Study of heavy-ion collisions at the NICA collider.
Status of the project.

Vadim Kolesnikov
(VBLHEP, JINR)

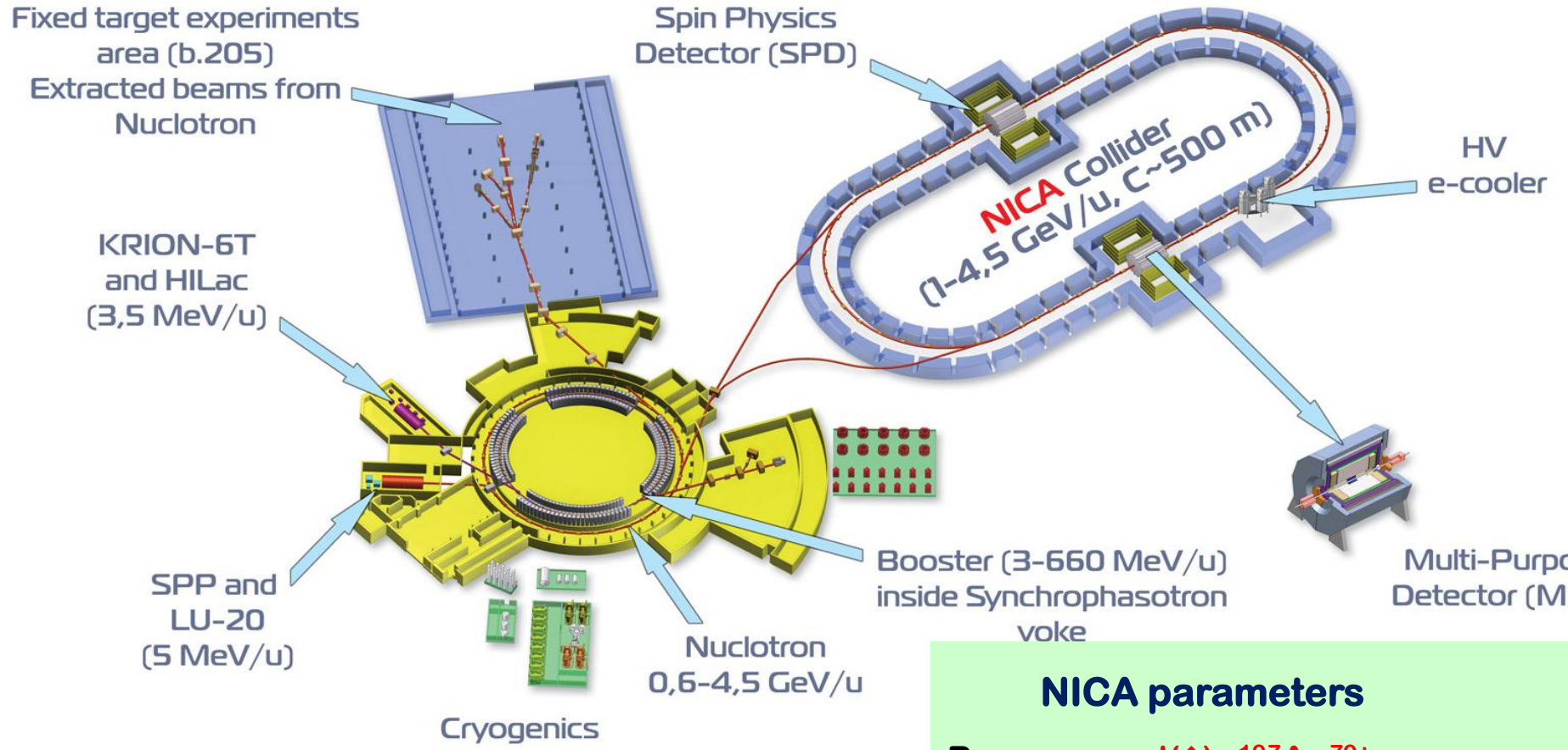
On behalf of the NICA team

11-th Polish Workshop on Relativitic Heavy-Ion Collisions
WUT, Warsaw, January 17-18, 2015

Outline

- Research program at NICA
- NICA complex : accelerator and detectors
- Current status of the project
- Summary

Superconducting accelerator complex NICA
(Nuclotron based Ion Collider fAcility)



Experiments:

2 Interaction points – **MPD** and **SPD**

Fixed target experiment **BM@N**

NICA parameters

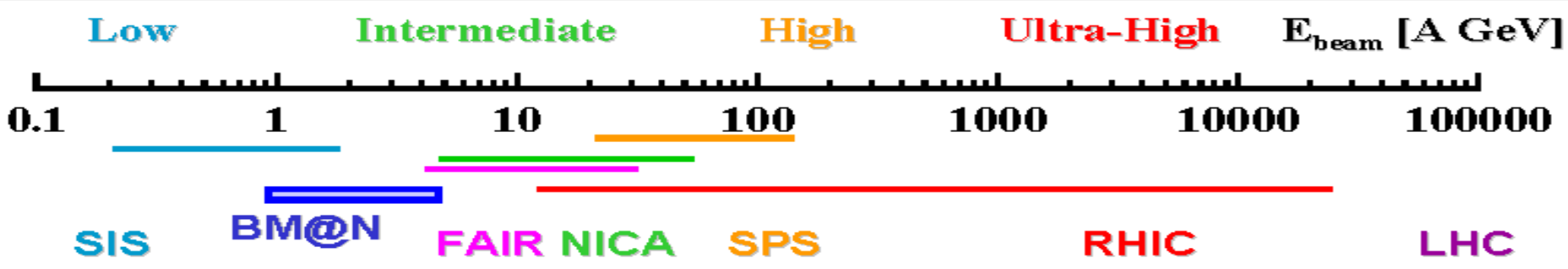
Beams – $p,d(\uparrow)..{}^{197}Au^{79+}$

Collision energy (collider) – **4-11** GeV

Luminosity: 10^{27} $cm^{-2}s^{-1}$(Au), 10^{32} (p)

Energy (fixed target) **1-6A** GeV (Au)

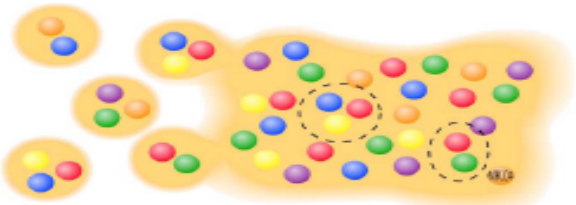
Heavy-ion collisions

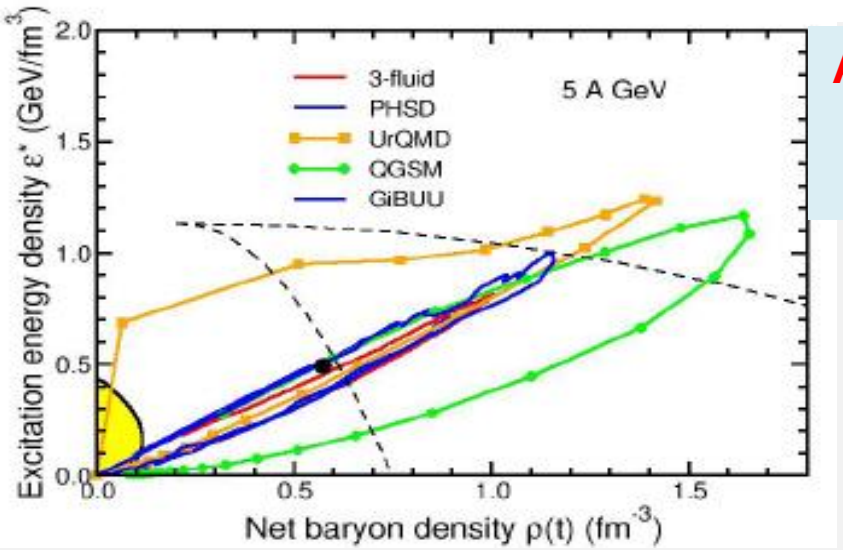


Baryonic matter
||
Meson and baryon spectroscopy
In-medium effects
EoS

‚Mixed' phase:
hadrons (baryons, mesons) + quarks and gluons
||
In-medium effects
Chiral symmetry restoration
Phase transition to sQGP
Critical point in the QCD phase diagram

QGP: quarks and gluons
||
Properties of sQGP





At NICA we probe dense (predominantly) baryonic matter. QGP fraction < 30% at the top. QGP→HRG transition

- **energy density is above the critical in the central reaction volume ($\varepsilon > \varepsilon_{crit} = 0.5$ GeV/fm^3)**
- **baryonic density up to 6 ρ_0**

NICA White Paper – International Effort

NICA

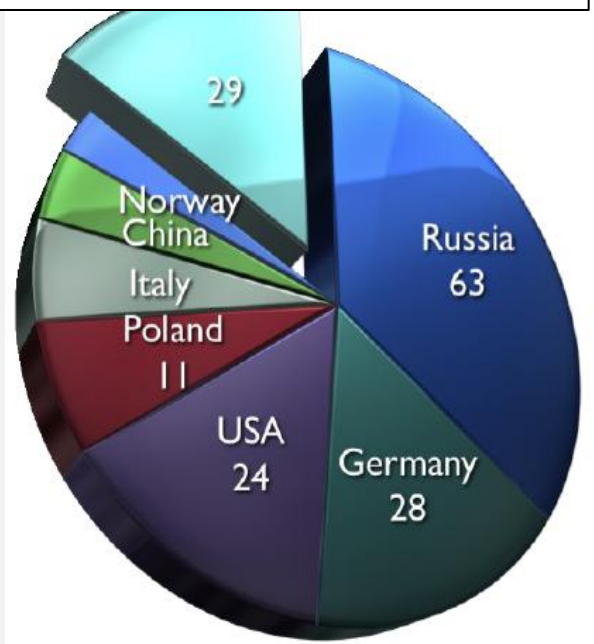
Draft v 8.03
January 24, 2013

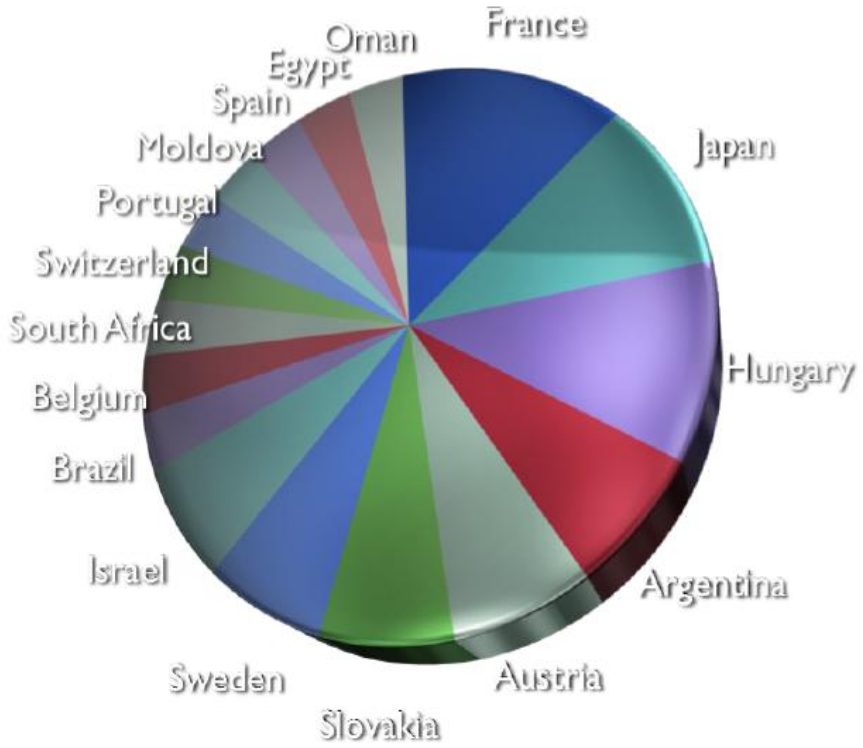
SEARCHING for a QCD MIXED PHASE at the
NUCLOTRON-BASED ION COLLIDER FACILITY
(NICA White Paper)

Statistics of White Paper Contributions

104 *contributions:*
188 *authors from* **70** *centers in* **24** *countries*

Indicates wide international interest to the physics at MPD & BM@N

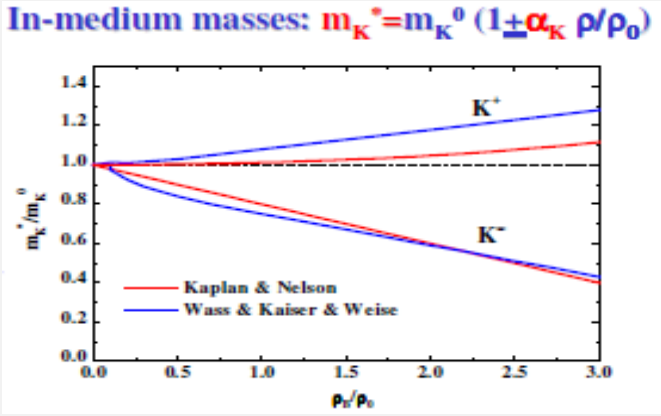




Priorities at Nuclotron energies (BM@N)

→ Ideally suited for exploration of reaction mechanisms & in-medium properties
→ Energy range formerly not accessible or of limited experimental information
→ Expectation of a rich structure of the QCD phase diagram @ high densities

