Heating triangle singularities in heavy ion collisions


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0 Abstract

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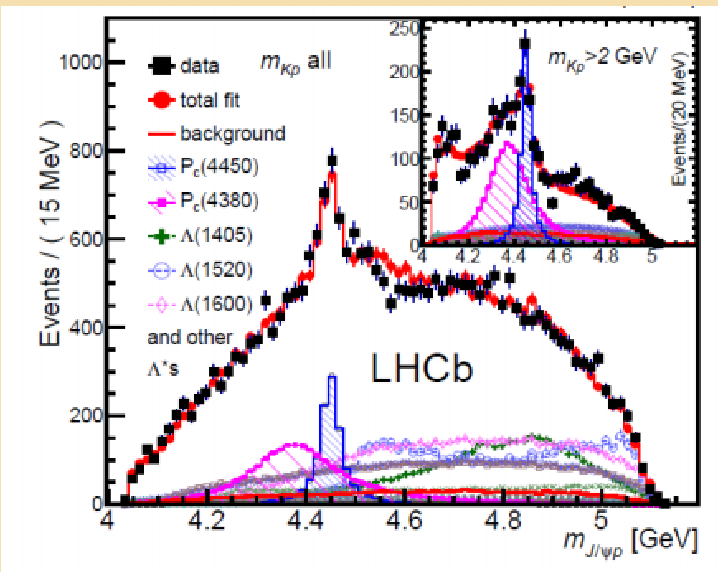
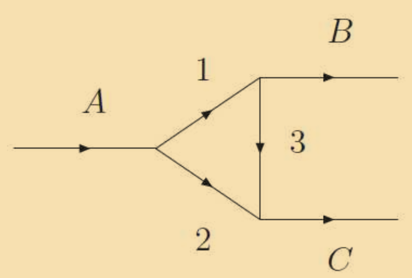
- We predict **triangle singularities of hadron spectroscopy** to be strongly affected in **heavy ion collisions** by examining various effects on the singularity-inducing triangle loop of **finite temperature** within the terminal **hadron phase**.
- Peaks seen in central heavy ion collisions are more likely to be **hadrons** than **rescattering effects** under two conditions. (1) The **flight-time** of the intermediate state must be comparable to the lifetime of the equilibrated fireball (else, the reaction mostly happens in vacuo after freeze out). (2) The medium sizeably modifies triangle-loop **particles mass or width.**
- When these (easily checked) conditions are met, **the medium quickly reduces the singularity**: at T about 150 MeV, even by two orders of magnitude, acting then as a spectroscopic filter.

1 New resonances or Landau singularities? A typical problem in hadron spectroscopy:



$$\Lambda_b^0 \to K^- \underbrace{(J/\psi p)}_{\text{LHCb pentaquark}}$$

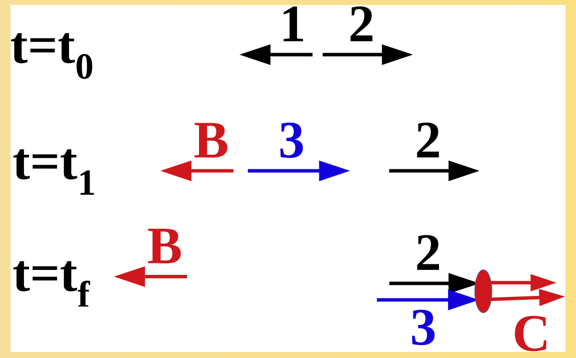


A pentaquark or a triangle singularity?

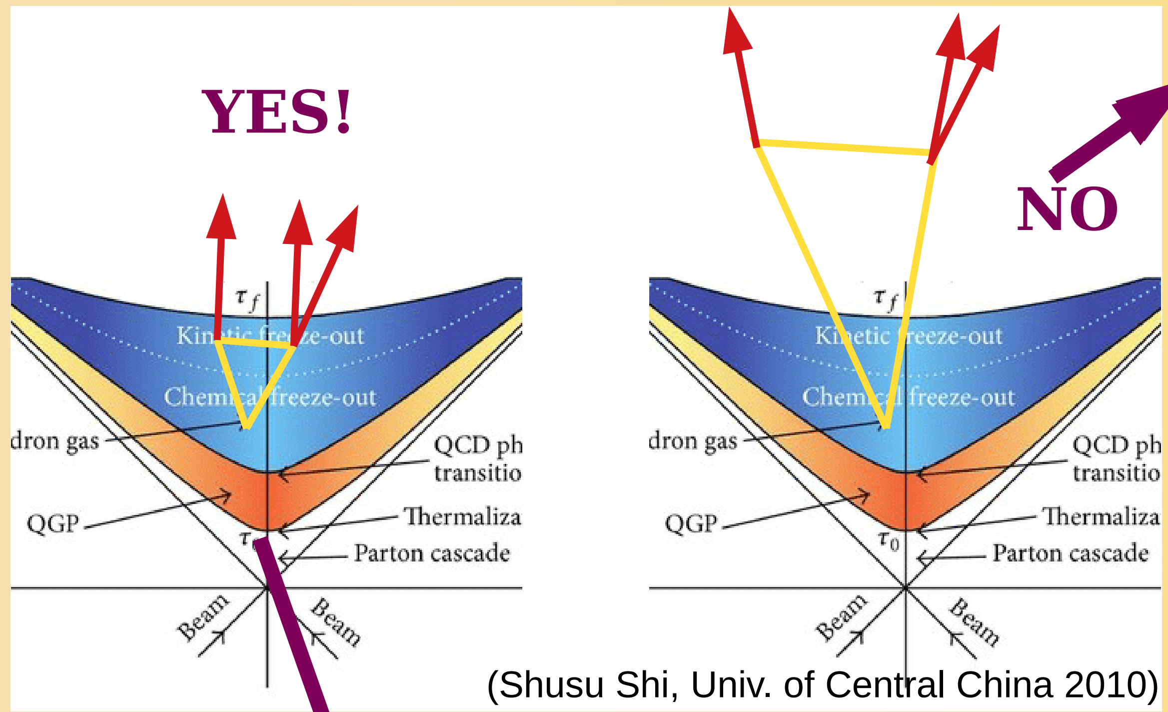
2 Triangle integral: singular when Coleman-Norton theorem applies

