

MPD - возможности исследования сильно взаимодействующей материи и состояние проекта

В. Кекелидзе

Объединенный Институт Ядерных Исследований



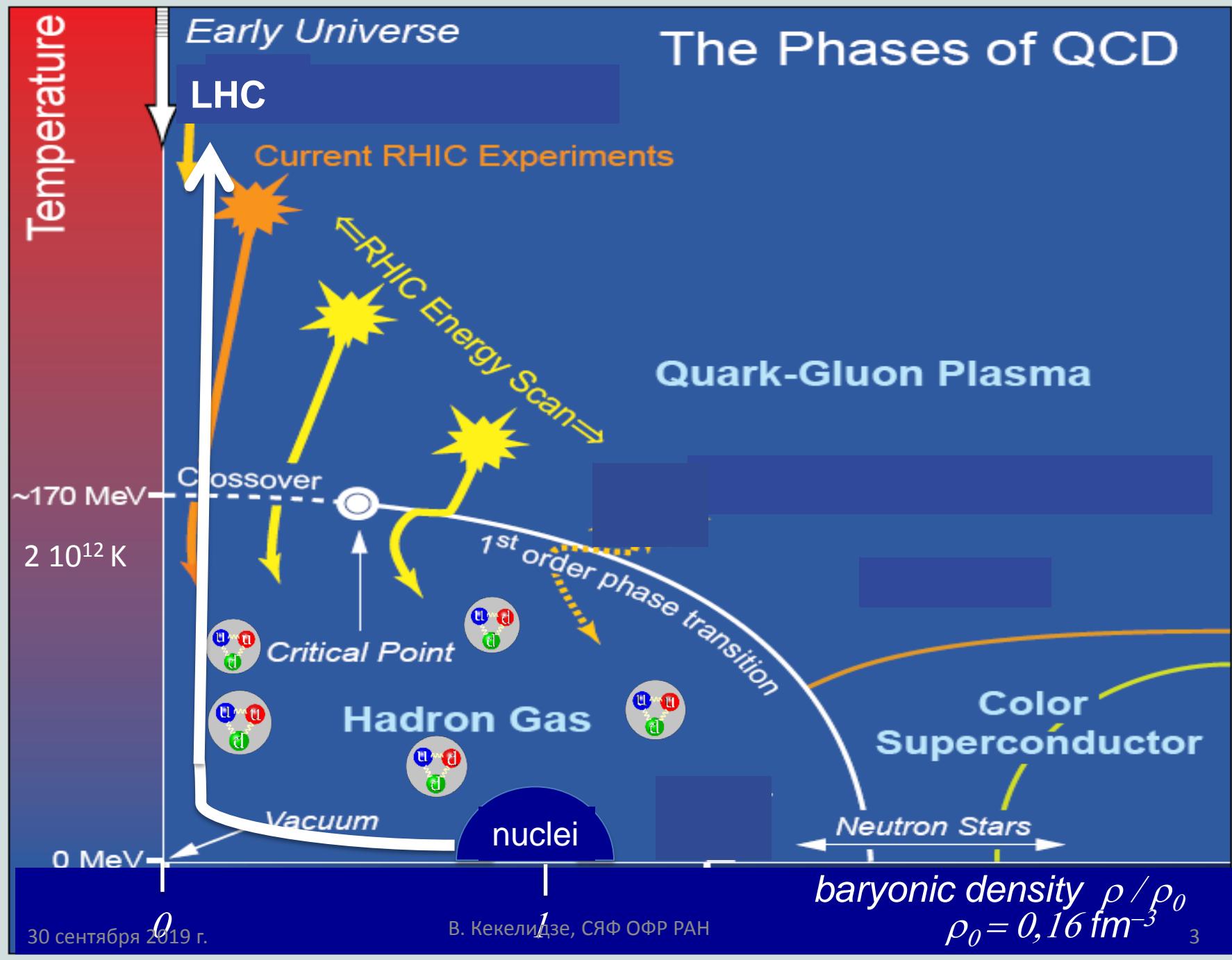
Сильные взаимодействия играют центральную роль в физике элементарных частиц и хорошо описываются **КХД, но остаются **вопросы**:**

- явления на больших расстояниях, например, удержание;
- коллективное поведение в экстремальных условиях, при высокой температуре, или **высокой плотности**;
- надежные прогнозы в непертурбативном режиме.

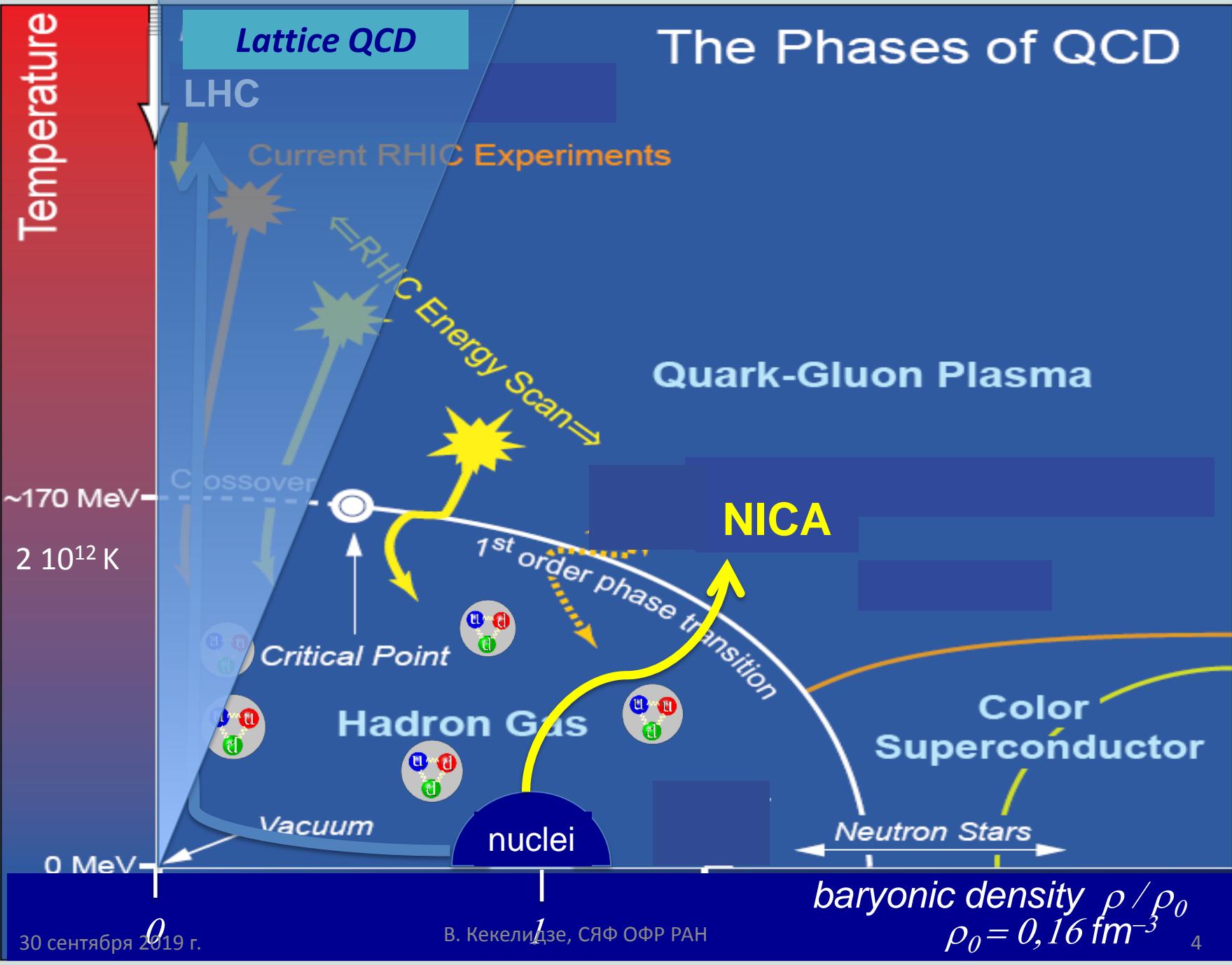
- можно ли из первых принципов **КХД** описать явления на границе низких и высоких энергий?
- как быстро движущиеся кварки и глюоны группируются в цвет-синглетные адроны ?

Расчеты **КХД на решетке предсказывают переход вещества в **кварк-глюонную плазму (КГП)**, в которой партоны не связаны и киральная симметрия восстановлена.**

The Phases of QCD



The Phases of QCD

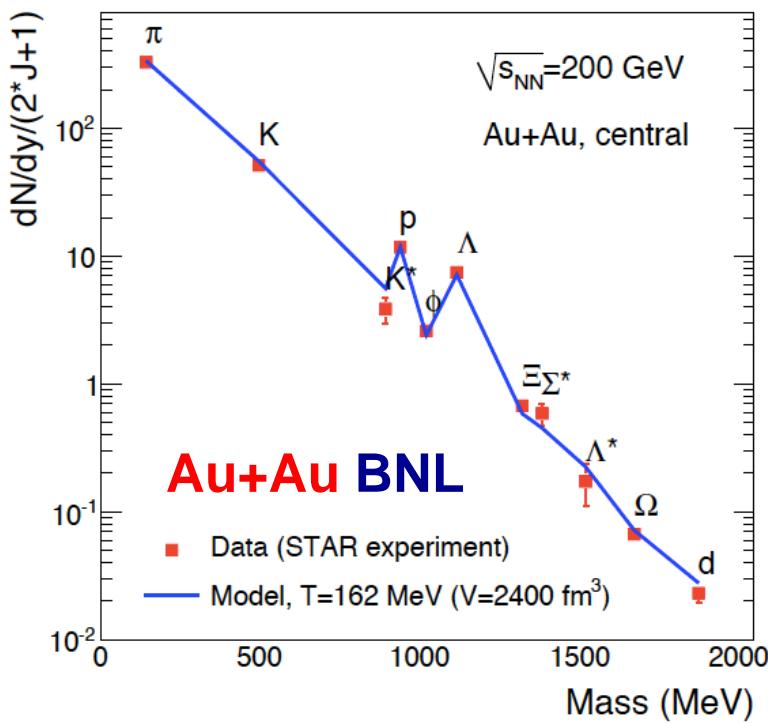


Термальная / Статистическая модель (без динамики)

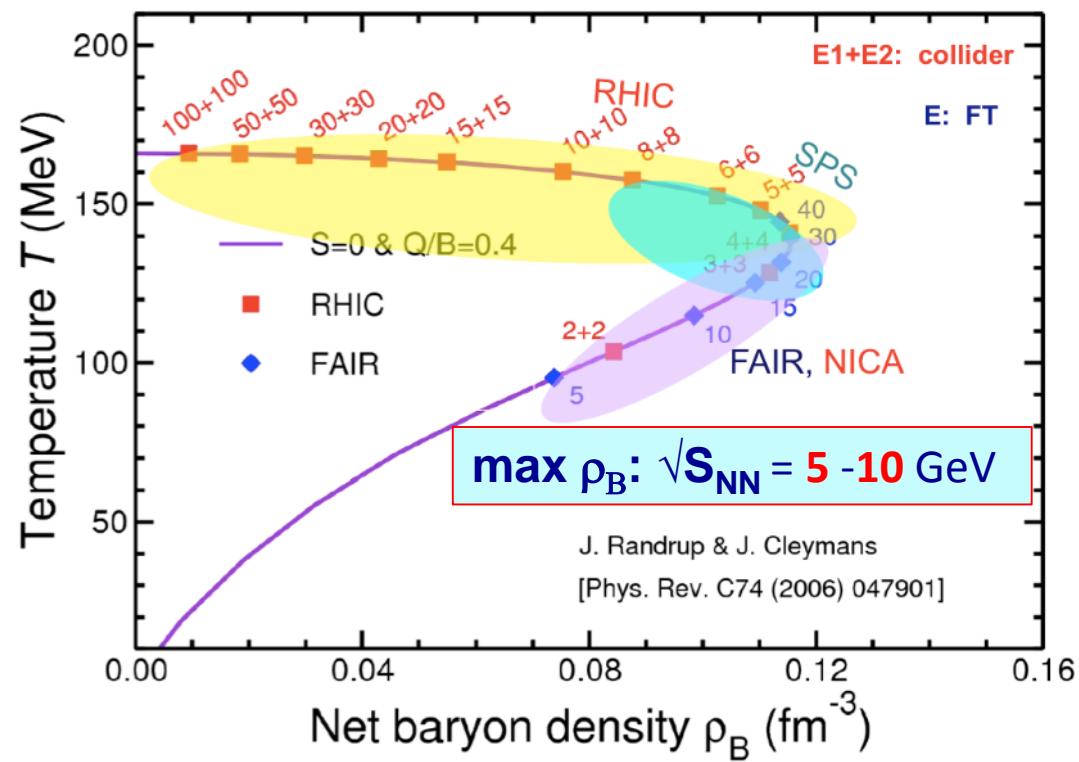
Система описывается **Большим каноническим ансамблем** невзаимодействующего адронного газа в состоянии равновесия (терм. и хим.) с мин. числом параметров T, μ_B (V -scale)

$$n_i = \frac{g_i}{2\pi^2} \frac{V}{N_{BW}} \int_{M_{thr}}^{\infty} dm \int_0^{\infty} \frac{\Gamma_i^2}{(m - m_i)^2 + \Gamma_i^2 / 4} \cdot \frac{p^2 dp}{\exp[(E_i^m - \mu_i)/T] \pm 1}$$

выходы частиц



условия замораживания



Чистая барионная плотность достижимая в Au + Au соударениях

◆ Гидродинамические модели:

законы сохранения + уравнение состояния;
предположение локального
термического и химического равновесия
(упрощенная динамика)

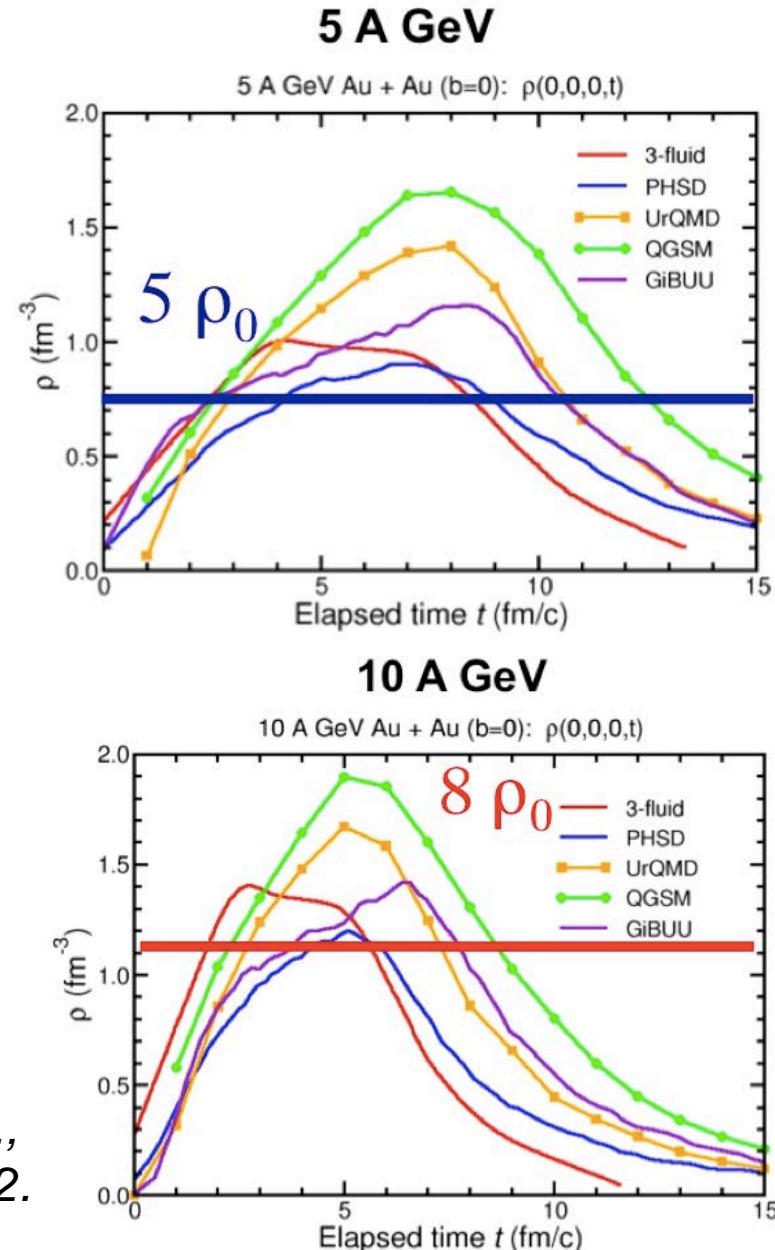
◆ Транспортные модели:

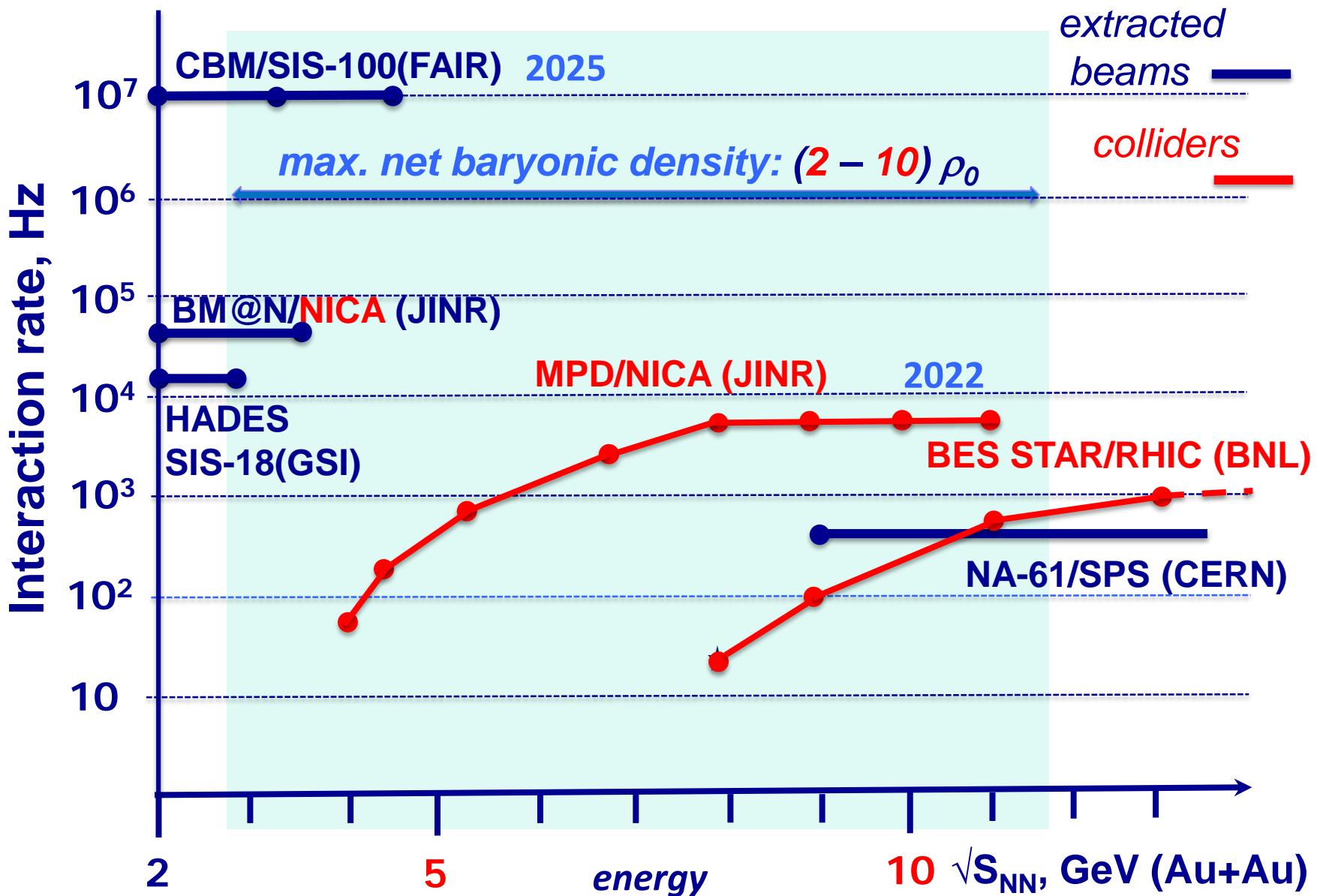
основаны на теории переноса
релятивистских квантовых систем
многих тел;

актуальные решения:

Monte Carlo симуляции
с большим числом тестовых частиц
(полная динамика)

I.C. Arsene *et al.*,
Phys. Rev. C75 (2007) 24902.





Главные задачи: получить максимально полные данные о

- горячей и плотной барионной материи:
 - существует ли фазовый переход 1-го рода ?
 - существует ли критическая точка?
- спиновой структуре нуклона



Главные задачи: получить новые данные о

- горячей и плотной барионной материи:
 - существует ли фазовый переход 1-го рода ?
 - существует ли критическая точка?
- спиновой структуре нуклона



- ◆ модернизация существующего ускорительного комплекса
- ◆ создание **Коллайдера** для столкновений
 - релятивистских ионов от **p** до **Au** при энергиях $\sqrt{S_{NN}} = 4 - 11 \text{ GeV}$
 - поляризованных **p** и **d** до энергии $\sqrt{S} = 27 \text{ GeV}$ (**p**)
- ◆ создание трех детекторов: : **Baryonic Matter @ Nuclotron (BM@N)**, **Multi Purpose Detector (MPD)** and **Spin Physics Detector (SPD)**

Изучаются:

- уравнения состояния
- поляризационные явления

поиск явлений:

- начала деконфайнмента
- начала восстановления киральной симметрии
- **фазового перехода первого рода**
- **критической точки**

Наблюдаемые:

- выход частиц
- рождение странности
- фемтоскопия
- пособытийные флуктуации
- дилептоны, векторные мезоны
- коллективные явления (потоки, гидродинамика)
- *vorticity* - поляризация

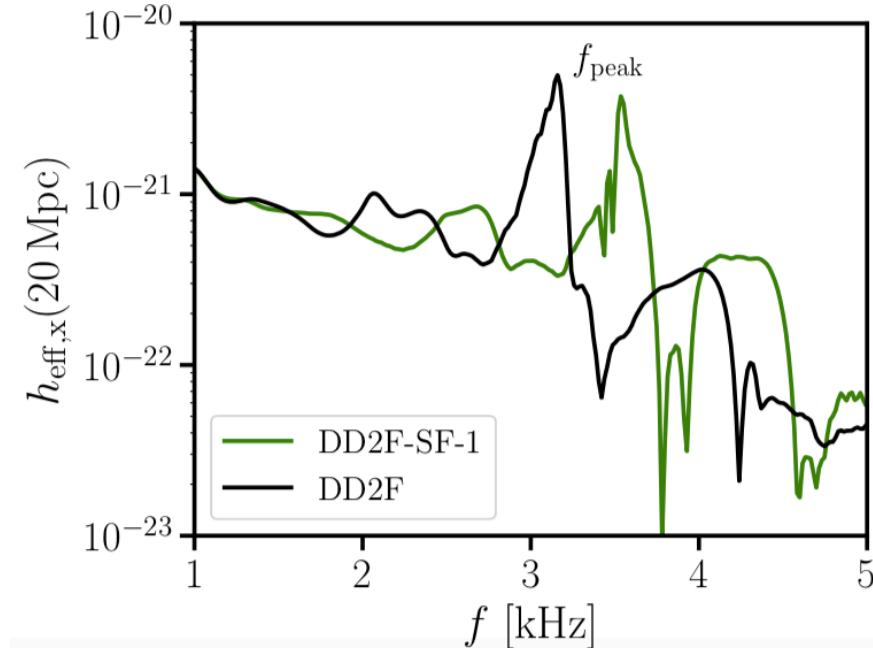
Similarity of Stellar Objects & Heavy Ion Collisions

Neutron Star Merger

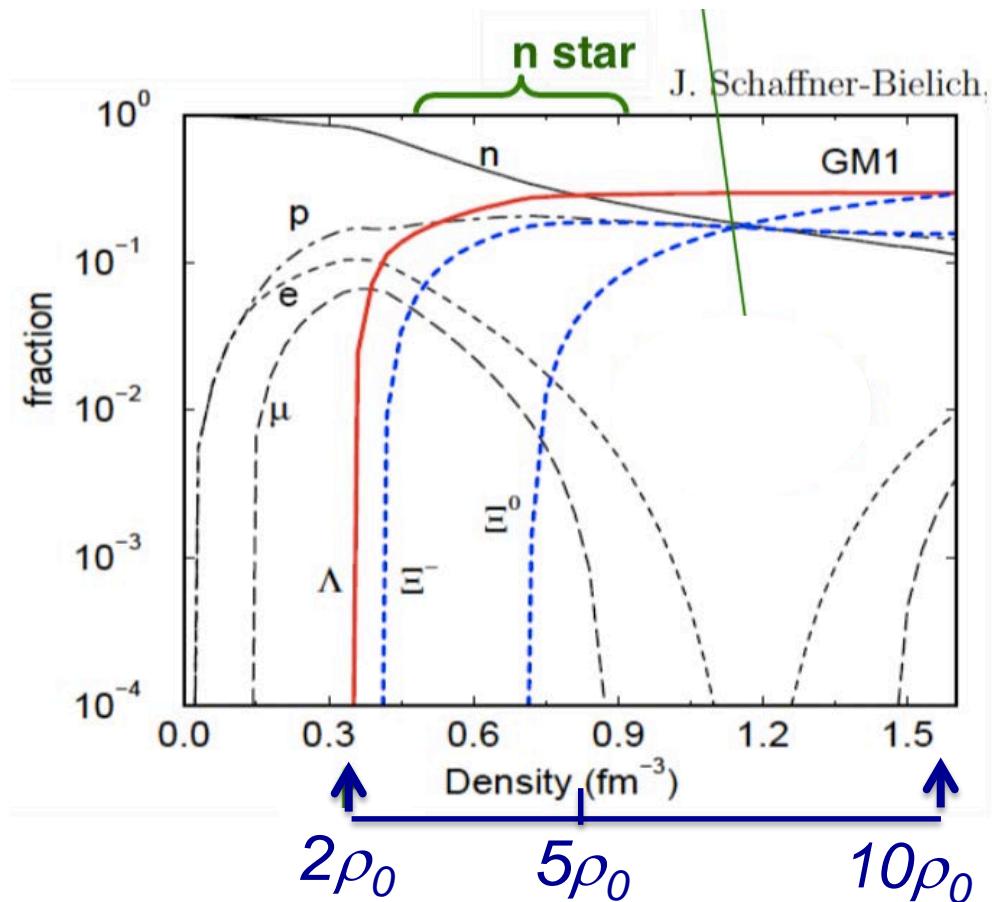


1st OPT:

gravitational waves from mergers

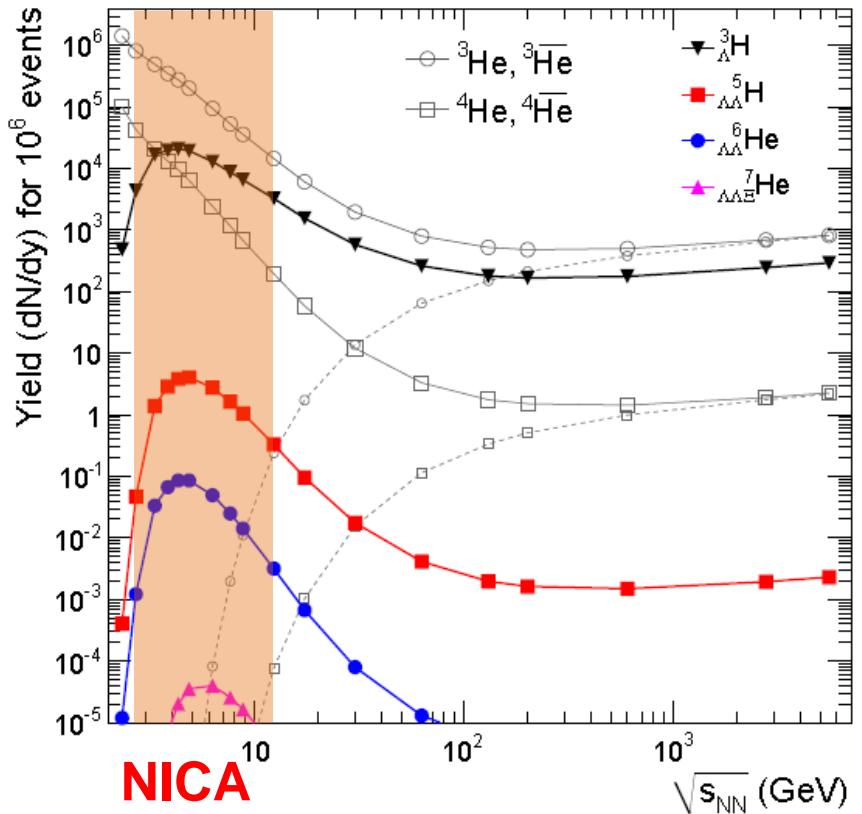


*appearance of strangeness changes EOS,
depends on strangeness-nucleon interaction*



Bauswein et. al.,
arXiv:1809.01116

Усиление рождения гиперядер при большой барионной плотности (**NICA**)



A. Andronic, P. Braun-Munzinger,
J. Stachel, H. Stoecker

30 сентября 2019 г.

Vorticity:

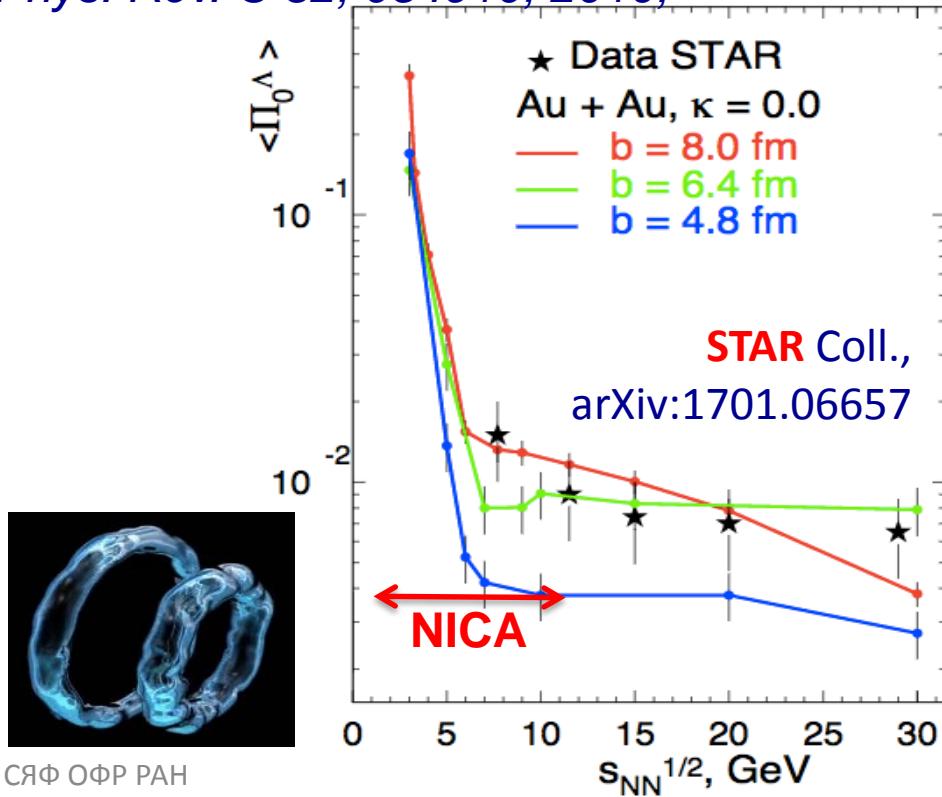
Λ поляризация из-за аномально индуцированного аксиального тока

$$\vec{J} = \frac{1}{\pi^2} \mu_5 \mu \vec{\omega}$$

$$\vec{\omega} = \frac{1}{2} \vec{\nabla} \times \vec{v}$$

$$J_A^\mu \sim \mu^2 \left(1 - \frac{2\mu n}{3(\epsilon + P)}\right) \epsilon^{\mu\nu\lambda\rho} V_\nu \partial_\lambda V_\rho$$

O. Rogachevsky, A. Sorin, O. Teryaev,
Phys. Rev. C 82, 054910, 2010;



В. Кекелидзе, СЯФ ОФР РАН

New issues: NICA White Paper, SQM proceedings



Physics targets for the exploration of first order phase transitions in the region of the QCD phase diagram accessible to NICA & FAIR and possible observable effects of a “mixed phase indicated in the release of the “NICA White Paper” as a Topical Issue of the EPJA (July 2016).