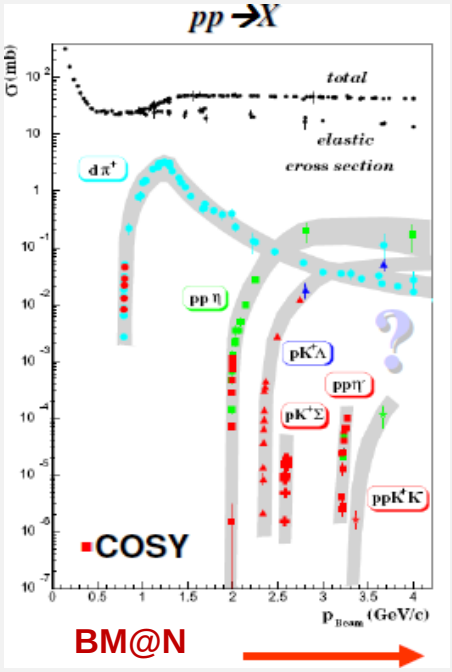
1) Bulk properties: pT and y distributions of hadrons
   → Information on densities reached, production processes and EoS
2) Measurement of K, Kbar
   * In-medium meson-nucleon potential at high ρ_B
   * the role of multi-particle production mechanisms



3) Measurement of sub-threshold production of strange hadrons in A+A

* ϕ and K*, K*bar mesons as well as Λ,Σ and Ξ baryons
* Possible observation of Ω as a result of multistep process

$$p + p \to K^+ \Lambda p \qquad \Lambda + \Lambda \to \Xi^- p \qquad \Lambda + \Xi^- \to \Omega^- + n$$

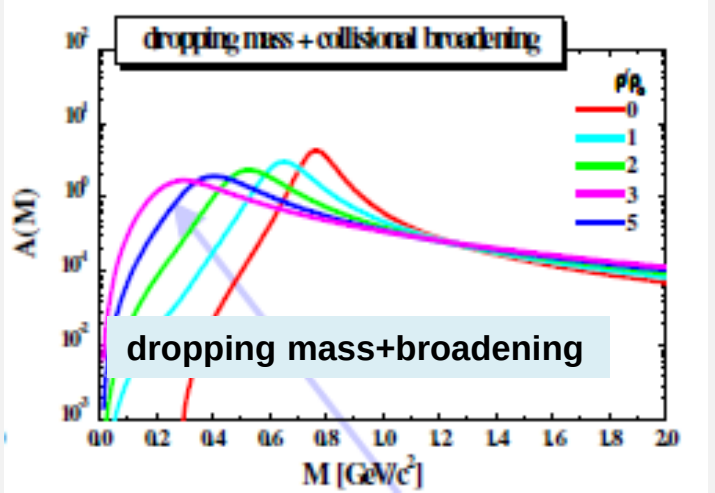


4) Measurement of elementary reactions p+p, d+p

- gap in experimental data (above COSY range)
- transition region betwee 2→3 reactions to multi-particle creation – not much known

Priorities at NICA-MPD

ρ-meson spectral function



❖ *Bulk properties, EOS*
particle yields & spectra, ratios, flow

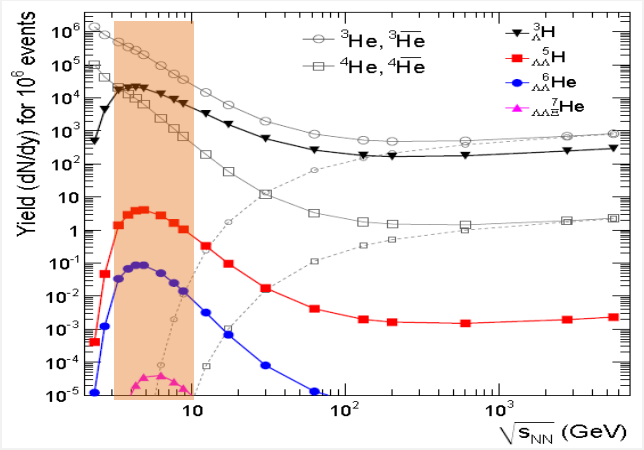
❖ *In-Medium modification of hadron properties*
onset of low-mass dilepton enhancement
measure: $\rho, \omega, \phi \rightarrow e^+e^-$

❖ *Deconfinement, Critical Point*
event-by-event fluctuations and correlations

Recommendation for first round of NICA experiments:

→ diagnostic observables of beam energy scan programs at SPS, RHIC
→ MPD detector to be optimized to study fluctuations an correlations
→ excitation functions of fluct./corr., dependence on centrality & system size

❖ *Strangeness in nuclear matter*
hypernuclei



MPD detector for Heavy-Ion Collisions & NICA

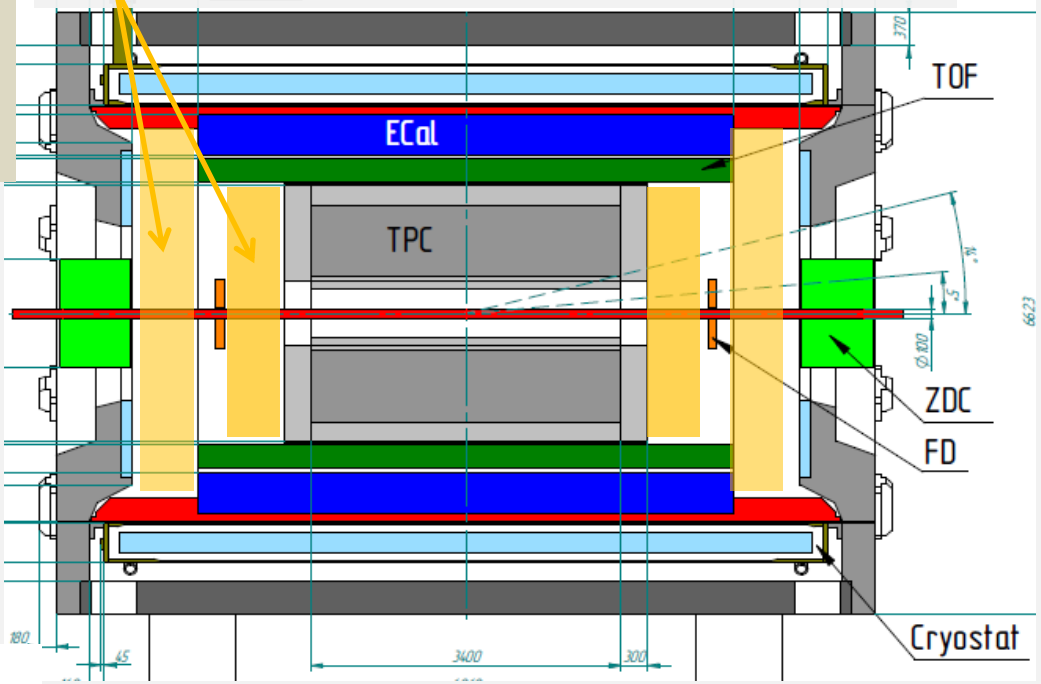
Tracking: TPC: |η|<2; TPC+ECT: |h|<3

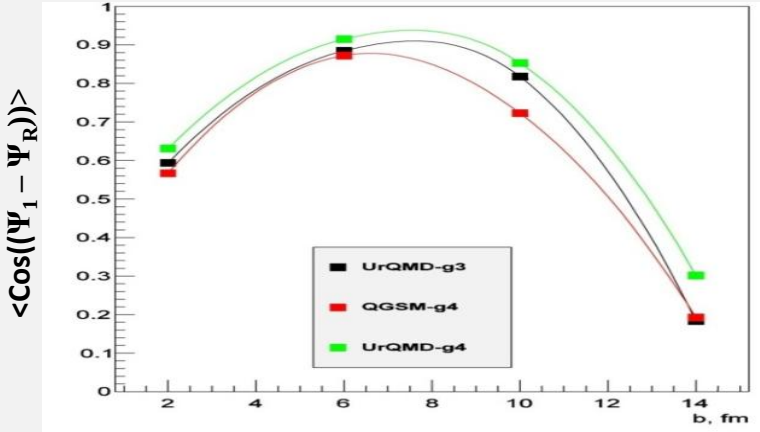
PID: hadr., e, γ (TOF, TPC, ECAL) |η|<1.3

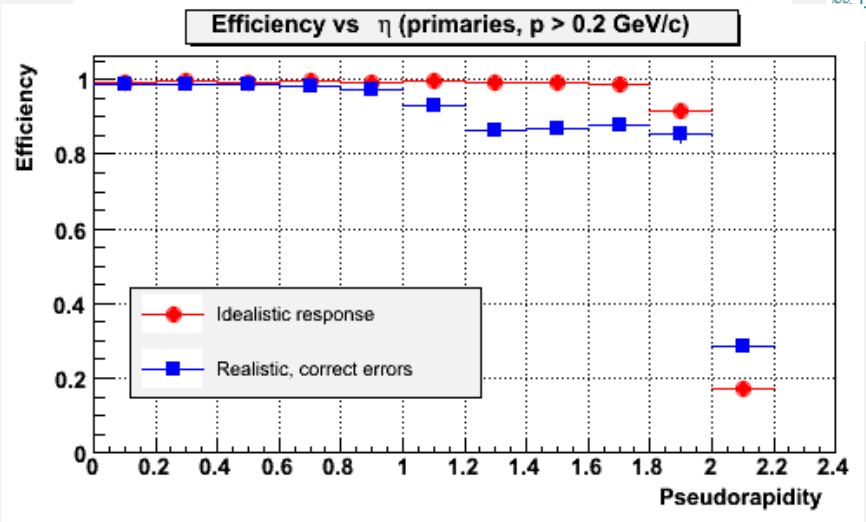
Event characterization: centrality & event plane (ZDC 2.2<(|h|<4.8)

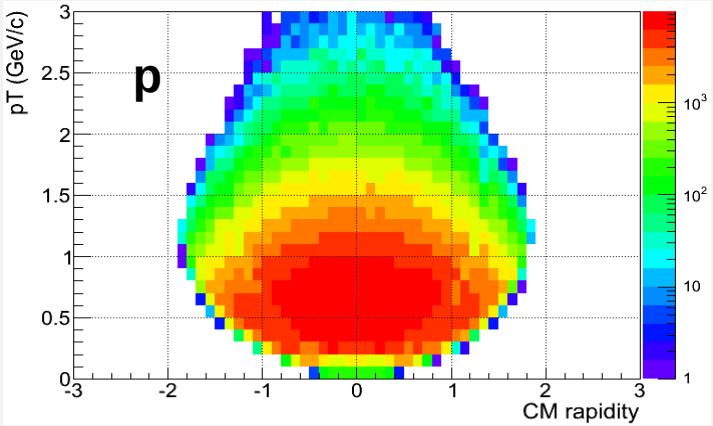
Stage 1:
TPC, TOF, ECAL, ZDC, FD

Stage 2: IT + Endcaps (tracker, TOF,ECAL)





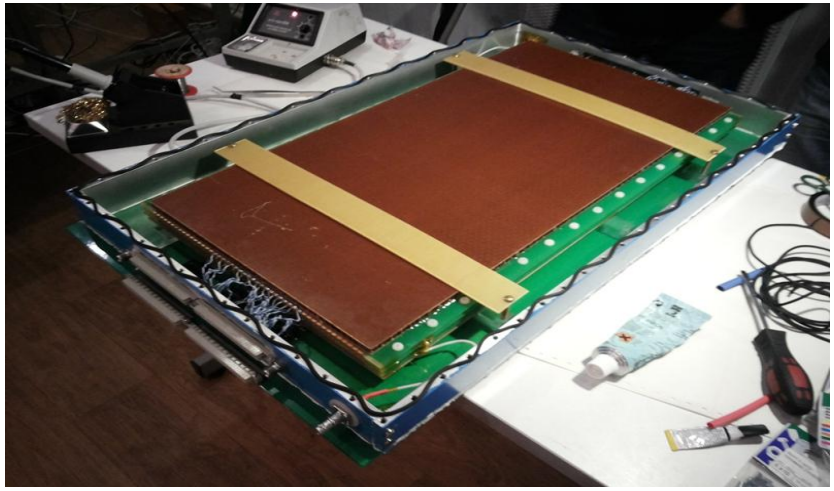


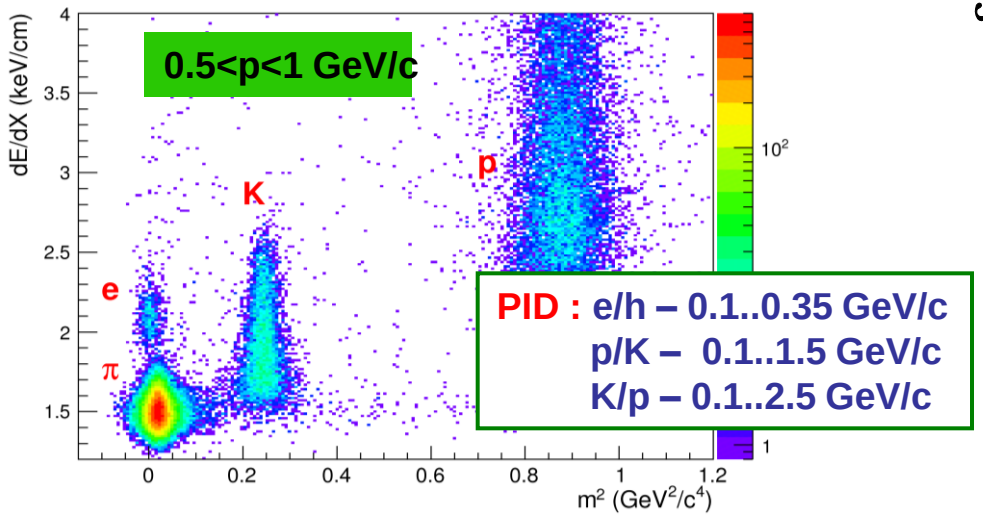


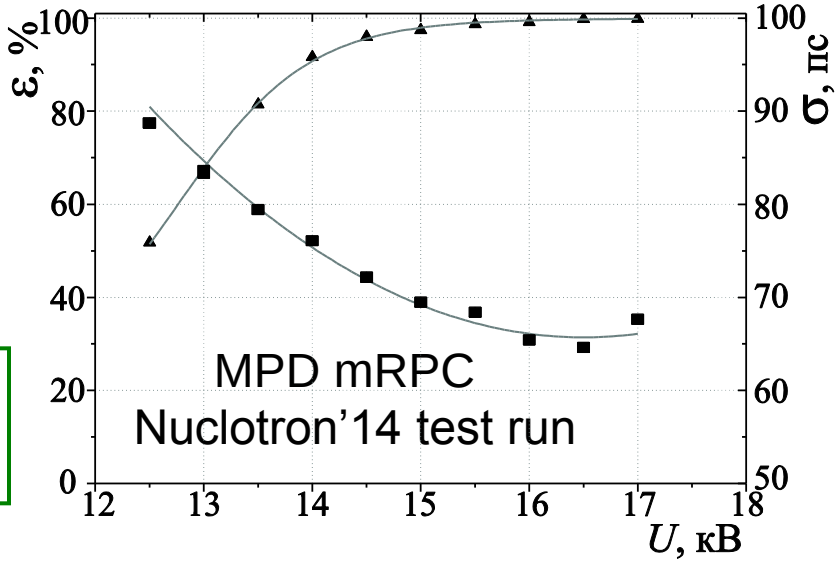
MPD Time Of Flight (TOF)

