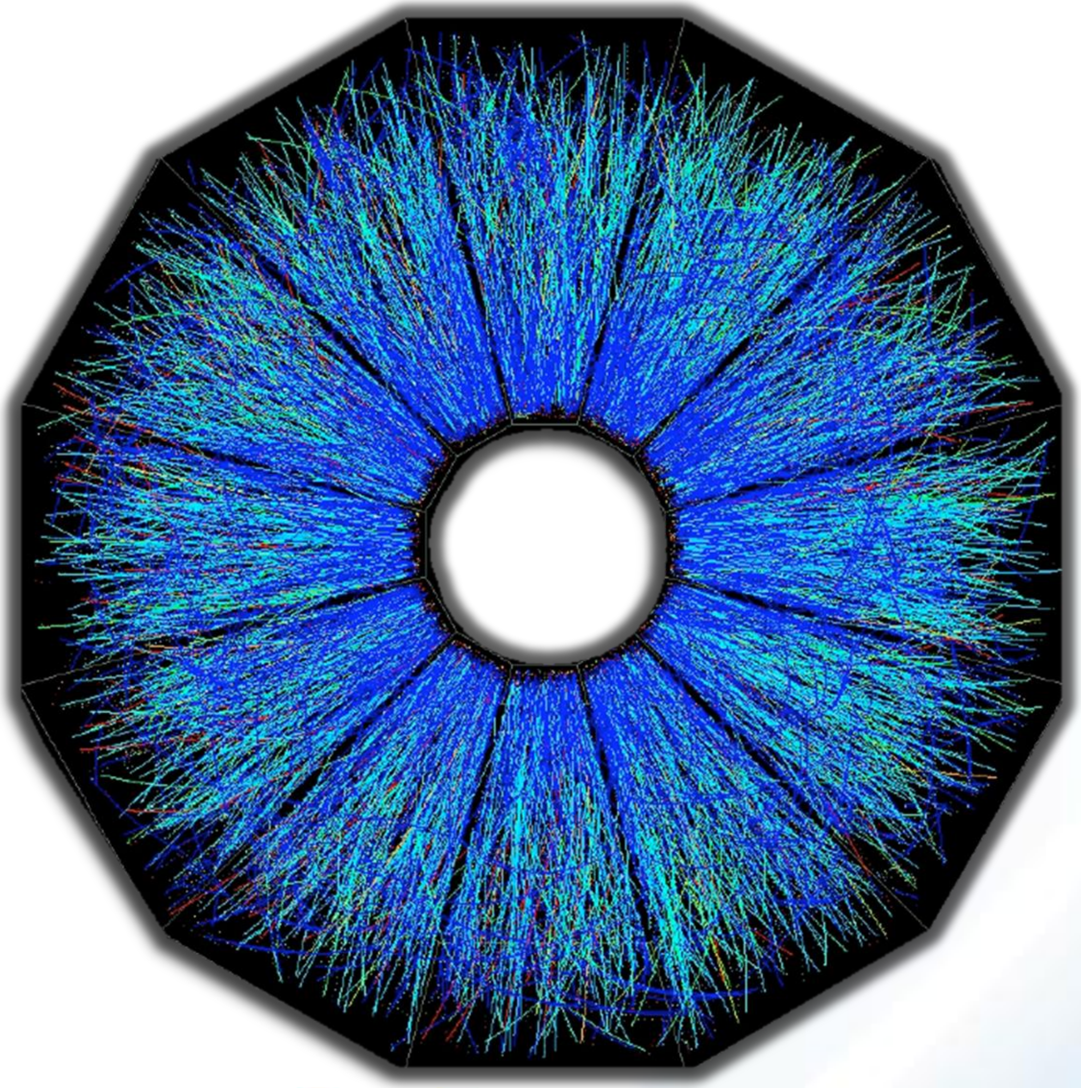
STAR Experiment at RHIC



JINR participation

STAR Experiment at RHIC

12 countries:

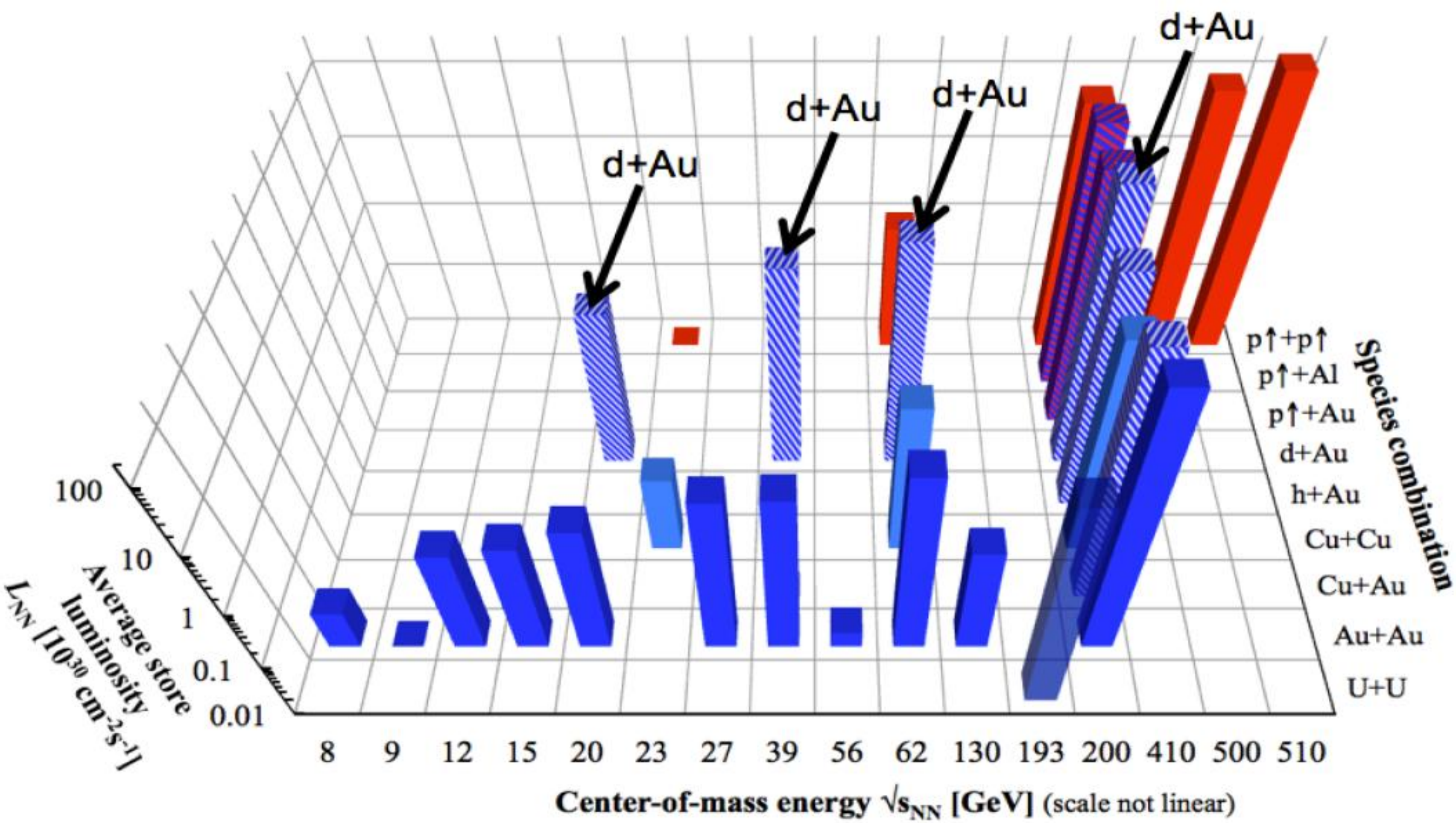
Brazil,
China,
Croatia,
Czech Republic,
England,
France,
Germany,
India,
Netherlands,
Poland,
Russia,
USA

52 institutions,

– total 586 collaborators

STAR/LHEP group: **G.S. Averichev, A.A. Aparin, N.A. Balashov, V.V. Belaga, I. Bunzarov, N. Chankova-Bunzarova, V.B. Dunin, T.G. Dedovich, J. Fedorishin, P. Filip, E.I. Golubeva, A.O. Kechechian, V.V. Korenkov, E.A. Kuznetsov, K.V. Klygina, R. Lednicky, V.V. Lyuboshitz, V.V. Mitsyn, M.P. Osmachko, G.A. Ososkov, Yu.A. Panebrattsev, E.V. Potrebenikova, O.V. Rogachevski, E. Shakhaliev, P.D. Semchukov, N.E. Sidorov, M.V. Tokarev, S. Vokal, N.I. Vorontsova , I. Zborovsky, A.N. Zubarev**

RHIC Delivers Whatever it Takes



RHIC's Physics Program is Diverse

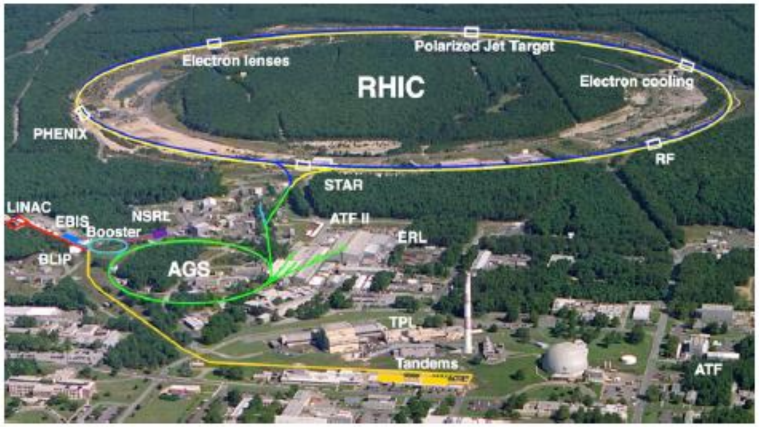
STAR

Quark Gluon Plasma

QCD Phase Diagram

Gluon Saturation

Parton Energy Loss



Parton Correlations

Hadron Formation

Transverse Spin Dynamics

Nuclear parton densities

Proton Spin Structure

Nuclear Tomography by UPC

JINR 7-year Plan


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 2016

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

JINR Results

Publications on the STAR/RHIC research with essential JINR contribution

The first high statistic measurement of ΛΛ correlation.
STAR Collaboration. Phys. Rev. Lett. 114, 022301 (2015)

Measurements of interactions between antiprotons.
STAR Collaboration. Nature 527 (2015) 345.

