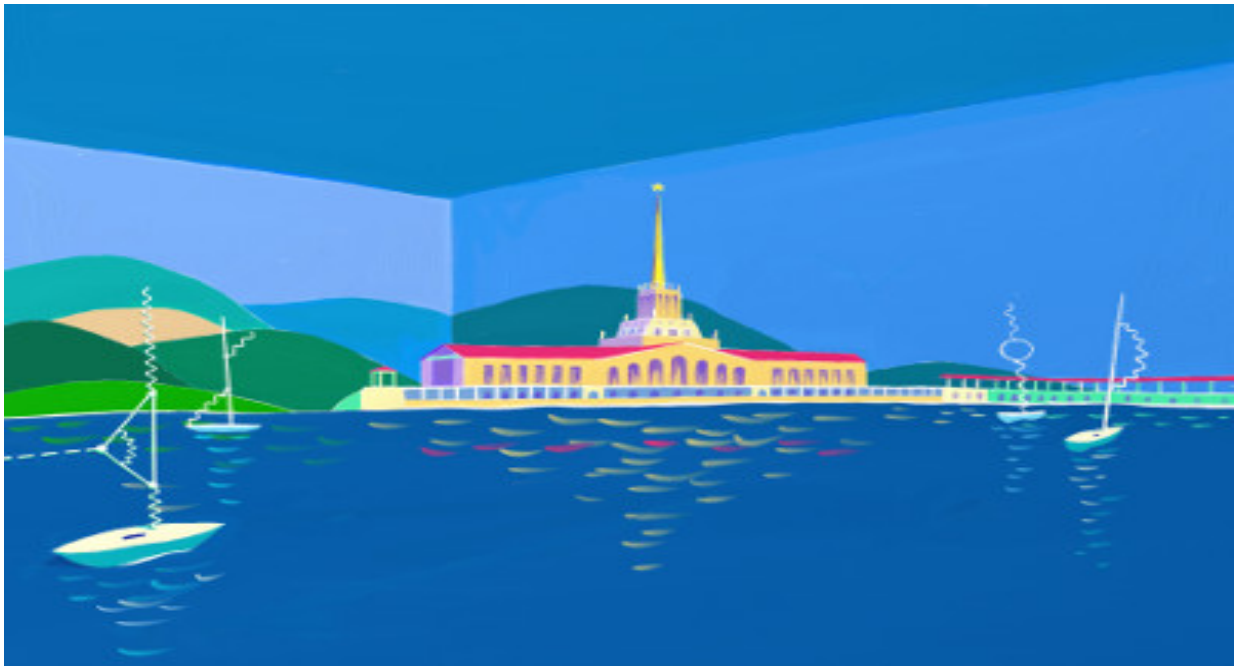
Measurement of the neutral and charged K* mesons in the MPD experiment at NICA

D. Ivanishchev, D. Kotov, E. Kryshen, M. Malaev, V. Riabov, Yu. Ryabov
for the MPD collaboration

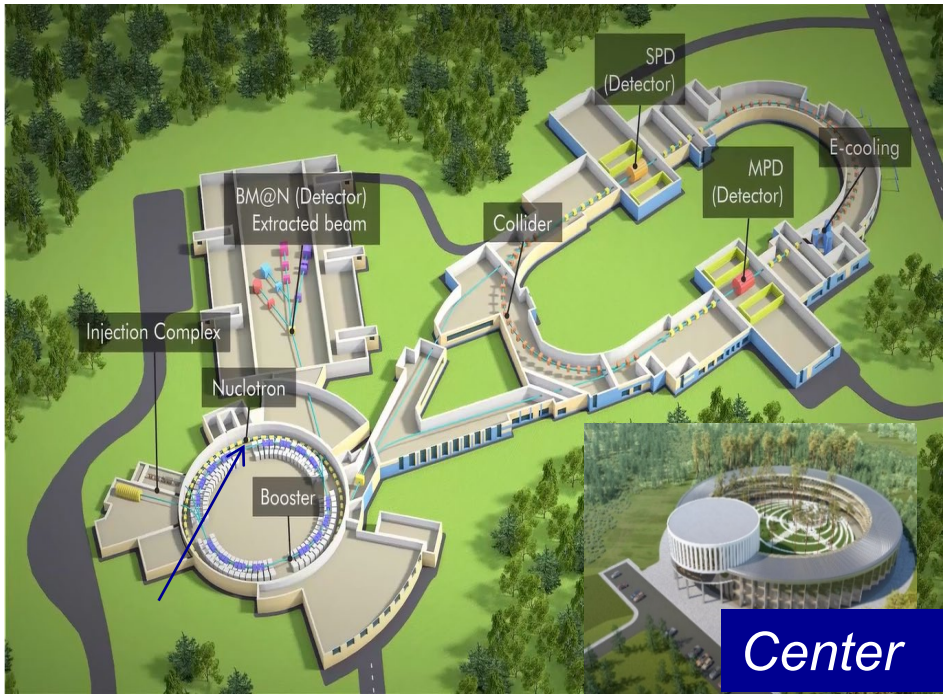
This work was supported by RFBR according to the research project № 18-02-40038

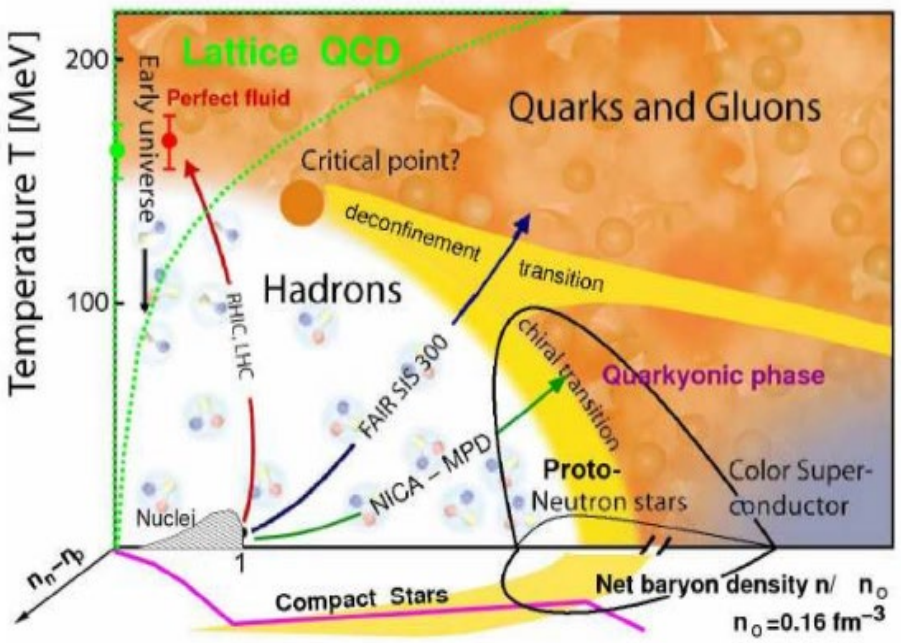


Outline

- Heavy ion collisions at NICA
- K^* as a probe of heavy-ion collisions
- Model predictions for K^* properties in heavy-ion collisions at NICA energies
- Studies for neutral and charged K^* reconstruction possibility at NICA-MPD
- Conclusions and outlook

