The MPD detector for the NICA heavy-ion collider at JINR (concept)

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On behalf of the NICA/MPD Collaboration

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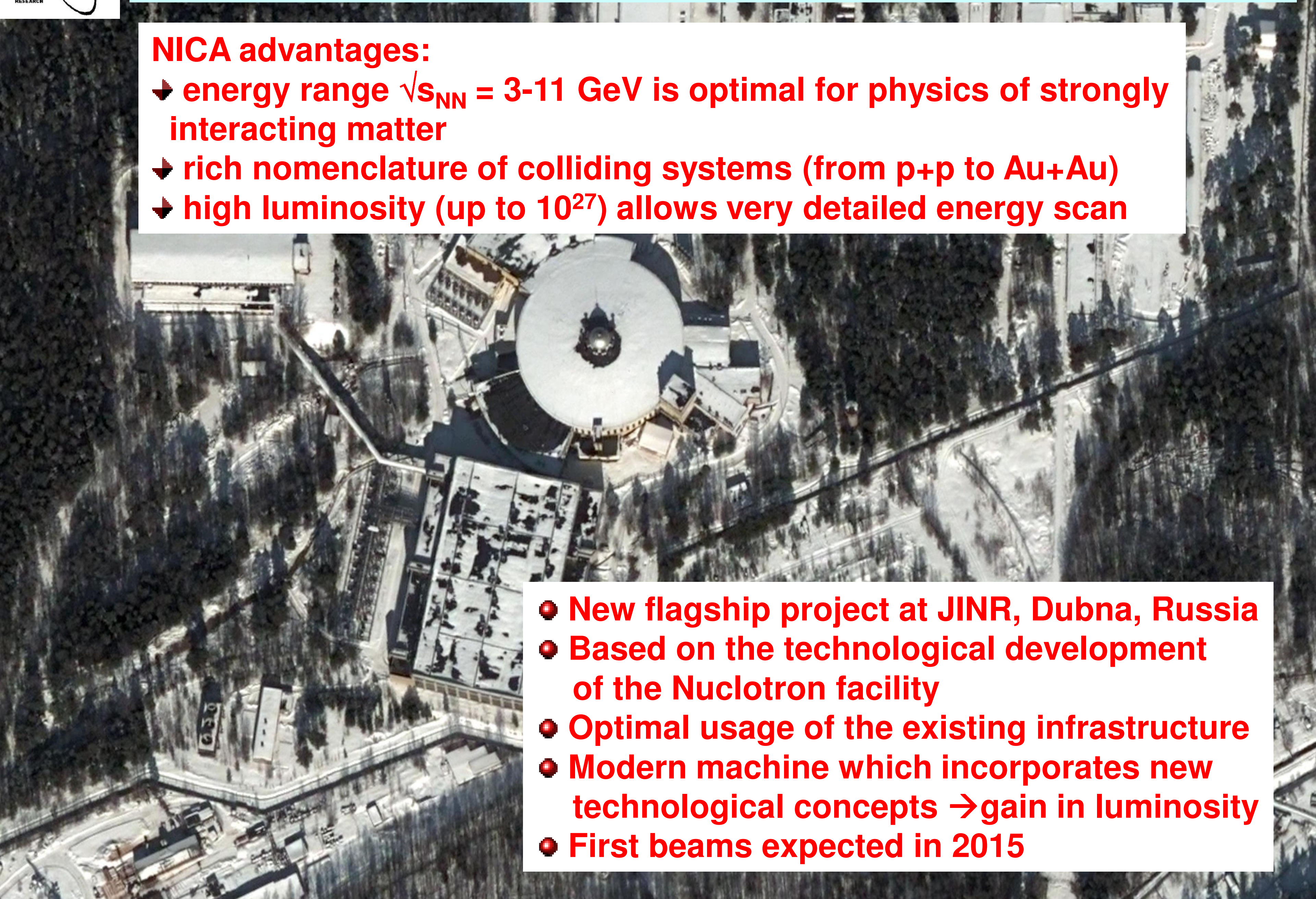
Outline

- Accelerator complex NICA
- Physics program
- MPD spectrometer concept
- Conclusion & Outlook

Nuclotron-based **I**on **C**ollider f**A**cility



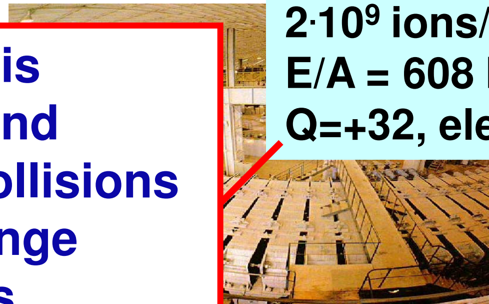
NICA advantages:

- energy range $\sqrt{s_{NN}}$ = 3-11 GeV is optimal for physics of strongly interacting matter
- rich nomenclature of colliding systems (from p+p to Au+Au)
- high luminosity (up to 10^{27}) allows very detailed energy scan

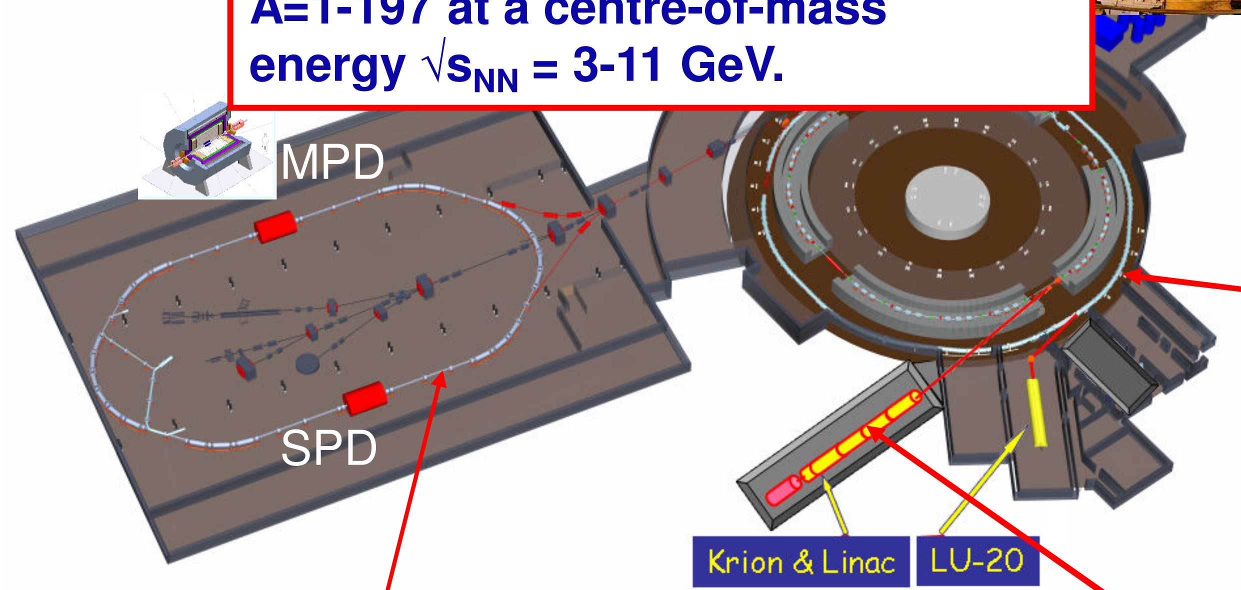
- New flagship project at JINR, Dubna, Russia
- Based on the technological development of the Nuclotron facility
- Optimal usage of the existing infrastructure
- Modern machine which incorporates new technological concepts → gain in luminosity
- First beams expected in 2015

NICA complex

The MultiPurpose Detector is proposed for study of hot and dense baryonic matter in collisions of heavy ions over mass range A=1-197 at a centre-of-mass energy $\sqrt{s_{NN}}$ = 3-11 GeV.

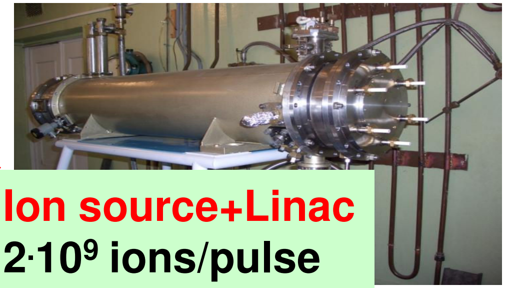


Booster
$2 \cdot 10^9$ ions/bunch
E/A = 608 MeV
Q=+32, electron cooling



Nuclotron
E/A = 1..5.5 GeV
Q=+79

Collider
Beams – p,d(↑)..$^{197}Au^{79+}$
Collision energy – $\sqrt{s}$ = 3-11 GeV
No bunches – 2x17
Luminosity: 10^{27} $cm^{-2}s^{-1}$(Au), 10^{32} (p↑)
Interaction points – 2 (MPD and SPD detectors)



Ion source+Linac
$2 \cdot 10^9$ ions/pulse
E/A = 6.2 MeV
Q = +32

NICA Collaboration

Budker INP

- ✓ Booster RF system
- ✓ Booster electron cooling
- ✓ Collider RF system
- ✓ Collider SC magnets (expertise)
- ✓ HV electron cooler for collider
- ✓ Electronics

IHEP (Protvino)

Injector Linac

FZ Jűlich (IKP)

