

K1(1270) decay in a hot hadronic medium

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Contents based on [arXiv:2603.21041](https://arxiv.org/abs/2603.21041) [hep-ph]



Introduction

Hot and dense QCD matter: A place for understanding fundamentals of QCD

Symmetries, vacuum structure, phase structures & order parameters, entanglement,

etc.

Temperature-frontier: QGP in relativistic heavy-ion collision experiments.

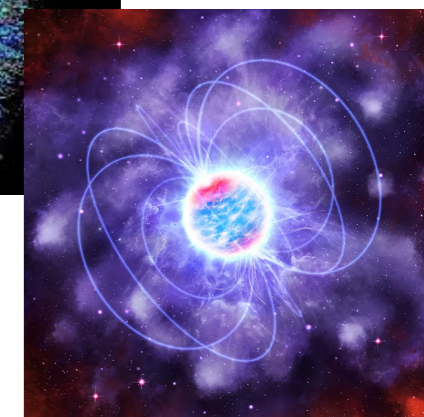
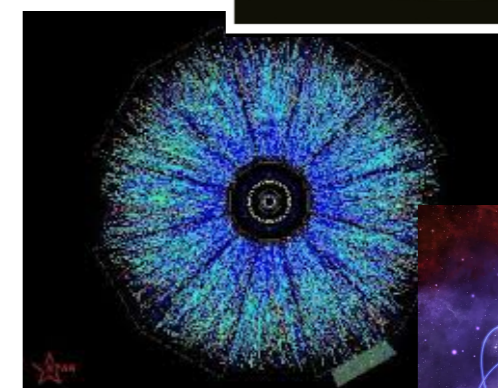
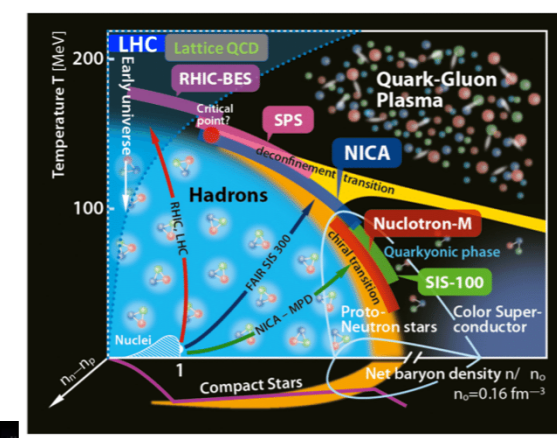
Density-frontier: Inner structures of Neutron stars, etc.

Model-dependent so far with insufficient LQCD simulations (sign problem, low-T noise, etc)

How to probe hot (and dense) matter experimentally to understand medium effects?

Nuclear modification factor, jet quenching, anomalous currents with B-field, flows, etc.

Complicated analyses with hadronization from QGP process: coalescence, fragmentation, confinement, etc.



Motivation

Is it possible to probe hot QCD with hadronic DoFs? cf) KEK-PS E325

Hadrons from the QGP experience a hot medium from chemical to kinetic freeze-out.

Chiral symmetry is gradually broken dynamically by the expansion of matter.

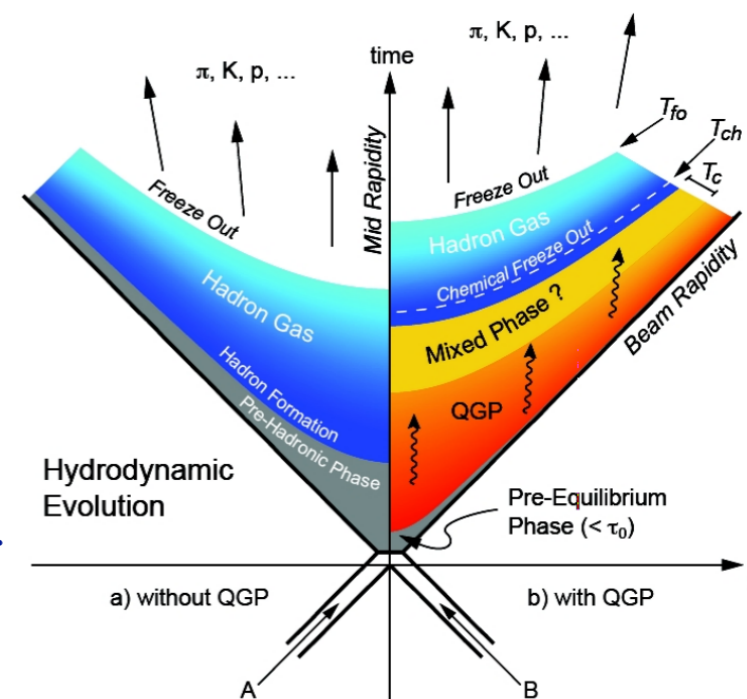
Hadrons' properties change: Masses, widths, decay couplings, etc.

P-S and A-V degeneracies indicate the dynamics of SCSB: Weinberg sum rule (WSR), for instance.

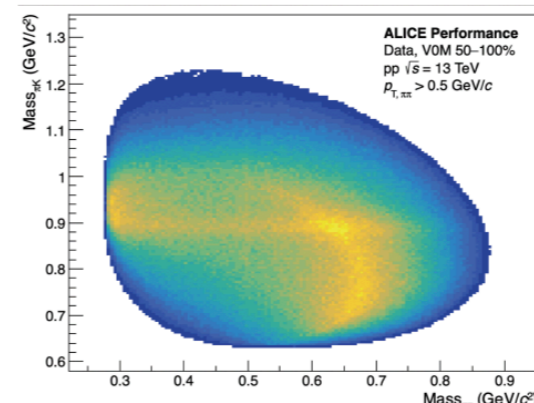
While P-S is complex to treat by coupling to UA(1),

A-V provides clean signals.

Recently, the K1-meson decay was analyzed at ALICE using p-p collisions (Su-Jeong Ji et al.).



2D INVARIANT MASS DISTRIBUTION

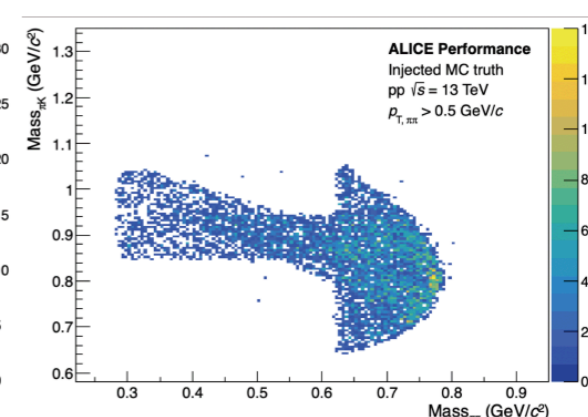
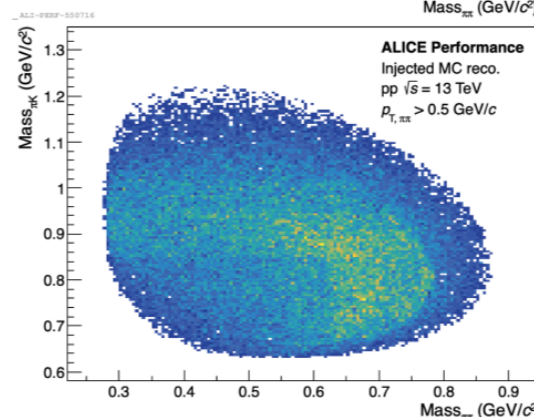