Heavy ion collisions at NICA

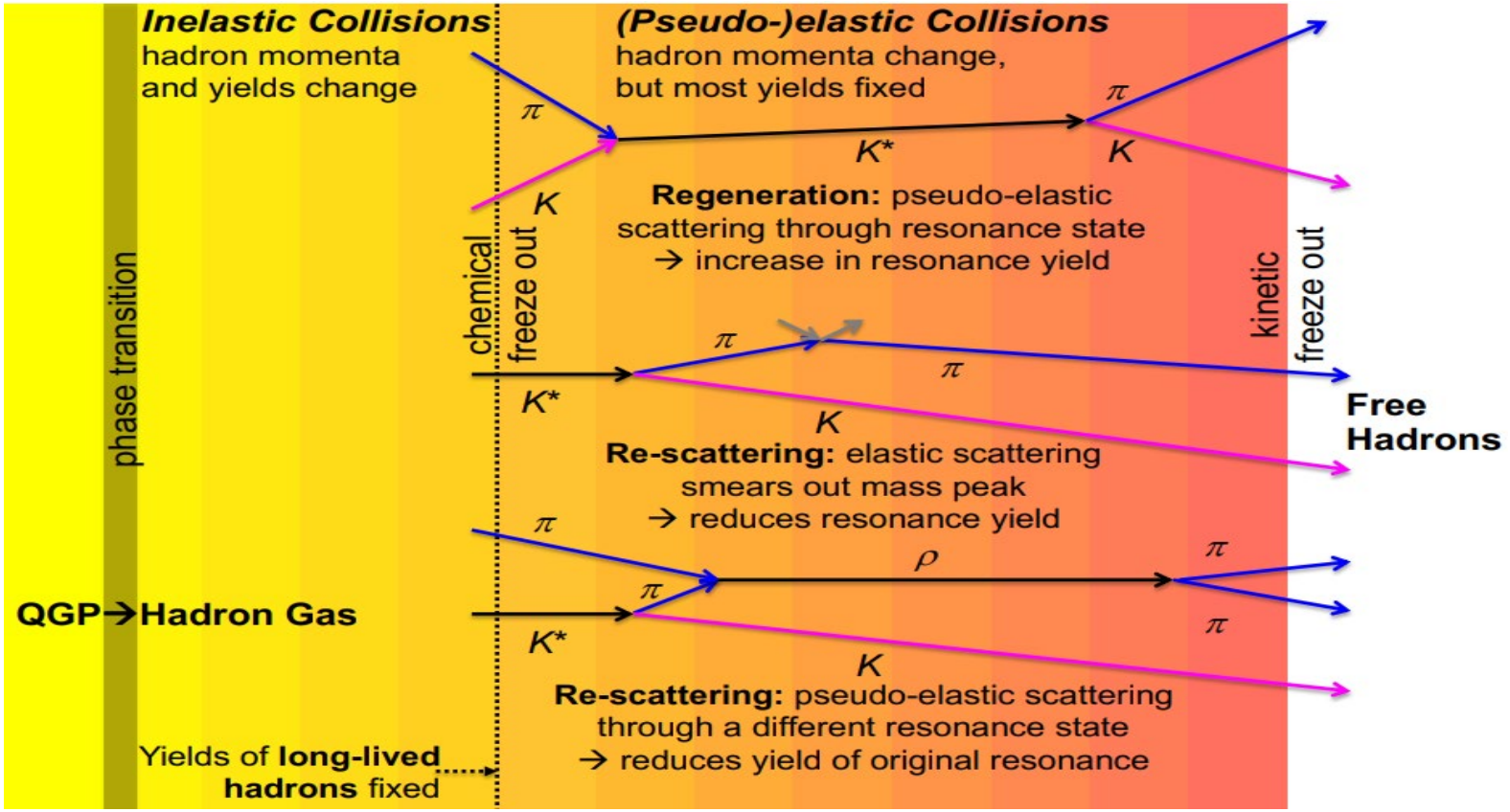




- One of a few mega-science projects in Russia
- Modernization of existing Nuclotron facility
- Construction of collider complex to collide:
  - ✓ relativistic ions up to Au, $\sqrt{s_{NN}}$ = 4-11 GeV
  - ✓ polarized p and d, $\sqrt{s_{NN}}$ = 27 GeV (for p)
- Two experimental setups: MPD, SPD

- Study of the properties of hot and dense QCD matter, phase transition to QGP
- Regime of the maximum baryon density at NICA
- Extension of modern heavy-ion programs at RHIC and the LHC to lower energies

Short-lived resonances as probes



- Resonances final yields and shape of the spectra are effected by:
  - ✓resonance yields at chemical freeze-out
  - ✓lifetime and properties of the hadronic phase and the resonance
  - ✓hadronic processes between chemical and kinetic freeze-outs: daughter particles rescattering and recombination

K^* in heavy-ion collisions

- $K^*(892)^0$ ($d\bar{s}$) and $K^*(892)^+$ ($u\bar{s}$) and their antiparticles are produced with high rate in heavy-ion collisions at ~ GeV energies
- Properties of the K^* in vacuum such as mass, lifetime, decay modes, branching ratios etc. are well measured
- Relatively easy to reconstruct and measure its properties in hadronic decay channels
- Probe reaction dynamics and particle production mechanisms vs. system size and collision energy:

  ✓ chemistry of hadrons

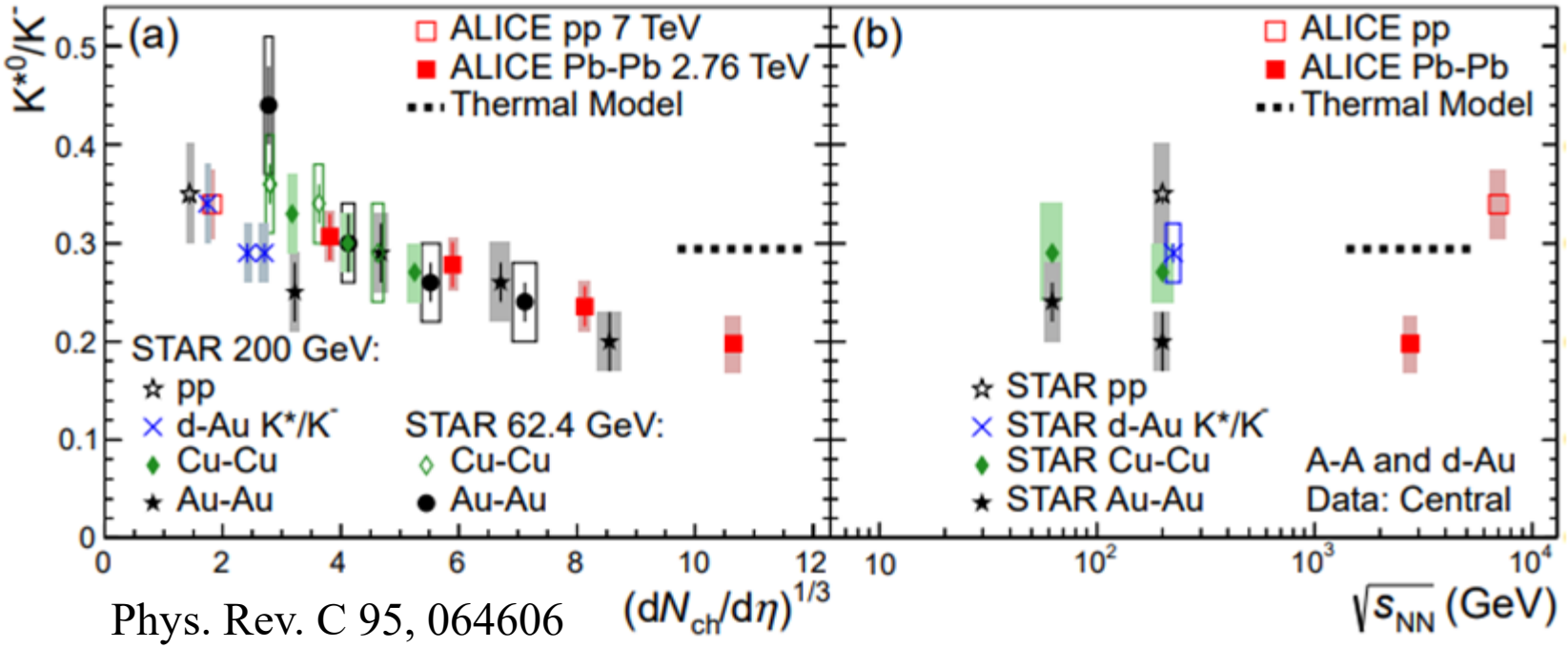
  ✓ particle p_T spectra and reaction dynamics

  ✓ properties and lifetime of the hadronic phase

  ✓ other mechanisms like jet quenching, background for other analyses, flow build-up, comparison with e^+e^- measurements, etc.

