | - | - | - | - | - | - | - |
| 8. | <u>Travel allowance, including:</u> | 210 | 12 | 65 | 4 | 60 | 4 | 85 | 4 |
| | (a) to non-rouble zone countries | 210 | 12 | 65 | 4 | 60 | 4 | 85 | 4 |
| | b) in the rouble zone | - | - | - | - | - | - | - | - |
| | c) protocol-based | 24 | 12 | 8 | 4 | 8 | 4 | 8 | 4 |
| Σ | | 299 | 24 | 98 | 8 | 93 | 8 | 108 | 8 |
| <u>Total direct expenses:</u> | | 323 | | 106 | | 101 | | 116 | |

Conclusions

- The present project has been prepared taking into account recommendations of 47th JINR PAC meeting for Particle Physics, June 26-27, 2017.
- The optimization of the number of project participants and their participation was made. The participation of members of the JINR group in the data analysis was increased.
- NA61/JINR members participated at five international conferences and were the coauthors of nine publications (in three publications – the key authors).

Conclusions

- A detailed R&D program for the NA61 ToF MRPC system for the period 2019-2021 is prepared. For further study of MRPC performance extensive beam tests at the CERN SPS are scheduled for Autumn 2018.
- An agreement with the leader of the NA61 experiment on providing dedicated heavy-ion data analysis training for young employees was reached. Thus, the creation of a "forge" of personnel for the NICA experiments opens.

June 8: SPSC recommended data taking

“The SPSC recognises the broad interest of the NA61 physics programme after Long Shutdown LS2 as outlined in the addenda CERN-SPSC-P-330-ADD-10/11.

The Committee recommends approval of beam times in 2021 for detector commissioning with hadron beams, for the measurement of hadron production with the T2K target with proton beams, and for the measurement of open charm production with Lead ion beams.”

**We ask you to recommend an approval of
JINR participation in the NA61 project
within
the theme 02-1-1087-2009/2020 for a
period of 3 years.**

Thank you!

BACKUP

PHYSICS GOALS OF NEW MEASUREMENTS

- FUNDAMENTAL PHYSICS:

- OPEN CHARM MEASUREMENTS IN Pb+Pb AT SPS

- REFERENCE MEASUREMENTS:

- NUCLEAR FRAGMENTATION CROSS-SECTION FOR COSMIC RAY EXPERIMENTS

- HADRON PRODUCTION FOR NEUTRINO EXPERIMENTS

RECENT DOCUMENTS:

— March 21, 2018, Addendum 10:

*Study of Hadron-Nucleus and Nucleus-Nucleus Collisions at the CERN SPS:
Early Post-LS2 Measurements and Future Plans,*
CERN-SPSC-2018-008, SPSC-P-330-ADD-10

— June 5, 2018, Addendum 11:

Reply to the SPSC questions on Addendum CERN-SPSC-2018-008,
CERN-SPSC-2018-019, SPSC-P-330-ADD-11

→ JUNE 8: SPSC RECOMMENDED
DATA TAKING IN 2021

OPEN THREAT INTELLIGENCE DISCIPLINE ATTACHES TRINITY

“What’s the threat?” “What’s the threat?” “What’s the threat?”

“What’s the threat?” “What’s the threat?” “What’s the threat?”

Open Production

TA ANSWER: “What’s the threat?”

Open Production

Open Production

Open Production

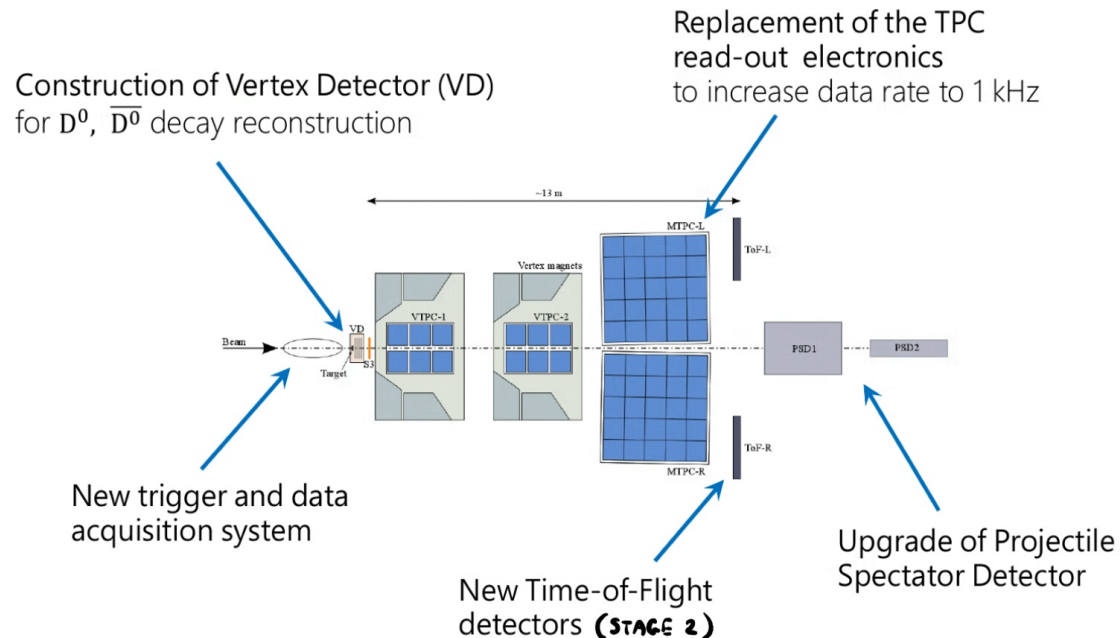
Open Production

Open Production

Open Production

Open Production

DETECTOR UPGRADES (2018-2021)