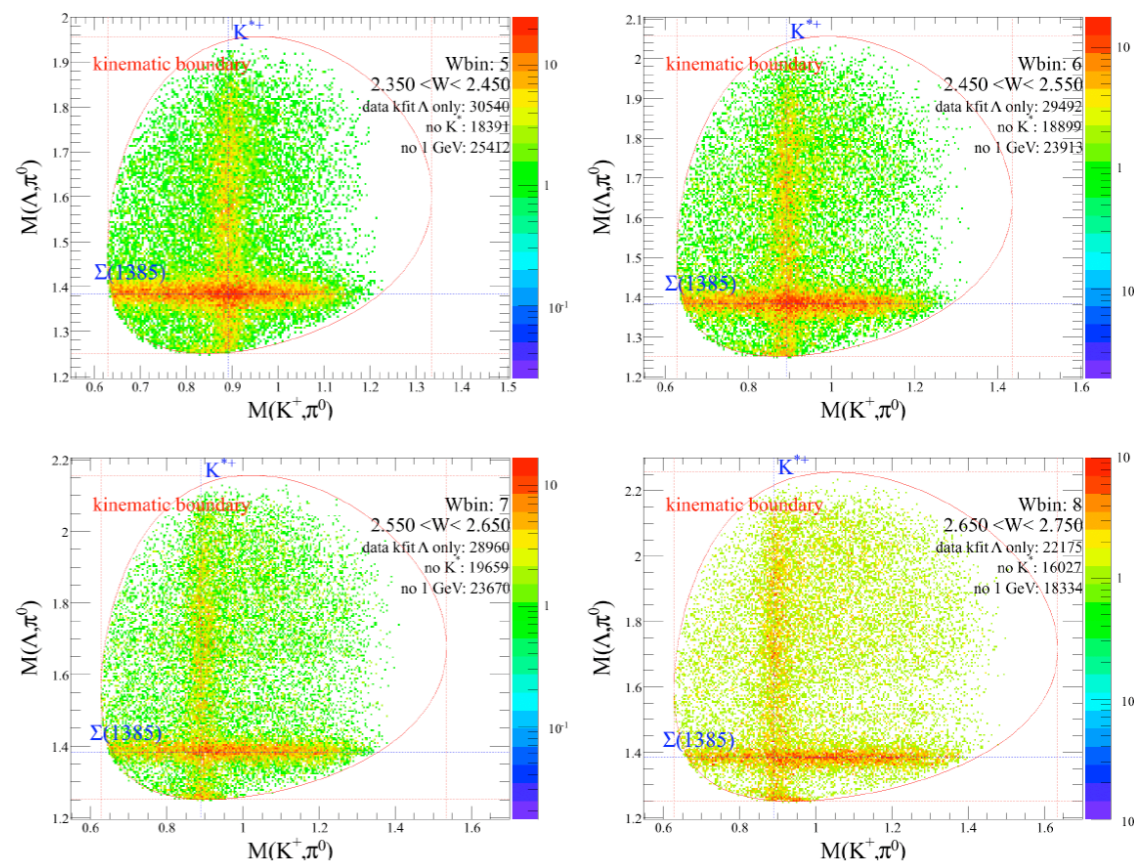
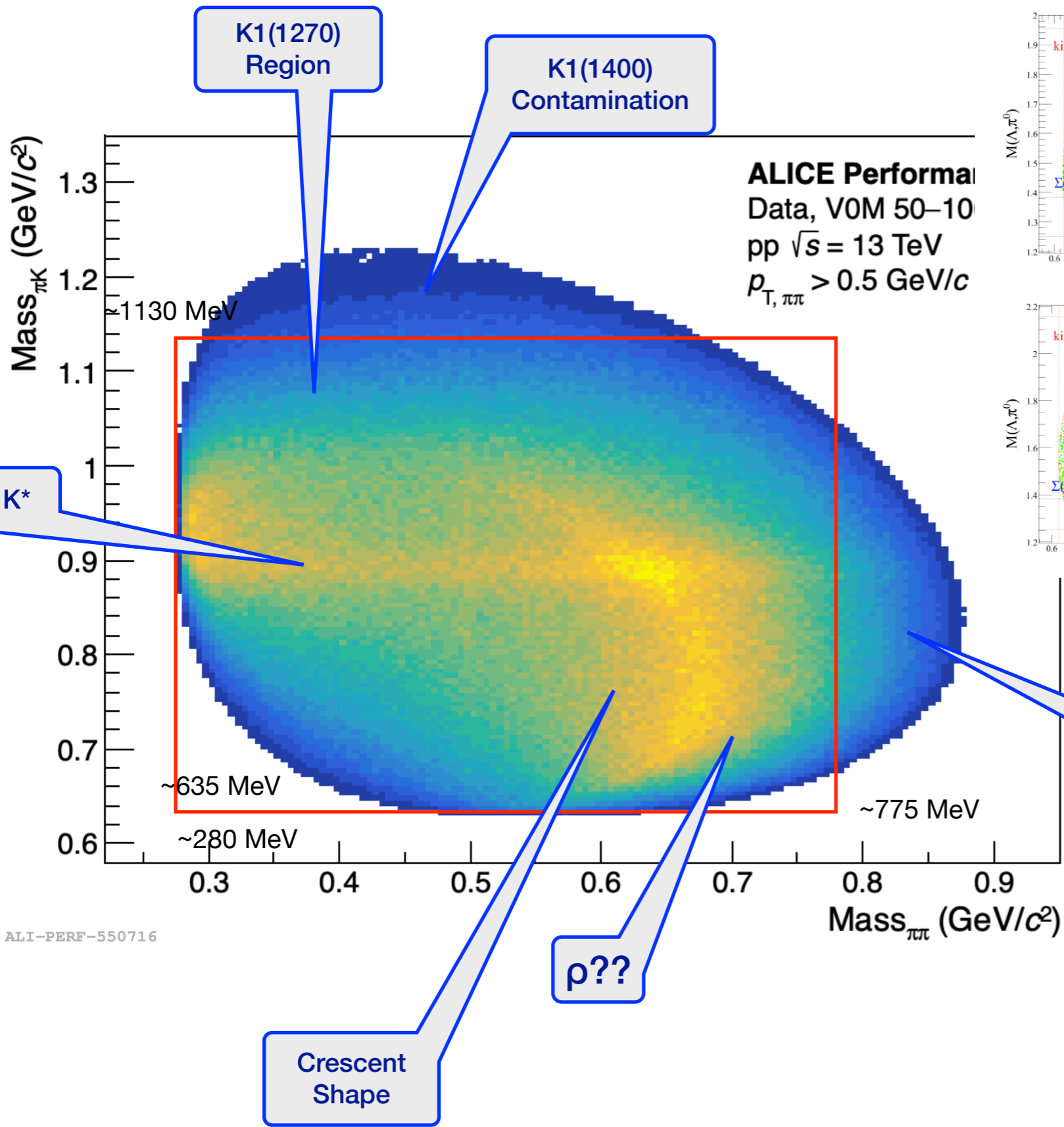
$M_{\pi\pi}$ vs $M_{\pi K}$ 2D invariant mass distribution when $1.170 < M_{\pi\pi K} < 1.370$ GeV/c²

◀ ALICE data

▼ ALICE simulation (left)

▼ MC truth tagging (right)





Usual fixed-target experiment (Jlab)

Motivation

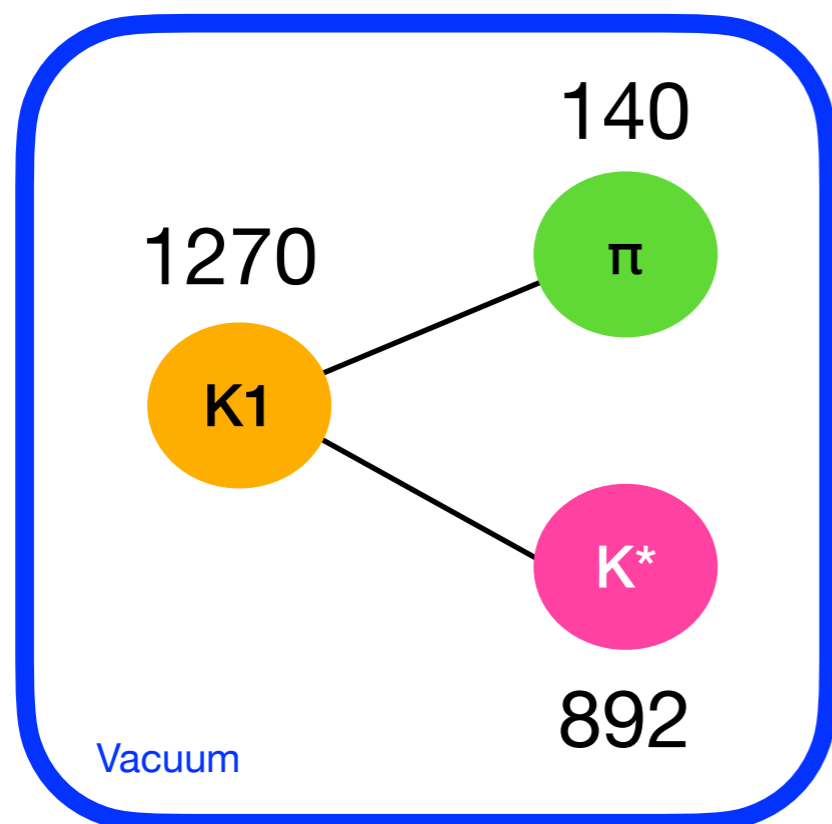
K1 meson (1270, 1+) is a chiral partner of $K^*(892, 1-)$: A-V degeneracy in hot medium via WSR

Also, its chiral properties have been studied extensively within models (Su Houng Lee, etc.).

How about combining K1 decay kinematics + meson chiral properties in a hot medium?

Basically, resonance decay is a positive-Q-value process: a heavier resonance decays into lighter ones.

If this is the case, if K1- K^* degenerated at high-T, K1 will not decay.



Mode		Fraction (Γ_i / Γ)
Γ_1	$K\rho$	$(38 \pm 13) \%$
Γ_2	$K_0^*(1430)\pi$	$(28 \pm 4) \%$
Γ_3	$K^*(892)\pi$	$(21 \pm 10) \%$
Γ_4	$K\omega$	$(11.0 \pm 2.0) \%$
Γ_5	$Kf_0(1370)$	$(3.0 \pm 2.0) \%$
Γ_6	γK^0	seen

Motivation

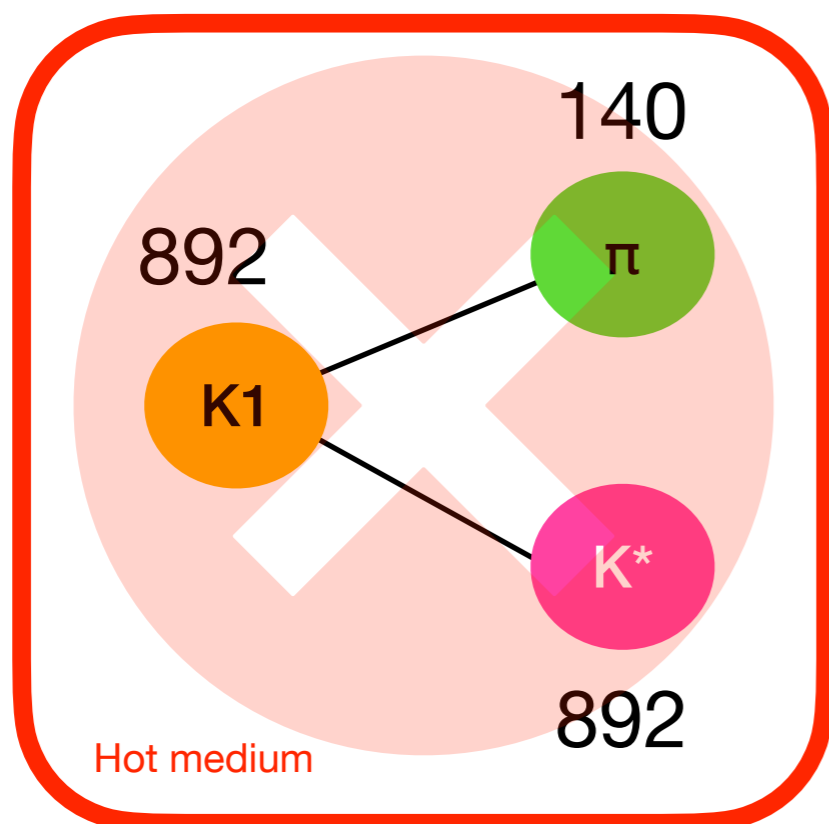
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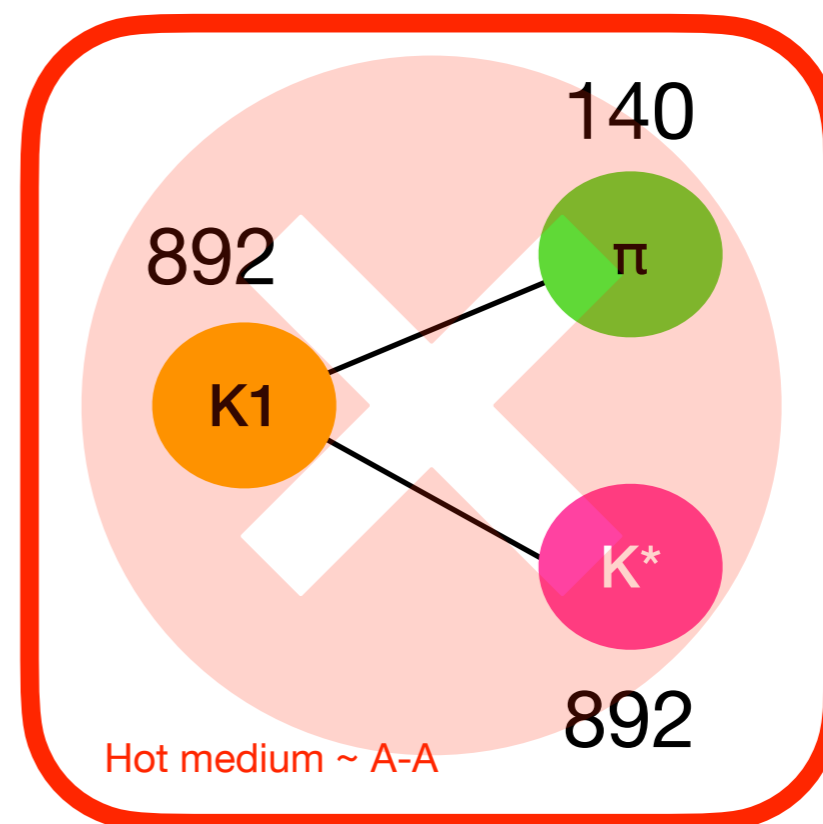
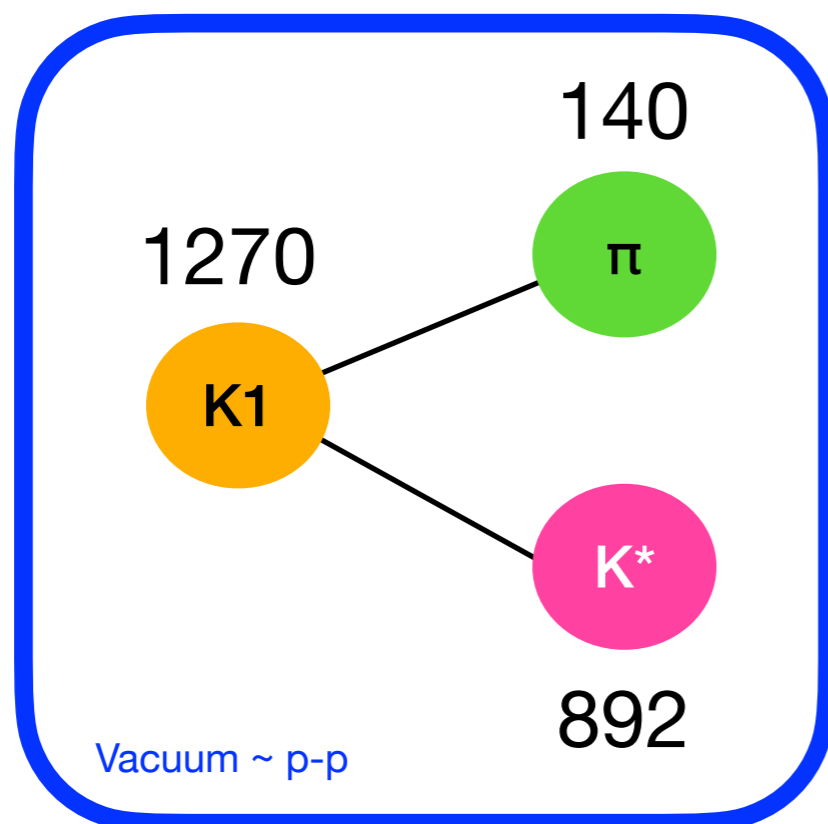
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Motivation