Hadronic phase and medium modifications

- K* have small lifetimes of $c\tau = 4.2$ fm
- Short lifetime: → chiral symmetry restoration: mass/width modifications
  → hadronic phase: lifetime, density



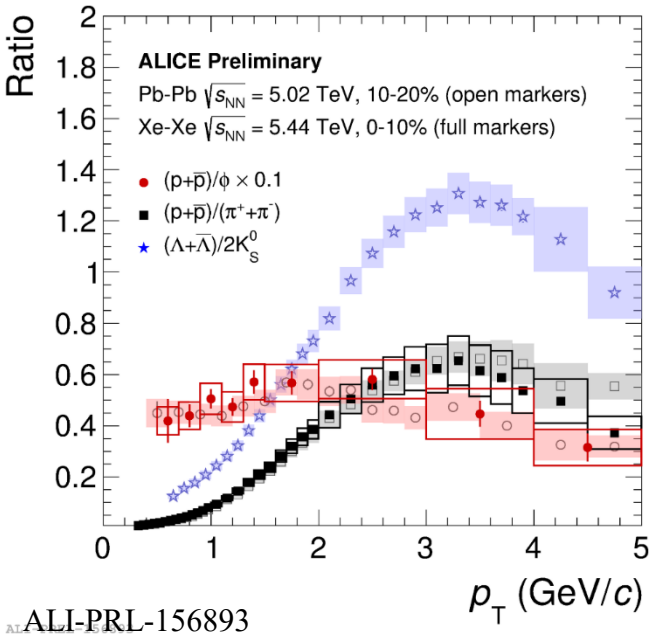
Phys. Rev. C 95, 064606

- ✓ significant suppression going from pp to central AA collisions
- ✓ Central AA results are inconsistent with thermal models

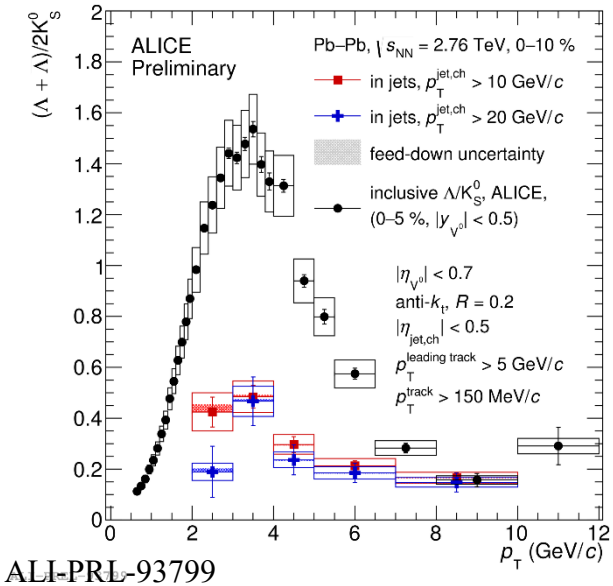
- Very weak energy dependence in a wide range $\sqrt{s_{NN}}$ = 20-2760 GeV

Baryon-to-meson ratio

- Enhanced baryon-to-meson ratios (p/π, Λ/K) in central heavy-ion collisions at intermediate p_T at RHIC and LHC
- Bulk effect, not present in jets
- Driving force of enhancement is not yet fully understood:
  - ✓ particle mass (hydrodynamic flow)?
  - ✓ quark count (baryons vs. mesons)?
- K^{*0} are well suited for tests as mesons with masses very close to that of a proton:
  - ✓ $\Delta m_{K^{*0}} \sim -45$ MeV/c^2



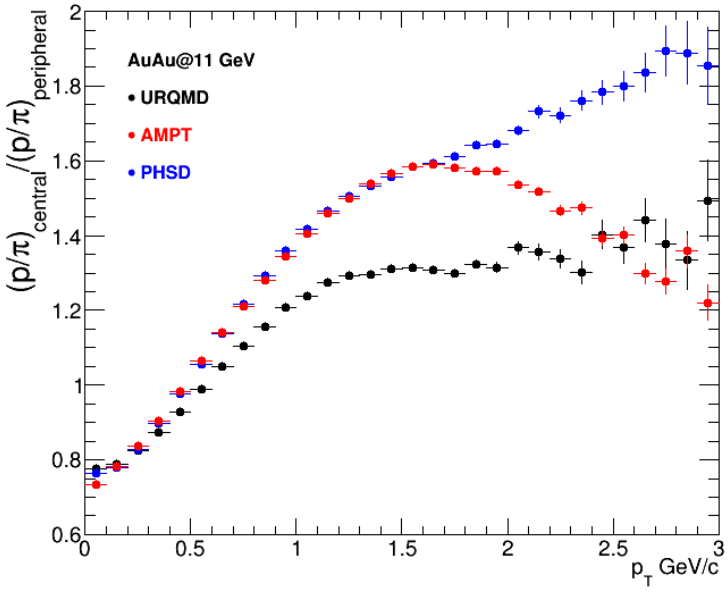
ALI-PRL-156893



ALI-PRL-93799

Model predictions for K* at NICA

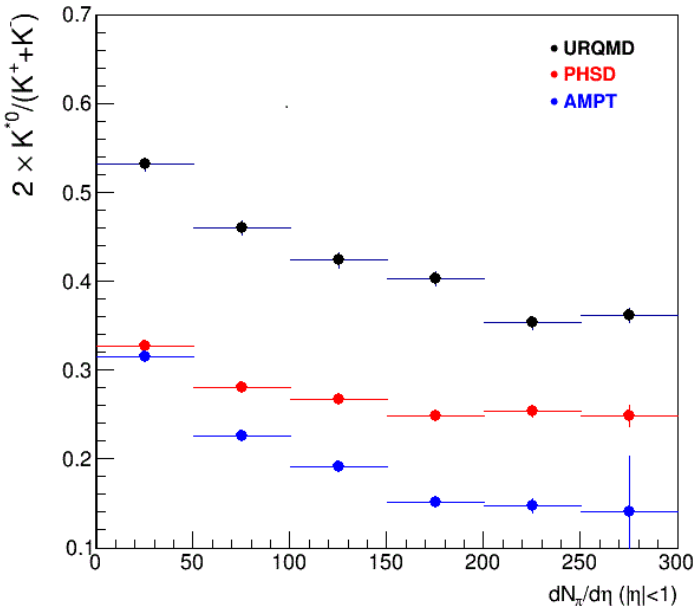
- The most popular generators: UrQMD, PHSD, PLUTO, AMPT, EPOS …
- Models predict different interplay of mechanisms responsible for shaping of the particle p_T spectra.
- General prediction - K* are produced in high rate and can be used to study physics of heavy-ion collisions

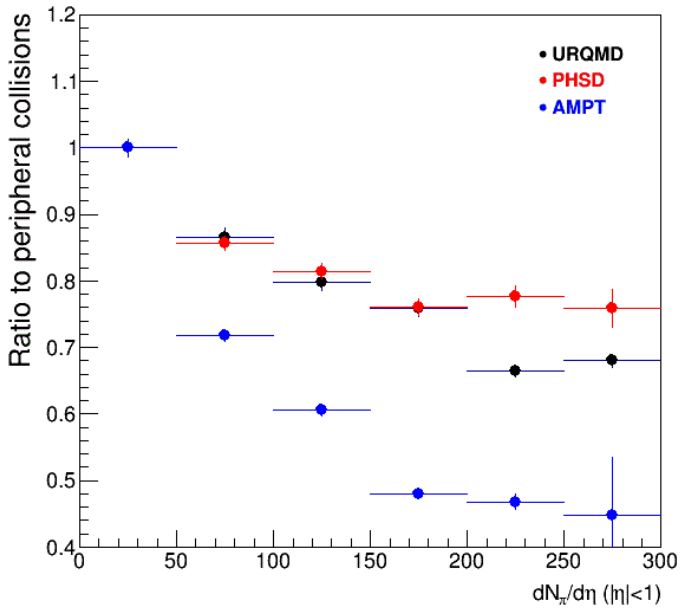


- Eventually, model predictions (integrated yields, $<p_T>$, particle ratios etc.) should be compared to data to differentiate different model assumptions

