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On behalf of the MPD & BM@N collaborations

RELATIVISTIC HEAVY ION PHYSICS AT JINR: STATUS OF THE BM@N AND MPD EXPERIMENTS

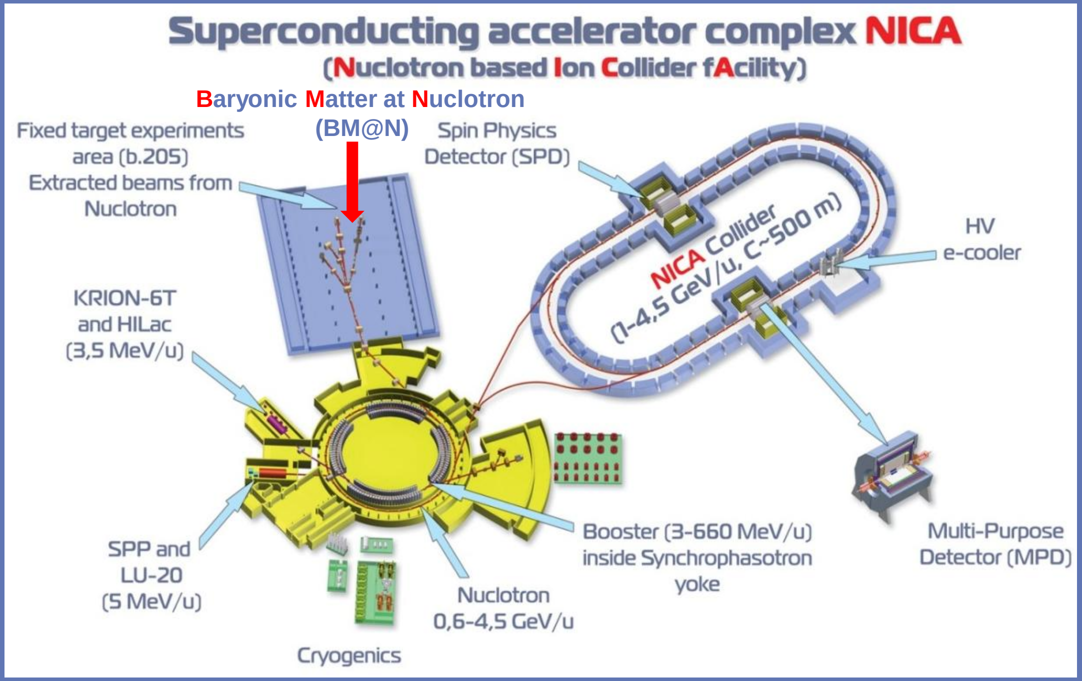
OUTLINE

- **MPD/NICA project**
  - Research program at MPD/NICA
  - MPD detector: R&D and performance studies
  - Current status of the MPD/NICA project
- **BM@N project**
  - Research program at BM@N
  - Proposed detector setup
  - Detector subsystems
  - Time schedule for BM@N setup development
- **Summary**

MPD/NICA PROJECT

COMPLEX NICA

- 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



NICA parameters

Beams: p,d(h)..$^{197}Au^{79+}$

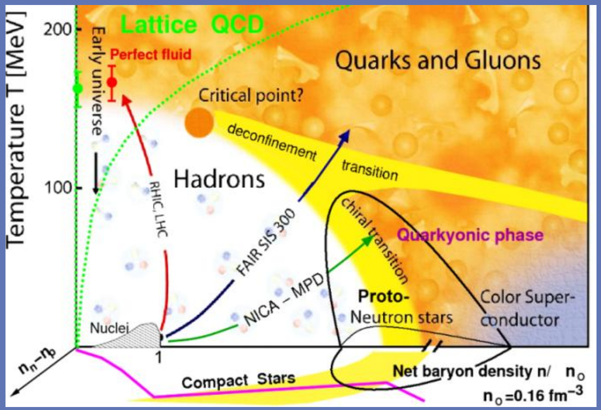
Collision energy: 4-11A GeV (nuclei)

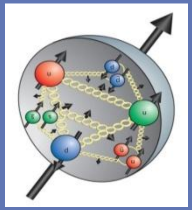
Luminosity: 10^{27} $cm^{-2}s^{-1}$ (Au), 10^{32} (p)

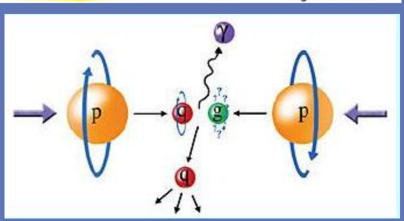
2 Interaction points: MPD and SPD

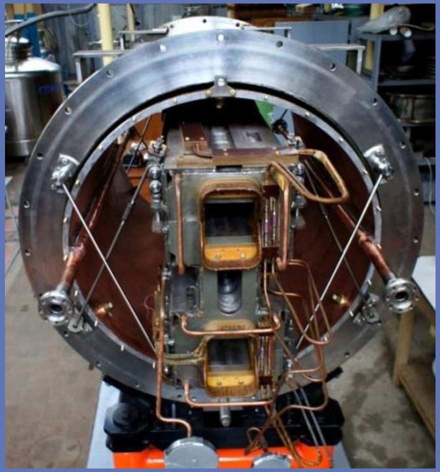
Fixed target: 1-6A GeV beams (BM@N)

RESEARCH PROGRAMS @ NICA









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

MPD PHYSICS TASKS AND OBSERVABLES

- **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: $\rho, \omega, \phi \rightarrow e^+e^-$
- **Deconfinement (chiral) phase transition at high r_B**

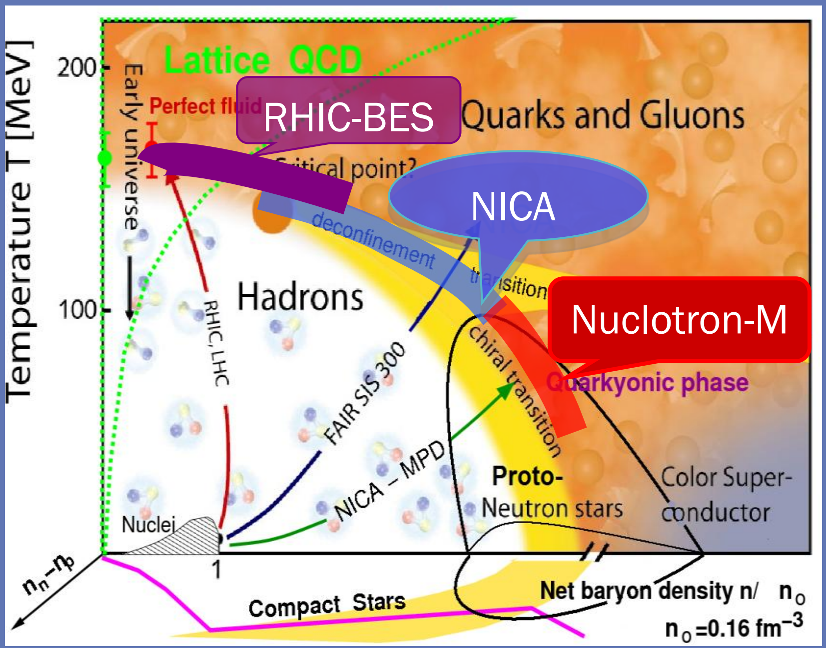
  enhanced strangeness production

  Chiral Magnetic (Vortical) effect, L polarization
- **QCD Critical Point**

  event-by-event fluctuations and correlations
- **Strangeness in nuclear matter**

  hypernuclei, exotica

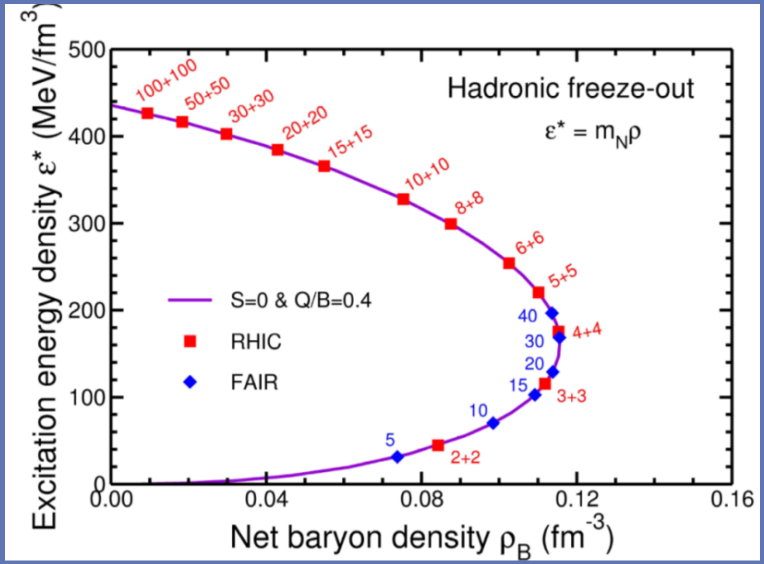
QCD PHASE DIAGRAM. PROSPECTS FOR NICA

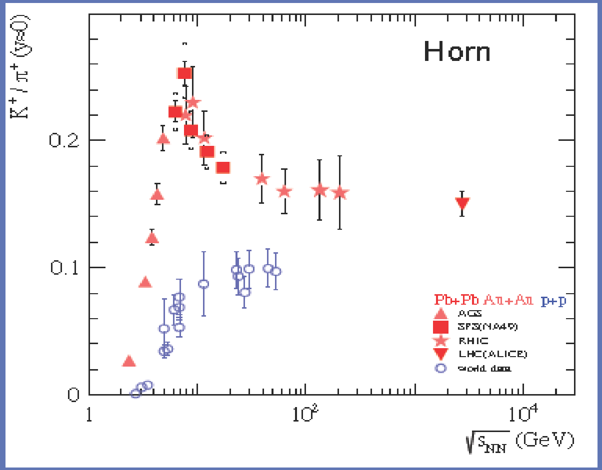


Energy Range of NICA

- Highest net baryon density
- Energy range brackets onset of deconfinement
- Complementary to the RHIC/BES, FAIR and CERN experimental programs

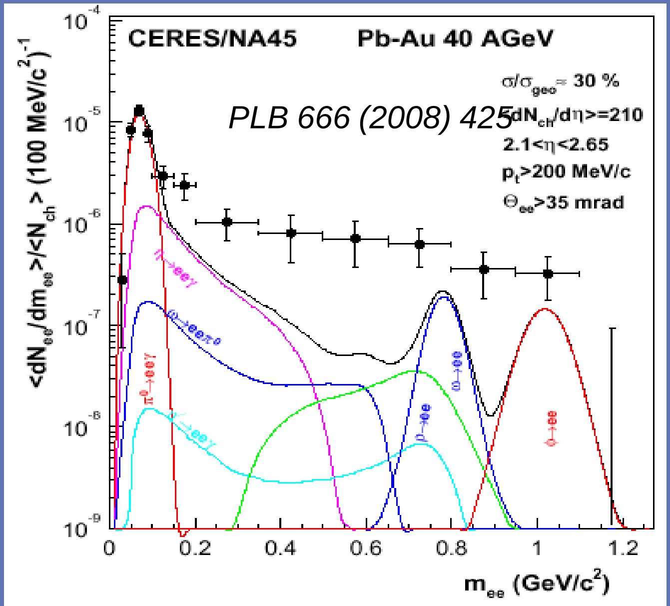
PHYSICAL REVIEW C 74, 047901 (2006)

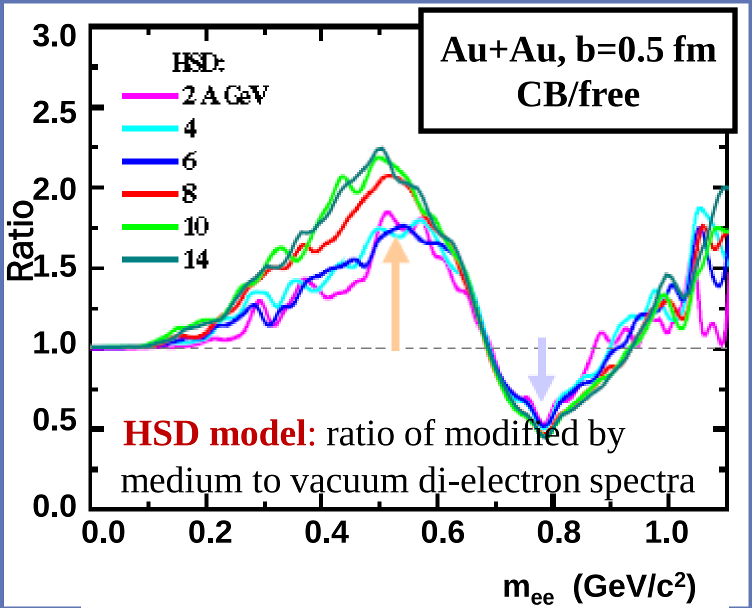




DENSE MATTER @ NICA. IN-MEDIUM MODIFICATION

- Changes of the particle properties (shift and broadening of spectral functions) in dense medium. Dileptons are ideal probes
- NICA is well situated to study in-medium effects due to highest baryon densities

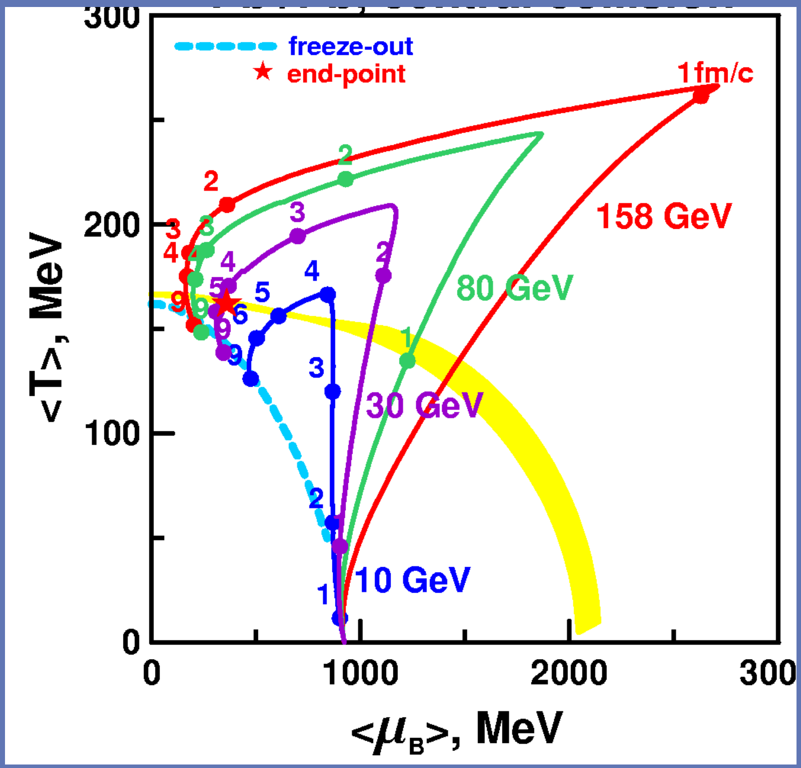




Particle	Yields		Decay mode	BR	Effic. %	Yield/1 w
	4π	y=0				
ρ	31	17	e^+e^-	$4.7 \cdot 10^{-5}$	35	$7.3 \cdot 10^4$
ω	20	11	e^+e^-	$7.1 \cdot 10^{-5}$	35	$7.2 \cdot 10^4$
φ	2.6	1.2	e^+e^-	$3 \cdot 10^{-4}$	35	$1.7 \cdot 10^4$