Spectra of charged particles production in BES-I
STAR Collaboration. Int. J. Mod. Phys. (2015) 1560103.

Coherent diffractive photoproduction of ρ0 mesons on gold nuclei at 200 GeV/nucleon-pair at the RHIC, STAR Collaboration , Phys.Rev. C96 (2017) 054904

Self-similarity of proton spin and asymmetry of jet production
M.V. Tokarev, I. Zborovsky. Physics of Particles and Nuclei Letters, 12 (2015) 313

Self-similarity of hadron production: *z*-scaling
Tokarev M.V. , Zborovsky I. Theor. Math. Phys., 84, 3, 1350-1360, 2016

New indication on scaling properties of strangeness production in pp collisions at RHIC
M.V. Tokarev, I. Zborovsky, Int. J. Mod. Phys. A 32 (2017) 1750029

Total number of publication in 2015–2017 – 12

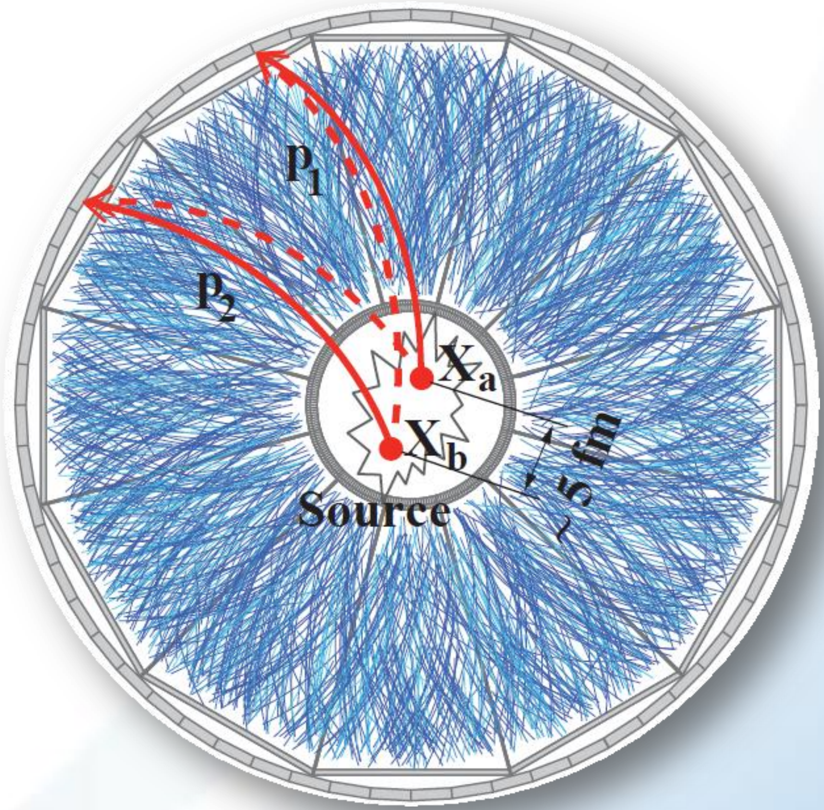
Data Analysis

R. Lednický, M. Šumbera, P. Chaloupka, L. Malinina, K. Mikhailov

Developments of the correlation femtoscopy to study particle production dynamics and narrow resonance formation

Progress of Theoretical Physics No. 193, 2012 (335)

The basics of correlation femtoscopy including resonance formation due to the final state interaction are given and the applicability conditions of this formalism are discussed. The example calculations of $\pi^+\Xi^-$ and K^+K^- correlation functions are done with the account of $\Xi^*(1530)$ and $\varphi(1020)$ resonances, respectively. It is shown that in the momentum region of the considered *p*-wave resonances the usual simple form of the smoothness approximation is inapplicable and should be substituted by a more general one. A strong sensitivity of resonance formation in the final state to the position-momentum correlations at particle freeze-out is demonstrated.



Data Analysis

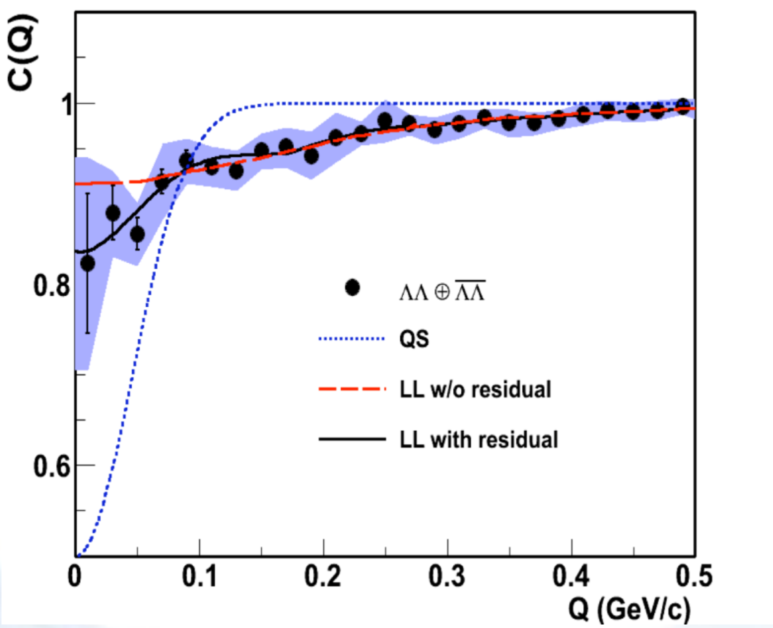
The first high statistics measurement of ΛΛ correlation

Phys. Rev. Lett. 114, 022301 (2015)

The first high statistics measurement of *ΛΛ* correlation function in Au + Au collisions at $\sqrt{s_{NN}}$ = 200 GeV. This research pioneered the venue of using RHIC as a hyperon factory to investigate hyperon-hyperon interactions. The STAR measurement can provide precious data for the understanding of hyperon-hyperon interaction which is an important input to various baryon-baryon interaction potential model as well as for the study of equation of state for neutron stars. The *ΛΛ* interaction is also closely related to the existence of the *H* dibaryon, one of the most searched for exotic hadrons in nuclear collisions.

$f_0 \approx$ -1 fm, $d_0 \approx$ 8 fm $\Rightarrow$ - no s-wave resonance

- bound state possible



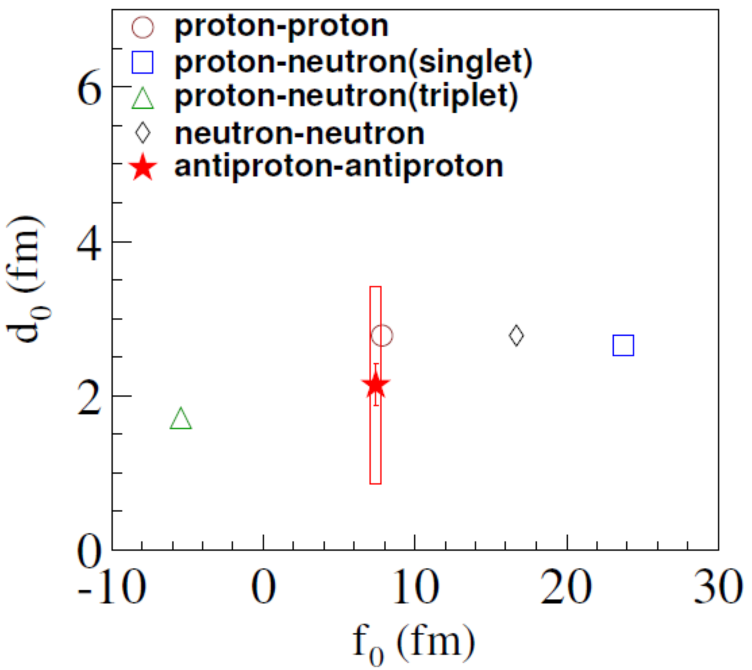
*The combined ΛΛ and anti-Λ anti-Λ correlation function for 0–80 % centrality Au + Au collisions at $\sqrt{s_{NN}}$ = 200 GeV. Curves correspond to fits using the **Lednicky and Lyuboshitz analytical model** with and without a residual correlation term. The dotted line corresponds to Fermi statistics with a source size of 3.13 fm.*

