Particles and Nuclei International Conference
24 - 29 August 2014

Evaluation of the MPD/NICA detector capabilities for studies of hyperon production in HIC

V.Vasendina, A.Zinchenko

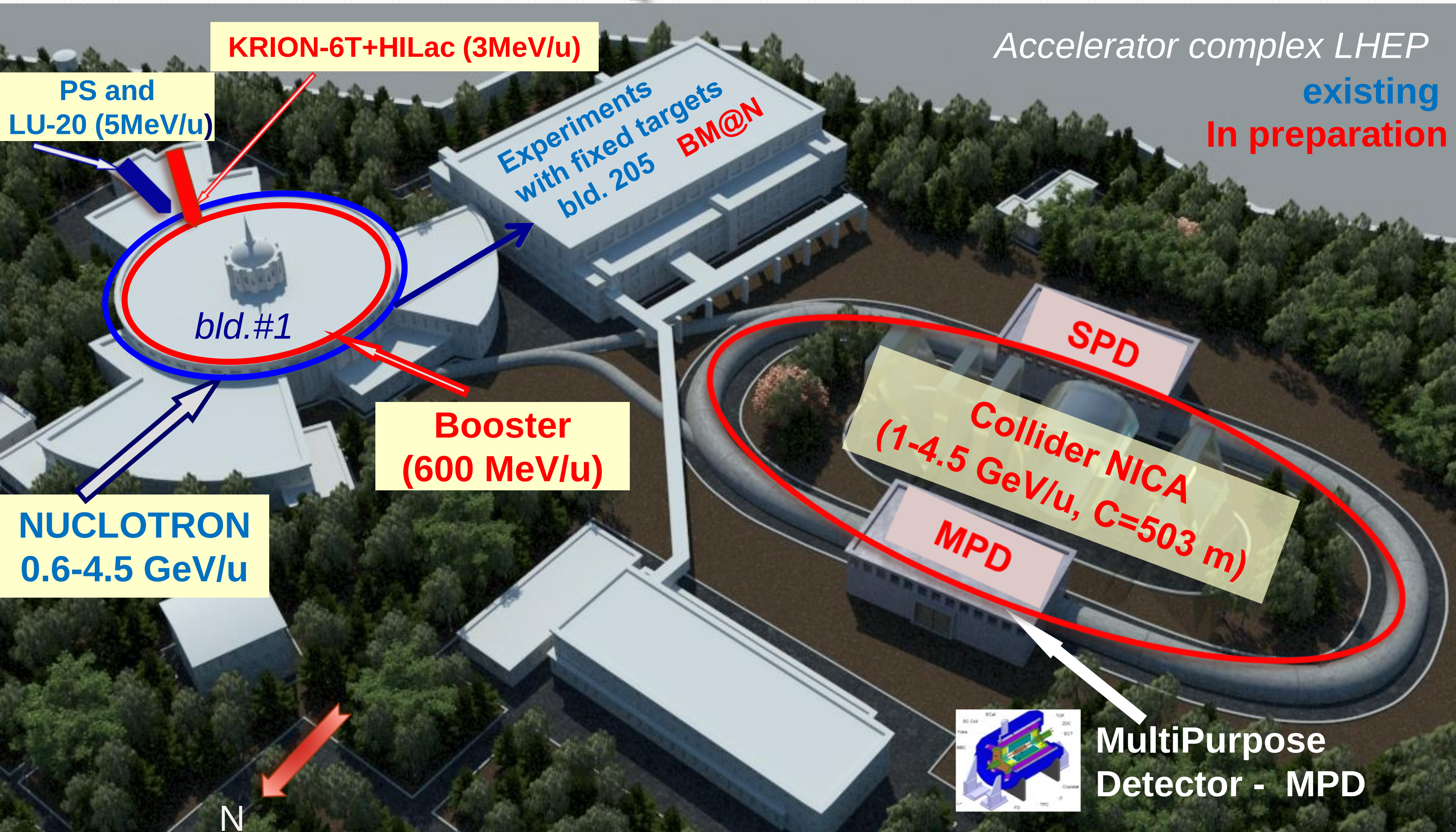
for the MPD collaboration

(VBLHEP, JINR, Dubna, Russia)

Outline

- **NICA program at JINR**
- **MPD detector for studying HIC: design & performance (Stage 1)**
  - TPC
  - TOF
  - ECAL
  - Particle Identification
- **Study of hyperon production with MPD**
  - MPD capability for reconstruction of **Λ, Ξ, Ω**
- **Stage 2: ITS & EndCap tracker**
- **Conclusions and outlook**

Complex NICA



NICA parameters & research programs

NICA parameters:

Beams: p,d(h)..$^{197}Au^{79+}$
Collision energy: 4-11A GeV (nuclei)
Luminosity: 10^{27} $cm^{-2}s^{-1}$ (Au), 10^{32} (p)
2 Interaction points: MPD and SPD
Fixed target: 1-6A GeV beams (BM@N)

- New flagship project at JINR (Dubna)
- Based on the technological development of the Nuclotron facility
- Optimal usage of the existing infrastructure
- Modern facility incorporating new technological concepts

QCD matter under extreme conditions

- Study of QCD phase diagram
  - deconfinement phase transition
  - mixed phase, Critical End Point
- In-medium properties, EoS
  - chiral symmetry restoration

Spin physics

- Nucleon spin structure
- Hadroproduction with polarized beams

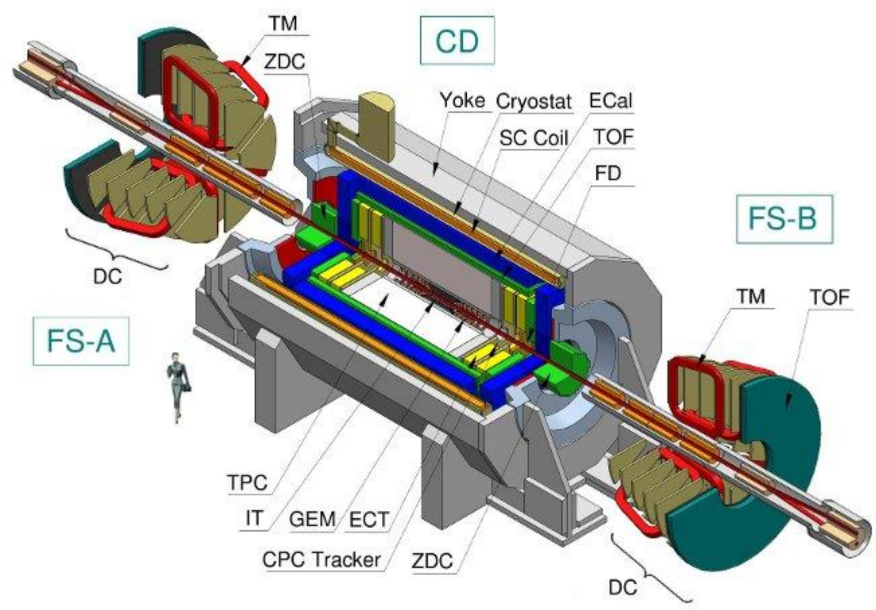
Applied research

- Cryogenic, material science, transmutation
- Medicine

Accelerator physics

- Superconducting magnets for high intensity ion beams
- Electron cooling for relativistic heavy ions