HV Electron cooler
Stoch. cooling

Fermilab

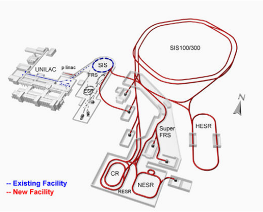
HV Electron cooler
Stoch. cooling

BNL (RHIC)

Electron &
Stoch. Cooling

All-Russian Institute for Electrotechnique

HV Electron cooler



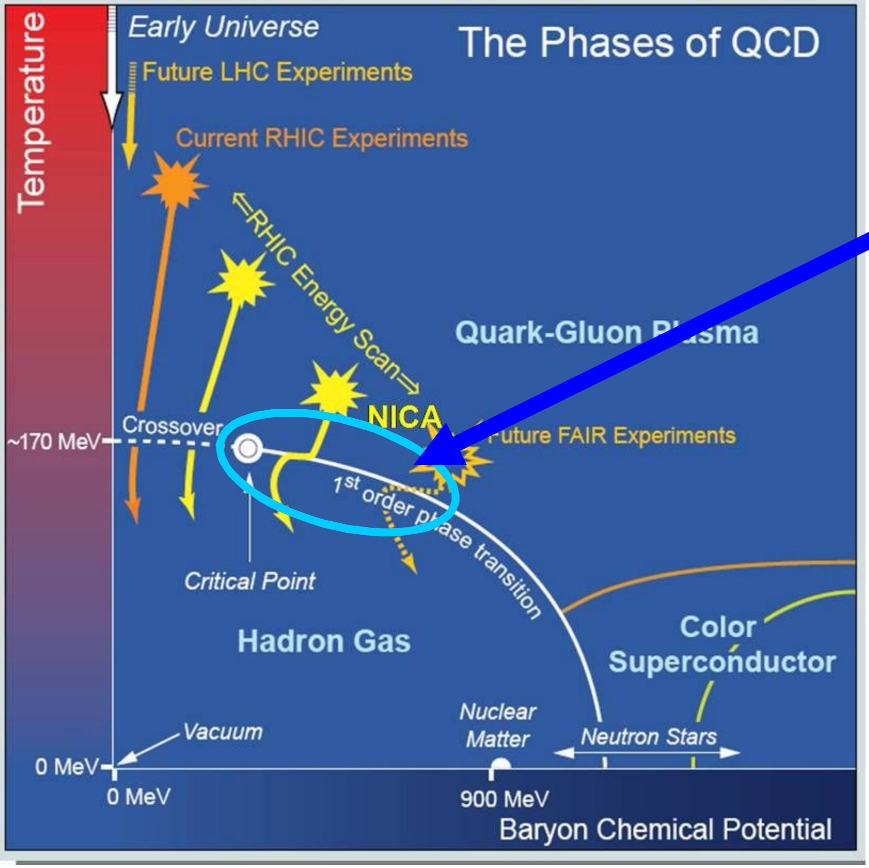
GSI/FAIR

SC dipoles for Booster/SIS-100
SC dipoles for Collider

ITEP: Beam dynamics in the collider

Corporation "Powder Metallurgy" (Minsk, Belorussia):
Technology of TiN coating of vacuum chamber walls for reduction of secondary emission

NICA physics. QCD phase diagram



The most intriguing and unexplored region of the QCD phase diagram:

- **characterized by the highest net baryon density**
- **detailed information about properties of the phase transition region can be deduced**
- **strong discovery potential:**
  a) Critical End Point
  b) Chiral Symmetry Restoration
- **very attractive for heavy-ion community: RHIC/BNL, SPS/CERN, FAIR/GSI, NICA/JINR**

Challenge: comprehensive experimental program requires scan over the QCD phase diagram by varying collision parameters : system size, beam energy and collision centrality

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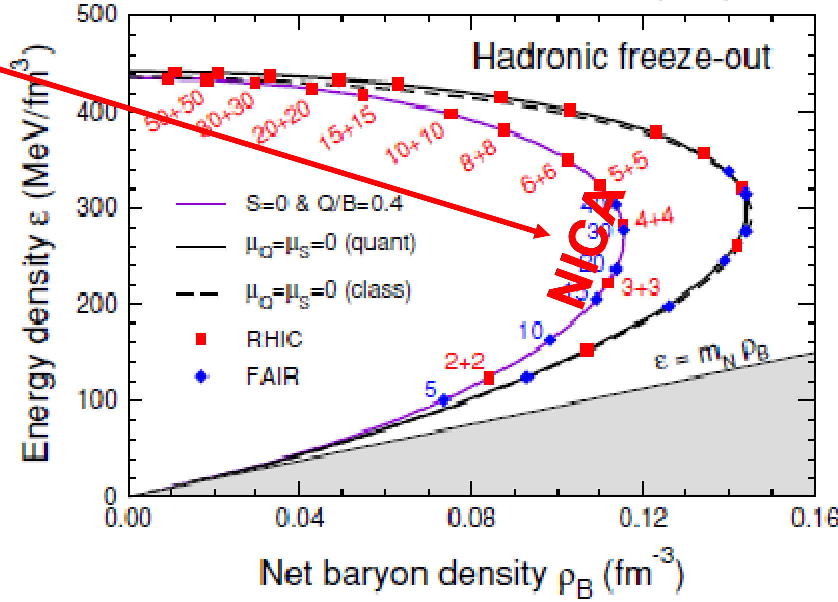
NICA Physics. Phase transition

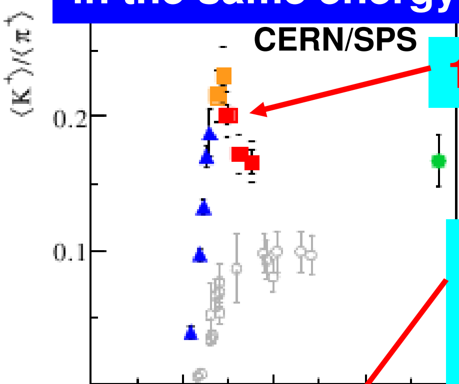
System of maximal net baryon density is created in HI collisions at NICA energies → optimum for the compressed nuclear matter exploration

PHYSICAL REVIEW C 74, 047901 (2006)

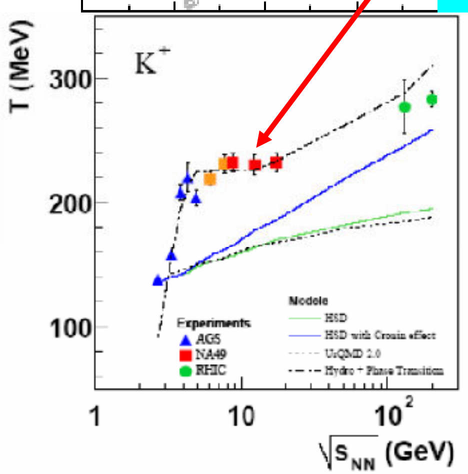


Anomaly in hadron production in the same energy range!

1^{st} order phase transition?



Co-existence of partonic and hadronic degrees of freedom (mixed phase)?



Goal: to establish the onset of the observed signatures

Program:

- energy scan
- system size scan

Hadronic observables!

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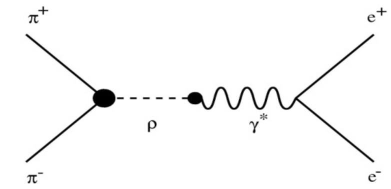
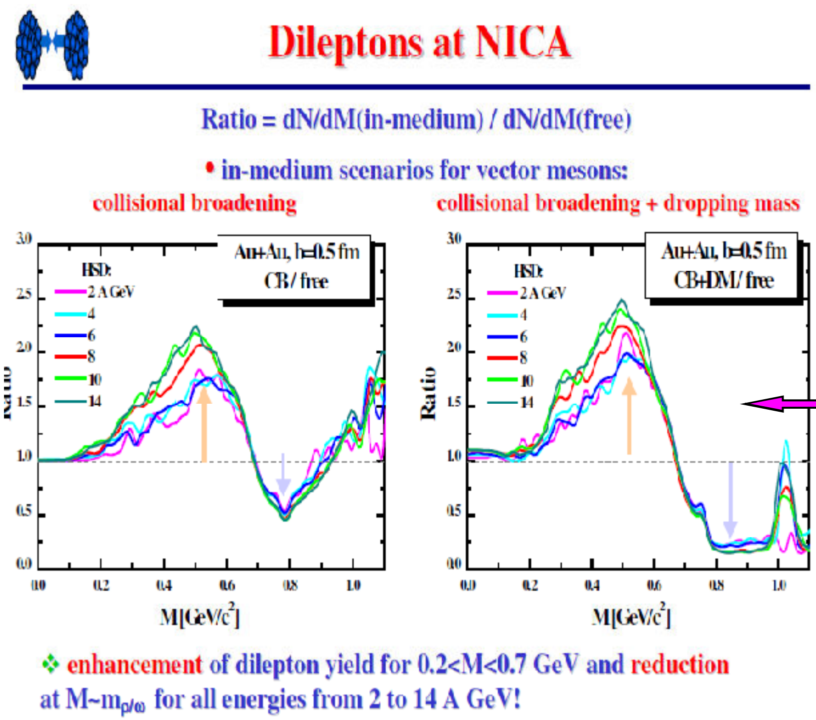
NICA Physics. Chiral Symmetry Restoration

Change in spectral function of vector mesons in HI → CSR signal

- dielectrons are penetrating probes directly connecting to CRS
- in-medium modification of vector meson properties





- **Strong enhancement of low-mass e+e- pairs in A+A (factor of ~ 2.5) ($0.2<m_{inv}<1.1$ GeV/c^2)**
- **No enhancement in p+p nor in p+A**
- **No measurement between 3-8 GeV yet!**

NICA's energy range very well suited to fill an important niche:

- **Unveil the onset of the low-mass pair enhancement.**
- **Systematic studies of pA collisions**
- **Study pair enhancement under highest baryon density conditions**

Main experimental challenge: large combinatorial background. Powerful electron PID and good mass resolution (~2%) required.