JINR + Hefei, Beijing(China)

Resistive Plate Chambers: > 30 m², |η|<3 σ ~ 80 ps

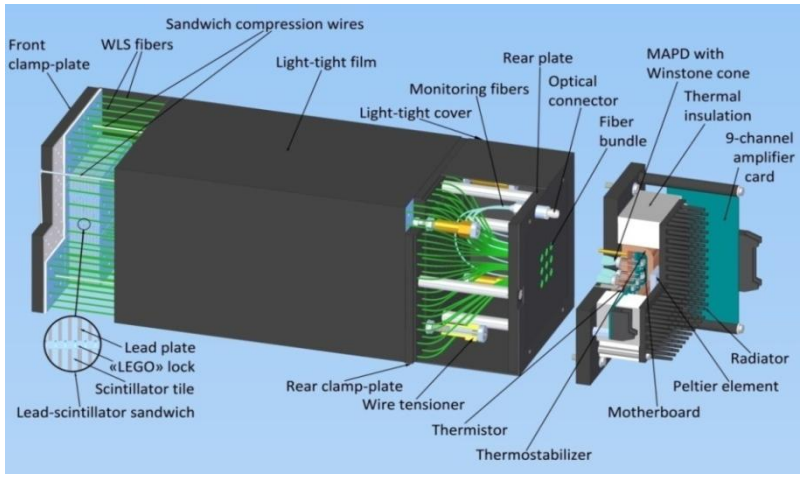




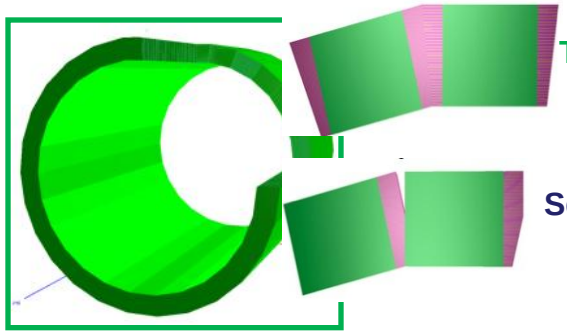


MPD Electromagnetic Calorimeter (ECAL)

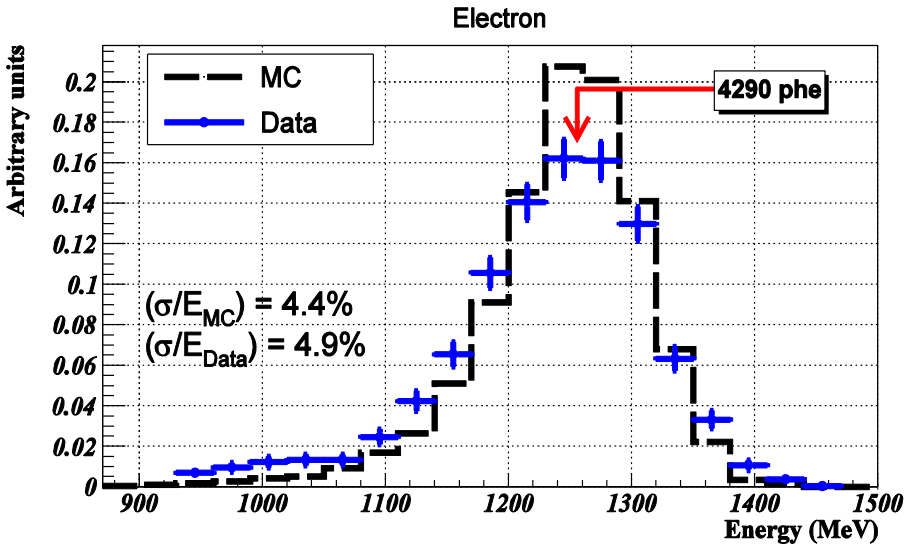
VBLHEP & DLNP (JINR) + ISM (Kharkiv)

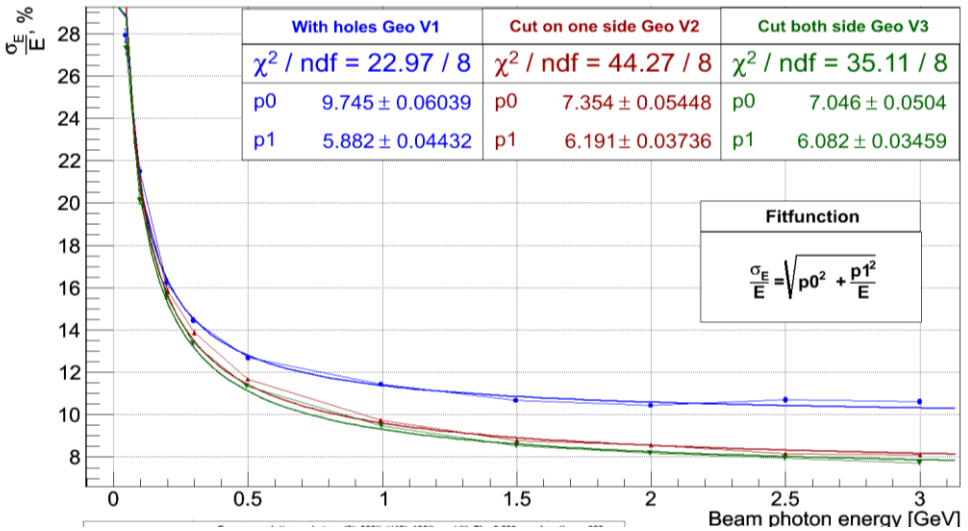


"Shashlyk" sampling calorimeter:
Pb(0.35 mm)+Scint.(1.5 mm)
4x4 cm² , L ~35 cm (~ 14 X_0)
read-out: WLS fibers + MAPD

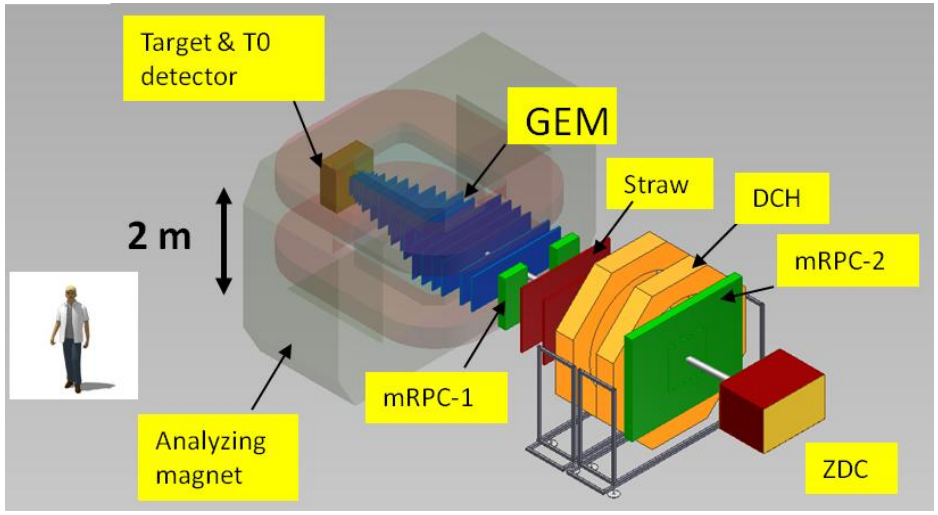


- High granularity with minimal dead space
- Sufficient energy and spatial resolution
- Low cost, easy and flexible manufacturing

