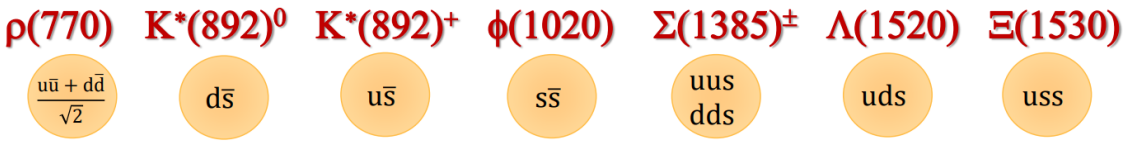
Resonance production at NICA energies

M.Malaev, D. Ivanishchev, V.Riabov

* We acknowledge support from Russian Ministry of Education and Science, state assignment for fundamental research (code FSEG-2025-0009)

Resonances in heavy-ion collisions

- ✓ Vacuum properties of resosnances are well defined; large branching ratios in hadronic decay channels → possible to measure
- ✓ Probe reaction dynamics and particle production mechanisms vs. system size and $\sqrt{s_{NN}}$:
  - ✓ hadron chemistry and strangeness production, ϕ with hidden strangeness is one of the key probes
  - ✓ reaction dynamics and shape of particle p_T spectra, p/K*, p/ϕ vs. p_T
  - ✓ lifetime and properties of the hadronic phase
  - ✓ spin alignment of vector mesons in rotating QGP (polarization of quarks from spin-orbital interactions)
  - ✓ flow, comparison with e^+e^- measurements, jet quenching, background for other probes etc.



Particle	Mass (MeV/c^2)	Width (MeV/c^2)	Decay	BR (%)
ρ^0	770	150	$\pi^+\pi^-$	100
$K^{*\pm}$	892	50.3	$\pi^\pm K_s$	33.3
K^{*0}	896	47.3	πK^+	66.7
ϕ	1019	4.27	K^+K^-	48.9
Σ^{*+}	1383	36	$\pi^+\Lambda$	87
Σ^{*-}	1387	39.4	$\pi\Lambda$	87
$\Lambda(1520)$	1520	15.7	K^-p	22.5
Ξ^{*0}	1532	9.1	$\pi^+\Xi^-$	66.7

Analysis Details (Pions)

- Data: Request 40, XeW@2.5 AGeV (fixed target mode), ~100M UrQMD events
- Rapidity range: $-1.0 < Y_{cms} < 0.$

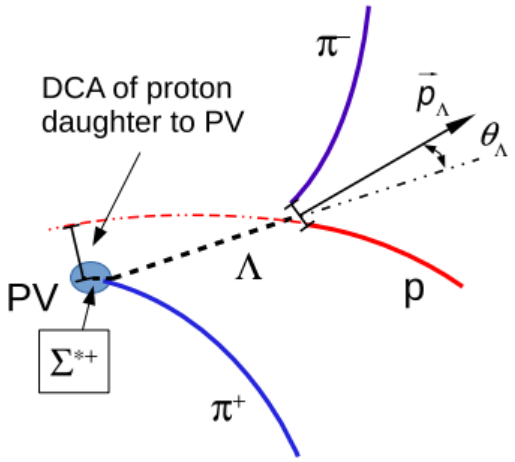
- Event selection: centrality 0-90%
- Track selection:
  TPC-hits > 24
  DCA-to-PV < $2\sigma_{x,y,z}$ (1σ in case of $\rho(770)$)
- TPC 2σ -PID selection for pion
  If track is 3σ -matched to TOF then TOF 2σ -PID selection for pion

Analysis Details (Kaons)

- Data: Request 40, XeW@2.5 AGeV (fixed target mode), ~100M UrQMD events
- Rapidity range: $-1.0 < Y_{cms} < 0.$

- Event selection: centrality 0-90%
- Track selection:
  TPC-hits > 24
  DCA-to-PV < $2\sigma_{x,y,z}$
- **TPC part (if track is not 3σ -matched to TOF):**
  TPC 2σ -PID selection for a given specie (K)
  TPC 3σ -veto-PID for other species (e/π veto)
- **TOF part (if track is not 3σ -matched to TOF):**
  TPC 2σ -PID selection for a given specie (K)
  TOF 2σ –PID selection for a given specie (K)
  TOF 3σ -veto-PID for other species (e/π veto)

Analysis Details: $\Sigma(1385)^{\pm} \rightarrow \pi^{\pm} + \Lambda$



Pair cuts:

mYCut -1.0 < Yscm < 0. // pair rapidity cut

Lambda cuts:

mChi2PionLam 25.0 // minimum Chi2-to-PV for pion from Lambda

mChi2ProtLam 11.0 // minimum Chi2-to-PV for proton from Lambda

mChi2Lam 3.0 // maximum Chi2 for Lambda secondary vertex

mPALam 0.04 // maximum pointing angle for Lambda

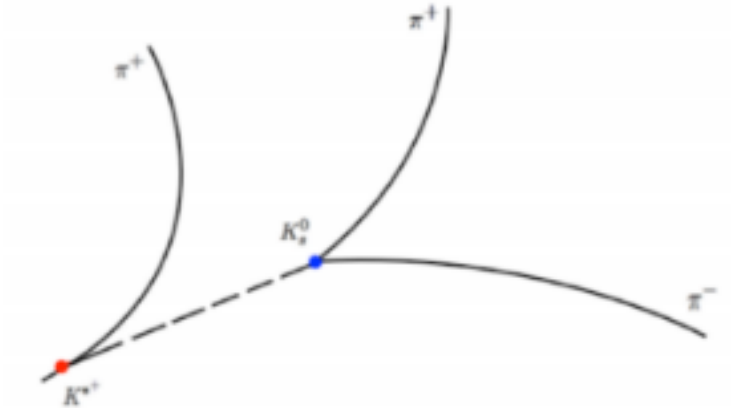
mDecayLam 3.0 // minimum decay distance for Lambda

mDistLam 0.8 // maximum distance between p-pi in the secondary vertex from Lambda

mNSigmaLam 2.0 // n-sigma selection for Lambda candidates

mWidthLam 2e-3 // width of Lambda peak

Analysis Details: $K^*(892)^{\pm} \rightarrow \pi^{\pm} + K_s$



Pair cuts:

mYCut -1.0 < Yscm < 0. // pair rapidity cut

Ks cuts:

mChi2PionKs 25.0 // minimum Chi2-to-PV for pion from Ks

mChi2Ks 3.0 // maximum Chi2 for Ks secondary vertex

mPAKs 0.04 // maximum pointing angle for Ks

mDecayKs 1.0 // minimum decay distance for Ks

mDistKs 1.0 // maximum distance between pi-pi in the secondary vertex from Ks

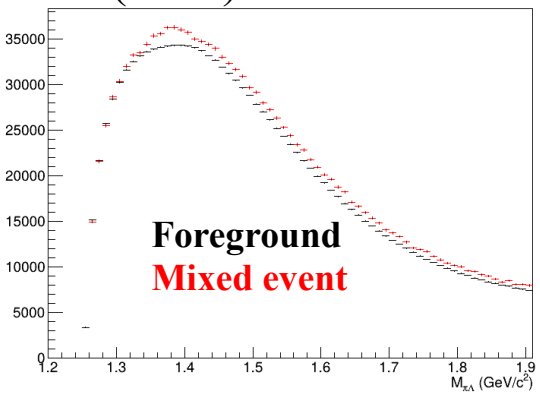
mNSigmaKs 2.0 // n-sigma selection for Ks candidates

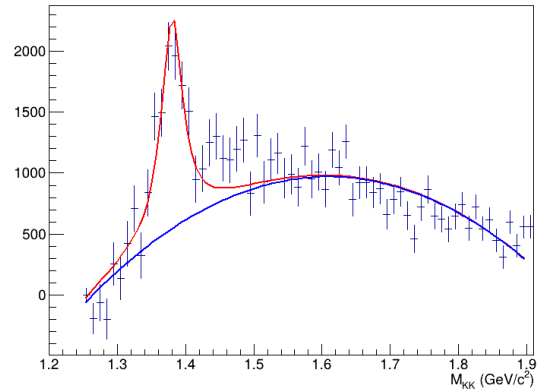
mWidthKs 5e-3 // width of Ks peak

$\Sigma^*(1385)^{\pm}$, reconstructed peaks

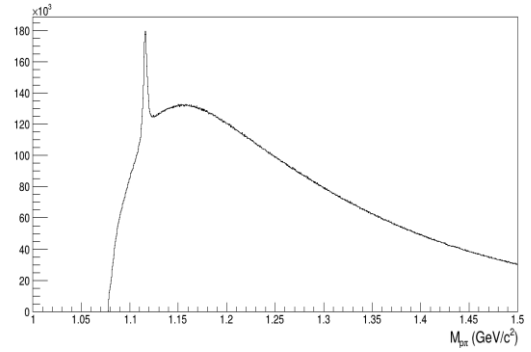
- Full chain simulation and reconstruction: $\Sigma(1385)^{\pm} \rightarrow \Lambda + \pi^{\pm}, (\Lambda \rightarrow p + \pi)$, $-1.0 < y < 0$.

