# MPD Project at Nuclotron Based Ion Collider Facility (NICA)

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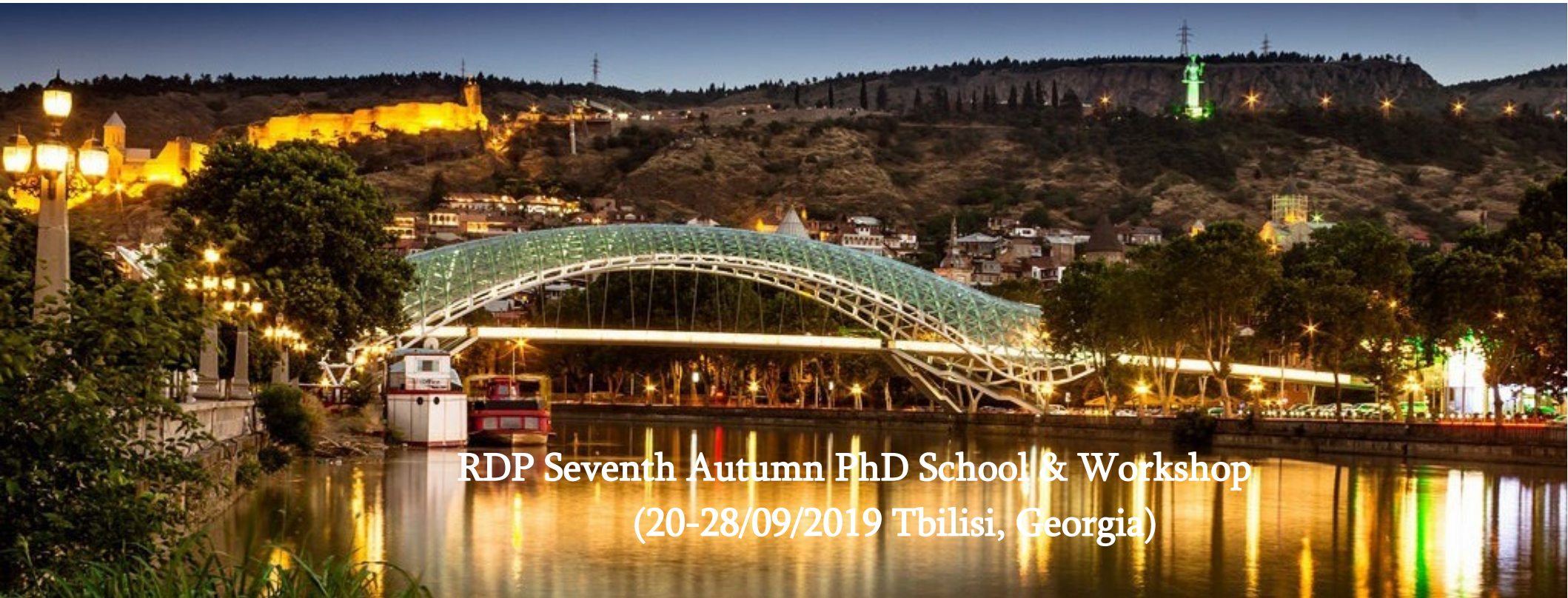


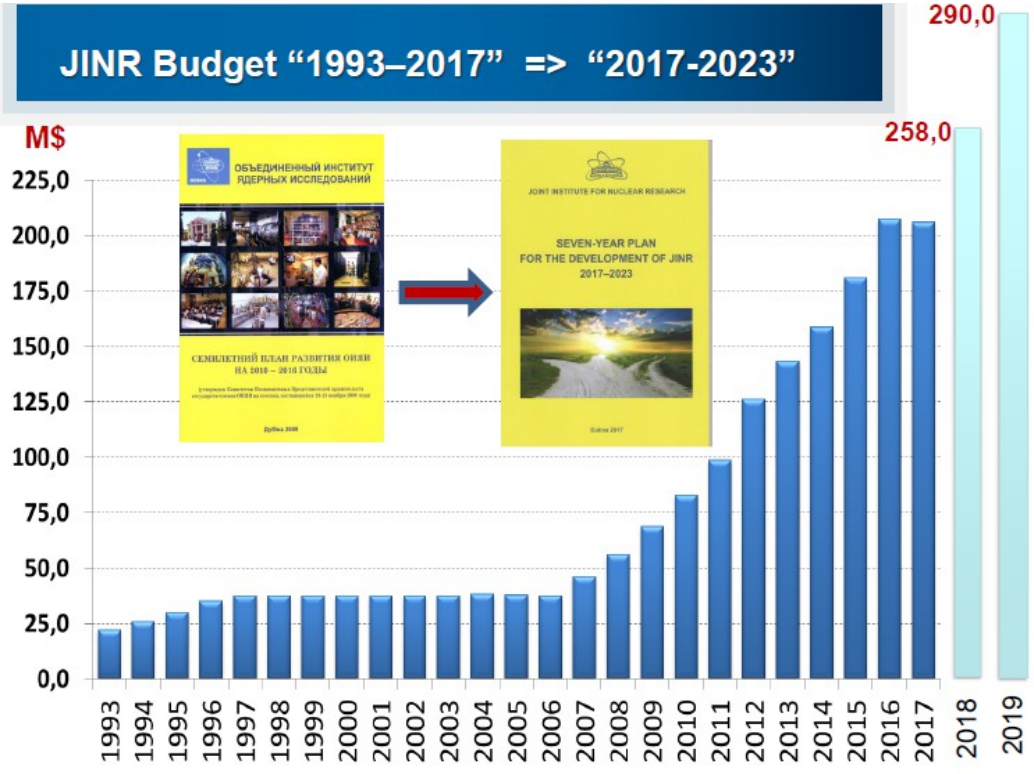
RDP Seventh Autumn PhD School & Workshop
(20-28/09/2019 Tbilisi, Georgia)

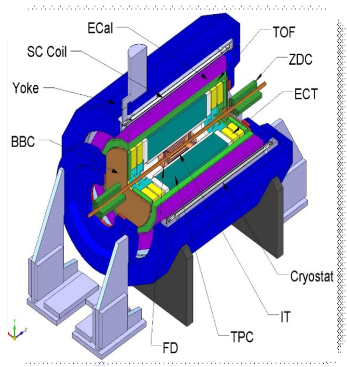
# Joint Institute of Nuclear Research (Dubna)

JINR/Dubna →
founded in 1956

May 2019: 18 member states

6 Associte member states: Egipt, Germany, Hungary, Italy, Serbia, South Africa

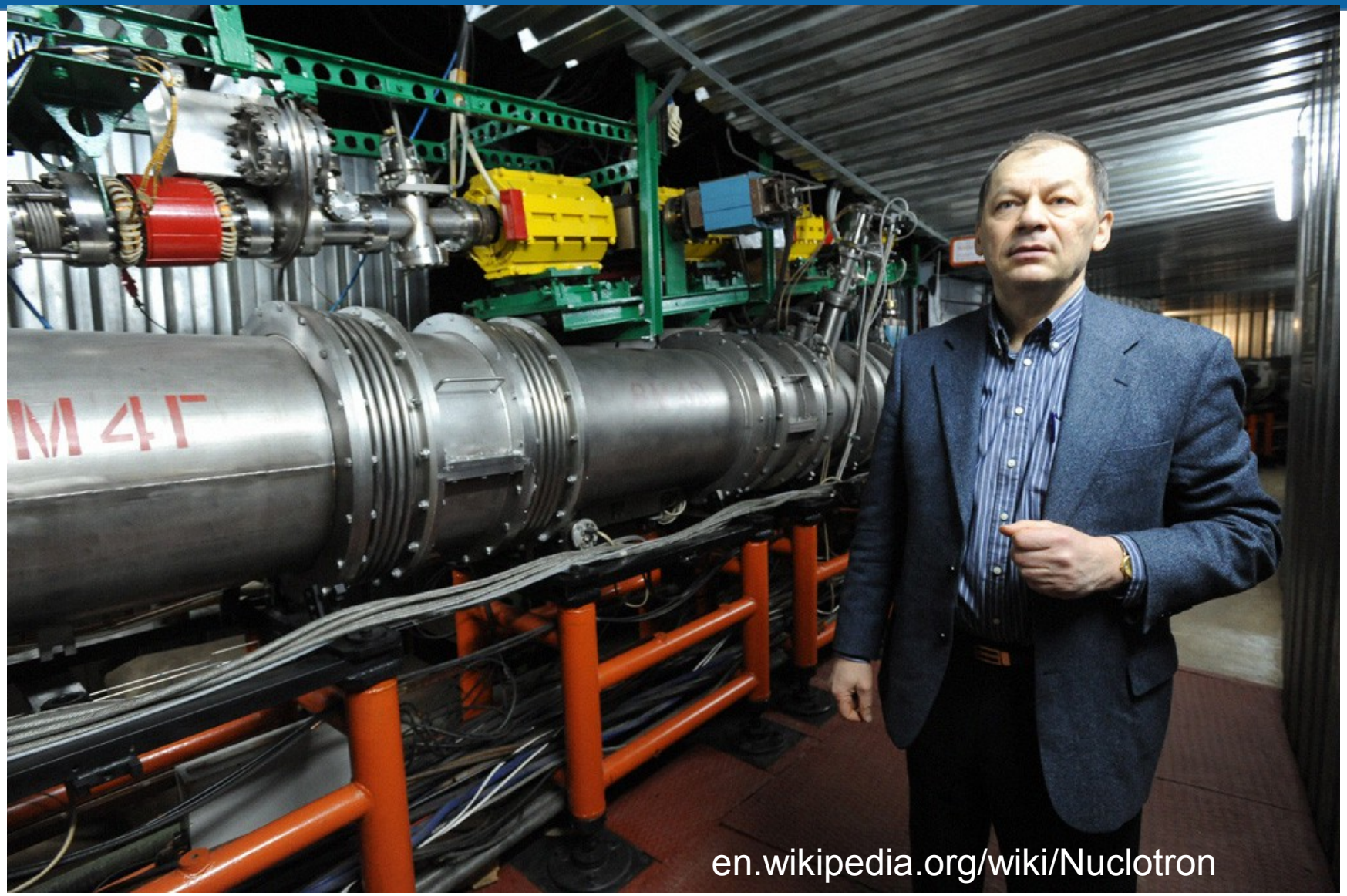


# JINR Synchrotron

JINR Synchroton (synchrophasotron): 10 GeV accelerator for protons and light ions. (1957 – 2003)

