Feasibility Study of $\phi(1020)$ Production at NICA/MPD

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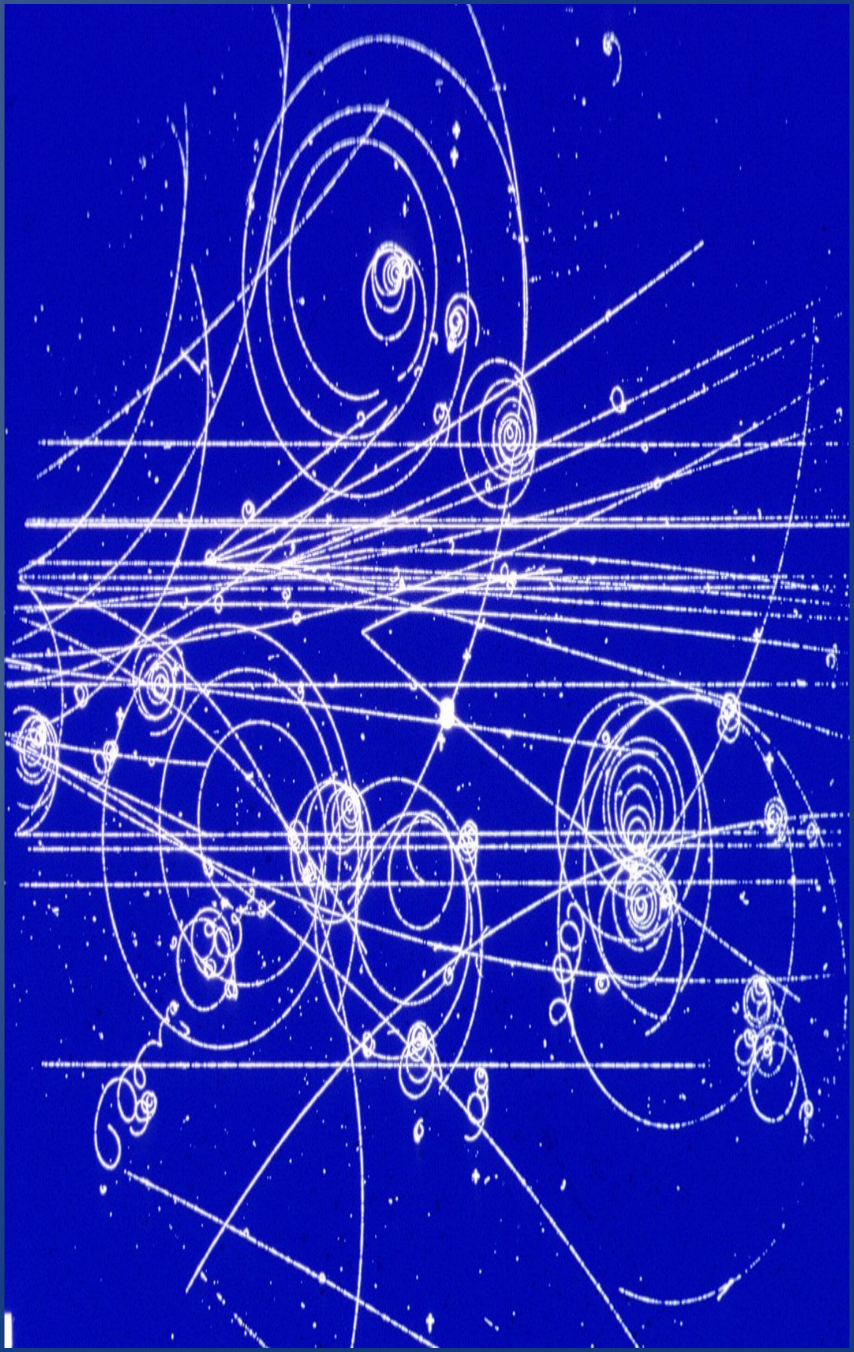
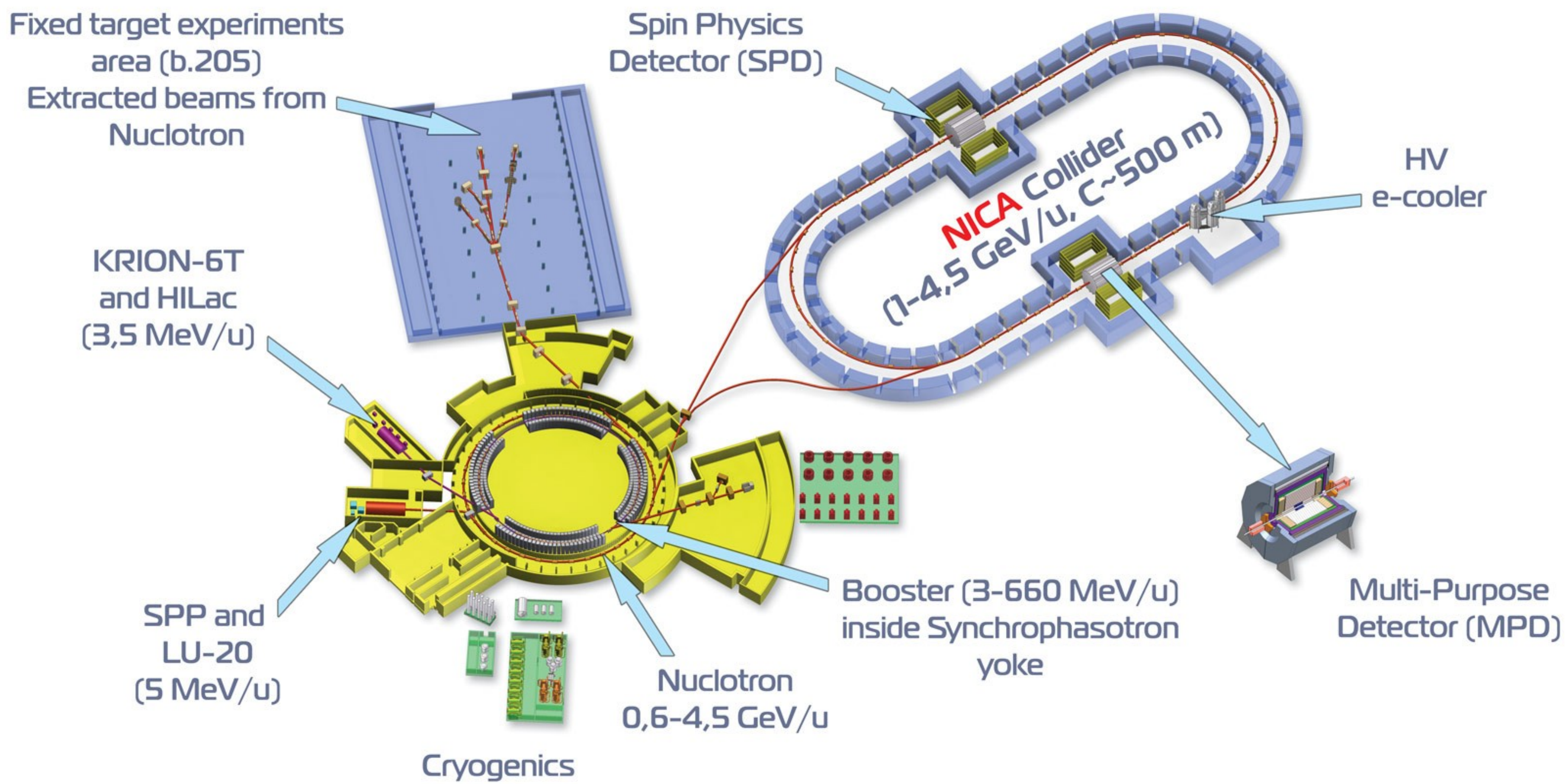
Contents:

1. Introduction
2. Multi-Purpose Detector MPD at NICA
3. Motivation for feasibility study of φ(1020)
4. UrQMD generator
5. Reconstruction of φ(1020)
6. Results
7. Summary

NICA



Superconducting accelerator complex NICA
(Nuclotron based Ion Collider fAcility)



NICA parameters

- **Energy range: $\sqrt{s_{NN}}$ = 4-11 GeV**
- **Beams : from p to Au**
- **Luminosity : L~10^{27} (Au), 10^{32} (p)**
- **2 Detectors: MPD (ions), SPD (spin physics)**

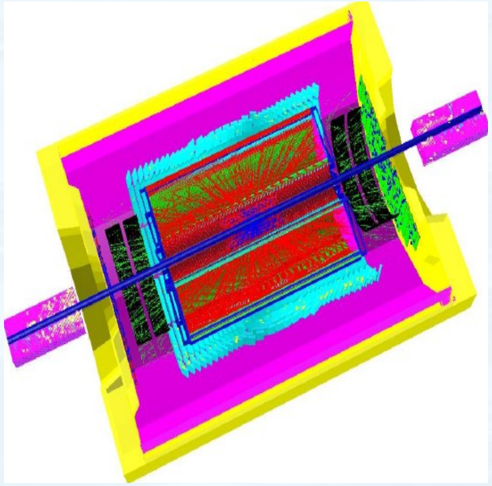
Staging of MPD at NICA

MPD staging is driven by:

- *the goal* to start energy scan as soon as the first beams are available
- the present constrains in resources and manpower