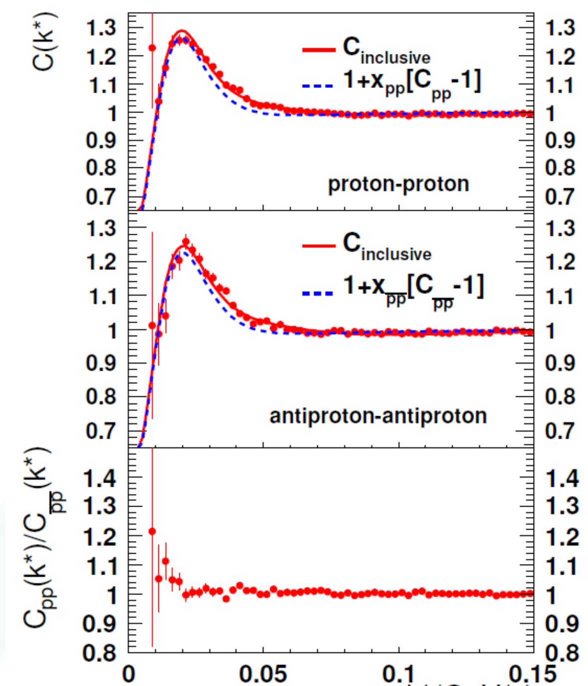
Data Analysis

Observation of interaction between anti-nucleons

Nature 527, 345–348 (19 November 2015)

The study of the two anti-proton correlation function with data taken by the STAR experiment at RHIC, we show the attracting nuclear force between two anti-protons, and present the measurement of the two key parameters that charactering the corresponding strong interaction, namely, the scattering length (f_0) and effective range (d_0). As a direct knowledge from the interaction between two anti-protons, the simplest system of anti-nucleons (nuclei), our result provides a fundamental ingredient for understanding the structure of more sophisticated anti-nuclei and their properties.





Data Analysis

nature International weekly journal of science

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Archive > Volume 527 > Issue 7578 > Letters > Article

NATURE | LETTER

日本語要約

Measurement of interaction between antiprotons

The STAR Collaboration

Affiliations | Contributions

Nature **527**, 345–348 (19 November 2015) | doi:10.1038/nature15724
Received 25 July 2015 | Accepted 11 September 2015 | Published online 04 November 2015 | Corrected online 18 November 2015

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One of the primary goals of nuclear physics is to understand the force between nucleons, which is a necessary step for understanding the structure of nuclei and how nuclei interact with each other. Rutherford discovered the atomic nucleus in 1911, and the large body of knowledge about the nuclear force that has since been acquired was derived from studies made on nucleons or nuclei. Although antinuclei up to antihelium-4 have been discovered[1] and their masses measured, little is known directly about the nuclear force between antinucleons. Here, we study antiproton pair correlations among data collected by the STAR experiment[2] at the Relativistic Heavy Ion Collider (RHIC)[3], where gold ions are collided with a centre-of-mass energy of 200 gigaelectronvolts per nucleon pair. Antiprotons are abundantly produced in such collisions, thus making it feasible to study details of the antiproton–antiproton interaction. By applying a technique similar to Hanbury Brown and Twiss intensity interferometry[4], we show that the force between two antiprotons is attractive. In addition, we report two key parameters that characterize the corresponding strong interaction: the scattering length and the effective range of the

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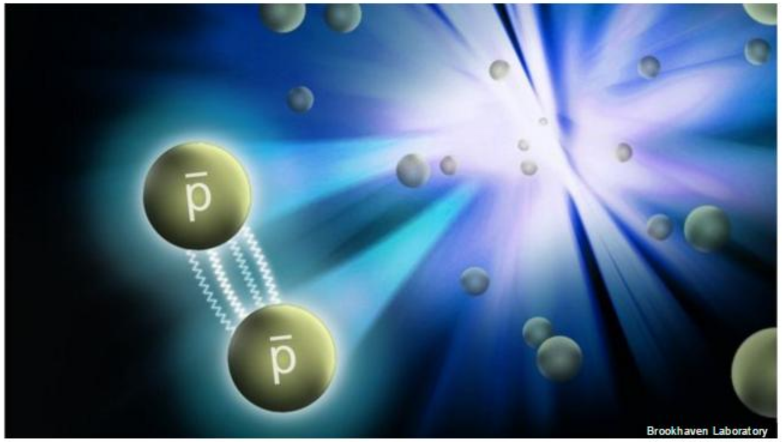
Science & Environment

Strong forces make antimatter stick

4 November 2015 | Science & Environment



Physicists have shed new light on one of the greatest mysteries in science: Why the Universe consists primarily of matter and not antimatter.

"There are many ways to test for matter/antimatter asymmetry, and there are more precise tests, but in addition to precision, it's important to test it in qualitatively different ways. This experiment was a qualitatively new test," said Richard Lednický, a STAR scientist from the Joint Institute for Nuclear Research, Dubna, and the Institute of Physics, Czech Academy of Sciences, Prague.

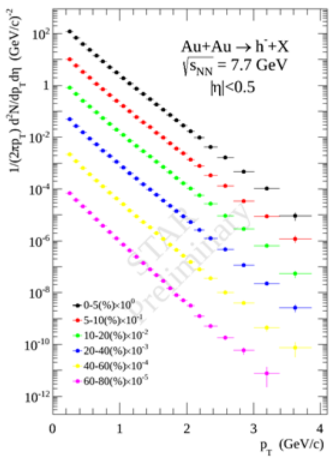
Self-Similarity and Fractality in Heavy Ion collisions

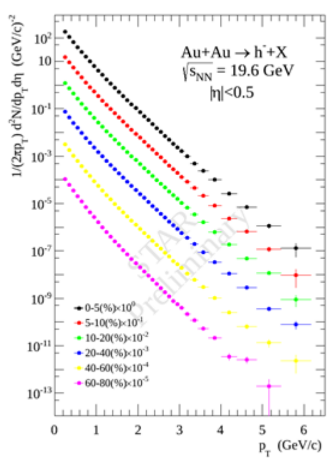
M. Tokarev, I. Zborovsky, A. Kechechyan,
T. Dedovich, A. Aparin, S. Vokal, P. Filip

Theor. Math. Phys. 84 (2016) 1350
Phys.Rev. D75 (2007) 094998
Int. J.Mod. Phys. A24 (2009) 1417

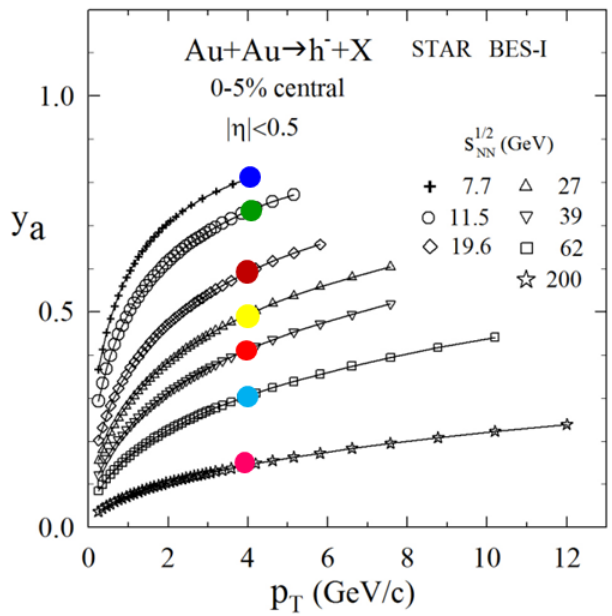
Self-similarity of negative particle production from the Beam Energy Scan Program at STAR,
International Journal of Modern Physics: Conference Series. Vol. 39 (2015) 1560103 (12 pages)

BES-I





Energy loss $\Delta E/E \sim (1-y_a)$



Constituent energy loss

- decreases with p_T
- increases with $\sqrt{s_{NN}}$
- increases with centrality

20 % energy loss $q \approx 5$ GeV/c
25 % energy loss $q \approx 5.3$ GeV/c
40 % energy loss $q \approx 6.7$ GeV/c
50 % energy loss $q \approx 8$ GeV/c
60 % energy loss $q \approx 10$ GeV/c
70 % energy loss $q \approx 13.3$ GeV/c
85 % energy loss $q \approx 26.6$ GeV/c

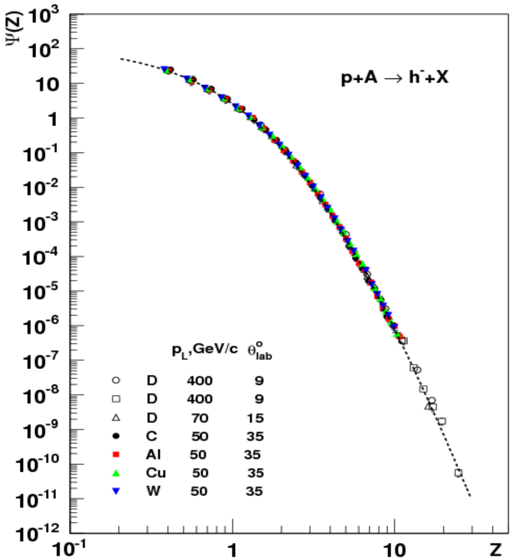
q – momentum of scattered constituent
$\mathbf{p_T}$ – transverse momentum of produced hadron