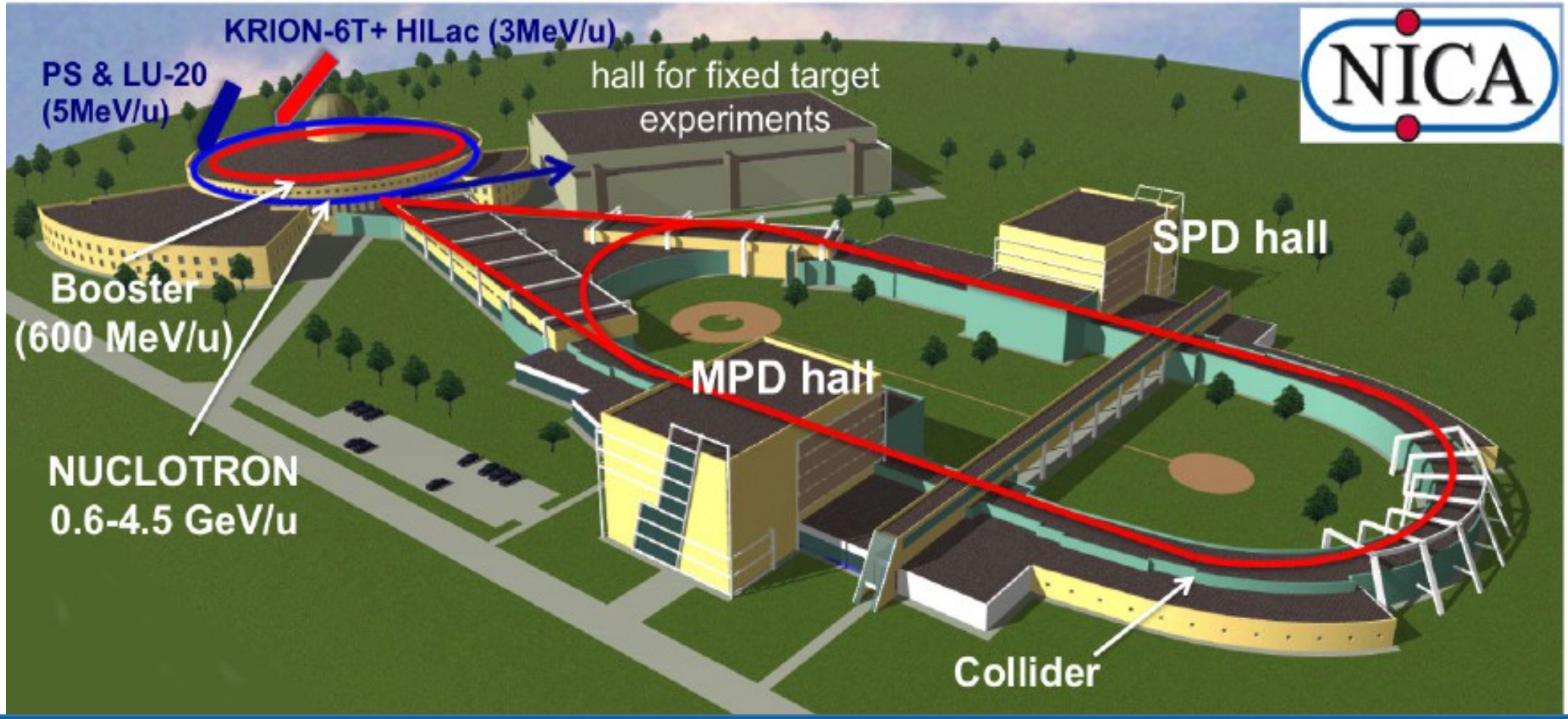
# JINR Nuclotron



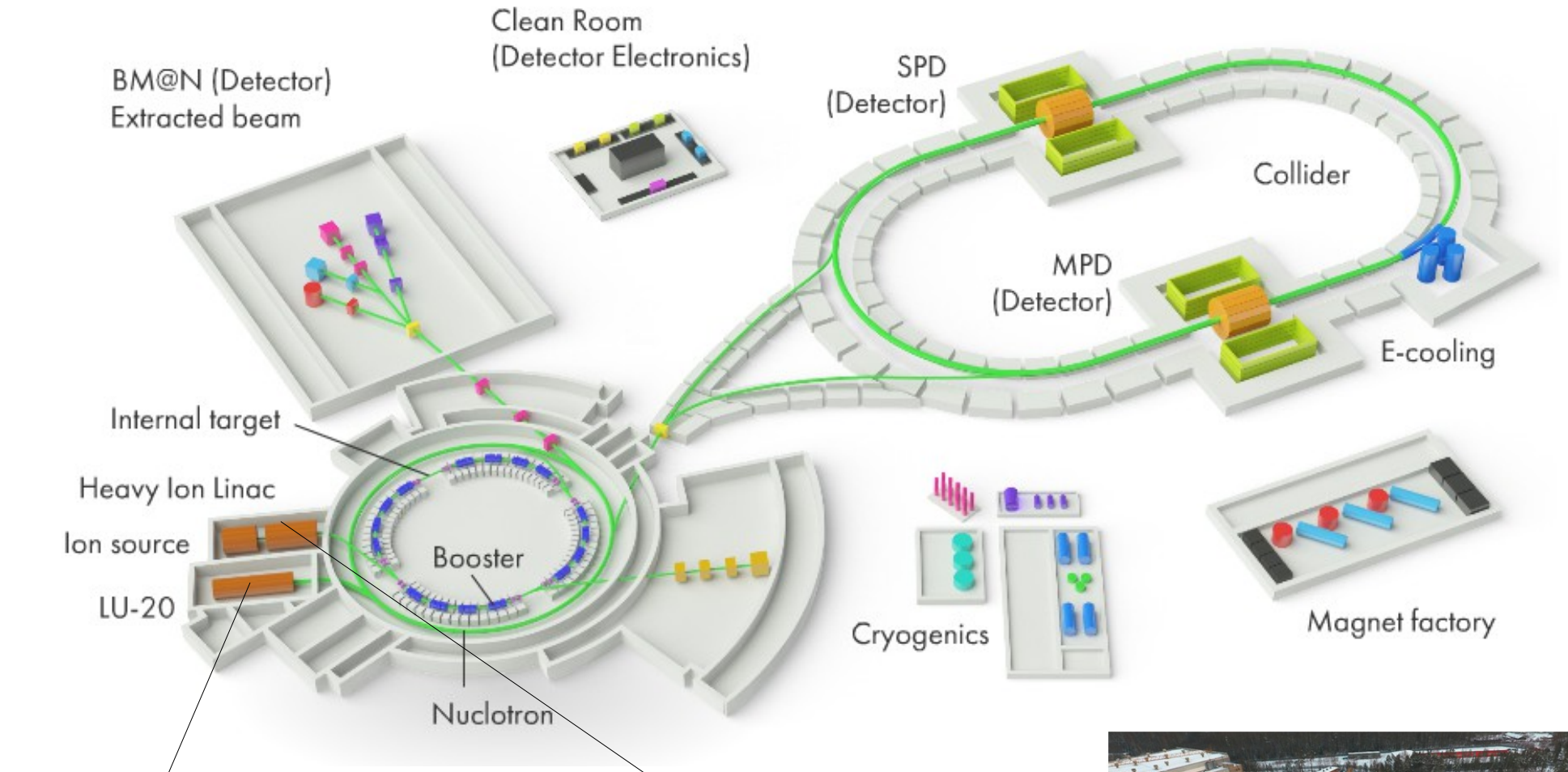

Nuclorton@JINR was build 1987-1992 (first superconductive synchrotron)
Nuclotron ring follows the outer perimeter of the synchrophasotron ring)

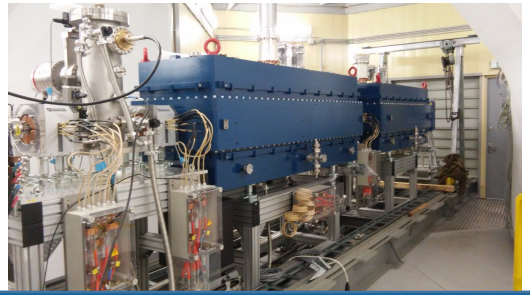
# NICA Project

- Main goals: study dense baryonic matter at the extreme conditions;
  investigation of nucleon spin structure with polarized protons and deuterons
- Modernization of JINR accelerator facility → construction of **Collider** of relativistic ions
  from **p** to **Au** at ($\sqrt{S_{NN}}$ = **4** - **11** GeV) polarized **p** and **d** at energy up to $\sqrt{S}$ =**27** GeV (p)



# NICA Complex



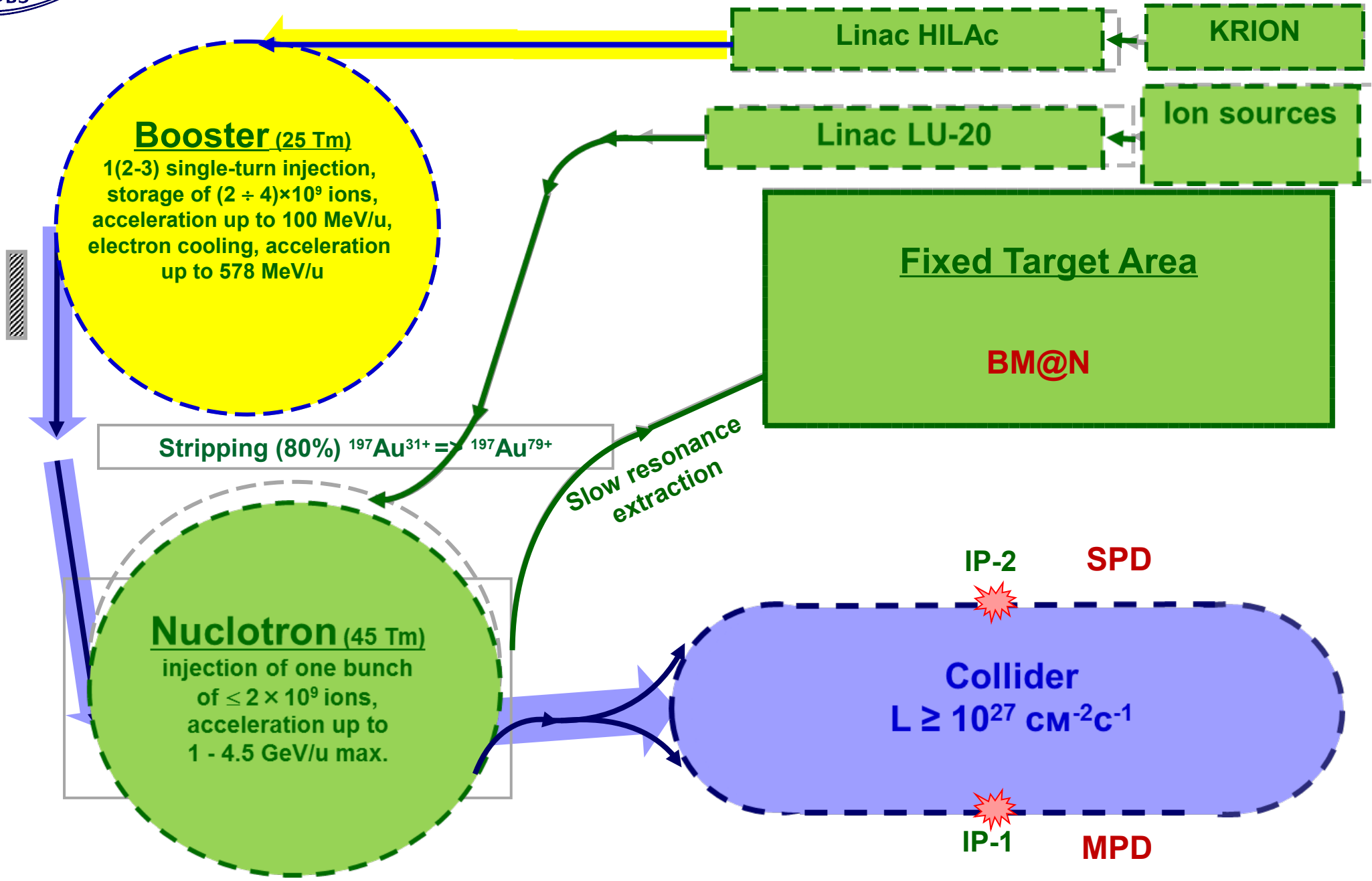
# Production of Superconductiong Magnets

