Status of the NICA project and prospects for the study of multi-strangeness and charm in p+p and A+A collisions

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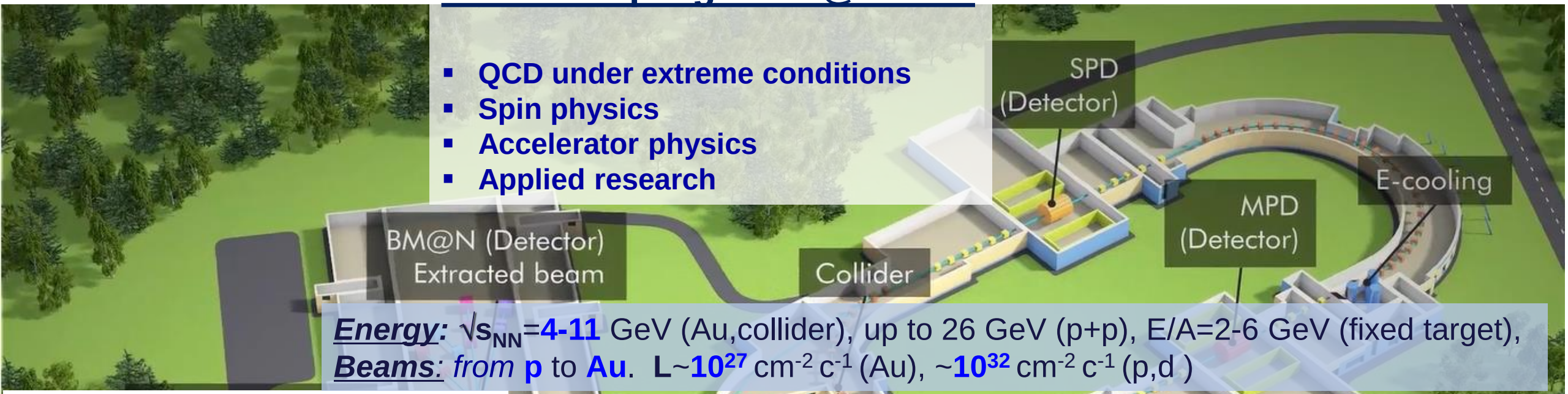
On behalf of the NICA-MPD

Outline

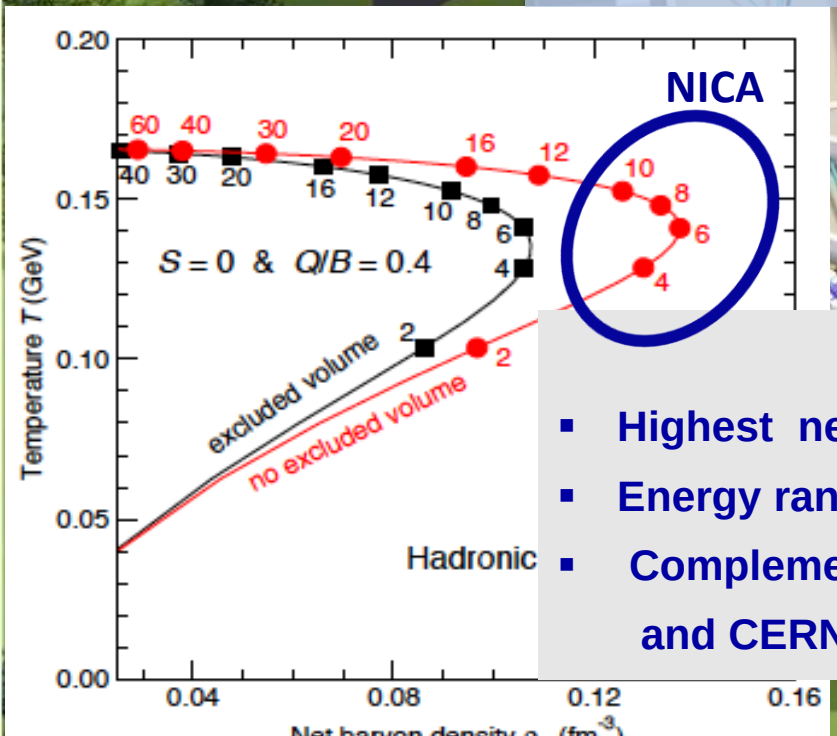
- Introduction
- Progress in the NICA project realization
  - accelerator: construction status
  - detectors @ NICA : preparation for mass-production
- Multistrangeness at the MPD detector: performance study
- Charmonium production in p+p at NICA-MPD: feasibility
- Summary

Research programs @ NICA

- QCD under extreme conditions
- Spin physics
- Accelerator physics
- Applied research

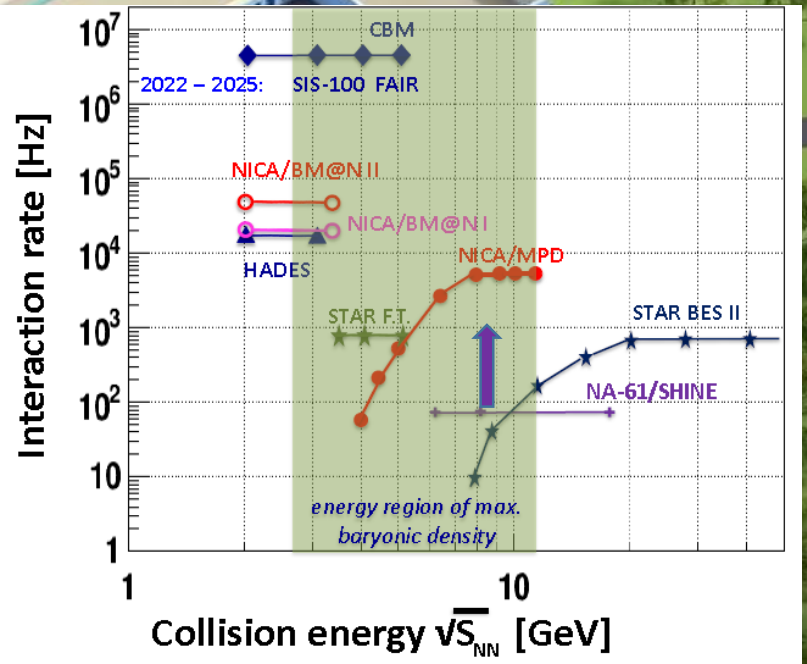


Energy: $\sqrt{s_{NN}}$=**4-11** GeV (Au,collider), up to 26 GeV (p+p), E/A=2-6 GeV (fixed target),
Beams: *from* **p** to **Au**. **L**~10^{27} cm^{-2} c^{-1} (Au), ~10^{32} cm^{-2} c^{-1} (p,d)



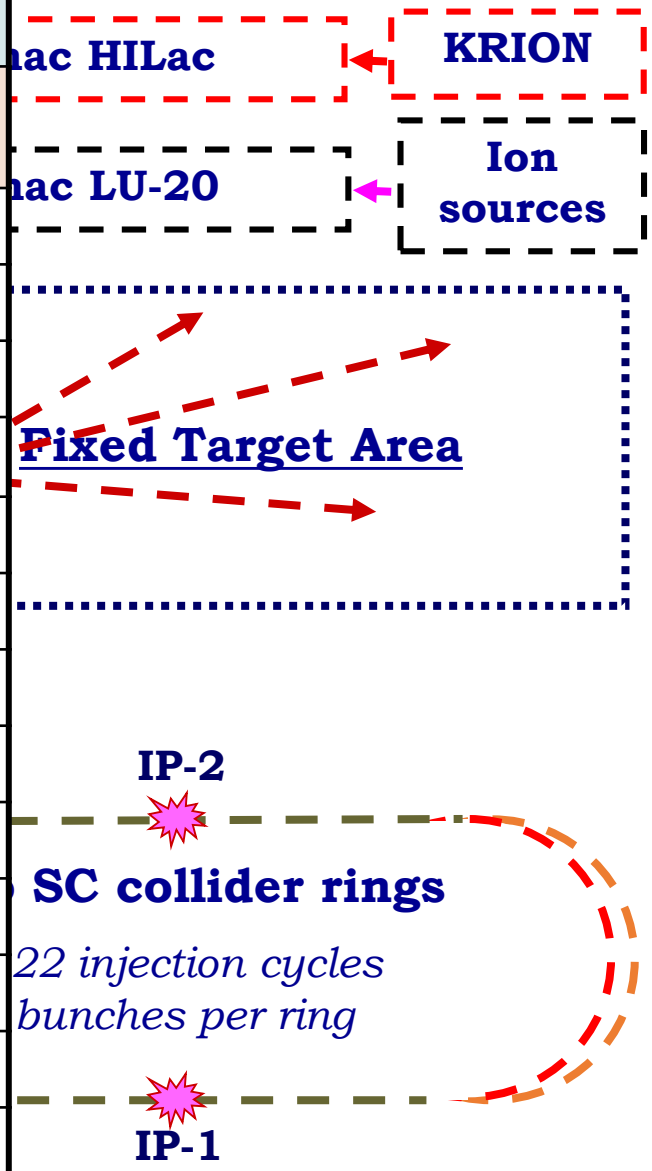
QCD matter at NICA :

- Highest net baryon density (CM energy 4-11A GeV)
- Energy range brackets onset of deconfinement
- Complementary to the RHIC/BES, FAIR, and CERN experimental programs



Nuclotron-based Ion Collider fAcility : Structure and Operation Regimes

Beam	Nuclotron beam intensity (particle per cycle)		
	Current	Ion source type	at NICA
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	$2 \cdot 10^{6}$	--- ,, ---	$1 \cdot 10^{10}$
^{84}Kr	$1 \cdot 10^{4}$	--- ,, ---	$2 \cdot 10^{9}$
^{124}Xe	$1 \cdot 10^{4}$	--- ,, ---	$2 \cdot 10^{9}$
^{197}Au	-	--- ,, ---	$2 \cdot 10^{9}$



NICA progress (accelerator facility)

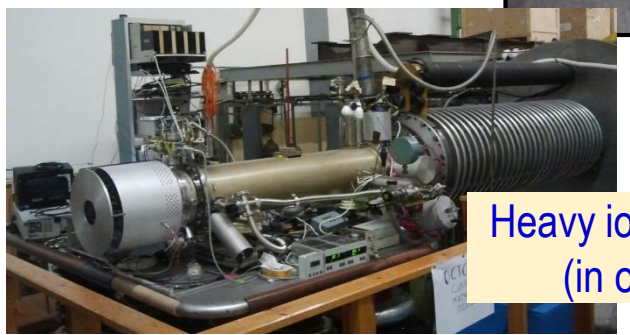
- ***Infrastructure developments: civil construction, service systems upgrade (water cooling, cryogenics, electric power, etc.)***
- ***Accelerator elements construction***

“Strabag" and 7 sub-contractors:
- **total number of engineers and workers – 154**
- **70% of reinforced concrete and piled works done**

New helium liquefier (10^3 l/h) at JINR

NICA HILac
(in operation since 2016)

Electron cooling system for the Booster
(assembled, under tuning)



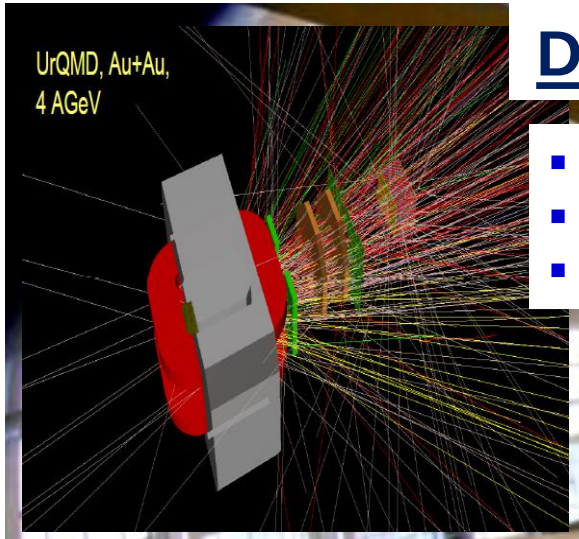
Heavy ion source: Krion-6T ESIS
(in operation since 2015)

SC Magnets for the NICA Booster, Collider & SIS-100/FAIR (workshop at VBLHEP JINR)

- The facility for SC-magnets: in operation since Nov. 2016
- **Working plans**:
  40 dipoles + **48** quadrupoles for the Booster
  80 dipoles + **86** quadrupoles for the Collider
  175 quadrupoles for SIS100 (FAIR)
- **NICA booster**: 33% of dipoles and 10% of doublets passed all the tests