QCD PHASE DIAGRAM. CRITICAL END POINT

Central Au+Au collisions



Trajectories calculated by a 3-fluid hydrodynamics model Toneev & Ivanov

If the trajectory is in the vicinity of the critical endpoint – abnormal fluctuations can be observed

Requirements to the apparatus:

- Large uniform acceptance
- Careful event characterization

HYPERNUCLEI @ NICA

Motivation:

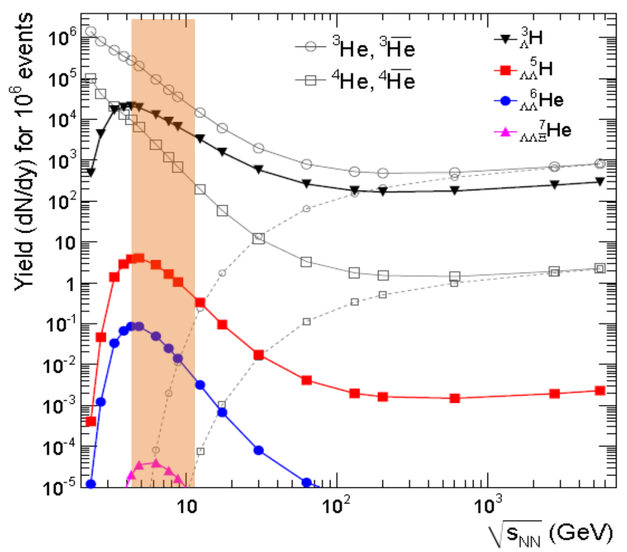
- Precise information on Y-N interaction: nuclear EOS, astrophysics
- Hypernuclei ground, excited states and life times: critical assessments

for QCD calculations and model predictions

- Production mechanism of bound states with hyperons: coalescence versus spectators-participants interactions, exotic states, dibaryons

To study hyper-nuclei, MPD detector must be able to detect and identify light nuclei in a wide rapidity range as well to have a good capability for precise secondary vertex reconstruction

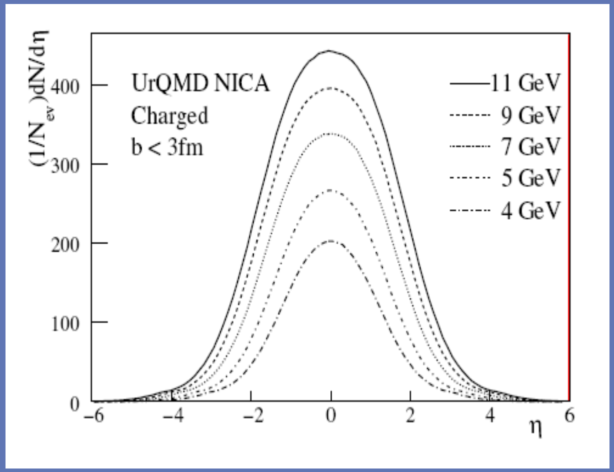
Hypernuclei production enhanced at high baryon densities (NICA)

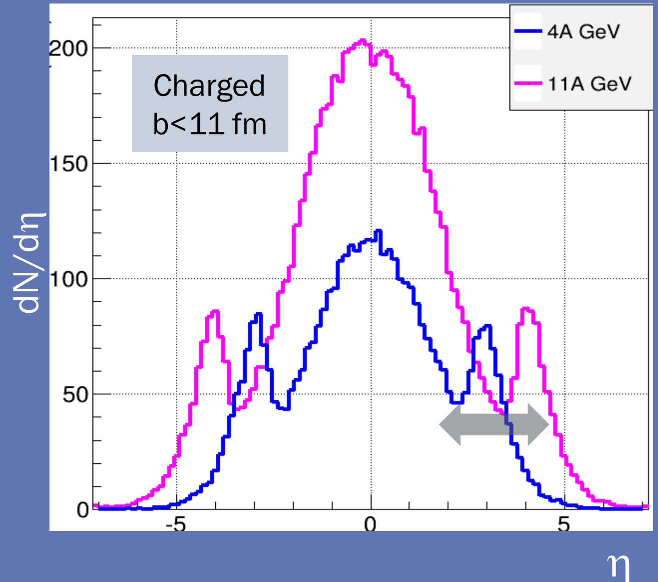


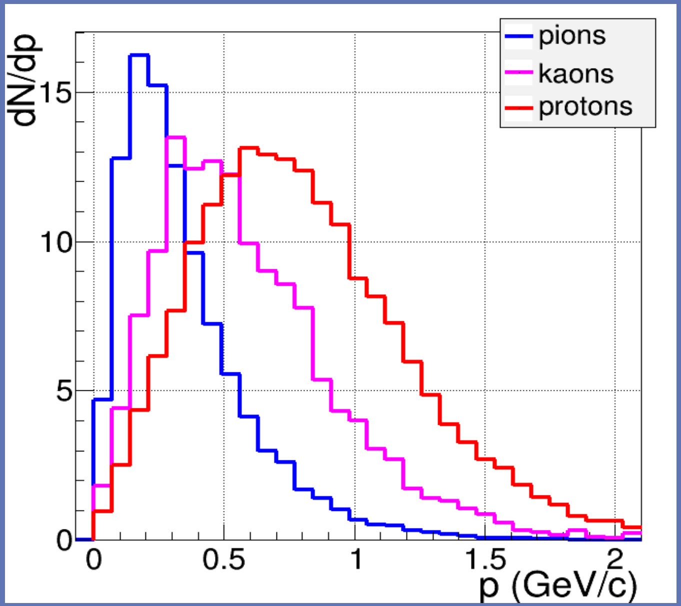
A.Andronic, P.Braun-Munzinger, J.Stachel, H.Stocker

Particle	Yield/10 w (NICA)	
	8 GeV	11 GeV
$_\Lambda H^3$	$4.5 \cdot 10^3$	$1.6 \cdot 10^3$

AU+AU COLLISIONS AT NICA (MODEL PREDICT.)







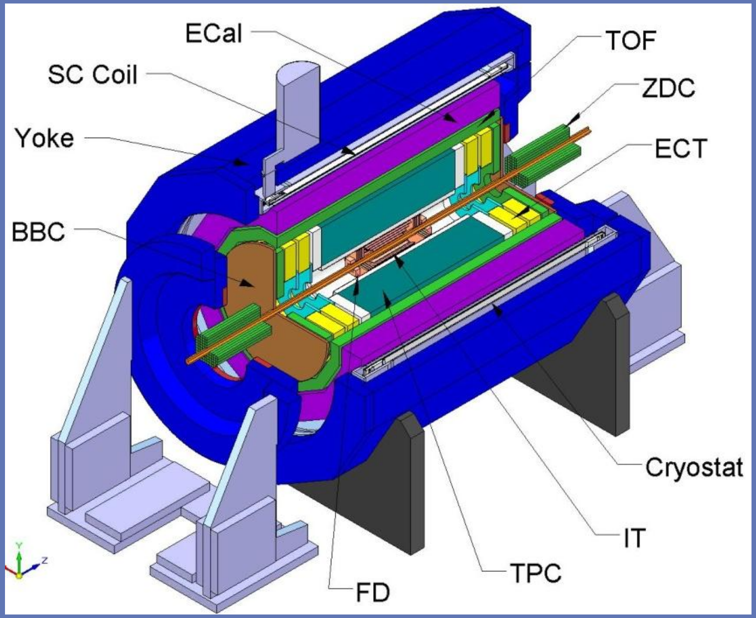
- dN/dη (charged) ~ 500 at midrapidity in central Au+Au
- $<p_t>$ ~ 300 MeV/c (pions, $|\eta|<1.0$)
- Centrality: eta-range from η=2 to 5 (granularity for event plane)

THE MPD APPARATUS

Magnet: 0.5 T superconductor
Tracking: TPC, ECT, IT
ParticleID: TOF, ECAL, TPC
T_0, Triggering: FFD
Centrality, Event plane: ZDC

Stage 1: TPC, Barrel TOF & ECAL, ZDC, FFD

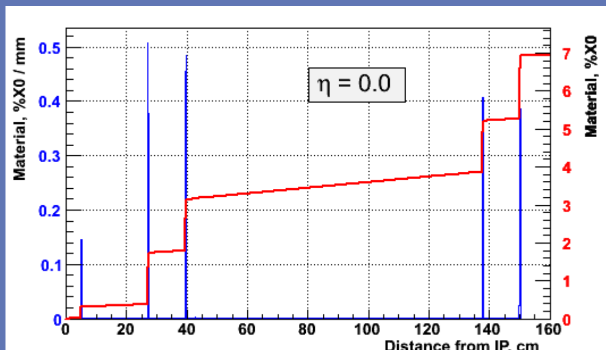
Stage 2: IT + EndCaps (tracker, TOF, ECAL)

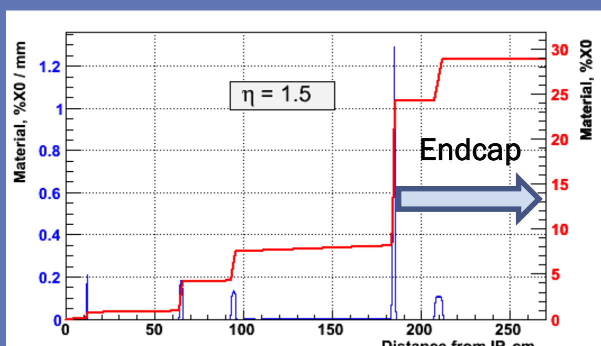


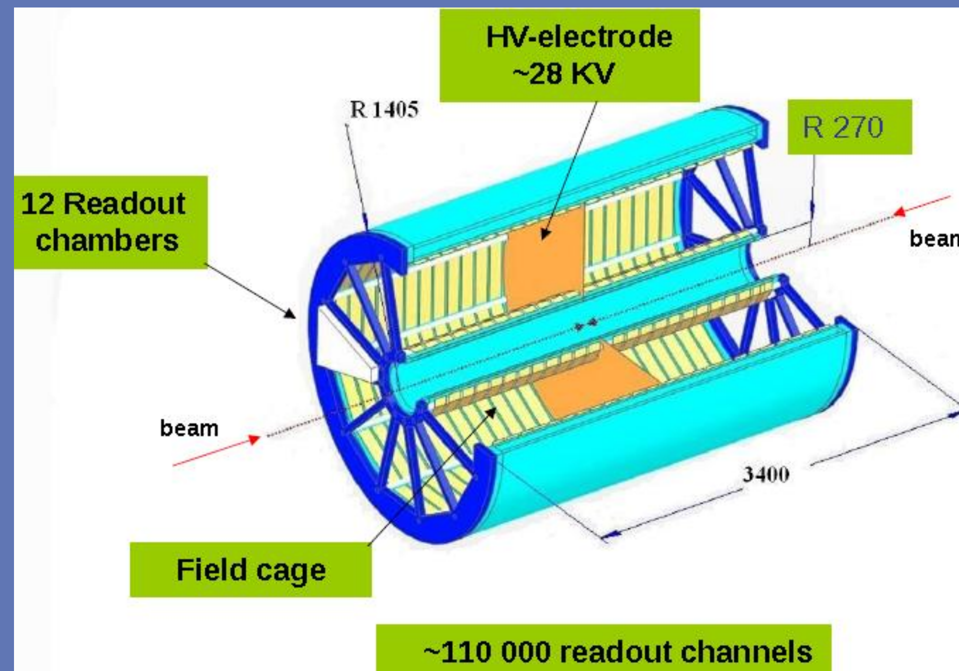
Requirements to the apparatus:

- Hermeticity, homogenous acceptance : 2π in azimuthal angle
- Highly efficient 3-D track reconstruction ($|\eta|<2$), 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

MPD TRACKING SYSTEM - TPC







MPD TPC

Dimensions: 4 m x 3 m

Drift Length: 170 cm

Gas: 90% Argon + 10% Methane

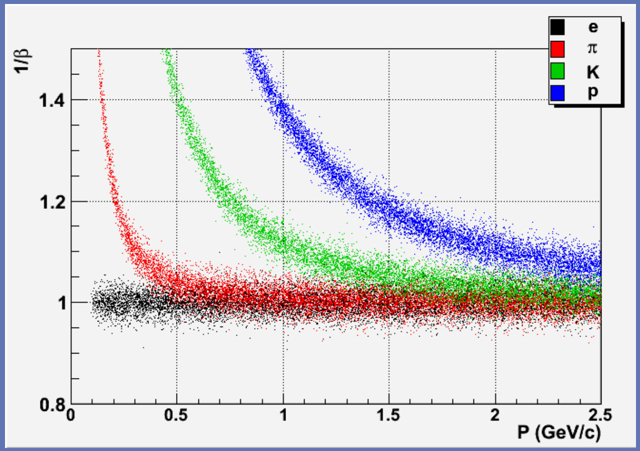
Readout: 2x12 sectors (MWPC or GEM)

Composite materials – transparent detector!