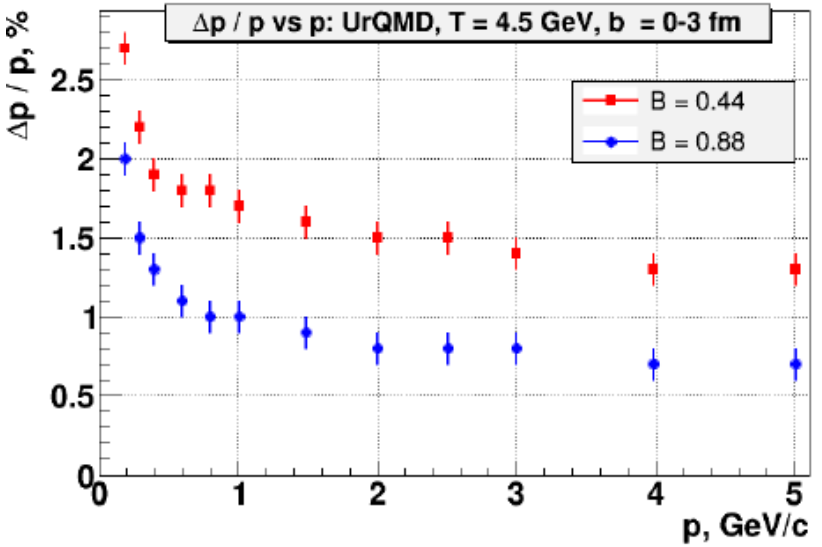


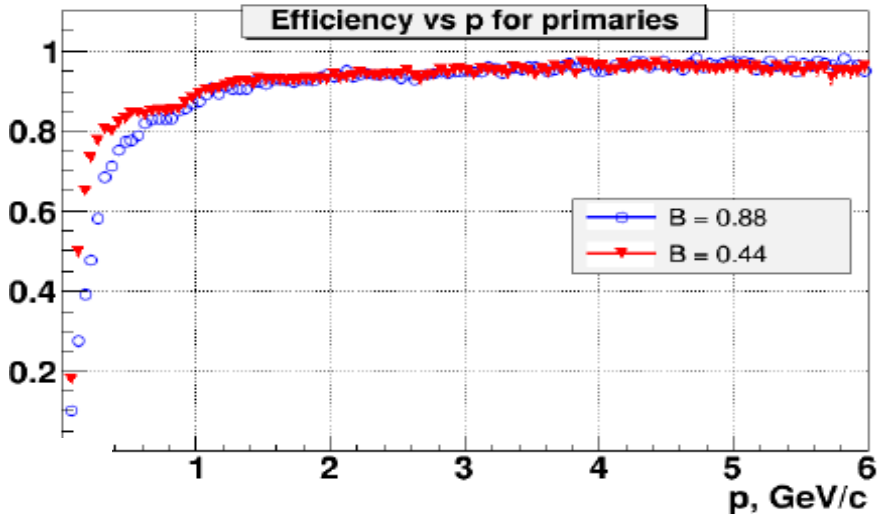


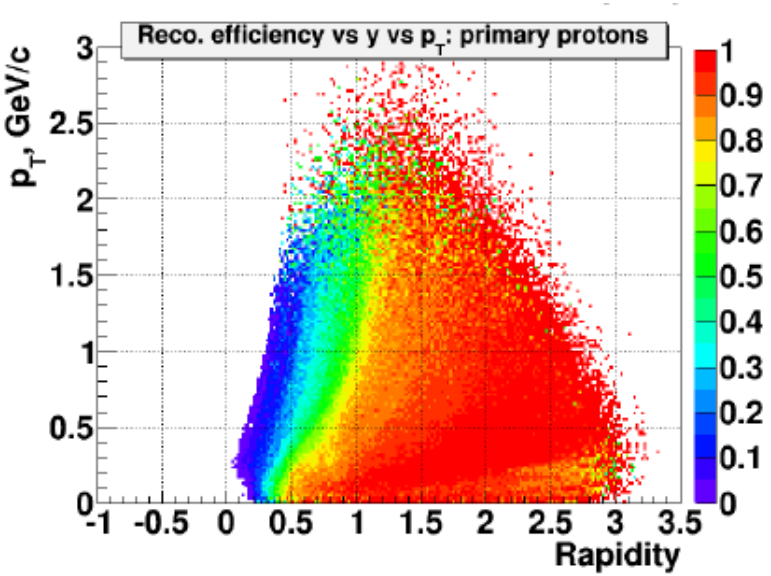
BM@N setup



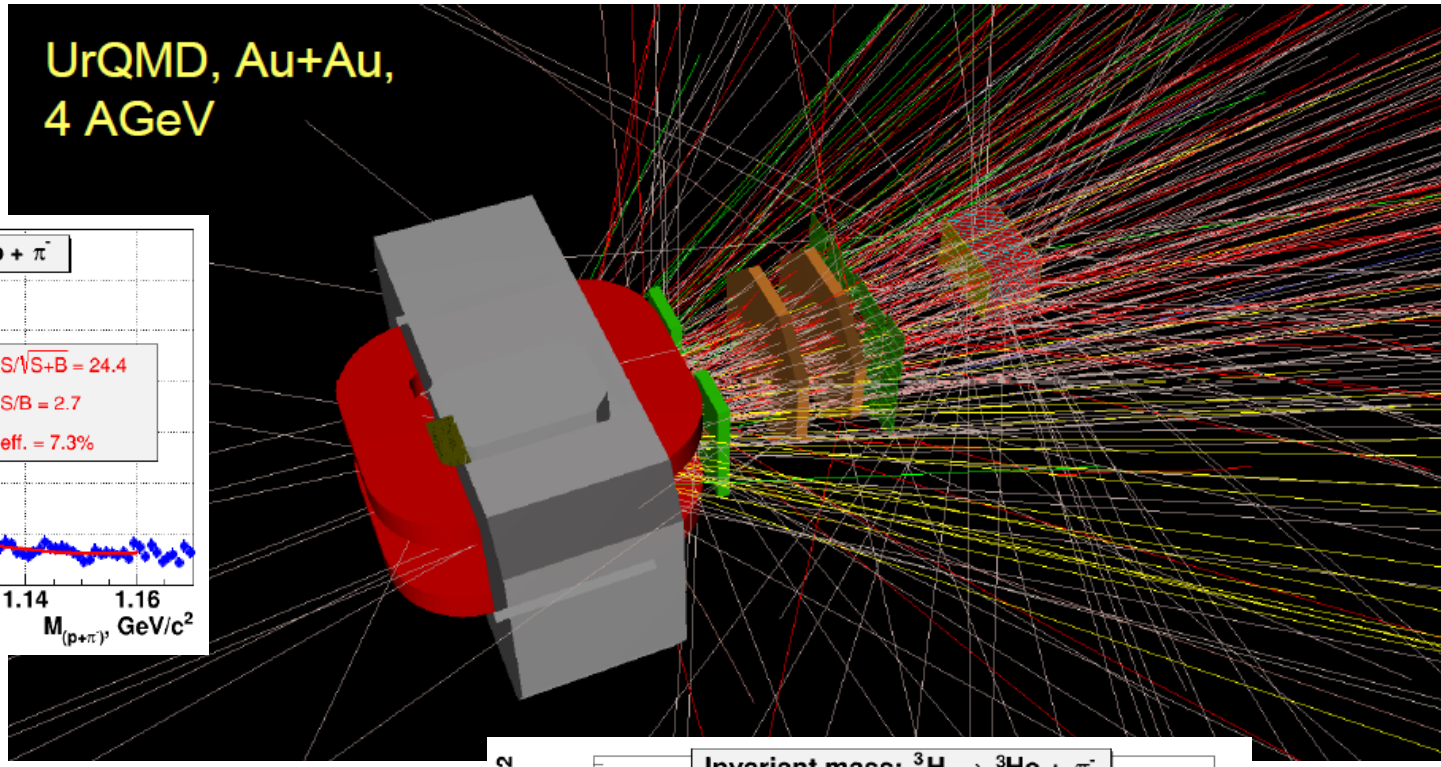
- Tracking with 12 GEM supe-rmodules placed over 3 meters from the target inside magnet
- XY-readout strips (pitch 400, 800 μm) divided into 4 zones to reduce track occupancy,
- odd/even planes inclined by +/- 15 degrees

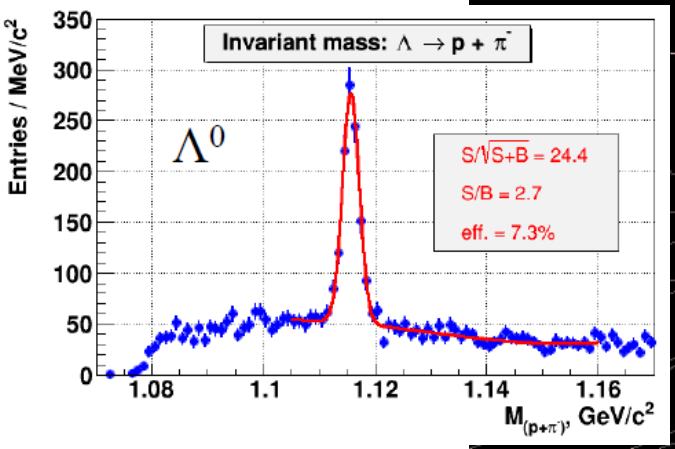


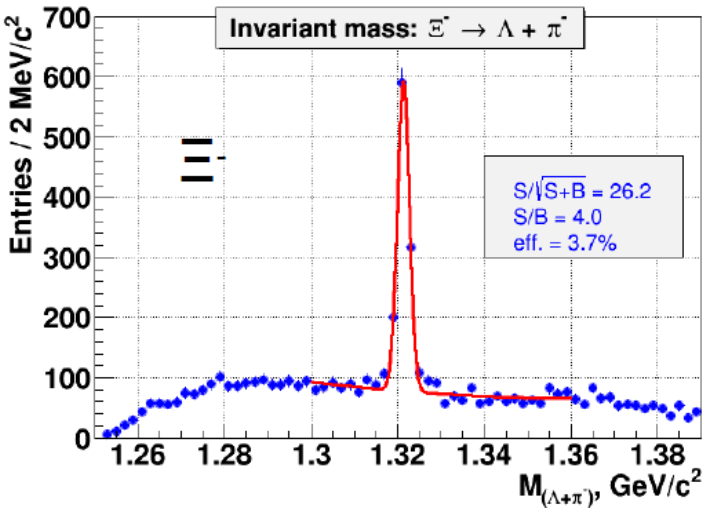


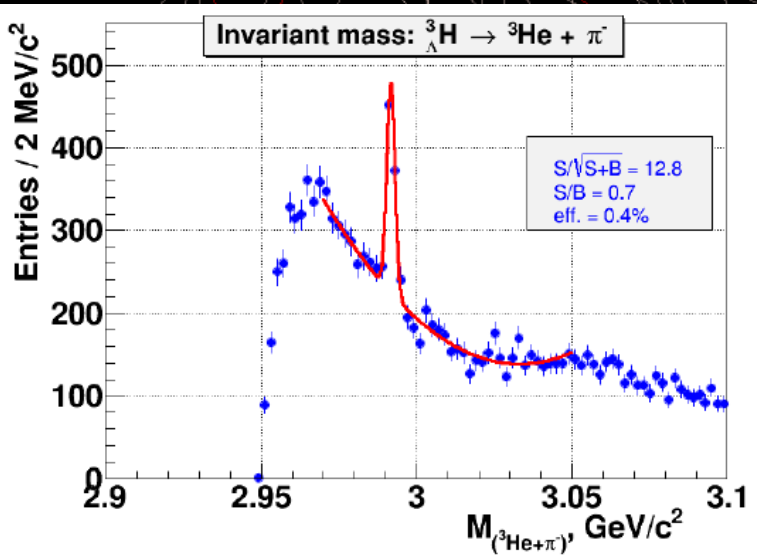


BM@N performance (MC simulation)









Progress in NICA project realization:

✓**Civil construction**

✓**Accelerator**
- **Source, Linac, Booster, Collider – R&D and mass production**

✓**Detector(s)**
- **R&D, beam tests and mass production**

✓**Physics & MC**

Civil Construction of the NICA Complex

International tender: 15 companies participated, 10 commission sessions conducted

By open voting the following rating had been recommended by Commission:

1.STRABAG AG/ЗАО «Штрабаг» (Austria/Slovakia/Russia)
2.PSJ, a.s. (Czech Rep.)
3. Budostal-3 Export SP z.o.o. (Poland)

The whole Complex is split into several Objects:

- *MPD Hall* *> 2016*
- *SPD Hall* *2020 ?*
- *West semi-ring* *+ ~1 year*
- *East semi-ring* *+ another year*

- *Beam extraction* } *affect Nuclotron operation*
- *Reconstruction of building #1*

The schedule of object constructions should be coordinated with:

- *Nuclotron operation plans*
- *MPD magnet fabrication schedule*
- *Equipment installation plans*

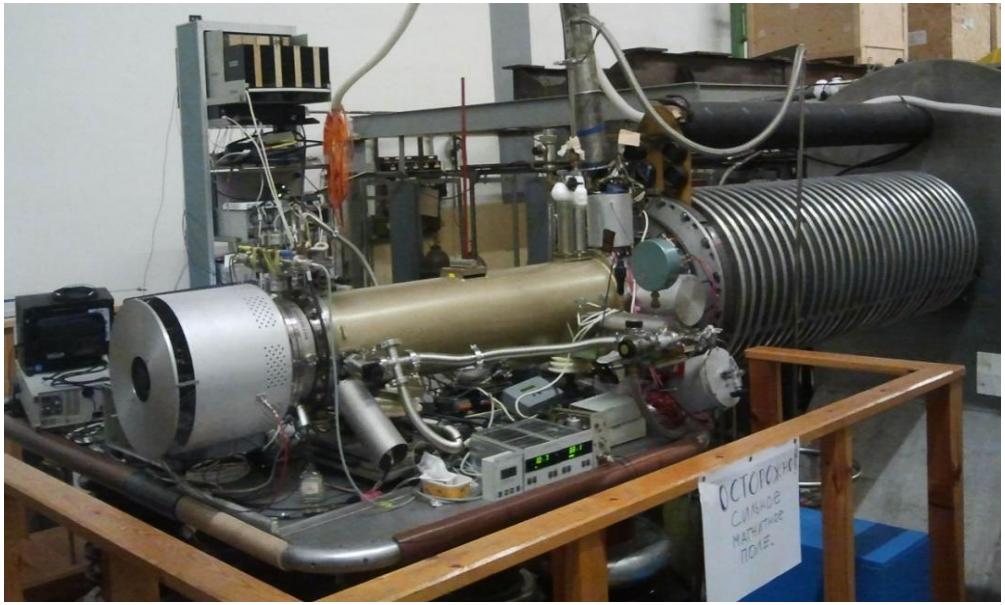
NICA: Civil Construction

The preparatory works are close to completion

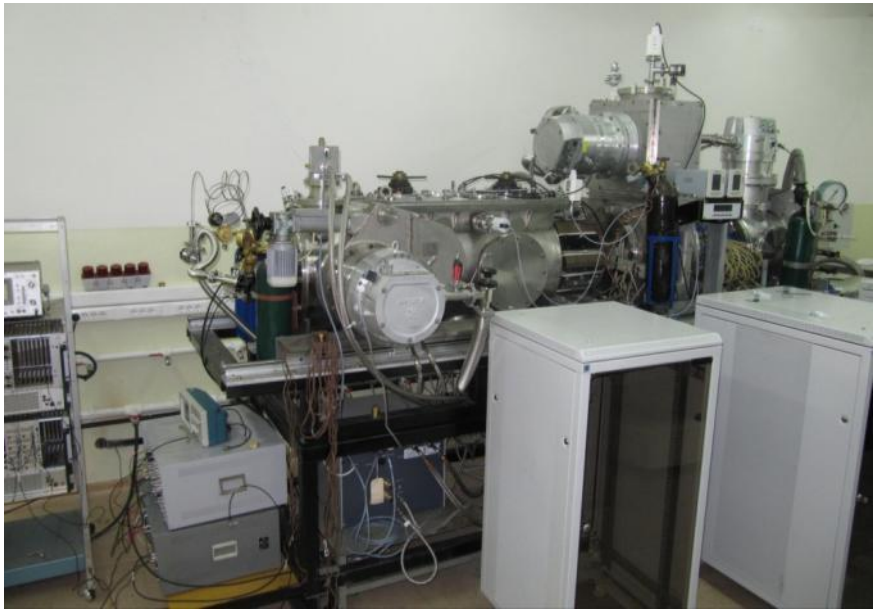
(no trees and tree stumps at ~60 000 m^2!)

NICA ion sources. Development & commissioning

Heavy ion source: Krion-6T ESIS



Source for polarized particles (SPP)



Status: ion beams up to $Au^{51+} \div Au^{54+}$ are produced. $6 \cdot 10^8$ ppp, repetition rate 50 Hz

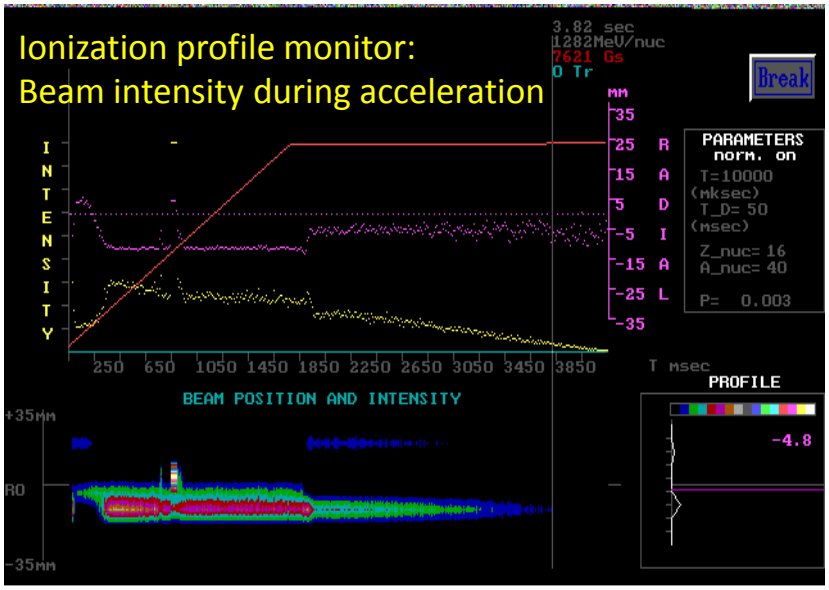
Now goal : production of $Au^{65+} \div Au^{69+}$ and injection into LU-20 -> Nuclotron.

