STRANGENESS FLUCTUATIONS FROM BROAD RESONANCES

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EMMI WORKSHOP 02 NOV 2015 GSI

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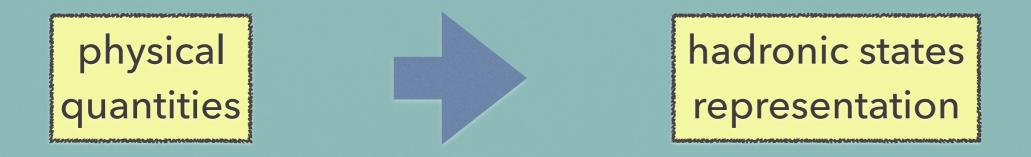
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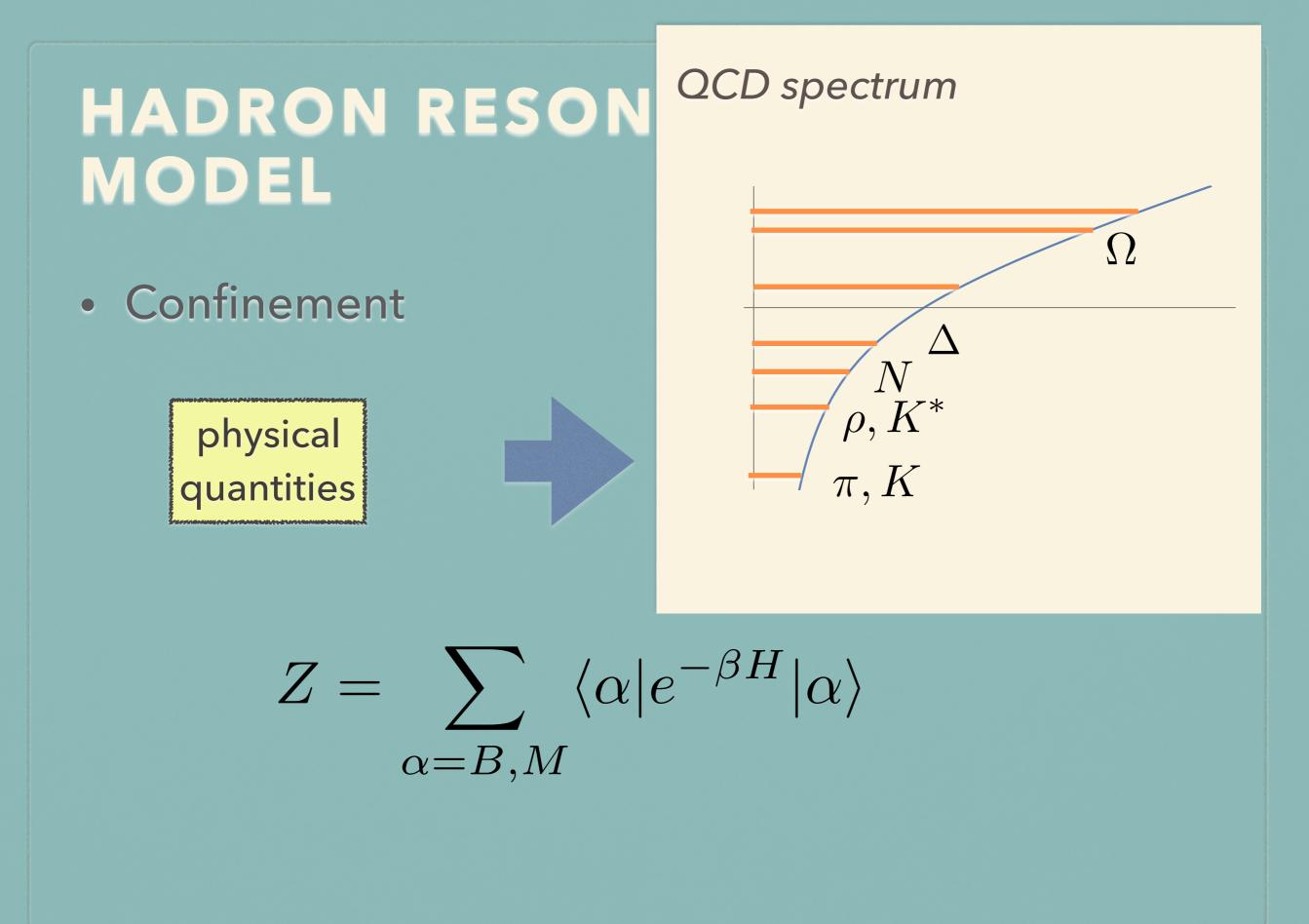
THE CASE OF MISSING STRANGENESS

HADRON RESONANCE GAS MODEL

Confinement



$$Z = \sum_{\alpha = B, M} \langle \alpha | e^{-\beta H} | \alpha \rangle$$



HADRON RESONANCE GAS MODEL

• Ground states $\pi, K, P, N...$

- Resonance formation dominates thermodynamics
- Resonances treated as point-like particles

$$P = T \sum_{\alpha = M, B} g_{\alpha} \int \frac{d^{3}k}{(2\pi)^{3}} \mp \ln(1 \mp e^{-\beta\sqrt{k^{2} + M_{\alpha}^{2}}})$$

an effect on the dissipative evolution; the frame describe these effects has been developedants+Ma be addressed in future work. Other rapidity dependent initial conditions are discussed in Ref. 36

In Fig. 1 we show the free tent-by the initial energy per unit rapidit justed to reproduce pathible multi dynamic evolution. This and all to Au+Au collisions at RH100 checgies midrapidity. The best fit is given b (NBD) distribution, as predicted in framework [37]; our result adds fur previous non-perturbative study [Glasma NBD distribution (Hts) tions over RHIC and LHC energies that our picture includes fluctuation

We now show the energy densi transverse plane in Fig. 2. We com model and to an MC-Gomber mo reproduce experimental data [4.8] In the latter ery participant nucleon? A Gaussianed Street

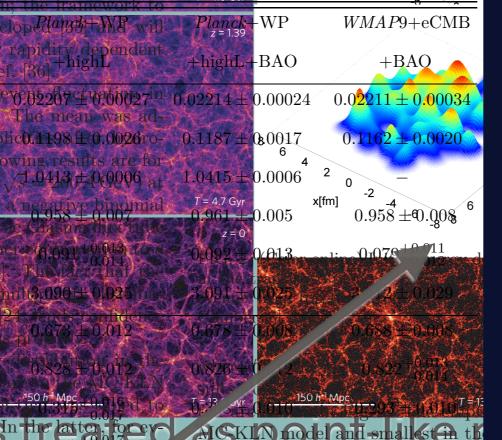
density is added. The parameters are an expanded of the 40 orders dimages with the base of the standard and model.

triangularity ε_3 of all models. Final flow of hadrons v_n is to good approximation proportional to the respective ε_n [39], which makes these eccentricities a good indicator of what to expect for v_n . We define

$$\varepsilon_n = \frac{\sqrt{\langle r^n \cos(n\phi) \rangle^2 + \langle r^n \sin(n\phi) \rangle^2}}{\langle r^n \rangle},$$

(6)

with the plaquette given extremely unit is a combination of CMB data only <math>- Planck temperature The explicit lattice expressions for the possible for the plus high-resolution data from ACT tric field in the second termanansperfound in the SDSS. We note that the boost-in BOSS, 6 dF, and WiggleZksurveys. For comparison the last column glects fluctuations in the repodist the final nine-year resplts from the WMAP satellite, combined flow at mid-rapdity is donwithtedelsaufle BAO idatai and high-resolution CMB data (which they transverse plane but flucturation GMB) a Univertainties have shown at 68% confidence. -2



d distribution of galaxies in the same corresponding times obtained by ni-analytic techniques to simulate tion in the Millennium simulation⁵ is weighted by its stellar mass, and ale of the images is proportional to n of the projected total stellar mass. atter evolves from a smooth, nearly tribution into a highly clustered state, the galaxies, which are strongly m the start.

particle data group July 2014 PARTICLE

y[fm]

PHYSICS BOOKLET

Extracted from the Review of Particle Physics K.A. Olive et al. (Particle Data Group), Chin. Phys. C, 38, 090001 (2014) See http://pdg.lbl.gov/ for Particle Listings, complete reviews and pdgLive (our interactive database)

Chinese Physics C

Available from PDG at LBNL and CERN

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NICS

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density is added. Its parameters are the same to ne 40 orders dienagestude. Ato the logice Sertin stelle destudent in stelle destudent account of observations of

odel. We next determine the participant entropy of the sense that the more luminous supernovae to sense the participant entropy of the sense that the more luminous supernovae to somological parameter values. Further data releases from WMAP We next determine the participant entropy of the sense that the more slowly are preferentially found in spiral galaxies. and rutario constraints such as PLANCK will shed light on these the participant entropy of the sense that the more slowly are preferentially found in spiral galaxies. is no parameter dependence of eccentricities and trian-

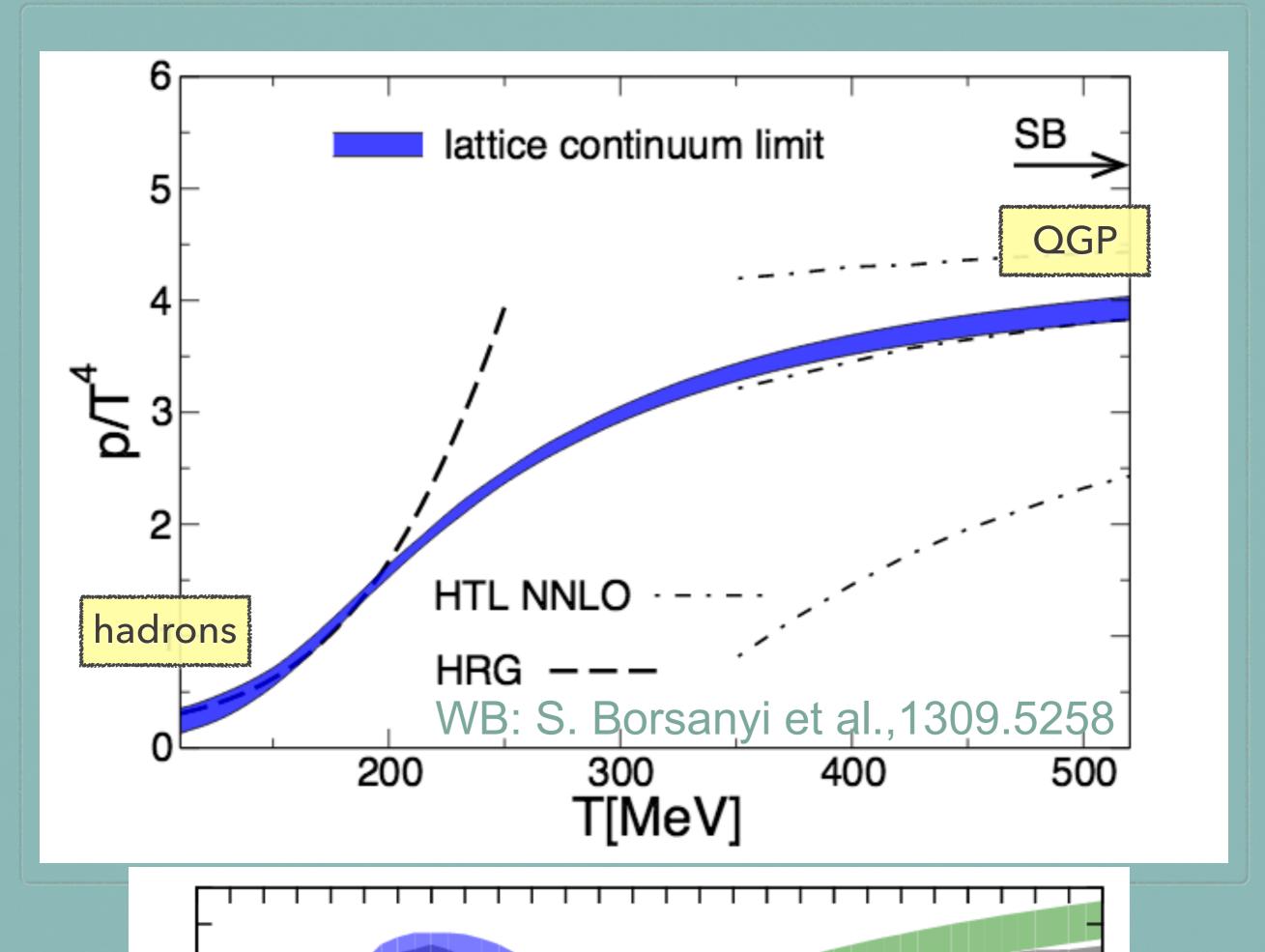
> gularities in the Instant change and the shown in Fig. 3. It is reassuring that both are close to those from the MC-Glauber model because the latter is tuned to reproduce data even though it does not have dynamical QCD fluctuations.