We plan to have 75% magnets for the booster at the end of 2017

Detectors at NICA: Baryonic Matter at Nuclotron

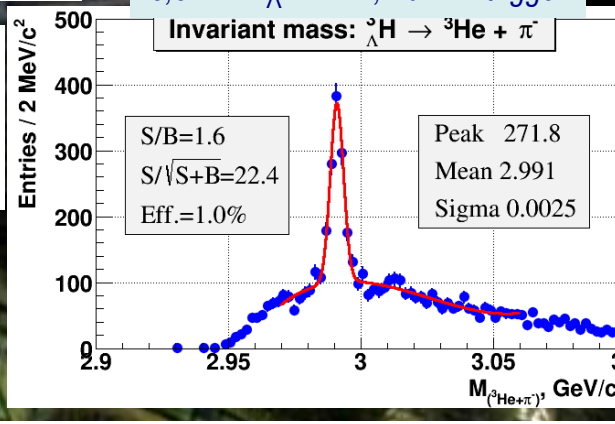


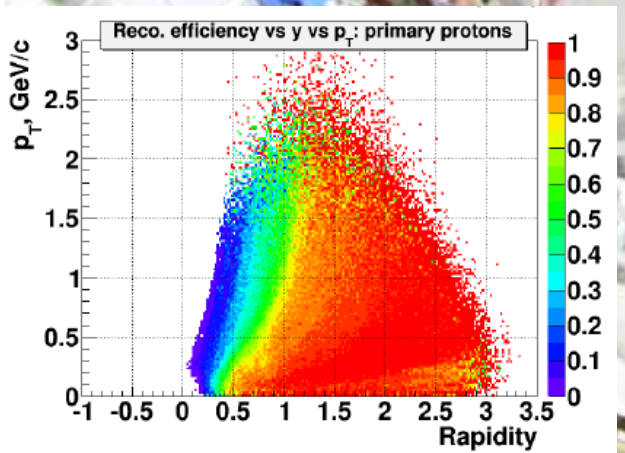
- Well suited for exploration of reaction mechanism & in-medium properties
- Energy range of limited experimental information
- Expectation of rich structure of the QCD phase diagram @ high densities

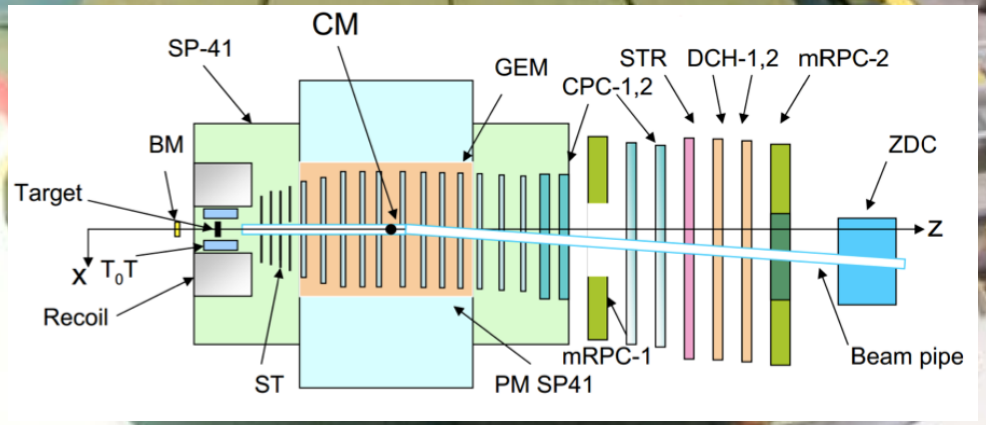
Physics cases:

- Bulk properties, EOS
- In-medium meson-nucleon potential at high ρ_B
- Sub-threshold production of strange hadrons in A+A
- Measurement of elementary reactions

2,6M central Au+Au
8,5M $^3H_\Lambda$ in 1 m, 20 kHz trigger



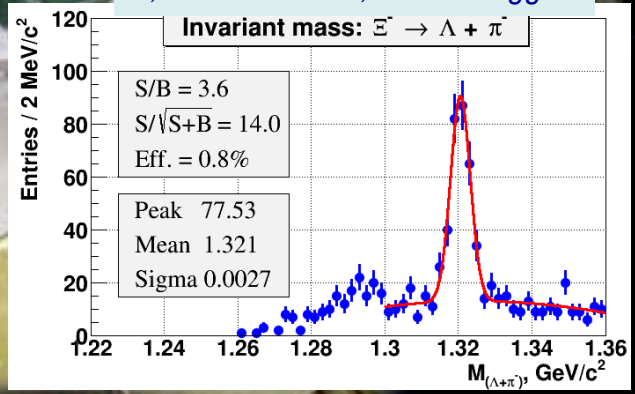




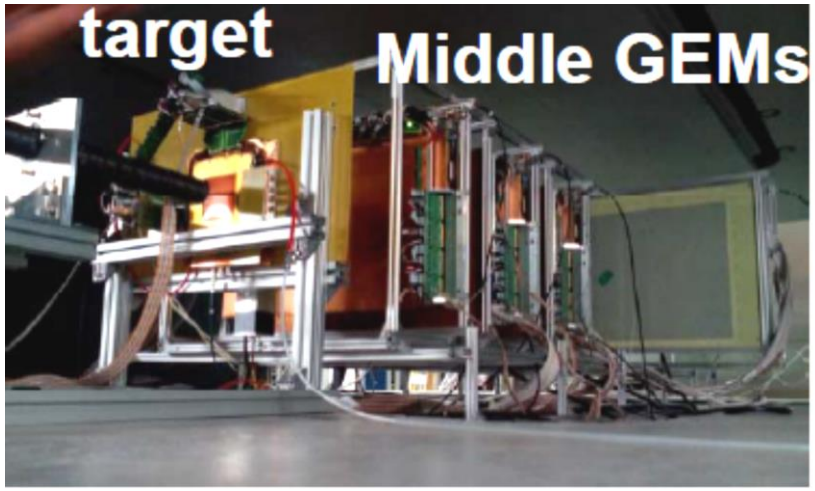
BM@N Collaboration:

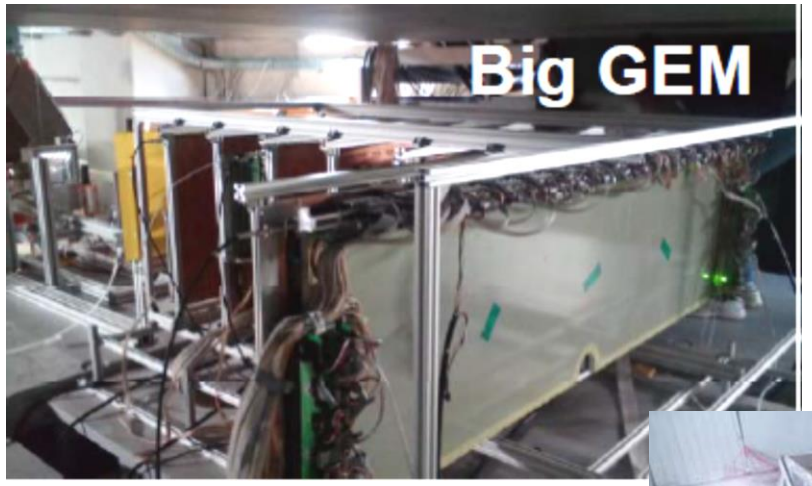
Russia: *INR, MEPhi, SINP, MSU, IHEP, S-Ptr Radium Institut*
Bulgaria: *Plovdiv University;*
China: *Tsinghua University, Beijin;*
Poland: *Warsaw Tech.University*
Israel: *Tel Aviv University, Weitzman Institut*
Germany: *Frankfurt University; GSI*
USA: *MIT*

900 k central events
7,5M Ξ^- in 1 m, 20 kHz trigger



BM@N status and data taking plans

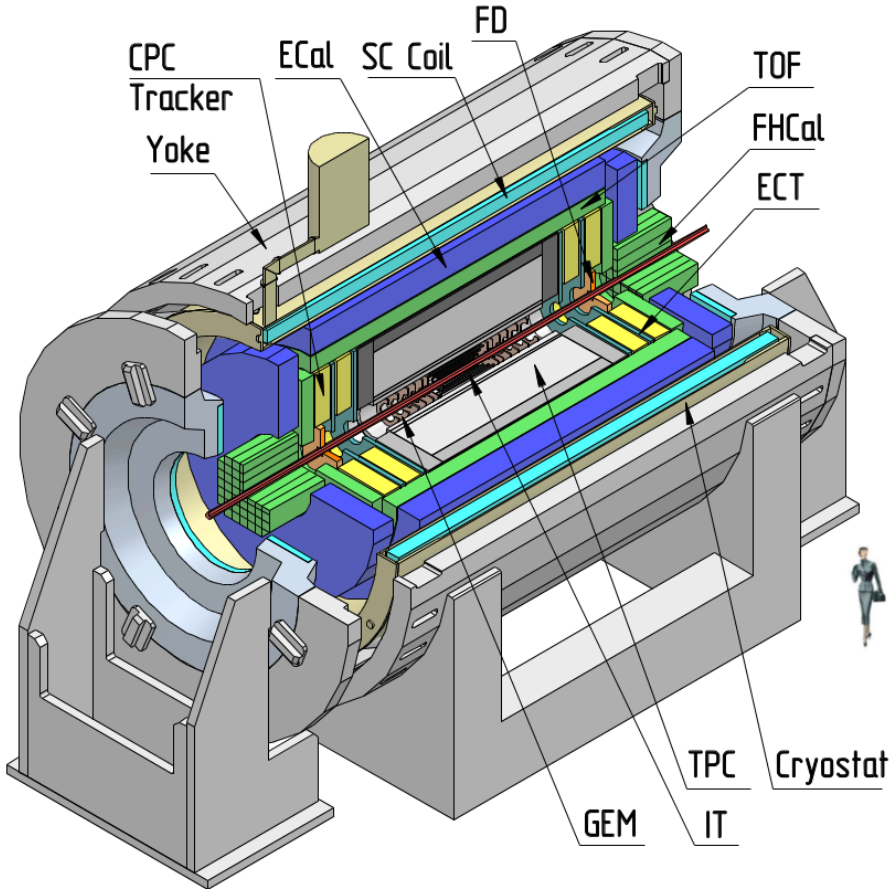




year	2016	2017 Feb.-Mar.	2017 Nov.-Dec.	2019	2020 + ..
beam	d ( )	C, Ar	Kr	Au	Au, p
maximum intensity, Hz	1M	1M	1M	1M	10M
trig. rate, Hz	10k	10k	20k	20k	50k
central tracker	6 GEM half pl.	8 GEM half pl.	10 GEM half pl.	8 GEM full pl.	12 GEM or 8+2Si
expiment status	techn. run	techn. run	commis.& physics run	physics stage 1	physics stage 2

MPD at NICA: design, tasks and observables

***Experimental strategy**: measure a large variety of signals systematically changing collision parameters (energy, centrality, system size). Reference data (i.e. p+p) will be taken in the same experimental conditions.*



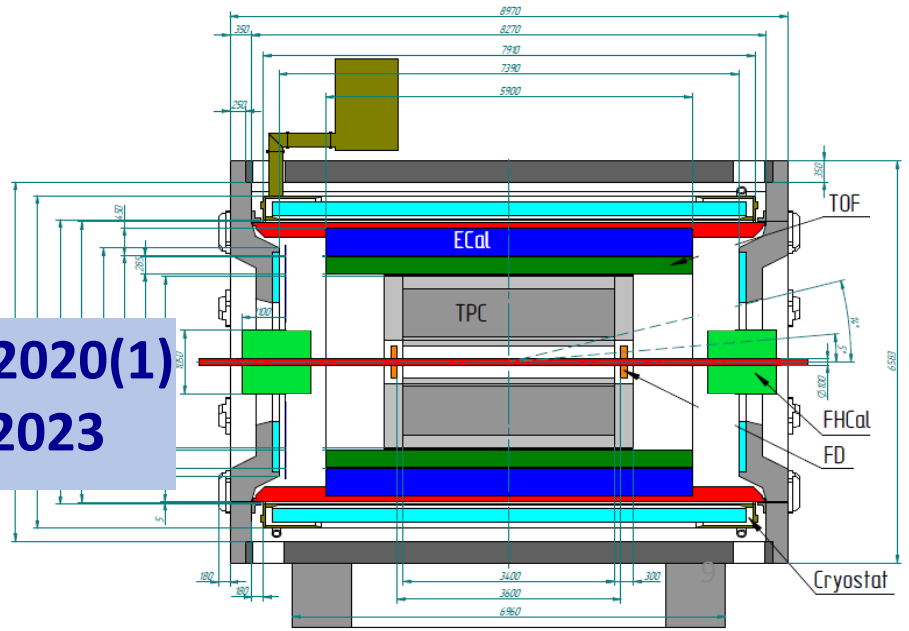
Bulk properties, EOS
particle yields & spectra, ratios, femtoscopy, flow
measure: γ, π, K, p, Λ, Ω, (anti)particles, light nuclei

In-Medium modification of hadron properties
onset of low-mass dilepton enhancement
measure: ρ, ω, $\phi \rightarrow e^+e^-$

Deconfinement (chiral) phase transition at high ρ_B
enhanced strangeness production
Chiral Magnetic (Votical) effect, Λ polarization

QCD Critical Point
event-by-event fluctuations and c

Strangeness in nuclear matter
hypernuclei, exotica



Magnet : 0.5 T superconductor
Tracking : TPC, ECT, IT
ParticleID : TOF, ECAL, TPC
T0, Triggering : FFD
Centrality, Event plane : FHCAL

