Thermal modification of $K1(1270)\to\pi+\pi-K+$ in a hot hadronic medium

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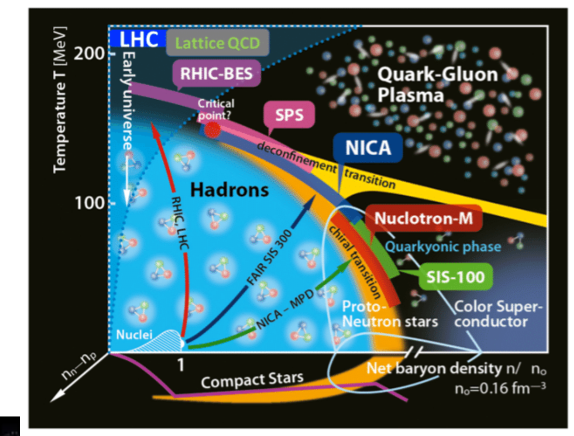
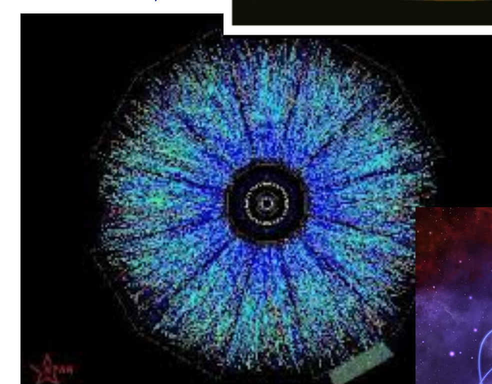
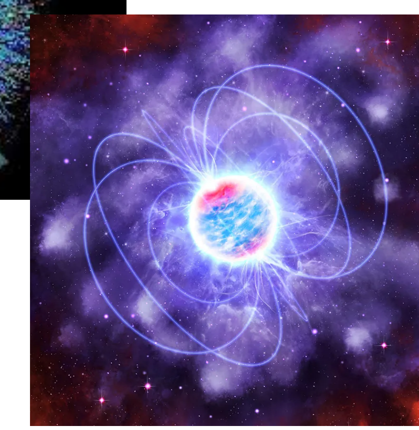
Contents based on arXiv:2603.21041 [hep-ph]

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)

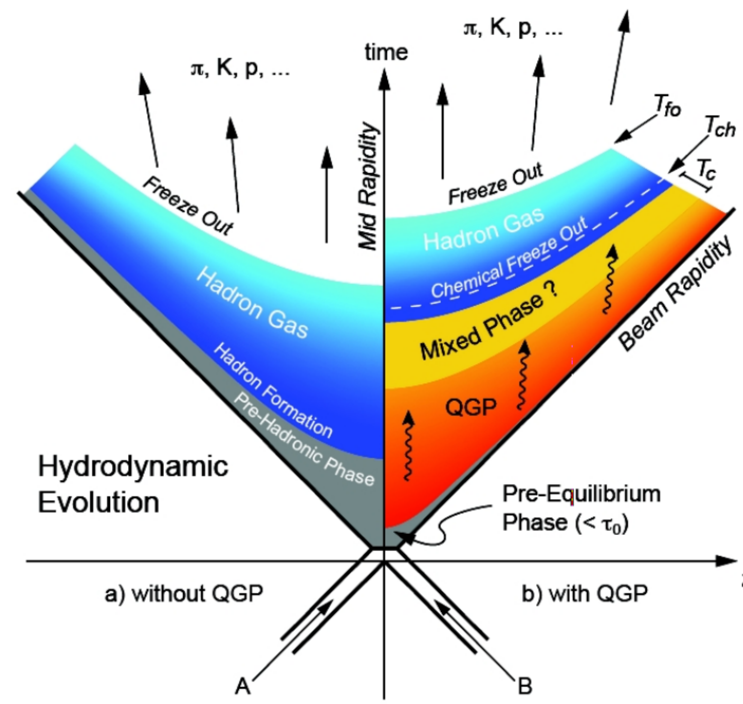
How to probe hot (and dense) matter experimentally to understand medium effects?

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.

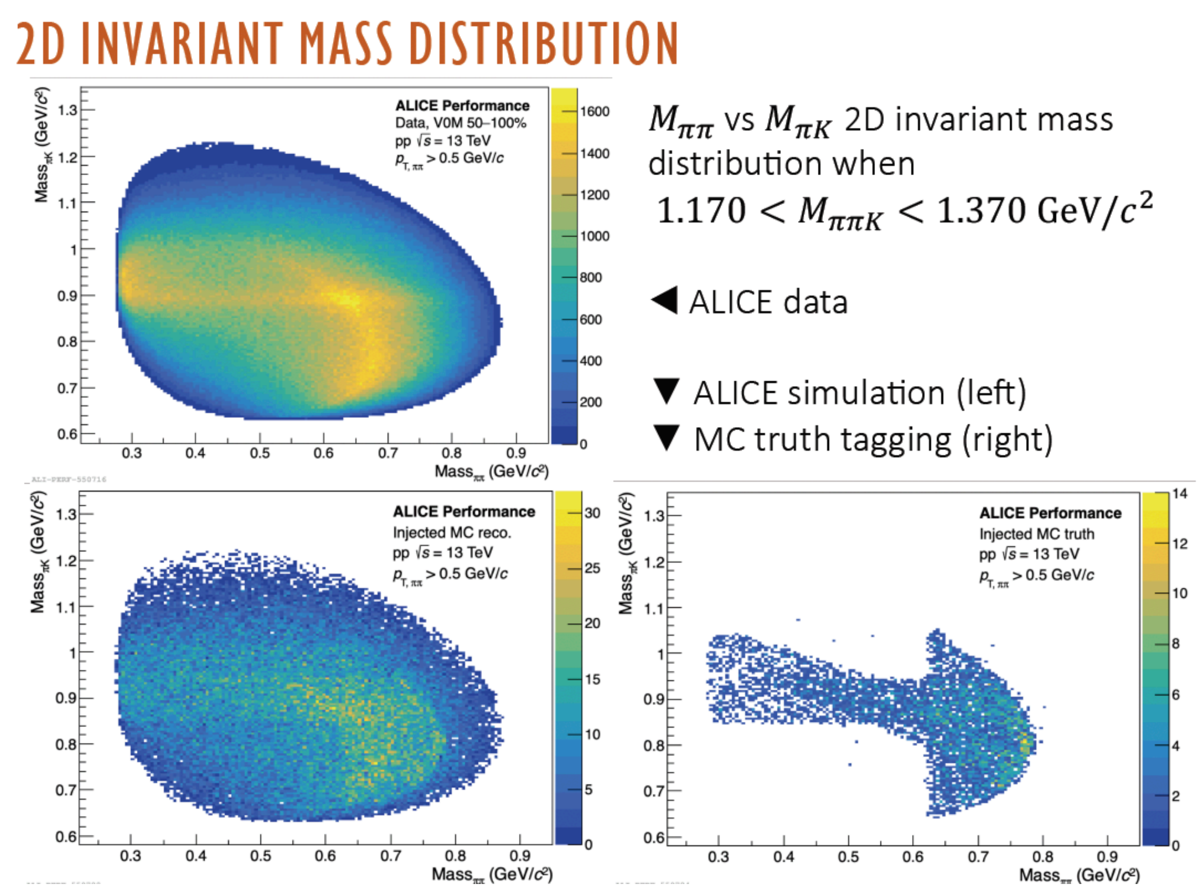
Chiral symmetry is gradually broken dynamically by the expansion of matter.

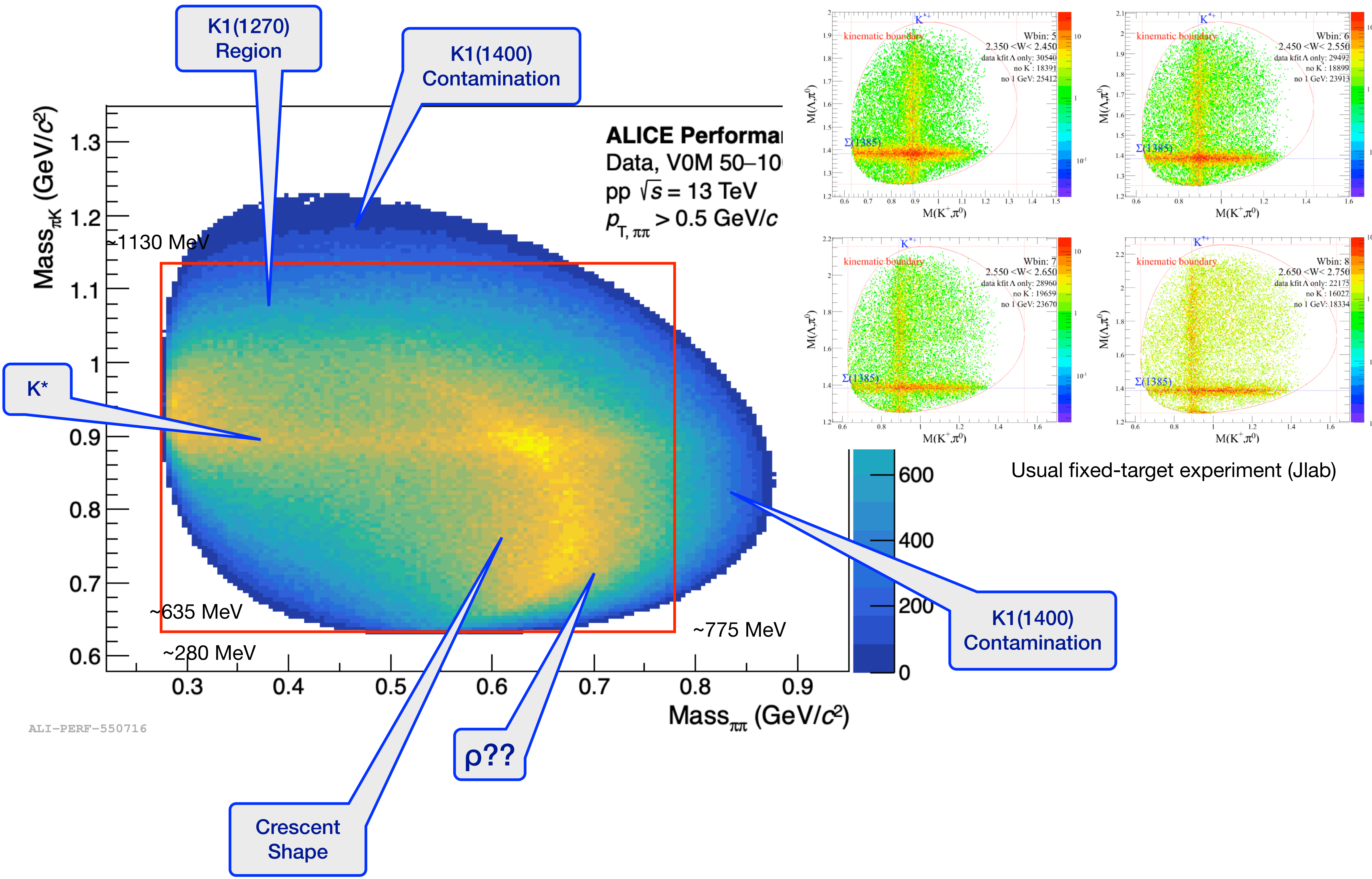
Hadrons' properties change: Masses, widths, decay couplings, etc.