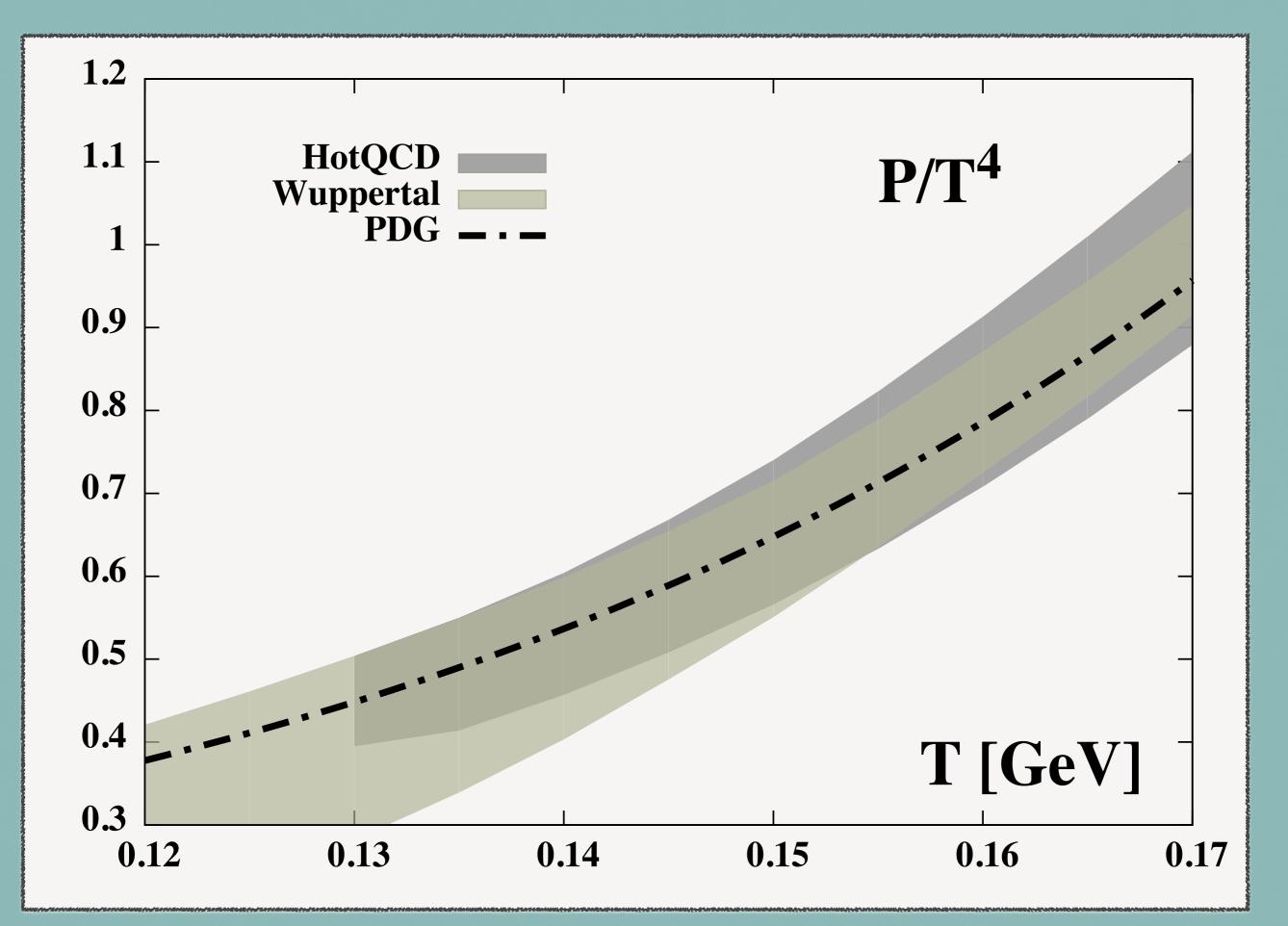
We have checked that our results for caller are inconsi

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FLUCTUATIONS

Baryon sector

$$P = T \sum_{\alpha = \mathcal{M}, B} g_{\alpha} \int \frac{d^3k}{(2\pi)^3} \mp \ln(1 \mp e^{-\beta\sqrt{k^2 + M_{\alpha}^2}})$$

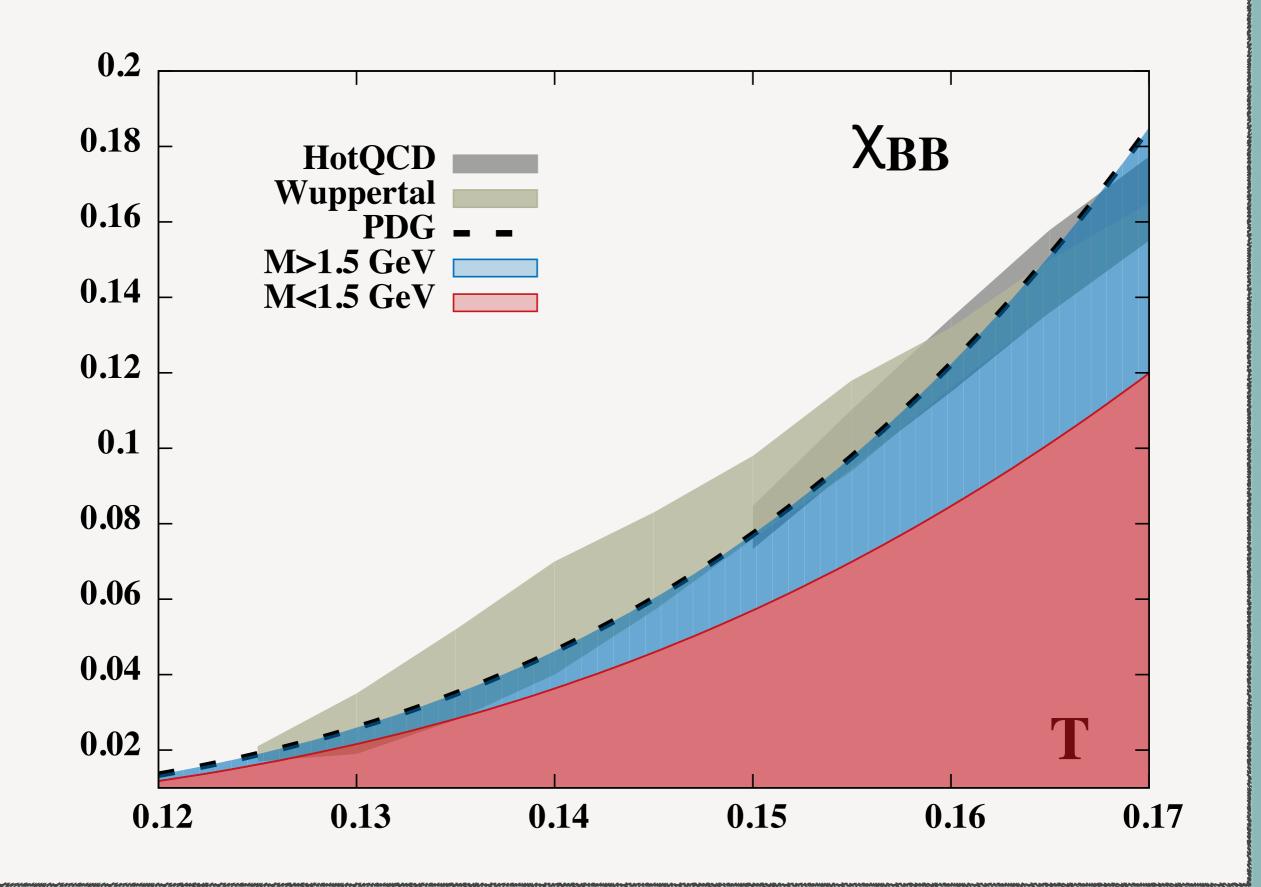
or introduce the chemical potential

$$P = T \sum_{\alpha=B,\bar{B}} g_{\alpha} \int \frac{d^3k}{(2\pi)^3} \ln(1 + e^{-\beta\sqrt{k^2 + M_{\alpha}^2} \pm \bar{\mu}_B})$$

FLUCTUATIONS

taking derivative

 $\chi_B = \frac{\partial^2}{\partial \bar{\mu}_B \partial \bar{\mu}_B} P \quad \text{at the limit} \quad \mu_B \to 0$ probes fluctuations $\chi_B = \frac{1}{\beta V} \frac{\partial^2}{\partial \bar{\mu}_B \partial \bar{\mu}_B} \ln Z$ $= T^2 \langle \langle \int d^4 x \, \bar{\psi}(x) \gamma^0 \psi(x) \bar{\psi}(0) \gamma^0 \psi(0) \rangle \rangle_c$

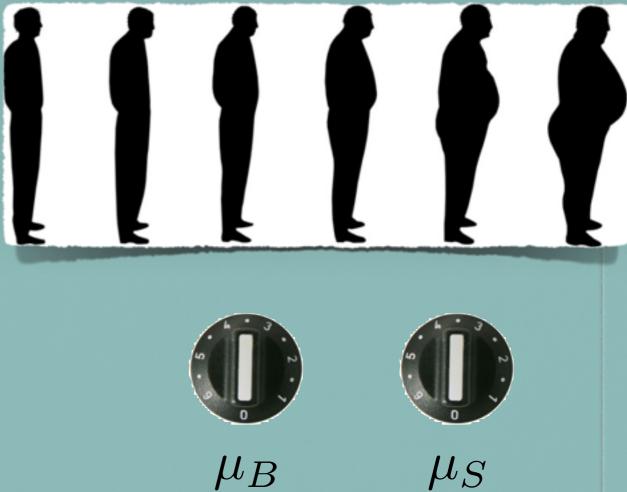


FLUCTUATIONS

 studying the system by linear response

$$\mu = \mu_B B + \mu_Q Q + \mu_S S$$

$$\chi_{\rm B,S,...} = \frac{1}{VT^3} \frac{\partial^2}{\partial \bar{\mu_B} \partial \bar{\mu_S} ...} \ln Z$$