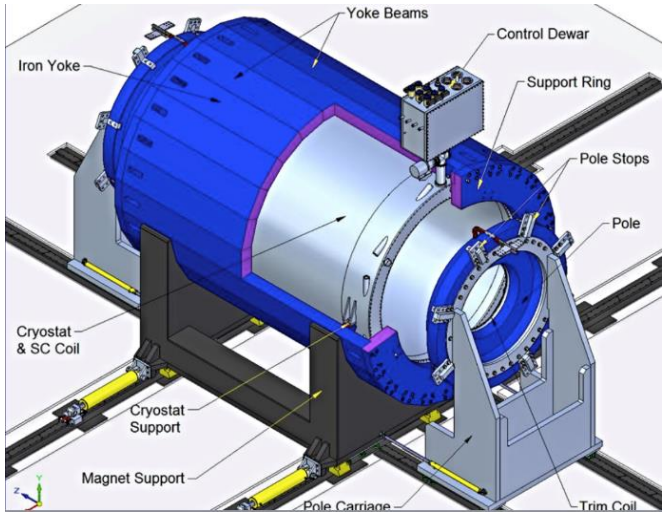
I stage (barrel) – **2020(1)**
upgraded (IT + endcaps) – **2023**

MPD magnet: construction status

MPD Solenoid production stages (AGS superconductors, Genova, Italy)

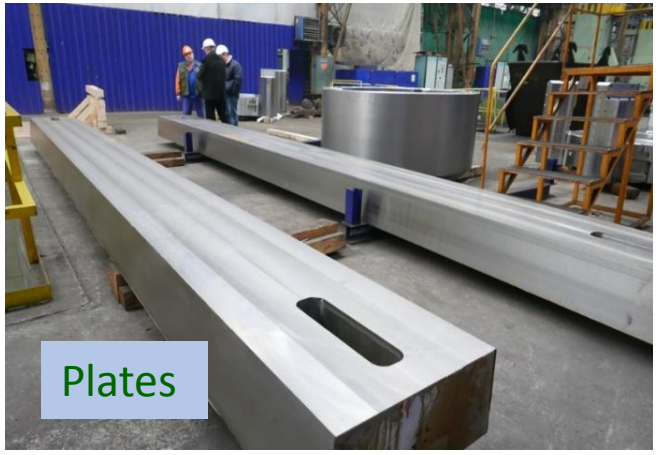
Manufacturing	Jan. 2016-Aug. 2018
Final Solenoid tests by AGS	Jun. 2018
Packaging and Transportation	Apr. 2018-Oct. 2018
Assembly at JINR, tests	Oct. 2018-Apr. 2019

Magnet yoke (VHM, Vitkovice, Cech Rep.) – 80% ready, control assembling in Oct. 2017



Support rings

Aluminum support cylinder blanks for SC coil during transportation



Plates

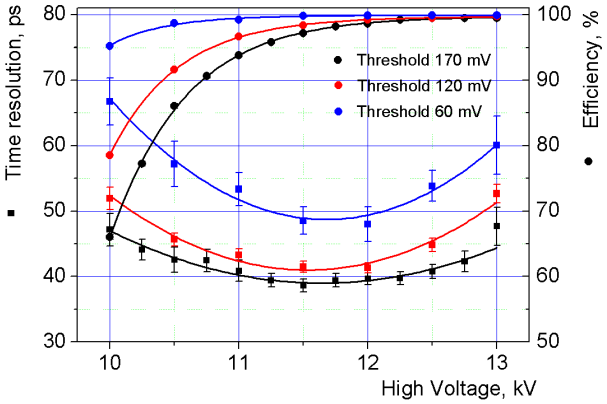
Winding machine for SC solenoid

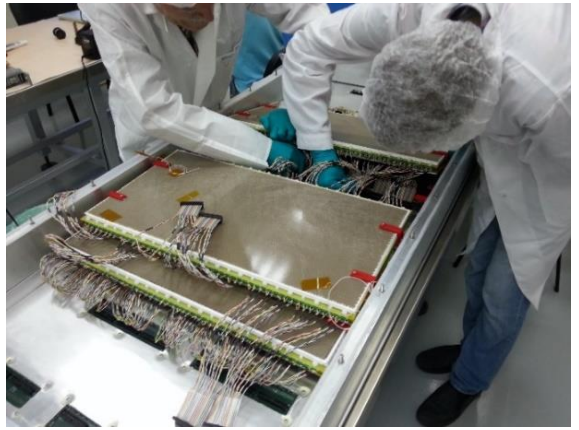
Poles

MPD tracker TPC: under construction

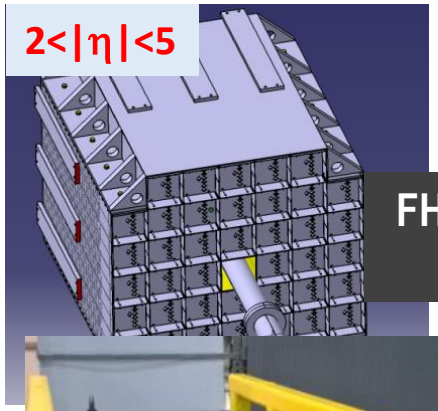
MRPC TOF: preparation to mass-production

(material ordering, equipment installation, personnel training)

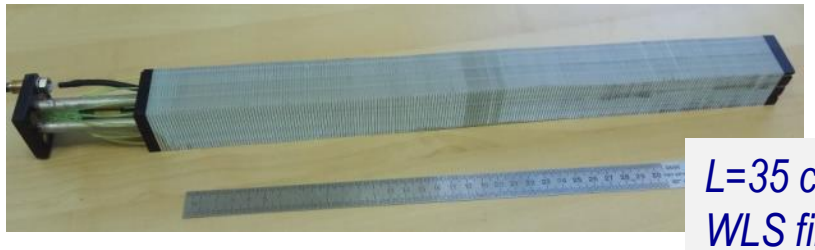




MPD Calorimetry: ECAL and FHCAL

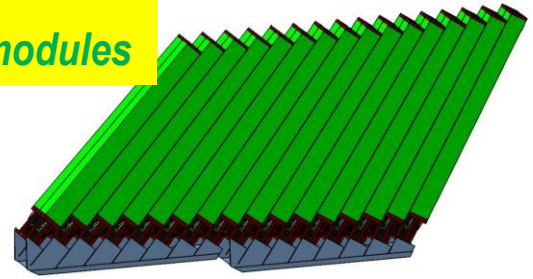


FHCAL calorimeter for centrality & event plane determination

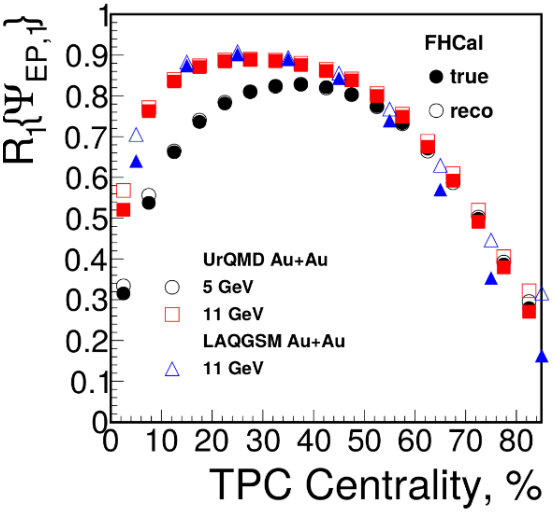


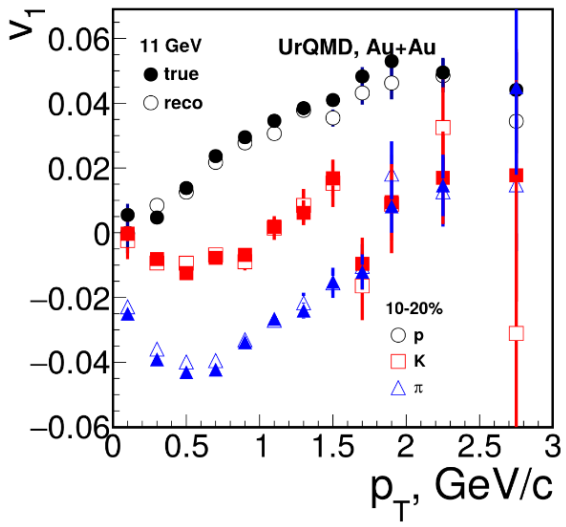
L=35 cm (~ 14 X_0), Pb+Scint. (4x4 cm^2)
WLS fibers + MAPD for readout

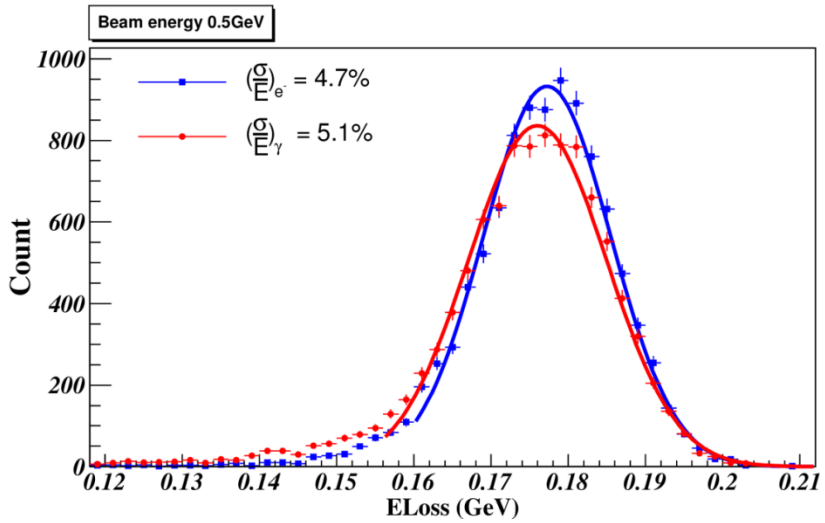
Projective geometry
Barrel ~ 43000 ECAL modules



Transverse granularity allows to measure:
- *the reaction plane with the accuracy* **~ 30^0**



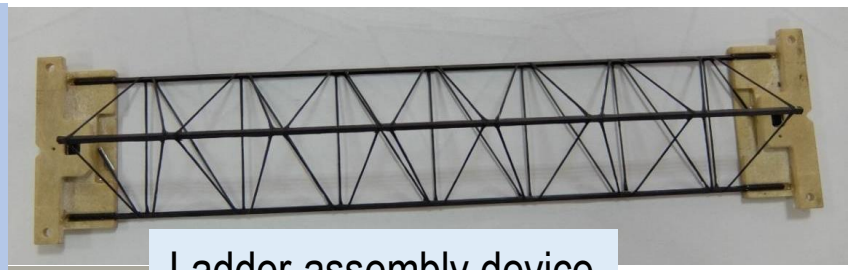




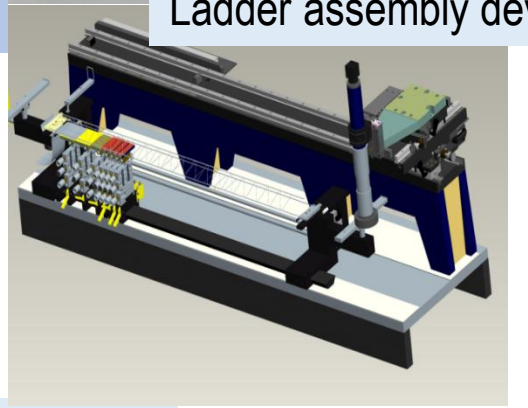
MPD after 2023: Inner Tracker System (status 2017)

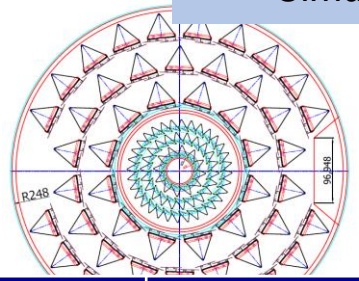
Site for module assembly: the main room (90m^2) is class 7 ISO

- Site for module assembling
- Ladder frames construction
- QA testing of sensors
- Mockuping
- Simulation: design and physics



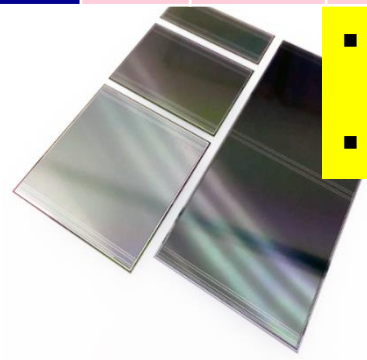
Ladder assembly device



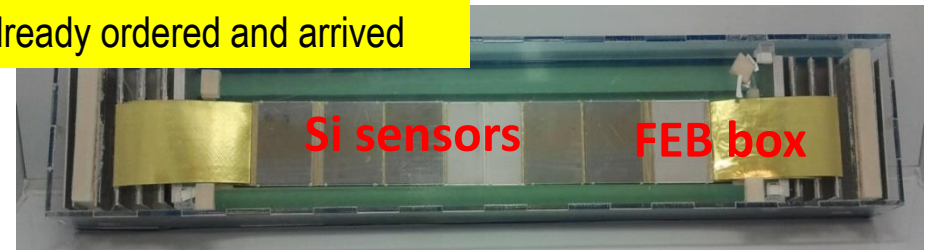


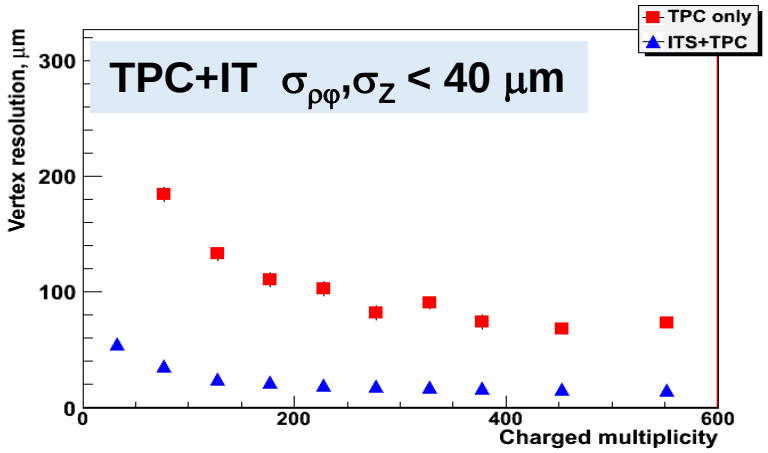
4 technicians are currently involved in module assembling

