# 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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**(JINR)**

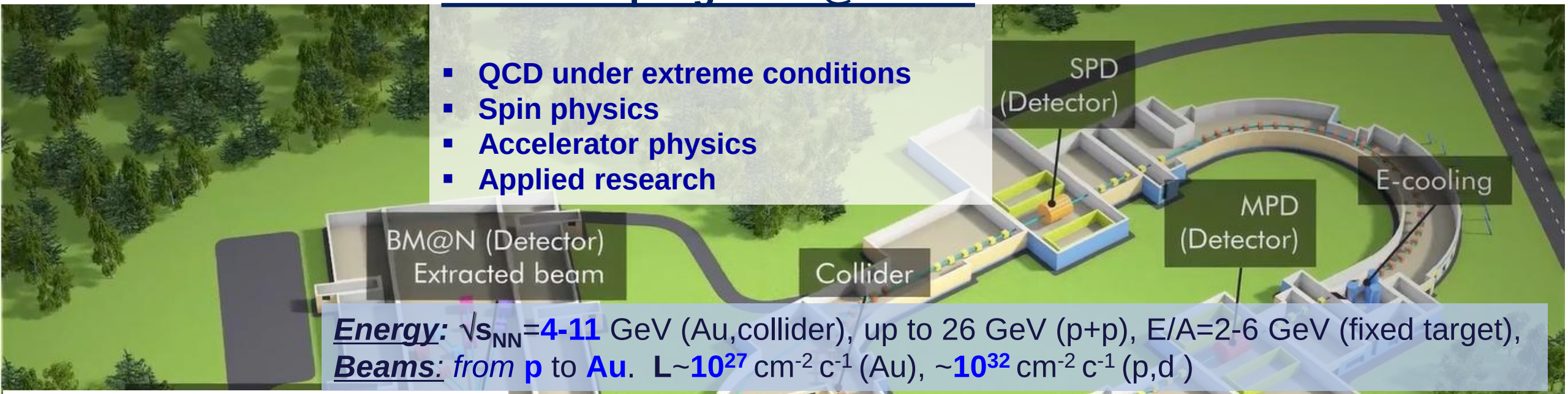
On behalf of the NICA-MPD

# Outline

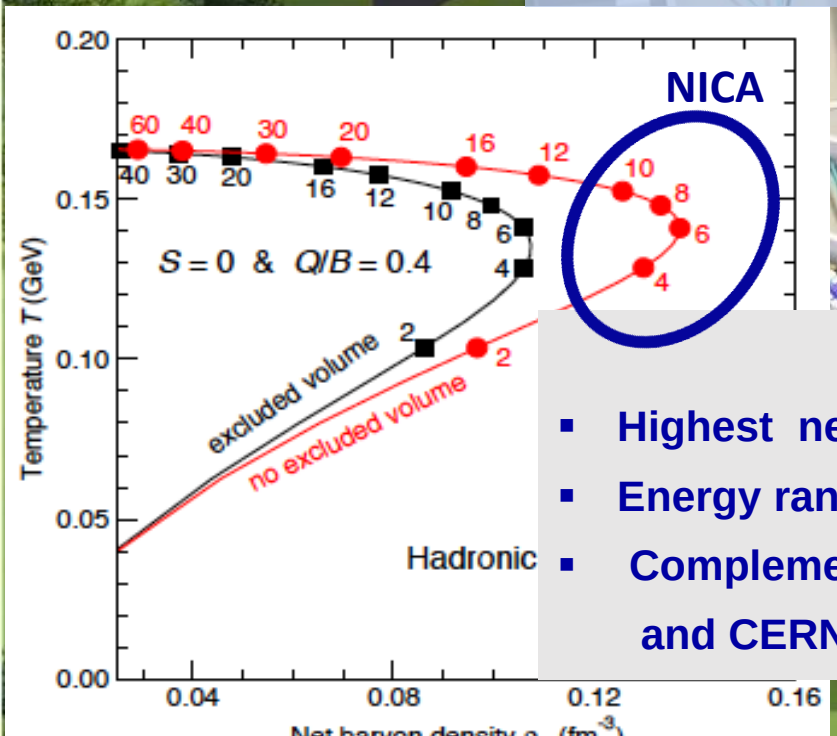
- Introduction
- Progress in the NICA project realization
  - accelerator: construction status
  - detectors @ NICA : preparation for mass-production
- Multistrangeness at the MPD detector: performance study
- Charmonium production in p+p at NICA-MPD: feasibility
- Summary

# Research programs @ NICA

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

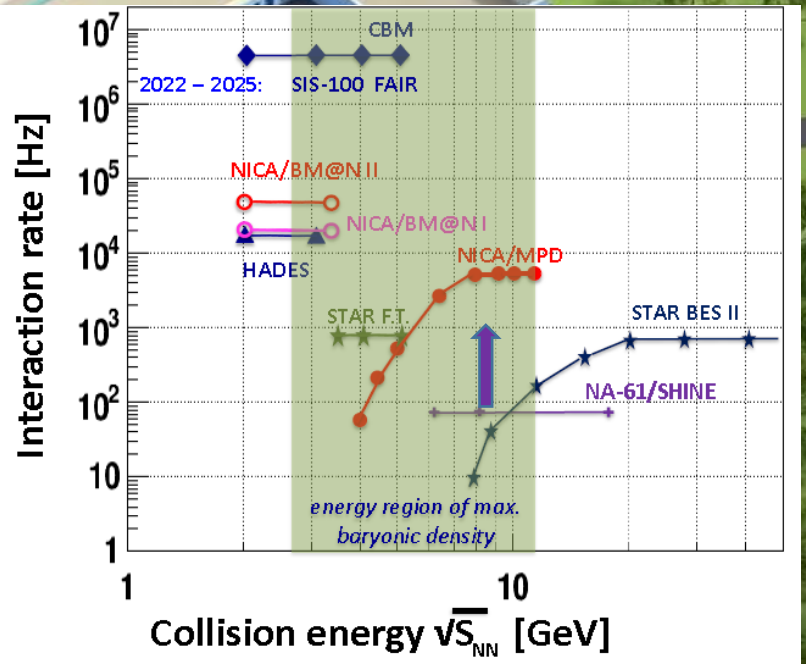



***Energy:*** $\sqrt{s_{NN}}$=**4-11** GeV (Au,collider), up to 26 GeV (p+p), E/A=2-6 GeV (fixed target),
***Beams:*** *from* **p** to **Au**. **L~$10^{27}$** $cm^{-2}$ $c^{-1}$ (Au), ~**$10^{32}$** $cm^{-2}$ $c^{-1}$ (p,d )



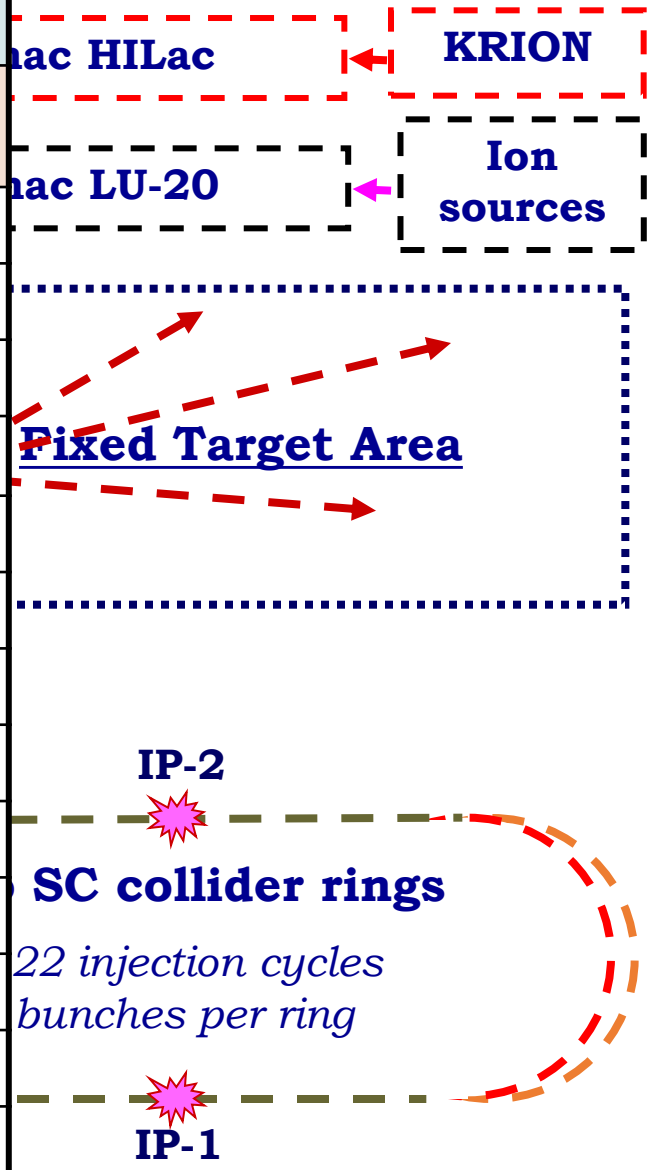

## QCD matter at NICA :

- 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)

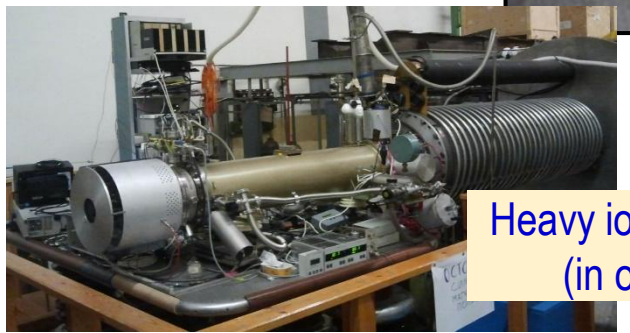
- ***Infrastructure developments: civil construction, service systems upgrade (water cooling, cryogenics, electric power, etc.)***
- ***Accelerator elements construction***

**“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)



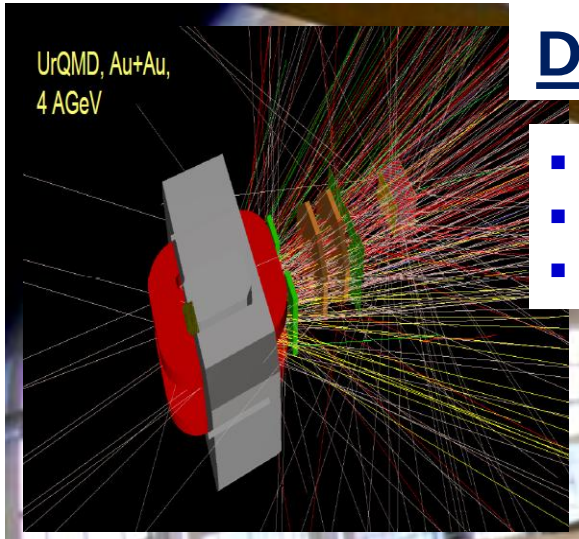
Heavy ion source: Krion-6T ESIS
(in operation since 2015)

# 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

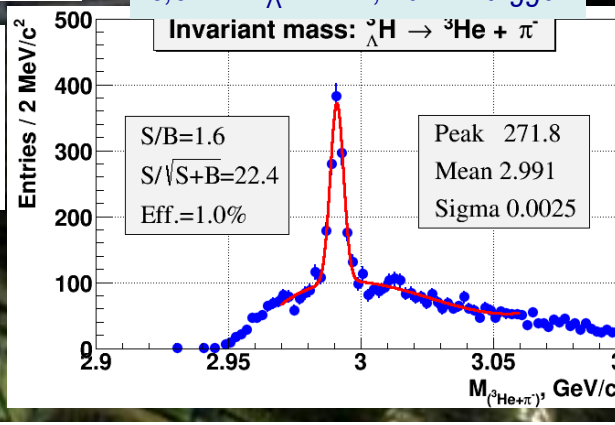



- Well suited for exploration of reaction mechanism & in-medium properties
- Energy range of limited experimental information
- Expectation of rich structure of the QCD phase diagram @ high densities