Dileptons are of interest!

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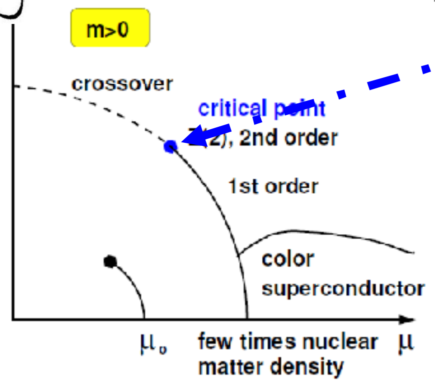
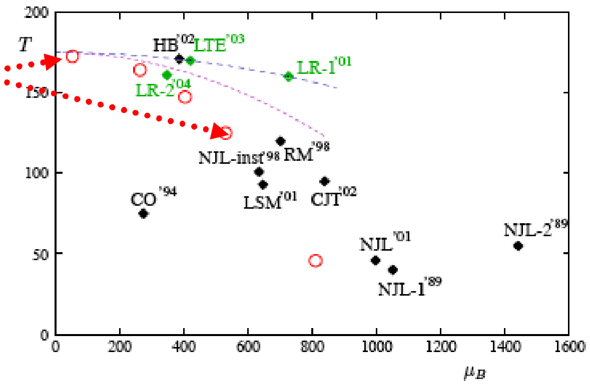
NICA Physics. QCD Critical End Point (CEP)



Lattice QCD calculations predict the existence of CEP (1[st] order phase transition ceases at CEP → crossover)

But, poor predictions from theory for CEP location (μ~180-500 MeV, $\sqrt{s_{NN}}$~5-20 GeV)



Method: fluctuation pattern of experimental observables (<pt>, multiplicity, athimuthal distributions, particle ratios, net-baryon number, etc..) are very sensitive to the proximity of the CEP, so non-monotonic variation of non-Gaussian moments with beam energy may serves as a signature for CEP.

Challenge: detector with large and uniform acceptance (close to 4π, total ϕ-coverage) having good tracking and PID performance in the whole phase space.

… and other observables

- **Enhanced multi-strangeness production (hyperons)**
- **Direct γ's → the best probe for the early stage matter!**
- **Collective effects, i.e. identified particle flow**
- **Multi-particle correlations**

to measure : γ, hadrons, multistrange hyperons

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Basic requirements to the apparatus

Physics	Observables
Deconfinement	particle yields (γ,π,K,p,Λ,Θ,Ω, fragments), flow
Critical point	fluctuations & correlations of identified particles
Chiral phase transition	dilepton (e^+e^-)

Challenges:

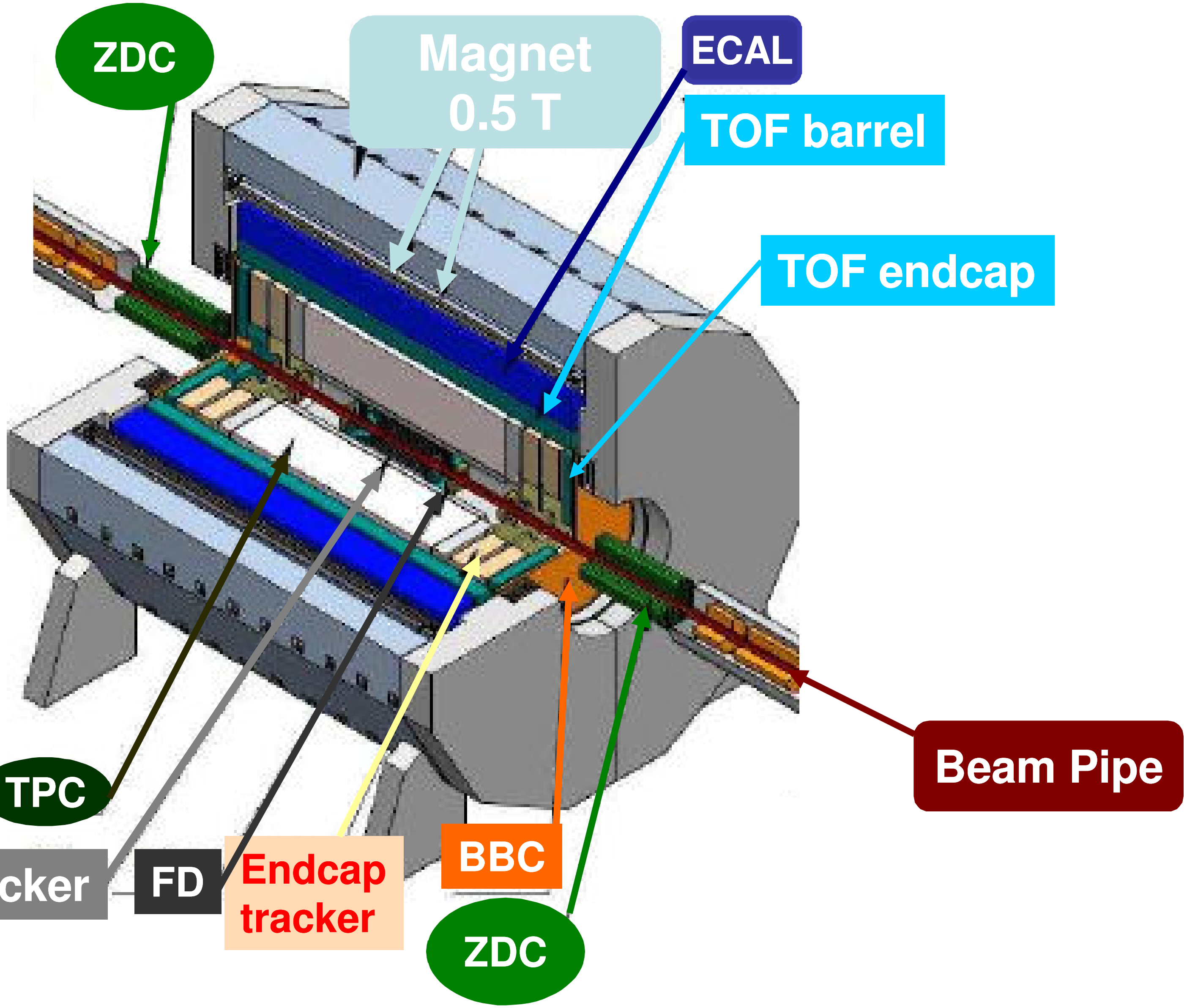
- Vast nomenclature of colliding systems – from p+p to Au+Au
- simultaneous observation of a variety of phenomena
- Small effects over large kinematical range, sensitivity to acceptance constrains (‘correlations & fluctuations’ studies)
- Pattern recognition in high track multiplicity environment

Detector requirements:

- Large homogenous acceptance : 2π in athimutal angle, $|\eta|<3$, $0.1<p_t<3$ GeV/c
- High efficient 3-D track reconstruction
- powerful PID: π/K up to 1.5 GeV/c, K/p up to 2.5 GeV/c
- ECAL for γ, e
- High resolution vertexing with low p_t ID, two track resolution ≤ 100 μm
- Excellent perfomance in V0 (and cascades) reconstruction
- careful event characterization: impact parameter & event plane reconstruction
- high event rate capability up to ~ 6 kHz

MPD Apparatus

Active volume:
5 m (length)
5 m (diameter)



