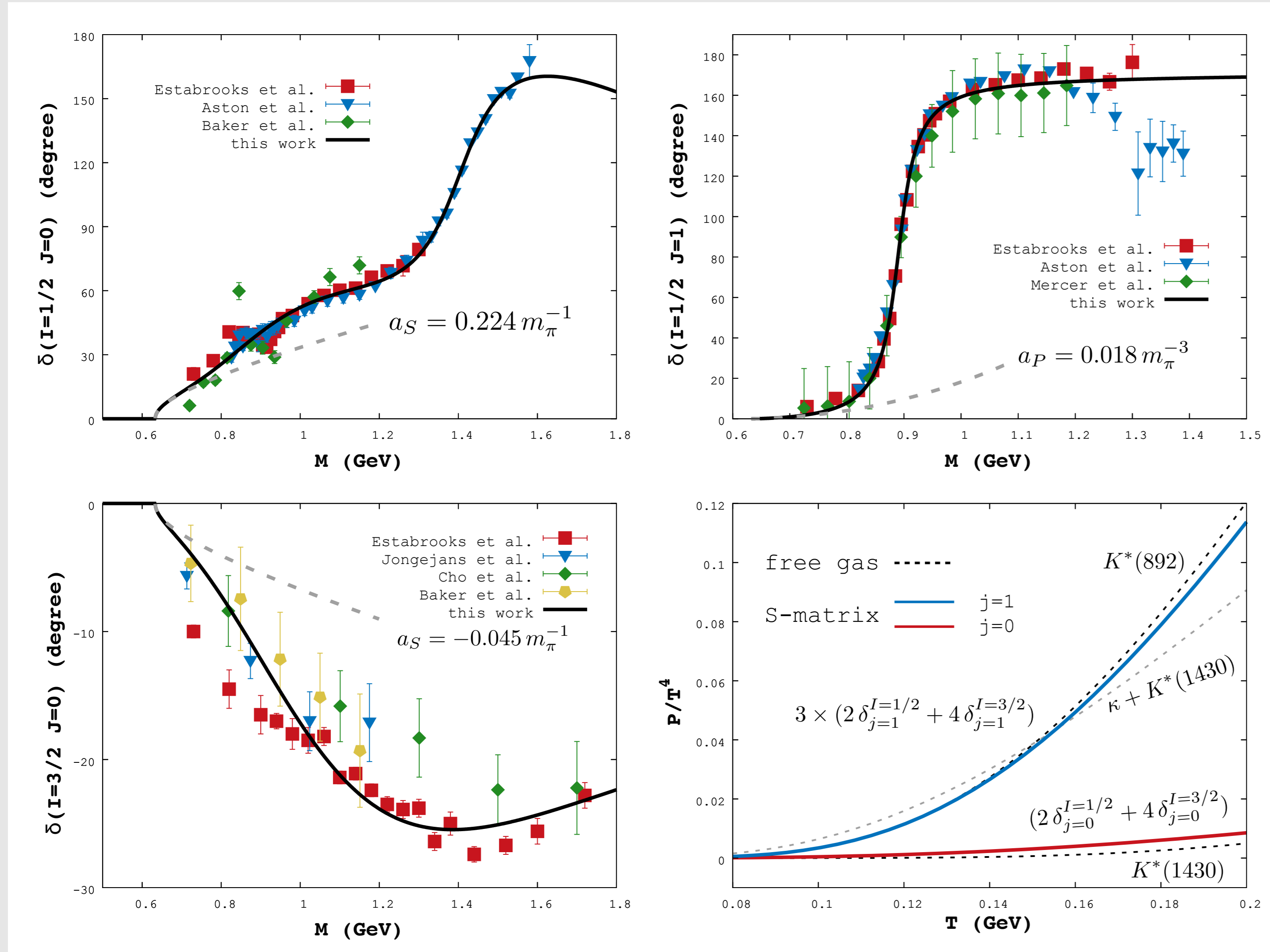


## S-matrix formulation of thermodynamics



empirical phase shifts  $\delta(\sqrt{s}) \rightarrow$  thermal pressure  $P(T)$

## PWA $\times$ S-matrix

### 1.) S-matrix approach

$$\Delta \ln Z = V \times \int d\sqrt{s} \frac{d^3P}{(2\pi)^3} e^{-\beta\sqrt{P^2+s}} \frac{\partial}{\partial \sqrt{s}} \text{tr} (\delta(\sqrt{s})).$$