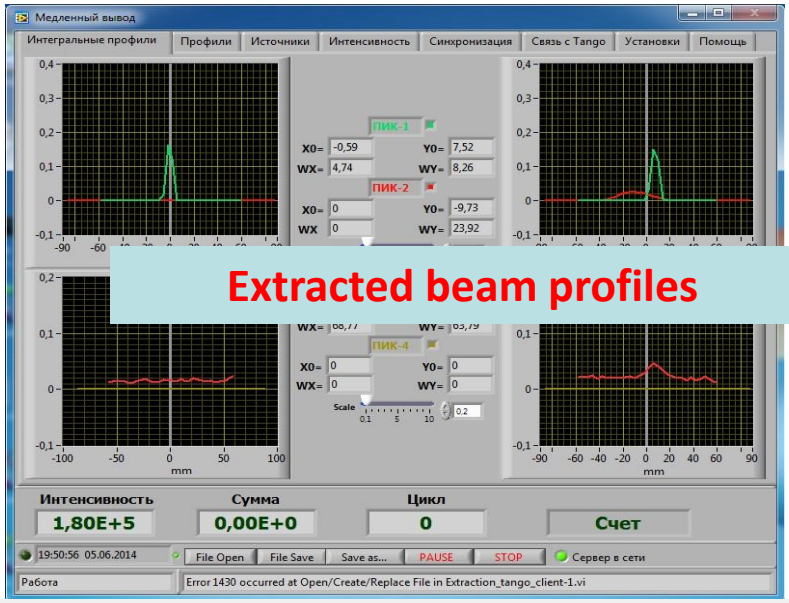
- Assembled in 2013
- Commissioning is ongoing
- Ultimate goal -10^{10} d/pulse

Nuclotron progress:

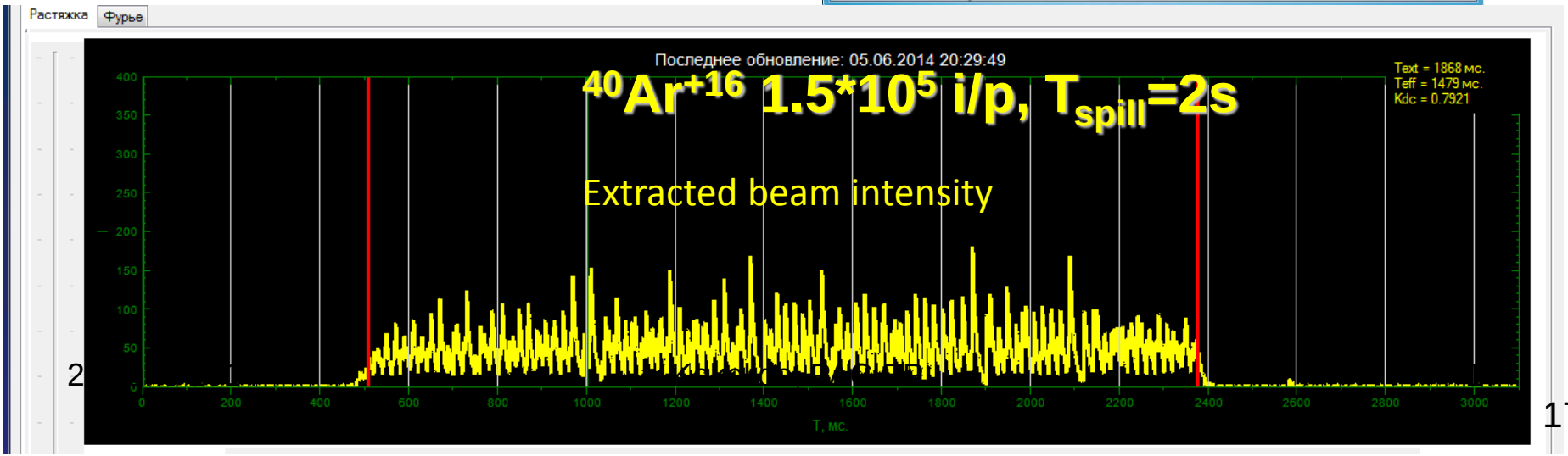
First operation of KRION-6T at Nuclotron

$^{40}Ar^{+16}$ ions acceleration (1.2 Gev/u) RUN #50 (June'14)



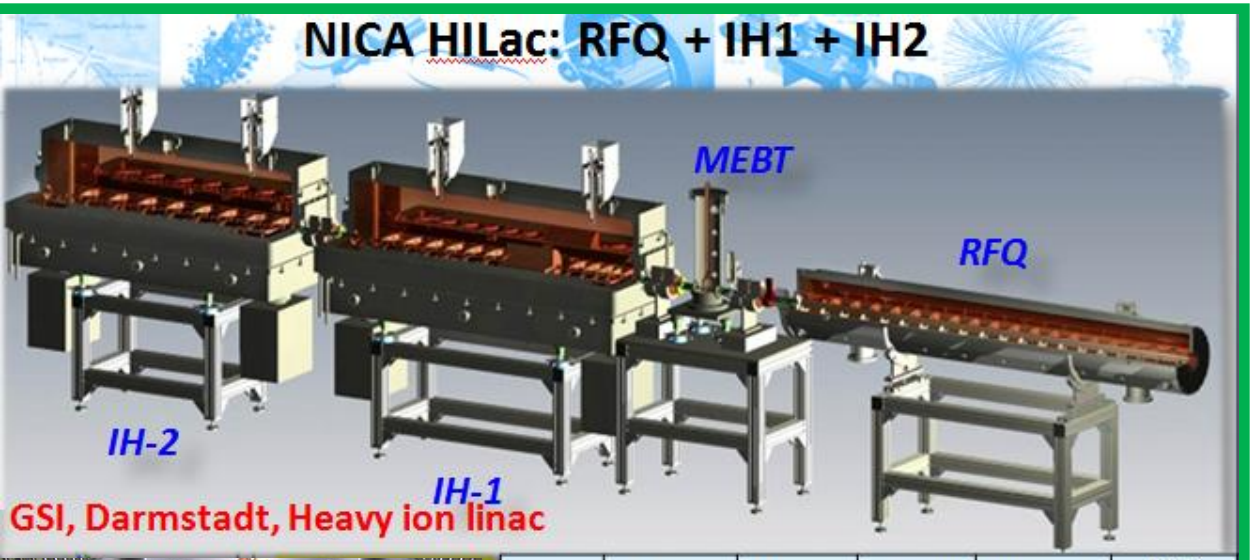


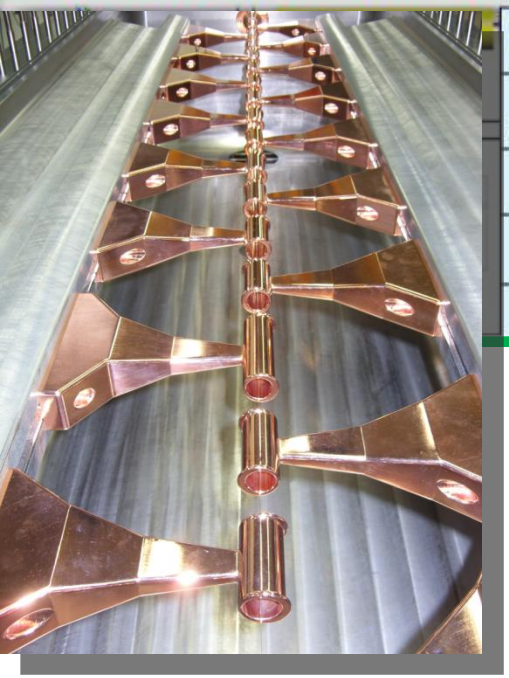
Extracted beam profiles



NICA HI Linac. Manufacturing

Design and fabrication by "BEVATECH OHG" Germany, Offenbach/Main



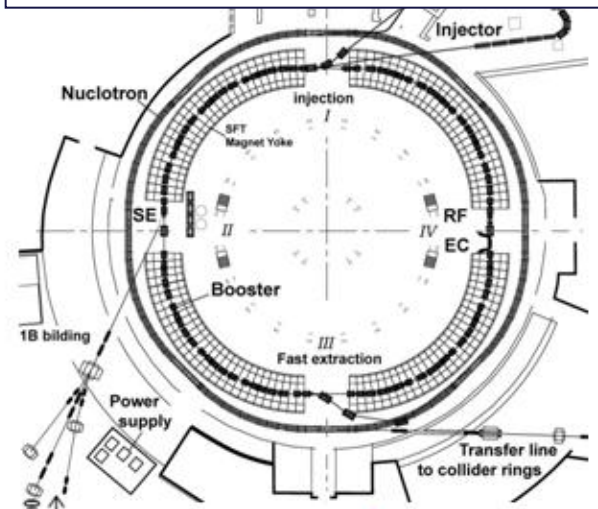


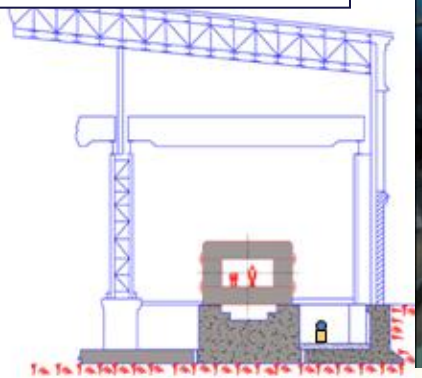
	Type	Weight	Length	RF power	Exit energy
RFQ	4 - rod	2000 kg	3.16 m	120 kW	0.3 MeV/u
MEBT	Two QD + buncher	500 kg	1.4 m	3 kW (buncher)	0.3 MeV/u
IH1	DTL + QT	4000 kg	2.3 m	296 kW	2 MeV/u

- ✓……
- ✓**IH1 ready for shipment** - *Oct. 2014*
- ✓**IH1 in JINR** - *Nov. 2014*
- ✓**IH2 RF measurements** - *end of May 2014*
- ✓**IH2 copper plating** - *end of May 2015*
- ✓**IH2 ready for shipment** - *June 2015*
- ✓**IH2 in JINR** - *end of June 2015*

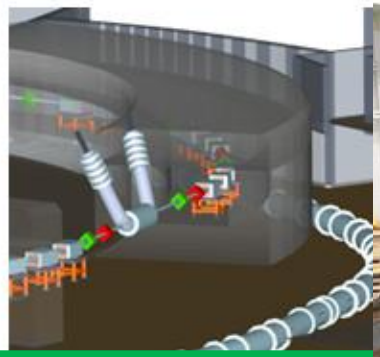
NICA accelerator. Booster and Collider

Booster synchrotron
C = 211 m, ultra high vacuum electron cooling





Dipole SC magnet (Dubna)



2-aperture SC
Magnet for collider

RF system & stochastic cooling (Novosibirsk)
Delivery of the last element mid-2015

NICA: SC magnet assembly & test area

in cooperation with GSI

- Contract with BMBF : manufacturing, assembling, cold testing of all QU's
- JINR is responsible for delivery of 175 Quadrupoles for SIS-100
- Test Facility will be used for assembly and testing of magnets for FAIR & NICA