TPC performance required

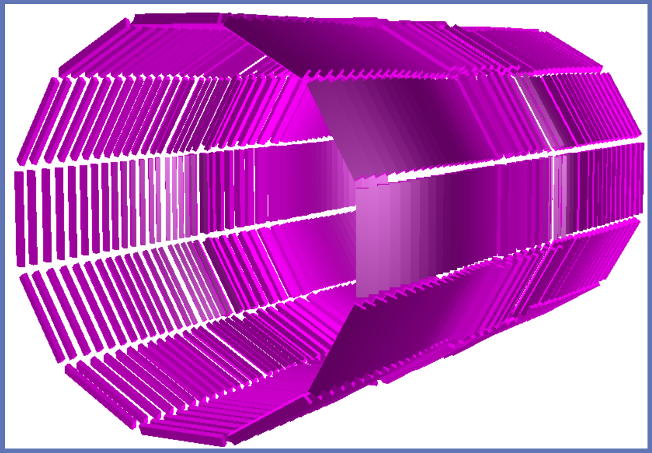
- Low material budget
- *Rate capability* up to 6 kHz
- *Spatial resolution:* $\sigma_{r\phi}$~300 mm, σ_z~ 2 mm
- *Momentum resolution:* Δp/p < 3% (0.2<p<1 GeV/c)
- *dE/dx resolution:* < 8%

TIME OF FLIGHT (TOF) (JINR + HEFEI, BEIJING(CHINA)



PID :

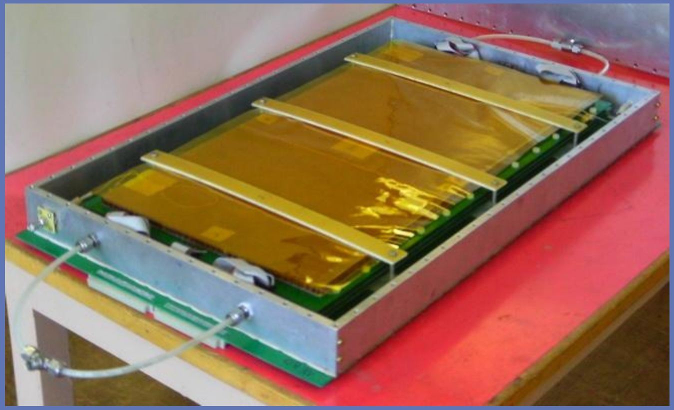
e/h–0.1..0.35 GeV/c
p/K–0.1..1.5 GeV/c
K/p–0.1..2.5 GeV/c



Basic requirements:

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

→ **Resistive Plate Chambers**



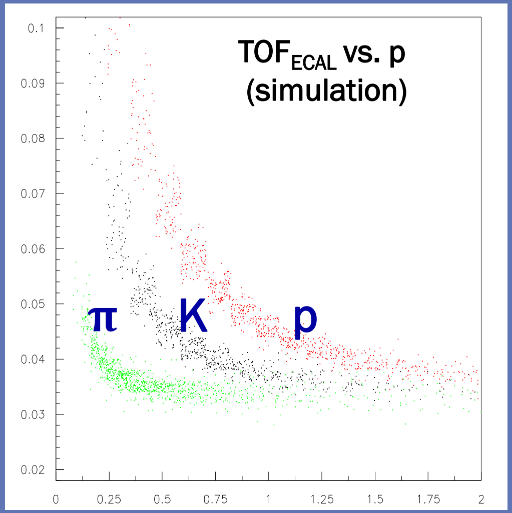
Dimensions:
barrel: 5 m (length), 2.5 m (diameter)
endcap: 2 x 2.5 m (diameter) disks
Gas: 90% $C_2H_2F_4$ + 5% iC_4H_{10} + 5% SF_6
Segmentation (barrel):
12 sectors x 55 modules (62x7 cm^2)
module: 10-gap RPC

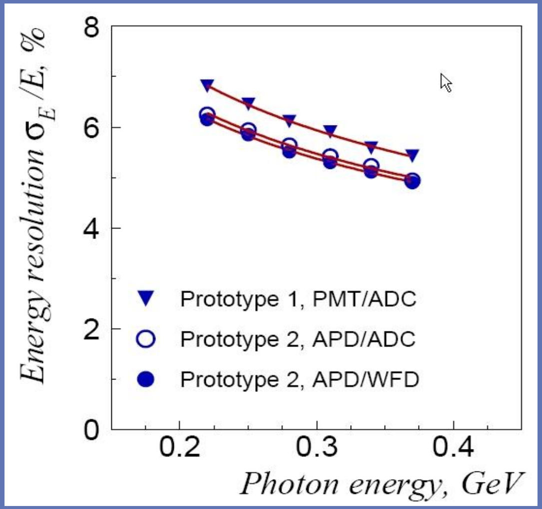
ELECTROMAGNETIC CALORIMETER (ECAL)

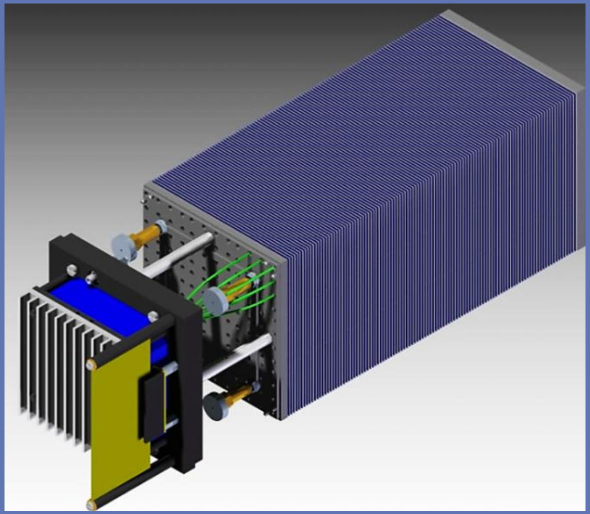
ECAL aimed at detecting electrons and gammas and has to fulfill:

- High granularity and hermeticity
- Energy, spatial (and also timing) resolutions
- Manufacturing technology & cost

- $\sigma/E \sim 3\%/\sqrt{E}$ + const
- $\sigma_{TOF} \sim 150$ ps







VBLHEP & DLNP (JINR) + ISM (Kharkiv)

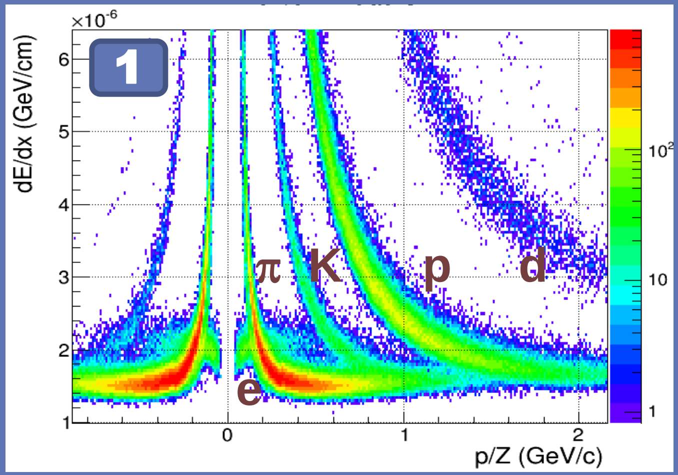
"Shashlyk" sampling calorimeter:

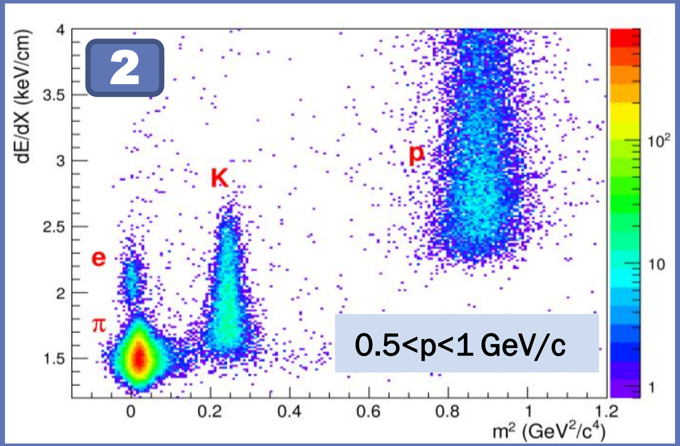
Pb (0.35 mm) + Scint. (1.5 mm)

4x4 cm^2 , L ~35 cm (~ 14 X_0)

read-out: WLS fibers + MAPD

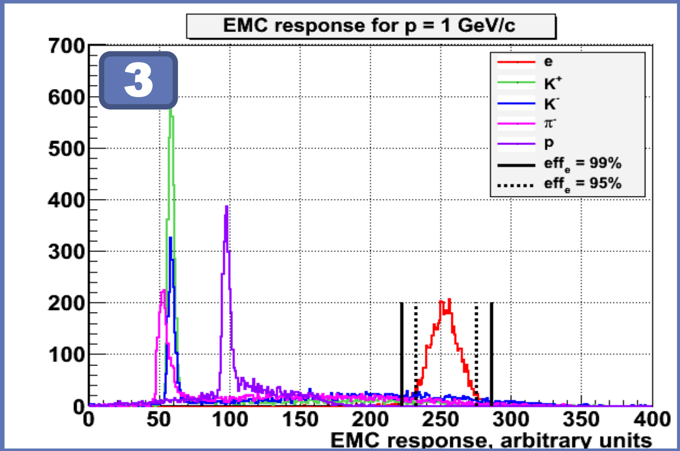
MPD PARTICLE IDENTIFICATION (PID) SYSTEM





Requirements :

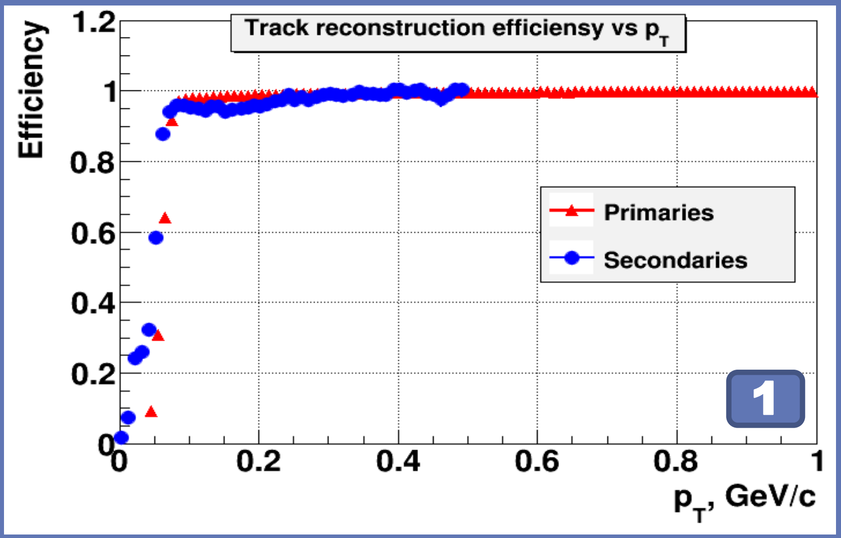
- Hadron (π, K, p) identification up to 3 GeV/c, midrapidity nuclei PID
- Electron PID with hadron suppression up to 10^5
- Secondary vertex reconstruction – hyperons & hypernuclei @ midrapidity

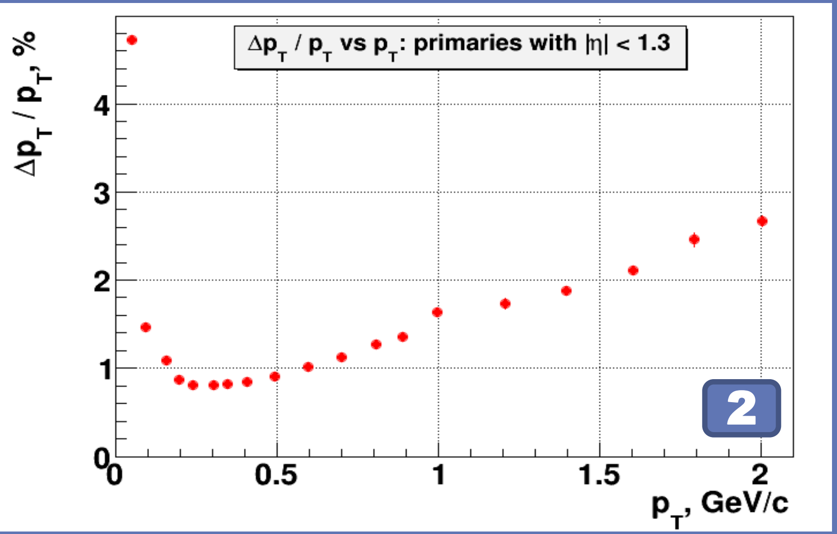


PID methods (in combination with a measurement of momentum in the B-field):

Fig.1: Energy loss (*dE/dx*) in the TPC gas
Fig.2: Combined *dE/dx* and TOF
Fig.3: Energy deposit in ECAL (γ and $e^{\pm}$)