# NICA Complex/Booster

# Construction of NICA Collaider Building

http://nucloweb.jinr.ru/nucloserv/205corp.htm

# NICA facility elements – present status (2019)

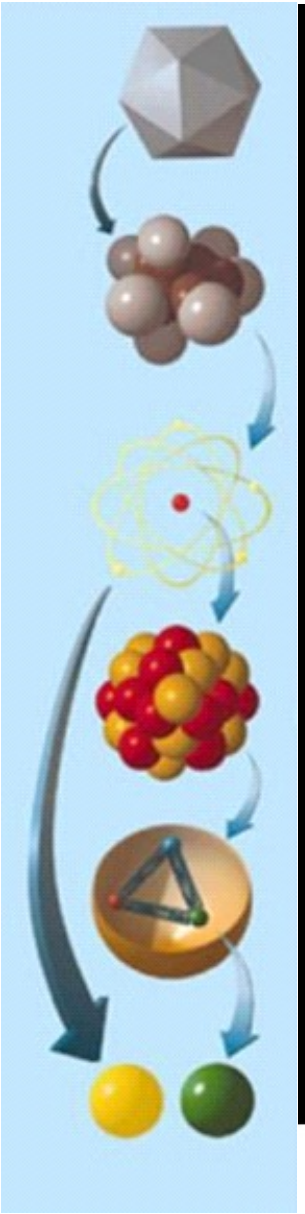


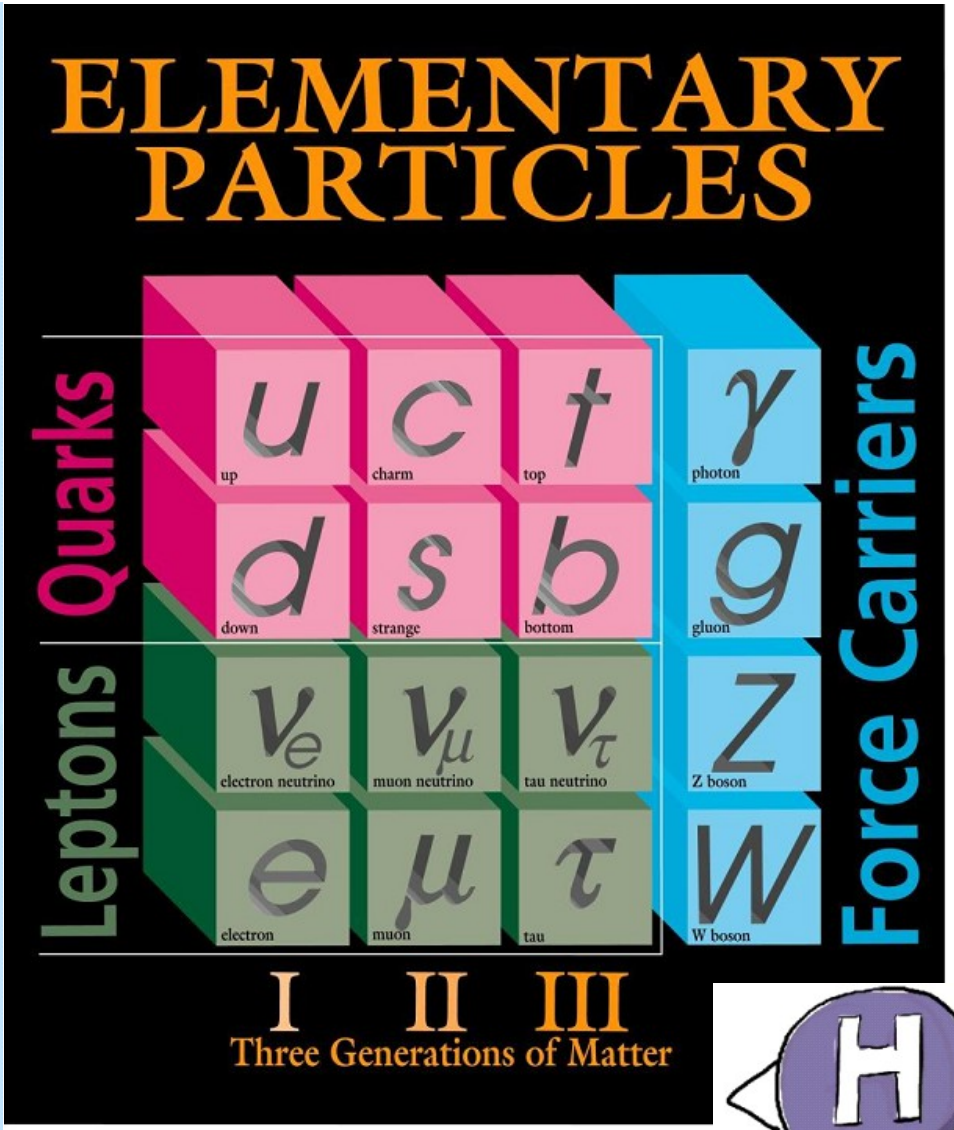

work in progress | assembly | commissioned / existing

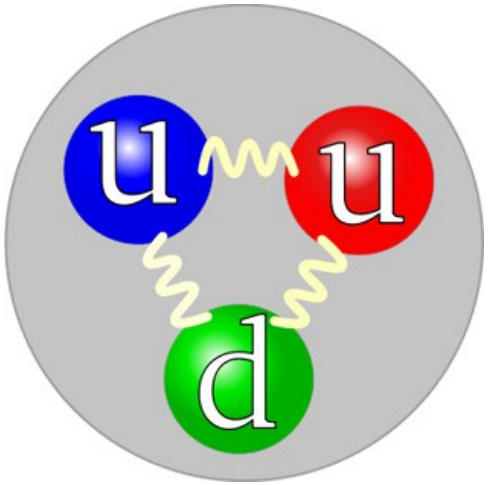
# NICA Accelerator Complex Parameters

- Ion source: $^{197}Au^{31+}$ $2 \cdot 10^9$ ions per pulse of about 7 μs / rate up to 50 Hz.
- Heavy ion linear accelerator (HILAc): ions at $A/q \leq 8$ up to the energy of 3 MeV/u at efficiency not less than 80 %;
- **Booster-synchrotron:** SC ring circumference of 215 m, max magnetic rigidity of 25T · m. Max. energy of $^{197}Au^{31+}$ ions 600 MeV/u; (electron cooling system).
- **Nuclotron** – superconducting (SC) synchrotron ( circumference of 251.52 m) with maximum magnetic rigidity of 45T · m
  Completely stripped $^{197}Au^{79+}$ up to 4.5 GeV/u and protons up to 12.6 GeV
- **Collider rings** - (about 503.4 m circumference) - max. magnetic rigidity of 45T · m electron and stochastic cooling systems
  Au-Au collision energy range $\sqrt{s_{NN}} = 4 - 11$ GeV $(10^{27}\ cm^{-2}\ sec^{-1})$
  p-p collisions at the energy up to $\sqrt{s} = 27$ GeV. $(10^{32}\ cm^{-2}\ sec^{-1})$

# Standard Model of Particle Physics






$$M_p = 1.672621898(21)\times10^{-27} \text{ kg}$$

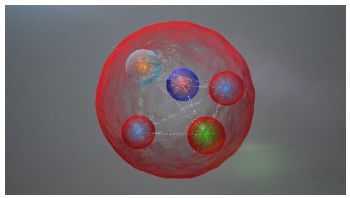
QCD exotic states:

XYZ states, pentaquarks

Talks at this workshop:

B.S. Zou and

Feng-Kun Guo

V. Matveev@ESHEP-2019

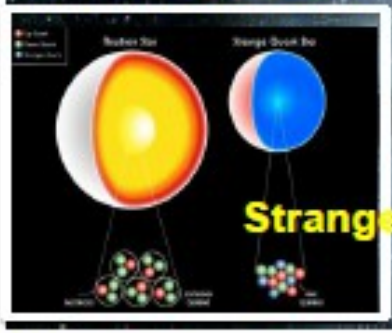
NICA

Au+Au collision at √s=11 AGeV event
Simulated within MpdROOT

Core of Neutron Stars reaches density several times nuclear density

Supernova

The Neutron Star



Strange quark star

- Highest density matter in the universe

  M = 1~2 $M_\odot$, R ~ 10~20 km

  => Density of the core = 3~10$\rho_0$ (1~3 Btons/cm$^3$)

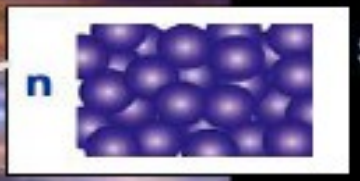
  $\rho_0$: nuclear density

- Various forms of matter made of almost only quarks

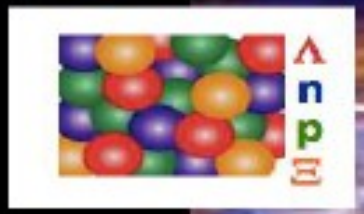
## Nuclear "Pasta"

Nuclear + Neutron Matter

## Neutron Matter

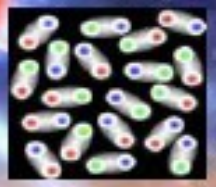



Superfluid




## Strange Hadronic Matter ?

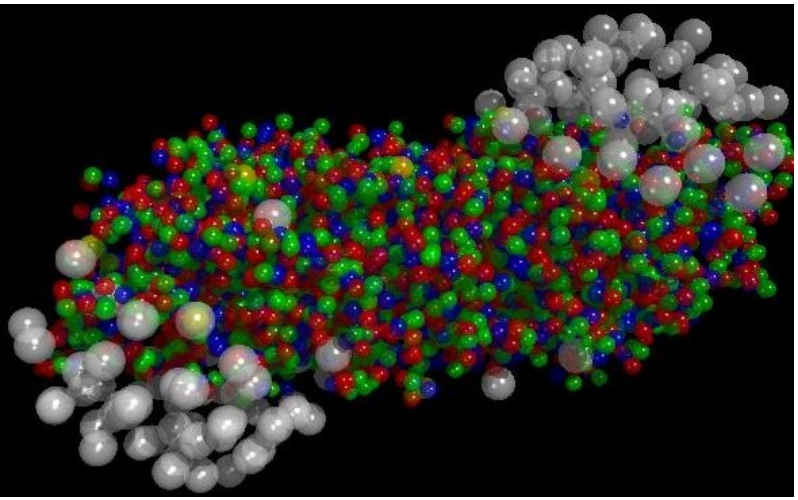
High density nuclear matter with hyperons (strange quarks)



## Quark Matter ??

Deconfined quarks
Color superconductivity

# Heavy Ion Program at CERN



## New State of Matter created at CERN

CERN special seminar

(press release, 10 Feb. 2000)

SPS: $E_{Pb} = Z_{pb} \times E_{p} = 82 \times 400$ GeV $= 33$ TeV

$E_{u} = E_{pb}/A_{pb} \approx 160$ GeV

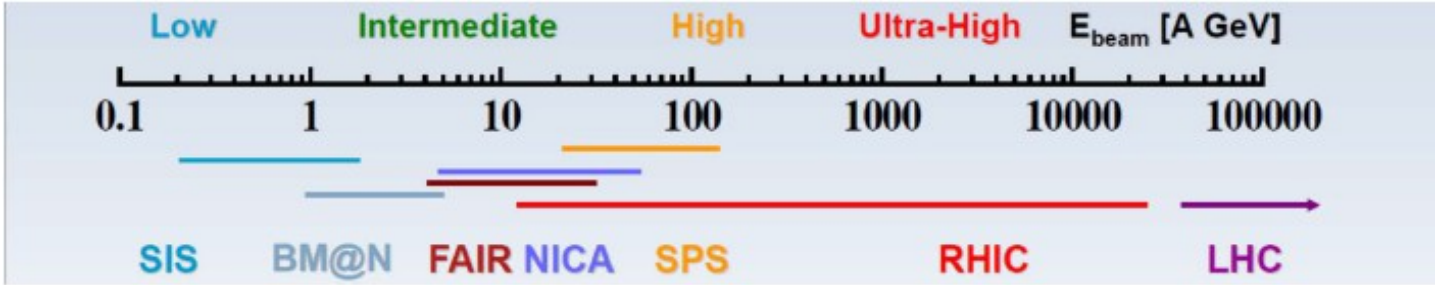
$\sqrt{S_{NN}} \approx 17$ GeV

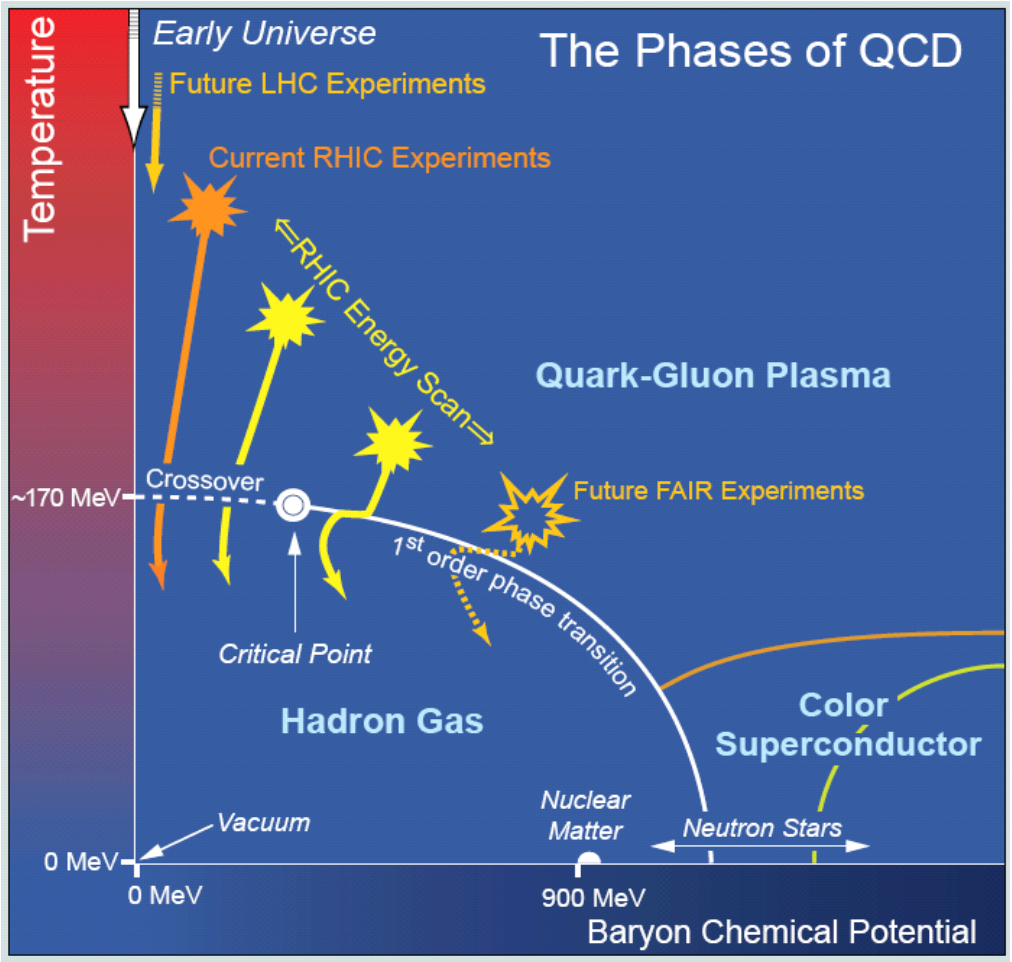
"The combined data coming from 7 experiments on CERN's Heavy Ion programme have given a clear picture of a new state of matter. . . . where quarks and gluons are not confined. There is still an entirely new territory to be explored concerning the physical properties of quark-gluon matter. The challenge now passes to the Relativistic Heavy Ion Collider(s) . . . ."