PhD and Master Thesis

Alexei Aparin, PhD (2017)

”Scaling in cumulative and high-p_T particle production in proton-nucleus collisions at high energies”

High-p_T & Cumulative

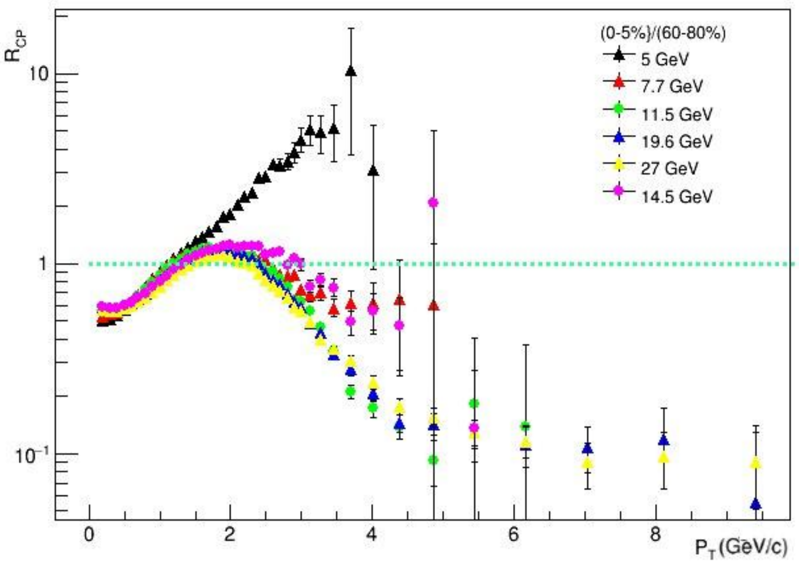


- Universality of the shape of $\Psi(z)$
- Power law: $\Psi(z) \sim z^{-\beta}$ for $z > 4$
- Additive law: $\delta_A = A\,\delta$

Timur Amangaliev, Ms (2017)

”Monte Carlo simulation of *Rcp* for BES-I energies”

$$R_{CP}(p_T) = \frac{\langle N_{coll}^{AA}\rangle_{60-80\%}}{\langle N_{coll}^{AA}\rangle_{0-5\%}} * \frac{d^2N_{AA}^{0-5\%}/dydp_T}{d^2N_{AA}^{60-80\%}/dydp_T}$$



UrQMD data

JINR Results

JINR group international conference reports

R. Lednický (for the STAR Collaboration)
“Correlation measurement of particle interaction at STAR ”, Hadron Structure and QCD – 2016 (HSQCD'2016), 27 June 2016 – 1 July 2016, PNPI NRC KI, Gatchina, Russia.

M.V. Tokarev (for the STAR Collaboration)
“Self-similarity of negative particle production from the Beam Energy Scan Program at STAR”, International Conference “Hadron Structure 15”, June 29–July 3, 2015, Slovak Republic.

M.V. Tokarev (for the STAR Collaboration)
“Recent STAR Heavy-Ion Results”,
The XXIII International Baldin Seminar on High Energy Physics Problems ”Relativistic Nuclear “Physics and Quantum Chromodynamics”, September 19–24, 2016, Dubna, Russia.

M.V. Tokarev (for the STAR Collaboration)
“Recent STAR spin results and spin measurements at RHIC”,
XVII Workshop on High Energy Spin Physics”, Dubna, Russia, September 11-15, 2017.

L. Hajdu at al (for the STAR Collaboration)
“STAR's approach to highly efficient end-to-end grid production”. XXVI International Symposium on Nuclear Electronics & Computing (NEC’2017), Becici, Budva, Montenegro, September 25–29, 2017

JINR Results

JINR group international conference reports

Peter Filip
“Internal structure modification and decay of hadrons in strong magnetic field”.
Hadron Structure Conference, Int. J.Mod.Phys.:Conference Series, 2015, vol. 39, 1560114.

Peter Filip
”Decay of resonaces in strong magnetic field”, 31st Winter Workshop on Nuclear Dynamics (WWND2015). Journal of Physics: Conference Series, 2015, vol. 636, 012013.

Peter Filip
“Excessive double strange baryon production due to strangeness oscillation in p+A, A+A collisions”, ICHEP2016 , PoS 2016, part F128556, p. 962.

Peter Filip
“Magnetic polarizability of virtual (ss) and (cc) pairs in the nucleon”, Journal of Physics: Conference Series, 2017, vol. 938, 012045.

Hejdar Agakishiev
“Progress report on STAR’s Expansion to JINR via GRID”, GRID2016, Dubna, JINR, 2016.

Valery V. Lyuboshitz
“Possible effect of mixed phase and deconfinement upon spin correlation in the pairs generated in relativistic heavy-ion collision”, EPS-HEP 2017 (Venice, Italy, July 5 – 12, 2017, *Proceedings of Science*, **314 (**2018) 653.

JINR Results

JINR group international conference reports

Valery V. Lyuboshitz
“On the pair correlations of neutral K, D, B and Bs mesons with close momenta produced in inclusive multiparticle processes”, HADRON 2017 (Salamanca, Spain, September 21–25, 2017), Proceedings of Science 310 (2018) 041.

Armen Kechechyan
“Fractional Momentum Loss of Hadrons in Au+Au Collisions at BES Energies”, STAR Regional Meeting , Warsaw, Poland, June 27–30, 2017.

Mikhail Tokarev
“Search for new symmetries: self-similarity of strangeness production”, Hadron Structure and QCD – 2016 (HSQCD'2016) 27 June 2016 – 1 July 2016, PNPI NRC KI, Gatchina, Russia. .

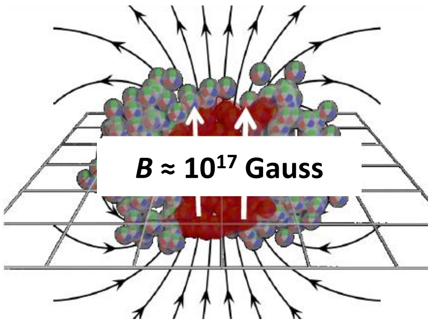
M.V. Tokarev, I. Zborovsky
“Fractality of strange particle production in pp collisions at RHIC”, 18th Lomonosov Conference on Elementary Particle Physics MSU, Moscow, Russia, August 24 – 30, 2017.

M.V. Tokarev, I. Zborovsky, A.O. Kechechyan
“Fractality of strange particle production in pp collisions at RHIC”, Regional STAR Meeting MEPhI, Moscow, Russia, August 23, 2017.

Total number of conference reports in 2015–2017 - 18

2018–2019

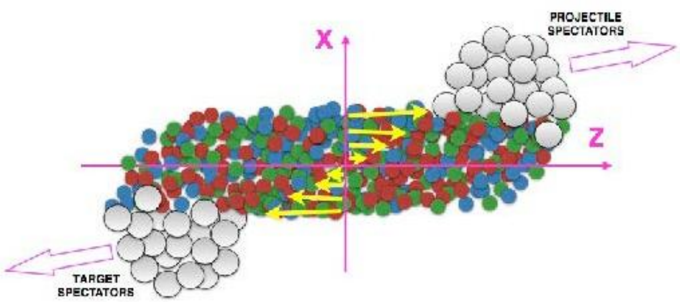
– High statistics isobar system $^{96}_{44}Ru$ & $^{96}_{40}Zr$ comparison run at 200 GeV



Chiral Magnetic Effect

The isobar comparison run in 2018 can tell us to with +/– 6% precision what fraction of the observed charge separation is due to the CME.

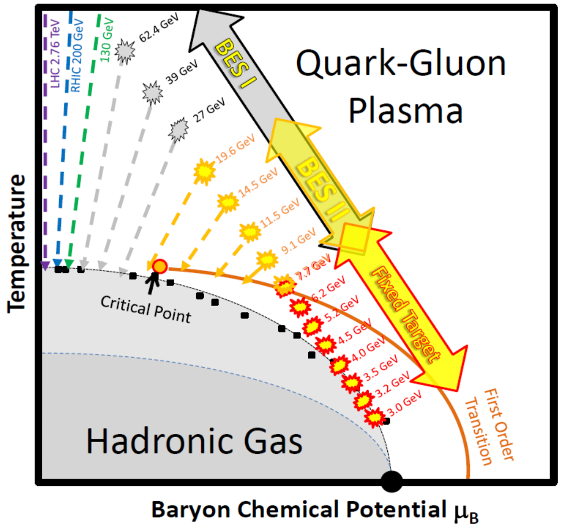
– High statistics global polarization measurement (Au+Au, 27 Gev)



Global collision angular momentum generates QGP vorticity

Global Lambda polarization is the signal of vorticity of “perfect fluid”.