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.).





Usual fixed-target experiment (Jlab)

Motivation

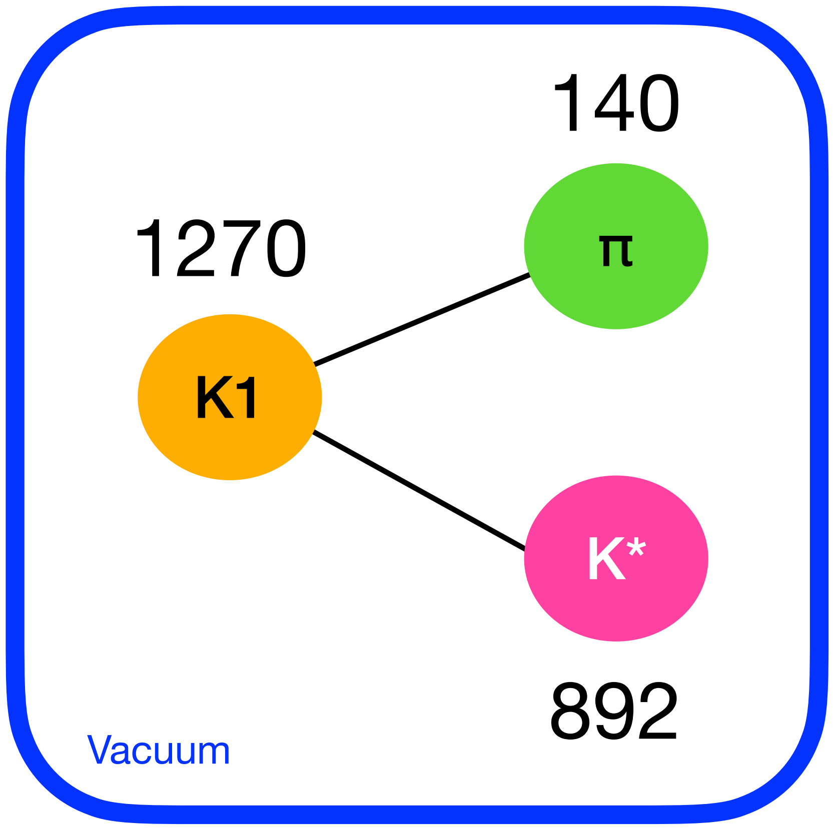
K1 meson (1270, 1+) is a chiral partner of K*(892, 1-): A-V degeneracy in hot medium via WSR

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 ± 13) %
Γ_2	$K_0^*(1430)\pi$	(28 ± 4) %
Γ_3	$K^*(892)\pi$	(21 ± 10) %
Γ_4	$K\omega$	(11.0 ± 2.0) %
Γ_5	$Kf_0(1370)$	(3.0 ± 2.0) %
Γ_6	γK^0	seen

Motivation

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

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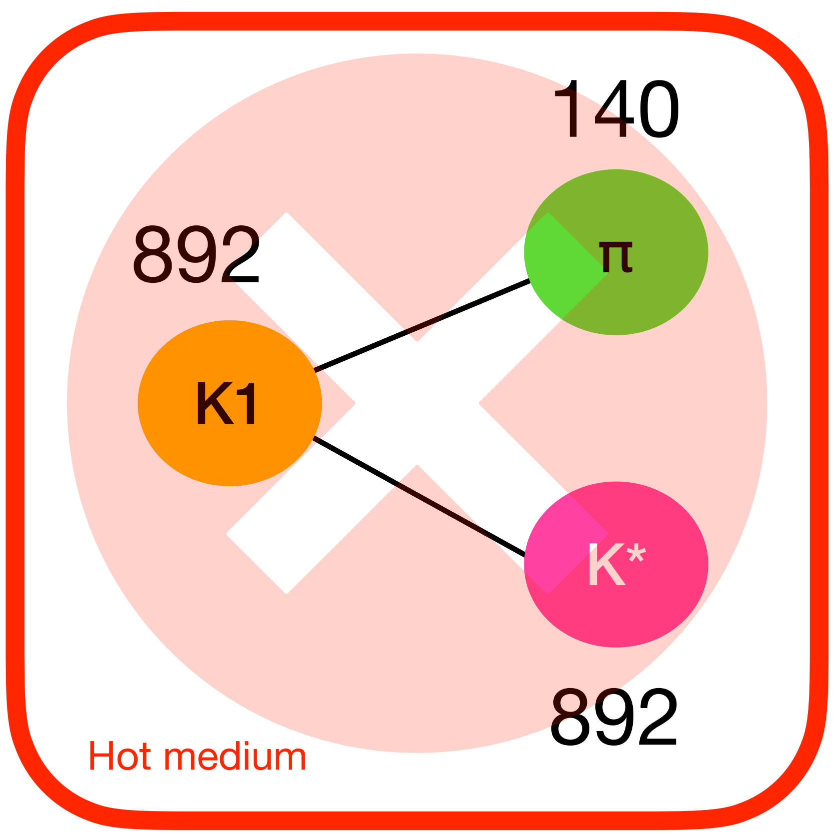

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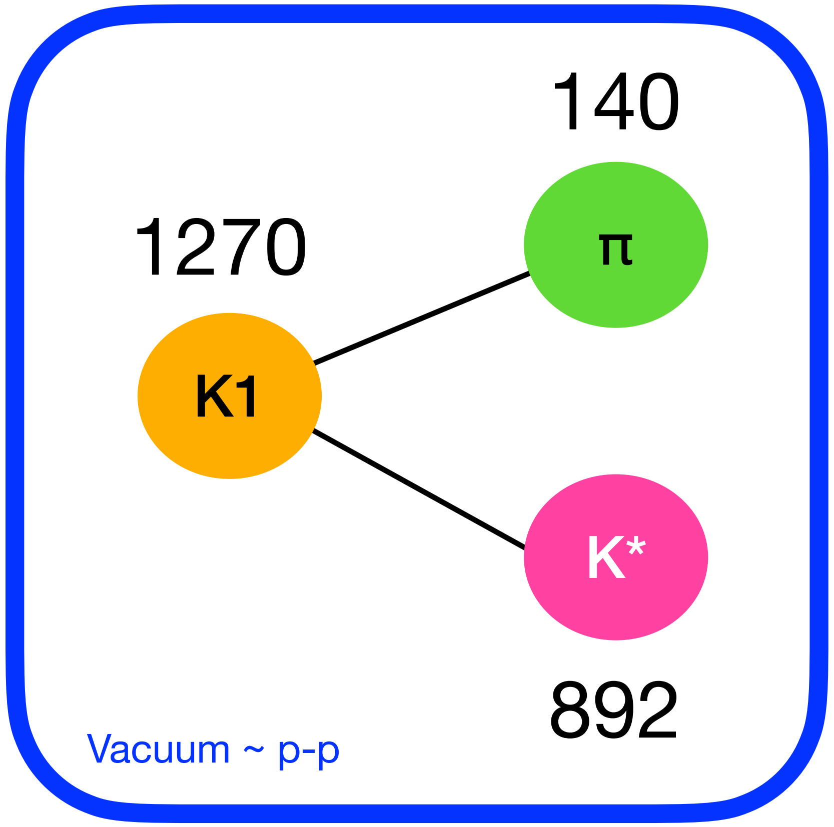
Γ_6	γK^0	seen

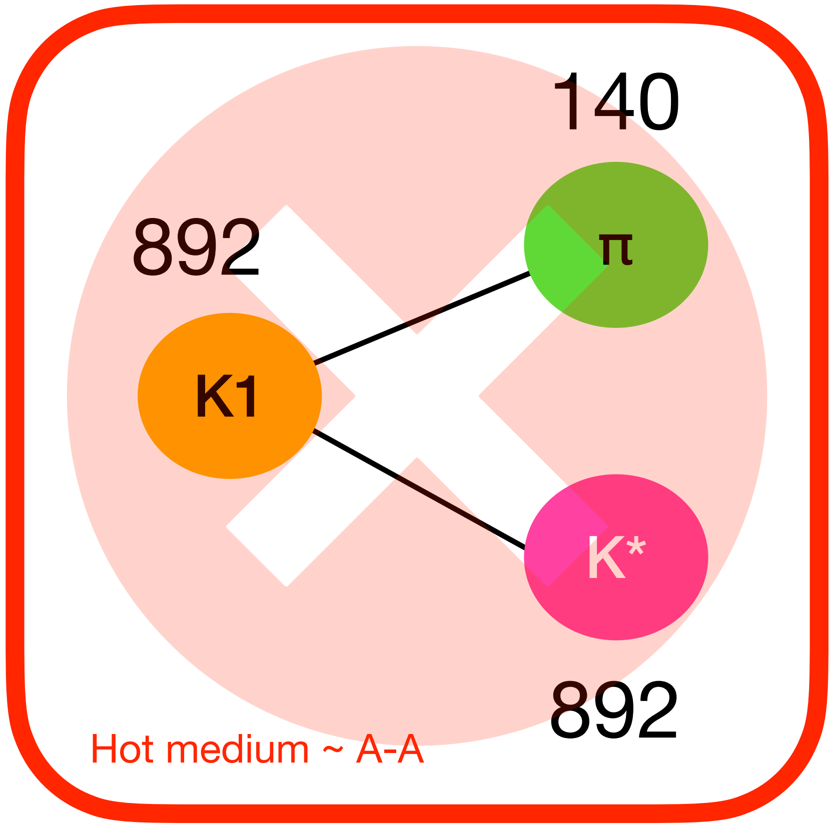
Motivation

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 K1 three-body decays on the Dalitz plot via the effective Lagrangian method: $K_1 \to \pi \pi K$

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 K1: coupled-channel method like FSI?