Experiments: NA44, NA45/CERES, NA49, NA50, NA51/NEWMASS, WA97/NA57, WA98

Boson interferometry - Collective expansion - Strange meson enhancement = Hardon production - Low-mass lepton pair production - J/Ψ suppression - Baryon and antibaryon production - strange and multistrange hadrons – direct photons

# Heavy Ion Experiments




- CERN (Switzerland)

  SPS (1989), LHC (2008)

- BNL (USA)

  RHIC (2000)

- JINR (Russia)

  Nuclotron(1994), NICA(2023)

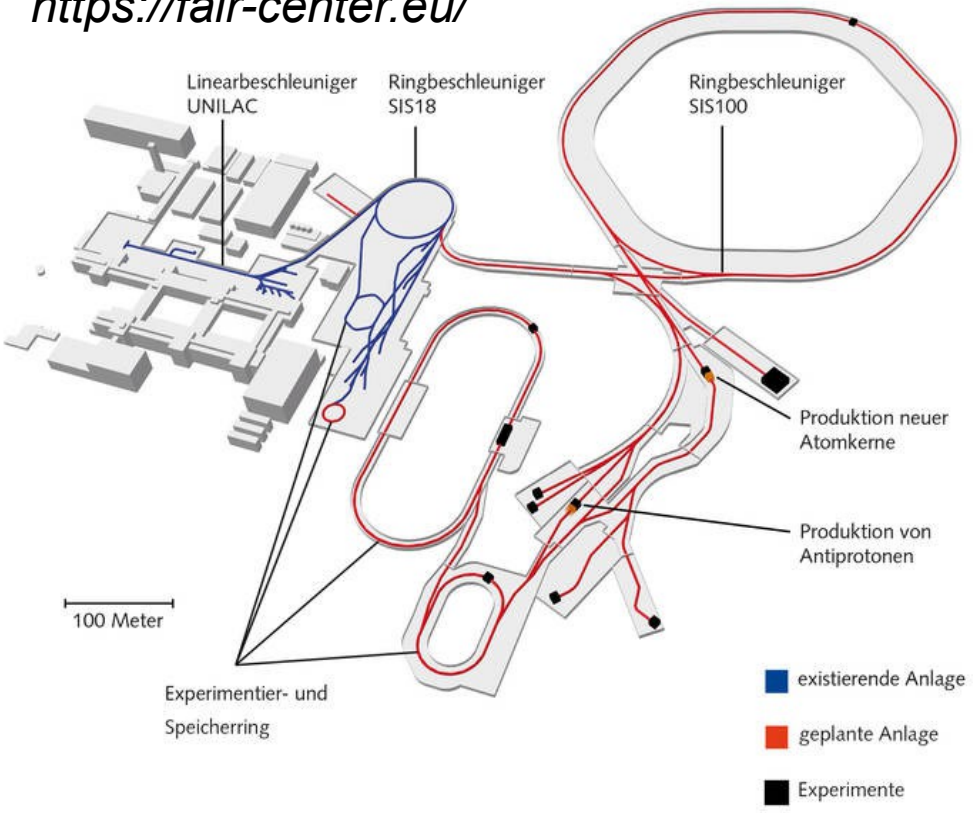
- GSI (Germany)

  FAIR (SYS-18, SYS-100, 2025)

# FAIR - Facility for Antiproton and Ion Research

FAIR — Facility for Antiproton and Ion Research in Europe

https://fair-center.eu/




FAIR: construction at GSI (Darmstadt)

SIS100: circumference of 1,100 m can accelerate the ions of all the natural elements in the periodic table.

- Beams of heavy ions (Au) up to 11A GeV,
- Light ions (e.g. Ca) up to 14A GeV
- protons up to 29 GeV.

FAIR GmbH
Shareholders from the 9 countries:
Finland, France, Germany, India, Poland, Romania, Russia, Slovenia and Sweden.

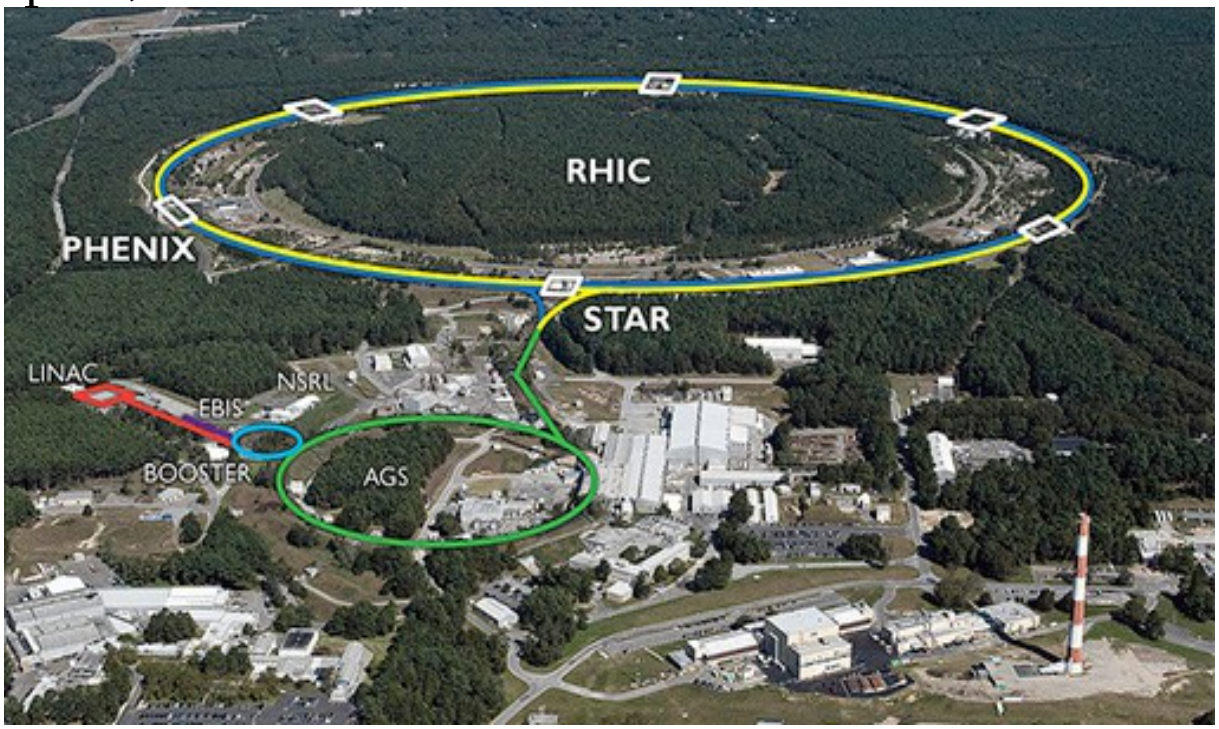
Associated: United Kingdom.
Aspirant partner: Czech Republic.

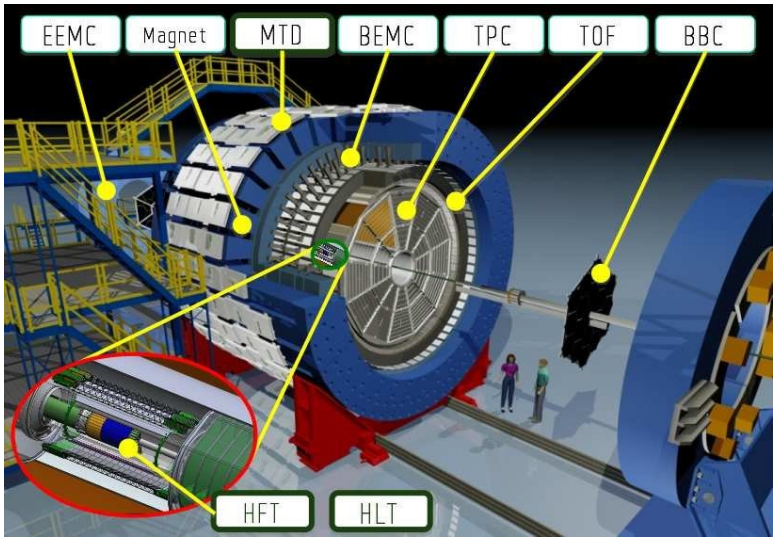
Commissioning: for 2025.

Investments (Planning status in 2015):
1.262 billion Euro
(based on price level of 2005).

# RHIC – Relavivistic Heavy Ion Collider (BNL, US)

Upton, New York




Experiment STAR
(**S**olenoidal **T**racker **A**t **R**HIC)

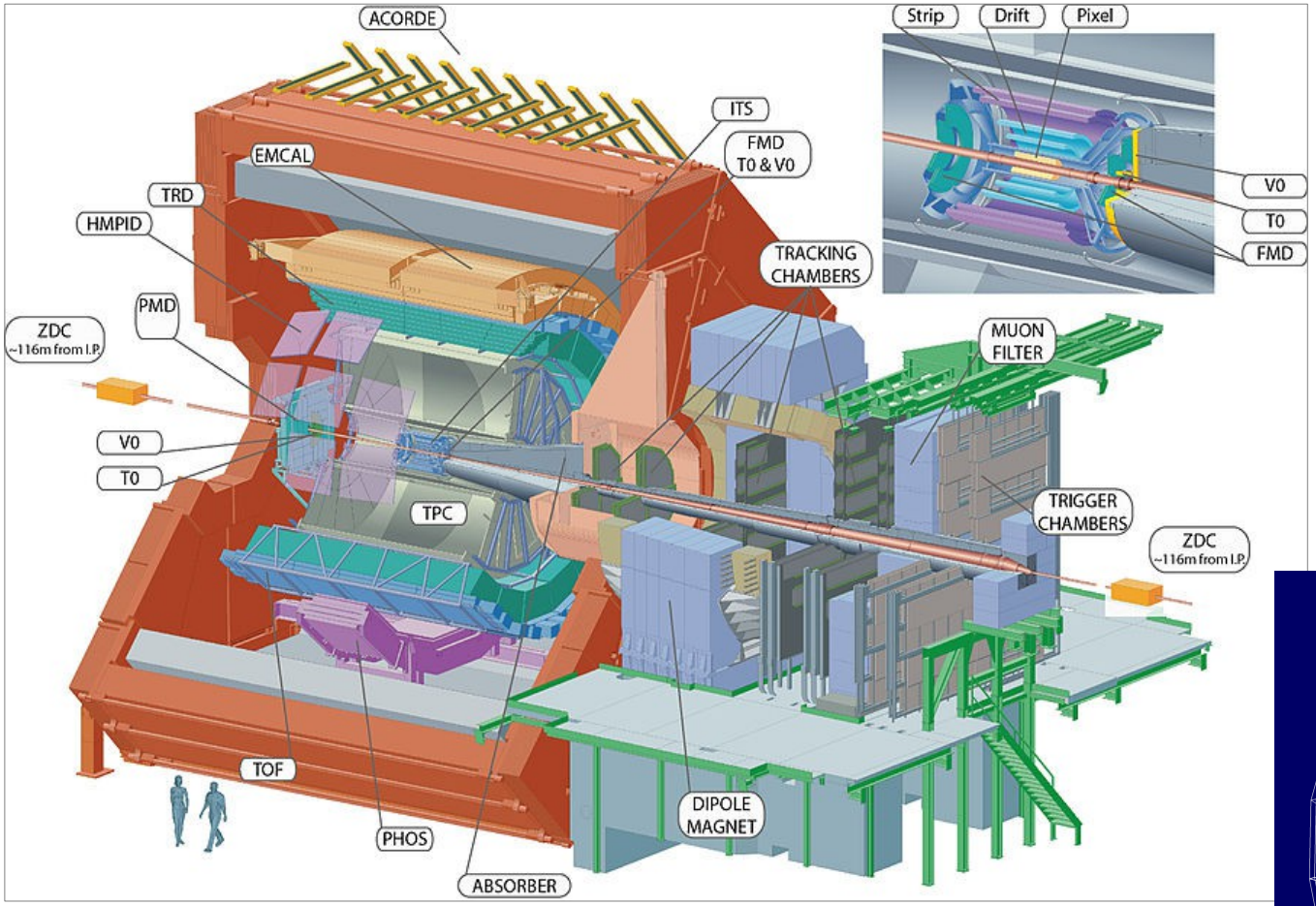
RHIC → all ion beam species (up to Uranium) at energies up to 100 GeV per nucleon.
(250 GeV for protons).