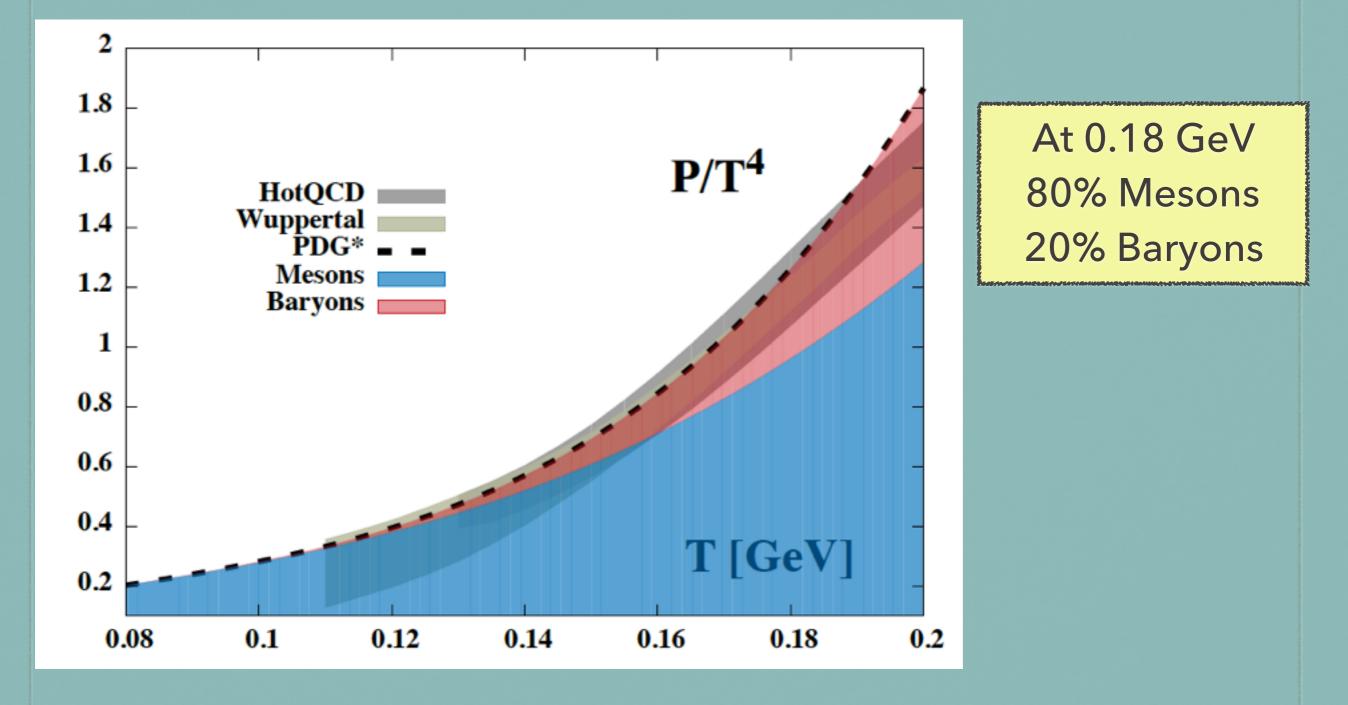


 μ_Q

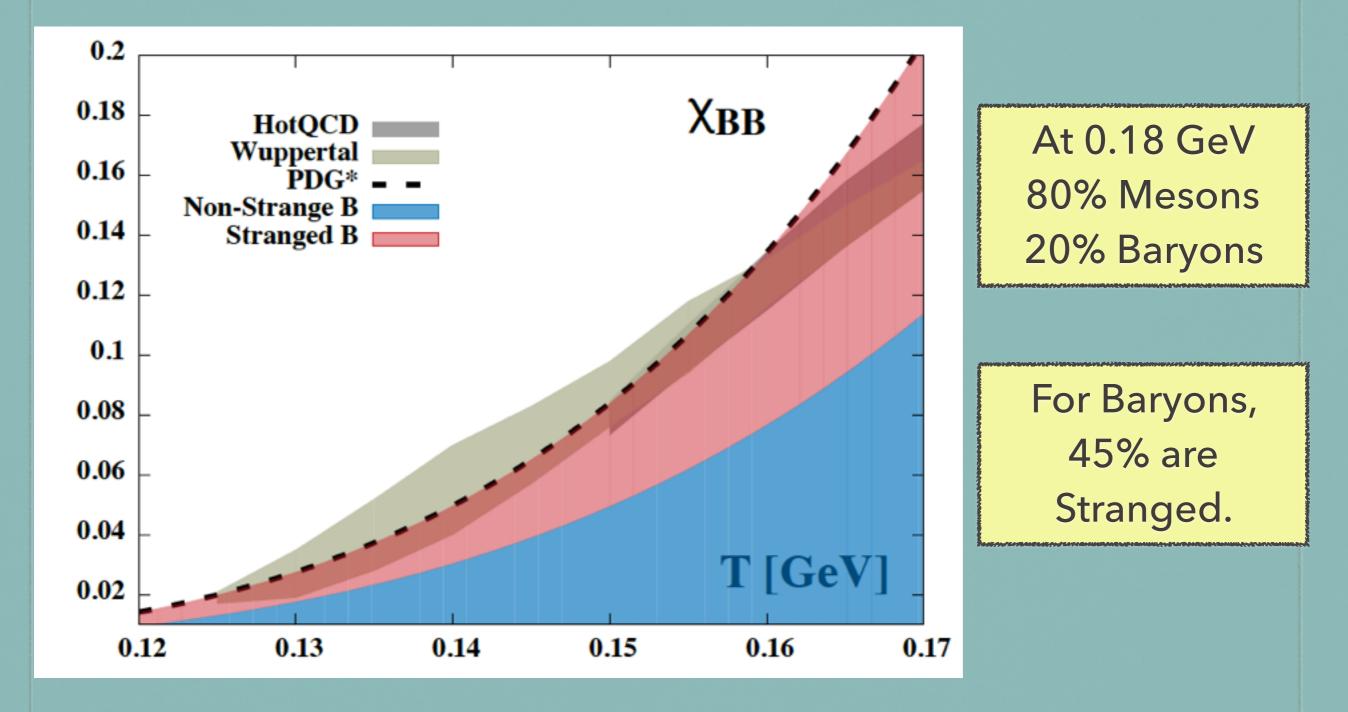


 m_q

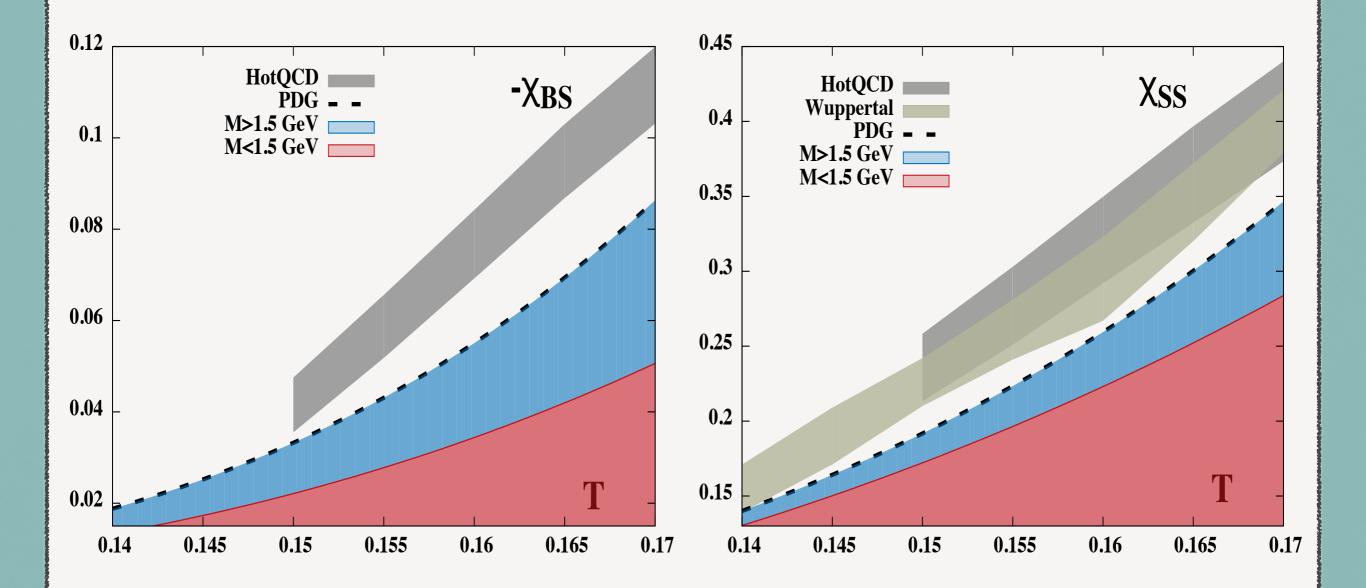
COMPOSITION OF HADRONS



COMPOSITION OF HADRONS

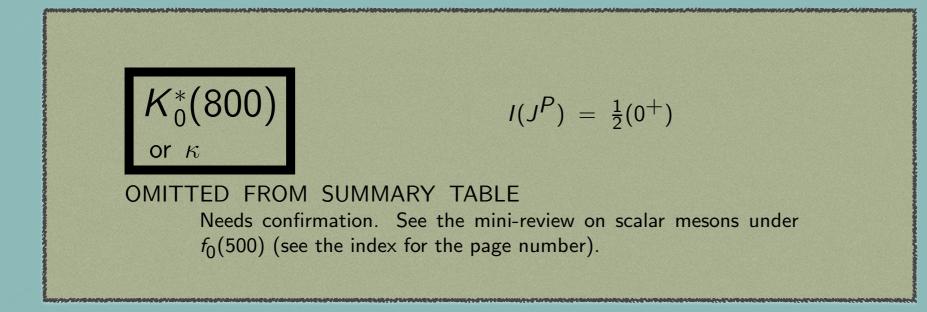


Missing resonances in the strange sector

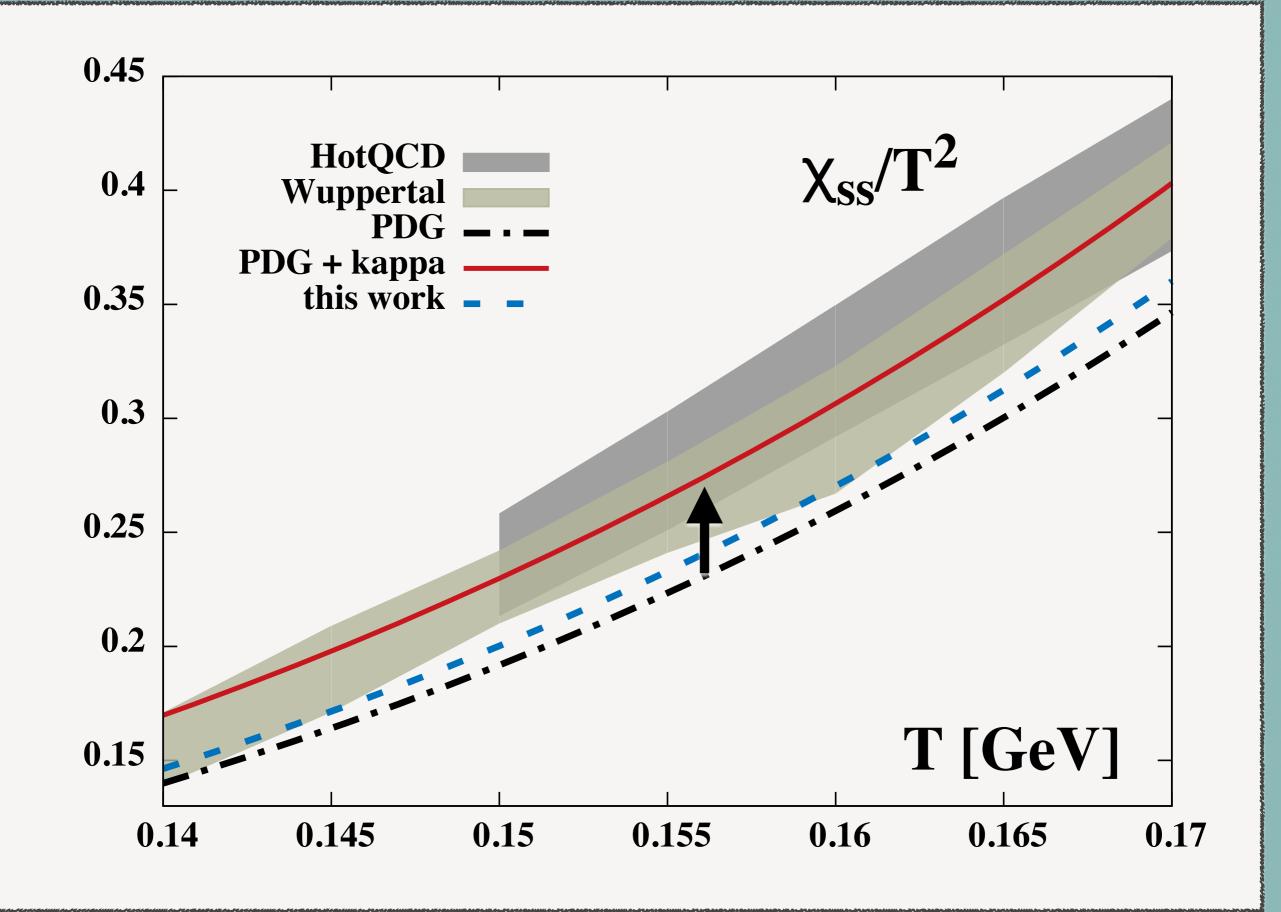


WHERE TO FIND THE MISSING RESONANCES?