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

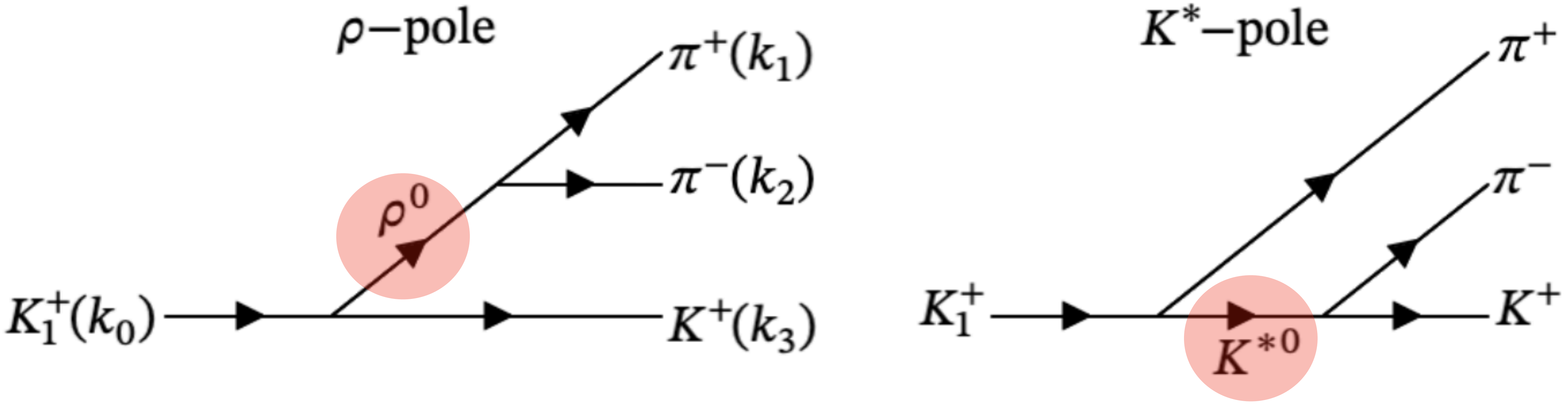
No cascading pions and kaons from different resonances: checking resonance production in ALICE

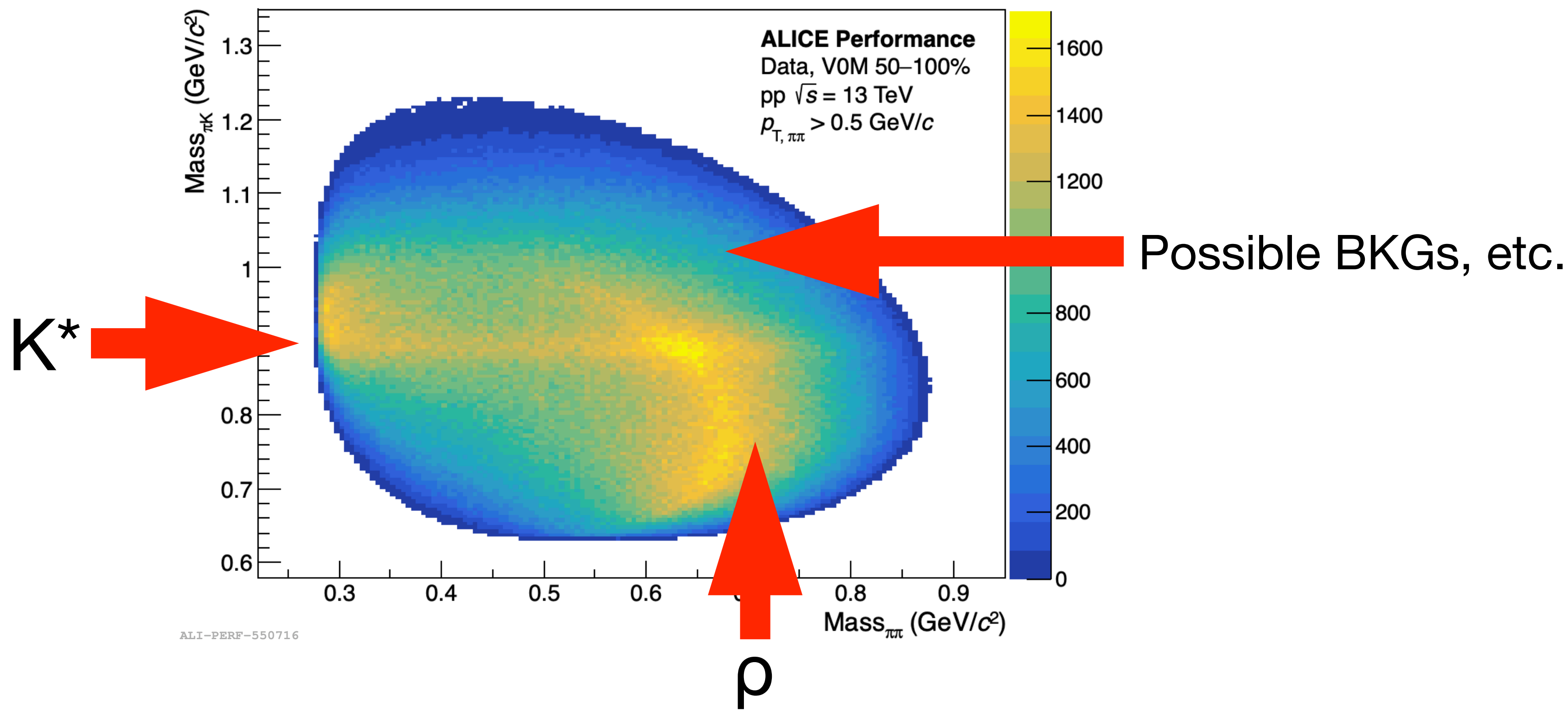
Unrealistic though but it captures physics of SCSB and opens a path to understand ALICE experiments

Model setups

Dominant contributions of K1+ three-body decay for I3=+1/2 channel

Comuting decay width

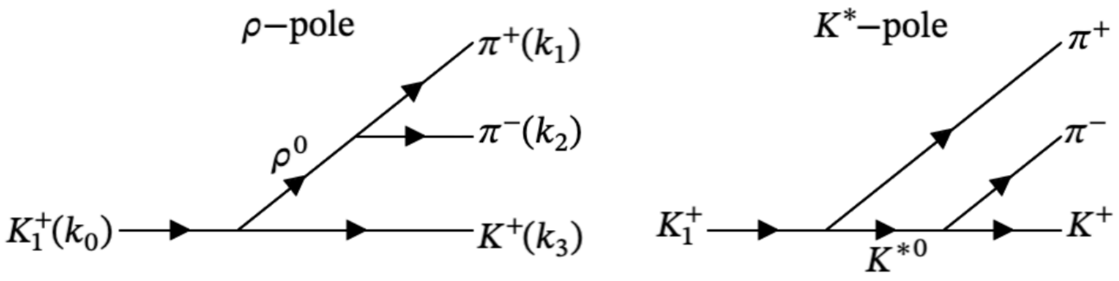




Effective Lagrangians for K1(1270) decay

Relative effective Lagrangians

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



Deacy invariant amplitudes

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

Deacy width

$$\Gamma_{K_1}^{(2)}\left(M_{K_1}\right) \equiv \frac{d^2\Gamma_{K_1}}{dM_{\pi^+\pi^-}dM_{\pi^-K^+}} = \frac{1}{3}\sum_{x=0,\pm1}\frac{M_{\pi^+\pi^-}M_{\pi^-K^+}}{64\pi^3 M_{K_1}^3}\left|\mathcal{M}_{\rho+K^*}(\epsilon_x)\right|^2.$$

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

$g_{\pi K^*K_1}$	$g_{\pi KK^*}$	$g_{K\rho K_1}$	$g_{\pi\pi\rho}$	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 qbar-q bound state, resulting in M_{meson} ~ $2M_q(T)$

Nonetheless, the PS meson does not follow this behavior: NG nature 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	~ Same	~ Same	~ Decreaing
Width of T	~ Same	~ Same	~ Decreaing

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

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

T-dependence of M_q

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

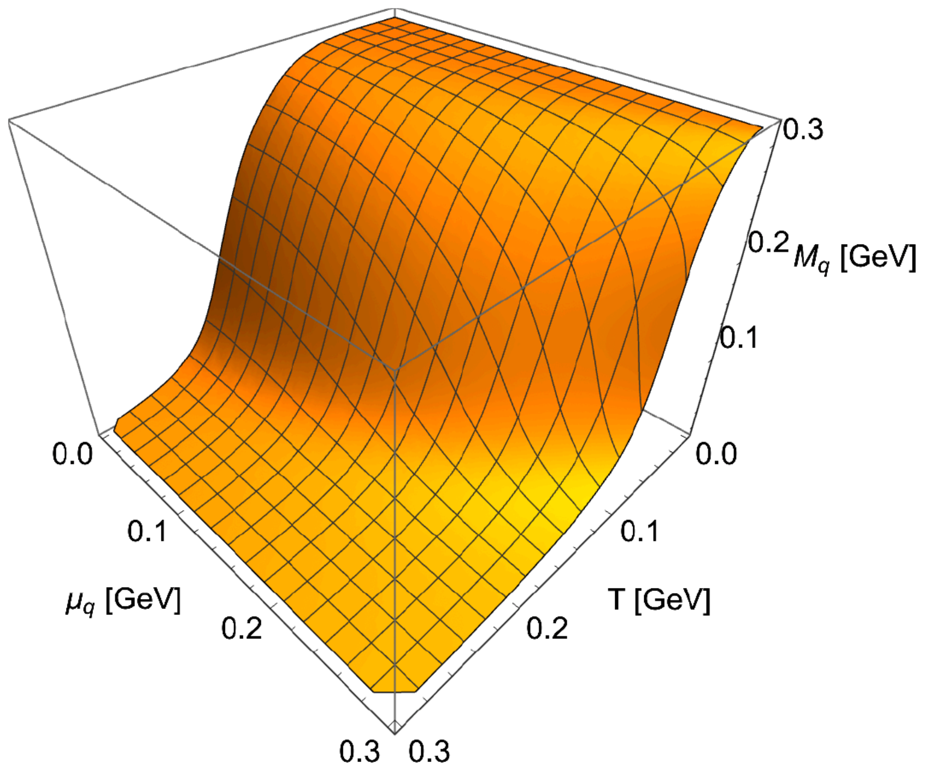
How to obtain $M_q(T)$: Lattice QCD, effective QCD-like models, Dyson-Schwinger, etc.