$$I_\triangle = i\int \frac{d^4q}{(2\pi)^4}\frac{1}{(P-q)^2-m_1^2+i\epsilon}\cdot\frac{1}{[(q^2-m_2^2+i\epsilon][(P-q-k)^2-m_3^2+i\epsilon]}$$

- All particles need to be on-shell
- All particles collinear
- Classically allowed: 3 can reach 2



3 Enough time in Heavy-Ion Collisions? Depends on reaction



A singularity coincident with $X(3872)$

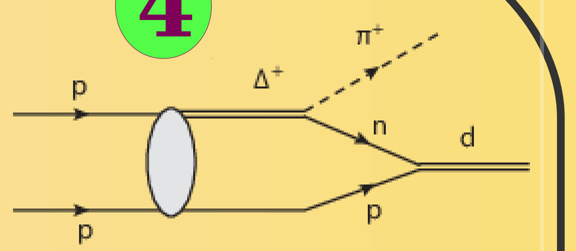
$$c\bar{c} \to \overbrace{(D^{*-}(1)D^{*0}(2))}^{(A)} \xrightarrow{D^0(3)} \overbrace{\pi^-}^{(B)} \overbrace{(J/\psi\pi^+\pi^-)}^{(C)}$$

$\tau_A \approx 2300$ fm >> 10 fm
no time!

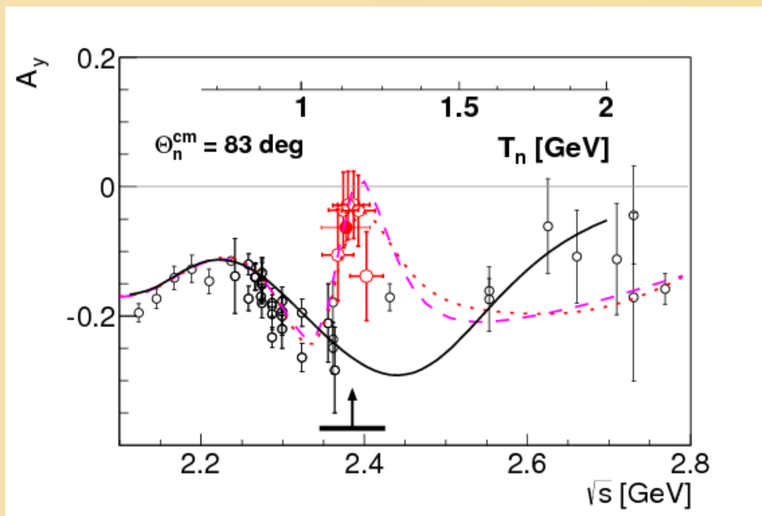
4

d^* deuteron/hexaquark a triangle singularity?

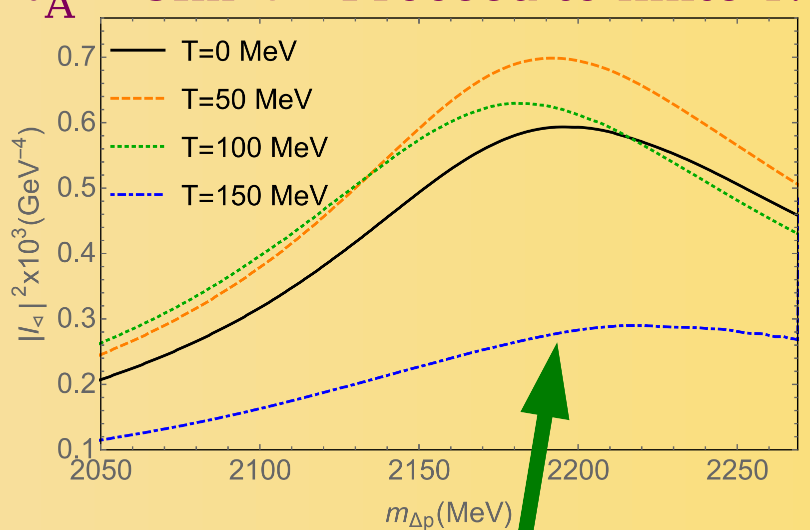
$$pp(A) \to \underbrace{\Delta(1232)^+(1)}_{\to\pi^+(B)n(3)} p(2) \xrightarrow{(2)+(3)} \pi^+(B)d(C)$$