unconfirmed light resonances in the strange sector



and friends... K(1460)0-, K(1580) 2-, Sigma(1480) ?-

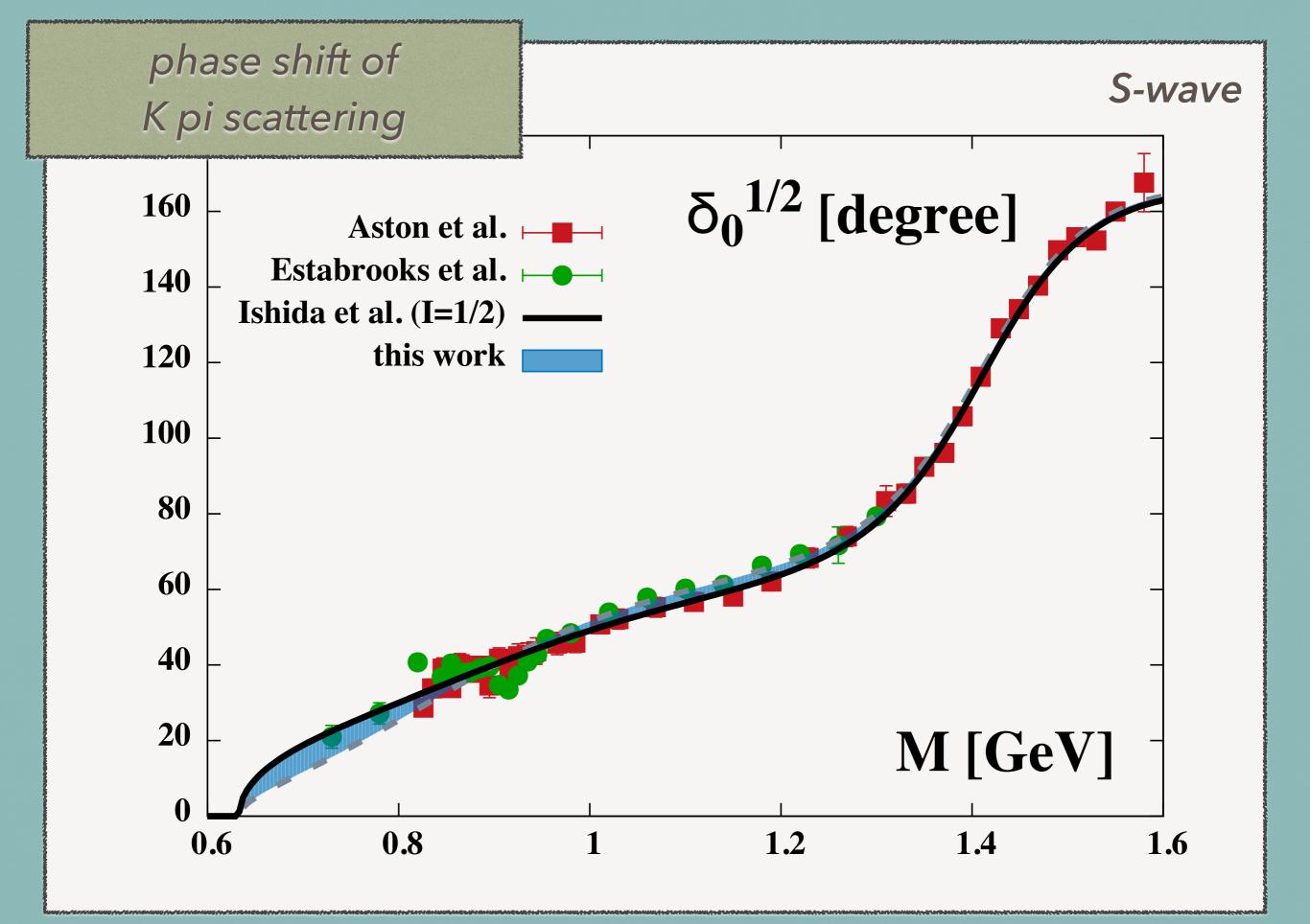


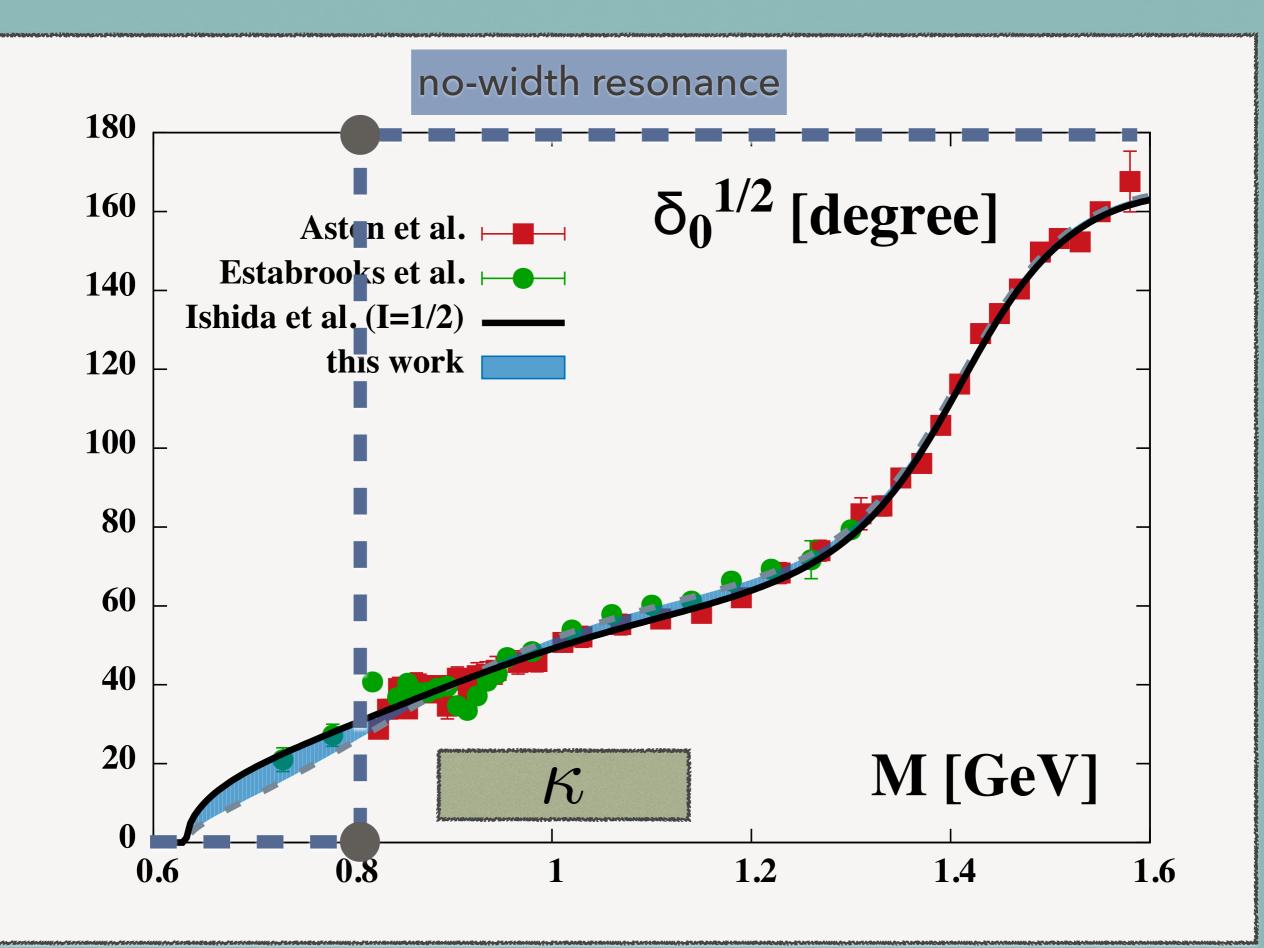
WHERE TO FIND THE MISSING RESONANCES?

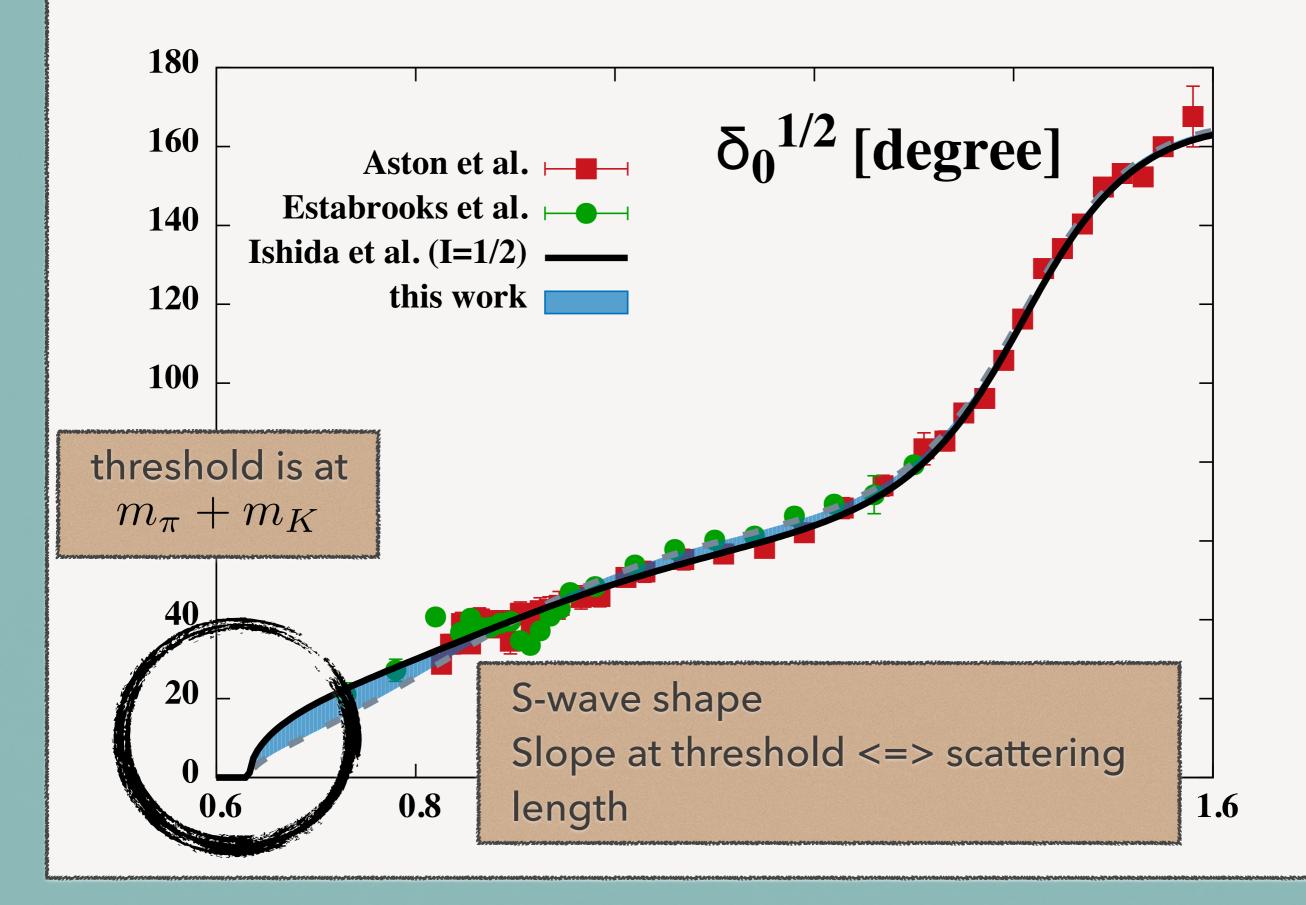
- The κ meson has the right mass range.
- But it also has a broad width!
- Question the assumption of HRG treatment for resonances: non-interacting and point-like.