Multi-Purpose Detector (MPD) @ NICA

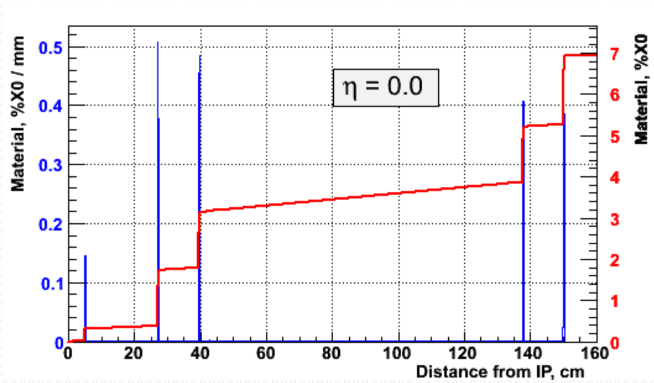


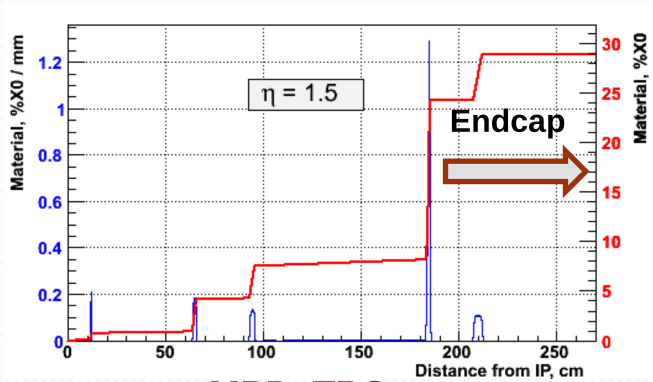
- **Magnet:** 0.5 T superconductor
- **Tracking:** TPC, ECT, ITS
- **ParticleID:** TOF, ECAL, TPC
- **T_0, Triggering:** FFD
- **Centrality, Event plane:** ZDC
- **Stage 1:** TPC, Barrel TOF & ECAL, ZDC, FFD
- **Stage 2:** ITS + EndCaps (tracker, TOF, ECAL)

Requirements to the apparatus:

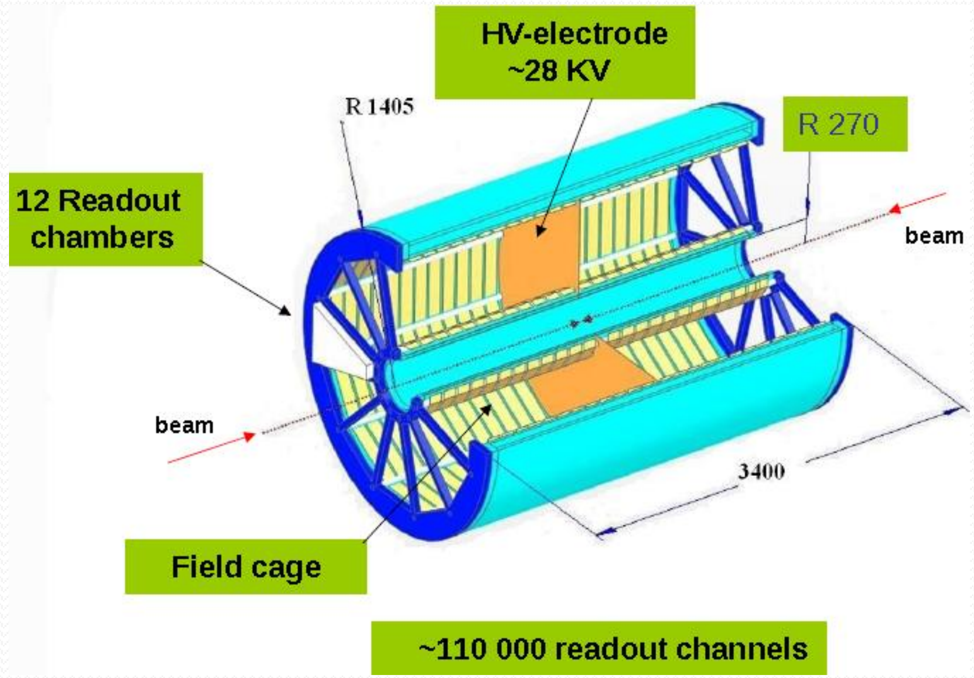
- Hermeticity, homogenous acceptance : 2π in azimuthal angle
- Highly efficient 3-D track reconstruction (|η|<2), high resolution vertexing
- Powerful PID: π/K up to 1.5 GeV/c, K/p up to 3 GeV/c, ECAL for γ, e
- Careful event characterization: impact parameter & event plane reconstruction
- Minimal dead time, event rate capability up to ~ 6 kHz

Time Projection Chamber (TPC)





TPC - MPD tracking system



MPD TPC

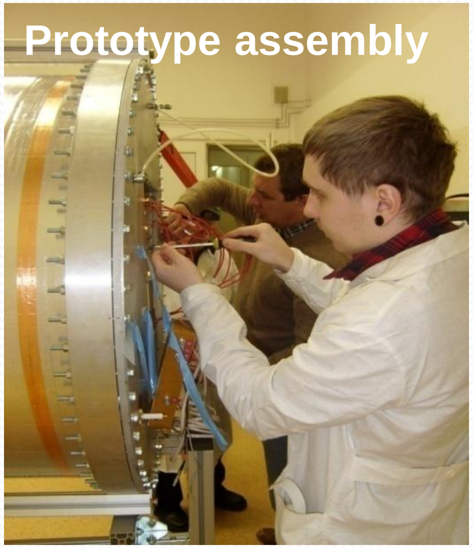
Dimensions: 4 m x 3 m
Drift Length: 170 cm
Gas: 90% Argon + 10% Methane
Readout: 2x12 sectors (MWPC or GEM)

Composite materials – transparent detector!

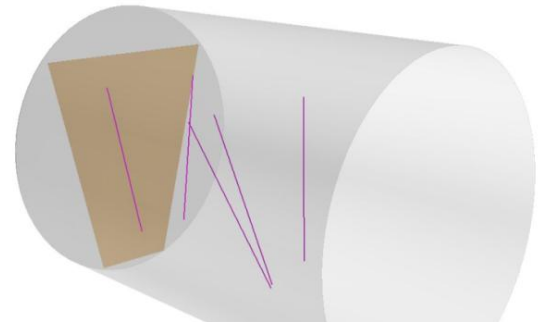
TPC performance required

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

TPC– technical project approved, fabrication stage


Prototype assembly


FEC-64 prototype
(ALTERA FPGA,
ALTRO, PASA chips)


Prototype1: UV laser tracks - reconstructed

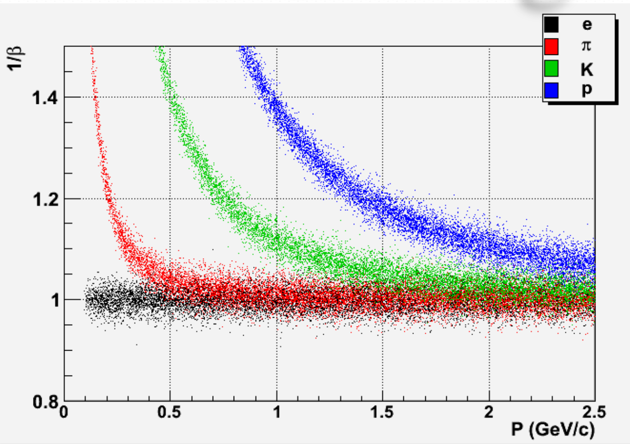

Cylinder C2, preparation for vacuum tests

⌀27 cm, L=3.4 m


Cylinder C3 manufactured in Dec. 2013

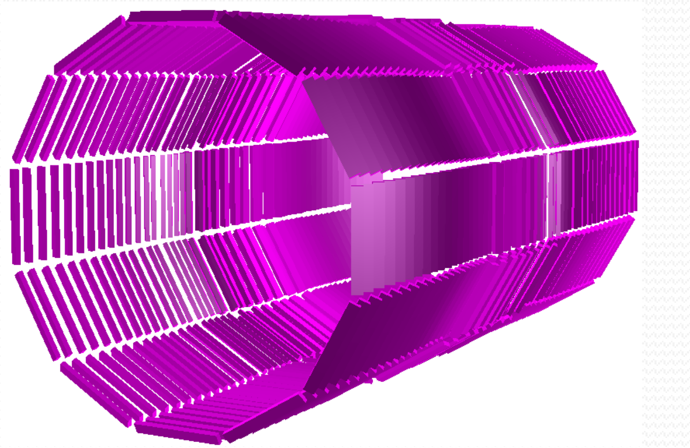
⌀140 cm, L=3.4 m
4 mm thickness
0,1 mm precision

Time Of Flight (TOF) (JINR+Hefei, Beijing(China))



PID :