MPD PERFORMANCE: TRACKING





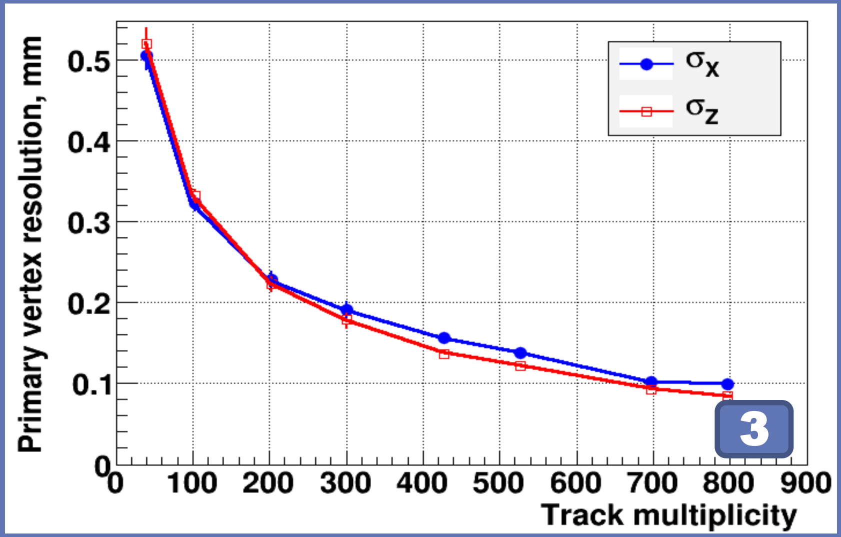
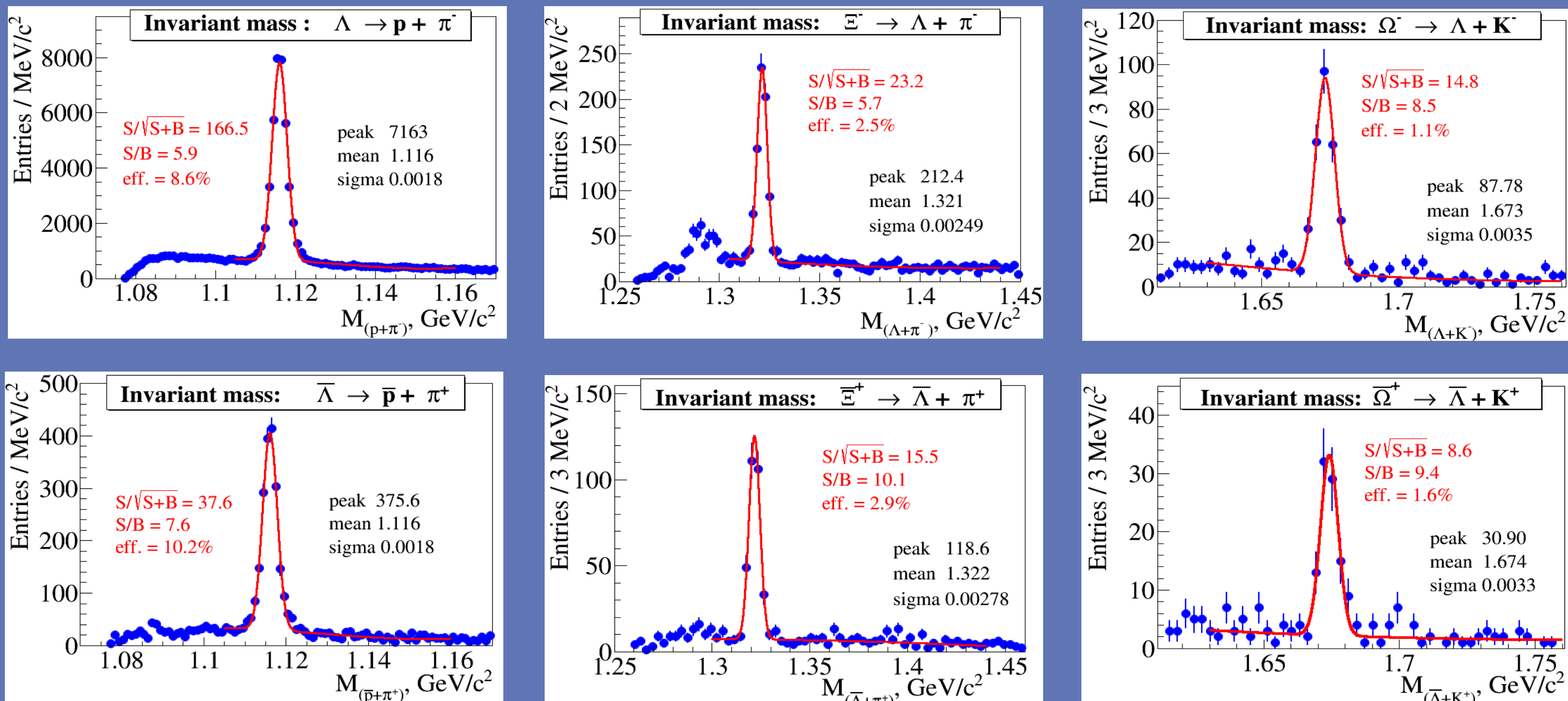


Fig.1: Track reconstruction efficiency
High efficiency: down to 100 MeV/c

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 PERFORMANCE: START VERSION (TPC & TOF)



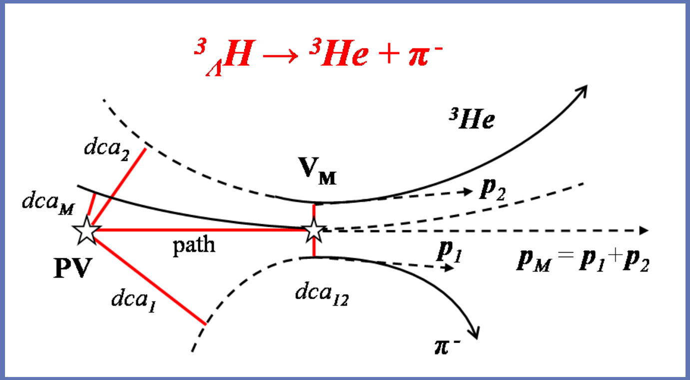
Figures: Reconstruction of Λ, Ξ, Ω hyperons
Detectors: start version of MPD with up-to-date TPC & TOF; **Generator:** UrQMD, Au+Au @ 9A GeV, central (0-3 fm), 10k - 500k events. (30 sec. - 28 min. of data taking time at NICA)

Realistic PID in TPC&TOF, realistic tracking and secondary vertex finding technique allow to reconstruct multistrange hyperons already with start version of MPD.

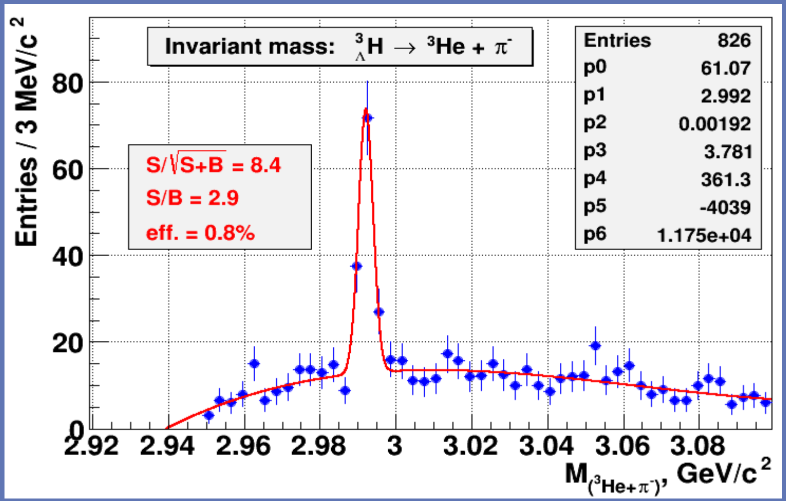
MEASUREMENT OF HYPER-TRITONS AT NICA/MPD

Motivation

- Study of YN interactions in nuclear matter
- Enhanced production of multi-strange composites at high baryon densities



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

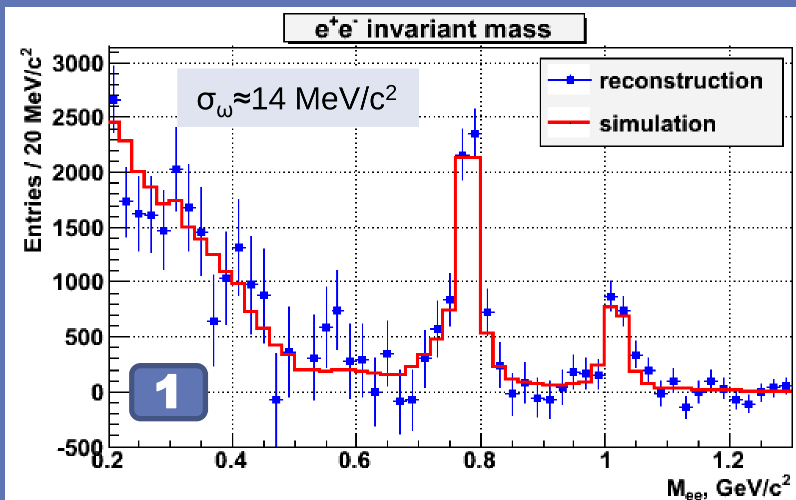


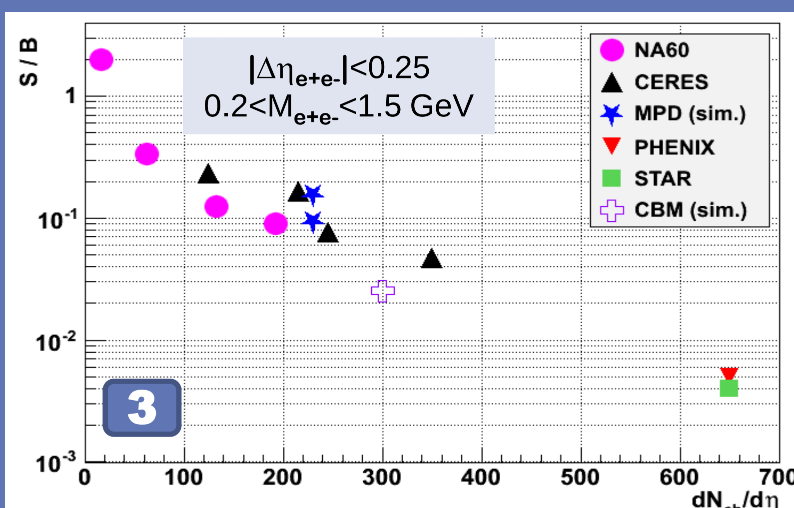
Analysis

- 500k central Au+Au @ 5A GeV (LAQGSM model [1])
- Realistic tracking & secondary vertex finding technique
- Track quality cuts & Particle ID for secondaries

[1] J. Steinheimer, K. Gudima, et al, Phys. Lett. B 714 (2012) pp 85-91

MPD PERFORMANCE FOR DILEPTONS (STAGE'1)





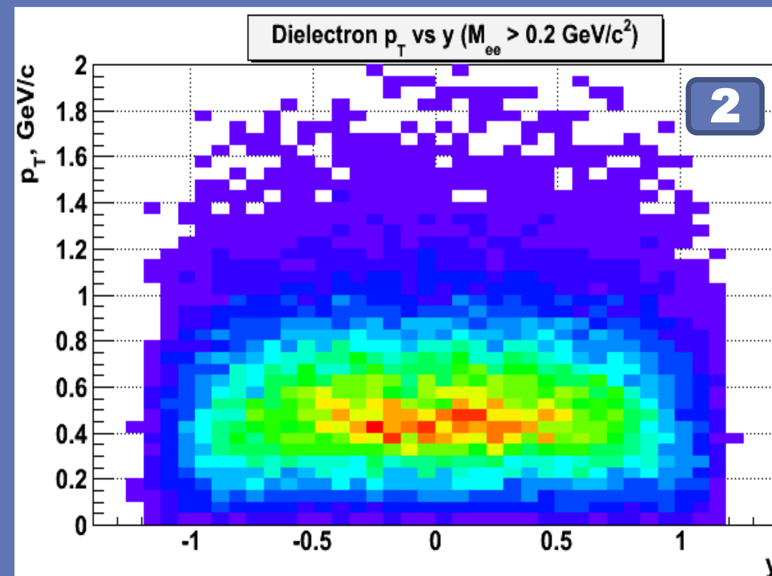


Fig. 1: Invariant mass for dileptons in central Au+Au at $\sqrt{s}$ = 7 GeV (background subtracted)

Fig.2: Dilepton phase-space (M_{inv} ~ 0.8)

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

NICA PHYSICS PLAN (STAGE 1)

In the beginning an energy-system size scan will be performed at NICA-MPD with the listed beam species varying the collisions energy from 4 to 11 GeV in steps of 1-2 GeV.

Beam	Luminosity ($cm^{-2} c^{-1}$)		Data sample per 1 week at $\sqrt{s}$ = 4 GeV
	$\sqrt{s}$=4 GeV	$\sqrt{s}$=11 GeV	
p	10^{32}	10^{32}	$1.5 \cdot 10^{10}$
^{12}C	$4 \cdot 10^{28}$	$2 \cdot 10^{29}$	$1.5 \cdot 10^{10}$
^{64}Cu	$6 \cdot 10^{27}$	$3.5 \cdot 10^{28}$	$5 \cdot 10^{9}$
^{124}Xe	$8 \cdot 10^{26}$	$6 \cdot 10^{27}$	$1 \cdot 10^{9}$
^{197}Au	$1.5 \cdot 10^{26}$	10^{27}	$3 \cdot 10^{8}$

Measurements of hadrons (π, K, (anti)p, (anti)hyperons, light (anti)nuclei and dilepton spectra as a function of energy, system size, centrality, p_T, rapidity and azimuthal angle.

The strategy

- Localize the QCD CEP, then investigate in detail the critical region (in finer steps)
- Detailed study of the LMR dilepton enhancement in the unexplored region of the highest baryon density. If an indication for dropping mass found → detailed look in this region
- Study of the QCD mixed phase - hadroproduction and rare probes

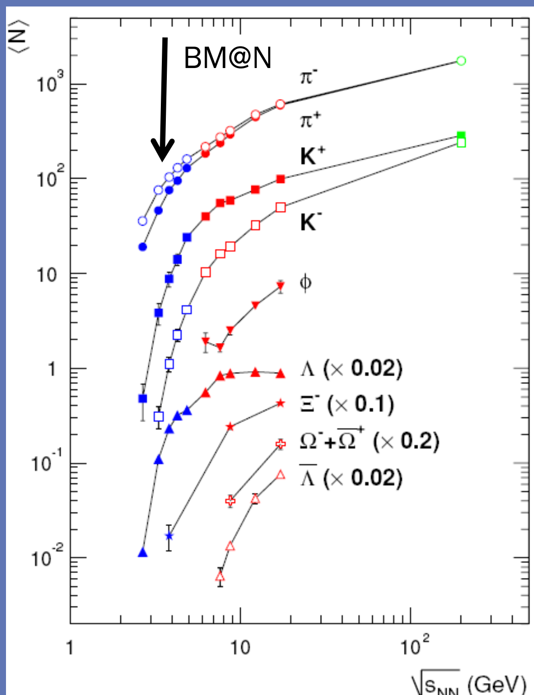
The preparatory works are close to completion

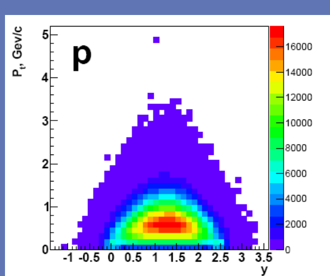
(no trees and tree stumps at ~60 000 m^2!)