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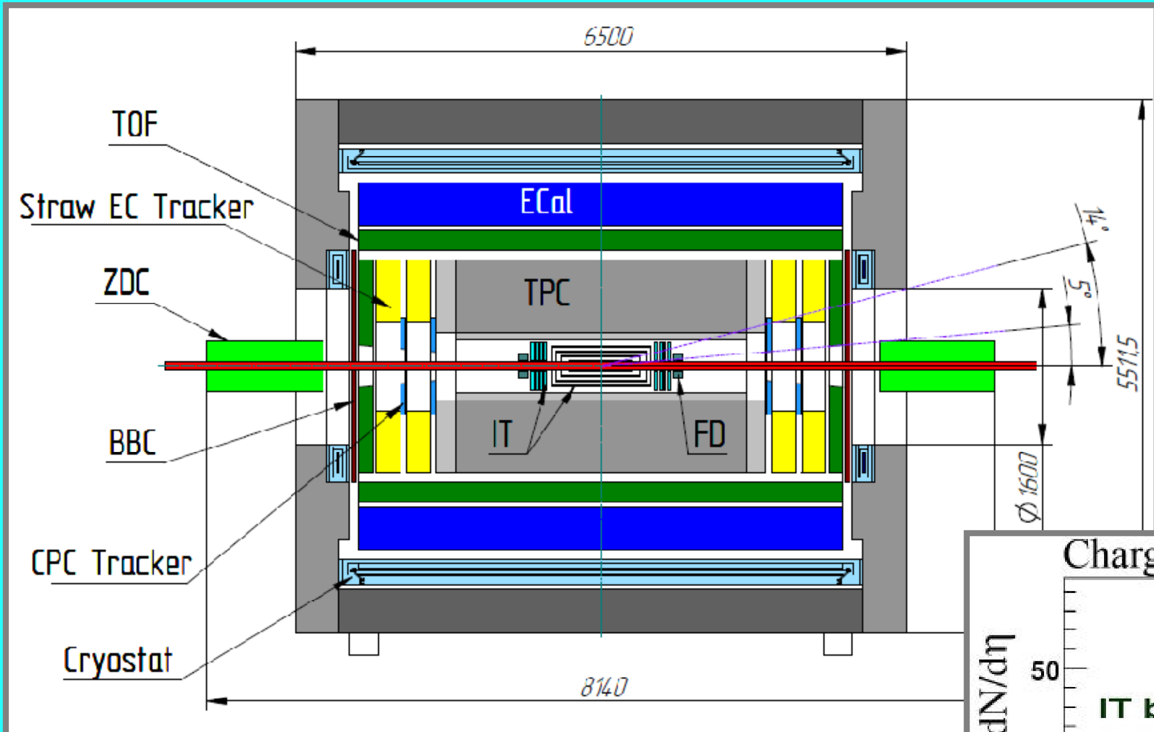
MPD Apparatus : dimensions & coverage



Acceptance (B=0.5 T):

Full azimuthal

IT (|η|<2.5)

TPC (|η|<2)

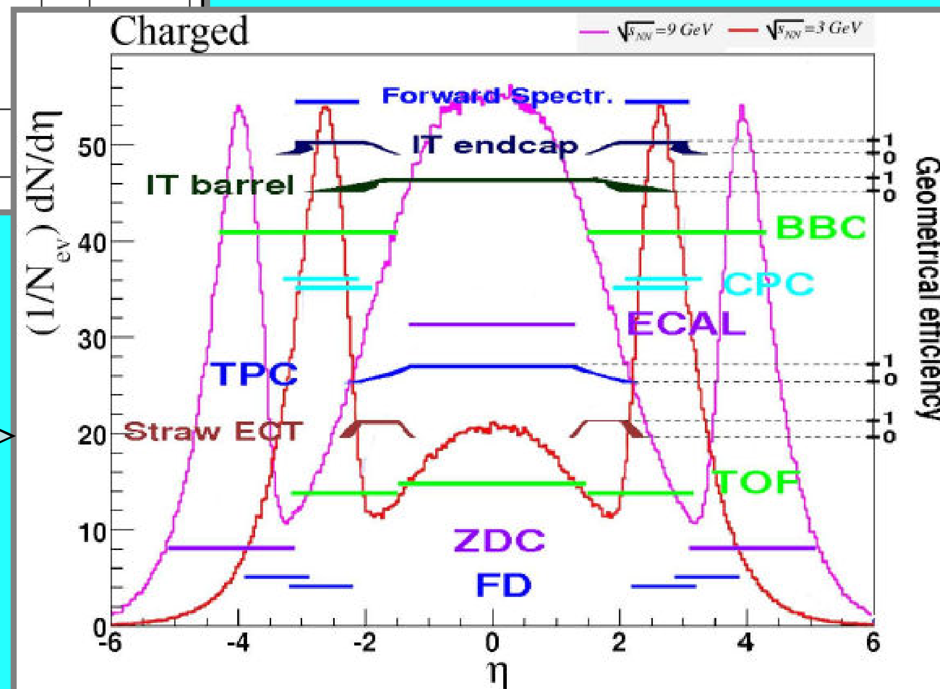
TOF (|η|<3)

ECAL (|η|<1.2)

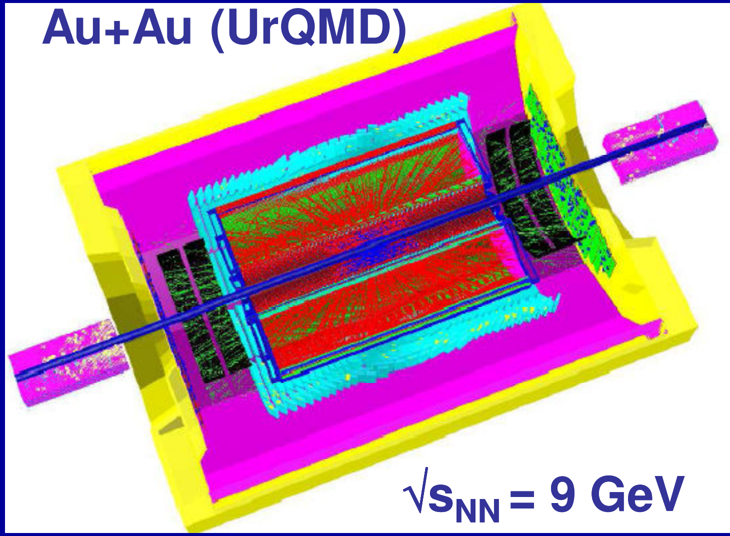
BBC (1.5<|η|<4.5)

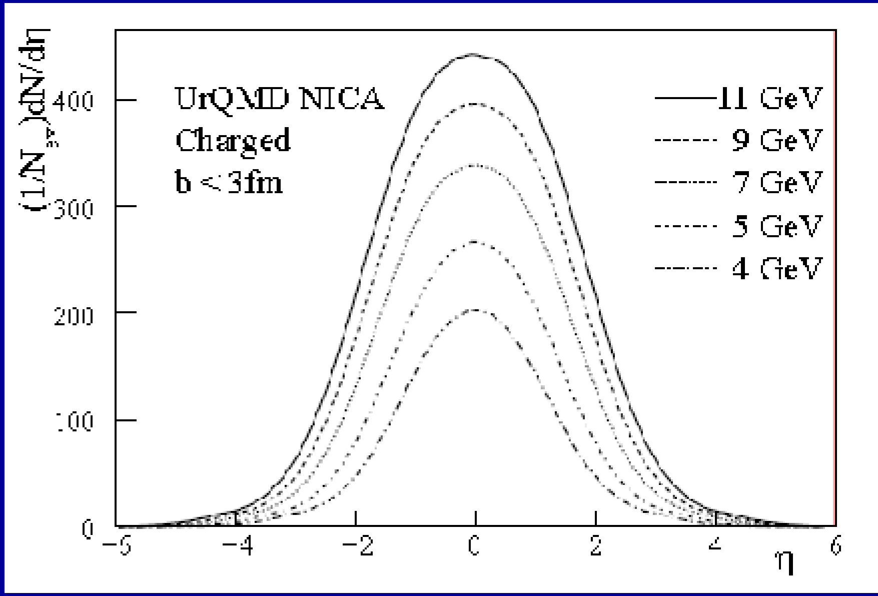
FD (2<|η|<4)

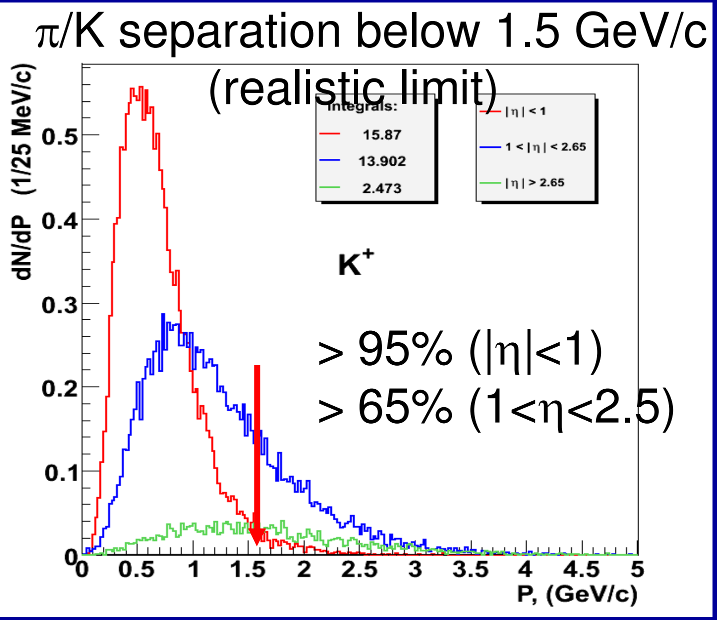
ZDC (|η|>3)