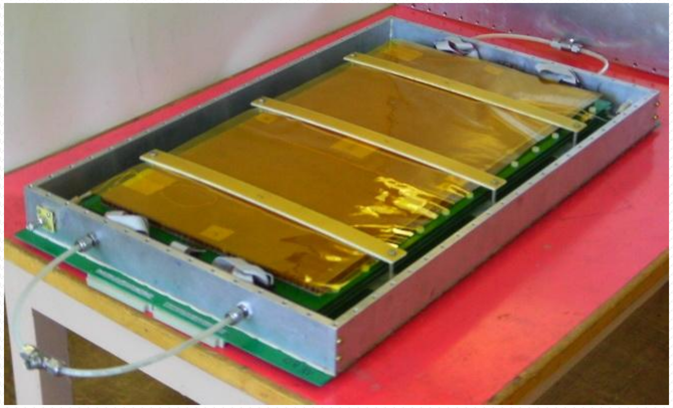
e/h – 0.1..0.35 GeV/c
p/K – 0.1..1.5 GeV/c
K/p – 0.1..2.5 GeV/c



Basic requirements:

- Coverage: > 30 m^2, |η|<3 (barrel+endcap)
- σ ~ 80 ps (100 ps overall)

→ **Resistive Plate Chambers**



Dimensions:

barrel: 5 m (length), 2.5 m (diameter)
endcap: 2 x 2.5 m (diameter) disks

Gas: 90% $C_2H_2F_4$ + 5% iC_4H_{10} + 5% SF_6

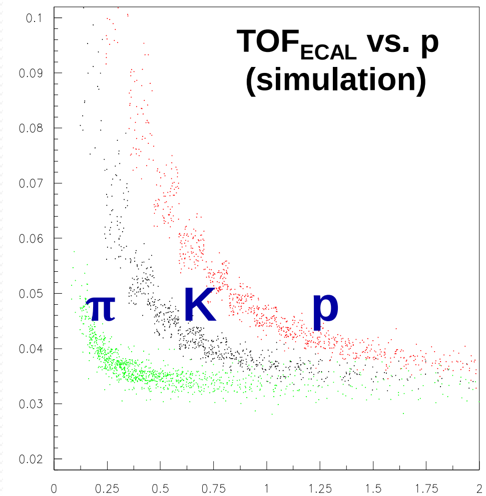
Segmentation *(barrel):*

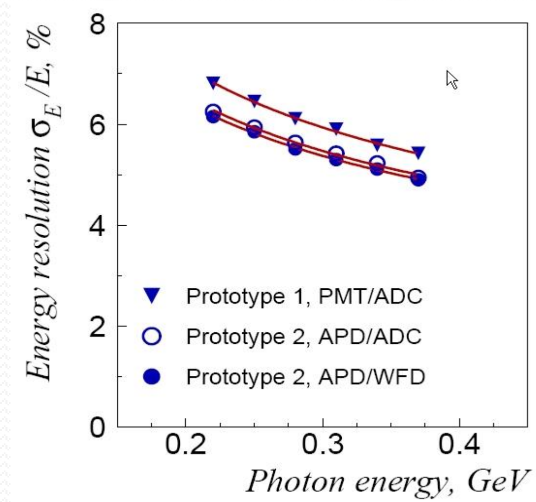
12 sectors x 55 modules (62 x 7 cm^2)
module: 10-gap RPC

Electromagnetic Calorimeter (ECAL)

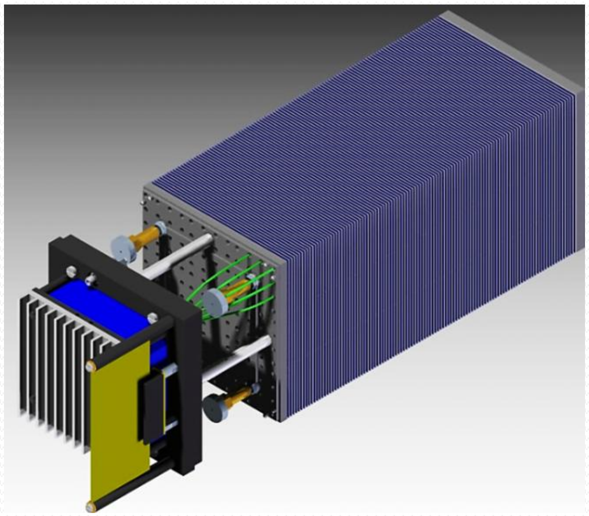
VBLHEP & DLNP (JINR) + ISM (Kharkiv)

- ECAL aimed at detecting electrons and gammas and has to fulfill:
- High granularity and hermeticity
- Energy, spatial (and also timing) resolutions
- Manufacturing technology & cost





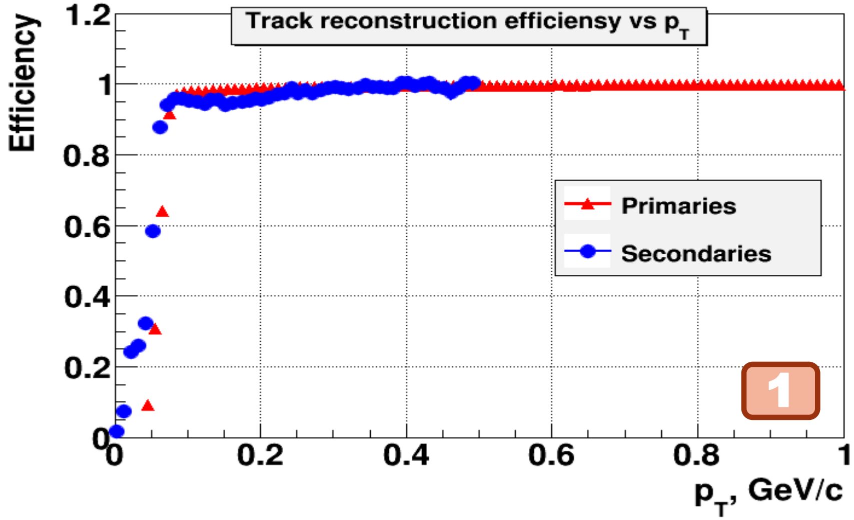
- s/E ~ 3%/√E + const
- s_{TOF} ~ 150 ps

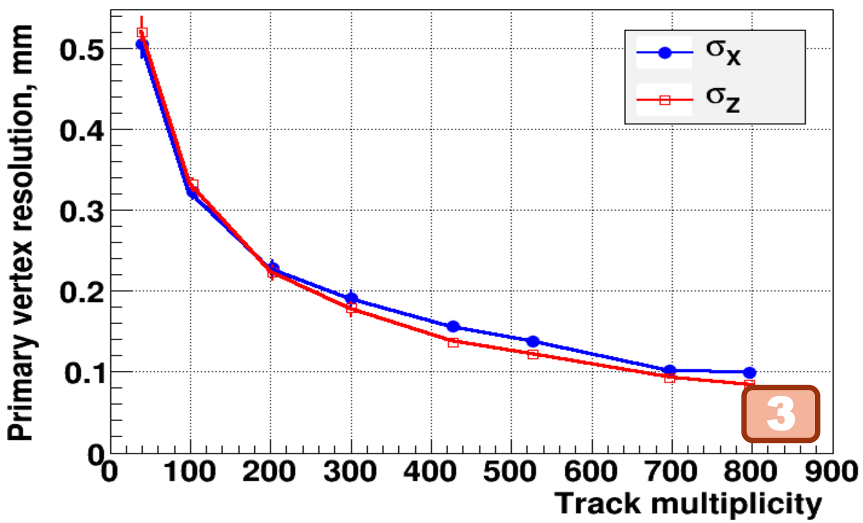


"Shashlyk" sampling calorimeter:

Pb (0.35 mm) + Scint. (1.5 mm)
4x4 cm^2 , L ~35 cm (~ 14 X_0)
read-out: WLS fibers + MAPD