### 2.) Coupled-channel analysis $\times$ S-matrix approach

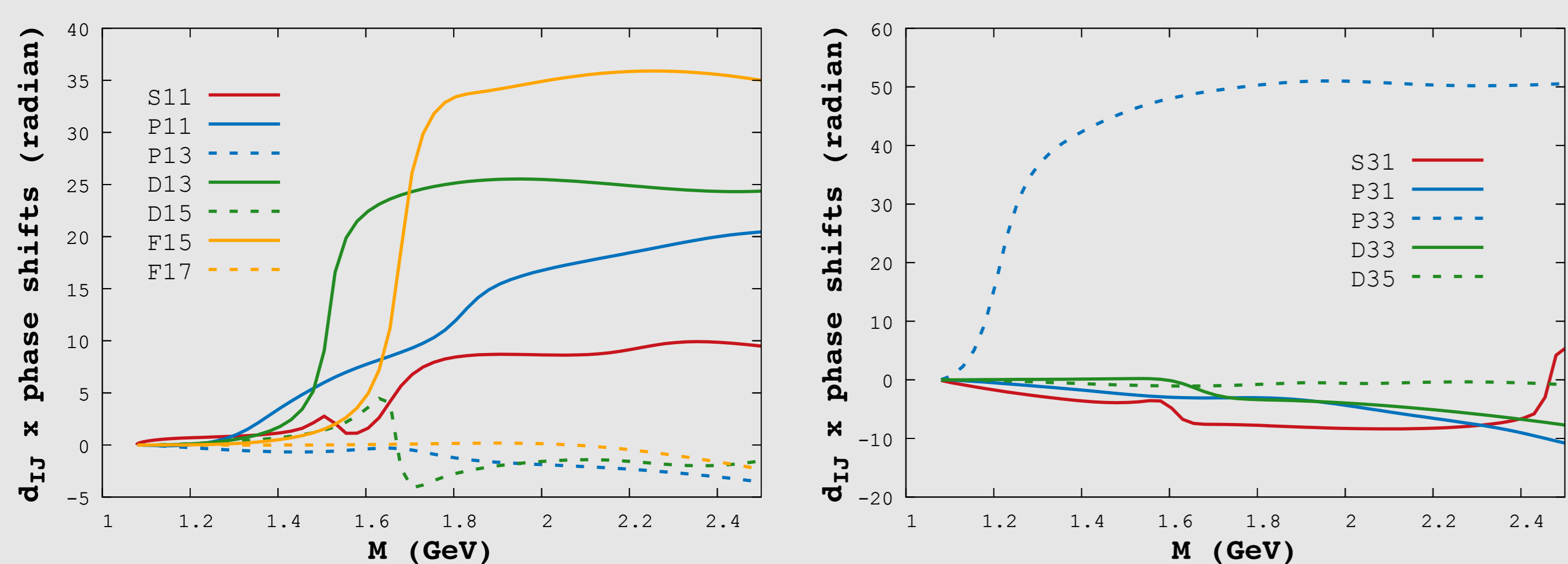
$$\delta(\sqrt{s}) \rightarrow Q(\sqrt{s}) = \frac{1}{2} \text{Im}(\text{tr} \ln S) = \frac{1}{2} \text{Im}(\ln \det S).$$