Two concentric accelerator rings 2.4 miles in circumference containing a total of 1,700 SC-magnets.

Independently accelerated and collide different beam species and for protons, different spin polarizations.

These capabilities make RHIC the most flexible and capable collider in the world for transformative studies of extreme states of nuclear matter and the origin of the proton spin.

# ALICE@LHC

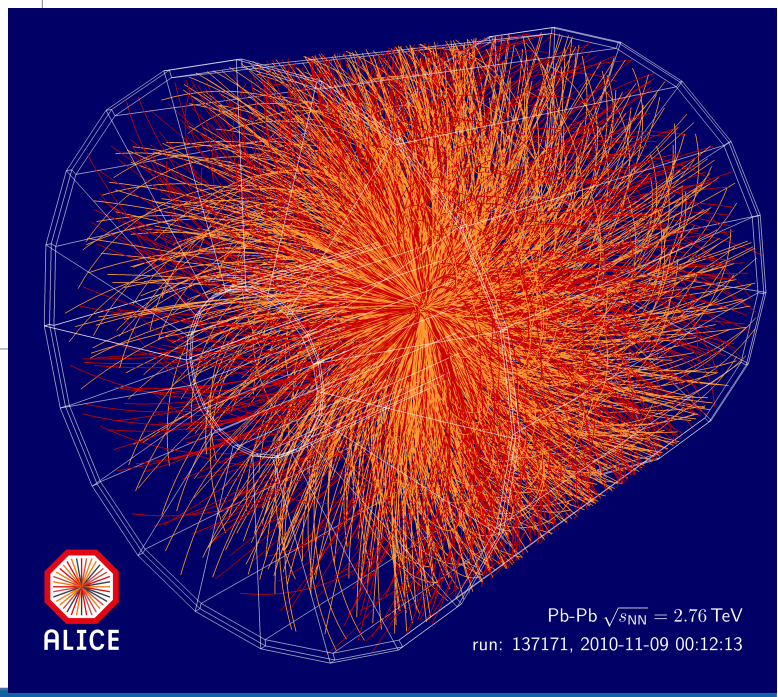



$$E_b = Z \times E_p \qquad E_N = E_b / A$$

$$_{82}Pb^{208}$$

$$Z/A \times E_p = 2.76 \text{ TeV}$$

$$E_{cms} = 5.5 \text{ TeV}$$

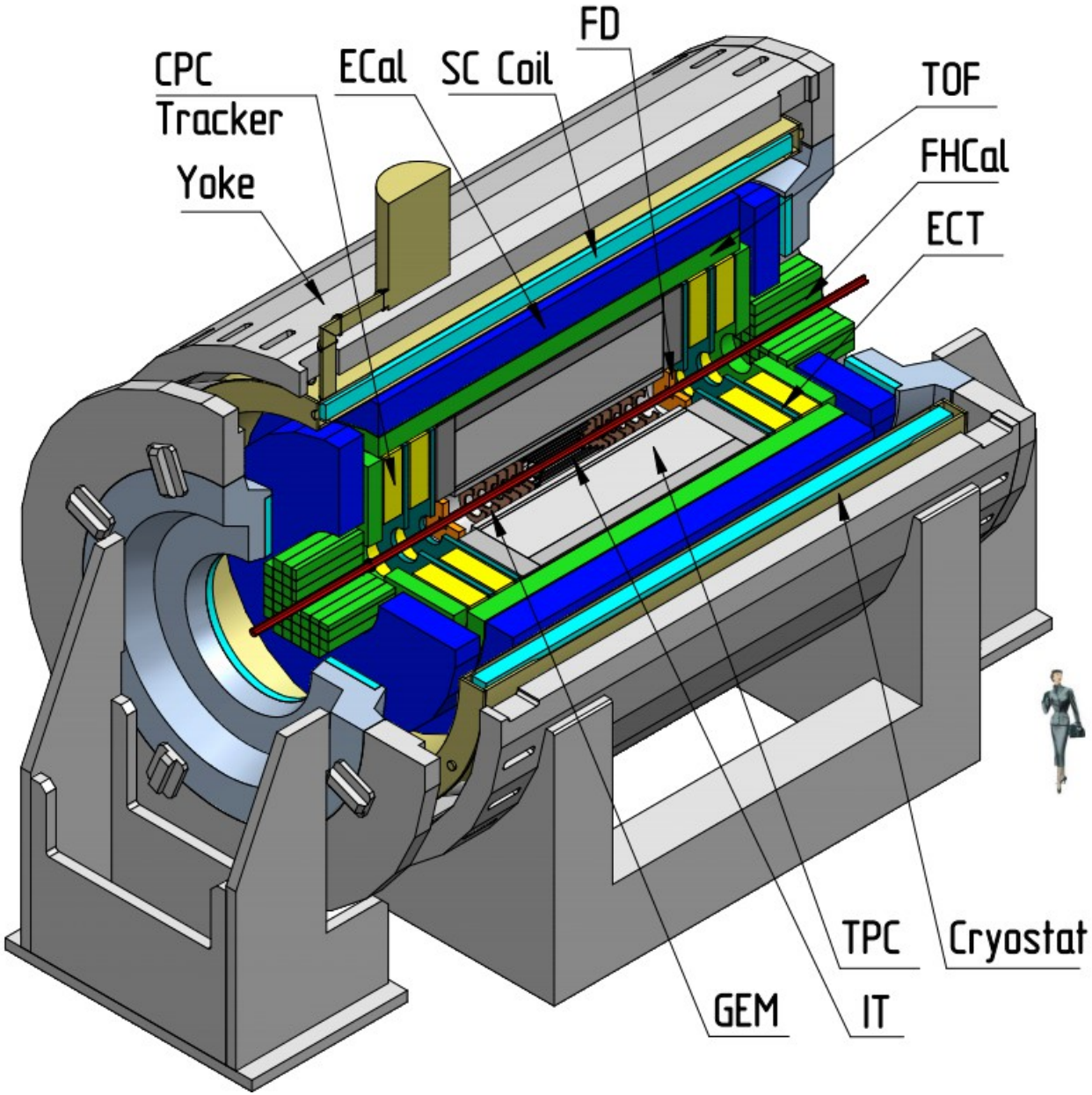



One of the first Pb-Pb collisions recorded by the ALICE@LHC (2010)
1209 positiv (darker tracks) and 1197 negative-charged (lighter tracks) (80% pions) in 0.5 T field of ALICE (0.5 T).

Recorded with TPC of ALICE, (5 m diamter and 5 m length), equivalent of 500 million pixels.

> 550 published papers

# MPD: Multi Purpose Detector / Collaboration




http://mpd.jinr.ru/experiment/

MPD Collaboration:

- Azerbaijan(1)
- Bulgaria(1)
- Chile(1)
- China(6)
- Czech Republic(2)
- Georgia(1)
- Germany(1)
- Israel(1)
- Kazkhstan(1)
- Mexico(1)
- Moldova(1)
- Poland(4)
- Russia(8)

# 1st Meeting of NICA Experiments (BM@N, MPD)


The kick-off meeting of formation of the MPD ana BM@N Collaborations.

(JINR/Dubna, 11-12 April 2018)

**220** participants from **18 countries** (Azerbaijan, Bulgaria, Chili, China, Czech Republic, Egipt, France, Georgia, Germany, Israel, Kazachstam, Mexico, Moldova, Poland, Switzerland, Russia, Ukraine, USA)

# TSU@MPD/NICA

- HEPI TSU is a member of the MPD Collaboration since April, 2018

  (T. Babutsidze, G. Kachlishvili, V. Kikvadze, A. Machavariani, M. Nioradze, R.Shanidze)

  + students: R. Nikolashvili, G. Qistauri (ECAL)

- @JINR:

  - Alexander Machavariani:

    Theory ($\rho$-meson production/polarization, spin density matrice, . .), **coordination**

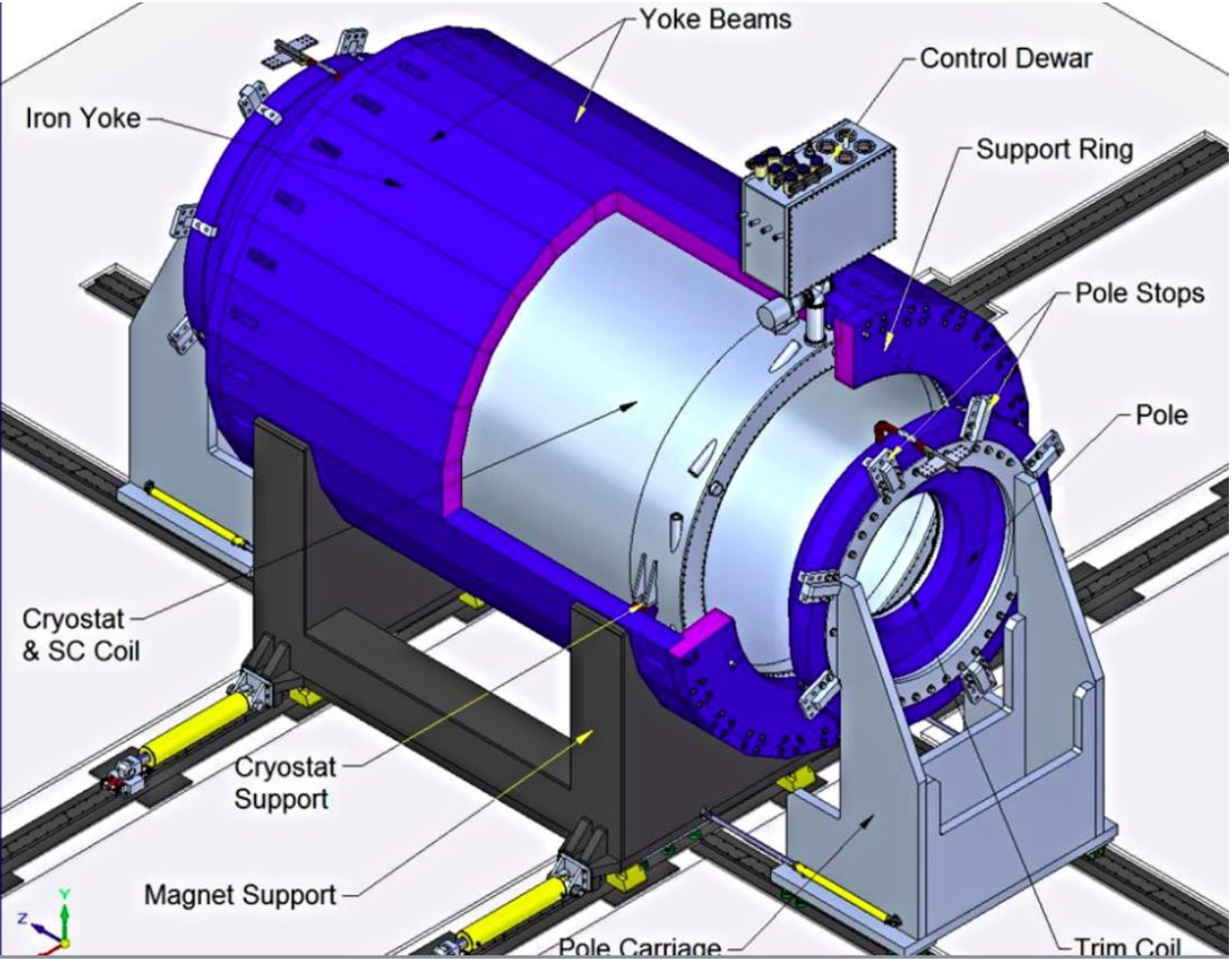
  - Valery Kikvadze

    MPD Ecal (FE, DAQ), test of ECal modules, . . .