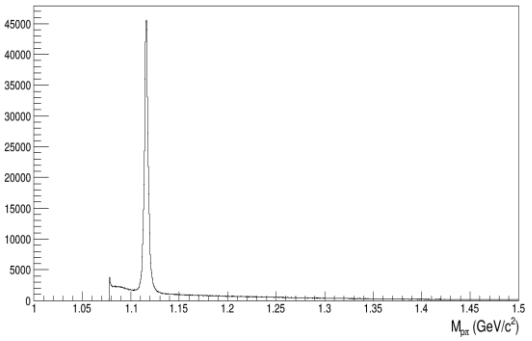
$\Sigma(1385)^{\pm} \rightarrow \Lambda + \pi^{\pm}$

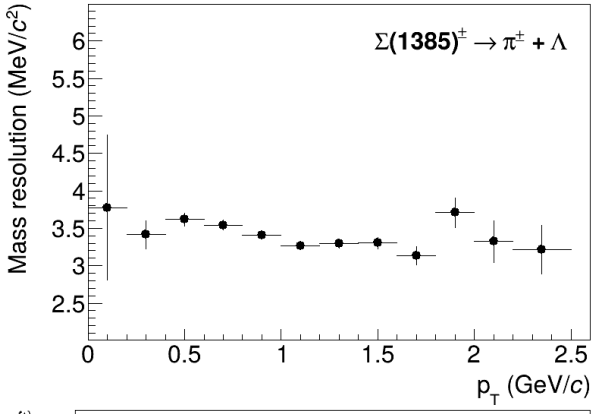


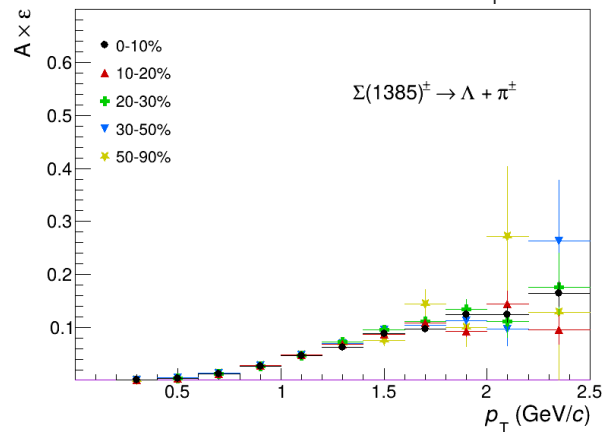


$\Lambda \rightarrow p + \pi$







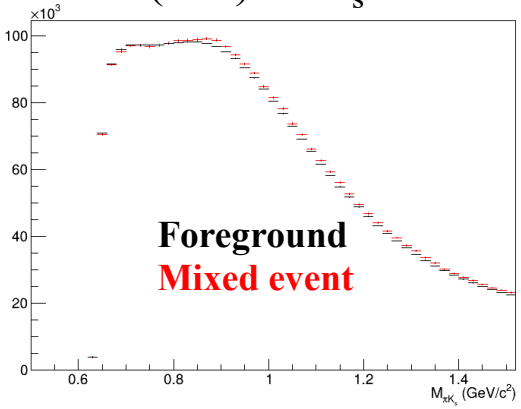


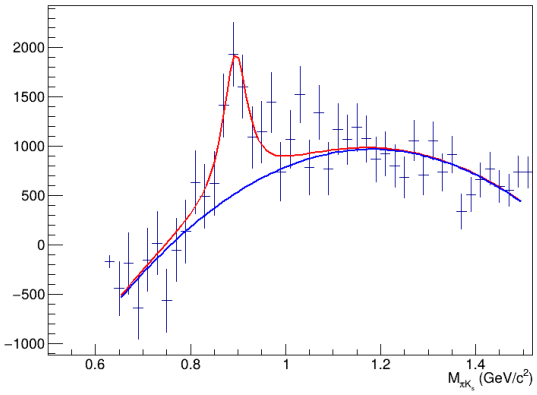
- Mixed-event combinatorial background is scaled to foreground at high mass and subtracted
- Distributions are fit to Voigtian function + polynomial (mass resolution fixed to estimated value, Γ - free parameter)
- Signal can be reconstructed at $p_T > 0.4$ GeV/c, high-p_T reach is limited by available statistics

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

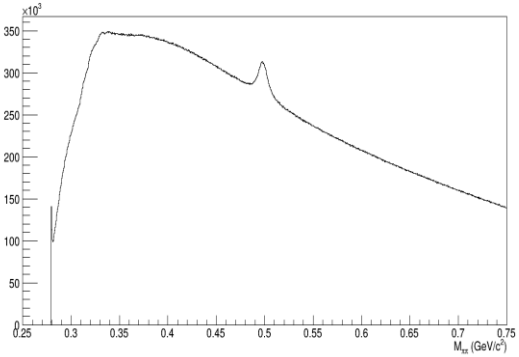
- Full chain simulation and reconstruction: $K^*(892)^{\pm} \rightarrow K_s + \pi^-$,$(K_s \rightarrow \pi^- + \pi^+)$ $-1.0 < y < 0$.

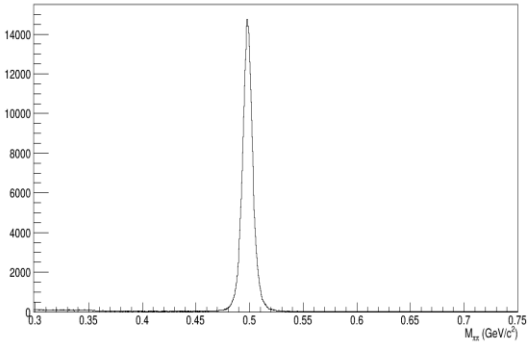
$K^*(892)^{\pm} \rightarrow K_s + \pi^-$

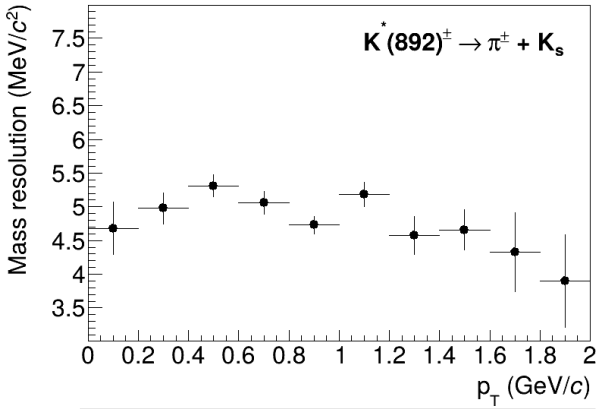


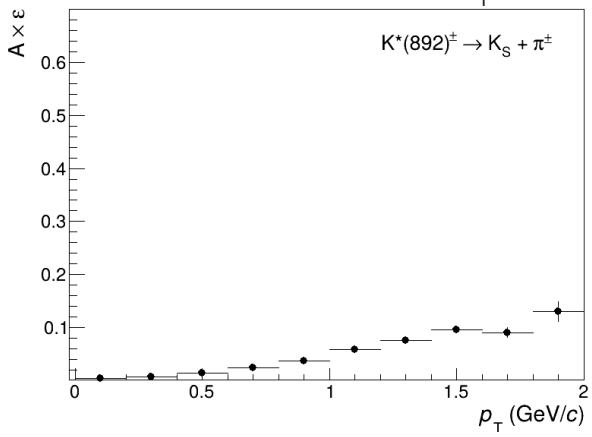


$K_s \rightarrow \pi^- + \pi^+$







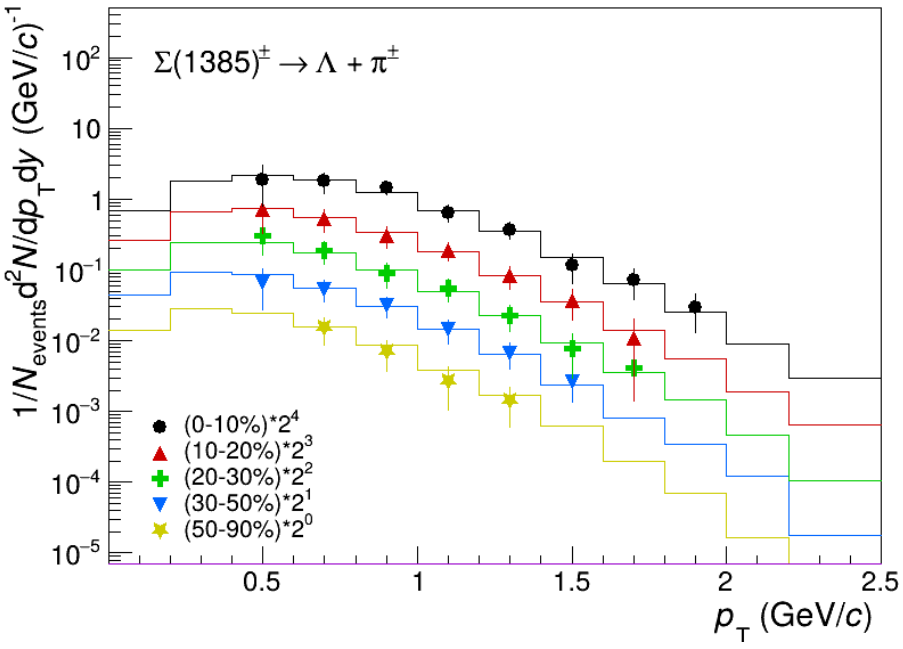


- Mixed-event combinatorial background is scaled to foreground at high mass and subtracted
- Distributions are fit to Voigtian function + polynomial (mass resolution fixed to estimated value, Γ - free parameter)
- Signal can be reconstructed at $p_T > 0.2$ GeV/c only in MB