ISSN 1742-6588

JOURNAL OF PHYSICS: CONFERENCE SERIES
The open access journal for conferences
15th International Conference on
Strangeness in Quark Matter
(SQM2015)

Dubna, Russia
6-11 July 2015

Editors: David E. Alvarez-Castillo, David Blaschke, Vladimir Kekelidze,
Victor Matveev and Alexander Sorin

Volume 668 · 2016

jpcs.iop.org

NICA

SQM DUBNA 2015

IOP Publishing

The European Physical Journal
volume 52 · number 8 · august · 2016

EPJ A
Recognized by European Physical Society

Hadrons and Nuclei

Topical Issue on Exploring Strongly Interacting Matter
at High Densities - NICA White Paper
edited by David Blaschke, Jörg Aichelin, Elena Bratkovskaya, Volker Friese,
Marek Gazdzicki, Jørgen Randrup, Oleg Rogachevsky, Oleg Teryaev, Viacheslav Toneev

NICA

From: Three stages of the NICA accelerator complex.
by V. D. Kekelidze et al.

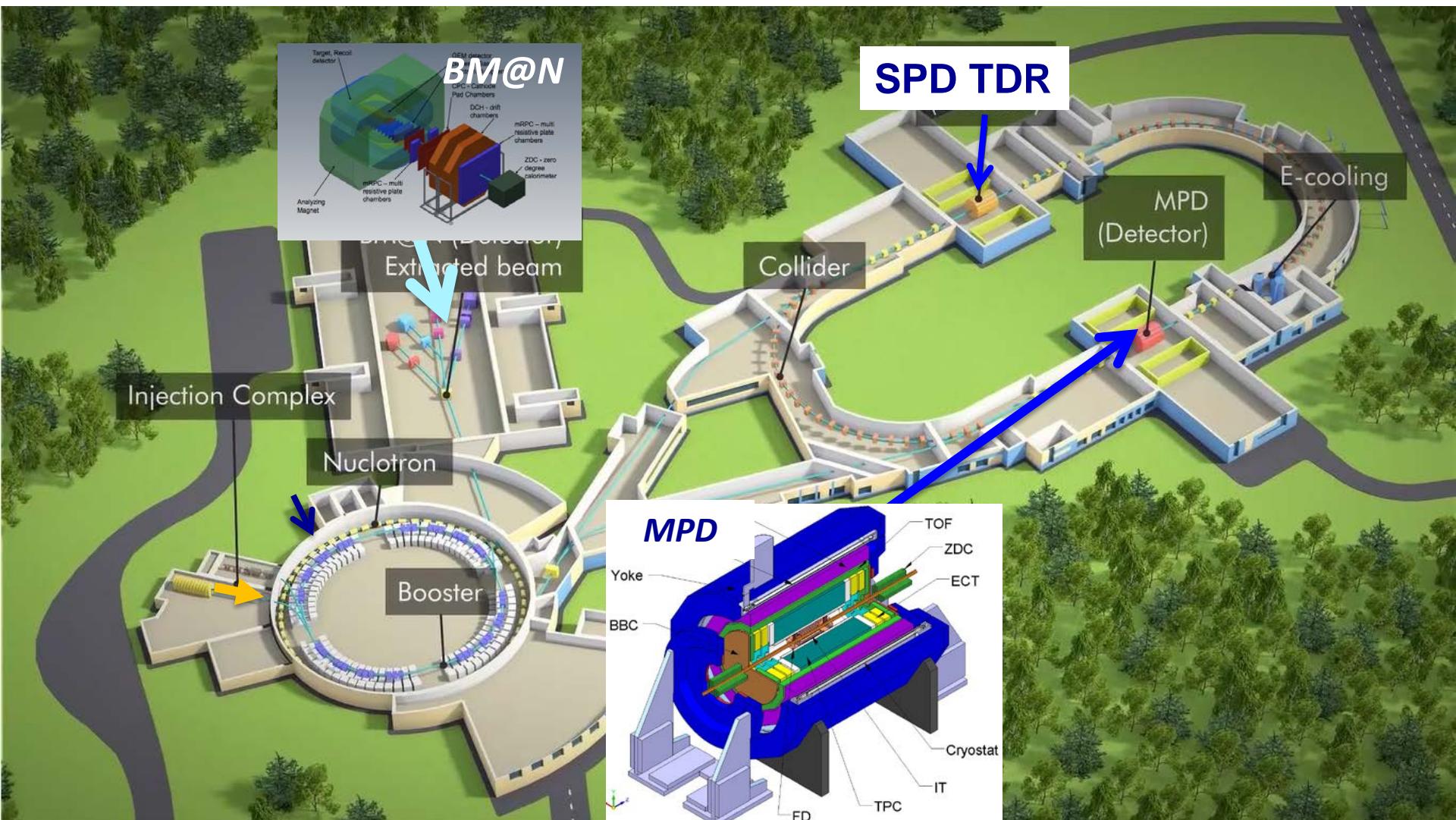
Springer

**111 contributions,
188 authors
from 24 countries**

Objects

Detectors:

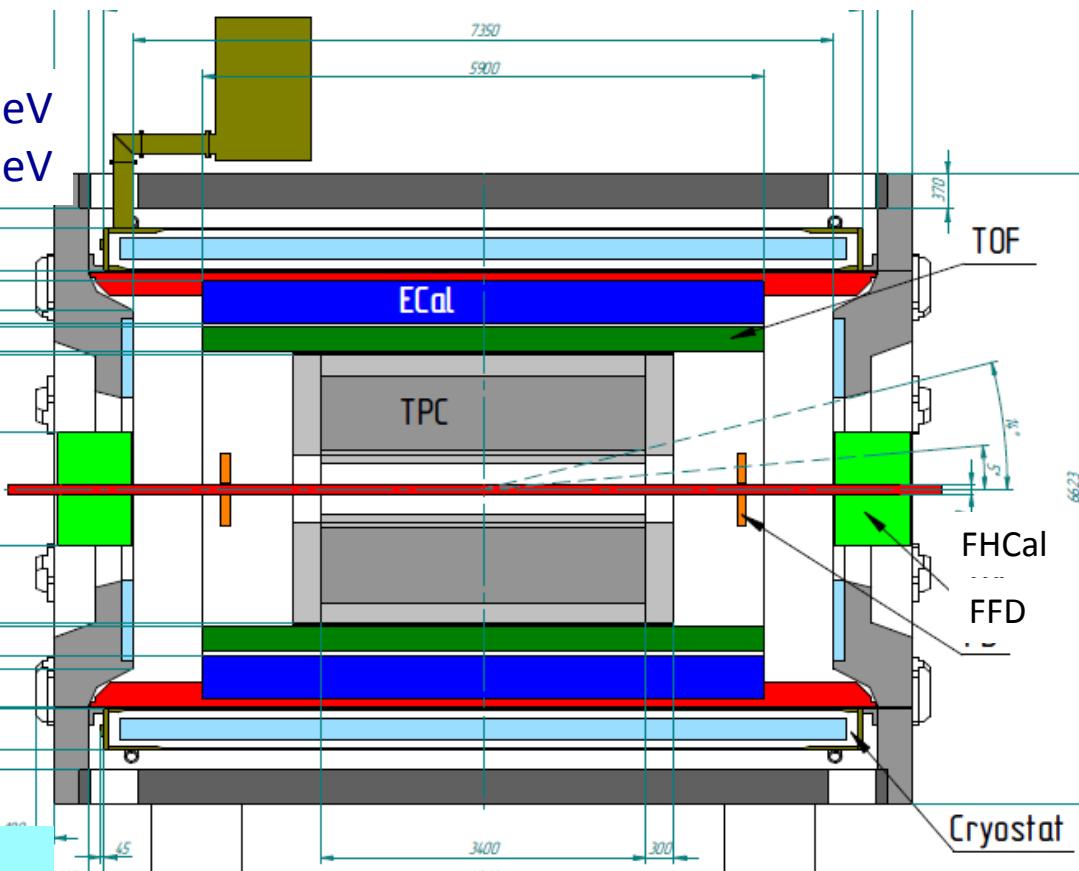
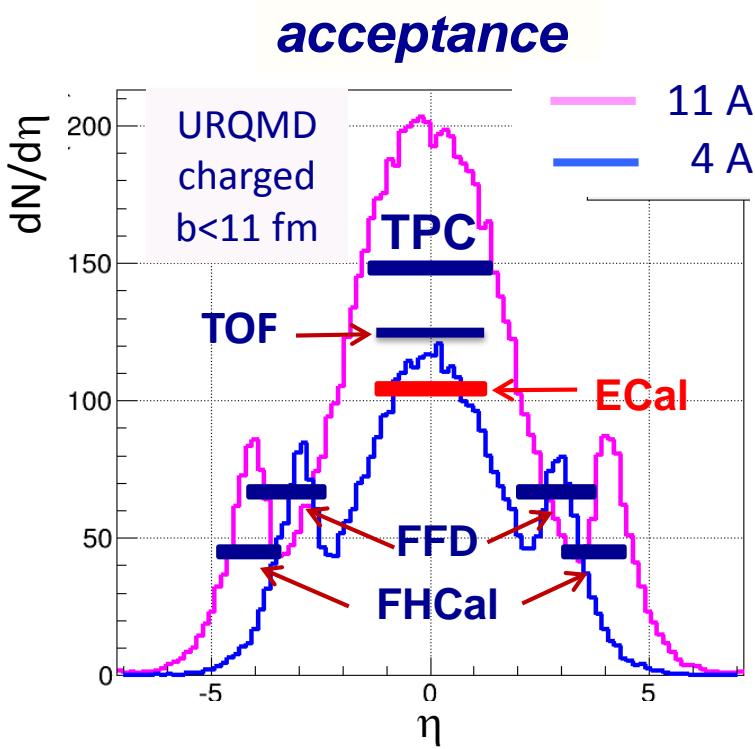
- *Baryonic Matter @ Nuclotron*
- *Multi Purpose Detector*
- *Spin Physics Detector*



Multi-Purpose Detector (MPD)



stage I: TPC, TOF, ECAL, FHCAL, FFD



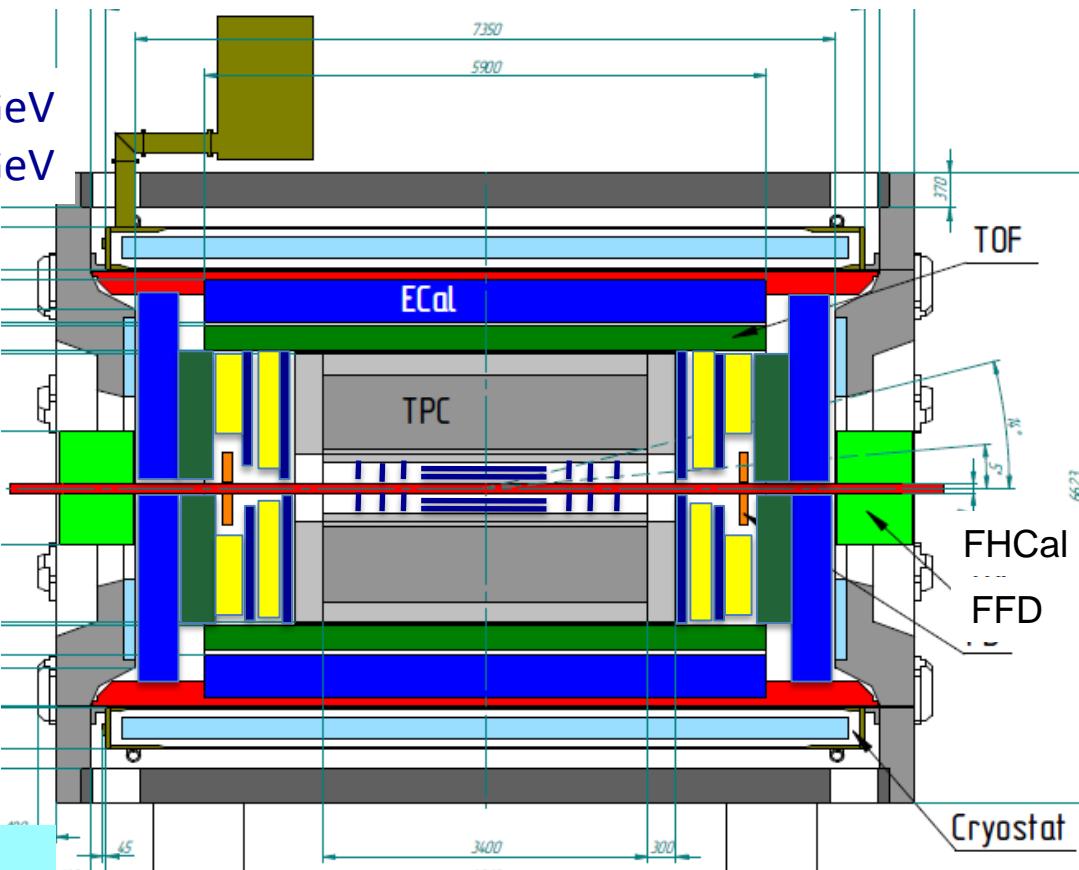
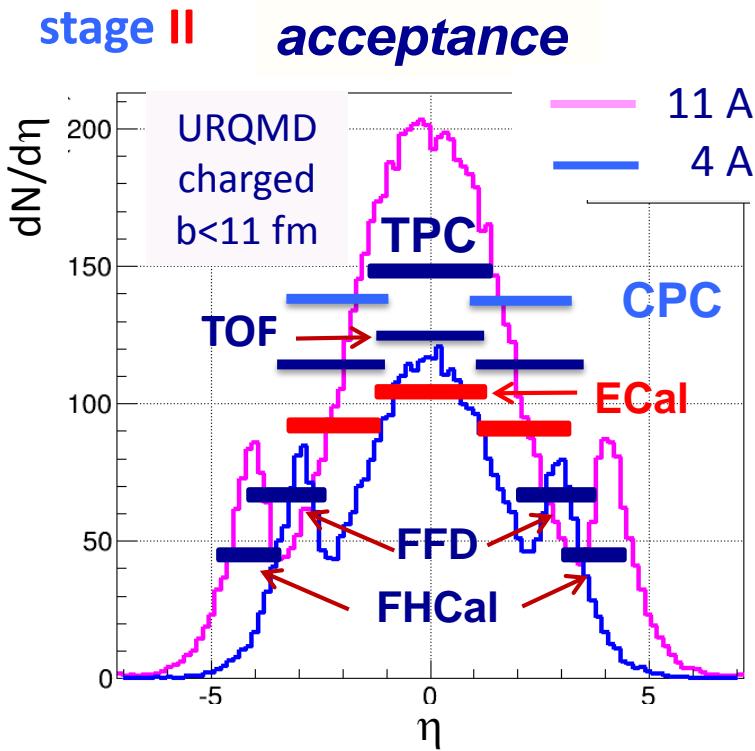
stage I: put in operation in 2022

Multi-Purpose Detector (MPD)