Model predictions for K* at NICA

- Models with hadronic cascades (UrQMD, PHSD, AMPT) can be used to study properties of the hadronic phase

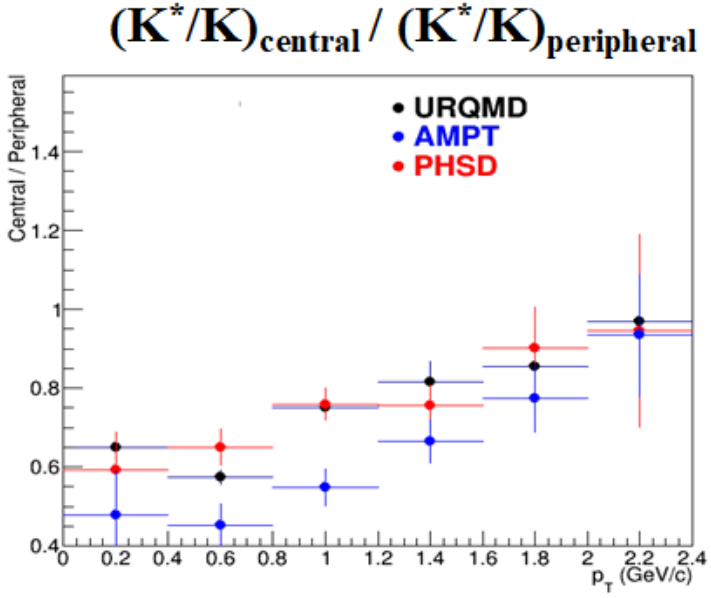




- Models predict centrality dependent modification of K^*/K ratios in AuAu@11 GeV

Model predictions for K^* at NICA

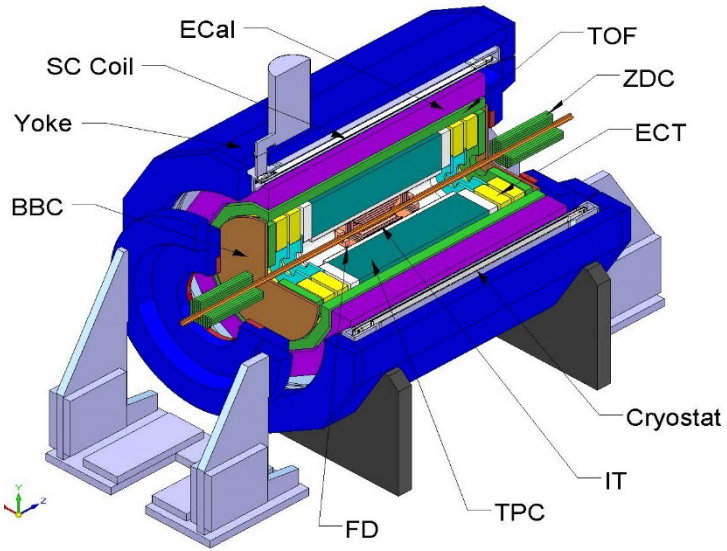
- Modifications occur at low momentum as expected for the hadronic phase effect
- Model predictions are consistent within 20-30%

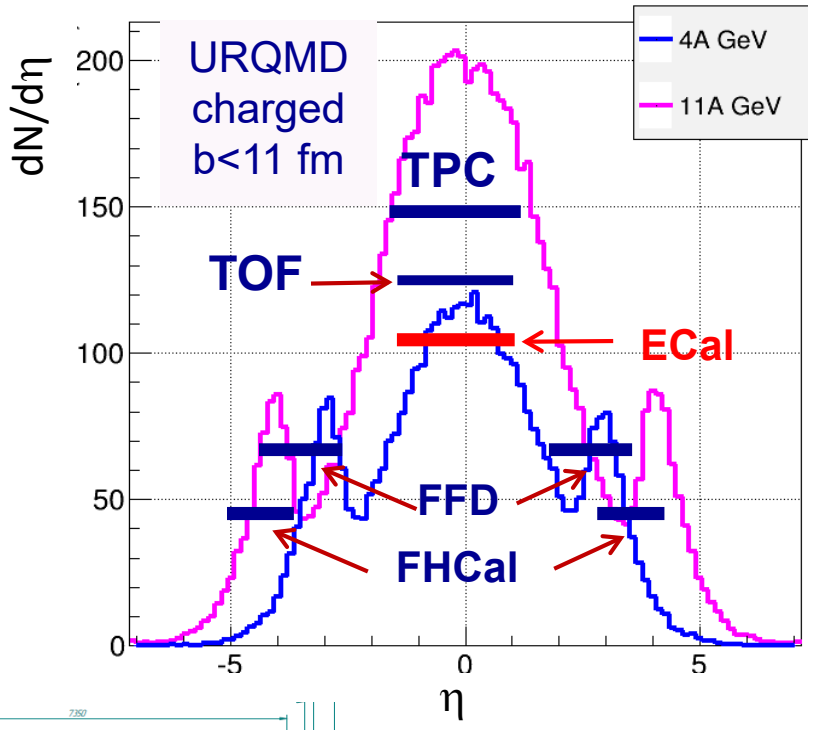


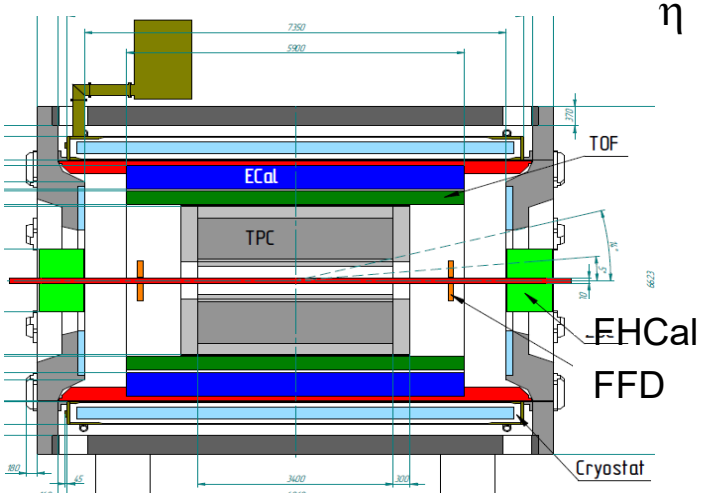
  - Models predict yield modifications for K^* qualitatively similar to those observed at higher collision energies:
    - ✓ lifetime and density of the hadronic phase are high enough
    - ✓ modification of particle properties in the hadronic phase should be taken into account when model predictions for different observables are compared to data
    - ✓ Data on resonance production can be used to tune models

Schematic view of the MPD experiment

- Phase 1: **TPC, TOF, FFD, FCAL and ECAL**
- Detector is ideologically and constructively close to STAR and ALICE
- Startup in 2021-2022