# layer	R0 mm	Active l, mm	N of staves	N of chips / layer	active area, cm2	number of pixel cells
1	24,4	542,4	12	216	889,9	113 246 208
2	42,0	542,4	22	264	1 087,7	138 412 032
3	60,0	542,4	32	384	1 582,1	201 326 592
4	107,	1477,5	12	1176	4 845,1	616 562 688
5	156,5	1477,5	18	1764	7 267,7	924 844 032
6	206,5	1477,5	24	2352	9 690,2	1 233 125 376
Total:				6156	25 362,7	3 227 516 928



- Quality assurance of the sensors: sophisticated optical and electrical methods established
- 400 sensors are already ordered and arrived



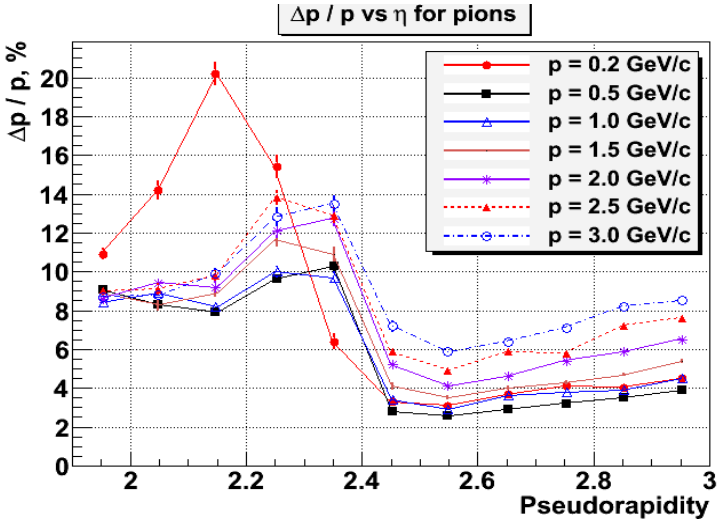


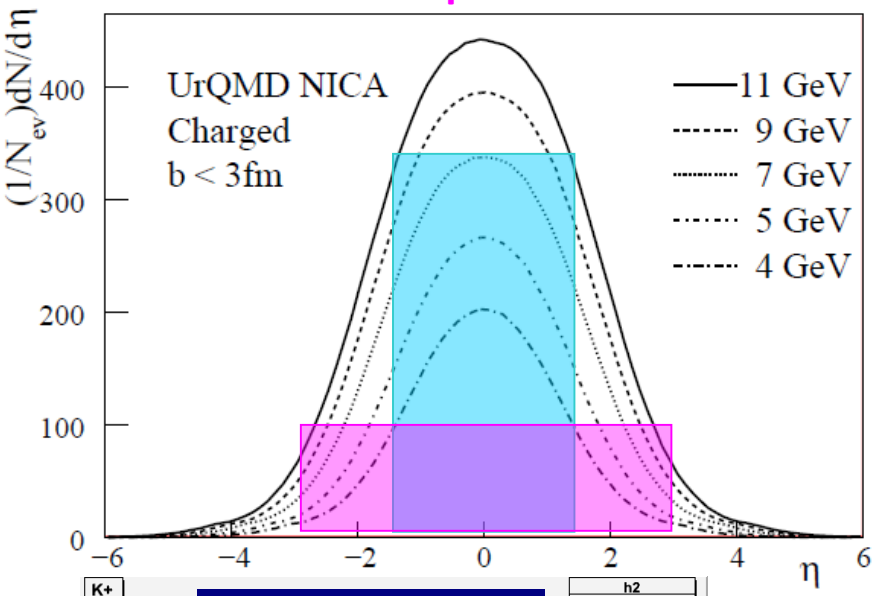
MPD beyond 2023: EndCap Tracker

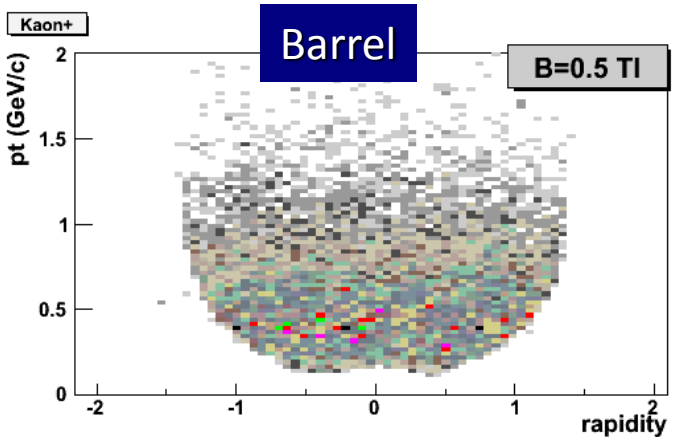
- A new technology developed to build straw detectors as multi-wheel structures
- ECT full size prototype : max. deviation ΔR < 300 mm for a R=1.1 m wheel

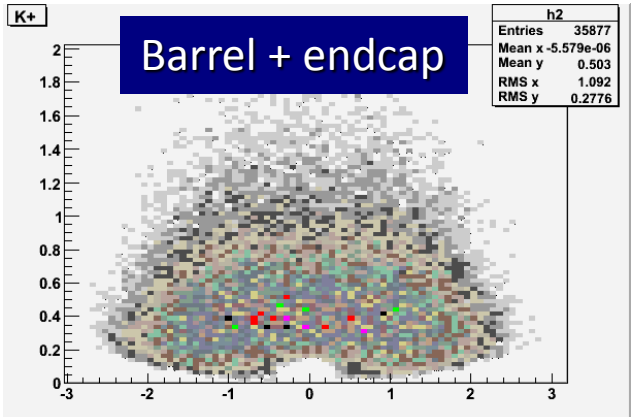
TPC+ECT+GEM tracking up to η=3

Barrel: ~60% for charged (σ_π~1.3)
Barrel+endcap: > 90%



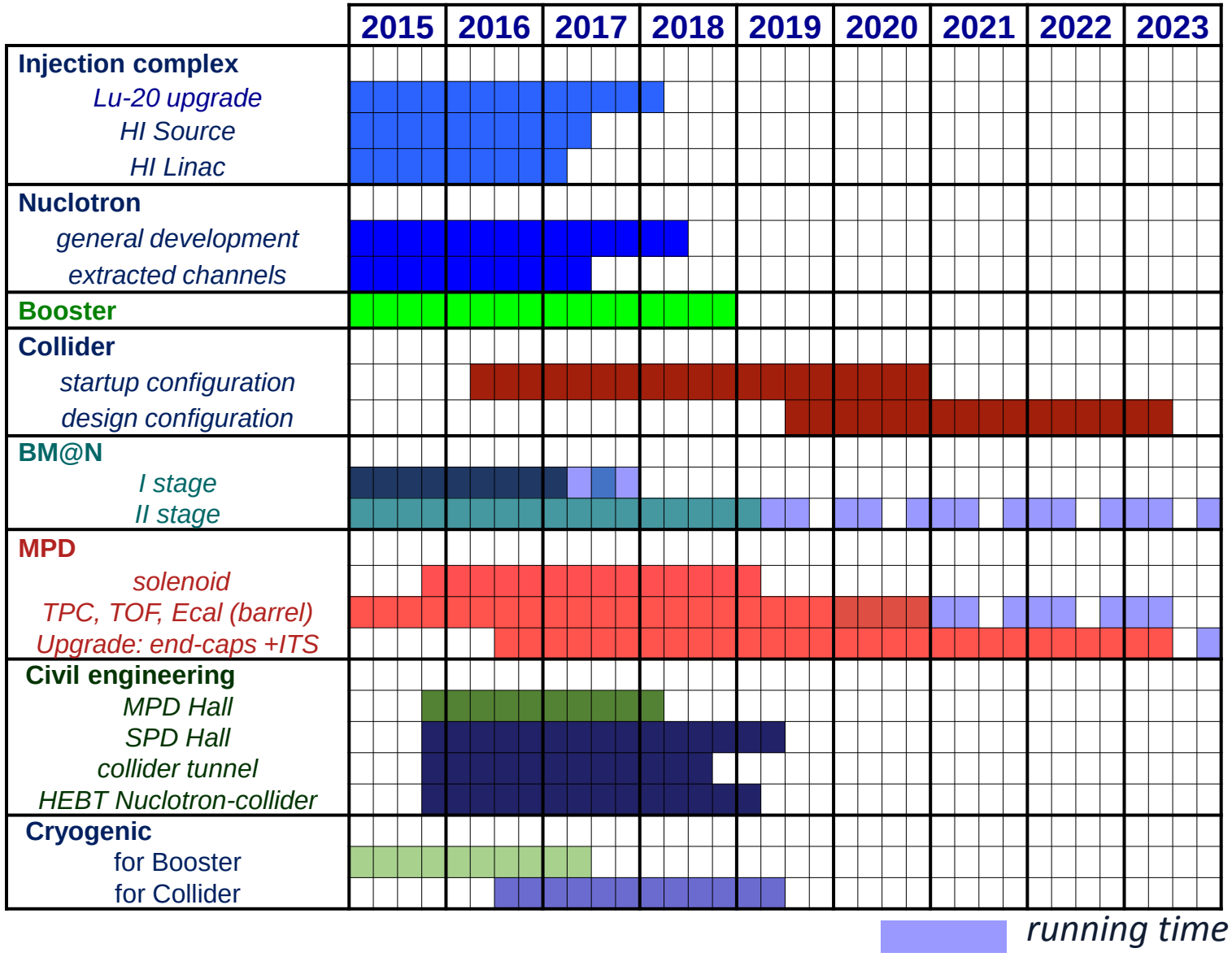






2x60 straw layers1.3<|η|<2.2
72000 straw tubes 4 mm x 60 cm

NICA schedule



NICA experimental strategy in 2021-2023

Collider: *energy and system size scan from 7 to 11(13,25) GeV in steps of 1-2*

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}

Limitations by the accelerator:

- *lower luminosity (w/o electron cooling for the collider)*
- *extra reduction by 40% because of a larger interaction region (beam diamond)*

Detector constrains:

- ***TPC*** *tracking: $|\eta|<1.8$ (Npoints>10)*
- ***TOF & ECAL*** *coverage: $|\eta|<1.5$*
- ***PID****: combined (dE/dx+TOF+ECAL) $|\eta|<1.5$, $0.1<pT<4$ GeV/c, limited in $1.5 < |\eta| < 1.8$ (only dE/dx)*
- ***FHCAL*** *coverage: $2.2<|\eta|<4.8$*
- ***FD*** *inside the TPC inner pipe*
- ***NO*** *endcaps and vertex detector*