MPD performance: tracking





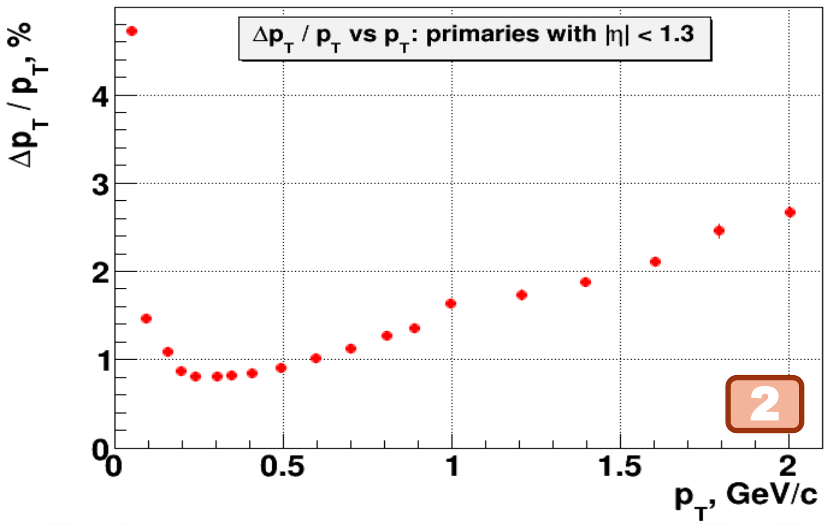
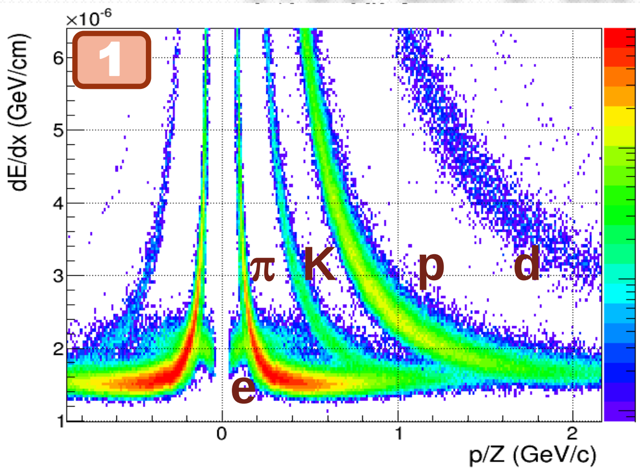


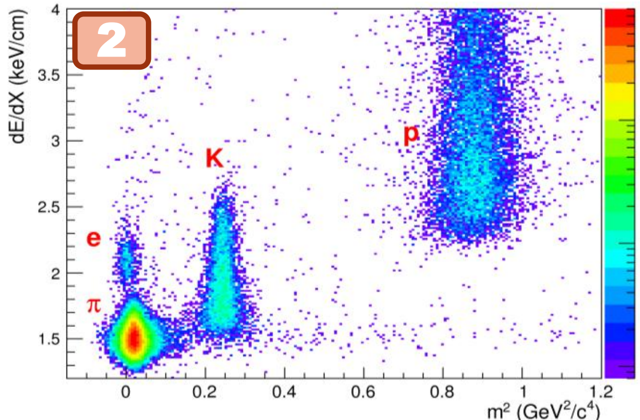
Fig.1: Track reconstruction efficiency.
High efficiency: down to 100 MeV/c

Fig.2: Momentum resolution.
$\Delta p/p$ < 2% @ p_T < 1.5 GeV/c

Fig.3: Primary vertex resolution.
σ_x & σ_z < 0.15 mm in central collisions at track multiplicity in TPC >500

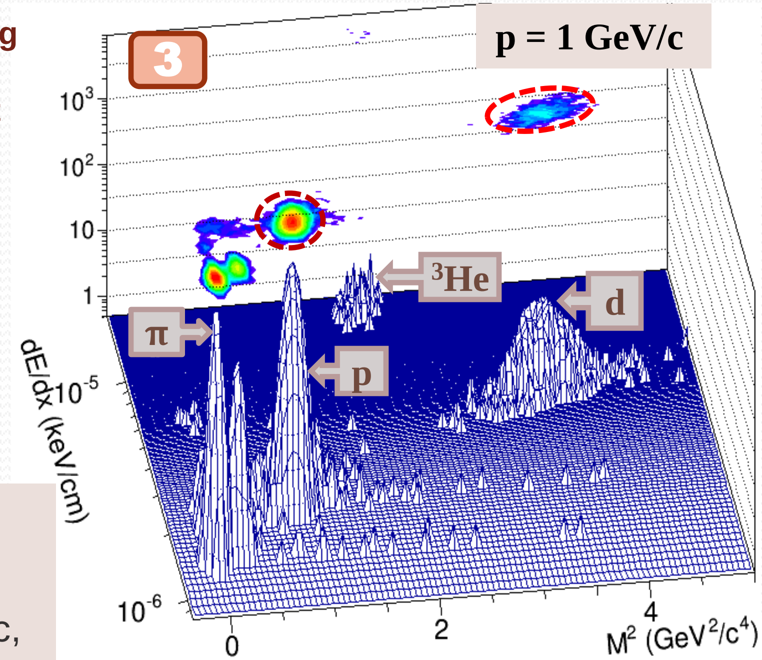
MPD Particle Identification (PID)





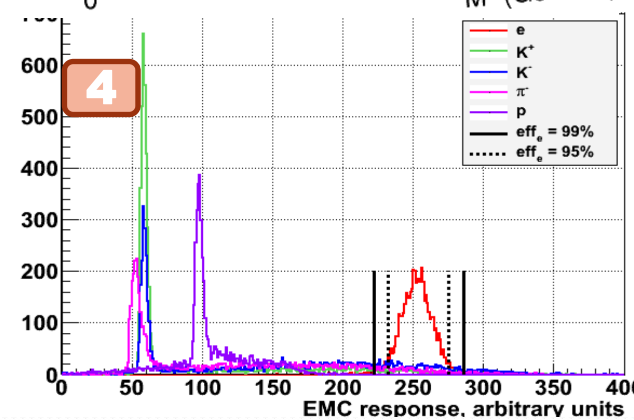
Mass square calculated using the measurements of momentum (p), time-of-flight (T) and trajectory length (L):

$$m^2 = p^2\left(\frac{c^2T^2}{L^2} - 1\right)$$



Requirements :

- 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



PID methods (in combination with measure of momentum in the B-field):

Fig.1: Energy loss (dE/dx) in the TPC gas

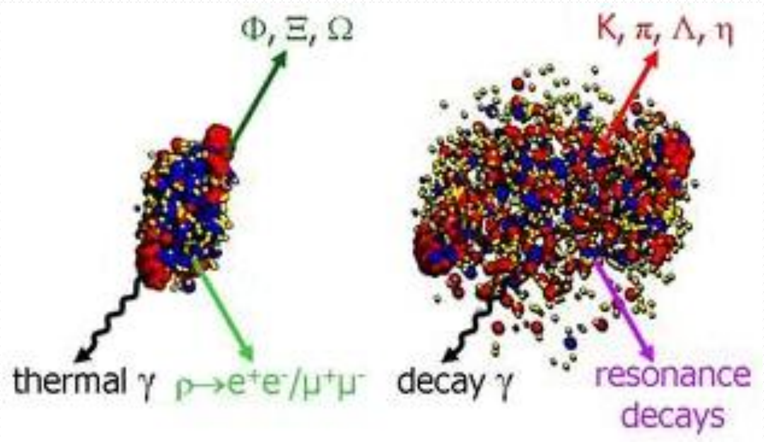
Fig.2: Combined dE/dx and TOF

Fig.3: Particle selection within ‘dE/dx vs m^2‘ space in momentum bins

Fig.4: Energy deposit in ECAL (γ and $e^{\pm}$)

Physics motivation

- The study of hyperons helps to understand strong interactions and QGP.
- Hyperons (especially Λ) are produced in relatively large quantities and have very attractive experimental features (resonance structure and simple decay mode). They can serve as detector performance monitoring tools.