$\tau_A \approx 5$fm ☺ Proceed to finite-T:



WASA-at-COSY Coll., P. Adlarson *et al.* PRL **112** (2014) 20, 202301

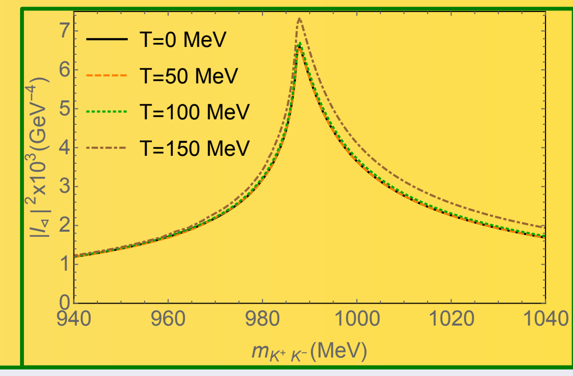


- **Triangle singularity drops out, but**
- **A true hadron visible @ RHIC**

5 Computed with thermal Matsubara formalism

$$\begin{aligned}I_\triangle \simeq\ & \frac{1}{2}\int\frac{d^3q}{(2\pi)^3}\frac{1}{8E_1E_2E_3}\frac{1}{\left(P^0-\tilde{E}_1-\tilde{E}_2\right)}\\ \times\ & \frac{1}{\left(P^0-k^0-\tilde{E}_2-\tilde{E}_3\right)}\frac{1}{\left(k^0-\tilde{E}_1+\tilde{E}_3\right)}\\ \times\ & \Big\{\left[1+2n_\beta(\tilde{E}_2)\right]\left(-k^0+\tilde{E}_1-\tilde{E}_3\right)\\ & +\left[1+2n_\beta(P^0-\tilde{E}_1)\right]\left(P^0-k^0-\tilde{E}_2-\tilde{E}_3\right)\\ & +\left[1+2n_\beta(k^0-P^0+\tilde{E}_3)\right]\left(P^0-\tilde{E}_1-\tilde{E}_2\right)\Big\}\end{aligned}$$

Another example: a singularity relevant for COMPASS $a_1(1420)$

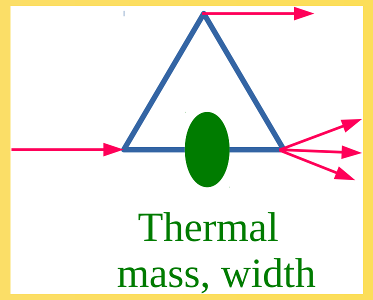


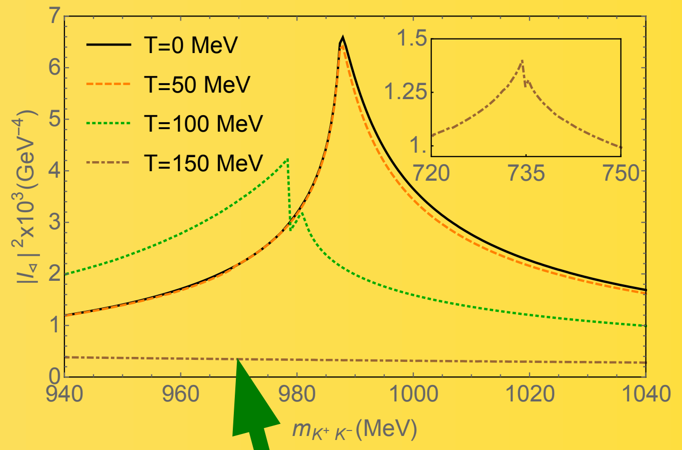
Apparently not much of an effect

$$A \to K^{*+}(1)K^-(2)K^+(3) \to \pi^0(B)(\pi^+\pi^-)/(\pi^0\eta)(C)$$

6 Thermal M, Γ are the key

T	0	0.05	0.1	0.15
$m_{K^\pm}$	0.49367	0.49367	0.4906	0.37
$m_{K^{*+}}$	0.89166	0.8877	0.8207	0.508
$\Gamma_{K^{*+}}$	0.0508	0.0509	0.0532	0.0588





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7 Acknowledgment

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