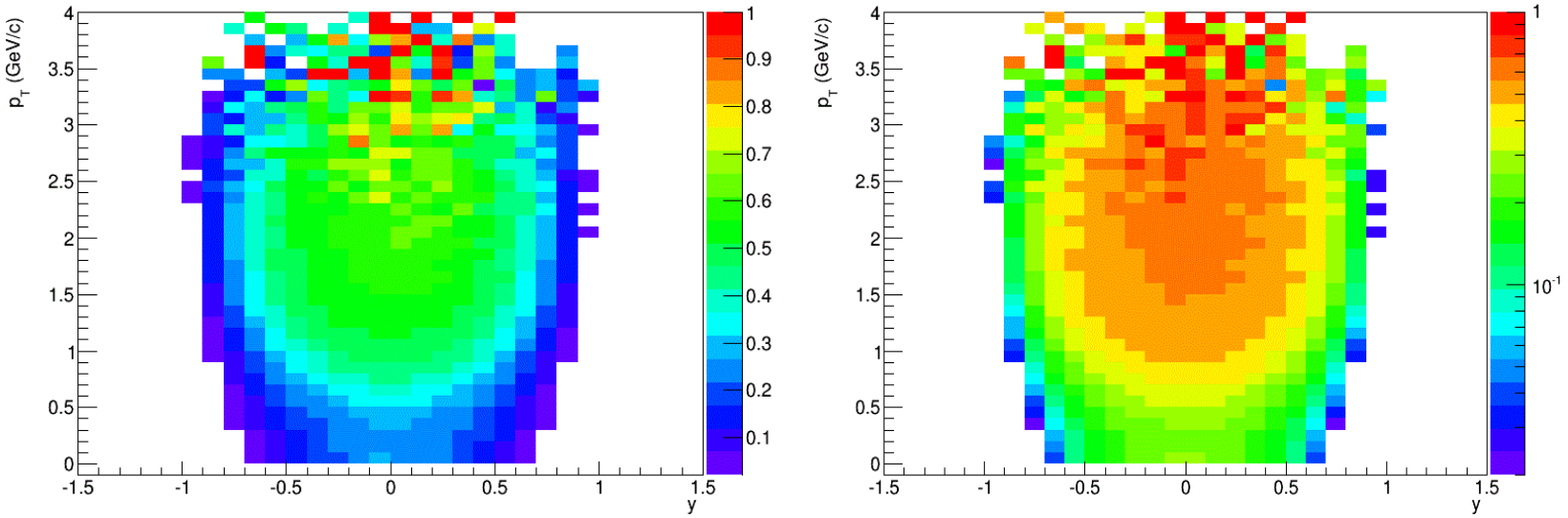




Feasibility studies, framework

- Simulated minbias AuAu@11 collisions using UrQMD 3.4 with default settings
- Tracked simulated particles through the MPD Phase-I detector using *mpdroot*
- Analysis cuts were optimized for higher signal significance (no p_T variation)
  - Event selection:
    - ✓ $|Z_{vrtx}| < 50$ cm, realistic distribution
  - Basic track selections:
    - ✓ number of TPC hits > 24
    - ✓ $|\eta| < 1.0$
    - ✓ $p_T > 50$ MeV/c
    - ✓ TPC-TOF combined PID, probability > 0.5
    - ✓ TPC-refit for kaons and protons based on track PID hypothesis
  - Primary tracks:
    - ✓ $|DCA(x,y,z)| < 2\sigma$
  - V0 & cascades:
    - ✓ topology cuts for weakly decaying secondary particles ($K_s \rightarrow \pi\pi$)
- Combinatorial background:
  - ✓ event mixing ($|\Delta_{Zvrtx}| < 2$ cm, $|\Delta_{Mult}| < 20$, $N_{ev} = 10$)

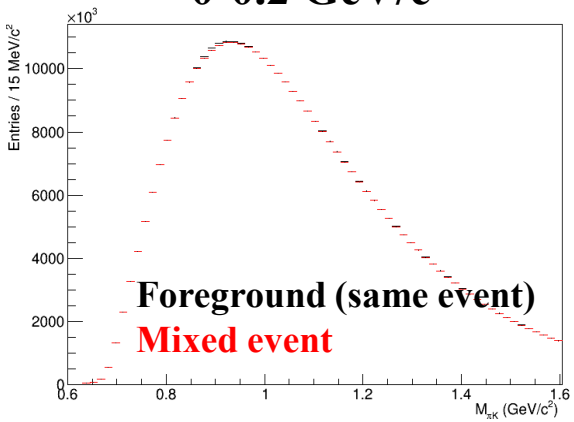
Feasibility study, $K^*(892)^0$

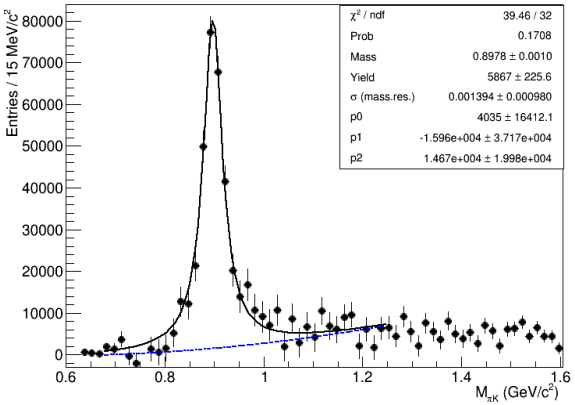


- $K^*(892)^0 \rightarrow \pi^{\pm}K^{\pm}$, BR = 66.7 %
- Acceptance x reconstruction efficiency: $A \cdot \in = N_{rec}(K^* \rightarrow \pi K) / N_{gen}(K^* \rightarrow \pi K)$
- Efficiency grows with transverse momentum
- Particles can be reconstructed in the rapidity range, $|y| < 1.0$