WHAT IS THE EFFECT OF RESONANCE'S WIDTH ON THERMODYNAMICS?

PHYSICS OF BROAD RESONANCES







S-MATRIX APPROACH

from phase shift to thermodynamics

$$\langle \hat{O} \rangle = \int_{M_{thres}}^{\infty} \frac{dM}{2\pi} B(M) \,\hat{O}[M]$$
$$B = 2 \frac{d}{dM} \delta(M) \qquad \rightarrow 2M \frac{2M\gamma_{\rm BW}}{(M^2 - M_0^2)^2 + M^2\gamma_{\rm BW}^2}$$

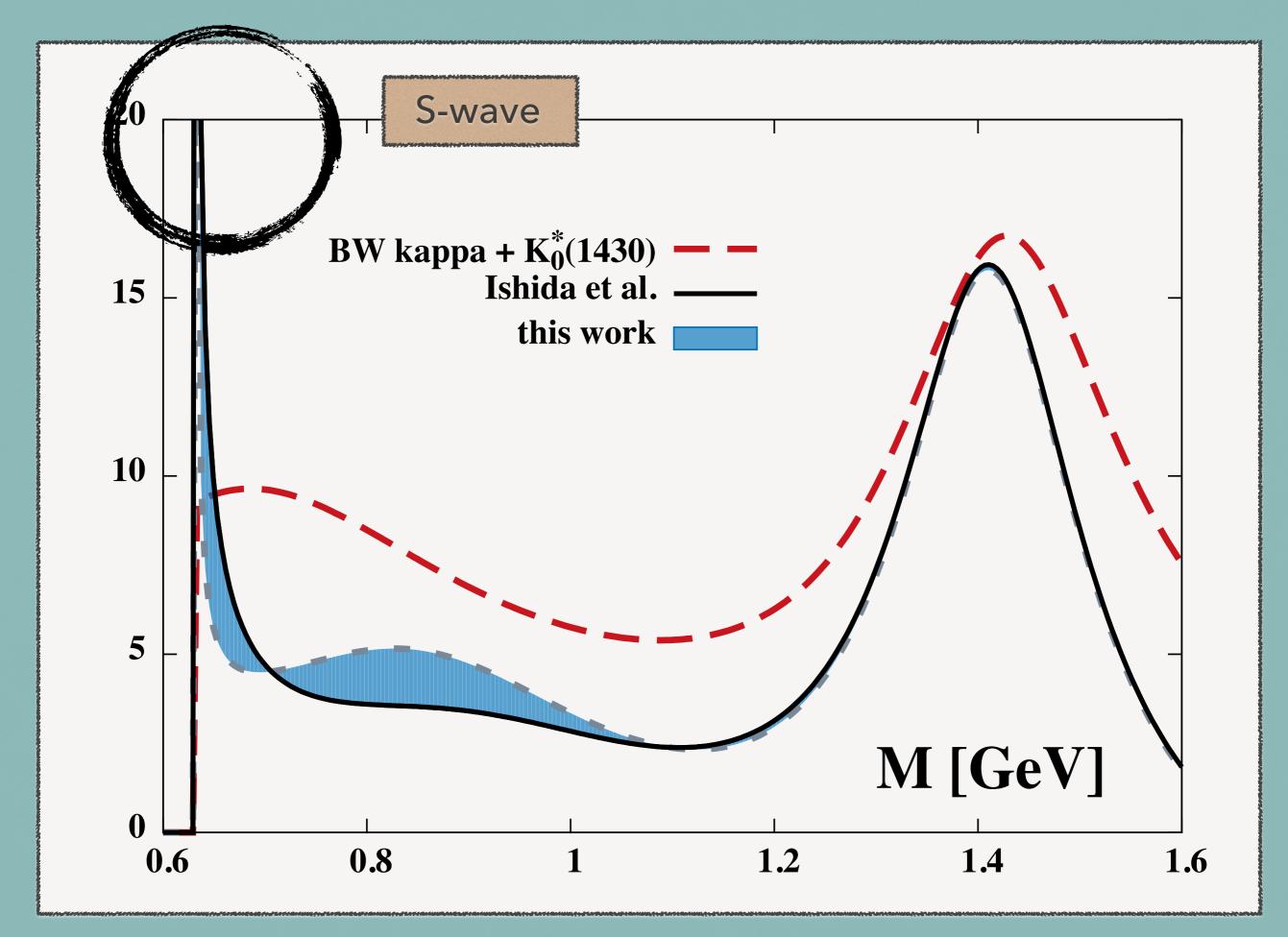
Breit-Wigner

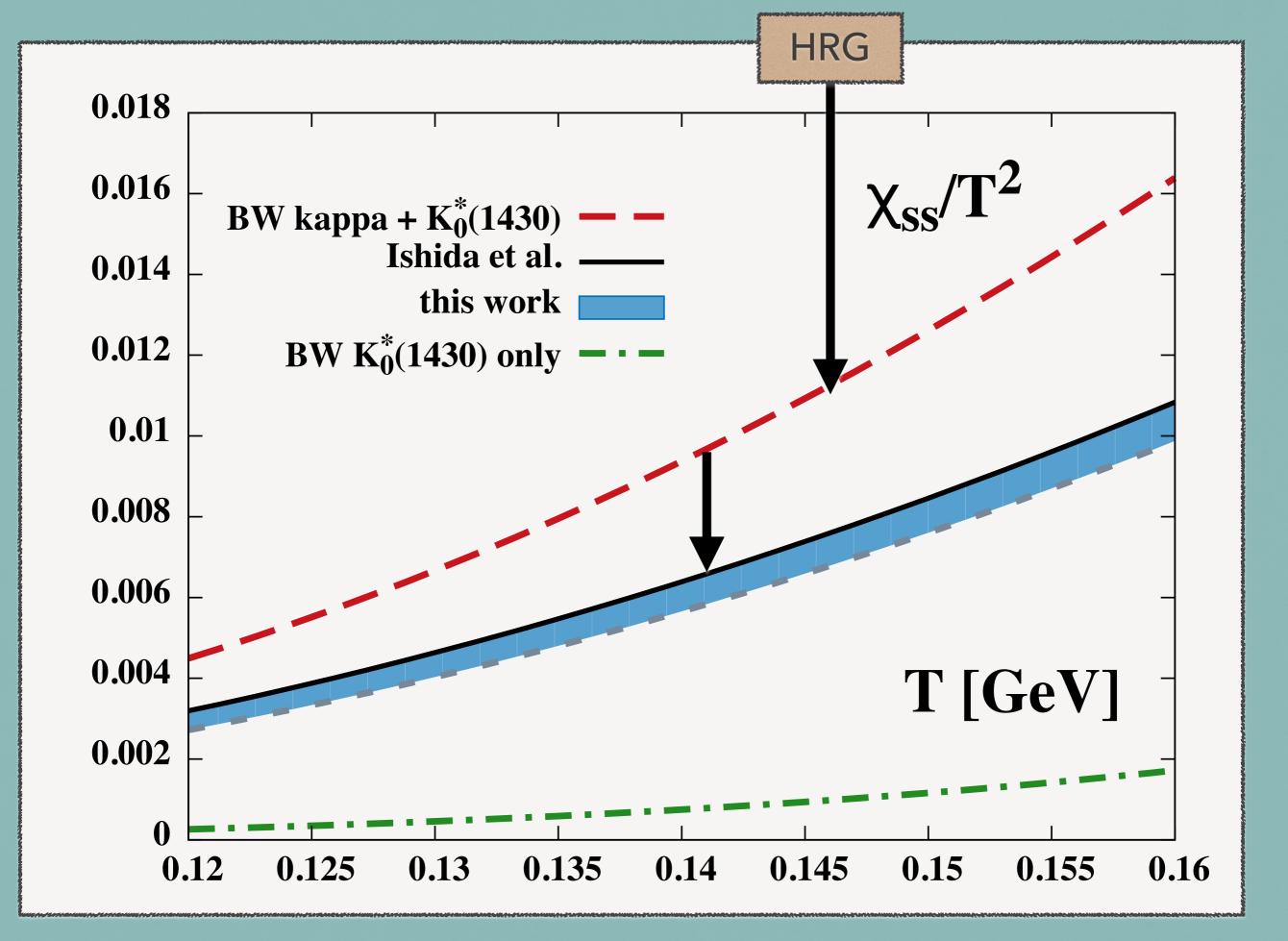
S-MATRIX APPROACH

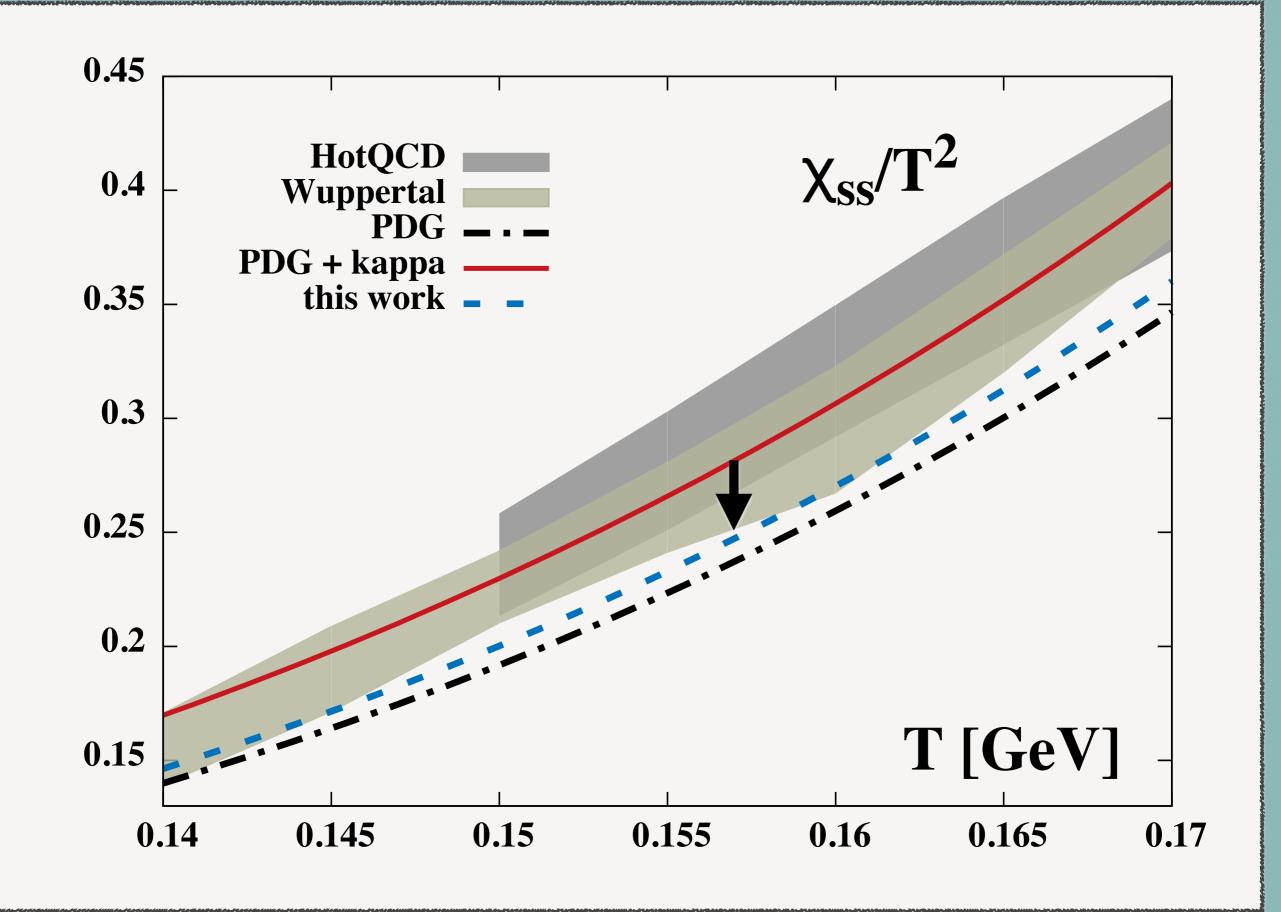
$$\Omega_{\rm int}^{\rm B} \approx 2TV \int_{m_{th}}^{\infty} \frac{dM}{2\pi} \int \frac{d^3p}{(2\pi)^3} \mathcal{B}(M) \\ \times \left\{ \ln[1 - e^{-\beta(\sqrt{p^2 + M^2} + \mu_S)}] + \ln[1 - e^{-\beta(\sqrt{p^2 + M^2} - \mu_S)}] \right\}.$$

$$B = 2\frac{d}{dM}\delta(M) \qquad \rightarrow 2M\frac{2M\gamma_{\rm BW}}{(M^2 - M_0^2)^2 + M^2\gamma_{\rm BW}^2}$$