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

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

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

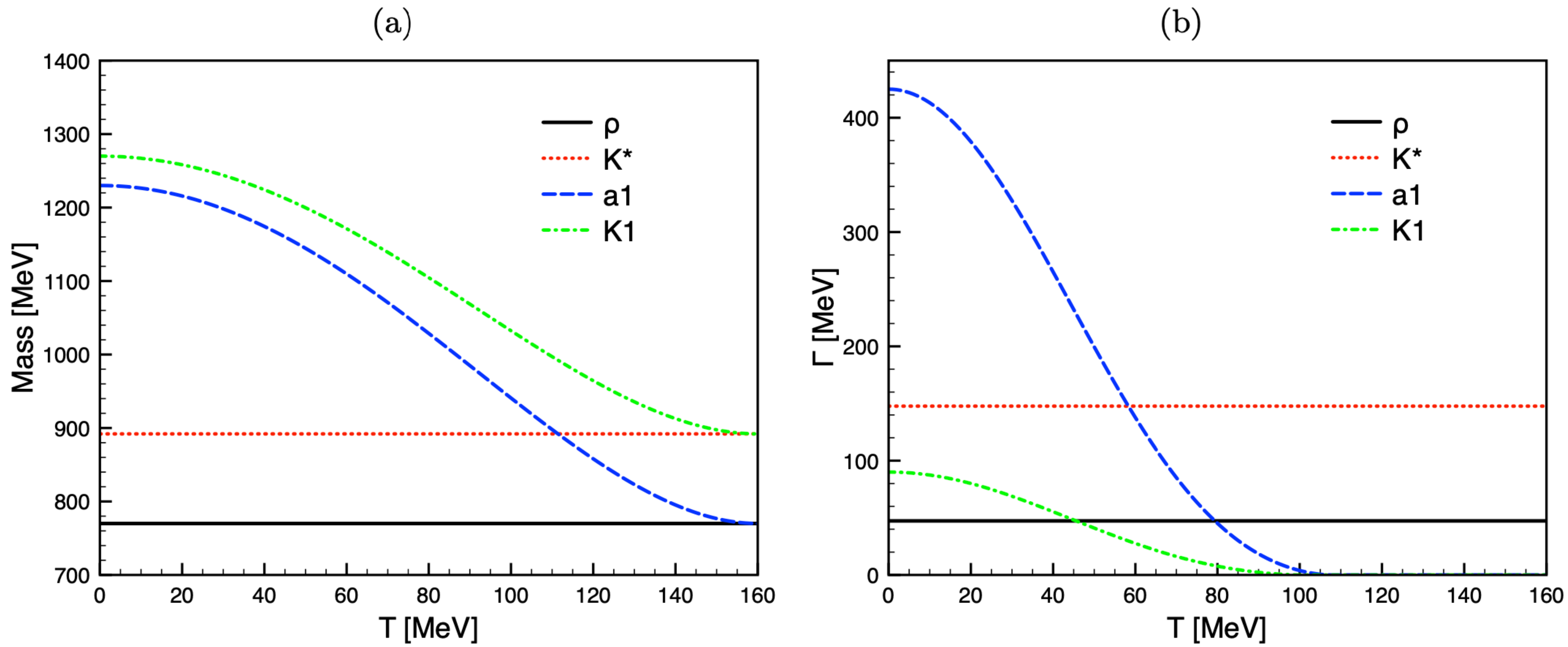
m_q [MeV]	Λ [MeV]	$G\Lambda^2$
5.25	631.4	2.14

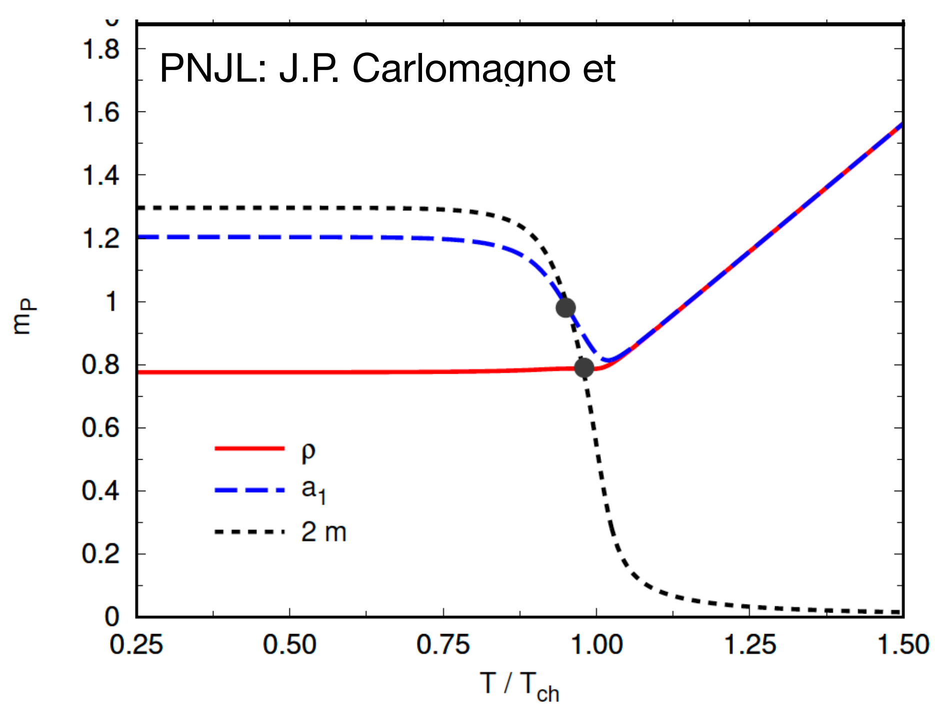


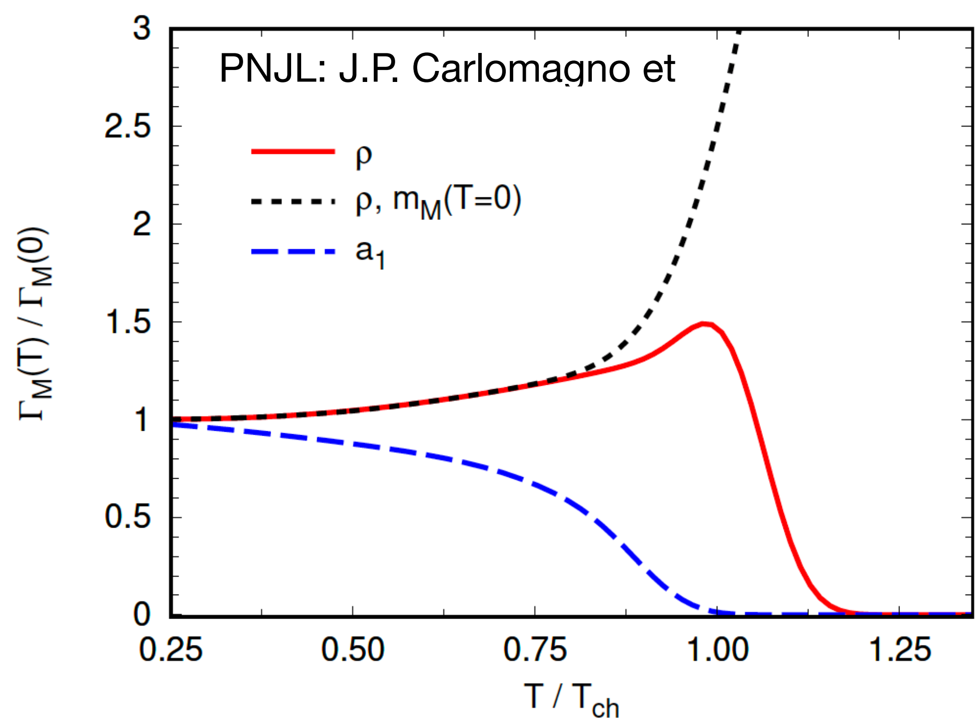
We observe that $M_q(T)$ follows ~ double Lorentzian parameterization