Messengers from the dense fireball: UrQMD

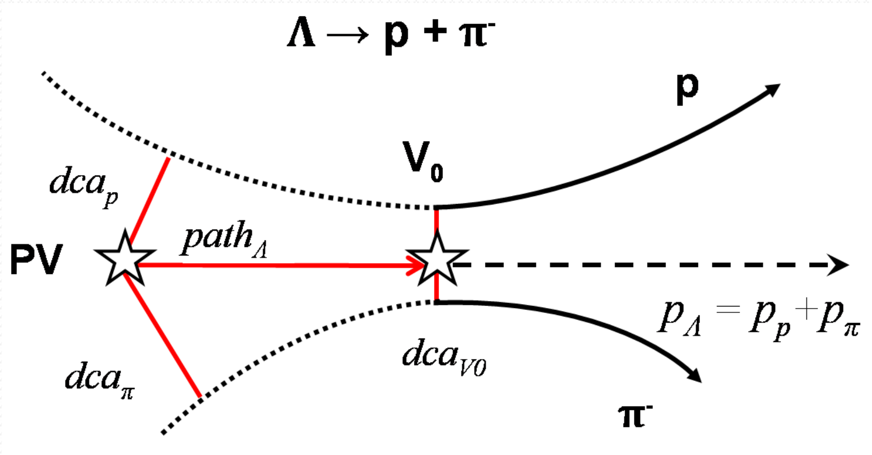
Data set

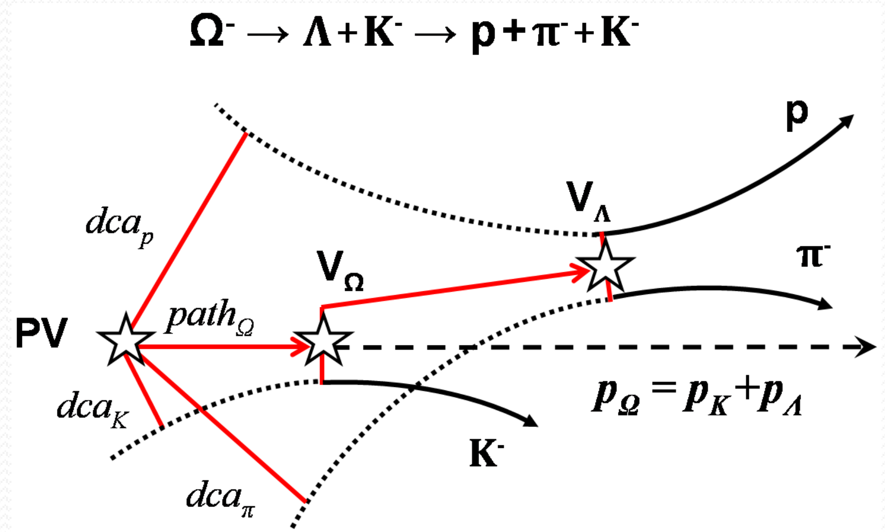
- **Generator:** UrQMD , Au+Au @ 9A GeV central (0-3 fm), 10k - 500k events (30 sec. - 28 min. of data taking time at NICA)
- **Detectors:** start version of MPD with up-to-date TPC & TOF

Analysis

- Track acceptance criterion: $|\eta| < 1.3$, $N_{hits} \geq 10$
- Particle identification in TPC & TOF

Analysis Method:
Secondary Vertex Finding Technique



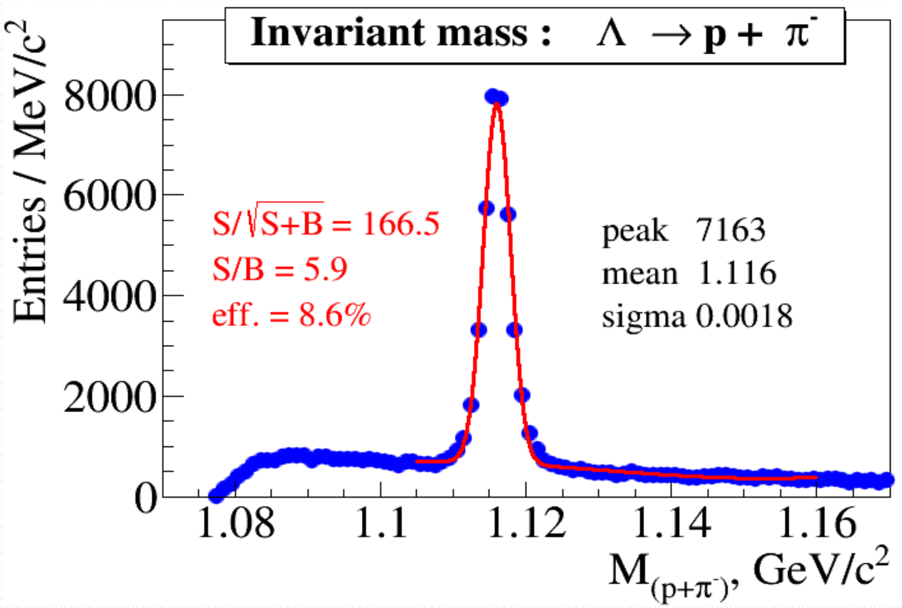


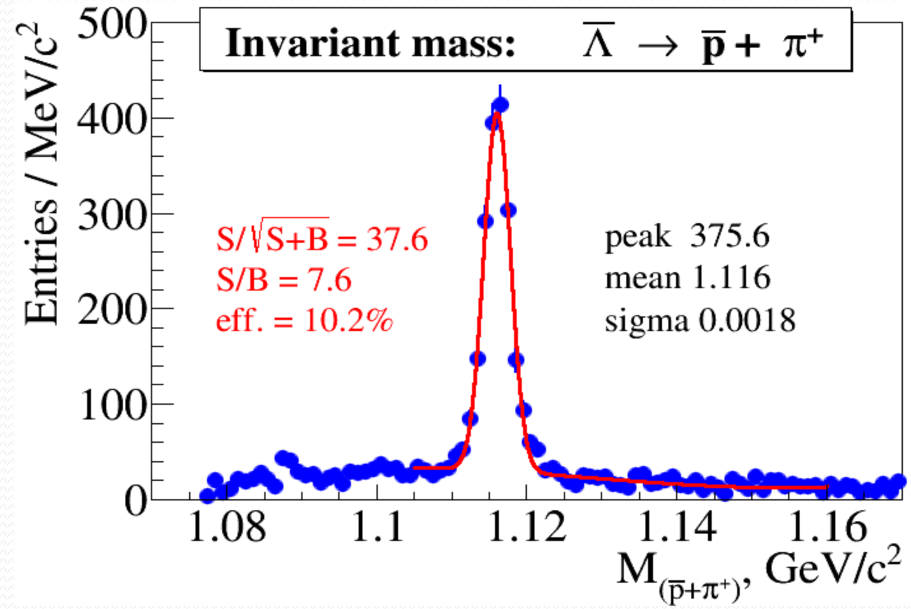
Event topology:

- PV – primary vertex
- V_0 – vertex of hyperon decay
- dca – distance of the closest approach
- path – decay length

Invariant mass at max. significance:

$\Lambda \to p + \pi^{-}$ & $\Lambda_{bar} \to p^{-} + \pi^{+}$





Λ multiplicity

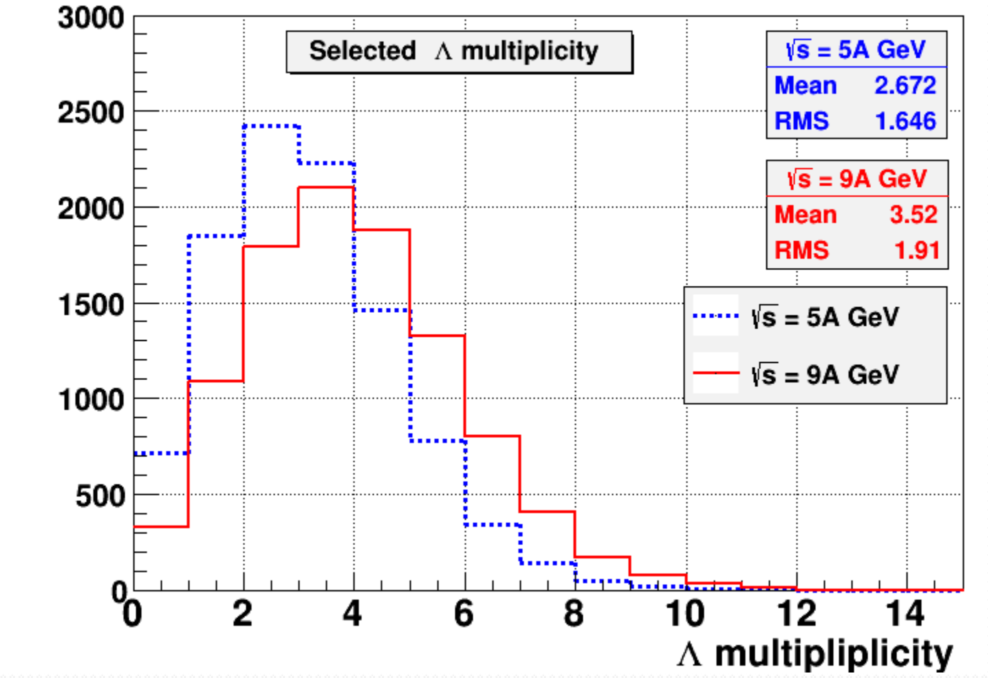
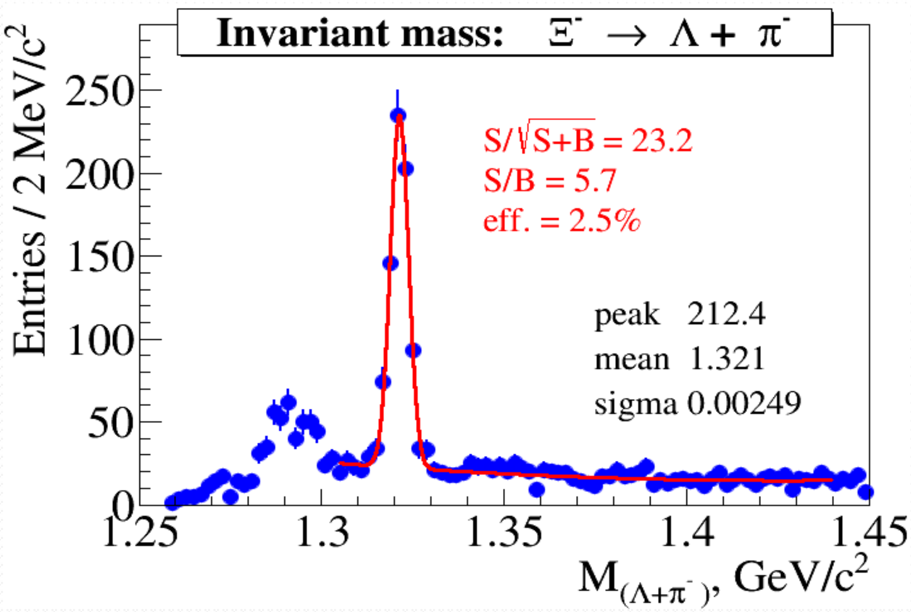


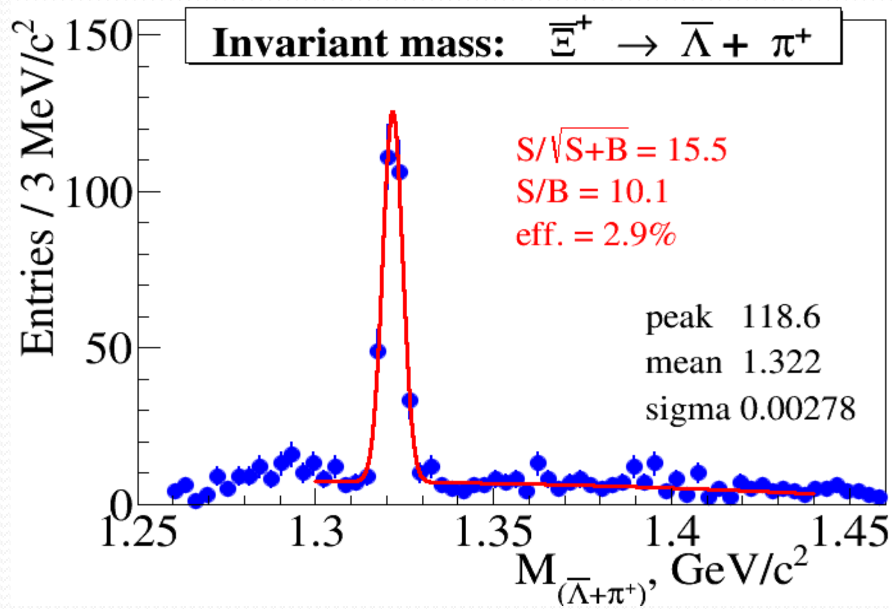
Figure: Multiplicity of reconstructed Λ at √s= 5A and 9A GeV from UrQMD generator.

The resulting efficiency will allow studying some multiparticle phenomena with hyperons (for example, Λ − Λ correlations).

Invariant mass at max. significance:

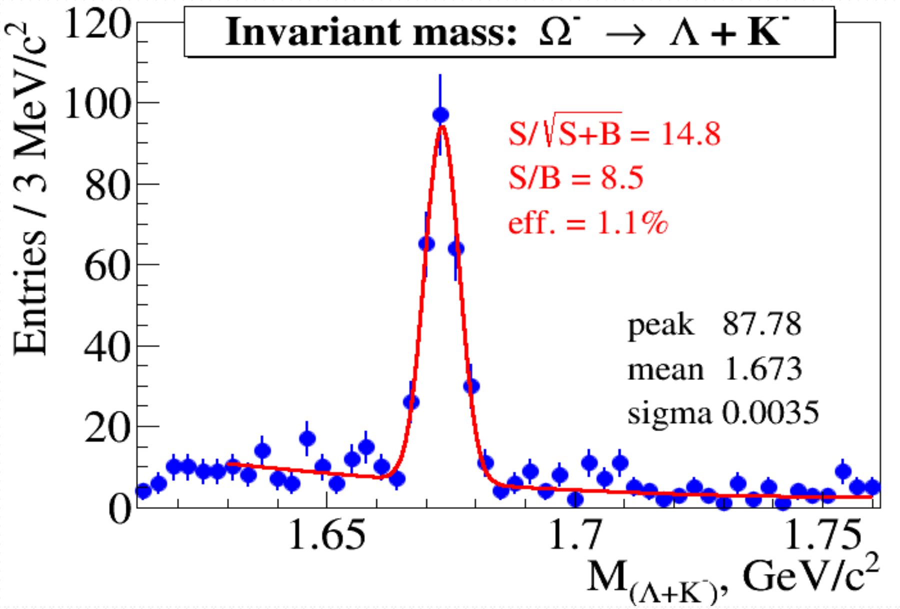
$\Xi^- \to \Lambda + \pi^-$ & $\Xi^+_{bar} \to \Lambda_{bar} + \pi^+$

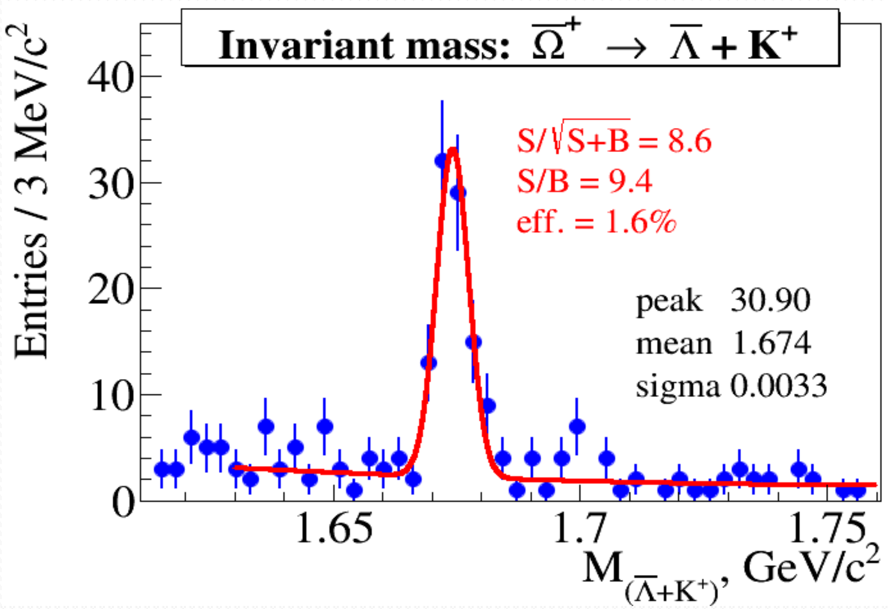




Invariant mass at max. significance:

$\Omega^- \rightarrow \Lambda + K^-$ & $\Omega^+_{bar} \rightarrow \Lambda_{bar} + K^+$