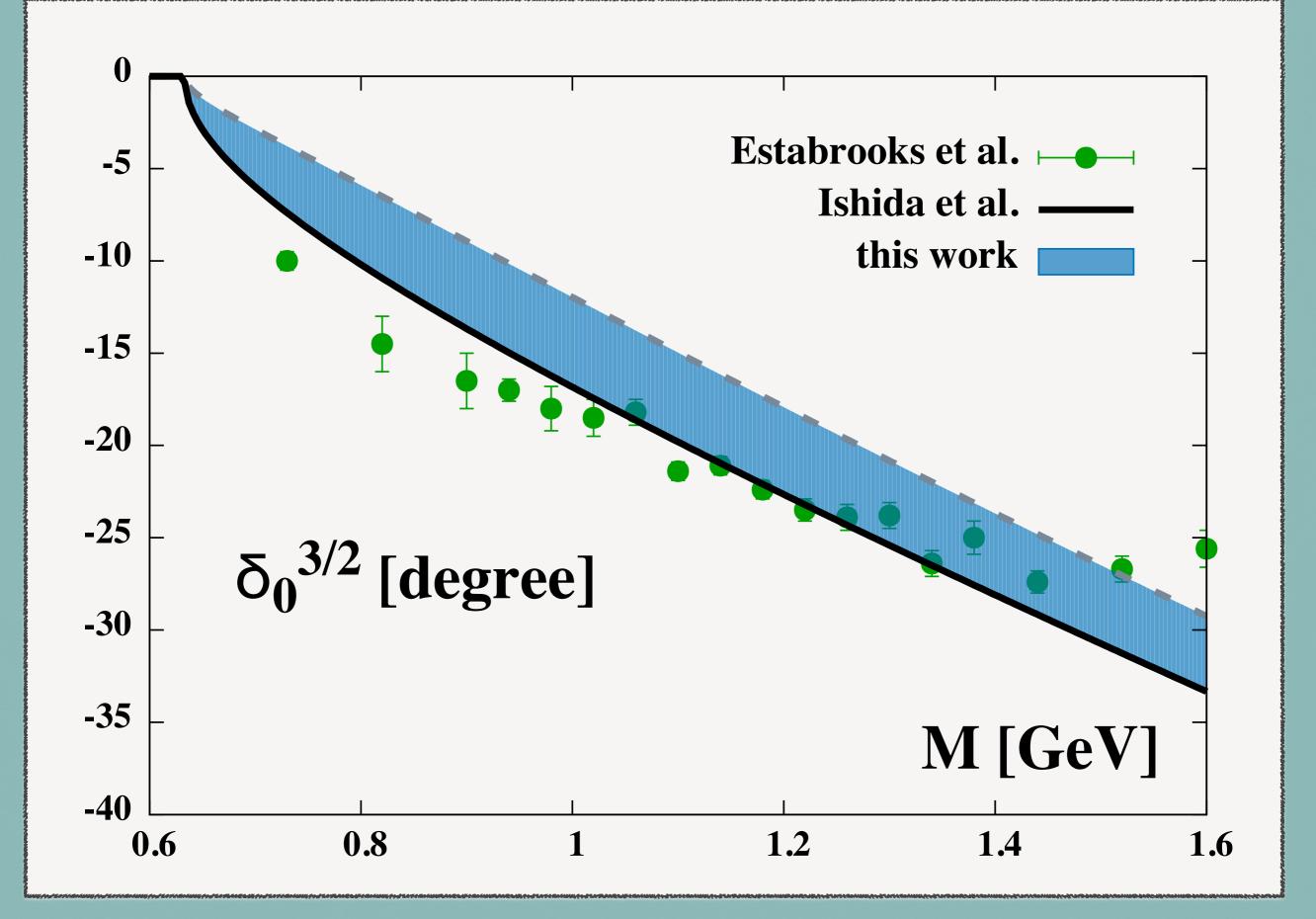
Breit-Wigner

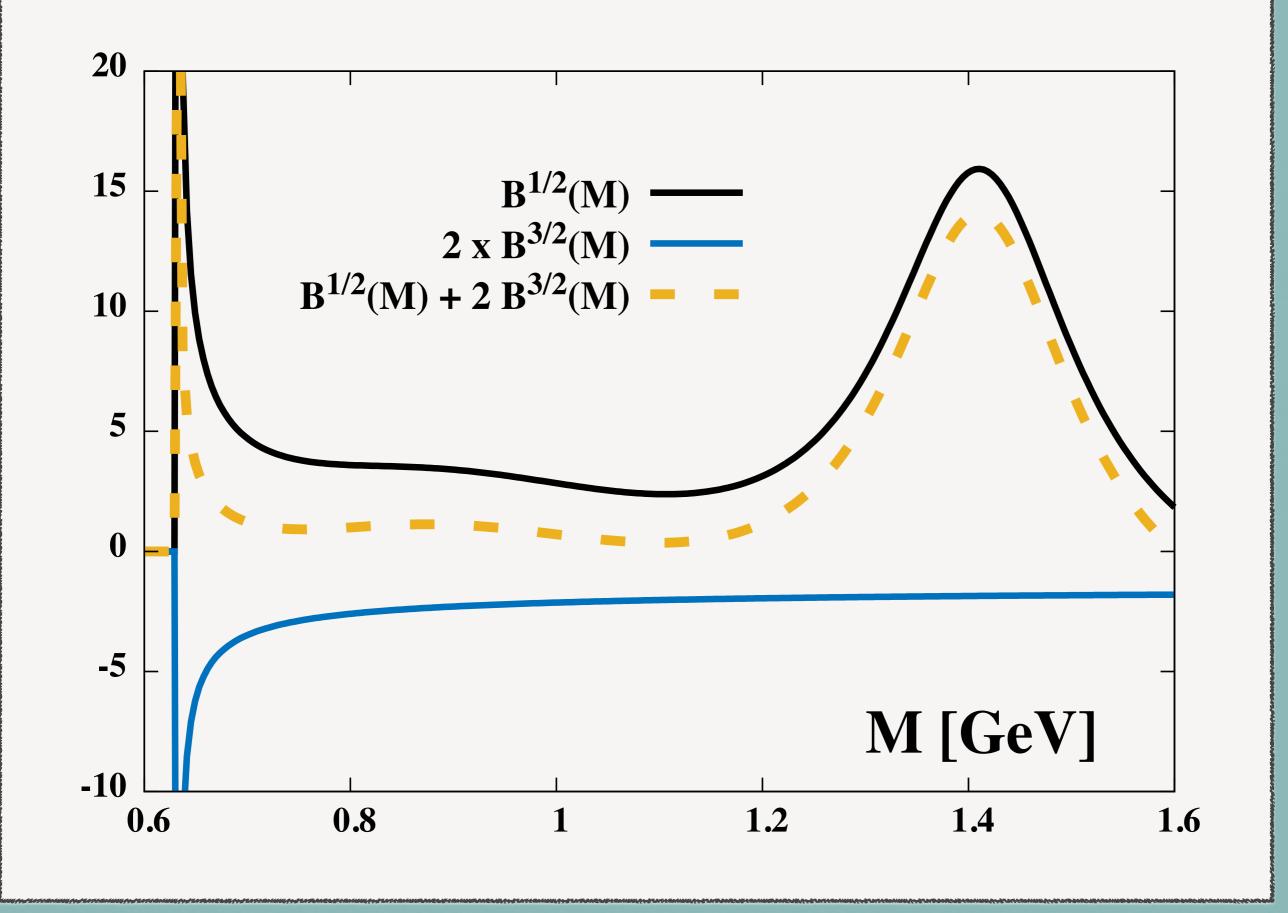


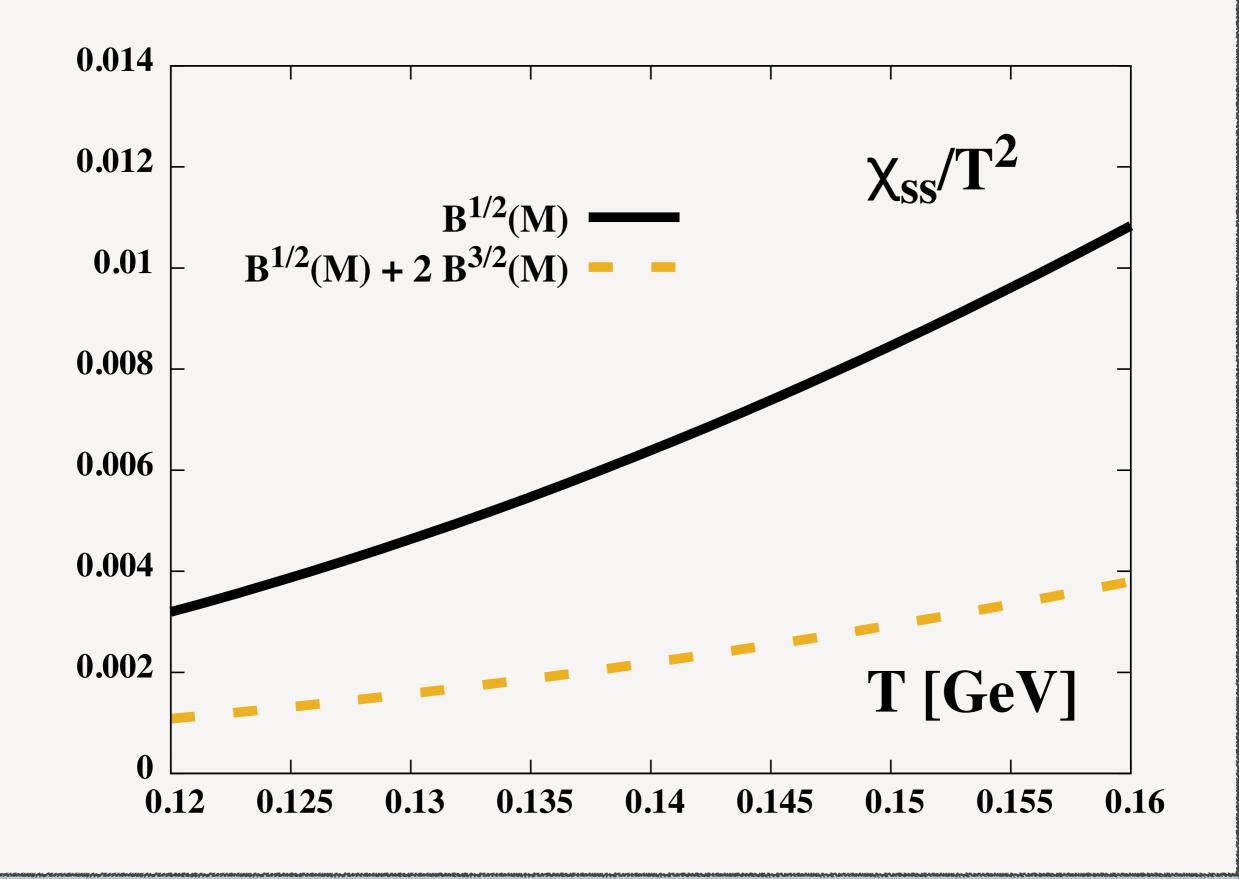




I=3/2 REPULSIVE CHANNEL







CONCLUSIONS

- HRG systematically overestimates the interaction contribution to strangeness fluctuation.
- S-matrix approach a consistent treatment for low-mass, broad resonances.
 resonant + non-resonant contribution