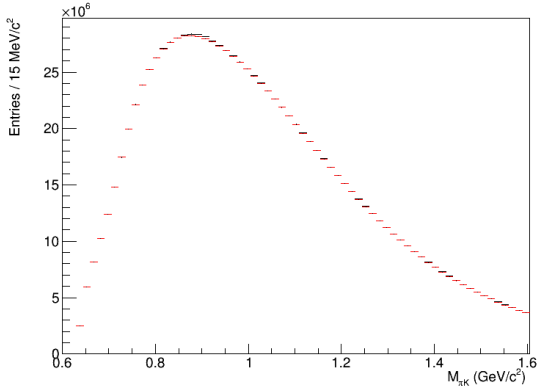
$K^*(892)^0$, reconstructed peaks

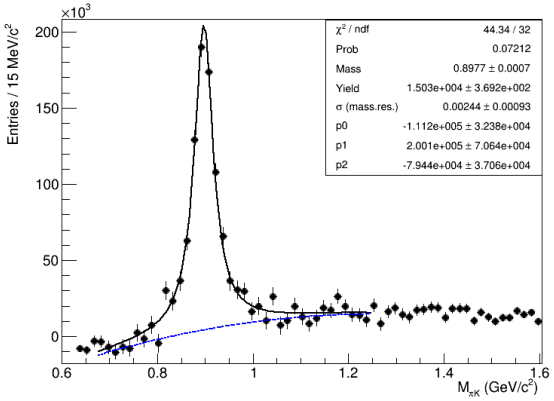
0-0.2 GeV/c



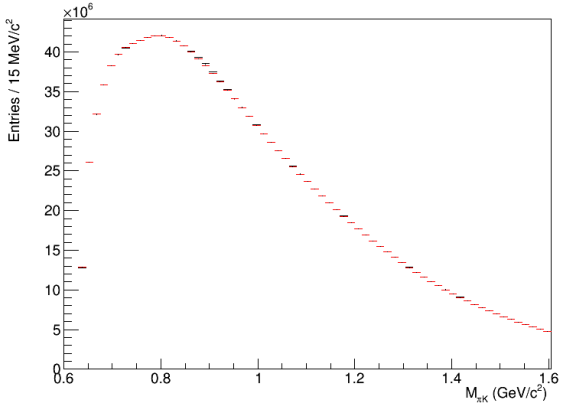


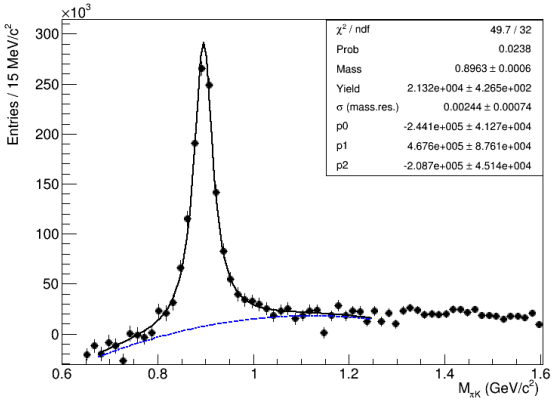
0.2-0.4 GeV/c





0.4-0.6 GeV/c

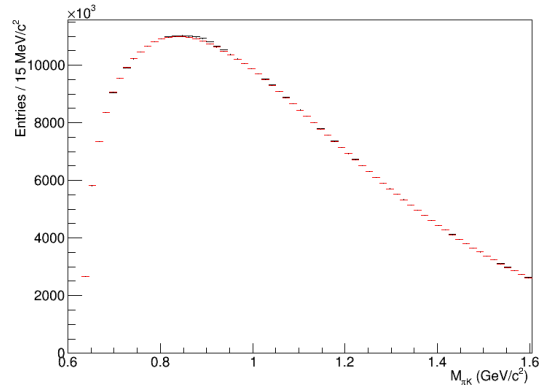


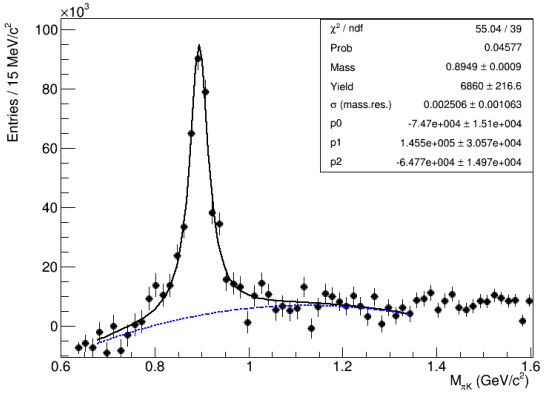


- Mixed-event combinatorial background is scaled to foreground at high mass and subtracted
- Fit to Voightian + pol2 (p0-p2)
- Signal can be reconstructed from zero momentum