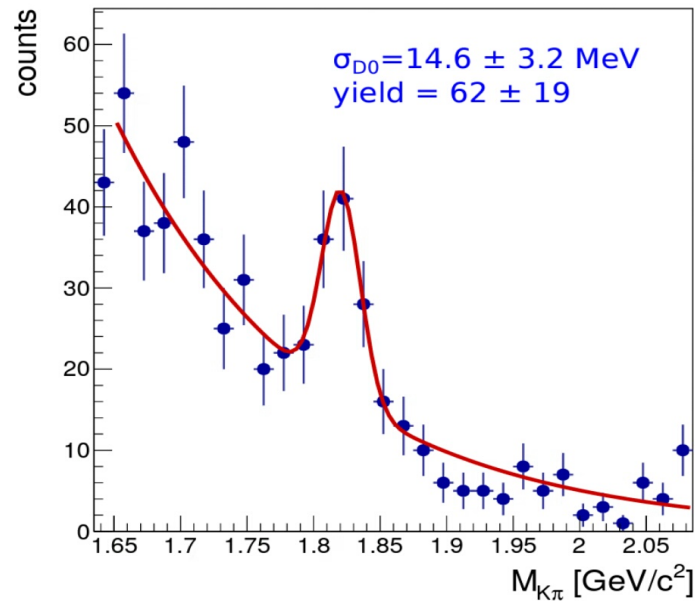


IN TOTAL: ≈ 850 K CHF (STAGE 1, HARDWARE ONLY)

MODERATE COSTS THANKS TO COLLABORATION WITH
ALICE (TPC, VD), CBM (PSD), MPD (MRPC)

RESULTS FROM THE 2016 TEST (Pb+Pb AT 150A GEV/c)

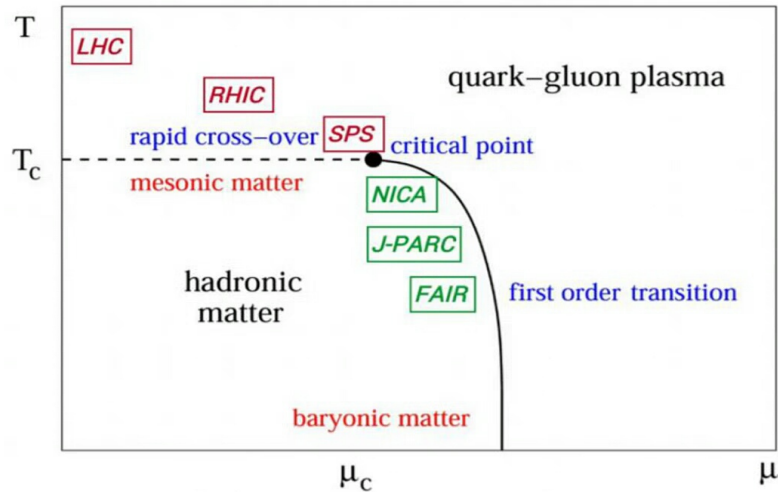
VERTEX DETECTOR PROTOTYPE



INDICATION OF $D^0 + \bar{D}^0$ PEAK

UNIQUENESS OF NAGI/SHINE PROGRAMME

LANDSCAPE OF PRESENT AND FUTURE HEAVY ION EXPERIMENTS



LHC and RHIC at high energies ($\sqrt{s_{NN}} \geq 200$ GeV):

measurements in limited phase space
due to collider geometry and kinematics

RHIC BES (3 – 39 GeV):

measurement not under consideration

NICA (< 11 GeV):

under consideration during stage 2

J-PARC (< 6 GeV) :

maybe possible after 2025

FAIR SIS-100 (< 5 GeV):

not possible at SIS-100,
planned at SIS-300 (< 7 GeV)

ONLY NAGI/SHINE IS ABLE TO MEASURE OPEN CHARM PRODUCTION
IN HEAVY ION COLLISIONS IN FULL PHASE SPACE AND
IN THE NEAR FUTURE

REQUESTED BEAMS

2021: 6 WEEKS FOR DETECTOR COMMISSIONING

5 WEEKS OF PROTON BEAM AT 31 GEV/C FOR
DATA TAKING FOR NEUTRINO PHYSICS

4 WEEKS OF Pb BEAM AT 150A GEV/C FOR
OPEN CHARM MEASUREMENT

RECOMMENDED
BY SPSC

2022-24: HADRON, LIGHT ION (SECONDARY) AND Pb BEAMS
IN ACCORDANCE TO THE PROPOSED PHYSICS PROGRAM