## Physics cases:

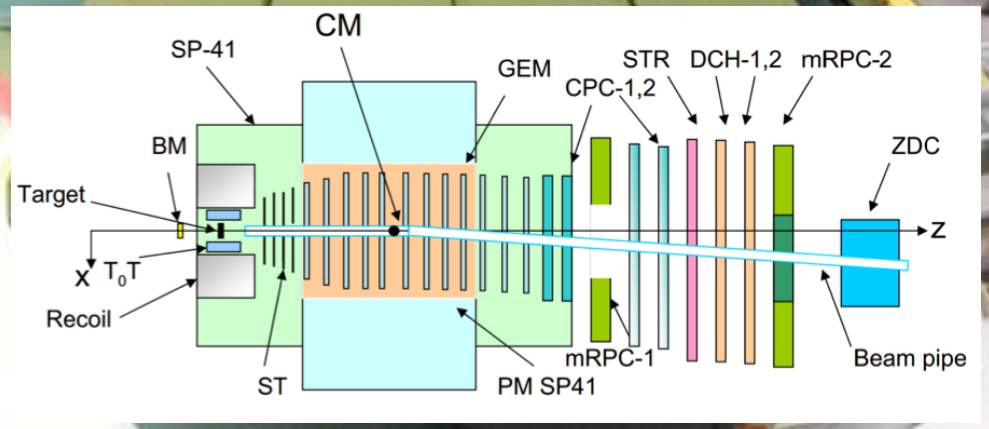
- Bulk properties, EOS
- In-medium meson-nucleon potential at high $\rho_B$
- Sub-threshold production of strange hadrons in A+A
- Measurement of elementary reactions

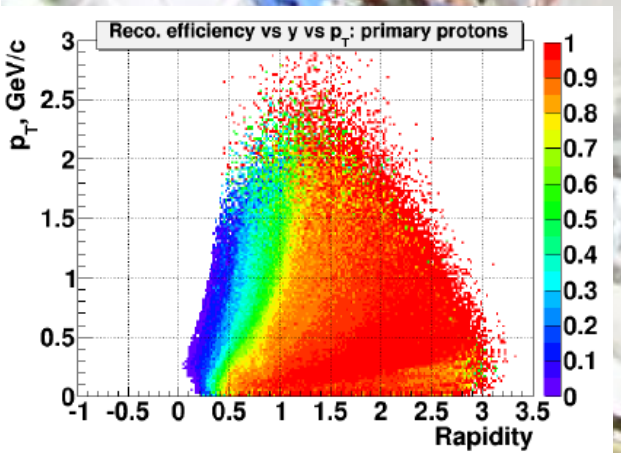
*2,6M central Au+Au*
*8,5M $^3H_\Lambda$ in 1 m, 20 kHz trigger*



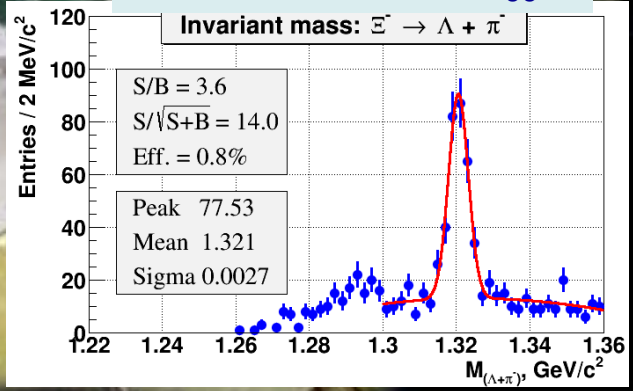

**BM@N Collaboration:**

**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*

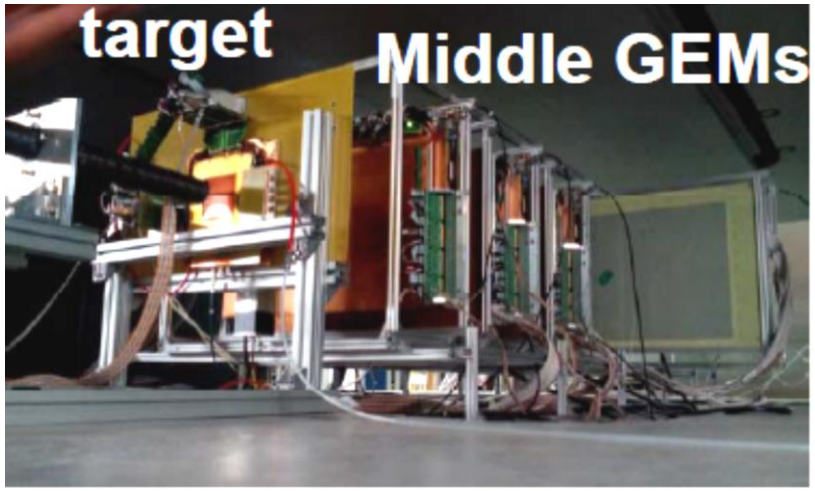


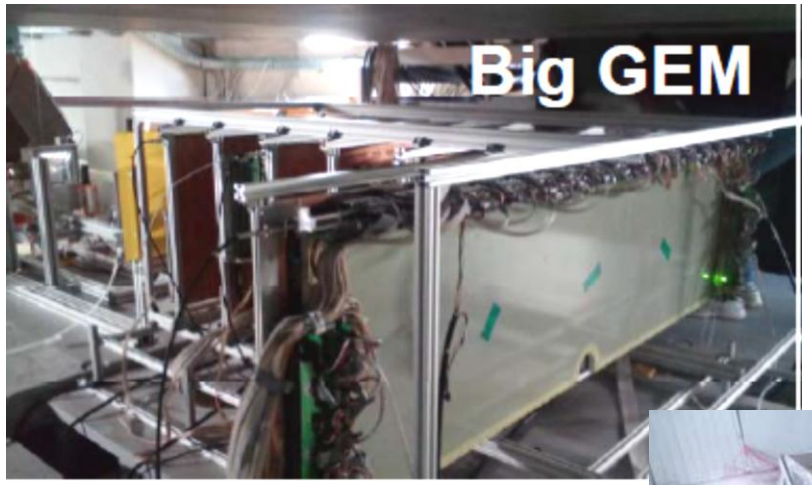




*900 k central events*
*7,5M $\Xi^-$ in 1 m, 20 kHz trigger*



# **BM@N** status and data taking plans



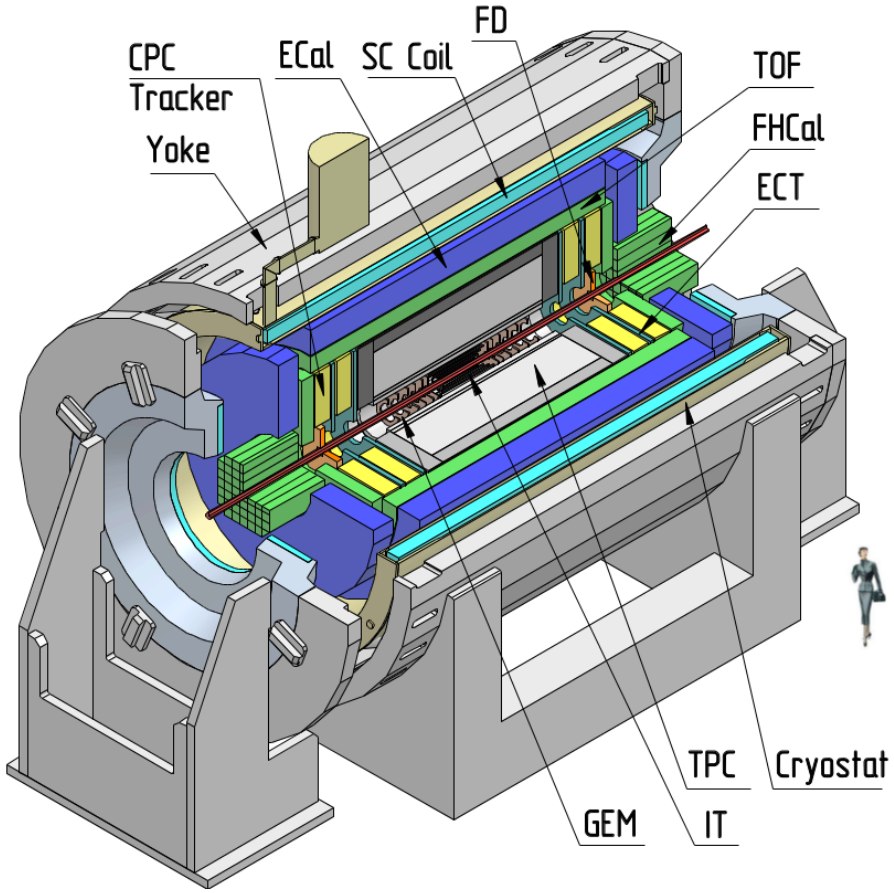




| year | 2016 | 2017 Feb.-Mar. | 2017 Nov.-Dec. | 2019 | 2020 + .. |
|---|---|---|---|---|---|
| *beam* | d ( ) | C, Ar | Kr | Au | Au, p |
| *maximum intensity, Hz* | 1M | 1M | 1M | 1M | 10M |
| *trig. rate, Hz* | 10k | 10k | 20k | 20k | 50k |
| *central tracker* | 6 GEM half pl. | 8 GEM half pl. | 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.*



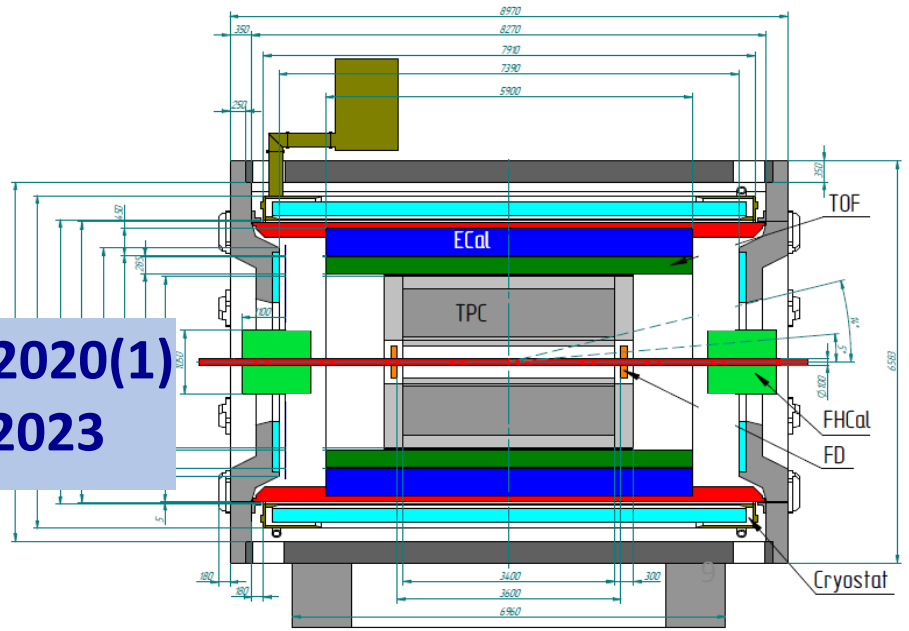

***Bulk properties, EOS***
particle yields & spectra, ratios, femtoscopy, flow
**measure:** $\gamma$, $\pi$, K, p, $\Lambda$, $\Omega$, (anti)particles, light nuclei

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

***Deconfinement (chiral) phase transition at high $\rho_B$***
enhanced strangeness production
Chiral Magnetic (Votical) effect, $\Lambda$ polarization

***QCD Critical Point***
event-by-event fluctuations and

***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

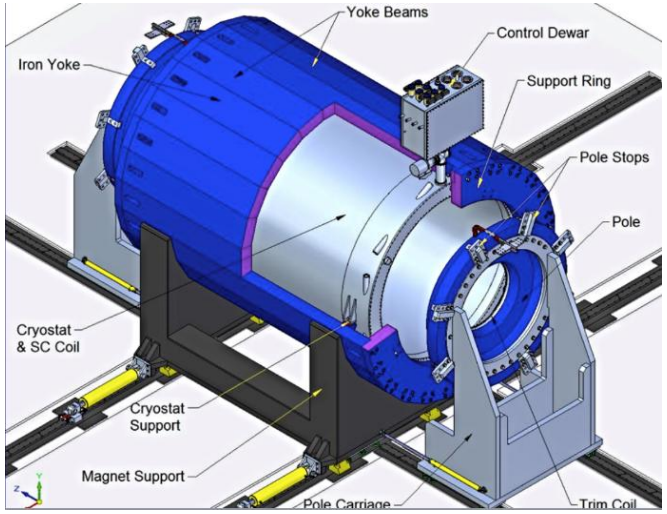
*I stage (barrel)* – **2020(1)**
*upgraded (IT + endcaps)* – **2023**