Numerical results

Mesonic properties at hot medium





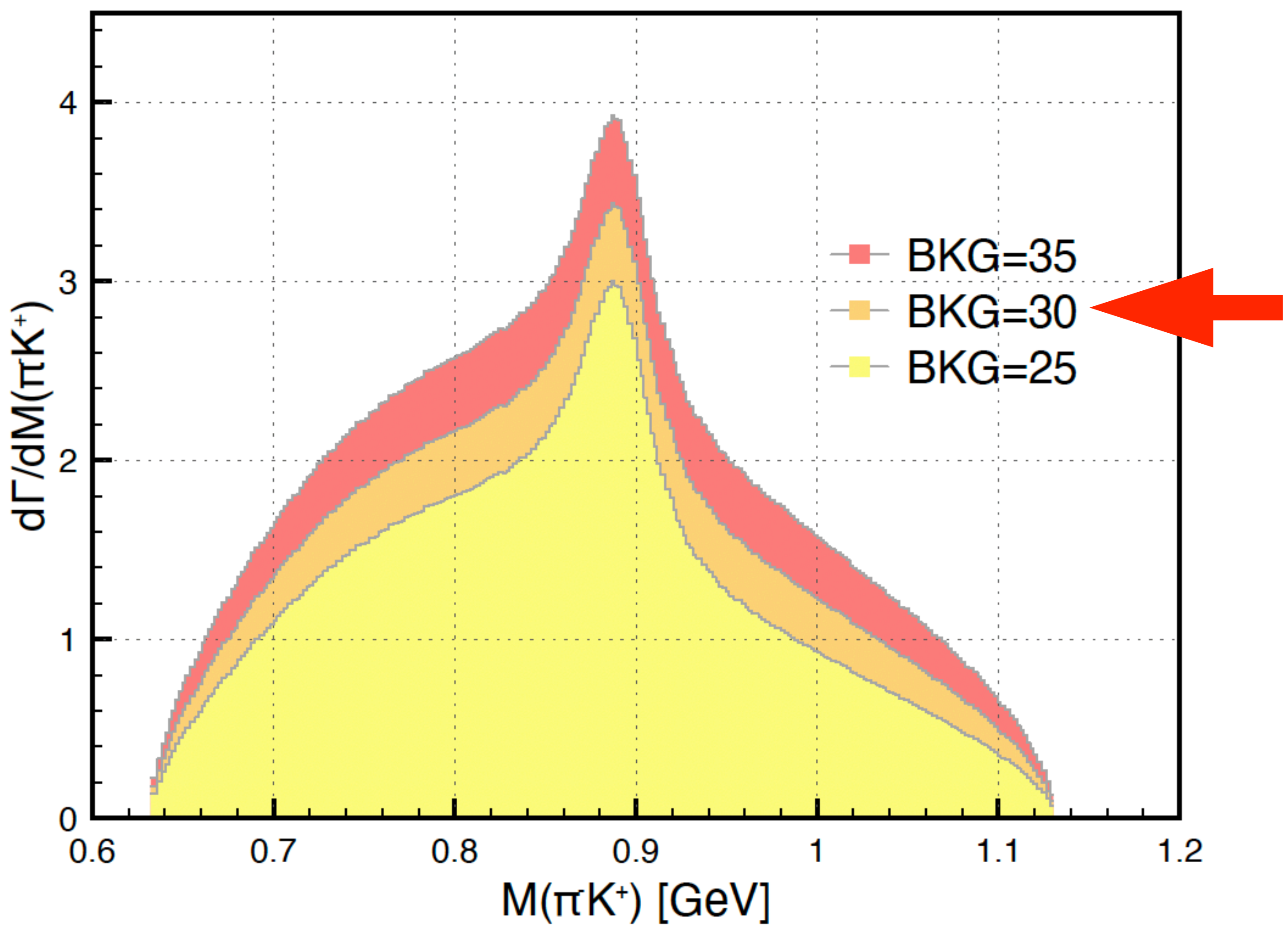


Numerical results

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

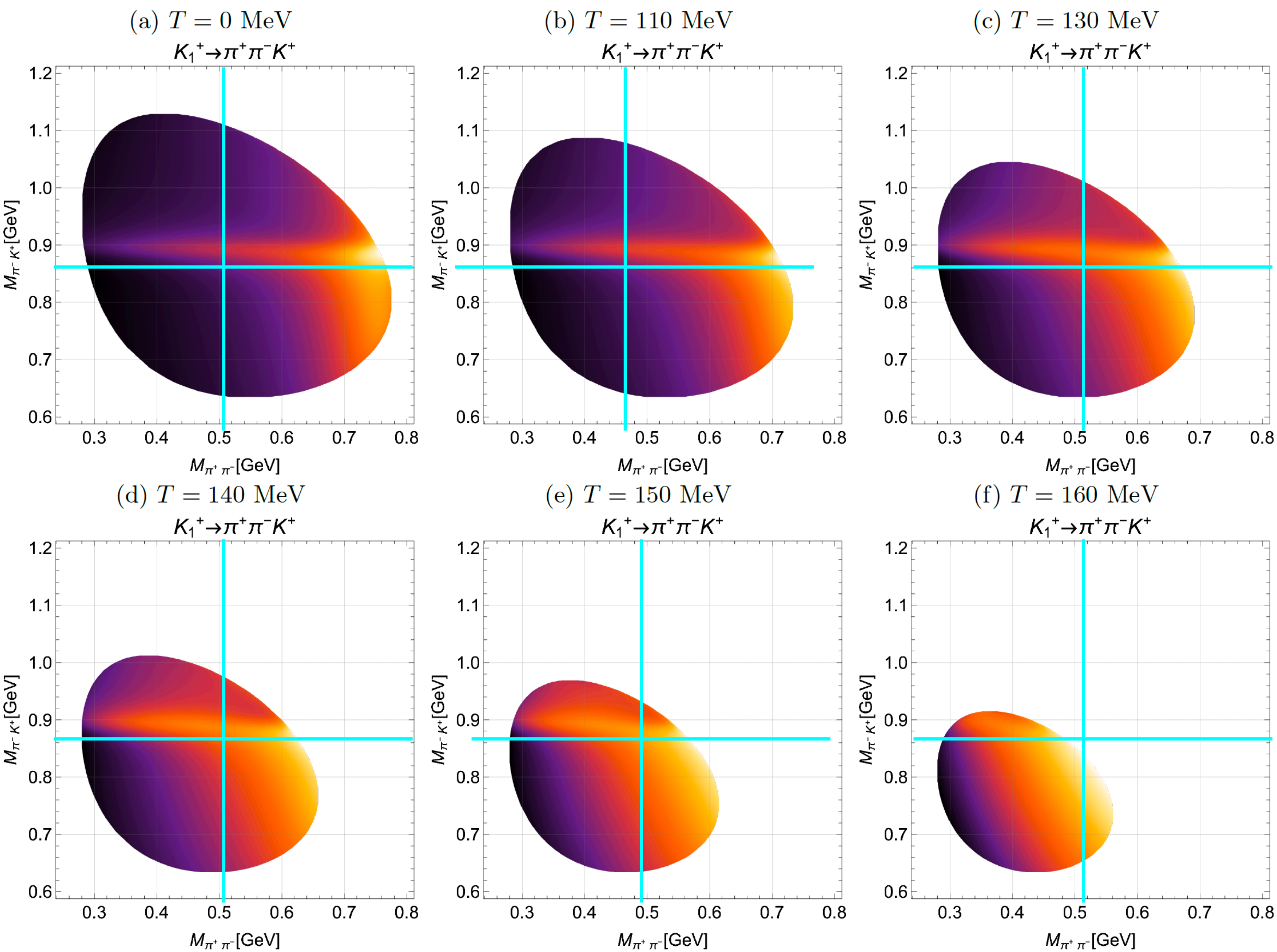
$$\begin{aligned}\mathcal{B}_{\rm est}[K_1(1270)^+ \to K^+\pi^+\pi^-] \;\approx\; & \mathcal{B}[K_1^+ \to K^+\rho^0]\mathcal{B}[\rho^0 \to \pi^+\pi^-] \\ + \; & \mathcal{B}[K_1^+ \to K^{*0}\pi^+]\mathcal{B}[K^{*0} \to K^+\pi^-] \\ + \; & \mathcal{B}[K_1^+ \to K_0^{*0}(1430)\pi^+]\mathcal{B}[K_0^{*0}(1430)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

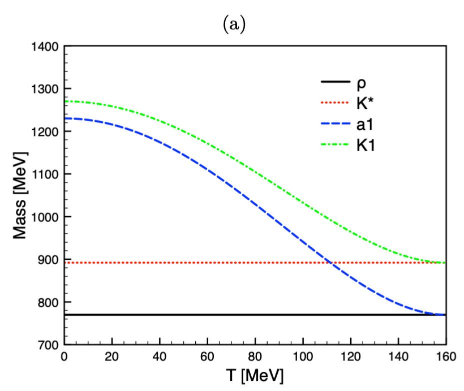
$$\Gamma^{\rm PDG}_{\rm est}[K_1(1270)^+ \to K^+\pi^+\pi^-] \approx 40\ {\rm MeV}.$$



Numerical results

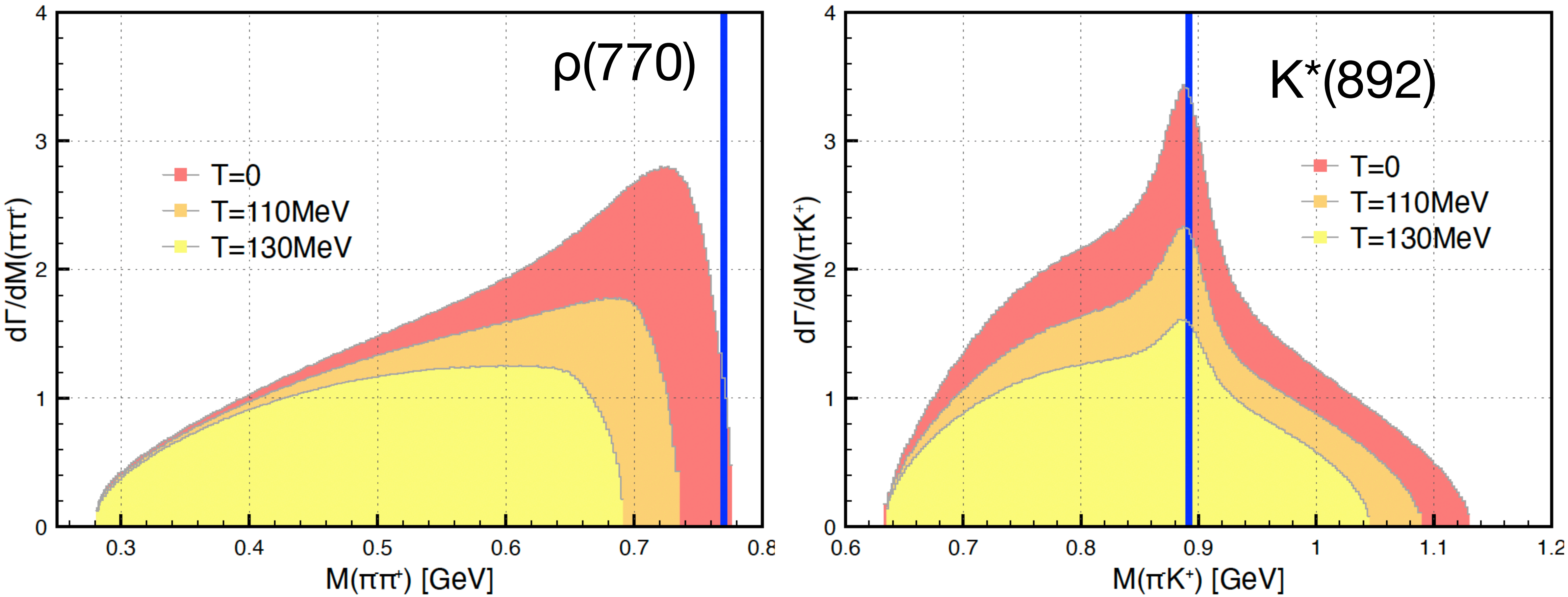
Dalitz plots at finite T: C(T) decreases w.r.t. T