Fixed target (BM@N) : No limitations

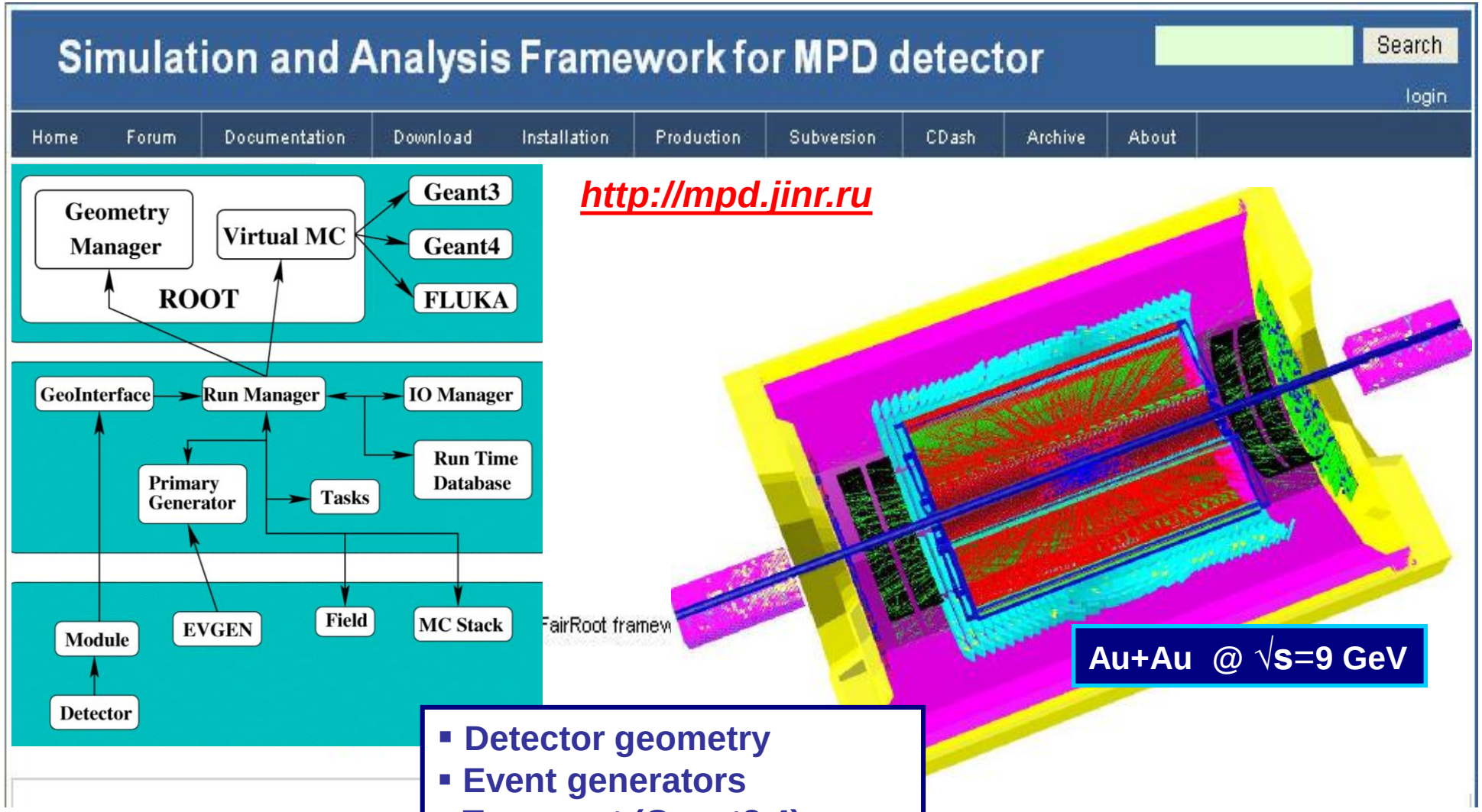
Particle yields in Au+Au collisions @ $\sqrt{s_{NN}}$ = 8 GeV
(*central collisions*)

Stage'1 (2021-23) one week of running at **L = 5 · 10^{25}cm^{-2}s^{-1}** *(duty factor = 0.5)*

Particle	Multiplicity	Decay mode	BR	*Efficiency %	Yield /1 w
π^+	293	----	---	61	$7.7 \cdot 10^8$
K^+	59	---	----	50	$1.5 \cdot 10^8$
p	140	---	----	60	$4.2 \cdot 10^8$
Λ	~35	$p+\pi^-$	64%	10%	$2 \cdot 10^7$
Ξ^-	~2	$\Lambda+\pi^-$	~100%	2.5%	$1.5 \cdot 10^5$
ρ	31	e+e-	$4.7 \cdot 10^{-5}$	35	$2.5 \cdot 10^3$
ω	20	e+e-	$7.1 \cdot 10^{-5}$	35	$2.5 \cdot 10^3$
φ	2.6	e+e-	$3 \cdot 10^{-4}$	5	$2.0 \cdot 10^2$
Ω	0.14	Λ+K	0.68	1	$1.0 \cdot 10^4$

*Efficiency includes the MPD acceptance, realistic tracking and particle ID.
Particle Yields from experimental data (NA49), statistical and HSD models.

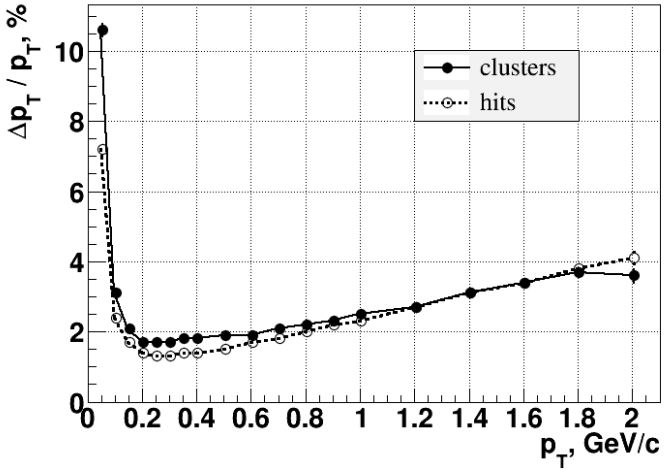
MC simulation - MPDRoot

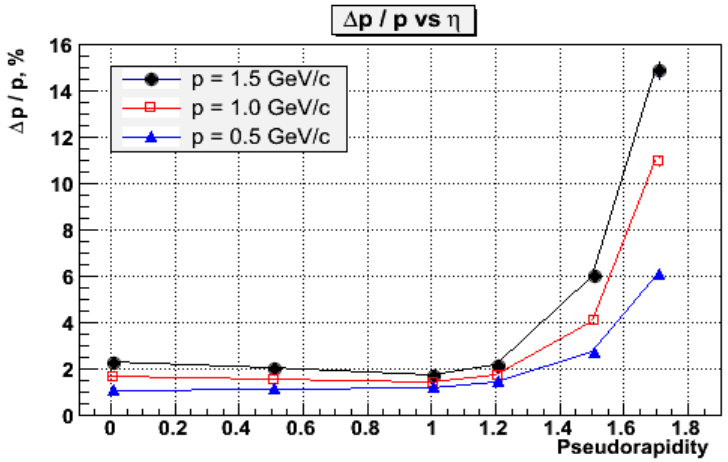


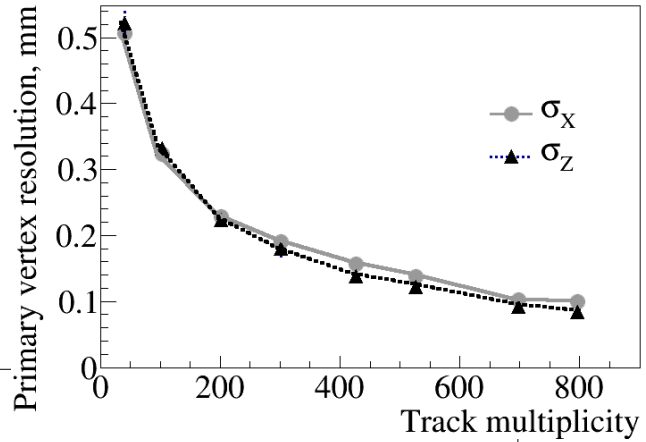
- Detector geometry
- Event generators
- Transport (Geant3,4)
- Response simulation
- Reconstruction algorithms
- Analysis tools

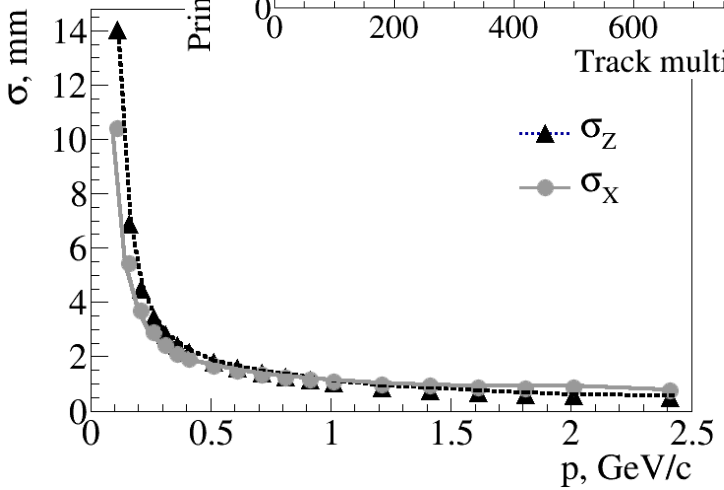
MPD tracking performance (TPC)

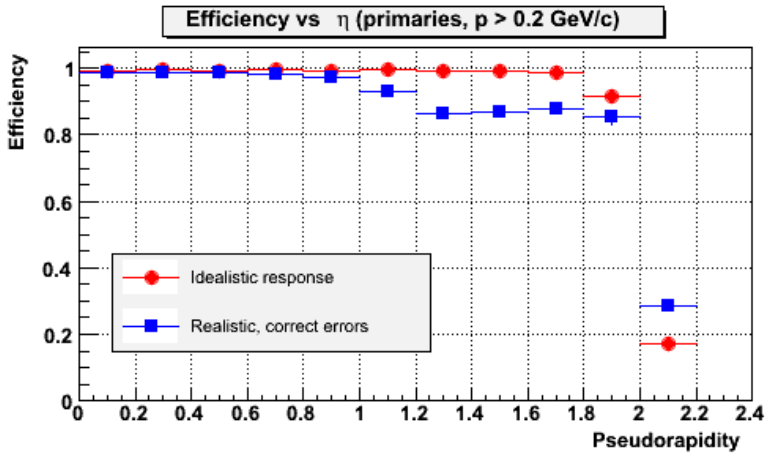
- Track reconstruction – Kalman filtering technique
- Tracking down to η= 1.8(1.6) with Npoints>10(20)
- Primary & secondary vertexing with Kalman filtering formalism (sub-cm precision w/o vertex detector)
- MPD tracking efficiency above 85% within |η|<1.8 && p_t>0.15 GeV/c
- Δp/p < 3% at midrapidity