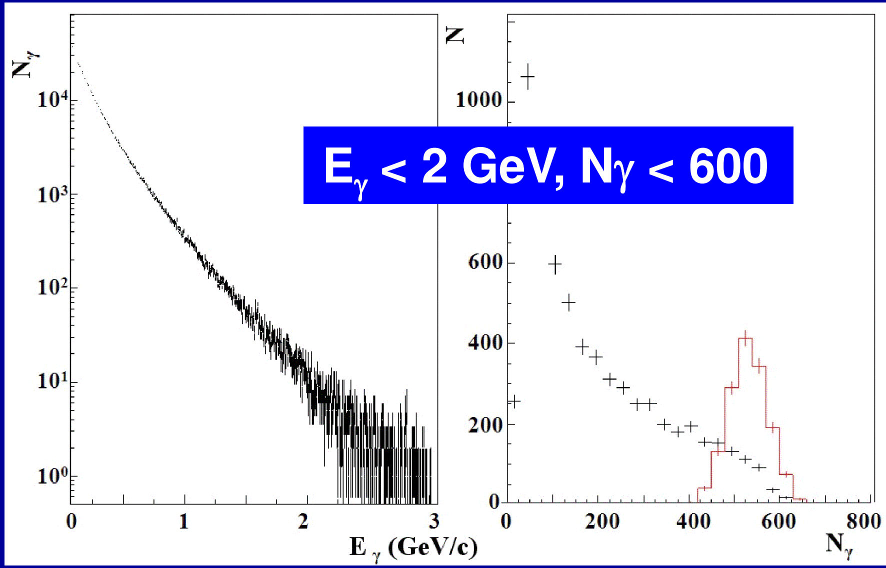


Detector requirements (2)
Au+Au collisions: multiplicities & spectra



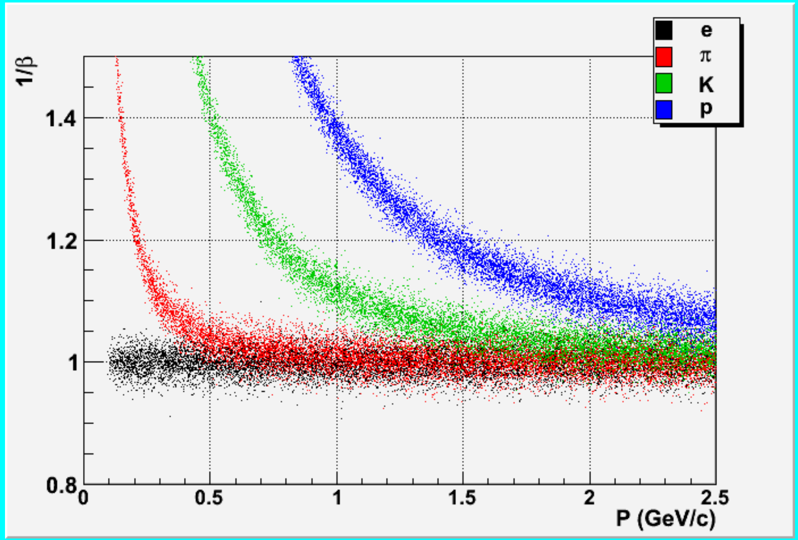




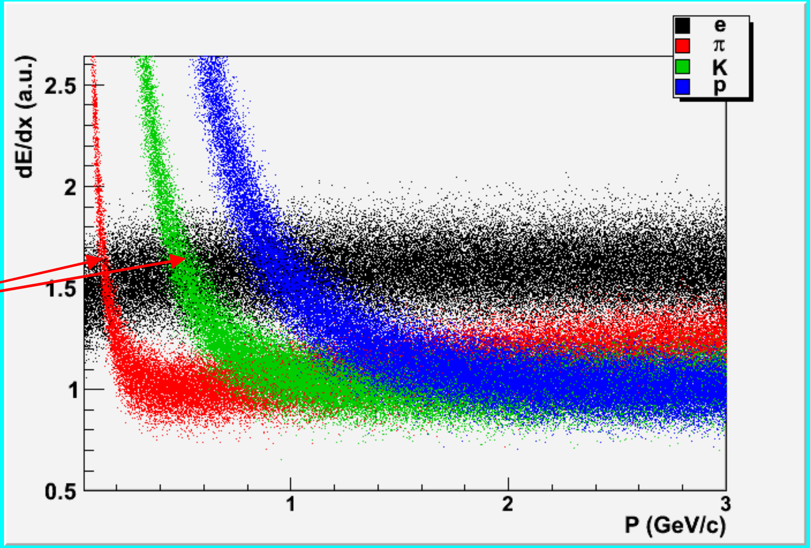


PID methods in MPD (hadrons+e)

PID method: Time Of Flight
PID separation : e/h – 0.1..0.35 GeV/c
π/K – 0.1..1.5 GeV/c
K/p – 0.1..2.5 GeV/c
Challenge: overall resolution < 100 ps, good start detector



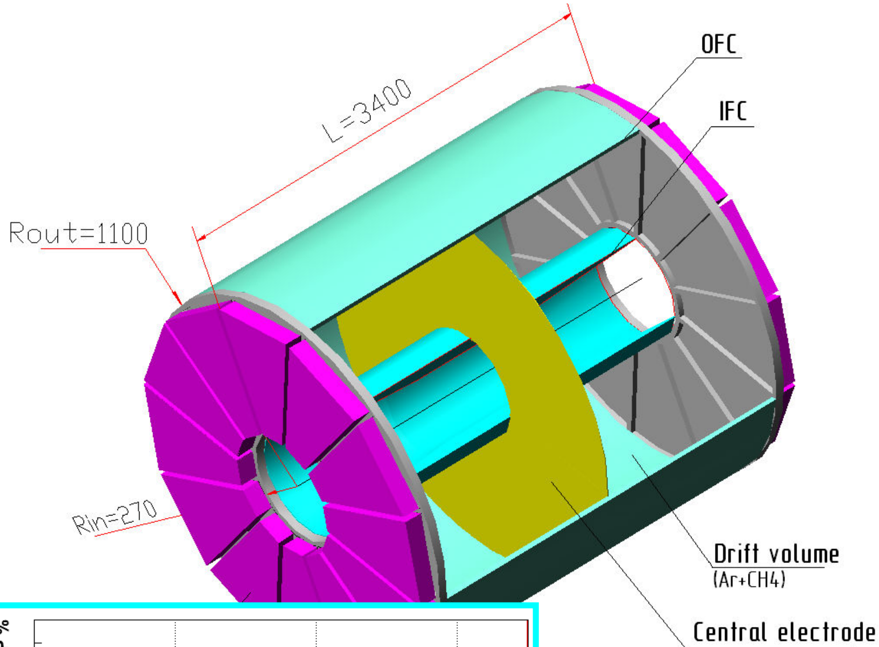
PID method: Ionization loss (dE/dx)
PID separation: e/h – 1.3..3 GeV/c
π/K – 0.1..0.6 GeV/c
K/p – 0.1..1.2 GeV/c
Challenge: resolution better than 8%, combined PID for the crossover regions



Time Projection Chamber

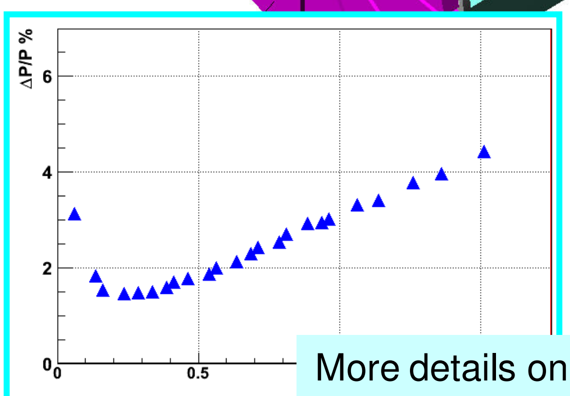
Challenges:

- **low material budget (especially in forward direction)**
- **high event rates (up to ~6 kHz)**
- **small distortions, stable conditions in long runs → UV laser for calibration & alignment**



TPC parameters

Size: 3.4 m (length) x 2.2 m (diameter)
Drift Length: 150cm
# of samples: 50
Electric field: 140V/cm
Magnetic field: 0.5 T (max.)
Gas: 90% Argon + 10% Methane (atm+2mbar)
Readout: 2x12 sectors (MWPC+pads or GEM)
Pad size – 4x10mm in inner sector area
6x12mm in outer sector area
Total # of pads: ~80000