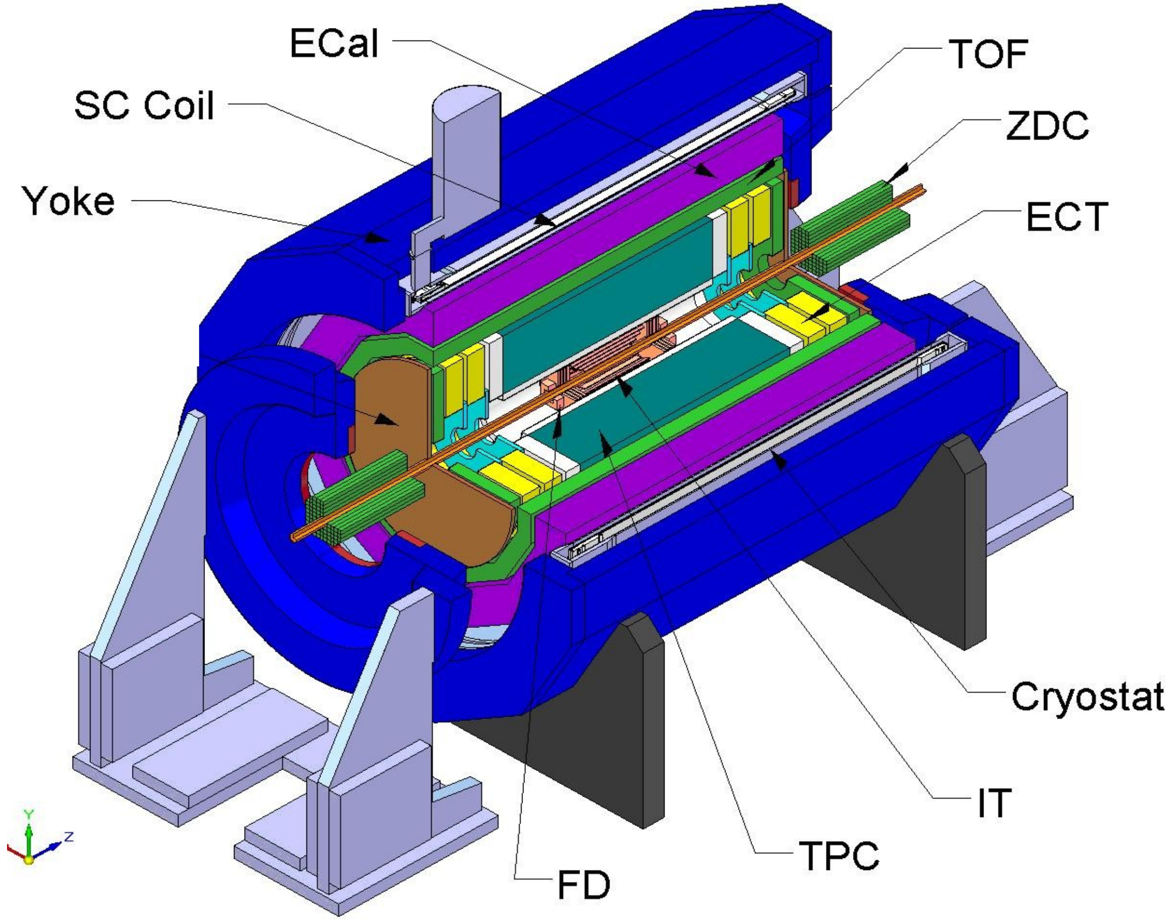
1-st stage - **Mid rapidity tracking + PID**
2-nd stage - **Vertex detector and tracking at forward rapidities**

I stage:
~Particle yields and spectra (π,K,p,Λ, Ξ ,Ω, ϕ)
~Event-by-event fluctuations
~Femtoscopy involving π, K, p, Λ
~Collective flow for identified hadron species
~Electromagnetic probes (electrons, gammas)
II stage:
~Total particle multiplicities
~Asymmetries study
~Di-Lepton precise study
~Charm
~Exotics (soft photons, hypernuclei)



The conditions to be fulfilled:
*Keeping flexibility for upgrading towards interesting physics
*Foreseeing possibility of new technology implementations
*Foreseeing fields of activities for new potential collaborators

Multi-Purpose Detector MPD at NICA



Central Detector Volume:
9.0 m (Length)
6.0 m (Diameter)

Magnet :
0.5 T superconductor (1st stage)

Tracking :
TPC (1st stage,|η|<2.0)
ECT, IT (2nd stage,|η<2.5)

Particle ID :
TOF, ECAL, TPC (1st stage, |η|<1.5)

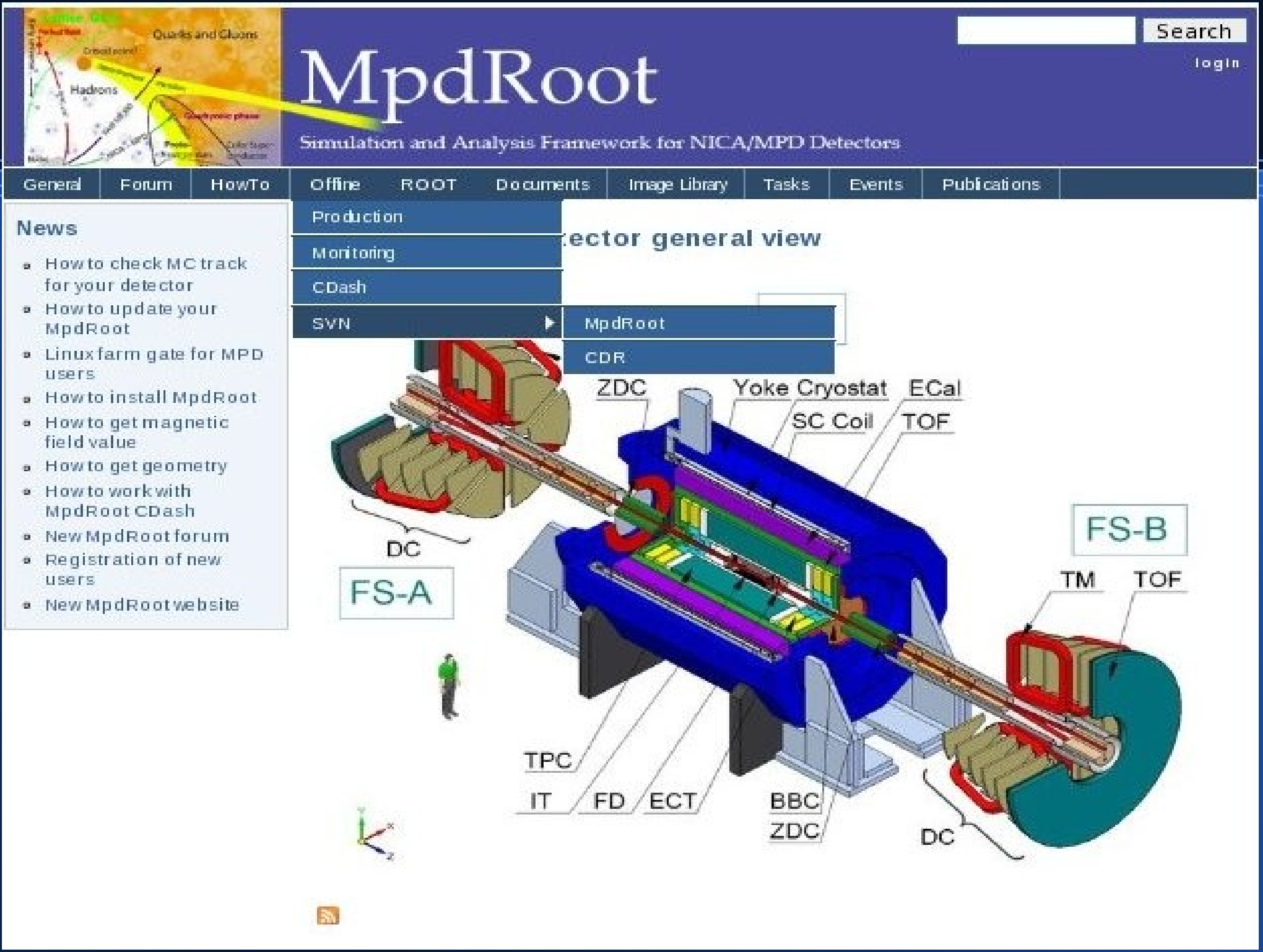
Triggering : FD (1st stage,2.0<|η|<4.0)