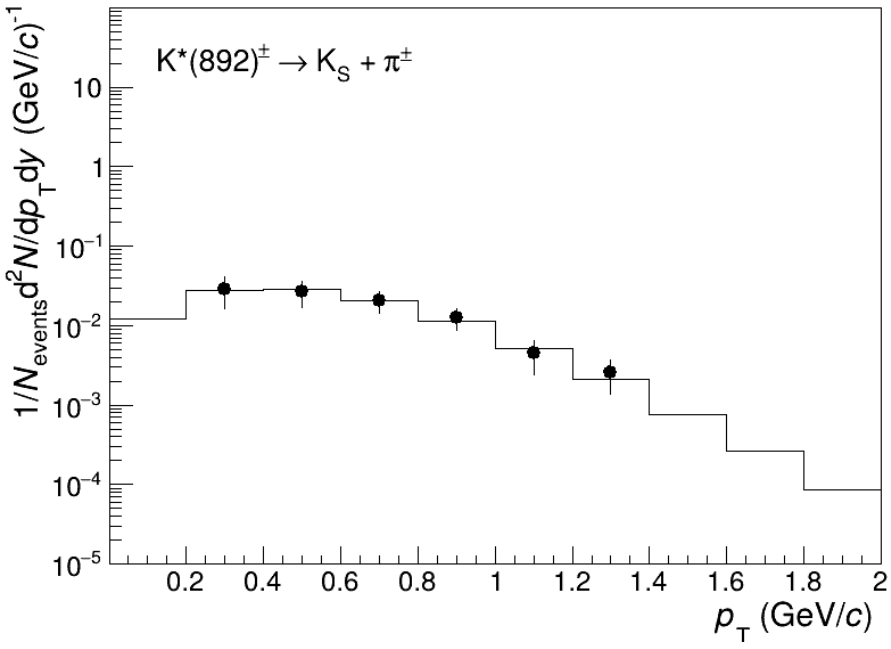
MC closure tests

- Full chain simulation and reconstruction, p_T ranges are limited by the possibility to extract signals, $-1.0 < y < 0$.

$\Sigma(1385)^{\pm}$



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

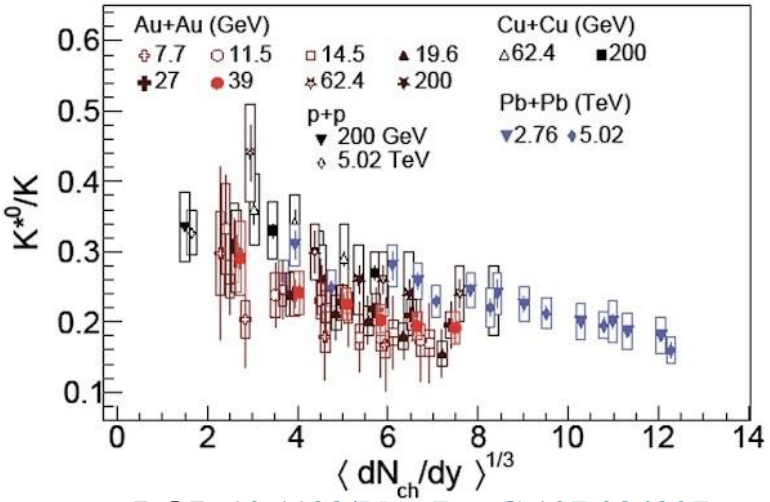


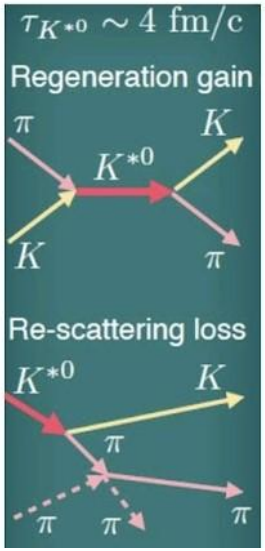
- Reconstructed spectra match the generated ones within uncertainties
- First measurements for Sigma in centrality dependent analysis will be possible with accumulation of ~ 10^8 A+A events
- Measurements of K* are possible only in MB analysis with current statistic and current analysis cuts

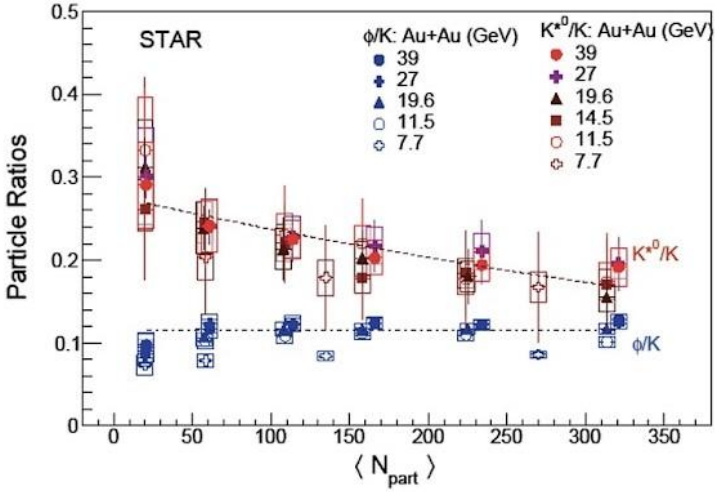
Hadronic phase and medium modifications

Ratio K^{*0} to K from BES data suggests re-scattering loss in medium due to shorter lifetime of K^{*0}

The K^{*0}/K ratio shows a centrality dependence and follows the same trend among different collision energies. On the contrary, the ϕ/K ratio is mostly independent of centrality.







DOI: [10.1103/PhysRevC.107.034907](https://doi.org/10.1103/PhysRevC.107.034907)

increasing lifetime ⟶

	ρ(770)	K*(892)	Σ(1385)	Λ(1520)	Ξ(1530)	ϕ(1020)
cτ (fm/c)	1.3	4.2	5.5	12.7	21.7	46.2
$\sigma_{rescatt}$	$\sigma_\pi\sigma_\pi$	$\sigma_\pi\sigma_K$	$\sigma_\pi\sigma_\Lambda$	$\sigma_K\sigma_p$	$\sigma_\pi\sigma_\Xi$	$\sigma_K\sigma_K$

Reconstructed resonance yields in heavy ion collisions are defined by:

- ✓ resonance yields at chemical freeze-out
- ✓ hadronic processes between chemical and kinetic freeze-outs:

rescattering: daughter particles undergo elastic scattering or pseudo-elastic scattering through a different resonance → parent particle is not reconstructed → loss of signal