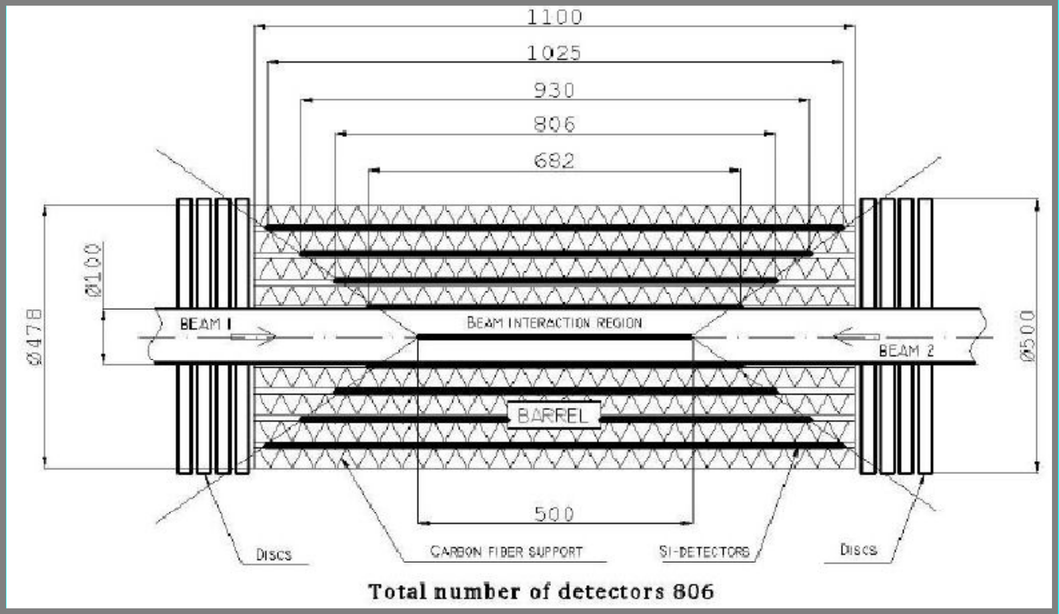


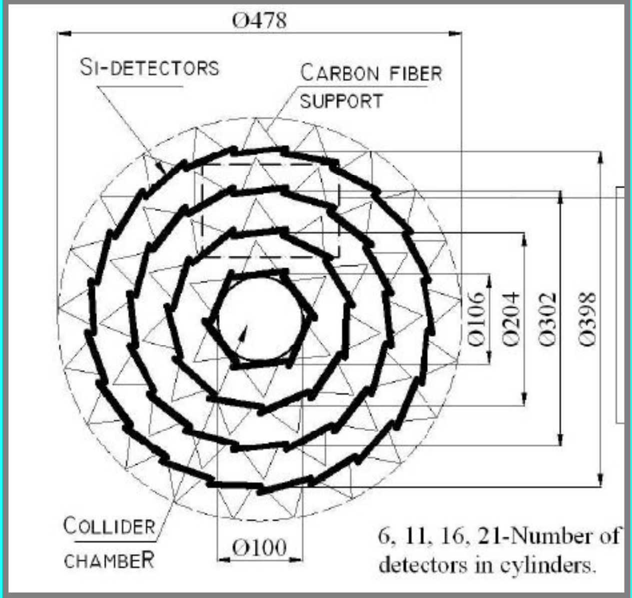
Performance required (MWPC option):

Spatial resolution: $\sigma_{r\phi}$~300 μm σ_z~ 2 mm
Two track resolution < 1 cm
Momentum resolution Δp/p < 3% (0.2<p<1 GeV/c)
dE/dx resolution < 8%

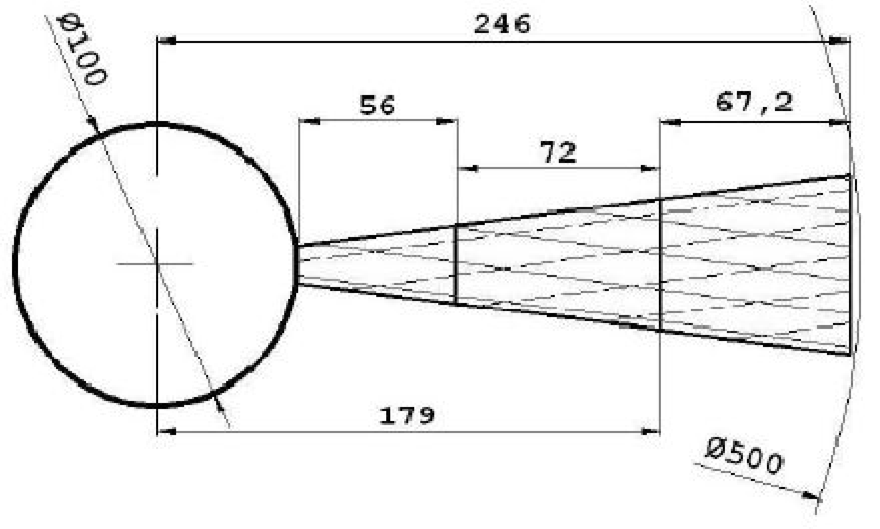
More details on MPD TPC see poster by V.Babkin (session B)

Inner Tracker





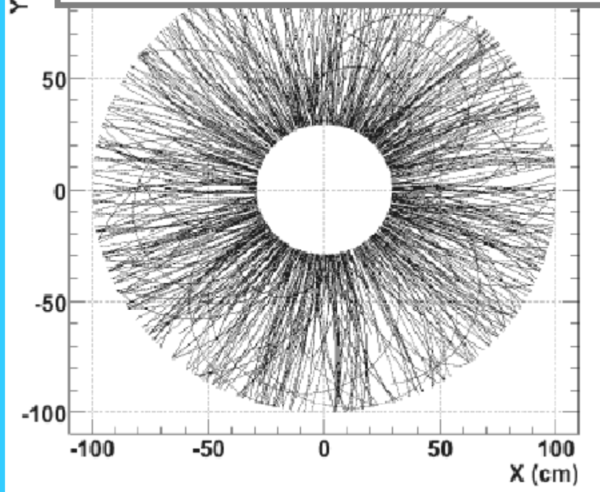
- 4 cylindrical & disk layers
- 300 μm double-sided silicon microstrip detectors, pitch - 100 μm
- Thickness/layer ~ 0.8% X_0
- Barrel: R=1-4 cm, coverage $|\eta|<2.5$ 806 sensors of 62x62 mm^2
- Disks: under optimization
- resolution: σ_z = 120 μm, $\sigma_{r\phi}$ = 23 μm



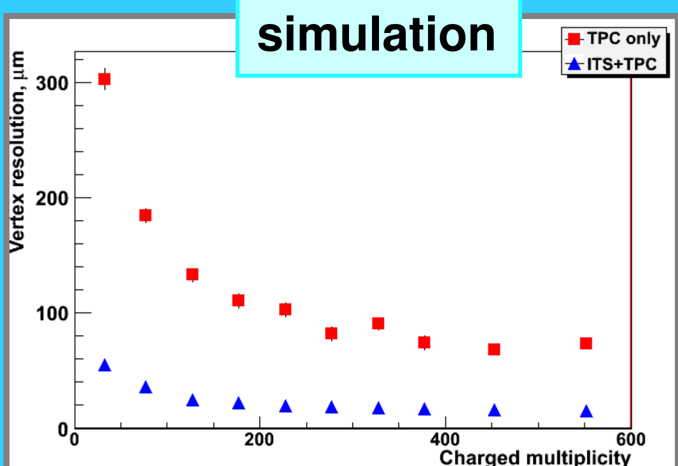
Inner Tracker (optimization)

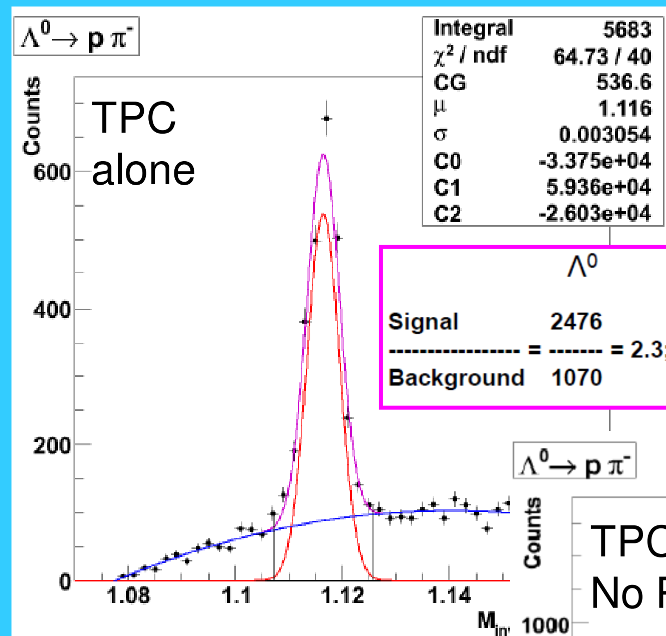
IT design optimization tasks (ongoing): best topology in terms of occupancy, event vertex resolution, performance of V0 and cascades reconstruction

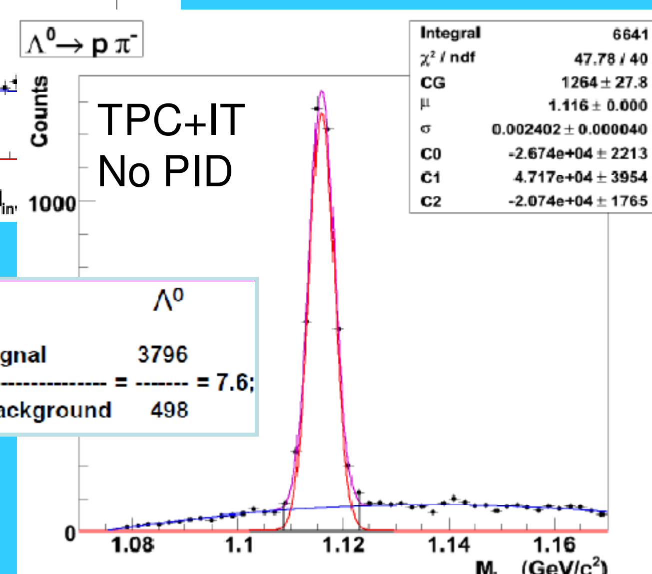
Occupancy (several models) – 10% for the inner-most layer, η=0, $\sqrt{s_{NN}}$ = 9 GeV