Compared A-A (or p-A) to p-p, considered a vacuum collision (small QGP?)

If we compare K1 decays in A-A and p-p, the signature of SCSB will be revealed via hadronic DoFs.

By seeing the signature, it may be possible to trace back to T_c , T_{chem} , T_{kin} etc.



Things to do

Computing K_1 three-body decays on the Dalitz plot via the effective Lagrangian method: $K_1 \rightarrow \pi \pi K$

Computing axial and vector meson chiral properties via models, parameterizations, etc.

Combining the above two in a hot medium

Extracting experimental observables from theory: multiplicity on centrality dependence, etc.

Caveats (as a toy model)

No regenerations of K_1 : coupled-channel method like FSI?

No other possible physical & combinatorial backgrounds: putting constant BKG?

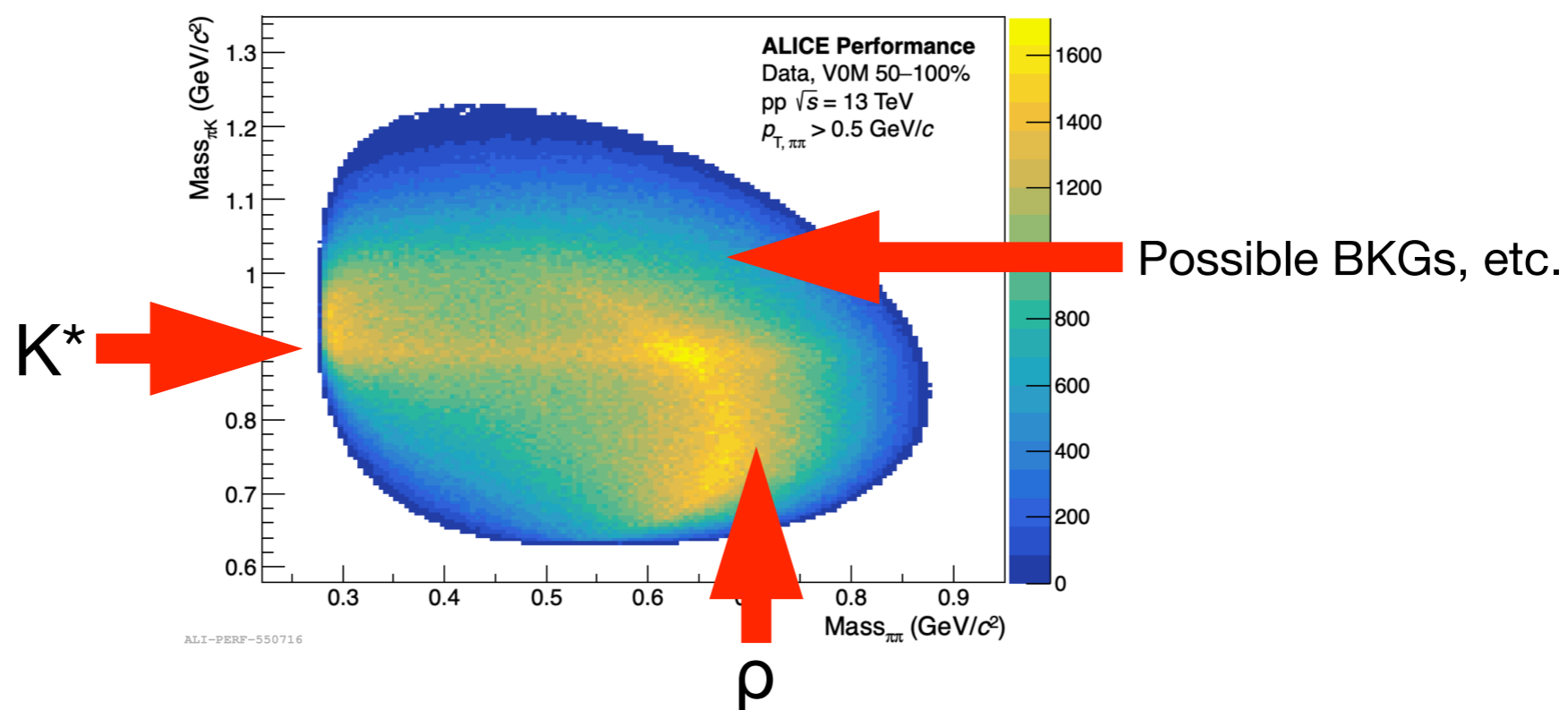
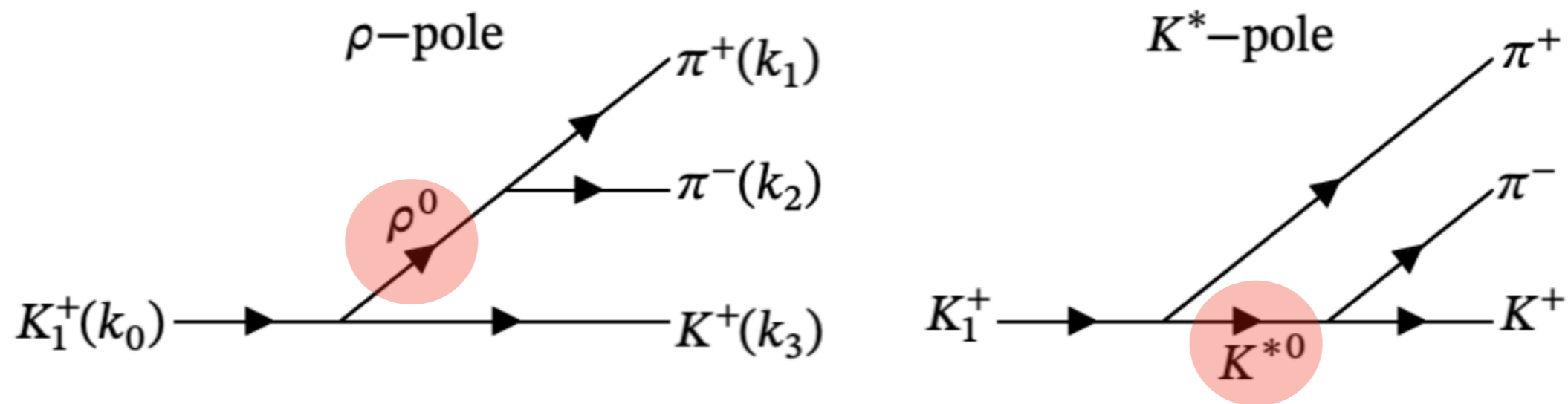
No cascading pions and kaons from different resonances: checking resonance production in ALICE

Unrealistic though but it captures physics of SCSB and opens a path to understand ALICE experiments