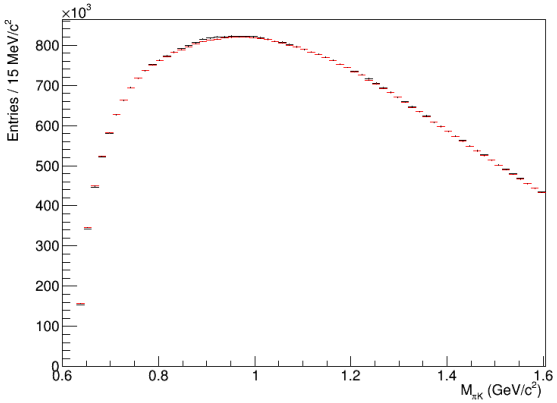
$K^*(892)^0$, reconstructed peaks

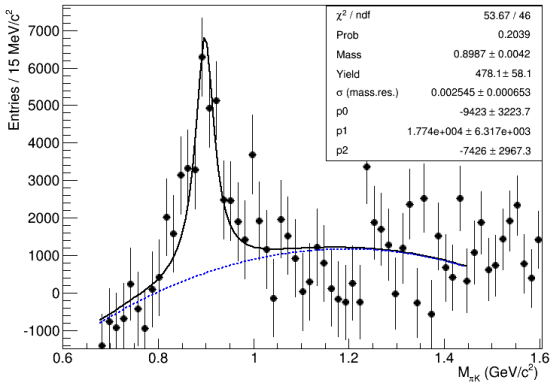
1.2-1.4 GeV/c



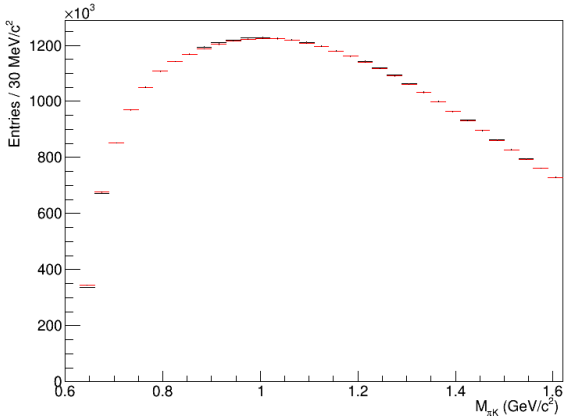


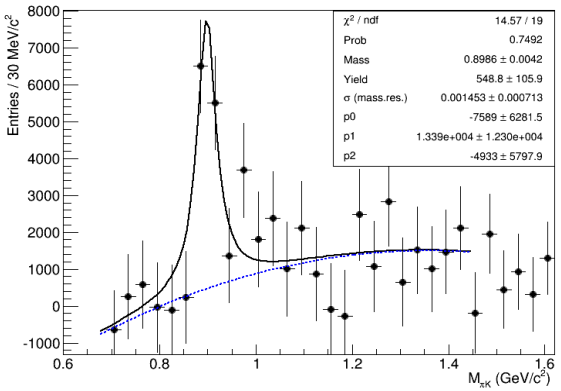
2.0-2.2 GeV/c





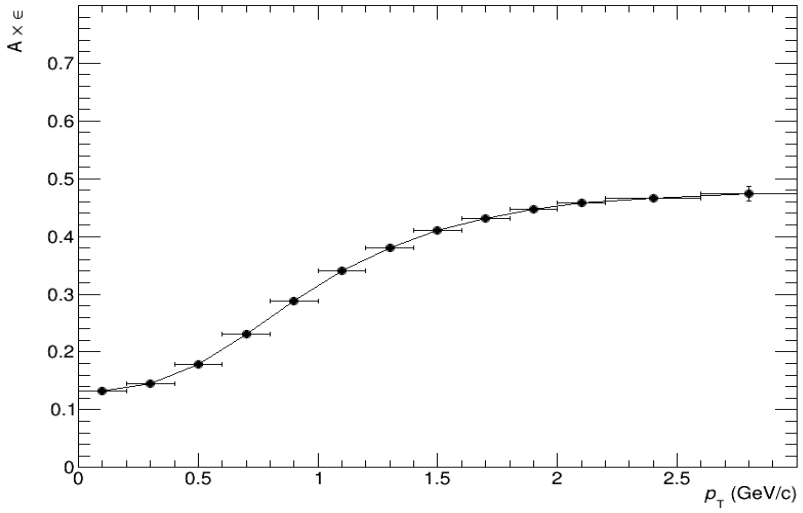
2.2-2.6 GeV/c

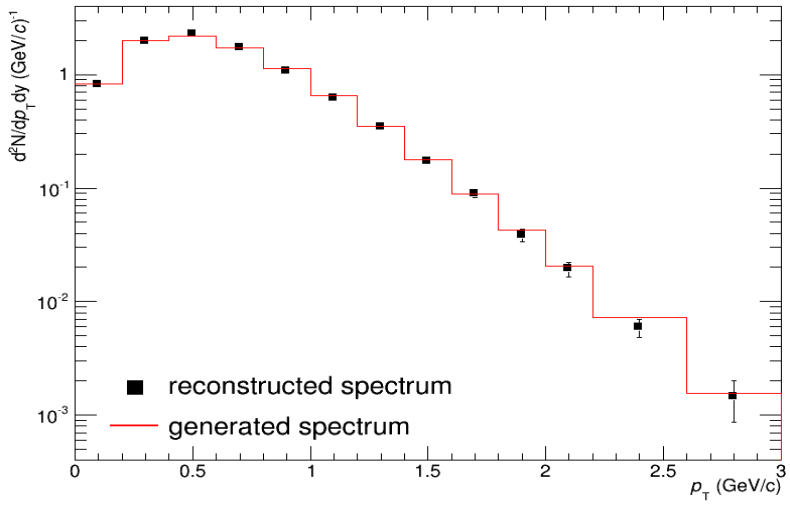




- High-p_T reach is limited by available statistics

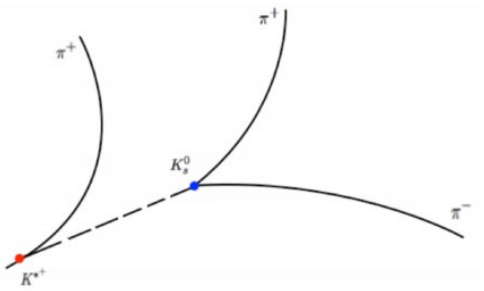
$K^*(892)^0$, reconstruction

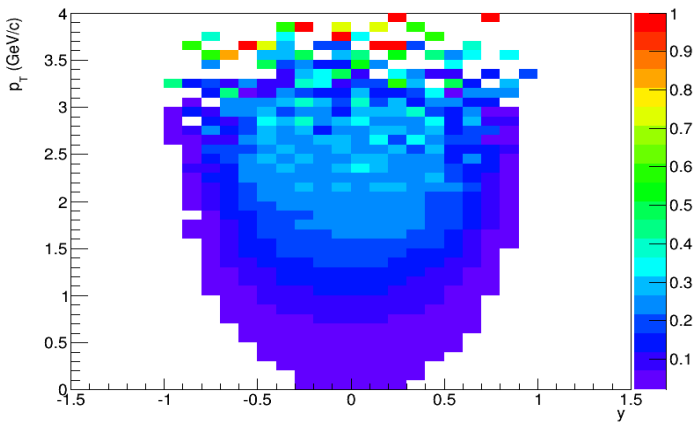


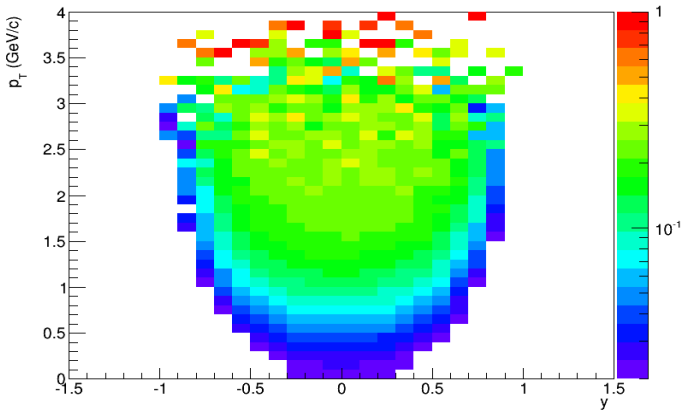


- Results of the Monte Carlo Closure Test
- Full chain reconstruction was done at $|y| < 1.0$
- Reconstructed and generated spectra match within uncertainties
- Measurements are possible at $p_T > 0$ GeV/c

Feasibility study, $K^*(892)^{\pm}$



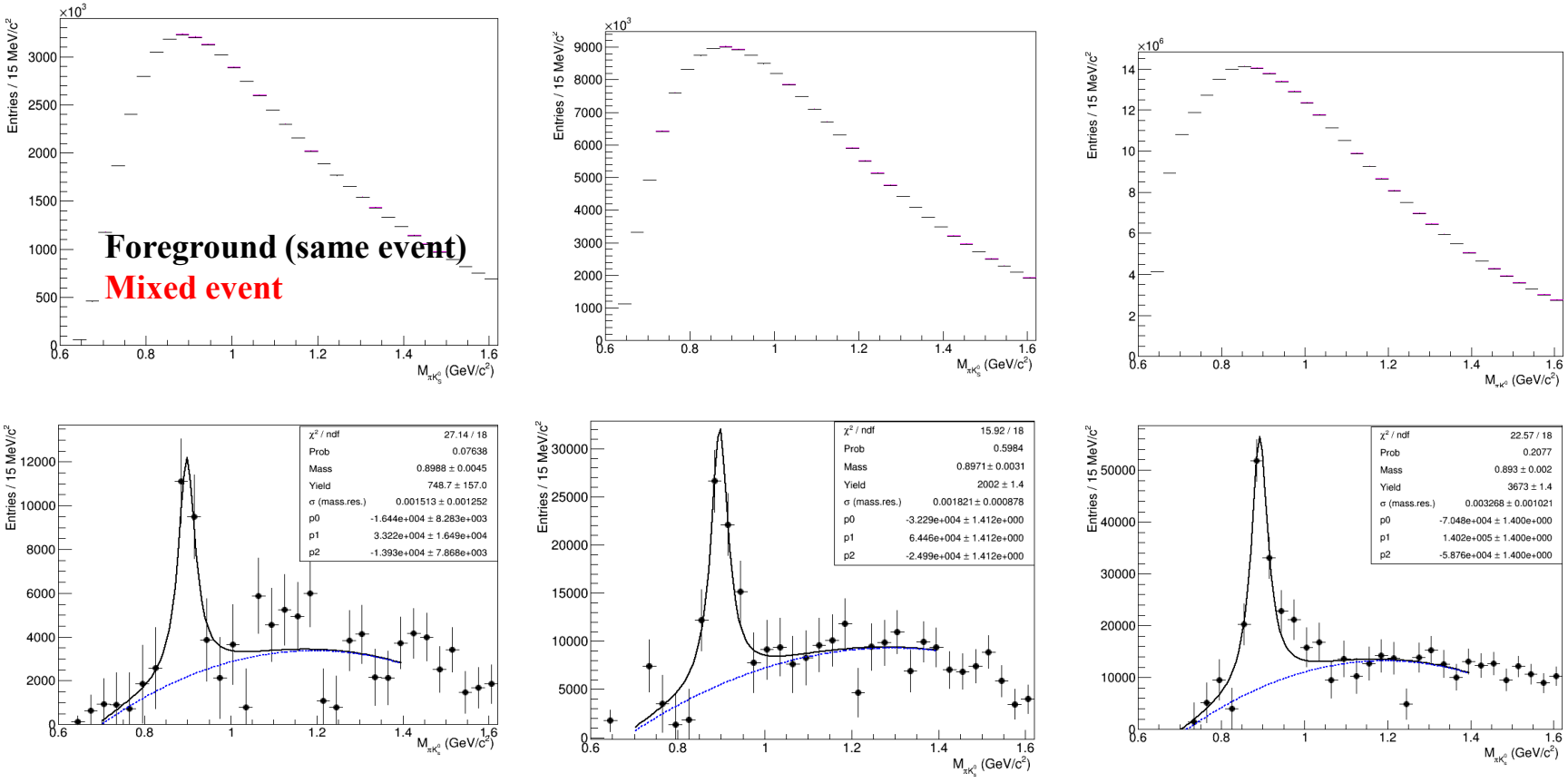




- $K^*(892)^{\pm} \rightarrow \pi^{\pm}K_s$ ($K_s \rightarrow \pi^+\pi^-$)
- Decay chain includes weak decay of K_s → V0 vertex
- Acceptance x reconstruction efficiency: $A \cdot \epsilon = N_{rec}(K^* \rightarrow \pi K_s) / N_{gen}(K^* \rightarrow \pi K_s)$
- Efficiency is lower, increases with transverse momentum
- Particles can be reconstructed in the rapidity range, $|y| < 1.0$

$K^*(892)^{\pm}$, reconstructed peaks

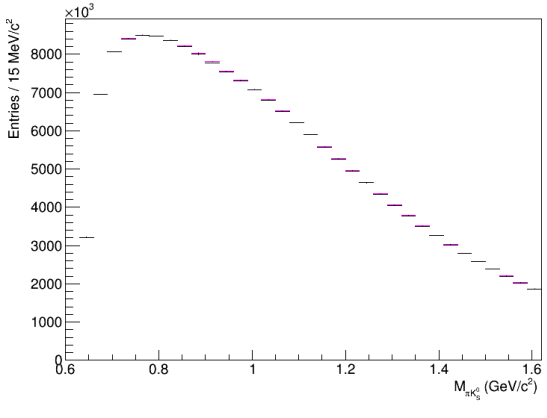
0-0.2 GeV/c | **0.2-0.4 GeV/c** | **0.4-0.6 GeV/c**