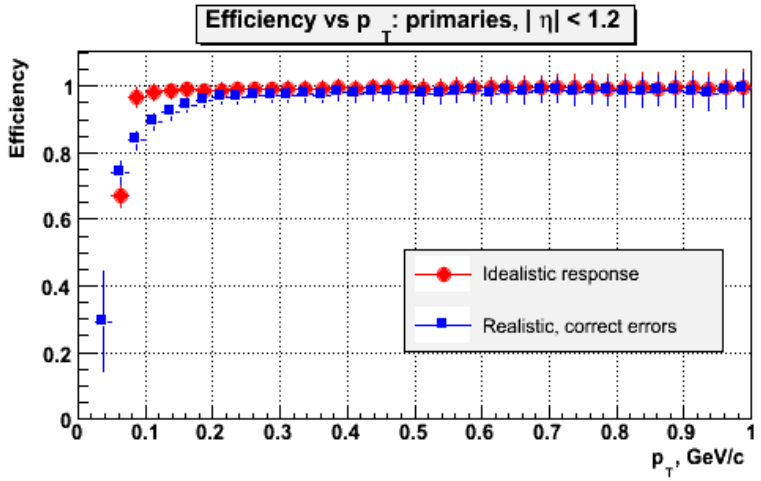






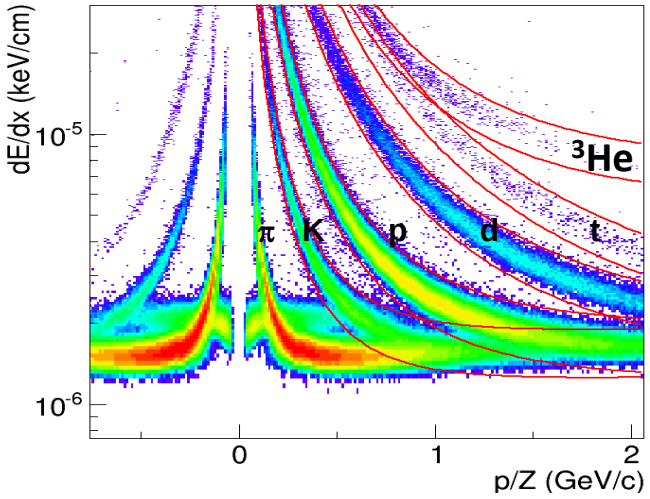


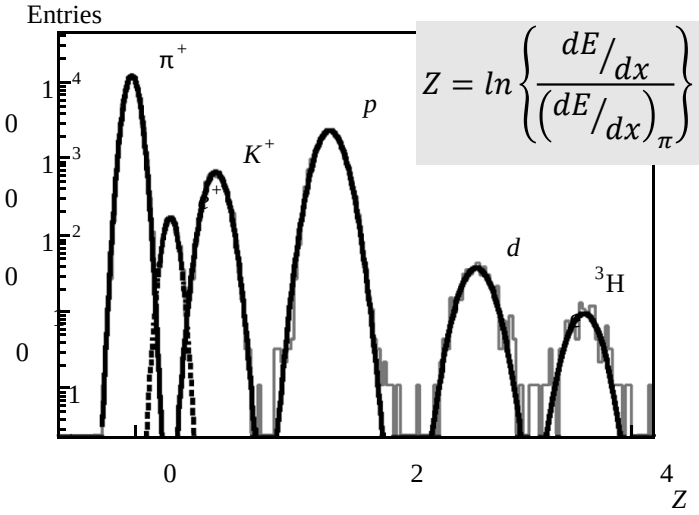


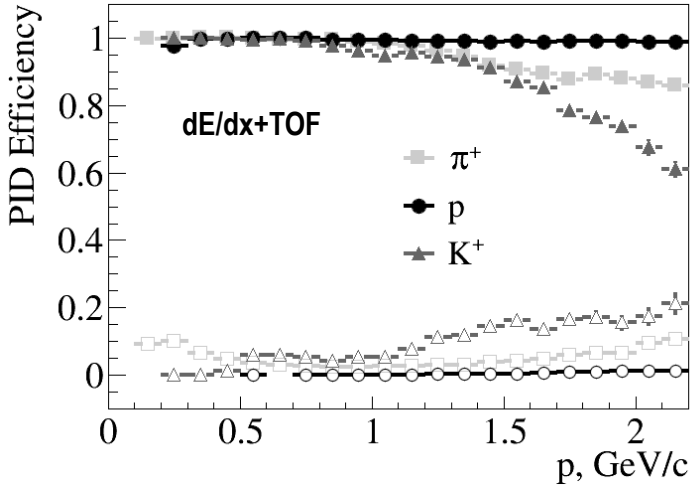


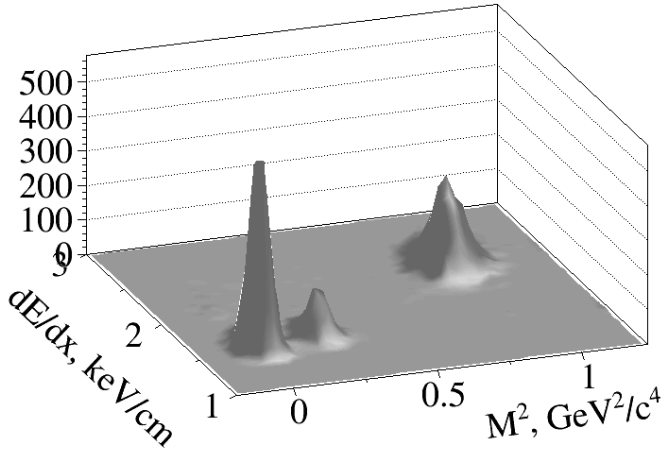
MPD Particle Identification

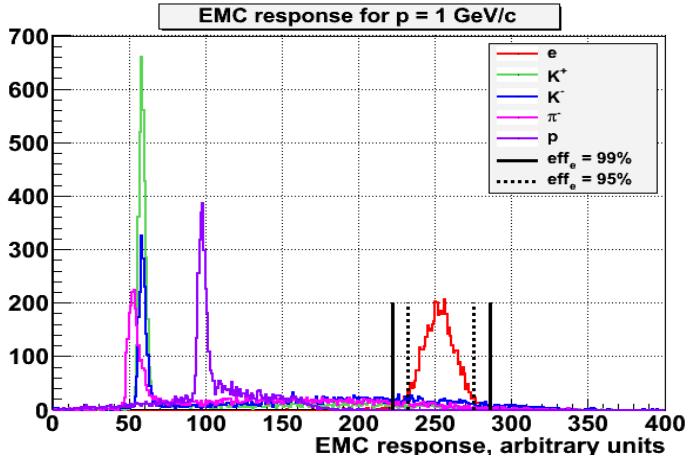
- Hadron (π,K,p) identification up to 3 GeV/c, midrapidity nuclei PID
- Electron PID with hadron suppression up to 10^5
- Secondary vertex reconstruction – hyperons & hypernuclei @ midrapidity

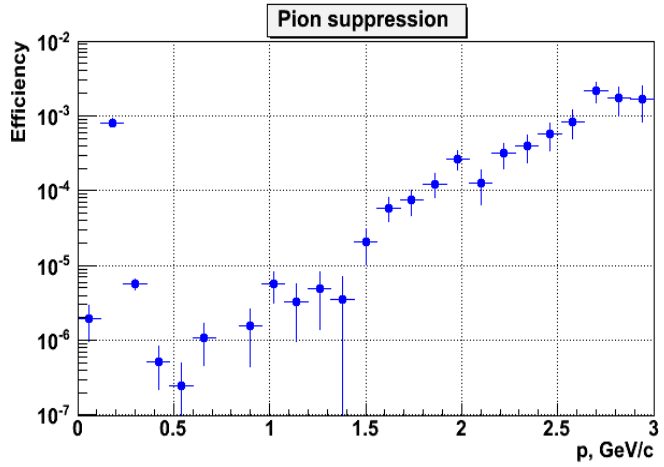




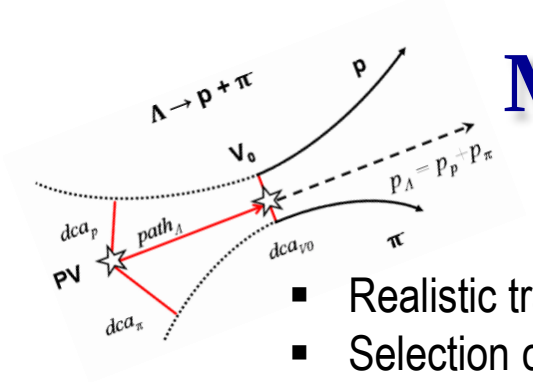




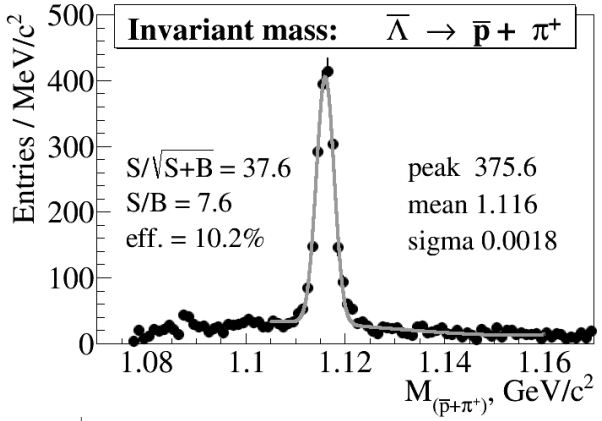


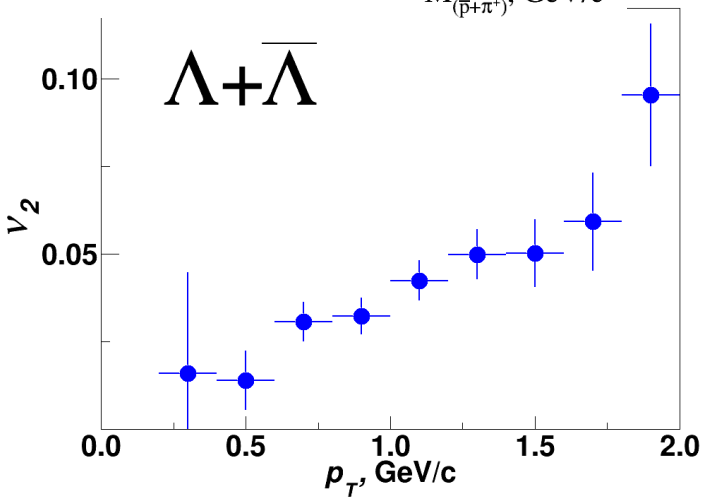


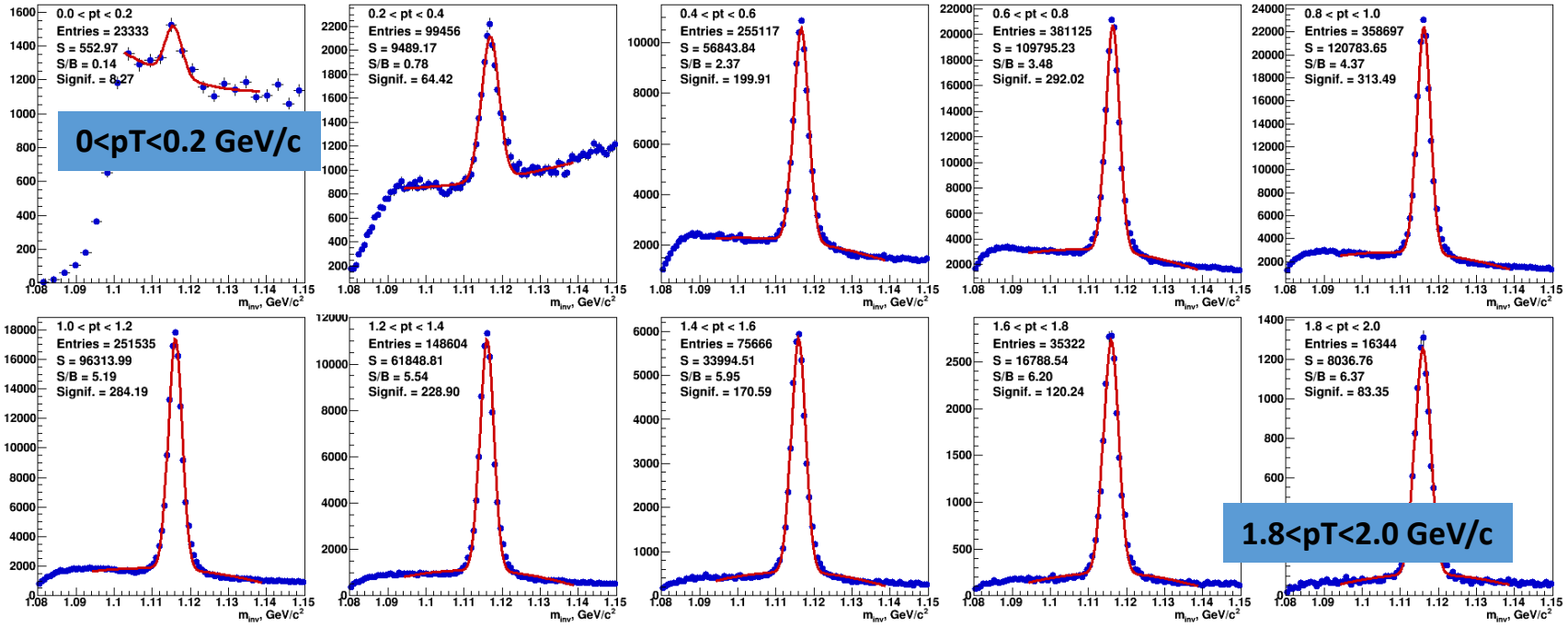
MPD performance: strangeness (Lambda flow)



- Realistic tracking and PID
- Selection criteria dictated by the decay topology
- Optimal cut values (i.e. DCA at the primary vertex, two-track separation, etc.) found from multidimentional scan over the set of criteria with a requirement to maximize the significance
- Hyperons studied up to pT=2 GeV/c, low-pT part of the spectra needs further optimization of the selection criteria

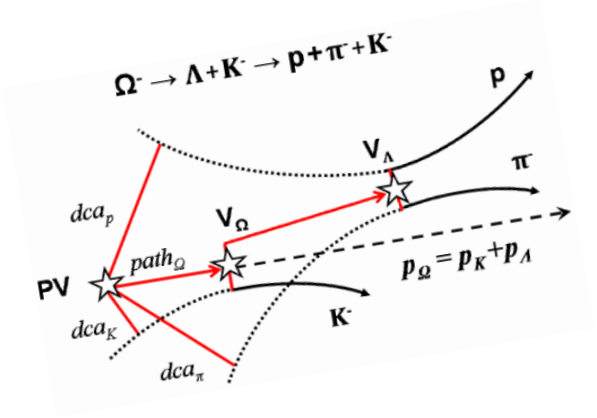






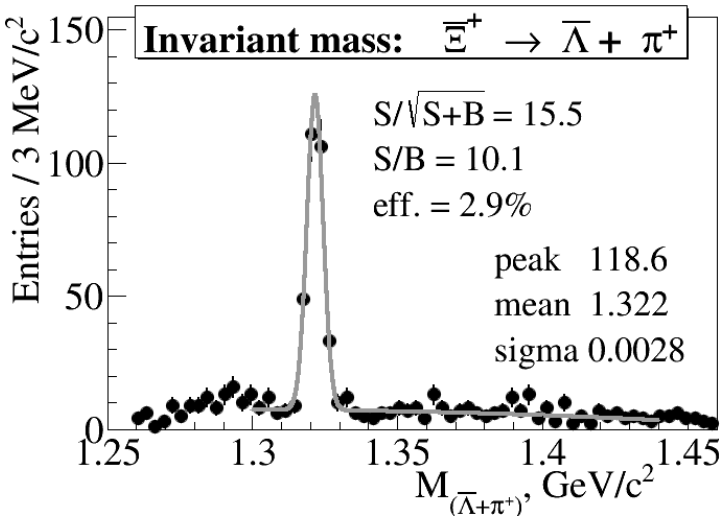
- Min. bias Au+Au @ 11A GeV (UrQMD), TPC+TOF barrel
- Secondary vertex reconstruction
- Event plane from TPC tracks

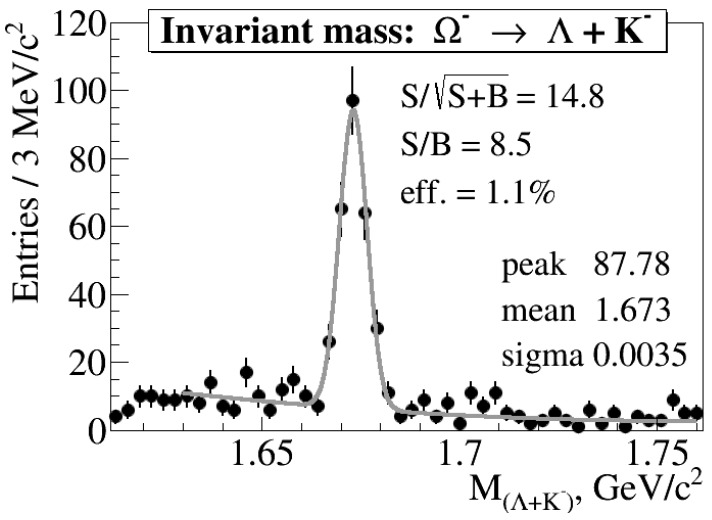
MPD performance: multi-strangeness (Stage1)