Centrality : ZDC (1st stage,2.2<|η|<4.8)

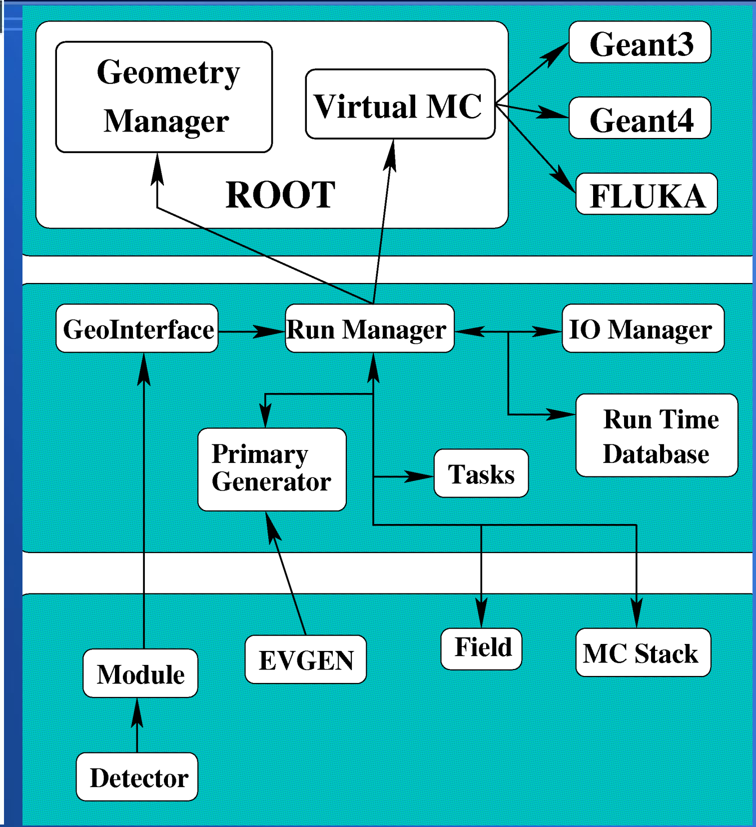
MPD Advantages:

*Hermeticity and homogenous acceptance (2π in azimuth)
*Excellent tracking performance and powerful PID
*High event rate capability and careful event characterization

Simulation and Analysis Framework for MPD detector

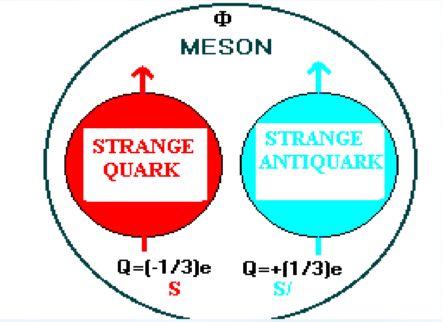


http://mpd.jinr.ru



- MpdRoot inherits basic properties from FairRoot (developed at GSI), C++ classes
- Extended set of event generators for heavy ion collisions (UrQMD, LAQGSM, HSD)
- Detector composition and geometry; particle propagation by GEANT3/4
- Advanced detector response functions, realistic tracking and PID included

Motivation for feasibility study of $\phi(1020)$ production at NICA/MPD



1. Strangeness as a probe of deconfinement

- the lightest bound state of hidden strangeness
- a relatively long life-time of ~46 fm/c

2. Nuclear dynamics and hadron production under extreme nuclear density

- p_T spectras and their dependence in terms of shape and normalization on centrality shed light on the constituents of the medium at the time of φ formation
- study of the mechanism through which φ is formed

3. Low cross-section in nuclear matter and early freeze-out

- fewer interactions in the hadronic stage
- v_2 signals can provide a clean signal from the early stage of the system's evolution