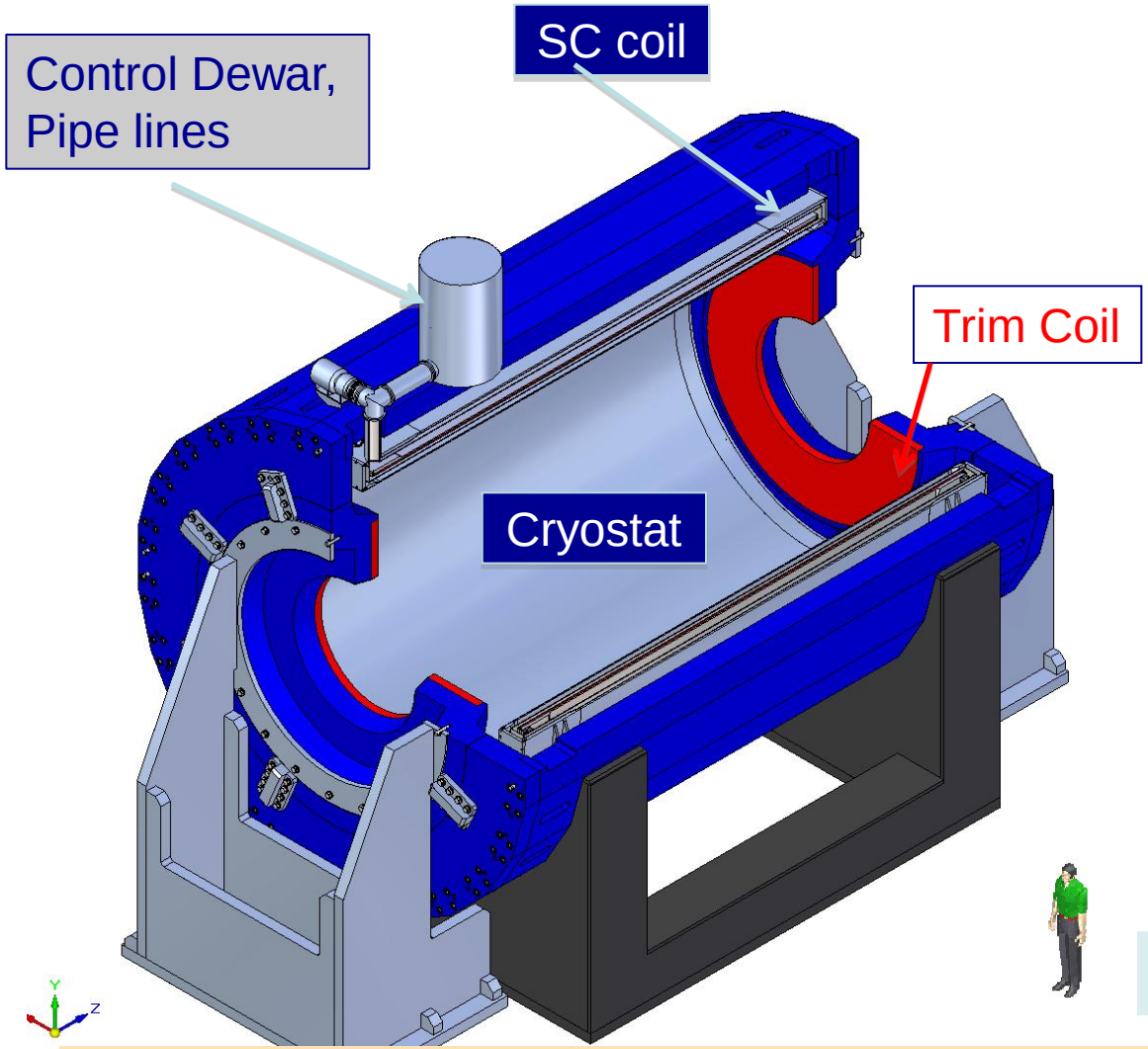
more than 400 SC magnets to be assembled & tested in the workshop

May 2014 - testing of the cable machine

Test series (~80m) of "Nuclotron" SC cable done for the pre-serial dipole for the NICA Booster

MPD Solenoid

Unique device ever build for JINR experiments!



Iron Yoke

Outer diameter	658 cm
Length	901 cm
Dist. In between poles	739 cm
Weight	727 ton

Cryostat

Length	791 cm
Inner diameter	466 cm
Outer diameter	544 cm
Cold mass weight	13.3 ton
Thermal screen weight	2.7 ton
Cryostat&coil weight	66 ton

Status: survey for producers

ASG Superconducting (Genoa, Italy) -> CMS Solenoid

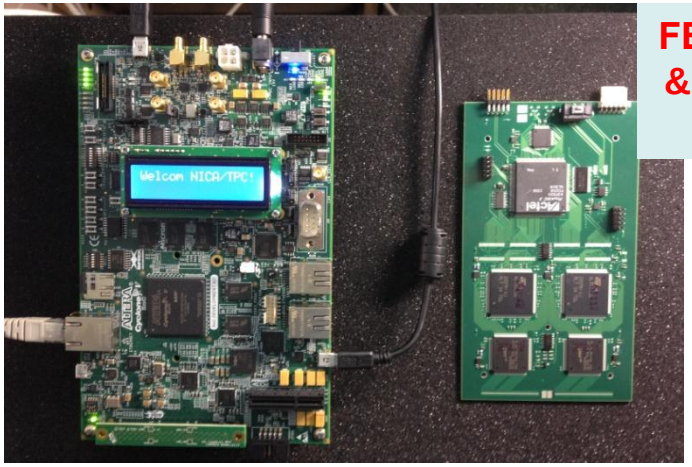
TOSHIBA (Japan) -> ATLAS Solenoid

MPD TPC status

TPC volume- *fabrication stage*; FEE – *under tests*

TPC outer vessel

Frame of a TPC Read-Out-Chamber



FEC's Readout Controller & Front-End Card FEC64S for MPD TPC

MPD TOF status

TOF- *TP approved, preparation for mass-production*

Ultra-sound cleaning of RPC glasses

Commissioning of modules

Room for testing of RPC modules

MPD ECal

ECal- *preparation for mass-production*

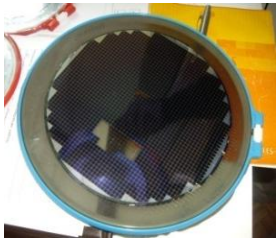
- Manufacturing facility has been established by JINR and Institute for Scintillation Materials (Kharkov, Ukraine)
- Technology for production of trapezoidal ECAL modules has been proven
- Certification procedure for MAPD wafers was developed
- Production of photodetector units was organized
- Feasibility of mass production of ECAL modules was investigated
- First study of ECAL performance with particle beams and cosmic rays was performed

Injection-molding of scintillation plates

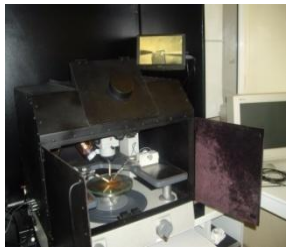
Painting of scintillators

A trapezoidal ECAL

Assembling of ECAL modules

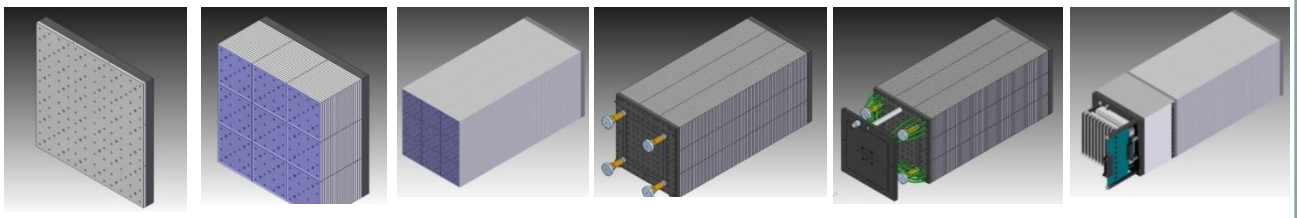


Wafer of MAPD-3N



Setup for wafer tests

MPD ECAL assembling (schematic)



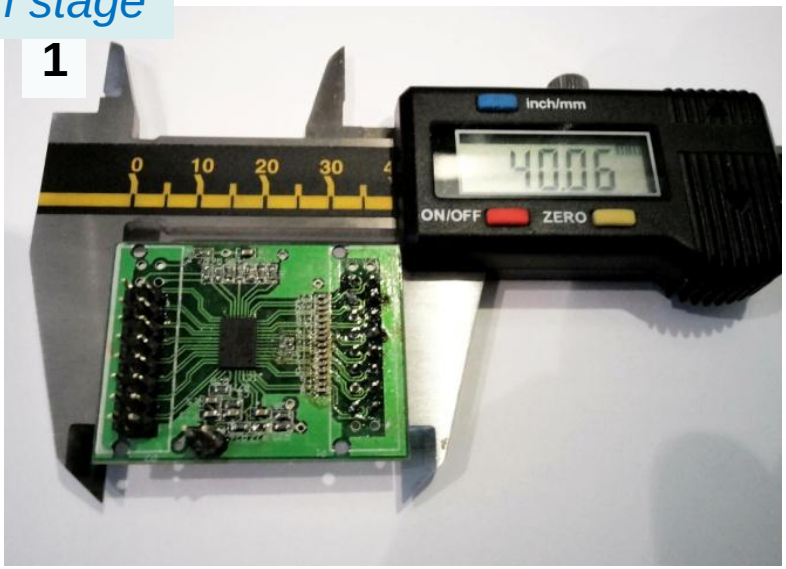
Readout Electronics for MPD TPC, TOF, and ECAL

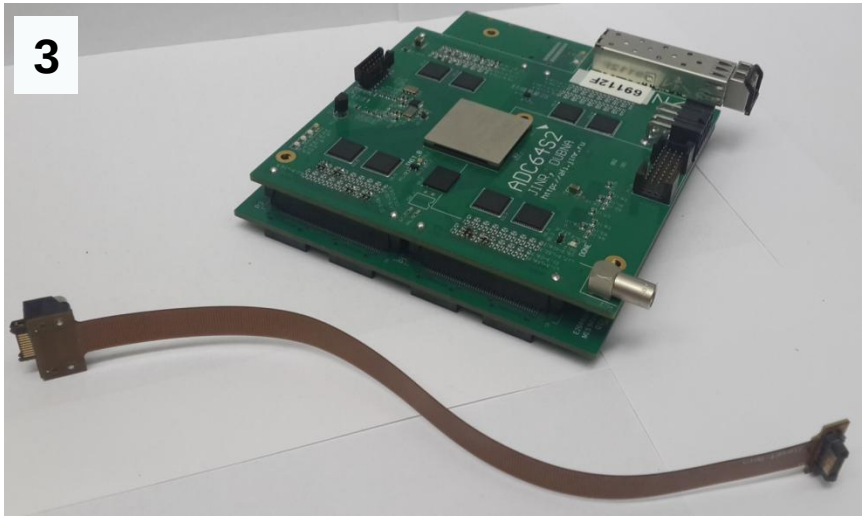
MPD Electronics *: preproduction stage*

1) Ultra fast NINO pre-amplifier for mRPC readout :
24- and 8-channel, rise time < 400 ps

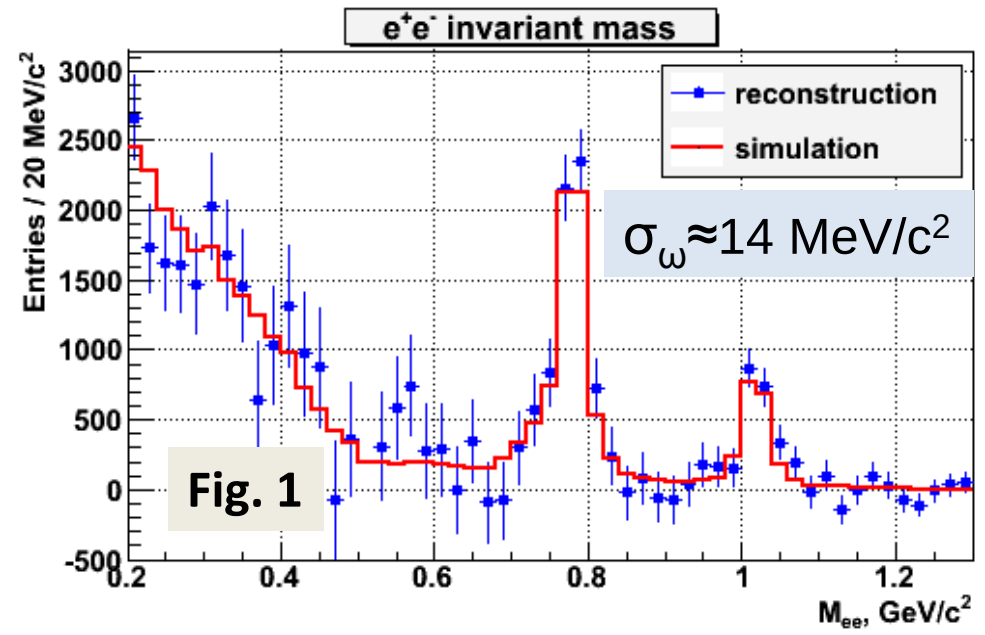
2) ALTRO-based TPC Front-End card prototype

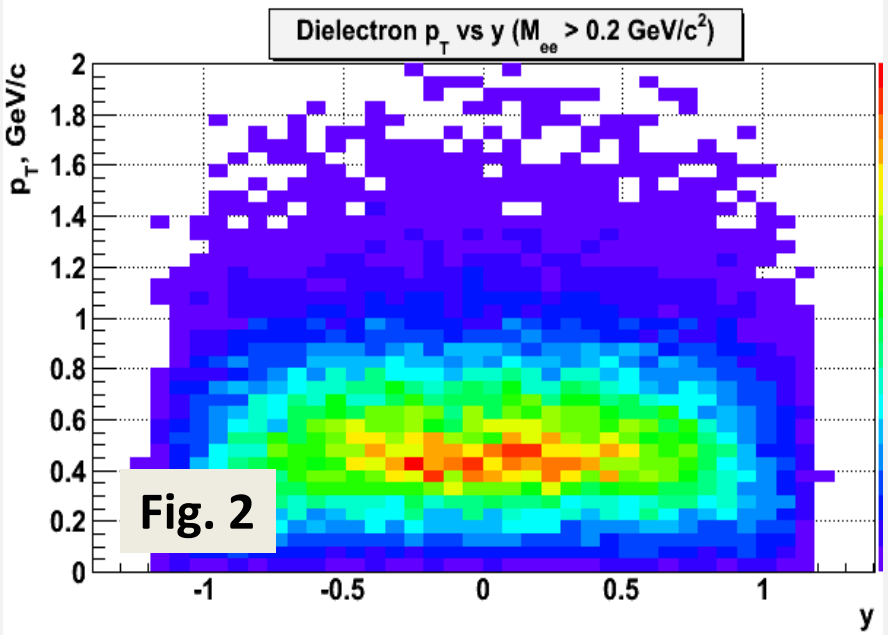
3) High performance ADC for ECAL read-out :
64 channels, 13-bit, 65 MSPS conversion rate