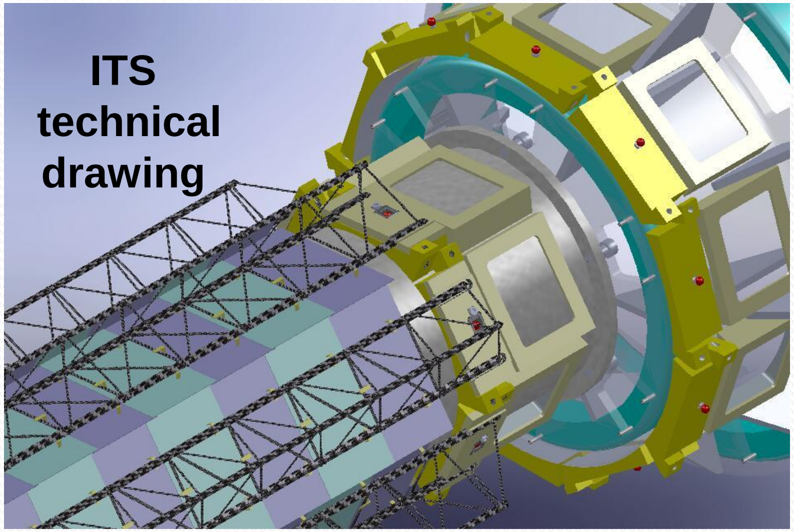
Expected yields of the hyperons for MPD

10 weeks of running time, 300 central events per second

Particles / Decay	Yields
$\Lambda \rightarrow p + \pi^-$	$5.8*10^9$
$\Lambda_{bar} \rightarrow p^- + \pi^+$	$7.3*10^7$
$\Xi^- \rightarrow \Lambda + \pi^-$	$2.9*10^7$
$\Xi^+{}_{bar} \rightarrow \Lambda_{bar} + \pi^+$	$1.6*10^6$
$\Omega^- \rightarrow \Lambda + K^-$	$1.4*10^6$
$\Omega^+{}_{bar} \rightarrow \Lambda_{bar} + K^+$	$2.5*10^5$

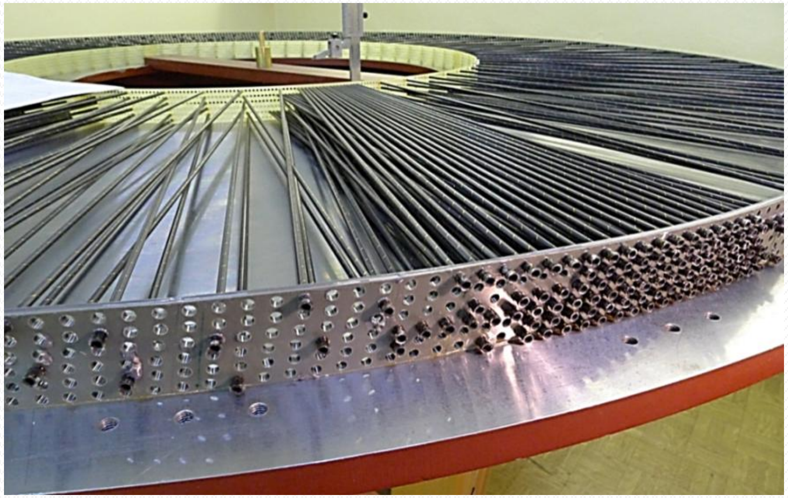
All efficiencies are included.

Stage 2: ITS & EndCap



Inner Tracker System (ITS)

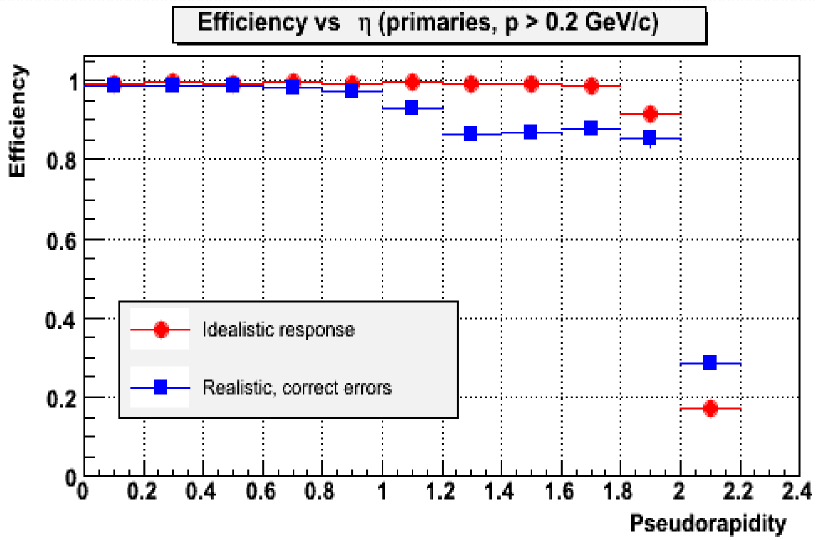
- 4 cylindrical & disk layers
- 300 mm double-sided silicon microstrip detectors, pitch - 100 mm
- Thickness / layer ~ 0.8% X_0
- Barrel: R = 6-25 cm, coverage $|\eta|<2.5$
- 806 sensors of 62x62 mm^2
- ***Resolution:*** σ_z = 120 mm, σ_{rf} = 23 mm

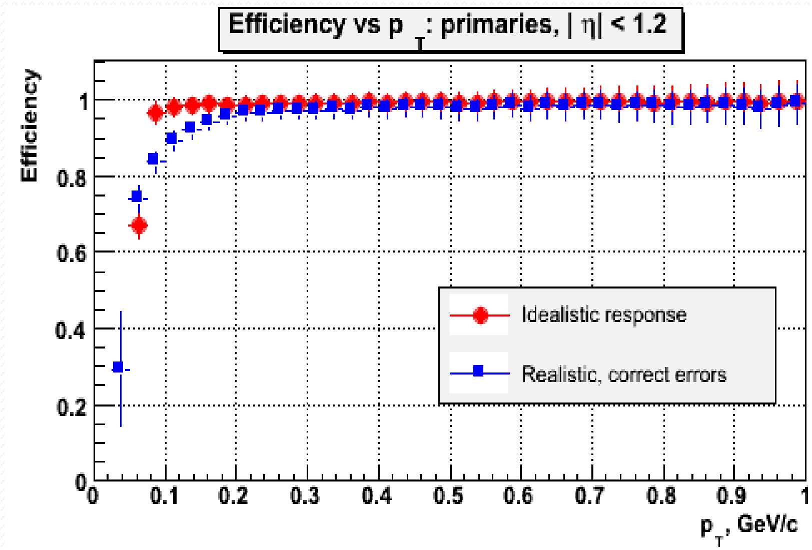


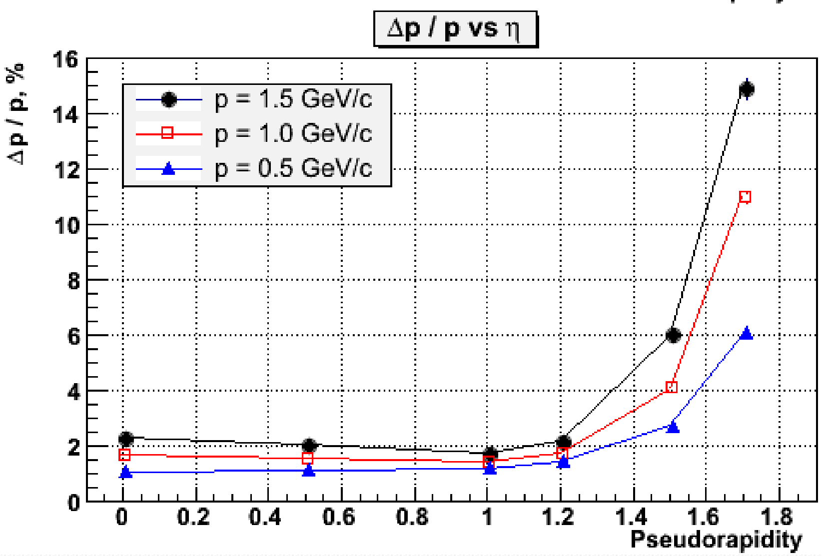
EndCap Tracker (straw ECT)

- 2x60 straw layers
- ~ 72000 straw tubes 4 mm x 60 cm
- ***Coverage:*** $1.3<|\eta|<2.2$