Motivation for feasibility study of $\phi(1020)$ production at NICA/MPD

4. Particle properties in dense nuclear matter

- information on the collectivity and possible deconfinement of the system in the early stage
- constraint of different dynamical models of elliptic flow and particle production

Challenge - ***Low yield of*** $\phi(1020)$

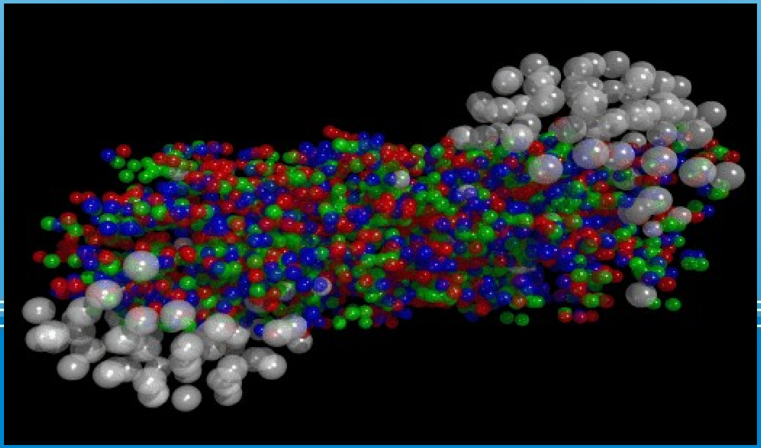
Why at NICA/MPD ? - ***High luminosity , high efficiency, detector with precise tracking***

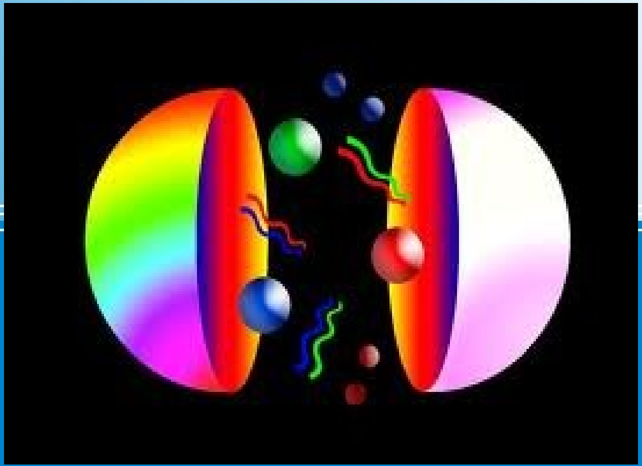
The UrQMD model

The Ultrarelativistic Quantum Molecular Dynamics model is a microscopic model used to simulate (ultra)relativistic heavy ion collisions in wide energy range.
Link of site: http://urqmd.org/

Main goals:

* Creation of dense hadronic matter at high temperatures
* Creation of mesonic matter and of anti-matter
* Creation and transport of rare particles in hadronic matter
* Creation, modification and destruction of strangeness in matter
* Emission of electromagnetic probes





Reconstruction of ϕ (1020)

Data set:

* The channel decay $\Phi \rightarrow K^+K^-$ is used to detect the formation of the φ-meson
* UrQMD event generator + HypYPt (φ added), central Au+Au
* Energy - $\sqrt{s}$ = 11 GeV (max NICA energy)

Method of reconstruction:

1. Selection of kaon pairs by track quality cuts and particle identification (PID)
2. Calculation of the invariant mass of the kaon pairs (signal distribution)

$$M_{inv} = \sqrt{((E_1 + E_2)^2 - (p_{x1} + p_{x2})^2 - (p_{y1} + p_{y2})^2 - (p_{z1} + p_{z2})^2)}$$

3. Calculation of the combinatorial background (combinatorial background distribution)
   * mixed-event technique (K+ and K- from different events)
   * same-event technique (K+K+ and K-K- from same events)

Reconstruction of ϕ (1020)

4. Determination of the raw signal distribution
   (subtraction of the scaled combinatorial background)

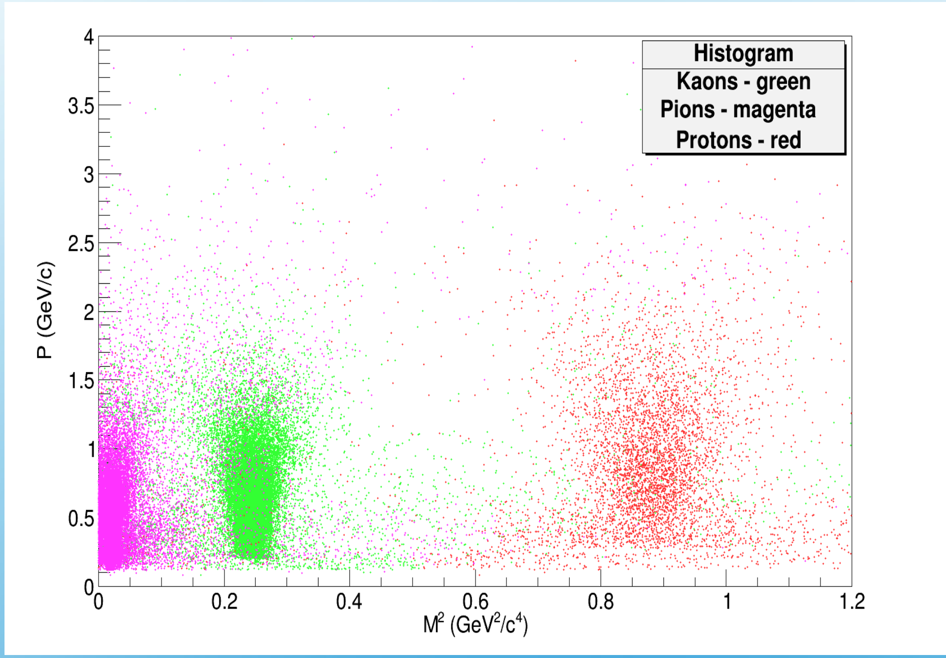
5. Fitting of the raw signal distribution by a Breit-Wigner function