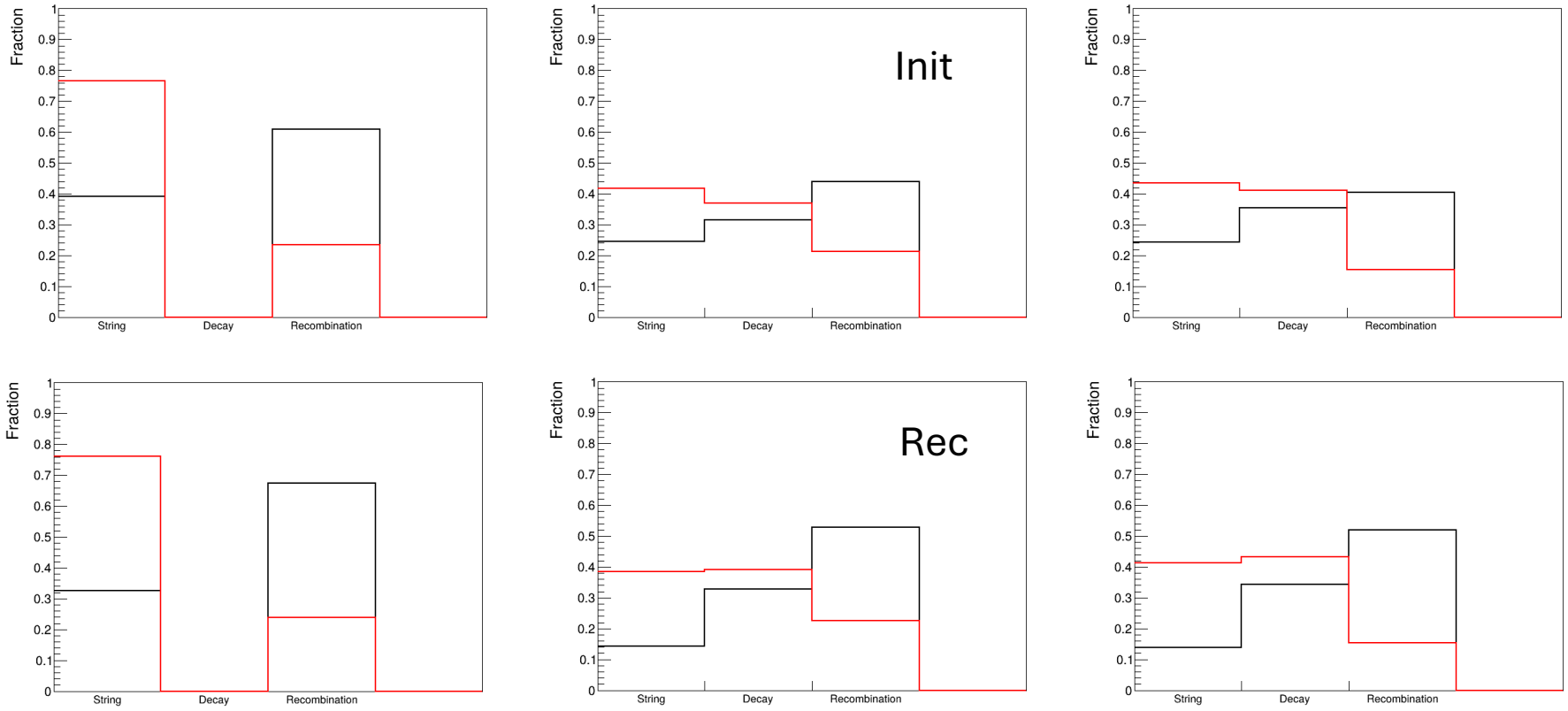
regeneration: pseudo-elastic scattering of decay products ($\pi K \rightarrow K^{*0}$, $KK \rightarrow \phi$ etc.) → increased yields

Analysis Details

- Data: BiBi@9.2 GeV, UrQMD (v3.4) no specific configurations
- Output.f14 – all final state particles at 200 fm
- Output.f15 – all collisions in the event
- Resonances: $\phi \rightarrow K^{+}K^{-}$ ($c\tau \sim 45$ fm/c), $K^{*}(892)^{0} \rightarrow \pi^{\pm}K^{\pm}$ ($c\tau \sim 4.2$ fm/c), $\rho(770)^{0} \rightarrow \pi^{+}\pi^{-}$ ($c\tau \sim 1.3$ fm/c)
- Rapidity range: $-1.0 < Y_{cms} < 1.0$
- Number of charged pions in the event → centrality estimation
- Init distributions – Invariant mass of the resonance reconstructed via daughter particles at decay moment
- Rec distributions – Invariant mass of the resonance reconstructed via daughter particles from Output.f14 (if present) – after all possible interactions in hadron gas stage

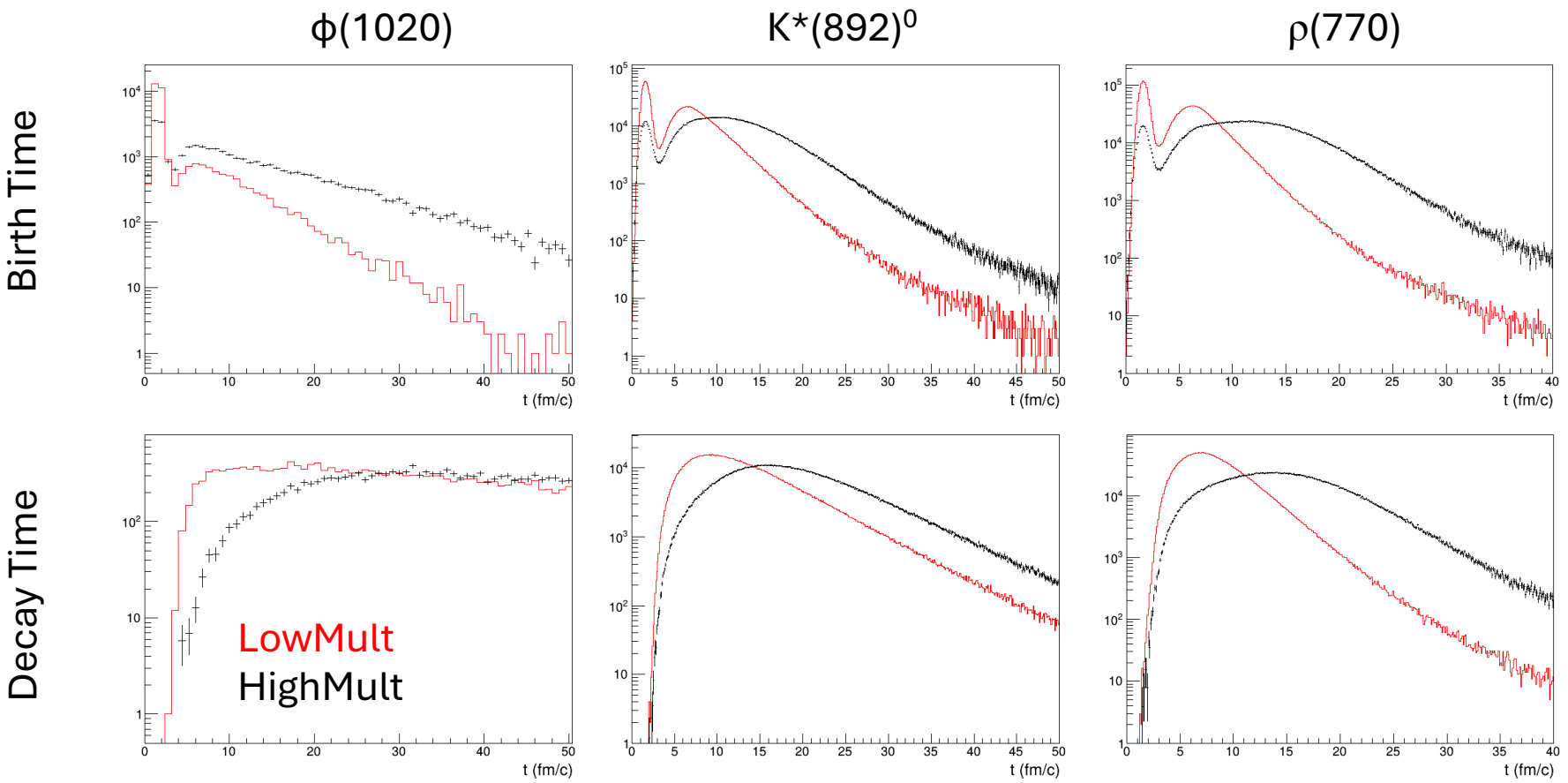
Production mechanisms

ϕ(1020) K*(892)^0 ρ(770)



- Fraction of: String, Decay, Recombination (Urqmd prediction)
- String is dominant for LowMult, Recombination is dominant for HighMult events
- Similar distribution for Rec and Init cases for φ(1020)
- For K*(892)^0 and ρ(770) in HighMult recombination fraction is higher in Rec than in Init

Birth&Decay Time

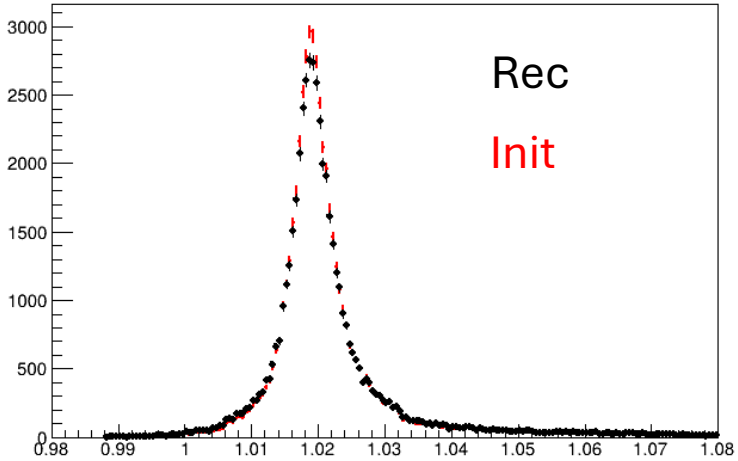


- All distributions for Rec resonances
- Similar distribution for HighMult and LowMult collisions for φ(1020) – no visible shift
- Shift to higher times in HighMult collisions for $K^*(892)^0$ and ρ(770)
- Observe $K^*(892)^0$ and ρ(770) produced at later stages of system evolution