Model setups

Dominant contributions of K_1^+ three-body decay for $I_3=+1/2$ channel

Computing decay width

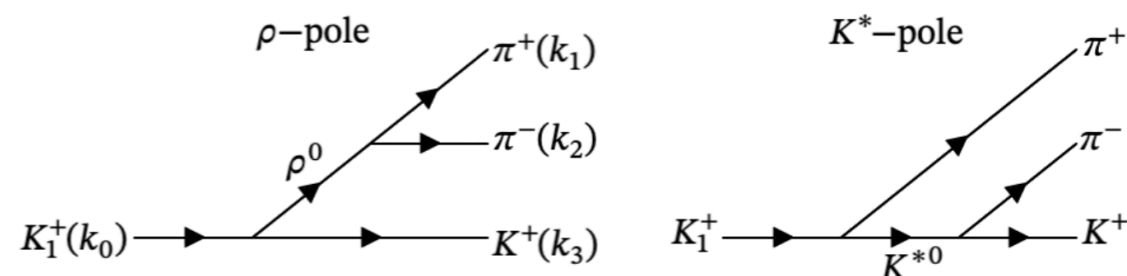


Effective Lagrangians for K1(1270) decay

Relative effective Lagrangians

$$\mathcal{L}_{VPP} = ig_{VPP} V^\mu (P \partial_\mu P^\dagger - P^\dagger \partial_\mu P) + \text{h.c.},$$

$$\mathcal{L}_{AVP} = ig_{AVP} A^\mu V_\mu P + \text{h.c.},$$



Decay invariant amplitudes

$$i\mathcal{M}_\rho = \frac{g_{K\rho K_1} g_{\pi\pi\rho} (\epsilon \cdot q_{1-2})}{q_{1+2}^2 - M_\rho^2 + i\Gamma_\rho M_\rho}, \quad i\mathcal{M}_{K^*} = \frac{g_{\pi K^* K_1} g_{\pi K K^*} \left[\epsilon \cdot q_{2-3} - \left(\frac{M_\pi^2 - M_K^2}{M_{K^*}^2} \right) \epsilon \cdot q_{2+3} \right]}{q_{2+3}^2 - M_{K^*}^2 + i\Gamma_{K^*} M_{K^*}},$$

Decay width

$$\Gamma_{K_1}^{(2)}(M_{K_1}) \equiv \frac{d^2 \Gamma_{K_1}}{dM_{\pi^+\pi^-} dM_{\pi^- K^+}} = \frac{1}{3} \sum_{x=0, \pm 1} \frac{M_{\pi^+\pi^-} M_{\pi^- K^+}}{64\pi^3 M_{K_1}^3} |\mathcal{M}_{\rho+K^*}(\epsilon_x)|^2.$$

Couplings via PDG for K1(1270); For K1(1400), scaled by mass

$g_{\pi K^* K_1}$	$g_{\pi K K^*}$	$g_{K\rho K_1}$	$g_{\pi\pi\rho}$	Γ_{K^*}	Γ_ρ
0.92 GeV	4.48	4.10 GeV	8.49	47.3 MeV	147.7 MeV

Meson properties in a hot medium

Basically, mesons are a $q\bar{q}$ bound state, resulting in $M_{\text{meson}} \sim 2M_q(T)$

Nonetheless, the PS meson does not follow this behavior: NG nature (large N_c) and coupling to $U_A(1)$

The PS meson mass remains (almost) the same for T via GOR, for instance: $m_\pi^2 = \frac{-(m_u + m_d)\langle\bar{q}q\rangle}{f_\pi^2}$

For the vector meson, it is protected by current conservation: HLS

Thus, we use sophisticated assumptions:

	PS	V	A
Mass of T	\sim Same	\sim Same	\sim Decreasing
Width of T	\sim Same	\sim Same	\sim Decreasing

$$\Gamma_A(T) \approx \Gamma_A(0) \left[\frac{M_A(0)}{M_A(T)} \right] \left[\frac{p_A(T)}{p_A(0)} \right]^3, \quad \Gamma_V(T) \approx \Gamma_V(0),$$

$$p_A(T) = \frac{\sqrt{[M_A^2(T) - (M_V + M_\pi)^2][M_A^2(T) - (M_V - M_\pi)^2]}}{2M_A(T)}.$$

T-dependence of M_q

Assuming that $M_A(T) \sim 2M_q(T)$

How to obtain $M_q(T)$: Lattice QCD, effective QCD-like models, Dyson-Schwinger, etc.

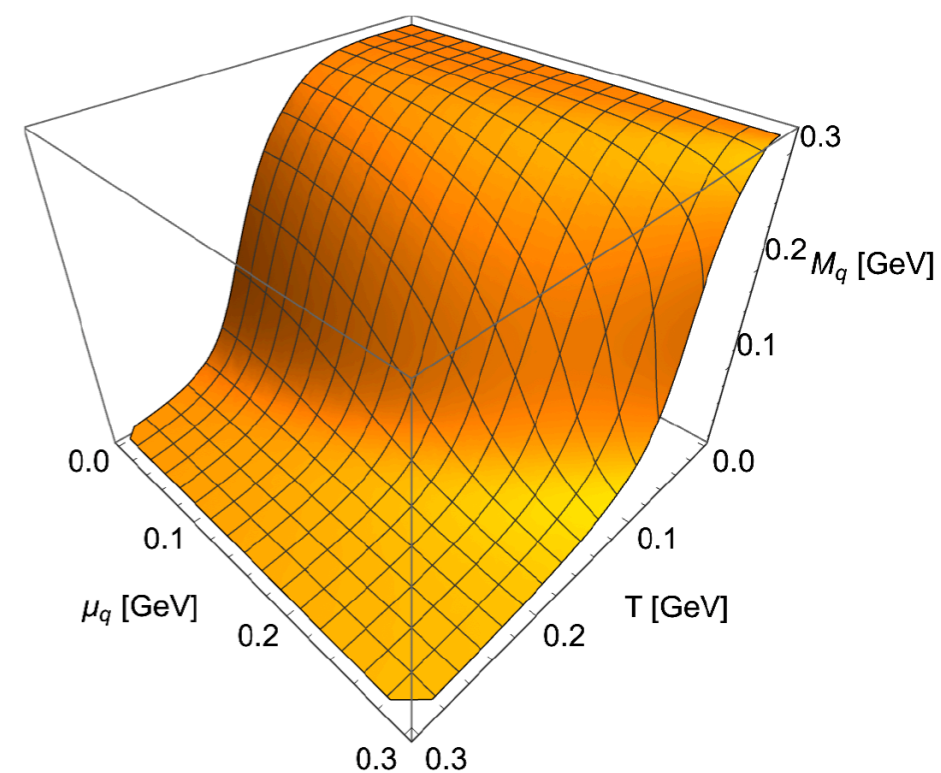
In this work, we employ NJL model (or the liquid-instanton model later)

$$\mathcal{L}_{\text{NJL}} = \bar{q}(i\gamma^\mu \partial_\mu - m_q)q + G [(\bar{q}q)^2 + (\bar{q}i\gamma_5 \boldsymbol{\tau} q)^2],$$

$$M_q(T, \mu) = m_q - 2G\langle \bar{q}q \rangle, \quad \langle \bar{q}q \rangle = -4N_c N_f \int_0^\Lambda \frac{d^3 \vec{k}}{(2\pi)^3} \frac{M_q}{E_k} [1 - n_+ - n_-],$$

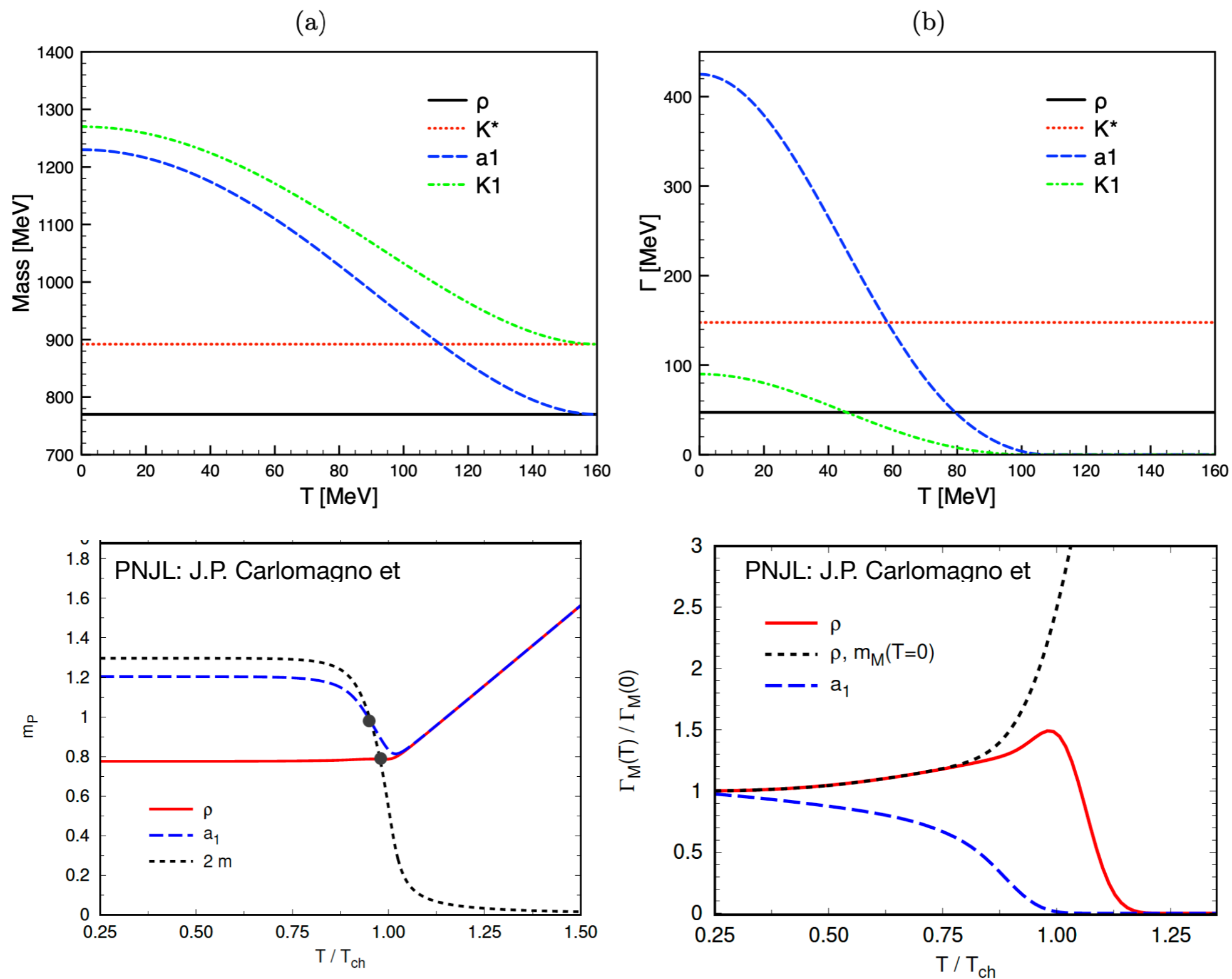
m_q [MeV]	Λ [MeV]	$G\Lambda^2$
5.25	631.4	2.14