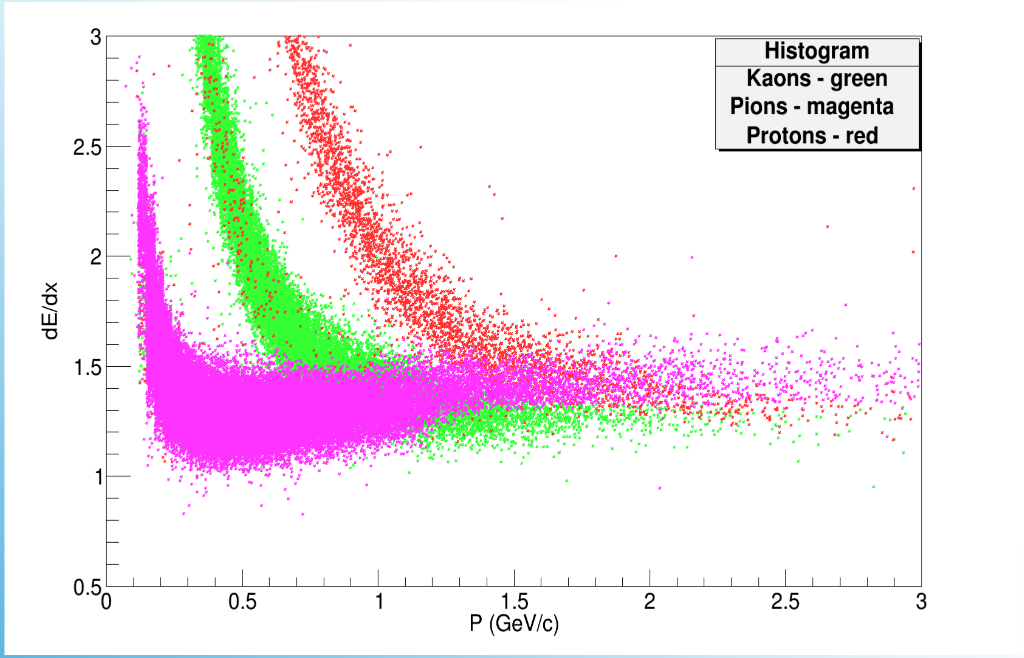
$$BW(m_{inv}) = \frac{1}{2\pi}\frac{A.W}{(m - m_{\phi})^2 + (W/2)^2}$$

A - Breit-Wigner area
W - Breit-Wigner width
m – Reconstructed invariant mass of the φ-meson