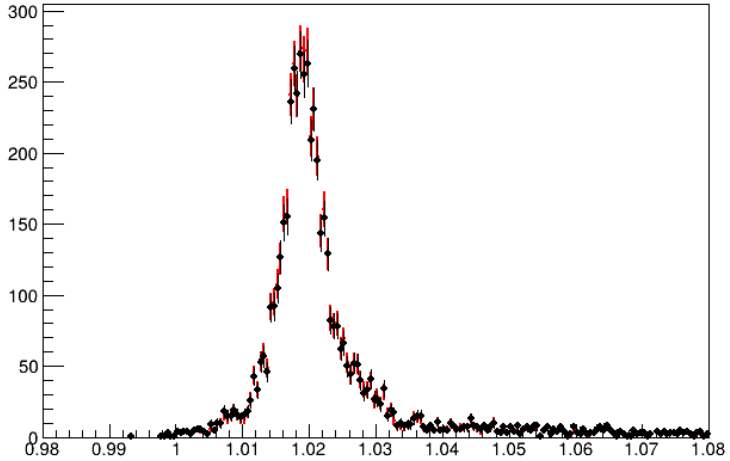
φ(1020) Peak Shape

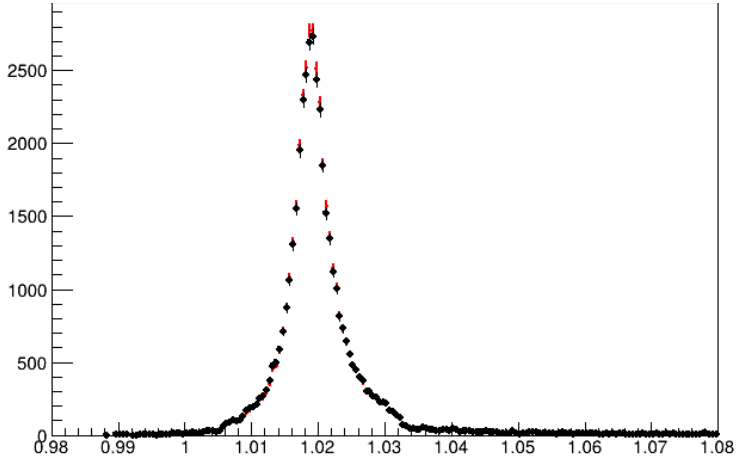
0 < pT < 0.5 GeV/c

pT > 1.5 GeV/c

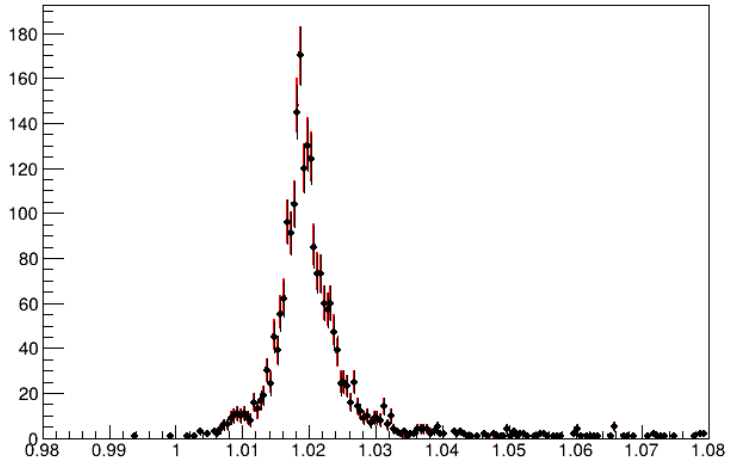


HighMult





LowMult

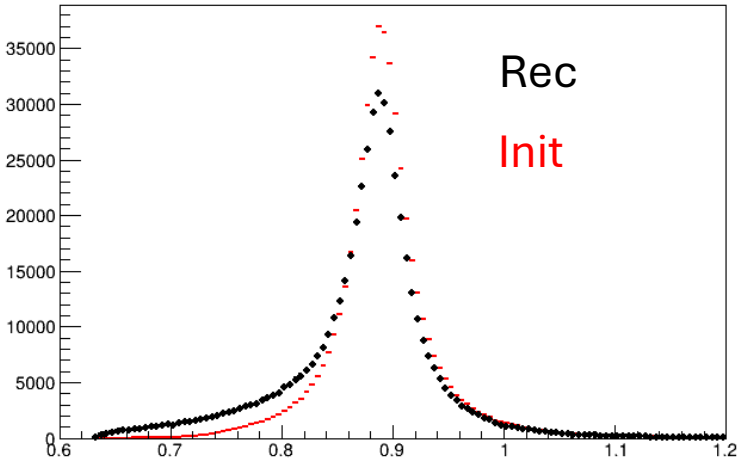


- Resonances are decayed by UrQMD, daughters participate in elastic and inelastic scattering
- Resonance are reconstructed by invariant mass method according to decay channels
- $\phi \rightarrow K^{+}K^{-}$ ($c\tau \sim 45$ fm/c): modest line shape modifications in central collisions at low p_T