The logo for NICA (National Institute for Child Abuse Countermeasures) features the acronym "NICA" in a bold, black, serif font. The letters are enclosed within a blue oval border. Two small red circles, one above the "I" and one below the "A", serve as decorative dots.

stage I: TPC, TOF, ECAL, FHCAL, FFD

stage II (2023): + ITS + EndCap (CPC, Straw, TOF, ECAL)



stage I: put in operation in 2021

СП соленоид

$B_0 = 0.5 \text{ Т}$ вес $\sim 900 \text{ т}$

Control Dewar

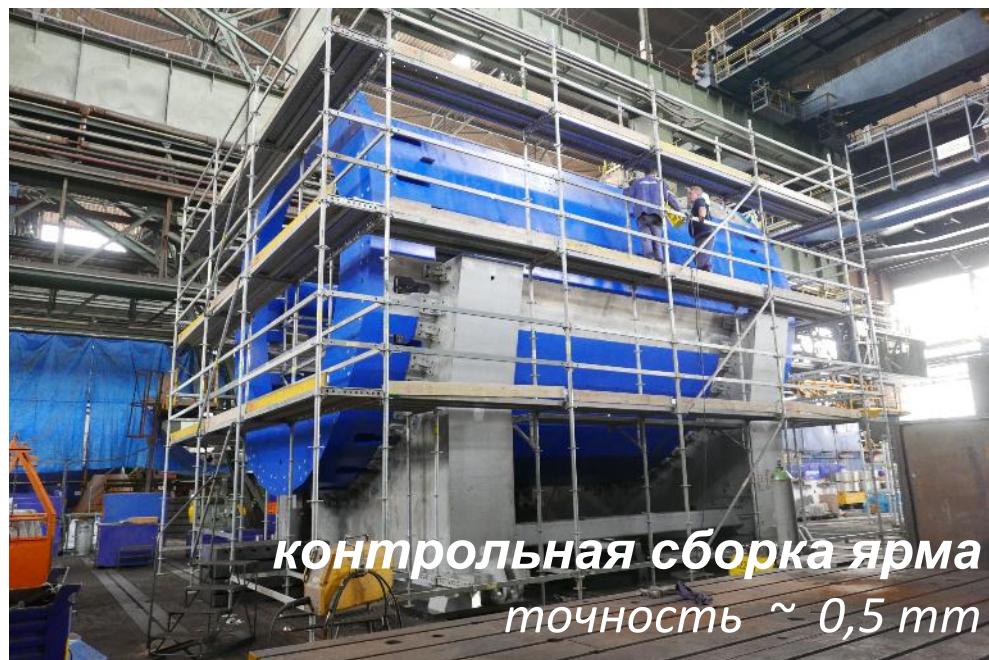
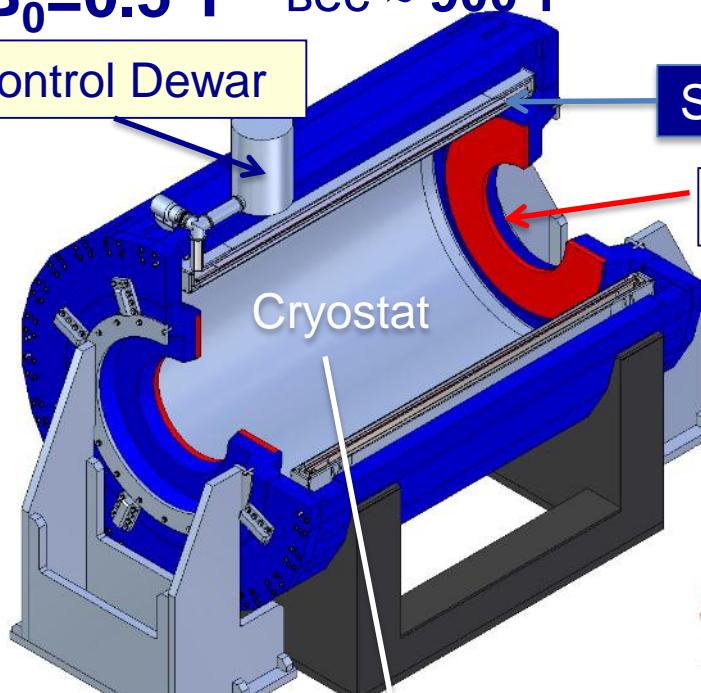
SC coil

Cryostat

Trim Coil



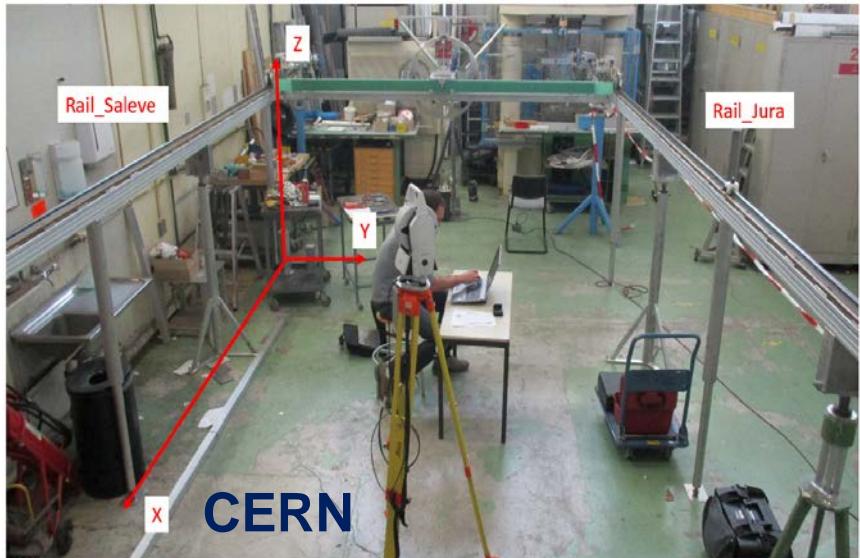
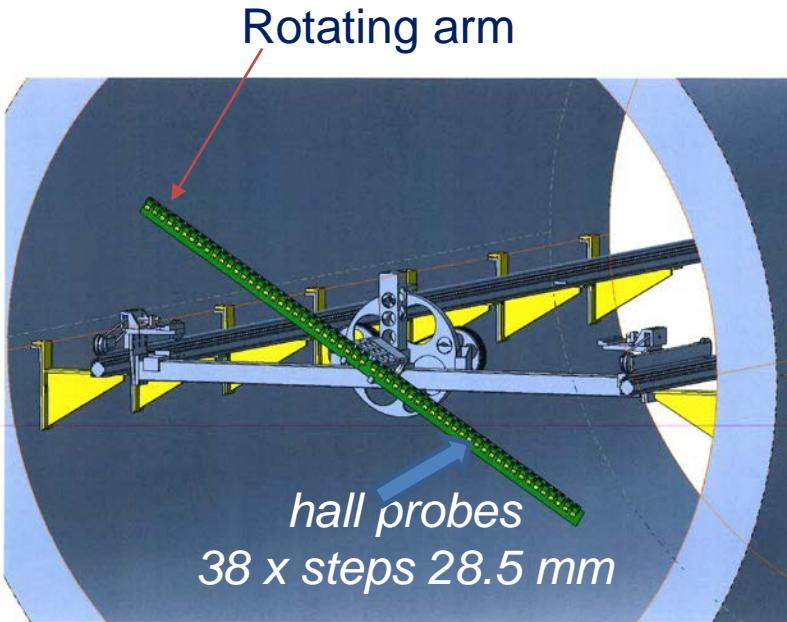
номинальный ток: **1790 А**
запасенная энергия: **14.6 Мдж**



криостат с СП катушкой
- готов к холодным тестам

Mapper for Magnetic Field measurements

F. Bergsma (CERN), R.Shindin, Yu.Lobanov, A.Efremov, N.Topilin

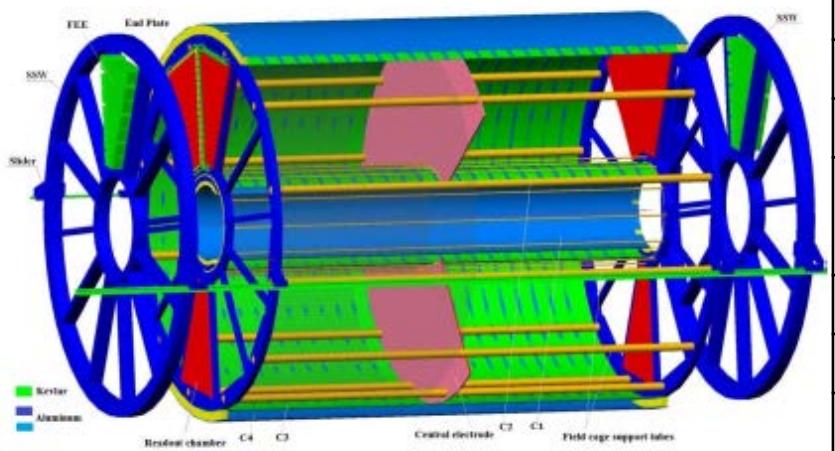


$$\left| \frac{B_r}{B_z} \right| = 5.2 \times 10^{-4} \quad \int_{-1700}^{1700} \frac{B_r}{B_z} dz \leq 1.5 \text{mm}$$

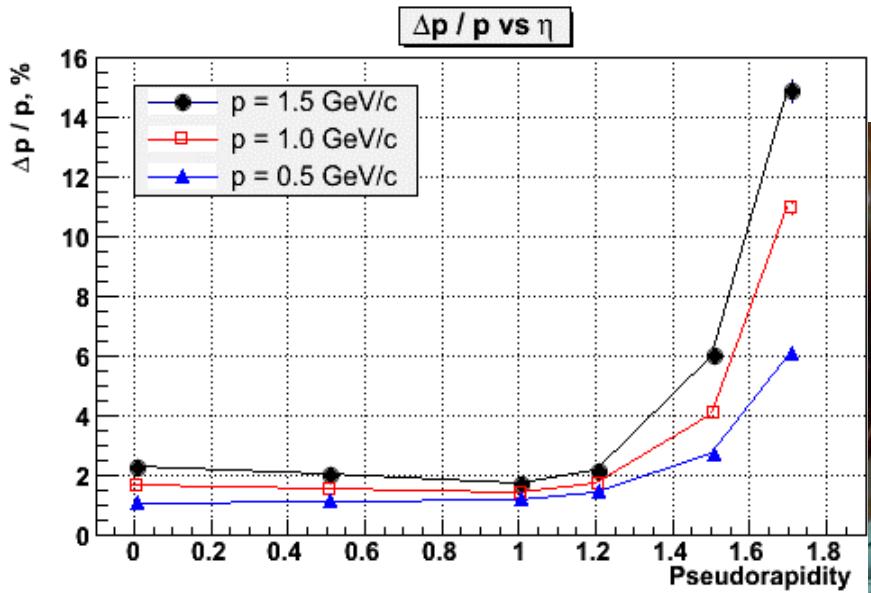
Готовится детальная программа работ по магнитным измерениям в ноябре 2020

Отв. Р.Шиндин, Ю.Лобанов

Time Projection Chamber (TPC) – basic tracker



length	340 cm
out Radii	140 cm
in Radii	27 cm
gas	90% Ar +10% CH ₄
drift velocity	5.45 cm / mks;
velocity time	< 30 mcs;
N R-O Chamb.	12 + 12
N pads / chan.	95 232
max event rate	~ 7 kGz



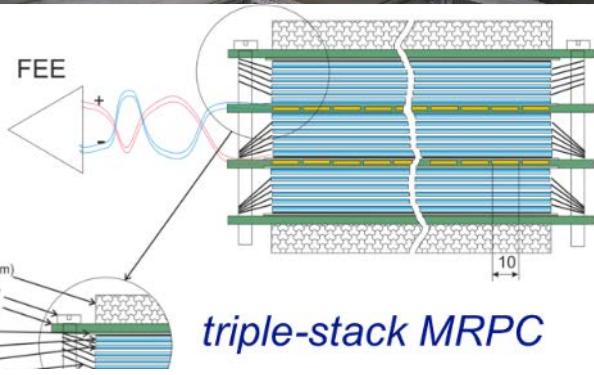
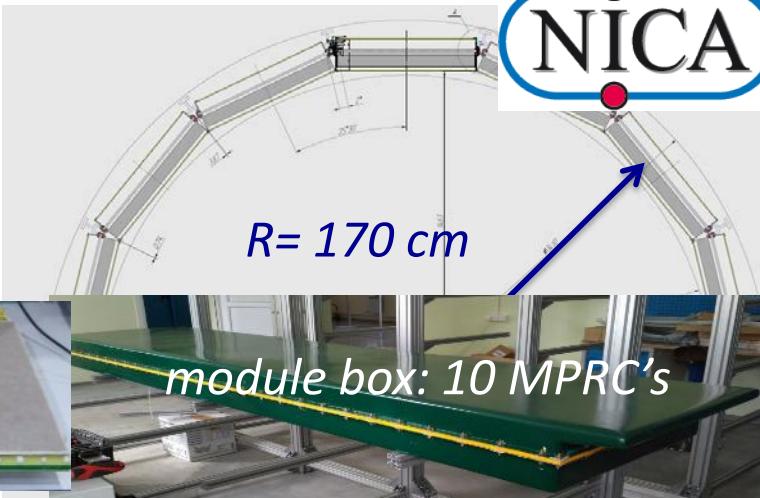
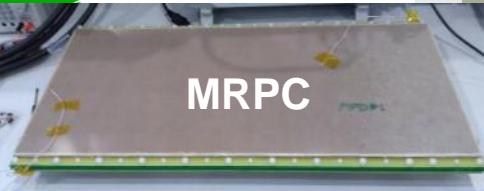
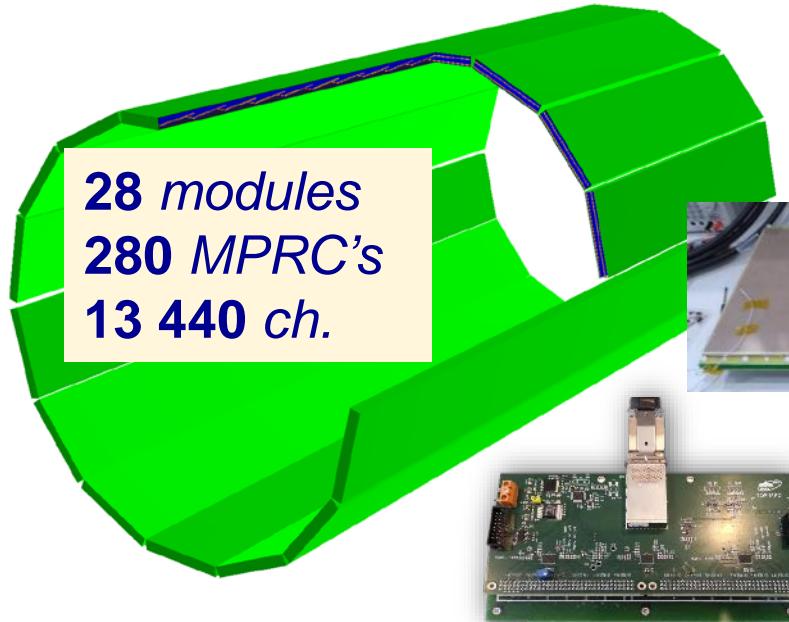
assembly in the clean room