  - Giorgi Kachlishvili

    NICA SC-magnets and technologies

# MPD Magnet




Mass 900 t

R = 2.3 m

$B_0$ = 0.5 T

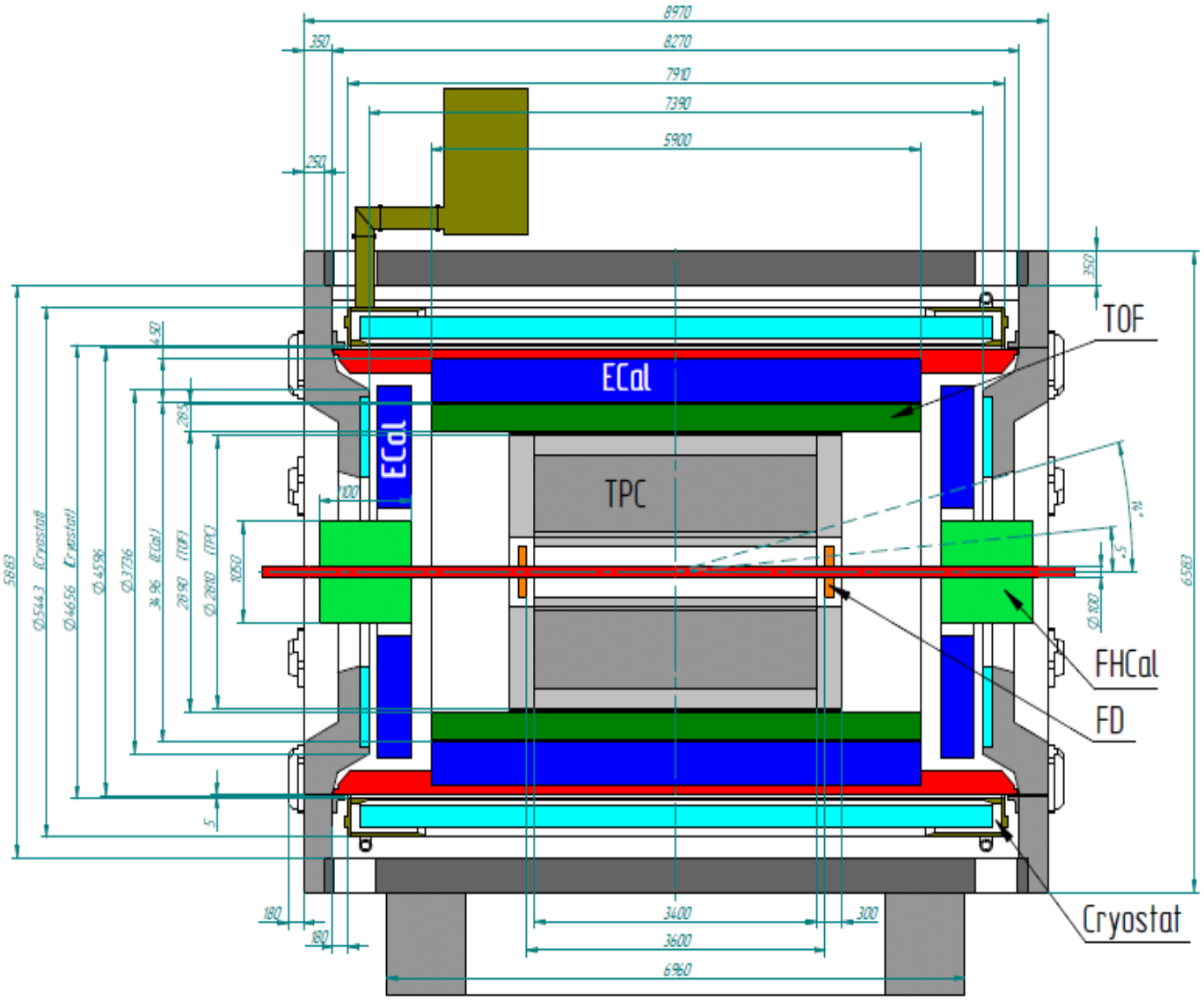
$p_T$ within the range 0.1–3 GeV/c.

Production:

ASG (Genova, Italy)

Vitkovice

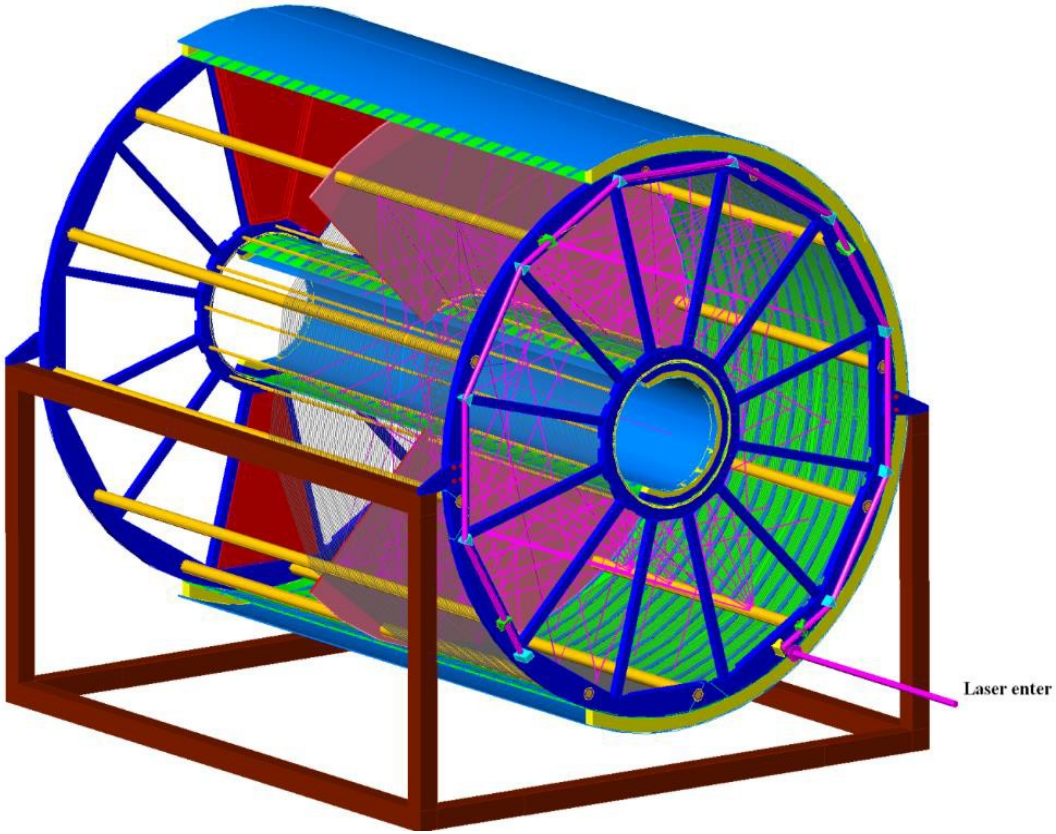
# MPD: Multi Purpose Detector




## MPD 1st stage

- 2π acceptance in azimuth
- 3-D tracking (TPC)
- Powerful PID (TPC, TOF, ECAL)
  - π/K up to 1.5 GeV/c,
  - K/p up to 3 GeV/c,
  - γ, e : 0.1<p<3 GeV/c
- Low material budget
- High event rate (up to ~ 6 kHz)

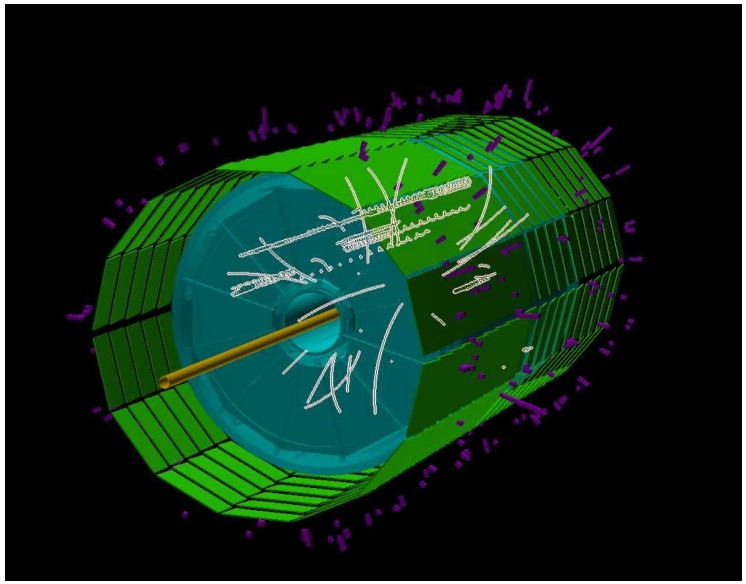
# MPD TPC (Time Projection Chamber)



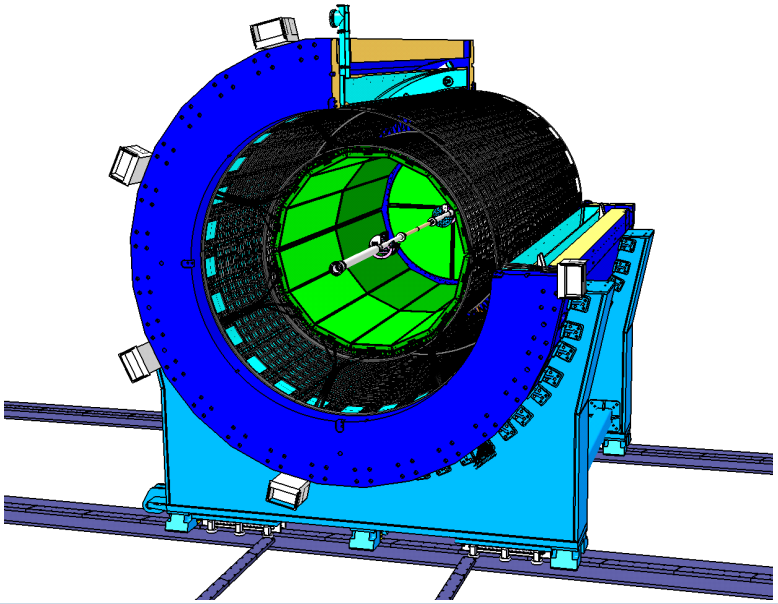

Commissioning of TPC with MPD: 2021

| Item | Dimension |
|---|---|
| Length of the TPC | 340cm |
| Outer radius of vessel | 140cm |
| Inner radius of vessel | 27 cm |
| Outer radius of the drift volume | 133cm |
| Inner radius of the drift volume | 34cm |
| Length of the drift volume | 170cm (of each half) |
| HV electrode | Membrane at the center of the TPC |
| Electric field strength | ~140V/cm; |
| Drift gas | 90% Ar+10% Methane, Atmospheric pres. + 2 mbar |
| Gas amplification factor | ~ $10^4$ |
| Drift velocity | 5.45 cm/μs; |
| Drift time | < 30μs; |
| Temperature stability | < 0.5 ℃ |
| Number of readout chambers | 24 (12 per each end-plate) |
| Segmentation in φ | 30 ♯ |
| Pad size | 5x12mm$^2$ and 5x18mm$^2$ |
| Number of pads | 95232 |
| Pad raw numbers | 53 |
| Maximal event rate | < 7 kHz ( Lum. $10^{27}$ ) |
| Electronics shaping time | ~180 ns (FWHM) |
| Signal-to-noise ratio | 30:1 |
| Signal dynamical range | 10 bits |
| Sampling rate | 10 MHz |
| Sampling depth | 310 time buckets |