# MPD magnet: construction status

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

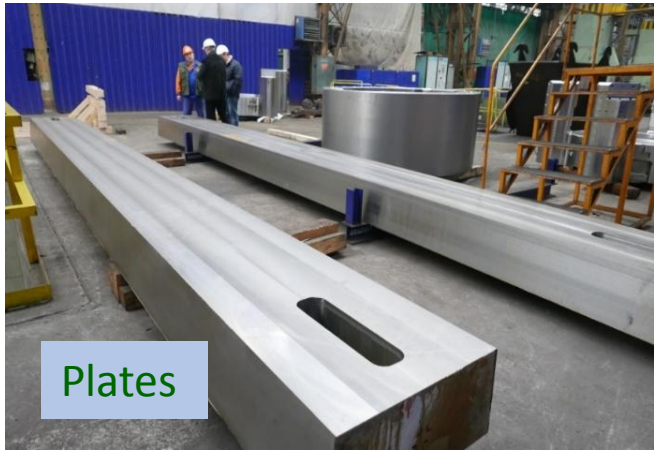
| | |
|---|---|
| Manufacturing | Jan. 2016-Aug. 2018 |
| Final Solenoid tests by AGS | Jun. 2018 |
| Packaging and Transportation | Apr. 2018-Oct. 2018 |
| Assembly at JINR, tests | Oct. 2018-Apr. 2019 |

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




Support rings

Aluminum support cylinder blanks for SC coil during transportation



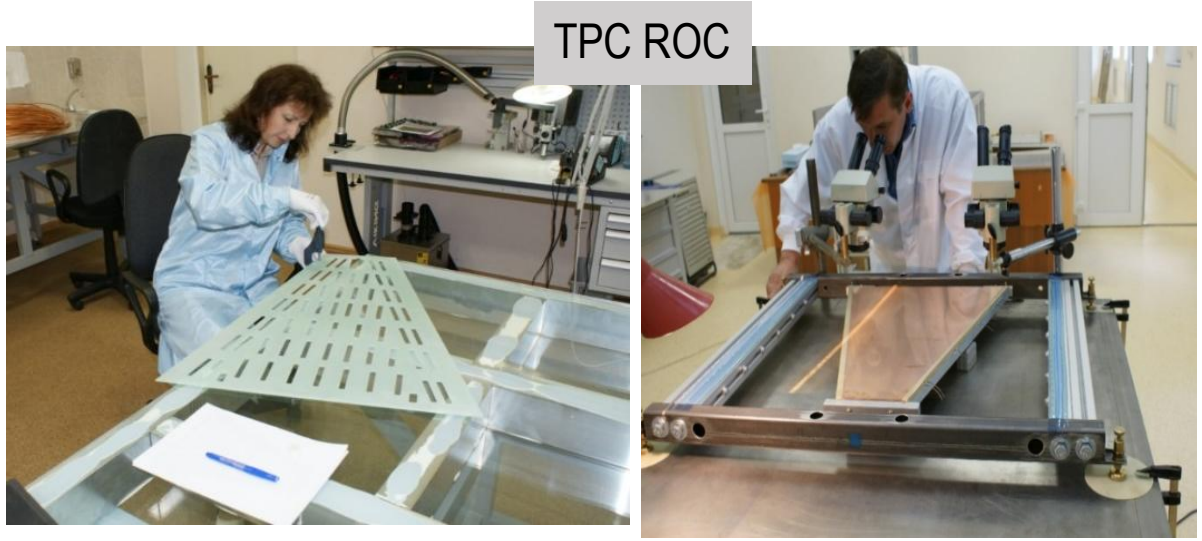
Plates

Winding machine for SC solenoid

Poles

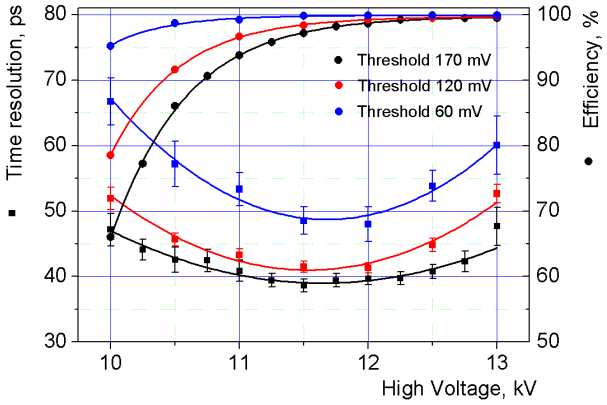
# MPD tracker TPC: under construction

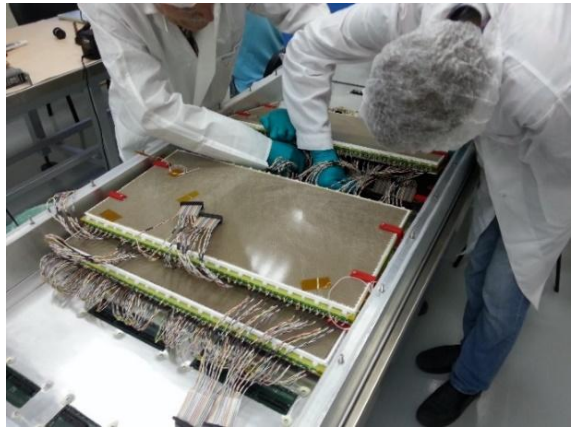




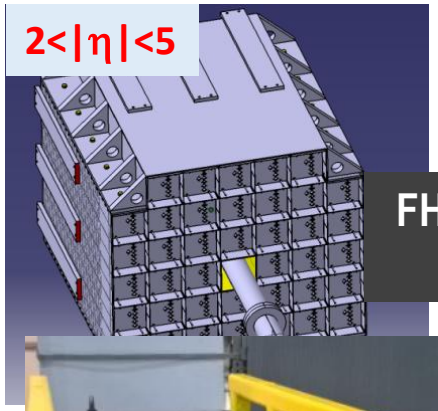

# MRPC TOF: preparation to mass-production

## (material ordering, equipment installation, personnel training)

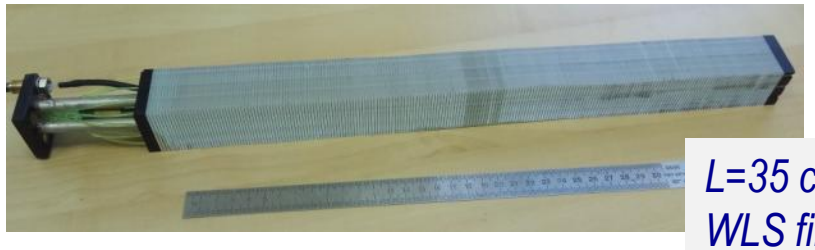


# MPD Calorimetry: ECAL and FHCAL

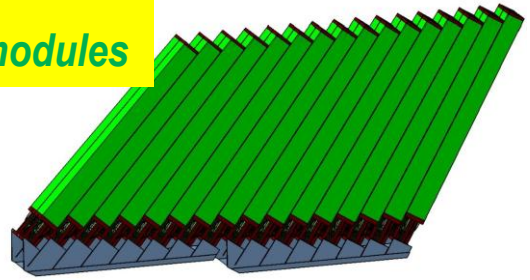



**FHCAL calorimeter for centrality & event plane determination**

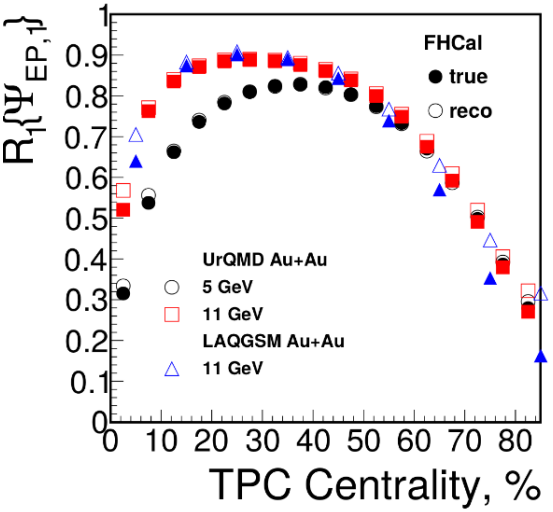


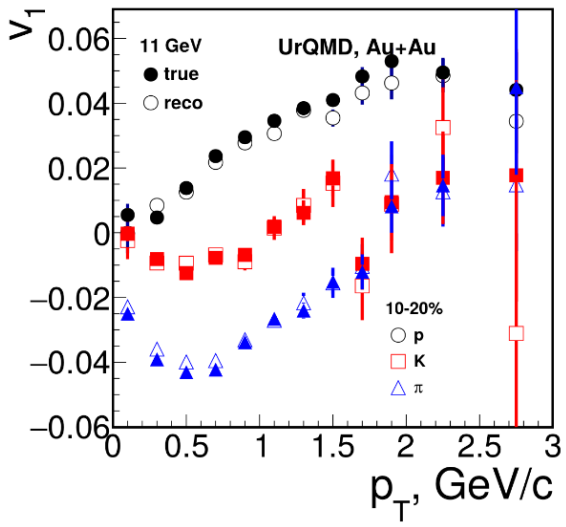
*L=35 cm (~ 14 $X_0$), Pb+Scint. (4x4 cm$^2$)*
*WLS fibers + MAPD for readout*

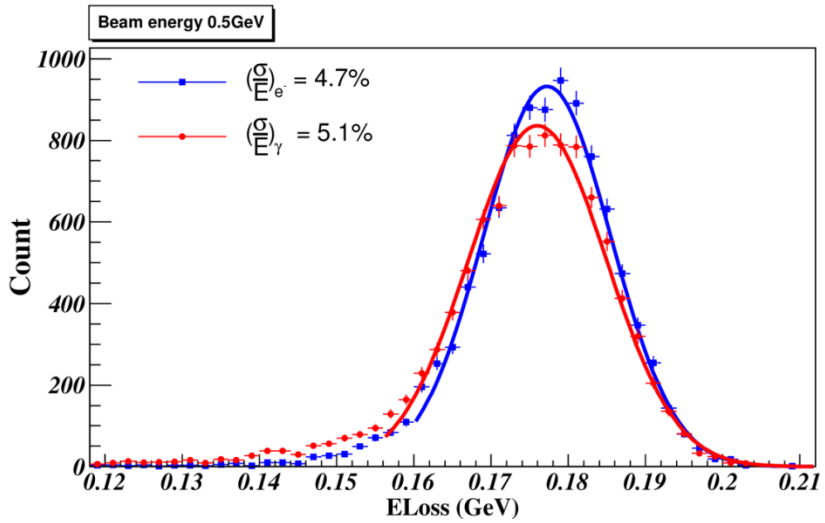
***Projective geometry***
***Barrel ~ 43000 ECAL modules***



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



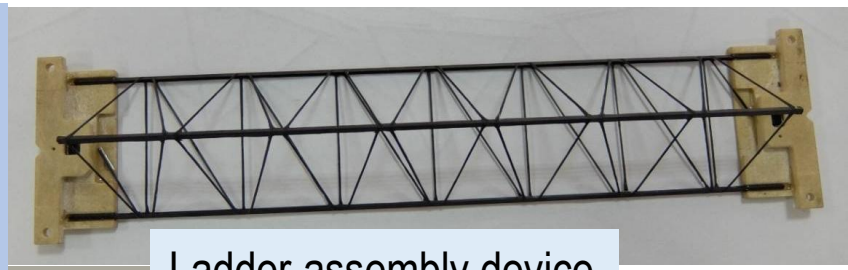



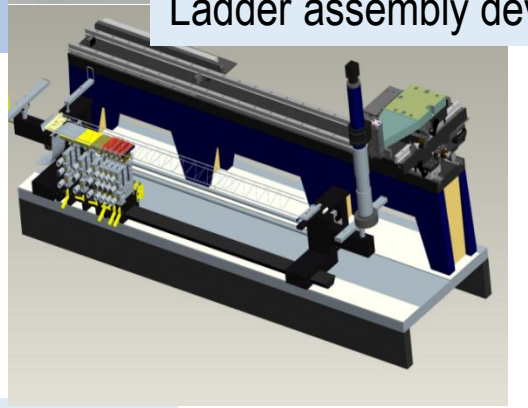
# MPD after 2023: Inner Tracker System (status 2017)