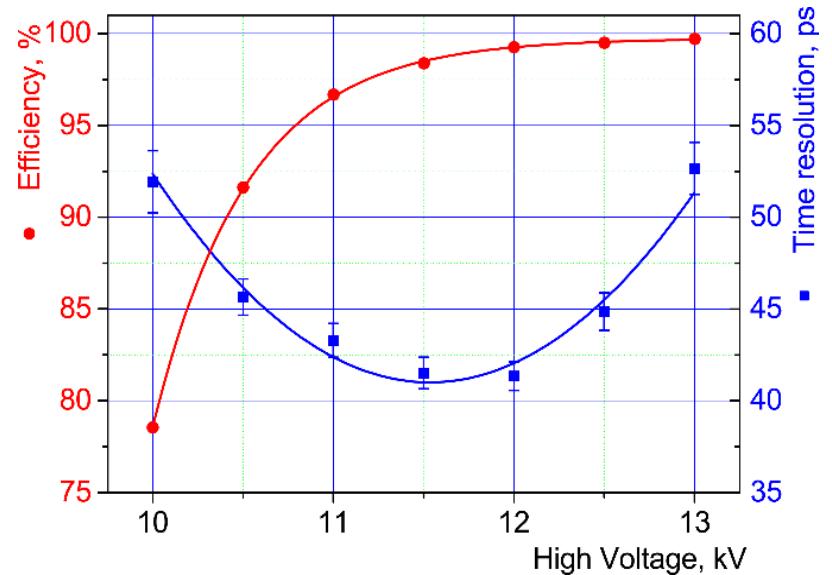
FEC64SAM:
4500 SAMPA V4
output: 2,5 GB/s;
– delivered from
CERN



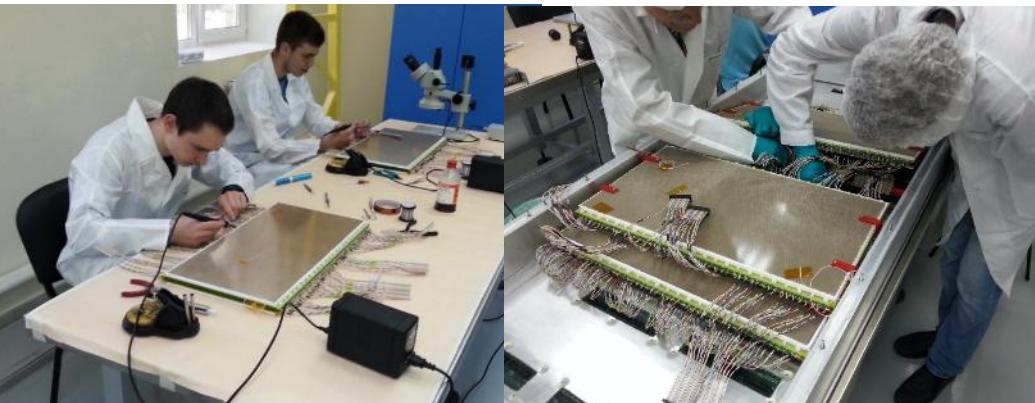
Time of Flight (TOF) system



efficiency and time resolution



*R/O elements - NINO & HPTC
designed & produced*



Fast Forward Detector: trigger L₀

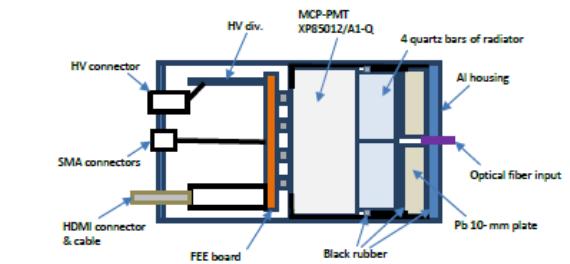
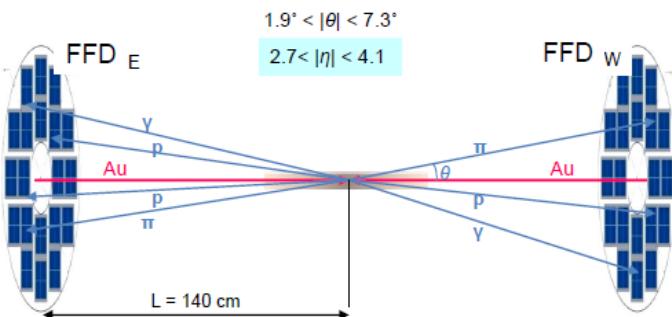
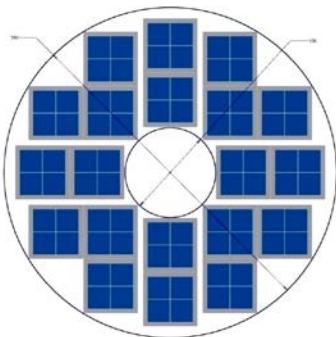
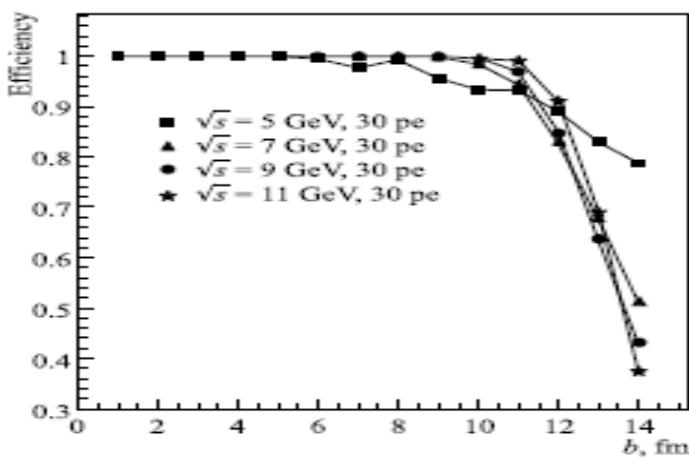


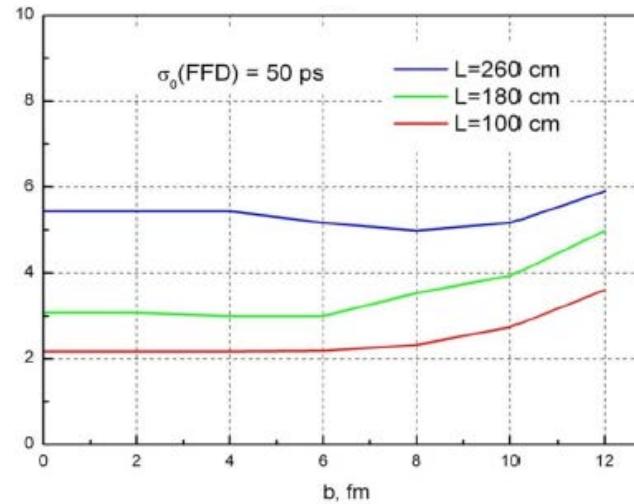
Fig. 4-1. A scheme of the FFD module.

20 modules based on
Planacon MCP-PMTs
80 independent channels

- interaction rate (L adjustment)
- bunch crossing region position



beam crossing fast signal for FFD
efficiency determination
for peripheral collisions



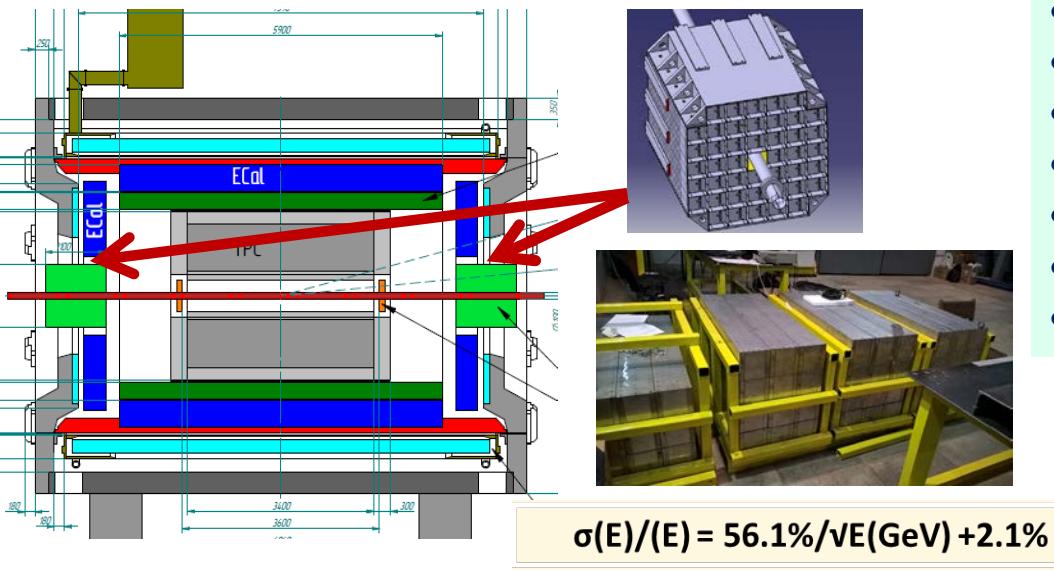
the vertex resolution for Au-Au collisions at $\sqrt{s} = 5 \text{ GeV/u}$
for three distances from interaction point



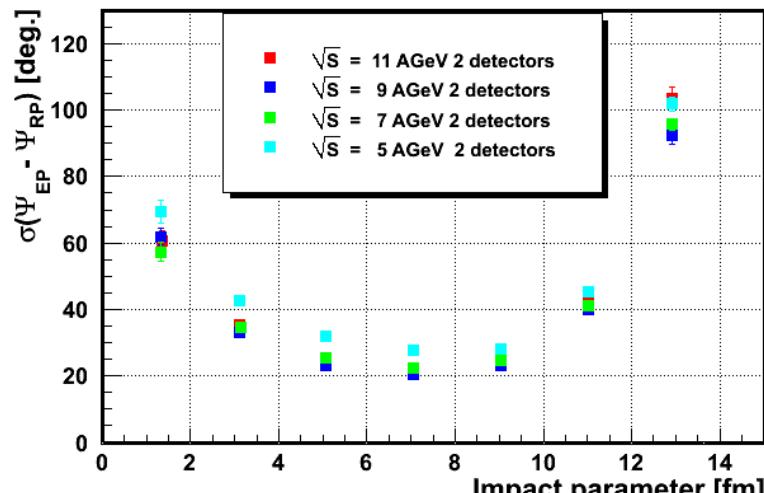
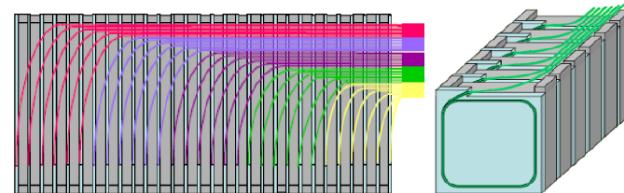
Forward Hadron Colorimeter

FHCAL can be used for beam tuning

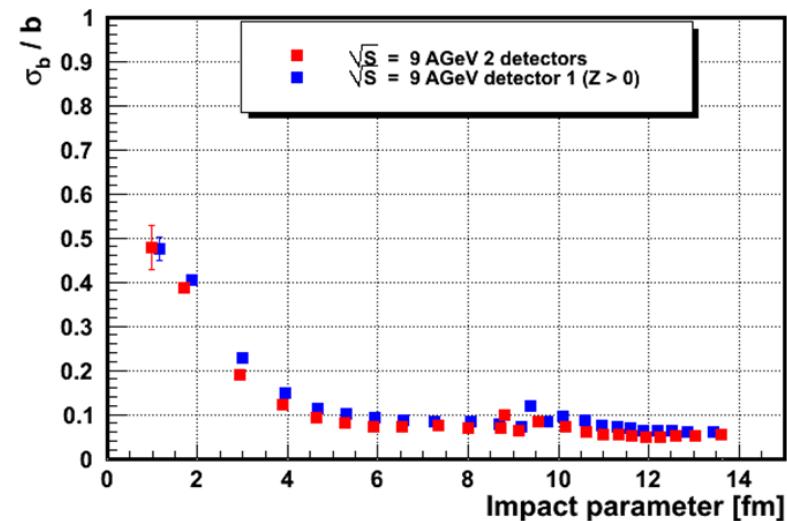
*Leaders: A. Ivashkin,
F. Guber (INR) + MiPhi*



- 2-arms at ~3.2 m from the IP;
 - each of 45 modules;
 - module: $15 \times 15 \times 110 \text{ cm}^3$ (55 layers)
 - $Pb(16\text{mm}) + \text{Scint.}(4\text{mm})$ sandwich
 - 7 longitudinal sections
 - 6 WLS-fiber/MAPD per section
 - 7 MAPDs/module



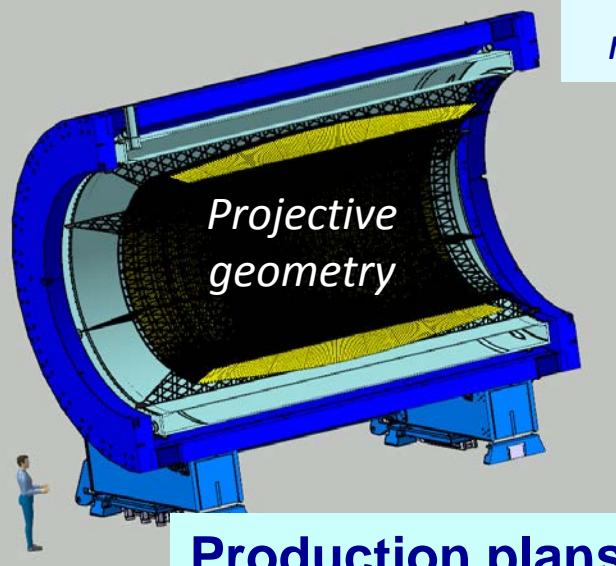
*reaction plane reconstruction
is in range 26-31 degrees*



Centrality measurement with accuracy ~ 10%

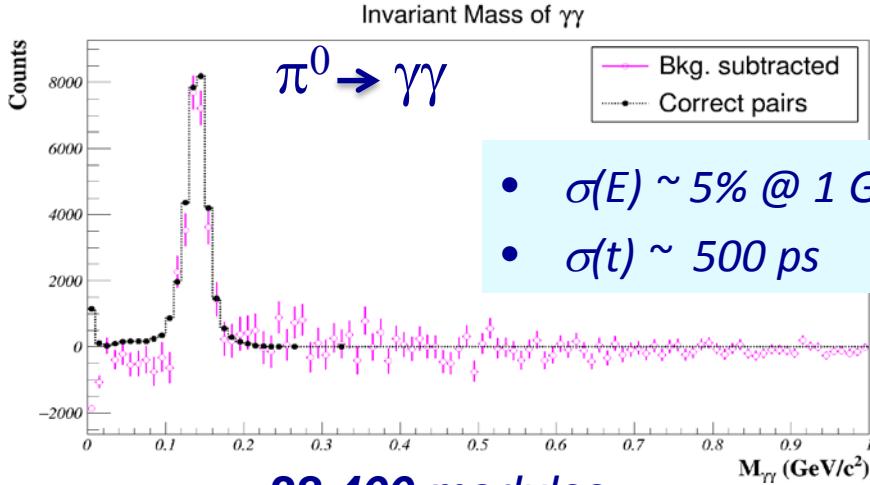
Electromagnetic calorimetry (ECal) system

38 400 modules «shashlyk» type ($Pb+Sc$)



r/o: WLS fibers +MAPD;

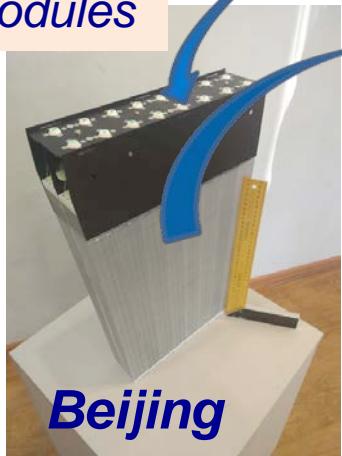
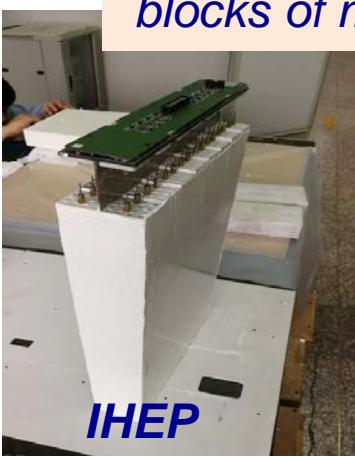
- $L \sim 35 \text{ cm} (\sim 14 X_0)$;
- Segmentation ($4 \times 4 \text{ cm}^2$).