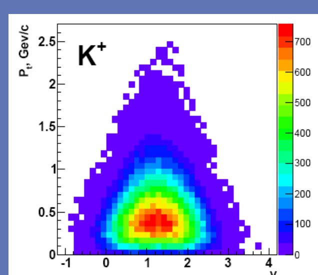
COMPLEX NICA – CIVIL CONSTRUCTION

BM@N PROJECT

RESEARCH PROGRAMS @ BM@N (STAGE 1)







- Medium and Heavy-ion collisions up to Au+Au, E_{kin} =4.5 GeV/nucl, √s ~ 3.5 A GeV: production mechanisms and modifications of hadron properties in dense nuclear matter – for strangeness (K^0,$K^{+/-}$) and vector mesons decaying in hadron modes ($\varphi \rightarrow K^+K^-$)
- Hyperons production in AA collisions: Λ, Ξ^-
- Measure energy / rapidity distributions of beam fragments (protons, neutrons, light nuclei)
- Collective flows for π/K/p, hadron femtoscopy
- Study of pA reactions as reference for AA Interactions
- Study of electromagnetic probes (γ, e^+e^- pairs)

→ Aim to measure momentum and identify charged particles with momentum p > ~200 MeV/c

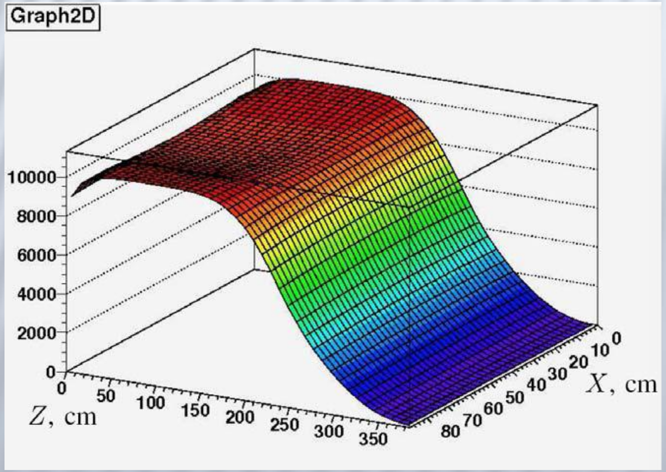
BM@N SETUP

- BM@N advantage: large aperture magnet

→ fill aperture with coordinate detectors which sustain high multiplicities of particles

→ divide detectors for particle identification to “near to magnet” and “far from magnet” to measure particles with low as well as high momentum (p > 1-2 GeV/c)

→ fill distance between magnet and “far” detectors with intermediate coordinate detectors for reliable link

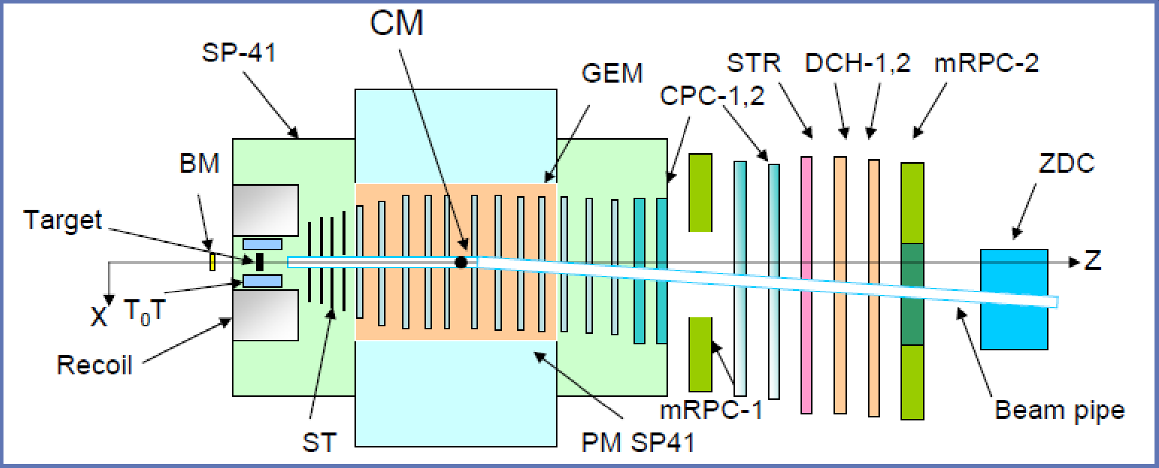


- Central tracker inside analyzing magnet to reconstruct AA interactions
- Outer tracker behind magnet to link central tracks to TOF mRPC detectors
- TOF system based on mRPC and T_0 detectors to identify hadrons and light nucleus
- ZDC calorimeter to measure centrality of AA collisions and form trigger
- Detectors to form T_0, L1 centrality trigger and beam monitors
- Recoil detector to measure event centrality
- ECAL for γ, e^+e^-

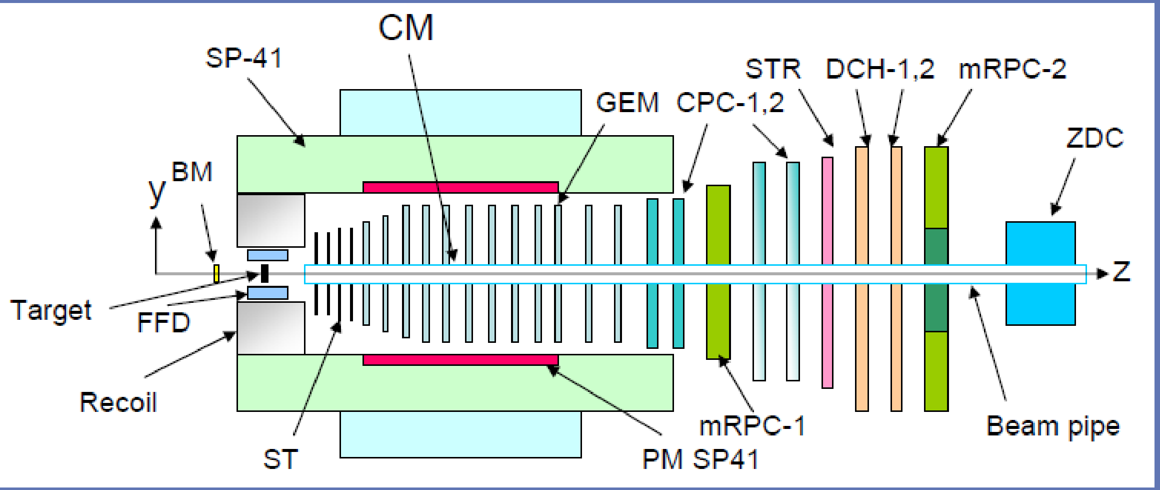
Magnetic field map

BM@N SETUP

SP-41M – analyzing magnet
CM – center of magnet
GEM – GEM Tracker, 12 planes
CPC - Cathode Pad chambers
DCH-1,2– Drift Chambers
Straw – Straw tubes (optional)
mRPC-2: “far” TOF detector
mRPC-1: “near” TOF detector
ZDC – Zero Degree Calorimeter
T_0T – detector to form T0 and L1 trigger
BM – Beam monitor
Recoil detector – not shown
ECAL – not shown
ST – Silicon Tracker (optional)



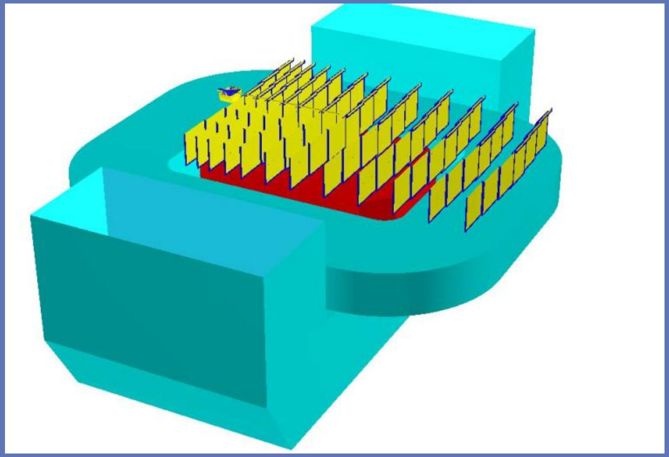
BM@N: xz projection

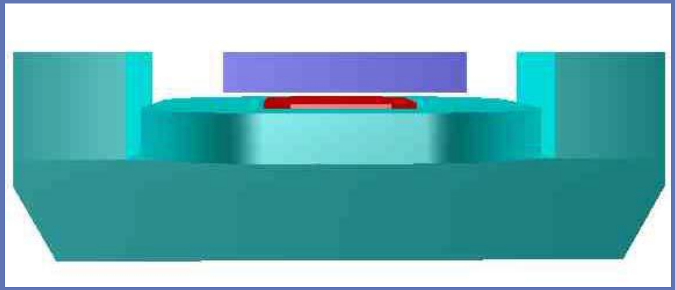


BM@N: yz projection

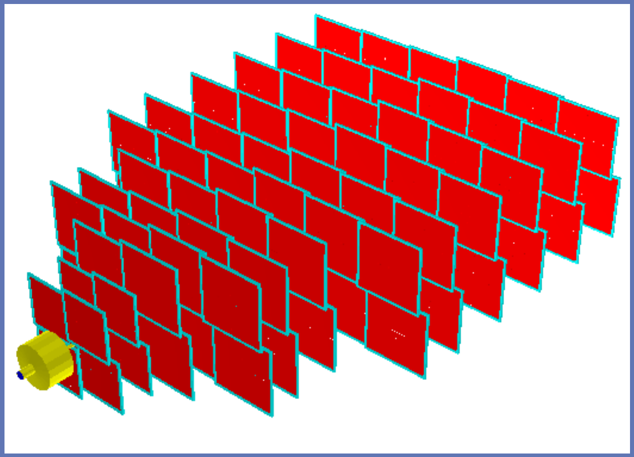
OPTIMIZATION OF GEM TRACKER

Tracking based on 12 GEM planes placed at 30 - 360 cm from target





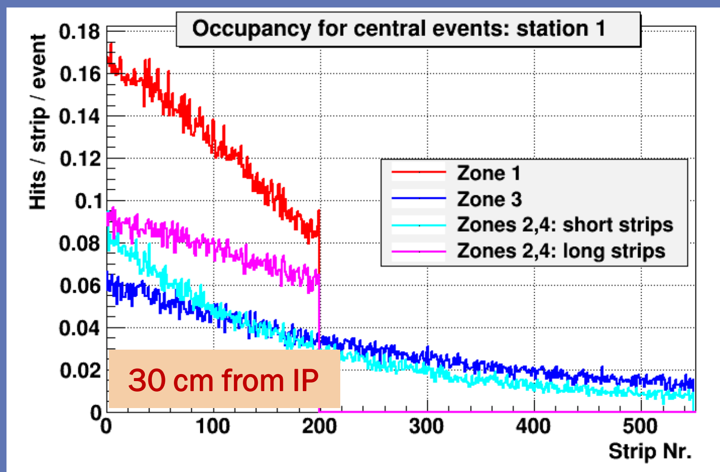
- Plane size is optimized for detection of $\varphi \rightarrow K^+K^-$, e^+e^-, $\Lambda \rightarrow p\pi^-$, $\Xi^- \rightarrow \Lambda\pi^-$
- Strip pitch 0.4 mm in planes 1-4, 0.8 mm in planes 5-12
- Strip inclination 0, +15° in odd, 0, -15° in even planes