Numerical results

Invariant masses at finite T

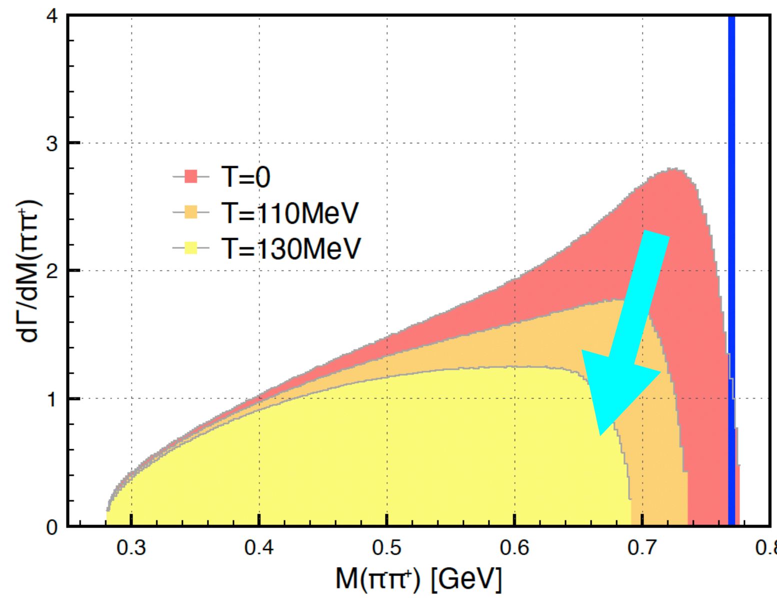


For π π channel, due to near phase-boundary effects, a peak observed below 770 MeV

Definitions of Shape observables of T

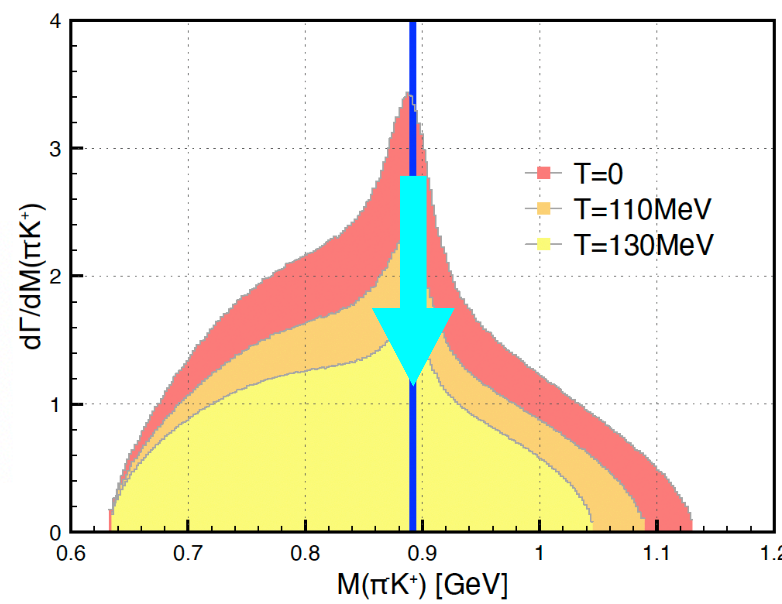
Spectral weight remains concentrated near the upper edge of the M(π+π–) distribution

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



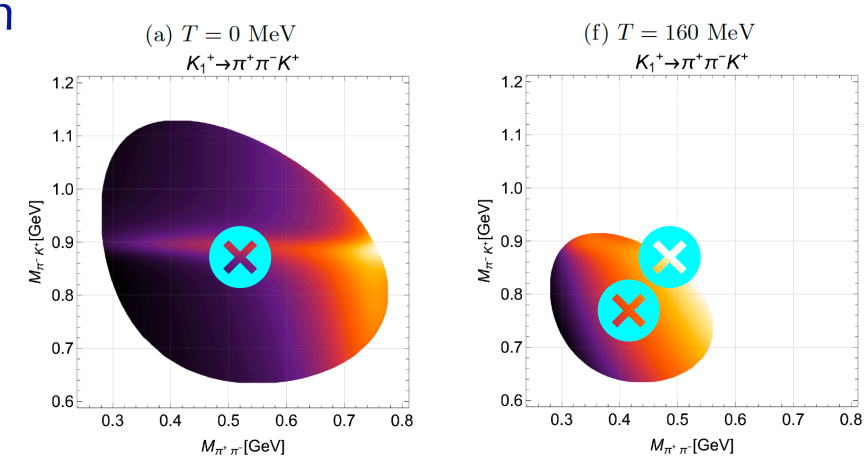
Reconstructed event population remains concentrated around the resonance-enhanced K* region

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



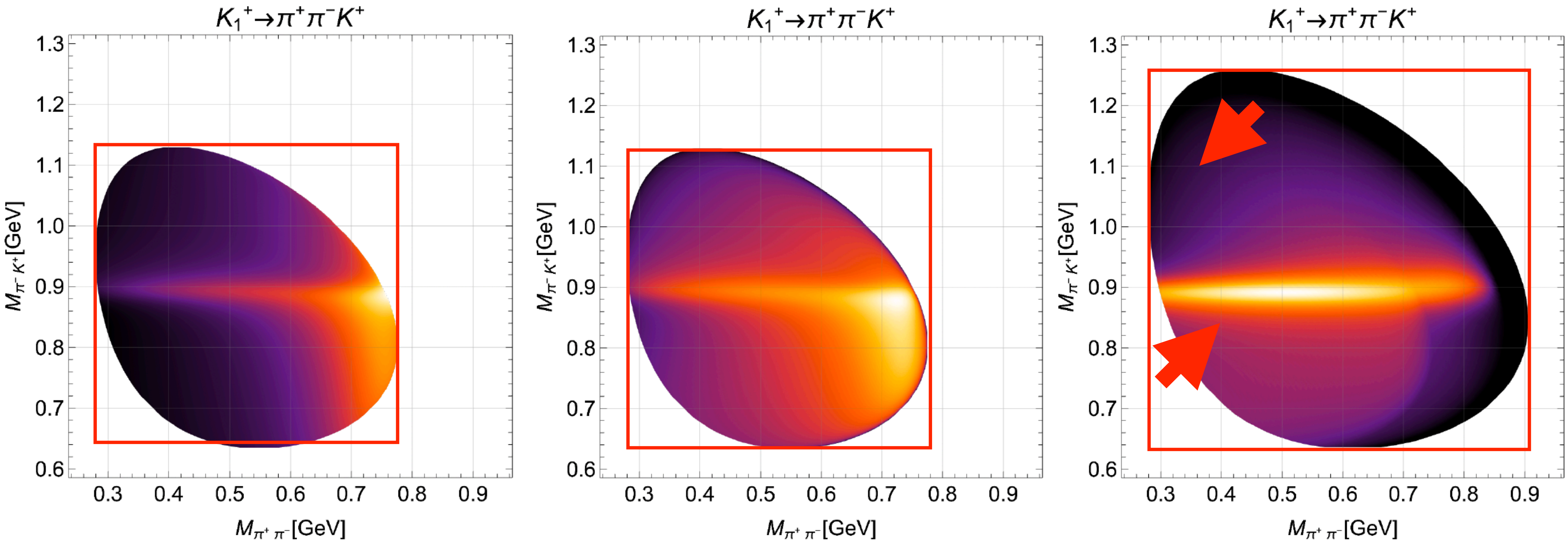
Dalitz event population remains globally compact around the vacuum reference centroid.