- $\sigma(E) \sim 5\% @ 1 \text{ GeV}$;
- $\sigma(t) \sim 500 \text{ ps}$

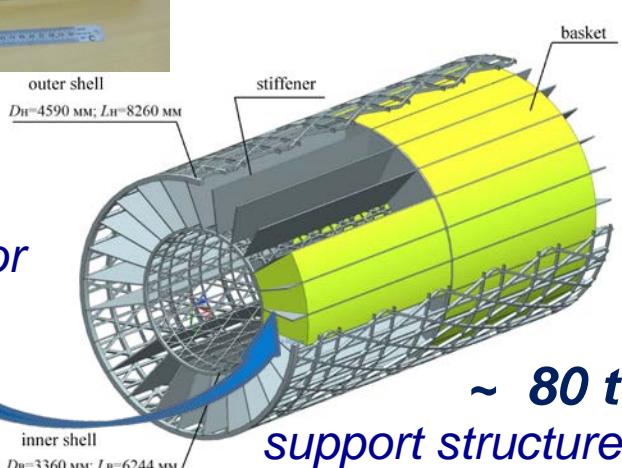
- Production plans:
- JINR, IHEP, Tensor + .. - 25%
 - China - 75%

blocks of modules



IHEP

Beijing



Integration

support structure of carbon fiber

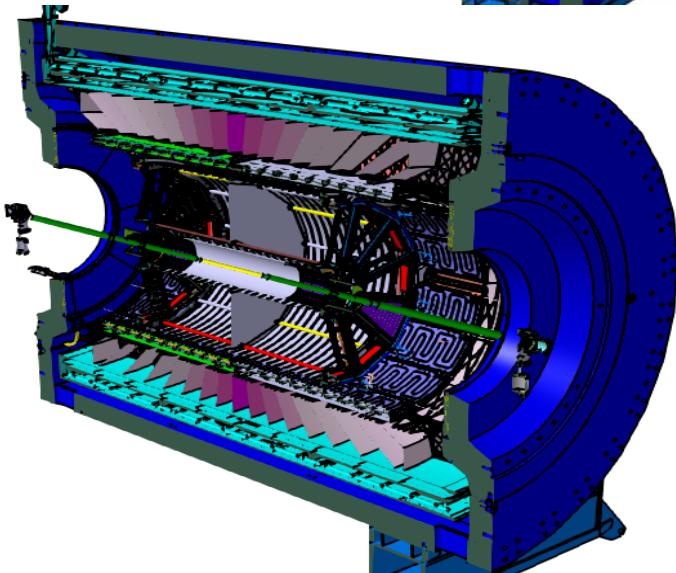
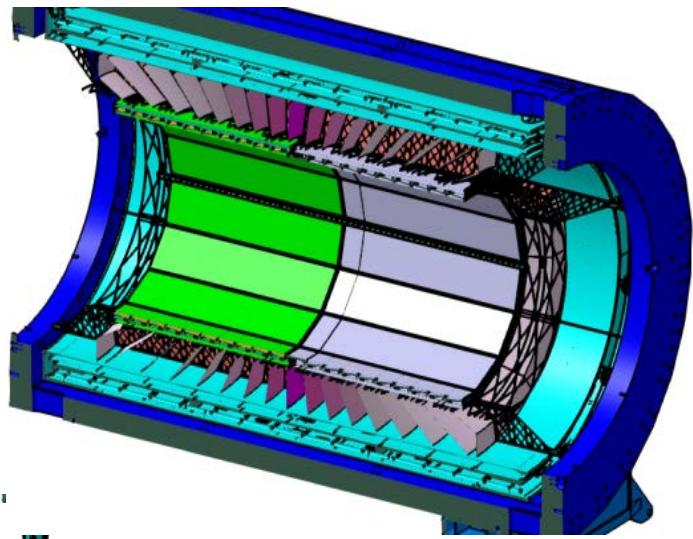
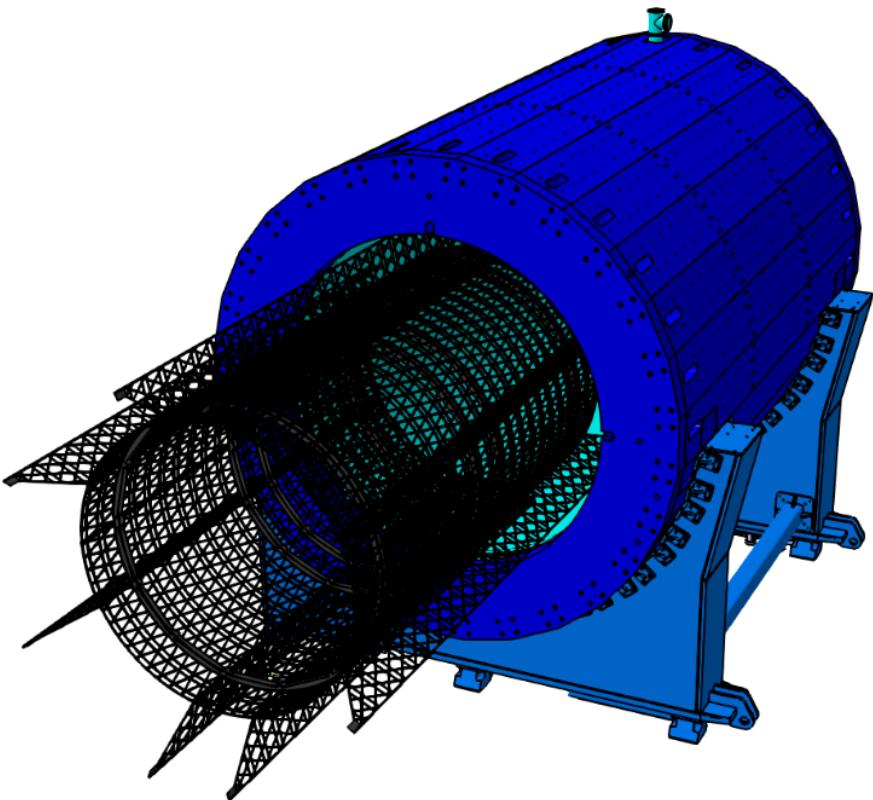
Contract signed AO «ЦНИИСМ»

power skeleton

ECal barrel ~ 80 t

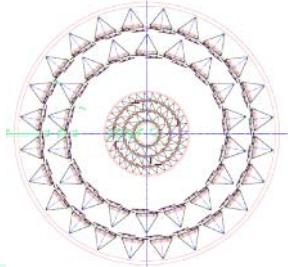
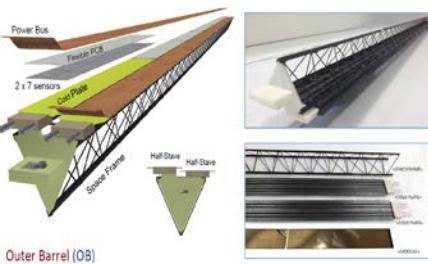
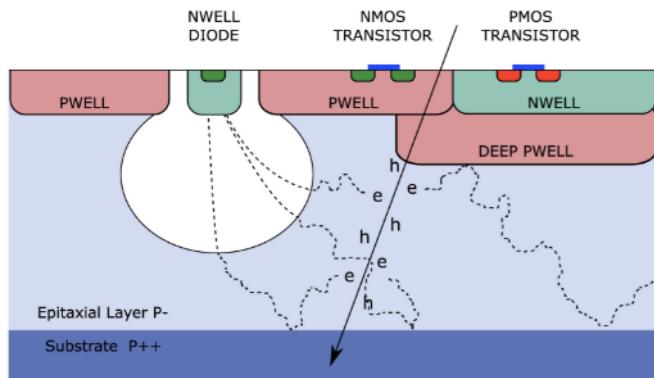
max sagite ~ 3 mm

R direction: material = 0,13 X₀

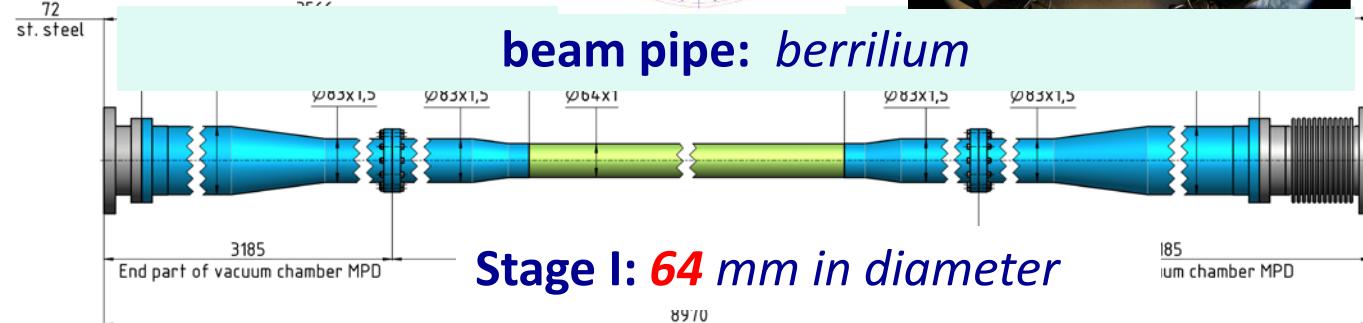


Coop with ALICE CERN

- **MAPS – CMOS technology**
- carbon fiber space frames;

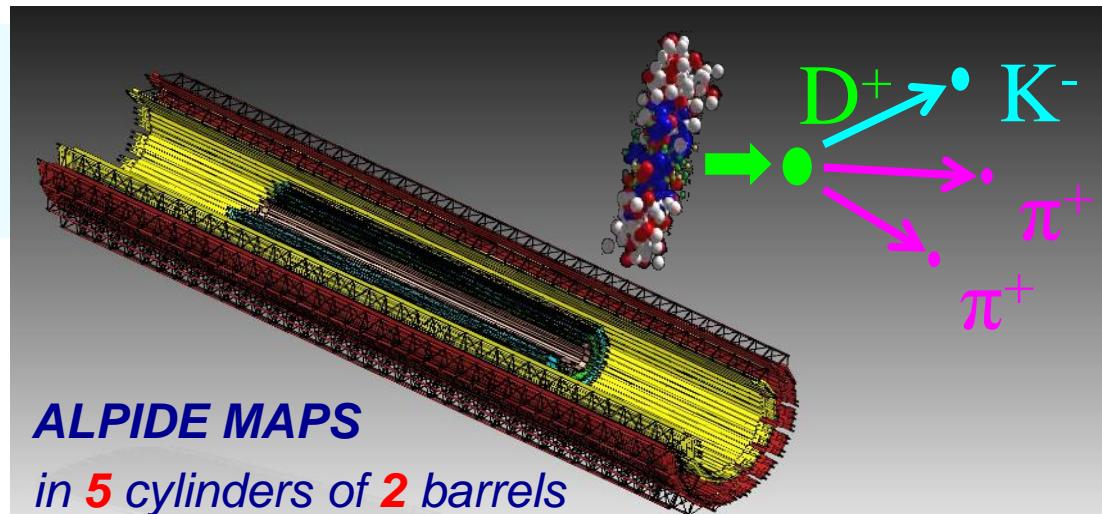


beam pipe: berrilium



Stage I: 64 mm in diameter

Stage II:
38 mm in diameter



4,9 · 10⁹ pixels, active area 3,9 m².