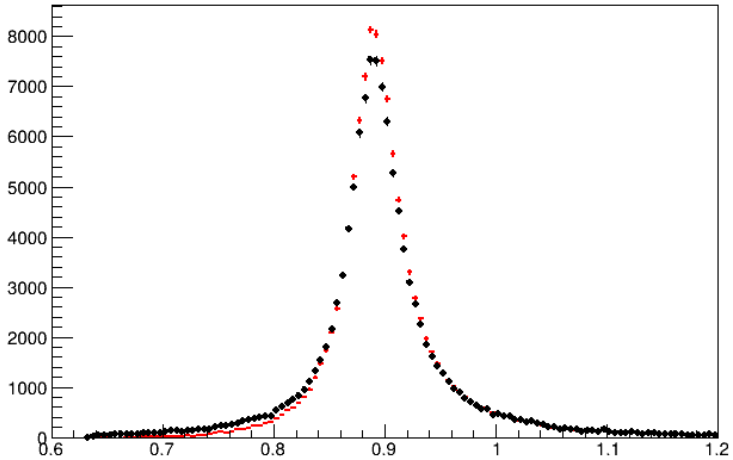
K*(892)^0 Peak Shape

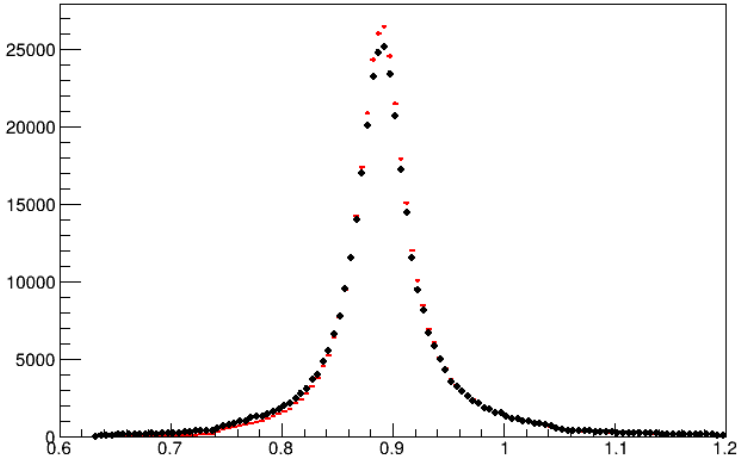
0 < pT < 0.5 GeV/c

pT > 1.5 GeV/c

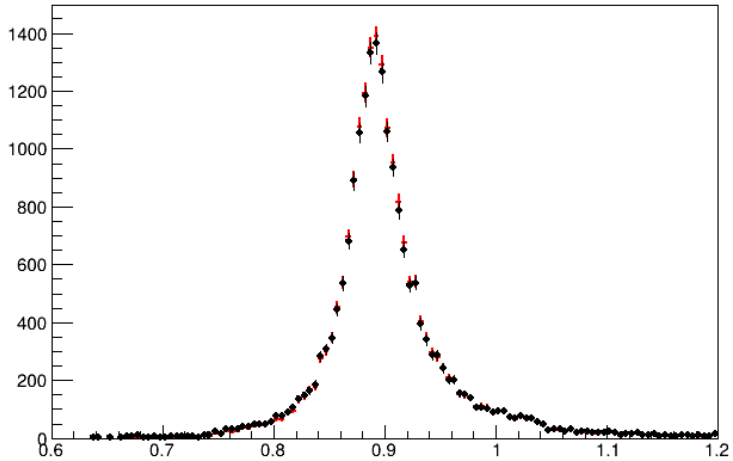


HighMult





LowMult

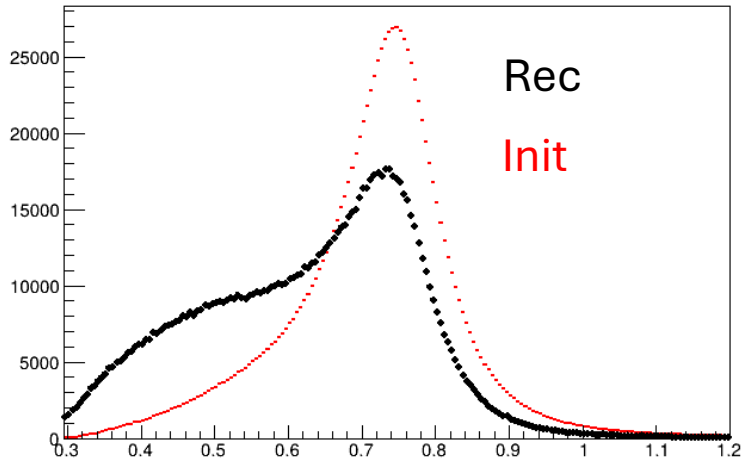


- Resonances are decayed by UrQMD, daughters participate in elastic and inelastic scattering
- Resonance are reconstructed by invariant mass method according to decay channels
- $K^*(892)^0 \rightarrow \pi^{\pm}K^{\pm}$ ($c\tau \sim 4.2$ fm/c): line shape modifications in central collisions

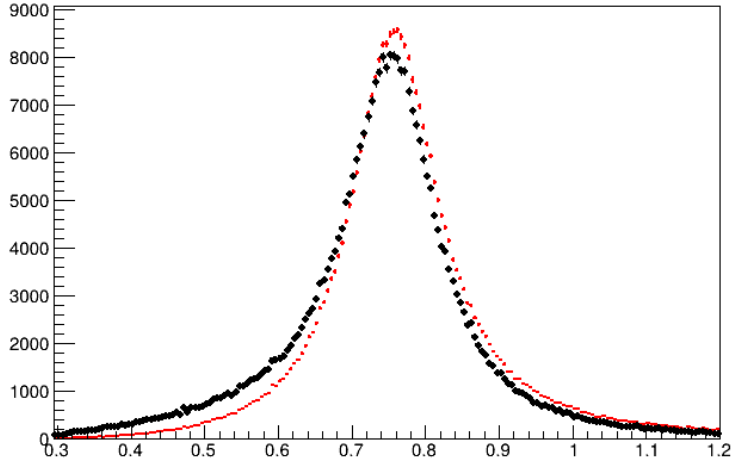
ρ(770) Peak Shape

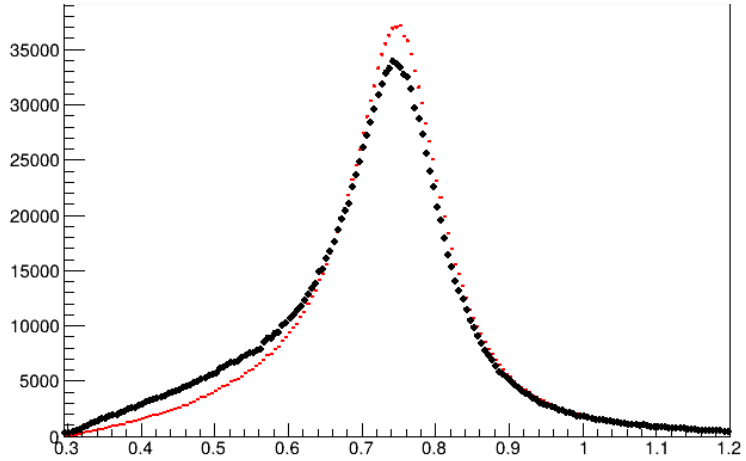
0 < pT < 0.5 GeV/c

pT > 1.5 GeV/c

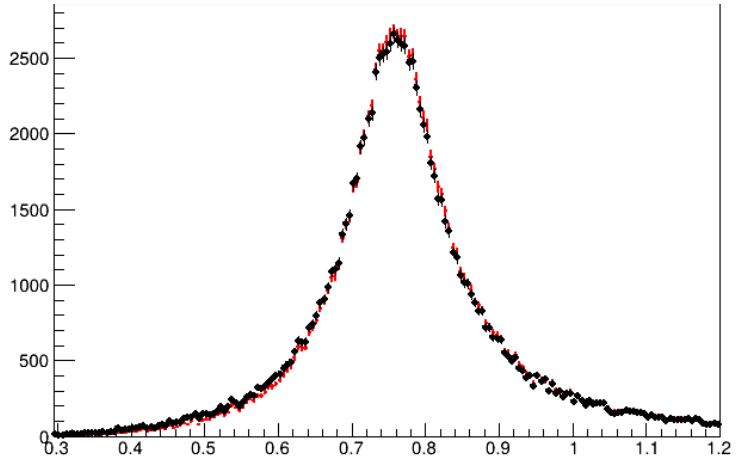


HighMult





LowMult



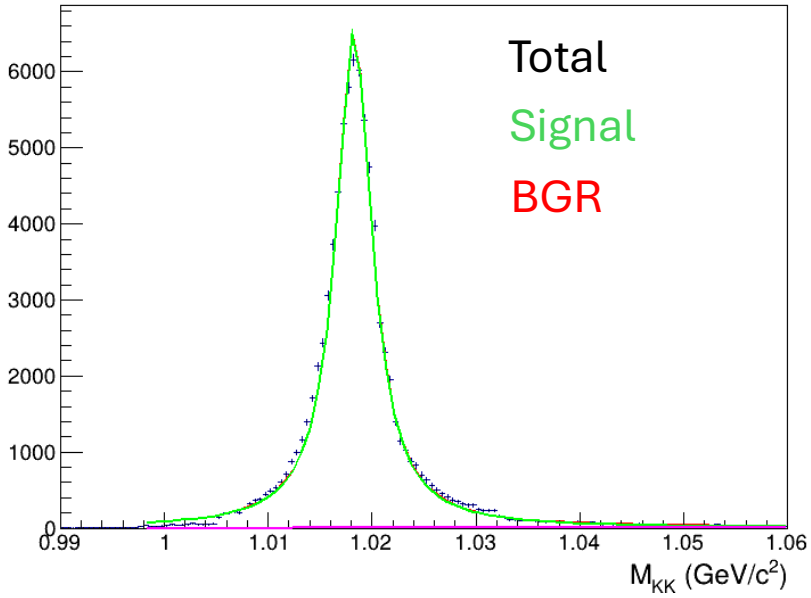
- Resonances are decayed by UrQMD, daughters participate in elastic and inelastic scattering
- Resonance are reconstructed by invariant mass method according to decay channels
- $\rho(770)^0 \rightarrow \pi^+\pi^-$ ($c\tau \sim 1.3$ fm/c): significant line shape modifications in central collisions at low p_T

Analysis Details

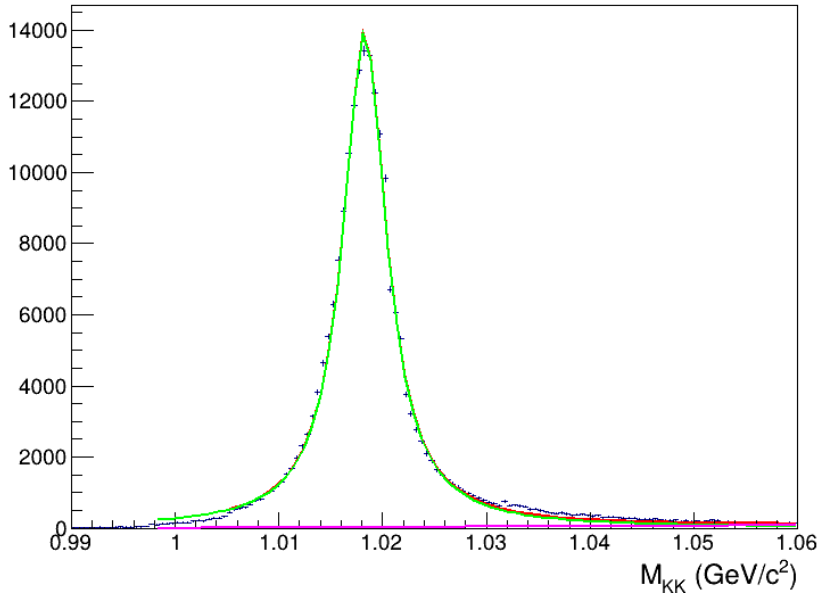
- Resonances: $\phi \rightarrow K^{+}K^{-}$ ($c\tau \sim 45$ fm/c), $K^{*}(892)^{0} \rightarrow \pi^{\pm}K^{\pm}$ ($c\tau \sim 4.2$ fm/c), $\rho(770)^{0} \rightarrow \pi^{+}\pi^{-}$ ($c\tau \sim 1.3$ fm/c)
- Rapidity range: $-1.0 < Y_{cms} < 1.0$
- Init distributions – Invariant mass of the resonance reconstructed via daughter particles at decay moment
- Rec distributions – Invariant mass of the resonances reconstructed via daughter particles from Output.f14 (if present)
- Use fitting function like in real data analysis (no mass resolution factor) for Rec distributions – Signal + BGR