MPD performance for dileptons (Stage'1)





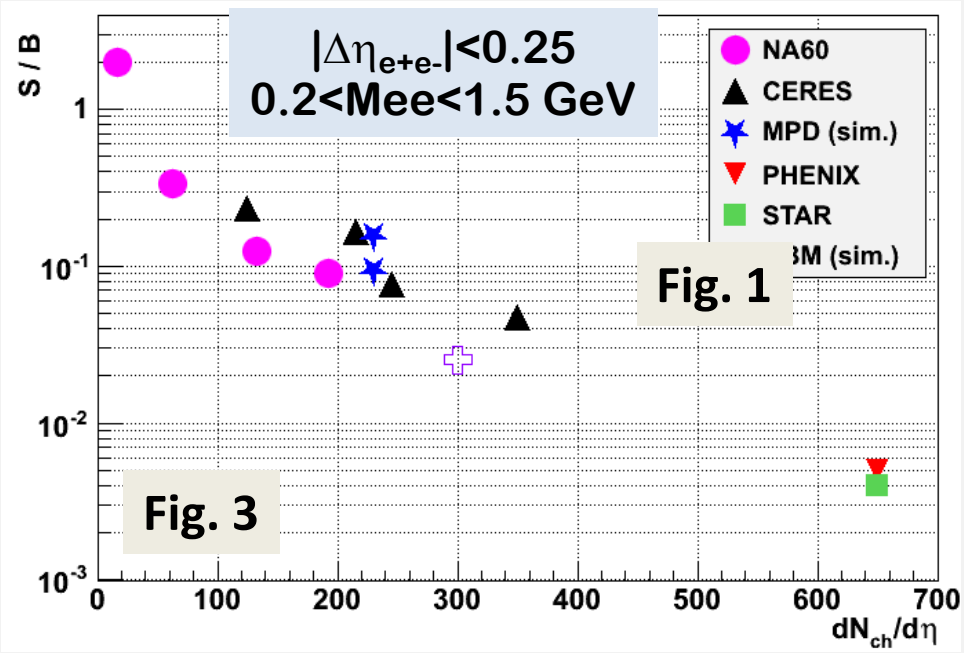


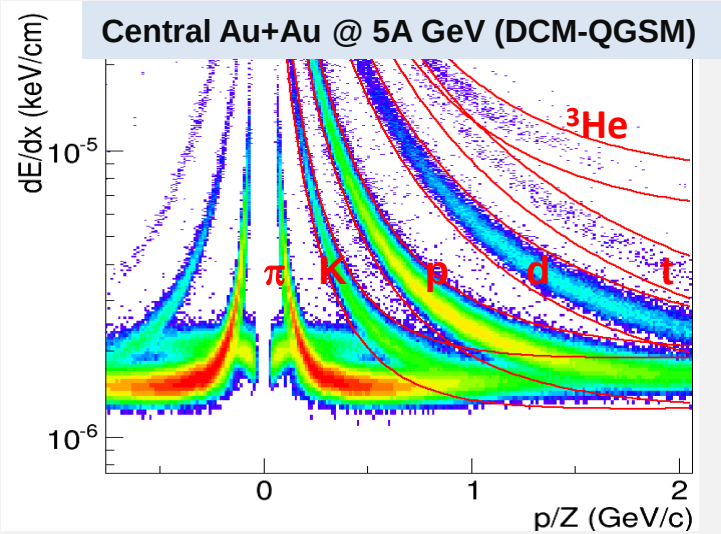
Fig. 1. Invariant mass for dileptons in central Au+Au at √s = 7 GeV (background subtracted)

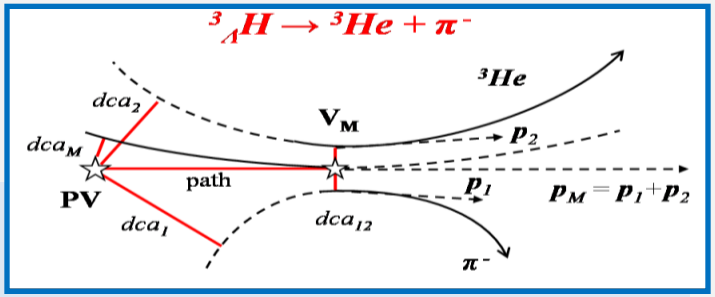
Fig.2. Dilepton phase-space (Minv ~ 0.8)

Fig. 3. Signal-to-Background ratio for dileptons vrs. charged track density in HIC experiments

Hypertritons at NICA-MPD. Feasibility study

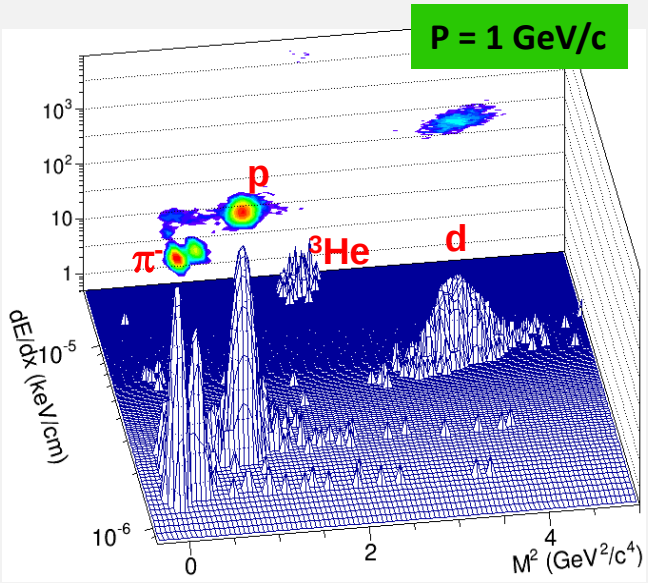
PID is achieved by dE/dx (TPC) and time-of-flight (TOF) measurements

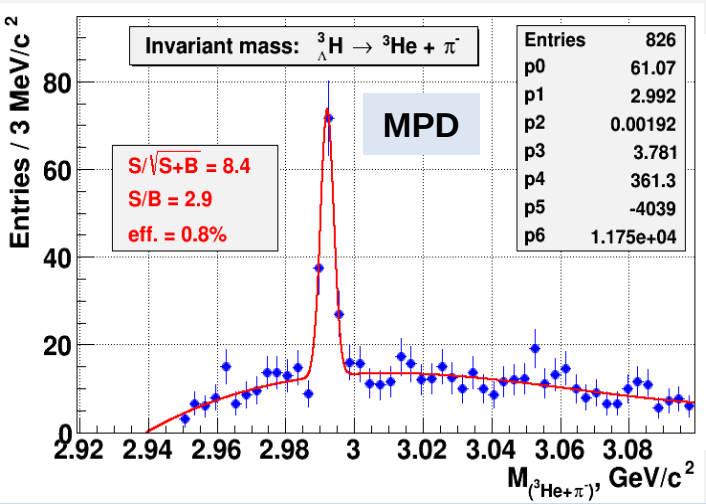


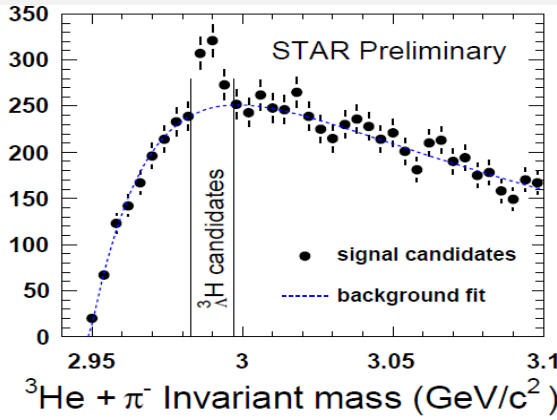


Analysis

- 500k central Au+Au @ 5A GeV (LAQGSM model)
- Realistic tracking & secondary vertex finding technique
- Track quality cuts & Particle ID for secondaries

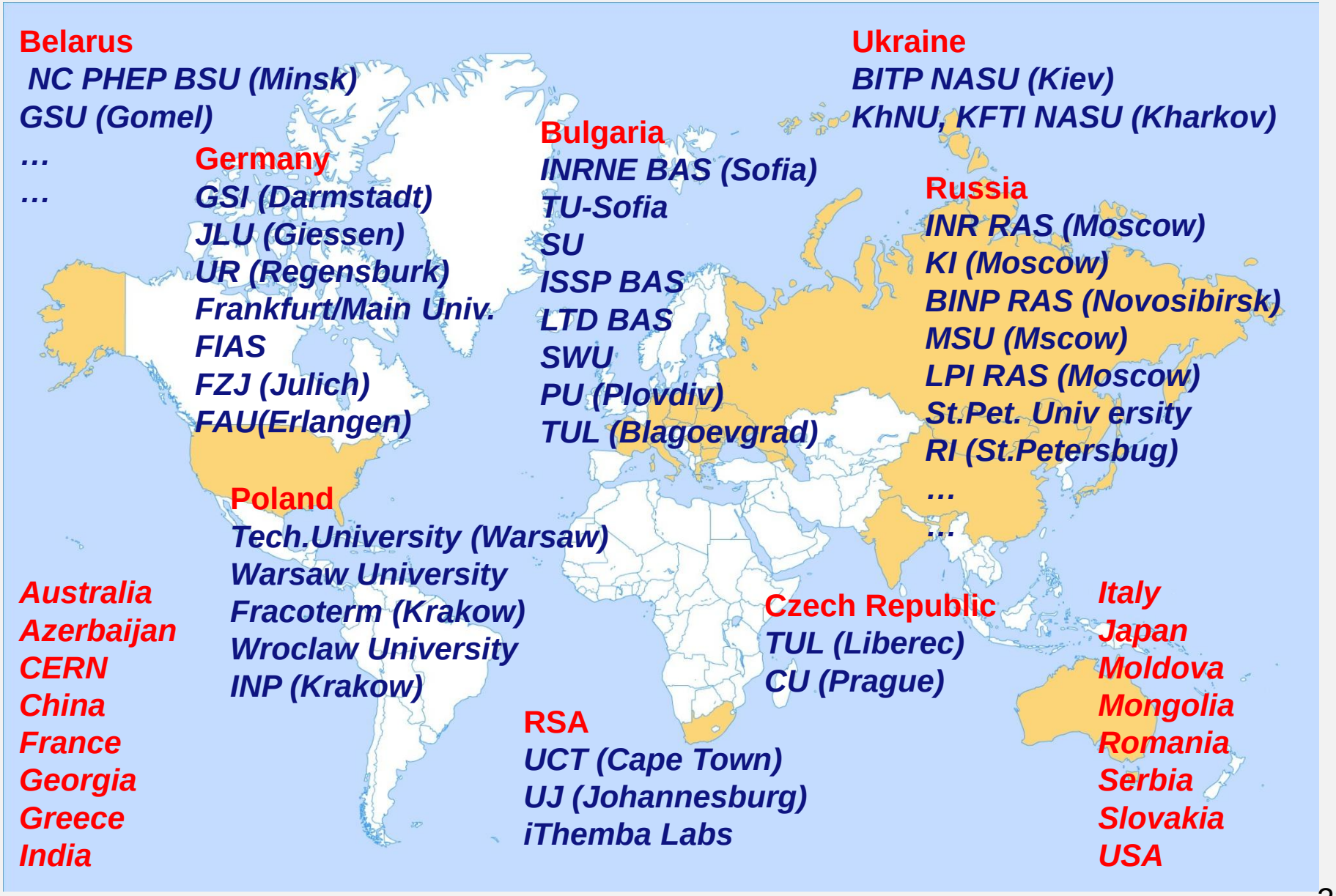






A signal of 70 $_\Lambda{}^3H$ is seen (one day of data taking)

Scientific cooperation of LHEP on the NICA projects



MPD Collaboration

1) Joint Institute for Nuclear Research (Dubna, Russia)
2) Institute for Nuclear Research (Troitsk, Russia)
3) Institute of Nuclear Physics (Moscow, Russia)
4) Institute for Theoretical Experimental Physics (Moscow, Russia)
5) St.Petersburg State University (St.Petersburg, Russia)
6) Radium Institute (St.Petersburg, Russia)
7) "Neva-Magnet" S&E, Ltd. (St. Petersburg, Russia)
8) Department of Engineering Physics, Tsinghua University (Beijing, China)
9) Center of Particle Physics and Technology of the University of Science and Technology of China (Hefei, China)
10) Warsaw University of Technology (Warsaw, Poland), Jan Pluta + 7 persons
11) Institute of Physics &Technology Mongolian Academy of Sciences (Ulan Bator, Mongolia)
12) Institute for Nuclear Research & Nuclear Energy (Sofia, Bulgaria)
13) Plovdiv University (Plovdiv, Bulgaria)
14) National Institute of Physics and Nuclear Engineering (Bucharest, Romania)
15) Bogolyubov Institute for Theoretical Physics (Kiev, Ukraine)
16) Institute for Scintillation Materials (Kharkiv, Ukraine)
17) State Enterprise Scientific & Technology Research Institute(Kharkiv, Ukraine)
18) Particle Physics Center of Belarusian State University (Minsk, Belorussia)
19) Physics Institute Az. AS (Baku, Azerbaijan)

Summary

- **NICA program gives a new impulse to Physics of Heavy Ion Collisions at JINR**
- **NICA complex civil construction shall start soon. Nuclotron performance is improving**
- **MPD detector R&D has completed. Contracts for procurements of MPD magnet packages will be prepared by in Beg. of 2015. The mass production of sub-detectors starts once the magnet construction is fully approved**
- **The BM@N project is progressing; the first commissioning run in February'15**

THANK YOU

FOR ATTENTION!