We observe that $M_q(T)$ follows \sim double Lorentzian parameterization



Numerical results

Mesonic properties at hot medium

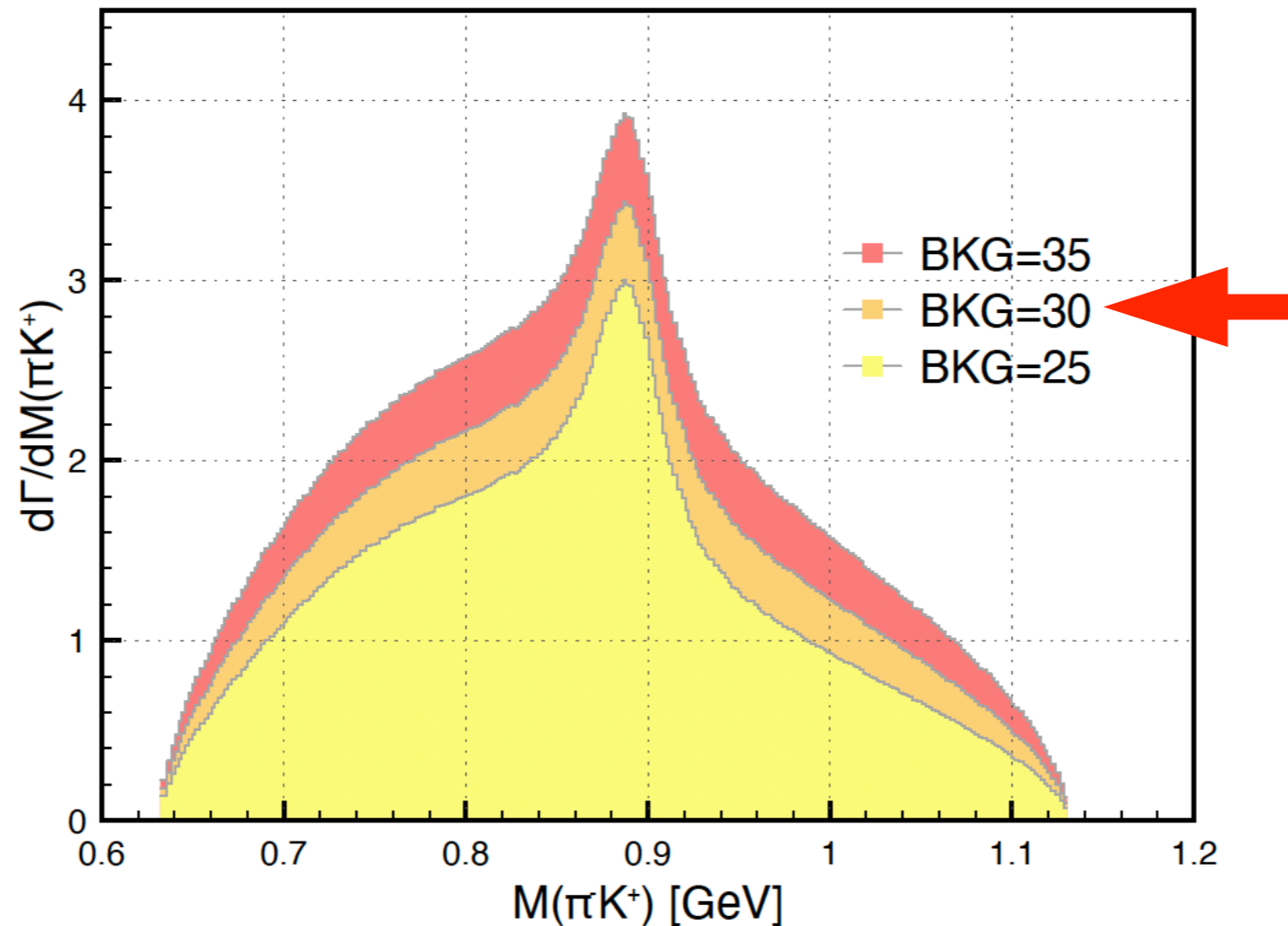


Numerical results

Model parameter determination: Strength of BKG to reproduce the partial decay

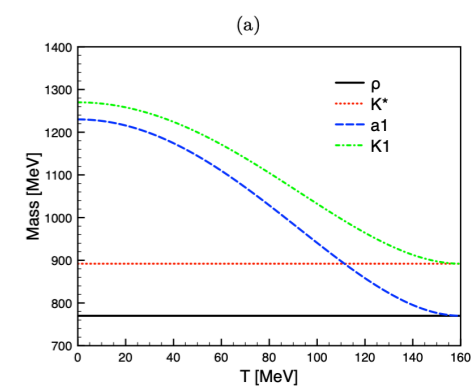
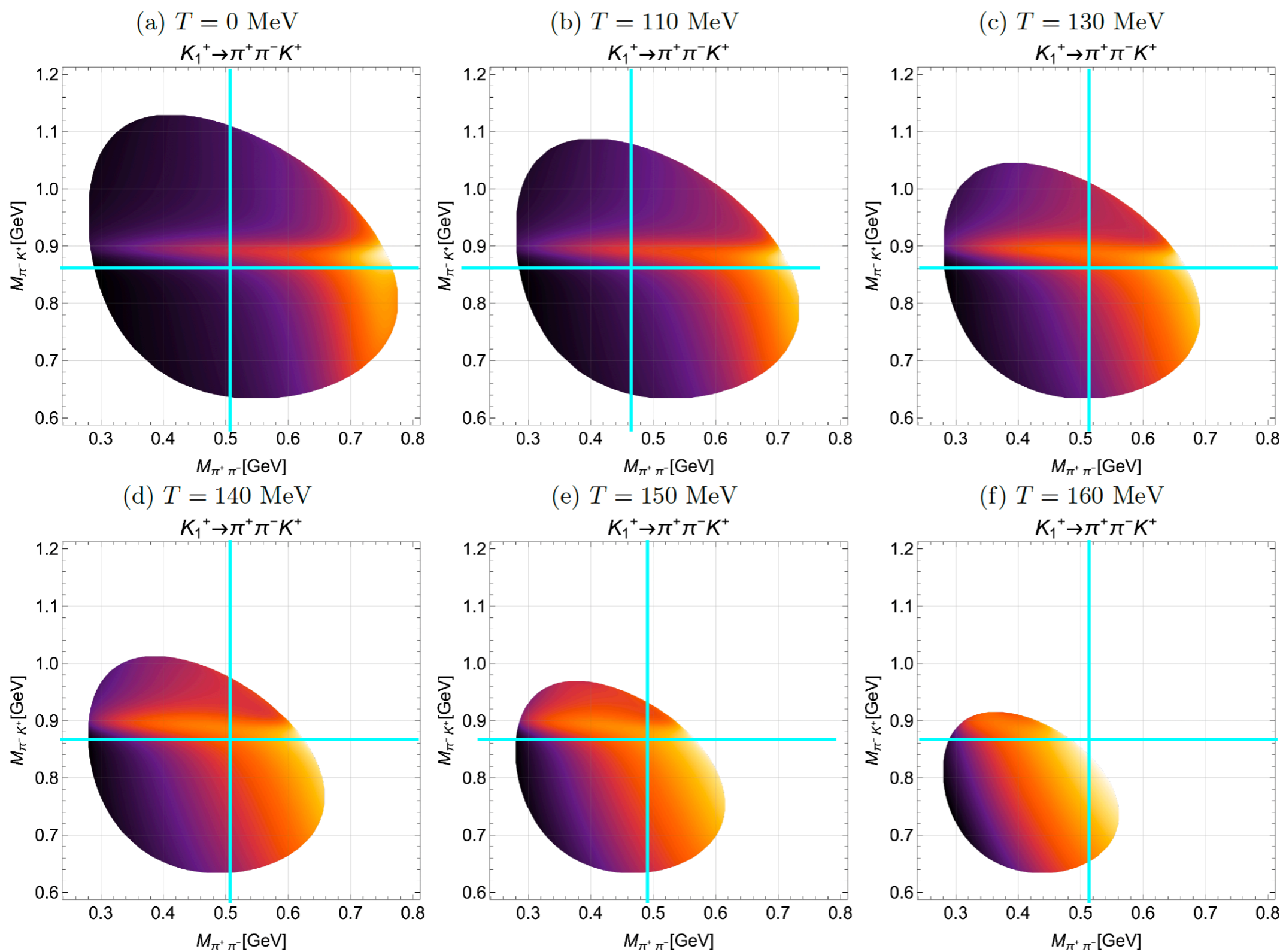
$$\begin{aligned} \mathcal{B}_{\text{est}}[K_1(1270)^+ \rightarrow K^+ \pi^+ \pi^-] &\approx \mathcal{B}[K_1^+ \rightarrow K^+ \rho^0] \mathcal{B}[\rho^0 \rightarrow \pi^+ \pi^-] \\ &+ \mathcal{B}[K_1^+ \rightarrow K^{*0} \pi^+] \mathcal{B}[K^{*0} \rightarrow K^+ \pi^-] \\ &+ \mathcal{B}[K_1^+ \rightarrow K_0^{*0}(1430) \pi^+] \mathcal{B}[K_0^{*0}(1430) \rightarrow K^+ \pi^-], \end{aligned}$$

$$\Gamma_{\text{est}}^{\text{PDG}}[K_1(1270)^+ \rightarrow K^+ \pi^+ \pi^-] \approx 40 \text{ MeV}.$$



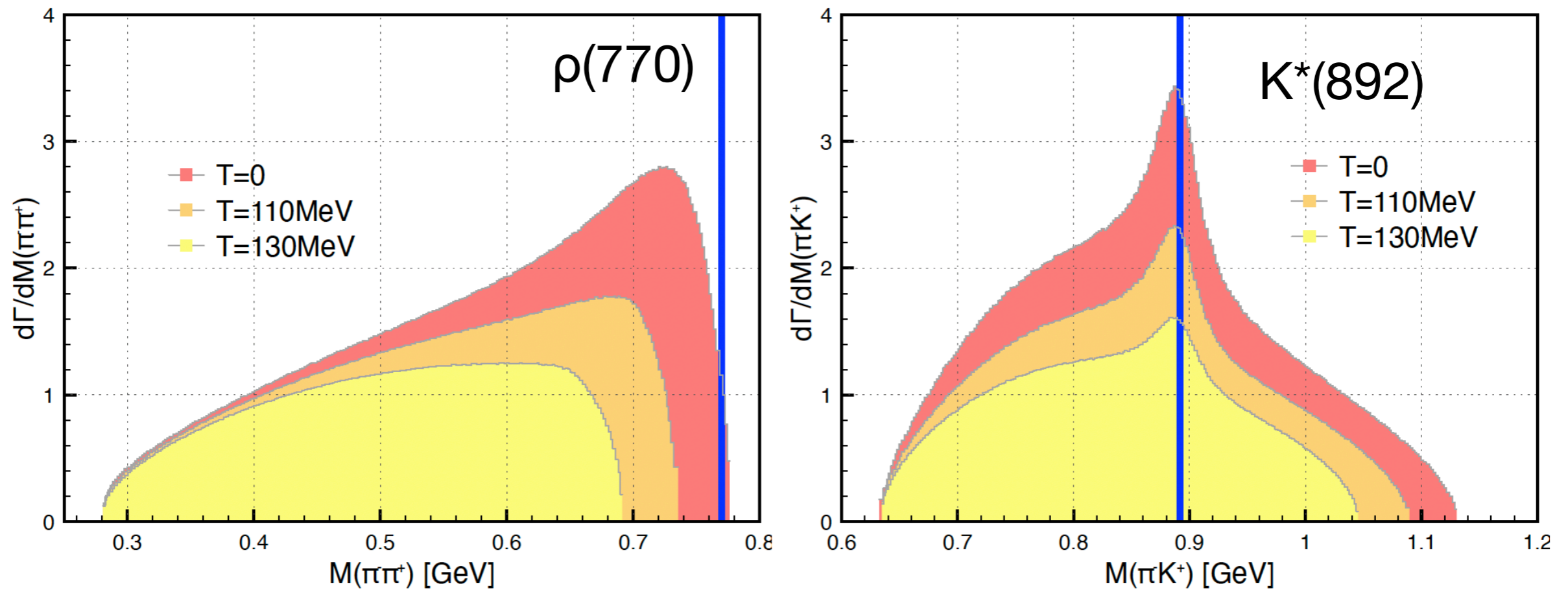
Numerical results

Dalitz plots at finite T: C(T) decreases w.r.t. T



Numerical results

Invariant masses at finite T



For $\pi\pi$ channel, due to near phase-boundary effects, a peak observed below 770 MeV