### 3.) 2-channel model

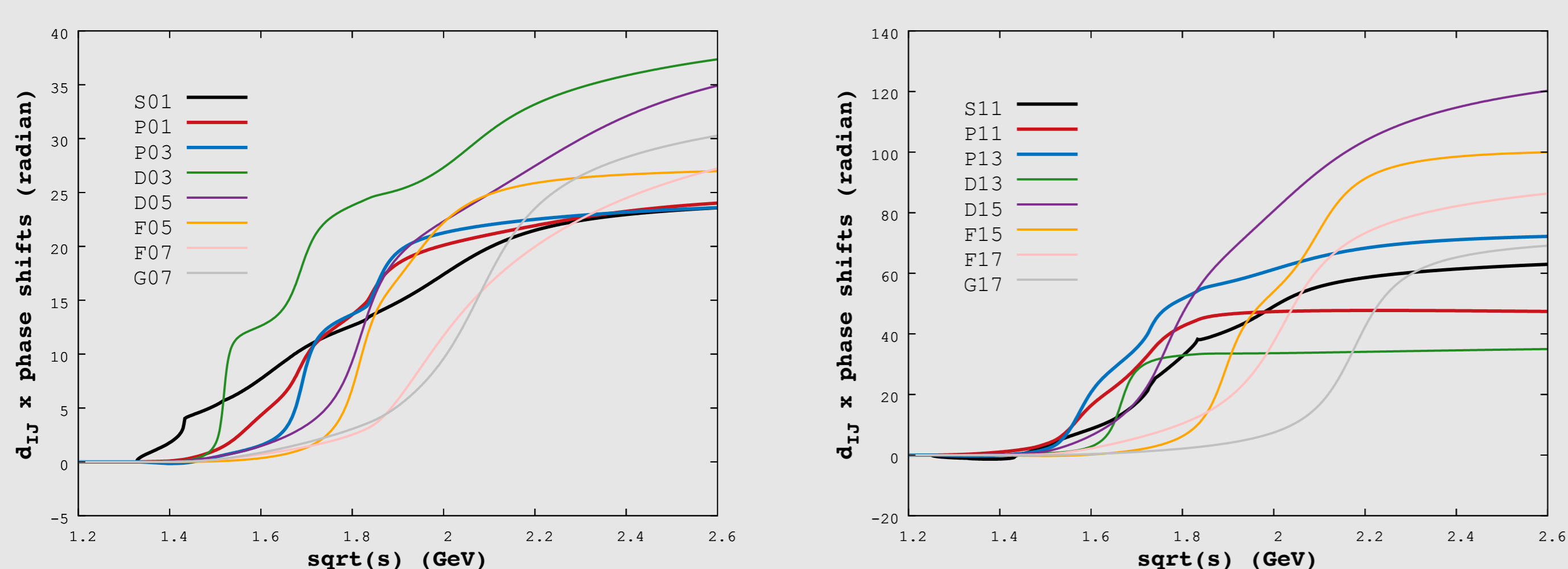
$$S = \begin{pmatrix} \eta e^{2iQ_a} & i\sqrt{1-\eta^2} e^{i(Q_a+Q_b)} \\ i\sqrt{1-\eta^2} e^{i(Q_a+Q_b)} & \eta e^{2iQ_b} \end{pmatrix}.$$