Beam Energy Scan II, 2019–2021



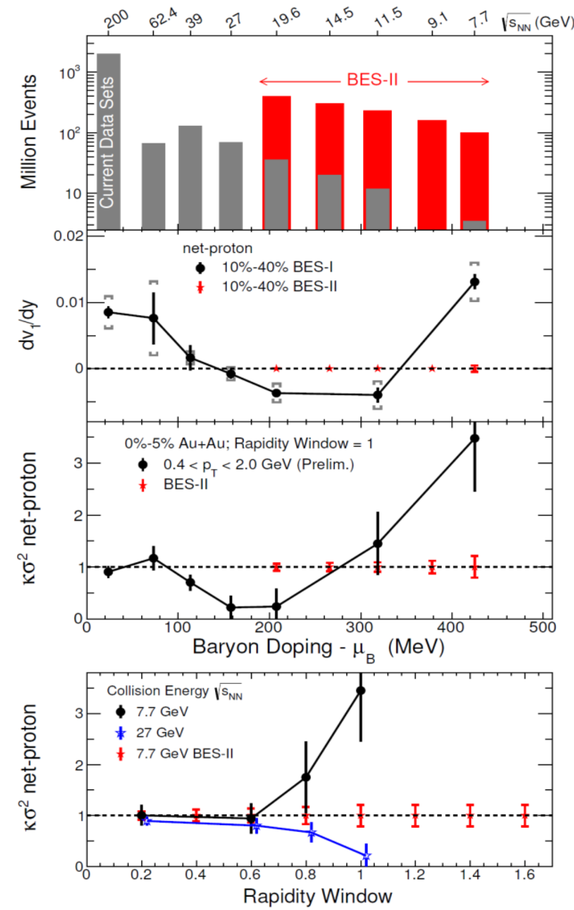
Collider mode

High statistics Au+Au beam energy scan at $\sqrt{s_{NN}}$ = 7.7–19.6 GeV

Fixed target mode

Au+Au beam energy scan at $\sqrt{s_{NN}}$ = 3–7.7 GeV

- **Improved $\kappa\sigma^2$ for net-protons**
  - The search for CP location
  - A non-monotonic or monotonic variation of the observable with beam energy
- **Improvements in v_2 of φ mesons**
  - To test in NCQ scaling detail for many particle species, including multistrange particles
  - To reach transverse momenta beyond 2.5 GeV/c even at the lowest energies
- **The low-mass dilepton measurements**
  - The combined improvement of the systematic and statistical uncertainties of BES-II data
  - better constraint of different models



Beam Energy Scan II

STAR

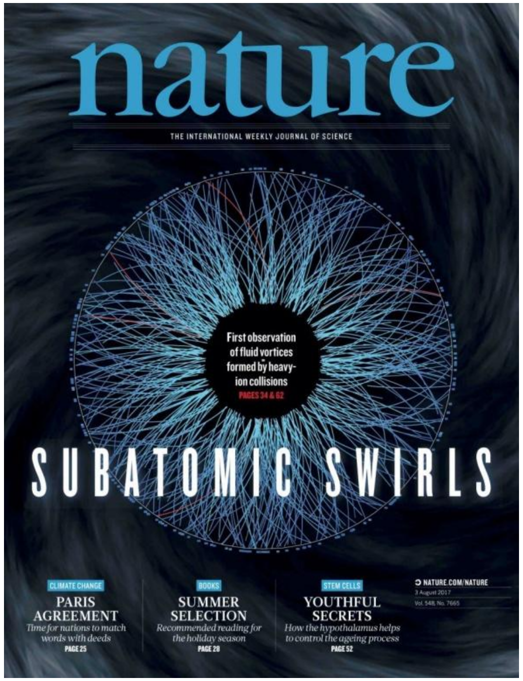
Summary of all BES-II and FXT Au+Au beam energies

Beam Energy (GeV/nucleon)	$\sqrt{s_{NN}}$ (GeV)	μ_B (MeV)	Run Time	Number Events
9.8	19.6	205	4.5 weeks	400M
7.3	14.5	260	5.5 weeks	300M
5.75	11.5	315	5 weeks	230M
4.55	9.1	370	9.5 weeks	160M
3.85	7.7	420	12 weeks	100M
31.2	7.7 (FXT)	420	2 days	100M
19.5	6.2 (FXT)	487	2 days	100M
13.5	5.2 (FXT)	541	2 days	100M
9.8	4.5 (FXT)	589	2 days	100M
7.3	3.9 (FXT)	633	2 days	100M
5.75	3.5 (FXT)	666	2 days	100M
4.55	3.2 (FXT)	699	2 days	100M
3.85	3.0 (FXT)	721	2 days	100M

Event statistics (in millions) needed in BES-II for various observables

Collision Energy (GeV)	7.7	9.1	11.5	14.5	19.6
μ_B (MeV) in 0-5% central collisions	420	370	315	260	205
Observables					
R_{CP} up to $p_T = 5$ GeV/c	-		160	125	92
Elliptic Flow (ϕ mesons)	80	120	160	160	320
Chiral Magnetic Effect	50	50	50	50	50
Directed Flow (protons)	20	30	35	45	50
Azimuthal Femtoscopy (protons)	35	40	50	65	80
Net-Proton Kurtosis	70	85	100	170	340
Dileptons	100	160	230	300	400
$>5\sigma$ Magnetic Field Significance	50	80	110	150	200
Required Number of Events	100	160	230	300	400

Global Polarization in Nuclear Collisions

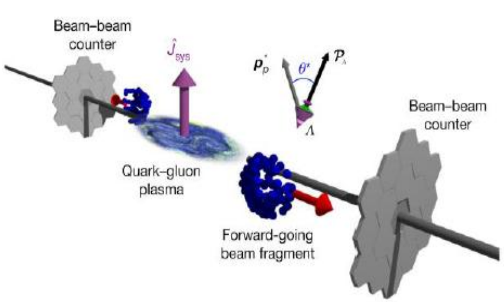


STAR has recently reported the first observation of global polarization of Λ hyperons in heavy ion collisions.

The discovery has been published in Nature 548, **62 (2017)**.

The polarization direction of the Lambdas is correlated at the level of several percent with the direction of the system angular momentum in non-central AuAu collisions.

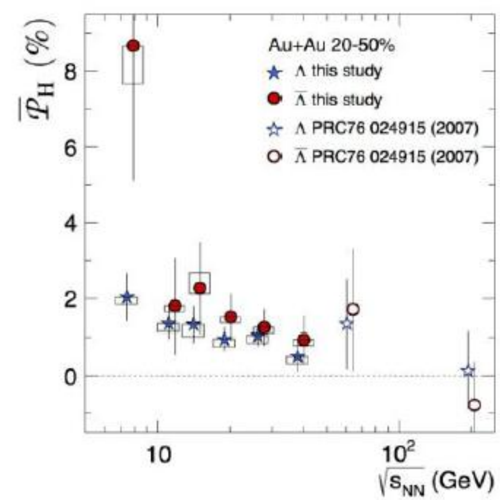
$$\frac{dN}{d\cos\theta^*} = \frac{1}{2}\left(1+\alpha_H|\mathcal{P}_H|\cos\theta^*\right)$$



HI collisions at RHIC produce the vortical fluid

$$\overline{\mathcal{P}}_H \equiv \langle \mathcal{P}_H \cdot \hat{J}_{sys} \rangle$$

The rotational substructure of the fluid nuclear matter created at RHIC represents an entirely new direction in hot QCD research (Chiral Magnetic and Chiral Vortical Effects) and are planned to study for the future.



Monte Carlo Simulation of Global Polarization for STAR and MPD Energy Range

STAR

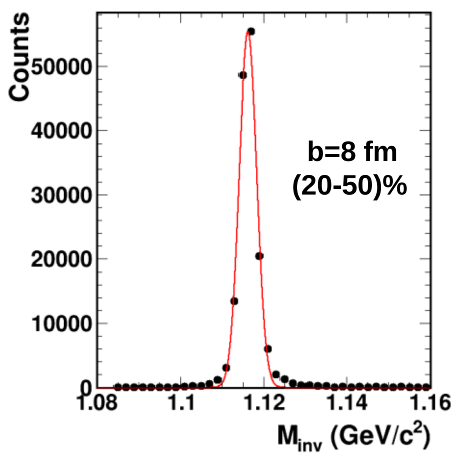
A.Kechechyan

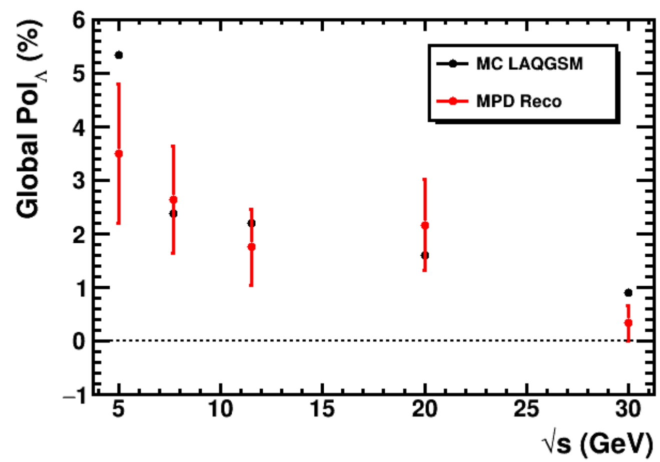
LAQGSM + Hydrodynamics

M. Baznat, K.Gudima, A.Sorin, O. Teryaev
Phys. Rev. C 93, 031902(R) (2016)

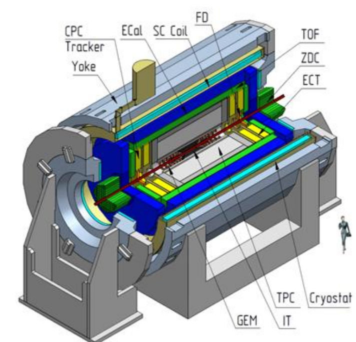
MC gen. → GEANT → Reconstruction → Global polarization