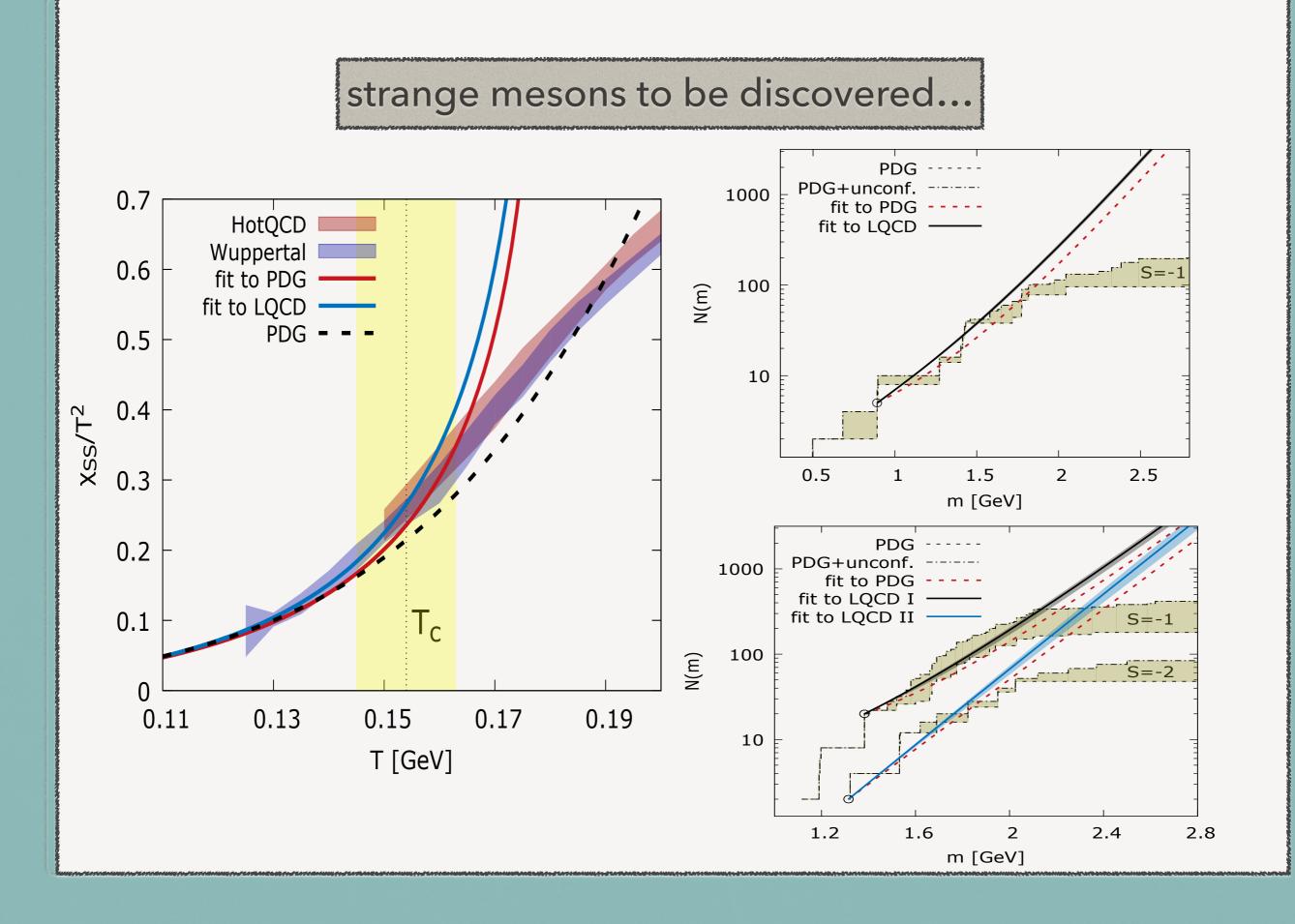
THANK YOU

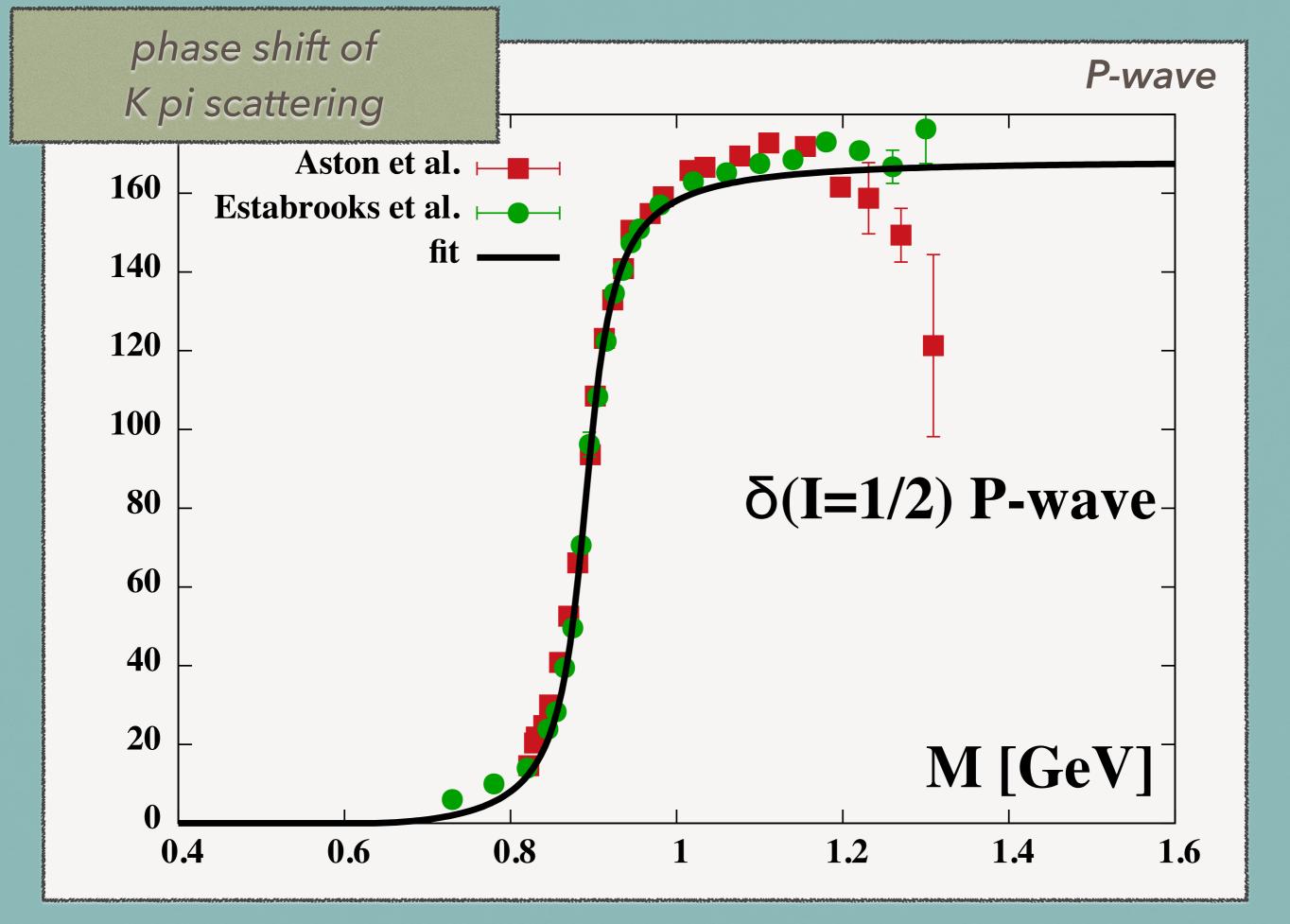
BACKUP SLIDES

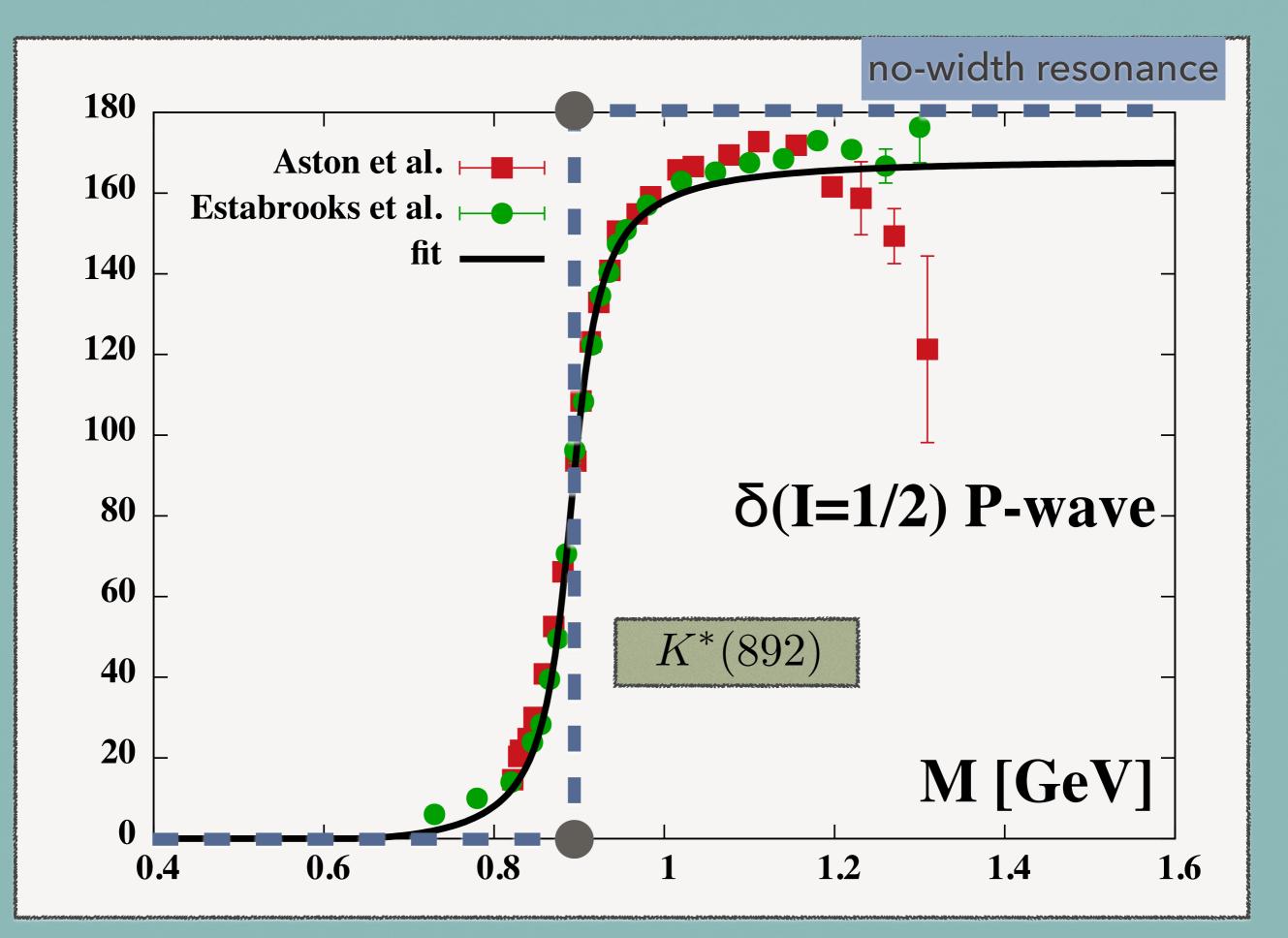
WHERE TO FIND THE MISSING RESONANCES?