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



Numerical results

Dalitz plot for K1(1270) decay in vacuum and hot medium



Vacuum | **Thermal averge** | **With K1(1400)**

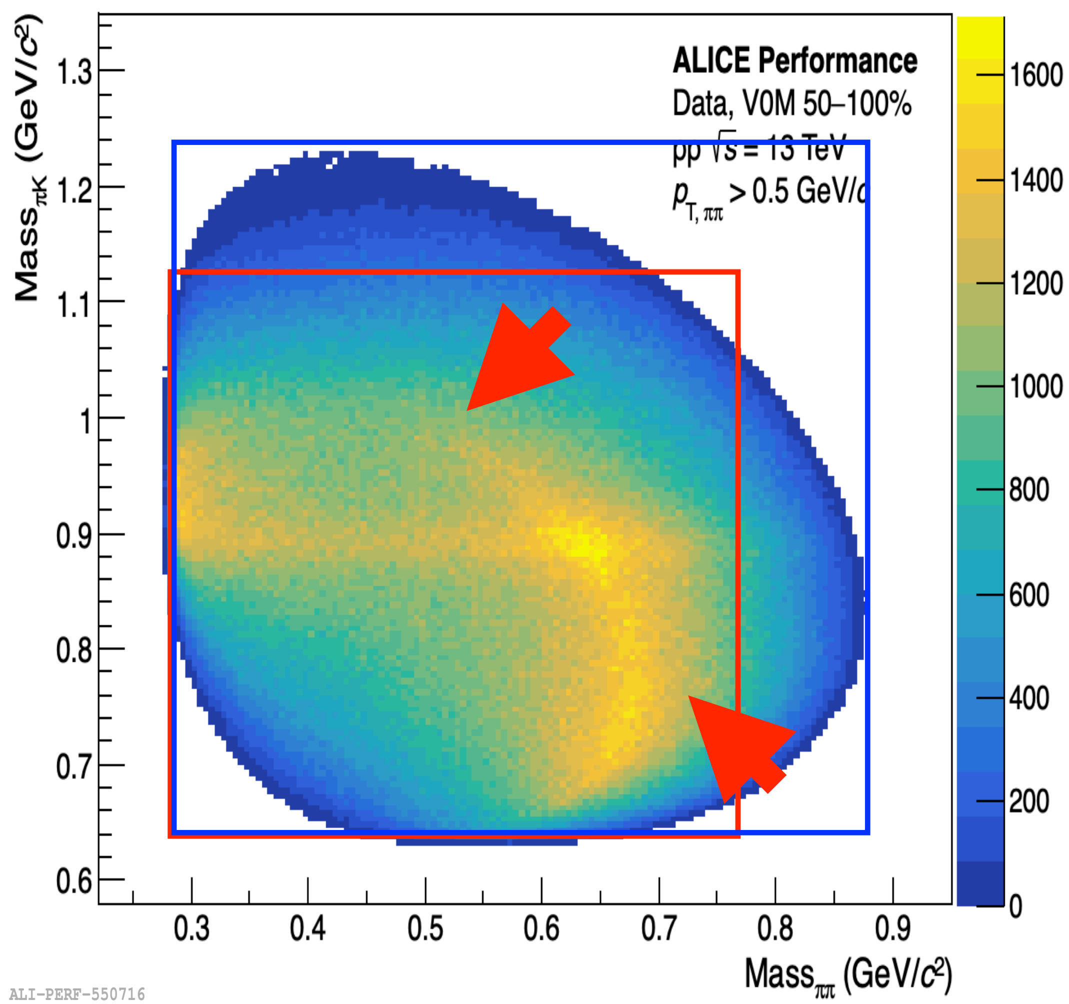
The thermal average from 160 MeV to 0 MeV provides a crescent structure by stacking phase spaces

ALICE experiment shows small but finite K1(1400) contamination

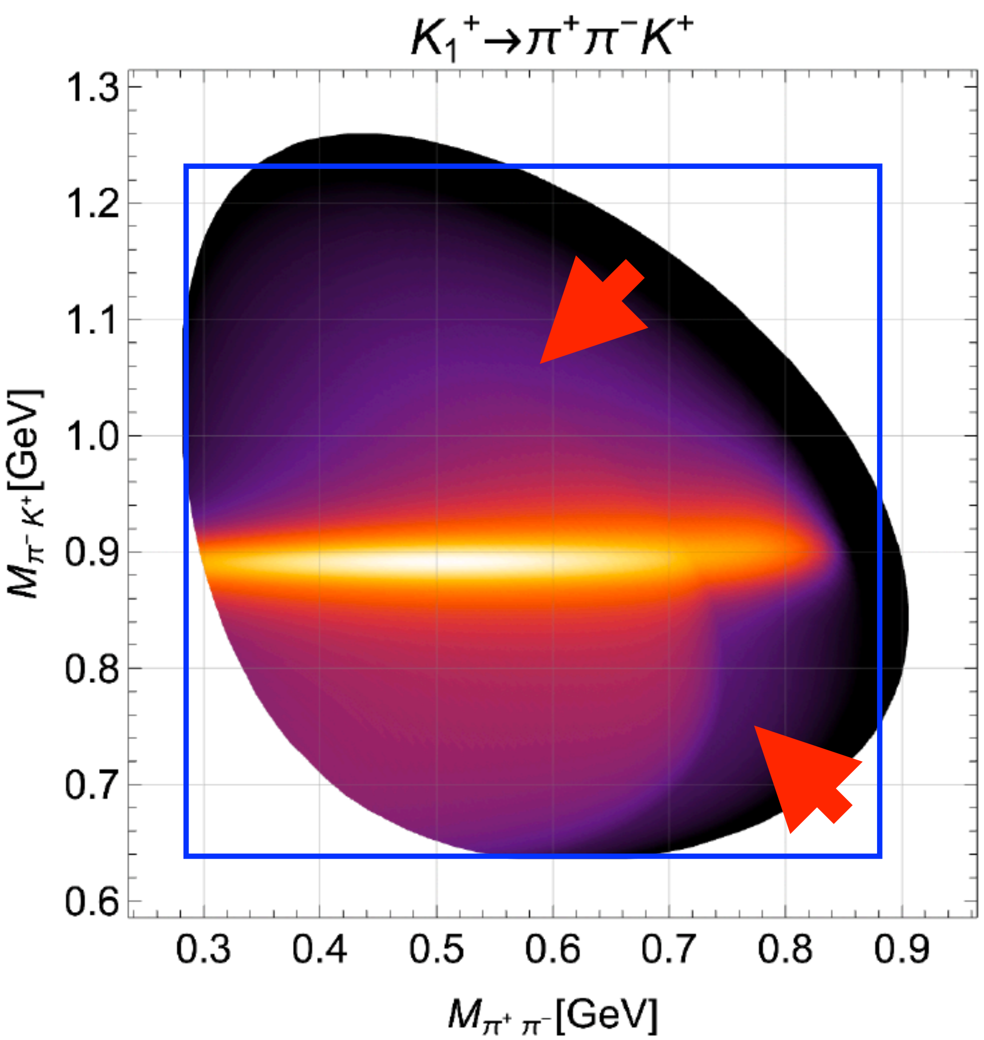
Still unknown structure and BKGs appear

Numerical results

Dalitz plot for K1(1270+1400) decay in vacuum and hot medium



ALICE by Ji



K1(1270)+K1(1400) w/ thermal average

Partial K1(1400) contamination looks like to explain those weird structures

Thus, the cut for K1(1400) becomes important to sinlge out K1(1270) in analyses

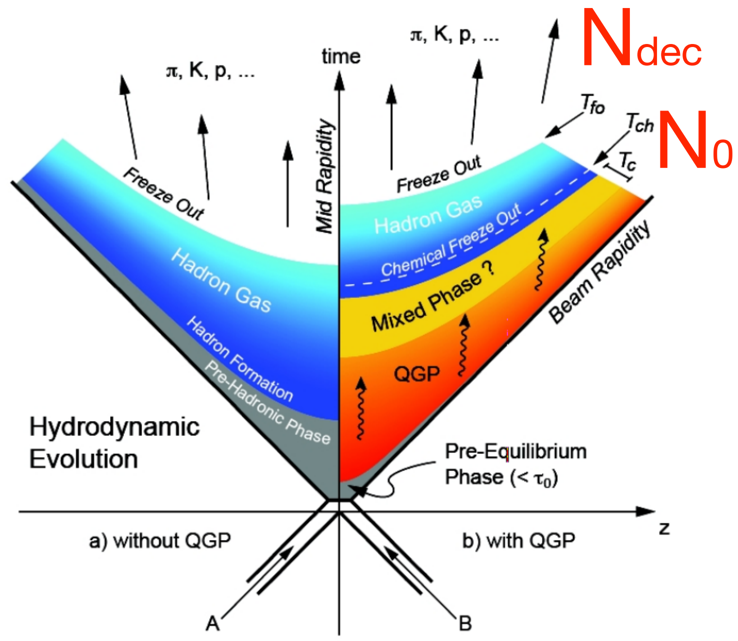
Analyses on K1 thermal decay (Just speculation not for experimetal analyses)

Temporal number of K1 mesons made in hot medium

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

And it solution becomes

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



Number of K1 meson decayings defined by

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

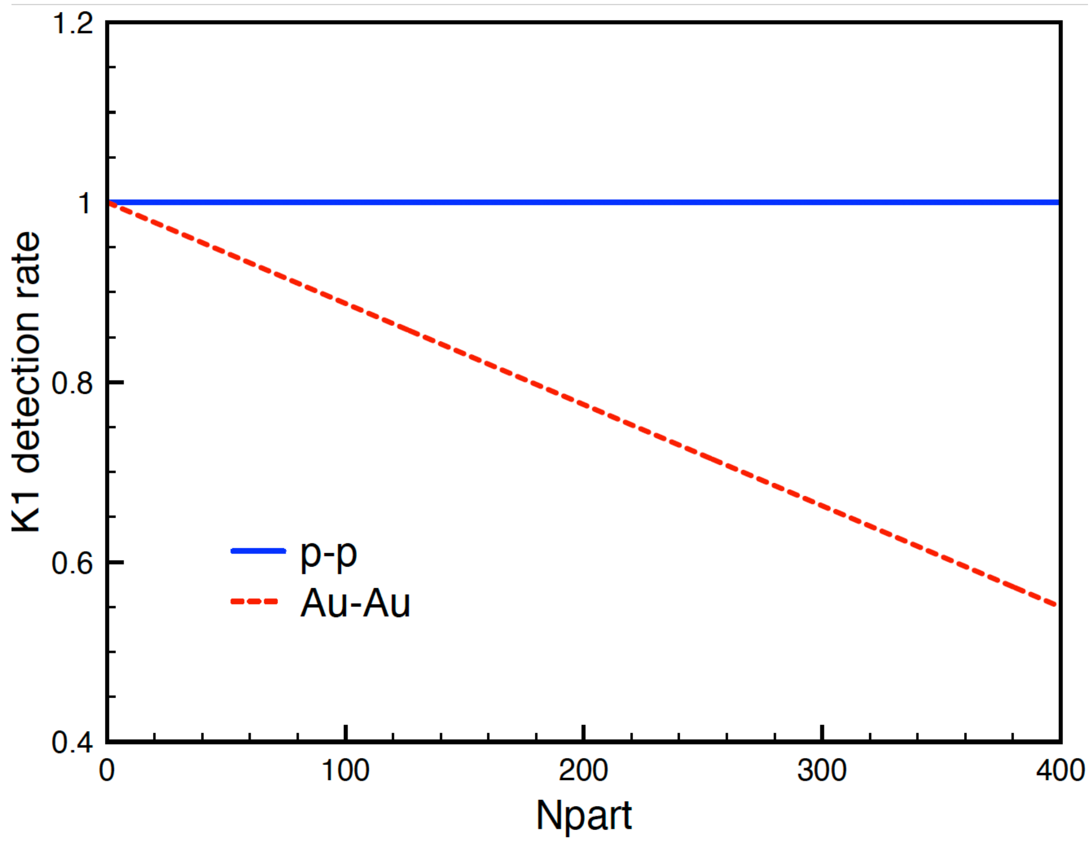
A ratio of A-A and p-p comparison, similar to nuclear modification factor