- Stage'1 MPD configuration (TPC+TOF)
- Selection criteria dictated by the decay topology

- ~ 5 · 10 [5] central Au+Au at 9 GeV
- Λ- candidates in the invariant mass window ±3σ around the peak combined with kaons
- Topological cuts optimized to maximize significance
- Constrained at low pT (pT>0.2 GeV/c)





Yields for 10 weeks of running

Particle	Λ	anti-Λ	Ξ⁻	anti-Ξ⁺	Ω⁻	anti–Ω⁺
Yield	$3 \cdot 10^8$	$3.5 \cdot 10^6$	$1.5 \cdot 10^6$	$8.0 \cdot 10^4$	$7 \cdot 10^4$	$1.5 \cdot 10^4$

Comments
(concerning charm at NICA)

- Primarily, the charm production **was not** in the list of the NICA physics cases

- Low X-section (close to the threshold for the open charm) and moderate event rate at the collider yields a statistics of about 10^4 (10^3) per 10 weeks of data taking for open (charmonium) in A+A at NICA

- Construction of an expensive vertex detector needed for such a study had a second priority for the NICA-MPD experiment (lack of experience, finance and man power at JINR), **No** realistic feasibility for charm

- Recently, this situation has changed (progress in technology , support from theory, plus stable financing situation). It is too late to include charm to the Stage'1 NICA program (2021-23), if, however, the potential of such studies at NICA energies is high - **there is a possibility to reconsider the priorities of the NICA physics cases beyond 2023.**

- **The main goal** of our participation in the Workshop is twofold: 1) to present current status of the NICA project and 2) hear about perspectives for the study of charm production in HIC at CM energies from 4 to 17 GeV (dense baryonic matter)

Particle yields in Au+Au collisions @ $\sqrt{s_{NN}}$ = 8 GeV
(central collisions)

Stage'2 (>2023) Expectations for 10 weeks of NICA running at L = $10^{27}cm^{-2}s^{-1}$ (duty factor = 0.5)

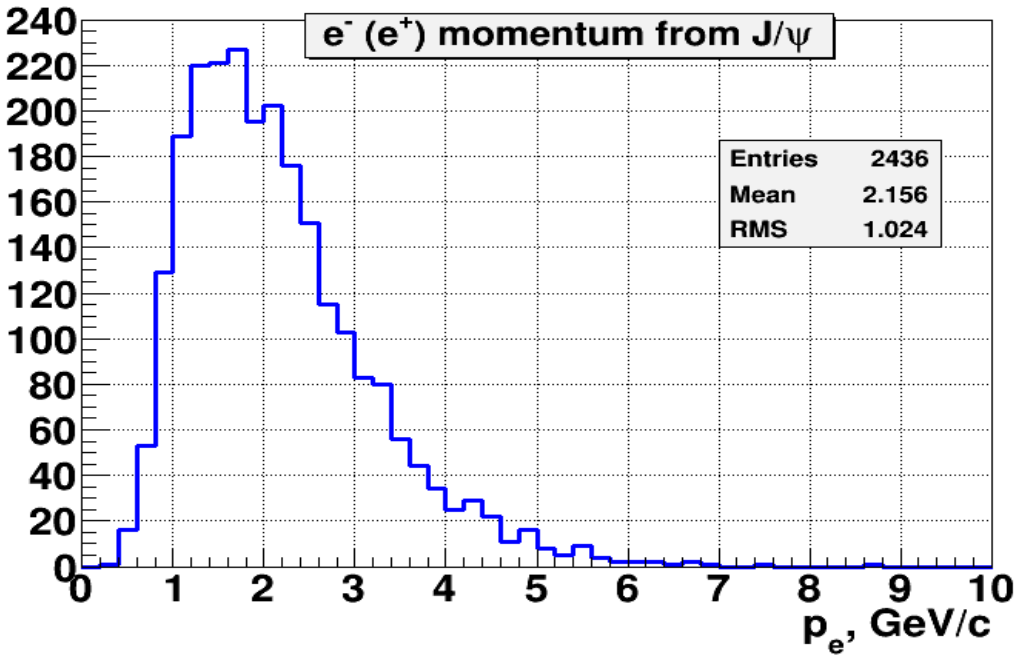
Particle	Multiplicity	Decay mode	BR	*Efficiency %	Yield/10 w
π^+	293	----	---	61	$2.6 \cdot 10^{11}$
K^+	59	---	----	50	$4.3 \cdot 10^{10}$
p	140	---	----	60	$1.2 \cdot 10^{11}$
ρ	31	e+e-	$4.7 \cdot 10^{-5}$	35	$7.3 \cdot 10^{5}$
ω	20	e+e-	$7.1 \cdot 10^{-5}$	35	$7.2 \cdot 10^{5}$
φ	2.6	e+e-	$3 \cdot 10^{-4}$	15	$1.7 \cdot 10^{5}$
Ω	0.14	ΛK	0.68	1	$1.5 \cdot 10^{6}$
D^0	$2 \cdot 10^{-3}$	$K^+\pi^-$	0.038	20	$2.2 \cdot 10^{4}$
J/ψ	$8 \cdot 10^{-5}$	e+e-	0.06	15	10^3

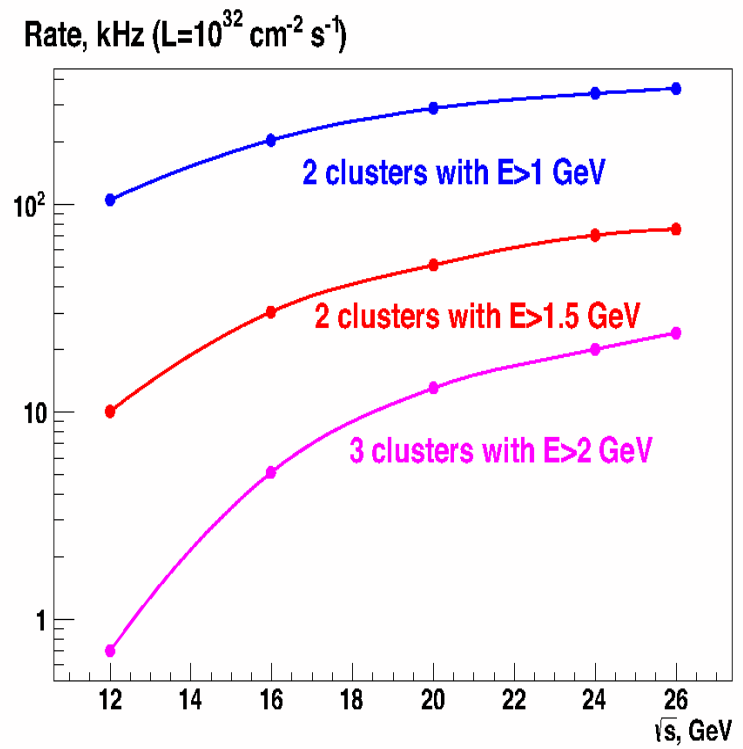
*Efficiency includes the MPD acceptance, realistic tracking and particle ID.
Particle Yields from experimental data (NA49), statistical and HSD models.

MPD potential for study charmonium-like states in p+p(A) collisions at NICA

- MPD detector has a potential to extend its physics program beyond the heavy-ion scope by studying heavy charmed objects via their decays to electrons, hadrons or photons

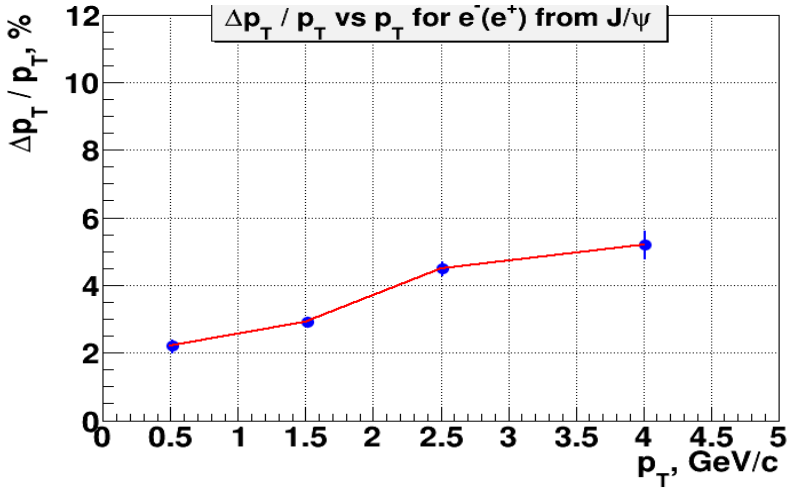
- At higher luminosity (p+p or light ions of Z/A~0.5) a high level trigger on high-pT leptons (ECAL) to enhance interesting event rates can be utilized (not exceeding 30kHz level)

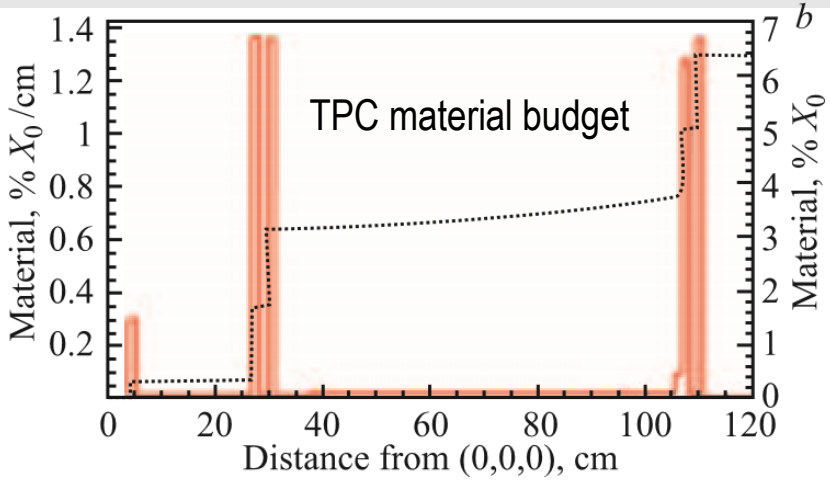


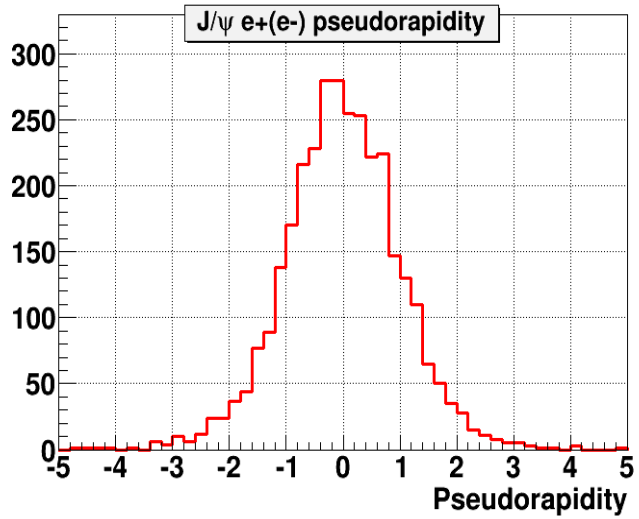


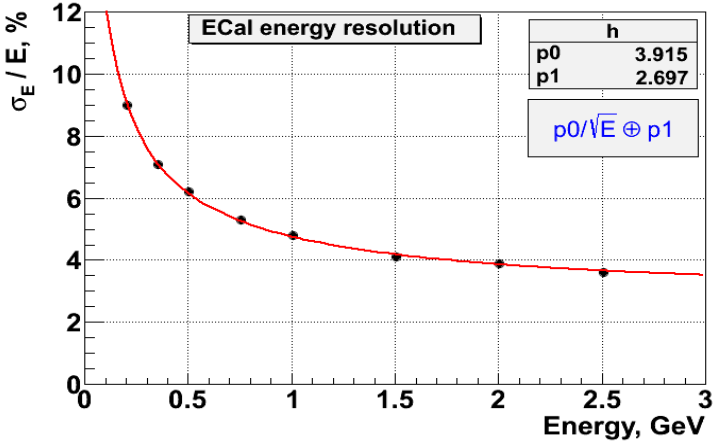
J/ψ in p+p collisions at NICA : feasibility study