# MPD PID: ToF (Time of Flight) System



MPD event display: tracks in TPC



Particle momentum: $p = \frac{m\beta c}{\sqrt{1-\beta^2}}$

$m = \frac{p}{c}\frac{\sqrt{1-\beta^2}}{\beta}$ ToF: $\beta = \frac{L}{cT}$

ToF system (in a 0.5 T field): PID 0.1–2 GeV/c

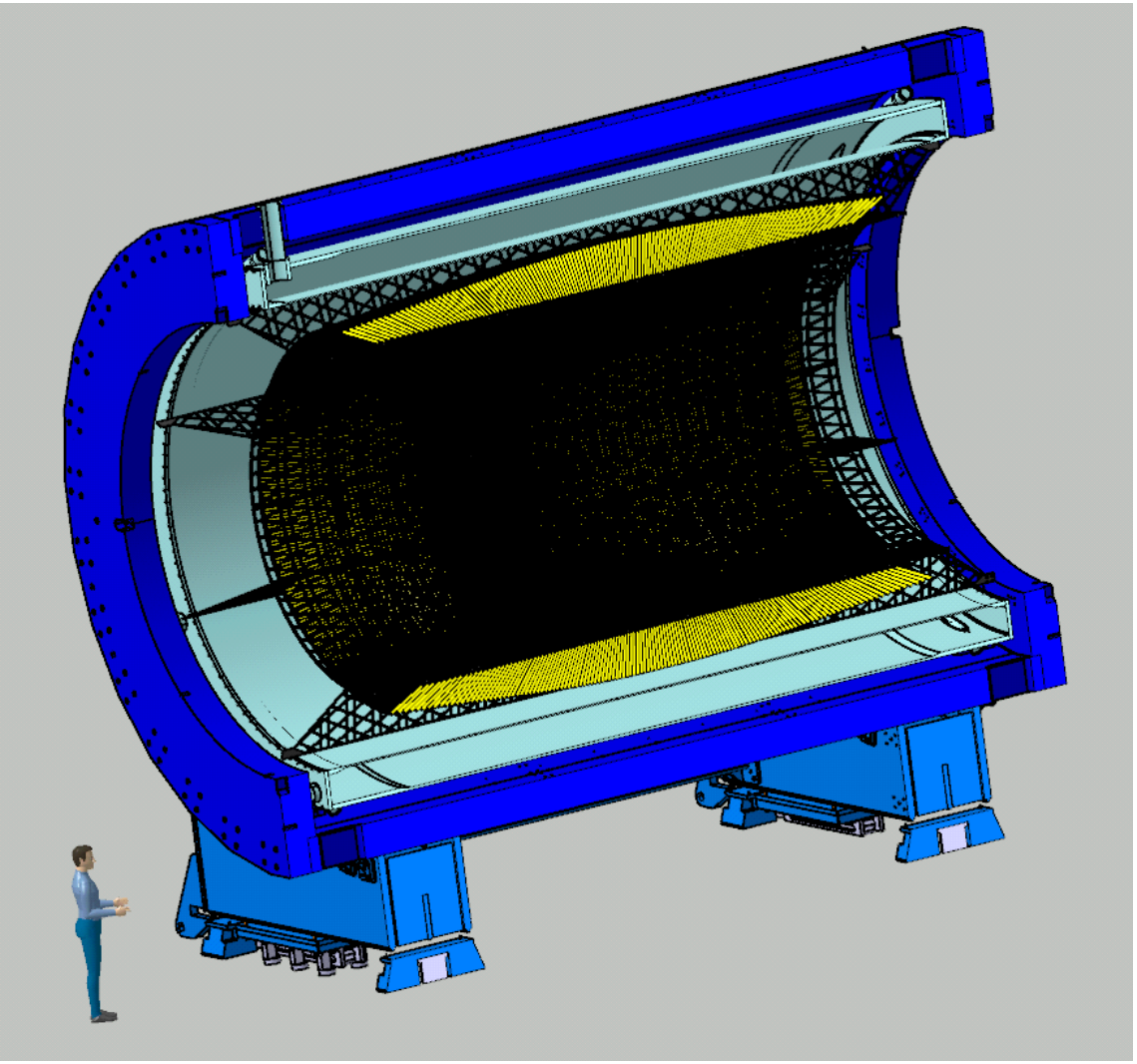
– large phase space coverage $|\eta| < 2$;

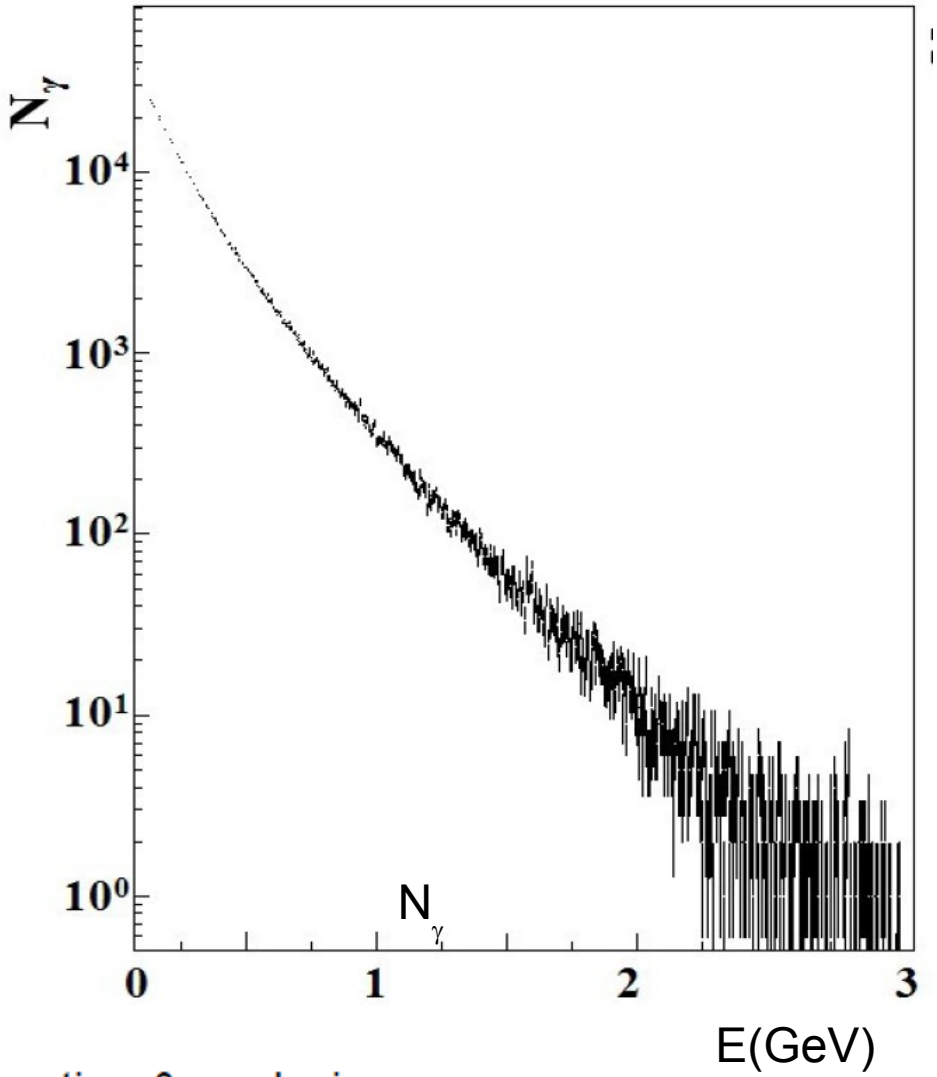
- system occupancy below 15%

– good position resolution (TOF/TPC tracks);

– identification of $\pi$/K and with $p_t < 1.5$ GeV/c;
(anti)protons with $p_t < 3$ GeV/c;

# MPD ECal

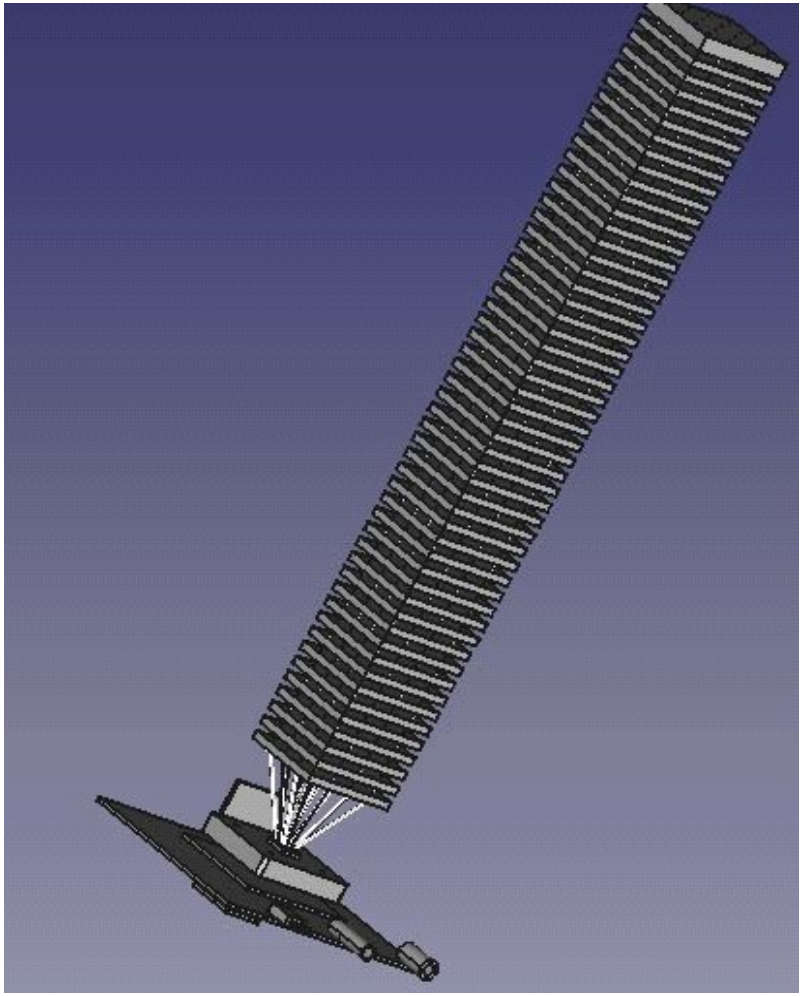





- Several groups participating in ECAL reconstruction & analysis
- Clusterizing, energy/space resolution, e/h separation, overlapping effects investigated
- $\pi^0$ ($\eta$) reconstruction demonstrated in Au+Au collisions

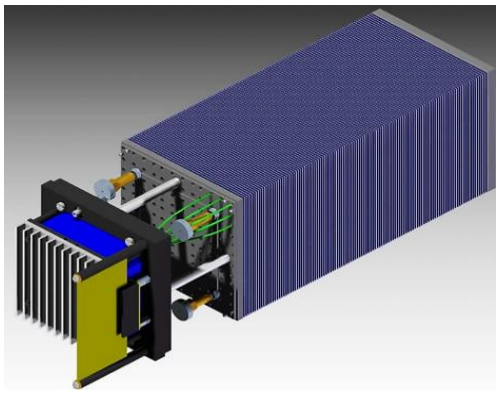
# MPD ECal (Electro-magnetic Calorimeter)

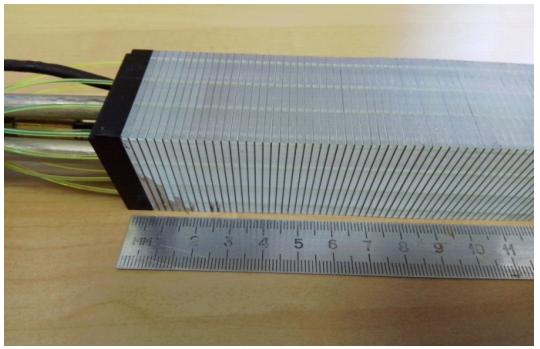
the "shashlyk" type calorimeter with MAPD (SiPM) photon detectors