Definitions of Shape observables of T

Spectral weight remains concentrated near the upper edge of the $M(\pi^+\pi^-)$ distribution

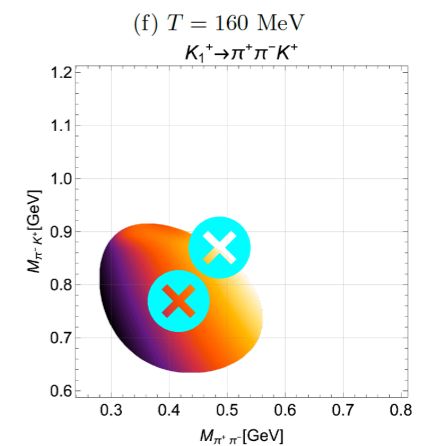
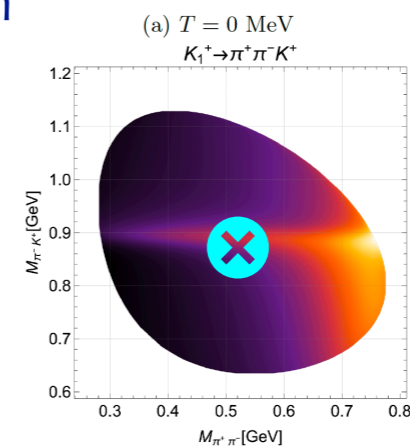
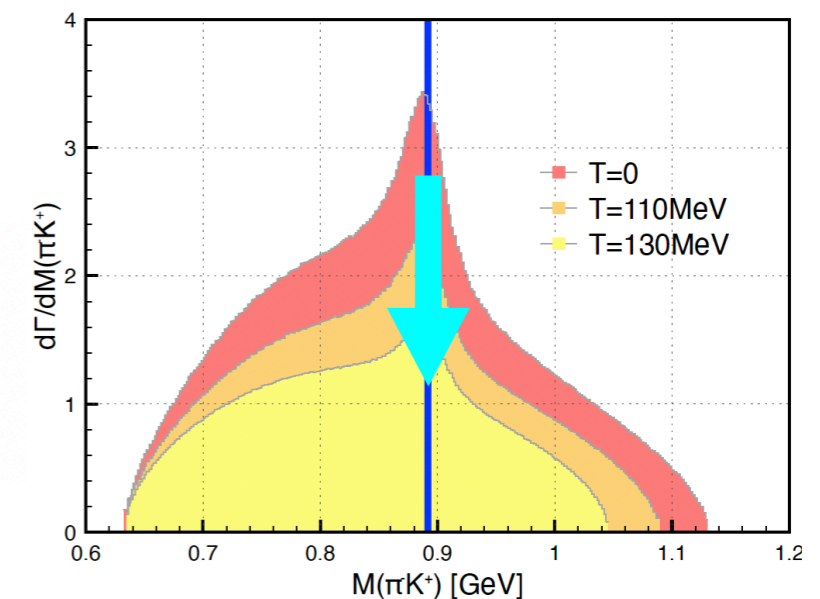
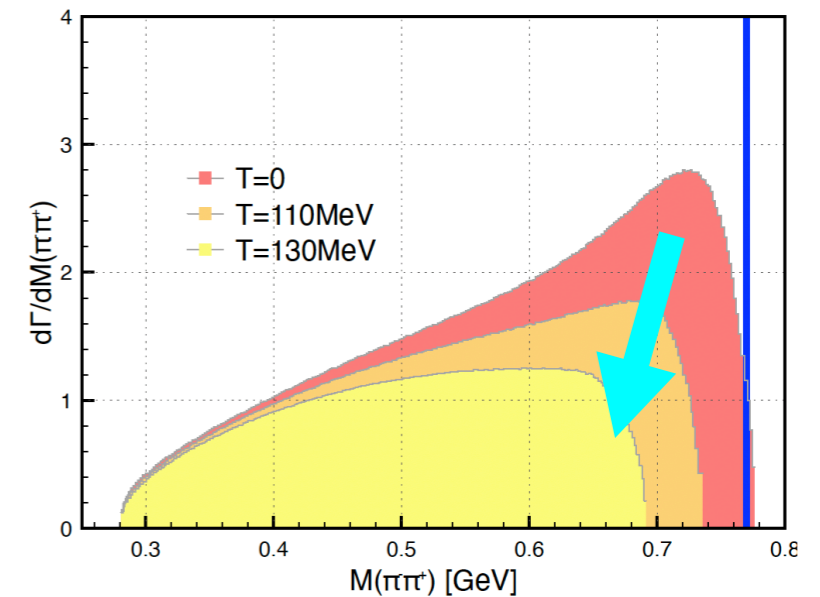
$$R_{\text{edge}}(T; M_{\text{cut}}) \equiv \frac{\int_{M_{\text{cut}}}^{M_{\pi\pi}^{\text{max}}(T)} dM_{\pi^+\pi^-} \frac{d\Gamma(T)}{dM_{\pi^+\pi^-}}}{\int dM_{\pi^+\pi^-} \frac{d\Gamma(T)}{dM_{\pi^+\pi^-}}}.$$

Reconstructed event population remains concentrated around the resonance-enhanced K^* region

$$R_{K^*}(T; \Delta_{K^*}) \equiv \frac{\int_{M_{K^*} - \Delta_{K^*}}^{M_{K^*} + \Delta_{K^*}} dM_{\pi^-K^+} \frac{d\Gamma(T)}{dM_{\pi^-K^+}}}{\int dM_{\pi^-K^+} \frac{d\Gamma(T)}{dM_{\pi^-K^+}}}.$$

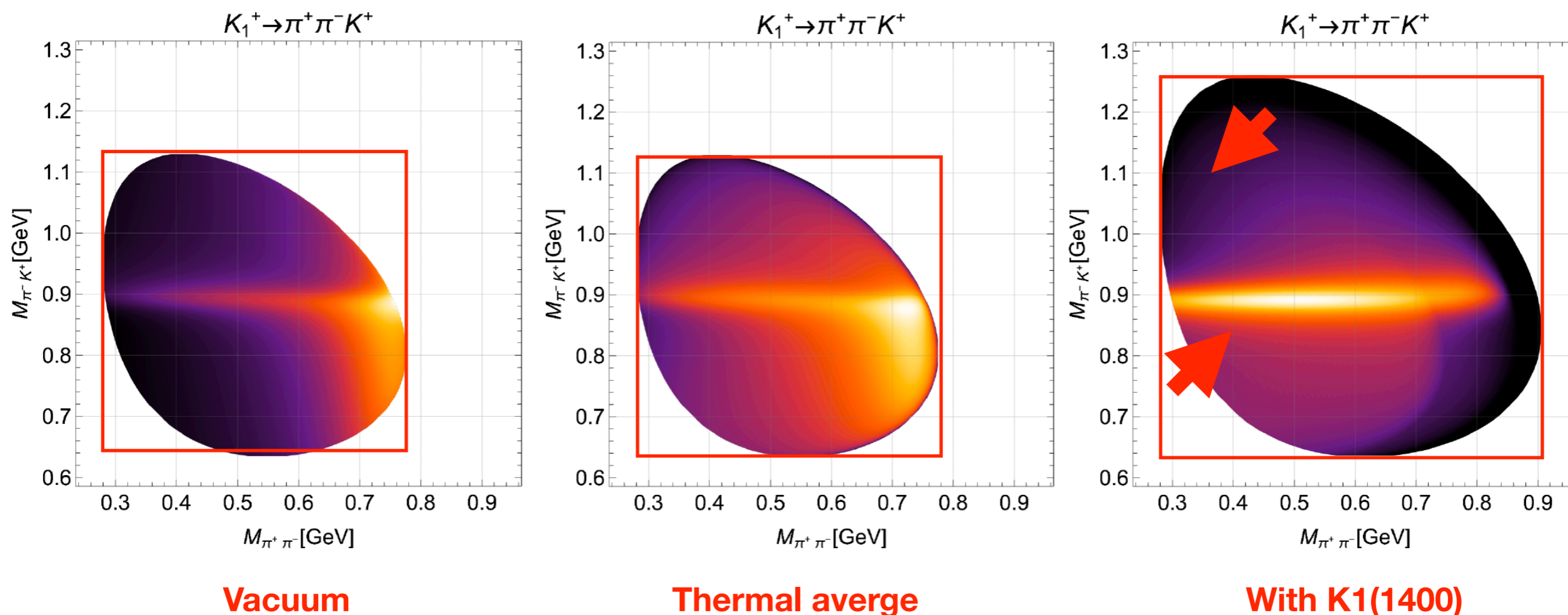
Dalitz event population remains globally compact around the vacuum reference centroid.

$$C(T) \equiv \frac{\int dM_{\pi^+\pi^-} dM_{\pi^-K^+} W(M_{\pi^+\pi^-}, M_{\pi^-K^+}) \frac{d^2\Gamma(T)}{dM_{\pi^+\pi^-} dM_{\pi^-K^+}}}{\int dM_{\pi^+\pi^-} dM_{\pi^-K^+} \frac{d^2\Gamma(T)}{dM_{\pi^+\pi^-} dM_{\pi^-K^+}}},$$