refit the Hagedorn spectrum

$$P = T \sum_{\alpha = M, B} g_{\alpha} \int \frac{d^{3}k}{(2\pi)^{3}} \mp \ln(1 \mp e^{-\beta\sqrt{k^{2} + M_{\alpha}^{2}}})$$
$$\sum_{\alpha = G, S} + \int dm \,\rho^{H}(m)$$
Improve the spectrum using lattice inputs







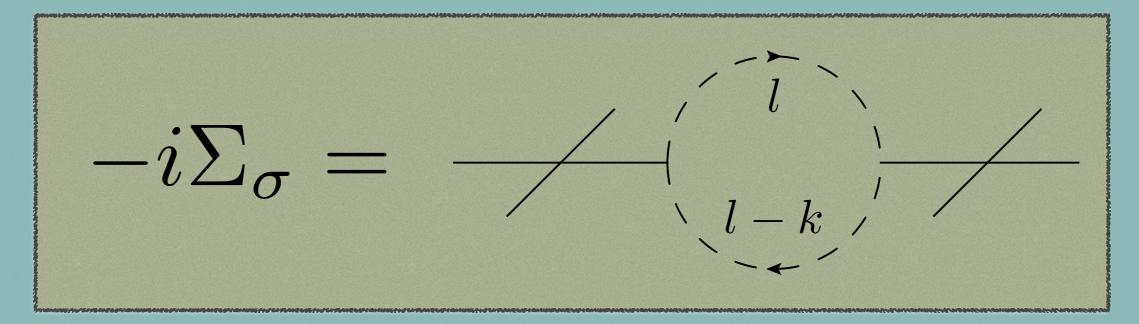
 Width => particle can decay => existence of an imaginary part in the self energy

$$G(t) \propto e^{-i\Sigma_R t + \Sigma_I t}$$
$$|G(t)|^2 \propto e^{2\Sigma_I t} \Longrightarrow e^{-\Gamma t}$$

N.R.
$$\Gamma = -2\Sigma_I$$

- Width comes from interactions.
- illustration:

$$\mathcal{L}_{int} = -g\sigma\phi_{\pi}^2$$



$$\Sigma_{\sigma}(k) = 2g^{2}i \int \frac{d^{4}l}{(2\pi)^{4}} \frac{1}{l^{2} - m_{\pi}^{2}} \frac{1}{(l-k)^{2} - m_{\pi}^{2}}$$

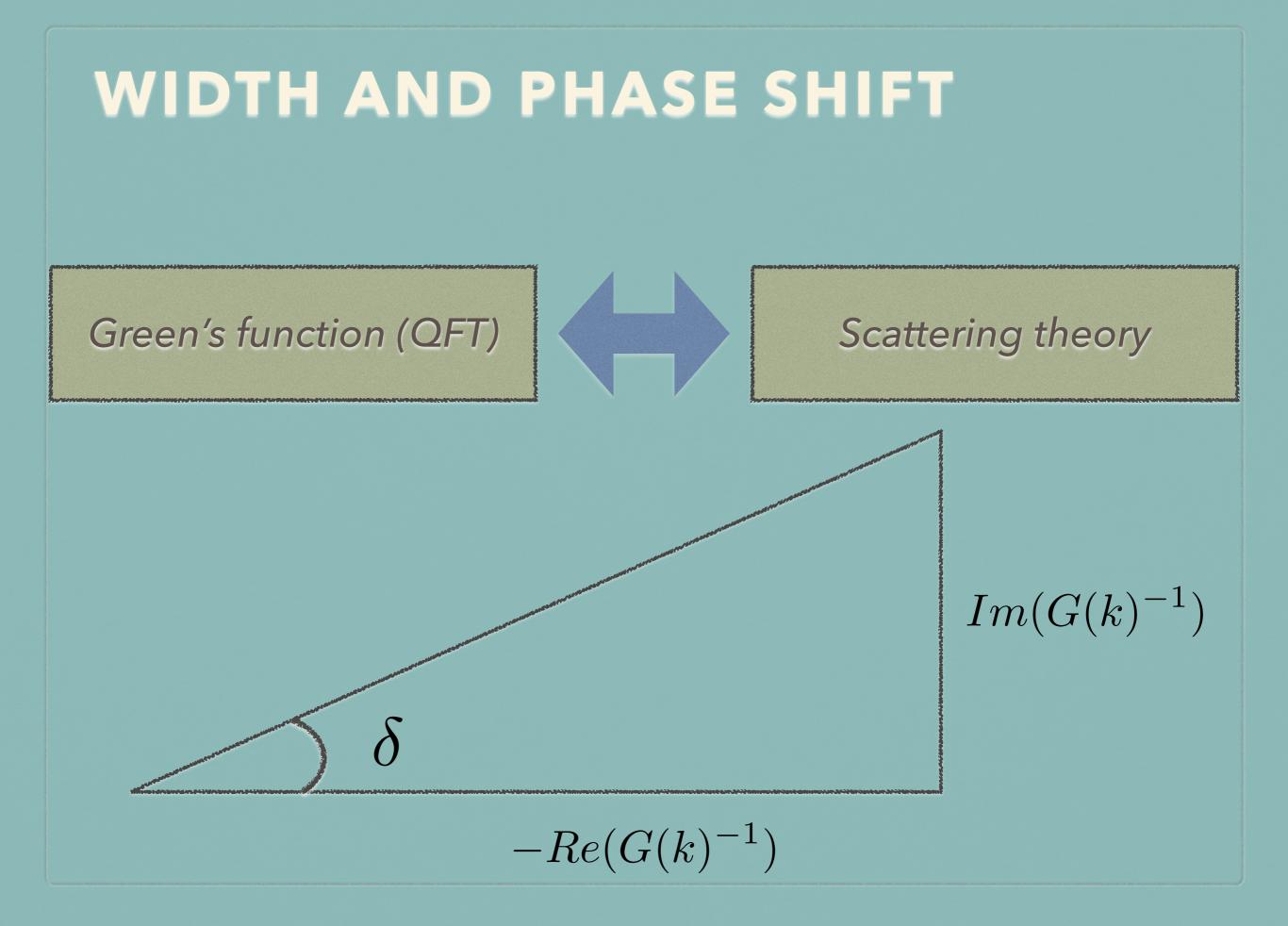
$$= \frac{1}{(2\pi)^{4}} 2g^{2}\pi^{2} \int_{0}^{1} dx \ln \left[(m_{\pi}^{2} - x(1-x)k^{2})\pi \right]$$
develops an imaginary part if
$$k^{2} \geq (2m_{\pi})^{2} \quad \text{threshold}$$

$$\ln(-1) = \pm i\pi$$

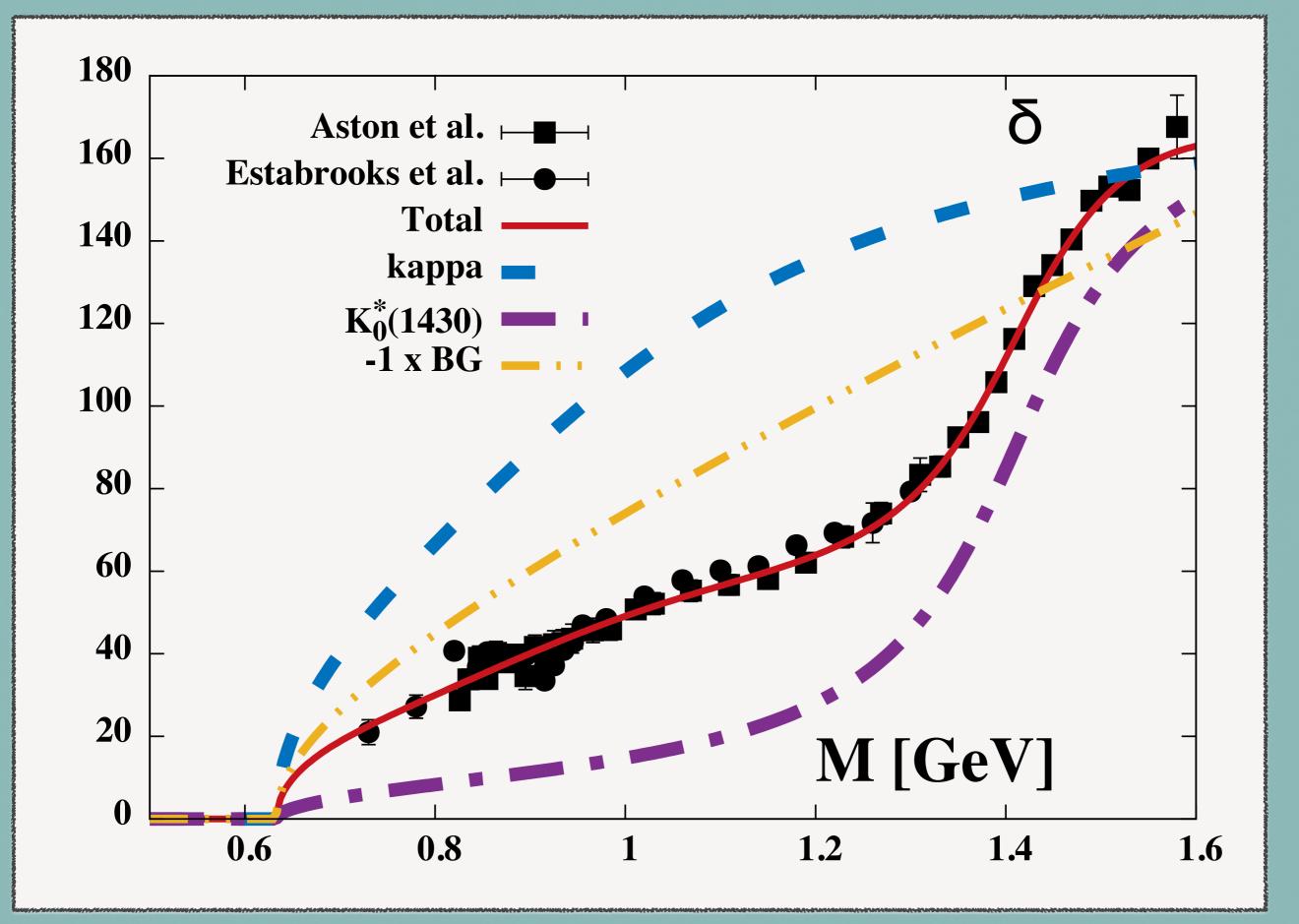
$$Rel. \qquad \Gamma = \frac{-\Sigma_{I}}{M}$$

- Field theory knows about the kinematics and phase space
- Width arises from interaction
- Angular momentum dependence $\propto k^{2l+1}$

$$\Gamma(M) = \frac{g_{\sigma\pi\pi}^2}{8\pi} \frac{P_{c.m.}(M)}{M^2}$$
$$\Gamma(M) = \frac{g_{\rho\pi\pi}^2}{6\pi} \frac{(P_{c.m.}(M))^3}{M^2}$$



DECOMPOSITION OF PHASE SHIFT IN CHIRAL MODELS



CHIRAL SYMMETRY

• Linear sigma model

$$U_{eff}(\sigma, \pi) = -\mu^2 (\sigma^2 + \pi^2) + \lambda (\sigma^2 + \pi^2)^2$$