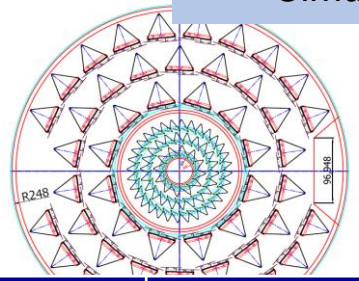
Site for module assembly: the main room (90m$^2$ ) is class 7 ISO

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



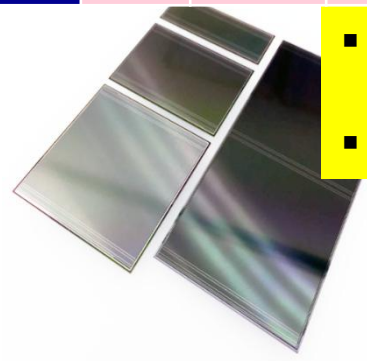
Ladder assembly device



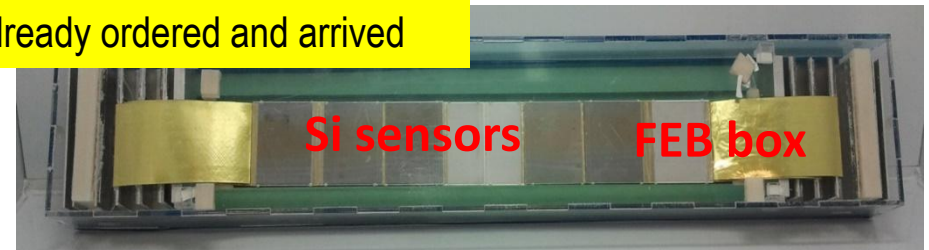


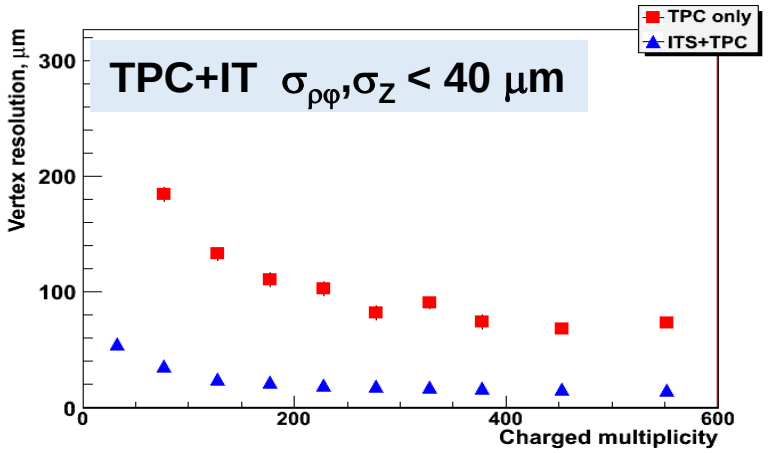
4 technicians are currently involved in module assembling

| # 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



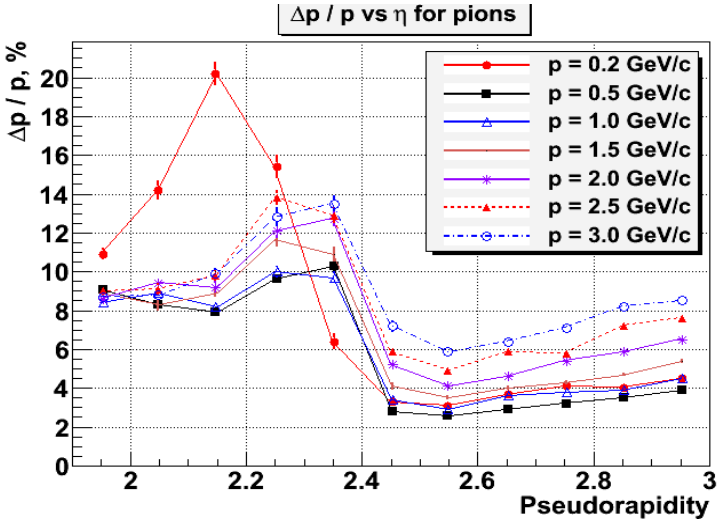



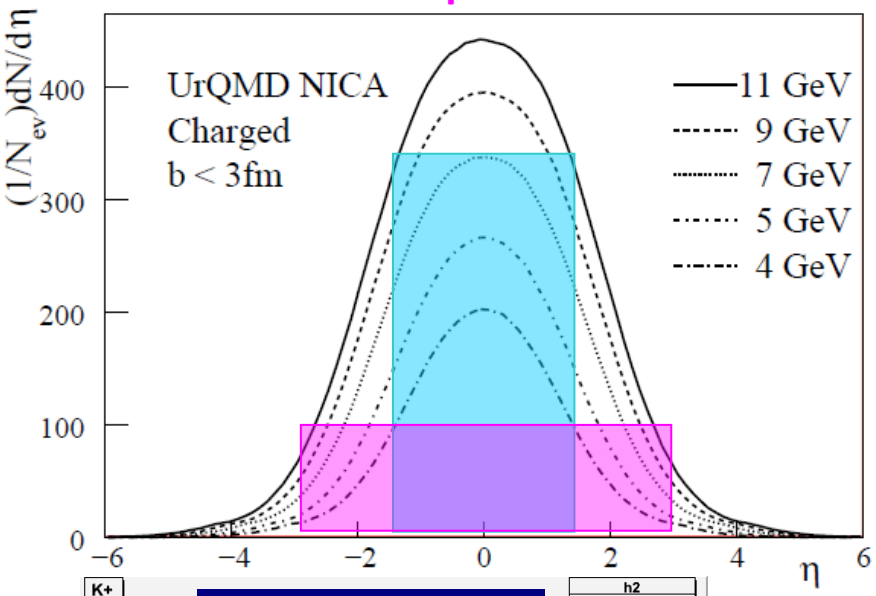
# MPD beyond 2023: EndCap Tracker

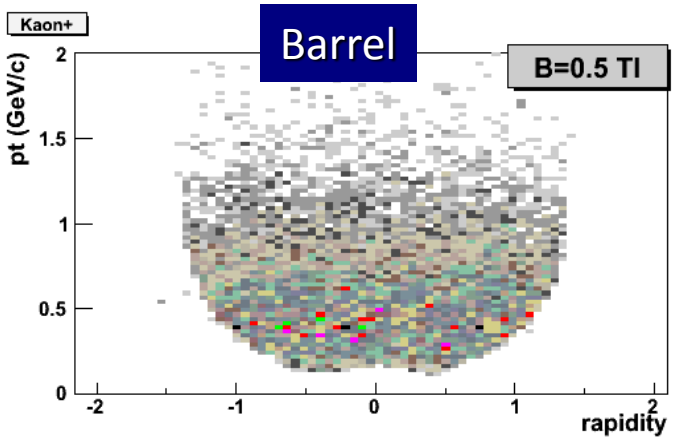
- A new technology developed to build straw detectors as multi-wheel structures
- ECT full size prototype : max. deviation ΔR < 300 mm for a R=1.1 m wheel