Numerical results

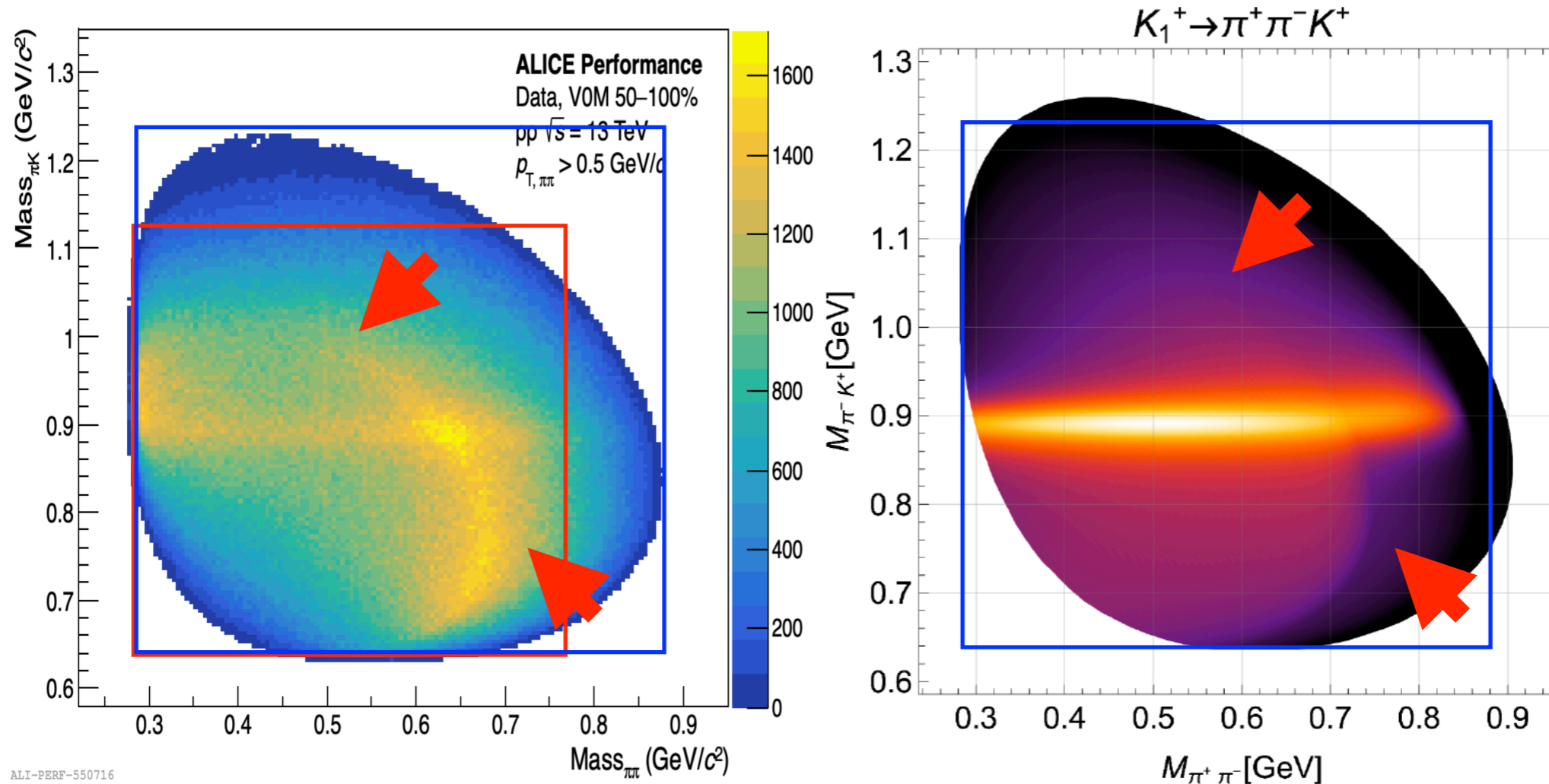
Dalitz plot for $K_1(1270)$ decay in vacuum and hot medium



The thermal average from 160 MeV to 0 MeV provides a crescent structure by stacking phase spaces
 ALICE experiment shows small but finite $K_1(1400)$ contamination
 Still unknown structure and BKGs appear

Numerical results

Dalitz plot for $K_1(1270+1400)$ decay in vacuum and hot medium



ALICE by Ji

$K_1(1270)+K_1(1400)$ w/ thermal average

Partial $K_1(1400)$ contamination looks like to explain those weird structures

Thus, the cut for $K_1(1400)$ becomes important to single out $K_1(1270)$ in analyses

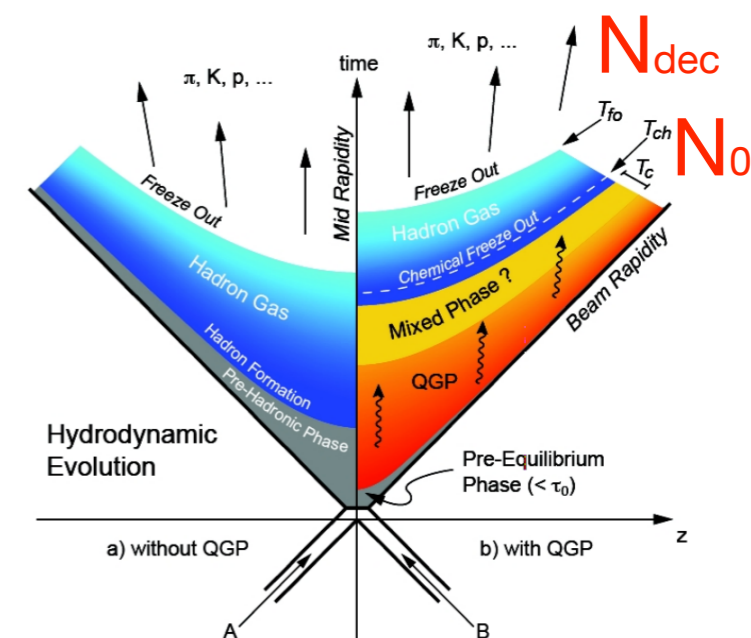
Analyses on K1 thermal decay (Just speculation not for experimental analyses)

Temporal number of K1 mesons made in hot medium

$$\frac{dN^{AA}(t)}{dt} = -\Gamma[T(t)] N^{AA}(t),$$

And its solution becomes

$$N^{AA}(t) = N_0^{AA} \exp \left[- \int_{t_{ch}}^t \Gamma[T(t')] dt' \right]$$



Number of K1 meson decayings defined by

$$N_{dec}^{AA} = N_0^{AA} - N^{AA}(t_{kin}) = N_0^{AA} \left\{ 1 - \exp \left[- \int_{t_{ch}}^{t_{kin}} \Gamma[T(t')] dt' \right] \right\}$$

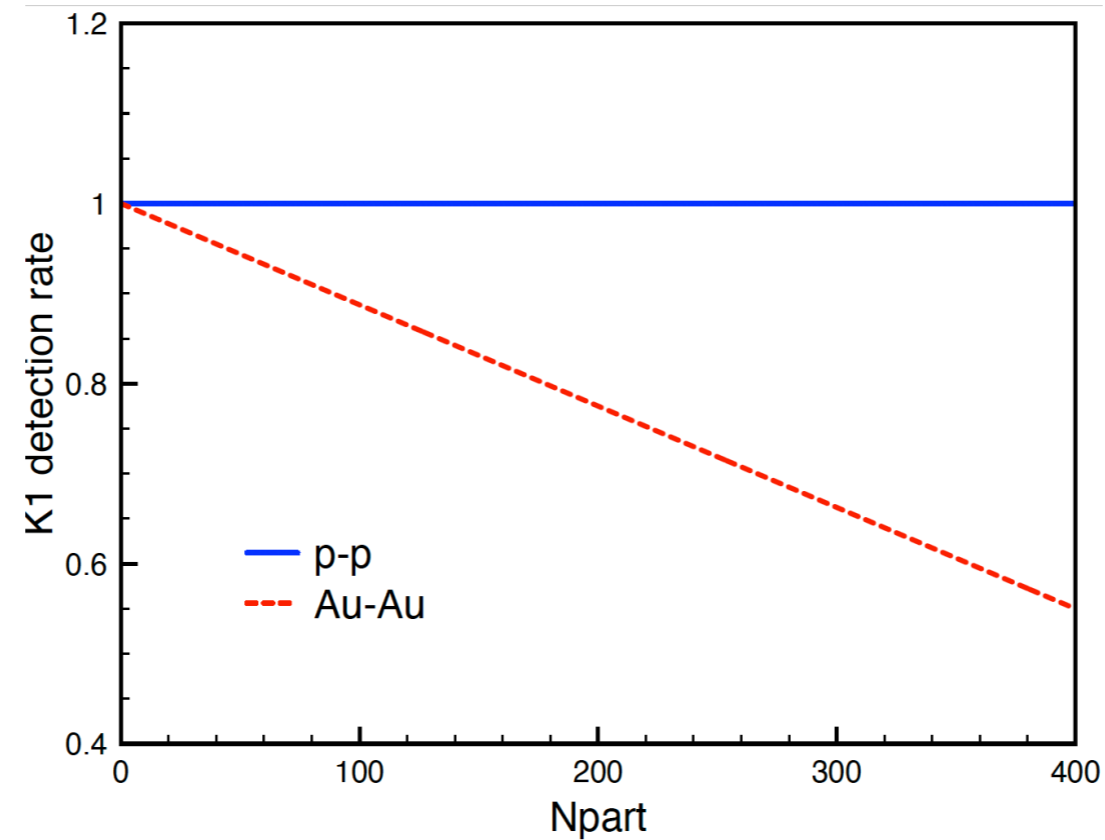
A ratio of A-A and p-p comparison, similar to nuclear modification factor

$$\mathcal{R}_{AA/pp} = \frac{N_{dec}^{AA}}{N_{dec}^{pp}} = \frac{N_0^{AA}}{N_0^{pp}} \frac{1 - \exp \left[- \frac{\Delta t}{\Delta T} \int_{T_{kin}}^{T_{ch}} \Gamma(T) dT \right]}{1 - e^{-\Gamma_0 \Delta t}} \approx \frac{A \left[1 - \exp \left[- \frac{\Delta t}{\Delta T} \int_{T_{kin}}^{T_{ch}} \Gamma(T) dT \right] \right]}{1 - e^{-\Gamma_0 \Delta t}}$$