Au+Au->Λ^0+…



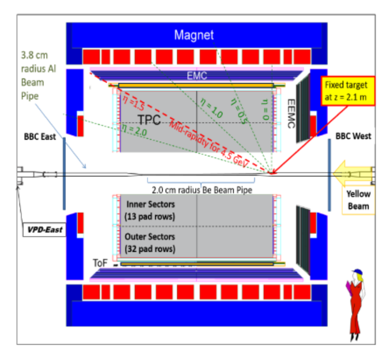


Collider mode



$<\varepsilon_\Lambda> = 22$ %

Fixed target

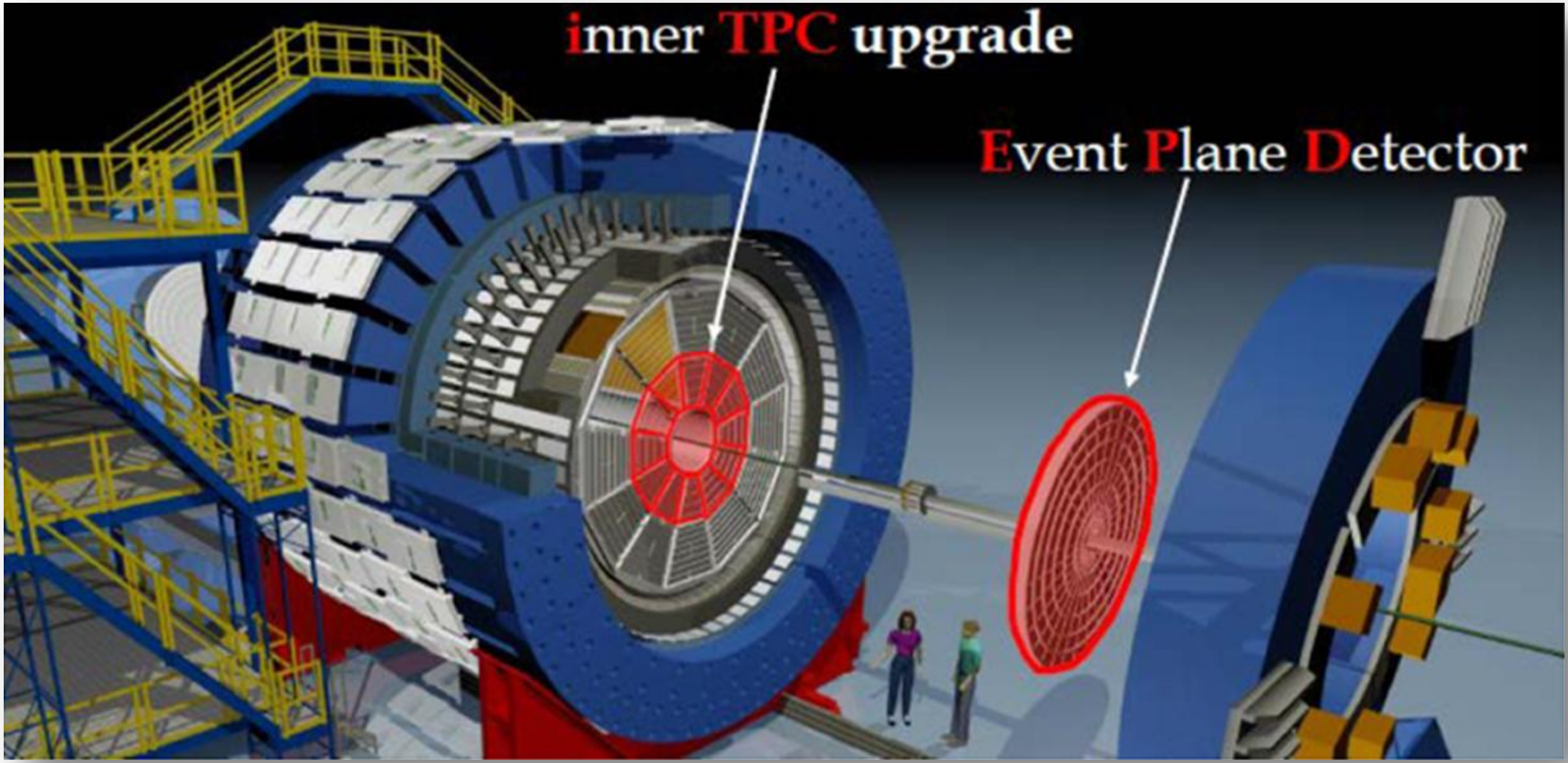


$<\varepsilon_\Lambda> = 6$ %

$\sqrt{s_{NN}}$ (GeV)	5.0	7.7	11.5	20.0	30.0
P_H (%)	3.50	2.65	1.76	2.18	0.34
n_σ	2.69	2.63	2.47	2.57	1.01

Cuts on daughter particles:
$p_T > 0.15$ GeV/c
$\eta < 2.0$
$L_\Lambda > 5.0$ cm
6.6 % no cuts
3.6 % with cuts

Beam Energy Scan II



iTPC upgrade:

Replace ageing wires;

Sparse pads → cover full area;

→ better *dE/dx*;

$-1 < \eta < 1$ → $1.7 < \eta < 1.7$;

$p_T > 125$ MeV/c → $p_T > 60$ MeV/c.

EPD upgrade:

Replaces ageing BBC, which wasn't designed for BES phys.

Greatly improved Event Plane info.

Better trigger & b/g reduction.

eTOF upgrade

$Z = -270$ cm

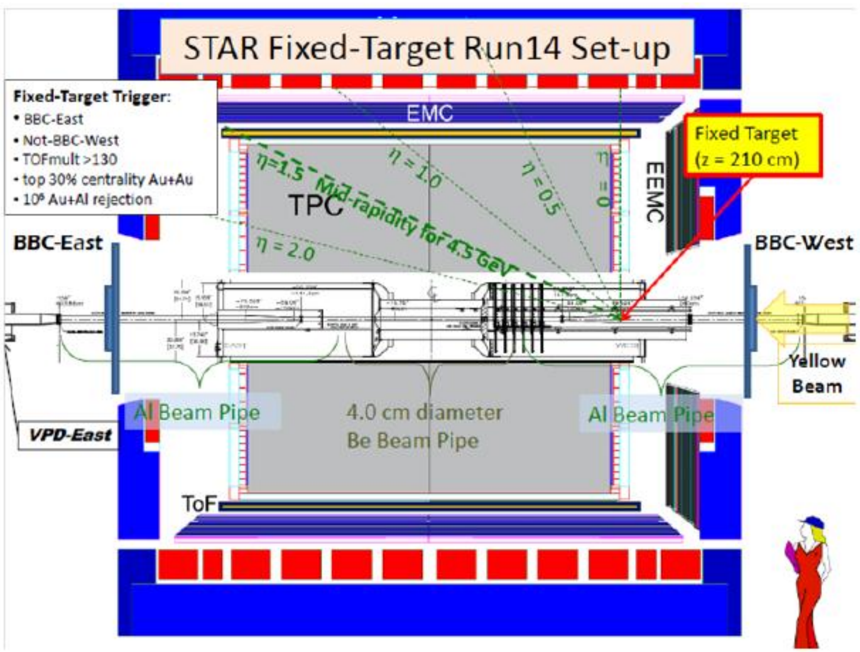
$R_{min} = 110$ cm

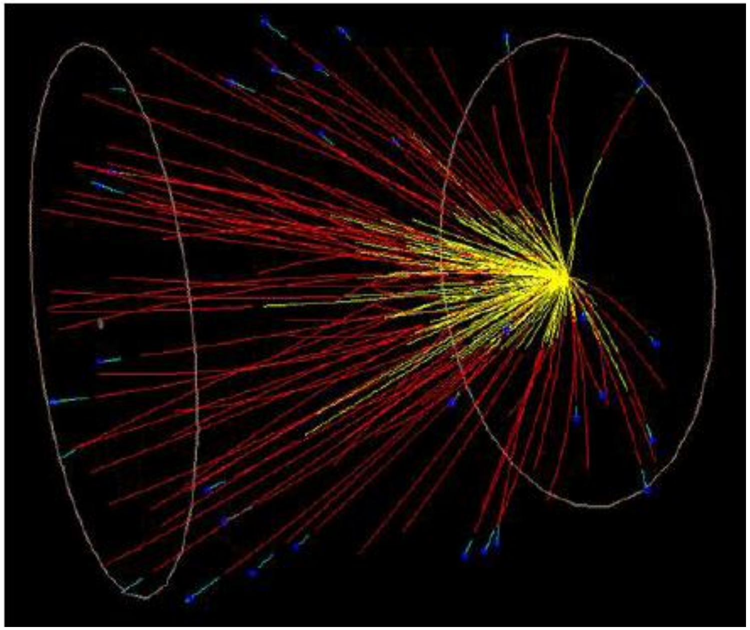
$R_{max} = 220$ cm

BES-II and Fixed Target Program

Collider Mode Energies (GeV)	5	7.7	11.5	15	19.6
Fixed Target $\sqrt{s_{NN}}$ (GeV)	2.5	3.0	3.5	4.0	4.5
Fixed Target μ_B (MeV)	775	720	670	625	585
Fixed Target y_{cm}	0.82	1.05	1.25	1.39	1.52