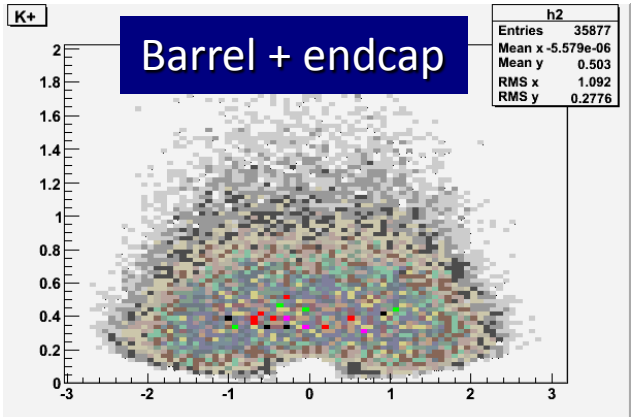
**TPC+ECT+GEM tracking up to η=3**

**Barrel: ~60% for charged ($\sigma_\pi$~1.3)**
**Barrel+endcap: > 90%**



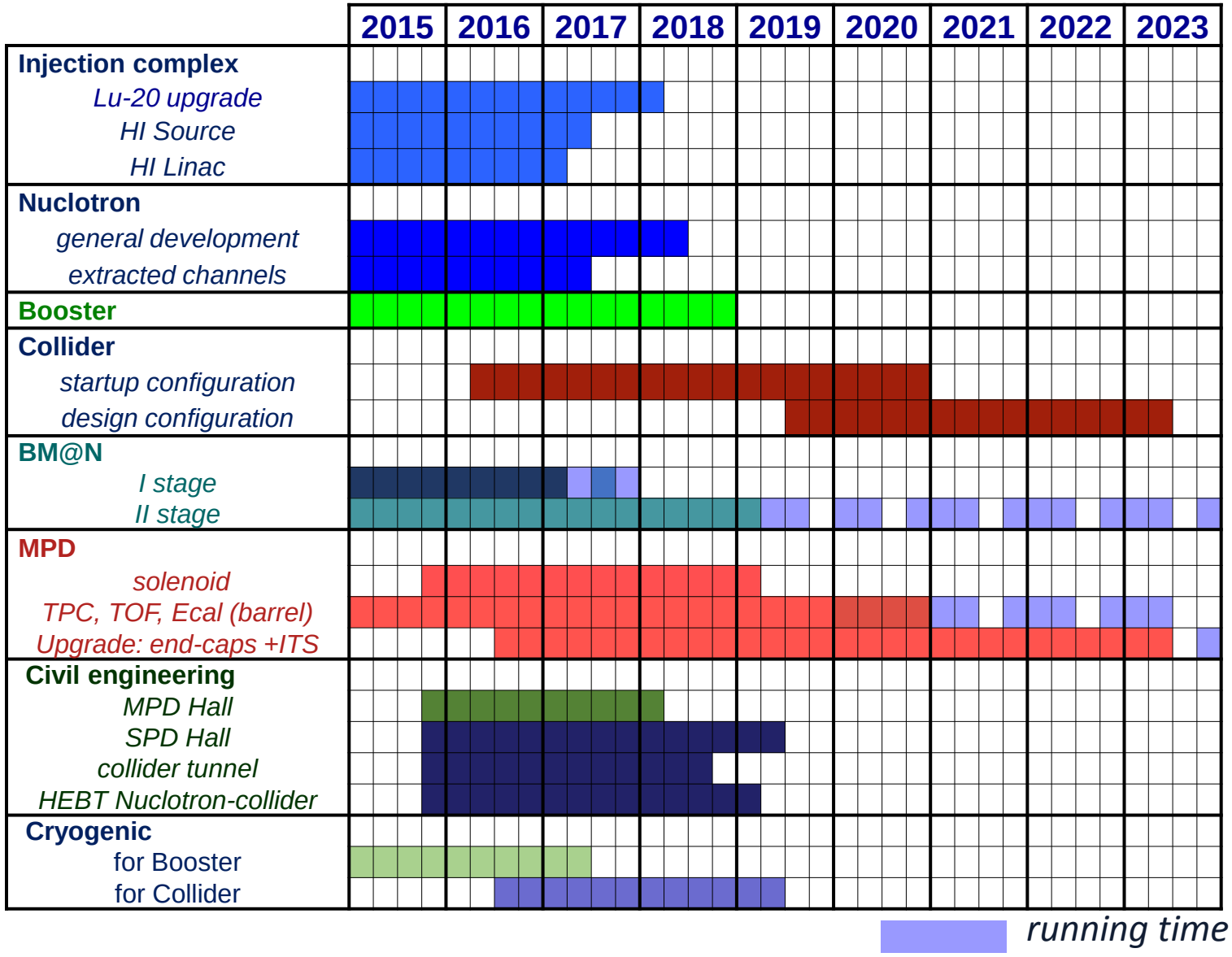




**2x60 straw layers1.3<|η|<2.2**
**72000 straw tubes 4 mm x 60 cm**

# 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**

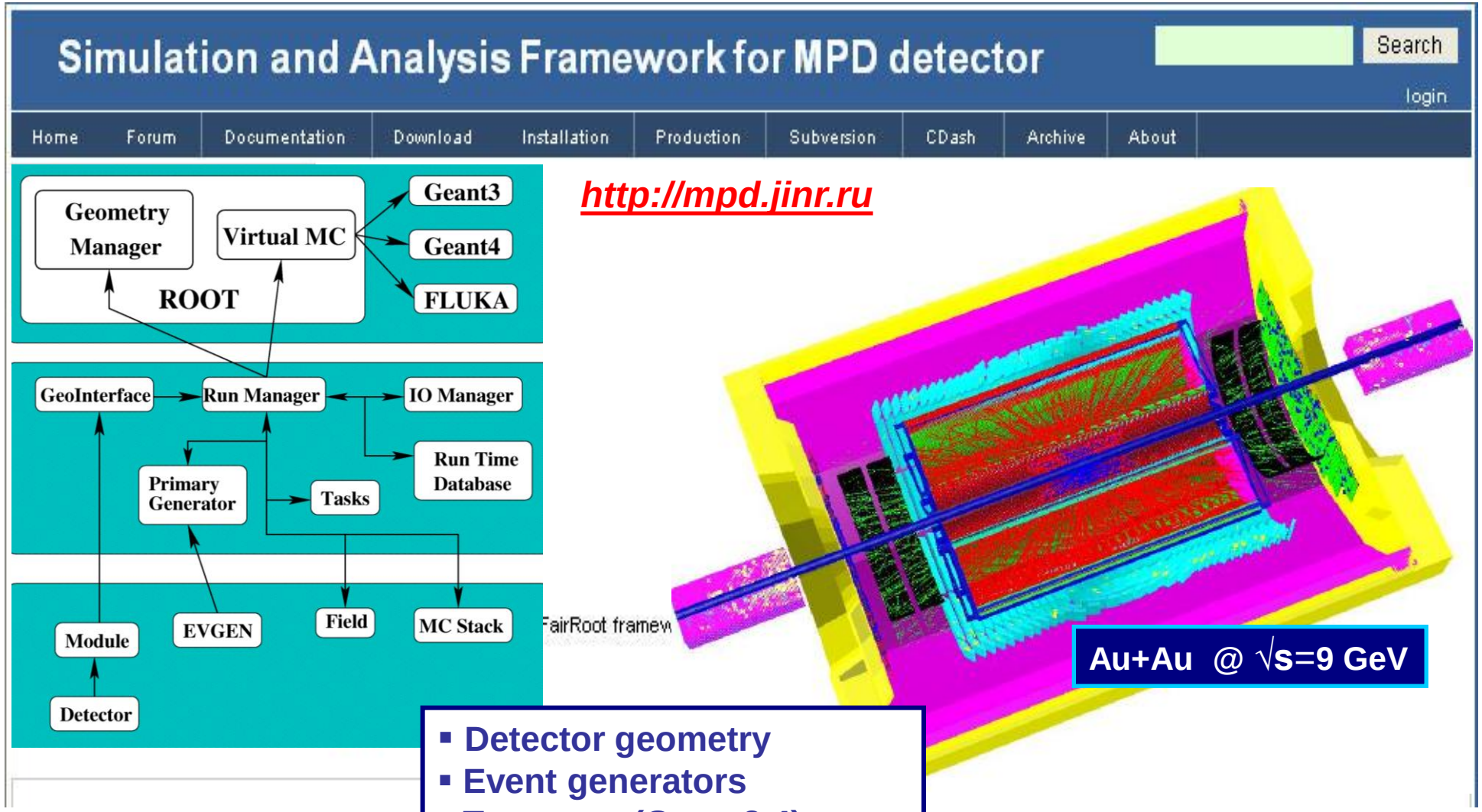
# Particle yields in Au+Au collisions @ $\sqrt{s_{NN}}$ = 8 GeV
## (*central collisions*)

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 |
|---|---|---|---|---|---|
| $\pi^+$ | 293 | ---- | --- | 61 | $7.7 \cdot 10^8$ |
| $K^+$ | 59 | --- | ---- | 50 | $1.5 \cdot 10^8$ |
| p | 140 | --- | ---- | 60 | $4.2 \cdot 10^8$ |
| $\Lambda$ | ~35 | $p+\pi^-$ | 64% | 10% | $2 \cdot 10^7$ |
| $\Xi^-$ | ~2 | $\Lambda+\pi^-$ | ~100% | 2.5% | $1.5 \cdot 10^5$ |
| $\rho$ | 31 | e+e- | $4.7 \cdot 10^{-5}$ | 35 | $2.5 \cdot 10^3$ |
| $\omega$ | 20 | e+e- | $7.1 \cdot 10^{-5}$ | 35 | $2.5 \cdot 10^3$ |
| $\varphi$ | 2.6 | e+e- | $3 \cdot 10^{-4}$ | 5 | $2.0 \cdot 10^2$ |
| $\Omega$ | 0.14 | $\Lambda+K$ | 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.

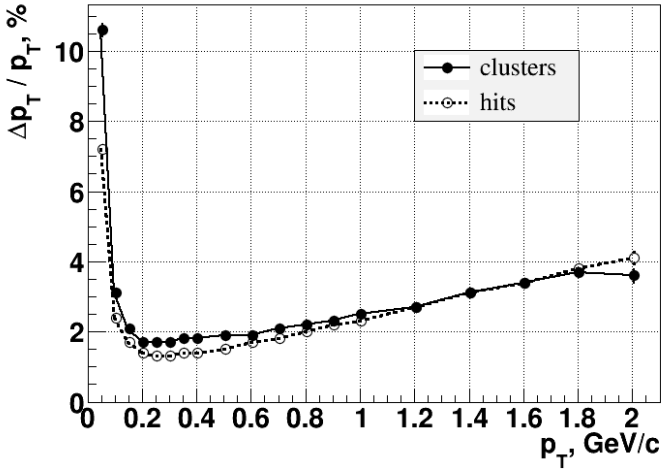
# MC simulation - MPDRoot

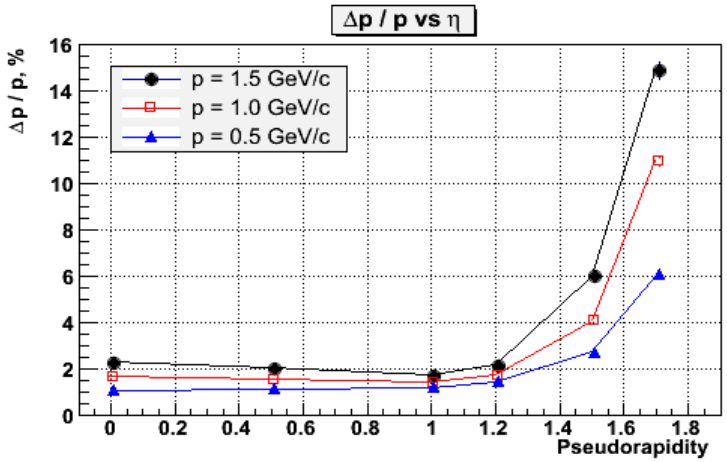


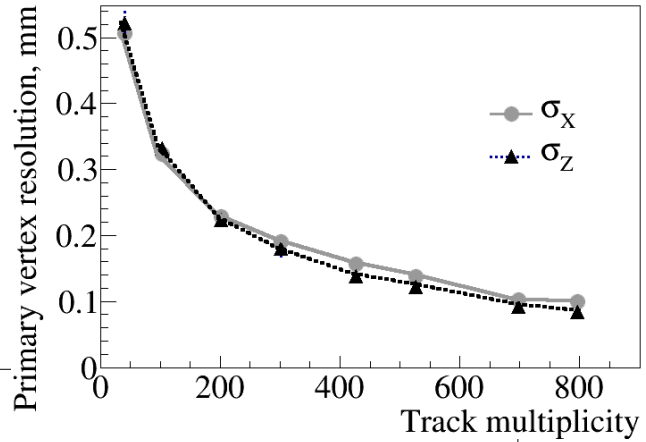

- Detector geometry
- Event generators
- Transport (Geant3,4)
- Response simulation
- Reconstruction algorithms
- Analysis tools

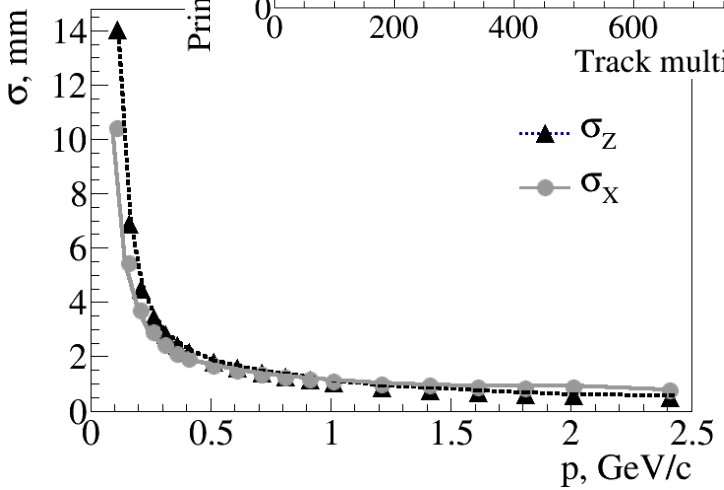
# MPD tracking performance (TPC)

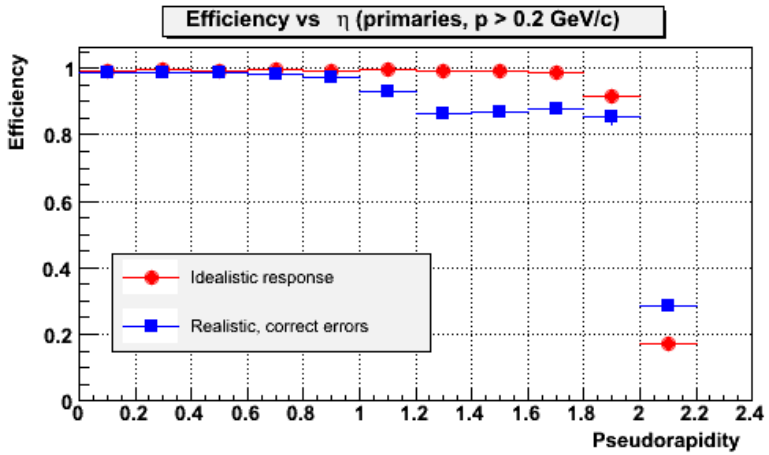
- Track reconstruction – Kalman filtering technique
- Tracking down to η= 1.8(1.6) with Npoints>10(20)
- Primary & secondary vertexing with Kalman filtering formalism (sub-cm precision w/o vertex detector)
- MPD tracking efficiency above 85% within |η|<1.8 && $p_t$>0.15 GeV/c
- Δp/p < 3% at midrapidity