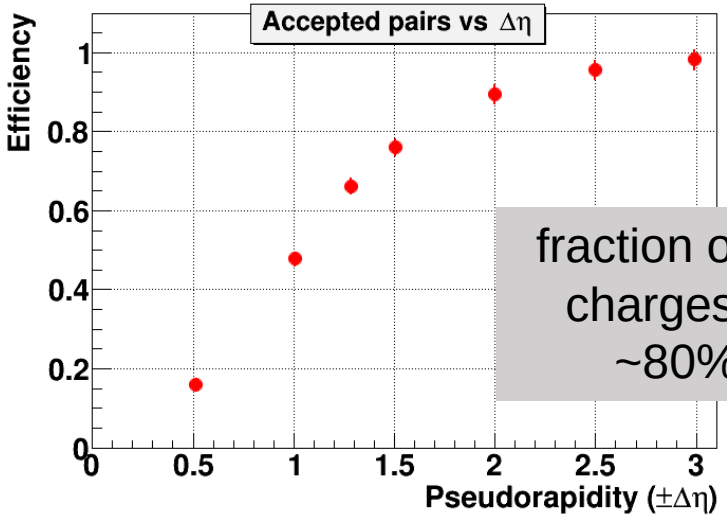
- *p+p at 25 GeV (Pythia8), event mixing*
- *10 weeks of running time: L = 10^{29} $cm^{-2}c^{-1}$ (Stage'1) L_{int} = 604.8 nb^{-1}*
- *Decay channel J/ψ → e^+e^- (branching ratio ~6%)*
- *MPD detector – TPC+TOF+ECAL (|η|<1.5), w/o vertex detector*
- *MpdRoot: Geant3, realistic track and vertex reconstruction*









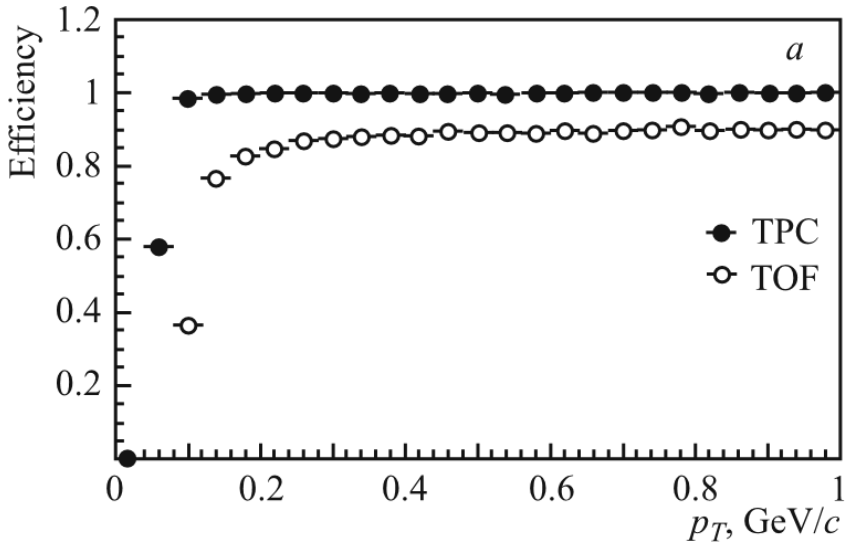


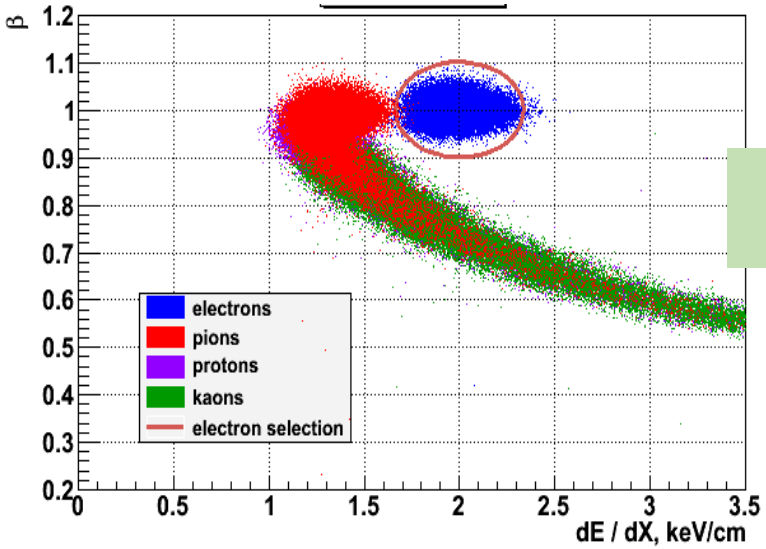
fraction of $J/\psi \rightarrow e^+e^-$ decays with both charges within the MPD acceptance ~80% acceptance for the |η|<1.5

J/ψ in p+p at NICA : analysis details

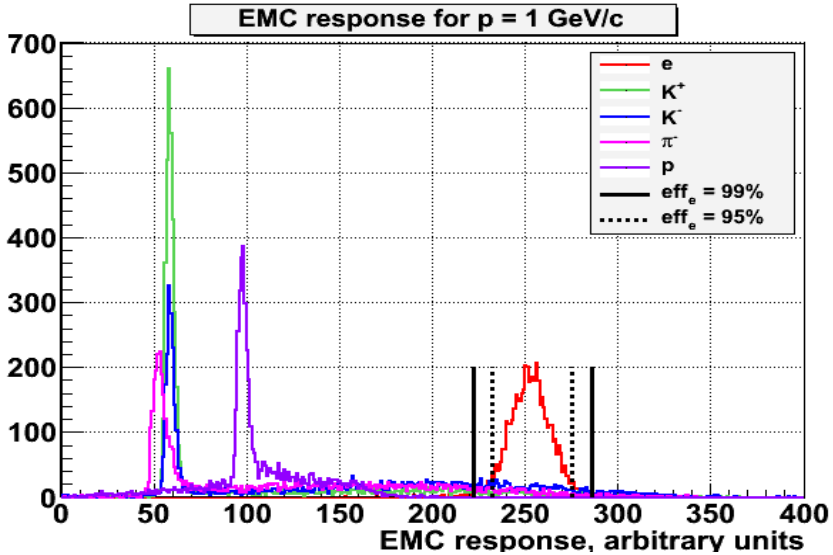
Cuts at Stage'1 MPD setup:

- Number of space points
- DCA to the primary vertex
- Cuts for removing conversion pairs
- Kinematical (low-pT) cut (pT>0.5 GeV/c)

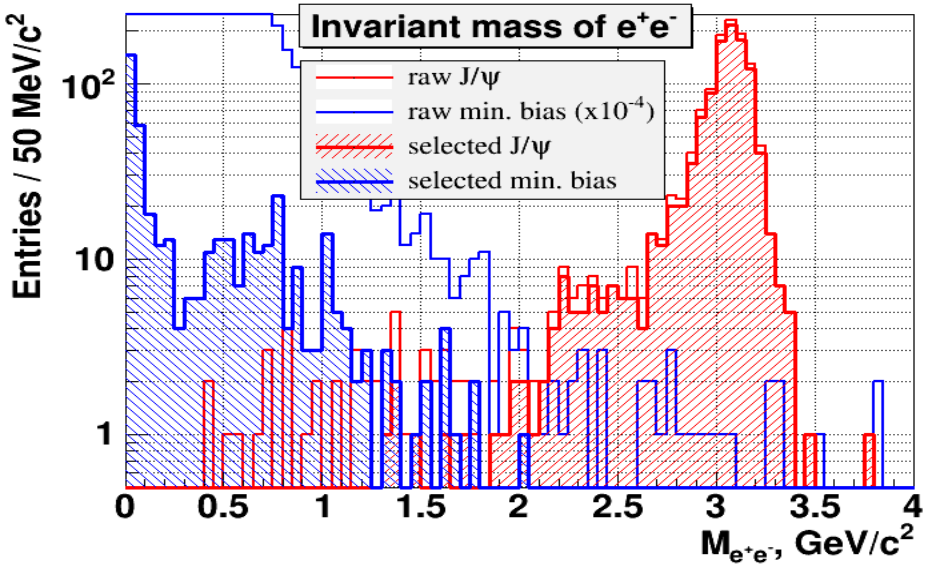


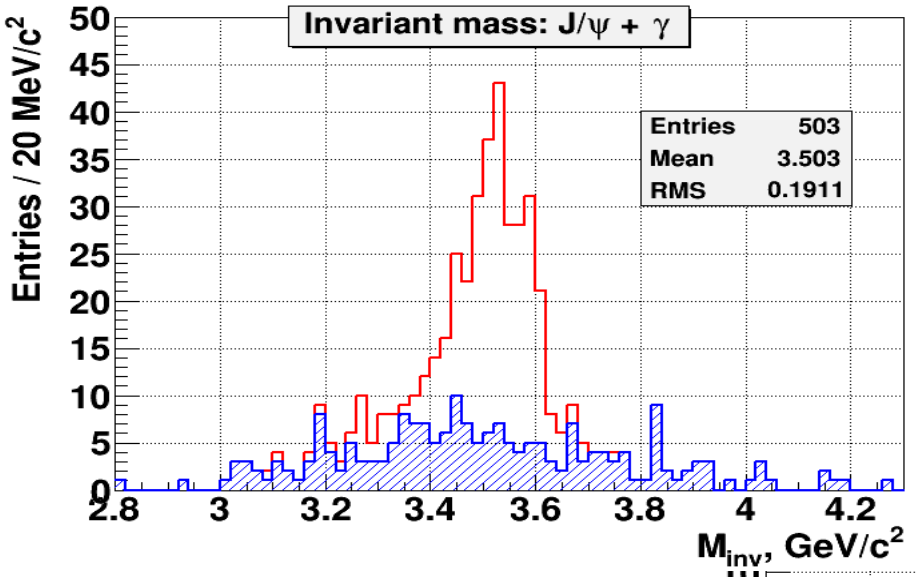


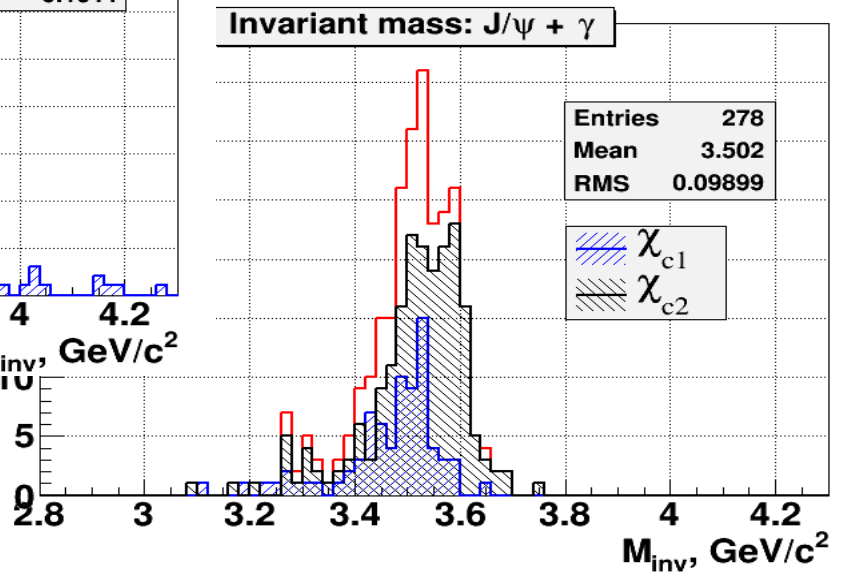
Electron PID: dE/dx+TOF+ECAL
Hadron suppression ~ 10^{-4}



Results: Invariant mass $e^- + e^+ + n\gamma$







Estimates for the NIAC-MPD (10 weeks Stage'1)

J/ψ – x-section *from Pythia 41.5 nb (factor ~2 below experiment)*

Statistics: $N_{J/\psi} = L_{int} \times \sigma_{J/\psi} \times Br_{J/\psi \to e+e-} \times Eff._{\Delta\eta<1.5} =$

604.8 x 41.5 x 0.06 x 0.8 = ***1205 (x 10..100 after 2023)***

$\sigma_{\chi c1}$ *from X-section from Pythia6 13.7 nb*

Statistics: $N_{\chi c1} = L_{int} \cdot \sigma_{\chi c1} \cdot Br_{\chi c1 \to \gamma+J/\psi} \cdot Eff._{\Delta\eta=\pm1.5} \cdot Br_{J/\psi \to e+e-} \cdot Eff._{\Delta\eta=\pm1.5} =$

$604.8 \cdot 13.7 \cdot 0.27 \cdot 0.9 \cdot 0.06 \cdot 0.8 = 97$

$\sigma_{\chi c2}$ *X-section from Pythia6 66.6 nb*

Statistics: $N_{\chi c2} = L_{int} \cdot \sigma_{\chi c2} \cdot Br_{\chi c2 \to \gamma J/\psi} \cdot Eff._{\Delta\eta=\pm1.5} \cdot Br_{J/\psi \to e+e-} \cdot Eff._{\Delta\eta=\pm1.5} =$

$604.8 \cdot 66.6 \cdot 0.14 \cdot 0.9 \cdot 0.06 \cdot 0.8 = 244$

Stage'1 @ NICA (p+p):

An extra suppression factor of 10-50 is needed (stronger cuts, vertex detector) to make charmonium feasible

Summary

- **Construction of the NICA complex is well in progress**
  (civil construction, accelerator components, service systems)

- **Substantial progress in the construction of the detectors:**
  - BM&N experiment – commissioning runs started
  - MPD design has optimized for Day'1 physics,
  preparation for mass-production ongoing

- **Stage'1 period of the NICA-MPD (until 2023) – up to S=-2 strangeness,**
  No charm before NICA accelerator upgrade and MPD completion

- **NICA-MPD potential for the charm at the Stage'2 is under investigation.**
  No promising results w/o vertex detector, IT realistic simulation is under development

Thank you for your attention!