φ(1020) Peak Shape

LowMult



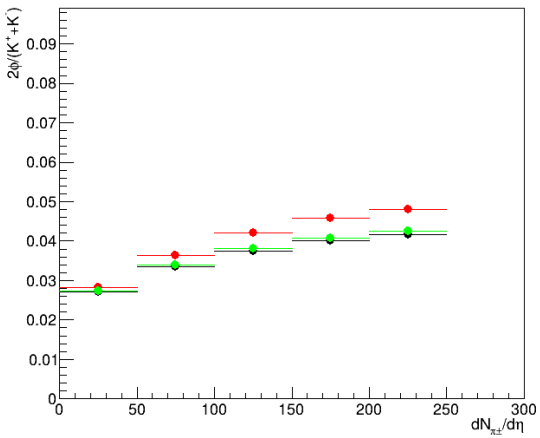
HighMult

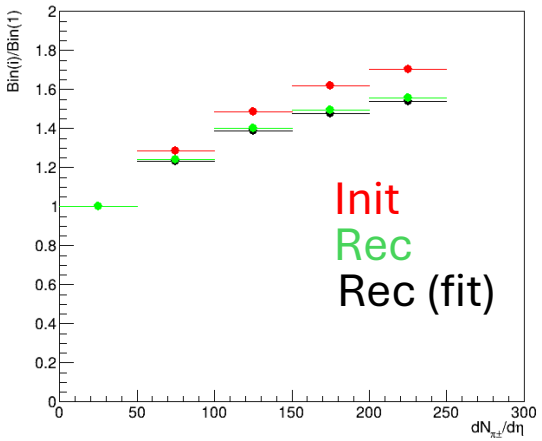


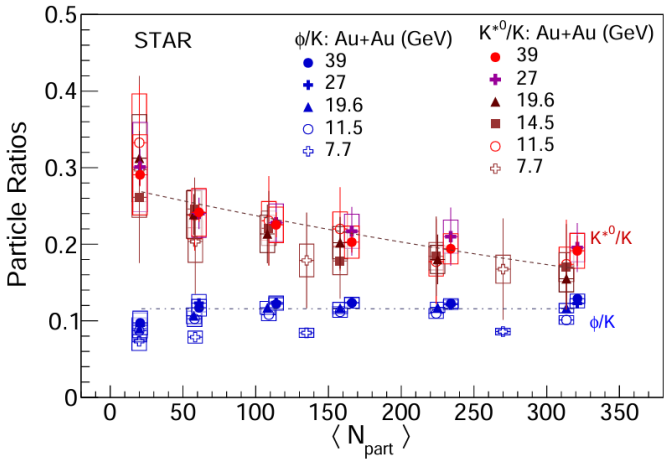
- $\phi \rightarrow K^+K^-$ ($c\tau \sim 45$ fm/c)
- Modest peak shape modifications only in high multiplicity events (central collisions)
- Rec peaks described by signal function, almost no contribution from BGR function

φ(1020) to K ratio

https://arxiv.org/pdf/2210.02909



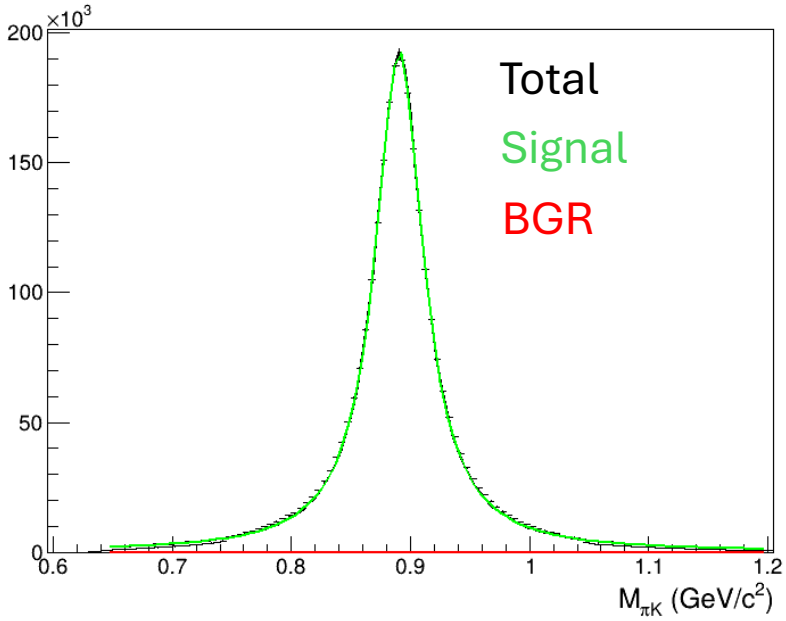




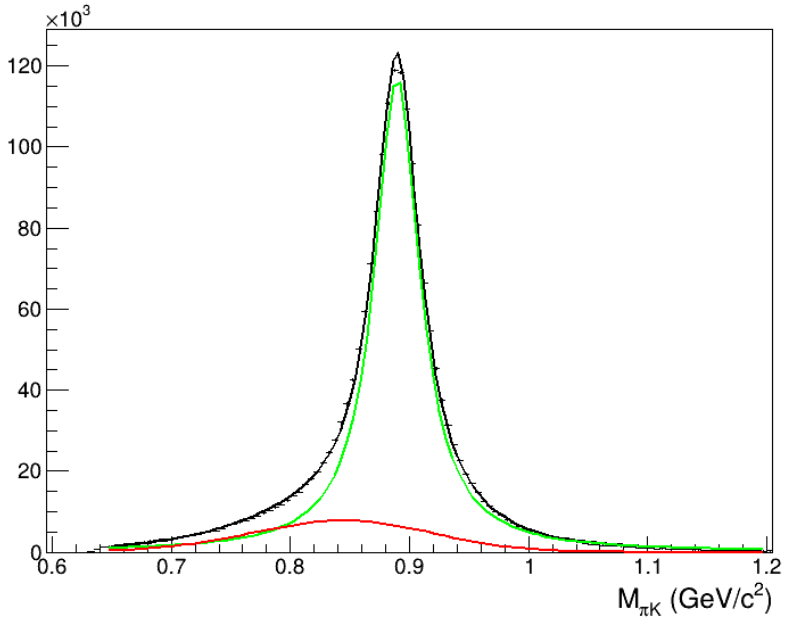
- $\phi \rightarrow K^{+}K^{-}$ ($c\tau \sim 45$ fm/c),
- Almost no losses due to peak shape modification
- Losses due to daughter annihilation or inelastic rescattering
- Increasing trend with increasing centrality
- Urqmd underestimates phi production

$K^*(892)^0$ Peak Shape

LowMult



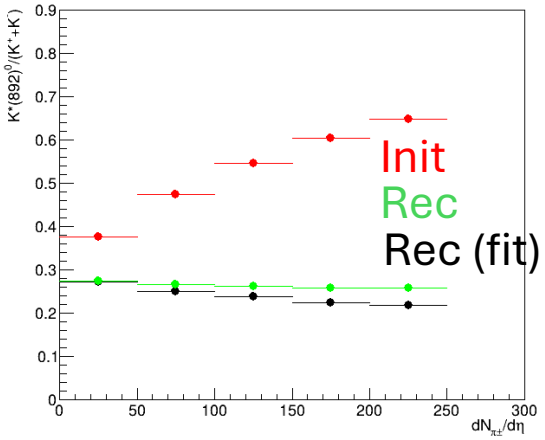
HighMult

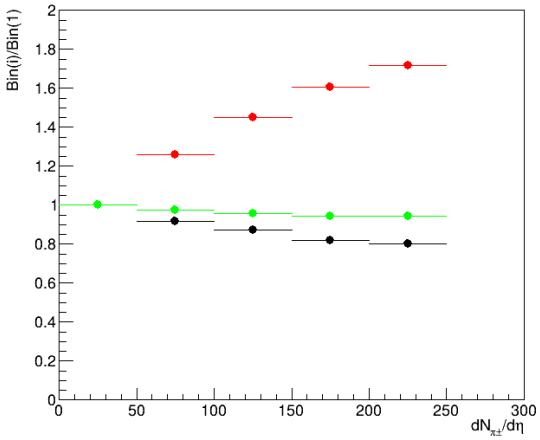


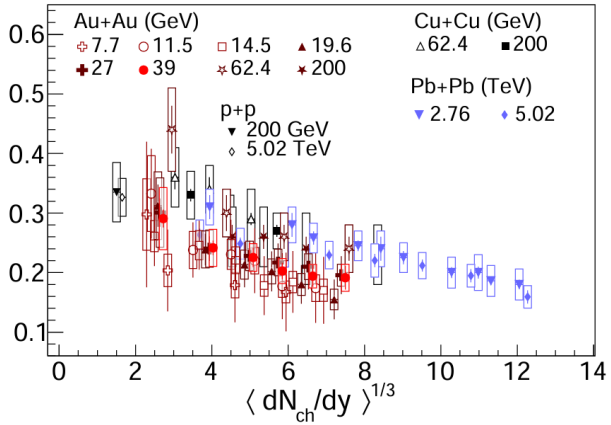
- $K^*(892)^0 \rightarrow \pi^{\pm}K^{\pm}$ ($c\tau \sim 4.2$ fm/c)
- Peak shape modifications in high multiplicity events (central collisions)
- Rec peaks described by signal function in low multiplicity events, contribution from BGR function in high multiplicity events