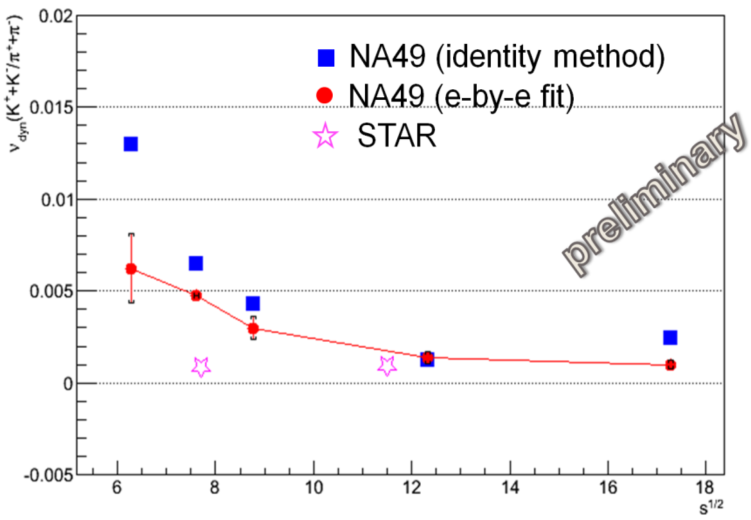
Fixed Target Program extends STAR's physics reach to region of compressed baryonic matter

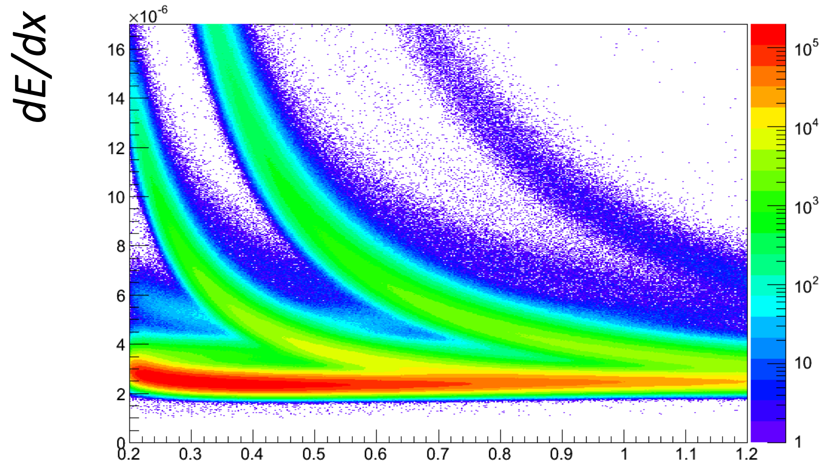


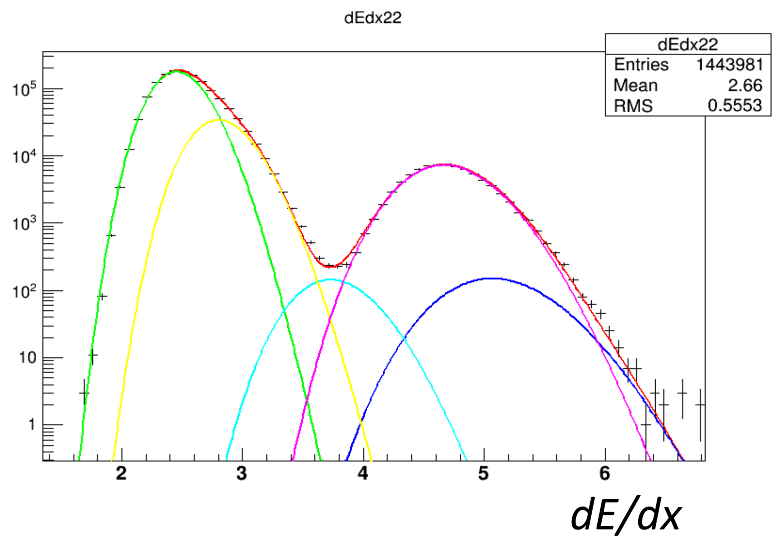


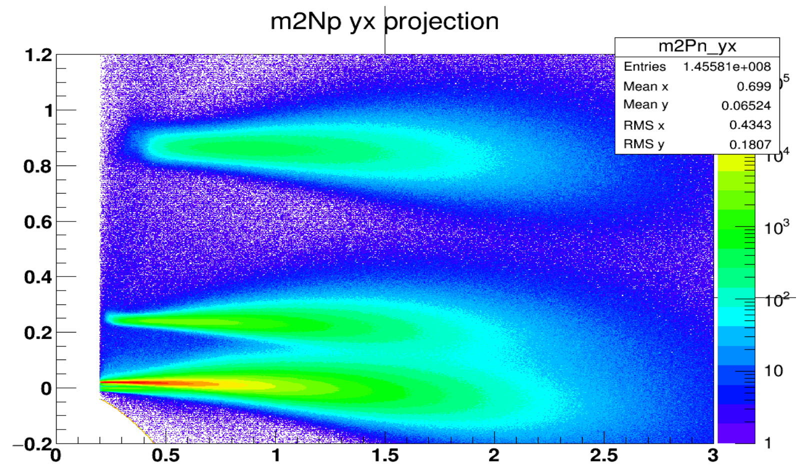
Development of new method of particle identification

The Statistical Method of PID at STAR (The Identity Method)