$$Q = Q_a + Q_b.$$

## $\pi N$ Phase Shifts

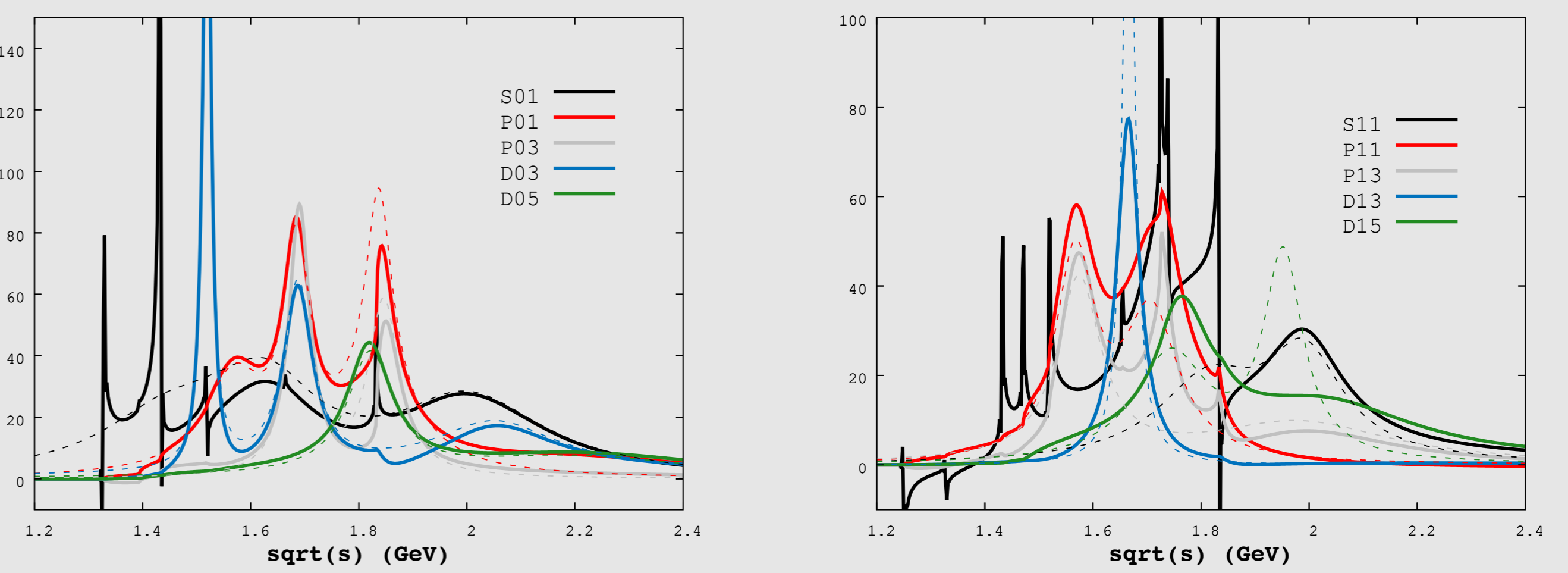


## Hyperon Phase Shifts

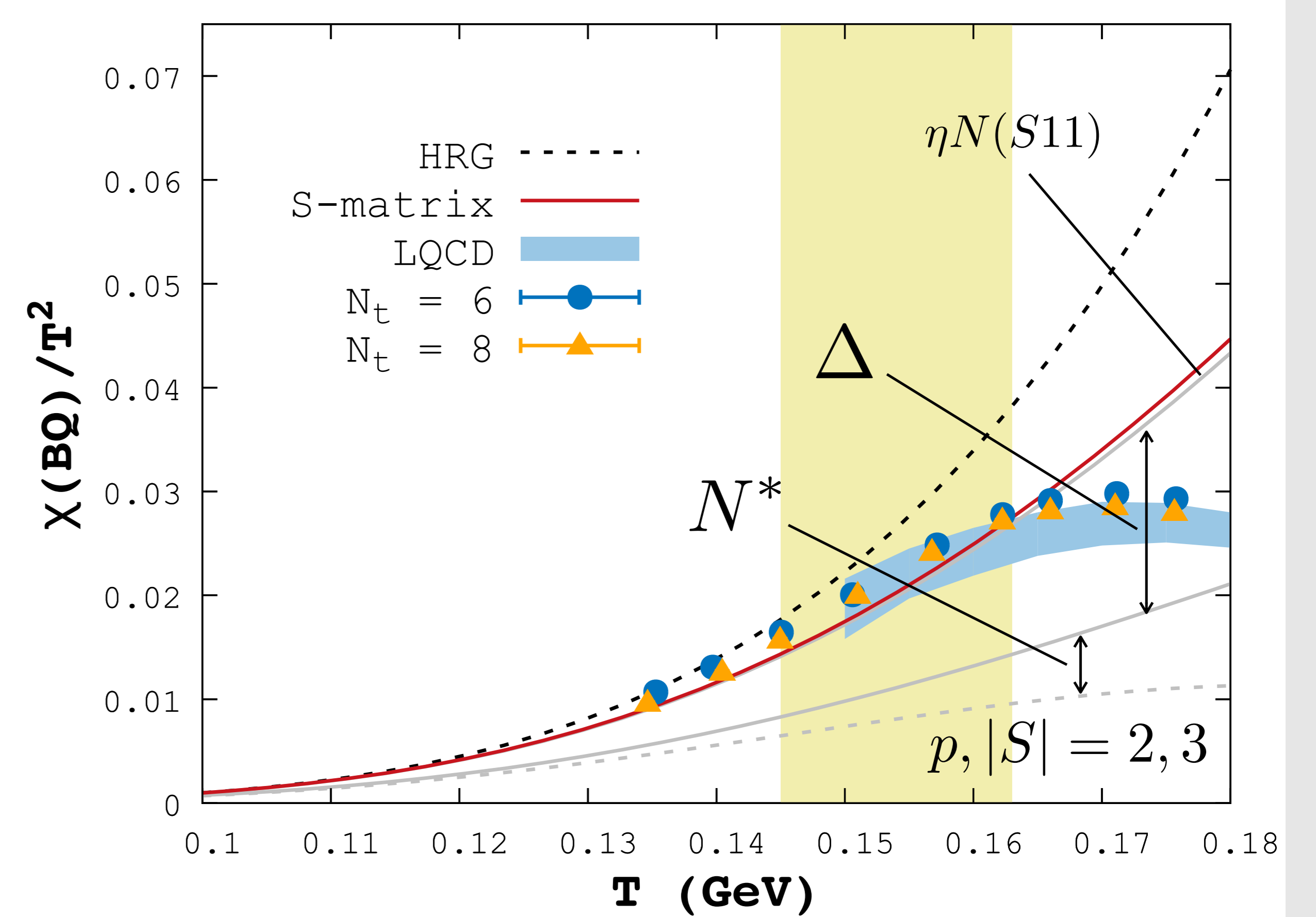


## Results

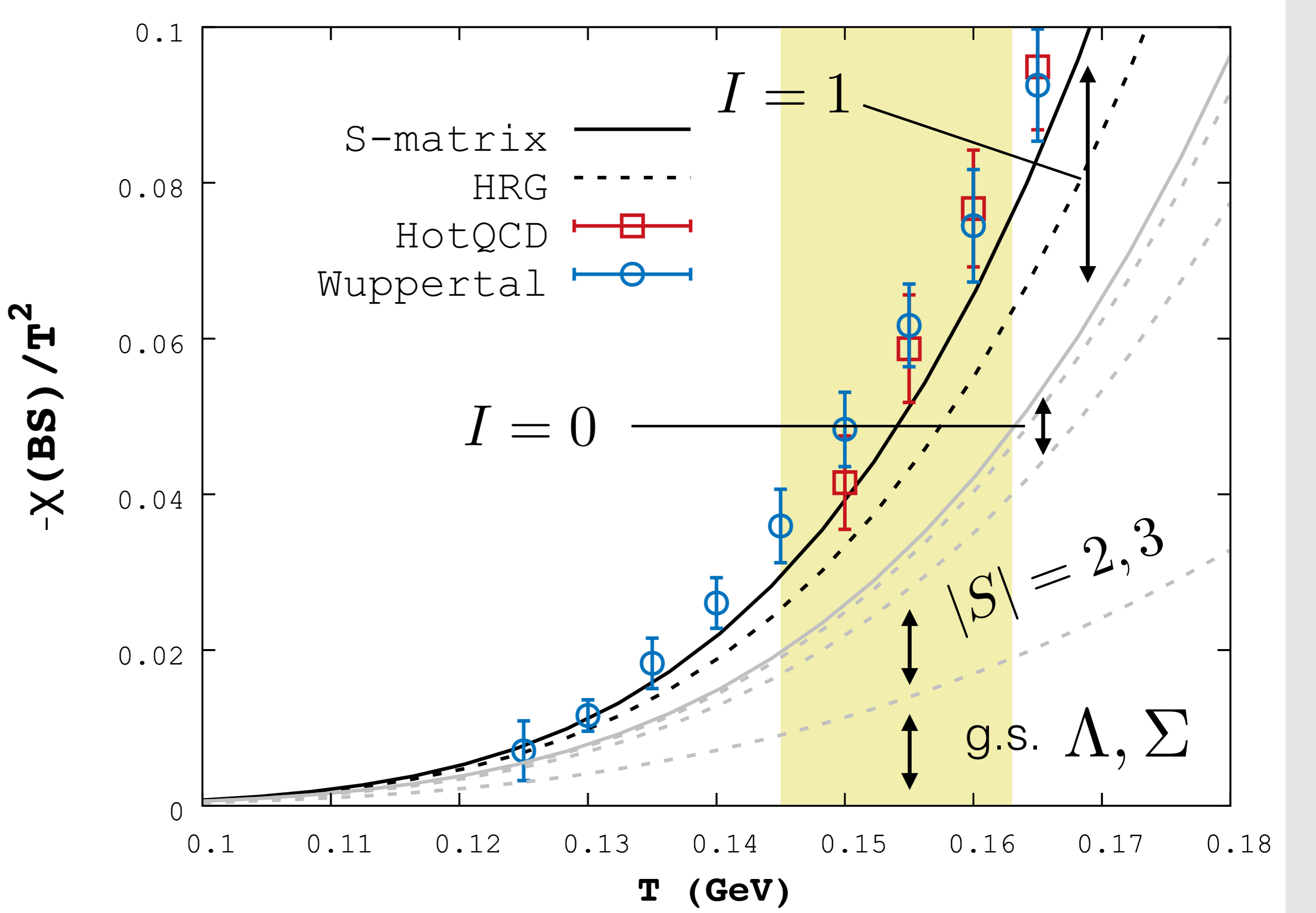
### (A) Spectral function



### (B) $\chi_{BQ}$



### (C) $\chi_{BS}$



## Conclusions

S-matrix approach offers:

- 1.) an improved description of LQCD data over HRG.
- 2.) a theoretical framework to bring hadron physics into the thermodynamics – resonance widths, repulsive channels, inelasticities, coupled-channel effects, ...

## References

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- [2] C. Fernandez-Ramirez, I. V. Danilkin, D. M. Manley, V. Mathieu and A. P. Szczepaniak, Phys. Rev. D **93**, no. 3, 034029 (2016).
- [3] P. M. Lo, B. Friman, K. Redlich and C. Sasaki, Phys. Lett. B **778**, 454 (2018).