$$A \approx N_{part}/2$$

Analyses on K1 thermal decay

K1 decay ($I_z=+1/2$) as a function N_{part}



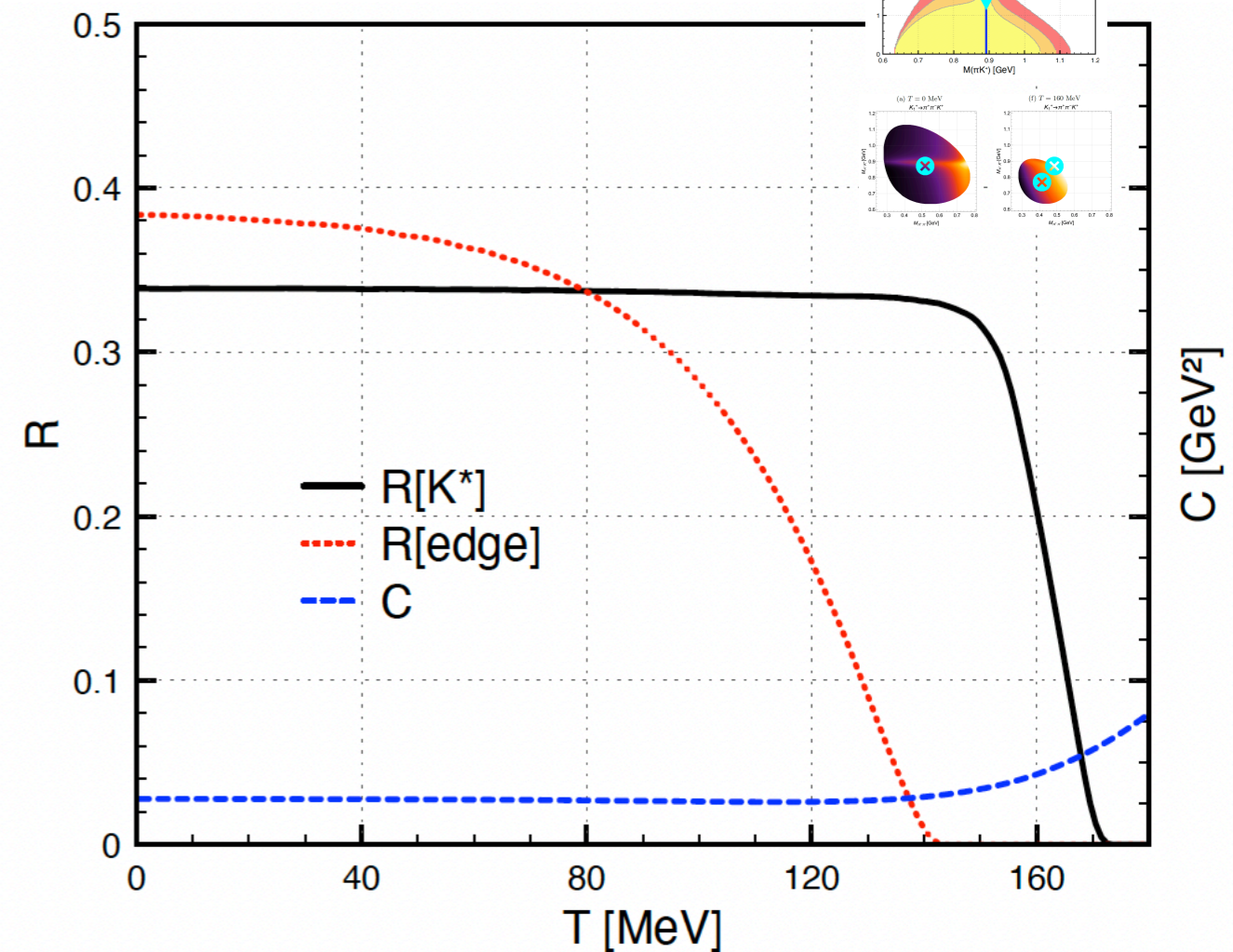
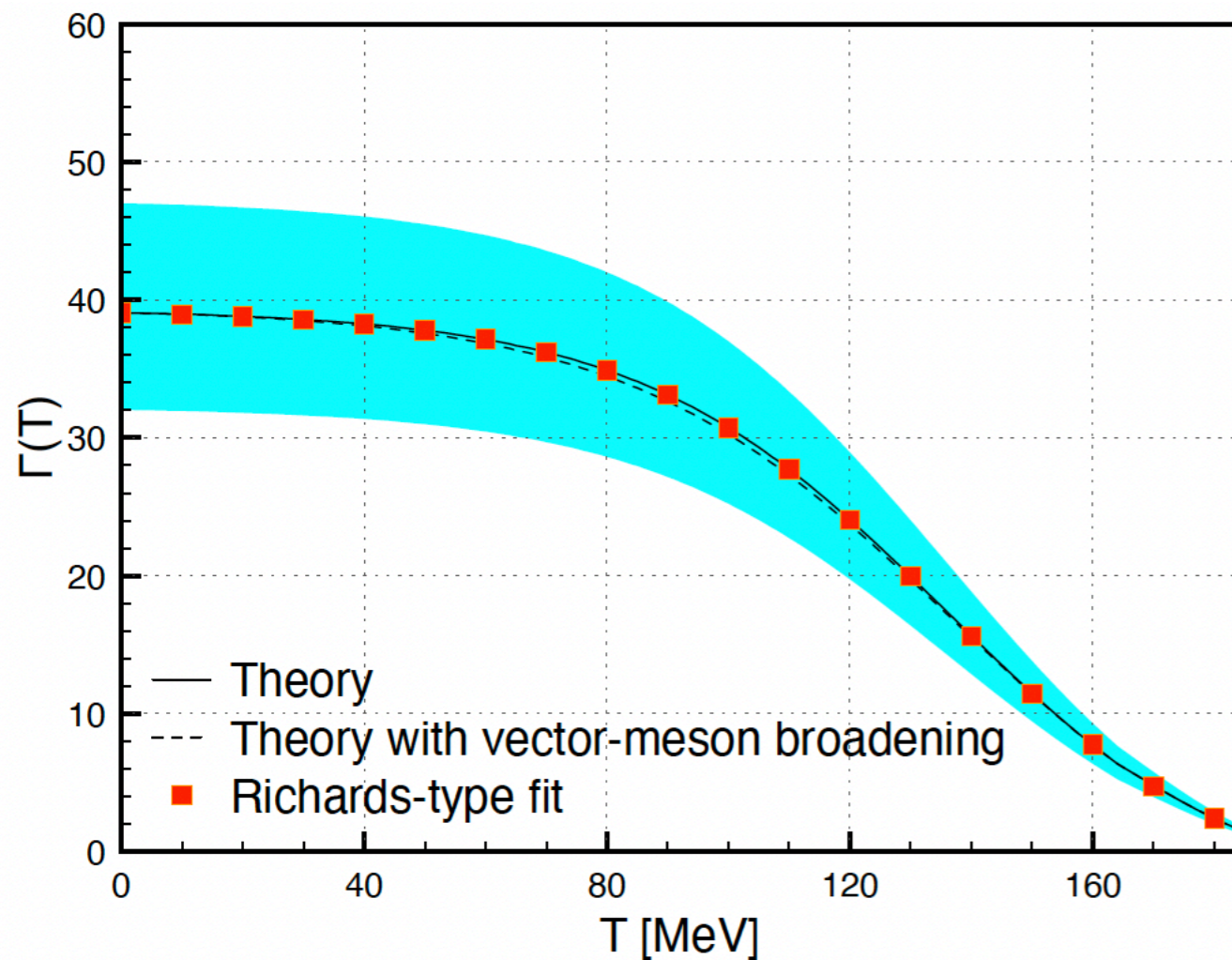
This is speculation

About 50% decrease in K1 decay at Au-Au head-on collision

Can this observation be found in ALICE experiment?

Analyses on K1 thermal decay

K1 decay ($I_z=+1/2$) with width broadening and Normalized shape observables



$$\Gamma_A(T) = \Gamma_A(0) \left[\frac{M_A(0)}{M_A(T)} \right] \left[\frac{p_A(T)}{p_A(0)} \right]^3, \quad \Gamma_V(T) \approx \Gamma_V(0),$$

Summary

Hot QCD matter created in heavy-ion collisions provides a laboratory to study chiral symmetry restoration.

The axial-vector meson $K_1(1270)$ is the chiral partner of the vector meson $K^*(892)$.

In a hot medium, axial–vector degeneracy is expected as (partial) chiral symmetry restoration

This degeneracy can reduce the phase for K_1 decay and suppress it.

The three-body decay $K_1 \rightarrow \pi\pi\pi K$ is studied using an effective Lagrangian approach and Dalitz plot analysis.

A comparison of A–A and p–p collisions may reveal suppressed K_1 decay yield, providing a potential signal of chiral symmetry restoration.

More realistic inputs (BKGs, t -dependent masses, widths, couplings for PS, V, A, etc) are under consideration

Extension to finite density for J-PARC HI underway

xQCD 2026

12 (Sun) - 17 (Fri) July 2026

PKNU, Busan, Korea



□ Scientific program

Ph.D school with 4 lecturers and ~40 students

Main program with 8 invited + 50 oral talks + 50 poster = 108

presentations

Gert Aarts (Swansea) ML + Langevin Equation + Stochastic Quantization

Kenji Fukushima (Tokyo) Neutron Stars & Gravitational Waves

Alexander Rothkopf (Korea) Non-equilibrium Physics & Open Quantum Systems

Sungwoo Park (Sejong) Fundamentals on lattice QCD simulation + nucleon structure

□ INDICO

Main: <https://indico.ibs.re.kr/event/1158/>

School: <https://indico.ibs.re.kr/event/1208/>

□ Timeline

Registration opening: February 16, 2026 (Mon)

Registration deadline: May 28, 2026 (Thu)

Registration fee payment deadline: June 12, 2026 (Fri)

Abstract submission opening: February 16, 2026 (Mon)

Abstract submission deadline: May 28, 2026 (Thu)

xQCD 2026

14 (Tue) - 17 (Fri) July 2026
Pukyong National University
Busan Korea

PhD School
12 (Sun) - 13 (Mon) July 2026

Topics

- QCD at Finite Temperature and Density
- Heavy-Ion Collision Phenomenology
- Phase Diagram of Strongly Interacting Matter
- Properties of the Quark-Gluon Plasma
- Properties of Strongly Interacting Gauge Theories
- The Sign Problem in Lattice QCD
- QCD in External Fields
- Neutron Stars and Cosmology in QCD
- New Algorithmic Developments in QCD
- New Aspects of Symmetries in QCD

Invited speakers

- Yoshimasa Hidaka (YITP)
- Toru Kojo (KEK)
- Minjung Kweon (Inha University)
- Violetta Sagun (University of Southampton)
- Chihiro Sasaki (University of Wroclaw)
- Volodymyr Vovchenko (University of Houston)
- Jana Günther (University of Wuppertal)
- Kai Zhou (Chinese University of Hong Kong)

PhD school lecturers

- Gert Aarts (Swansea University)
- Kenji Fukushima (University of Tokyo)
- Alexander Rothkopf (Korea University)
- Sungwoo Park (Sejong University)

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