simulation







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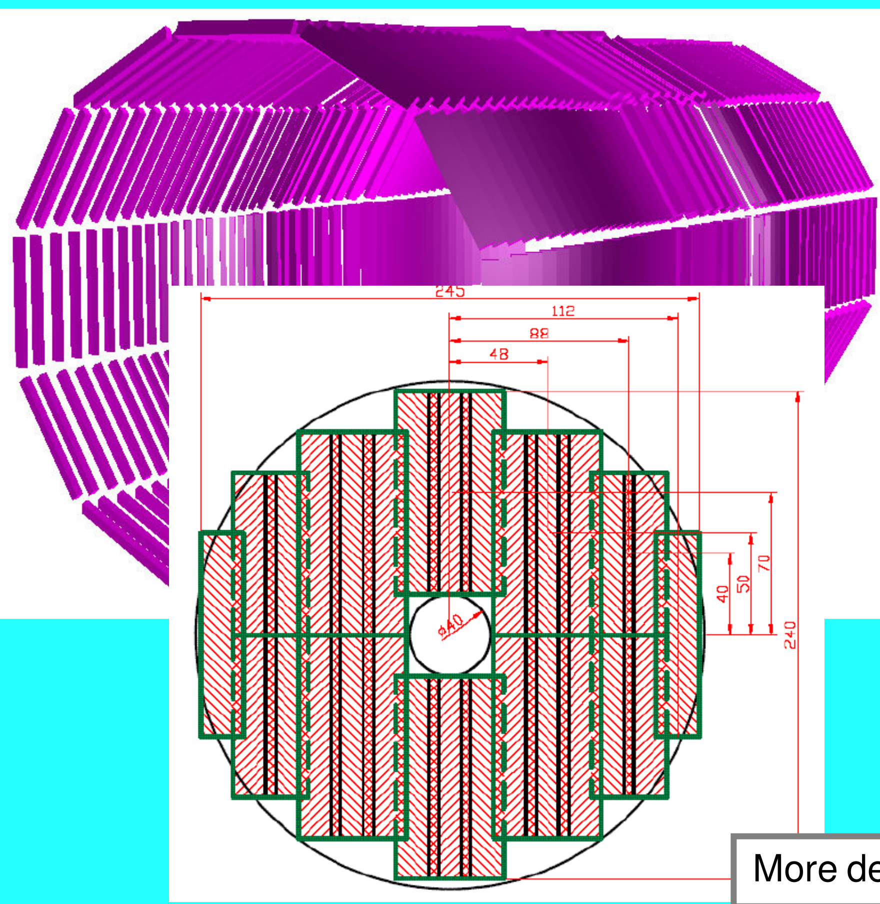
Time Of Flight System

Basic requirements:

- **Coverage: > 30 m², |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

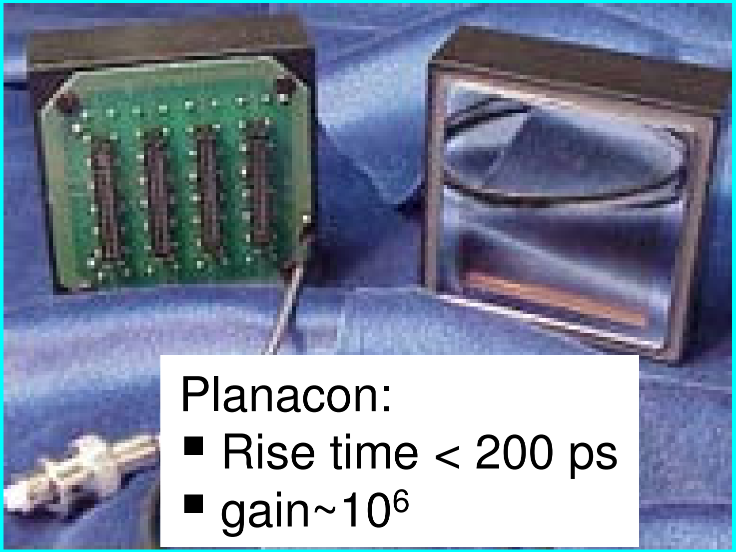
Segmentation (barrel):
12 sectors x 55 modules (62x7 cm²)
module: 10-gap RPC, 48 pads 2.5x3.5 cm²

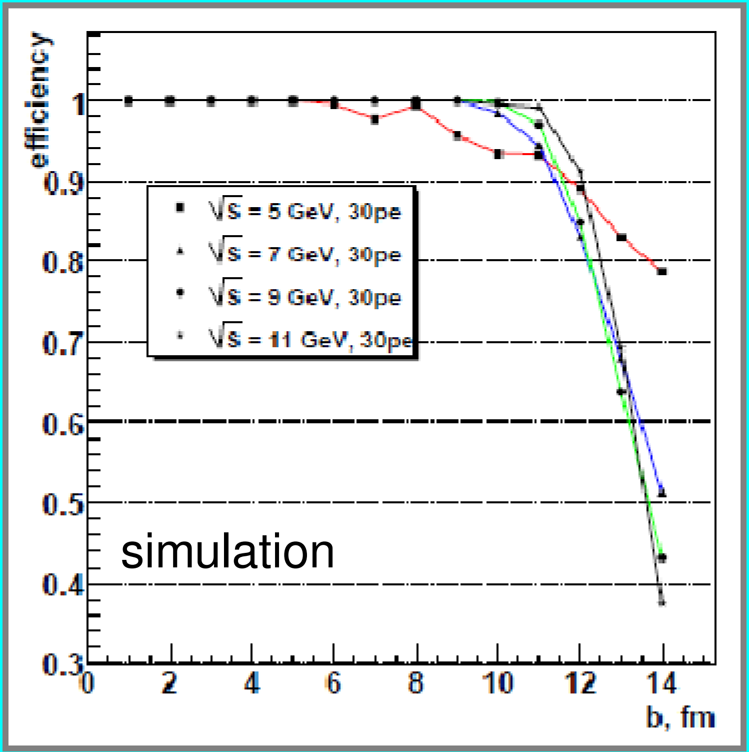
endcaps:
24 mRPC 53,37,21x80-100 cm²
pad size : 4x4 cm²
# of readout channels – 34500
geom. efficiency ~ 95%

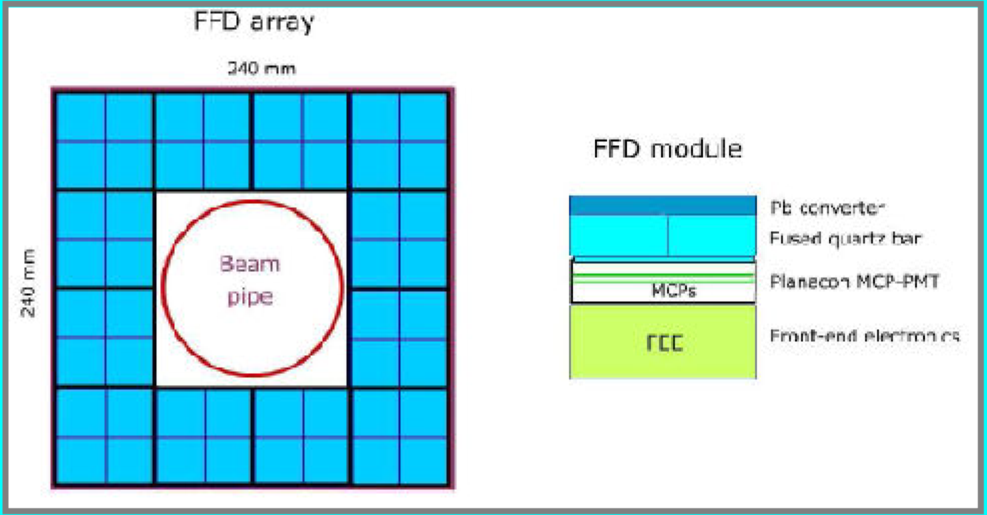
More details on MPD TOF see poster by V.Babkin (session B)

Time of Flight : T0-timing (FFD)

FFD Tasks: provide TOF with T0 ("Start"), L0-trigger, beam diagnostic
Requirements: σ < 60 ps, high efficiency, insensitive to B-field
Technology: quartz Cherenkov radiator with micro-channel plate PMT, sensitive to γ's



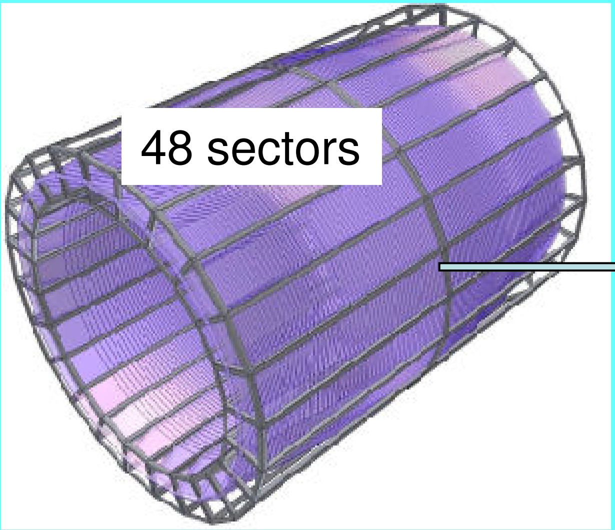


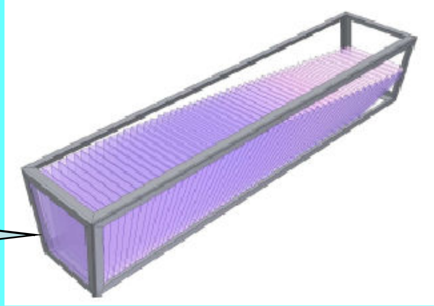


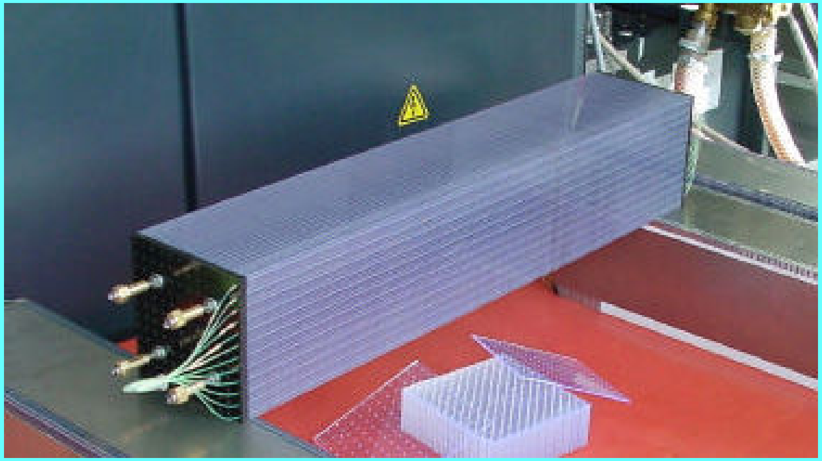
Electromagnetic calorimeter (ECAL)