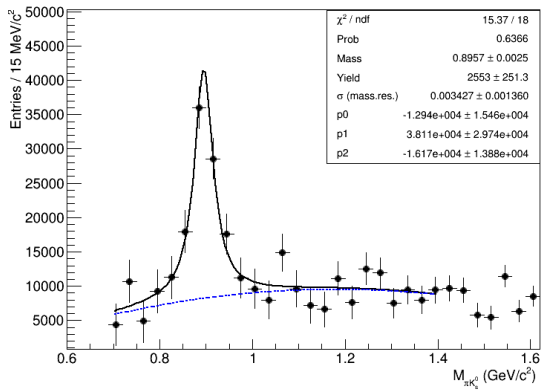


- Mixed-event combinatorial background is scaled to foreground at high mass and subtracted
- K^* peak is fit to Voightian + pol2 (p0-p2)
- Signal can be reconstructed starting from zero momentum

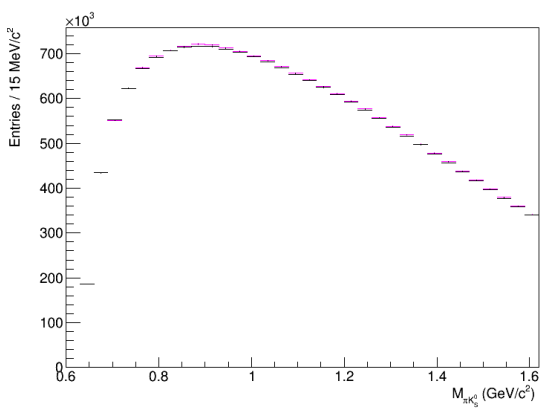
$K^*(892)^{\pm}$, reconstructed peaks

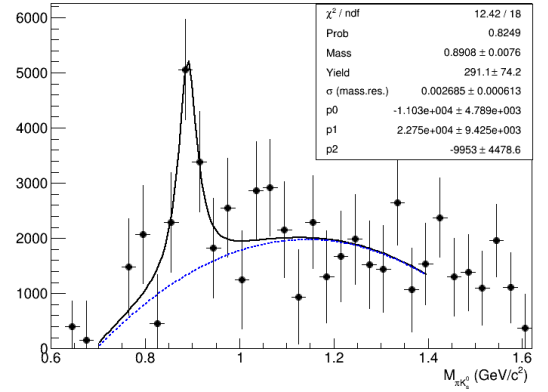
1.2-1.4 GeV/c



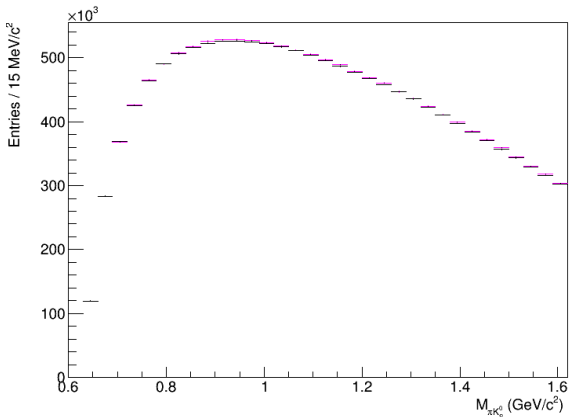


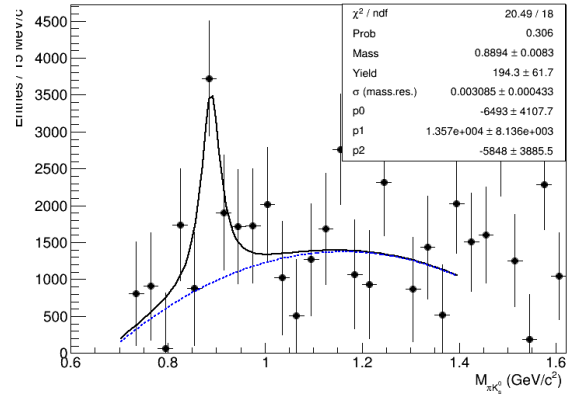
2.0-2.2 GeV/c





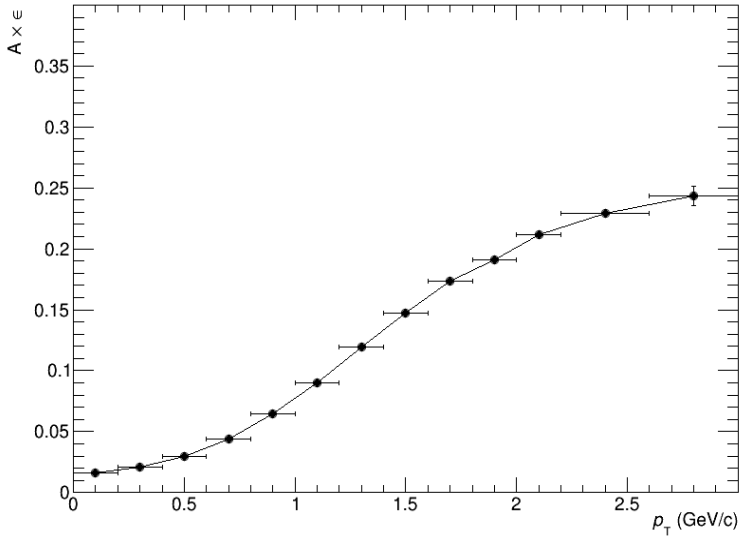
2.2-2.6 GeV/c

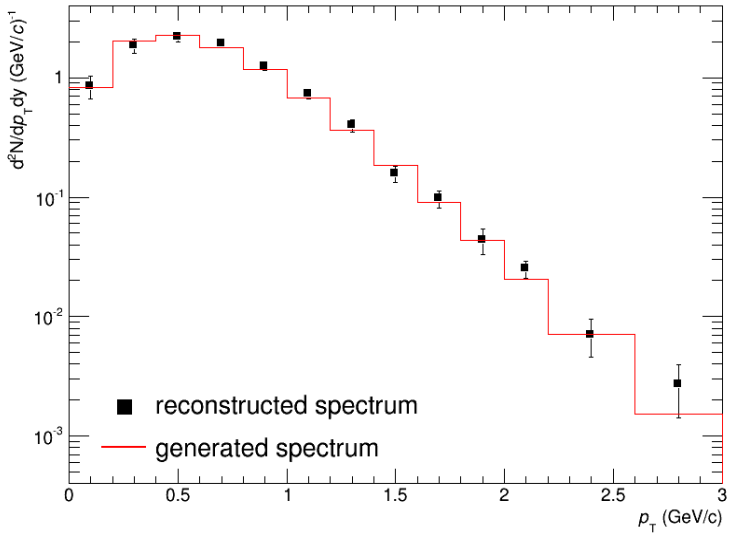




- The possibility to measure at high-p_T is limited by available statistics

$K^*(892)^{\pm}$, reconstruction





- Results of the Monte Carlo Closure Test
- Full chain reconstruction was done at $|y| < 1.0$
- Reconstructed and generated spectra match within uncertainties
- Measurements are possible starting from $p_T > 0$ GeV/c

Summary

- ✓ Model predictions shows that the K* production will be sensitive to properties of the partonic/hadronic medium produced in heavy-ion collisions at NICA energies
- ✓ Measurement and study of K* production is an important part of the MPD physical program
- ✓ Feasibility study of K* production showed that K* can be reconstructed/measured using the MPD detector
  - ✓ from zero momentum to ~ 3 GeV/c with 10^7 minimum bias events sample
  - ✓ 10^8 events is needed for multiplicity dependent study
  - ✓ within expectations for year-1 running

This work was supported by RFBR according
to the research project № 18-02-40038