Extra slides

Beam	Nuclotron beam intensity (particle per cycle)		
	Current	Ion source type	New Injection facility + booster
p	$3 \cdot 10^{10}$	Duoplasmotron	$5 \cdot 10^{12}$
d	$3 \cdot 10^{10}$	--- „ ---	$5 \cdot 10^{12}$
^{4}He	$8 \cdot 10^{8}$	--- „ ---	$1 \cdot 10^{12}$
d↑	$2 \cdot 10^{8}$	SPI	$1 \cdot 10^{10}$
^{7}Li	$8 \cdot 10^{8}$	Laser	$5 \cdot 10^{11}$
^{11,10}B	$1 \cdot 10^{9,8}$	--- „ ---	
^{12}C	$1 \cdot 10^{9}$	--- „ ---	$2 \cdot 10^{11}$
^{24}Mg	$2 \cdot 10^{7}$	--- „ ---	
^{14}N	$1 \cdot 10^{7}$	ESIS (“Krion-6T”)	$5 \cdot 10^{10}$
^{40}Ar	$1 \cdot 10^{9}$	--- „ ---	$2 \cdot 10^{11}$
^{56}Fe	$2 \cdot 10^{6}$	--- „ ---	$5 \cdot 10^{10}$
^{84}Kr	$1 \cdot 10^{4}$	--- „ ---	$1 \cdot 10^{9}$
^{124}Xe	$1 \cdot 10^{4}$	--- „ ---	$1 \cdot 10^{9}$
^{197}Au	-	--- „ ---	$1 \cdot 10^{9}$

Particle yields in Au+Au collisions

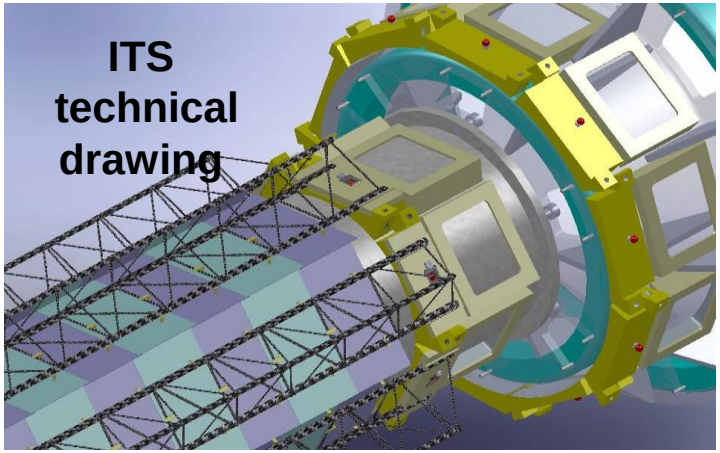
$\sqrt{s_{NN}}$ = 7 GeV (central)

Luminosity $L = 10^{27} cm^{-2} s^{-1}$ **duty factor 50%**

Particle (mass)	Multi-plicity	decay mode	BR	ε (%)	yield (s^{-1})	yield 10w
K^+ (494)	55	--	--	20	$7.7 \cdot 10^3$	$2.3 \cdot 10^{10}$
K^- (494)	16	--	--	20	$2.2 \cdot 10^3$	$6.7 \cdot 10^9$
ρ (770)	23.6	e^+e^-	$4.7 \cdot 10^{-5}$	2	$1.6 \cdot 10^{-2}$	$4.7 \cdot 10^4$
ω (782)	14.2	e^+e^-	$7.1 \cdot 10^{-5}$	2	$1.4 \cdot 10^{-2}$	$4.3 \cdot 10^4$
φ (1020)	2.7	e^+e^-	$3 \cdot 10^{-4}$	2	$1.1 \cdot 10^{-2}$	$3.4 \cdot 10^4$
Ξ^- (1321)	2.4	$\Lambda\pi^-$	1	4	67	$2.0 \cdot 10^8$
Ω^- (1672)	0.16	ΛK^-	0.68	2	1.5	$4.6 \cdot 10^6$
D^0 (1864)	$7.5 \cdot 10^{-4}$	$K^+\pi^-$	0.038	1	$2.0 \cdot 10^{-4}$	600
J/ψ (3097)	$3.8 \cdot 10^{-5}$	e^+e^-	0.06	5	$8.0 \cdot 10^{-5}$	240

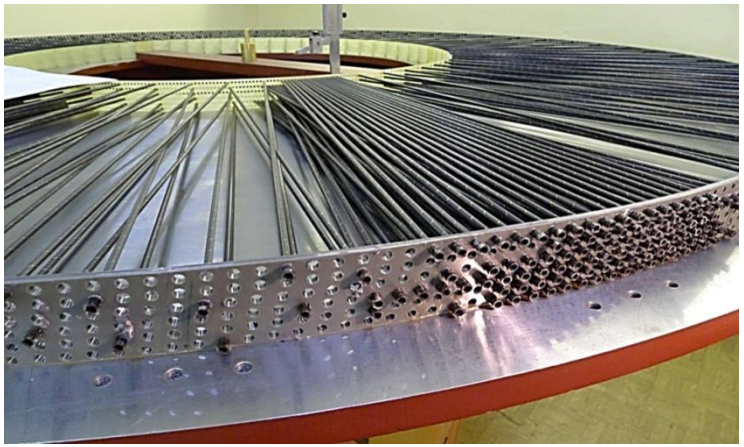
NICA-MPD physics cases

Observable	Set-up	Coverage	New insights
Hadron yields & ratios	TPC, TOF ZDC	$\|\eta\| < 1.5$ pT < 3 GeV/c	Data for $5<\sqrt{s}<7$ GeV, critical assessment of y-spectra and K/π-ratio
Hyperons: yields, flow, Polarization	TPC, TOF ZDC	$\|\eta\| < 1.5$ pT < 3 GeV/c	High statistics data on yields, flow and polarization $\sqrt{s} < 7$ GeV
Dileptons	TPC, TOF ECAL, ZDC	$\|\eta\| <$ **1.1** pT < 3 GeV/c	New data at $\sqrt{s} > 5$ GeV
Fluctuations & Correlations	TPC, TOF ECAL, ZDC	$\|\eta\| < 1.5$ pT < 3 GeV/c	New data on Ev-by-Ev fluct. for $\sqrt{s} > 4$ GeV
Anti-protons Anti-nuclei	TPC, TOF ZDC	$\|\eta\| <$ **1.1** pT < **2** GeV/c	New data on antinuclei, Flow of Pbar and antiL
Flow (v1,2,3) Hadrons & nuclei	TPC, TOF ZDC	$\|\eta\| < 1.5$ pT< 3 GeV/c	New measure @ $\sqrt{s}<7$GeV Precise $\mathbf{v_n}$ data for ϕ,Ω
Chiral Magnetic & vortical effects	TPC, TOF ZDC	$\|\eta\| < 1.5$ pT < 3 GeV/c	Data @ $\sqrt{s} < 7$GeV (CME) Vortical @ $4 < \sqrt{s} < 11$ GeV
(Hyper)Nuclei	TPC, TOF ZDC	$\|\eta\| < 1.5$ pT< 5 GeV/c	New data at $5 < \sqrt{s} < 11$



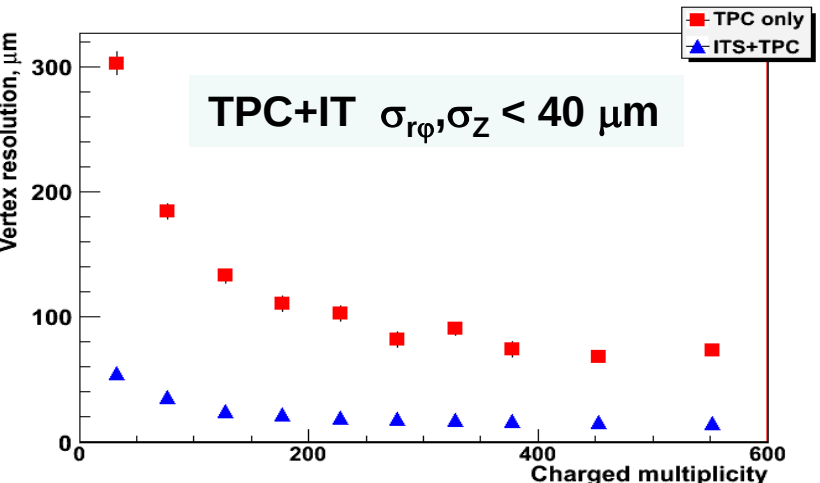
Inner Tracker System

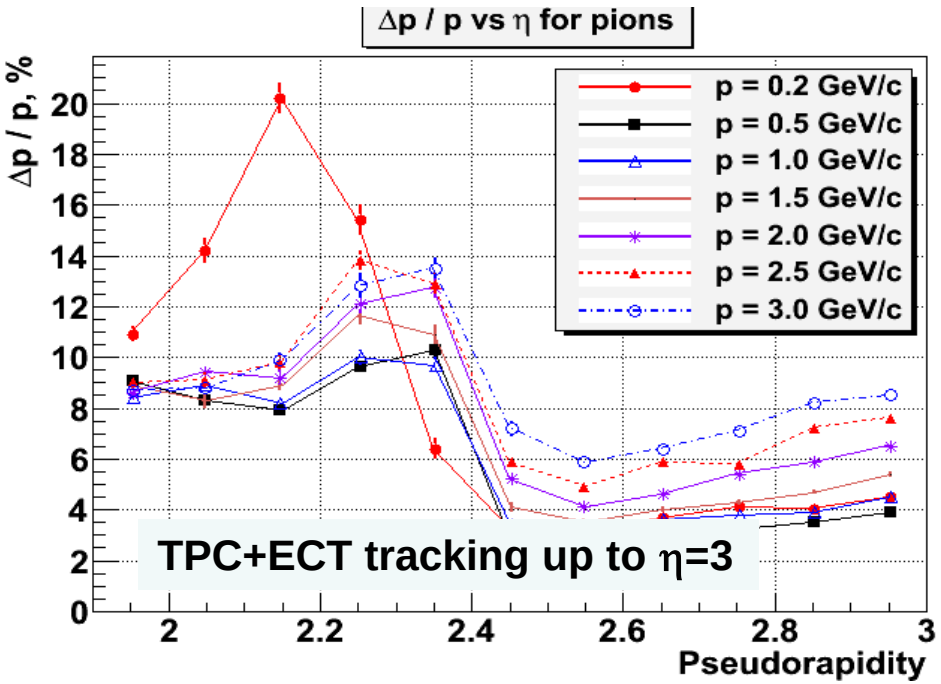
- 4 cylindrical & disk layers |h|<2.5
- 300 μm double-sided microstrip 100 μm pitch
- Thickness/layer ~ 0.8% X_0
- Resolution: σ_z = 120 μm, $\sigma_{r\phi}$ = 23 μm



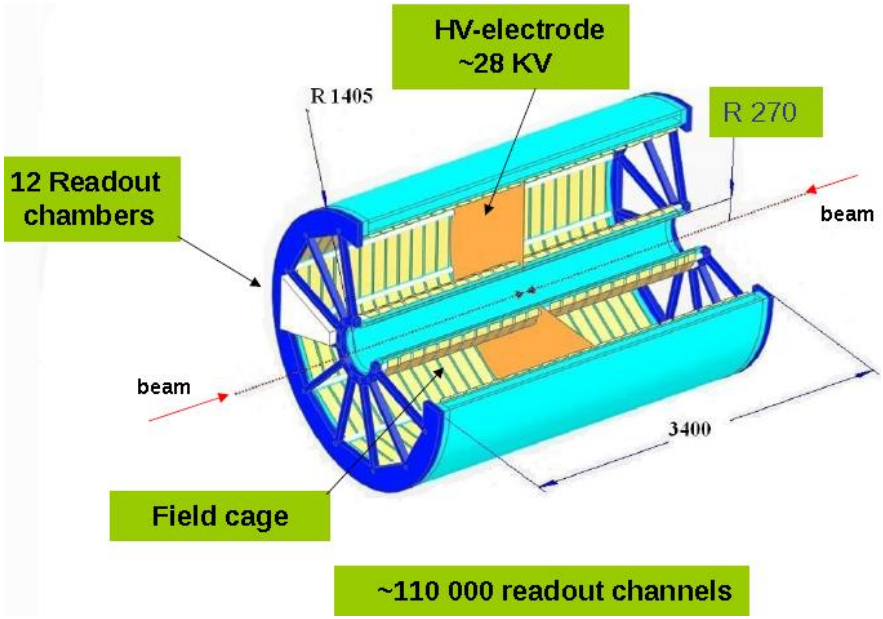
EndCap straw Tracker

- 2x60 straw layers1.3<|h|<2.2
- ~ 72000 straw tubes 4 mm x 60 cm





MPD Time Projection Chamber (TPC)



TPC performance required

Low material budget
Rate capability up to 6 kHz
Spatial resolution: $\sigma_{r\phi}$~300 μm, σ_z~ 2 mm
Momentum resolution: $\Delta p/p < 3\%$ (0.2<p<1 GeV/c)
dE/dx resolution: < 8%

MPD TPC

Dimentions: 4 m x 3m
Drift Length: 170cm
Gas: 90% Argon + 10% Methane
Readout: 2x12 sectors (MWPC or GEM)
Composite materials – transparent detector !

BM@N GEMs: segmentation