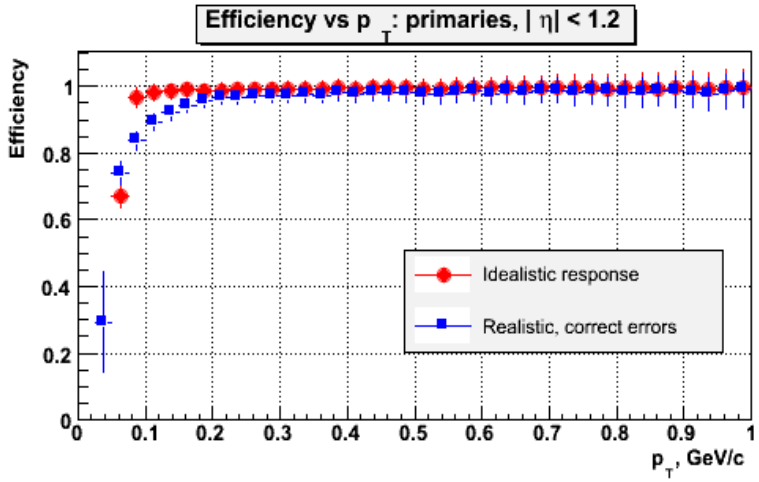


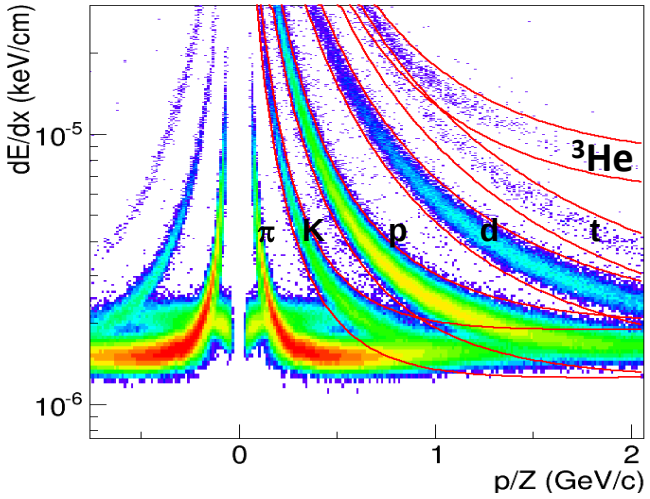



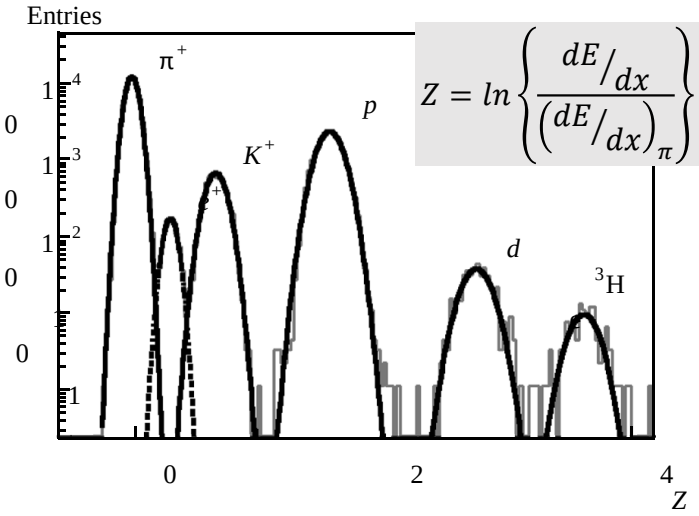



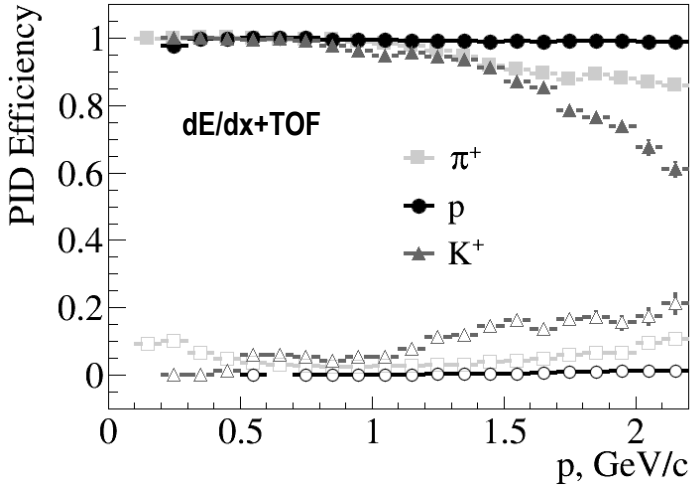



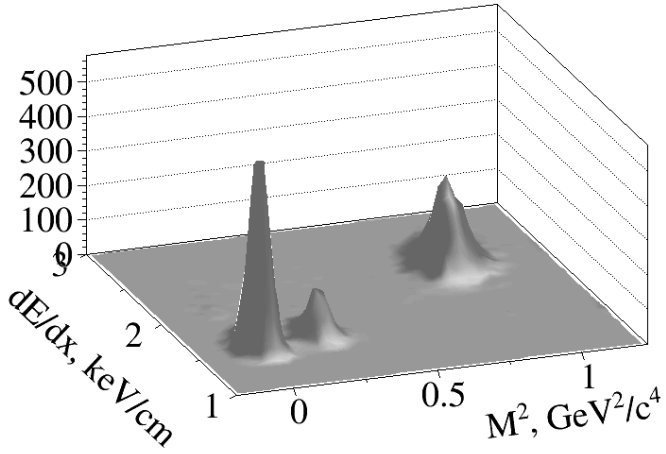
# MPD Particle Identification

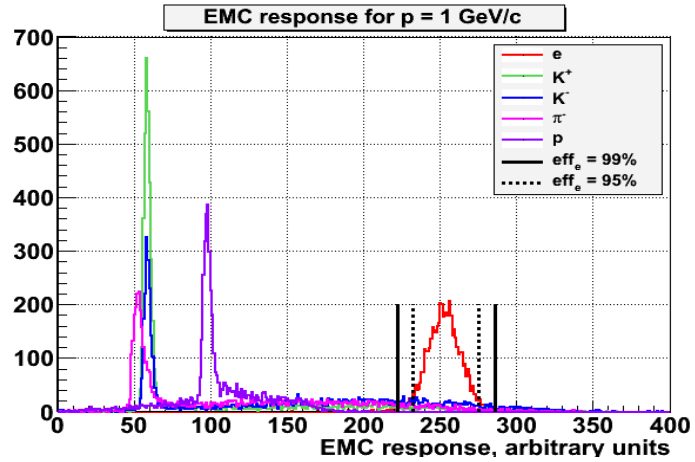
- Hadron (π,K,p) identification up to 3 GeV/c, midrapidity nuclei PID
- Electron PID with hadron suppression up to $10^5$
- Secondary vertex reconstruction – hyperons & hypernuclei @ midrapidity

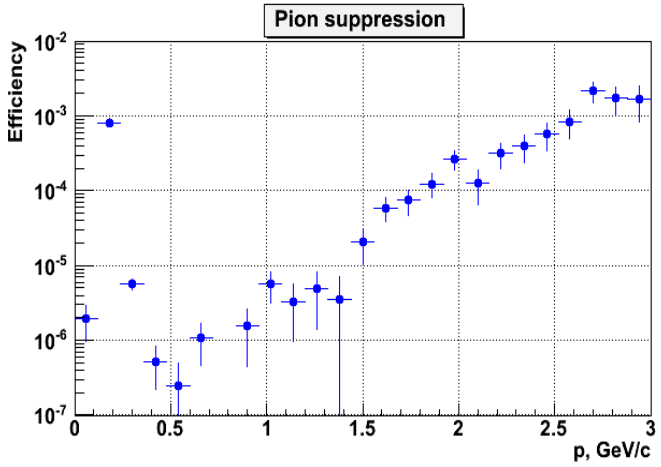


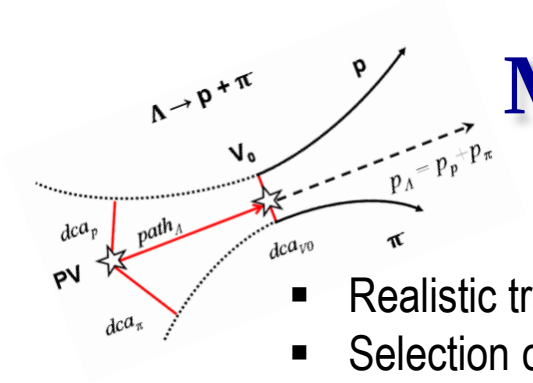



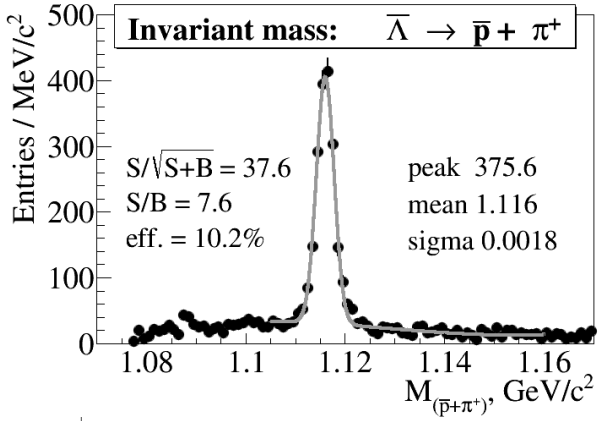



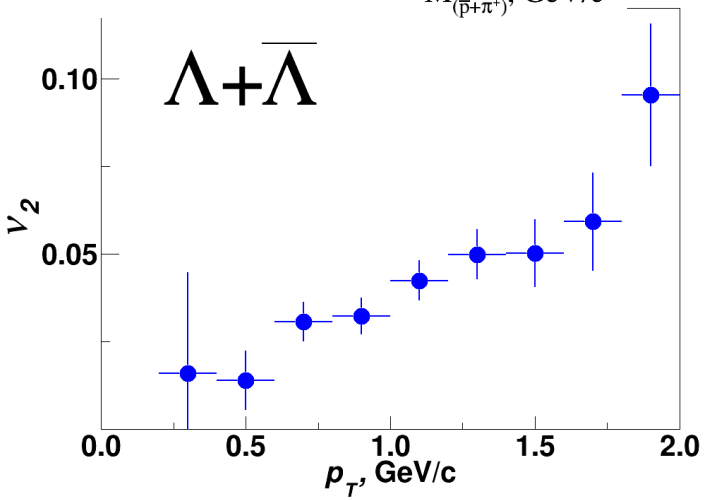



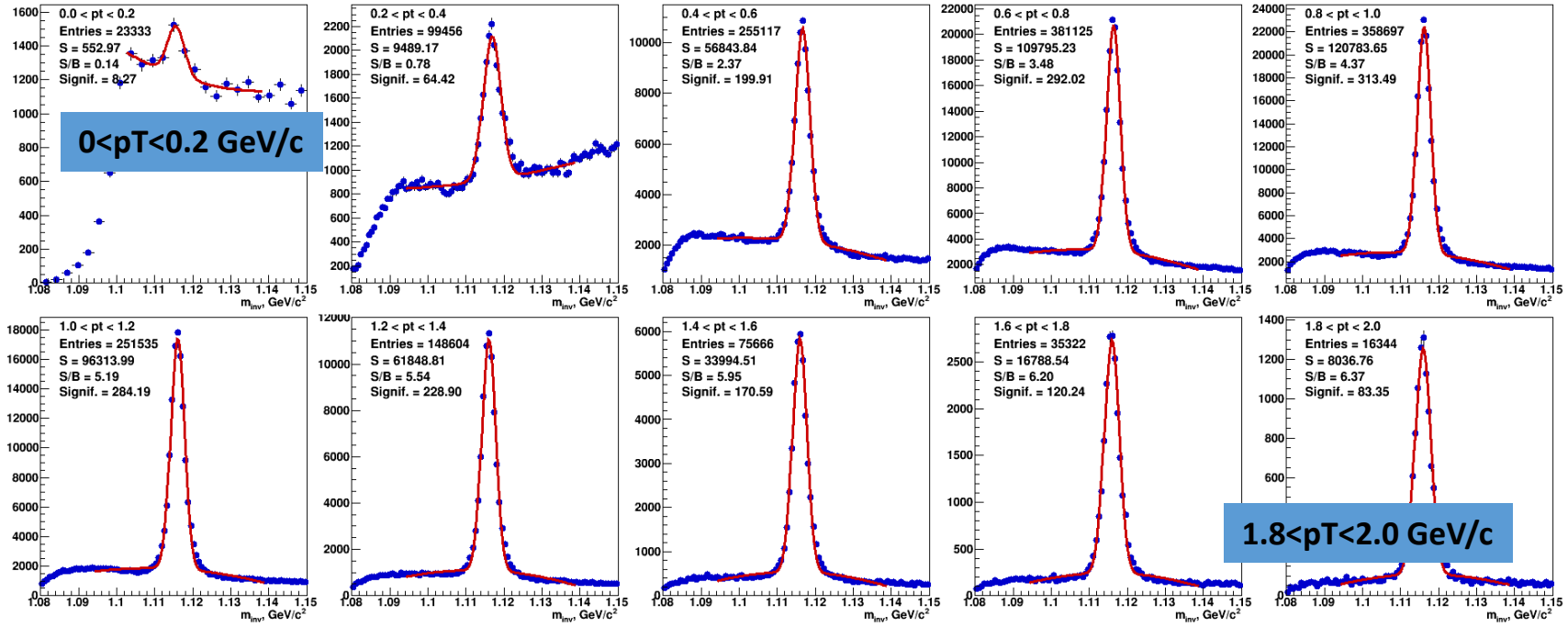
# MPD performance: strangeness (Lambda flow)