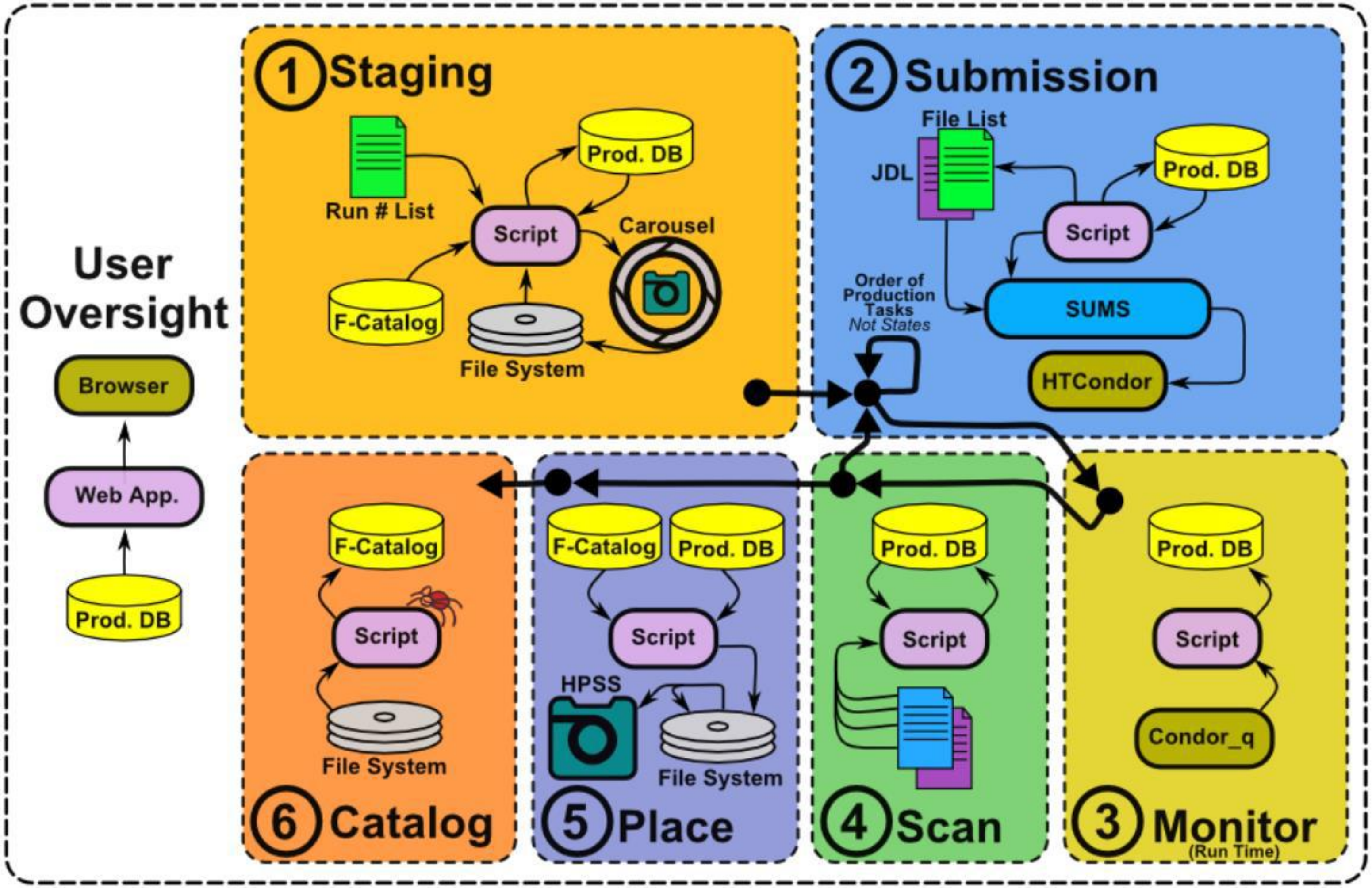






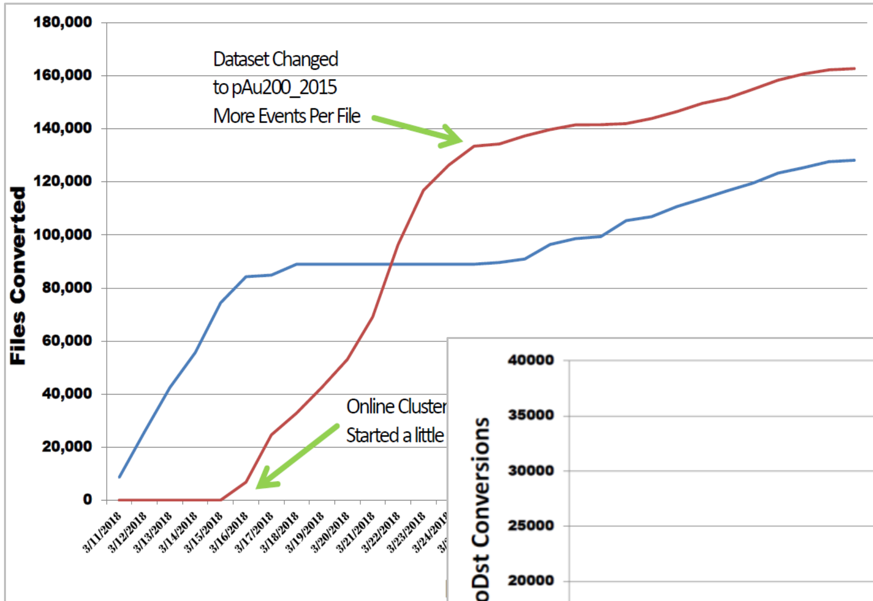
H. Agakishiev, V.V. Belaga, T.G. Dedovich, A. Kekechyan, G.A. Ososkov (LIT)

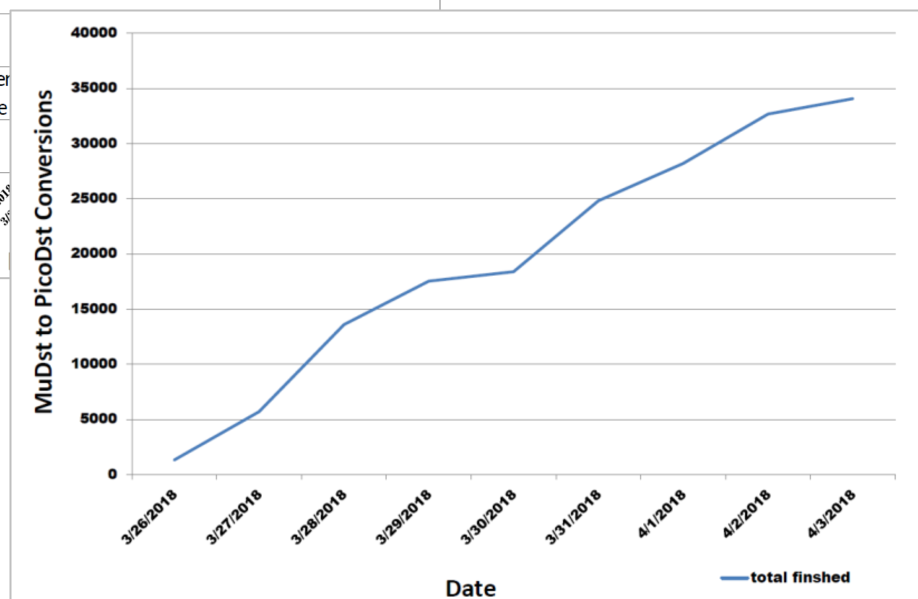
Software development and use of the JINR infrastructure (GRID, TIER-1) for the STAR data processing at Dubna

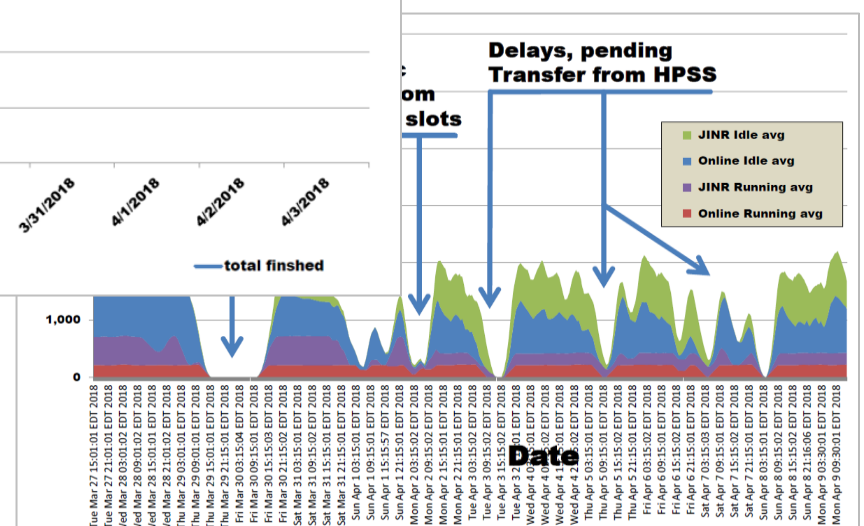


V. Korenkov (LIT), V. Mitsyn (LIT), H. Agakishiev, V. Belaga, L. Didenko (BNL), L. Hajdu (BNL), J. Lauret (BNL)

Statistics of MuDst to PicoDst Conversions on April 3, 2018



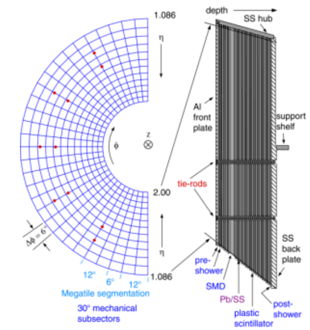




* Note: idle jobs get buffered on stargrid01 before getting pushed over to host site

Dubna Group Participation

- EEMC – Dubna group responsibility.



- EPD – assembling, testing and installation.

- RUNs – participation in data taking and data analysis from BES-II.

Dubna Group Participation

Participation in the STAR runs:

- JINR group responsibility in runs is the support of End Cap EMC in working condition
- Participation in assembly and testing of Event Plane Detector
- Development of new approach for data analysis – statistical method particle identification
- Participation in data taking and data analysis for BES-II

Correlation femtoscopy:

- Use of the correlation femtoscopy as a powerful tool to study strong interaction of particle species hardly available by other means and reveal space-time evolution of the nuclear matter produced in heavy ion collisions, including signatures of phase transition and critical point in BES-II program.

Global polarization study:

- Participation in data analysis of global polarization (isobaric nuclei, high statistic measurement at 27 GeV, BES-II measurements).
- Comparison of the polarization of Lambda hyperons in collisions of the ruthenium and zirconium nuclei. Studies of rapidity dependence of Λ hyperon polarization and possibility to measure Ξ hyperon polarization. It may allow us to distinguish the “vortex” model from model associated with the magnetic field effects.

Dubna Group Participation

Scaling and fractal structure study:

-The analysis of experimental data on energy scan for studying the scaling properties and the fractal structure of nucleus-nucleus collisions to search for signatures of phase transition and the critical point in nuclear matter.

- Fractal analysis of nucleus-nucleus collisions on event-by-event basis. Selection of events according to the fractal dimensions can give additional criteria to facilitate model verification and search for new phenomena.
- Verification of self-similarity of charged hadron production (*z*-scaling) with higher accuracy in BES-II. Estimation of energy loss and search for discontinuity of the model parameters ("heat capacity" and fractal dimensions).
- Study of cumulative of hadron production at high transverse momenta at BES-II energies.

STAR–JINR GRID:

STAR is interested in developing newer and more compact analysis data format and in 2016 the Data Summary file format known as a "MuDST" (micro-DST) was complemented by an emerging format known as "picoDST". Using GRID technologies for processing data from the STAR facility at JINR computer cluster we plan to convert over a million of files from MuDST to PicoDST in 2019–2021.

Schedule of the Project

Activity		Years				
		2018	2019	2020	2021	2022
1.	Study of nuclear collisions.					
1.1.	Ru, Zr measurements at 200 GeV.					
1.2.	Global polarization measurements at 27 GeV.					
1.3.	Fixed targetmeasurements at 3 GeV.					
2.	Data analysis.					
2.1.	Ru, Zr measurements at 200 GeV.					
2.2.	Global polarization measurements at 27 GeV.					
2.3.	Fixed targetmeasurements at 3 GeV.					
3.	BES Phase-II program to search for the QCD critical point.					
3.1.	Data taking runs.					
3.2.	Data analysis of accumulated statistics.					
3.3.	Data taking with fixed target.					
3.4.	Data analysis with fixed target.					
4.	Final data taking run for BES-II.					

Cost Estimate of the Project

№	Name	Full Cost (kUSD)	Expenses per Year (kUSD)		
			2019	2020	2021
1.	Materials and Equipment	**45,0**	15,0	15,0	15,0
2.	Payments for agreement based research	**45,0**	15,0	15,0	15,0
3.	Travel Expenses	**165,0**	55,0	55,0	55,0
	Total direct expenses	**255,0**	**85,0**	**85,0**	**85,0**

Thank you for attention!!!