Collider building (№ 17) civil construction



Construction completion – December 2020

August 2019



BM@N

tunnel – preparation for equipment installation



**MPD
Hall**

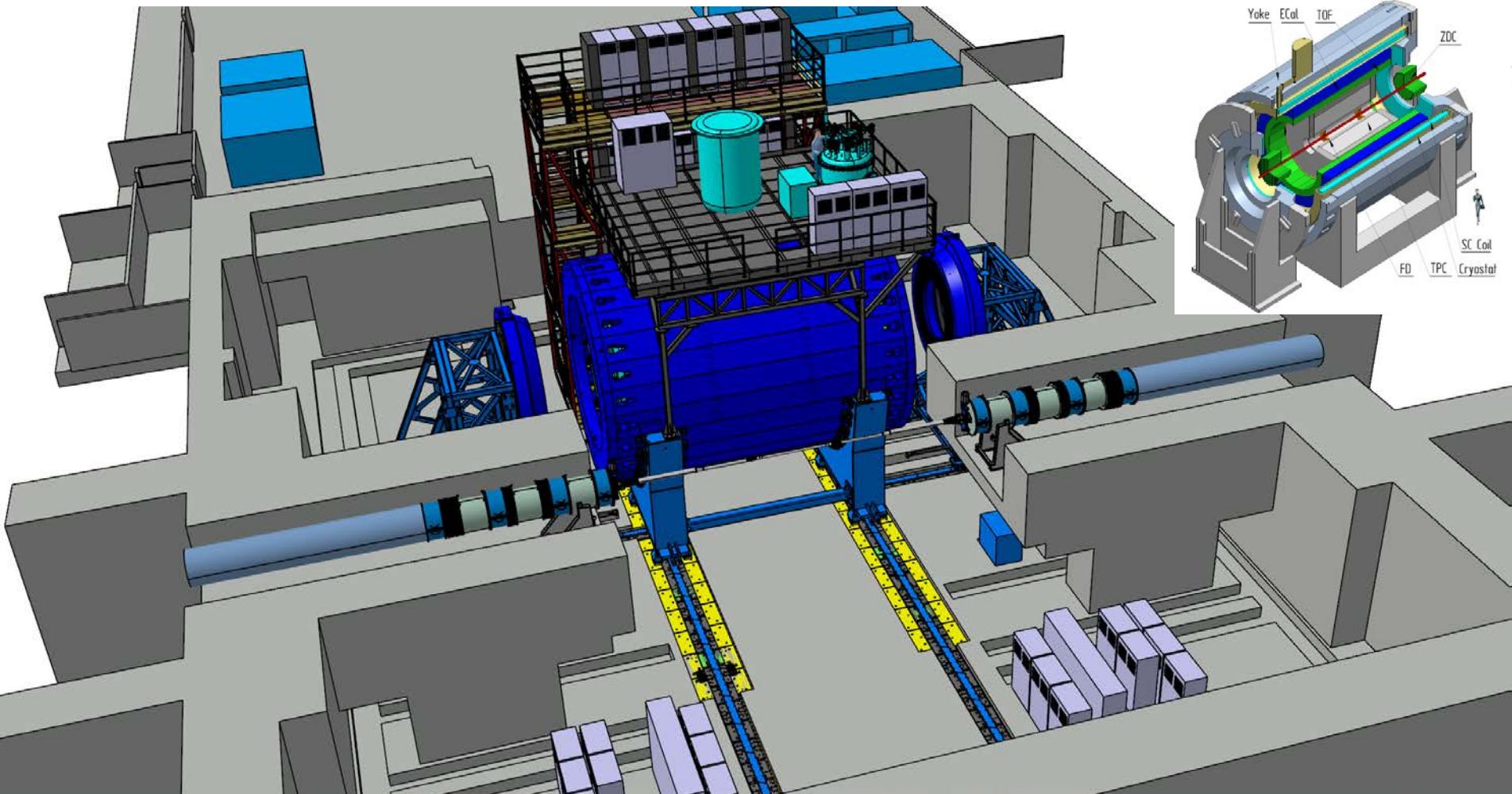


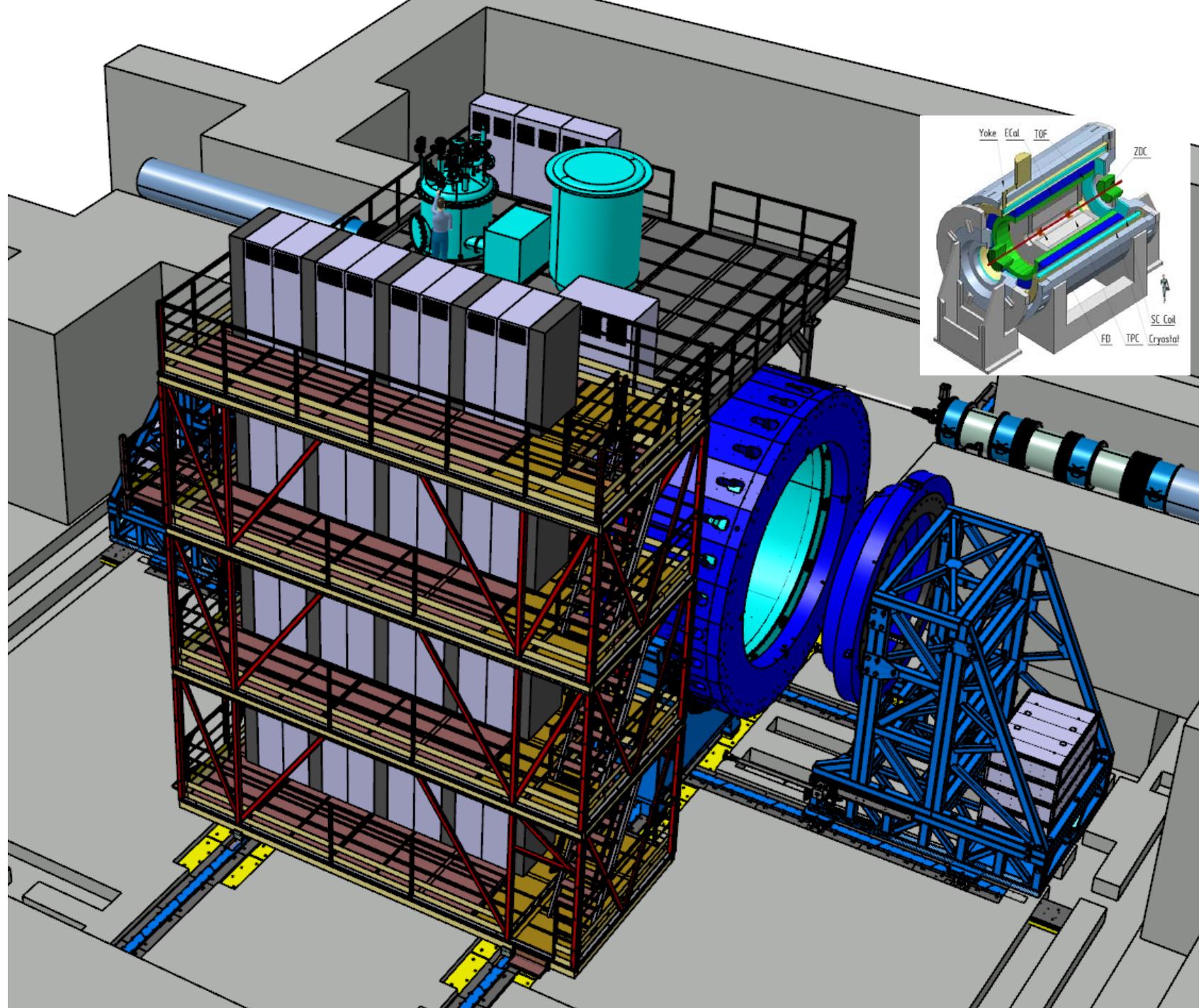
Staging of object commissioning:
MPD - April '20
Collider – July '20;



Magnet yoke rings in the MPD Hall







The kick-off meeting of MPD and BM@N Collaborations

took place in Dubna on 11-13 April, 2018

<https://indico.jinr.ru/conferenceDisplay.py?ovw=True&confId=385>

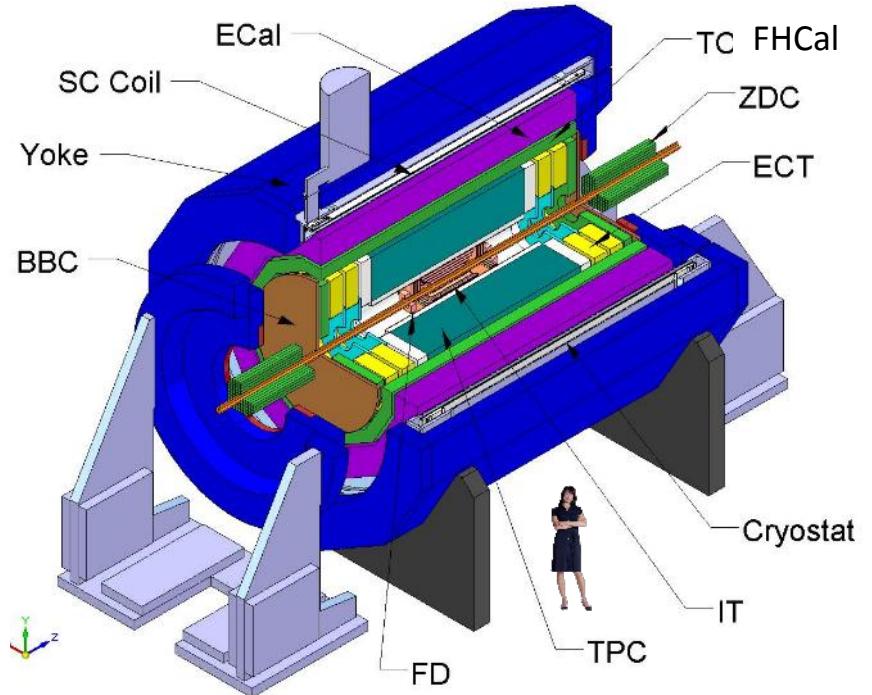


Two Institutional Boards (IB) were formed for both collaborations:

18 members for BM@N, and 27 members for MPD.

The bylaws have been adopted and signed by the IB's.

11 Countries, 38 Institutes, 505 participants



Baku State University, NNRC, Azerbaijan;

University of Plovdiv, Bulgaria;

University Tecnica Federico Santa Maria, Valparaiso, Chili;

Tsinghua University, Beijing, China;

USTC, Hefei, China;

Huizhou University, Huizhou, China;

Institute of Nuclear and Applied Physics, CAS, Shanghai, China;

Central China Normal University, China;

Shandong University, Shandong, China;

IHEP, Beijing, China;
University of South China, China;
Palacky University, Olomouc, Czech Republic;
NPI CAS, Rez, Czech Republic;
Tbilisi State University, Tbilisi, Georgia;
Tubingen University, Tubingen, Germany;
Tel Aviv University, Tel Aviv, Israel;
Joint Institute for Nuclear Research;
IPT, Almaty, Kazakhstan;
Consortium MEXNICA, Mexico;
Institute of Applied Physics, Chisinev, Moldova;
WUT, Warsaw, Poland;
NCN, Otwock – Swierk, Poland;
UW, Wroclaw, Poland;
Jan Kochanowski University, Kielce, Poland;

INR RAS, Moscow, Russia;
MEPhI, Moscow, Russia;
PNPI, Gatchina, Russia;
INP MSU, Moscow, Russia;
KI NRS, Moscow, Russia;
SPSU - Dept. of NP, Russia;
St. Petersburg, Russia;
SPSU – Dept. of HEP, St. Petersburg, Russia;
North Ossetia State University, Vladikavkaz, Russia;

IB of MPD:

Tagir Aushev

Alejandro Ayala

Mircea Baznat

Marcin Bielewicz

David Blaschke

Dmitry Blau

Deging Fang

Oleg Fedin

Deqing Feng

Grigory Feofilov

Vyacheslav Golovatyuk

Mei Huang

Alexander Ivashkin

Adam Kisiel

Andrej Kugler

Sergey Kuleshov

Viacheslav Kulikov

Feng Liu

Miroslav Maslan

Mikhail Merkin

Nalli Pukhaeva

Anar Rustamov

Maciej Rybczynski

Revaz Shanidze

Zebo Tang

Arkadiy Taranenko

Vanio Tcholakov

Kristina Vokhmyanina

Fuqiang Wang

Yi Wang

Xiaodong Wang

Qinghua Xu

Chengxin Zhao

- *IB Chair - Fuqiang Wang, Huzhou University, China;*
- *Spokesperson – Adam Kisiel, Warsaw University of Technology, Poland;*
- *Deputy Spokesperson - Victor Riabov, PNPI St. Petersburg, Russia;*
- *Deputy Spokesperson - Zebo Tang, USTC in Hefei, China;*
- *Project manager– Vyacheslav Golovatyuk, JINR.*



MultiPurpose Detector (MPD)

Project leader: V. Golovatyuk

Detector Advisory Committee:

Hans Gutbrod, GSI - chairman

Itzhak Tserruya, Weizmann Institute

Hans Rudolf Schmidt, Tübingen Uni.

Jean Cleymans, Cape Town Uni.

Nu Xu, BNL

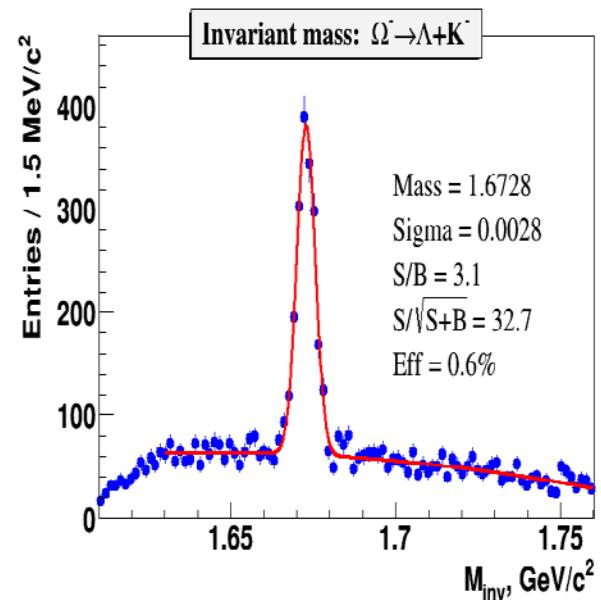
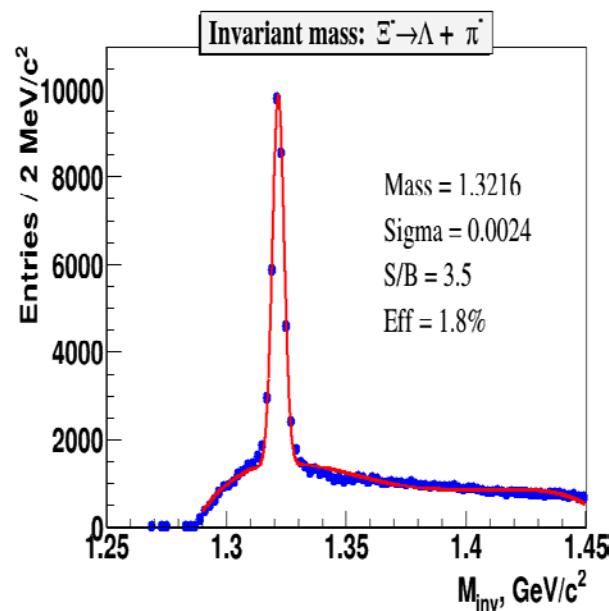
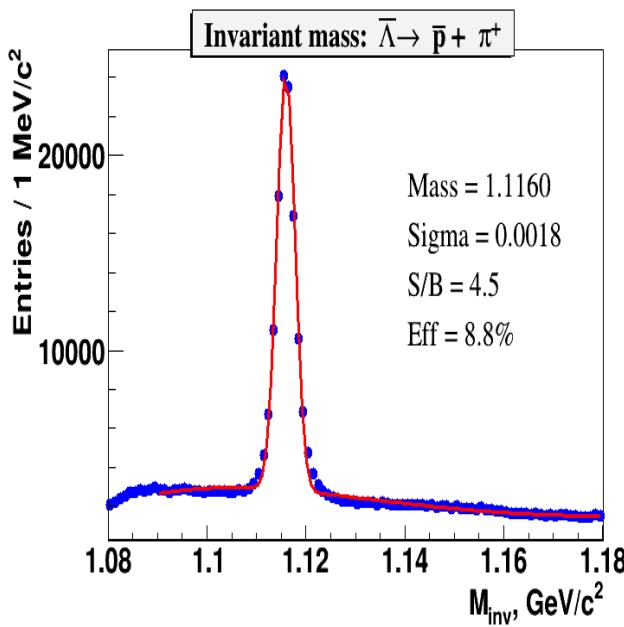
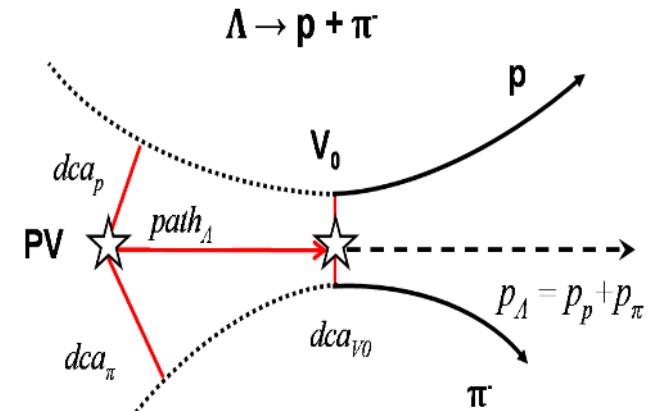
Study of hyperons

V. Vasendina, A. Zinchenko, V. Kolesnikov

- **8M minbias Au+Au @ 11 GeV (PHSD model)**
- **TPC & TOF, $|\eta| < 1.3$**
- **track reconstruction and PID ($dE/dx + TOF$)**
- **secondary vertex finding technique**

Yields for 10 weeks of running

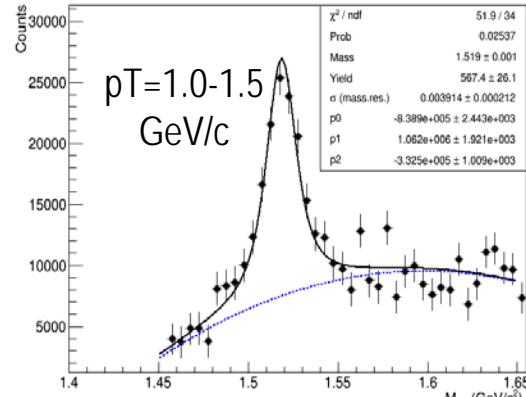
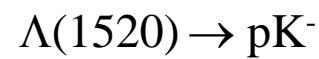
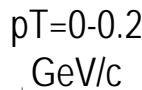
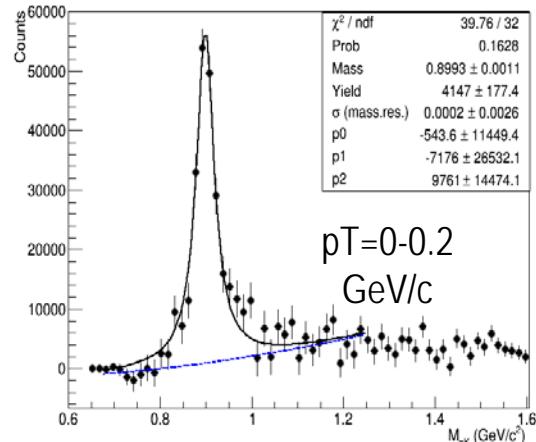
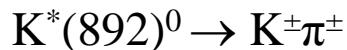
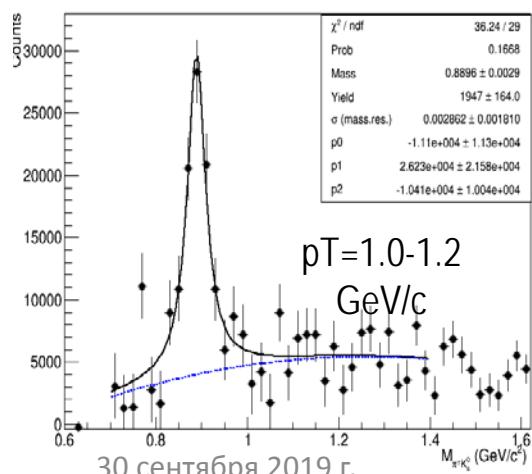
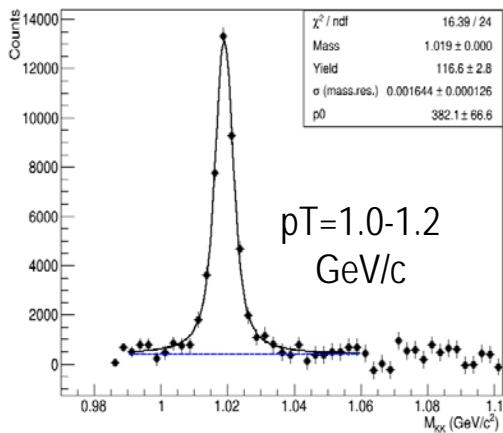
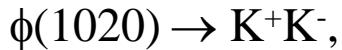
Λ	$\bar{\Lambda}$	Ξ^-	Ξ^+	Ω^-	Ω^+
$6 \cdot 10^9$	$7.3 \cdot 10^7$	$3 \cdot 10^7$	$1 \cdot 10^6$	$1 \cdot 10^6$	$3 \cdot 10^5$