- 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

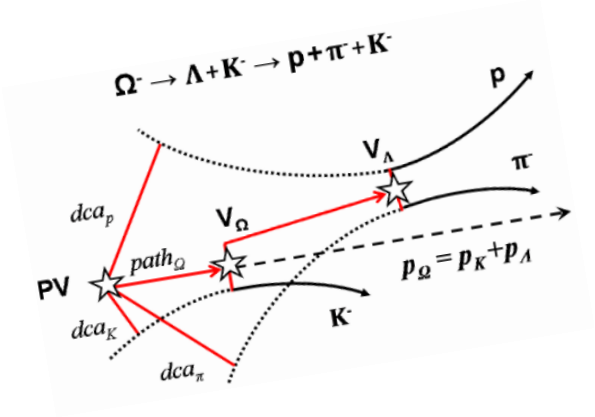


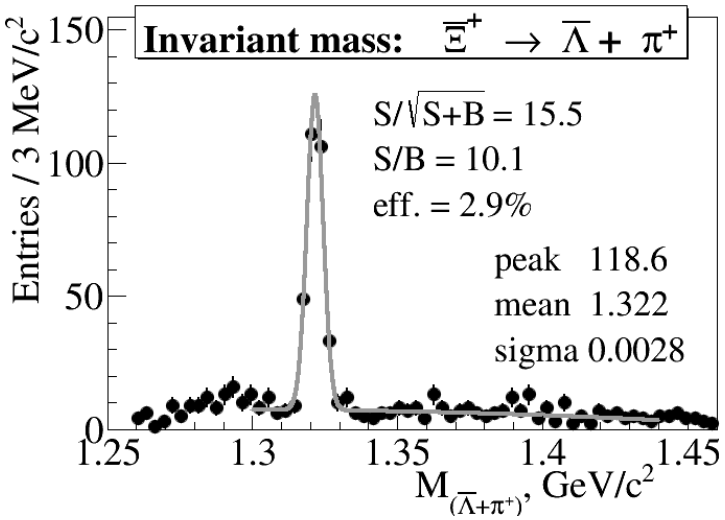

- Min. bias Au+Au @ 11A GeV (UrQMD), TPC+TOF barrel
- Secondary vertex reconstruction
- Event plane from TPC tracks

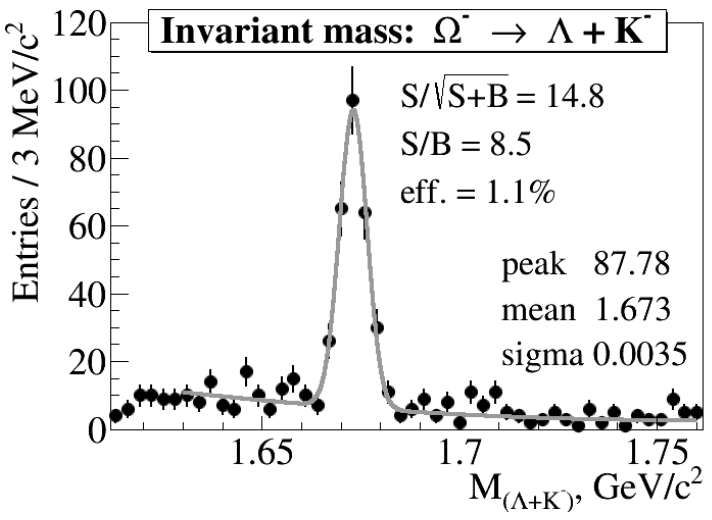
# MPD performance: multi-strangeness (Stage1)




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

- ~ $5 \cdot 10^5$ 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 | $\Xi^-$ | anti-$\Xi^+$ | $\Omega^-$ | anti–$\Omega^+$ |
|---|---|---|---|---|---|---|
| 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)

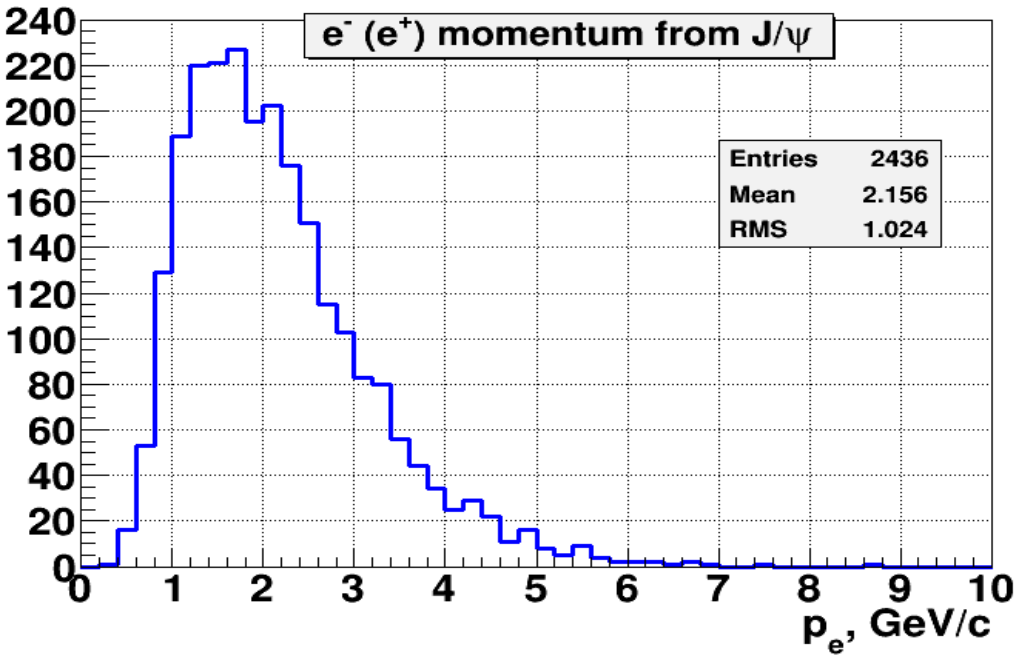
| Particle | Multiplicity | Decay mode | BR | *Efficiency % | Yield/10 w |
|---|---|---|---|---|---|
| $\pi^+$ | 293 | ---- | --- | 61 | $2.6 \cdot 10^{11}$ |
| $K^+$ | 59 | --- | ---- | 50 | $4.3 \cdot 10^{10}$ |
| p | 140 | --- | ---- | 60 | $1.2 \cdot 10^{11}$ |
| $\rho$ | 31 | e+e- | $4.7 \cdot 10^{-5}$ | 35 | $7.3 \cdot 10^{5}$ |
| $\omega$ | 20 | e+e- | $7.1 \cdot 10^{-5}$ | 35 | $7.2 \cdot 10^{5}$ |
| $\varphi$ | 2.6 | e+e- | $3 \cdot 10^{-4}$ | 15 | $1.7 \cdot 10^{5}$ |
| $\Omega$ | 0.14 | $\Lambda K$ | 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/$\psi$ | $8 \cdot 10^{-5}$ | e+e- | 0.06 | 15 | $10^3$ |

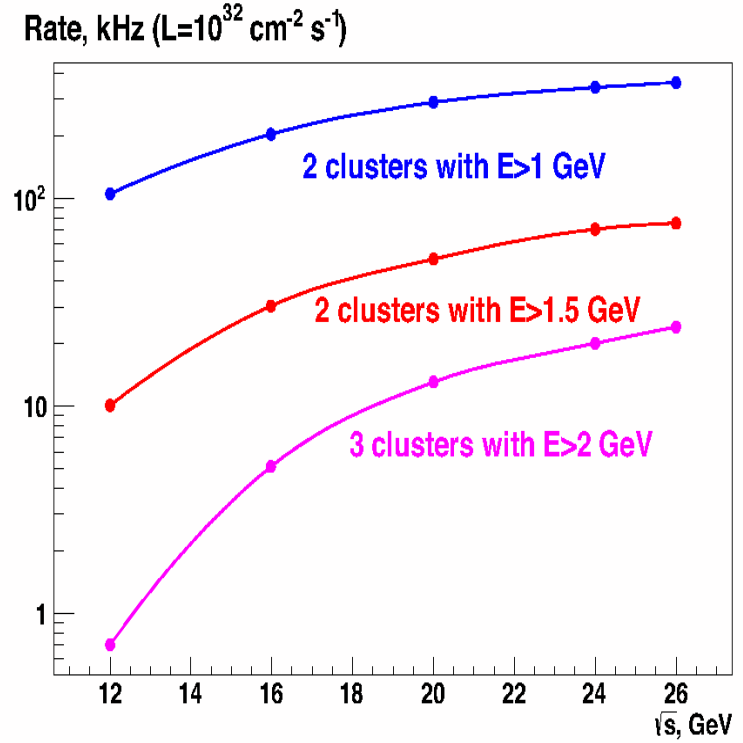
*Efficiency includes the MPD acceptance, realistic tracking and particle ID.
Particle Yields from experimental data (NA49), statistical and HSD models.

# 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

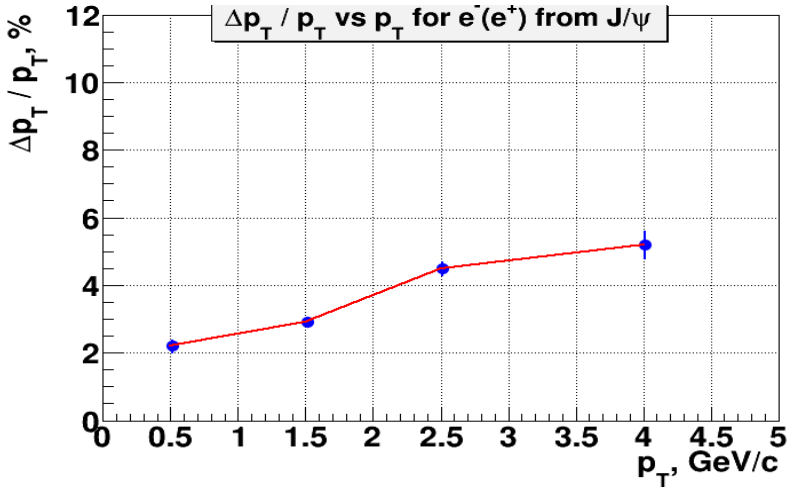
- At higher luminosity (p+p or light ions of Z/A~0.5) a high level trigger on high-pT leptons (ECAL) to enhance interesting event rates can be utilized (not exceeding 30kHz level)

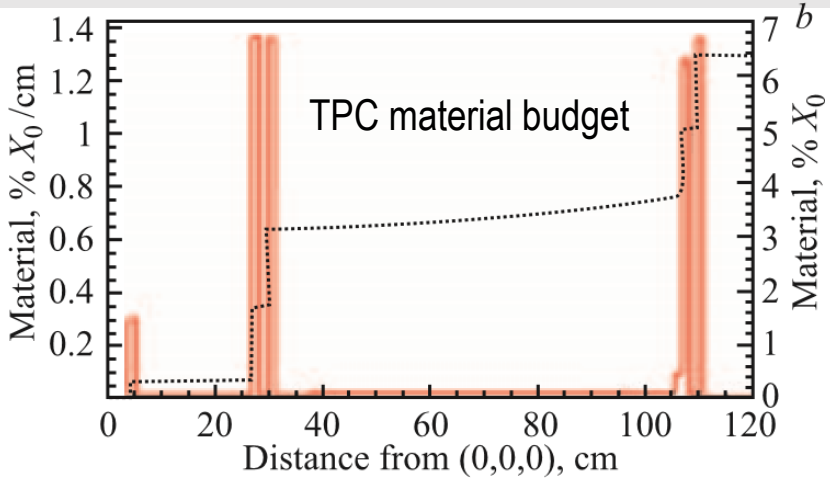


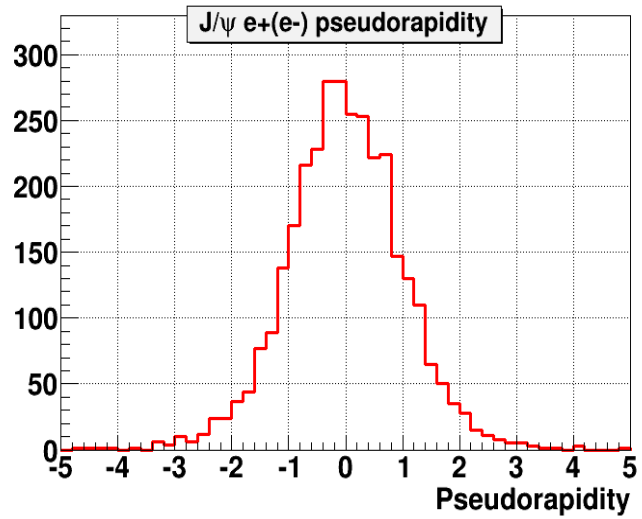



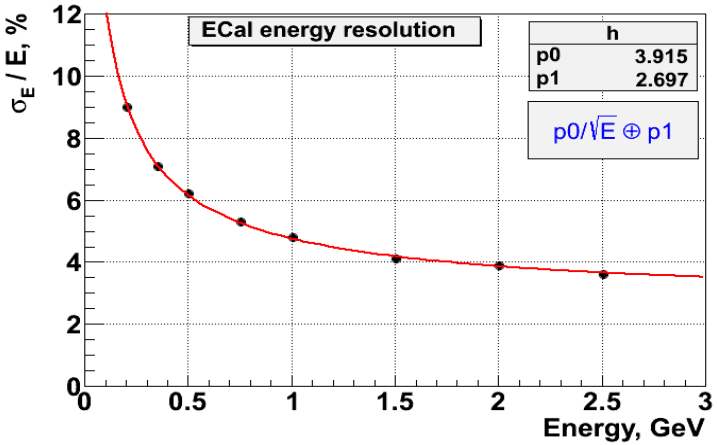
# J/ψ in p+p collisions at NICA : feasibility study