$K^*(892)^0$ to K ratio

https://arxiv.org/pdf/2210.02909



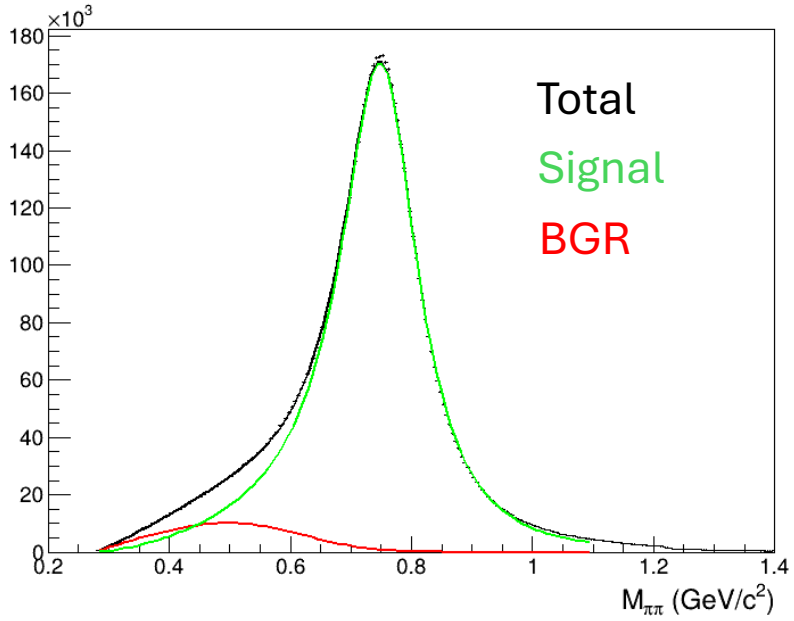




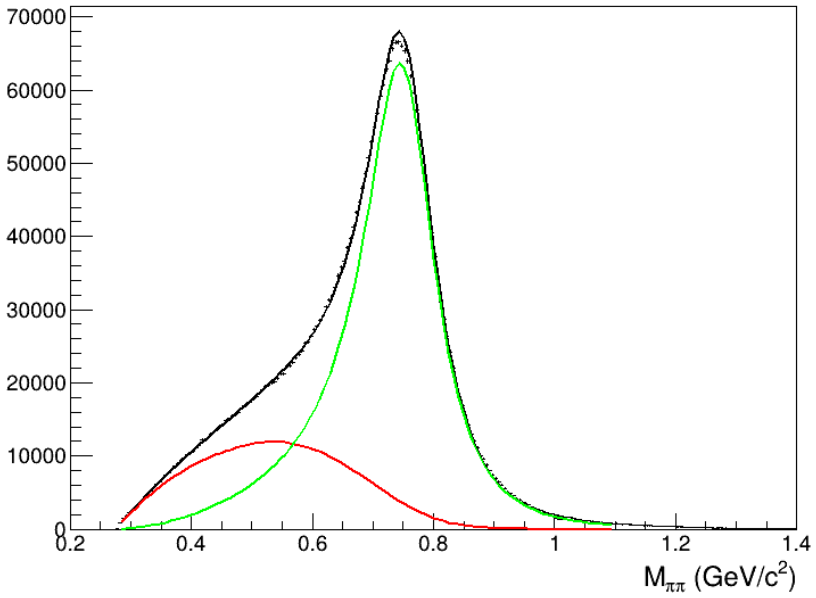
- $K^*(892)^0 \rightarrow \pi^{\pm}K^{\pm}$ ($c\tau \sim 4.2$ fm/c)
- Losses due to peak shape modification increase with increasing centrality
- Losses due to daughter annihilation or inelastic rescattering
- Decreasing trend with increasing centrality
- Comparable to STAR results

ρ(770) Peak Shape

LowMult



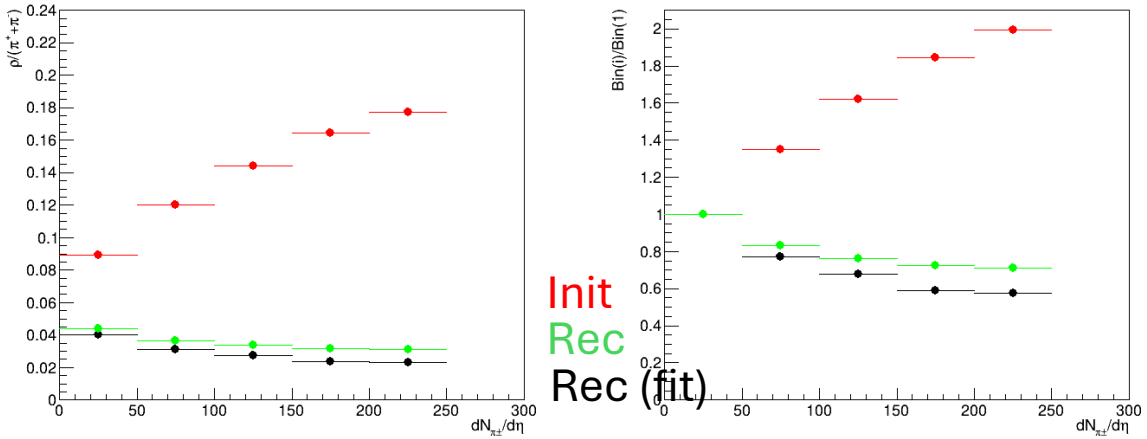
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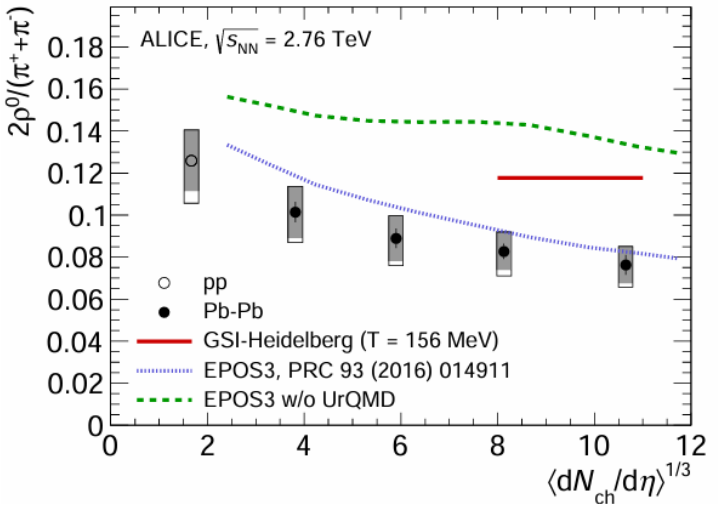


- $\rho(770)^0 \rightarrow \pi^+\pi^-$ ($c\tau \sim 1.3$ fm/c)
- Peak shape modifications even in low multiplicity events
- Rec peaks described only by combination of signal and background, considerable contribution from BGR function in high multiplicity events

ρ(770) to π ratio

https://arxiv.org/pdf/1805.04365





- $\rho(770)^0 \rightarrow \pi^+\pi^-$ ($c\tau \sim 1.3$ fm/c)
- Losses due to peak shape modification increase with increasing centrality
- Losses due to daughter annihilation or inelastic rescattering
- Decreasing trend with increasing centrality

Summary

- First look results for SigmaSt and K*+- reconstruction in XeW@2.5GeV collisions (fixed target mode): optimistic for SigmaSt, only minimum bias spectrum for K*+- with current statistic and analysis cuts
- Results of peak shape modifications studies for φ(1020), $K^*(892)^0$ and ρ(770) – resonances in BiBi@9.2GeV collisions