Particle Identification - PID

PID: TOF + dE/dx

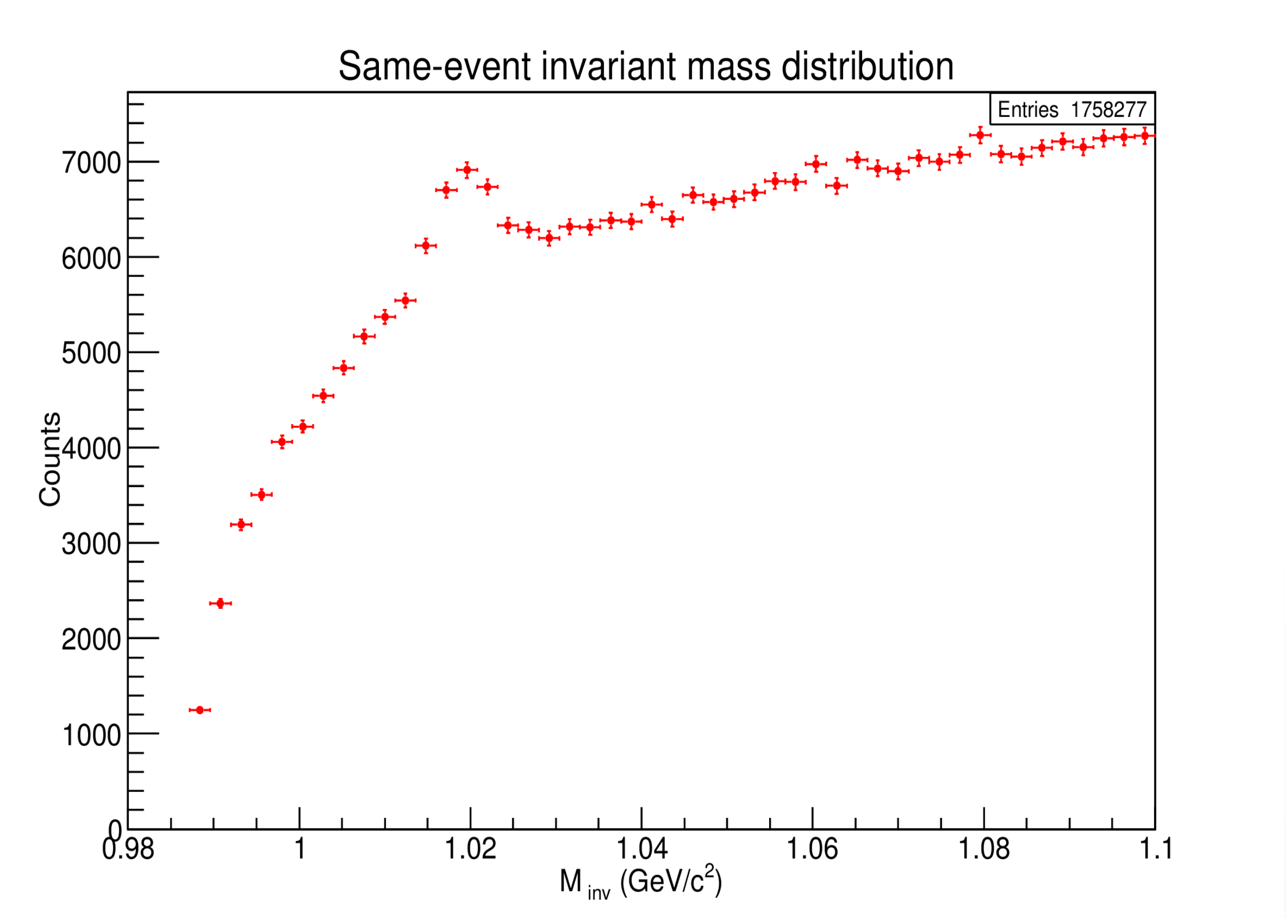




Species	Species identified as kaons after reconstruction, %			
	All momentum interval	P <= 0.5 GeV/c	0.5<=P<=1.0 GeV/c	1.0<=P<=1.5 GeV/c
k	80.27	96.02	73.65	58.33
π	17.83	2.01	24.92	40.87
p	1.11	0.85	0.71	0.77
e	0.79	1.12	0.72	0.03

Results: Signal Distribution

* Channel of decay: $\varphi \longrightarrow K^+K^-$
* Central Au+Au
* UrQMD+HypYPt (φ added)
* Energy - $\sqrt{s}$ = 11 GeV
* PID: TOF, dE/dx
* Selection by track quality cuts and PID (mid-rapidity, 0.5 <=P<= 1.0 GeV/c)