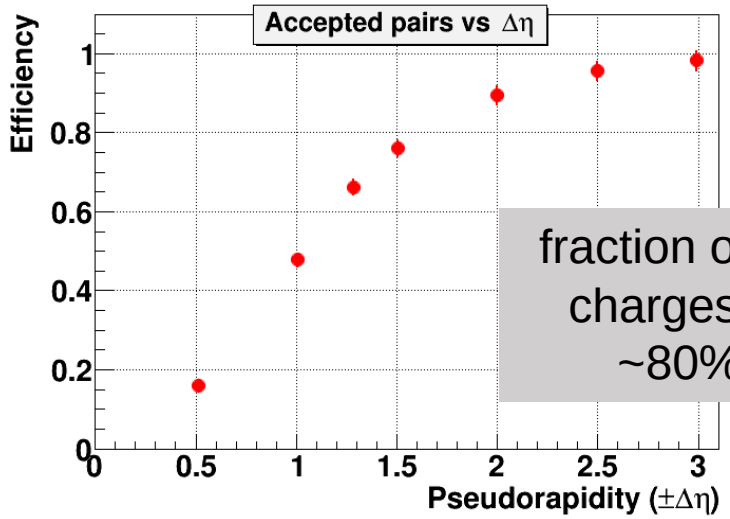
- *p+p at 25 GeV (Pythia8), event mixing*
- *10 weeks of running time: L = $10^{29}$ $cm^{-2}c^{-1}$ (Stage'1) $L_{int}$ = 604.8 $nb^{-1}$*
- *Decay channel J/ψ → $e^+e^-$ (branching ratio ~6%)*
- *MPD detector – TPC+TOF+ECAL (|η|<1.5), w/o vertex detector*
- *MpdRoot: Geant3, realistic track and vertex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



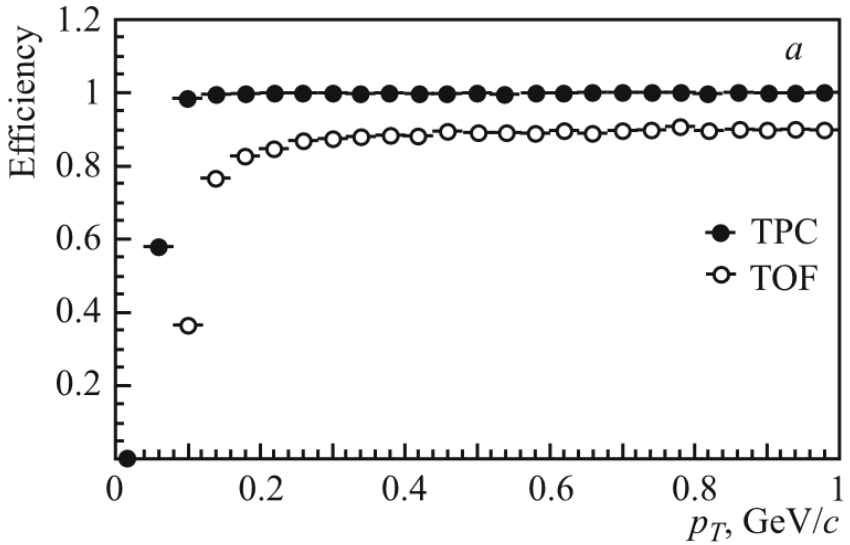



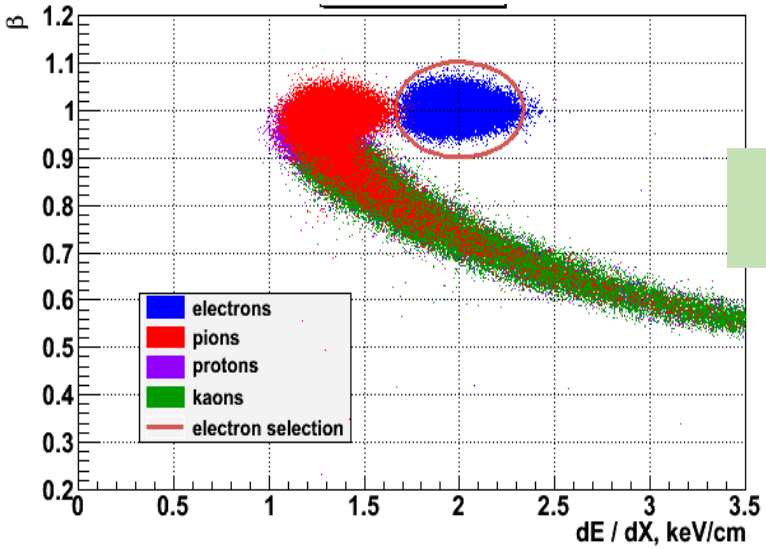

fraction of *J/ψ → $e^+e^-$* decays with both charges within the MPD acceptance ~80% acceptance for the |η|<1.5

# J/ψ in p+p at NICA : analysis details

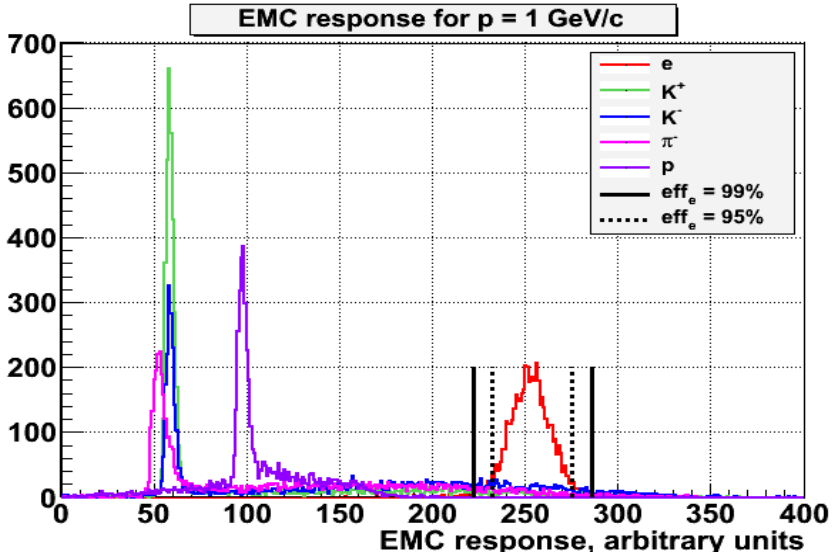
**Cuts at Stage'1 MPD setup:**

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

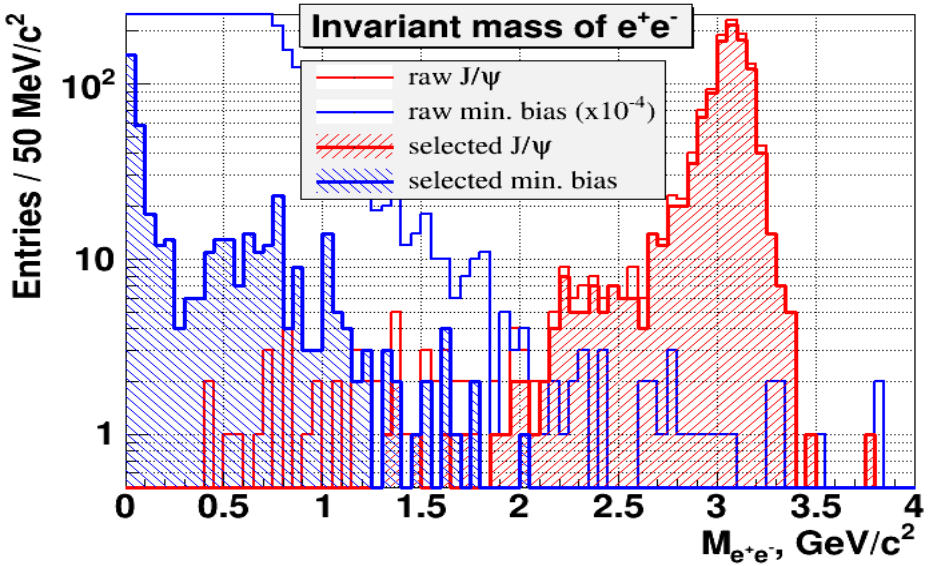


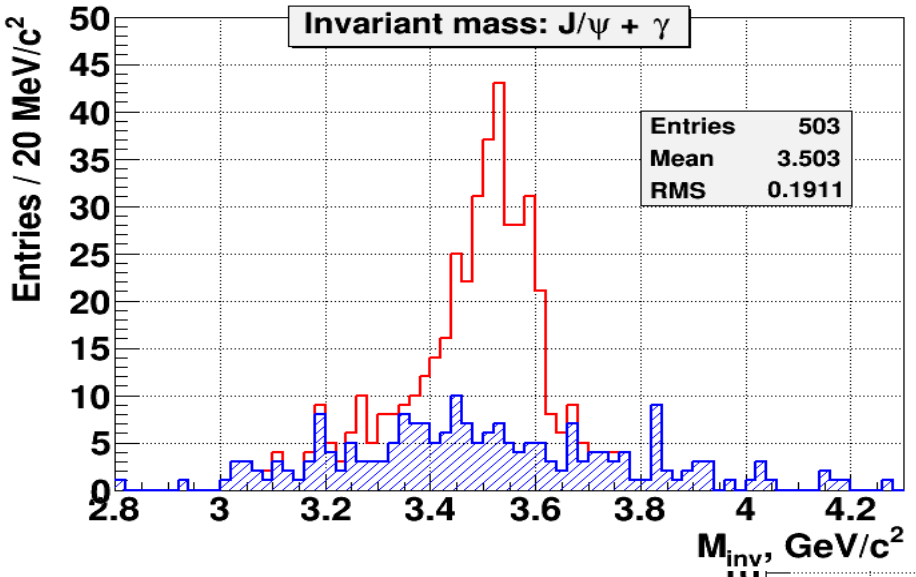



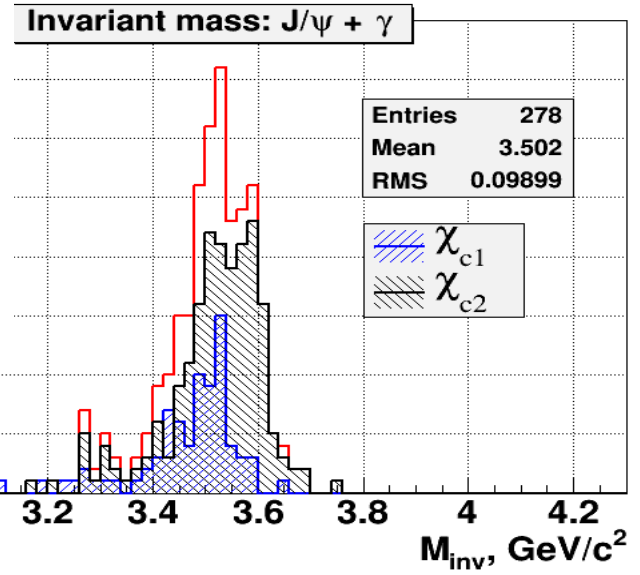

Electron PID: dE/dx+TOF+ECAL
Hadron suppression ~ $10^{-4}$



# 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!*