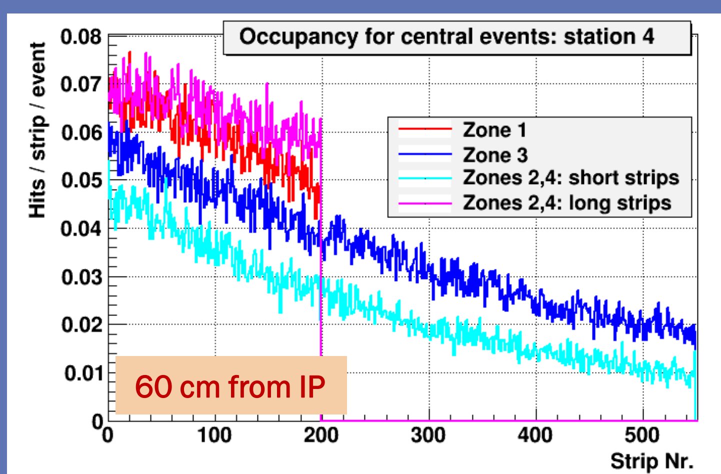


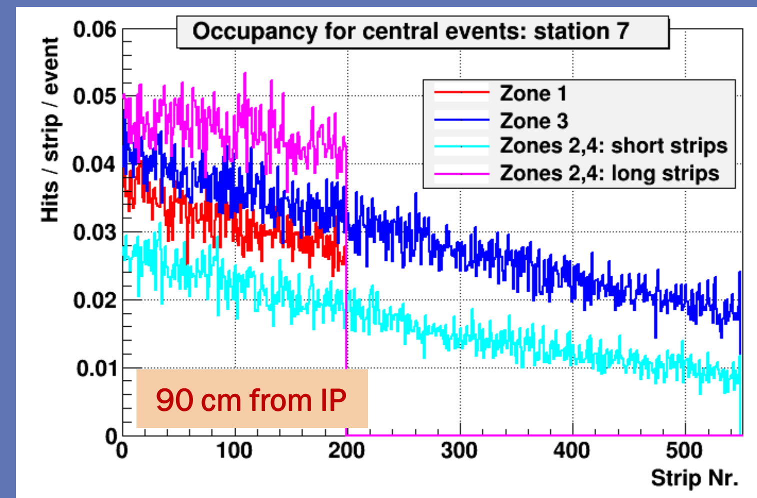
BMNRoot software framework

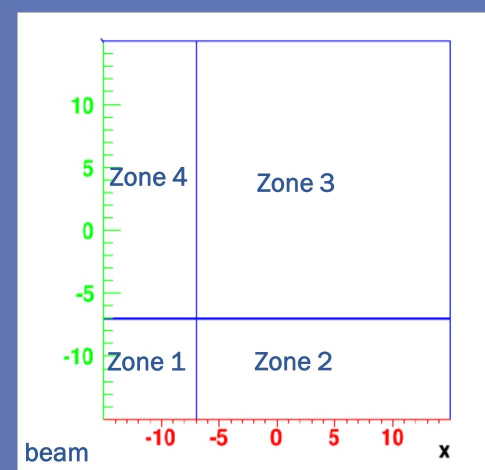
GEM DETECTOR OCCUPANCY

UrQMD: Au+Au @ E_{lab} = 4 GeV/nucl, b= 0-3 fm



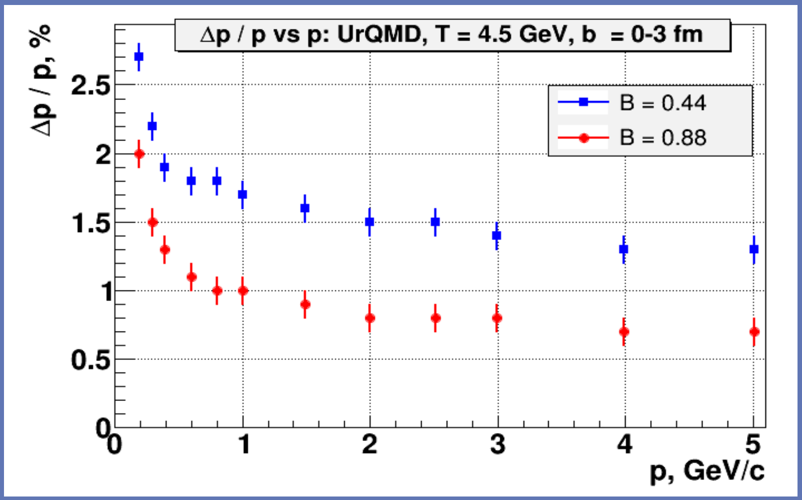




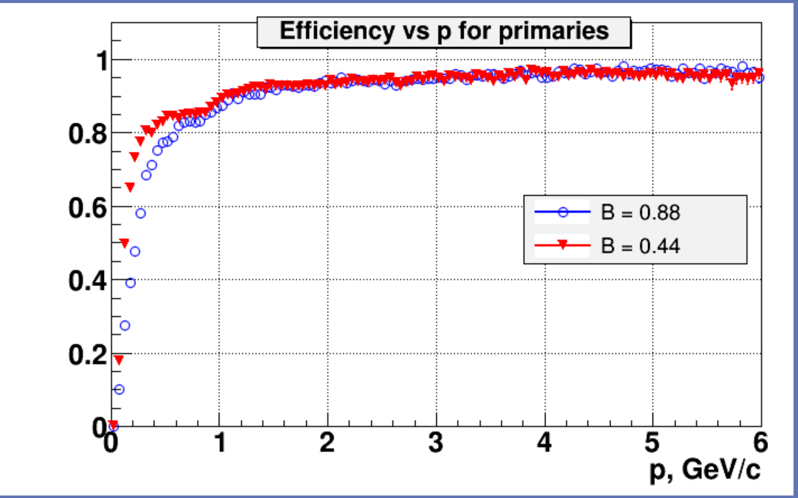


GEM`s zones

GEM TRACKER: RECONSTRUCTION

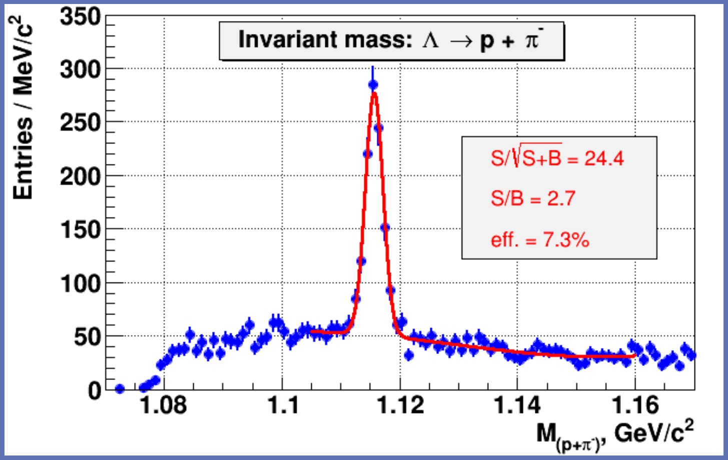


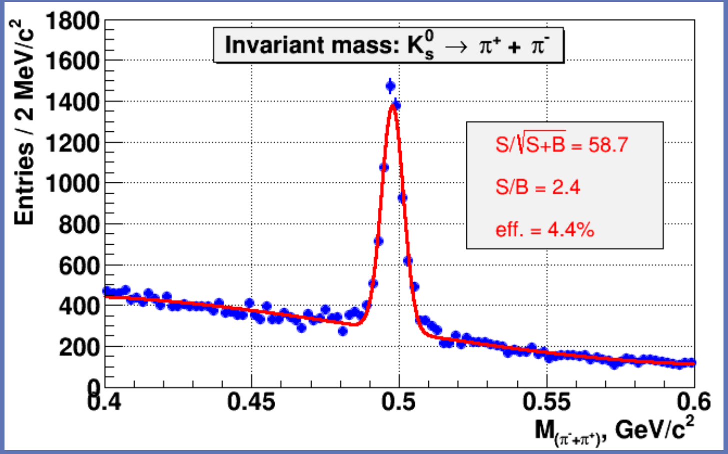
Track momentum resolution in GEM tracker



Detection efficiency in dependence on particle momentum

Hyperon / kaon reconstruction



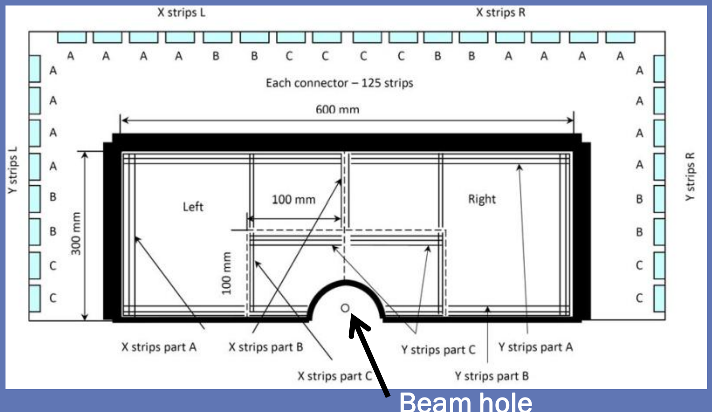


POSSIBLE DESIGN OF GEM DETECTORS

GEM detectors for BM@N produced by CERN workshop:

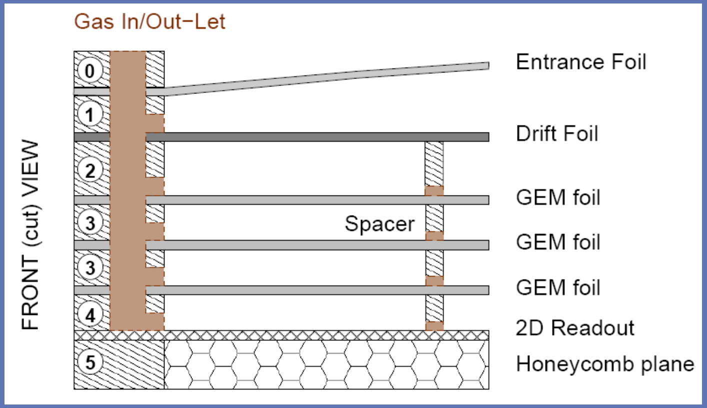
- Inner planes with X-Y strips, 2 GEM detectors of 60x30cm^2 in 1 plane, anode strips divided into 6 zones, 400 µm pitch
- Outer planes with X-Y strips, 4 GEM detectors of 40x120cm^2 in 1 plane (placed as in simulation), anode strips divided into 4 zones, 800 µm pitch

Half of inner X-Y plane

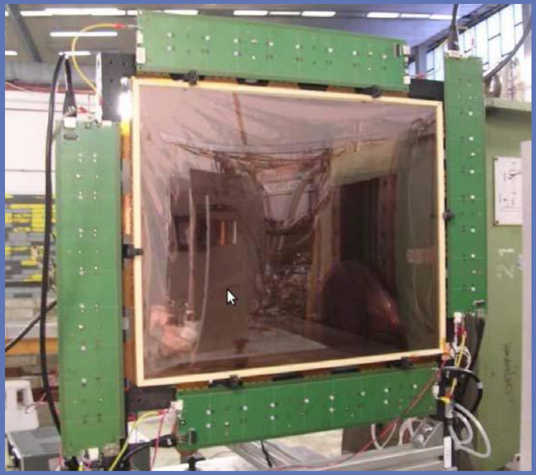


→ minimum material in sensitive area

Structure of triple GEM detector

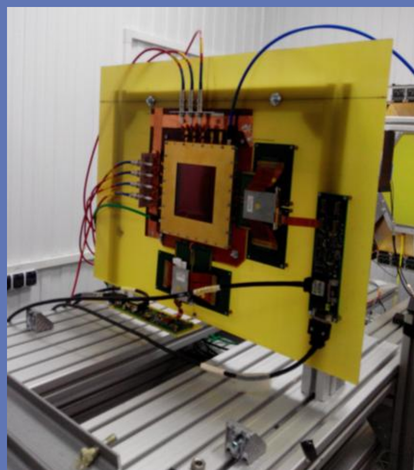


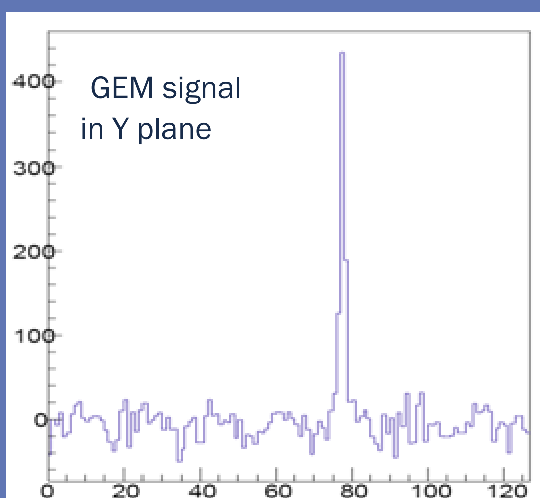
Triple GEM detector for JLAB tracker 40 x 50 cm