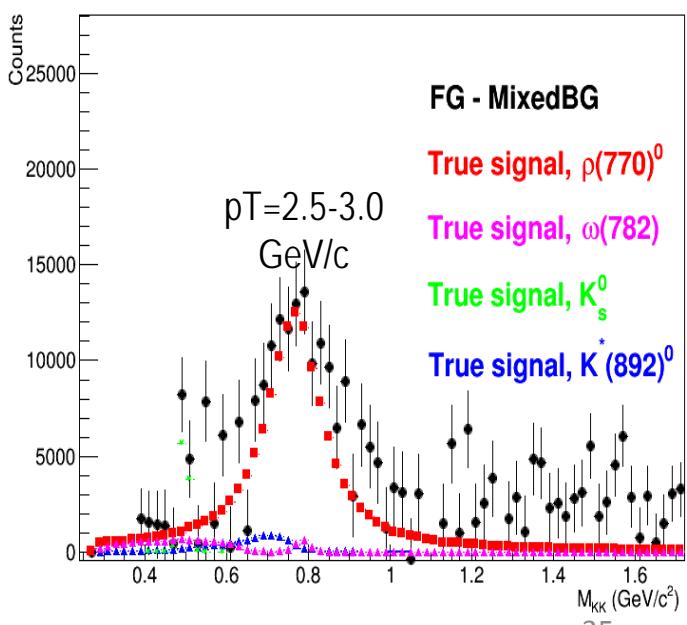
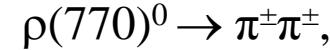
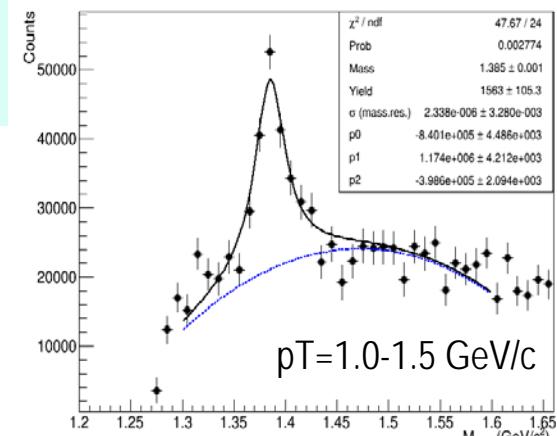
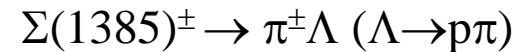
Resonances

D. Ivanishchev, D. Kotov, M. Malaev, V. Riabov, Yu. Ryabov

- Minbias Au+Au@11 (UrQMD module)
- Full event reconstruction and realistic PID
- Topoly cuts and secondary vertex finding for hyperons
- Event mixing for background estimation



В. Кекелидзе, СЯФ ОФР РАН

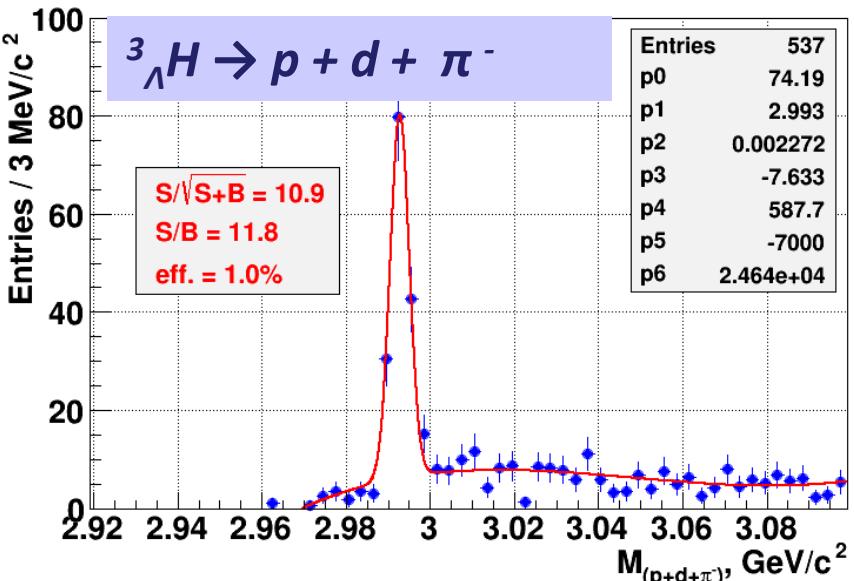
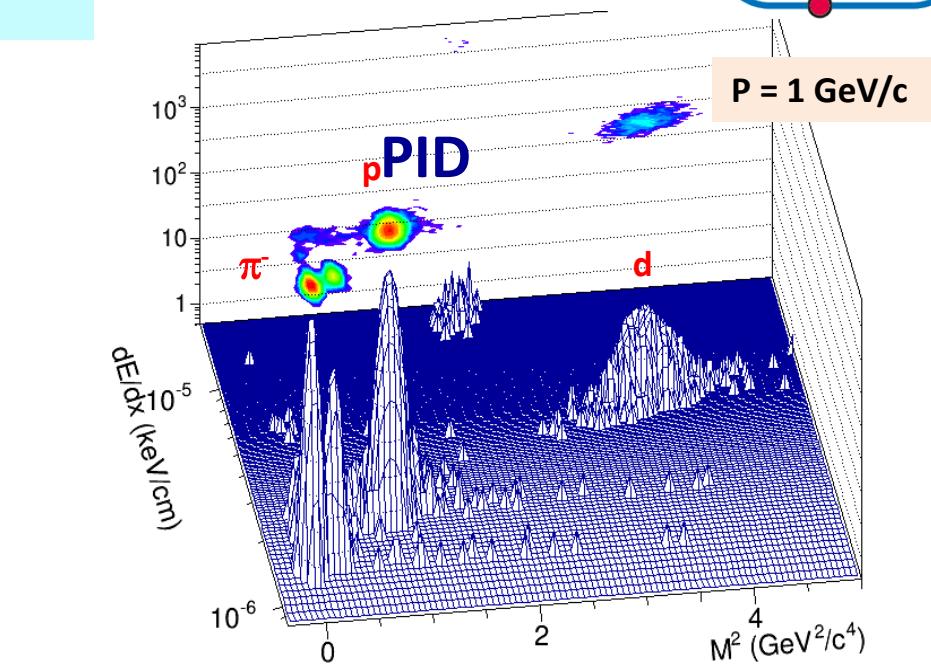
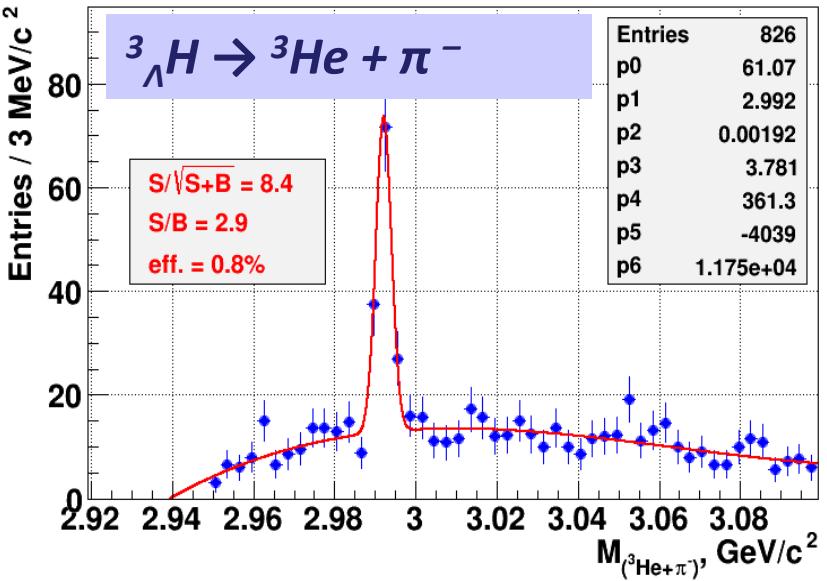


Hypernuclei @ MPD

Hypertritons

central Au+Au @ 5A GeV
(DCM-QGSM)

$\sim 10^6 {}^3\Lambda H$ are expected
in 10 weeks

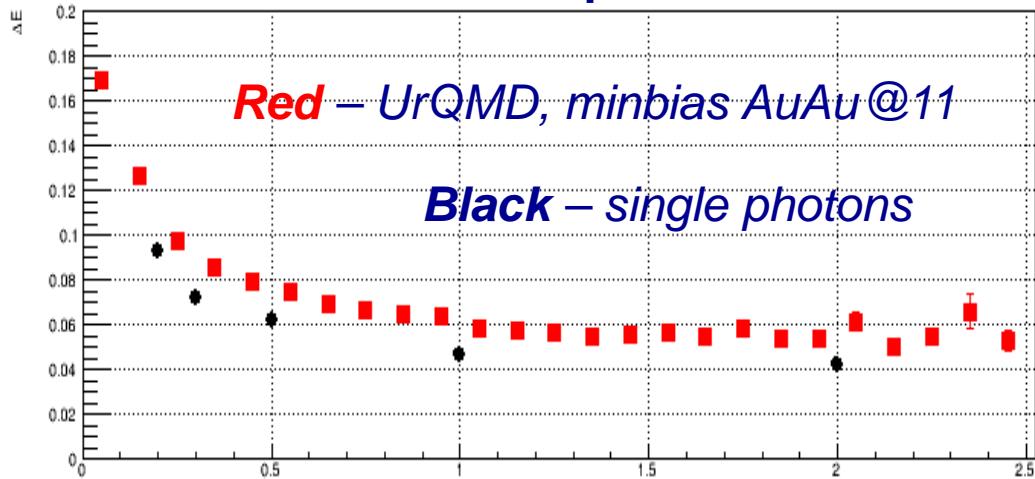


ECAL simulation

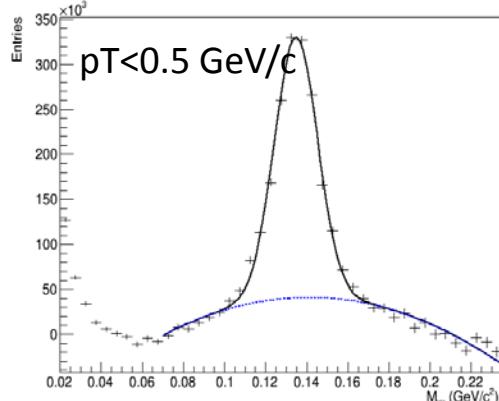
V. Riabov, A. Zinchenko, M. Martemyanov, V. Kulikov

Realistic ECAL reconstruction & analysis – large acceptance **ECAL**
of good energy resolution is an ideal tool for measurement of neutral mesons
in a wide momentum range

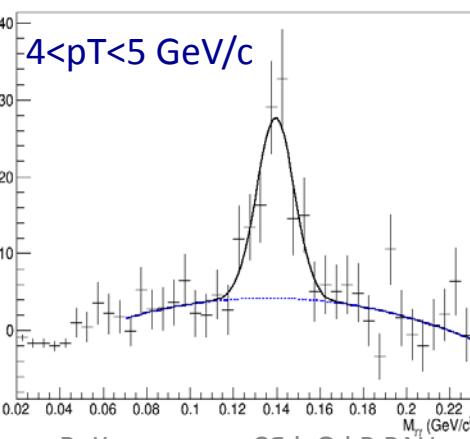
ECAL resolution for photons



π^0 -meson in central Au+Au

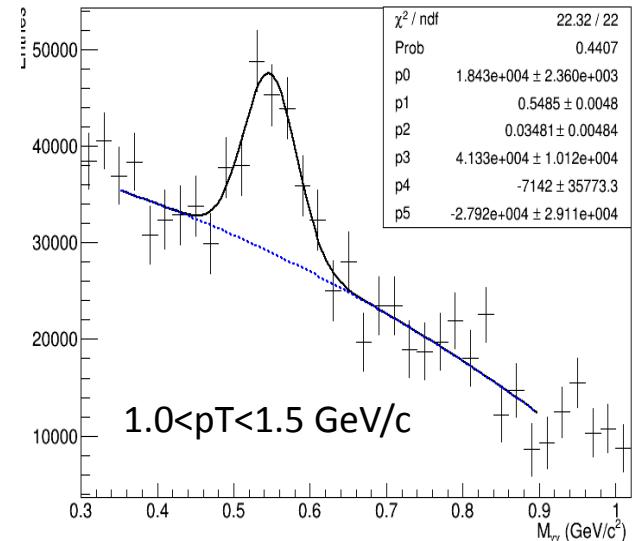


30 сентября 2019 г.



В. Кекелидзе, СЯФ ОФР РАН

η -meson in minbias Au+Au



π^0 (η) reconstruction
with ECAL – feasible!

First Physics with MPD

- Preparation of the report on expected physics results on the first run of MPD
- Initial running plan for the NICA Complex (beam types, collision energies)
- Status of the readiness of the MPD detector subsystems
- Calibration and computing readiness
- Selection of physics observables with largest discovery potential for the initial data sample
- Schedule for preparation of first scientific publications from MPD data

First Physics with MPD Experiment at the NICA Accelerator Complex*

Vladimir D. Kekelidze, Adam Kisiel,[†] and Viacheslav Golovatyuk[‡]

Joint Institute for Nuclear Research, Dubna, Moscow Region, Russian Federation

(MPD Collaboration)

(Dated: February 17, 2020)

The Nuclotron-based Ion Collider fa(cility (NICA) is in construction at the Joint Institute for Nuclear Research (JINR). The accelerator complex will consists of several components, specifically the Nuclotron accelerator, the Booster support accelerator, two ion sources, as well as the NICA collider ring with the corresponding transfer lines from Nuclotron. The expected date of putting the NICA collider ring in operation is N-th Month of 202X. At the same time the Multi-Purpose Detector (MPD) has been designed to operate at NICA. Components of MPD are currently in production. The assembly of the detector on-site is expected to start on March of 2020, while on May of 2021 the detector setup will start the commissioning, to be ready for datataking on first beam from NICA.

This documents details the preparation schedule for the construction and commissioning of MPD. It presents the plans for the first physics measurements at NICA and puts them into context of existing and planned physics experiments in the area of QCD phase diagram investigation.

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* A report for the Scientific Council of JINR

[†] Also at Faculty of Physics, Warsaw University of Technology, Warsaw, Poland.

[‡] Second.Author@institution.edu

ВЫВОДЫ

- **Предельно достижимая барионная плотность**
 - мало изученная область фазовой диаграммы КХД, исследования которой могут прояснить ряд актуальных вопросов сильных взаимодействий
- **NICA Комплекс обладает потенциалом**
 - конкурентных исследований в этой области
- **В ходе создания детектора MPD**
 - решен ряд технологических и методических задач, позволяющих получить высокоточные результаты
- **Формирование международной коллаборации MPD**
 - обеспечивает надежную экспертизу ведущихся работ, расширяет круг решаемых задач
 - и тем самым повышает научный потенциал эксперимента
- **Физики ИЯФ приглашаются к участию в исследованиях на MPD**

«Всякий человек знает, что ему нужно делать не то, что разъединяет его с людьми, а то, что соединяет его с ними.»

Л.Н. Толстой



Спасибо!