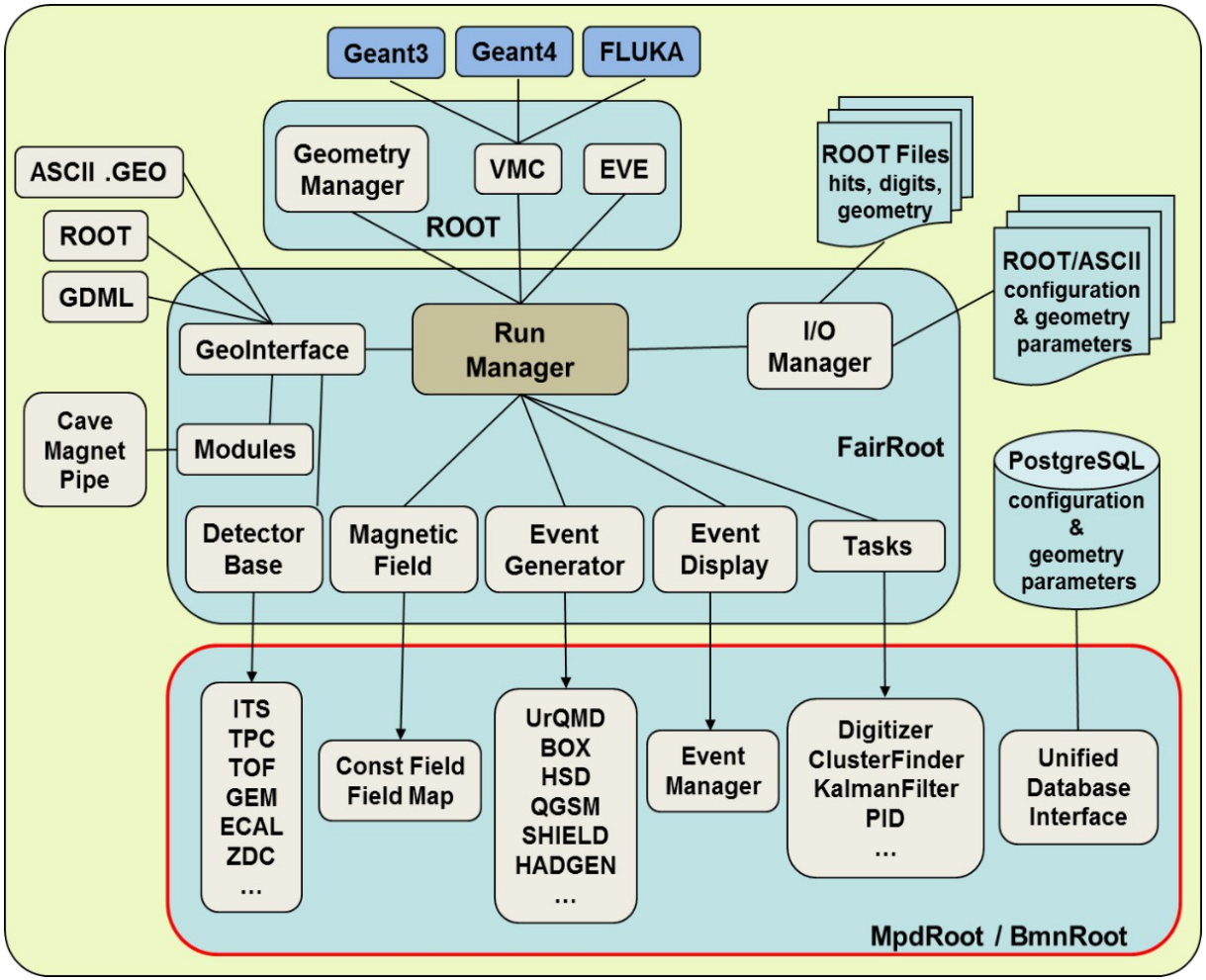
ECal: 43000 “Shashyk“ detectors:
China(75%), Russia (25%)

| Parameters | |
|---|---|
| Maximum transverse dimensions of the tower, $mm^2$ | 40x40 |
| Maximum transverse dimensions of the module, $mm^2$ | 80x320 |
| Number of layers | 219 ÷ 221 |
| Paint free lead absorber thickness, mm | 0.3 |
| Paint lead absorber thickness, mm | 0.4 |
| Thickness of scintillator plate, mm | 1.5 |
| Effective radiation length, mm | 32.4 |
| Moliere radius, mm | 62 |
| Radiation length, $X_0$ | 11.8 |





# NICA/MPD Software




GitLab repository: https://git.jinr.ru/nica/mpdroot

The framework **MpdRoot** is based on ROOT and FairRoot.

MPD event simulation, reconstruction of experimental or simulated data

Physical analysis of NICA/MPD events.

TPC (v8, 2018), TOF(v7, 2016),
ECAL(v8, 2018), FHCal(v2, 2018),
ITS(v3, 2015), FFD (v0, 2016,)
BBC(v2, 2019)

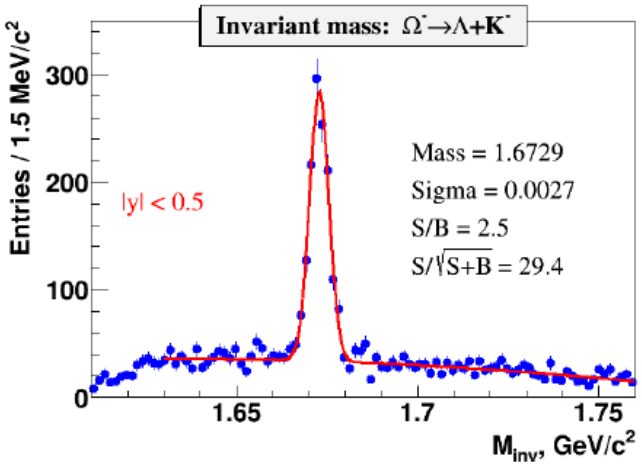
# MPD Physics Performance

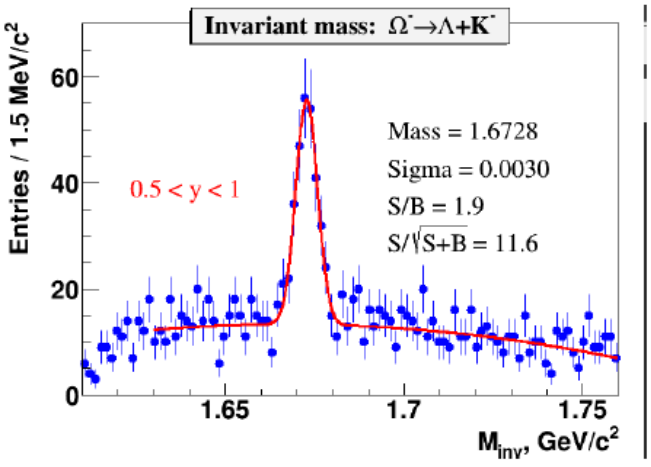
## Simulation of MPD physics cases:

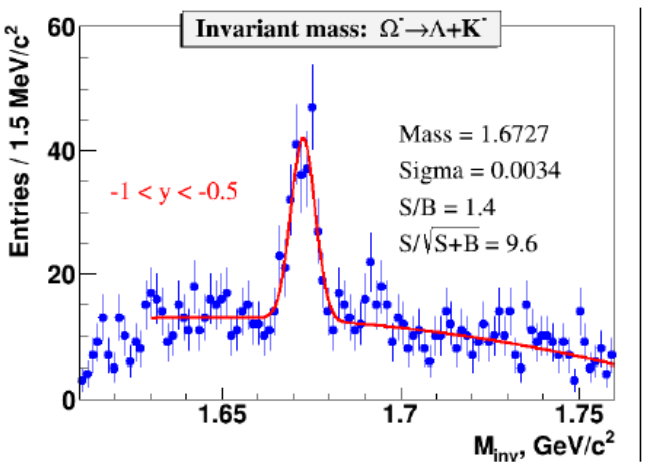
- Multistrange hyperons
- Flow analysis status (charged hadrons and hyperons)
- Ev-by-Ev fluctuations of net-protons
- ECal reconstruction and resonances
- Femtoscopy and correlations

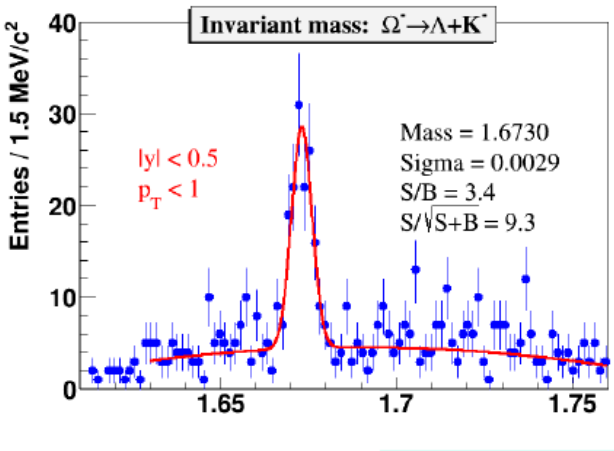
| Beam | CM Energy, AGeV | L 2021-23, $cm^{-2} c^{-1}$ | L >2023, $cm^{-2} s^{-1}$ |
|---|---|---|---|
| Heavy ions (Au) | 11 | $5 \cdot 10^{25}$ | $10^{27}$ |
| Intermediate (Z/A~0.45) | 13 | $3 \cdot 10^{26}$ | $10^{29}$ |
| p | 25 | $\sim 10^{29}$ | $10^{32}$ |

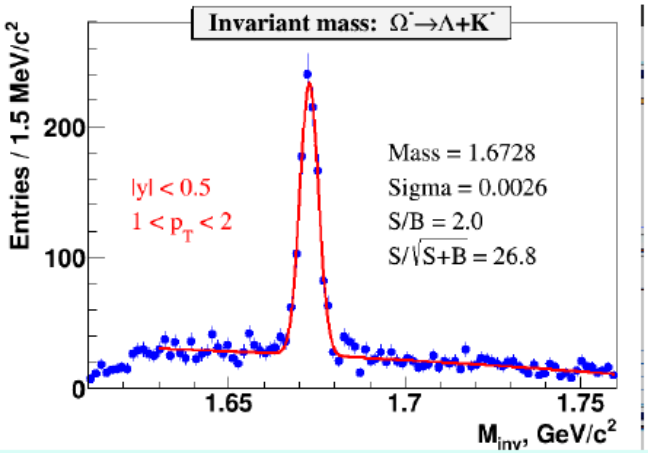
# MPD Physics Simulations

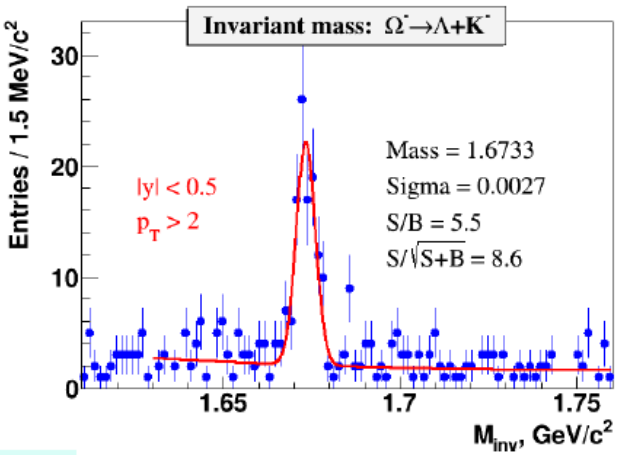


# MPD Workong Groups

**PWG1**
**Global observables**
- Total event multiplicity
- Total event energy
- Centrality determination
- Total cross-section measurement
- Vertex determination
- Event plane measurement at all rapidities
- Spectator measurement

**PWG2**
**Spectra of light flavor and hypernuclei**
- Light flavor spectra
- Hyperons and hypernuclei
- Total particle yields and yield ratios
- Kinematic and chemical properties of the event
- Mapping QCD Phase diagram

**PWG3**
**Correlations and Fluctuations**
- Collective flow for hadrons
- Vorticity, Λ polarization
- E-by-E fluctuation of multiplicity, momentum and conserved quantities
- Femtoscopy
- Forward-Backward corr.
- Jet-like correlations

**PWG4**
**Electromagnetic probes**
- Electromagnetic calorimeter measurements
- Photons in ECAL and central barrel
- Low mass dilepton spectra and search for in-medium modification of resonances and intermediate mass region

**PWG5**
**Heavy flavor**
- Study of open charm production
- Charmonium with ECAL and central barrel
- Charmed meson through secondary vertices in ITS and HF electrons
- Explore production at charm threshold

# დიდი მადლობა !