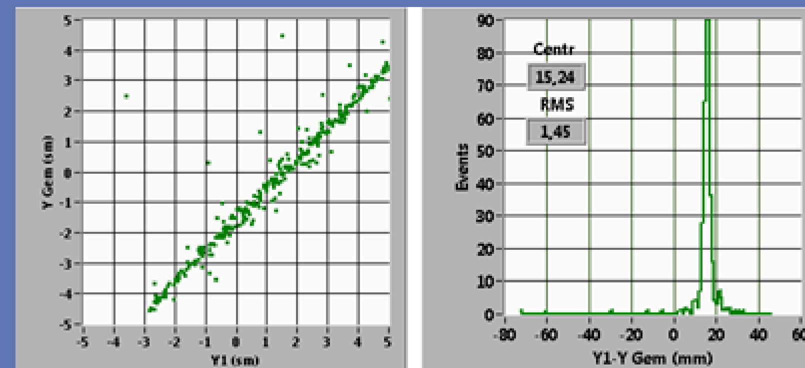


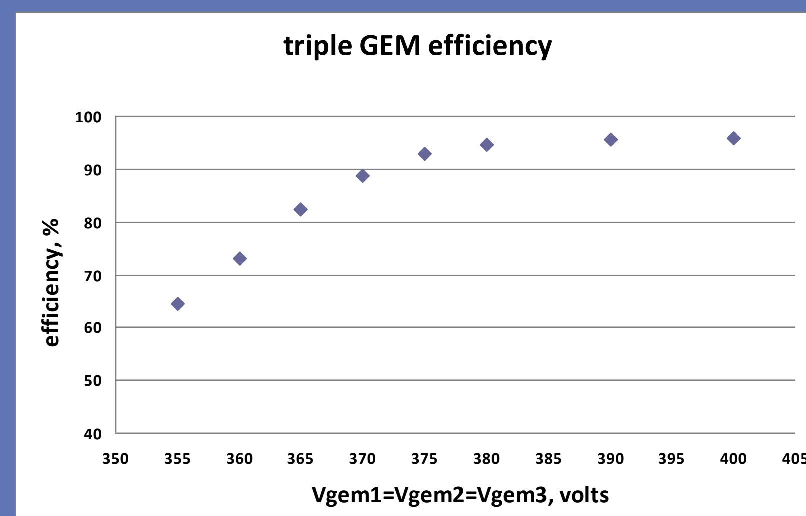
GEM & PROP CHAMBERS

Proton beam at Nuclotron in Feb 2014





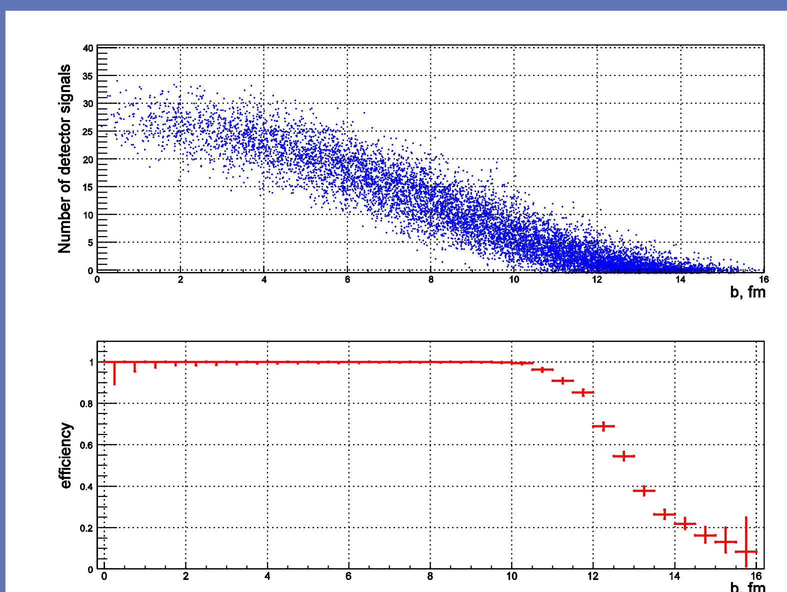




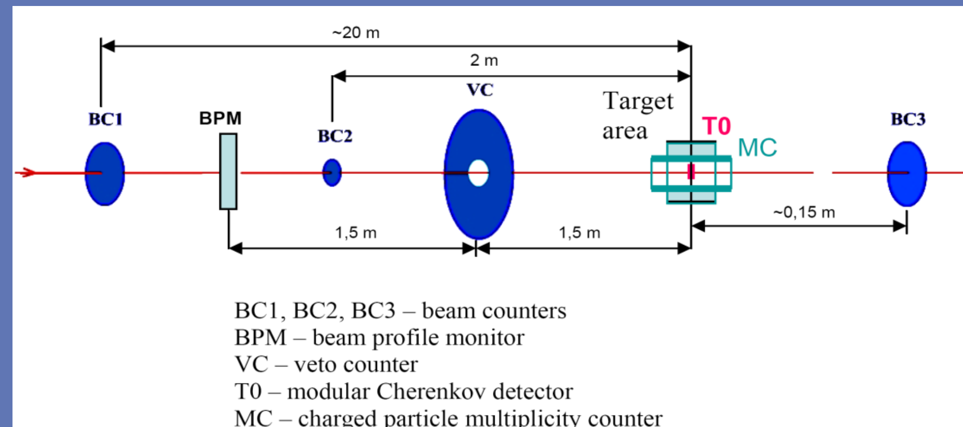
MC SIMULATION AND T_0T DETECTOR SETUP

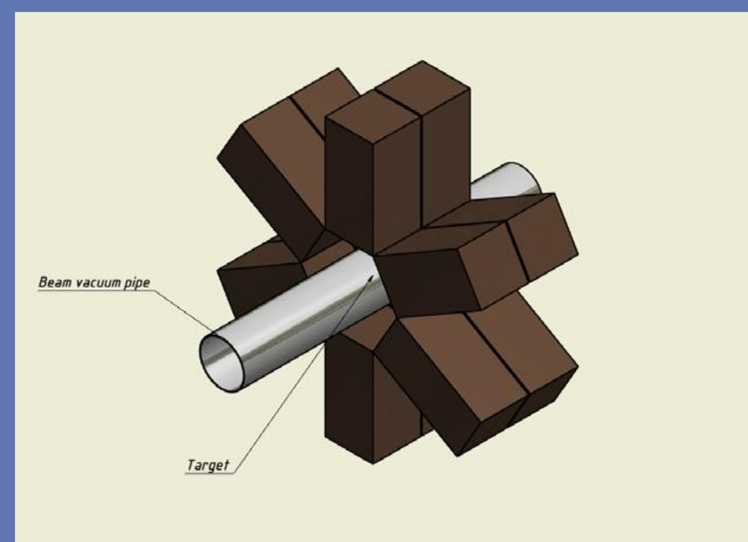
Au+Au 4 GeV/n, QGSM

Number of hit channels vs centrality



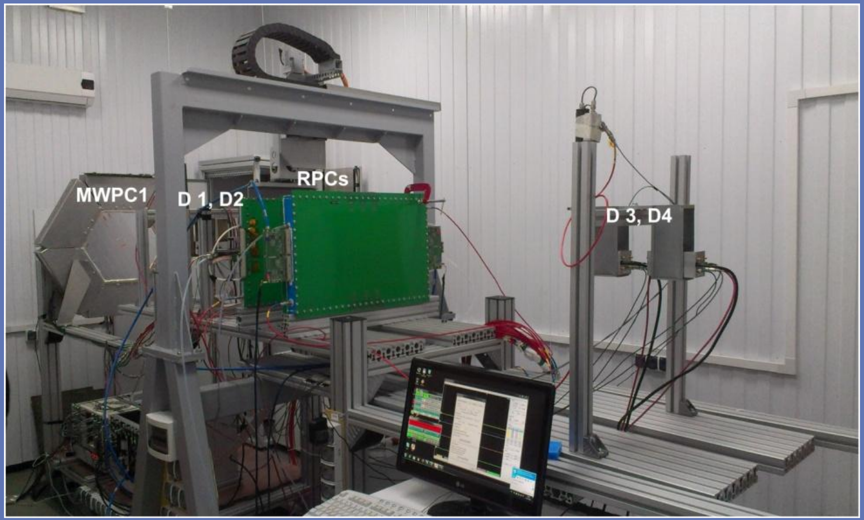
T_0T Efficiency vs centrality

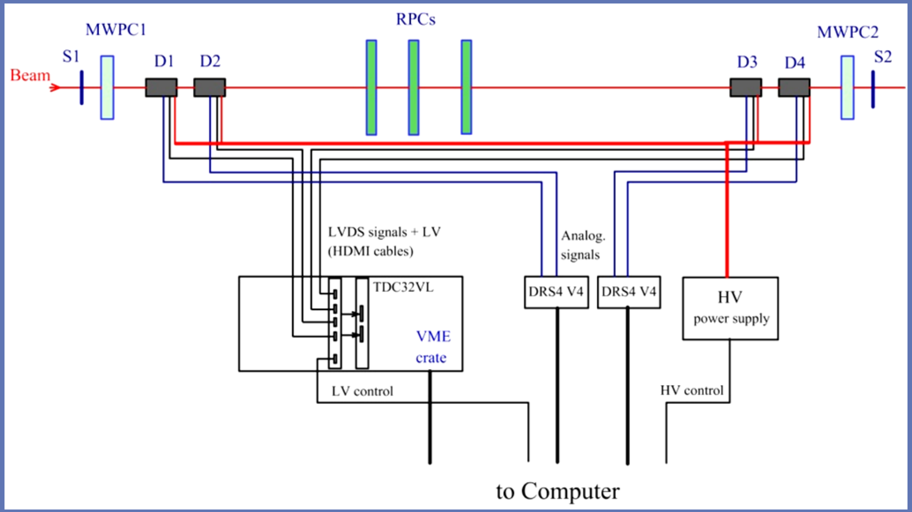


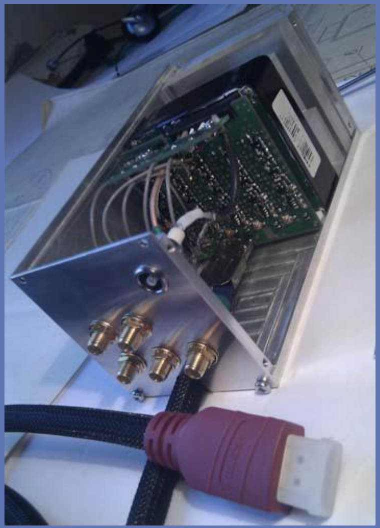


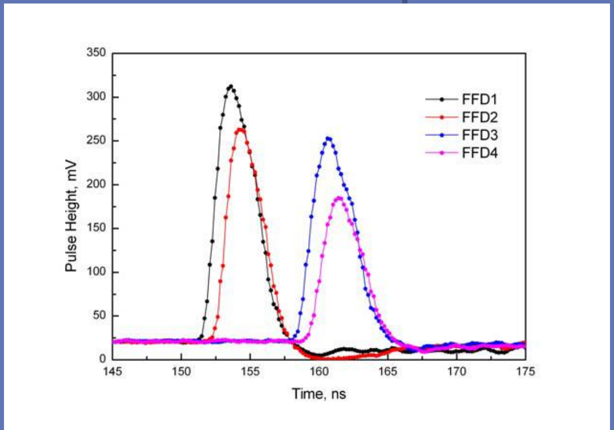
T_0 detector design

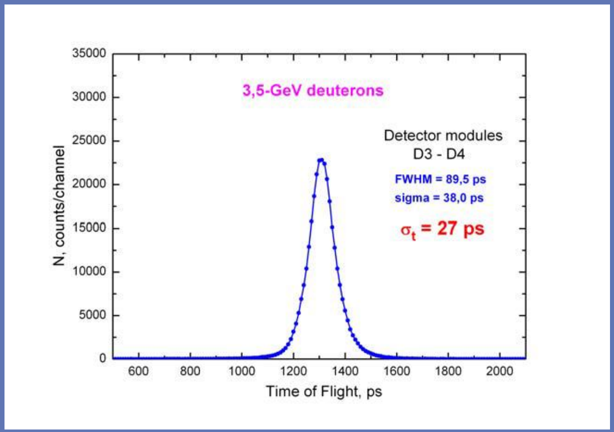
TEST BEAM MPD: TEST OF T_0 DETECTOR PROTOTYPE







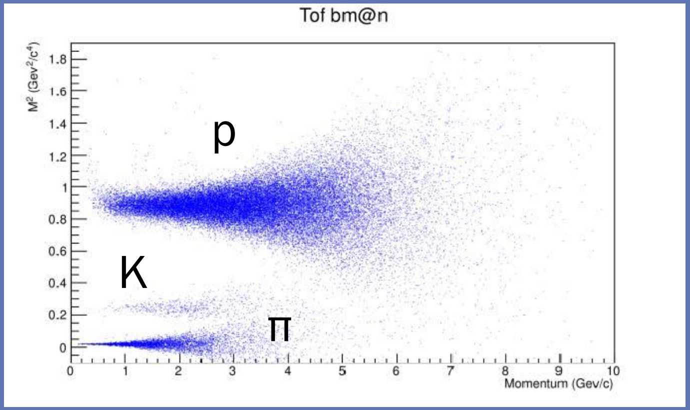




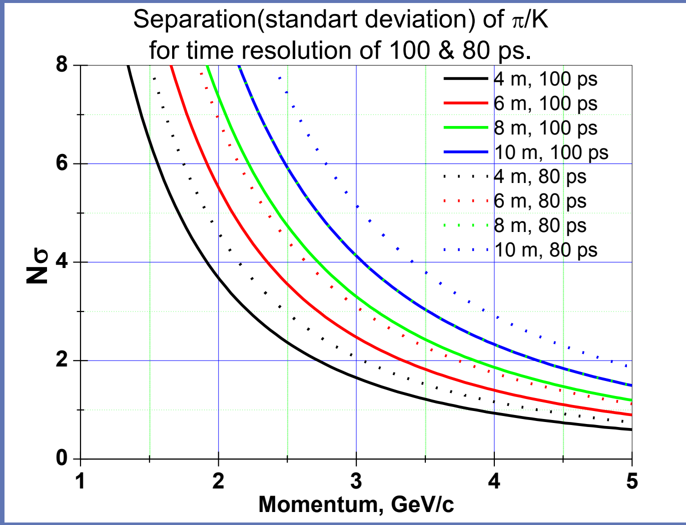
Time resolution for 3.5 GeV deutron beam ~30 ps

BM@N TOF SYSTEM BASED ON 2 MRPC WALLS

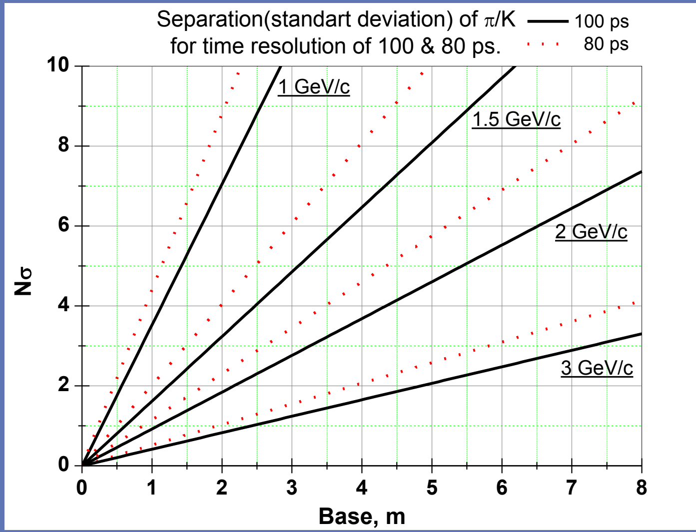
1st Team: MPD design → “near” mRPC-1
2nd team: IHEP design → “far” mRPC-2
First aim → 2 mRPC setups (2 x 160 channels) for BM@N test beam in Feb 2015



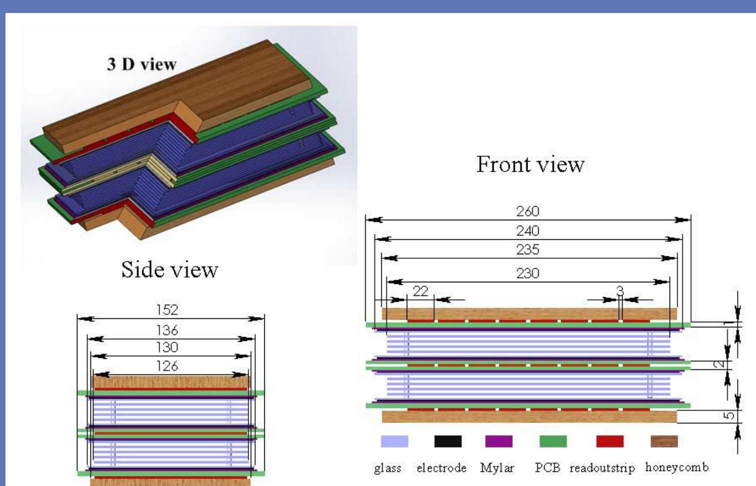
“Near” mRPC-1 wall at z ~ 4-5 m from IP to identify π / K / p with p<2 GeV/c

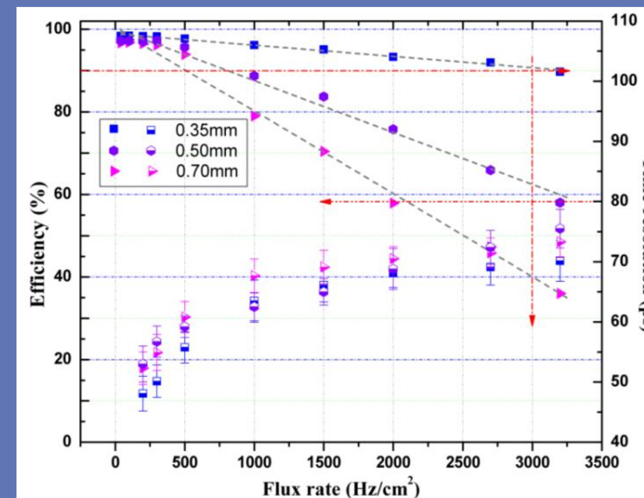


“Far” mRPC-2 wall at z ~ 7-8 m from IP to identify π / K / p with p>1 GeV/c and light nuclei