MPD Tracking performance with ITS & ECT

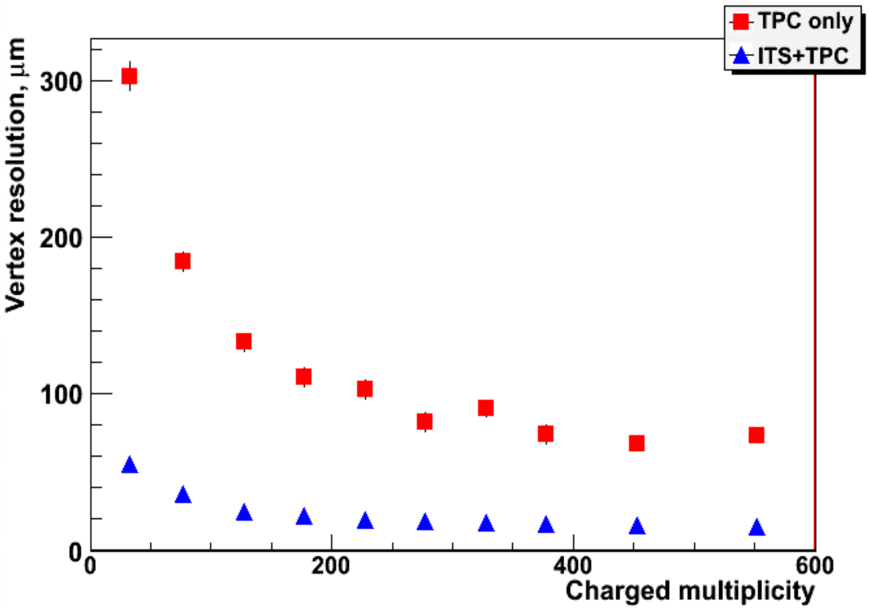


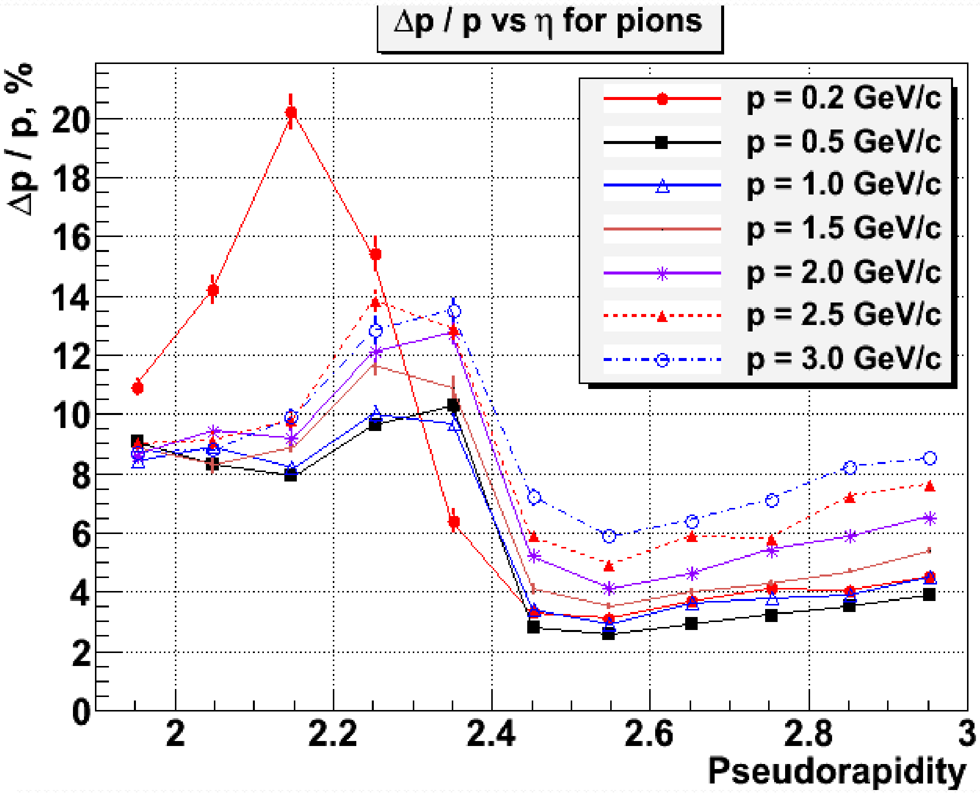




- MPD tracking efficiency above 85% within $|\eta|<2.0$ && $p_t>0.15$ GeV/c
- $\Delta p/p$ < 3% at midrapidity

MPD Tracking capability with ITS & ECT





- TPC+ITS $\sigma_{r\varphi},\sigma_Z < 40\ \mu m$
- TPC+ECT provides tracking up to η=3
- Considerable gain in vertex finding capability with TPC+ITS

Conclusions and Outlook

- MPD start version will provide a good opportunity for a study of the strangeness production at NICA (mass resolution 2-3 MeV/c^2 and high enough yields).
- More realistic detector response simulation is in progress.
- Effects of increased detector acceptance (higher η-coverage, detector upgrade) are under evaluation.

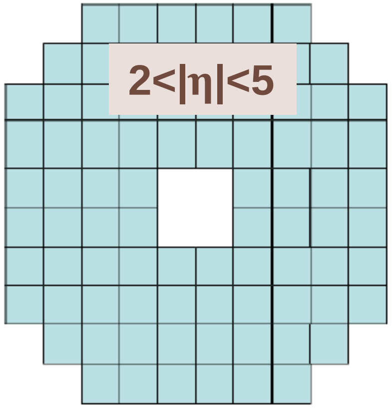
Complex NICA – civil construction

The preparatory works are close to completion

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

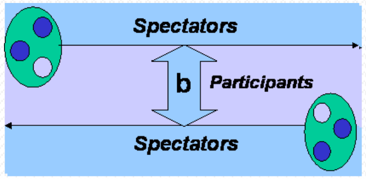
Thank You for attention!

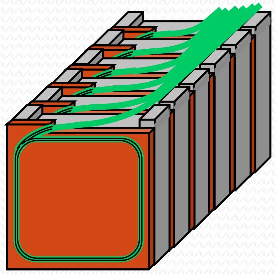
Zero Degree Calorimeter (INR, Troisk+VBLHEP, JINR)



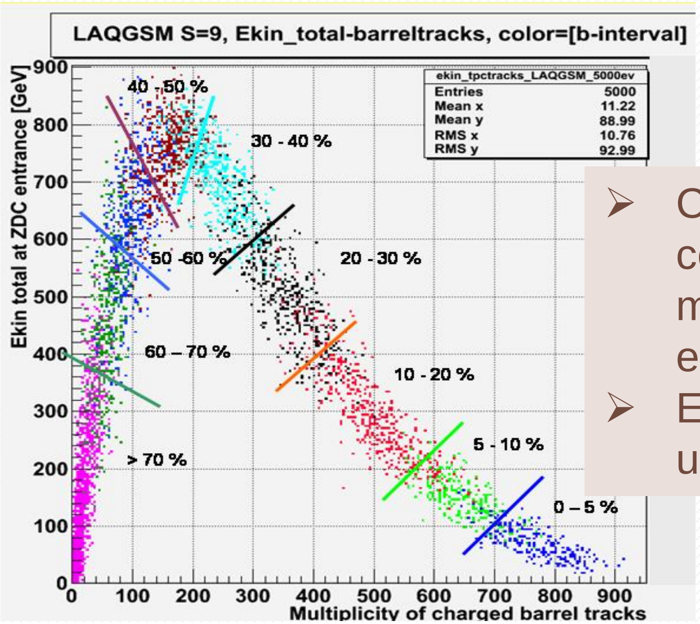
.. to measure the energy deposited by spectators. ZDC provides:

- ➢ Off-line event centrality determination → transverse dimensions motivated by the spectator spot size
- ➢ Measure of the assymetry in athimuthal distribution (event plane)





- ➢ Pb(16mm)+Scint.(4mm) sandwich
- ➢ 45 layers of lead-scintillator (4λ)
- ➢ Read-out: WLS fibers + MAPD
- ➢ similar to ZDCs for NA61 and CBM



- ➢ Centrality is defined by combined TPC track multiplicity and ZDC energy deposit
- ➢ Event plane resolution up to 0.9