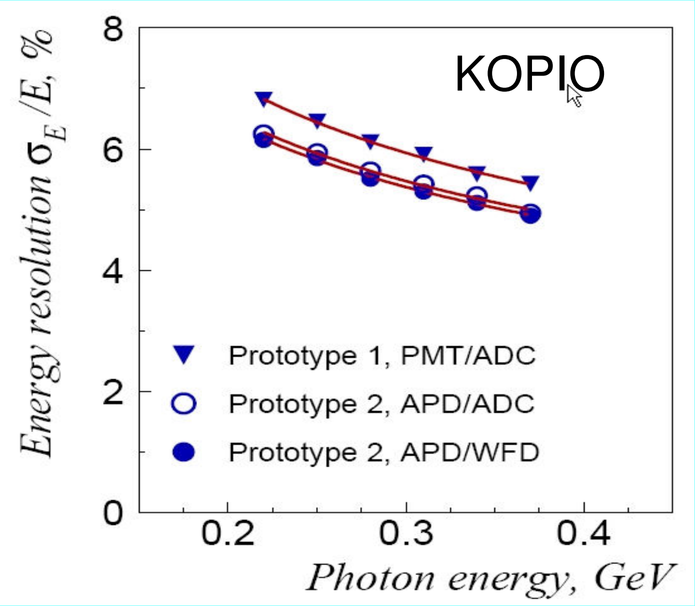
Requirements:
- high granularity
- $\sigma/E \sim 3\%/\sqrt{E}$ + const.

Technology:
"Shashlyk" calorimeter
Pb(0.275 mm)+Scint.(1.5 mm)
size: 3x3 cm^2
length: 40 cm (~ 18 X_0)
read-out: WLS fibers + MAPD









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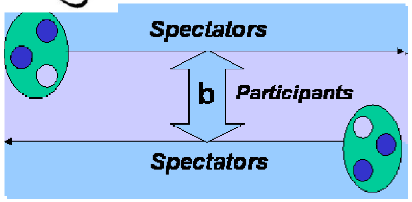
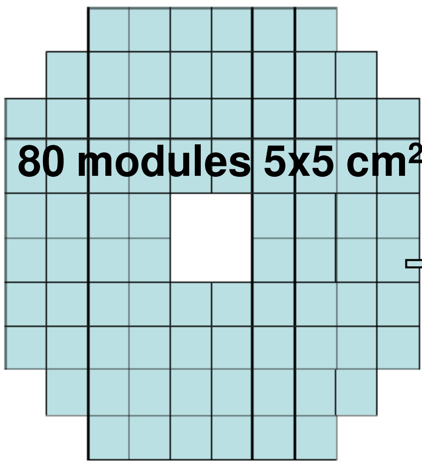
Zero Degree Calorimeter

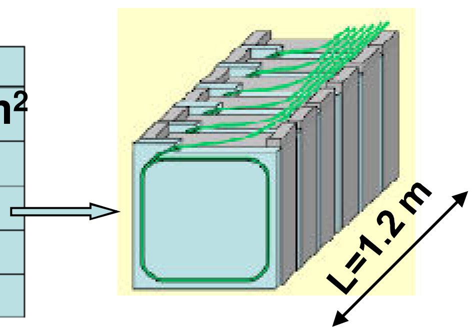


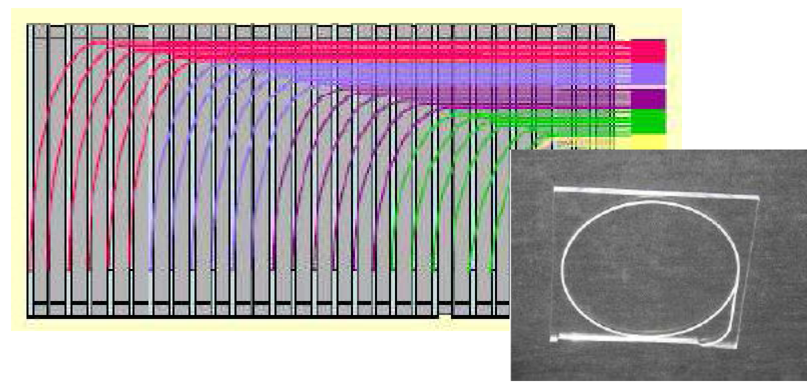
..measures the energy deposited by spectators,
event centrality determination (offline b-selection)

Requirements:

- transverse dimensions determined by the spectator spot size (> 50 cm at $\sqrt{s}$=4 GeV)
- measure of assymetry in athimuthal distribution → fine ϕ-segmentation
- energy resolution < 60%/ $\sqrt{E}$







- Pb(16mm)+Scint.(4mm) sandwich
- 60 layers of lead-scintillator (1.2m, 6λ)
- 1mm WLS fibers + micropixel APD (Zecotek)
- produced by INR, Troitsk, Russia
- similar to ZDCs for NA61 and CBM

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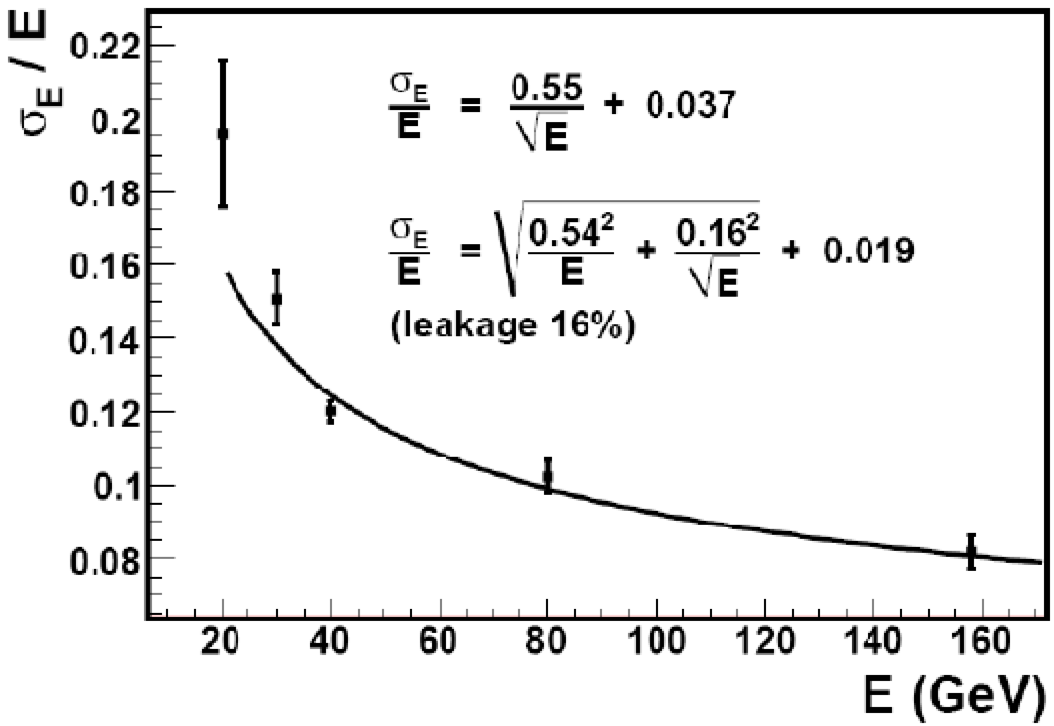
Zero Degree Calorimeter (2)

Beam test at CERN-SPS (using beams of π) with 30x30 cm^2 prototype → leakage ~16%



Design resolution ~ 60%/ $\sqrt{E}$ is proven

Conclusion & Outlook

- **NICA/MPD project – new heavy-ion program at JINR, Dubna aimed at comprehensive study of the QCD phase diagram**

- **NICA physics program requires a multipurpose detector with extreme performances in:**
  - **hermeticity → towards 4π geometry**
  - **tracking and PID**
  - **robust event selection algorithms**

- **Next steps:**
  - **Design optimization,**
  - **R&D prototyping (TDR in 2012)**

The MultiPurpose Detector – MPD

to study Heavy Ion Collisions at NICA
(Conceptual Design Report)

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- JINR ~ 100
- Other Institutions 42

Participating Institutions

- JINR
- 10 Institutes from 5 countries

The size of the Collaboration is growing continuously, new members are welcome

Thank you

for your attention!