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

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

Analyses on K1 thermal decay

K1 deacy (I_z=+1/2) as a fucntion N_{part}



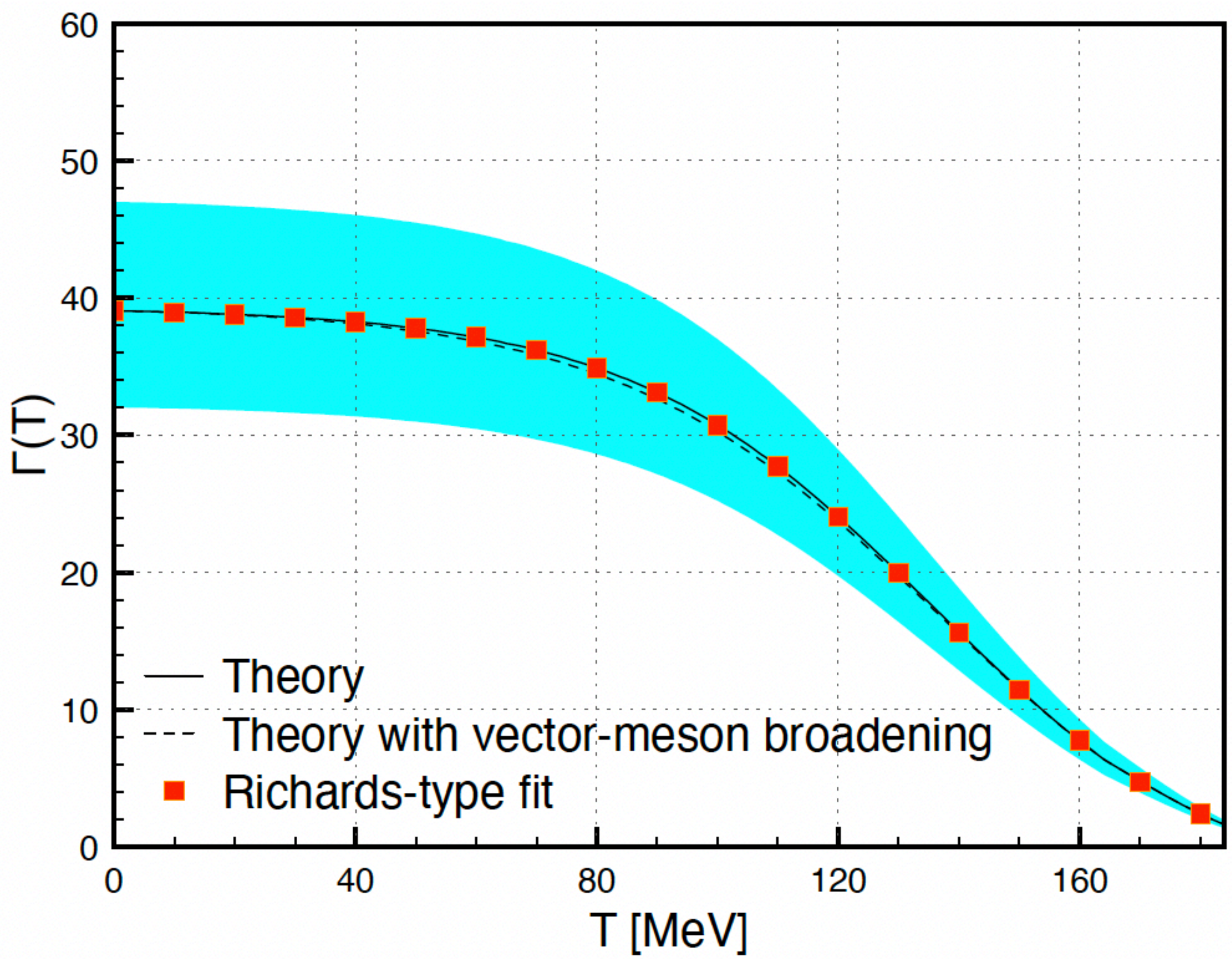
This is speculation

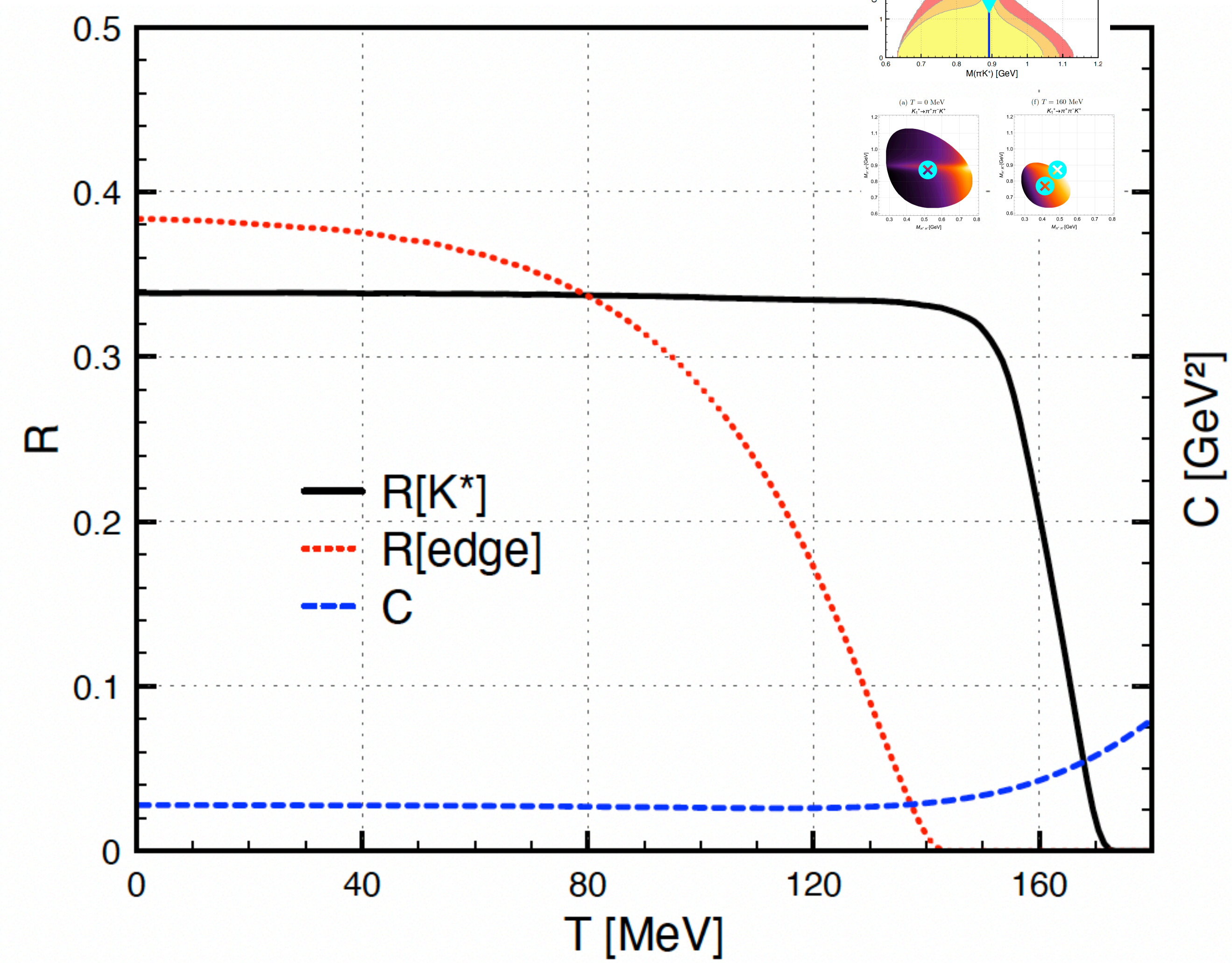
About 50% decrease in K1 deacy at Au-Au head-on collision

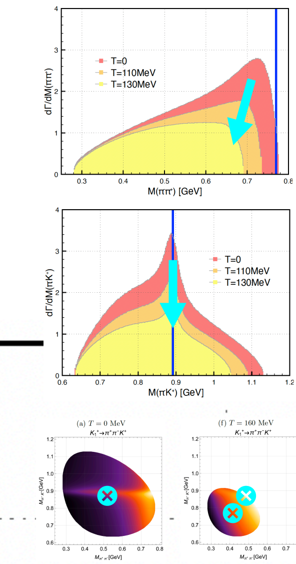
Can this observeation be found in ALICE experiment?

Analyses on K1 thermal decay

K1 deacy (Iz=+1/2) with width broadening and Normalized shape observables







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

Summary

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

The axial-vector meson K1(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 K1 decay and suppress it.

The three-body decay $K1 \to \pi\pi K$ is studied using an effective Lagrangian approach and Dalitz plot analysis.

A comparison of A–A and p–p collisions may reveal suppressed K1 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

xQCD 2026
14-17 July 2026
PKNU Busan Korea

- ☐ **Scientific program**

Ph.D school with 4 lecturers and ~40 students

Main prgram 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 srtructure**

- ☐ **INDICO**

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

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

- ☐ **Timeline**

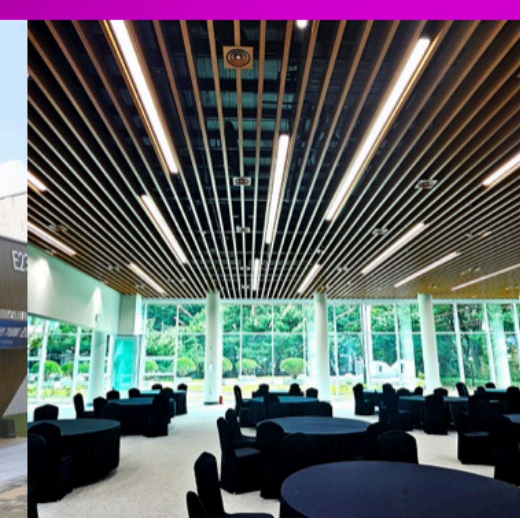
Registration opening: February 16, 2026 (Mon)

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 14, 2026 (Thu)



Thank you for your attention!

Acknowledgement

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