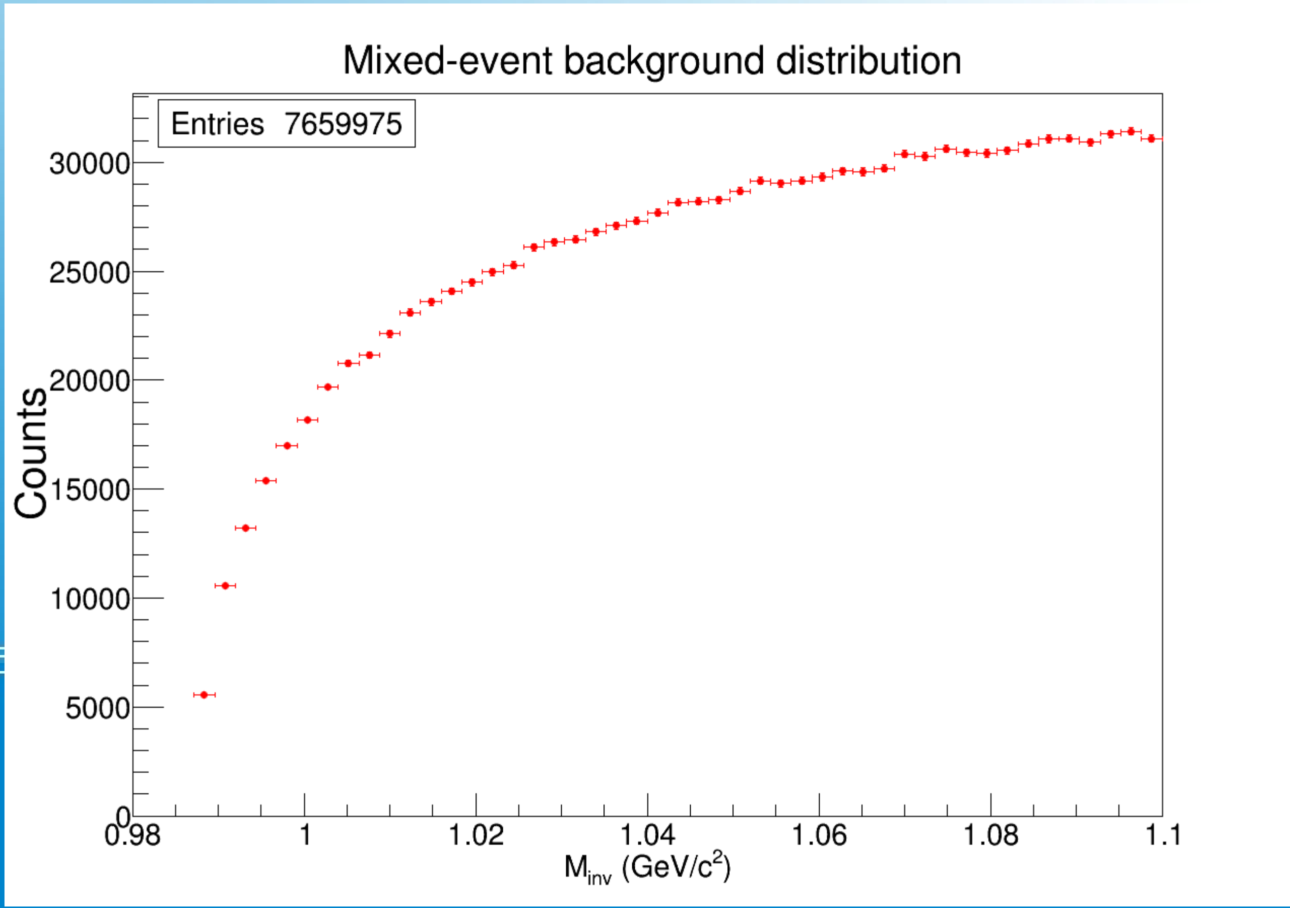


$$M_{inv} = \sqrt{((E_1 + E_2)^2 - (p_{x1} + p_{x2})^2 - (p_{y1} + p_{y2})^2 - (p_{z1} + p_{z2})^2)}$$

Results:
Combinatorial Background

*** Mixed-event technique (K+ and K- from different events):**

- **better possibility for combining selected kaons**
- **efficiency even in low statistics**
- **precise performance**



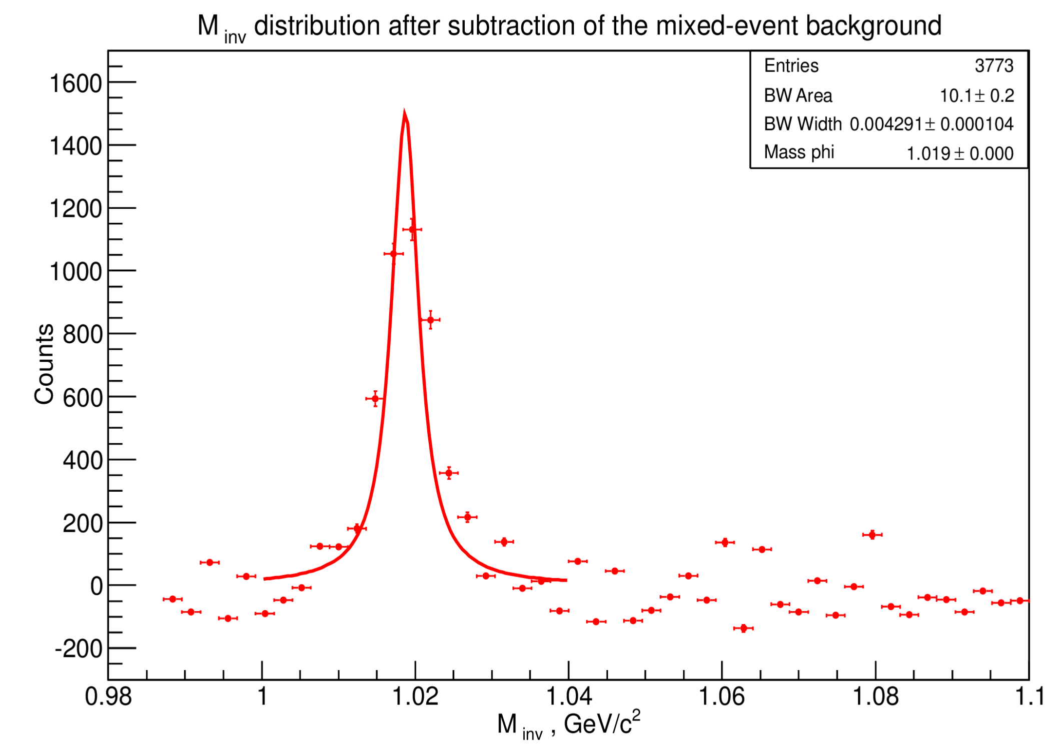
Results:
Raw Signal Distribution

$$M_{inv} = \sqrt{((E_1 + E_2)^2 - (p_{x1} + p_{x2})^2 - (p_{y1} + p_{y2})^2 - (p_{z1} + p_{z2})^2)}$$

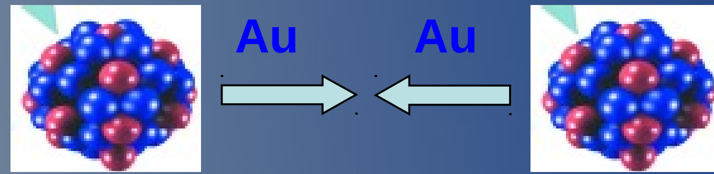
$$BW(m_{inv}) = \frac{1}{2\pi} \frac{A.W}{(m - m_\phi)^2 + (W/2)^2}$$

Measured values:
BW Width = 4.29 ± 0.10 (MeV/c^2)
M_{inv} = 1019.640 ± 0.080 (MeV/c^2)
S/√(S+B) = 18.11

PDG values:
BW Width = 4.26 ± 0.04 (MeV/c^2)
M_{inv} = 1019.455 ± 0.020 (MeV/c^2)



The measured values of the φ mass and width are consistent with the PDG values



Summary

* Measurements of the production of strange particles such as the φ-meson can provide important information on the properties of the medium and particle production mechanisms in ultra-relativistic Au-Au collisions at NICA/MPD.

* The recent developed methods and algorithms for reconstruction of the φ-meson at max NICA energy in central Au-Au collisions are shown.

* The obtained values of the φ-meson parameters (mass and width) are consistent with the PDG values.

Thank you for your attention!