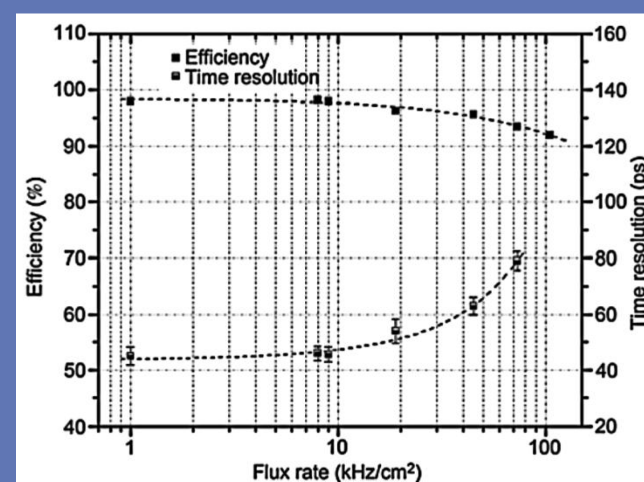


MRPC-1: MPD DESIGN / CHARACTERISTICS





NIM A, 735 (2014) 277–282

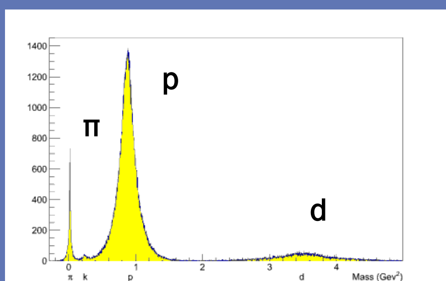


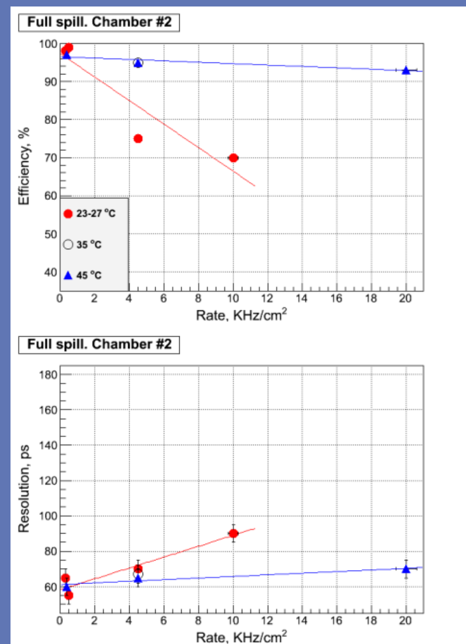
MRPC-2: IHEP DESIGN / CHARACTERISTICS

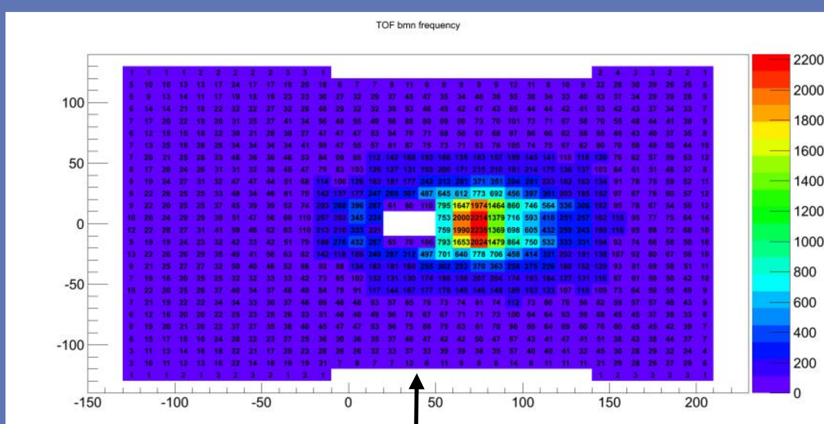
- For region of low hit rate (~400 Hz/ cm^2): 10 gap RPC with “big” strip/pad ~50-120 cm^2
- For region of high hit rate (~4 KHz/ cm^2): 12 gap “warm” RPC with “small” strip/pad ~15cm^2

Time resolution ~65 ps, efficiency >94%.

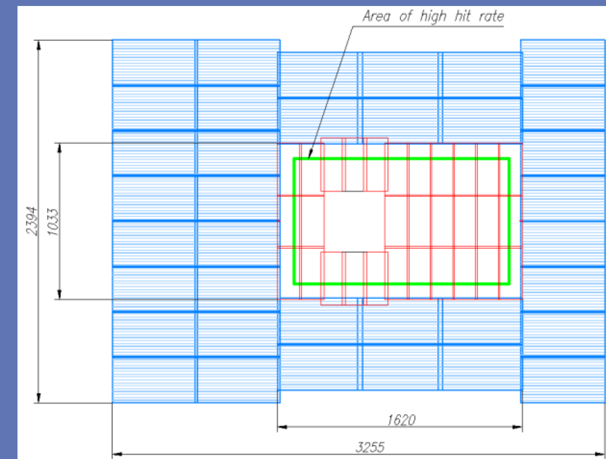
Total number of strips - 1536

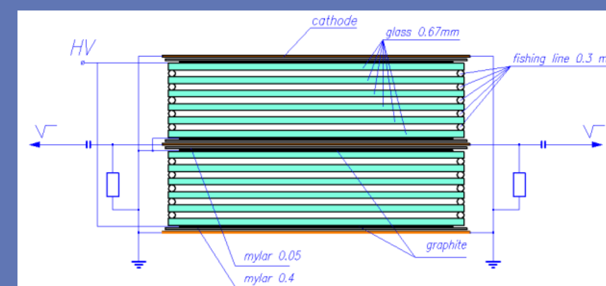


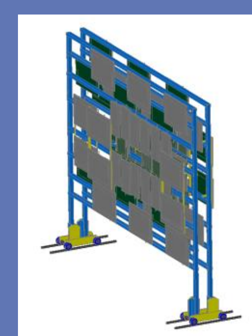


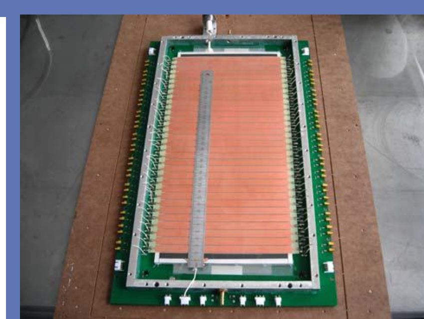


BM@N beam axis

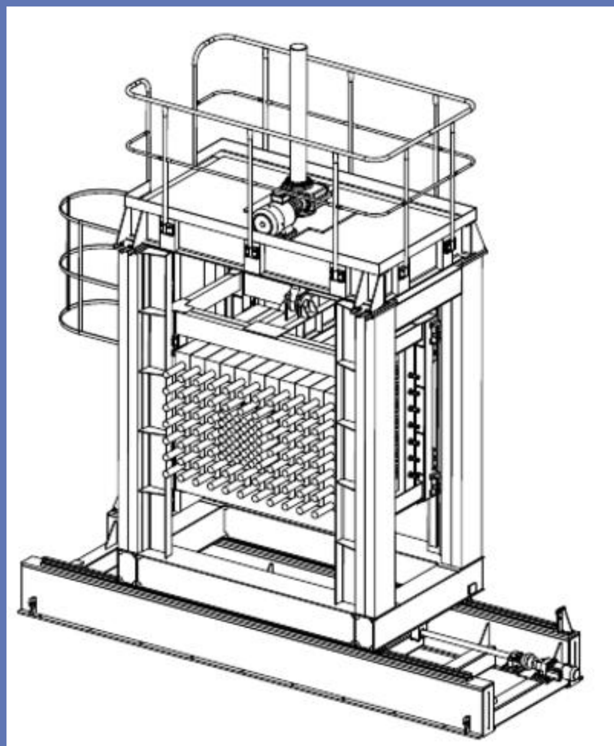




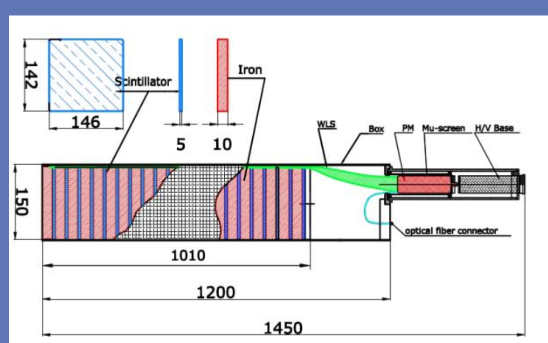


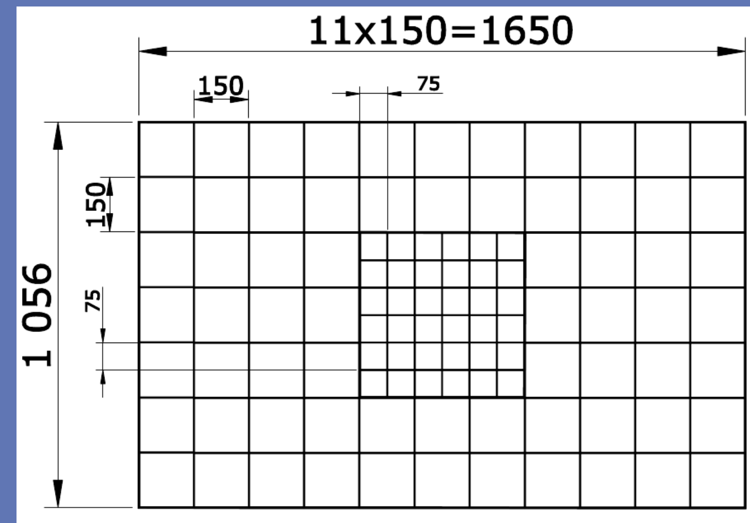


ZDC CALORIMETER

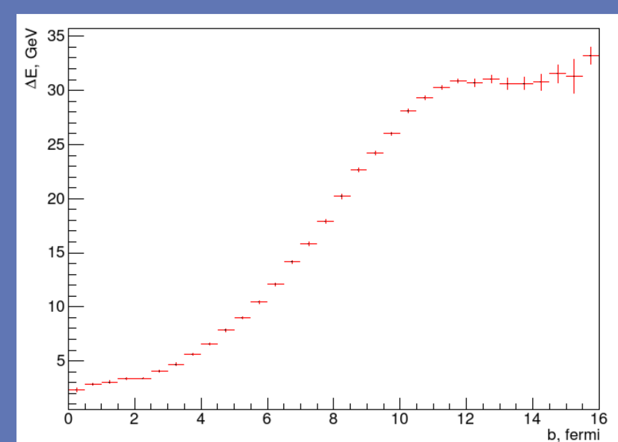


Sci-Pb sandwich calorimeter with PMT readout, 104 modules

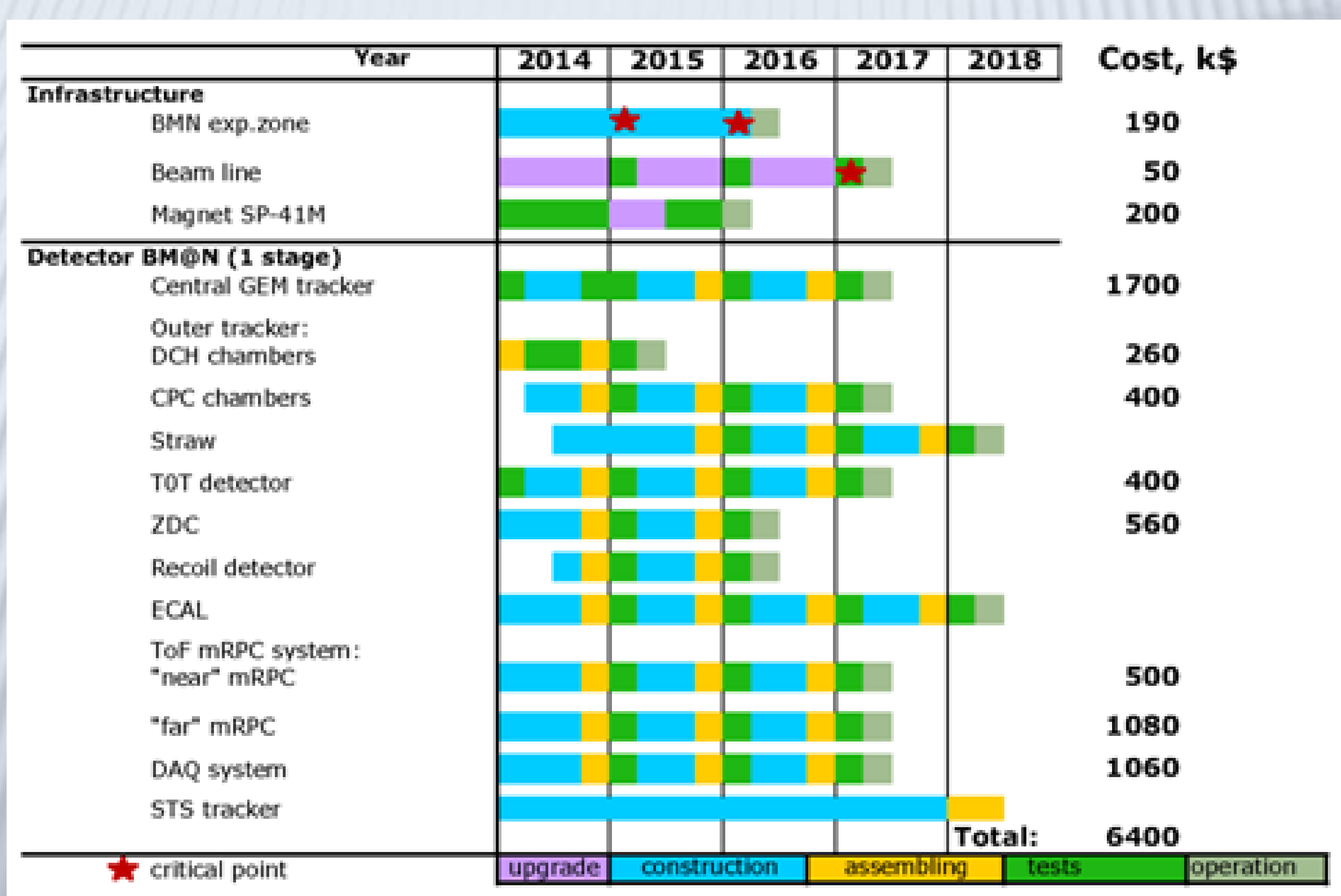




Energy deposited in ZDC vs collision impact parameter



TIME SCHEDULE FOR BM@N SETUP DEVELOPMENT IN 2014 - 2017



SUMMARY

- NICA site has been prepared to start civil construction work
- MPD simulation is in progress to prepare well justified physics program
- R&D and detector prototyping is under way both for MPD and BM@N experiments
- BM@N configuration is being optimized
- Young people are getting involved in software and hardware tasks: BM@N activity can help to gain experience for larger-scale experiment MPD

ACKNOWLEDGEMENTS